Role and Contributions to the National Nuclear Science Program of the Association for Research at University Nuclear Accelerators (ARUNA)

Presentation to the Nuclear Science Advisory Committee
on October 28, 2016

by

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Department of Physics, Duke University
and
Triangle Universities Nuclear Laboratory

Outline:

- ARUNA membership
- Current nuclear physics research activities and facility capabilities
- ARUNA contributions to the national nuclear physics workforce
- Broader impact research
- Summary

Some facts about ARUNA

- Founded in 2011
- 10 university-based accelerator facilities
- Research programs in frontier areas: nuclear structure, nuclear astrophysics, fundamental symmetries and low-energy QCD
- Applied and Interdisciplinary research
- Educate about 16% of the nation's PhD's in experimental nuclear physics
- Hands-on and small group research experiences

Member Institutions:

Florida State University, John D. Fox Accelerator Laboratory
Hope College, Hope College Ion Beam Analysis Laboratory
Ohio University, John E. Edwards Accelerator Laboratory
Texas A&M University, Cyclotron Institute
Triangle Universities Nuclear Laboratory, TUNL
Union College, Union College Ion Beam Analysis Laboratory
University of Kentucky, Accelerator Laboratory
University of Massachusetts-Lowell, Radiation Laboratory
University of Notre Dame, ISNAP: Institute for Structure and Nuclear Astrophysics
University of Washington, CENPA: Center for Experimental Nuclear Physics and Astrophysics

Summary of Accelerators

Institution	Van de Graaff	Tandem	Cyclotron	Linac	Beam A range	RIB	Other
FSU		9 MV		+ 9 MV	A < 40	A < 40	
Hope College		1.7 MV			A < 5		
Ohio Univ.		4.5 MV			A < 40		
Texas A&M			K-150 + K-500		A < 90	A < 90	
TUNL	1 MV & 200-kV ECR	10 MV			A < 5		HIGS: LC gammas 1 – 110 MeV
Union College		1.1 MV			A < 5		
Univ. Kentucky	7 MV				A < 5		
Univ. Mass-Lowell	5.5 MV				A < 5		
Univ. Notre Dame	5 MV	10 MV & 3 MV			A < 20	A < 20	CASPAR: 1-MV UG
Univ. Washington		9 MV			A < 20		

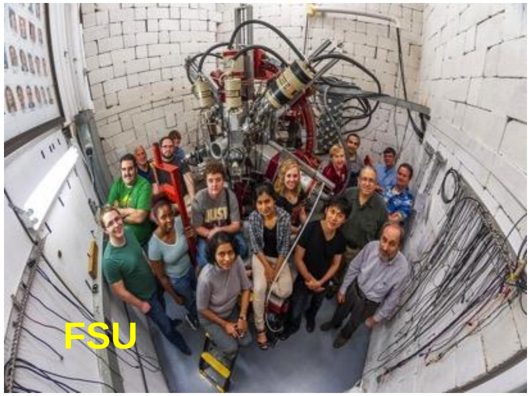
Research Area Summary

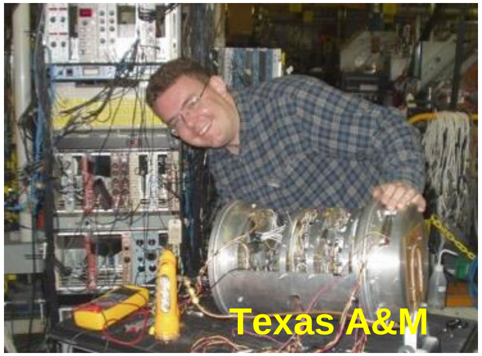
Institution	Nuclear Structure	Nuclear Astrophysics	Fundamental Symmetries	LE QCD	Applications
FSU	X	X			
Hope College	X				X
Ohio Univ.	X	X			
Texas A&M	X	X	X		X
TUNL	X	X		X	X
Union College					X
Univ. Kentucky	X				X
Univ. Mass-Lowell					X
Univ. Notre Dame	X	X	X		X
Univ. Washington			X		

Summary of Accelerator Operation

Institution	Accelerator	Operation (hrs/y)
FSU	Tandem + linac	3,000
Hope College	Tandem	
Ohio Univ.	Tandem	920
Texas A&M	K-500	6,210
Texas A&M	K-150	2,920
TUNL	HIGS	1,500
TUNL	LENA	1,860
TUNL	Tandem	3,000
Union College	Tandem	
Univ. Kentucky	Van de Graaff	4,000
Univ. Mass-Lowell	Van de Graaff	
Univ. Notre Dame	Tandem	3,100
Univ. Notre Dame	Van de Graaff	2.070
Univ. Washington	Tandem	550

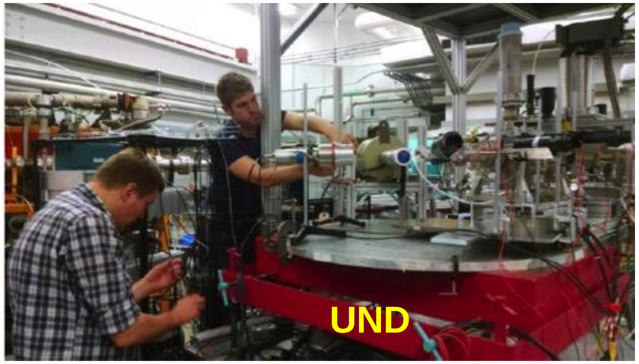
Research Features

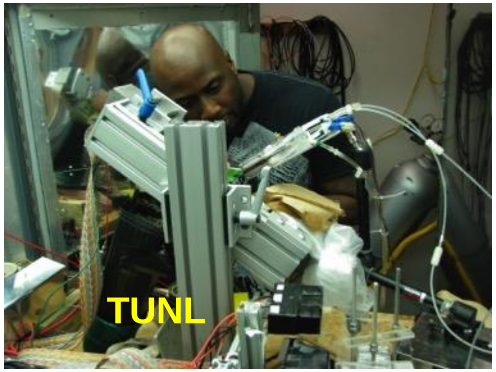




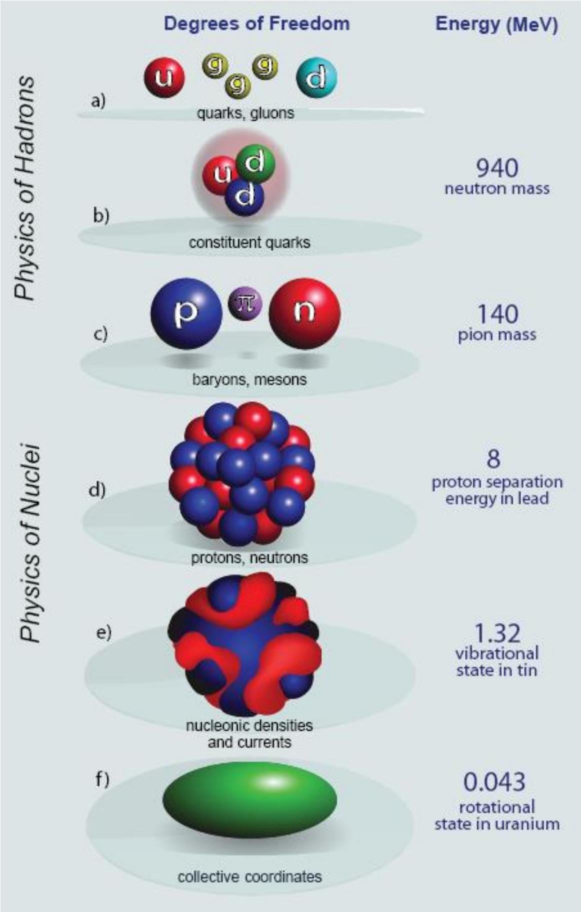
Accelerator laboratories in ARUNA enable subatomic experimental physics to be conducted in a table-top style, similar to atomic-optical-molecular and condensed-matter experimental research

- Small sized collaborations (< 20 people);
- In lab hands-on experience;
- Duration of projects is normally less than 6 years, allowing students to be involved in most stages of their thesis research from concept to dissemination of results; and
- Opportunities to optimize experiments at both ends of the accelerator, from ion source to accelerator capabilities to target-room instrumentation to data acquisition.





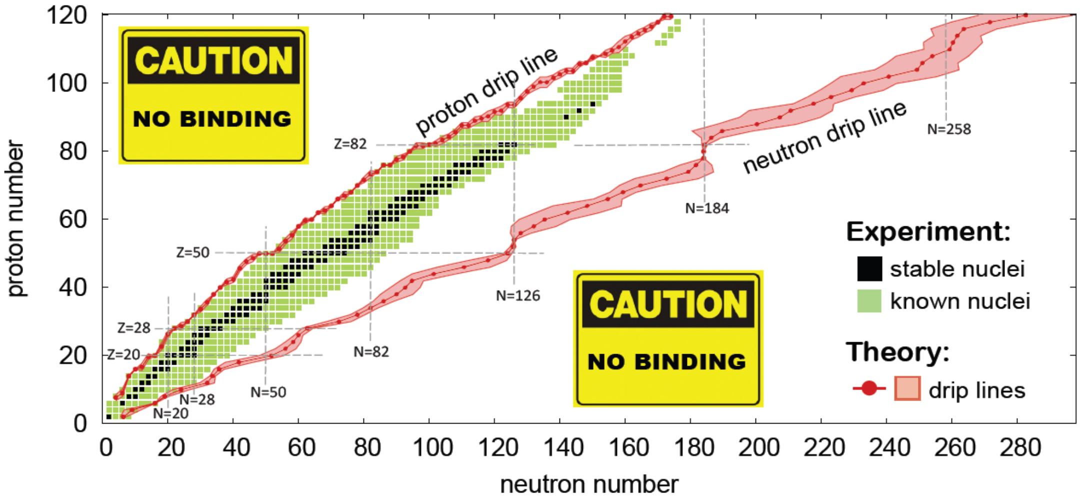
Nuclear Structure: many-body strongly interacting systems



From 2007 Nuclear Science LRP

US 2015 Nuclear Science LRP: Organizing Themes

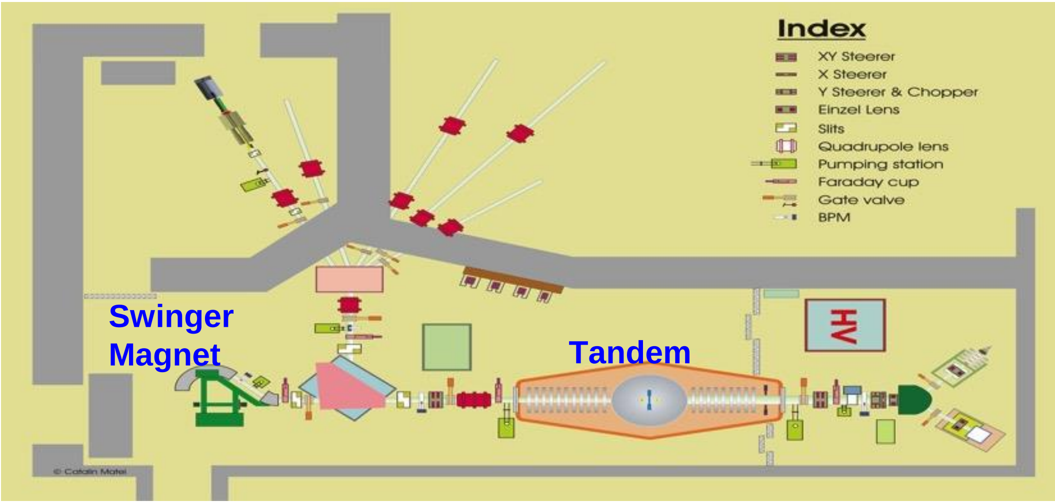
- **May the strong force be with you:** Emergence of the nuclear strong force from QCD
- **Life in the nuclear borderlands:** Nuclear structure at the extremes of the N/Z ratio, i.e., beyond the proton and neutron drip lines
- **Dancing in Unison:** Collective properties of nuclei
- **Neutron Rich Matter in the Cosmos and on Earth:** The neutron skin in heavy nuclei and the nuclear equation of state of neutron-rich matter (neutron stars)

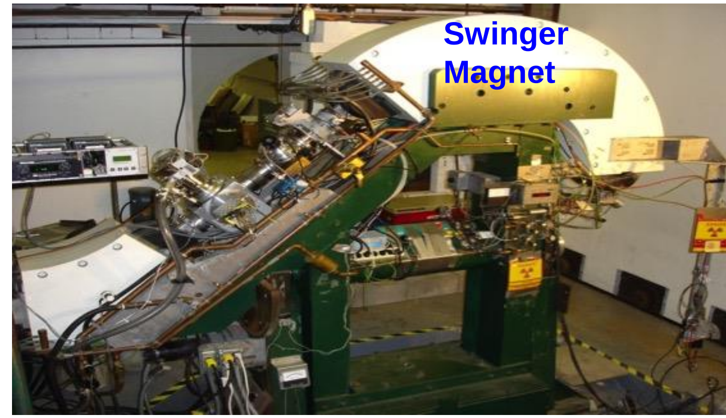


From 2015 Nuclear Science LRP

NS: Ohio University: Edwards Accelerator Lab

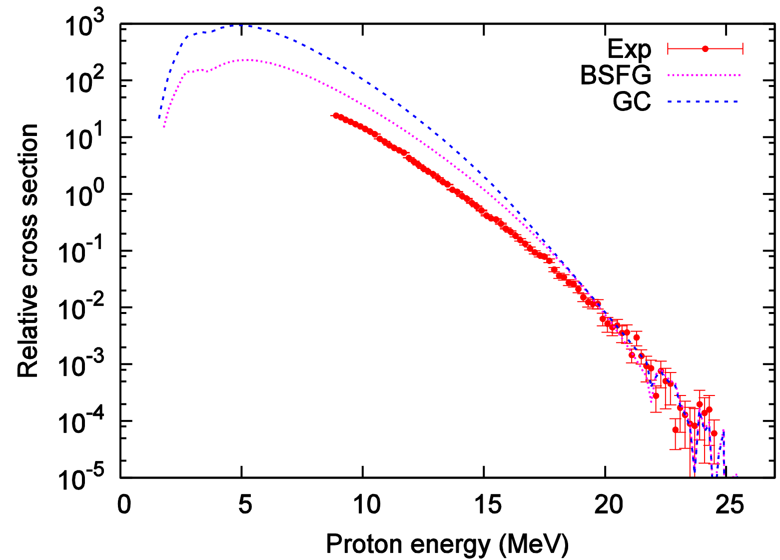
Fusion evaporation from Li-induced reactions





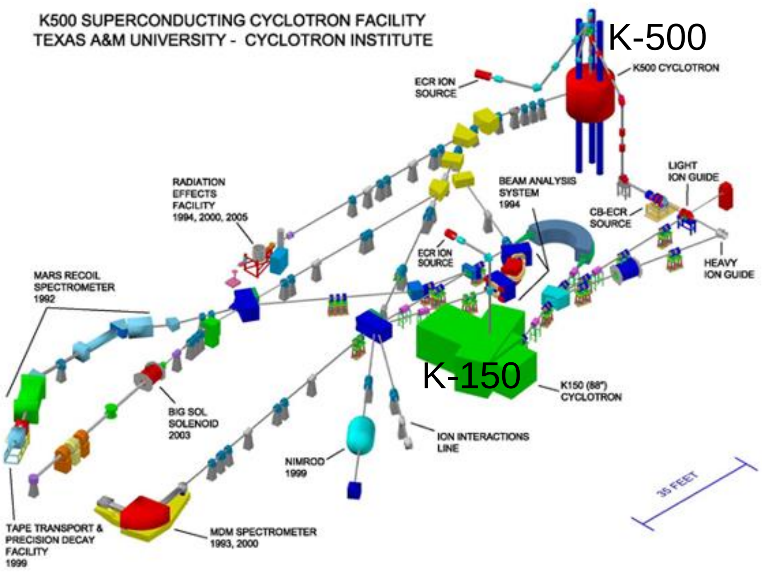
$^{7}Li+^{70}Zn \rightarrow ^{76}Ge+p$ results courtesy of T. Renstrom (Oslo student)
Proton spectrum does not agree with level density models!

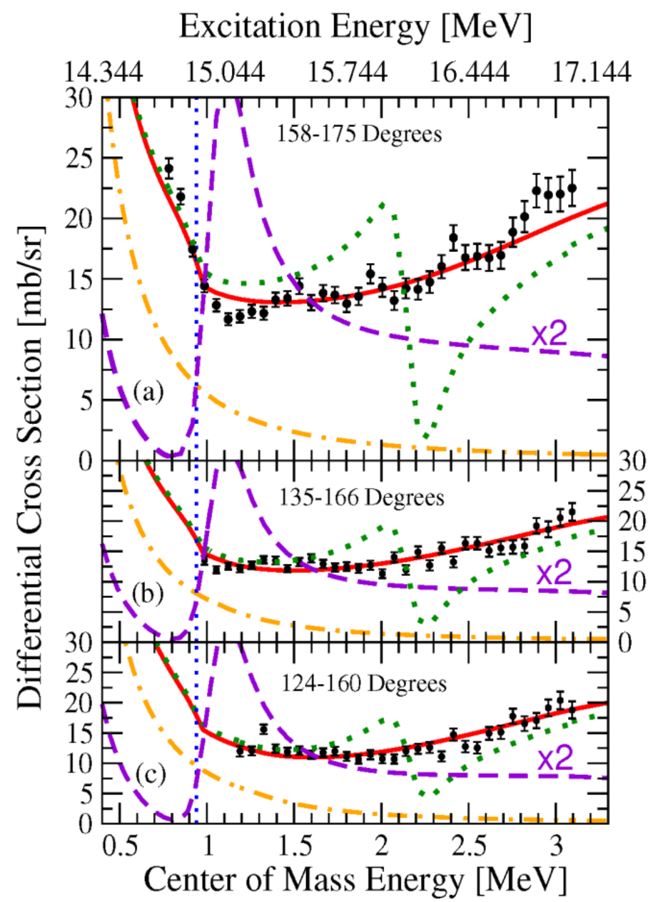
Led by Alexander Voinov (Ohio) and Oslo. Collaboration also includes LLNL, Michigan State University, and Central Michigan University. Experiment performed in January 2016.



