
# ARUNA-
# Association for Research at University Nuclear Accelerators

An Association of

Florida State University Accelerator Lab
Hope College Ion Beam Laboratory
Ohio University Accelerator Lab
Texas A&M Cyclotron Lab
TUNL Triangle Universities Nuclear Lab
(Duke, University of N.Carolina, N.Carolina State U.)
Union College Ion Beam Analysis Laboratory
University of Kentucky Accelerator Lab
University of Mass. (Lowell), Radiation Lab
University of Notre Dame, ISNAP
University of Washington, CENPA

An Organization of the users

at these non-user labs.
today: 176 registered users

**http://aruna.physics.fsu.edu**

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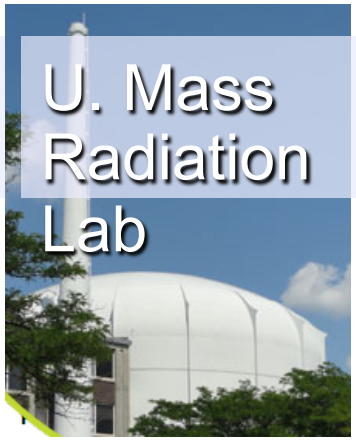
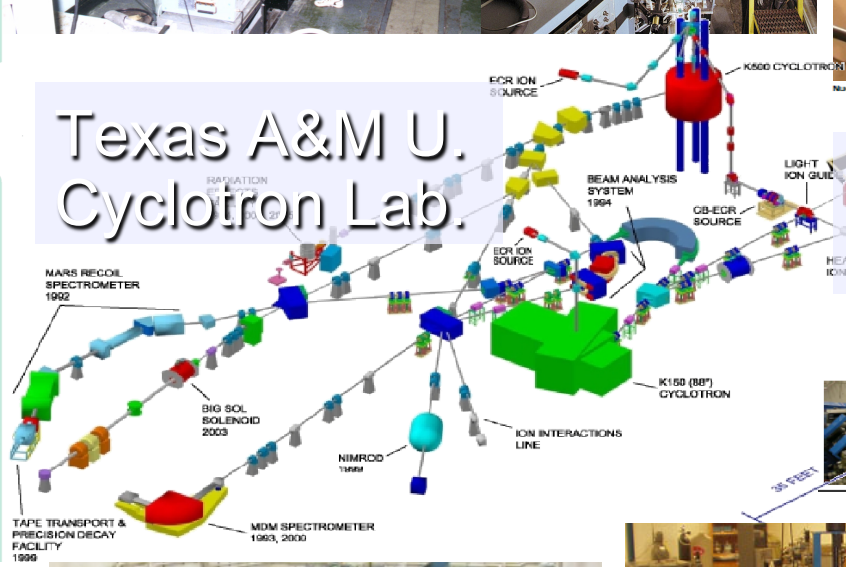
FSU
John D. Fox Laboratory

U. Kentucky
Accelerator Lab



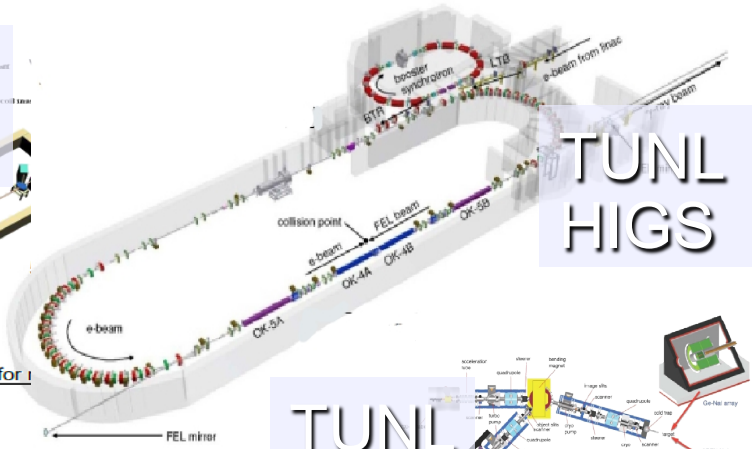
U. Mass
Radiation
Lab

Ohio U
Edwards Lab.




Texas A&M U.
Cyclotron Lab.

Notre Dame Univ.
ISNAP facilities




TUNL
HIGS

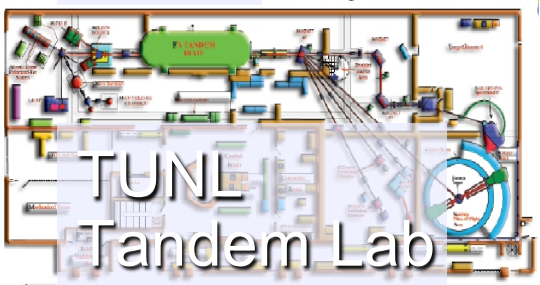


TUNL
LENA

University of
Washington
CEPNAP

Hope College
Ion Beam Lab

Union College
Ion Beam Lab



TUNL
Tandem Lab

# ARUNA Whitepaper Workshop
# June 12-13, 2014
# University of Notre Dame

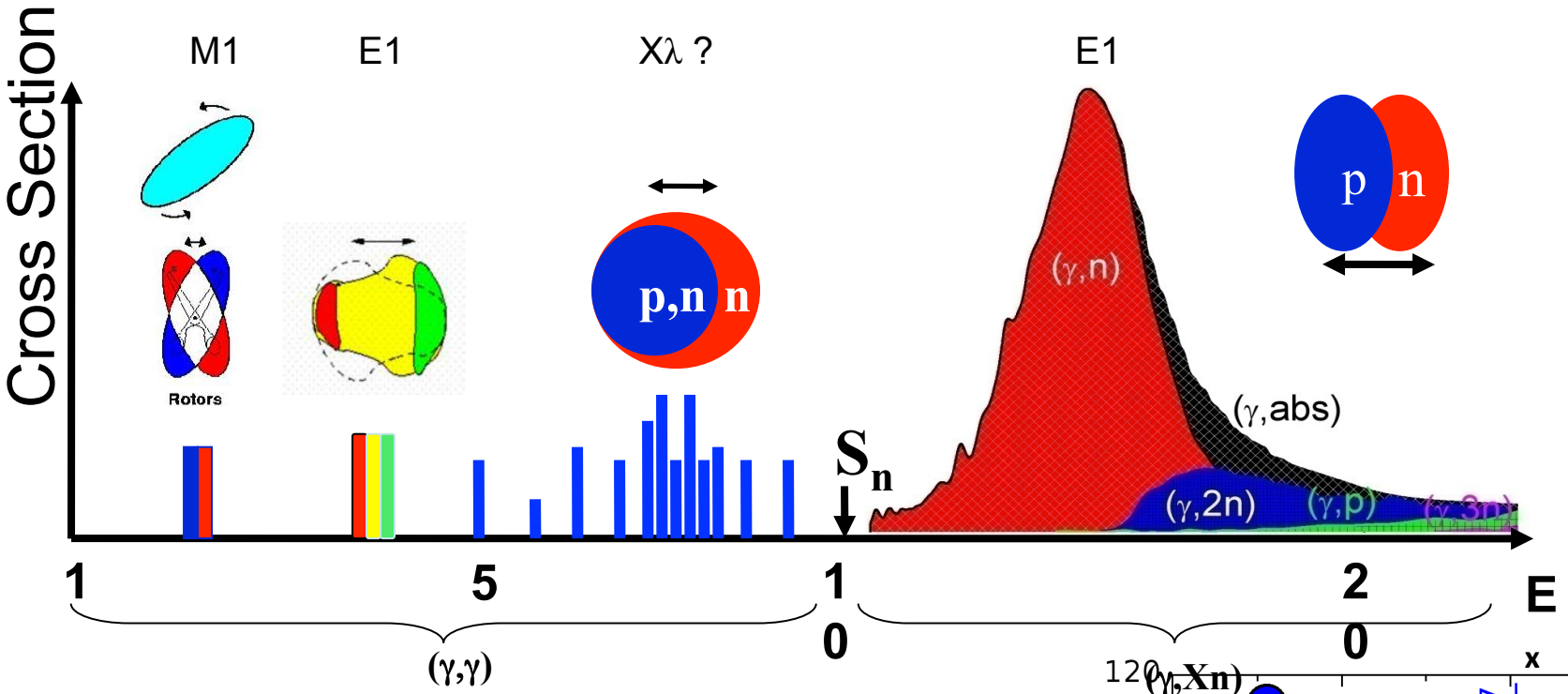
59 Registered Participants from 20 Institutions
7 Sessions on

- Operations, Capabilities and Future Plans (see Facilities)
- Nuclear Structure and Reactions (Wiedenhoever)
- Nuclear Astrophysics (Brune)
- Fundamental Symmetries, (Garcia)
- Applications (Couder, Peaslee)
- Education and Workforce development (Yennello)

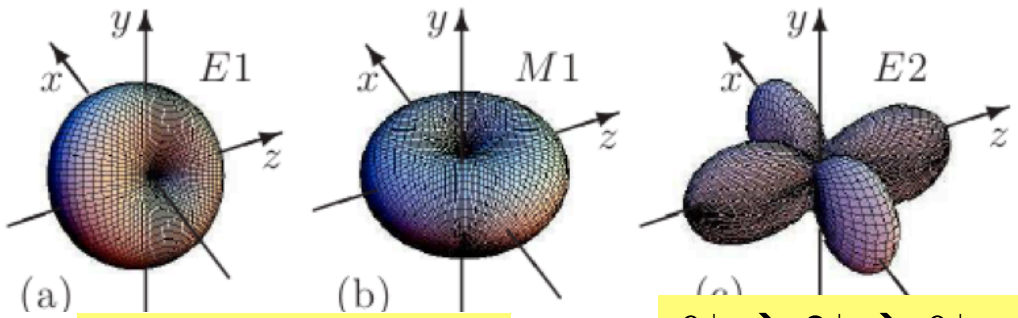
# Nuclear Structure and Reactions: Programs

- Structure of exotic nuclei:
  RIB and scattering, transfer (Texas A&M, FSU, UND),
  SIB and gamma-spectroscopy (FSU)
- Collective excitations
  Gamma-beams (TUNL-HIGS)
  Neutron-beams (UKAL)
- Structure for ($0\upsilon\beta\beta$) decay (UKAL, TUNL-HIGS)
- Equation of State:
  Symmetry energy and density-dependence EOS (Texas A&M)
- Statistical Nuclear Physics: Light-ion reactions (Ohio U)
- Super-heavy elements:
  Surrogate reactions, Online chemistry (Texas A&M)
- Surrogates for (n,fission) (URichmond@Texas A&M)

# Nuclear Resonance Fluorescence (NRF) with Linearly Polarized Gamma-rays Enable Unambiguous Distinction between E1 and M1 Excitations

