PNNL-SA-83512

Simulations for Tracking Cosmogenic Activation in Germanium and Copper

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November 2011

AARM S4 Meeting, Minneapolis

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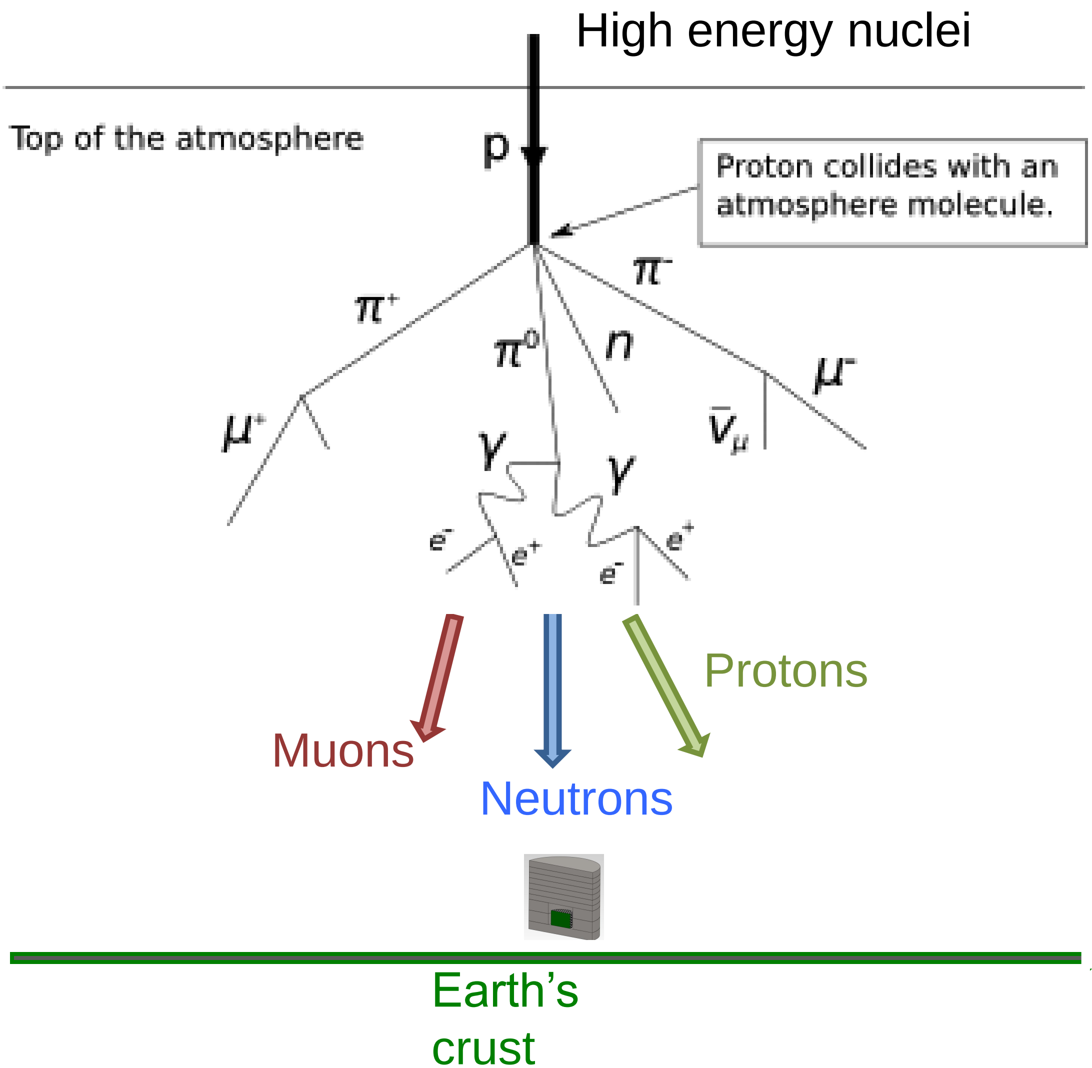
Cosmic Activation at Sea-Level



Big questions:

- What is the production rate of Ge77, Ge68, Ga68, Co60 (in germanium and copper)?
- What is the best shield to attenuate this production?
- How can we estimate the amount of these isotopes in the detector material?
- With what level of accuracy?

