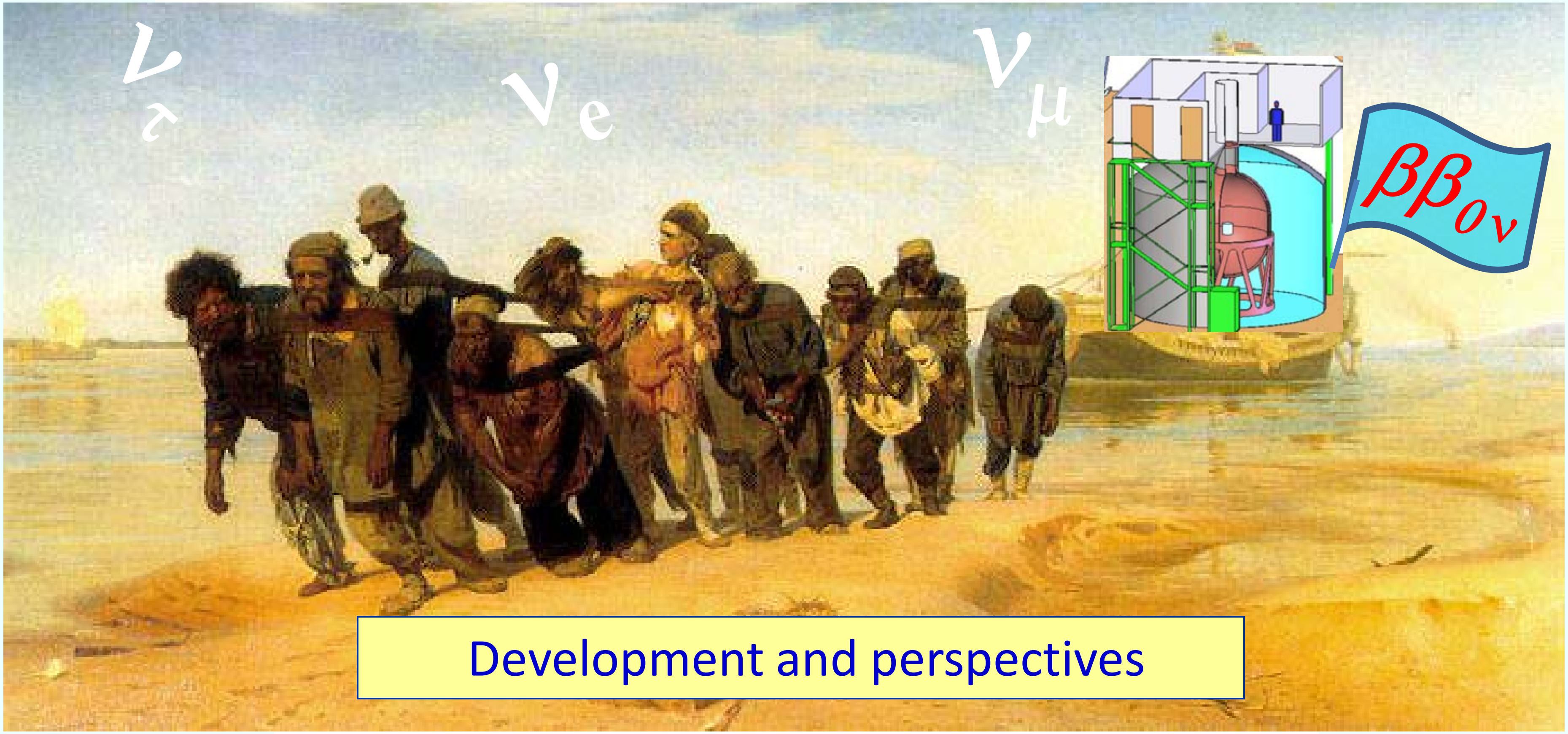
New generation of experiments

aimed to search for neutrinoless ββ decay

and very large efforts during R&D and installation are required



Development and perspectives

New generation of experiments

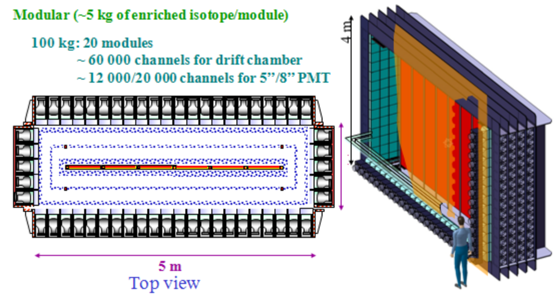
aimed to search for neutrinoless ββ decay

Development and perspectives

NEMO

CUORICINO

HdM & IGEX



Source (40 mg/cm²) 12m², tracking volume (~3000 channels) and calorimeter

Modular (~5 kg of enriched isotope/module)

100 kg: 20 modules

~ 60 000 channels for drift chamber

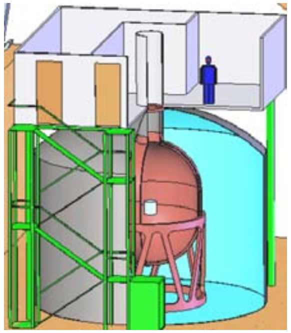
~ 12 000/20 000 channels for 5"/8" PMT

Super NEMO

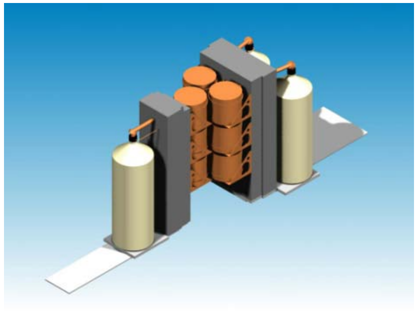
Many thanks

GuidoDrexlin

CUORE



GERDA



MAJORANA

- Majorana vs. Dirac, effective mass , hierarchy, CP phases

0νββ decay rate

$$1/\tau = G(Q,Z) \cdot |M_{nucl}|^2 \cdot \langle m_{\beta\beta} \rangle^2$$

Phase space factor (~$Q_{\beta\beta}^5$)

Nuclear matrix element

Effective Majorana neutrino mass

$$\langle m_{\beta\beta} \rangle = |\sum_j m_j U_{ej}^2|$$

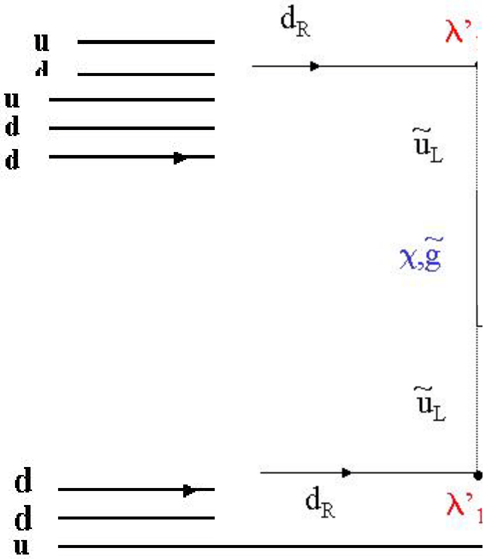
coherent sum

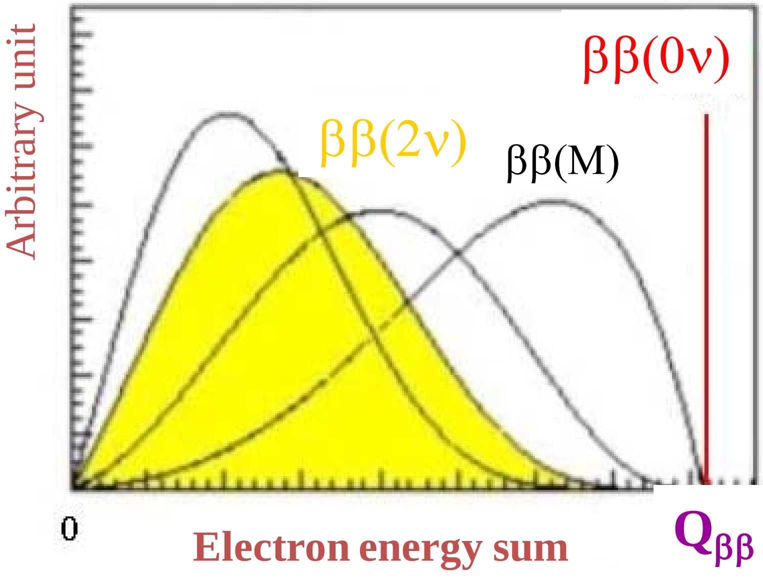
Neutrinoless double beta decay

$(A,Z) \longrightarrow (A,Z+2) + 2\,e^-$

Discovery implies ΔL=2 and Majorana neutrino

Process:	**parameters**
Light neutrino exchange	$<m_\nu>$
(V+A) current	$<m_\nu>,<\lambda>,<\eta>$
Majoron emission	$<g_M>$
SUSY	$\lambda'_{111},\lambda'_{113}\lambda'_{131},\ldots\ldots$





Nuclear matrix element

Nuclear matrix element

$,Z) |M|^2 <m_\nu>^2$

tion $T_{1/2}$ depends on

nd squarks mass

$|^2 <g_M>^2$

ective mass:

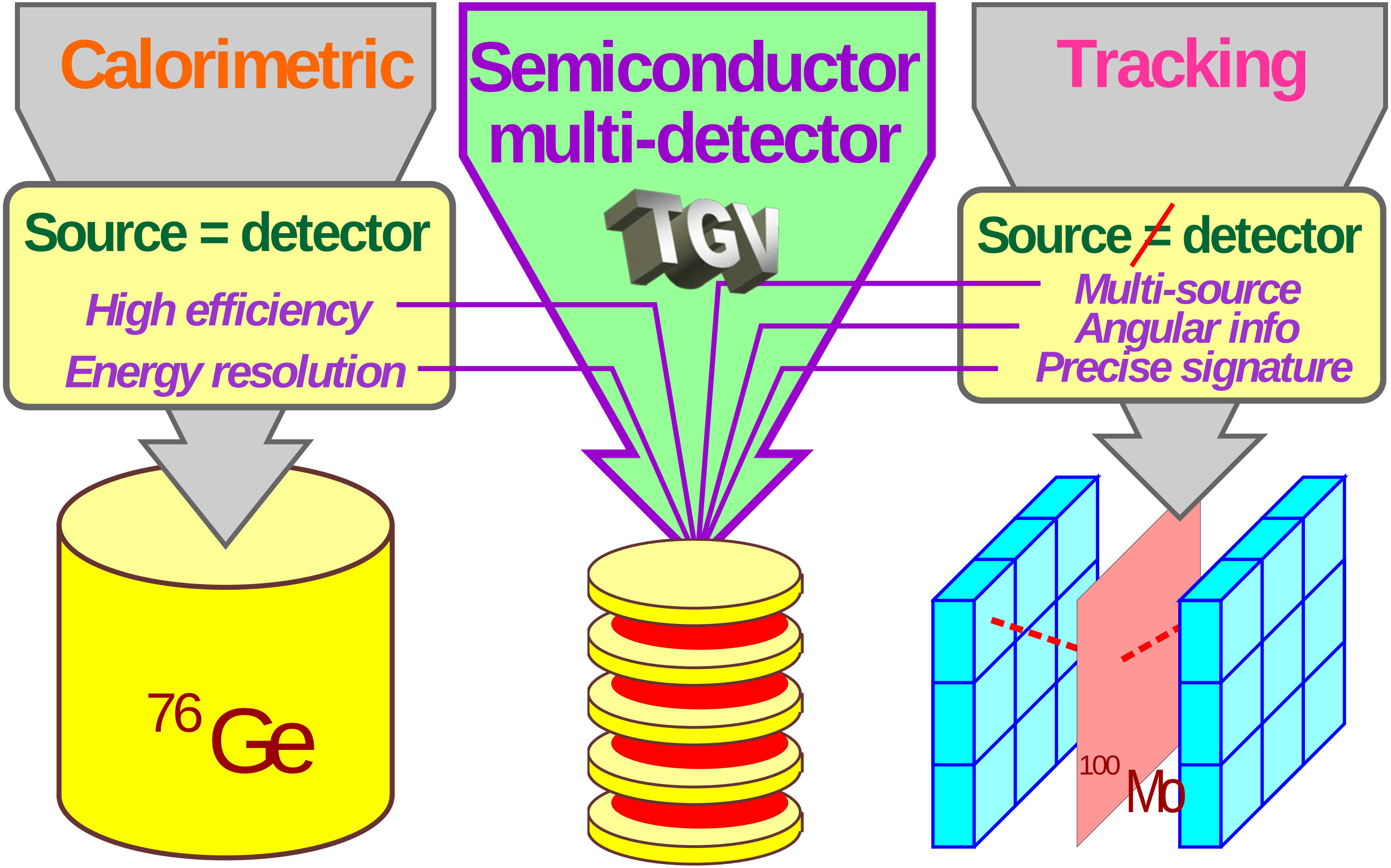
etween Majoron and neutrinos

$+ m_2|U_{e2}|^2.e^{i\alpha 1} + m_3|U_{e3}|^2.e^{i\alpha 2}$

ment

ase

Double Beta Spectrometers



Calorimetric

Source = detector

High efficiency

Energy resolution

Semiconductor multi-detector

Tracking

Source ≠ detector

Multi-source

Angular info

Precise signature

Development and installation of the **GERDA** experiment

GERDA: the **GER**manium **D**etector **A**rray

to search for Neutrinoless Double Beta Decay

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 (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

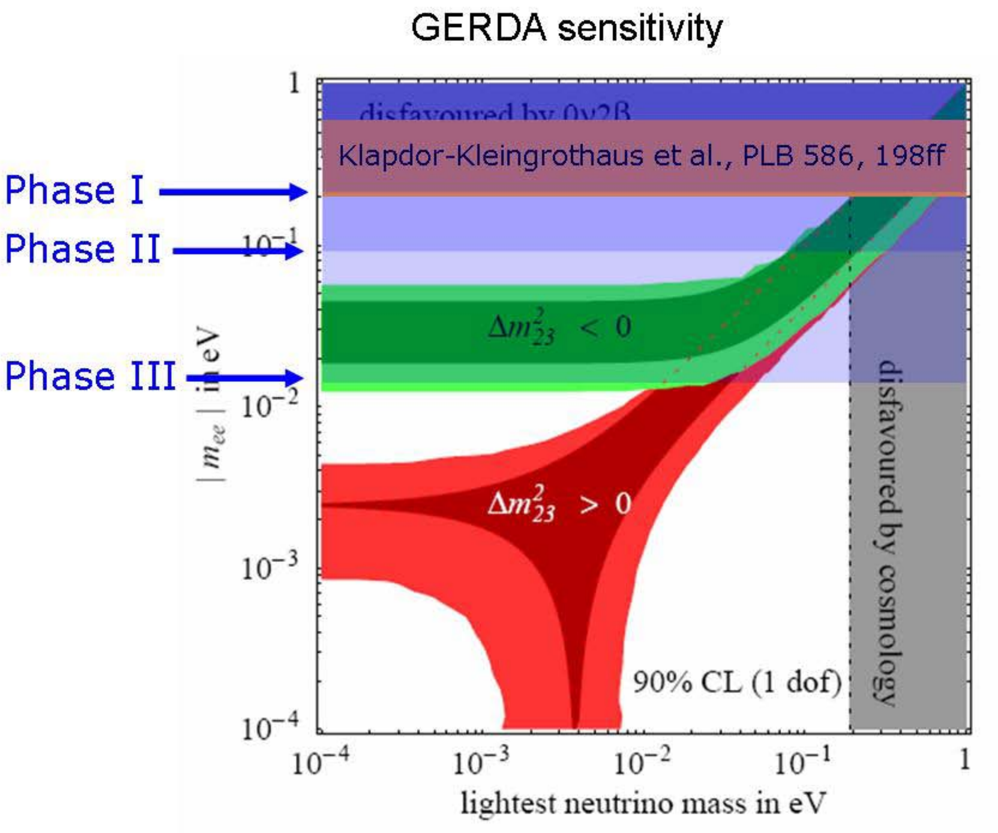
in the predecessor experiments **Heidelberg-Moscow & IGEX**

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 **$T_{1/2} = 1.2\times10^{25}$ *y*, | m_{ee} | = 0.44 eV**

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

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**

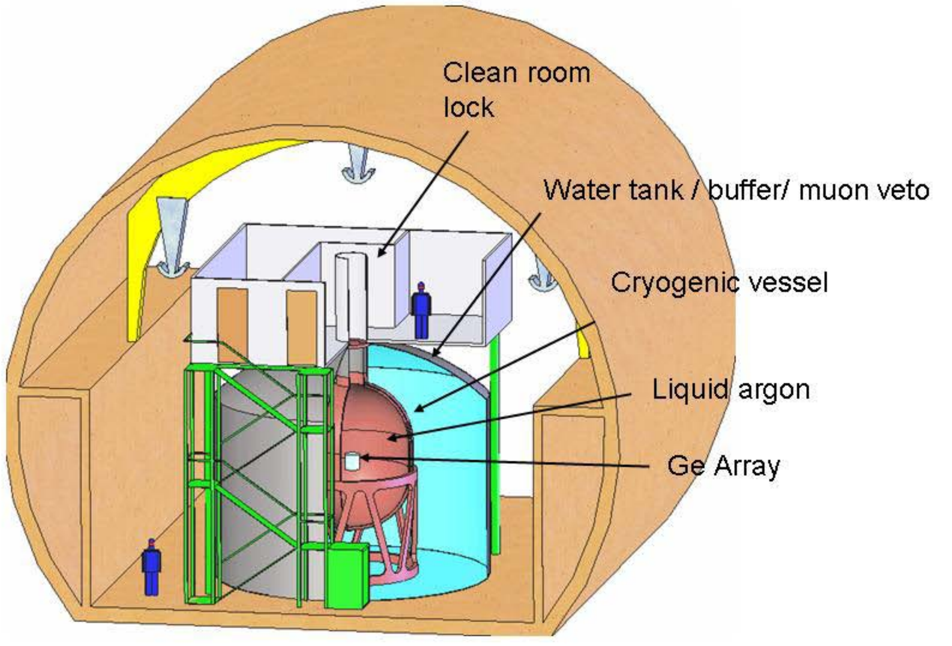
$<m_{ee}>$ ~10 meV

To achieve the planned sensitivity the **novel experimental concepts** are developed.

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.



In the framework of the extensive R&D program the main GERDA experimental concepts were proven and the methods of further background reduction were developed and tested.

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:

