

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

CJ Barton, on behalf of the LEGEND Collaboration

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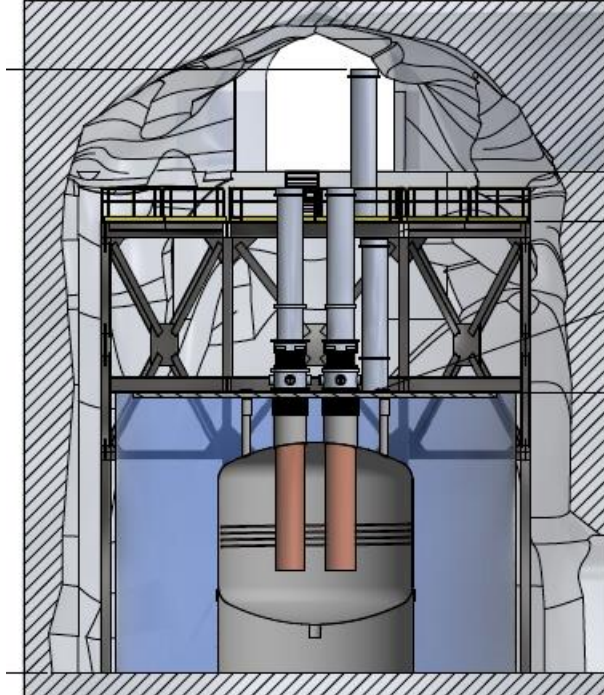
Mission of LEGEND: "The LEGEND (Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay) collaboration aims to develop a phased, Ge-76 based double-beta decay experimental program with discovery potential at a half-life beyond 10^{28} years, using existing resources as appropriate to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

Project overview



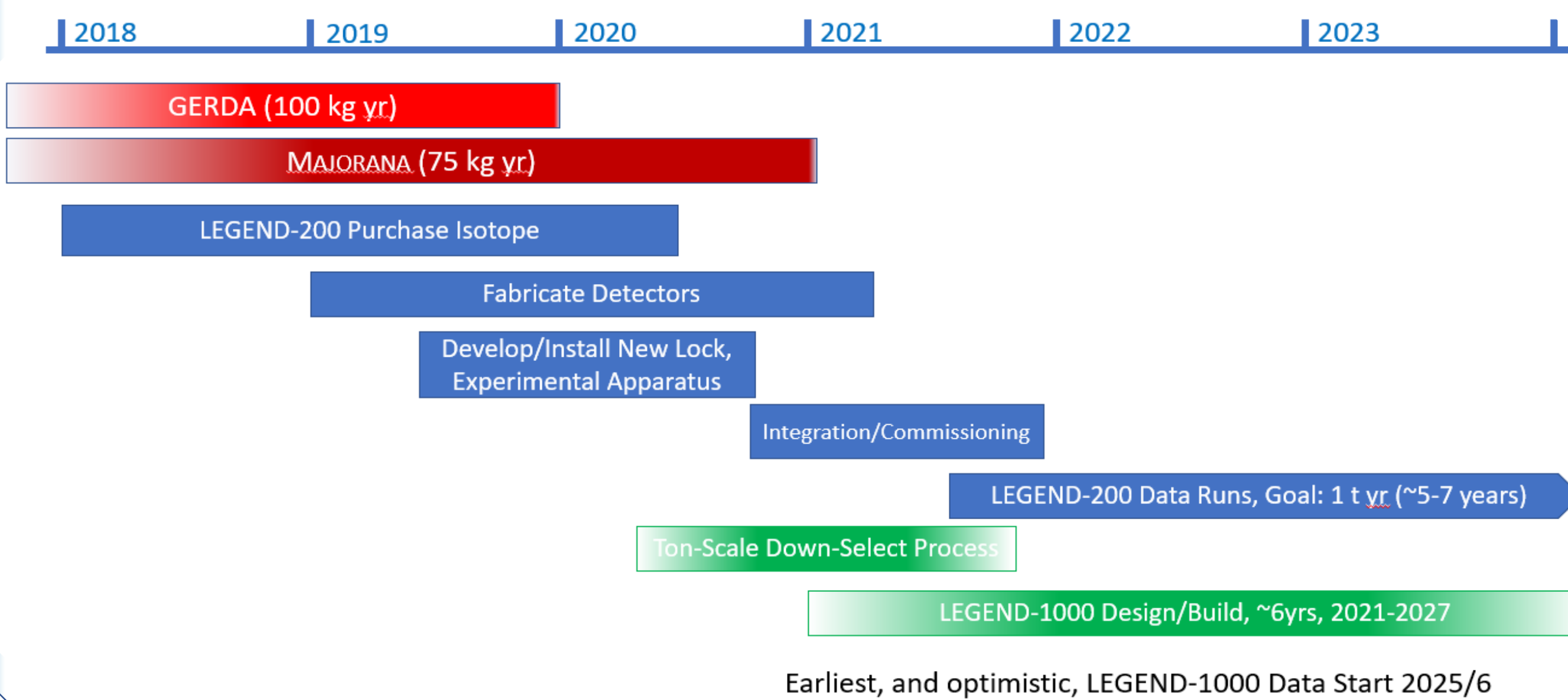
First phase:

- Up to 200 kg in upgrade of existing infrastructure at LNGS
- BG goal: <0.6 c/(FWHM t yr)
- Discovery sensitivity at a half-life of 10^{27} years
- Data start ~2021



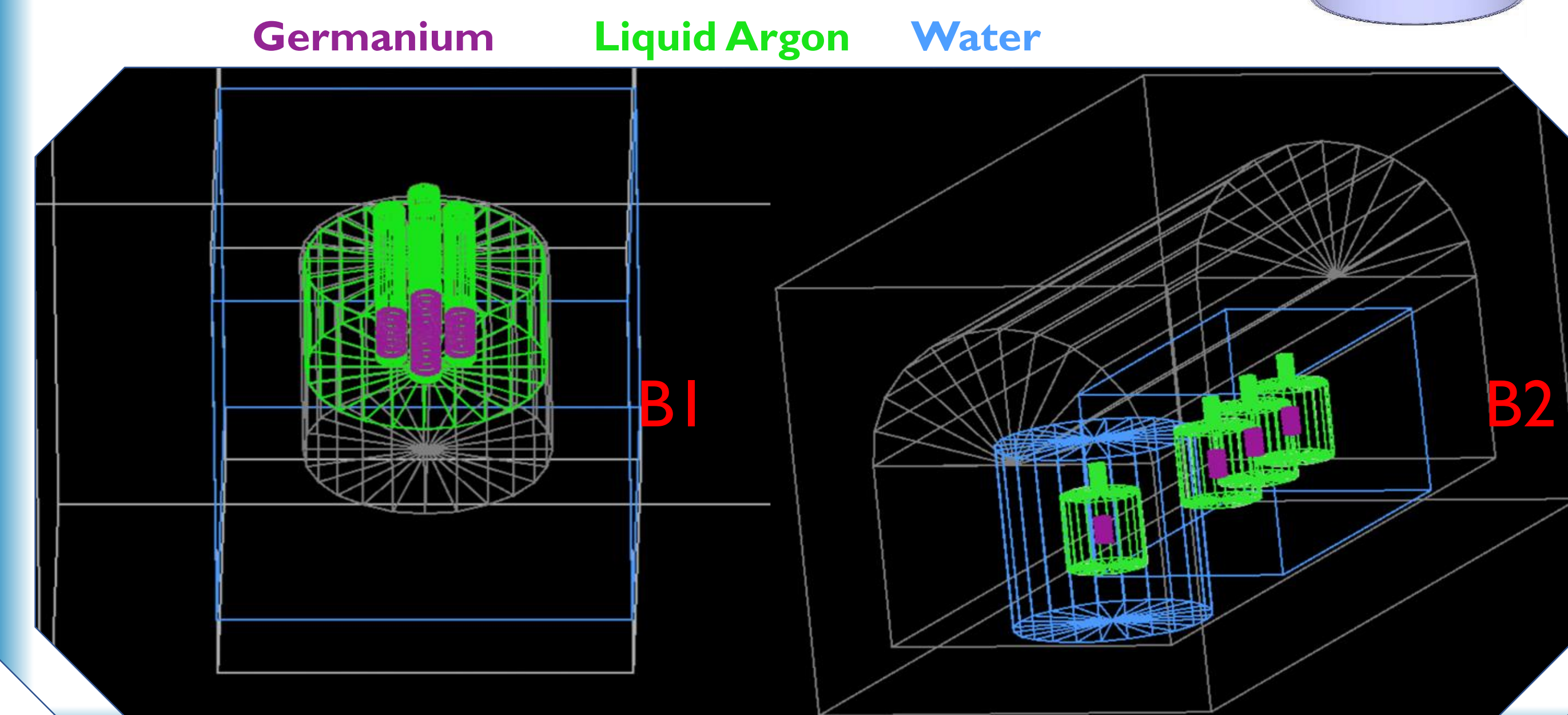
Subsequent stages:

- 1000 kg, staged via individual payloads
- Timeline connected to review process
- Background goal <0.03 cts/(FWHM t yr)
- Location to be selected



Simulation setup

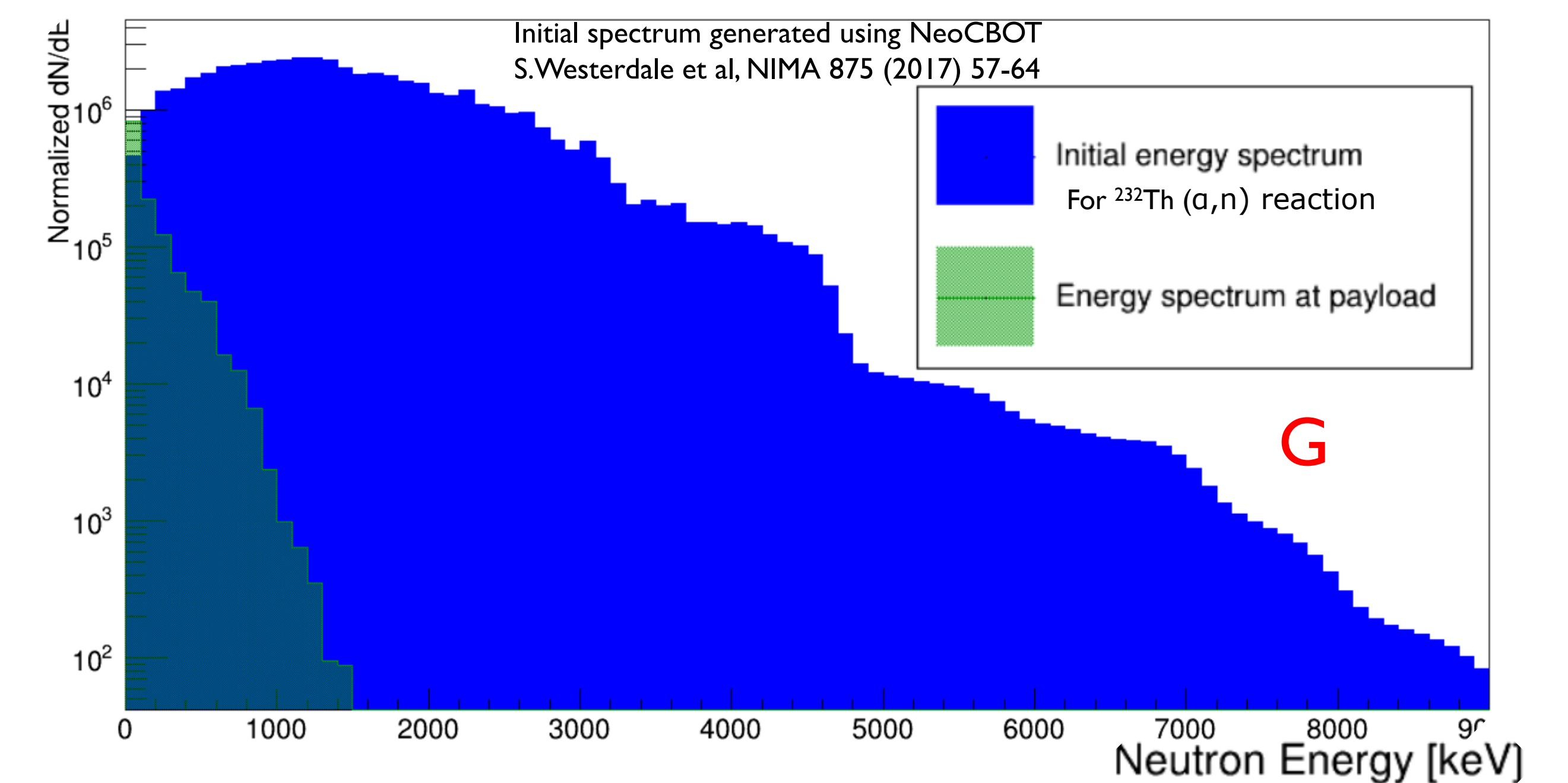
- Particle simulation in custom Geant4 10.02.02 module
- Event reconstruction and analysis in ROOT/C++
- Exchangeable geometry options for easy comparison
 - Fig B1 represents baseline design of LEGEND-1000 in simulation (see also Fig. A for CAD drawing)
 - Fig B2 is alternative multiple-tank design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



