The GERDA Experiment:

a search for neutrinoless double beta decay

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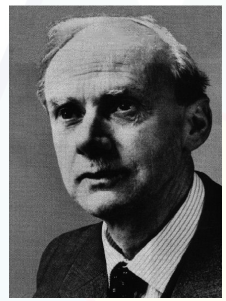
GERDA

Outline:

- Motivation for Search for $0\nu\beta\beta$
- Double Beta Decay and Experimental Signatures
- GERDA Goals and Concept
- Current Status
- Summary

Motivation

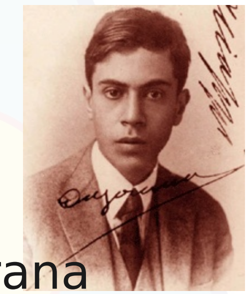
- **GER**manium **D**etector **A**rray (GERDA) experiment built to search for neutrinoless double beta decay ($0\nu\beta\beta$) of ^{76}Ge
- $0\nu\beta\beta$ is the only experimentally feasible way to unveil the nature of neutrinos



Dirac

or

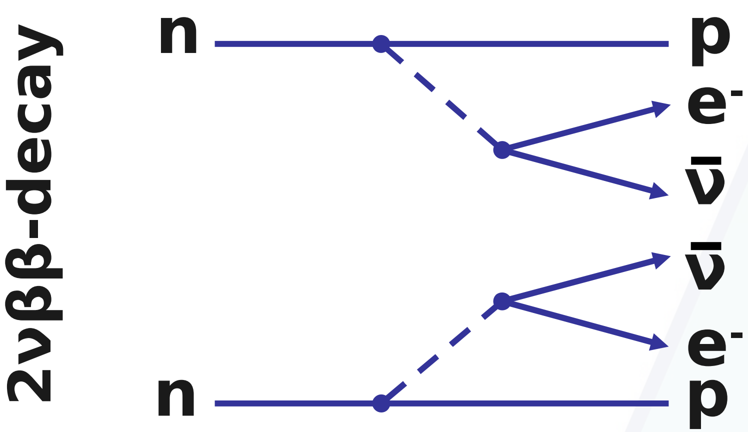
Majorana



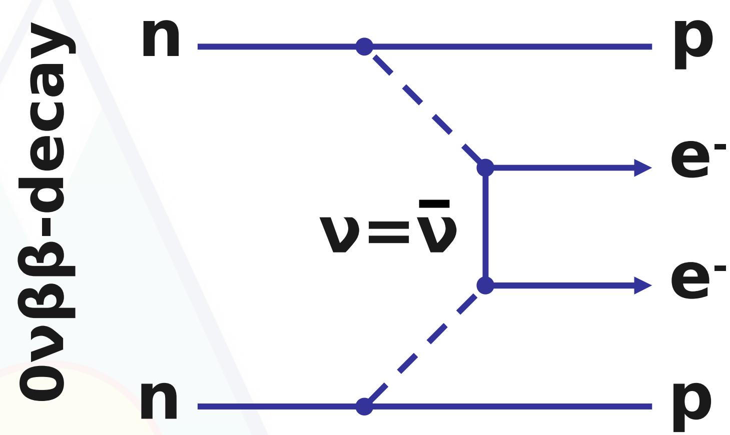
$\nu \neq \bar{\nu}$ $\quad\quad$ $\nu = \bar{\nu}$

- If $0\nu\beta\beta$ observed:
  - lepton number violation $\Delta L = 2$
  - neutrino is Majorana type — **Schechter-Valle theorem** (Phys. Rev. D (1982) 25, 2951)
  - type I seesaw mechanism $m_\nu = \frac{m_D^2}{M_R} << m_D$
  - possible to determine absolute neutrino mass scale
  - possible to determine neutrino hierarchy

What is $\beta\beta$ Decay



- allowed process
- observed for several isotopes
- $T_{1/2} \sim O(10^{20})$ y



- forbidden process in SM, needs Majorana neutrino
- $T_{1/2}(^{76}Ge) \geq 1.9 \cdot 10^{25}$ y (90% C.L.)

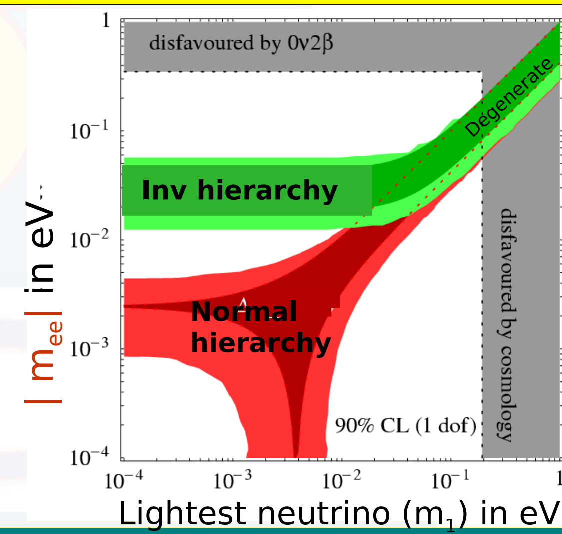
  Eur. Phys. J. A12, 147-154 (2001)
- claim of signal from parts of HdM

  NIM A 522 (2004) 371-406

effective Majorana neutrino mass:

