FIRST GERDA RESULTS ON 0νββ OF 76Ge

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INFN Milano Bicocca
on behalf of the GERDA Collaboration
EPS 2013, 18-24 July 2013

Greetings from Dubna!
The GERDA Collaboration

http://www.mpi-hd.mpg.de/gerda

Outline

16 institutions
~100 members
Outline

- The experiment
- The Energy scale
- The Background model
- Data Treatment
  - The Pulse shape discrimination
- ..............results
- Conclusion
**ββ Decay**

2ν  0ν

Proposed by Majorana (and Racah) in 1937:

A ν is exchanged between two neutrons

It is a forbidden process in SM and requires

- Lepton number violation

\[ \Delta L = 2 \quad \nu_e = \bar{\nu}_e \]

- Can be mediated by a light Majorana ν finite mass

\[ < m_\nu > \neq 0 \]

---

**Experimental sensitivity on T1/2**

\[ T_{1/2}^{0\nu} \propto a \varepsilon \sqrt{MT} \]

\[ 1 \propto G_{0\nu} |M_\nu|^2 \frac{< m_{\beta\beta} >^2}{m_e} \]

\[ < m_{\beta\beta} > = \text{effective } \nu \text{ mass} \]

\[ M_\nu = \text{Nuclear Matrix Element} \]

\[ G_{0\nu} = \text{Phase Space Factor} \]

\[ < m_{\beta\beta} > = \left| \sum_i U_{ei}^2 m_{vi} \right| \]

**Ideal case: no bckgd**

\[ T_{1/2}^{0\nu} \propto a \varepsilon MT \]

---

Electron spectrum

\[ Q_{\beta\beta}(^{76}\text{Ge}) = 2039 \text{ keV} \]
The GERDA setup

- cryo-mu-lab
- control room
- water plant
- Rn monitor
- phase I detector array
- FE electronics
- LAr
- cryostat
- water tank
- μ veto
- clean room
- Lock to insert detectors

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A tour in GERDA
Building the exposure up.....

- Total of 21.6 kg y: from 6 November 2011 to 3rd May 2013
- 6 of 8 Coaxial $^{enr}\text{Ge}$ detectors of the former IGEX and HdM in the $0\nu\beta\beta$ data sets (2 diodes high LC)
- 1 $^{nat}\text{Ge}$ coaxial detector (not in the $0\nu\beta\beta$ data set)
- June 2012: 5 new $^{enr}\text{BEGe}$ detectors deployed to compensate the lost of two coax.

Exposure is monitored by:
- Weekly $^{228}\text{Th}$ calibrations
- Pulser
Main detectors parameters remeasured

