Opportunities in γ Spectroscopy at FRIB

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INFN-Padova
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MICHIGAN STATE UNIVERSITY

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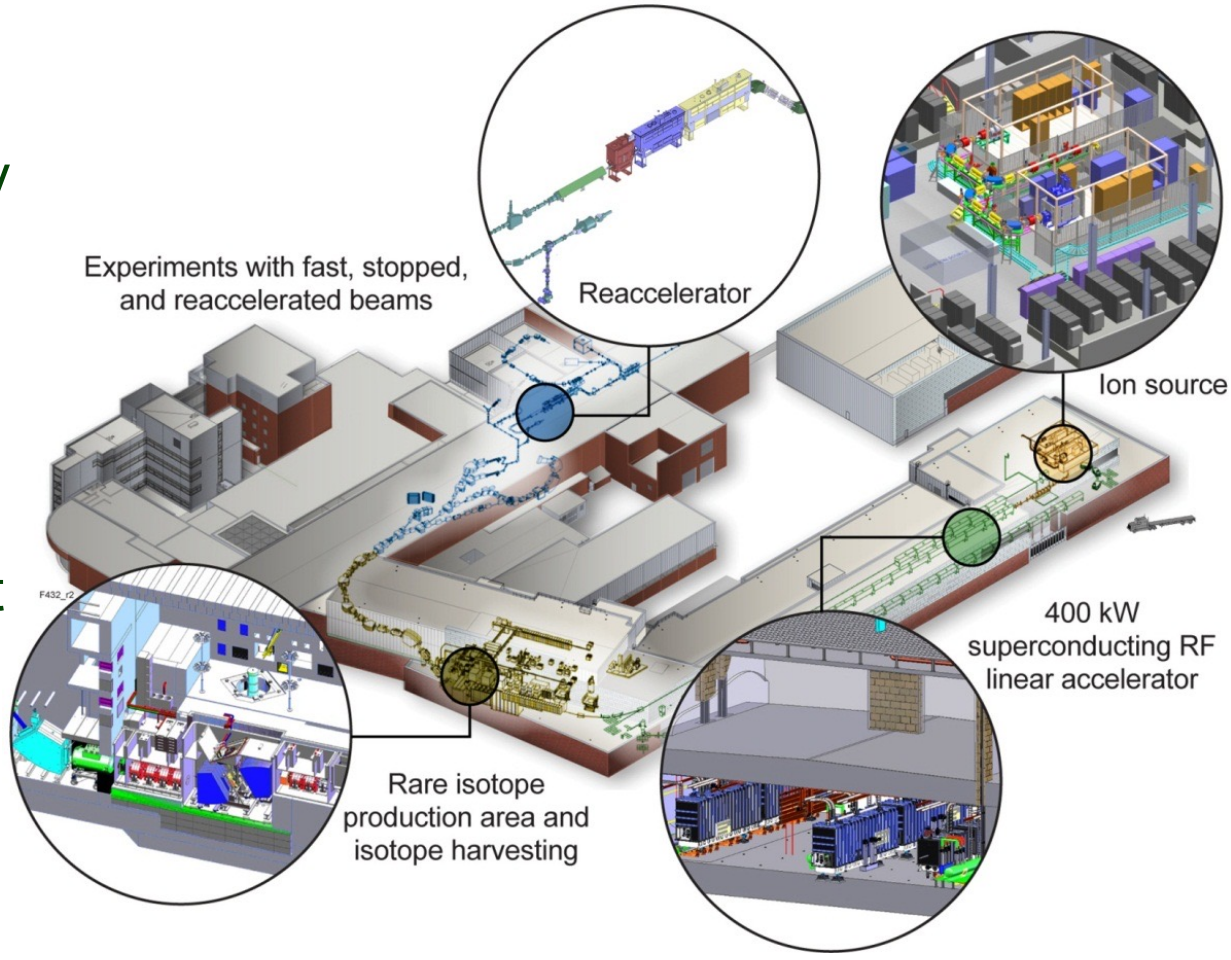
Outline

- Introduction to experimental program at FRIB (focused on gamma spectroscopy)
- FRIB Decay Station initiator (FDSi)
- Post-trap decay spectroscopy experiments
- In-beam γ-ray spectroscopy opportunities
  - GRETA
  - CAESAR
  - SeGA

Facility for Rare Isotope Beams
A DOE-SC National User Facility

- Funded by DOE–SC Office of Nuclear Physics with contributions and cost share from Michigan State University
- Serving over 1,400 users
- Key feature is 400 kW beam power for all ions (e.g. $5x10^{13}$ $^{238}U/s$)
- Separation of isotopes in-flight provides
  - Fast development time for any isotope
  - All elements and short half-lives
  - Fast, stopped, and reaccelerated beams

