GERDA experiment
A search for neutrinoless double beta decay

Roberto Santorelli
(Physik-Institut der Universität Zürich)
on behalf of the GERDA collaboration

ÖPG/SPS/ÖGAA meeting – 04/09/09

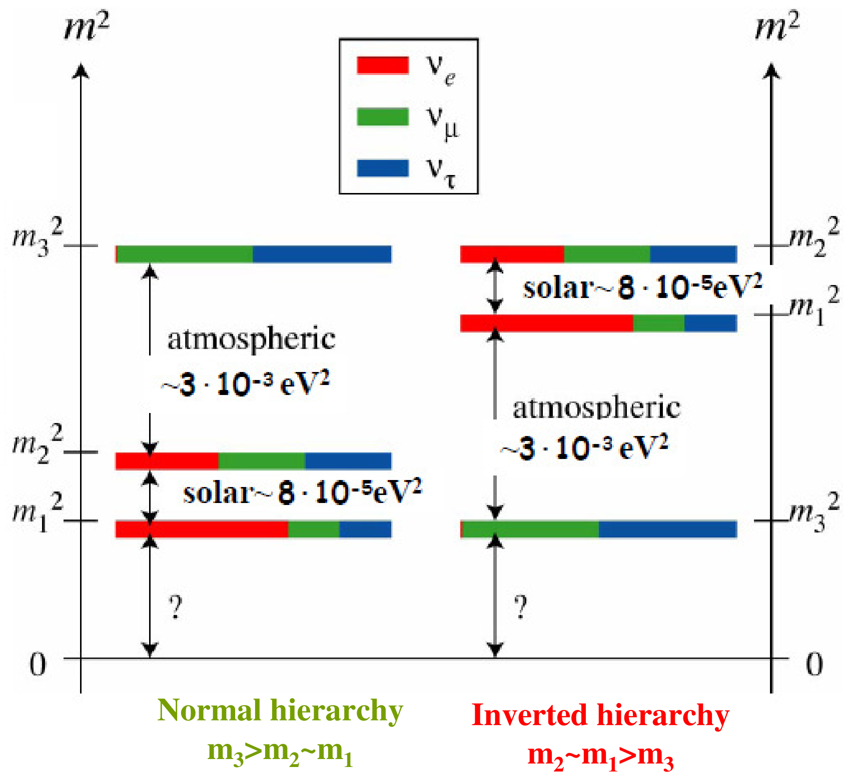
MOTIVATIONS

Neutrinos mixing matrix Uij characterized by:

Three mixing angles $\theta_{12}\ \theta_{23}\ \theta_{13}$
One Dirac phase δ
Two Majorana phases $\phi_2\phi_3$

$\theta_{12}\ \theta_{23}$ measured – limits on θ_{13}

Mass scale $\Delta m^2_{12}\ |\Delta m^2_{13}|$

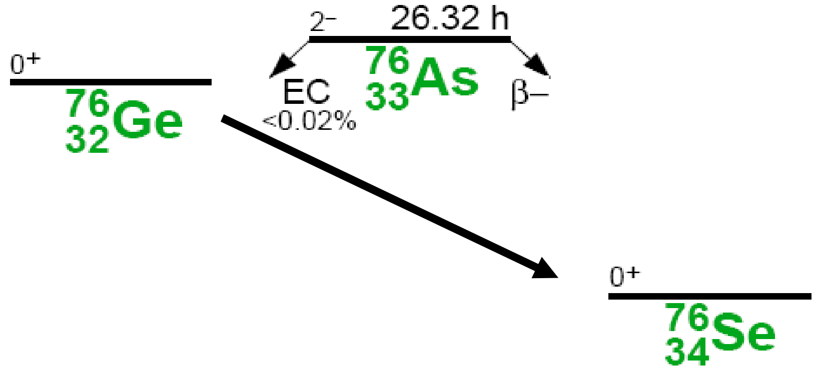


Next challenges in neutrino physics:

- Majorana or Dirac nature of the particle
- Mass hierarchy
- Absolute mass scale

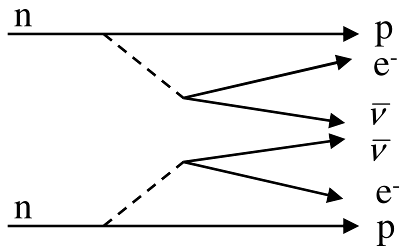
NEUTRINOLESS DOUBLE BETA DECAY

Second order process detectable if the first order process is energetically forbidden



Candidate	Q(MeV)	Abund(%)
$^{48}Ca \rightarrow ^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2.040	7.8
$^{82}Se \rightarrow ^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow ^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow ^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.533	34.5
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

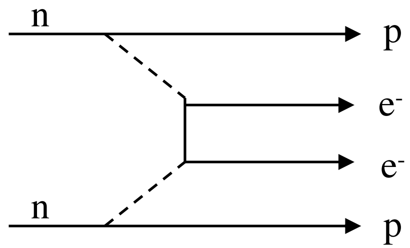
$2\nu\beta\beta$ decay



$(Z,A) \rightarrow (Z+2,A) + 2e^- + 2\bar{\nu}$

$T_{1/2} \sim 10^{21}$y

$0\nu\beta\beta$ decay



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

$T_{1/2} > 10^{25}$y

$^{76}Ge \rightarrow ^{76}Se + 2e^-$

$Q_{\beta\beta}(76Ge) = 2039$keV

0ν mode forbidden in the SM

$\Delta L = 2$

Possible only for $\begin{cases} \nu = \bar{\nu} & \text{(Majorana particle)} \\ m_\nu \neq 0 \end{cases}$

