

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

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On behalf of the LEGEND Collaboration



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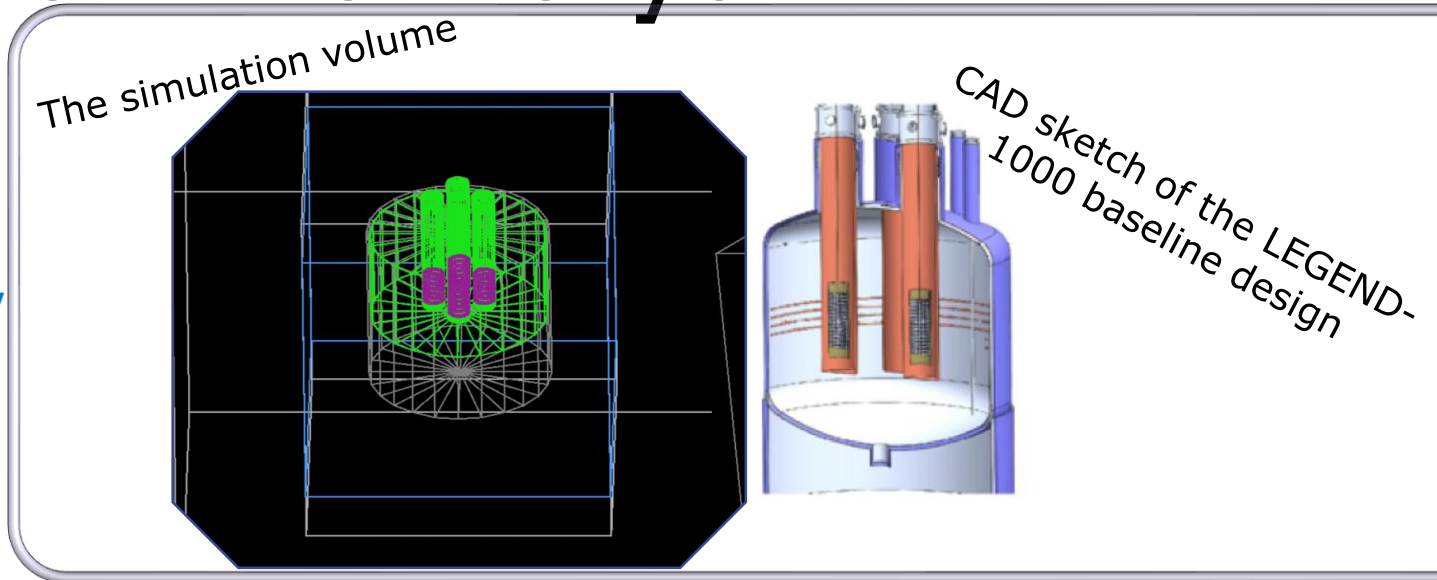
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LEGEND and Neutrons from cryostat wall

Mission statement : The LEGEND (Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay) collaboration aims to develop a phased, **Ge-76 based** double-beta decay experimental program with discovery potential at a **half-life beyond 10^{28} years**, using existing resources as appropriate to expedite physics results.



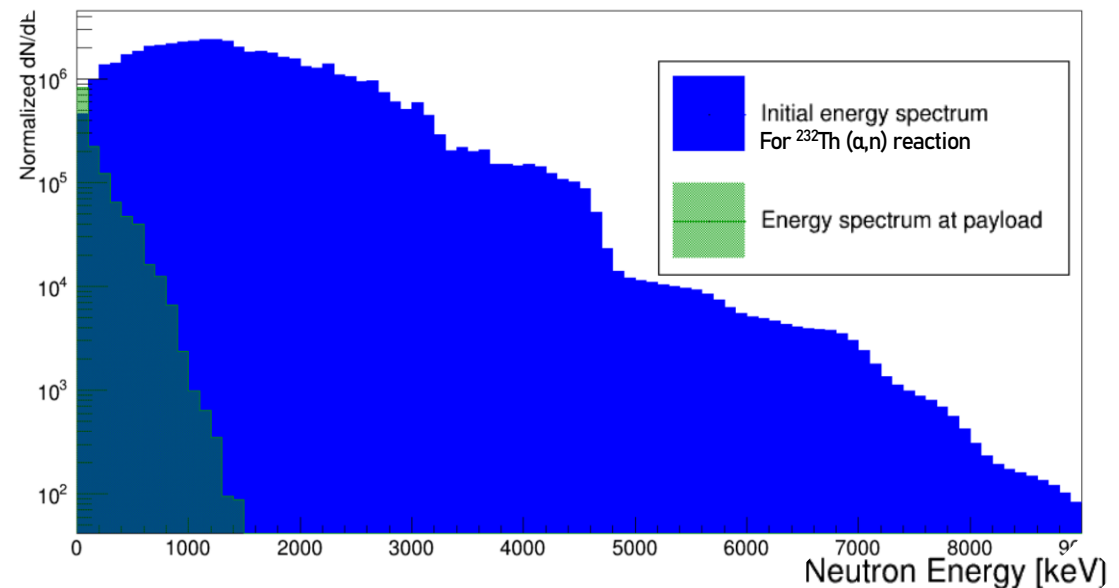
Dominant contributor of radiogenic neutrons

