EBERHARD KARLS UNIVERSITÄT TÜBINGEN
Physikalisches Institut
Kepler Center for Astro and Particle Physics

GERDA

HEROICA: a test facility for the characterization of BEGe detectors for the GERDA experiment

Raphael Falkenstein

for the GERDA collaboration

05.02.2013 DPG-Frühjahrstagung, Dresden

Outline

- GERDA – The Germanium Detector Array
  - (Neutrinoless) double beta decay
  - The GERDA setup
  - GERDA Phase I → GERDA Phase II
- Broad Energy Germanium detector (BEGe)
- Production chain of the Phase II detectors
- The HEROICA project, acceptance tests of enriched BEGe detectors
  - Motivation
  - HADES
  - Infrastructure
  - Test stands
  - Test protocol/Measurements
- Conclusions

(Neutrinoless) Double Beta Decay

- **2νββ:** Two neutrons in a nucleus are converted to protons, two e⁻ and two $\bar{\nu}_e$
- **0νββ:** The same decay, without the emission of two $\bar{\nu}_e$
- **Problem for observing the 0νββ:** Extremely large half life, background
- **Sensitivity:**

limit

$$T^{0\nu}_{1/2} \propto a \epsilon \eta \sqrt{\frac{Mt}{B \Delta E}}$$

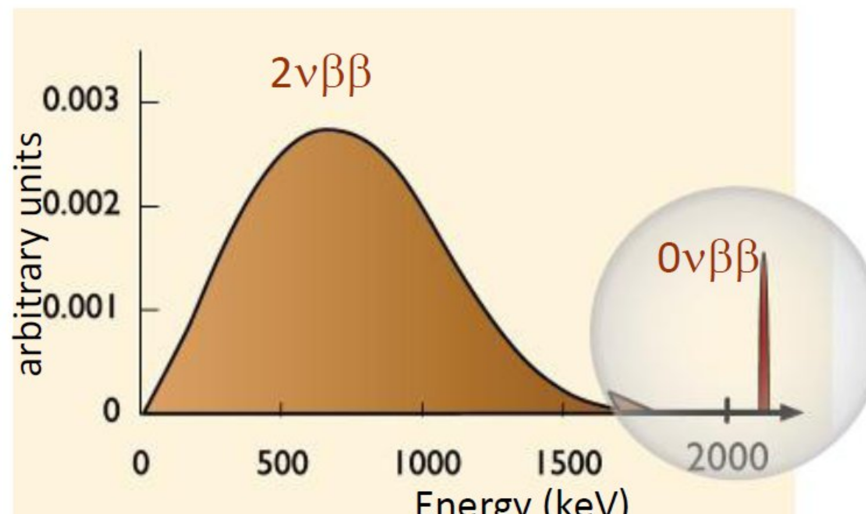
- a = istotopic abundance
- ϵ = detection efficiency
- η = active volume fraction
- Mt = exposure
- B = background index
- ΔE= energy resolution

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

SM allowed

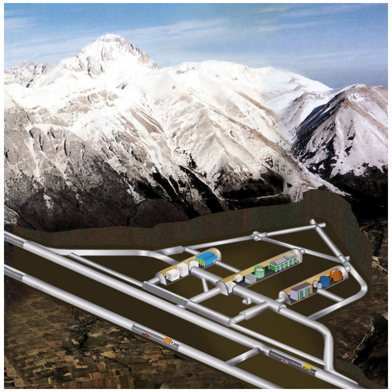
$$0\nu\beta\beta: \; (Z,A) \rightarrow (Z+2,A) + 2e^-$$

