July 21 – 25, 2014
Vancouver, BC, Canada

CONFERENCE GUIDE

This guide belongs to:

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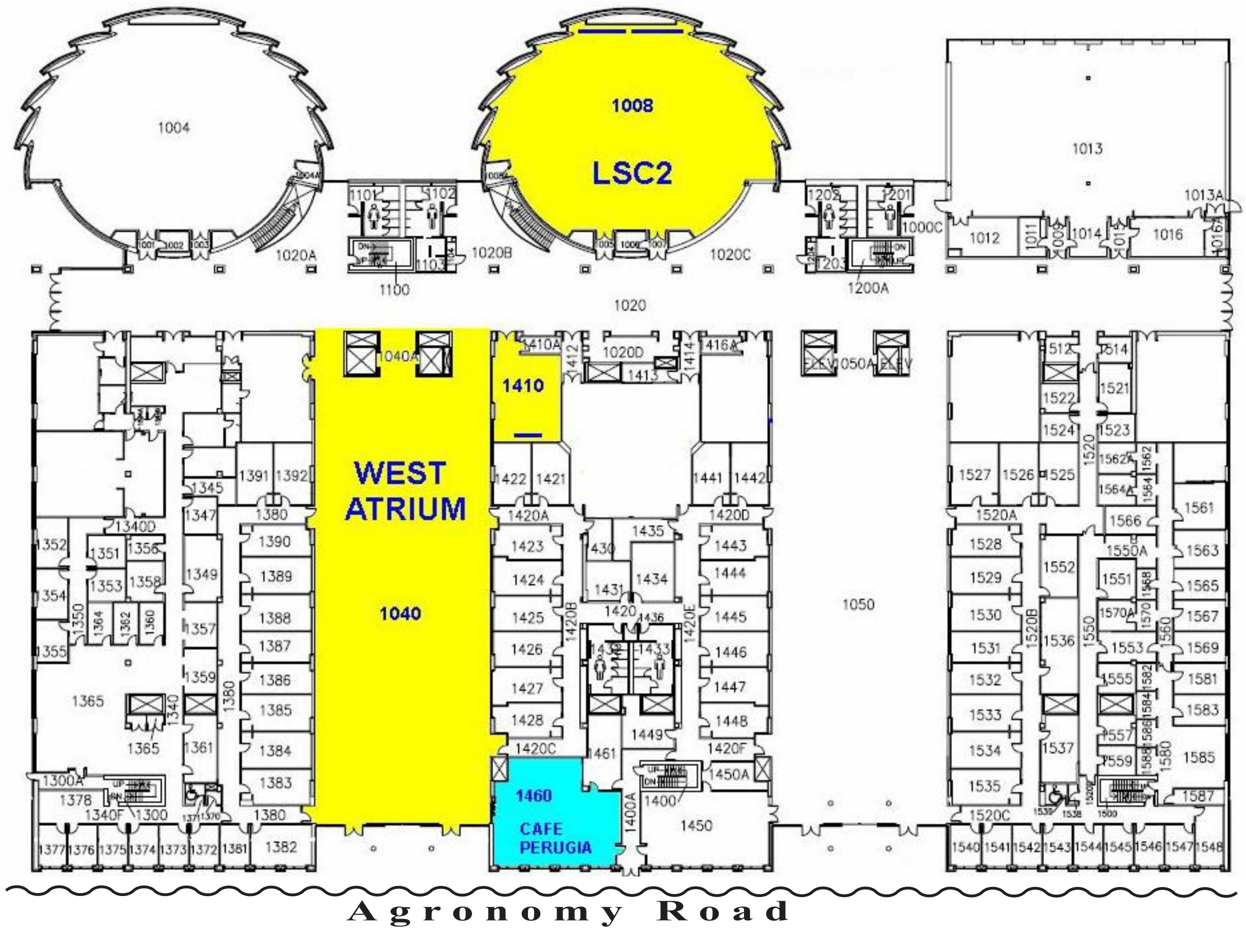
LIFE SCIENCES CENTRE



Nuclear Structure 2014

July 21—25, 2014

Vancouver, British Columbia, Canada

ns2014.triumf.ca

NS2014 is held
on the campus of the
University of British Columbia

Life Sciences Centre
2350 Health Sciences Mall

Hosted by
TRIUMF

Contents

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EMERGENCY PHONE NUMBERS:

Vancouver emergency number for fire, ambulance, police	**911**
UBC Campus Security	604-822-2222

HOSPITALS:

UBC Campus
University Hospital – Koerner Pavillion 604-822-7121
2211 Wesbrook Mall
www.vch.ca/EN/find_locations/find_locations/?&site_id=164
Urgent care available daily 8:00 am to 10:00 pm

UBC Area
Vancouver General Hospital (Emergency) 604-875-4111
920 West 10th Avenue
www.vch.ca/EN/find_locations/?&site_id=471
Emergency open 24/7

Downtown Vancouver
St. Paul's Hospital 604-682-2344
1081 Burrard Street
www.providencehealthcare.org
Emergency open 24/7

WALK-IN CLINICS (on Campus):

University Village Medical & Dental Clinic 604-222-2273
228 – 2155 Allison Road
http://members.shaw.ca/universityvillageclinic/
Medical Clinic hours:
Monday – Friday, 8:00 am to 6:00 pm
Saturday, 10:00 am to 4:00 pm
Dental Clinic hours:
Monday – Saturday 9:00 a.m. to 5:00 pm

UBC Health Clinic 604-822-5431
310 – 5950 University Boulevard
clinic.familymed.ubc.ca
Monday – Friday, 9:00 am to 5:00 pm

PHARMACIES (on Campus):

I.D.A. University Pharmacy 604-224-3202
5754 University Boulevard
Monday – Friday, 9:00 am to 8:00 pm
Saturday & Sunday, 10:00 am to 6:00 pm

Save-on Foods 604-221-5999
5945 Berton Avenue
Open daily 7:00 am to 9:00 pm

Shoppers Drug Mart 604-228-1533
5950 University Boulevard
Daily 8:00 am to 10:00 pm

COPYING:

Staples Business Depot Ltd. 604-221-4780
101 - 2135 Allison Road
www.staples.ca
M-F 9:00a.m.-7:00p.m., Sat 10:00a.m.-6:00p.m.,
Sun 11:00a.m.–5:00p.m.

BANKING:

In addition to the banks listed, there are several automated teller machines (ATMs) located on campus. You will also find a number of banks on West 10th Avenue near Sasamat Street.

Bank of Montreal 604-665-7076
105 – 2142 Western Parkway (in Student Union Building)
M-W 9:00a.m.-5:00p.m., Th-F 9:00a.m.-6:00p.m., Sat/Sun closed

Royal Bank of Canada (RBC) 604-221-5702
5905 Berton Avenue
M-Th 9:30a.m.-5:00p.m., Fri 9:30a.m.-6:00p.m.,
Sat 9:00a.m.-4:00p.m., Sun closed

CIBC 604-221-3550
5796 University Boulevard
M-F 9:30a.m.-5:00p.m., Sat 9:30a.m.-4:00p.m., Sun closed

GROCERY SHOPPING

Save-on Foods 604-221-5999
5945 Berton Avenue
(there is a pharmacy at this location)

University Market Place 604-221-5900
(also known as University Village)
5755 Dalhousie Road
www.universitymarketplace.net/shopping.htm

The University Market Place includes a bank (Bank of Montreal), gym, tanning salon and spa, optical shop, medical/dental clinic, flower shop, restaurants, bakeries, tea and coffee shops, clothing store, discount store, produce store, convenience store and a copy centre.

WEATHER

In July, the mean daily maximum temperature is 24 C (75 F) and the mean daily minimum is 15 C (59 F). Contrary to Vancouver's wet reputation, during the summer months it is actually the second driest major Canadian city.

TRAVEL INFORMATION

Bus and Skytrain information	www.translink.bc.ca
Via Rail	www.viarail.ca
BC Ferries	www.bcferries.com
Vancouver International Airport	www.yvr.ca

TAXI SERVICE

A taxi from Vancouver Airport to UBC costs approximately $30 – $40 CAD.

Black Top Cabs	603-731-1111
MacLure's Cabs	604-731-9211
Vancouver Taxi	604-255-5111
Yellow Cab	604-681-1111

QUICK REFERENCE ADDRESSES

Gage Residence
5959 Student Union Blvd.
Vancouver

Life Sciences Bldg
2350 Health Sciences Mall
Vancouver

Marine Drive Residence
2205 Lower Mall
Vancouver

TRIUMF
4004 Wesbrook Mall
Vancouver

University of British Columbia Campus Dining -- 2014 Summer Hours

University Village		
A & W	Burgers, Fries, Shakes	always open
5 Tastes Chinese Bistro	Chinese Food	Daily 10am-2am
Fresh Slice Pizza	Pizza	M-Sat 10am-midnight
McDonald's	Burgers, Fries, Shakes	always open
Mio Japan	Japanese Food	Daily 11am-9pm
One More Sushi (upstairs)	Japanese Food	M-F 11am-3pm, 5pm-10pm
Pita Pit	Pitas, Salads	M-Th 10:30am-1am
Red Burrito	Tacos, Burritos, Fajitas	M-Sat 11am-9:30pm
Subway	Sandwiches, Salads	M-F 7am-10pm
Suga Suishi (upstairs)	Japanese/Korean Food	M-Sat 11am-9:30pm
Vera's Burger Shack	Burgers, Fries, Licensed	Sun-Th 11am-9pm
International Food Court (University Village, Lower Level)		
My Home Cuisine	Chinese Food	Daily 11am-8pm
Osaka Sushi	Japanese Food	Daily 11am-8pm
Timpo Mongolian Grill	Buffet-style Stir-fry	Daily 11am-8pm
Traditional Soup Company	Soup	Daily 11am-8pm
Student Union Building (SUB)		
A & W (Pacific Spirit Place)	Burgers, Fries, Shakes	M-F 7:30am-3pm
Bernoulli's Bagels	Montreal-style Bagels	M-F 7am-2pm
Breakfast Buffet	Breakfast	Daily 6:45am-9am
The Gallery Restaurant & Lounge	Breakfast, Lunch, Licensed	M-F 9am-3pm
The Honour Roll	Sushi	M-F 10am-5pm
The Moon Noodle House	Chinese Food	M-F 11am-5pm
Pasta Bar (Pacific Spirit Place)	Pasta	M-F 10am-2pm
Pie R Squared	Pizza	M-Sun 11am-9pm
The Pit Pub Burger Bar	Burgers, Fish and Chips	M-Sat 11am-9pm
Salad and Soup Bar (Pacific Spirit Place)	Salads, Soup	M-F 11am-2pm
Subway (Pacific Spirit Place)	Sandwiches, Salads	M-Th 8:30am-7pm
Food Outlets Around Campus		
Café MOA	Coffee, Light Meals	M 10am-2pm, T 10am-8pm
Caffe Perugia (Life Sciences Centre)	Coffee, Light Meals	M-Th 7:30am-4:30pm
Hungry Nomad Food Truck	Sandwiches	M-F 11am-2pm
Ike's Café (Irving K. Barber Learning Ctr.)	Coffee, Snacks	M,Th,F 9am-5pm
Koerner's Pub (Grad Centre)	Pub-style Food	M-W 11:30am-9pm
The Loop Café at CIRS	Salad Bar, Vegan, G-F	M-F 9am-2pm
Mahoney and Sons (on University Blvd.)	Pub-style Food	M-W 11am-midnight
Mercante (Ponderosa Commons)	Italian Food	M-F 8am-5pm
Niche Café (Beaty Bodiversity Museum)	Snacks, Light Meals	T-F 11am-3pm
Point Grill (Marine Drive, Bldg. #4)	Bistro-style, G-F, Halal	Daily 11am-10pm
Sage Bistro	Lunch, Licensed	M-F 11:30am-2pm
Sauder Exchange Café (Henry Angus)	Coffee, Light Meals	M-F 8am-3pm
Stir It Up Café (Buchanan Building)	Snacks, Light Meals	M-F 7:30am-2:30pm
Tim Horton's (Forest Sciences Centre)	Coffee, Light Meals	M-F 7am-6pm
Triple O's (David Lam Research Centre)	Burgers, Pasta, Licensed	Daily 11am-7pm

See also: http://www.food.ubc.ca/locations-and-hours *Hours subjec to change without notice. Updated June 28, 2014.*

REGISTRATION

The registration desk will be in the lobby of Gage Towers on Sunday, July 20. It will move to the West Atrium of the Life Sciences building Monday, July 21.

Registration hours*:

Sunday, July 20	16:00 to 21:00
Monday, July 21	07:00 to 18:00
Tuesday, July 22	07:00 to 18:00
Wednesday, July 23	07:30 to 12:00
Thursday, July 24	07:30 to 16:00
Friday, July 25	07:00 to 12:00

*Times are subject to change.

Participants are asked to wear their conference badges at all NS2014-sponsored events.

Your registration includes:

Full Delegate & Students	• Attendance at all sessions • Reception, Poster Session, Banquet • TRIUMF tour • Excursion • Coffee breaks • Copy of the conference guide • Delegate package
Companion A	• Coffee breaks • Reception, Poster Session, Banquet • TRIUMF tour • Excursion
Companion B	• Excursion & Banquet only
Companion C	• Excursion only
Companion D	• Banquet only
Exhibitors	• 1-6’x2’ skirted table & 2 chairs • Attendance at all sessions • Reception, Poster Session, Banquet • TRIUMF tour • Excursion • Coffee breaks • Copy of the conference guide • Delegate package

Extra Tickets

Individual tickets for the Banquet are limited. If there are any tickets left, they will be available at Registration.

Cancellation of Registration

All cancellations must be made in writing to ns2014@conferences.triumf.ca. No refunds will be provided for cancellations after June 6, 2014. This policy also applies to extra tickets, exhibitor and companion registrations. Refunds may be granted under extenuating circumstances. All refunds will be processed after the conference.

Security and Insurance

Nuclear Structure 2014 is not responsible for any materials left unattended. The conference organizers cannot accept liability for personal injuries sustained or for loss or damage to participants' (or companions') personal property during the conference. Please note that the West Atrium of the Life Sciences building is a public space.

Message Board

A message board is located beside the registration desk.

SOCIAL EVENTS

Sunday

Reception 18:00 - 21:00
Sage Bistro (upstairs), 6331 Crescent Road, UBC Campus

Monday

TRIUMF Tour and light refreshments 18:00

A tour of TRIUMF, Canada's National Laboratory for Nuclear and Particle Physics, will be offered following the last talk on Monday, July 21. TRIUMF is a thriving research institution active in the areas of subatomic physics (including particle physics, nuclear structure, fundamental symmetries and astrophysics), life sciences (including cancer therapy and radioisotope production), and materials sciences. Please ensure you wear sensible footwear as the tour route involves a variety of different floor surfaces and stairs. For more information about TRIUMF, visit http://www.triumf.ca.

Pacemaker / ICD Warning: Due to the magnetic fields present on the TRIUMF site, people with heart pacemakers or ICDs (implantable cardioverter defibrillators) may be at risk. Please inform your tour guide if you have a heart pacemaker as the guide will have to take an alternate route.

Tour participants must stay together with the tour guide at all times for the duration of the tour. Persons having had a nuclear medicine scan within the last week should identify themselves with the tour guide. They would likely trigger the portal monitor when entering or leaving the site.

Tuesday

Evening Poster Session 18:00 –20:30
Life Sciences Building, West Atrium

Join us for light refreshments during the poster session on Tuesday evening. This is a great opportunity to check out the posters and network with your fellow scientists.

The exhibitors will be on-hand as well to answer any questions you may have for them.

Wednesday

Wednesday afternoon is a free afternoon with excursions planned for Grouse Mountain and Indian Arm. The outing you have chosen has been selected specifically to give you a West Coast/Vancouver experience. Lunch is included in both excursions.

Buses will leave promptly from in front of Gage Towers at 12:30 p.m.

Thursday

Museum of Anthropology 17:00
6393 North West Marine Drive

Banquet (at Museum of Anthropology)
Reception 18:00
Dinner 19:00

Companion ticket $130.

Enjoy stunning views of the Pacific Ocean and coastal mountains during the NS2014 banquet. Dine amidst the Haida Big Houses and soaring totem poles at the Museum of Anthropology (MOA) on the north end of the UBC campus. Dinner will be served outdoors; please dress accordingly. The MOA's world-class collection showcases objects from around the world, emphasizing the achievements and concerns of the First Peoples and British Columbia's cultural communities. Its exhibitions are designed to stimulate thought and discussion of cross-cultural issues. You will have time to explore the museum's Great Hall and extensive exhibitions before heading outside to dine.

Presentations and Exhibitor Information

ORAL PRESENTATIONS

Speakers are requested to preview/test their presentations prior to their presentation date/time. A computer has been set up in room 1410 for this purpose. Please note that all speakers must give their presentations from the computer systems set up in the session room. Use of individual laptops cannot be accommodated.

All talks MUST be previewed and uploaded at least 24 hours in advance.

POSTER PRESENTATIONS

The poster boards will have a single surface measuring 4' x 4' (1.22 m x 1.22 m) so they will accommodate an ARCH E or A0 sized poster in either landscape or portrait orientation. Poster boards will be provided in the West Atrium of the Life Sciences building.

Day	***Time***
Monday	08:00 - 17:30
Tuesday	08:00 - 20:30 (social event 18:00 - 20:30)
Wednesday	08:00 - 11:45
Thursday	08:00 - 12:00

Posters can be posted Monday morning. Any posters not removed by 14:00 Thursday, July 24 will be removed by staff and discarded.

EXHIBITORS

Exhibitors' tables will be set up in the West Atrium of the Life Sciences building. They will be strategically placed for the best exposure to delegates during the coffee breaks and poster sessions. The West Atrium is a public space that will have security overnight. Room 1410 can be used as an overnight secure storage location for Exhibitors. It will be locked.

Hours:

Monday, July 21	08:00 – 18:00
Tuesday, July 22	09:00 – 18:00
Wednesday, July 23	09:00 – 12:00
Thursday, July 24	08:00 – 12:00

Scientific Program Summary

Monday, July 21

Session M1 (Chair: Petr Navrátil)

08:45 Jonathan Bagger, *Director of TRIUMF*
Welcome

08:55 H.L. Crawford
Neutron knockout to probe 3N forces in the Ca isotopes

09:25 J.D. Holt
Nuclear forces and exotic oxygen and calcium isotopes

09:55 J. Papuga
Laser spectroscopy of neutron-rich K and Ca isotopes up to N=32

10:15 P. Van Duppen
Structure of ^{68}Ni: new insights on the low-lying 0^+ and 2^+ states from two-neutron transfer on ^{66}Ni and β-decay of ^{68}Co

10:35 COFFEE BREAK

Session M2 (Chair: Bruce Barrett)

11:05 A. Gezerlis
Quantum Monte Carlo with modern nuclear forces

11:35 A. Gottardo
Quadrupole collectivity in the Ni isotopes: relativistic Coulex of ^{73,74,75}Ni

11:55 D. Miller
Direct lifetime meaurements of excited states in ^{72}Ni

12:15 E. Sahin
Beta-delayed gamma-ray spectroscopy of neutron-rich ^{75,77}Cu nuclei

12:35 LUNCH

Session M3 (Chair: Jon Batchelder)

14:00 P. Doornenbal
Spectroscopy of exotic nuclei with EURICA

14:30 G. Lorusso
Measurement of 20 new β-decay half-lives into the *r*-process path and the physical conditions of the *r*-process

14:50 P. Baçzyk
The $i_{13/2}$ neutron single particle energy in the ^{132}Sn region

15:10 A. Poves
^{32}Mg + ^{32}Mg = ^{64}Cr: A walk on the neutron rich side

15:30 COFFEE BREAK

Session M4 (Chair: Sonia Bacca)

16:00 G. Hagen
Coupled-cluster computations of medium mass and neutron rich nuclei

16:30 T.R. Rodriguez
Shape transitions, shape mixing and shape coexistence from beyond self-consistent mean field calculations

16:50 P.C. Bender
Exploring the onset of shape coexistence with the d(^{94}Sr,p)^{95}Sr reaction

17:10 K. Nowak
Shape coexistence around N=28: The structure of ^{46}Ar through (t,p) reactions in inverse kinematics

18:00 TRIUMF TOUR

Scientific Program Sumary

Tuesday, July 22

Session T1 (Chair: Furong Xu)

08:45 L.P. Gaffney
Nuclear structure goes pear-shaped

09:15 M. Albers
Octupole strength in neutron-rich nuclei: Multi-step Coulomb excitations of ^{144}Ba with re-accelerated CARIBU beams

09:35 J.F. Smith
New perspectives on octupole collectivity in ^{222}Th from combined γ-ray and electron spectroscopy

09:55 Th. Kröll
Quadrupole collectivity in neutron-rich Cd isotopes .

10:15 J.M. Allmond
Coulomb excitation of radioactive ^{136}Te

10:35 COFFEE BREAK

Session T2 (Chair: Mike Carpenter)

10:55 TBA

11:15 P.T. Greenlees
Shell structure in heavy nuclei

11:45 D. Seweryniak
Study of isomeric states in ^{254}Rf using digital DAQ

12:05 F.G. Kondev
Classification of *K*-forbidden transition strengths

12:25 P. Chowdhury
Rotations built on the highest neutron orbitals

12:45 LUNCH

Session T3 (Chair: Corina Andreoiu)

14:00 D. Rudolph
Superheavy element studies with TASCA at GSI: Spectroscopy of element 115 decay chains

14:30 J.M. Gates
Decay spectroscopy of element 115 daughters

14:50 A.N. Andreyev
Shape coexistence in gold, thallium and astatine isotopes studied by in-source laser spectroscopy at ISOLDE

15:10 A. Voss
Evolution of ground state properties in neutron-deficient francium isotopes

15:30 COFFEE BREAK

Session T4 (Chair: Elena Litvinova)

16:00 S. Quaglioni
Toward a fundamental understanding of nuclear reactions and exotic nuclei

16:30 K. Wimmer
Single-particle structure of neutron-rich N=40 isotopes: A new island of inversion

16:50 M. Petri
Low-lying structure of ^{30}Na and the *sd-pf* shell gap

17:10 R. Roth
Frontiers in ab initio nuclear structure theory

17:30 A. Gargano
Shell structure beyond N=82

18:00 Poster Session - West Atrium

Scientific Program Summary

Wednesday, July 23

Session W1 (Chair: Simon Mullins)

08:45 M. Block
High-precision mass measurements for nuclear structure studies and fundamental physics

09:15 D. Lunney
Recent exploits with the ISOLTRAP mass spectrometer

09:35 A.A. Kwiatkowski
TITAN: mass measurements of short lived and highly charged radionuclides

09:55 Conference Group Photo - location TBD

10:05 COFFEE BREAK

Session W2 (Chair: Iris Dillmann)

10:35 Y.H. Zhang
Precision mass measurements of short-lived nuclides at storage ring in Lanzhou

11:05 R. Grzywacz
Gamow-Teller decay of ^{78}Ni core from beta delayed neutron spectroscopy

11:25 K. Yoshida
Gamow-Teller excitations and β-decay properties of deformed neutron-rich Zr isotopes

11:45 Walk to Gage for excursions

12:30 Buses leave from Gage for excursions

Scientific Program Summary

Thursday, July 24

Session J1 (Chair: Fred Sarazin)

08:45 T. Kibédi
The structure of Hoyle state via pair conversion spectroscopy

09:15 A.N. Kuchera
3*n* decay from ^{15}Be

09:35 C.J. Lister
Precise measurement of the first 2^+ level lifetime in ^{12}Be

09:55 O. Tengblad
Nuclear structure of light halo nuclei determined from scattering on heavy targets at ISAC-II

10:15 A.H. Wuosmaa
Aligned states in ^{12,13}B with the (d,α) reaction

10:35 COFFEE BREAK

Session J2 (Chair: Paul Garrett)

11:05 J. Engel
Nuclear structure theory and double beta decay

11:35 S.W. Yates
Nuclear structure of ^{130,132,134,136}Xe: relevance to shape transitions and 0νββ decay

11:55 A.T. Laffoley
High-precision half-life measurements for the superallowed Fermi β^+ emitters ^{14}O and ^{18}Ne

12:15 C. Ji
Nuclear polarization effects in muonic helium

12:35 LUNCH

Session J3 (Chair: Patrick Regan)

14:00 M.A. Bentley
Spectroscopy of isobaric analogue states in exotic proton-rich nuclei

14:30 R. Wadsworth
Collectivity and shapes of N=Z nuclei at A~70

14:50 S.L. Tabor
Split isobaric analog state in ^{55}Ni: a case of isospin mixing

15:10 H.M. David
Low-lying T=0 states in the odd-odd N=Z nucleus ^{62}Ga

15:30 COFFEE BREAK

Session J4 (Chair: Wolfram Korten)

16:00 O. Sorlin
Spin orbit force and nuclear forces at the drip line

16:30 C. Barbieri
Ab-initio Green's function theory and impact of chiral three-body forces in mid mass isotopes

16:50 P. Morfouace
Decorrelated behaviour of spin-orbit partners in neutron-rich copper isotopes

17:10 S. Leoni
Systematic investigation of coupling of particle-octupole phonon states around closed shell nuclei by transfer, (n,γ) and neutron induced fission reactions

Conference Banquet at Museum of Anthropology, UBC

17:00 Museum of Anthropology opens

18:00 RECEPTION

19:00 DINNER

Scientific Program Summary

Friday, July 25

Session F1 (Chair: Helen Boston)

08:45 R. Palit
Nuclear structure studies with INGA

09:10 G. de Angelis
Gamma ray spectroscopy with AGATA with slow and fast beams

09:35 A.O. Macchiavelli
GRETINA: physics highlights and future plans

10:00 A.B. Garnsworthy
The GRIFFIN spectrometer at TRIUMF-ISAC

10:20 A. Chester
The TIGRESS integrated plunger device for electromagnetic transition rate studies at TRIUMF

10:35 COFFEE BREAK

Session F2 (Chair: Reiner Krücken)

11:05 G. Bollen
Facility for rare isotope beams under construction

11:30 G. Savard
Measurements on neutron-rich isotopes with low-energy and reaccelerated beams at CARIBU

11:55 L. Merminga
The ARIEL facility

12:20 Closing Remarks

14:00 *3rd North American Workshop on Beta-Delayed Neutron Emission*
Iris Dillmann, *Chair*

Abstracts

Part I:

Oral Presentations

in program order

Neutron Knockout to Probe 3N Forces in the Ca Isotopes *

H. L. Crawford[1] for the E12029 Collaboration
[1]*Department of Physics and Astronomy,*
Ohio University, Athens,
OH 45701, USA

Recent calculations by Holt *et al.* [1,2] have suggested that the inclusion of 3N forces to describe the structure of neutron-rich Ca isotopes provides a realistic description of the nuclear structure. Mass measurements [3,4] have confirmed the importance of including 3N forces when starting from basic NN-only interactions, but do not discriminate between these and predictions of well-tested phenomenological interactions in the neutron-rich Ca isotopes.

Neutron knockout along the Z=20 isotopes provides an opportunity to benchmark the more subtle results of NN+3N calculations. The calculations of Holt *et al.* [1] predict a fragmentation of the $1f_{7/2}$ neutron strength from the first $7/2^-$ state in ^{49}Ca into higher lying states, in contrast to the predictions of both the GXPF1 and KB3G phenomenological models, which concentrate the strength in the lowest-lying $7/2^-$ state. Thus, a measurement of neutron spectroscopic factors in neutron knockout from ^{50}Ca provides a test of these calculations. Differences are also predicted for the summed $f_{7/2}$ strength to bound nuclear states in both ^{50}Ca and ^{49}Ca neutron knockout. We will report on a systematic study of one-neutron knockout along the Ca isotopes using GRETINA + S800. A relative measurement, anchored at ^{48}Ca, and a comparison of experimental spectroscopic factors to calculations will be presented, providing insight into the success of NN+3N forces in describing the Z=20 isotopes.

[1] J. D. Holt *et al.*, J. Phys. G **39**, 085111 (2012).
[2] J. D. Holt *et al.*, J. Phys. G **40**, 075105 (2013).
[3] A. T. Gallant *et al.*, Phys. Rev. Lett. **109**, 032506 (2012).
[4] F. Wienholtz *et al.*, Nature **498**, 346 (2013).

*GRETINA was funded by the US DOE - Office of Science. Operation of the array at NSCL is supported by NSF under Cooperative Agreement PHY-1102511(NSCL) and DOE under grant DE-AC02-05CH11231(LBNL).

Notes

Nuclear Forces and Exotic Oxygen and Calcium Isotopes

Jason D. Holt[1,2*]
[1]*Technische Universität Darmstadt, Germany*
[2]*TRIUMF, Vancouver, BC, Canada*

With the advent of next-generation rare-isotope beam facilities worldwide, thousands of undiscovered nuclei, often existing at the limits of stability, will be created and studied in the laboratory. The quest to understand from first principle the properties of these exotic nuclei, many critical for understanding the origin of heavy elements in the universe, represents a cornerstone of modern nuclear science. At the heart of these efforts are three-nucleon (3N) forces. Within the context of valence-space Hamiltonians derived from different ab initio many-body methods, I will discuss the importance of 3N forces in understanding and making new discoveries in two of the most exciting regions of the nuclear chart: exotic oxygen and calcium isotopes.

Beginning in oxygen, I will show that the effects of 3N forces are decisive in explaining why ^{24}O is the last bound oxygen isotope. Furthermore, 3N forces play a key role in reproducing spectra, including signatures of doubly magic ^{22,24}O, as well as properties of isotopes beyond the dripline. The calcium isotopes, with potentially three new magic numbers beyond the standard N=20,28, present a unique laboratory to study the evolution of shell structure in medium-mass nuclei. From the viewpoint of two-neutron separation energies and spectroscopic signatures of doubly magic systems, I emphasize the impact of 3N forces in reproducing the N=28 magic number in ^{48}Ca and in predicting properties of $^{50\text{-}56}$Ca, which indicate new N=32,34 magic numbers. Finally, I will highlight the close connection of this work with recent and future experimental efforts in these regions.

