The GERDA experiment,

a search for neutrinoless double beta decay

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Daniel Lenz
Max-Planck-Institute for Physics, Munich

on behalf of the
GERDA Collaboration

Outline:

- Motivation
- Experimental considerations
- GERDA concept
- Current status
- R&D
- Summary

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GERmanium Detector Array

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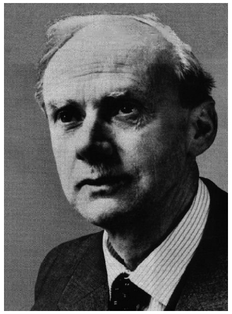
Motivation

- Neutrinoless double beta decay ($0\nu\beta\beta$) is the only way to unveil the nature of neutrinos



Dirac

$\nu \neq \bar{\nu}$

or

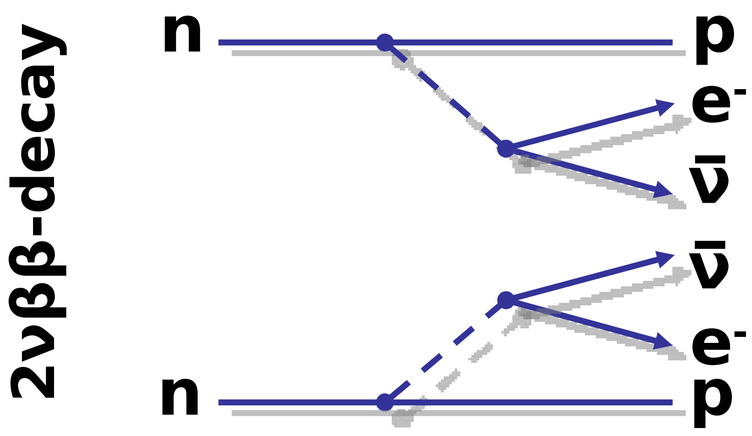
Majorana

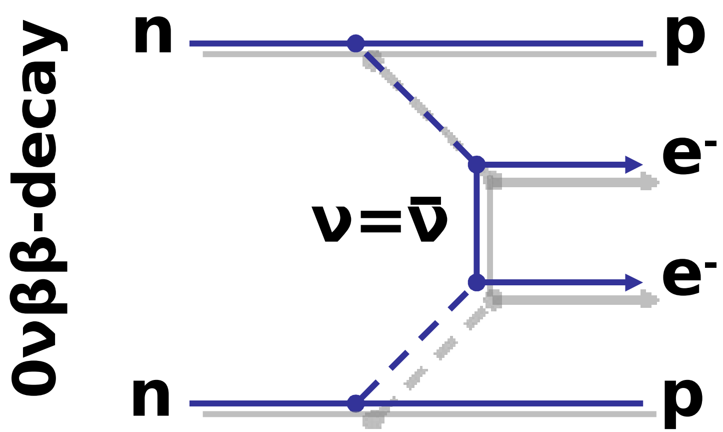
$\nu = \bar{\nu}$

- If $0\nu\beta\beta$ observed:
  - neutrino is Majorana type
  - lepton number violation ΔL = 2
  - seesaw mechanism $m_\nu = \frac{m_D^2}{M_R} << m_D$
  - possible to determine absolute neutrino mass scale
  - possible to determine neutrino hierarchy

Schechter-Valle theorem

What is $\beta\beta$ Decay





- allowed process
- observed for several isotopes

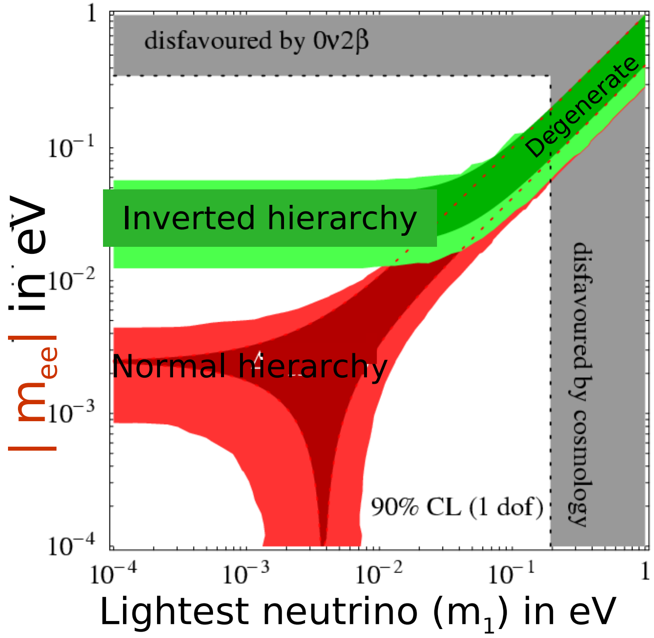
- forbidden process in SM, needs Majorana neutrino
- halflife limits available

effective Majorana neutrino mass:

$$|m_{ee}| = |\sum_j m_j U_{ej}^2|$$

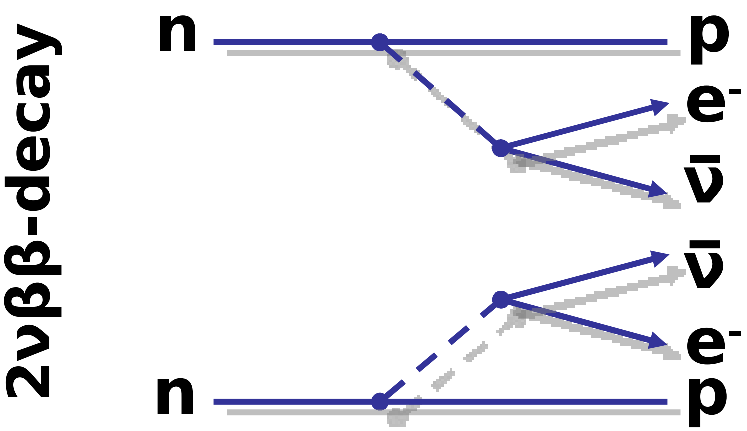
$$| m_1 \cdot |U_{e1}|^2 + m_2 \cdot |U_{e2}|^2 e^{i(\alpha_2-\alpha_1)} + m_3 \cdot |U_{e3}|^2 e^{i(-\alpha_1-2\delta)} |$$

