Status of GERDA Phase II

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on behalf of the GERDA collaboration

MAX-PLANCK-GESELLSCHAFT

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(Werner-Heisenberg-Institut)

GERDA

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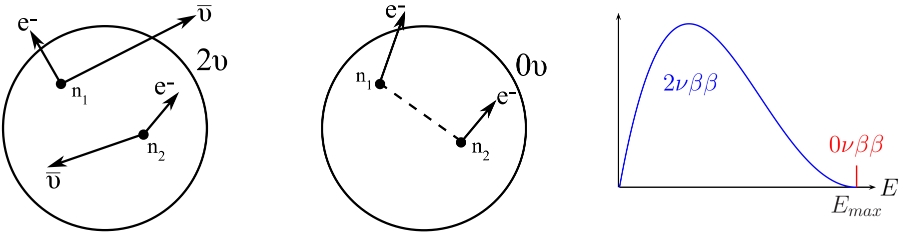
Lake Louise Winter Institute,
Feb. 22rd, 2018

$0\nu\beta\beta$ Decay

- Single β decay not allowed for some isotopes, only double β decay
- Also $0\nu\beta\beta$ decay, due to Majorana-ν ($\nu = \bar{\nu}$)?



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

- Discovery of $0\nu\beta\beta$ decay would
  - Imply lepton-number violation
  - Tell us about nature of ν (Majorana component?)
  - Give information about absolute Neutrino mass / hierarchy?

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Low-Background Challenge

- Expected $0\nu\beta\beta$ decay half lives very long ($\geq 10^{26}$ years):
  [Agostini et al., Phys. Rev. D 96, 053001 (2017)],
  [Caldwell et al., Phys. Rev. D 96, 073001 (2017)]
- Ideal experiment (almost) background-free:
  < 1 counts within 1 FWHM of $Q_{\beta\beta}$ up to design exposure
- Need high source mass
  $\rightarrow$ Isotope enrichment
- Need to get rid of radioactive background:
  - Cosmic background
    $\rightarrow$ Need underground location
  - Environmental radiation
    $\rightarrow$ Need excellent shielding
  - Radiation from materials used in setup
    $\rightarrow$ Need very radio-pure materials
  - Intrinsic $2\nu\beta\beta$ background
    $\rightarrow$ Need good energy resolution

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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
- Ultra-low background setup, located underground at LNGS (1400 m rock overburden, 3500 m water equivalent)
- Phase I completed successfully, limit for $^{76}\mathrm{Ge}$ $0\nu\beta\beta$ decay: $T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr (90% CL)
- Phase II: Increased active mass, new BEGe detectors lower background, active LAr veto
- Phase II design goals:
  - Sensitive to half-life of $\geq 10^{26}$ yr with exposure of 100 kg $\cdot$ yr
  - Lower background: $1 \times 10^{-2} \rightarrow 1 \times 10^{-3}$ cts/(keV$\cdot$ kg$\cdot$ yr)
  - Understand whether technology is suitable for ton-scale
- Current status: Phase II data taking

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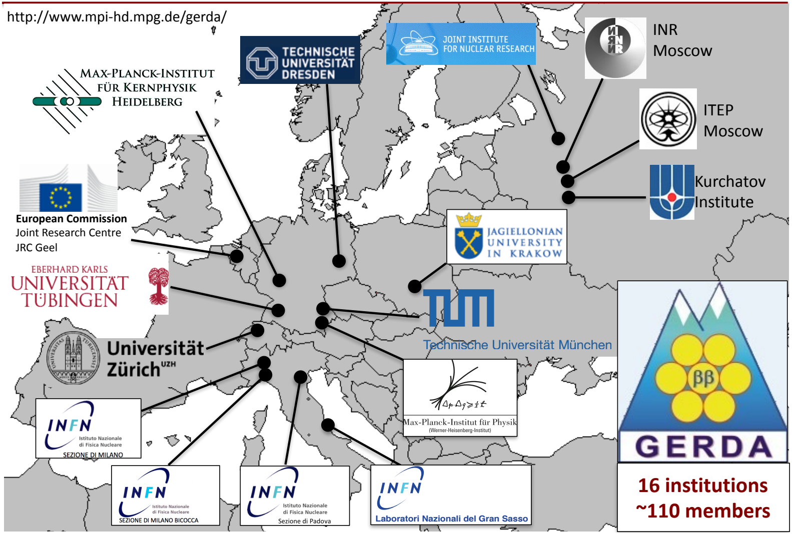
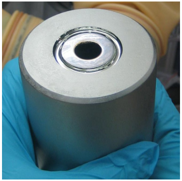
The GERDA Collaboration