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Previous Work

- Neutrons mostly responsible for activation
- Calculated production rates in germanium
  - Avignone et al. [Nuclear Physics B 28A (1992)]
    - ISABEL simulated cross sections
    - Hess [Phys. Rev. Let. 116, 1959] neutron spectrum
  - Baravanov et al. [NIM B 251 pp 115-120 (2006)]
    - SHIELD code (2-6 times > ISABEL) simulated cross sections
    - Ziegler [NIM 191, 1981] neutron spectrum
- Measured production rate by members of the collaboration
  - Avignone et al. [Nuclear Physics B 28A (1992)] (natural Ge)
  - Elliott et al. [Phys. Rev. C 82, 054610 (2010)] (enrGe in the LANCSE beam)
  - M. Marino [Ph.D. Thesis University of Washington (2010)] (natural Ge that had flown on a plane)

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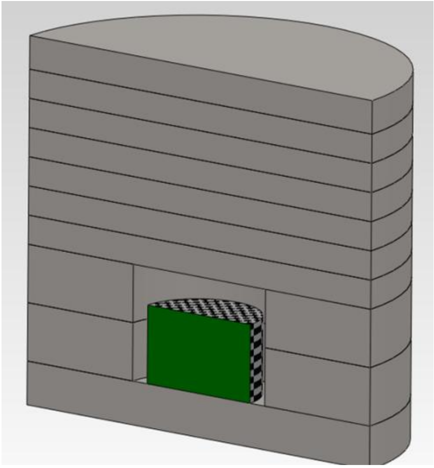
End-to-End Monte Carlo Simulation

- How does this simulation tool work?
- Number of isotopes/number of particles
  - Geant4.9.2.p01: G4NDL3.14, QSGP_BERT_HP
  - Different neutron spectra as input
- Simulated geometries
  - No shield
  - GERDA shield (14500 Kg of iron)
    - Cylindrical iron block with cavity
      - Total height: 126.5 cm
      - Diameter: 140 cm
      - Bottom thickness: 15 cm
      - Cavity height: 40 cm
      - Cavity diameter: 54 cm
    - Enriched germanium
      - Radius: 42 cm
      - Height: 27 cm
  - Enhanced shield (modified GERDA shield)



Volume: 0.037 m^3
Weight: 0.037*5323 kg/m^3 = 197 Kg
Enriched Ge composition:
- ^{76}Ge = 0.914
- ^{74}Ge = 0.086
- ^{73}Ge = 0.033
- ^{72}Ge = 0.011
- ^{70}Ge = 0.006

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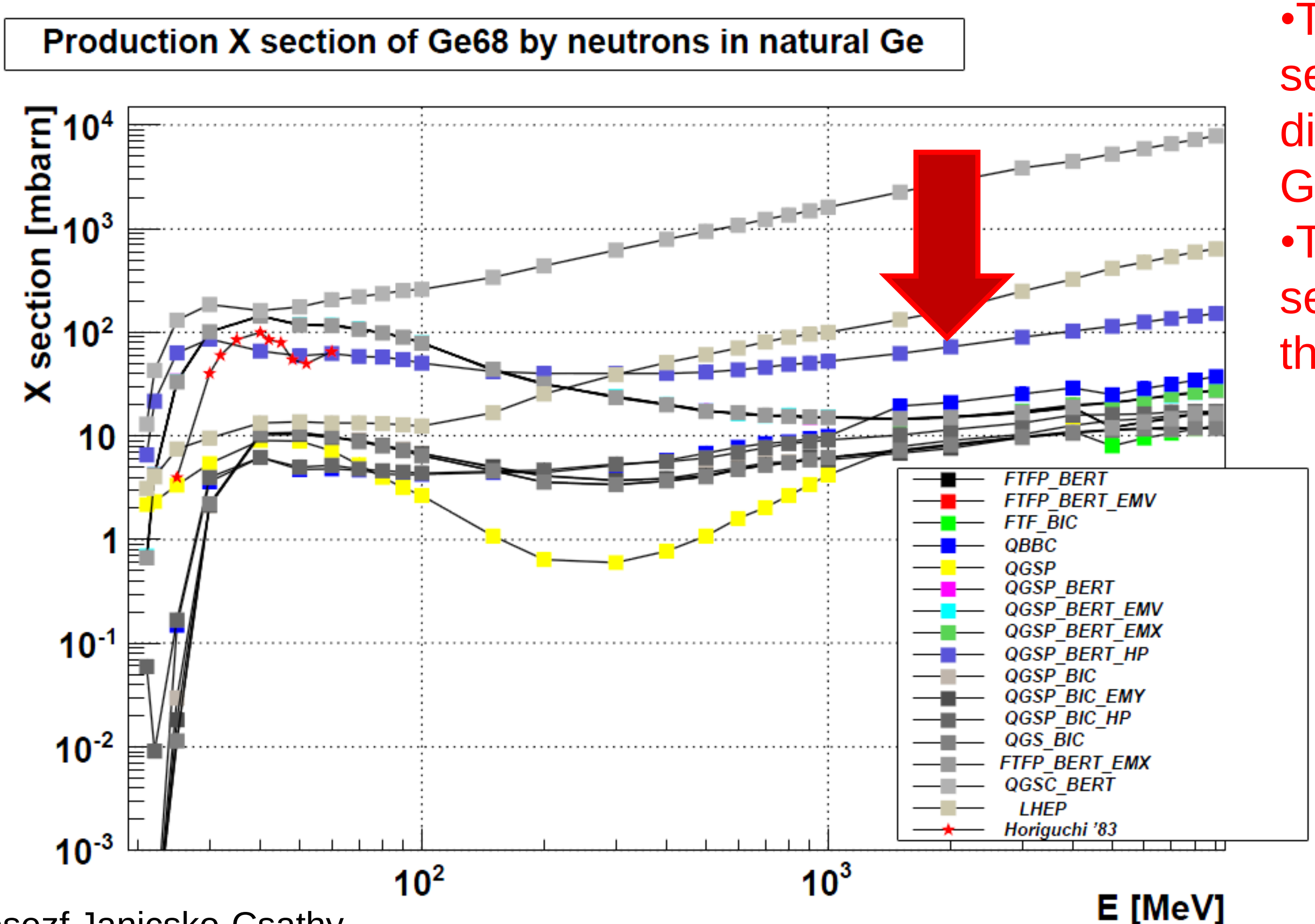
Different Physics Lists in Geant4