EXPERIMENTAL SIGNATURE

$2\nu\beta\beta$ in ^{76}Ge: $T_{1/2} \sim 1.5 \pm 0.1 \cdot 10^{21}$ y

$Q_{\beta\beta}(^{76}Ge) = 2039$keV

Peak at $Q_{\beta\beta} = E_{e1} + E_{e2} - 2m_e$

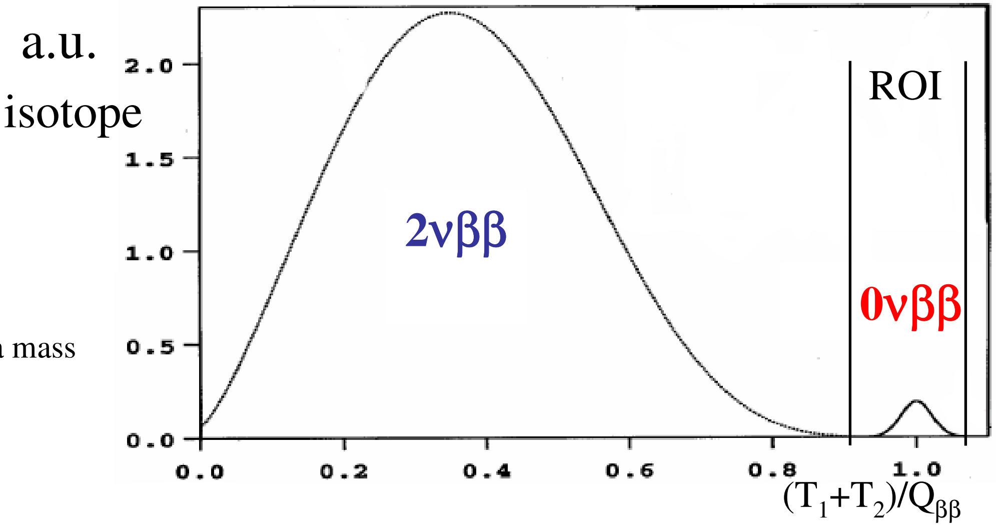
2 electrons from the vertex + daughter isotope

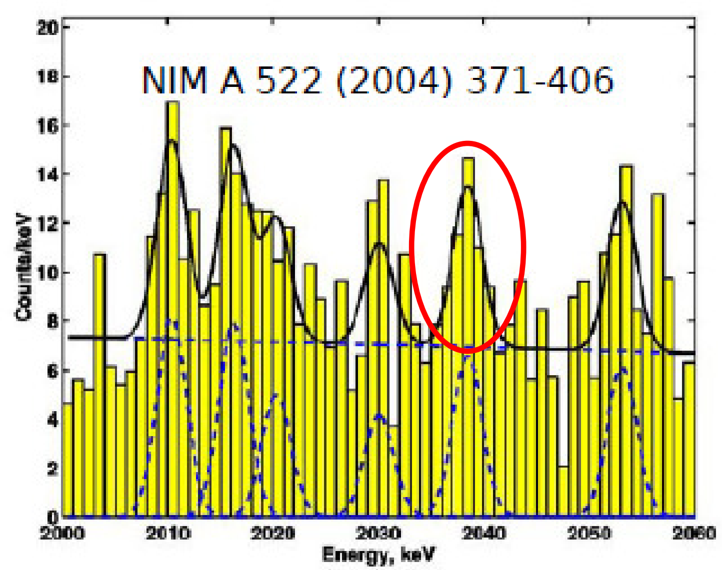
$$\frac{1}{\tau} = G(Q_{\beta\beta}, Z)\,|M_{nucl}|^2 < m_{ee} >^2$$

Phase space $\propto Q^5_{\beta\beta}$

Nucl. matrix element

Effective Majorana mass





Heidelberg-Moscow experiment:

- 5 enriched Ge p-type crystals
- background index ~0.1 cts/(keV·kg ·y)
- 71.7 kg·y
- $T_{1/2} = (0.69 - 4.18) \cdot 10^{25}$ y
  Claim of a signal by part of the collaboration

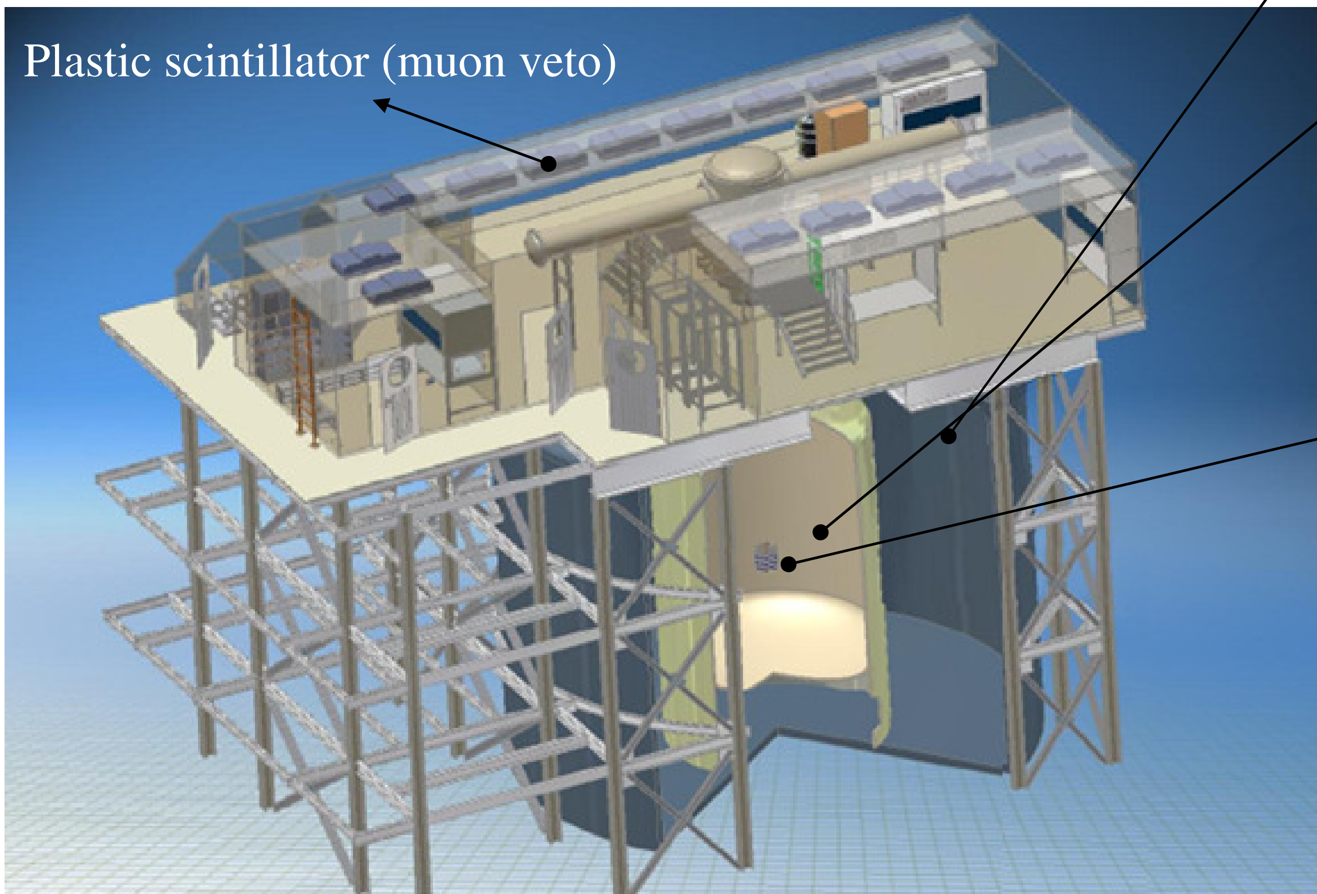
Klapdor-Kleingrothaus et al., Phys. Lett. B 586 (2004) 198.

