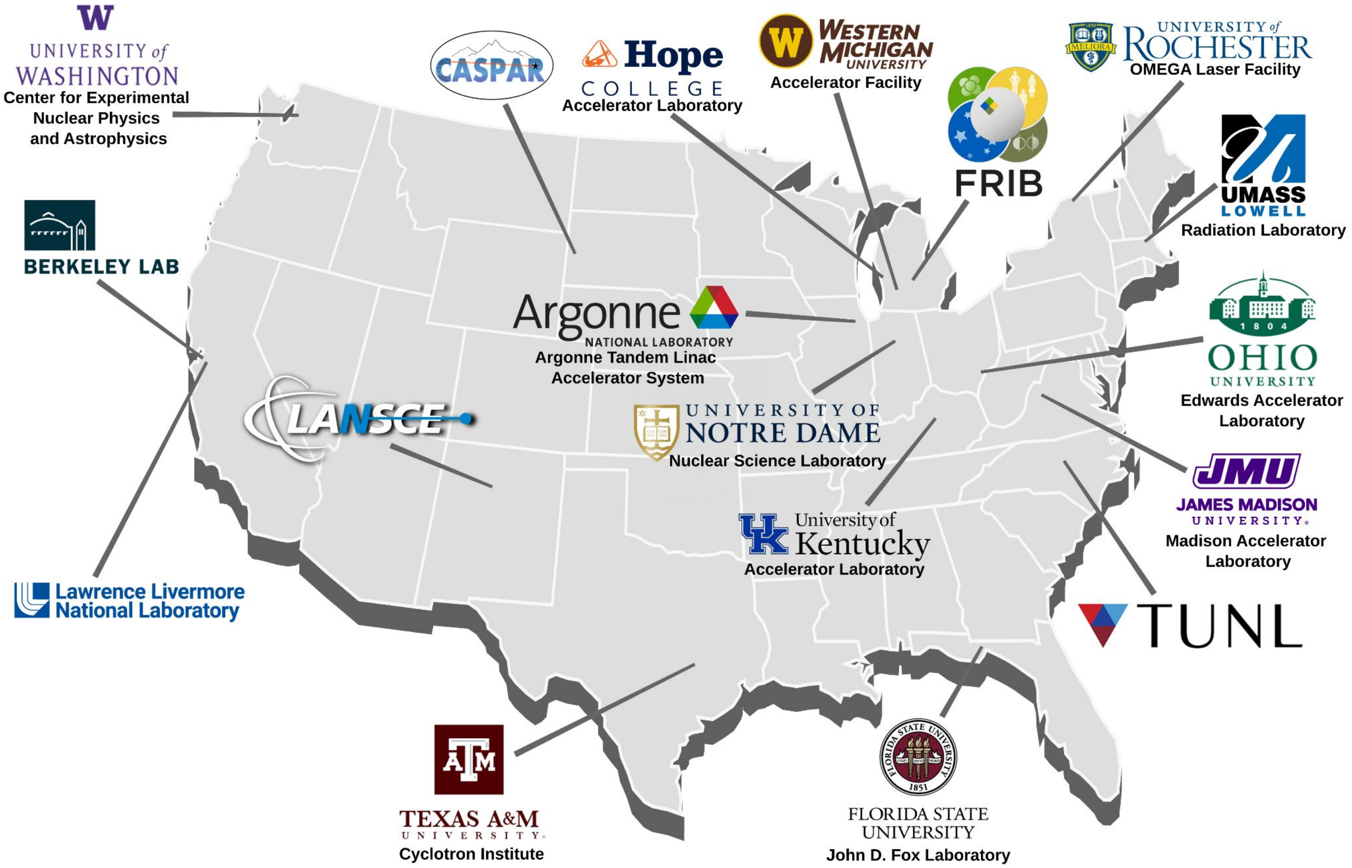
Recent astrophysics results from the Enge split-pole spectrograph program at the Triangle Universities Nuclear Laboratory

Presenter: R. Longland (TUNL/NCSU)


UNIVERSITY of WASHINGTON
Center for Experimental Nuclear Physics and Astrophysics
CASPAR
Hope COLLEGE
Accelerator Laboratory
WESTERN MICHIGAN UNIVERSITY
Accelerator Facility
FRIB
UNIVERSITY of ROCHESTER
OMEGA Laser Facility
UMASS LOWELL
Radiation Laboratory
BERKELEY LAB
Argonne NATIONAL LABORATORY
Argonne Tandem Linac Accelerator System
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JMU JAMES MADISON UNIVERSITY
Madison Accelerator Laboratory
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TUNL overview