Why use $^{76}\mathrm{Ge}$?

Advantages:



- Source = Detector
- Production of enriched detectors up to 86% well established (though expensive)
- HPGe has excellent energy resolution, only way to reduce $2\nu\beta\beta$ decay background, also important since sensitivity is
  $T_{1/2} \propto a \cdot \epsilon \sqrt{\frac{M \cdot t}{b \cdot \Delta E}}$ (BG-free: $T_{1/2} \propto a \cdot \epsilon \cdot M \cdot t$)
- Intrinsically pure

Challenges:

- Detector operation under cryogenic conditions
- Cosmic activation of detector material ($\rightarrow$ $^{60}\mathrm{Co}$ and $^{68}\mathrm{Ge}$)

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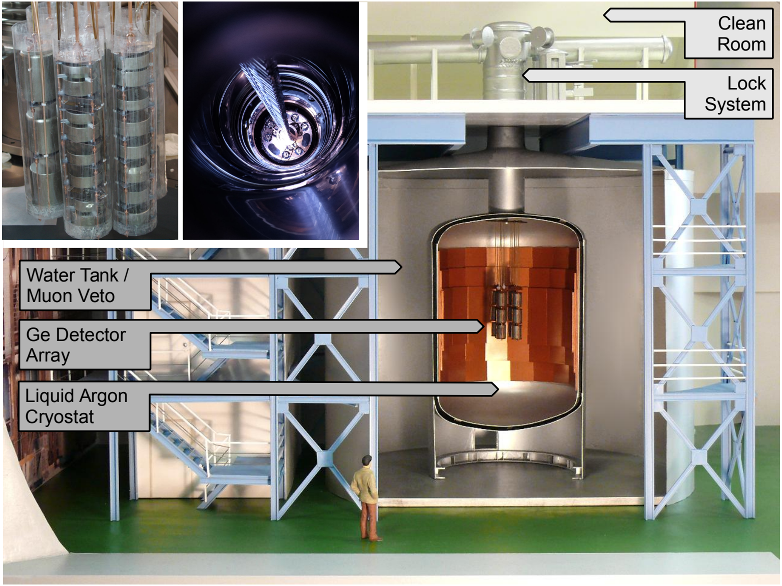
The Gerda Setup



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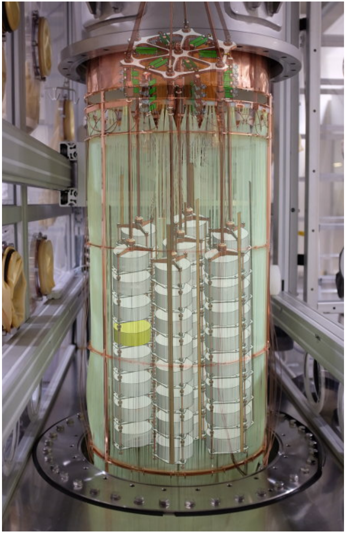
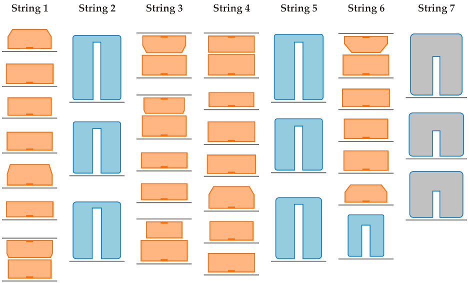
GERDA Phase-II Detector Array



[arXiv:1711.01452]



