The FRIB Decay Station (FDS)

J.M. Allmond – ORNL

On behalf of the FDS Group and Community

Challenges of Decay Measurements at FRIB

- Long decay chains of short-lived isotopes (~40 isotopes populated)
- Short and similar (10-100 ms) lifetimes
- Simultaneous or sequential charged particles, gamma rays, and neutrons
- Multi-neutron branching ratios
- Large dynamic ranges

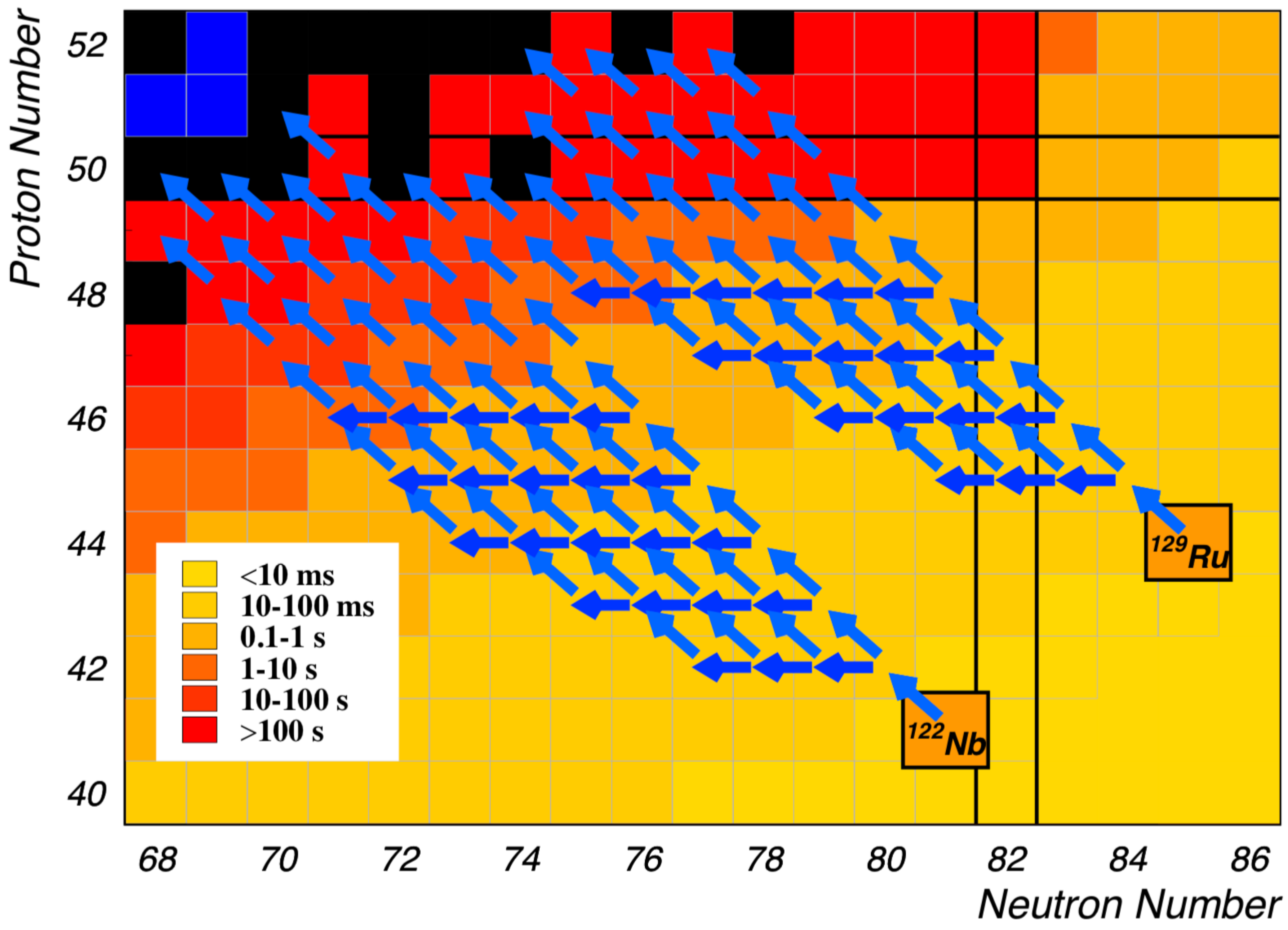


Figure Courtesy of R. Grzywacz

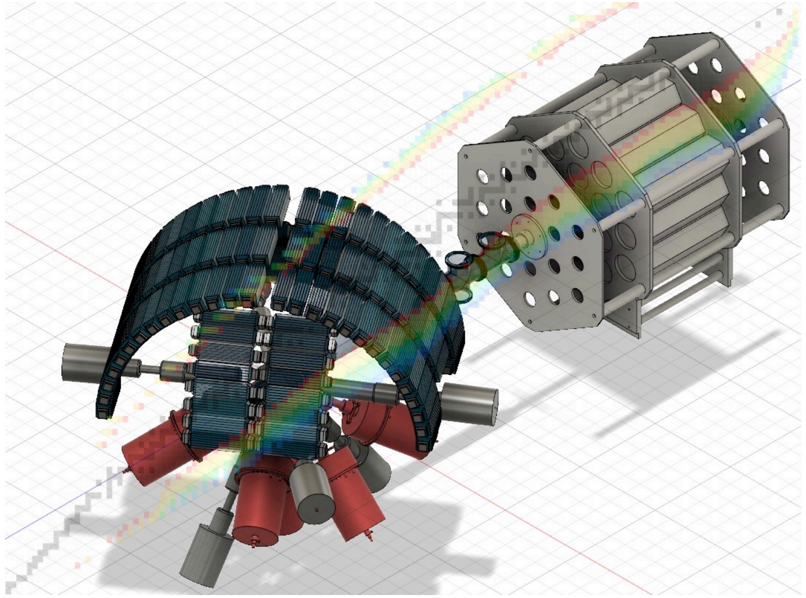
The FRIB Decay Station (FDS)

