$^{42}$Ar/$^{42}$K Background
in the GERDA Experiment

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Neutrinoless Double Beta Decay

$$(Z, A) \rightarrow (Z + 2, A) + 2e^-$$

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu} \cdot |\mathcal{M}^{0\nu}|^2 \cdot |m_{ee}|^2$$

Effective Majorana neutrino mass

**Phase I**
- Exposure: $15 \text{ kg} \cdot \text{yr}$
- Background index (BI): $10^{-2} \text{ cts/(kg} \cdot \text{yr} \cdot \text{keV})$
- Goal: Test HDM claim $T^{0\nu}_{1/2} = 2.23^{+0.44}_{-0.31} \cdot 10^{25} \text{ yr}$

(Klapdor-Kleingrothaus et al. Eur Phys J A12 147)

**Phase II**
- Exposure: $100 \text{ kg} \cdot \text{yr}$
- BI: $10^{-3} \text{ cts/(kg} \cdot \text{yr} \cdot \text{keV})$
The GERDA Idea

Novel idea: Operate HPGe detectors naked in liquid Argon

- Serving as cooling
- Serving as shielding
- Possible to implement as active veto
The Cryostat

- Two walls of stainless steel
- 16 t copper as shielding
- 89 t liquid argon
- Radon shroud to prevent convection
High Purity Germanium Detectors - HPGe

p-type coaxial germanium detectors

Phase I - recycled detectors
- 6 natural detectors (GENIUS)
- 5 enriched detectors (HDM)
- 3 enriched detectors (IGEX)

Phase II - new detectors
- BEGe’s (Matteo Agostini T108.3)
The First Data

Measured background spectrum
91.7 d exposure July-Nov 2010

Decay chain:
$^{42}\text{Ar} \rightarrow ^{42}\text{K} \rightarrow ^{42}\text{Ca}$

$^{42}\text{Ar}$: $Q = 599 \text{ keV}$, $T_{1/2} = 32.9 \text{ yr}$
$^{42}\text{K}$: $Q = 3525.4 \text{ keV}$, $T_{1/2} = 12.36 \text{ h}$
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91.7 d exposure July-Nov 2010

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Simulated spectrum (homogeneous distribution)

42\text{Ar} production:
\( ^{\text{nat}}\text{Ar} > 99 \% \) 40\text{Ar} and 0.934 \% vol in air

Cosmic \( \alpha \)'s: 40\text{Ar} (\( \alpha,2p \)) 42\text{Ar}

Nuclear explosions:
40\text{Ar} (\( n,\gamma \)) 41\text{Ar} (\( n,\gamma \)) 42\text{Ar}

42\text{Ar}/\( ^{\text{nat}}\text{Ar} < 4.3 \times 10^{-21} \text{ g/g (90 \% CL)} \)
The First Data

Measured background spectrum
91.7 \text{d exposure July-Nov 2010}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{spectrum.png}
\caption{Simulated spectrum (homogeneous distribution)}
\end{figure}

### Decay chain:

\begin{align*}
42 \text{Ar} & \rightarrow 42 \text{K} \rightarrow 42 \text{Ca} \\
42 \text{Ar: } Q &= 599 \text{ keV, } T_{1/2} = 32.9 \text{ yr} \\
42 \text{K: } Q &= 3525.4 \text{ keV, } T_{1/2} = 12.36 \text{ h}
\end{align*}

\begin{itemize}
\item 42\text{Ar production: }
\text{nat} \text{Ar} > 99\% \text{ 40Ar and 0.934 \% vol in air}
\item Cosmic \alpha's: 40\text{Ar}(\alpha,2p)^{42}\text{Ar}
\item Nuclear explosions: 40\text{Ar}(n,\gamma)^{41}\text{Ar}(n,\gamma)^{42}\text{Ar}
\end{itemize}

\textbf{Exp limit:} (Ashitkov et al. arXiv:nucl-ex/0309001)

\begin{align*}
42\text{Ar}/\text{nat Ar} & < 4.3 \cdot 10^{-21} \text{ g/g (90 \% CL)} \\
0.094 \text{ cts/(kg \cdot d)}
\end{align*}
The First Data

**Measured background spectrum**
91.7 d exposure July-Nov 2010

![Graph showing background spectrum with Cts/keV values.](image)

**Simulated spectrum (homogeneous distribution)**

![Graph showing simulated spectrum with energy and Cts/keV values.](image)

