ARUNA Focus: TUNL

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LOW ENERGY COMMUNITY MEETING

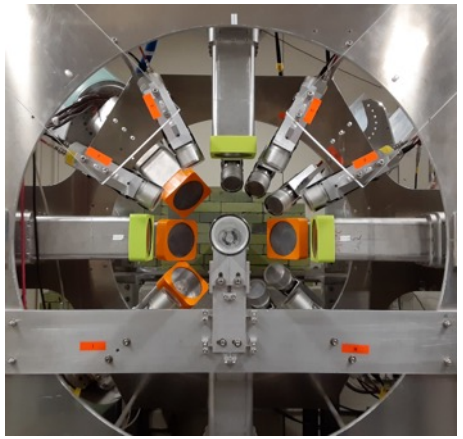
Research Programs at TUNL



Nuclear Astrophysics
LENA Upgrade

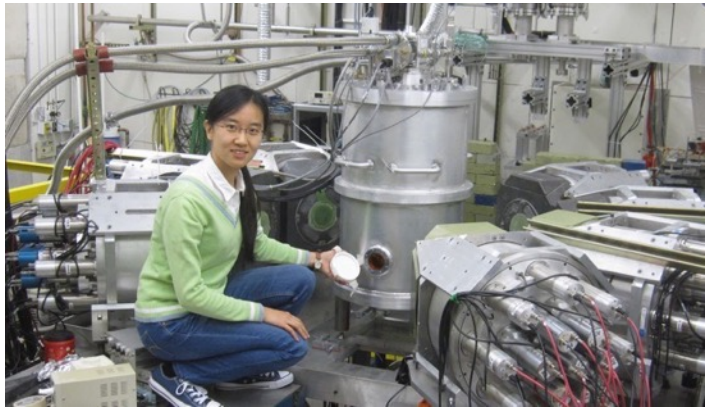
Globular clusters, classical novae, astrophysical s-process, grains

- New 2-MV Singletron accelerator with terminal ECR source and chopper/buncher



Nuclear Structure:
New γ-ray Array at HIγS

- Identify in stable nuclei new excitation modes found in n-rich systems
- Properties of states important for nucleosynthesis
- Strength functions, level density



Medium Energy:
Low-Energy QCD at HIγS

- Compton scattering on H, D and ^{3,4}He to determine nucleon polarizabilities with high precision
- Develop HIγS beams toward pion threshold



Fundamental Symmetries
0νββ

- Analysis of Majorana Demonstrator data
- Commission LEGEND-200
- Prepare for LEGEND-1000

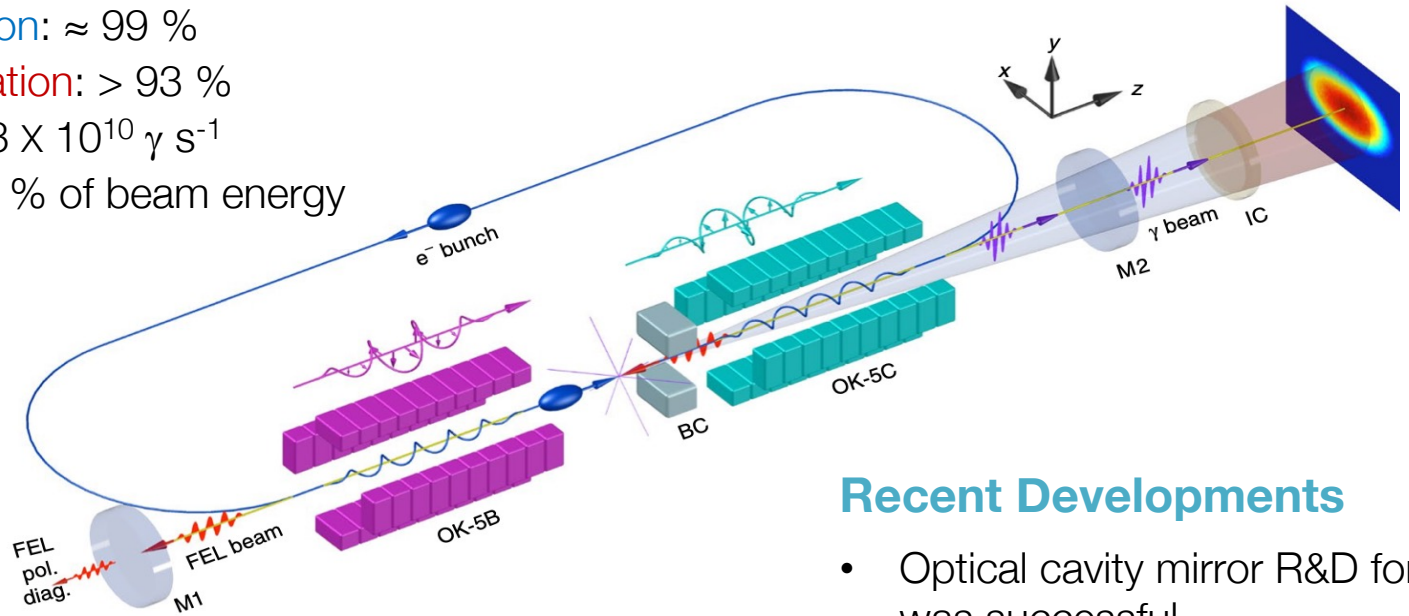
Neutron EDM
- Systematics with polarized UCN and ^{3}He
- Neutron cell development and UCN storage time determination

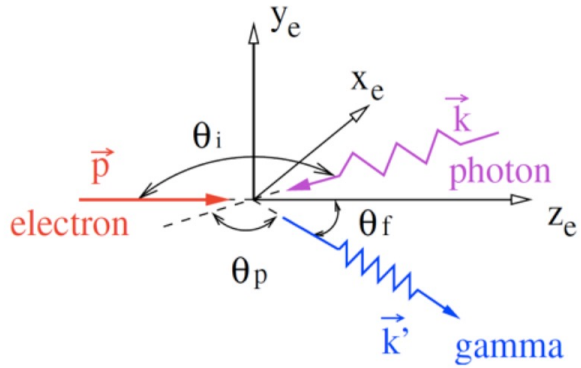
Nuclear Data Program
Nuclear Structure and Decay Data Network

The HIγS Facility

The High Intensity Gamma-ray Source is a **Compton-backscattering** γ-ray source dedicated for nuclear science research.

- **Linear** polarization: ≈ 99 %
- **Circular** polarization: > 93 %
- **Photon flux**: ~ 3 X 10^{10} γ s^{-1}
- **Bandwidth**: 2-5 % of beam energy





New Initiative

- R&D for 155 nm mirror in order to reach 150 MeV γ-ray energy
- Maximum sensitivity for Compton Scattering program on p, d, ^{3,4}He ←LEQCD
- Approach the energy **threshold of pion-photoproduction**.

Recent Developments

- Optical cavity mirror R&D for 175-nm VUV FEL operation at HIγS was successful.
- This accomplishment enables HIγS **operation up to 120 MeV** γ-ray beam energy and enables Compton-scattering measurements with increased sensitivity to nucleon polarizabilities → Tests of Low-Energy QCD (LEQCD)

Nuclear Astrophysics: NRF of ^{40}Ca at HIγS

TUNL

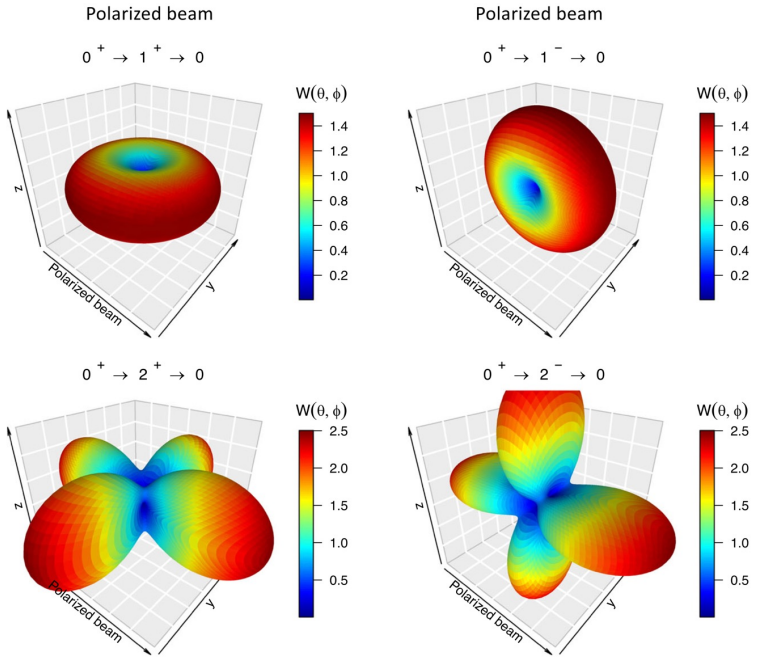
Eur. Phys. J. A (2021) 57:190
https://doi.org/10.1140/epja/s10050-021-00472-1

THE EUROPEAN PHYSICAL JOURNAL A

Review

Linear polarization–direction correlations in γ-ray scattering experiments

Christian Iliadis[1,2,a] , Udo Friman-Gayer[1,2]

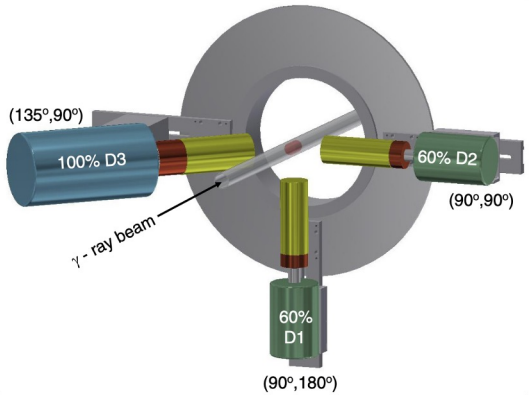


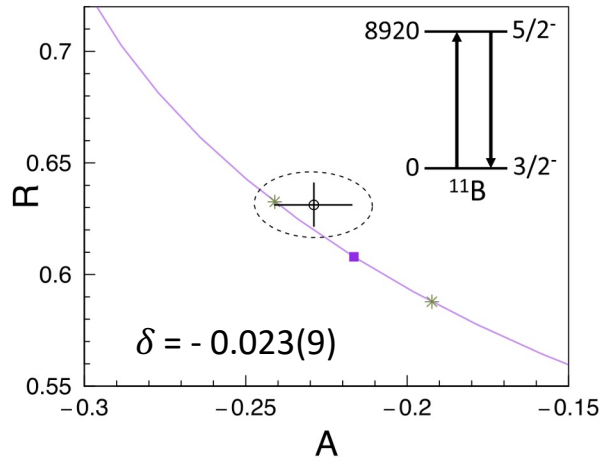
Using linearly polarized beams for precise Energy & Multipolarity determinations

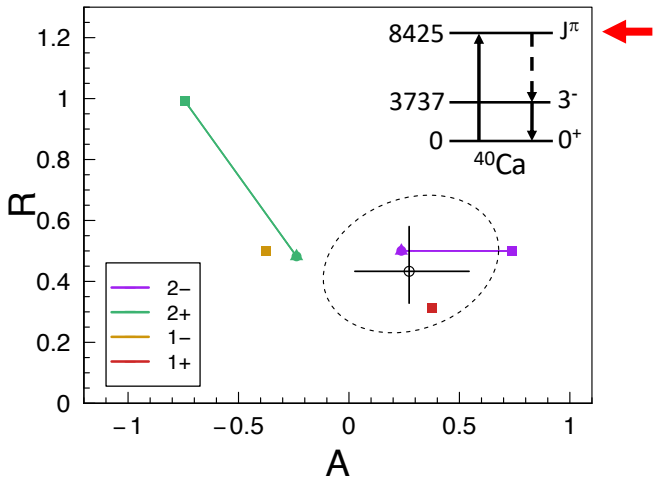
PHYSICAL REVIEW C **106**, 014308 (2022)

Investigation of ^{11}B and ^{40}Ca levels at 8–9 MeV by nuclear resonance fluorescence

