Radiogenic Neutrons and External Gamma-ray Backgrounds at LEGEND-1000

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on behalf of the LEGEND Collaboration

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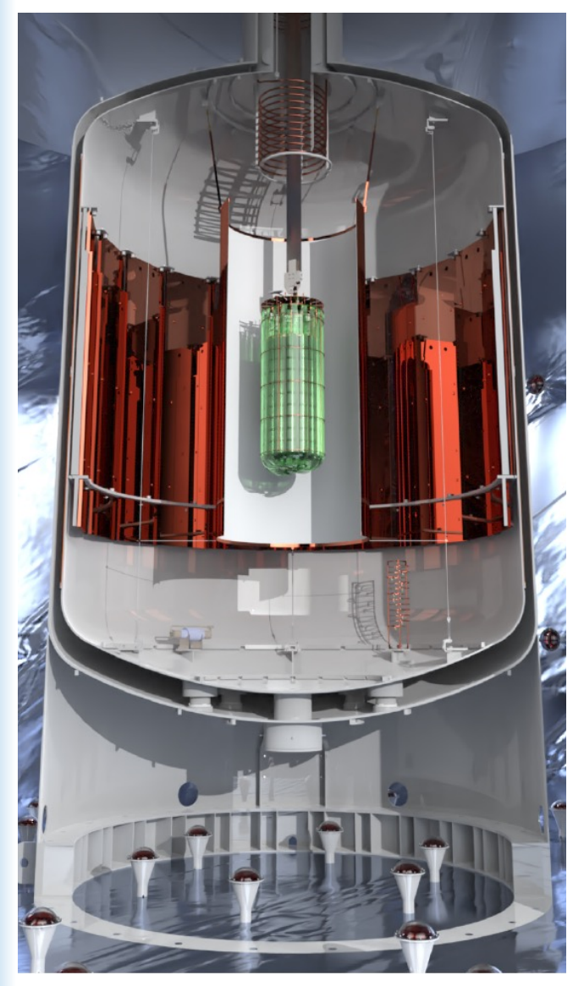
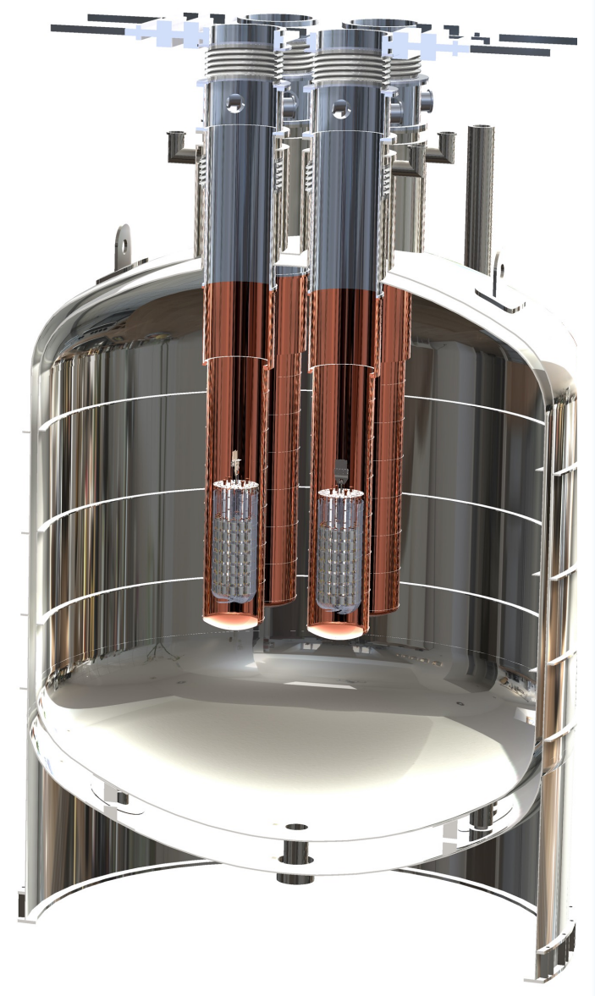
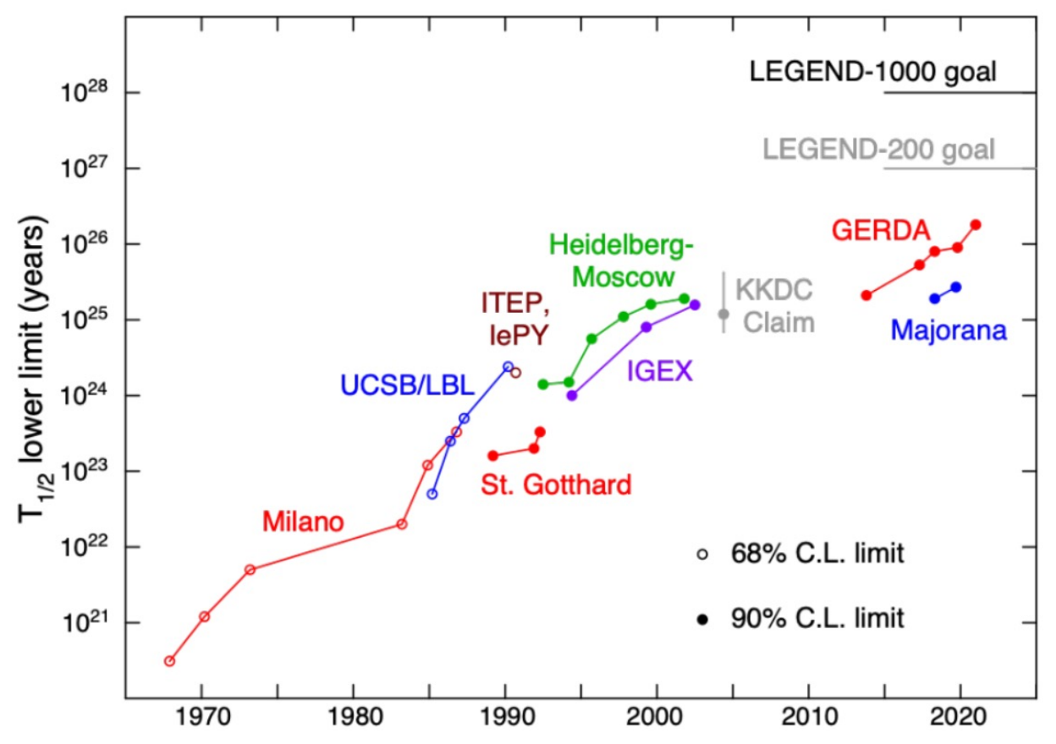
The Large Enriched Germanium Experiment for Neutrinoless double beta Decay (LEGEND) Collaboration aims to develop a phased, Ge-76 based double-beta decay experimental program with discovery potential at a half-life beyond 10^{28} years, using existing resources as appropriate to expedite physics results. In order to achieve an unprecedented background goal of 1×10^{-5} cts/(keV kg yr) at the Q-value of 2039 keV, backgrounds are being carefully investigated in LEGEND-1000. Both ambient neutrons from the laboratory room and neutrons generated by (α,n) reactions and fissions in apparatus materials are important backgrounds. Similarly, gamma rays from far-way components such as the stainless-steel cryostat are also important. Geant4 simulations developed for the LEGEND Collaboration explore these neutrons and gamma-rays backgrounds.