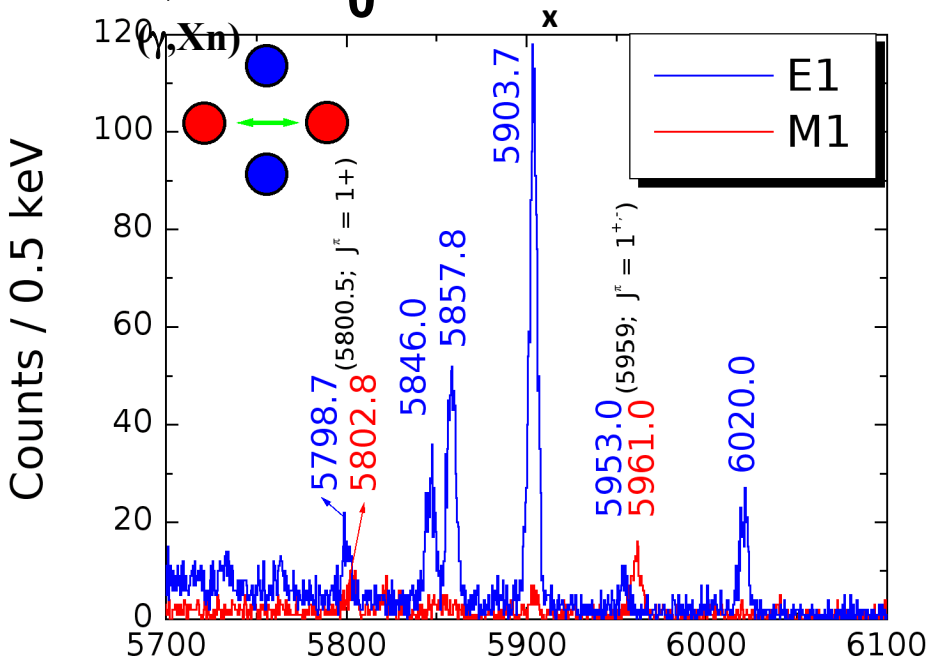



## Dipole and Quadrupole Excitations




$0^+ \rightarrow 1^{(+,-)} \rightarrow 0^+$

$0^+ \rightarrow 2^+ \rightarrow 0^+$




Measured $^{206}$Pb($\gamma,\gamma'$) energy spectrum

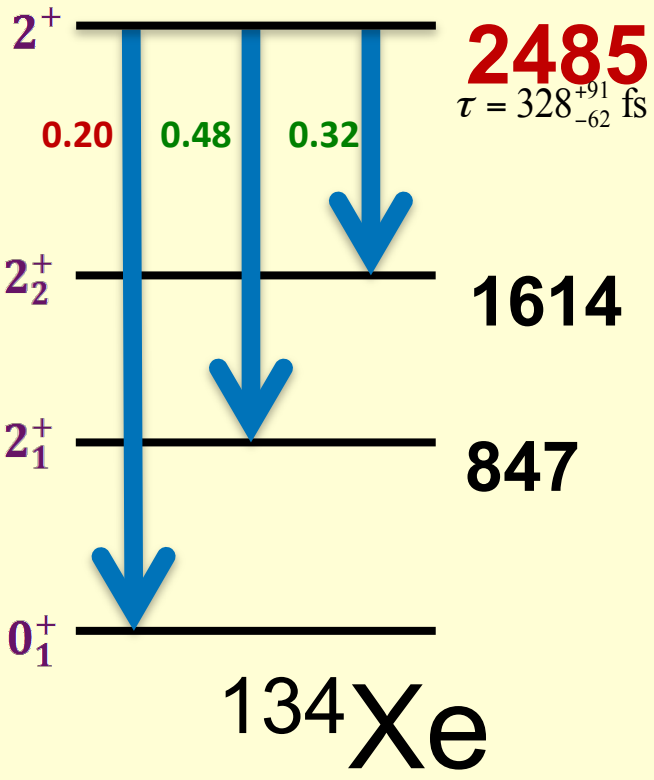
# Nuclear Structure Studies for neutrinoless double beta-decay

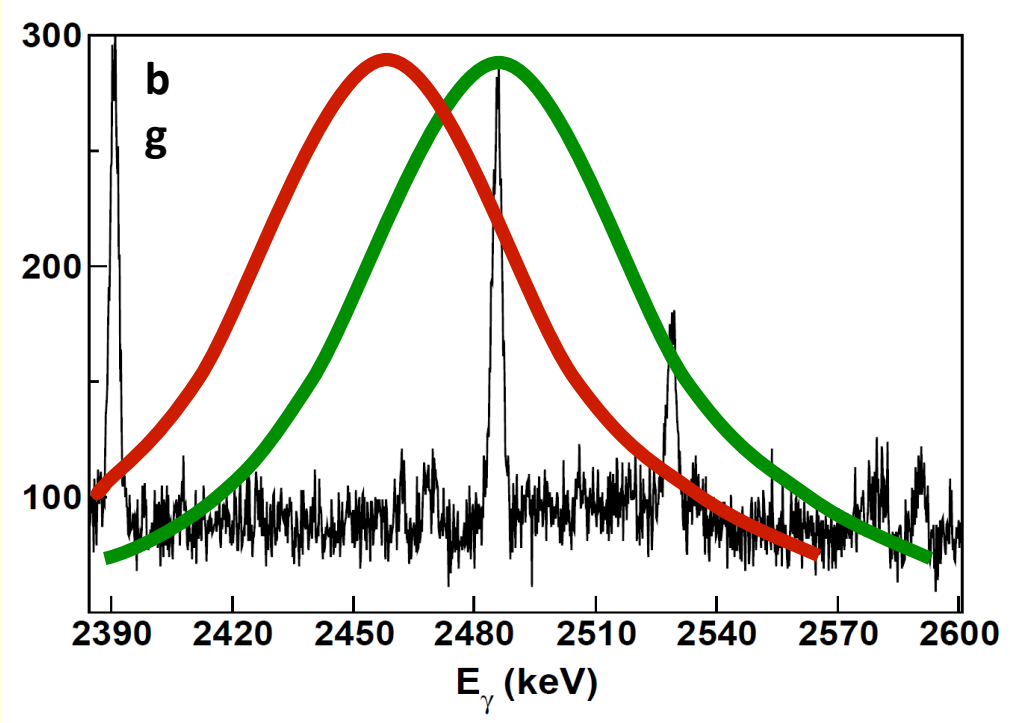
EXO Enriched Xenon Observatory

**EXO-200: 200 kg of Xe**
**80.6% 136Xe, 19.4% 134Xe**

Study with mono-energetic Neutrons,
Solid XeF2 samples of 130Xe, 132Xe, 134Xe, 136Xe
of **multi-phonon excitations**, p-n **mixed symmetry states**

## Quantifying the (n,γ)- induced background for EXO



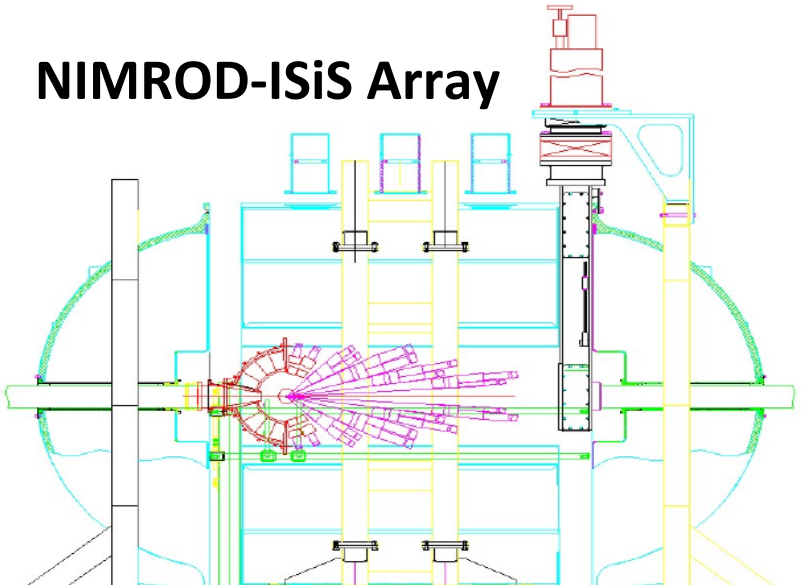



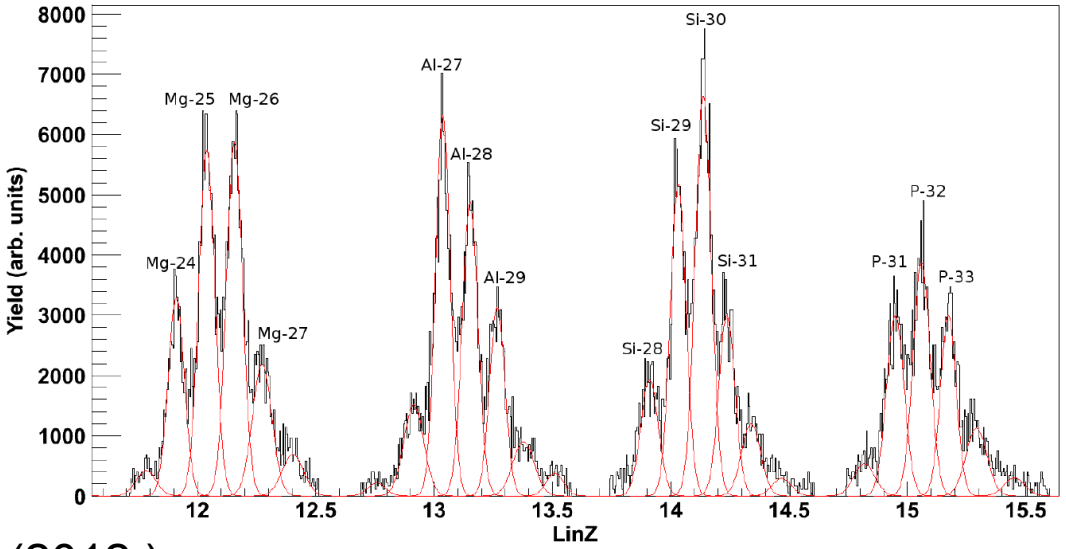

**0νββ Q-value: 2458 keV**
**EXO-response to 2485 keV**

# Nuclear Dynamics and Thermodynamics

J.B. Natowitz & S.J Yennello

**NIMROD-ISiS Array**

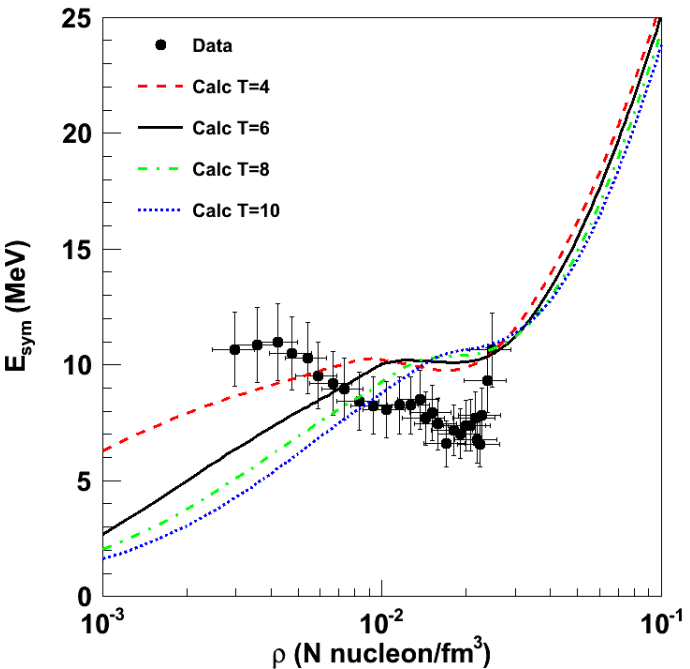





R. Wada et al.Phys. Rev. C 85, 064618 (2012 )
J.B. Natowitz et al., Phys.Rev.Lett.104:202501 (2010) and Viewpoint: Lee G. Sobotka, Physics 3, 42 (2010)