D. Gribble[1,2] C. Iliadis[1,2] R. V. F. Janssens[1,2] U. Friman-Gayer[2,3] Krishichayan[2,3] and S. Finch[2,3]

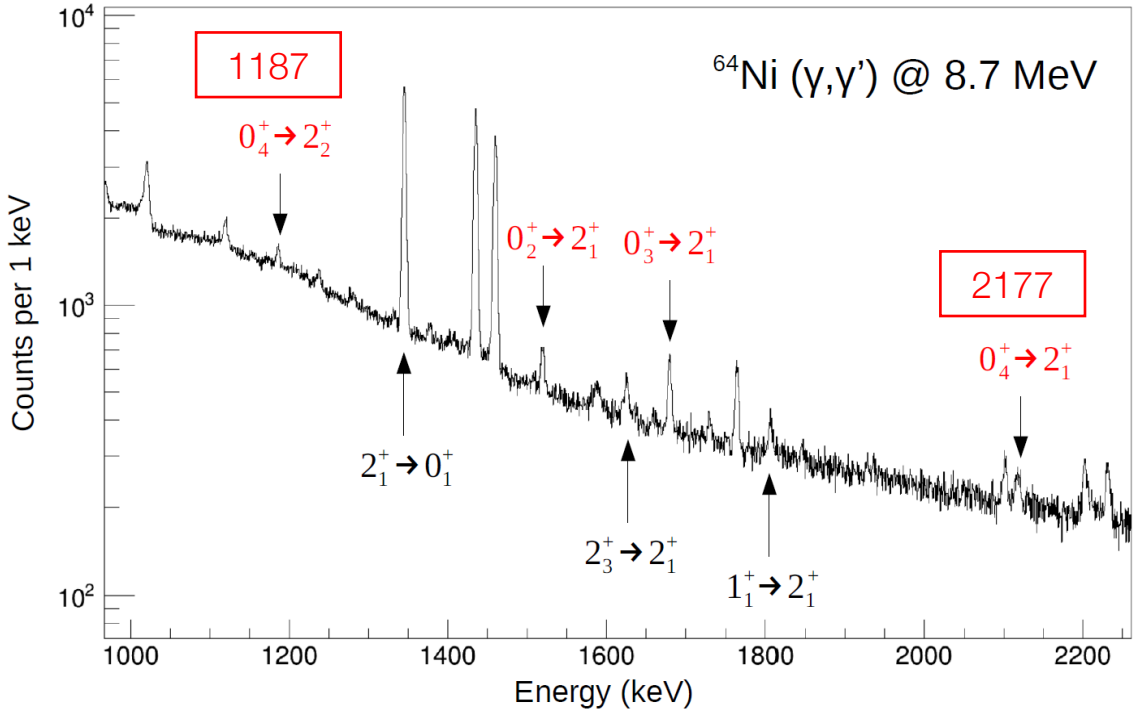


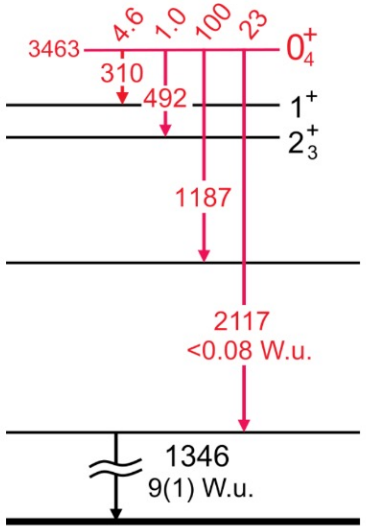


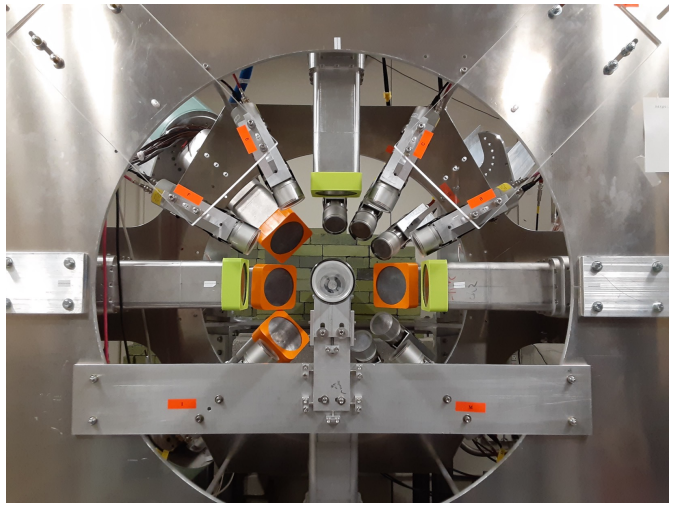


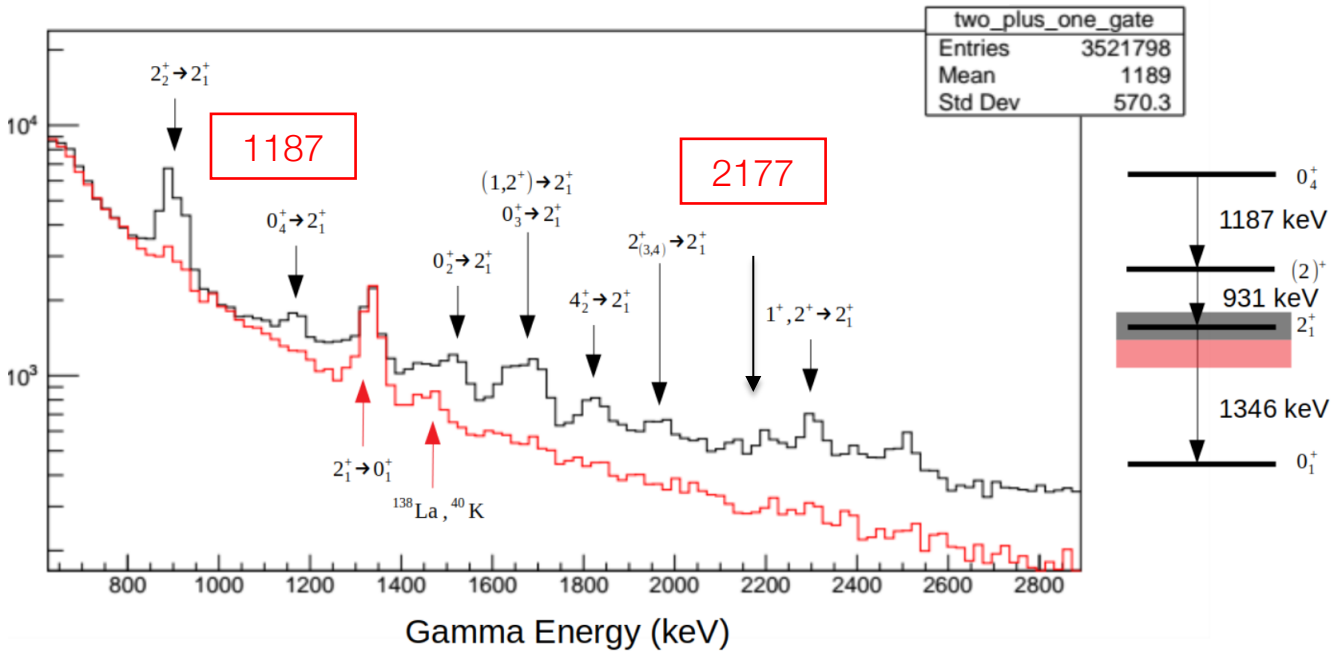
- Improved excitation energies for ^{40}Ca and an unambiguous 2^- assignment for the 8425-keV state.
- This rules out a purported role in the in the ^{39}K(p,g)^{40}Ca reaction, a key reaction in potassium nucleosynthesis, relevant for understanding potassium abundance anomalies in globular clusters

Nuclear structure: Exploring triple shape coexistence in ^{64}Ni at HIγS







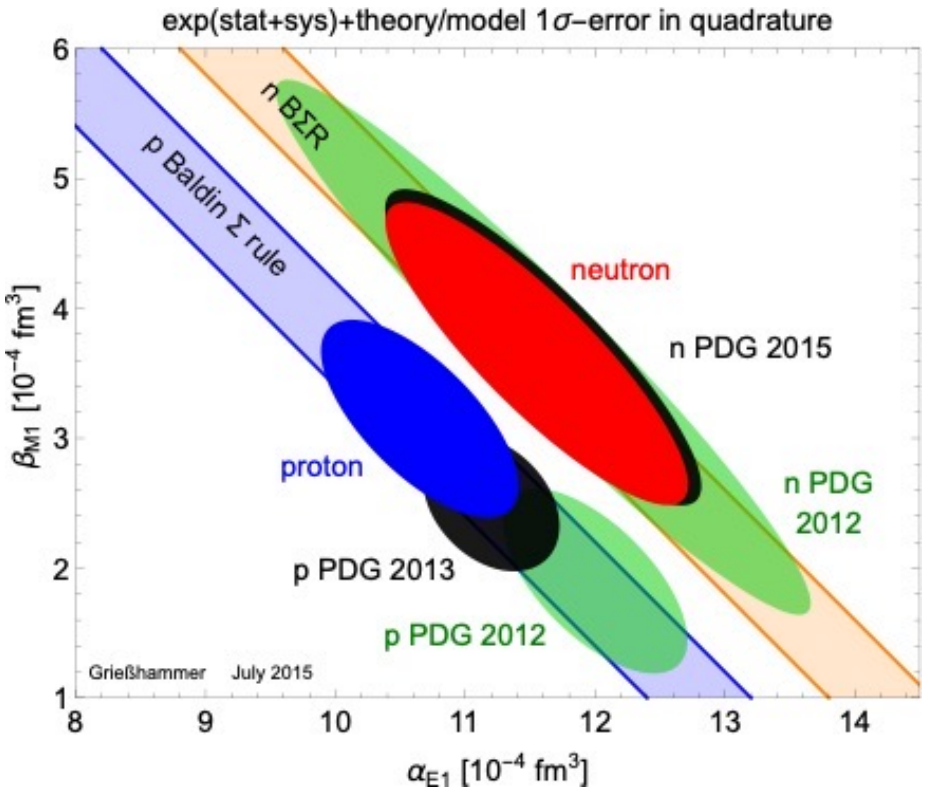


- Unambiguously assigned 15 J = 1$^-$ and 4 J = 1$^+$ states between 8.5 MeV and 9.2 MeV.
- Coincidences confirm level scheme
- Branching ratios, multipole mixing ratios for transitions

X. K. James, UNC Ph.D. Thesis

Nucleon Structure: Nucleon polarizabilities at HIγS

- **Nucleon polarizabilities** characterize the response of the nucleon to low-frequency light: **Structure Functions**
- e.g., the β_M (magnetic polarizability) of a nucleon is an interplay between diamagnetic charged pion currents and paramagnetic Δ resonance



Polarizabilities have been parameterized in various frameworks:

- Low-Energy Expansion (LEX) $\omega < 70$ MeV
- Dispersion Relations (DR)
- Chiral Effective Field Theories (cEFT) ($\omega < \Lambda_b \sim 650$ MeV)
- Lattice QCD (L-QCD)

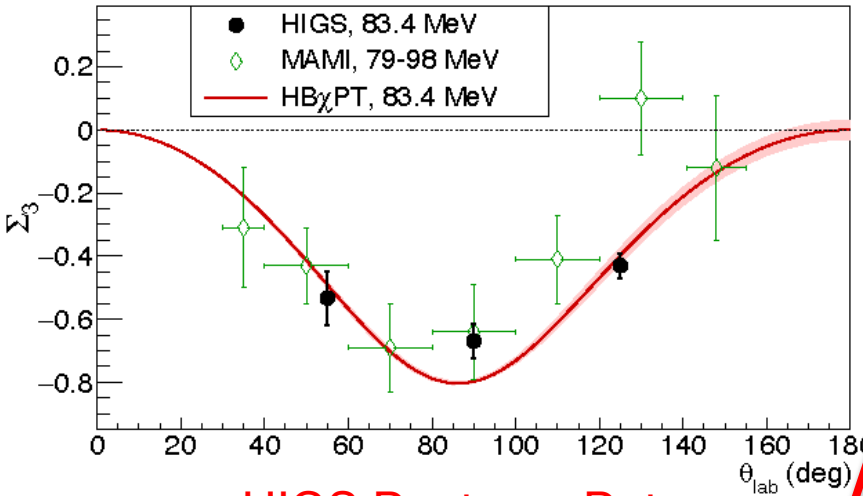
α_{E1}	(p) $10.65 \pm 3.2\%\ (stat) \pm 0.2\ (Baldin) \pm 0.3\ (theory)$
	(n) $11.55 \pm 10.8\%\ (stat) \pm 0.2\%\ (Baldin) \pm 0.8\ (theory)$
β_{M1}	(p) $3.15 \pm 11.1\%\ (stat) \pm 0.2\ (Baldin) \pm 0.3\ (theory)$
	(n) $3.65 \pm 34.2\%\ (stat) \pm 0.2\ (Baldin) \pm 0.8\ (theory)$

Nucleon Polarizabilities: Compton Scattering at HIγS

TUNL

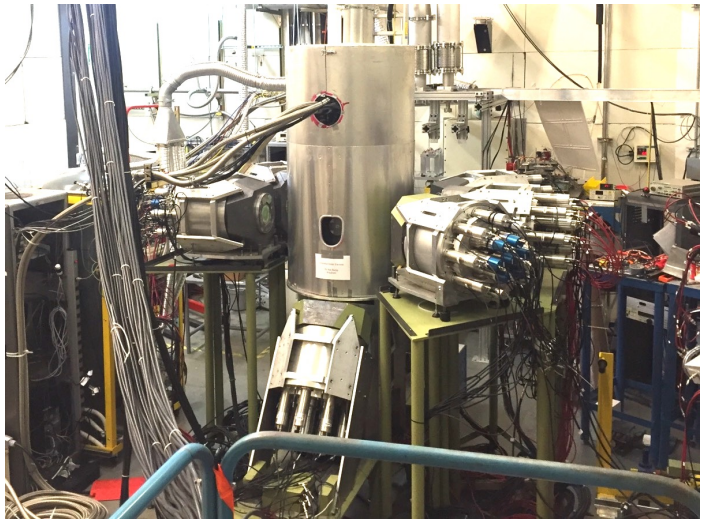
HIGS Proton Data (80 MeV)

