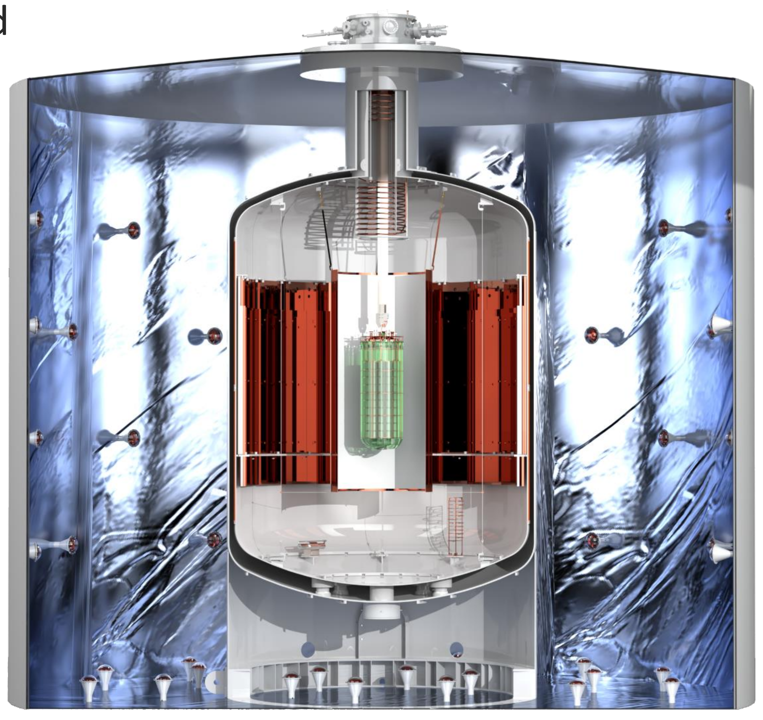
Muon Veto of the LEGEND Experiment

Gina Grünauer and Josef Jochum on behalf of the **LEGEND collaboration**
University of Tübingen, Germany
Contact: gina.gruenauer@uni-tuebingen.de

LEGEND Experiment

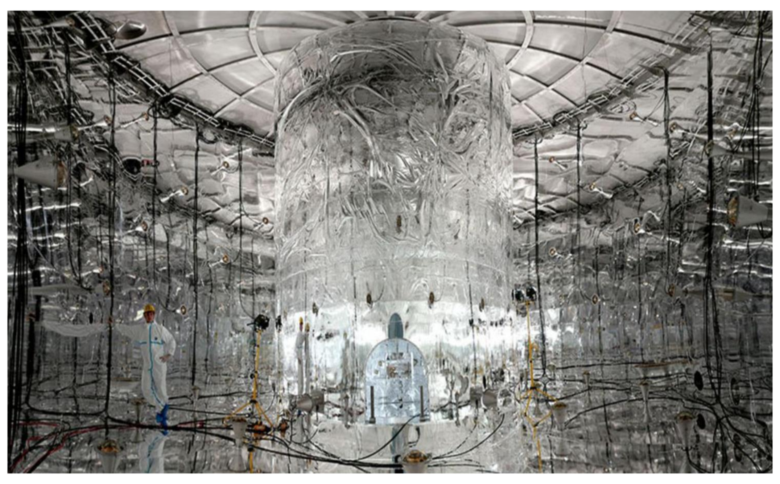
- **L**arge **E**nriched **G**ermanium **E**xperiment for **N**eutrinoless ββ **D**ecay
- Search for the neutrinoless ββ decay of enriched ^{76}Ge
- Two phased experiment:
  - Current experimental phase LEGEND-200:
    → 200 kg of High Purity Germanium (HPGe) detectors
    → Data taking for about 5 years, achieving a sensitivity of $T_{1/2} > 10^{27}$ yr
  - Planned experimental phase LEGEND-1000:
    → 1000 kg of HPGe detectors with background goal of around 0.025 cts/(FWHM·t·yr)
    → Sensitivity goal of $T_{1/2} > 10^{28}$ yr[1]