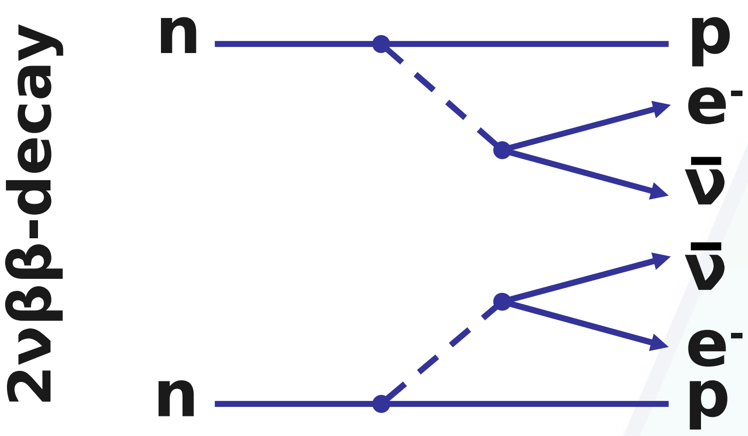
$$|m_{ee}| = |\sum_j m_j U_{ej}^2|$$

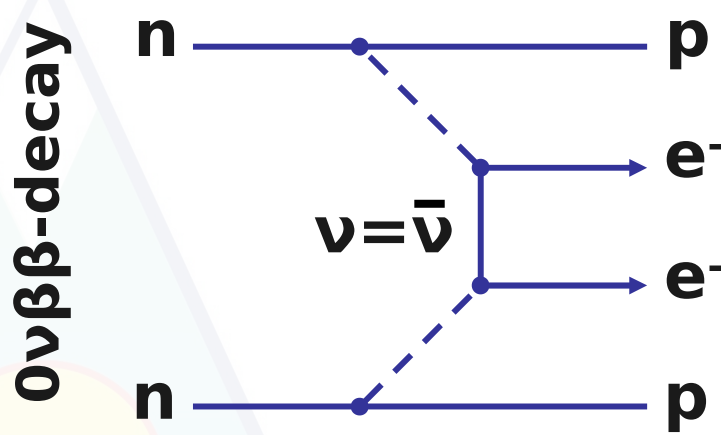
$$T_{1/2} \propto |m_{ee}|^{-2}$$



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

Experimental Signature





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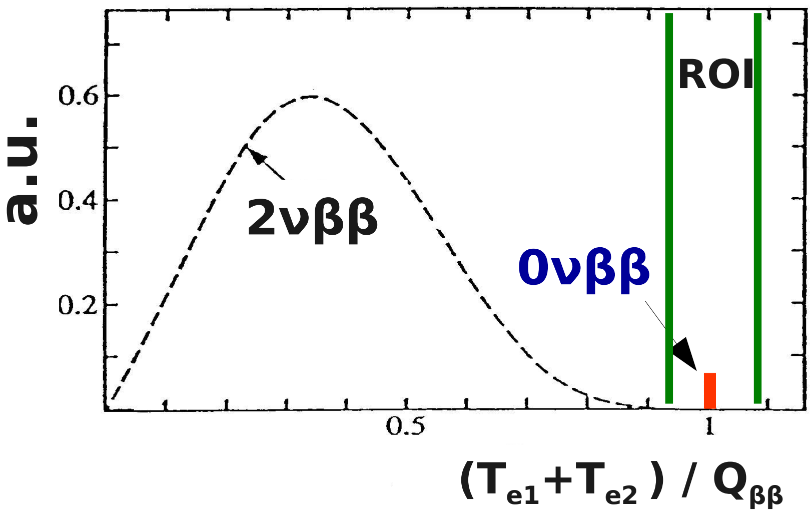

