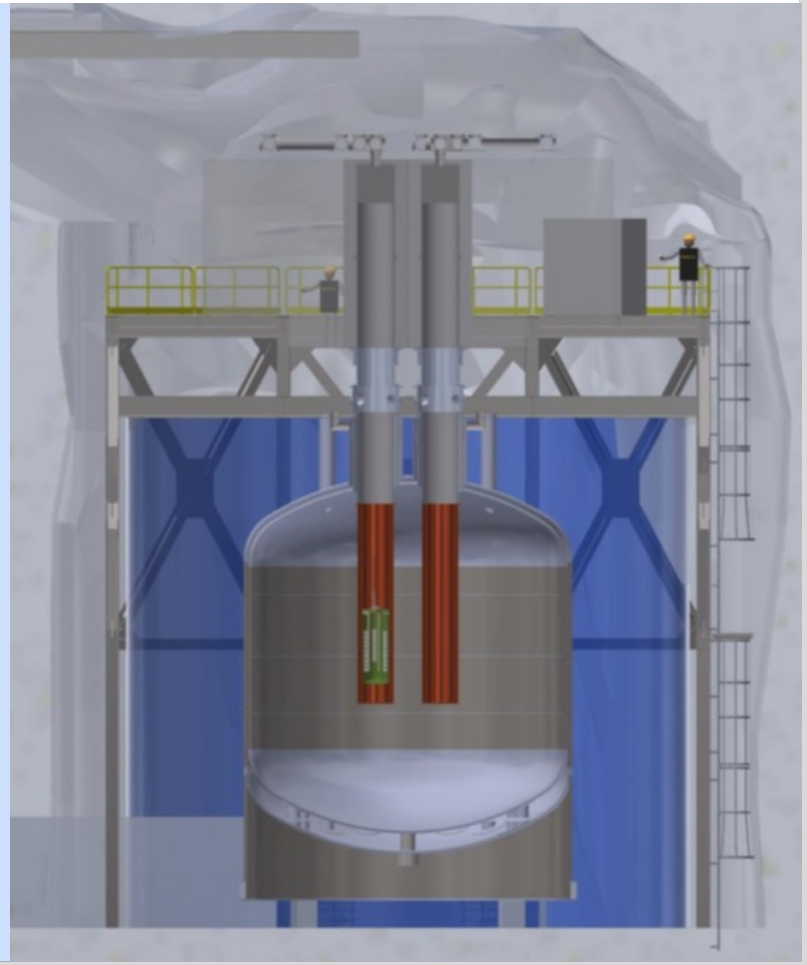
The search for neutrinoless double beta decay with LEGEND: status and outlook

LEGEND

Large Enriched
Germanium Experiment
for Neutrinoless ββ Decay



George Marshall on behalf of the LEGEND Collaboration

3rd –9th July 2023

WIN 2023

UCL

WIν2023
ZHUHAI CHINA

Large **E**nriched **G**ermanium **E**xperiment for **N**eutrinoless ββ **D**ecay – LEGEND
47 institutions, About 260 scientists

LEGEND mission: "The collaboration aims to develop a phased, ^{76}Ge 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."

Univ. New Mexico
L'Aquila University and INFN
Lab. Naz. Gran Sasso
University Texas, Austin
Lawrence Berkeley Natl. Lab.
University California, Berkeley
Leibniz Inst. Crystal Growth
Indiana University
Comenius University
Simon Fraser University

University of North Carolina
University of South Carolina
Tennessee Tech University
University of Warwick
Jagiellonian University
Technical University Dresden
Joint Inst. Nucl. Res.
Duke University
Polytechnical University of Milan

Triangle Univ. Nuclear. Lab.
Joint Research Centre, Geel
Max Planck Institute, Heidelberg
Queens University
University Tennessee
Lancaster University
University Liverpool
University College London
Los Alamos National Lab.

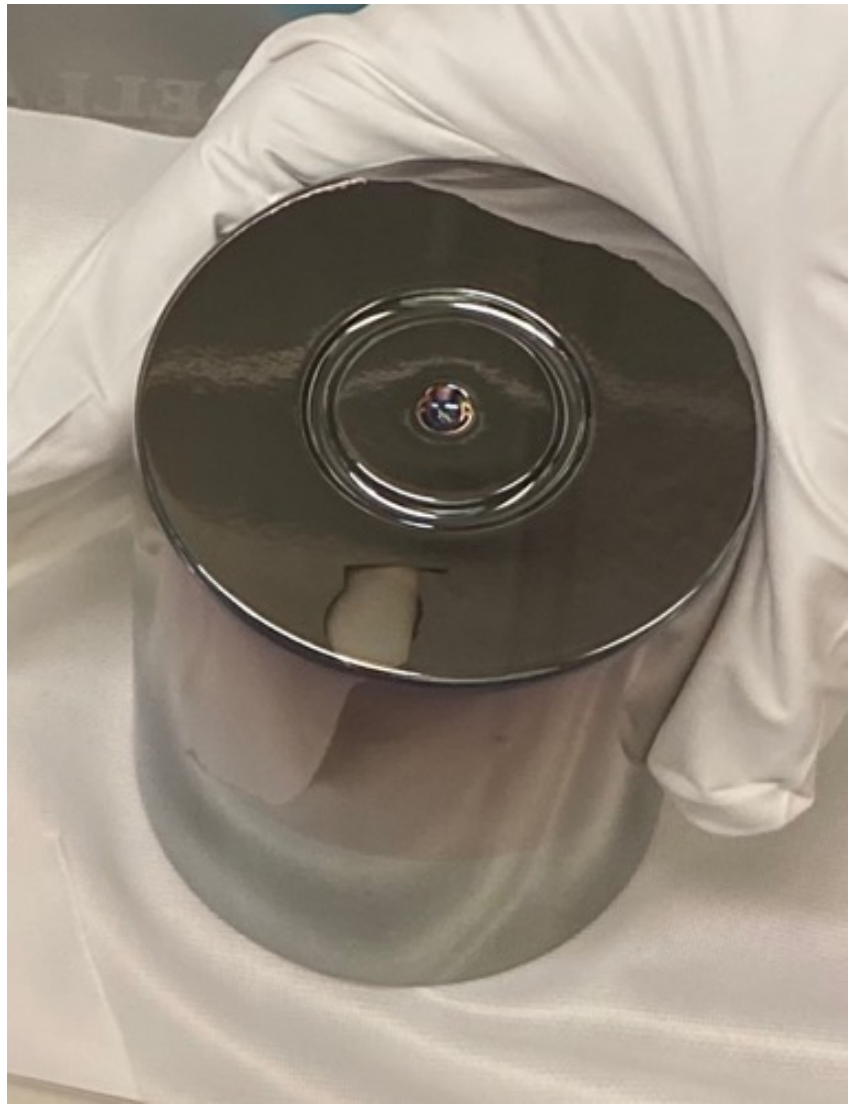
INFN Milano Bicocca
Milano University and Milano INFN
Institute Nuclear Research Russ. Acad. Sci.
National Research Center Kurchatov Inst.
Lab. Exper. Nucl. Phy. MEPhI
Max Planck Institute, Munich
Technical University Munich
Oak Ridge National Laboratory
Padova University
Padova INFN
Daresbury Laboratory

Czech Technical University Prague
North Carolina State University
South Dakota School Mines Tech.
University Washington
University Tübingen
University South Dakota
Williams College
University Zurich
University of Regina

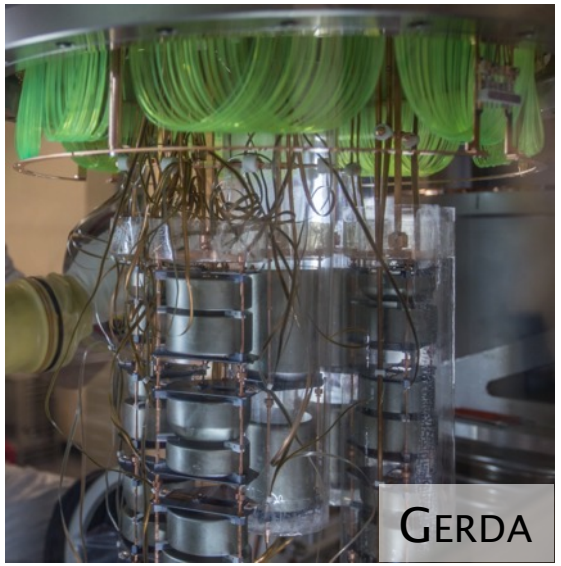
Why Germanium?