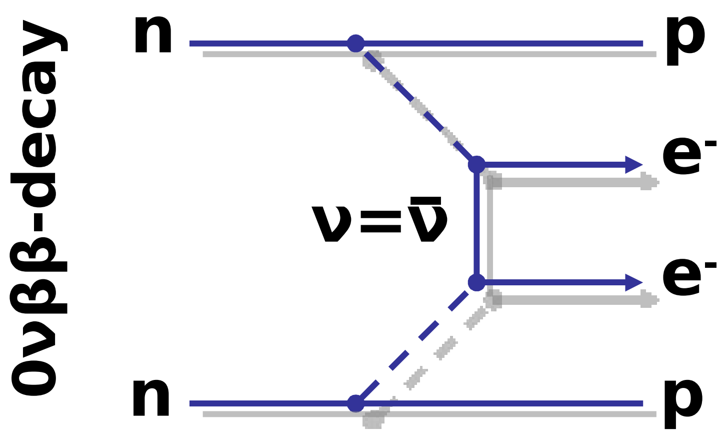
$$T_{1/2} \propto |m_{ee}|^{-2}$$



F. Feruglio,
A. Strumia,
F. Vissani,
NPB 637

Experimental Signature





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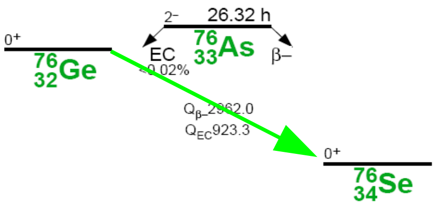
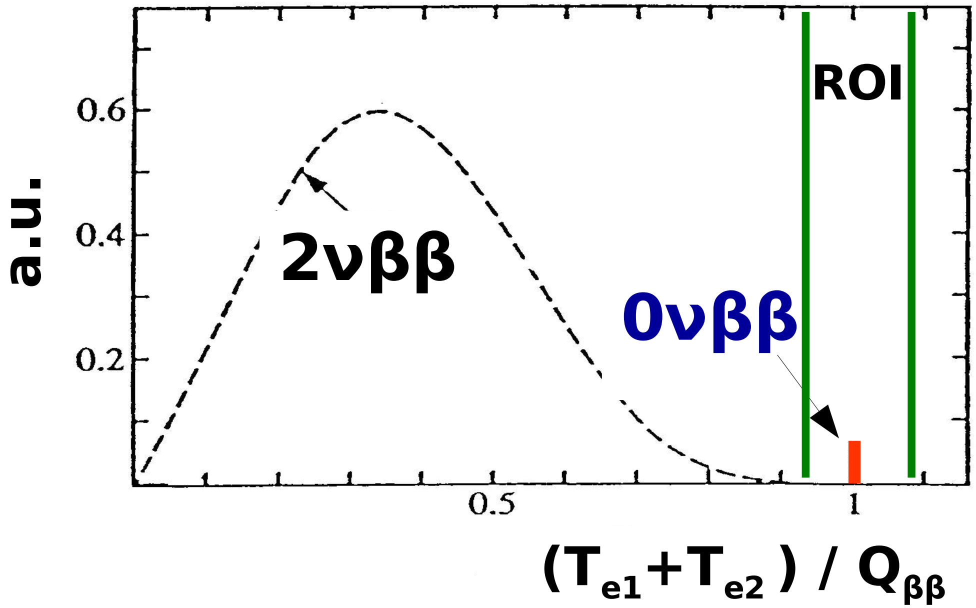




$Q_{\beta\beta}(^{76}Ge) = 2039 keV$

Halflife Limits

Heidelberg-Moscow experiment:

- 5 enriched Ge p-type crystals
- background index ~0.1 cts/(keV kg y)
- $T_{1/2} \geq 1.9 \cdot 10^{25}$ y (90% C.L.)   35.5 kg y

Eur. Phys. J. A12, 147-154 (2001)

- part of collaboration claims a signal

Mod. Phys. Lett. A16 2409-2420 (2001), NIM A 522 (2004) 371-406

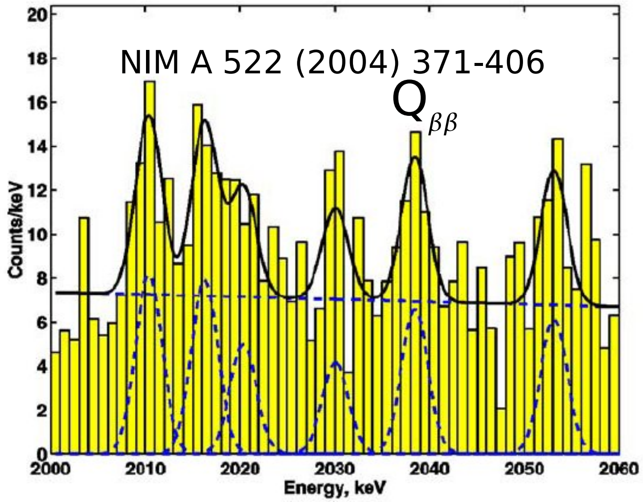
IGEX:

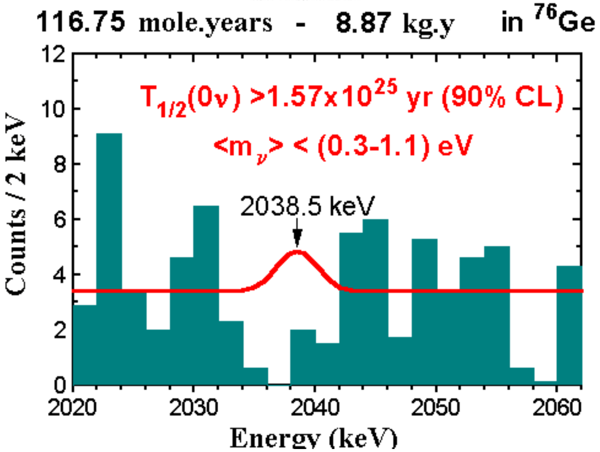
- 3 enriched Ge p-type crystals
- $T_{1/2} \geq 1.57 \cdot 10^{25}$ y (90% C.L.)   8.87 kg y

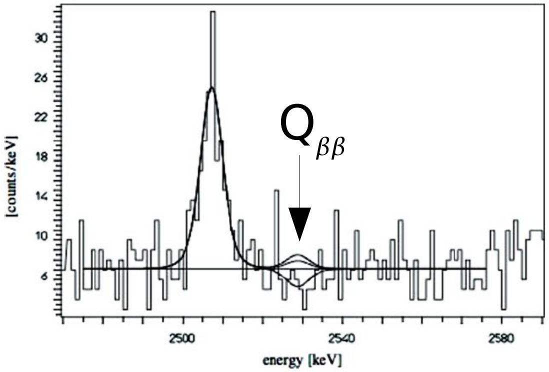
NP B (Proc.Suppl.) 87 (2000) 278

Cuoricino: *Phys. Rev. C 78 (2008) 035502*

- 62 TeO_2 bolometers 40.7kg
- $T_{1/2} \geq 3.0 \cdot 10^{24}$ y (90% C.L.)   11.83 kg y







Experimental Considerations - Germanium Detectors

$$T_{1/2} \propto \text{const} \bullet \epsilon \bullet (M \bullet T / b \bullet \Delta E)^{1/2}$$ if background

