Status of the GERDA Experiment

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for the GERDA collaboration

MAX-PLANCK-GESELLSCHAFT

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(Werner-Heisenberg-Institut)

GERDA

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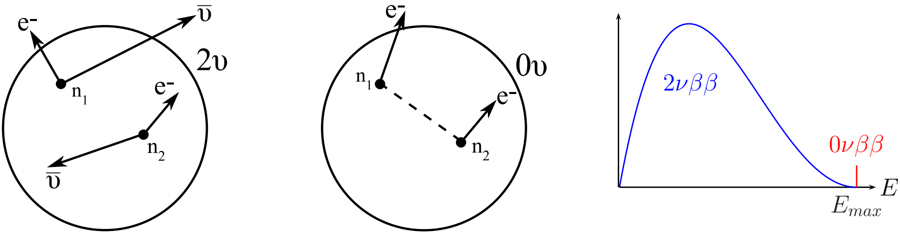
10th PATRAS Workshop on Axions, WIMPs and WISPs,
June 30th, 2014

$0\nu\beta\beta$-Decay

- Single β-decay not allowed for some isotopes, only double β-decay
- If $0\nu\beta\beta$-decay exists, ν must be a Majorana Particle ($\nu = \bar{\nu}$)



$$\left(T_{1/2}^{0\nu}\right)^{-1} = G(Q, Z)\ |M_{\text{nucl}}|^2\ \langle m_{ee}\rangle^2$$

- Study of $0\nu\beta\beta$-decay can
  - Discover lepton-number violation (several BSM processes)
  - Determine nature of ν (Majorana or Dirac).
  - Give information about absolute Neutrino mass / hierarchy?

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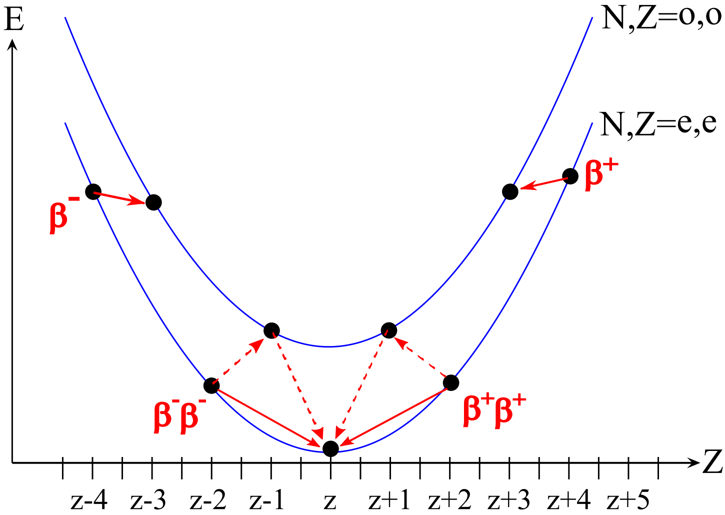
Single and Double Beta Decay



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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
- Previous results for $^{76}\mathrm{Ge}$ $0\nu\beta\beta$-Decay:
  - Limit: $T_{1/2} > 1.9 \cdot 10^{25} yr$ at 90% conf. HDM and IGEX
  - Claim: $T_{1/2} = 1.2 \cdot 10^{25} yr$ Klapdor-Kleingrothaus et al., PL B586 (2004) 198
- Ultra-low background setup, located underground at LNGS
- Phase-I completed, Klapdor claim strongly disfavoured
- Phase-II will go beyond: Increased total detector mass, even lower background