$$^{76}\mathrm{Ge} \longrightarrow {}^{76}\mathrm{Se} + 2e^{-}$$

- Q-value of 2039 keV
- Source = detector -> high detection efficiency
- Excellent energy resolution
- Low intrinsic background
- High density -> point like events
- Can be enriched to >90% in isotope of interest ^{76}Ge

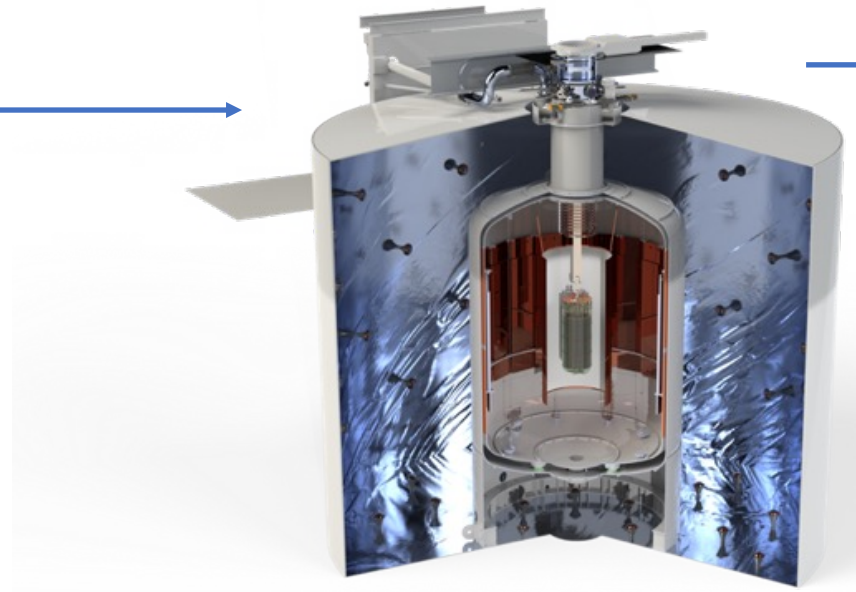


LEGEND



- Formed from the merger of Majorana and Gerda
- Following a phased approach towards a discovery

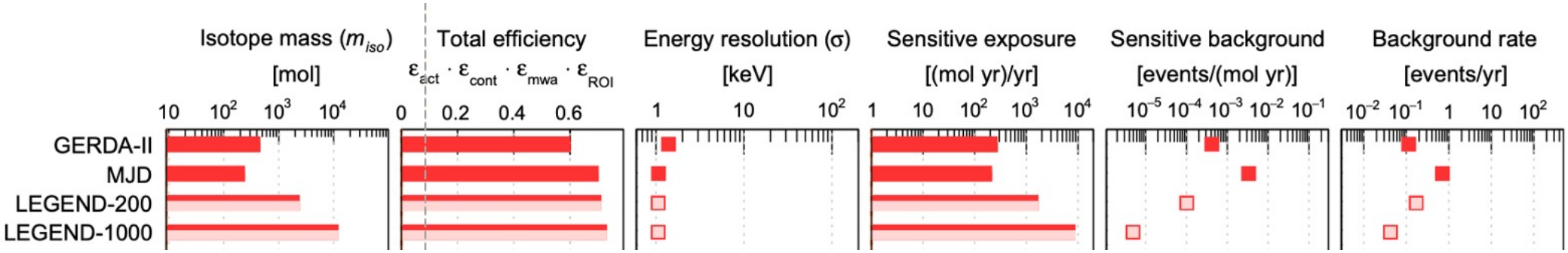
LEGEND-200



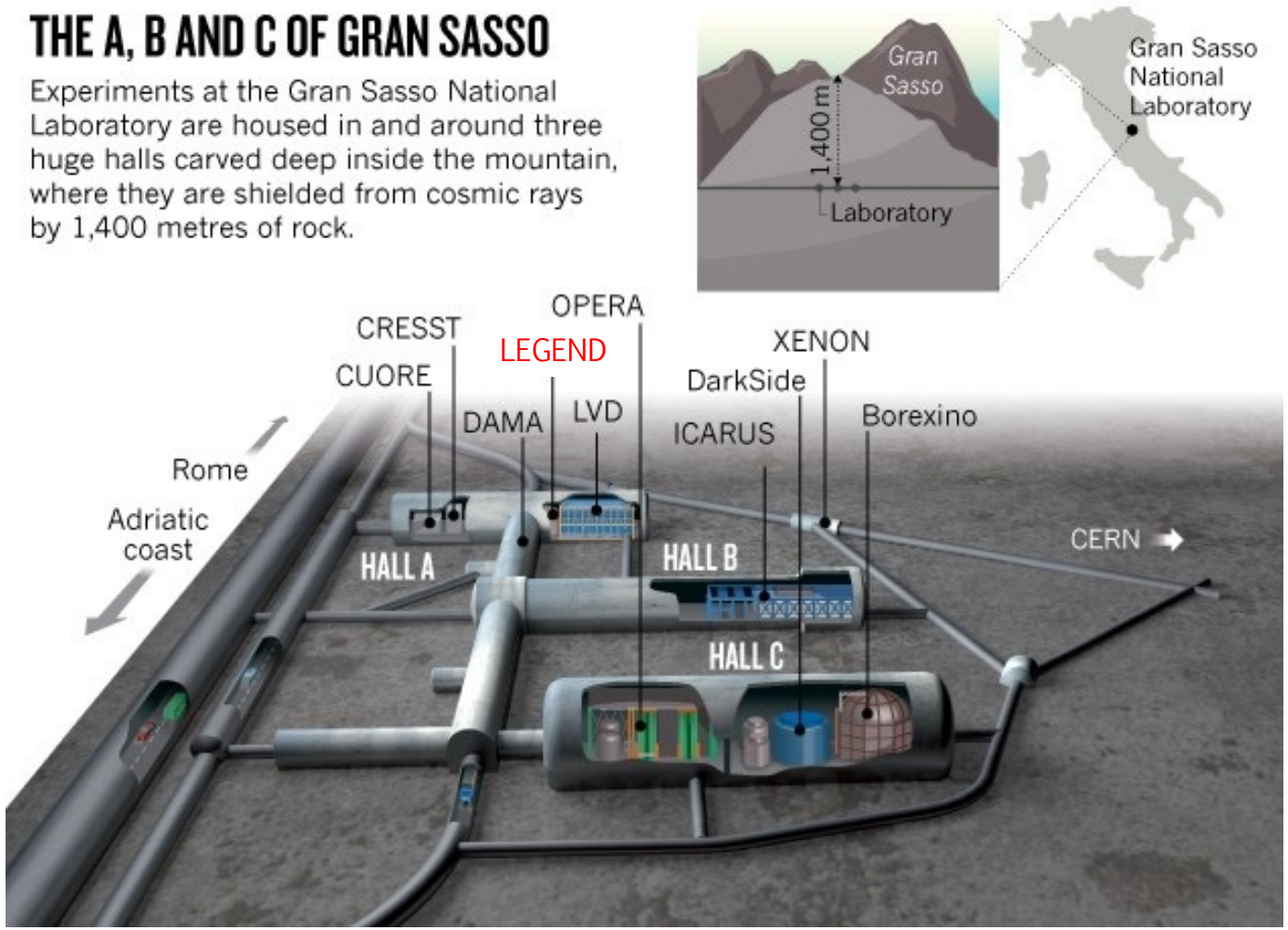
LEGEND-1000

LEGEND

- At each stage:
  - Increase target mass by order of magnitude
  - Decrease background by order of magnitude
  - Increase sensitivity by order of magnitude
  - While preserving excellent energy resolution and efficiency



