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 <u>best limits</u> on (0νββ)-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

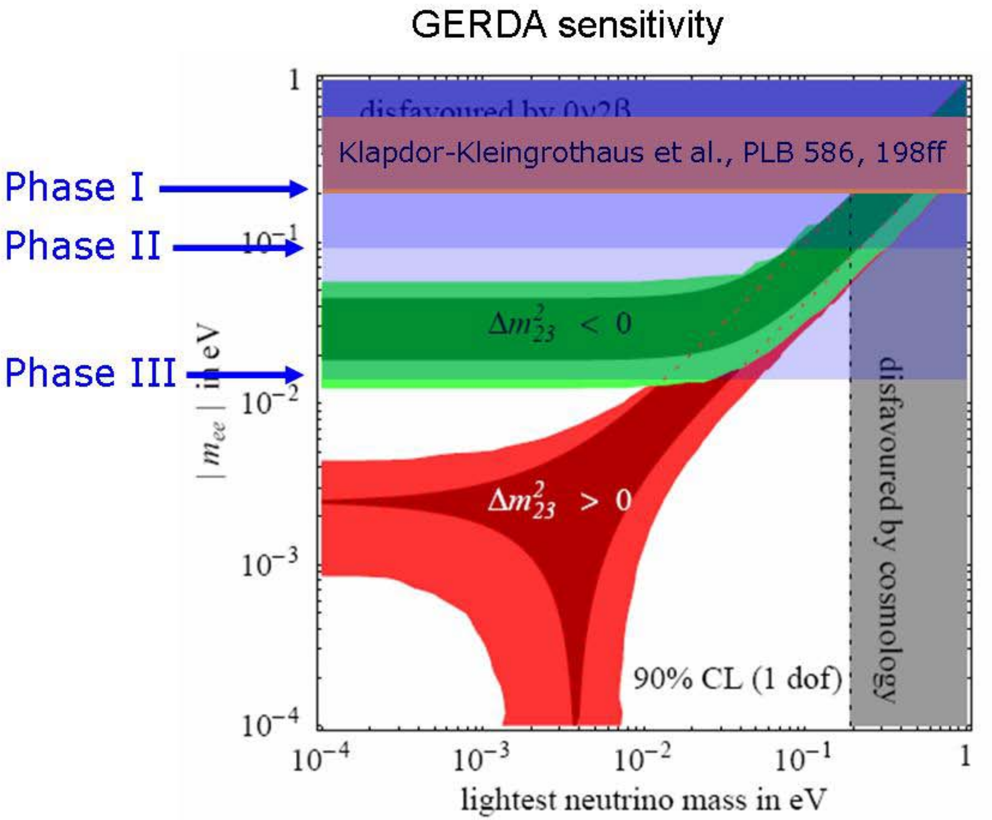
with using Enriched Germanium (86% in ^{76}Ge, $Q_{\beta\beta}$=2038,5 keV)

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 0νββ observation with the best fit **$T_{1/2}$ = 1.2×10^{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

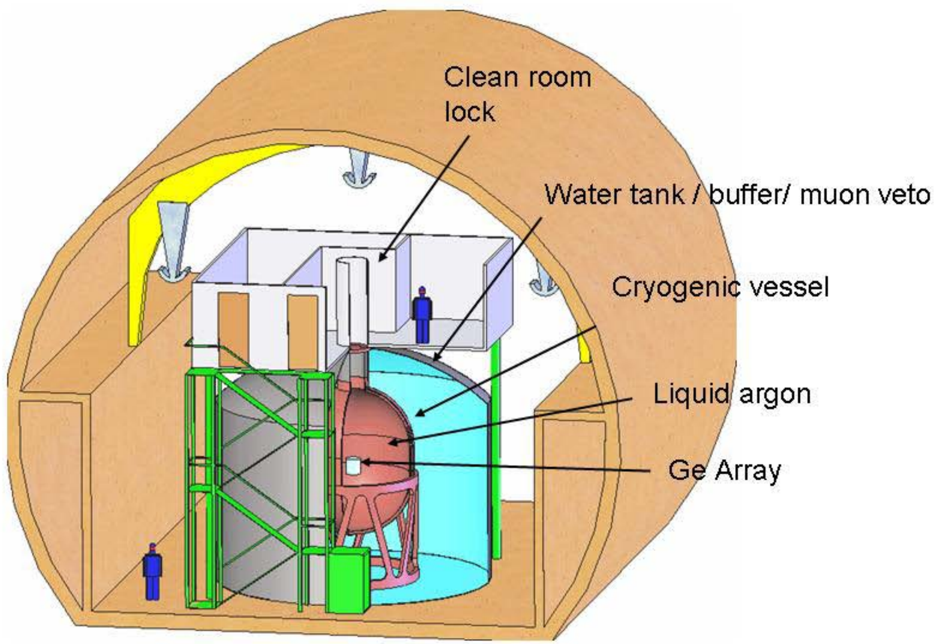
To achieve the planned sensitivity it is necessary
to reduce the previous background level dramatically
(**several orders of magnitude !)**

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:

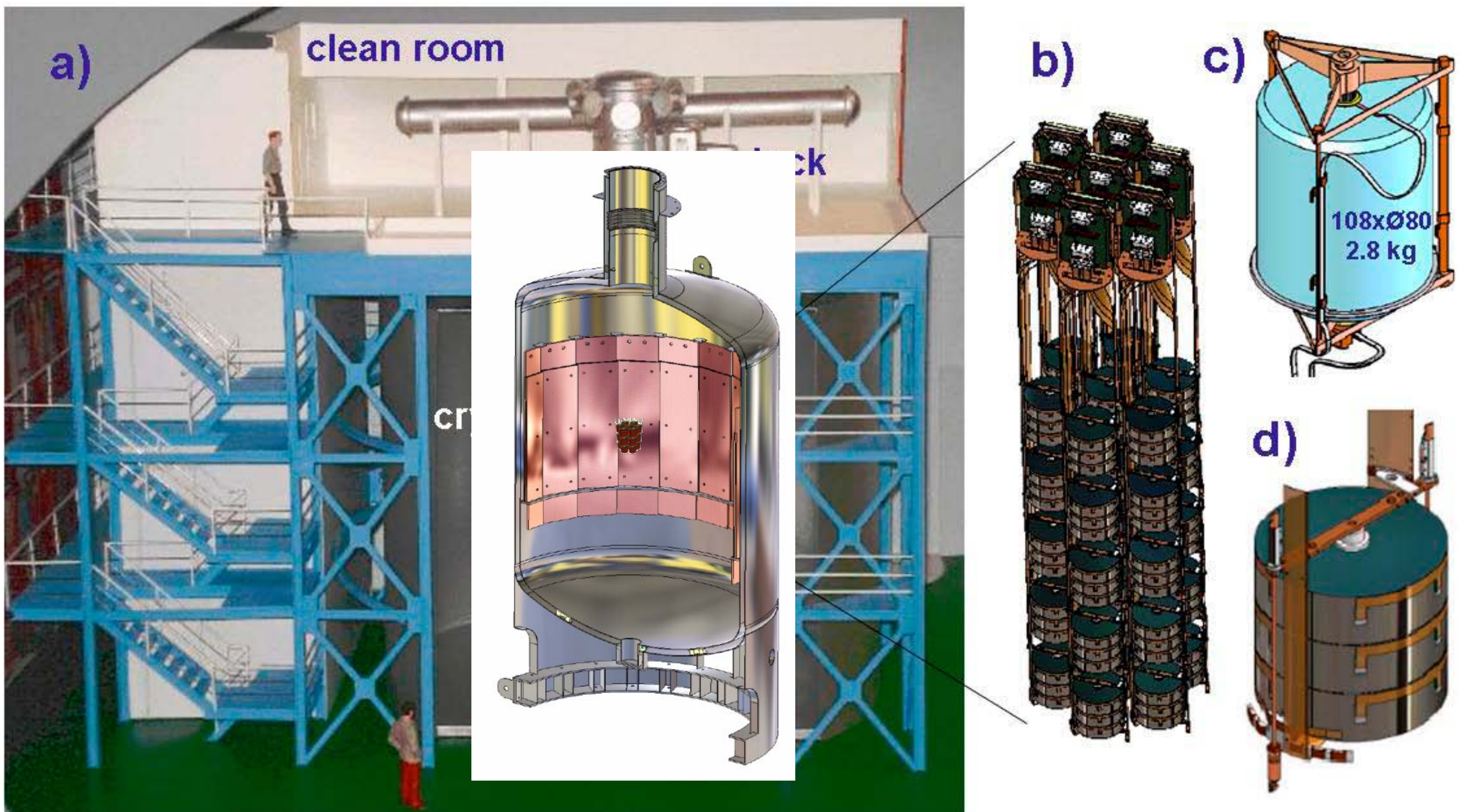
1) the higher reduction factor of the external background due to **higher LAr density (1.4 g/cm^3);**
2) **anti-coincidence with LAr scintillation** should reduce both the inner and external background;

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)**.

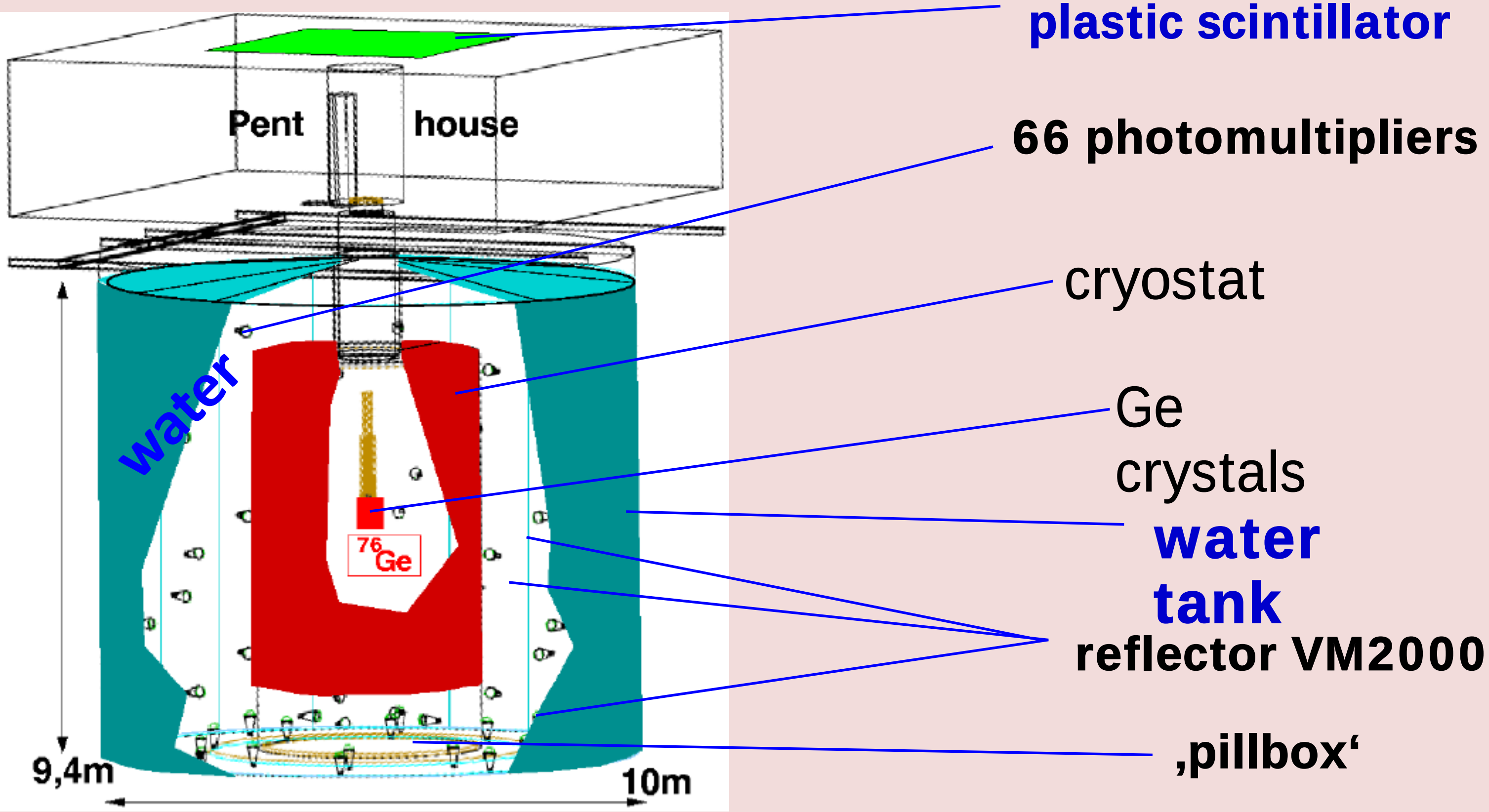
The Ge detector array is made up of individual detector strings and is situated in the central part of the **cryostat.**



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.

