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Title: Measurement of Neutron-Induced Nuclear Reaction Cross Sections on Fission-Product Nuclides

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# Neutron-Induced Cross Sections on Fission Product Nuclei (P163)

70 YEARS OF CREATING TOMORROW



**Los Alamos**  
NATIONAL LABORATORY

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CEA/NNSA Collaboration on Fundamental Science

May 30, 2013

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# Providing nuclear data to test and benchmark reaction models in relation to neutron economy in the fission environment

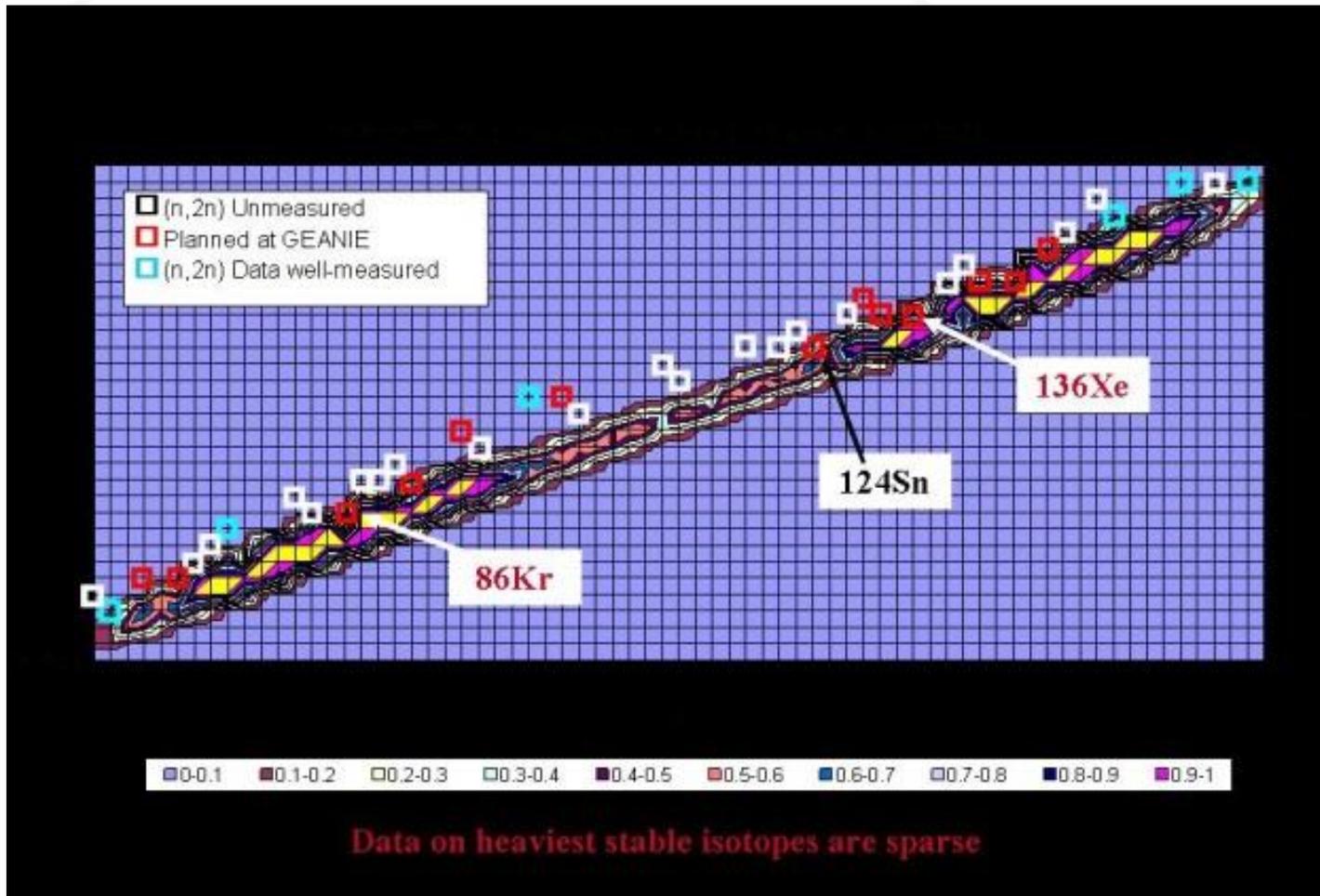
- Goals

- Determine significant  $(n,n')$ ,  $(n,2n)$ ,  $(n,3n)$ ,  $(n,p)$  and  $(n,\alpha)$  cross sections on stable fission product nuclei
- Provide data to serve as benchmarks for nuclear reaction model calculations
- Improve neutron economy and transport calculations
- Add levels and gammas to nuclear database

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# Chart of the Nuclides Showing Fission Products for $E_n=14$ MeV



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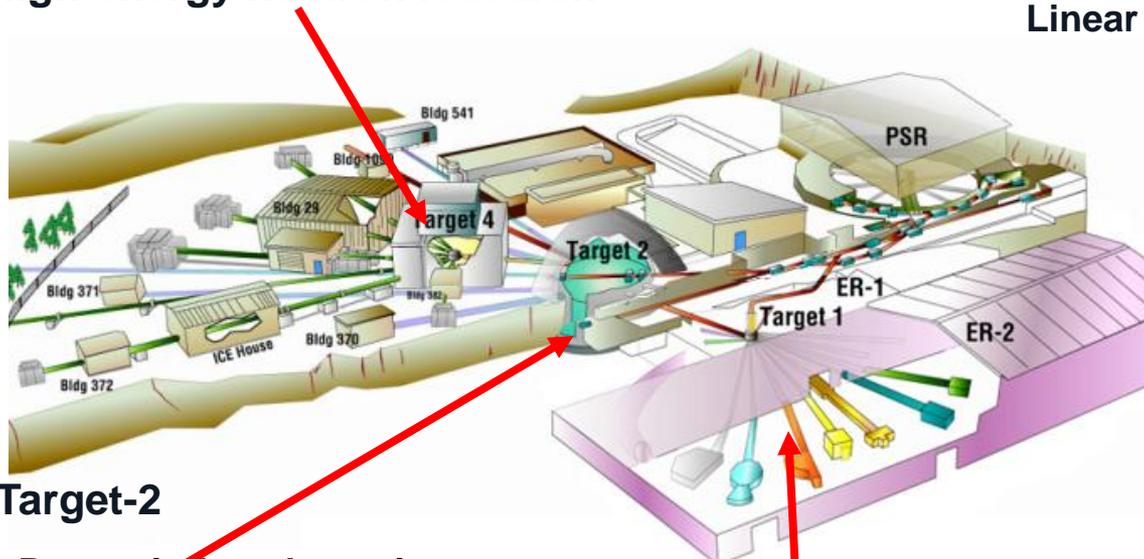