- Tool is very sensitive to the different knobs in Geant4!!
- The physic list selected is the one that MaGe uses

Josezf Janicsko-Csathy
GERDA scientific report GSTR-08-002
November, 2007

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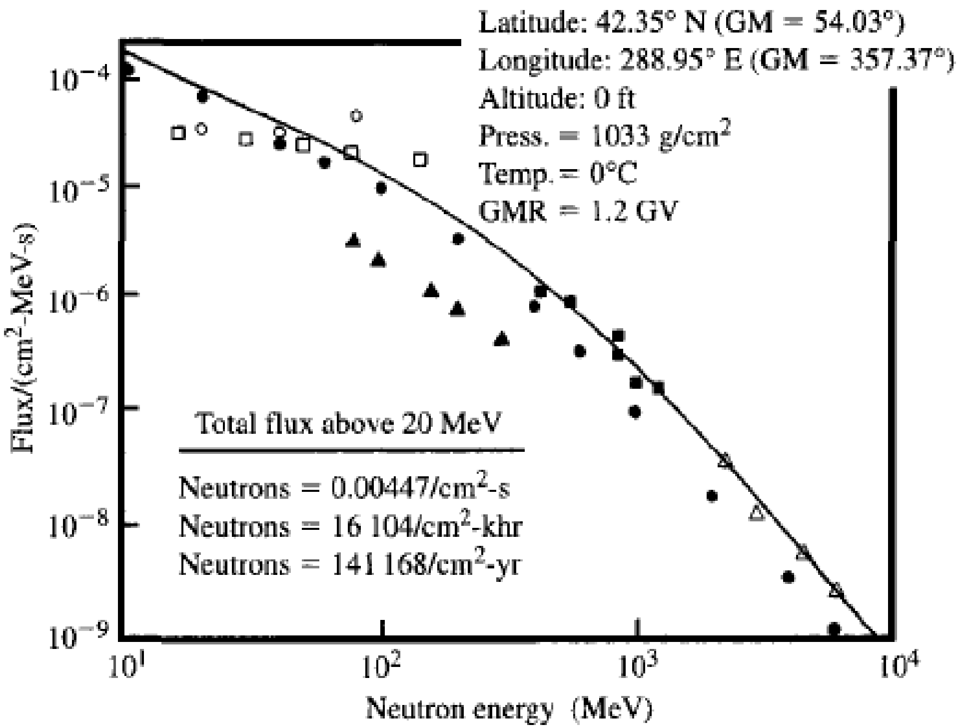
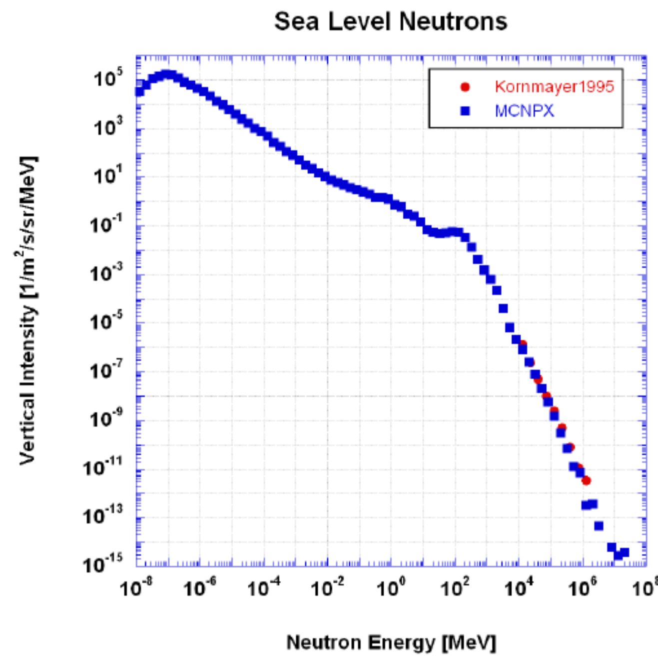
Cosmic Neutron Spectrum at Sea-Level

