GERDA Status Report

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DPG Spring Meeting, Dresden, Mar 4-8 2013

Outline

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Double beta decay

The Gerda experiment

Gerda Phase I: status and first results

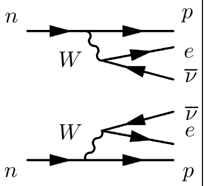
Plan and preparation of Phase II

Theoretical aspects

Second order nuclear transitions $\rightarrow$ decay of two neutrons into two protons:

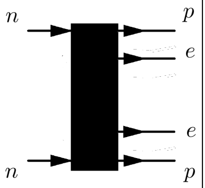
2-neutrino final state ($2\nu\beta\beta$):

- $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$
- allowed in the standard model
- measured in several isotopes
- $T^{2\nu}_{1/2}$ in the range $10^{19} - 10^{24}$ yr



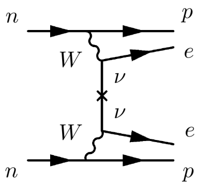
0-neutrino final state ($0\nu\beta\beta$):

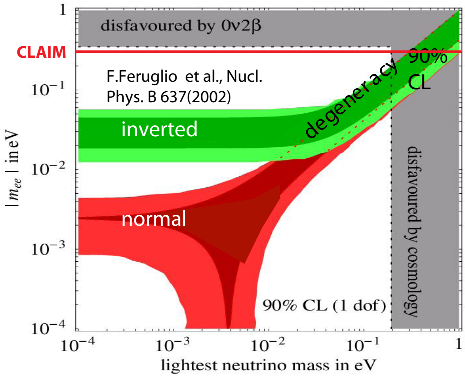
- $(A, Z) \rightarrow (A, Z+2) + 2e^-$
- lepton number violation ($\Delta L = 2$)
- physics beyond the standard model (e.g. right-handed weak currents, super-symmetric particles. . .)
- ν majorana mass component (Schechter-Valle theorem)
- $T^{0\nu}_{1/2}$ limits in the range $10^{21} - 10^{25}$ yr
- one unconfirmed claim (subset of HdM experiment)



Neutrinoless double beta decay & neutrino physics

Assuming light-majorana neutrino exchange as dominant $0\nu\beta\beta$ channel:

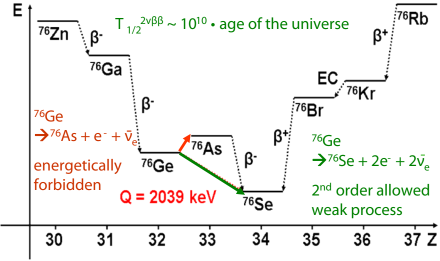


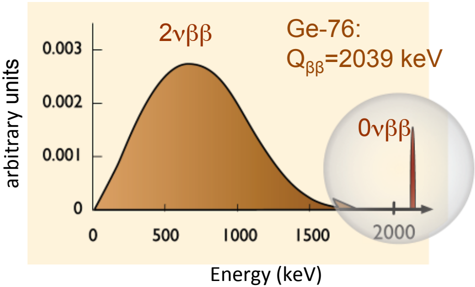


Many implications:

- $(T^{0\nu}_{1/2})^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)|\mathcal{M}_{0\nu}(A, Z)|^2 \langle m_{\beta\beta}\rangle^2$
- effective majorana mass: $\langle m_{\beta\beta}\rangle \equiv \left|\sum_i U^2_{ei} m_i\right|$
- neutrino oscillations: 3 angles, 2 delta mass squared, 1 phase
- $0\nu\beta\beta$ mass spectrum (inverted/normal hierarchy, absolute mass scale)

Experimental aspects of $0\nu\beta\beta$ search in Ge-76





Advantages:

- HPGe detectors can be realized from enriched Ge material (typical enriched to ∼87%)
- detectors well established technology
- $\Delta E \approx 0.1\%$ at $Q_{\beta\beta}$
- ultra-radiopure material (low background)
- Calirimeter detector —> source=detector
  → high detection efficiency

Disadvantages:

- low Q-value ($Q_{\beta\beta} = 2039$ keV)
  → small phase-space factor
  → below Tl-208 and Bi-214 gamma-lines
- natural Ge-76 abundance (7.6 %)

Until recently (EXO, Kamland-Zen) best limits from:

- IGEX $T_{1/2}^{0\nu} \geq 1.6 \cdot 10^{25}$ yr at 90% C.L.
- HdM $T_{1/2}^{0\nu} \geq 1.9 \cdot 10^{25}$ yr at 90% C.L.