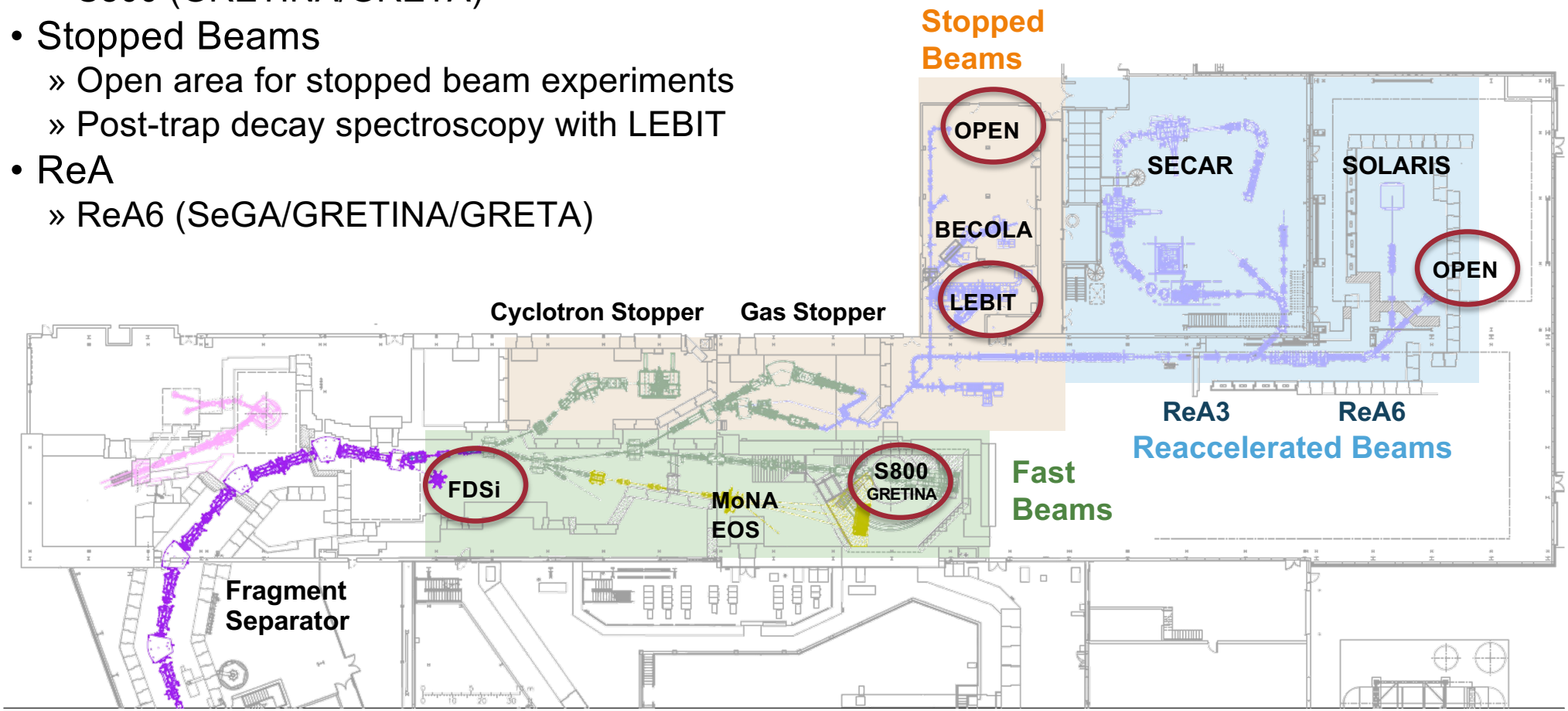


Slide adapted from S. Liddick

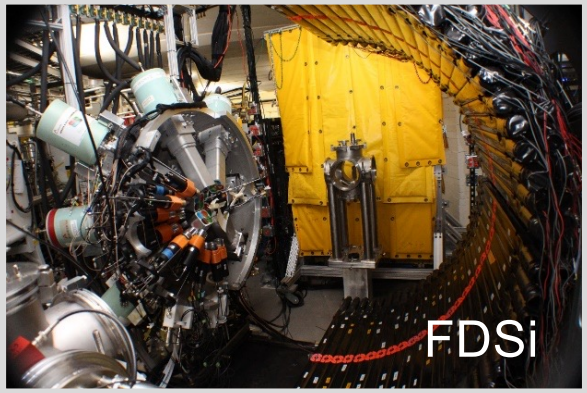
γ-ray Spectroscopy at FRIB

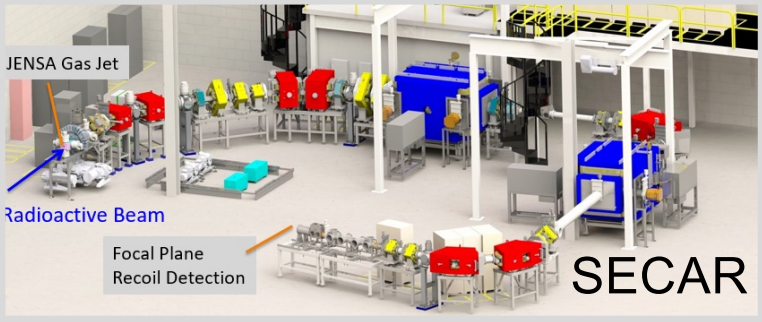
- The FRIB γ-ray spectroscopy performed in three areas:
  - Fast beams
    - » FDSi
    - » S800 (GRETINA/GRETA)
  - Stopped Beams
    - » Open area for stopped beam experiments
    - » Post-trap decay spectroscopy with LEBIT
  - ReA
    - » ReA6 (SeGA/GRETINA/GRETA)

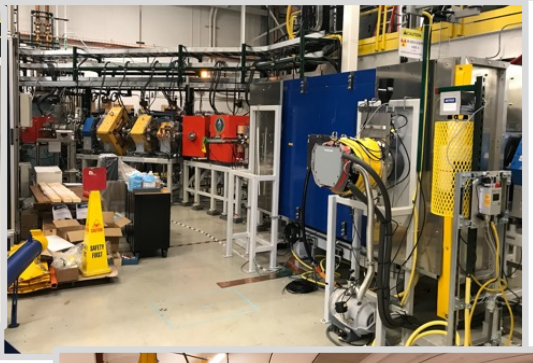
FRIB Experimental Program

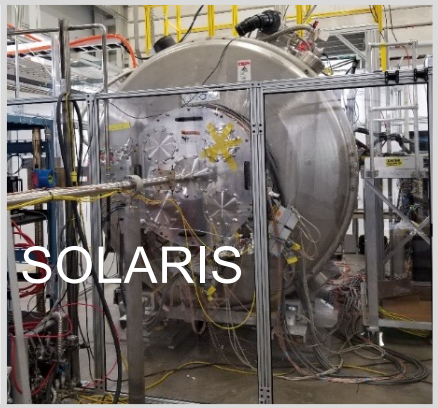


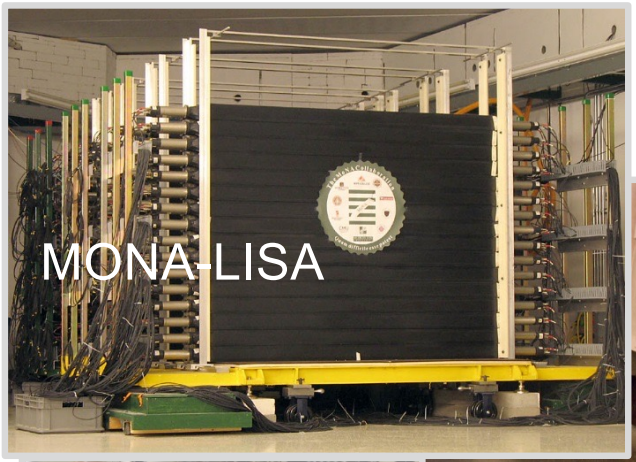
Available and New Instruments to Come

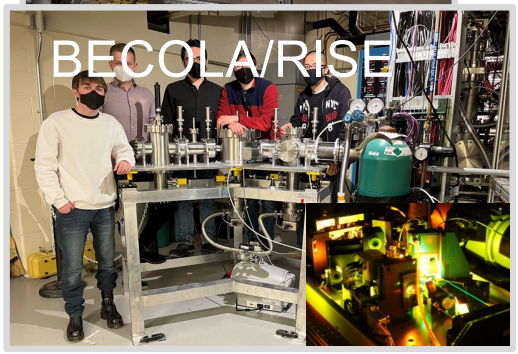


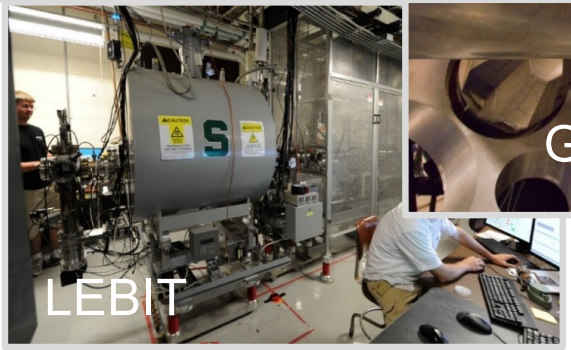


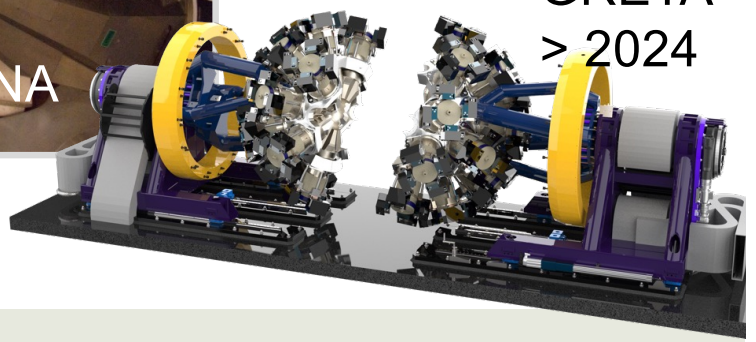












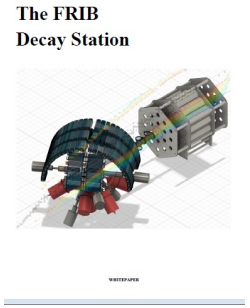
INFN PADOVA

Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

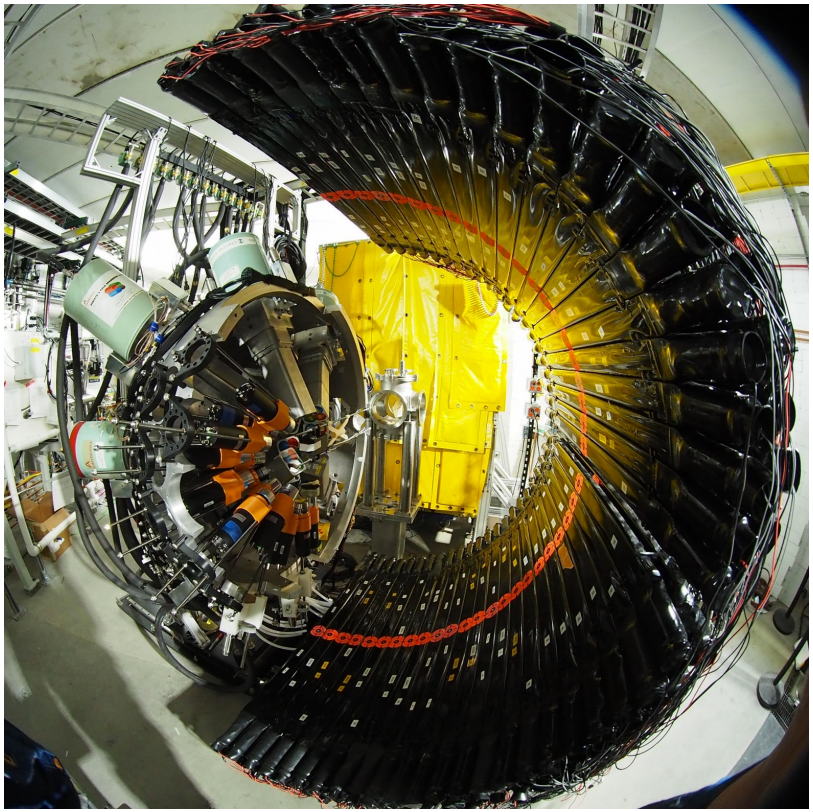
Slide adapted from S. Liddick

The FRIB Decay Station Initiator

Nuclear Structure	Nuclear Astrophysics	Fundamental Symmetries	Applications of Isotopes
How does subatomic matter organize itself and what phenomena emerge?	*How did visible matter come into being and how does it evolve?*	*Are the fundamental interactions that are basic to structure of matter fully understood?*	*How can the knowledge and technical progress provided by nuclear physics best be used to benefit society?*
1. Shell structure	**1. Shell structure**	**12. Atomic EDM**	**10. Medical**
2. Superheavies	6. Equation of state	**15. Mass surface**	**11. Stewardship**
3. Skins	**7. r-Process**	**17. Weak interactions**	
4. Pairing	**8. $^{15}O(\alpha,\gamma)$**		
5. Symmetries	**9. ^{59}Fe s-process**		
6. Equation of state	**13. Limits of stability**		
13. Limits of stability	**15. Mass surface**		
14. Weakly bound nuclei	**16. rp-process**		
15. Mass surface	**17. Weak interactions**		