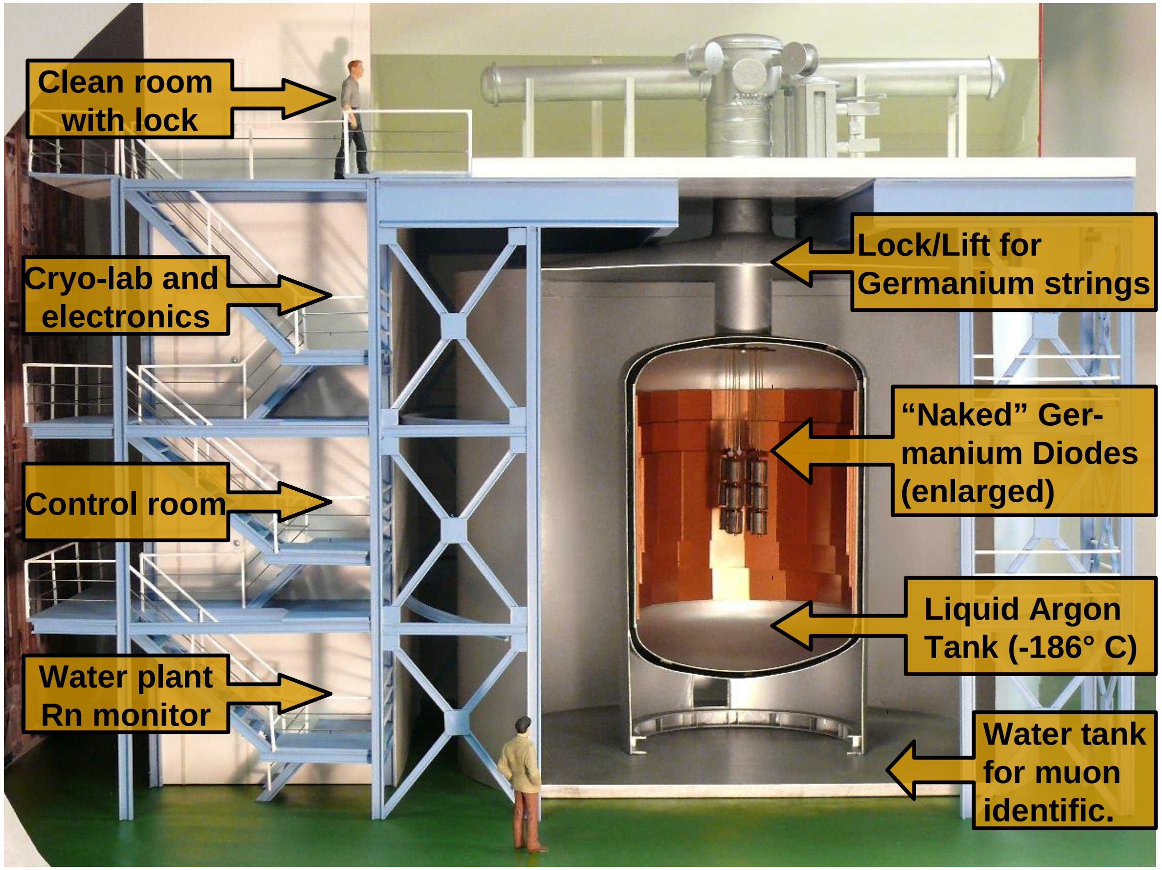
$$\Delta L = 2$$



GERDA – Germanium Detector Array

- Experiment designed to investigate the **0νββ decay in Ge76**
- Located at the Laboratori Nationali del Gran Sasso **(LNGS)**, Italy, with a natural shielding from cosmic radiation of ~ **3800 m** water equivalent.
- Uses **Ge diodes** enriched in Ge76 as **source and detector**

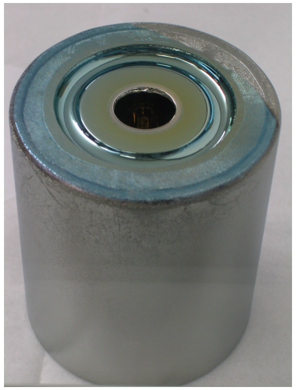




- **Liquid Argon (LAr)** is used as γ-shield and cooling medium
- The Germanium detectors are operated "naked" in LAr

Phase I

- Data taking since 9. Nov. 2011 with ~ 18 kg of ^{enr}**Ge** diodes (mostly coax type)



Phase II

- ~ 20 kg of **BEGe** detectors enriched in Ge76 at 86 % level will be additionally deployed
- 5 BEGe's with a total mass of ~ 3 kg already deployed in GERDA since July 2012
- **Physical goal of Phase II** is to increase our sensitivity and especially the reduction of the background index in the Region Of Interest ($Q_{\beta\beta}$ = 2039 keV) to a level of **10^{-3} cts/(keV · kg · yr)**

Phase I

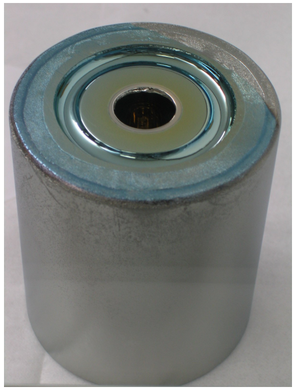
- Data taking since 9. Nov. 2011 with ~ 18 kg of ^{enr}**Ge** diodes (mostly coax type)

$$T^{0\nu}_{1/2} \propto a \epsilon \eta \sqrt{\frac{M t}{B \Delta E}}$$

$$M \rightarrow 2 \cdot M$$

First improvement: Doubling of detector mass

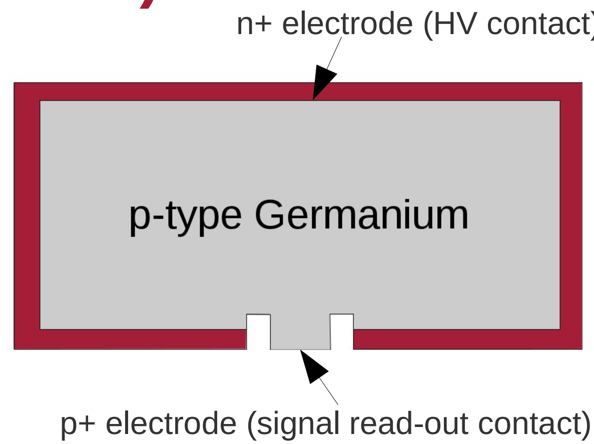
HEROICA project
→ Acceptance test of new detectors