Phys. Rev. Lett. 128, 132502

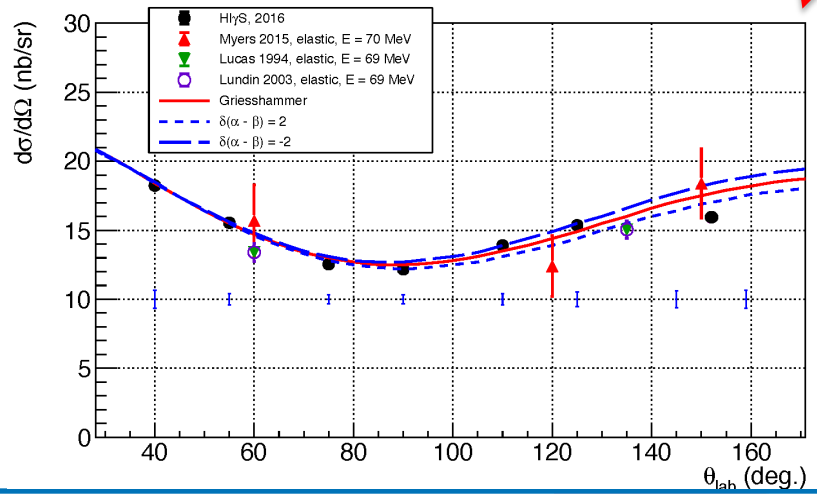


Sample of Present data on H and D

Setup at HIγS

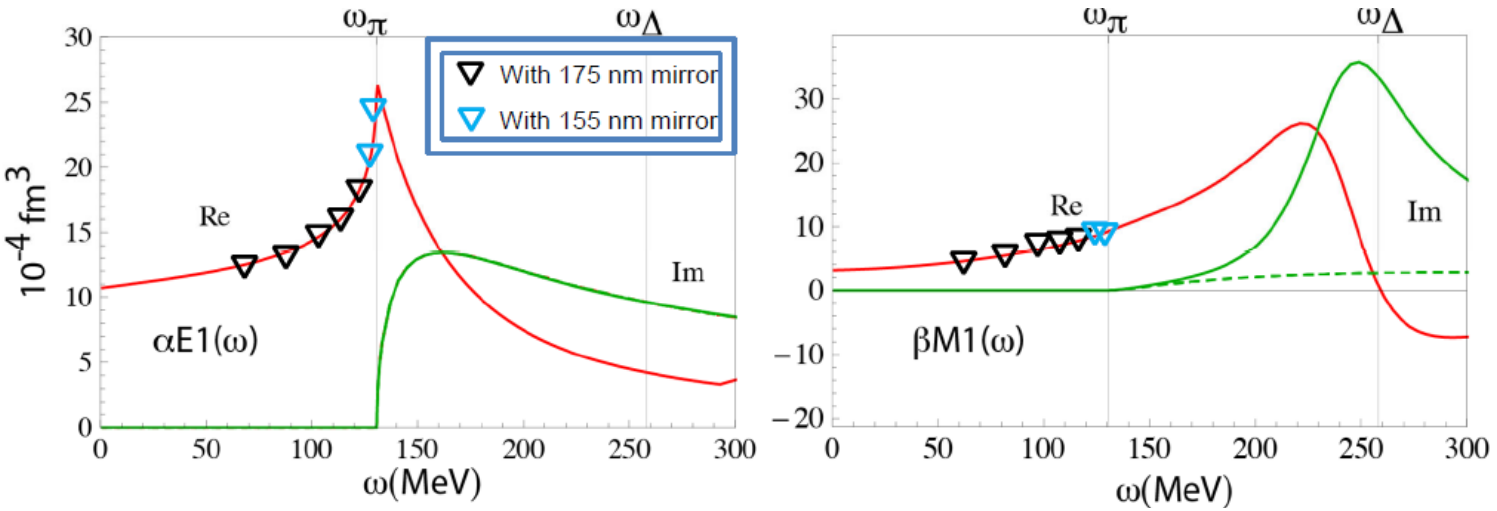


HIGS Deuteron Data



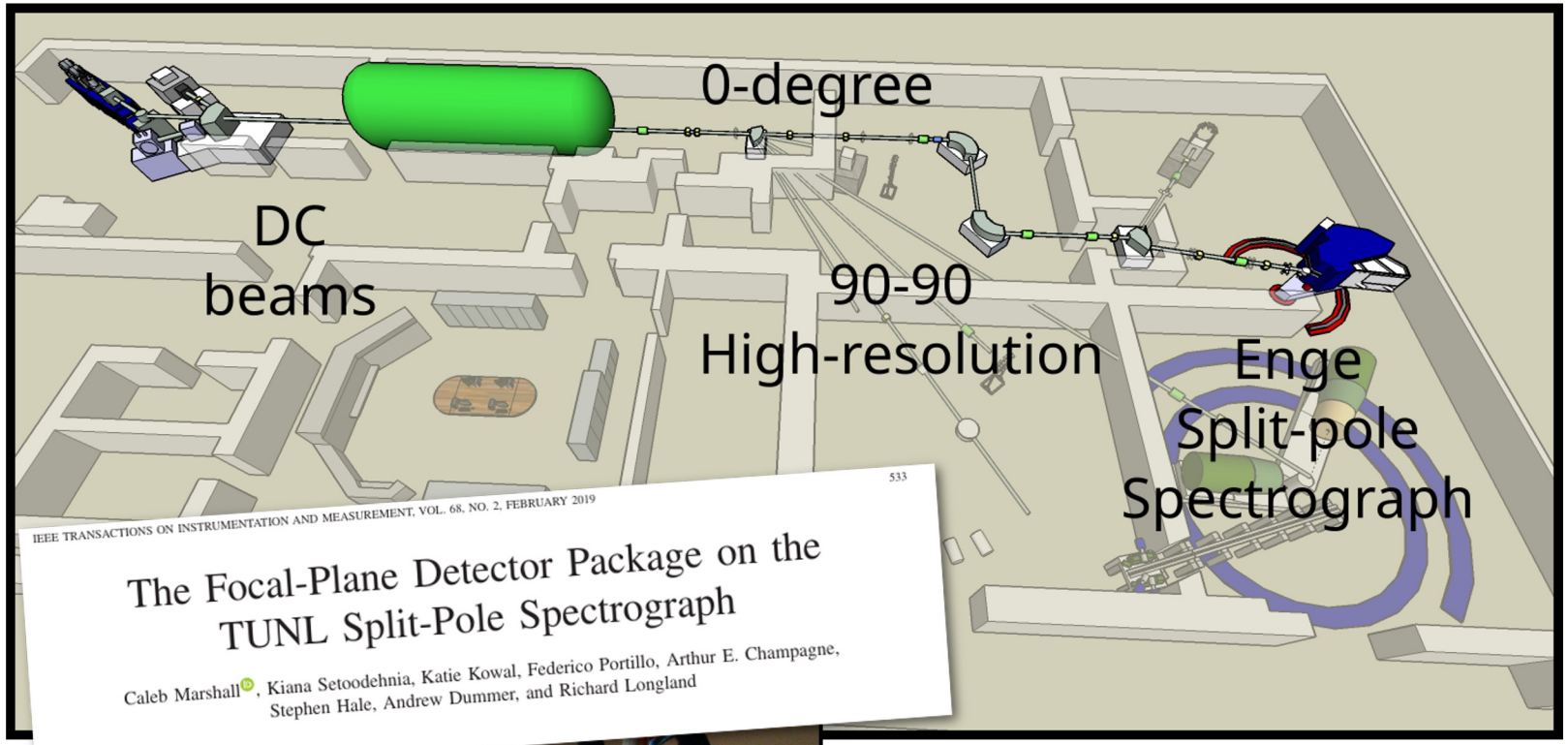
<u>Next 3 – 5 years</u>: focus on measurements of neutron EM polarizabilities

- Compton scattering from liquid H,D,^{3}He, and ^{4}He targets at E_γ = 65 - 120 MeV



Tandem Lab: Origins of matter with the Enge SPS spectrograph

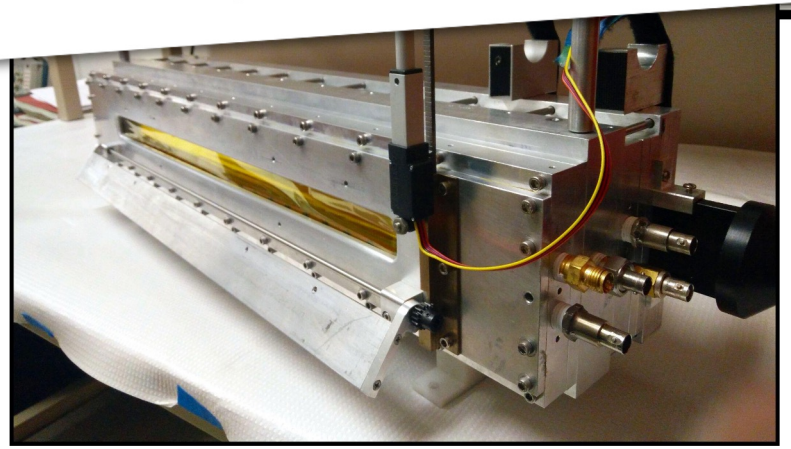
TUNL

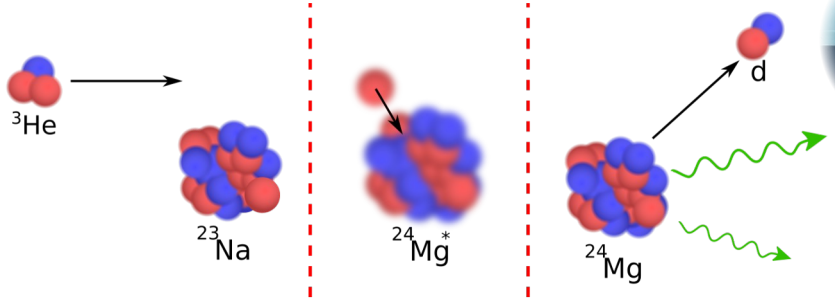


IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 68, NO. 2, FEBRUARY 2019 533

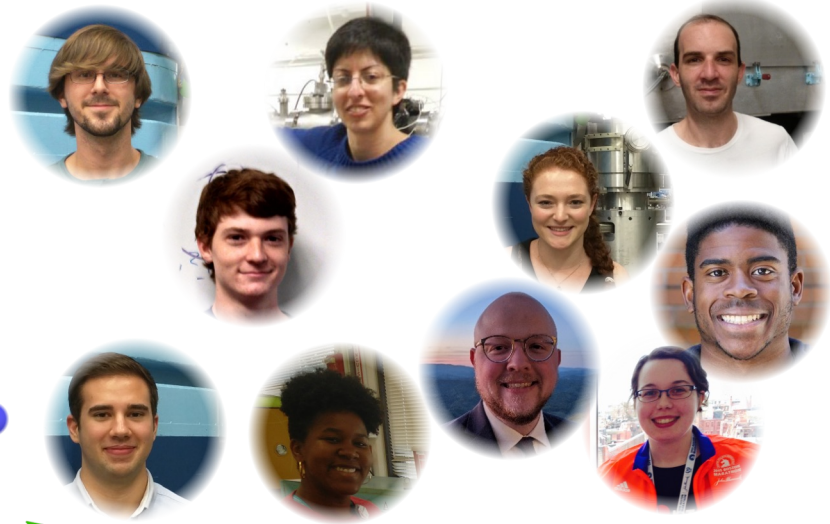
The Focal-Plane Detector Package on the TUNL Split-Pole Spectrograph

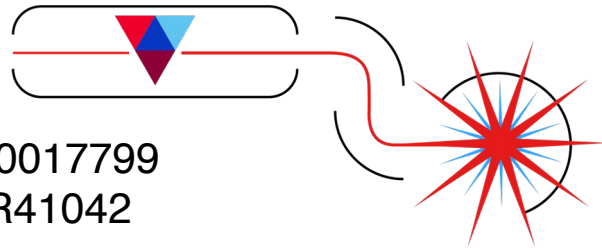
Caleb Marshall, Kiana Setoodehnia, Katie Kowal, Federico Portillo, Arthur E. Champagne, Stephen Hale, Andrew Dummer, and Richard Longland