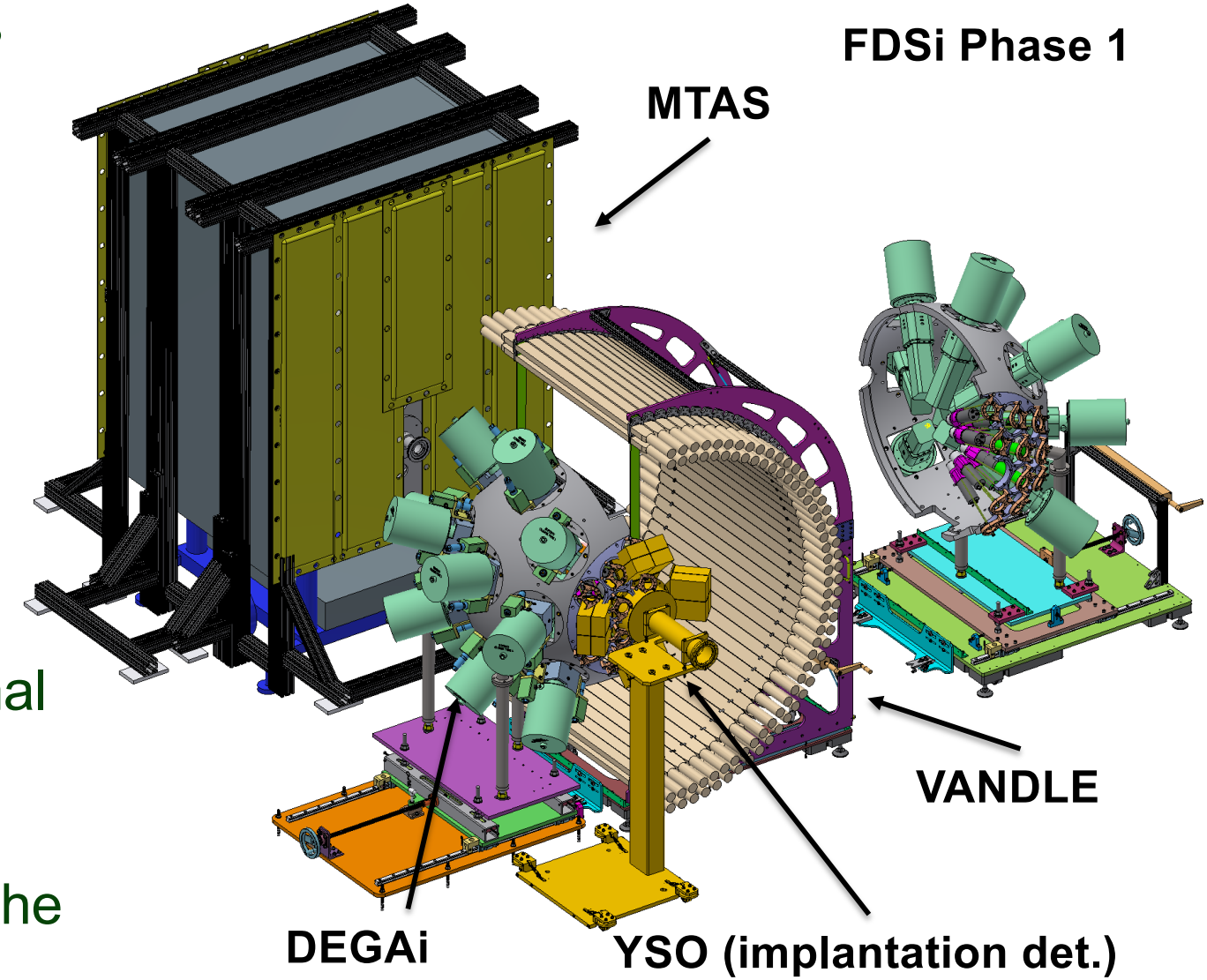


- FDSi aligned to the FRIB experimental program and national priorities.
- Suite of complementary decay detectors
- FDSi organizing committee: R. Grzywacz (UTK), D. Seweryniak (ANL), S.N. Liddick (FRIB), M. Allmond (ORNL)



FDSi is a flexible and modular assembly of community owned equipment

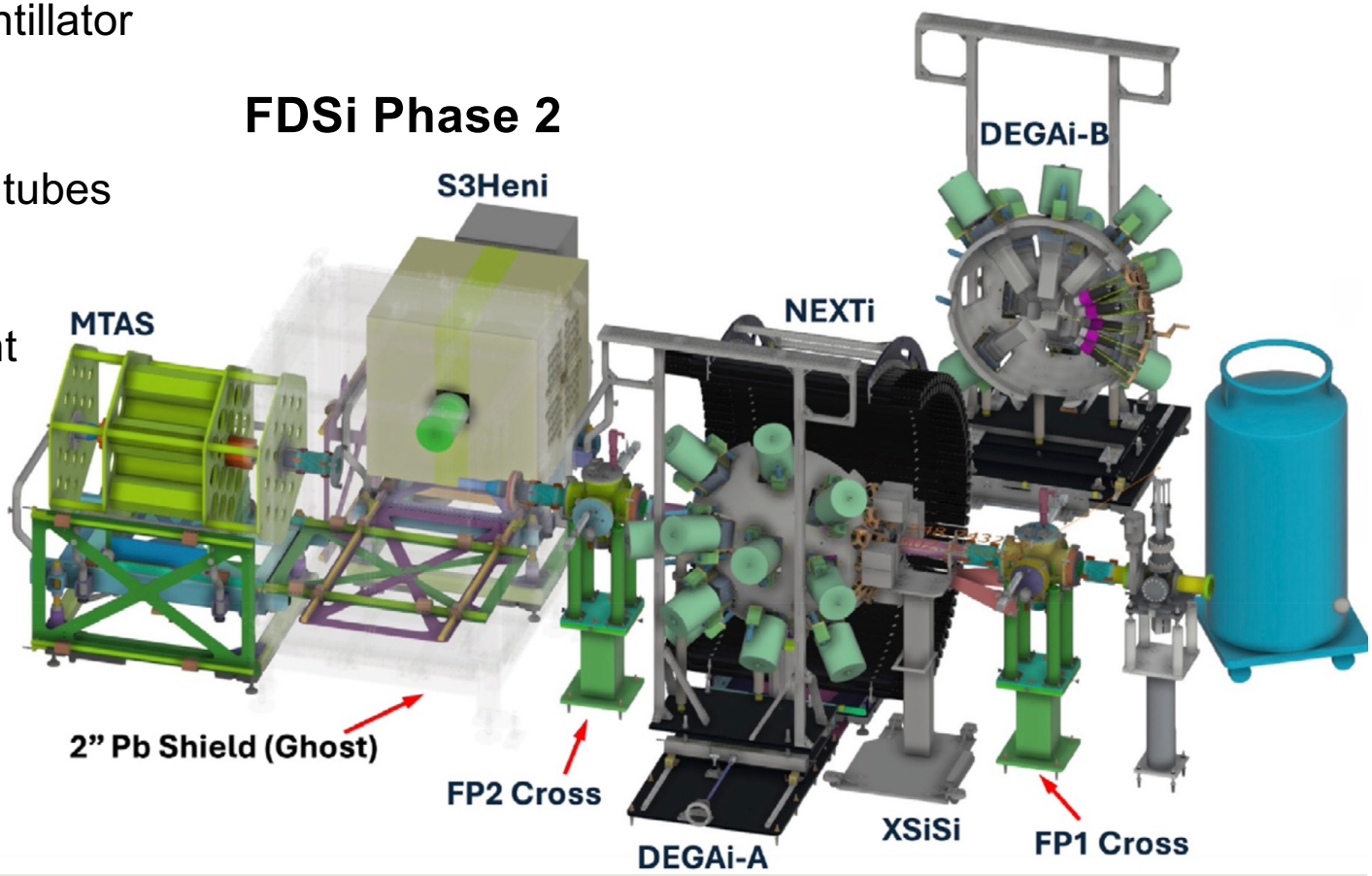
- FDSi includes detectors for
  - Charged particles
  - Neutrons
    - Thermal
    - Time-of-flight
  - Photons
    - High energy resolution
    - High time resolution
    - Calorimetry
- Overall system can be reconfigured with minimal effort according to experimental needs
- Two focal points along the beam line.



