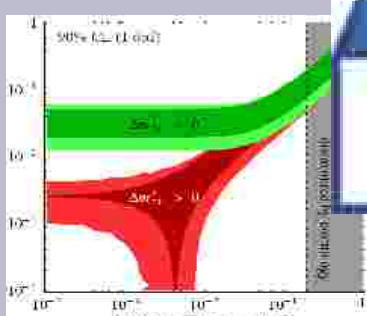
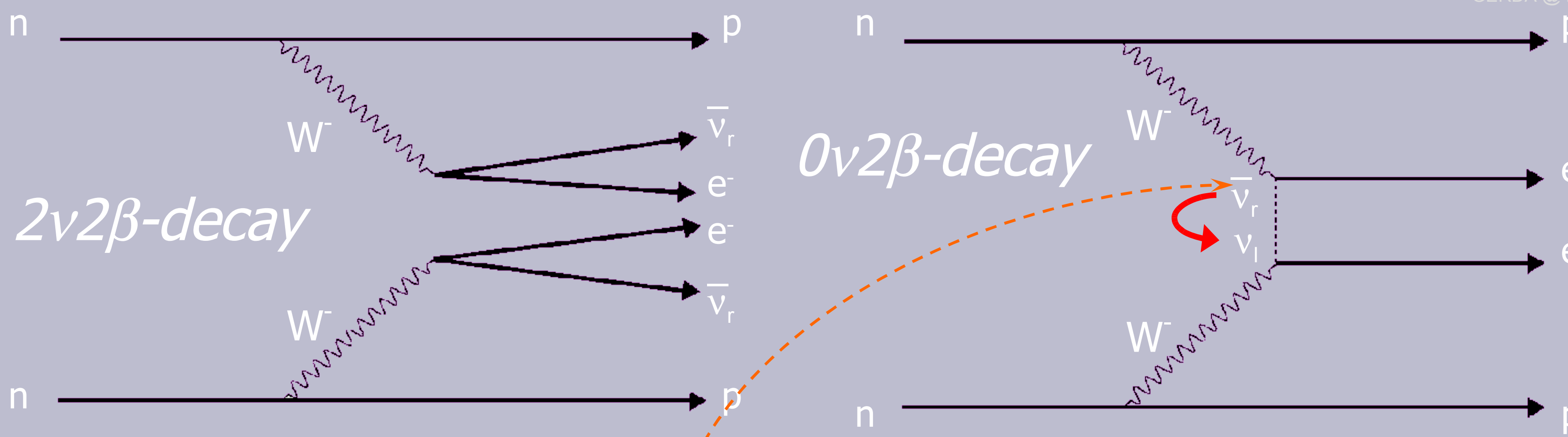
GERmanium **D**etector **A**rray – *search for 0ν2β decay*



Josef Jochum
Kepler Center for Astro and Particle Physics
University Tübingen

$0\nu 2\beta$ decay

$\Delta L=2$

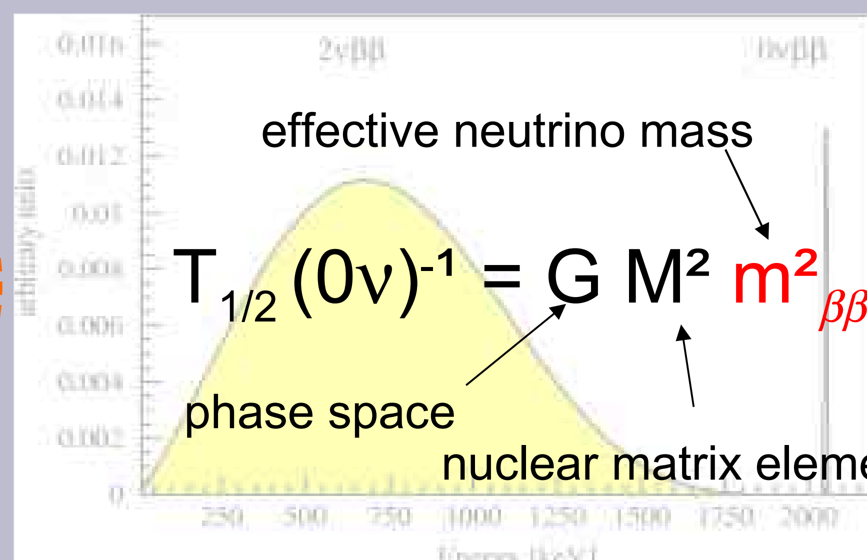


$0\nu 2\beta$- only if:

$\bar{\nu} = \nu$ Maiorana-particle

$\nu_r \leftrightarrow \nu_l$ other helicity

$\sim(1-(v/c)^2)$ **for $m_\nu > 0$**



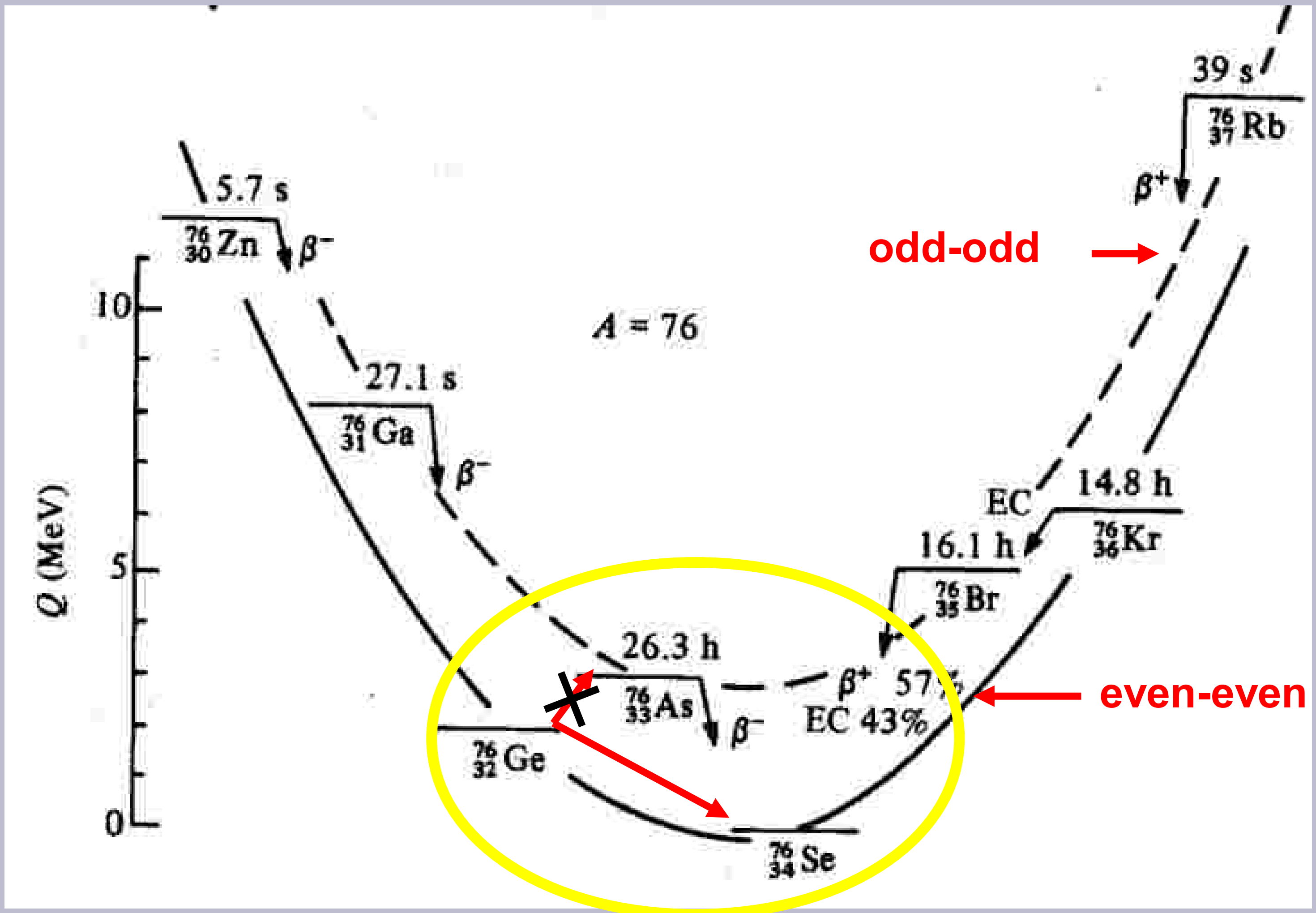
effective neutrino mass

$$T_{1/2}(0\nu)^{-1} = G\, M^2\, m^2_{\beta\beta}$$

phase space

nuclear matrix element