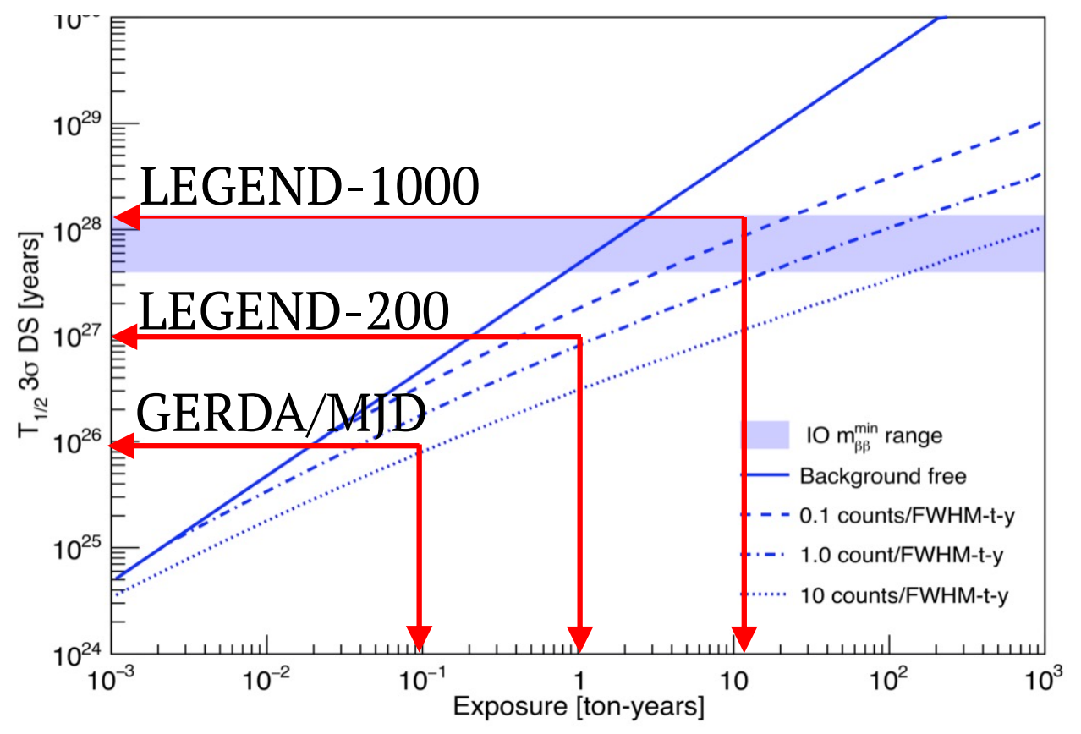
LEGEND Goals and Sensitivity



LEGEND-200		LEGEND-1000
200	Active detector mass kg	1000
5	Expected runtime yrs	10
10^{27}	$T_{1/2}$ sensitivity yrs	10^{28}
34 – 78	mββ upper limit meV	9 – 21
2x10^{-4}	Background index cts/(keV kg yr)	1x10^{-5}

