2015 European Nuclear Physics Conference
Groningen, 31 August-4 September 2015

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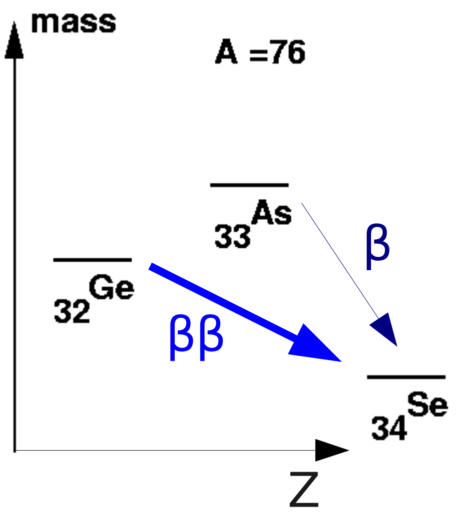
on behalf of the
GERDA Collaboration

Searching for the neutrinoless double beta decay with GERDA

Outline:

- Double Beta Decay
- GERDA design
- Results from Phase I
- Status of Phase II
- Summary

$2\nu\beta\beta$ and $0\nu\beta\beta$ decays



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

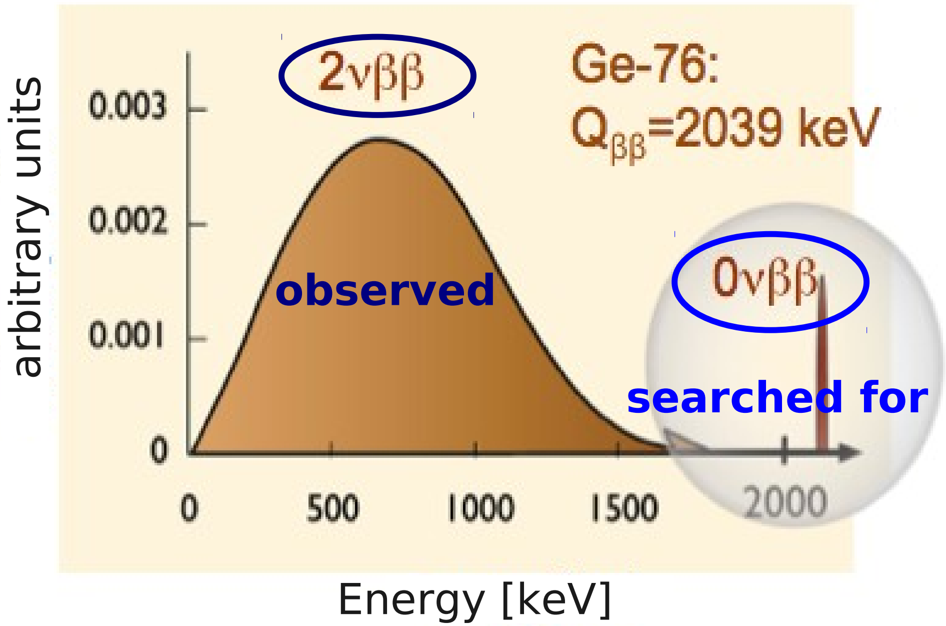
2nd order process, observed, $T_{1/2}$ ~ 10^{19}-10^{24} yrs

^{76}Ge: $T_{1/2}$ ~ 10^{21} yrs

$$0\nu\beta\beta : (A, Z) \rightarrow (A, Z+2) + 2e^-$$

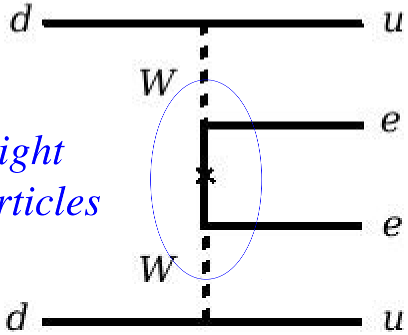
new physics, $T_{1/2} > 10^{25}$ yrs

Signature for $0\nu\beta\beta$ decays:



motivation for $0\nu\beta\beta$ decay searches

- would establish ***lepton number violation*** $\Delta L = 2$
- more ***physics beyond standard model***
- Only way to determine if neutrino is its own antiparticle:



exchange of light Majorana particles

$\nu = \bar{\nu}$ ⇨ ***Majorana particle***

If YES:

- would provide access to ***absolute neutrino mass scale***

$$\left(T_{1/2}^{0\nu}\right)^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\ \left|M^{0\nu}\right|^2 \left(\frac{\langle m_\nu \rangle}{m_e}\right)^2$$

nuclear matrix element

phase space factor

$$\langle m_\nu \rangle = \left|\sum_i U_{ei}^2 m_i\right|$$

effective Majorana neutrino mass

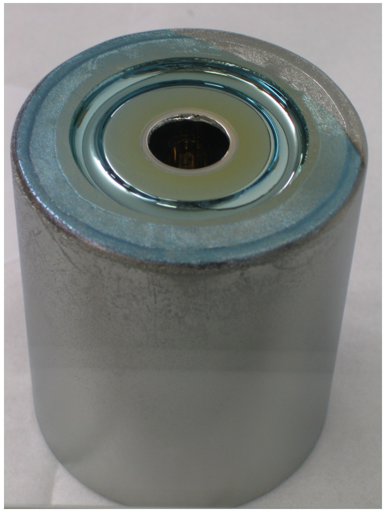
- would provide ***important input to cosmology***

Searching in ^{76}Ge

$$S \sim \epsilon \cdot f \cdot \sqrt{\frac{M \cdot t_{run}}{BI \cdot \Delta E}}$$

S: sensitivity
ε: efficiency
f: abundance of 0νββ isotope
M: detector mass

t_{run}: measurement time
BI: background index
ΔE: energy resolution at $Q_{\beta\beta}$



Germanium detector

Advantages of Germanium:

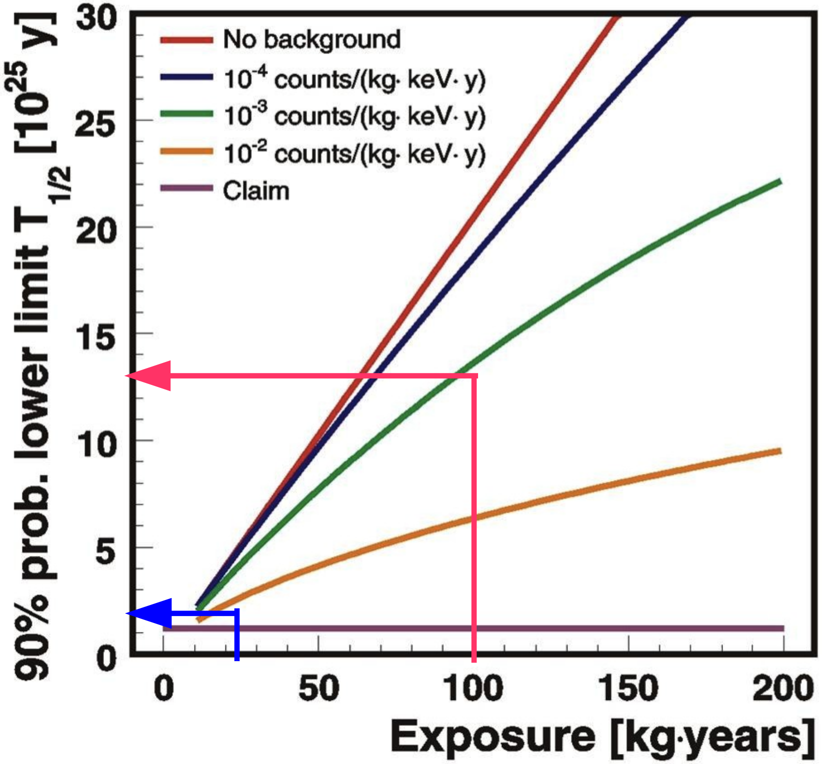
- **High ε**: Source = Detector
- **Small instrinsic BI**: High purity Ge
- **Excellent ΔE**: FWHM ~ (0.1-0.2)%
- Well-established technology

Disadvantages of Germanium:

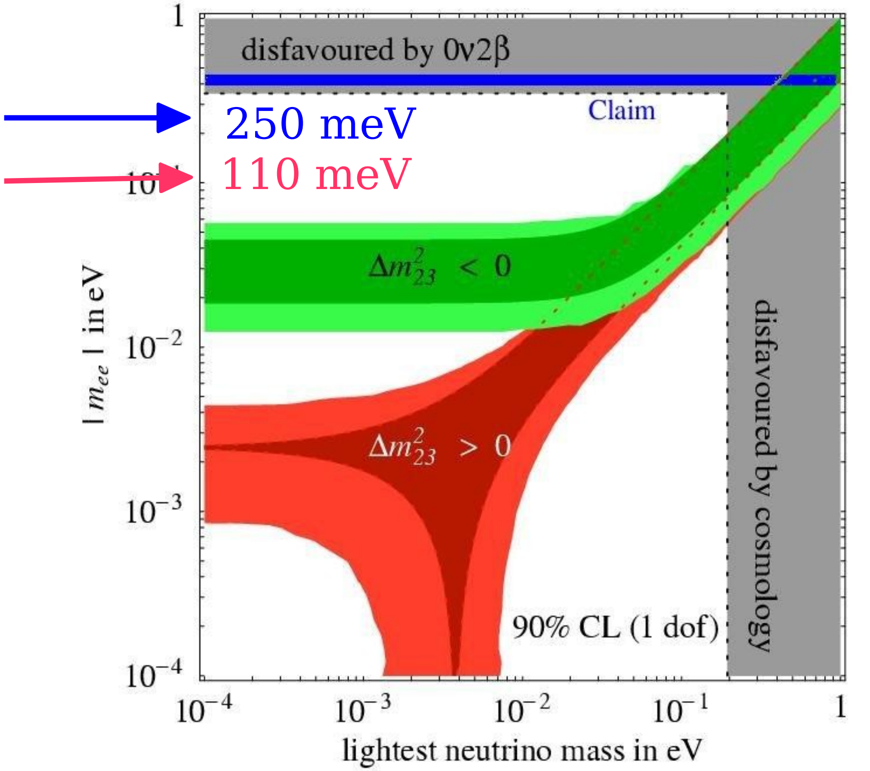
- at $Q_{\beta\beta}$= 2039keV more challenging to reach **low enough background**
- **Small f of ^{76}Ge:** 7.8% → Enrichment needed! → ~ **86% in GERDA**
- Limited sources of crystal & detector manufacturers
- Small $G^{0\nu}(Q_{\beta\beta},Z)$

GERDA physics goal

Phys. Rev. D 092003 (2006)



F. Feruglio, A. Strumia, F. Vissani, NPB 659



Phase I:

- reach background of **10^{-2} cts/(keV·kg·yr)**
- Exposure of 20 kg·yr → $T_{1/2} > 2 \cdot 10^{25}$ yr at 90% C.L.
- $<m_{\beta\beta}> \leq$ 0.23-0.39 eV
- → **check claim** *(Phys. Lett. B586, 184 (2004))***!**

Phase II:

- reach background of **10^{-3} cts/(keV·kg·yr)**
- Exposure of 100 kg·yr → $T_{1/2} > 1.35 \cdot 10^{26}$ yr
- $<m_{\beta\beta}> \leq$ 0.09-0.15 eV

Gerda @ LNGS: Background reduction

- **GERDA situated in LNGS underground laboratories**

- 3800 m.w.e.