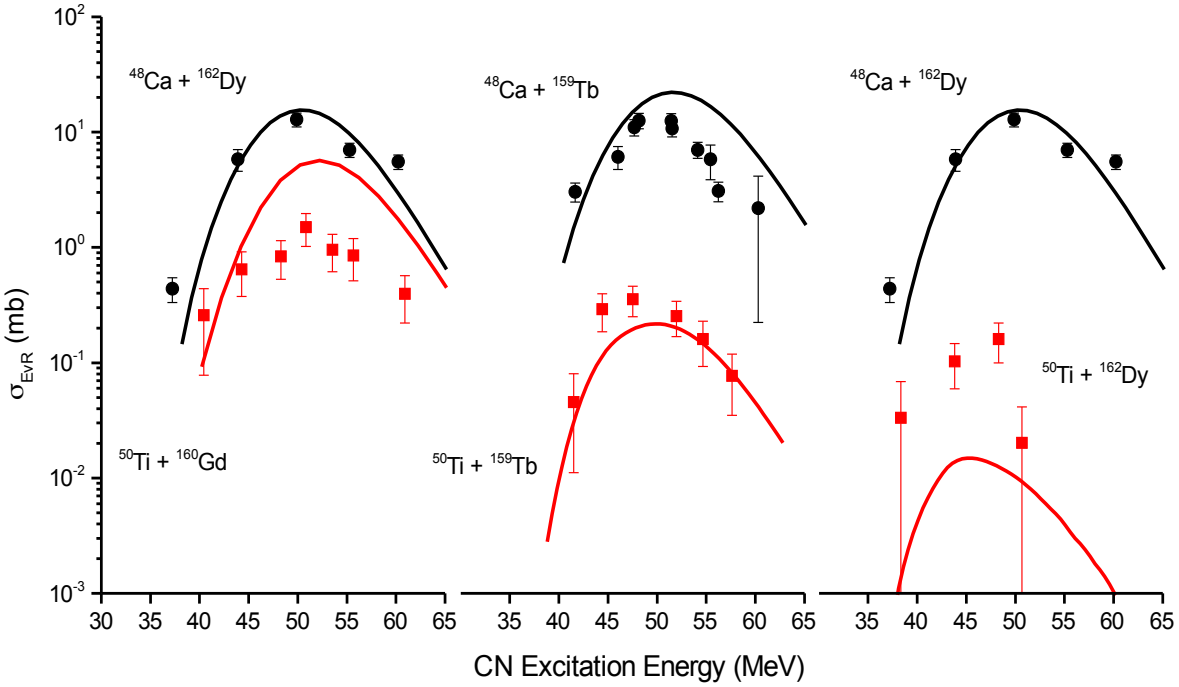
Analysis of Cluster Yield Ratios: For Different N/Z Systems:

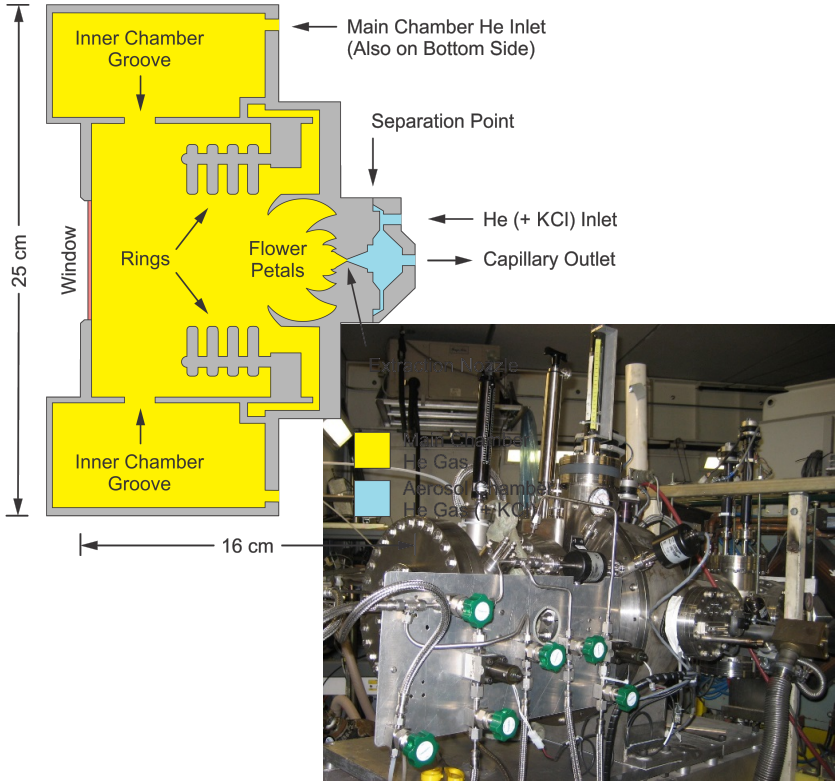
At low density, the symmetry energy is determined by cluster formation



# Heavy Element Reaction Studies at the Cyclotron Institute

- Study analogue reactions for SH synthesis:
- Substantially reduced cross sections are observed for $^{45}Sc$ and $^{50}Ti$ compared to $^{48}Ca$: |
  Production of A>118 will be difficult (10-50 nb)
- Recent development: On-line chemistry setup at MARS



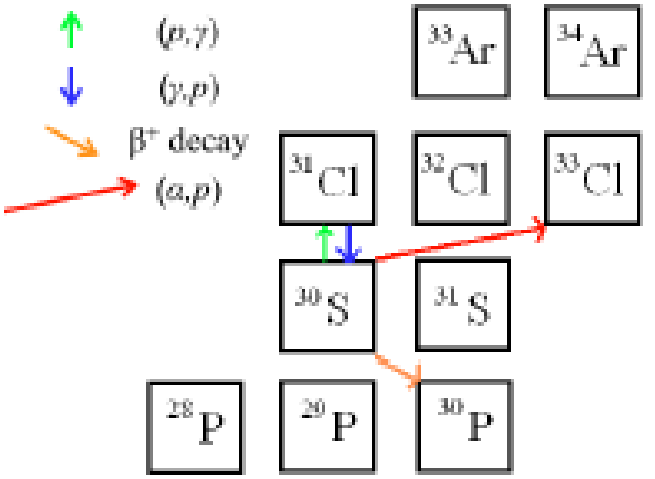
# Nuclear Astrophysics Programs

- P and α-resonance spectroscopy for explosive nucleosynthesis,
  high-res Spectrographs (TUNL-Tandem, LSU@FSU)
  (new initiatives)

  high-res n-spectroscopy (Ohio U)
  surrogate transfer and direct measurements with RIB (FSU,UND)
- Direct cross sections measurements of (p,γ) and (α,γ) , (α,n)
  solar v-sources, n-sources, CNO-cycle, Helium and C-burning
  (TUNL-LENA, UND:St.Ana, UND:Caspar)
  Measurement of $^{16}O(\gamma,\alpha)^{12}C$ (TUNL-HiGS)

(Also: Following talk by C. Brune)

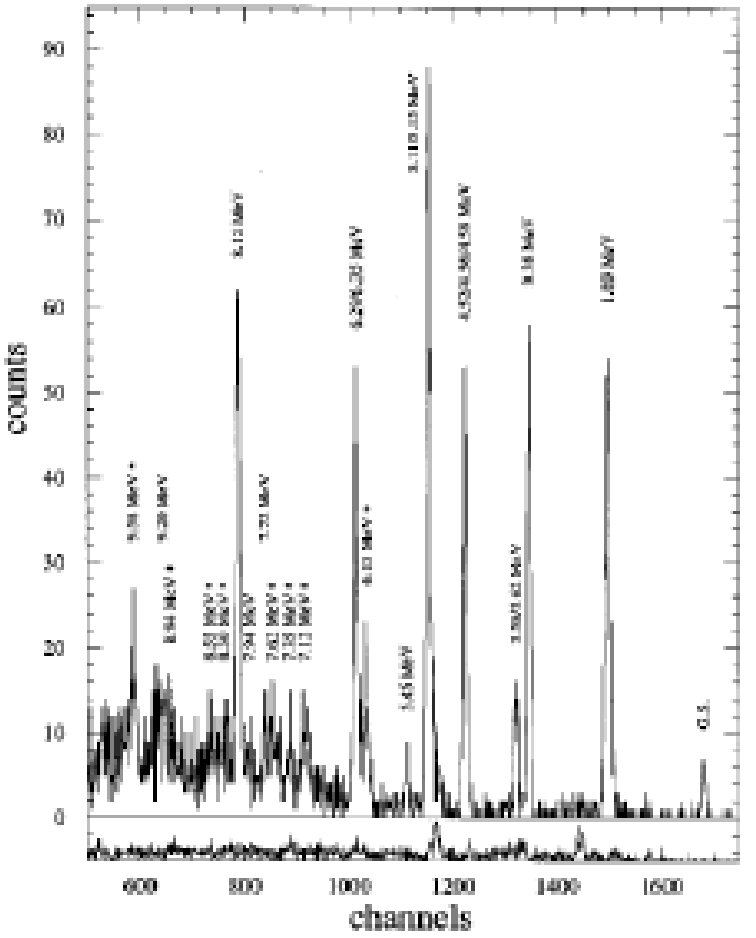
# X-Ray Bursts: $\alpha p$ process



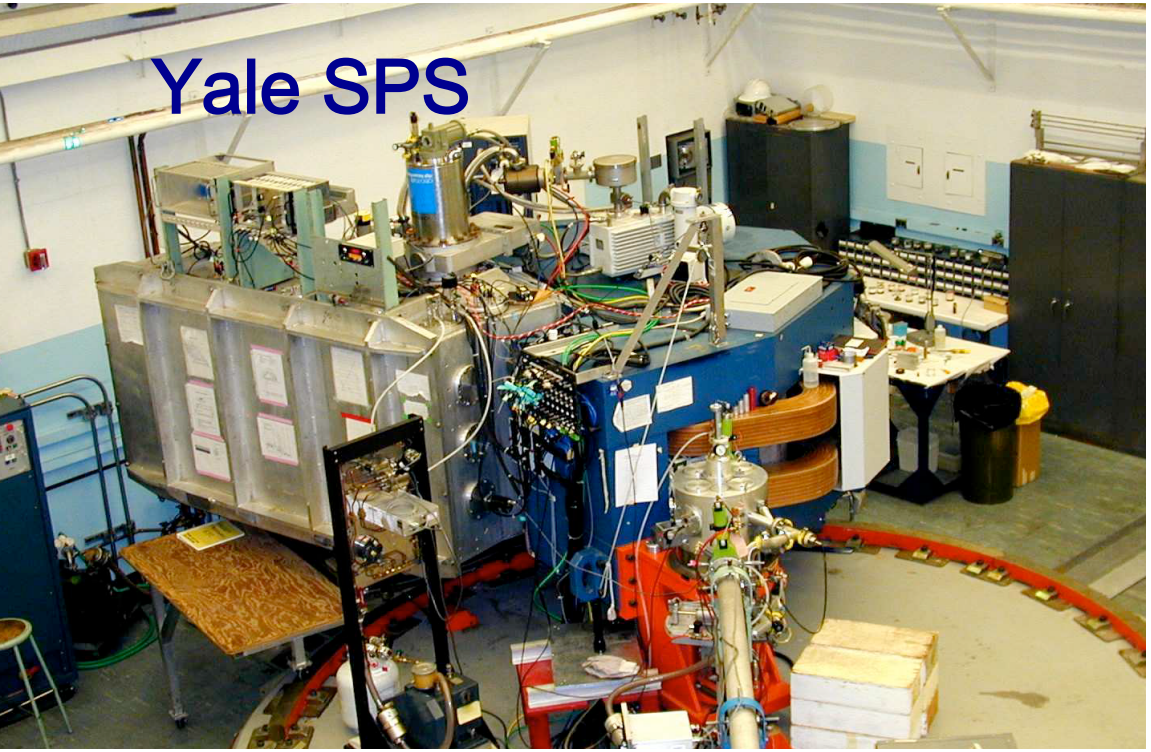

- Indirect studies of level structure of compound nuclei in $(\alpha,p)$ reactions on waiting point nuclei ($^{26}$Si, $^{30}$S, $^{34}$Ar, $^{38}$Ca)