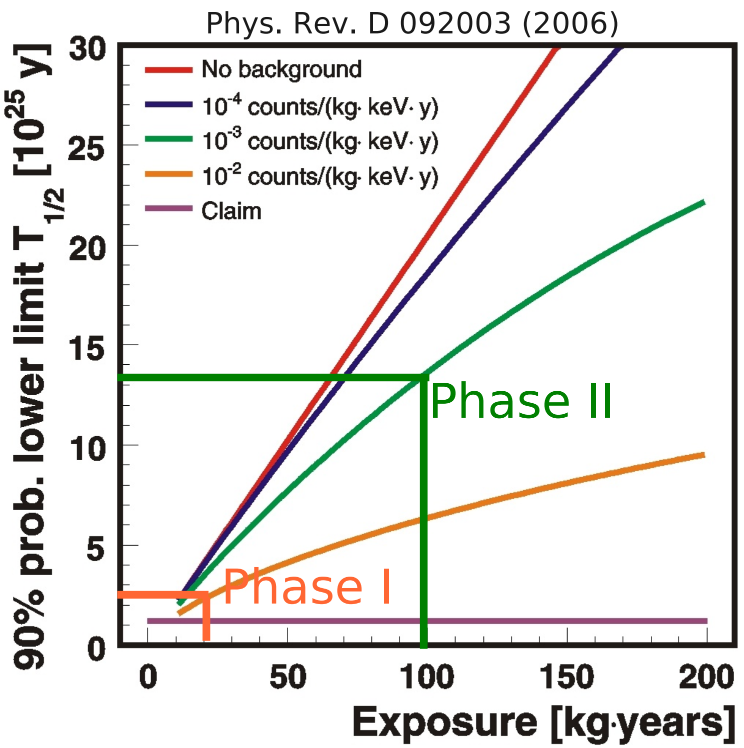

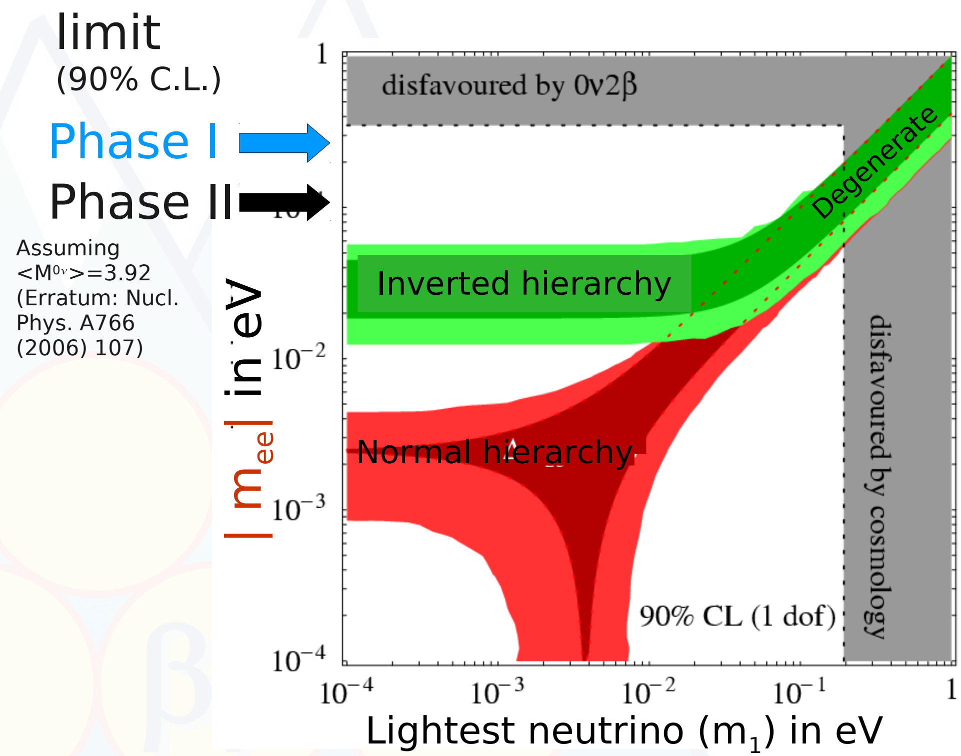

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A. Strumia,
F. Vissani,
NPB 637

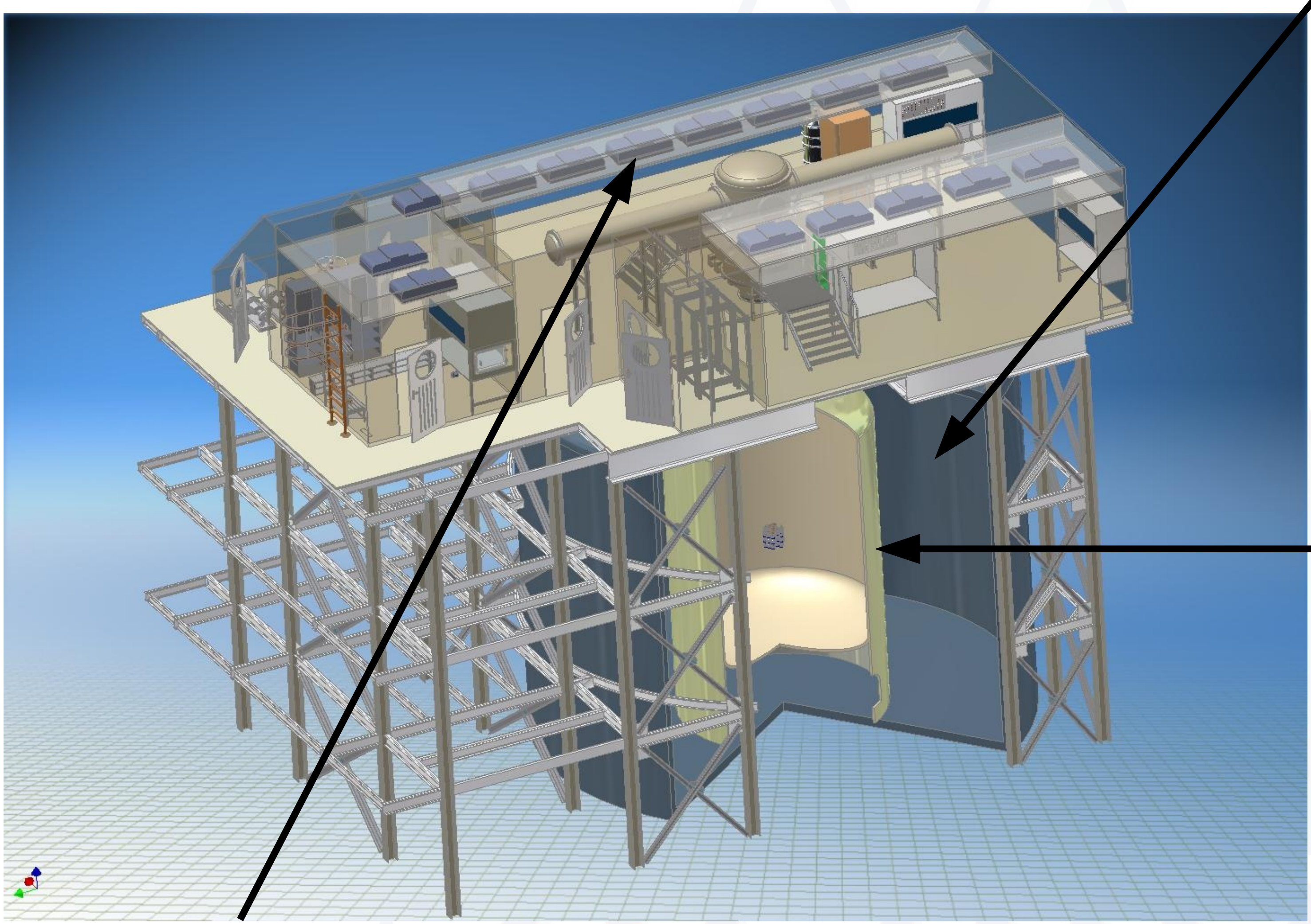
Phase I:
- operate existing ^{76}Ge detectors from HdM and IGEX + natGe Diodes
- reach background of 10^{-2} cts/(keV kg y)
- exposure of ~ 15kg y, **check claim**

