ARUNA Overview

Andrew M. Rogers
University of Massachusetts Lowell

Low-Energy Community Meetings 2018— 08/10/2018

Association for Research at University Nuclear Accelerators

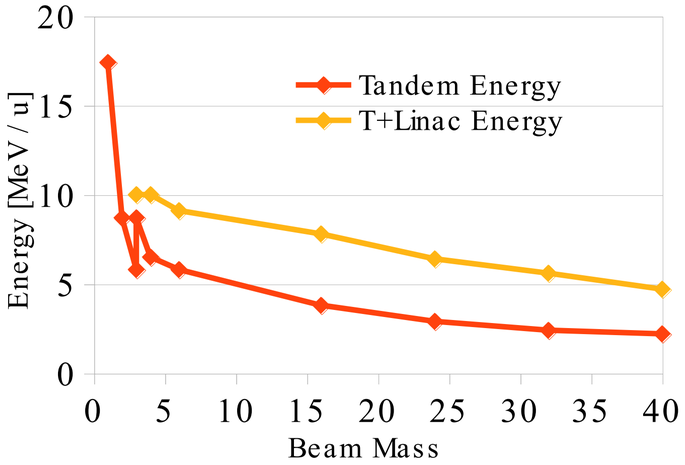
Association for Research at University Nuclear Accelerators

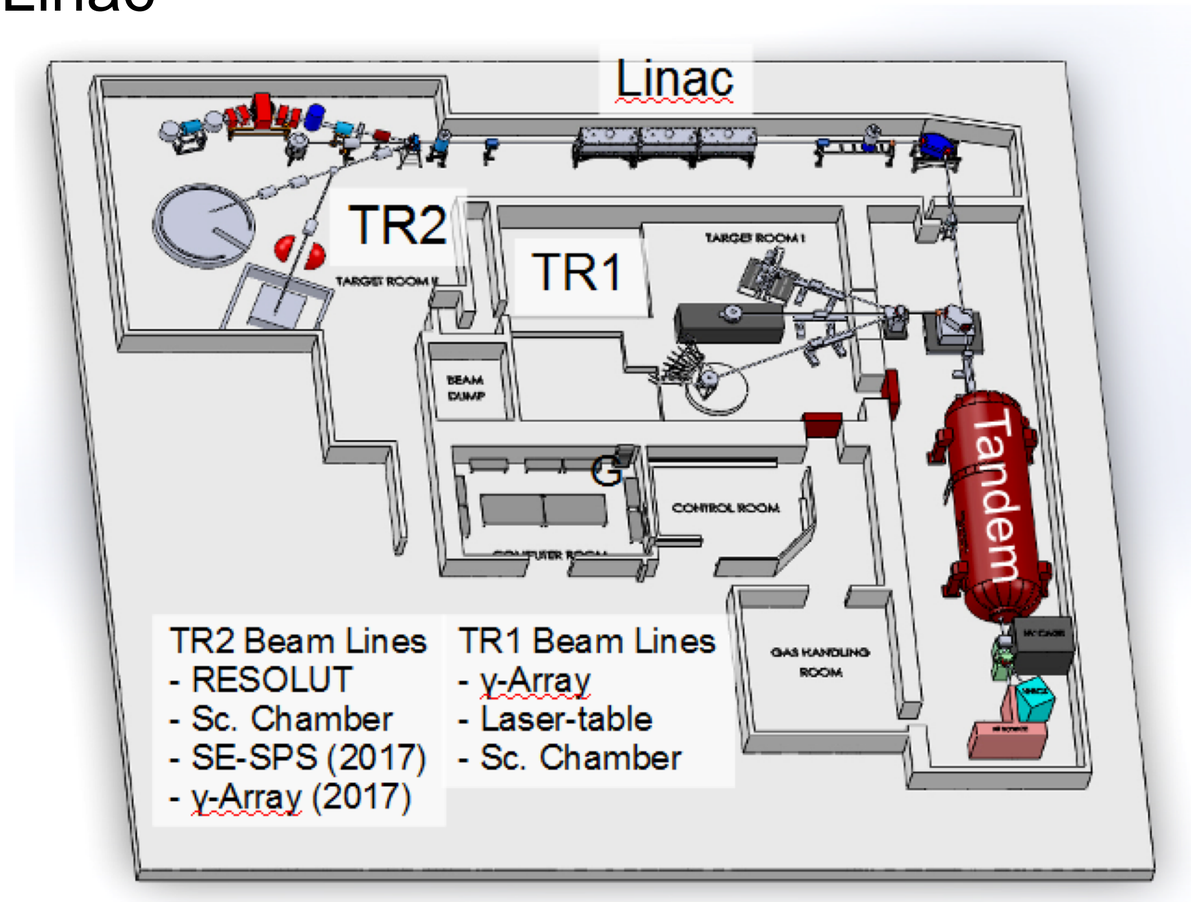
- ~10 institutions and ~200 members
- Maximize and optimize the use of all nuclear accelerator facilities at universities in the U.S.
- Increase the opportunities for education of the science- and technology-literate work force at these facilities
- Document and coordinate the scientific capabilities available
- Coordinate the scientific program at these facilities and place it in the context of the national science endeavor

Importance of ARUNA and activities has been emphasized in numerous presentations this week.

The John D. Fox Accelerator Laboratory

- 9 MV Tandem + 8 MV Linac
- Beam Energy profile



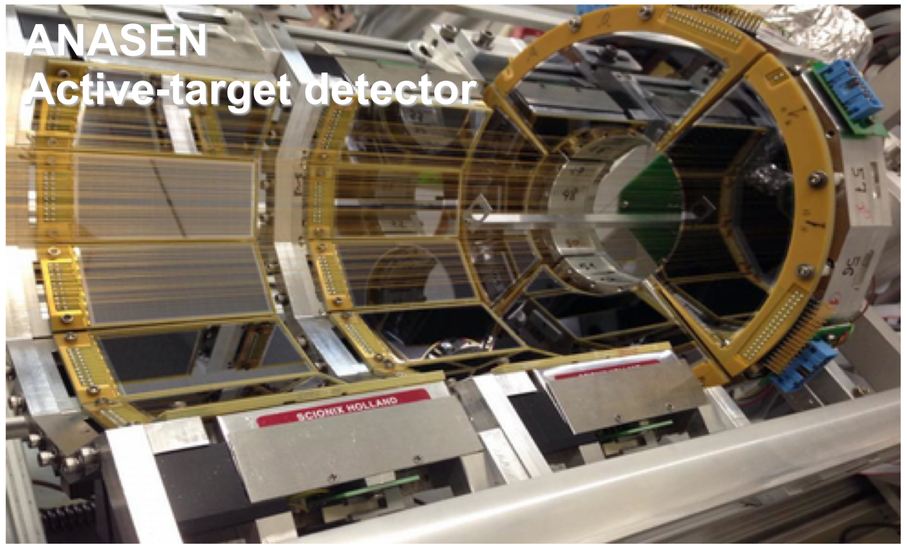


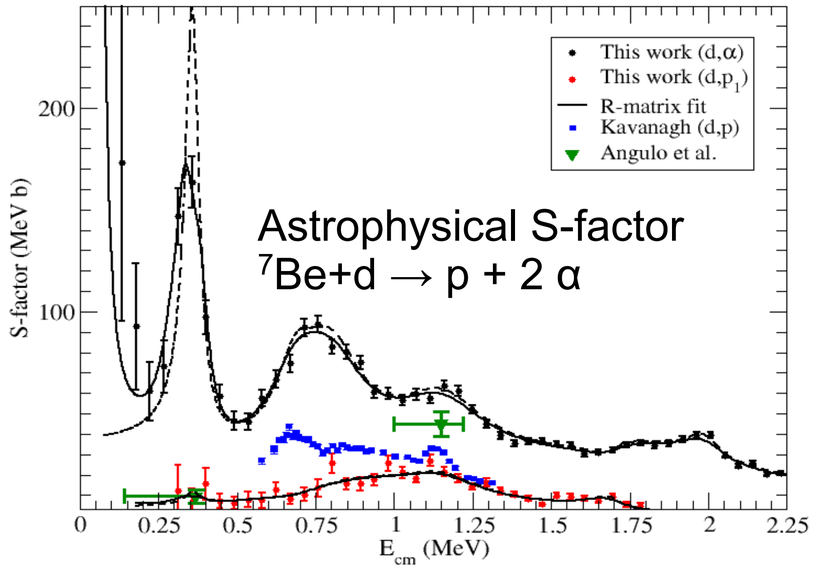
- In-flight radioactive beams with Resolut
- Clover HPGe γ-array (TR1 → TR2)
- New: Super-Enge Split Pole Spectrograph

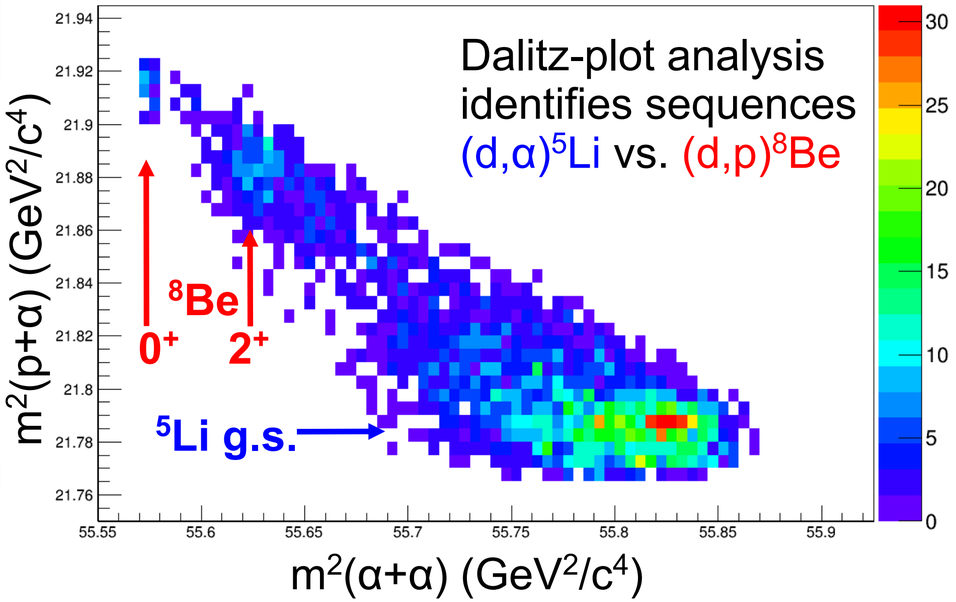
Tandem: Pelletron-charged 9 MV FN-tandem
Linac: 14 Superconducting cavities
Niobium on Cu, Split-Ring (Atlas-design)

- Member of CENTAUR Center of Excellence (Texas A&M)

^{7}Be+d reactions measured at FSU for primordial Lithium problem



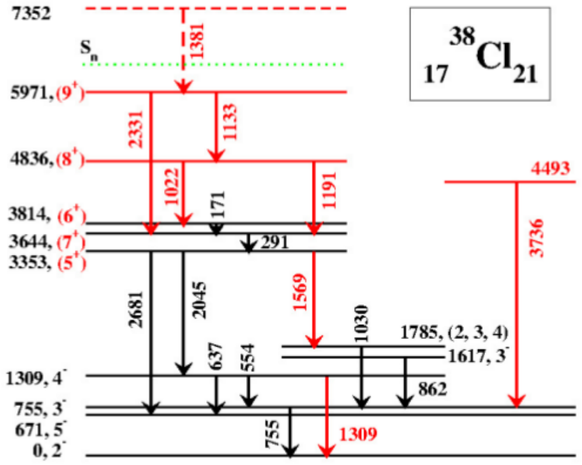


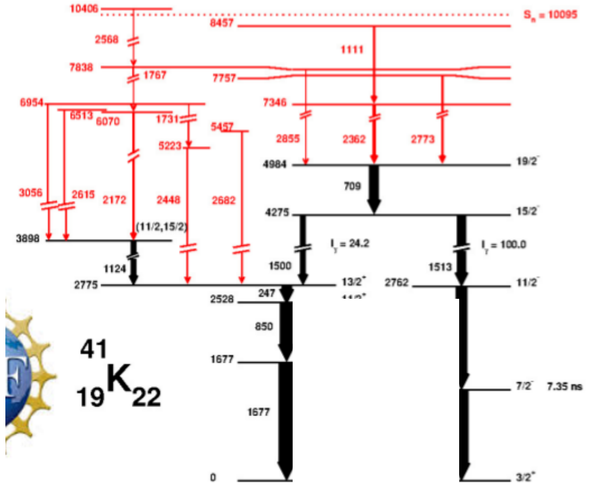


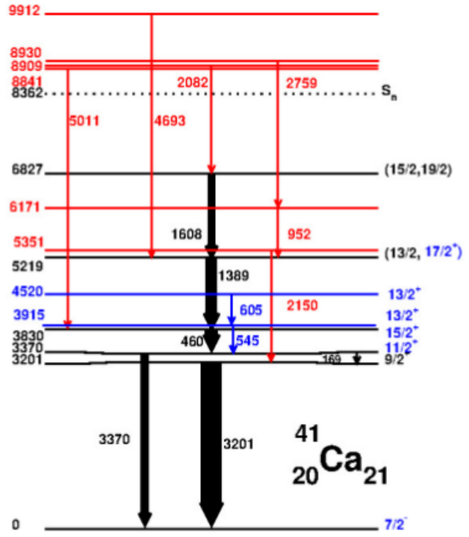
- FSU accelerator lab:
- Measured ^{7}Be+d excitation function with ANASEN
- Observe (5/2+) resonance in Gamow window of Big-Bang nucleosynth.
- N. Rijal et al.

Gamma-spectroscopy of cross-shell excitations

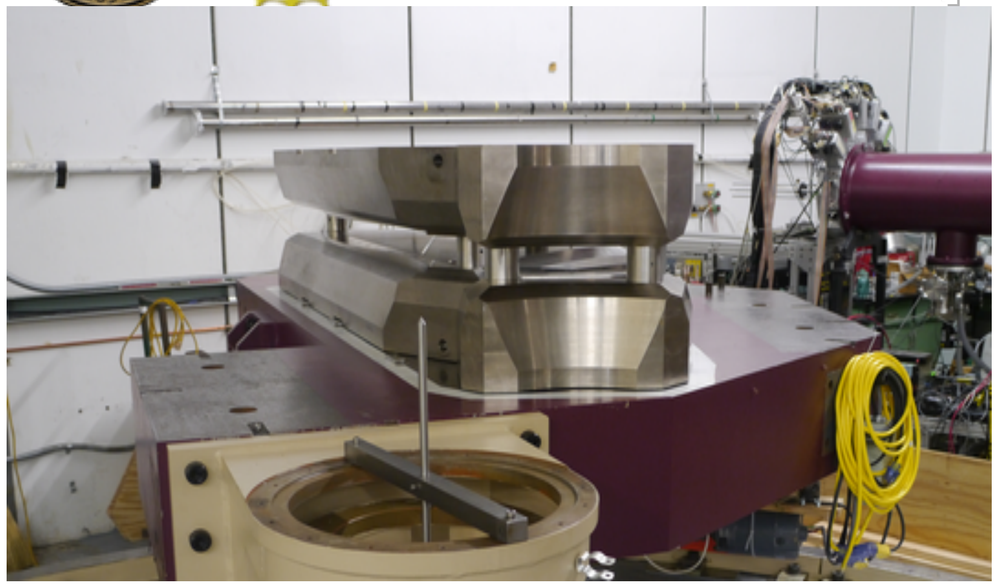
- Using neutron-rich beams ^{18}O,^{14}C
- CLOVERS + HPGe (FSU & ORNL)
- d-dE particle telescope at 0°
- With J.M. Allmond (ORNL)
- Cross-shell interactions benchmarking (A. Volya and K. Kravvaris)



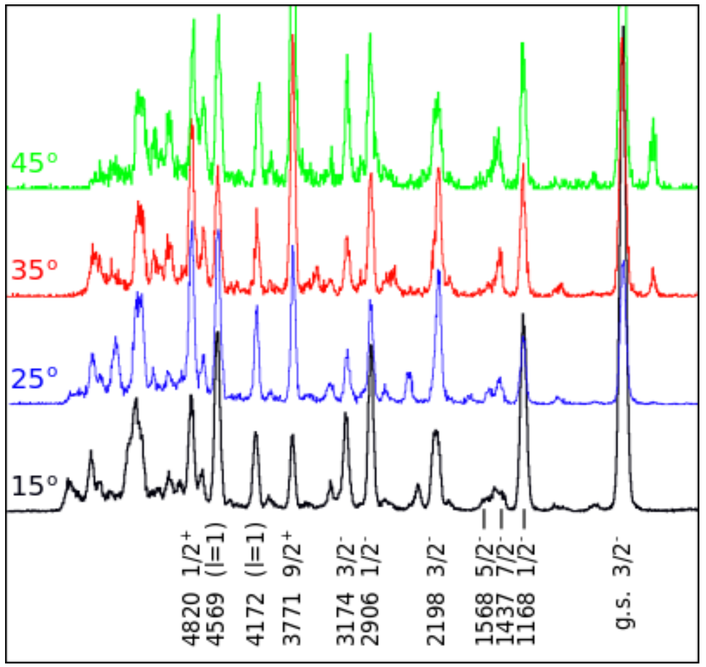




It's back: Super-Enge Split-Pole Spectrometer



- Ex-Yale SE-SPS re-commissioned at FSU
- Spectroscopy of resonances for nuclear astrophysics, nuclear structure in the continuum
- First science: L.Riley *et al.* ^{50}Ti(d,p)^{51}Ti
- Collaborators welcome



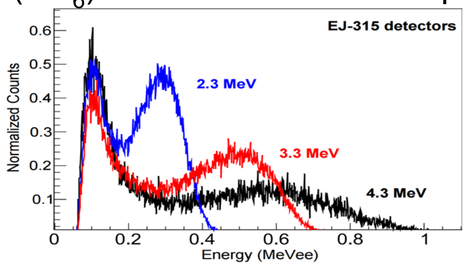
Almaraz-Calderon: New Initiatives and Detectors for Nuclear Astrophysics

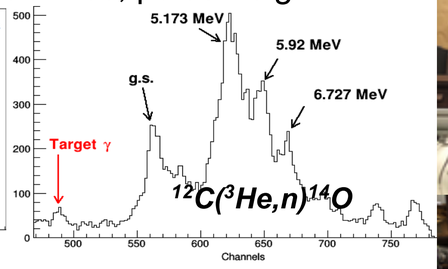
The *CATRINA* Deuterated neutron detector array (FSU grad student: Jesus Perello)

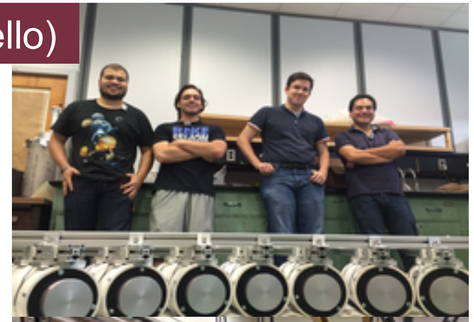
An array of 16 liquid scintillator (CD_6) detectors with PSD capabilities, pulse-height energy dependence

We have performed

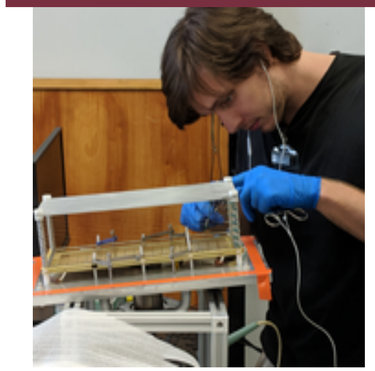
- MCNP & Geant simulations
- n-γ source tests
- Measurements:
- $^{7}Li(p,n)^{7}Be$, $^{12}C(^{3}He,n)^{14}O$



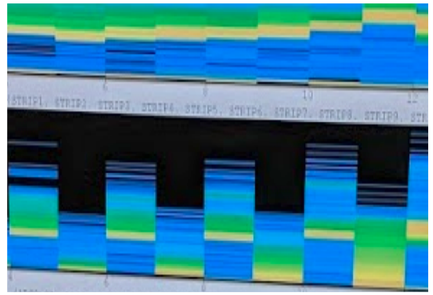




ENCORE: The MUSIC-type detector at FSU (FSU grad student: Ben Asher)



We developed a MUSIC-type detector @ FSU consisting of an active-target gas detector based on a segmented anode that measures energy losses as the beam passes trough. Fusion measurements currently underway!