Four-university consortium

- North Carolina State University
- North Carolina Central University
- The University of North Carolina at Chapel Hill
- Duke University

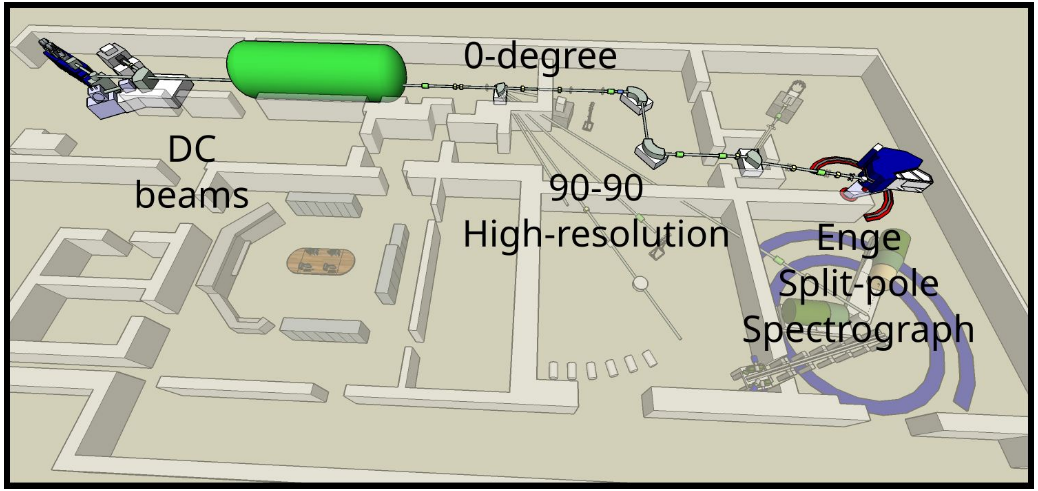
Three accelerator facilities

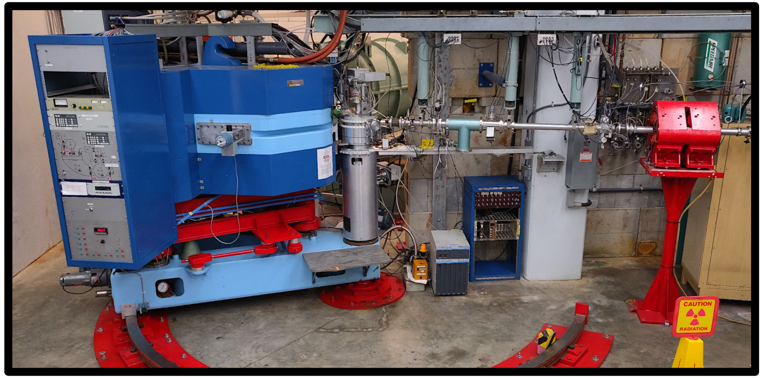
- Tandem Accelerator Lab.
- Laboratory for Experimental Nuclear Astrophysics (LENA)
- High-Intensity γ-ray Source (HIγS)

Enge split-pole spectrograph

Beam Capabilities

- p,d (~ 1 μA)
- ^{3}He, ^{4}He (~ 500 enA)
- 10 MV Tandem Accelerator
- High-resolution beamline (ΔE < 1 keV)

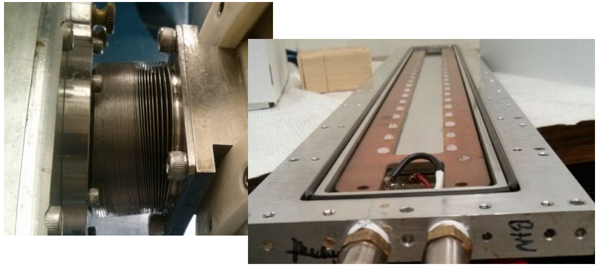




Enge split-pole spectrograph

- 0.125 – 5 msr acceptance
- 1.5 T maximum field
- 0° and 180° capabilities
- $\Delta\rho$ ~ 0.3 mm (~ 10 keV for ^{20}Ne(d,p)^{21}Ne)