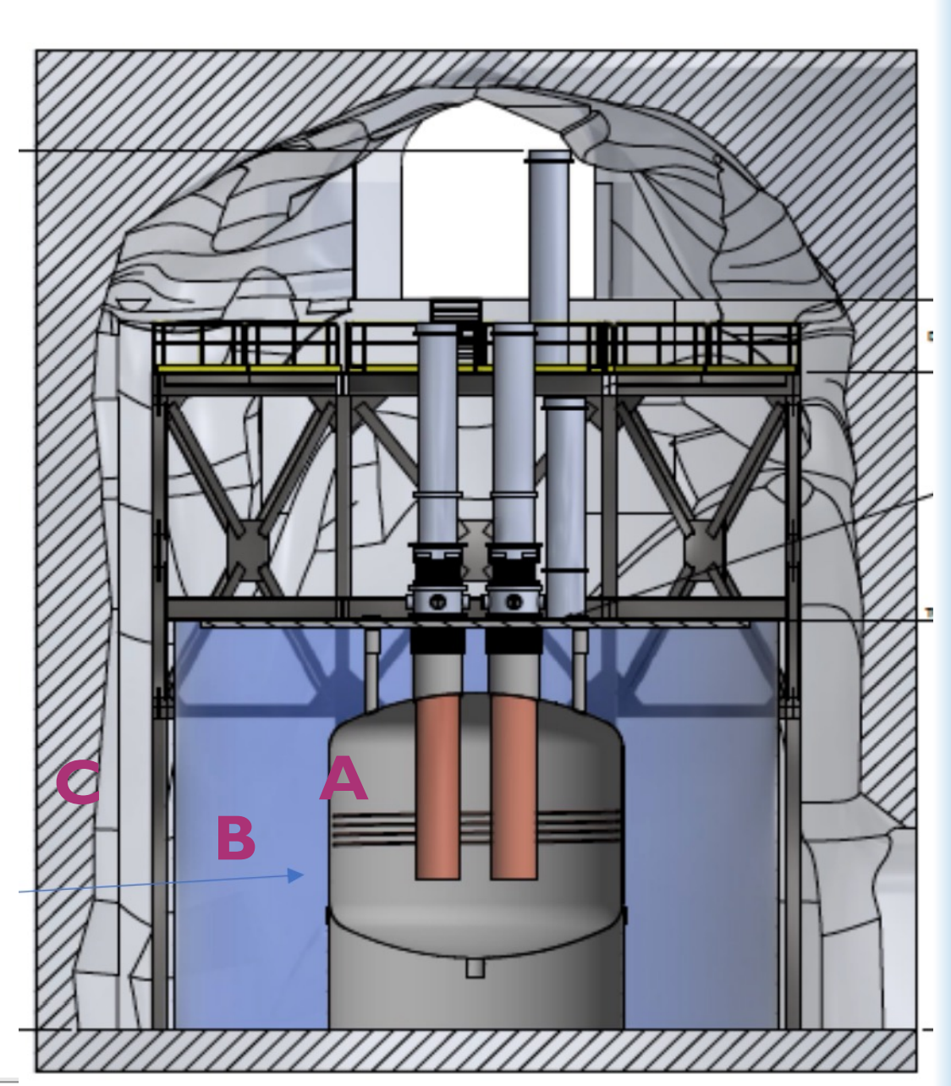


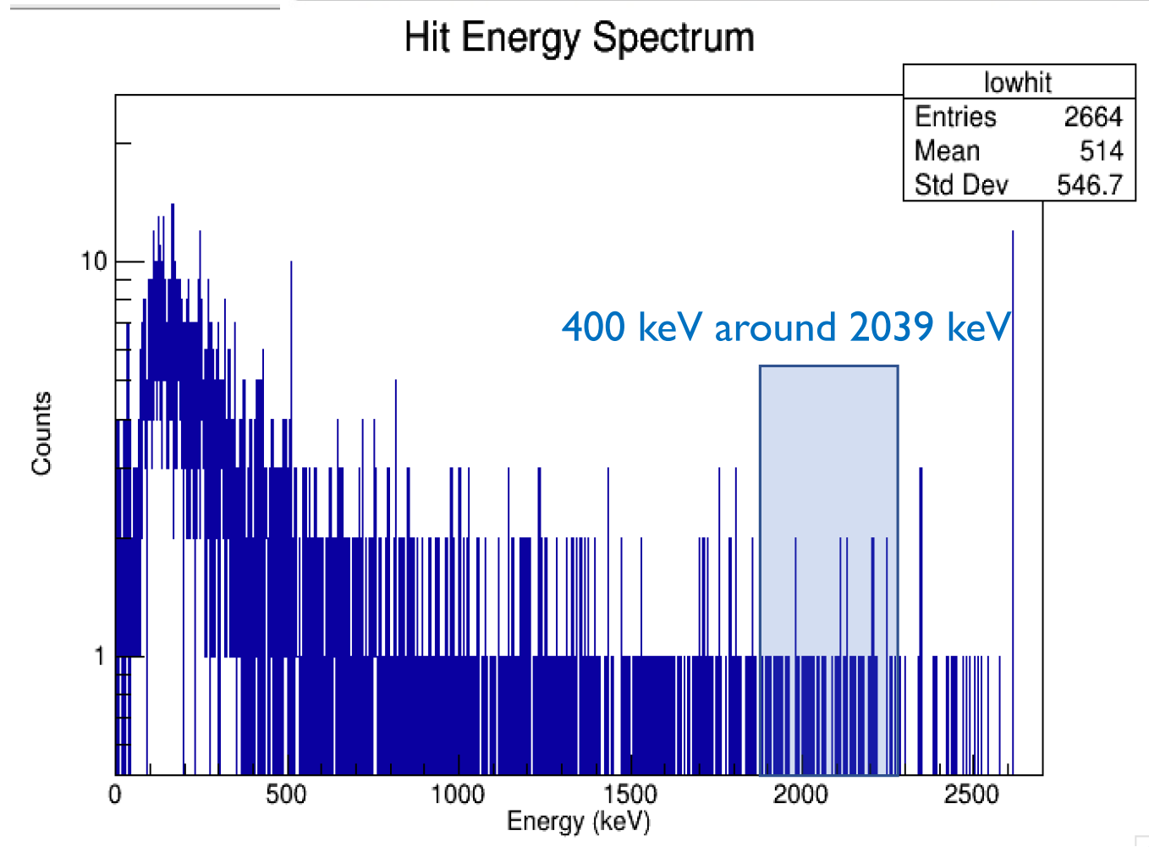




External Gamma-ray Backgrounds

- ❖ The stainless-steel cryostat (A), water tank (B), and the laboratory environment (C) can potentially contribute to the background via gamma-rays.
- ❖ The main contribution to the background at $Q_{\beta\beta} =$ 2039 keV of ^{76}Ge comes from the 2614-keV gamma line of ^{208}Tl, which is a shorter-lived progeny of the ^{228}Th decay chain.
- ❖ Standard set of analysis cuts: Multiplicity, Pulse Shape Discrimination (PSD), and Liquid Argon (LAr) veto help to suppress the background effectively. Assumed PSD+LAr has a $\frac{1}{20}$ efficiency in pre–Conceptual Design Report (pCDR).
- ❖ The contribution to the background index from the cryostat after all standard cuts is (BI) $= (5.3 \pm 1.0) \times 10^{-7} \frac{Cts}{KeV\ Kg\ Yr}$, or 5 % of the total background budget (see pCDR of L-1000 for more details*).
- ❖ A conservative estimation shows the negligible contribution to BI from the gammas from the water tank and laboratory environment.