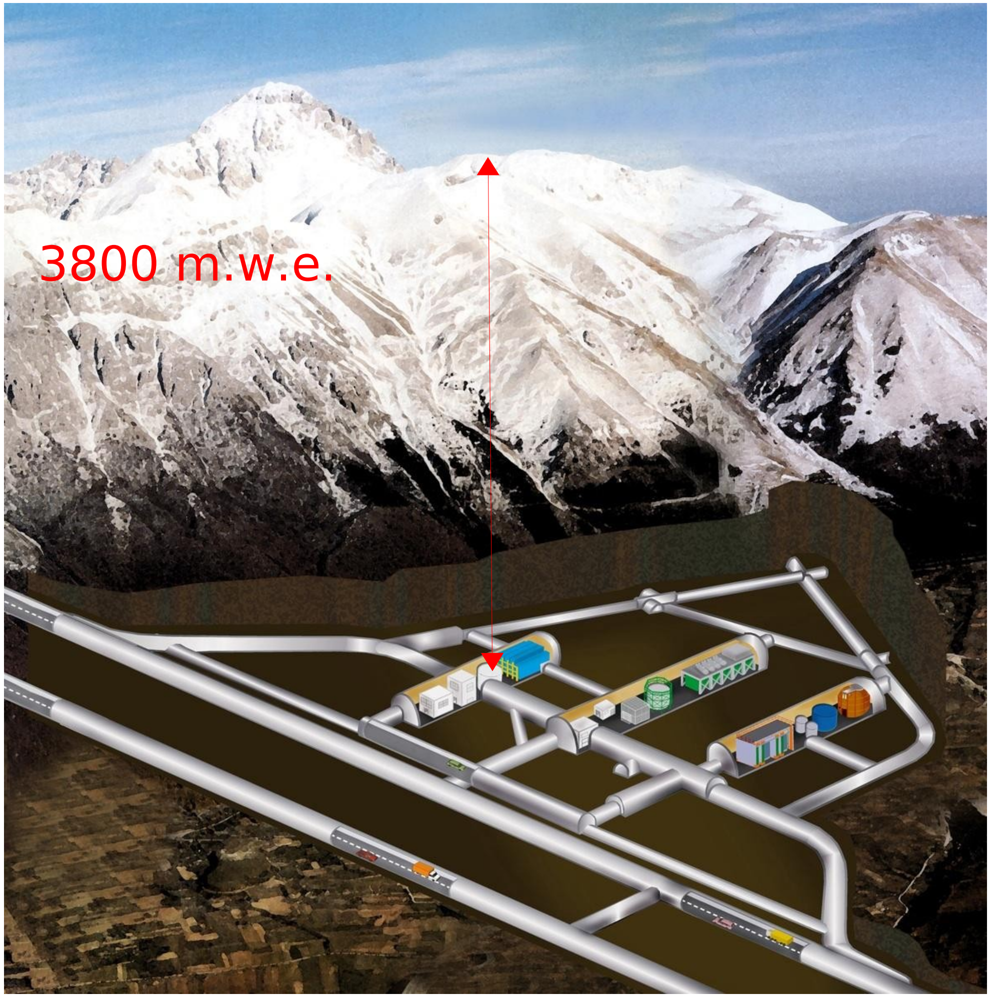
Possible **backgrounds** from:

External:

- γ from Th and U chain
- neutrons
- μ from cosmic rays (prompt and delayed)

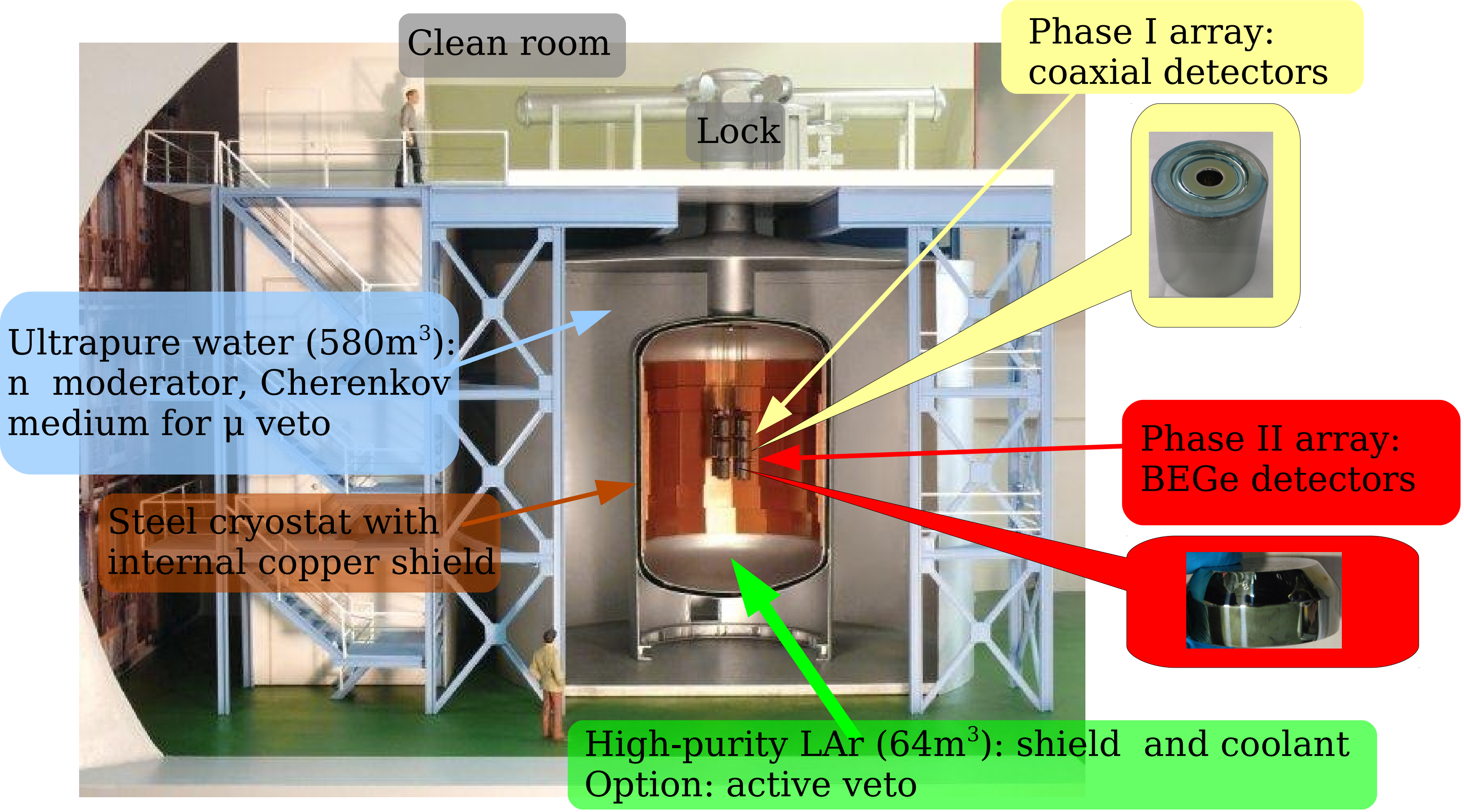
Internal:

- cosmogenic ^{60}Co ($T_{1/2}$=5.3 yr)
- cosmogenic ^{68}Ge ($T_{1/2}$=271 d)
- Radioactive surface contaminations



Gerda @ LNGS: Background reduction

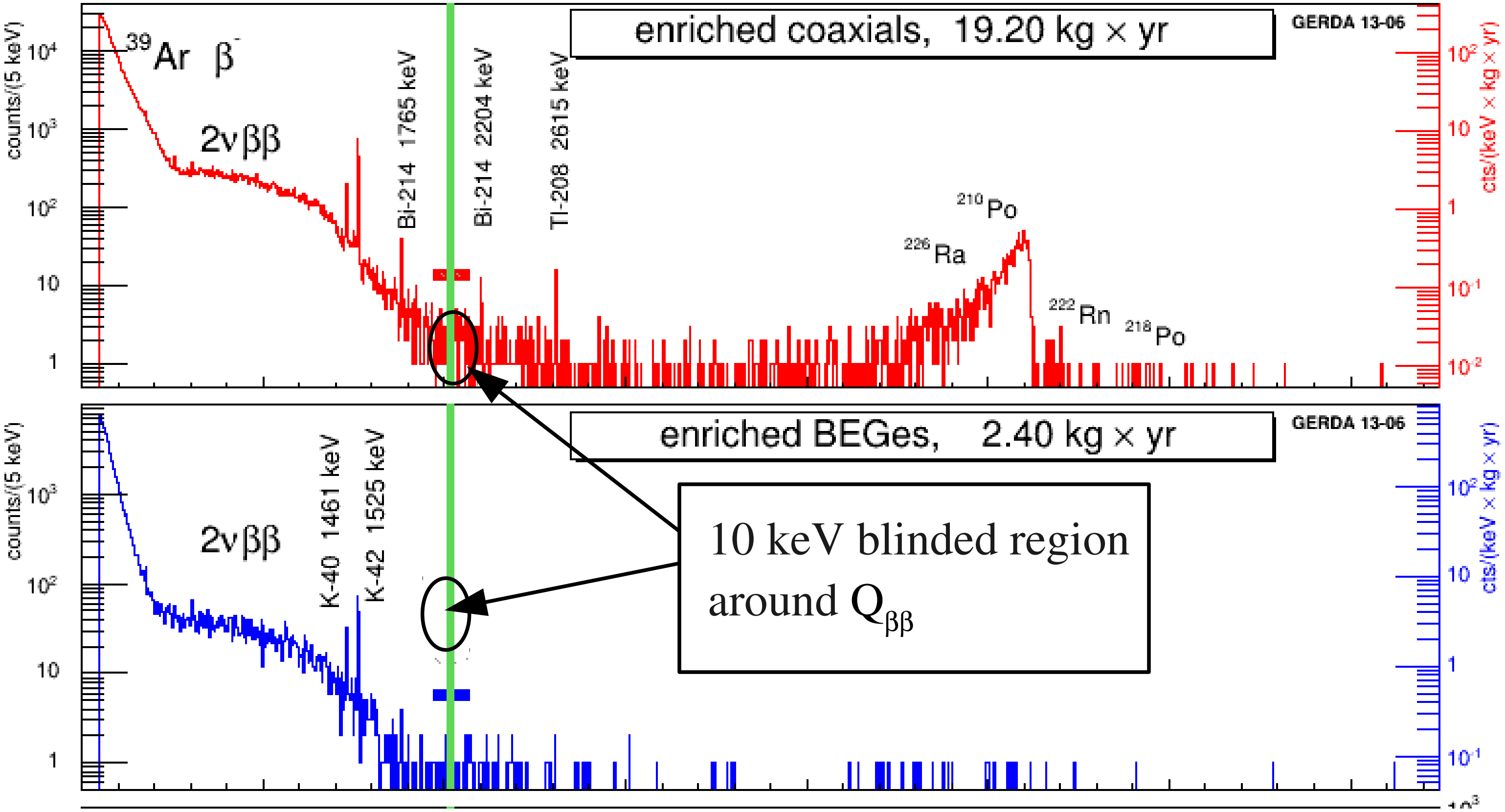
- Graded shielding against ambient radiation
- Rigorous material selection, avoid exposure above ground for detectors