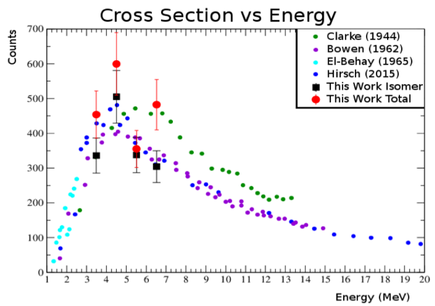


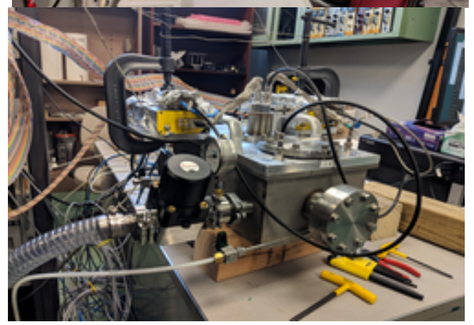
Isomer beam production at FSU: ^{24m}Na (FSU grad student: Nate Gerken)

We have measured the cross section for beam production of an isomeric beam of ***^{24m}Na*** *via the* ***^{23}Na(d,p)^{24}Na*** *reaction* & Identified the production energy to get a high isomer content

Next: measurement of the ***^{24m}Na(d,p)*** reaction

^{24}Na		
E	$T_{1/2}$	J^{π}
0.0 MeV	15 h	4^{+}
0.47 MeV	20.2 ms	1^{+}





FSU@CENTAUR

Nuclear Medicine and Science Summer Camp for rising 9th graders

July 23-27, Panama City, Florida

THE FLORIDA STATE UNIVERSITY

ARUNA

The Edwards Accelerator Laboratory at Ohio University

Research Areas:

Nuclear Astrophysics, Applications, & Structure

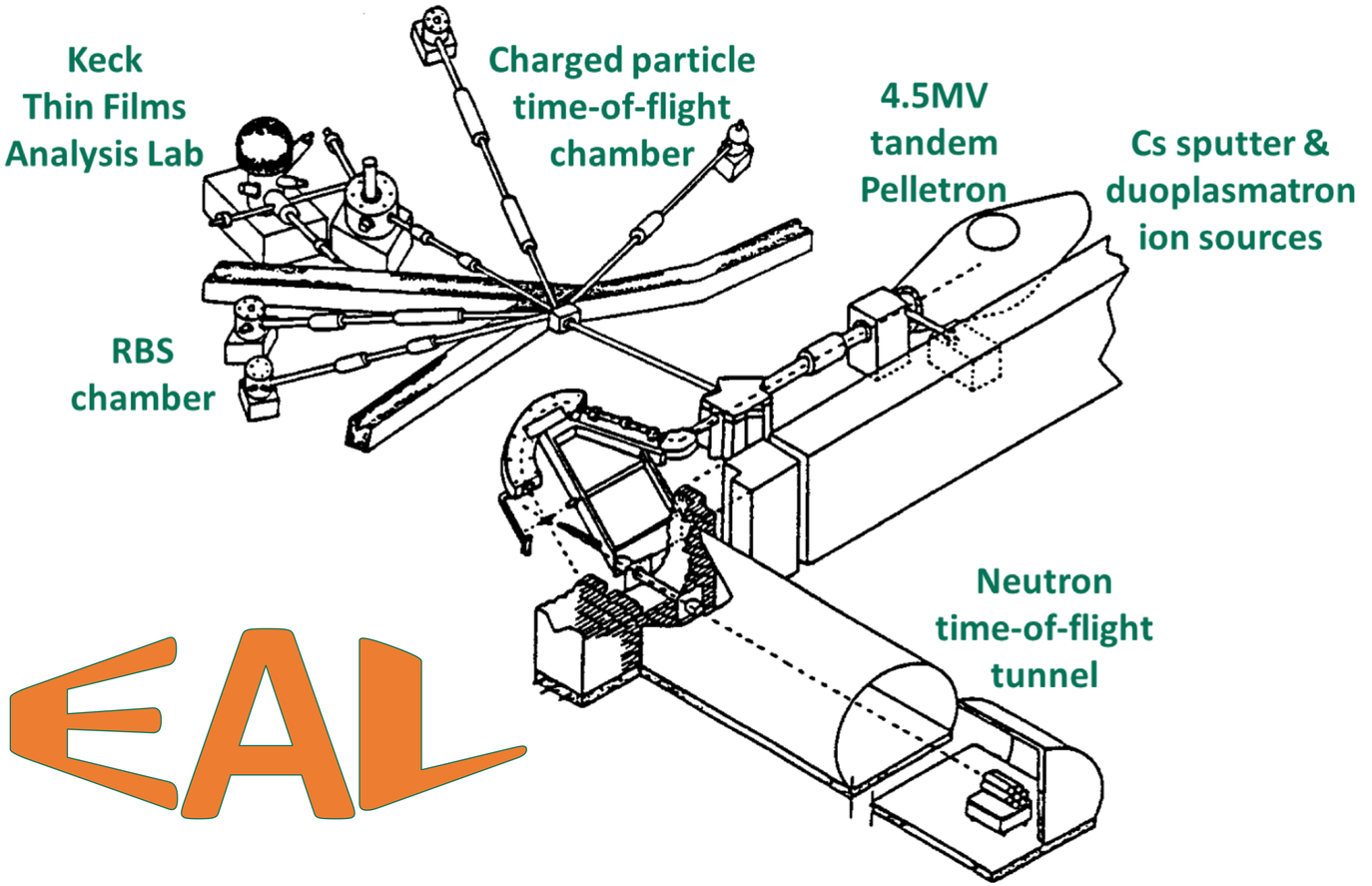
Thin Films & Surface Science

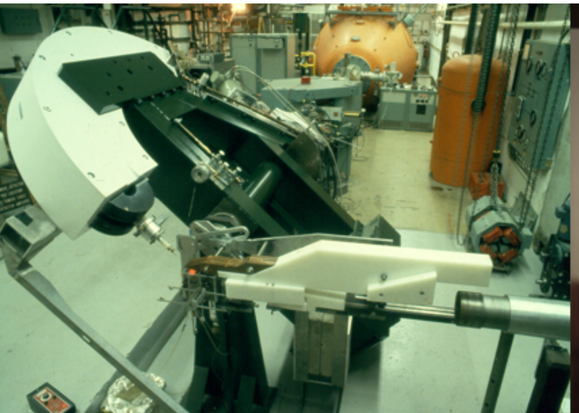
Senior Researchers:

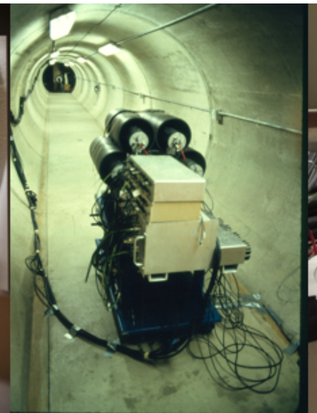
Carl Brune, Steve Grimes, Tom Massey, Zach Meisel, Alexander Voinov

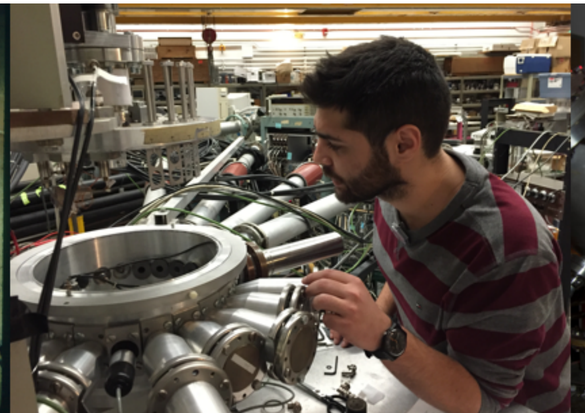
Technical Staff:

Don Carter, Devon Jacobs







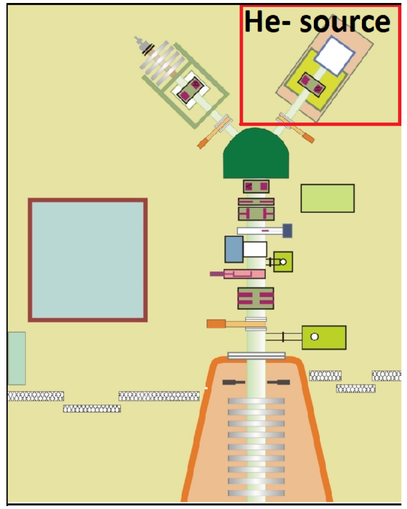


The Edwards Accelerator Laboratory at Ohio University

Upcoming Facility Upgrade:

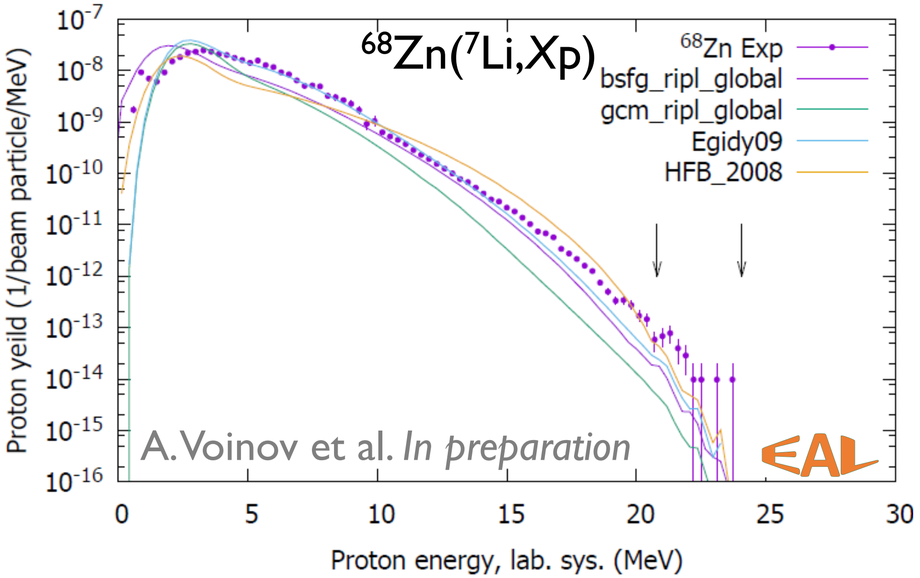
- Alphatross RF-exchange ion source (NEC),

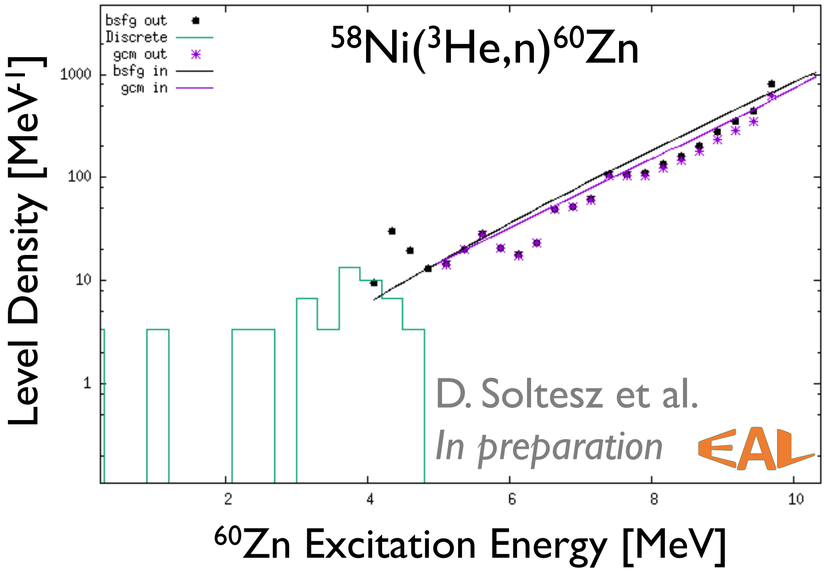
  - *8x intensity of present He ion source*
  - *2x more efficient for ^{3}He consumption*



Science Highlight:

Particle evaporation spectra show reduced nuclear level-density off of β-stability.
This has potentially interesting implications for nuclear astrophysics & applications.





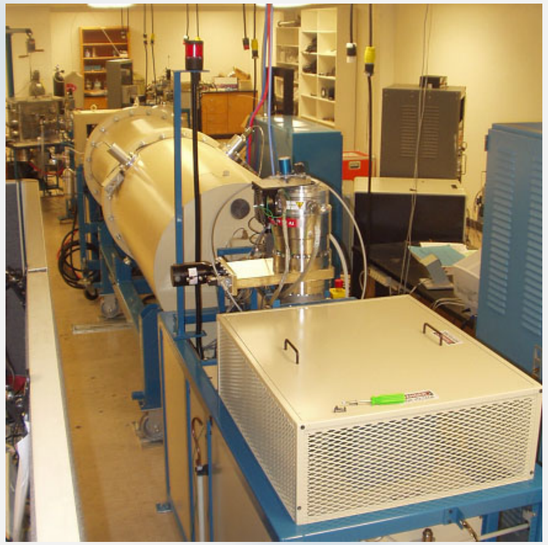
Spectra collected using charged-particle and neutron time-of-flight target stations.

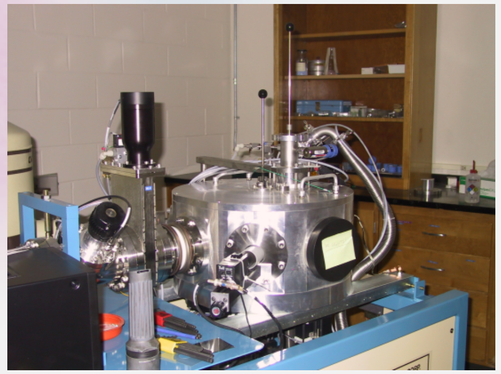
Analyses leverage the unique connection between the residual nucleus level density and the ejected particle energy distribution in the Hauser-Feshbach framework.

While the nuclear level density traditionally is only A-dependent, these measurements indicate there may also be A-Z dependence.