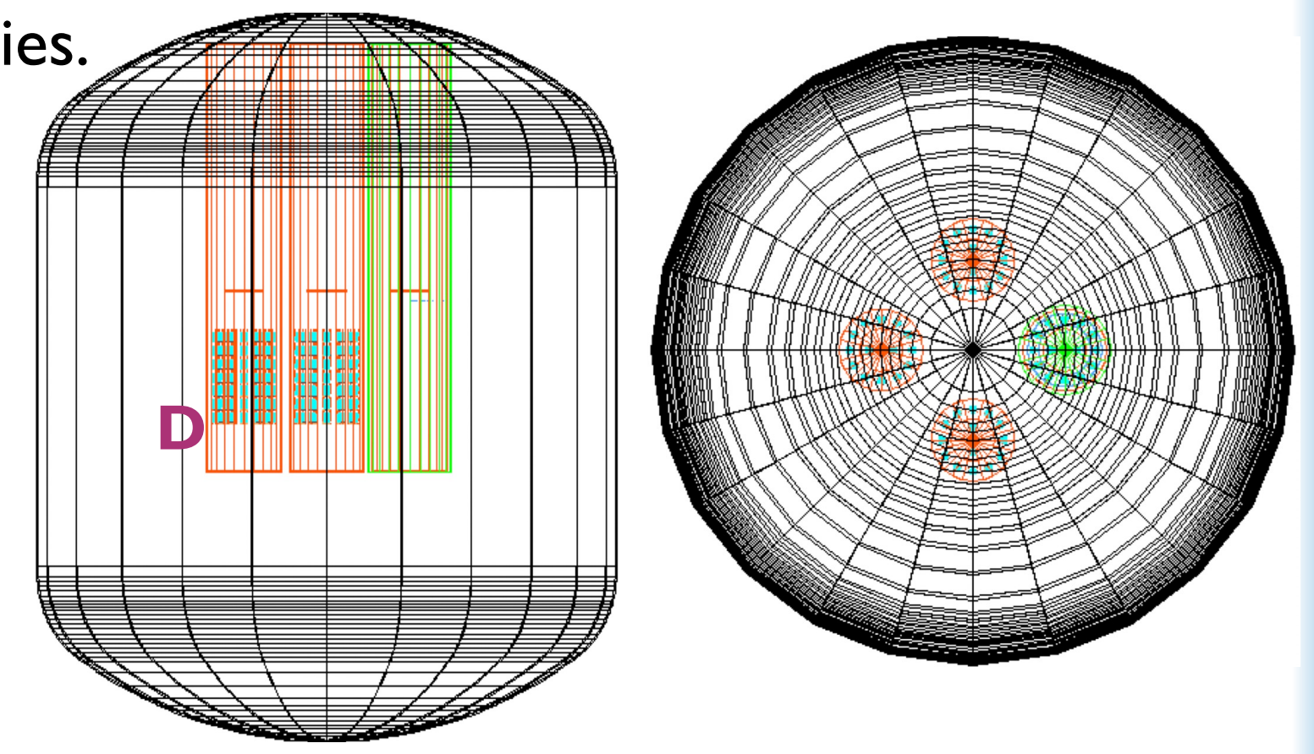


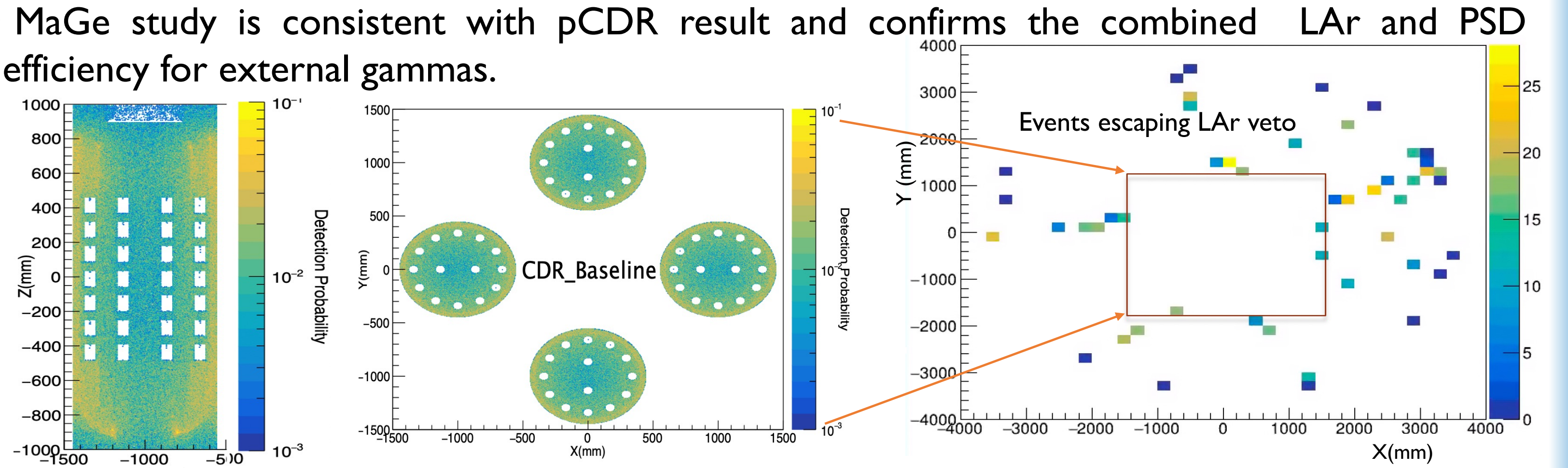


* http://arxiv.org/abs/2107.11462

Analysis Cut Efficiency for Cryostat Gammas

- ❖ The Monte Carlo software MaGe, developed and maintained by the Majorana and GERDA simulation groups, is used to estimate the efficiencies.
  - ➢ Number of photoelectrons (PE) production is estimated using the pre-calculated optical map (shown in figure below)
  - ➢ ~ half of the 400-keV ROI events escape the LAr veto due to lack of PE.
  - ➢ $\frac{1}{20}$ events in 400-keV ROI remain after LAr+ PSD cut --- confirming the pCDR assumption
- ❖ MaGe study is consistent with pCDR result and confirms the combined LAr and PSD efficiency for external gammas.