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*e-mail: jholt@triumf.ca

Notes

M1

Laser spectroscopy of neutron-rich K and Ca isotopes up to N = 32

J. Papuga[1], M.L. Bissell[1], K. Kreim[2], R.F. Garcia-Ruiz[1], K. Blaum[2], M. De Rydt[1], H. Heylen[1], M. Kowalska[3], R. Neugart[4], G. Neyens[1], W. Nörtershäuser[4,5], M.M. Rajabali[1], R. Sánchez[6], and D.T. Yordanov[2,7]

1) *Instituut voor Kern- en Stralingsfysica, KU Leuven, B-3001 Leuven, Belgium*

2) *Max-Planck-Institut für Kernphysik, D-69117 Heidelberg, Germany*

3) *Physics Department, CERN, CH-1211 Geneva 23, Switzerland*

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5) *Institut für Kernphysik, TU Darmstadt, D-64289 Darmstadt, Germany*

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Hyperfine spectra of $^{48\text{-}51}$K (Z = 19) and ^{49,51,52}Ca (Z = 20) isotopes were measured at ISOLDE (CERN) for the first time, providing nuclear structure information when filling the $\nu 2p_{3/2}$ orbit up to N = 32. The experiments were performed at the high-resolution collinear laser spectroscopy set-up (COLLAPS) with an improved highly efficient optical detection system. The nuclear spin, nuclear moments and differences in mean square charge radii were determined for isotopes between N = 20 and N = 32. Highlights from these studies will be presented.

The measured ground-state spins of ^{49}K (I = 1/2) and ^{51}K (I = 3/2) shed light on the evolution of the $\pi 2s_{1/2}$ and $\pi 1d_{3/2}$ levels beyond N = 28. The observed re-inversion of these levels points to the role of the monopole interaction in the evolution of the shell structure. In addition, magnetic moments probe the configuration and purity of the ground-state wave function. A considerable mixing of the $(\pi 1d_{3/2}^{-1}\, \nu(fp)_{2+})$ configuration with the $\pi 2s_{1/2}^{-1}$ is needed to reproduce the measured magnetic moment and spin of ^{49}K [1] and also the ground state of ^{48}K has a very mixed structure [2].

The nuclear spin of ^{51}Ca is measured to be 3/2, originating from a hole in the $\nu 2p_{3/2}$. Quadrupole moments of ^{47,49,51}Ca and magnetic moments of ^{49,51}Ca were measured for the first time and form a stringent test of different modern theories far from stability [3].

The mean square charge radii $\langle r^2 \rangle$ in the region beyond N = 28 reveal a monotonic increase which points to a strong N-dependence [4], while below N = 28 a substantial Z-dependence was observed.

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Notes

M1

Structure of ^{68}Ni: new insights on the low-lying 0^+ and 2^+ states from two-neutron transfer on ^{66}Ni and β-decay of ^{68}Co

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Despite a significant set of experimental and theoretical information available on ^{68}Ni [1-8], the origin of its structure is still being questioned. A recent clarification of the energy and spin assignment of several low-lying 0^+ and 2^+ states [4-6] and state-of-the-art shell model calculations [8] hinted to the possibility of triple shape coexistence and highlighted the need of additional experimental investigation.

To better understand the structure of ^{68}Ni, two complementary experiments concerning the two-neutron transfer reactions on ^{66}Ni at 2.85 MeV/u and the β-decay of ^{68}Co were performed at ISOLDE, CERN and will be presented in this talk. On one hand, the ^{66}Ni(t,p)^{68}Ni probed the nature of 0^+ states in ^{68}Ni. Coincidences between the outgoing light charged particles and γ rays were detected using the combined MINIBALL and T-REX detection setup. Angular distributions of the reaction products, revealing the most populated states, will be presented and interpreted via DWBA calculations and shell model two-nucleon amplitudes. On the other hand, the measurement of the β-decay of the low-spin isomer in ^{68}Co selectively produced in the decay chain of ^{68}Mn allowed us to build a revised decay scheme to ^{68}Ni based on the clear identification of β-γ-E0 delayed coincidences. A strong emphasis will be put on the connections between the three lowest lying 0^+ and 2^+ determined from observed transitions and upper limits.

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Notes

Quantum Monte Carlo with modern nuclear forces *

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I will introduce the family of accurate microscopic simulation methods known as Quantum Monte Carlo (QMC). I will also discuss historically significant QMC simulations of light nuclei and pure neutron matter, which used phenomenological nuclear forces as input. I will then go over the efforts toward connecting Quantum Chromodynamics with many-nucleon studies (via chiral Effective Field Theory [EFT]). QMC and chiral EFT were recently fused, via a local reformulation of chiral EFT, which makes it possible to use such modern potentials within the framework of Quantum Monte Carlo. I will show results for light nuclei and neutron matter, including non-perturbative estimates of the theoretical uncertainties.

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M2

Quadrupole collectivity in the Ni isotopes: relativistic Coulex of ^{73,74,75}Ni

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The isotopes from ^{68}Ni to ^{78}Ni are the object of intense studies in modern radioactive beam facilities. The interest in the study of these very exotic isotopes originates from the possible doubly-magic character of the ^{78}Ni isotope, also in connection to the role played by the tensor part of the nuclear Hamiltonian [1]. This force induces shifts of the effective single-particle energies with orbital filling. In the specific case of $^{68-78}$Ni isotopes, it is predicted that the Z=28 gap for protons in the pf-shell becomes smaller moving from ^{68}Ni to ^{78}Ni as a result of the attraction between the proton $f_{5/2}$ and the neutron $g_{9/2}$ orbits and repulsion between the proton $f_{7/2}$ and neutron $g_{9/2}$ configurations thus modifying or even inverting the effective single particle states [1]. This change in the nuclear structure should induce significant quadrupole collectivity in the 2^+ excited states. Indeed, the cause of the large $B(E2 : 2^+ \rightarrow 0^+)$ value observed in ^{70}Ni has been attributed to these effects [2].
Within an experimental EURICA [3] campaign around the ^{78}Ni region, we have simultaneously performed a Coulomb excitation experiment of ^{73,74,75}Ni. Neutron-rich Ni isotopes were produced by fission of a ^{238}U beam. The resulting fragments were analyzed using the BigRIPS separator [4] and transported to a secondary natural Pb target for Coulex reactions. The γ rays from Coulex have been detected by the DALI2 spectrometer [5] in coincidence with the recoiling ions identified at the focal plane of the ZeroDegree spectrometer. The observation of the first excited states in ^{73,74,75}Ni and the measurement of their B(E2) will be presented. They seem to indicate a standard seniority-like structure for the Ni isotopes approaching ^{78}Ni, with no increasing collectivity, at variance with the aforementioned previous work.

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A-13

M2

Direct lifetime measurements of excited states in ^{72}Ni*

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We present the results of an experiment with the TRIPLEX plunger at National Superconducting Cyclotron Laboratory. We measured the lifetimes of the 2_1^+ and 4_1^+ states in ^{72}Ni populated in a proton knockout reaction at intermedate energies using the recoil distance method. The γ-ray spectrum measured by GRETINA was directly compared to that produced by a comprehensive GEANT4 simulation [1] with modifications to incorporate the GRETINA geometry to determine the lifetimes of the states.

The electromagnetic transition strengths deduced from these lifetimes provide a stringent test of shell model calculations due to the small number of valence nucleons involved. Recent $B(E2)$ measurements in ^{70,74}Ni [2,3] indicate increased collectivity in the mid-shell when compared to shell model predictions in the fpg model space and a ^{56}Ni core.

Moreover, recent Monte Carlo shell models [4] including the $d_{5/2}$ orbital fail to reproduce the enhanced $B(E2)$'s shown by the recent experiments [2,3] despite producing a variety of nuclear shapes. The presented lifetime results in ^{72}Ni disagree with this increased collectivity while being in accord with the most current calculations.

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A-15

M2

Beta-delayed gamma-ray spectroscopy of neutron-rich ^{75,77}Cu nuclei

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Shell structure in atomic nuclei is strongly associated with magic numbers originated from a certain arrangement of single-particle states and thus one of the fundamental properties describing the nuclear structure in atomic nuclei. However, for nuclei towards the driplines, in particular where the neutron excess is larger, it is still an open question as to what extent single-particle states will differ from those in stable nuclei. Over a decade ago, T. Otsuka et al. [1] suggested that the tensor interaction has to be taken into account in order to explain expected modifications on the effective single-particle energies when going to the exotic regions in the nuclear chart. It is predicted that the Z=28 gap for protons in the pf-shell becomes smaller when departing from ^{68}Ni towards ^{78}Ni as a result of the attraction between the $\pi f_{5/2}$ and the $\nu g_{9/2}$ orbits and repulsion between the $\pi f_{7/2}$ and $\nu g_{9/2}$ configurations. In such contest, neutron-rich Cu isotopes, having one proton outside of the Z=28 shell, are particularly interesting since they are good probes to see the changes on the single-particle structure close to ^{78}Ni. The aim of the present work is, therefore, to identify the location of low-lying excitations in ^{75,77}Cu which will allow us to trace the evolution of the proton single-particle states towards the Z=28 and N=50 shell closures. The experiments in the region of ^{78}Ni have been performed at RIBF in RIKEN Nishina Center, Japan. Radioactive isotopes were produced via in-flight fission of ^{238}U with an energy of 345 MeV/nucleon on a thick ^{9}Be target. After being selected and identified in the BigRIPS fragment separator, the nuclei of interest were implanted in the WAS3ABi active stopper. The EURICA array with 12 Ge cluster detectors was surrounding the active stopper. The excited states of ^{75,77}Cu were accessed via the β decay of ^{75,77}Ni for the first time. γ coincidence data has been used to build level schemes. Large-scale shell-model calculations are performed using advanced Monet Carlo Shell Model with the pf-$g_{9/2-d5/2}$ model space for both protons and neutrons [2] . A scientific paper is being prepared for Phys. Rev. Lett. and the results in detail will be presented in this contribution.

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M3

Spectroscopy of exotic nuclei with EURICA

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Within the EUROBALL RIKEN Cluster Array (EURICA) project [1,2], exotic nuclei are studied at the Radioactive Isotope Beam Factory (RIBF) via beta, beta-gamma, and isomer spectroscopy. The exotic nuclei are separated in-flight with the BigRIPS fragment separator following fragmentation and induced fission reactions of primary beams at 345 MeV/nucleon. EURICA is located at the end of this BigRIPS/ZeroDegree beam line and consists of twelve Cluster detectors, each containing seven HP-Ge crystals. The produced exotic nuclei are implanted in the highly segmented active stopper WAS3ABi mounted inside EURICA.

After commissioning in early 2012, several campaigns have been performed at the RIBF employing very intense 124Xe and 238U primary beams. In my presentation, I will report on details of the experimental setup and initial results of experiments focusing on the most exotic nuclei spectroscopically studied to date, notably the regions around the doubly-magic ^{78}Ni, ^{100}Sn, and ^{132}Sn.

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Measurement of 20 new β-decay half-lives into the r-process path and the physical conditions of the r-process

M3

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The β decay of about 20 very neutron-rich nuclei with neutron number $N \sim 82$ were studied at the RIBF facility for the elements Ru–Sn. New results include the half-lives of the six r-process waiting points: $^{127}\mathrm{Rh}_{82}$, $^{128}\mathrm{Pd}_{82}$, $^{131}\mathrm{Ag}_{84}$, $^{134}\mathrm{Cd}_{86}$, $^{137}\mathrm{In}_{88}$, and $^{138}\mathrm{Sn}_{88}$. These nuclei determine the formation of the $A = 130$ peak of the solar system abundance pattern and the breakout of the $N = 82$ r-process bottleneck.

The nuclei of interest were produced by in-flight fission of a ^{238}U beam with an energy of 345 MeV/u colliding in a Be target. After identification, fission fragments were implanted into the silicon active stopper WAS3ABi working in conjunction with the EURICA HPGe detector array.

The new data are of great significance for both nuclear structure and astrophysics. The unknown evolution of the $N = 82$ shell closure is, in fact, a main challenge for nuclear models, whose predictions across the shell gap are often diverging. In addition, the new measurements allow a more reliable comparison between the solar system abundance pattern and the predictions of stellar models that constrain the r-process path and its conditions.

This contribution will present the experiment and will discuss its results, with a particular focus on its astrophysics implications.

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M3

The $i_{13/2}$ neutron single-particle energy in the ^{132}Sn region

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The growing knowledge of the nuclei around the ^{132}Sn doubly-magic core helps to predict properties of some, yet unknown, nuclei lying on the path of the astrophysical r-process or to explain the role of tensor forces and the monopole shifts [1, 2]. The reliability of such investigations critically depends on the accuracy of the basic input data, such as single-particle energies.

Around the ^{132}Sn core one encounters an opportunity to study the $i_{13/2}$ neutron orbital which was, for the first time, reported in our previous work [3], where its single-particle energy has been estimated to 2694(200) keV. This puts the $\nu i_{13/2}$ level above the neutron separation energy of 2404(4) keV in ^{133}Sn [4]. The above value has rather large uncertainty. Despite this deficiency this result is the only one available to date and has been used in all the relevant studies. It is now of importance to verify and improve the $\nu i_{13/2}$ experimental energy in ^{133}Sn, both its value and the precision.

Further studies [5-8] as well as our current work, based on the high-fold gamma coincidences from fission of ^{248}Cm and ^{252}Cf, measured with the Eurogam2 and the Gammasphere Ge arrays, respectively, have improved the knowledge of ^{134}Sb and revealed in ^{135}Sb and ^{137}Xe new levels comprising the $i_{13/2}$ neutron. Combining all these results we have determined more precisely the $\nu i_{13/2}$ energy in the region of ^{132}Sn. In this paper we will present the new, improved single-particle energy for the $\nu i_{13/2}$ orbital in the ^{132}Sn core potential and discuss some, incorrect in our opinion, claims presented in previous studies of ^{134}Sb.

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^{32}Mg + ^{32}Mg = ^{64}Cr
A walk on the neutron rich side.

M3

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The N=20 and N=28 "islands of inversion" are be described by Large Scale Shell Model calculations using the interaction SDPF-U-MIX [1] which makes it possible to mix configurations with different N$\hbar\omega$ or equivalently with different number of particles promoted from the sd-shell to the pf-shell. It connects the classical sd-shell calculations below N=18, with the sd(protons)-pf(neutrons) calculations beyond N=24-26, for all the isotopes from Oxygen to Argon, using the same interaction. For some isotopes this range contains all the nuclei between the proton and the neutron drip lines and includes the N=20 and N=28 islands of inversion. The existence of islands of inversion/deformation is explained as the result of the competition between the spherical mean field which favors the 0$\hbar\omega$ configurations and the nuclear correlations which favor the deformed N$\hbar\omega$ configurations. The Magnesium chain is exceptional because in it, the N=20 and N=28 "islands of inversion" merge, enclosing all the isotopes between N=19 and N=30. Indeed, this would be also the case for the Neon and Sodium chains if their drip lines would reach N=28.

The next "island of deformation" at N=40 can be understood as well through LSSM calculations using the effective interaction LNPS [2], which reproduce nicely the experimental data available. At its shore we have to deal with the triple (shape?) coexistence in the low energy spectrum of ^{68}Ni, showing that the highly deformed band based upon the excited 0^+ state at 2627 keV is in fact the natural gateway to the island.

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Coupled-cluster computations of medium mass and neutron rich nuclei

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M4

In this talk I will present recent highlights in computing properties of medium mass and neutron rich nuclei using coupled-cluster theory. The coupled-cluster method is a microscopic theory that can naturally account for (i) effects of three nucleon forces, (ii) the presence of open decay channels and particle continuum, and (iii) many-nucleon correlations. All these ingredients are necessary in order to build a framework with predictive capabilities applicable at the extremes of the nuclear chart and with relevance for experimental programs at rare isotope beam facilities. Recently we used coupled-cluster theory to construct ab-initio effective interactions for the shell model, our first application to the spectra of neutron rich oxygen- and carbon isotopes are very promising [1]. Other recent highlights include ab-initio coupled-cluster calculation of the giant dipole resonance in ^{16}O [2], coupled-cluster calculations of neutron rich calcium isotopes, with an emphasis on the evolution of shell structure. In particular we address the question regarding shell closure in ^{54}Ca [3] and address Efimov physics around the very neutron rich isotope ^{60}Ca [4].

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Shape transitions, shape mixing and shape coexistence from beyond self-consistent mean field calculations*

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M4

The study of the shape evolution, shape coexistence and shape mixing in nuclei [1] from a microscopic point of view has been performed thoroughly with mean field approaches based on energy density functionals. However, it is mandatory to include beyond mean effects to compare with experimental spectra. Hence, symmetry restorations as well as shape mixing included within the generator coordinate method are the perfect tools to study these phenomena [2].
In the last few years, these methods have been implemented with Skyrme [3], relativistic [4] and Gogny [5] functionals including the triaxial degree of freedom. However, due to the high computational cost of such calculations, very few of them have been performed so far, usually focused on individual nuclei rather than isotopic chains. In this contribution, beyond mean field calculations including exact particle number and angular momentum restoration and shape mixing of axial and non-axial shapes with the Gogny force will be presented. In particular, results for ^{44}S [6] and ^{80}Zr [7] nuclei, which exhibit shape mixing and multiple shape coexistence respectively, will be discussed. Finally, the shape evolution of the neutron deficient Kr isotopes (that show shape coexistence [8]), Nd isotopes (related to a possible quantum phase spherical-prolate transition [9]) and Os-Pt isotopes (prolate-oblate transition [10]) will be shown and compared to the most recent experimental data.

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A-29

Exploring the Onset of Shape Coexistence with the d(^{94}Sr,p)^{95}Sr Reaction*

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M4

The structure of nuclei in the $Z \sim 40$, $N \sim 60$ mass region is perhaps best characterized by the deformation seen in the transition from $N = 58-60$ [1]. The competition of both spherical and deformed shell gaps near the Fermi surface in this region leads to a unusually sudden onset of deformation with the addition of only a few nucleons. The similarities in the size of the energy gaps allow a nucleus to have a coexistence of shapes, as has been observed in ^{96}Sr. Work to better understand the competition and stabilization of different shapes in these nuclei is of substantial interest both experimentally and theoretically. To help drive the ongoing theoretical discussion of both mean field [2, 3] and shell model [4] calculations, measurements of the occupations of shape-driving orbitals in this mass region are critical.

The present experiment probes this shape transition region by using a one-neutron transfer reaction with a high mass ($A > 30$) radioactive beam in inverse kinematics, the first such experiment performed at the TRIUMF ISAC-II facility. A ^{94}Sr was produced by impinging a 500 MeV proton beam on an ISAC UC$_x$ target. The extracted beam was charge bred using an ECR to 15^+ before being accelerated to 5.47 MeV/u. The experimental station where the d(^{94}Sr,p)^{95}Sr reaction was performed consisted of the TIGRESS gamma-ray spectrometer [5] used in conjunction with the SHARC charged particle detector [6].

The combination of detected gamma-rays as well as light charged particles is being used to extract energy levels, cross-sections, and proton angular distributions of low-lying states. Analysis of Doppler-corrected gamma-ray transitions show evidence for direct population of at least four excited states in ^{95}Sr. These results will be presented and discussed in the context of the evolution of single-particle structure and compared to modern shell model calculations.

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Shape coexistence around N = 28: The structure of ^{46}Ar through (t,p) reactions in inverse kinematics

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M4

New data on the very exotic nuclei ^{42}Si and ^{44}S that have become available recently [1][2] show a continuous dilution of the N=28 shell gap with decreasing proton number. Located below ^{48}Ca, ^{42}Si is characterized as a well deformed rotor whereas for ^{44}S comparison of experimental data to calculations indicate a prolate-spherical shape. Calculations for ^{46}Ar also show significant 2p-2h excitations, although two very different experimental B(E2) values have been determined [3][4].
In the region around ^{32}Mg it was impressively shown that (t,p) reactions offer an alternative access to the single particle but also collective properties of exotic nuclei. For the latter, the localization of the second excited 0_2^+ state works as a tool to test the underlying shell structure. Therefore, a two neutron transfer experiment t(^{44}Ar,p)^{46}Ar has been performed at the REX-ISOLDE facility at CERN. With a unique, clean and high-intensity radioactive ^{44}Ar beam and a tritium-loaded target, the setup T-REX with an angular coverage close to 4π was used for particle detection. The identification of transfer protons allowed to determine the reaction channel, the excitation energy and the angular distribution, whereas the gamma-ray detection by the T-REX surrounding MINIBALL allowed selection of individual states.
In the combined analysis of particles and gamma-rays, several new states have been identified. Especially the 0_2^+ state as well as its excitation strength are supposed to give information about the 2p-2h excitation in ^{44}Ar. We have clear indications that the first excited 0_2^+ is located much higher in energy than expected by previous measurements [5].

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Nuclear structure goes pear-shaped *

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T1

Deformation in atomic nuclei has become a familiar topic in nuclear structure physics and axial- and reflection-symmetric quadrupole shapes are common across the chart of nuclides. There exists strong circumstantial evidence, however, that nuclei in certain regions of the nuclear chart possess octupole deformed nuclei, or reflection-asymmetric pear-like shapes. It can be expected that the actinide region is the most promising in this respect but so far, only ^{226}Ra, with its relatively long lifetime of 1600 years, has had its octupole collectivity quantified.

Atoms with octupole-deformed nuclei are very important in the search for permanent atomic electric-dipole moments (EDMs). Any non-zero atomic EDM implies a violation of CP-symmetry and is a stringent test to the Standard Model, which predicts EDM values much below the detection limit. The sensitivity of these experiments can be improved by a factor of 100-1000 over the current best case, ^{199}Hg, using octupole-deformed nuclei. Nuclear structure input to these experiments is severely lacking so far.

With the advent of radioactive ion beams and in particular, the ground-breaking ability to post-accelerate the heavy elements radon and radium at REX-ISOLDE, we have recently overcome challenges limiting our knowledge in this region. Coulomb excitation was successfully performed on ^{220}Rn and ^{224}Ra and the $E1$, $E2$ and $E3$ matrix elements connecting the lowest-energy states have been determined [1].

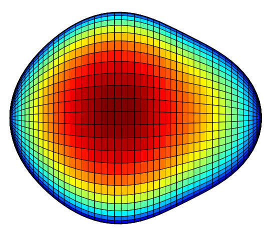

FIG. 1: Representation of the surface of ^{224}Ra

During this talk I will briefly review octupole deformation in nuclei and discuss the results of these pioneering experiments as well as outlining plans for the future. The results are not only significant for nuclear structure, but also on the search for atomic EDMs. The consequence of our results for experiments designed to use octupole-deformed nuclei as a laboratory in their search for EDMs, will also be discussed.

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Notes

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T1

Octupole Strength in Neutron-Rich Nuclei: Multi-step Coulomb Excitation of ^{144}Ba with Re-accelerated CARIBU Beams*

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T1

The strength of octupole collectivity in the Ba region near N = 90 is currently a subject of much interest. While the characteristic E1 transitions between positive and negative parity states have been observed ($I^+ \rightarrow I^- - 1$ and $I^- \rightarrow I^+ - 1$), direct information on octupole strength is missing.

Nuclei in this region are now becoming available as radioactive beams, and Coulomb-excitation experiments can be performed as a result. Recently, the new CARIBU source was installed at the ATLAS facility of the Argonne National Laboratory. In 2013, in a first test, radioactive ^{144}Ba nuclei were successfully extracted from CARIBU and post-accelerated by ATLAS to an energy of ~4.6 MeV/A. In a multi-step Coulomb-excitation reaction on a thin ^{208}Pb target, scattered recoils were detected with the parallel-plate avalanche counter CHICO2 while emitted γ rays were detected by the Gammasphere array. Based on a clear identification of ^{144}Ba particles in CHICO2, coincident γ rays up to spin and parity 8^+ were observed. A follow-up, long-duration experiment is planned for early May 2014 with CHICO2 and the γ-ray tracking array GRETINA.

Results of both experiments will be presented.

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New perspectives on octupole collectivity in ^{222}Th from combined γ-ray and electron spectroscopy

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T1

The recent measurement of E3 moments in $_{86}$Rn and $_{88}$Ra nuclei [1] has heralded a renaissance of interest in octupole collectivity. The largest octupole correlations on the nuclear chart are in the light-actinide region where orbitals with $\Delta\ell=\Delta j=3$ lie close to the Fermi surface for both neutrons ($g_{9/2}$ and $j_{15/2}$) and protons ($f_{7/2}$ and $i_{13/2}$) [2]. The experimental signatures of octupole correlations are typically two rotational sequences of states with opposite parities, connected by enhanced E1 transitions (~10^{-2} W.u. cf. 10^{-5} W.u. in reflection-symmetric nuclei). Such features have now been observed in over 20 nuclei in the light actinide region [3][4]. Despite the wealth of information for the ground-state bands, there is generally very little spectroscopic information in these nuclei beyond that.

The nucleus ^{222}Th has one of the best known examples of a ground-state octupole band. Recently a second, excited rotational band consisting of $\Delta I=1$ and $\Delta I=2$ transitions has been observed in this nucleus. In order to characterize this new band, and to determine the multipolarities of associated transitions, an experiment has been performed at the JYFL laboratory in Finland using the SAGE spectrometer [5]. Prompt γ rays and electrons detected by SAGE at the reaction site were tagged by characteristic α decay of recoils at the focal plane of RITU. The new states in ^{222}Th have been observed and transition multipolarities have been determined through e-γ coincidence analysis. The results and their implications for octupole collectivity in ^{222}Th will be presented.

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Quadrupole collectivity in neutron-rich Cd isotopes *

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T1

The isotope ^{128}Cd, only two proton and two neutron holes away from the shell closures at $Z = 50$ and $N = 82$, exhibits an irregularity unique throughout the nuclear chart: instead of a steep increase approaching $N = 82$ the tentatively assigned excitation energy of the first 2^+ state in ^{128}Cd (652 keV) is slightly lower than in the lighter neighbour ^{126}Cd (645 keV). The value is more than 300 keV smaller than in the isotone ^{132}Te ($E(2^+) = 974$ keV), but also smaller than in the neighbouring ^{126}Pd ($E(2^+) = 693$ keV).

This feature cannot be explained even by the most recent shell model calculations. Currently, only a beyond-mean-field (BMF) approach is capable to reproduce the anomaly predicting a considerable prolate deformation [1]. In particular, a possible shell quenching is also important for nuclear astrophysics to describe the solar abundances around the $A \approx 130$ peak.

In a naive understanding of low-lying collective states, lower $E(2^+)$ values are correlated with larger $B(E2)$ values as reflected in Grodzins' rule. We investigated the exotic isotopes ^{122,123,124,126,128}Cd for the first time by "safe" Coulomb excitation at the REX-ISOLDE facility at CERN. Scattered particles were detected by a DSSSD in coincidence with the γ-rays measured by the 24 6-fold segmented HPGe detectors of the MINIBALL array [2]. Additionally, we studied ^{126}Cd in a lifetime measurement applying the DSA method.

For the isotopes ^{122,124,126}Cd evidence for larger $B(E2)$ values compared to shell model predictions has been found [3]. The quadrupole moments $Q(2^+)$ are more consistent with rather spherical nuclei than strong deformations. The most exotic isotope ^{128}Cd, already 12 neutrons off stability, follows this trend [4].

In this contribution we will present and discuss the results for the ^{122,123,124,126,128}Cd isotopes in comparison with state-of-the-art shell model calculations as well as new BMF calculations including triaxiality.

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Coulomb excitation of radioactive ^{136}Te *

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T1

A HPGe and CsI γ-particle array (CLARION+HyBall) was used to study the Coulomb excitation of radioactive ^{136}Te ($Z = 52$ and $N = 84$) in inverse kinematics with a titanium target. The 2_1^+ and 4_1^+ states of ^{136}Te were populated and $B(E2; 2_1^+ \rightarrow 0_1^+)$, $Q(2_1^+)$, and $B(E2; 4_1^+ \rightarrow 2_1^+)$ were measured. The new $B(E2; 2_1^+ \rightarrow 0_1^+)$ value is larger than the previously published value [1] and it is in better agreement with microscopic calculations. Scattered target nuclei were measured at forward angles relative to the beam direction (corresponding to backward angles in the center-of-mass frame) to provide a clean trigger for selecting the γ-ray transitions from the Coulomb-excited beam and to normalize the integrated beam current through Rutherford scattering; the emitted γ rays from the titanium target provided an additional normalization. A Bragg-curve detector was used at zero degrees to measure the beam composition and energy loss through the target. The emergence of quadrupole deformation and collectivity for two protons and two neutrons outside of the double-magic ^{132}Sn core will be discussed.

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Notes

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T1

Shell structure in heavy nuclei*

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T2

Over the past decade or so, advances in detection technology have lowered the observational limit for studies of heavy and superheavy nuclei. In particular, exploitation of variations of the recoil-decay tagging technique have enabled a great deal of new data to be obtained in nuclei in the so-called ”transfermium” region [1]. In-beam spectroscopic studies can now be carried out at the level of 10 nb and up to Z=104 [2,3].

The transfermium nuclei have proton number Z around 100 and neutron number N around 152, and are quadrupole deformed. Use of coincident α-γ spectroscopy, in-beam spectroscopy of rotational bands, and studies of high-K states has led to a consistent picture of the single-particle structure of nuclei in this region. In turn, this consistent picture from experimental data can be used to confront modern approaches of theoretical nuclear structure physics. An interesting case is the poor reproduction of the deformed shell gaps at Z=100 and N=152 in modern self-consistent approaches based on Skyrme energy-density functionals or relativistic mean field. Attempts to improve the theoretical description of these nuclei are under way [4].

An overview of the most recent experimental and theoretical studies of heavy nuclei will be given.

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Study of isomeric states in ^{254}Rf using digital DAQ*

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T2

Deformed, axially-symmetric nuclei in the transfermium region are known to exhibit high-K isomerism, owing to the presence of high-K orbitals near both the proton and neutron Fermi surfaces. The properties of such isomers provide important information on the single-particle structure in the region, as well as on the role played by the pairing and residual nucleon-nucleon interactions.

^{254}Rf nuclei were produced using the ^{50}Ti+^{206}Pb reaction with a cross section of only 2 nb and studied using the Fragment Mass Analyzer at ANL and the Berkeley Gas-Filled Separator at LBNL. A digital data acquisition system was employed to measure decays as fast as ~100 ns. Recoil implantation followed by fast bursts of electrons and γ rays and subsequent fission of the ^{254}Rf ground state were observed. The electrons and γ rays were interpreted as being emitted from two isomeric states in ^{254}Rf with halflives of ~4 μs and ~300 μs and isomeric ratios of ~15% and ~1%, respectively, analogous to the two- and four-quasiparticle isomers in ^{254}No.

The data will be shown and the results will be compared with predictions of multi-quasiparticle blocking calculations that include empirical estimates for the residual configuration-dependent, nucleon-nucleon interactions.

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Classification of K-forbidden transition strengths*

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T2

Electromagnetic transitions from high-K states in deformed nuclei are usually discussed in terms of the nominal forbiddenness, ν = ΔK - λ which, for $\nu > 1$ represents the shortfall between the change in the projection K and multipolarity λ. The usual analysis procedure has been to extract the so-called reduced hindrances given by f_ν = $F_W^{1/\nu}$, where $F_W = \frac{\tau_\gamma}{\tau_W}$, the partial lifetime compared to the Weisskopf estimate. Early work by Gallagher [1] and Rusinov [2] was followed by Löbner [3] who confirmed that the observed hindrances roughly scale, with a dependence that implies that f_ν is approximately a constant of magnitude $\sim$ 100. This has been the basis of much of the subsequent discussion of K-hindrances.