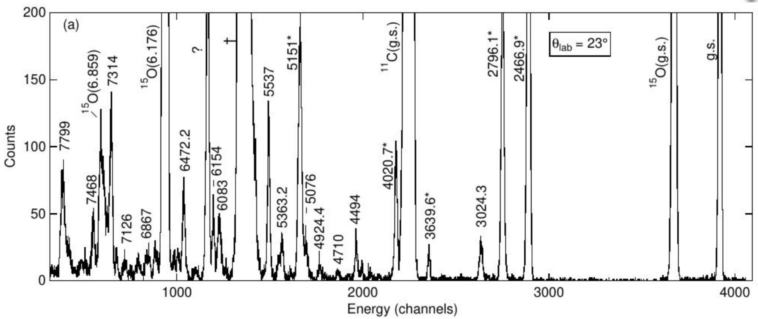
Timeline



R. Longland hired at NCSU

Rebuilding efforts

First science runs



2016

2020

2014

1st Beam on Target

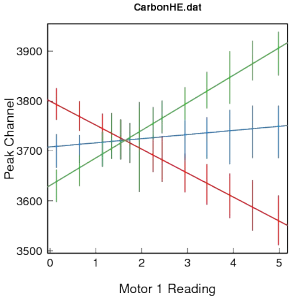
Reliable Beam on Target

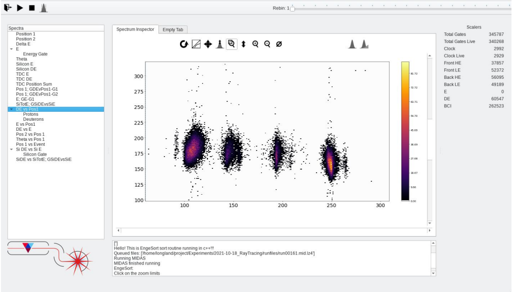
2018

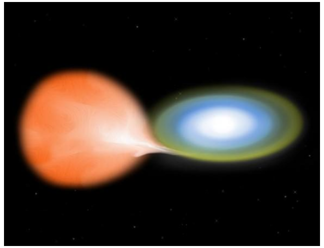
DAQ upgrades

2022

Continued Scientific program

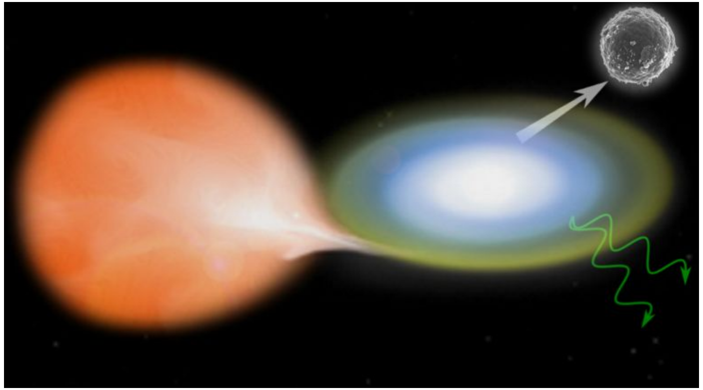






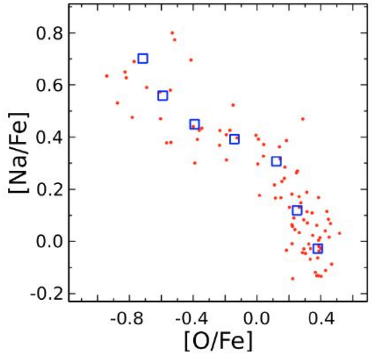
Astrophysics program

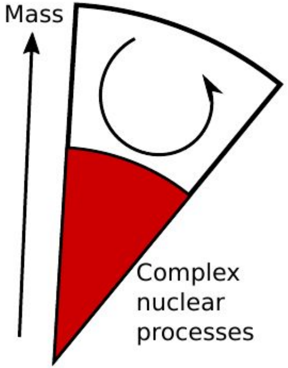
Novae



- Nova explosions can produce
  - γ rays
  - Grains
  - + more
- These messengers provide tight constraints on nova conditions
- Nuclear physics uncertainties prevalent

AGB Stars





Prantzos et al., A&A 149 (2006) 18

- Oxygen-sodium anti-correlation in globular clusters
- Hot bottom burning in AGB stars can explain sodium production
- Uncertainty dominated by ^{23}Na+p destruction channels