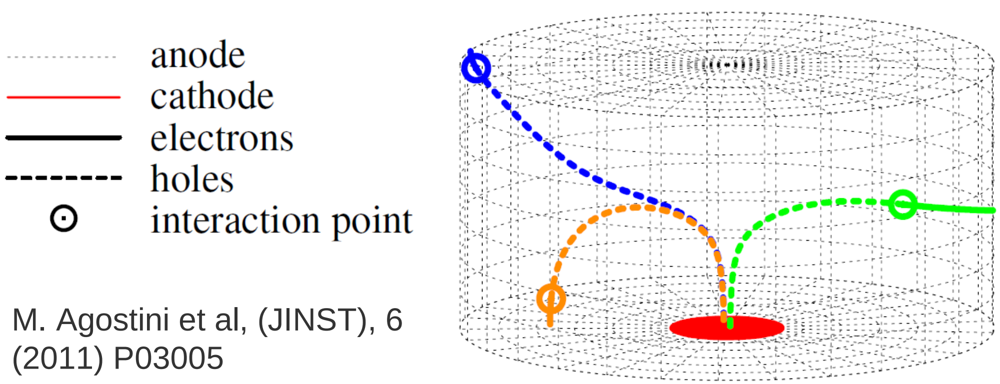
Phase II

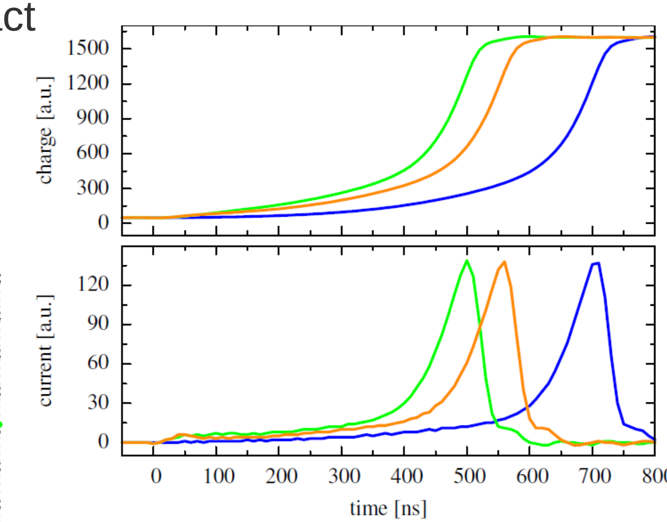
- ~ 20 kg of **BEGe** detectors enriched in Ge76 at 86 % level will be additionally deployed
- 5 BEGe's with a total mass of ~ 3 kg already deployed in GERDA since July 2012
- **Physical goal of Phase II** is to increase our sensitivity and especially the reduction of the background index in the Region Of Interest ($Q_{\beta\beta}$ = 2039 keV) to a level of **10^{-3} cts/(keV · kg · yr)**

Broad Energy Germanium detector (BEGe)



- Manufactured by Canberra, Olen, Belgium
- **Smaller size** compared to the Phase I coaxial detectors
- Smaller size of **read-out-electrode**
  - Lower capacitance
  - Lower noise
  - Better **energy resolution** (~ 1.75 keV @ 1.33 MeV)
- Enhanced **pulse shape discrimination** performance due to peculiar electric field created by the small contact
  → Allows in particular to discriminate
  single-site events (0νββ-decay-like) from
  multi-site events (gamma-ray background events)





(b) Charge and current pulses

M. Agostini et al, (JINST), 6 (2011) P03005

The BEGe Production chain
A big logistical challenge

- **Minimization of the cosmic ray exposure** of the enriched Germanium material, due to production of radio-isotopes including **Co60** and **Ge68** mostly done by cosmic ray **neutrons**
- These nuclides can **mimic 0νββ** decays in our detectors

Activation mostly by spallation reactions of fast nucleons from cosmic rays

- Transport in **shielded containers**
- Find **underground locations** in the vicinity of the plants during the various production phases for the storage of the material
- Need of **exposure tracking**

BEGe Production chain

- Production of enriched $^{76}GeO_2$ at ECP Zelenogorsk, Russia

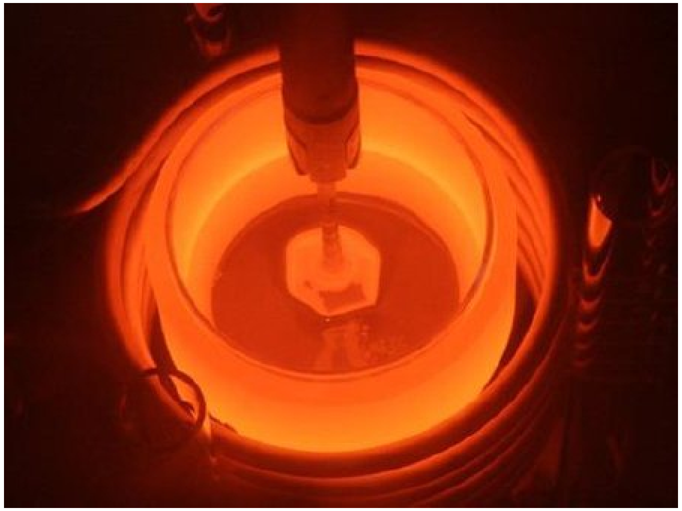
BEGe Production chain

- **Metal reduction and zone refinement** at PPM in Langelsheim, DE (08.03.2010 – 30.04.2010) 35.5 kg enriched 6N material
- **Underground storage** in Rammelsberg mining museum

- Production of enriched $^{76}GeO_2$ at ECP Zelenogorsk, Russia

BEGe Production chain

- Crystal pulling and further zone refinement at Canberra in Oak Ridge, USA



- Production of enriched $^{76}GeO_2$ at ECP Zelenogorsk, Russia
- Metal reduction and zone refinement at PPM in Langelsheim, DE, 35.5 kg enriched 6N material
- Underground storage in Rammelsberg mining museum