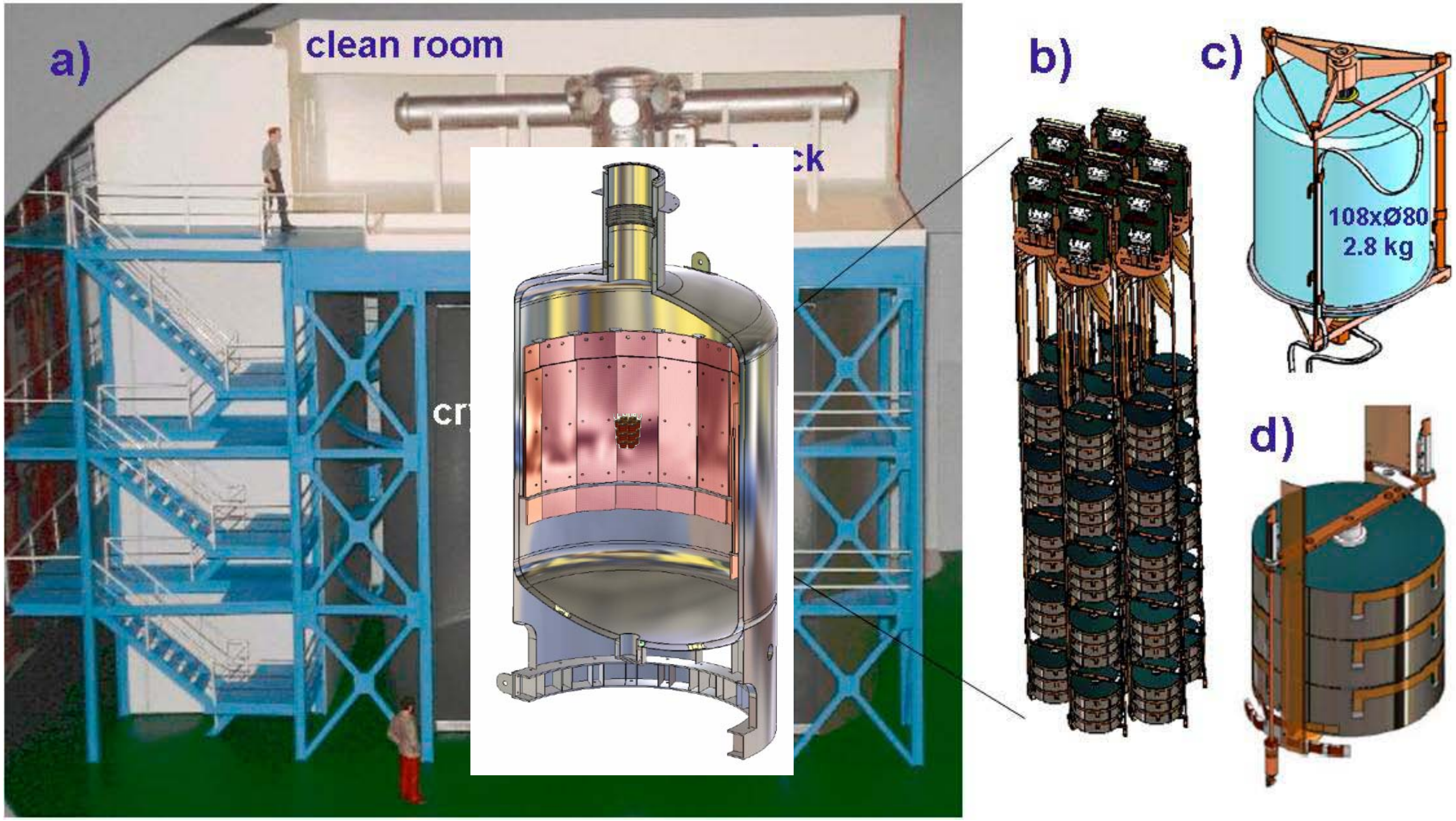
1) the higher reduction factor of the external background due to **higher LAr density (1.4 g/cm^3);**
2) **anti-coincidence with LAr scintillation** should reduce both the inner and external background;

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

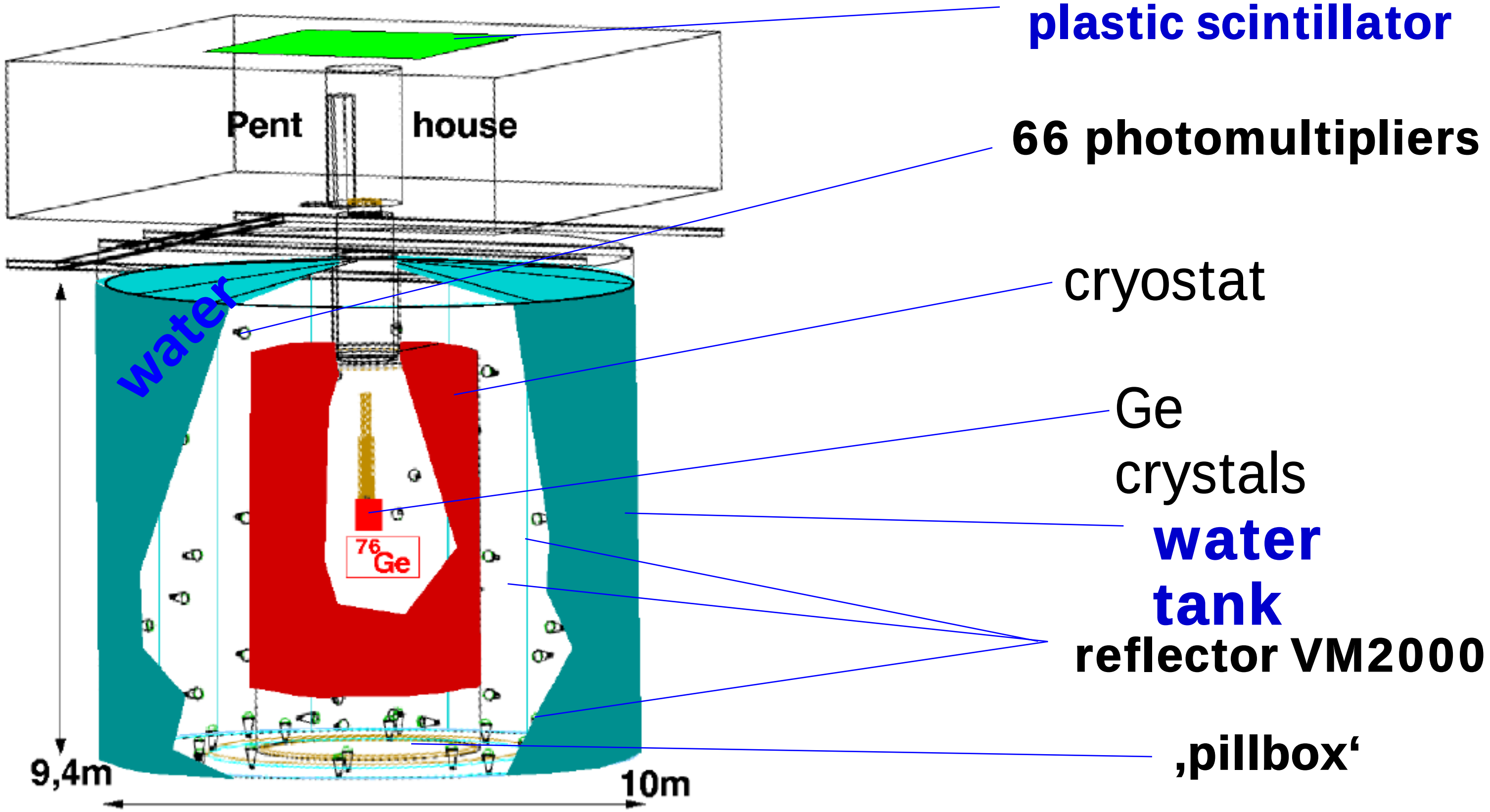
The Ge detector array is made up of individual detector strings and is situated in the central part of the **cryostat.**



Water tank and Veto system

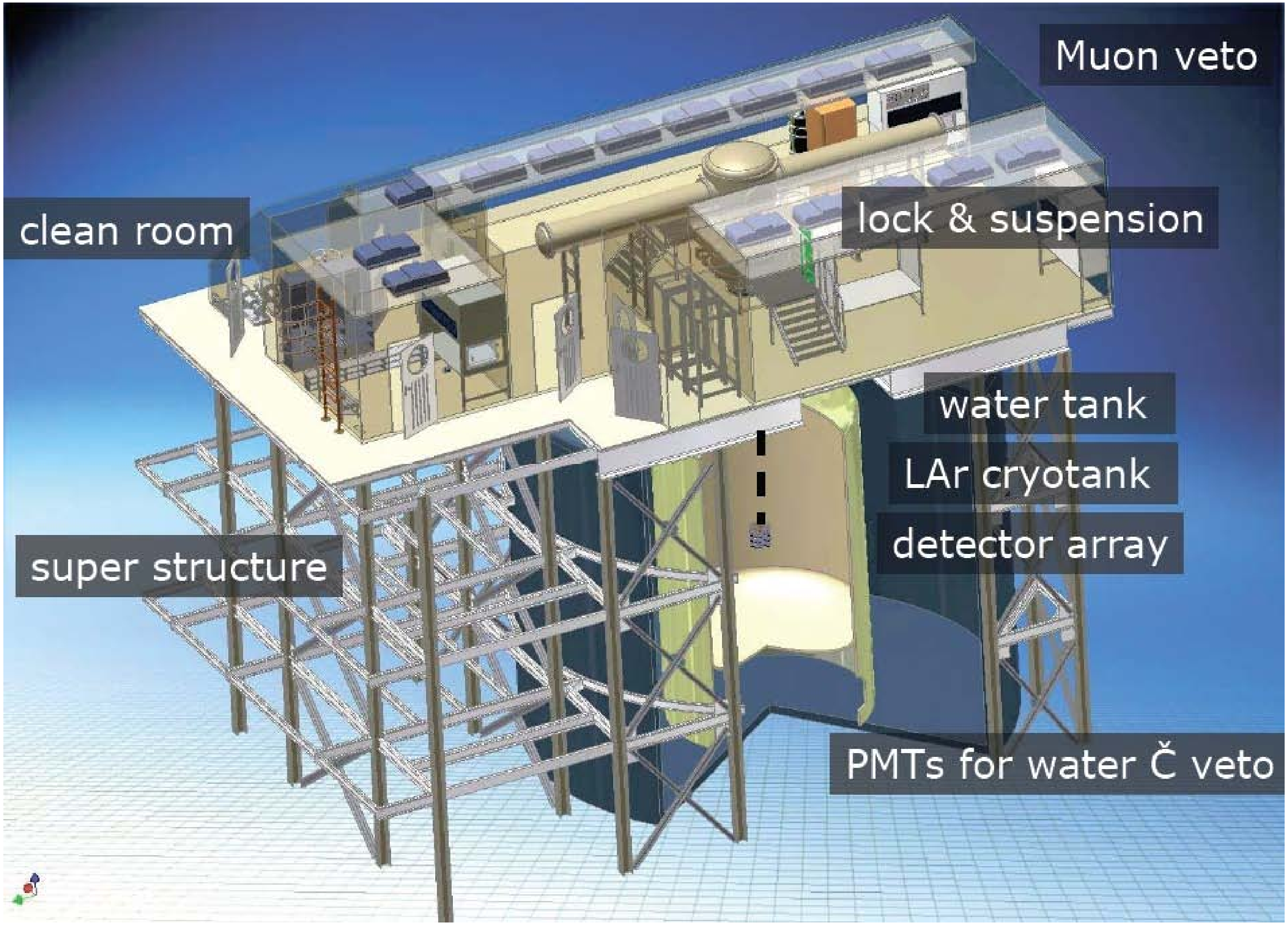
The **ultra-pure water buffer** serves as **a gamma and neutron shield** and, instrumented with 66 photomultipliers, as Cherenkov detector **for efficiently vetoing** cosmic muons. Recent simulations show, that an **efficiency of more than 99 % can** be achieved, reducing the muon induced background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

Plastic scintillator panels **(20 m^2, 20 x 2 = 40 modules)** on top of the detector will tag muons which enter the cryostat through the neck with the **vetoing efficiency of about 98 %** .