Hope Ion Beam Analysis Lab

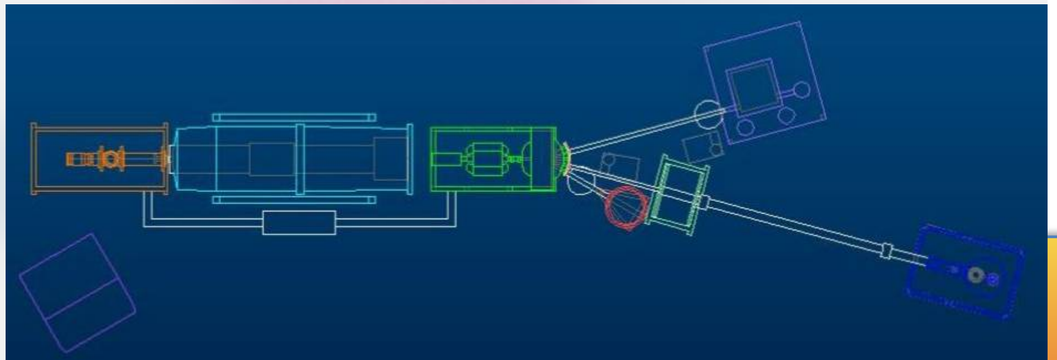
- NEC 1.7 MV Tandem
- Protons or alpha beams
- Microfocusing ability
- PIXE, RBS, PIGE, IBL, NRA
- Replaced…
  - Control system with LABVIEW
  - Target drive with LABVIEW Motion
  - Endstation vacuum control with Raspberry PI
- Accelerator operations course for undergraduates





Recent Work

- RBS characterization of photovoltaic films (Union College – India)
- PIXE analysis of electrodeposited films (Hope)
- PIXE confirmation of steel alloys (local industry)
- Creation of lattice defects is SiC (Calvin College)
- RBS channeling measurements (Hope)
- PIGE measurements of water and consumer samples (Notre Dame)
- deyoung@hope.edu

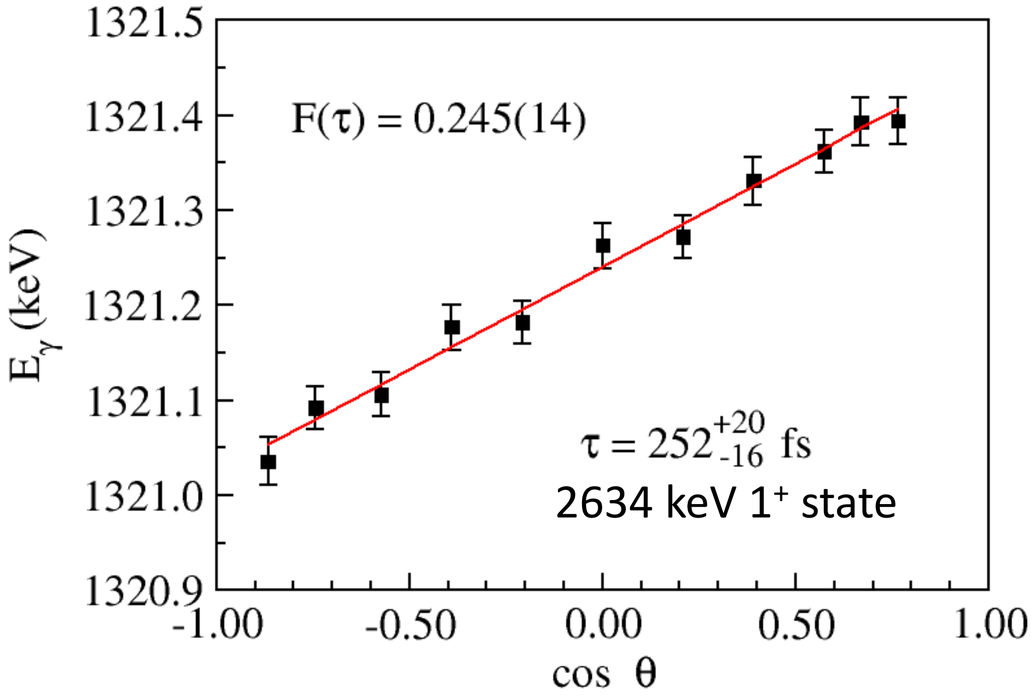


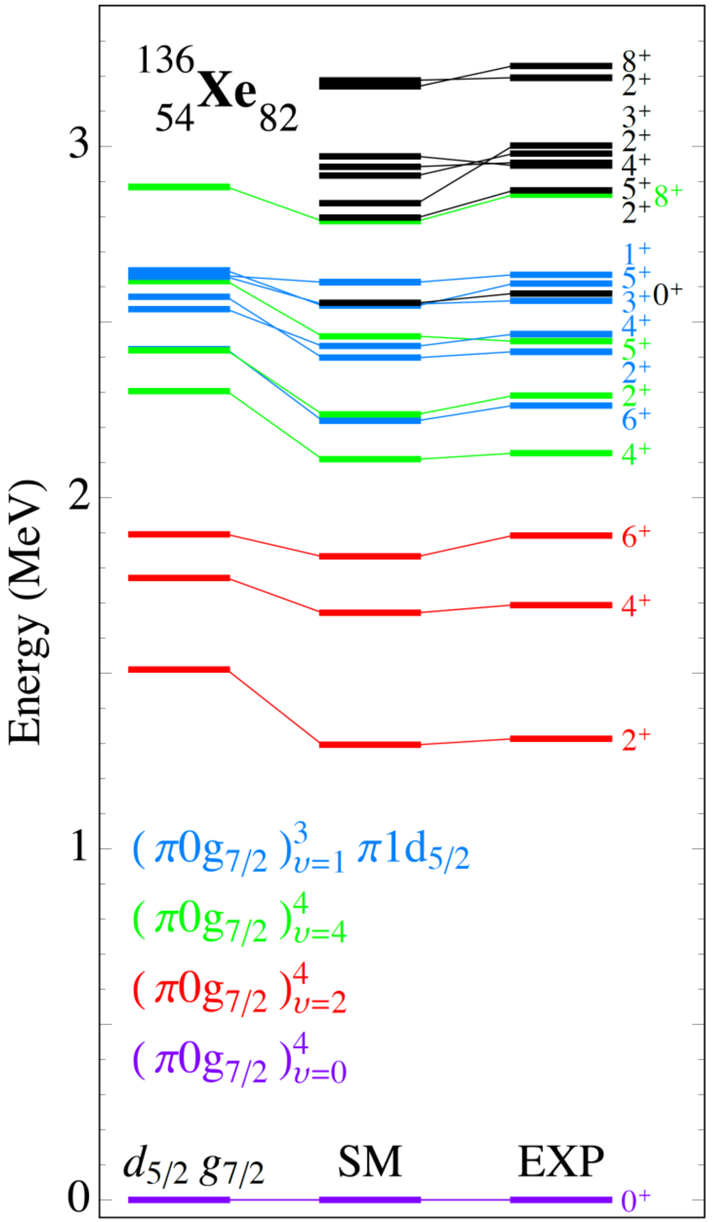
University of Kentucky Accelerator Laboratory

- 7-MV single-ended Van de Graaff; ^{1}H, ^{2}H, ^{3}He, and ^{4}He beams; terminal and post-acceleration bunching (<1 ns)
- Monoenergetic (ΔE_n < 100 keV) neutrons; 0.5 to 10 MeV neutrons with ^{3}H(p,n) and ^{2}H(d,n); extended up to 25 MeV with ^{3}H(d,n);
- Nuclear spectroscopy with neutron time-of-flight and γ-ray detection
- Research program continuously supported by the NSF since accelerator installation in 1964; upgrade in 1990s
- NNSA National Nuclear Security Administration funding of precision neutron scattering cross section measurements on materials for advanced reactors
- Neutron detector development (with outside collaborators)
- DSAM level lifetime determinations for nuclear structure relevant to neutrinoless double-β decay and shape transitions
- Corporate and homeland security applications
- **A hands-on, student-run facility** **www.pa.uky.edu/accelerator**

ARUNA

Nuclear Level Lifetimes by DSAM following Inelastic Neutron Scattering





^{136}Xe is a neutrinoless double-β decay candidate.

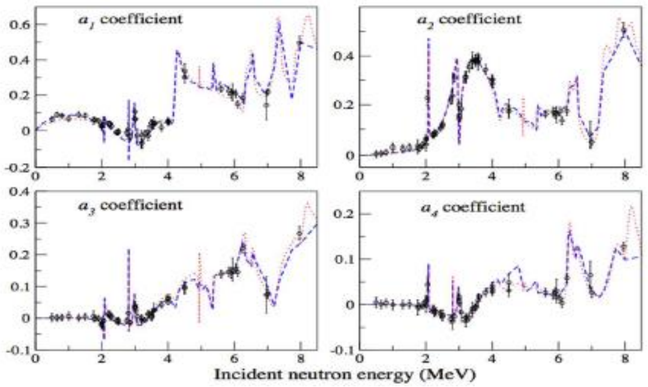
$d_{5/2}g_{7/2}$ – limited to only those two orbitals
SM – full Z=50-82 model space

Neutron Cross Section Measurements

Elastic & Inelastic Neutron Scattering Cross Sections on Fe, Si, and C

$$W(\theta) = A_0 \sum_L a_L P_L(\cos\theta) \quad ; a_0 = 1$$

$$a_L^{ENDF} = \frac{a_L^{exp}}{2L+1}$$



Legendre Coefficients for n+^{12}C elastic scattering with R-matrix calculation

During current 3-year grant:

WORKFORCE DEVELOPMENT

11 undergraduates + 1 postdoc

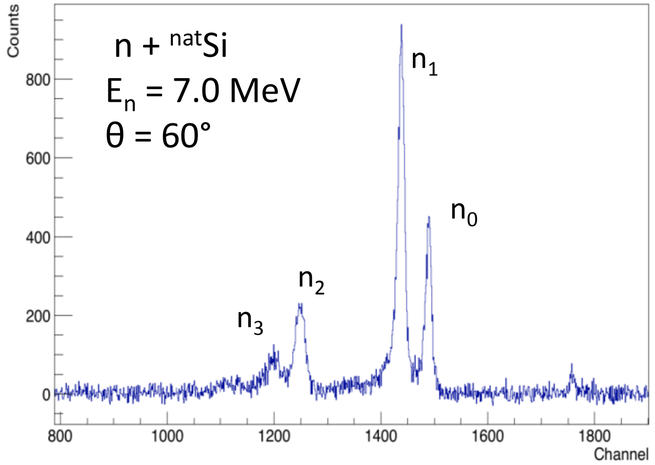
EXPERIMENTAL RUNS

Targets: ^{12}C, ^{nat}Si, ^{56}Fe, ^{nat}Li, ^{19}F

159 days beam-on-target

51 (n,n') angular distributions

16 (n,n'γ) angular distributions



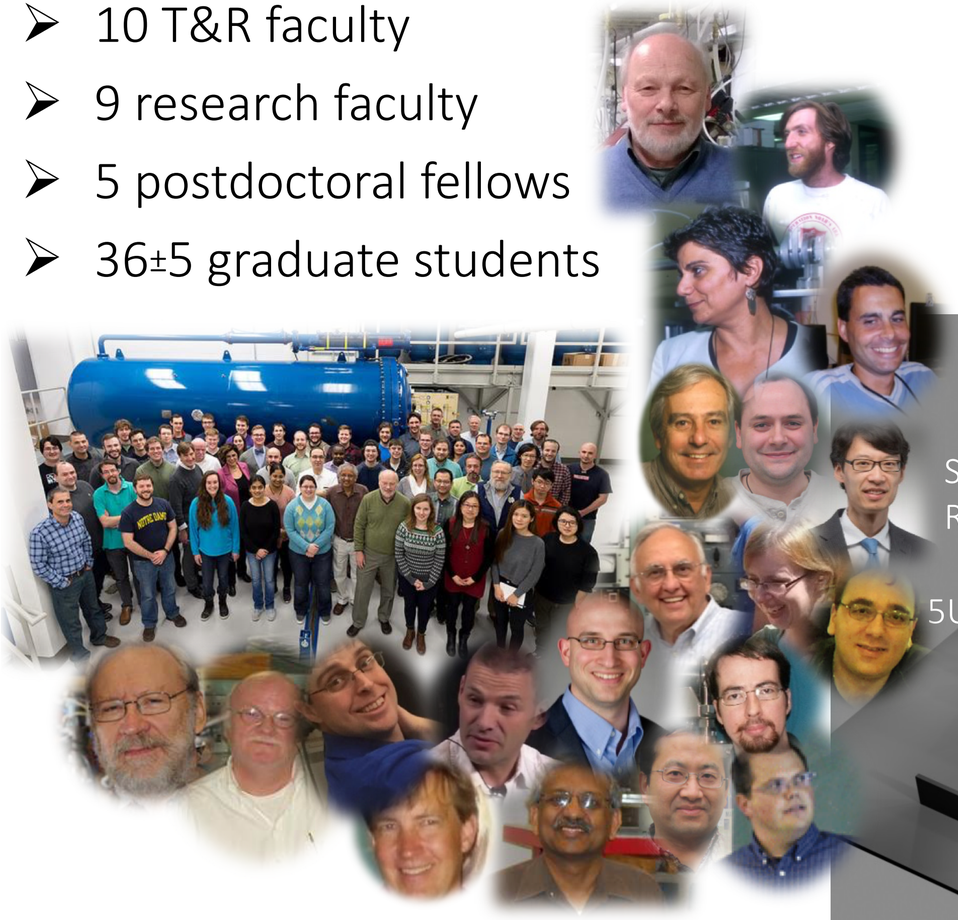
Neutron TOF spectrum for ^{nat}Si

The Notre Dame Nuclear Science Laboratory (NSL)

an ARUNA Facility

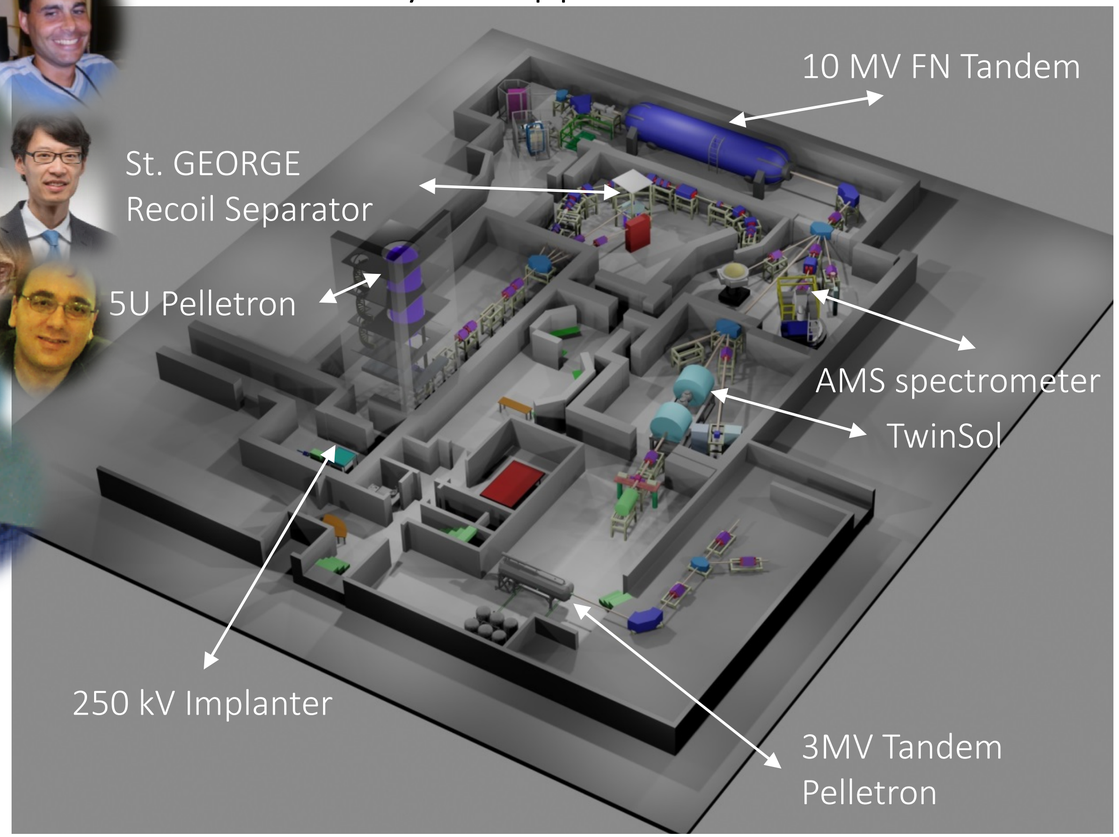
The NSL and its Workforce

- 10 T&R faculty
- 9 research faculty
- 5 postdoctoral fellows
- 36±5 graduate students



Funded by the National Science Foundation
For research in Low Energy Nuclear Physics

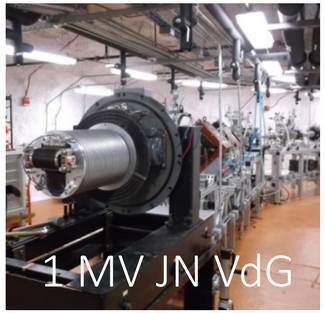
- Nuclear Astrophysics
- Nuclear Structure Physics
- Fundamental Physics
- Nuclear Physics Applications from AMS to PIXE



Founding Member of JINA,
(Joint Institute for Nuclear Astrophysics)

NSL operates 5 Accelerators

^{1}H, ^{4}He, ^{14}N, ^{16}O, ^{20}Ne, ^{40}Ar



^{1}H, ^{4}He

^{7}Be, ^{10}Be, ^{12}B, ^{10}C, ^{11}C, ^{12}N, ^{14}O, ^{15}O, ^{17}F, ^{19}Ne, ^{23}Mg, ^{25}Al, ^{26}Al: 10^{3}-10^{7} pps

Three accelerators for basic research, one accelerator for applied research, TwinSol as radioactive beam facility

NSL research in AMS, recoil separator technologies, and deep underground physics

- AMS for characterizing meteoritic sample and investigating stellar p-process reactions
- St. GEORGE for inverse kinematics astrophysics reactions
- SECAR (NSCL) for inverse kinematics radioactive beam reactions
- CASPAR (SURF) study of stellar (α,n) neutron sources at very low energies
- NIF(LLNL) study of low energy nuclear reactions at plasma conditions

The NSL Science Program

- Nuclear astrophysics
  - Low energy reactions, fusion reactions, late stellar evolution, explosive hydrogen burning, s-process nucleosynthesis, r-process nucleosynthesis, p-process nucleosynthesis
- Nuclear structure physics
  - Vibrational modes in nuclei, E0 transitions, alpha cluster structure in light nuclei, γ-strength functions, nuclear life times, reaction theory (R-matrix, HF method)
- Radioactive ion beam physics
  - Elastic scattering, transfer reaction measurements with radioactive beams
- Accelerator mass spectrometry
  - Nuclear reaction studies, analysis of geological, astrophysical, and cultural samples
- Fundamental symmetries
  - super-allowed mirror transitions with light nuclei in ion traps, life-time and decay properties of light nuclei
- Applied nuclear physics
  - AMS, PIXE, PIGE, reaction analysis

Recent NSL research achievements

$^{17}F(d,n)^{18}Ne$ using ^{17}F TwinSol beams
(P. D. O'Malley, D. W. Bardayan, et al.)