Outline

The Gerda collaboration

~100 members
18 institutions
6 countries

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GERDA

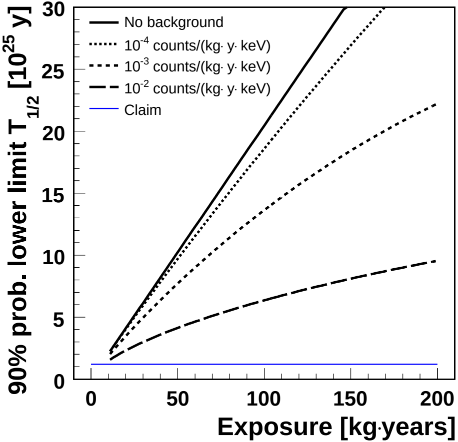
Goals

Phase I (Nov 2011 - Spring 2013)

- 8 ^{enr}Ge coaxial detectors from HdM and IGEX experiments (17.7 kg, 86% ^{76}Ge)
- background 10^{-2} cts/(keV· kg· yr) at $Q_{\beta\beta}$
- exposure 20 kg·yr
- sensitivity to scrutinize claim

Phase II (start transition in Summer 2013)

- new custom-made ^{enr}Ge BEGe detectors (additional 20 kg, 87% ^{76}Ge)
- background $\lesssim 10^{-3}$ cts/(keV· kg· yr) at $Q_{\beta\beta}$ (active techniques for background suppression)
- exposure $\gtrsim$ 100 kg·y
- start the exploration of $T^{0\nu}_{1/2}$ in the 10^{26} yr range

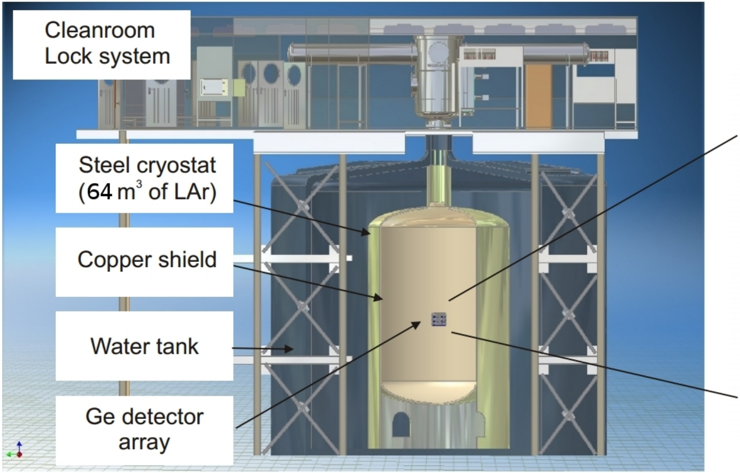


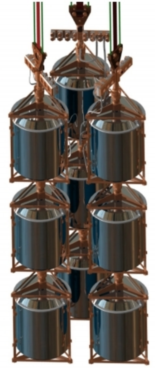
Phase III

- Contingent to the outcome of the present generation of $0\nu\beta\beta$ experiments
- collaboration between GERDA and MAJORANA
- background $\lesssim 10^{-4}$ cts/(keV· kg· yr) at $Q_{\beta\beta}$
- exposure of several 1000 kg·yr
- $T^{0\nu}_{1/2} \gtrsim 10^{27}$ yr