- Exploits FRIB capabilities with versatile & state-of-the-art instrumentation
- Capable of "complete" decay information in single experiment
- Multiple proposals & papers per experiment
- Experimental program focused on all four strategic areas of FRIB: NS, NA, FS, Apps
- Uniquely positioned for discovery experiments at the extremes due to low-rate sensitivity
- A priority for USA competitiveness over RIKEN
- A leap forward in
  - efficiencies (**x10 for βnγ** and **x50 for β2n2γ**),
  - resolution (**x2 for** γ and **x6 for n),**
  - granularity, rate, background suppression, reliability, and readiness,

  critical for most exotic nuclei approaching drip lines.
- *Cost range $24-30M*

The FRIB Decay Station

66 contributors
24 institutions



WHITEPAPER

Document with FRIB management and DOE

https://fds.ornl.gov

The FRIB Decay Station (FDS)

Contributors and Workshop Participants

(24 institutions, 66 individuals)

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Chris Wrede
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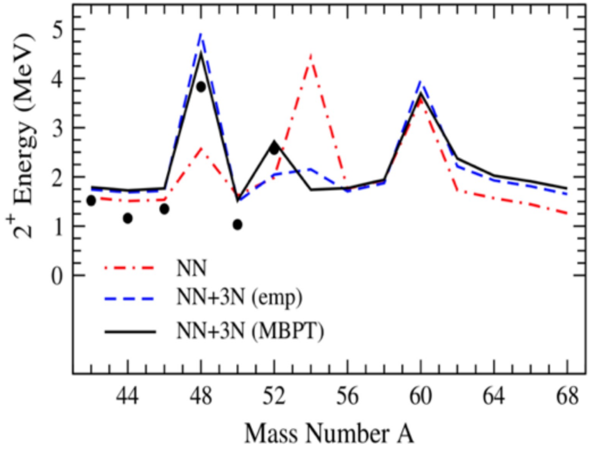
"Close collaborations between universities and national laboratories allow nuclear science to reap the benefits of large investments while training the next generation of nuclear scientists to meet societal needs." – [NSAC15]

A Few Scientific Highlights

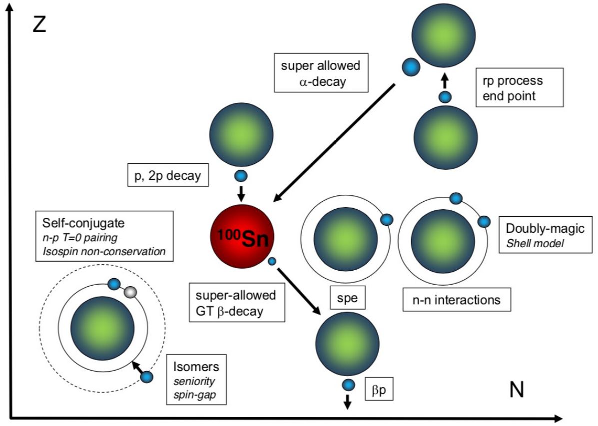
- **^{60}Ca region –** the heaviest nuclei for which the neutron drip line and effects related to weak binding and many-body forces can be studied.

A possible signature for a giant halo in 60Ca may be the simultaneous and correlated emission of β-delayed neutrons. The FDS will be more sensitive towards this signature than previous generation systems by more than an order of magnitude [FDS WP].



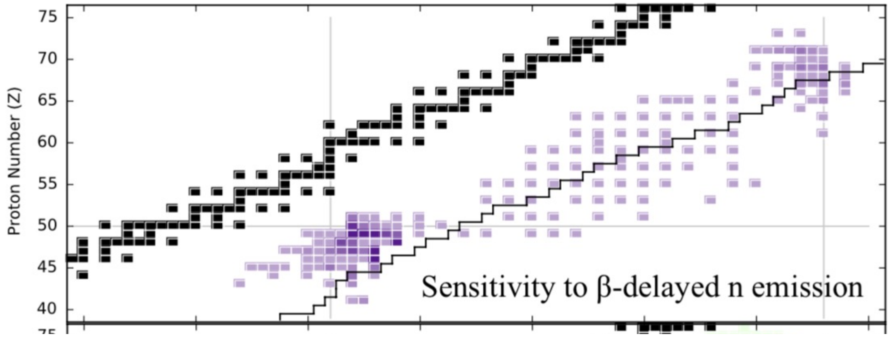
- **^{100}Sn region –** the heaviest N = Z nuclei where the effects of proton-neutron correlations and new types of nuclear condensates can be studied.