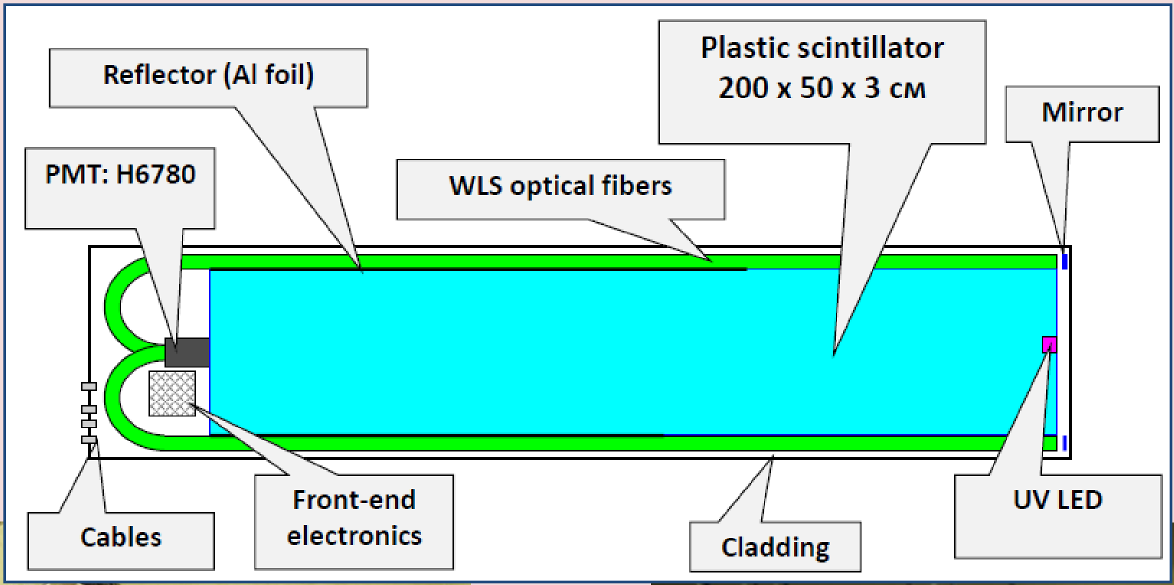


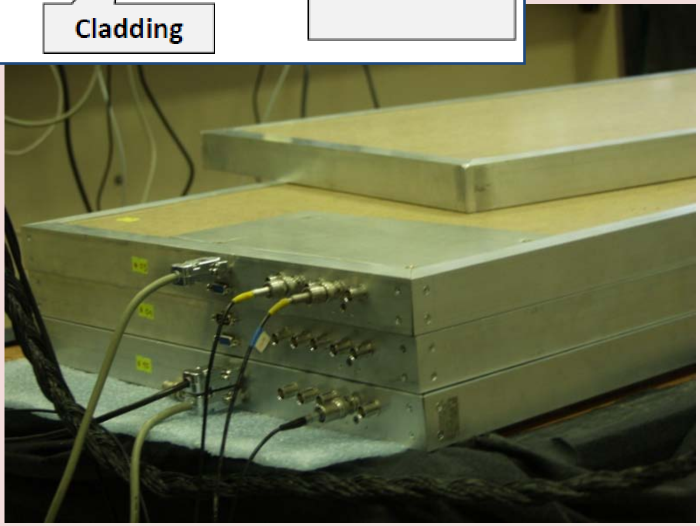
For more details see **"The GERDA Muon Veto Cherenkov Detector"**, presented by **Markus Knapp** at the TAUP 2009 Poster Session

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).

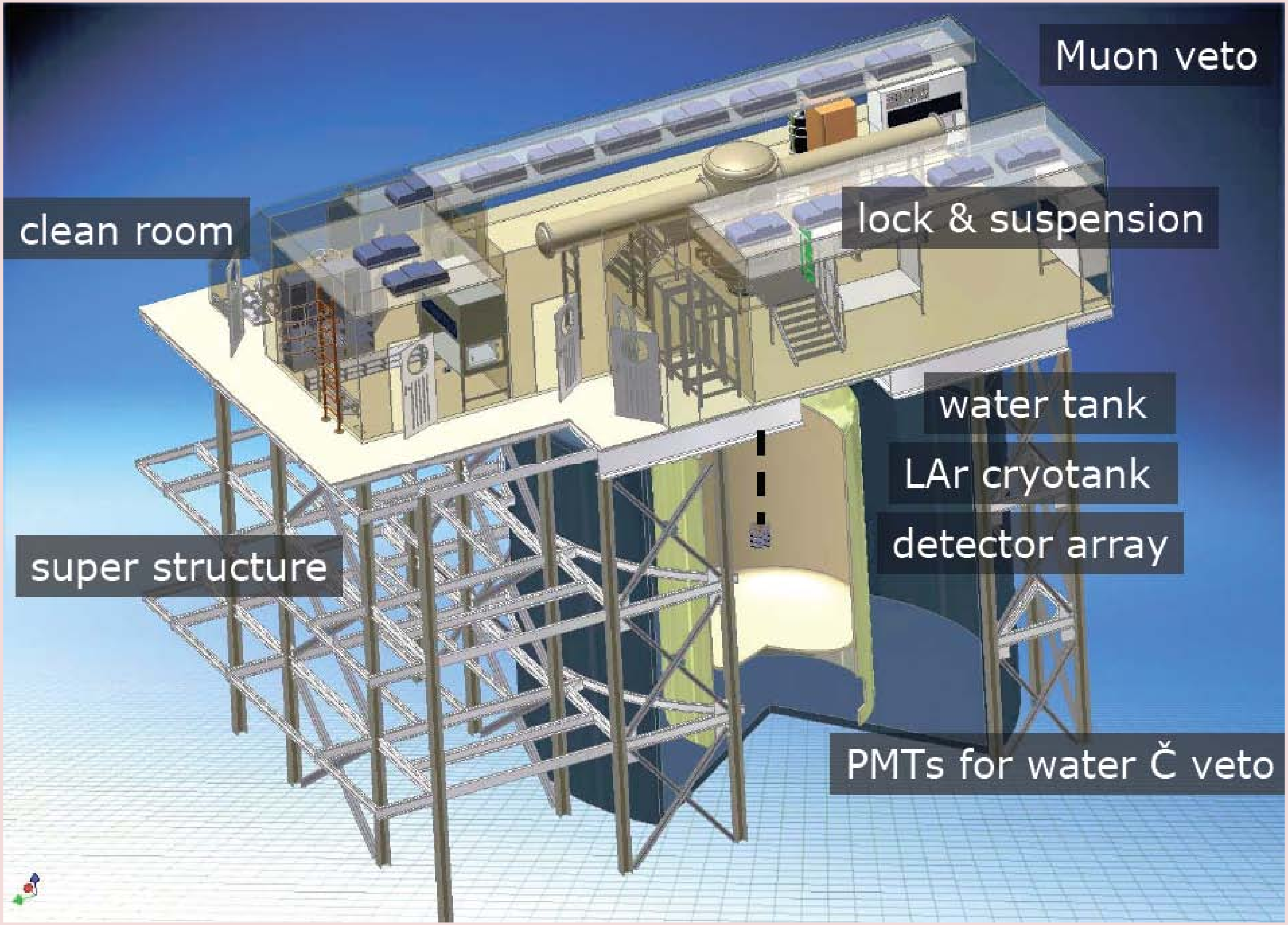
It is shown that the **muon vetoing efficiency of about 98 %** can be achieved.





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

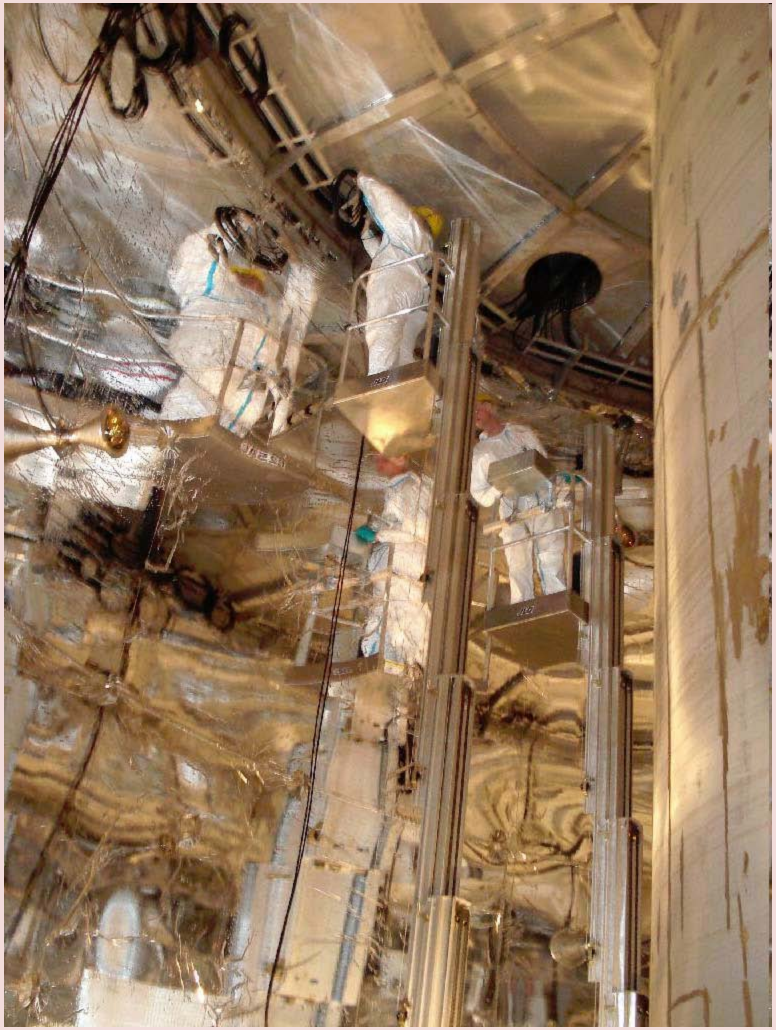
in the deep underground facility

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

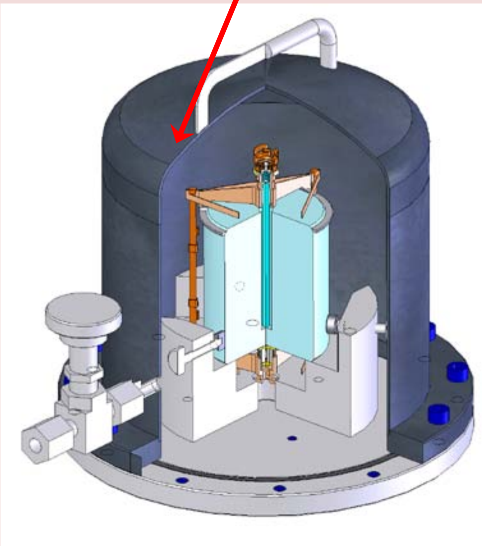
Phase I detectors

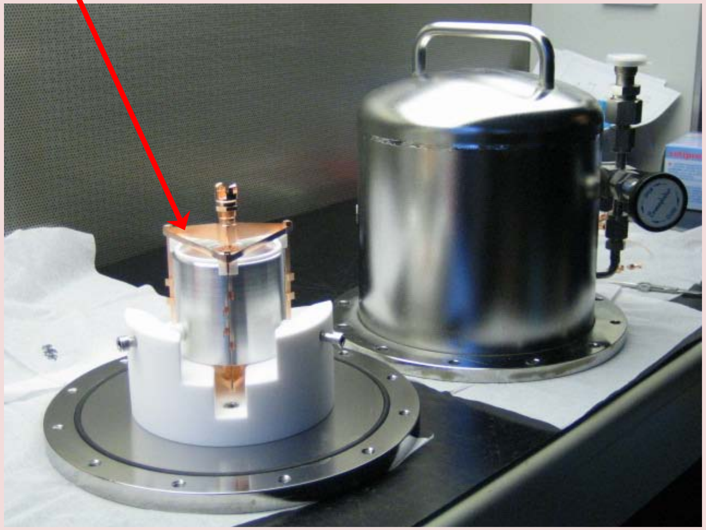
- 8 enriched (IGEX and HdM) and
  6 non-enriched crystals (GENIUS-TF)