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

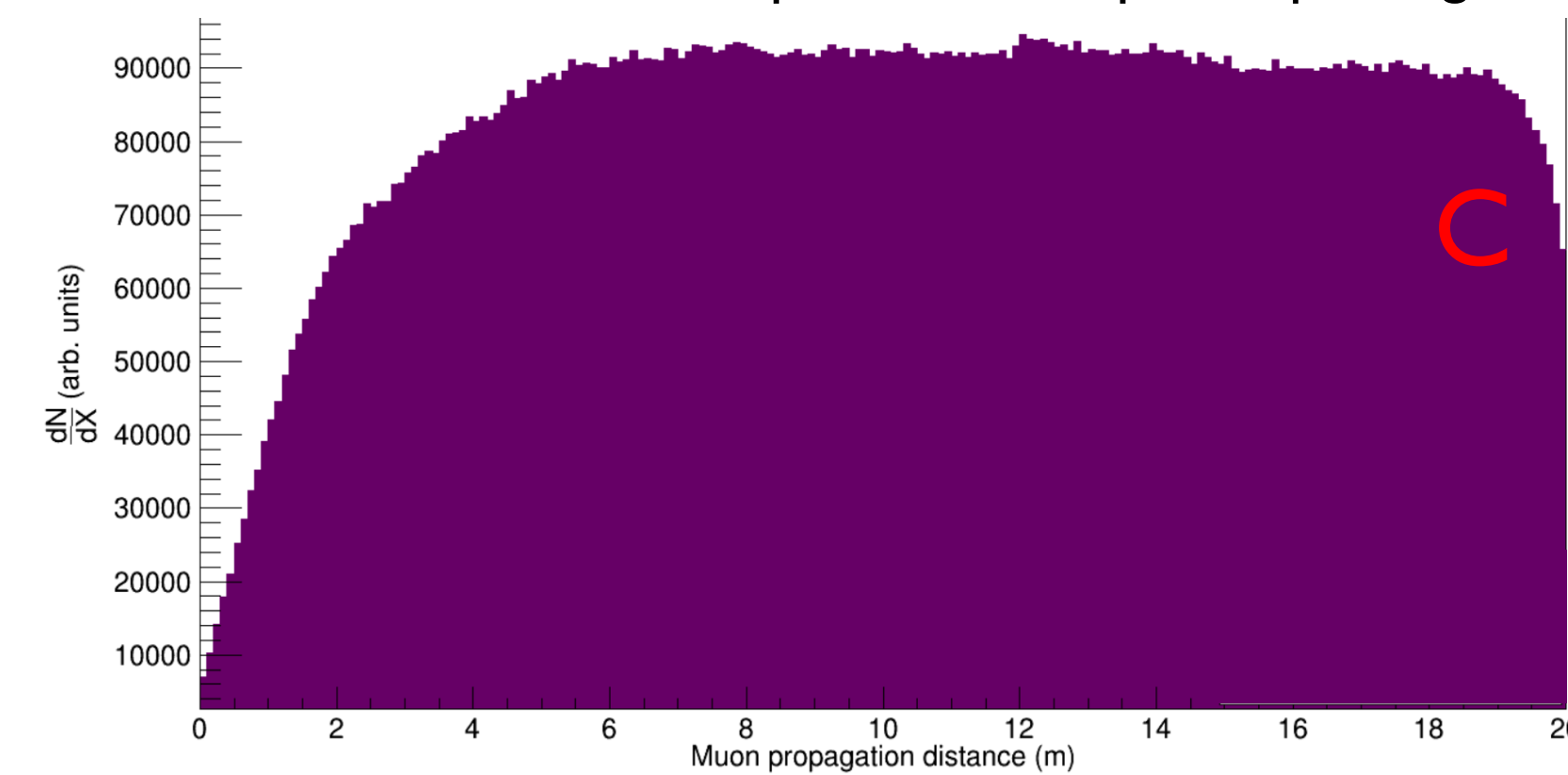
Normalized sampling spectrum and spectrum of neutrons reaching a payload