2β-decay - ^{76}Ge



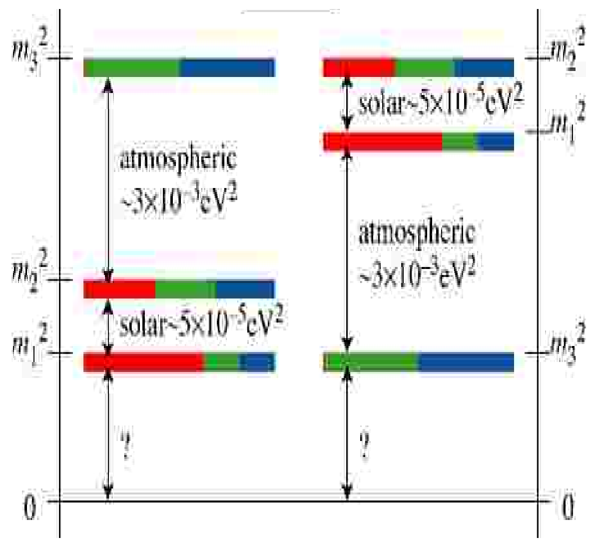
Known knowns and known unknowns

knowns

neutrino-oscillations
nonzero neutrino mass
large mixing angles

unknowns:

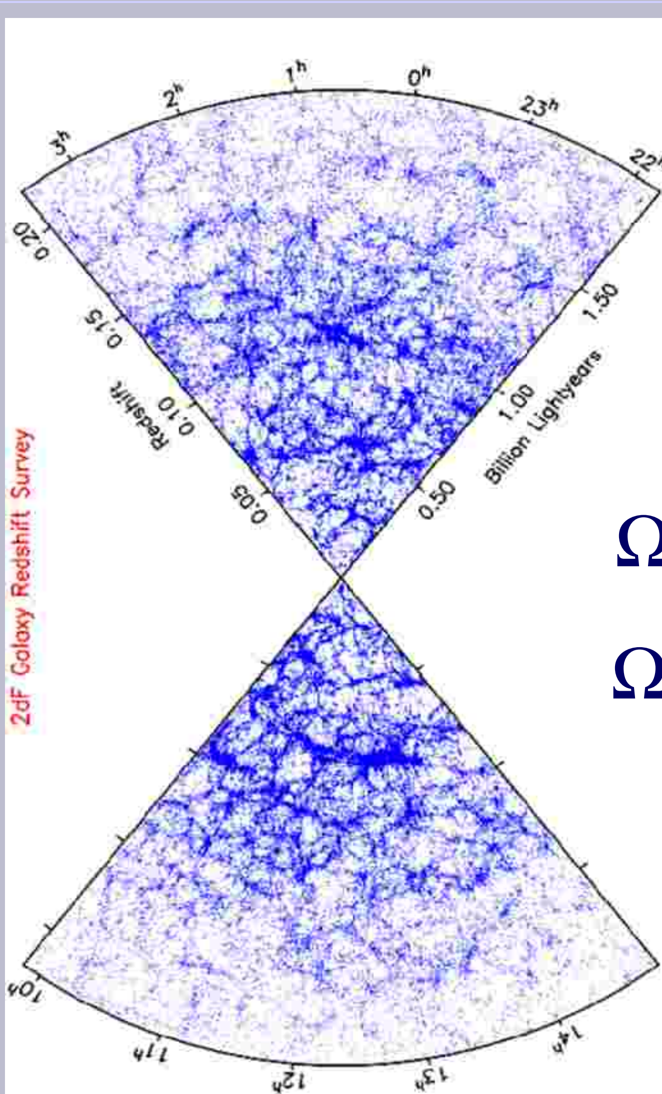
absolute mass scale?
mass hierarchy?
Majorana- or Dirac?
…