FRIB Decay Station initiator → FRIB Decay Station

- Phase 2 of FDSi:
  - Focal Plane 1
    - DEGAi—HPGe + $LaBr_3$
    - NEXTi—neutron ToF
    - XsiSi—xy-pixelated scintillator detectors
  - Focal Plane 2
    - S3Hen—HDPE and H^3 tubes
    - MTAS
    - xy-pixelated scintillator detectors and Si implant detectors
- Phase 3 of FDSi
  - Low Energy FDSi

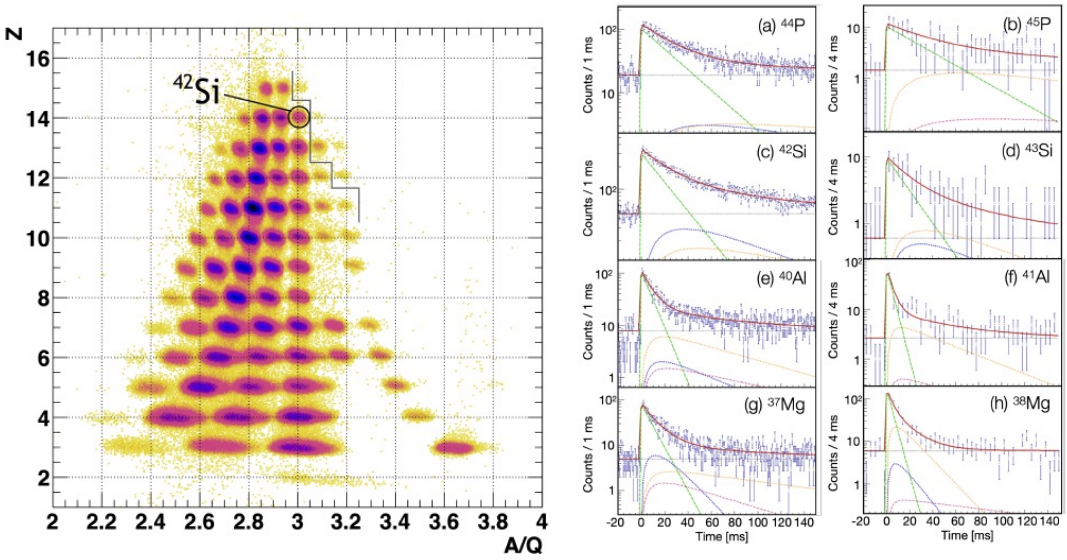
FDSi will continue to evolve to FDS in phases



Selected Experimental Results

Crossing $N = 28$ Toward the Neutron Drip Line: First Measurement of Half-Lives at FRIB

H. L. Crawford[1,*], V. Tripathi[2], J. M. Allmond[3], B. P. Crider[4], R. Grzywacz[5], S. N. Liddick[6,7], A. Andalib[6,8], E. Argo[6,8], C. Benetti[2] *et al.*



Universal Effective Charges in the sd and fp Shells

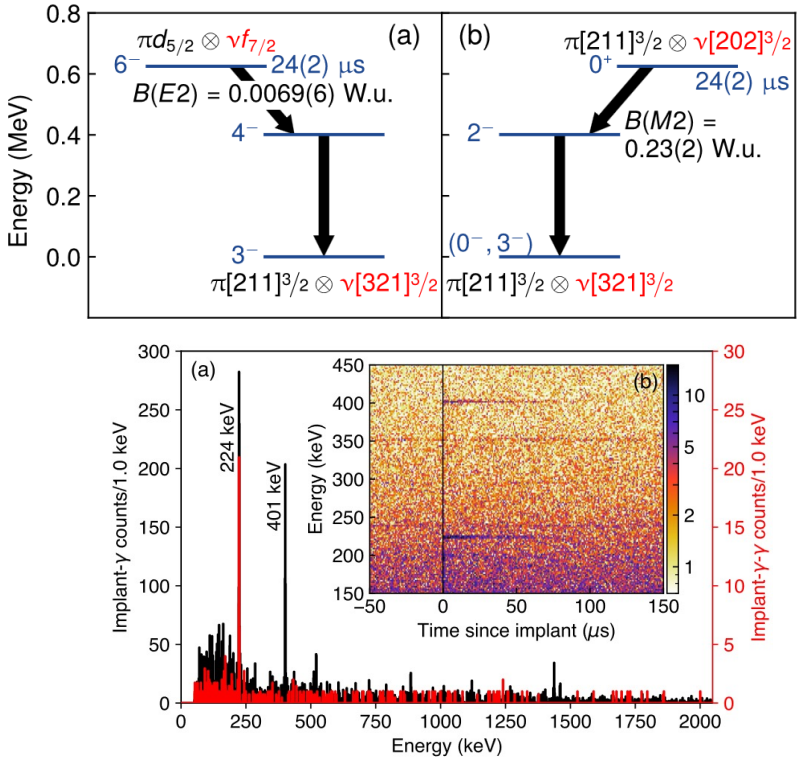
T. H. Ogunbeku[1], J. M. Allmond[2], T. J. Gray[2,3], W.-J. Ong[1], B. A. Brown[4], A. Gargano[5], R. Grzywacz[3], J. D. Holt[6,7], A. O. Macchiavelli[2] *et al.*

β decay of ^{36}Mg and ^{36}Al: Identification of a β-decaying isomer in ^{36}Al

R. S. Lubna[1,*], S. N. Liddick[1,2], T. H. Ogunbeku[1,3], A. Chester[1], J. M. Allmond[4], Soumik Bhattacharya[5], C. M. Campbell[6], M. P. Carpenter[7], K. L. Childers[8,2] *et al.*

Microsecond Isomer at the $N = 20$ Island of Shape Inversion Observed at FRIB

T. J. Gray[1], J. M. Allmond[1], Z. Xu[2], T. T. King[1], R. S. Lubna[3], H. L. Crawford[4], V. Tripathi[5], B. P. Crider[6], R. Grzywacz[2,1] *et al.*



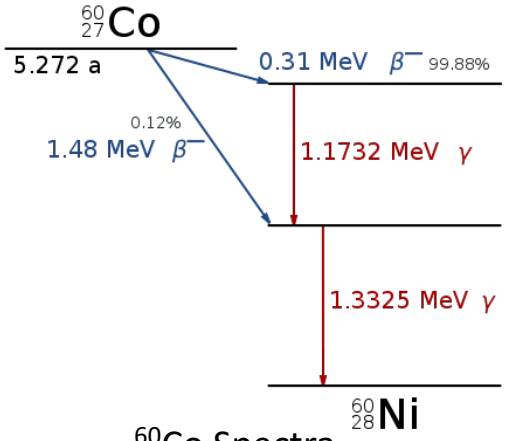
Proton Shell Gaps in $N = 28$ Nuclei from the First Complete Spectroscopy Study with FRIB Decay Station Initiator

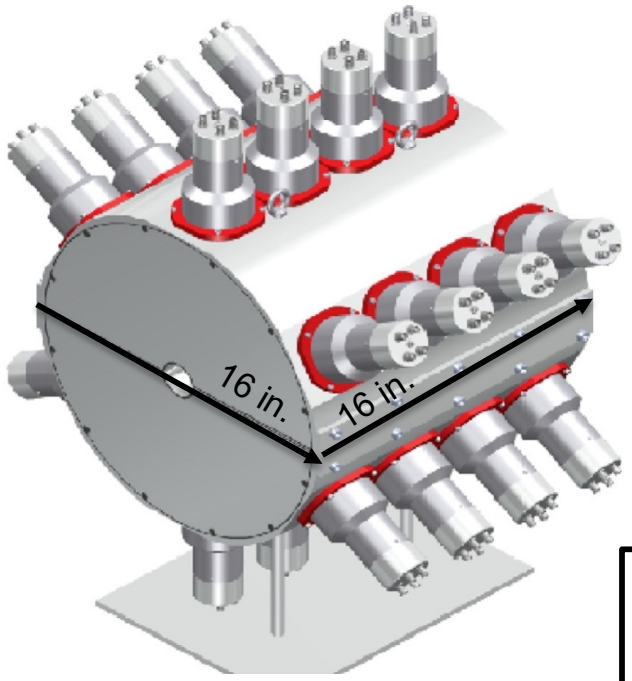
I. Cox[1], Z. Y. Xu[1], R. Grzywacz[1,2], W.-J. Ong[3], B. C. Rasco[2], N. Kitamura[1], D. Hoskins[1], S. Neupane[1,3], T. J. Ruland[2,4] *et al.*