"The territory at and beyond the proton drip line offers unique opportunities to study other exotic nuclear decays and correlations, such as ground-state one- and two-proton decay, a class of radioactivity that exists nowhere else but that provides unique insight into correlation effects." – [NSAC15]



- **Neutron-rich N = 82 and 126 regions –** two regions near the limits of FRIB production where r-process simulations of the natural abundances of the elements can be studied.

"A study of these reactions, and of the decay and structure characteristics of the nuclei along the reaction path, provides fundamental insight into the nature of these processes, the rapid timescale of the explosion, the associated energy release, and, of course, nucleosynthesis." – [NSAC15]



Majority of Scientific Benchmarks Met (14 of 17)

17 benchmark programs determined by the NSAC Rare-Isotope beam Task Force [NSAC RIB07] organized under the four priority questions in nuclear physics identified by the Nuclear Science Advisory Committee [NSAC15] and the National Academy of Sciences [NRC13]

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**		

FDS Status

- FRIB and DOE received FDS White Paper in Winter-Spring 2019
- FDS cost range of $24-30M
- The FDS initiator (FDSi), implemented in 2022 with older / existing community detectors, provides a first step towards the FDS and a solution for Year 1 and early FRIB years
- FDS is ready to proceed upon funding availability

FDSi

ORNL
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R. Grzywacz
K. Rykaczewski
C. Rasco
A. Macchiavelli
T. King

UTK
R. Grzywacz
M. Madurga
K.L. Jones

ANL
D. Seweryniak
M. Carpenter

FRIB
S.N. Liddick
A. Spyrou
C. Wrede
H. Schatz

Other
K. Kolos (LLNL)
J.T. Harke (LLNL)
M. Karny (Warsaw)
R.V.F. Janssens (UNC)
H. Crawford (LBNL)
V. Tripathi (FSU)
B. Crider (MSState)
L. Riley (URSinus)
A. Rogers (LLNL)

The FDS Initiator (FDS_i)

The FRIB Decay Station (FDS) — an efficient, granular, and modular multi-detector system designed under a common infrastructure — will be staged, beginning with equipment from existing arrays and subsequently upgraded, increasing the energy resolution, granularity, and combined efficiencies along the way; this will increase the scientific output and extend the scientific reach towards the drip lines.

The FDS Initiator (FDS_i) is the initial stage of the FDS that will be ready for Day One FRIB, and the FDS Initiator Group is the body of contributors responsible for establishing the FDS_i, which will occur before official FDS funding, in accord with the vision outlined in the FDS White Paper. The FDS Initiator Group will work towards the FDS_i in coordination with the FDS Users Executive Committee (FDS UEC) and FRIB, ultimately providing a means for FRIB users to conduct world-class decay spectroscopy experiments with the best equipment possible. This document represents a joint agreement between the FDS Initiator Group and the FDS UEC, which represents the wider community, and it outlines the opportunities, procedures, and conditions for using the FDS_i. The terms within this document may be renegotiated only once per year with suggestions for possible changes presented at the one of the annual nuclear physics community meetings (e.g., LECM or APS DNP).

- Prior to each PAC cycle, the FDS UEC, in coordination with the FDS Initiator Group, will provide a list of available detector systems for decay spectroscopy studies, points-of-contact for each detector system, and nominal array configurations to FRIB and the user community. Users interested in other configurations or additions should communicate their needs with the FDS UEC prior to a PAC cycle.

- Anyone can submit a FDS_i proposal, regardless of country or affiliation. However, PIs should coordinate their proposals with the detector points-of-contact for technical review.

- Primary authorship and data sharing are to be negotiated and resolved amongst the proposal PIs and detector points-of-contact. All FDS Initiator Group contributors are permitted to participate in all FDS_i experiments if they desire. All people who contribute to a proposal, detector setup, experiment, analysis, or manuscript are to be included as authors. FRIB data management and authorship policies must be strictly followed for continued use of the FDS_i. The experimental PI is ultimately responsible in fulfilling any FRIB defined pre-experiment procedures but the FDSi Group will make the best effort to assist in this process.

- PIs are encouraged to submit a short abstract (one-page limit) to the UEC that communicates the aim of their intended proposal 30 days before a proposal deadline. The UEC and FDS Initiator Group will use this information to recommend possible bundling of proposals that can be achieved simultaneously. In such situations, the UEC, in coordination with the FDS Initiator Group, will contact the involved parties and broker an agreement on the nominal detector configuration and data sharing.

- All issues surrounding duplicate or overlapping proposals should be resolved amongst the proposal PIs and detector points-of-contact if possible before final submission.

- When contributors within the FDS Initiator Group submit proposals surrounding their own hardware, they must follow the rules set in this document and those of the FDS Users Group Charter if they rely on FDS_i resources that do not belong to their institution, or, if they use the FDS_i branding.