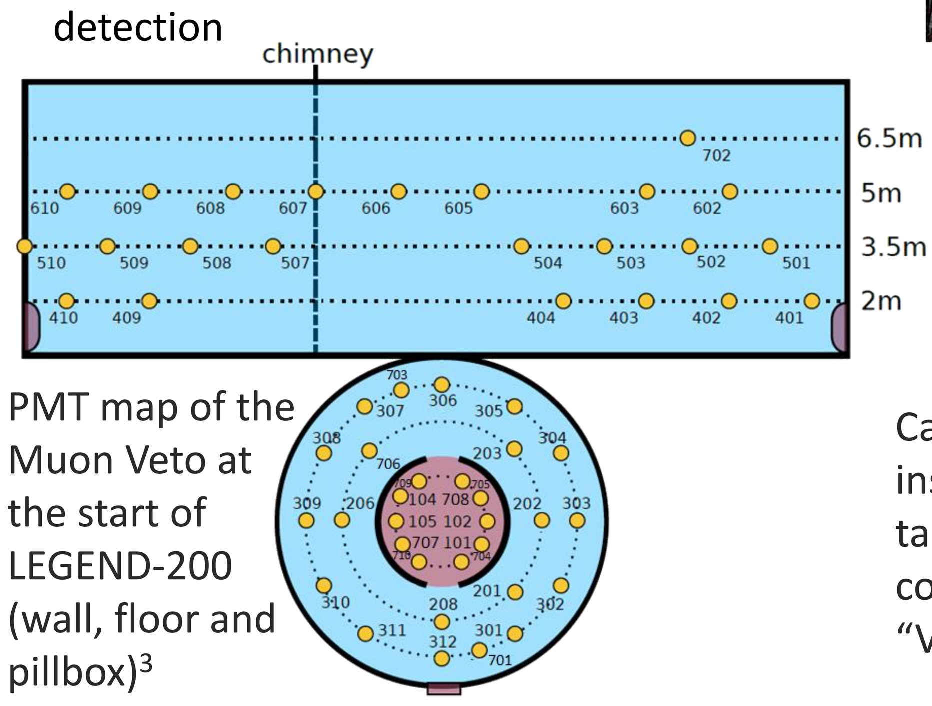


LEGEND-200:
HPGe detectors: mainly inverted coaxial point contact (ICPC) with an active mass up to 3 kg
LAr Instrumentation: background rejection using scintillation light from energy depositions in LAr
Muon Veto: Water-Cherenkov-Veto with photomultiplier tubes (PMTs) as light detectors

LEGEND-200 Muon Veto

- Water-Cherenkov-Veto system as active background rejection
- PMTs as light detectors
- Stainless steel tank filled with ultrapure water and covered with a reflective foil to increase the light yield
- Muon Veto is reused from GERDA[2] with changes in PMT positions for better muon detection