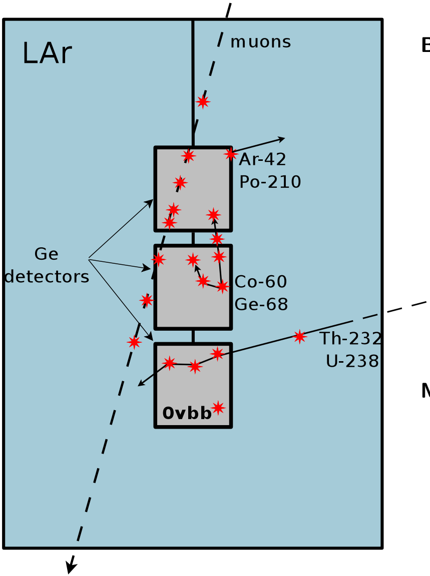
Concept: detectors & apparatus

- Bare detectors in liquid Argon
- Shield: high-purity LAr/H_2O
- Radio-pure material selection
- deep underground (LNGS, 3800 m.w.e.)





Backgrounds and mitigation techniques



Background sources:

- natural radioactivity (Th-232 and U-238 decay chain)
- α-emitting isotopes from surface contamination (e.g. Po-210)
- Rn-222 in LAr
- cosmogenic isotopes of Ge decaying inside the detectors (Ge-68, Co-60)
- unstable Ar isotopes (Ar-39,Ar-42)
- non-vetoed μ

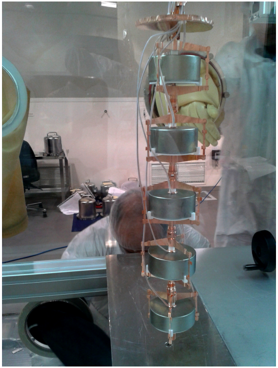
Mitigation strategy:

- detector anti-coincidence (already used in Phase I)
- time-coincidence (Bi-Po or Ge-68)
- pulse shape analysis (in future)
- LAr-scintillation (only Phase II)

Outline

Detector array assembly

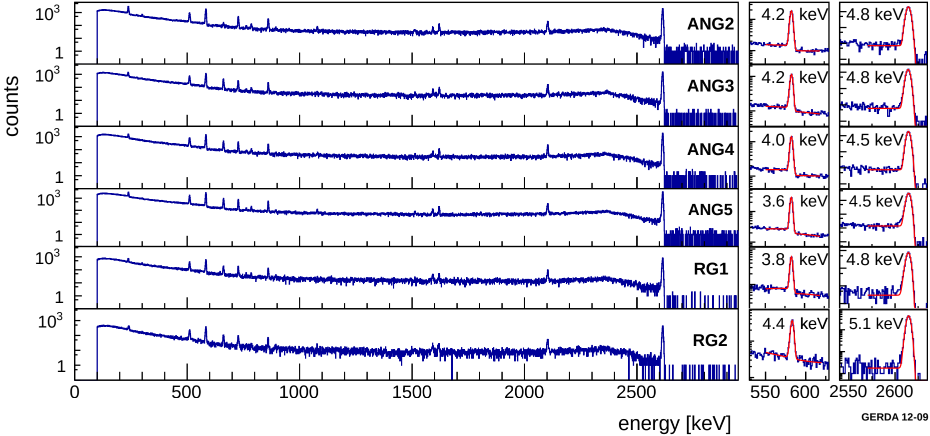




- 3 + 1 strings
- 8 ^{enr}Ge coaxial detectors (2 not considered in the analysis)
- 3 ^{nat}Ge coaxial detectors
- 5 ^{enr}Ge BEGe detectors (R&D for Phase II)

^{enr}Ge mass for physics analysis: 14.6 kg (coaxial) + 3.6 kg (BEGe)

