Neutron Background Simulations for LEGEND-1000 in a Geant4-based Framework

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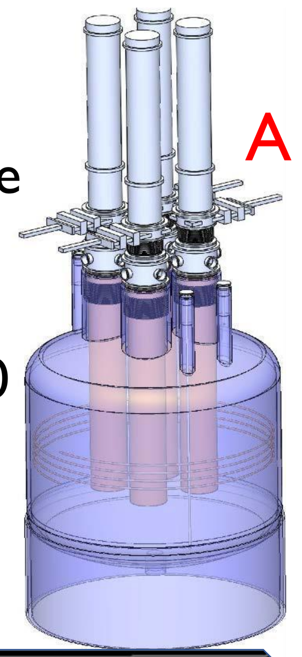
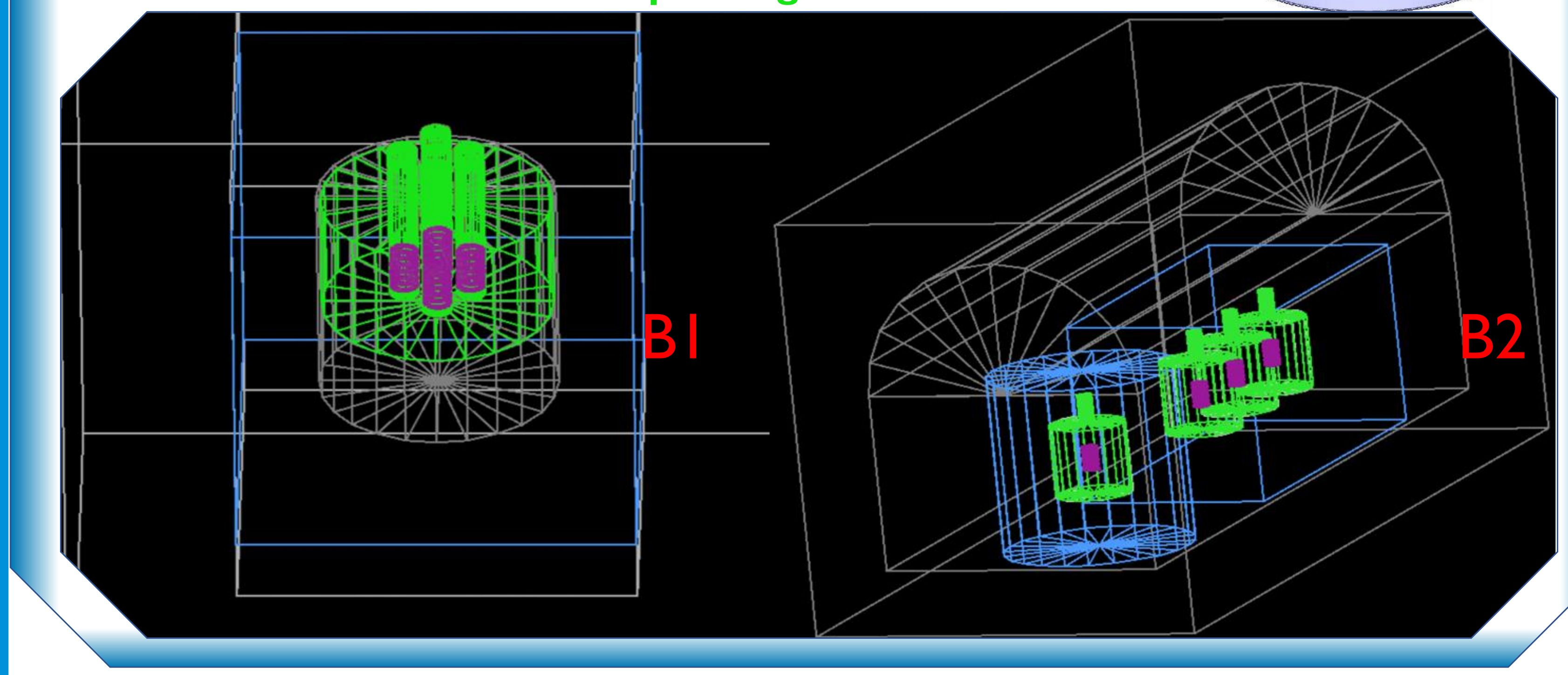
LEGEND (Large Enriched Germanium Experiment for Neutrinoless Double-Beta Decay) is a next-generation project searching for neutrinoless double-beta decay (NLDBD) in ^{76}Ge. The second phase, LEGEND-1000, will require a background rate lower than has ever been achieved in an NLDBD search. A potential source of background is radioactive decay of isotopes created via neutron capture. A simulation campaign is underway to understand the production and interactions of neutrons in baseline designs for LEGEND-1000, and to estimate the effect of various neutron shielding options on this background.

