Semiconductor-based experiments for $0\nu\beta\beta$ decay search

Marik Barnabé Heider, MPIK Heidelberg
for the GERDA collaboration

XXIV International Conference on Neutrino Physics and Astrophysics
Athens, Greece, June 14-19 2010

Outline

1. **Semiconductor technology for the search of 0νββ decay**

2. **The COBRA experiment (CdZnTe detectors)**

3. **Germanium detector experiments**
   - **MAJORANA**
   - **GERDA**

1. **Semiconductor technology for the search of $0\nu\beta\beta$ decay**

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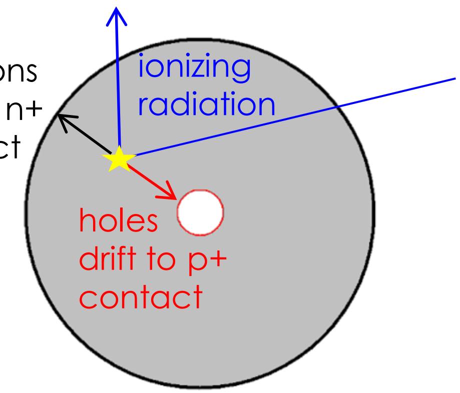
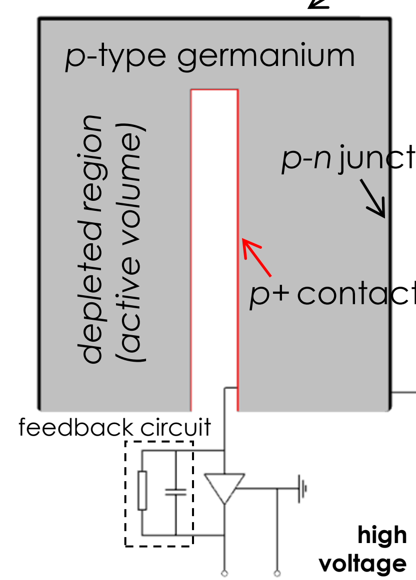
Semiconductor detectors

Advantages for 0νββ decay search:

- detector-grade semiconductors are high-purity materials (low background)
- very good detection efficiency due to: detectors made of source material
- established detector technologies ⇒ industrial support
- very good energy resolution: ~2-3 keV for Ge (~15-20 keV for CdZnTe)





germanium detector operating principle (CZT principle similar)

COBRA: CdZnTe detectors

Room temperature operation

Coplanar grid detector

GERDA&MAJORANA: Ge det.

Cryogenic operation

Coaxial p-type detector

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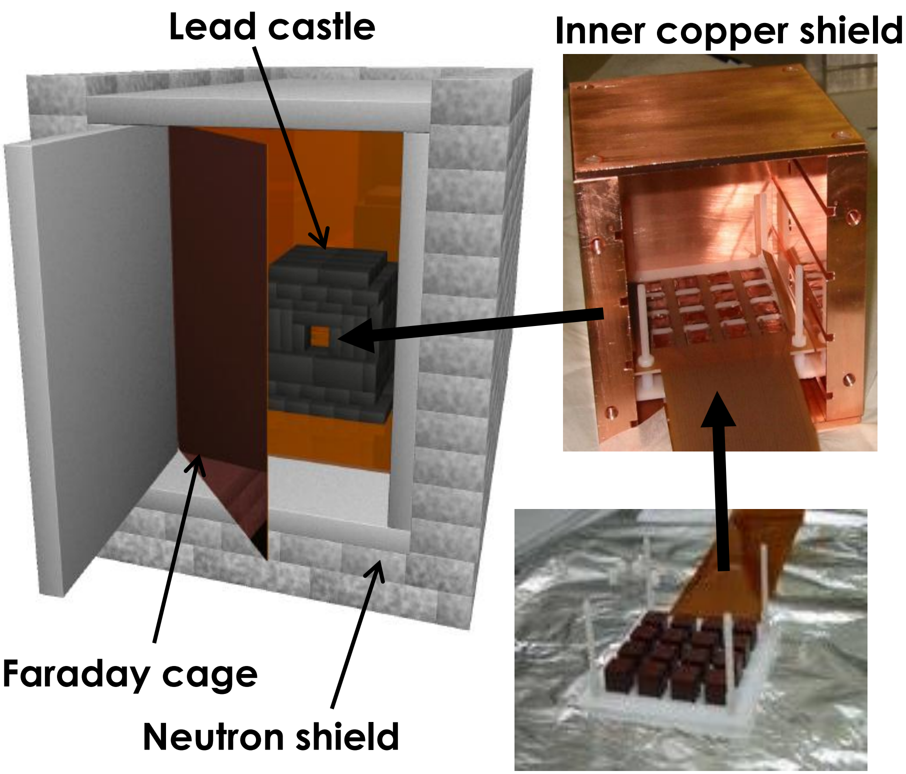
   - MAJORANA
   - GERDA

COBRA

K. Zuber, Phys. Lett. B 519,1 (2001)

- CdZnTe detectors
- Most promising ^{116}Cd, $Q_{\beta\beta}$=2809 keV

COBRA Setup at LNGS

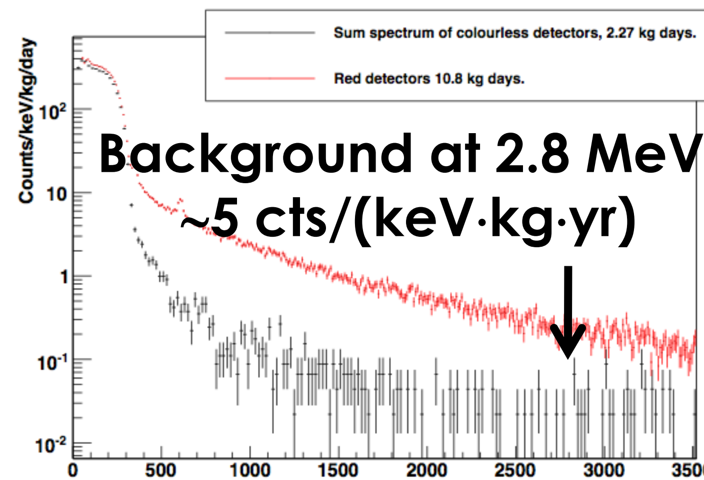


1st layer, 16 x 1 cm^3 crystals, ~6.5 g each

- 1st layer of 16 crystals
  - FWHM 3.5% - 8.5% @ 2.8 MeV
  - stopped end of 2008
  - exposure18 kg*days
- Physics results on ^{113}Cd & DBD limits:

J.V. Dawson et al., Nucl. Phys. A 818, 264 (2009), Phys. Rev. C 80,025502 (2009)

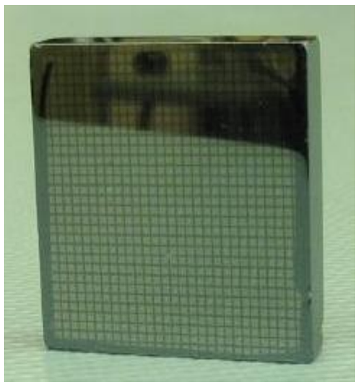
- **Upgrade to 64 detectors in near future**

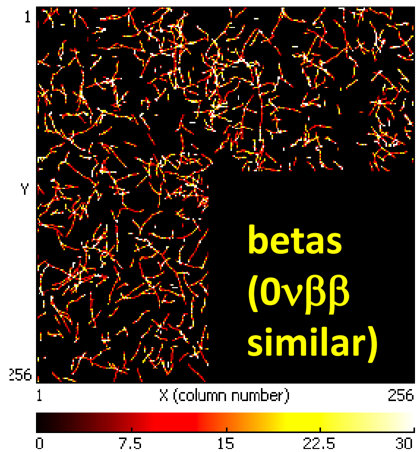


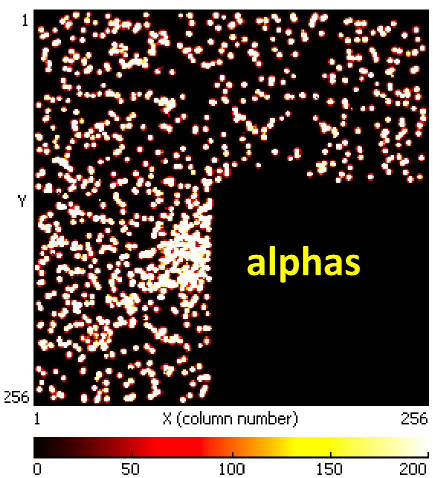
COBRA: outlook

R&D: Detector pixelisation to reduce background

1) Energy and tracking: solid-state TPC





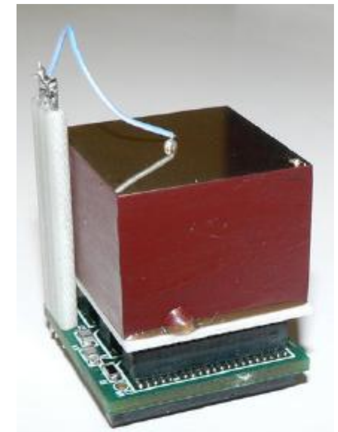


Particle identification: 55 µm pixel size

⇒ **Rejection of alphas, muons**

2) Fiducial cut

20x20x15 mm^3 detector (11x11 pixel, 36 grams)



In collaboration with Zhong He (UMichigan)

- Fiducial cut excludes edge pixels
- No low background tuning
- Running at LNGS Sep 09-Jan 10 → no event in peak range at 2809 keV in 124 days

see poster 85

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2. **The COBRA experiment (CdZnTe detectors)**