BEGe Production chain

- Shipping to Belgium for diode production at Canberra, Olen

Transport in 26 t container, shielded with water and steel. Lowest possible position on deck

- Production of enriched $^{76}GeO_2$ at ECP Zelenogorsk, Russia
- Metal reduction and zone refinement at PPM in Langelsheim, DE, 35.5 kg enriched 6N material
- Underground storage in Rammelsberg mining museum
- Crystal pulling and further zone refinement at Canberra in Oak Ridge, USA

HEROICA

Hades Experimental Research Of Intrinsic Crystal Appliances

Motivation and Goal

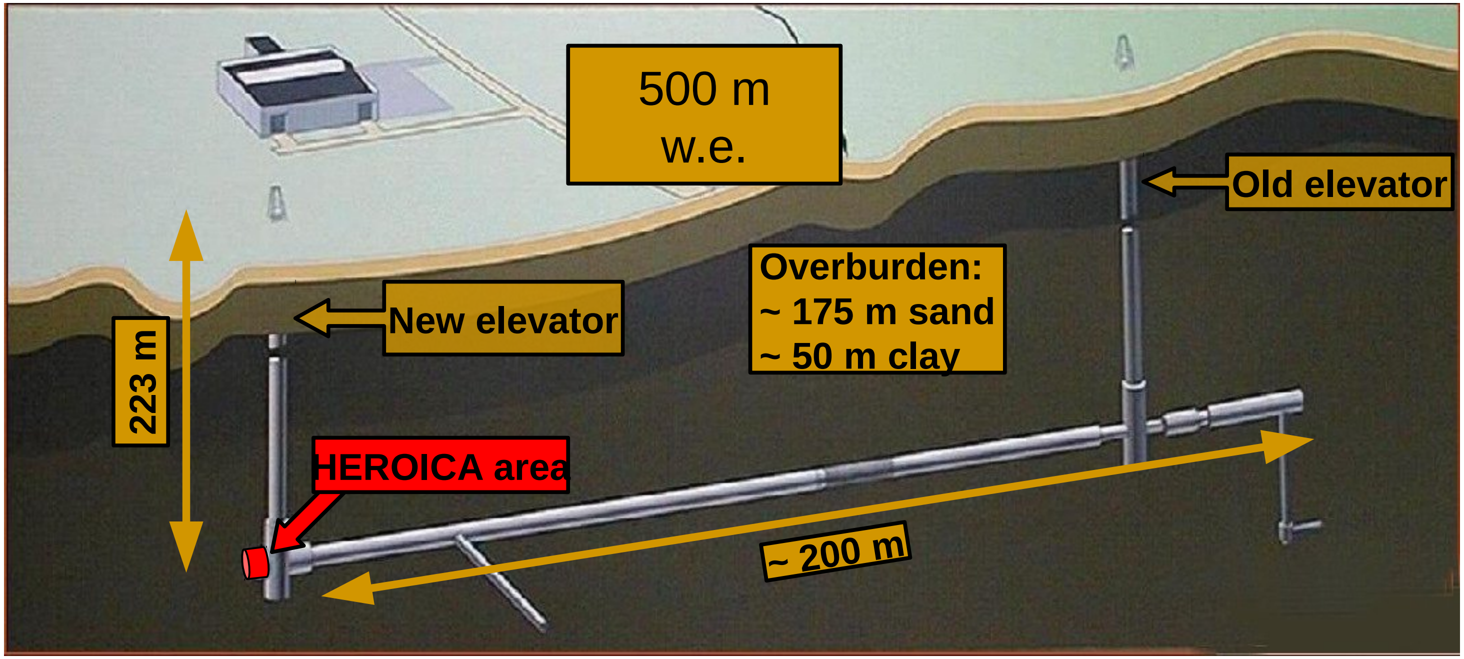
- **Acceptance tests** of enriched BEGe detectors
- Do the detectors fulfill our requirements and the specifications of the manufacturer?

- To verify that the necessary requirements are met, a **complete characterization** of the detector properties is needed prior to their installation in the GERDA experiment
- Determine all the important **detector parameters**, like depletion voltage, detector active volume, dead layer uniformity over the surface, charge collection uniformity and test the performance of the diodes in terms of energy resolution and quality of pulse shape discrimination
- Ge detectors **depleted in the Ge76 content** (byproduct of the enrichment procedure) were used to define the acceptance test protocol