Fit to measured data



Terrestrial cosmic rays - J. F. Ziegler
Journal IBM Journal R&D- Special issue: terrestrial cosmic rays and soft errors archive Volume 40 Issue 1, Jan. 1996

MCNPX Simulated flux



H. Kornmayer et al., J. Phys. G: Nucl. Part. Phys. 21, 439 (1995).

Monte Carlo Simulation of Proton-induced Cosmic-ray Cascades in the Atmosphere, Chris Hagmann, David Lange, Doug Wright (LLNL) UCRL-TM-229452

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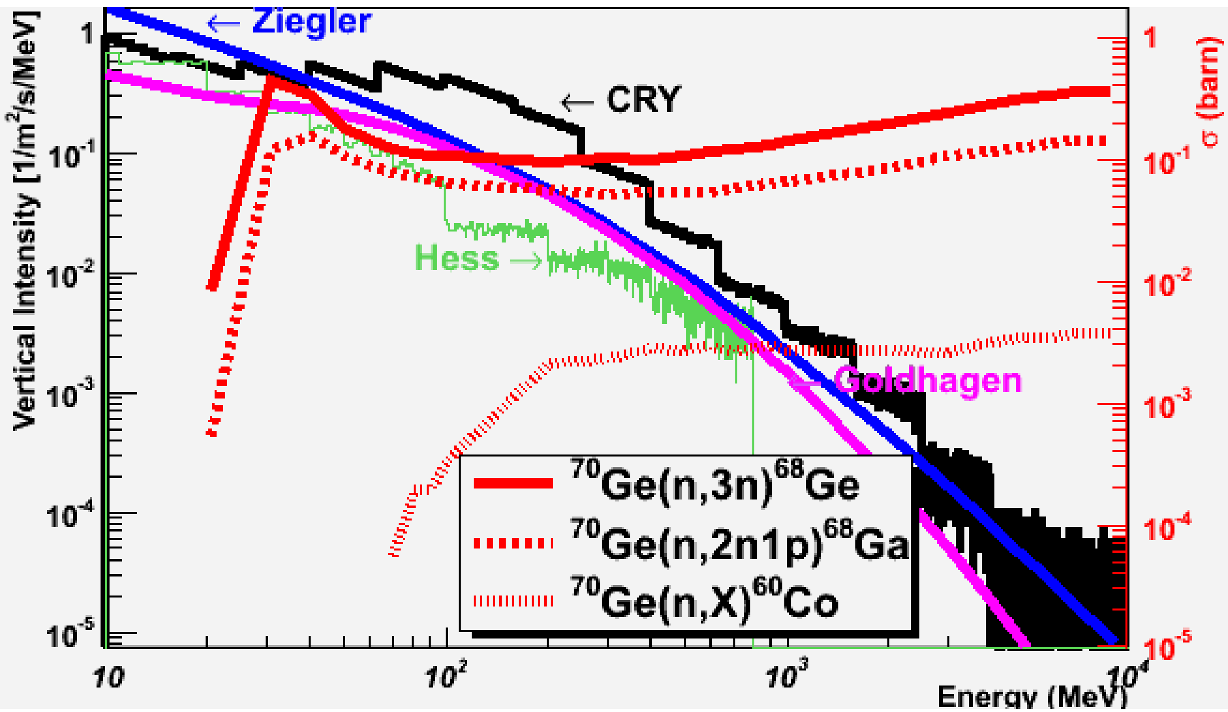
Energy range of interest

