The Calibration System for the GERDA Experiment

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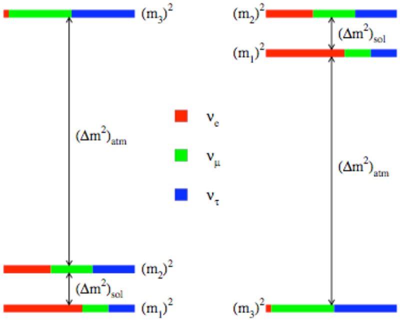
Neutrino Physics

We know

- Neutrinos have a mass
- Mass difference between eigenstates

Three big questions

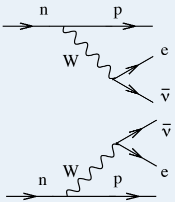
- Absolute mass scale
- Mass hierarchy
- Majorana vs. Dirac



Double Beta Decay

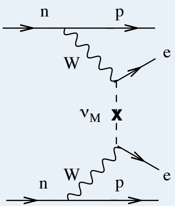
$2\nu\beta\beta$

- $(Z, A) \rightarrow (Z+2, A) + 2e^- + 2\bar{\nu}_e$
- $\Delta L = 0$
- $\left|T_{1/2}^{2\nu}\right|^{-1} = G^{2\nu}(Q_{\beta\beta}, Z)\,|M_{2\nu}|^2 \sim \left|10^{20}\ \mathrm{y}\right|^{-1}$



$0\nu\beta\beta$

- $(Z, A) \rightarrow (Z+2, A) + 2e^-$
- $\Delta L = 2$
- $\left|T_{1/2}^{0\nu}\right|^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\,|M_{0\nu}|^2\,\langle m_{\beta\beta}^2\rangle \sim \left|10^{25}\ \mathrm{y}\right|^{-1}$
- $\langle m_{\beta\beta}\rangle = \left|\sum_i U_{ei}^2\ m_i\right|$



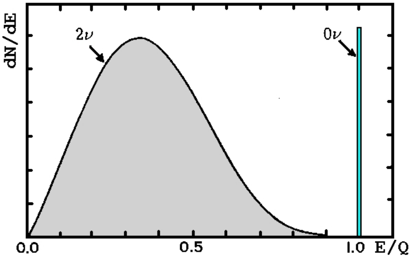
Signature

Measuring the energy of both electrons

- $2\nu\beta\beta$: Continuous energy spectrum
- $0\nu\beta\beta$: Sharp peak at Q value of decay

$$Q = E_{\text{mother}} - E_{\text{daugther}} - 2m_e$$

- Schechter & Valle (1982): Measuring $0\nu\beta\beta \Rightarrow \nu$ Majorana particle



Heidelberg-Moscow Experiment
The Claim

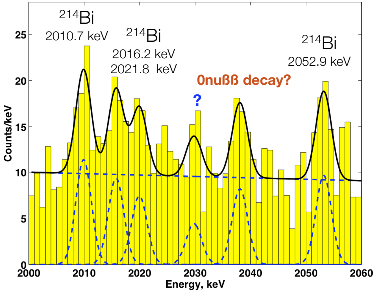
- 5 HPGe crystals with 71.7 kg y
- Peak at Q value:

$$T^{0\nu}_{1/2} = 1.2 \times 10^{25} y \qquad (4\sigma)$$
$$\langle m_{\beta\beta} \rangle = 0.44\,\text{eV}$$

- Problem: Confidence depends on background model and energy region selected for analysis

$\Rightarrow$ New experiments with higher sensitivity needed

H.V.Klapdor-Kleingrothaus et al., Phys. Lett. B 586 (2004) 198



The GERmanium Detector Array (GERDA)

Overview

Naked High purity ^{76}Ge crystals placed in LAr

Phase I goals

Exposure	15 kg y
Background	10^{-2} cts/(keV kg y)
Half-life	$T_{1/2} > 2.2 \times 10^{25}$ y
Majorana mass	$m_{ee} < 0.27$ eV

Phase II goals

Exposure	100 kg y
Background	10^{-3} cts/(keV kg y)
Half-life	$T_{1/2} > 15 \times 10^{25}$ y
Majorana mass	$m_{ee} < 0.11$ eV

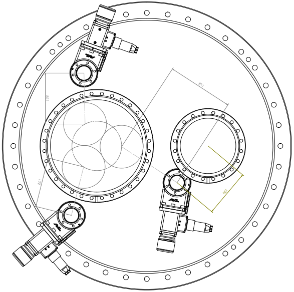
Progress

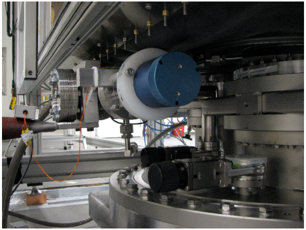
Summer/autumn 09	Integration test of Phase I detector string, FE, lock, DAQ
Nov/Dez 09	Liquid argon filling
May 10	Deployment of FE & detector mock/up, followed by first deployment of a non-enriched detector
June 10	Water tank filling
June 10	Commissioning run with ^{nat}Ge detector string • Test all subsystems • Determine background
Oct 10	Operation of enriched detectors

