GERDA and LEGEND

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on behalf of the GERDA and LEGEND collaborations

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Lake Louise Winter Institute,
Feb. 14th, 2019

The GERDA Experiment

- Search for $0\nu\beta\beta$ decay in $^{76}\mathrm{Ge}$ at $Q_{\beta\beta} = 2039$ keV
- Array of isotopically enriched HPGe detectors, suspended in liquid argon
- Ultra-low background setup, located underground at LNGS (1400 m rock overburden, 3500 m water equivalent)
- Phase I completed successfully
- Phase II: Increased target mass (BEGe detectors), lower background, active LAr veto
- Current status: Phase II data taking continues, after upgrade in Summer 2018

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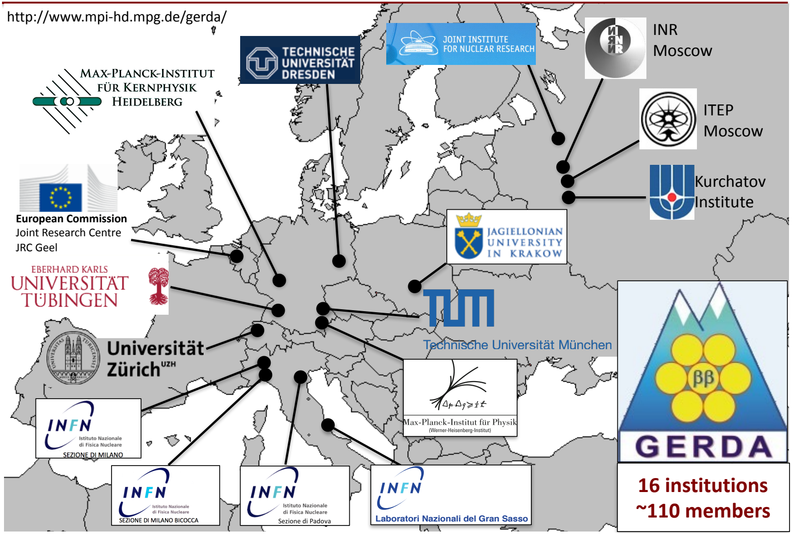
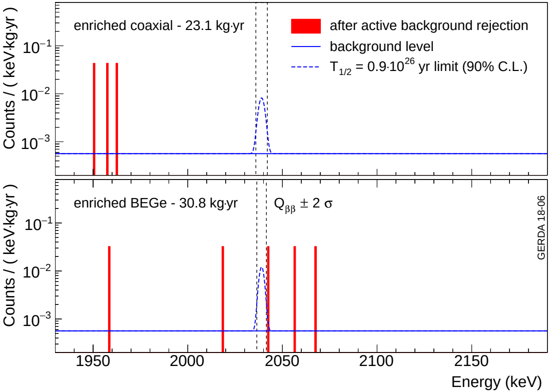
The GERDA Collaboration



Current GERDA Result



Phase I plus Phase II:

- Total exposure: 82.4 kg yr
- $T^{0\nu}_{1/2} > 0.9 \times 10^{26}$ yr (Frequentist)
- $T^{0\nu}_{1/2} > 0.8 \times 10^{26}$ yr (Bayesian)

Phase II design goals reached:

- Background in ROI $\approx 6 \times 10^{-4}$ cts/(keV· kg· yr)
- Sensitive to $T^{0\nu}_{1/2}$ of 1×10^{26} yr (90% CL)

NEUTRINO 2018, all limits: 90% CL/CI

The next step: LEGEND

- Large fractions of GERDA and MAJORANA plus new groups: New LEGEND collaboration [http://legend-exp.org/], 46 institutes world-wide.
- Two Phases:
  - LEGEND-200: 200 kg detector mass in GERDA cryostat, funding mostly in place
  - LEGEND-1000: 1000 kg detector mass, proposal for the future, host-lab search ongoing

[arXiv:1709.01980]