Study of reactions in the αp process using (p,t) transfer
(A. Long, M. Wiescher et al.)

The $^{12}C(\alpha,\gamma)^{16}O$ reaction
(R. J. DeBoer, M. Wiescher et al.)

Improving r-process calculations through precision mass measurements
M. Brodeur, A. Aprahamian et al.

Design of SECAR
G. Berg, M. Couder et al.

Giant Dipole resonances and nuclear incompressibility
(U. Garg, G. Colo)

^{11}C half-life measurement at the NSL
(A. A. Valverde M. Brodeur, et al)

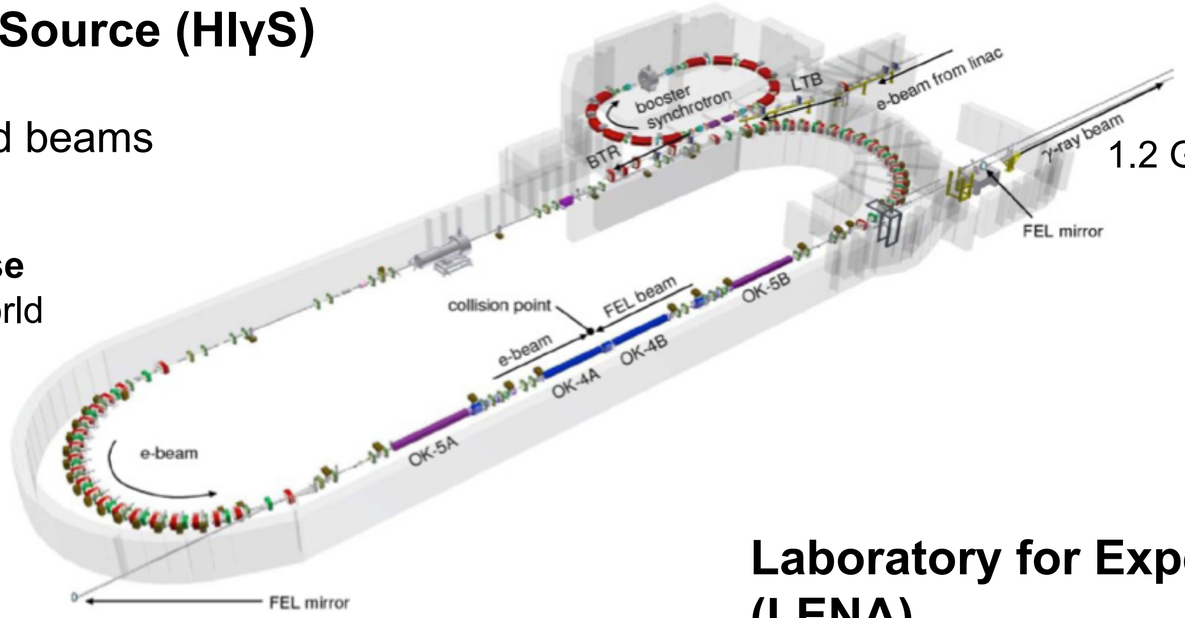
TUNL: Accelerator Facilities

High Intensity Gamma Source (HIγS)

E_g = 2 – 100 MeV

Linear and circular polarized beams

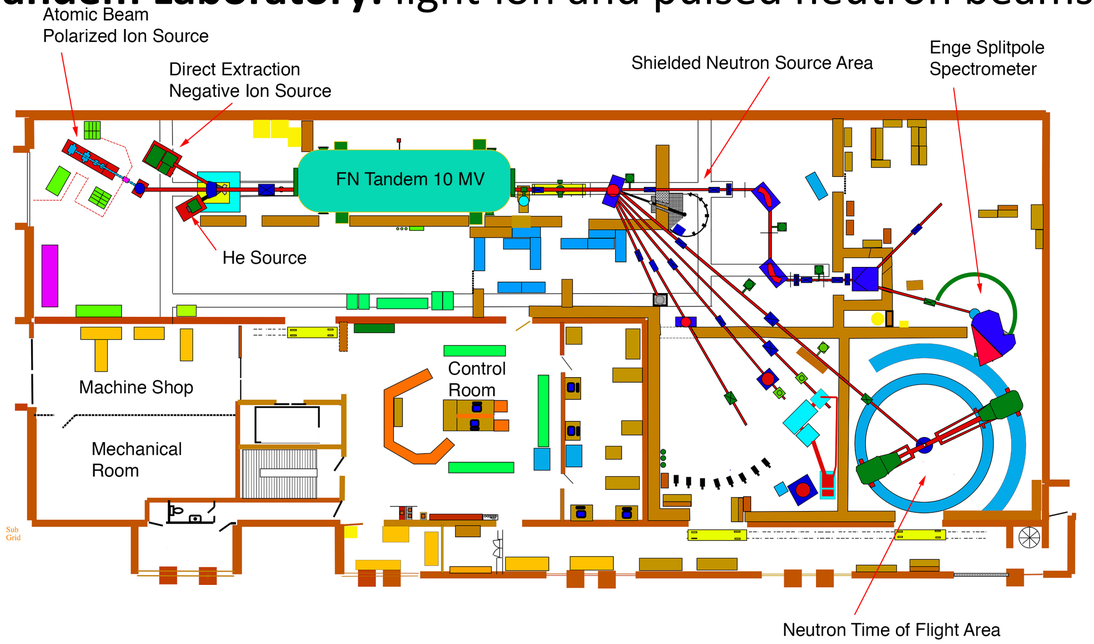
Delivering up to 10^3 γ/s/eV on target, **HIgS is the most intense** Compton γ-ray source in the world



1.2 GeV Storage Ring FEL

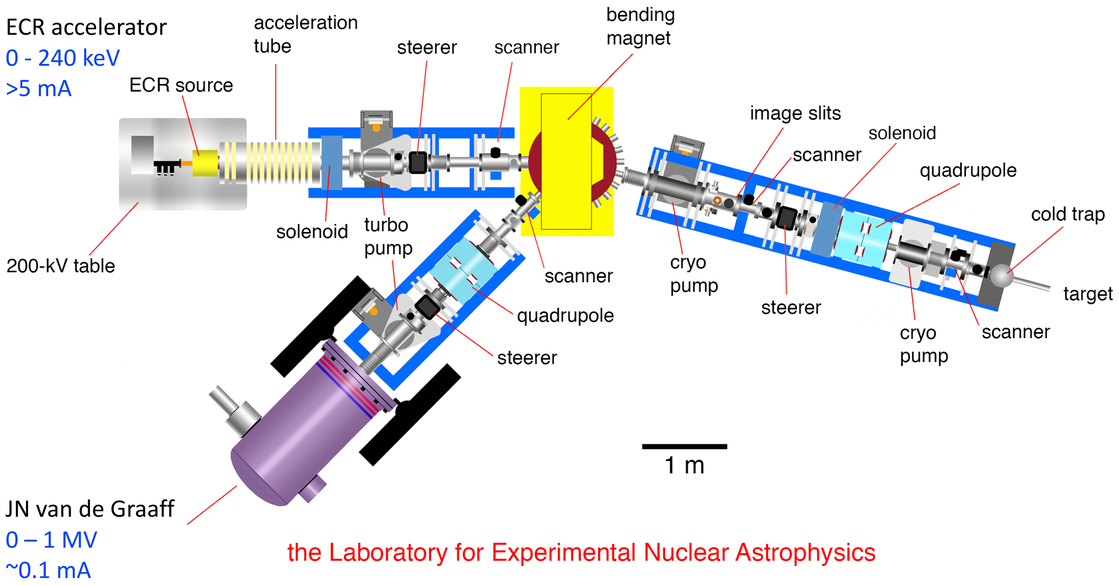
TUNL

Tandem Laboratory: light-ion and pulsed neutron beams



Laboratory for Experimental Nuclear Astrophysics (LENA)

World's highest current proton beam for nuclear astrophysics research



the Laboratory for Experimental Nuclear Astrophysics

Overview of Research at TUNL Accelerator Facilities

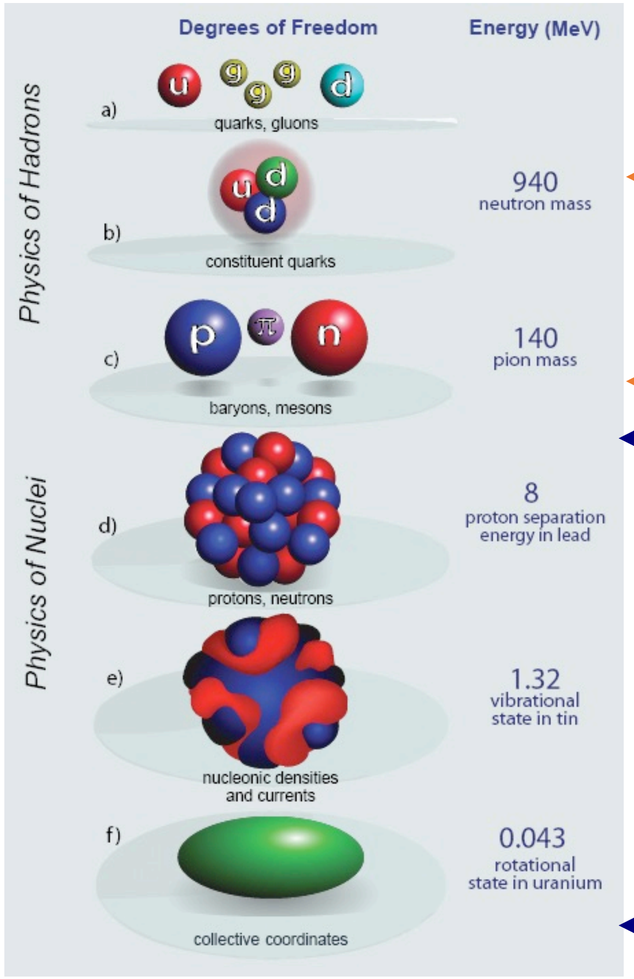


Figure from 2007 USA Nuclear Science LRP

HIγS

Low-Energy QCD:

Compton Scattering
nucleon electric and magnetic polarizabilities
nucleon spin polarizabilities

Few-nucleon Systems

Nuclear Structure and Nuclear Astrophysics:
- NRF, i.e., (γ,γ')
- Gamma-induced reactions
- Gamma-induce fission

Applications:
- Nuclear Security
- Medical Isotope R&D
- Particle Detector R&D

Tandem

Low-Energy QCD:

Few-nucleon Systems

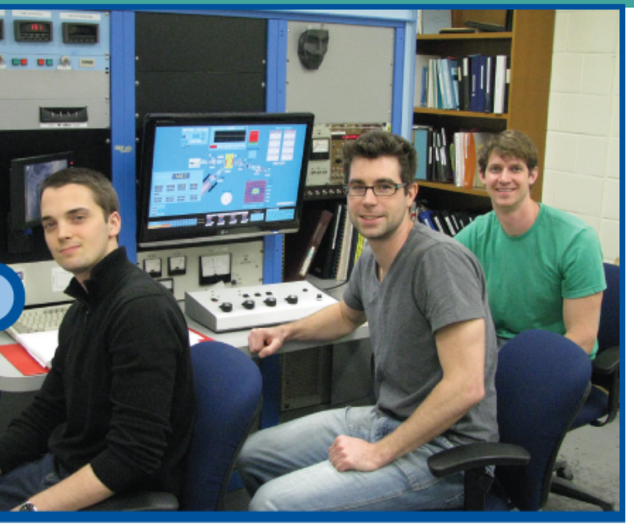
Nuclear Structure and Nuclear Astrophysics:
- Neutron-induced reactions
- Neutron-induced fission
- Charged-particle induced reactions

Applications:
- Nuclear Security
- Particle Detector R&D
- Plant biology

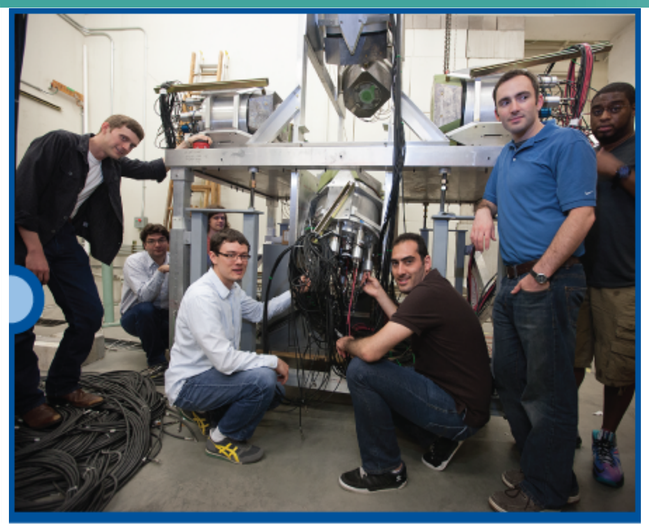
LENA

Nuclear Astrophysics:
- Proton-induced reactions
- Alpha-induced reactions

Student training at TUNL



UNC graduate students Matthew Buckner, John Cesaratto, and Stephen Daigle use the LENA accelerator facilty for studies related to nuclear astrophysics.

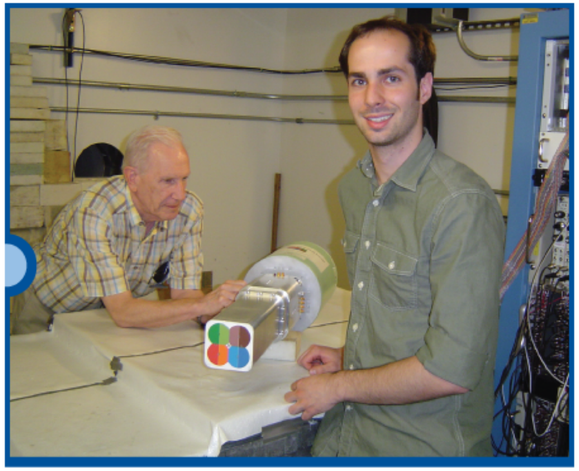


Members of the Compton scattering collaboration pose in front of the HIGS NaI Detector Array (HINDA).

TUNL REU students.

UNC graduate students Padraic Finnerty and Sean MacMullin are cleaning materials for low background studies as part of the MAJORANA project.

Duke graduate student Larry Cumberbatch tunes the beam at the tandem accelerator.



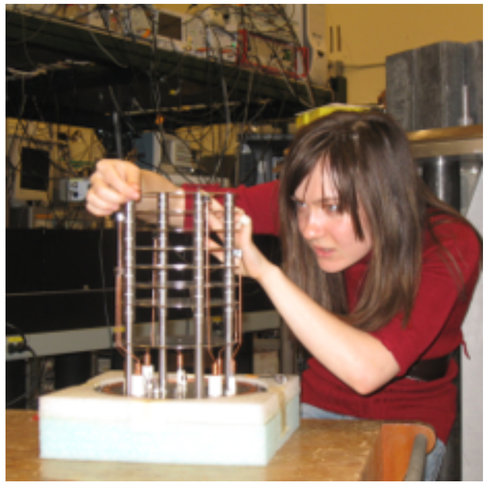
Professor Werner Tornow along with graduate student Brent Fallin and post-doc Megha Bhike during data taking at HIGS.n

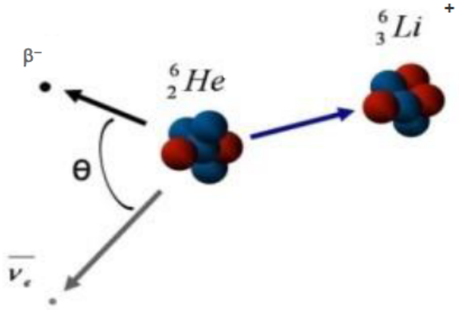
^{6}He β-ν correlation at U. of Washington

Y. Bagdasarova[1], K. Bailey[2], X. Fléchard[3], A. Garcia[1,*], R. Hong[1], A. Knecht[4], A. Leredde[2], E. Liennard[3], P. Mueller[2,*], O. Naviliat-Cuncic[5], T. O'Connor[2], M. Sternberg[1], H.E. Swanson[1], F. Wauters[1]

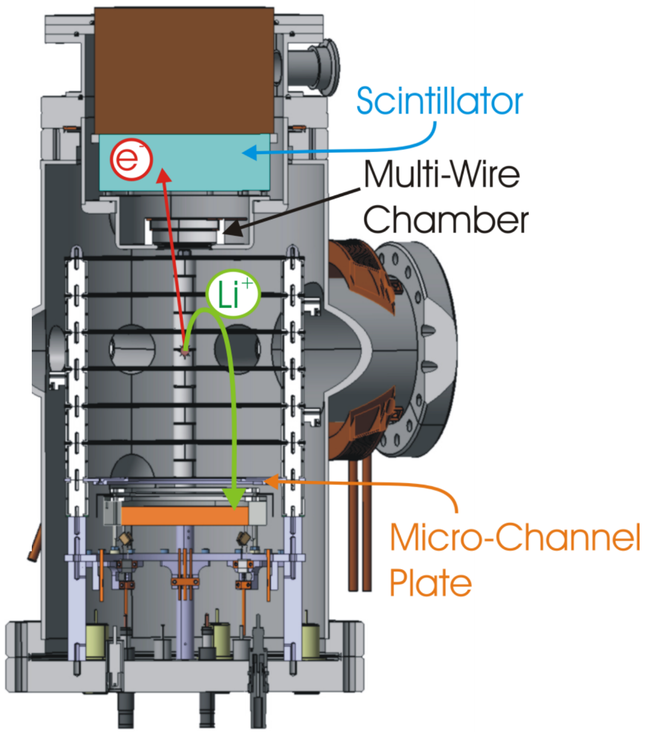
[1]*University of Washington,* [2]*Argonne National Lab,* [3]*LPC, CAEN, France*
[4]*PSI,* [5]*NSCL, Michigan State University*