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.



Testing of naked HPGe detectors in LN_2 / LAr

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

Detectors were tested in **liquid Argon** with FWHM ~2.5keV (at 1332keV), and a stable leakage current

Problems reported from GENIUS-TF

about "limited long-term stability of naked detectors in liquid nitrogen"

[H.V.Klapdor-Kleingrothaus end I.Krivosheina, NIM A556 (2006) 472]

have been overcomen by GERDA.

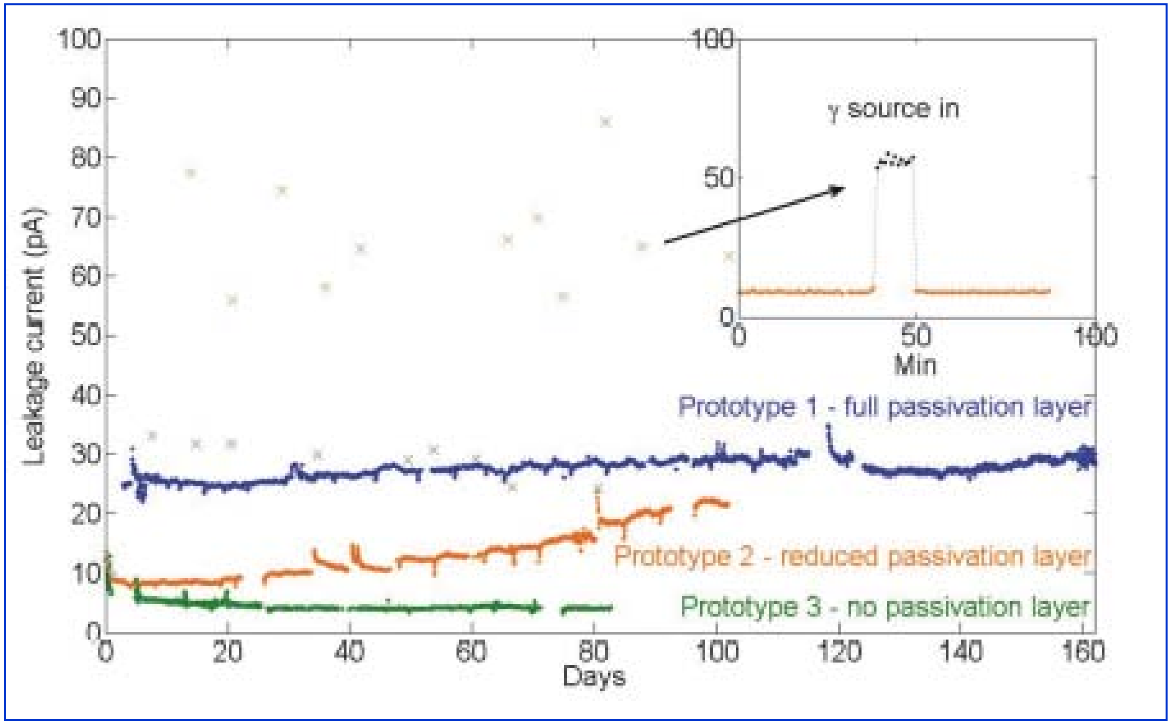
Long term stability for > 1 year.

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

Installation of the GERDA set up

Construction of the GERDA set up
started in 2007
in the INFN Gran Sasso National
Laboratory (LNGS), Italy.
The “nested type” assembly
has already installed
in the deep underground facility
(Hall A) at 3500 m w.e.

Detector string
Glove box & lock
Clean room
Cryostat & μ-veto
Heat exchanger & pipes

The commissioning of Gerda has started with
the cooling of the cryostat on November 2

The **liquid argon filling will** be completed by the end of November.

The **single-string commissioning lock** is scheduled for installation **in February 2010**
and **non-enriched detectors will be deployed in the cryostat**
as the final step of the commissioning phase.

R&D for GERDA Phase II

Additional background reduction techniques

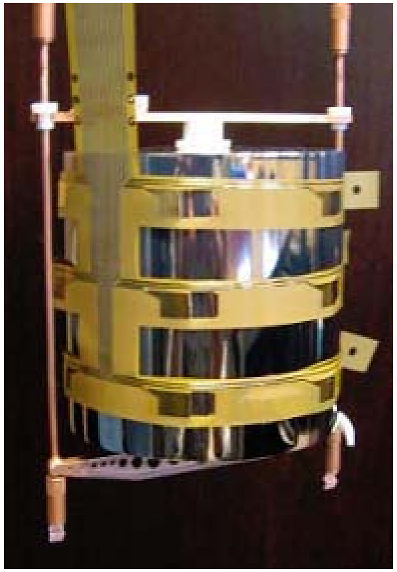
To reach the background level **required for the Phase II** **10^{-3} cts/(keV·kg·y),** additional new methods are required mostly to suppress the intrinsic background of the detectors.

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.

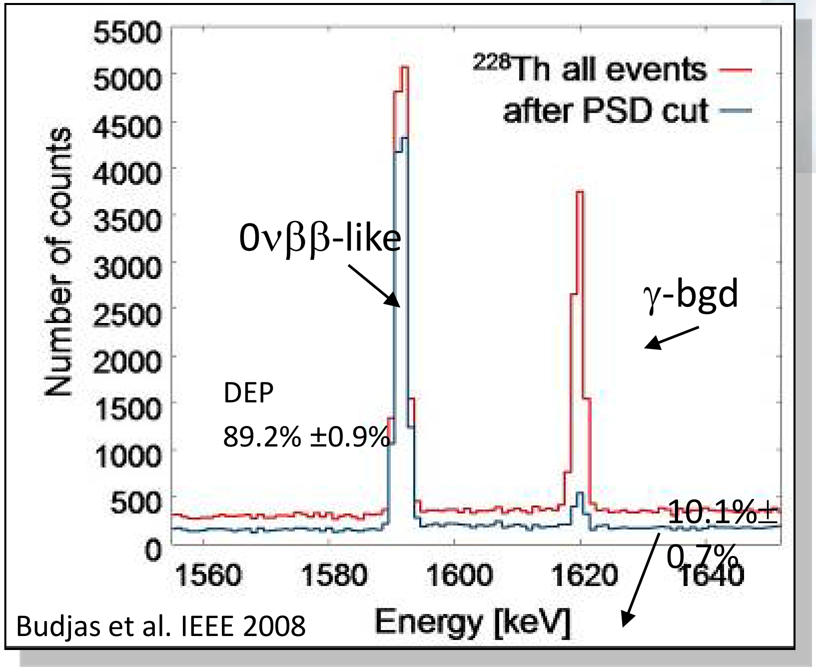
3. The novel concept to use the **LAr scintillation light as anti-coincidence signal** **for further background suppression** is developed.

Novel Ge-detectors with advanced 0νββ-signal recognition & background suppression



n-type detectors with 18-fold segmented electrodes

- **0νββ:** point-like events
- **Bgd:** multi-site or partial energy deposition outside crystal



0νββ-like

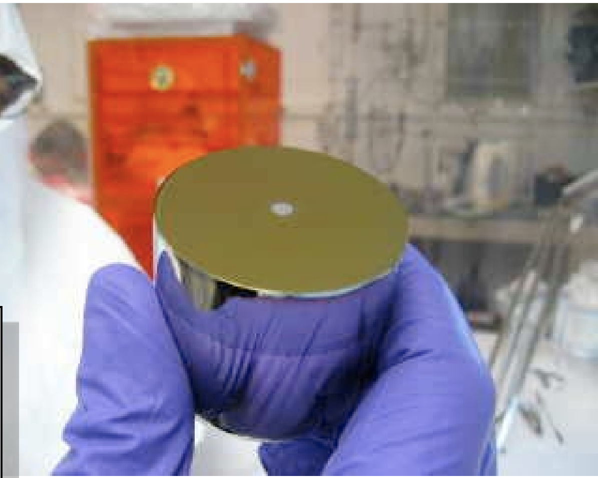
γ-bgd

DEP

89.2% ±0.9%

10.1%± 0.7%

Budjas et al. IEEE 2008



p-type with small readout electrode; Similar performance with thick-window BEGe detectors

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

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**

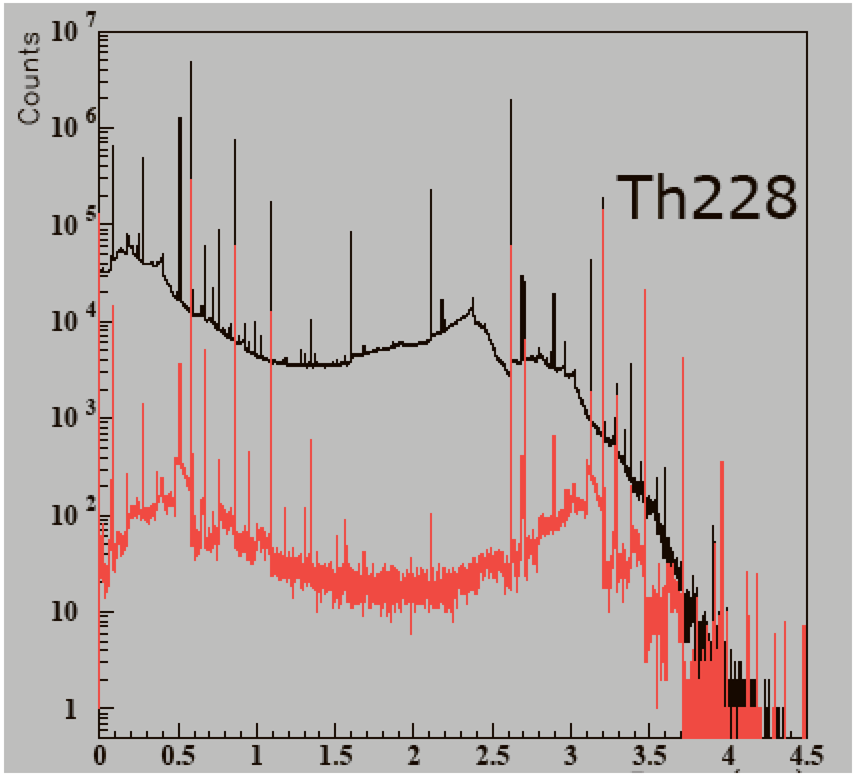
   (for direct measurement of gamma background inside the GERDA facility)
2. **Large volume Neutron detector**

