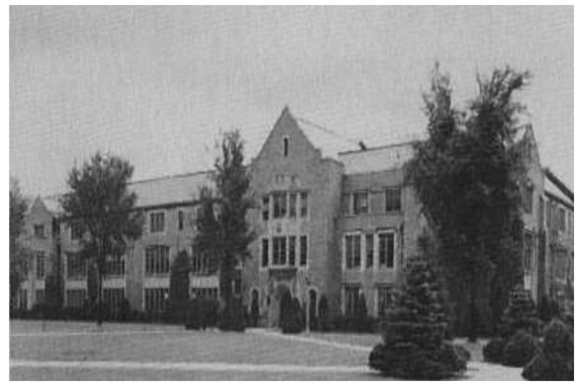
Nuclear Science at the University of Notre Dame

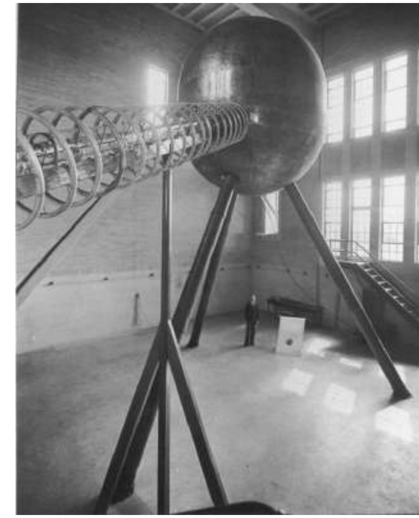
Patrick O'Malley
on behalf of the Nuclear Science Laboratory
University of Notre Dame

Historical Development of NSL

1936-1938 Construction of 1st Accelerator

Home built 1 MV open air machine for electron beams.

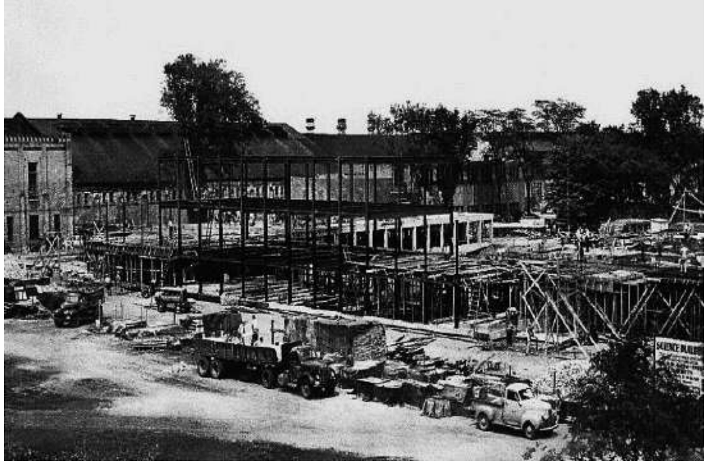




1940- 1942 Construction of 2nd Accelerator

a home built 8MV (4MV) VDG machine. It served the Manhattan (Hanford) project until 1950.

1953 Nieuwland Science Hall
1968 NSL Tandem Accelerator

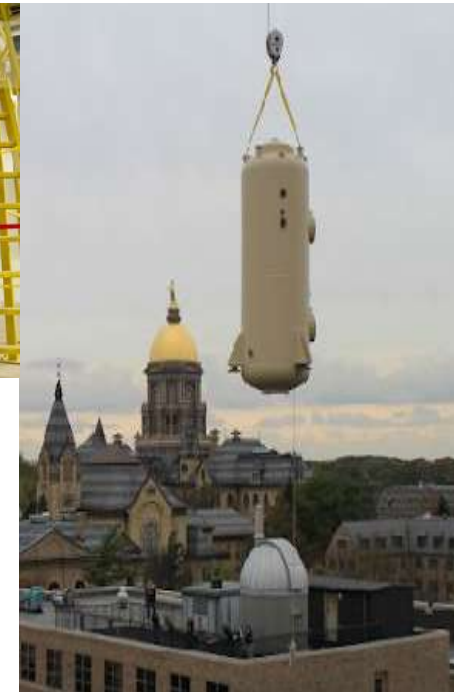


Continuous funding of Nuclear Physics at Notre Dame since 1946 through the Office of Naval Research and from 1953 by the National Science Foundation founded in 1950.

The first accelerator in Nieuwland Science Hall was a 4 MV machine, complemented in 1968 by an FN tandem from HV Engineering ($2.5M). The construction started in 1966, the building was complete in winter 1967, the accelerator was delivered in early 1968. Operation started in 1969. Upgrade to Pelletron system in 1995.

Can never have enough accelerators!

Santa Ana (5U) accelerator



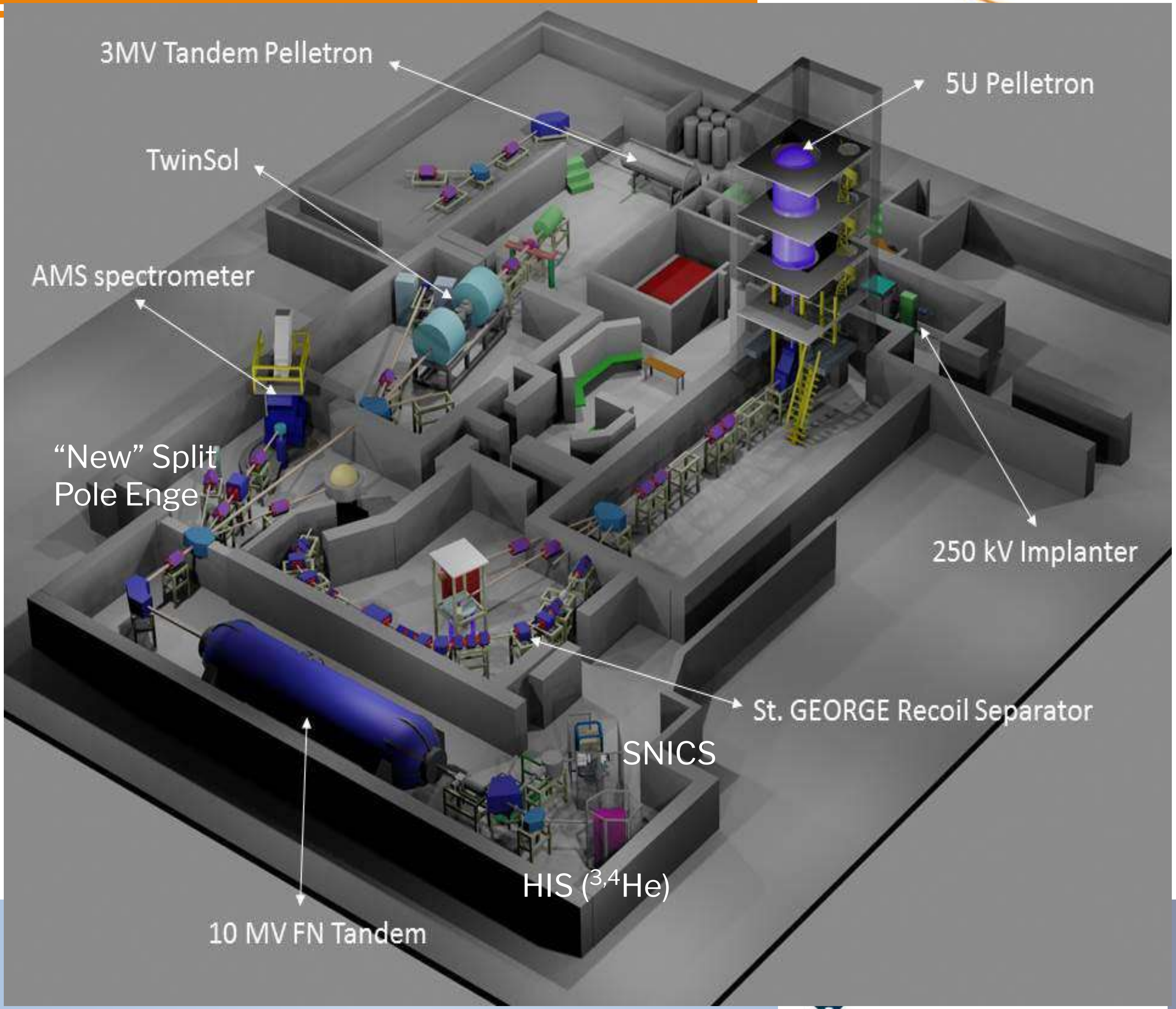
9S First Beam
Dec 2017

Can never have enough accelerators!