FDS UEC 2019-2022

B. Crider (MSState)
K. Kolos (LLNL)

C. Rasco (ORNL)
A. Spyrou (FRIB)
V. Tripathi (FSU)

FDS UEC 2022-Pressent

K. Kolos (LLNL)
M. Madurga (UTK)

H. Crawford (LBNL)
B. Crider (MSState)
H. Schatz (FRIB)

FDSi Relies on Community Contributions (clovers 3 decades old)

ORNL: 11 Clovers, MTAS, 3He tubes, CLARION / DEGAi frame, simulations, electronics, and engineering

UTK: VANDLE, segmented scintillator-based implant detectors, 30 $LaBr_3$ detectors, simulations, machining, Si detectors, and associated electronics

ANL: 8 clovers, 15 $LaBr_3$ detectors, CAGRA (slow beam) frame, HV, engineering

FRIB-NSCL-MSU: Pixie16 pool (67 modules), GADGET2, SUN, PXCT, GeDSSD, 16 $LaBr_3$ detectors, vacuum pumps and gauges, engineering, and machining

FSU: 3 clovers**, HV, and prototype machining

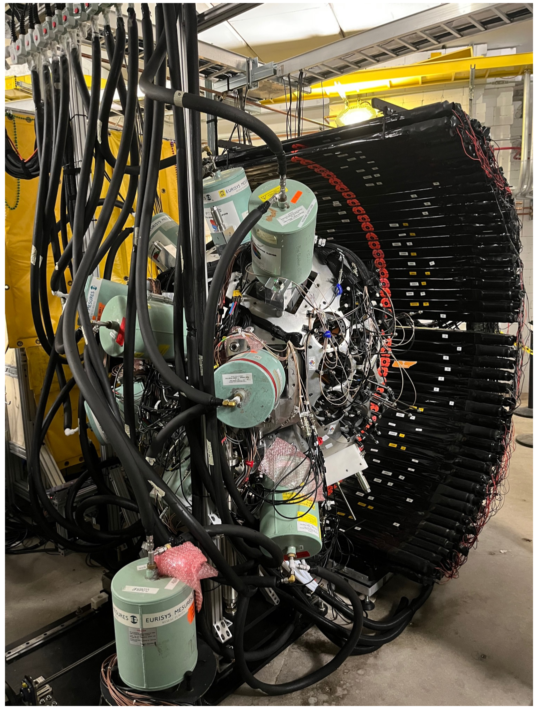
MSU (Mississippi): 4 $CeBr_3$ and 10 $LaBr_3$ detectors, and $CeBr_3$-based implant detector

URSinus: Simulations

UNC: 12 $CeBr_3$ detectors

LLNL: 8 clovers (3 are ORTEC), cables, solenoids, and HV

LBNL: 2 clovers**

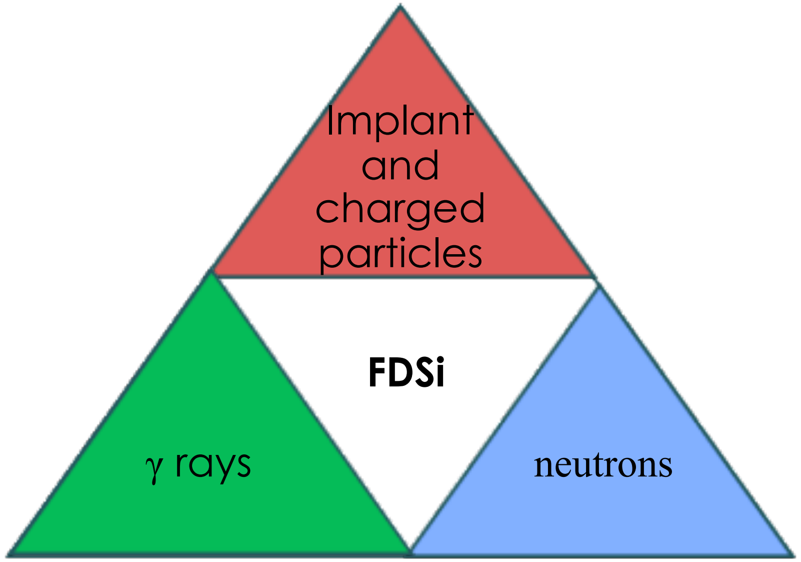


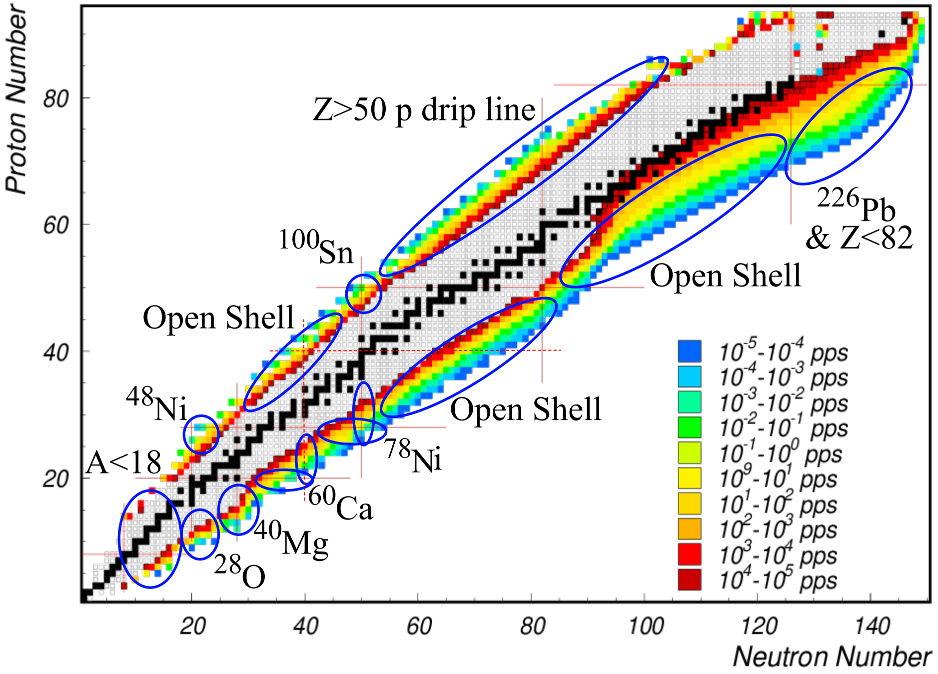
**On limited occasions and contingent on schedule due to local program / facility needs.