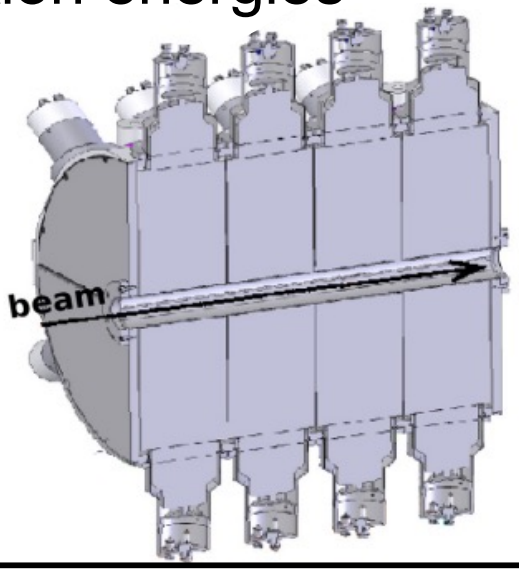
Summing NaI(Tl) Total Absorption Spectrometer

Summing NaI(Tl) (SuN) total absorption spectrometer

- 8 Segments give information about individual γ-rays
- Summing γ-rays from all segments gives information about excitation energies

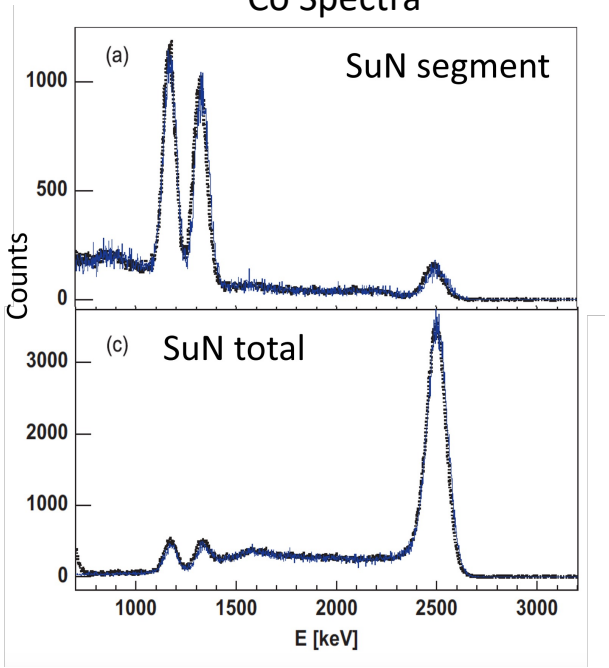






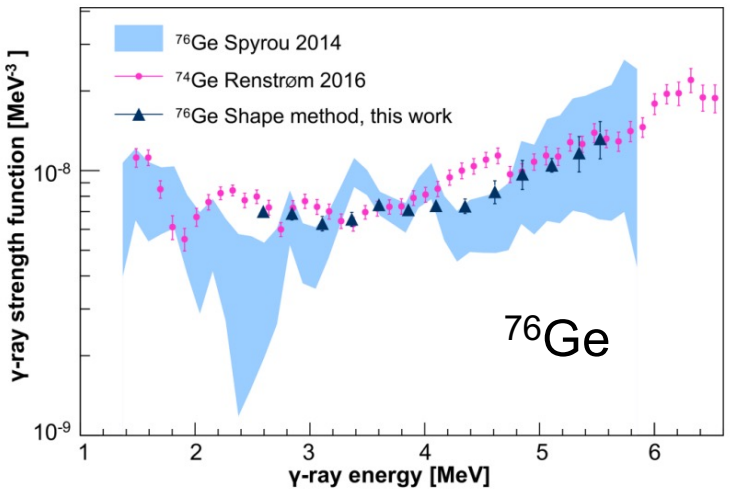
Efficiency at 2.5 MeV—65%
Resolution at 1 MeV—6%

^{60}Co Spectra

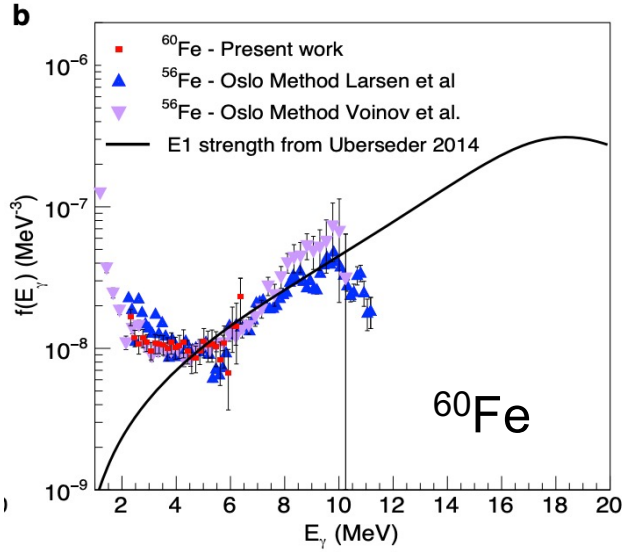


Simon et al., NIM A 703 (2013): 16-21

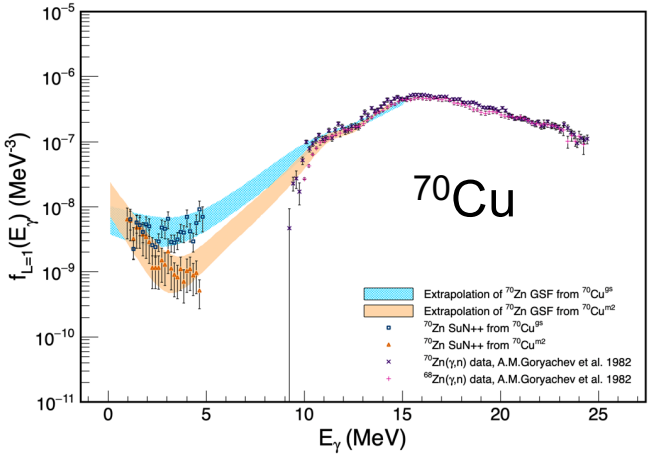
γ-ray strength functions (γSF) and Nuclear Level Densities (NLD) measured with SuN



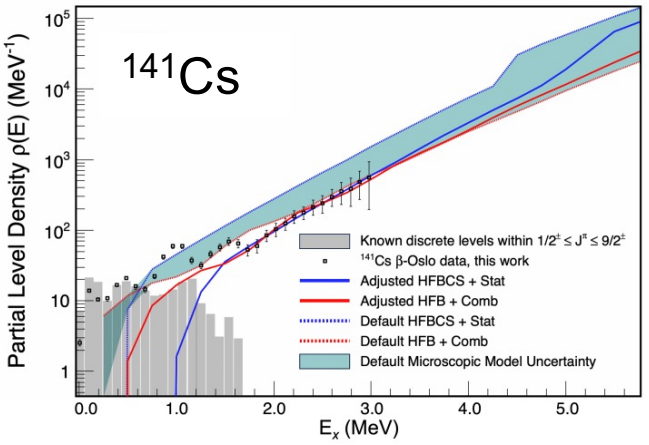
Mucher et al. PRC Letters, 2023



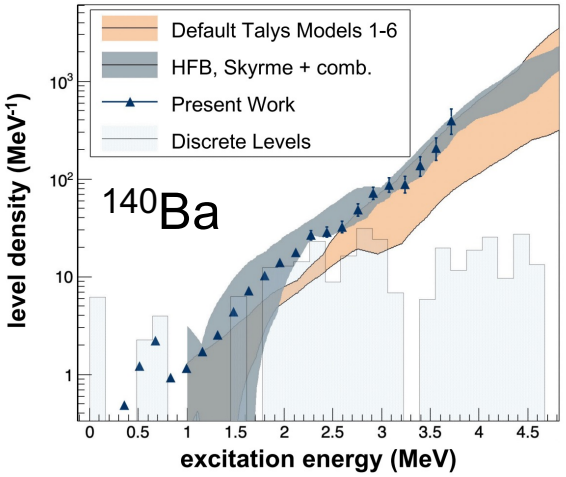
Spyrou et al. Nature Communications, 2025