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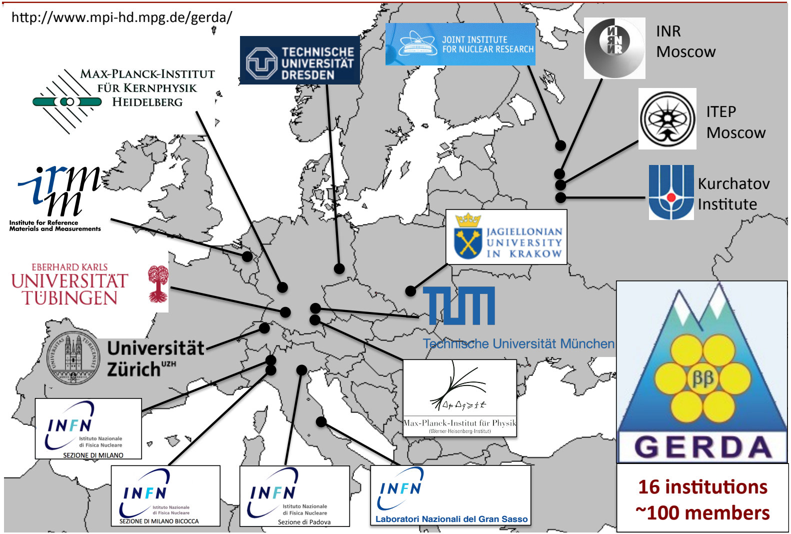
The GERDA Collaboration



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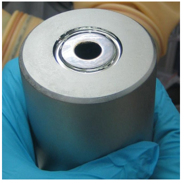
Why use ^{76}Ge?



Advantages:

- Source = Detector
- Production of enriched detectors up to 86% well established (though expensive)
- HPGe has excellent energy resolution, important since:
  $T_{1/2} \propto \epsilon \cdot A \sqrt{\frac{M \cdot T}{b \cdot \Delta E}}$
- Intrinsically pure

Challenges:

- For all $0\nu\beta\beta$experiments:
  - Must be well shielded from cosmics and external radiation
  - Radio-pure setup, carefully select and screen all materials
- Detector operation under cryogenic conditions
- Cosmic activation of detector material ($\rightarrow$ ^{60}Co and ^{68}Ge)

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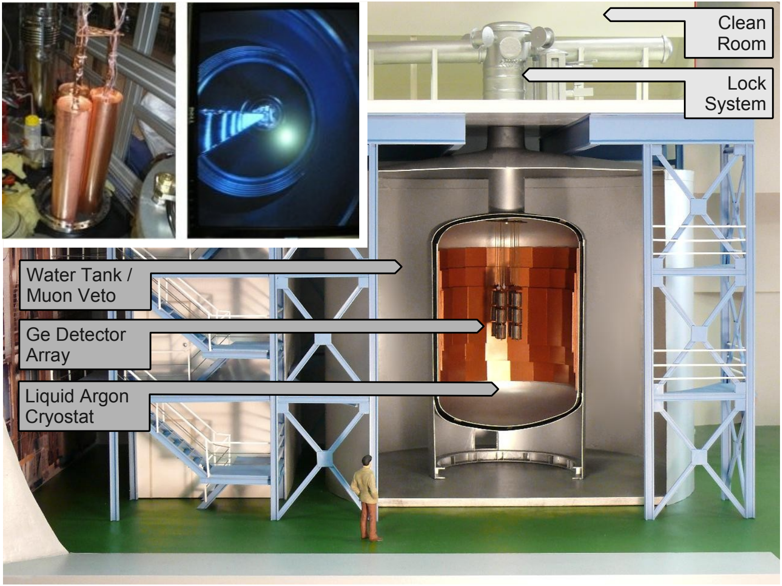
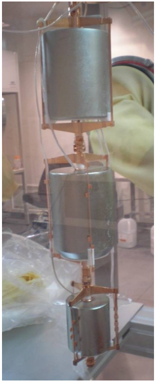
The Gerda Setup



Gerda Phase-I Detectors




- 8 enriched coaxial detectors from HDM and IGEX (17.7 kg, Nov. 2011 - June 2013)
- 1 non-enriched coaxial detector (3.0 kg)
- May 2012 to June 2013: 5 enriched Phase-II BEGe detectors (3.6 kg)

