Development and installation of the GERDA experiment

GERDA: the GERmanium Detector Array

to search for Neutrinoless Double Beta Decay

A.Smolnikov
for the GERDA collaboration

The 11-th International Conference on Topics in Astroparticle and Underground Physics, TAUP2009, Rome, Italy, July 1-5, 2009

The **GERDA** project is based

on using very low background High-Purity-Germanium (HPGe) detectors.

HPGe detector fabricated from germanium enriched in **^{76}Ge isotope (up to 86 %)**

is simultaneously

the ββ decay source and the 4π detector.

The advantages of such type experiments (in comparison with the other types)

are due to:

1) the excellent energy resolution (3 keV at 2 MeV) ,
2) the high purity of Ge crystals (very low intrinsic background),
3) and the high signal detection efficiency (close to 100%).

Disadvantages:

1) not the highest ββ–transiton energy for **^{76}Ge:** **$Q_{\beta\beta}$=2039 keV**

(in comparison with the more promising isotopes, such as Mo-100,Nd-150,Ca-48)

2) only one characteristic of ββ decay **- sum energy of two electrons –** is possible to detect.

In spite of these disadvantages, up to now such type of experiments are the most sensitive tools in searching for (0νββ)-decay .

So far the best limits on $(0\nu\beta\beta)$-decay **half-life**

1.9×10^{25} *y* and 1.6×10^{25} *y* , which correspond to **$| m_{ee} | < 0.3$ - 1.1 eV** ,

have been obtained with HPGe detectors

in the predecessor experiments **Heidelberg-Moscow & IGEX**

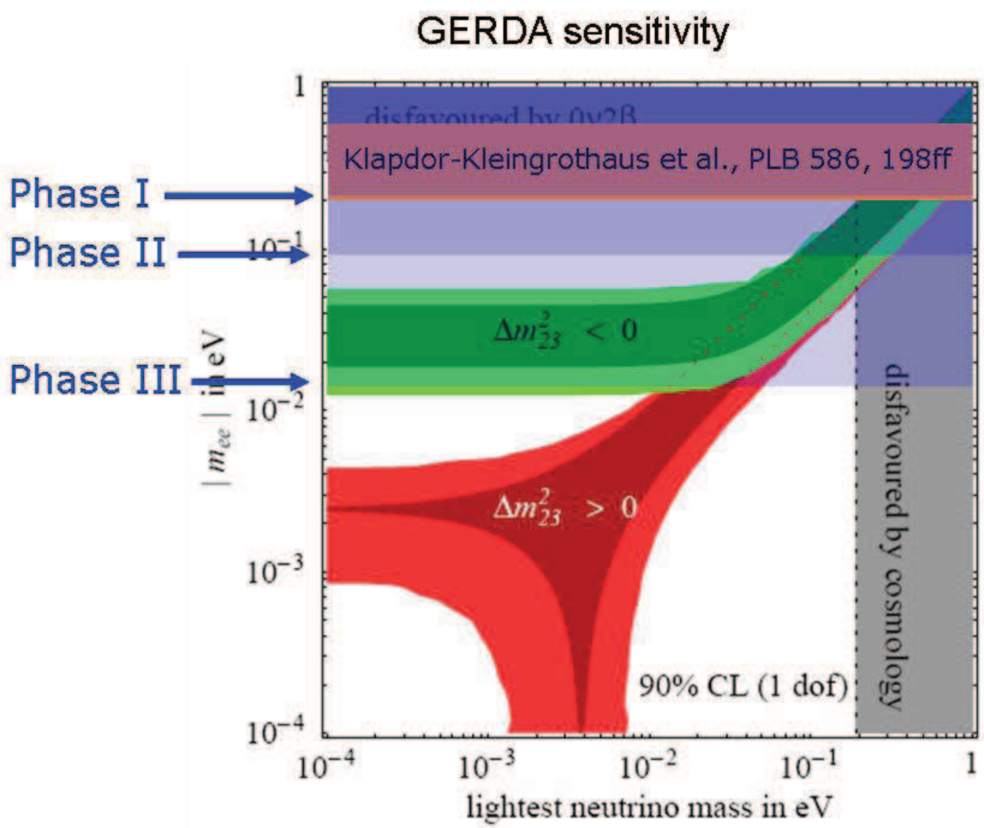
with using Enriched Germanium (86% in ^{76}Ge, $Q_{\beta\beta}$=2038,5 keV)

Moreover, the **part** of H-M Collaboration, after additional data treatment , claimed the presence of an excess of events in ROI, which they interpreted as the evidence for $0\nu\beta\beta$ observation with the best fit **$T_{1/2} = 1.2\times10^{25}$ *y*, $| m_{ee} | = 0.44$ eV**

H.V. Klapdor-Kleingrothaus, A. Dietz, I.V. Krivosheina, O. Chkvorets, NIM A 522 (2004)

The main goal of the **GERDA** experiment
is searching for **neutrinoless double beta decay** of **^{76}Ge**
with considerable reduction of background
(and, correspondently, increasing sensitivity)
in comparison with predecessor experiments.

Expected sensitivity of the **GERDA** experiment



GERDA

will probe **Majorana nature of neutrino**

with sensitivity at

GERDA phase I :

with background **0.01 cts / (**kg・keV・y)

► to **scrutinize KKDC result within 1 year**

GERDA phase II :

with background **1 cts** / (**ton !**・keV・y)

► to cover **the degenerate neutrino mass hierarchy (<m_{ee}> < 0.08 – 0.29 eV)**

phase III :

world wide **GERDA –MAJORANA** collaboration

background **0.1 cts** / (**ton**・keV・y)

► to cover **the inverted neutrino mass hierarchy**

<m_{ee}> ~10 meV

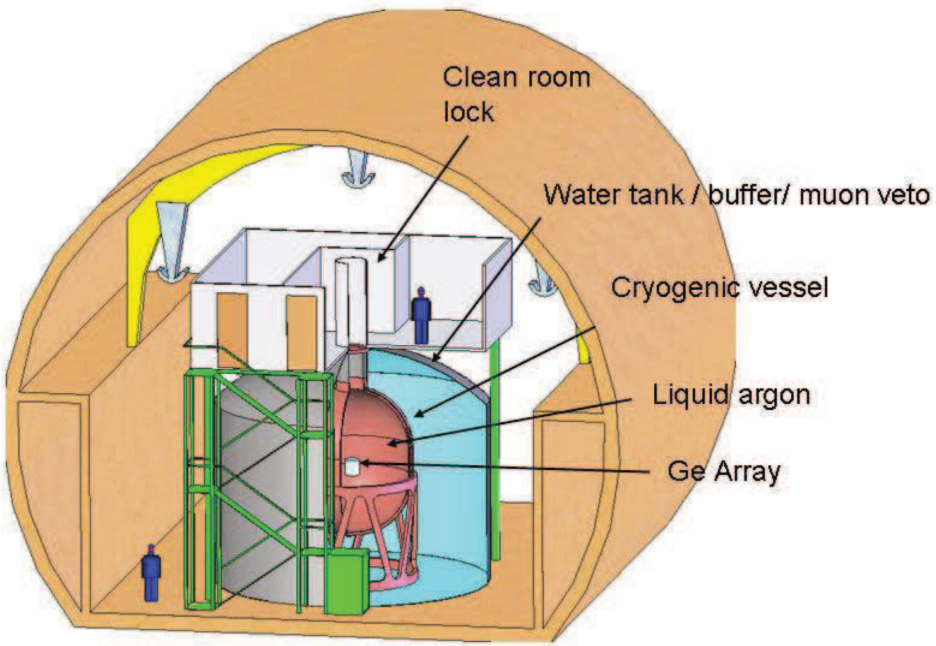
To achieve the planned sensitivity it is necessary
to reduce the previous background level dramatically
(**several orders of magnitude !)**

To do this the **novel experimental concepts** are needed.

Main GERDA experimental concepts

The main conceptual design of the GERDA experiment is to operate with "naked" HPGe detectors (enriched in Ge-76) submerged in high purity liquid argon supplemented by a water shield.

"Naked" detector means the bare Ge crystal without traditional vacuum cryostat.



As it was shown in the IGEX and H-M experiments, the main part of the detector background is due to radioactive contamination in the surrounding materials, including the cupper cryostats.

Thus, **minimizing of the support material** mass in the case of using “naked” Ge detectors **should provide considerable (up to 100) reduction of the inner background**.

naking Ge crystalls

minimizing
of the support mass

30g Cu, 6.3g PTFE, 1g Si per detector

Using of ultra pure LAr (instead of LN) both **as a cooling media and shielding material** is the other perspective idea of the GERDA project.