NS: Texas A&M University

Structure of super neutron rich helium Isotope – ^{9}He





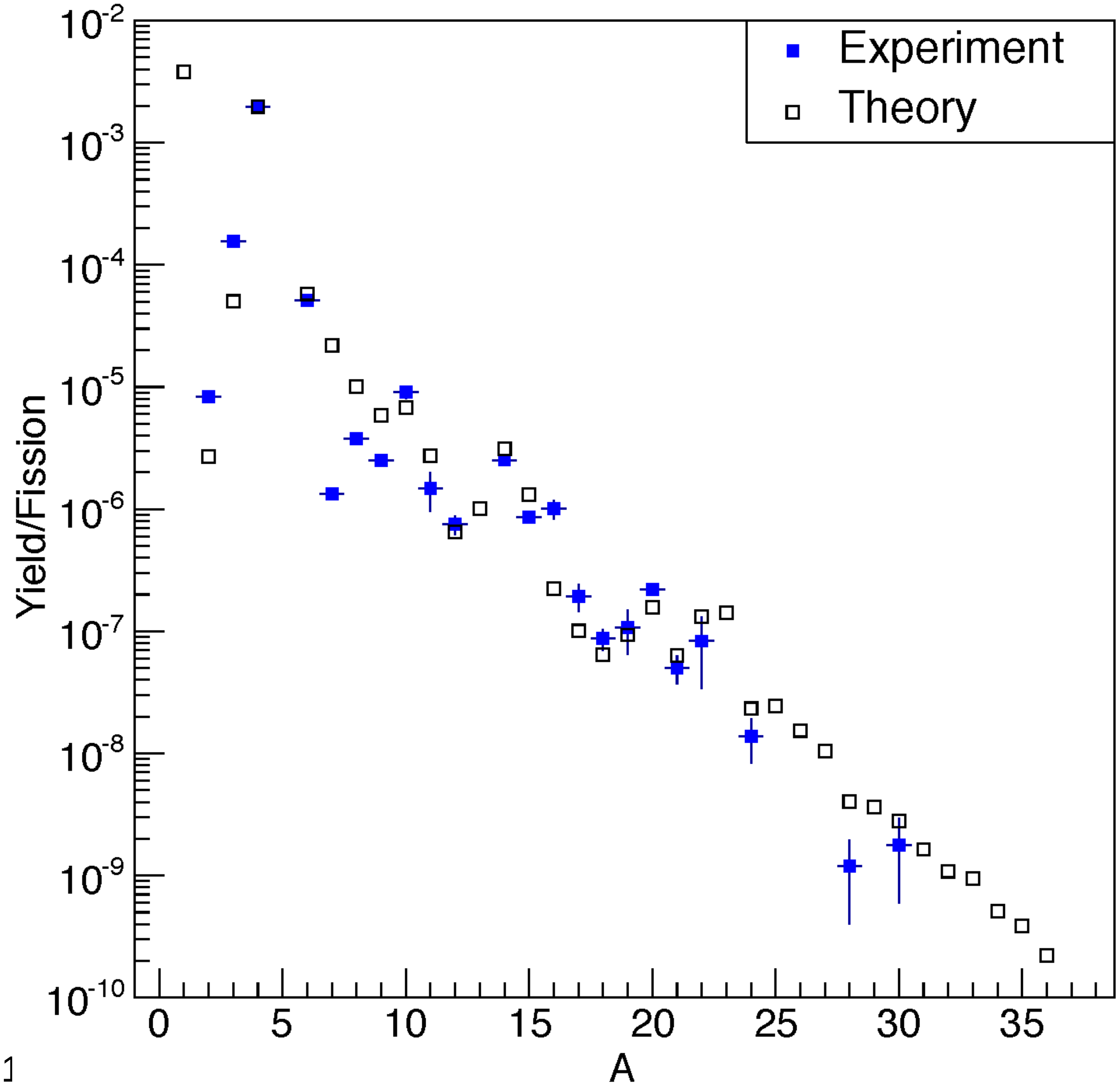
^{8}He+p elastic scattering excitation function measured at three different lab. angles. No narrow structures are observed in the proton spectrum. The sensitivity of these data to the hypothetical narrow T=5/2 isobaric analog resonances in ^{9}Li is demonstrated by purple dashed and green dotted lines.

E. Uberseder et al., “Nuclear Structure beyond the neutron drip line: The lowest energy states in ^{9}He via their T=5/2 isobaric analogs in ^{9}Li”. Physics Letters B **754** 323 (2016). [DOI:http://dx.doi.org/10.1016/j.physletb.2016.01.014]

NS: Texas A&M University

Nucleation and cluster formation as a mechanism for ternary fission fragment production

Yield per fission event as a function of ternary fragment mass number (A). Solid points represent $^{241}Pu(n_{th},f)$ experimental yields. Open data points are the product of nucleation moderated nuclear statistical equilibrium (NSE) model

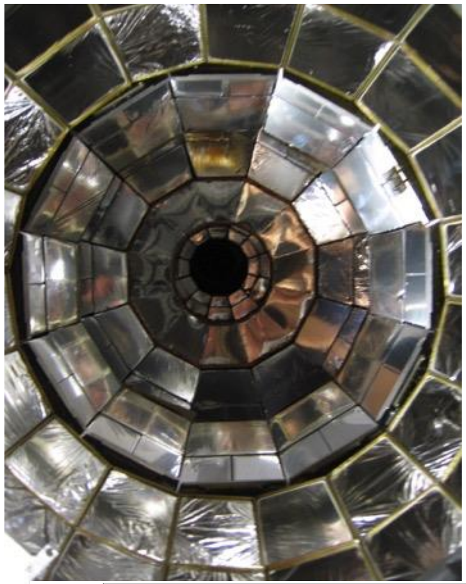


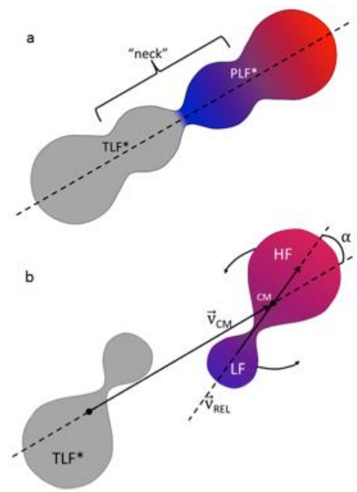
S. Wuenschel, et al, *Phys. Rev. C* **90**, 01

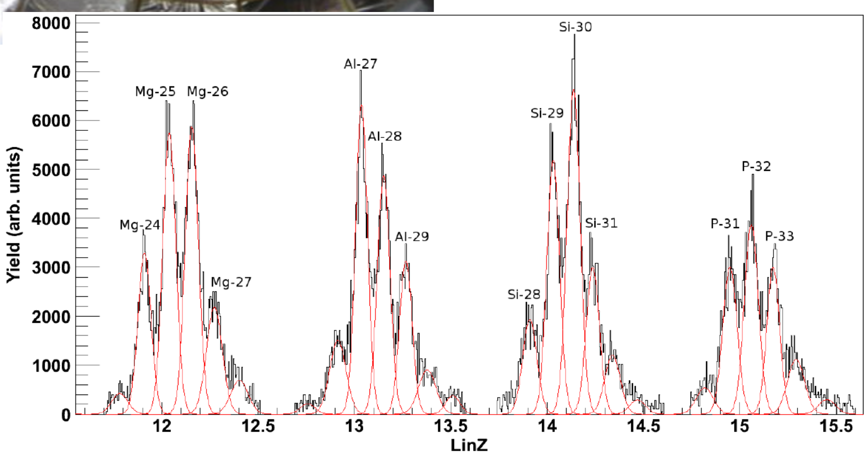
NS: Texas A&M University

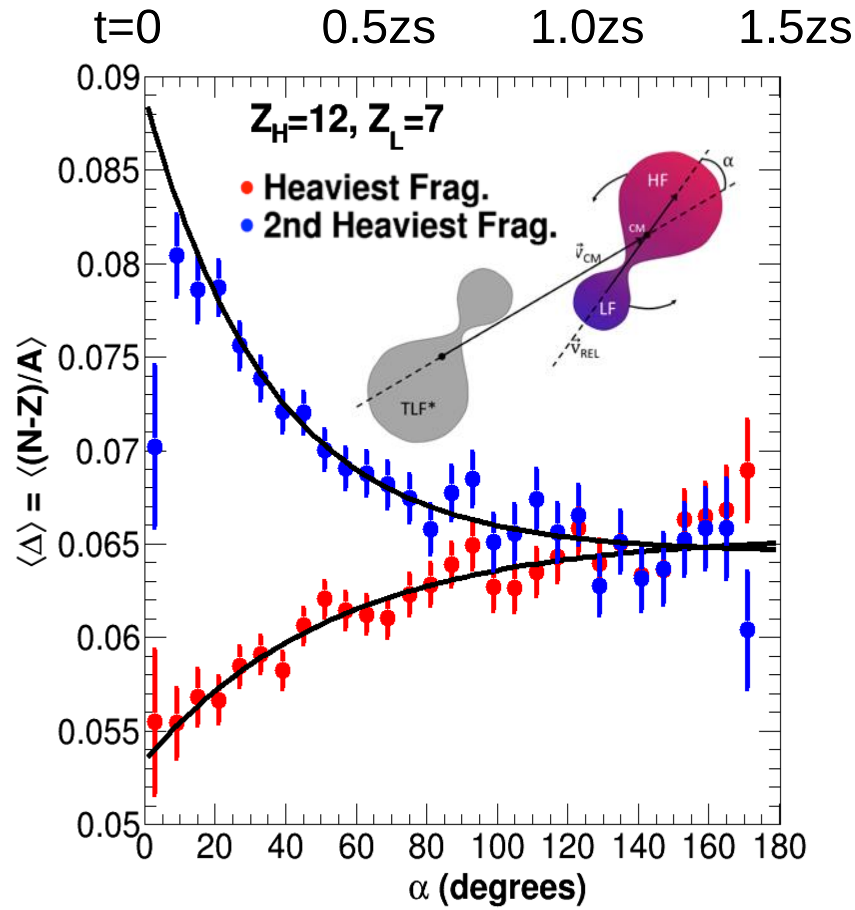
Equilibration Chronometry Offers a New View on the Nuclear Equation of State

NIMROD 4π Array $^{70}Zn + ^{70}Zn$ @ 35A MeV





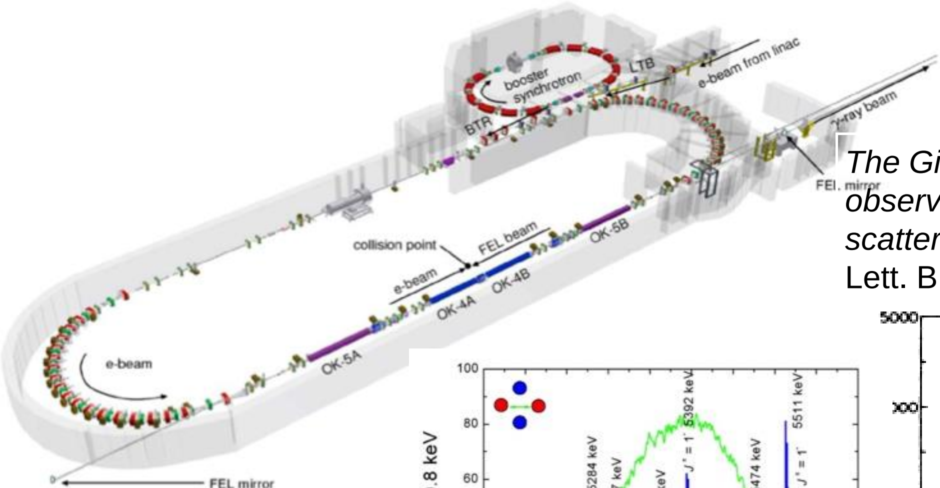


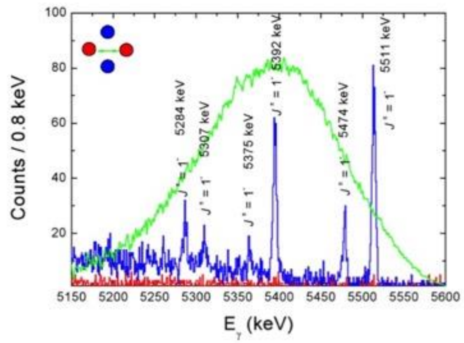


A. Jedele, submitted PRL

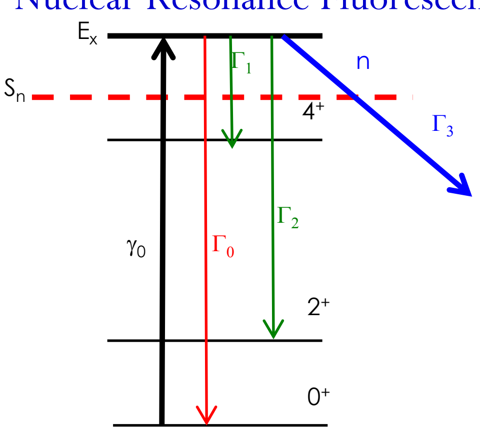
NS: TUNL/High Intensity Gamma-ray Source

Fine structure of the giant M1 resonance in ^{90}Zr

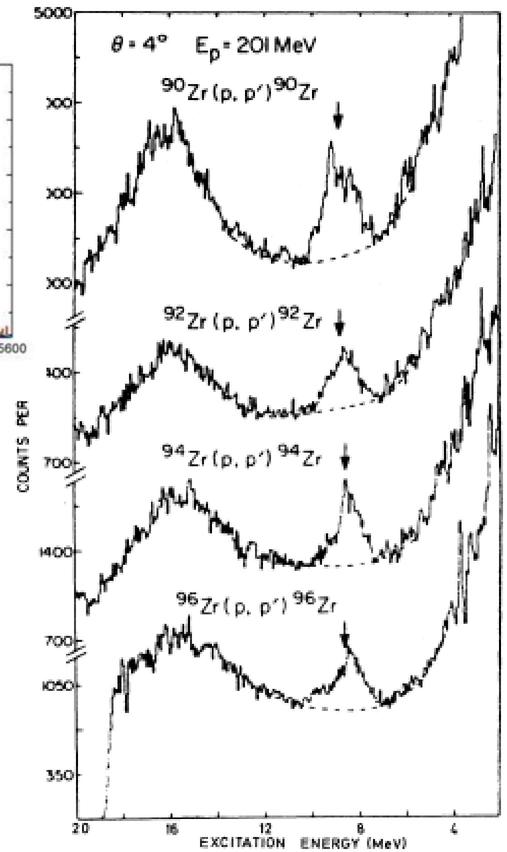




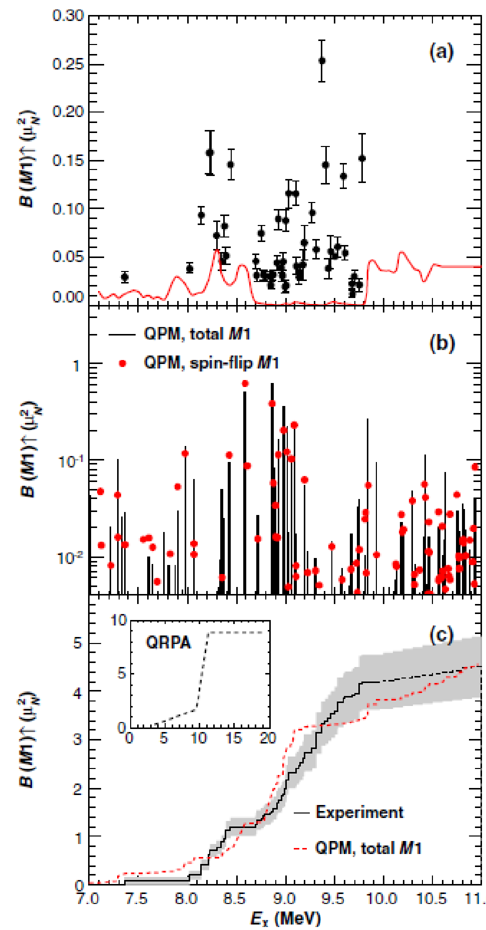
Nuclear Resonance Fluorescence



The Giant M1 Resonance in ^{90}Zr observed via inelastic proton scattering, G. Crawley et al., Phys. Lett. B 127, 322 (1983).

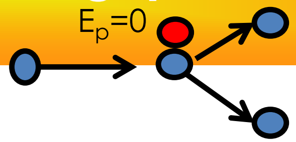


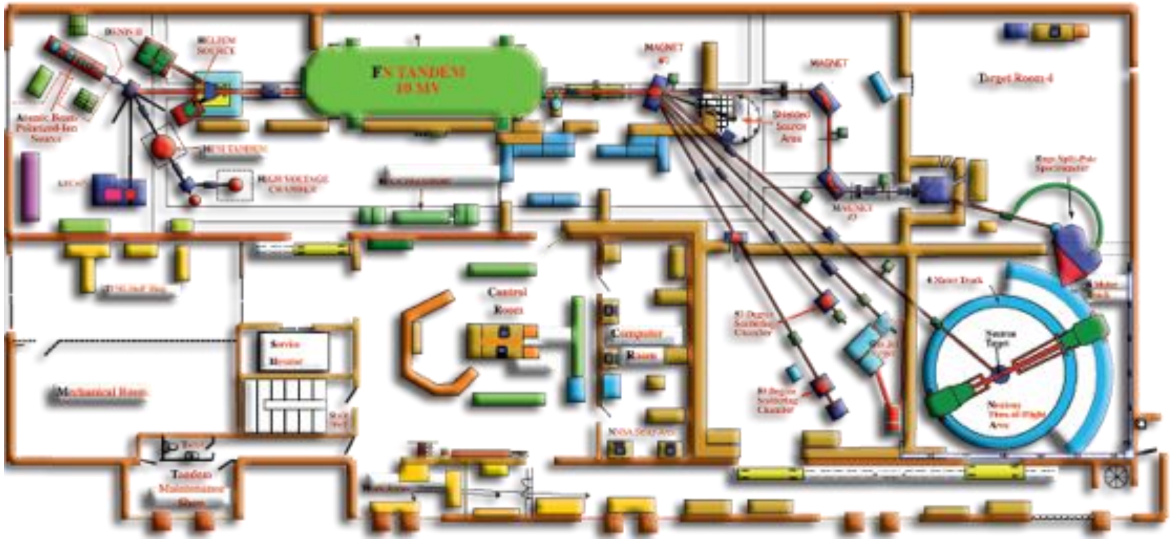
Fine Structure of the Giant M1 Resonance in ^{90}Zr, G. Rusev et al., **Phys. Rev. Lett. 110**, 022503 (2013).