ICPMS

Low E $\gamma$-sources

<table>
<thead>
<tr>
<th>detector</th>
<th>$f_{78}$</th>
<th>$M$ (g)</th>
<th>$M_{act} (\Delta M_{act})$ (g)</th>
<th>$f_{av} (\Delta f_{av})$</th>
<th>$d_{dl}$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>enriched coaxial detectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANG 1 †</td>
<td>0.859(29)</td>
<td>958</td>
<td>795(50)</td>
<td>0.830(52)</td>
<td>1.8(5)</td>
</tr>
<tr>
<td>ANG 2</td>
<td>0.866(25)</td>
<td>2833</td>
<td>2468(145)</td>
<td>0.871(51)</td>
<td>2.3(7)</td>
</tr>
<tr>
<td>ANG 3</td>
<td>0.883(26)</td>
<td>2391</td>
<td>2070(136)</td>
<td>0.866(57)</td>
<td>1.9(7)</td>
</tr>
<tr>
<td>ANG 4</td>
<td>0.863(13)</td>
<td>2372</td>
<td>2136(135)</td>
<td>0.901(57)</td>
<td>1.4(7)</td>
</tr>
<tr>
<td>ANG 5</td>
<td>0.856(13)</td>
<td>2746</td>
<td>2281(132)</td>
<td>0.831(48)</td>
<td>2.6(6)</td>
</tr>
<tr>
<td>RG 1</td>
<td>0.855(15)</td>
<td>2110</td>
<td>1908(125)</td>
<td>0.904(59)</td>
<td>1.5(7)</td>
</tr>
<tr>
<td>RG 2</td>
<td>0.855(15)</td>
<td>2166</td>
<td>1800(115)</td>
<td>0.831(53)</td>
<td>2.3(7)</td>
</tr>
<tr>
<td>RG 3 †</td>
<td>0.855(15)</td>
<td>2087</td>
<td>1868(113)</td>
<td>0.895(54)</td>
<td>1.4(7)</td>
</tr>
<tr>
<td>enriched BEGe detectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GD32B</td>
<td>0.877(13)</td>
<td>717</td>
<td>638(19)</td>
<td>0.890(27)</td>
<td>1.0(2)</td>
</tr>
<tr>
<td>GD32C</td>
<td>0.877(13)</td>
<td>743</td>
<td>677(22)</td>
<td>0.911(30)</td>
<td>0.8(3)</td>
</tr>
<tr>
<td>GD32D</td>
<td>0.877(13)</td>
<td>723</td>
<td>667(19)</td>
<td>0.923(26)</td>
<td>0.7(2)</td>
</tr>
<tr>
<td>GD35B</td>
<td>0.877(13)</td>
<td>812</td>
<td>742(24)</td>
<td>0.914(29)</td>
<td>0.8(3)</td>
</tr>
<tr>
<td>GD35C †</td>
<td>0.877(13)</td>
<td>635</td>
<td>575(20)</td>
<td>0.906(32)</td>
<td>0.8(3)</td>
</tr>
<tr>
<td>natural coaxial detectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTF 32 †</td>
<td>0.078(1)</td>
<td>2321</td>
<td>2251(116)</td>
<td>0.97(5)</td>
<td>0.4(8)</td>
</tr>
<tr>
<td>GTF 45 †</td>
<td>0.078(1)</td>
<td>2312</td>
<td>2251(116)</td>
<td>0.97(5)</td>
<td>0.4(8)</td>
</tr>
<tr>
<td>GTF 112</td>
<td>0.078(1)</td>
<td>2965</td>
<td>2251(116)</td>
<td>0.97(5)</td>
<td>0.4(8)</td>
</tr>
</tbody>
</table>
The Energy Scale: COAX

**From 1525 keV $^{42}$K $\gamma$-line summed COAX spectra**

<table>
<thead>
<tr>
<th>Detector</th>
<th>FWHM @ 2039 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANG2</td>
<td>5.8 ± 0.3</td>
</tr>
<tr>
<td>ANG3</td>
<td>4.5 ± 0.1</td>
</tr>
<tr>
<td>ANG4</td>
<td>4.9 ± 0.3</td>
</tr>
<tr>
<td>ANG5</td>
<td>4.2 ± 0.1</td>
</tr>
<tr>
<td>RG1</td>
<td>4.5 ± 0.3</td>
</tr>
<tr>
<td>RG2</td>
<td>4.9 ± 0.3</td>
</tr>
<tr>
<td>Mean COAX</td>
<td>4.8 ± 0.2</td>
</tr>
</tbody>
</table>

**Energy**: From semi-gaussian DSP of the acquired waveforms

**DAQ facts**: 14 bit, 100 MHz continuous running ADC. TRG thrsd: 40-100 keV
The Energy Scale: BEGЕs

From 1525 keV $^{42}$K γ-line summed BEGе spectra

<table>
<thead>
<tr>
<th>detector</th>
<th>FWHM @ 2039 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>GD32B</td>
<td>2.6 ± 0.1</td>
</tr>
<tr>
<td>GD32C</td>
<td>2.6 ± 0.1</td>
</tr>
<tr>
<td>GD32D</td>
<td>3.7 ± 0.5</td>
</tr>
<tr>
<td>GD35B</td>
<td>4.0 ± 0.1</td>
</tr>
<tr>
<td>Mean BEGE</td>
<td>3.2 ± 0.2</td>
</tr>
</tbody>
</table>

$^{1}$еnr BEGe not used in the 0νββ data sets because of instabilities
GERDA Data Sets