   (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)

LAr scintillation veto by tagging extra energy in LAr

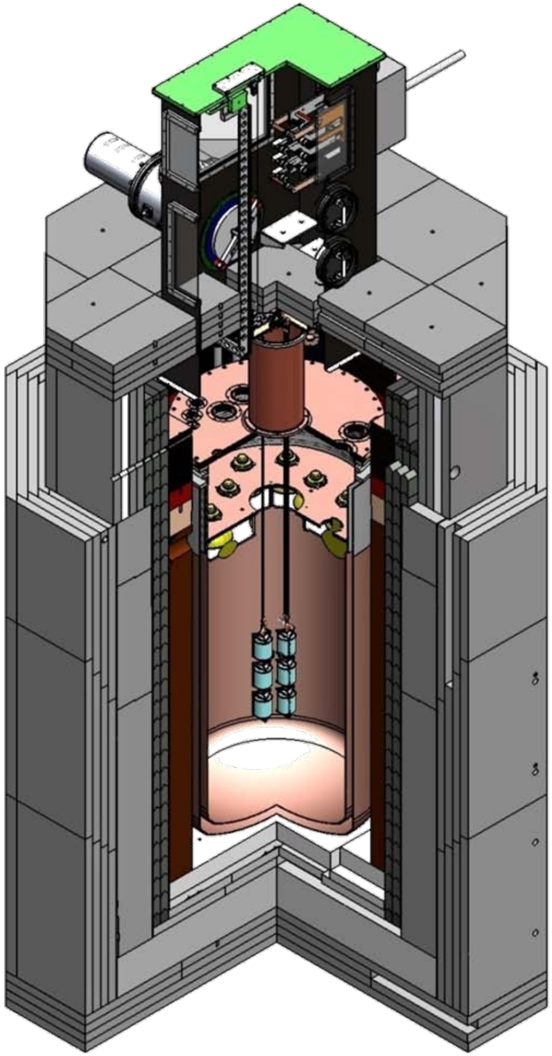
P. Peiffer et al., Nucl. Phys. B. Proc. Supp. 143(2005) 511



Factor 300 reduction in ROI

The LArGe Setup

with 1.3 tons of LAr



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

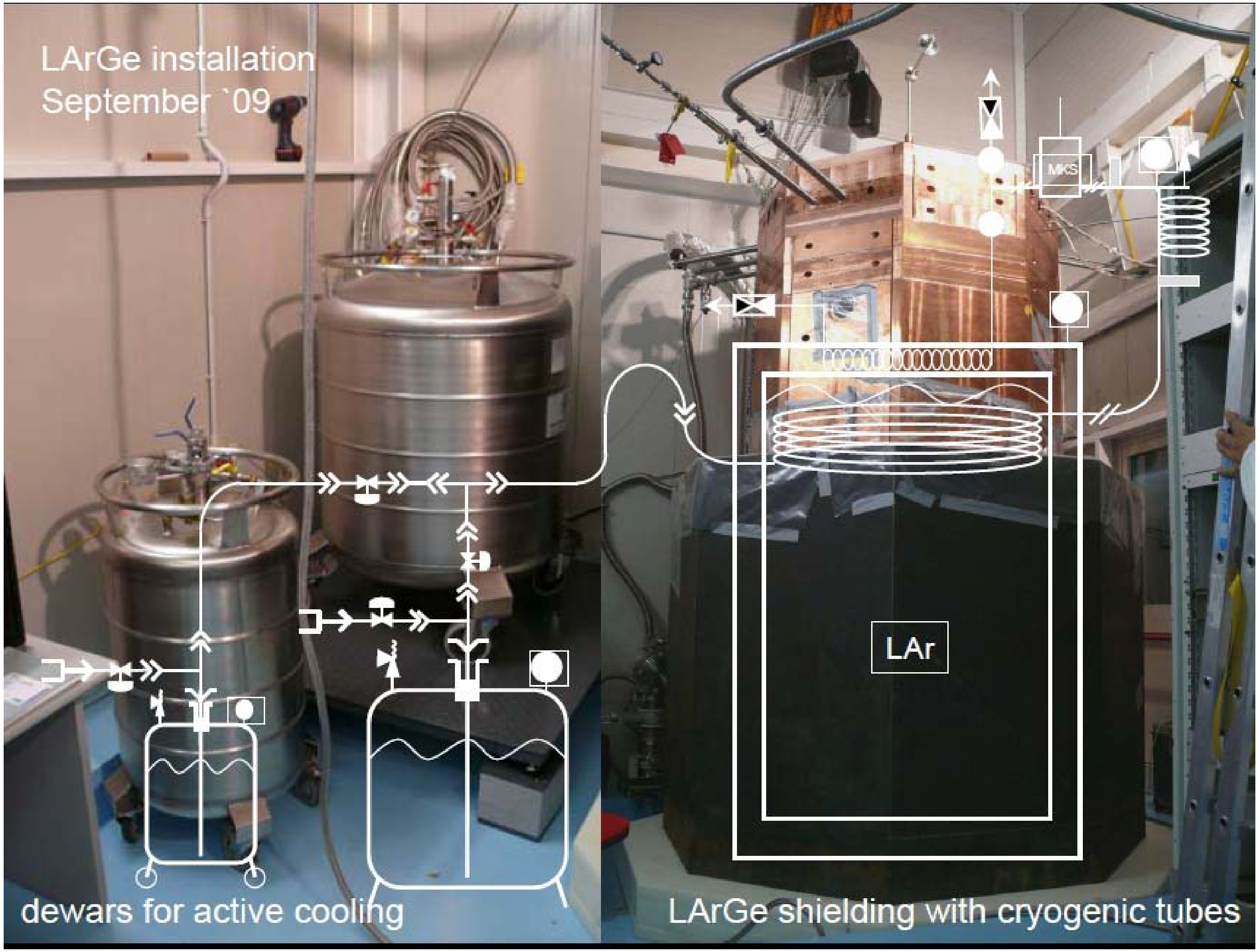
9 PMTs: 8” ETL9357

VM2000 & **wavelength shifter**

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

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

The main parts of **LArGe are installed**
in the LNGS underground facility GDL

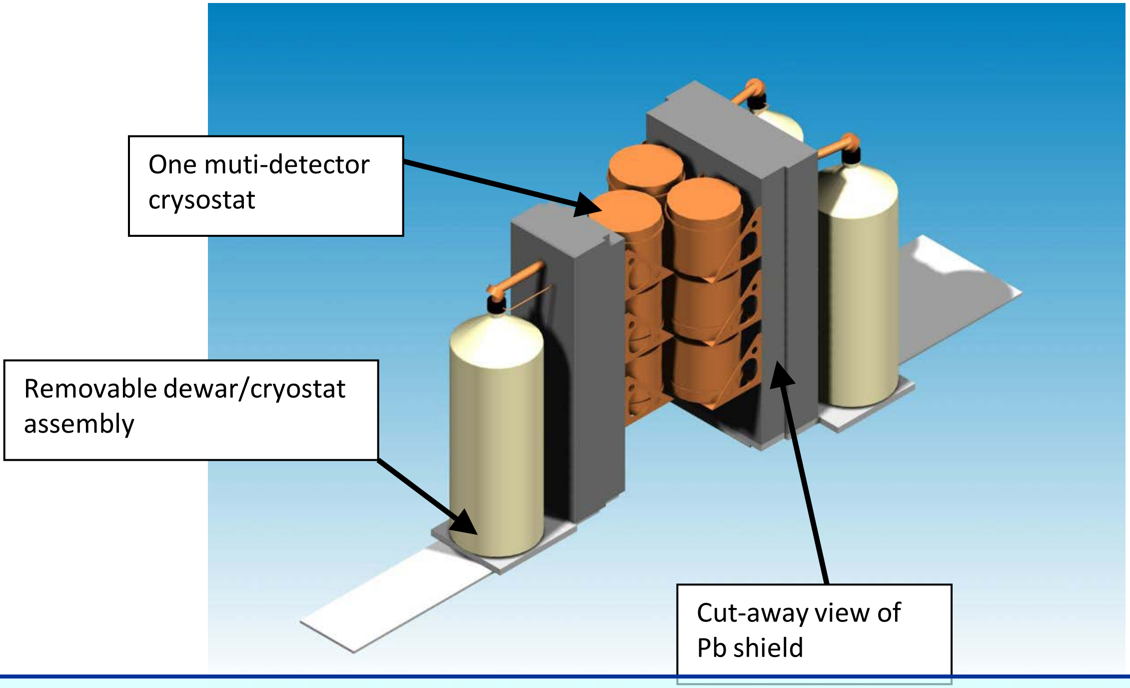


The **liquid argon filling** was carried out **on November 1**.
LAr is sub-cooled to -188 C (boiling temperature is -186 C) with a liquid nitrogen flow corresponding to 2.2 m3/hour. The filling level is stable and **no argon is lost** in this operational mode. The next steps are the start-up of the PMTs, their calibration, monitoring of the scintillation light yield and first background measurements of ^{39}Ar and of radon.

The MAJORANA project

The planned MAJORANA experiment will consist of a few hundred detectors enriched in ^{76}Ge grouped into a collection of modules constructed from electroformed copper.

All detectors will be segmented or point contact types and instrumented for pulse-shape analysis. The plan is to house about 55 kg of crystals per cryostat, arranging cryostats in pairs such that 500 crystals of about 1.05 kg each would comprise the 525 кг of ^{76}Ge in the total experiment.