**Decay chain:**

\[ {}^{42}\text{Ar} \rightarrow {}^{42}\text{K} \rightarrow {}^{42}\text{Ca} \]

\[ {}^{42}\text{Ar}: \quad Q = 599 \text{ keV}, \quad T_{1/2} = 32.9 \text{ yr} \]
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**42Ar production:**

\( \text{nat Ar} > 99\% \quad 40\text{Ar} \) and 0.934 \( \%_{\text{vol}} \) in air

**Cosmic \( \alpha \)'s:**

\( 40\text{Ar(}\alpha,2p\text{)}^{42}\text{Ar} \)

**Nuclear explosions:**

\( 40\text{Ar(n,}\gamma\text{)}^{41}\text{Ar(n,}\gamma\text{)}^{42}\text{Ar} \)

**Exp limit:**

(Ashitkov et al. arXiv:nucl-ex/0309001)

\[ {}^{42}\text{Ar}/\text{nat Ar} < 4.3 \times 10^{-21} \text{ g/g (90\% CL)} \]

**Question 1:** Why does data not agree with MC (hom, exp limit)
Background Index at $Q_{\beta\beta}$ (2039 keV)

First data around $Q_{\beta\beta}$ (28.5 d exposure)

Without mini-shroud: 0.169 counts/(keV $\times$ kg $\times$ year)

0.17 cts/(keV $\times$ kg $\times$ yr)
Background Index at $Q_{\beta\beta}$ (2039 keV)

First data around $Q_{\beta\beta}$ (28.5 d exposure)

$^{42}\text{K}$ contributions:

▷ 2424 keV $\gamma$-line (0.02 %)

▷ $\beta$ with 3525 keV endpoint (81.9 %)

Position of $^{42}\text{K}$ decays with E-deposition in detector (MC for homogeneous distribution)
Background Index at $Q_{\beta\beta}$ (2039 keV)

First data around $Q_{\beta\beta}$ (28.5 d exposure)

$42K$ contributions:
- 2424 keV $\gamma$-line (0.02 %)
- $\beta$ with 3525 keV endpoint (81.9 %)

Question 2: Where is the background coming from? $42K$?
Answering Question 1 - Inhomogeneous $^{42}\text{K}$ distribution?

**Assumption**

Charge collection

- $^{42}\text{Ar} \rightarrow ^{42}\text{K}^{\pm}$
- $^{42}\text{K}$ ions get attracted by detector HV

**Approach:**

Installation of the mini-shroud

- Close field lines
- Restrict LAr volume / Prevent drift
- Repel ions from detectors

**Results**

Exp runs with different E-field configurations

- Mini-shroud installation reduced peak count rate by factor 4..5
- Charge collection can be seen
- Indication on + and – charged $^{42}\text{K}$ ions

*Same conditions but different E-field*

Black: -700 V, red: +400 V on mini-shroud
Answering Question 2: Is the Background coming from $^{42}\text{K}$?

**Assumption**

- Counts around $Q_{\beta\beta}$ come from $^{42}\text{K}$ β’s penetrating dead layer

**Approach**

- Detector encapsulated
- Bore hole capping

**Result**

- Count rate at $Q_{\beta\beta}$ mainly insensitive to encapsulation
- BI is not dominated by $^{42}\text{K}$
Current Situation

Field free configuration
HV on the inside
Outside grounded

Current background index:
$0.055 \pm 0.015\text{ cts/(kg \cdot yr \cdot keV)}$ (68 % CL for 0.59 kg \cdot yr):
Conclusions for $^{42}$K

Major experimental effort of the collaboration in the last 6 months
- Installation of mini-shroud and investigation of charge collection
- Investigation of detector encapsulating
- Parallel investigation with LArGe (R&D setup)

Question 1: Discrepancy between data and MC
- Charge collection can be seen
- Explains some of the discrepancy

Question 2: High background at $Q_{\beta\beta}$
- $^{42}$K is not the dominating background contribution around $Q_{\beta\beta}$
- Present BI: 6 times higher than the goal for Phase I
- GERDA BI already two times better than in previous $^{76}$Ge experiments
- Investigations ongoing - all results preliminary
Thanks for the attention.
Backup
Bonus Question - Is Charge Collection the Reason for the High BI?

MC simulations in different volumes and at different positions

None of the MC scenarios can explain consistently

- the peak count
- the background index

Problem: MC simulations very dependent on precision of dead layer implementation
BI Evolution

Run History

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<th>Date</th>
<th>background index, counts/(keV × kg × year)</th>
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