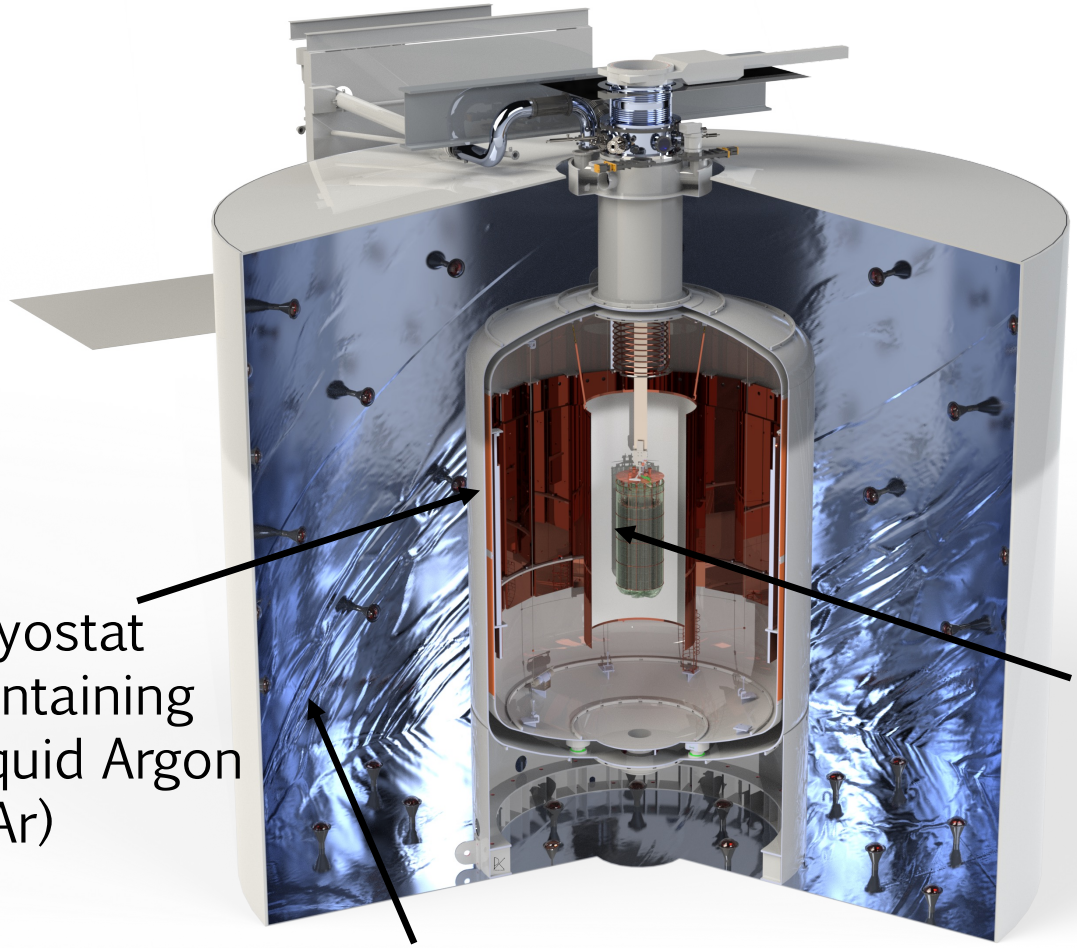
LEGEND-200 – Location



- Located in Hall A at Gran Sasso, Italy
- Reusing the Gerda infrastructure
- 3600 m.w.e. depth to reduce cosmic flux

Nosengo, N. Gran Sasso: Chamber of physics. *Nature* **485**, 435–438 (2012). https://doi.org/10.1038/485435a

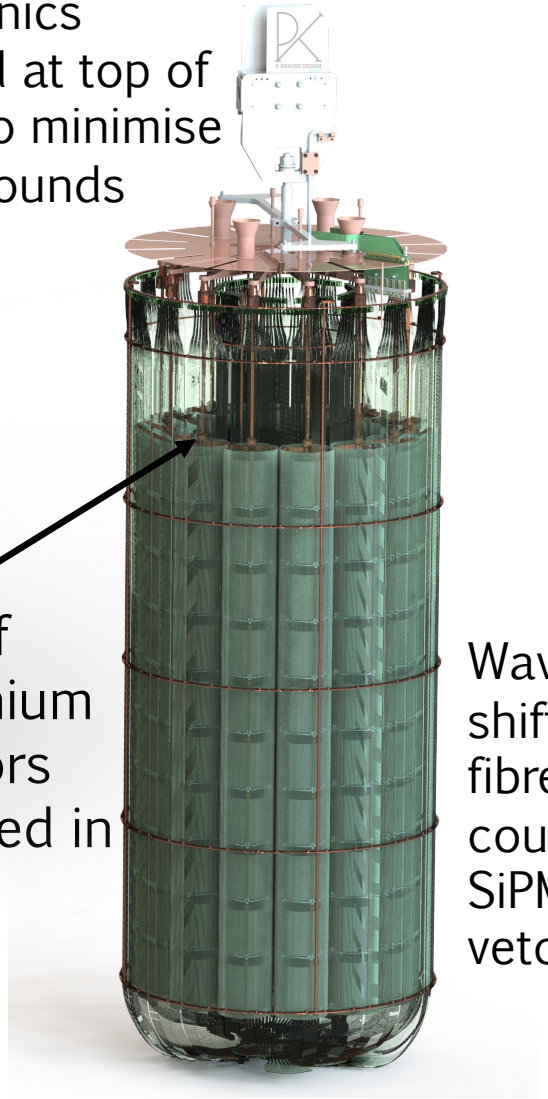
LEGEND-200 – Design



Cryostat containing Liquid Argon (LAr)

Water Tank instrumented with PMTs for muon veto

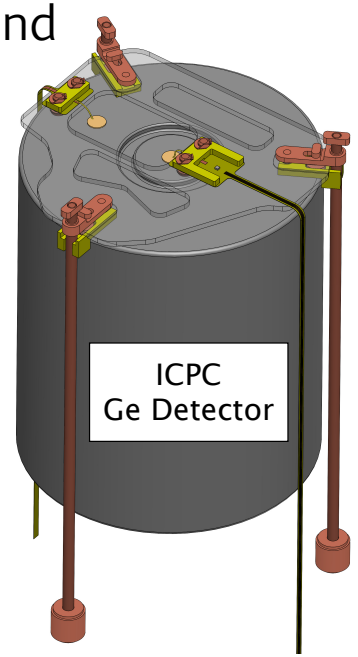
Electronics located at top of array to minimise backgrounds



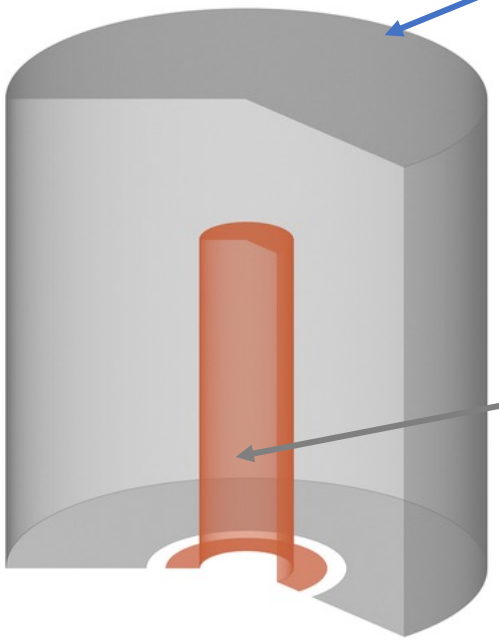
Array of Germanium Detectors organised in strings