# Nuclear Science research is performed at many experimental areas at LANSCCE

## Weapons Neutron Research Facility

**Target-4**  
High-energy neutron research



**Target-2**

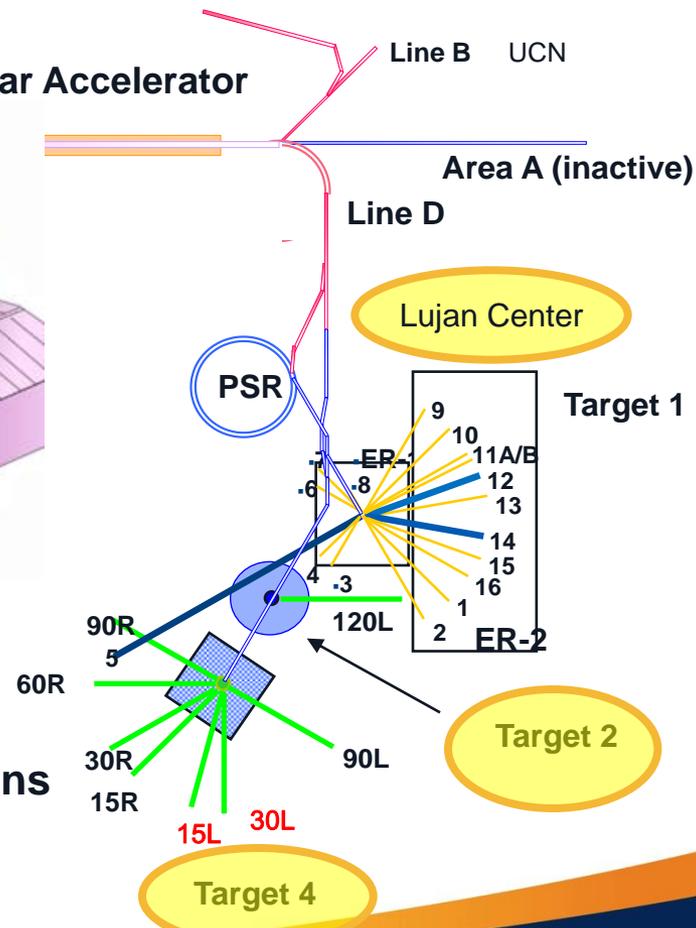
- Proton-induced reactions
- Single-pulse experiments (Sandia)
- Lead Slowing-Down Spectrometer
- SNS target testing
- Isotope production testing
- <sup>99</sup>Mo production tests

**Lujan Center**

- Low-energy neutrons
- Material science
- Nuclear science

Proton Radiography

Linear Accelerator



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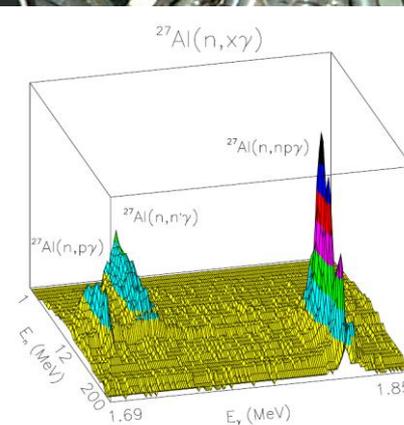




# GEANIE is an Array of High-Resolution Gamma-Ray Detectors

- Combination of planar Ge (x-ray and  $\gamma$ ) detectors and coaxial Ge detectors – 20 total
- Photon energy range  $15 \text{ keV} < E_\gamma < 9 \text{ MeV}$
- BGO background suppression shields
- Measure gamma-ray pulse height, neutron time of flight,  $100 \text{ keV} < E_n < 400 \text{ MeV}$
- Built using elements of the former HERA array from LBL
- Collaboration with LLNL and CEA Bruyères-le-Châtel

## GEANIE $\gamma$ -ray Spectrometer Array



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# GEANIE Experiments at LANSCE with Samples from Bruyeres-le-Chatel

- Measurements on fission fragments
  - Light:  $^{86}\text{Kr}$ ,  $^{93}\text{Nb}$ ,  $^{100}\text{Mo}$
  - Symmetric:  $^{112,124}\text{Sn}$
  - Heavy:  $^{127}\text{I}$ ,  $^{130}\text{Te}$ ,  $^{136}\text{Xe}$ ,  $^{138}\text{Ba}$
- Data on lightest and heaviest Sn isotopes can test reaction models
  - Surprisingly little data on heaviest stable nuclei
- $^{124}\text{Xe}$  –  $^{136}\text{Xe}$  planned