From a recent compilation of K-forbidden transition strengths [4], it has been possible to quantify and expand the analysis of [3], which gave only a simple range for each value of ΔK, to show the distribution for $E1$, $M1$ and $E2$ multipolarities. This leads us to the suggestion of a factorization of the total hindrance into two components, (as already implied by Löbner [3]), so that

$$F = F_0 \times (f_0)^\nu = F_0 \times (f_0)^{\Delta K - \lambda}$$

where F_0 is the underlying (multipolarity-dependent) intrinsic hindrance and f_0 is the additional factor due to K-forbiddenness.

Values for each of the factors can be extracted by fitting to the centroids of the observed distributions, noting that there are anomalous cases that can significantly skew the distributions if not accounted for. The nuclear structure effects - Coriolis mixing, random interactions etc. - which contribute to these will be outlined. The analysis shows that the extracted value of f_0 for the three multipolarities is an order of magnitude smaller than the rule-of-thumb value of $f_\nu \sim 100$ normally used in interpreting the nuclear structure.

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T2

Rotations built on the highest neutron orbitals*

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T2

Deformation and angular momentum play a key role in providing an experimental basis for probing the physics of very heavy nuclei, and, in shell-stabilized A~250 nuclei, high-spin studies provide important checks for theoretical model predictions. While fusion-evaporation reactions with stable beams and targets are the only method for populating $Z \geq 100$, inelastic and transfer reactions can populate nuclei with the highest neutron numbers ($N \leq 154$), using long-lived radioactive $94 < Z < 98$ targets.

High-spin states in ^{245,246}Pu (Z=94), $^{246\text{-}250}$Cm (Z=96) and $^{248\text{-}251}$Cf (Z=98) nuclei were populated in a series of experiments using ^{208}Pb and ^{209}Bi beams from the ATLAS facility at Argonne, incident on radioactive ^{244}Pu, ^{248}Cm, ^{249}Cf, and mixed $^{249\text{-}251}$Cf targets. Multiple new rotational bands in 150<N<154 nuclei were identified using the Gammasphere array up to typical spins of ~25$\hbar$ [1]. The new results, coupled to recent studies in this region [2], provide spectroscopic information on the alignment frequencies for the first nucleon pair over an N-Z landscape that includes the highest neutron orbitals. With sparse data to date, prevalent models have been chronically deficient in predicting the competition between $i_{13/2}$ proton and $j_{15/2}$ neutron pairs in these heaviest nuclei. The new odd-A results allow a disentangling of competing alignments by comparing rotations built on configurations where the $\nu j_{15/2}$ alignment is either allowed or blocked. Higher multipole deformations, namely β_6, appear crucial for understanding the observed alignments. Finally, new insight is gained on the evolution of neutron pairing as the Fermi level traverses the N=152 sub-shell gap.

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Superheavy Element Studies with TASCA at GSI: Spectroscopy of Element 115 Decay Chains

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T3

During the past decade, correlated α-decay chains, which all terminate by spontaneous fission, have been observed in several independent experiments using ^{48}Ca-induced fusion-evaporation reactions on actinide targets. These are interpreted to originate from the production of neutron-rich isotopes with proton numbers up to $Z = 118$ [1].

Following successful studies on the synthesis and decay [2, 3] as well as the chemistry [4] of flerovium ($Z = 114$), the reactions ^{48}Ca + ^{243}Am, ^{48}Ca + ^{249}Bk, ^{50}Ti + ^{249}Bk, and ^{50}Ti + ^{249}Cf have been investigated recently at the gas-filled ”TransActinde Separator and Chemistry Apparatus” (TASCA) at GSI Darmstadt. In several-months long campaigns, high sensitivity was reached, especially in the search for element 119. Decay chains of element 117 are being reported [5].

Since neither the mass, A, nor the atomic number, Z, of any of the new elements had been measured directly, the TASISpec set-up [6, 7] was employed for high-resolution α, electron, X-ray and γ-ray coincidence spectroscopy to search for α-X-ray events to identify uniquely atomic numbers of isotopes along $Z = 115$ decay chains [8–10].

Latest results of this 2011-2012 TASCA campaign are going to be presented, with a focus on nuclear structure aspects of the comparatively comprehensive spectroscopic data on element 115 and its daughters.

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Decay Spectroscopy of Element 115 Daughters*

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T3

Over the last 15 years, a collaboration working at Flerov Laboratory for Nuclear Reactions [FLNR] has reported the discovery of six new superheavy elements (SHE) with proton number Z=113-118 [1]. Despite knowing about SHE for more than a decade, little is known about the structure of these nuclei. However, modern separators and detectors now allow for detailed α-γ or e^--γ spectroscopy of the heaviest elements [2].

In April – June 2013, forty-three decay chains matching those reported for ^{288}115 were produced during a five-week long experiment at Lawrence Berkeley National Laboratory (LBL) using the ^{243}Am(^{48}Ca,x*n*) reaction. The element 115 evaporation residues were separated with the Berkeley Gas-filled Separator [3] and implanted into the Corner-Cube-Clover (C3) detector. The C3 detector is designed for the detection of γ-rays in prompt coincidence with the α-decay of heavy elements (i.e. element 115 and its daughters). A similar experiment at GSI involving the LUND/GSI/LBL collaboration reported 22 correlated decay chains assigned to ^{288}115 [4]. Here we report results from the LBL experiment interpret the combined data set.

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Shape coexistence in gold, thallium and astatine isotopes studied by in-source laser spectroscopy at ISOLDE

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T3

The competition between spherical and deformed configurations at low energy gives rise to shape coexistence in the neutron-deficient isotopes around Z~82 and N~104 [1], while on the neutron-rich side effects due to octupole deformation in the vicinity of N~133 could be important. In order to determine to which extend the ground and isomeric states of these nuclides are affected by these phenomena, an extended campaign of investigation of changes in the mean-square charge radii is being conducted at ISOLDE by the Windmill Collaboration. The measurements rely on the high sensitivity provided by a combination of the in-source laser spectroscopy with RILIS, ISOLDE mass separation and Windmill spectroscopy setup [2].

In this contribution, we will present the systematics of charge radii recently obtained for the light thallium isotopes [3,4], the astatine chain and the lightest isotopes $^{177\text{-}182}$Au [5]. In the gold and astatine cases, the Multi-Reflection Time-of-Flight (MR-ToF) mass separation technique [6], involving the ISOLTRAP collaboration, was used for the first time. With the newly-acquired data, the gold chain demonstrates the unique behavior whereby the transition occurs from the nearly-spherical shapes in $^{187\text{-}197}$Au, to strongly-deformed in $^{180\text{-}186}$Au, and finally back to more spherical ones in ^{177,179}Au.

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Evolution of Ground State Properties in Neutron-Deficient Francium Isotopes

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T3

Francium is the heaviest known alkali metal. As one of the very few elements with no stable isotope, it is also the least well studied of the alkali group. Francium isotopes recently attained much interest as their relatively simple atomic structure with just one valence electron outside otherwise closed shells and high nuclear charge (hence a large nuclear volume) make it an ideal laboratory for the investigation of parity non-conservation effects in atoms as well as investigations into the time evolution of fundamental constants. However, for either of these effects to be extracted with any degree of certainty, it is important to understand both the nuclear and atomic structures involved, in both experiment and theory, over as large a range of isotopes as possible. Detailed measurements of the nuclear spin, electromagnetic moments and change in root mean-squared charge radii provide invaluable input and benchmark tests for theoretical treatments of the systems.

Collinear laser spectroscopy has been the workhorse at radioactive ion beam facilities for decades and is at the forefront of today's nuclear physics. If performed with high-resolution, collinear laser spectroscopy on fast beams provides a model-independent determination of some of the most fundamental nuclear properties, including the nuclear spin, electromagnetic moments as well as changes in mean-squared charge radii, through atomic hyperfine structures and isotope shifts along isotopic chains.

In this contribution, the laser spectroscopic work performed at TRIUMF-ISAC [?] probing the neutron-deficient isotopes around the $N = 118$ neutron subshell closure will be presented. In addition to the standard photon background reduction using bunched beams a new technique was developed to further minimise the laser scattered background as well as to reduce hyperfine pumping. That method will be introduced alongside interpretation of the nuclear physics results.

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Toward a fundamental understanding of nuclear reactions and exotic nuclei

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T4

Nuclear systems near the drip lines offer an exciting opportunity to advance our understanding of the interactions among nucleons, which has so far been mostly based on the study of stable nuclei. However, this is not a goal devoid of challenges. From a theoretical standpoint, it requires the capability to address within an *ab initio* framework not only bound, but also resonant and scattering states, all of which can be strongly coupled. The *ab initio* no-core shell model with continuum [1] provides a unified framework for the description of structural and reaction properties of light nuclei. In this approach the nuclear many-body states are seen as superimpositions of continuous cluster wave functions in the spirit of the resonating-group method [2] and square-integrable eigenstates of the A-nucleon system. Each cluster of nucleons and the compound nuclear states are obtained within the ab initio no-core shell model [3]. In this talk I will present *ab initio* calculations of nucleon [4] and deuterium scattering on light nuclei starting from chiral two- and three-body Hamiltonians as well as the first investigation of the low-lying continuum spectrum of ^{6}He within an *ab initio* framework that encompasses the ^{4}He+n+n three-cluster dynamics characterizing its lowest decay channel.

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Single-particle structure of neutron-rich $N = 40$ isotopes: A new Island of Inversion*

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T4

The region around neutron-rich $N = 40$ nuclei has recently attracted a lot of interest. The high-lying 2^+ state in ^{68}Ni and its small transition probability to the ground state are a result of the $N = 40$ harmonic oscillator shell gap between the fp shell and the $1g_{9/2}$ orbital. This shell gap is reduced for the more neutron-rich Fe and Cr isotopes; both the $N = 40$ isotones ^{66}Fe and ^{64}Cr show an increase in quadrupole collectivity [1]. This behavior is caused by quadrupole correlations which favor energetically the deformed intruder states from the neutron $\nu g_{9/2}$ and $\nu d_{5/2}$ orbitals. In the shell model the increase in $B(E2)$ values and the decrease in 2^+ excitation energy can be reproduced if the neutron $\nu g_{9/2}$ and $\nu d_{5/2}$ intruder orbitals are included in the model space [2].

Spectroscopic studies of neutron-rich nuclei around $N = 40$ have been performed at the NSCL utilizing the S800 spectrometer and the GRETINA gamma detector array. The study focused on the one-neutron removal reactions from ^{68}Ni and ^{64,66}Fe. The longitudinal momentum distribution of reaction residues indicates the angular momentum of the removed nucleon, and spectroscopic factors can be extracted from the measured cross section for the population of individual states in the odd-mass residual nucleus. An experimental challenge in this region of the nuclear chart is the occurrence of low-lying isomeric states resulting from the neutron $\nu g_{9/2}$ intruder orbital. This experiment employs a new technique of combined prompt and delayed γ-spectroscopy allowing to quantify the occupancy of the intruder neutron $\nu g_{9/2}$ and $\nu d_{5/2}$ orbitals in ^{68}Ni and ^{64,66}Fe. Comparison of the measured spectroscopic factors with large-scale shell model calculations show a significant occupation of the intruder orbitals across the $N = 40$ sub-shell gap. Therefore the existence of a new "Island of Inversion" at $N = 40$ has been experimentally verified for the first time.

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Low-lying structure of ^{30}Na and the *sd-pf* shell gap*

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Light neutron-rich nuclei around N≈20 show properties that are not in line with their expected magicity but rather imply a deformed shape. These nuclei lie in the so-called "Island of Inversion" where the deformation is due to neutron cross-shell excitations, namely $\nu(sd)^{-2}(fp)^{2}$ configurations, dominating their ground and low-lying states. Recently, there has been much interest in studying the transition towards this region to determine the evolution of the N=20 shell gap and to provide a stringent test for nuclear models.

In this work the odd-odd nucleus ^{30}Na is studied via 1p, 1p1n and 1n knockout reactions at the NSCL using ^{31}Mg, ^{32}Mg and ^{31}Na radioactive beams, respectively. Combining high-resolution γ-ray spectroscopy with the selectivity of the various reaction mechanisms we are able to distinguish multiple distinct configurations. Negative parity states in ^{30}Na are identified for the first time, providing an important measure of the excitation of the 1p1h configuration. Gamma rays de-exciting both K=1 and K=2 2p2h structures have been observed, while the rotational band built on the ground state has been established. These new results provide a stringent test for the state-of-the-art effective interactions used in this region and constrain the *sd-pf* shell gap.

T4

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Frontiers in Ab Initio Nuclear Structure Theory*

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T4

Low-energy nuclear theory has entered a new era of ab initio nuclear structure and reaction calculations connected to QCD via chiral effective field theory. The universal input for these calculations are two- and three-nucleon interactions constructed within chiral effective field theory. On this basis, ab initio theory is advancing into different directions, covering an increasing range of nuclei and nuclear observables.

In this talk we summarize recent developments on the theoretical inputs and tools, ranging from the chiral interactions over similarity renormalization group transformations to various ab initio many-body approaches, that enable us to attack new frontiers in nuclear theory. We address ab initio calculations for the structure and spectroscopy of p- and sd-shell nuclei, e.g., throughout carbon and oxygen isotopic chains, using the importance truncated no-core shell model [1] and we compare to in-medium similarity renormalization group calculations [2,3]. We discuss recent breakthroughs in the ab initio description of ground states of medium-mass and heavy nuclei up to the tin isotopes in the coupled-cluster framework with chiral two- plus three-nucleon interactions [4,5,6]. Finally, we present the first ab initio calculations for p-shell hypernuclei using chiral Hamiltonians [7]. Together with the corresponding advances in low-energy reaction theory these examples highlight the broad and exciting perspectives that ab initio nuclear theory offers nowadays.

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T4

Shell structure beyond $N = 82$

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T4

A central theme of modern nuclear physics is the evolution of the shell structure when approaching the neutron drip line. Thanks to the availability of radioactive ion beams (RIBs) and advances in detection techniques, experiments performed in the last twenty years have evidenced shell structure changes when nuclei have a large excess of neutrons, leading to the breakdown of the traditional magic numbers and the appearance of new ones. These findings, which have come out in particular for light and medium mass nuclei, have driven a great theoretical effort to understand the microscopic mechanism underlying the shell evolution, with special attention to the role of the different components of the nuclear force (see, for istance, [1]).

While experimental information for nuclei around ^{132}Sn is now available, data for systems with $N > 82$ remain still scarce. In this case, some peculiar properties have been observed which do not seem, however, to be a clear signature of a modification in the shell structure. New data are certainly needed to clarify this point, which may be provided by the next generation of RIB facilities.

Over the past several years, we have performed various shell-model studies [2] of neutron-rich nuclei beyond ^{132}Sn, which have all yielded results in very good agreement with experiment. In all these studies a unique Hamiltonian has been used with single-particle energies taken from experiment and the two-body effective interaction derived from the CD-Bonn nucleon-nucleon potential [4] without using any adjustable parameter.

Here we shall present some selected results and show how our microscopic effective interaction is able to account for the available observed properties. Predictions that may provide guidance to future experiments will be also discussed.

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High precision mass measurements for nuclear structure studies and fundamental physics

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High precision mass measurements with Penning traps are employed for nuclear structure studies of exotic nuclides. Structural effects such as shell closures and the onset of deformation are reflected in nuclear binding energies that are obtained from masses. Masses allow us to track the evolution of magic numbers and to measure the strength of shell effects even far away from stability. The combination of buffer gas stopping and advanced ion manipulation techniques has extended the reach of Penning trap mass spectrometry to radionuclides of essentially all elements. Recently, direct mass measurements have been performed also in the region of the heaviest elements [1]. In addition, new developments like the novel PI-ICR method [2], where the mass is obtained based on a phase measurement of the ion motion, pave the way to reach shorter-lived and ever more exotic nuclides.

W1

In my presentation I will show results concerning the structure of the heaviest elements and discuss the shell effects at $N = 152$ and $N = 162$, also in comparison with theoretical predictions. In addition, I will introduce the PI-ICR method and present selected results for mass measurements of nuclides relevant in the context of neutrino physics.

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W1

Recent exploits with the ISOLTRAP mass spectrometer

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W1

Mass measurements have a long tradition in the elucidation of nuclear structure and the advent of Penning-trap mass spectrometry has made a substantial impact. The associated development of ion traps at on-line facilities has also enabled new approaches for the study of exotic nuclides.

This contribution is centered on the recent integration of an electrostatic ion-beam trap, also called a multi-reflection time-of-flight (MR-ToF) mass spectrometer [1], into the ISOLTRAP experiment at ISOLDE. The MR-ToF MS is a versatile device that achieves very high resolving power (above 100,000) very quickly (tens of milliseconds). In conjunction with a new ion-stacking technique [2], we describe the use of the MR-ToF device as: a separator, enabling isobaric purification of ISOL beams for a Penning-trap mass measurement of ^{82}Zn to probe neutron-star crusts [3]; a spectrometer, to measure the mass of ^{54}Ca, highlighting the magic stature of the $N = 32$ nuclide ^{52}Ca [4]; and a fast isobar-resolving monitor of the ISOLDE beam while changing target parameters [5]. Using the MR-ToF MS for hyperfine structure scans with in-source laser ionization [5,6] has provided exciting results concerning shape transitions in neutron-deficient nuclides below $Z = 82$.

The ISOLDE facility will re-open in the summer of 2014 and future experimental plans will be discussed.

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TITAN: mass measurements of short lived and highly charged radionuclides*

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W1

The atomic mass encompasses all underlying interactions among the constituent particles and, thus, provides crucial insight into nuclear structure, nuclear astrophysics, and fundamental symmetries, including neutrino physics, among other disciplines. Currently Penning trap mass spectrometry (PTMS) offers the highest precision and accuracy. TRIUMF's Ion Trap for Atomic and Nuclear (TITAN) science facility has leveraged its fast beam preparation and the high yields at TRIUMF-ISAC to perform PTMS on ^{34}Mg ($T_{1/2}$ = 20 ms), the second shortest lived nuclide measured with PTMS, and its neighbors in the island of inversion. These measurements are critical to understanding the intruder mechanism and the transition from the spherical Si isotopes to the highly deformed Mg isotopes. Investigations of isospin symmetry breaking have led to mass measurements of ^{20,21}Mg to test the isobaric multiplet mass equation (IMME) and to compare to shell model predictions. TITAN has also pioneered charge breeding of radionuclides for PTMS. These efforts have resulted in a high-precision mass measurement of the superallowed β emitter ^{74}Rb as well as high-precision Q-value determinations to clarify the "gallium anomaly" in neutrino physics. Recent highlights from the TITAN research program will be presented.

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Notes

A-75

W1

Precision mass measurements of short-lived nuclides at storage ring in Lanzhou*

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W2

Nuclear mass is the fundamental property of a nucleus. The complex interplay of strong, weak and electromagnetic interactions in the nucleus contributes to the difference between its mass and the sum of the masses of its constituent nucleons. Precise and systematic measurements of nuclear masses not only provide information on nuclear structure, but also find their important applications in nuclear astrophysics.

Recent commissioning of the Cooler Storage Ring at the Heavy Ion Research Facility in Lanzhou (HIRFL-CSR) has allowed us for direct mass measurements at the Institute of Modern Physics in Lanzhou (IMP), Chinese Academy of Sciences (CAS). In the past few years, a series of mass measurement experiments have been carried out using the CSRe-based isochronous mass spectrometry (IMS). Masses of short-lived nuclides of both neutron-rich and neutron-deficient have been measured up to a relative precision of $10^{-6} \sim 10^{-7}$ via fragmentation of the energetic beams of ^{58}Ni, ^{78}Kr, ^{86}Kr, and ^{112}Sn [1-4]. In this talk, the experiments and the results will be presented. The implications of our experimental results with respect to nuclear structures and stellar nucleosynthesis in the rp-process of x-ray bursts are discussed.

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* This work was supported by many agencies under several contracts: the 973 Program of China (2013CB834401), the NSFC (11035007, U1232208), BMBF (Projekt-Nr. 01DO12012), and CAS (2009J2-23).
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Notes

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W2

Gamow-Teller decay of ^{78}Ni core from beta delayed neutron spectroscopy

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Beta-delayed neutron emission (βn) is the dominant decay channel for the majority of very neutron-rich nuclei. Because this process directly probes relevant physics on the microscopic level, energy-resolved measurements of the beta-decay strength distribution constitute a strong test of nuclear models. A new detector system called the Versatile Array of Neutron Detectors at Low Energy (VANDLE) [1,2] was constructed in order to study decays of very neutron-rich fission fragments. In its first experimental campaign at the Holifield Radioactive Ion Beam Facility neutron energy spectra, in key regions of the nuclear chart were measured: near the shell closures at ^{78}Ni and ^{132}Sn, and for the deformed nuclei near ^{100}Rb. Many of the studied nuclei lie directly on proposed paths of the r-process. In several cases, unexpectedly intense and concentrated, high-energy neutron transitions were observed. Furthermore, models suggest that these decays are due to large amplitude Gamow-Teller transformations of the ^{78}Ni core.

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* This research was sponsored in part by the National Nuclear Security Administration under the Stewardship Science Academic Alliances program through DOE Cooperative Agreement No. DE-FG52-08NA28552 and the DOE Office of Nuclear Physics.

Gamow-Teller excitations and β-decay properties of deformed neutron-rich Zr isotopes *

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The Gamow-Teller (GT) strength distribution has been extensively investigated not only because of interest in nuclear structure but also because β-decay half-lives set a time scale for the rapid-neutron-capture process (r-process), and hence determine the production of heavy elements in the universe. The r-process path is far away from the stability line, and involves neutron-rich nuclei. They are weakly bound and many of them are expected to be deformed according to the systematic Skyrme-EDF calculation.

Recently, β-decay half-lives of neutron-rich Kr to Tc isotopes with $A \simeq 110$ located on the boundary of the r-process path were newly measured at RIBF [1]. The ground-state properties such as deformation and superfluidity in neutron-rich Zr isotopes up to the drip line had been studied by the Skyrme-EDF method, and it had been predicted that the Zr isotopes around $A = 110$ are well deformed in the ground states [2].

To investigate the GT mode of excitation and β-decay properties of the deformed neutron-rich Zr isotopes, we constructed a new framework of the deformed HFB + proton-neutron QRPA employing the Skyrme EDF self-consistently in both the static and dynamic levels [3]. We find that the $T = 0$ pairing enhances the low-lying strengths cooperatively with the $T = 1$ pairing correlation, which shortens the β-decay half-lives by at most an order of magnitude. The new calculation scheme reproduces well the observed isotopic dependence of the β-decay half-lives of deformed $^{100-110}$Zr isotopes.

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W2

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The structure of the Hoyle state via pair conversion spectroscopy *

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J1

Carbon is a major player in the evolutionary scheme of the universe because of its abundance and its ability to form complex molecules. Although it is well established that the source of carbon is the 3α (triple-alpha) nuclear reaction, the rate at which this process occurs in stars, via the Hoyle state in ^{12}C, is surprisingly poorly known. The current uncertainty of $\sim$12.5% on the radiative width of the 7.654 MeV E0 and 3.215 MeV E2 transitions de-exciting the Hoyle state limits our understanding of stellar evolution and nucleosynthesis. We propose to directly observe the electron-positron pairs of both electromagnetic transitions from the Hoyle state using the ANU superconducting electron spectrometer, Super–e [1]. The radiative width of the Hoyle state will be deduced from the relative intensity of the E0 and E2 transitions, from the theoretical pair conversion coefficient of the E2 transition and from the pair–width of the 7.6 MeV E0 transition. The spectrometer was significantly modified to detect high energy electron–positron pairs with well defined energy–sharing and separation angle. Key component of the measurements is an array of six Si(Li) detectors, each 9 mm thick to fully absorb electrons and positrons up to 3.5 MeV energy. The detector is well shielded from the intense photon background produced in the ^{12}C(p,p') reaction at 10.5 MeV resonant energy. In comparison to previous measurements based on bare scintillator detectors, the new magnetic pair spectrometer offers a much higher selectivity for electrons and positrons, combined with improved energy resolution.

This talk will focus on the development of the new pair spectrometer, and the analysis procedures required to determine the relative pair yields of the 7.654 MeV and 3.215 MeV transitions with high precision. Results of the first experiments with the new magnetic pair spectrometer will be also reported.

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3*n* decay from ^{15}Be*

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The neutron-unbound nucleus ^{15}Be was recently observed for the first time [1]. A resonance at 1.8(1) MeV which decays to the ground state in ^{14}Be was found using a (*d,p*) reaction from a ^{14}Be beam and tentatively assigned to have a spin and parity of $5/2^+$. Previously, a two-proton knockout reaction from ^{17}C, which was expected to populate the $3/2^+$ state, did not produce a significant number of one-neutron decay events from ^{15}Be, therefore only an upper limit for the cross section could be determined [2]. Both experiments used the Modular Neutron Array (MoNA) together with the Sweeper dipole magnet and charged particle detectors to make measurements of the neutron-fragment coincidences from the decay of the neutron-unbound systems. The $^{17}\mathrm{C}-2p\rightarrow{}^{15}\mathrm{Be}$ data was recently analyzed to search for the missing $3/2^+$ state in the 3*n* decay channel. This unbound state in ^{15}Be would then sequentially decay through the first excited unbound state of ^{14}Be, which then decays by two neutrons to ^{12}Be.

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* This work was supported by the National Science Foundation under Grant Nos. PHY-06-51627, PHY-06-06007, PHY-10-68217, and PHY11-02511; the Department of Energy National Nuclear Security Administration under Award No. DE-NA0000979; and DOE Award No. DE-FG02-92ER40750.
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Precise Measurement of the First 2^+ Level Lifetime in ^{12}Be*

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For many years, it has been suggested that ^{12}Be exhibits a breakdown of the N=8 shell gap. This reflects the tension between the propensity for alpha clustering in beryllium, with ^{12}Be appearing as a 2-alpha dumb bell bound by a cloud of four poorly bound neutrons, and a conventional Shell Model picture with the N=8 neutrons filling the p-shell and holding the nucleus to a near spherical shape. Evidence for this tension can be seen in 1-neutron knockout where nearly equal s and p spectroscopic strengths were first discovered [1] and later even a significant d wave component [2] in the ground state wave function. The first 2^+ level energy decreases dramatically from 3.3 MeV in ^{10}Be to 2.1 MeV in ^{12}Be, suggesting a loss of sphericity at N=8 and the occurrence of an "island of inversion" driven by clustering. However, the corresponding B(E2) strength from the first 2^+ also decreases somewhat in moving from ^{10}Be to ^{12}Be, although the latter value stems from a single measurement [3] with large uncertainty.

To provide a better understanding of the extend of the breakdown of the N=8 shell gap, the lifetime of the first 2^+ state in ^{12}Be was measured using intermediate-energy inelastic scattering of a ^{12}Be beam combined with the Doppler Shift attenuation method. Gamma rays emitted at the target position were measured with GRETINA in coincidence with reaction residues detected in the S800 spectrometer at NSCL. Three different targets were measured, allowing for consistency checks and a better understanding of systematic effects. Preliminary results on the B(E2) transition strength from the first 2^+state in ^{12}Be will be presented.

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J1

Nuclear Structure of light halo nuclei determined from Scattering on heavy targets at ISAC-ll

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The loosely bound structure of halo nuclei should affect the collisions with heavy targets at energies around the Coulomb barrier. One can thus expect a departure from Rutherford scattering. This deviation shed light on the structure as well as on how the scattering process depends upon the coupling to the continuum.

The interplay of two effects will occur: Firstly, the Coulomb break-up reduces the elastic cross section. Secondly, the distortion of the wave function, generated by the displacement of the charged core with respect to the centre of mass of the nucleus, reduces the Coulomb repulsion, and thus the elastic cross sections.

We report here on a series of experiments performed at ISAC-ll at TRIUMF to study the behaviour of the scattering of the light halo nuclei ^{11}Li and ^{11}Be on heavy targets.

The results are interpreted in the framework of 4-body Continuum-Discretized Coupled-Channel calculations. The departure from Rutherford scattering at energies below the barrier is well beyond the expected behaviour. Further more, the breakup probability data shed light on the effective breakup energy as well as on the slope of the B(E1) distribution.

J1

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Aligned states in ^{12,13}B with the (d,α) reaction*

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We have used the ^{14,15}C(d,α)^{12,13}B reactions in inverse kinematics to study aligned states at high excitation energy in the neutron-rich isotopes of boron, ^{12,13}B. It has long been known that due to both nuclear structure and reaction kinematics the (d,α) and (α,d) reactions are highly selective [1]. In particular, these reactions strongly favor the case where the proton and neutron are transferred either from, or to the same j orbital with their spins aligned, coupling to the maximum possible angular momentum ($J=2j$, $T=0$). For light nuclei near stability, with comparable Fermi energies for protons and neutrons such states are typically at low excitation energy. With $N>Z$, such states involve orbitals that are unequally bound and more highly excited, and are usually not populated in single-nucleon transfer. They have generally not been explored in very neutron-rich nuclei.

We have used HELIOS [2] at the ATLAS facility at Argonne National Laboratory to study the ^{14,15}C(d,α)^{12,13}B reactions with beams of ^{14}C and ^{15}C at 17.1 and 15.7 AMeV, respectively. Recoiling boron nuclei were identified in a silicon-detector telescope array, permitting the isolation of γ, 1n and 2n decay branches of states in ^{12,13}B. In ^{12}B, we observe the strong excitation of the known 3^+ state at 5.61 MeV formed by the removal of an aligned pn pair from the $0p_{3/2}$ orbital. In ^{13}B the spectrum reveals a strong peak near E_X=11 MeV which likely corresponds to the doublet formed by the coupling of the ^{12}B $[\pi(0p_{3/2})^{-1}\nu(0p_{3/2})^{-1}]_{3+}$ state to a $1s_{1/2}$ neutron. Details of the experiment will be presented, with a discussion of the implications of such studies for other exotic nuclei.

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Nuclear Structure Theory and Double Beta Decay*

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Extracting the neutrino mass scale from an observation of neutrinoless double-beta decay requires knowing the values of nuclear matrix elements that govern the decay. At present the matrix elements carry a larger uncertainty than experimentalists can happily tolerate. I describe recent developments in nuclear-structure theory that should let us reduce the uncertainty considerably. Initial calculations both in nuclear density-functional theory and in coupled-cluster theory are promising.