- **Golden coax**: all the coax runs apart from 30 days just after the BEGe insertion in June 2012
- **Silver coax**: The coax data collected in the 30 days following the BEGe insertion
- **BEGe**: Treated separately because of intrinsic differences (better FWHM, intrinsic PSD, lower alfa contamination)
The energy spectra

- **2νβ**
  - Bi-214: 1765 keV
  - Bi-214: 2234 keV
- **2νβ**
  - K-40: 1461 keV
  - K-40: 1525 keV
- **39Ar β−**
- **GTF 112, 3.13 kg × yr**
  - enriched coaxials, 16.70 kg × yr
  - enriched BEGe, 1.80 kg × yr
  - 226Ra, 222Rn, 210Po, 218Po

FWHM: 4.47(0.12) keV
FWHM: 3.08(0.31) keV

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Identification of Background Components

- $\alpha$ contamination from $^{210}$Po.
- contamination at time of refurbishment mostly on thin p+ contact
- $^{210}$Po decaying away ($t_{1/2}=138$ d)
- Large differences among detectors
- BEGes much cleaner (> factor 10)
The model reproduces a flat background around $Q_{\beta\beta}$.

No $\gamma$-lines visible in the 30 keV range around the $Q_{\beta\beta}$.

Spectra can be fitted with a flat background apart from $^{214}$Bi lines @ 2104 keV and 2119 keV.

arXiv: 1306.5084v1
PSD to discriminate $\beta\beta$-like (SSE) to $\gamma$-like (MSE) events

Different weighting potentials for Coax and BEGe

COAX: Artificial Neural Network (ANN) estimator used as PSD parameter

BEGe: Amplitude of Current/Amplitude of Charge Pulse (A/E) is the PSD parameter
PSD for coax

ANN trained on

SIGNAL (SSE) : $^{208}$TI (2614 keV) Double Escape Peak (DEP) @ 1592 keV line

BACKGROUND (MSE): $^{212}$Bi @ 1620 keV $\gamma$-line

- Required 90% acceptance of DEP
- $\varepsilon$ for other classes of events derived
- acceptance of SSE verified on Compton edges (CE) and $2\nu\beta\beta$
..to conclude PSD efficiencies and their systematics are evaluated arXiv: 1307.2610

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{2\nu\beta\beta}$</th>
<th>$\varepsilon_{0\nu\beta\beta}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coax</td>
<td>$0.85 \pm 0.02$</td>
<td>$0.90 \pm 0.1$</td>
</tr>
<tr>
<td>BEGe</td>
<td>$0.91 \pm 0.05$</td>
<td>$0.92 \pm 0.02$</td>
</tr>
</tbody>
</table>

Bckgrd rejection= 33 of 40 events rejected in ±200 keV range.

$B_{PSD} = 0.7 \times 10^{-2}$ cts/(keV kg y)
Summary of parameters and systematics relevant to $T_{1/2}^{0\nu}$

Energy Windows at $Q_{\beta\beta} = 2039$ keV

<table>
<thead>
<tr>
<th>Data set</th>
<th>FWHM [keV]</th>
<th>ROI [keV]</th>
<th>$&lt;f_{76}&gt;$</th>
<th>$&lt;f_{av}&gt;$</th>
<th>$&lt;\epsilon_{\text{fep}}&gt;\ (\text{FEP})$</th>
<th>$&lt;\epsilon_{\text{PSD}}&gt;$</th>
<th>$&lt;\epsilon&gt;$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coax</td>
<td>$4.8 \pm 0.2$</td>
<td>$\pm 5$</td>
<td>0.86</td>
<td>0.87</td>
<td>0.92</td>
<td>$0.90^{+0.05}_{-0.09}$</td>
<td>$0.619^{+0.044}_{-0.070}$</td>
</tr>
<tr>
<td>BEGe</td>
<td>$3.2 \pm 0.2$</td>
<td>$\pm 4$</td>
<td>0.88</td>
<td>0.92</td>
<td>0.90</td>
<td>$0.92 \pm 0.02$</td>
<td>$0.663 \pm 0.022$</td>
</tr>
</tbody>
</table>