- 7 string, 40 detectors in total:
  - 7 enriched Coax-type (15.8 kg)
  - 30 enriched BEGe-type (20 kg) (newer detector technology)
  - 3 natural Coax-type (7.6 kg)
- Array enclosed by LAr veto
- Operational since Dec. 2015

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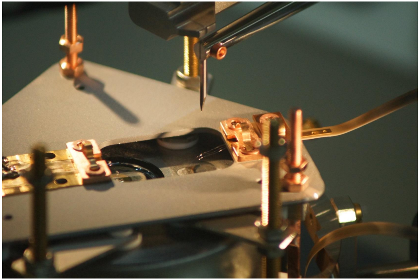
Radiopure Detector Surroundings



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

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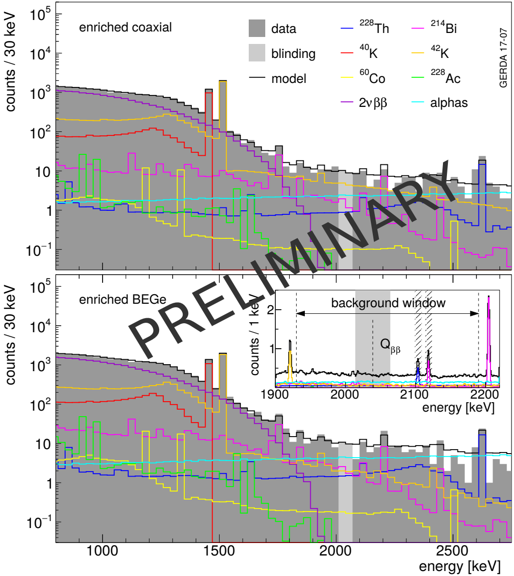
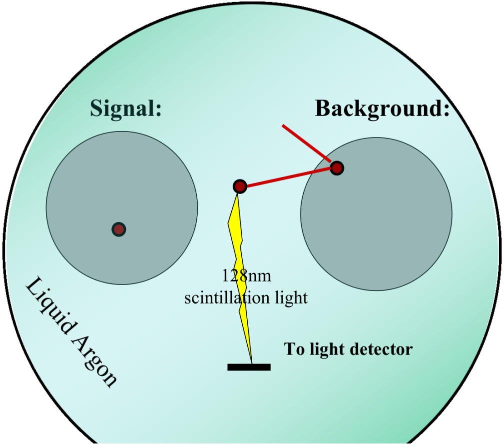
Phase II Background Model



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

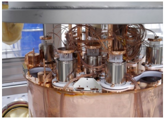
LAr Scintillation as Background Veto

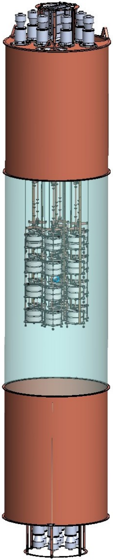


- Liquid Argon scintillates: High potential for for background reduction (esp. γ)

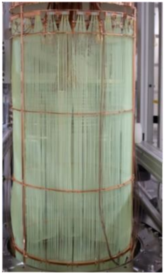
LAr Instrumentation

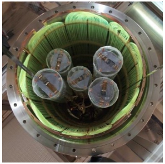
Top PMTs



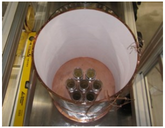


Fiber Cylinder





Bottom PMTs



- Instrumentation of LAr volume around detectors as background veto
- 800m WLS-coated fibers, 90 SiPMs, 16 PMTs
- WLS-coated nylon mini-shroud around each detector string

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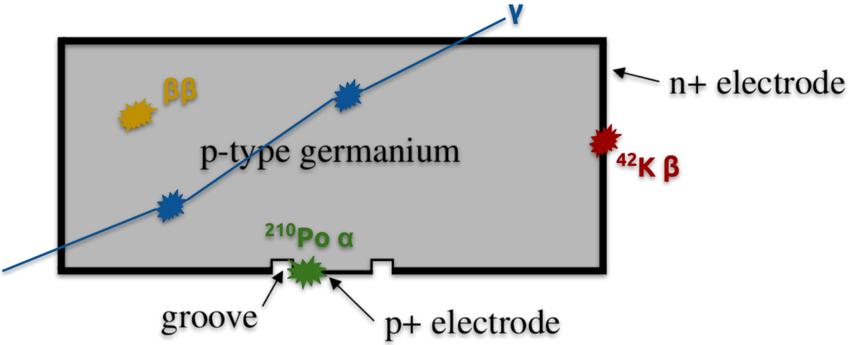
Pulse-Shape Discrimination