J2

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A-93

Nuclear structure of ^{130,132,134,136}Xe: Relevance to shape transitions and $0\nu\beta\beta$ decay*

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The stable isotopes of xenon span a region which exhibits an evolution of nuclear structure from spherical to gamma-soft behavior; thus these nuclei may provide insight into the nature of this transition. Highly enriched (>99.9%) ^{130}Xe, ^{132}Xe, ^{134}Xe, and ^{136}Xe gases were converted to solid $^{130}XeF_2$, $^{132}XeF_2$, etc., and were used as scattering samples for inelastic neutron scattering measurements at the University of Kentucky Accelerator Laboratory. Lifetimes of levels up to 3.5 MeV in excitation energy in each xenon isotope were measured using the Doppler-shift attenuation method. Gamma rays corresponding to new transitions and levels have been observed and reduced transition probabilities have also been determined. This new information will be examined in an effort to elucidate the structure of these nuclei in a transitional region.

The nuclear structure of ^{134,136}Xe are also of relevance for neutrinoless double-beta decay ($0\nu\beta\beta$) experiments, specifically those searching for the decay of ^{136}Xe to ^{136}Ba. For example, the detector constructed by the EXO collaboration utilizes liquid xenon as the source and detector and is enriched to 80% in ^{136}Xe, while the remaining 20% is ^{134}Xe. As neutrons may be produced by either incident muons or natural radionuclides present in the surroundings, excited states in either isotope may be populated by inelastic neutron scattering. Therefore, γ rays emitted upon de-excitation of either ^{136}Xe or ^{134}Xe which have energies near the $0\nu\beta\beta$ decay end-point energy, 2458.7 keV, may obscure the observation of this rare decay. New γ rays corresponding to transitions in ^{134}Xe have been observed in this energy region, within the resolution of the EXO detector. Gamma-ray production cross sections have been measured and will be discussed.

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† Presenter

Notes

High-Precision Half-Life Measurements for the Superallowed Fermi β^+ Emitters ^{14}O and ^{18}Ne*

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J2

High-precision measurements of the ft values for superallowed Fermi β decays have provided invaluable probes of the Standard Model description of the electroweak interaction [1]. These measurements have been used to test the CVC hypothesis, provide the most precise determination of V_{ud}, and search for possible extensions of the Standard Model. Half-life measurements for ^{14}O and ^{18}Ne are of particular interest as the low-Z superallowed decays are most sensitive to a possible scalar current contribution in the electroweak interaction. The current precision of the ^{18}Ne half-life and branching ratio are not yet at the required level of precision to be included in the calculation of the world average corrected $\mathcal{F}t$ value for superallowed Fermi β^+ emitters. A recent high-precision branching-ratio measurement for ^{18}Ne performed at GANIL has prompted us to improve the precision of its half-life at TRIUMF. Using the 8π γ-ray Spectrometer, an array of 20 HPGe detectors; the ancillary Zero-Degree Scintillator, a fast plastic scintillator placed behind the beam implantation point on the tape transport system within the 8π; as well as a 4π proportional continuous-flow gas counter, two simultaneous and independent half-life measurements were made for each of ^{14}O [2] and ^{18}Ne, the precision of the latter being improved by a factor of 3, to $\pm 0.025\%$. These new high-precision half-life measurements for ^{14}O and ^{18}Ne will be presented and their importance for setting limits on scalar currents in β decay will be discussed.

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Nuclear polarization effects in muonic helium*

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The proton radius extracted from recent high-precision measurements of the 2S-2P transition frequencies in muonic hydrogen μH [1, 2] disagrees significantly with that determined from eH spectroscopy or e-p elastic scattering. Intrigued by the proton radius puzzle, new measurements of the Lamb shift in muonic helium, *i.e.*, $\mu^4\mathrm{He}^+$ and $\mu^3\mathrm{He}^+$, will be performed at PSI. These measurements aim to extract the nuclear charge radius with a relative accuracy of 3×10^{-4}, limited by the uncertainty in the nuclear polarization corrections. To resolve the radius puzzle, the nuclear polarization contributions, which strongly rely on our knowledge of nuclear forces and structures, need to be calculated to 5% accuracy [3].

To achieve this accuracy, we present an *ab-initio* calculation of the nuclear polarization effects to the Lamb shift in $\mu^4\mathrm{He}^+$ [4, 5]. Combining the Lorentz integral transform method [6] and the hyperspherical harmonics expansion few-body method [7], we have obtained the $^4\mathrm{He}$ response functions for two different state-of-the-art nuclear potential models. With the newly developed application of Lanczos algorithm [8], we studied different energy-dependent sum rules of the response functions, which result in the leading multipole contributions to the nuclear polarization, plus Coulomb, relativistic, and finite-nucleon-size corrections. The systematic accuracy of our analysis, based on the uncertainty from both nuclear and atomic physics, is estimated to be comparable with the desired 5% goal. We will also discuss the extension of the calculations to the nuclear polarization in $\mu^3\mathrm{He}^+$ and $\mu^3\mathrm{H}$.

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J2

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Spectroscopy of isobaric analogue states in exotic proton-rich nuclei

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The very small differences in excitation energy between isobaric analogue states can be interpreted in terms of Coulomb, and other isospin-non-conserving, effects, and the analysis of these mirror- and triplet-energy differences (MED/TED) have been shown to be a remarkably sensitive probe of nuclear structure effects as well as shedding light on isospin non-conserving (INC) interactions (e.g. [1-5]). New experimental techniques have been applied in the last few years to access excited states in proton-rich nuclei heading towards the proton drip-line to perform these studies. Recently-developed techniques, which have been shown to be extremely effective, include mirrored fragmentation/knockout reactions [4,6] and recoil-beta tagging [3] and have yielded spectroscopy of excited states in the heaviest studied $T_z = -1, -\frac{3}{2}$ and -2 nuclei. In this talk, results from mirrored knockout reactions performed at the NSCL facility will be presented for the $T = 2$ and $T = \frac{3}{2}$ mirror pairs with A=52, 53 and 51 and also data on one-neutron knockout from the high-spin proton-emitting isomer in ^{53}Co, leading to a comprehensive new scheme for $T_z = -1$ ^{52}Co. Mirror energy differences (MED) for these nuclei have been analysed in the context of the shell-model and results interpreted in terms of the influence of isospin non-conserving phenomena. In this talk, an attempt is made to bring together all the data on mirror-energy differences in the $f_{\frac{7}{2}}$ shell to draw conclusions on the influence of isospin-non conserving interactions in this region (see e.g. [1,4,7]) such as the previously established $J = 2$ anomaly in this region. To do this, global fits of the shell-model predictions to experimental MED data have been performed, across the $f_{\frac{7}{2}}$ shell, and the results will be presented. Some latest results from MED/TED studies above ^{56}Ni will also be presented.

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[5] K. Kaneko *et. al.*, Phys. Rev. C **89** 031302(R) (2014)
[6] J. R. Brown *et. al*, Phys. Rev. C **80**, 011306 (2009)
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Collectivity and shapes of N=Z nuclei at A~70

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The study of nuclei residing at and close to the N=Z line in the mass 60-80 region is of significant interest because of the presence of the $g_{9/2}$ intruder orbital and the fact that neutron-proton shell effects and correlations can influence the structure of nuclei in the region. This is also a region where nuclear shapes can vary very rapidly with both nucleon number and angular momentum. In this work we have performed the first low energy Coulomb excitation measurement using a 2.85 MeV/u beam of ^{72}Kr produced by the REX-ISOLDE facility at CERN. The beam impinged on a ^{104}Pd target and gamma rays were detected by the MINIBALL array.
We have also made the first measurements of the lifetimes of the low-lying states in the odd-odd nucleus ^{70}Br using a one nucleon knockout reaction at the NSCL facility at MSU [1].
For ^{72}Kr data analysis has been performed with GOSIA and the results then combined with the known B(E2: $2^+ \rightarrow 0^+$) value deduced from relativistic Coulex/ lifetime measurements [2,3]. Our initial results indicate that the 2^+ state in this nucleus has a negative spectroscopic quadrupole moment, which is consistent with a prolate shape. Since many calculations and previous experimental work [4] suggest that the ground state is oblate the results provide evidence for a rapid change in nuclear shape occurring at low-spin. This result is reproduced by calculations using a five dimensional collective Hamiltonian with parameters determined by the mean-field wave functions.
The lifetime results for ^{70}Br reveal a staggering of the B(E2: $2^+ \rightarrow 0^+$) values along the N=Z line, which can be explained by shell model calculations using the GXPF1A interaction in an *fp* model space including the Coulomb, spin-orbit and isospin non-conserving interactions. The lifetime results for the 2^+ state and other low-lying states in ^{70}Br suggest that the $g_{9/2}$ orbit does not play an important role at low-spin in these nuclei.

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J3

Split Isobaric Analog state in ^{55}Ni: A case of isospin mixing

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Isospin symmetry first proposed by Heisenberg allows us to treat neutrons and protons as two states of the same particle [1]. However the fact that the Coulomb force differentiates between protons and neutrons makes this only an approximate symmetry. Still isospin is a relatively good quantum number as the level of violation is quite small and mostly neglected. With the ability to produce exotic nuclei far from the valley of stability, exploring the isospin degree of freedom is at the forefront of nuclear physics. The neutron deficient region near N=Z is of great interest for exploration of isospin mixing.

Finding examples in nature where violations are enhanced and allow for quantitative examination remains a challenge. The β decay of the exotic Tz=-3/2 nucleus ^{55}Cu allowed us to demonstrate breakdown of isospin symmetry in a model independent manner [2]. The Fermi transition in this case is expected to populate the Isobaric Analog State (IAS) in ^{55}Ni with a log *ft* of 3.31. Isospin symmetry prevents any fragmentation of the Fermi transition; however the study of β decay of ^{55}Cu revealed a strongly isospin mixed doublet (20 keV apart) in ^{55}Ni which represents the fragmented IAS (based on log *ft* values) in violation of the isospin symmetry, thus representing its breakdown. From the experimental distribution of strength and energy spacing the isospin mixing matrix element was extracted which is quite small, 9(1) keV. Instead the near degeneracy of a pair of $3/2^-$ levels with different isospin in ^{55}Ni resulted in this strong splitting of the Fermi strength.

J3

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Low-lying $\mathrm{T} = 0$ states in the odd-odd $\mathrm{N} = \mathrm{Z}$ nucleus $^{62}\mathrm{Ga}$*

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New, low-lying levels in the odd-odd, $\mathrm{N} = \mathrm{Z}$ nucleus $^{62}\mathrm{Ga}$ have been identified using a sensitive technique, wherein a variation of the recoil decay tagging method has been allied with a mass-separator device for the first time. In the system, in-beam γ rays from short-lived nuclei are tagged with β decays following recoil mass identification. High levels of selectivity can then be achieved by taking advantage of fast β decays exhibited by exotic nuclei near the proton drip-line, which are not observed in more stable isobaric contaminants. A comparison of the new results with shell-model and IBM-4 calculations demonstrates good agreement between theory and experiment, with the majority of predicted low-lying, low-spin $\mathrm{T} = 0$ states now identified. There is a dramatic change in the level density at low excitation energies for the $\mathrm{N} = \mathrm{Z}$ nucleus $^{62}\mathrm{Ga}$ when compared with neighbouring odd-odd Ga isotopes where, in contrast, the low-lying level structure is dominated by configurations with $\mathrm{T} = 1$ pairing interactions between excess neutrons. This illustrates the distinctively different aspects of nuclear structure exhibited by nuclei with $\mathrm{N} = \mathrm{Z}$. The $^{62}\mathrm{Ga}$ results and possibilities for future studies will be presented in this talk.

J3

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Spin Orbit force and Nuclear forces at the drip line *

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The advent of radioactive beams worldwide and the growing of detector capabilities has brought access to the study of nuclear structure evolution far from stability. Different facets of the nucleon-nucleon interactions (central, tensor, spin-orbit) can be now explored as various combinations of protons and neutrons orbits are filled by nuclei spanning from the valley of stability to the drip-line. Moreover the effect of the drip-line on the effective nucleon-nucleon force can also be studied as several experimental results can lead information on unbound states.

In this presentation I shall show in the first part experimental results that intend to bring information on the spin-orbit force. For this purpose I will present recent data on the bubble nucleus ^{34}Si obtained at GANIL using (d,p) reaction with MUST2 and EXOGAM [1] as well at the NSCL/MSU facility using one-proton knock-out reactions with the Gretina array and the S800 spectrometer. In a second part I propose to study the effect of the presence of continuum on nuclear structure. For this purpose, I will present recent results in the odd-odd nuclei ^{24,26}F and obtained at GANIL [2] and at GSI using one-proton knock out reaction with the crystal ball and the LAND neutron array. Comparison to modern nuclear models will be given as well. Moreover I shall present a selected choice of recent results obtained at GANIL using the EXOGAM array and present some perspectives to be achieved in the forthcoming AGATA campaign at GANIL.

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J4

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Ab-initio Green's function theory and impact of chiral three-body forces in mid mass isotopes*

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The talk will discuss the effects of three-nucleon forces (3NFs) on the structure of medium mass and neutron rich isotopes. Chiral interactions, including 3NF at NNLO, have been tested in ab-initio theory along several isotope chains near to oxygen, calcium and Nitrogen. We find that physics in the one valence shell is correctly reproduced [1,2]. Higher mass isotopes are still predicted slightly over bound and with underestimated radii, which should be addressed in improved chiral models for the nuclear interactions.

Calculations of long chains of open shell isotopes are possible through extensions of self-consistent Green's function theory. These include the Gorkov reformulation of the method and the addition of many-body interactions [3,4].

We also exploit the same formalism to derive microscopic, ab-initio, description of nucleon-nucleus optical potentials. Implications of tensor force and non-locality on scattering at medium energies are pointed out.

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J4

J4

Decorrelated behaviour of spin-orbit partners in neutron-rich copper isotopes

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In two (d,^{3}He) transfer reactions with MUST2 at Ganil and the split-pole at Orsay, we have determined the position of the proton hole states in the neutron-rich ^{71}Cu and ^{69}Cu isotopes. We have found that in ^{71}Cu the effect of the $N = 40$ subshell crossing is contrary to expectation. From β-decay, the $f_{5/2}$ first excited particle state in these isotopes was known to come down rapidly in energy when passing $N = 40$ and even become the ground state in ^{75}Cu. This sudden energy shift has been explained in a number of theoretical works. The prediction for the $f_{7/2}$ spin-orbit partner was that it would lower in energy as well through a related effect. The present result, however, unveils that the hole strength of the $f_{7/2}$ orbital lies at higher excitation energies than expected, indicating a decorrelated behaviour between the spin-orbit partners. We remeasured the single-particle strength in ^{69}Cu in the corresponding (d,^{3}He) reaction in order to extend the existing data and in particular to make sure that there is a consistent analysis of spectroscopic factors between both isotopes. Taking together the results from both reactions, we find that additional mechanisms may have to be included to understand the nuclear structure of the neutron-rich copper isotopes and constrain the weakening of the $Z = 28$ shell gap towards doubly magic ^{78}Ni. State of the art shell model calculations performed by the Strasbourg group will be presented.

J4

Systematic investigation of coupling of particle-octupole phonon states around closed shell nuclei by transfer, (n,γ) and neutron induced fission reactions

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The coupling between a particle and a phonon is a very important issue in nuclear structure studies, being a key process at the origin of the anharmonicities of vibrational spectra, quenching of spectroscopic factors and damping mechanism of giant resonances. The experimental and theoretical investigation of this problem is presented in connection with a systematic gamma spectroscopy study around closed shell Ca, Ni, Sn and Pb nuclei. Different reaction mechanisms are employed, such as transfer, (n,γ) and neutron induced fission. The focus is, in particular, on ^{47}Ca, ^{49}Ca [1,2] and ^{65}Cu [3] nuclei, which provide evidence for particle-phonon coupled states based on the 3^- octupole phonons of the ^{48}Ca and ^{64}Ni cores, respectively. They are among the few fully established examples of particle-vibration coupling in nuclei with mass A<100, showing the robustness of nuclear collectivity in rather light systems. Preliminary results are also given for similar type of studies around the doubly magic ^{208}Pb and ^{132}Sn cores, following (n,γ) reaction on ^{209}Bi and neutron induced fission on ^{235}U and ^{241}Pu targets. Of particular interest is the investigation around the ^{132}Sn core, which is very relevant for future experiments with radioactive beams.

The presented results are from several experiments performed at Legnaro National Laboratory, NIPNE (Bucharest) and ILL (Grenoble), using complex detection systems based on HpGe arrays, such as CLARA, ROSPHERE and EXOGAM, coupled to magnetic spectrometers (PRISMA) or fast $LaBr_3$ scintillator detectors for lifetime measurements by fast timing techniques.

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J4

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Nuclear Structure Studies with INGA *

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An experimental campaign aimed at studying various high spin phenomena using Indian National Gamma Array (INGA) at the BARC-TIFR Pelletron Linac Facility has been successfully completed. INGA is a collaborative research endeavour by the nuclear physics groups from universities and research institutions across India. The array consisting of a large number of Compton suppressed clover detectors was coupled to a digital data acquisition system with 96 channels. The present system provides higher throughput, better energy resolution and better stability of gain for the multi-detector Compton suppressed clover array compared to its previous conventional system with analog shaping. Selected results from this array will be discussed which highlight the exotic shapes, novel excitation modes and interesting isomers of nuclei. Preliminary results from the experimental efforts to improve the sensitivity and capability of the array by adding ancillary detectors will be described. In addition, simulation studies to improve the selectivity and photopeak efficiency of the large gamma detector array in future will be presented.

F1

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F1

Gamma ray spectroscopy with AGATA with slow and fast beams

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The study of neutron-rich nuclei with unusually large neutron/proton ratio is challenging the conventional description of the structure of nuclei. Almost a decade of investigation has established that when moving from the β - stability to the drip line, the shell structure undergoes important modifications with the possible disappearance of the usual shell gaps and the emergence of new magic numbers. This behaviour has been attributed to the dynamic effects of the nucleon-nucleon interaction, its density dependence, linked to the reduction of the spin-orbit contribution for more diffuse systems, and the influence of the proton-neutron interaction and of its higher order term, the tensor force. Recently also three-nucleon forces have been invoked in order to justify the stabilization of the nuclear shells. Unexpected shell erosions have been found all over the nuclear chart, together with the appearance of low lying intruder states in supposedly semi-magic nuclei, giving rise to the so-called islands of inversion. One example is the Ni isotopic chain (Z=28) which covers two doubly-closed shells with neutron numbers N=28 and 50 therefore providing an almost unique testing ground for investigating the evolution of the shell structure in neutron rich nuclei.

Binary reactions such as Coulomb excitation, deep-inelastic and multi-nucleon transfer reactions are a powerful tool to populate yrast and non yrast states in neutron-rich nuclei using stable or radioactive nuclear beams, particularly in combination with high resolution gamma-ray detector arrays. Results from the AGATA experimental campaigns at LNL and recently at GSI, together with selected examples from others high and low resolution gamma ray spectroscopy detectors, will be presented. Future experimental campaigns and perspectives of the AGATA array will also be illustrated.

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F1

GRETINA:
Physics Highlights and Future Plans*

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GRETINA [1] is a first implementation of a gamma-ray spectrometer which is capable of tracking gamma-rays through its active detector volume. It consists of seven, four-crystal modules (6x6 segments). Each crystal is individually encapsulated with all four crystals sharing a common cryostat. The irregular, tapered hexagonal crystals pack into a spherical shell with the seven modules spanning 1π solid angle.

GRETINA was constructed and commissioned at LBNL. It completed its first physics campaign at NSCL/MSU in July of 2013 and is now running at ATLAS/ANL. In this talk, I will give a short overview of the project, discuss some technical aspects and the performance of the array, present highlights from the experimental program carried out at NSCL, and some initial results from the ATLAS campaign.

Future plans for GRETINA as well as its evolution into GRETA, a full 4π array, will also be discussed.

[1] S. Paschalis, I.Y.Lee, *et al*. NIM **A709** (2013) 44-55

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The GRIFFIN Spectrometer at TRIUMF-ISAC *

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Gamma-Ray Infrastructure For Fundamental Investigations of Nuclei (GRIFFIN) is the new decay spectroscopy facility for TRIUMF-ISAC, which will begin physics experiments in the fall schedule of 2014. GRIFFIN is an array of 16 large-volume hyper-pure germanium clover detectors coupled with a suite of ancillary detector systems and a custom-built digital data acquisition system. The absolute singles photo-peak efficiency will be $\sim$17% at 1.3 MeV. The suite of ancillary detector systems presently includes the SCEPTAR array of plastic scintillators for beta-tagging, the PACES array of cryogenically-cooled lithium-drifted silicon counters for high-resolution internal conversion electron spectroscopy and an array of lanthanum bromide scintillators for fast gamma-ray timing measurements. In addition, beginning in 2015, GRIFFIN will be combined with arrays of neutron detectors, such as the DESCANT array, developed by the University of Guelph and TRIUMF, to enable studies of beta-delayed neutron emitting nuclei relevant to the astrophysical r-process.

The low-energy area of ISAC-I has been reconfigured and the new experimental equipment is being installed during the first half of 2014. Experiments are planned for an early-implementation of the GRIFFIN facility during the fall schedule of 2014. The array will be completed in 2015 with the full complement of 16 clovers. GRIFFIN will greatly enhance the capabilities in the nuclear structure, nuclear astrophysics and fundamental symmetries research programs with stopped radioactive beams available from ISAC and in the future ARIEL. A detailed overview of the GRIFFIN project as well as an update on the installation and commissioning will be presented.

F1

*The GRIFFIN spectrometer is funded jointly by the Canada Foundation for Innovation (CFI), TRIUMF and the University of Guelph. Operational funding for GRIFFIN is provided by the Natural Sciences and Engineering Research Council of Canada (NSERC).

The TIGRESS Integrated Plunger Device for Electromagnetic Transition Rate Studies at TRIUMF

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Quantifying the evolution of nuclear structure with increasing proton-neutron asymmetry is a major focus of current experimental efforts. At TRIUMF, accelerated beams from ISAC-II permit access to this information for a wide range of radionuclides via in-beam gamma-ray spectroscopy with TIGRESS. Doppler-shift lifetime and Coulomb excitation measurements play an important role in this pursuit, shedding light on the processes which govern nucleon motion and benchmarking theoretical models.

Accordingly, the development of the TIGRESS Integrated Plunger (TIP) [1] presents the opportunity for nuclear structure studies using TIGRESS in combination with a suite of ancillary detector systems for charged-particle tagging and light-ion identification following a variety of nuclear reaction mechanisms. The TIP silicon PIN diode wall, annular silicon segmented detector, and CsI(Tl) scintillator wall have enabled particle-gamma correlation investigations for reaction channel selectivity and kinematic reconstruction.

The first in-beam tests have highlighted the flexibility of TIP. Exit channel selectivity via pulse-shape analysis of CsI(Tl) waveforms has been demonstrated. Moreover, complementary transition rate studies of self-conjugate ^{36}Ar by Doppler-shift attenuation and Coulomb excitation techniques have been performed to help resolve discrepancies in the literature. Such measurements can grant access to both lifetimes and quadrupole moments with the same setup, minimizing systematic uncertainties. An overview of the TIP device and a discussion of recent results and analysis will be presented.

[1] P. Voss *et al.* Nucl. Instr. and Meth. **A746**, (2014) 87.

F1

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Facility for Rare Isotope Beams under Construction*

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FRIB, the US's "Facility for Rare Isotope Beams" under construction at Michigan State University (MSU), will be based on a 400 kW, 200 MeV/u heavy ion linac. Once realized, FRIB will be a world-leading rare isotope beam facility, providing a wide variety of high-quality beams of unstable isotopes at unprecedented intensities, opening exciting research perspectives with fast, stopped, and reaccelerated beams. This talk will summarize the science opportunities with FRIB and present the status of the FRIB project.

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Notes

Measurements on neutron-rich isotopes with low-energy and reaccelerated beams at CARIBU*

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The Californium Rare Ion Breeder Upgrade (CARIBU) of the ATLAS superconducting linac facility provides low energy and reaccelerated neutron-rich radioactive beams to address key nuclear physics, astrophysics and application issues. These beams are obtained from fission fragments of a 1.7 Ci ^{252}Cf source, thermalized and collected into a low-energy particle beam by a helium filled RF gas catcher, mass analyzed by an isobar separator, and charge bred to higher charge states for acceleration in ATLAS. The methods used by CARIBU are fast and universal so that the short-lived isotope yield scales essentially with Californium fission yield.

So far, mass separated radioactive beams of over 100 neutron-rich species have been used for experiments at low energy and a few experiments have been carried out with higher-energy radioactive beams charge bred with an efficiency of up to 14% and reaccelerated to 6 MeV/u. Experimental results obtained through mass measurements and beta-delayed gamma and beta-delayed neutron measurements with the low-energy beams, and Coulomb excitation with the reaccelerated beams, will be presented. Ongoing improvements to CARIBU with the introduction of a new EBIS charge breeder and an MRTOF mass selection system to improve the purity and intensity of the CARIBU beams will also be presented.

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F2

Notes

F2

The ARIEL Facility

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TRIUMF has embarked on the construction of ARIEL, the Advanced Rare IsotopE Laboratory, with the goal to substantially expand TRIUMF's existing capabilities in rare isotope production and utilization for nuclear physics and astrophysics, materials science and health science.

ARIEL will use proton-induced spallation and electron-driven photo-fission of ISOL targets for the production of short-lived rare isotopes that are delivered to experiments at ISAC.

The first stage of ARIEL, funded in 2010 and on-track for completion in 2014, consists of a state-of-the-art 25 MeV, 100 kW superconducting radio-frequency electron linear accelerator (e-linac) and the ARIEL building.

The next stage of ARIEL, ARIEL-II, will add new isotope production and delivery systems to begin a broad program of up to 3 simultaneous experiments, with a wider variety of exotic isotope species that will significantly increase both the science productivity and impact.

The project is organized in five phases designed to interleave science and construction to ensure a continuous stream of scientific results while new capabilities are brought on line.

I will present an overview of ARIEL, beginning with an update on the e-linac commissioning, and will discuss the phases, capabilities, science objectives, and timeline.

F2

Abstracts

Part II:

Poster Presentations

in alphabetical order by presenting delegate

The Active-Target Time-Projection-Chamber: First Results*

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Reaccelerated radioactive beams near the Coulomb barrier that will soon be available with the ReA3 accelerator at NSCL will open up new opportunities for the study of nuclear structure approaching the driplines. To take full advantage of these radioactive beams, a new detector, the Active-Target Time-Projection-Chamber (AT-TPC), has been developed, which has the ability to image charged-particle tracks in its gas-filled volume. The use of this volume simultaneously as the target for nuclear reactions allows for an increase in luminosity while maintaining good energy resolution. A commissioning experiment was recently performed to characterize the performance of the detector under real experimental conditions. An α beam of 1.5 MeV/n from the ReA3 accelerator was used to investigate $\alpha + \alpha$ scattering where the measurement of the Mott cross section at 90° can give information on the long range part of the nuclear potential [1]. The first results from the commissioning experiment will be presented.

[1] L. F. Canto et al., Phys. Rev. C 89, 024610 (2014).

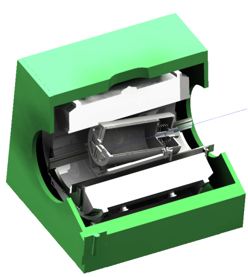

FIG. 1. An illustration of the AT-TPC detector inside of the solenoid magnet.

* This work was supported by NSF MRI Award PHY-0923087.
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Single-particle and collective excitations in neutron-rich Ni isotopes*

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Argonne, Florida State University, University of Manchester, University of Massachusetts, Lund University, University of Maryland, Michigan State University Collaboration

In order to obtain information on shell-driving effects in neutron-rich Ni isotopes between neutron numbers N = 28–40 from their behavior at high spins, a study of excited nuclear states up to an excitation energy of ~28 MeV and probable spins up to 28 ħ was carried out with the ^{26}Mg(^{48}Ca,2αXnγ) reaction at ATLAS with Gammasphere and the FMA at beam energies between 275 MeV and 320 MeV. Several collective bands, built upon states of single-particle character, were identified in ^{62,63,64}Ni. Transition quadrupole moments were extracted for some of those bands, herewith quantifying the deformation at high spin. The results have been compared with shell-model and cranked Nilsson-Strutinsky calculations. Despite the Z = 28 shell closure and the approach to the purported N = 40 subshell, the ^{62}Ni, ^{63}Ni, and ^{64}Ni isotopes are able to sustain collective excitations at moderate and high spin.

The results of this work will be shown and discussed.

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A walk in PARADISE at ISOLDE

Purification-Assisted RadioActive Decay and Ionisation Spectroscopy of Exotic nuclei

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The study of exotic nuclei at radioactive ion beam facilities often suffers from high isobaric contamination as interests gravitate towards more exotic nuclei. At the CERN-ISOLDE facility, several avenues have been recently explored to address this issue.

Selective ionisation with the Resonance Ionisation Laser Ion Source (RILIS) combined with the suppression of contaminants with the Laser Ion Source and Trap (LIST) has been successfully used online at ISOLDE. It has allowed the first study of the neutron-rich isotopes ^{217,219}Po for laser and α-decay spectroscopy [1] at the border of the region of reflection asymmetry.

At the ISOLTRAP mass spectrometer, state-of-the-art ion traps and a new Tape Station (TS) are combined for decay spectroscopy of ultra-pure samples. This setup can alternatively be used for isotope identification, and subsequent mass measurement in the high-resolution Penning trap. This technique has recently been applied to isomers in the neutron-deficient thallium isotopic chain [2], revealing new information about shape coexistence in the vicinity of ^{186}Pb.

Finally, the Collinear Resonance Ionisation Spectroscopy (CRIS) technique has recently been applied by means of a new experimental setup to study the ground-state properties of the francium isotopes from ^{202}Fr to ^{231}Fr. A key point of the technique is the combination of high resolution collinear laser spectroscopy with particle identification. This is exemplified in the case of ^{204}Fr, where pure beams of the ground state and each of the two long-lived isomers have been produced and the branching ratio in the decay of the (10^-) isomer has been determined accurately for the first time [3].

In this contribution, I shall report on those recent developments and their impact on nuclear structure in the vicinity of $Z = 82$.

[1] D. A. Fink et al. *Nucl. Inst. and Meth. B*, 317:417–421, 2013.
[2] J. Stanja et al. *Phys. Rev. C*, 88:04322, 2013.
[3] K. M. Lynch et al. *Phys. Rev. X*, 4:011055, 2014.

