Nuclear masses and decays for cross-cutting needs

NSAC Long Range Plan Town Hall Meeting

November 15, 2022

Kay Kolos

Lawrence Livermore National Laboratory

On behalf of the FDS UEC and Community,
and the CPT Collaboration

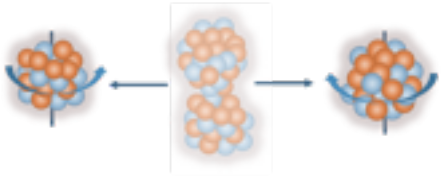
LLNL-PRES-842384
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

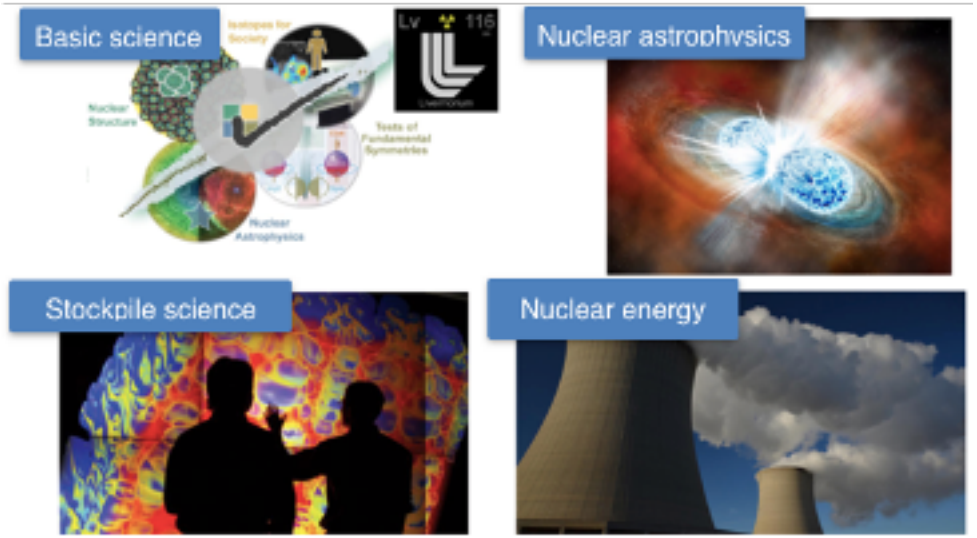
Lawrence Livermore National Laboratory

Nuclear masses and decay properties play an important cross-cutting role in nuclear science

Ground state and isomer masses:

- **nuclear structure:** used to test mass predictions, nuclear structure models, evaluations
- **astrophysical process** calculations: Q values help determine flow of the r –process, isomers can change the pathway of the r process
- important components when modeling fission spectra for various **applications** (neutron spectra, gamma spectra), fission dynamics and angular momentum in fission reaction





Beta decay properties like half-lives, branching ratios, neutron-emission probabilities:

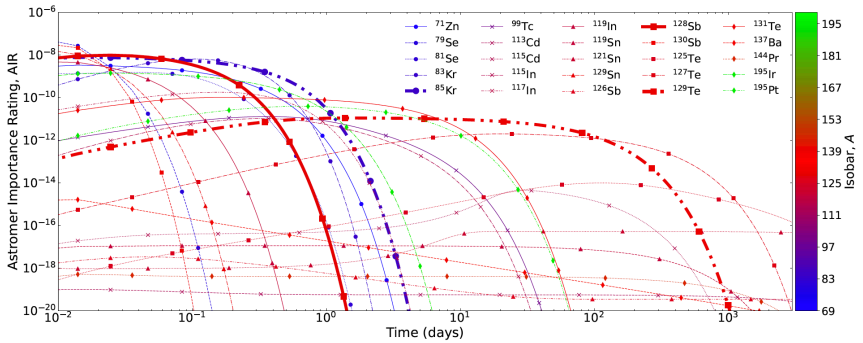
- **nuclear structure.** shape coexistence, limits of stability
- **astrophysics** network calculations rely of beta decay properties
- **applications** including nuclear energy, nuclear medicine, nuclear forensics and stockpile science

Needs for new and improved data on nuclear masses for ground states and isomers

Nuclear isomers play a significant role in determining the abundances of the elements in the universe