One muti-detector crysostat

Removable dewar/cryostat assembly

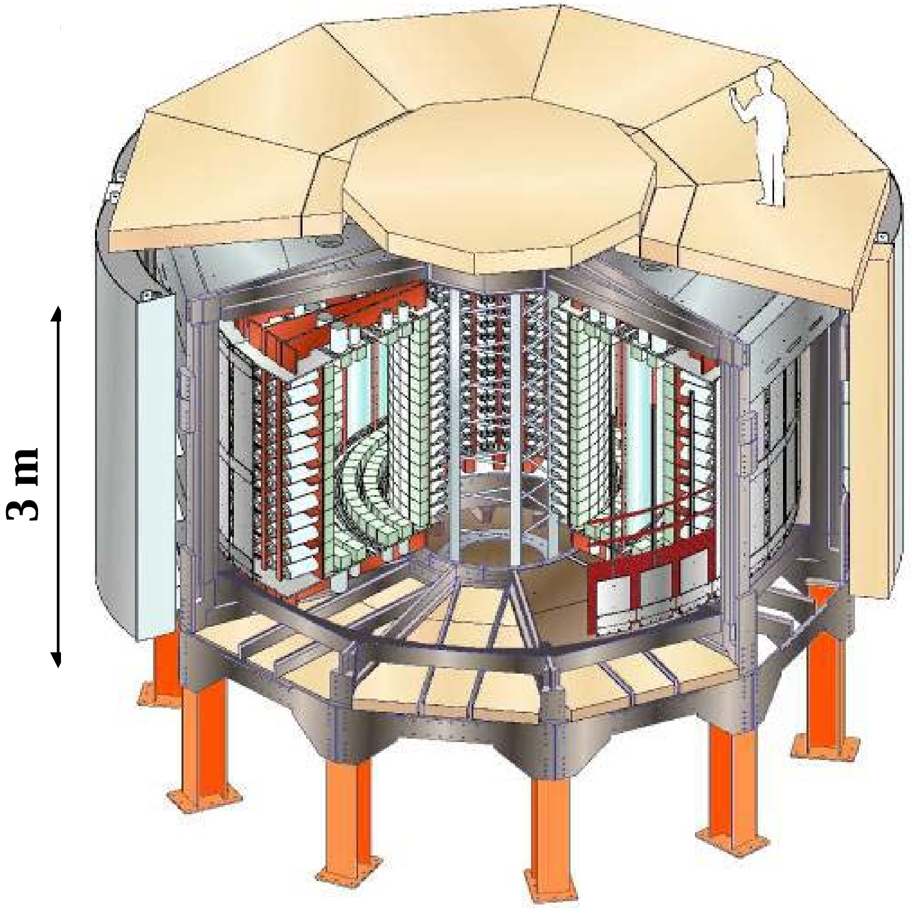
Cut-away view of Pb shield

Now the **MAJORANA** project is in the **R & D stage.**

Initial phase: **R&D demonstrator module**: Total 60 kg (30 kg **of ^{76}Ge** .)

The 2νββ factory NEMO-3

The NEMO-3 is a combined (track gas detectors + scintillation calorimeters + magnetic field) facility capable to measure not only the total energy of ββ-decay electrons but also all other parameters of this process for ββ-interesting isotopes of total mass up to 10 kg



Source: 10 kg of ββ isotopes
cylindrical, S = 20 m^2, 60 mg/cm^2

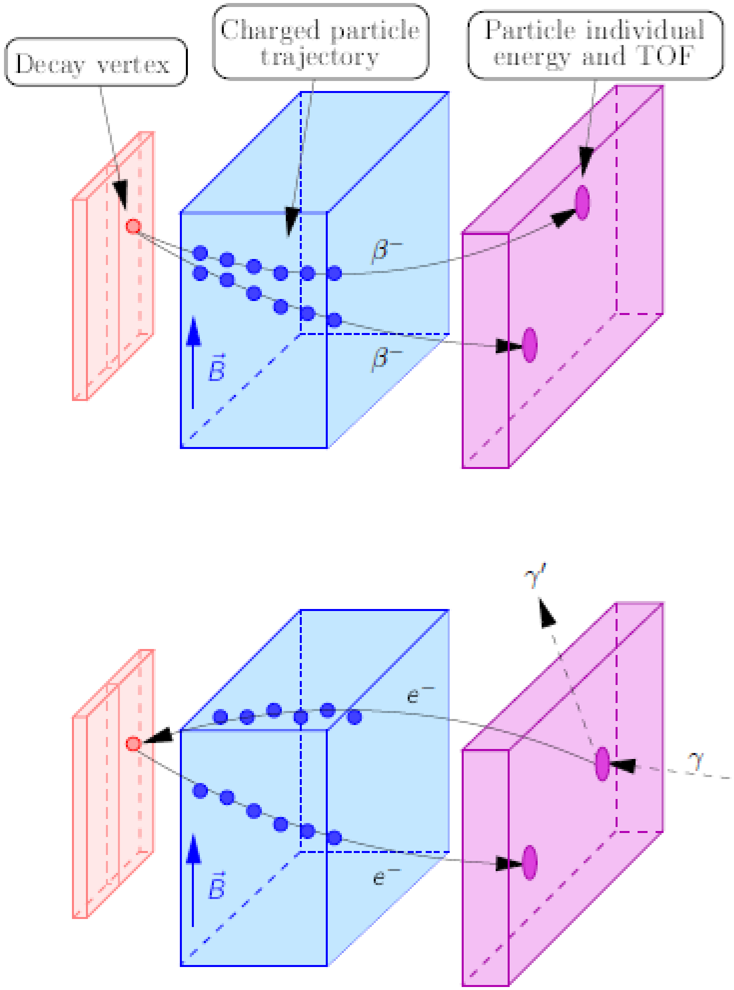
Tracking detector:
drift wire chamber operating
in Geiger mode (6180 cells)

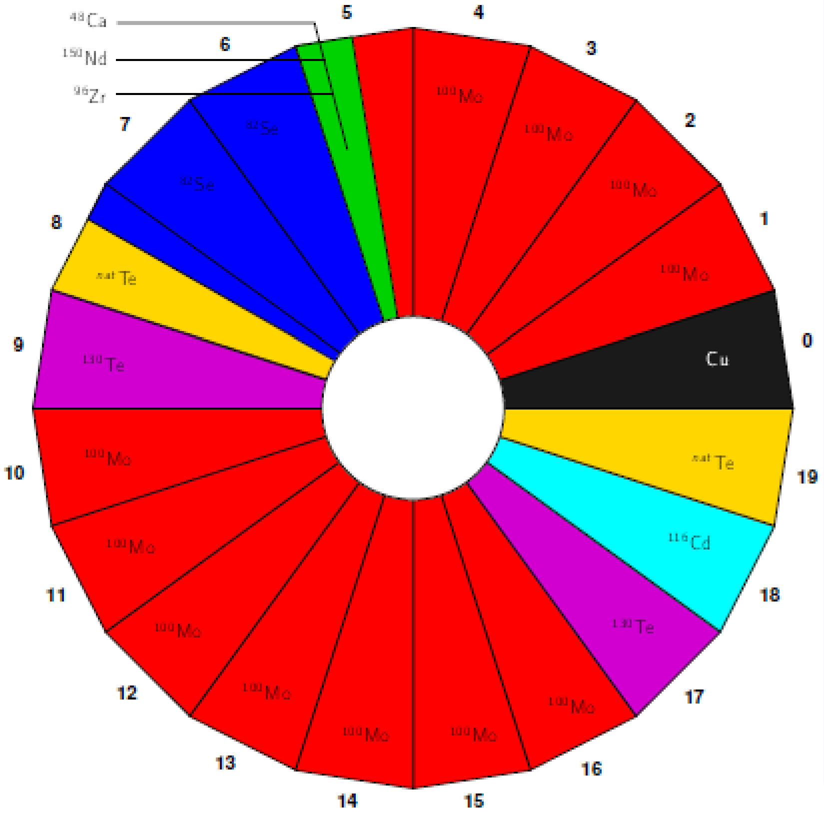
Calorimeter:
1940 plastic scintillators
coupled to low radioactivity PMTs

Magnetic field: 25 Gauss
Gamma shield: Pure Iron (18 cm)
Neutron shield: borated water
+ Wood

Calorimetry + Tracking

- Reconstruction of final state topology and kinematics for double beta decays, and nuclear decays from natural radioactivity:
    - $e^{\pm}$ individual energy (100 keV-10MeV),
    - charged particle trajectory ($e^{\pm}$, α, μ)
    - angular distribution, vertex, magnetic field curvature
    - time of flight,
- Background rejection through particle identification: e^-, e^+, γ, α
- Source is separated from the detector: can measure several $\beta\beta$ isotopes





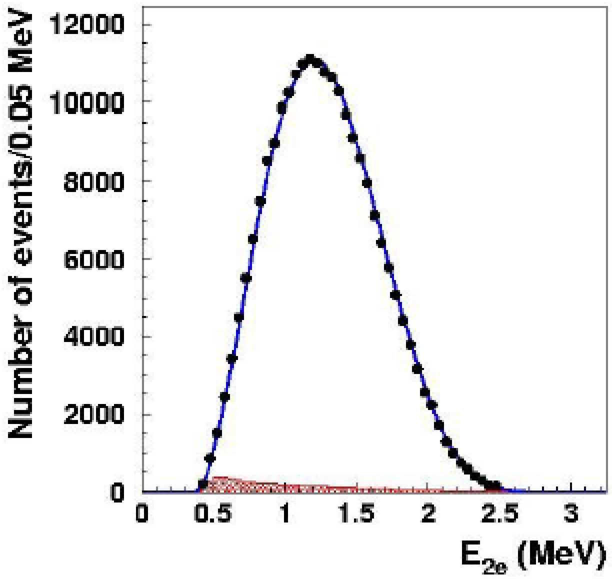
$\beta\beta$ decay isotopes

Isotope	Mass (g)	$Q_{\beta\beta}$ (keV)
$0\nu\beta\beta$ search + $2\nu\beta\beta$ meas.		
^{100}Mo	6914	3034
^{82}Se	932	2995
$2\nu\beta\beta$ measurement		
^{116}Cd	405	2805
^{96}Zr	9.4	3350
^{150}Nd	37.0	3367
^{48}Ca	7.0	4272
^{130}Te	454	2529
External background measurement		
^{nat}Te	491	see ^{130}Te
Cu	621	-