- Recent studies of $(p,t)$ and ($^{3}$He,$n$) reactions find new states in Gamow window
  - 2$n$ transfer highly selective
  - multiple states seen in mirror nuclei are not accounted for

- Complimentary information needed
  - ($^{12}$C,$^{6}$He) reaction less selective
  - determination new $^{21}$Ne states with resolution of ~ 20 keV with Yale Enge SPS
    - K.I. Hahn *et al.*, PRC **54**, 1999 (1996)



# Two high-resolution spectrographs at ARUNA





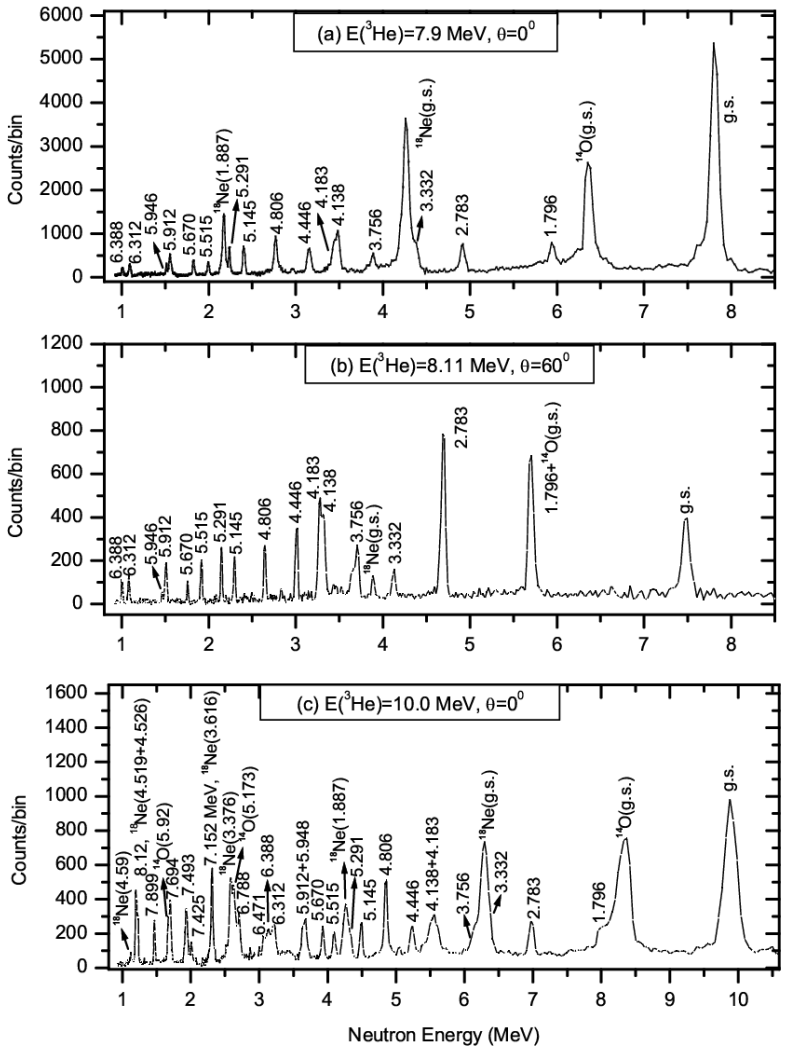
The (ex-Yale) Enge Split-Pole Spectrograph has been relocated to FSU. (NSF-MRI) (Deibel / Blackmon / Wiedenhoever / Cottle) Commissioning: 2016

The TUNL SPS will be re-commisioned shortly (R. Longland)

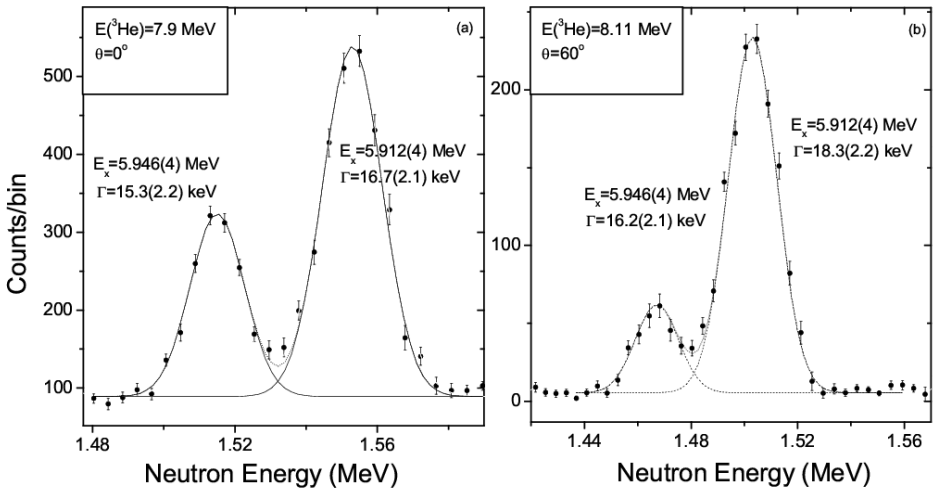
# Ohio University: Neutron Energy Spectra

(Y. Parpottas)

full spectra




$^{24}Mg(^{3}He,n)^{26}Si(*)$




Key Result

Mirror nucleus leads us to expect $3^+$ and $0^+$ in this region.

THE FLORIDA STATE UNIVERSITY

# ANASEN @ FSU / MSU(ReA3)

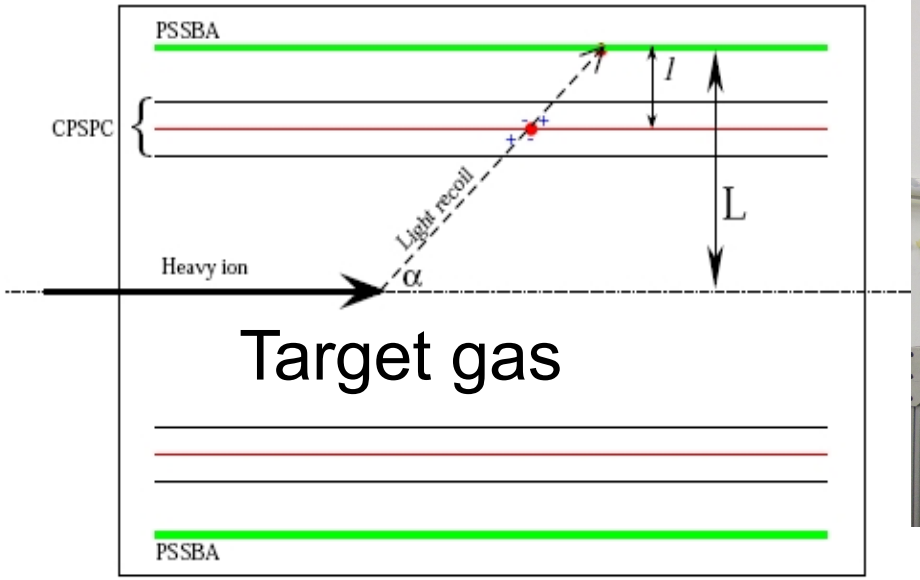
## Array for Nuclear Astrophysics Studies with Exotic Nuclei