Phase II:
- operate **new** ^{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: 1/10 < HdM

GERDA Concept

LNGS: ⇧ **3400 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**

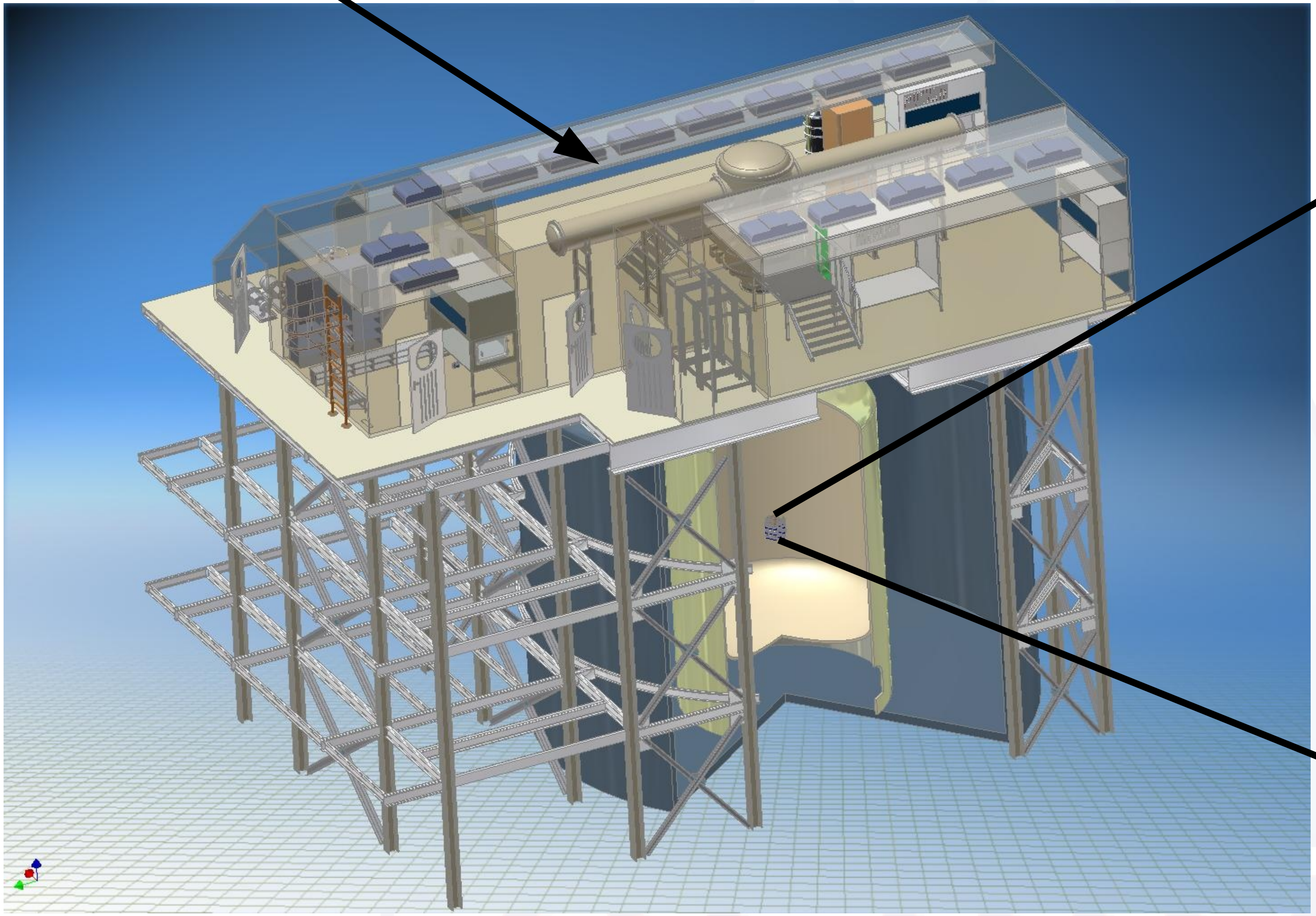
acts as:

- shielding medium
- cooling medium

Plastic scintillators on top as muon veto

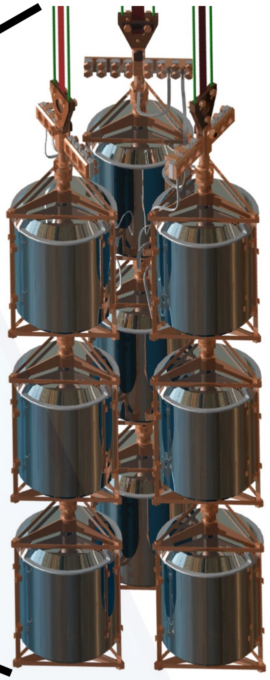
GERDA Concept

Clean room: Class 10.000

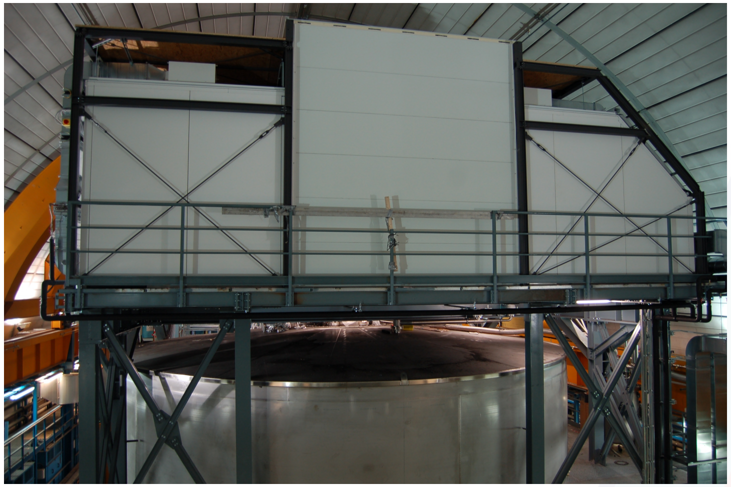


Detector array:

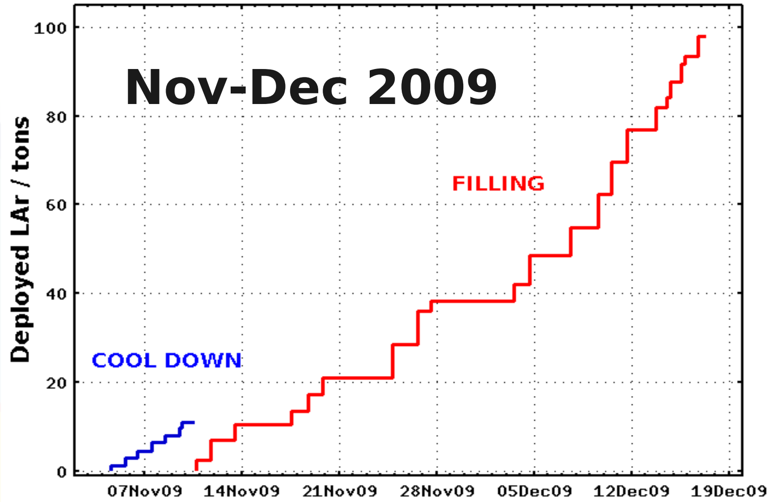
- 3 detectors per string
- up to 16 strings



Status



cryostat filled since Dec. 17
active cooling prevents evaporation



watertank filled for emergency drainage test

November 2009

first cable arm installed, full installation can hold all Phase I detectors

gas and cryo Infrastructure is in place and operational

March 2010

DAQ installed

First non-enriched detector string to be lowered soon

Status

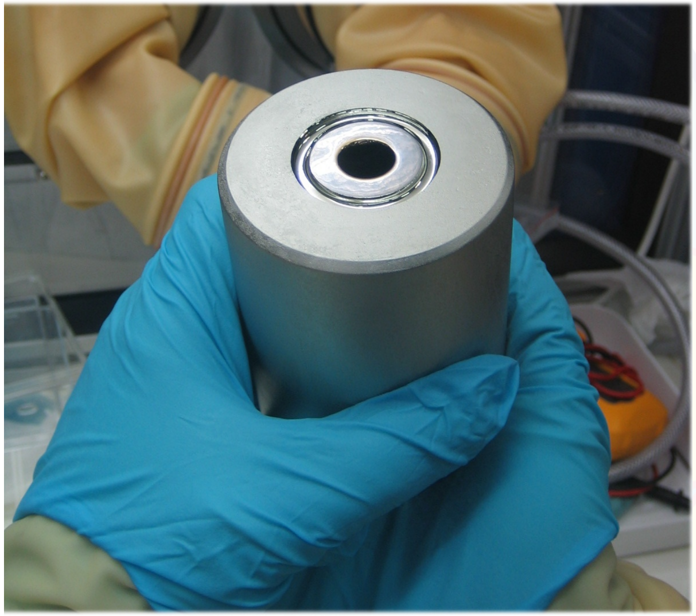
- Cherenkov muon veto **installation finished** August 2009

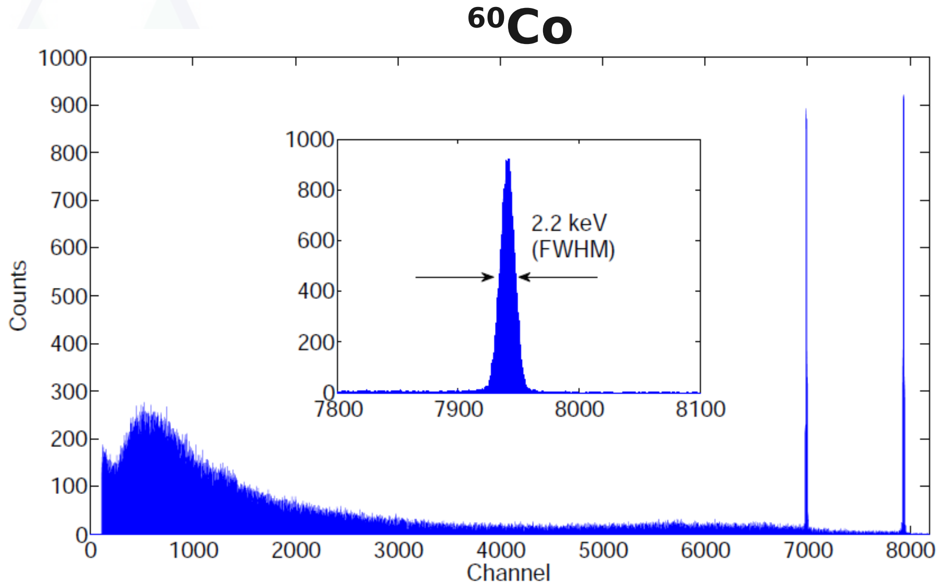
March 2010:

- test of PMTs in tank, readout with DAQ, muon candidates
- light from diffusorballs visible everywhere
- 2 problematic PMTs: 1 exchanged, 1 cable problem
- Cherenkov veto in good shape

Status

Phase I detectors: p-type coaxial detectors



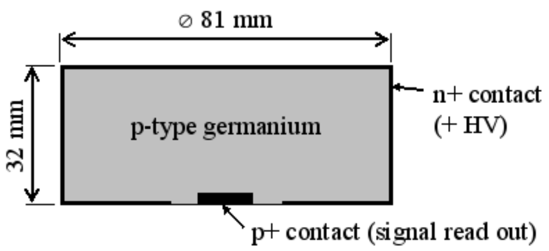


- well tested procedures for detector handling
- all detectors reprocessed and tested in LAr
- FWHM (1.33MeV) ~ 2.5 keV
- leakage current stable

Phase II Detector R&D

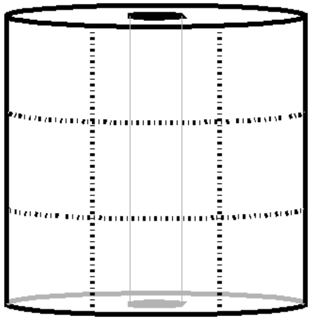
Germanium:
- 37.5 kg of enriched Ge (86% ^{76}Ge) bought by MPI Munich
- Purification PPM Pure Metals **finished** end of April, 35.45 kg 6N material, **94% yield** reached
- only **5.2 days integrated exposure** above ground

BEGe



- succesfull production of 2 p-type BEGes in full production chain from depleted germanium

Segmented



- production of n-type crystals at IKZ Berlin
- impurity density $|N_D - N_A| \sim 10^{12}$ cm^{-3} (10^{10} cm^{-3} needed)

- prototypes sucessfully tested in lAr
- pulse shape analysis & simulation in place

Summary & Outlook

GERDA experiment is in commissioning phase

First non-enriched detector string to be lowered soon

Phase I:

Detectors refurbished and ready

Reach background index 10^{-2} cts/(keV kg y)

Test neutrinoless double beta decay claim

Phase II:

Germanium purified, 35.45kg 6N material

R&D towards Phase II detectors ongoing

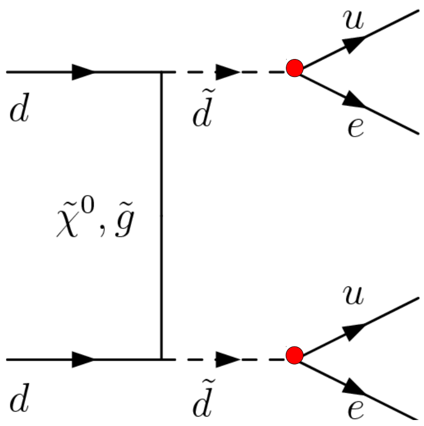
Reach background index 10^{-3} cts/(keV kg y)

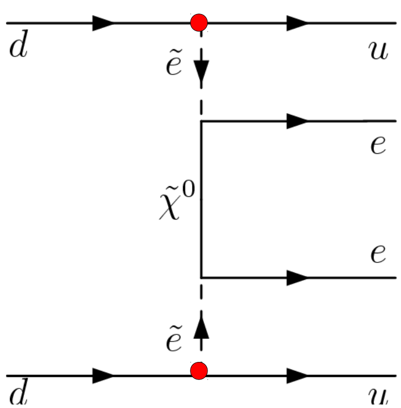
Extras – GERDA Collaboration

- 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

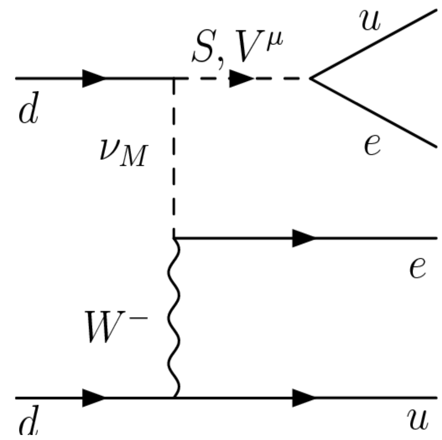
Other Possibilities of $0\nu\beta\beta$

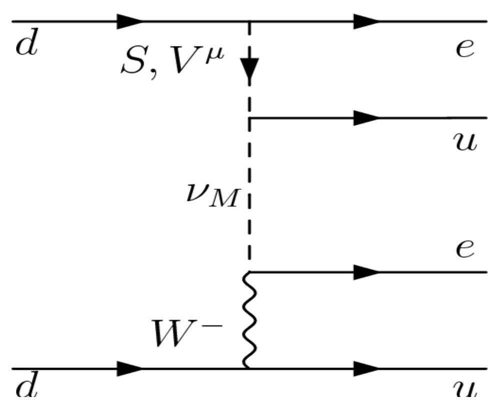
R-Parity violation SUSY:





Leptoquarks:





Even more:

- Theories allowing for right handed currents
- Compositness
- Heavy Majorana neutrino exchange