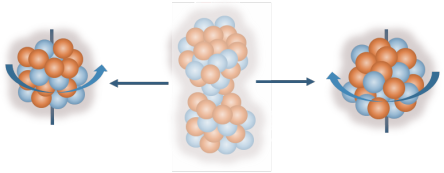
- ^{26m}Al can impact the amount of ^{26}Al produced at high temperatures [R. C. Runkle, et al. ApJ 556, 970–978 (2001)]
  - Recent studies [G.M. Misch, T.M. Sprouse and M.R. Mumpower, ApJ Letters 913, 1 (2021)] **impact of isomers on r-process**
  - isomers influence energy generation of the ejecta [S. Fujimoto and M. Hashimoto MNRAS 493, L103–L107 (2020)]

Additional data on ground state and isomer energies in N = 82 and N = 126 regions will help our understanding of the nucleosynthesis processes



Isomer - to - ground state ratios important for understanding of **fission dynamics and angular momentum**

- modeling of fission reaction: fission product yields, fission spectrum (neutrons, gammas), evaluations



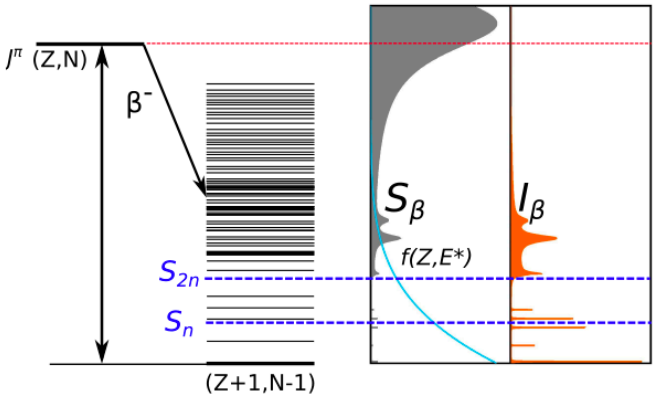
Isomer-to-ground state data will greatly benefit fission yield models, evaluations, as well as our fundamental understanding of fission dynamic

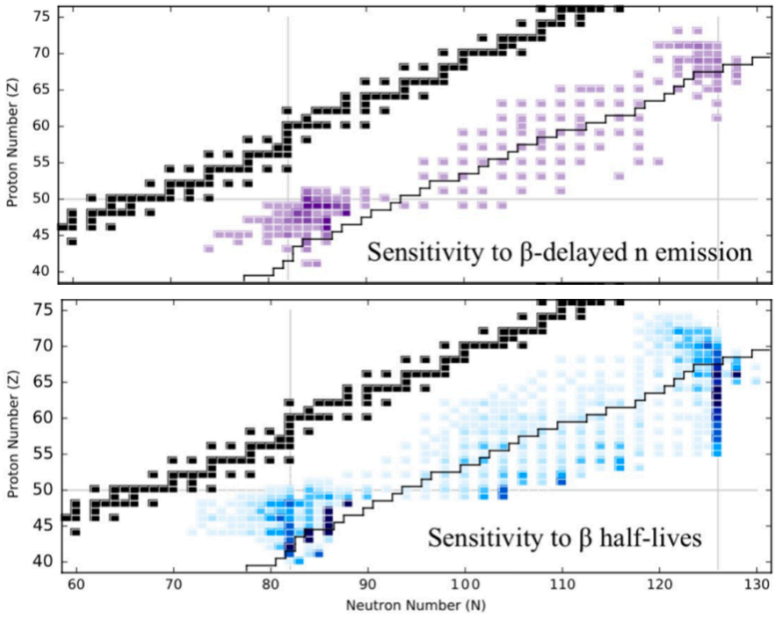
Needs for new and improved data on beta decay properties of neutron-rich isotopes

Beta decay is the most common nuclear decay mode that impacts many different fields of basic and applied science

- Sensitivity of **r-process** to half-lives and neutron emission probabilities
  [M.R. Mumpower et al., Prog. Part. and Nucl. Phys. 86, 86 (2016)]