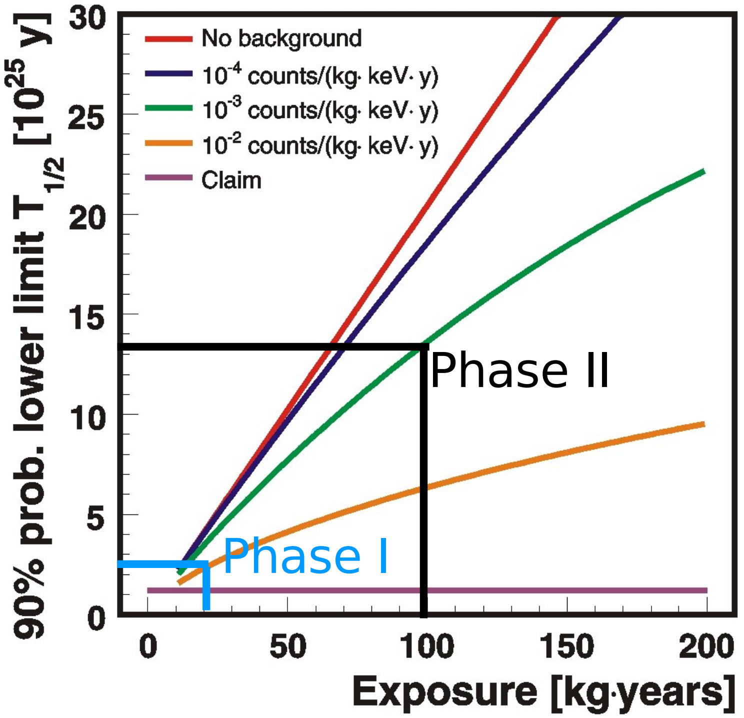
general considerations

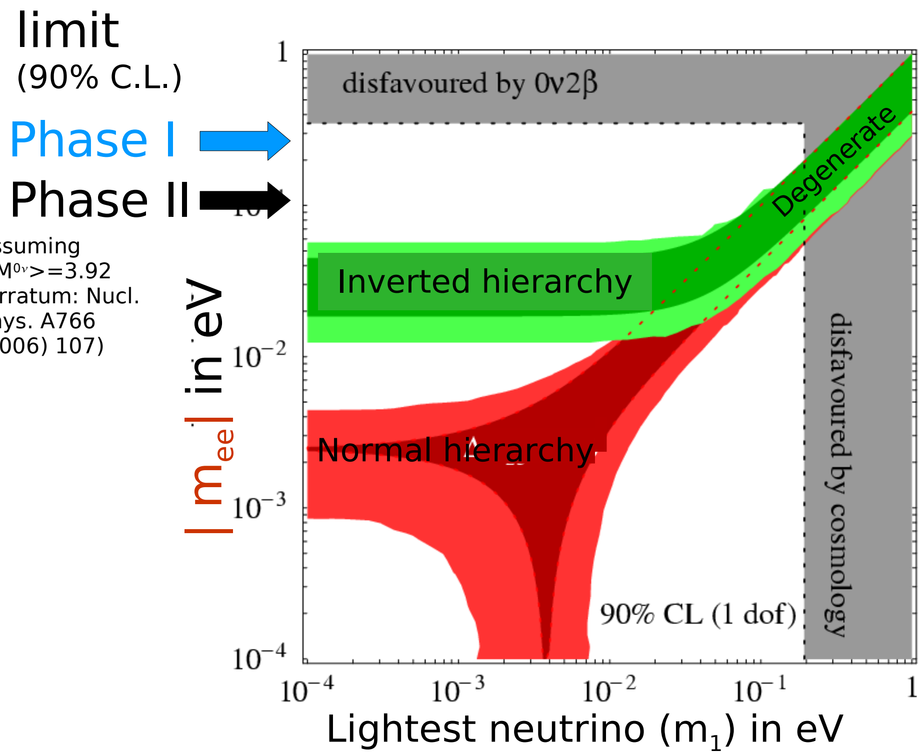
- high Q-value:
  - phase space scales with Q^5
  - natural radioactivity contribution reduced
- large target mass M; large natural abundance, or enrichment
- high signal effiency ϵ
- **low background rate b** in ROI **crucial**! rate := counts/(keV · kg·y)
- **good energy resolution ΔE** to seperate $0\nu\beta\beta$ from $(2\nu\beta\beta +$ other bkg)

Ge detectors

- $Q_{\beta\beta}(^{76}Ge) = 2039$ keV
- enrichement in ^{76}Ge of 86%
- source = detector
- germanium is one of the purest materials to produce
- excellent energy resolution FWHM($Q_{\beta\beta}$) < 5keV; $\Delta E/E = 0.2\%$

GERDA Goals





Assuming $<M^{0\nu}>=3.92$ (Erratum: Nucl. Phys. A766 (2006) 107)

F. Feruglio,
A. Strumia,
F. Vissani,
NPB 637

Phase I:

- operate existing ^{76}Ge detectors from HdM and IGEX + natGe Diodes
- reach background of 10^{-2} cts/(keV kg y)
- exposure of ~ 15kg y, **check claim**

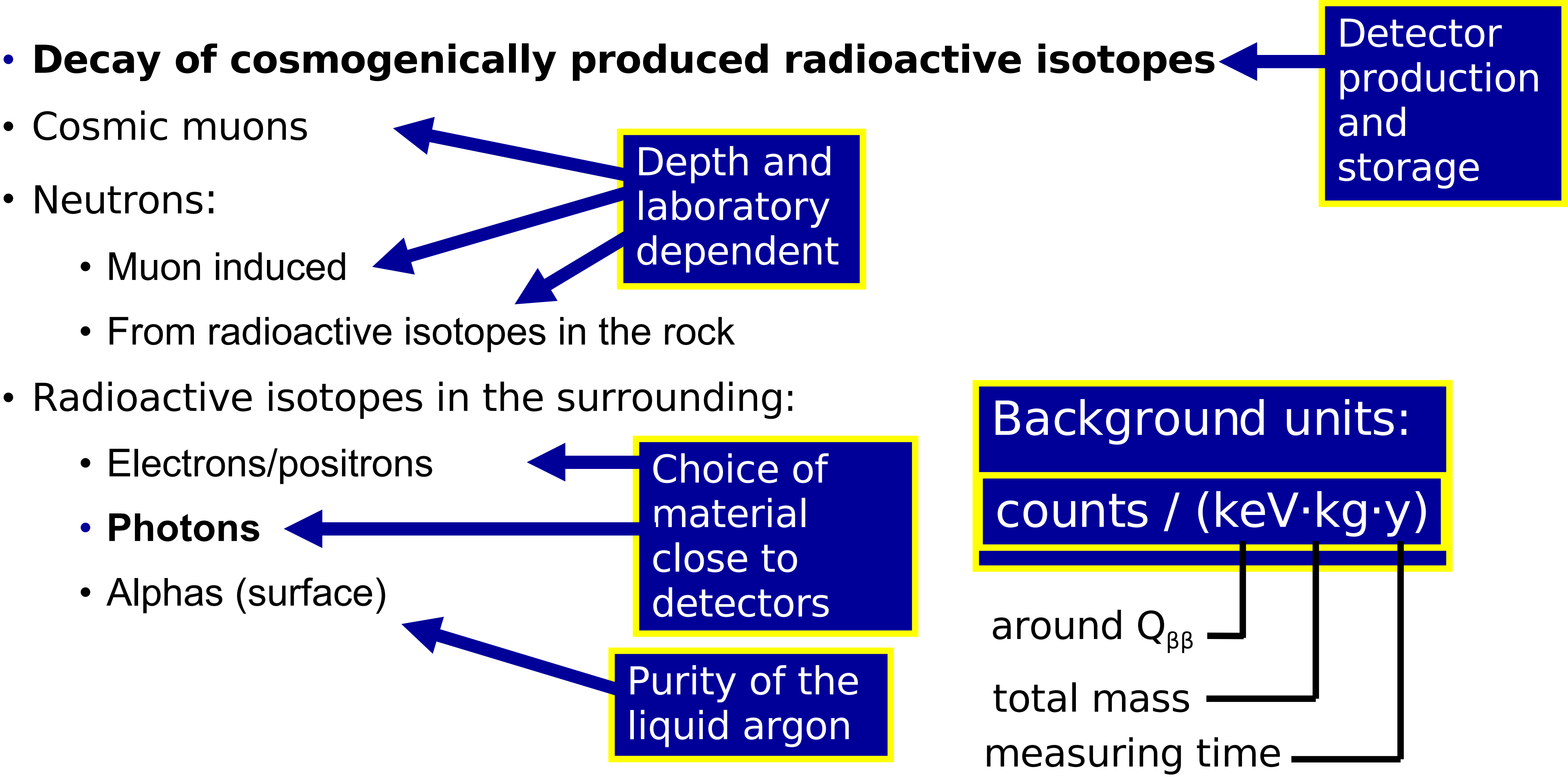
Phase II:

- operate new segmented or BEGe ^{76}Ge detectors
- reach background of 10^{-3} cts/(keV kg y)
- exposure of ~100kg y ⇒ $T_{1/2} \geq 1.35 \cdot 10^{26}$ y

Key issue:
low background rate
Phase I: O(10^1) < HdM

Background

Background: processes which cause energy deposition inside ROI



- **Decay of cosmogenically produced radioactive isotopes**
- Cosmic muons
- Neutrons:
  - Muon induced
  - From radioactive isotopes in the rock
- Radioactive isotopes in the surrounding:
  - Electrons/positrons
  - **Photons**
  - Alphas (surface)

Detector production and storage

Depth and laboratory dependent

Choice of material close to detectors

Purity of the liquid argon

Background units:

counts / (keV·kg·y)