NS: TUNL/Tandem Laboratory

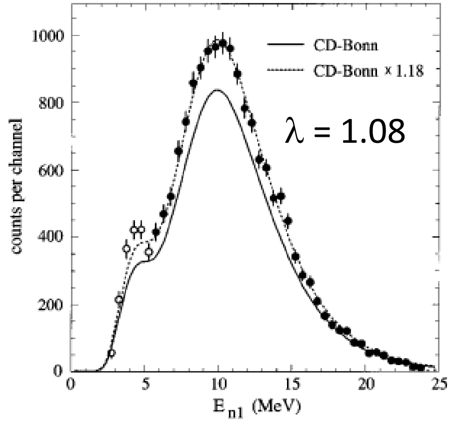
Neutron-neutron quasifree scattering: probe 3N Interactions

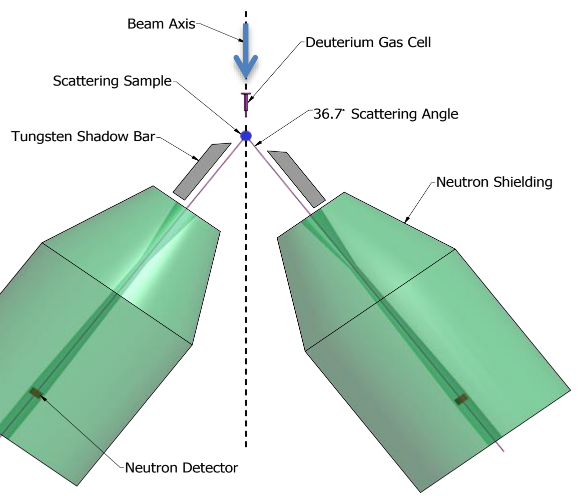


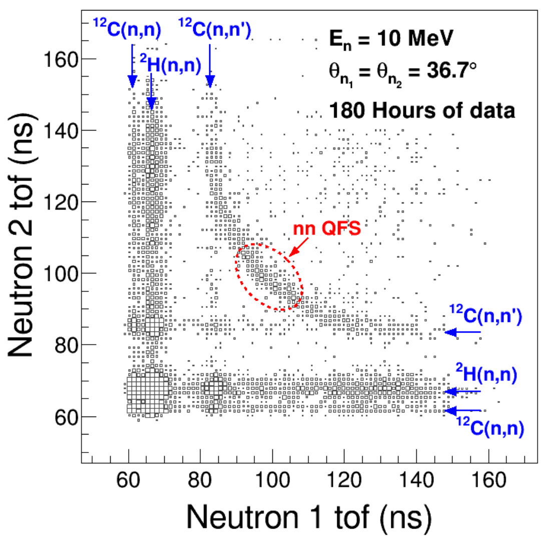


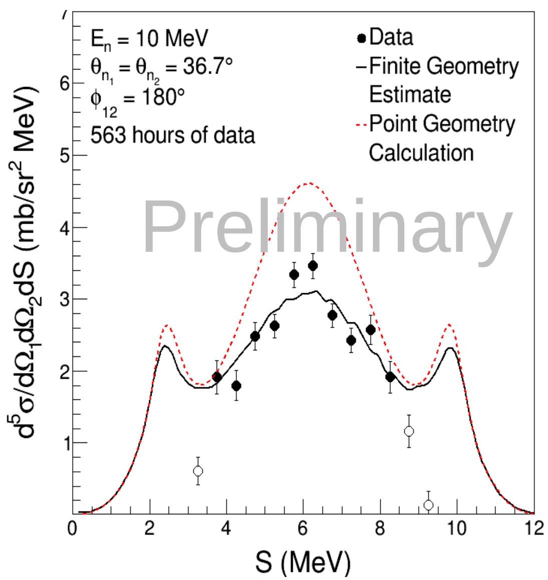
Univ. Bonn, E_n=26 MeV

A. Siepe et al., Phys. Rev. C **65,** 034010 (2002).





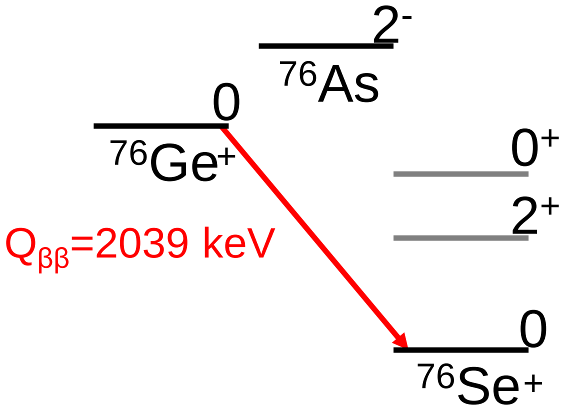


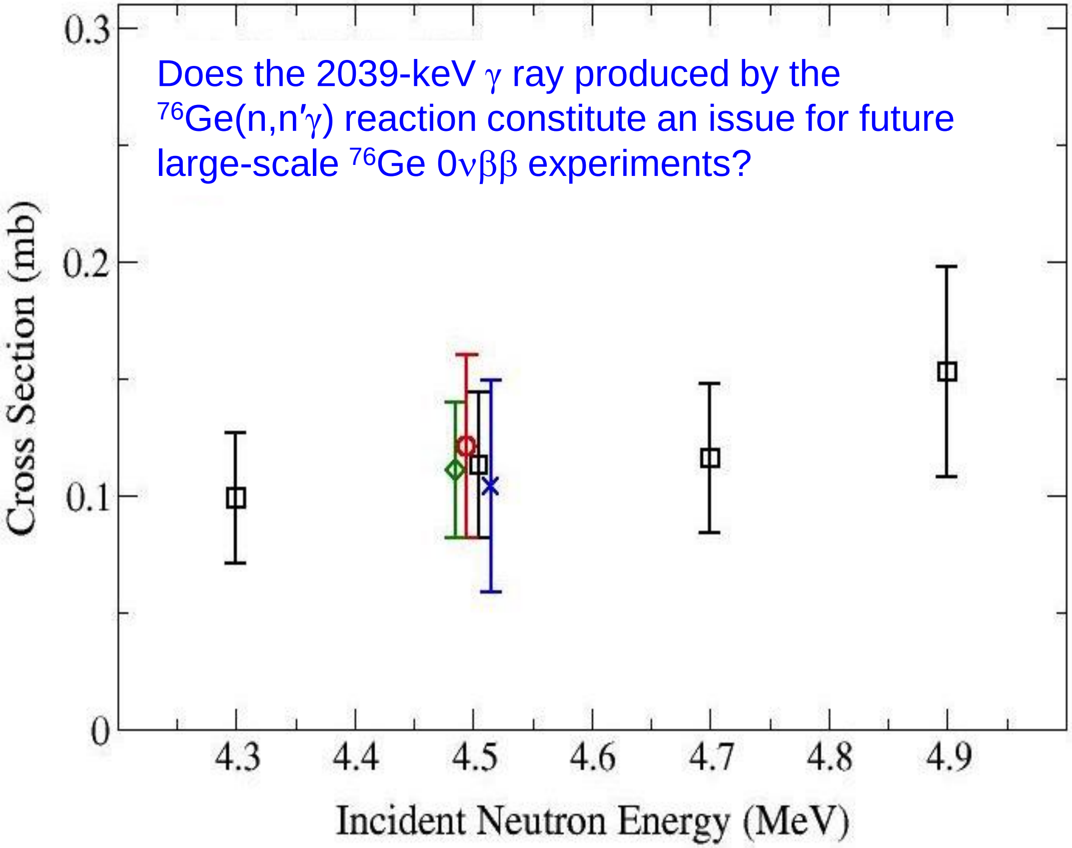


NS: University of Kentucky

Fast-neutron-induced Background Near the *Q* value for 0νββ

A detailed study of the nuclear structure of ^{76}Ge via the $^{76}Ge(n,n'\gamma)$ reaction

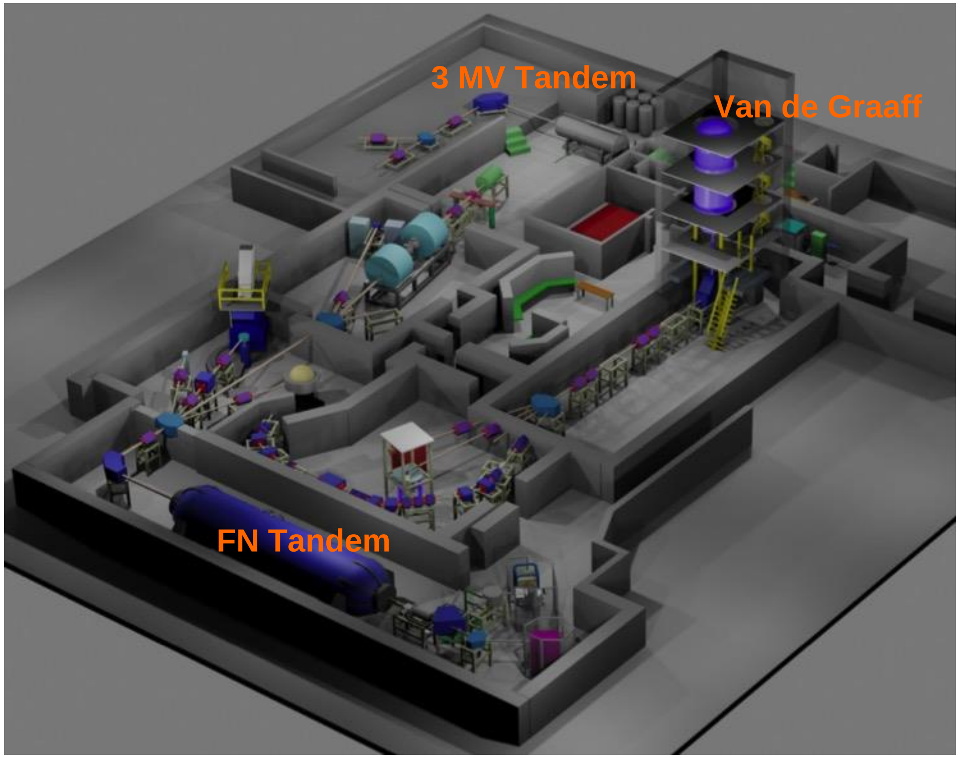




B.P. Crider *et al*., Phys. Rev. C 92, 034310 (2015).

NS: University of Notre Dame

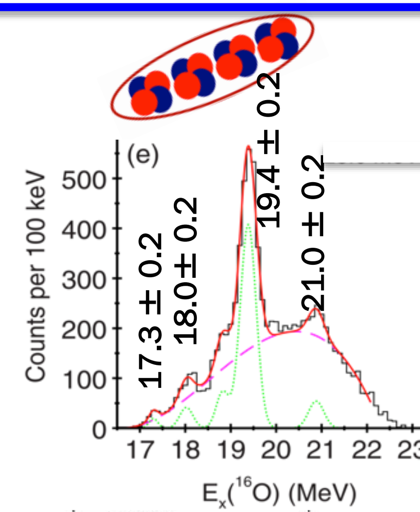
Alpha clusters in ^{16}O

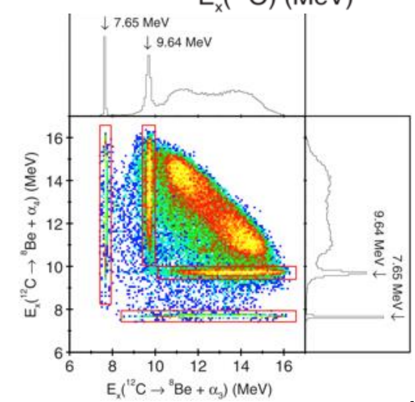


Research in Nuclear Structure

- Giant resonances and the incompressibility of nuclear matter
- Quantum modes of vibrations and rotations in nuclei
- Alpha-cluster structure of nuclei

Alpha cluster structures in light nuclei like ^{16}O are of great interest in both nuclear structure and astrophysics, in particular, the helium burning process in stars. The ^{8}Be+^{8}Be and ^{12}C+α breakup states in ^{16}O have been populated via the $^{13}C(^{4}He,4\alpha)n$ reaction at the University of Notre Dame FN tandem accelerator.



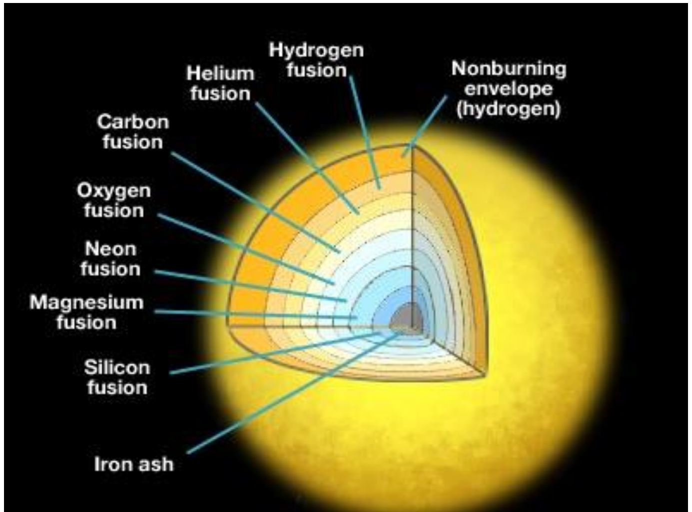


Four-alpha coincident events were measured by an array of four double sided silicon strip detectors. Observation of the cluster states could shed new light on the possible existence of the four-α linear chain structure in ^{16}O and potentially enhance the helium burning rate in stars .

N. Curtis et. al, Phys. Rev. C 94, 034313 (2016)

ARUNA

Nuclear Astrophysics:



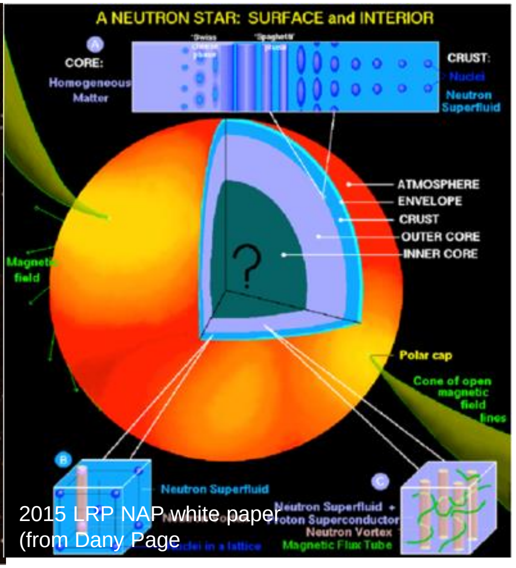
https://www.e-education.psu.edu/astro801/sites/www.e-education.psu.edu.astro801/files/image/massivestar_core_KL.jpg

US 2015 Nuclear Science LRP: Organizing Themes

- **The origin of the elements:** Nucleosynthesis in the interior of stars
- **The life of stars:** The energy producing nuclear reaction cycles, e.g., pp chain, CNO cycle, triple α burning, fusion of light nuclei
- **The death of stars:** stellar explosions (core collapse and thermonuclear explosions resulting from stellar accretion)
- **The matter of neutron stars:** nuclear equation of state for neutron rich dense nuclear matter

2015 LRP NAP white paper; Credit: David A. Hardy http://www.astroart.org & Science and Technology Facilities Council.

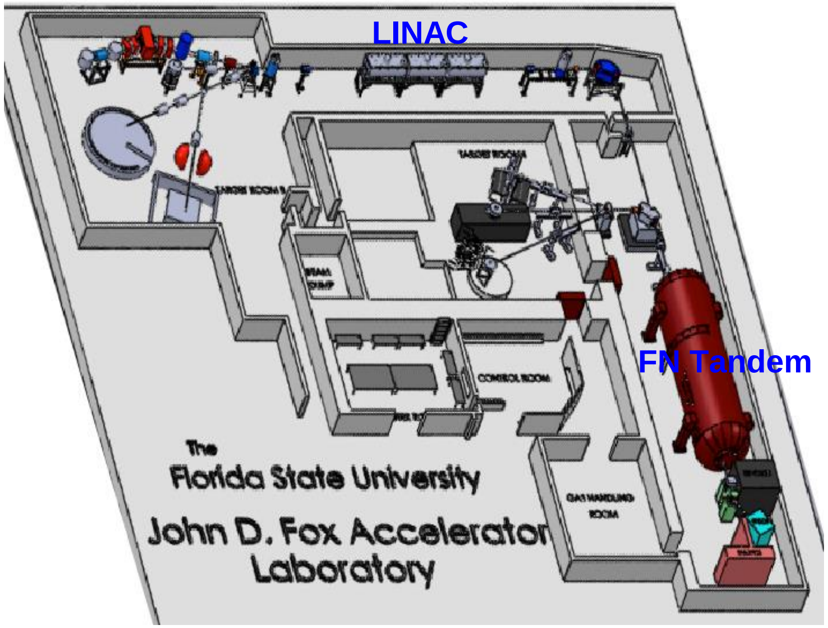
2015 LRP NAP white paper
(Image Credit: NASA/JPLCaltech/CXC/SAO)

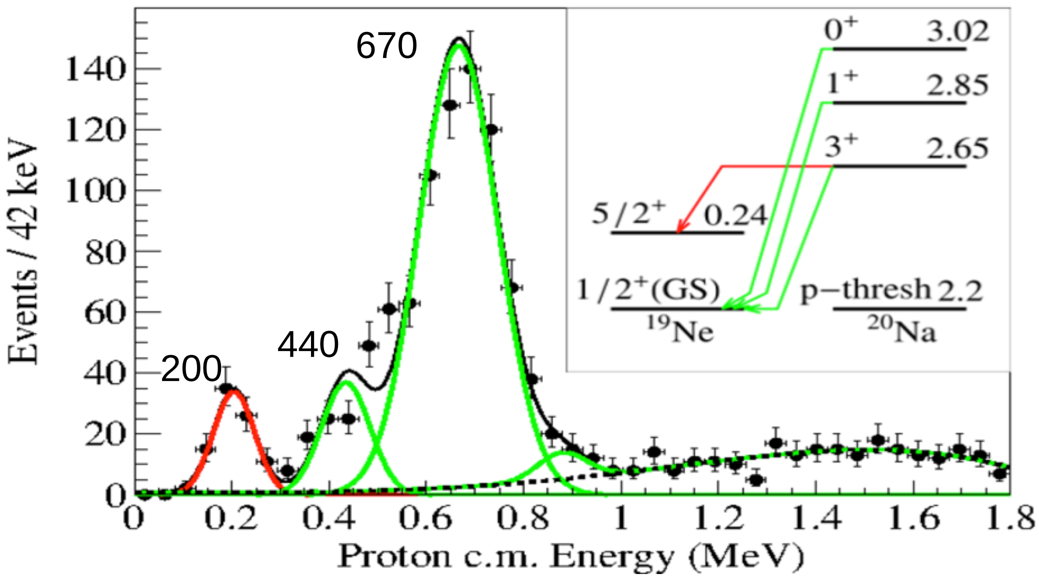


2015 LRP NAP white paper
(from Dany Page

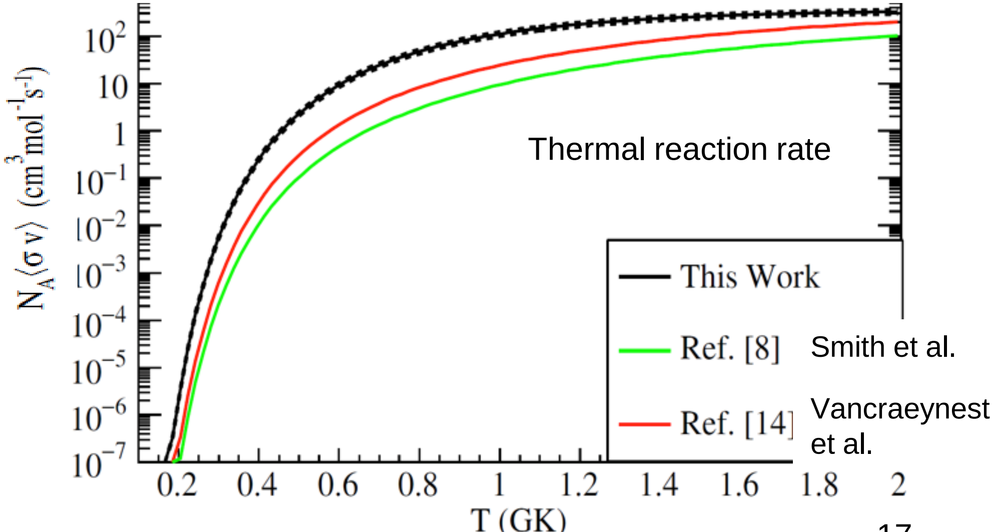
NAP: Florida State University

Effective capture in $^{19}Ne(p,\gamma)^{20}Na$: $^{19}Ne(d,n)^{20}Na\ (p)\ ^{19}Ne$