Santa Ana (5U) accelerator

9S First Beam
Dec 2017

Nuclear Science Laboratory



Solid Target Line

- (a,n) cross sections on light elements are needed for a wide range of applications
- Past measurements are nearly all total cross sections. Partial cross sections are needed!
- A cost effective and efficient solution for (a,n) measurements
  - Deuterated liquid scintillators for prompt neutron detection
  - HPGe or LaBr3 for secondary gamma ray detection

James DeBoer
R-matrix development

Michael Wiescher, Nuclear Astrophysics & Nuclear Applications

ORNL Deuterated Spectroscopic Array - ODeSA

Light Response Matrix

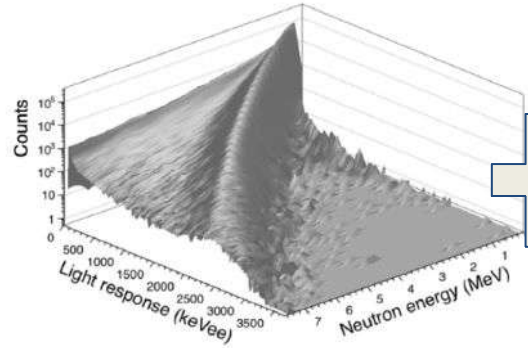
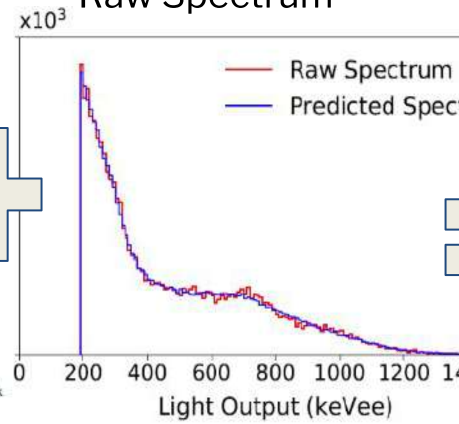
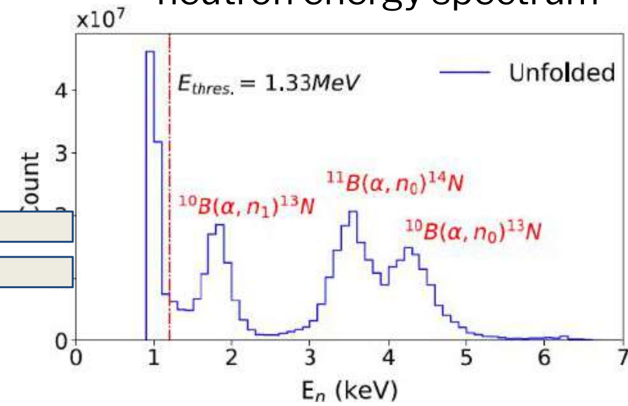


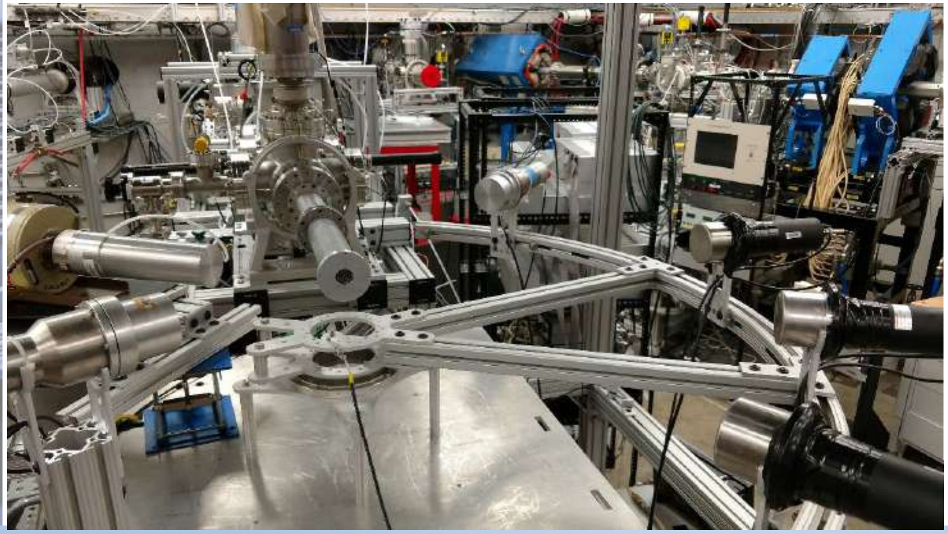
Fig. 9. Response matrix generated using a broad energy neutron source from a thick target $^{27}Al(d,n)$ reaction at E_d = 7.44 MeV [12].

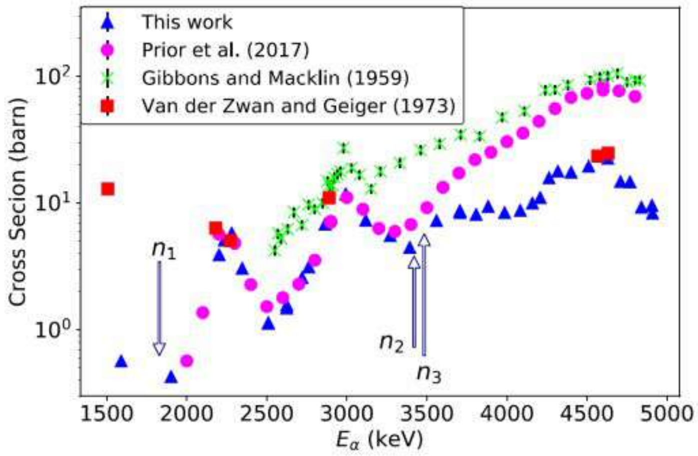
Raw Spectrum



neutron energy spectrum



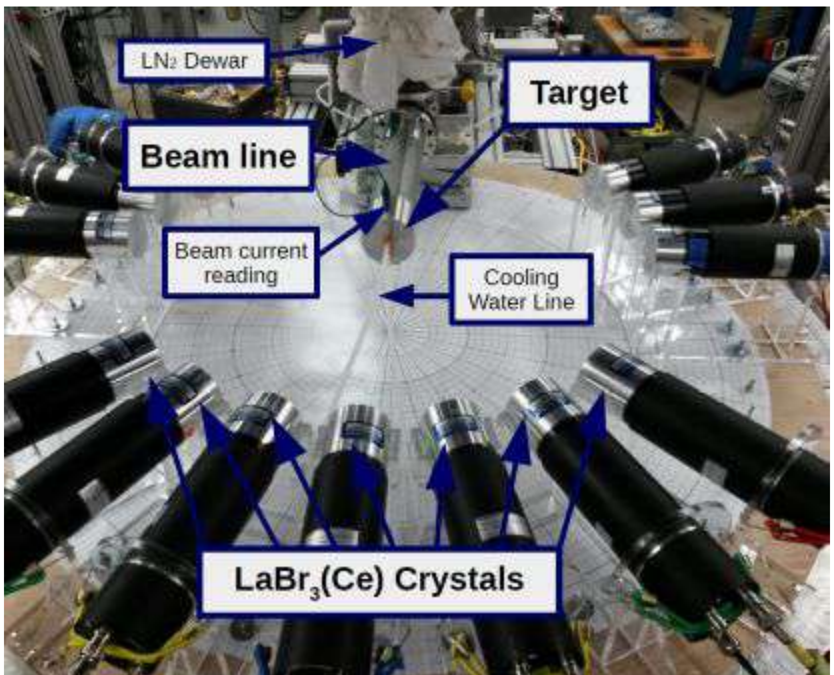


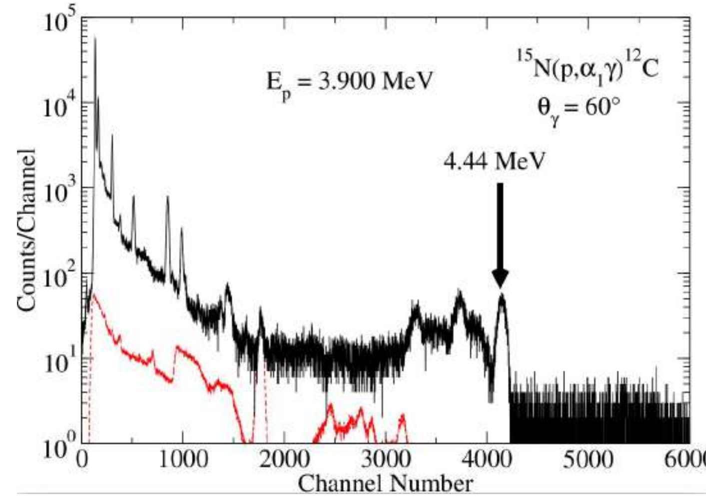


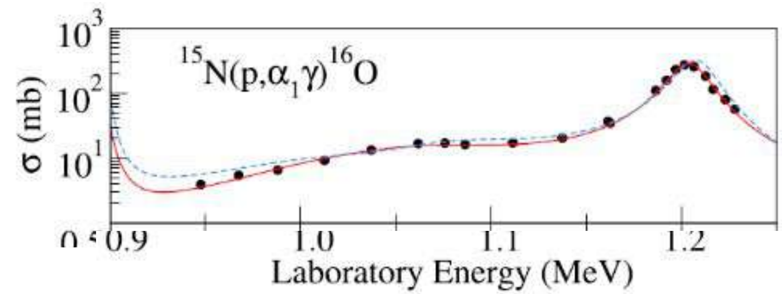
Febbraro et al. (2019)