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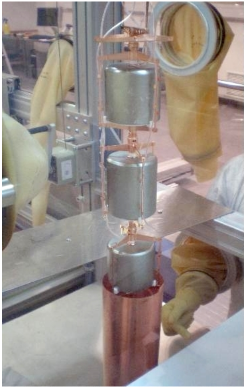
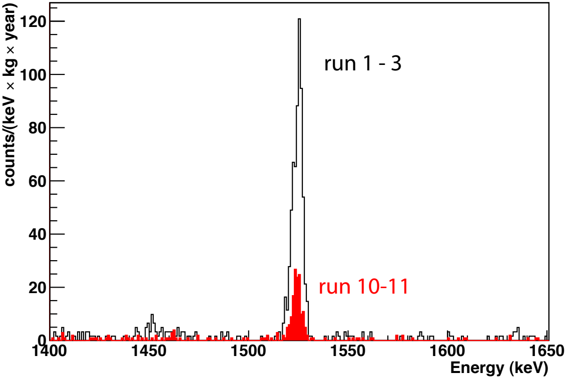
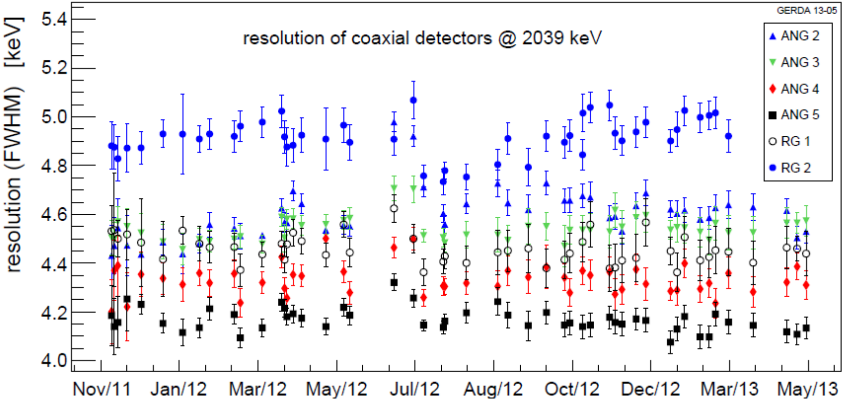
An Unexpected Background





- Observed background 10 × higher than expected
- $^{42}Ar \rightarrow {}^{42}K$, charged ^{42}K drift in E-field of detectors and decay there
- Copper mini-shrouds shield detector strings

Phase-I Calibration Stability



- Regular calibrations with $^{228}\mathrm{Th}$ sources
- Continuous monitoring of electonics gain with test pulser

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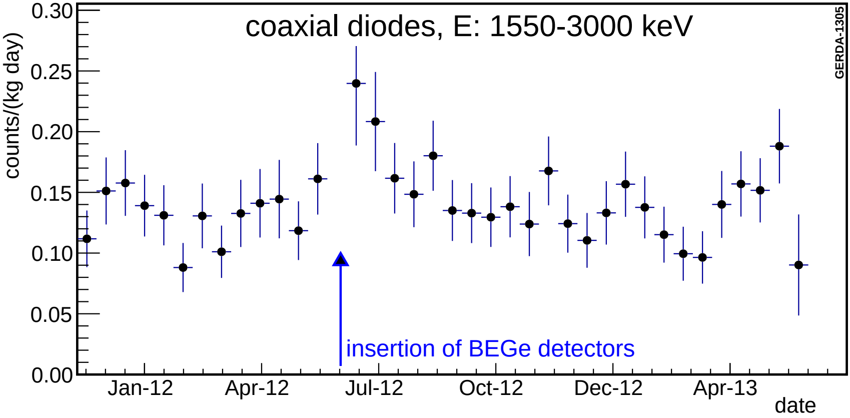
Phase-I Background Stability



- Background index (1550 to 3000 keV) stable over time, temporary increase due to BEGe detector insertion

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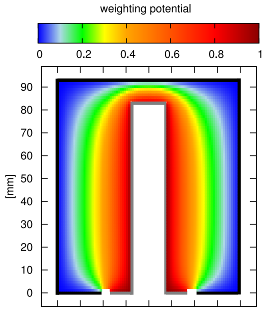
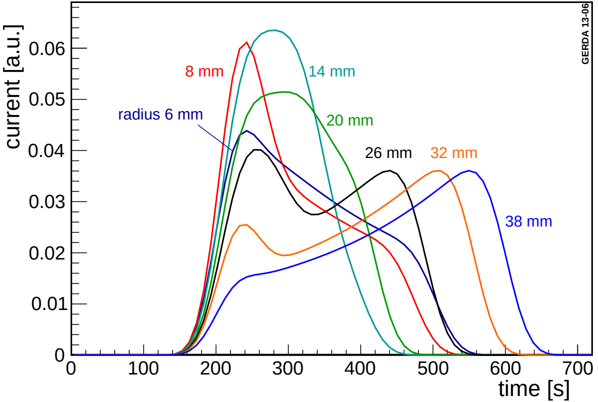
Coax Detector PSD