Created by fission and (α, n) reactions due to decay of heavy element impurities in the steel

Initial spectrum generated using NeoCBOT
S.Westerdale et al, NIMA 875 (2017) 57-64

GEANT4-based simulations suggest radiogenic neutron background subdominant to the cosmogenic neutron background

Normalized sampling spectrum and spectrum of neutrons reaching a payload



In-situ cosmogenic neutrons

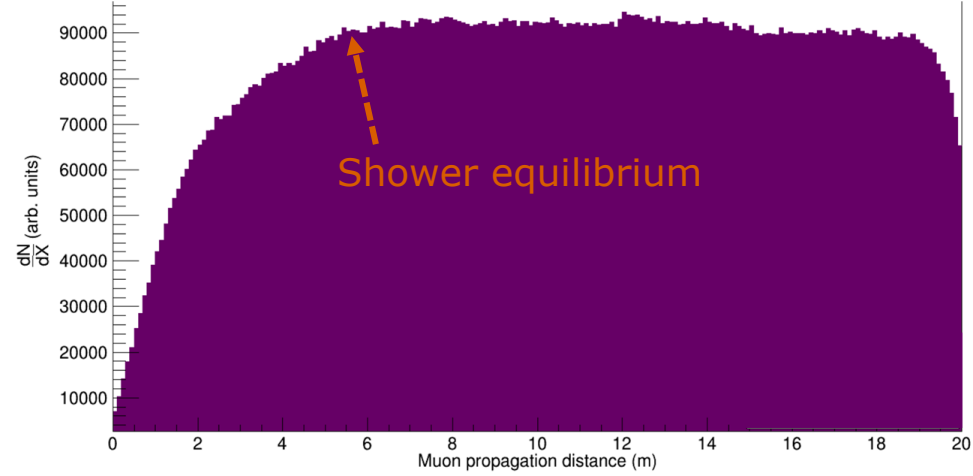
Primarily created in hadronic muon showers

Large shielding with high Z material may lead to significant cosmogenic backgrounds