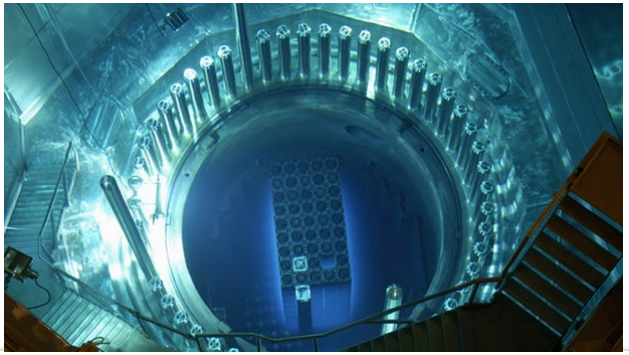
- Neutron emission needed for refining **nuclear reaction theories**





- Decay rates and branching ratios of neutron-rich isotopes needed for **nuclear forensics** and **stockpile science**

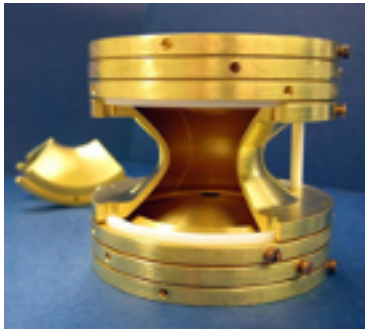
- Beta decay spectrum and feeding needed to understand **reactor neutrino anomaly**

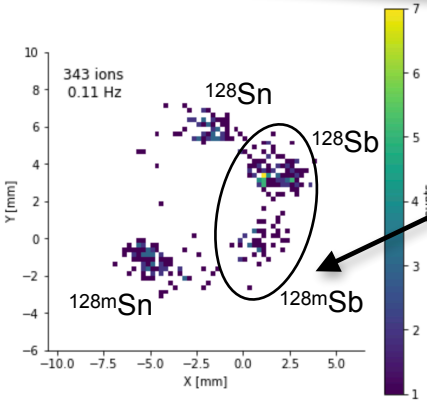


Mass and ratios measurements with the Canadian Penning Trap and Phase-Imagining Technique at ANL

Numerous mass measurements performed with the CPT at CARIBU:

- Precision **mass measurements** of neutron-rich ^{252}Cf fission products [R. Orford et al. PRL 120, 262702 (2018) and others],
- **isomer** (astromer) measurements,





Isomer energy (astromer) measurement

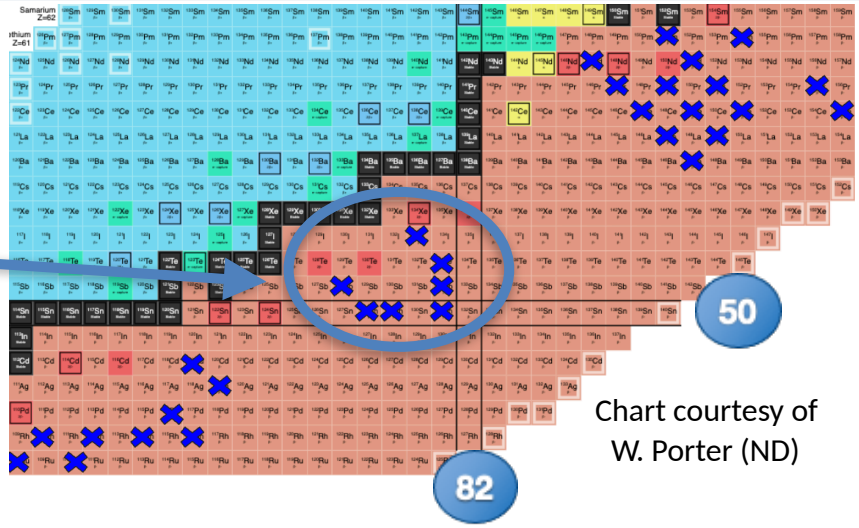
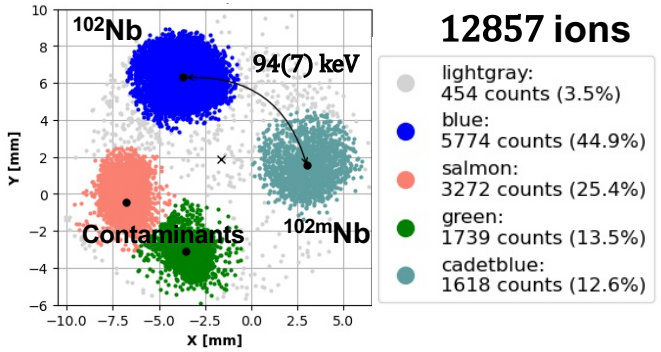