HAGRiD

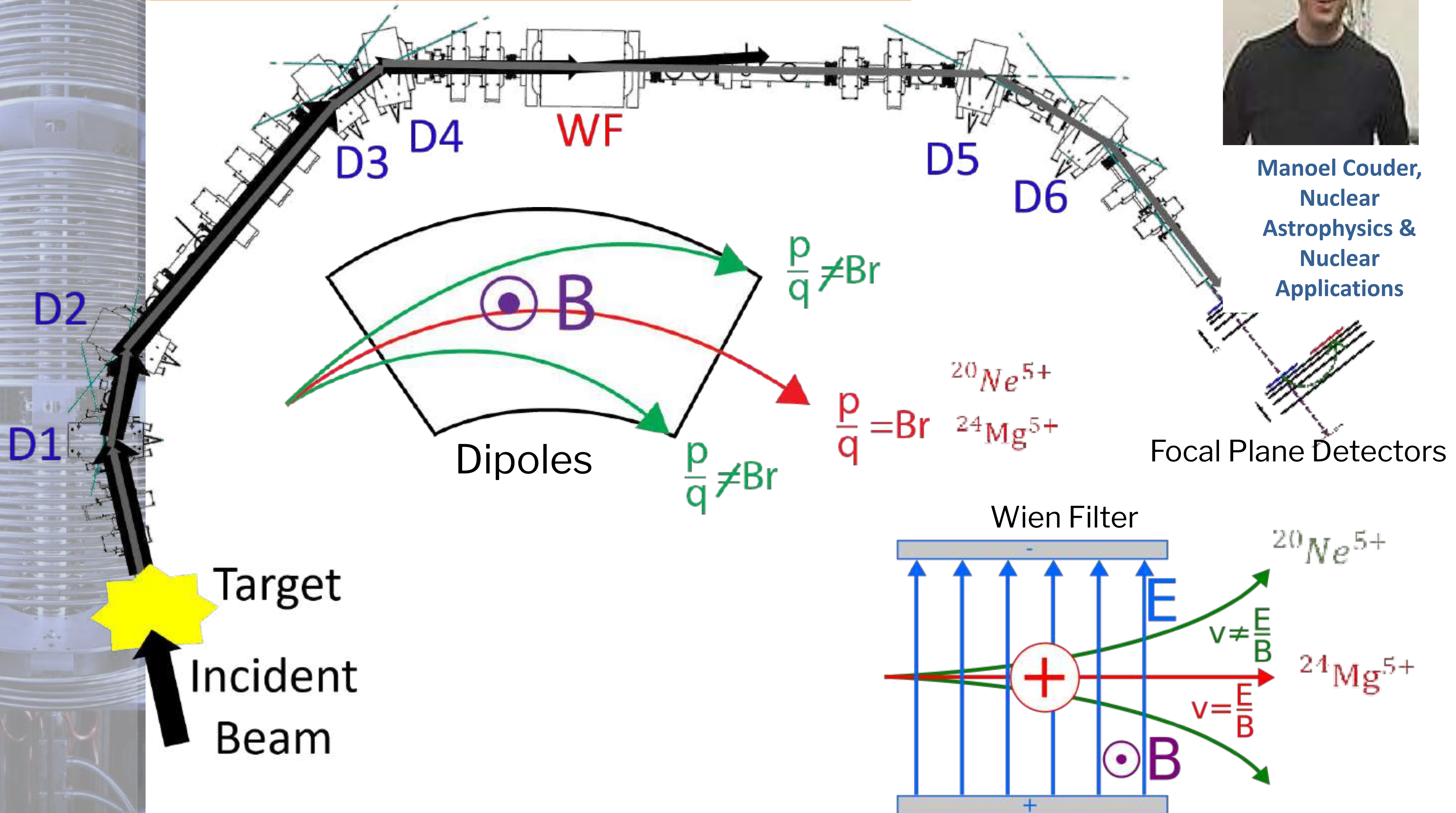
- HAGRiD is an array of LaBr3 detectors from Kate Jones at UTK
  - relatively high efficiency at high gamma ray energies
- Future (α,nɣ) measurements include
  - $^{13}C(\alpha,n\gamma)^{16}O$
  - $^{17}O(\alpha,n\gamma)^{20}Ne$
  - $^{18}O(\alpha,n\gamma)^{21}Ne$
  - $^{25}Mg(\alpha,n\gamma)^{28}Si$





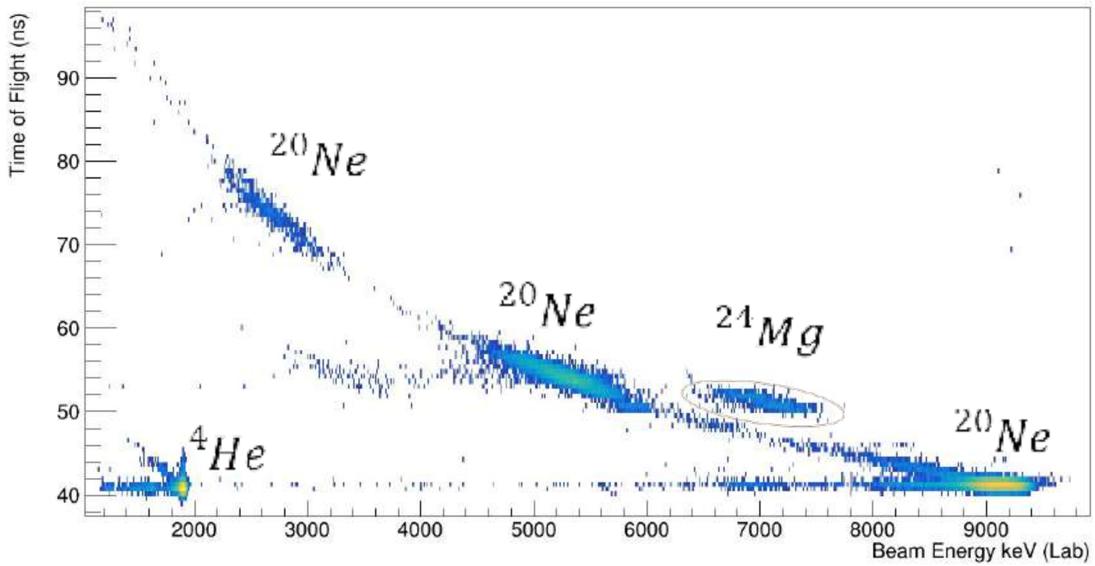


Inverse Kinematics with St. George

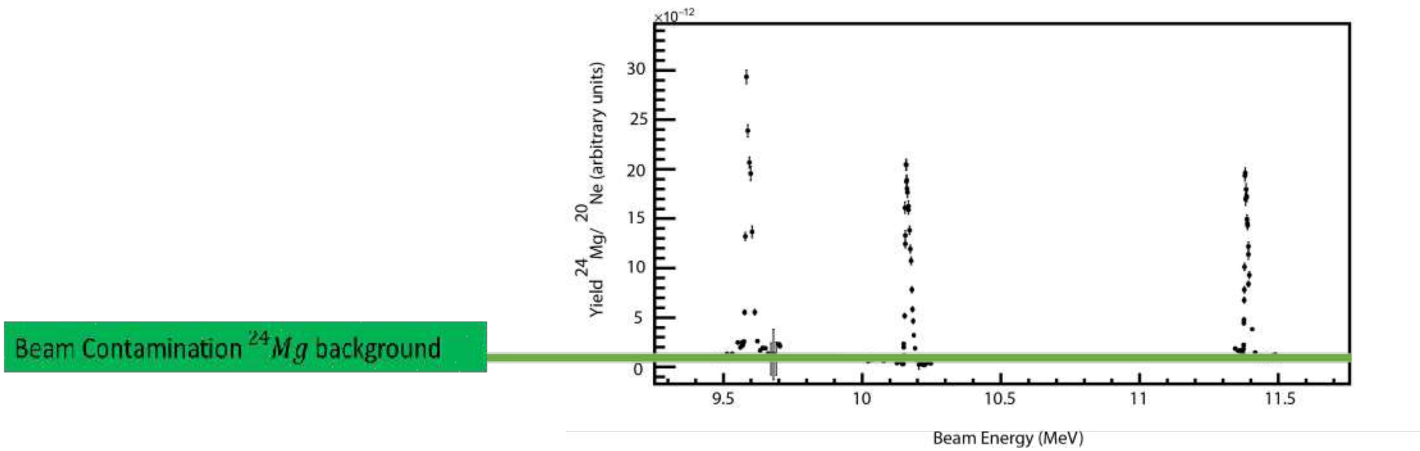


Manoel Couder, Nuclear Astrophysics & Nuclear Applications

$^{20}Ne(\alpha,\gamma)^{24}Mg$



- Commissioning run for St. George run by student **Luis Morales**
- identified a background from the beam
- installing new wien filter on upstream beamline



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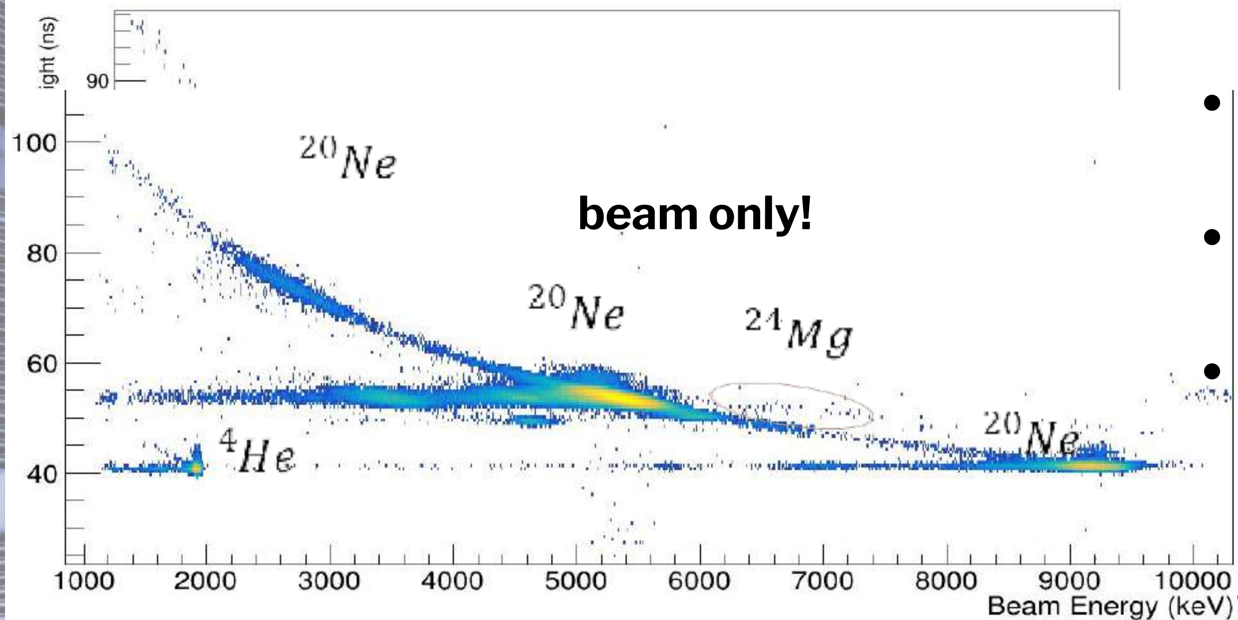