The Gerda experiment for the search of $0\nu\beta\beta$ decay in ^{76}Ge

Eur. Phys. J. C (2013) 73:2330

Gerda Phase I: The Energy spectrum

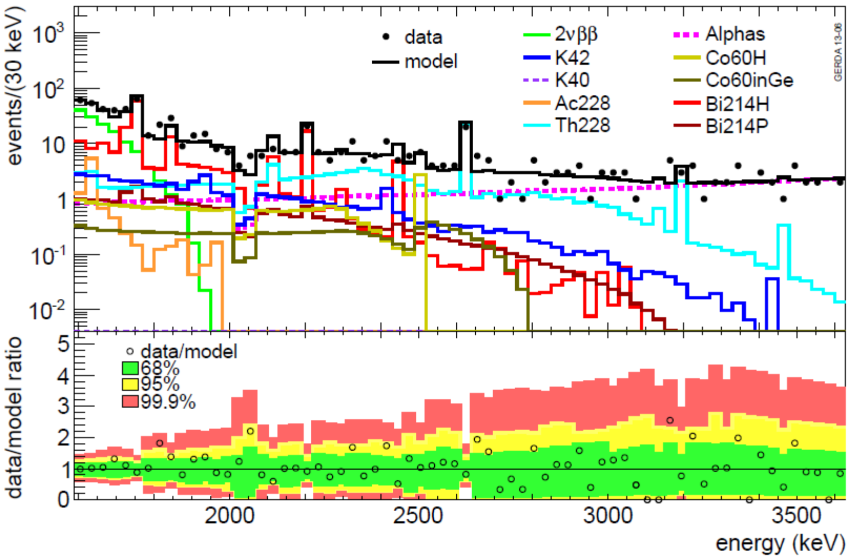


10 keV blinded region around $Q_{\beta\beta}$

- Low- energy dominated by the β spectrum of ^{39}Ar (Q_β = 565 keV). Coaxial detectors show surface α (^{210}Po)
- Most intense **γ-line**: **1525 keV from ^{42}K** (and 1460 keV from ^{40}K)
  - Only a few more γ-lines detected with statistical significance (^{214}Pb/^{214}Bi, ^{208}Tl,^{228}Ac)

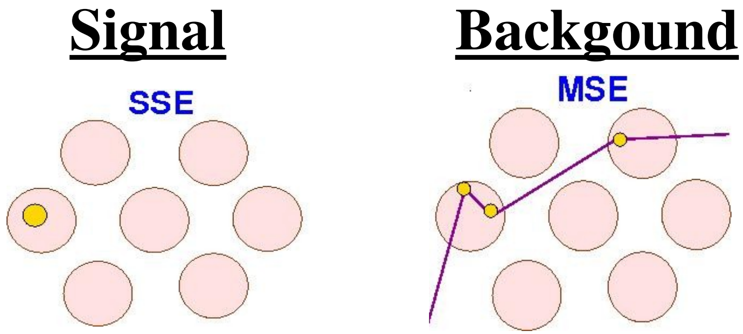
Gerda Phase I: $0\nu\beta\beta$ analysis

PRL 111 (2013) 122503
EPJC 73 (2013) 2583
EPJC 74 (2014) 2764



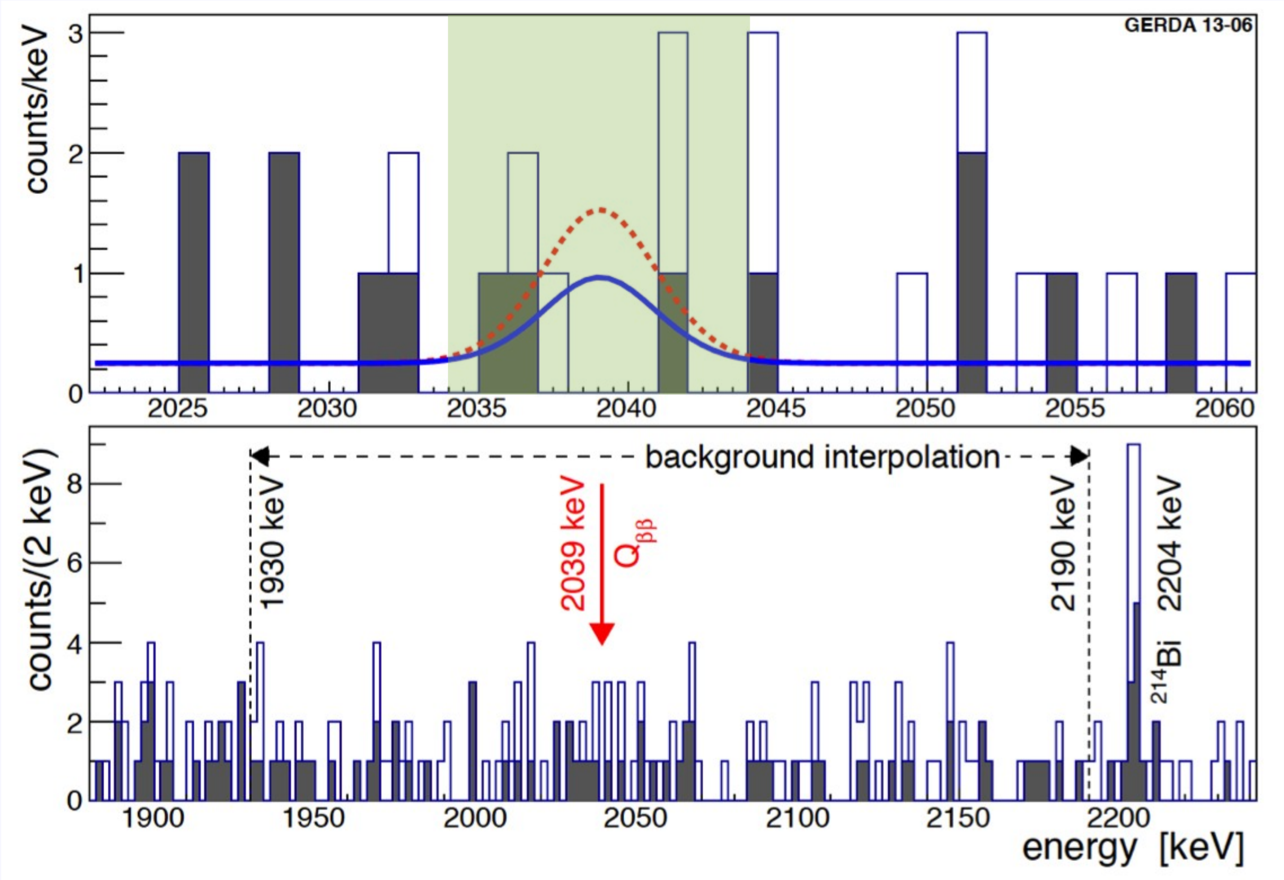
- **Background components at $Q_{\beta\beta}$:**
  - γ-emitters (close): ^{214}Bi, ^{208}Tl (2/3)
  - surface contaminations: ^{42}K, α (1/3)
- Background model predicts a **flat background** around $Q_{\beta\beta}$
  - No intense γ-lines expected around $Q_{\beta\beta}$ (spectra can be fitted with a flat bkg apart from lines 2104 keV and 2119 keV)