3. **Germanium detector experiments**
   - **MAJORANA**
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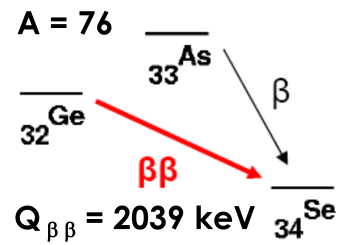
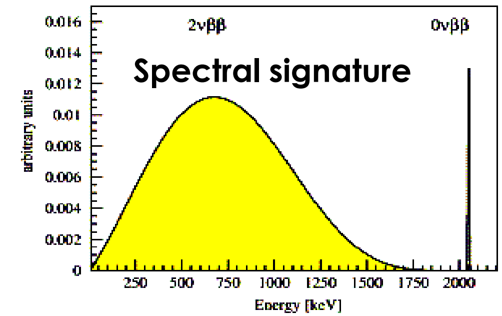
Search for the half-life of $0\nu\beta\beta$ decay of ^{76}Ge

- Enrichment in ^{76}Ge to ~87%
- Best limits on $0\nu\beta\beta$-decay used Ge (IGEX & Heidelberg-Moscow):

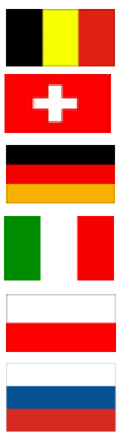
  $T_{1/2} > 1.9 \times 10^{25}$y (90%CL)

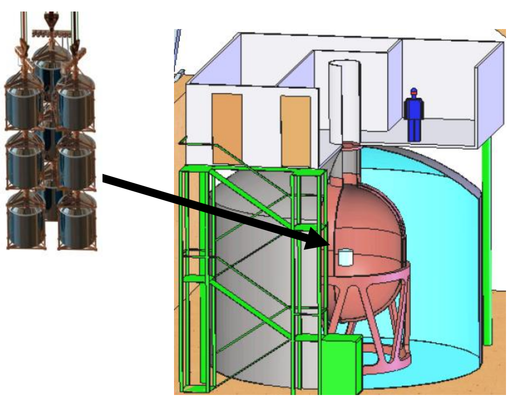
  (& claim for evidence)





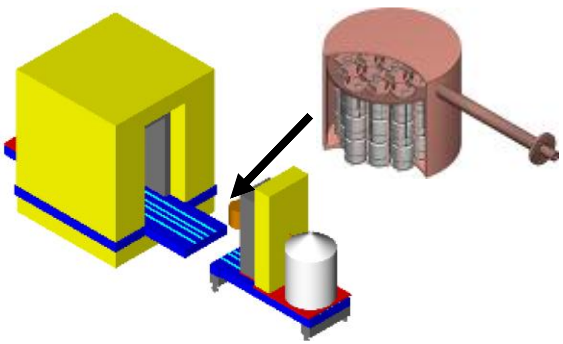
GERDA

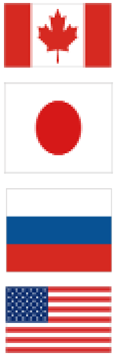




- Bare Ge-diodes array in LAr
- Shield: high-purity LAr/ H_2O

MAJORANA





- Arrays of Ge-diodes in high purity electroformed Cu cryostats
- Shield: electroformed Cu, Pb

Open exchange of knowledge & technologies
Intent to merge for a ton scale experiment

Marik Barnabé Heider

MPIK Heidelberg

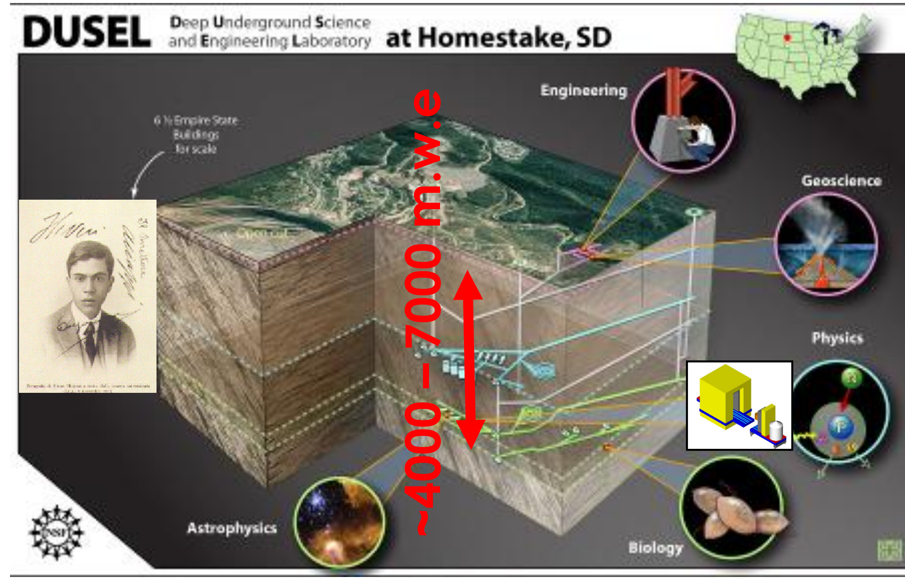
Background reduction

Deep underground sites for suppression of cosmic ray muons

GERDA in Hall A @ LNGS, Italy

Suppression of μ-flux > 10^6

MAJORANA @ DUSEL, USA



Partly funded; under construction

Phase I: B < 10^{-2} cts/(keV · kg · y)

Phase II: B < 10^{-3} cts/(keV · kg · y)

Demonstrator: B ~ 10^{-3} cts/(keV · kg · y)

↘ **Full scale experiment**: B ~ 10^{-4} cts/(keV · kg · y) ↙

⇒ **Background reduction by factor 10^2 - 10^3 relative to past experiments**

Background suppression techniques required for B ≤ 10^{-3} cts/(keV · kg · y)

Standard
- Material cleaning
- Passive shield (Cu & Pb)
- Muon veto

Novel
- Pulse shape analysis
- Array anti-coincidence
- R&D: Segmentation, LAr scintillation

Phases and physics reach

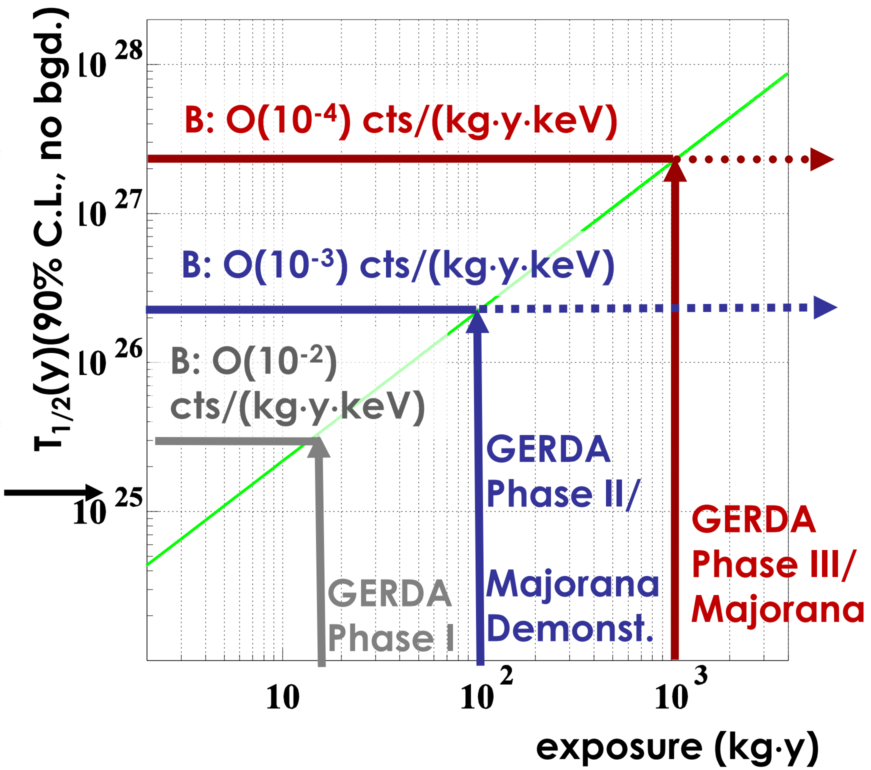
2 ·10^{27} (90 % CL) *

2 ·10^{26} (90 % CL) *

3 ·10^{25} (90 % CL) *

KK

*: no event in ROI



Mass scale:

<24 - 41 meV
⇒ Inverted

<75 - 129 meV
⇒ Degenerate

assuming
$|M^{0\nu}|$=2.99-8.99 †
and 86% enrichment

† [Smolnikov&Grabmayr PRC 81 (2010) 028502]

Exposure:

GERDA

Phase I: 18 kg (HdM/IGEX) for 1 y
Phase II: total ~40 kg ^{enr}Ge for 3 y

MAJORANA

Demonstrator: ~ 30 kg ^{enr}Ge for 3 y

GERDA Phase III & MAJORANA: 1 ton · year

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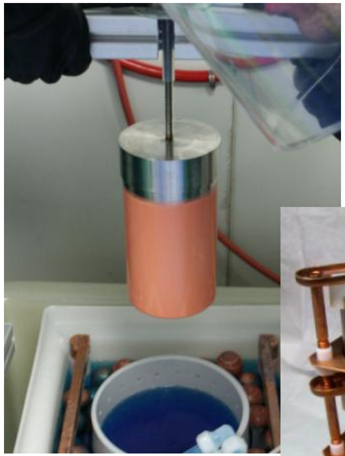
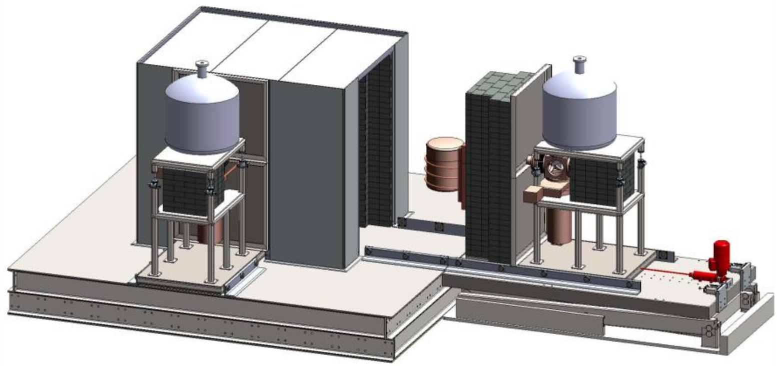
MAJORANA project status