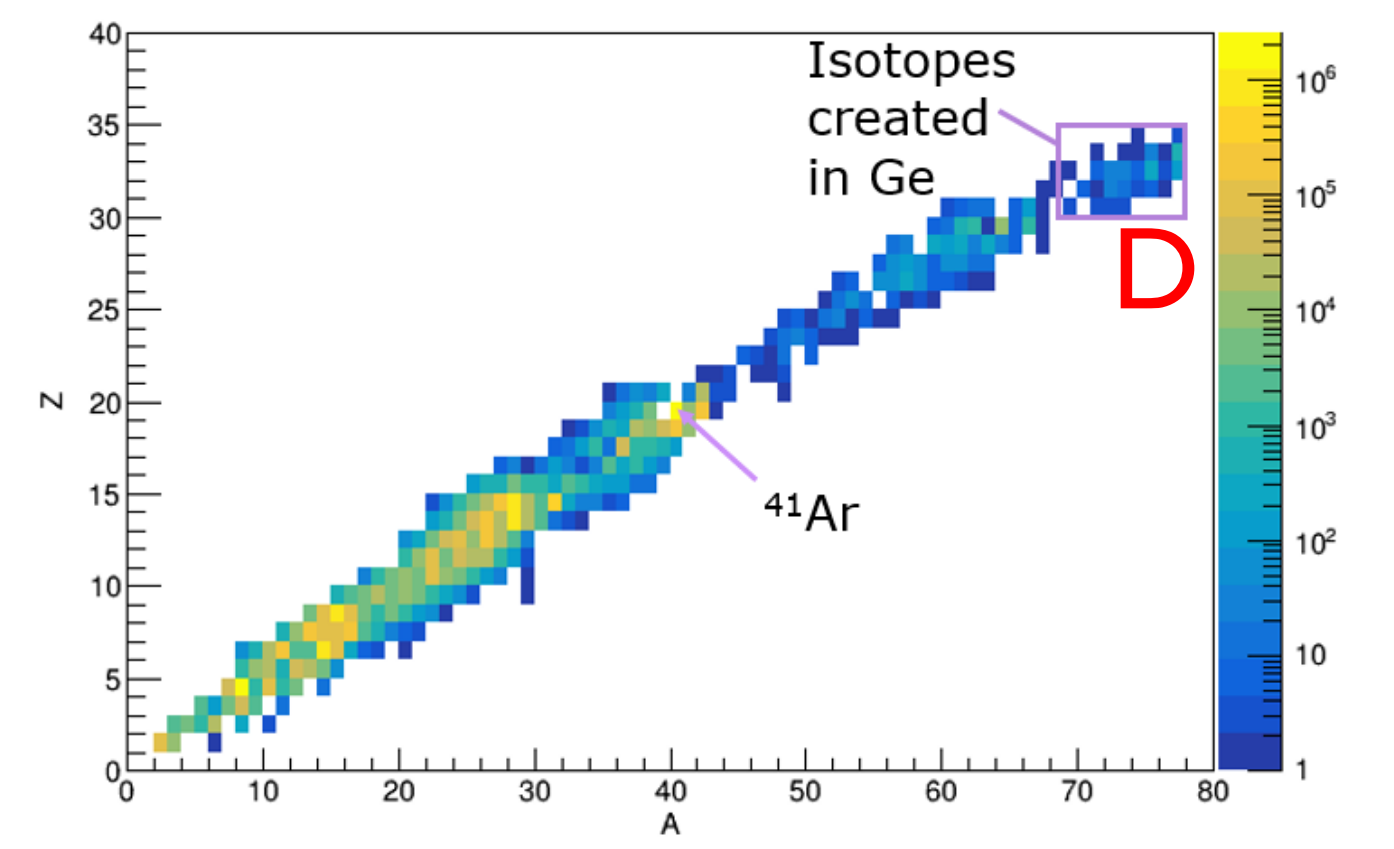
Cosmogenic neutrons

- 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 $^{77\text{m}}\text{Ge}$, 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