- **Background reduction tools:**
  - **Anti-coincidence** with **the muon veto**
  - **Anti-coincidence between detectors:** suppression of Multi Site Events (**MSE**) respect to Single Site Events (**SSE**)
  - **Pulse shape discrimination** (**PSD**)
    - Cut MSE within one detectors and surface events
    - Very efficient for BEGe detectors
    - Accept > 90% SSE, while rejecting 90% of MSE and surface events
    - Less efficient with coaxial detectors, but still doable (acc. 90%; suppr. 50%)



Gerda Phase I: $0\nu\beta\beta$ analysis

PRL 111 (2013) 122503



☐ before PSD

■ after PSD

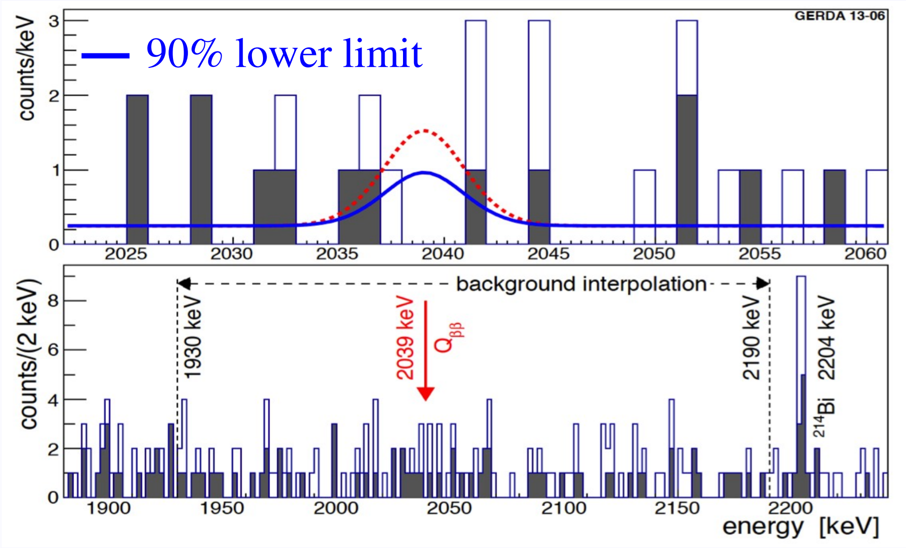
Full data set: **7** events in the blinded window (± 5 keV around $Q_{\beta\beta}$) → **5.1** events expected (bkg only)

3 events after PSD → **2.5** events expected (bkg only)

0 events in $Q_{\beta\beta} \pm \sigma_E$

Gerda Phase I: $0\nu\beta\beta$ analysis

PRL 111 (2013) 122503



Discovery claim of *Phys. Lett. B586, 184 (2004)*

refused by GERDA result:

- *with high probability*:

  Bayes factor*: P(*H1*/*H0*) = 0.024

  (* GERDA only)

  H1 = claimed signal; *H0* = background only

  Bayes factor**: P(*H1*/*H0*) = $2 \cdot 10^{-4}$

  (** GERDA+IGEX+HdM)

- *independently from nuclear matrix elements*
- *independently from any physical process producing* $0\nu\beta\beta$

Limits on $T^{0\nu}_{1/2}$

- 90% lower limit fom a profile likelihood fit of 3 datasets;
- Best fit: **$N^{0\nu} = 0$**;
- No exess of signal events above the bkg;
- 90% C.L. lower limit:

$$\boxed{T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}\ \text{yr @ } 90\%\ \text{C.L.}}$$