- **Demonstrator** approved for FY 2010-2013
  - 30 kg ^{nat}Ge & 30 kg ^{enr}Ge
  - Running 3 years (90 kg·y) → $T_{1/2} \geq 10^{26}$ y (90% CL))
  - B =10^{-3} cts/(kg·keV·y)
- **Objective**: Demonstrate background low enough to justify building a ton scale Ge experiment
- **Schedule**:
  - Start of Cu electroforming deep underground at DUSEL this year
  - First cryostat with 20 kg of ^{nat}Ge modified BEGe p-type detectors ready in fall 2011





See posters 4, 95 & 120

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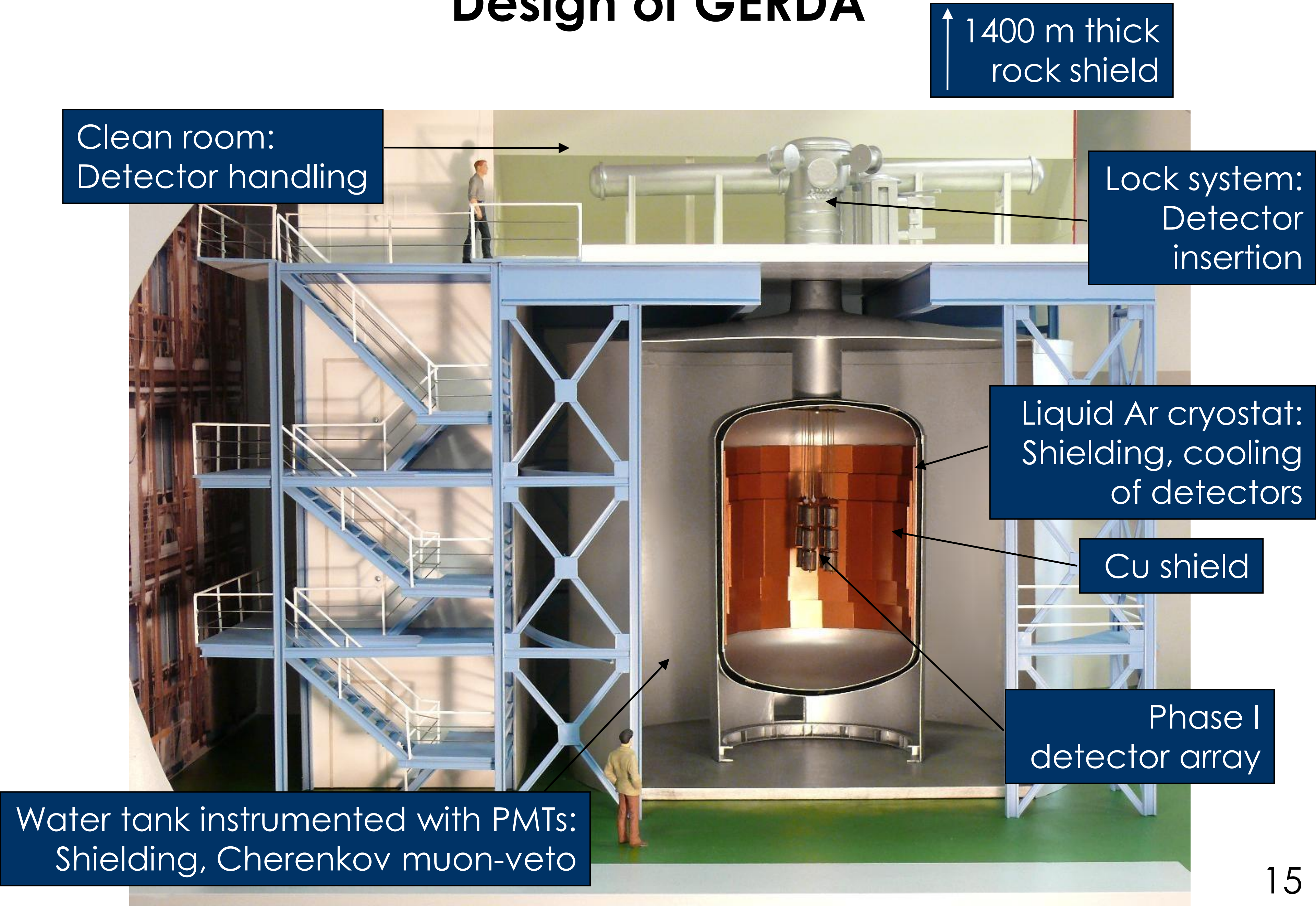
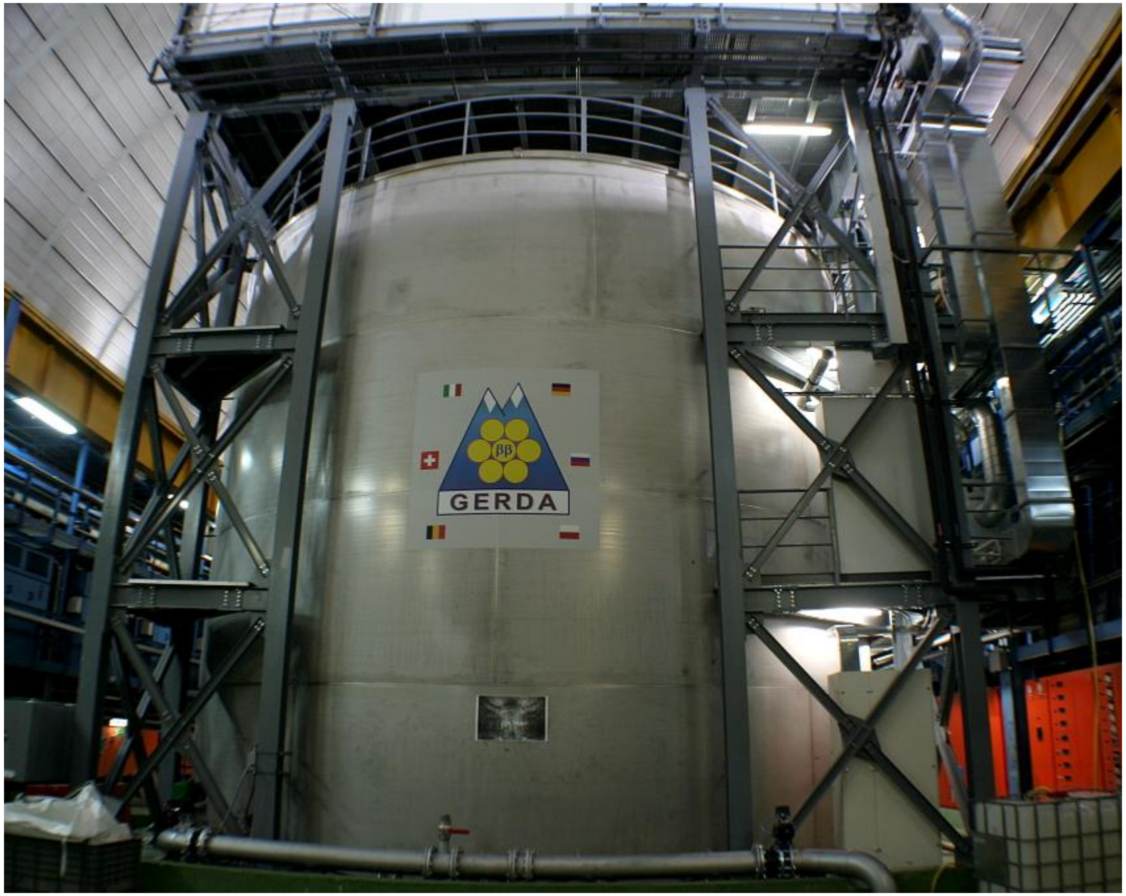
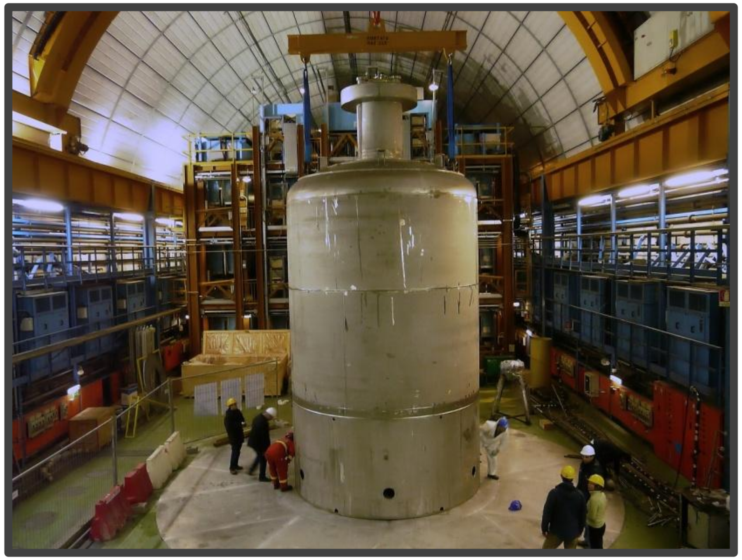
Design of GERDA