  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]

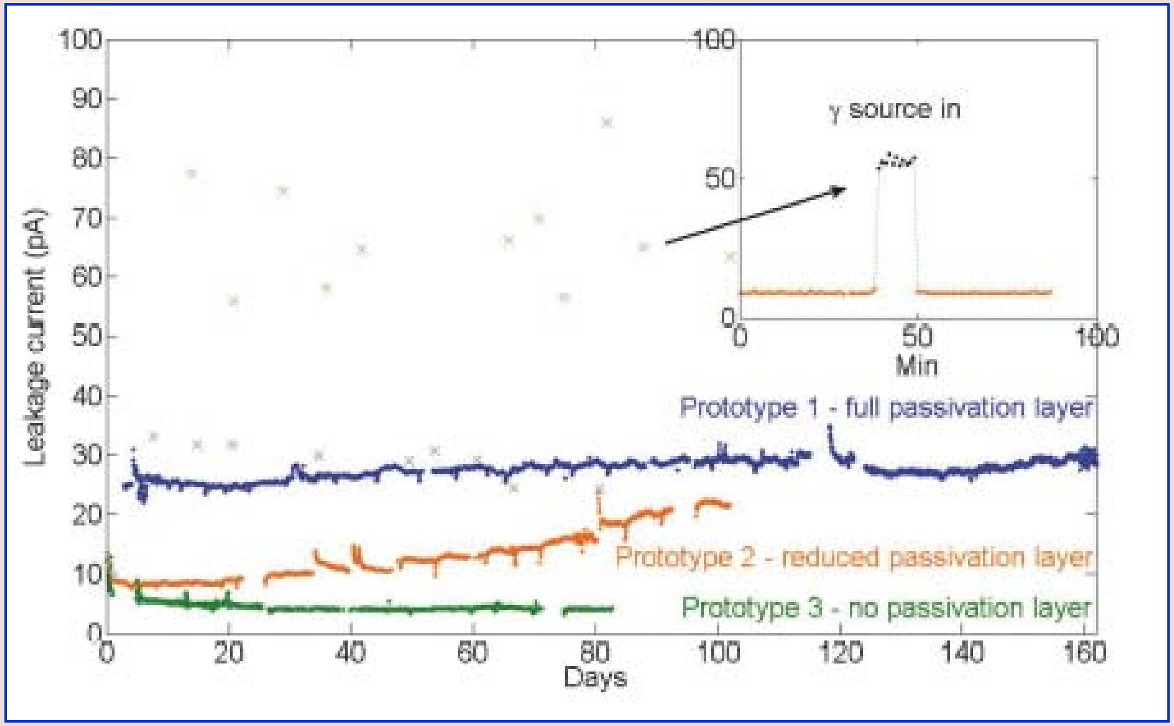
have been overcome by GERDA.

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.

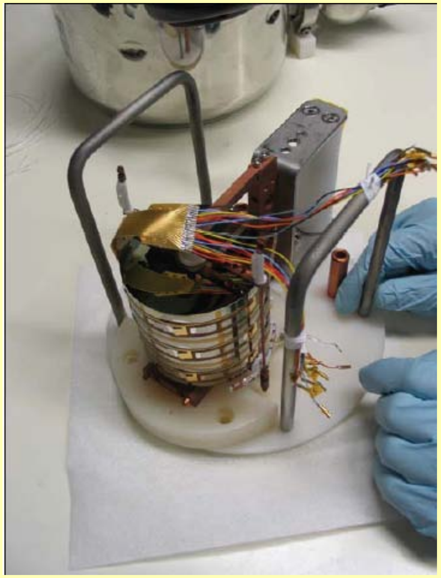
1. Research and development are carried out to produce new segmented and BeGe types of germanium detectors which can **resolve multi-site energy deposits**.

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

$\Delta E/E$ (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

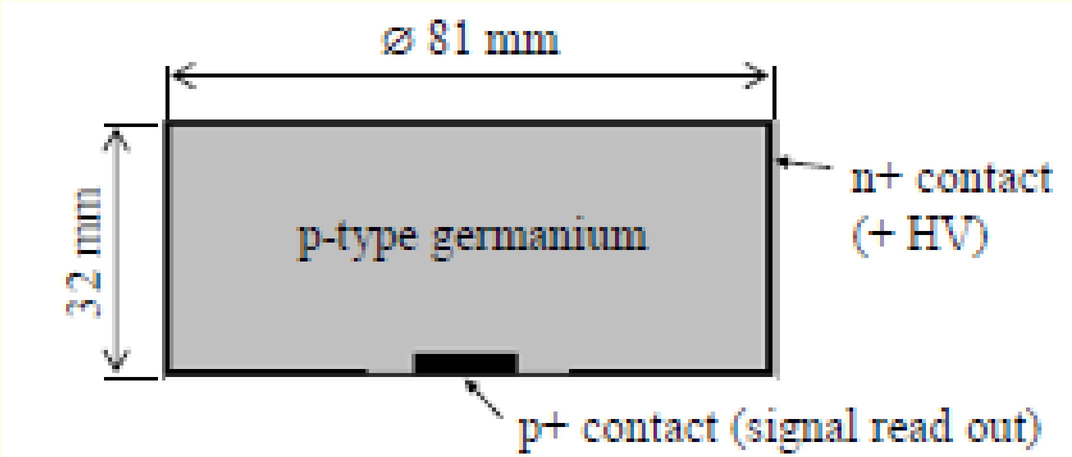
For more details see
“First Time Ever: 18-fold Segmented HPGe Detector in LN2”,
presented by Jing Liu at the TAUP 2009 Poster Session

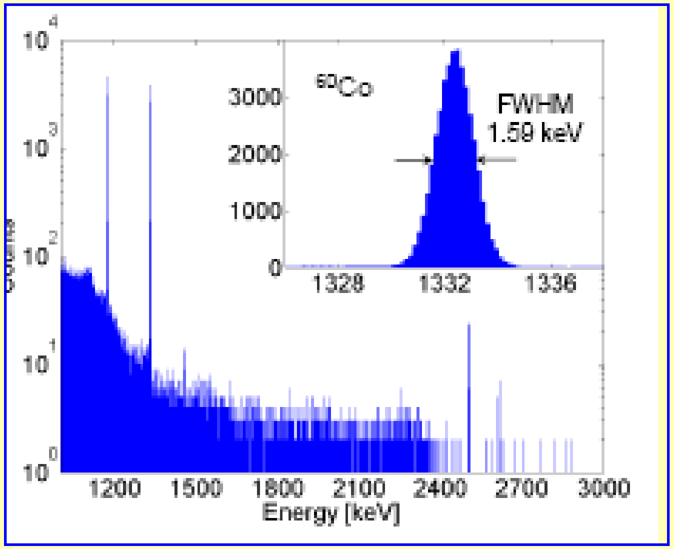
Phase-II detector candidate # 2:
BeGe (broad-energy) detector

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

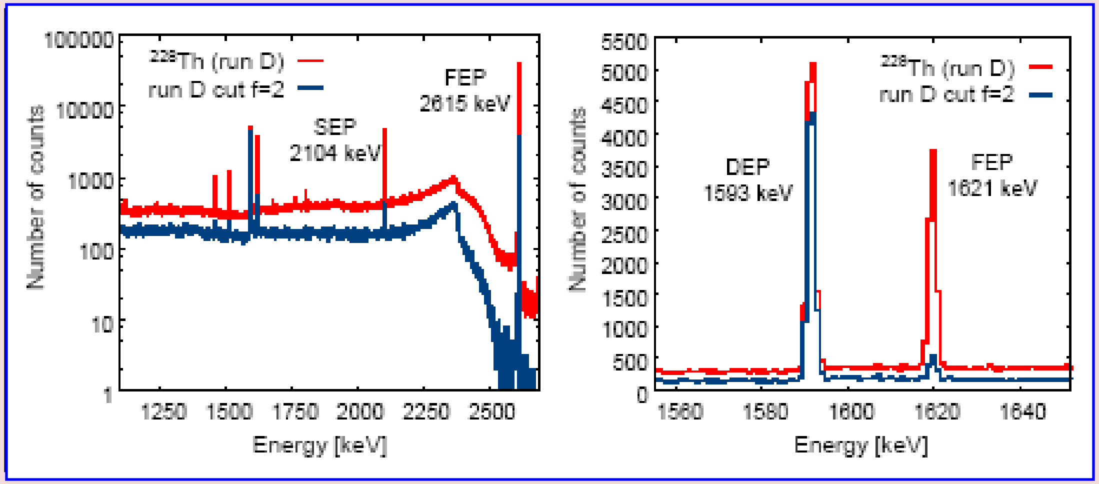
Parameters obtained during R&D for GERDA:

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

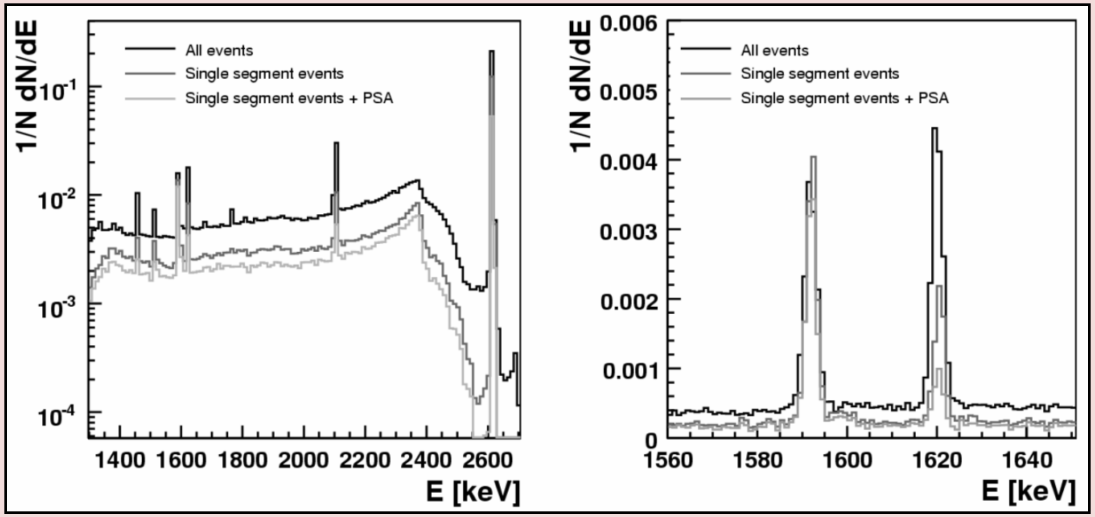
Comparison of discrimination power for ^{228}Th spectrum



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

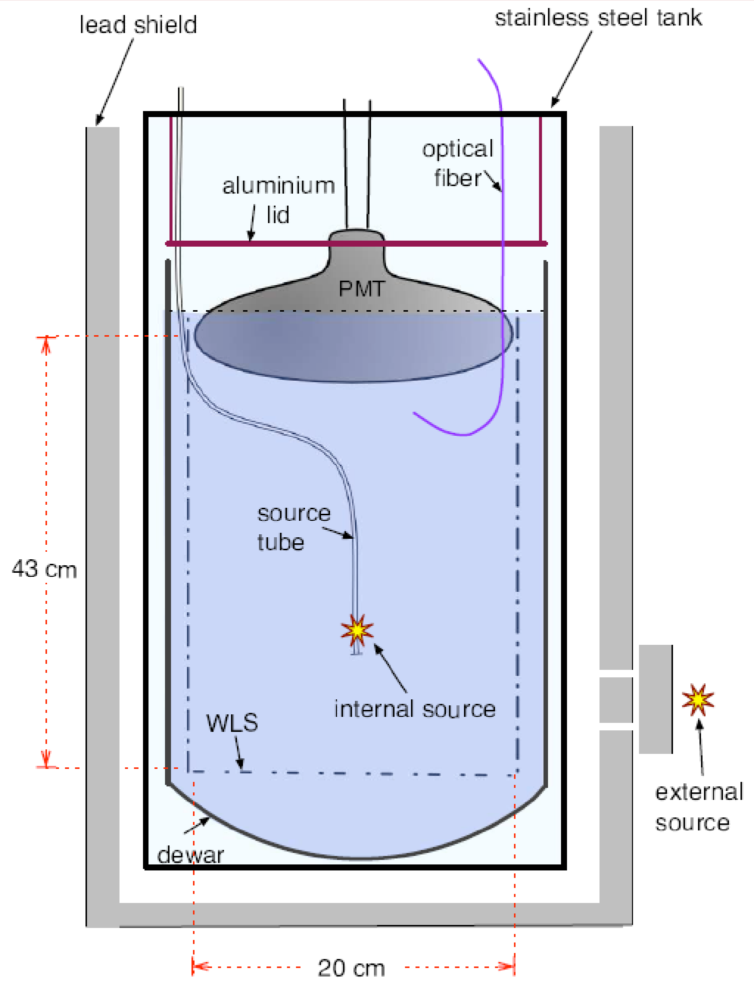
Fractions remaining after combined single-segment and PSA cut:

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%**

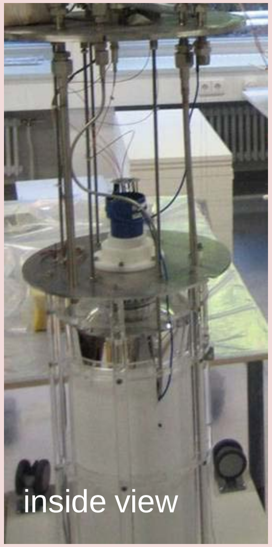
(PSA data without Compton background subtraction)

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)

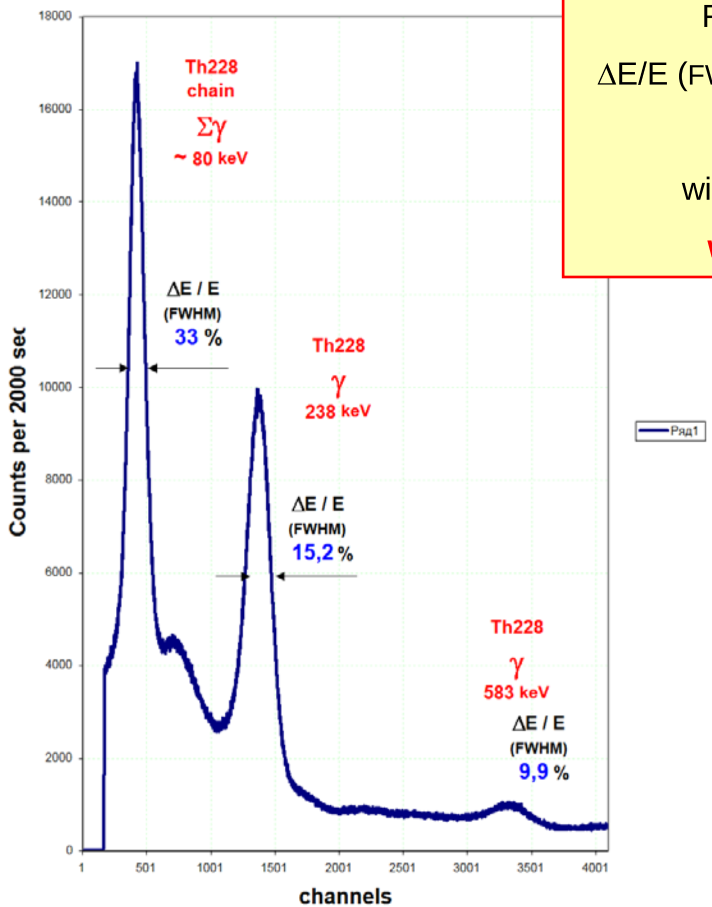
3. **Radon detector / alpha-spectrometer**

   (for direct monitoring of Radon inside the GERDA facility)

MiniLArGe as Gamma-spectrometer

MiniLArGe

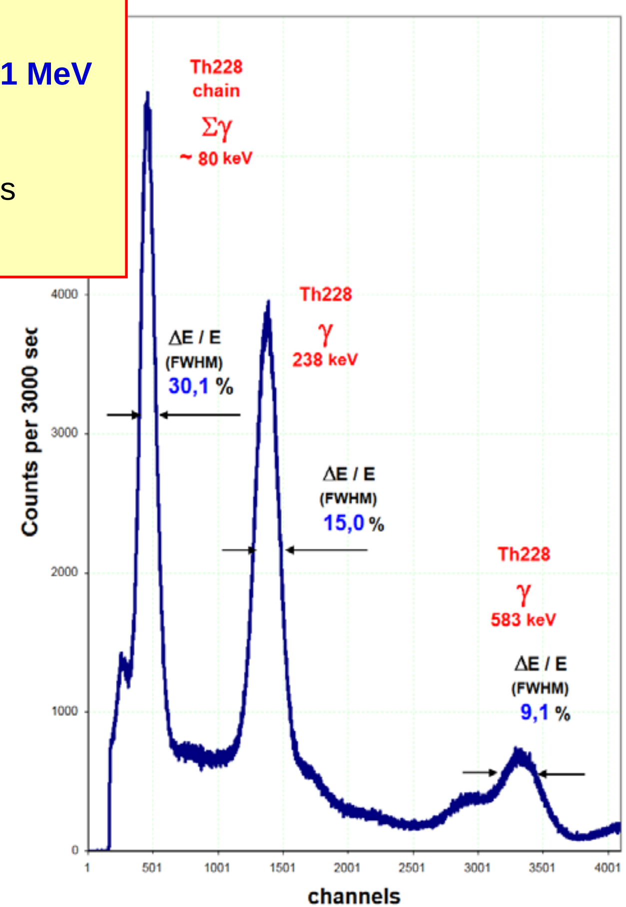
Th228 internal source (3 kBq)
Amplification = 50 x0,683
Spectrum accumulated with MCA



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

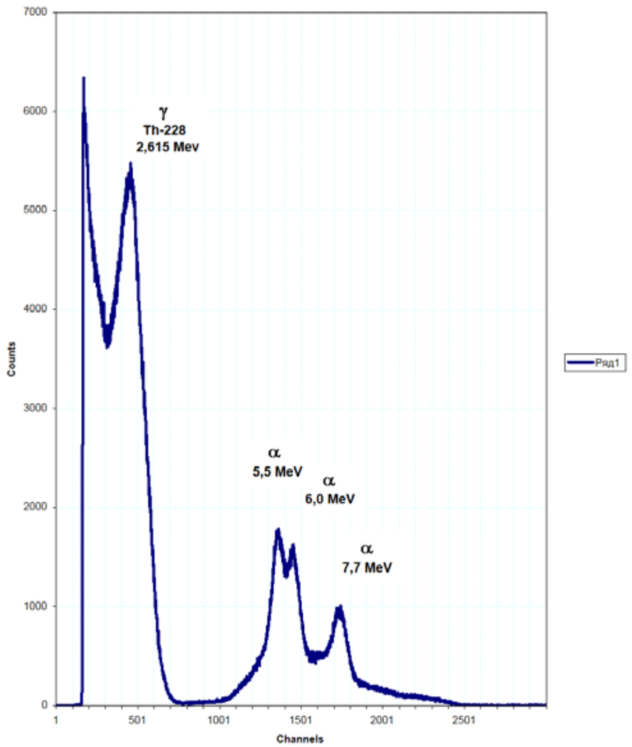
NaI (3“ x 3“)

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

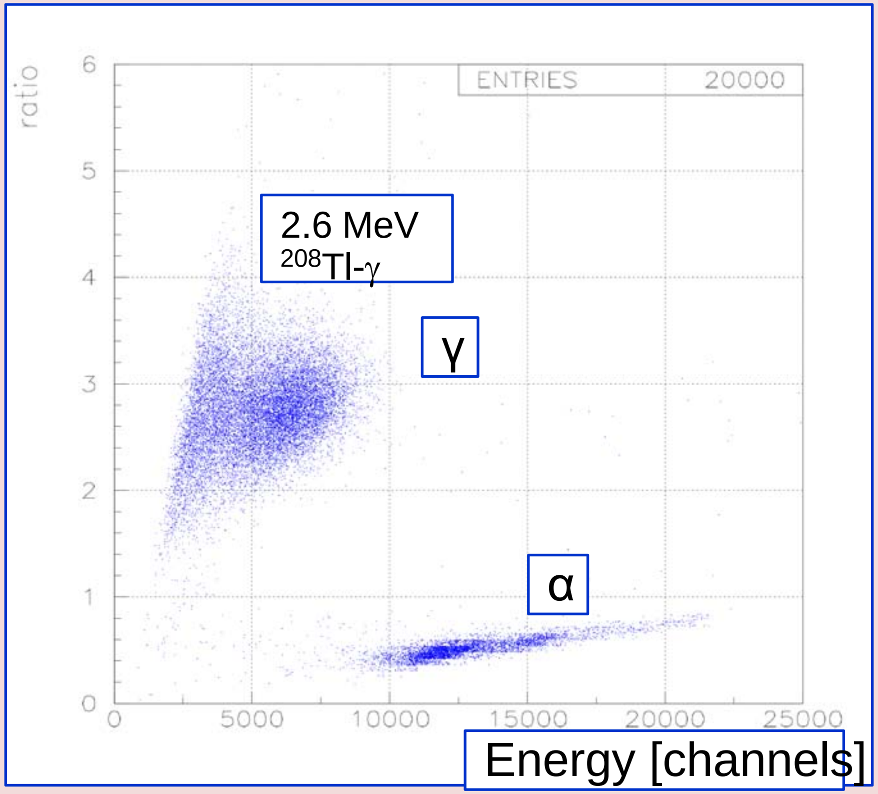


MiniLArGe as Radon detector / Alpha-spectrometer

Rn222 + Th228 (3 kBq inner)
in L-Ar test facility
(- 1520 HV, anode output)

