The GERDA experiment on $0\nu\beta\beta$ decay

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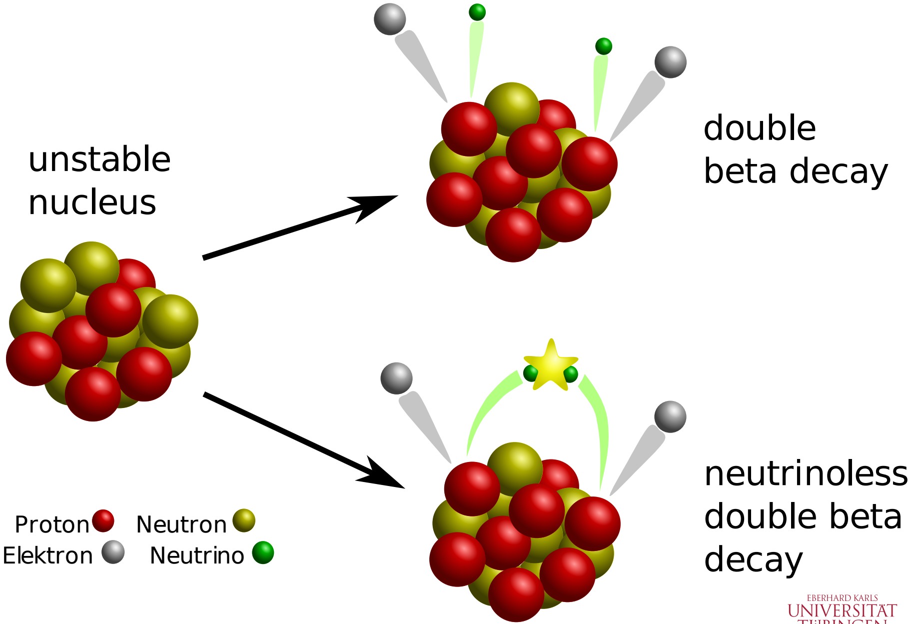

unstable nucleus
double beta decay
neutrinoless double beta decay
Proton
Neutron
Elektron
Neutrino

Neutrinoless Double Beta Decay

$2\nu\beta\beta$:

$(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$

$\Delta L = 0$

Observed in more than 10 isotopes

$T^{2\nu}_{1/2}$: $10^{18} - 10^{21}$ years

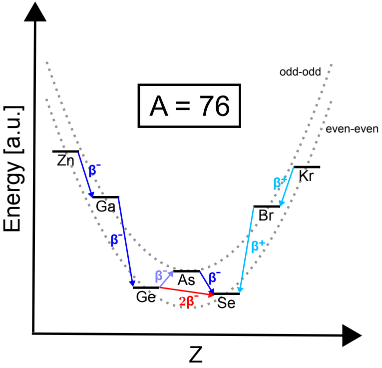
$0\nu\beta\beta$:

$(A, Z) \rightarrow (A, Z+2) + 2e^- + 0\bar{\nu}_e$

$\Delta L = 2$

One claim and many limits...

$T^{0\nu}_{1/2} > 10^{23}$ years



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Neutrinoless Double Beta Decay

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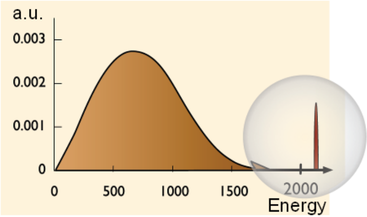

Energy sum of two β

- continuous spectrum ($2\nu\beta\beta$)
- peak at $Q_{\beta\beta}$ ($0\nu\beta\beta$)

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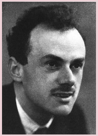
Neutrino Properties

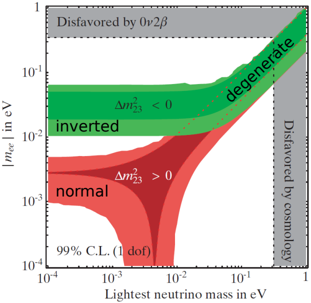
Dirac



- $\nu = \nu_L$
- $\bar{\nu} = \nu_R$

Majorana

- $\nu_L = \bar{\nu}_L$
- $\nu_R = \bar{\nu}_R$
- $M_\nu \neq 0$



[Feruglio et al., Nucl. Phys. B 637(2002)]

Absolute m_1, m_2, m_3 masses?
Δm^2_{ij} known from ν oscillations

Mass hierarchy

- hierarchal
  - normal $m_3 > m_{2,1}$
  - inverted $m_3 < m_{2,1}$
- degenerate

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What do we learn from $0\nu\beta\beta$?