Production of isotopes in germanium of interest starts at 20MeV
Cross section peaks in the 20MeV to 100MeV energy depending on the isotope

Ziegler: No knee
CRY: knee and higher flux (shark fins due to MCNPX simulation)
Goldhagen: Shows knee but lower flux
Hess: No knee, lowest flux (only valid up to 800 MeV)



Right axis: Flux comparison from different references (Hess and CRY from actual simulation runs)
Left axis: Cross section of an example reaction of interest with lowest Q-value

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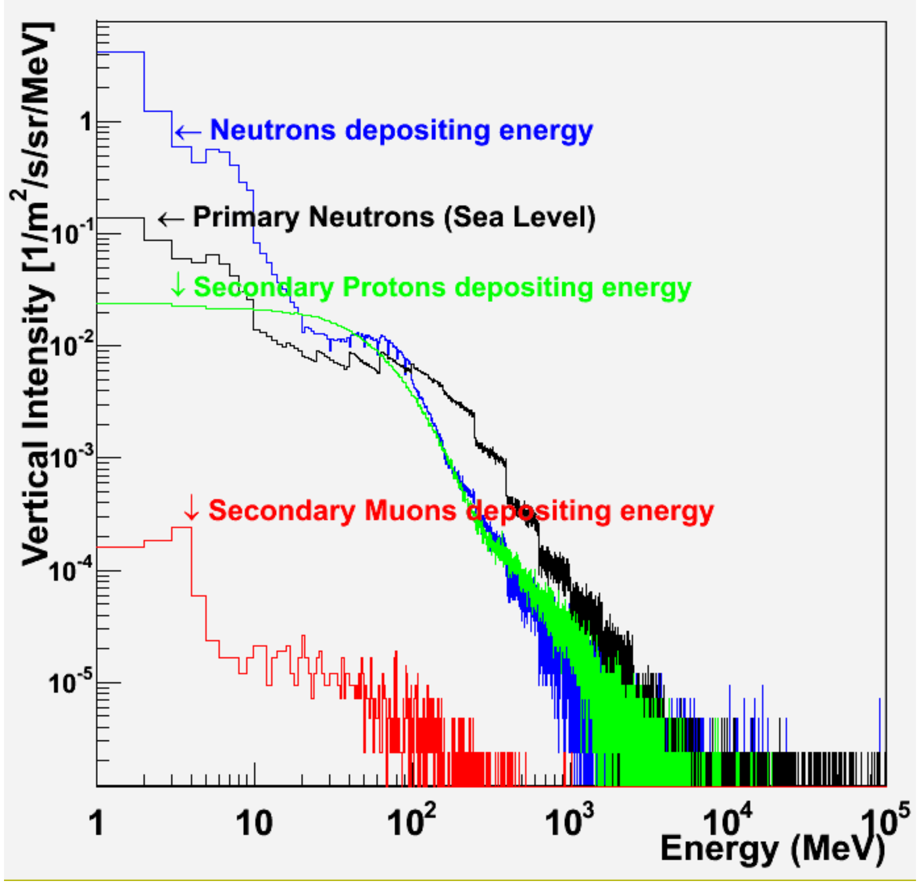
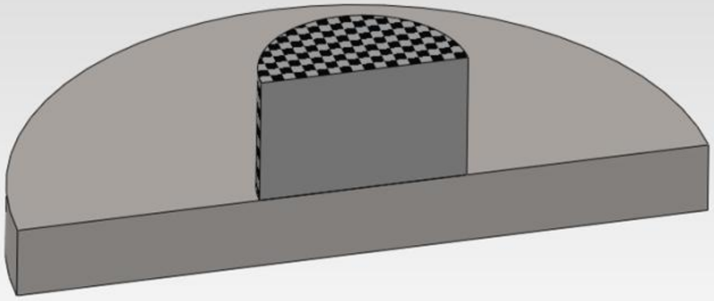
Example of a Simulation Run: No shield + CRY

- Input particle: Neutron
- Particles simulated: 10^6
- Source surface: $1m^2$
- Equivalent real time: 0.48 days
- Enriched Germanium target
- Plotted energy is energy deposited