Chart courtesy of W. Porter (ND)

- **Isomer-to-ground state ratio** measurements:
  - $^{102, 102m}$Nb g.s.-to-isomer = 0.32(5)
  - more fission products ratio measurements completed and under analysis



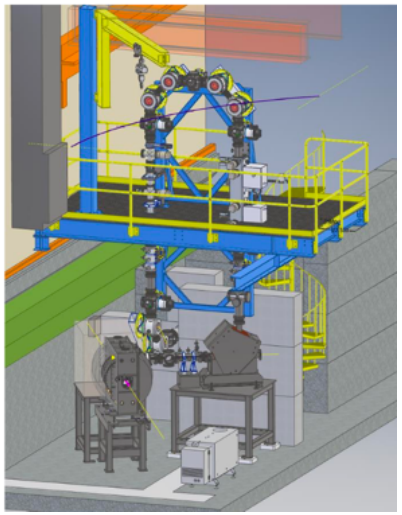
- Obtained also with decay spectroscopy: ^{134,134m}Sb ratio iso-to-gs = 2.03(5) measured with the X-Array [K. Siegl, K. Kolos, N. Scielzo et al. PRC 98, 054307 (2018)]

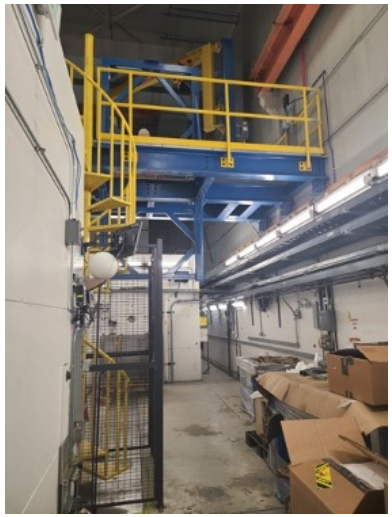
More measurements with the X-Array/ Gammasphere planned at nuCARIBU (ANL)

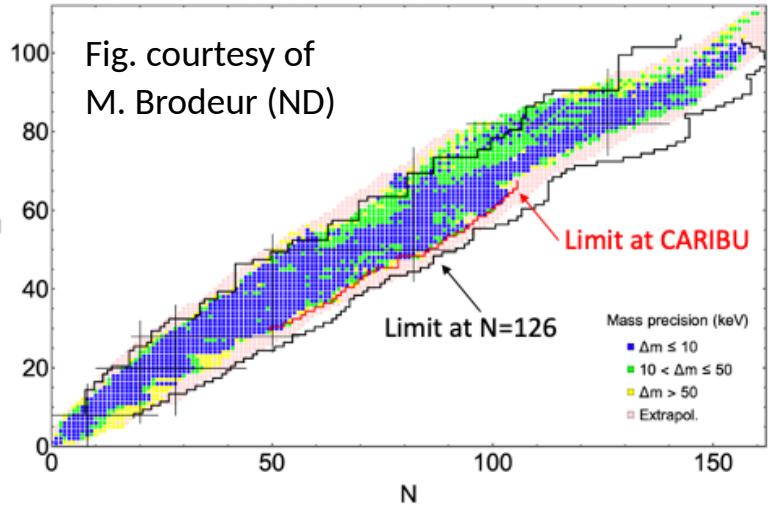
Extending the reach of mass measurements at the N = 126 Factory and FRIB

With the CPT and PI-ICR at the **N=126 Factory** we will be able to:

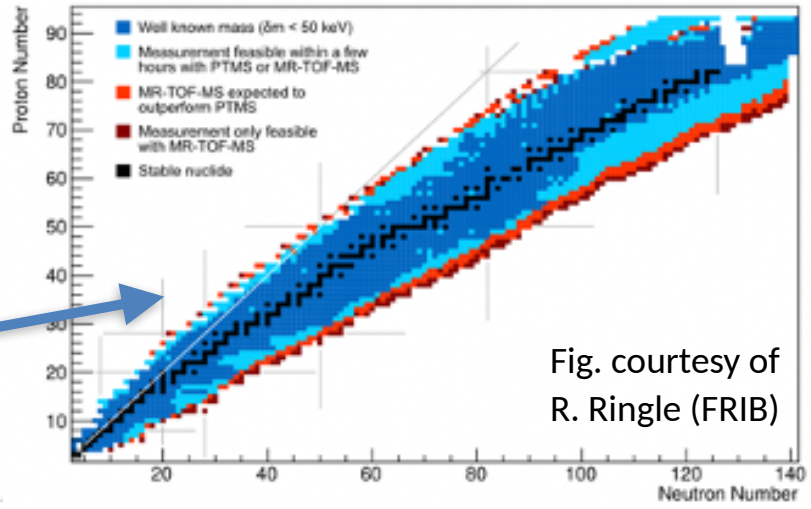
- perform **mass measurements** of nuclei in rare-earth peak and N = 126 regions,
- find previously **undiscovered isomers** (potential astromers?)
- improve **the precision** on the energy of ground and isomeric states over a large swat of the chart of the nuclide.







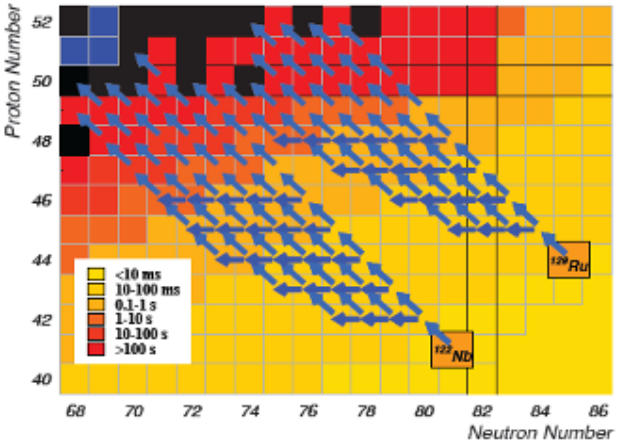
The CPT at the N=126 Factory and LEBIT at **FRIB** will have complementary reaches in terms of the masses that can be measured.

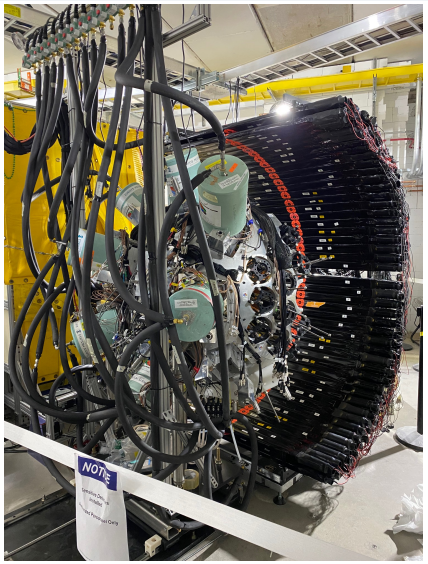


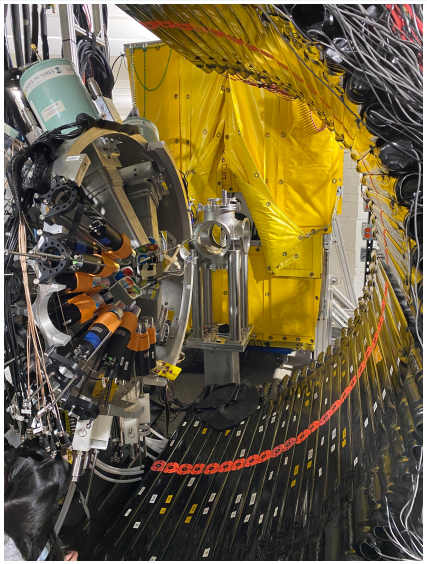
Decay measurements with FRIB Decay Station (FDS)

The FDS (currently FDSi):

- pursue research in the four strategic areas of FRIB: **nuclear structure, nuclear astrophysics, tests of fundamental symmetries, and applications** of isotopes for society
- Versatile state-of-the art array of implant, charged particle, gamma-ray, neutron and TAS detectors capable of **"complete" decay information**
- Fragmentation beam allows for **multiple isotope** measurements in one experiment
- Uniquely positioned for discovery experiments at the extremes due to **low-rate sensitivity**





