Status of the development of the water tank neutron tagger of LEGEND-1000

LEGEND
Large Enriched Germanium Experiment for Neutrinoless ββ Decay

TAUP XICHANG

Tobias Sterr on behalf of the **LEGEND collaboration**
Eberhard Karls University, Tübingen

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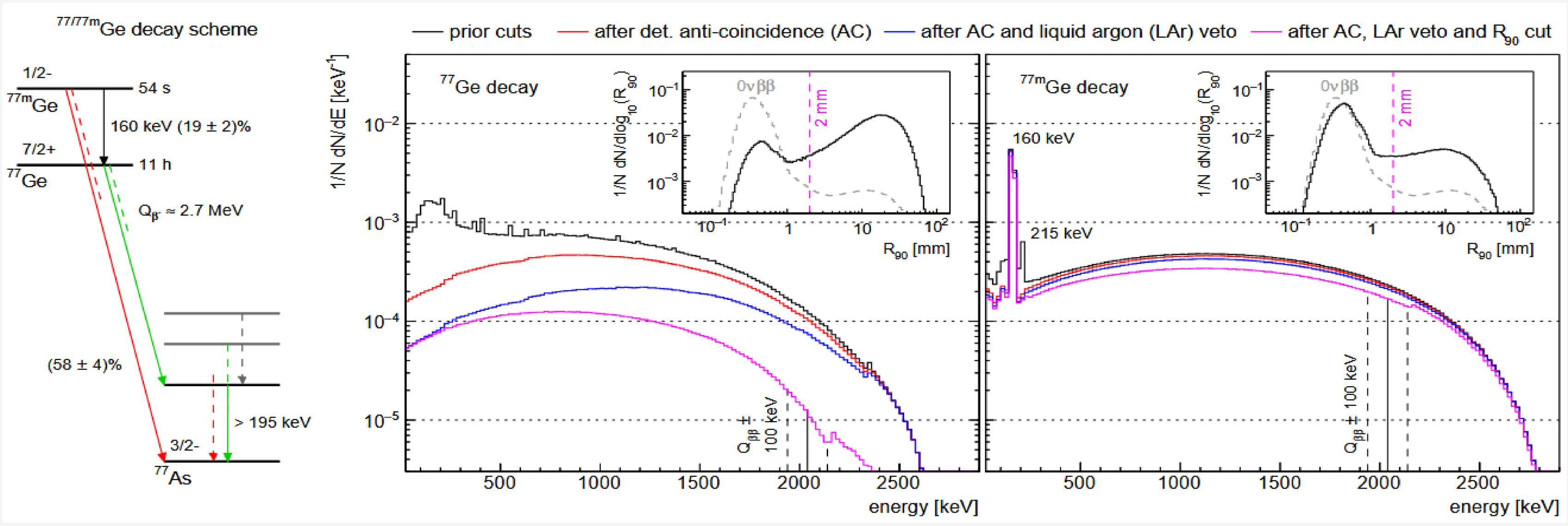
Introduction

LEGEND-1000 will be the next stage of the Large Enriched Germanium Experiment for Neutrinoless ββ Decay (LEGEND). It is currently in the planning stage with an expected start of installation in 2028. Like its predecessor LEGEND-200, LEGEND-1000 will be located at the Laboratori Nazionali del Gran Sasso (LNGS) in Italy.
To reduce the backgrounds introduced by muons, two independent veto systems have been introduced: A water Cherenkov veto and an instrumented liquid argon volume. This poster will highlight the working principle, status of the simulations and the investigated backgrounds of the water Cherenkov veto of LEGEND-1000.

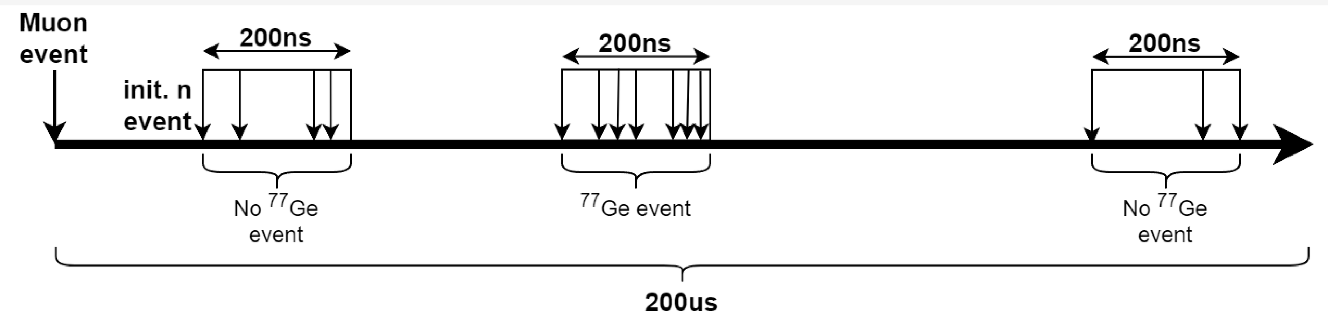
Neutron tagger

The decay of ^{77}Ge and ^{77m}Ge has been identified as the main delayed cosmogenic background of LEGEND. Since both isomers are produced via muon-induced neutron capture, it is crucial to tag the β-decays of these isomers to avoid faux signals within the 0νββ region of interest, which is (2039 ± 100) keV.