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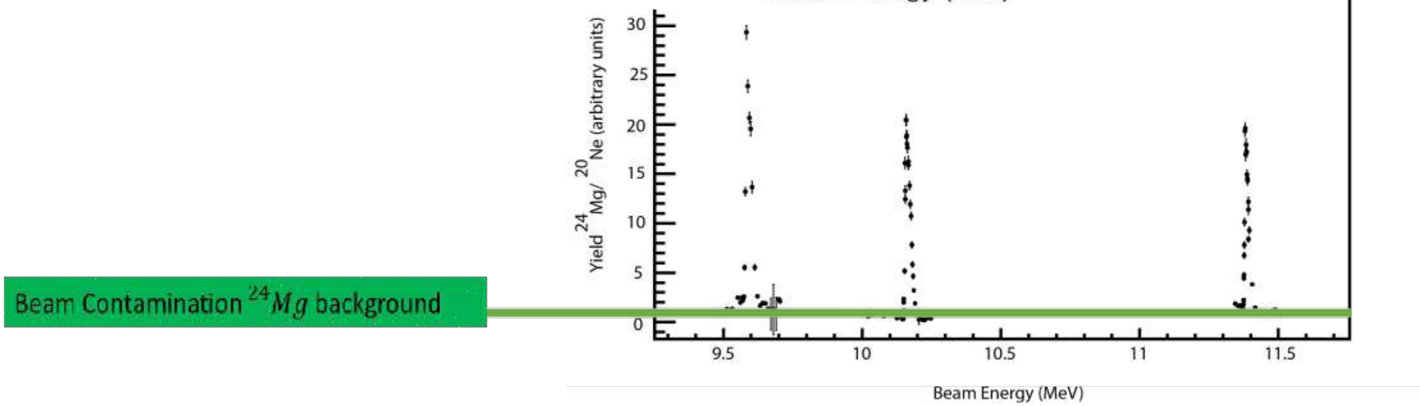
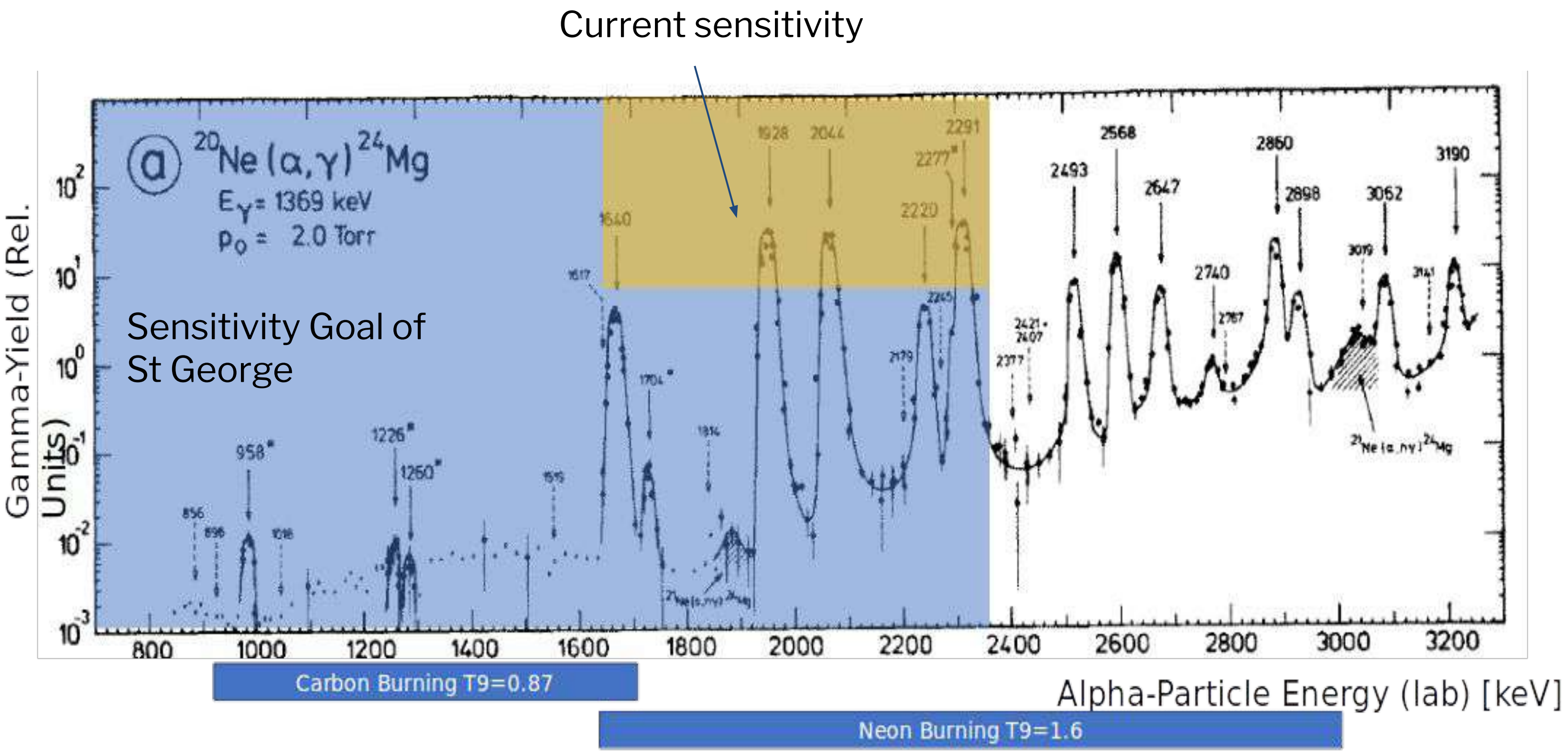


Status of St. George

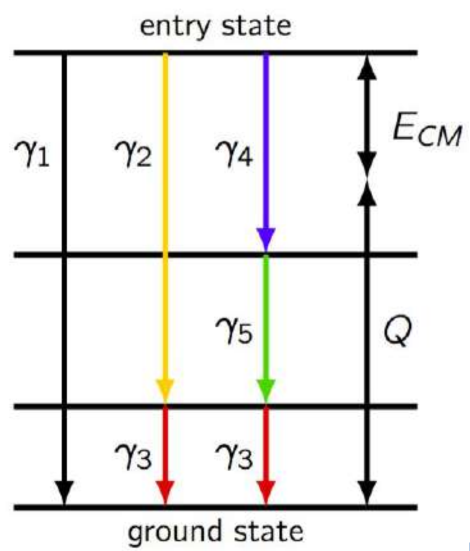


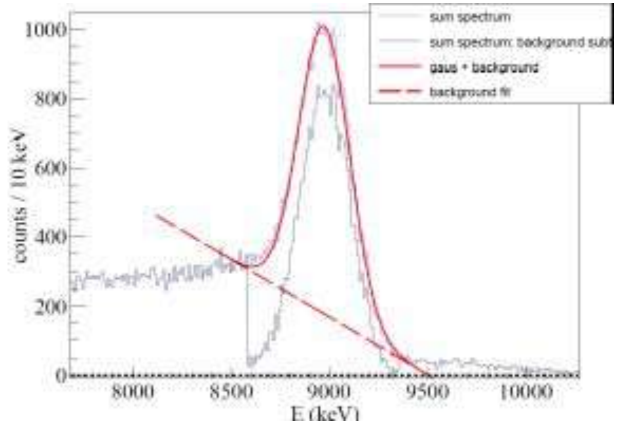
P. Schmalbrock, Stellar reaction rate of 20Ne(α, γ)24Mg, 1983 https://doi.org/10.1016/0375-9474(83)90488-8

HECTOR

- High EffiCiency TOtal absorption spectrometeR
- 16 separate segments, each read by two PMTs
- crystal size: 4x8x8 inch,
- 1 mm Al casing surrounding each crystal
- 12 mm Al on the outer walls of the array
- 60 mm borehole

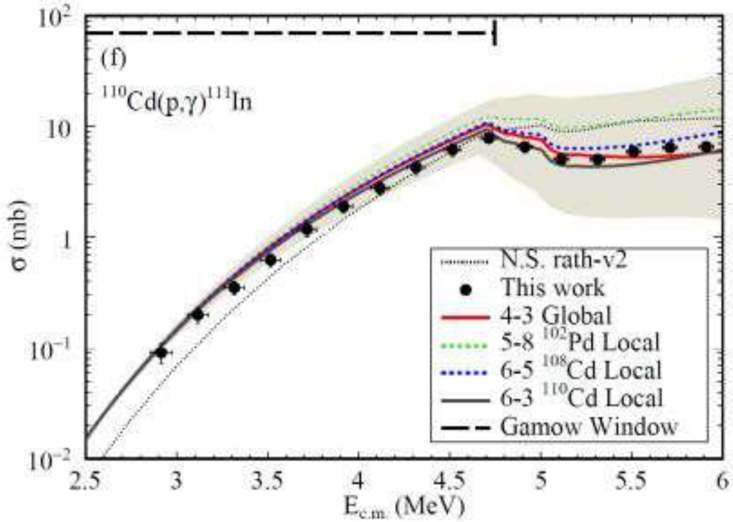
Anna Simon, Nuclear Astrophysics & Nuclear Reactions

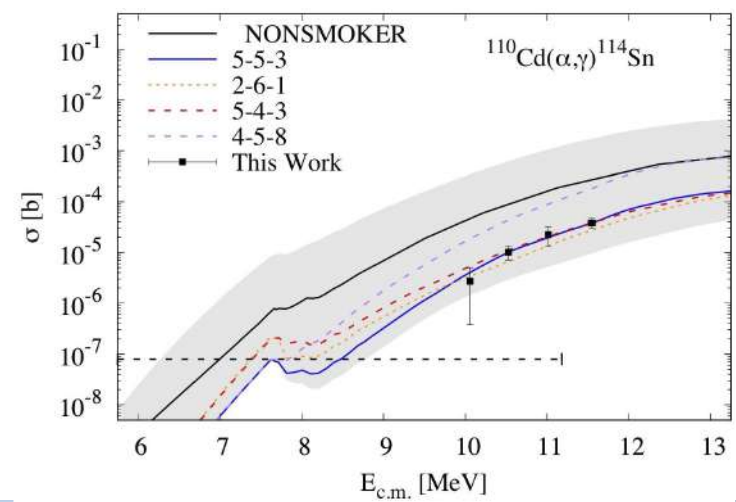




HECTOR

- ^{111}In had a poorly-constrained temperature of the (γ,p)/(γ,n) branching point, where the (γ,p) becomes dominant over the (γ,n) reaction.
- Constrained the (γ,p)/(γ,n) branching point to 2.71 ± 0.05 GK.
  - This may have a significant impact on the predicted p-nuclei abundances.
- The reaction flow in the astrophysical γ-process, the (α,γ) cross sections were measured for ^{90}Zr, ^{102}Pd, ^{108}Cd, and ^{110}Cd
- Goal is to pinpoint the nuclei at which the (γ,α) become dominant over the (γ,n) reactions and redirect the nucleosynthesis path towards lighter nuclei
- As a result a new branching point at ^{114}Sn was identified for T9<1.7 GK.