GERDA status report

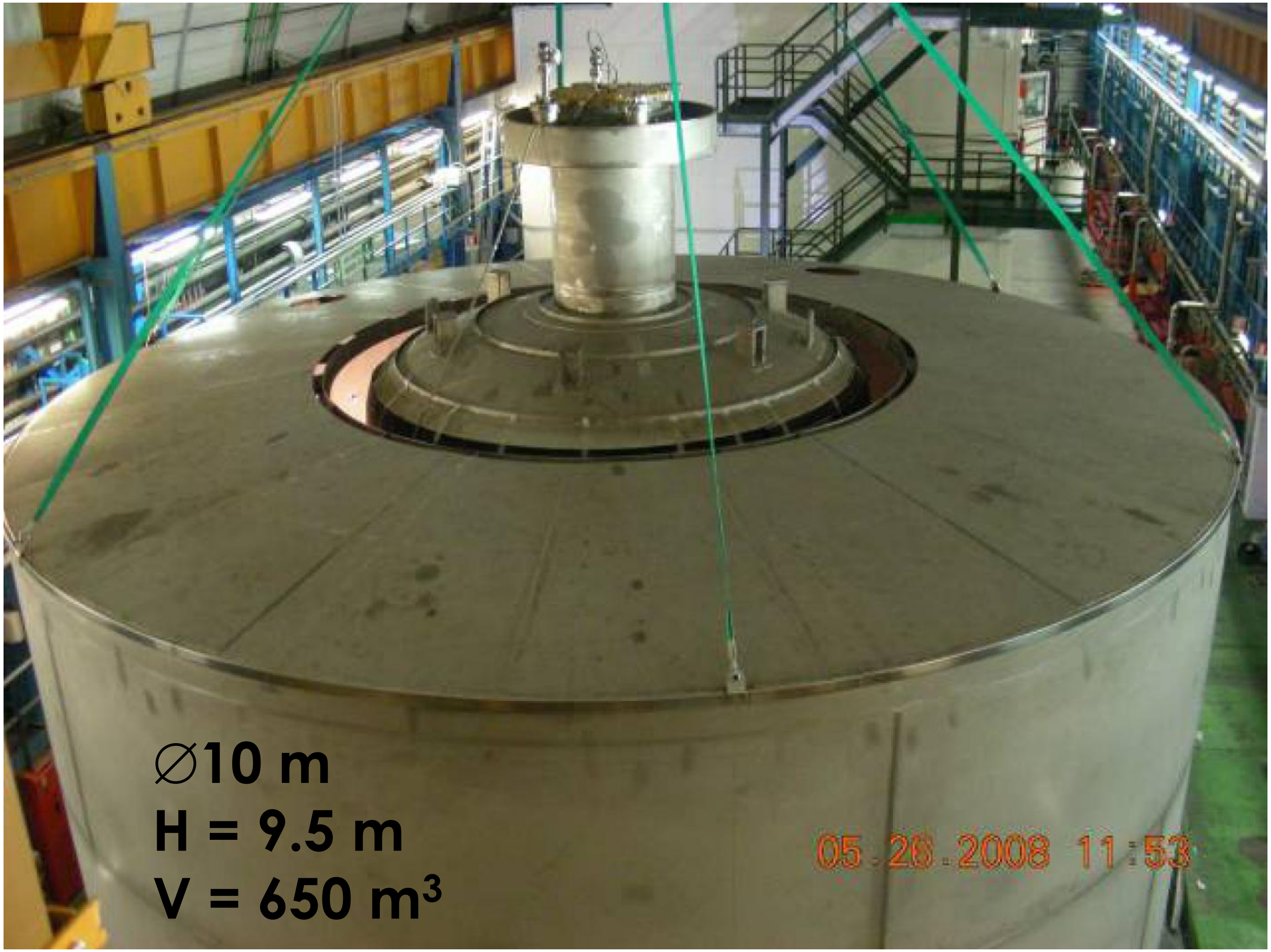


Cryostat installated in Hall A of LNGS – 6th March 2008



Produced from selected low-background austenitic steel

Construction of water tank – May 2008



Designed for external γ,n,μ background ~10^{-4} cts/(keV·kg · y)

Clean room construction – February 2009

Muon veto completed – August 2009

Muon veto completed – August 2009

Phase I detectors

Ge diodes before and after the reprocessing ↕

<u>8 diodes (from HdM, IGEX):</u>

- Enriched 86% in ^{76}Ge
- All diodes reprocessed with new contacts optimized for LAr
- Well tested procedure for detector handling
- Long term stability in LAr established
- All detectors mounted in low-mass holder & tested in LAr
- Energy resolution in LAr: ~2.5 keV (FWHM) @1.3 MeV
- Total mass 17.66 kg

<u>6 diodes from Genius-TF ^{nat}Ge:</u>

- Same reprocessing & testing as enriched diodes
- Total mass: 15.60 kg

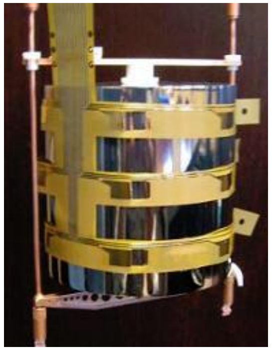
Detector handling under N_2 atmosphere

Low-mass holder and electrical contacts

Phase II detectors

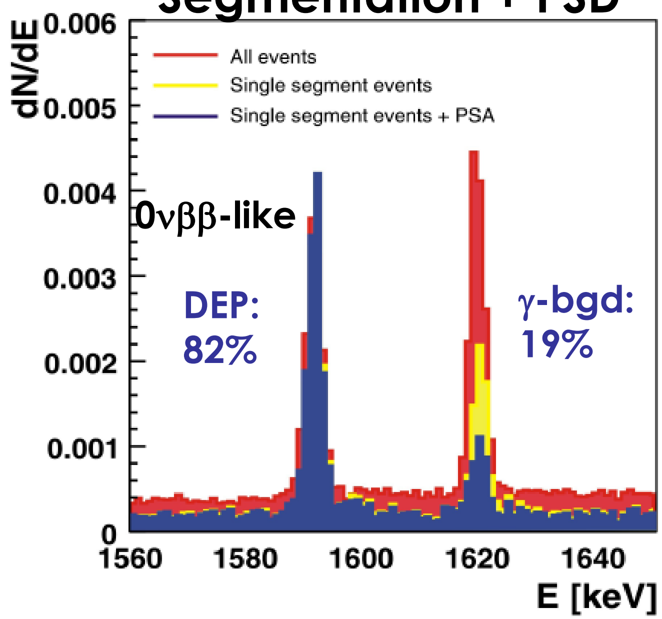
Two technologies pursued with advanced 0νββ-signal recognition & bgd suppression

1) n-type segmented



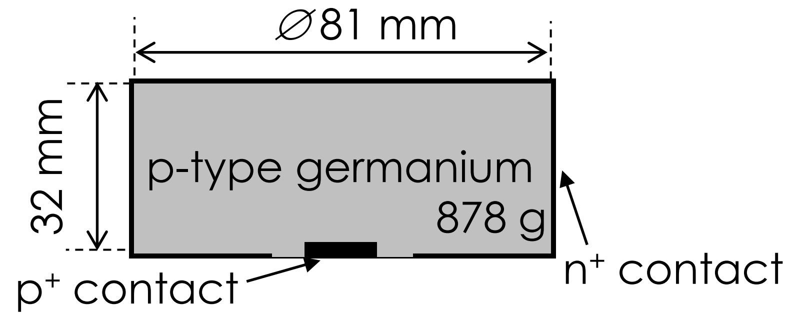
n-type detectors with 18-fold segmented electrodes, 1.6 kg

Segmentation + PSD

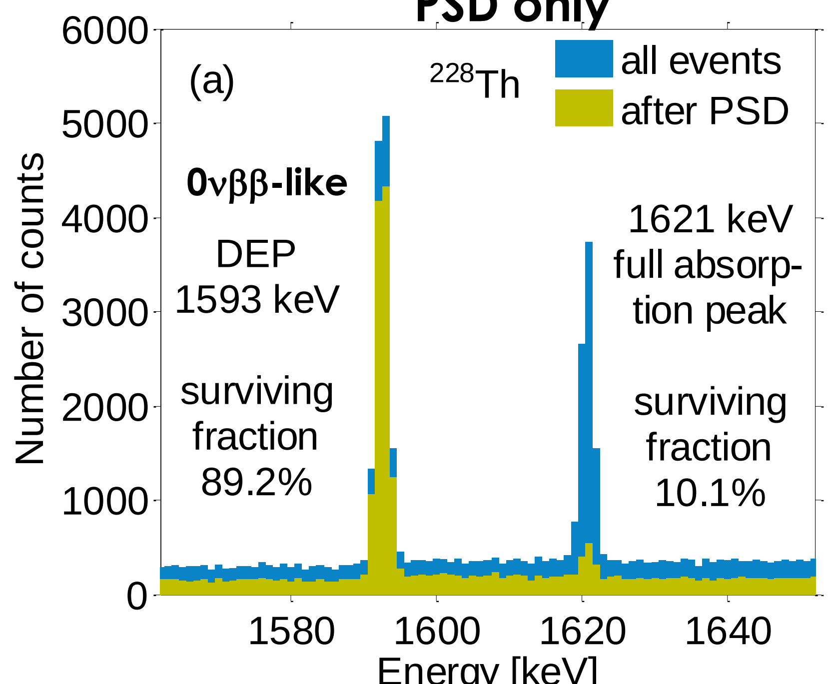


I.Abt et al., NIMA 583 (2007), Eur. J. Phys. C 52 (2007)