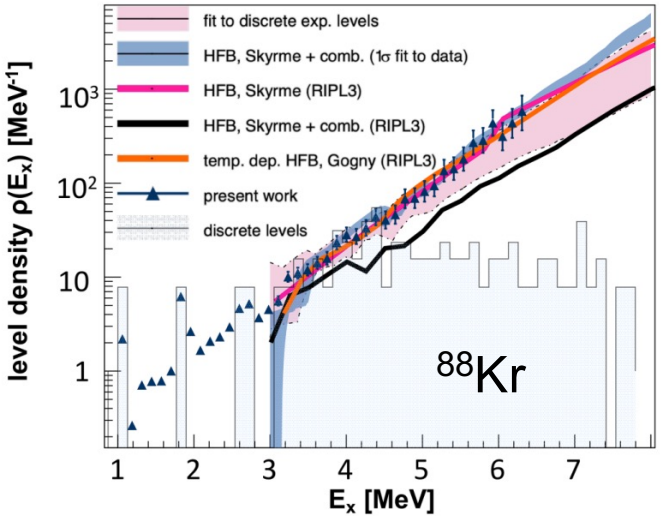
Ronning et al., in prep 2025



Greaves et al. PLB, submitted 2025

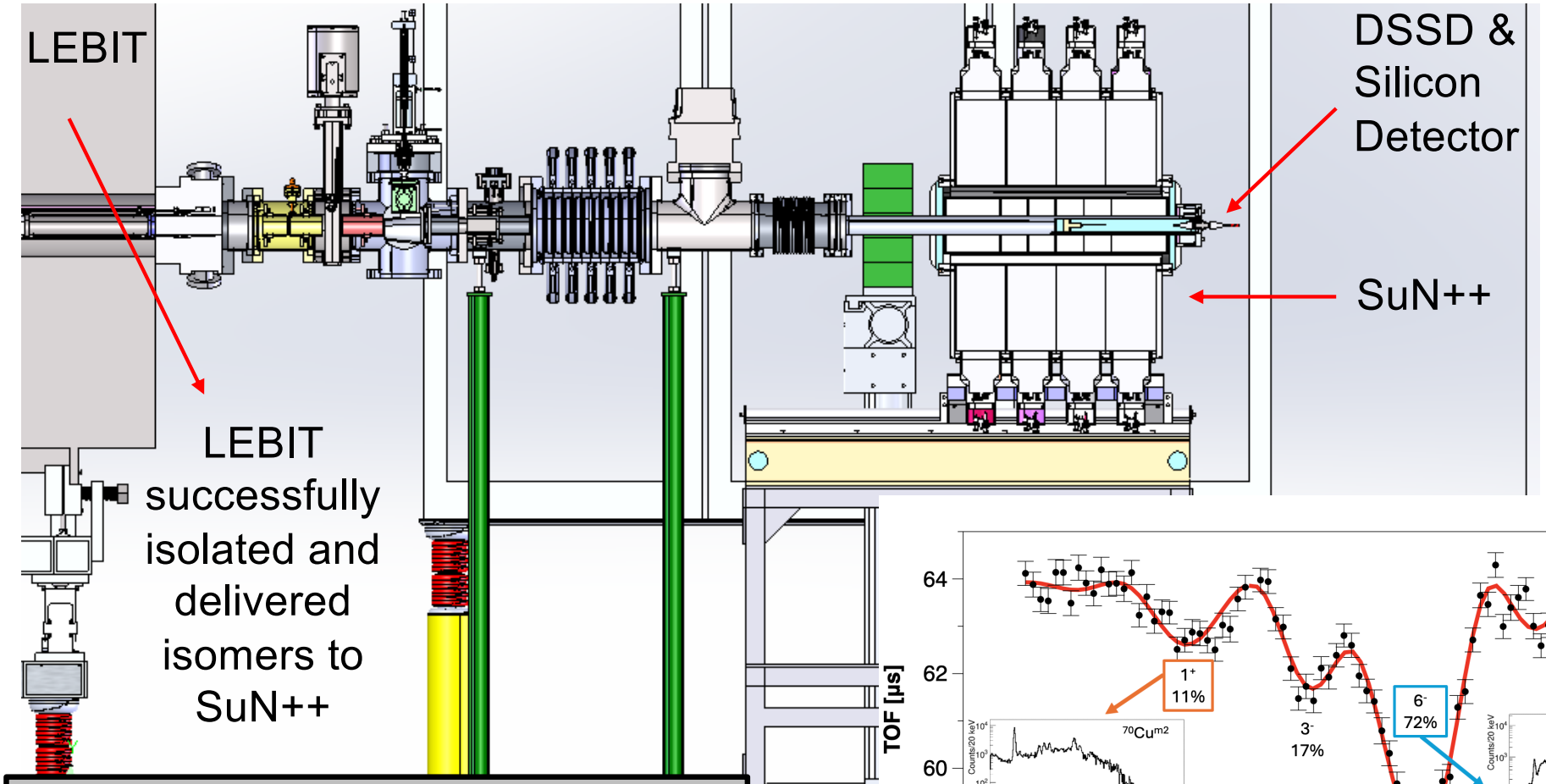


Spyrou et al. PRL 2024

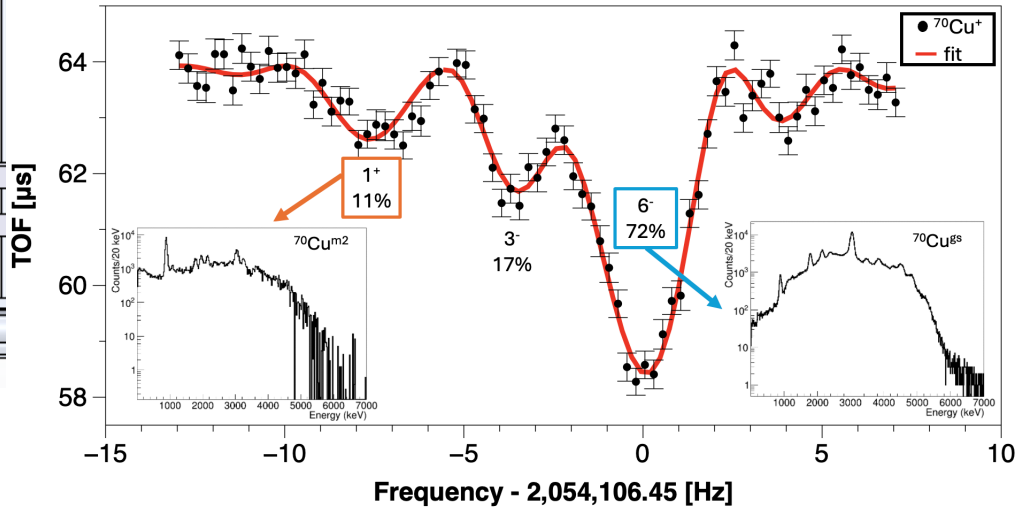


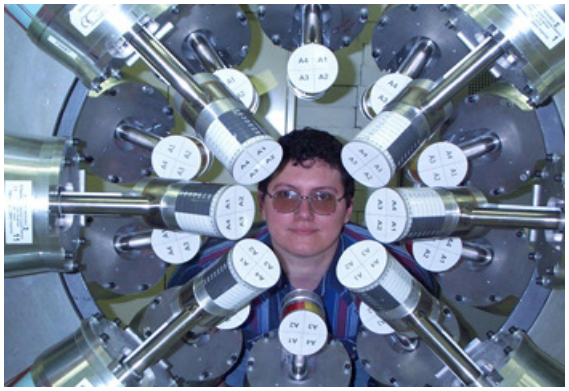
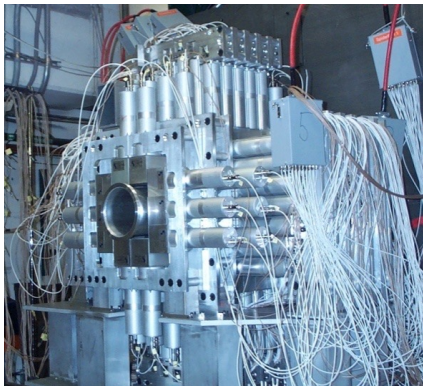
Mucher et al. PRC Letters 2023

First isomer-separated beam experiment at FRIB with LEBIT and SuN++



- ^{82}Se primary beam at 215 MeV/u
- ^{12}C target (4.88 mm thick)
- ^{70}Cu Ions selected for by ARIS



