Los Alamos

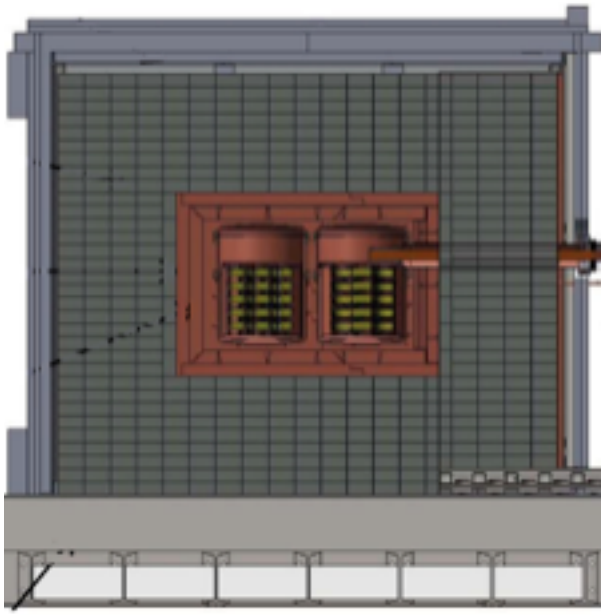
# Inelastic neutron scattering and background in double beta decay

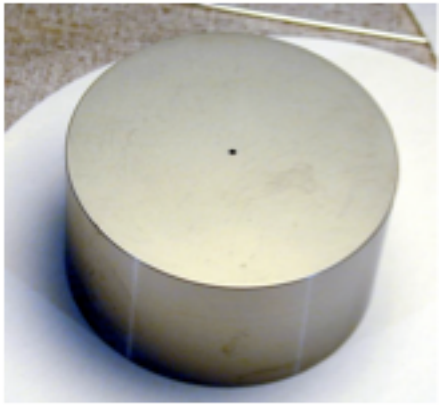
Steve Elliott

# Neutron-Related Backgrounds

- The Majorana Demonstrator uses Ge, Cu and Pb as its 3 largest material components. GERDA uses lots of Ar (also related to our dark matter program.

- Need to measure:
  - A(n,X)A' cross sections
  - Detector Activation (MJD
  - (n,n'$\gamma$) cross sections

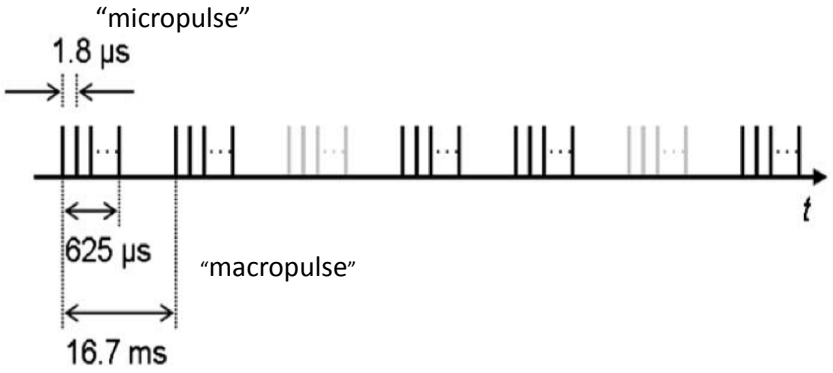




# LANSCE/WNR

Broad spectrum pulsed neutron beam at LANL

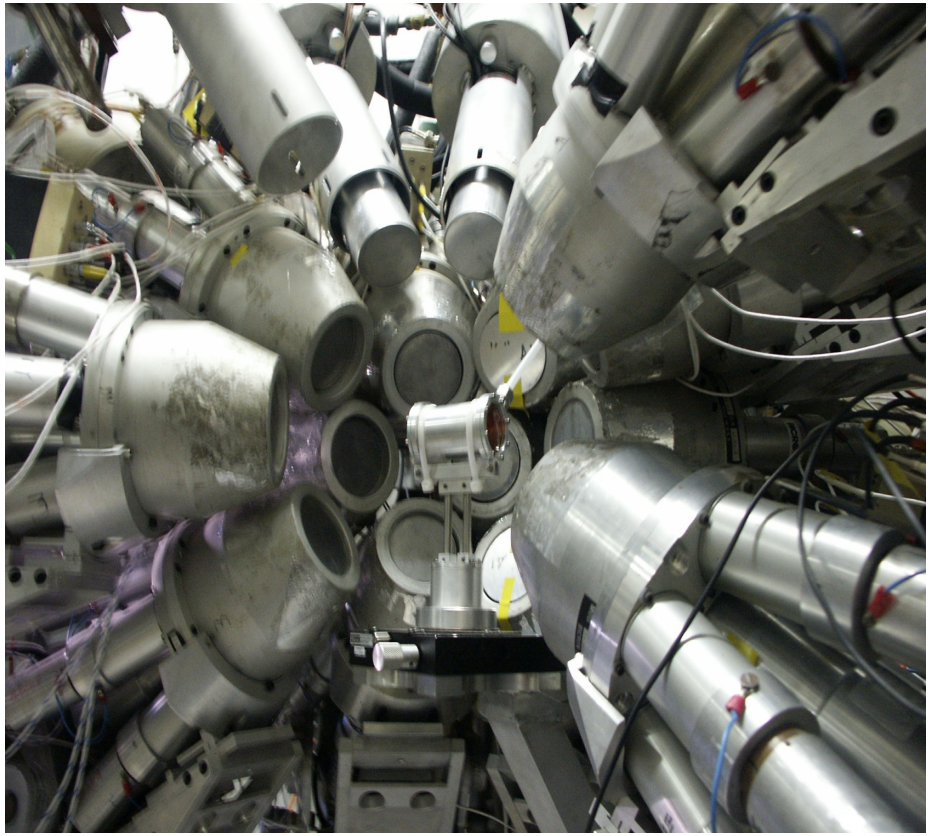
800 MeV proton LINAC:
Neutrons produced via spallation on a tungsten target