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The LEGEND Collaboration

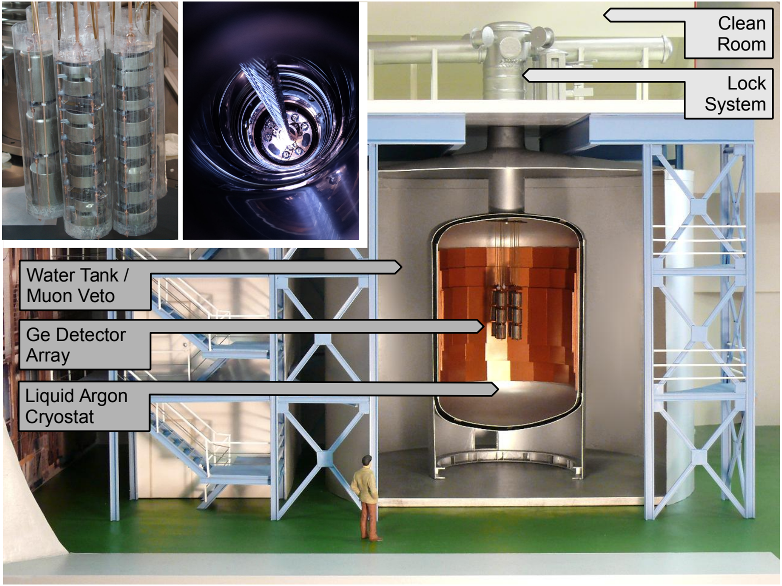
Univ. New Mexico
L'Aquila Univ. and INFN
Gran Sasso Science Inst.
Lab. Naz. Gran Sasso
Univ. Texas
Tsinghua Univ.
Lawrence Berkeley Natl. Lab.
Leibniz Inst. Crystal Growth
Comenius Univ.
Lab. Naz. Sud
Univ. of North Carolina
Sichuan Univ.
Univ. of South Carolina
Jagiellonian Univ.
Banaras Hindu Univ.
Univ. of Dortmund
Tech. Univ. – Dresden
Joint Inst. Nucl. Res. Inst.
Nucl. Res. Russian Acad. Sci.

Joint Res. Centre, Geel
Chalmers Univ. Tech.
Max Planck Inst., Heidelberg
Dokuz Eylul Univ.
Queens Univ.

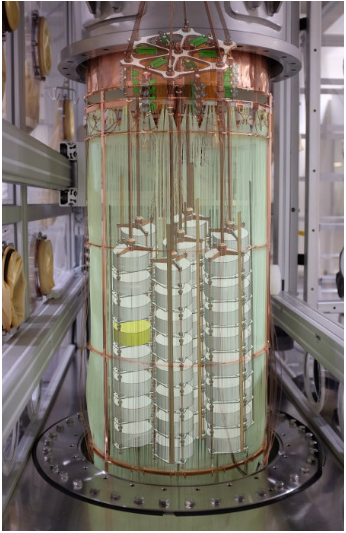
Univ. Tennessee
Argonne Natl. lab.
Univ. Liverpool
Univ. College London
Los Alamos Natl. Lab.

Lund Univ.
INFN Milano Bicocca
Milano Univ. and Milano INFN
Natl. Res. Center Kurchatov Inst.
Lab. for Exper. Nucl. Phy. MEPhI
Max Planck Inst., Munich
Tech. Univ. Munich
Oak Ridge Natl. Lab.
Padova Univ. and Padova INFN
Czech Tech. Univ. Prague
Princeton Univ.
North Carolina State Univ.
South Dakota School Mines Tech.
Univ. Washington
Academia Sinica
Univ. Tuebingen
Univ. South Dakota
Univ. Zurich

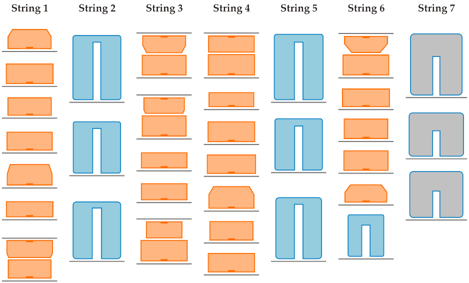
GERDA and future LEGEND-200 Setup



GERDA Phase-II Detector Array



[arXiv:1711.01452]



- 7 string, 40 detectors in total:
  - 7 enriched coax-type (15.8 kg)
  - 30 enriched BEGe-type (20 kg)
  - 3 natural coax-type (7.6 kg) (replaced Summer 2018)
- Array enclosed by LAr veto
- Operational since Dec. 2015