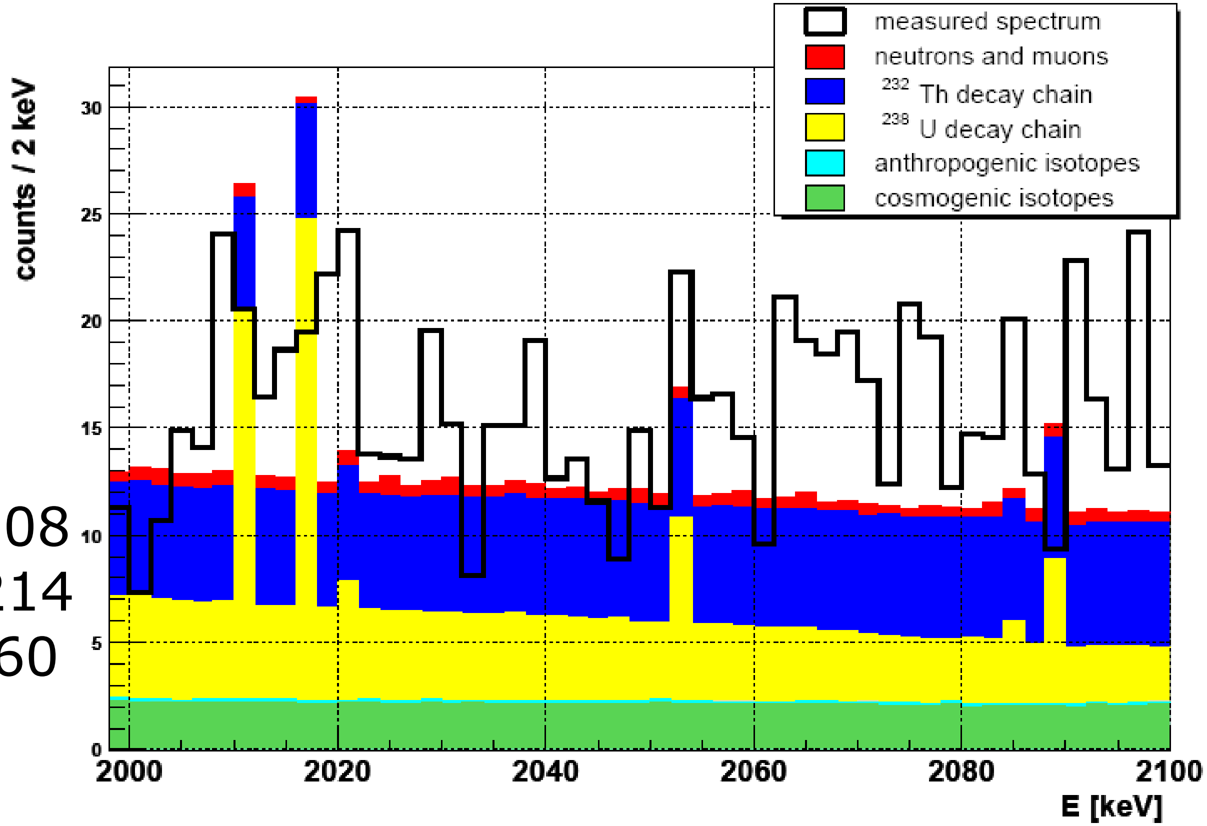
around $Q_{\beta\beta}$

total mass

measuring time

HdM Background Revisit

HdM energy spectrum + simulation



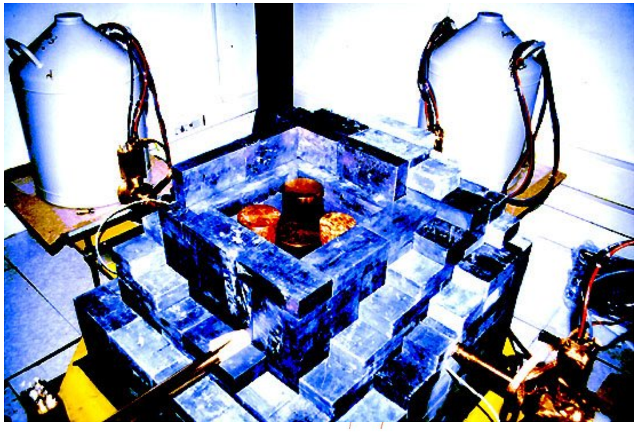
Tl208
Bi214
Co60

setup:

copper cryostat

lead shield

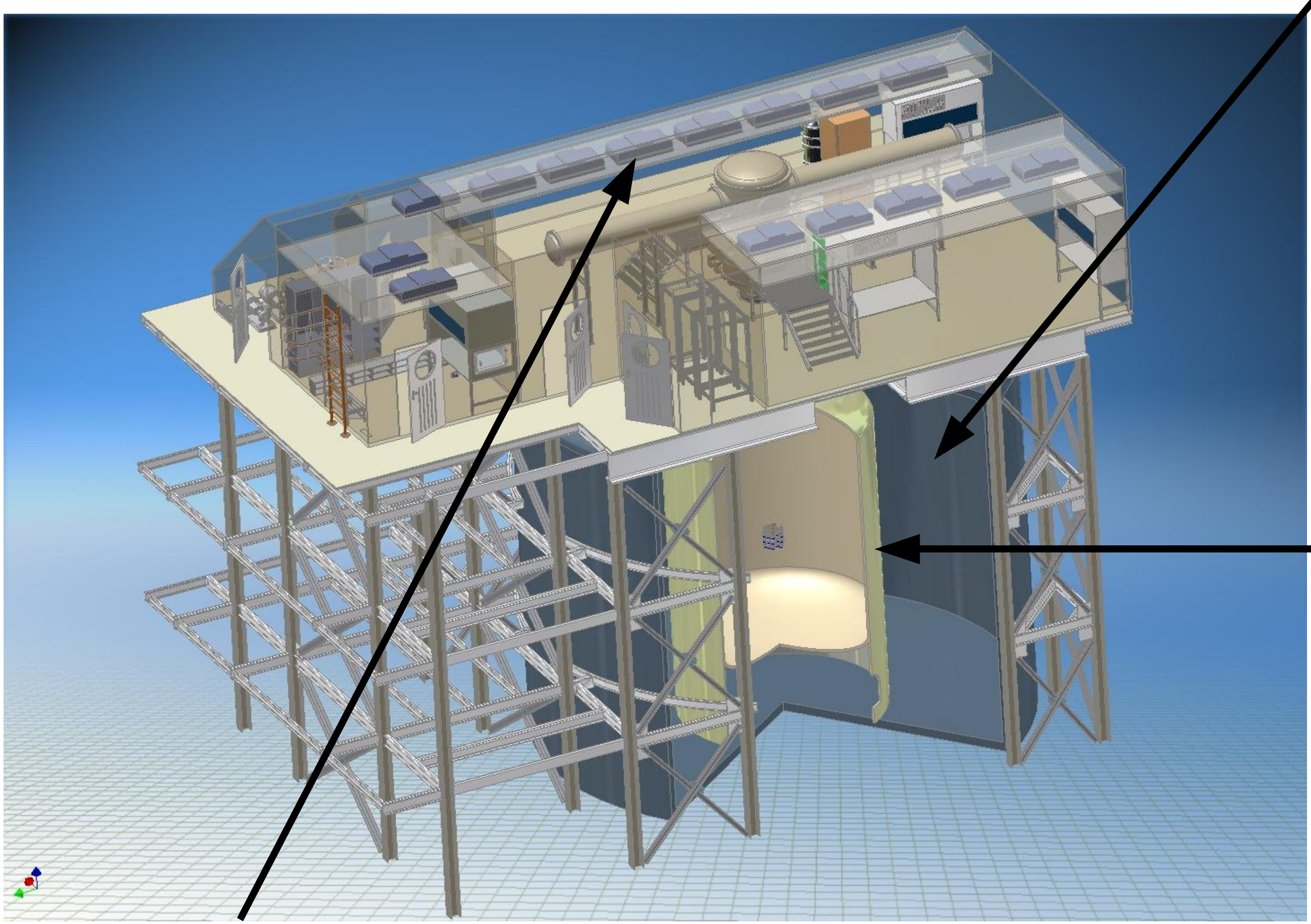
conventional cooling



Main background from natural decay chains from Cu-cryostat and CuPb-shield

GERDA Concept

LNGS: ⇧ **3800 m. w. e. rock above** ⇧



Watertank:

r = 5m, h = 9.0m

590m³ ultra-pure **water**

acts as:

- n moderator
- μ cherenkov veto

Cryostat: (copper-lining)

r = 2.1m, h = 5m

70m³ **liquid Argon**

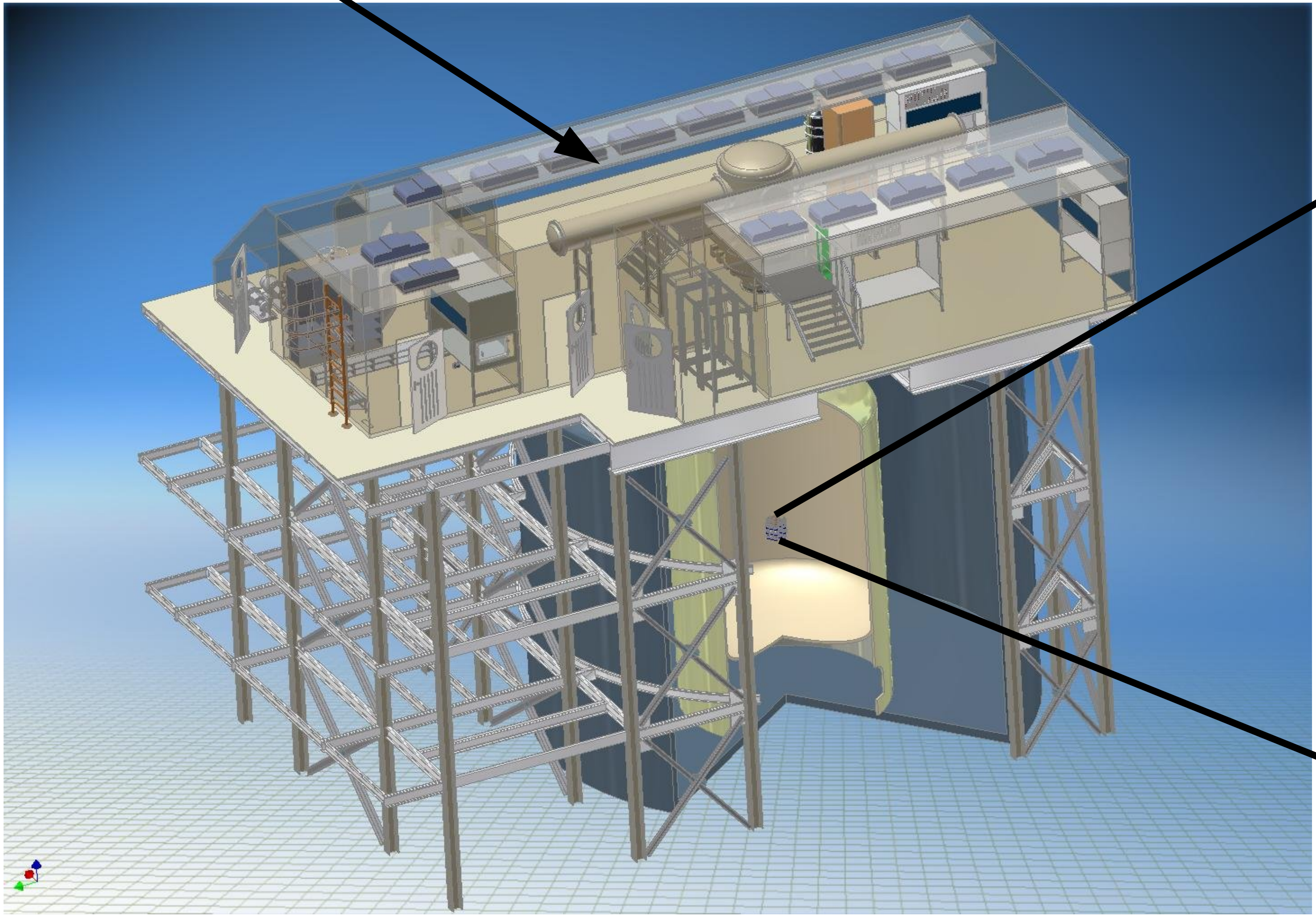
acts as:

- shielding medium
- cooling medium

Plastic scintillators on top as muon veto

GERDA Concept

Clean room: Class 10.000



Detector array:

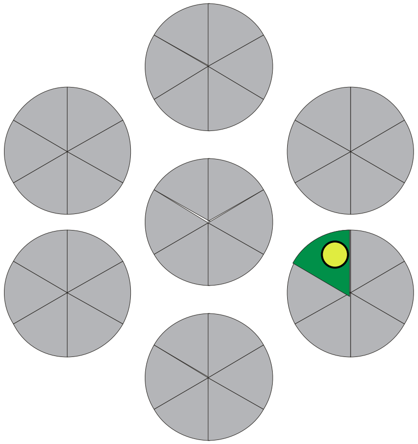
- 3 detectors per string
- up to 16 strings

- little (high-Z) material close to detectors

Active Background Reduction

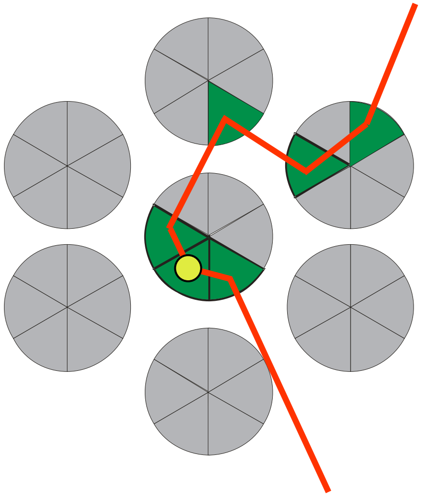
Anti-Coincidences:

Signal:



Single Site Event
(SSE)

Background:



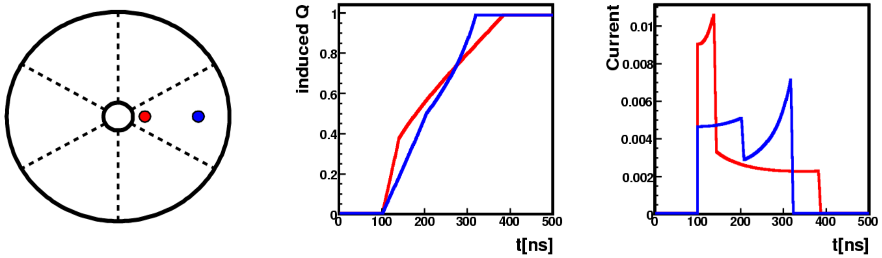
Multi Site Event
(MSE)

- crystal and segment anti-coincidence possible

Pulse Shape Analysis:

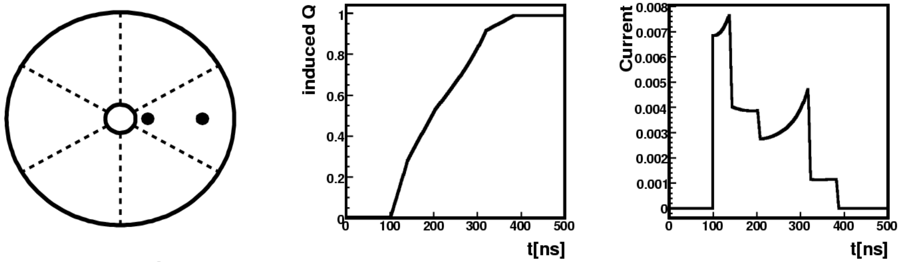
(PSA)

Single Site Event (SSE):



Knee indicates that one charge carrier reaches electrode and stops drifting

Multi Site Event (MSE):



MSE tends to have more complicated pulse structures.