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Single-particle and Collective Band Structures in ^{61}Co*

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An extensive study of the level structure of ^{61}Co has been performed following the ^{26}Mg(^{48}Ca, $2\alpha 4np\gamma$)^{61}Co reaction at a beam energy of 320 MeV, using Gammasphere and the fragment mass analyzer (FMA). Two quasi-rotational bands consisting of stretched-$E2$ transitions have been observed up to spins $39/2\hbar$ and $41/2\hbar$, and excitation energies of 10 and 17 MeV, respectively. These bands are built upon states with single-particle character. In addition, two $\Delta I = 1$ bands, reminiscent of the magnetic rotational bands observed in ^{58}Fe [1] have also been identified, along with a number of other single-particle levels. A detailed discussion, complemented by theoretical calculations, of the observed band structures will be presented within the context of shell structure evolution and collectivity in the $A \sim 60$ mass region.

[1] D. Steppenbeck, R. V. F. Janssens, *et. al.* Phys. Rev. C **85** 044316 (2012)

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* This work was supported in part by the U.S. DOE, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357 and Grants Nos. DE-FG02-94ER40834 and DE-FG02-08ER41556, by the NSF under Contract No. PHY-0606007, and by the UK Science and Technology Facilities Council (STFC).

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RESONEUT- A Low Energy Neutron Detector Setup for studying (d,n) Reactions in Inverse Kinematics.

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A compact array of low energy neutron detectors have been developed for use with the RESOLUT radioactive beam facility at the superconducting accelerator laboratory at the Florida State University. The array consists of 12 P-Terphenyl crystals coupled to mcp-pmt's with excellent timing and has excellent characteristics for discriminating neutrons and gamma radiations through pulse shape analysis. The main motivation for installing these detectors is to study the l=0 and l=1 resonances in astrophysically significant nuclei populated through (d,n) reactions. Combined with charged particle detectors and a large acceptance NaI array surrounding the target area, this setup allows the study of either proton decaying resonances or gamma-decaying states in nuclei of interest. A number of test runs with $^{12}C(d,n)^{13}N$ reaction has demonstrated the sensitivity of this setup for detecting and discriminating low energy neutrons.

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Deriving the Nuclear Shell Model Microscopically *

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One of the long term goals of nuclear-structure theory has been to derive the input for standard, inert-core shell-model (SM) calculations from the fundamental nucleon-nucleon (NN) and three-nucleon (NNN) interactions. Advances in our understanding of these basic forces, along with new and/or improved nuclear many-body techniques and enhanced computer capabilities, have created a Renaissance in nuclear structure and reaction theory, especially for light nuclei, *i.e.*, $A \leq 18$. Thus, one would like to use what has been learned for light nuclei to derive the standard SM parameters, *i.e.*, the core energies, the single-particle (s.p.) energies, and the two-nucleon effective interactions, from the bare NN and NNN interactions. With the No Core Shell Model (NCSM) [1,2,3] one can perform such a derivation by first performing a standard NCSM calculation for a nucleus with a doubly-magic closed core plus two-valence nucleons, *e.g.*, ^{18}F. The results of such a converged NCSM calculation can be used to do a projection into the lowest possible energy state of that nuclide. These projected matrix elements can then be separated into a core energy, s.p. energies and two-nucleon effective-interaction matrix elements, appropriate for performing standard SM calculations [4,5]. This procedure will be described in detail and applied to nuclei in the sd-shell.

[1] P. Navrátil, J. P. Vary, and B. R. Barrett, Phys. Rev. Lett. **84**, 5728 (2000); Phys. Rev. C **62**, 054311 (2000).
[2] P. Navrátil, S. Quaglioni, I. Stetcu, and B. R. Barrett, J. Phys. G. **36**, 083101 (2009).
[3] Bruce R. Barrett, Petr Navrátil and James P. Vary, Prog. Part. Nucl. Phys. **69**, 131 (2013).
[4] A. F. Lisetskiy, B. R. Barrett, M. K. G. Kruse, P. Navrátil, I. Stetcu, and J. P. Vary, Phys. Rev. C **78**, 044302 (2008).
[5] E. Dikmen, A. F. Lisetskiy, B. R. Barrett, P. Maris, A. M. Shirokov, and J. P. Vary, to be published.

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P

Levels in ^{120,122,124,126}Cd Isotopes Beta decays of ^{120,122,124,126}Ag *

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The lowest lying levels in the neutron-rich even-even Cd isotopes have structures that resemble an anharmonic vibrator coupled to 2-proton intruder states. Deviations from this simple picture have been shown to occur in $^{112-116,120}$Cd isotopes [1,2]. In particular, none of the observed 0^+ and 2^+ states previously assigned as three phonon states decay in a manner consistent with a multiphonon state. If the explanation for the discrepancy between observed and expected decays of these states at least partially arises from mixing with intruder states, the picture should become more clear further from the neutron mid-shell as there will be less mixing of the N-phonon and intruder levels due to the increase in energy of intruder states. In order to determine the systematics of these states in Cd across the neutron shell we have measured the beta decays of the heavier even-mass ^{122,124,126}Ag isotopes.

Silver-122,124,126 ions were produced via the proton-induced fission of 238U at the HRIBF at ORNL. Fifty MeV protons were bombarded on a UCx target, and the fission products were then separated by the High Resolution Isobar Separator and deposited on a moving tape collector directly in the center of the LeRIBSS (Low-Energy RIB Spectroscopy Station) array. Many new levels in ^{122,124,126}Cd have been observed. These results will be presented and discussed.

[1] K. L. Green, *et al.*, Phys. Rev. C **80**, 032502(R) (2009).

[2] J. C. Batchelder, *et al.*, Phys. Rev. C. **86**, 064311 (2012).

*This work has been supported by the U. S. Department of Energy, Office of Nuclear Physics under contracts DE-AC05-76OR00033 (UNIRIB), DOE-AC05-00OR22725 (ORNL), DE-FG05-88ER40407 (Vanderbilt University), DE-FG02-96ER40983 (University of Tennessee).
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In-beam γ-ray spectroscopy of ^{63}Mn*

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Neutron-rich, even-mass chromium and iron isotopes approaching neutron number $N = 40$ have been important benchmarks in the development of shell-model effective interactions incorporating the effects of shell evolution in the exotic regime. Odd-mass manganese nuclei have received less attention, but provide important and complementary sensitivity to these interactions. We report the observation of two new γ-ray transitions in ^{63}Mn, and the low-lying level scheme and the excited-state lifetimes are compared with large-scale shell-model calculations using different model spaces and effective interactions in order to isolate important aspects of shell evolution in this region of structural change.

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P

The Search for Cluster Structure in ^{14}C with the Prototype Active Target-Time Projection Chamber (pAT-TPC) *

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Certain light nuclei are known to have inherent cluster structure, and there is much discussion of a possible triple-alpha structure in the Hoyle state of ^{12}C. The study of clustering in neutron-rich nuclei could shed light on how neutrons affect alpha clustering, making ^{14}C a logical candidate for study [1]. We performed an experiment at the University of Notre Dame with the pAT-TPC [2] (Fig. 1 a.) to study the elastic and inelastic scattering of a 40 MeV secondary ^{10}Be beam on a ^{4}He gas active target. The pAT-TPC combines the active target and time projection chamber techniques allowing for the study of reactions induced by secondary beams with high resolution and efficiency. The angular distribution of resonant states in ^{14}C are shown in Fig. 1 b. Spin-parity state assignment to the resonant states will be shown and compared to the existing cluster theoretical predictions.

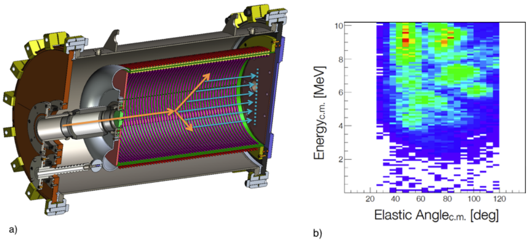

FIG. 1: a) Schematic view of the pATTC. b) ^{14}C excitation energy versus angle for the elastic scattering events.

[1] Suhara and Kanada-Enyo, Phys Rev C 82, 044301 (2010)
[2] D. Suzuki, et al., Nucl. Instr. and Meth. A 691 (2012) 39

*This work was supported by NSF MRI award PHY-0923087.

DESCANT - A new neutron detector array at TRIUMF *

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The DESCANT array at TRIUMF is designed to track neutrons from RIB experiments. For this purpose DESCANT can either be coupled to the TIGRESS array at ISAC-II with beam energies between 1.5 and 15 MeV/nucleon or to the GRIFFIN array at ISAC-I with low beam energies (30-60 keV).

DESCANT is comprised of 70 close-packed deuterated liquid organic scintillators coupled to digital fast read-out ADC modules. Deuterated benzene has the same PSD capabilities to distinguish between neutrons and γ-rays interacting with the detector as un-deuterated scintillators. In addition, the anisotropic nature of n-d scattering as compared to the isotropic n-p scattering allows the determination of the neutron energy spectrum directly from the pulse-height spectrum, complementing the time-of-flight information.

A detailed overview of DESCANT will be presented together with first designs of the firmware written for the fast sampling ADC modules.

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β-decay half-lives and β-delayed neutron emission measurements for very exotic nuclei beyond N=126*

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This contribution reports on the status of the data analysis of the experiment performed at the GSI-FRS facility (Germany), where very exotic nuclei, beyond N=126, were produced and isotopes of Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn and Fr were precisely identified using tracking detectors with the method of time-of-flight. Thanks to the detection system which comprised two detection systems: a Double-sided Silicon Strip Detector and a high efficiency Neutron detector, the decay properties of the implanted isotopes of Hg, Tl and Pb were measured via implant-beta-neutron correlations. Around 14 isotopic species were implanted with enough statistics to determine their half-life. About half of them are expected to be neutron emitters, in such cases it will be possible to obtain the β-delayed neutron emission branching ratios Pn. The relevance of these data and the role of this kind of measurements in nuclear structure and r-process nucleosynthesis will be discussed.

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P

Coexisting shapes at low excitation energies in ^{70}Ni *

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Recent experimental studies [1,2] have demonstrated a likely shape-coexistence picture for the low-lying structure of ^{68}Ni, supporting the predictions of Monte Carlo Shell Model calculations [3]. These calculations also suggest that a similar situation is expected in neighboring ^{70}Ni. In this context, as well as to provide additional data in the neutron-rich Ni region with which to test effective interactions in modern shell-model calculations, the structure of ^{70}Ni was investigated in two experiments.

Excited states in ^{70}Ni, produced in ^{70}Zn + ^{208}Pb deep-inelastic reactions at the ATLAS facility at Argonne National Laboratory, were studied up to moderate spins. Prompt and delayed γ rays were detected with the Gammasphere Ge-detector array. A complementary experiment was performed using knockout reactions at the National Superconducting Cyclotron Laboratory at Michigan State University to populate low-spin states in ^{70}Ni. Prompt γ rays were detected with the GRETINA Ge-detector array located in front of the S800 separator.

The data demonstrate the presence of an oblate sequence in ^{70}Ni that is consistent with shell-model calculations involving solely neutron excitations, and the strong likelihood of a prolate sequence that requires additional proton basis states in the model space. The level scheme has also been extended to higher spins by the addition of presumed negative-parity levels involving neutron excitations across the $N = 40$ gap into $g_{9/2}$ orbitals. Modifications to the previously known ^{70}Ni decay scheme provide better agreement with shell-model calculations.

[1] F. Recchia *et al.*, Phys. Rev. C **88**, 041302(R) (2013).
[2] S. Suchyta *et al.*, Phys. Rev. C **89**, 021301(R) (2014).
[3] Y. Tsunoda *et al.*, Phys. Rev. C **89**, 031301(R) (2014).

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P

Doppler shift lifetime studies following fusion-evaporation: ^{28}Mg and ^{68}Se using the TIGRESS Integrated Plunger

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Doppler shift lifetime measurements offer an opportunity to directly access information about electromagnetic transition rates and discriminate between model calculations. The current TIGRESS Integrated Plunger (TIP) infrastructure [1] supports such measurements via gamma-ray spectroscopy with the TIGRESS segmented HPGe array and coincident charged-particle detection as part of the experimental program at the ISAC-II facility of TRIUMF.

Initial studies using TIP employed fusion-evaporation reactions and a 24-element CsI(Tl) wall for light charged-particle identification. Reaction channel selectivity was demonstrated following a Doppler shift attenuation method experiment performed at TRIUMF. The ^{28}Mg two proton evaporation channel was successfully identified following the ^{18}O +^{12}C reaction and lineshapes for the 1.2(1)ps $2^+ \rightarrow 0^+$ transition and 105(35)fs $4^+ \rightarrow 2^+$ transition in ^{28}Mg have been observed.

One of the main goals of the TIP experimental program is the investigation of shape evolution and shape coexistence along the $N = Z$ line, in particular in the $N = Z = 34$ ^{68}Se nucleus. The matrix elements of electromagnetic operators are planned to be extracted from Doppler shift lifetime measurements with charged particle identification provided by the CsI(Tl) wall. A Geant4-based code for TIP is being developed as a tool to aid this analysis and for the optimization of future experiments. The device, experimental approach, analysis, and preliminary results will be presented and discussed.

[1] P. Voss et al., Nucl. Instr. and Meth. **A746**, (2014) 87.

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P

Model-independent approach to electromagnetic transitions in deformed nuclei *

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We develop an effective theory for the model-independent description of electromagnetic transitions in deformed nuclei. Minimal coupling (gauging the Hamiltonian) and non-minimal couplings enter, and for a single rotational band, the leading-order deviations from the rigid rotor are linear in angular momentum. The effective theory is richer in structure than phenomenological models and also gives an improved description of the much weaker inter-band transitions.

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P

BELEN detector for β-delayed neutron emission measurements*

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The study of β-delayed neutron emission probabilities of nuclei far from the stability is very important to understand processes that take place in different fields related with nuclear technology, nuclear astrophysics and nuclear structure. The improvement of data bases with high precision experimental data implies the need to do very accurate measurements. The main restrictions to measure β-delayed neutrons of many nuclei is their low neutron emission intensities and also the lack of enough information about the neutron energy spectrum. This restrictions means that is needed a neutron detector with high neutron detection efficiency and a low dependence with neutron energy from thermal energies up to 5 MeV. In this work we describe the BELEN detector (BEta deLayEd Neutron detector), a high efficiecy neutron detector, designed, constructed and tested [1] by an international collaboration between the UPC(Barcelona-Spain), IFIC(Valencia-Spain), GSI(Darmstadt-Germany) and CIEMAT(Madrid-Spain). The BELEN detector has been developed for the HISPEC/DESPEC experiment (NUSTAR Collaboration), a research area of the FAIR facility, that will be built in GSI. The BELEN detector is based on 48 ^{3}He counters (10 counters at 10 atm, and 38 counters at 8 atm) embedded in a polyethylene matrix. The mean neutron detection efficiency for neutron energies from 0.1 keV to 2 Mev is around a 45 %, with an efficiency ratio of 1.07. For neutron energies up to 5 MeV the mean neutron detection efficiency is 43 %, with an efficiency ratio of 1.31. The BELEN detector has been tested in IGISOL and GSI and has been calibrated at the PTB (Physikalisch-Technische Bundesanstalt, Germany), giving a very good agreement between Monte Carlo simulations and experimental data.

[1] M. B. Gómez-Hornillos et al., β-delayed neutron emission studies, Hyperfine Interactions, January 2014, Volume 223, Issue 1-3, pp 185-194

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Inelastic Neutron Scattering Studies of ^{76}Se and ^{76}Ge Relevant to Neutrinoless Double-β Decay *

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Observation of neutrinoless double-β decay ($0\nu\beta\beta$), if such a process were to exist, would allow for understanding of the nature of the neutrino and point to physics beyond the standard model. The search for $0\nu\beta\beta$ from ^{76}Ge to ^{76}Se is the focus of the MAJORANA and GERDA collaborations, as ^{76}Ge can serve as both detector and source for the experiment. There are many difficulties with the large-scale efforts to observe $0\nu\beta\beta$; perhaps principal among them are the sensitivites required to observe a process with such a long expected half-life ($>10^{25}$ y). To reach these extreme levels of sensitivity, knowledge of potential sources of background is key.

If $0\nu\beta\beta$ is observed, complications still exist in extracting the absolute mass scale of the neutrino. The nuclear matrix element involved in the calculation of the $0\nu\beta\beta$ rate is dependent upon nuclear structure models, thus experimental knowledge of the structure of the participating nuclei is critical.

In an effort to supply information on the above-mentioned areas relevant to $0\nu\beta\beta$, excitation function and gamma-ray angular distribution measurements utilizing the ^{76}Ge$(n, n'\gamma)$ and ^{76}Se$(n, n'\gamma)$ reactions were performed at the University of Kentucky at neutron energies ranging from 2.0 MeV to 4.0 MeV. Analysis of these data has yielded new spin-parity assignments as well as transition probabilities, while also addressing issues with the currently accepted level schemes. Additionally, γ-ray cross sections were studied with inelastic neutron scattering for ^{76}Ge. This work has shown that there appears to be greater spectral activity near the 2039-keV region of interest (the $Q_{\beta\beta}$ for the decay of ^{76}Ge to ^{76}Se) than had been previously anticipated.

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The Study of ^{116}Sn via Conversion-Electron Spectroscopy*

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Motivated by a study of the prevalence of collectivity in nuclei at closed shells [1], and studies of isotopes of cadmium [2] we have revisited ^{116}Sn (Z=50; N=66), which is already known to exhibit evidence for shape co-existence [3]. Because the phonon-vibrational model appears to have deficiencies in describing the structure of cadmium isotopes, we have begun to re-examine the mixing between bands in ^{116}Sn, where E0 transition strengths are associated with changes of shape and with the degree of mixing of states in a nucleus.

A high-statistics decay experiment was conducted using a ^{116}In beam produced via the ISOL technique at TRIUMF. The beta decay of ^{116}In to ^{116}Sn has been measured using the 8π spectrometer of HPGe detectors coupled to the PACES array of Si(Li) detectors for conversion-electron spectroscopy.

In this presentation, we will discuss the spectroscopy of the ^{116}Sn nucleus in order to augment and improve the existing knowledge of the structure of ^{116}Sn. In particular, re-measurements of internal conversion coefficients and E0 strengths will be discussed as they pertain to the possibility of mixing of different shapes between bands in ^{116}Sn.

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Online neutron energy, timing and n-γ discrimination for DESCANT using digital electronics *

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DESCANT is a newly constructed deuterated scintillator neutron detector array that will be used in conjunction with TIGRESS for fusion evaporation reactions and with GRIFFIN for high-statistics β-delayed neutron studies at TRIUMF. The use of a deuterated scintillator allows in principle the extraction of neutron energies using both time-of-flight and pulse-height spectrum analysis.

The waveforms from the DESCANT detectors will be sampled at 1 GHz by custom TIG/GRIF-4G cards using 125 MHz FPGAs using 8 parallel data streams. Energy, time and particle identification are determined in firmware and recorded in the data stream.

I will be presenting the development and implementation of constant fraction discrimination, charge-charge comparison, zero-crossover-time, pulse gradient analysis and energy determination algorithms used with DESCANT.

*This work was supported by the Canadian Foundation for Innovation, Ontario MRI and NSERC.

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Structure study of ^{110}Cd via a high-statistics β^+/EC-decay ^{110}In measurement

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The collective Bohr model and the IBM have used the stable even-even Cd isotopes as classic examples of vibrational nuclei for decades. Experiments with the $(\alpha, 2n)$ reaction, β decay measurements and an $(n, n'\gamma)$ study have identified multi-phonon states in the ^{110}Cd decay scheme indicating vibrational motion. These studies have also suggested intruder configurations based on more deformed 2p-4h proton excitations. There is evidence, however, of systematic deviations at the three-phonon level across the Cd isotopic chain suggesting a breakdown of vibration motion in the low-spin states [1]. Through work done [2] on ^{112}Cd, an alternative interpretation has been proposed where the three-phonon 0^+ state is assigned as an intruder excitation.

A study of the ^{110}In β^+/EC decay was performed at the TRIUMF Isotope Separator and Accelerator (ISAC) facility to probe the inherent nature of the ^{110}Cd nucleus. The data were collected in scaled-down gamma singles, gamma-gamma coincidence, and gamma-electron coincidence mode. A random-background subtracted $\gamma\gamma$-coincidence matrix was created containing a total of 850 million events. We expanded the level scheme of ^{110}Cd significantly, doubling the number of previously observed transitions under 3.8 MeV. Branching fractions as low as $5.1(3) \times 10^{-4}$ have been extracted. New log(*ft*) have been measured and a detailed study will be presented. The new β-decay results combined with a re-analysis of $(n, n'\gamma)$ data has led to the suggestion that ^{110}Cd presents a γ-soft rotational spectrum.

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P

Alternative Similarity Renormalization Group generators in *ab initio* nuclear structure*

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The Similarity Renormalization Group (SRG) has been successfully applied to soften interactions for *ab initio* nuclear calculations. In almost all practical applications in nuclear physics, an SRG generator with the kinetic energy operator was used. With this choice, a fast convergence of many-body calculations can be achieved, but at the same time substantial three-body interactions are induced even if one starts from purely two-nucleon (*NN*) Hamiltonian. Three-nucleon (*3N*) interactions can be handled by modern many-body methods. However, it has been observed that when including initial chiral *3N* forces in the Hamiltonian, the SRG transformations induce non-negligible four-nucleon interaction that cannot be currently included in calculations for technical reasons. Consequently, it is essential to investigate alternative SRG generators that might suppress the induction of many-body forces while at the same time might preserve the good convergence. In this work we test different alternative generators with operators of block structure in the harmonic oscillator basis. In the no-core shell model calculations for ^{3}H, ^{4}He and ^{6}Li with chiral forces, we demonstrate that they appear quite promising.

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Reference Database for Beta-delayed Neutron Emission

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The field of β-delayed neutron emission has been of interest since the discovery of nuclear fission. In nuclear power reactors, excessively large uncertainties in the delayed neutron data lead to costly conservatism in the design and operation of reactor control systems. Reliable β-delayed neutron data are also important for summation calculations to determine the decay heat produced in a nuclear reactor, and for the accurate quantification of the antineutrino spectra produced by the fission products. The latter is believed to be a significant asset in the non-invasive monitoring of reactor operations and its possible application in safeguards.

Apart from their applications, improved β-delayed neutron data will also have a significant impact in nuclear structure studies, as in the region near the neutron drip line β-delayed neutron emission may be the only source of information for the neutron-rich nuclei. In nuclear astrophysics, on the other hand, the competition between β-delayed neutron emission and β-decay influences r-process abundances during the freeze-out phase when the material decays back to stability. During the last decade there has been a renewed interest in the experimental and theoretical study of neutron-rich nuclei far off the stability line at the next generation of radioactive beam facilities. A large number of these neutron-rich nuclei, which could be reached in the future, are potential delayed neutron emitters. Although half-lives and P_n data are scattered in several compiled and evaluated libraries such as ENSDF, NUBASE, NuDat, etc., complete documentation of measurements and evaluation procedures is often missing for these properties. Previous dedicated compilations and evaluations suffer from incompleteness as well, and have in the meantime become outdated. Measured neutron spectra are not available in any database.

With these aspects in mind, a Coordinated Research project was initiated by the IAEA with the purpose of producing a Reference Database for Beta-delayed neutron Emission data [1]. This paper will present the objectives of this CRP and recent achievements.

[1] http://www-nds.iaea.org/beta-delayed-neutron/

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Towards an *ab initio* description of the nucleus-nucleus bremsstrahlung*

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Nucleus-nucleus bremsstrahlung designates a radiative transition between continuum states where the photon emission is induced by a nuclear collision. The interest for this type of process has been revived by recent experimental and theoretical advances. On the experimental side, there are the study of electromagnetic transitions in the unstable ^{8}Be via the $\alpha + \alpha$ bremsstrahlung [1] and the perspective of using the $t(d, n\gamma)\alpha$ bremsstrahlung to diagnose plasmas in fusion experiments [2]. On the theoretical side, there is the development of a Siegert approach of the bremsstrahlung, i.e. based on the charge density rather than on the current [3,4]. At low photon energies, the Siegert approach enables one to take implicitly the main part of the meson exchange currents into account and leads to more simple calculations than the current approach.

We present the first *ab initio* study of the $\alpha + N$ bremsstrahlung. This is a necessary preliminary step to the *ab initio* study of the $t(d, n\gamma)\alpha$ bremsstrahlung since it describes the final channel. The bremsstrahlung cross sections are calculated from the matrix elements of the electromagnetic transition multipole operators evaluated between the $\alpha + N$ scattering wave functions. These scattering wave functions are obtained from a description of the $\alpha + N$ collision by the no-core shell model/resonating-group method including two- and three-nucleon interactions derived from chiral effective field theory [5]. The bremsstrahlung cross sections obtained in this *ab initio* approach are compared with the few experimental data available for the $\alpha + p$ system [6] and with the bremsstrahlung cross sections obtained in a microscopic cluster approach based on an effective nucleon-nucleon interaction [4]. The impact of the inclusion of the three-body forces on the results is discussed.

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[3] J. Dohet-Eraly and D. Baye, *Phys. Rev. C* **88** (2013) 024602.
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P

Data Analysis with Geant for Experiments with TIGRESS & ISACII *

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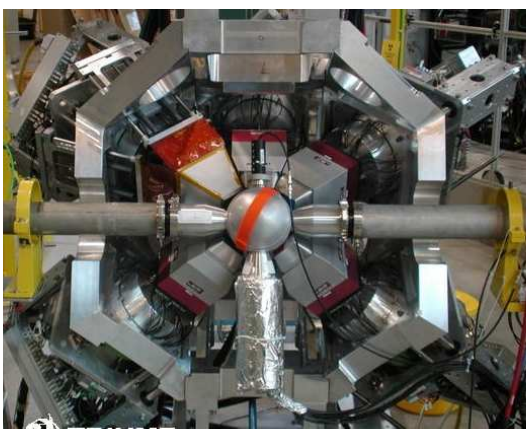
As we move further from the valley of stability, our radioactive beam facilities deliver low beam intensities, which with thicker targets, yield sparce statistics. Such data need a model to compare with experiment.

For Coulomb-excitation and for particle-transfer experiments with TIGRESS at ISACII, I have developed and included Tigress classes into Geant4 to simulate and to analyse data for Tigress experiments with auxillary detectors.

Any theoretical code giving cross sections and reaction product angular distributions can be inserted into this Geant4 data analysis approach. Comparison is made with Gosia and I present some illustrations from our Tigress collaboration DSAM and Coulomb excitation experiments.

Fig.1 TIGRESS



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High-Precision Half-Life Measurements for the Superallowed β^+ emitter ^{10}C *

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High-precision measurements of superallowed Fermi β transitions between 0^+ isobaric analogue states allow for stringent tests of the electroweak interaction described by the Standard Model. These transitions provide an experimental probe of the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, the Conserved-Vector-Current (CVC) hypothesis, as well as set limits on the existence of scalar currents in the weak interaction. The lightest superallowed emitters are of particular interest as the low-Z superallowed decays are most sensitive to a possible scalar current contribution.

There are two methods used to measure the half-life of ^{10}C: via directly counting the β particles or measuring the γ-ray activity following β decay. Previous results for the ^{10}C half-life measured via these two methods differ at the 1.5σ level, prompting simultaneous and independent measurements of the ^{10}C half-life using both techniques. Since ^{10}C is the lightest nucleus for which superallowed β decay is possible, a high precision measurement of its half-life is essential for obtaining an upper limit on the presence of scalar currents in the weak interaction. Half-life measurements of ^{10}C via both γ-ray photopeak and direct β counting were performed at TRIUMF's Isotope Separator and Accelerator facility using the 8π spectrometer and a 4π proportional gas counter, respectively. This presentation will highlight the importance of these measurements and preliminary half-life results will be presented.

*Work supported by the Natural Sciences and Engineering Research Council of Canada.

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P

Branching-Ratio Measurements for A ≥ 62 Superallowed Fermi β-decays and Future Prospects with GRIFFIN*

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High-precision measurements of superallowed Fermi β decays allow for the extraction of the weak-vector coupling strength, and provide stringent tests of the electroweak Standard Model. Superallowed decays of $A \geq 62$ nuclei are of particular interest as the nucleus-dependent isospin-symmetry-breaking corrections in these nuclei are relatively large and hence provide demanding tests of the theoretical models. However, branching ratio measurements for the $A \geq 62$ decays present a unique challenge due to the large Q_{EC} values and large level density of available states in the daughter nucleus. This results in weak, but significant, Gamow-Teller β-feeding distributed over a large number of states and limits the precision of the branching ratio measurements. Therefore, very-high efficiency detectors are of paramount importance in determining the branching ratio for these decays.

The 8π γ-ray spectrometer at TRIUMF's Isotope Separator and Accelerator (ISAC) has already provided world-record precision for $A \geq 62$ superallowed branching ratios. Later this year, the new high-efficiency GRIFFIN detector array will replace the 8π spectrometer at ISAC-I. In this talk, the importance of one of the results from the 8π — the high-precision measurement of the branching ratio for the superallowed Fermi β-decay of ^{74}Rb — will be discussed, as well as the use of GRIFFIN in future superallowed β decay studies at ISAC.

* Work supported by the National Science and Engineering Research Council of Canada and the National Research Council of Canada.

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Optimizing kinematic correction algorithms for in-beam electron spectroscopy with the SPICE detector

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The SPectrometer for Internal Conversion Electrons (SPICE), which has recently been constructed at TRIUMF, is designed to probe the admixed structures in exotic nuclei via in-beam electron spectroscopy. The main component of SPICE is the 6 mm thick segmented Si(Li) detector located upstream of the target which is shielded from γ rays by a multi-layered photon shield. Internal conversion electrons emitted from the target are directed around the photon shield by NdFeB permanent magnets. The recoiling heavy ions and γ rays are detected by a downstream Si CD and the TIGRESS HPGe array respectively.

At relativistic velocities of the residual heavy-ion, the energy of the emitted electron is both shifted in the lab frame. In order to reconstruct the electron energy in the rest frame of the emitting heavy ion, its angle of emission is required, yet only the final position on the Si(Li) and energy in the lab frame are known. Using Geant4, a relationship was found relating the final position and energy to the emission angle of the electron. For the particular case of Coulomb excitation, calculated yields were used in conjunction with Geant4 to simulate these kinematic effects. This allowed for an algorithm to be developed calculating the energy of the electron in the rest frame of the heavy ion on an event-by-event basis, using the measured position and energy of both particles (electron and heavy ion) in the lab frame.