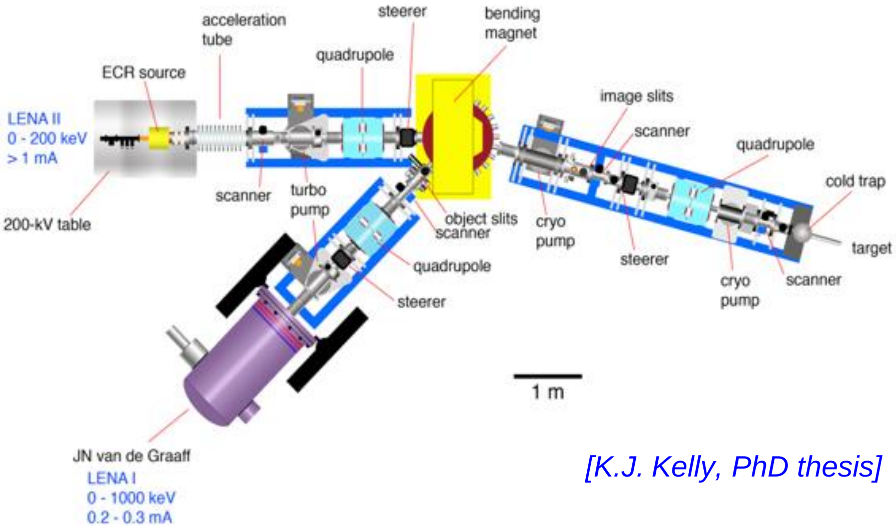


Radioactive ^{19}Ne beam from RESOLUT
Reconstruct p-resonance spectrum,
(d,n) angular distribution
440, 670 keV resonances known,
additional 200 keV peak is
"inelastic" l=0 proton-emission
from 440 keV resonance to excited state
populated through **l=2**
Effective capture in $^{19}Ne(p,\gamma)^{20}Na$,
no bottleneck in hot-CNO breakout



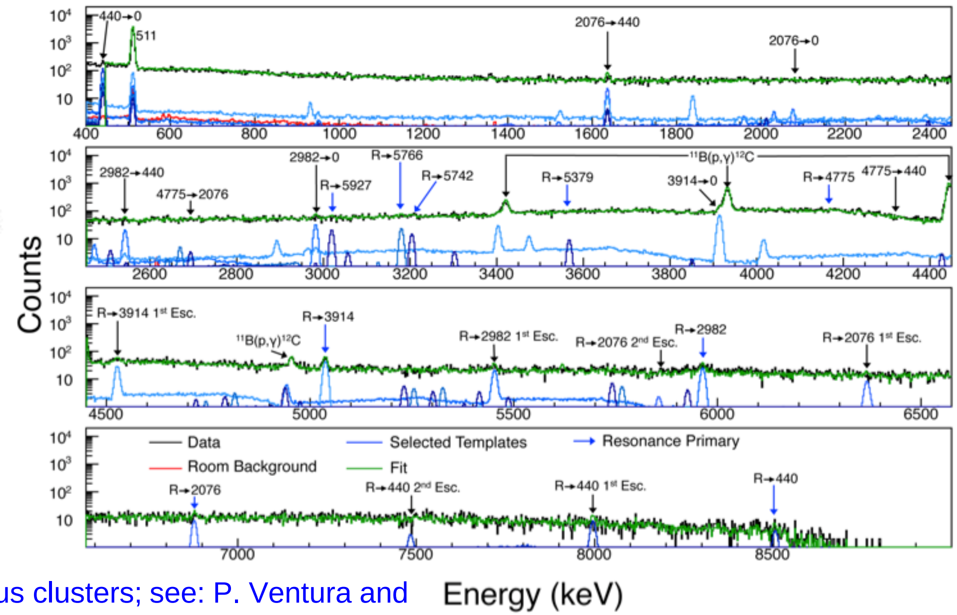
NAP: TUNL/Laboratory for Experimental Nuclear Astrophysics

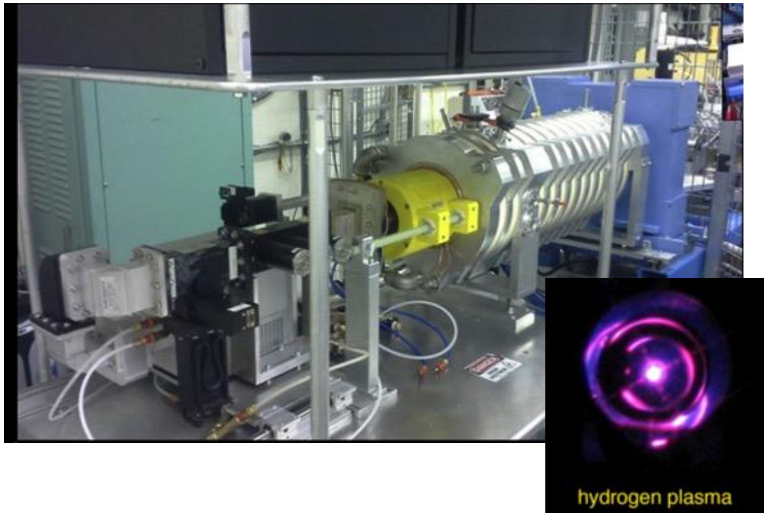
^{22}Ne(p,γ)^{23}Na and abundance anomalies in globular clusters



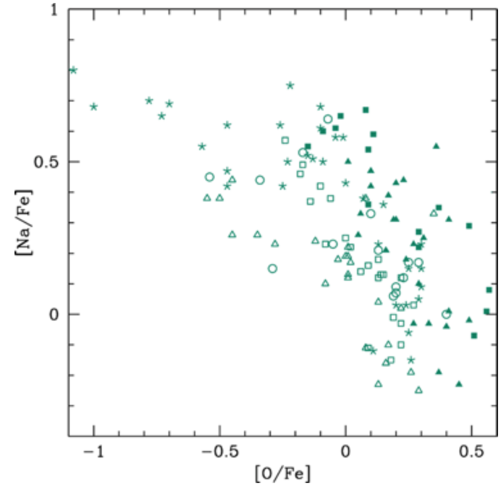
[K.J. Kelly, PhD thesis]

E_{cm} = 151 keV resonance; $\omega\gamma$ = 0.203(40) μeV

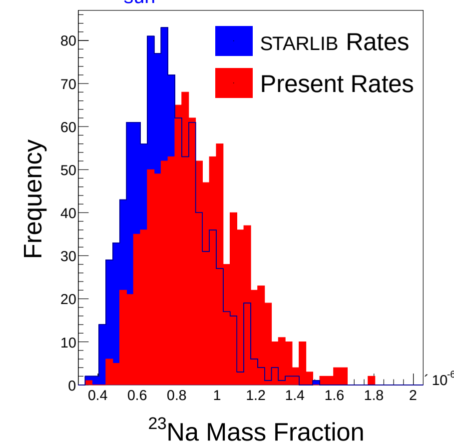




various clusters; see: P. Ventura and F. D'Antona, A&A 457, 995 (2006)



Revised ^{23}Na abundance for 5 M_{sun} AGB model

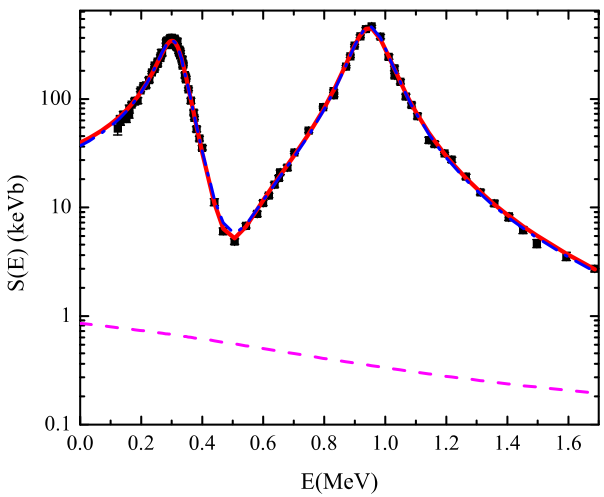


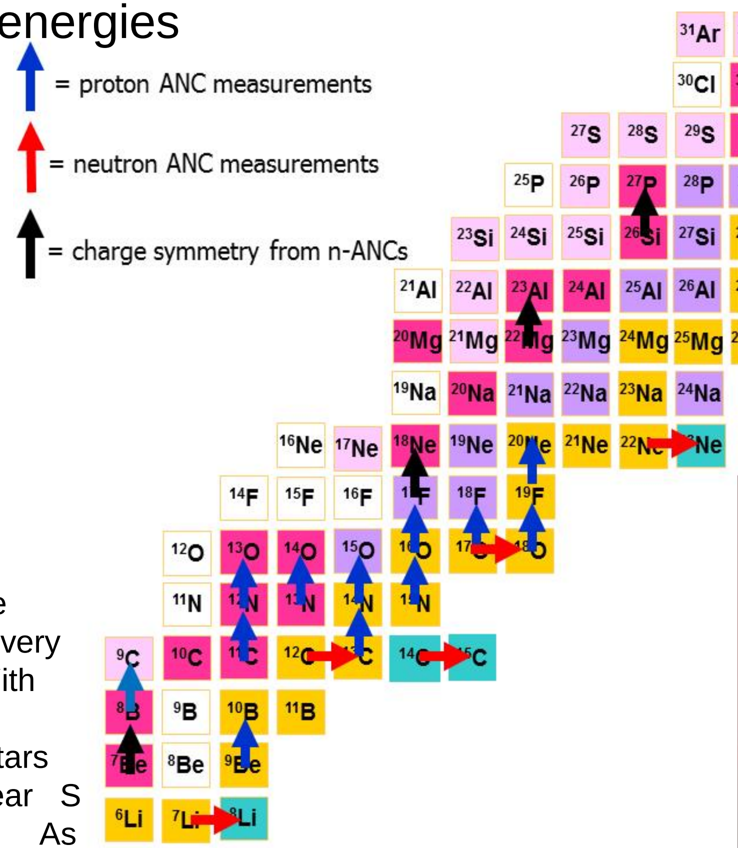
NAP: Texas A&M University

Measurement fo the Asymptotic Normalization Coefficients for the ^{14}N(p,g)^{15}O reaction

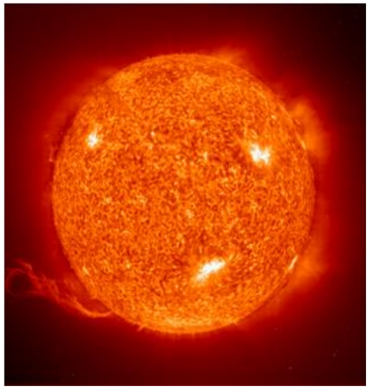
Looking in the Lab to Better Understand the Stars :

Determining reaction rates at stellar energies





Understanding stellar evolution, including processes like supernovae, requires knowing nuclear reaction rates at very low energies for both stable and radioactive material. With few exceptions, laboratory measurements are limited to stable isotopes at energies much higher than occur in stars and thus must be extrapolated to lower energies. Nuclear S cientists at Texas A&M University have developed the As ymptotic Normalization Coefficients (ANC) method to de termine many rates at stellar energies using conventional nu clear reactions.

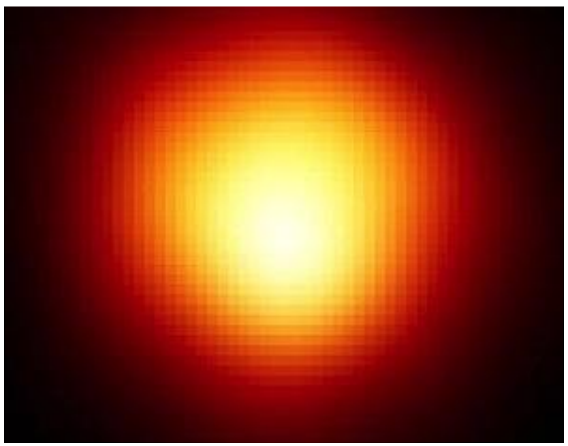


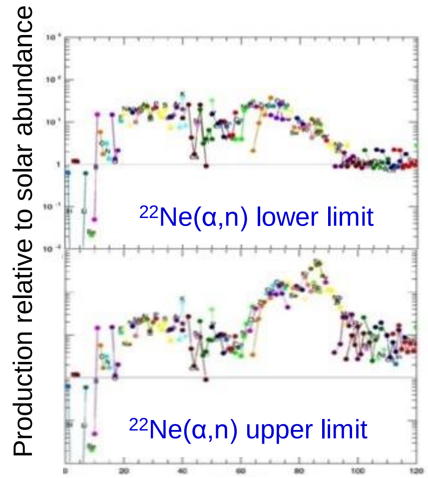
R.E. Tribble et al, Rep. Prog. Phys. 77 106901 (2014)

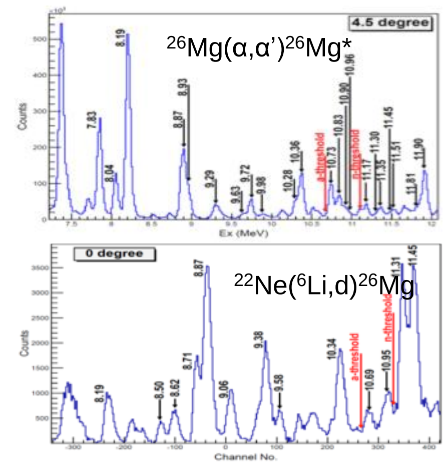
NAP: University of Notre Dame

The $^{22}Ne(\alpha,n)$ neutron source in stellar helium burning

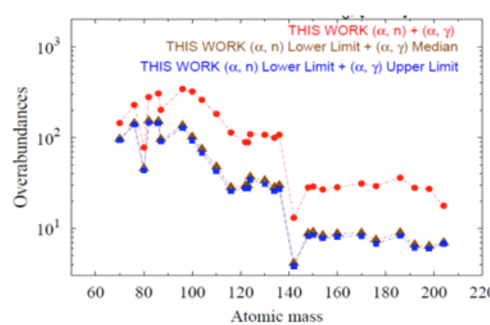
One of the main uncertainties in the production of heavy elements is the strength of the $^{22}Ne(\alpha,n)$ neutron source for the slow neutron capture (s) process. This neutron source determines the efficiency of the heavy element production for the main and the weak s-process environments in low mass AGB stars and massive RGB stars, respectively.

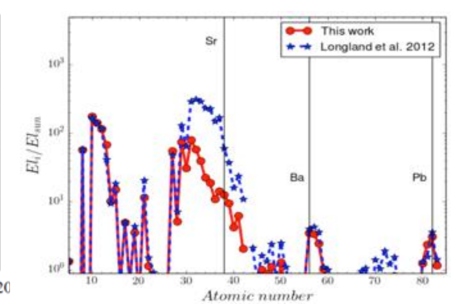






Using α transfer and α scattering to investigate the critical unbound states in the compound nucleus ^{26}Mg near the threshold, the possible resonances contributing to the reaction were investigated and the reaction rate was found to substantially deviate from previous predictions.

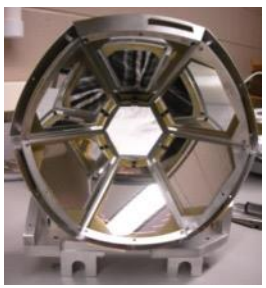




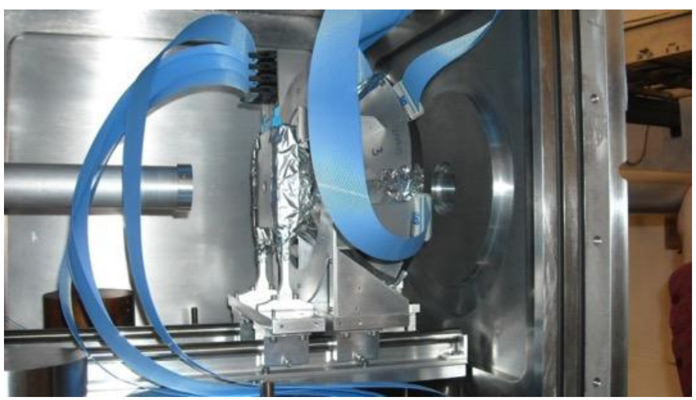
NAP: University of Notre Dame

Measuring $^{12}C+^{16}O$ Fusion Cross Section with the St. ANA accelerator

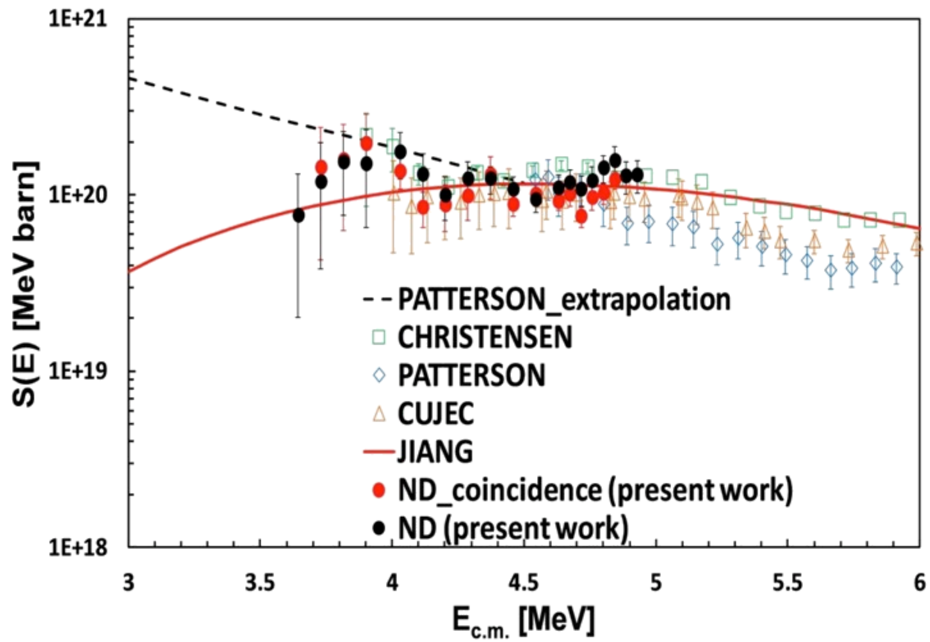
The total cross section of the $^{12}C+^{16}O$ fusion, crucial for late stellar evolution burning phases, has been measured with the high-intensity St. Ana 5MV accelerator at Notre Dame. Both protons and gamma-rays have been detected simultaneously in the center-of-mass energy range of 3.64 to 4.93 MeV. Statistical model calculations were employed to interpret the experimental results. This provided more reliable cross sections of the $^{12}C+^{16}O$ fusion reducing substantially the uncertainty for stellar model simulations.