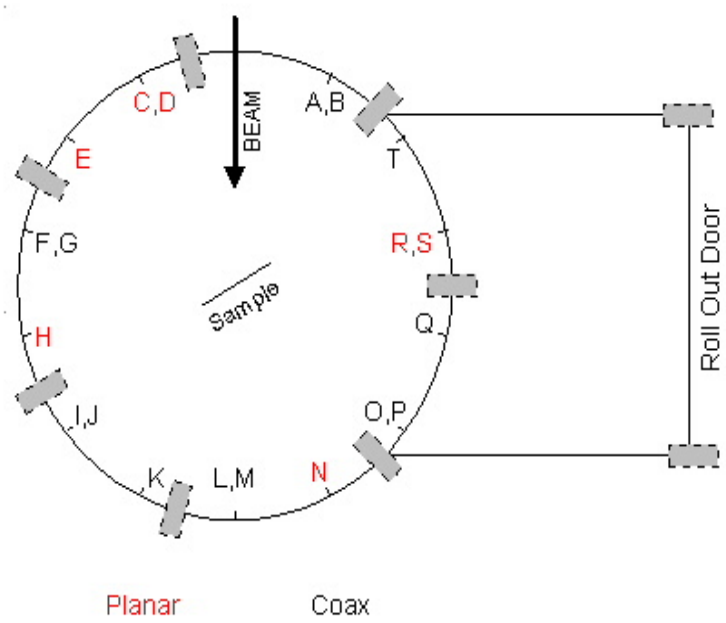

In-beam neutron flux measurement made with $^{238}U/^{235}U$ fission chamber

# GEANIE

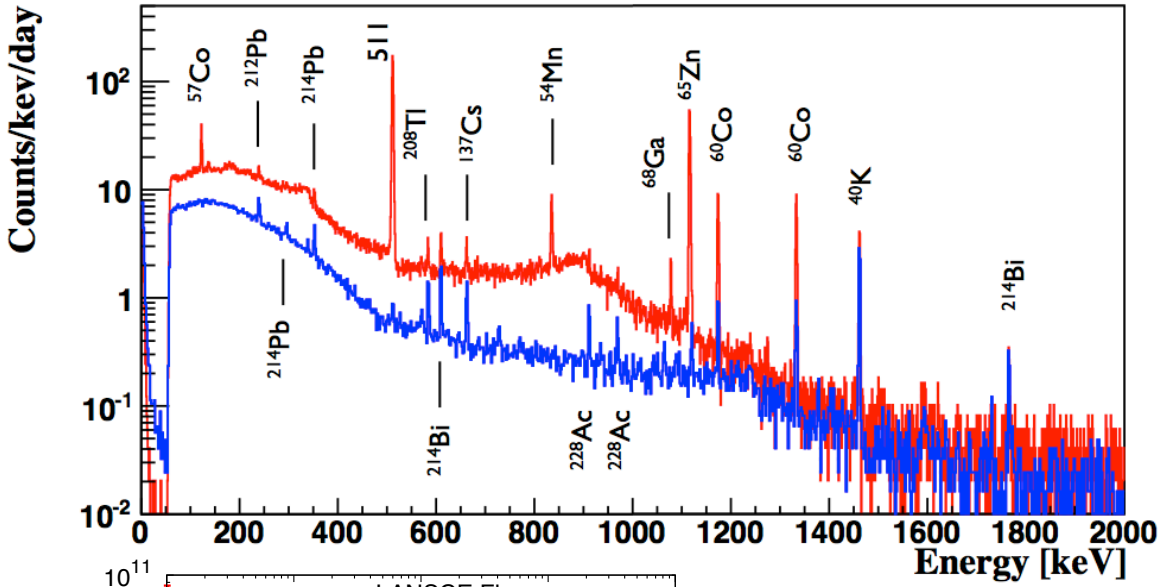
(Germanium Array for Neutron Induced Excitations)

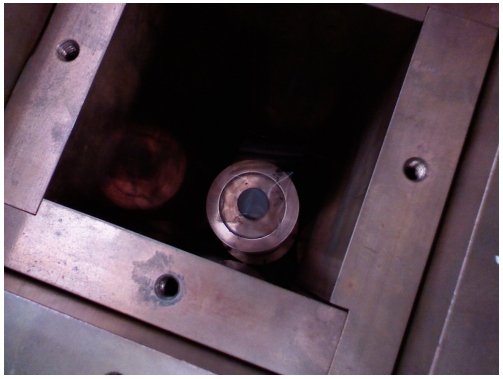


- 20 BGO suppressed HPGe detectors
  - 13 coaxial ($E_\gamma < 4$ MeV)
    - 2.2 keV at $E_\gamma$=1332 keV
    - 15 ns FWHM
  - 7 planar ($E_\gamma < 1$ MeV)
    - 0.9 keV at $E_\gamma$=122 keV
    - 10s ns FWHM

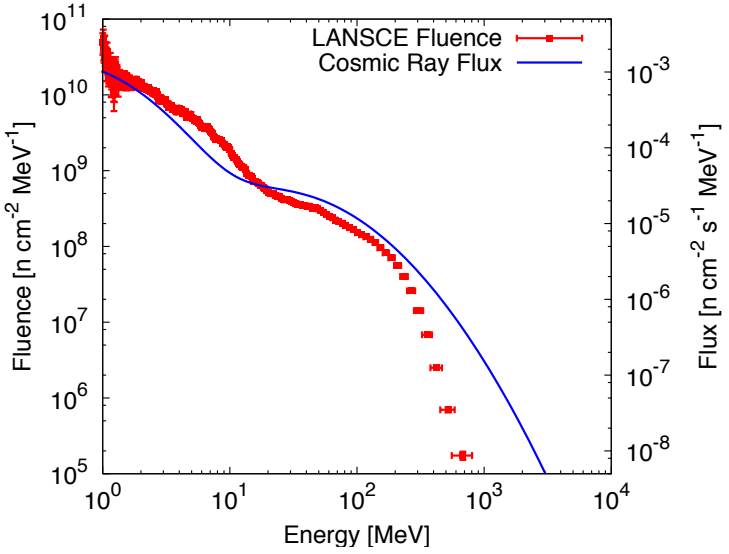


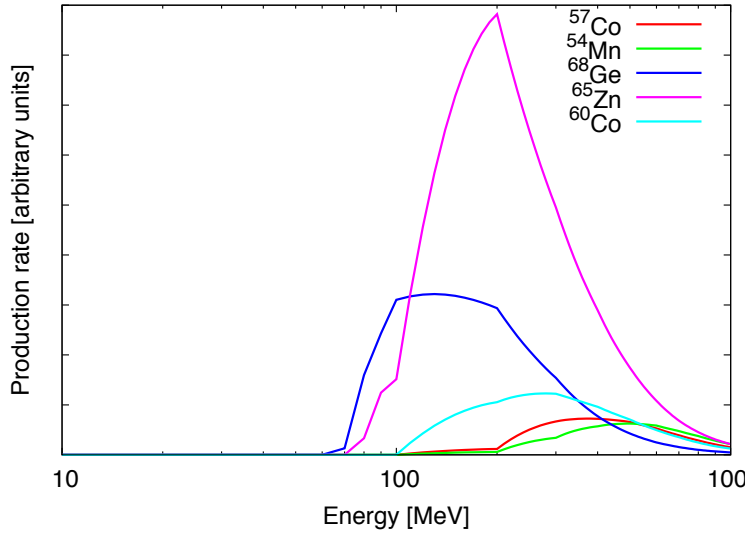
# Enriched Ge activation



Enriched Ge sample activated at GEANIE, and counted on low-background Ge detector at WIPP.