Simulated geometry



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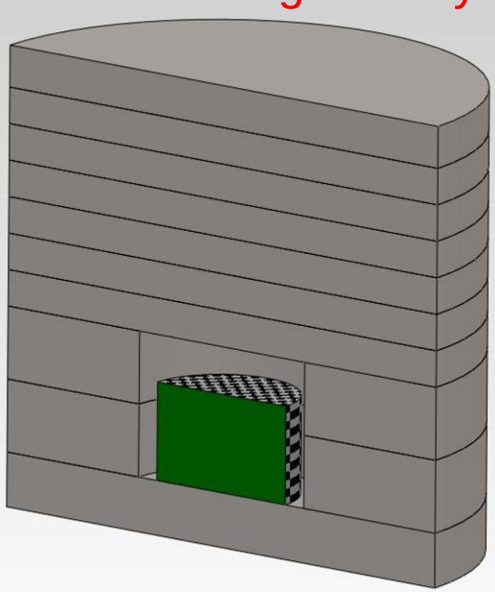
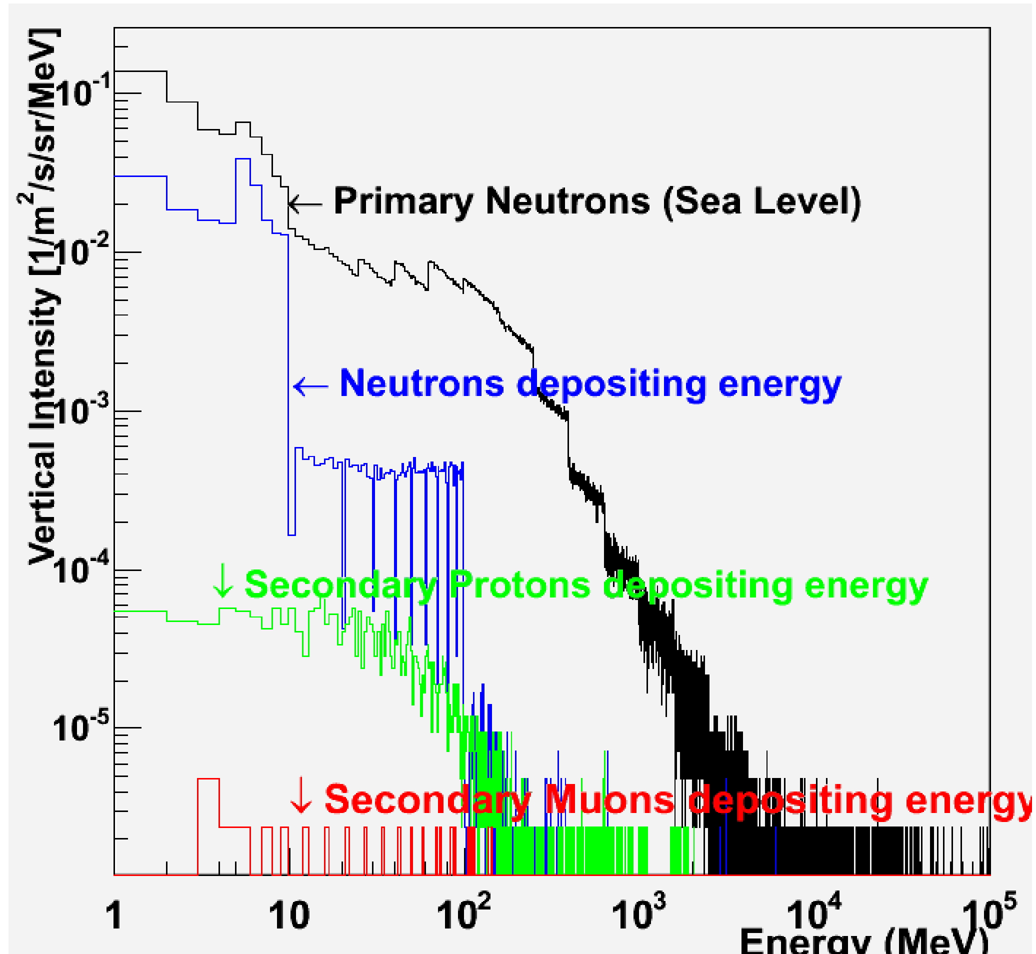
Example of a Simulation Run: CRY + Shield

- Particles simulated: 10^7
- Input particle: Neutron
- Source surface: 1 m^2
- Equivalent real time: 4.8 days