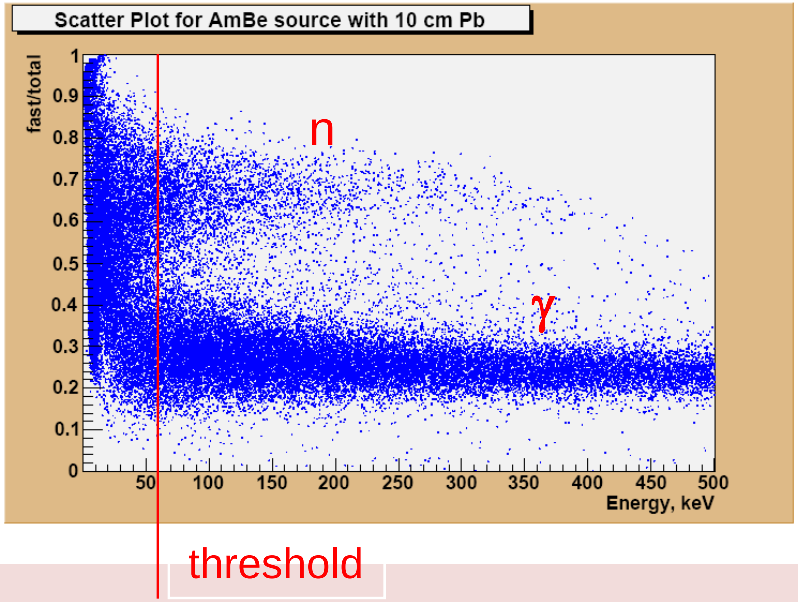


^{228}Th + ^{222}Rn – ratio s/f vs. energy



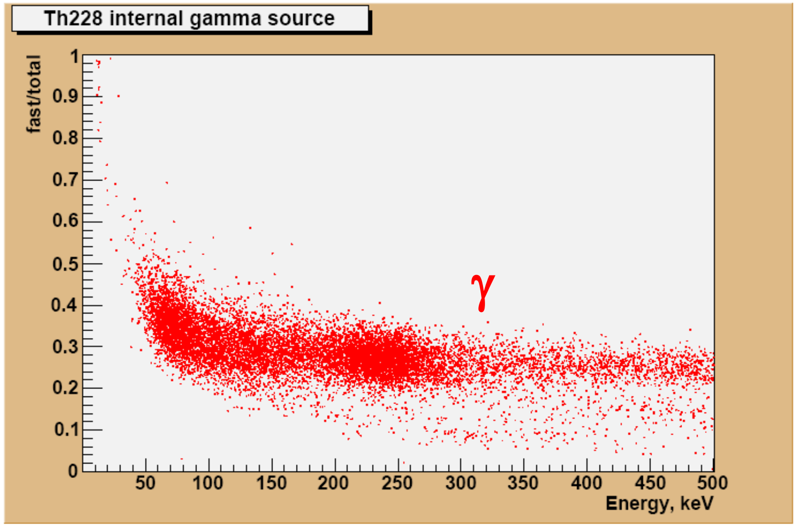
MiniLArGe as Neutron detector

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

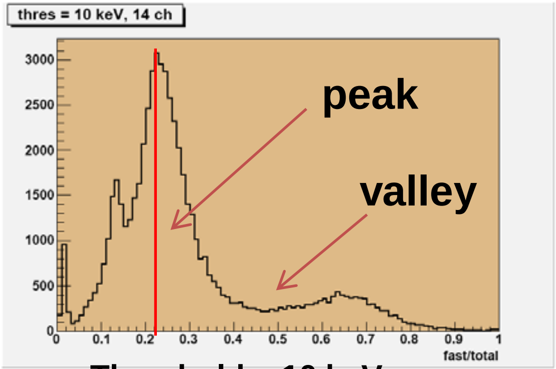


Scatter plot fast/total vs energy

Th-228 gamma sources



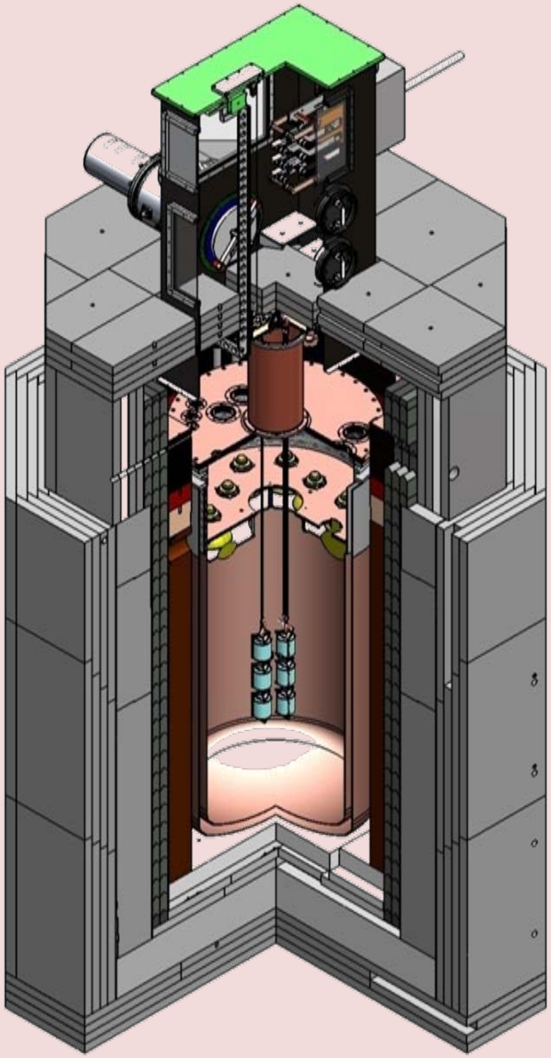
Scatter plot fast/total vs energy



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

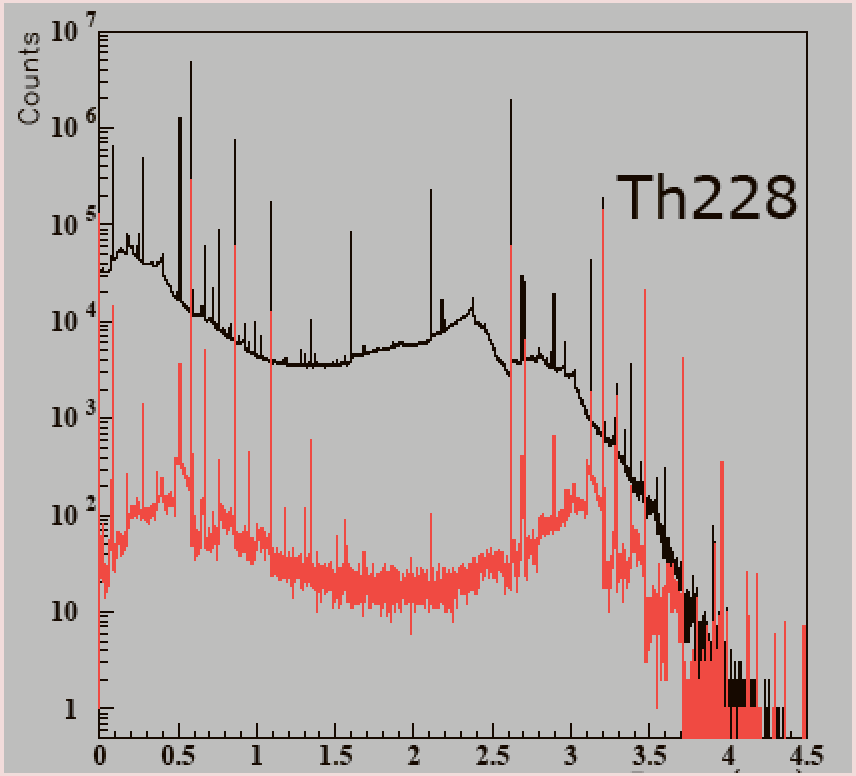
VM2000 & **wavelength shifter**

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

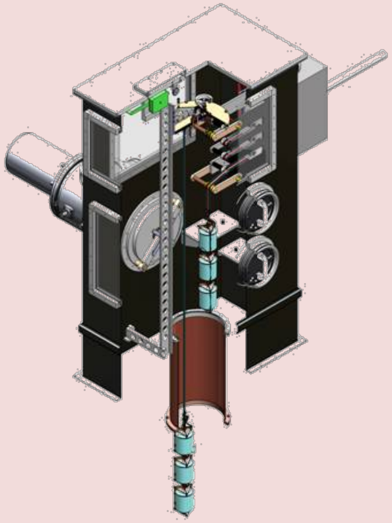
P. Peiffer et al., Nucl. Phys. B. Proc. Supp. 143(2005) 511

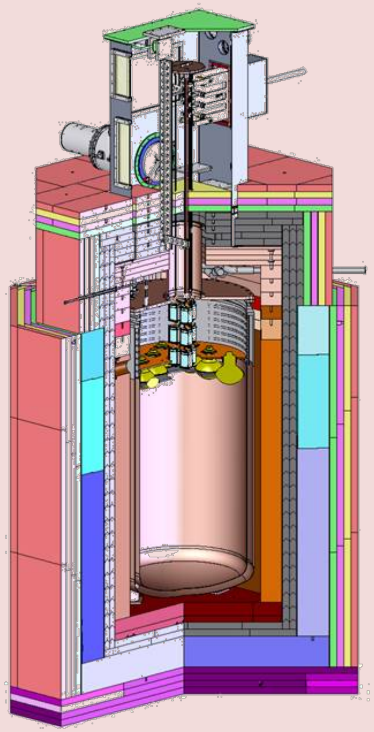


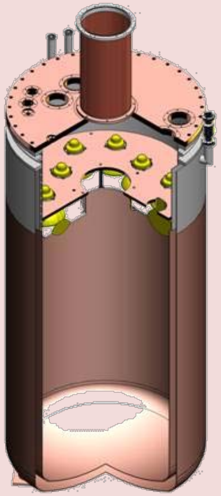
Factor 300 reduction in ROI

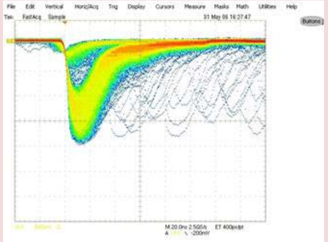
LArGe was assembled and testing
in the day surface lab.

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 $\beta\beta0\nu$ 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_ν < 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 **> 1.5×10^{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

Back up slides

PHYSICAL REVIEW C **79**, 044301 (2009)

Neutrinoless double-β decay in the microscopic interacting boson model

J. Barea and F. Iachello

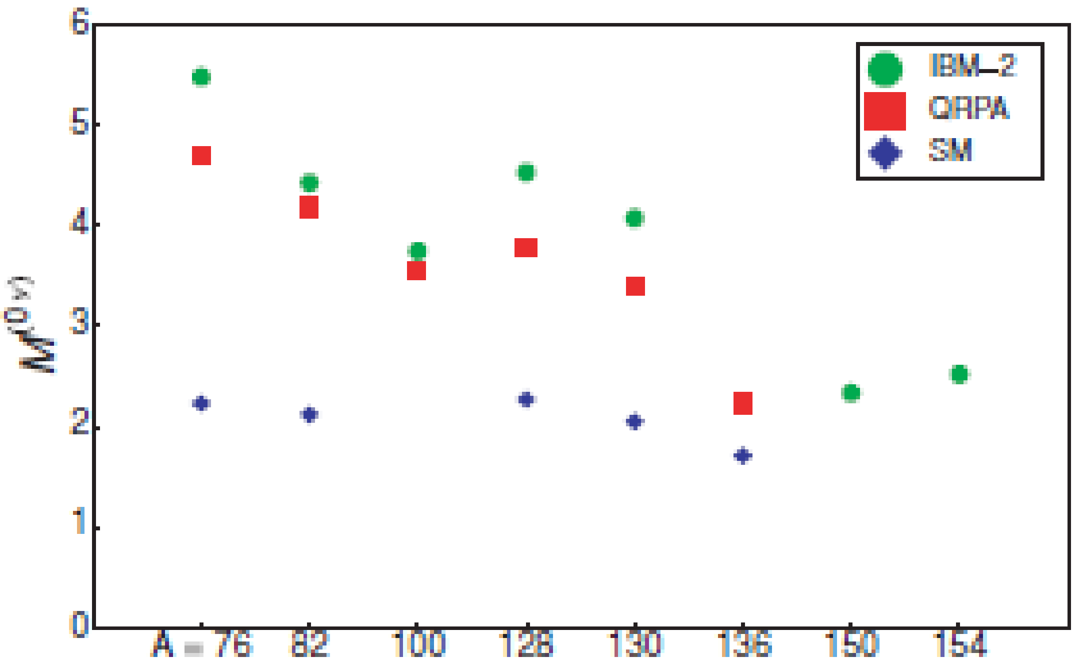


FIG. 2. (Color online) Neutrinoless double-β decay matrix elements in the formulation of Šimkovic *et al.* [10] for IBM-2, Set I (this work), QRPA with $g_A = 1.25$ and Jastrow SRC [20], and SM [8].

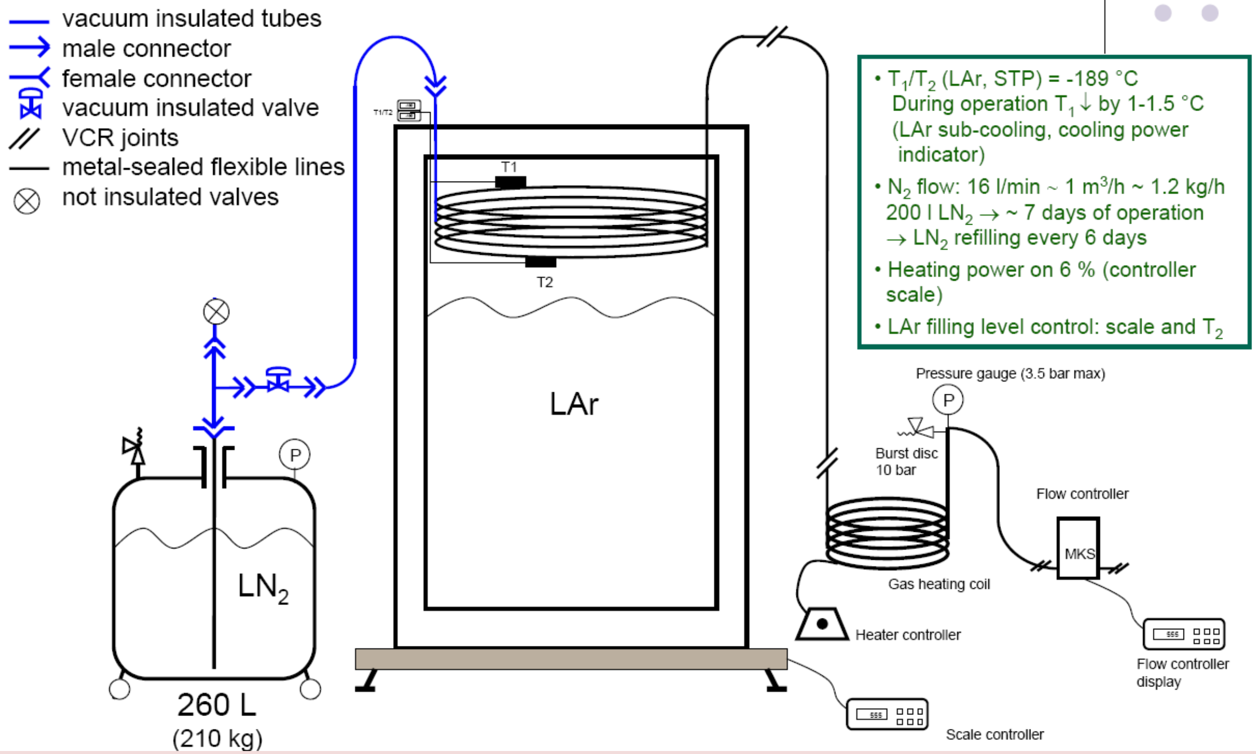
TABLE IV. Neutrinoless nuclear matrix elements to ground state including HOC calculated in IBM-2, SM [8], and QRPA [20] (last three columns). Previous three columns show the break down in F, GT and T contribution to IBM 2. All matrix elements in dimensionless units.