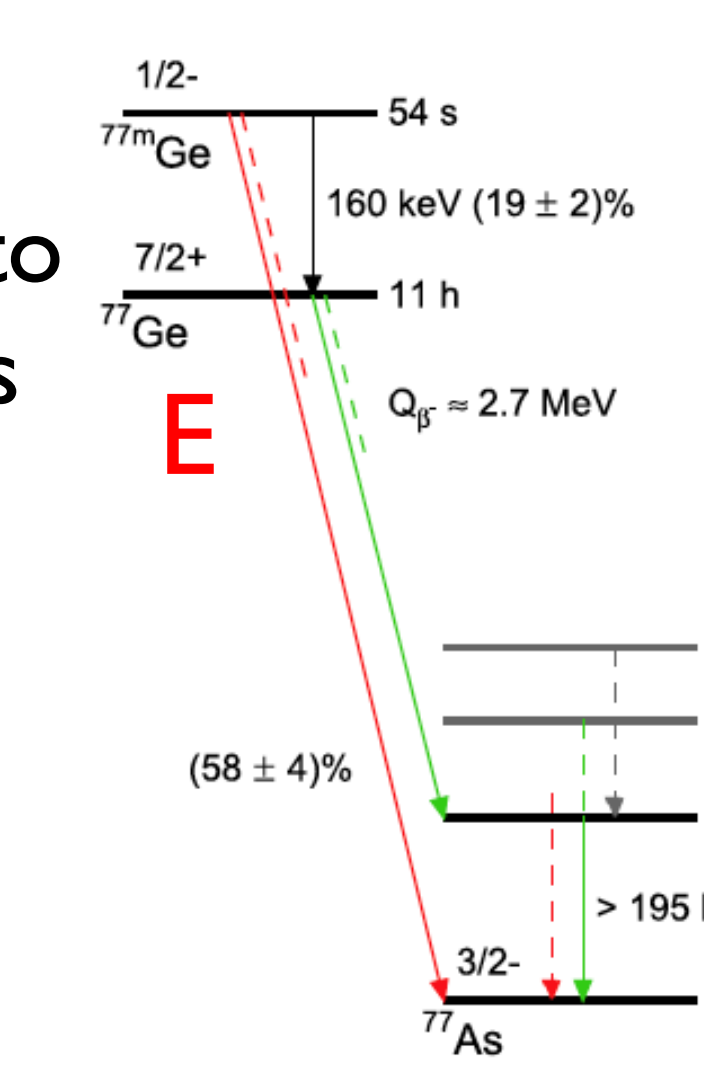
Muon-induced neutron production in pure liquid argon



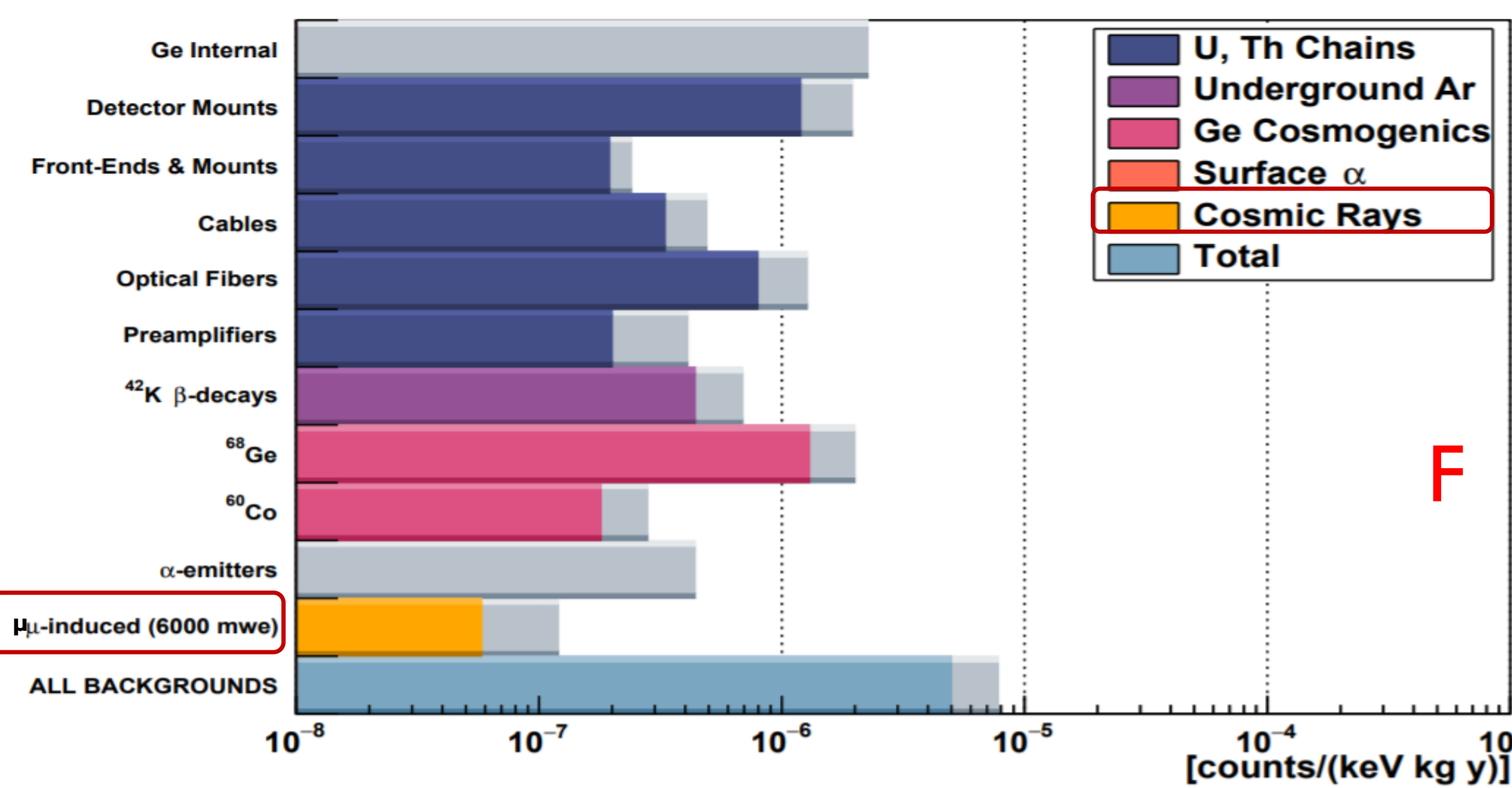
A and Z numbers of nuclear isotopes generated (all materials)