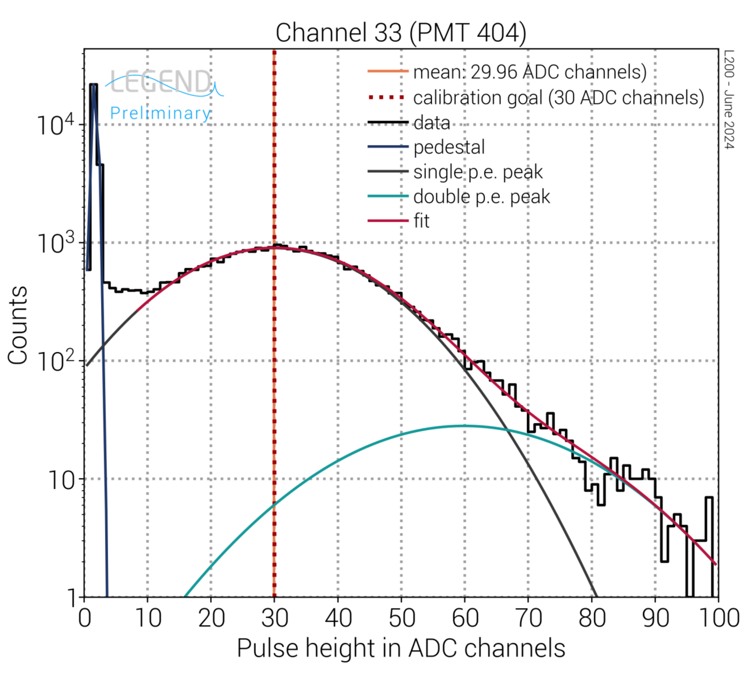


PMT map of the Muon Veto at the start of LEGEND-200 (wall, floor and pillbox)[3]

- Higher PMT coverage across the Floor and Pillbox (red area on the left) than across the Wall

Capsuled PMT inside the water tank which is covered with "VM2000"[4]

Muon Veto Calibration



- 5 LED diffuser balls pulsed
- Measure the single photoelectron (p.e.) peak
- Calibration goal: gain corresponding to 30 ADC channels for 1 p.e.
  → show peaks up to 100 p.e. with used 12-bit ADC

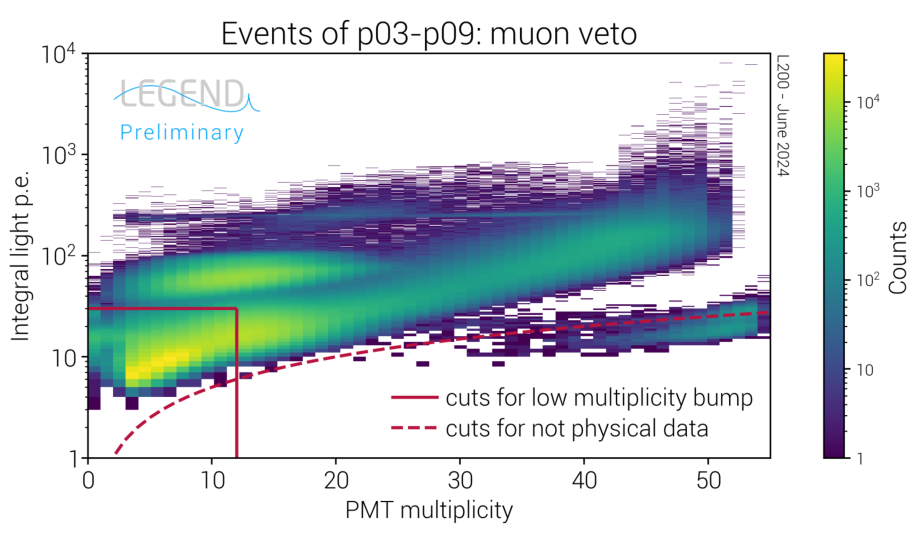
Calculation of supplied PMT voltage:

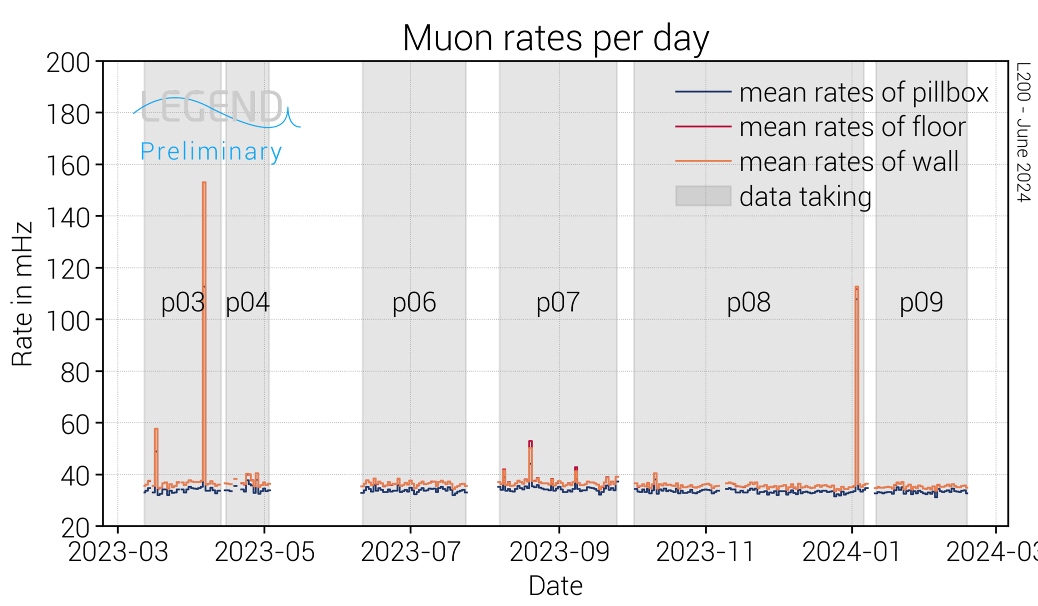
$$V_{target} = V\left(\frac{g_{target}}{g}\right)^{\frac{1}{kn}}$$