1st FRIB PAC: Accepted Proposals and POC multiple spokespeople per proposal

13 Submitted and 8 Accepted → Wide community interest in decay station studies at FRIB

1. "Correlation of Triaxial Deformation with Inertial Dynamics, Masses and r-Process Nucleosynthesis" - J.M. Allmond (**ORNL**)
2. "Decoding the doubly magic stronghold - decay spectroscopy of ^{78}Ni " - Krzysztof Rykaczewski (**ORNL**)
3. "Complete decay spectroscopy of ^{100}Sn and its neighbors" - Robert Grzywacz (**ORNL-UTK**)
4. "Decay spectroscopy of the N=35 nuclei ^{55}Ca, ^{54}K and ^{53}Ar and the search for dripline nucleus ^{50}S" - Wei Jia Ong (**LLNL**)
5. "Decay Spectroscopy Near N=28: Shell Structure, Shapes and Weak Binding" - Heather Crawford (**LBNL**)
6. "Strength of the key ^{15}O(a,g)^{19}Ne resonance in X-ray bursts" - Christopher Wrede (**FRIB-MSU**).
7. "Constraining neutron capture rates for the r-process" - Artemis Spyrou (**FRIB-MSU**)
8. "Decay spectroscopy in the vicinity of the N=126 shell closure" - Jin Wu (**ANL**)