ASIC electronics and SAND detector array



The S(E) factor of $^{12}C+^{16}O$ fusion

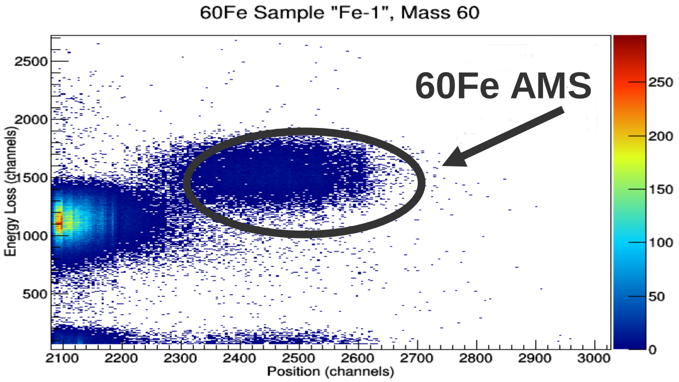


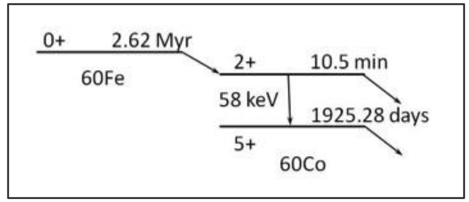
X. Fang, W. P. Tan, M. Beard, R. de Souza, G. Gilardy, S. Hudan, H. Jung, Q. Liu, S. Lyons, D. Robertson, K. Setoodehnia, C. Seymour, E. Stech, X. D. Tang, E. Uberseder, B. Vande Kolk, M. Wiescher. , to be submitted.

NAP: University of Notre Dame

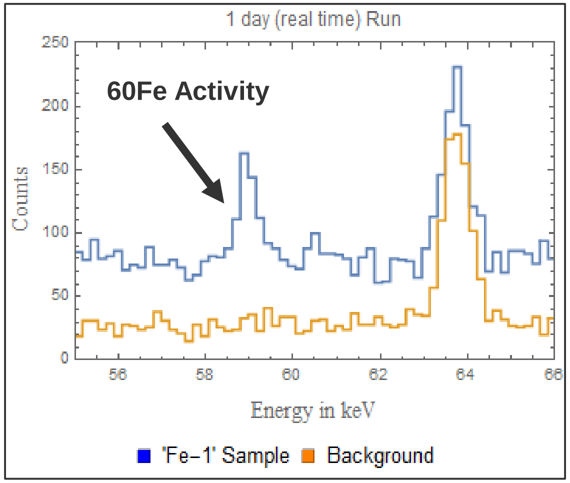
Measurement of the Half-life of ^{60}Fe for Stellar and Early Solar System Models

The radioactive isotope, ^{60}Fe is only naturally produced in massive stars and is ejected into the Universe through supernova explosions and the end stages of AGB stars. Trace amounts of ^{60}Fe has been discovered in Earth's ocean crust, dating back to several millions of years ago. As the half-life of ^{60}Fe is on the order of millions of year, it can be used as a chronometer for past Solar System events.





$T_{1/2}$ of ^{60}Fe has been in question in recent years. Work is currently being done at the NSL to confirm it. The work is two-parted: Using Accelerator Mass Spectrometry and Gas-Filled Magnet techniques, the number of ^{60}Fe atoms in a sample can be measured. Together with an activity measurement on the same sample, the half-life can be calculated.

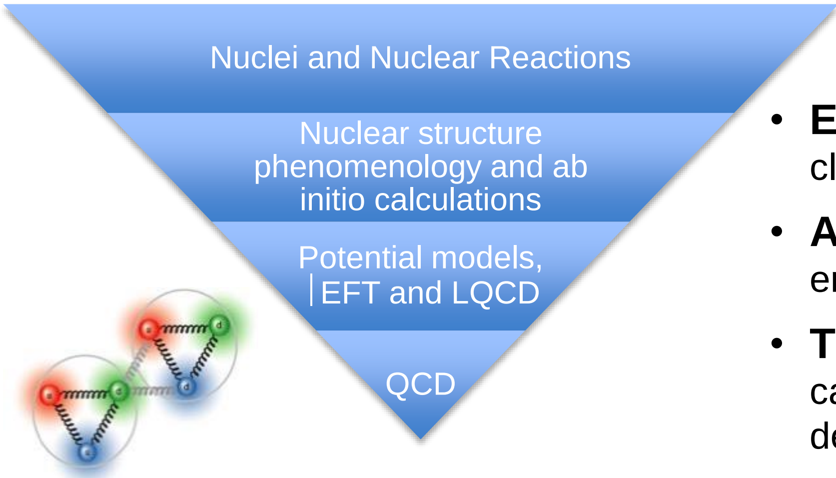


In the following equation, dN/dt is the samples' activity and N is the number of atoms in the sample. λ, is ln(2) / $t_{1/2}$ where $t_{1/2}$ is the isotope's half-life.

During the spring of 2015, the activity measurement was finalized and recently in October 2015, the AMS measurement as been completed. Further work is needed to finalize the half-life.

K. Ostdiek, et al.Towards a Measurement of the Half-Life of 60Fe for Stellar and Early Solar System Models. 2015. NIMB

Low-energy QCD

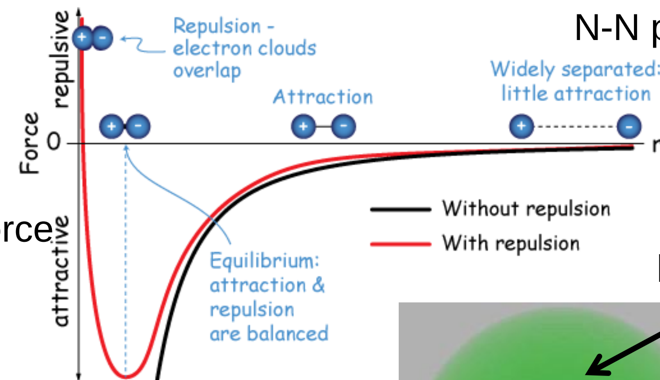


US 2015 Nuclear Science LRP: Organizing Themes

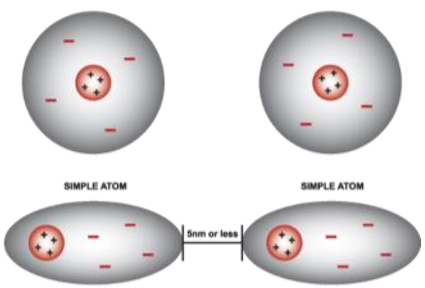
- **Expressions of chiral dynamics in hadrons:** Pion-cloud physics
- **A new era in the theory of hadron structure:** Low-energy effective field theories and Lattice QCD
- **Theory of nuclei: to explain, predict and use:** ab-initio calculations (few-nucleon systems and light nuclei), nuclear density functional theory for heavy nuclei

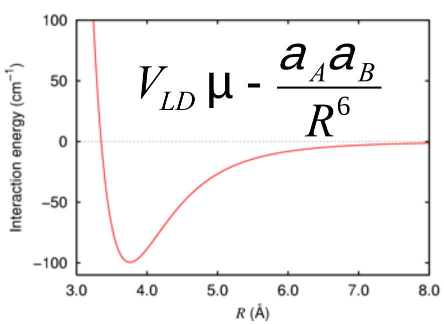
Nuclear Force:
interaction of colorless hadrons ➔ must be due to residential and dynamic interactions analogous to Van der Waals forces.

N-N potential

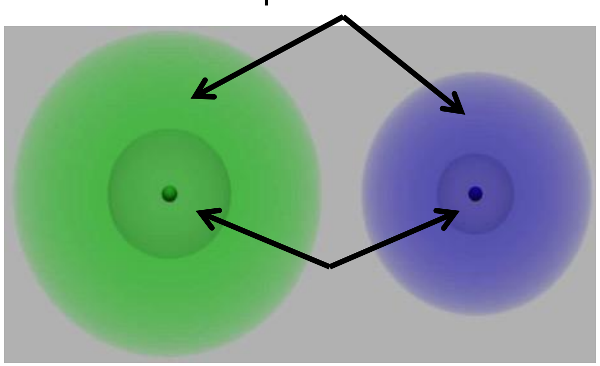


Van der Waal interaction, e.g., London dispersive force

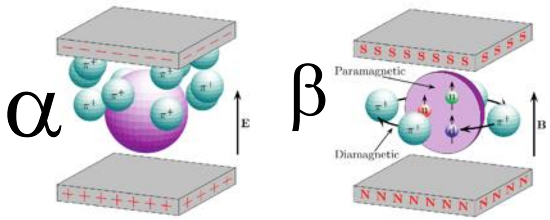


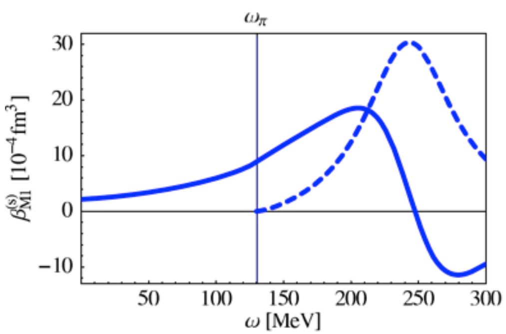


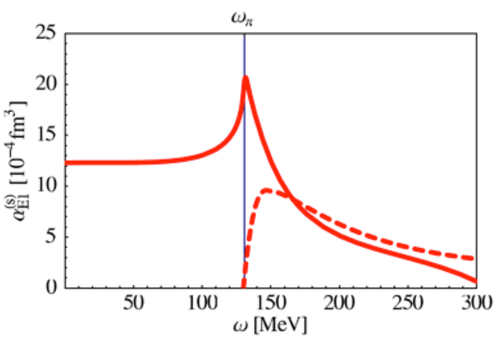
pion cloud



LEQCD: TUNL/HIGS
Nucleon electric and magnetic polarizabilities



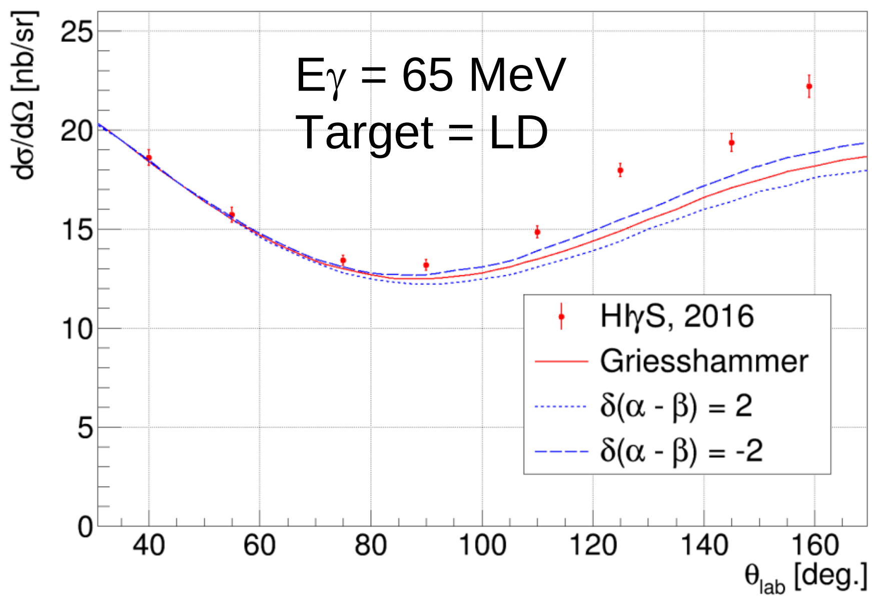




R. P. Hildebrandt, H.W. Griesshammer, T.R. Hemmert and B. Pasquini, Eur. Phys. J. A **20**, 293 (2004).

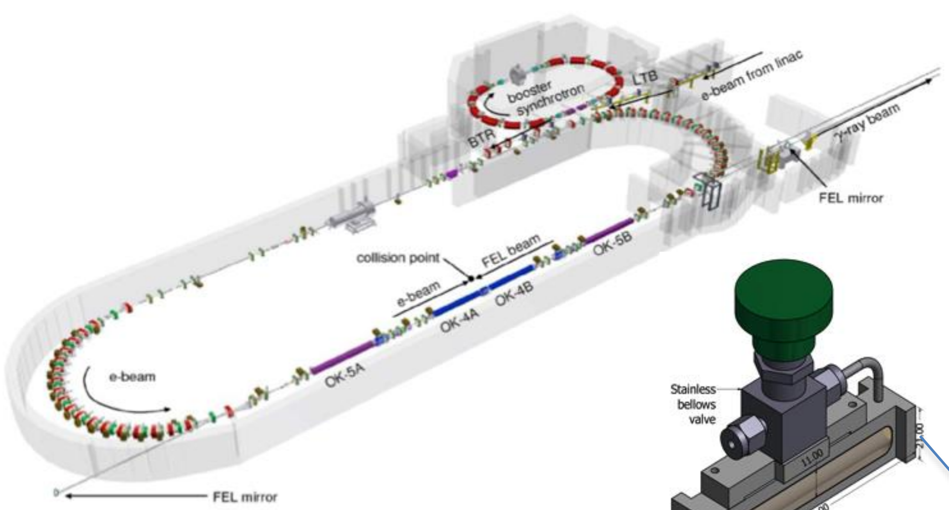
Provides insights about:
- Freq. response of system
- Binding energy of charged constituents
- Confinement volume of charged constituents
- $\Delta\beta_n$ causes a significant uncertainty in calc. m_n-m_p
- β_p input to Lamb-shift corr. In μH atoms
- Collective response of internal spin dof to em pulse

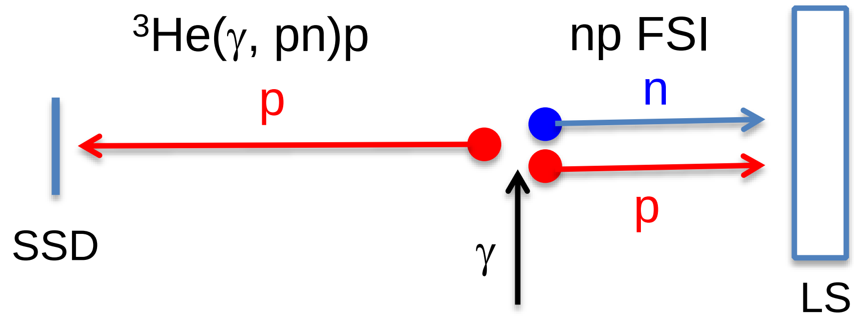
Expt. goals:
- sum-rule independent meas. of β_p
- reduce $\Delta\beta_n$ by ~ factor of 2

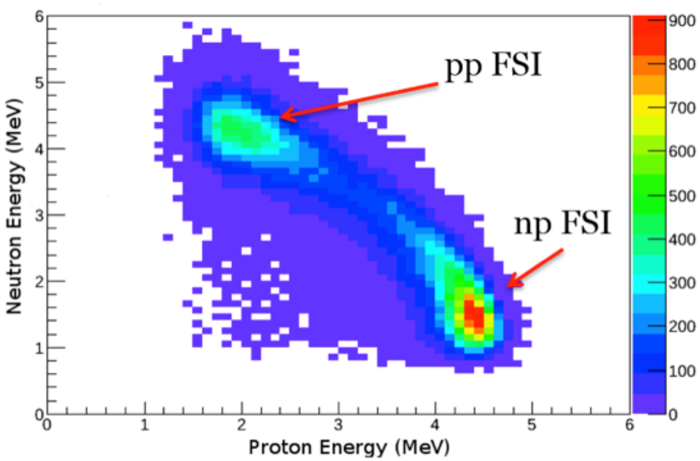


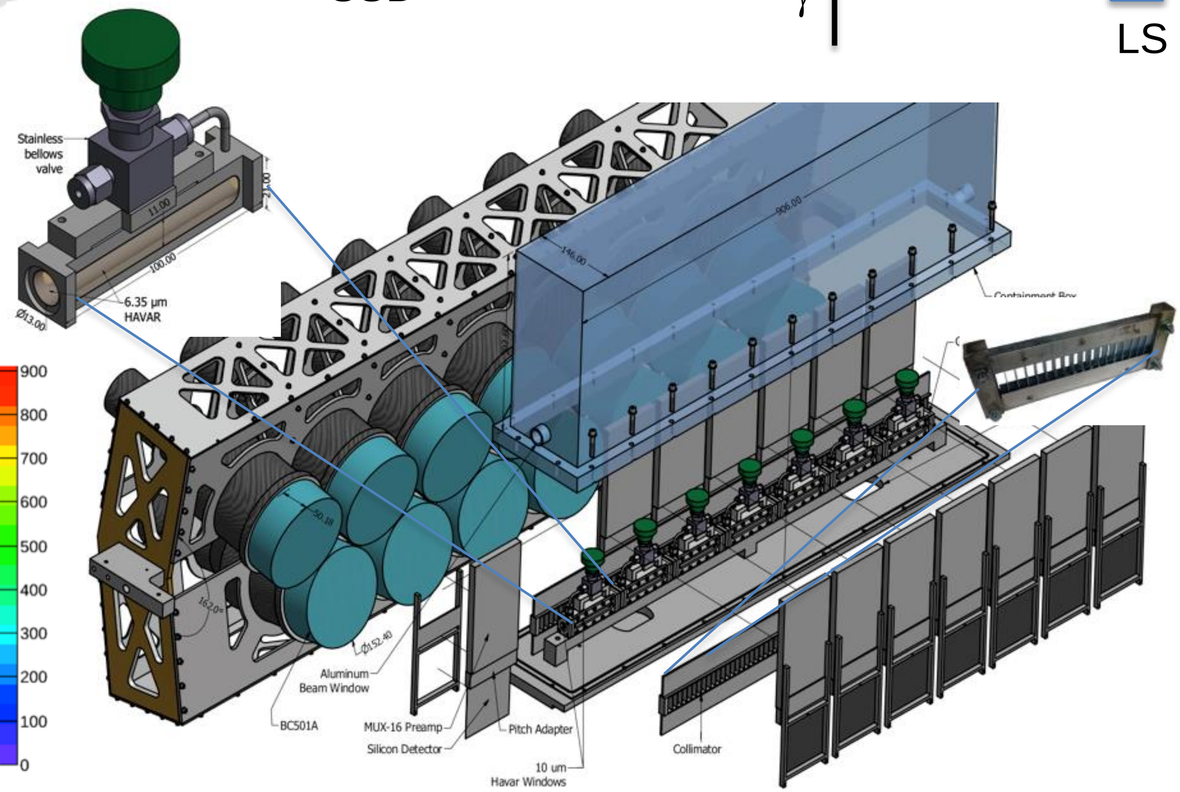
LEQCD/NS: TUNL/HIGS

Exclusive Photodisintegration of ^3He and ^3H: probe 3N Interactions

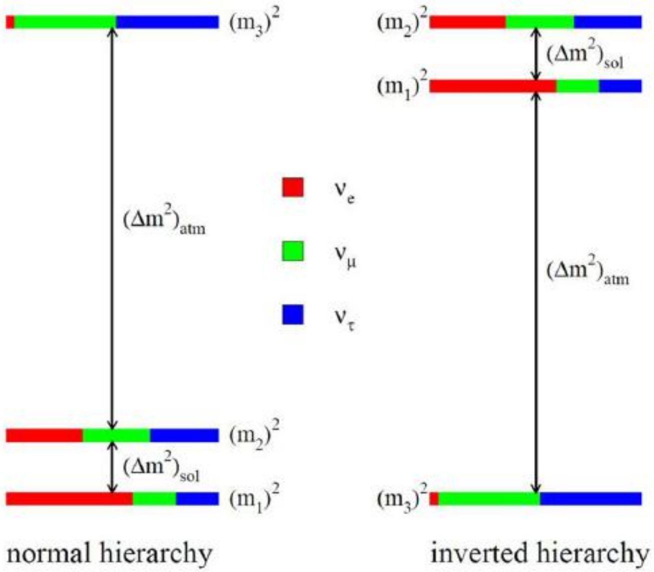






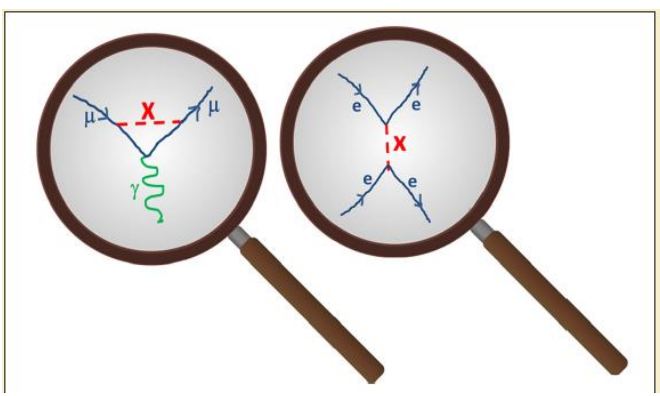


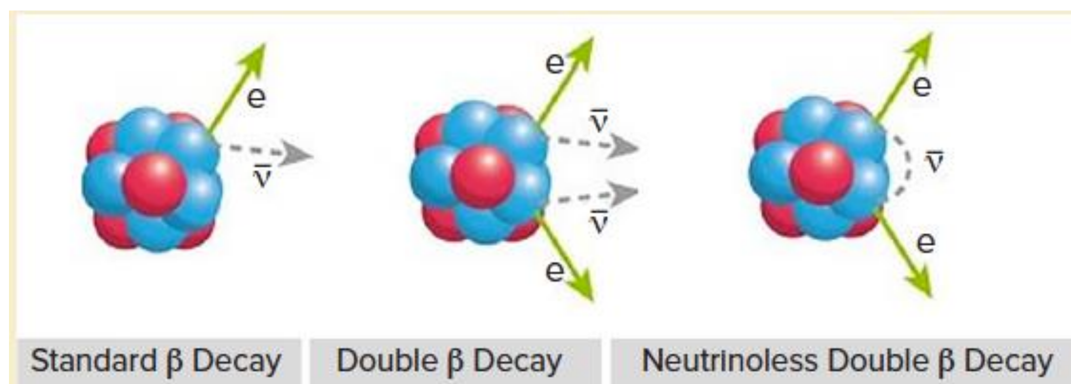
Fundamental Symmetries and Neutrinos



US 2015 Nuclear Science LRP: Organizing Themes

- **Neutrinoless double beta decay**
- **Neutrino mass, mixing and other prizes**
- **Electric dipole moments**
- **Further probes of the new standard model**