In this case there are several advantages:

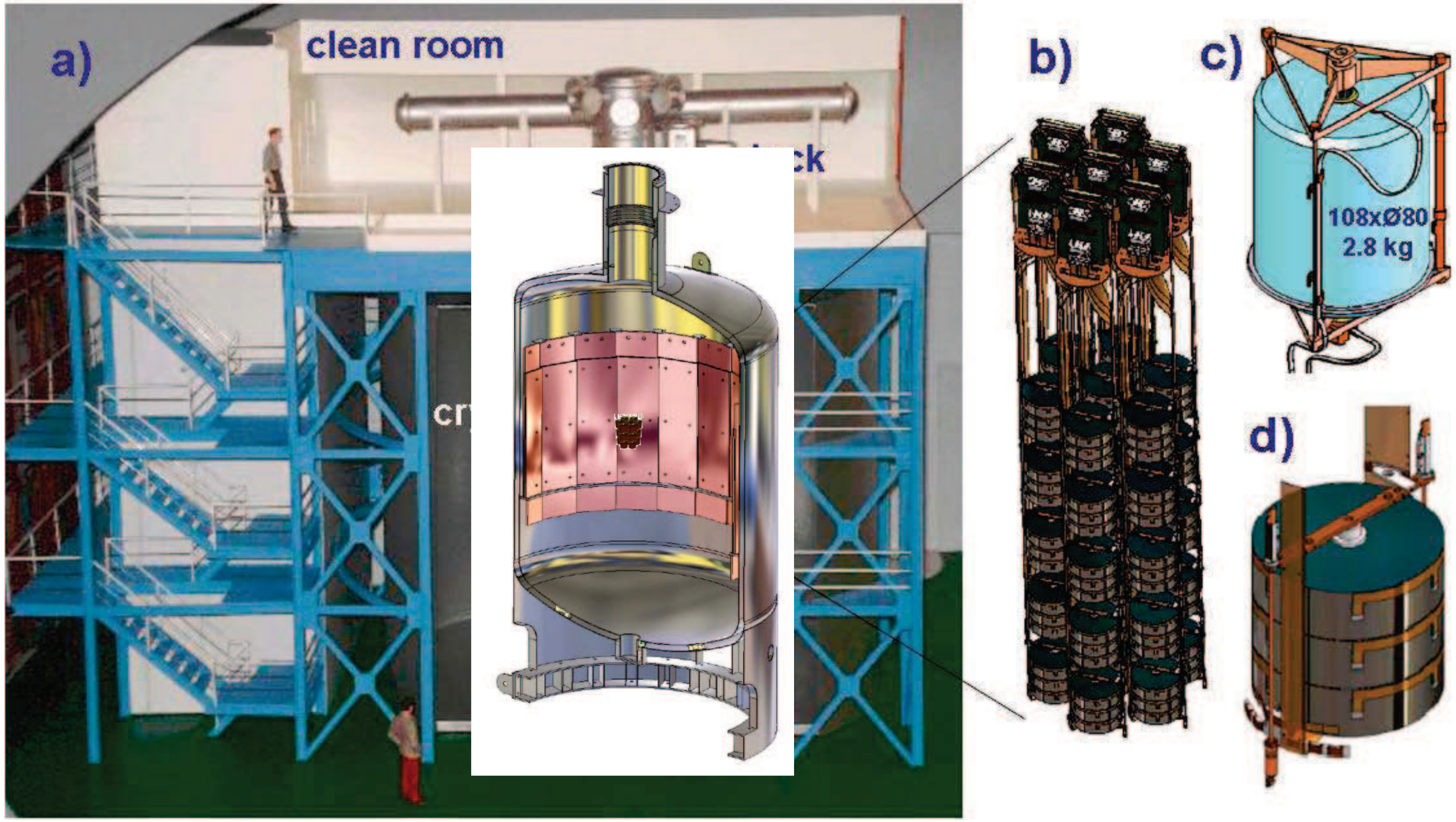
1) the higher reduction factor of the external background due to **higher LAr density (1.4 g/cm^3);**
2) **anti-coincidence with LAr scintillation** should reduce both the inner and external background;

In the Phase I all **8 existing and reprocessed enriched detectors** (in total **18 kg of ^{76}Ge**) from the previous Heidelberg-Moscow and IGEX experiments, and **6 reprocessed natural HPGe detectors** (in total **15 kg of ^{Nat}Ge**) from the Genius Test-Facility will be deployed in strings.

In the Phase II the new segmented or BeGe detectors (>20kg of ^{76}Ge) made from recently produced **enriched in ^{76}Ge material** added. **In total: 40 kg of ^{76}Ge + 15 kg of ^{Nat}Ge.**
In addition several detectors from **depleted in 76Ge material** (**DepGe**) will be incorporated too.

A stainless steel cryostat (25 t, U/Th ≤ 5 mBq/kg**)**
with **internal Cu shield (20 t,** U/Th ≤ 16 μBq/kg **)**
will contain **100 tones of LAr,** ^{222}Rn = ≤ 1 μBq/m^3 **.**
The cryostat is immersed in a water tank **(590 t of water)**.

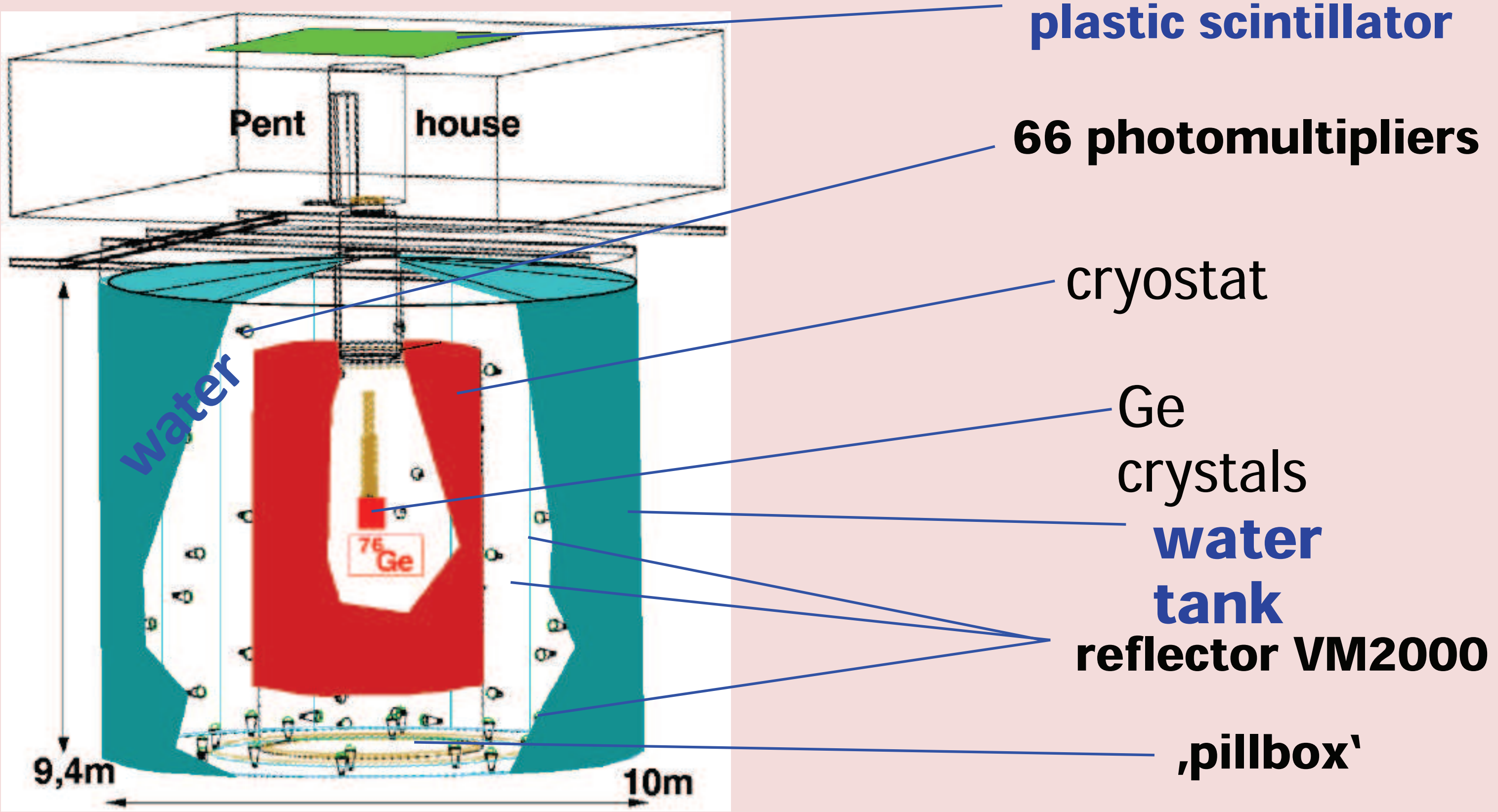
The Ge detector array is made up of individual detector strings and is situated in the central part of the **cryostat.**



Water tank and Veto system

The **ultra-pure water buffer**
serves as **a gamma and neutron shield** and, instrumented with 66 photomultipliers, as Cherenkov detector **for efficiently vetoing** cosmic muons. Recent simulations show, that an **efficiency of more than 99 % can** be achieved, reducing the muon induced background to a level of 10^{-5} events/(keV · kg · y).

Plastic scintillator panels **(20 m², 20 x 2 = 40 modules)**
on top of the detector will tag muons which enter the cryostat through the neck.