This algorithm will be tested in-beam during the commissioning experiment in September 2014, which will investigate shape coexistence in neutron deficient Krypton isotopes. In this first measurement, a beam of ^{78}Kr ions at 5.5 MeV/u will be made incident upon various targets to Coulomb excite the beam nucleus. The observed electron peaks will have significant kinematic effects which will need to be corrected. A detailed investigation and description of these effects and techniques will be presented.

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Pairing collectivity of the Borromean nucleus ^{6}He

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We study the pairing collectivity in the ground state of the Borromean ^{6}He nucleus. The neutron single-particle unbound p-resonances of the ^{5}He system are calculated in a simple shell model picture (and checked with a more refined phase-shift analysis) for continuum energies ranging from threshold up to 10 MeV in steps of 0.1 MeV using a Dirac delta normalization. This large set of continuum wavefunctions is used to construct the two-particle ^{6}He states by proper angular momentum couplings to give the set of states 0+,0+,1+,2+,2+ coming from the $(p_{3/2})^2$ $(p_{3/2}\ p_{1/2})$ and $(p_{1/2})^2$ configurations. A contact-delta pairing interaction matrix is calculated (up to 4 Gb of data) and it is then diagonalized in this large basis set. The pairing strength is adjusted to reproduce the bound ground state of ^{6}He. We show how this state displays a collective nature, taking contribution from many different oscillating continuum states that coherently sum up to give an exponentially decaying bound wavefunction. We study various properties of this state and we investigate electromagnetic transitions to the continuum (break-up) that might be of help in disentangling the still poorly known low-energy resonances of this nucleus.

We compare our findings with the information available in public databases [1,2] and in more recent experimental works [3].

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ACTAR TPC: An active target and time projection chamber for nuclear physics *

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One of the main challenges facing experiments with rare-isotope beams is the need to extract high quality data of key physical observables from extremely limited numbers of incident ions and ever decreasing production cross sections for nuclei furthest from stability. Experiments are performed in inverse kinematics and must rely on thick reaction targets but this is often with the cost of a significant reduction in the efficiency for detection of low-energy particles, energy resolution, and overall sensitivity.

We have adopted an alternative approach and are presently developing a high-luminosity gas-filled active target and time projection chamber (ACTAR TPC) for experiments at GANIL, ISOLDE, and worldwide. In an active target, the filling gas is used as both a sensitive detection medium for charged particles and as a thick reaction target with relatively low energy loss per-unit-length compared to conventional solid-targets. Another main advantage of these detectors is their ability to track the individual trajectories of reaction or decay products through its volume to provide a complete 3-dimensional reconstruction on an event-by-event basis.

The core detection system will consist of micro pattern gaseous detectors (MPGDs) coupled to a highly pixelated 2x2 mm^2 pad plane for a total of 16k electronic channels. Technical challenges associated with mechanics and readout of such a high-density front end have required several parallel developments including the design and construction of a comprehensive ASIC-based electronics system called General Electronics for TPCs (GET). A detailed overview of the ACTAR TPC project, whose aim is to perform first experiments in 2016, and first results obtained with a 2048-channel prototype version of the final design will be presented.

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First online FEBIAD ion source results at SPIRAL/GANIL: New beams, intensities and precision half-life measurements of the T=1/2 mirror nuclei ^{17}F, ^{21}Na and ^{33}Cl

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A new FEBIAD ion source is part of an upgrade to the existing SPIRAL ISOL facility at GANIL that will significantly extend the number of available radioactive ion beams starting in 2016 for nuclear structure, astrophysics and fundamental tests of the Standard Model. The first online experiment was performed in December 2013 to test the VADIS FEBIAD source [1] coupled to a graphite production target at SPIRAL/GANIL using a 1.2 kW ^{36}Ar^{18+} primary beam. Yield measurements and beam purities were measured with the recently upgraded SPIRAL identification station [2]. The impact of the availability of these new high-intensity beams on the physics program using radioactive ion beams at GANIL and at the future DESIR facility will be discussed.

New half-life measurements for three T=1/2 mirror decays (^{17}F, ^{21}Na, ^{33}Cl) were also performed during the experiment with improved precision (up to factor of 6). The precise knowledge of the half-lives of these mirror decays contributes to the determination of their *ft* values, which gives information about non-standard model contributions to the weak interaction. These new high-precision half-life measurements for ^{17}F, ^{21}Na and ^{33}Cl will be reported along with their impact on the new world averages.

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P

Understanding the Proton Radius Puzzle: “Nuclear Polarizability Corrections in μD ”

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In 2010 the accuracy of the rms proton radius was improved ten-fold [1] by new spectroscopic measurements of the Lamb shift [2] in muonic hydrogen, where a proton is surrounded by a muon instead of an electron. However, this new value differed by 7σ from what was previously determined in ordinary hydrogen [3]. This large discrepancy was coined the “proton radius puzzle” and challenges our understanding of physics based on the standard model. New high-precision measurements on various muonic atoms are planned at PSI to study whether this discrepancy persists or varies with mass and charge numbers. In particular, the CREMA collaboration [4] plans to measure the Lamb shift and isotope shifts in several light muonic atoms, such as muonic deuterium (μD) and muonic helium. The accuracy of the nuclear charge radii determination from their data is limited by the uncertainty in the nuclear polarizability corrections. For μD, these nuclear corrections have been most recently calculated by Pachucki with the AV18 nuclear potential [5]. In this contribution I would like to show how we complement Pachucki’s pioneering work by performing ab-initio calculations in μD with state-of-the-art nuclear potentials from chiral effective field theory. We take into account multipole corrections, Coulomb, relativistic and finite-nucleon-size corrections. We found small but non-negligible differences between our results and Pachucki’s for the the relativistic corrections that may have an impact on improving the accuracy of the experimental program. Furthermore, performing a systematic study in chiral effective field theory will allow us to better assess the theoretical error associated to the polarizability calculations.

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P

Possible observation of a high-spin *K*-isomer in ^{184}Hf via γ-ray spectroscopy*

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The search for *K*-isomers in prolate deformed *A* ~ 180 nuclei has long been at the fore-front of nuclear structure research. While neutron-deficient hafnium (Z = 72) nuclei in this region are now well studied, much less is known concerning the neutron-rich isotopes. Recent mass measurement studies have found a *4-qp* isomer in ^{184}Hf, four neutrons beyond the line of β-stability, which appears to β-decay [1], to a high spin state in ^{184}Ta. In the present work we report the possible observation of a high-*K* isomer in ^{184}Hf that γ-ray decays to the $K^{\pi} = 8^{-}$ band and would lie above the isomer identified in [1].

High-spin states in ^{184}Hf were populated using deep-inelastic and multi-nucleon transfer reactions induced on a neutron-rich ^{186}W target by a ^{136}Xe beam from the ATLAS facility at Argonne National Lab. Emitted γ-rays were detected by the Gammasphere array. The new weakly-populated isomer feeds a rotational band sequence that is in coincidence with hafnium x-rays, with corresponding yields from various targets suggesting a provisional assignment to ^{184}Hf. This band has properties that are consistent with those expected for the $K^{\pi} = 8^{-}$ band in ^{184}Hf. In addition, several known high-*K* isomeric states in ^{180,181,182}Hf are now found to have different life-times compared to the previous measurements [2]. Multi-quasiparticle calculations using the Lipkin-Nogami formalism and Nilsson single-particle energies have been used to support the configuration assignment of the new isomer in ^{184}Hf together with other states in neutron-rich hafnium nuclei.

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P

Investigation of the shape-transitional samarium nuclei around N=90 via the (p,d) and (p,t) reactions *

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The samarium nuclei around N=90 display a rapid increase in deformation across the isotopic chain with increasing neutron number. The (p,d) and (p,t) reactions provide an excellent tool with which to probe the low/medium spin excited states of these nuclei. For this purpose, a 25 MeV proton beam was used to bombard ^{152}Sm and ^{154}Sm targets at the Cyclotron Institute of Texas A&M University. The STARLiTeR arrays, consisting of the STARS (silicon telescope array for reaction studies) segmented ΔE-E silicon telescope and six BGO shielded HPGe clover detectors, were used to detect the gamma rays and outgoing particles (p,d and t) in the exit channels. The setup allows particle-gamma and particle-gamma-gamma coincidence measurements as well as particle identification, energy and angular distribution measurements of the outgoing light ions. The relative cross sections for excited states in ^{150}Sm and ^{152}Sm produced via the (p,t) reaction were measured and are presented here. These results, particularly the ^{152}Sm results, provide an interesting test for collective models.

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P

Investigating shape coexistence with Coulomb excitation above and below Z=82

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Shape coexistence, whereby near-degenerate states characterized by different shapes appear at low energy, is an intriguing phenomenon that occurs in various mesoscopic systems. In the region around the light lead isotopes, with proton number *Z*=82, a substantial amount of information has been collected using a wide spectrum of experimental probes such as decay studies, optical spectroscopy studies and in-beam spectroscopy investigations. However, direct experimental information on the exact nature of the quadrupole deformation or on the mixing of the states belonging to the coexisting structures, is limited.

In order to probe the electromagnetic properties of yrast and non-yrast states of the radioactive even-even $^{182\text{-}188}$Hg [1] and $^{196\text{-}202}$Po isotopes [2], Coulomb excitation experiments were performed at the REX-ISOLDE facility in CERN with a beam energy around 2.9 MeV/u. Next to that, lifetimes of yrast states in ^{184,186}Hg were determined with the Recoil Distance Doppler-Shift (RDDS) method using the Gammasphere array at ANL and the Köln Plunger device [3] and γ-ray branching ratios and conversion coefficients were determined from a decay study of the ^{182,184}Tl isotopes [4]. All the experimental data were combined in the Coulomb excitation analysis to obtain, for the first time, magnitudes and relative signs of E2 matrix elements that couple ground and low-lying excited states in $^{182\text{-}188}$Hg. Information on the deformation of the ground and the first excited 0^+ states was deduced using the quadrupole sum-rules approach. The results show that the ground state of the light mercury isotopes is slightly deformed, and of oblate nature, while the deformation of the excited 0^+ states of ^{182,184}Hg is larger. A comparison with beyond mean field and interacting-boson based models and an interpretation within a two-state mixing model firmly establishes the presence of two different structures in the light even-mass mercury isotopes that coexist at low excitation energy.

The study of the polonium isotopes focuses around ^{200}Po that appears to be a transitional nucleus between a general-seniority-type regime observed in the heaviest polonium isotopes and a shape-coexistence character in the lightest polonium isotopes. New results will be shown in comparison with recent results from beyond mean-field calculations [5].

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P

Fine structure of the Gamow-Teller (GT) and first forbidden (FF) β^+/EC decay strength functions

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The probability of the β transition is proportional to the product of the lepton part described by the Fermi function $f(Q_\beta - E)$ and the nucleon part described by the β transition strength function $S_\beta(E)$. The function $S_\beta(E)$ is one of the most important characteristics of the atomic nucleus [1,2] defined as the distribution of the moduli squared of the matrix elements of the β-decay type in nuclear excitation energy E. Until recently, experimental investigations of the $S_\beta(E)$ structure were carried out using total absorption gamma-ray spectrometers (TAGS) and total absorption spectroscopy methods, which had low energy resolution. With TAGS spectroscopy, it became possible to demonstrate experimentally the resonance structure of $S_\beta(E)$ for GT β transitions [1,2]. However, TAGS methods have some disadvantages arising from low energy resolution of NaI-based spectrometers. Modern experimental instruments allow using nuclear spectroscopy methods with high energy resolution to study the fine structure of $S_\beta(E)$ [2]. In this work the experimental measurement data on the fine structure of $S_\beta(E)$ in spherical and deformed nuclei are analyzed. The split of the peaks caused by nuclear deformation is observed in $S_\beta(E)$ for GT transitions. The resonance nature of $S_\beta(E)$ for FF transitions in both spherical and deformed nuclei is experimentally proved. It is shown that at some nuclear excitation energies FF transitions can be comparable in intensity with GT transitions.

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P

S- and P-wave two-neutron halos in effective field theory*

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In recent years, the development in rare isotope beam research has brought tremendous opportunities in investigating properties and reaction mechanisms of light nuclei beyond the drip line. The exotic neutron-rich nuclei, containing valence neutrons distributed far beyond the size of the core, are known as *neutron halos* and display widely separated intrinsic scales. Therefore, they provide an ideal testbed for effective field theories (EFTs) built upon neutron-core clustered degrees of freedom. We present our work on investigating the properties of two-neutron ($2n$) halos in the EFT framework. By solving the Faddeev-AGS equations in a three-body model [1], we calculate the ground-state properties of $2n$ halos at leading order based on the EFT expansion. Our focuses are on two different types of Borromean $2n$ halos, *i.e.*, ^{22}C and ^{6}He, whose neutron-core interactions are dominated respectively by a shallow S-wave virtual state and a shallow P-wave resonance.

The matter radius of ^{22}C was extracted from recent measurements of the ^{22}C-p reaction cross section [2]. At leading order in the EFT, we describe the matter radius of any S-wave $2n$ halo by its universal correlation with the neutron-core scattering length and the $2n$ separation energy (S_{2n}) of the halo. We combine this correlation with the measured ^{22}C matter radius, to set limits on the ^{22}C S_{2n} and the possibility of existing a ^{22}C excited state at a wide range of possible values of the ^{21}C resonance energy [3].

In ^{6}He, the $n\alpha$ interaction is dominated by the $^{2}\mathrm{P}_{3/2}$ channel, where both the scattering length and effective range appear at leading order [4]. We demonstrate necessity of introducing a $nn\alpha$ contact interaction to renormalize the system, and adjust its coupling constant to reproduce the measured ^{6}He S_{2n} [5]. The matter radius and point proton radius of ^{6}He are predicted, at leading order in the EFT, through their correlations with S_{2n}.

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P

High-Statistics β^+/EC-Decay Study of ^{122}Xe *

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Neutron deficient ^{122}Xe is centrally located with respect to the evolution of collectivity in the $Z > 50$, $N < 82$ region, which exhibits an extraordinarily smooth evolution of simple collective signatures. This smooth onset of collectivity is unprecedented on the nuclear mass surface. However, collectivity in this region is very poorly characterized because of a lack of spectroscopic data for low-spin states. It is the characterization of low-spin states, e.g., relative and absolute $B(E2)$ decay strengths and the occurrence of $E0$ decays, that are essential for describing the collective nature of these nuclei.

Excited 0^+ states in $^{124-132}$Xe [1] are very strongly populated in $(^3He, n)$ reactions, suggesting that there are important proton subshell gaps influencing the low-lying structure of these isotopes and possibly shape-coexistence that would lead to strong $E0$ transitions. There are $E0$ transitions observed in $^{118-124}$Xe [2], but they are not fully characterized. In order to provide detailed spectroscopy, especially of weak low-energy decay branches and possible $E0$ transitions, a high-statistics ^{122}Cs β^+/EC-decay experiment was performed at the TRIUMF-ISAC facility using the 8π γ-ray spectrometer and its auxiliary detectors including PACES, an array of five Si(Li) detectors, for spectroscopy of internal conversion electrons. The status of the data analysis and preliminary results will be presented.

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Study of 0^+ States at iThemba LABS

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Reactions where protons are stripped off the beam nucleus, so that the outgoing particle is a neutron, are difficult to carry out. In particular it is especially challenging to obtain sufficient neutron energy resolution. Examples of these neutron emitting direct reactions are (d,n) and (^{3}He,n) which donate one and two protons to the target nucleus respectively. One proton stripping can be made with the (^{3}He,d) reaction, but two proton stripping requires reactions using heavy ions such as (^{16}O,^{14}C) and very good resolutions are still difficult to achieve. The (^{3}He,xn) reaction has been applied, using the detection of the neutrons, to search for excited 0^+ states in the residual nucleus. Excellent energy resolution is achieved by the use of γ-ray detection.

The Sn isotopes (Z=50) are particularly interesting as their stable isotopes have their neutrons in the middle of the N=50-82 shell but have a closed proton shell at Z=50. This proton shell closure keeps the lowest energy levels in these nuclei spherical. But as soon as the proton closed shell is broken by proton excitation, the neutron orbitals drive the nuclei to become deformed [1]. Experimental results from these first high resolution measurements of L=0 two proton stripping to both spherical and deformed nuclei across the Z=50 proton shell closure have been obtained and will be presented.

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P

Dineutron correlation in p-shell neutron-rich nuclei

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Recently, studies of neutron-rich unstable nuclei have been advanced and many exotic and interesting phenomena are suggested. Dineutron correlation is one of the most attractive phenomena in the physics of neutron-rich nuclei. A dineutron is a pair of two neutrons coupled to a spin-singlet having strong spatial correlation to be compact, considered as a kind of cluster. It is suggested that the spatial correlation between two neutrons enhances in the neutron-halo or neutron-skin region of neutron-rich nuclei. Two neutrons are unbound in free space so that the properties of dineutron correlation in neutron-rich nuclei, for example, the degree of formation and the size, would strongly depend on the circumstances such as the number of protons and neutrons, and core deformation and excitation. However, the existing frameworks to investigate dineutron correlation cannot be applicable to most neutron-rich nuclei because of assumptions such as an inert and/or spherical core, and as a result, the universal properties of dineutron correlation are not well-known.

In order to investigate dineutron correlation in neutron-rich nuclei systematically, we constructed a framework, "a dineutron condensate (DC) wave function", which is useful to describe dineutron correlation about a core having various structure [1]. In this work, we apply the DC wave function to p-shell neutron-rich nuclei, ^{8}He [2], ^{9}Li, and ^{10}Be [3], and investigate dineutron correlation in the ground states of these nuclei. These nuclei have six neurons and, in a naive sense, $(0p_{3/2})^4$ subshell closure component would be significant to gain the spin-orbit attraction. On the other hand, we have suggested that a compact dineutron can be generally formed at the nuclear surface in the p-shell neutron-rich nuclei [1]. Investigating ^{8}He, ^{9}Li, and ^{10}Be systematically, we have shown that dineutron formation (wherein two neutrons couple to a spin-singlet and become compact) and dineutron dissociation due to the spin-orbit interaction (wherein two neutrons occupy the $0p_{3/2}$ orbits independently) compete at their surface and that the degree of formation of a dineutron strongly depends on the binding strength between a core and valence neutrons, that is, the degree of dineutron formation is clearly different between ^{8}He, ^{9}Li, and ^{10}Be. In this presentation, we will show the results about dineutron correlation in ^{8}He, ^{9}Li, and ^{10}Be.

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The role of the tensor component for reducing cutoff scale dependence of many-body calculations using 2N and 3N forces of the chiral effective field theory

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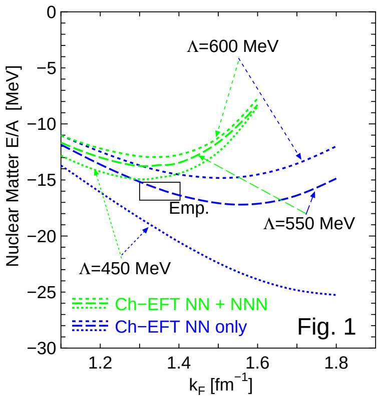
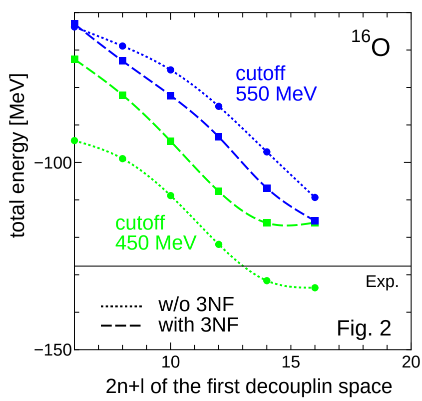
The chiral effective field theory provides accurate descriptions of NN interactions and defines three-nucleon forces consistent with the NN sector [1,2]. As an effective theory of pion degrees of freedom and low-energy constants, the description has a cutoff scale. Physical observables should not depend on the adopted scale. Although experimental NN data are well described by tuning the coupling constants, results of microscopic many-body calculations using the NN interactions only vary. This reminds us the old recognition that the nuclear matter saturation point moves in a so-called Coester band by changing the off-shell character of NN forces. Sophisticated few-nucleon system calculations also show such variation. The change of the tensor component when the cutoff scale Λ is altered is mainly responsible for this variation.





The large difference in the nuclear matter energies for the different Λ's of NN interactions, calculated in the lowest-order Brueckner theory, is much reduced when the effect of the 3NF in the form of the density dependent NN interaction is incorporated [3], as shown in Fig.1. The resulting saturation curve is close to the empirical one. A similar reduction of the Λ-dependence is also seen in the calculations for finite nuclei. Fig. 2 shows UMOA calculations [4] for ^{16}O. The mechanism bringing about the reduction of the cutoff dependence of the calculated results will be presented.

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P

Lifetime measurements in neutron-rich Xe isotopes*

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The region around the doubly magic nucleus ^{132}Sn is of special interest as both single-particle and mean-field approaches can be applied by theory. It is important in an astrophysical aspect, as ”waiting points” of the r-process lie in this region and the nuclear structure there has an impact on the modelling of nucleosynthesis. The $B(E2; 0^+_{gs} \rightarrow 2^+_1)$ values in ^{122,124,126}Cd are well reproduced by Grodzins type systematics but show higher collectivity than predicted by shell model [1]. In ^{136}Te a $B(E2)$ considerably smaller than expected from systematics is observed. In ^{140}Xe two values were known, one following the systematics and one lower than it, as in ^{136}Te. “Safe” Coulomb excitation measurement at REX-ISOLDE (CERN) [2] addressed this discrepancy and confirmed the higher value. Additional constraints from lifetime measurements would allow the determination of the quadrupole moments of the short-lived nuclear states. Furthermore, higher-lying states become accessible in the direct lifetime measurement. Of interest are the negative parity states where the increasing induced electric dipole moment is interpreted as a sign of increasing octupole correlations, maybe peaking at an octupole “magic” number N = 88 [3].

Within the EXILL-FATIMA campaign at ILL, Grenoble, in spring 2013, the lifetimes of excited states in the neutron-rich xenon isotopes ($^{138-144}$Xe), populated in neutron-induced fission of ^{235}U and ^{241}Pu, were measured. The setup consisted of 16 $LaBr_3$(Ce) fast scintillators and 8 Ge Clover detectors. It is characterized with high efficiency which enables even quadruple $(Ge)^2$-$(LaBr_3(Ce))^2$ γ coincidences. Using the generalized centroid difference method [3], lifetimes as short as several picoseconds can be determined.

In this work we present the directly measured lifetimes in the neutron-rich xenon isotopes. The quadrupole moments of the 2^+ states in the even-even isotopes were determined using the existing information on the Coulomb excitation cross section. A clearer picture on the evolution of quadrupole collectivity in the Xe isotopic chain is obtained.

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High Spin Spectroscopy and Shape Changes in ^{105}Cd

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Study of transitional nuclei in mass ∼105 region is interesting due to existence of various structural phenomena. For example lighter cadmium isotopes predicted to have rapid shape transitions as a function of rotational frequency due to the occupation probability of valance quasiparticles in deformation driving high-J, low-Ω orbitals.

High spin states in ^{105}Cd were populated using the fusion evaporation reaction ^{92}Mo(^{16}O, 2pn)^{105}Cd at an incident beam energy of 75 MeV. Beam of ^{16}O ions with current of 1 pnA was delivered by the 14UD Pelletron accelerator at TIFR, Mumbai. The de-exciting γ- rays were detected by the Indian National Gamma Array (INGA) [3] facility at TIFR. The coincidence data was collected in list mode with digital data acquisition system using Pixie-16 Module by XIA-LLC software. The measured coincident events were then sorted in to Eγ -Eγ symmetric matrix and analysed with RADWARE [4] package. The level scheme of ^{105}Cd was examined and fit well with the previously reported level scheme in Ref.[3] except few levels in negative and positive parity bands. we have placed 30 new transitions in the level scheme based on coincidence and intensity arguments. The origin of observed band structures and shape evolution will be presented in detail.

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P

In-trap decay spectroscopy on highly-charged ions with the TITAN facility *

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The TITAN ion-trap facility at TRIUMF consists of a unique combination of ion traps for high-precision mass spectrometry. Additionally, it provides the opportunity to perform backing-free in-trap spectroscopy on radioactive isotopes produced by the ISAC radioactive ion-beam facility. A total of seven Si(Li) X-ray detectors surround TITAN's charge-breeder Penning-trap (EBIT) perpendicular to the beam axis. This new in-trap spectroscopy setup is currently developed in the context of measuring weak electron-capture branching ratios (ECBR) of the intermediate odd-odd nuclei in $\beta\beta$-decay. The EC branches are, in most cases, suppressed by several orders of magnitude relative to their beta-counterparts. The presence of the 6 T B-field in the ion trap offers the advantage that electrons from the β^+-decays are directed on axis out of the trap and away from the X-ray detectors, thereby significantly reducing the background caused by 511 keV positron annihilation and thus increasing the sensitivity of the detection of low-energy photons. By using the EBIT's charge breeding function, i.e. trapping with an electron beam to optimize ion-cloud confinement and charge breeding the ions, trapping times of the order of minutes without significant ion losses have been realized. The current status and progress of the facility including the results of the first successful measurement of highly charged ^{124}Cs and a recent experiment on ^{116}In where multiple-ion stacking into the EBIT was performed, will be presented.

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Isospin mixing at finite temperature in proton rich ^{80}Zr nucleus

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The knowledge of the isospin impurity (i.e. isospin mixing) is important since it affects the properties of the Isobaric Analog States (IAS) and the Fermi β decay of the N = Z nuclei near the proton drip-line. Indeed, the effect of the isospin impurity on the β decay has implications in the Fermi transition rates, and thus on the Cabibbo-Kobayashi-Maskawa matrix. The breaking of isospin symmetry, increasing with Coulomb interaction, can be observed through decays which would be forbidden by selection rules. This is the case of the E1 decay from self-conjugate nuclei in a I=0 configuration. To fully exploit this property, one should go in the region of the Giant Dipole Resonance (GDR), where most of the E1 strength is concentrated. This approach has been employed to measure the isospin mixing in nuclei at finite temperature T, formed in fusion evaporation reactions. In this type of experiments the use of self-conjugate projectile and target nuclei ensures the population of a compound nucleus (CN) with I=0. The hindrance of the GDR gamma decay can be measured and thus the mixing amplitude deduced. A partial restoration of the isospin symmetry is expected at high temperature due to the decreasing of CN lifetime for particle decay. In the present case isospin mixing was measured in the hot CN ^{80}Zr. This is the heaviest N=Z nucleus so far studied and for which only one datum exists at finite temperature [1]. In this mass region the deviations between different predictions are the largest and thus this nucleus provides a good test for theory [2]. The experimental method is based on the analysis of the GDR γ-ray emission in the fusion reactions ^{40}Ca+^{40}Ca at E= 136 MeV. The experiment was performed in Laboratori Nazioni di Legnaro using an array of segmented HPGe detectors and a large volume $LaBr_3$:Ce (AGATA-HECTOR$^+$ array).

From data analysis three relevant results were obtained:

1. The Coulomb spreading width was found not to depend on the excitation energy of the nucleus, in agreement with theory.

2. The comparison between this measurement and that at higher temperature shows clearly the restoration effect of isospin symmetry.

3. The combined analysis of the experimental data allowed to deduce for this nucleus the isospin mixing at T=0, information that in not accessible in other ways. A constraint to theory can thus be given [2].

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P

Electron screening in nuclear reactions

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In regular nuclear physics we can forget about the electron screening effect. However, the effect becomes important in nuclear astrophysics, where most reactions between charged nuclei happen much below the Coulomb barrier and even small changes to the barrier result in large changes in the cross section. The effect of electron screening can be and was observed in many nuclear reactions when we made dedicated efforts to measure cross sections and resonance strengths at low energies. On the other hand, the field of electron screening research in nuclear reactions is a messy one, with both the theoretical predictions failing to explain the experimental results and some measurements turning out to be wrong altogether. We will slowly have to admit to ourselves that we have no idea what happens to the cross sections in stellar plasma. The way forward is to first understand and explain the results of laboratory measurements. I will concentrate on one class of measurements for which we have no plausible explanation. Namely, it is now well established that when light nuclei are implanted in metallic targets, the nuclear reaction cross sections increase by more than an order of magnitude above any theoretical prediction. This was observed in the $^{2}H(d,p)^{3}H$ reaction by several research groups [1-3]. The magnitude of electron screening depends strongly on the metallic host material and this dependence is currently not understood. In the $^{1}H(^{7}Li,\alpha)^{4}He$ reaction in inverse kinematics we also observed a dependence of the screening effect on the host material, but a different one than in the $^{2}H(d,p)^{3}H$ reaction. These results revealed that the magnitude of electron screening depends on where in the crystal lattice the implanted target nuclei end up microscopically. Our further studies of the Z dependence of electron screening with heavier beams will hopefully reveal what happens to the implanted nuclei at their dislocated positions in the crystal lattice. Large electron densities that are needed to explain the measurements in the static picture of electron screening [4] can certainly be ruled out. This implies that electron screening is a dynamic effect both in a laboratory on Earth and in stellar plasma. The effect may turn out to be important for reactions with radioactive beams, where inverse kinematics is often employed and targets of light nuclei may be prepared by implantation.

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Spin-isospin response of exotic nuclei in relativistic framework *

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The spin-isospin response associated with finite spin and isospin transfer is one of the most important properties of nuclei. This type of response provides information about a variety of weak interaction processes such as beta-decay, electron capture, neutrino capture and scattering in nuclei and stars. Lately the models which are commonly used to describe nuclear spin-isospin response, such as Quasiparticle Random Phase Approximation and Shell Model, have advanced considerably. However, a self-consistent model which can simultaneously reproduce data on the overall strength distribution up to high excitation energy, quenching and on the fine structure of the low-lying strength is still a challenge.

This work attempts to develop such a model based on the recent self-consistent extensions of the covariant energy density functional (CEDF) theory. The effective one-boson exchange interaction spans effective mesons and emerging collective modes. While heavy mesons are treated as classical fields, the low-lying collective phonons are included non-perturbatively within the time-blocking approximation. Thus, the covariant spin-isospin response theory has been advanced to the inclusion of temporal and spatial non-localities [1,2] while pairing correlations of the superfluid type are included on the equal footing by means of the Gorkov's Green functions. The approach based on a few parameters of the CEDF provides a high-quality description of nuclear excitation spectra in both neutral and charge-exchange channels. Results of the recent calculations for spin-isospin response of exotic medium-mass nuclei studied at NSCL and RIKEN are presented and discussed.