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The blinded/unblinded data

• Data blinded since January 2012:
  Events in ± 20 keV around $Q_{\beta\beta}$ removed from Tier1

• Unblinding in two steps:
  • May 2013: Unblinded ± 15 keV around still blinded ± 5 keV @ $Q_{\beta\beta}$
  • 17 June 2013 @ GERDA Plenary meeting in Dubna (RU):
    Unblinded the ± 5 keV region @ $Q_{\beta\beta}$

| Table 1: List of all events within $Q_{\beta\beta} \pm 5$ keV |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| data set        | detector        | energy [keV]    | date            | PSD passed      | ANN             | A/E             | Cut             |
| golden          | ANG 5           | 2041.8          | 18-Nov-2011 22:52 | no              | 0.344           | 0.366           |
| silver          | ANG 5           | 2036.9          | 23-Jun-2012 23:02 | yes             | 0.518           | 0.366           |
| golden          | RG 2            | 2041.3          | 16-Dec-2012 00:09 | yes             | 0.682           | 0.364           |
| BEGe            | GD32B           | 2036.6          | 28-Dec-2012 09:50 | no              | 0.750           | 0.965±1.070     |
| golden          | RG 1            | 2035.5          | 29-Jan-2013 03:35 | yes             | 0.713           | 0.372           |
| golden          | ANG 3           | 2037.4          | 02-Mar-2013 08:08 | no              | 0.205           | 0.345           |
| golden          | RG 1            | 2041.7          | 27-Apr-2013 22:21 | no              | 0.369           | 0.372           |

arXiv: 1307.4720v1
The unblinded spectrum @ Q_{bb}

- Coax golden
- Coax silver
- BEGe

Counts/keV

- PSD
- NO PSD

Energy [keV]

Counts/(2 keV)

- 1930 keV
- 2039 keV
- 2190 keV
- 2204 keV
- 214^{Bi}
From counts to $T_{1/2}^{0\nu}$: the relevant numbers

$$T_{1/2}^{0\nu} = \frac{\ln 2 \cdot N_A}{m_{enr} \cdot N_{0\nu}} \cdot \mathcal{E} \cdot \epsilon$$

$$\epsilon = f_{76} \cdot f_{\alpha\nu} \cdot \varepsilon_{\text{fep}} \cdot \varepsilon_{\text{psd}}$$

Expected bckgd only

<table>
<thead>
<tr>
<th>data set</th>
<th>$\mathcal{E}[	ext{kg}\cdot\text{yr}]$</th>
<th>$\langle \epsilon \rangle$</th>
<th>bkg</th>
<th>BI $^\dagger$</th>
<th>cts</th>
</tr>
</thead>
<tbody>
<tr>
<td>without PSD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>golden</td>
<td>17.9</td>
<td>0.688 ± 0.031</td>
<td>76</td>
<td>18 ± 2</td>
<td>5</td>
</tr>
<tr>
<td>silver</td>
<td>1.3</td>
<td>0.688 ± 0.031</td>
<td>19</td>
<td>63 ± 16</td>
<td>1</td>
</tr>
<tr>
<td>BEGe</td>
<td>2.4</td>
<td>0.720 ± 0.018</td>
<td>23</td>
<td>42 ± 16</td>
<td>1</td>
</tr>
<tr>
<td>with PSD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>golden</td>
<td>17.9</td>
<td>0.619$^{+0.044}_{-0.070}$</td>
<td>45</td>
<td>11 ± 2</td>
<td>2</td>
</tr>
<tr>
<td>silver</td>
<td>1.3</td>
<td>0.619$^{+0.044}_{-0.070}$</td>
<td>9</td>
<td>30 ± 11</td>
<td>1</td>
</tr>
<tr>
<td>BEGe</td>
<td>2.4</td>
<td>0.663 ± 0.022</td>
<td>3</td>
<td>5 ± 4</td>
<td>0</td>
</tr>
</tbody>
</table>

$^\dagger$ in units of $10^{-3}$ cts/(keV·kg·yr).