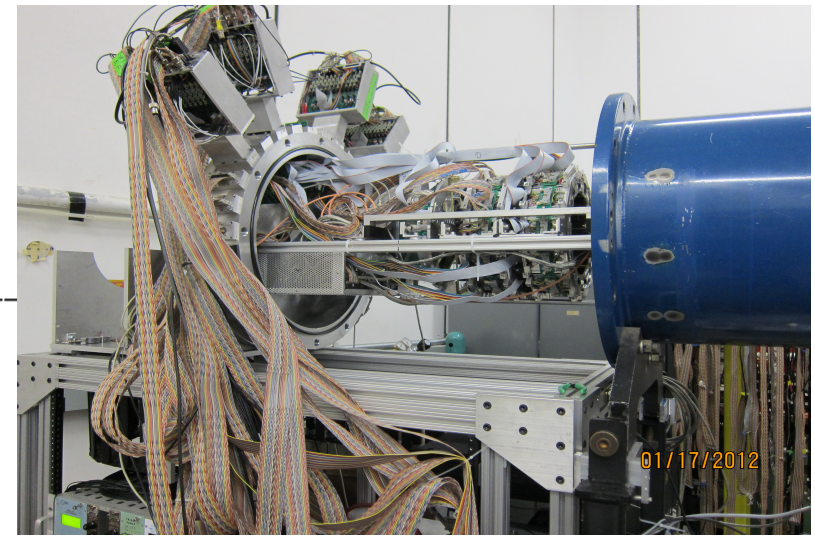
LSU LOUISIANA STATE UNIVERSITY

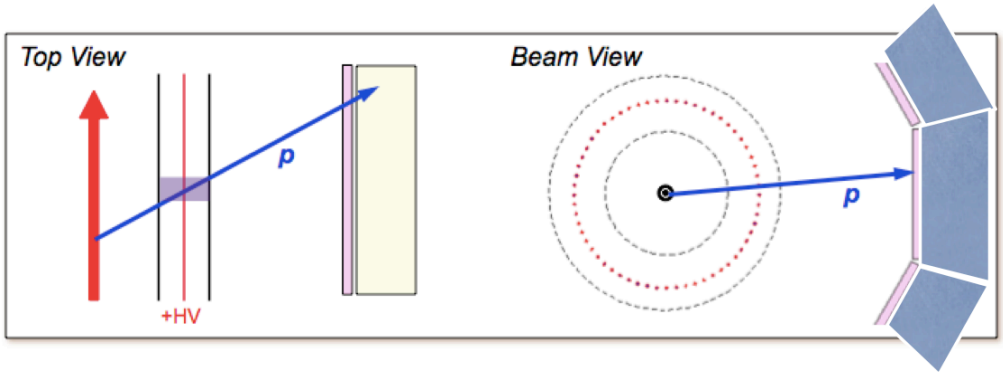
NSF NATIONAL SCIENCE FOUNDATION

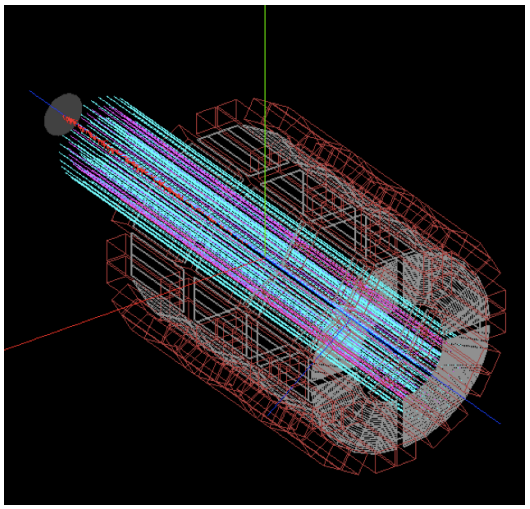
NSCL

JINA



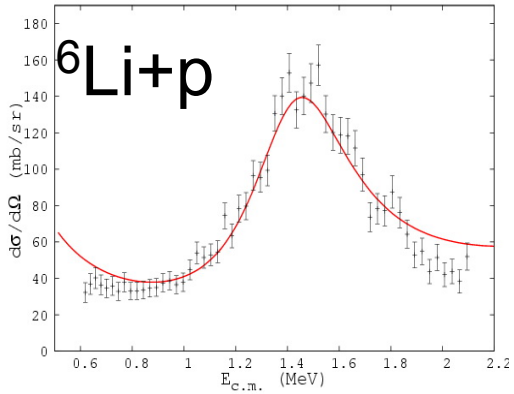



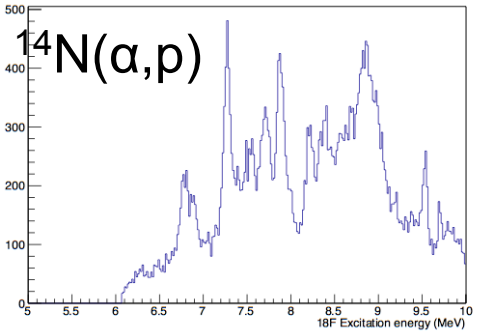



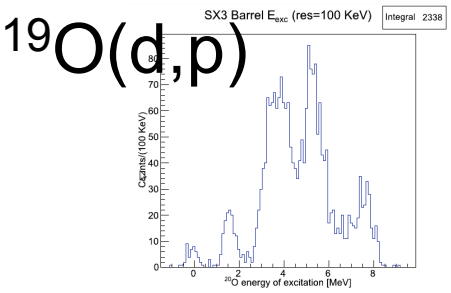
ANASEN is designed to perform astrophysically relevant measurements with r/a beams:

- Resonance scattering to identify and characterize astrophysically important resonances
- Direct measurements of (α,p) reactions involved in (α,p) process
- Nucleon transfer reactions to determine properties of astrophysically relevant states

## Results of the test runs

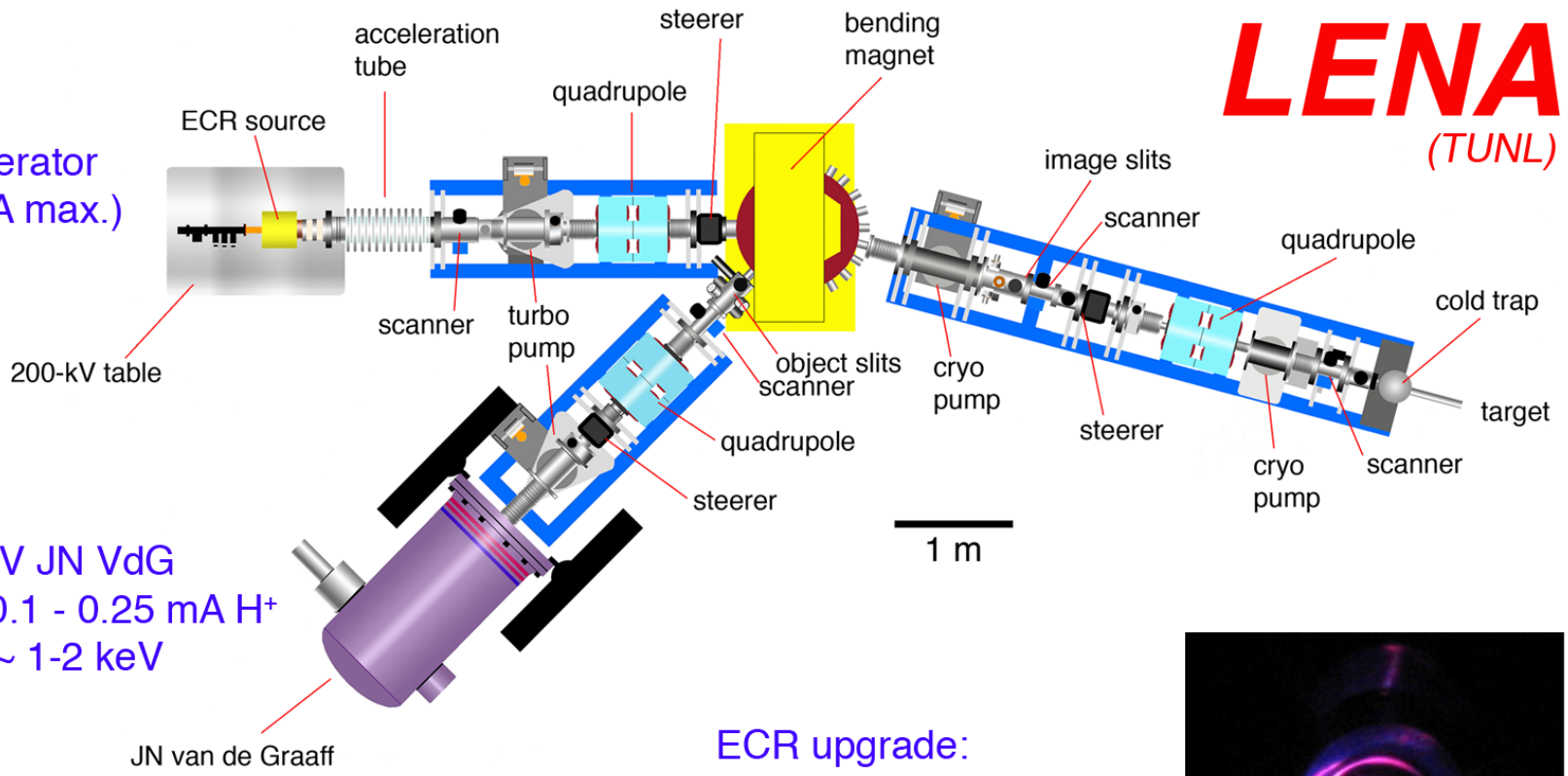


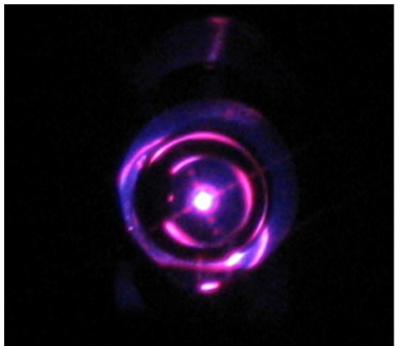
# LENA
(TUNL)

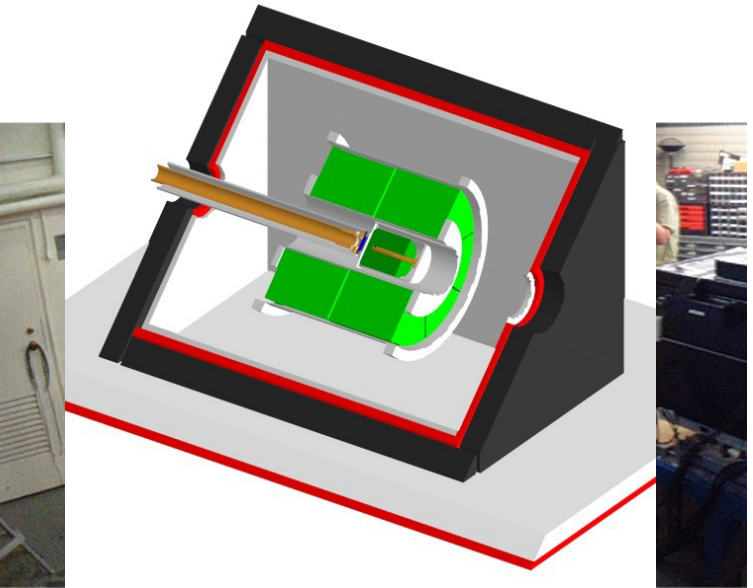
200-kV ECR accelerator
I > 1 mA $H^+$ (1.6 mA max.)
ΔE < 800 eV

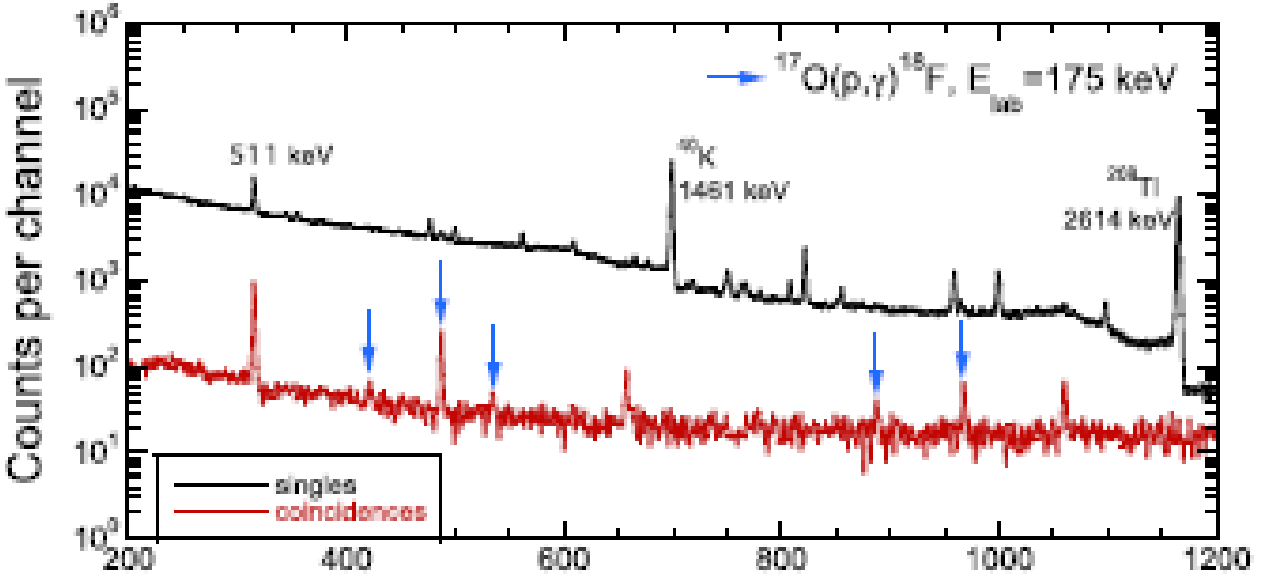



1-MV JN VdG
I = 0.1 - 0.25 mA $H^+$
ΔE ~ 1-2 keV

ECR upgrade:
$I_{DC}$ > 10 mA
pulsed at 10% duty cycle
(in progress)