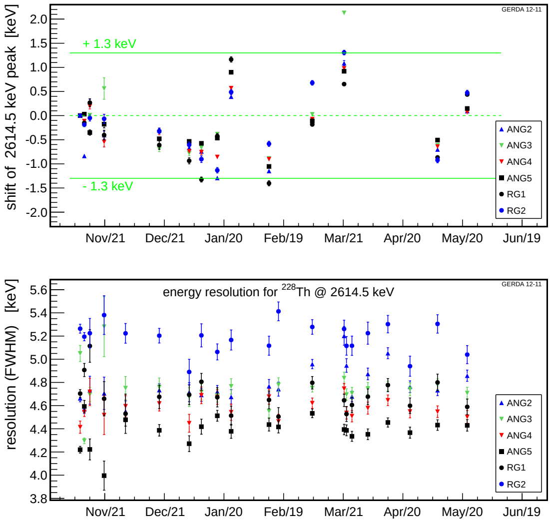
Detector calibration (Th-228)



Energy resolution at $Q_{\beta\beta}$ (FWHM, mass weighted average):

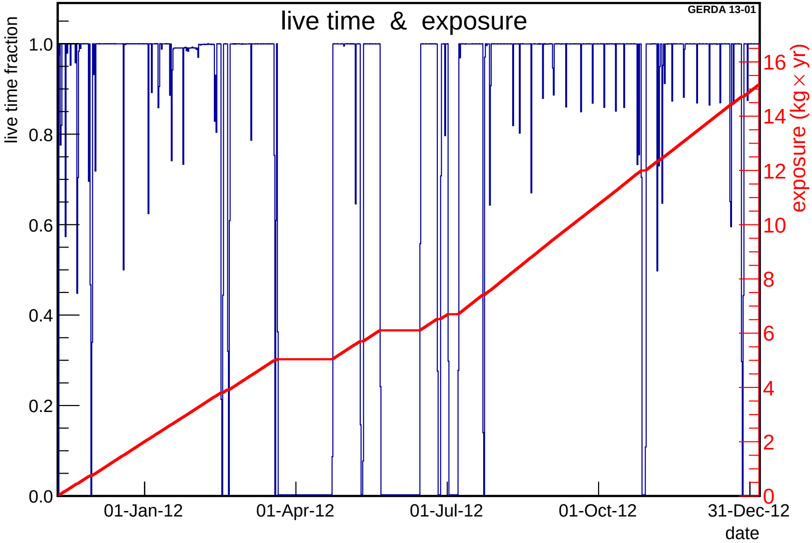
- ∼ 4.5 keV for coaxials
- ∼ 3 keV for BEGes

Detector stability



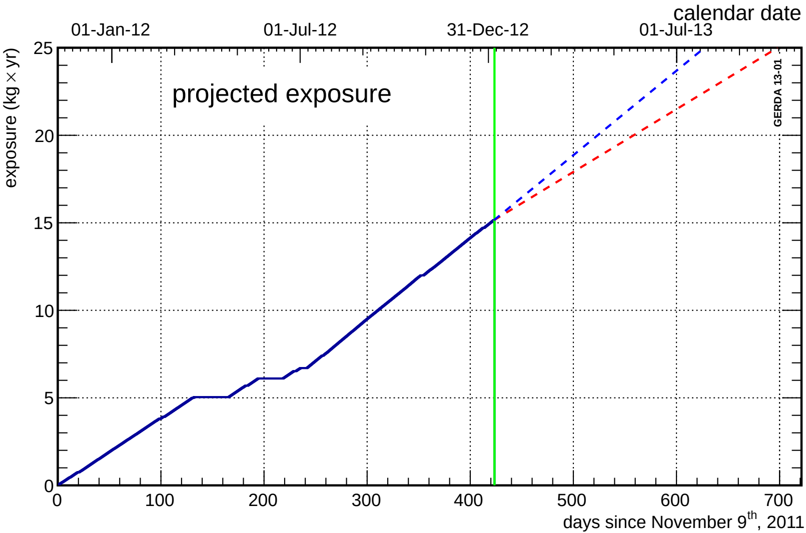
- calibration every one/two weeks
- energy shift between successive calibration runs usually $\lesssim 1$ *keV*
- energy resolution stable

Duty cycle (Nov 2011 - Jan 2013)