	IBM-2 $M_F^{(0\nu)}$	$M_{GT}^{(0\nu)}$	$M_T^{(0\nu)}$	IBM-2	QRPA $M^{(0\nu)}$	SM
$^{76}Ge \to {}^{76}Se$	−2.529	4.096	−0.250	5.465	4.680	2.220
$^{82}Se \to {}^{82}Kr$	−2.197	3.260	−0.254	4.412	4.170	2.110
$^{100}Mo \to {}^{100}Ru$	−0.327	3.318	0.204	3.732	3.530	
$^{128}Te \to {}^{128}Xe$	−1.897	3.463	−0.161	4.517	3.770	2.260
$^{130}Te \to {}^{130}Xe$	−1.693	3.119	−0.144	4.059	3.380	2.040
$^{136}Xe \to {}^{136}Ba$					2.220	1.700
$^{150}Nd \to {}^{150}Sm$	−0.279	2.034	0.108	2.321		
$^{154}Sm \to {}^{154}Gd$	−0.255	2.226	0.118	2.507		

LArGe cryostat

1.3 tons of LAr

Nitrogen active cooling



- T_1/T_2 (LAr, STP) = -189 °C
  During operation $T_1 \downarrow$ by 1-1.5 °C
  (LAr sub-cooling, cooling power indicator)
- N_2 flow: 16 l/min ~ 1 m^3/h ~ 1.2 kg/h
  200 l $LN_2 \rightarrow$ ~ 7 days of operation
  $\rightarrow LN_2$ refilling every 6 days
- Heating power on 6 % (controller scale)
- LAr filling level control: scale and T_2

A Cryogenic Low-noise JFET-CMOS Preamplifier for the HPGe Detectors of GERDA

A. Pullia, F. Zocca, S. Riboldi, D. Budjáš, A. D'Andragora, C. Cattadori

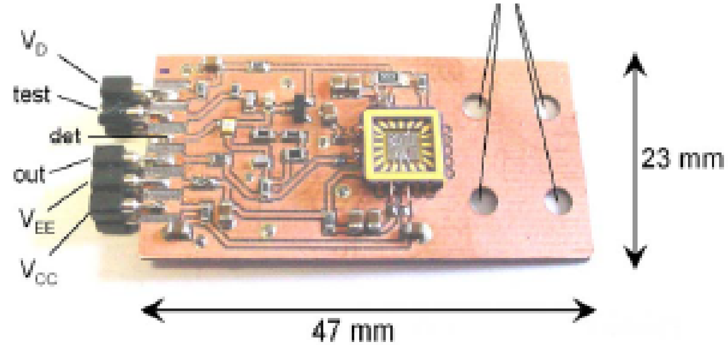


Fig. 3. Picture of the realized JFET-CMOS preamplifier as mounted on a PCB of 0.8 mm teflon laminate. The ASIC is realized in a 5V 0.8µm silicon CMOS technology.

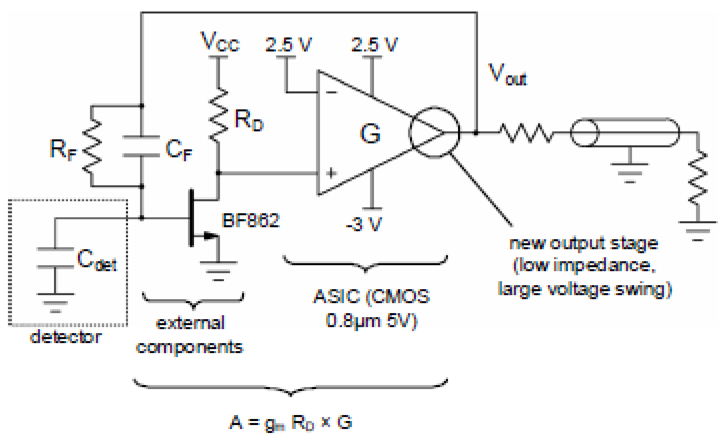


Fig. 2. Charge sensitive preamplifier structure, consisting of an external JFET, an external feedback network, and an ASIC used as low-noise operational amplifier along the negative-feedback loop.

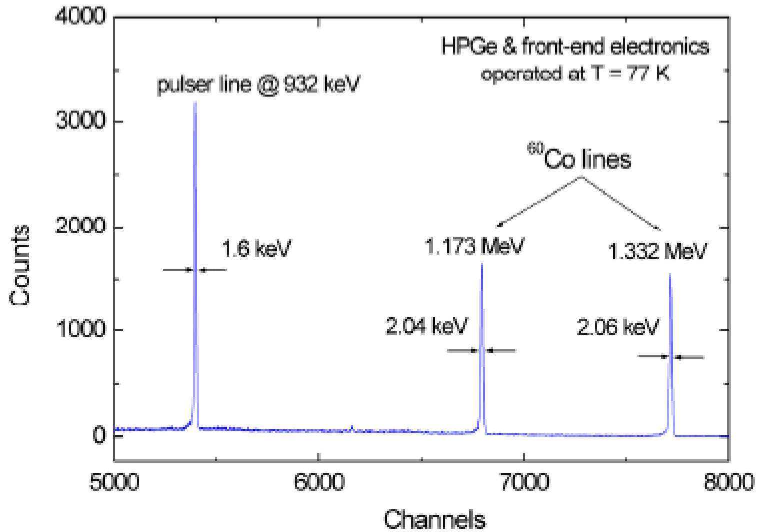


Fig. 12. Spectrum collected in the presence of a ^{60}Co source. A resolution of 2.04 and 2.06 keV fwhm has been obtained for the two ^{60}Co lines.

TABLE II
PREAMPLIFIER SPECIFICATIONS

Working temperature	from -196°C to 55°C (from 77 K to 328 K)
Negative output voltage swing on150 Ω impedance	~ 2.5 V (against a negative power supply of -2.7V)
Energy sensitivity (C_F = 0.2 pF)	~ 290 mV/MeV at preamp output ~ 217 mV/MeV after 150Ω termination
Input dynamic range	~ 8.6 MeV
Rise time	~ 16 ns with ~ 10m terminated coaxial cable
Fall time	~ 250 μs (R_F = 1.2 GΩ)
Open-loop gain	~ 3.5 *10^5
Loop gain	~ 600
Resolution at T= 77 K (τ = 6μs)	2.2 keV @ 1.332 MeV (^{60}Co) 1.6 keV @ 932 keV pulser line
Power required at T=77K	23.4 mW (V_{FET} = +4V I_D = 3mA V_{CC}= +3.6V V_{EE} = -2.8V)

Cryostat design

Vacuum-insulated double wall stainless steel cryostat
U/Th ≤ 5 mBq/kg

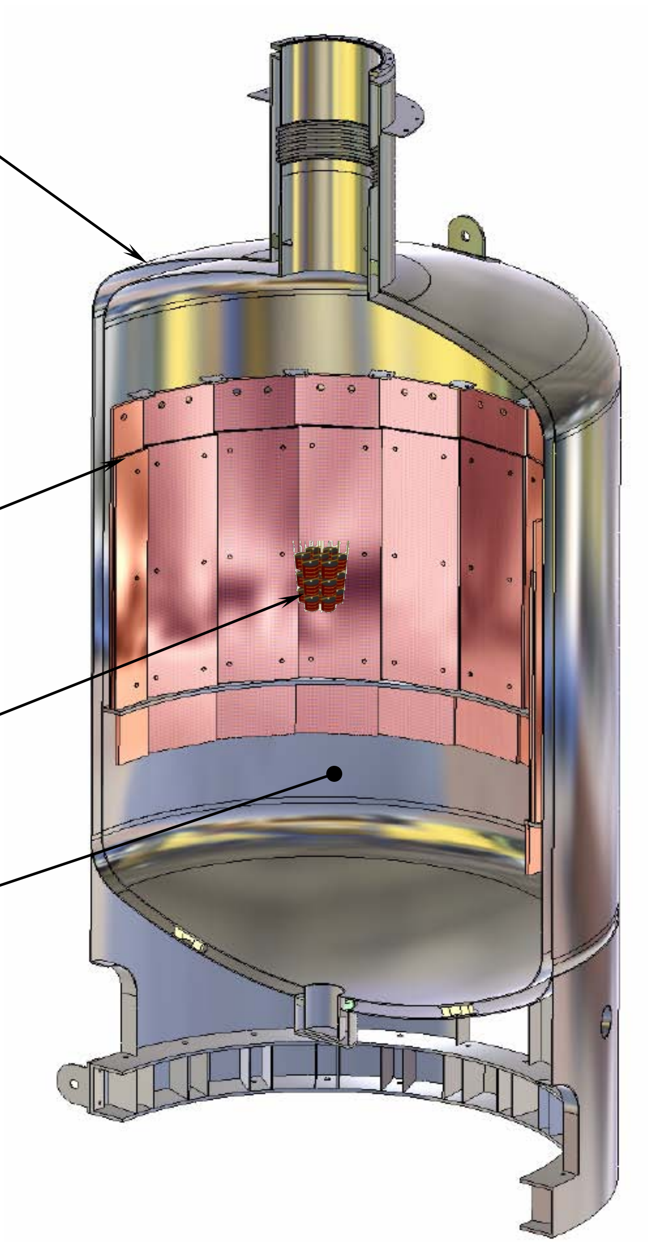
Ø outer×height 4200×8900 [mm×mm]
inner vessel volume 70 [m3]
empty vessel 25,000 [kg]
max. load inner vessel: LAr 98,000 [kg]
Cu shield 20,000 [kg]

Additional inner copper shield
U/Th ≤ 16 μBq/kg

Detector holders

U/Th ≤ 16 μBq/kg

Liquid argon
^{222}Rn = ≤ 1 μBq/m^3



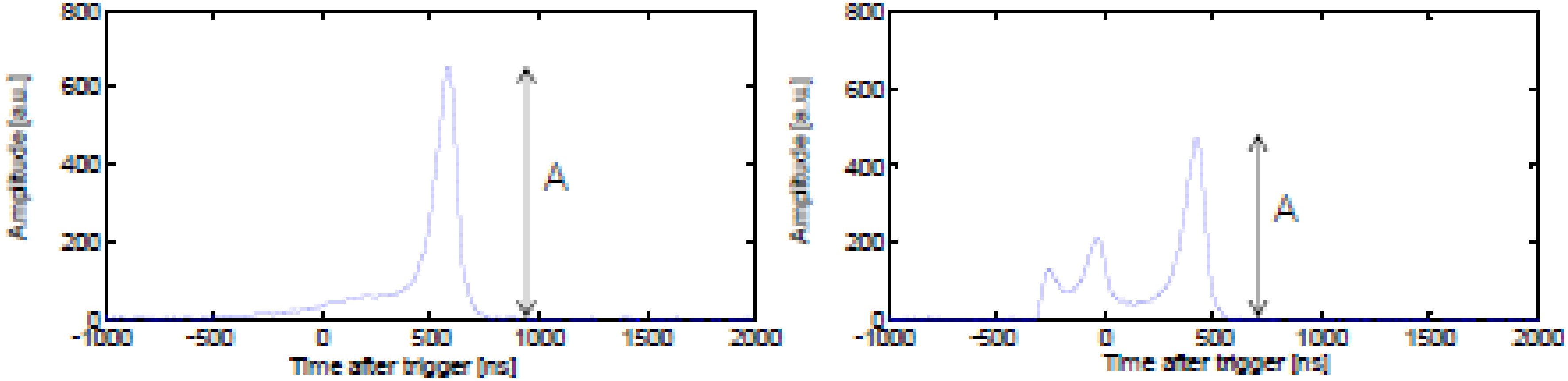


Figure 5. Recorded candidate SSE (left) and MSE (right) current signals from the BEGe detector (reproduced by differentiation of voltage signals), with an approximately equal energy. The maximal current amplitude A is proportional to the highest energy deposition within an event.