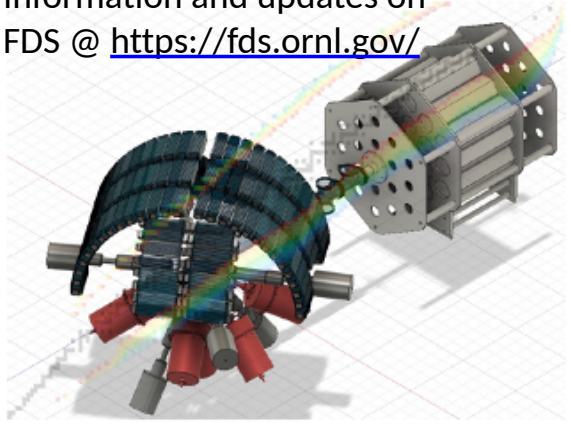


The FRIB Decay Station Whitepaper

66 contributors

24 institutions

Information and updates on FDS @ https://fds.ornl.gov/

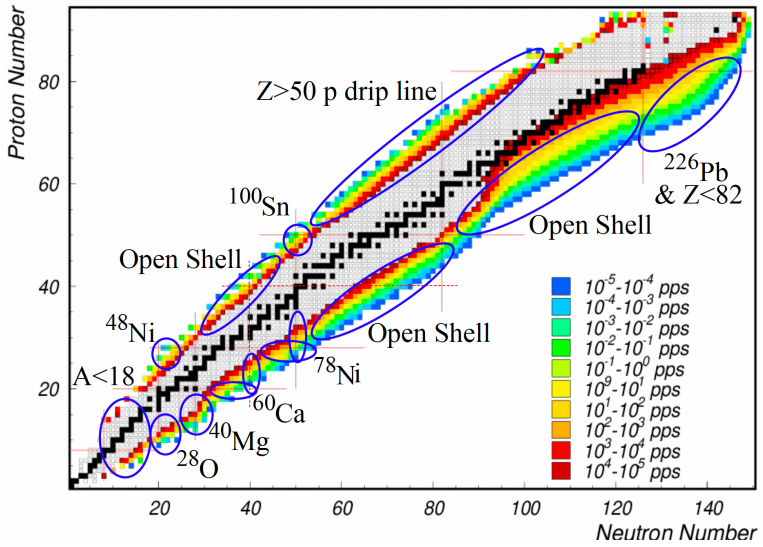


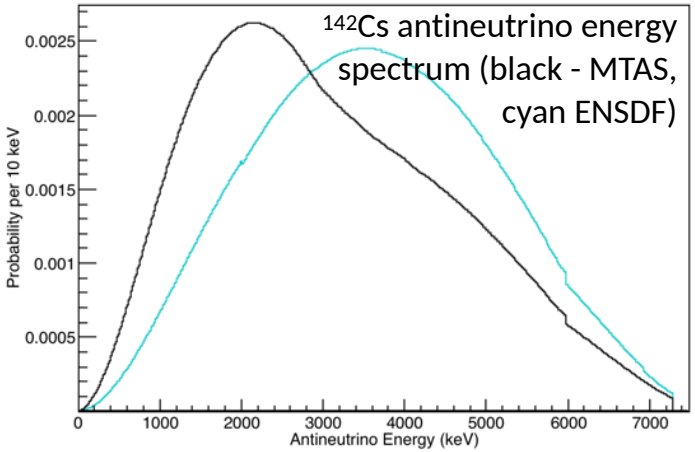
First FDS experiments completed and more nuclear data measurements to come

Wide community interest in decay station studies at FRIB, FRIB PAC1 there was 13 FDSi proposals, 8 accepted:

- First two experiment performed in May and June 2022:
  - "Decay Spectroscopy Near N=28: Shell Structure, Shapes and Weak Binding" - Heather Crawford (LBNL) **First results** H. L. Crawford et al. Crossing N=28 toward the neutron drip line: First measurement of **half-lives** at FRIB accepted in Phys. Rev. Lett.
  - "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) **First FDS experiment with two focal points: discrete array and MTAS**
- Third FDS experiment with GADGET scheduled to run later this month

Incomplete or inaccurate nuclear data is one possible source of the reactor antineutrino anomaly - measurements of important to **reactor antineutron anomaly isotopes** at FRIB.. and more!