HADES

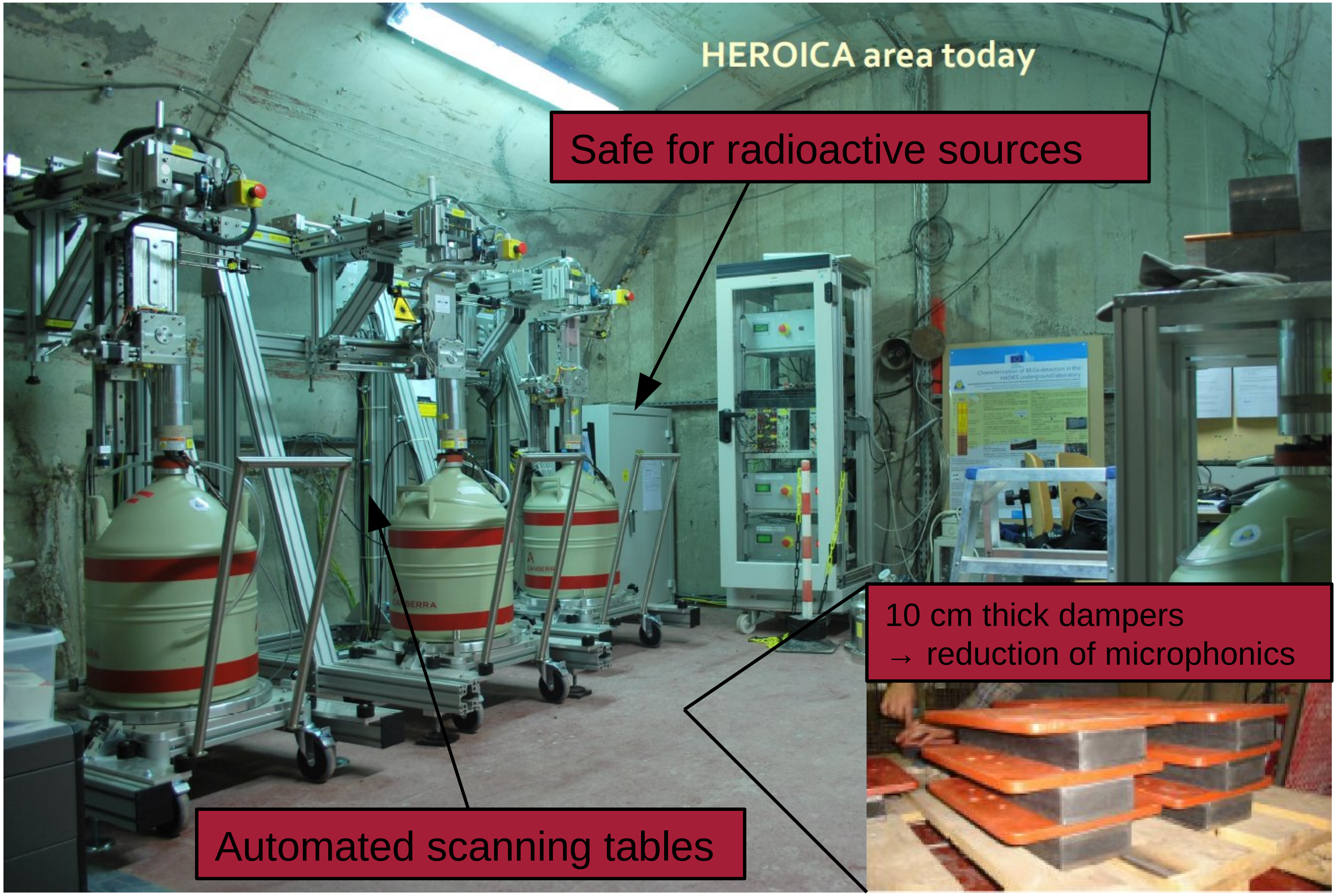
High Activity Disposal Experimental Site

- Location for **acceptance testing** and **storage** of the Diodes
- Located in at the Belgian Nuclear Research Center SCK•CEN, Mol, Belgium
- **Close to the diode manufacturer** (~20 km) in Olen
- **223 m deep** (~ 500 m w.e.) → **Minimize cosmic activation** of Germanium



Infrastructure

Infrastructure



Test stands

"Fixed setup"

- 2 test stands
- Lead + copper shielding
- Measurements done at **fixed source-detector distance**

"Automated Scanning setup"

- 3 test stands
- Equipped with **motor controlled movable arm**, for the top and lateral scanning of the detector surface
- Collimated source
- Laser system for the alignment of the detector

33 radioactive sources

MCA and FADC DAQ

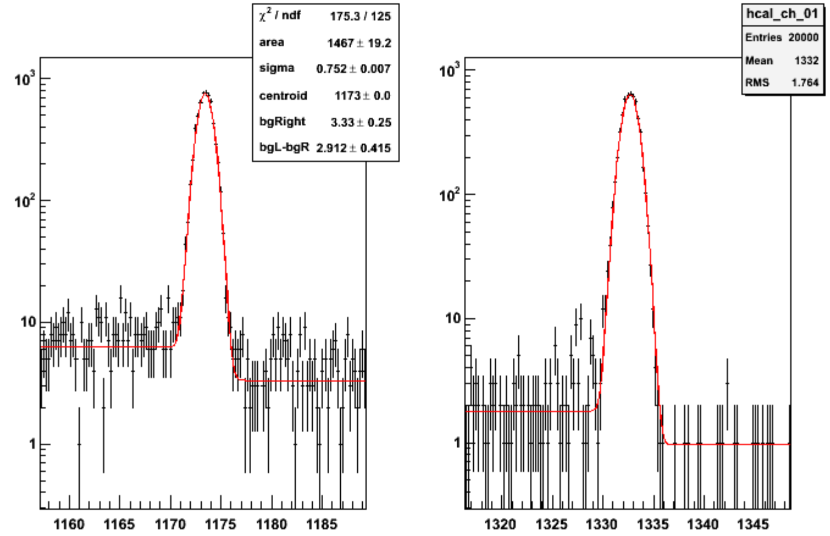
Test Protocol

- **Co60, uncollimated**
  - Energy resolution
  - Automated HV scans
    - Depletion voltage
    - Energy resolution as a function of the HV
    - Peak position as a function of the HV
    - Peak rate as a function of the HV
    - Leakage current as a function of HV
  - Active Volume measurement
- **Uncollimated Am241 and Ba133**
  - Average upper surface dead layer
- **Uncollimated Th228**
  - Pulse shape discrimination (PSD) efficiency
- **Collimated Am241 scans at nominal voltage**
  - Charge collection uniformity
  - Homogeneity of dead layer / active volume edges
  - Position dependance of pulse shape properties (signal risetime, A/E, ...)