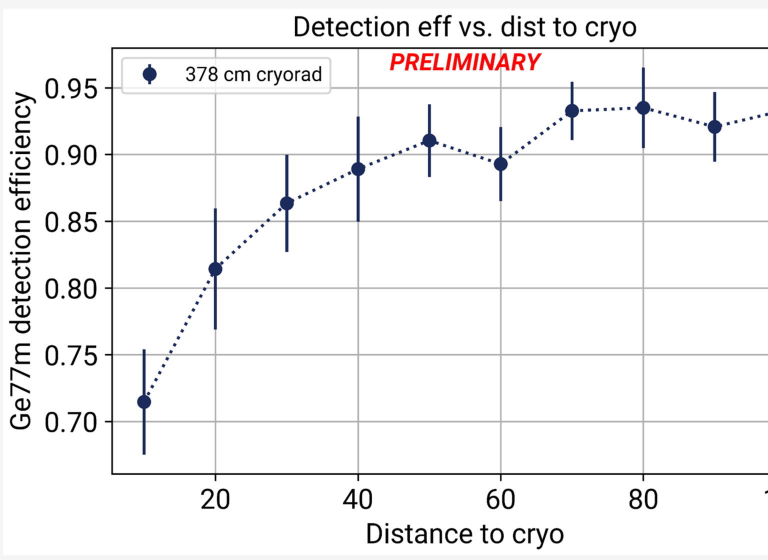
Decay scheme of $^{77(m)}$Ge (right) and the corresponding spectra (mid/right). Marked is the $Q_{\beta\beta}$ value of the 0νββ decay. Plots taken from [1].

The LEGEND water tank instrumentation uses a correlated trigger scheme to identify these signals. After a muon event, a 200 µs window is investigated for γs from neutron moderation. If within a window of 200 ns after a neutron event six other neutrons are observed, a moderated neutron was found, and the detector is vetoed for ≈ 6 min.

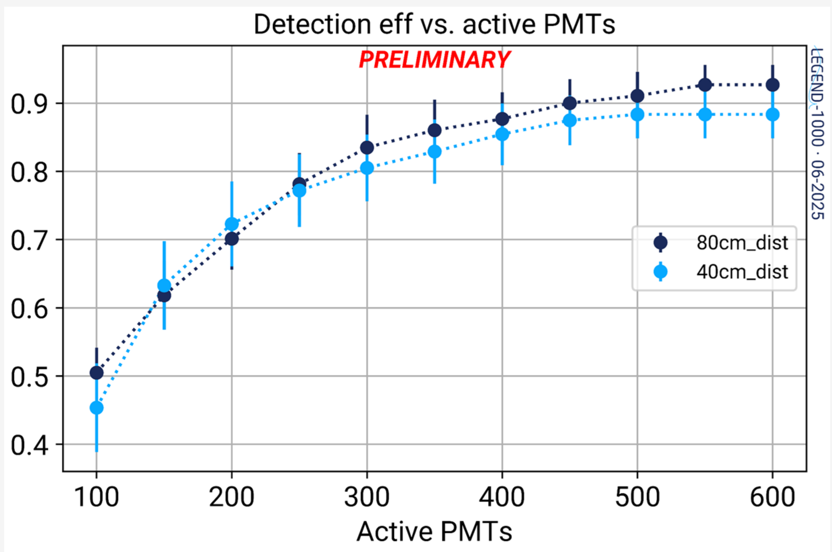


Trigger scheme of the neutron tagger as used in LEGEND.

To guarantee the sensitivity of the water tank instrumentation to such events, the tagging performance needs to be carefully investigated. Given the limitation to events that create at least six neutron captures, the analysis is limited to ≈50% of all $^{77(m)}$Ge producing events. Hence, a thorough set of simulations regarding the tagging performance has been conducted.