In-beam γ-ray spectroscopy opportunities at FRIB

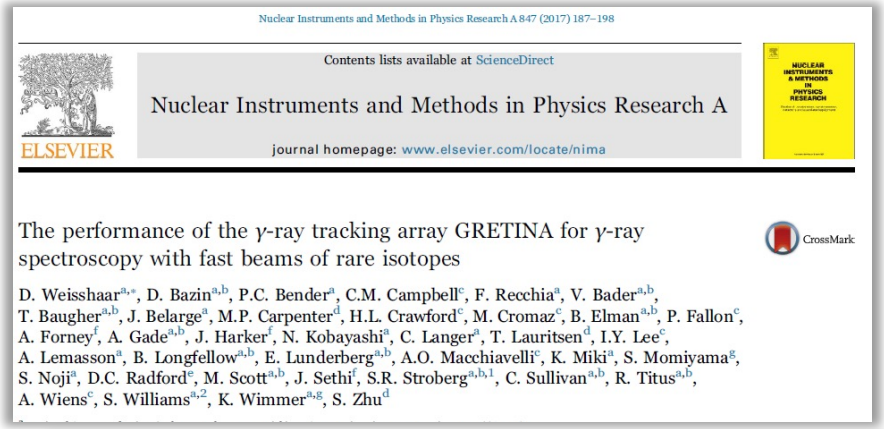
Instruments maintained and supported by the
Gamma Group at FRIB

Slides by A. Gade

Highest-resolution spectroscopy with GRETA –to be used with fast and reaccelerated beam

- Most of GRETA has arrived at FRIB and infrastructure is being installed at ReA6 in preparation for offline commissioning (throughout remainder of 2025)
- Locations for GRETA at FRIB
  - Fast beams [at the S800, GRETA will always use the GRETINA frame]
    - » Short-term: GRETA@S800
    - » Long-term: GRETA@HRS and S800
    - » Aspiration: GRETA@HRS at FRIB400, GRETA@S800
  - Reaccelerated beams
    - » GRETA@ReA6

GRETINA at MSU technical publications that apply to GRETA


Nuclear Instruments and Methods in Physics Research A 847 (2017) 187–198

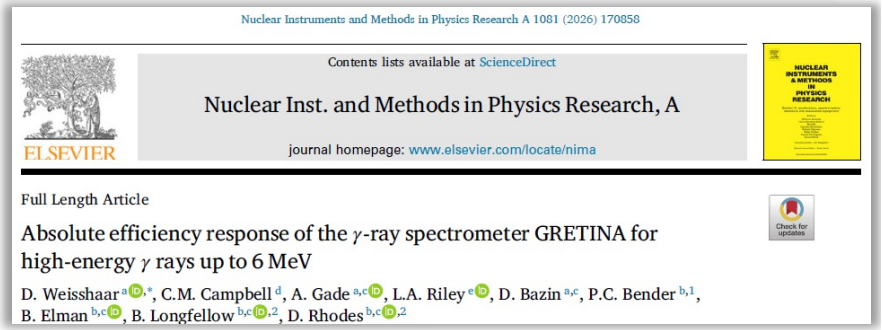
Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

The performance of the γ-ray tracking array GRETINA for γ-ray spectroscopy with fast beams of rare isotopes

D. Weisshaar[a,*], D. Bazin[a,b], P.C. Bender[a], C.M. Campbell[c], F. Recchia[a], V. Bader[a,b], T. Baugher[a,b], J. Belarge[a], M.P. Carpenter[d], H.L. Crawford[c], M. Cromaz[c], B. Elman[a,b], P. Fallon[c], A. Forney[f], A. Gade[a,b], J. Harker[f], N. Kobayashi[a], C. Langer[a], T. Lauritsen[d], I.Y. Lee[c], A. Lemasson[a], B. Longfellow[a,b], E. Lunderberg[a,b], A.O. Macchiavelli[c], K. Miki[a], S. Momiyama[g], S. Noji[a], D.C. Radford[e], M. Scott[a,b], J. Sethi[f], S.R. Stroberg[a,b,1], C. Sullivan[a,b], R. Titus[a,b], A. Wiens[c], S. Williams[a,2], K. Wimmer[a,g], S. Zhu[d]


Nuclear Instruments and Methods in Physics Research A 1081 (2026) 170858

Contents lists available at ScienceDirect

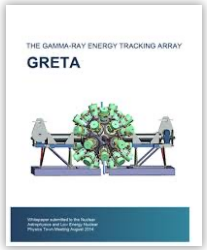
Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

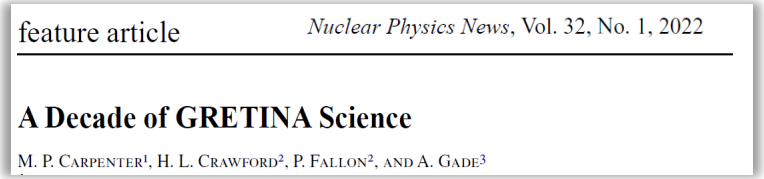
Full Length Article

Absolute efficiency response of the γ-ray spectrometer GRETINA for high-energy γ rays up to 6 MeV

D. Weisshaar[a,*], C.M. Campbell[d], A. Gade[a,c], L.A. Riley[e], D. Bazin[a,c], P.C. Bender[b,1], B. Elman[b,c], B. Longfellow[b,c,2], D. Rhodes[b,c,2]

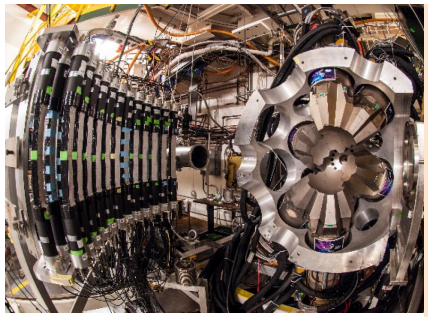


See for science opportunities

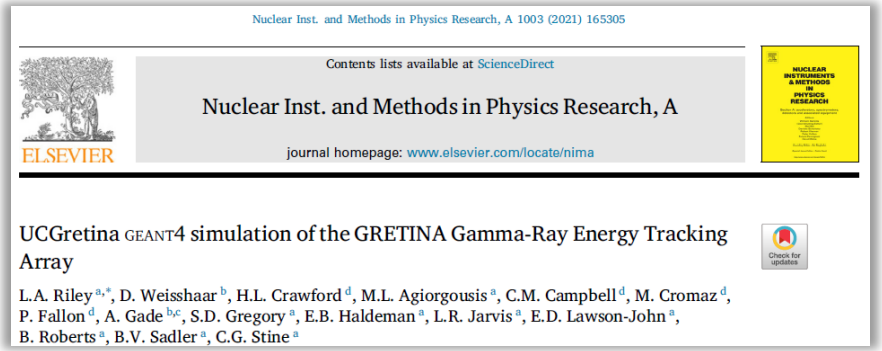

feature article *Nuclear Physics News*, Vol. 32, No. 1, 2022

A Decade of GRETINA Science

M. P. Carpenter[1], H. L. Crawford[2], P. Fallon[2], and A. Gade[3]



Like GRETINA, envision operations with auxiliary instruments such as LENDA, FAUST, ORRUBA, LH_2 target, TRIPLEX plunger at the S800/HRS and ORRUBA or CHICOx at ReA


Nuclear Inst. and Methods in Physics Research, A 1003 (2021) 165305

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

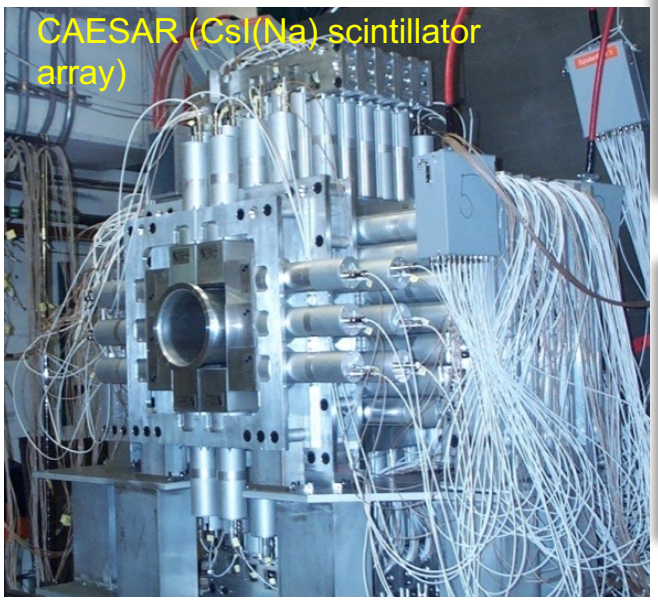
journal homepage: www.elsevier.com/locate/nima