Drop offs at 10 MeV and 100 MeV of unknown origin, more testing on the tool is required

Simulated geometry





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Production Rates in enriched Ge

	Normalization	^{68}Ge (atoms/day*kg)	^{60}Co (atoms/day*kg)
Geant4.9.2.p01	CRY	56.9 ± 0.4	1.02 ± 0.09
Geant4.9.2.p01	Hess	4.9 ± 0.2	0.018 ± 0.008
Avignone et al.	Hess	0.94	-
Barabanov et al.	Ziegler	4.22 (4%)	3.31(4%)
Elliott et al.	(Exp.)	2.1 ± 0.4	2.5 ± 1.2

Simulation tool predicted production rates vary with input flux. Reported production rates do not help when trying to understand what the tool is doing.

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Improved Movable Shield Design

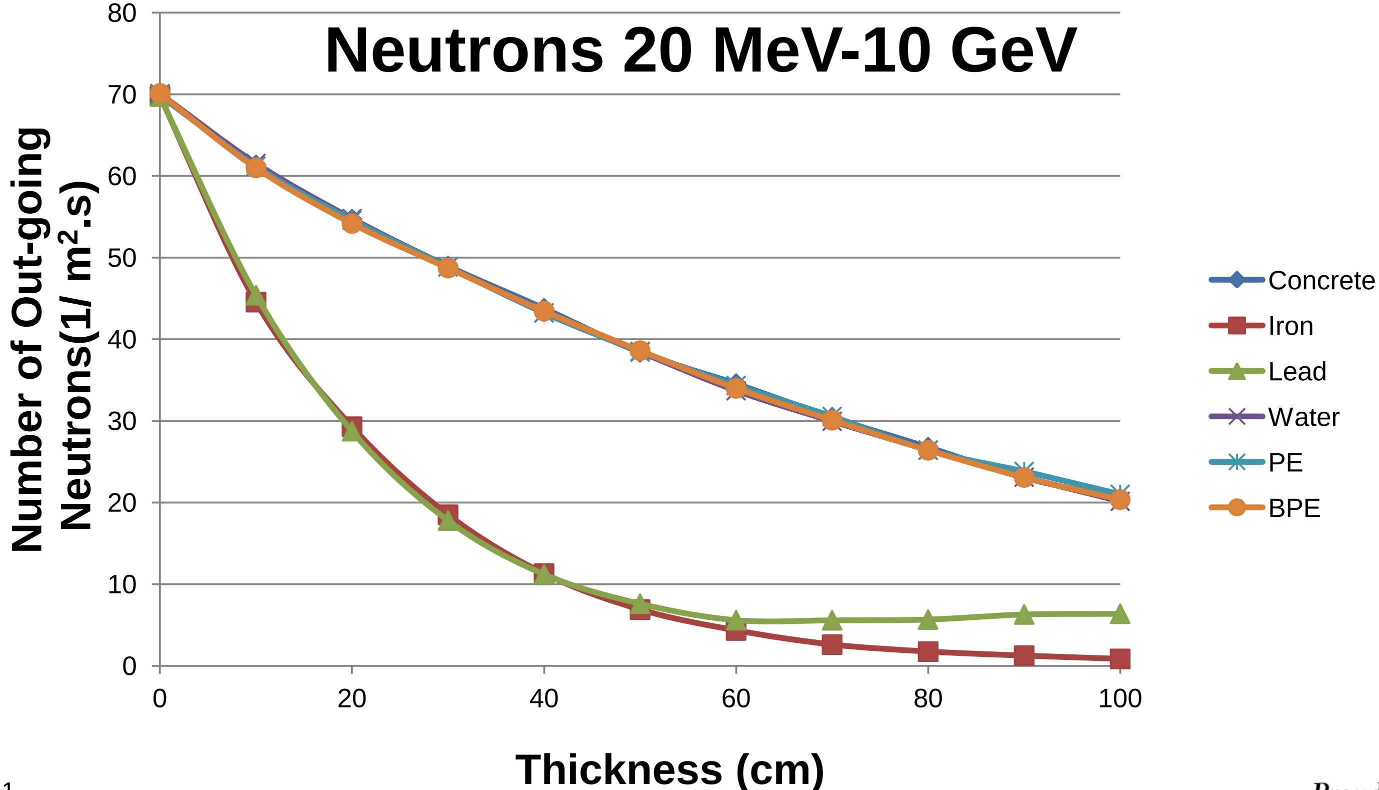
Is neutron attenuation at high energy being model correctly in Geant4?