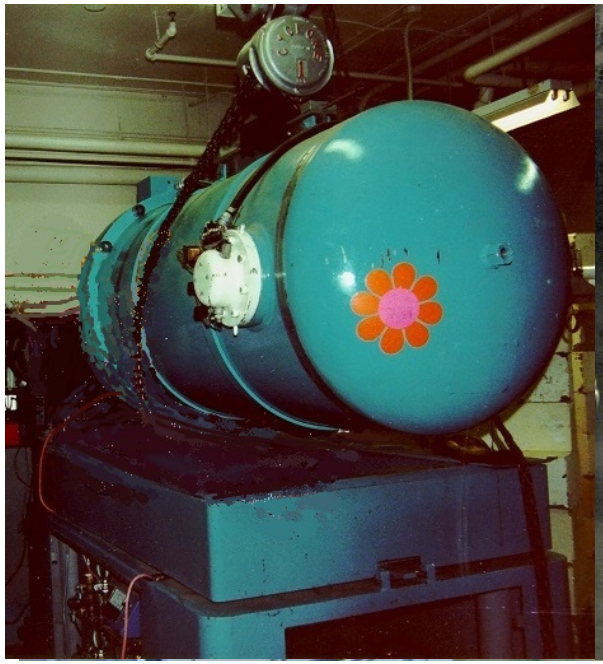


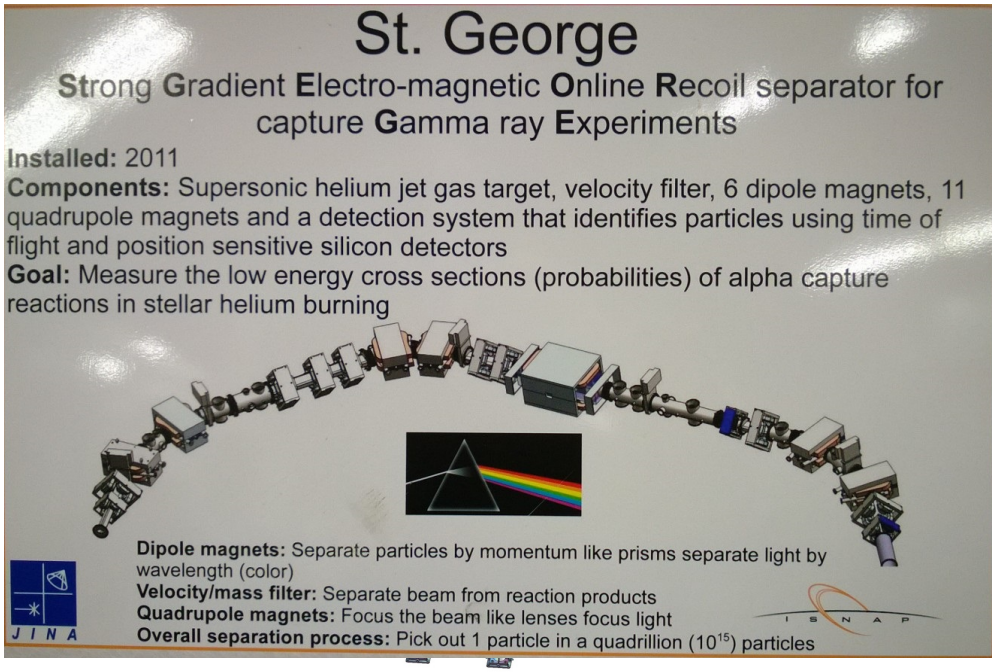


# Experimental complementarity with forward and inverse kinematics

Light ion on heavy target with measurement of light reaction products, limited by solid angle and detection efficiency.

Heavy ion on light target with measurement of heavy ion recoil yield, limited by initial beam intensity and acceptance of recoil separator

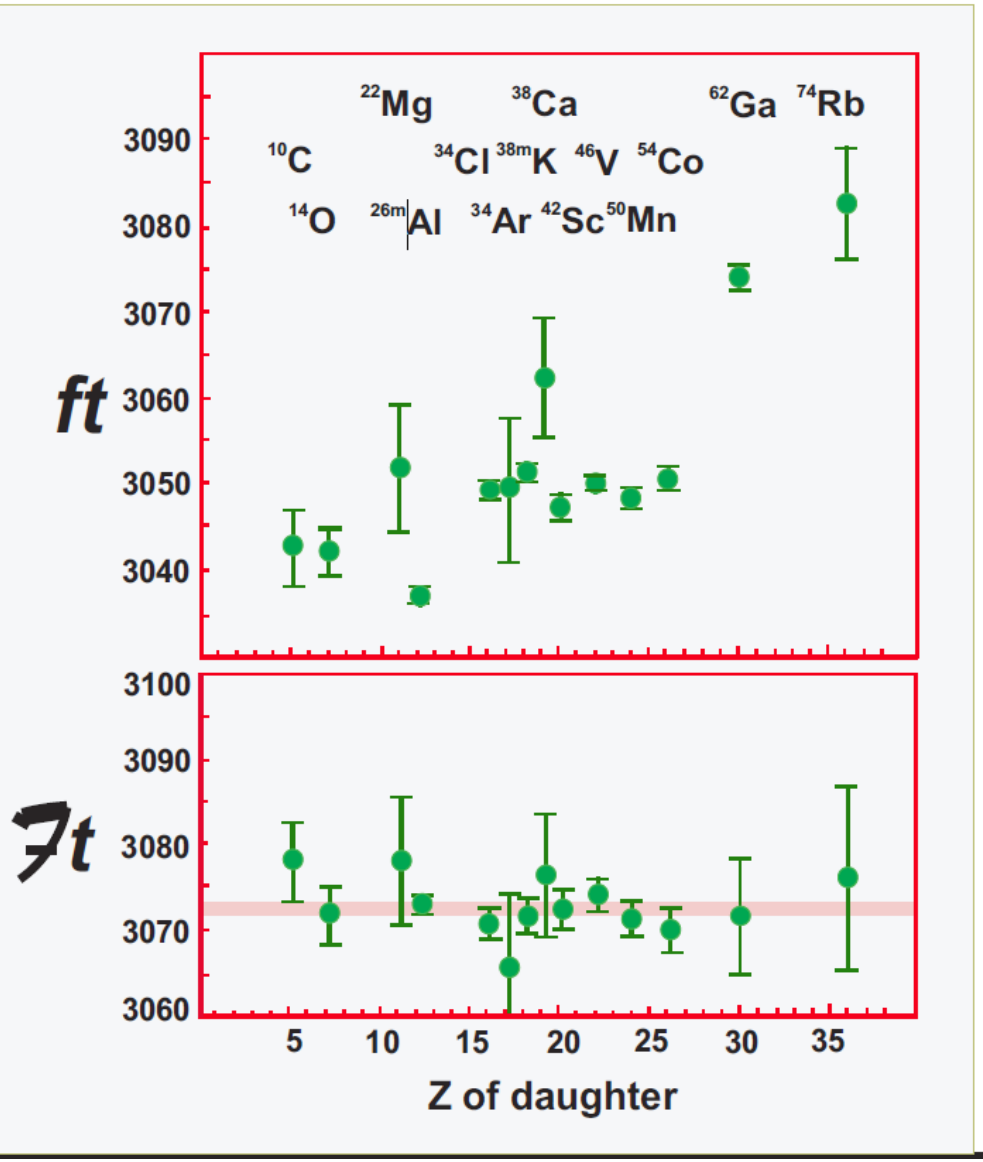




# Fundamental Symmetry Studies

- Superallowed beta-decay matrix elements
  CKM unitarity (Texas A&M)
- Search for Scalar Currents in T=2 β-decay
  Melocian (Texas A&M)
- Search for Tensor Currents
  6He trap spectroscopy (ANL@UWashington)
  Electrosctatic Ion Beam Trap (EIBT) Berkeley

Texas A&M (and Jyvaskyla): measurements of lifetimes, *Q*-values, branches and isospin-breaking calculations have determined *Vud* and verified CVC.




- CVC verified
- $V_{ud} = 0.97417(21)$

**CKM unitarity test:**

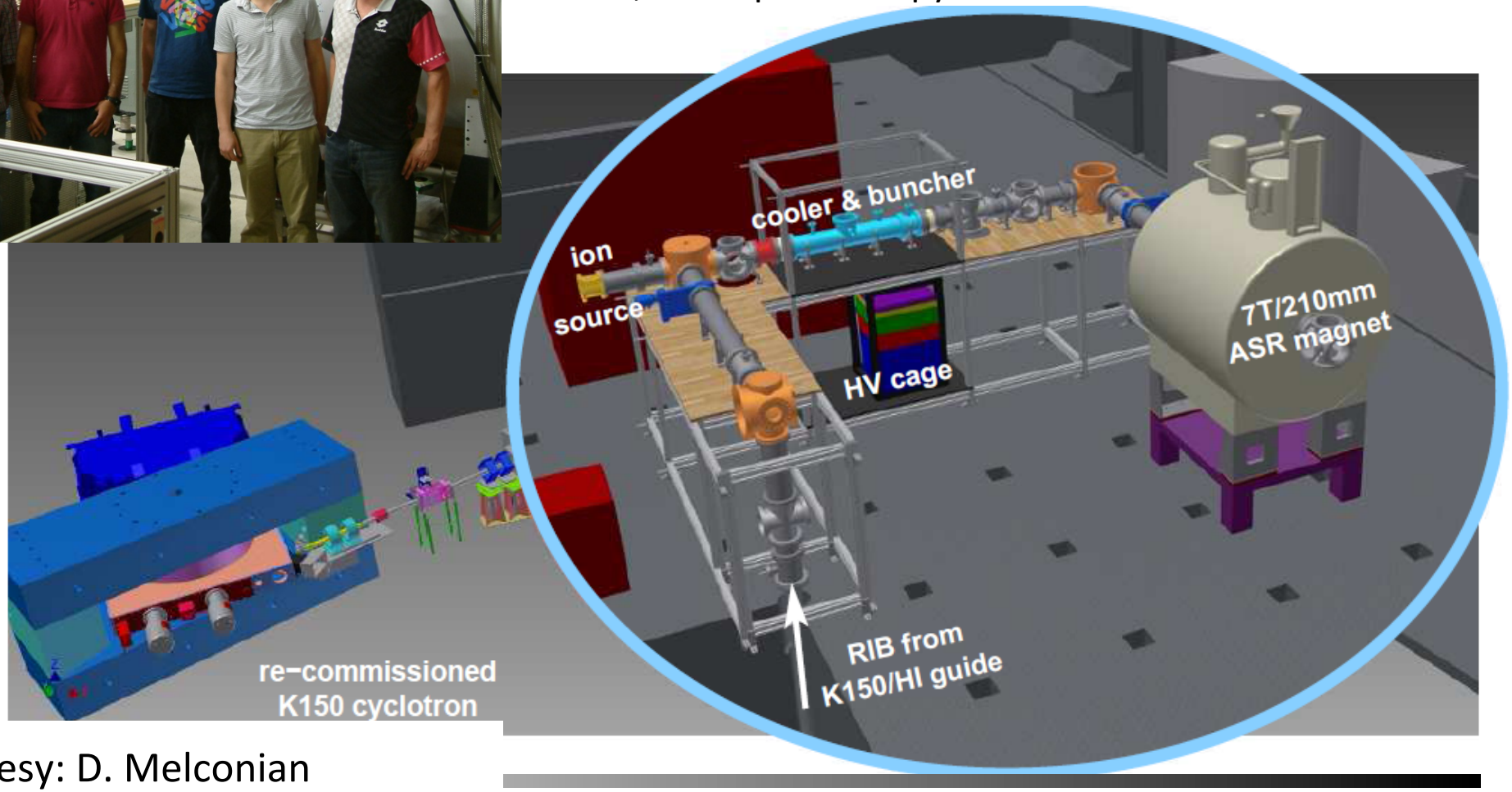
$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.9999(5)$$

Courtesy: J. Hardy

Texas A&M: world's most open-geometry ion trap; will determine isospin-breaking corrections and search for scalar currents in *T=2* decays.