# $^{enr}$Ge Results (atoms/kg-d) (Phys Rev C **82 054610 (2010)**

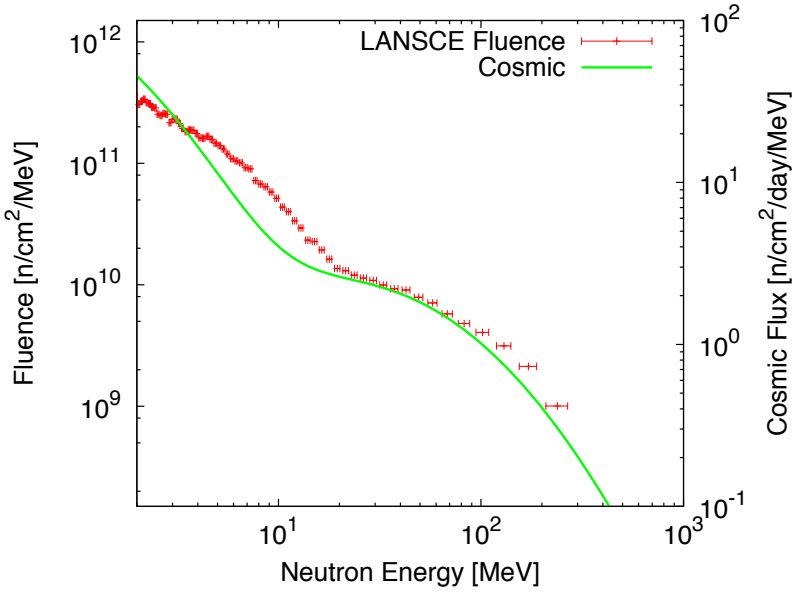
| Isotope | Ref. [14] | Ref. [15] | Ref. [22] | Ref. [20] | Ref. [16] | Ref. [23] | Ref. [21] | This work |
|---|---|---|---|---|---|---|---|---|
| $^{57}$Co | 0.1 | 1.0 | 1.6 | | 2.3 | 2.9 | 6.7 | $0.7 \pm 0.4$ |
| $^{54}$Mn | | 1.4 | 2.3 | | 5.4 | 2.2 | 0.87 | $2.0 \pm 1.0$ |
| $^{68}$Ge | 1.2 | 1.2 | | 5.7 | 13 | 7.6 | 7.2 | $2.1 \pm 0.4$ |
| $^{65}$Zn | 6.0 | 6.4 | 11.0 | | 24 | 10.4 | 20.0 | $8.9 \pm 2.5$ |
| $^{60}$Co | 3.5 | | | 3.3 | 6.7 | 2.4 | 1.6 | $2.5 \pm 1.2$ |


[14] H. S. Miley, F. Avignone, R. Brodzinski, W. Hensley, and J. Reeves, Nucl. Phys. B (Proc. Suppl.) 28A, 212 (1992).
[15] F. T. III. Avignone et al., Nucl. Phys. B (Proc. Suppl) 28A, 280 (1992).
[22] A. Balysh *et al., in Proceedings of the XXVIIth Rencontre de Moriond Progress in Atomic Physics Neutrinos and Gravitation* (Editions Frontieres, Singapore, 1992), p. 177.
[20] I. Barabanov, et al., Nucl. Instrum. Meth.B 251, 115120 (2006).
[16] S. Cebrian et al., Journal of Physics: Conference Series 39, 344346 (2006), TAUP 2005: Proc. Ninth Int. Conf. on Topics in Astroparticle and Underground Physics.
[23] J. Back and Y. Ramachers, Nucl. Instrum. Meth. A 586, 286 (2008).
[21] D.-M. Mei, Z.-B. Yin, and S. R. Elliott, Astropart. Phys. 31, 417420 (2009), arXiv:0903.2273

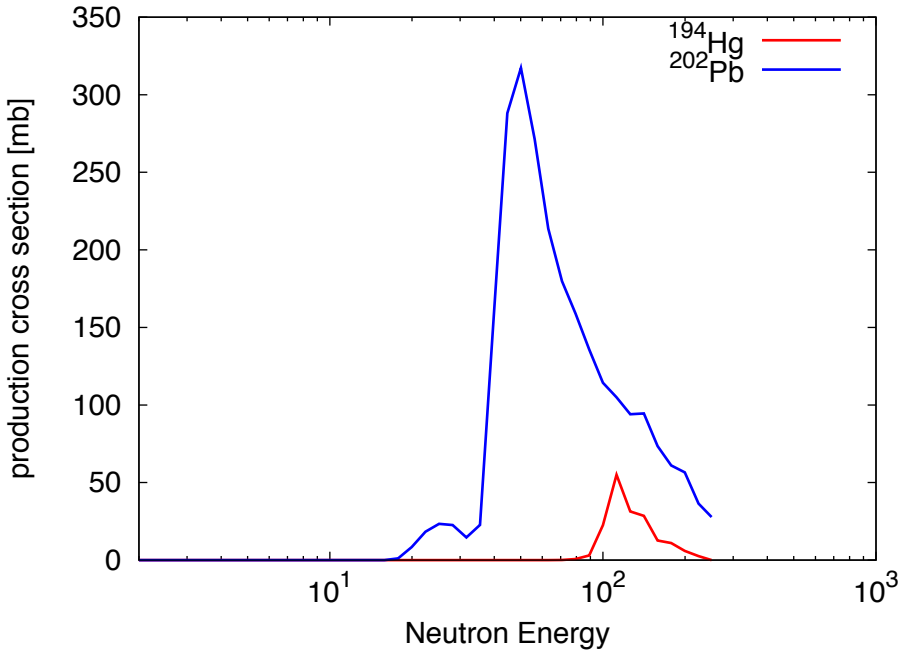
# Pb Activation

**Pb activation (presence of long-lived nuclides) previously unknown**
**Pb irradiated at 4FP60R (GEANIE) in 2003 and 2006**
**Counted on low background detector at WIPP**