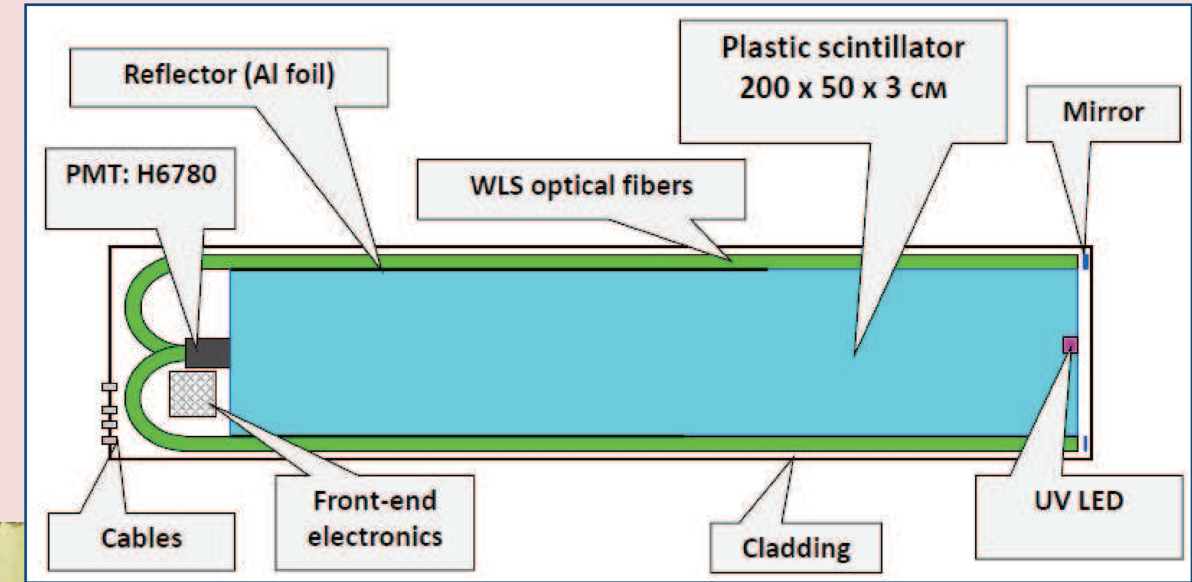


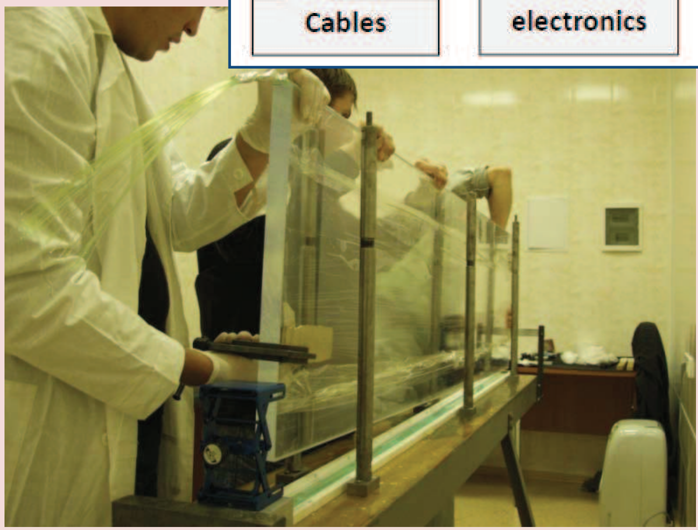
For more details see "The GERDA Muon Veto Cherenkov Detector", presented by Markus Knapp at the TAUP 2009 Poster Session

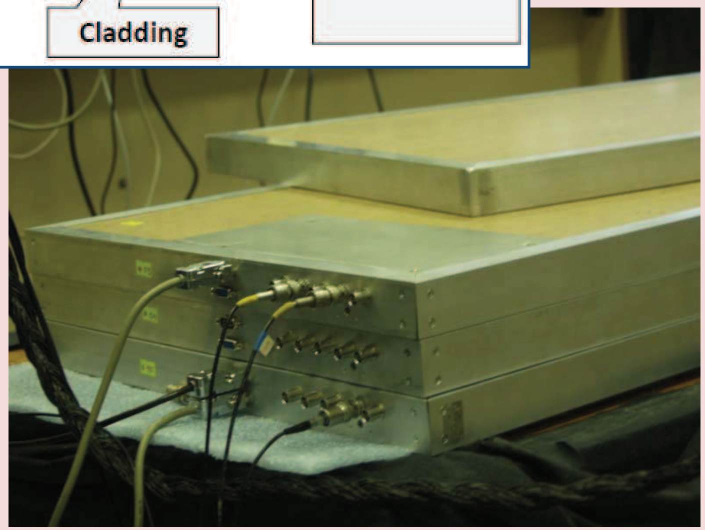
The optimal for the GERDA purpose the **muon veto modules on the base of plastic scintillator** have been developed, assembled and tested.

(with the light collection non-uniformity less than 15 % for the 200 x 50 x 3 cm^3 dimensions).

It is shown that the **muon vetoing efficiency of about 98 %** can be achieved.

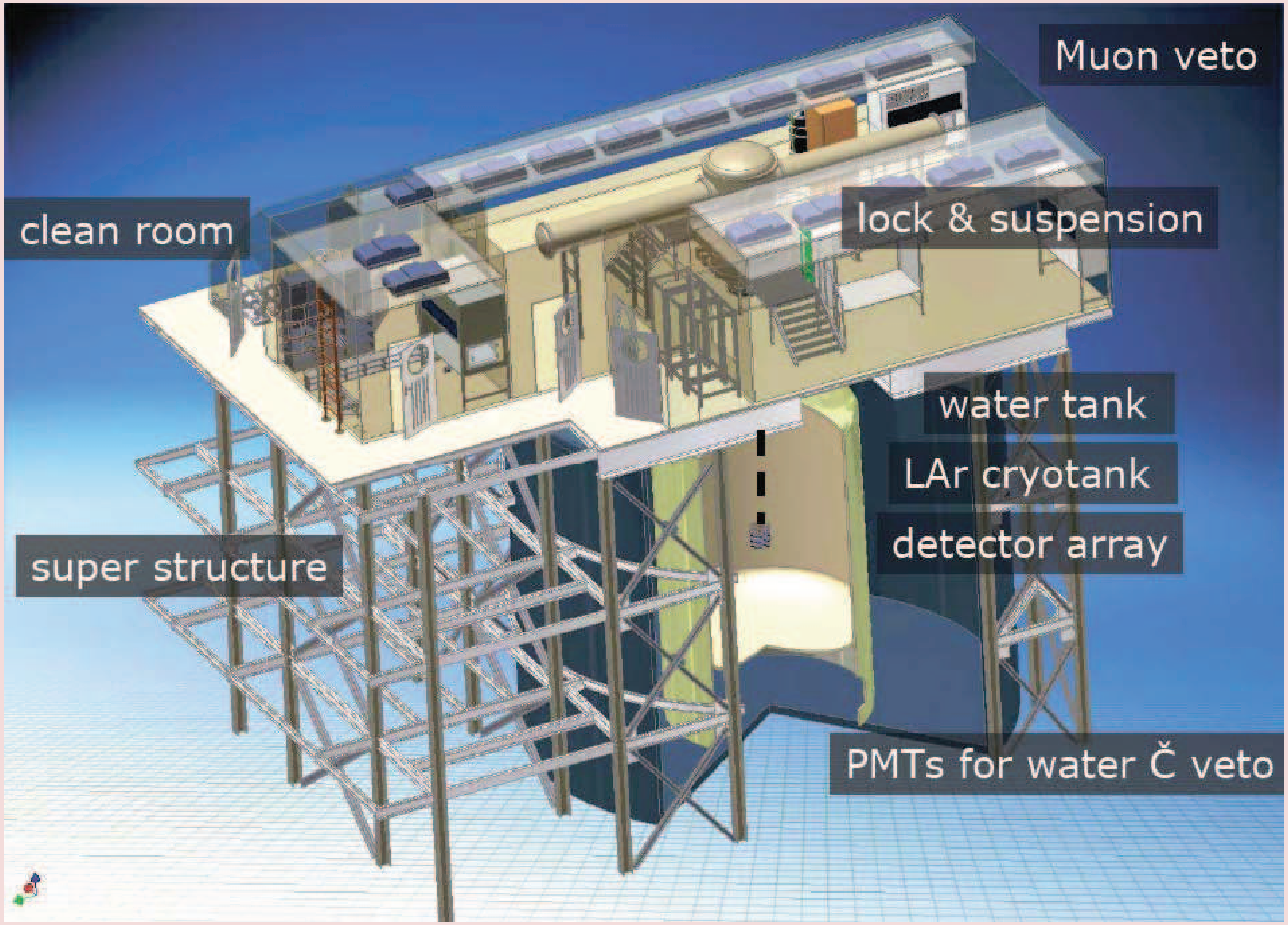






General Infrastructure of the GERDA set up

A **cleanroom** and **radon tight lock** on top of the vessel assembly allow to insert and remove individual detector strings without contaminating the cryogenic volume.



Installation of the GERDA set up

The main GERDA set up

is currently under construction

(starting from 2007)