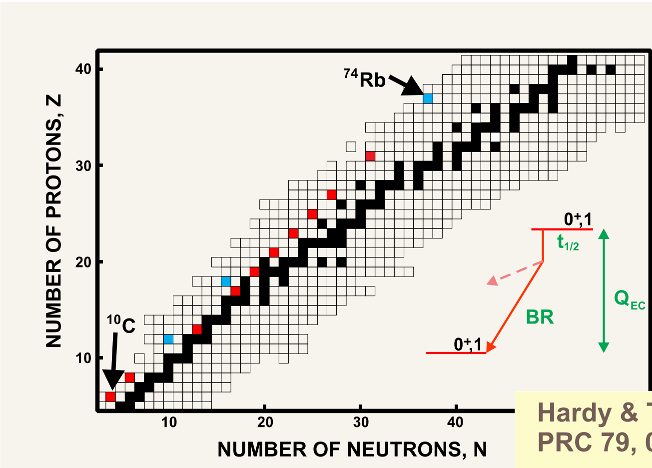


ARUNA

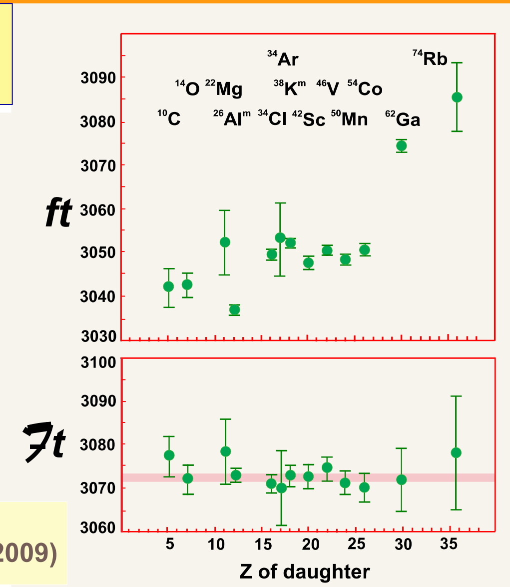
FS: Texas A&M University

SUPERALLOWED $0^+ \rightarrow 0^+$ BETA DECAY

$$\mathcal{F}t = ft\,(1 + \delta_R')[1 - (\delta_C - \delta_{NS})] = \frac{K}{2G_V^2\,(1 + \Delta_R)}$$



Hardy & Towner
PRC 79, 055502 (2009)



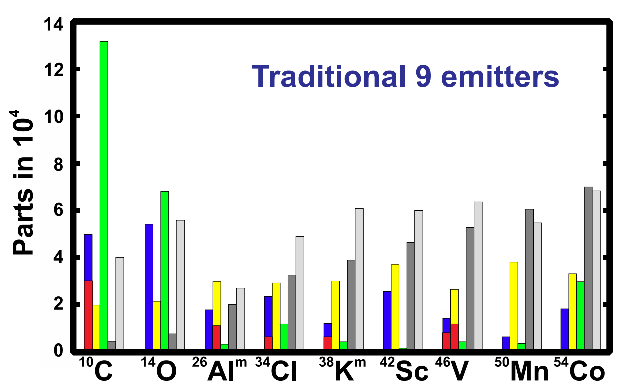
- CVC verified
- $V_{ud} = 0.97425(22)$

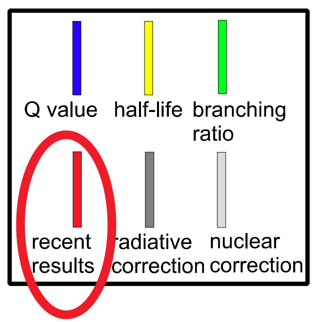
CKM unitarity test:

$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.9999(6)$

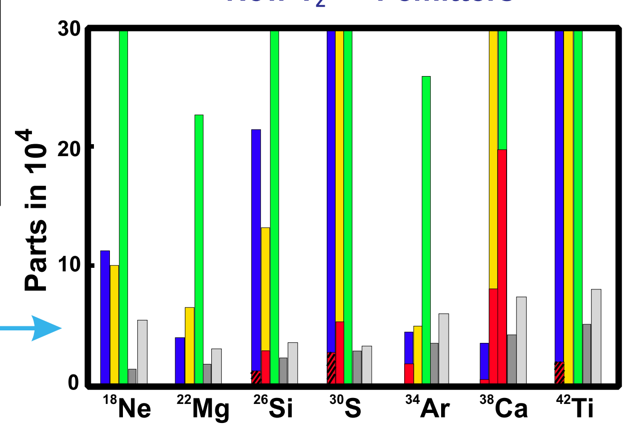
Improvements since 2009

(Most done at, or in collaboration with TAMU)





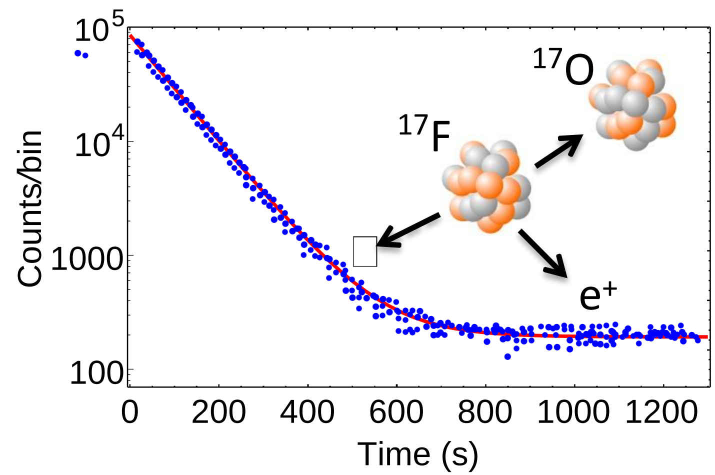
Uncertainty budgets

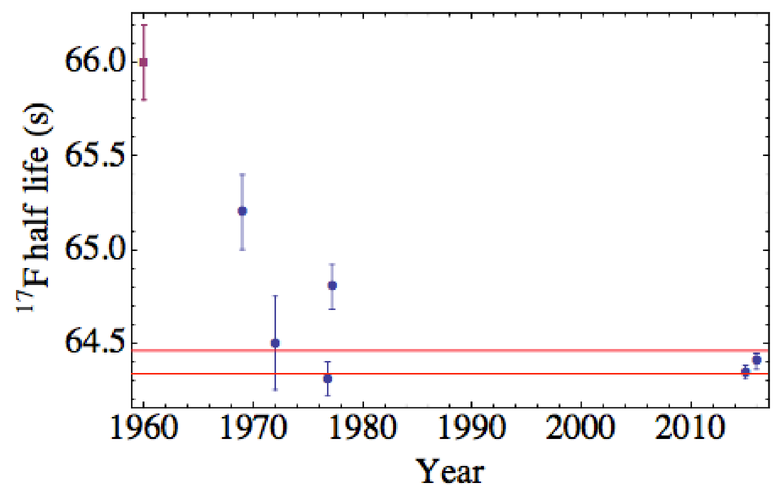


FS: University of Notre Dame

^{17}F half-life measurement at the NSL

We perform our first precision half-life measurement on ^{17}F using a dedicated □ counting station behind *TwinSol*. Our new data gives a strong experimental incentive to measure the missing mixing ra9o for that transition, which will allow to extract the V_{ud} matrix element. More half-life are under analysis and are planed in the future.

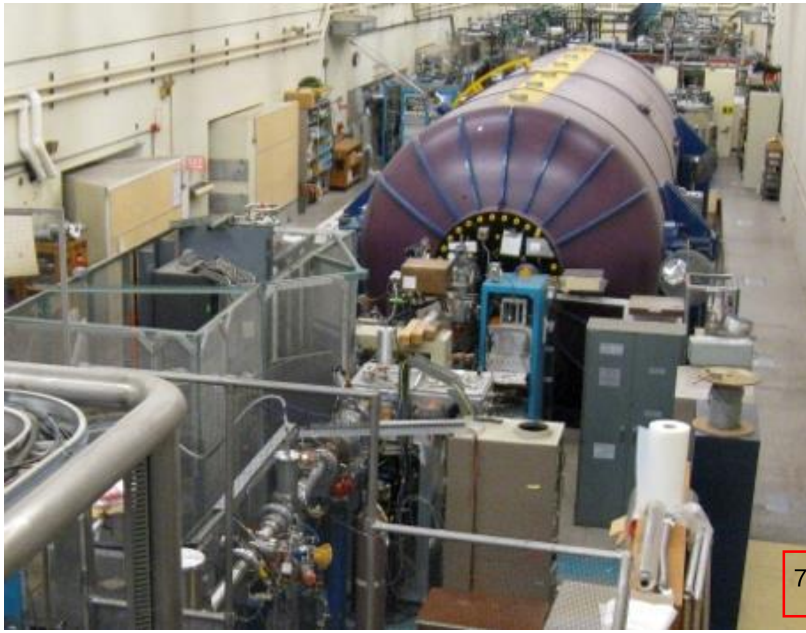




M. Brodeur, C. Nicoloff, T. Ahn, J. Allen, D. W. Bardayan, F. D. Becchetti, Y. K. Gupta, M. R. Hall, O. Hall, J. Hu, J. M. Kelly, J. J. Kolata, J. Long, P. O'Malley, and B. E. Schultz, PRC **93,** 025503 (2016)

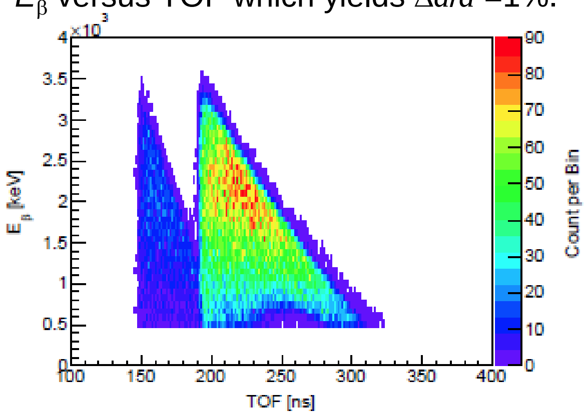
FS: University of Washington

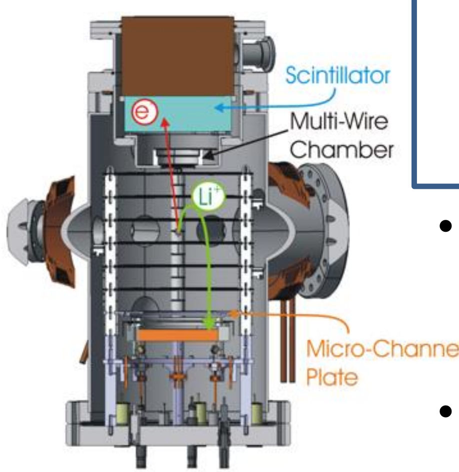
^{6}He β-ν angular correlation measurement



^{7}Li(d,^{3}He)^{6}He

Example of data taken recently:
E_β versus TOF which yields $\Delta a/a$ =1%.





Decay rate: C_T and C_T' represent the new physics. C_A is the usual axial coupling constant for Weak Int.

$$dw = dw_0 \left[1 + a \frac{\vec{p}_e}{E_e} \cdot \frac{\vec{p}_\nu}{E_\nu} + b \frac{\Gamma m_e}{E_e} \right]$$

$$a \approx -\frac{1}{3} \frac{2|C_A|^2 - |C_T|^2 + |C_T'|^2}{2|C_A|^2 + |C_T|^2 + |C_T'|^2}$$

$$b \approx \frac{\mathrm{Re}\left[2C_A\left(C_T + C_T'\right)\right]}{2|C_A|^2 + |C_T|^2 + |C_T'|^2}$$

Little-*b* is called "Fierz interference" and depends linearly on the new couplings. This makes it a more sensitive probe of the new physics.

- Goal: measure "little a" to 0.1% in ^{6}He
  - pure Gamow-Teller decay
  - sensitive to tensor couplings
  - simple nuclear and atomic structure
- Laser cooling and trapping to prepare ^{6}He source (t ≈0.8 s)
- Detect electron and ^{6}Li in coincidence

FS: University of Washington

^{6}He little-*b* measurement

LRP: *…weak decay measurements with an accuracy of 0.1% or better provide a unique probe of new physics at the TeV energy scale, offering discovery potential complementary to muon and electron weak force measurements.*

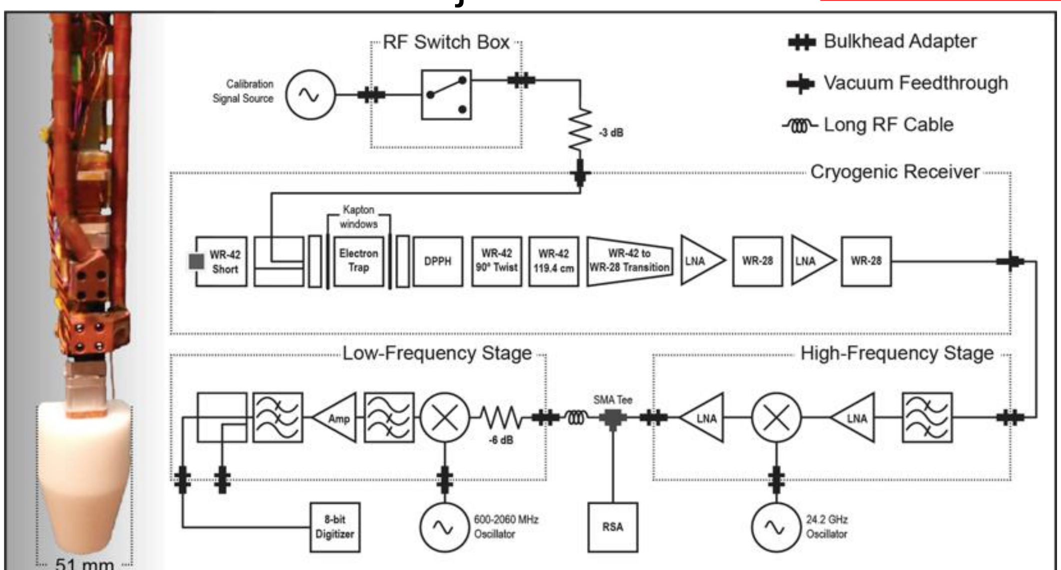
- Goal: measure beta spectrum with high precision to search for "little b" deeper than 10^{-3} in ^{6}He.
- Most sensitive experiment ever proposed to search for chirality-flipping interactions. Sensitivity more than 1 order of magnitude higher than LHC!

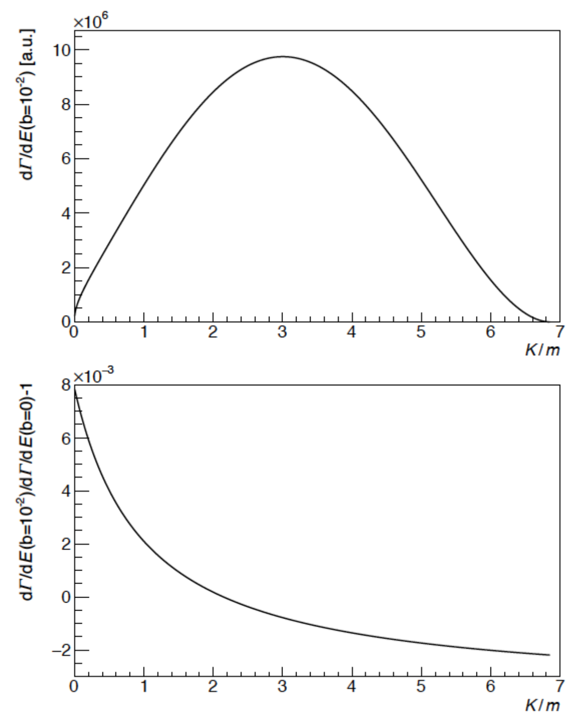
$$dw = dw_0 \left[1 + a \frac{\vec{p}_e}{E_e} \cdot \frac{\vec{p}_\nu}{E_\nu} + b \frac{\Gamma m_e}{E_e} \right]$$

Little-*b* is called "Fierz interference" and depends linearly on the new couplings. This makes it a more sensitive probe of the new physics.