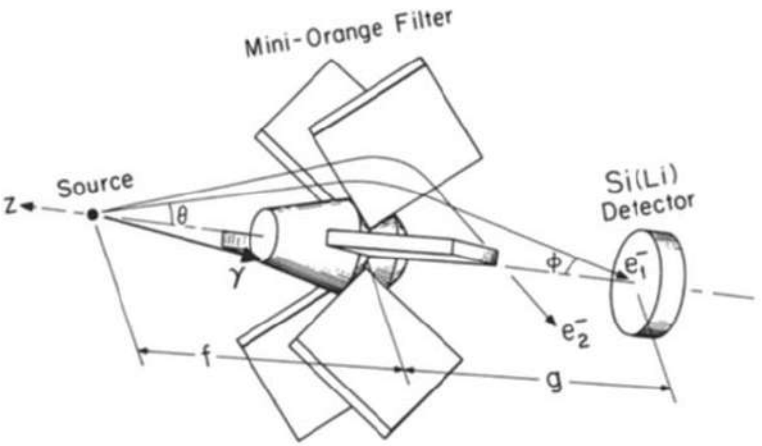
Putting ICEBALL to the Fire

Ani Aprahamian
Nuclear Astrophysics & Nuclear Structure Physics

Wanpeng Tan
Nuclear Structure and User Support

- ICEBall consists of six annular Si(Li) detectors that are 5 mm thick and have an active area of 750 mm^2 each.

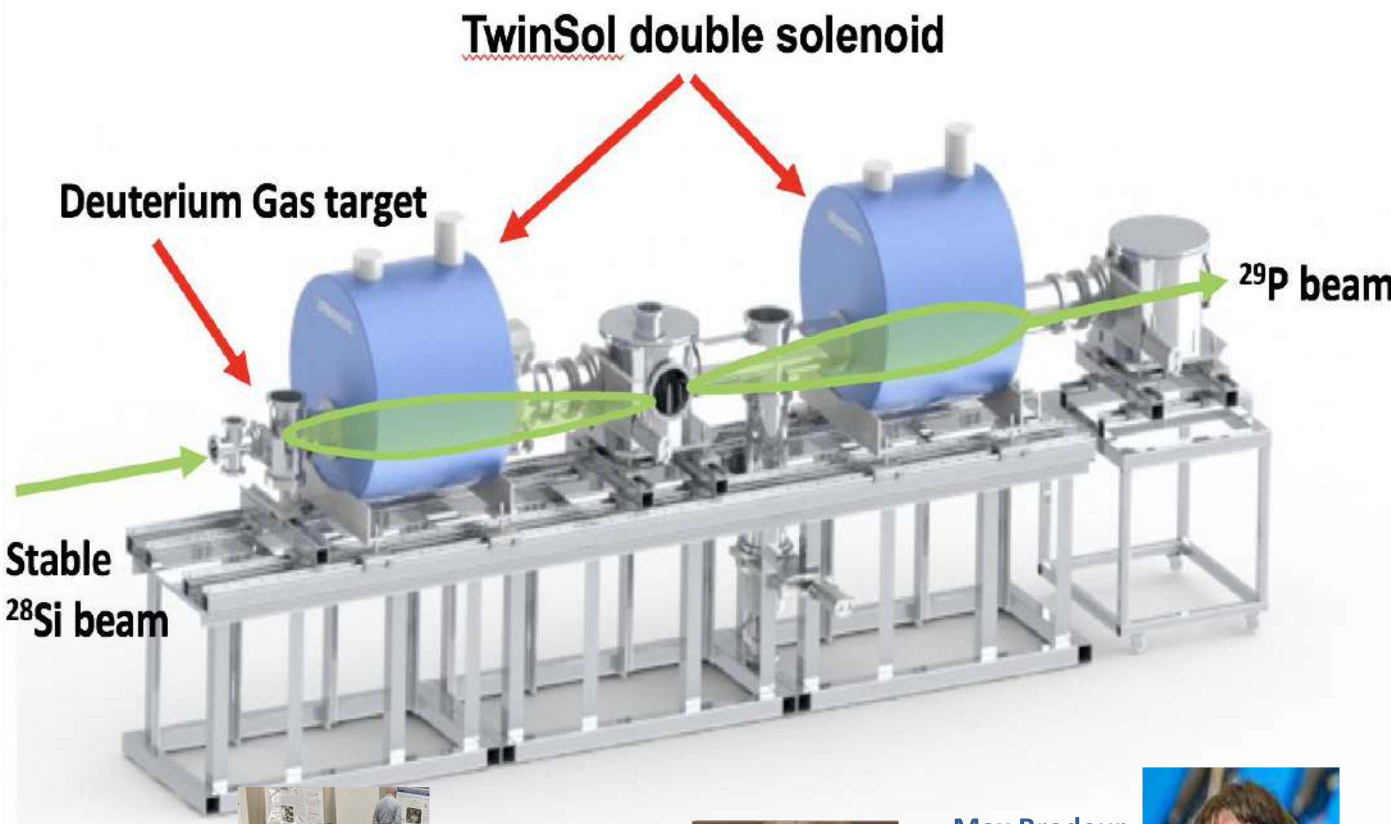
- ICEBall has a measured absolute efficiency of 15% at 356 keV and a resolution of 3-5 keV FWHM for electrons.



fIREBall ('fabulous' Internal conveRsion Electron Ball Array) is funded

- New Si(Li) detectors
- New designs of magnetic filters
- Modern digitizer readout
- Modern Geant4/COMSOL simulations
- BGO shields coupled with HPGe detectors (Georgina)