Expected Background Phase II

- simulation of an array with 21 segmented detectors, 7 strings, each 3 detectors
- simulation carried out with **MaGe** (MajoranaGerda) GEANT4 based framework
- background including segment anti-coincidence

Part	Background contribution [10^{-4} counts/(keV·kg·y)]	
Crystal	18	^{68}Ge main source
Holder	3	
Cabling	18	R&D for new cable
Electronics	5	
Muons	~ 0.1	including muon veto
Neutrons	~ 0.1	external n negligible
Total	~ 44	

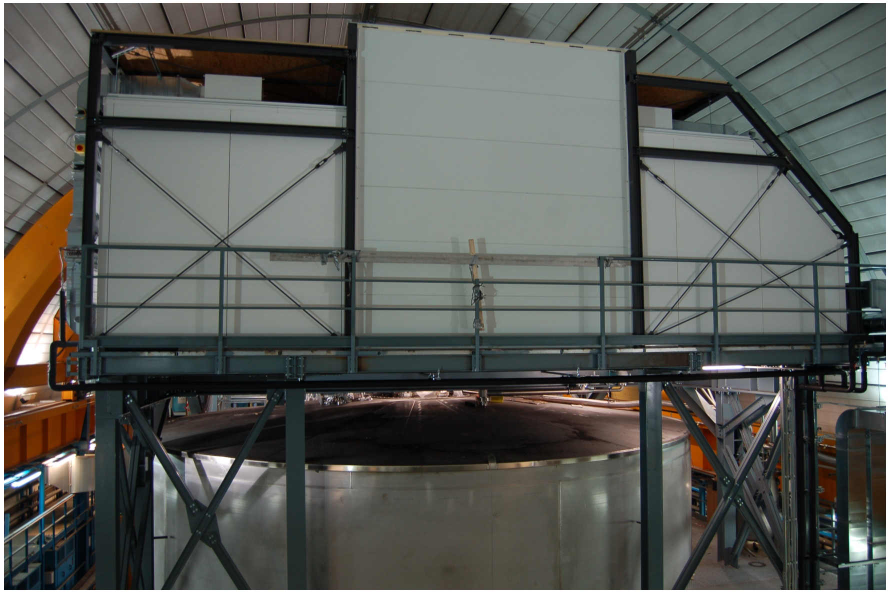
- More recent, more detailed simulation of realistic array yields comparable values

Current Status - Cryostat & Watertank finished

Cryostat
March 2008

Watertank and Superstructure
August 2008

Current Status - Cleanroom & Cherenkov Veto finished

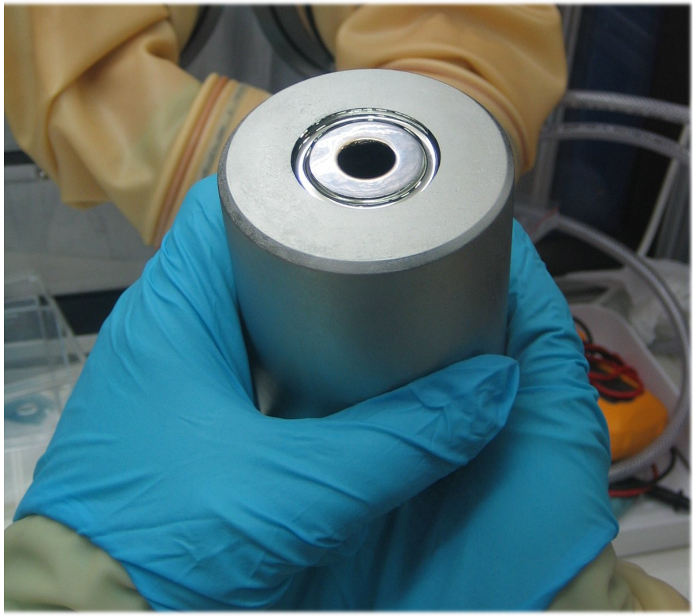


Clean room
May 2009

mounting of PMTs in water tank
August 2009

Current Status - Detectors

Phase I detectors: p-type coaxial detectors



Total of 17.9kg enriched Ge

- well tested procedures for detector handling
- all detectors reprocessed and tested in LAr
- FWHM (1.33MeV) ~ 2.5 keV
- leakage current stable

Phase II Detector R&D

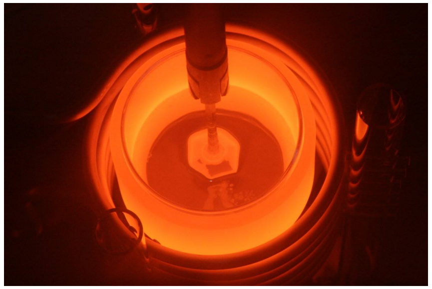
Enriched Germanium:

- 37.5 kg of enriched Ge (86% ^{76}Ge) bought by MPI Munich, currently stored underground

Germanium Purification @ PPM Pure Metals:

- no isotopic dilution
- total yield(6N) 88%
- total exposure @ sea level < 3 days / purification

Crystal Growing:



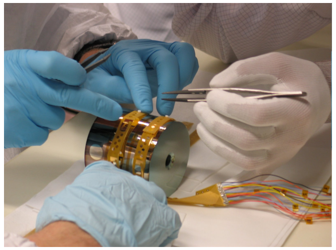
- first natural Ge crystals pulled from 6N material with Czochralski method by the Institut für Kristallzüchtung (IKZ) in Berlin
- impurity density $|N_D - N_A| \sim 10^{11} - 10^{13}$ cm^{-3} (10^{10} cm^{-3} needed)
  - main problem is As, needs to be reduced

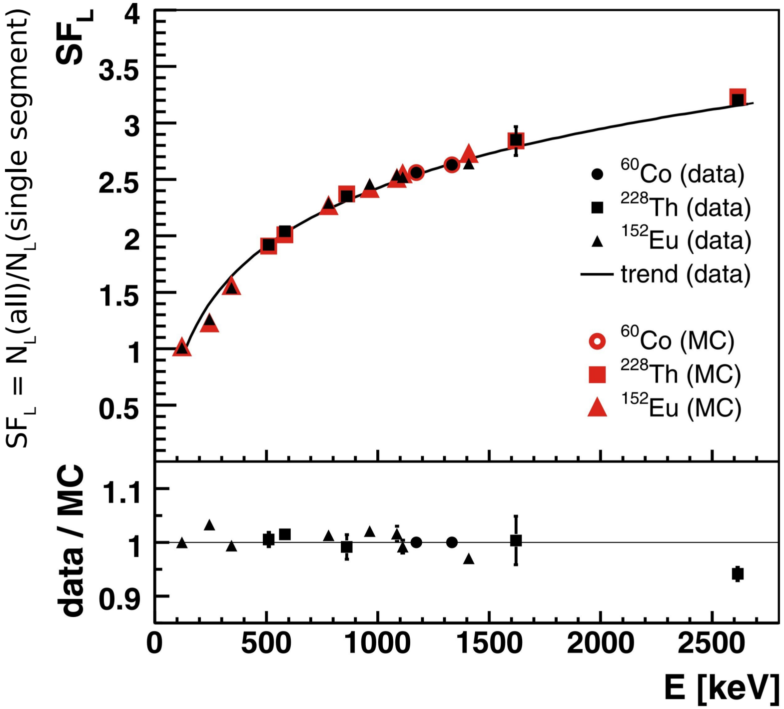
Phase II Detector R&D

Detectors:

- first true coaxial, n-type, 3x6 fold segmented, detector with low mass contacting scheme succesfully tested **in vacuum**

(Abt et al, NIM A 577 (2007) 574)