EXPERIMENTAL REQUIREMENTS

- Large amount of $0\nu\beta\beta$ isotopes
- Good energy resolution
- Extremely low background

GERDA $\rightarrow$ ^{76}Ge detectors for $0\nu\beta\beta$

- High Q-value
- Very pure detectors $\rightarrow$ natural radioactivity contribution reduced
- Large target mass $\rightarrow$ Enrichment in ^{76}Ge (86%)
- Very good energy resolution $\rightarrow$ $\Delta E/E\ (Q_{\beta\beta}) \sim 0.2\%$
- LAr as cooling and shielding
- Surrounding materials minimized

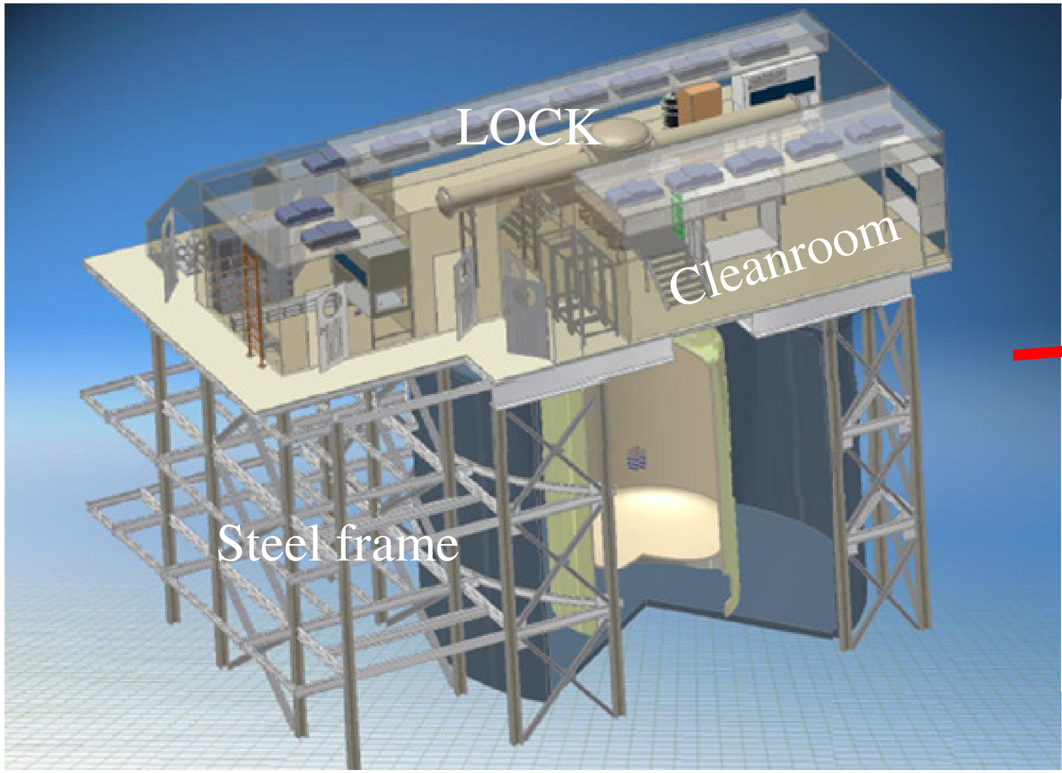


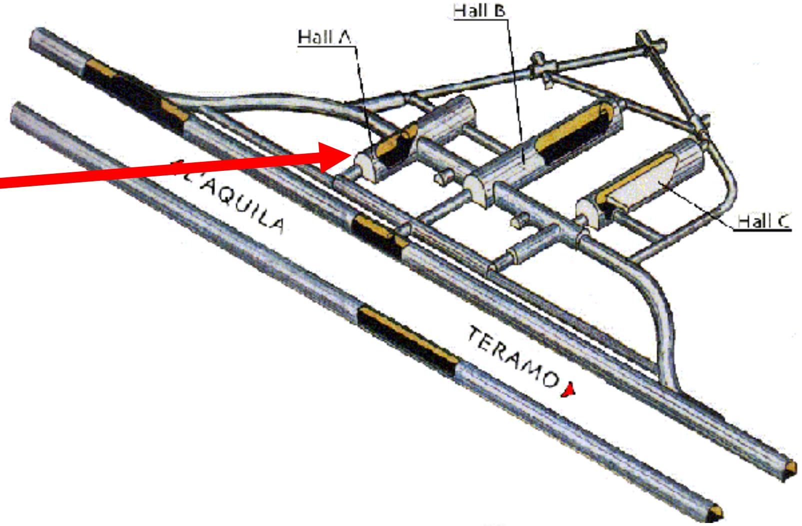
Water tank
(r=5.0m h=9.0m)
- n shield
- Cherenkov veto