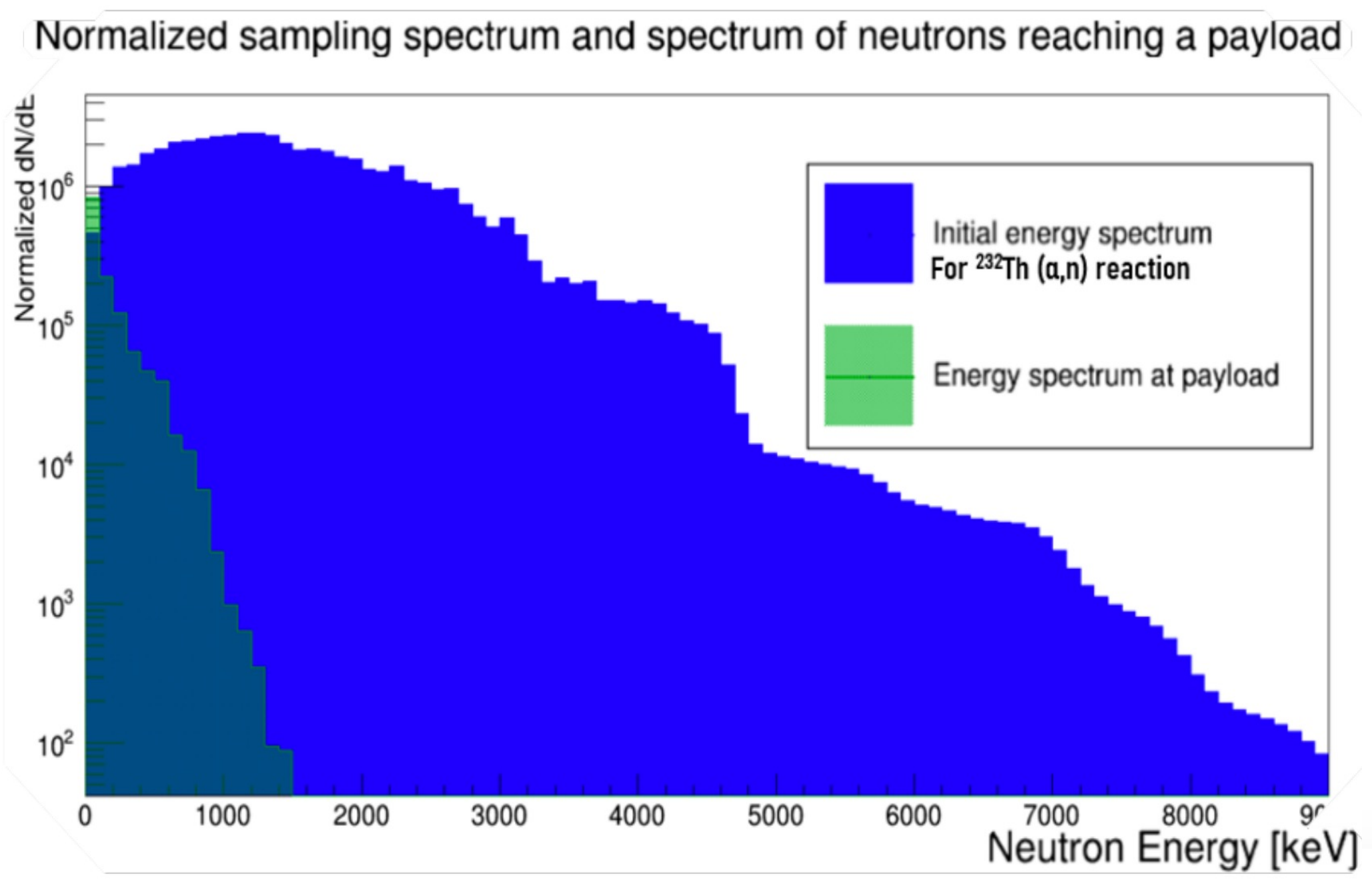


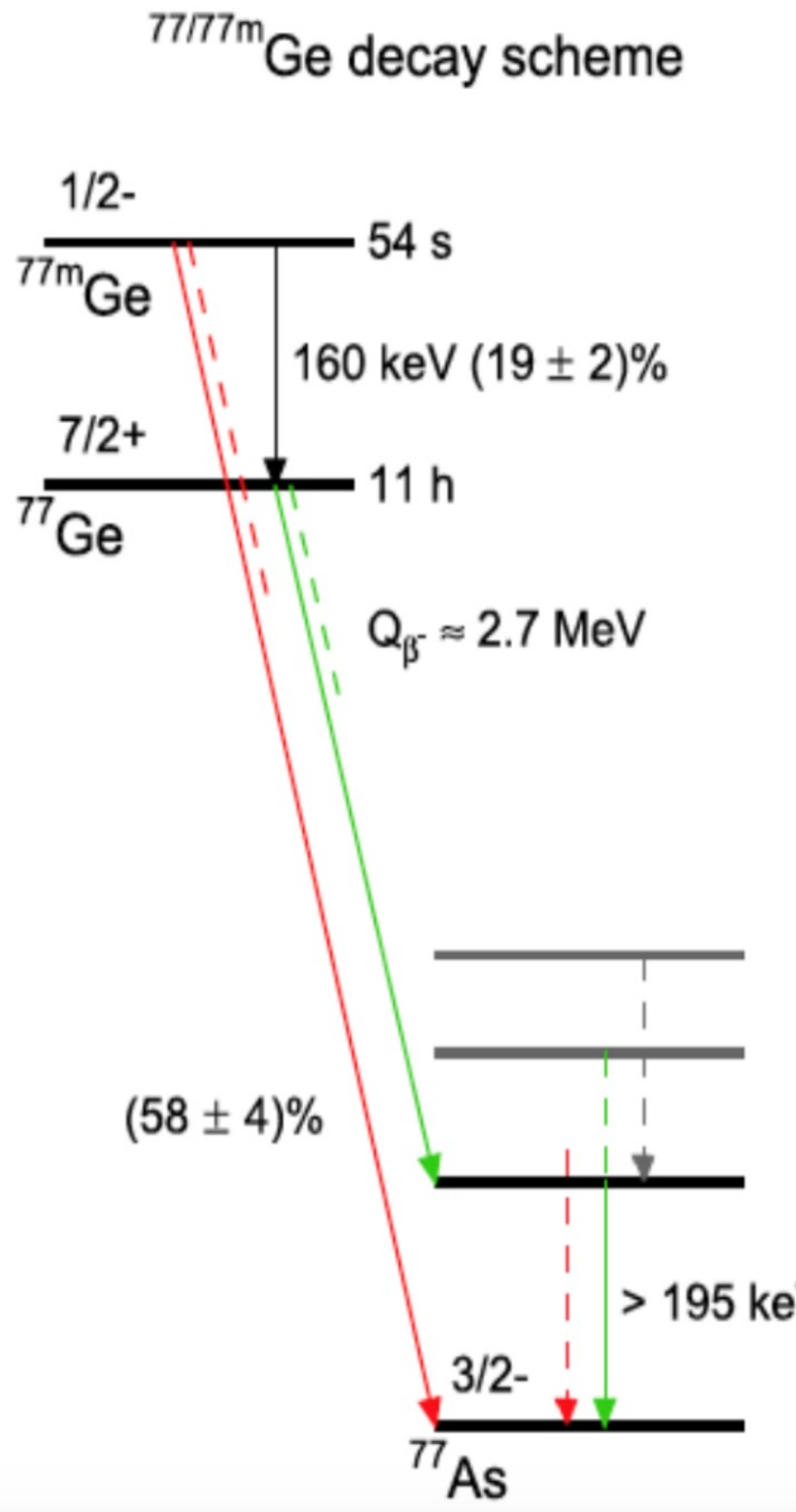


Figures: Top row: (12+2) strings CDR_Baseline geometry in MaGe. Bottom row: (left and middle) Optical map for VUV Argon scintillation photons generated in CDR geometry, and (right) spatial distribution of events that produce 0 PE inside re-entrant tubes (D). The square in the plot shows the region where the optical map is produced, and the optical photon detection is possible.