The Sol-ful Folk



Dan Bardayan, Nuclear Astrophysics

Tan Ahn, Nuclear Astrophysics & Nuclear Structure

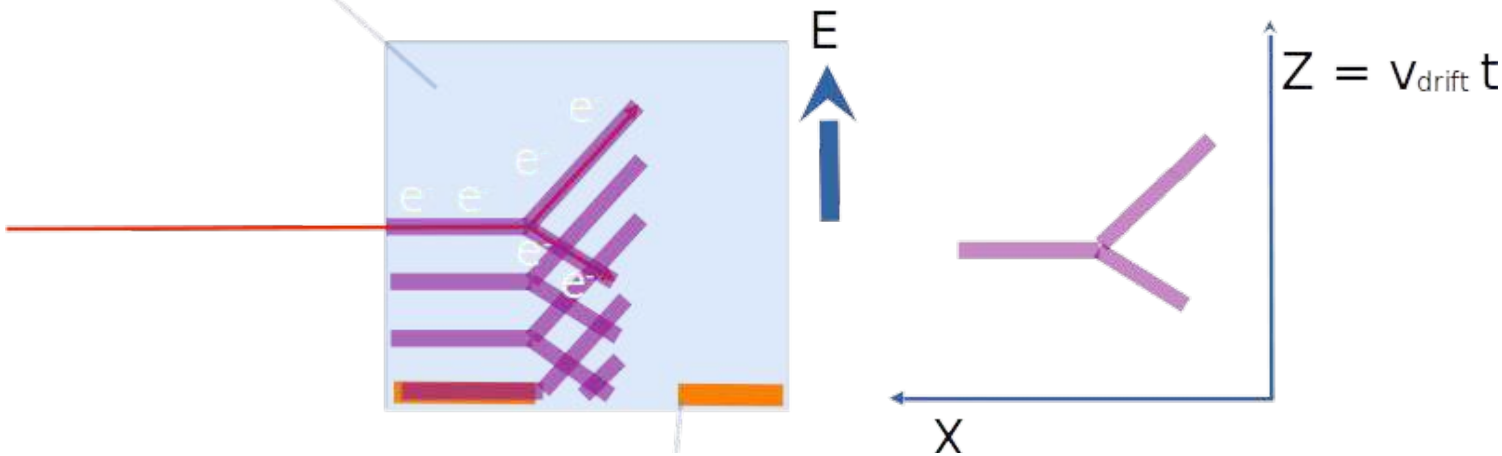
Patrick O'Malley TwinSol/St. Benedict

James Kolata, Fusion Barrier Studies Emeritus Faculty

Max Brodeur, Nuclear Astrophysics & Fundamental Symmetries

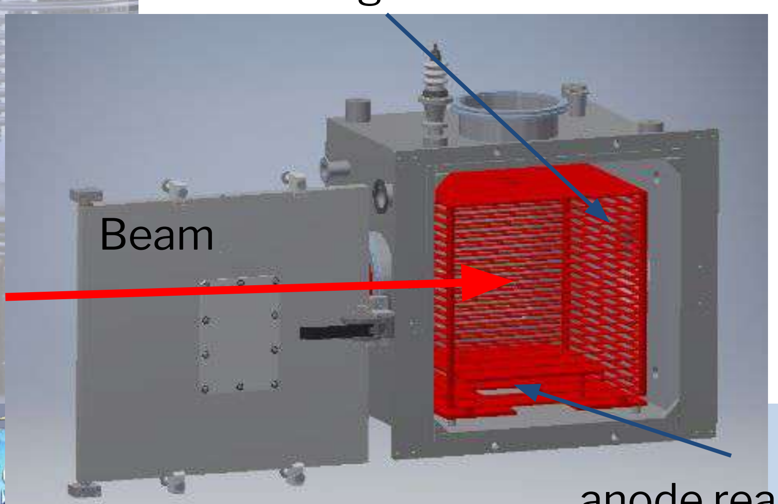
ND-CUBE- Active Target TPC

tracking medium

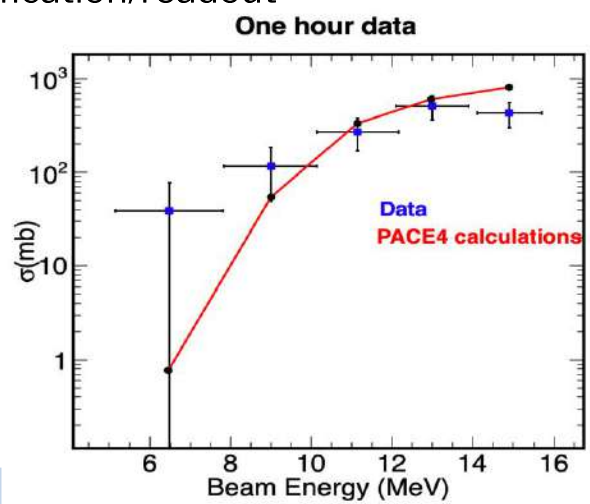


electron amplification/readout

Field cage

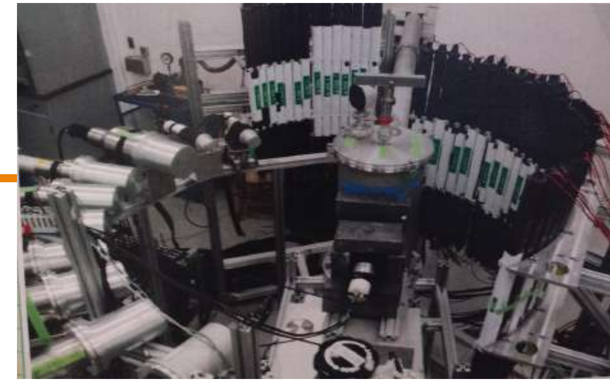


anode readout

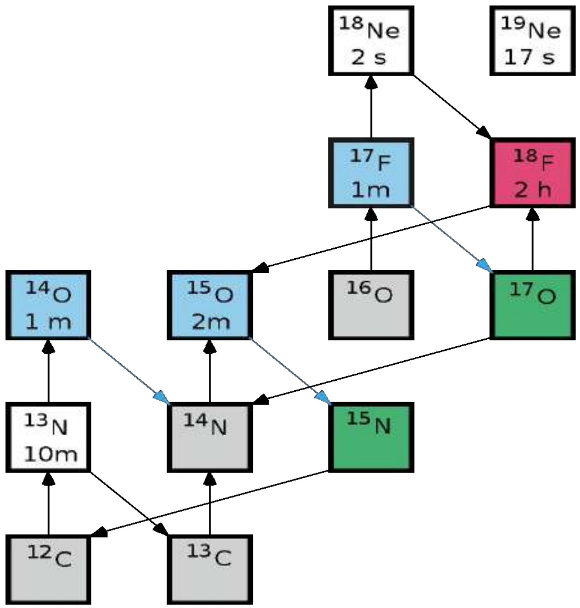


$^{7}Li + ^{40}Ar$ fusion cross section for commissioning run

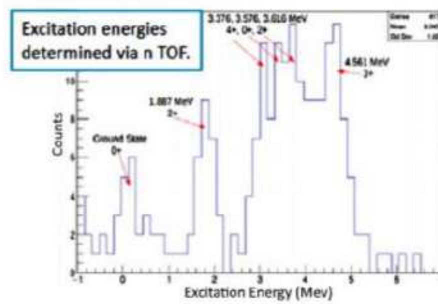
Origins of ^{18}F



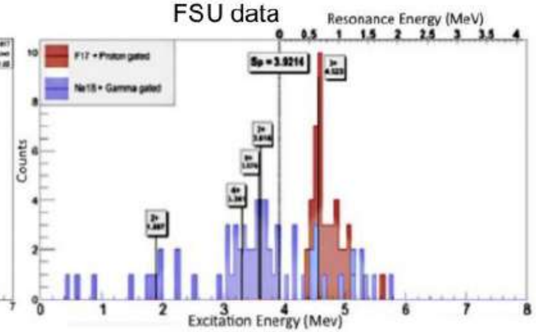
$^{17}F(d,n)^{18}Ne$



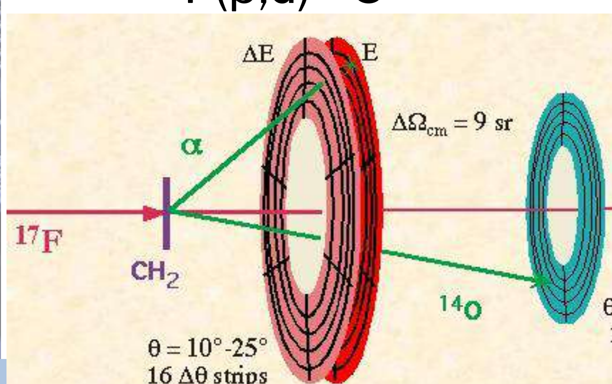
Notre Dame data

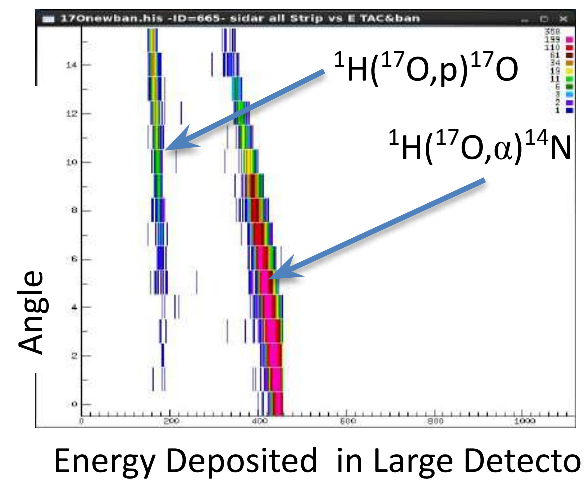


FSU data



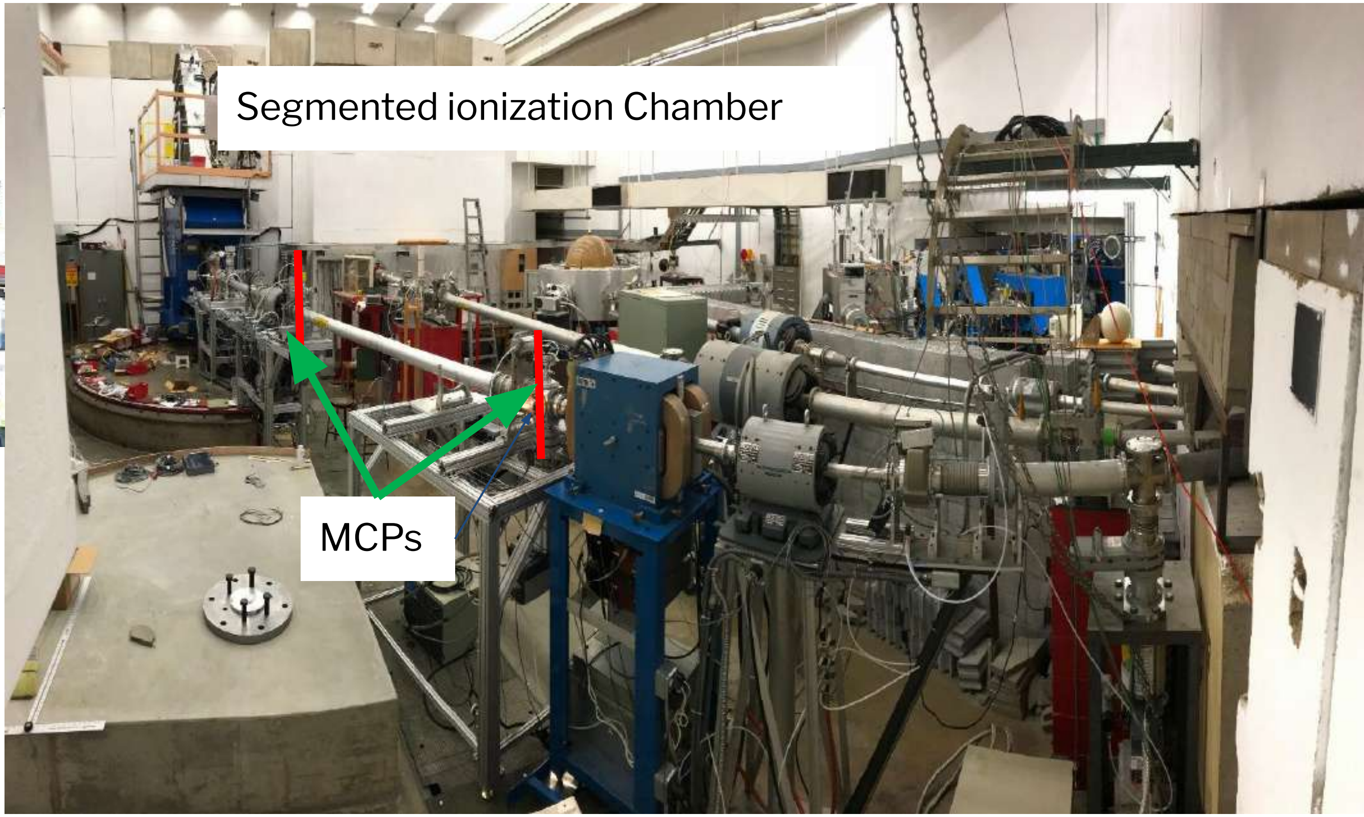
$^{17}F(p,\alpha)^{14}O$





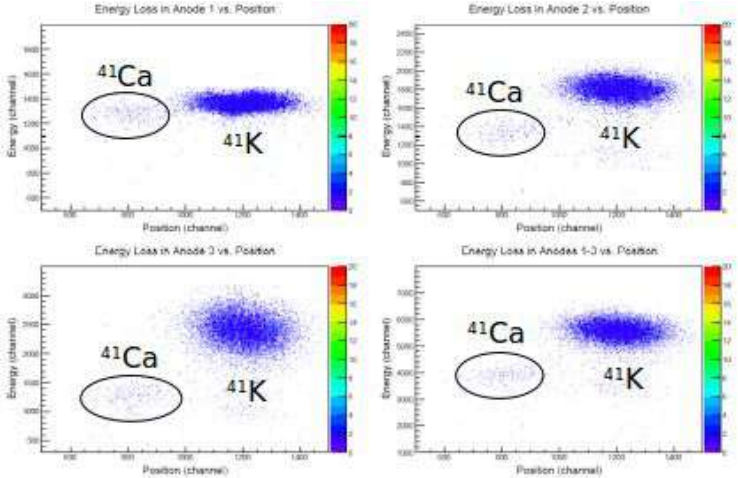
Atomic Mass Spectroscopy

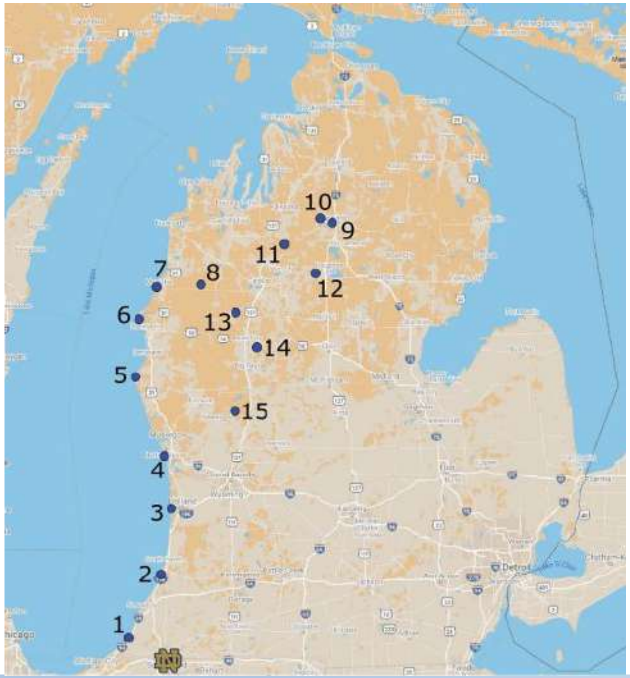