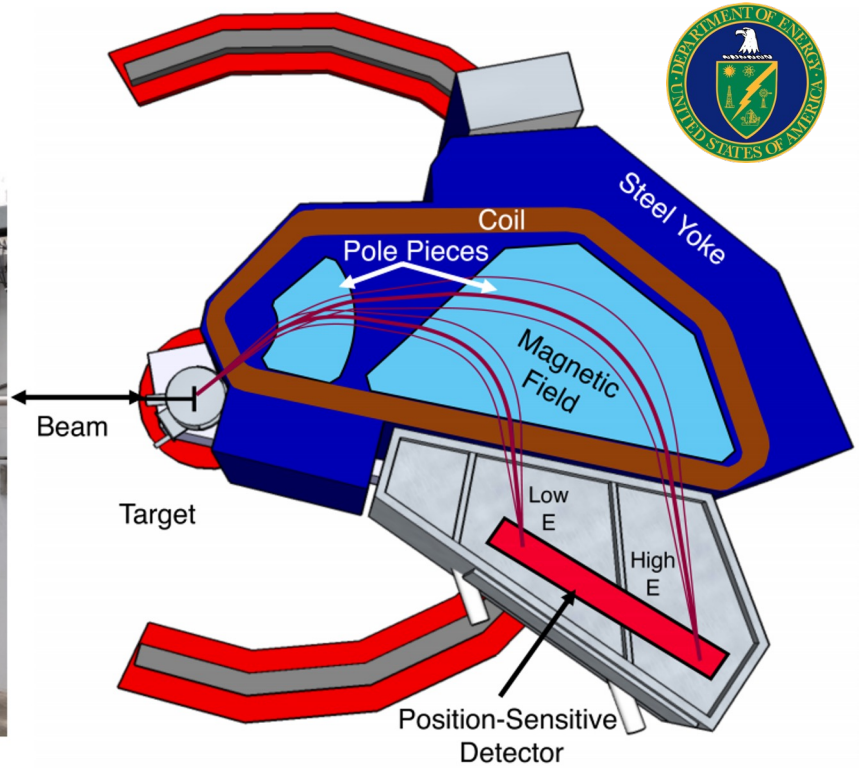
DOE Award Number DE-SC0017799
Contract No. DE-FG02-97ER41042

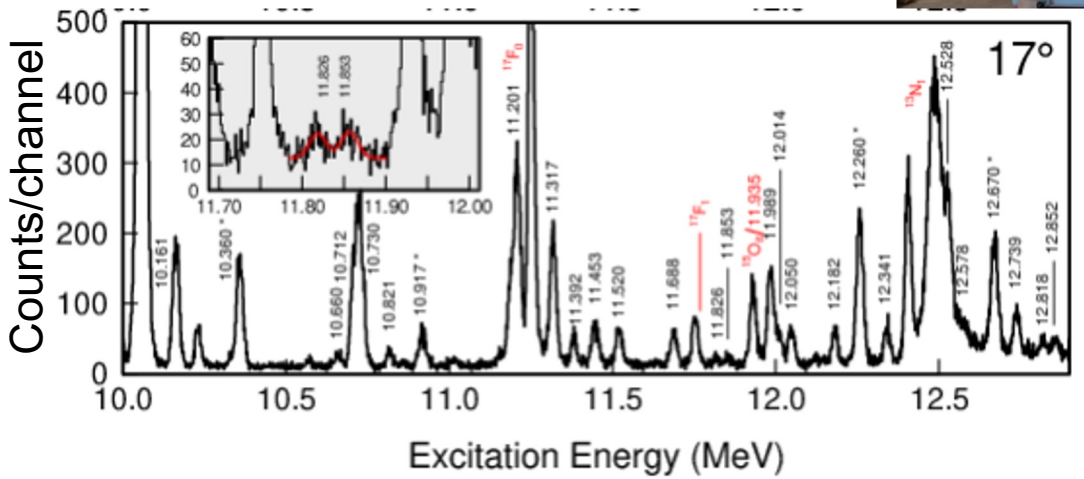
The Tandem Lab: Origins of matter with TUNL's Enge split-pole

TUNL

- Using particle transfer reactions to **study the structure of nuclides important for nucleosynthesis**.
- High-resolution beams, precise target manufacture, and **high-resolution detector technology** enable world-leading nuclear astrophysics measurements.
- Developing sophisticated **analysis techniques** to modernize particle transfer measurements







Recent (experimental) spectrograph highlights:

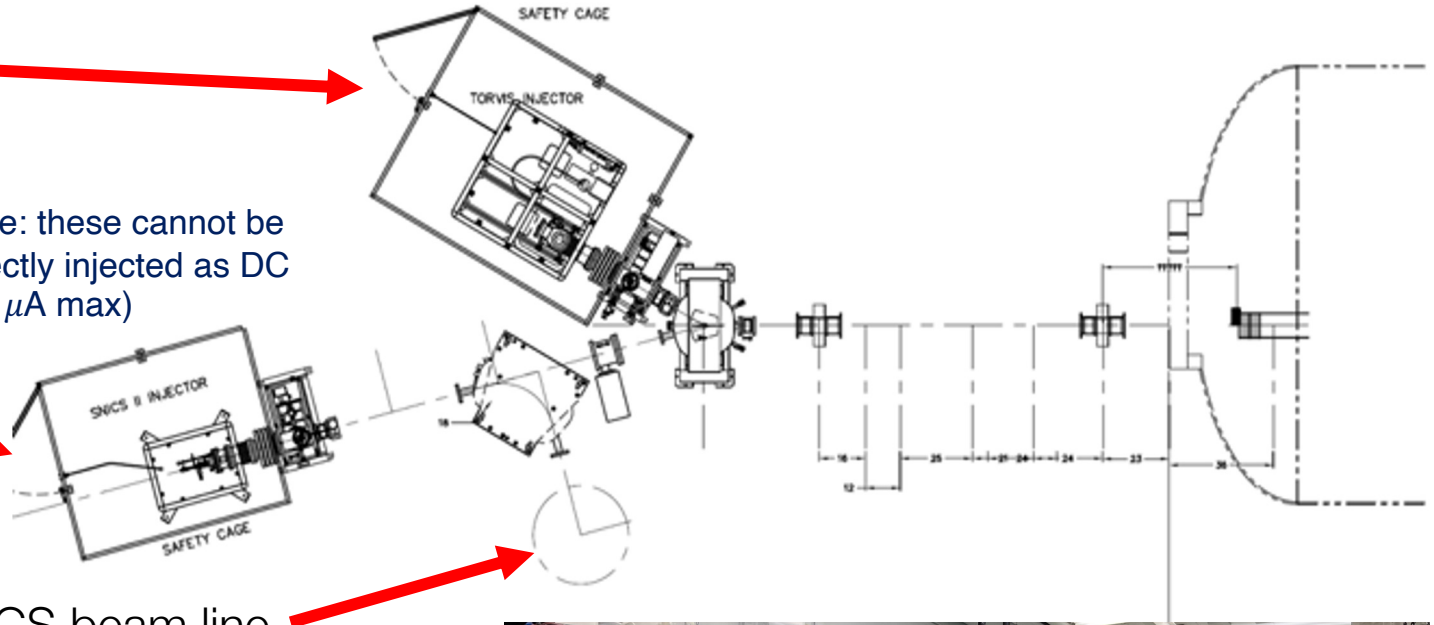
- Portillo et al., PR C 107, 035809 (2023) [^{20}Ne(^{3}He,^{4}He)^{19}Ne]
- Frost-Schenk et al., MNRAS 514, 2650 (2022) [^{20}Ne(d,p)^{21}Ne]
- Marshall et al., PR C 104, L032801 (2021) [^{23}Na(^{3}He,d)^{24}Mg]
- Hamill et al., EPJ A 56, 36 (2020) [^{25}Mg(d,p)^{26}Mg]

TUNL's Tandem Injectors Upgrade: Two New Sources

Performance Specifications

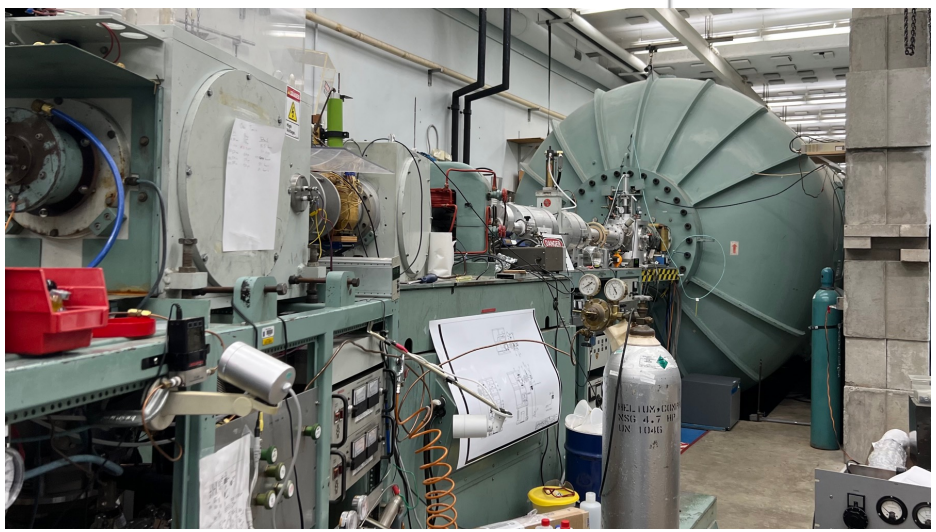
- TORVIS H/He ion source
  - 75 kV source deck (acceleration)
  - 100 μA H^-
  - 20 μA He^-
- SNICS-II ion source
  - Heavy ion beams
  - 90-degree magnet for implantation

Note: these cannot be directly injected as DC (20 μA max)



Additional upgrades

- Provide **implantation** capability from SNICS beam line
- Complete replacement of low-energy beam line
- Optics designed to couple both sources to Tandem
- Chopper system, including chopper plates, pulse generator, DC offset power supply, but using our (superior) clock signals