BI Rej $\text{PSD}_{\text{Coax}} \approx 43\%$
BI Rej $\text{PSD}_{\text{BEGe}} \approx 87\%$

In 230 keV @ $Q_{\beta\beta}$
In ± 5 keV @ $Q_{\beta\beta}$

arXiv: 1307.2610

Coax ~ 43%
$T_{1/2}^{0\nu}$ from GERDA data sets

Performed Profile Likelihood fit of the 3 data sets
- B+S: described by constant term + $\text{Gaus}(Q_{\beta\beta}, \sigma_E)$
- 4 free parameters in the fit $B_{\text{gold}}, B_{\text{silv}}, B_{\text{BEGe}}, 1/T_{1/2}^{0\nu}$
- Systematics folded in

Frequentist approach
Best fit: $N^{0\nu} = 0$
$N^{0\nu} < 3.5 \text{ cts @ 90\% C.L.}$
$T_{1/2}^{0\nu} > 2.1 \times 10^{25} \text{ yr @ 90\% CL}$

Bayesian approach
Flat prior for $1/T_{1/2}^{0\nu}$
Best fit: $N^{0\nu} = 0$
$T_{1/2}^{0\nu} > 1.9 \times 10^{26} \text{ yr @ 90\% CI}$
Median sensitivity:
$T_{1/2}^{0\nu} > 2.1 \times 10^{25} \text{ yr}$
GERDA (all data sets) vs KK (2004) claim

For $T_{1/2}^0 = 1.19 \times 10^{25}$ yr

- Expected Signal (after PSD): $5.9 \pm 1.4$ cts in $\pm 2\sigma$
- Expected Bckgd (after PSD): $2.0 \pm 0.3$ cts in $\pm 2\sigma$
- Observed: $3.0$ (0 in $\pm 1\sigma$)

From profile likelihood
Assuming $H_1$,
$P(N^0=0 \text{ for } H_1) = 1\%$

Comparing
$H_1$: Claimed signal
$H_0$: Background only

Bayes factor
$P(H_1)/P(H_0) = 0.024$
(uncertainties on claim included)

Claim poorly credible
Combining GERDA, HdM, IGEX & Xe

arXiv: 1307.2610

**H1**: signal with $T_{1/2}^{0v} = 1.19 \times 10^{25} \text{ yr}$

**H0**: background only

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$P(H_1)/P(H_0)$</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>GERDA</td>
<td>$^{76}\text{Ge}$</td>
<td>0.024</td>
</tr>
<tr>
<td>GERDA +HdM+IGEX</td>
<td>$^{76}\text{Ge}$</td>
<td>0.0002</td>
</tr>
<tr>
<td>KamLAND-Zen*</td>
<td>$^{136}\text{Xe}$</td>
<td>0.40</td>
</tr>
<tr>
<td>EXO-200*</td>
<td>$^{136}\text{Xe}$</td>
<td>0.23</td>
</tr>
<tr>
<td>GERDA+KLZ* +EXO*</td>
<td>$^{76}\text{Ge} + ^{136}\text{Xe}$</td>
<td>0.002</td>
</tr>
</tbody>
</table>

*: with conservative NME ratio $M_{0v}(^{136}\text{Xe})/M_{0v}(^{76}\text{Ge}) \approx 0.4$ from:

NME from P.S. Bhupal Dev et al (2103), arXiv:1305.0056

Combining GERDA, HdM, IGEX

3 GERDA Data sets, 1 HdM, 1 IGEX
Profile likelihood function w. 5 independent bckgds $T_{1/2}^{0v} > 3.0 \times 10^{25} \text{ yr } @ 90\% \text{ CL}$
Conclusions and outlooks

- GERDA achieved its design goals
  - Phase I Exposure: 21.6 kg yr
  - Background Index: $\sim 10^{-2}$ cts / (Kev kg y)  Unprecedented value!
  - Scrutinize the KK claim in 1.5 yr data taking

- No excess of counts above background is found @ $Q_{\beta\beta}$ after unblinding: 7 (3 after PSD) cts in ± 5keV region

- GERDA : $T_{1/2}^{0v} > 2.1 \times 10^{25}$ yr @ 90% CL
- GERDA combined w. IGEX & HdM $T_{1/2}^{0v} > 3.0 \times 10^{25}$ yr @ 90% CL
- $m_{\beta\beta} < (0.2 \,-\, 0.4)$ eV depending on NME and Phase Space Factors