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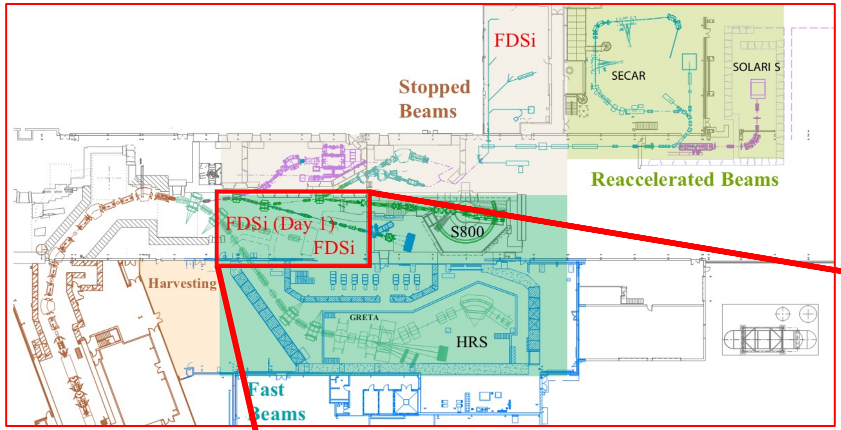
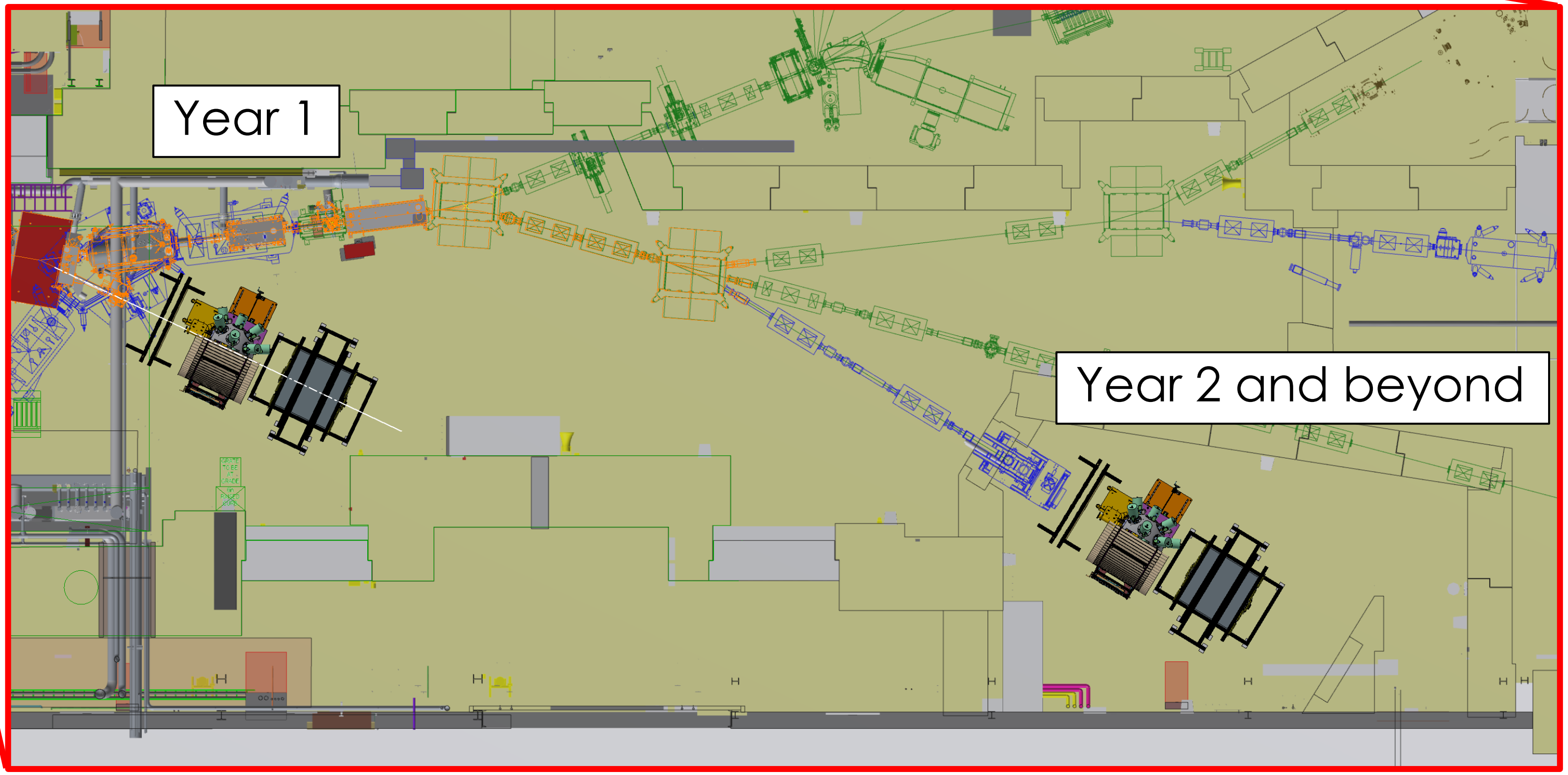
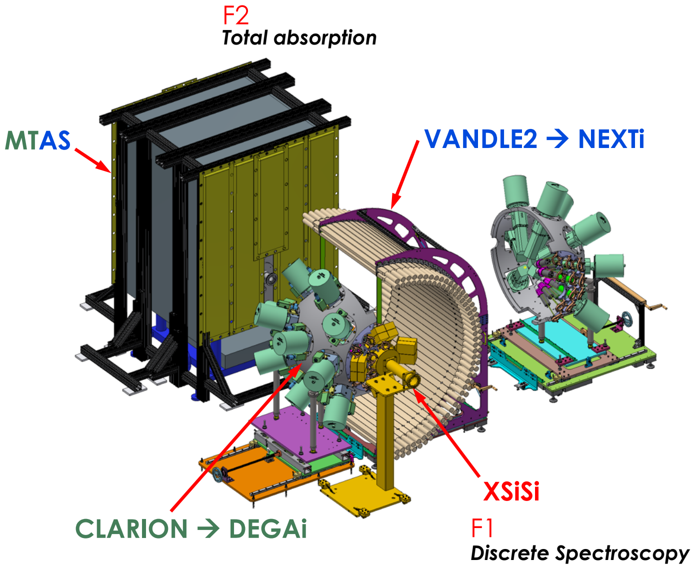
Locations


FDSi
Stopped
Beams
SECAR
SOLARI S
Reaccelerated Beams
FDSi (Day 1)
FDSi
S800
Harvesting
GRETA
HRS
Fast
Beams

