GERDA / EXO

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Universität Zürich

Neutrinoless Double Beta Decay

Status

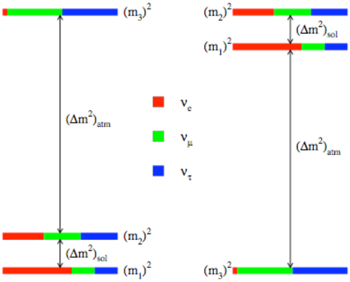
3 Big Questions in ν Physics

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

$0\nu\beta\beta$ As Possibility To Anwer Them

- Several isotopes known which show $2\nu\beta\beta$
- Best upper limit with $m_{ee} \lesssim 0.3$eV from HdM & IGEX; NEMO3 and CUORICINO with comparable sensitivity
- Claim of signal from parts of HdM at $\langle m_{\beta\beta} \rangle = 0.44$ eV

  NIM A 522 (2004) 371-406



EXO Project & EXO-200 Phase

EXO searches for neutrino-less double beta decay using ^{136}Xe

- Ton scale implementation either as liquid or gas phase TPC
- Relatively large Q value (2457.8 keV) and straight forward enrichment technique
- 136Ba daughter tagging either in-situ or in external RF cage

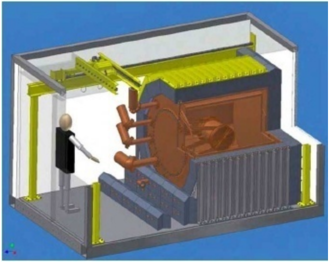
EXO-200 is the first phase using 200 kg of 80% enriched Xe

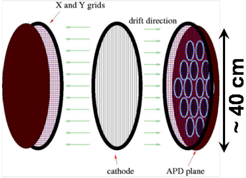
- Major R&D effort precursory to the ton-scale experiment
- Exploration of the quasi-degenerate region with ^{136}Xe
- Allowed double beta decay never observed in Xe ($T_{1/2}$ >1022 y Bernabei et al., 2002)
- No Ba ion tagging but massive progress for radioactive background reduction

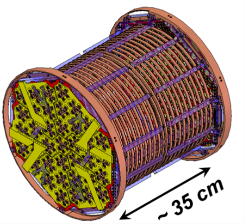
Detector	Mass [ton]	Efficiency [%]	Run time [year]	Energy resolution at Q value [%]	Background [events]	Half-life, limit at 90% CL [year]	Effective Majorama mass [meV]
EXO-200	*0.2*	*70*	*2*	*1.6*	*40*	*6.4E+25*	*130*
EXO conservative	*1*	*70*	*5*	*1.6*	*0.5*	*2E+27*	*24*
EXO aggressive	*10*	*70*	*10*	*1*	*0.7*	*4.1E+28*	*5.3*

EXO-200 Detector

- Liquid xenon TPC with two cylindrical drift volumes
  - Charge collection using 114 by 114 wire planes (at 60° pitch)
  - Scintillation light readout using 37 groups of 7 bare LAAPD (Large Area Avalanche Photodiodes) at both end caps
- High purity copper cryostat with external refrigeration-based cooling





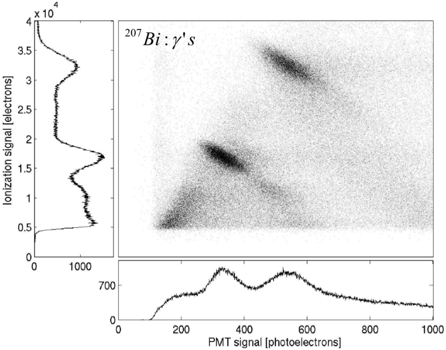


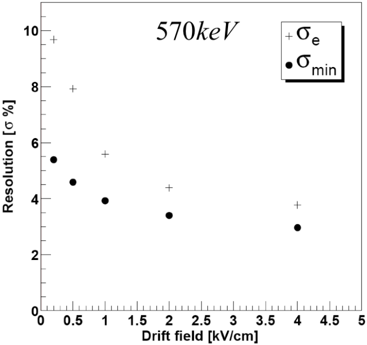
Radio-Purity Survey

- Large effort to determine the residual radioactive contamination of the materials employed for the construction of EXO-200 detector
  - Mass spectrometry (MS)
  - Neutron activation analysis (NAA)
    ⇒ Very sensitive but expensive, potential background from main elements
  - Alpha counting (evaluation of the 210Pb concentration in the shield lead)
  - Glow discharge MS (GD-MS), inductively coupled plasma MS (ICP-MS)
    ⇒ ICP-MS has better sensitivity when pre-concentration procedures are employed but the samples have to be soluble in acids (preferably HNO3)
  - Direct gamma counting
    ⇒ Large mass samples and long duration exposures are necessary
- Published database of over 300 characterized materials
  Nucl. Instr. Meth. A 591, 3, 490 (2008)
- Detailed Monte Carlo simulation of expected background