2) p-type BEGe



PSD only

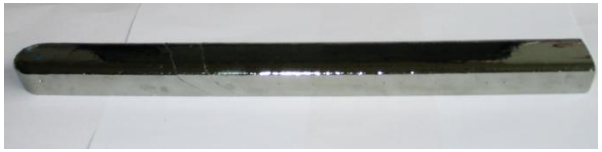


D. Budjáš et al., JINST 4 P10007 (2009)

Phase II detectors

^{enr}Ge & ^{depl}Ge:
- 37.5 kg of 86% ^{enr}Ge and 58 kg of ^{dep}Ge acquired

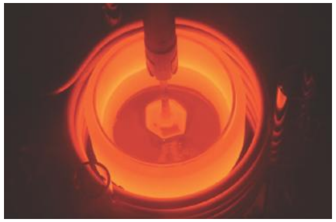
Reduction & purification:



- procedure tested and optimized with ^{dep}Ge at PPM Pure Metals GmbH
- no isotopic dilution
- minimal exposure to cosmic rays (underground storage)
- purification of enriched material completed:

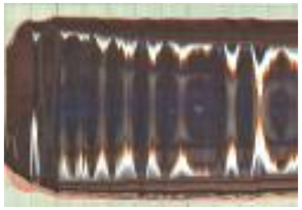
⇒ 35.4 kg (94% yield) of 6N grade material (+ 1.1 kg tail ⇒ 97%)

Crystal pulling:



n-type for segmented detectors:
- R&D for n-type pulling by Institut für Kristallzüchtung, Berlin

p-type for BEGe detectors:
- four crystals pulled from ^{depl}Ge material at Canberra, Oakridge, US
- first two ^{depl}BEGe detectors working

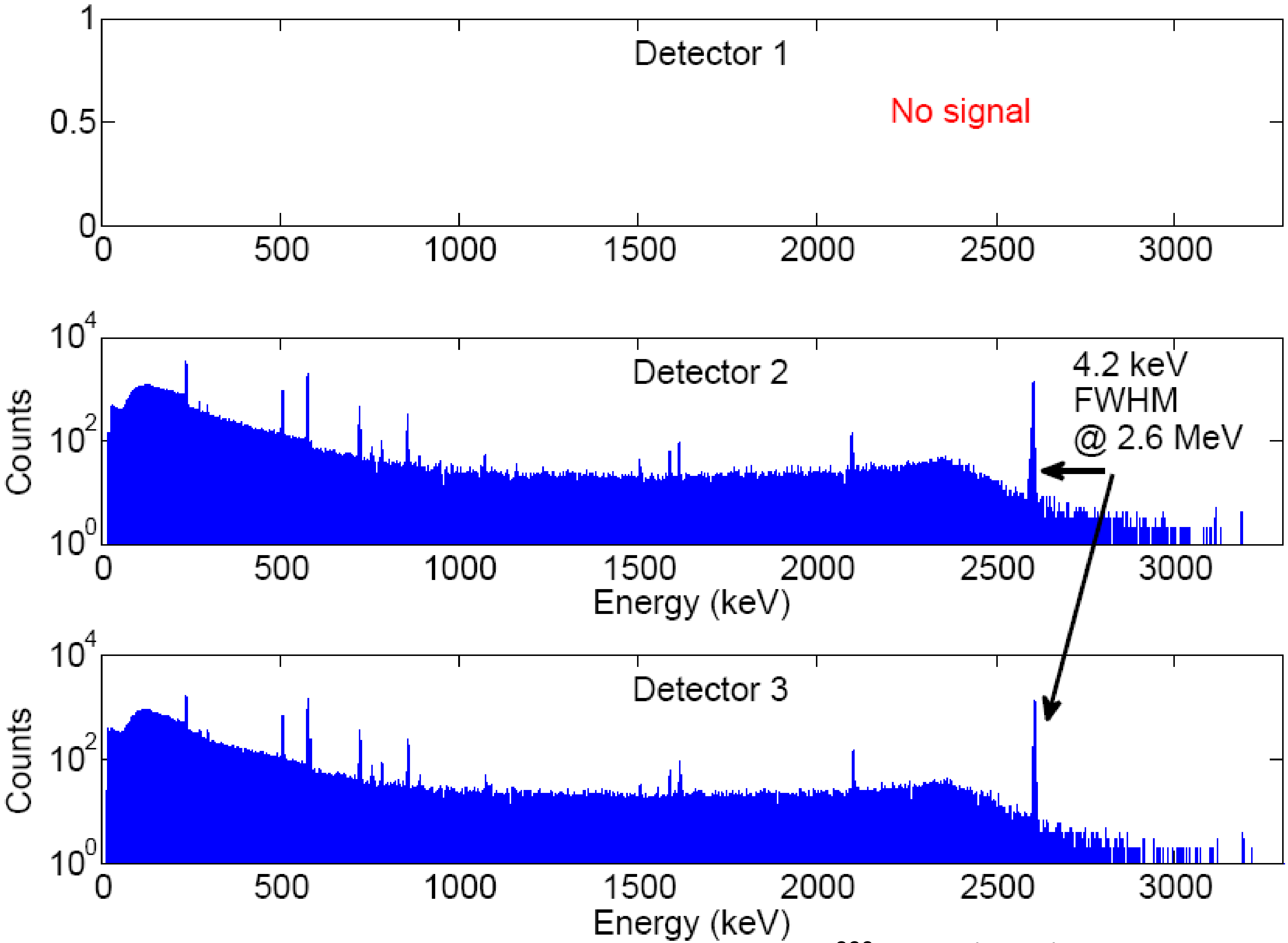


See poster 138

GERDA status

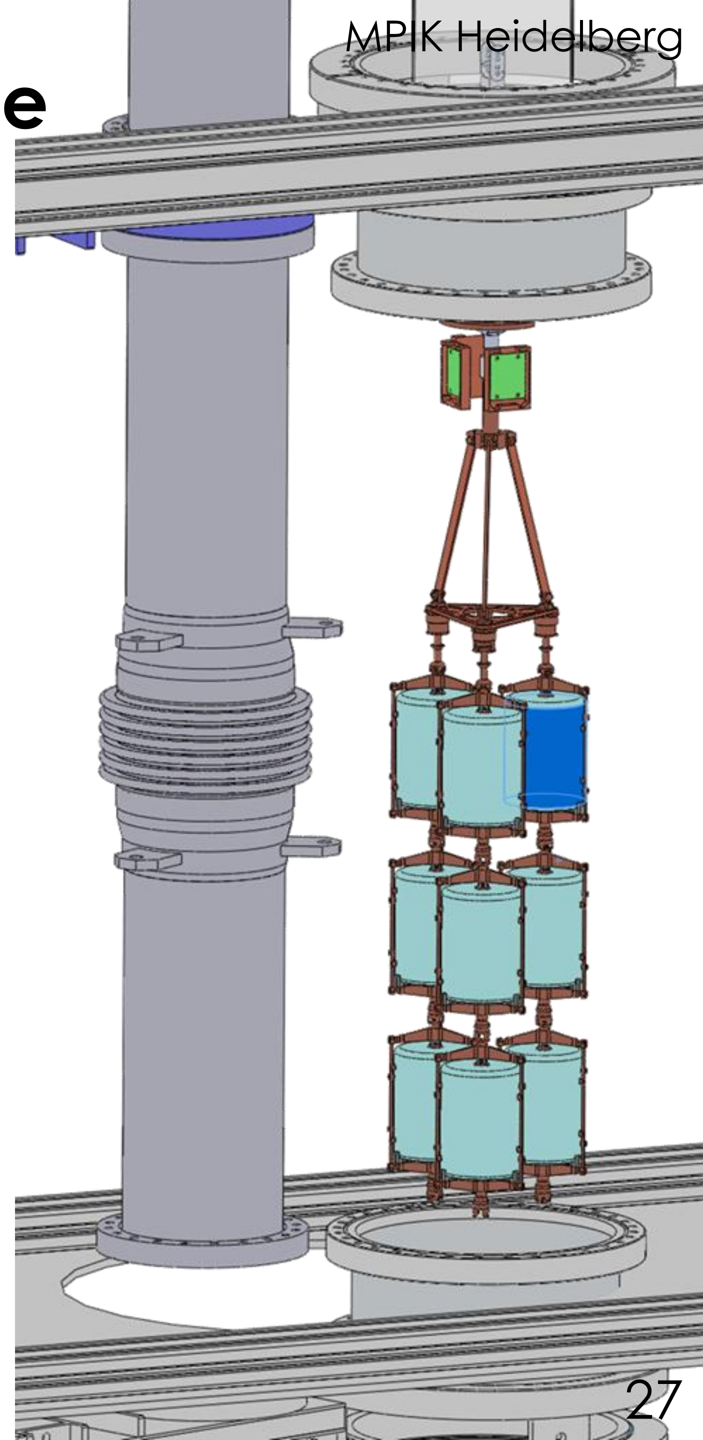
- Summer/autumn '09: Integration test of Phase I detector string, FE, lock, DAQ
- Nov/Dec.'09: Liquid argon filling
- Apr/May'10: Installation of 1-string lock in the GERDA cleanroom
- May '10: Deployment of FE & detector mock-up, followed by first deployment of a of non-enriched detector
- June '10: Water tank filling
- **June '10: Commissioning run with ^{nat}Ge detector string**

GERDA status



^{228}Th calibration spectrum

GERDA Schedule



- **One month run with ^{nat}Ge detector string to measure:**
  - background
  - stability (weekly calibration)