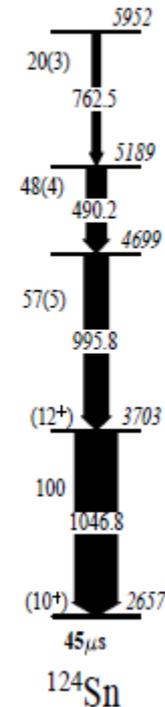
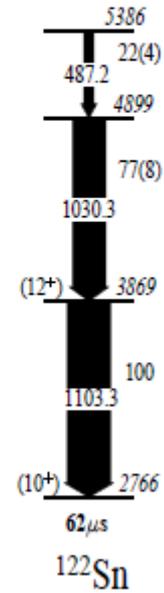
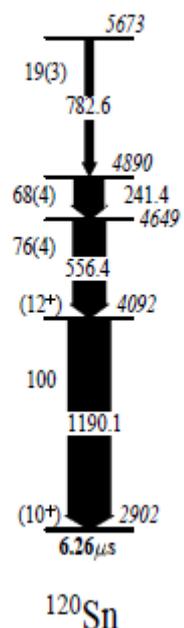
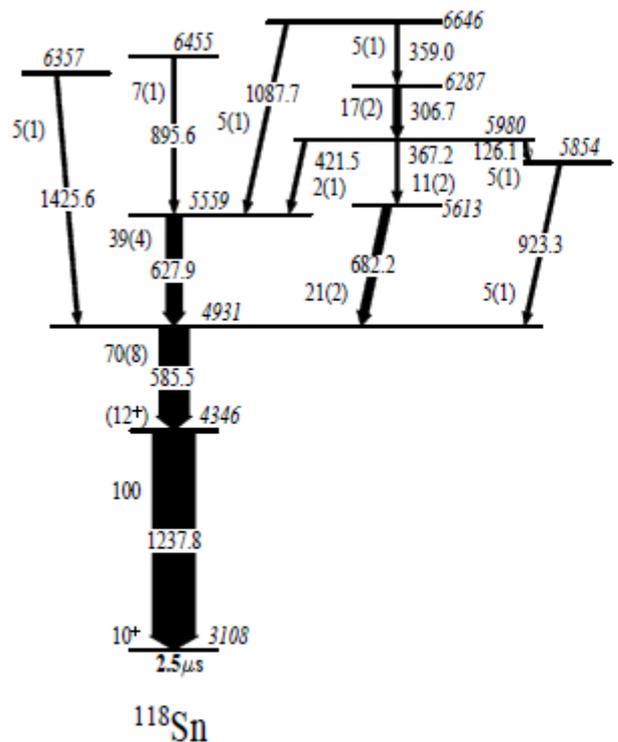


CEA gas cell for Xe and Kr samples

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# Measured Feeding of $10^+$ Isomers in Tin Isotopes – from GEANIE and Gammasphere Data