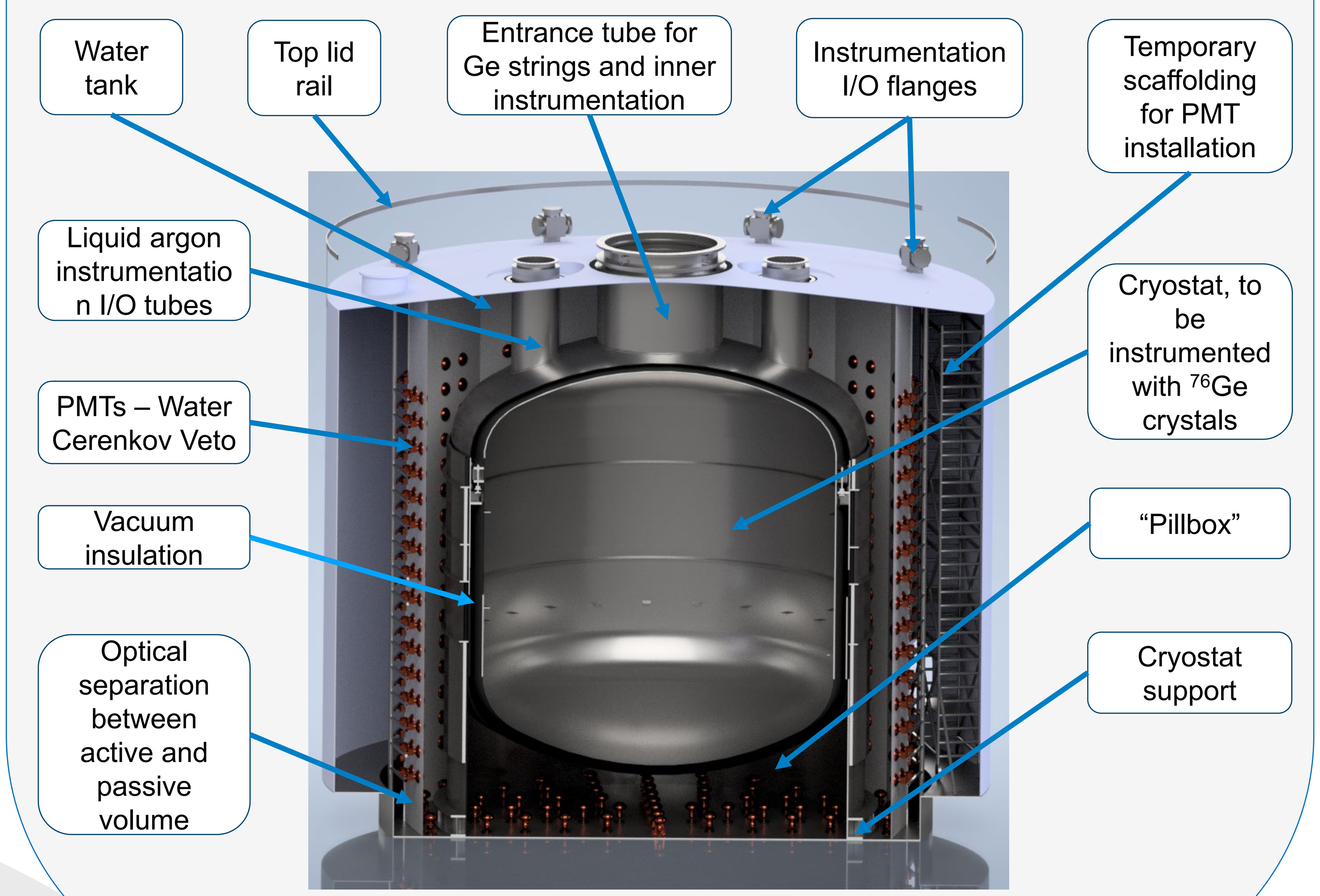
Simulation results of the ^{77m}Ge detection efficiency of all events that produce at least six neutron captures as a function of the distance of the PMTs to the cryostat



Simulation results of the ^{77}Ge detection efficiency of all events that produce at least six neutron captures as a function of PMTs

The final verdict of these simulation led to the final design of the water tank instrumentation: The PMTs will be placed 50cm away from the outer cryostat wall, with 350 PMTs used. These parameters provide the optimal balance between cost, performance and infrastructural requirements (mounts, FADCs, etc.).