[*]Spokepersons

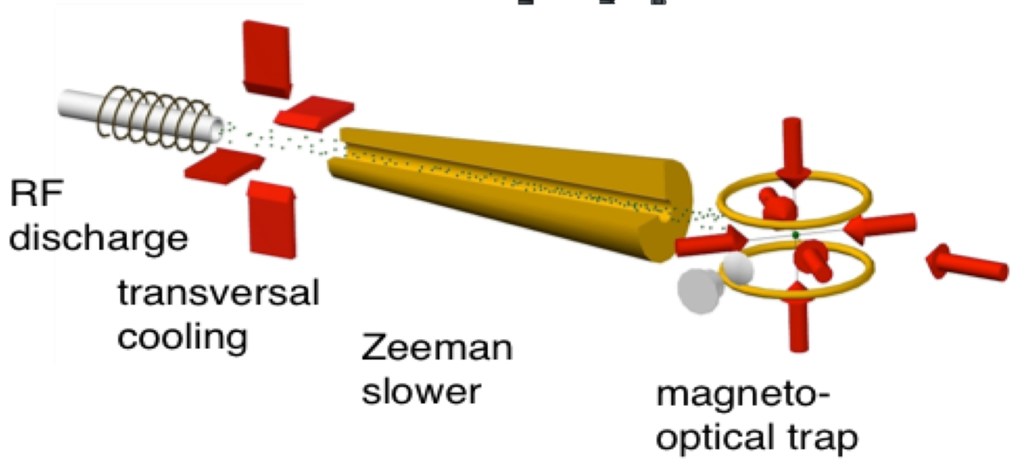




^{6}He Trap/Detector Chamber



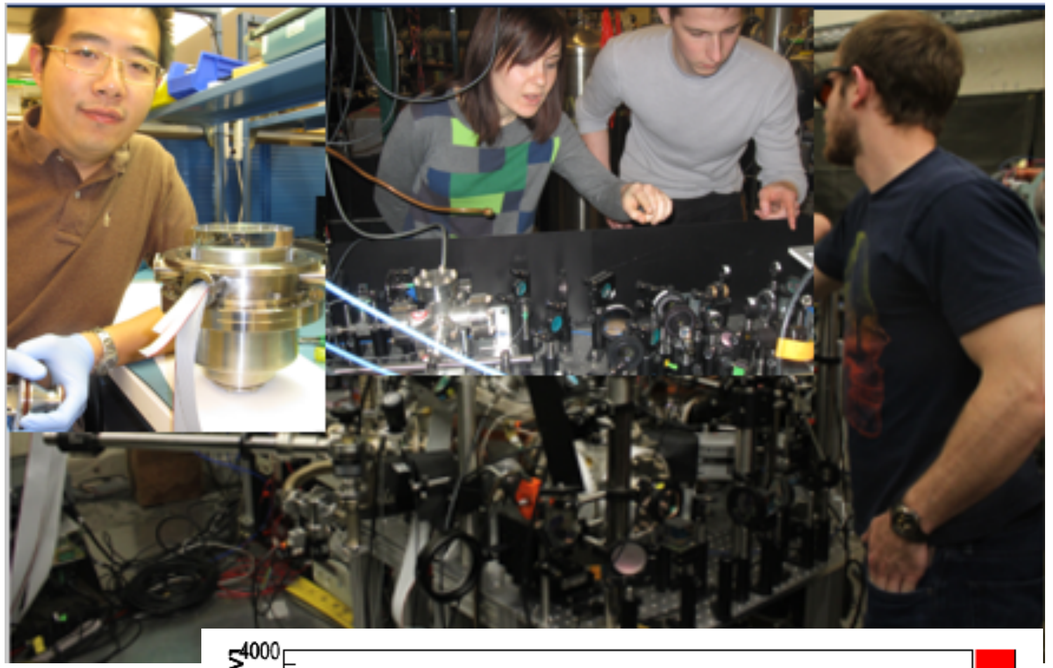
- Goal: measure "little a" to 0.1% in ^{6}He
  - pure Gamow-Teller decay
  - sensitive to tensor couplings
  - simple nuclear and atomic structure
- Laser cooling and trapping to prepare ^{6}He source (t ≈0.8 s)
- Detect electron and ^{6}Li in coincidence



^{6}He β-ν correlation at U. of Washington

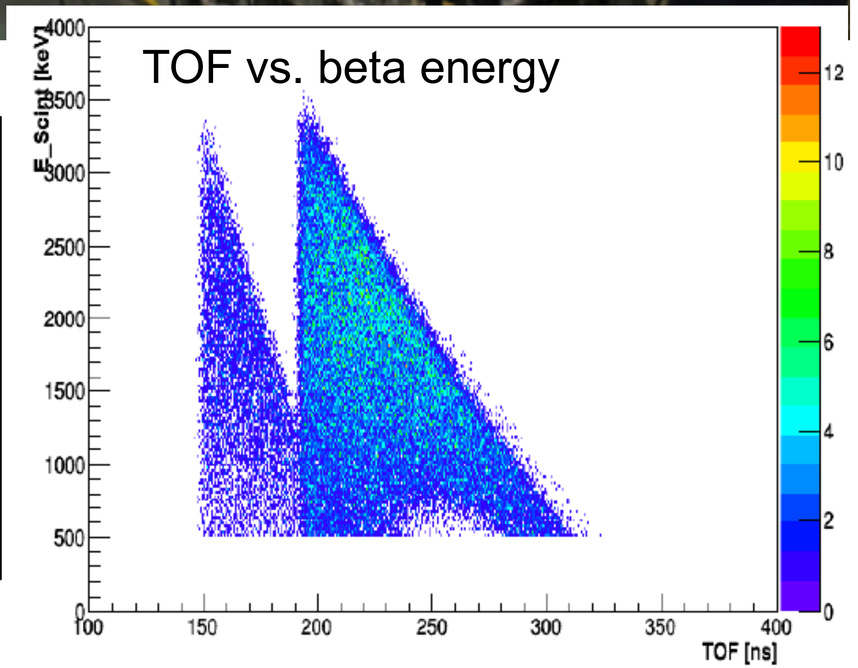
6He Source:
Reliable source of ~10^{10} ^{6}He's/s in low-background environment
NIM A **660**, 43 (2011).
Laser trapping and detection systems:
All systems working after much development.

First physics results:
Measurement of Li-ions charge distribution and comparison with atomic theory.
Interesting discrepancies.
PRA **96**, 053411 (2017).



Status

- Data collected for ~0.7% statistical uncertainty in ***a***
- Study of systematic effects from recoil spectrometer and beta detector on-going
- Pending results, runs with higher statistics & improved detector system are anticipated for FY2019

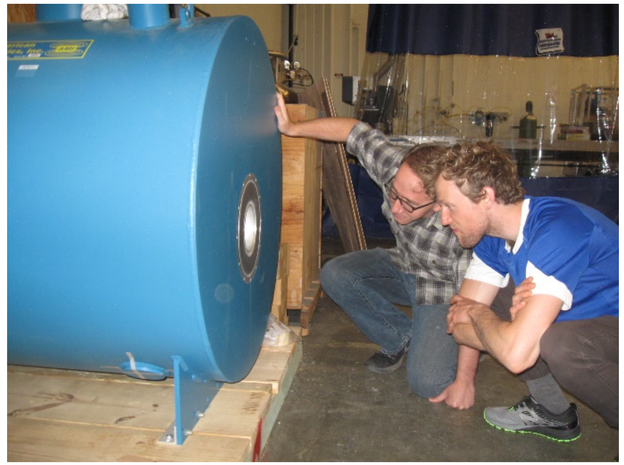


LRP: *…weak decay measurements with an accuracy of 0.1% or better provide a unique probe of new physics at the TeV energy scale, offering discovery potential complementary to muon and electron weak force measurements.*

^{6}He little-*b* measurement

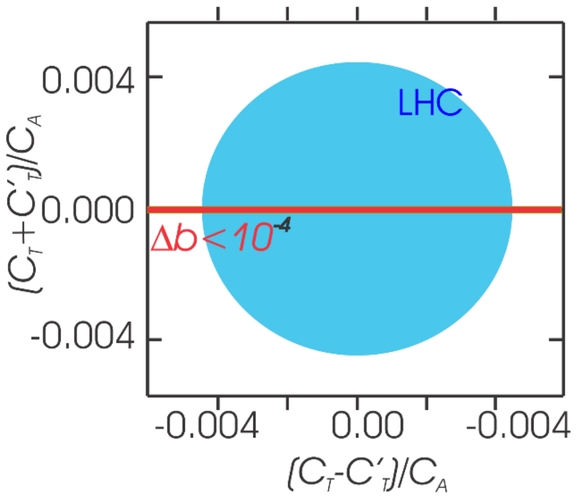
W. Byron[1], M. Fertl[1], A. Garcia[1], G. Garvey[1], B. Graner[1], B. Graner[1], M. Guigue[4], D. Hertzog[1], K.S. Khaw[1], P. Kammel[1], A. Leredde[2], P. Mueller[2], N. Oblath[4], R.G.H. Robertson[1], G. Rybka[1], G. Savard[2], D. Stancil[3], H.E. Swanson[1], B.A. Vandeevender[4], F. Wietfeldt[5], A. Young[3]

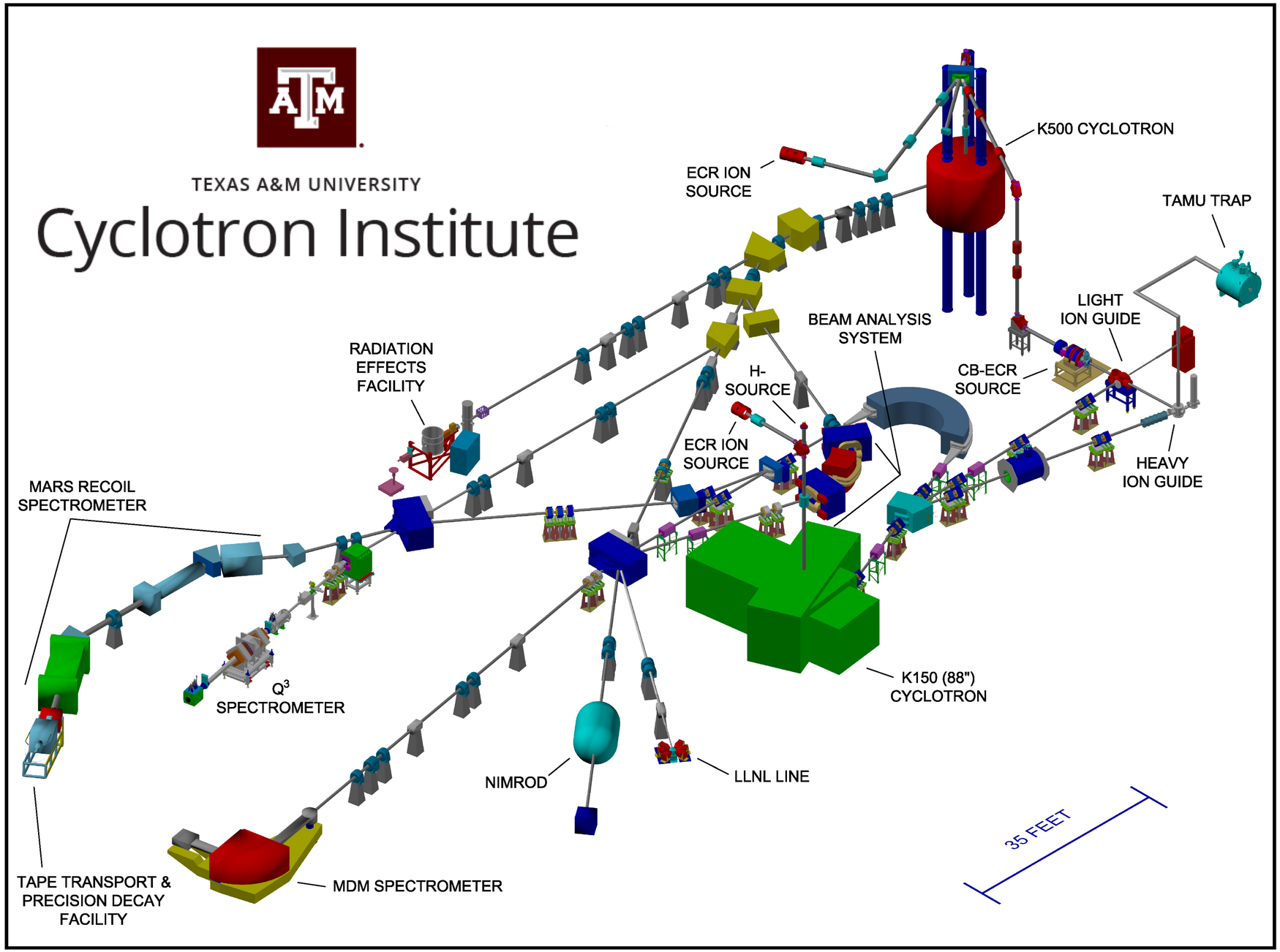
[1]*University of Washington,*
[2]*Argonne National Lab,*
[3]*North Carolina State University,*
[4]*Pacific Northwest National Laboratory*
[5]Tulane University



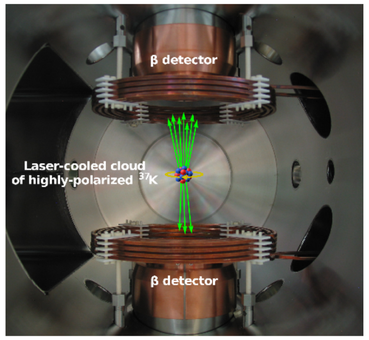
Apparatus presently being set up. Use Cyclotron Radiation Emission Spectroscopy.

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

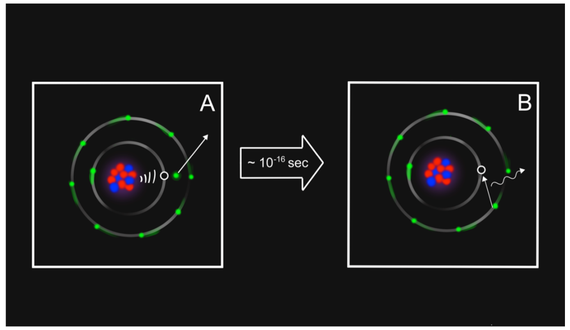



TEXAS A&M UNIVERSITY
Cyclotron Institute
K500 CYCLOTRON
ECR ION SOURCE
TAMU TRAP
LIGHT ION GUIDE
BEAM ANALYSIS SYSTEM
RADIATION EFFECTS FACILITY
H- SOURCE
CB-ECR SOURCE
ECR ION SOURCE
HEAVY ION GUIDE
MARS RECOIL SPECTROMETER
Q3 SPECTROMETER
K150 (88") CYCLOTRON
NIMROD
LLNL LINE
35 FEET
TAPE TRANSPORT & PRECISION DECAY FACILITY
MDM SPECTROMETER

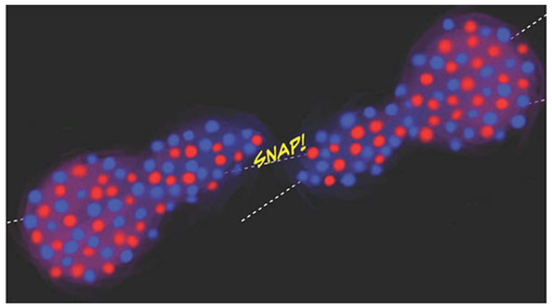
Recent DOE Highlights



Is nature exclusively left handed? Using chilled atoms to find out.
Elegant atomic techniques of trapping and polarizing atoms open new vistas for β-decay tests of fundamental symmetries.

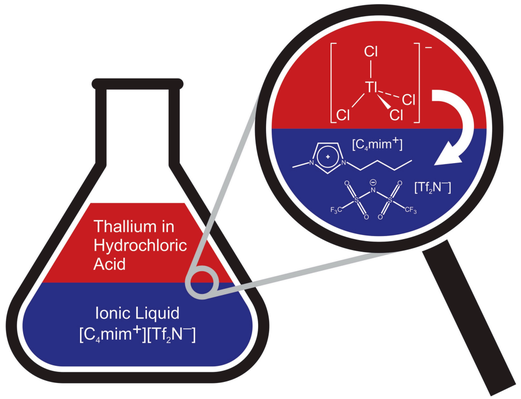


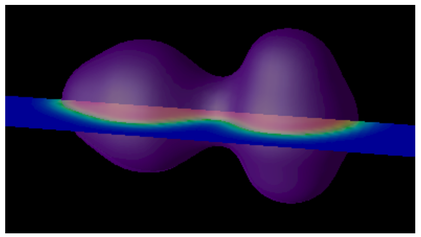
Precise radioactivity measurements: A controversy settled
Simultaneous measurements of x-rays and gamma rays emitted in radioactive nuclear decays probe how frequently excited nuclei release energy by ejecting an atomic electron.