UCGretina GEANT4 simulation of the GRETINA Gamma-Ray Energy Tracking Array

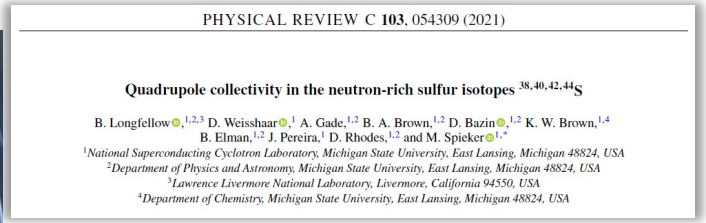
L.A. Riley[a,*], D. Weisshaar[b], H.L. Crawford[d], M.L. Agiorgousis[a], C.M. Campbell[d], M. Cromaz[d], P. Fallon[d], A. Gade[b,c], S.D. Gregory[a], E.B. Haldeman[a], L.R. Jarvis[a], E.D. Lawson-John[a], B. Roberts[a], B.V. Sadler[a], C.G. Stine[a]

Modest-resolution, high-efficiency in-beam γ-ray spectroscopy

- The Caesium Iodide Array (CAESAR) - consisting of 196 CsI(Na) scintillators in compact, modular geometry - is available for fast-beam experiments at the S800, with the Sweeper Magnet, and in the future at the HRS (often combined with charged-particle or neutron detection)
- Can be used when resolution is not an issue or high-energy γ rays are of interest (and when GRETA is at Argonne National Laboratory)



Recent example:


PHYSICAL REVIEW C **103**, 054309 (2021)

Quadrupole collectivity in the neutron-rich sulfur isotopes ^{38,40,42,44}S

B. Longfellow,[1,2,3] D. Weisshaar,[1] A. Gade,[1,2] B. A. Brown,[1,2] D. Bazin,[1,2] K. W. Brown,[1,4] B. Elman,[1,2] J. Pereira,[1] D. Rhodes,[1,2] and M. Spieker[1,*]

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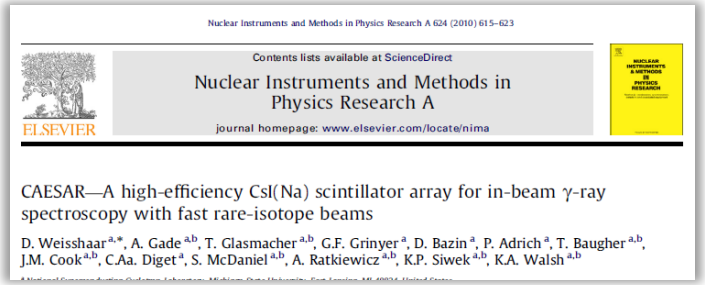
CAESAR NIM A paper:


Nuclear Instruments and Methods in Physics Research A 624 (2010) 615–623

Contents lists available at ScienceDirect

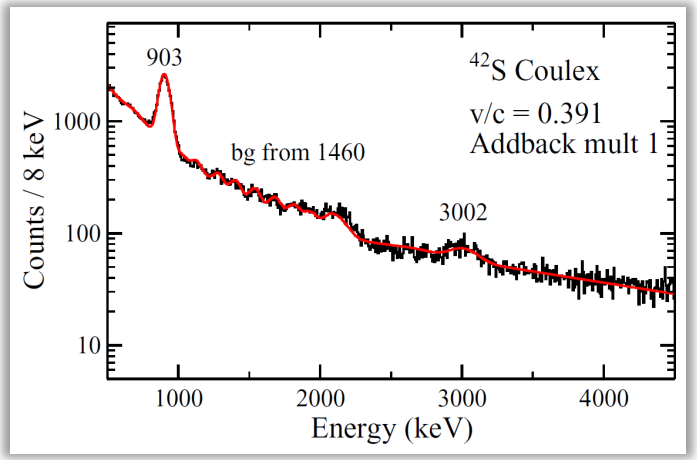
Nuclear Instruments and Methods in Physics Research A

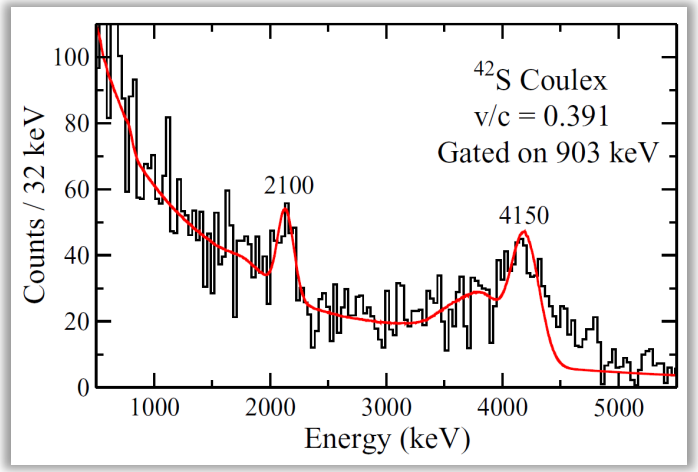
journal homepage: www.elsevier.com/locate/nima

CAESAR—A high-efficiency CsI(Na) scintillator array for in-beam γ-ray spectroscopy with fast rare-isotope beams

D. Weisshaar [a,*], A. Gade [a,b], T. Glasmacher [a,b], G.F. Grinyer [a], D. Bazin [a], P. Adrich [a], T. Baugher [a,b], J.M. Cook [a,b], C.Aa. Diget [a], S. McDaniel [a,b], A. Ratkiewicz [a,b], K.P. Siwek [a,b], K.A. Walsh [a,b]

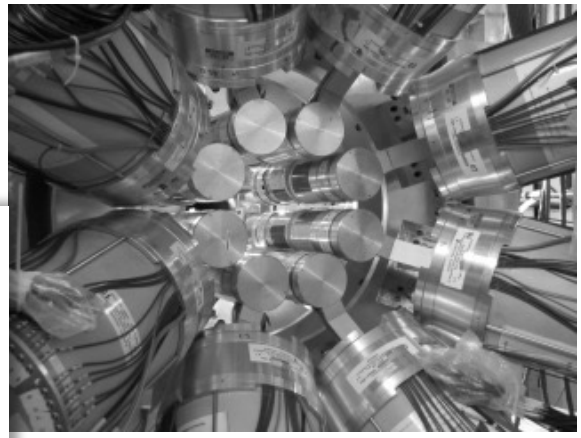
New NIM A paper on electronics and DAQ upgrade submitted: S. Gillespie *et al.* (2025)

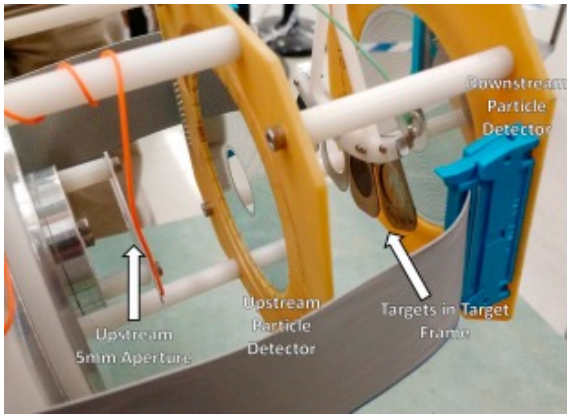




Since GRETINA was offered for experiments at MSU, SeGA has been used within JANUS for barrier-energy Coulomb excitation

- SeGA was one of the first highly segmented Ge arrays and was used extensively at NSCL with fast beams at the S800 until GRETINA became available





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Nuclear Instruments and Methods in Physics Research A 466 (2001) 492–498

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

Thirty-two-fold segmented germanium detectors to identify γ-rays from intermediate-energy exotic beams

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- In JANUS, SeGA surrounds two Micron S3 annular Si detectors in a high-efficiency barrel configuration
- JANUS is run in a collaboration of FRIB, LLNL, and the University of Surrey and is not a supported instrument that can be requested

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journal homepage: www.elsevier.com/locate/nima

JANUS — A setup for low-energy Coulomb excitation at ReA3☆

E. Lunderberg[a,b], J. Belarge[a,1], P.C. Bender[a], B. Bucher[c], D. Cline[d], B. Elman[a,b], A. Gade[a,b,*], S.N. Liddick[a,e], B. Longfellow[a,b], C. Prokop[a,e], D. Weisshaar[a], C.Y. Wu[c]

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JANUS: Joint Array for NUclear Structure studies

Thank you!

- FRIB Decay Station initiator (FDSi)
  - Contact: Rebeka Lubna + Sean Liddick
- Post-trap decay spectroscopy experiments
  - Contact: Eleanor Ronning (me ☺) + Ryan Ringle
- In-beam γ-ray spectroscopy opportunities
  - Contact: Alexandra Gade (speaking in the afternoon session)