- PSD works well mainly for BEGEs
- Phase II challenge: achieve another factor 10 in BI and sensitivity

............ who will live will see it.
EXTRA slides
2νββ spectrum generated by DECAY0 (V.Tetryak)

- 6 independent models for the 6 detectors (5 x 6 = 30 detector parameters)
- T^{2\nu \frac{1}{2}} common in 6 detectors

Background from 3 sources: 42K, 40K, 214Bi (γ-lines used for normalization)
- 42K: homogeneously distributed
- 40K & 214Bi: close sources

Detectors active masses and enr. factors are nuisance parameters in the fit.

T^{2\nu \frac{1}{2}} pdf is quasi-gaussian

ββ spectrum: 8796 events:
Model of the residual background: 80% 2νββ, 14% 42K, 3.8% 214Bi, 2% 40K,
GERDA vs previous measurements of $T^{2\nu}_{1/2}$

\[ T^{2\nu}_{1/2} = (1.84^{+0.09}_{-0.08\, \text{fit}} \pm 0.11_{-0.06\, \text{syst}}) \cdot 10^{21} \, \text{yr} = (1.84^{+0.14}_{-0.10}) \cdot 10^{21} \, \text{yr}, \quad (2) \]

- GERDA is consistent with HdM
  \[
  T^{2\nu}_{1/2} = 1.78^{+0.07}_{-0.09}
  \]

- Thanks to our BI comparable $\sigma_{\text{stat}}$ with $\sim 1/10$ exposure

- GERDA results can improve by
  - New measurement of coax active volumes
  - Increased statistics (already available)
The KK 2006 claim


- 71.7 kg year - Bgd 0.17 / (kg yr keV)
- 28.75 ± 6.87 events (bgd:~60)
- Claim: 4.2σ evidence for 0νββ
- reported $T_{1/2}^{0\nu} = 1.19 \times 10^{25}$ yr

N.B. Half-life $T_{1/2}^{0\nu} = 2.23 \times 10^{25}$ yr $T_{1/2}$ after PSD analysis (Mod. Phys. Lett. A 21, 1547 (2006).) is not considered because:

- reported half-life can be reconstructed only (Ref. 1) with $\epsilon_{psd} = 1$ (previous similar analysis $\epsilon_{psd} \approx 0.6$)
- $\epsilon_{fep} = 1$ (also in NIM A 522, PLB 586 (2004))
  (GERDA value for same detectors: $\epsilon_{fep} = 0.9$)

(1) B. Schwingenheuer in Ann. Phys. 525, 269 (2013):
Precursor Ge experiments

Heidelberg-Moscow
(H.V. Klapdor-Kleingrothaus et al.)

53.9 kg y (35.5 kg y): $T_{1/2}^{0v} > 1.3 \times 10^{25}$ yr ($1.9 \times 10^{25}$ yr)
(90% C.L.)

IGEX
(Aalseth et al.)

8.8 kg y: $T_{1/2}^{0v} > 1.6 \times 10^{25}$ yr (90% C.L.)
<table>
<thead>
<tr>
<th></th>
<th>Golden Coax</th>
<th>BEGe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BI[10^{-3}] in 10 keV</td>
<td>BI[10^{-3}] in 10 keV</td>
</tr>
<tr>
<td>Interpolation</td>
<td>17.5 [15-20]</td>
<td>36.1 [26-49]</td>
</tr>
<tr>
<td>Minimal</td>
<td>18.5 [17.6-19.3]</td>
<td>38.1 [37.5 – 38.7]</td>
</tr>
<tr>
<td>Maximal</td>
<td>21.9 [20.7–23.8]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cts in 40 keV</td>
<td>Cts in 32 keV</td>
</tr>
<tr>
<td>data</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Minimal</td>
<td>8.6 [8.2-9.1]</td>
<td>2.2 [2.1 – 2.2]</td>
</tr>
<tr>
<td>Maximal</td>
<td>10.3 [9.7-11.1]</td>
<td></td>
</tr>
</tbody>
</table>
The background index evaluated in the 230 keV region centered at $Q_{bb}$

Table 10: The total background index and individual contributions in 10 keV (8 keV for BEGe) energy window around $Q_{\beta\beta}$ for different models and data sets. Given are the values due to the global mode together with the uncertainty intervals [upper,lower limit] obtained as the smallest 68% interval (90%/10% quantile for limit setting) of the marginalized distributions.