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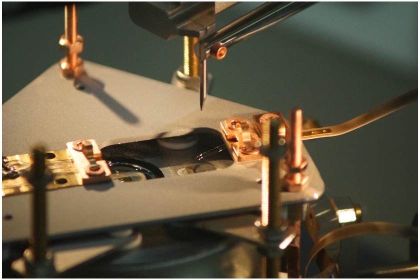
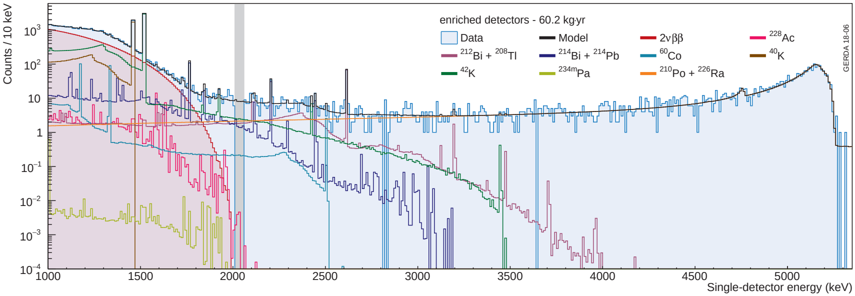
Radiopure Detector Surroundings



- Lightweight detector holders, built from monocrystalline silicon and OFC copper
- Detectors contacted by wire-bonding
- Holders connected to form strings

GERDA Phase II Background Model



- Blinded window: 50 keV around $Q_{\beta\beta} = 2039$ keV
- Main background components in ROI:
  - α from $^{210}\mathrm{Po}, ^{226}\mathrm{Ra}$
  - β from $^{42}\mathrm{K}$
  - γ from $^{214}\mathrm{Bi}, ^{208}\mathrm{Tl}$

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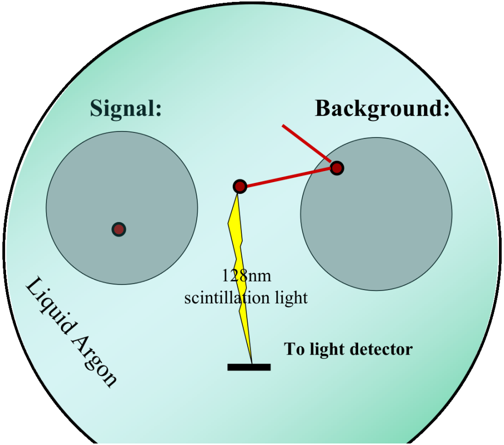
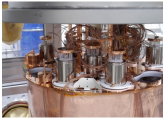
LAr Scintillation as Background Veto

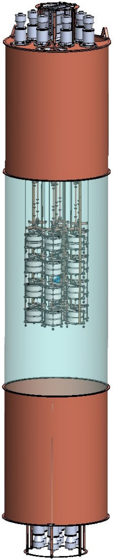


- Liquid argon scintillates: High potential for for background reduction (esp. γ)

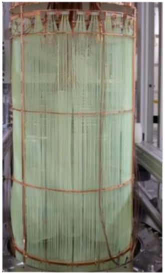
LAr Instrumentation

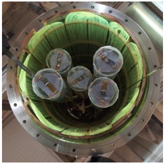
Top PMTs



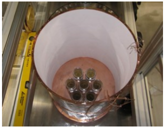


Fiber Cylinder





Bottom PMTs



- Instrumentation of LAr volume around detectors as background veto
- WLS-coated fibers with SiPMs, plus PMTs
- WLS-coated nylon mini-shroud around each detector string