Strongest bounds on λ'_{111} from $0\nu\beta\beta$

e.g. Physics Reports 420: 1-202, 2005

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

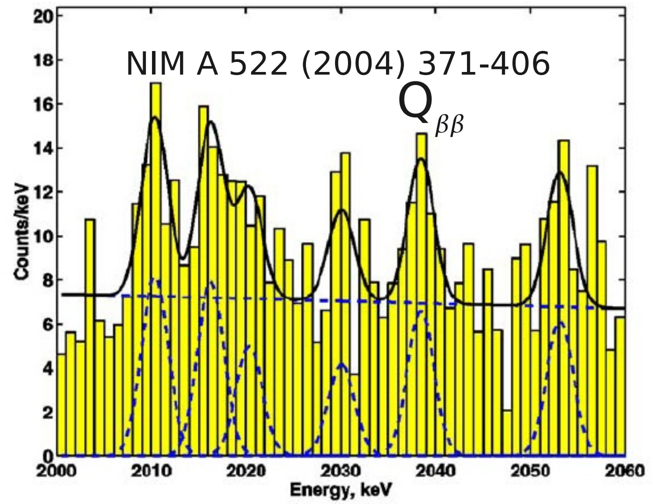
IGEX:

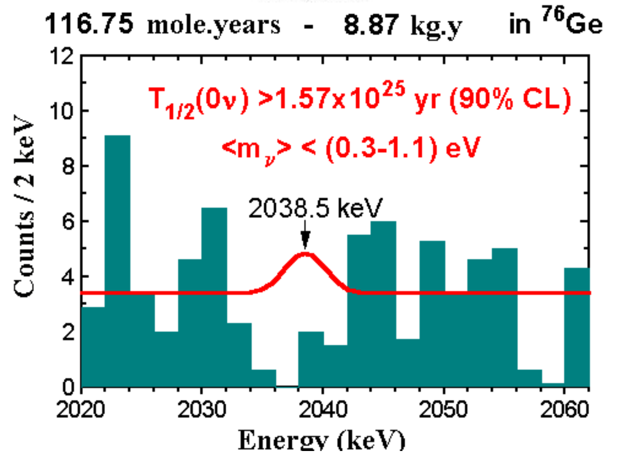
- 3 enriched Ge p-type crystals
- $T_{1/2} \geq 1.57 \cdot 10^{25}$ y (90% C.L.) 8.87 kg y

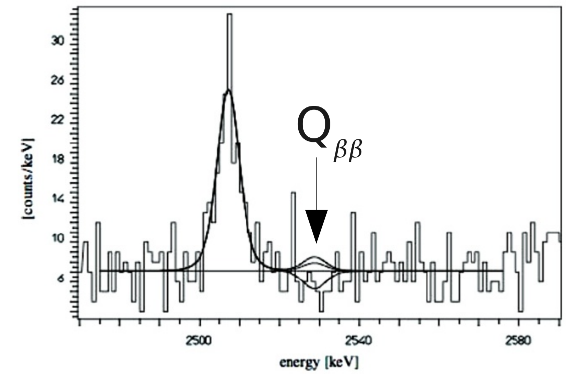
NP B (Proc.Suppl.) 87 (2000) 278

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

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

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%

Background

Background: processes which cause energy deposition inside Region Of Interest

- **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)

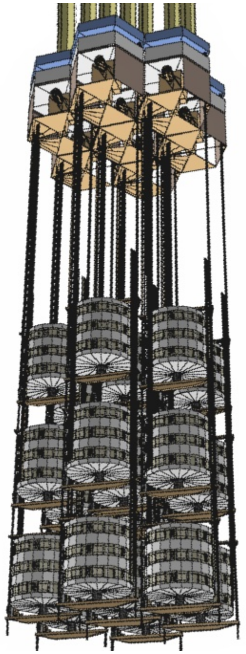
around $Q_{\beta\beta}$

total mass

measuring time

Expected Background Phase II

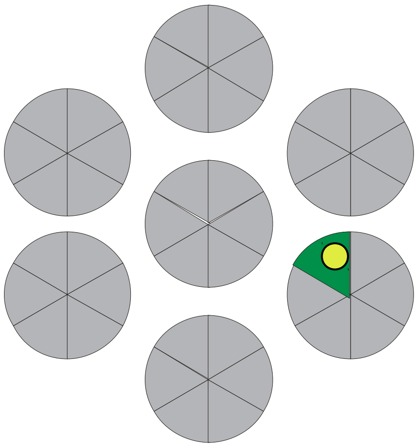
- simulation of an array with 21 segmented detectors, 7 strings, each 3 detectors
- simulation carried out with **MaGe** (MajoranaGerda) GEANT4 based framework
- background including segment anti-coincidence



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	

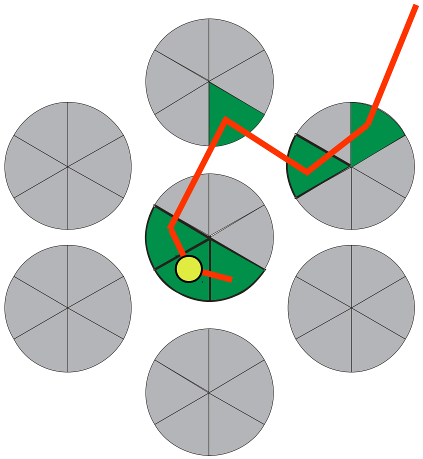
Anti-Coincidences:

Signal:



Single Site Event (SSE)

Background:



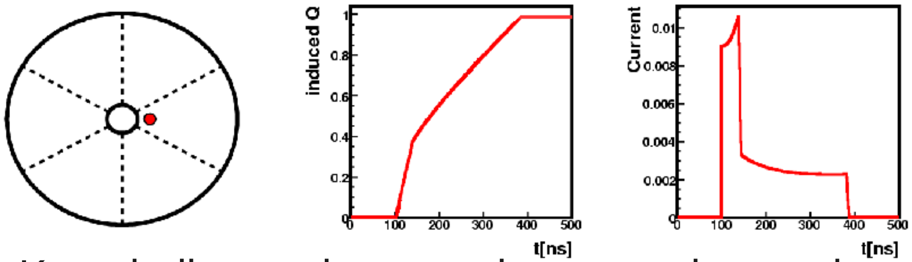
Multi Site Event (MSE)

- 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

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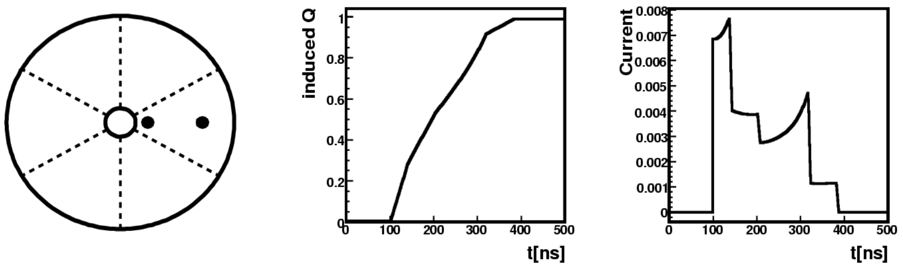
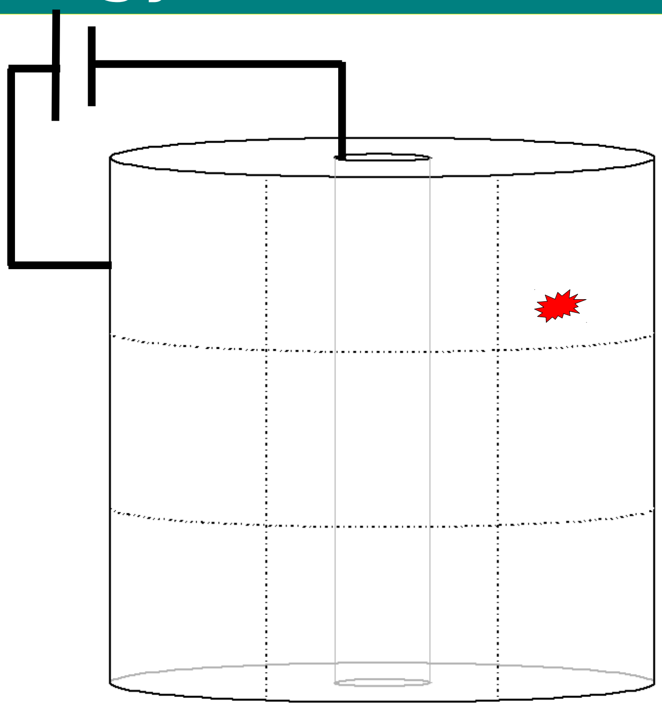


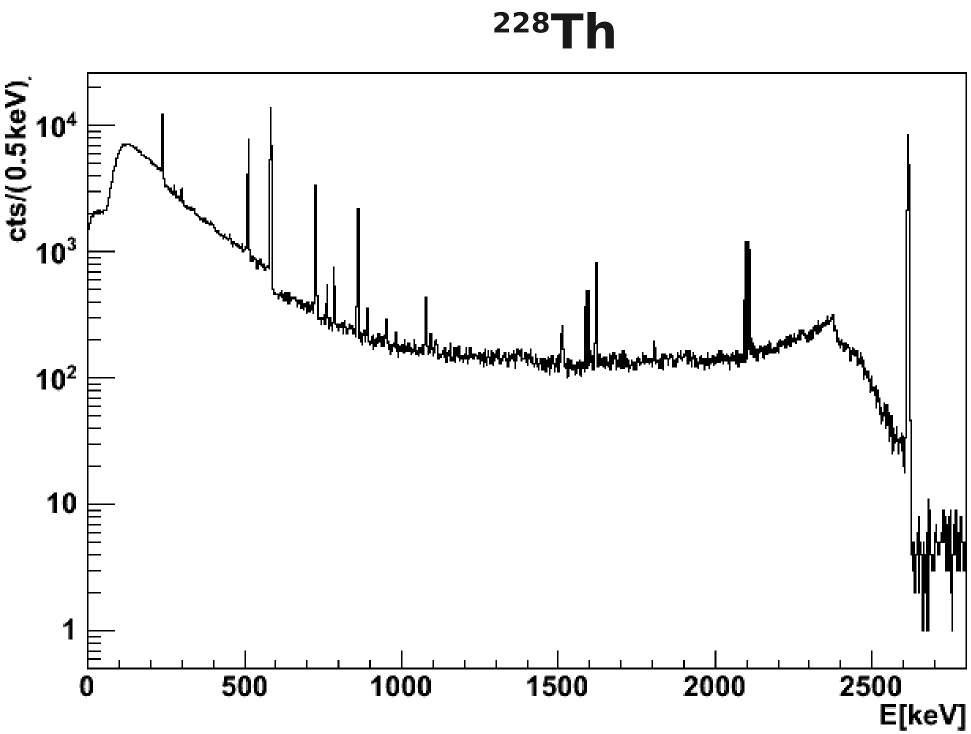
MSE tends to have more complicated pulse structures.

- up to factor 2 better background recognition for certain backgrounds

Energy Measurement



- **energy deposit** ⇒ electrons and holes created
- charges **drift** under influence of **E-Field**
- drifting charges **induce pulses** on electrodes



- excellent energy resolution
  FWHM($Q_{\beta\beta}$) < 5keV   ΔE/E <0.2%