in the INFN Gran Sasso National

Laboratory (LNGS), Italy,

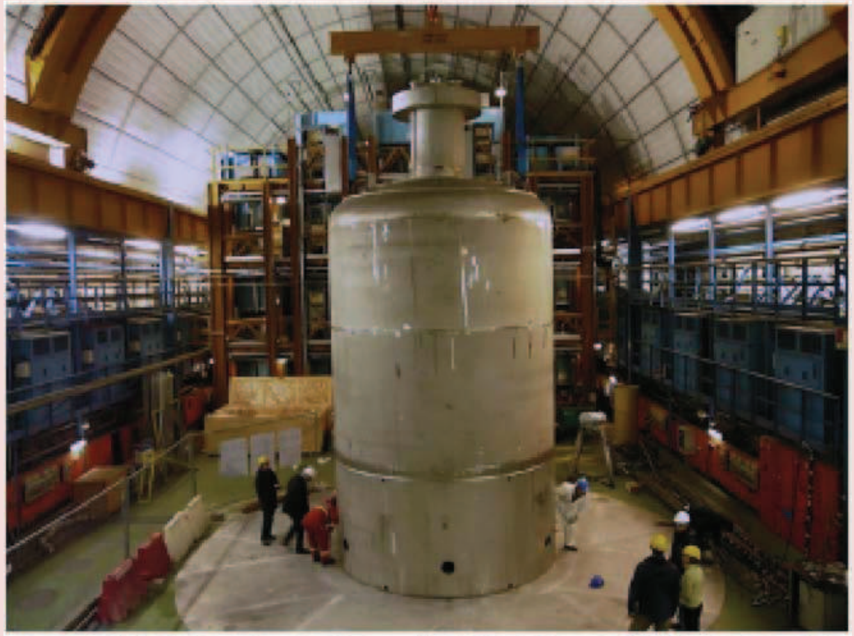
and the main parts

of the “nested type” assembly

have already installed

in the deep underground facility

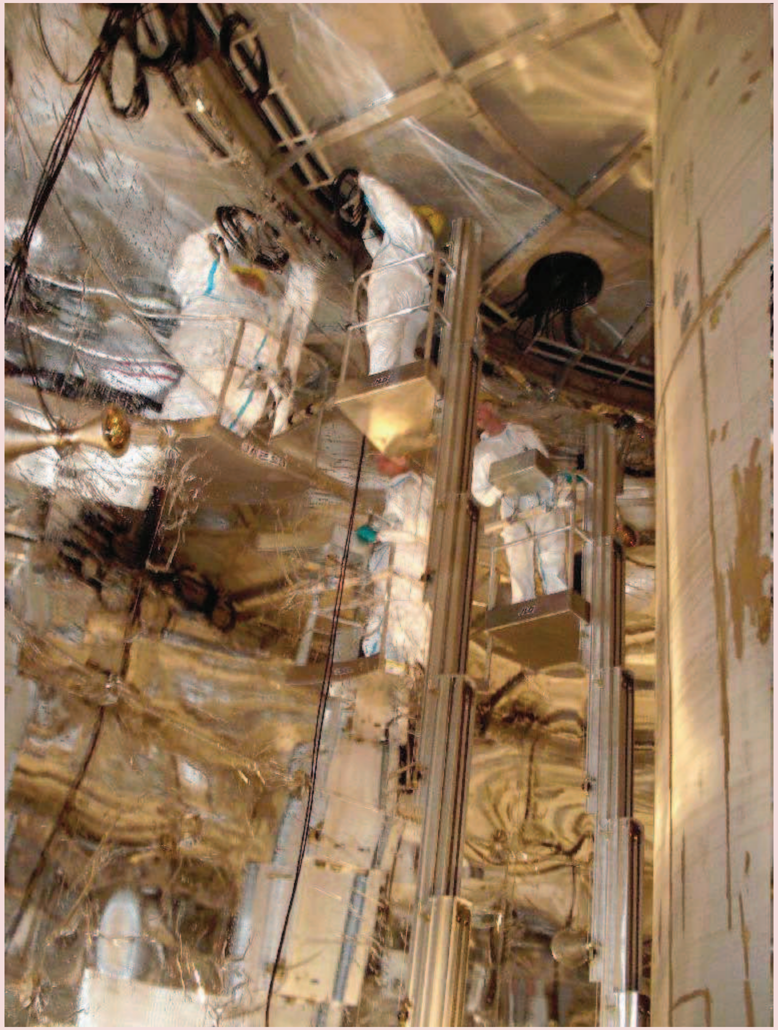
at 3500 m w.e.



Clean room almost ready

May 2009

Mounting PMT modules in water tank



June 2009

Water tank, inside view

June 2009

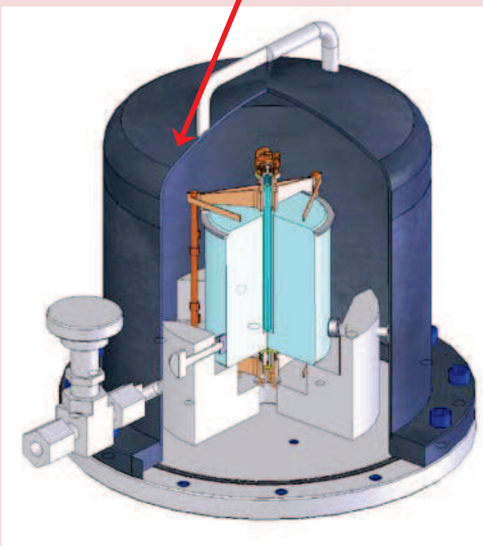
Phase I detectors

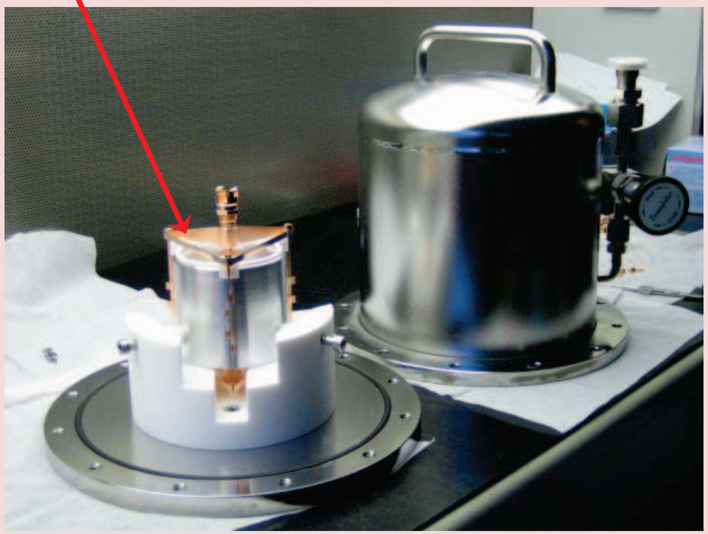
- 8 enriched (IGEX and HdM) and
  6 non-enriched crystals (GENIUS-TF)

  The IGEX and HdM crystals were removed from thier parent vacuum copper cryostats

- All detectors were refurbished by Canberra (no passivation layer !)

- The detectors were stored underground during reprocessing (HADES), (with less than 1 week exposure above ground).
- Each detector is equipped with a low-mass holder.
- Now they are stored at LNGS under vacuum in special transport containers





Testing of naked HPGe detectors in LN_2 / LAr

Long-term stability tests (3 HPGe detectors in LN2/LAr during 2 years)

tested in liquid Argon
FWHM ~2.5keV (at 1332keV),
leakage current stable

Problems reported from GENIUS-TF
[H.V.Klapdor-Kleingrothaus end I.Krivosheina, NIM A556 (2006) 472]

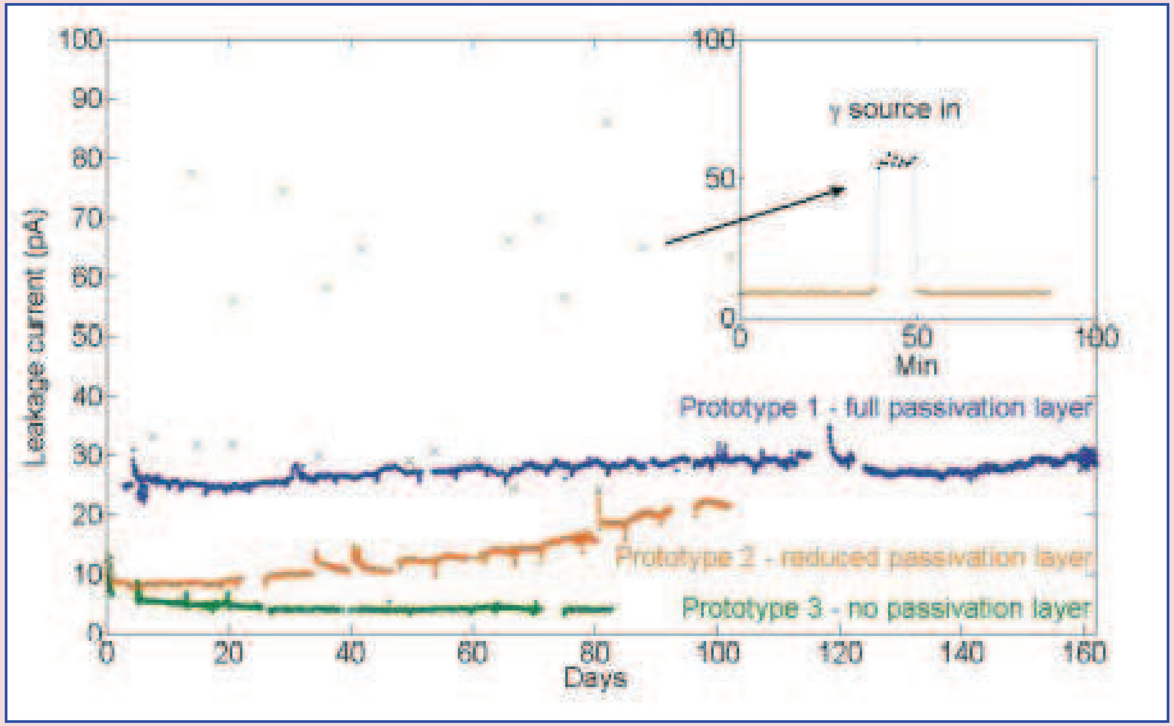
have been overcome by GERDA.

Long term stability for > 1 year.
Detector performances are stable in LAr !

The main results achieved during modification of naked HPGe detectors and tests in LAr

1. It was shown that **naked Ge crystals can work directly in liquid argon** with the leakage current and energy resolution corresponding to their standard values in the traditional cryostats .

2. Their parameters **are stable during several months** after a few dozen cycles of removing and submerging from/in the LAr even after irradiation with intensive gamma sources (modification without passivation layer).



It shows the feasibility of the overall GERDA project

Additional background reduction techniques

To reach the background level **required for the Phase II**

10^{-3} cts/(keV·kg·y),

additional new methods

are required to suppress the intrinsic background of the detectors.