- PSD: Reject multi-site and surface events based on detector signal shape
- Methods: A/E (BEGe detectors), ANN (coaxial detectors)

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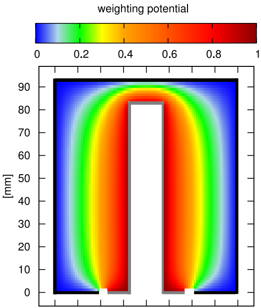
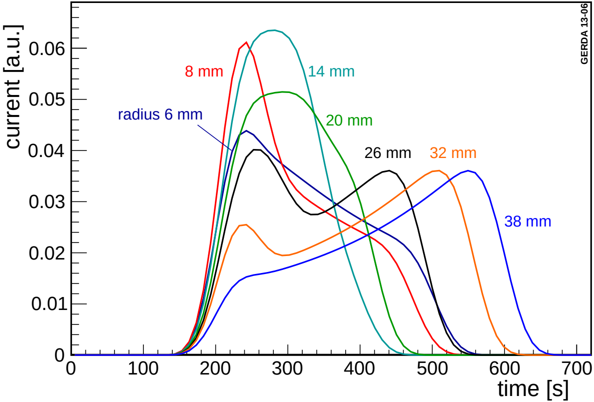
Coaxial Detector PSD





- PSD for Coax detectors very complex
- Custom PSD algorithm [EPJC 73 (2013) 2583], uses artificial neural networks (ANNs)
- Easier for BeGe detectors (newer detector technology)

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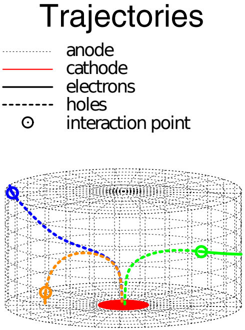
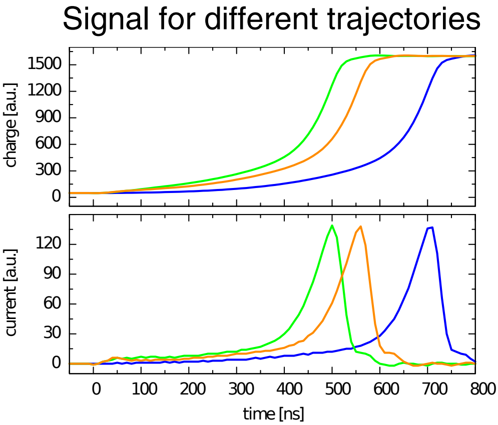
BeGe Detector PSD





- BeGe: Broad-Energy Germanium Detector (Canberra)
- No bore-hole, small contact:
  - Small capacitance, higher energy resolution
  - Strong weighting field
- Charges from different points → signals at different times

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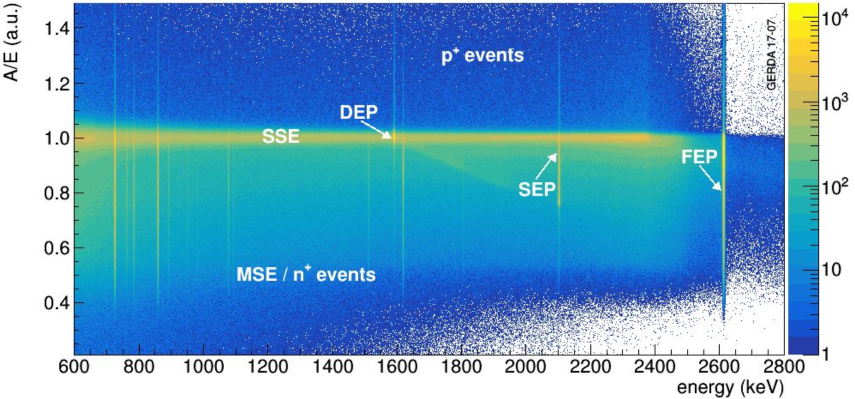
BeGe Detectors PSD