Wavelength shifting fibres coupled to SiPMs for LAr vetoing

Solid State TPC, use event topology reconstruction to flag background



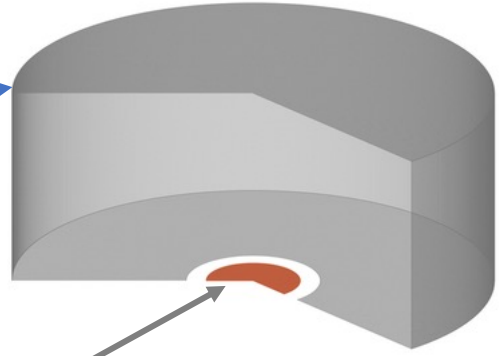
Detectors



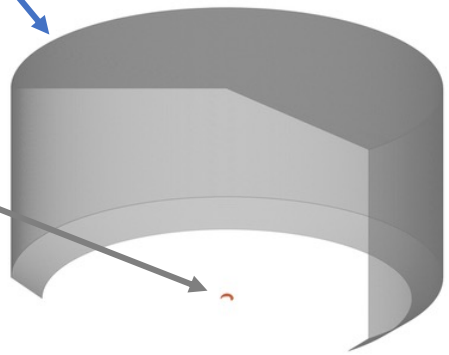
COAX

n+
contact

p+
contact



GERDA - BEGe



MAJORANA - PPC

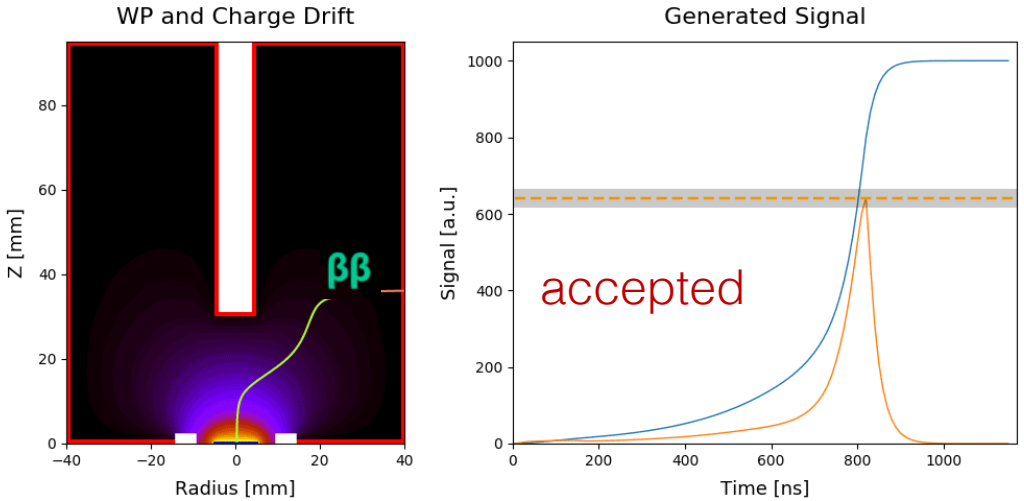
n+
contact

p+
contact

LEGEND - ICPC

Pulse Shape Analysis

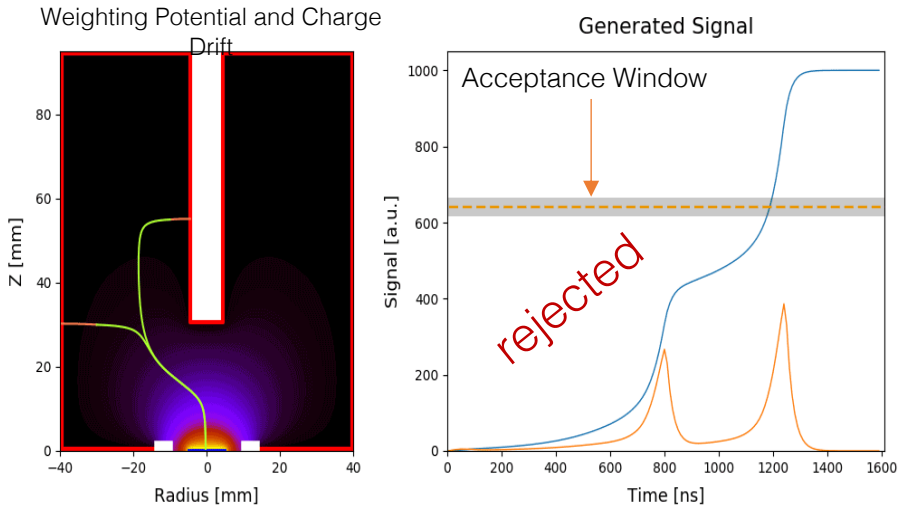
$0\nu\beta\beta$ signal candidate (single-site)



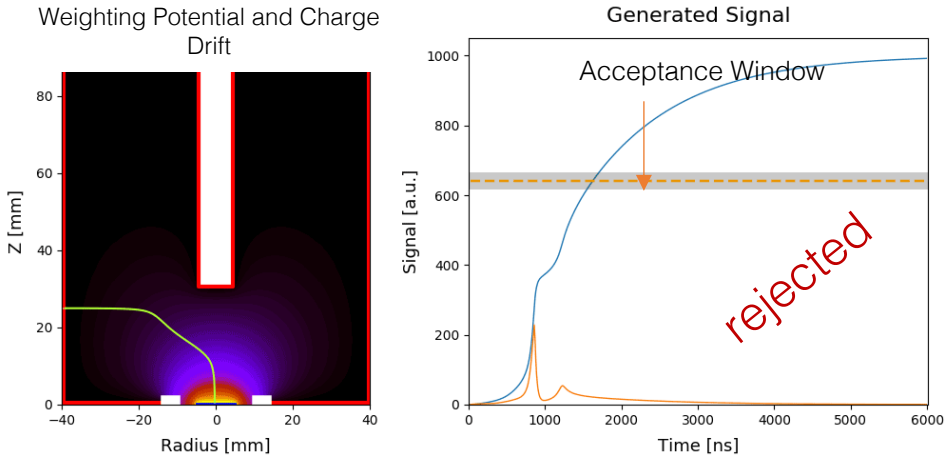
Charge signal

Current signal

γ-background (multi-site)



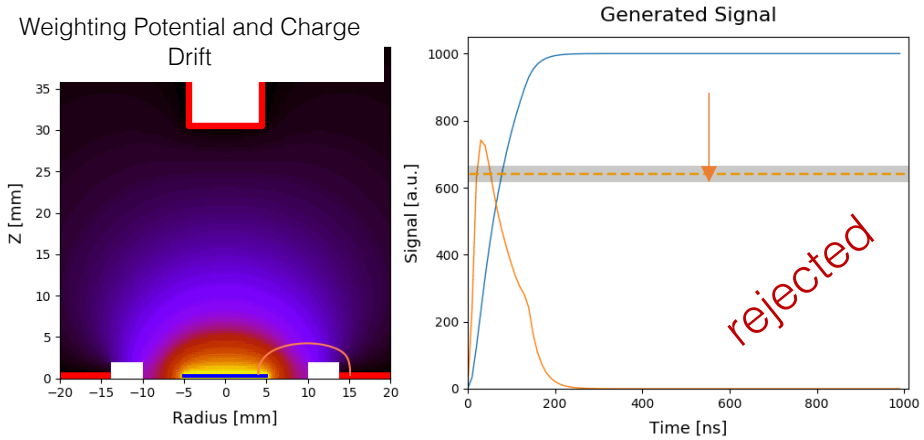
Surface-β-background ^{42}K (^{42}Ar) on n+ contact