## Neutron energy spectrum at LANSCE 4FP60R (GEANIE)

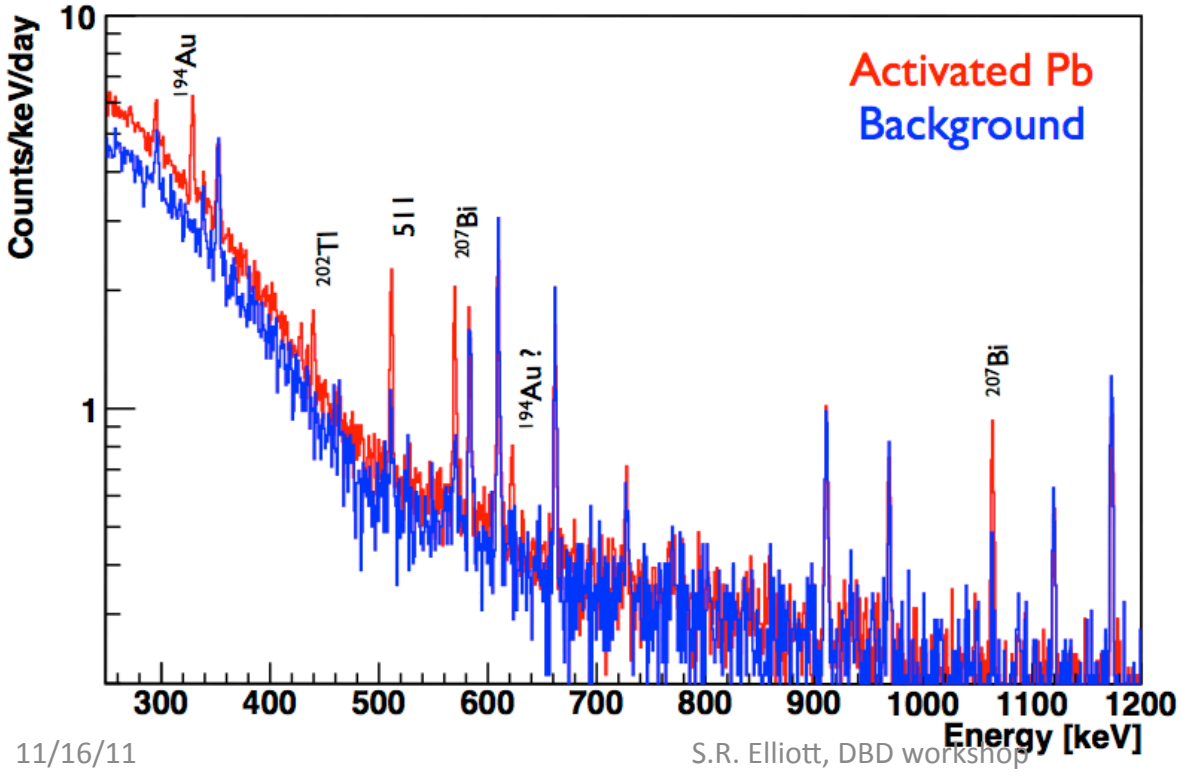



## TALYS production cross section



# Results - Preliminary

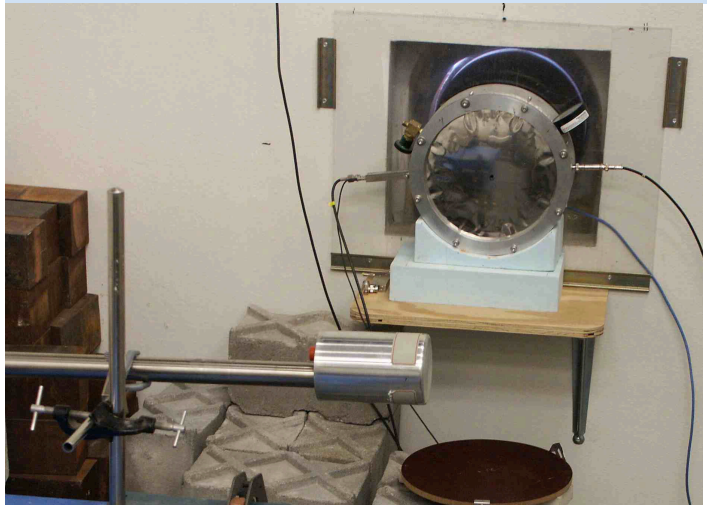
| Isotope | Meas. Rate | TALYS |
|---|---|---|
| $^{194}$Au (via $^{194}$Hg) | 7.1 ± 1.1 atoms/kg-d | 16 |
| $^{202}$Tl (via $^{201}$Pb) | 26 ± 6 | 77 |
| $^{207}$Bi | 0.14 ± 0.03 | N/A |



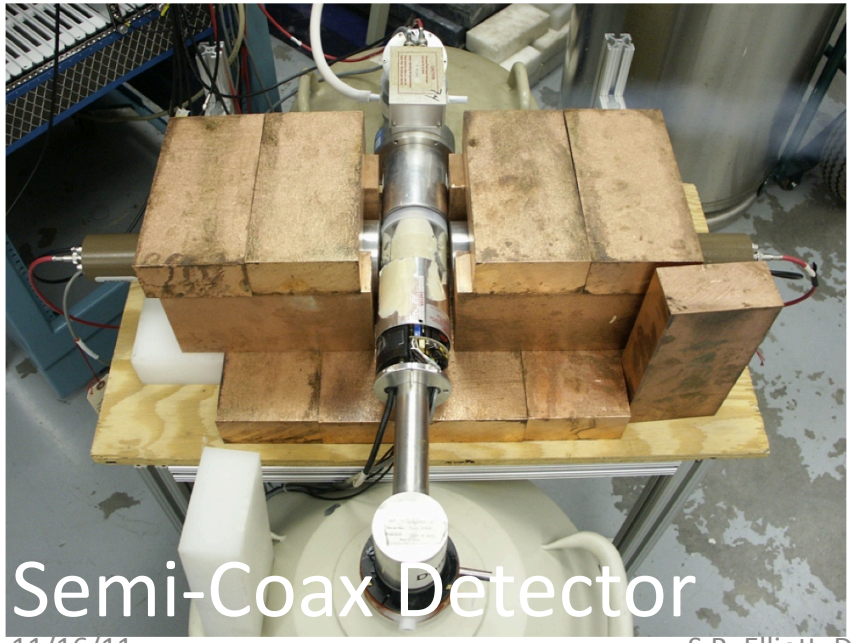

**Au and Bi both have high Q values. Could be ββ background for Ge.**

**Surface exposures of less than 35 years result in negligible background.**

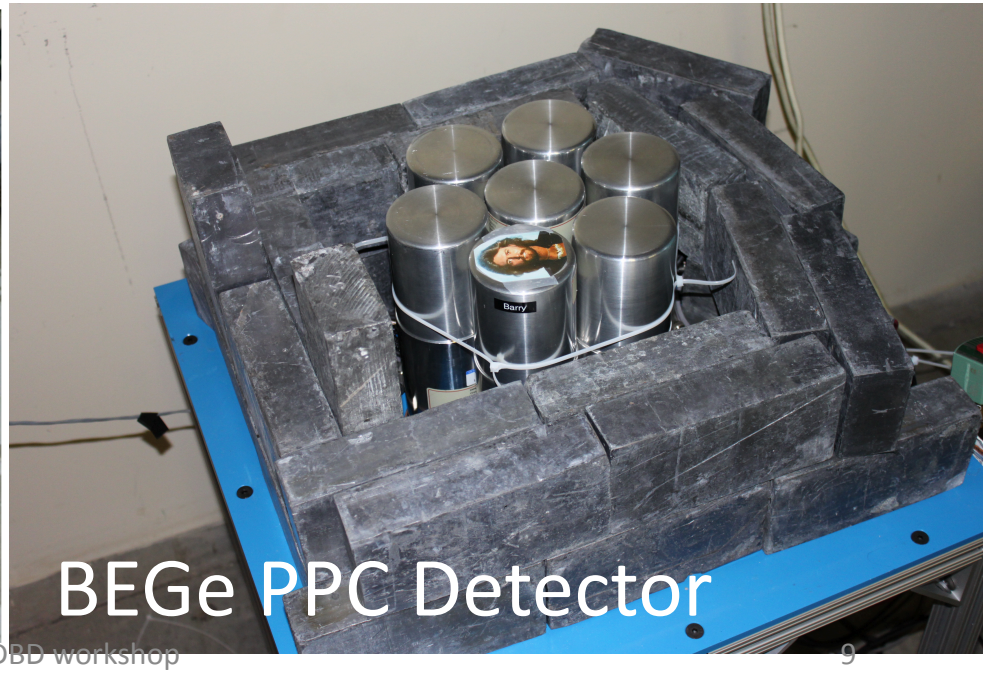
# Detector Activation



**Ice House beam similar to cosmic ray spectrum. Produces cosmogenic isotopes in detector. Want to show that external calibrations acurately describe internal decays.**