Cryostat
(r=2.1m h=5m)
- cooling medium
- passive/active shield

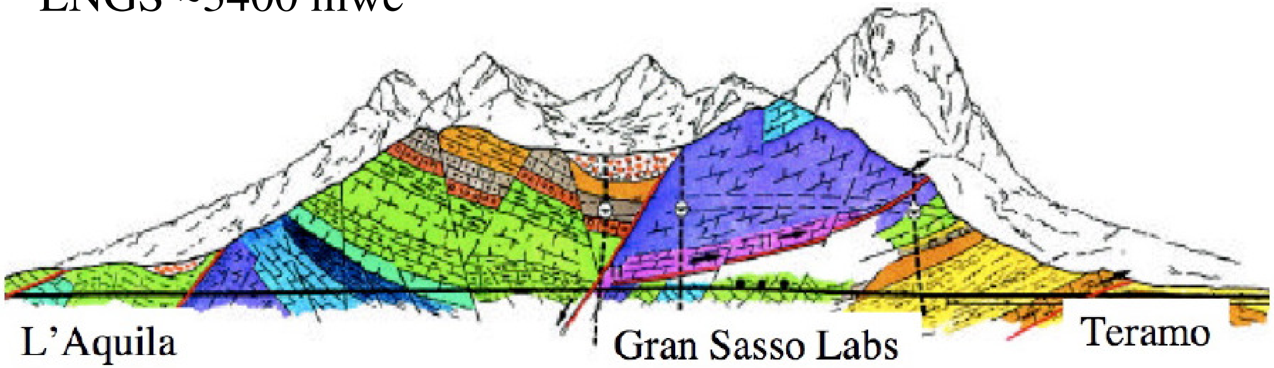
Up to 16 strings

Detector loaded from top of the thank
through a clean room area





LNGS ~3400 mwe

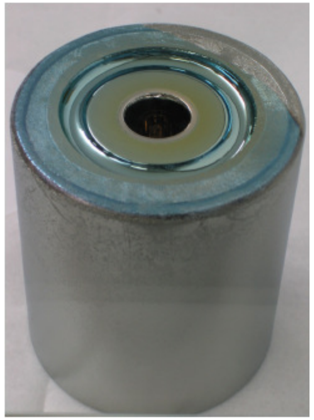


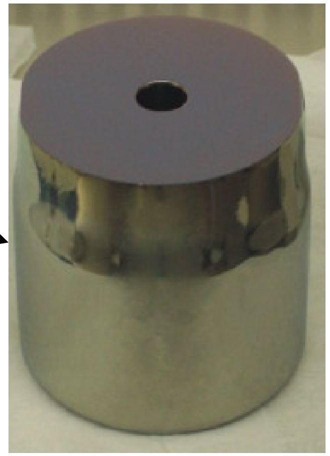
- Jagellonian University - Cracow, Poland
- Technische Universität - Dresden, Germany
- Joint Institute for Nuclear Research - Dubna, Russia
- Institute for Reference Materials and Measurements - Geel, Belgium
- Max-Planck-Institut für Kernphysik - Heidelberg, Germany
- Russian Academy of Sciences - Moscow, Russia
- Institute for Theoretical and Experimental Physics - Moscow, Russia
- Russian Research Center Kurchatov Insitute - Moscow, Russia
- Gran Sasso National Laboratory - L'Aquila, Italy
- Universita Milano Bicocca - Milano, Italy
- Max-Planck-Institut für Physik - München, Italy
- Universita di Padova - Padova, Italy
- Eberhard Karls University - Tübingen, Germany
- University of Zürich - Zürich, Switzerland

GERDA

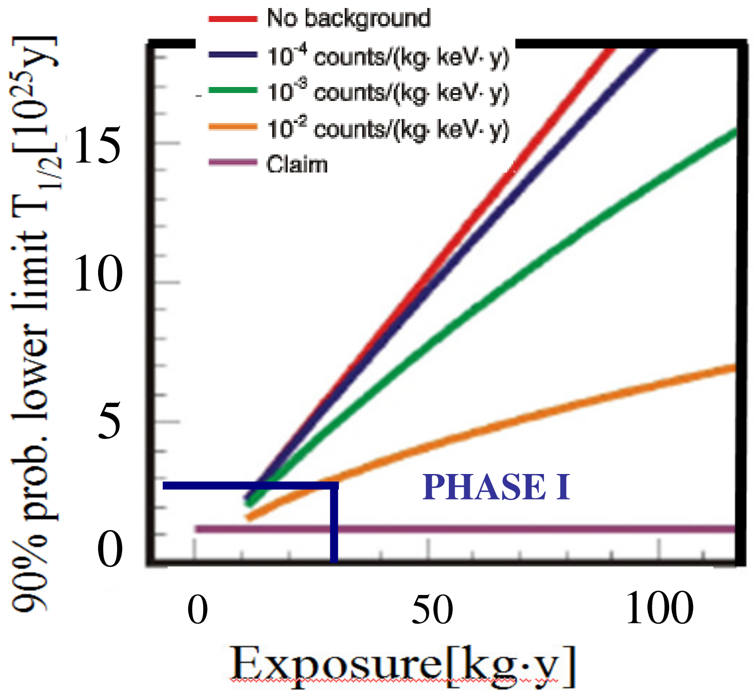
14 institutions

PHASE I





- p-type coaxial detectors
- 5 He-Mo detectors
- 3 IGEX
- Refurbished by Canberra and tested in LAr
- Total 17.9 kg enriched Ge
- Exposure ~ 30 kg · y
- bck: 0.01 cts/(keV · kg · y)
- $T_{1/2} \rightarrow 2 \cdot 10^{25}$ y