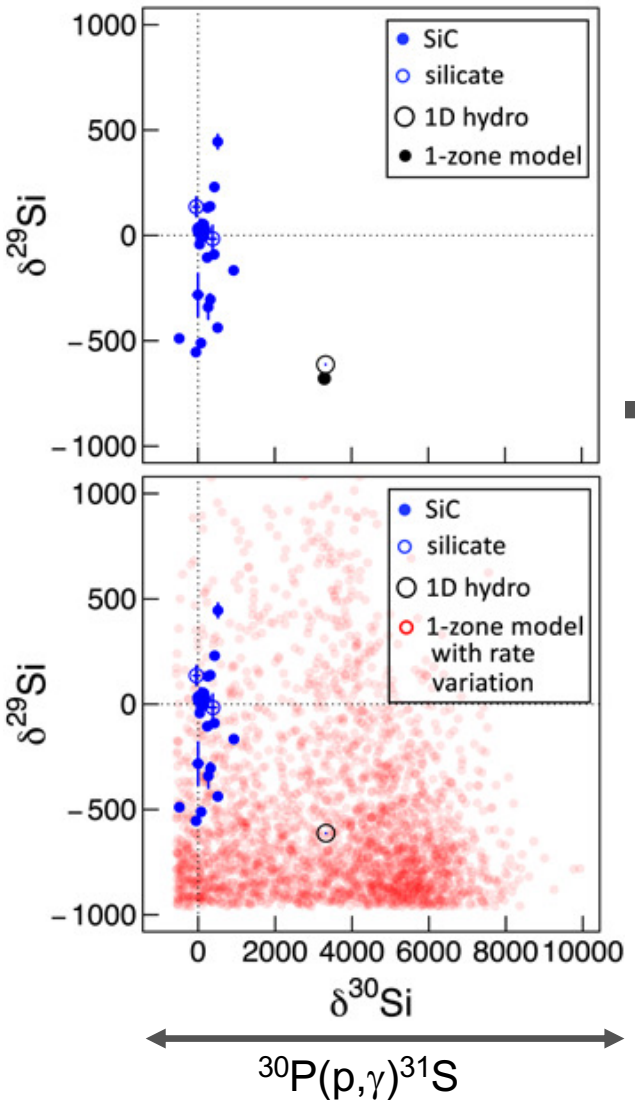


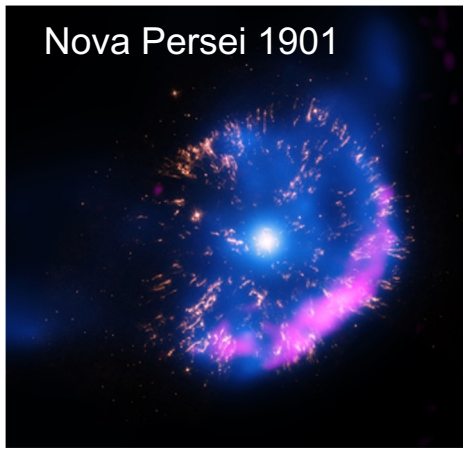
Enables

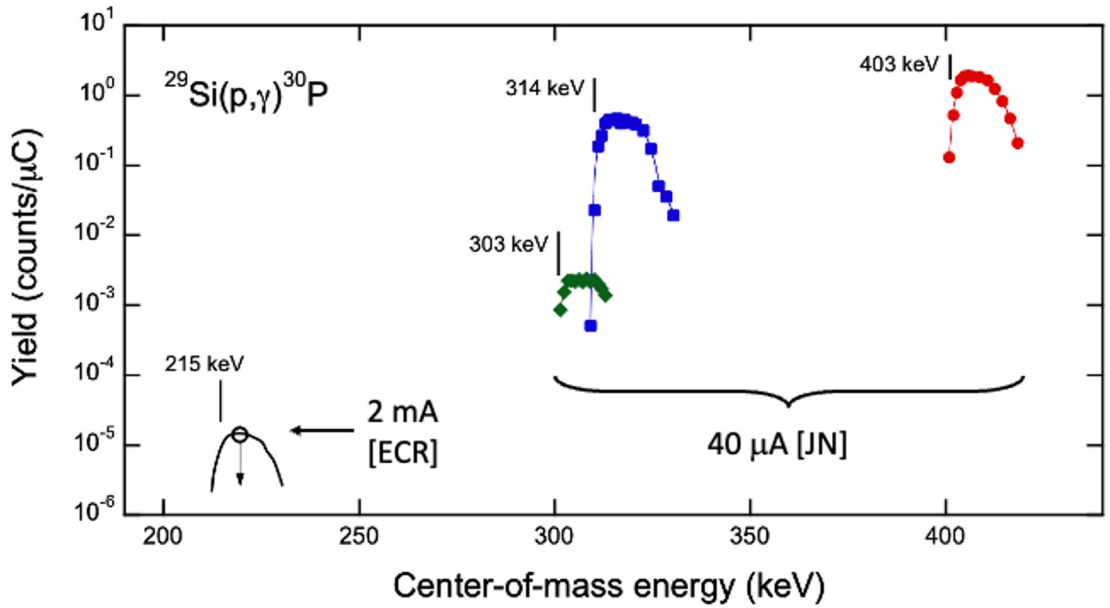
- **High-resolution studies** with long-term source stability
- **Factor-of-two** improvement in timing resolution for NTOF
- Heavy ion beams

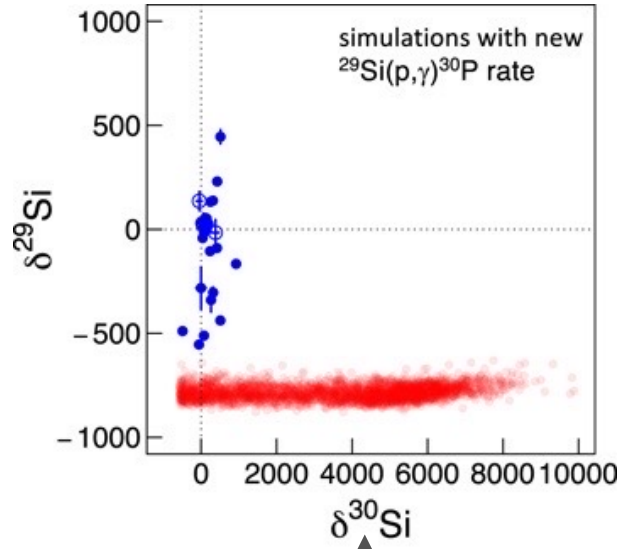
LENA Science Highlight: $^{29}Si(p,\gamma)^{30}P$

Explaining the origin of meteoritic grains in stellar explosions





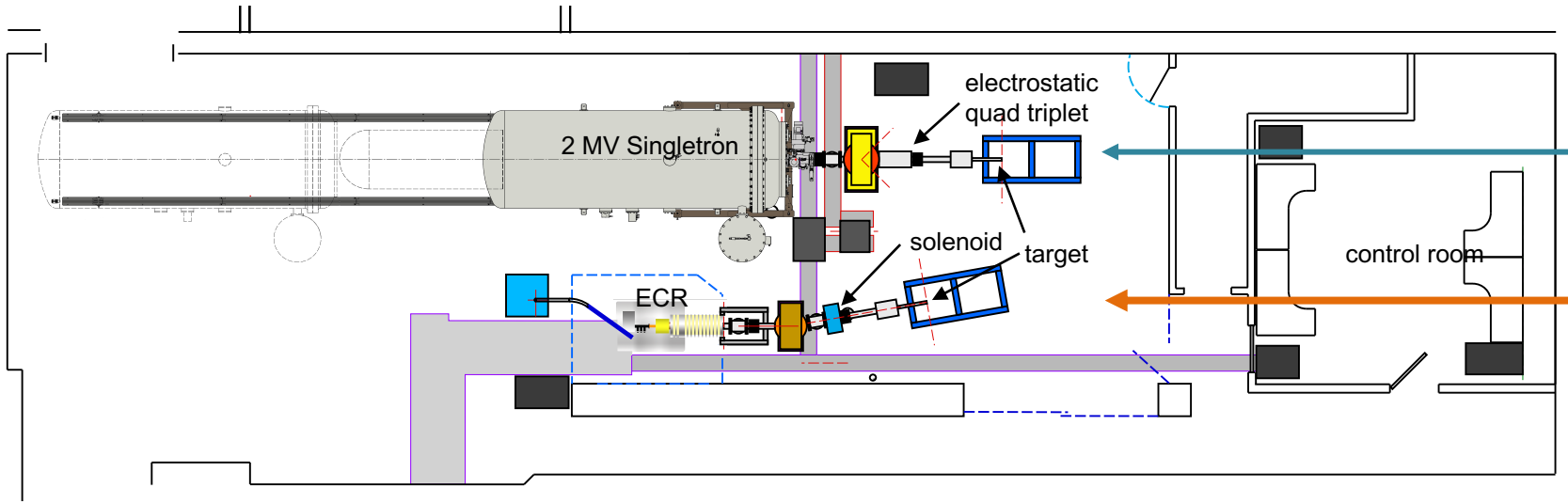






L. Downen, et al., *Ap. J* **928**, 128 (2022)

LENA II Upgrade: Present Status



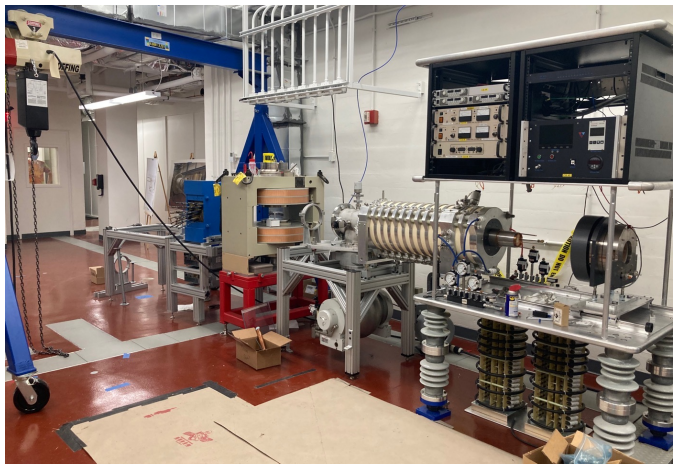
2-MV **Singletron accelerator** with new 2.45 GHz ECR ion source

Refurbished **ECR** on HV platform with pulsing capabilities

230-kV ECR Accelerator

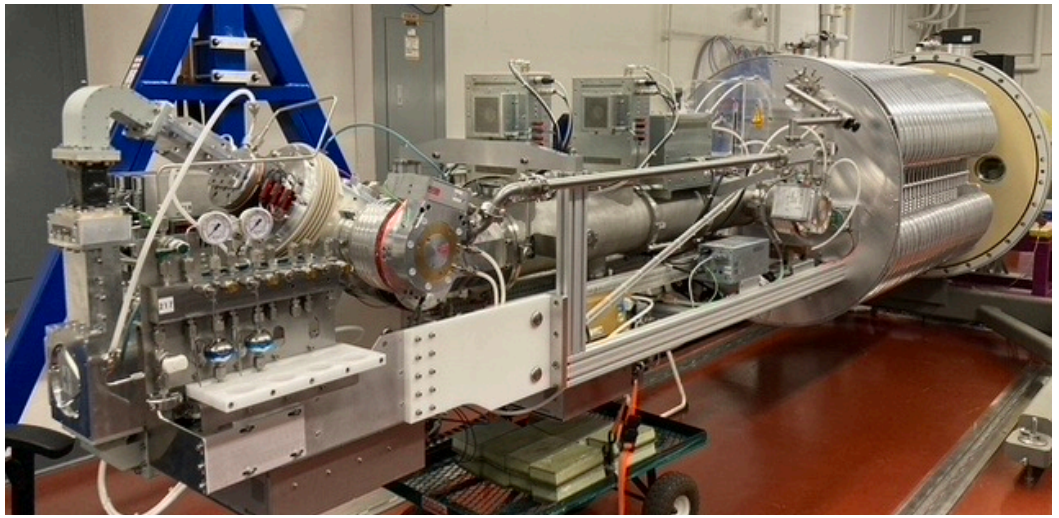
~ 20 mA DC H^+

Slow pulsing (10% duty cycle)



2-MV HVEE Singletron

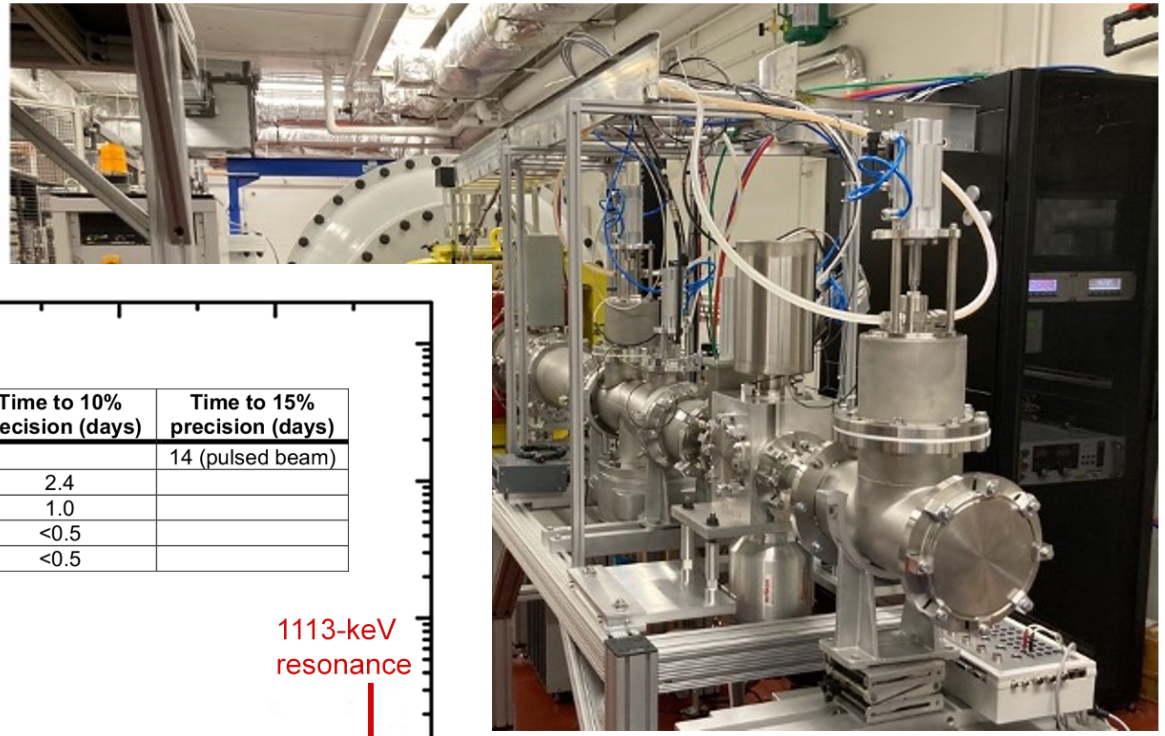
- DC beam current at 250 kV: 0.5 mA (H), 0.4 mA (He)
- DC beam current at 1 - 2 MV: 2 mA (H and He)
- Pulse frequency: 0.125, 0.25, 0.5, 1, 2, 4 MHz
- Pulse width: 2 – 20 ns