Philippe Collon, Nuclear Astrophysics & Nuclear Applications



Range of Applications of AMS

- With a half life of 9.94 x 10^4 yrs, ^{41}Ca is a useful chronometer for studying the formation of the Early Solar System
- Currently being used to study the cross section for the $^{40}Ca(^3He,d)^{41}Ca$ reaction





- $^{129}I/I$ concentrations have been measured for environmental sampling for ^{129}I contamination in the surrounding Great Lakes region
- Est. Sensitivity limit of ~3.7x10-14
- Development towards high sensitivity actinide detection is underway $^{236}U/U$ concentrations from various ore materials

PIGE Analysis for ^{19}F

Use PIGE as a rapid screening tool for chemicals of concern in the environment, consumer products…

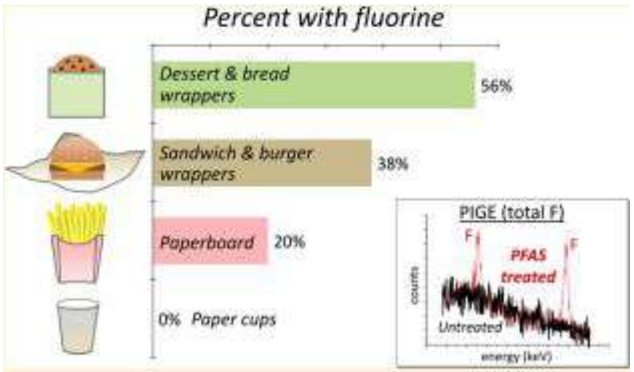
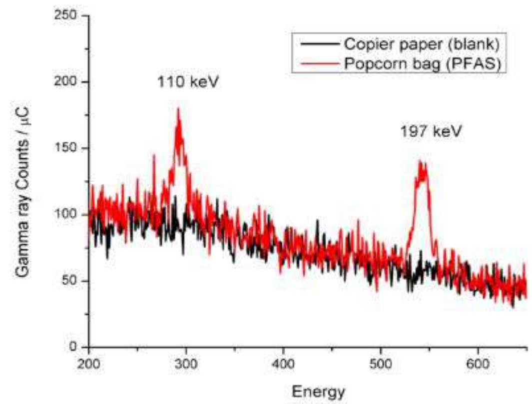
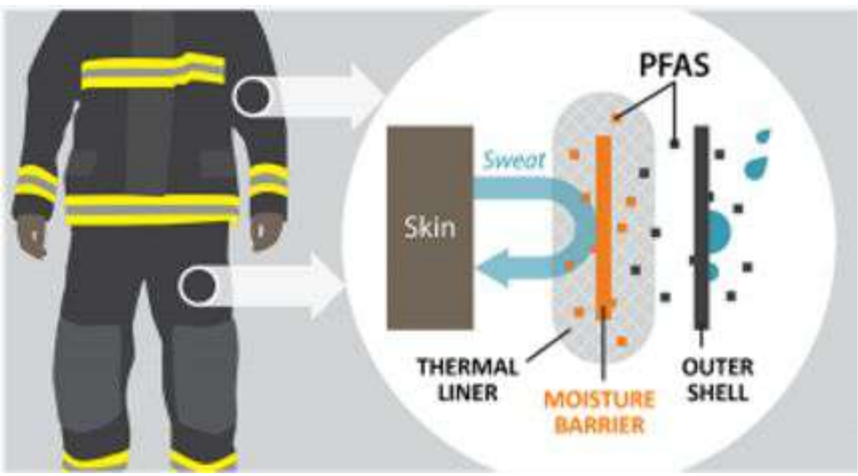
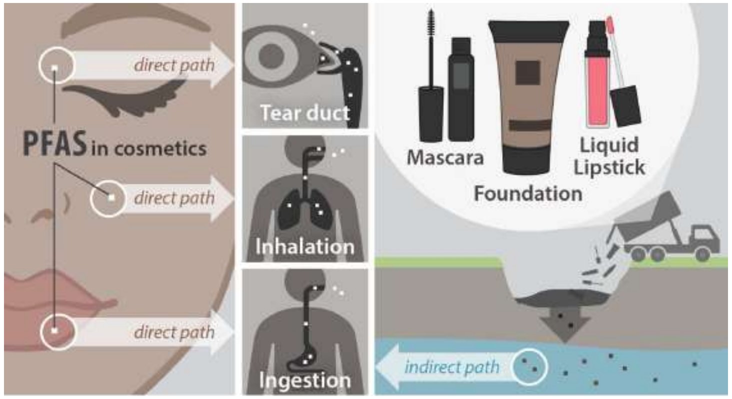


Fig. 3: PFAS-coated paper sample compared with uncoated paper. Irradiation time of 180 second with 9 nA of 3.4 MeV protons.

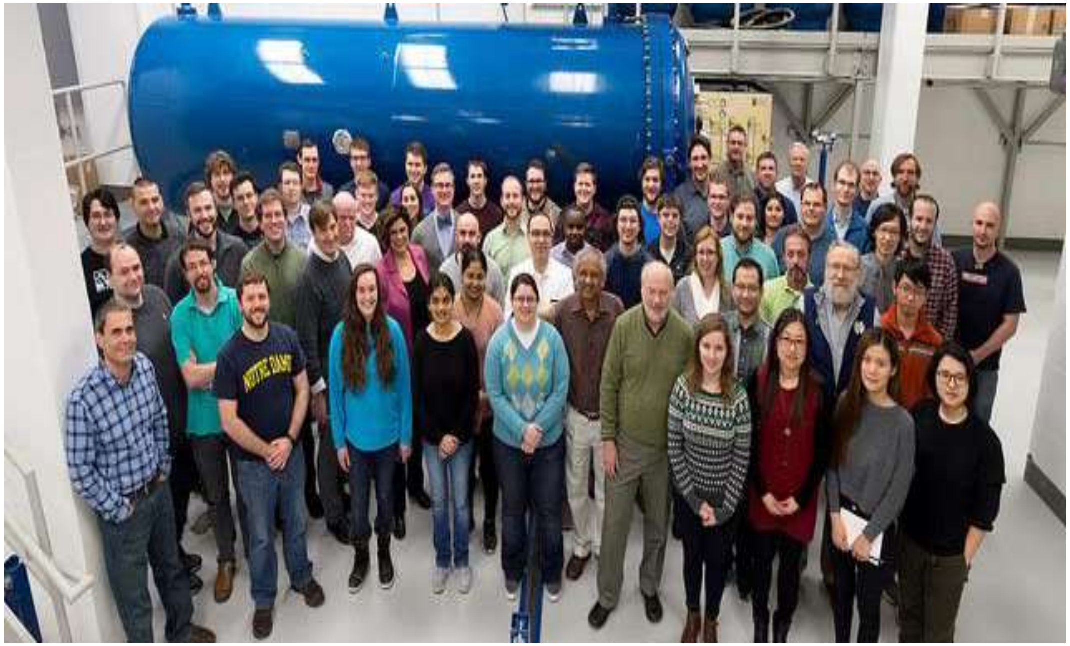






But wait, there's more!