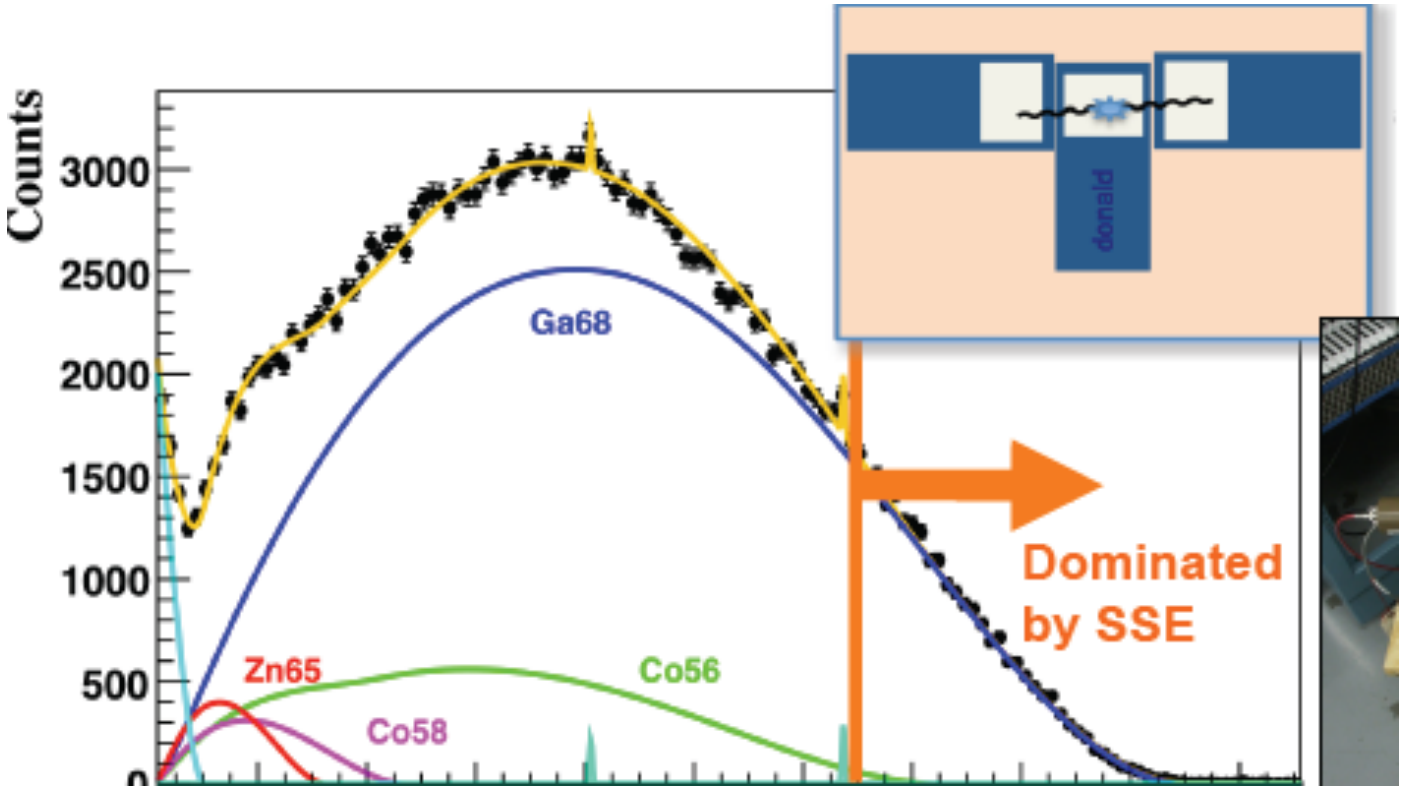
Semi-Coax Detector



BEGe PPC Detector

# Single Site Events

**Identified a nearly pure sample of SSE, $\beta^+$ events in detector triple-coincidence data (tagging 511-keV annihilation gammas externally. $^{68}$Ge is critical background in Ge experiments.**