Simple problem: stuffing material for the GERDA movable shield, limited by the size of the transport container

Approach: Evaluate different materials with thicknesses that fit the container

Result: Iron best shielding material, in agreement with Baravanov et al.

Sea-level CRY predicted cosmic neutron flux through different materials

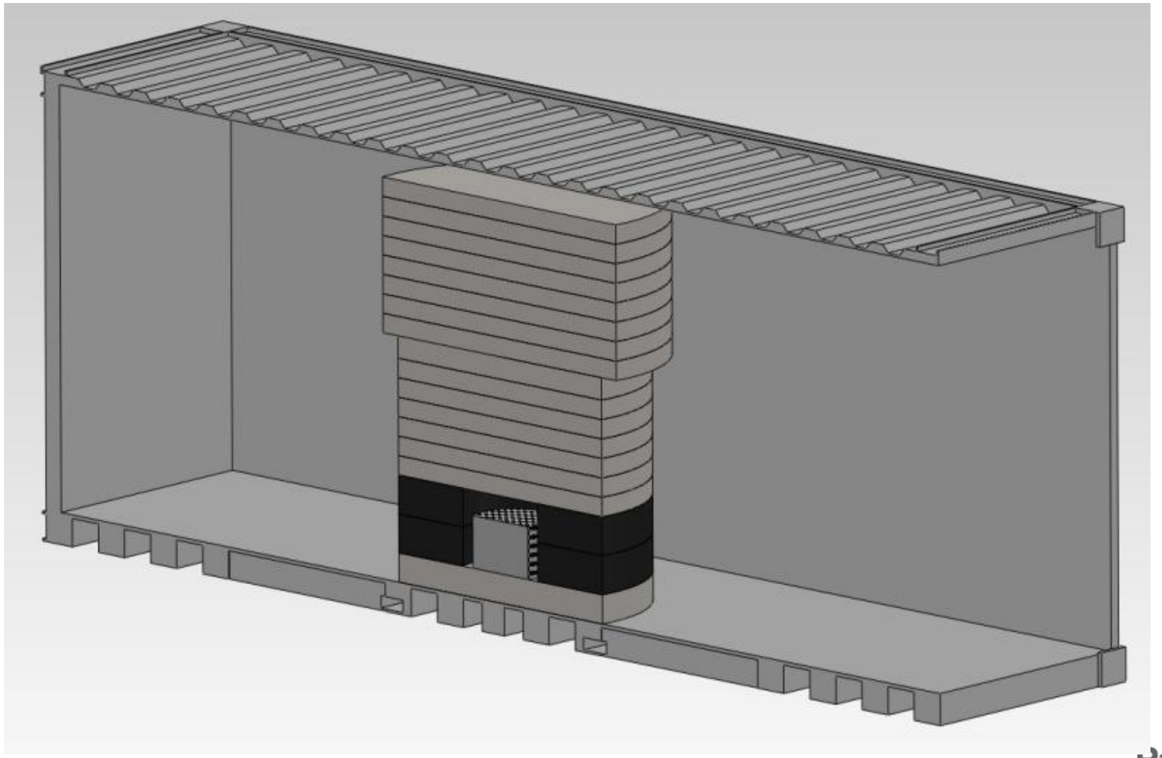


PNNL-20693 Tech report
Cosmic Ray Interactions in Shielding Materials
E Aguayo, RT Kouzes
AS Ankney, JL Orrell
TJ Berguson, MD Troy

Improved Germanium Transport Shield

- Majorana collaboration already purchased a GERDA style container
- Add on to this shield to achieve a total Weight of 29000 Kg (allowable dry freight container weight)
- Cosmic neutron angular distribution: $\cos^3\Theta$ (Ziegler et al.)

Best design: pile up the iron on top of the previous shield



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Conclusions

- Production rate calculation VERY dependent on assumed sea-level cosmic neutron spectrum
- Monte-Carlo methods presented have large uncertainties in the production rate calculations
- Additional bench mark measurements required

Future work

- Experimental measurements of cosmogenic production rates with accurately controlled exposure times and geometries
- Investigate further neutron attenuation in G4
- Try new Shielding physics list in G4
- Port CRY event generator, shielding geometry into MaGe
- Evaluate best estimate of activation rates for our materials with their exposure histories inside of our shields

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The MAJORANA Collaboration (Feb. 2011)

Note: Red text indicates students

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