$^{77\text{m}}\text{Ge}$ decay scheme



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Neutron shielding options

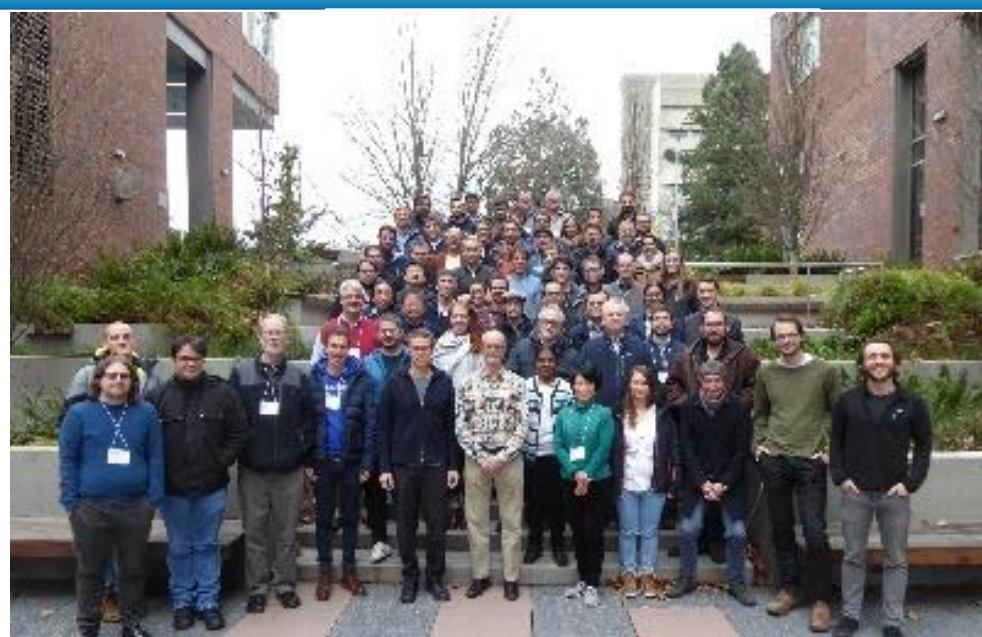
Polyethylene (PE) shields

- 10 cm thick shields with outer radius 2m centered on detector array
- Polyethylene to slow neutrons, with gadolinium or boron to capture
- Both options significantly reduced neutron flux on detectors
 - ^{77}Ge and $^{77\text{m}}\text{Ge}$ 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
 - ^{131}Xe , in 100ppm and 1000 ppm quantities
 - ^3He , 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 ^3He study show significantly reduced neutron flux
 - More expensive to implement in practice

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