Hardware: Status



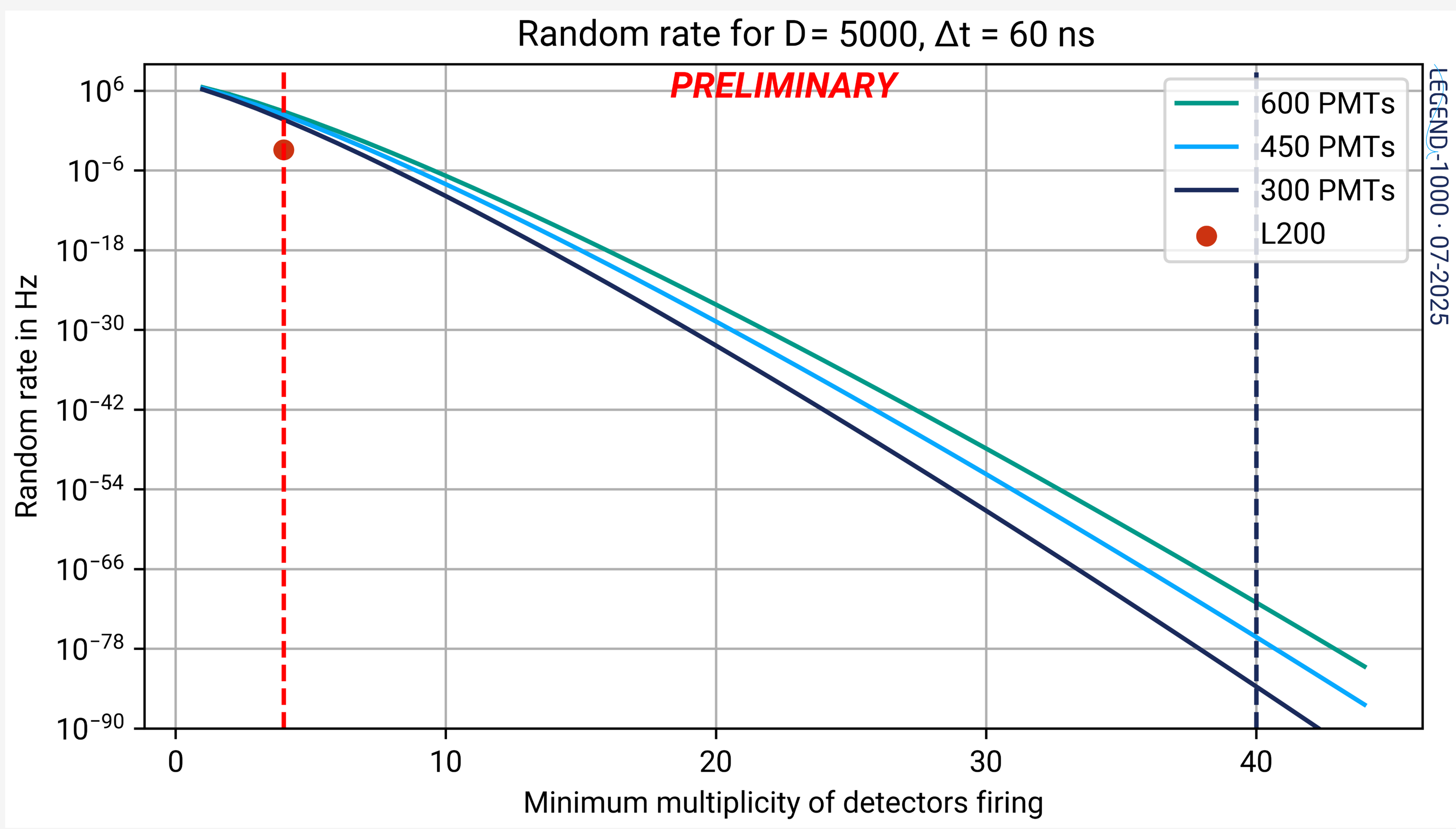
Muon veto

In addition to the possible creation of $^{77(m)}$Ge, muons inflict an additional background to the measurements of LEGEND. This includes direct energy deposition in the germanium crystals as well as Cherenkov radiation which can deposit energy in the crystals creating background signals. Using a two-volume veto design, one covering the space around and above the cryostat and one covering the space below, simulations show that the water Cherenkov muon veto reaches a veto efficiency of >99%.
Since the number of used PMTs (see box on the left) impacts the expected random coincidence rate and hence the veto performance, calculations have been done to estimate the expected rates:

$$D_C = \binom{F}{N} D^N \cdot (\Delta t)^{N-1} = \frac{F!}{N! \cdot (F-N)!} D^N \cdot (\Delta t)^{N-1}$$

Random coincidence (D_C) with the dark count rate (D) of the PMTs, the coincidence window (Δt), the number of PMTs (F) and the triggering multiplicity (N).

This leads to the majority level of 40 which will be used by LEGEND-1000, leading to a veto efficiency of >99% whilst reducing the random coincidence level to a negligible level. Due to the limitations provided by the $^{77(m)}$Ge tagging requirements (box on the left), the final number of PMTs of the water tank instrumentation will be 350.



Random coincidence in the muon veto vs. trigger multiplicity of the system. Both, the chosen value for LEGEND200 as well as the desired level for LEGEND1000 are shown.

Acknowledgements

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Footnotes

[1] Institutional Board membership suspended since April 26, 2022
[2] https://doi.org/10.1140/epjc/s10052-018-6079-3

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