If the neutrino is a Majorana particle (beyond SM):

Neutrino Mass:

$$\frac{1}{T^{0\nu}_{1/2}} = G^{0\nu} \left|M^{0\nu}\right|^2 \left|\frac{\langle m_{ee}\rangle}{m_e}\right|^2$$

$G^{0\nu}$ - phase space integral

$|M^{0\nu}|$ - nuclear matrix element

m_e - electron mass

$\langle m_{ee}\rangle = |\sum_i U^2_{ei} m_i|$ - effective neutrino mass

Observation of $0\nu\beta\beta$:

- Majorana / Dirac nature
- mass hierarchy
- effective neutrino mass

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Experimental challenges

$0\nu\beta\beta$ counts:

$$N^{0\nu} \approx \epsilon\, a\, M\, t\, T_{1/2}^{-1}$$

Background counts:

$$N^{obs} = \sqrt{N^{bg}} \approx \sqrt{M\, t\, B\, \Delta E}$$

Real counts:

$$N^{0\nu}/N^{obs} \approx \epsilon\, a \sqrt{(M\, t)/(B\, \Delta E)}\, T_{1/2}^{-1}$$

ϵ - efficiency
a - fraction of $0\nu\beta\beta$ isotope
M - detector mass
t - measured time

B - background in cts/(keV kg y)
ΔE - detector resolution

- high exposure (M t)
- enriched isotope
- efficient detector

- no/low background
- good resolution

Isotope and experimental detection technique are crucial to the observation!

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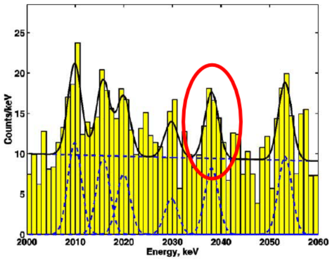
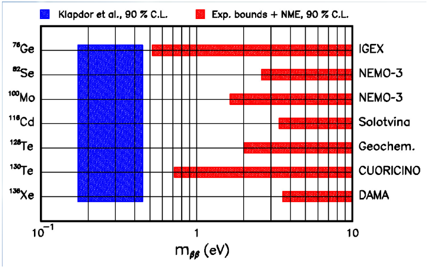
Claim and Limits

- Part of Heidelberg-Moscow
- 5 HPGe, 72 (kg y) exposure
- Claim: $T^{0\nu}_{1/2} = 0.69 - 4.18 \times 10^{25}$ y (3σ)



[Klapdor et al., Physics Letters B 586 (2004) 198-212]

- Several limits given
- Contenders: EXO, Kamland-Zen, Cuore, Super-Nemo etc...



[Rotunno, TAUP, 2009]

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GERDA: Experimental Ideas

Challenges:

- Low rate: 0-10 cts/yr (Phase I)
- Expensive detectors, limited time
- Inherent background: cosmic muons, “dirty” materials, activation, ambient radioactivity

Solution: background reduction

- Naked Ge-diodes enriched to 86% shielded by low-Z materials
- Source = detector, resolution $\approx 0.1\%$
- LNGS: 3500 m.w.e. muons flux red. by $\approx 10^6$
- Pulse shape analysis

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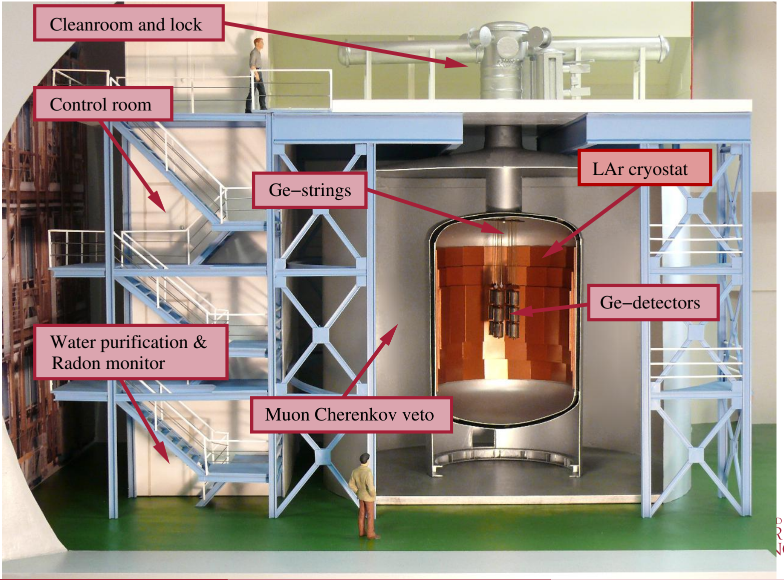
GERDA: Experimental Setup