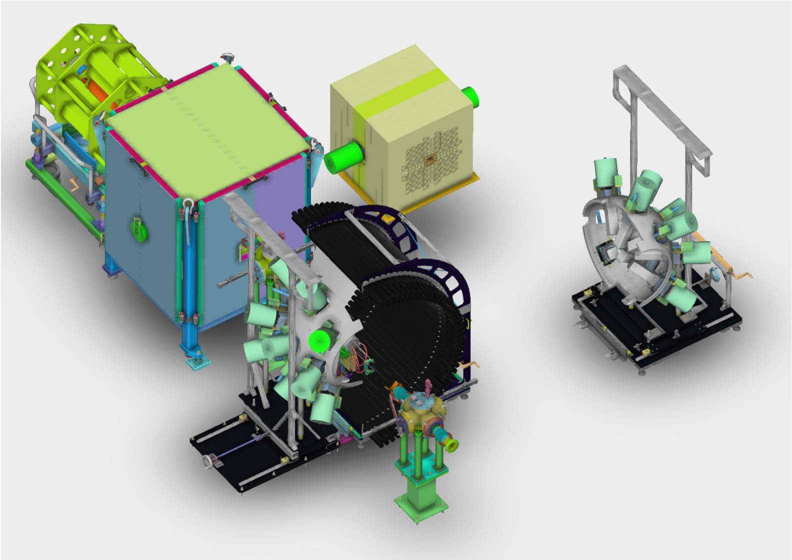

Year 1
Year 2 and beyond

Evolution

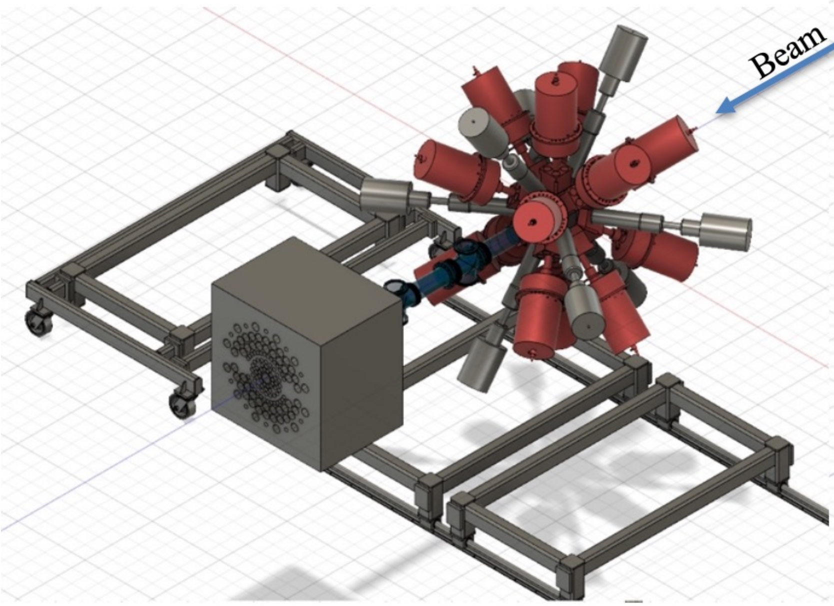
FDSi Phase 1 (2022)

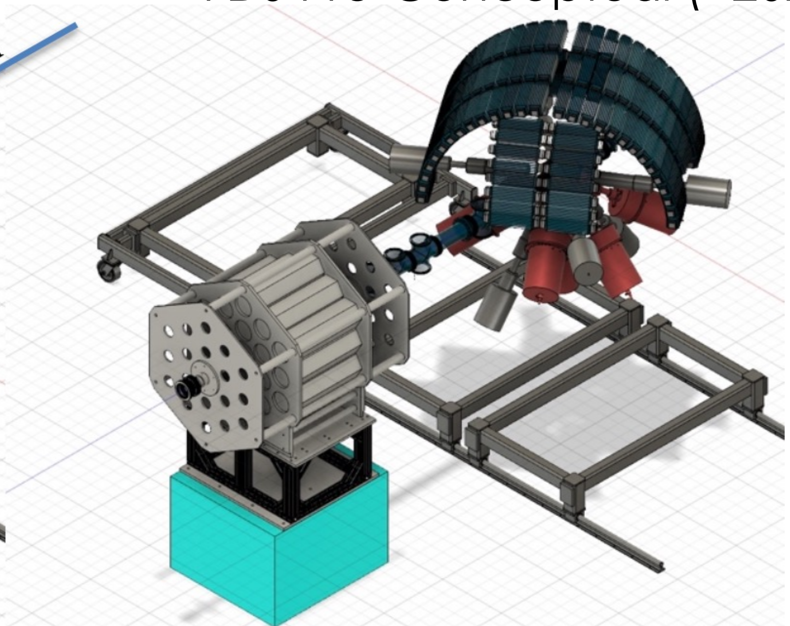


FDSi Phase 2 (2023)



FDS Pre-Conceptual (>2025)





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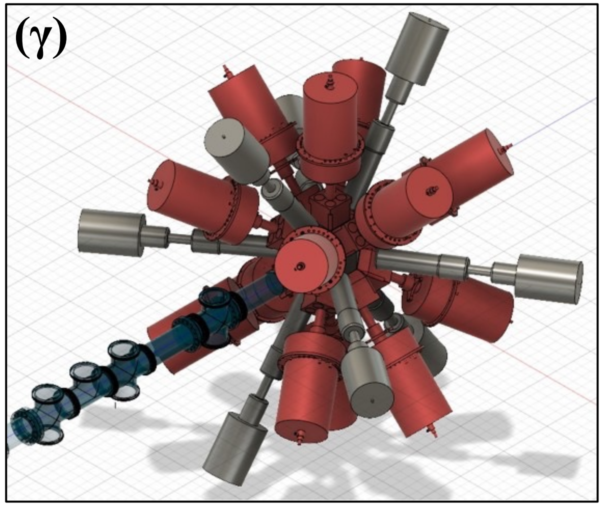
Major New FDS Instruments

A leap forward in efficiencies (**x10 for βnγ** and **x50 for β2n2γ**), resolution (**x2 for γ** and **x6 for n),** granularity, rate, background suppression, reliability, and readiness, critical for most exotic nuclei approaching drip lines.