Radiogenic Neutrons Backgrounds

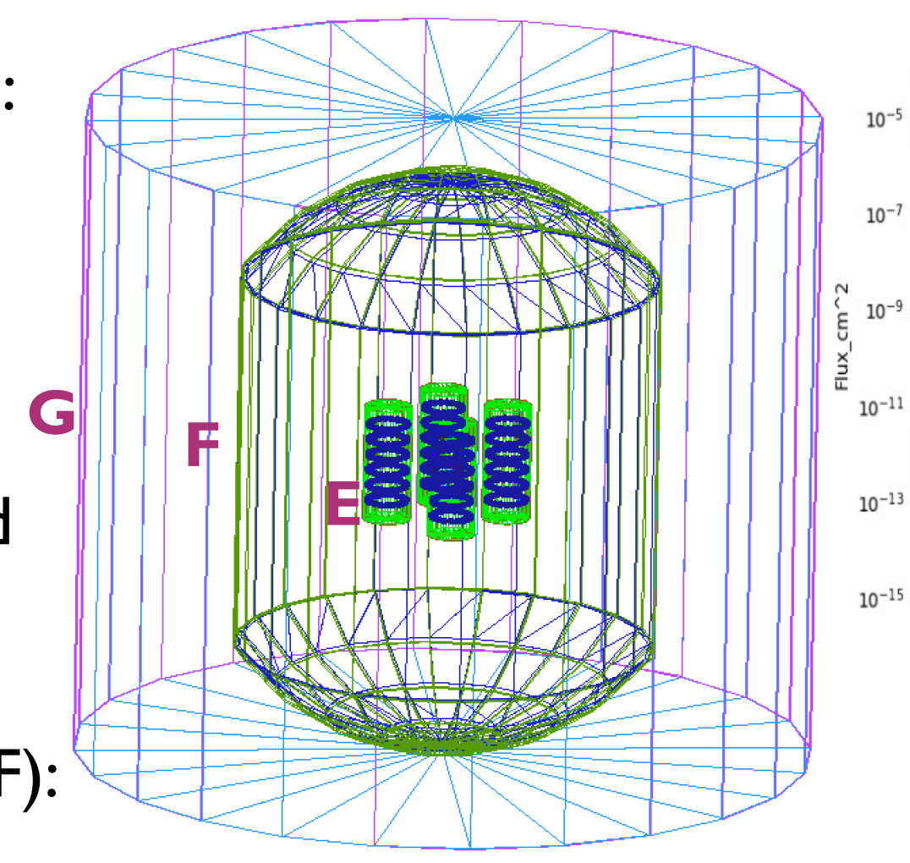
- ❖ Neutrons from (α, n) reactions induced by alpha particles from the natural radioactivity of various components surrounding the detectors.
- ❖ Spontaneous fission of ^{238}U and ^{232}Th and their daughters, especially of the ^{238}U chain.
- ❖ Neutrons can be captured in ^{76}Ge and produce ^{77}Ge and ^{77m}Ge, Q-value of which is greater than $0\nu\beta\beta$ decay region of interest (ROI).