Project 8

^{7}Li(d,^{3}He)^{6}He





Workforce Development: Statistics

PhD Students who conducted thesis research at an ARUNA lab and was supervised by an ARUNA faculty member

Institution	Period	Number	Average PhD/yr
FSU	2006 - 2015	18	1.8
Ohio Univ.	2006 - 2014	7	0.8
Texas A&M	2006 - 2015	19	1.9
TUNL	2005 - 2014	31	3.1
Univ. Kentucky	2006 - 2014	7	0.8
Univ. Mass-Lowell	2006 - 2014	1	0.1
Univ. Notre Dame	2001 - 2015	33	2.2
Univ. Washington	2002 - 2015	5	0.4
Total			11.1

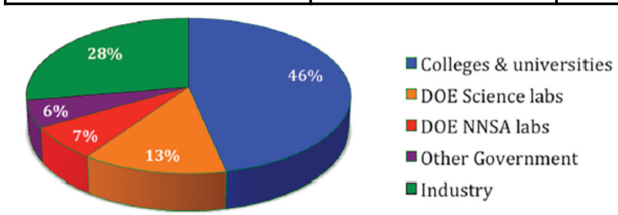


Figure 8.3: Distribution of careers of nuclear science Ph.D. recipients from 2006 to 2009. Adopted from the 2015 white paper Nuclear Science Education and Innovation.

from US 2015 Nuclear Science LRP

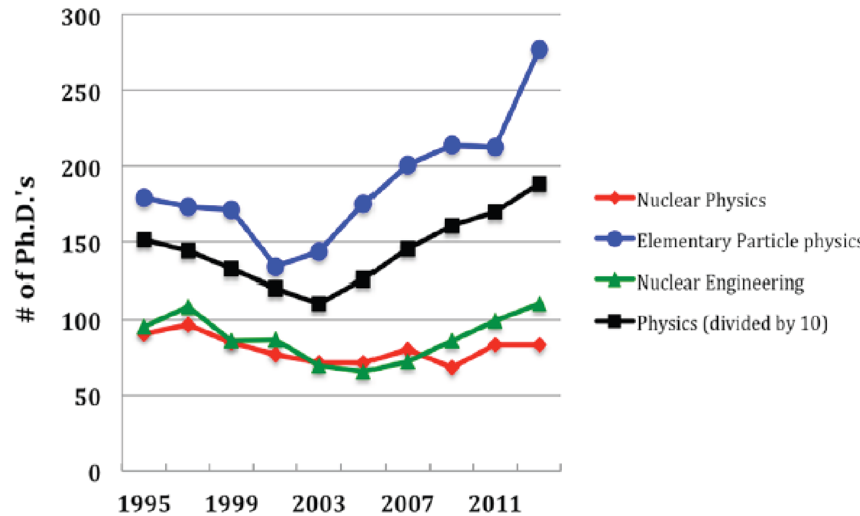


Figure 8.2: Two-year averages of the number of Ph.D. degrees awarded from 1993 to 2013 in physics, elementary particle physics, nuclear engineering, and nuclear physics based on data from the NSF Survey of Earned Doctorates.

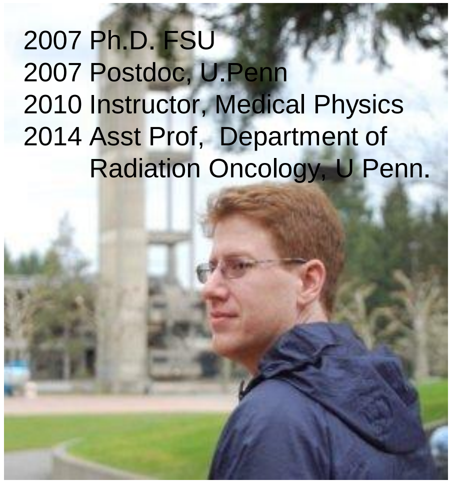
Total PhD recipients = 80/year
Assume 85% are experimentalist:
Nuclear expt. PhDs = 0.85*(80/year) = 68/year
Percent ARUNA = (11.1/68)*100% = **16.3%**

The career paths of ARUNA graduates are consistent with the national tends.

WF: Florida State University

Recent PhD Graduates

Robert Laird (2001, Riley) Professor, Florida International U.
Mathew Cooper (2002, Tabor *) Pacific Northwest Natl. Lab.
William Weintraub (2003, Kemper *) (deceased)
David Campbell (2004, Riley) Staff scientist, LLNL
John Pavan (2004, Tabor *) Software Engineer, Nokia Corporation
Mathis Wiedeking (2005, Tabor *) Staff scientist IThemba Laboratory, South Africa
P. Pipidis (2006, Riley) Research Associate, INFN Legnaro, Italy
Brian Roeder (2006, Kemper *) Staff scientist, Texas A & M U.
Warren Cluff (Riley, 2007 *) Department of Homeland Security
Eric Diffenderfer (2007, Wiedenhöver *) Asst. Prof. Radiation Oncology, U. Pennsylvania
Trisha Hinners (2008, Tabor *) Northrop-Grumman Aerospace
Aaron Aguilar (Riley, 2008) Lawrence Livermore Nat. Lab.
Charles Teal (Riley, 2009) Nuclear Regulatory Commission
Sangjin Lee (2008, Tabor *) Research Associate, Indiana University
Eric Johnson (2008, Rogachev *) Research Associate, Flagler Trust, Florida
Calem Hoffman (2009, Tabor) Staff Scientist, Argonne National Laboratory
Patrick Peplowski (2009, Wiedenhoever *) Staff Scientist, Applied Physics Lab., Johns Hopkins U.
Robert Reynolds (2010, Cottle) Medical Physics, Georgia Institute of Technology
Alexander Rojas (2011, Wiedenhoever *) Radiation Safety, State Government of Sasketchewan
Peter Bender (2011, Tabor *) Research Associate NSCL, Michigan State U.
Joseph Mitchell (2012, Rogachev *) , Research Associate U. Bonn
Melina Avila (Ph.D. 2013, Rogachev *) Staff scientist ANL
Anthony Kuchera (2013, Rogachev *), Research Associate NSCL
Daniel Santiago (2013, Wiedenhöver *), Research Associate LSU@ANL
Scott Miller (2015, Riley *) Systems Manager
Justin VonMoss (2015 Tabor *), Research Associate, ORNL
David McPherson (2015, Cottle) self-employed
Joe Belarge (2015, Wiedenhöver *), Research Associate NSCL
Sean Kuvin (2015, Wiedenhöver *), Research Associate UConn@ANL
Jessica Baker (2015, Wiedenhöver *) Navy Intel. Washington
Rutger Dungan (2016, Tabor *) Northrop-Grumman Aerospace
Pei-Luan Tai (2016, Tabor) Research Associate ORNL



WF: Ohio University

Recent PhD Graduates

Daniel Sayre

2005: BS in Physics. Ohio University

2011: PhD, Ohio University, thesis project at the Edwards Accelerator Laboratory measuring the $^{12}C(a,\gamma)^{1}6O$ reaction

2011 – 2014: Postdoc, Lawrence Livermore National Laboratory

2014 – present: Staff Scientist, Lawrence Livermore National Laboratory

Cody Parker

2009: BS in Physics, Indiana University of Pennsylvania

2016: PhD, Ohio University, thesis project at the Edwards Accelerator Laboratory measuring the $^{3}H(d,\gamma)$ reaction

2016 – present: Postdoctoral Associate, MIT Plasma Science and Fusion Center

WF: Texas A&M University

Recent PhD graduates

August Keksis

- 2000 – B.S. in Biology and Chemistry, Northern Arizona University
- 2007 – Ph.D. in Nuclear Chemistry, Texas A&M University
- 2007-Present – Research Scientist at Los Alamos National Laboratory in the Nuclear & Radiochemistry Group.

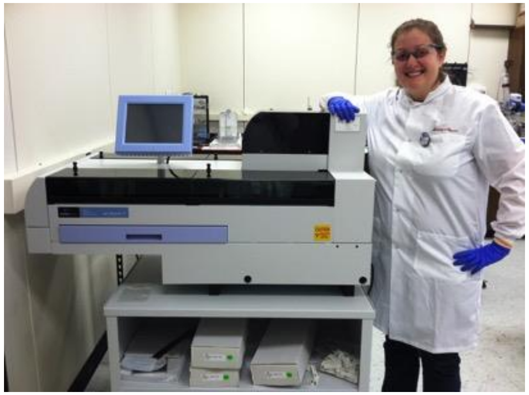
Douglas Rowland

- 1994 – B.A. from Kenyon College
- 2000 – Ph.D. from Texas A&M University, 2000-2003 – Post-doctoral Scholar, Washington University in St. Louis
- 2003-2006 – Research Instructor, Washington University in St. Louis
- 2007-Present – Principal Research Scientist at the Center for Molecular and Genomic Imaging, University of California Davis

Elizabeth Bell

- 1996 – B.S. in Chemistry, University of San Antonio
- 2005 – Ph.D. in Chemistry, Texas A&M University,
- 2006-Present – Professor at Blinn College

MARISA ALFONSO



- 2008 – B.S. in Chemistry, University of Texas
- 2016 – Ph.D. Texas A&M University,
- 2016-Present – Currently working at Eckert & Ziegler Analytics in Atlanta, GA

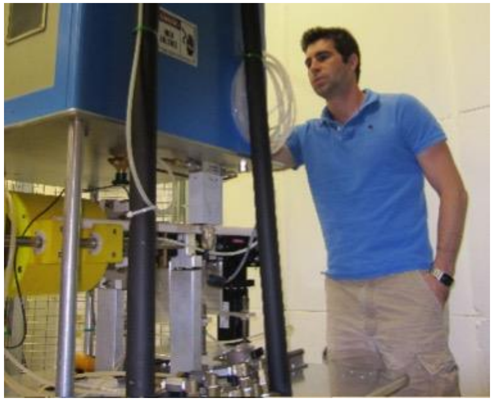
Mason Anders

- 2009 – B.A. in Physics, Austin College
- 2015 – Ph.D. in Physics, Texas A&M University, thesis project on Determination of Constraints on the Skyrme Energy Density Functional and the Mean Field via 3s State in 206Pb, 205Tl
- 2015-Present – Post-doctoral Researcher at the University of Texas Southwestern in the Medical Physics division of the Radiation Oncology department.

WF: Triangle Universities Nuclear Lab

Recent PhD Graduates

John Cesaratto



2005: BS in Physics, John Carroll Univ., Cleveland, OH

2011: PhD, University of North Carolina at Chapel Hill,

2011 – 2014: Toohig Fellow in Accelerator Science at SLAC with the LHC Accelerator Research Program.

2014-2015: Staff Development Engineer, Phillips Lumileds

2015-present: Senior Staff Development Engineer**,** Lumileds

Mary Kidd

2004: BS in Physics
Tennessee Technology University

2010: PhD, Duke University,

2010 – 2012: Postdoc, Los Alamos National Laboratory

2012 – present: Assistant Professor of Physics, Tennessee Technology University

Matthew Kiser

2002: BS in Physics and Mathematics,
King College

2008: PhD, Duke University,

2008 – 2014: Senior Scientist, Remote Sensing Laboratory at Joint Base Andrews, MD (National Security Technologies, LLC).

2014 – present: Detector Physicist at PHDs Co.

Kevin D. Veal

1993: BS in Physics, Mississippi State University

1998: Ph.D. , Univ. of North Carolina at Chapel Hill.

1999 - 2010: Los Alamos National Lab, Safeguards Science and Technology Directorate (N-1)

2004 - 2007: Temporary assignment to NNSA Headquarters in Washington as Technical Adviser, Office of International Safeguards (NA-243) and the Office of Dismantlement and Transparency (NA-241)

2005 - 2007- Leading technical representative on US delegation to 6-Party Talks seeking an end to North Korea’s nuclear weapons program

2011 - present: Acting Director of the Office of Nuclear Safeguards and Security within DOE/NNSA’s Office of Defense Nuclear Nonproliferation

WF: University of Kentucky

Recent PhD Graduates

Ben Crider,
Ph.D. 2014

Erin Peters,
Ph.D. 2014

Degrees Awarded, last 10 years:

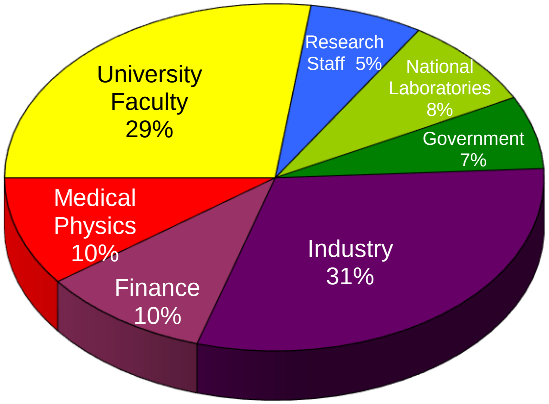
- Monica Gail Mynk, M.S., Chemistry, 2006, High School Teacher in Kentucky
- Shelly R. Lesher, P&A, 2004, Assistant Professor, University of Wisconsin at LaCrosse
- Sadia Naeem Choudry, P&A, 2007, Jefferson Community and Technical College
- Sharmistha Mukhopadhyay, P&A, 2008, Staff Scientist, RMD; Postdoc at UK
- Esmat Elhami, P&A, 2008, Assistant Professor, University of Winnipeg
- Benjamin Crider, P&A, 2014, Postdoc, NSCL
- Erin Peters, Ph.D., Chemistry, 2014, Postdoc UK

WF: University of Notre Dame

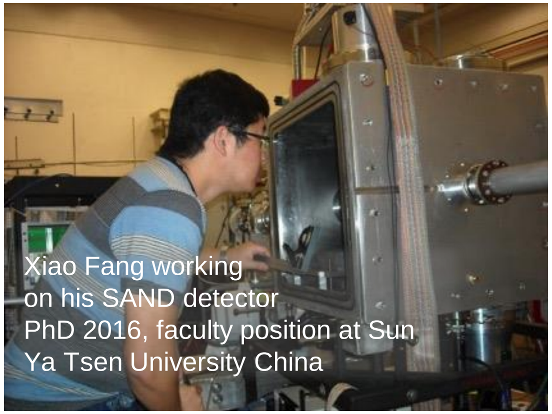
Recent PhD graduates

- Peter Santi, PhD 2000, Staff, LANL
- Rebecca Detwiler, PhD 2001, Faculty, U. Florida
- Shao Fei Zhu, PhD 2003, Staff, ANL
- Aaron Couture, PhD 2005, Staff, LANL
- Hye Young Lee, PhD 2006, Staff, LANL
- Mathew Quinn, PhD 2010, Staff, Fermi-Lab
- Sergio Almaraz-Calderon, PhD 2012, Faculty, FSU
- Akaa Daniel Ayangeakaa, PhD 2013, Faculty, US Naval Academy
- Brian Bucher, PhD 2014, Staff, Idaho Natl. Lab

Graduate student career choices since 1990 (N=52); 33 conducted research at the NSL.



Ethan Uberseder setting up GEORGINA array
PhD 2014, postdoc at Texas A&M, staff position at U. Michigan



Xiao Fang working on his SAND detector
PhD 2016, faculty position at Sun Ya Tsen University China

Alex Long during target preparation.
PhD 2016, Postdoc at Los Alamos

WF: University of Washington
Recent PhD graduates

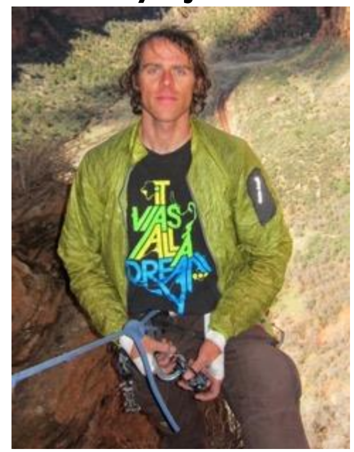
Erik Mohrmann

2001: BS in Physics
Rensselaer Polytechnic,Troy, NY.

2009: PhD, U. of Washington, thesis project The $^{7}Be(p,\gamma)$ cross section at solar energies.

present: Dean of Faculty, Department Chair, Physics, at DigiPen Institute of Technology.

Sky Sjue



2002: BS in Physics and Mathematics,
U. Texas, Austin.

2008: PhD, U. of Washington, thesis on Nuclear Structure Related to Double Beta Decays.

2008 – 2011: Postdoc at TRIUMF, Canada.

2008 – 2014: Postdoc and staff at LANL.

Present: Staff Scientist at LANL.

Anne Sallaska

2003: BS in Physics
U. Cal, Berkeley

2009: PhD, U. of Washington, thesis project The $^{22}Na(p,\gamma)^{23}Mg$ Reaction Rate: Consequences for Nucleosynthesis of 22Na in Novae

2010 – 2012: Postdoc, U. of North Carolina

2012-2015: Staff, NIST.

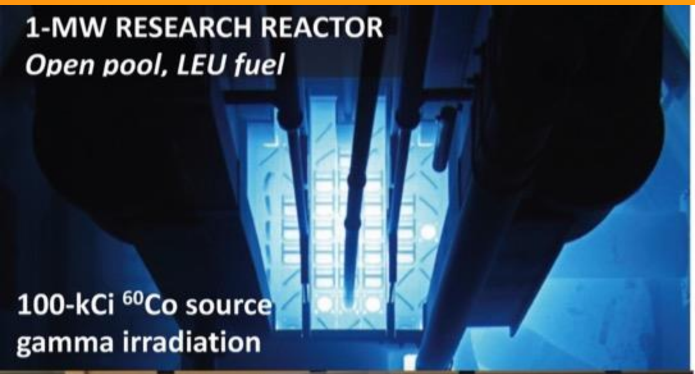
2012 – present: Senior Data Scientist at MITRE Corporation.

<u>Other Students</u>

- Minesh Bacrania, PhD 2007
- David Zumwalt, PhD 2015, Data Scientist, Porch
- Ran Hong, PhD 2016, Postdoc, Argonne National Laboratory

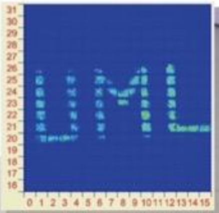
Broader Impact: Research

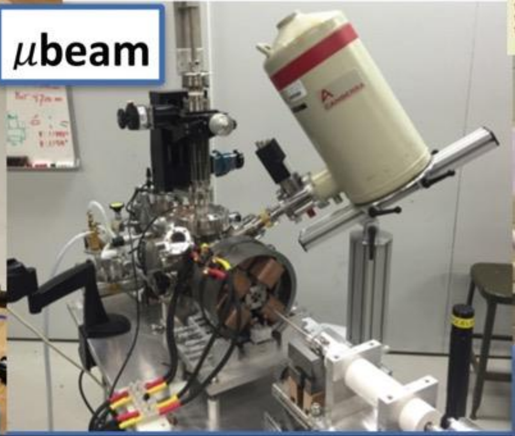
University of Massachusetts-Lowell



Current local science highlights

- Development of enriched **C^7LYC array** for neutron spectroscopy with experiments at Lowell, ANL, LANSCE, and other facilities.
- Neutron damage tests, charge collection studies, and continued research for advanced designs of **HPGe DSSDs**.
- Characterization of large 3"x3" C^7LYC.
- Measurements using a newly constructed Compton-suppressed HPGe array for assays of BLIP/BNL **medical isotopes** and nuclear science. (LARA)
- Assays of fuel plate burn-up.
- Commissioning of **μbeam** for interdisciplinary and applied science.
- Advanced XIA Pixie-4e DAQ.
- Improvements in accelerator operations.