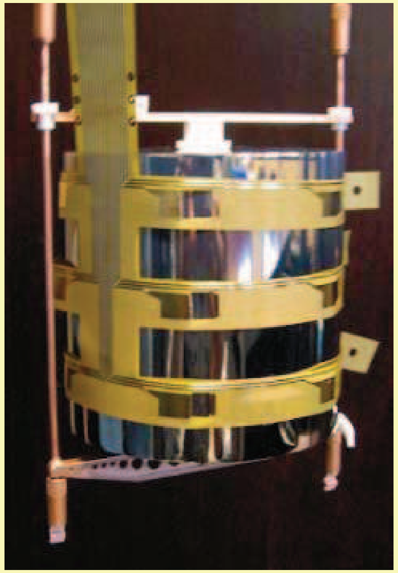
1. Research and development are carried out to produce new segmented and BeGe types of germanium detectors which can **resolve multi-site energy deposits**.

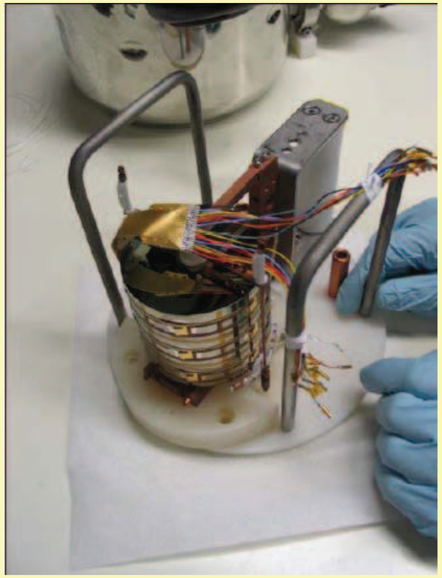
2. Another effective approach is **to discriminate multi-site deposits** from the pulse shape analysis of the signal as well as to use anticoincidence between nearby detectors assembled in several strings.

3. The novel concept to use the LAr scintillation light as anti-coincidence signal **for further background suppression** is developed.

Phase-II detector candidate #1:

18-fold segmented detector

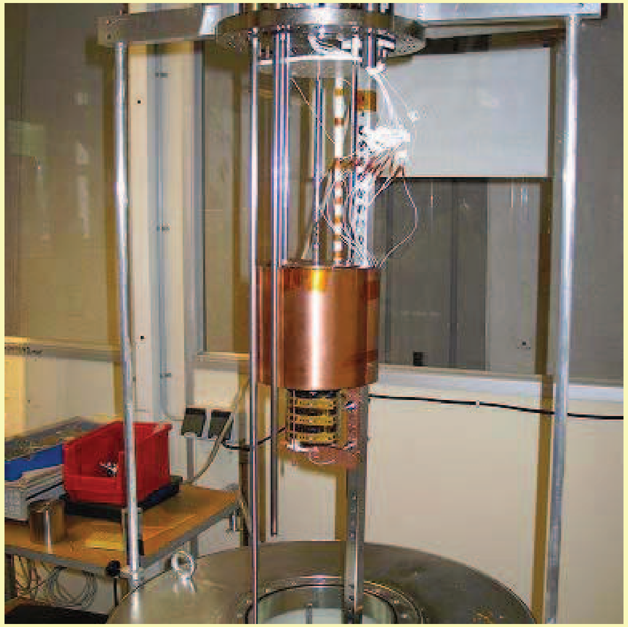




novel “snap contact” -> small amount of extra material

(19g Cu, 7g PTFE, 2.5g Kapton per each detector)

Segmented prototype detector tested in LN



ΔE/E (FWHM): core 4.1 keV, segments 3.6 - 5.7 keV

leakage current 30 ± 5 pA

This detector works in liquid nitrogen,
stable performance for 5 months

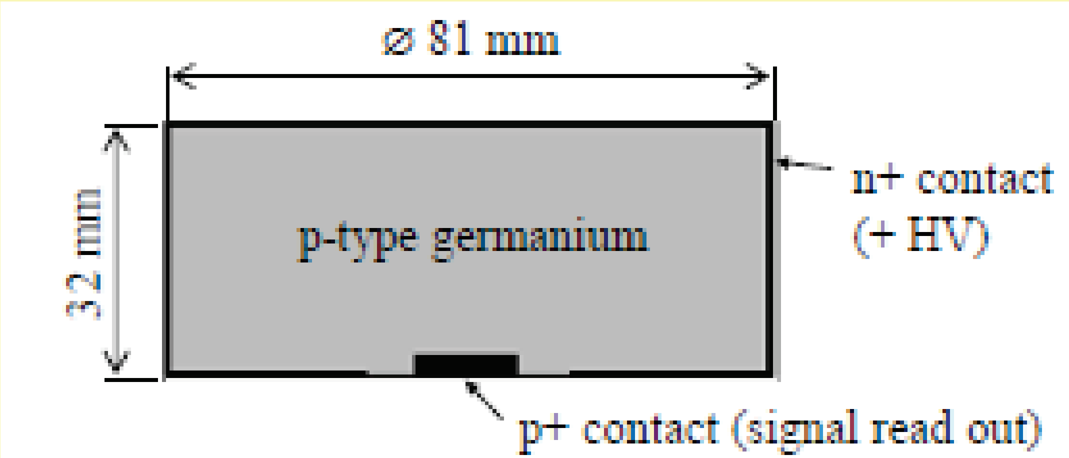
For more details see
“First Time Ever: 18-fold Segmented HPGe Detector in LN2”,
presented by Jing Liu at the TAUP 2009 Poster Session

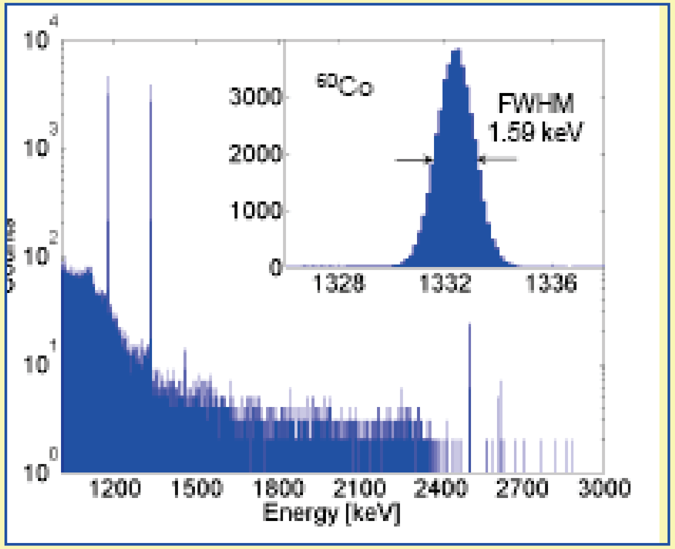
Phase-II detector candidate # 2:
BeGe (broad-energy) detector

energy range 3 keV - 3 MeV
enhanced efficiency for low-energy gammas
low capacitance (⇒ low noise)

modified model BE5030

the largest BEGe detector
commercially available from Canberra Semiconductor, N.V. Olen





Specifications from Canberra:

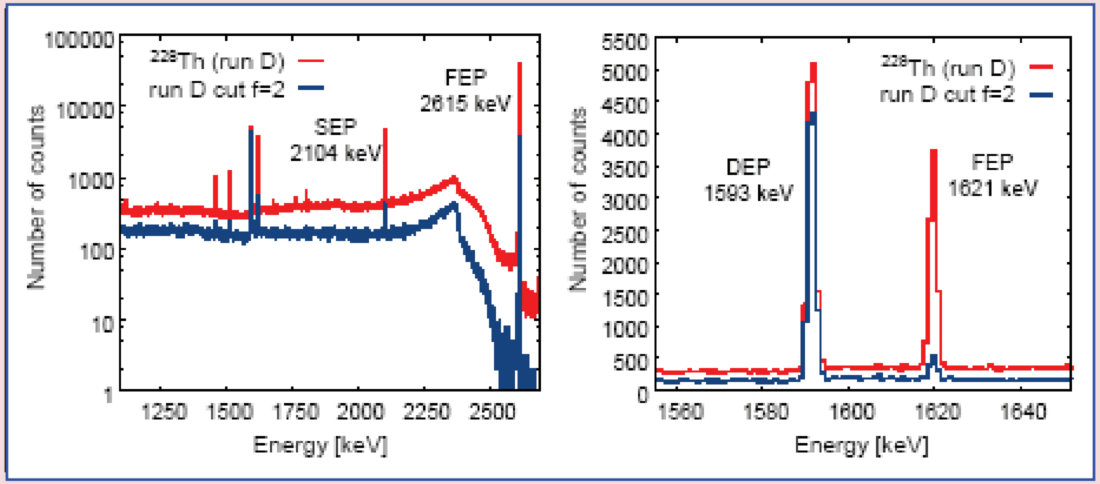
depletion voltage	4000 V
FWHM @ 122 keV	0.63 keV
FWHM @ 1.33 MeV	1.8 keV
mass	870 g

Parameters obtained during R&D for GERDA:

depletion voltage	3800 V
FWHM @ 59.5 keV	0.49 keV
FWHM @ 1.33 MeV	1.59 keV
mass	878 g