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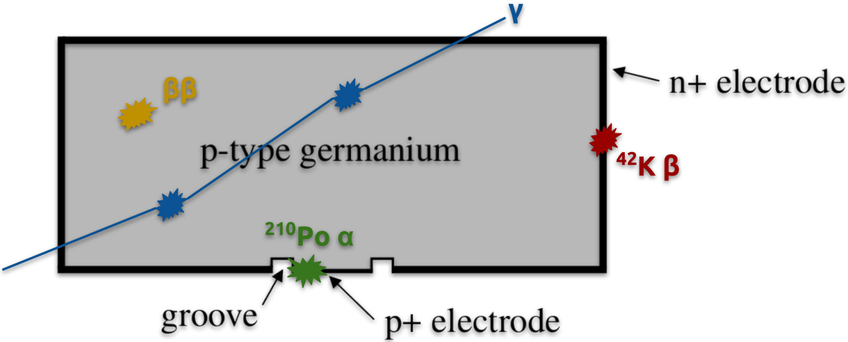
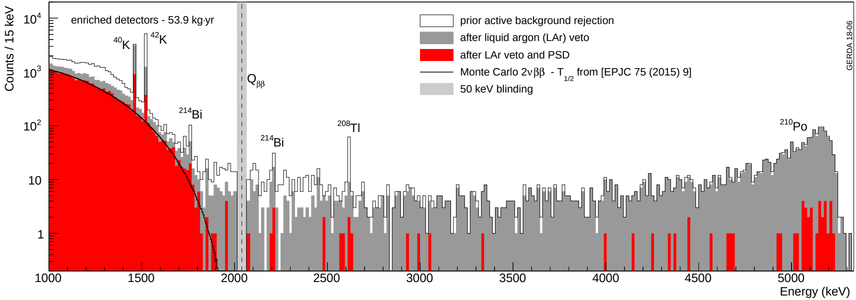
Pulse-Shape Discrimination



- PSD: Reject multi-site and surface events based on detector signal shape

GERDA Background Reduction Efficiency



- Almost pure $2\nu\beta\beta$ spectrum after LAr veto
- Background in ROI $\approx 6 \times 10^{-4}$ cts/(keV· kg· yr) after PSD

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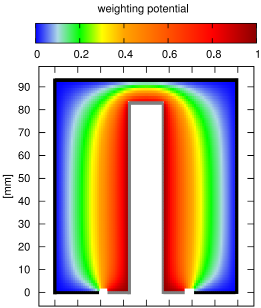
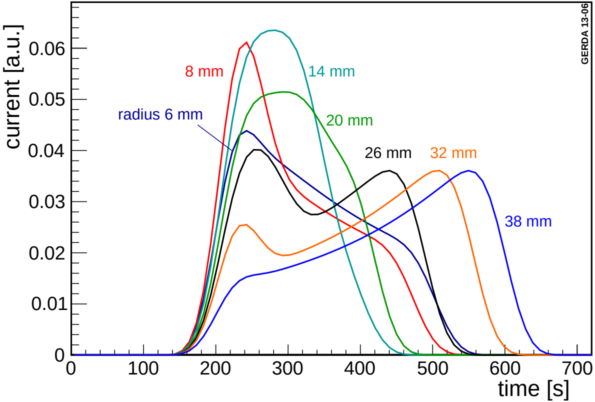
Coaxial Detectors





- Main GERDA Phase-I technology
- Pros: High mass
- Con: PSD very complex, needs artificial neural network (ANNs) [EPJC 73 (2013) 2583]

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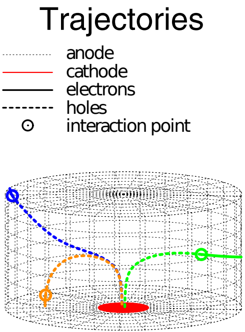
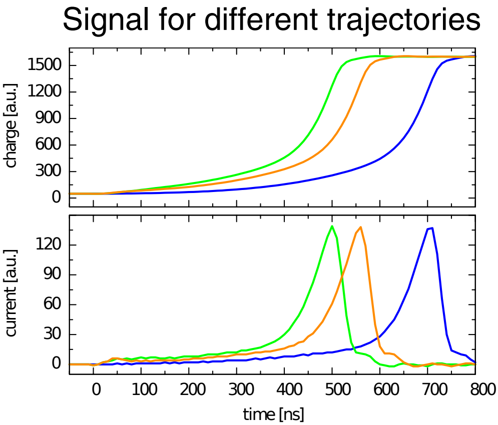
BeGe Detectors





- Main GERDA Phase-II technology, similar to MAJORANA PPC detectors
- Pro: Easy and effective PSD via A/E
- Cons: Low mass (bigger detectors hard to deplete)