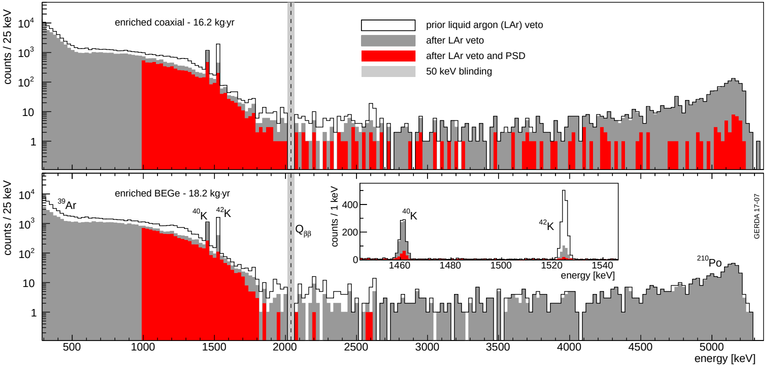
- A/E (ratio of max. current and charge) yields powerful event topology discrimination feature

SSE: single-site event, MSE: multi-site event, SEP: single-escape peak, DEP: double-escape peak

Background after Vetos and Cuts

Coax detectors

BEGe detectors



Phase II background index (1930 - 2190 keV):

- Almost pure $2\nu\beta\beta$ spectrum after LAr veto (600-1300 keV)
- Coax detectors: $2.7^{+0.8}_{-1.0} \times 10^{-3}$ cts/(keV·kg·yr)
- BEGe detectors: $1.0^{+0.4}_{-0.6} \times 10^{-3}$ cts/(keV·kg·yr)
- Background-free up to design exposure 100 kg · yr

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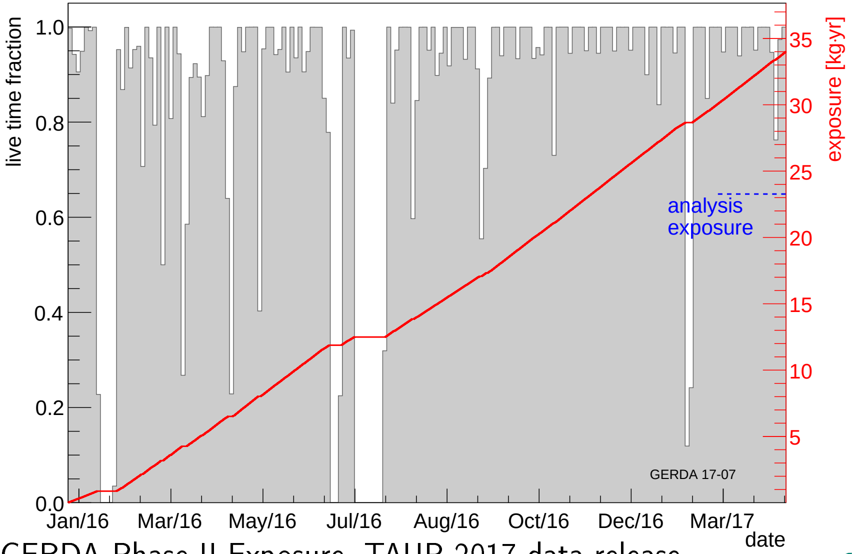
Current Phase II Exposure