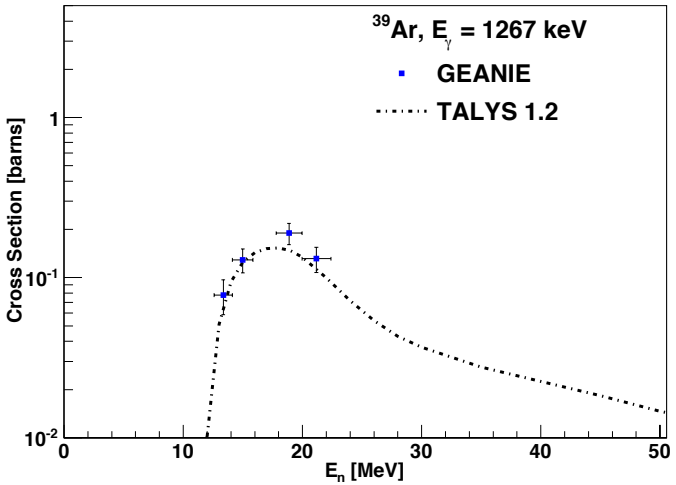


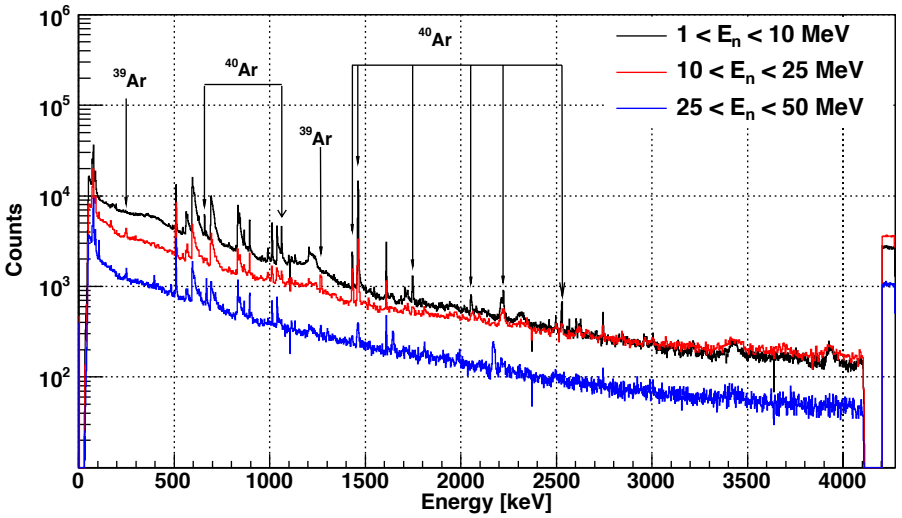
# Results

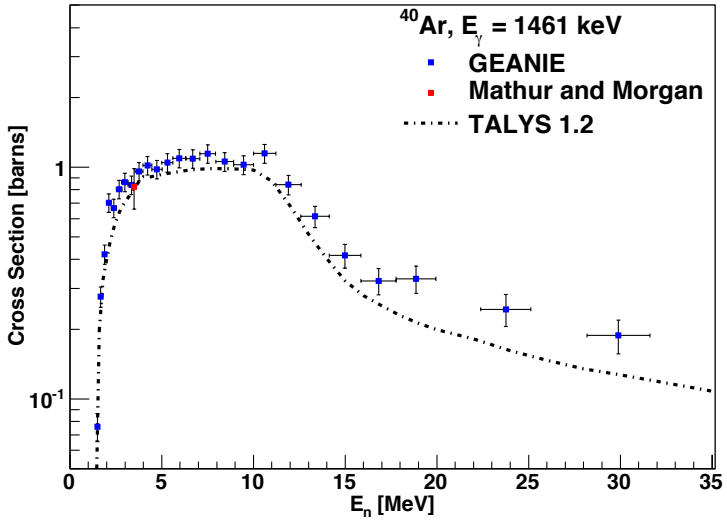
- **The Semi-coax PSA work has come to a conclusion!**
  - A systematic error of ~-15% observed in SSE survival probability compared to expectation (moment-based PSA).
  - Attributable to bias in DEP event location.
  - PPC PSA methods should not be susceptible to this bias
- **About 100 days of BEGe 7-detector array data collected, more on the way.**

# Energy dependent spectra

**(n,n') reactions excite a large number of possible states in a variety of isotopes. Hence the background almost becomes a continuum. At the tonne scale with background goals of 0.1 – 1 count/ROI-tonne-year, these become a major concern.**

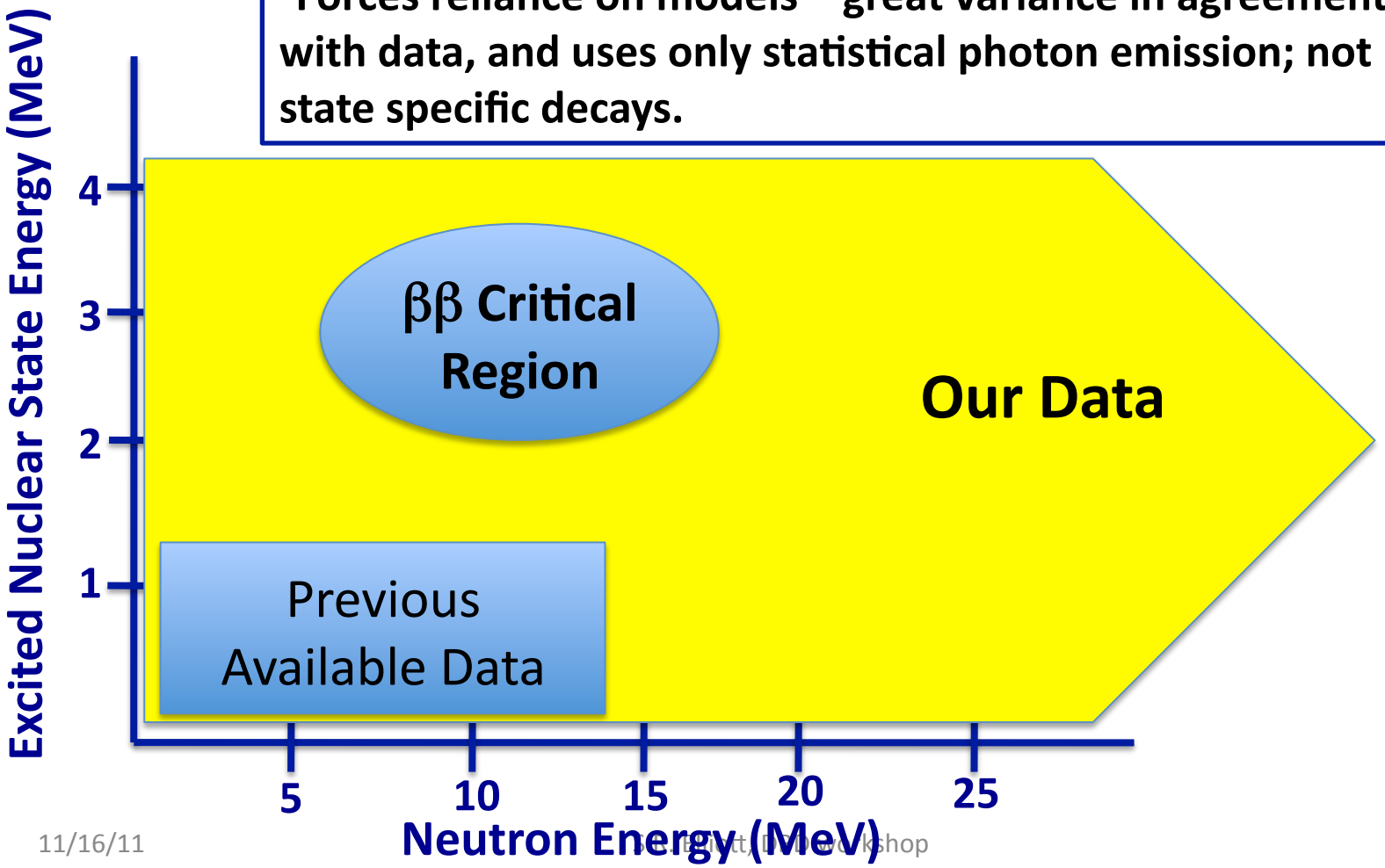


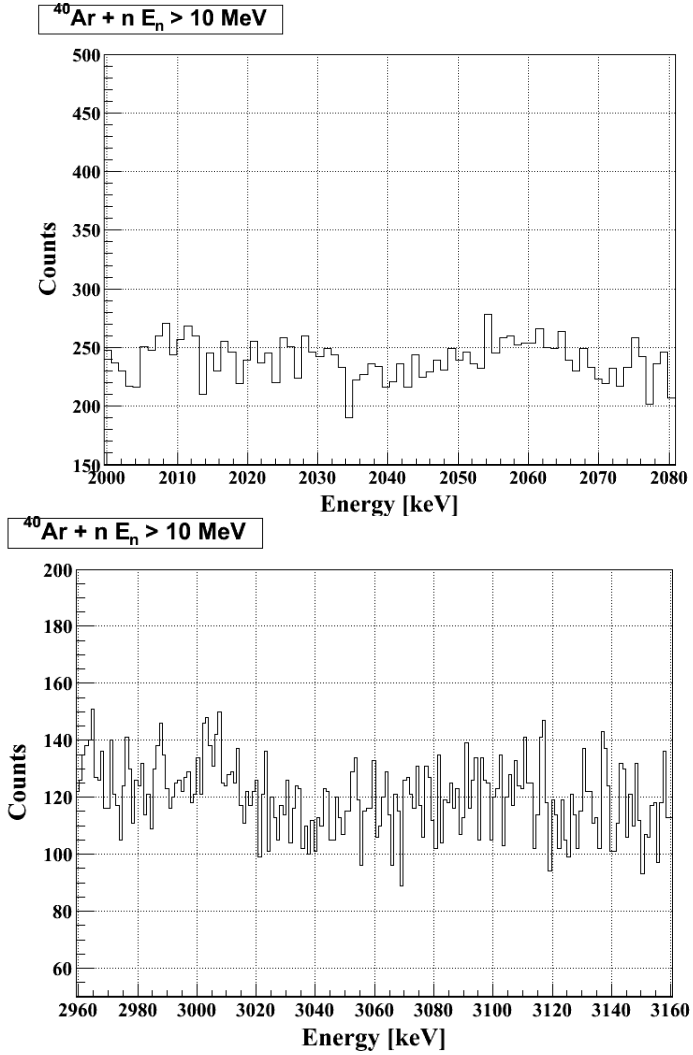



# (n,n') Program

- Few measurements in ββ critical region.
- Cross sections set to zero when no measurements available.
- Forces reliance on models – great variance in agreement with data, and uses only statistical photon emission; not state specific decays.