Novae

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PHYSICAL REVIEW C **99**, 055812 (2019)

Experimental study of ^{35}Cl excited states via ^{32}S(α, p)

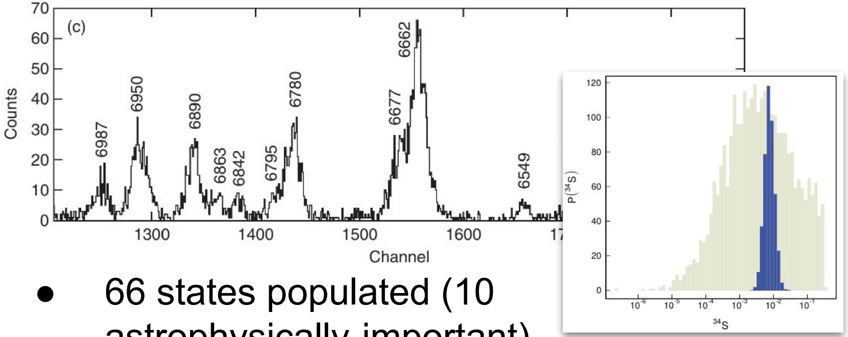
K. Setoodehnia,* J. H. Kelley, C. Marshall, F. Portillo Chaves, and R. Longland
Department of Physics, North Carolina State University, Raleigh NC 27695, USA
and Triangle Universities Nuclear Laboratory, Duke University, Durham NC 27710, USA

PHYSICAL REVIEW C **107**, 035809 (2023)

Spin-parities of subthreshold resonances in the ^{18}F(p, α) ^{15}O reaction

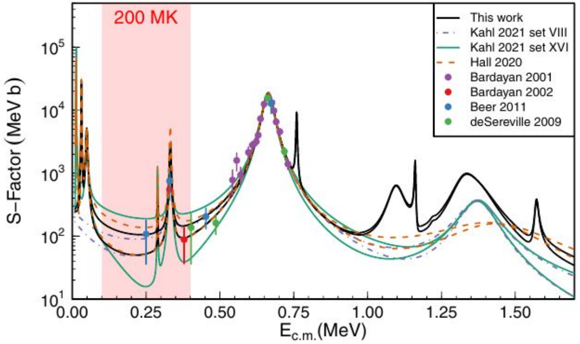
F. Portillo,[1,2] R. Longland,[1,2,*] A. L. Cooper,[3,2,†] S. Hunt,[3,2] A. M. Laird,[4] C. Marshall,[1,2] and K. Setoodehnia[1,2,‡]
[1]*Department of Physics, North Carolina State University, Raleigh, North Carolina 27695, USA*
[2]*Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708, USA*
[3]*Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27599, USA*
[4]*Department of Physics, University of York, York YO10 5DD, United Kingdom*

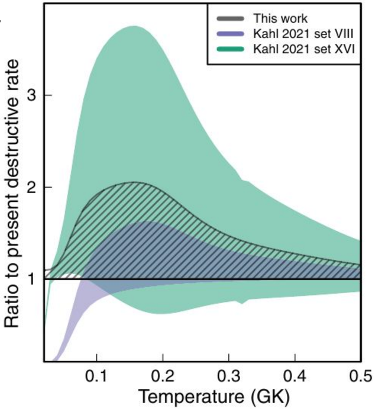
- Nova models cannot explain ^{34}S anomalies in nova grains
- ^{34}S(p,γ)^{35}Ar was purely theoretical



- 66 states populated (10 astrophysically-important)
- Reaction rate uncertainty reduced by order of magnitude

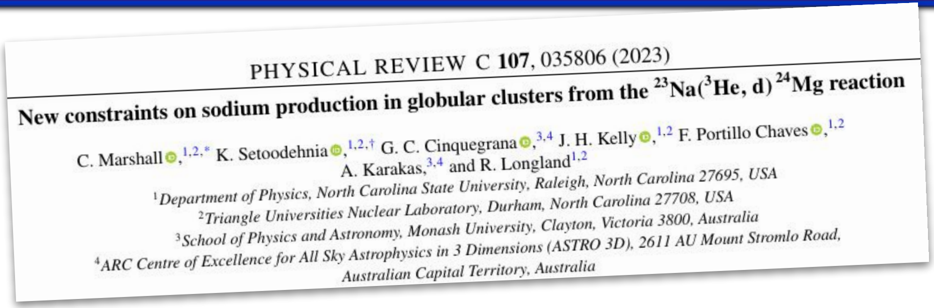
- ^{18}F(p,α)^{15}O rate needed for γ-ray observations of novae
- Unknown interference effects dominate uncertainty