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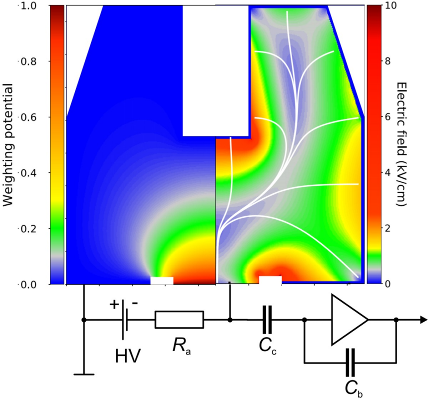
Inverted-Coaxial Point-Contact Detectors



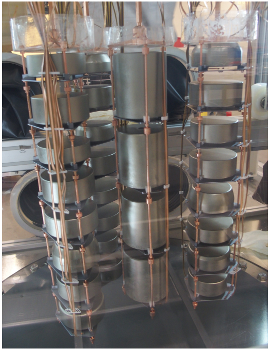
- Original concept by D. Radford

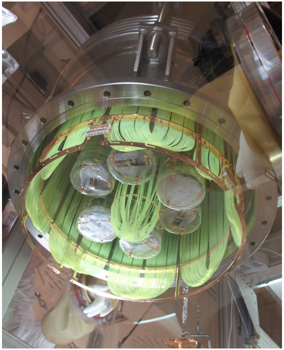
  (ORNL, Majorana), [NIMA 665 (2011) 25]

- ICPC Combines advantages of coax and BEGe/PPC detectors:
  - High mass
  - Easy BEGe/PPC-like PSD

- Technology of choice for all new LEGEND-200 detectors

GERDA Upgrade Summer 2018





- Successfully replaced non-enriched coax detectors by 9.5 kg enriched inverted-coax detectors validating technology for LEGEND-200
- New LAr fiber curtain with higher density and additional new central module
- Improved cable routing, lower noise

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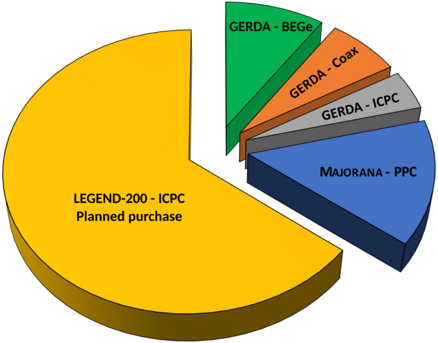
Changes from GERDA to LEGEND-200



- Increased detector mass: GERDA + MAJORANA + new
- ROI background target: < 0.6 cts/(FWHM t yr), (factor 3 below achieved GERDA value)
- Use ultra-pure electroformed copper (MAJORANA tech.)
- Low-mass electronics frontend on detector holders (MAJORANA tech.)
- New lock system and even cleaner cables with lower mass

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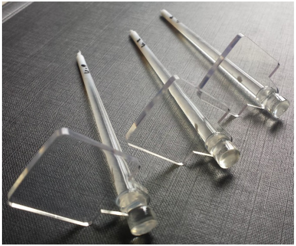
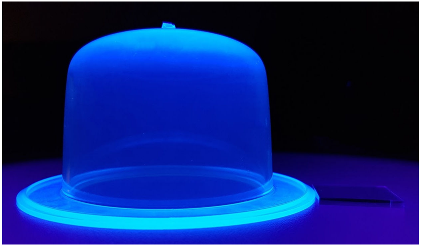
LEGEND-200 Status of Preparations

- Funding basically secure
- Procured significant amounts of enriched Ge
- Detector production starts now, expecting first deliveries in first half 2019
- Electroformed copper production ongoing (SURF)
- Testing combined MAJORANA and GERDA electronics
- Intense MC simulation campaign ongoing
- Started major overhaul of analysis software
- Aim: Data taking by mid-2021

R&D: PEN, an Active Structural Material





- Polyethylene Naphthalate (PEN) is both a scintillator and wavelength-shifter, emits blue light (around 450 nm)
- Mechanically strong
- Injection molding allows (almost) arbitrary shape
- Commercial material has decent radiopurity, R&D on custom synthesis to improve and also increase attenuation length
- LEGEND-200: Replace detector holder silicon plates with optically active PEN plates?
- LEGEND-1000: Detector encapsulation in PEN?