normal inverted
hierarchical or degenerate

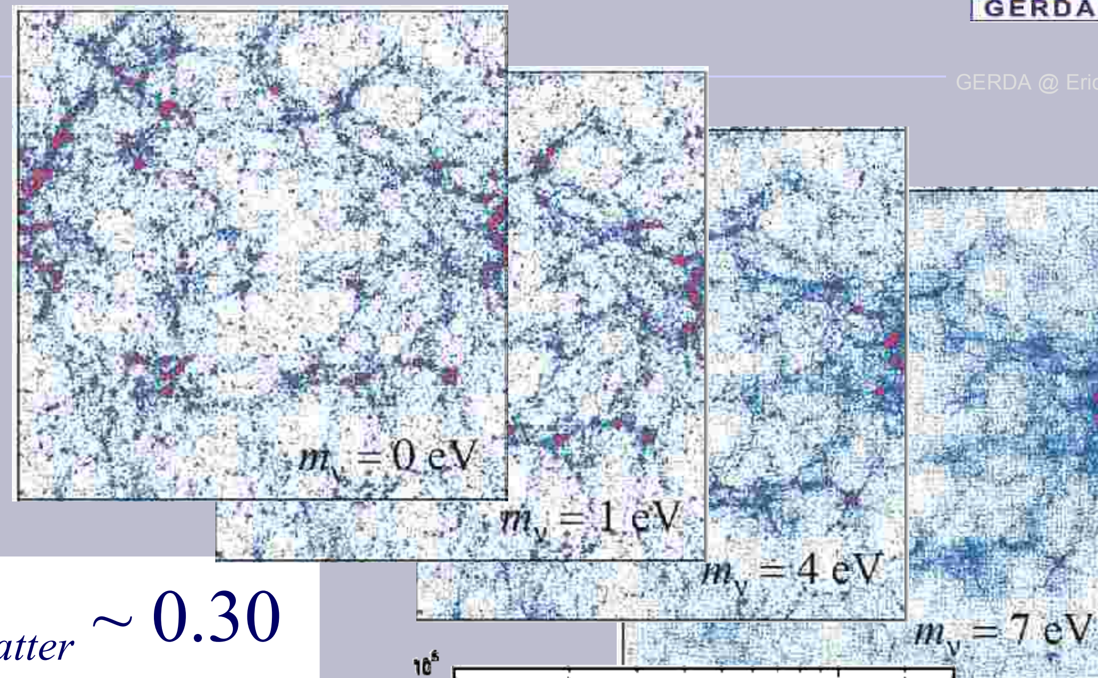
$$\nu \stackrel{?}{=} \bar{\nu}$$

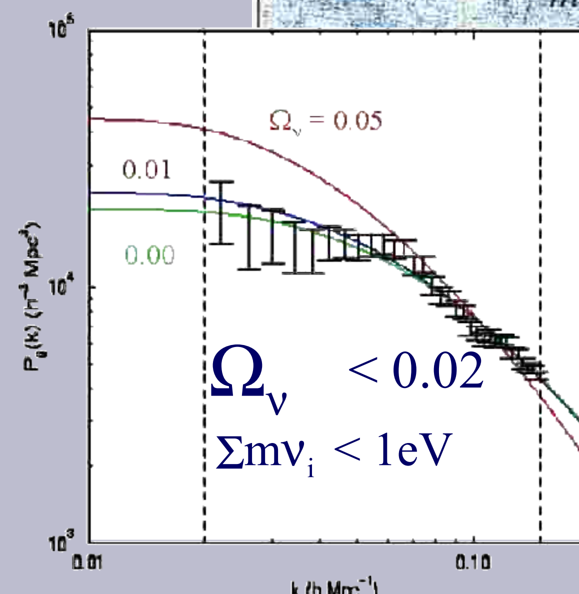
Neutrinos in Cosmology - structure formation