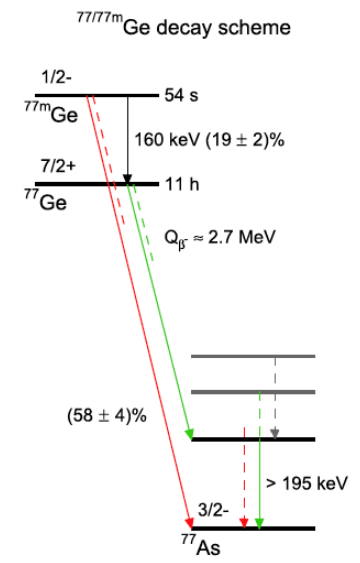
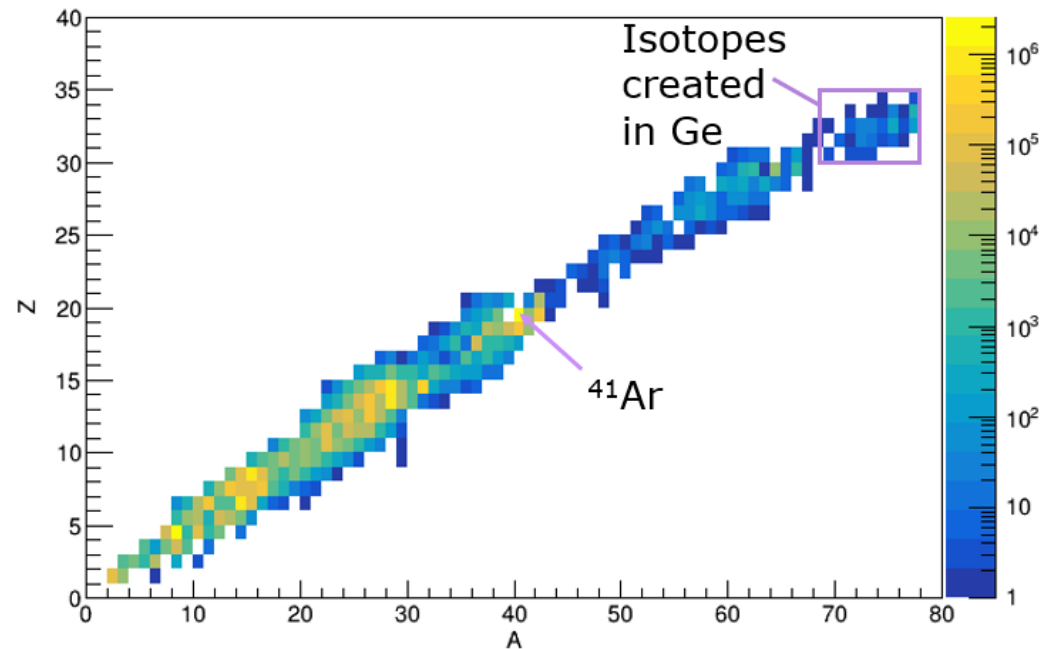
Complex shower development, largely dictated by muon path length and material

Shower development/isotope production investigated using Geant4 simulations

Muon-induced neutron production in pure liquid argon



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

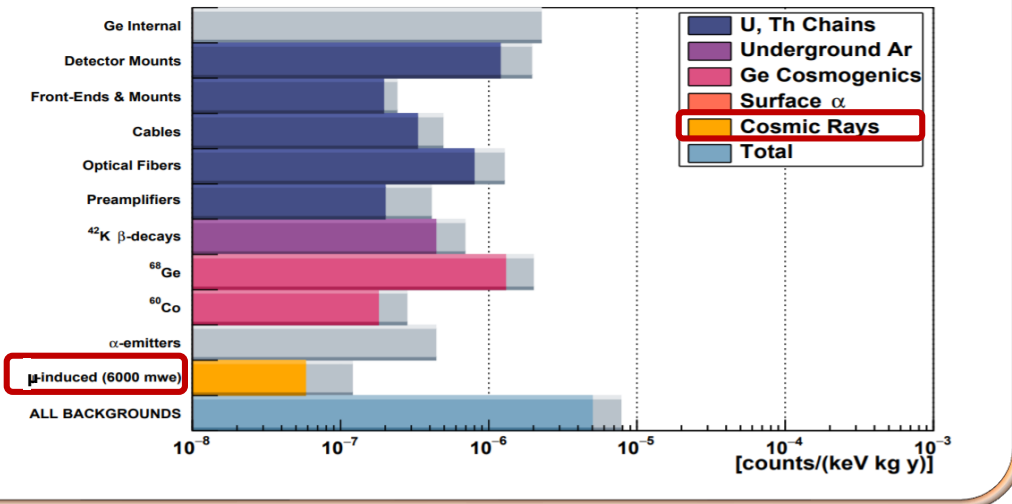


From Eur. Phys. J. C (2018) 78:597

Wide variety of isotopes generated by muon passage
 Few isotopes can contribute to ^{76}Ge $0\nu\beta\beta$ background
 Cosmogenic isotopes ^{77}Ge and $^{77\text{m}}\text{Ge}$ expected to contribute, based on decay energies and mean lifetime
 Mitigated by shielding, active veto, and analysis cuts

Mitigation options for cosmogenic neutrons

Cosmogenic background highly dependent on host site for LEGEND-1000. SNOLAB depth assumed



Polyethylene + neutron absorber

- 10 cm thick shields with outer radius 2m centered on detector array
- Polyethylene moderator, with gadolinium or boron to capture
- Both options significantly reduced neutron flux on detectors
 - ⁷⁷Ge 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

Liquid argon doping

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

Neutron energy spectra before and after shielding options