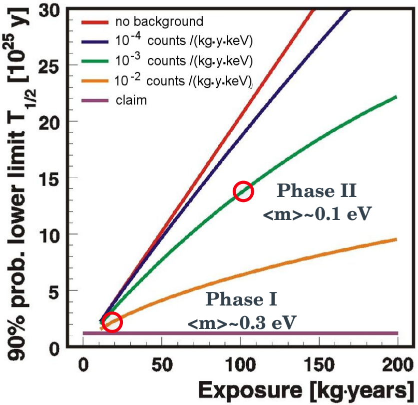
GERDA Sensitivity: Aims

Phase I

- check claim with HPGe
- exposure: ≈15 kg y,
  BI: 1×10^{-2}cts/(keV kg y)

Phase II

- enr. BEGe (+ 20 kg)
- exposure: ≈100 kg y,
  BI: 1×10^{-3}cts/(keV kg y)



[Caldwell,Kröninger;PhysRevD.74.092003]

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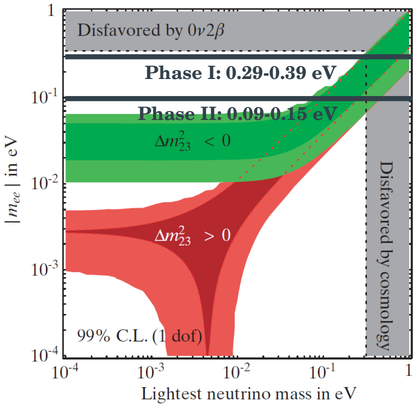

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GERDA Background

^{42}Ar and its daughter nuclei

unexpected BG:

- ^{42}Ar $\times 10$ expectation
- ^{42}K: β^- @ 3.5 MeV
- ^{42}Ca*: γ @ 1.525 MeV

Cu mini-shroud:

field-free configuration
reduction of ion drift

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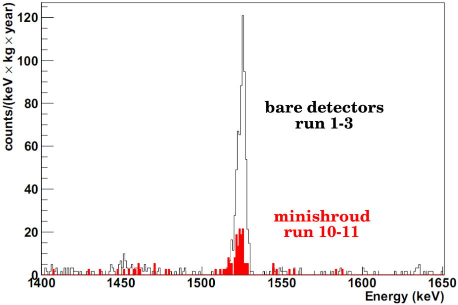

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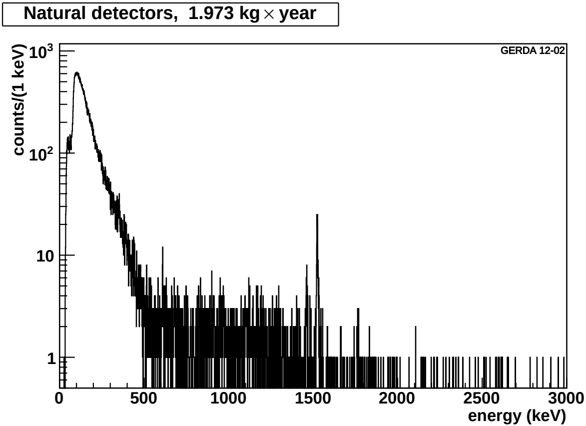
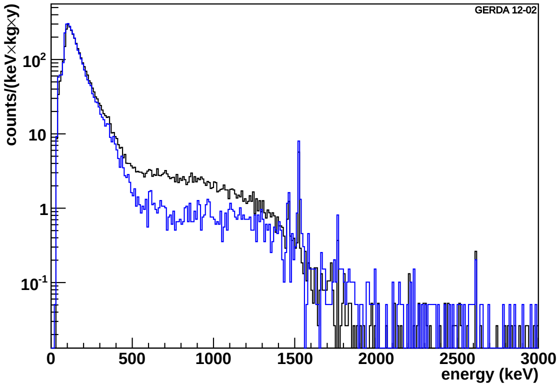
GERDA Spectra



Observed lines:

- 1525 keV (^{42}K)
- 1460 keV (^{40}K)
- 1764 keV (^{214}Bi)
- 2614 keV (^{208}Tl)
- 609 keV (^{214}Bi, natGe)

GERDA Spectra



^{nat}Ge, 2.0 kg y ^{enr}Ge, 3.8 kg y

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$2\nu\beta\beta$ clearly visible in normalized spectrum