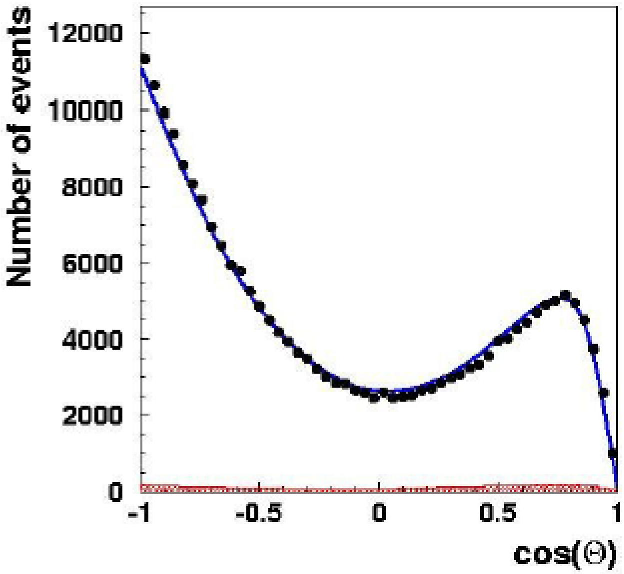
Enriched isotopes produced by centrifugation in Russia

$2\nu\beta\beta$ results for ^{100}Mo

Energy sum



Angular distribution



^{100}Mo

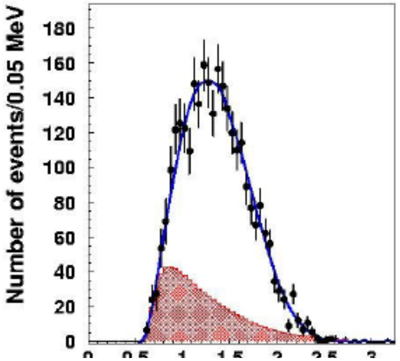
- Statistics: 219 000 events
- Exposure: 6914 g × 389 days
- S/B = 40

● data (background subtracted)

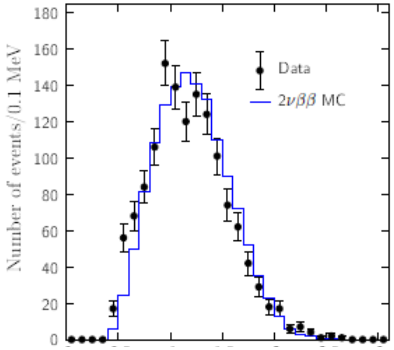
– $2\nu\beta\beta$ Monte Carlo

– background

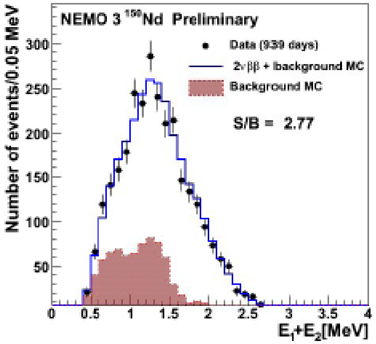
Energy sum ^{82}Se
background subtracted



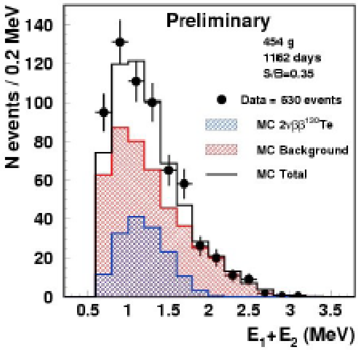
Energy sum ^{116}Cd
background subtracted



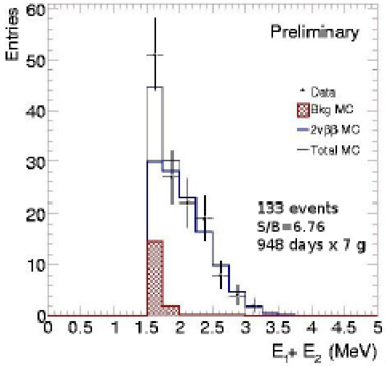
^{150}Nd



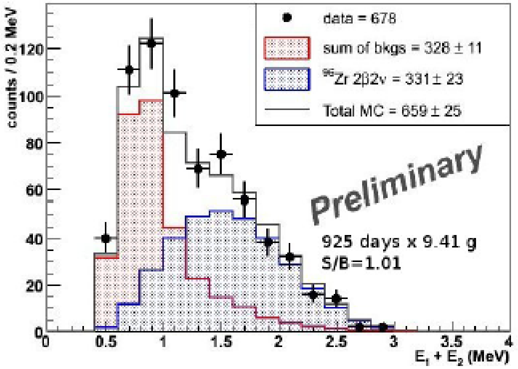
^{130}Te



^{48}Ca



^{96}Zr



The NEMO 3 $\beta\beta$ factory: a tool for precision tests

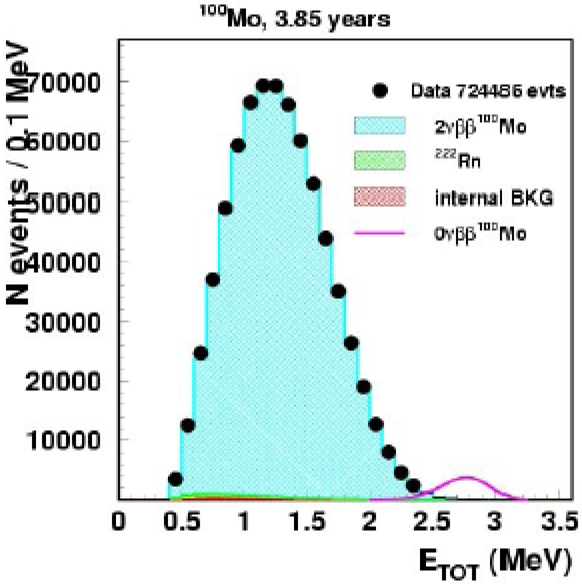
Isotope	$T_{1/2}^{2\nu\beta\beta}$ (y)
^{100}Mo	$[7.11 \pm 0.02(stat) \pm 0.54(syst)] \times 10^{18}$ * (SSD favored)
^{100}Mo(0_1^+)	$\left[5.7^{+1.3}_{-0.9}(stat) \pm 0.8(syst)\right] \times 10^{20}$ **
^{82}Se	$[9.6 \pm 0.3(stat) \pm 1.0(syst)] \times 10^{19}$ *
^{116}Cd	$[2.8 \pm 0.1(stat) \pm 0.3(syst)] \times 10^{19}$ **
^{130}Te	$[6.9 \pm 0.9(stat) \pm 1.0(syst)] \times 10^{20}$ ***
^{150}Nd	$\left[9.20^{+0.25}_{-0.22}(stat) \pm 0.73(syst)\right] \times 10^{18}$ ***
^{96}Zr	$[2.35 \pm 0.14(stat) \pm 0.19(syst)] \times 10^{19}$ ***
^{48}Ca	$\left[4.4^{+0.5}_{-0.4}(stat) \pm 0.4(syst)\right] \times 10^{19}$ ***

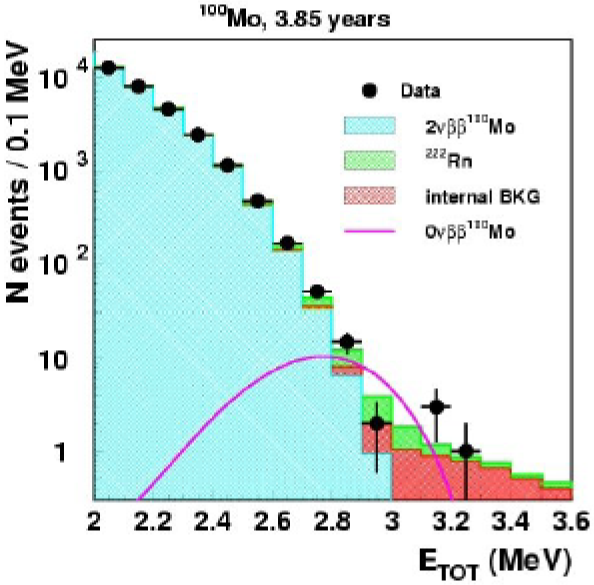
* Phase 1 (high radon data), Phys. Rev. Lett. 95 (2005) 182302
(additional statistics are being analysed, to be published soon)

** Phase 1 data

*** Phases 1 and 2, preliminary

$0\nu\beta\beta$ results for ^{100}Mo, 2003-2008 data: 3.85 years





Counting [2.8 – 3.2] MeV

- Data: 20 events
- Expected background: 18.6 events
- Excluded 90% C.L.: 9.6 events
- Efficiency = 0.0726

Likelihood [2.0 – 3.2] MeV

- Excluded 90% C.L.: 18 events
- Efficiency = 0.174
  $T_{1/2}^{0\nu\beta\beta} > 1.1\ 10^{24}$ y @ 90 %C.L.
  $< m_\nu > <$ 0.45–0.93 eV

- Current limits on neutrinoless DBD (90% C.L.):

Isotope	Exposure (kg.y)	$T_{1/2}^{0\nu\beta\beta}$ (y)	$< m_\nu >$ (eV)	[nme ref.]
^{100}Mo	26.6	$>1.1\ 10^{24}$	<0.45-0.93	[1-3]
^{82}Se	3.6	$>3.6\ 10^{23}$	<0.9-1.6 <2.3	[1-3] [7]
^{150}Nd	0.095	$>1.8\ 10^{22}$	<1.7-2.4 <4.8-7.6	[4-5] [6]
^{130}Te	1.4	$>9.8\ 10^{22}$	<1.6-3.1	[4,5]
^{96}Zr	0.024	$>8.6\ 10^{21}$	<7.4-20.1	[2,3]
^{48}Ca	0.017	$>1.3\ 10^{22}$	<29.6	[7]

- nme: nuclear matrix element:

[1] M.Kortelainen and J.Suhonen, Phys.Rev. C 75 (2007) 051303(R)