- Pulse shape discrimination (PSD) can separate single-site events (e.g. $0\nu\beta\beta$-decay) from multi-site events (Compton-scattering + X)
- New PSD algorithm used in Phase-I [EPJC 73 (2013) 2583]

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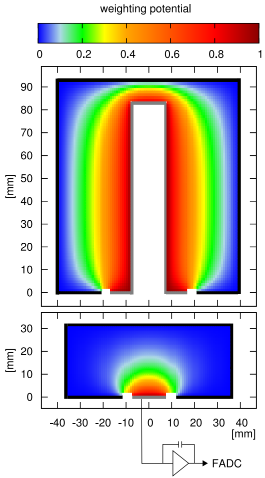
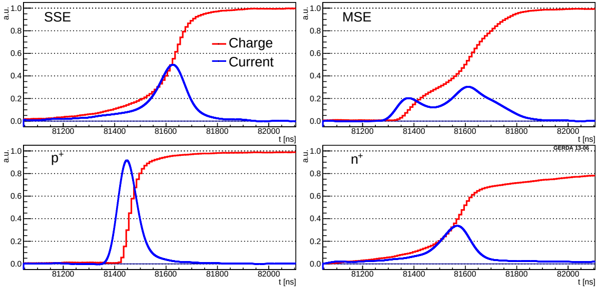
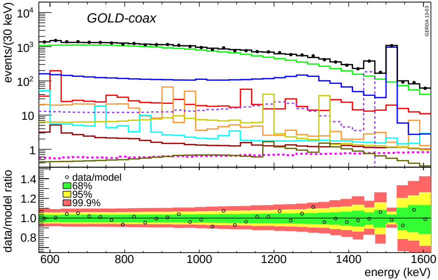
BEGe Detector PSD

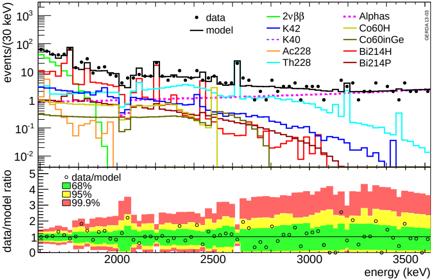


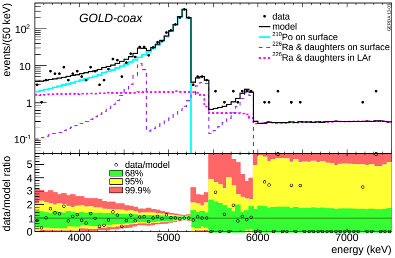


- BEGe detectors have steep weighting potential
  $\rightarrow$ PSD more effective
- Also rejection of surface backgrounds

Phase-I Background Decomposition







Background index:

- 2×10^{-2} cts/(keV·kg·yr) [EPJC 74 (2014) 2764]
- 1×10^{-2} cts/(keV·kg·yr) after PSD
- Design goal reached

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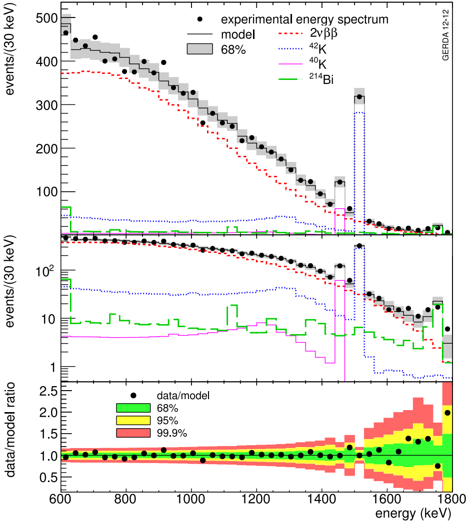
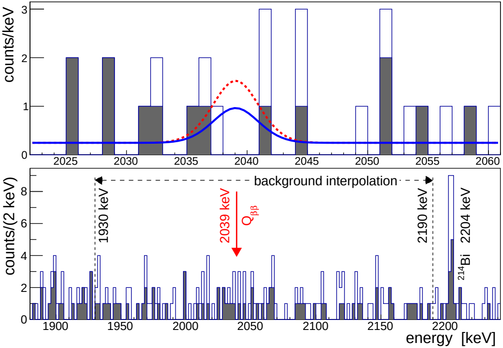
Measurement of $^{76}\mathrm{Ge}$ $2\nu\beta\beta$ Half-Life