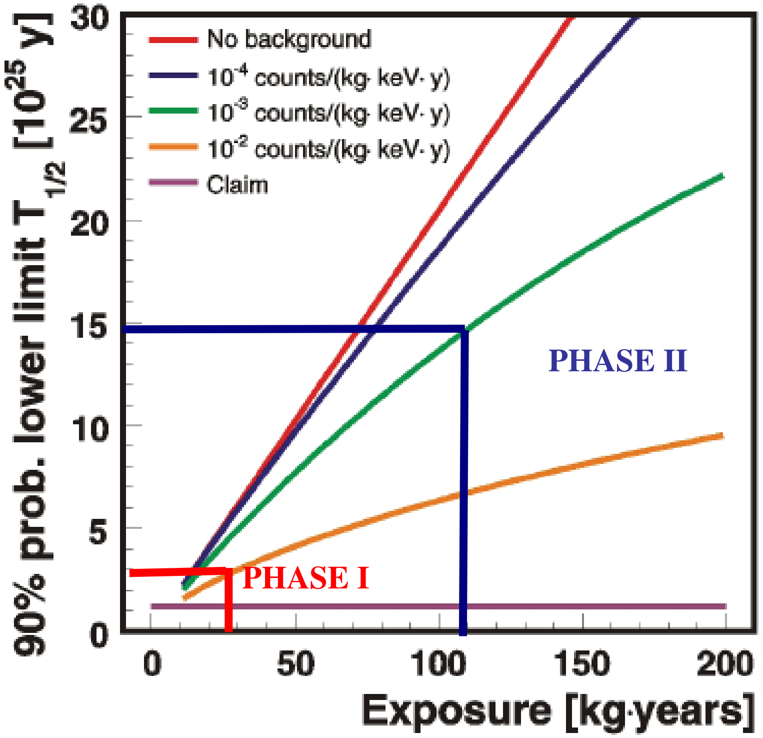
Check claim of Hd-Mo

Cryotank (Mar. 08)

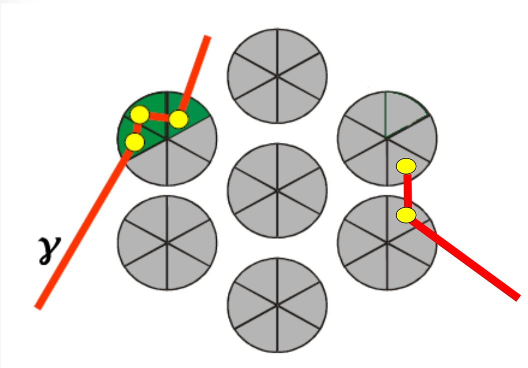
Water tank (Aug. 08)

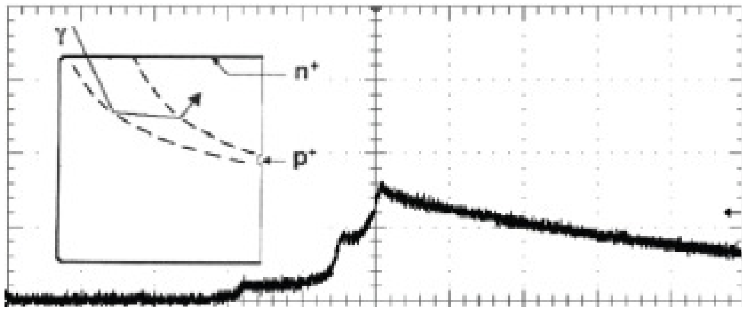
PHASE II

PHASE II : add new p/n-type coaxial detector
- 86% enrichment
- 37.5 kg already available
- segmentation? unsegmented Broad Energy det?
  (R&D on ongoing)
- Exposure ~ 100 kg · y
- bck: 0.001 cts/(keV · kg · y)
- $T_{1/2} \geq 15 \cdot 10^{25}$ y



Single and Multi-site event discrimination:





- segmented detectors
- point contact BEGe detector

Effective bkg reduction

PRESENT STATUS

• Installation of the clean room (May 09)

• Mounting of the muon veto PMTs (Aug 09)

• Cryostat filling (Sep 09)

• Temporary commissioning lock for Phase I completed by the end of the year

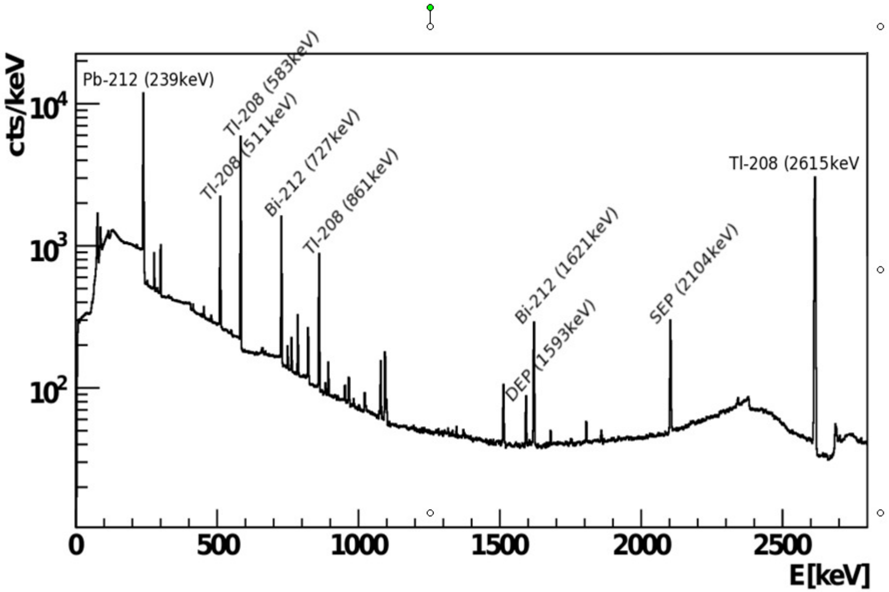
• Phase I detector reprocessed and tested in LAr