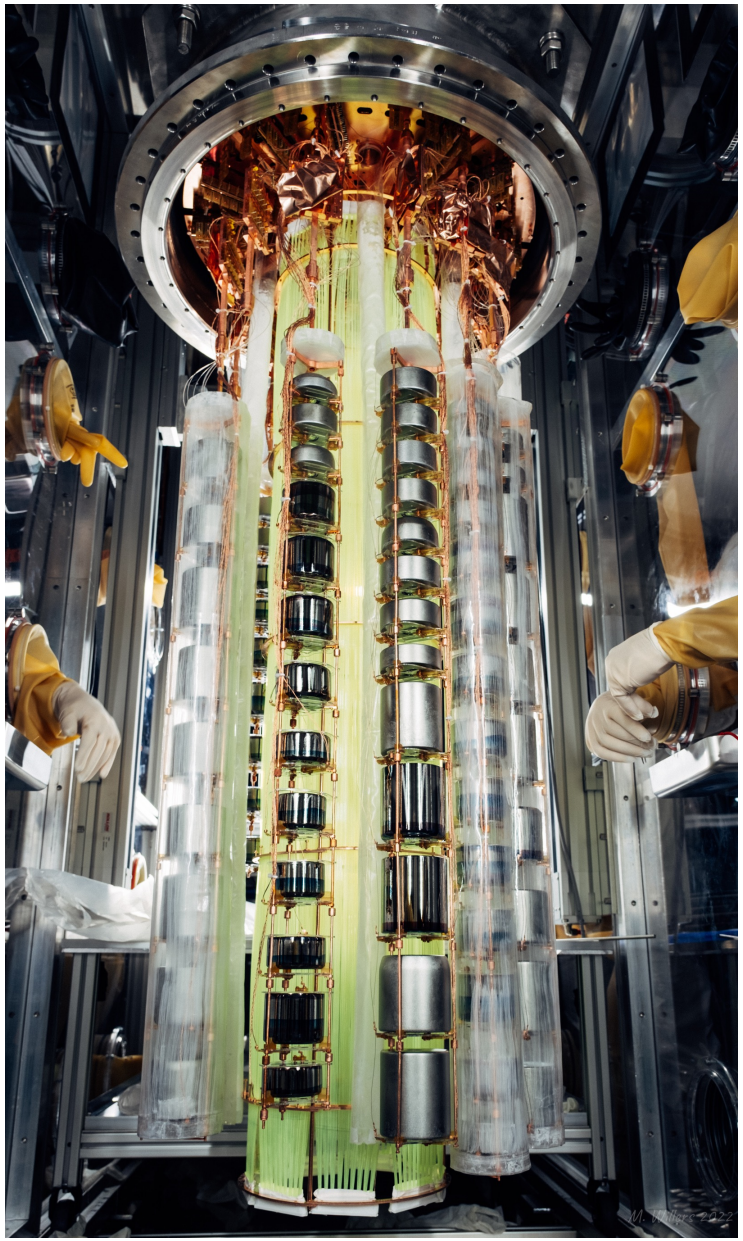
Charge signal

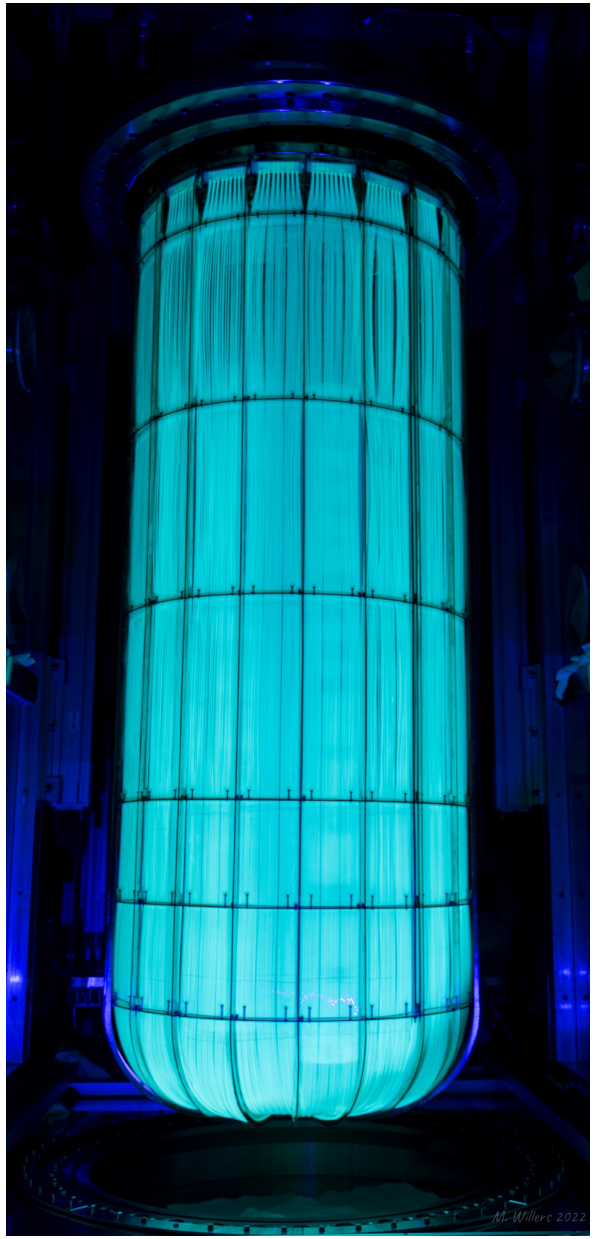
Current signal

α-background on p+ contact

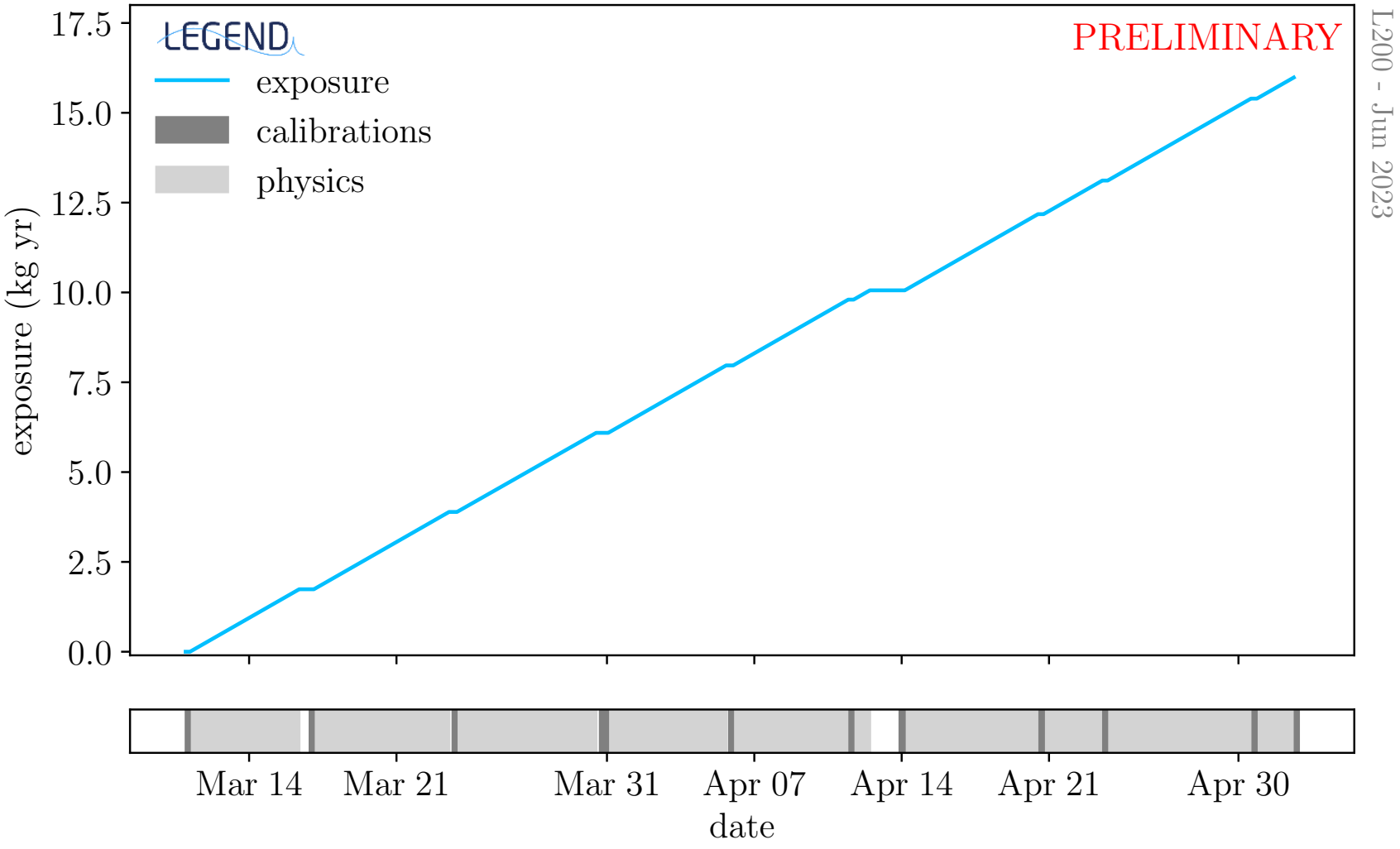


LEGEND-200 Deployment

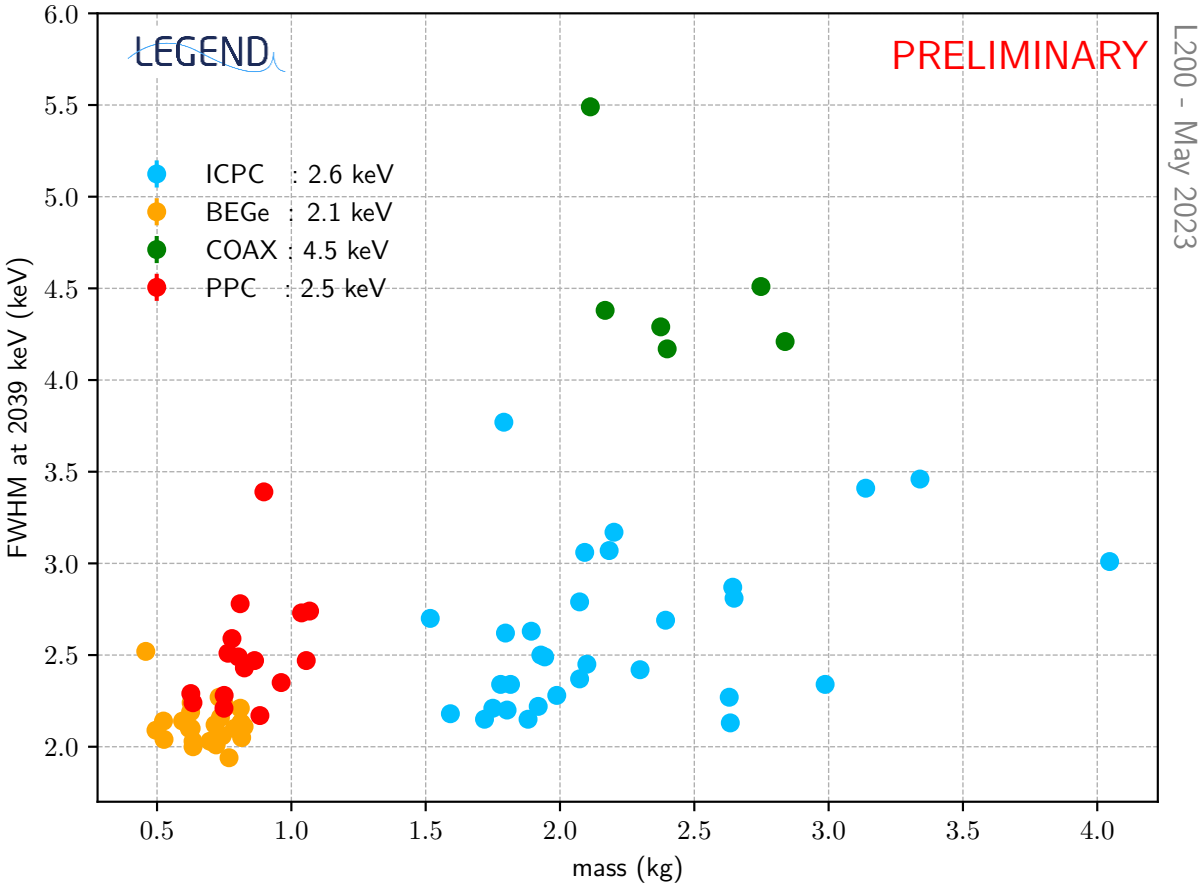