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The BRIKEN project: β-delayed neutron measurements at RIKEN / Japan

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Very neutron-rich nuclei can emit neutrons after a β-decay when their reaction Q-value is larger than the (1-/2-/3-...) neutron separation energy. This decay mode is called "β-delayed (1-/2-/3-...)-neutron emission" and celebrates its 75th anniversary in 2014. βn emitters are of special interest for the astrophysical rapid neutron capture process (r process), for nuclear structure and nuclear technologies. In the r process βn-branches lead to a deviation of the reaction flow to lower mass chains during the freeze-out phase, and the released neutrons can be recaptured and further alter the abundance distributions. An exact knowledge of the βn-emission probabilities is thus a prerequisite to interpret the observed solar r-abundance peaks and draw conclusions from this about the participating progenitor isotopes and their contributions. For nuclear structure studies of e.g. light neutron-rich nuclei the βn-decay is the dominant decay channel and strongly suppresses other β-delayed emission processes. It allows to study the β-strength above the neutron separation energy. For the kinetics of a nuclear reactor the βn's released by the fission fragments play an important role to sustain and control the chain reactions, and after shutdown for the decay heat of the fission products.

With the next generation of fragmentation and ISOL facilities presently being built or already operating, one of the main motivation of all projects is the investigation of these very neutron-rich isotopes. However, reaching more neutron-rich isotopes means also that multiple neutron-emission becomes the dominant decay mechanism which is presently not well investigated. Nowadays, more than 600 βn-emitters are identified but only for a fraction ($\sim$30%) measured branching ratios are available, with strongly decreasing quantity and quality towards multiple neutron emission branches and away from the fission peaks.

The BRIKEN campaign is a joint experimental effort of 23 international partner institutes that will combine one of the presently most powerful radioactive beam facilities (RIKEN), a highly pixelized implantation detector (AIDA) and a highly efficient neutron detector setup to measure half-lives and neutron branching ratios of the most exotic neutron-rich isotopes which are presently accessible. In this talk we will give an overview about the setup and the experimental program which is planned for 2015/16.

P

TOWARDS AB-INITIO CALCULATIONS OF ELECTROMAGNETIC REACTIONS IN MEDIUM-MASS NUCLEI

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Electromagnetic reactions with nuclei are important in many fields of physics ranging from nuclear physics to astrophysics. The response of a nucleus to the interaction of an external electromagnetic probe is a crucial observable to test our understanding of nuclear dynamics. Until very recently, most of the ab-initio calculations of such reactions where the nucleus is broken in several pieces, were restricted to very light nuclei ($A \leq 7$). By merging coupled-cluster theory and the Lorentz integral transform method one can extend the ab-initio study of electromagnetic break-up reactions to the region of medium-mass nuclei . We first benchmark the new method in ^{4}He and then address the photo-disintegration of ^{16}O [1]. We then move to ^{40}Ca and ^{48}Ca, and investigate the electric dipole polarizability [2]. Preliminary results indicate a correlation between the polarizability and the neutron-skin radius of ^{48}Ca. This latter is attracting a lot of attention in nuclear physics and experiments to measure both the polarizability [3] and the neutron-skin radius [4] are planned/ongoing at RCNP and JLAB respectively.

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Universal features of oscillator basis extrapolations*

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Recent developments in extrapolation techniques for nuclear many-body methods that use harmonic oscillator basis expansions focus on the infrared (IR) and ultraviolet (UV) cutoffs induced by a truncated basis [1]. A finite oscillator basis effectively imposes a hard-wall boundary condition in coordinate space, motivating infrared extrapolation formulas for the energy and other observables. Energy and radius corrections were first calculated using this approach in [2]. These results were refined in [3], where we accurately determined the box size as a function of the model space parameters, computed scattering phase shifts in the oscillator basis, and discussed the extension of this approach to other localized bases.

In Ref. [4] we revisit these results to identify and test a consistent and systematic IR expansion for the energy and radius of two-body bound states. We find that the energy corrections can be written purely in terms of the $S-$matrix and therefore depend only on observables (but they will vary with the nucleus). We also generalize the energy extrapolation formula to nonzero angular momentum, and apply it in detail to the deuteron.

These systematic IR extrapolation results so far rely on the possibility of making UV corrections negligible. Our ongoing work [5] deals with systematic UV extrapolations, which are based on an effective cutoff in momentum space dual to the IR cutoff in coordinate space. Corrections are dependent on the potential, but may scale simply for different nuclei. We will present the recent results from [4] and [5], underscoring the similarity and differences in IR and UV extrapolations and how they combine.

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Results of recent lifetime studies at NSCL and a new Plunger Technique

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Nuclei along the $N = Z$ line have generated a lot of interest due to the occurrence of strong collective features in its vicinity. Especially for nuclei in the mass 70 – 80 region, the rapid changes in collective properties of nuclei with small changes in both spin and isospin have provided diverse opportunities to understand collective behavior in nuclear structure. Recent work at the NSCL has measured the B(E2) for the self-conjugate nucleus ^{76}Sr and shown that it has a large collectivity [1], and a study of ^{72}Kr was undertaken and investigated the possibility of a shape transition among the low-lying states of this nucleus [2]. Here we demonstrate a new method for studying collective properties of nuclei, the Differential Recoil Distance Doppler Shift Method [3], employing GRETINA with the NSCL TRIPLEX plunger. This technique is an efficient method to measure the lifetimes of excited states in nuclei and was used for the first time in an experiment at the NSCL in 2012. The method will be discussed and if time permits new results obtained with the method will be presented.

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P

Commissioning of the SPICE detector for in-beam electron spectroscopy

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A new ancillary detector, SPICE (SPectrometer for Internal Conversion Electrons) has been constructed and tested at the ISAC-II facility of TRIUMF. SPICE is designed to be coupled with the TIGRESS HPGe array to enable simultaneous in-beam gamma-ray and conversion-electron spectroscopy in both stable and radioactive ion beam experiments. The main features of SPICE are the effective reduction of beam-induced backgrounds and a large energy-acceptance range for electrons between 100 and 3500 keV. These are achieved using a magnetic lens formed of permanent NdFeB magnets positioned upstream of the target and surrounding a high-Z-material photon shield. The internal conversion electrons emitted from the target are guided around the photon shield and detected by a large-area annular lithium-drifted silicon detector which is segmented into 120 individual sector elements. Reactions induced by a stable ^{12}C beam at 67 MeV impinging on a ^{196}Pt target were studied with SPICE. The scattered ^{12}C particles were detected with a double-sided annular silicon detector positioned at forward angles. SPICE will be a powerful tool to measure conversion coefficients and $E0$ transitions in atomic nuclei, which are not accessible from decay, thus providing a useful probe to study shape coexistence and quantum state mixing in exotic nuclei. An overview of the main features of SPICE and results from source and in-beam test will be presented as well as a look at future opportunities.

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The Rialto laser ion source at IPN Orsay

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Resonant Ionization Laser Ion Sources (RILIS), based on the stepwise excitation of atomic transitions, offer an outstanding combination of excellent elemental selectivity and high ionization efficiency. It has become a powerful and versatile tool for the generation of pure radioactive isotope beams at on-line mass separator facilities worldwide. Initiated in 2009, IPN-Orsay has installed RILIS in the Isotope Separator On-Line (ISOL) system at the photofission facility Alto, which aims at the measurements of the nuclear properties of exotic nuclei through $\beta\gamma$ and βn spectroscopy, among other techniques.

Rialto consists of two dye lasers pumped with a 532-nm 10-kHz Nd:YAG laser with wavelength extension options of two frequency doublers and one tripler, and was successfully put into its first operation in 2011. Gallium isotopes were resonantly ionized and an enhancement factor of 15 was observed compared to surface ionization. The β-decay of ^{84}Ga was studied in a first physics run. In 2013 and early 2014, zinc isotopes up to ^{80}Zn were resonantly ionized on-line with frequency tripling in the first step. An experiment of tin is planned in September 2014.

To provide the optimal laser ionization scheme and operational parameters for different elements during on-line radioactive beam deliveries, an off-line reference cell has been built to test laser ionization of different elements via different ionization schemes. The first commissioning of the off-line reference cell is expected starting in April 2014. Developments of antimony and tellurium are planned.

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Effect of temperature and spin on GDR widths*

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Giant dipole resonance (GDR) is one of fundamental mode of excitation in nuclei at finite temperatures. It is also one of the few known experimental probes to study nuclear properties at high excitation energies. The resonance observables, namely, energy centroid could be related to nuclear deformation and widths could be related to damping mechanism of the resonance. At a given excitation energy, the increase in GDR widths are due to coupled effect of spin and temperature and it is an experimental challenge to decouple them. In a series of experiments, performed using 15UD Pelletron accelerator facility at Inter University Accelerator Centre, we have extracted GDR observables over a large range of temperature and angular momentum to draw a systematic study of evolution of these variables. ^{28}Si+^{116}Cd reaction was populated at bombarding energies of 125-196 MeV. The exclusive GDR γ-rays were measured using large NaI(Tl) detector in coincidence with 4π spin spectrometer which recorded low energy γ rays. The experimental data was analysed under framework of statistical model of decay of compound nucleus, and compared with thermal shape fluctuation model (TSFM) incorporating shell corrections. In the present conference, we would like to show these results in detail.

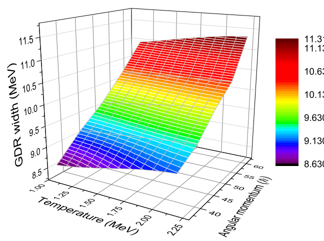

FIG. 1. 3D contour surface depicting GDR widths at different spin and temperature in ^{144}Sm using TSFM calculations.

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Spectroscopy of ^{234}U and study of the ^{232}Th(^{9}Be, $\alpha 3n$) reaction mechanism

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There are longstanding predictions of hyperdeformed, reflection-asymmetric third minima in the potential-energy surfaces of many nuclei near ^{232}Th. Several calculations using different approaches have shown these minima over the past forty years [1,2]. In 1994, calculations of the potential-energy surfaces of the Rn to U isotopes showed much deeper third minima than those previously predicted in Th and U nuclei [3]. The results revealed third minima with large quadrupole deformations ($\beta_2 \approx 0.85$) and significant reflection asymmetry ($0.35 < \beta_3 < 0.65$). For U isotopes with A > 228, two minima were predicted, one with a lower degree of reflection asymmetry than the other.

In order to test the predictions for ^{234}U, an experiment has been performed using the ^{9}Be+^{232}Th incomplete-fusion reaction together with the Gammasphere gamma-ray spectrometer and the Microball charged-particle detector array. In addition to facilitating channel selection and suppression of gamma rays from fission, spectra from the Microball show a complex fragmentation of the projectile, including incomplete fusion and noncapture breakup. By selecting the $\alpha 3n$ evaporation channel, the yrast ground-state band of ^{234}U has been observed up to 22 $\hbar$ along with a previously unobserved sideband, connected to the yrast band through several linking transitions. Initial results from both Gammasphere and the Microball will be presented.

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Investigating the Reactor Antineutrino Anomaly with Beta Spectroscopy in Ion Traps *

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The Reactor Antineutrino Anomaly is a discrepancy between the expected flux of antineutrinos from nuclear reactors and the detected flux. Only 94.3(23)% of expected antineutrinos are detected[1]. Calculations of the expected flux assume that all the fission product β decays have spectral shapes that are nearly identical to the allowed shape[2]. However, many of the highest energy transitions are first forbidden and may have a different spectral shape which could alter the predicted antineutrino flux and explain the anomaly.

We will perform measurements of the shapes of β decay spectra on the isotopes that have the biggest impact on the Reactor Antineutrino Anomaly. Those nuclei, where ^{92}Rb is the most important, will be produced at the CARIBU facility at Argonne National Laboratory and trapped in a Beta-decay Paul Trap[3]. The trapped ions will undergo β decay and the β spectra will be measured in plastic scintillators. A novel calibration technique will be utilized where the allowed β decay of ^{8}Li will be measured with the same detectors. The ^{8}Li β decay populates a broad excited state in ^{8}Be that breaks up into two alpha particles. By measuring the momentum directions of the β and alpha particles and the energies of the alphas using double-sided silicon strip detectors the full decay kinematics can be determined independently from the scintillator measurement. This provides a powerful tool for characterizing the scintillator detector response. This new nuclear data will provide more confidence in the antineutrino flux predictions.

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New multi-quasiparticle isomers in ^{182}Ta and ^{183}Ta*

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Excited states in neutron-rich tantalum isotopes have been studied with deep-inelastic reactions [1] using the Gammasphere array at Argonne National Laboratory. A beam of 840 MeV ^{136}Xe ions from the ATLAS facility was incident on a gold-backed ^{186}W target. The out-of-beam γ-ray coincidence data revealed new level structures that were fed by isomers and were in coincidence with tantalum x-rays. Measurements of the corresponding yields from various targets [2,3], together with coincidences with known tantalum γ-rays [3,4,5], enabled isotopic assignments for these new structures.

Two new isomeric states that feed towards the known 10^- state in ^{182}Ta [4] were identified. Extracted transition decay strengths and angular correlations for the depopulating transitions suggest a $K^\pi = 14^+$ assignment for the lower of the new isomeric states, while the level scheme is further extended up to a higher isomer at 3.4 MeV. High-spin states in ^{183}Ta feeding a known 1.3 MeV isomeric state [5] were also identified up to new isomer at 3.9 MeV. Some of these initial results for ^{183}Ta have been reported previously [6].

Configuration assignments for a range of intrinsic states in both ^{182}Ta and ^{183}Ta have been made possible through a comparison of observed intrinsic state energies with the results of multi-quasiparticle calculations using Nilsson energies and Lipkin-Nogami pairing. In a number of cases, the magnetic properties and alignments, inferred from rotational band structures, further support the assignments. The current presentation will discuss these new results in the context of systematic observations of high-K states across the chain of neutron-rich tantalum isotopes.

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In-beam γ-ray and conversion electron spectroscopy of ^{188}Pb

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In the atomic nucleus, the interplay between single-particle motion, collectivity and pairing is seen as a rich tapestry of coexisting nuclear shapes and exotic excitations. One of the richest regions is formed by very neutron-deficient nuclei with the proton number Z close to the magic 82 and the neutron number N close to the mid-shell at N=104 [1–3]. A considerable body of both theoretical and experimental evidence has been gathered for coexisting configurations possessing different shapes in this region, but there are many open questions left.

This presentation will focus on experimental results from a simultaneous in–beam γ–ray and conversion electron spectroscopic study of ^{188}Pb using the SAGE spectrometer [4, 5] at the Accelerator Laboratory of Jyväskylä, Finland.

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Investigation of the properties of the Pygmy Dipole Resonance in ^{124}Sn via inelastic scattering of ^{17}O

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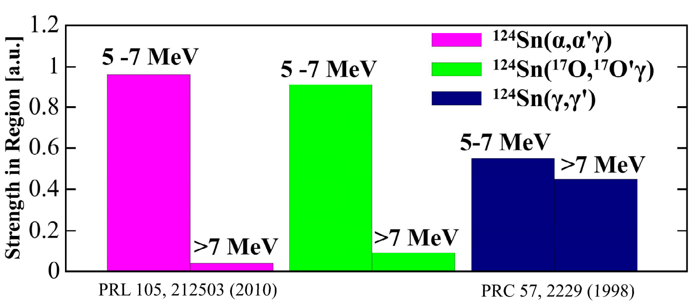
The study of the Pygmy Dipole Resonance (PDR), the low energy part of the electric dipole response in nuclei, is particularly relevant to investigate the nuclear structure and also in connection with photo-disintegration reaction rates in astrophysical scenarios. Its description, within the hydrodynamical model, corresponds to a vibration of the neutron skin against a N=Z core. In recent years, the study of the PDR has attracted particular attention since its microscopic structure is presently under discussion. Efforts in the direction of understanding its nature require its excitation using different probes. Indeed, recent works comparing results of photon and α scattering experiments show the presence of a different behaviour in the population of these states. While a set of states at lower energy is excited with both types of reactions, the other set at higher energies is not populated by α scattering. This interesting finding has motivated further work based on the use of another probe with strong isoscalar character as ^{17}O. The experiment was recently made for the nucleus ^{124}Sn using a set up including the AGATA detector array and a system of Si telescopes to measure the scattered particles. With AGATA, the gamma decay up to the neutron separation energy was measured with high resolution. The angular distribution was measured both for the gamma-rays and the scattered ^{17}O ions. The figure below shows the present results integrated over two excitation energy regions in comparison with the previous findings for (α, α') and (γ, γ'). It is interesting to observe that also in this case only the low energy region is populated. Moreover in present case a DWBA analysis was made both for the pygmy states, for other excited states, and for the elastic channel. This give an overall consistent description of the experiment.



Examining the Mixing of Intruder and Spherical States in ^{116}Sn with the 8π Spectrometer *

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The even-even tin isotopes are well-known to exhibit shape coexistence, which is the phenomenon where deformed and spherical nuclear shapes can coexist within a narrow energy region at relatively low-lying levels of the nucleus. The deformed structures, known as intruder states, are quasi-rotational bands that are the result of a $2p-2h$ proton excitation across the $Z = 50$ shell gap. The major challenge to investigating intruder states is the lack of sensitivity for observing low-energy intra-band transitions that carry the information linked to shape coexistence, due to the phase space energy factor associated with electromagnetic decay (E^5 for $E2$ decays). High-statistics γ-ray spectroscopy can be utilized to observe these transitions with the gating "from below" technique extensively described in [1]. In the current investigation of ^{116}Sn, an 85 keV and a 166 keV transition were directly observed, and their transition strengths were determined to be 83.1(44) and 140(70) $W.u.$ respectively. The observation of these collective transitions has lead to new insights on the mixing that occurs between intruder and spherical states in ^{116}Sn.

The experiment was conducted at TRIUMF, Canada's National Laboratory for Nuclear and Particle Physics. A high-intensity and high-purity beam of ^{116}In was used to populate states in ^{116}Sn via β^- decay. The resulting γ rays were observed with the 8π detector array, which consists of twenty high-purity germanium detectors coupled to a suite of ancillary detectors.

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*This work was supported by the National Science and Research Council of Canada.

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Experimental measurement of an isomeric state in ^{98}Rb and changes in mean-square charge radii of the rubidium isotope chain.

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Fast-beam collinear laser spectroscopy has been performed on the neutron-rich rubidium isotopes at the TRIUMF radioactive ion beam facility. The experiment was performed using the collinear laser spectroscopy setup and utilised an RFQ ion buncher and a novel cw laser-chopping technique to minimise the effects of optical pumping [1]. These latest sets of measurements have looked into extending the neutron-rich side of the isotope chain up to ^{99}Rb and beyond to investigate the possibility of shape coexistence and the evolution of single particle energies in this region. From these experiments two nuclear states in ^{98}Rb have been clearly observed for the first time using laser spectroscopy.

Previous experiments into the rubidium campaign have measured the charge radius of the neutron-deficient isotopes down to ^{74}Rb for C-K-M matrix applications [2]. The measured properties of the neutron-rich ground and isomeric nuclear states will be presented along with a summary of the changes in the mean-square charge radii of the entire rubidium chain to investigate the effects of a specific-mass-shift in the D_2 line.

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Nuclear structure of ^{124}Xe studied with β^+/EC-decay *

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The Xe isotopes in the N<82 region are thought to be weakly deformed. To better characterize the nuclear structure of ^{124}Xe, a β^+/EC-decay study of the isomers of ^{124}Cs was performed at the 8π spectrometer at TRIUMF. The 8π has a high sensitivity to weak branches, which would provide the low-spin spectroscopic data needed to determine collective properties of the nucleus.

A beam of 9.8x10^7 ions/s ^{124}Cs (J^π = 1^+, $T_{1/2}$ = 30.8 s) and 2.6x10^6 ions/s ^{124m}Cs (J^π = $(7)^+$, $T_{1/2}$ = 6.3 s) was implanted at the center of the 8π spectrometer$-$a spherically symmetric array of 20 Compton-suppressed high-purity germanium detectors$-$where these nuclei underwent β^+/EC-decay into stable ^{124}Xe. High-statistics γ-γ coincidence measurements were analyzed to expand the level scheme of ^{124}Xe considerably, with the addition of over 180 new transitions and 60 new levels. The data set has revealed a previously unobserved decay branch from the ^{124}Cs high-spin isomer.

Gamma-rays at 360 keV ($2^+_3 \to 0^+_2$) and 289 keV ($2^+_4 \to 0^+_3$) were clearly observed in the present data set but were unobserved in a previous Coulomb excitation experiment (^{12}C (^{124}Xe, ^{124}Xe*)) at Gammasphere [1]. The matrix elements for these in-band transitions were deduced based on γ-ray yields of other decay branches observed in the Coulex experiment. In the present decay study, B($E2$) transition strengths were measured for transitions into excited 0^+ states using the new branching ratios. Comparison with the Coulex results and implications on the collective structure of ^{124}Xe will be presented.

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In Gas Laser Ionization and Spectroscopy of rare isotopes

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The In-Gas Laser Ionization and Spectroscopy (IGLIS) technique is employed at the LISOL facility to produce highly-pure radioactive beams and to obtain important information about their ground-state and isomer properties. Laser spectroscopy inside the gas cell has successfully been performed on neutron deficient copper and silver isotopes [1,2]. Recent experiments on the heavier mass region allowed to efficiently produce actinium beams and to resolve the hyperfine structure in the neutron deficient isotope ^{212}Ac. The investigations on actinium are complemented by measurements on the neutron rich isotopes at TRIUMF where ^{225}Ac was measured with in-hot-cavity laser spectroscopy.

To improve the resolution of in-gas laser spectroscopy the ionization in the supersonic gas jet in front of the orifice of the gas cell is explored at the off-line HELIOS laboratory at KU Leuven. Unlike in-gas-cell laser spectroscopy studies, laser ionization in the low-temperature and low-density gas jet allows essential reduction of Doppler and pressure broadenings. This improves the spectral resolution by one order of magnitude, as recently demonstrated in off-line experiments on the stable copper isotopes [3].

In this talk the most recent on-line results obtained for the actinium isotopes at LISOL and TRIUMF will be discussed and will be compared with those obtained off-line for the long-lived reference isotope ^{227}Ac. In addition, a summary on the experimental activities to be performed at the off-line HELIOS laboratory, being commissioned at KU Leuven, as well as the future plans to link in-gas spectroscopy [4] with the Superconducting Separator Spectrometer (S^3) at the new radioactive beam facility SPIRAL2 (GANIL) will be presented.

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Nonlocal energy density functionals for low-energy nuclear structure

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We introduced a new two-body finite-range pseudopotential built as an expansion in derivatives up to next-to-next-to-next-to-leading order (N^3LO), considering it as effective interaction generating a nonlocal energy density functional (EDF) [1]. The nonlocal EDF was derived by averaging the pseudopotential over the uncorrelated nuclear wavefunction. This derivation guarantees that the obtained EDF is free from the self-interaction problem and allows for expressing the EDF coupling constants through the parameters of the central, spin-orbit, and tensor terms of the pseudopotential.

A restricted version of the EDF stemming from a local finite-range pseudopotential and built as an expansion in powers of a regularizing scale was constructed in the framework of the effective-theory (ET) methodology [2]. For this EDF, a rapid convergence of the expansion, independence of computed observables on the regularization scale, and naturalness of the EDF coupling constants were shown.

Preliminary calculations with the new pseudopotential and corresponding EDF at NLO were performed in infinite nuclear matter [3], and the mechanism of saturation in the equation of state was well reproduced without including density-dependent term. These results, complemented with the formal developments and the ET proof-of-principle presented in this work, open up interesting perspectives for the use of nonlocal EDFs in nuclear-structure calculations at the mean-field level and beyond.

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β-decay of $^{33-35}$Mg near the island of inversion *

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Nuclei in the island of inversion, near the $N = 20$ shell closure, exhibit a fascinating behaviour where the nuclear ground states (gs) show deformed configurations dominated by particle hole excitations across the neutron shell gap. $^{31-35}$Mg nuclei are in or at the border of this island displaying intruder gs configurations. $^{31-35}$Al are suggested to have a mixed gs configurations of normal and intruder type and thus serve as a transition from intruder dominated Mg isotopes to the normal gs configuration in Si isotopes.

An experiment was performed in the ISAC-I facility at TRIUMF with the goal of populating states in $^{33-35}$Al via the beta decay of $^{33-35}$Mg. A UC_x target with laser-ionization from TRILIS was bombarded with 500 MeV protons to produce pure beams of Mg ions. The ions were transported and implanted on a moving Mylar tape at the center of the 8π facility [1]. A set of 10 plastic scintillators (SCEPTAR) and a zero degree scintillator were used for beta tagging. This was surrounded by 20 Compton-suppressed HPGe detectors for γ-spectroscopy and 6 $LaBr_3$ detectors for fast-timing measurements.

First results obtained from this experiment will be presented. The level schemes produced for states in ^{33,34}Al will be compared to shell model calculations [2] to understand the influence of intruder states in the neutron-rich $^{33-35}$Al isotopes. In addition, previous experimental results from studies of ^{33,34}Mg [3] and ^{33,34}Al will be clarified.

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P

Investigation of the E2 and E3 matrix elements in ^{200}Hg using direct nuclear reactions *

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A nuclear-structure campaign has been initiated to investigate the isotopes of Hg around mass 199. To date, ^{199}Hg provides the most stringent limit on an atomic electric dipole moment (EDM) [1]. The observation of a permanent EDM would represent a clear signal of CP violation from new physics beyond the Standard Model. Theoretical nuclear-structure calculations for ^{199}Hg are challenging, and give varied predictions for the excited-state spectrum. Understanding the E2 and E3 strengths in ^{199}Hg will make it possible to develop a nuclear structure model for the Schiff strength based on these matrix elements, and thereby constrain present models that predict the contribution of octupole collectivity to the Schiff moment of the nucleus.

The most direct way of measuring the matrix elements connecting the ground state to excited states is through inelastic hadron scattering. The high level density of a heavy odd-A nucleus like ^{199}Hg makes a measurement extremely challenging. Complementary information can, however, be determined for states in the neighbouring even-even isotopes of ^{198}Hg and ^{200}Hg, and single-nucleon transfer reactions on targets of even-even isotopes of Hg can yield important information on the single-particle nature of ^{199}Hg.

The work presented here comprises two experiments which use a 22 MeV deuteron beam incident on an isotopically enriched target of ^{200}Hg^{32}S. The first experiment was an inelastic deuteron scattering experiment, $^{200}\mathrm{Hg(d, d')}^{200}$Hg, and included 20 angles ranging from 10° to 115° up to an excitation energy of $\sim$ 6 MeV. The second experiment was a single-nucleon transfer reaction into ^{199}Hg, $^{200}\mathrm{Hg(d, t)}^{199}$Hg, and included 10 angles from 5° to 50° up to an excitation energy of $\sim$ 3 MeV. These experiments were performed using the Q3D magnetic spectrograph at the Maier-Leibnitz Laboratory. Preliminary results from these experiments will be presented.

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P

Triaxiality in the neutron-rich rhenium isotopes*

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The region with $Z \sim 76$ and $N \sim 116$ has been predicted to exhibit changes in nuclear deformation [1]. Indeed, our observations in ^{188,190}W [2] and ^{191,193}Ir [3], show signatures of a transition to triaxial shapes. The present focus is on the neutron-rich isotopes ^{187}Re, ^{189}Re and ^{191}Re, accessed via multinucleon transfer or deep inelastic reactions, specifically using a pulsed or chopped ^{136}Xe beam from the ATLAS accelerator at Argonne National Laboratory, incident on gold-backed ^{187}Re and ^{192}Os targets. The γ rays from excited reaction products were measured using the Gammasphere detector array.

Previous experiments have identified delayed γ rays from isomeric states in ^{187}Re [4] and ^{191}Re [5]. In addition to γ-ray spectroscopic studies, low spin states in ^{187}Re,^{189}Re and ^{191}Re have also been the subject of particle transfer experiments [6]. In the current measurement, the $9/2^{-}[514]$ proton orbital and its associated rotational band were observed, populated in the decay of 3-quasiparticle isomers, in all three isotopes and for the first time in ^{189}Re and ^{191}Re. Progression towards higher neutron numbers shows a decrease in K-hindrances for the isomeric decays, an increase in the signature splitting of the $9/2^{-}[514]$ rotational band and a lowering in energy of the γ-vibrational bandhead, these properties suggest the development of triaxiality. This scenario is explored using three theoretical approaches: potential energy-surface, triaxial particle-rotor and total routhian surface calculations.

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GRIFFIN Detector Acceptance Tests

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Gamma-Ray Infrastructure For Fundamental Investigation of Nuclei (GRIFFIN) is a state-of-the-art facility for spectroscopic studies following nuclear decay being built at TRIUMF. It will accommodate 16 detectors, each made of four high purity germanium crystals arranged in a clover configuration. GRIFFIN's efficiency will allow decay spectroscopy to be extended to regions far from stability that are currently not accessible at TRIUMF.

Individual GRIFFIN detectors are delivered to SFU for acceptance tests. To accommodate these detectors an automatic LN_2 cooling system, as well as analog and digital data acquisition systems have been set up to carry out the acceptance tests. Software analysis tools and experimental procedures have also been established to examine the consistency of the hardware with the list of specifications provided by the GRIFFIN collaboration.

The acceptance tests include measurements of energy resolution, absolute efficiency, analog timing resolution with respect to a BaF_2 scintillator, preamplifier and cryogenic properties, and mechanical dimensions. As of March 2014, twelve GRIFFIN detectors have been delivered by the manufacturer and ten have been fully accepted and transferred to TRIUMF.

Several additional investigations of the GRIFFIN clover performance have been undertaken. These include improvement in photopeak efficiency via energy add back of gamma rays which scatter between clover crystals using standard calibration sources, digital timing resolution with respect to a BaF_2 scintillator on a 14-bit, 100 MHz digitizer card and an absolute efficiency response curve in the 80-3500 keV energy range. GRIFFIN detectors were also incorporated into a charged-particle-gamma-ray coincidence setup enabling studies of the angular distribution of gamma rays following ^{241}Am alpha decay. Details of the aforementioned tests will be presented.

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P

Three-cluster dynamics within the *ab initio* NCSM/RGM *

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Ab initio approaches in nuclear physics describe nuclear systems considering its nucleons as their fundamental components. The aim is to predict the properties of nuclei from the fundamental inter-nucleon interactions.

The *ab initio* no-core shell model/resonating group method (NCSM/RGM) introduced in [1,2] is a technique able to describe both structure and reactions in light nuclear systems. This approach combines a microscopic cluster technique with the use of realistic inter-nucleon interactions and a consistent microscopic description of the nucleon clusters.

In this work we introduce three-body cluster configurations into the method and provide, for the first time within an *ab initio* framework, the correct asymptotic behaviour for the three-cluster wave functions. This is particularly important when studying continuum states. For this reason, the approach is suitable for the investigation of resonant states in two-nucleon halos or scattering states in reactions in which there are channels with three fragments.