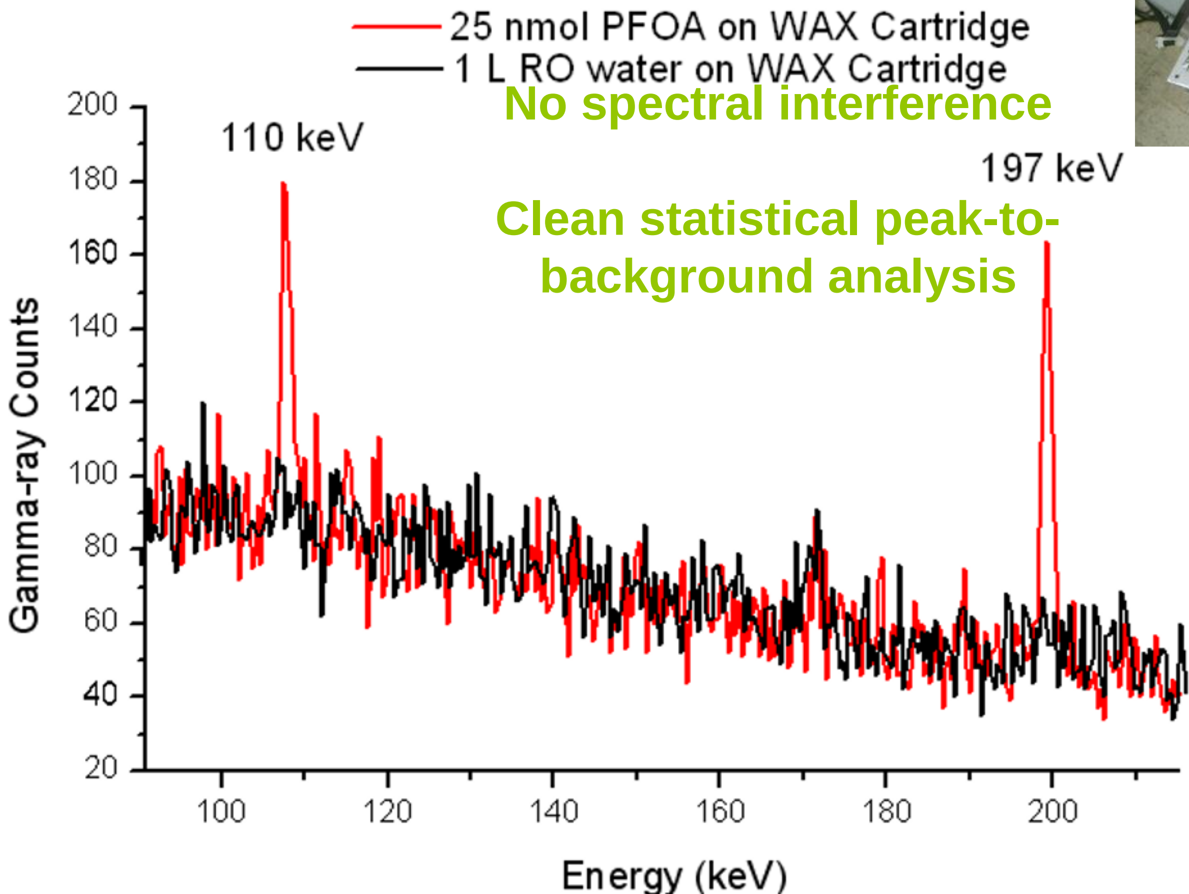


Broader Impact: Research

Hope College

PIGE Spectroscopy for Total Fluorine in Groundwater

1.7 MV Pelletron tandem accelerator with a nuclear microprobe



No spectral interference

Clean statistical peak-to-background analysis

Broader Impact: Research
University of Notre Dame

AMS Dating of materials
(U. Vienna, Hebrew U.) (P. Collon, D. Robertson)

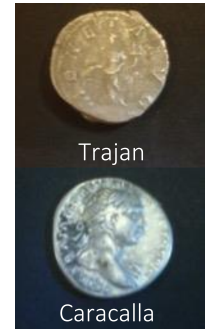
PIXE/XRF on historical artifacts
(Architecture, Anthropology, Chemistry, Snite, Library) (K. Manukyan, G. Peaslee, E. Stech, M. Wiescher)

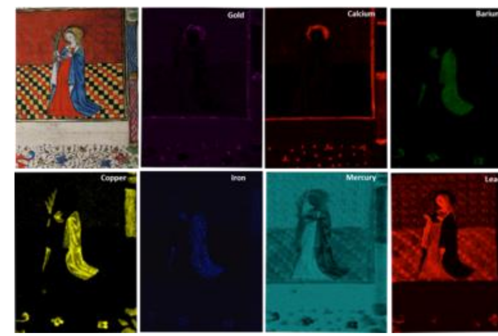
PIGE water pollution and aerosol analysis
(Hope College) (G. Peaslee, D. Robertson, E. Stech)

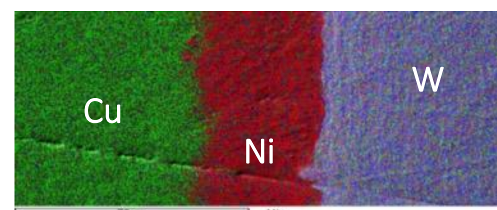
Nanomaterial modification & explosion under beam
(ND Engineering, John Hopkins U., MIT, I. Moscow) (K. Manukyan)

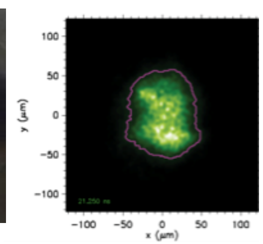
Radiation chemistry for long term storage, nuclear reactor material, and nuclear medicine
(ND RadLab, U. Manchester, UK) (J. LaVerne, D. Robertson)

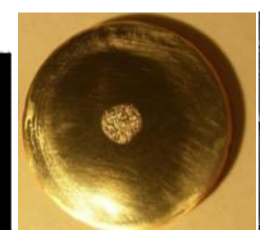
Nuclear diagnostics for forensic analysis
(LLNL) (M. Couder, G. Peaslee, M. Wiescher)

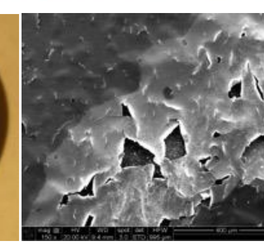




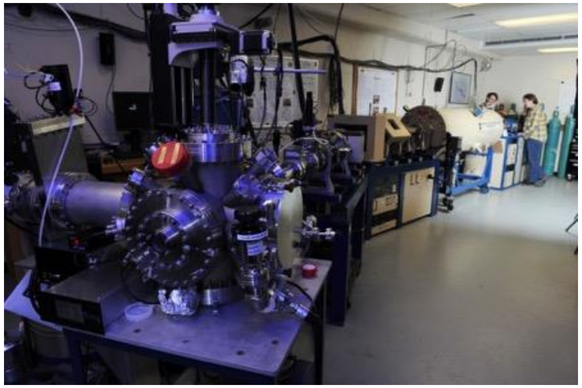




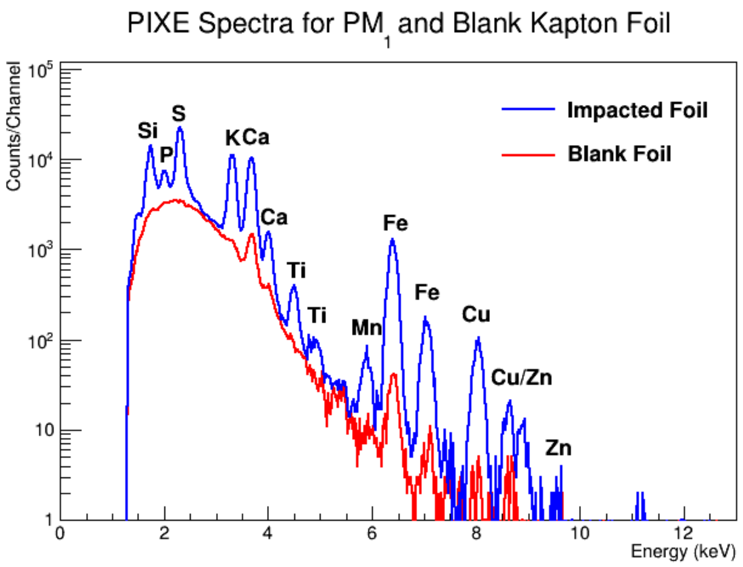


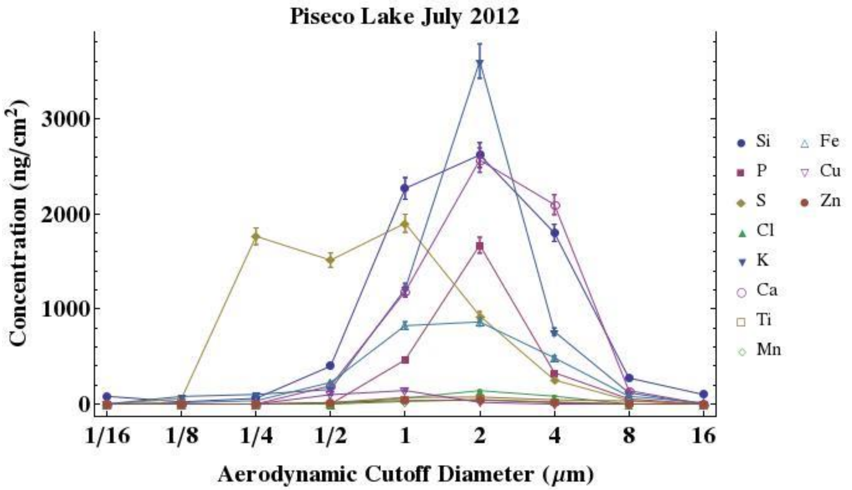


Broader Impact: Research
Union College Ion-Beam Analysis Laboratory



- Primary instrument is a 1.1-MV tandem Pelletron Accelerator
- Used in
  - Undergraduate research projects
  - First-Year Seminar in Physics
  - Advanced Laboratory
  - High school outreach
- Main emphasis on IBA of environmental samples
- Example: Characterization of atmospheric aerosols in the Adirondack Mountains [NIMB 350 (2015) 77]
  - PIXE analysis of airborne particulate-matter (PM) pollution as a function of particle size

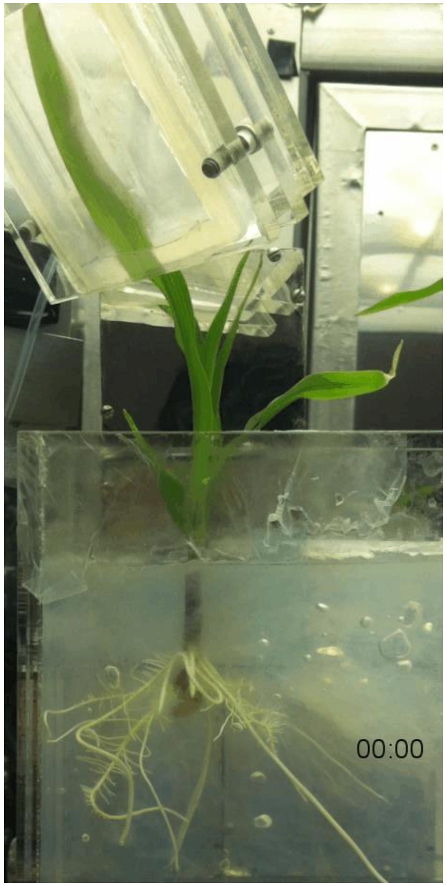


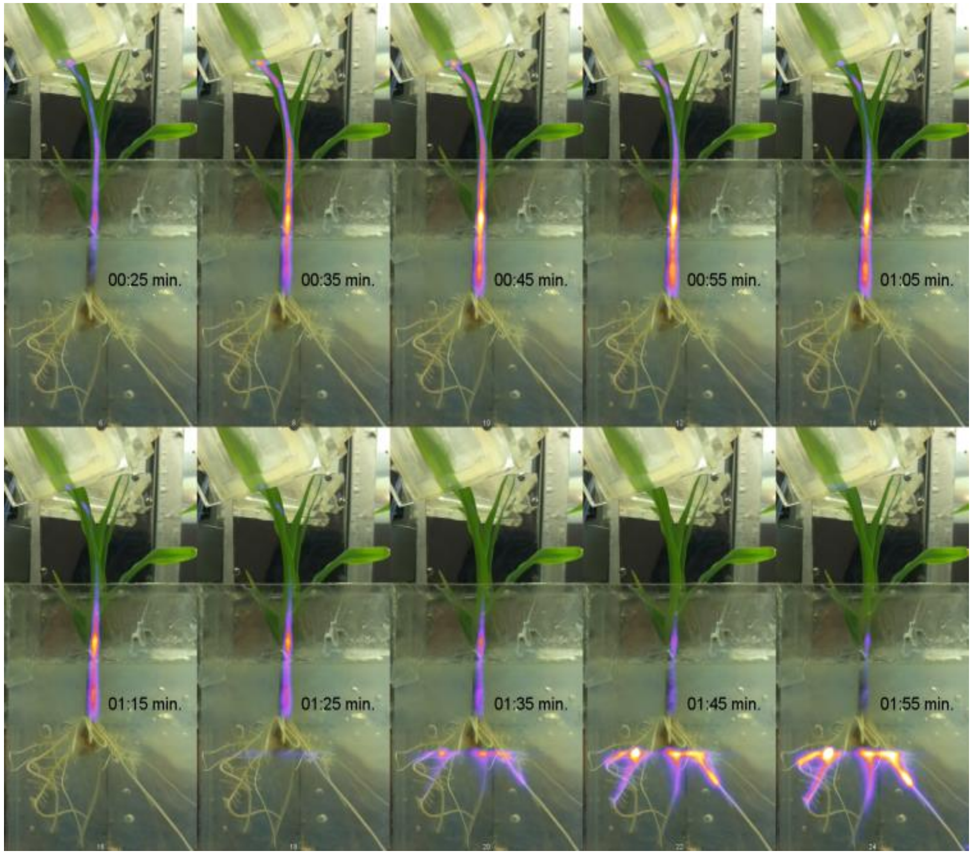


Broader Impact: Research
Triangle Universities Nuclear Laboratory

C-11 radioisotope labeling to trace sugar allocations in plants:

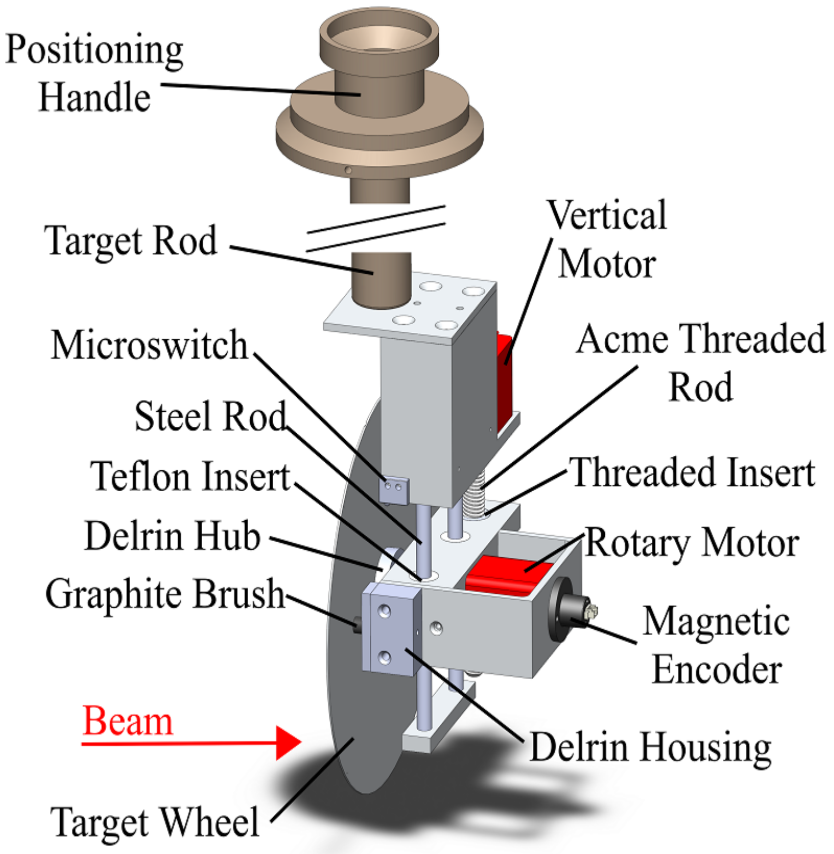
- $^{14}N + p \rightarrow {}^{11}C + \alpha$
- Image taken using PET
- PET image co-registered with photograph

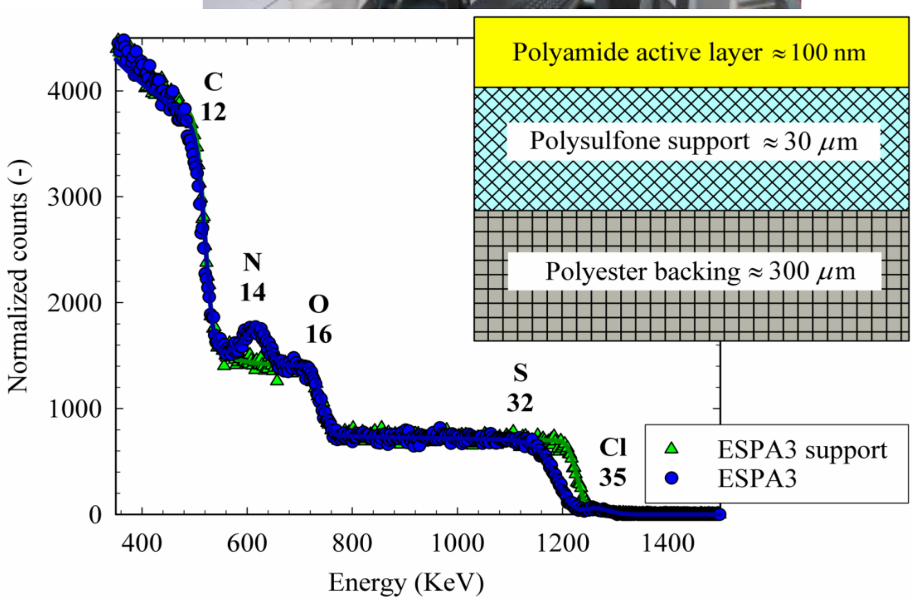




Broader Impact: Research
Triangle Universities Nuclear Laboratory

Characterization of membranes for water purification by Rutherford Backscattering Spectrometry (RBS) and Elastic Recoil Detection (ERD)





Attayek et al., Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip. 676 (2012) 21–25

Summary

- The ARUNA facilities enable frontier to be carried out by small collaborations;
- About 15% of the nation's PhD recipients in experimental nuclear physics conduct their thesis research at an ARUNA facility;
- The unique capabilities and features of the ARUNA facilities add nimbleness to the national nuclear physics program;
- ARUNA facilities provide unique opportunities for experiment concept evaluation and instrumentation testing;
- ARUNA facilities attract students and help nuclear science compete for talent at the universities; and
- ARUNA facilities are flagships for universities and generate a lot of leverage support.

Acknowledgements

I thank the following people and their associates for providing materials for this presentation:

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Hamish Robertson, University of Washington

Michael Vineyard, Union College

Ingo Wiedenhoever, Florida State University

Michael Wiescher, University of Notre Dame

Steven Yates, University of Kentucky

Sherry Yennello, Texas A&M Univ.

Thank You