Simulation setup

- Particle simulation in custom Geant4 10.02.02 module
- Event reconstruction and analysis in ROOT/C++
- Exchangeable geometry options for easy comparison
  - Fig B1 represents baseline design of LEGEND-1000 in simulation (see also Fig. A for CAD drawing)
  - Fig B2 is alternative multiple-tank design option



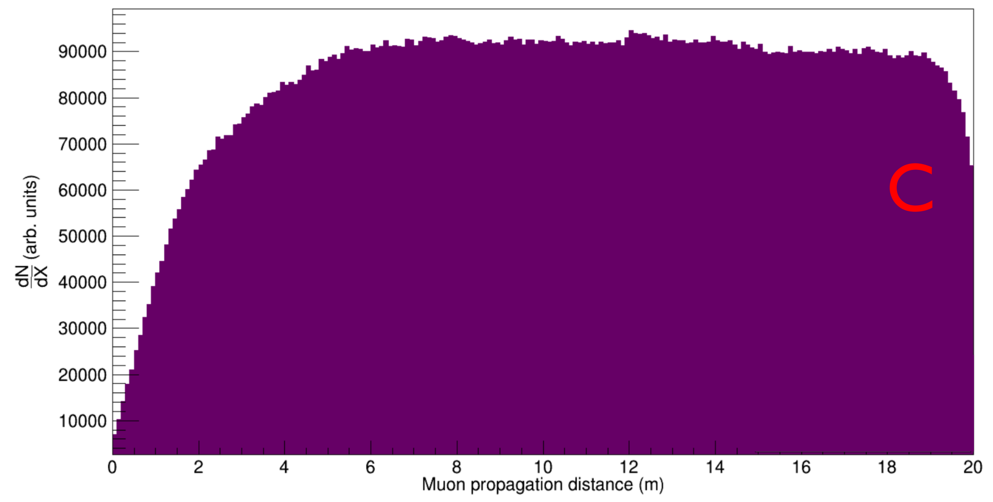
Germanium Liquid Argon Water



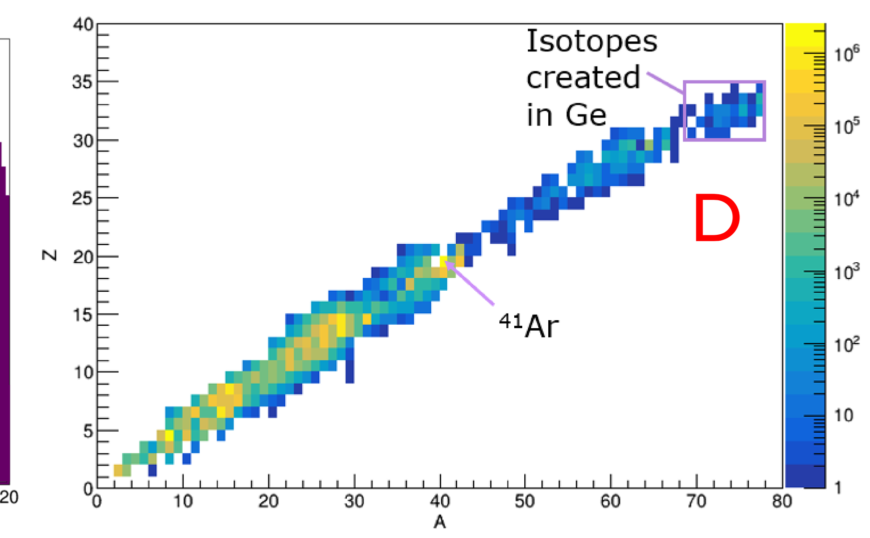
Cosmogenic neutrons

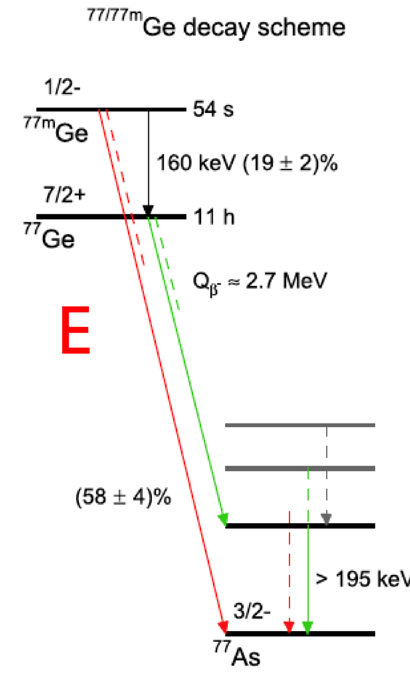
- Primarily created in hadronic component of muon showers
  - Large shielding with high Z material may lead to significant cosmogenic backgrounds