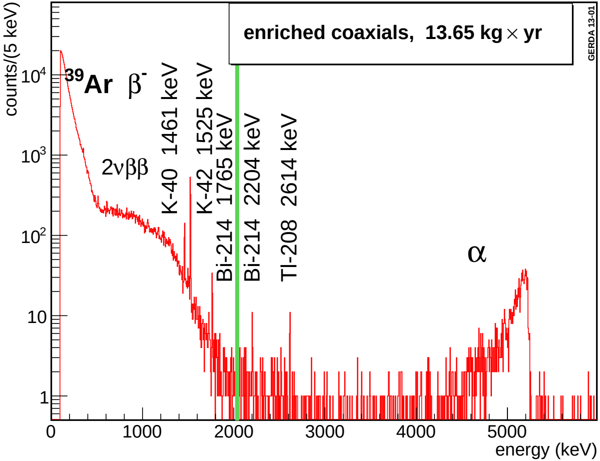
Live time = 341 days	Duty cycle = 80.6% (89.3% without unstable runs)

Integrated exposure



15 kg·yr in Jan 2013 —> 20 kg·yr (Phase I exposure goal) in Spring 2013

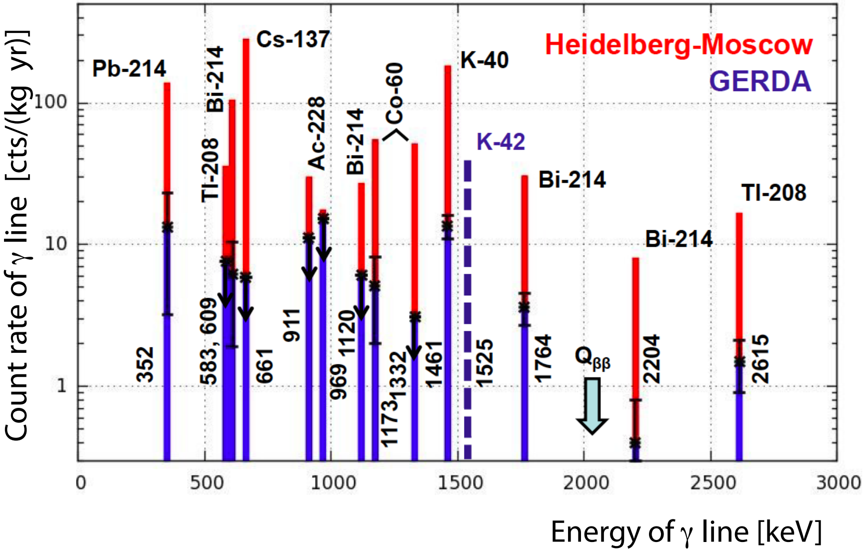
Main structures in the energy spectrum



- ^{39}Ar (up to 565 keV)
- $2\nu\beta\beta$(dominant up to 1400 keV)
- ^{40}K (γ at 1461 keV)
- ^{42}K (γ at 1525 keV)
- ^{214}Bi (γ at 1765 and 2204 keV)
- ^{208}Tl (γ at 2615 keV)
- ^{210}Po (α peak at 5.3 MeV)

Blinded analysis —> events at $Q_{\beta\beta}\pm 20$ keV are not available for analysis

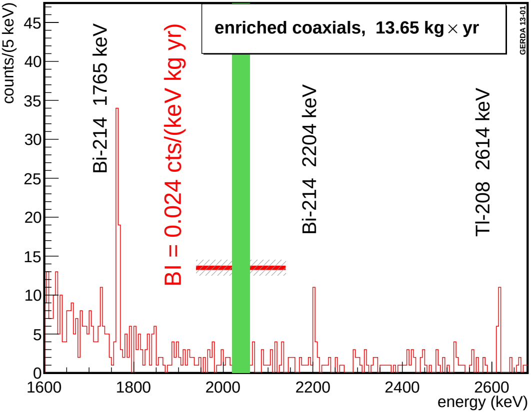
Gamma-line intensities



Background index in the $Q_{\beta\beta}$ region

Average background index values in $Q_{\beta\beta}\pm100$ keV (excluding central 40 keV):