We present the results obtained for ^{6}He within a ^{4}He(g.s.)+n+n basis [3]. We find a bound state in the $J^\pi T = 0^+1$ channel, corresponding to the ^{6}He ground state. All other states are in the continuum. We calculated the phase shifts from the three-body scattering matrix for channels $J^\pi = 0^\pm, 1^\pm$ and $2^\pm$. We obtained the experimentally well-known 2_1^+ resonance as well as the second low-lying 2_2^+ resonance recently measured at GANIL [4]. In addition, we predict low-lying resonances in J^π= 1^+, 2^-, and 0^- channels. The phase shifts for J^π=1^- and 0^+ do not show evidence of low-lying resonances in those channels. Therefore, we do not find a low-lying state that could be identified as the 1^- soft dipole mode.

Finally, we will include core excitations through the no-core shell model with continuum (NCSMC) coupling and present initial calculations for ^{5}H within a ^{3}H+n+n basis.

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Nuclear shape evolution through lifetime measurement in neutron rich nuclei

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A new interest for very exotic nuclei further away from the valley of stability arises due to the possibility to use refined experimental methods. In particular, the neutron rich side of the valley of stability still offers a lot of interesting features to be discovered e.g. the evolution of nuclear shapes. Our recent experiments on nuclei around A = 100 (Z~40, N~60) aim at discovering part of these features trough lifetime measurements and will help understanding nuclear shape evolution in neutron rich unstable nuclei. In this mass region, shapes are changing rapidly, which is reflected in the theoretical calculations by the prediction of occurrence of prolate, oblate, or triaxial shapes. These predictions vary as a function of the theoretical model used, thus experimental measurements will have important implications.

The neutron-rich isotopes were produced trough a fusion-fission reaction performed at GANIL in inverse kinematics with a ^{238}U beam. The aim of this experiment was to extend information on the evolution of the collectivity in this mass region by measuring the lifetimes of excited states in more neutron-rich nuclei and up to higher spins. A and Z identification of the fission fragments was performed with the VAMOS spectrometer, while the EXOGAM spectrometer was used for the γ-ray detection. The RDDS (Recoil Distance Doppler Shift) method has been applied to extract the lifetime of excited states. To our knowledge this is the first experimental attempt to perform a RDDS experiment on fission fragments, which are identified in A and Z on an event-by-event basis. Results on the complex analysis performed to achieve the identification of the fission fragments up to Z=54 and A=150 and on the new lifetime values will be presented.

The perspective of this neutron-rich fission fragments study will be given: one complementary experiment has already been performed at ILL and we will take advantage of the installation of the AGATA γ-array at GANIL to propose a new experiment.

Study of ^{10}Li as a halo subsystem via the ^{11}Li(p,d) reaction

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The unbound system ^{10}Li is of great interest for the description of the structure of the halo nucleus ^{11}Li [1]. E.g., the momentum distribution of the two neutron removal from ^{11}Li has been interpreted as exhibiting the presence of a low-lying $s_{1/2}$ virtual state in ^{10}Li [2]. This is supported by a measurement of ^{9}Li(d,p) that also observed a $p_{1/2}$ resonance with an energy of $E_r \simeq 0.38$ MeV [3]. The first resonance of ^{10}Li was observed at $E_r = 0.81 \pm 0.25$ MeV in transfer reaction ^{9}Be(^{9}Be,^{8}B)^{10}Li [4]. An invariant-mass spectroscopy experiment at GSI showed the ground state at 0.21 ± 0.05 MeV and the first excited state at 0.62 ± 10 MeV [5]. While the majority of measurements have indicated possible resonances in ^{10}Li, it is still not well established which resonance contributes to the ground state configuration of ^{11}Li and by what spectroscopic factor. To obtain such information one can investigate the transfer of one-neutron from ^{11}Li. The presentation will report observations on ^{10}Li studied through the p(^{11}Li,d) one-neutron transfer reaction at beam energy of 6A MeV. This was performed using a solid H_2 target at the newly constructed IRIS facility at TRIUMF.

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P

Two-neutron tranfer reaction mechanisms in ^{12}C(^{6}He,^{4}He)^{14}C using a realistic three-body ^{6}He model *

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The reaction mechanisms of the two-neutron transfer reaction ^{12}C(^{6}He,^{4}He) have been studied at $E_{\rm lab}$ = 30 MeV at the TRIUMF ISAC-II facility using the SHARC charged-particle detector array. Optical potential parameters have been extracted from the analysis of the elastic scattering angular distribution. The new potential has been applied to the study of the transfer angular distribution to the 2^{+}_{2} 8.32 MeV state in ^{14}C, using a realistic 3-body ^{6}He model and advanced shell model calculations for the carbon structure, allowing to calculate the relative contributions of the simultaneous and sequential two-neutron transfer. The reaction model provides a good description of the 30 MeV data set and shows that the simultaneous process is the dominant transfer mechanism. Sensitivity tests of optical potential parameters show that the final results can be considerably affected by the choice of optical potentials. A reanalysis of data measured previously at $E_{\rm lab}$ = 18 MeV however, is not as well described by the same reaction model, suggesting that one needs to include higher order effects in the reaction mechanism.

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P

Beta-delayed neutron spectroscopy using trapped ions: The BPT at CARIBU

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Studies of β-delayed neutrons provide valuable information to better understand the structure of exotic nuclei and the *r* process. In addition, precise measurements for fission products are needed in nuclear-energy and stockpile-stewardship applications. However, the fundamental nuclear data available today for individual nuclei is limited – for the vast majority of cases, the energy spectrum has not been measured and discrepancies in some branching ratios have been uncovered.

Radioactive ions held in an ion trap are an appealing source of activity for improved measurements of both β-delayed neutron branching ratios and energy spectra as the problems associated with direct neutron detection can be circumvented by instead studying the nuclear recoil. This novel approach has been successfully demonstrated [1] by confining fission products in the Beta-decay Paul Trap (BPT) [2]. Since then, the ion trap and detector array have been upgraded and a campaign of measurements has been carried out at the CARIBU facility. Recent results and future plans will be presented.

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An Implementation of Monte Carlo Simulation for Electron Capture Branching Ratio Measurements using In Trap Decay Spectroscopy*

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A GEANT4 based simulation has been developed to optimize the measurements of electron capture branching ratios (ECBR) of key intermediate nuclei involved in double-β decay. The ECBR information is important for determination of nuclear matrix elements of double-β decay (2νββ) and which is essential to probe the theoretical framework of neutrino-less double beta decay (0νββ). In most cases of interest, the ECBRs are poorly known because the EC process is suppressed by several orders of magnitude relative to its β-decay counterpart.

To overcome these problems, in-trap X-ray and gamma-ray spectroscopy are performed using the unique ion trap facility of TITAN, TRIUMF's Ion Trap for Atomic and Nuclear science, where radioactive ions are stored and decays observed. In these experiments, the Electron Beam Ion Trap (EBIT) is used as spectroscopy Trap, where the electrons from β-decay confined by the strong magnetic field and X-rays from EC are detected by Si(Li) X-ray detectors that are radially installed around the trap through seven open ports towards the trap's center.

The GEANT4 simulation includes the TITAN's EBIT with its electrodes and superconducting coils, and the 7-Si(Li) detector array with detailed geometry. Through these simulations, systematic studies have been made to investigate detector efficiencies, the impact of different background shielding, and the effect of the size and shape of the trapped ion cloud. Furthermore, simulations were carried out for ^{100}Tc, ^{110}Ag, $^{116g,\, m1,\, m2}$In and $^{124g,\, 124m}$Cs with different levels of beam contamination. These results, a comparison with experimental data, and other validation of the simulations will be presented.

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Incomplete fusion as a spectroscopic tool*

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Recently, a substantial contribution of incomplete fusion (ICF) has been observed at slightly above barrier energies, where complete fusion (CF) is supposed to be the sole contributor [1,2]. In Ref. [3], Walker and Dracoulis suggested that ICF can be used as a spectroscopic tool to study high spin states, which is also emphasized in our recent letter [4]. This suggests a systematic study of ICF dynamics and the possibility to populate high angular momenta even at constant projectile energy. With a view to obtain the qualitative information on the driving input angular momenta associated with the low energy ICF events, an experiment has been performed at Inter University Accelerator Centre, New Delhi for ^{16}O+^{159}Tb system at $\approx$ 99 MeV. In this experiment, particle-γ-coincidence technique has been employed using a Gamma Detector Array (GDA) along with a Charged Particle Detector Array (CPDA) setups. Several xn/pxn/αxn channels have been identified using various gating conditions, and the spin-distributions alongwith feeding intensity profiles have been measured to figure out associated ℓ-values in different CF and ICF channels.

The spin-distributions for direct α-emitting channels (associated with ICF) have been found to be distinctly different than that observed for fusion-evaporation (CF) channels. The deduced mean value of driving input angular momenta associated with direct α-emitting channels (ICF reactions) have been found to be higher than that observed for the fusion-evaporation channels (CF reactions). The mean value $<\ell>$ for the ICF-α is found to 50% higher as compared to the CF-xn/pxn/αxn *i.e.* $\ell_{(ICF-\alpha xn)} \approx 1.5\ \ell_{(CF-xn/pxn/\alpha xn)}$. Further details will be presented during the conference.

[1] Vijay R. Sharma et al., Phys. Rev. C 89, 024608 (2014)
[2] Abhishek Yadav et al., Phys. Rev. C 85, 064617 (2012)
[3] P. Walker et al., Nature (London) 399, 35 (1999)
[4] Pushpendra P. Singh et al., Phys. Lett. B 671, 20 (2009)

* BPS, RP and VRS thank to the DST for the financial support from the project no. SR/S2/HEP-30-2012

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Mixed-symmetric one-phonon $2^+_{1,ms}$ state in the heavy nuclei ^{202,204}Hg*

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In the framework of the Interacting Boson Model proton-neutron mixed-symmetric states result as representatives of valence-shell excitations of isovector character. The building block of mixed-symmetric structures in weakly collective vibrational nuclei is the one-quadrupole-phonon $2^+_{1,ms}$ state. It decays by a strong M1 transition to the 2^+_1 state. Hitherto such states have been investigated in nuclei in the region of $A \approx 90$ and recently also around $A \approx 130$. In the vicinity of the most heavy stable doubly-magic nucleus ^{208}Pb however no such states have been identified, so far. The Hg isotopes represent good candidates for first searches for $2^+_{1,ms}$ states in this $A \approx 200$ mass region. An experiment was conducted at Argonne National Laboratory, in which ^{202,204}Hg projectiles were accelerated to 890 MeV using the ATLAS accelerator before impinging on a ^{nat}C target for Coulomb excitation. γ rays were detected using the Gammasphere spectrometer. Clear signals for a $2^+_{1,ms}$ state were found for ^{204}Hg. Preliminary results will be presented.

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P

Study of Beta-delayed Neutrons from ^{77}Cu using VANDLE*

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As nuclei become more neutron rich, the nuclear structure changes their properties. For example, beta decays will access increasingly more neutron unbound states. The measurement of neutrons emitted from these states is critical, as beta-delayed neutron emission becomes a dominating decay mode.

To this end, the Versatile Array of Neutron Detectors at Low Energy (VANDLE)[1,2] measures the energy of neutrons emitted from excited states above the neutron separation energy populated through beta decay or transfer reactions. The time-of-flight technique determines the energy, which requires a time resolution on the order of 1 ns. In addition, the detector requires a low detection threshold to measure neutron energies of 100 keV or lower.

A successful experimental campaign at the Holifield Radioactive Ion Beam Facility, using ions produced via proton induced fission on ^{238}U, has yielded results on beta-delayed neutrons emitted during the decay of ^{77,78}Cu. Of particular interest, is the observation of low-energy neutrons emitted from states well above the neutron separation energy. Results from this experiment will be presented.

[1] C. Matei et al., Proceedings of Science, NIC X, 138 (2008)
[2] S. V. Paulauskas et al., NIMA 797, 22 (2014)

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IGISOL-IV — The Next Generation (a Laser Spectroscopic Perspective)

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The year 2010 marked the end of an era of IGISOL-3 at the Accelerator Laboratory of the University of Jyväskylä, Finland. Since then, the laboratory move has been completed and the new facility, IGISOL-4, has been commissioned.

From a laser spectroscopic perspective, modifications to both the front end of the facility as well as the beamline layout downstream of the gas-filled linear Paul trap improved optical access for spectroscopy to be performed within the gas cell and the gas jet, as well as optical manipulation of ions in the RF cooler-buncher. The gas jet environment benefits from substantial reductions in Doppler and pressure broadening hence allowing high-resolution resonance ionisation spectroscopy to be performed. Current resolution limitations arising from GHz-wide laser bandwidths are being addressed with an injection-locked Ti:Sa laser wherefore a linewidth of 20MHz has recently been demonstrated.

The collinear laser spectroscopy program was successfully recommissioned in 2013. In a new development, efforts are underway to realise ion-resonance-ionisation (IRIS) whereby an ion is resonantly ionised to a higher ionisation state. This will ultimately allow the element-selective purification of ionic beams and hence reduce the ion-beam related laser background scatter. In progress towards achieving IRIS, spectroscopy has been performed on Y^{2+} ions from the natural production. This experiment does not only mark the first ever on-line collinear laser spectroscopy on doubly-charged ions but also allows for a calibration of the atomic factors in yttrium.

This contribution summarises the new IGISOL-4 facility with respect to laser spectroscopic features. The latest developments regarding both the collinear as well as in-source program will be highlighted.

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β-decay study of the 16^+ spin-gap isomer in ^{96}Cd

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It has been shown that the isomeric nature of the 16^+ state in ^{96}Cd is a direct consequence the T=0 np interaction [1], the effects of which have also been observed at low-spin in ^{92}Pd [2]. LSSM calculations for ^{96}Cd, performed in a model space including the *sdg* orbitals, indicate that ~30% of the B(GT) strength of the β-decay from the 16^+ isomer should populate resonance-like states in ^{96}Ag, which proton decay to excited states in ^{95}Pd. Calculations, performed in a more restricted model space involving only the $p_{1/2}$, $g_{9/2}$ orbitals, indicate the decay of the 16^+ isomer to the known 15^+ state in ^{96}Ag dominates. The observation of β-delayed proton emission from 16^+ isomer in ^{96}Cd would provide evidence for the involvement of orbitals beyond the N = Z = 50 shell gap in the configuration of the 16^+ state. In our work ^{96}Cd was produced using a 345 MeVA ^{124}Xe primary beam and identified by the BigRIPS separator. The active stopper SIMBA, constructed from a stack of 3 highly segmented DSSD's, in which ions of interest are implanted, and a stack of 20 SSSD that act as a β calorimeter, was employed to identify β-decays. -rays were recorded using EURICA, an array of Ge detectors. The -ray and particle spectroscopy following the β-decay of ^{96}Cd will be compared with LSSM calculations.

[1] B. S. Nara Singh, et al. Phys Rev Lett, 107(17), 172502, (2011)
[2] B. Cederwall, et al. Nature, 469(7328), 68, (2010)

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Radioactive Beam Diagnostics at the National Superconducting Cyclotron Laboratory*

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The National Superconducting Cyclotron Laboratory at Michigan State University produces rare isotope beams at energies of ~100 MeV/A using the fast fragmentation technique. A recent expansion of the facility enables low energy (< 60 keV) and post-accelerated (< 3 MeV/A) beams to be delivered to experiments. To achieve this, the fragmentation products are thermalized in a helium-filled linear gas cell. Depending on the chemistry of the species being extracted, the resulting low energy beam may be singly or doubly charged atomic or molecular ions. In order to select the correct mass for further transport the LEBT dipole magnet follows the gas cell. The beam can be further transported to the electron-beam ion trap (EBIT) charge breeder and post-accelerated to energies around the Coulomb barrier. Energies up to 3 MeV/A are currently available at the ReA facility and in the future energies up to 12 MeV/A for ^{238}U.

In order to optimize and characterize these facilities, which provide radioactive ion beams at very distinct energies, NSCL has installed an extensive array of beam diagnostics devices. Both the gas cell and the EBIT can produce stable backgrounds orders of magnitude higher in intensity than the isotope of interest. Scanning the fields in the LEBT magnet and the charge-over-mass (Q/A) separator following the EBIT provides selectivity, but the diagnostics giving feedback to this process must be able to provide information on the intensity and species of the isotopes on the single-ion-counting level. This requirement leads to a natural overlap of methods originating from the disciplines of traditional beam diagnostics and experimental nuclear physics.

This contribution will discuss the array of traditional and radioactive beam diagnostics available at the laboratory, and show data obtained during the tuning and characterization of the gas cell and EBIT. The first post-acceleration of a radioactive beam at the NSCL was recently achieved and data from this experiment will also be shown.

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Hartree-Fock-Bogoliubov descriptions of deformed weakly bound nuclei in large coordinate-spaces

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To describe weakly-bound nuclei, the theoretical tool should properly taking into the continuum coupling, deformations, and large spatial extensions simultaneously. There have been numerous theoretical studies about weakly bound nuclei, but most of them are spherical. In particular, for weakly bound deformed nuclei, exotic deformed halos with decoupled surface deformations from cores are predicted. Due to the subtle interplay among surface deformations, surface diffuseness, and continuum coupling in deformed weakly bound nuclei can result in exotic structures, and theoretical studies require precise HFB solutions.

We study weakly bound deformed nuclei by Skyrme Hartree-Fock-Bogoliubov approach in large coordinate-space, in which a large box is employed for treating the continuum and large spatial extensions. We study particle density and pairing density distributions at nuclear surfaces, the near-threshold resonant and continuum quasiparticle spectra. We found an exotic "egg" like halo structure in ^{38}Ne with a spherical core plus a prolate halo, for which the near-threshold nonresonant continuum is essential. The deformation decoupling has also been shown in the pairing-density distribution and this phenomenon in pairing-density distribution are sensitive to the effective pairing Hamiltonian. In particular, the box-size dependence of the HFB calculations of weakly bound nuclei are investigated. The box size have larger influences in pairing properties than in other bulk properties. This is related to the fact that the pairing density distributions have larger surface deformations and larger spatial extensions than particle densities do.

[1] Pei, J. C., Kruppa, A. T., Nazarewicz, W., Phys. Rev. C 84, 024311(2009)
[2] Pei, J. C., Zhang, Y. N., Xu, F. R. Phys. Rev. C 87, 051302 (2013)
[3] Zhang, Y. N., Pei, J. C., Xu, F. R. Phys. Rev. C 88, 054305(2013)

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β-Decay Studies with CARIBU and Gammasphere: ^{142}Cs $\rightarrow$ ^{142}Ba and ^{144}Cs $\rightarrow$ ^{144}Ba *

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The CARIBU facility at ANL has been in operation for the past few years. This unique facility produces isotopically-enriched beams of rare isotopes by extracting fission products from a ^{252}Cf source. Near the peak of heavy fission products are neutron-rich Ba and Ce nuclei. Evidence for octupole collectivity in these nuclei has been found in prompt γ-ray studies of fission fragments. Due to limited data, there are many open questions regarding the stability and enhancement of octupole collectivity in this neutron-rich region.

We have started a program to study octupole collectivity in neutron-rich Ba and Ce nuclei using CARIBU. As part of this project, beams of ^{142}Cs and ^{144}Cs ions from CARIBU were charge bred and, subsequently, accelerated to $\sim$ 6 MeV/A by the ATLAS superconducting linac before being transported to the target location of the Gammasphere spectrometer and implanted in a Pb foil. Gamma radiation following decay was measured by Gammasphere consisting of $\sim$100 Compton-suppressed Ge detectors.

The known ^{142}Ba and ^{144}Ba level schemes were considerably expanded. Furthermore, a large number of spin-parity assignments were made for levels in both nuclei, based on the measured angular correlations. High-precision log ft values were determined as well. The data provide important new information about the nature of low-spin excitations in these two nuclei. In particular, new information is obtained about the strength of octupole correlations and the nature of other low-lying excitations.

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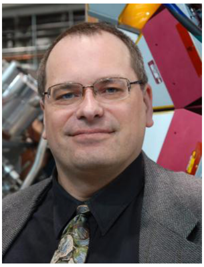

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NUCLEAR STRUCTURE 2014 (July 21-25, 2014)

Monday, July 21

7:00	Registration: Life Sciences West Atrium
M1	**Chair: Petr Navratil**
8:45	Bagger *Welcome*
8:55	H. Crawford *Neutron knockout to probe 3N forces in …*
9:25	Holt *Nuclear forces and exotic oxygen and …*
9:55	Papuga *Laser spect. of neutron-rich K & Ca …*
10:15	Van Duppen *Structure of ^{68}Ni: new insights …*
10:35	**Coffee Break**
M2	**Chair: Bruce Barrett**
11:05	Gezerlis *Quantum MC with modern nuclear forces*
11:35	Gottardo *Quadrupole collectivity in Ni isotopes …*
11:55	Miller *Direct lifetime measurements of …*
12:15	Sahin *Beta-delayed gamma-ray spectroscopy…*
12:35	**Lunch**
M3	**Chair: Jon Batchelder**
14:00	Doornenbal *Spectroscopy of exotic nuclei with EURICA*
14:30	Lorusso *Measurement of 20 new ß-decay …*
14:50	Baczyk *The $i_{13/2}$ neutron single-particle energy …*
15:10	Poves *^{32}Mg+^{32}Mg=^{64}Cr: A walk on neutron …*
15:30	**Coffee Break**
M4	**Chair: Sonia Bacca**
16:00	Hagen *Coupled-cluster computations …*
16:30	Rodriguez *Shape transitions, shape mixing …*
16:50	Bender *Exploring onset of shape coexistence …*
17:10	Nowak *Shape coexistence around N=28 …*
17:30	**End of talks**
18:00–21:00	TRIUMF Tour

Tuesday, July 22

7:00	Registration: Life Sciences West Atrium
T1	**Chair: Furong Xu**
8:45	Gaffney *Nuclear structure goes pear-shaped*
9:15	Albers *Octupole strength in neutron-rich nuclei …*
9:35	Smith *New perspectives: octupole collectivity …*
9:55	Kroell *Quadrupole collectivity in neutron-rich …*
10:15	Allmond *Coulomb excitation of radioactive ^{136}Te*
10:35	**Coffee Break**
T2	**Chair: Mike Carpenter**
10:55	TBA
11:15	Greenlees *Shell structure in heavy nuclei*
11:45	Seweryniak *Study of isomeric states in ^{254}Rf …*
12:05	Kondev *Classification of K-forbidden …*
12:25	Chowdhury *Rotations built on the highest …*
12:45	**Lunch**
T3	**Chair: Corina Andreoiu**
14:00	Rudolph *Superheavy element studies … TASCA*
14:30	Gates *Decay spectroscopy of element 115…*
14:50	Andreyev *Shape coexistence in gold, thallium and…*
15:10	A. Voss *Evolution of ground state properties in …..*
15:30	**Coffee Break**
T4	**Chair: Elena Litvinova**
16:00	Quaglioni *Toward a fundamental understanding …*
16:30	Wimmer *Single-particle structure of neutron-rich …*
16:50	Petri *Low-lying structure of ^{30}Na and sd-pf …*
17:10	Roth *Frontiers in ab initio nuclear …*
17:30	Gargano *Shell structure beyond N = 82*
17:50	**End of talks**
18:00–20:30	Poster Session

Wednesday, July 23

7:30	Registration: Life Sciences West Atrium
W1	**Chair: Simon Mullins**
8:45	Block *High precision mass measurements for …*
9:15	Lunney *Recent exploits with ISOLTRAP mass …*
9:35	Kwiatkowski *TITAN: mass measurements of …*
9:55	*Conference Photograph*
10:05	**Coffee Break**
W2	**Chair: Iris Dillmann**
10:35	Zhang *Precision mass measurements of …*
11:05	Grzywacz *Gamow-Teller decay of ^{78}Ni core …*
11:25	Yoshida *G-T excitations and β-decay properties …*
11:45	**Walk to Gage for Excursion**
12:30	Buses leave Gage
	Lunch and Excursion Grouse Mountain or Indian Arm Cruise
18:00	

Thursday, July 24

7:30	Registration: Life Sciences West Atrium
J1	**Chair: Fred Sarazin**
8:45	Kibedi *Structure: Hoyle state via pair …*
9:15	Kuchera *3n decay from ^{15}Be*
9:35	Lister *Precise measurement of the first 2+ …*
9:55	Tengblad *Nuclear structure of light halo nuclei …*
10:15	Wuosmaa *Aligned states in ^{12,13}B with the (d,α) …*
10:35	**Coffee Break**
J2	**Chair: Paul Garrett**
11:05	Engel *Nuclear structure theory/double beta decay*
11:35	Yates *Nuclear structure of ^{130,132,134,136}Xe …*
11:55	Laffoley *High-precision half-life measurements …*
12:15	Ji *Nuclear polarization effects in …*
12:35	**Lunch**
J3	**Chair: Patrick Regan**
14:00	Bentley *Spectroscopy: isobaric analogue states …*
14:30	Wadsworth *Collectivity and shapes of N=Z nuclei …*
14:50	Tabor *Split isobaric analog state in ^{55}Ni …*
15:10	David *Low-lying T = 0 states in the odd-odd …*
15:30	**Coffee Break**
J4	**Chair: Wolfram Korten**
16:00	Sorlin *Spin orbit force and nuclear forces …*
16:30	Barbieri *Ab-initio Green's function theory …*
16:50	Morfouace *Decorrelated behaviour of spin-orbit …*
17:10	Leoni *Systematic investigation of coupling …*
17:30	**End of talks**
17:00	Museum of Anthropology opens
18:00	Reception
19:00–22:00	Dinner at MOA

Friday, July 25

7:00	Registration: Life Sciences West Atrium
F1	**Chair: Helen Boston**
8:45	Palit *Nuclear structure studies with INGA*
9:10	de Angelis *Gamma ray spectroscopy with AGATA …*
9:35	Macchiavelli *GRETINA: physics highlights, future plans*
10:00	Garnsworthy *GRIFFIN spectrometer at TRIUMF-ISAC*
10:20	Chester *TIGRESS integrated plunger device for …*
10:35	**Coffee Break**
F2	**Chair: Reiner Kruecken**
11:05	Bollen *Facility for rare isotope beams …*
11:30	Savard *Measurements on … CARIBU*
11:55	Merminga *The ARIEL facility*
12:20	*Closing Remarks*
12:35	**End of NS2014**
14:00	**Start of Beta Delayed Workshop**

Nuclear Structure 2014

July 21-25, 2014

University of British Columbia
Vancouver BC

Accommodation

D 6 Walter Gage Residence & the West Coast Suites
G 1 Marine Drive Residence

Breakfast

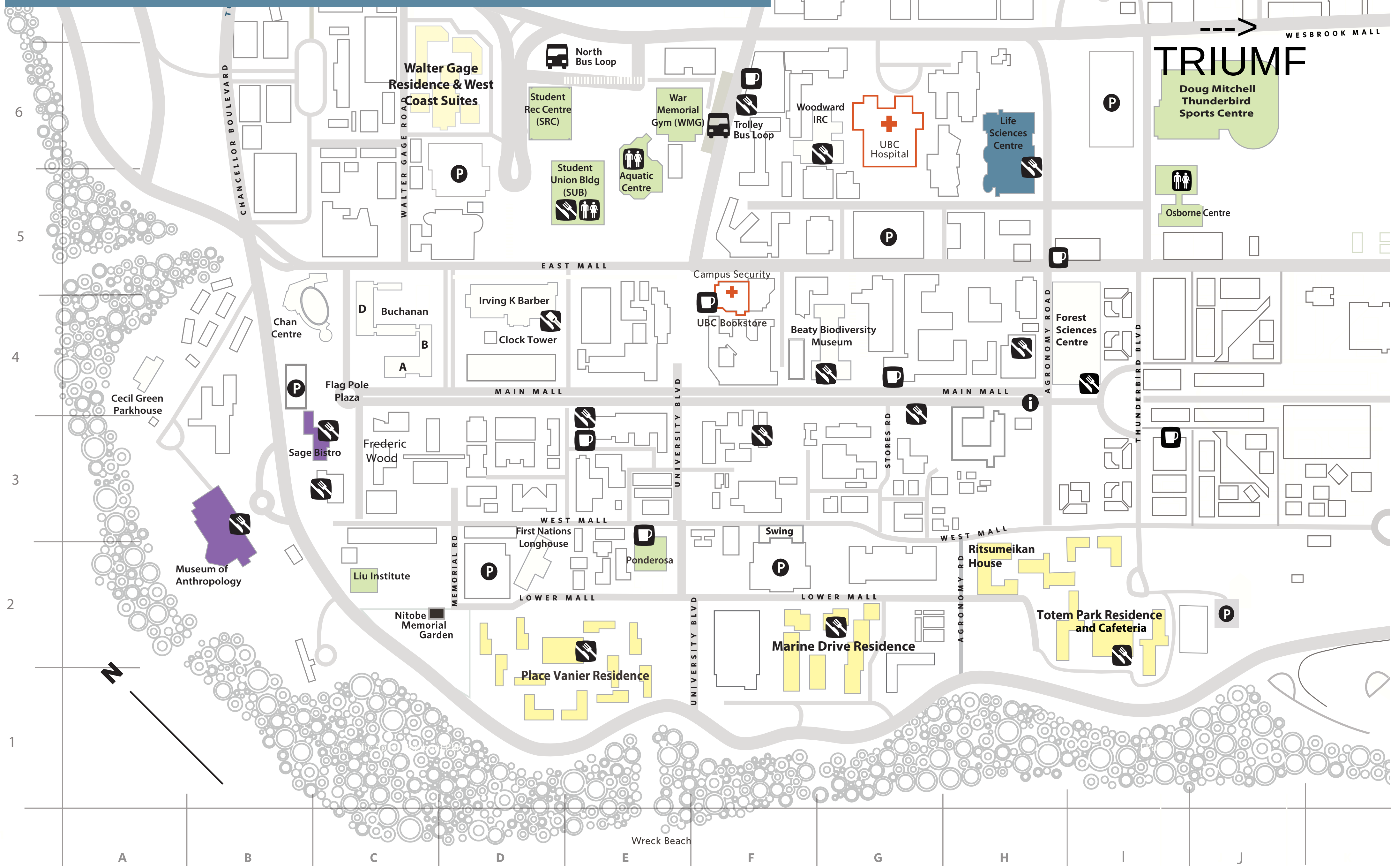
E 5 Pacific Spirit Cafeteria - Student Union Building

Meeting Space

H 4 Life Sciences Centre

Dinner/Reception

B 3 Museum of Anthropology
C 3 Sage Bistro



P Parking

Public Washrooms

G6 UBC Hospital

F4/5 UBC CAMPUS SECURITY

In Memory of
George Dracoulis
1944 – 2014