$\Omega_{matter} \sim 0.30$

$\Omega_{\nu} < 0.02$

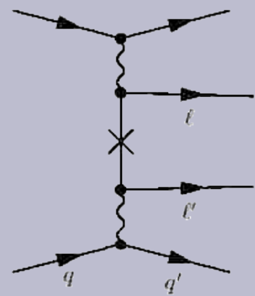




0ν2β decay – effective neutrino mass $m_{\beta\beta}$

GERDA @ Erica

$0\nu2\beta\text{-decay} \propto$



$\propto |\langle m_{\beta\beta} \rangle| = |\sum m_i U_{ei}^2|$

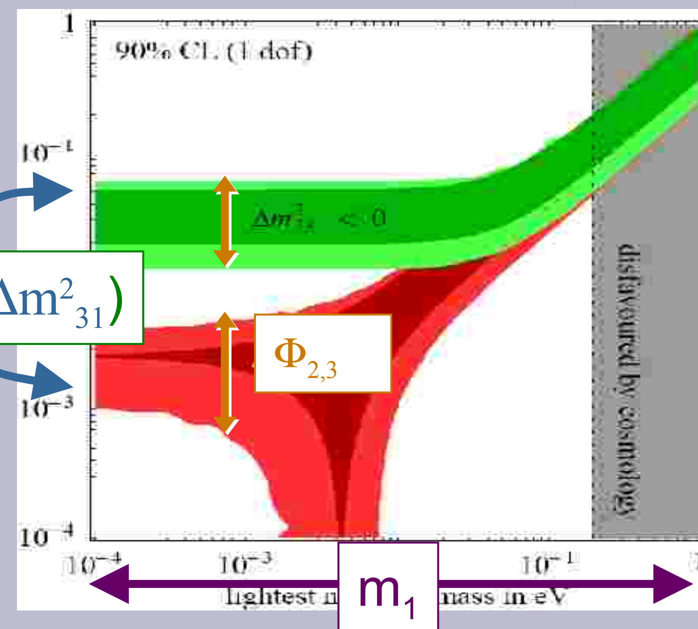
$$m_{\beta\beta} = |m_{\beta\beta}^{(1)}| + |m_{\beta\beta}^{(2)}| \cdot e^{i\Phi_2} + |m_{\beta\beta}^{(3)}| \cdot e^{i\Phi_3}$$

$$|m_{\beta\beta}^{(1)}| = |U_{e1}|^2 m_1$$
$$|m_{\beta\beta}^{(2)}| = |U_{e2}|^2 \sqrt{m_1^2 + \Delta m_{21}^2}$$
$$|m_{\beta\beta}^{(3)}| = |U_{e3}|^2 \sqrt{m_1^2 + \Delta m_{31}^2}$$

solar $\Rightarrow$ $|U_{e1}|^2, |U_{e2}|^2, \Delta m_{21}^2$

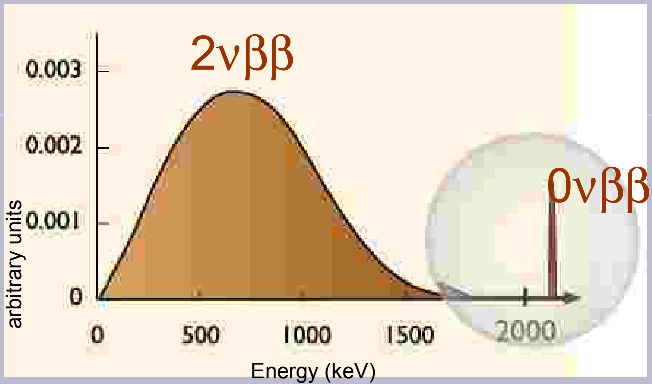
atmosph. $\Rightarrow$ $|\Delta m_{31}^2|$

CHOOZ $\Rightarrow$ $|U_{e3}|^2 < 0.05$



➔unknown parameters: m_1
sign(Δm^2_{31})
CP-phases Φ_2, Φ_3

Sensitivity of *0ν2β* - decay search



theory:

$$T_{1/2}(0\nu) = (G\, M^2\, m^2_{\beta\beta})^{-1}$$

experiment:

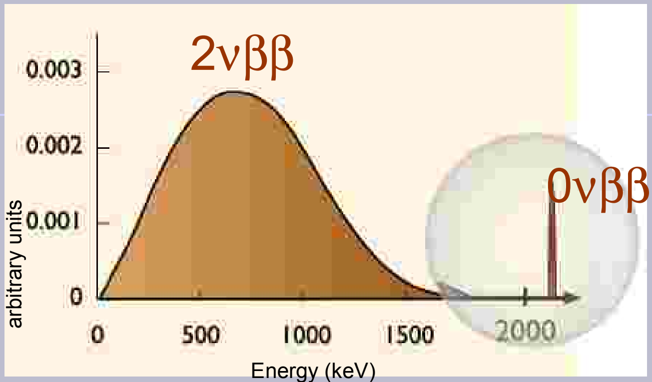
$$T_{1/2}(0\nu) > 4.2\cdot 10^{26}\mathrm{y} \cdot \varepsilon \cdot (a/A) \cdot \sqrt{Mt \,/\, B\, \Delta E}$$