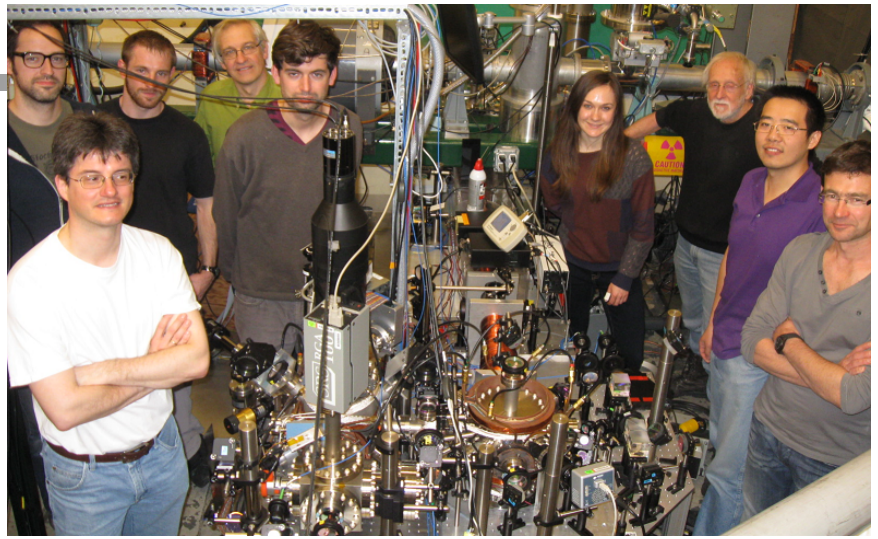
Uniquely suited for studying β-delayed proton decays:

- β – ν correlations, ft values / Vud,
- amendable to mass measurements, EC studies, laser spectroscopy.



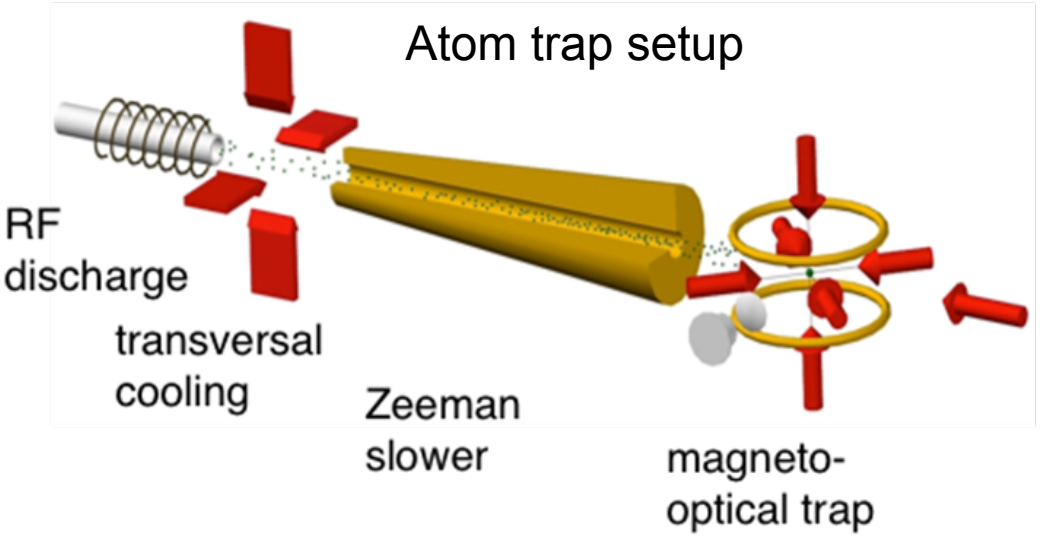

Courtesy: D. Melconian

# Argonne – CENPA $^{6}$He-little-a collaboration: laser trapping of $^{6}$He in search for tensor currents

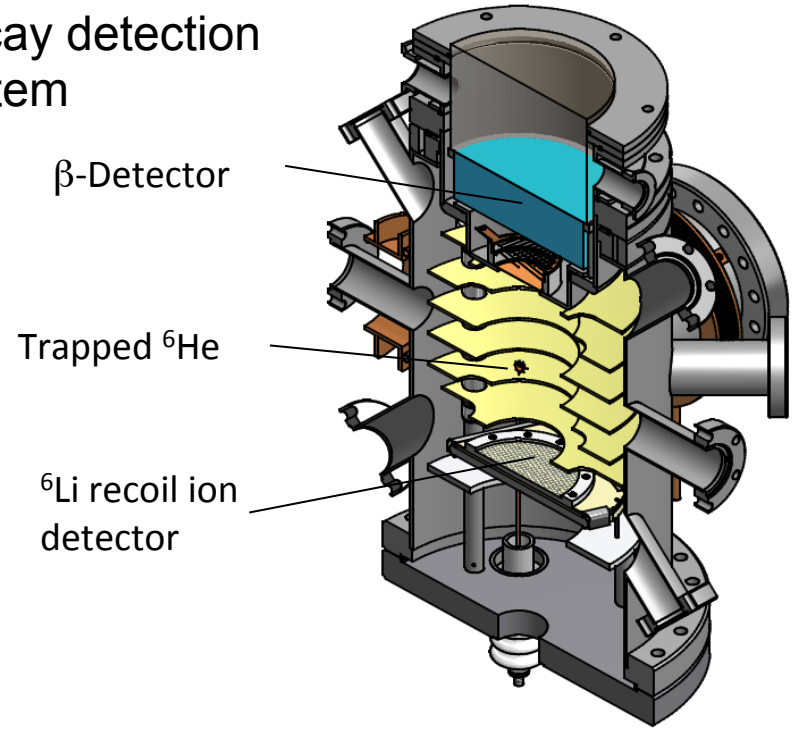



**$^{6}$He little-a collaboration (P. Mueller, A. Garcia spokepersons)**
P. Mueller, A. Leredde, K. Bailey, T.P. O'Connor *(Argonne)*
X. Fléchard, E. Liennard, (*LPC, CAEN, France)*
O. Naviliat-Cuncic (*NSCL, MSU)*
A. Knecht (*PSI, Switzerland)*
Y. Bagdasarova, A. Garcia, R. Hong, M. Sternberg, D. Storm, H.E. Swanson, F. Wauters, D. Zumwalt *(University of Washington)*


- CENPA produces ~ $10^{10}$ $^{6}$He/s
- Allows for laser trapping and other experiments
- Goal: determination of little-a to 0.1%.




Decay detection system

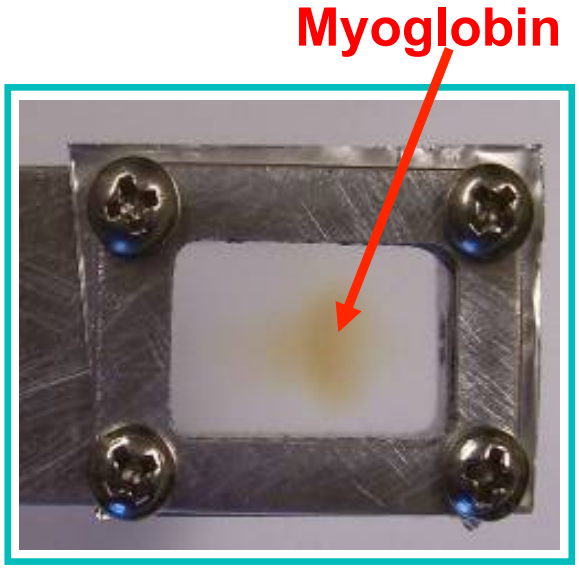



Courtesy: P. Mueller (Argonne), A. Garcia (UW)


# Applied Programs

# ARUNA facilities perform a broad range of applied and interdisciplinary nuclear physics experiments(1)

- Hope College Ion Beam Analysis Laboratory
  - Goal of facility #1: Applied research in multiple disciplines (surface science, environmental science, forensic science, limnology, biochemistry, geology, public health) using nuclear physics techniques of Ion Beam Analysis. Published peer-review research.
  - Goal #2 of facility: Offer research experiences to a wide variety of undergraduate students, provide STEM workforce training and attract good students into nuclear chemistry and nuclear physics disciplines.