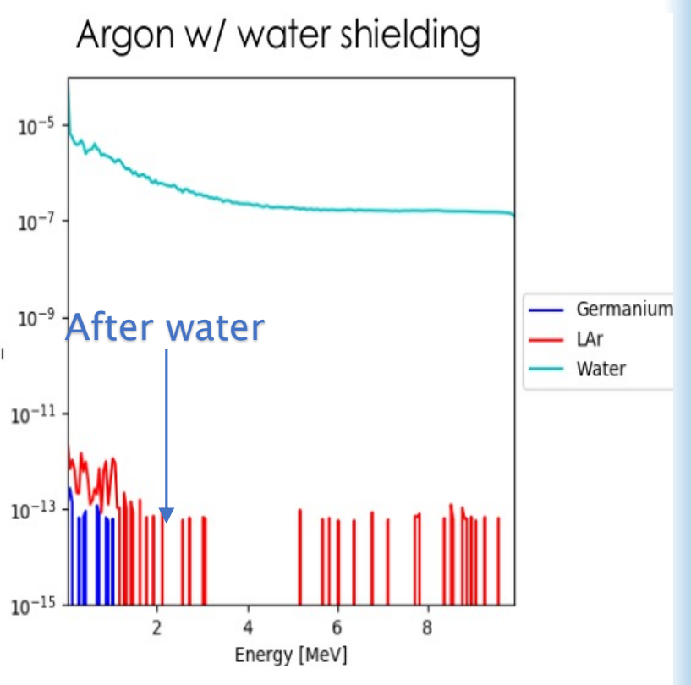


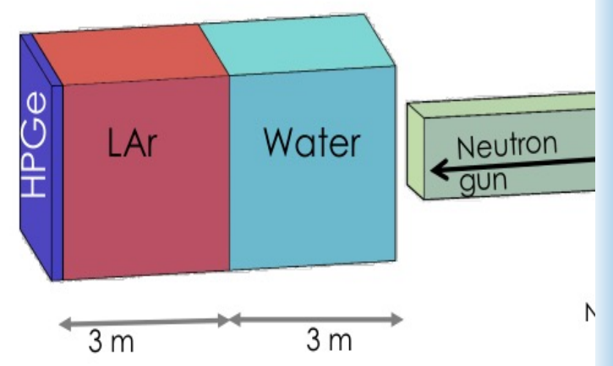


Neutrons Bkg Contribution From Different Parts

- ❖ Neutrons From Nearby Parts (E):
  - ➢ Radiopure and/or small in masses
  - ➢ Negligible contribution to BI from prompt (10^{-8} to 10^{-7} $\frac{\mathrm{Cnts}}{\mathrm{KeV\ Kg\ Yr}}$ before any cuts) and Delayed signals.
- ❖ Neutrons from the Cryostat (F):
  - ➢ Because neutrons are all highly moderated in LAr, prompt signals are found to be mostly due to secondary gammas, which can be effectively suppressed.
  - ➢ Delayed signals are more difficult to reject due to a lack of timing information
  - ➢ The contribution to the background is $(2.0 \pm 0.5) \times 10^{-7}$ $\frac{\mathrm{cts}}{\mathrm{keV\ Kg\ Yr}}$, or 2% of background budget.
- ❖ Environmental Neutrons (G):
  - ➢ Based on MCNP simulations, for the 1-2 MeV neutrons, 3 meter of water reduces them by a factor of at least 10^6, and we have 2.6m of water.
  - ➢ At most, (0.1-0.2)% contribution to background budget.