with $n = 12$ Dynodes, $g_{target} = 30$ ADCs, the gain $g = \frac{Q}{e}$, the supplied voltage V, constant k

Muon Veto Events

- Muon induced events selected by two cuts (see plot on the right):
  - So-called "low multiplicity bump" caused by scintillation of the reflective foil: $multiplicity \leq 12$ and a $p.e. \leq 30$
  - "Nonphysical data" caused by digital noise: $\frac{p.e.}{multiplicity} \leq 0.5$
- Islands above muon branch caused by bright flashes during PMT breaks (lasting for a few seconds)





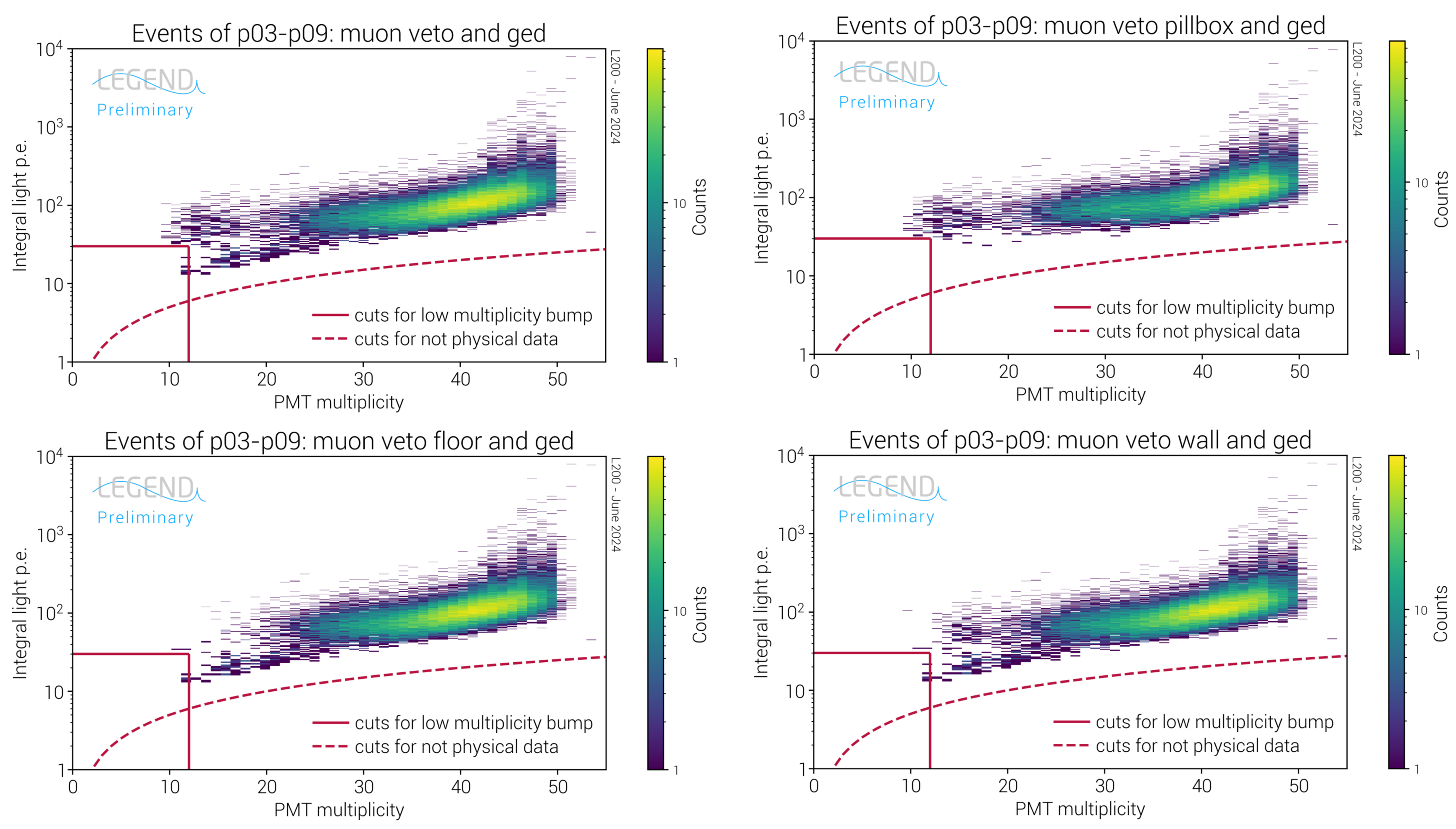
- Corresponding muon rates (without PMT breaks) per day shown on the plot on the left side
- Minor gaps due to calibrations between the runs and larger gaps due to data validation
- Peaks caused by PMT flashes for a few seconds, not affecting other data taking
- Total muon rate stable at around 35 mHz