  - Shower development is complex, largely dictated by muon path length and material, as demonstrated in Fig. C
- Wide variety of isotopes generated, as shown in Fig. D
  - Few isotopes can contribute to background index in ROI for LEGEND-1000
  - Cosmogenic isotopes expected to contribute the most to background are ^{77}Ge and ^{77m}Ge, based on decay energies and mean lifetime in Fig. E
  - Mitigated by shielding, active veto, and analysis cuts
- Cosmogenic background highly dependent on host site for LEGEND-1000. SNOLAB depth is assumed for it in Fig. F

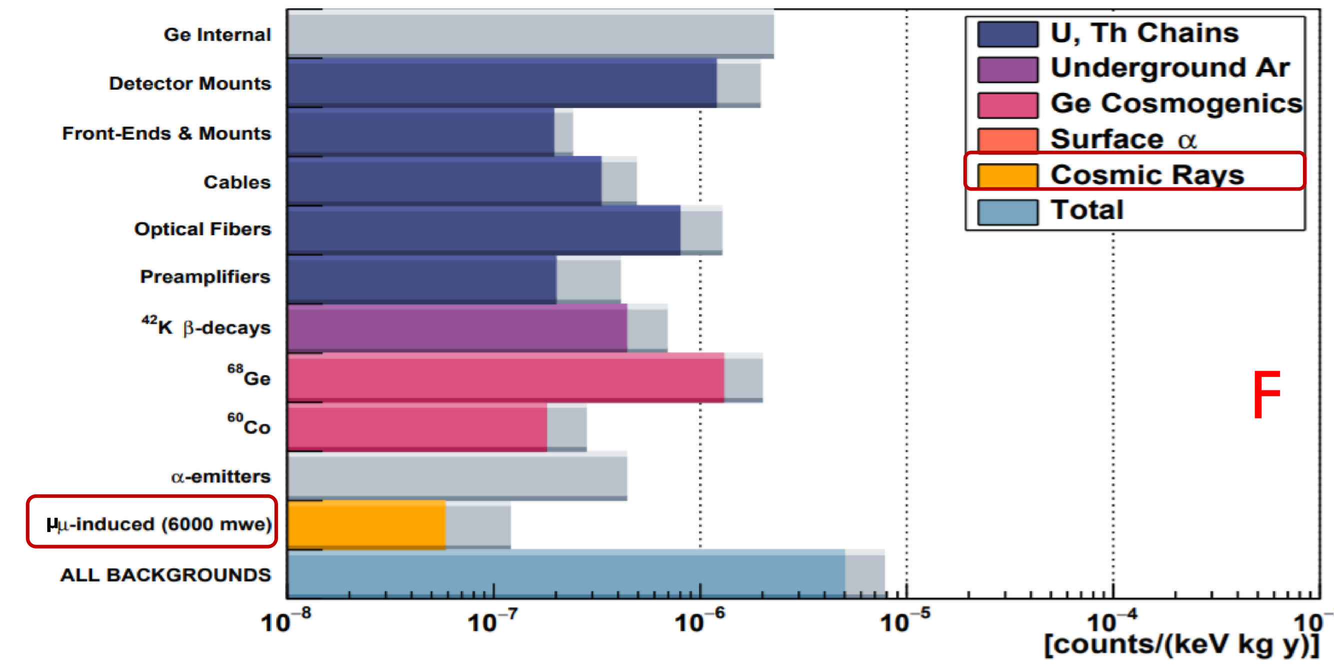
Muon-induced neutron production in pure liquid argon



A and Z numbers of nuclear isotopes generated (all materials)