Exposure

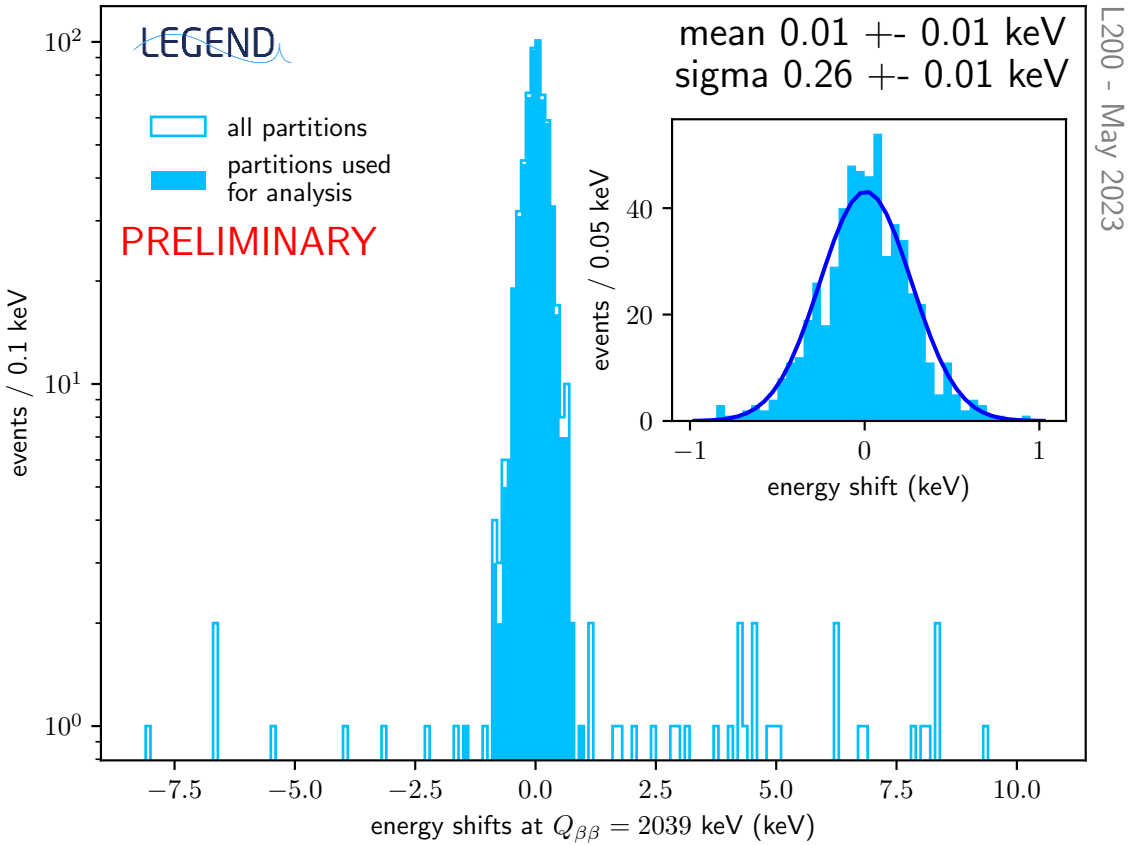

LEGEND
PRELIMINARY
exposure
calibrations
physics
exposure (kg yr)
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
Mar 14
Mar 21
Mar 31
Apr 07
Apr 14
Apr 21
Apr 30
date
L200 - Jun 2023