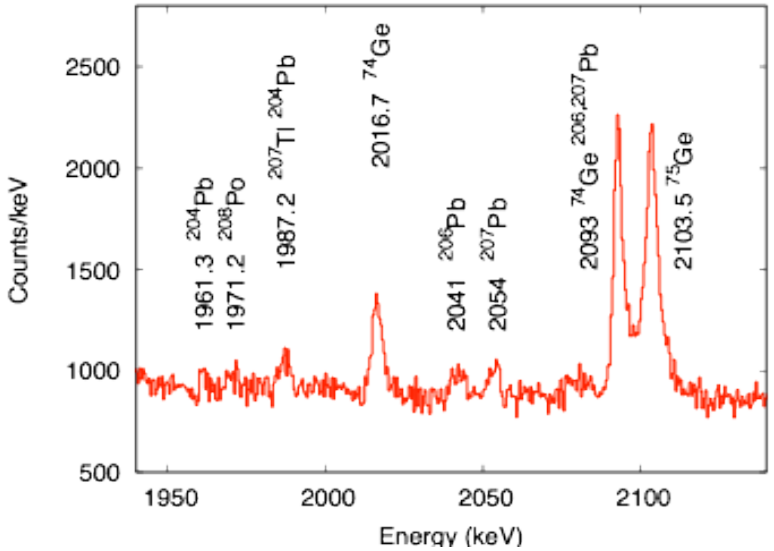
# Ar(n,n'γ) in Ge ROI

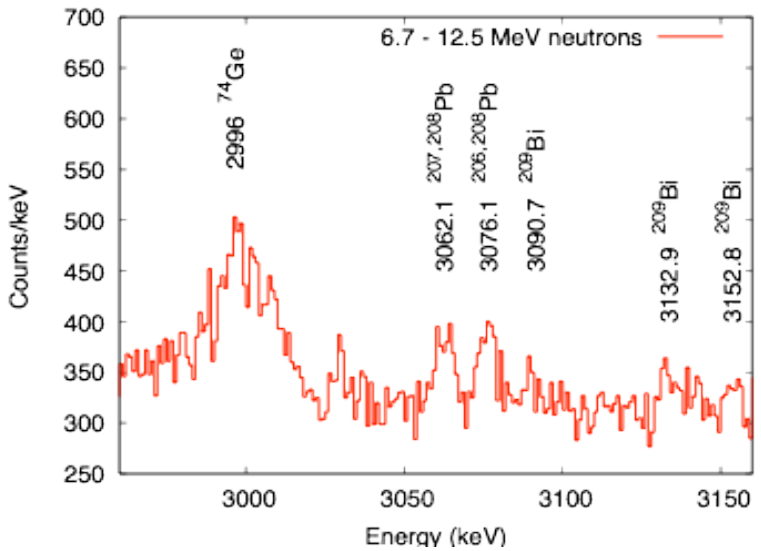



We have searched for such dangerous lines in many ββ isotopes.

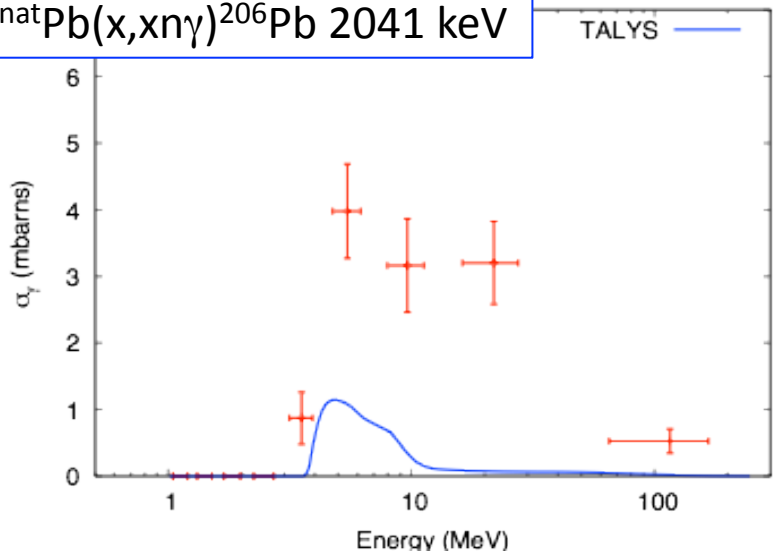
| | Cross Section [mb] | |
|---|---|---|
| $E_n$ [MeV] | $E_\gamma = 2039$ keV | $E_\gamma = 3061$ keV |
| 1.58 – 3.98 | < 0.22 | < 0.21 |
| 3.98 – 10.0 | < 1.12 | < 1.10 |
| 10.0 – 25.1 | < 4.09 | < 4.84 |
| 25.1 – 50.0 | < 9.90 | < 11.1 |
| 50.0 – 100 | < 15.3 | < 16.3 |