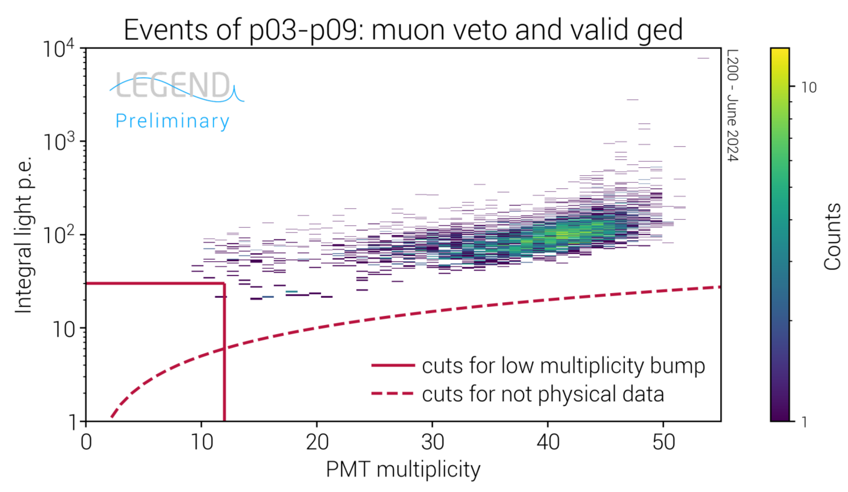
References

[1][arXiv:2107.11462]
[2]https://www.mpi-hd.mpg.de/gerda/public/2008/c08_ndip08_MuonVeto_mk.pdf
[3]https://www.mpi-hd.mpg.de/gerda/public/2014/phd2014_kaiFreund.pdf
[4][arXiv:1601.05935]