Phase-II detector candidates:
BEGe detector vs. 18-fold segmented detector

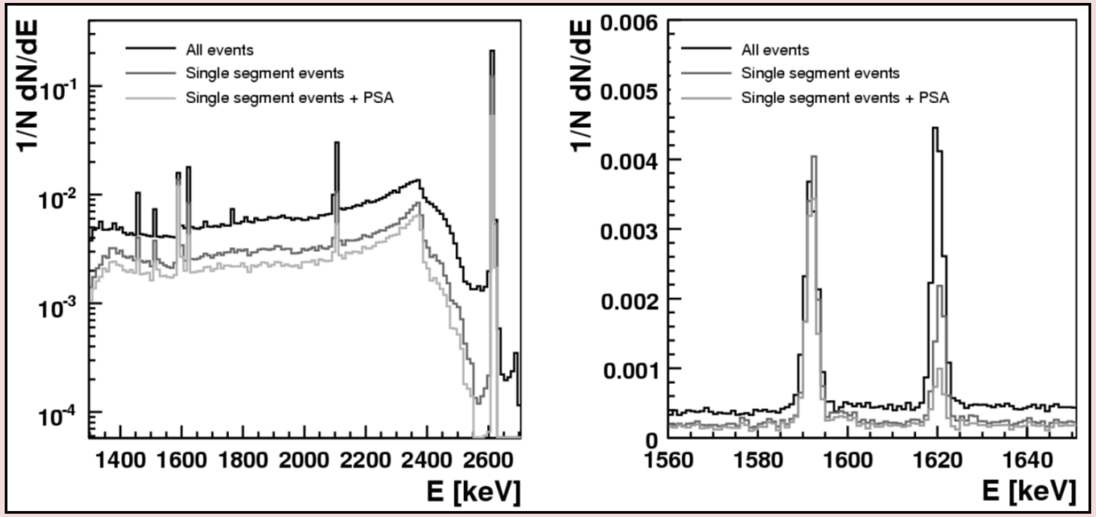
Comparison of discrimination power for ^{228}Th spectrum



BEGe point-contact

Fractions remaining after PSA cut:

DEP	89.2% ± 0.9%
1.62 MeV	10.1% ± 0.7%
2.61 MeV	9.8% ± 0.4%
ROI $Q_{\beta\beta}$	**40.2% ± 1.6%**



18-fold segmented coax

Fractions remaining after combined single-segment and PSA cut:

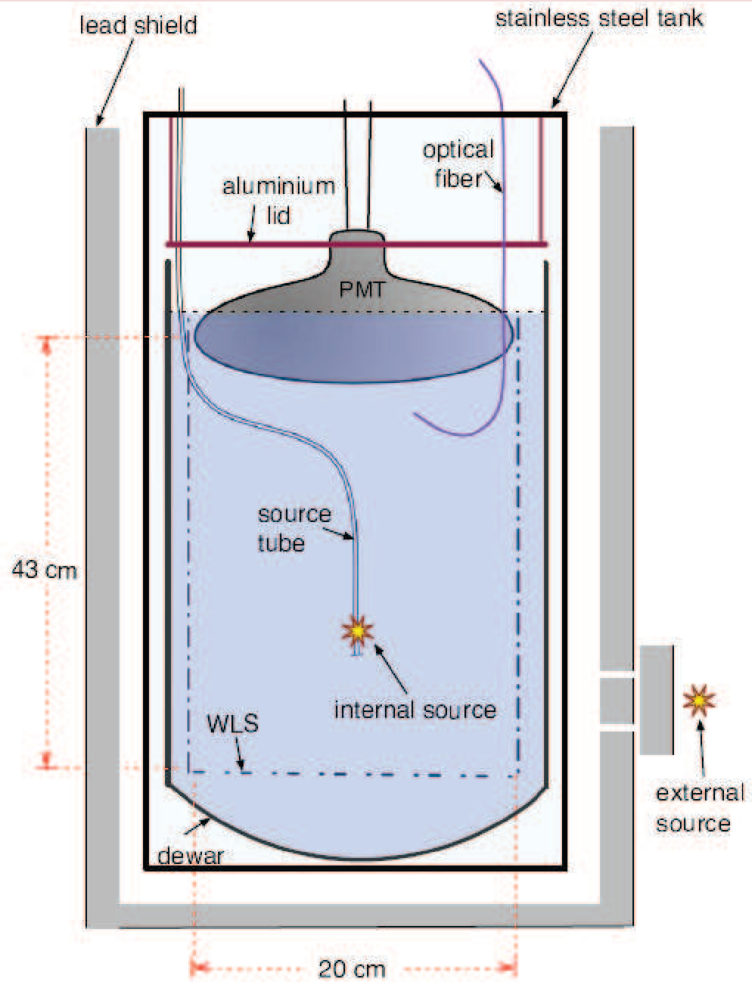
DEP	81.93% ± 2.22%
1.62 MeV	18.98% ± 0.39%
2.61 MeV	14.57% ± 0.31%
ROI $Q_{\beta\beta}$	**48.10% ± 1.12%**

(PSA data without Compton background subtraction)

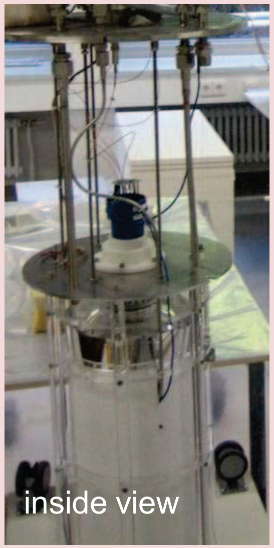
SSE/MSE discrimination with BEGe is comparable with 18-fold segmented detector

Pilot set up MiniLArGe

for developing LAr scintillation methods



Dewar:	∅29 cm, h=65 cm ≈ 60 kg **LAr** (43 L) total volume
Light detection:	wavelength shifter/reflector foil (VM2000 + TPB/PST) + PMT(8“, ETL 9357-FLB)
Active volume:	∅20 cm, h=43 cm ≈ **19 kg LAr** (13,5 L)
Shielding:	5 cm lead (+ 10 cm BP for n) +15 mwe underground



The pilot setup **Mini-LArGe on the base of LAr scintillator** was successfully operated and demonstrates the power of the LAr scintillation concept.

A long-term stability (**about 2 year**) with light yield of **1800 pe/MeV** was achieved.

The **Pulse Shape Discrimination** methods were developed, which allow to perform gamma / alpha / neutron selection with a strong discrimination factor for background suppression.

It was shown that the LAr scintillator is a powerful tool

to be used in the GERDA PhaseII and III as:

1. **Gamma spectrometer with large active volume**

   (for direct measurement of gamma background inside the GERDA facility)

2. **Large volume Neutron detector**

   (for direct measurement of neutron background and neutron – gamma delayed (anti-) coincidence inside the GERDA facility)

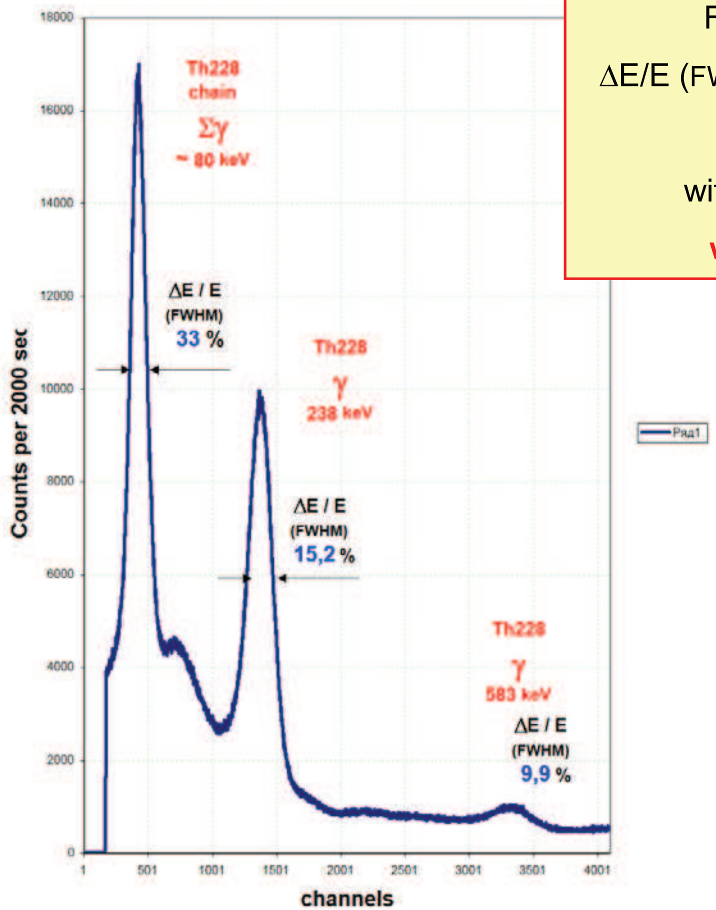
3. **Radon detector / alpha-spectrometer**

   (for direct monitoring of Radon inside the GERDA facility)

MiniLArGe as Gamma-spectrometer

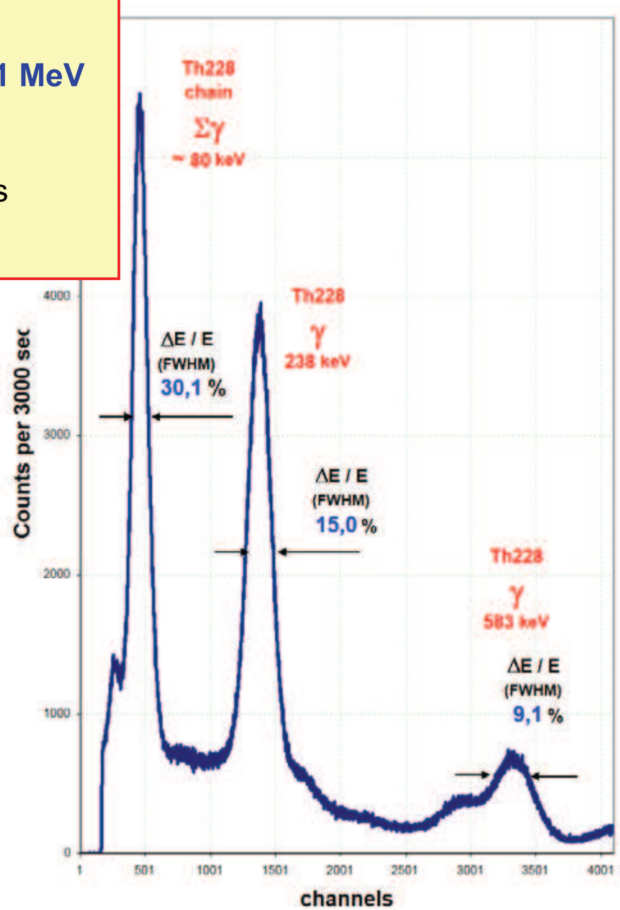
MiniLArGe

Th228 internal source (3 kBq)
Amplification = 50 x0,683
Spectrum accumulated with MCA