Pulse shape discrimination method for BEGe detector

A special feature of the BEGe detector is that a region of highly increased electric field is present near the small p+ electrode.

Qualitatively, peaks in the output current are induced by clusters of charge carriers passing through this region .

In case of a SSE, only one charge cluster drifts towards the p+ electrode, and only one peak is present in the current signal
(Figure 5, left).

The amplitude of the induced current peak is directly proportional to the charge contained in the cluster, and in turn to the energy of the interaction that created it.

In case of a MSE, the energy is distributed between two or more smaller charge clusters, creating current peaks with smaller amplitudes
(Figure 5, right).

These features of the BEGe current signals allow discrimination based on a single parameter:
the ratio A/E of the maximal current signal amplitude A to the total event energy E.

The detector current pulses were reconstructed by 10 ns differentiation and 50 ns smoothing of preamplifier voltage pulses,
performed in the offline Analysis.

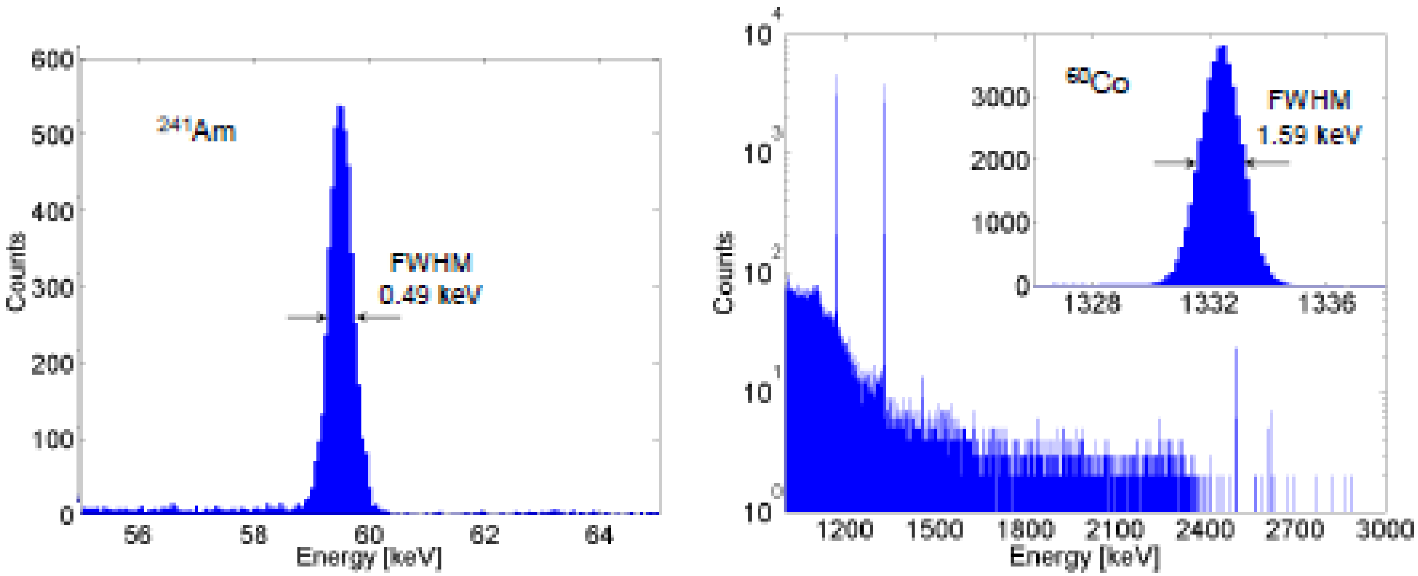


Figure 2. The best energy resolution achieved with the BEGe detector using 8 μs shaping with rise-time compensation.

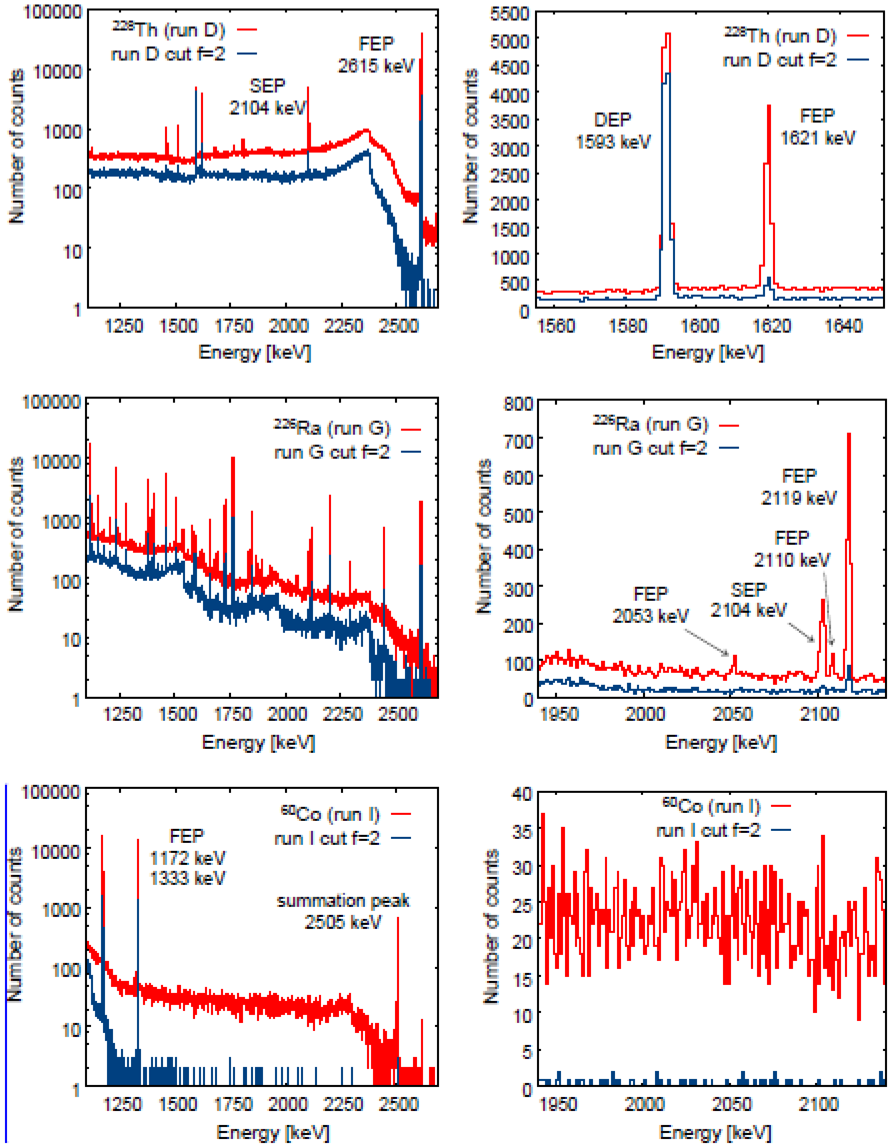
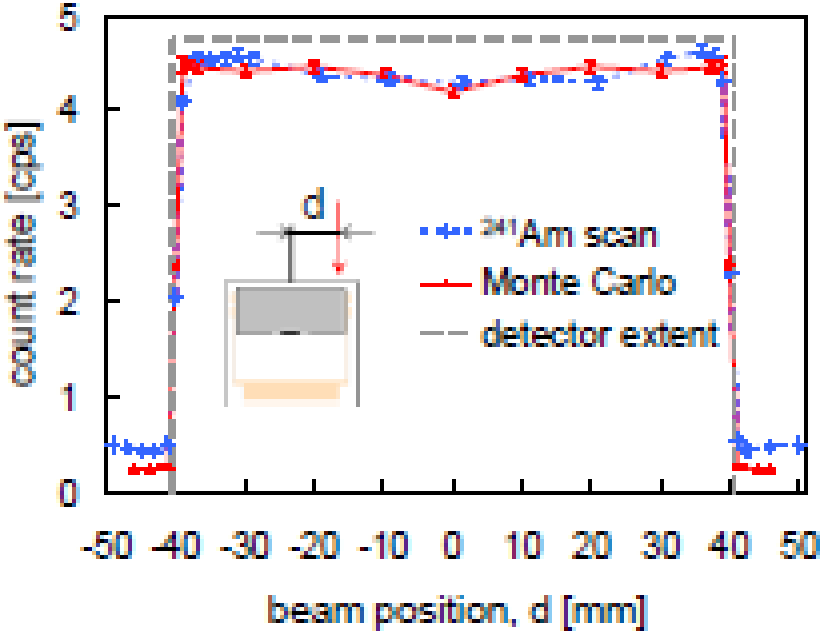
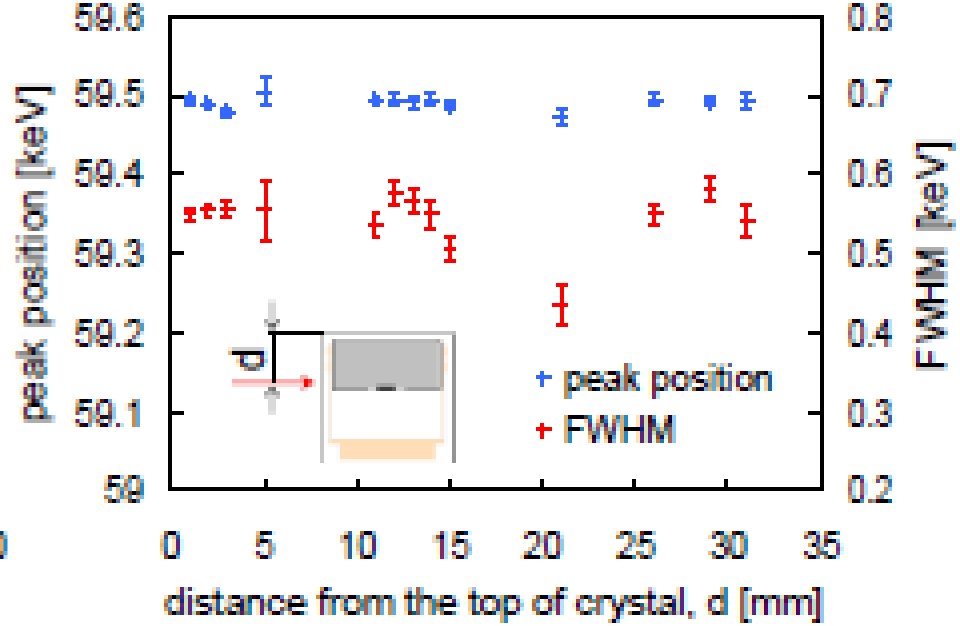


Figure 17. Recorded spectra from some of the most important sources of background for 0νββ-decay, before and after the PSD cut: **a)** ^{228}Th; **b)** zoom on the DEP of the 2.6 MeV line, and the 1.6 MeV FEP of ^{212}Bi; **c)** ^{226}Ra (with ^{228}Th and ^{40}K background), **d)** zoom on the energy region around ^{76}Ge $Q_{\beta\beta}$. The 2.1 MeV SEP is from background ^{228}Th; **e)** ^{60}Co; **f)** higher statistics measurement of the energy region around ^{76}Ge $Q_{\beta\beta}$.