Test Protocol

- **Co60, uncollimated**
  - Energy resolution
  - Automated HV scans
    - Depletion voltage
    - Energy resolution as a function of the HV
    - Peak position as a function of the HV
    - Peak rate as a function of the HV
    - Leakage current as a function of HV
  - Active Volume measurement
- **Uncollimated Am241 and Ba133**
  - Average upper surface dead layer
- **Uncollimated Th228**
  - Pulse shape discrimination (PSD) efficiency
- **Collimated Am241 scans at nominal voltage**
  - Charge collection uniformity
  - Homogeneity of dead layer / active volume edges
  - Position dependance of pulse shape properties (signal risetime, A/E, ...)

$$T^{0\nu}_{1/2} \propto a\epsilon\eta\sqrt{\frac{Mt}{B\Delta E}}$$

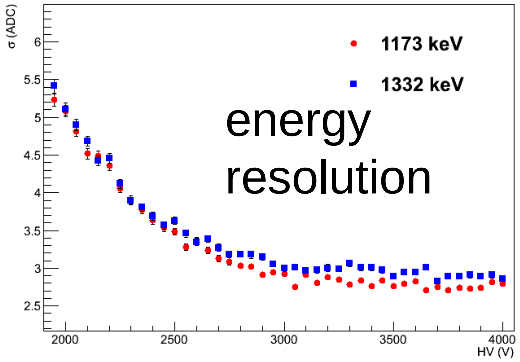


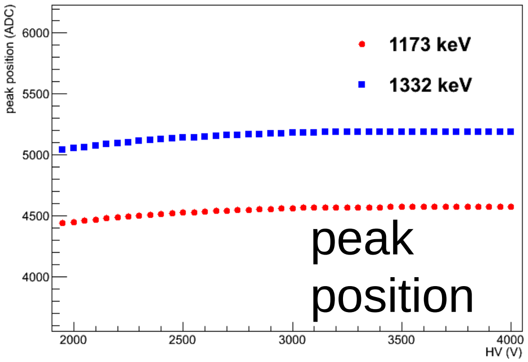
FWHM between
1.64 keV and 1.86 keV at 1.3 MeV
for all 30 detectors
(ø 1.74 keV)

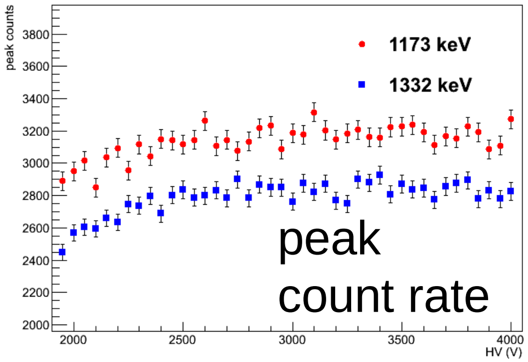
Test Protocol

- **Co60, uncollimated**
  - Energy resolution
  - Automated HV scans
    - Depletion voltage
    - Energy resolution as a function of the HV
    - Peak position as a function of the HV
    - Peak rate as a function of the HV
    - Leakage current as a function of HV
  - Active Volume measurement
- **Uncollimated Am241 and Ba133**
  - Average upper surface dead layer
- **Uncollimated Th228**
  - Pulse shape discrimination (PSD
- **Collimated Am241 scans at nomin**
  - Charge collection uniformity
  - Homogeneity of dead layer / activ
  - Position dependance of pulse sh properties (signal risetime, A/E, .

- **Determine depletion voltage:** Minimal voltage at which the spectroscopic characteristics are optimal
- **Important for GERDA:** How much can the HV be lowered from operational voltage without loosing detector performance







Test Protocol

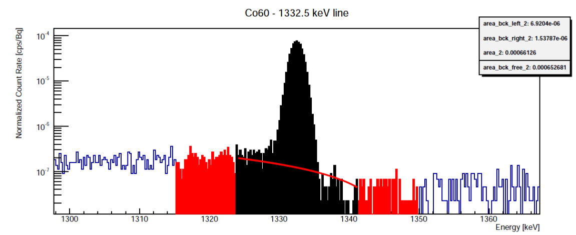
- **Co60, uncollimated**
  - Energy resolution
  - Automated HV scans
    - Depletion voltage
    - Energy resolution as a function of the HV
    - Peak position as a function of the HV
    - Peak rate as a function of the HV
    - Leakage current as a function of HV
  - Active Volume measurement
- **Uncollimated Am241 and Ba133**
  - Average upper surface dead layer
- **Uncollimated Th228**
  - Pulse shape discrimination (PSD) efficiency
- **Collimated Am241 scans at nominal voltage**
  - Charge collection uniformity
  - Homogeneity of dead layer / active volume edges
  - Position dependance of pulse shape properties (signal risetime, A/E, ...)