Watching Neutrons Flow
Like water, neutrons seek their own level, and watching how they flow may teach us about how the chemical elements were made

CHEMISTRY for the Bottomof the Periodic Table
Techniques to investigate chemical properties of super heavy elements lead to improved methods for separating heavy metals

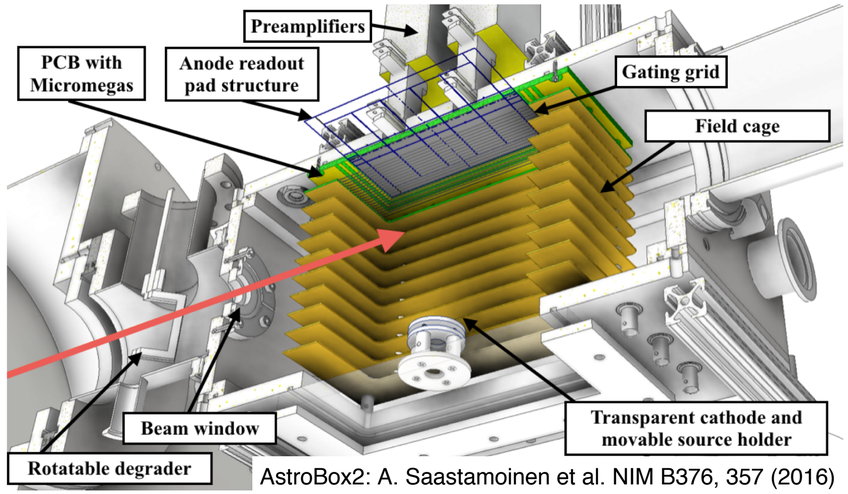




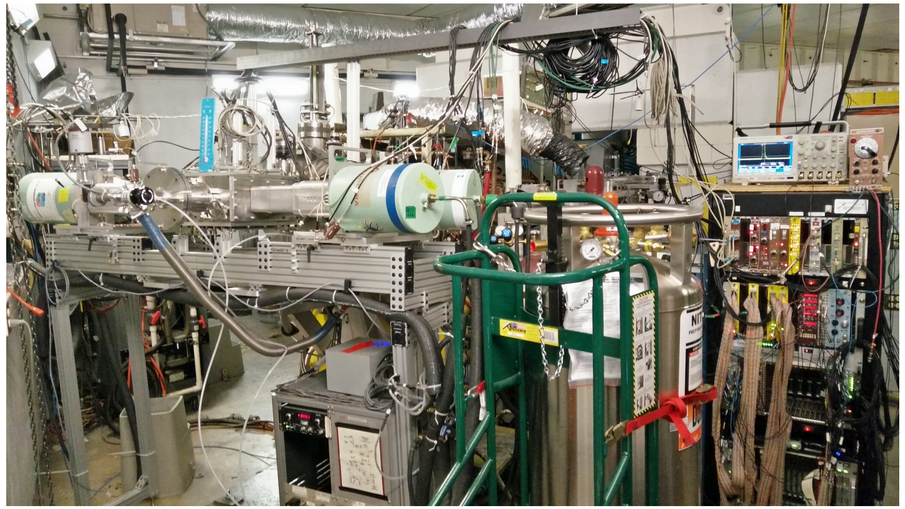
A Search for New Super Heavy Isotopes
Using the energy of alpha particles and their times to search for new heavy isotopes.

ARUNA

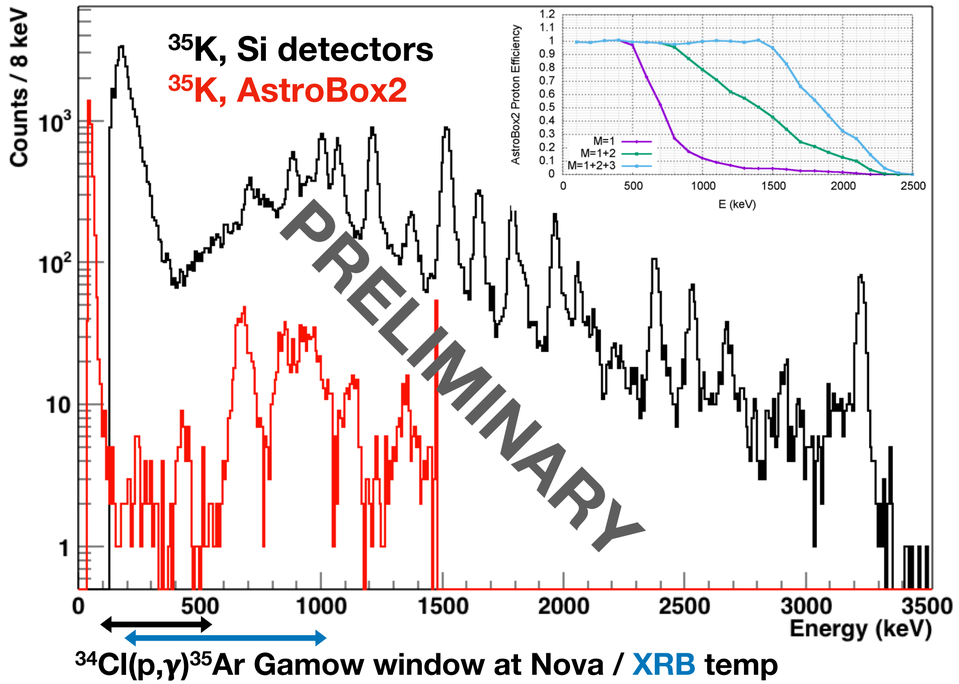
βp-decay of ^{35}K for ^{34g,m}Cl(p,γ)^{35}Ar with AstroBox2



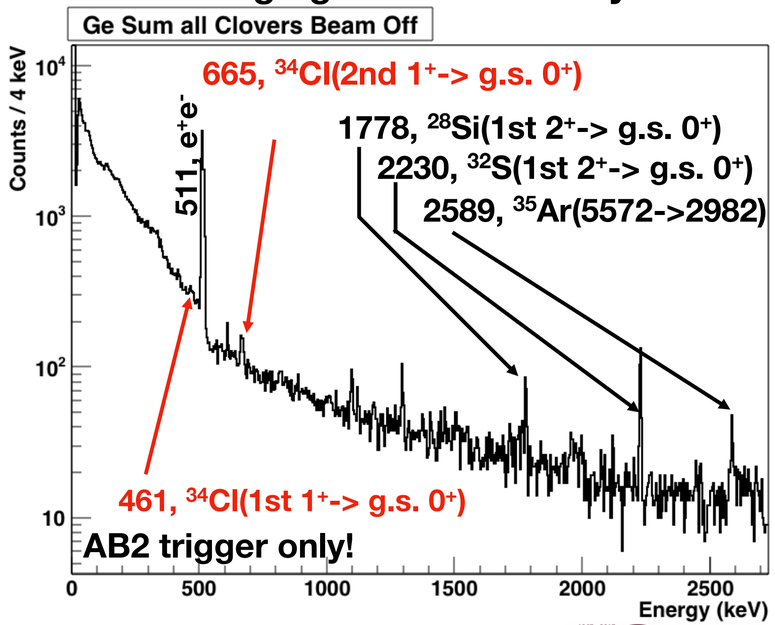
AstroBox2: A. Saastamoinen et al. NIM B376, 357 (2016)



HPGe clovers from Hyperion array (LLNL) for high gamma efficiency

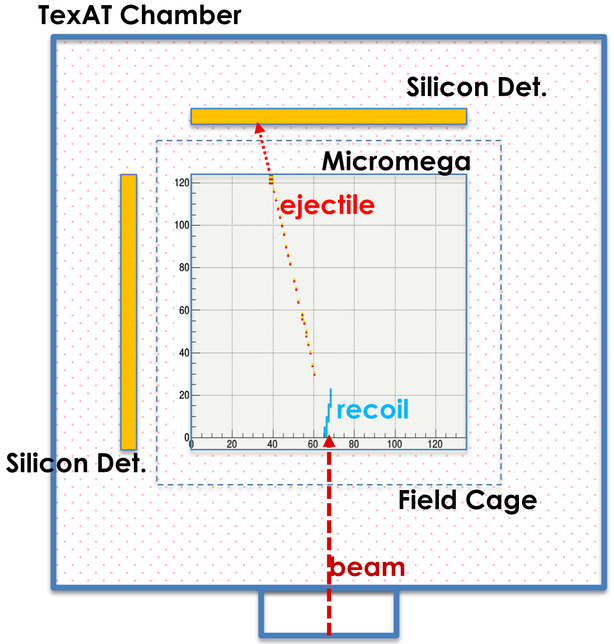


^{34}Cl(p,γ)^{35}Ar Gamow window at Nova / XRB temp

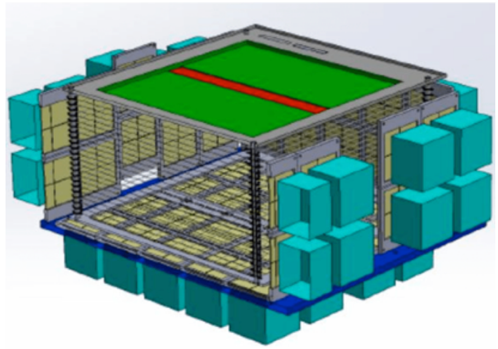


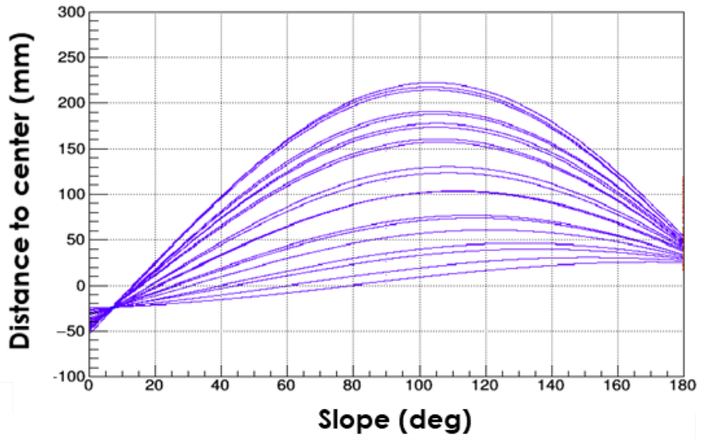
Si data: A. Saastamoinen et al. J. Phys. Conf. Ser. 940, 012004 (2018)
AB2 data: exp in Jul, Oct 2017, R. Chyzh PhD thesis (work in progress)

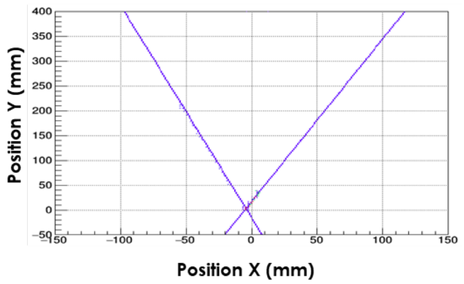
Texas Active Target - TexAT



particle track from sample data



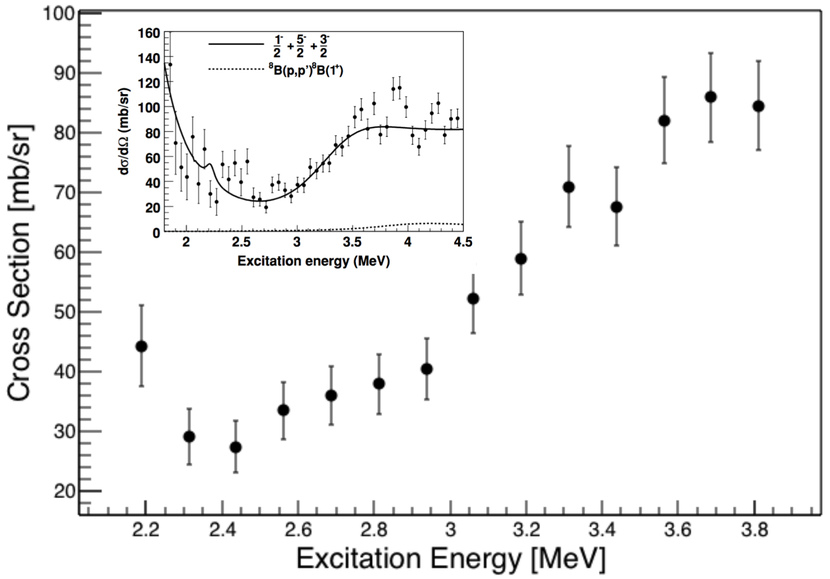




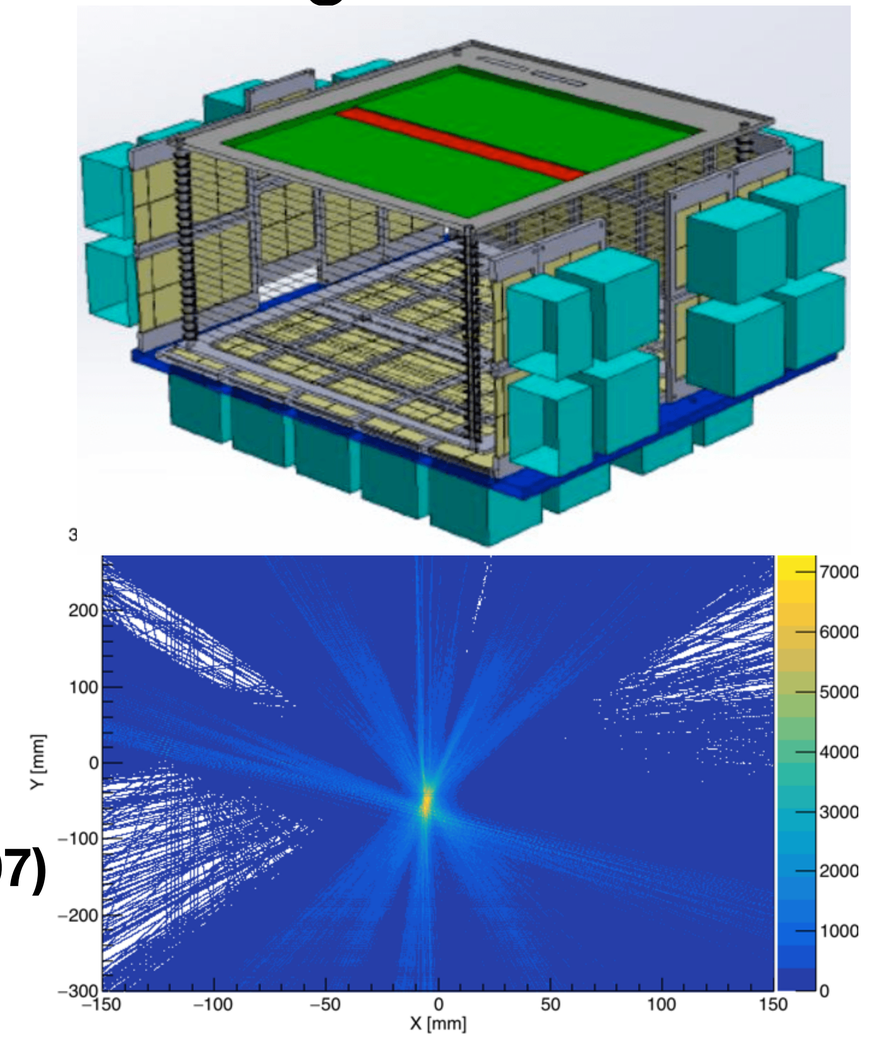
Finding track lines
using Hough Transformation

A picture for TexAT and Micromega Plate

Structure of ^{9}C
TexAT commissioning run - excitation function for $^{8}B+p$ elastic scattering



Preliminary $^{8}B+p$ excitation function measured with TexAT compared to the previous data G. Rogachev, PRC (2007)

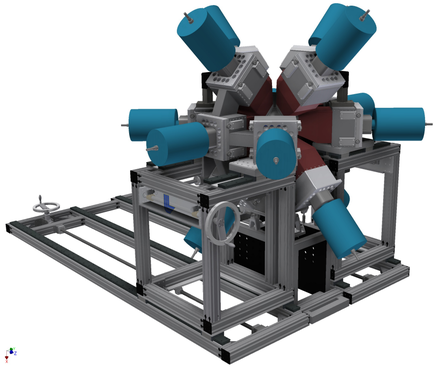


Tracks in TexAT (alpha source data)

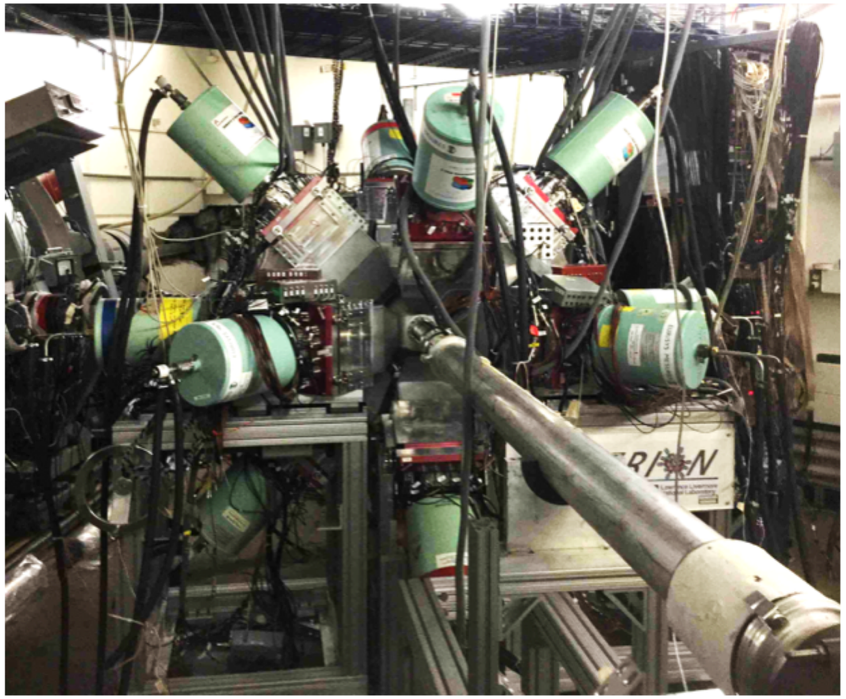
Hyperion array for fundamental and applied science

J.T. Burke, R.O. Hughes, R.J. Casperson, J.E. Escher, S. Fisher, J. Parker, T. Wu

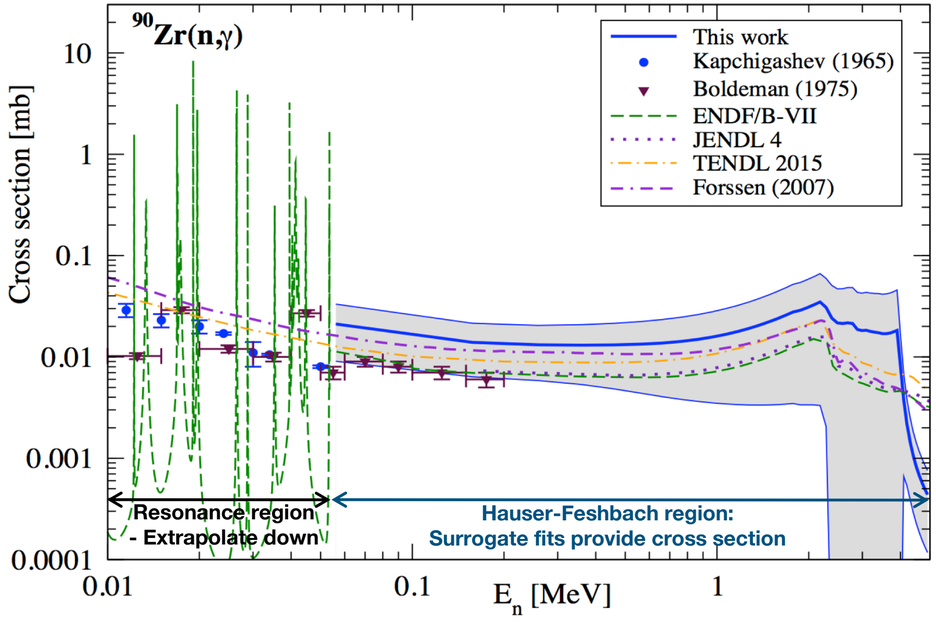
High efficiency, highly segmented gamma ray array for surrogate (n, γ) cross section and nuclear structure measurements. Hyperion is a 14 HPGe Clover array with BGO Compton suppression. Located at Texas A&M Cyclotron Institute which provides light ion beams from the K150 Cyclotron.