→ FWHM (1.33MeV) ~ 2.5 keV

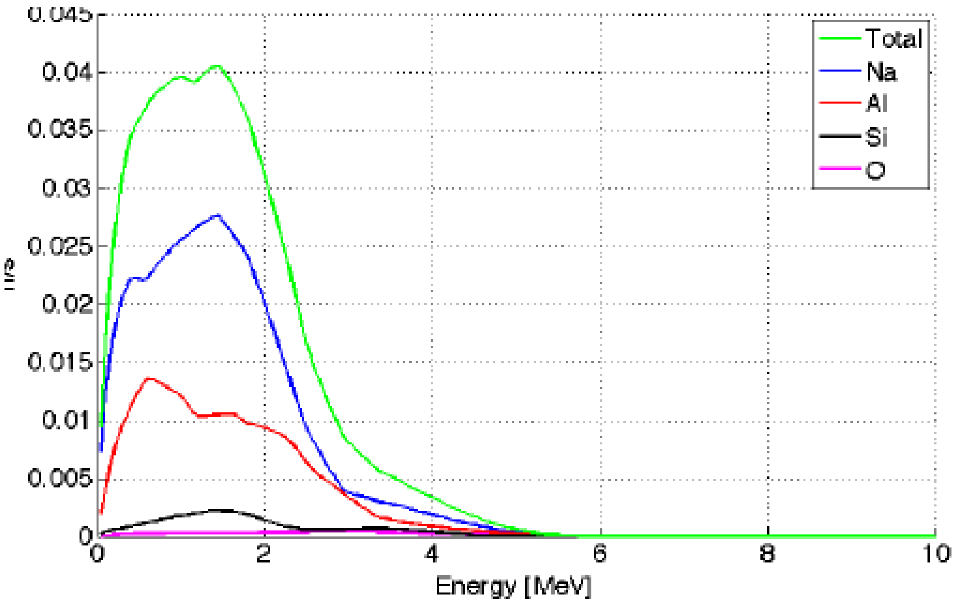
→leakage current stable

• Phase II R&D ongoing

^{228}Th calibration source



Neutron fluxes for different materials



- Sufficient number of lines
- Energy calibration in the region of interest (SEP – ^{208}Tl)
- Pulse shape discrimination

- 228Th → α emitter $\overline{E}(\alpha) \sim 6.5$ MeV

  $E_{max}(\alpha) = 8.8$ MeV

⇒ neutrons produced through (α,n) with the ceramic pallet of the commercial sources

Neutron Rate = 3.8 10^{-2} n/(s ·kBq)

$E_{mean} = 1.45$ MeV

MC simulations:

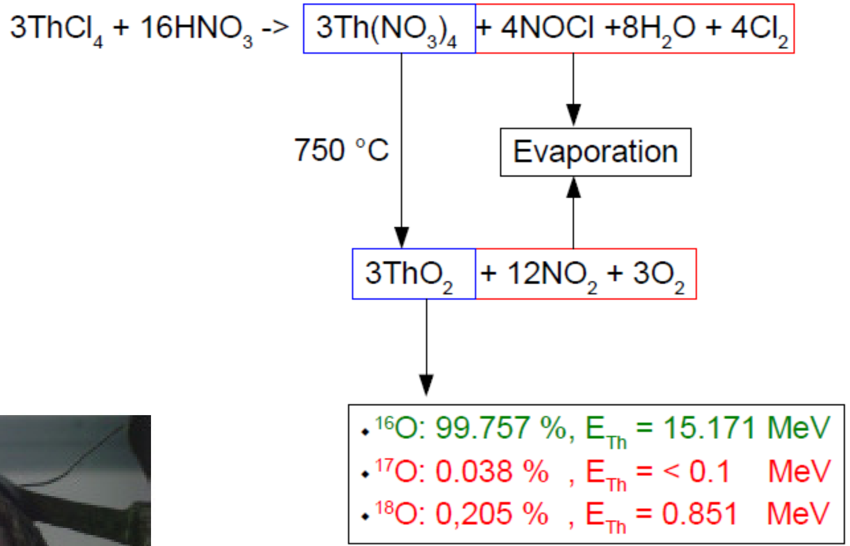
350 cm LAr attenuation

6.7 ·10^7 neutrons considered

⇓

- Mean interaction probability ~ $4 \cdot 10^{-4}$
- 1.0×10^{-5} cts/(keV·kg·y·kBq)
- 6.0×10^{-4} cts/(keV·kg·y) @ 3×20kBq

New low-n rate source development



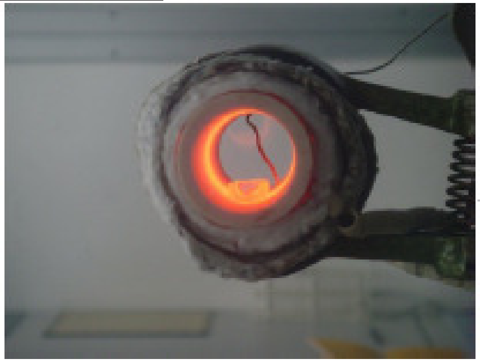
Aim: reduction of the neutron flux through the development of a new setup

Gold: no oxidation

Threshold for $(\alpha,n) \sim 9.94$ MeV

Collaboration with PSI

200 °C



750 °C

MC simulations:

Neutron flux ~ 5.0×10^{-4} n/(s ·kBq)

$E_{mean} = 2.5$ MeV

$B = 8.6\times10^{-8}$ cts/(kg · keV · y · kBq)