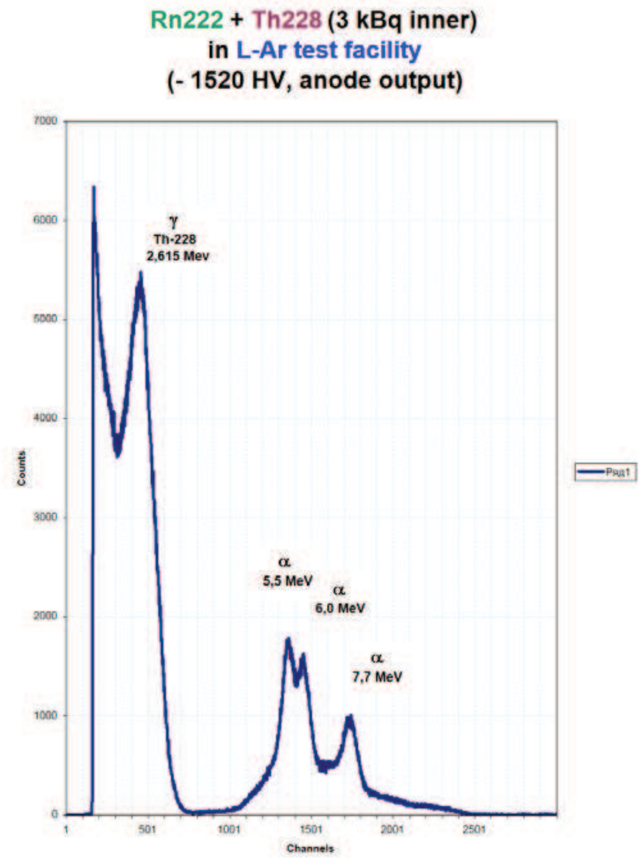
NaI (3“ x 3“)

Th228 source (3 kBq)
Amplification = 50 x0,683
Spectrum accumulated with MCA

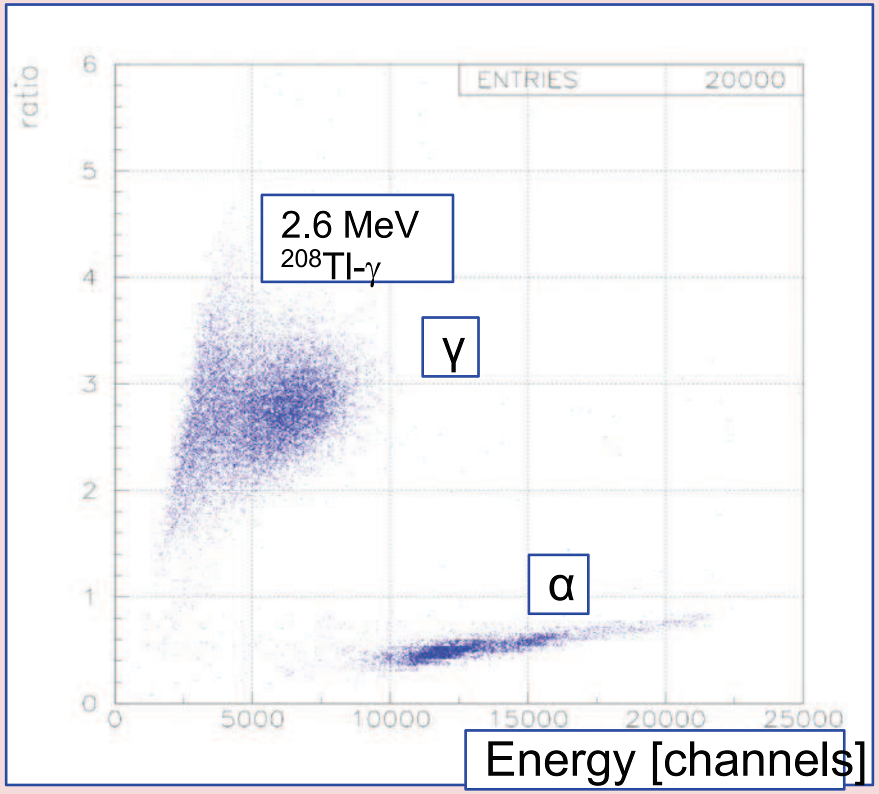


For MiniLArGe
ΔE/E (FWHM): 7,5 % at 1 MeV
compartable
with NaI detectors
was achieved

MiniLArGe as Radon detector / Alpha-spectrometer

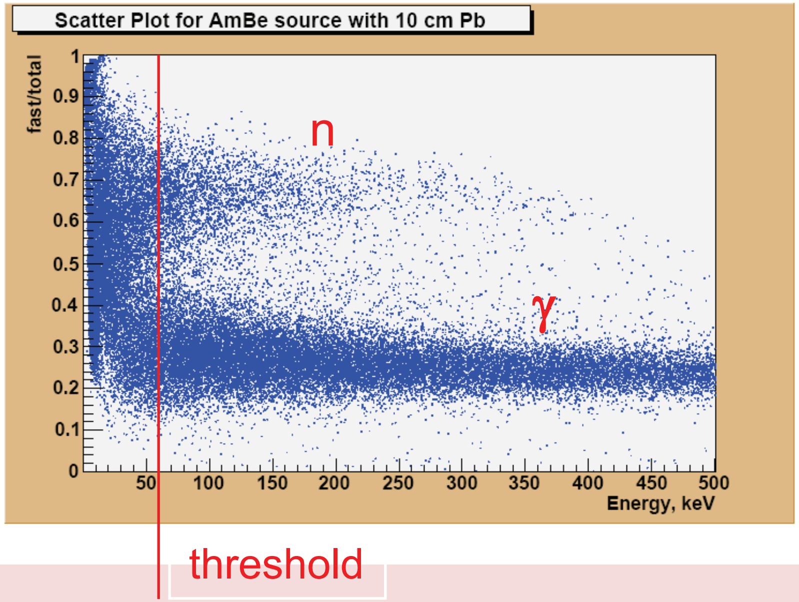


^{228}Th + ^{222}Rn – ratio s/f vs. energy



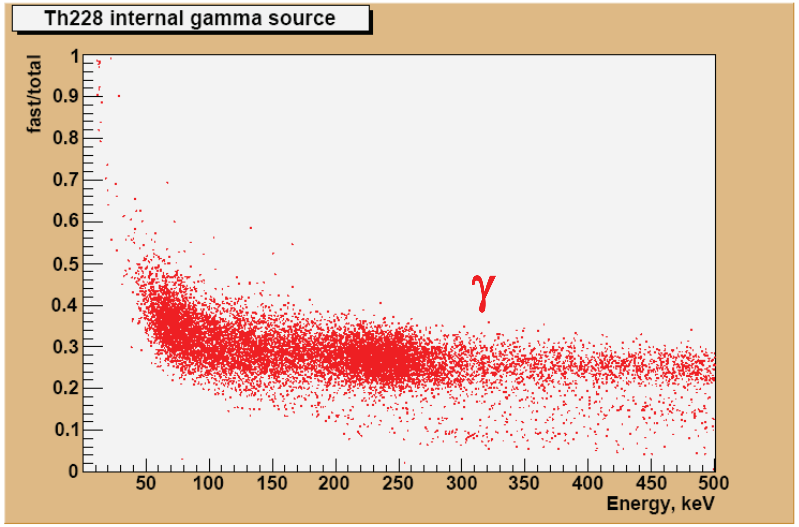
MiniLArGe as Neutron detector

AmBe (neutron+gamma) source
Neutron flux is 2x 10^3 1/sec

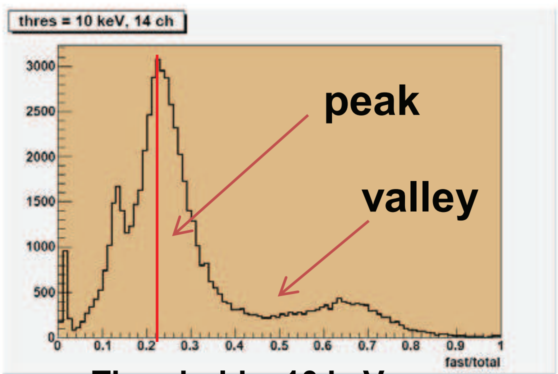


Scatter plot fast/total vs energy

Th-228 gamma sources



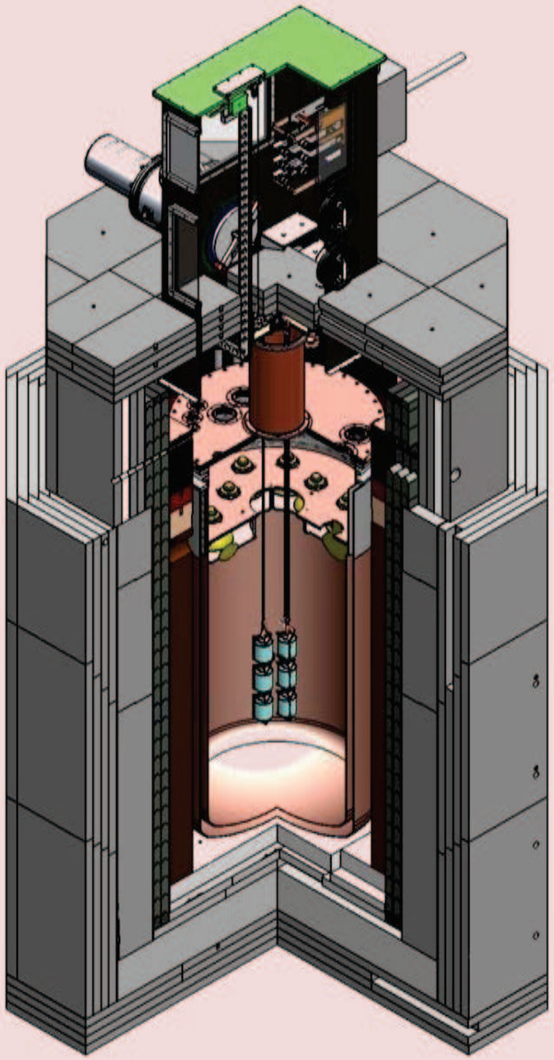
Scatter plot fast/total vs energy



Threshold =10 keV

For more details see P.Peiffer et al., "Pulse shape analysis of scintillation signals from pure and xenon-doped liquid argon for radioactive background identification", JINST (2008) 3 P08007.