- Determined spin-parity of key sub-threshold state
- Factor of 2 uncertainty reduction

AGB Stars


PHYSICAL REVIEW C **107**, 035806 (2023)

New constraints on sodium production in globular clusters from the $^{23}Na(^{3}He, d)^{24}Mg$ reaction

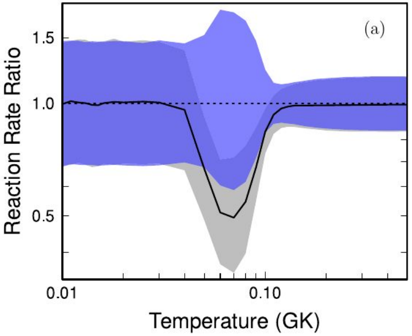
C. Marshall,[1,2,*] K. Setoodehnia,[1,2,†] G. C. Cinquegrana,[3,4] J. H. Kelly,[1,2] F. Portillo Chaves,[1,2] A. Karakas,[3,4] and R. Longland[1,2]

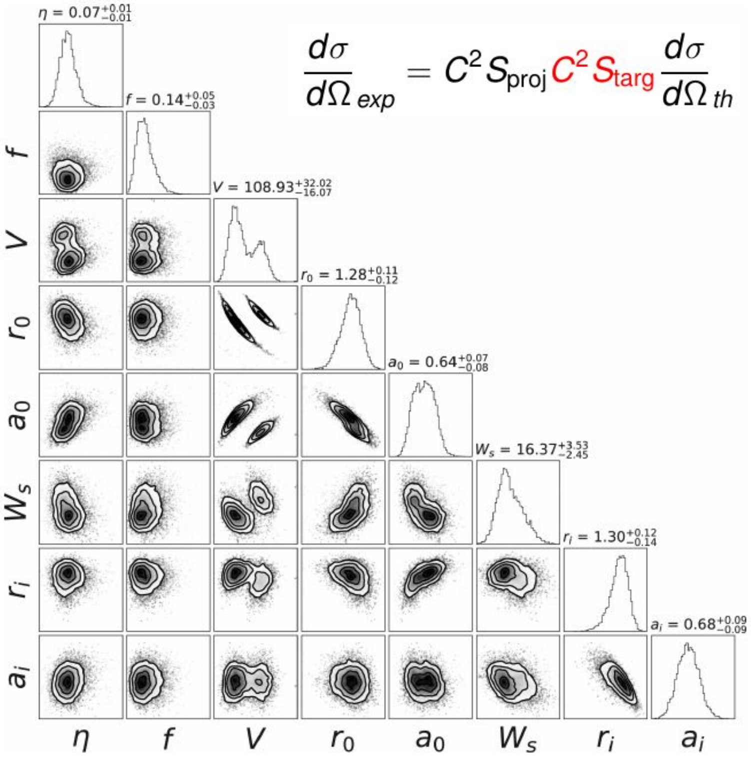
[1]Department of Physics, North Carolina State University, Raleigh, North Carolina 27695, USA
[2]Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708, USA
[3]School of Physics and Astronomy, Monash University, Clayton, Victoria 3800, Australia
[4]ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D), 2611 AU Mount Stromlo Road, Australian Capital Territory, Australia

$$\langle \sigma v \rangle = \left(\frac{2\pi}{\mu k T}\right)^{3/2} \hbar^2 \sum_i \omega\gamma_i e^{-E_r/kT} \qquad \sigma^{DC}_{total}(E) = \sum_i C_i^2 S_i \sigma_i^{DC}(E)$$

$$\frac{d\sigma}{d\Omega}_{exp} = C^2 S_{proj}\, C^2 S_{targ} \frac{d\sigma}{d\Omega}_{th}$$

- Sodium production in AGB stars can explain sodium-oxygen anticorrelation in globular clusters
- Extracted energies and C^2S for key states
- Reaction rate factor of 2 higher than previous
- Low-energy states under analysis -> direct capture





Also:
Marshall et al., Phys. Rev. C 102 (2020) 024609
Marshall et al., Phys. Rev. C 104 (2021) L032801