Coincidences

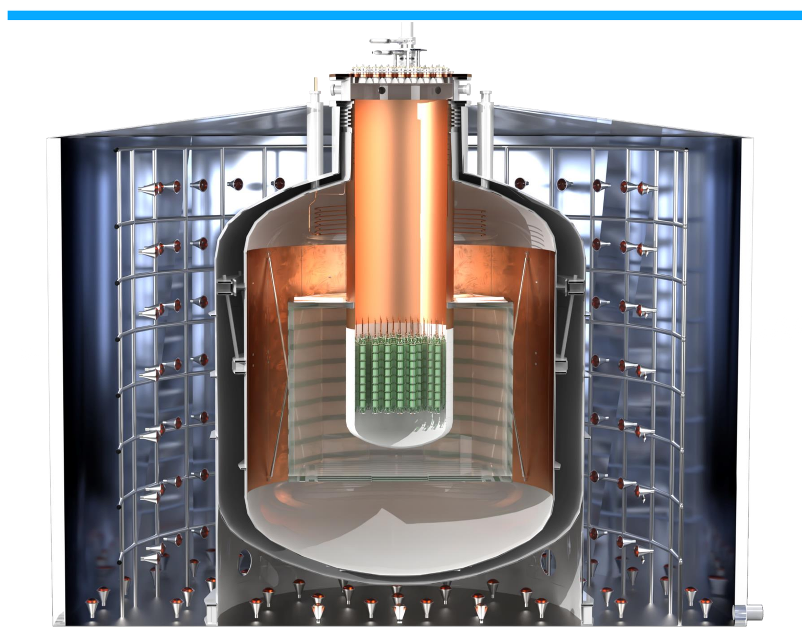
- Coincident muon events between HPGe events and the muon veto (see plots below)
- Comparison of individual areas led to a muon identification of:
  - 73.8% pillbox
  - 99.4% floor
  - 99.8% wall
- Measuring all the coincident muons
  → Need combination of the pillbox with only one of the other two areas (floor or wall)





With additional quality cuts (multiplicity, pulse shape, …) of HPGe detectors:
→ 7.8% of coincident events are valid HPGe events (see plot on the left side)

Muon Veto Plans for LEGEND-1000



Schematic representation of outer muon veto and inner neutron tagger around the cryostat of LEGEND-1000

Current plans for the muon veto of LEGEND-1000:
- Larger tank (5 times higher detector mass)
  → more PMTs
- Muon veto PMTs placed only on floor and pillbox
- New reflective foil to avoid low multiplicity bump
- Discussions about additional neutron tagger:
  - PMTs mounted on a scaffolding directly surrounding the LAr cryostat
  - Increase light yield for neutron capture
    → Gadolinium loaded moderator

Centre for Energy, Environmental and Technological Research
Comenius University
Czech Technical University in Prague and IEAP
Daresbury Laboratory
Duke University and Triangle Universities Nuclear Laboratory
Gran Sasso Science Institute
Indiana University Bloomington
Institute for Nuclear Research Russian Academy of Sciences
Jagiellonian University
Joint Institute for Nuclear Research
Joint Research Centre Geel
Laboratori Nazionali del Gran Sasso
Lancaster University
Leibniz Institute for Crystal Growth
Leibniz Institute for Polymer Research
Los Alamos National Laboratory
Max Planck Institute for Nuclear Physics
Max Planck Institute for Physics
National Research Centre "Kurchatov Institute"
National Research Nuclear University MEPhI
North Carolina State University
Oak Ridge National Laboratory
Polytechnical University of Milan
Princeton University
Queen's University
Roma Tre University and INFN
Simon Fraser University
SNOLAB
South Dakota School of Mines and Technology
Technical University of Dresden
Technical University of Munich
Tennessee Technological University
University of California and Lawrence Berkeley National Laboratory
University College London
University of L'Aquila and INFN
University of Cagliari and INFN
University of California San Diego
University of Houston
University of Liverpool
University of Milan and INFN
University of Milano Bicocca and INFN
University of New Mexico
University of North Carolina at Chapel Hill
University of Padova and INFN
University of Regina
University of South Carolina
University of South Dakota
University of Tennessee, Knoxville
University of Texas at Austin
University of Tuebingen
University of Warwick
University of Washington and Center for Experimental Nuclear Physics and Astrophysics
University of Zurich
Williams College