$B = 5.1\times10^{-6}$ cts/(keV·kg·y) @ 3×20kBq

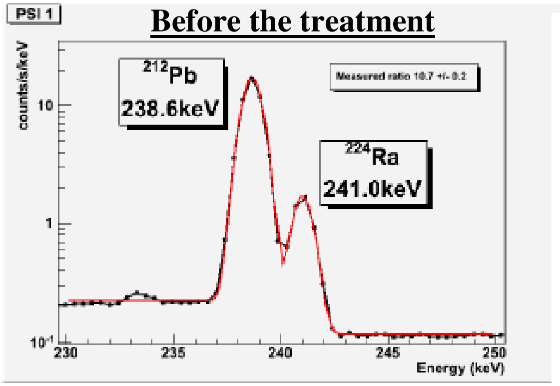
⇒ $\phi \sim 0.01$ n/s @ 20kBq

RESULTS

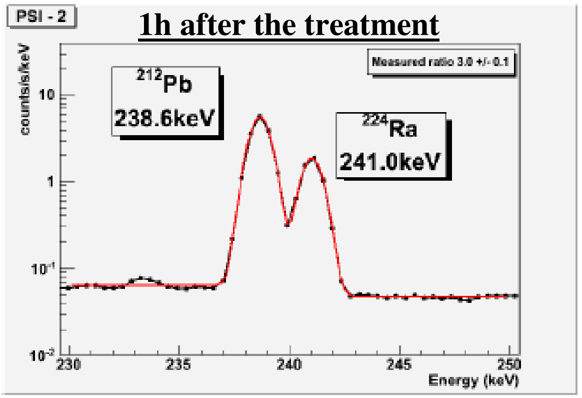
Equilibrium broken due to Rn gas emanation during the procedure

$^{228}Th \rightarrow {}^{224}Ra \rightarrow {}^{220}Rn \rightarrow {}^{216}Po \rightarrow {}^{212}Pb \rightarrow {}^{212}Bi \rightarrow ({}^{212}Po \mid {}^{208}Tl) \rightarrow {}^{208}Pb$

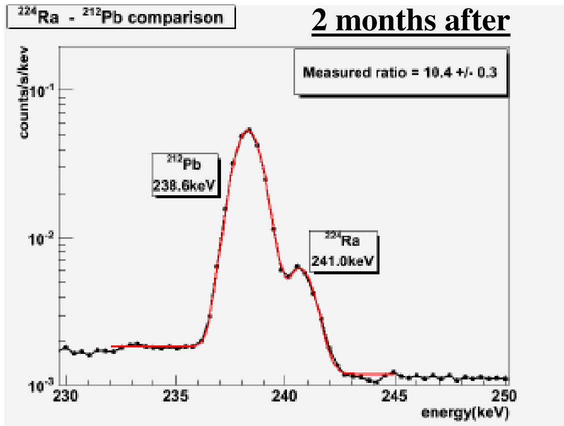
Relative peak height ratio: $^{212}Pb/^{224}Ra \cong 10.6$



$^{212}Pb/^{224}Ra = 10.7 \pm 0.2$

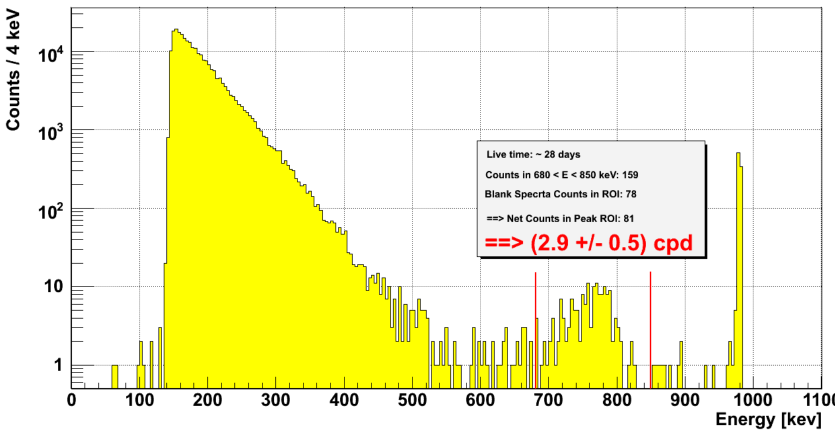


$^{212}Pb/^{224}Ra = 3.0 \pm 0.1$



$^{212}Pb/^{224}Ra = 10.4 \pm 0.3$

Equilibrium restored in few weeks!



^{3}He neutron counter @ LNGS (*28d* livetime)

ϕ: (0.017 +/ - 0.003) n/s @ 20kBq

Good agreement with the predictions!

OK FOR PHASE II!

CONCLUSIONS

- Construction is ongoing
- **Phase I** : 8 diodes (~18 kg) refurbished and ready
- Complete installation and start apparatus commissioning by the end of 2009
- Expected bkg level ~ 0.01 cts/(keV · kg · y)
- Parallel R&D for **Phase II** (Goal: 0.001 cts/(keV · kg · y)