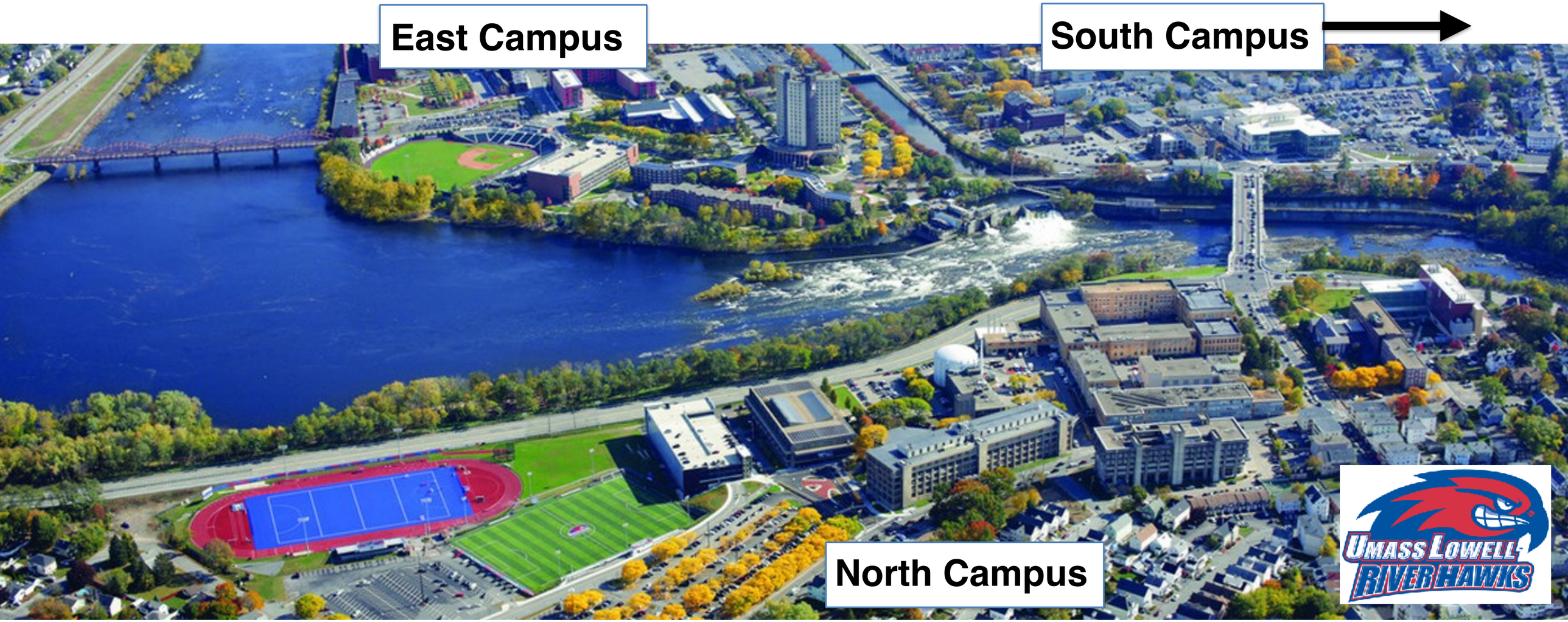
Hyperion conceptual design 2013



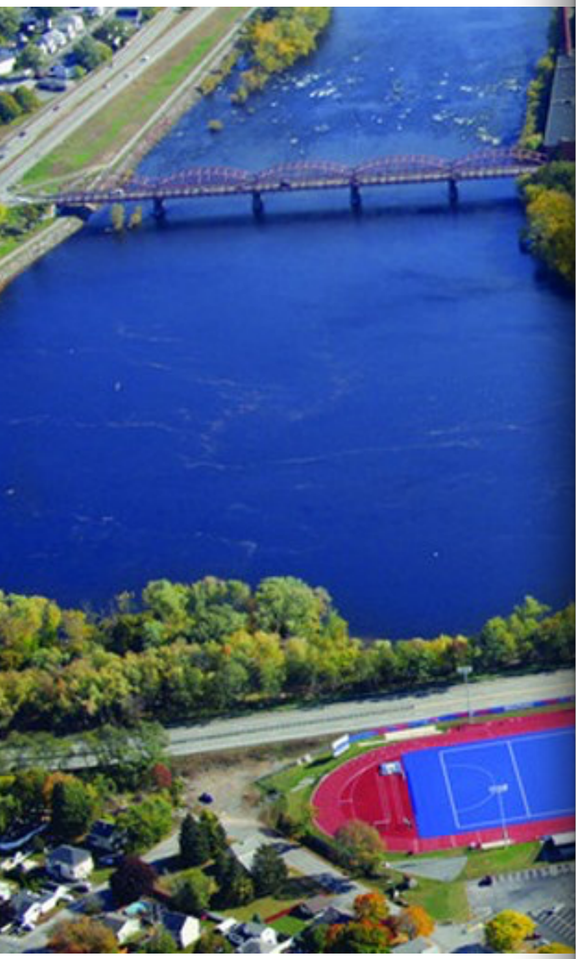
Hyperion installed at TAMU 2015



UML Campus and Radiation Laboratory



UML Campus and Radiation Laboratory



mpus

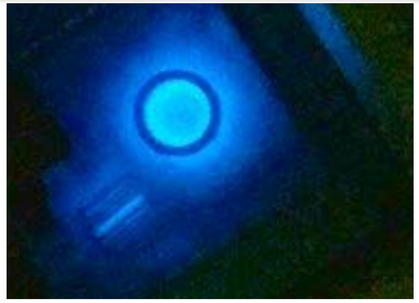
UML Nuclear Physics Group

EXPERIMENTAL LOW-ENERGY NUCLEAR PHYSICS




- Supported mainly by the Department of Energy and the National Nuclear Security Agency
- Undergraduates: ~ 3 — 8
- Graduate students: ~ 4 — 6 plus a visiting University of Surrey student
- Post-doctoral Fellows: **Ed Lamere (Ph.D. Notre Dame) and Dan Hoff (Ph.D. Wash U.)**

Radiation Laboratory - facilities



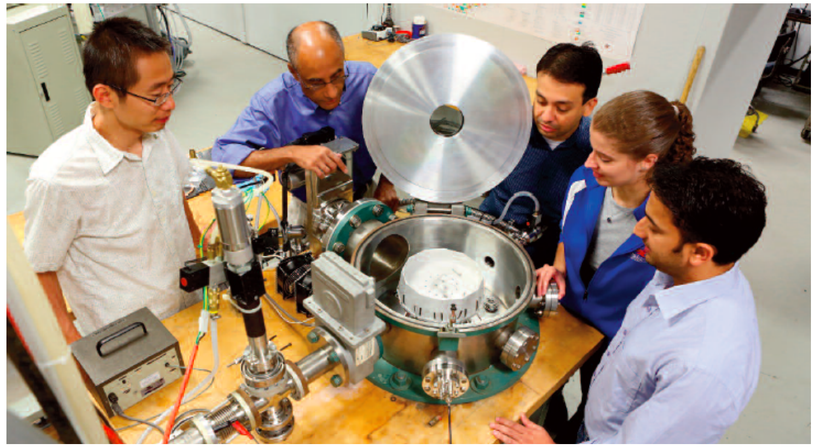
DIRECTOR
Partha Chowdhury

1-MW RESEARCH REACTOR
Open pool, LEU fuel

100-kCi ^{60}Co source
gamma irradiation

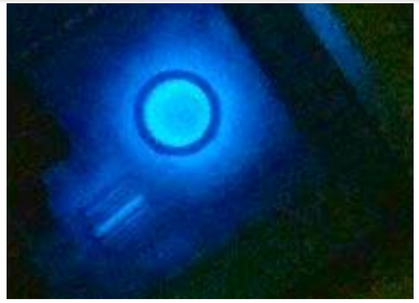
CAPABILITIES
in-core sample(~10^{13} n/cm^2/s)
graphite thermal column (~10^6 n/cm^2/s)
digital neutron radiography
hot cell with remote manipulators

CAPABILITIES
- *p*, *d*, He, … ions
- 100 μA DC beam
- Sub-ns pulsing
- Mono-energetic pulsed neutrons via ^{7}Li(*p*,*n*) reaction
- Fast-neutron beamline (goniometer, neutron scattering, ToF)
- Ion microprobe
- General purpose scattering chamber



5.5 MV CN single-ended Van de Graaff

Radiation Laboratory - facilities



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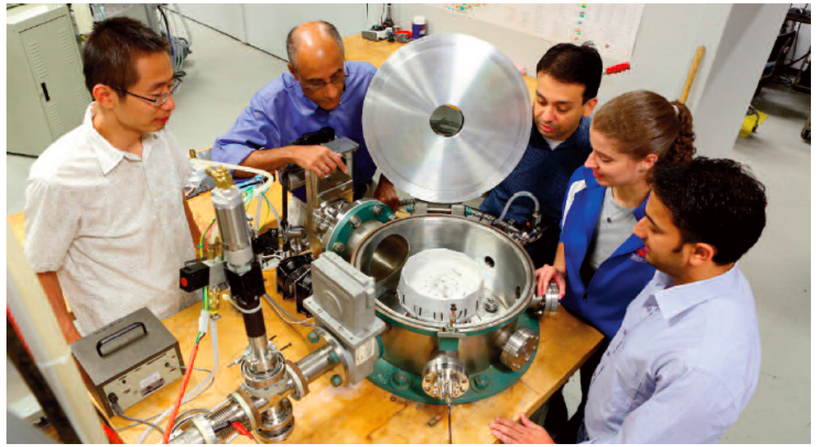
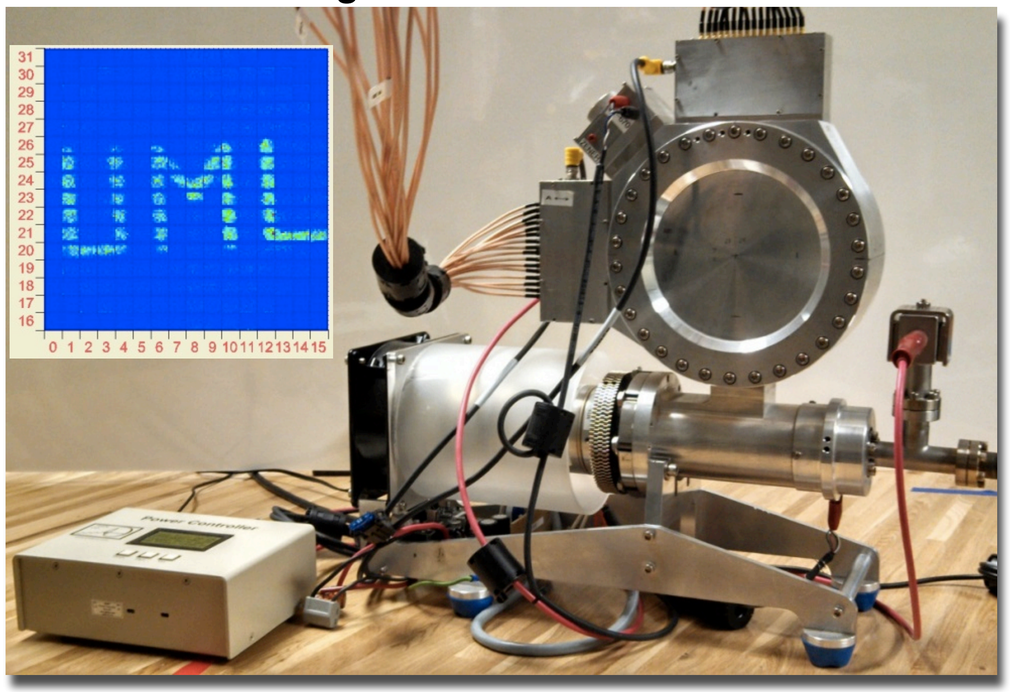


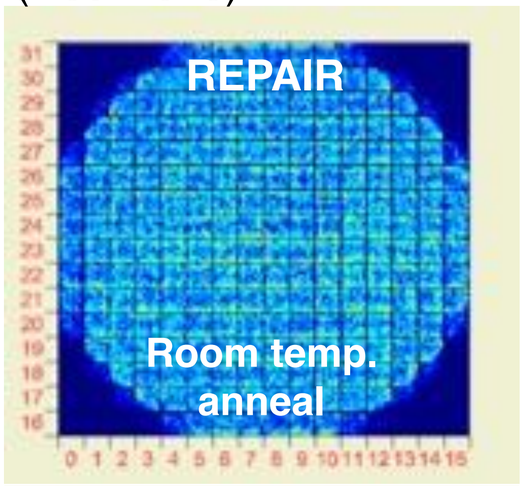
5.5 MV CN single-ended Van de Graaff

Neutron Damage & Recovery: Segmented HPGe

- ✦Segmented large planar Ge with new contact technology.
- ✦Applications in imaging and high count rate capabilities.
- ✦Neutron damage tests and “repairability” at UML accelerator for in-beam physics.
- ✦SBIR Phase2 grant with PHDS Co. to design a streamlined cryostat for “in-beam” spectroscopy of superheavy elements.
- ✦**Controlled dose of mono-energetic neutrons from accelerator to induce lattice damage and charge trapping.**
- ✦**In-house annealing** to assess robustness of contacts.



Ph.D. thesis Bilal Amro (Dec. 2018)

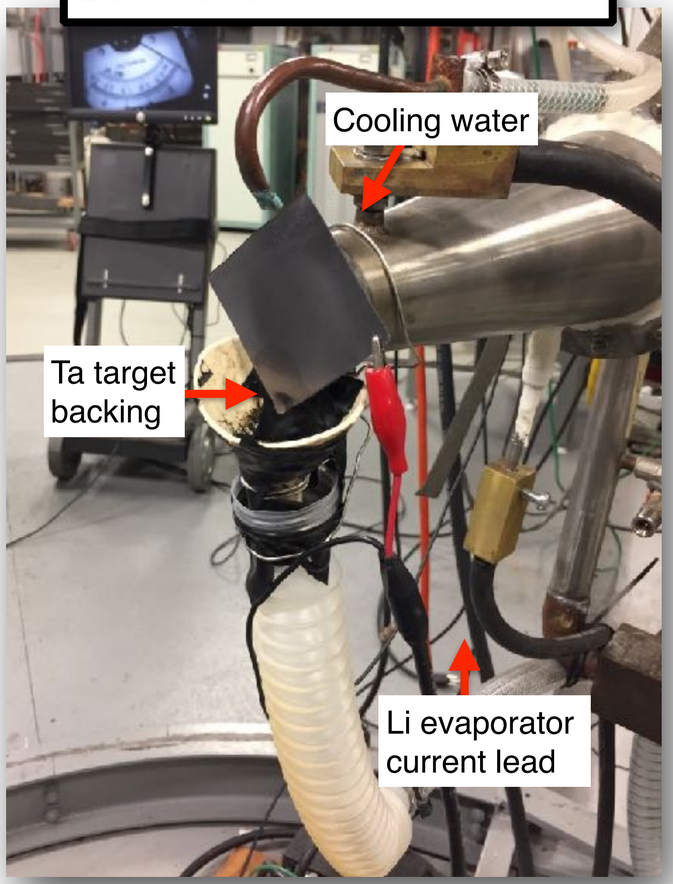


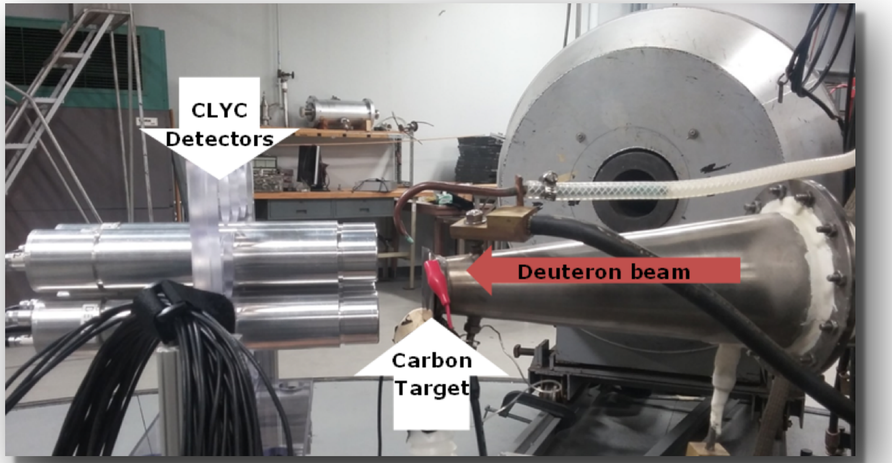
Emily Jackson
Postdoc
Naval Research Lab

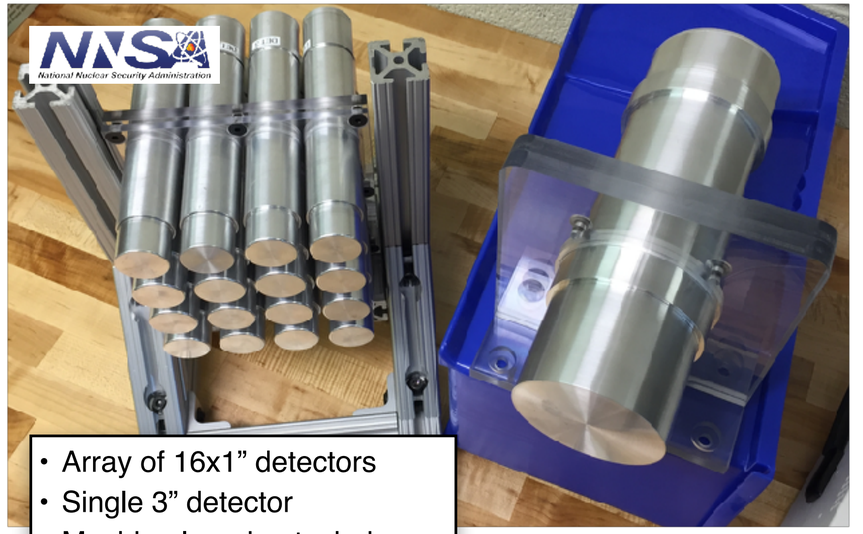
Nathan D’Olympia
Scientist
Passport Systems, Inc.