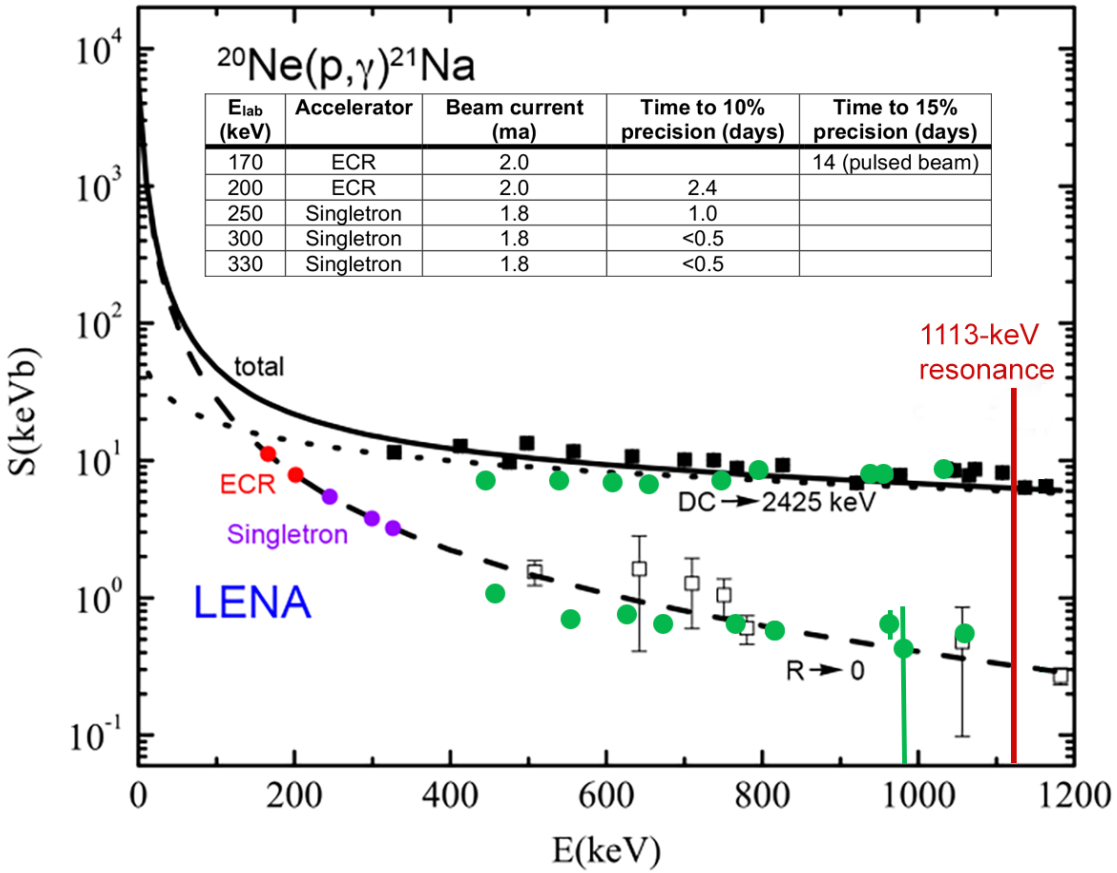


Singletron Experiments

- Hydrogen Burning
  - $^{20}Ne(p,g)^{21}Na$
- Helium Burning
  - $^{12}C(a,g)^{16}O$
- s-Process
  - $^{22}Ne(a,g)^{26}Mg$







E_{lab} (keV)	Accelerator	Beam current (ma)	Time to 10% precision (days)	Time to 15% precision (days)
170	ECR	2.0		14 (pulsed beam)
200	ECR	2.0	2.4	
250	Singletron	1.8	1.0	
300	Singletron	1.8	<0.5	
330	Singletron	1.8	<0.5	

abundance anomalies in globular clusters

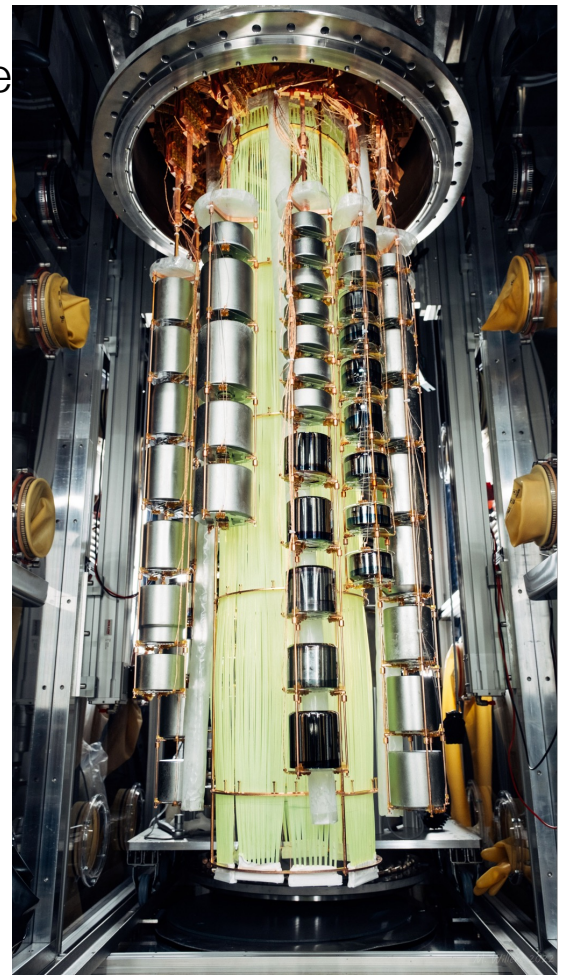
(adapted from A.M. Mukhamedzhanov et al., Phys. Rev. C 73 (2006), 035806; black: C. Rolfs et al., Nucl. Phys. A241 (1975), 460; green: S. Lyons et al., Phys. Rev. C 97 (2018), 065802)

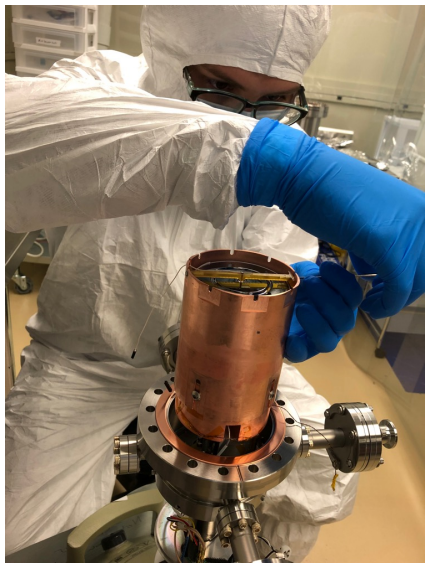
LEGEND-1000

- 1000 kg, Search for Neutrinoless Double-beta Decay
- Background goal <0.03 cts/(FWHM t yr) — completely probe inverte hierarchy

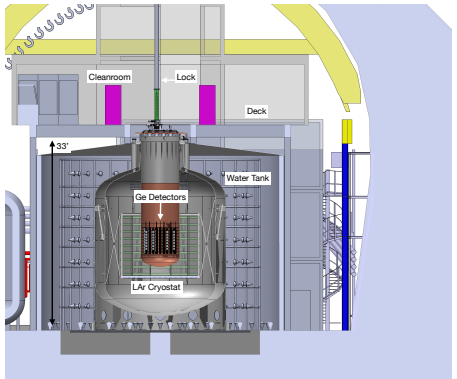
- TUNL LEGEND-1000 **Leadership and Major Responsibilities**
  - Project management
  - Simulations and Analysis
  - Host Lab Infrastructure and Cryostat Systems
  - Ge Detector Production
  - Electronics and DAQ

- **TUNL has an ideal balance** of science, technical capabilities, and analysis/simulations expertise
  - Cohesive coverage of Ge detector production
  - Integrated testing (Full chain) and DAQ, Engineering
  - Simulations and analysis
  - Strong connections to ORNL group, lead DOE laboratory
  - R&D on advanced characterizations, new detector technologies





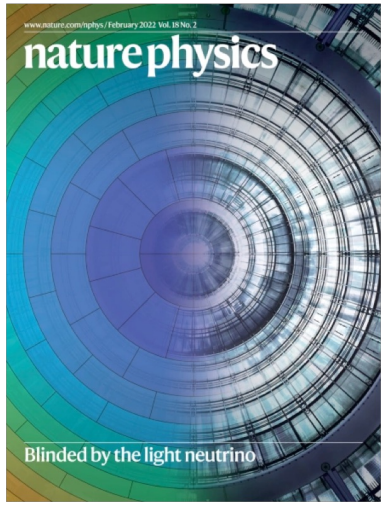
UNC Grad Student **Erin Engelhardt** Installing HPGe Detector in Test Stand

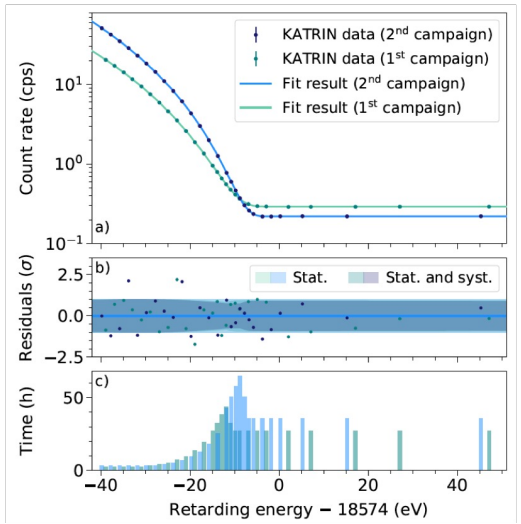


KATRIN Neutrino Mass Experiment

First direct neutrino-mass measurement with sub-eV sensitivity

Nature Physics **18**, 160-166 (2022)
https://doi.org/10.1038/s41567-021-01463-1





Upper Limit (KNM1 & KNM2): $m_\nu < 0.8$ eV/c² (90%) CL

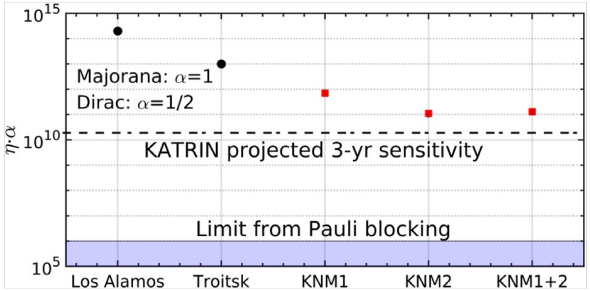
PHYSICAL REVIEW LETTERS **129,** 011806 (2022)

Editors' Suggestion | Featured in Physics

New Constraint on the Local Relic Neutrino Background Overdensity with the First KATRIN Data Runs

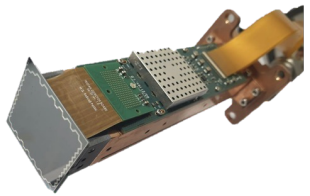
DOI: 10.1103/PhysRevLett.129.011806

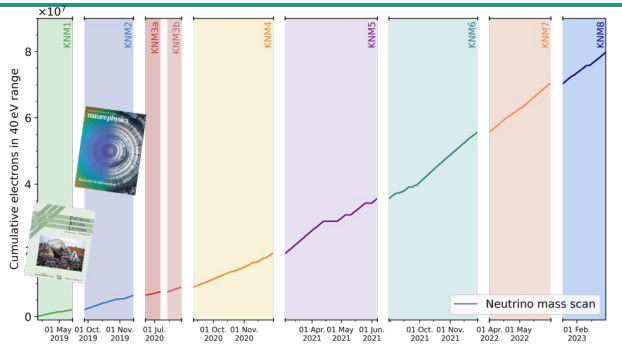
Direct search for cosmic relic neutrinos using data acquired during the first two science campaigns of the KATRIN experiment



Upper Limit (KNM1 & KNM2): $\eta < 9.7 \times 10^{10}/\alpha$ (90% CL)
$\alpha = 1$ (0.5) for Majorana (Dirac) neutrinos

- KATRIN has acquired 80 million electrons in 40 eV range below endpoint over 407 days of beta scanning (KNM1-8). (Using ORCA DAQ)
- Continue to acquire data (205 science days per year)
- Contributions to TRISTAN detector upgrade (Sterile Neutrino Search)
- Completion of initial quantum sensor e-tagging study