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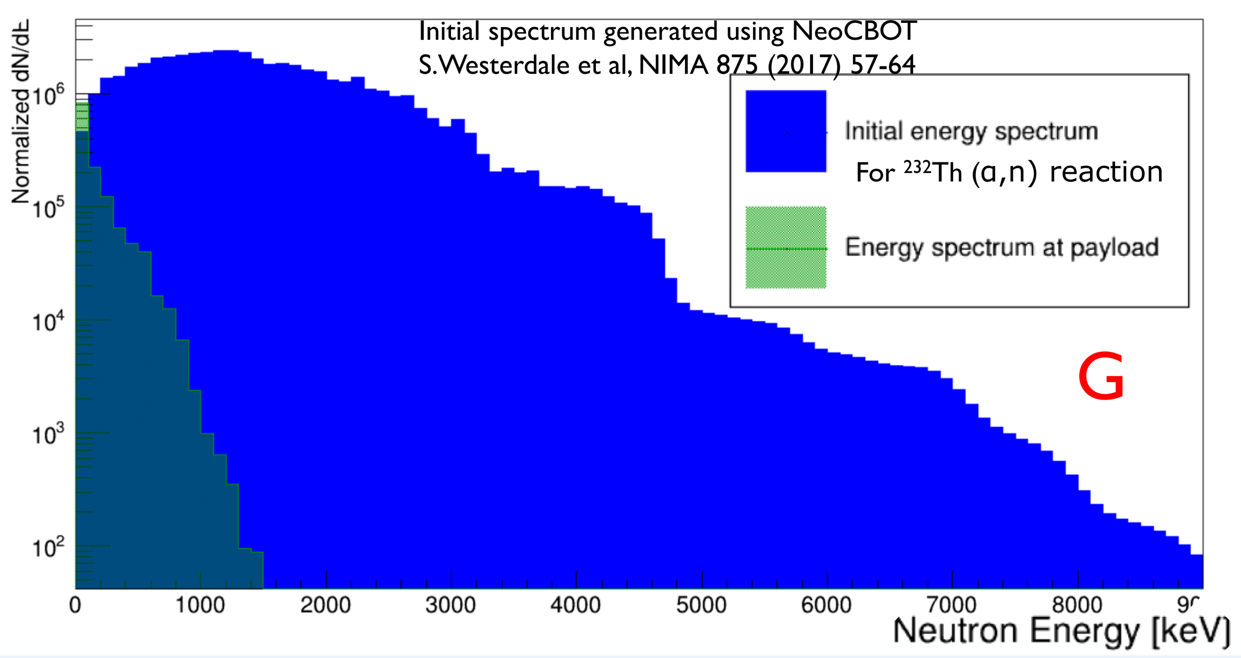
Radiogenic neutrons

- Created in fission and (α,n) reactions due to decay of heavy element impurities in the materials surrounding the detectors
- Radioassays performed for materials in baseline designs
- Simulation results (such as Fig. G) suggest this to be a subdominant source of neutron background in current baseline designs

Normalized sampling spectrum and spectrum of neutrons reaching a payload

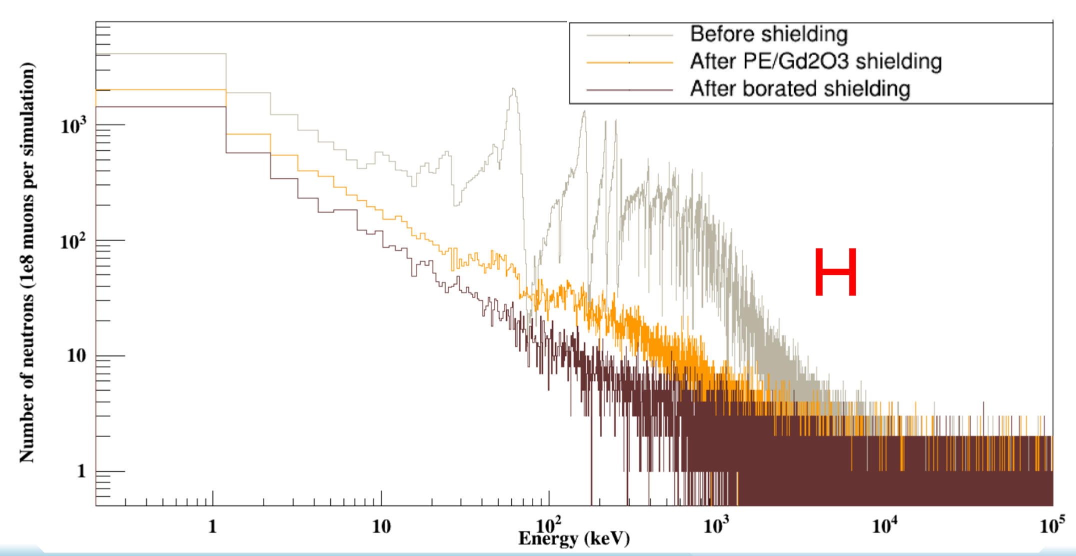


Neutron shielding options

Polyethylene (PE) shields

- 10 cm thick shields with outer radius 2m centered on detector array
  - Pure PE with 5mm gadolinium oxide inner lining, orange in Fig. H
  - PE mixed with 5% mass fraction boron (borated), brown in Fig. H
- Both options significantly reduced neutron flux on detectors
  - ^{77}Ge and ^{77m}Ge production rate roughly halved in both cases
  - Additional radiogenic neutrons, such as (α,n) neutrons from borated PE impurities, reduce shielding effectiveness