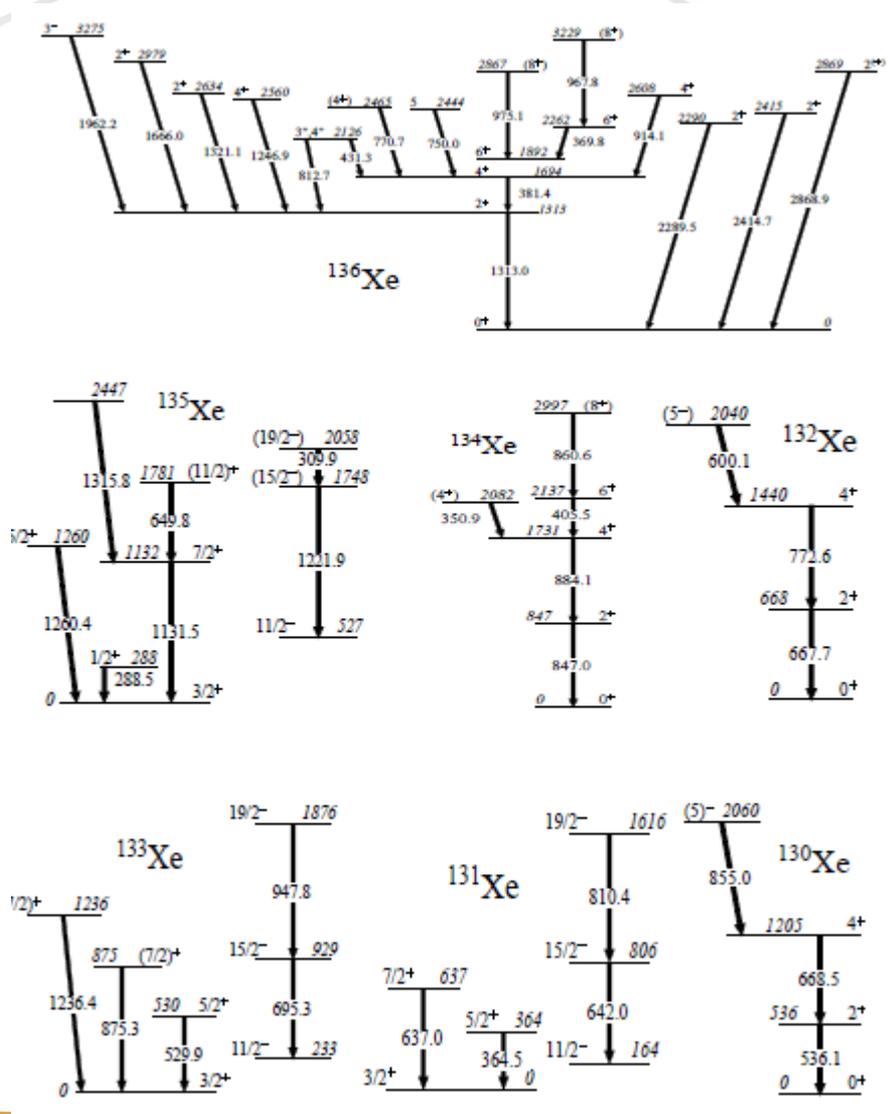


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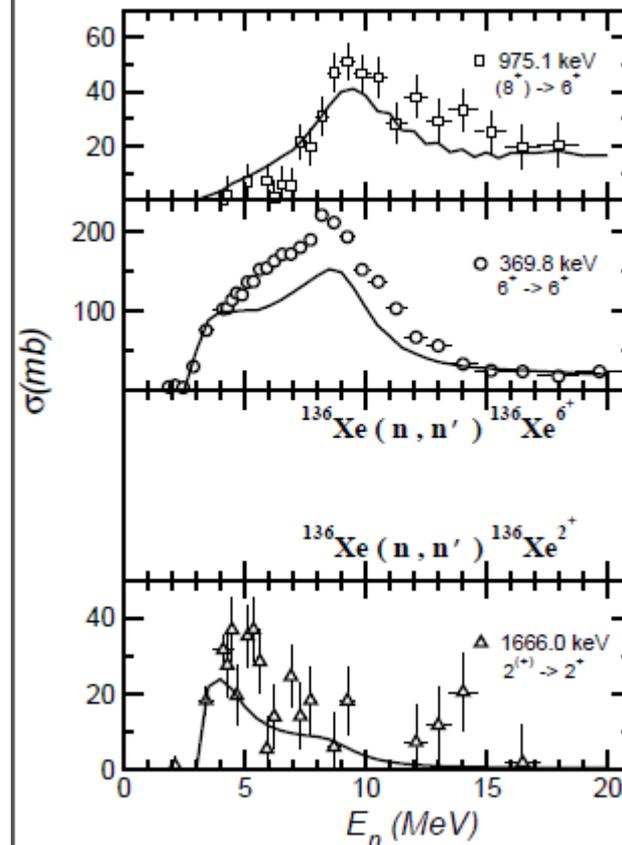
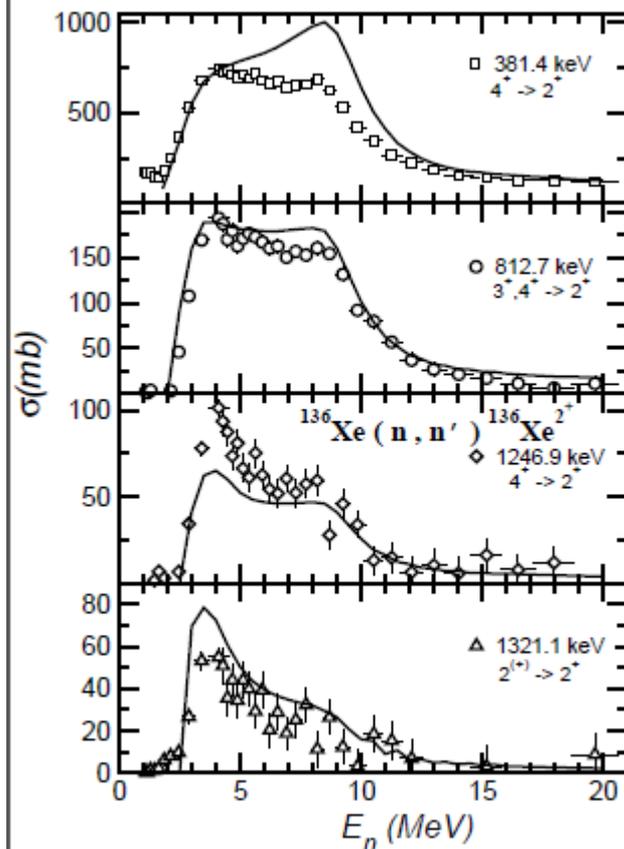