The LArGe Setup
with 1.3 tons of LAr



Lock: Can house up to 3 strings (9 detectors)

9 PMTs: 8” ETL9357

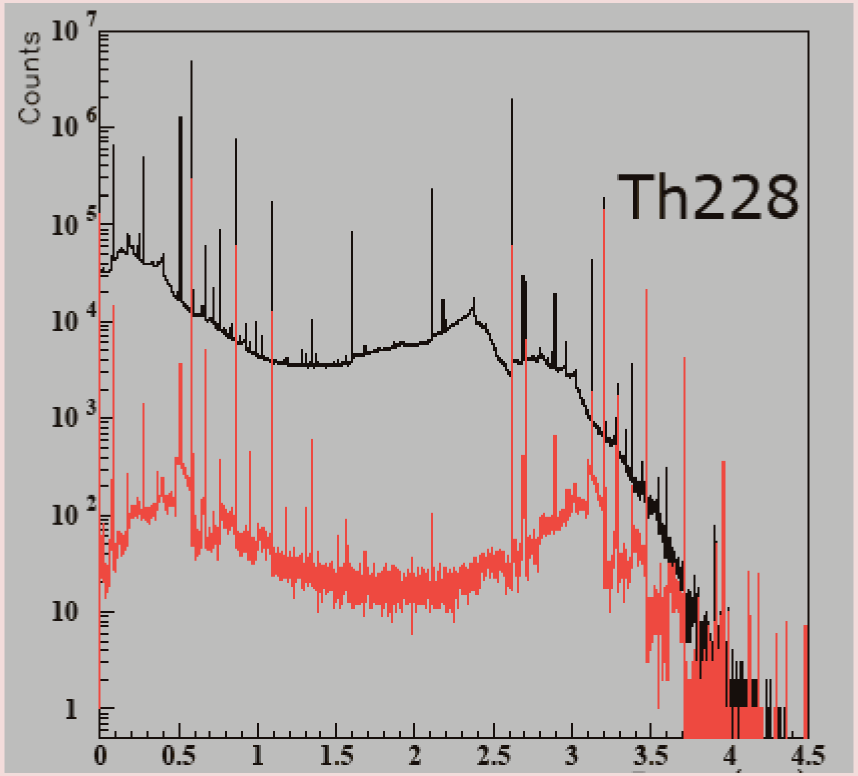
VM2000 & **wavelength shifter**

Cryostat: Inner diameter: 90 cm,
Volume: **1000 liter**

Shield:	Cu	15 cm
	Pb	10 cm
	Steel	23 cm
	PE	20 cm

LAr scintillation veto by tagging extra energy in LAr

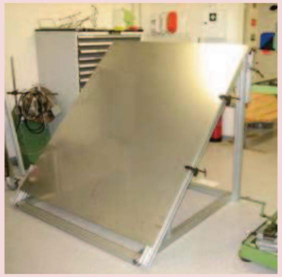
P. Peiffer et al., Nucl. Phys. B. Proc. Supp. 143(2005) 511

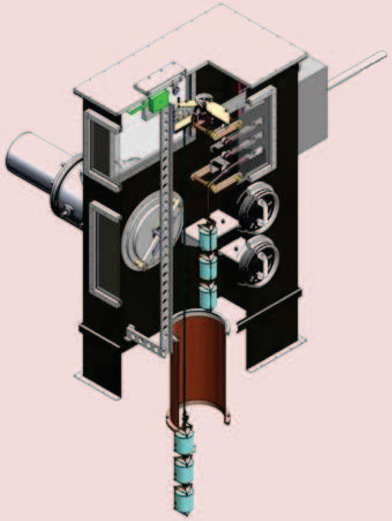


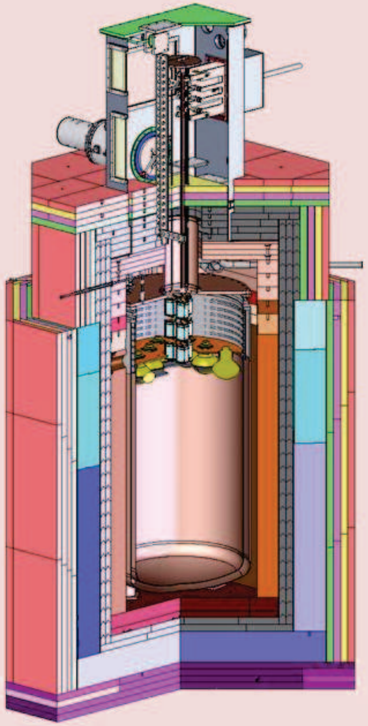
Factor 300 reduction in ROI

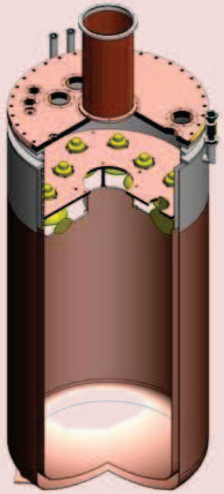
LArGe was assembled and testing
in the day surface lab.

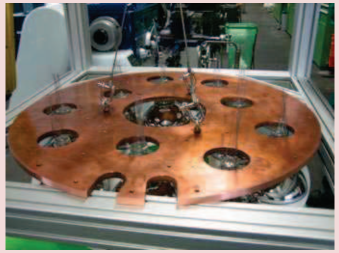
Ready to go to LNGS underground facility GDL

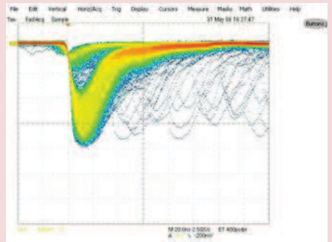


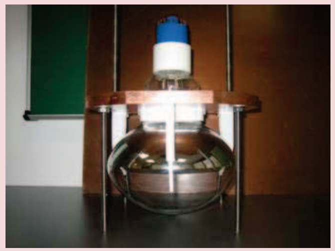












Outlooks & Plans

Final assembling of **the LArGe test facility** is planned on Autumn 2009.
It is planned to perform the test & background measurements in this facility.
The commissioning of the main **GERDA** setup at LNGS will start from September **2009**.

Phase I (2009 – 2011):

After 1year of data taking (an exposure of 15 kg x y), with the background **10^{-2} counts/(keV kg y),** the GERDA can either confirm the claimed observation of ββ0ν decay or refute it at the high statistical level without problems with uncertainties in NME.

If no events will be observed, the limit on the half life would amount to **$T_{1/2} > 3 \times 10^{25}$ y** or, translated into an effective neutrino mass, **$m_\nu < 0.2 – 0.9$ eV**, depending on NME used (*for instant, **m_ν < 194 meV** corresponds to **$|M_{0\nu}|$ =5.46** from the recent paper : J. Barea and F. Iachello, Phys.Rev. C **79**, 044301 (2009)*)

Phase II (from 2011):

The total mass with the new types of ^{76}Ge detectors will be 40 kg.
After exposure of 100 kg x years and with the background reduced up to **10^{-3} counts/(keV kg y),** the limit on $T_{1/2}$ would improve to **$> 1.5 \times 10^{26}$ y.**
This translates to an upper limit on the effective neutrino mass of **0.08 - 0.29 eV.**

*Phase I will cover the area of sensitivity **required to scrutinize the claim** and Phase II will cover **the degenerate neutrino mass hierarchy.***

Phase III :

A **ton scale** ^{76}Ge experiment

with further background reduction up to **10^{-4}counts/(keV_kg_y)**

undertaken in the worldwide **GERDA-MAJORANA** collaboration

will be required ***to cover the inverted hierarchy region***.

The full scale **GERDA-MAJORANA** experiment is proposed **to start from 2014**.

The GERDA collaboration consists
of about 90 physicists from 14 institutions coming from 6 countries

GERDA Collaboration

INFN LNGS, Assergi, Italy

JINR Dubna, Russia

MPIK, Heidelberg, Germany

Univ. Köln, Germany

Jagiellonian University, Krakow, Poland

Univ. di Milano Bicocca e INFN, Milano, Italy

INR, Moscow, Russia

ITEP Physics, Moscow, Russia

Kurchatov Institute, Moscow, Russia

MPI, München, Germany

Univ. di Padova e INFN, Padova, Italy

Univ. Tübingen, Germany

IRMM, Geel, Belgium

University Zurich, Switzerland

90 physicists / 14 institutions / 6 countries

http://www.mpi-hd.mpg.de/ge76

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