[2] M.Kortelainen and J.Suhonen, Phys.Rev. C 76 (2007) 024315

[3] F.Simkovic, et al. Phys.Rev. C 77 (2008) 045503

[4] V.A.Rodin et al. Nucl.Phys. A 793 (2007) 213

[5] V.A. Rodin et al. Nucl.Phys. A 766(2006) 107

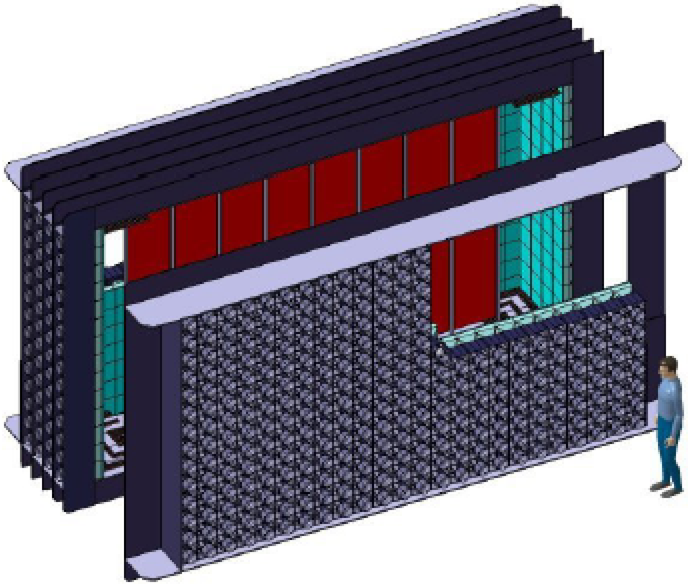
[6] J.H.Hirsh et al. Nucl.Phys. A 582(1995) 124

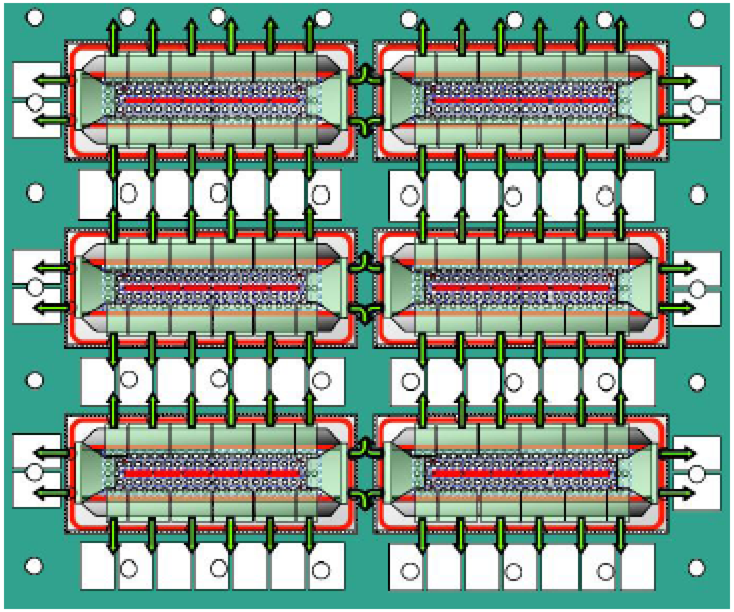
[7] E.Caurier et al. Phys.Rev.Lett 100 (2008) 052503

SuperNEMO project

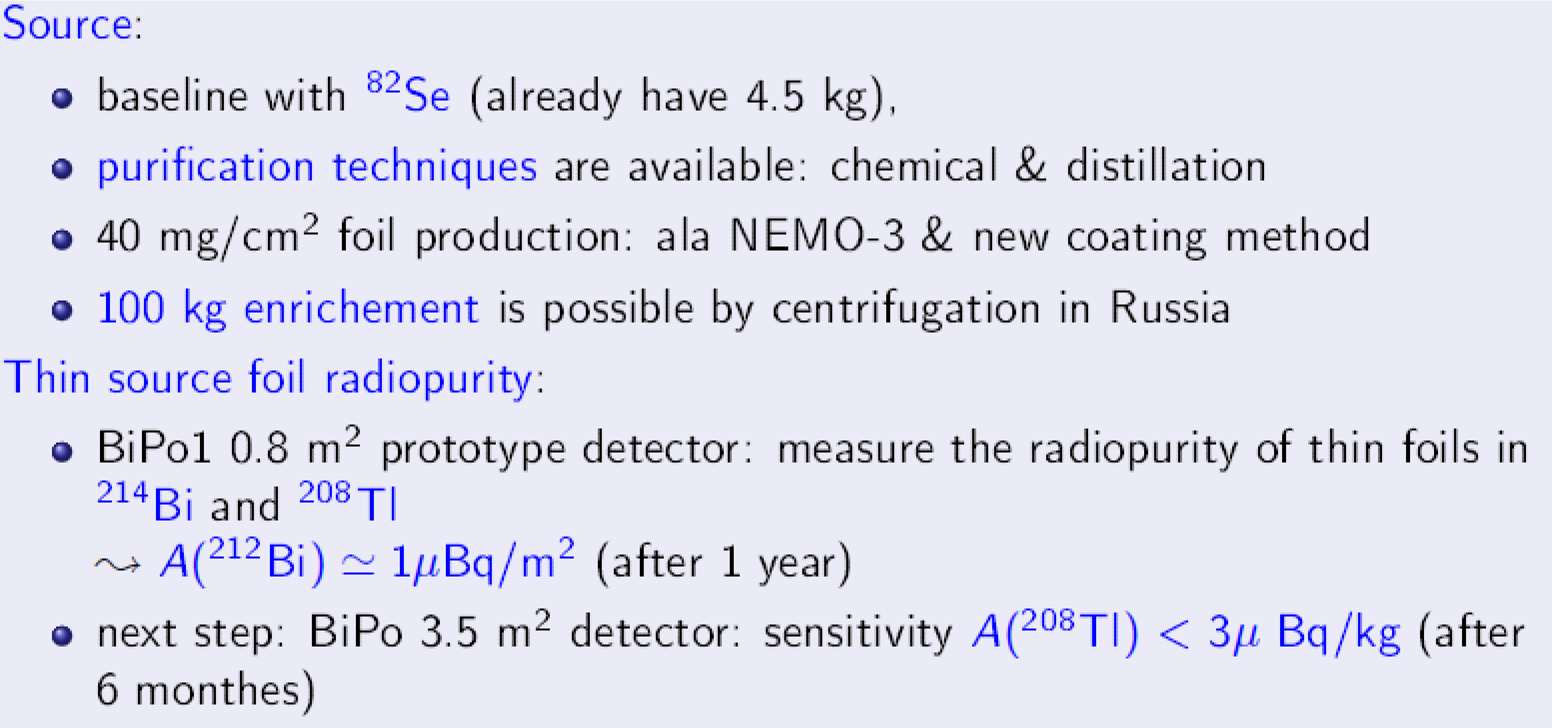
Physics goals and technique

- Search for $0\nu\beta\beta$ decay at $T_{1/2} \simeq 10^{26}$ y $\rightsquigarrow$ $< m_\nu > \simeq$ 50 meV
- Extends and improves NEMO-3 technique:
  tracker+calorimeter, modular design, baseline $\simeq$ 100 kg ^{82}Se
- R&D phase: 2005-2009





R&D stages



Source:

- baseline with ^{82}Se (already have 4.5 kg),
- purification techniques are available: chemical & distillation
- 40 mg/cm^2 foil production: ala NEMO-3 & new coating method
- 100 kg enrichement is possible by centrifugation in Russia

Thin source foil radiopurity:

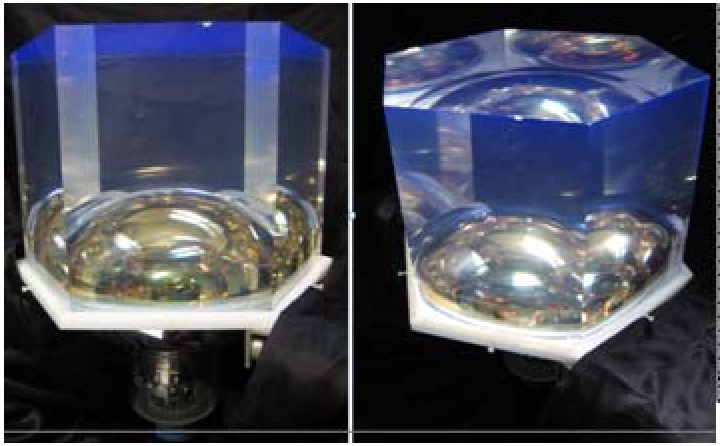
- BiPo1 0.8 m^2 prototype detector: measure the radiopurity of thin foils in ^{214}Bi and ^{208}Tl
  $\rightsquigarrow$ $A(^{212}\mathrm{Bi}) \simeq 1\mu\mathrm{Bq/m}^2$ (after 1 year)
- next step: BiPo 3.5 m^2 detector: sensitivity $A(^{208}\mathrm{Tl}) < 3\mu$ Bq/kg (after 6 monthes)

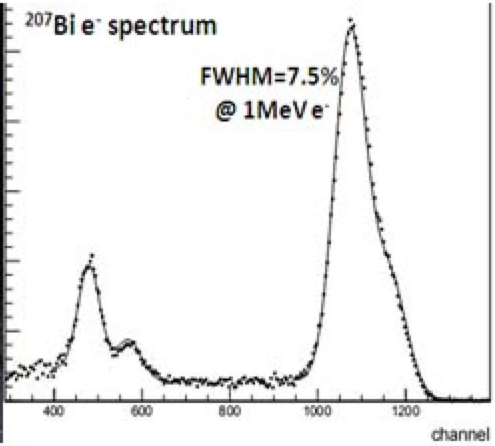
Tracker:

- 90 cells prototype shows good tracking performances (efficiency and resolution)
- wiring robot is under development (full detector is ≃500000 wires)

Calorimeter:

- main goal is r=7% FWHM @ 1 MeV (scintillator block + 8" PMT)
- accurate calibration and control quality of mass production
- r=6.7 % and 7.8 % have been reached resp. with Photonis and Hamamatsu high QE PMTs + 10 cm thick plastic scintillator block.
- Calorimeter design to be choosen between:
  - blocks (15000 channels @ r=7%)
  - or bars (7500 ch. @ r=10%)





CONCLUSION

New generation of the of the 0νββ experiments

has a good chance to penetrate deeper in understanding of the neutrino properties