# $^{135}\text{Xe}$ Levels and Gammas





# $^{136}\text{Xe}(n,n')$ Excitation Functions Compared to Model Calculations



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# New gammas and levels

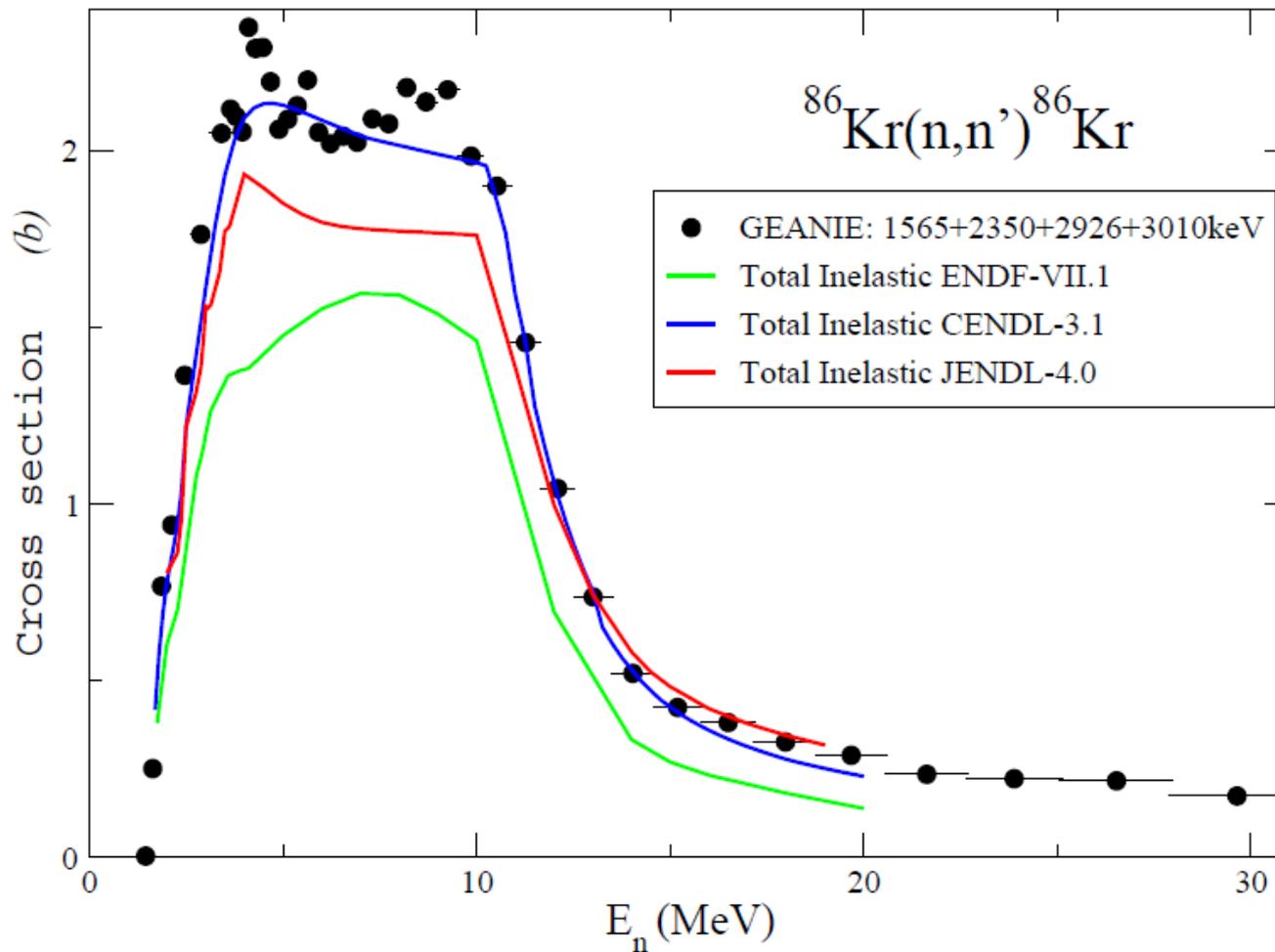
- $^{86}\text{Kr}$ 
  - 10 gamma rays observed for the first time
  - 1 previously unknown energy level identified
- $^{124}\text{Sn}$ 
  - Many new levels and gammas
- Will be sent to evaluators for inclusion in databases