- **Subsequently**
  - operation of enriched detector strings

Summary

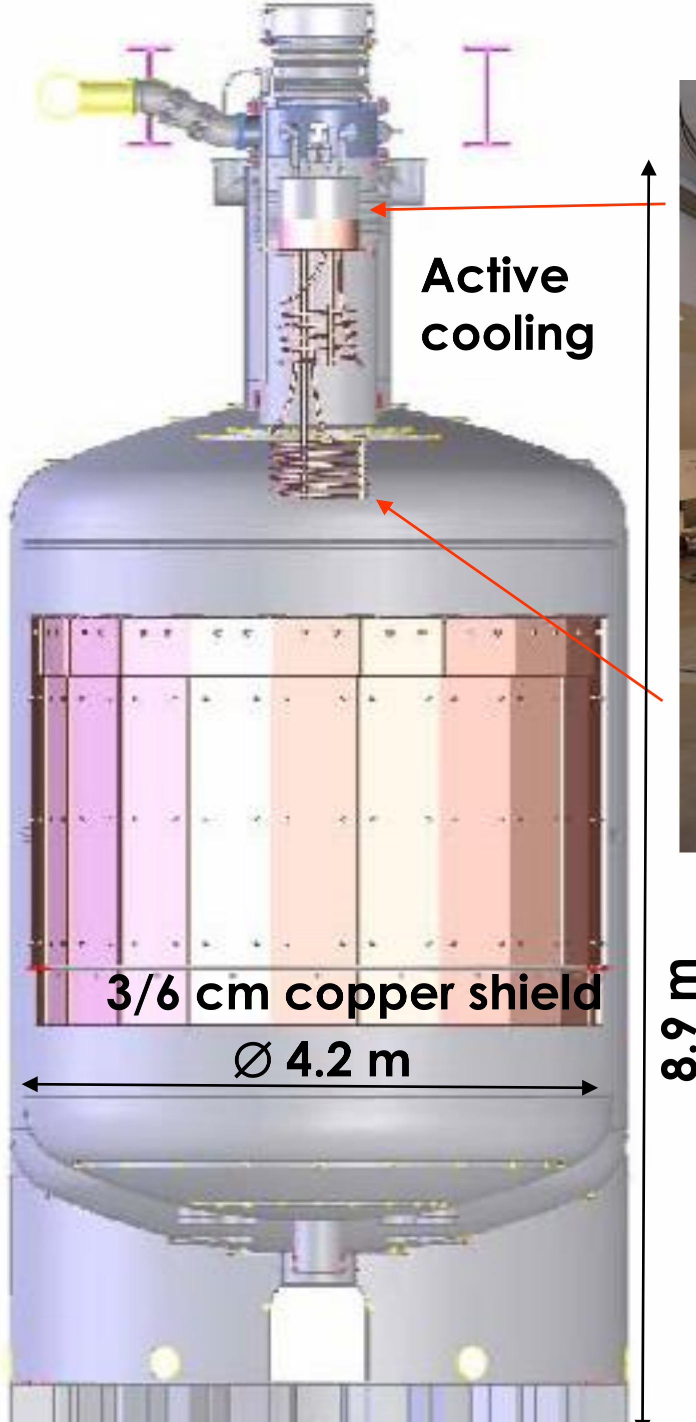
Three semiconductor based $0\nu\beta\beta$ experiments

- **COBRA**:
  - 16 CdZnTe detector run at LNGS completed
  - Upgrade to 64 detectors in near future
  - R&D on background reduction (pixellisation)
- **MAJORANA**:
  - 1st ^{nat}Ge detectors for Demonstrator acquired
  - Cu electroforming in DUSEL (4000 m.w.e. deep)
  - First cryostat with ^{nat}Ge running in 2011
- **GERDA**:
  - Construction completed in LNGS Hall A
  - Cryostat and water tank filled
  - Since June 2, first ^{nat}Ge detector string operating in LAr
  - ^{enr}Ge detector deployment in near future
  - Phase I physics result in 2011

GERDA cryostat

- 65 m^3 volume for LAr
- 200 W measured thermal loss
- active cooling with LN_2
- internal copper shield
- detailed risk analysis of cryostat in 'water bath'

Screening of all stainless steel sheet batches by underground γ-spectroscopy at MPI-HD and LNGS prior construction



MC ⇒ cryostat + copper shield + LAr
$<2 \cdot 10^{-4}$ cts / (keV · kg · y)

NIM A593 (2008) 448, NIM A606 (2009) 790

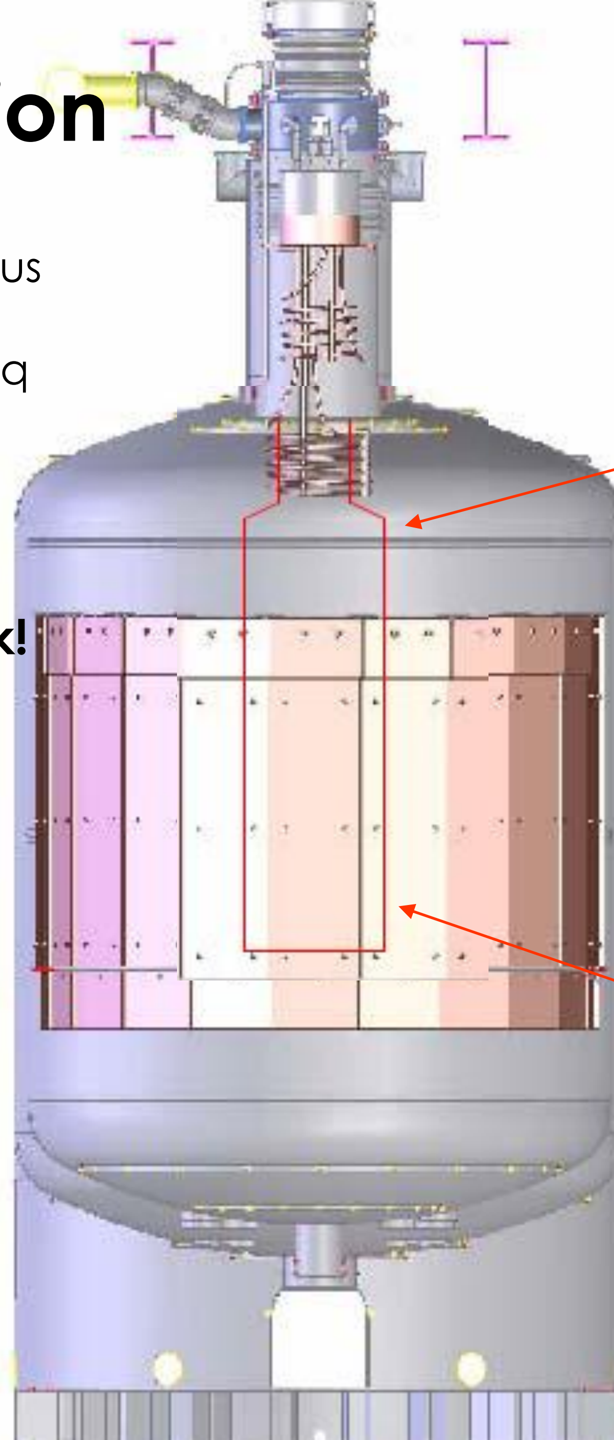
Cryostat: Rn emanation

Measurements of Rn emanation [a] at various fabrication/installation steps with MoREx[b]

after 1./2. cleaning	23±4 / 14±2 mBq
after copper mount	34±6 mBq
after 3. cleaning	31±2 mBq
after cryogenics mount	55±4 mBq**

****evidence: ^{222}Rn concentrated in neck!**

Rn shroud: 30 μm copper
Ø 0.8m , 3 m height
to prevent convective transport of Rn from walls/copper to Ge diodes
B ~ 1.5 10^{-4} cts / (keV·kg·y)



[a] **Uniform ^{222}Rn distribution of 8 mBq implies b = 10^{-4} cts/(keV kg y) in phase I.**

[b] **Appl.Rad.Isot. 52(2000) 691**

Background summary in a nutshell

Source	B [10^{-3} cts/(keV kg y)]
Ext. γ from ^{208}Tl (^{232}Th)	<<1
Ext. neutrons	<0.05
Ext. muons (veto)	<0.03
Int. ^{68}Ge ($t_{1/2}$= 270 d)	**12**
Int. ^{60}Co ($t_{1/2}$= 5.27 y)	**2.5**
^{222}Rn in LN/LAr	<0.2
^{208}Tl, ^{238}U in holder	<1
Surface contam.	<0.6

Muon veto

180 days exposure after enrichment + 180 days underground storage

30 days exposure after crystal growing

derived from measurements and MC simulations

Target for phase II: Σ B $\leq 10^{-3}$ cts/(keV kg y)