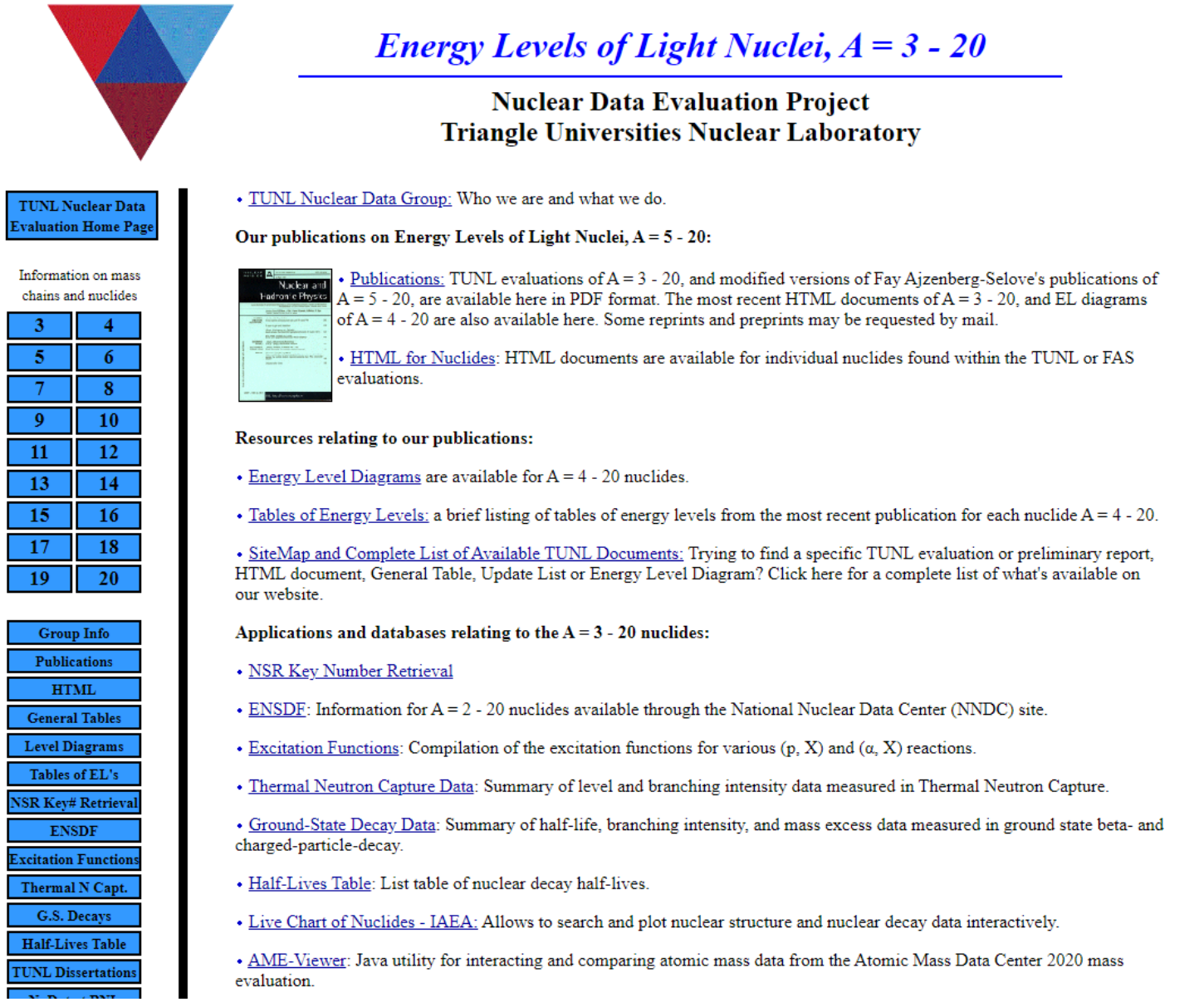




TUNL

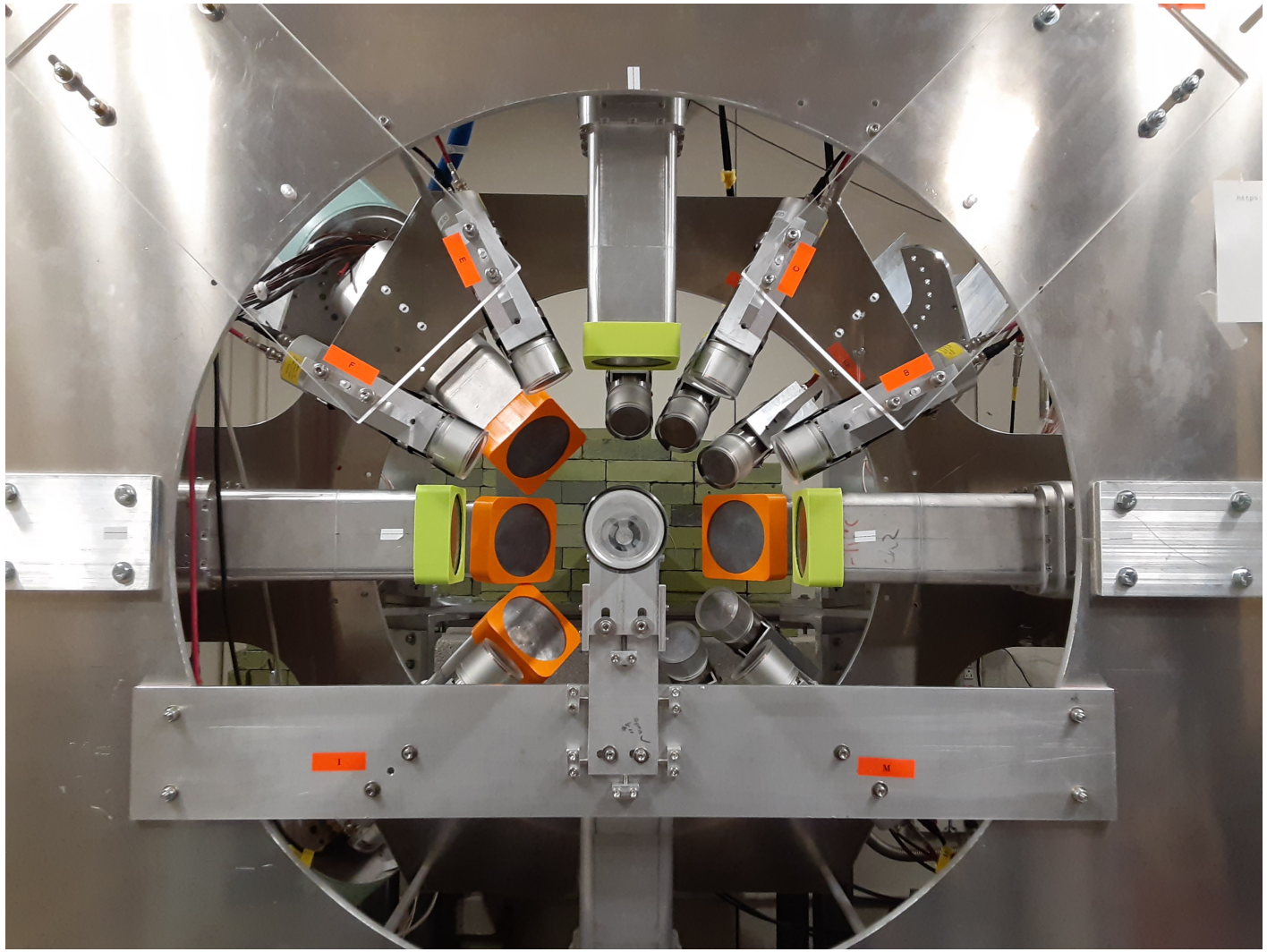
- TUNL is involved in data evaluation as part of the US Nuclear Data Program and as part of the international Nuclear Structure and Decay Data Network.
- Effort is focused on production of ENSDF evaluations and XUNDL compilations.
- ARUNA labs at TUNL and Texas A&M have data centers who contribute in these activities.

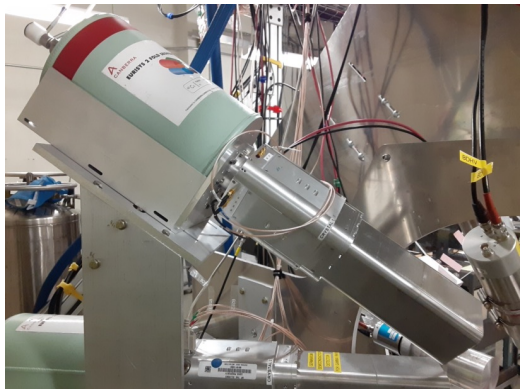
The Nuclear Structure and Decay Data network formed in 1974, under the leadership of Katherine Way (UNC-1938), and it represents an international effort dedicated to the production of ENSDF and other evaluated nuclear structure data.

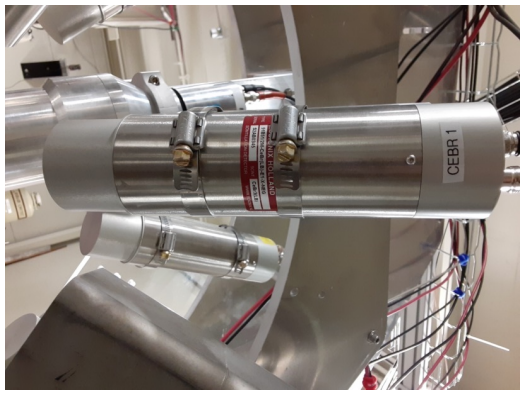


Thank You

γ-ray Detectors at HIγS: The Clover Array







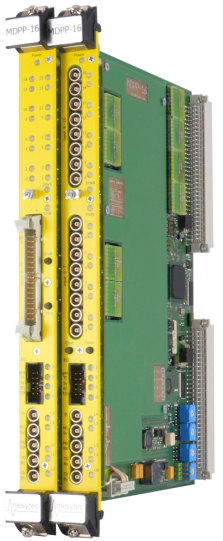
HPGe **CeBr**

- 10 (16) clover-type HPGe** and 12 (2′′ × 2′′) CeBr detectors.
- Higher HPGe rates due to segmentation.
- Higher granularity.
- No intrinsic radioactivity.
- Solid angle coverage: 14%

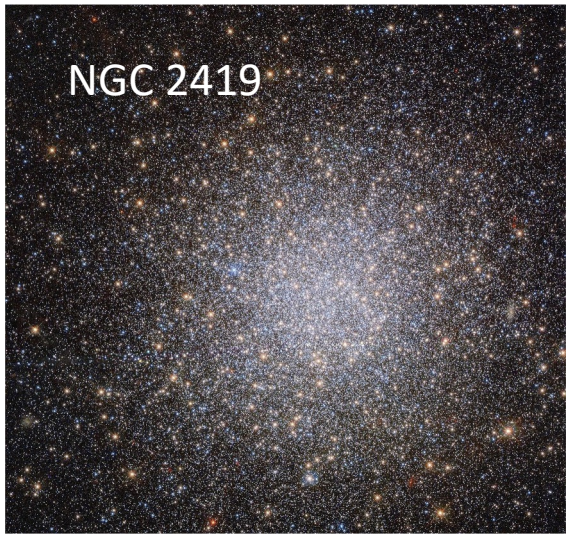
**Provided by the Clovershare Consortium, the US Naval Academy, the US Army Research Lab, and TUNL