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# $^{86}\text{Kr}$ summed inelastic gamma-ray data compared with total inelastic evaluations



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# GEANIE Is Providing Valuable Data for Neutrino-less Double-Beta Decay and Dark Matter Search Experiment Designs

- $^{136}\text{Xe}$  is a  $0\nu\beta\beta$  decay detector candidate
- Liquid Argon detectors are one detector design for dark matter searches
- In deep underground experiments, cosmic ray produced neutrons may create backgrounds in critical energy regions
- GEANIE data provide limits on those backgrounds

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# Publications

- “Low-spin states in  $^{86}\text{Kr}$  from the (n,n') reaction,” N. Fotiades, M. Devlin, R. O. Nelson, and T. Granier, *Phys. Rev. C* **87**, 044336 (2013)
- “States built on the  $10^+$  isomers in  $^{118,120,122,124}\text{Sn}$ ,” N. Fotiades, M. Devlin, R. O. Nelson, J. A. Cizewski, R. Krücken, R. M. Clark, P. Fallon, I. Y. Lee, A. O. Macchiavelli, and W. Younes, *Phys. Rev. C* **84**, 054310 (2011)
- “High-Spin States in  $^{135}\text{Xe}$ ,” N. Fotiades, R. O. Nelson, M. Devlin, J. A. Cizewski, J. A. Becker, W. Younes, R. Krücken, R. M. Clark, P. Fallon, I. Y. Lee, A. O. Macchiavelli, T. Ethvignot, and T. Granier, *Phys. Rev. C* **75**, 054322 (2007)

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# Summary

- Good progress on data acquisition
- Analysis is continuing
- Work with reaction modelers on these data sets is starting
- New nuclear structure and reaction data has been obtained – 3 journal articles
- Gas sample work benefiting neutrinoless double beta decay/dark matter searches

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