$\Rightarrow$ additional bgd. reduction techniques

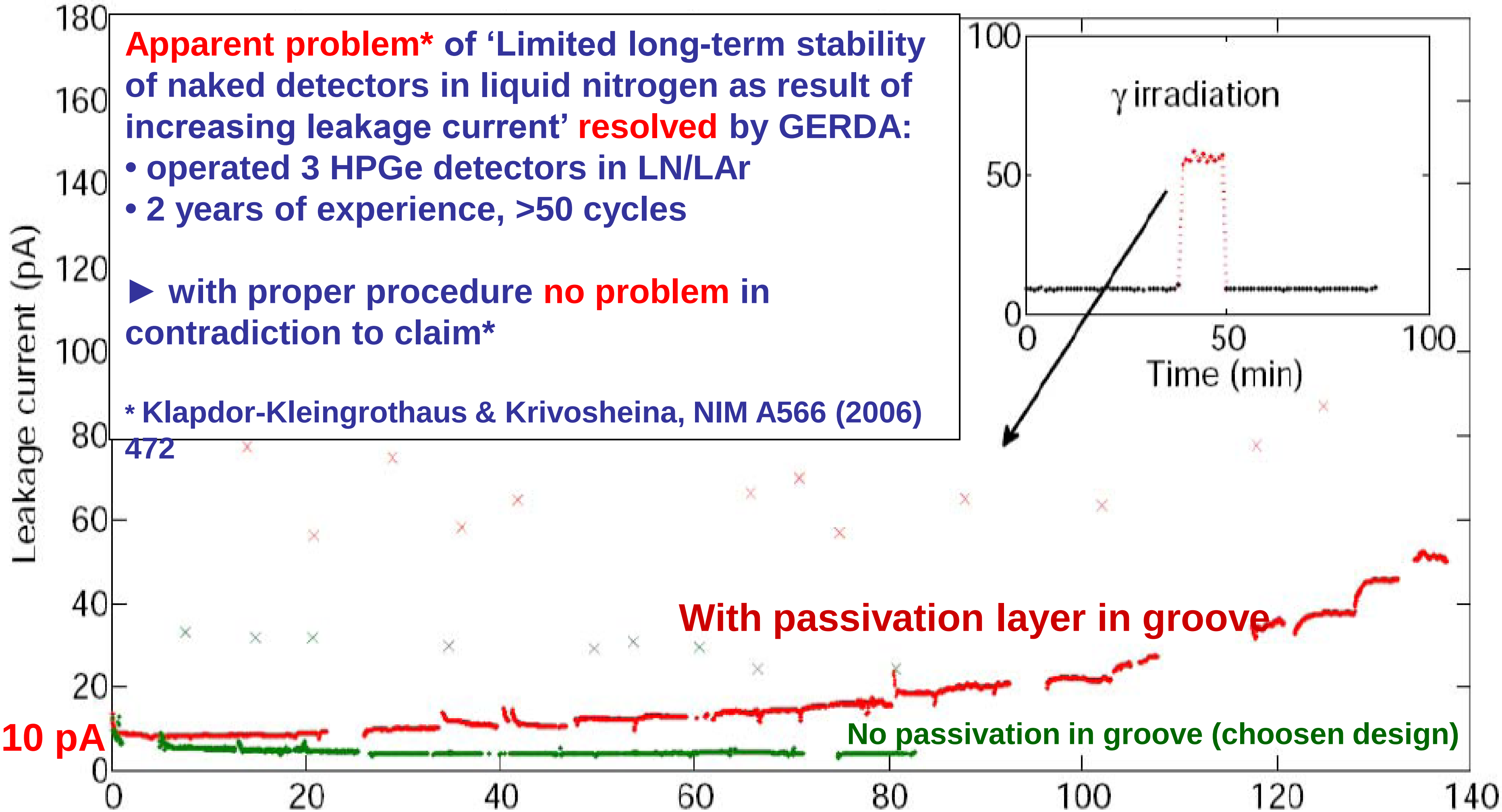
R&D long-term stability of phase I detectors in LAr/LN_2

Apparent problem* of ‘Limited long-term stability of naked detectors in liquid nitrogen as result of increasing leakage current’ resolved by GERDA:

- **operated 3 HPGe detectors in LN/LAr**
- **2 years of experience, >50 cycles**

► with proper procedure no problem in contradiction to claim*

* Klapdor-Kleingrothaus & Krivosheina, NIM A566 (2006) 472



no deterioration after 1 year of operation in LAr

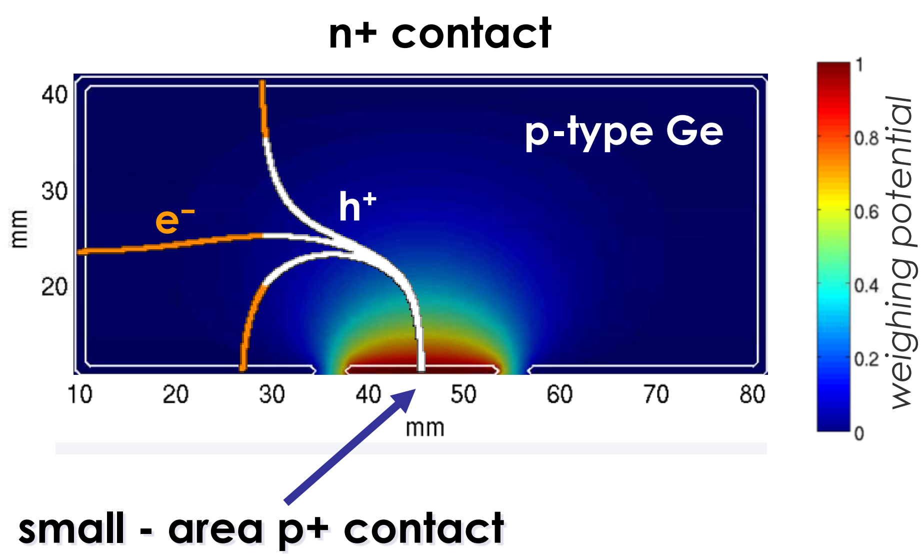
M. Barnabé-Heider, PhD thesis ‘09

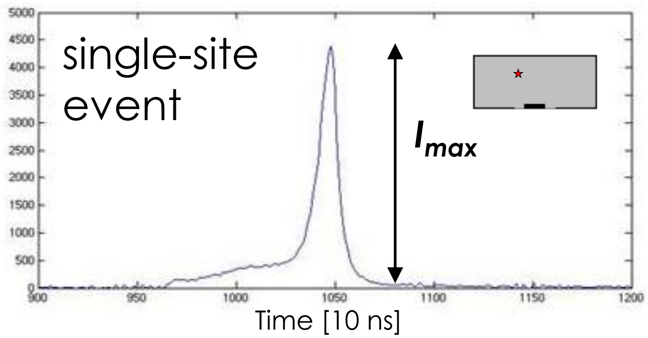
Broad-Energy Germanium Detector (BEGe)

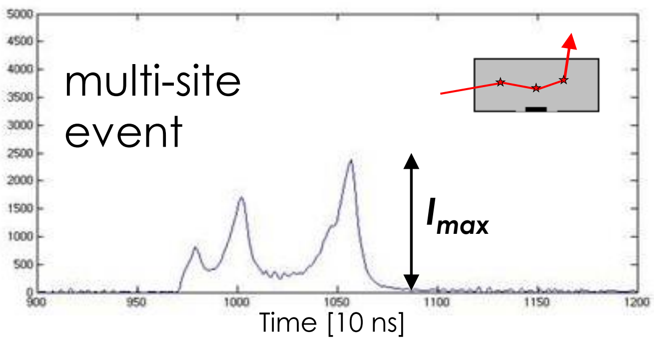
GERDA Phase II:

- **active background rejection** capability

Candidate: **BEGe**



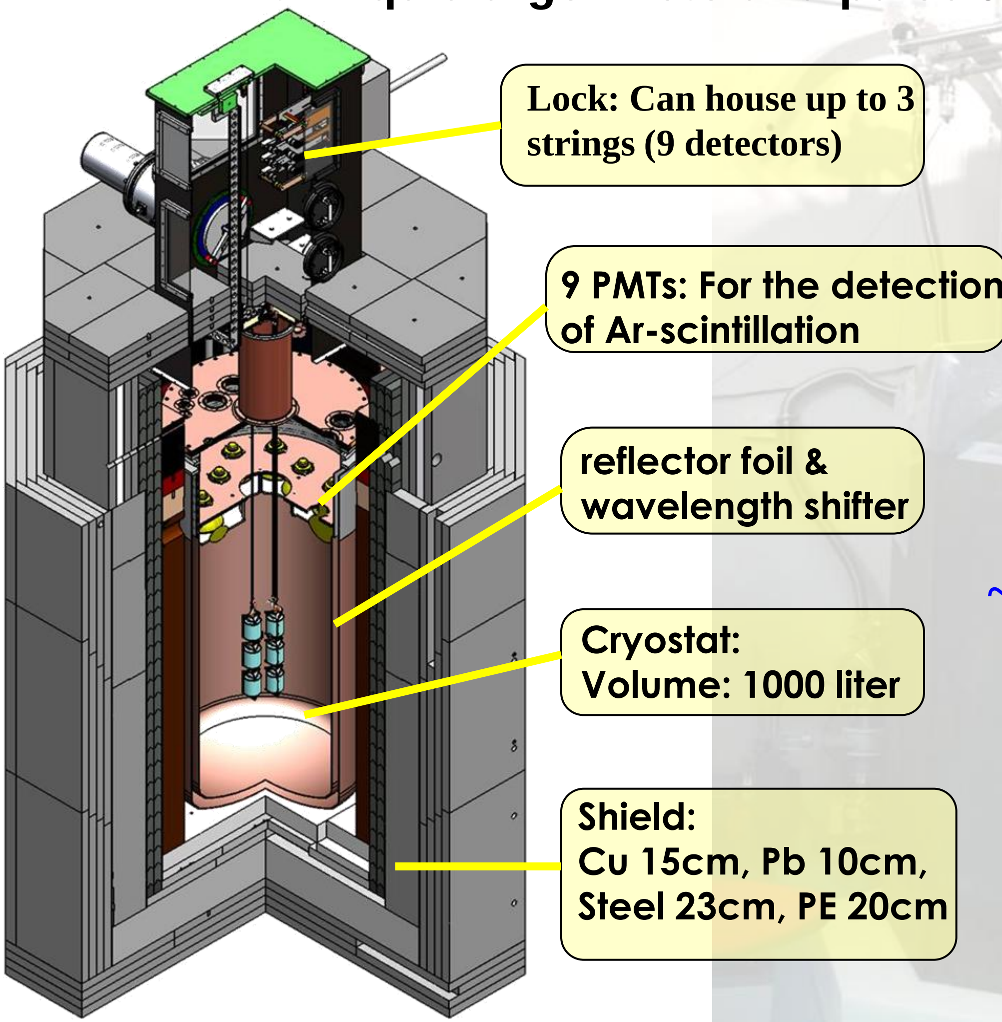


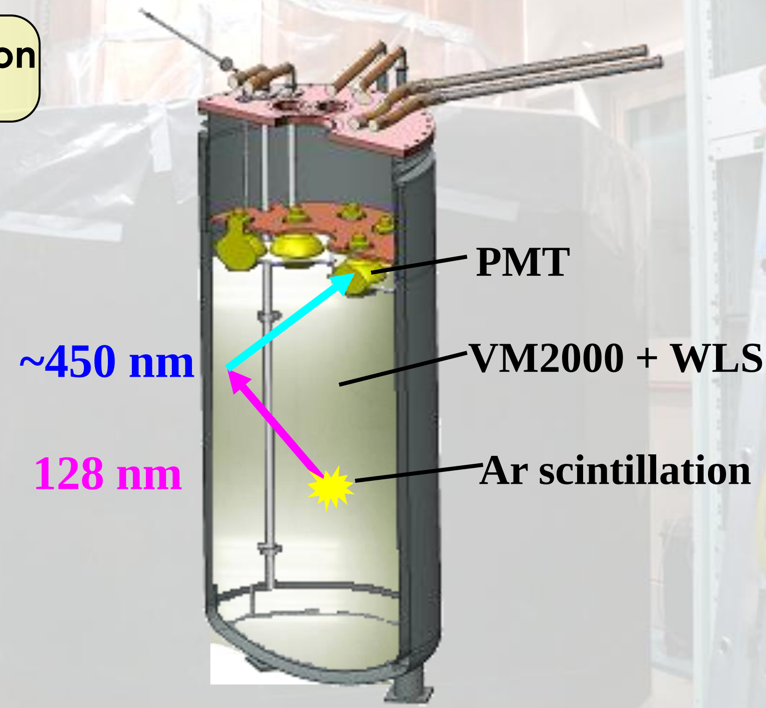


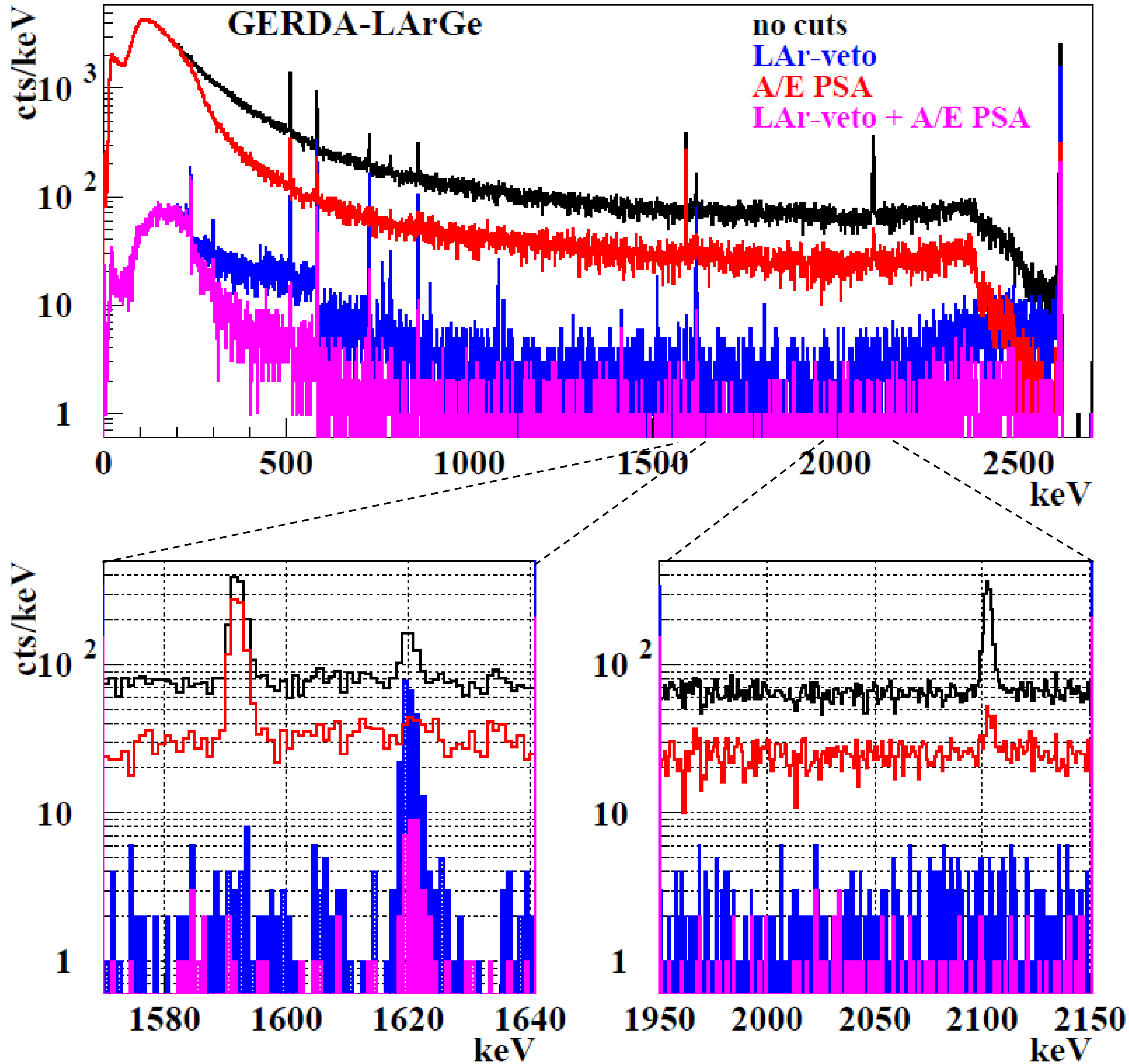
- **excellent multi-site / single-site event discrimination**
- avoids **external background** from multiple contacts
- also: excelent energy resolution and low-energy threshold

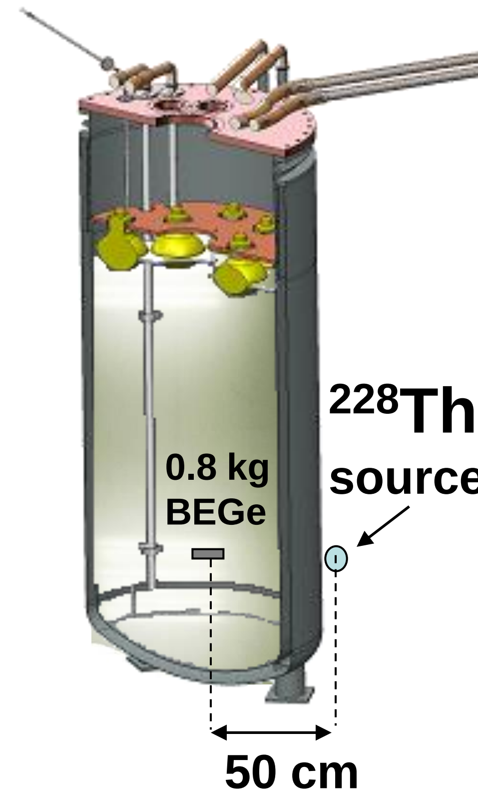
R&D for Phase II/III: the GERDA-LArGe test stand at LNGS

First (& yet preliminary) results of a bare BEGe detector operated with liquid argon veto and pulse shape discrimination





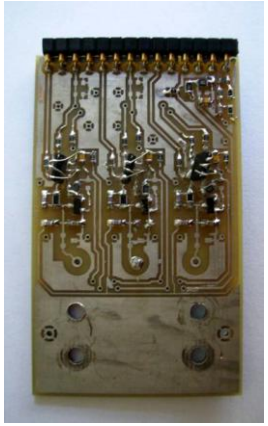


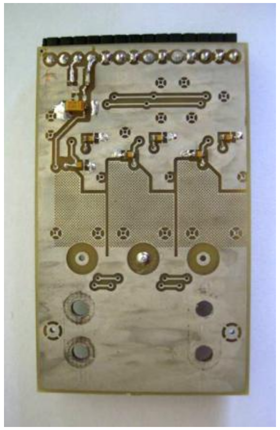


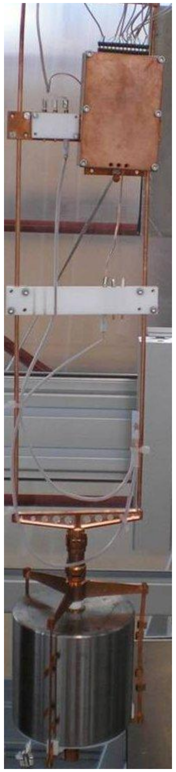
Survival prob. @ $Q_{\beta\beta}$: ~1%

CSA Based on Commercial CMOS OPAMP
Architecture: external JFET + CMOS OPAMP and Rf,Cf

- Reduced PCB Size (38 mm x 50 mm)
- 15 MeV guaranteed energy dynamic range
- 50 W drive capability with 10 m long cables
- Power consumption < 140 mW (down to 100 mW for 10 Mev dynamic range)
- Rise time < 55 ns with 50 Ohm terminated, long cables and energy up to 15 Mev
- Cross-talk : < 0.1%
- Mechanical Stability (4 distributed holes: M25)
- Reduced Connector Pin Number (11 vs 14)
- Eliminated Feedback and Test Capacitors (implemented with PCB copper traces)







~ 40 cm from 1st detector (+15 cm 2nd, +15 cm 3rd)