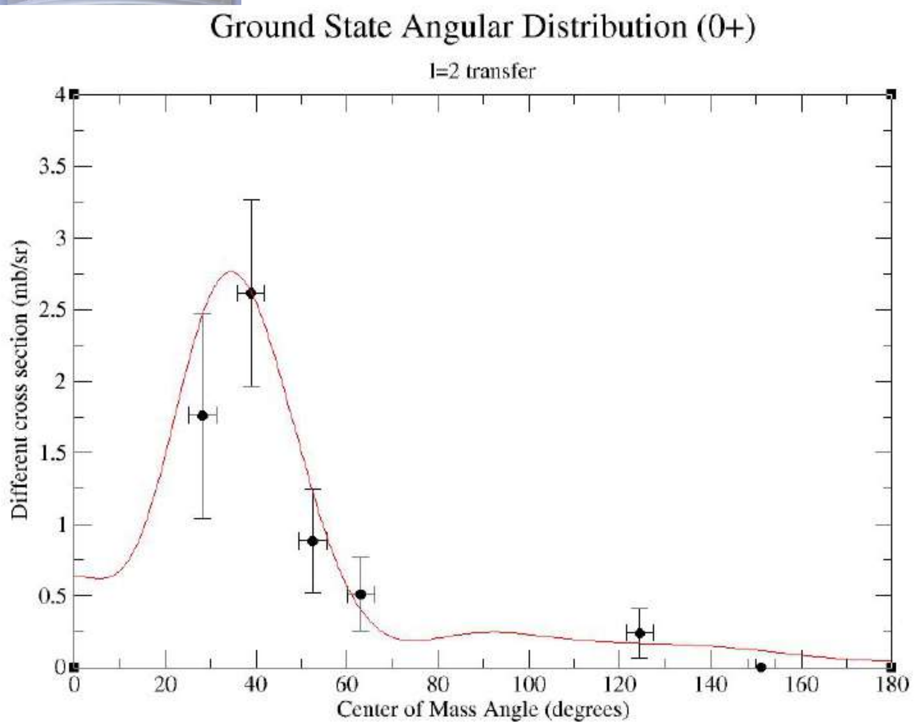
- There are many more things happening at Notre Dame
  - SF_6 upgrade of FN tandem
  - TRISOL
  - St. Benedict
  - Enge Split-pole
  - Actinide Target Program

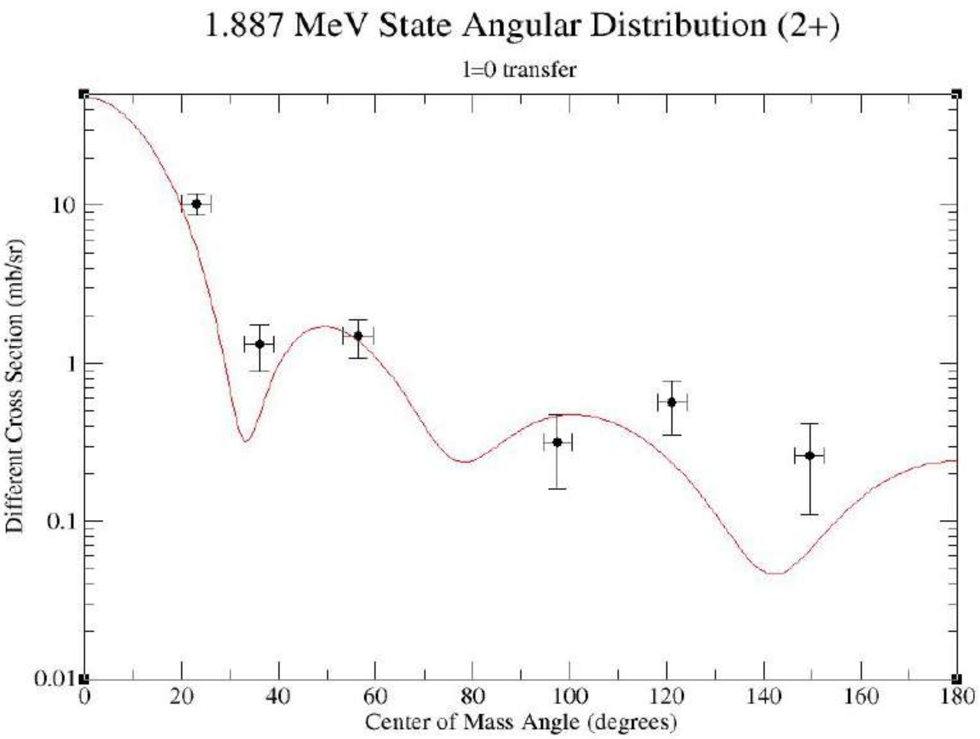


NSF grant (PHY-0959816 & PHY-1062819)

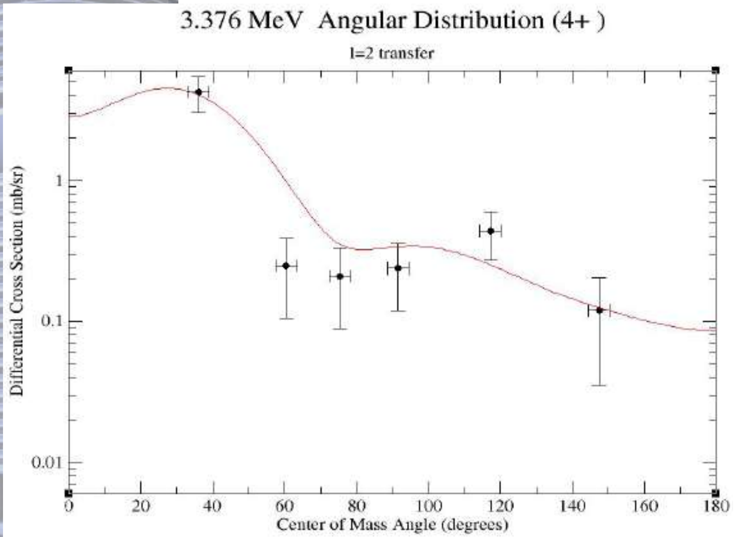
Questions???

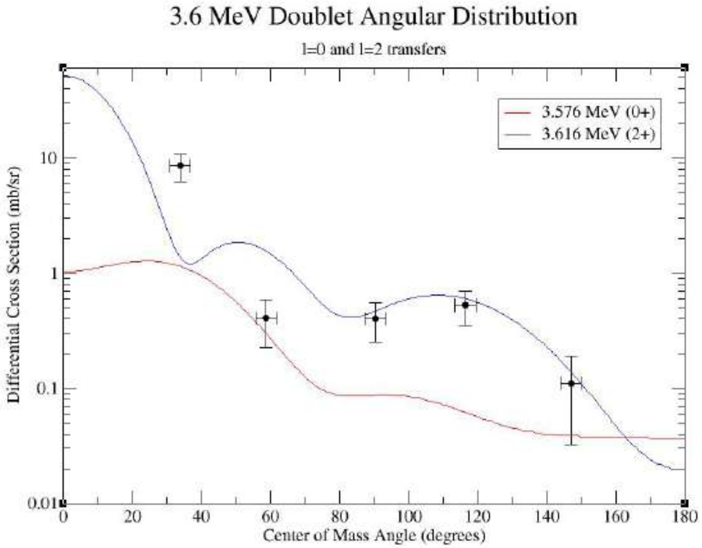
Angular Distributions

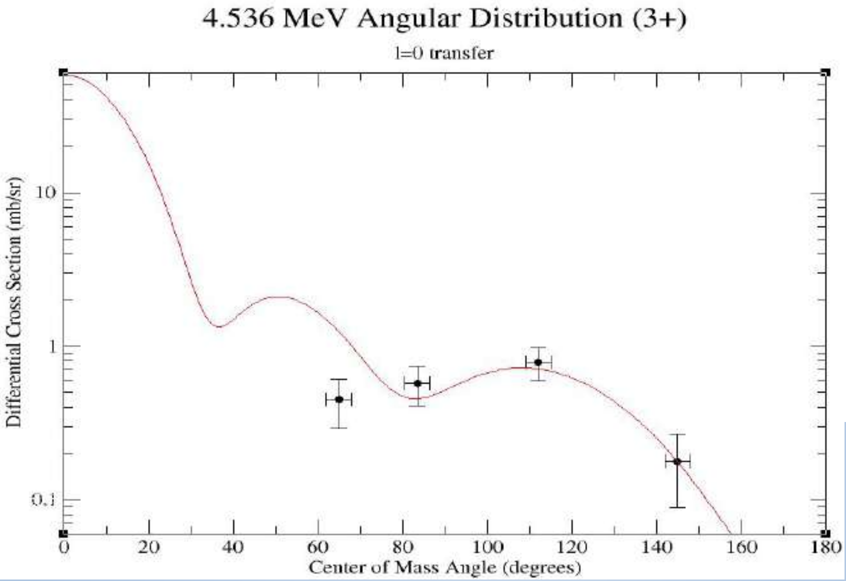




Angular Distributions







T & R faculty involved in variety of research

The number of nuclear physics teaching and research (T&R) faculty funded by the NSF grant has grown significantly from five in 2010, to seven in 2013, eight in 2016 and finally to nine in the present proposal.

Michael Wiescher, Nuclear Astrophysics &

Dan Bardayan, Nuclear Astrophysics

Ani Aprahamian Nuclear Astrophysics & Nuclear Structure Physics

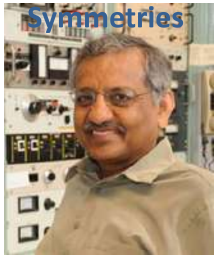
Max Brodeur, Nuclear Astrophysics & Fundamental Symmetries

Manoel Couder, Nuclear Astrophysics & Nuclear Applications

Tan Ahn, Nuclear Astrophysics & Nuclear Structure

Philippe Collon, Nuclear Astrophysics & Nuclear Applications

Anna Simon, Nuclear Astrophysics & Nuclear Reactions



Umesh Garg, Nuclear Astrophysics & Nuclear Structure

Graham Peaslee, Nuclear Applications

NSL research faculty

JINA
ort

James DeBoer
R-matrix
development

Khachatur Manukyan
Materials,
Applications, &
Targets

NSF
pc

Daniel Robertson
CASPAR
Development

Patrick O'Malley
TwinSol/St.

Project based DOE

Georg
Berg
SECAR/
HRS

Jay
Laverne
Rad.
Chemistry

University

Joachim
Görres
Research
Support

Ed Stech
NSL
Operation

Wanpeng
Tan
User
Support