1/4 of desired exposure

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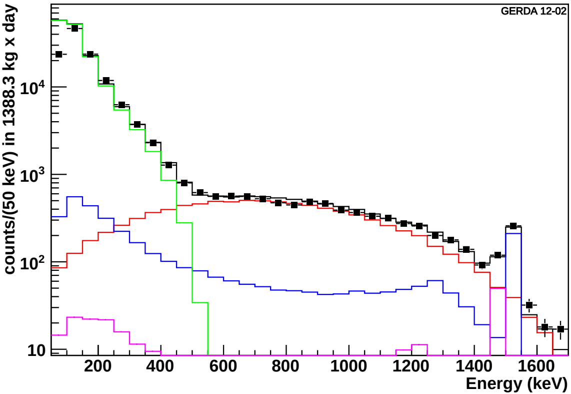
GERDA Background Model (preliminary)



^{39}Ar spec., 1.01 Bq
[NIM A 574 (2007) 83]

$2\nu\beta\beta$ spec., 1.74×10^{21} y
85% active volume
[NIM A 513 (2003) 596]

norm. ^{40}K spec. (MC), source: holders

norm. ^{42}K spec. (MC), source: uniform

■ data of 3.8 kg y enr. Ge

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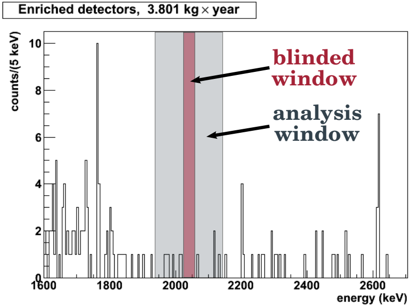
GERDA Current Status

- **data taking** since Nov. 2011
- 8 enr. detectors, 2 taken out (14.6 kg enr. + 7.6 kg nat.)
- **blinding** since Jan. 2012 ($Q_{\beta\beta} \pm 20$ keV)
- **unblinding** once sufficient exposure / BI reached



current ^{enr}BI, 3.8 kg y

$0.017\,^{+0.009}_{-0.005}$ cts/(keV kg y)

≈10 times better than HdM
no PSD applied yet

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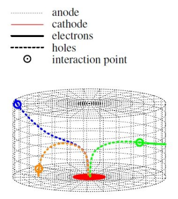
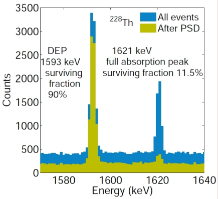
Future BG Reduction

Pulse Shape Discrimination

- PPC / BEGe detectors
- inhomog. field
- MSE discrimination



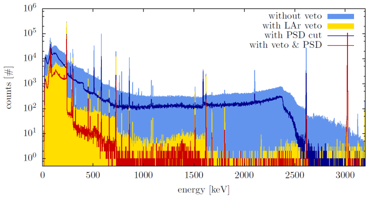


[M. Agostini et. al.;(JINST), 6 (2011) P03005]

[M. Barnabé Heider et.al., (JINST), 5 (2010) P10007]

LAr Instrumentation / LArGe

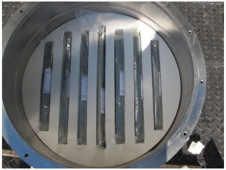
- utilize scintillation of LAr
- Active veto system
- multiple designs studied:
  $\Rightarrow$ PMT / WLS fibers
  $\Rightarrow$ no additional BG

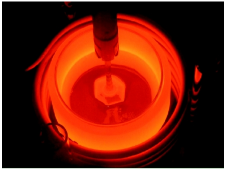


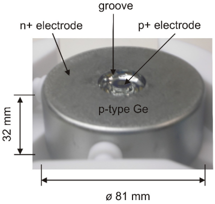
[M.Heisel; PhD thesis]

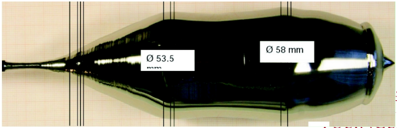
Ge-Procurement and Detector fabrication

- 2009: GeO_2 produced by ECP, Zelengorsk, Russia
- 2010: Reduction and zone refinement, PPM Metals GmbH, Rammelsberg, Germany
- 2011: Transport to Oak Ridge, United States
- 2011-12: Crystal pulling and cutting, Canberra, Oak Ridge
- 2012: Diode fabrication & testing, Canberra, Geel, Belgium. First 7 enr. BEGes produced with excellent res. 1.7 keV (FWHM) @ 1.3 MeV









Conclusions and Outlook

- The $0\nu\beta\beta$ decay can prove physics beyond the SM
- GERDA tries to determine
  $T_{1/2}$ of ^{76}Ge via an innovative approach
- The current BI of 1.7×10^{-2}cts/(kg y keV) is very promising
- The crucial / blinded phase of data taking has begun
  1/4 of desired exposure (Phase I) has been reached
- Production of next-generation Ge detectors in under way.
- First BEGes produced and tested with excellent resolution (1.7 keV FWHM @1.3 MeV)

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T116.1 M. Heisel
T116.4 V. Wagner