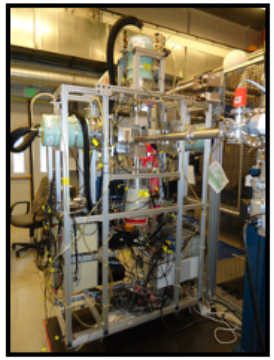


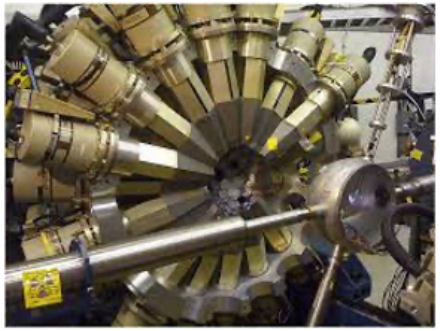
Multiple opportunities to measure influential nuclear data at ANL and FRIB facilities

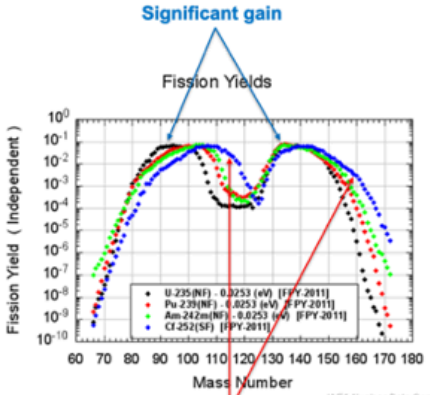
- **Isomer – to – ground state ratio** measurements and **decay spectroscopy** of fission products with the X-Array/Gammasphere at nuCARIBU

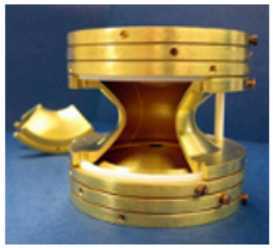
- Previously inaccessible **mass measurements and isomer** discovery at N = 126 Factory with the CPT PI-ICR technique

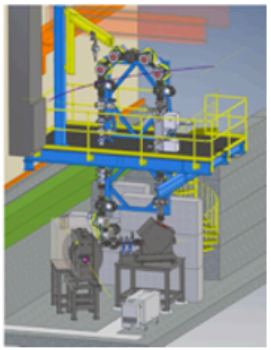
- "Complete" **decay spectroscopy** (decay rates, beta feeding, neutron emission) of neutron-rich isotopes with the FRIB Decay Station

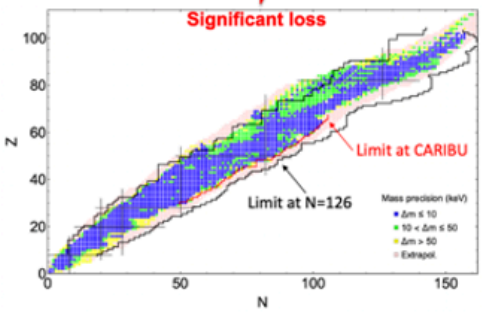




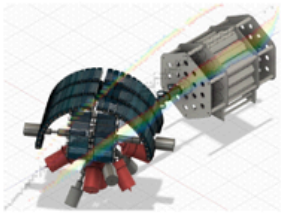


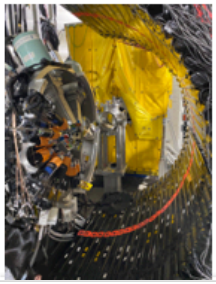


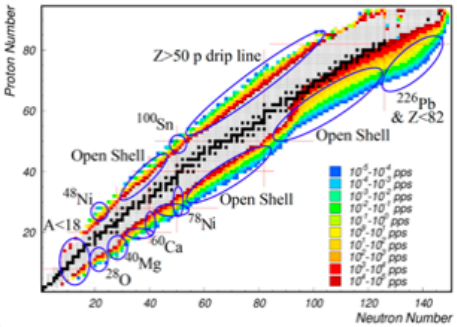




The FRIB Decay Station







Thank you