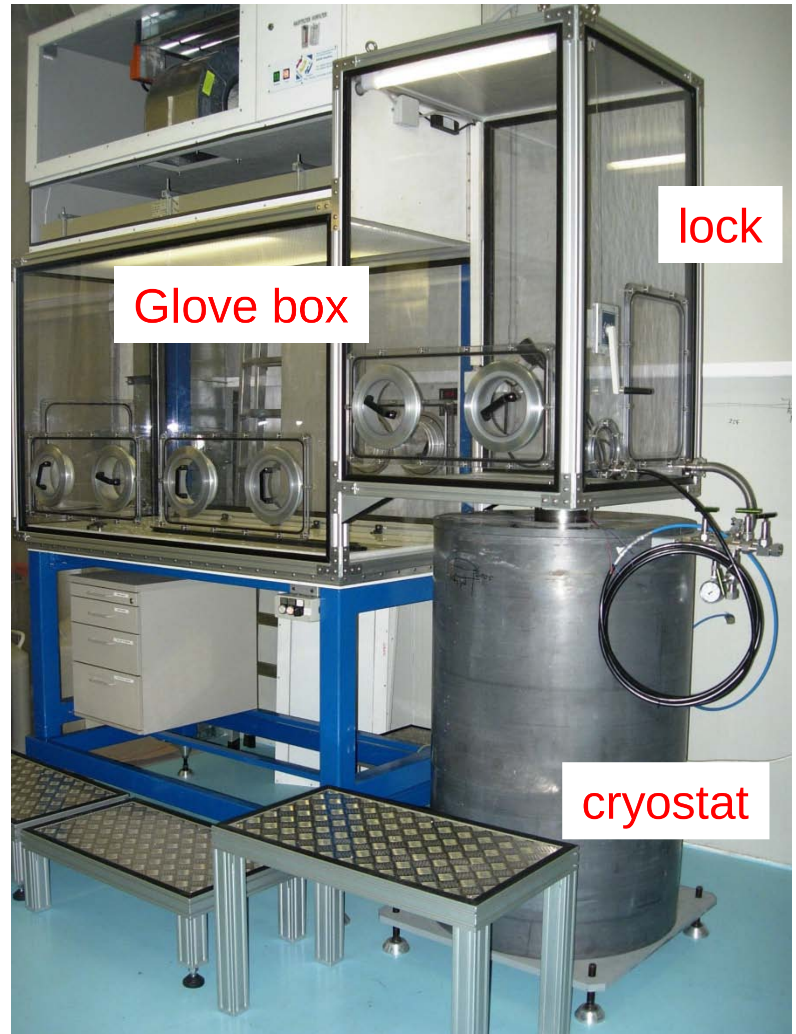


count rate [cps]
beam position, d [mm]
d
241Am scan
Monte Carlo
detector extent



peak position [keV]
FWHM [keV]
distance from the top of crystal, d [mm]
d
peak position
FWHM

GERDA Detector Laboratory (GDL) at LNGS



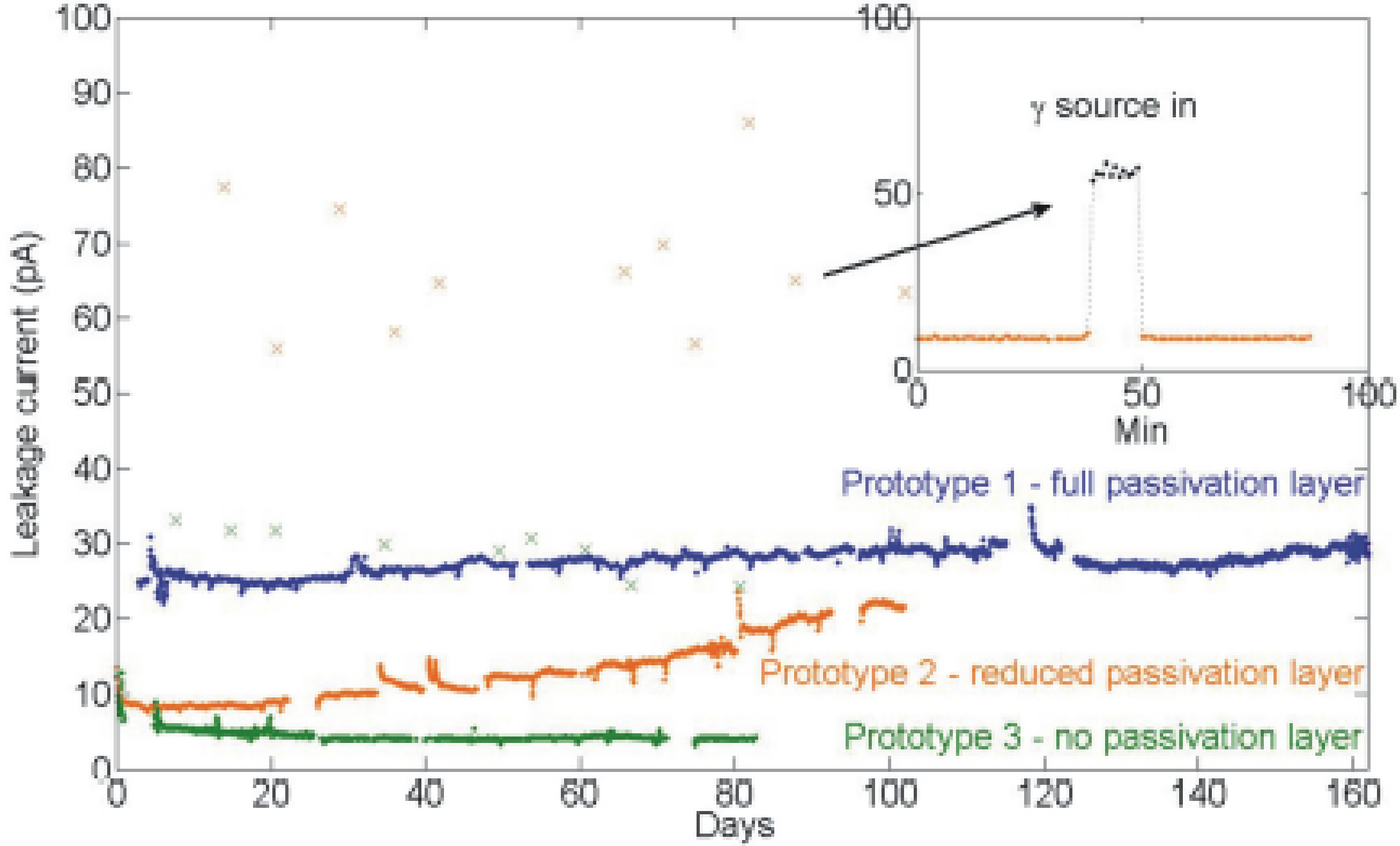


Fig. 6. Long-term stability measurements in LAr with the three prototype detectors. Prototype 1 mounted with a PTFE/Cu/PTFE disk covering its passivation layer, Prototype 2 and Prototype 3 were operated for seven, four and three months respectively. Prototype 2 and 3 were exposed to a ^{60}Co source once a week during 10 minutes.

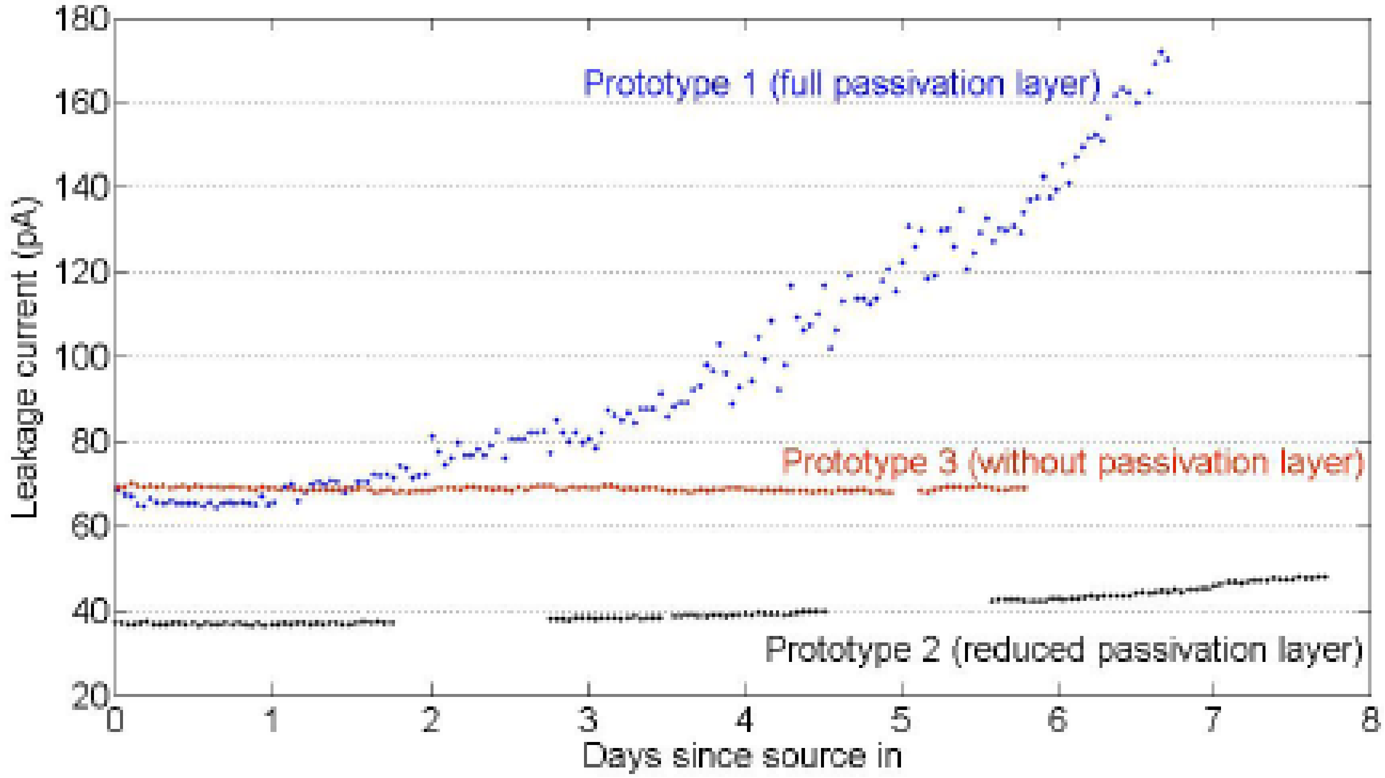


Fig. 4. Leakage current in function of days of γ irradiation for 3 detectors with different passivation layers. The LC increase is strongly reduced for Prototype 2 and no increase is observed with Prototype 3.

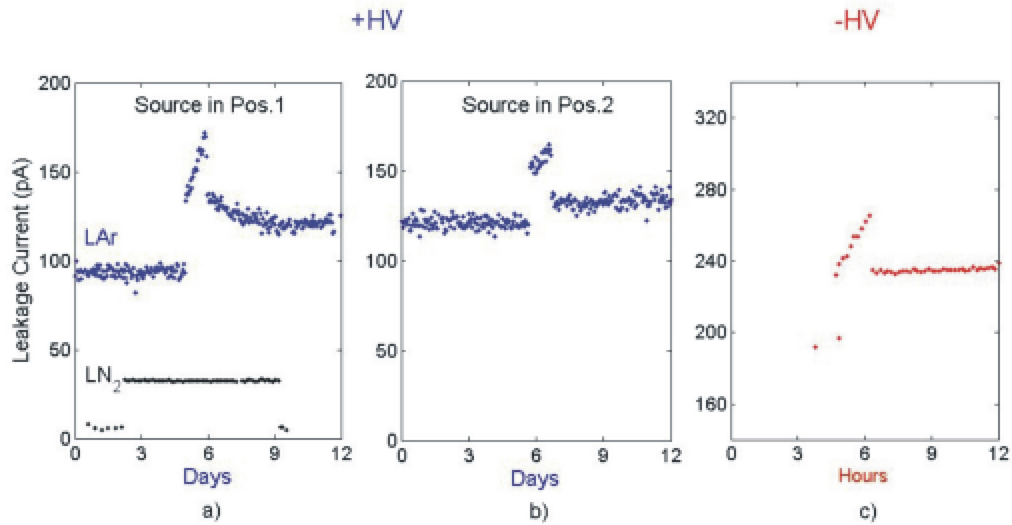


Fig. 3. a) Gamma-radiation induced LC of the first prototype in LAr. The bulk current step ($\sim$35 pA) as the source is inserted in the setup is followed by a continuous increase of the LC. After one day of irradiation, the source is removed and the LC stabilizes at a higher value than prior to the irradiation (ΔLC$\sim$30 pA). No increase of the LC is observed in LN_2 after one week of irradiation. b) Gamma-radiation induced LC with the source in Pos.2. c) Gamma-radiation induced LC with - HV applied to the detector.