GERDA Phase II Exposure, TAUP 2017 data release

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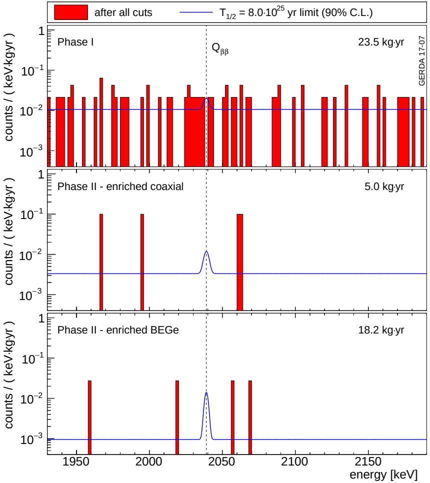
Current Combined Phase I and II Result



- Phase I:
  $T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr
- Phase-II:
  - First 10.8 kg·yr unblinded June 2016
    [Nature 554 (2017) 47]
  - Additional 12.4 kg·yr unblinded June 2017
    [TAUP: arXiv:1710.07776]
    New paper accepted by PRL
- Phase I plus Phase II:
  - $T^{0\nu}_{1/2} > 8.0 \times 10^{25}$ yr (Profile likelihood)
  - $T^{0\nu}_{1/2} > 5.1 \times 10^{25}$ yr (Bayesian)

All limits: 90% CL/CI

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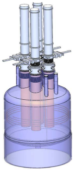
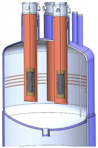
The next step: LEGEND





- Gerda Phase-II sensitivity will scratch inverted hierarchy
- But: Need about 1 ton of enriched $^{76}\mathrm{Ge}$ to cover it
- Large fractions of GERDA and MAJORANA plus new (and old) players in the field: New LEGEND collaboration [http://legend-exp.org/], 46 institutes (Europe, USA, China)
- Two Phases:
    - LEGEND-200: 200 kg detector mass GERDA cryostat
    - LEGEND-1000: 1000 kg detector mass, host-lab search ongoing

[arXiv:1709.01980]

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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 $100\ \mathrm{kg} \cdot \mathrm{yr}$ design exposure
- First unblinding in June 2016, $T_{1/2}^{0\nu} > 5.2 \times 10^{25}$ yr (P.L.)
- Smooth operation of GERDA in 2017,
  new data released at TAUP 2017
- Next GERDA data release (provisional): Neutrino 2018
- LEGEND collaboration plans to continue
  after GERDA Phase-II, with 200/1000 kg of Ge

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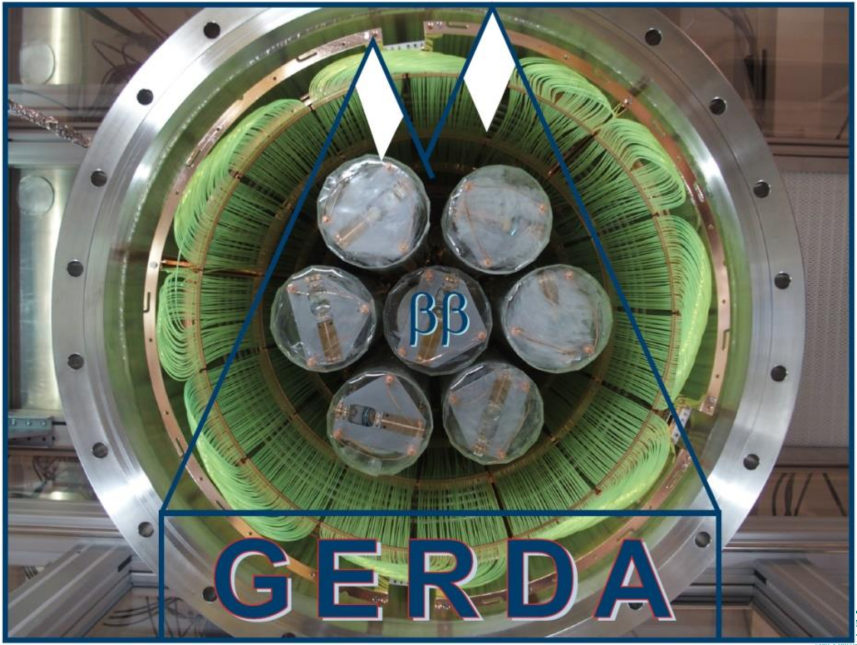

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