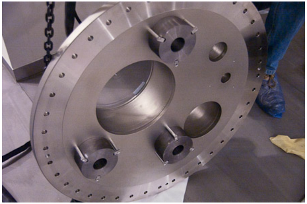
The Calibration System
Phase I

Overview

- 3 custom made ^{228}Th sources with $A \simeq 20$ kBq with low n rate
- Park position in the lock of the experiment
- Sources shielded by 6 cm of Ta
- Manual lowering system built by LNGS
- 1 calibration run of ~ 30 min per detector layer







Mounting & Testing the System

Vacuum test

- 90° angle leaking
- After glueing with two-component glue leak rate of 10^{-7} mbar l/s reached

External Lowering Cycles

- Several lowering cycles down to 10 m went smoothly
- Oscillations could be traced back to ventilation at experimental site

Lowering into GERDA

- When entering LAr boiling leads to oscillations
  $\rightarrow$ Wait until system cools down
- Several lowering cycles went well

Upgrade

Motorization plus smaller improvements in progress

Monte Carlo Simulations

MaGe

- Geant4 based framework
- Developed together with Majorana collaboration
- Includes detailed GERDA geometry as well as all relevant physics processes

Geometry

- 8 ^{enr}Ge and 4 ^{nat}Ge detectors in 4 strings
- ^{228}Th source embedded in gold sphere placed in stainless steel capsule
- Ta cylinder with $r = 17.5$ mm and $h = 60$ mm

Simulations

- Full ^{228}Th decay chain simulated
- 100 ms gap between different isotopes to prevent pile ups

γ Background

Linear Attenuation

- Take flux of sources in 1 year
- Flux reduction because detector covers just small area but source radiates isotropically
- γ with highest energies have 2.6 MeV (36%)
- Calculate linear attenuation of 250 cm of LAr and 6 cm of Ta absorber

Monte Carlo Simulation

- Photon beam downwards 1m above detector array
- Rescale hits in ROI to flux calculated above

Result for 3 20kBq sources

$$B_\gamma = 0.3 \times 10^{-5} \text{ cts/(keV kg y)}$$

n Background

Inelastic Scattering

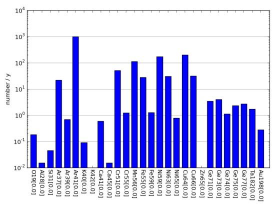
- Sources4A to estimate neutron flux produced by (α-n) reactions
- MCS to estimate background contribution in ROI:

$$B_n = 2.4 \times 10^{-5} \text{ cts/(keV kg y)}$$

Activated isotopes

- MCS to isotopes activated by neutrons during calibration and in parking position
- Only crucial isotope: ^{77}Ge
  $T_{1/2} = 11.3$ h, $E_{\gamma,max} = 2.35$ MeV
- MCS to estimate background contribution in ROI:

$$B_{^{77}Ge} = 0.7 \times 10^{-5} \text{ cts/(keV kg y)}$$

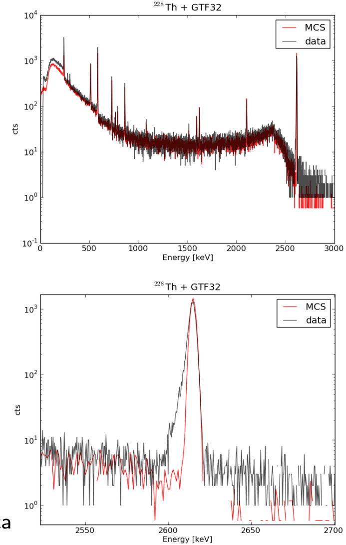


Total Background (n & γ)

$$B_{tot} = 3.4 \times 10^{-5} \text{ cts/(keV kg y)} \quad \Rightarrow \text{Well below GERDA limit}$$

First Calibration Results

- 3 ^{nat}Ge detectors operating stably
- Energy resolution achieved so far: 3.8 keV FWHM @ 2.6MeV
- Good agreement of ^{228}Th calibration data (MCA) with Monte Carlo simulations
- Further investigations especially on ADC data necessary



Calibration run with ^{228}Th source: MCS vs data

Outlook
Data Analysis

Energy Calibration

- Compare data with MCS
- Test and optimize different energy reconstruction algorithms
  $\Rightarrow$ Important to achieve best possible energy resolution
  $\Rightarrow T_{1/2}^{0\nu} \propto \langle m_{\beta\beta} \rangle^{-2} \propto const \sqrt{\frac{M \times t}{\Delta E \times B}}$

Pulse Shape Analysis

- Distinguish between single-site and multi-site events
  $\Rightarrow$ Background reduction
- Test different sets of parameters to determine optimal procedure

Summary

- Calibration system installed and tested successfully
- Upgrade on its way
- Background contribution from calibration sources with $B = 3.4 \times 10^{-5}$ cts/(keV kg y) well below GERDA limit
- First data taken with ^{nat}Ge detectors in good agreement with MCS
- ^{enr}Ge detectors will be submerged in Oct
- Future work will focus on data analysis