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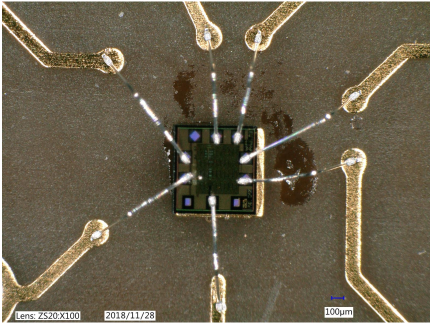
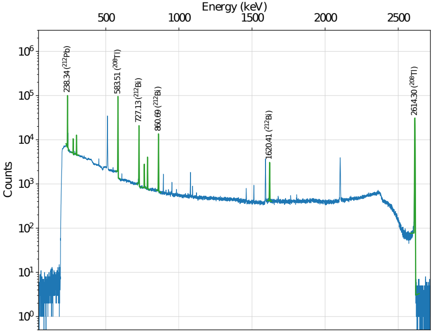
R&D: ASIC-based Frontend Electronics

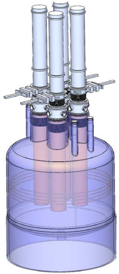


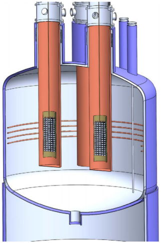
MPP/TUM Munich



- Current electronics frontend is compromise between radiopurity and signal quality
- ASIC-based preamplifier on detector holder could deliver optimal signal quality
- First tests with XGlab CUBE ASIC show excellent energy resolution and encouraging PSD performance
- Radiopurity still needs to be assessed in detail

LEGEND-1000 Baseline Design





- Aim: 10 ton-years exposure with 1 ton detector to reach 10^{28} year limit
- ROI background target: < 0.1 cts/(FWHM t yr)
- 4-5 separate arrays, each payload 200/250 kg detector mass, phased installation
- LAr detector volumes separated by thin electro-formed Cu from main cryostat volume
- Depleted LAr in inner detector volumes
- Modest LAr cryostat in water tank or large LAr cryostat with separate neutron moderator?
- Many R&D Projects: Very-high-mass detectors, etc.

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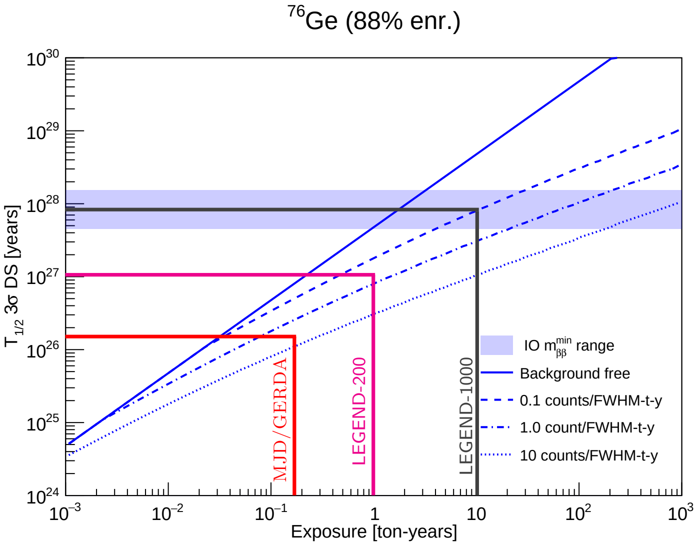
LEGEND Discovery Sensitivity Projection



[arXiv:1810.00849]

3-sigma discovery sensitivity projection at full exposure

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Conclusions and Outlook

- Searching for extremely rare decays is a tricky business
- GERDA Phase II: Background-free due to new materials, LAr veto and PSD:
  Expect < 1 BG count over 100 kg $\cdot$ yr design exposure
- LEGEND collaboration will continue work of GERDA and MAJORANA
- New detector technology (ICPC) for LEGEND-200 already proven in GERDA cryostat
- LEGEND-200 preparations on track
- Design studies and technology R&D for LEGEND-1000 ongoing

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