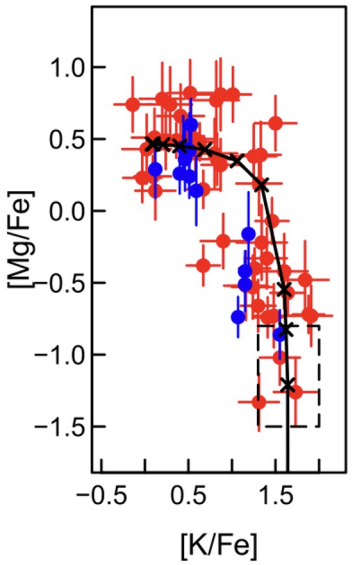
For certain applications: $LaBr_3$

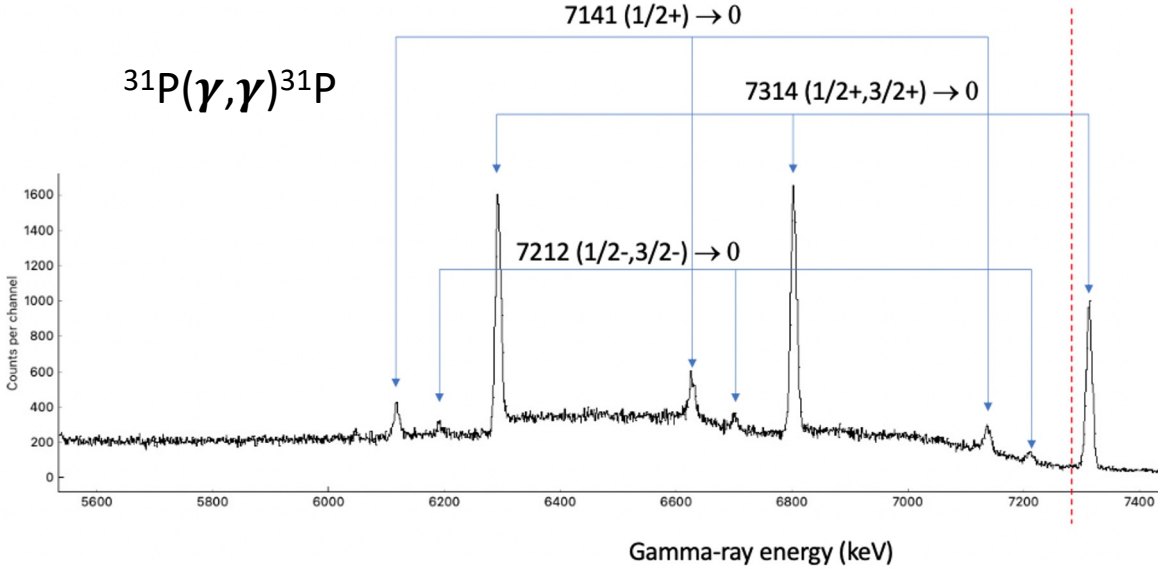
- **Mesytec** Hardware

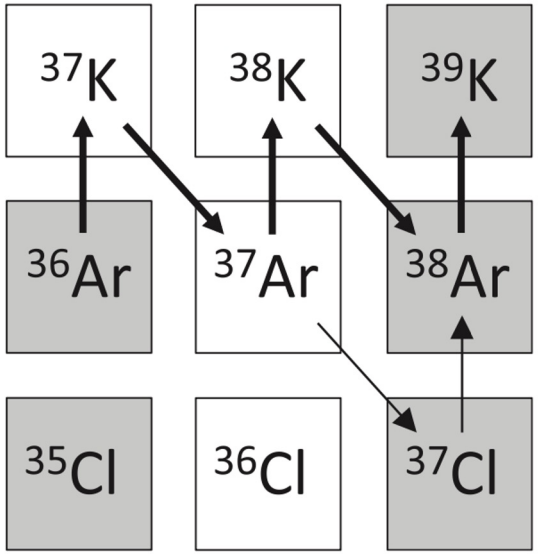


31P(γ,γ)31P and 39K(γ,γ)39K by NRF: ongoing





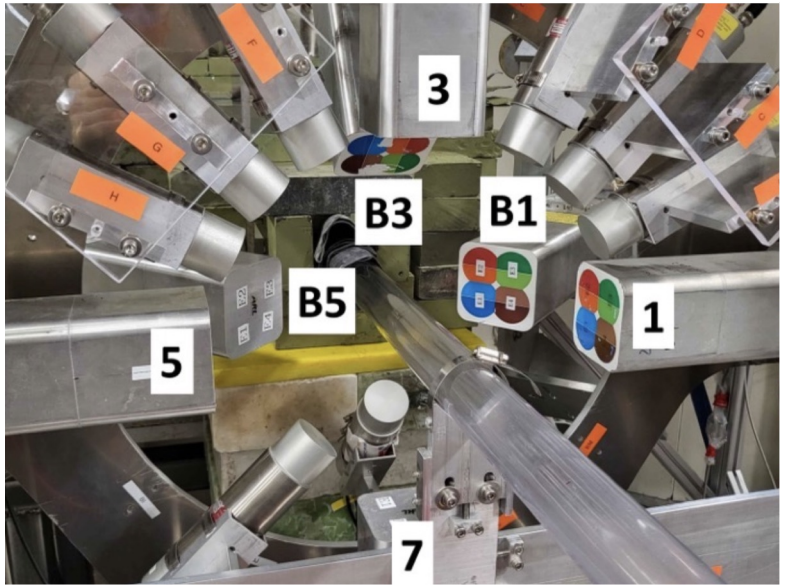




Iliadis et al.,
ApJ 818, 98 (2016)



David Gribble



LENA Measurements For Globular Clusters



PHYSICAL REVIEW C **102**, 014609 (2020)

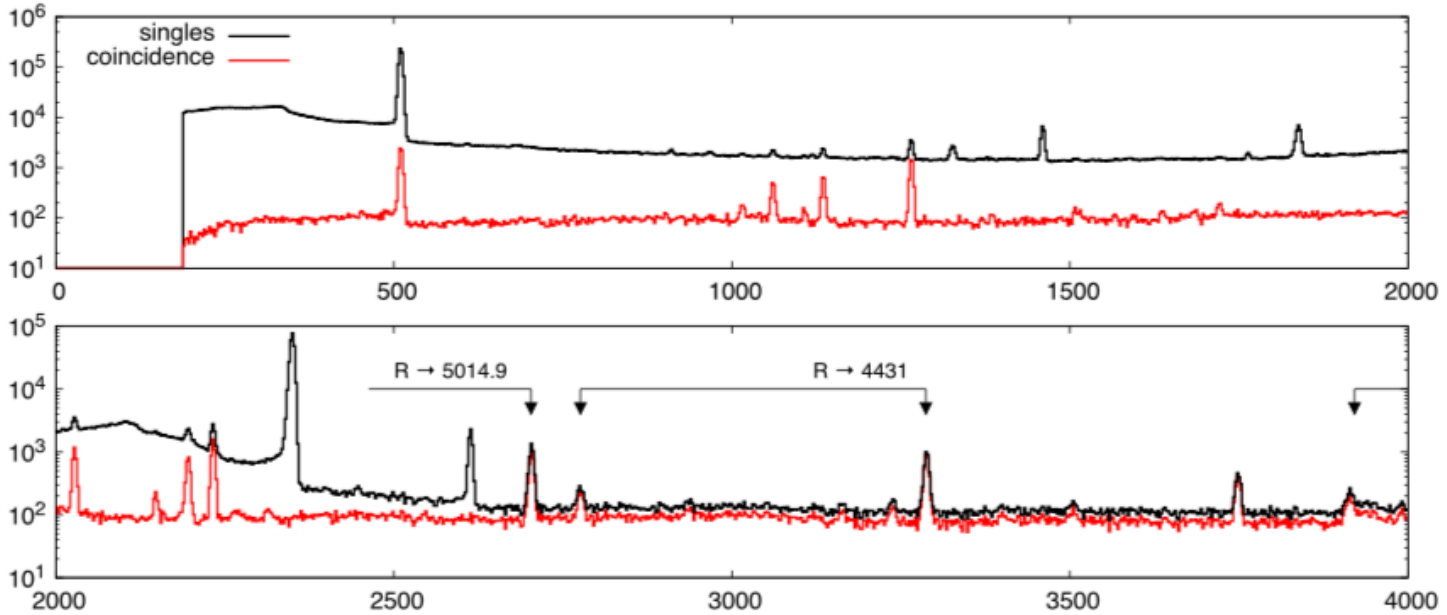
Thermonuclear reaction rate of ^{30}Si(p, γ) ^{31}P

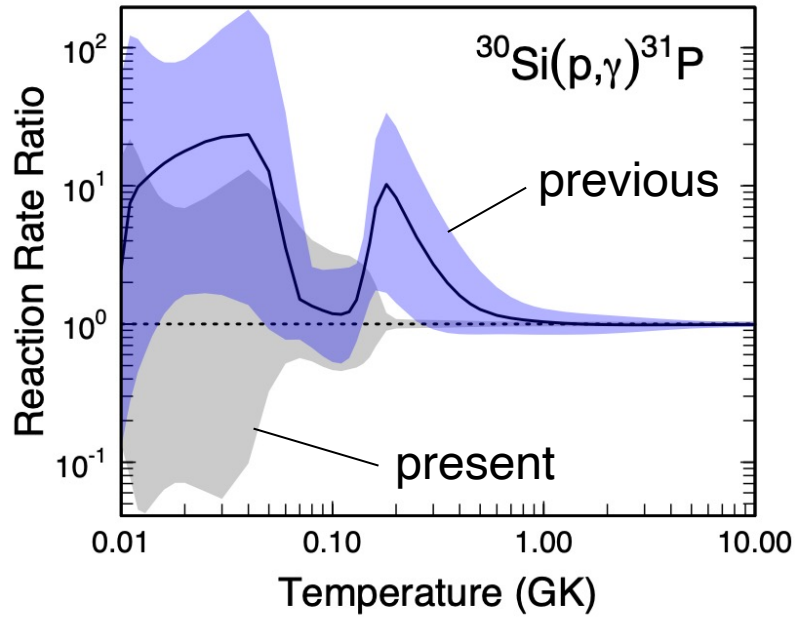
John Dermigny,[1,2,*] Christian Iliadis,[1,2,†] Art Champagne,[1,2] and Richard Longland[2,3]
[1]*Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27599, USA*
[2]*Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708, USA*
[3]*Department of Physics, North Carolina State University, Raleigh, North Carolina 27695, USA*



Jack Dermigny, PhD 2019

New 435-keV resonance

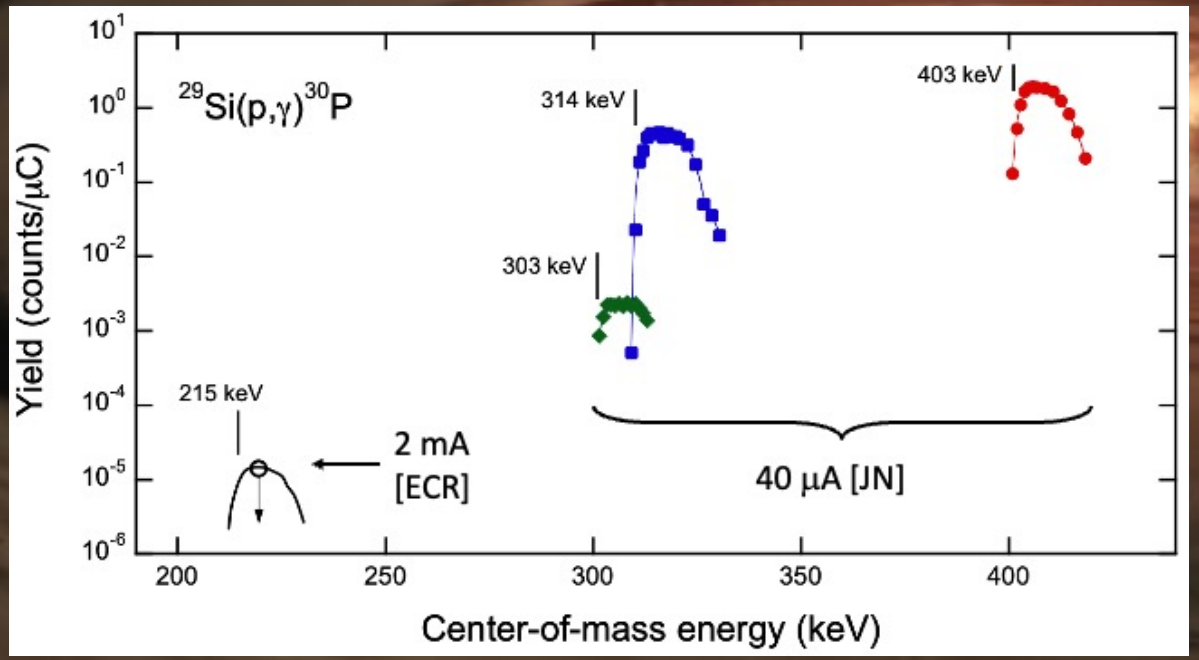




Science Highlights at (old) LENA: $^{29}Si(p,\gamma)^{30}P$

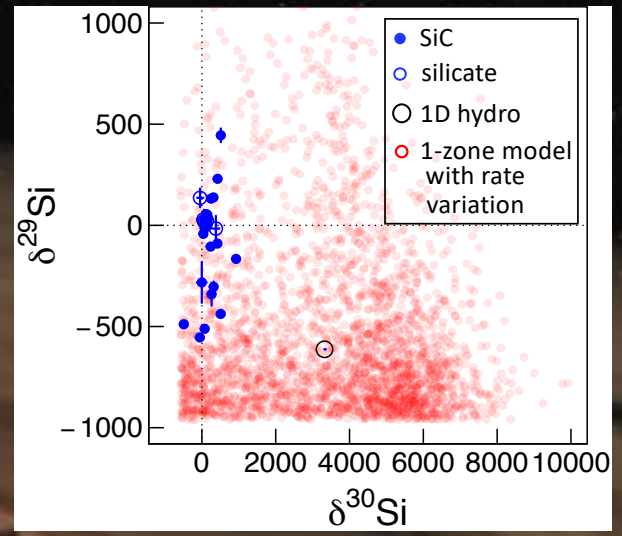

Nova Persei 1901

explaining the origin of meteoritic grains in stellar explosions

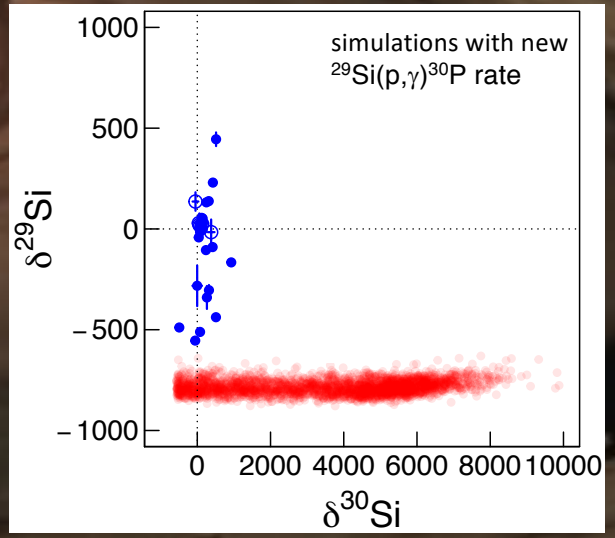



Lori Downen's PhD project

old rate



new rate



Downen et al., Phys. Rev. C 105, 055804 (2022); Downen et al., Astrophys. J 928, 128 (2022)