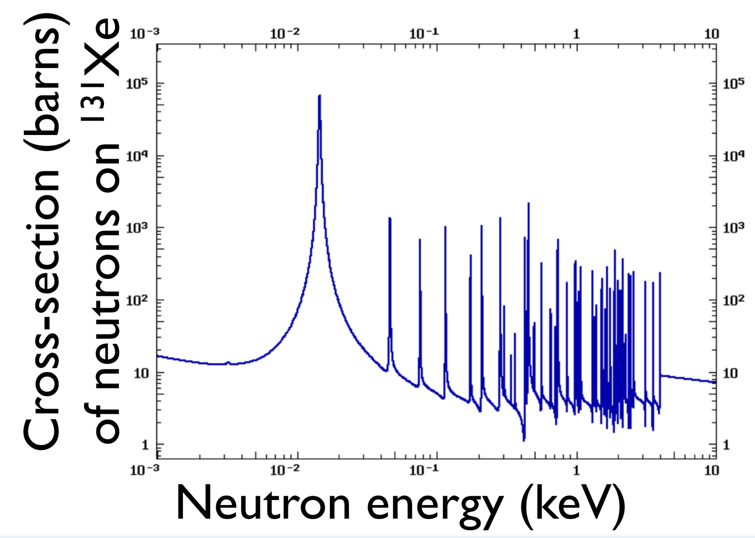
Neutron energy spectra before and after shielding options

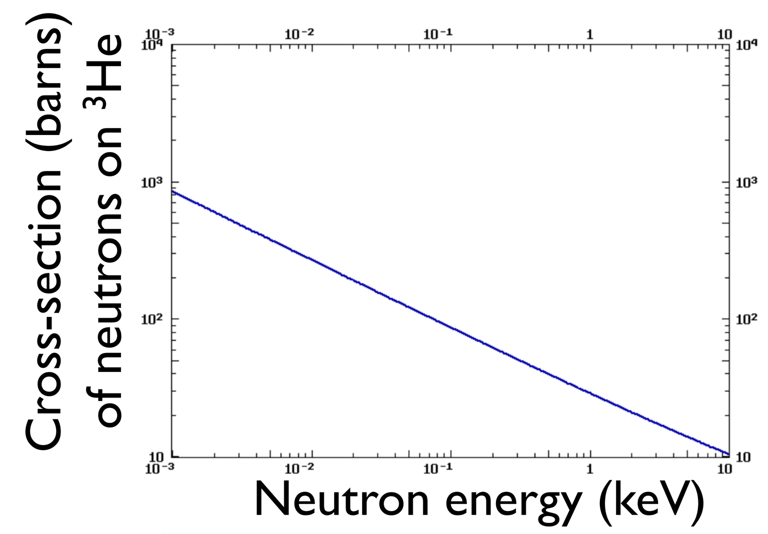


Liquid argon doping

- Isotopes added to liquid argon surrounding detectors
  - ^{131}Xe, in 100ppm and 1000 ppm quantities
  - ^{3}He, in 0.1% and 1% mass fraction
- No significant change in neutron flux for ^{131}Xe doping
- Neutrons moderated, but new neutrons created in other channels
- Initial results of ^{3}He study show significantly reduced neutron flux
- More expensive to implement in practice

ENDF neutron cross section data retrieved from www-nds.iaea.org/





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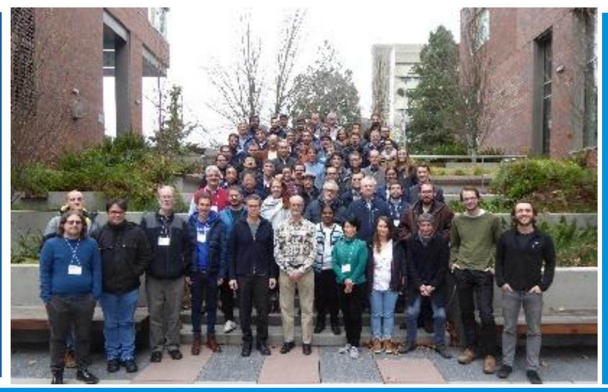

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