$$T_{1/2}^{2\nu} = \left(1.84^{+0.09}_{-0.08\,\mathrm{fit}}\ {}^{+0.11}_{-0.06\,\mathrm{syst}}\right) \times 10^{21}\,\mathrm{yr} = \left(1.84^{+0.14}_{-0.10}\right) \times 10^{21}\,\mathrm{yr}$$

J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110

Phase-I Result



- Blind analysis: Everything frozen before unblinding of last $\pm$ 5 keV window around 2039 keV in June 2013
- 7 events in blinded region, 3 remain after PSD
- Phase-I Result: $T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr (90% C.L.), $T^{0\nu}_{1/2} > 3.0 \times 10^{25}$ yr in combination HDM and IGEX results [Phys. Rev. Lett. 111 (2013) 122503]

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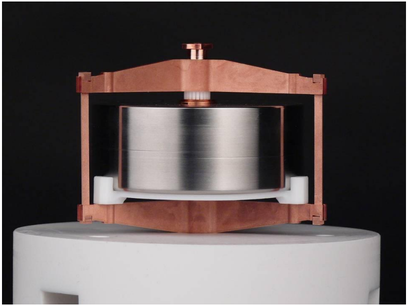
GERDA Phase-II

- GERDA Phase-I completed successfully.
  Time for the next step: GERDA Phase-II
- Design goals:
  - Sensitive to half-life of 10^{26} yr with exposure of 100 kg yr
  - Understand whether technology is suitable for ton-scale
- Increased active mass: 18 kg $\rightarrow$ 38 kg
  - 30 new BEGe-type HPGe detectors, additional mass of 21 kg
  - Phase-I coaxial detectors (18 kg) will be re-used in Phase-II
- Lower background: $1 \times 10^{-2} \rightarrow 1 \times 10^{-3}$ cts/(keV·kg·yr)
  - New detector technology: BEGe detectors
    (already tested a few in Phase-I)
  - Cleaner materials: new detector holders, electronics, cables
  - Active veto around detectors: LAr instrumentation

BeGe Detector Production



- 2005: 37.5 kg GeO_2 produced by ECP, Zelengorsk, Russia
- 2010: Reduction and zone refinement, PPM Metals GmbH, Rammelsberg, Germany
- 2011-12: Crystal pulling and cutting, Canberra, Oak Ridge
- 2012: Detector production at Canberra, Olen (Belgium) & testing (HADES underground lab, Mol (Belgium).
- All Ge transport in shielded shipping container (Water plus Steel shield)

[JINST 8 P04018, JINST 8 P06012]

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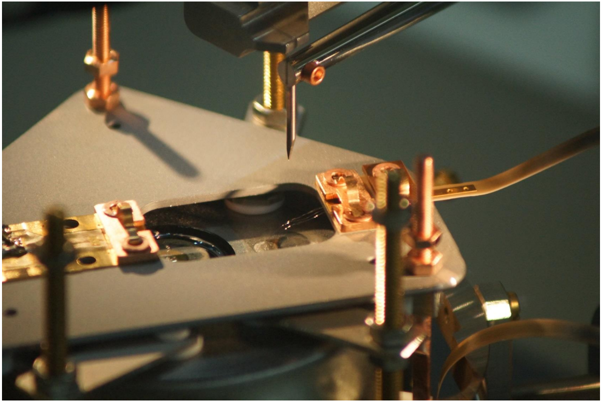
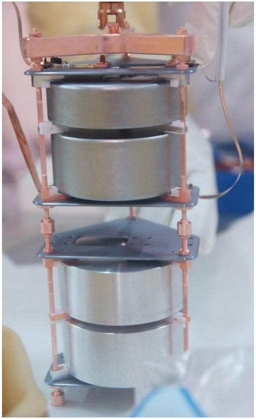
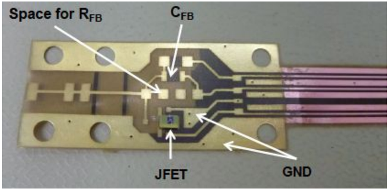
New Detector Holders