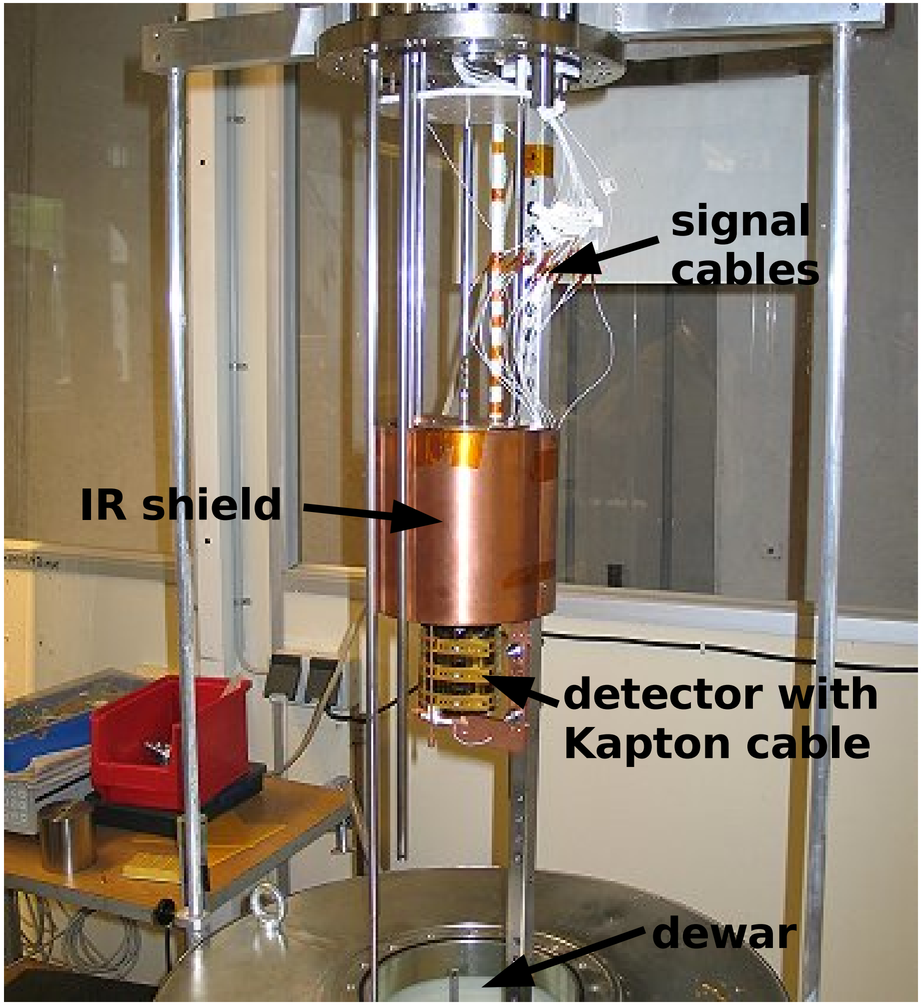


FWHM(1.33MeV) 3keV, core and segments

suppression factors due to **segment anti-coincidence** as **estimated** from MC

- low mass holder, little high-Z material
  19g Cu, 7g PTFE, 2.5g Kapton per 1.62kg detector

Phase II Detector R&D



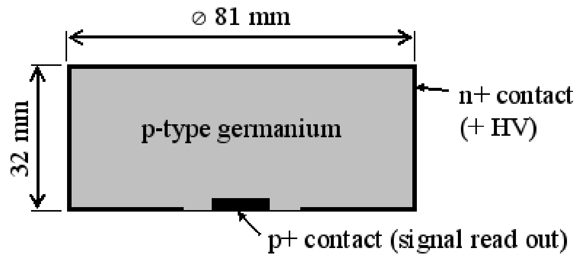
- second 3x6 fold n-type detector operated **in liquid N**
- contacting scheme functioning
- cable and component (placement) not optimized for resolution

FWHM(1.33MeV)
Core: 4-5keV
Segments: 3.5-6keV

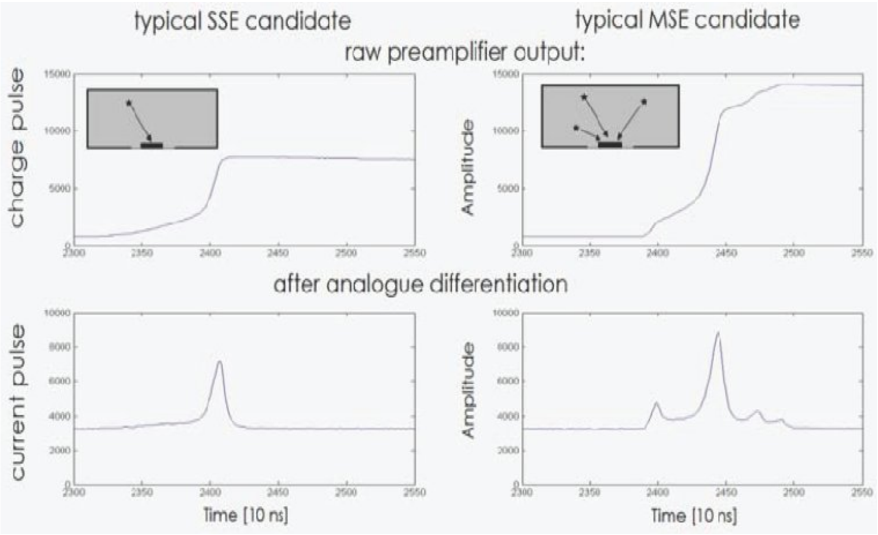
- operation stable for 5 month
- leakage current 30±5 pA
- test in liquid argon are ongoing

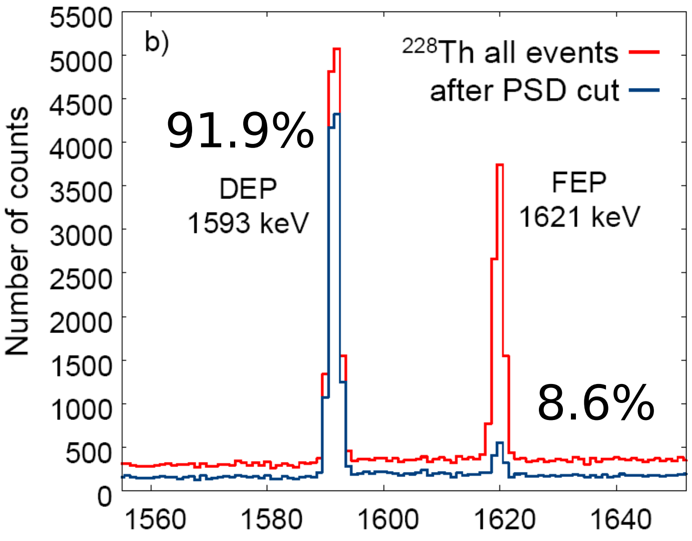
Phase II Detector R&D

- p-type unsegmented Broad Energy (BE)Ge detector



- potential of powerful PSA





Budjas *et al*, submitted to JINST
August 2009

- no charge collection inefficency

- BEGe mass production and yield under investigation with Canberra

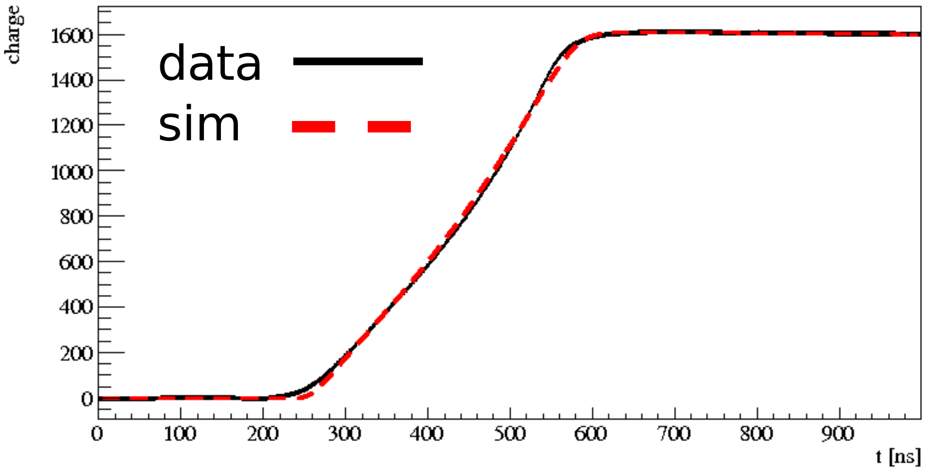
R&D Pulse Shape Simulation

- needed to fully understand PSA recognition and rejection efficiencies
- gives inside into crystal properties
- helps reconstructing interaction positions
  - input:

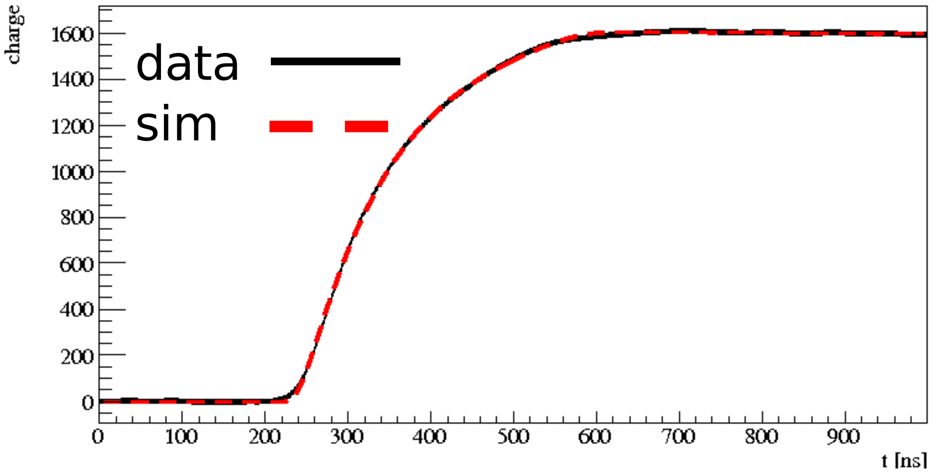
impurity density distribution $\rho \Rightarrow$ EField
different for each crystal

crystal axis orientation
different for each crystal

drift model for charge carrier
same for all crystals

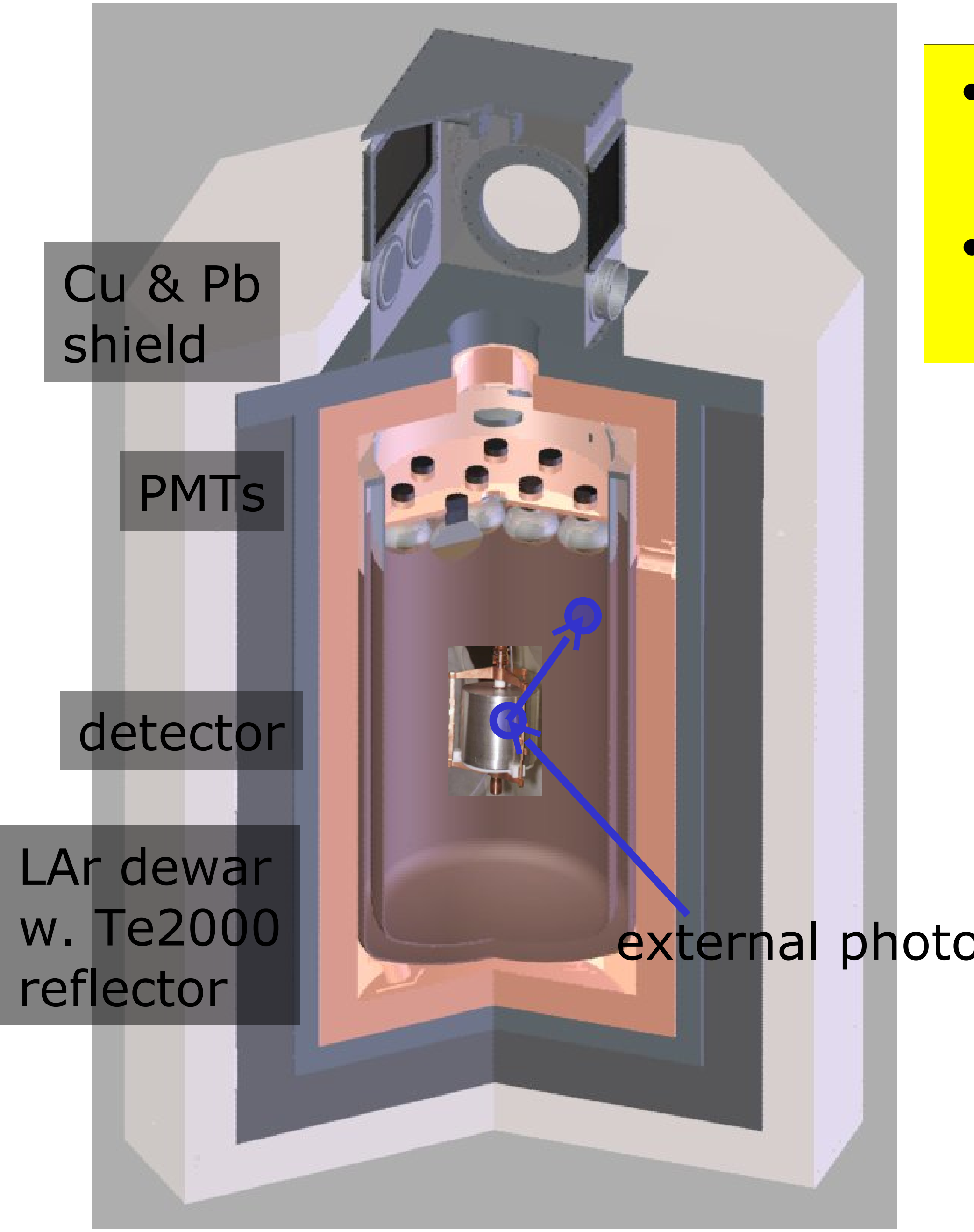


core electrode

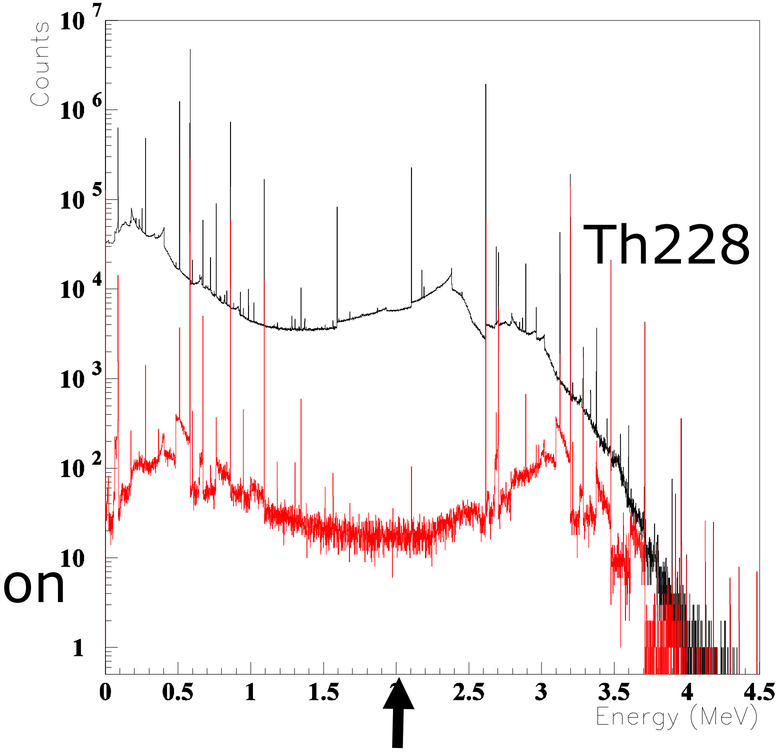


segment electrode

R&D LArGe (liquid argon scintillation veto)



- veto background by tagging extra energy in LAr
- proof of principal
  P. Peiffer *et al.*, Nucl. Phys. B. Proc. Supp. **143** (2005) 511



MC: factor 300 reduction in ROI

Summary and Outlook

- Construction started and is ongoing
- **Phase I:**
  - Phase I detectors refurbished and ready
  - Reach 10^{-2} cts/(keV kg y)
  - Test neutrinoless double beta decay claim
- Parallel R&D for **Phase II:**
  - Reach 10^{-3} cts/(keV kg y)
  - Test $T_{1/2} \geq 1.35 \bullet 10^{26}$ y
  - Rich R&D program
    - n-type segmented detector working in lN2
    - p-type unsegmented detector strong PSA
- Apparatus commissioning will start this year

Summary and Outlook

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  - Rich R&D program
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Stay tuned!

GERDA Collaboration

- Jagellonian University, Cracow Poland
- Technische Universität Dresden, Germany
- Joint Institute for Nuclear Research, Dubna Russia
- Institute for Reference Materials and Measurements, Geel Belgium
- Max-Planck-Institut für Kernphysik, Heidelberg Germany
- Institute for Nuclear Research of the Russian Academy of Sciences, Moscow Russia
- Institute for Theoretical and Experimental Physics, Moscow Russia
- Russian Research Center Kurchatov Insitute, Moscow Russia
- Gran Sasso National Laboratory, Assergi Italy
- Universita Milano Bicocca and INFN, Italy
- Max-Planck-Institut für Physik, Munich Germany
- Universita di Padova and INFN, Italy
- Eberhard Karls University, Tübingen Germany
- University of Zürich, Switzerland