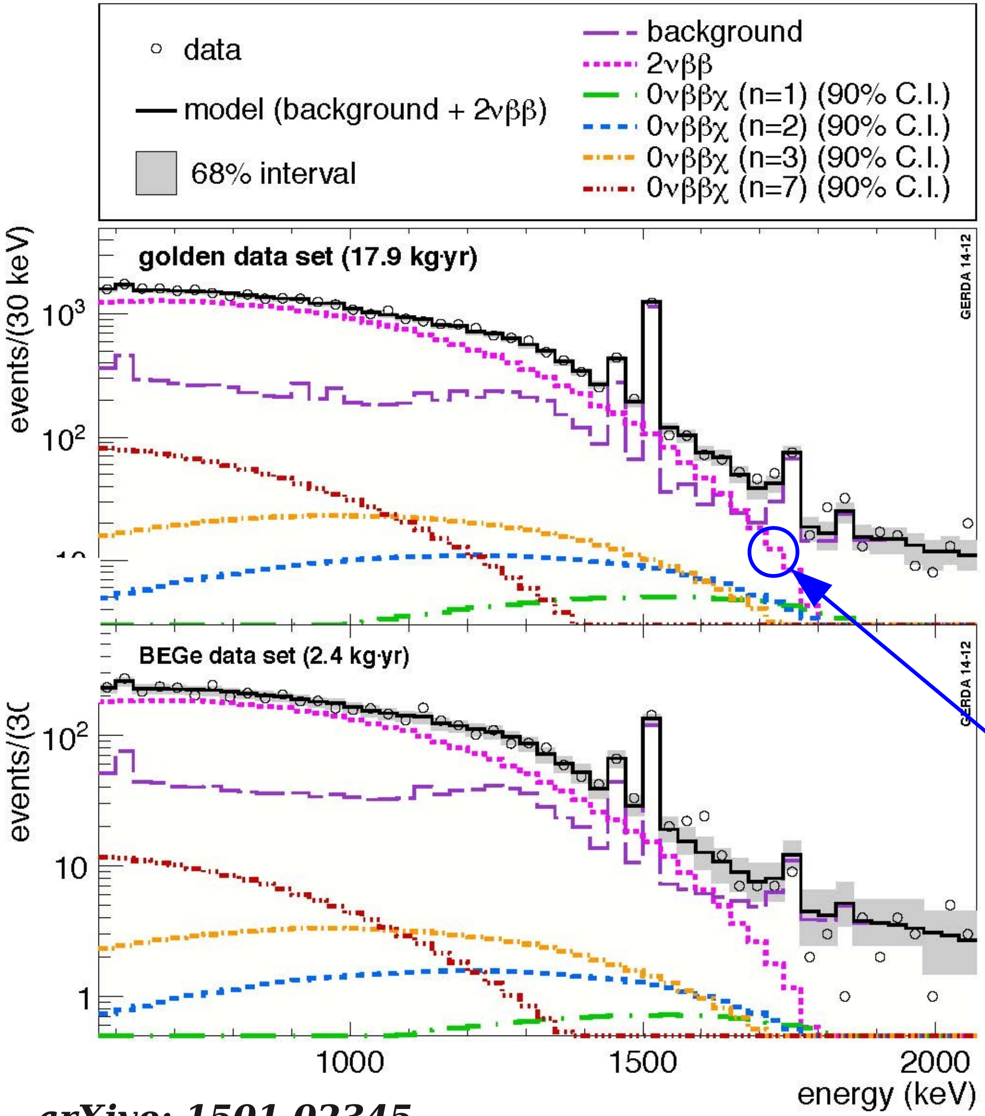
- the limit corriesponds to **$N^{0\nu} < 3.5$ cts**;
- median sensitivity (90%C.L.): **$> 2.4 \cdot 10^{25}$ yr**
- **similar numerical values for a Bayesian analysis**

- **Adding to GERDA** the other ^{76}Ge experiments (**HdM+IGEX**):

$$\boxed{T^{0\nu}_{1/2} > 3.0 \cdot 10^{25}\ \text{yr @ } 90\%\ \text{C.L.}}$$

- Ge combined: $< m_{ee} > < 0.2 - 0.4$ eV

Gerda Phase I: Majoron(s) emission + $T^{2\nu}_{1/2}$



arXive: 1501.02345

- Alternative mechanisms of $0\nu\beta\beta$ searched for in the Phase I data: **Majoron(s) emission**
- Many models/candidates available
  - Continuous spectra, but different shape $2\nu\beta\beta$ than decay (specral index n=5)
  - **Global fit** of the energy spectrum
  - Same procedure as for background identification
- Most stringent limits for ^{76}Ge, improvement by **a factor > 6**

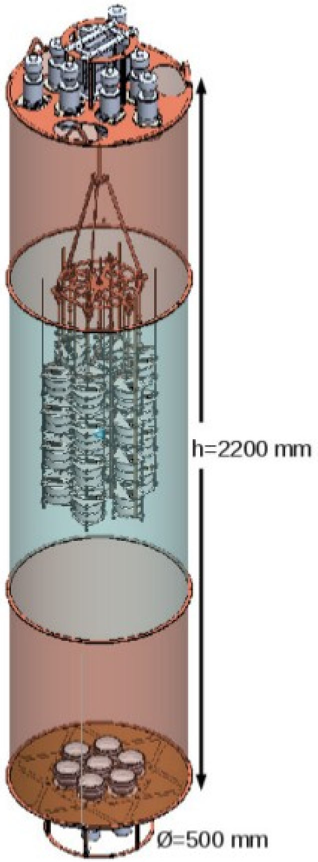
- **New $T^{2\nu}_{1/2}$ measurement:**

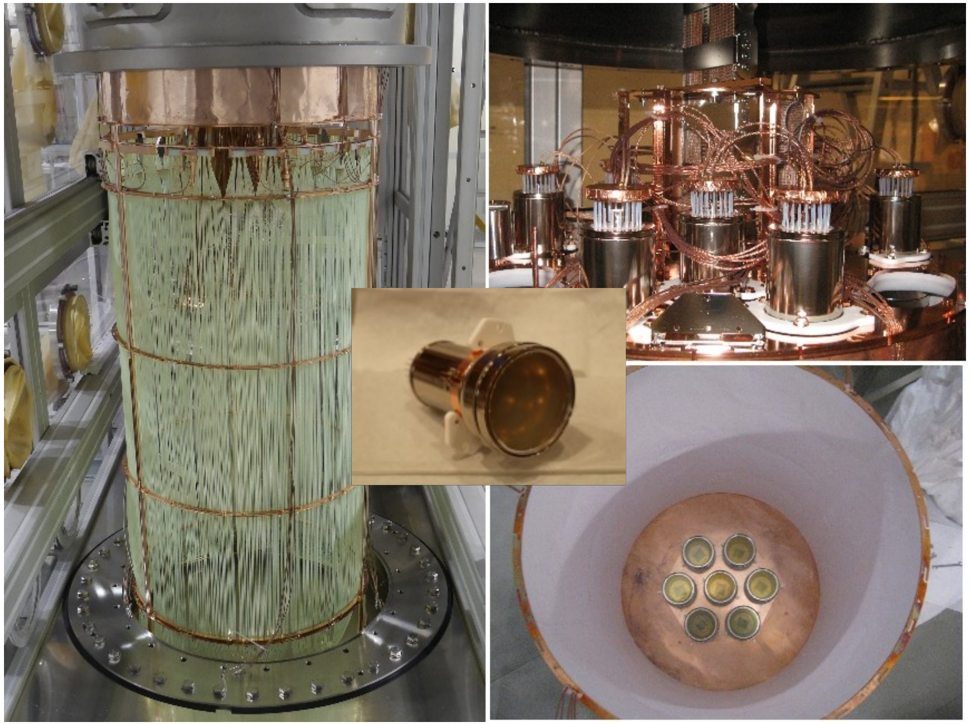
$$\boxed{T^{2\nu}_{1/2} = (1.926 \pm 0.094)\times 10^{21}\ \text{yr}}$$