<table>
<thead>
<tr>
<th>component</th>
<th>location</th>
<th>$GOLD-coax$ minimum model</th>
<th>$GOLD-coax$ maximum model</th>
<th>$GOLD-nat$ minimum model</th>
<th>$GOLD-nat$ minimum model</th>
<th>$SUM-bege$ minimum model + $n^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td>18.5</td>
<td>[17.6, 19.3]</td>
<td>21.9</td>
<td>[20.7, 23.8]</td>
<td>29.6 [27.1, 32.7]</td>
</tr>
<tr>
<td>$^{42}$K</td>
<td>LAr homogeneous</td>
<td>3.0 [2.9, 3.1]</td>
<td>2.6 [2.0, 2.8]</td>
<td>2.9 [2.7, 3.2]</td>
<td>2.0 [1.8, 2.3]</td>
<td></td>
</tr>
<tr>
<td>$^{42}$K</td>
<td>$p^+$ surface</td>
<td>4.6 [1.2, 7.4]</td>
<td></td>
<td></td>
<td></td>
<td>20.8 [6.8, 23.7]</td>
</tr>
<tr>
<td>$^{42}$K</td>
<td>$n^+$ surface</td>
<td>0.2 [0.1, 0.4]</td>
<td></td>
<td></td>
<td></td>
<td>&lt;4.7</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>det. assembly</td>
<td>1.4 [0.9, 2.1]</td>
<td>0.9 [0.3, 1.4]</td>
<td>1.1 [0.0, 2.5]</td>
<td></td>
<td>&lt;4.7</td>
</tr>
<tr>
<td>$^{68}$Ge</td>
<td>germanium</td>
<td>0.6 &gt;0.1 †</td>
<td>0.6 &gt;0.1 †</td>
<td>9.2 [4.5, 12.9]</td>
<td>1.0 [0.3, 1.0]</td>
<td>1.5 (&lt;6.7)</td>
</tr>
<tr>
<td>$^{214}$Bi</td>
<td>LAr homogeneous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.1 [3.1, 6.9]</td>
</tr>
<tr>
<td>$^{214}$Bi</td>
<td>$p^+$ surface</td>
<td>5.2 [4.7, 5.9]</td>
<td>2.2 [0.5, 3.1]</td>
<td>4.9 [3.9, 6.1]</td>
<td></td>
<td>5.1 [3.1, 6.9]</td>
</tr>
<tr>
<td>$^{214}$Bi</td>
<td>close to $p^+$</td>
<td>3.1 [4.7]</td>
<td></td>
<td></td>
<td></td>
<td>5.1 [3.1, 6.9]</td>
</tr>
<tr>
<td>$^{214}$Bi</td>
<td>radon shroud</td>
<td>1.4 [1.0, 1.8] †</td>
<td>1.3 [0.9, 1.8] †</td>
<td>3.7 [2.7, 4.8] †</td>
<td>0.7 [0.1, 1.3] †</td>
<td></td>
</tr>
<tr>
<td>$^{228}$Th</td>
<td>det. assembly</td>
<td>4.5 [3.9, 5.4]</td>
<td>1.6 [0.4, 2.5]</td>
<td>4.0 [2.5, 6.3]</td>
<td>4.2 [1.8, 8.4]</td>
<td></td>
</tr>
<tr>
<td>$^{228}$Th</td>
<td>radon shroud</td>
<td>1.7 &lt;3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>p$^+$ surface</td>
<td>2.4 [2.4, 2.5]</td>
<td>2.4 [2.2, 2.5]</td>
<td>2.8 [2.5, 4.2]</td>
<td>1.5 [1.2, 1.8]</td>
<td></td>
</tr>
</tbody>
</table>

†) prior: discussed in sec. 5