Upcoming upgrades

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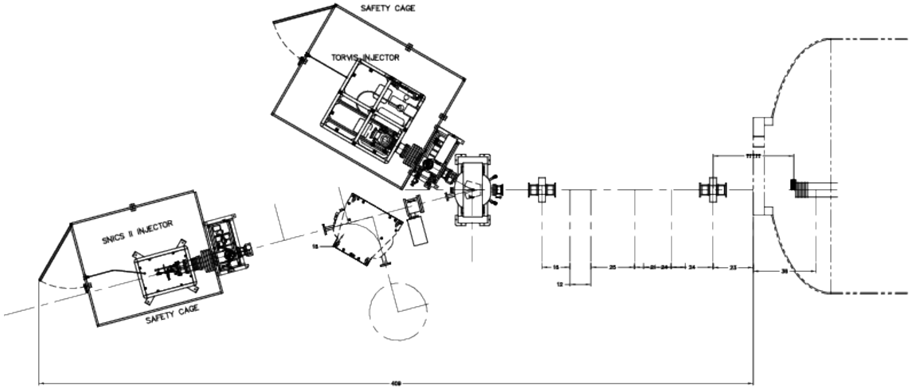
TUNL

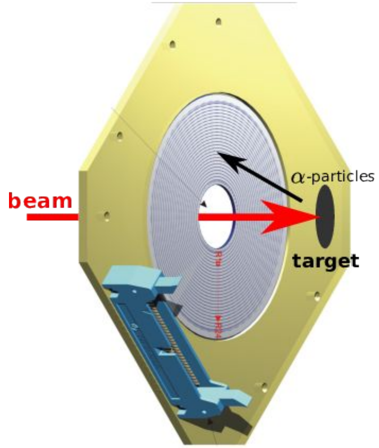
Ion source upgrade



- TORVIS H/He injector
  - 5x more hydrogen
  - 10x more helium
  - Stability upgrade
- SNICS-II
  - Target implantation
  - Heavy beam capabilities

Auxiliary detectors

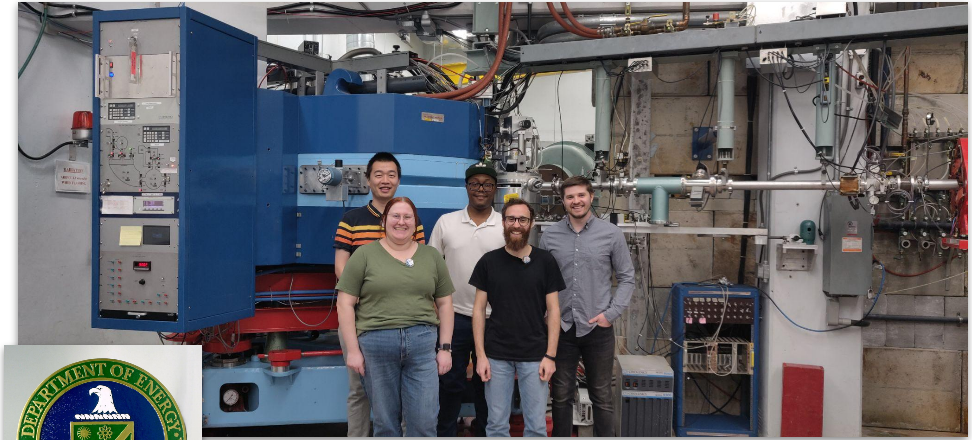
- Silicon detectors to measure decay branches in coincidence
- γ-ray detectors (CeBr3) for decay schemes



- DAQ development complete
- Detector characterization underway
- Requires stability improvements associated with ion source upgrade

Summary

- TUNL's Enge split-pole spectrograph nuclear astrophysics program
- Beam-on-target since 2016
- In "production mode"
- Upgrades to ion sources, detector construction, controls, coincidence capabilities



https://go.ncsu.edu/rlongland

Experimental papers since 2018

Portillo et al., Phys. Rev. C 107 (2023) 035809

Marshall et al., Phys. Rev. C 107 (2023) 035806

Frost-Schenk et al., MNRAS 514 (2022) 2650

Marshall et al., Phys. Rev. C 104 (2021) L032801

Hamill et al., EPJ 56 (2020) 36

Setoodehnia et al., Phys. Rev. C 99 (2019) 055812

Marshall et al., IEEE TIM 68 (2019) 533

Setoodehnia et al., Phys. Rev. C 98 (2018) 055804

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