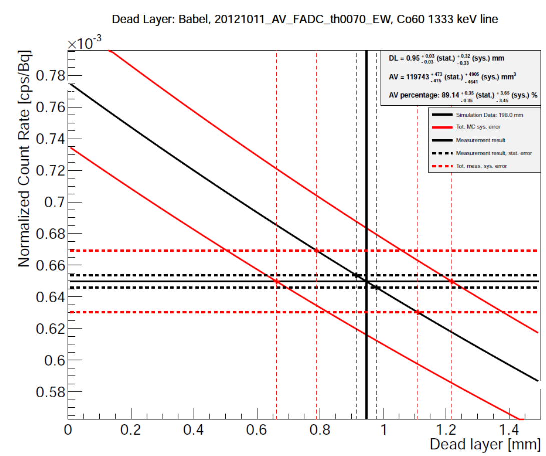
Dedicated Talk by
B. Lehnert at 17:20 in this session

Active volume fraction

$$T_{1/2}^{0\nu} \propto a\,\epsilon\,\eta\sqrt{\frac{Mt}{B\Delta E}}$$

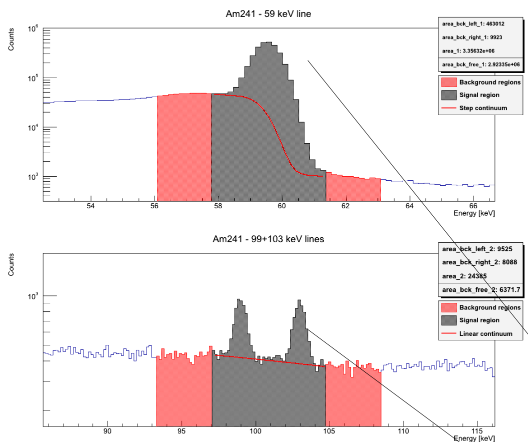
- Determined by comparing the measured γ-line detection efficiency with MC simulations





Test Protocol

- Co
  -
  -



of the HV
ne HV
V
f HV

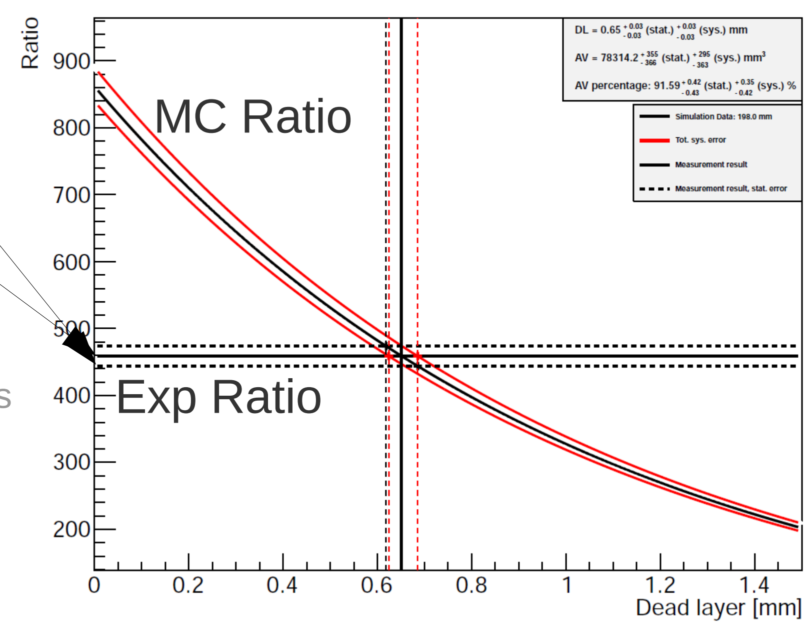
  - Active volume measurement
- **Uncollimated Am241 and Ba133**
  - Average upper surface dead layer
- **Uncollimated Th228**
  - Pulse shape discrimination (PSD) efficiency
- **Collimated Am241 scans at nominal voltage**
  - Charge collection uniformity
  - Homogeneity of dead layer / active volume edges
  - Position dependance of pulse shape properties (signal risetime, A/E, ...)

Dedicated Talk by
B. Lehnert at 17:20 in this session

$$T^{0\nu}_{1/2} \propto a\,\epsilon\,\eta\sqrt{\frac{Mt}{B\,\Delta E}}$$

- Compare the measured ratio between the count rate of two γ-lines with the corresponding MC ratio