- $2.2^{+0.3}_{-0.3}\cdot10^{-2}$ cts/(keV· kg· yr), ^{enr}Ge coaxials, 13.6 kg·yr
- $1.7^{+0.3}_{-0.3}\cdot10^{-2}$ cts/(keV· kg· yr), ^{enr}Ge coaxials, 12.3 kg·yr (w/o run 34/35, 8% exp)
- $4.1^{+1.5}_{-1.2}\cdot10^{-2}$ cts/(keV· kg· yr), ^{enr}Ge BEGe's, 1.5 kg·yr



Previous experiments:

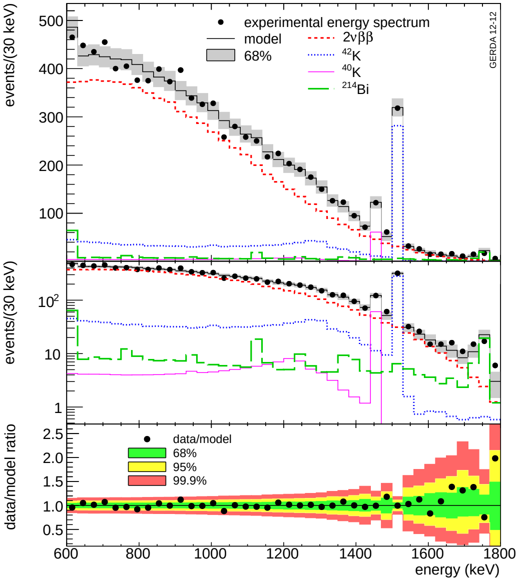
- HdM: BI = 0.17 cts/(keV· kg· yr)
- IGEX: BI = 0.17 cts/(keV· kg· yr)

Background contributions at $Q_{\beta\beta}$:

- γ: Tl-208 and Bi-214
- β: K-42 and Bi-214
- α: Po-210, Rn-222 chain

Background Model discussed in:
T 103.4 (N. Becerici-Schmidt)

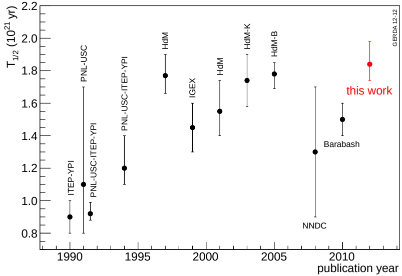
$2\nu\beta\beta$ half-life



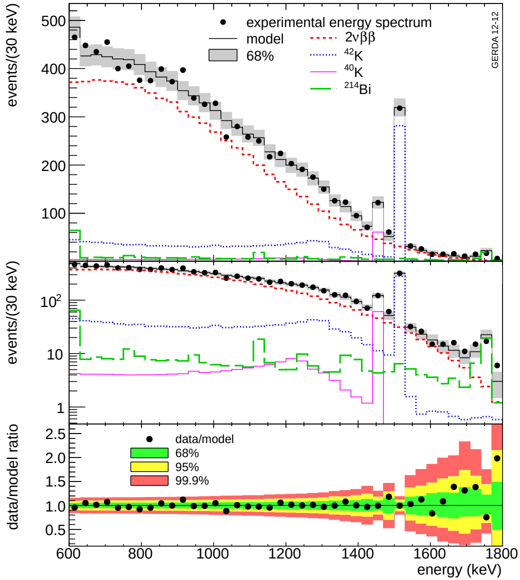
- Binned maximum likelihood (5 kg·yr)
- Nuisance parameters:
  - Active detector masses (6+1)
  - Ge-76 fractions (6)
  - Background contributions (3x6)
- $T^{2\nu}_{1/2}$ common to all detectors
- After marginalizing:

$$T^{2\nu}_{1/2} = (1.84^{+0.09}_{-0.08}\ _{\text{fit}}\ ^{+0.11}_{-0.06}\ _{\text{syst}}) \cdot 10^{21}$$

[J.Phys.G 40 (2013) 035110]