Energy Resolution

- Strong anti-correlation between ionization and scintillation signals in liquid xenon!
- $\frac{\Delta E}{E} = 1.4\% \text{ @ } Q = 2457.8 \text{ keV}$

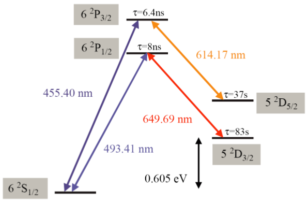


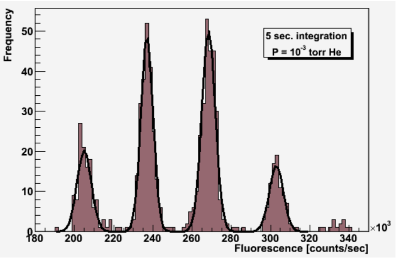


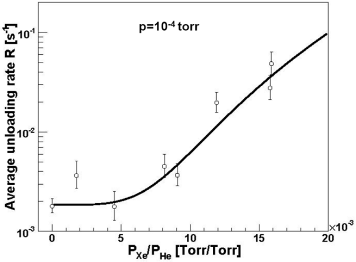
Ba^{+} Tagging using Resonant Light Scattering

$Ba^{++} \rightarrow Ba^{+}$ conversion expected

- Ionization potentials:
    - $Xe^{+} = 12.13$ eV vs. $Ba^{+} = 5.21$ eV
    - $Xe^{++} = 21.21$ eV vs. $Ba^{++} = 10.00$ eV
- Solid Xe band gap: $E_G = 9.22 \pm 0.01$ eV
  (Phys. Rev. B10 4464 1974)
- Liquid Xe ionization potential close to EG: 9.28 to 9.49 eV range (J. Phys. C: Solid State Phys. Vol. 7 1974)
- Use of additives for gas based detectors



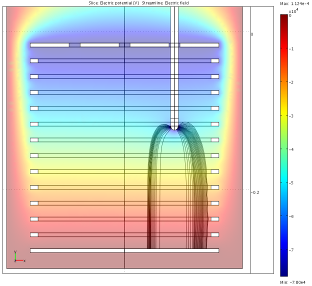


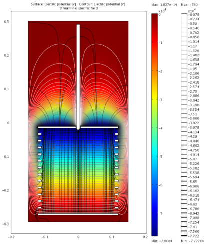


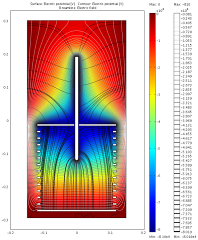
M.Green et al., Phys Rev A76 (2007) 023404
B.Flatt et al., NIM A578 (2007) 409

Probe Insertion R&D

Test cryostat for probe insertion in liquid Xe TPC and COMSOL based simulations of the electric field configuration

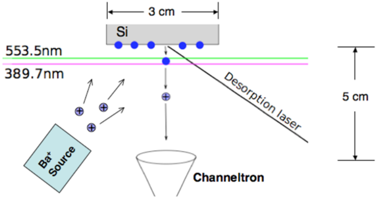


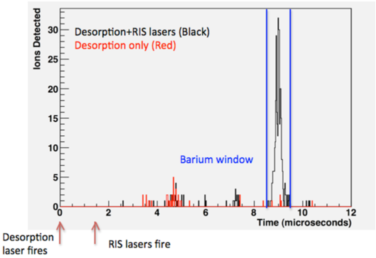




Resonant Ionization Spectroscopy

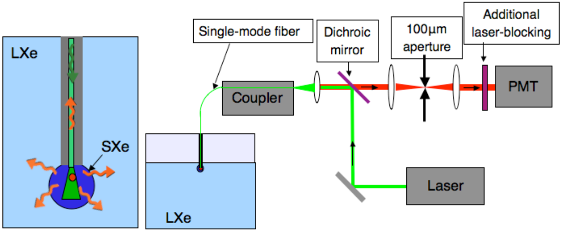
- Use of atomic resonances to selectively obtain a high yield for Ba ionization
- Lasers tuned to specific Ba atomic transitions push the atom to a highly excited state from which it decay to a lower energy ionized state
- Reached efficiency $\sim 10^{-3}$
- New setup targeting single ion detection in preparation