Cheops, 20121127_DL_MCA_EW, Am241 measurement



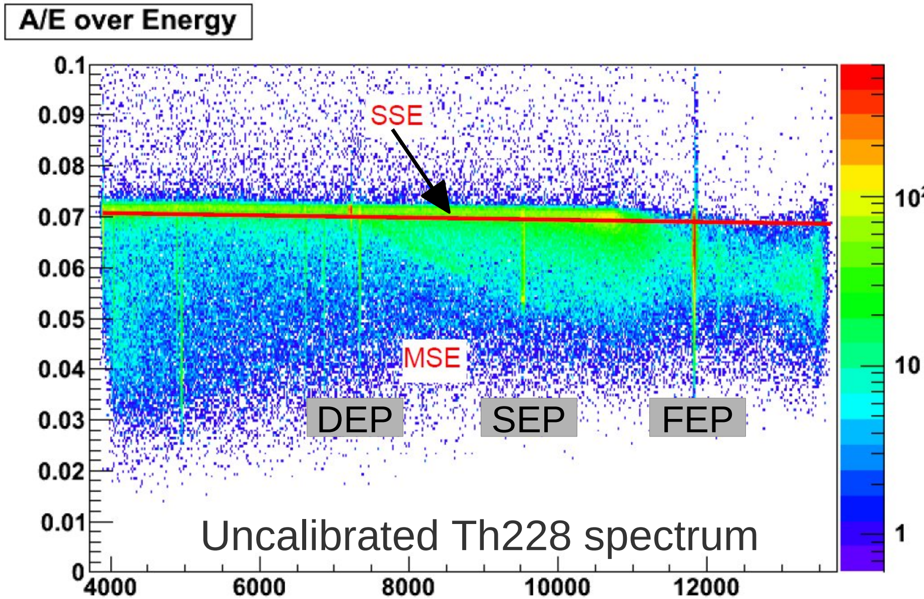
Test Protocol

$$T^{0\nu}_{1/2} \propto a \epsilon \eta \sqrt{\frac{Mt}{B \Delta E}}$$

- **Co60, uncollimated**
  - Energy resolution
  - Automated HV scans
    - Depletion voltage
    - Energy resolution as a function of the HV
    - Peak position as a function of the HV
    - Peak rate as a function of the HV
    - Leakage current as a function of HV
  - Active Volume measurement
- **Uncollimated Am241 and Ba133**
  - Average upper surface dead layer
- **Uncollimated Th228**
  - Pulse shape discrimination (PSD) efficiency
- **Collimated Am241 scans at nominal voltage**
  - Charge collection uniformity
  - Homogeneity of dead layer / active volume e
  - Position dependance of pulse shape properties (signal risetime, A/E, ...)

Dedicated Talk by
V. Wagner after this talk

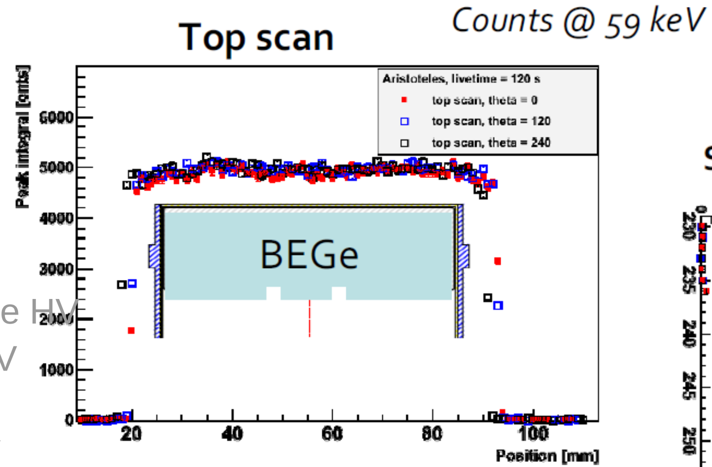
- Ratio of current signal amplitude (A) and charge signal amplitude (E) different for **SSE** (0νββ-decay-like) and **MSE** (γ - ray background events)

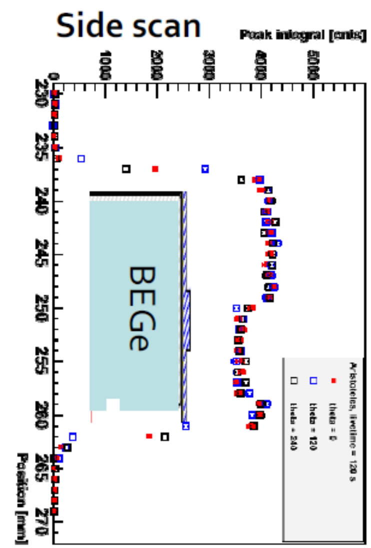


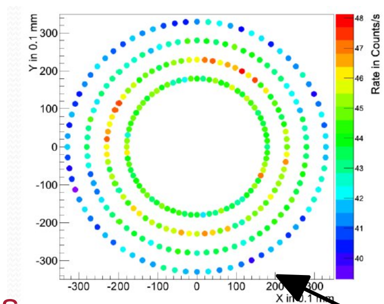
Test Protocol

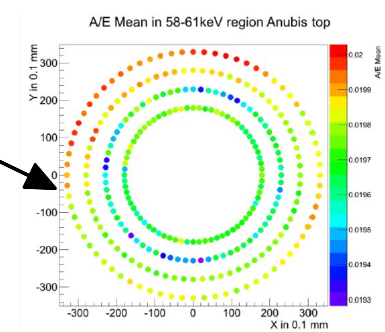
- **Co60, uncollimated**
  - Energy resolution
  - Automated HV scans
    - Depletion voltage
    - Energy resolution as a function of the HV
    - Peak position as a function of the HV
    - Peak rate as a function of the HV
    - Leakage current as a function of HV
  - Active Volume measurement
- **Uncollimated Am241 and Ba133**
  - Average upper surface dead layer
- **Uncollimated Th228**
  - Pulse shape discrimination (PSD) efficiency
- **Collimated Am241 scans at nominal voltage**
  - Charge collection uniformity
  - Homogeneity of dead layer / active volume edges
  - Position dependance of pulse shape properties (signal risetime, A/E, ...)

See Talk by
V. Wagner after this talk









Top surface scans

Conclusions

- We developed a test facility for the fast screening of BEGe detectors in the HADES underground lab
- Minimized exposure of the detectors to cosmic radiation as much as possible
- Test protocol, which allows for the complete characterization of the BEGe detectors spectroscopic performances, active volume, depletion voltage, PSD properties and other parameters
- All 30 new enriched BEGe detectors are tested and operating