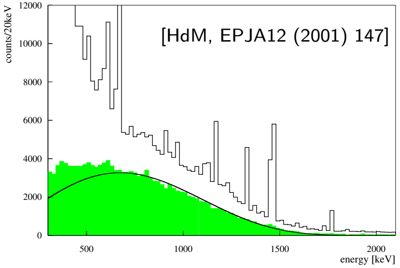
$2\nu\beta\beta$ half-life



- Binned maximum likelihood (5 kg·yr)
- Nuisance parameters:
  - Active detector masses (6+1)
  - Ge-76 fractions (6)
  - Background contributions (3x6)
- $T_{1/2}^{2\nu}$ common to all detectors
- After marginalizing:

$$T_{1/2}^{2\nu} = (1.84^{+0.09}_{-0.08}\,_{\mathrm{fit}}\,{}^{+0.11}_{-0.06}\,_{\mathrm{syst}}) \cdot 10^{21}$$

[J.Phys.G 40 (2013) 035110]



Outline

Double beta decay

The Gerda experiment

Gerda Phase I: status and first results

Plan and preparation of Phase II

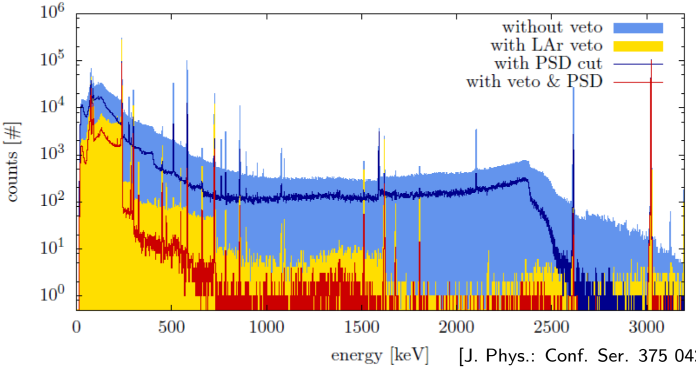
Phase II detectors and liquid argon scintillation

BEGe detectors:

- excellent energy resolution (1.6 keV @ 1.3 MeV)
- enhanced pulse shape discrimination performance
- 30 new ^{enr}Ge BEGe detectors produced (20 kg)

LAr-scintillation (combined design):

- low-background photo-multipliers
- WLS fibers read-out with Si photo-multipliers



[J. Phys.: Conf. Ser. 375 042009]

Strong integration effort:

LAr
T 109.1, 109.2
HK 22.1, 46.8, 66.7

Detector
T 109.4 110.1, 110.2, 110.3
HK 7.2, 7.3, 7.4, 7.5, 66.6

Assembly
T 109.3

Pulse shape analysis combined with LAr-scintillation (in LArGe setup): measured suppression factor of $(5.2 \pm 1.3) \cdot 10^3$ at $Q_{\beta\beta}$ for close Th-228

Conclusion

- GERDA Phase I started in Nov 2011

- Data taking ongoing —> collected more than 15 kg·yr of exposure

- Background order of magnitude lower than previous experiments

$$\underline{\sim 0.02\,\text{cts}/(\text{keV}\cdot\text{kg}\cdot\text{yr})\text{ at }Q_{\beta\beta}}$$

- Measured $2\nu\beta\beta$ half-life with a strong reduction of systematic uncertainties with respect to the previous experiments

$$\underline{T_{1/2}^{2\nu} = (1.84^{+0.09}_{-0.08}\,_{\text{fit}}\,^{+0.11}_{-0.06}\,_{\text{syst}}) \cdot 10^{21}}$$

- Phase I almost complete: data unblinding at 20 kg·yr of exposure.

Assuming present background index, expected $0\nu\beta\beta$ sensitivity of

$$\underline{T_{1/2}^{0\nu} \gtrsim 1.9 \cdot 10^{25}\,\text{yr (90\% C.I.)}}$$

- Transition to Phase II in preparation (starting in summer 2013): major upgrade for further reduction of the background to the level of 10^{-3} cts/(keV· kg· yr) at $Q_{\beta\beta}$ (pulse shape analysis with BEGe detectors and LAr instrumentation).