  - unprecedented precision (<5 %) with respect to previous ^{76}Ge experiments

Gerda Phase II

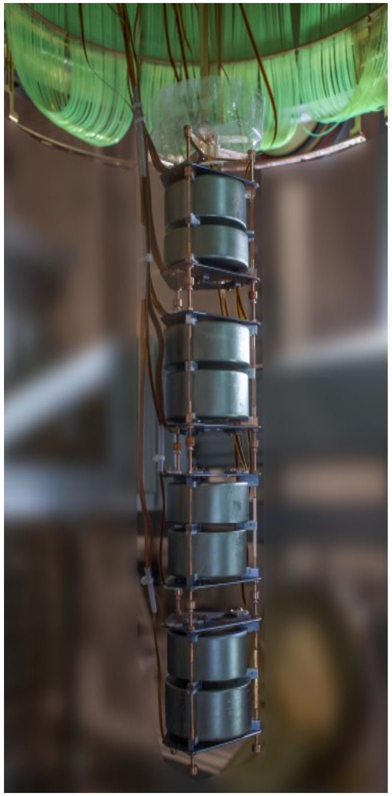
- **Target**: push $T_{1/2}$ sensitivity into the 10^{26} **yr range**
  - Increase the exposure: 20 kg·yr ⇒ **100 kg·yr**
  - Reduce background: 10^{-2} cts/keV·kg·yr ⇒**10^{-3} cts/keV·kg·yr**
- **Mass increase**: +30 enriched BEGe detectors
  - already produced (by CANBERRA) and tested (at HADES)
  - 5 already tested during Phase I



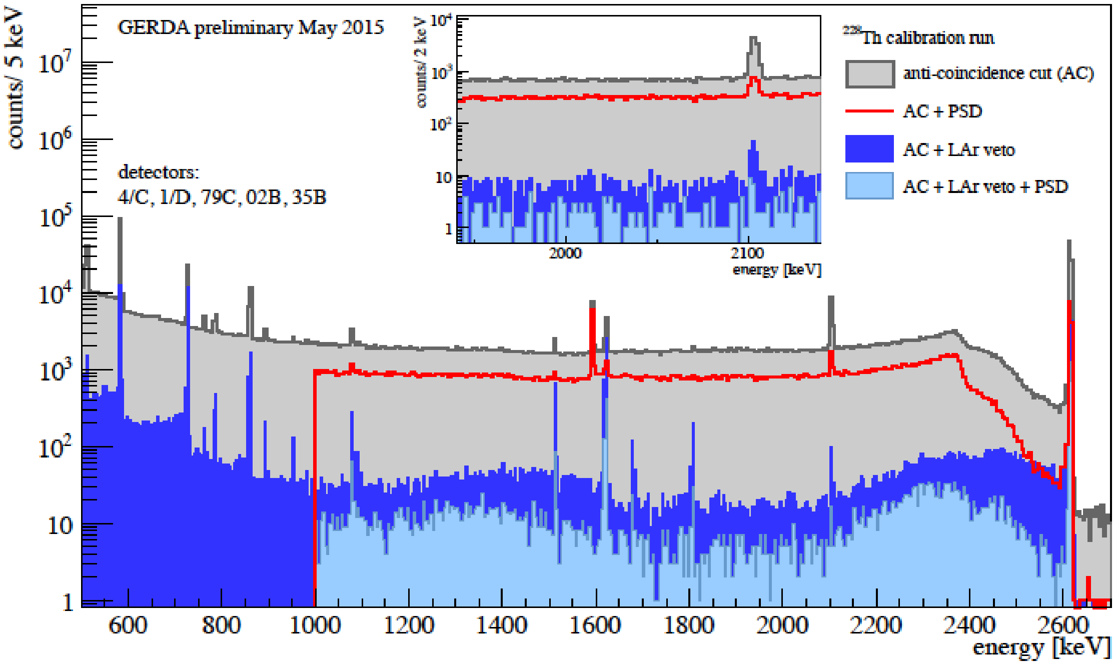


- **×10 background reduction**
  - new holders with improved radiopurity
  - new FE electronics
  - **PSA** discrimination with BEGe's
  - **Liquid argon veto instrumentation** to detect scintillation light

Gerda Phase II: Commissioning



- Commissioning with one string with up to **8 BEGes**
- **PSD + LAr instrumentation concept working**
  - Global suppression factor at $Q_{\beta\beta}$ for ^{228}Th source ~ **300**
  - Factor of **100** from LAr veto
  - **80%** signal acceptance
  - depends strongly on **source** and **position**



Starting from end of July:

◆ **27 detectors** were deployed

◆ for ~ **25 kg** of mass

Further deployments within the end of this year.

summary

- **GERDA** experiment (^{76}Ge) at LNGS **Phase I completed** (2011-2013)
  - **21.6 kg·yr** of exposure, **blind** analysis, **no positive signal** at $Q_{\beta\beta}$
  - $T^{0\nu}_{1/2}$ **> 2.1·10^{25} yr** @ 90% CL (GERDA alone), **> 3.0·10^{25} yr** (with other Ge experiments)
  - **Existing claim** strongly **disfavoured**, in a **model-independent** way
- GERDA upgrade to **Phase II**
  - **Increase** deployed ^{76}Ge mass (new BEGe detectors)
  - Further **suppression** background by **PSD** and **instrumentation of LAr** as active veto (hybrid approach) ⇒ **concept validated**
  - **Commissioning started** ⇒ **on good path**

backup slides