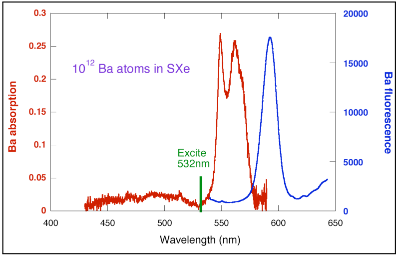


In-situ tagging using Ba fluorescence

Cryogenic probe carrying an optical fiber for both excitation and light collection



- Current detection limit ∼ 105 atoms
- Exploring avenues for single atom and / or ion detection:
  - Increasing laser intensity by 102
  - Increasing fluorescence light collection by 104



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

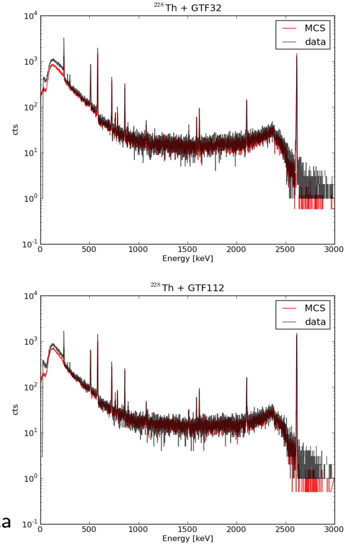
Exposure	100 kg y
Background	10^{-3} cts/(keV kg y)
Half-life	$T_{1/2} > 15 \times 10^{25}$ y
Majorana mass	$m_{ee} < 0.11$ eV

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

First results

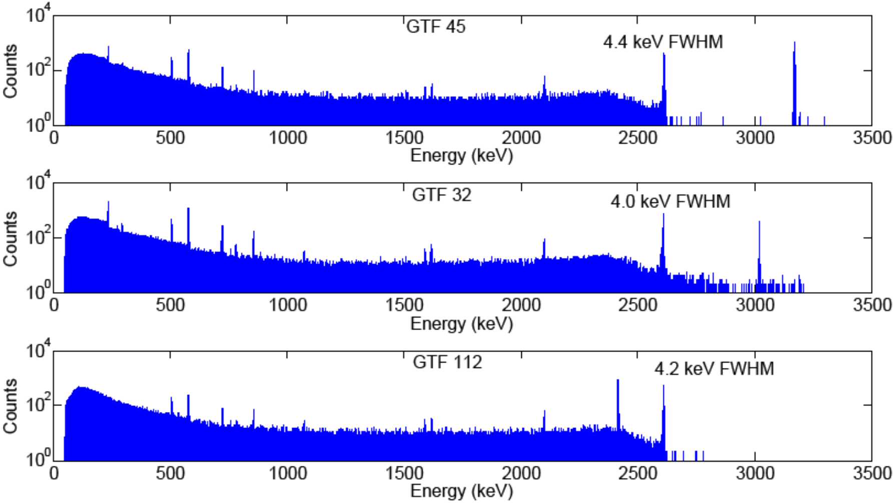
- 3 ^{nat}Ge detectors operating stable
- Energy resolution achieved so far: 4.0-4.4 keV FWHM @ 2.6MeV
- Good agreement of ^{228}Th calibration data with Monte Carlo simulations



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

First results

^{228}Th calibration data + pulsar



UZH Contribution

Calibration system

- Hardware
- Analysis pipeline
- Database
- Web interface

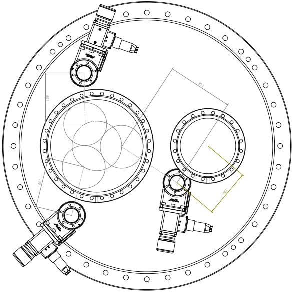
Phase II detectors

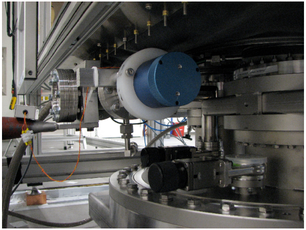
- R&D for Broad-Energy Germanium detectors (BEGe's)
  $\Rightarrow$ Chosen as the Phase II detector technology