Germanium Detector Performance – Energy



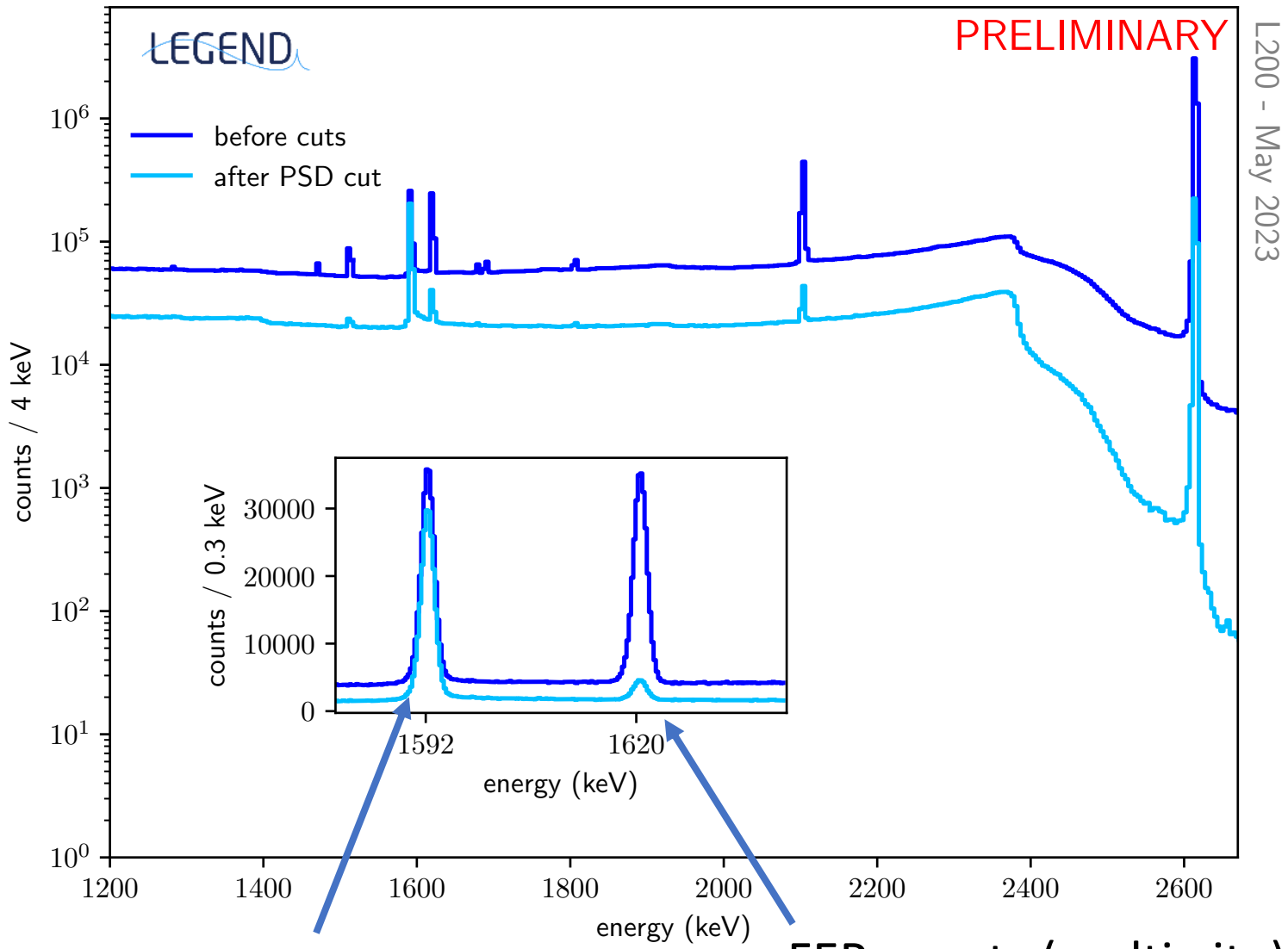
World Leading Energy Resolution ~2.5 keV

Detectors are very stable



All plots from ^{228}Th calibration data

Germanium Detector Performance – PSD

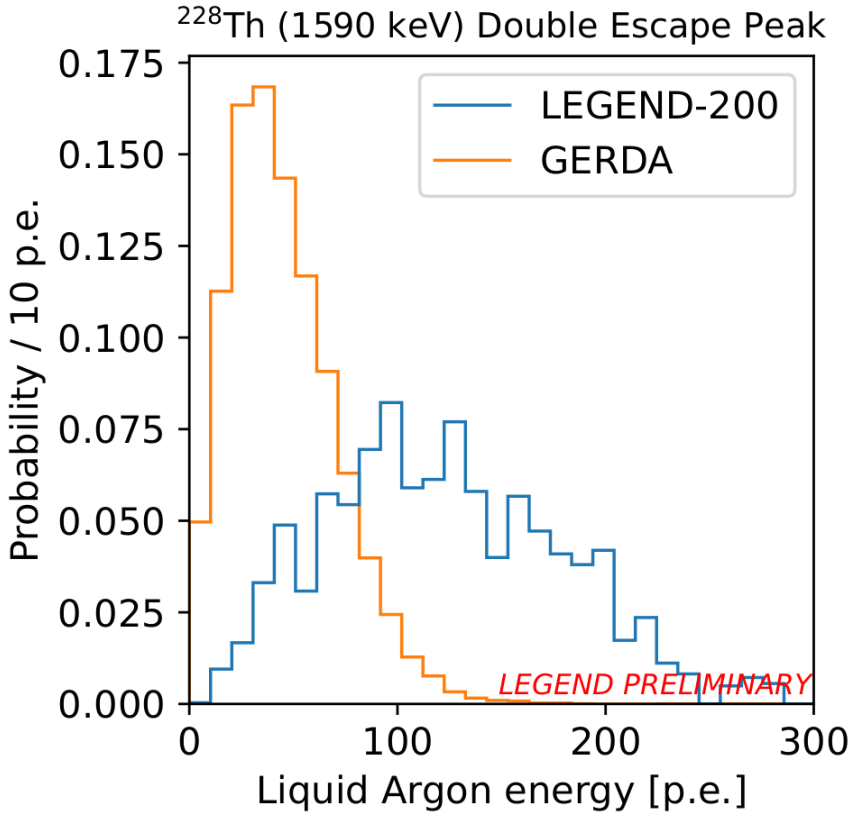


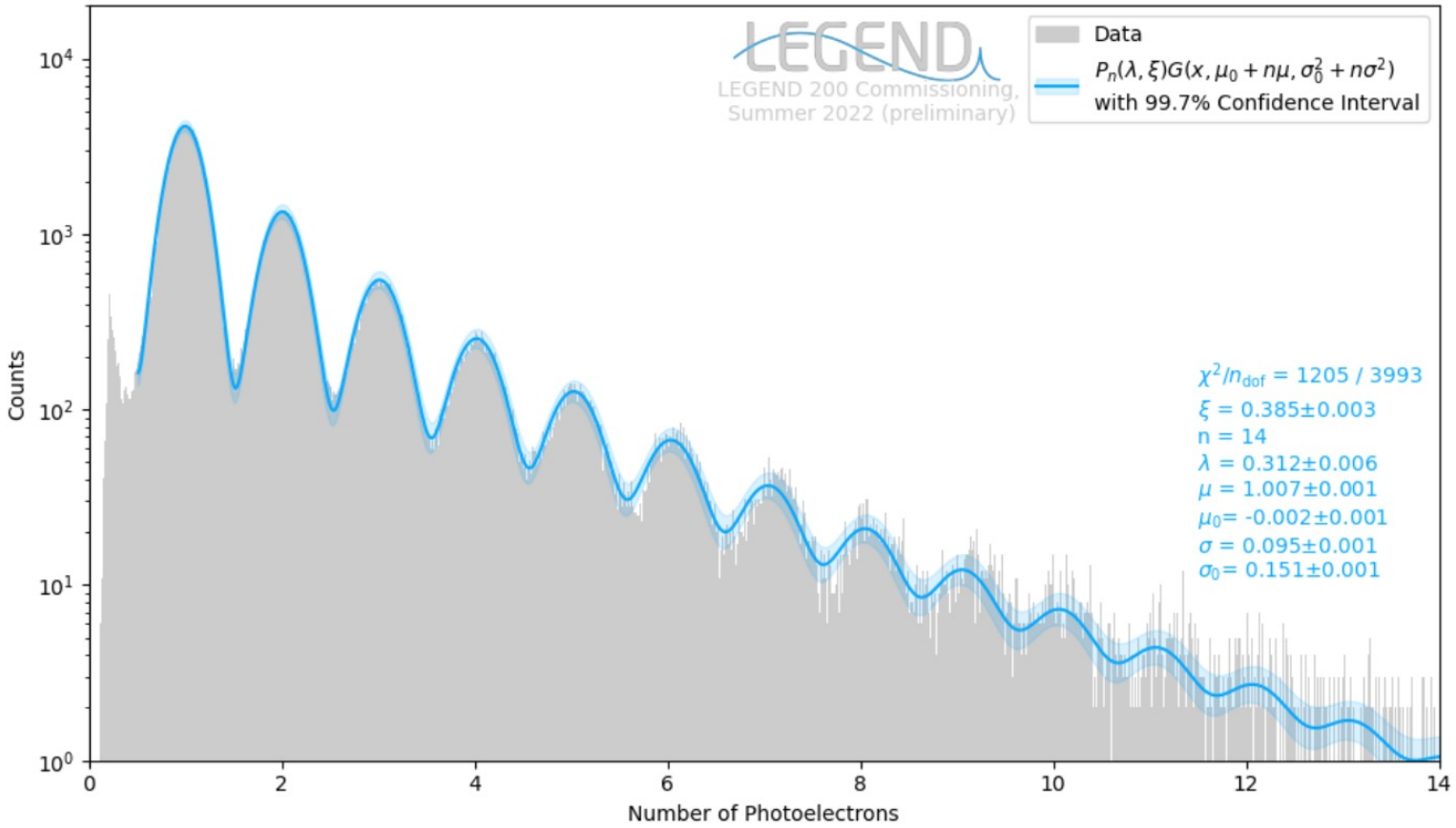
DEP events (single site proxy) well preserved