Detector development: C⁷LYC

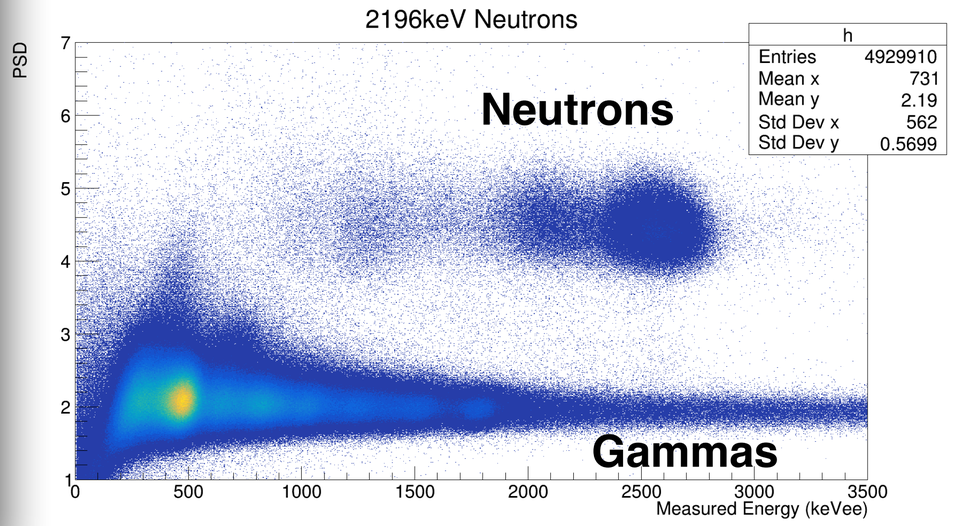
Go to Ed Lamere's talk
Fri. 5:40-5:50
Neutron Detection WG
BPS 1410

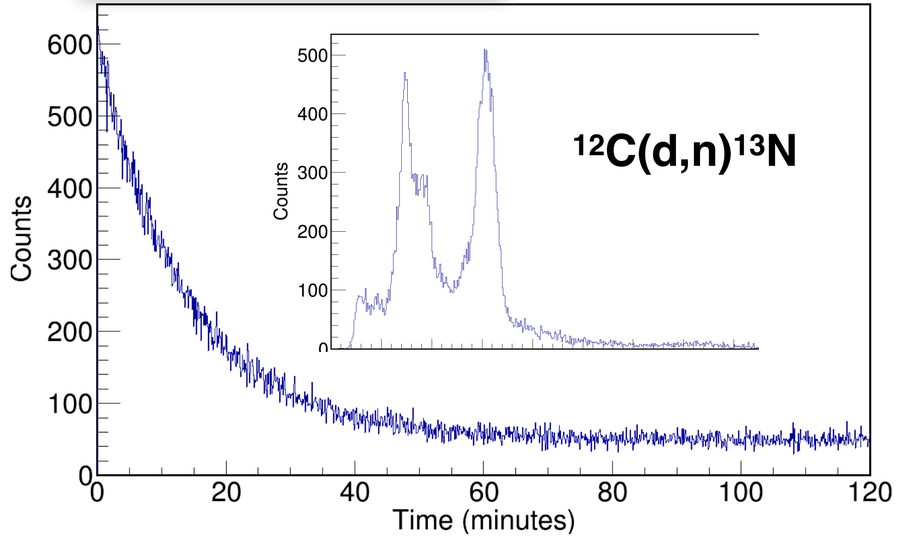




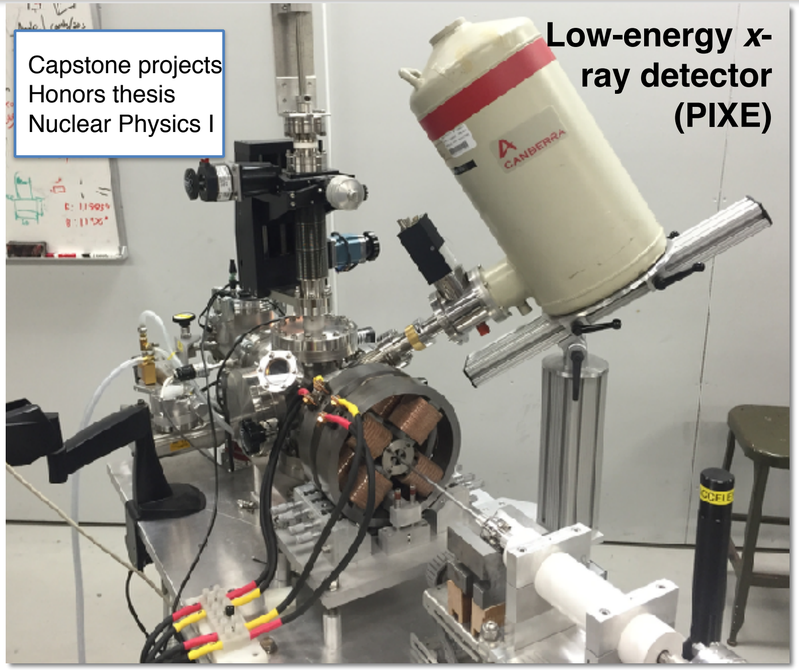


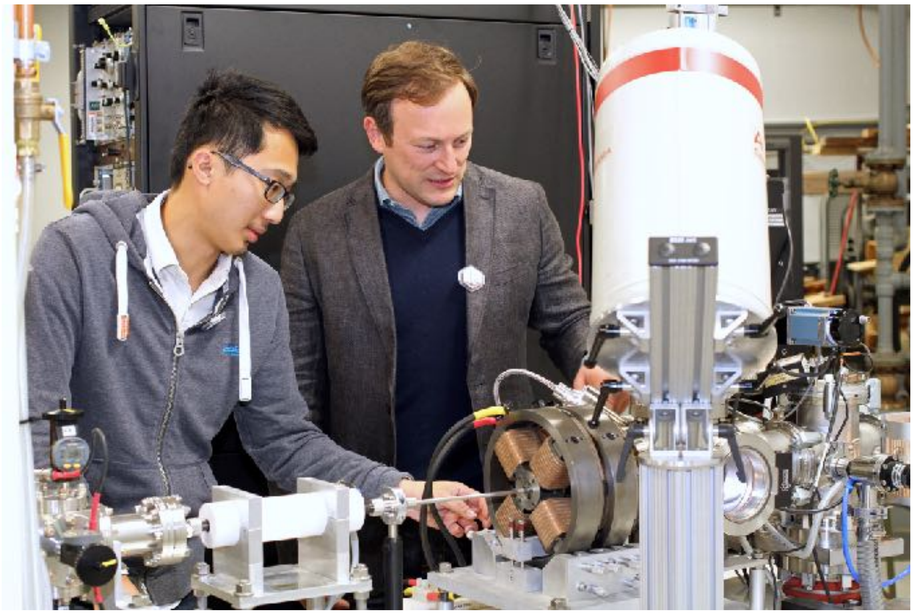
- Array of 16x1" detectors
- Single 3" detector
- Machine learning techniques

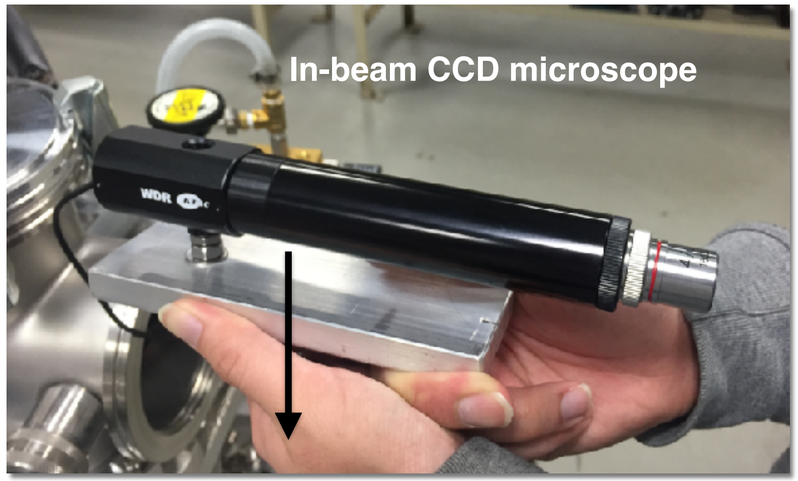


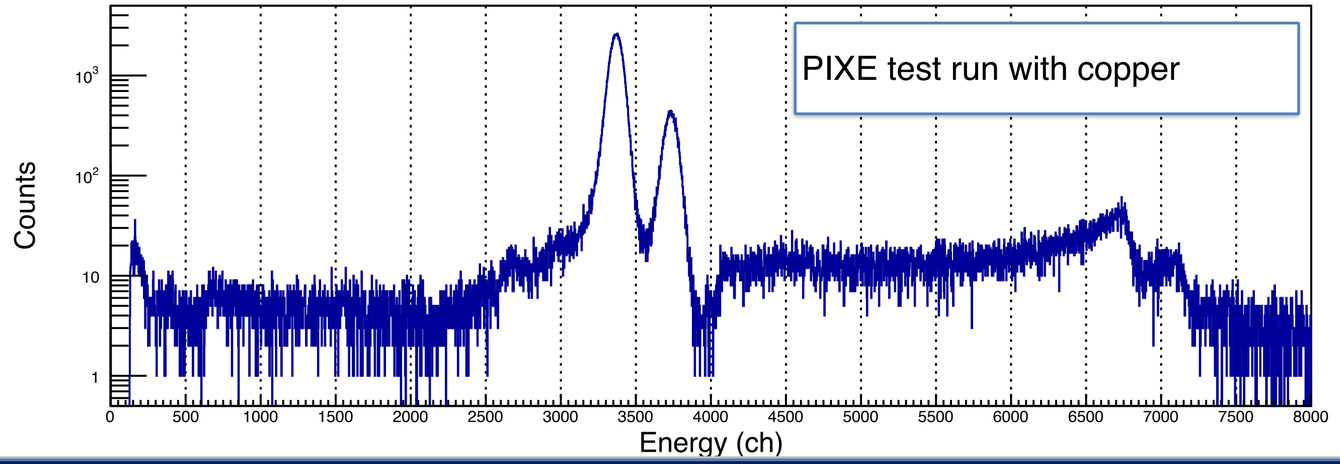


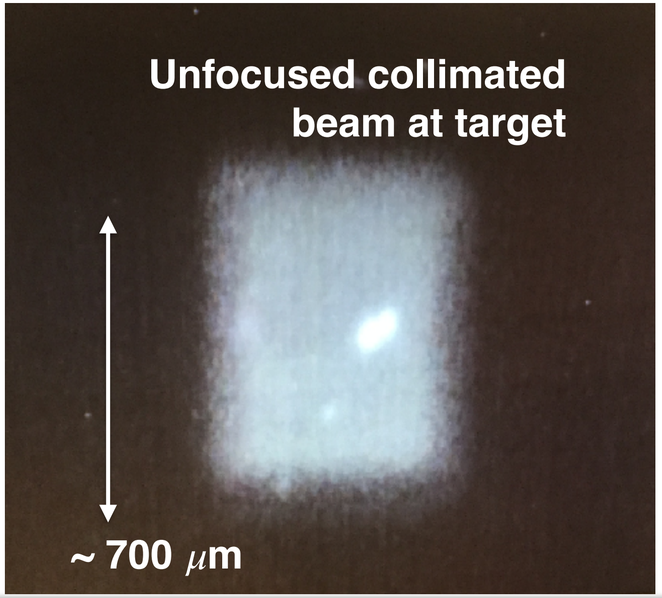
UML ion microprobe











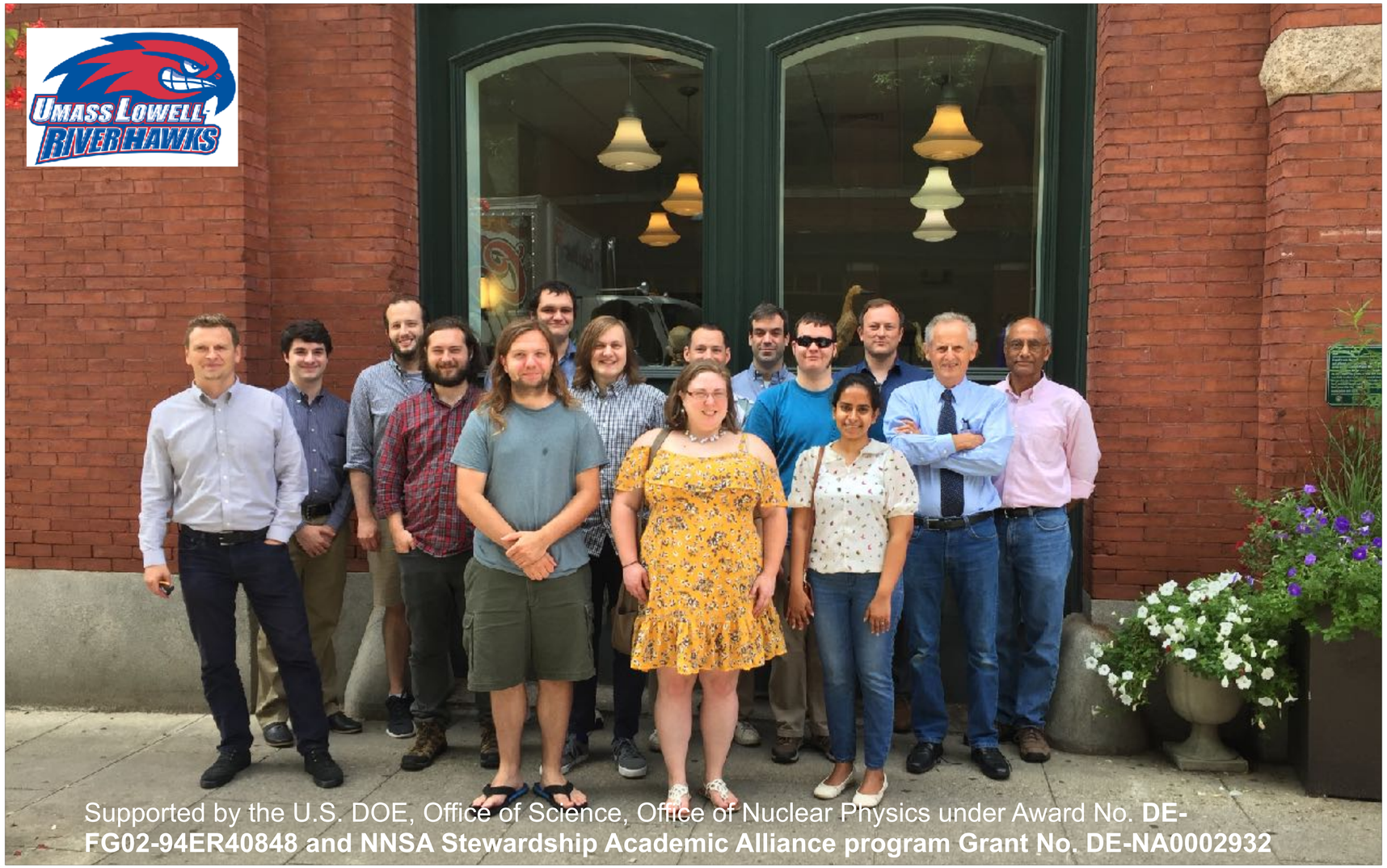
UML Nuclear Instrumentation Course

(Nuclear medicine, nuclear engineering, radiological sciences, physics, and others)

UML Nuclear Instrumentation Course

(Nuclear medicine, nuclear engineering, radiological sciences, physics, and others)

UML Nuclear Physics



Supported by the U.S. DOE, Office of Science, Office of Nuclear Physics under Award No. **DE-FG02-94ER40848 and NNSA Stewardship Academic Alliance program Grant No. DE-NA0002932**

Summary

Thanks to everyone who gave me slides and contributed!!!

- ARUNA institutions and facilities play a critical role in the scientific community and supports the broader national interest.
- High-quality, relevant and ***exciting*** local science programs (attracts students!).
- Training for students that enter academia, industries and other technical spaces.
- Adds to a vibrant, rich and creative enterprise that would not exist otherwise.

END