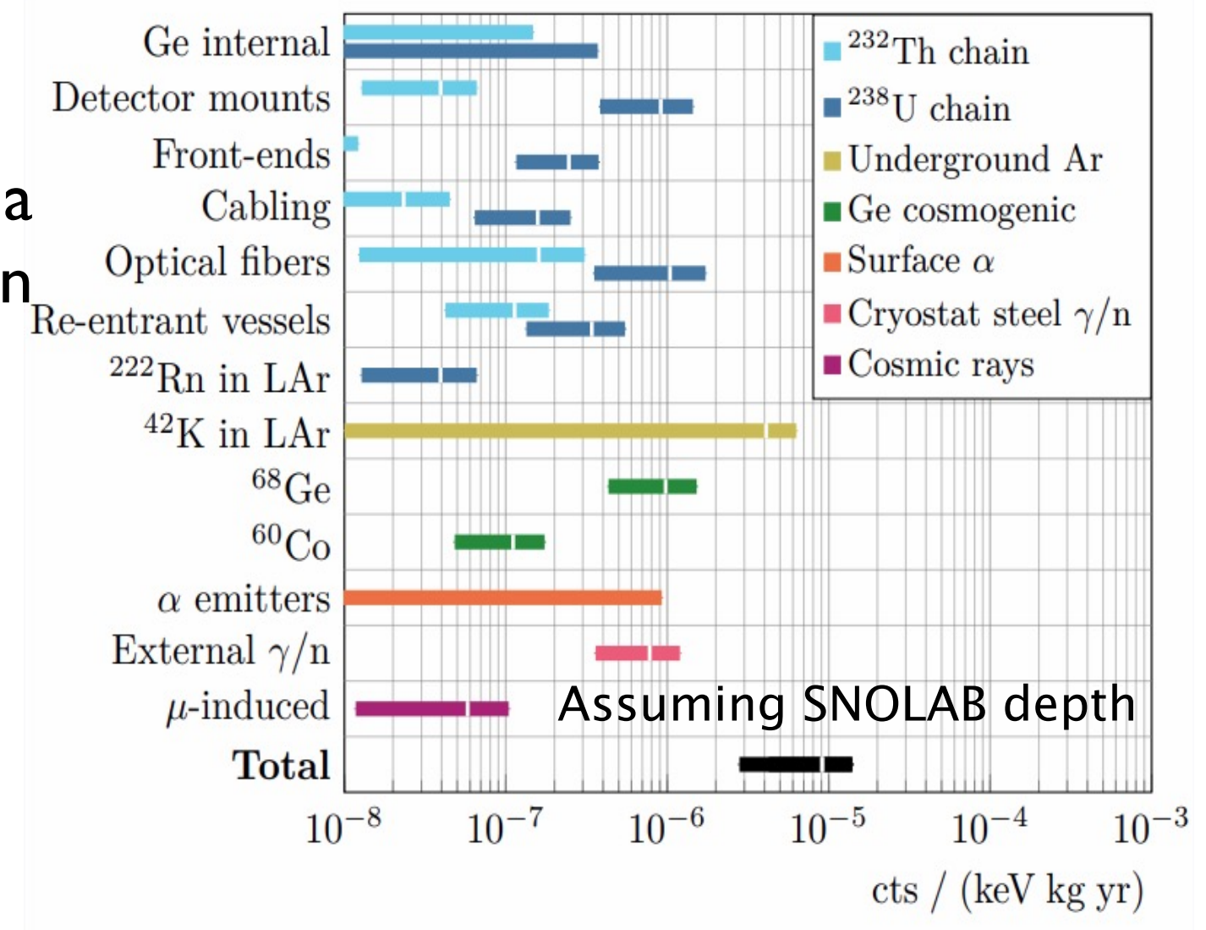


MCNP by LEGEND ORNL team

Summary

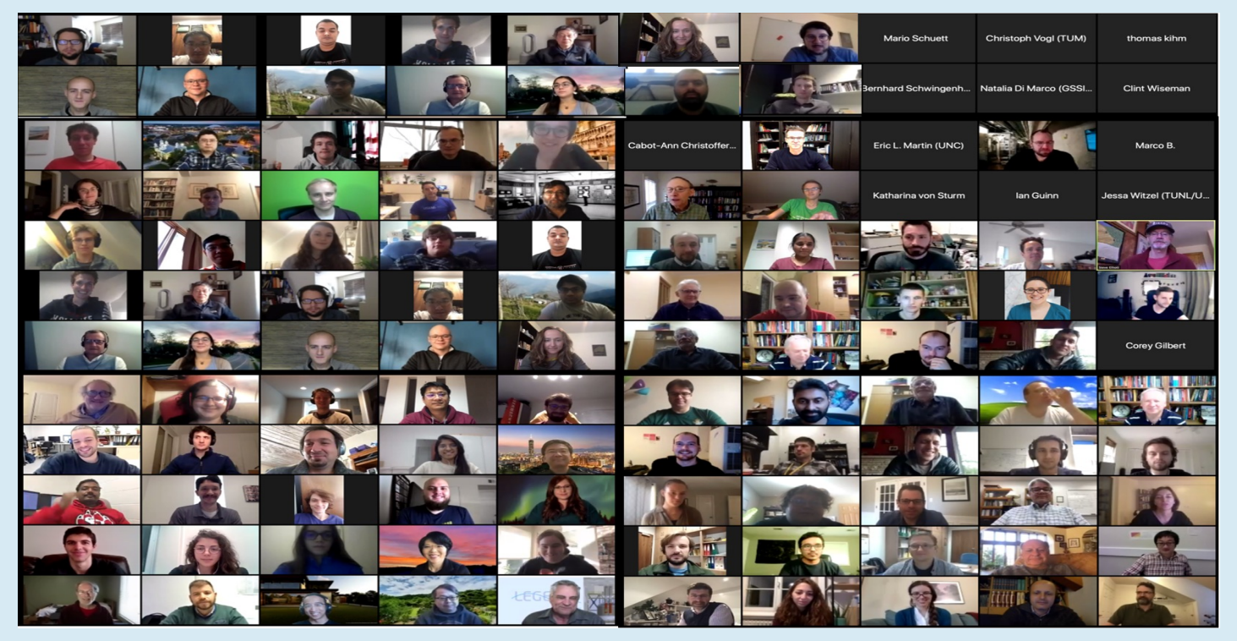
Source	Contribution to Background Budget	Comments
External gammas	≈ 5%	Main contributor is LAr cryostat. Negligible contribution from the water tank and laboratory environment.
Cryostat neutrons	≈ 2%	Without Delayed Coincidence cut
Room neutrons	Negligible	Due to water shielding
Near-by parts neutrons	Negligible	Due to extra-clean and low mass material

- ❖ Analysis cuts suppress the cryostat gamma background by a factor of 20.
- ❖ Combined radiogenic neutron and external gamma backgrounds in the LEGEND-1000 baseline design projected to be less than 10%.
- ❖ If necessary, additional techniques can be used to further reduce neutrons (not discussed in this poster), for eg., passive neutron shields and active Ge-77 reduction techniques (more details can be found in these references*).



*CJ Barton, PANIC 2021
M. Neuberger et al, TAUP2021

Acknowledgement:



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