# Pb(n,n'γ) Measurements

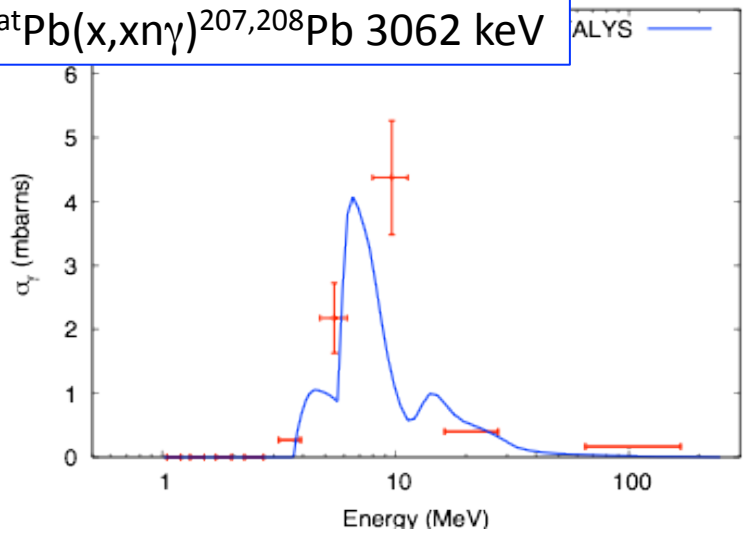



$^{nat}$Pb(x,xnγ)$^{206}$Pb 2041 keV




$^{nat}$Pb(x,xnγ)$^{207,208}$Pb 3062 keV




V.E. Guiseppe *et al. (2009) PRC* ***79, 054604***

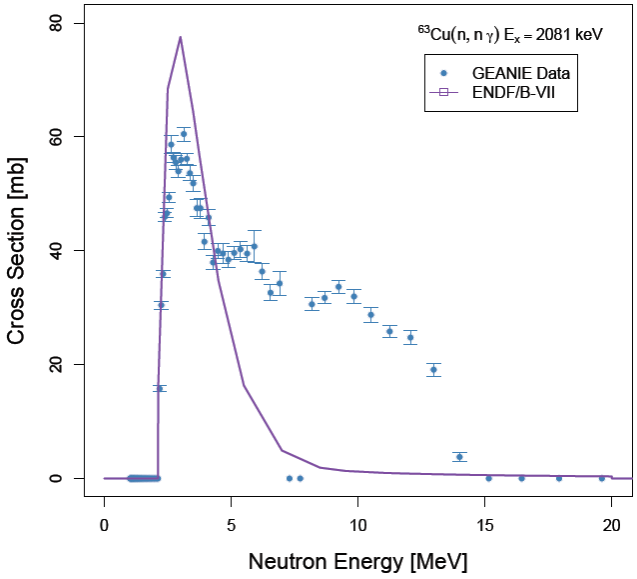
# Pb(n,n'γ) near ROI

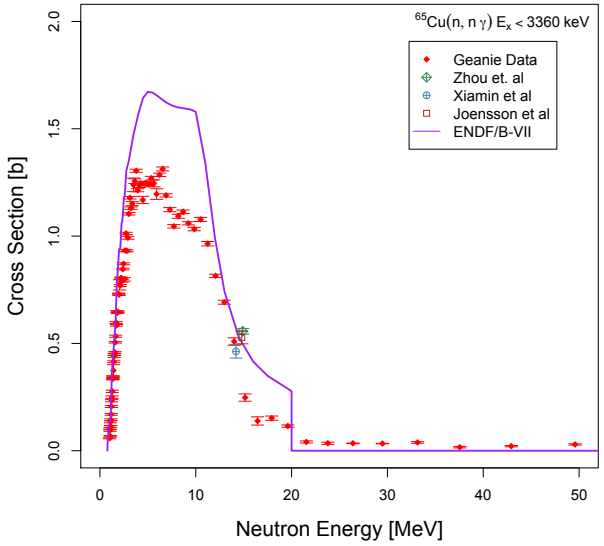
| Neutron energy (MeV) | Cross section (mb) | |
|---|---|---|
| | $^{nat}Pb(n,xn\gamma)^{206}Pb$ 2041 keV | $^{nat}Pb(n,xn\gamma)^{207,208}Pb$ 3061,3062 keV |
| 2.87–4.20 | $0.72 \pm 0.44$(stat.) $\pm$ 0.07 (syst.) | <0.3 |
| 4.20–6.72 | $4.0 \pm 0.6$ (stat.) $\pm$ 0.4 (syst.) | $3.0 \pm 0.5$ (stat.) $\pm$ 0.3 (syst.) |
| 6.72–12.50 | $3.6 \pm 0.7$ (stat.) $\pm$ 0.3 (syst.) | $3.9 \pm 0.8$ (stat.) $\pm$ 0.4 (syst.) |
| 12.50–31.15 | $3.3 \pm 0.6$ (stat.) $\pm$ 0.3 (syst.) | <0.4 |
| 31.15–200 | $0.50 \pm 0.17$ (stat.) $\pm$ 0.05 (syst.) | <0.2 |

| $\beta\beta$ isotope | $Q_{\beta\beta}$ (keV) | $\gamma$ ray | SEP | DEP |
|---|---|---|---|---|
| $^{76}$Ge | $2039.00 \pm 0.05$ | $^{206}$Pb $\sigma = 3.6 \pm 0.8$ mb | | $^{207,208}$Pb $\sigma = 3.9 \pm 0.9$ mb |
| $^{82}$Se | $2995.5 \pm 1.9$ | | | $^{208}$Pb $\sigma$ NA |
| $^{100}$Mo | $3034.40 \pm 0.17$ | $^{208}$Pb $\sigma < 0.4$ mb | $^{206}$Pb $\sigma = 2.7 \pm 0.6$ mb | $^{206}$Pb $\sigma$ NA |
| $^{116}$Cd | $2809 \pm 4$ | | $\sigma = 0.69 \pm 0.49$ mb | |
| $^{130}$Te | $2530.3 \pm 2.0$ | | $^{208}$Pb $\sigma < 0.4$ mb | |
| $^{136}$Xe | $2457.83 \pm 0.37$ | $^{206,208}$Pb $\sigma < 0.3$ mb | | |
| $^{150}$Nd | $3367.7 \pm 2.2$ | | | $^{207}$Pb $\sigma$ NA |

# Cu(n,n'γ) Measurements

Comparison of partial γ-ray production cross section for 2081-keV state in $^{63}$Cu with the ENDF/B-VII evaluation for this state. Based on this measurement, the ENDF/B-VII significantly over predicts the peak cross section. Feeding from higher-lying states are responsible for the high energy strength. The integrated cross section is 67% higher than the ENDF/B-VI evaluation. In the evaluation there are no higher lying states, and therefore feeding of this level will only be taken into account by states considered in the statistical model. This state lies in the vicinity of the $^{76}$Ge endpoint.



# Summary of Measurements

- Pb(n,n'$\gamma$) - published
- Cu(n,n'$\gamma$) – Paper just about ready
- CZT(n,n'$\gamma$) – still in analysis
- $^{enr}$Ge(n,n'$\gamma$) – still in analysis
- Ar(n,n'$\gamma$) – Paper just about ready
- Ne(n,n'$\gamma$) - proposed for this year
- $^{enr}$Ge(n,X)$^{68}$Ge, Cosmogenic activation - published
- Pb(n,X)A, Cosmogenic activation – Paper just about ready
- Zn,Nb,Zr,Cd(n,X)A, Cosmogenic activation – measurements in progress
- $^{nat}$Ge[HPGe](n,X)$^{68}$Ge, Cosmogenic activation
  - Semi coax – Paper just about ready
  - BEGe - measurements in progress

# Collaborators

- **$^{enr}$Ge(n,X)**: S.R. Elliott, V.E. Guiseppe, B. LaRoque, R. Johnson, S. Mashnik
- Pb(n,X): V.E. Guiseppe, S.R. Elliott, N. Fields, D. Hixon
- Activated Detectors: D. Steele, S.R. Elliott, V.M. Gehman, V.E. Guiseppe
- Ar(n,n'$\gamma$): S. MacMullin, M. Boswell, S. Elliott, V. Guiseppe, R. Henning, B. LaRoque, M. Devlin, N. Fotiades, R. Nelson, J O'Donnell
- Pb(n,n'$\gamma$): V. E. Guiseppe, M. Devlin, S. R. Elliott, N. Fotiades, A. Hime, D.-M. Mei, R. O. Nelson, D. V. Perepelitsa
- Cu(n,n'$\gamma$): M.S. Boswell, S.R. Elliott, D.V. Perepelitsa, M. Devlin, N. Fotiades, R.O. Nelson, V.E. Guiseppe