FEP events (multi-site) suppressed

All plots from ^{228}Th calibration data

Lar Scintillation-Light Detection Performance





LEGEND-1000

- 1000 kg of detectors
- Background level of $< 10^{-5}$ counts/kev.kg.yr
  - Mainly driven by switch to Underground Liquid Argon
  - Larger detectors >3 kg – less supporting material
- Discovery sensitivity of $> 10^{28}\ yrs$
- Highest ranked project in DOE Portfolio review
- CD1 in Dec
- DOE report on site selection expected soon

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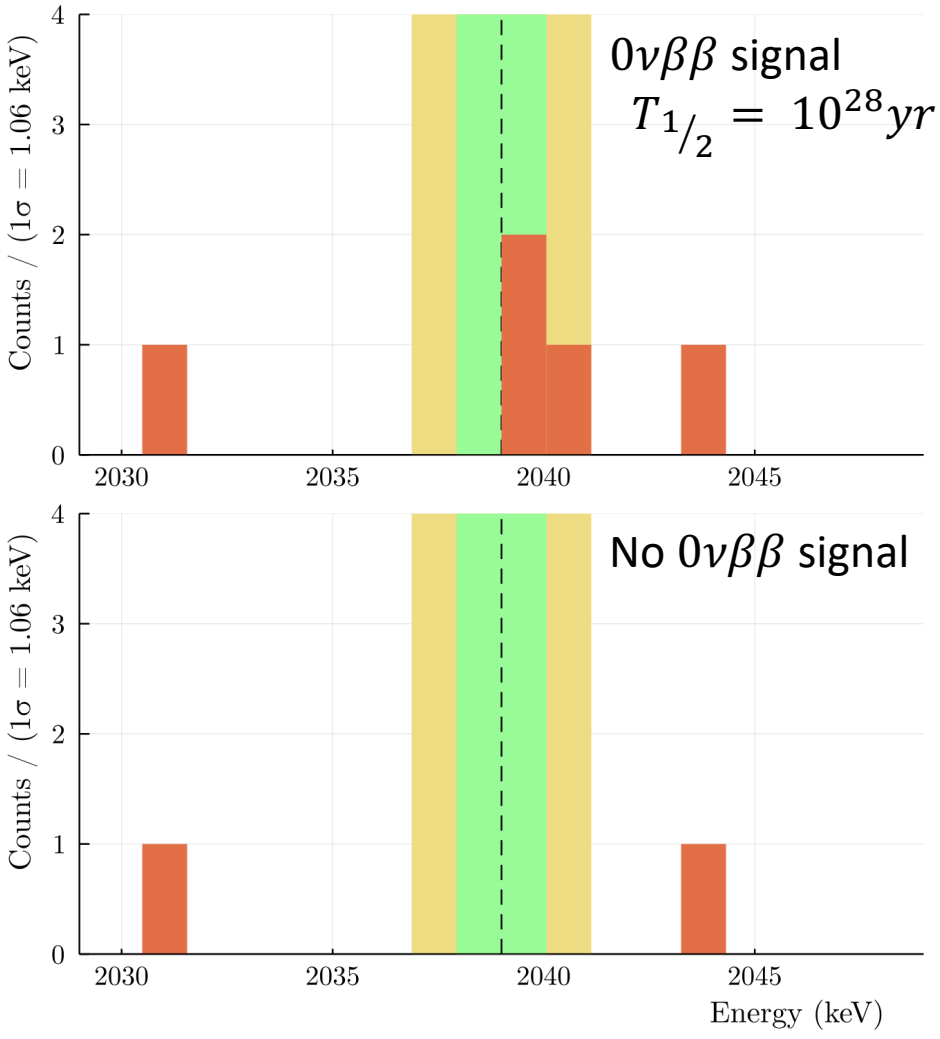
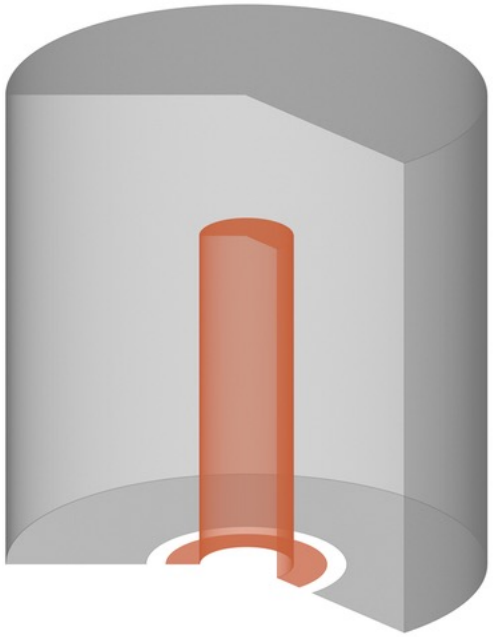


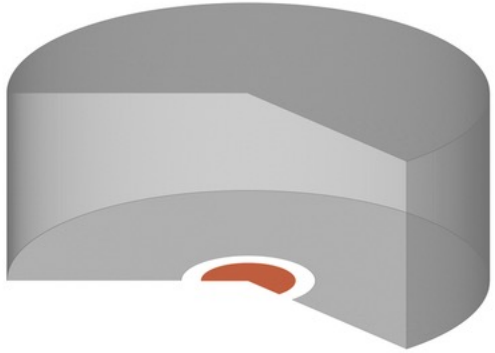
Summary

- Neutrinoless double beta decay would show neutrinos are Majorana and show that lepton number is violated
- LEGEND is searching for this process using germanium diodes
- LEGEND-200 is now taking physics data with performance as expected
- LEGEND-1000 aims to reach a discovery sensitivity of $> 10^{28}\ yrs$

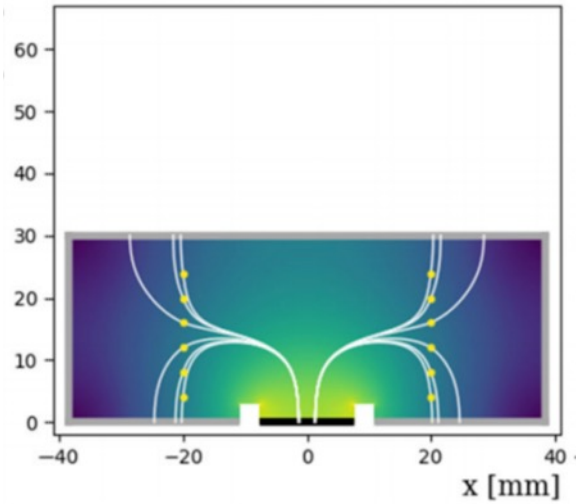
Detectors

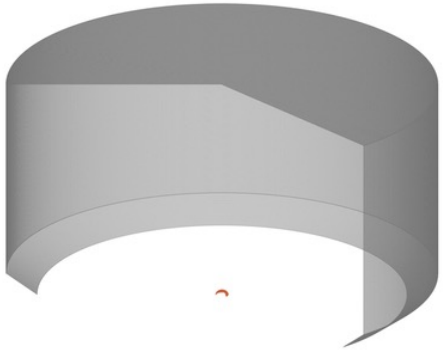
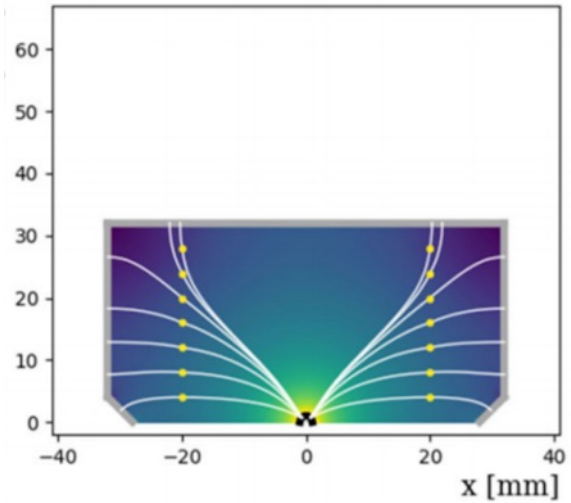


COAX



GERDA - BEGe





MAJORANA - PPC