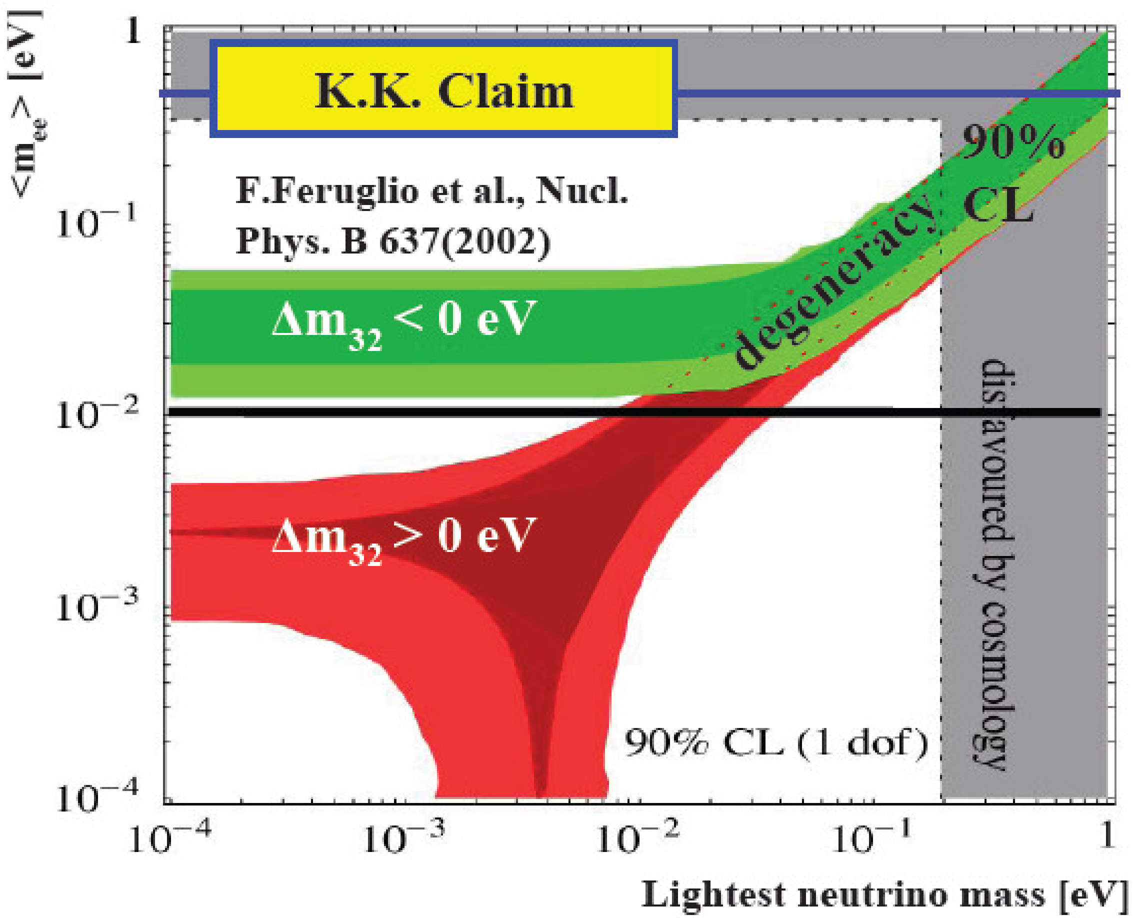
Sensitivity of 0νββ decay experiments

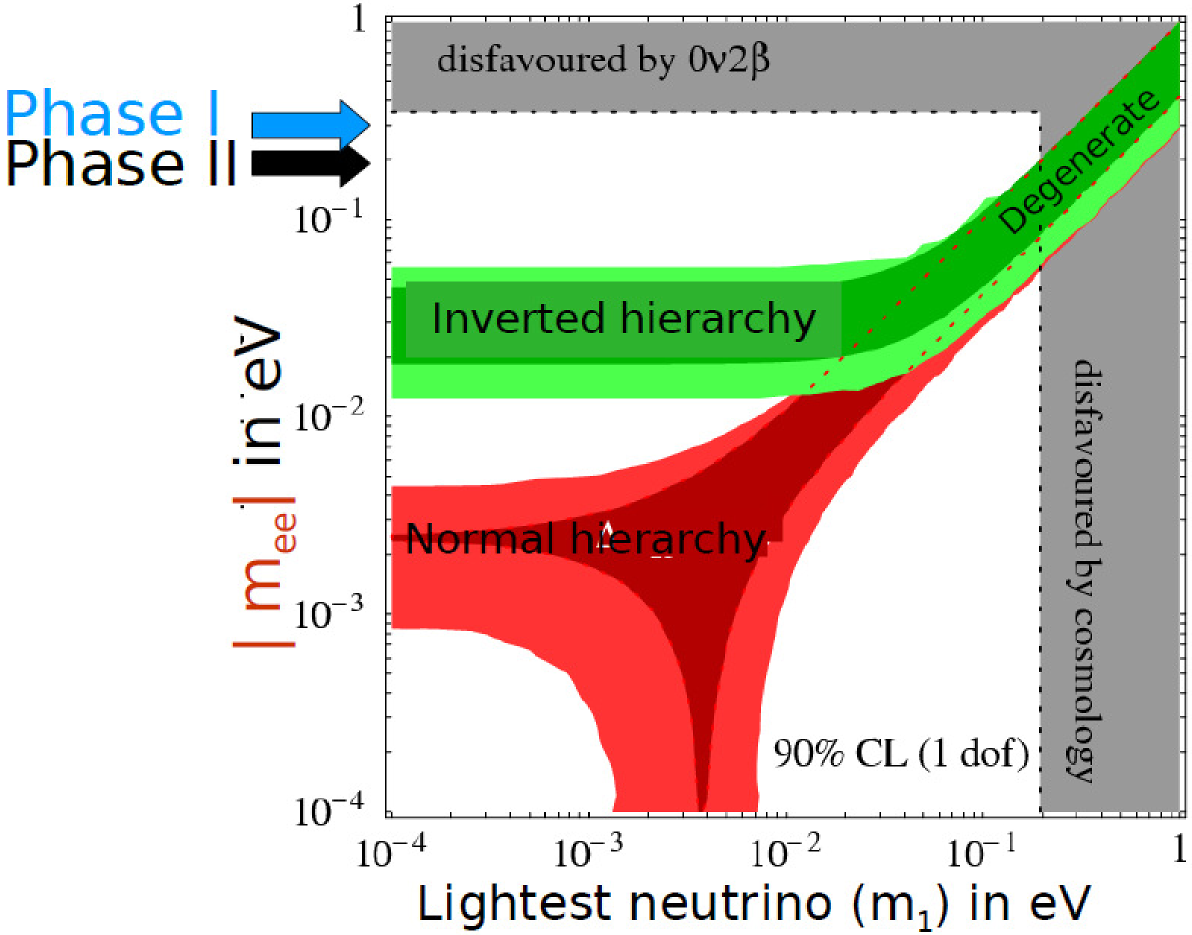
Half life →

$$T_{1/2} \sim a \cdot \varepsilon \cdot \sqrt{\frac{m \cdot t}{\Delta E \cdot B}} \cdot M_{nucl}$$

m → active target mass
B → background rate
a → enrichment of isotopes (<1)
ε → signal detection efficiency (<1)
ΔE → energy resolution
t → measuring time
M → nuclear matrix elements

In order to discriminate between normal and inverted hierarchy, we need an experiment with sensitivity down to ~10mV scale





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