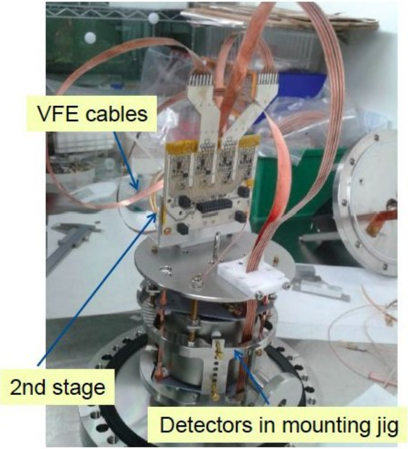




- Materials: Semiconductor-grade silicon and electrolytic copper
- Two BEGe or one Phase-I coax detector(s) per holder unit
- New Al-metalization technique on detectors allows wire-bonding

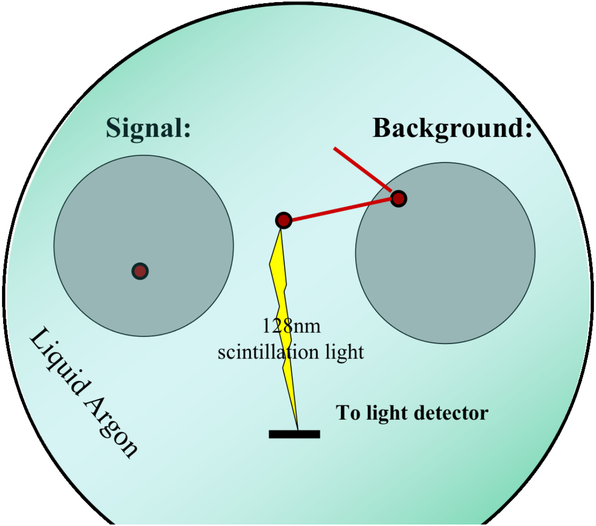
New Front-End Electronics and Cables





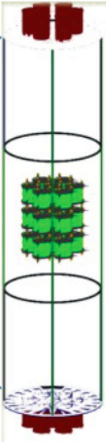
- CuFlon flex-cable for the last meter
- Clean FET and feedback network bonded directly on flex
- 2nd stage of amplifier spacially separated

LAr Scintillation as Background Veto



LAr Instrumentation, Design

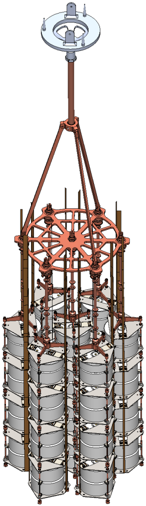
Top/bottom: PMTs



Central cylinder:
SiPM/Fiber readout

- Liquid Argon scintillates:
  Untapped potential for background reduction (esp. γ)
- Instrumentation of LAr volume around detectors as BG veto

Mechanical Challenges



- Phase-II array is very different:
  - Single array with 7 strings → large diameter
  - Increased weight
  - Additional weight of LAr instrumentation
  - A lot more channels → a lot more cables
- New lock system

Conclusions and Outlook

- Gerda Phase-I successful:
  Background index of 1×10^{-2} cts/(keV·kg·yr)
- New limit on $0\nu\beta\beta$ decay: $T_{1/2}^{0\nu} > 2.1 \times 10^{25}$ yr
- Gerda Phase-II adds
  additional 20 kg of detector mass (new technology)
- New materials and techniques for lower background
- With BEGe detectors and liquid argon instrumentation, confident to reach new background target:
  1×10^{-3} cts/(keV·kg·yr)

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