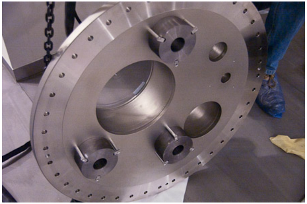
The Calibration System
Phase I

Overview

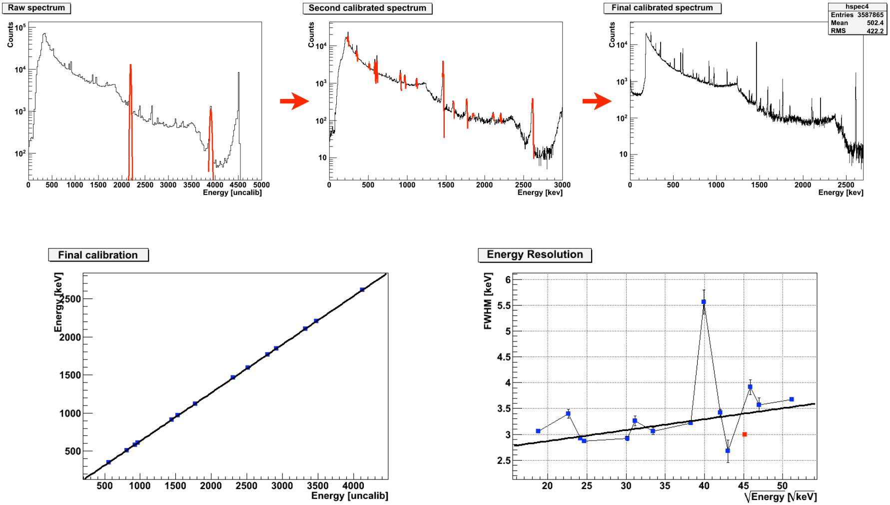
- 3 custom made ^{228}Th sources with $A \simeq 20$ kBq with low n rate
- Park position in the lock of the experiment
- Sources shielded by 5 cm of Ta
- Manual lowering system built by LNGS
- 1 calibration run of $\sim$ 30 min per detector layer





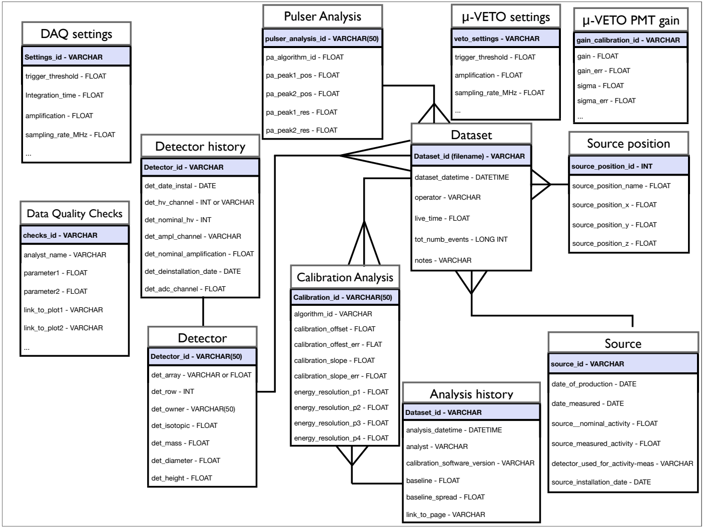


Automated Calibration



Database

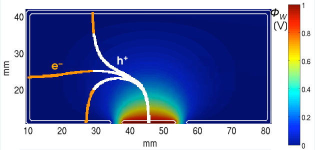
- Storing calibration parameters
- Possibility to blind data
- Monitor stability of parameters



Broad-Energy Germanium Detectors

The detector

- p-type detector with small p^+ readout electrode
- Good pulse shape discrimination between single-site (SSE) and multi-site events (MSE)
- Good energy resolution



The material

- 37.5 kg of 86% ^{enr}Ge in form of GeO_2 stored underground
- Full production cycle tested successfully with 34 kg of ^{depl}Ge

Depleted BEGe characterization

- Energy resolution: FWHM of 1.6 keV @1.3 MeV
- Pulse shape discrimination: 10% survival of MSE with 90% acceptance of SSE in DEP
- Long term stability: No instabilities found since May 2010

Summary

EXO

- EXO-200 installed and commissioned!
- Data taking starting this fall!
- Various techniques are explored for barium tagging in preparation of EXO full

GERDA

- Taking data with ^{nat}Ge
- Testing subsystems
- Start taking data with ^{enr}Ge in October
- BEGe's chosen as Phase II detector technology
- Production starts beginning of next year