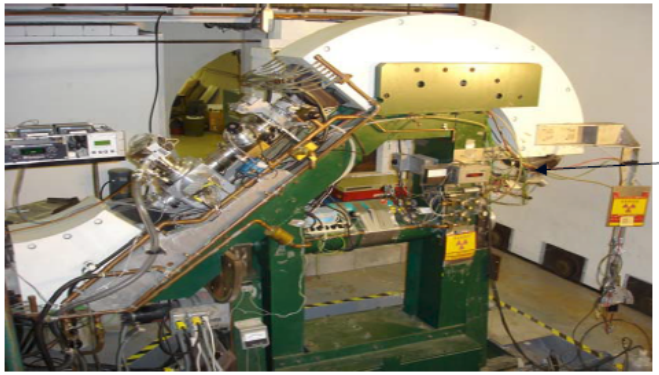

JD Warner *et al.*, Nucl Instr. Meth. B (2010)
SAJ Messing *et al.*, Nucl Acids Res (2012)

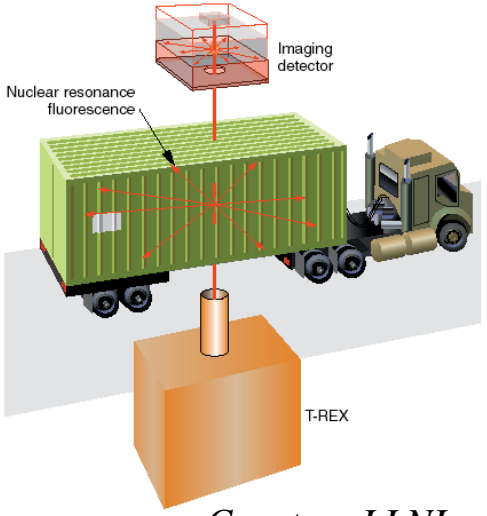
- University of Notre Dame Institute for Structure and Nuclear Astrophysics & Radiation Laboratory
  - Examination of radiation effects
  - Nuclear power industry
  - Medical therapy
  - Space study and exploration
  - Homeland security
  - IBA in collaboration with archeology department and lots of undergrad involvement
  - Isotope production studies

PIXE at Hope College

# ARUNA facilities perform a broad range of applied and interdisciplinary nuclear physics experiments(2)

- Ohio University Edwards Accelerator Laboratory
  - Medical Physics -- neutron spectra for cancer therapy
  - Neutron Imaging (LLNL / Jim Hall)
  - Neutron-induced single-event upset studies (LLNL)
  - Neutron Detector Development (Photonics, Inc.)
  - Dosimeter Calibration (Overhoff Technology, Inc.)
  - Fast neutron transmission in iron
  - Cross section measurements for Inertial Confinement Fusion: $^{3}H(d,\gamma)$ $\gamma$-ray production 14-MeV neutrons
  - $^{12}C(n,2n)^{11}C$ (Houghton College, SUNY Geneseo)



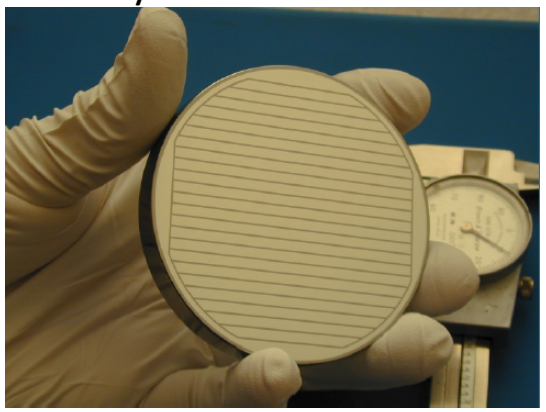

*Courtesy LLNL*

- Triangle Universities Nuclear Laboratory
  - Photonuclear measurements on actinides (Homeland security)
  - Nuclear resonance fluorescence measurements (Homeland security)
  - Photofission induced with polarized $\gamma$-ray beams (Energy and Homeland security)
  - Neutron induced reaction (National nuclear security)
  - Plant Physiology studies using radioisotope tracing
  - Characterization of membrane for water purification by filtration

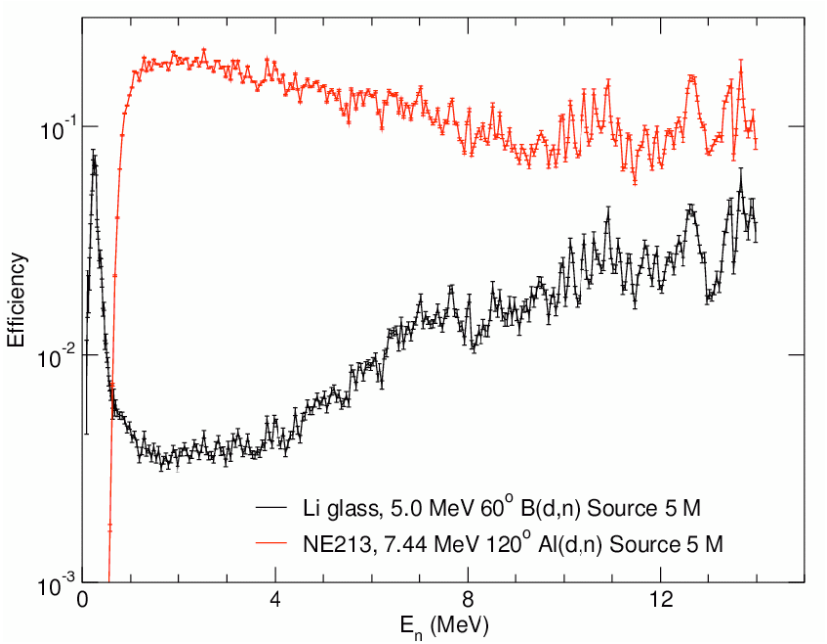
# ARUNA institutions test, develop and design new detectors

- University of Massachusetts Lowell
  - Development of a "proof-of-concept" array of CLYC detectors for fast neutron spectroscopy
  - GeDSSD
    - Imaging and high count rate capabilities
    - Test of neutron damage "reparability"

$Cs_2LiYCl_6:Ce$ (CLYC)



- Ohio University Edwards Accelerator Laboratory
  - Detector calibration




- University of Notre Dame
  - SuN detector testing for NSCL/FRIB
  - AT-TPC prototype testing for NSCL/FRIB
  - Measurement of Scintillation and Ionization of Nuclear Recoils in Noble Elements for Dark Matter Searches (Princeton, Fermi lab)

# Education

- Undergraduate Education (all of ARUNA)
- Graduate Education (most of ARUNA)
- Workforce Development (all of ARUNA)
- Outreach (all of ARUNA)


# Educating Nuclear Scientists: FSU, Kentucky, Notre Dame, Ohio, TUNL, TAMU, UMass

143 current graduate students

- At Notre Dame 43% female

63 graduates in last 10 years

75 current undergraduate researchers

37 current postdocs

# What students gain from participation in research as undergraduates

Technical skills

Creative problem solving

Scientific communication skills

Dealing with frustrations / perseverance

Self confidence

Time management

Project planning

Working within a collaboration

Leadership development

# Undergraduate students of Prof. Sally F. Hicks, University of Dallas, who have worked at UKAL

## NSF Supported (17):

Eric Meier (1991), Christopher Bennett (1991), Suzy Maska (1992), Carl Lundstedt (1993), Chris Davoren (1994), William Faulkner (1995), Stephen Etzkorn (1997), Peter Burkett (1997), Corey Collard (1998), Gary Alexander (1998), Meghan Walbran (1999), Beth Sklaney (1999), Chris Aubin (1999), Patrick Roddy (2000), Matt Burns (2001), J. C. Boehringer (2001), Jeff Ellis (2002)

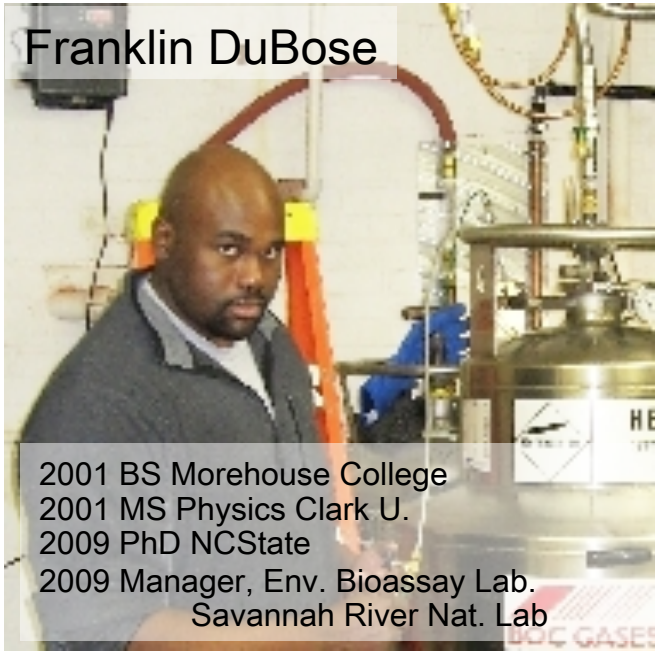
## DOE Supported (13):

Peter McDonough (2010), Luke Kersting (2010), Collin Lueck (2010), Anthony Sigillito (2011), Jessie Girgis (2011), Laura Downes (2011), Jeff Schniederjan (2011), Leslie Sidwell (2012), Brett Combs (2012); Samuel Henderson (2013); Aaron French (2014); Thaddeus Howard (2014); Luke Pecha (2014)

# TAMU Research Experiences for Undergraduates

- The Cyclotron Institute has hosted REU programs every year since the Summer of 2004.
- Approximately 12 students/yr
- Entirely focused on nuclear science
- Emphasis on students from schools that do not offer thee types of research opportunities

# Educating the (Nuclear) Workforce

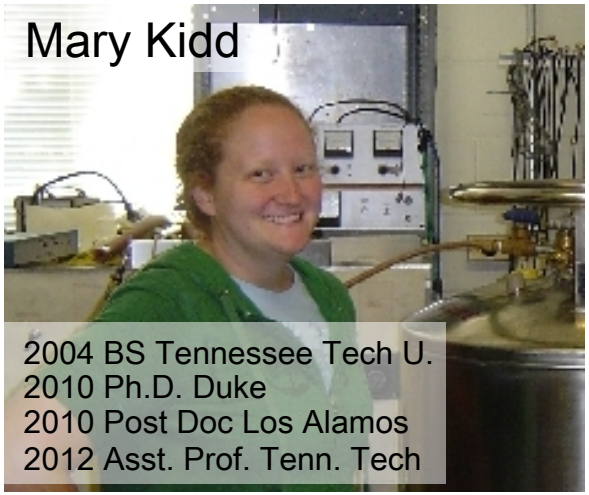


## Franklin DuBose

2001 BS Morehouse College
2001 MS Physics Clark U.
2009 PhD NCState
2009 Manager, Env. Bioassay Lab.
Savannah River Nat. Lab

## Calem Hofman

2003 FSU Undergrad
2010 Ph.D. FSU / MSU
APS Dissertation Awa
2012 Argonne Staff Scientist



## Mary Kidd

2004 BS Tennessee Tech U.
2010 Ph.D. Duke
2010 Post Doc Los Alamos
2012 Asst. Prof. Tenn. Tech

## Matthew Kiser

2002: BS King College
2008: PhD Duke
2008 – present: Senior Scientist,
National Security Technologies
2012: Secretary of Energy Achievement Award

## Rihannon Meherchand

2005 FSU undergrad
2011 PhD MSU
2011 Los Alamos
Director's Fellow

## Kevin D. Veal

1993: BS – Physics – Mississippi State
1998: Ph.D. – UNCarolina
1999 - 2010: Los Alamos National Lab,
Safeguards Science
2005 - 2007- Leading US technical representative
US delegation to North Korea 6-party talks
2011 - Acting Director,Office of Nuclear
Safeguards / DOE

# Outreach Nuclear Science Merit Badge of the Boy Scouts of America


# There is nothing like a scientist in the laboratory for inspiring a young person – get students into ARUNA facilities!


# Summary

1. ARUNA facilities do first rate science.
2. ARUNA facilities provide unique opportunities for new developments and testing that is not possible at big facilities.
3. ARUNA facilities attract students and help nuclear science compete for talent at the universities.
4. ARUNA facilities are flagships for universities and generate a lot of leverage support.
5. Scientists from ARUNA facilities are a major part of the user community of large facilities.
6. Scientists from ARUNA facilities are a intellectual resource, if not a motor for the field.

# Recommendation

In order to ensure the long-term health of the field, it is critical to maintain a balance between funding of operations at major facilities and the needs of university-based programs,
both for operations and new initiatives.