DEGA (HPGe for gammas)

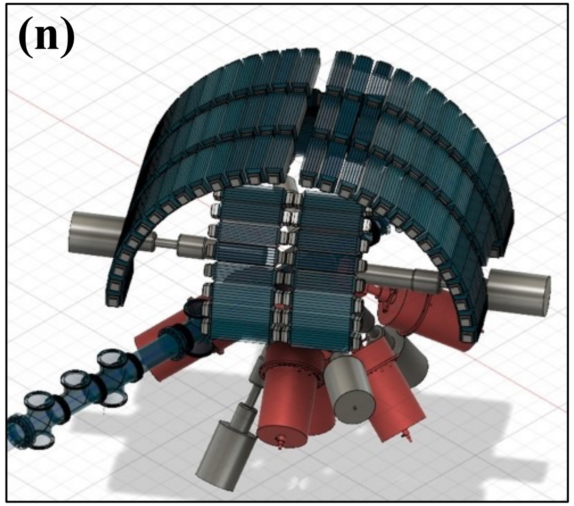


$10-12M

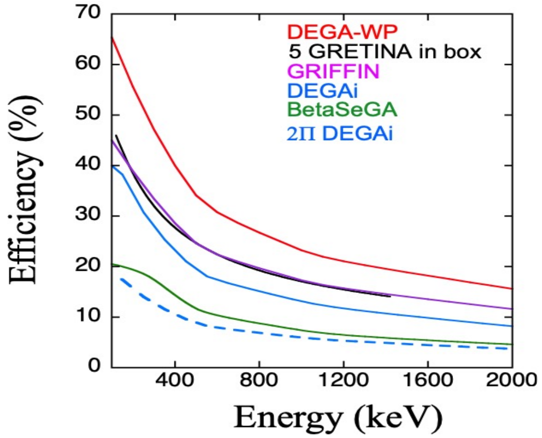
"The detection of γ-ray emissions from excited nuclei plays a vital and ubiquitous role in nuclear science." – [NSAC02]

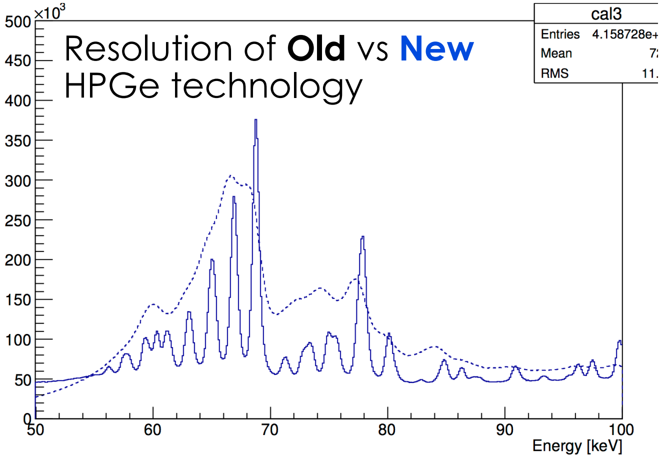
"Single- and even multiple-neutron emission are expected to characterize nuclei at the neutron drip line, while β-delayed neutron decay is prevalent among neutron-excess nuclei before the drip line is reached. Both forms of radioactivity only occur among nuclei far from stability." – [NSAC15]

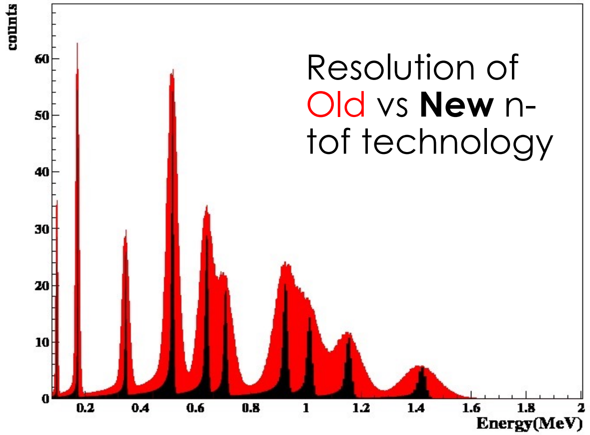
NEXT (neutrons)



$8-12M







Look for Updates @ https://fds.ornl.gov

OAK RIDGE National Laboratory

Home Science Users Project Management Subsystems Initiator Documents

What is the FRIB Decay Station?

The FRIB Decay Station (FDS) is an efficient, granular, and modular multi-detector system designed under a common infrastructure. The FDS will bring multiple complementary detection modes together in a framework capable of performing spectroscopy with multiple radiation types over a range of beam production rates spanning ten orders of magnitude. At the core of the FDS is a system to stop the incoming exotic ions and detect subsequent charged-particle decay emissions. Additional detector arrays will surround this system to measure emitted photons, neutrons, or both. The exact configuration of the charged-particle, photon, and neutron detection arrays will be dependent on the specific science goals of each experiment, and it will be adaptable to optimize tradeoffs between energy resolution, time resolution, efficiency, and background. Three new major devices have been proposed for the FDS: (1) a large-volume HPGe array, "DEGA", (2) a neutron time-of-flight (TOF) array, "NEXT", and (3) a silicon-scintillator hybrid implant detector, "XSiS". The FDS will surpass previous generation systems through improvements to combined efficiencies (by factors of approximately 10 for $\beta n\gamma$ and 50 for $\beta 2n2\gamma$), granularity, background suppression, and resolution.

The FDS experimental program will focus on four strategic areas of FRIB: nuclear structure, nuclear astrophysics, tests of fundamental symmetries, and applications of isotopes for society. The FDS will be uniquely positioned for discovery experiments at the extremes of the accessible regions due to the high sensitivity and relatively low beam-rate requirements of decay spectroscopy techniques. In addition, for nuclei produced at higher rates, the FDS will be able to conduct high-precision measurements for thorough characterization of emergent phenomena, which can be used to benchmark and differentiate between leading models