$$m_{\beta\beta} < \sqrt{\frac{\sqrt{B\,\Delta E / Mt}}{\varepsilon a}}$$

$$\sim 1 / \sqrt{T_{1/2}(0\nu)}$$

- ε - detection efficiency at $Q_{\beta\beta}$
- a - ββ isotope fraction
- M - mass of detector in kg
- t - measurement time in years
- B - background in cts/(keV kg y)
- ΔE - FWHM energy resolution at $Q_{\beta\beta}$ in keV
- A - mass number

Sensitivity of $0\nu 2\beta$ - decay search



$$m_{\beta\beta} < \sqrt{\frac{\sqrt{B\,\Delta E / Mt}}{\varepsilon a}}$$

Germanium => Detector = Source
high ε - detection efficiency at $Q_{\beta\beta}$ — done

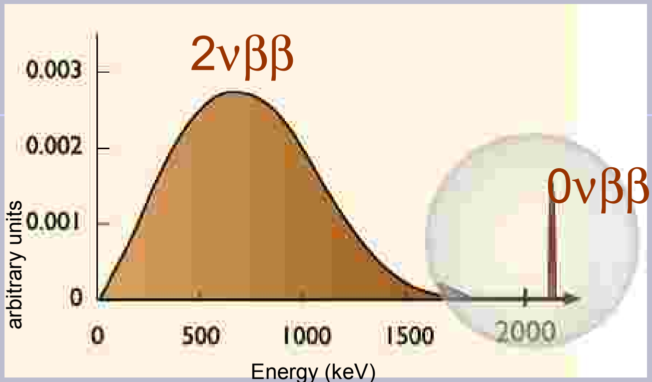
as large as possible number of target atoms
enrichment of ^{76}Ge to 86% => high a - ββ isotope fraction — can be done, just needs money
large array (up to 100 kg) => large M - mass of detector in kg

Germanium Detectors
=> very good ΔE - FWHM energy resolution — done

Long measurement time t — can be done, just needs time

REDUCE BACKGROUND B !!!!! — tricky, needs GERDA

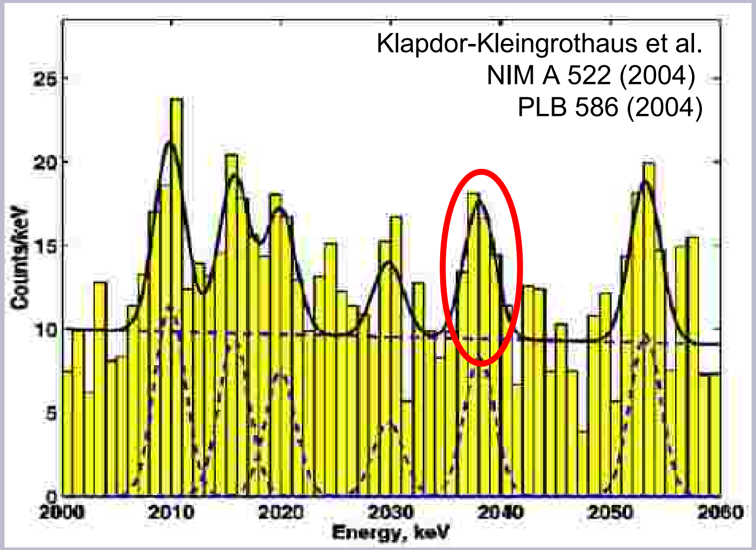
Sensitivity of $0\nu2\beta$ - decay search



$$m_{\beta\beta} < \sqrt{\frac{\sqrt{B\ \Delta E\ /\ Mt}}{\varepsilon a}}$$

state of the art for Ge before GERDA
IGEX, Heidelberg-Moscow experiments

Mt = 71.7 kg y
B = 0.11 / (keV kg y)
a = 86%, $\varepsilon \sim 1$, $\Delta E \sim$ 3keV



Sensitivity **$T_{1/2} \sim 2 \times 10^{25}$y**
$m_{\beta\beta}$ < 350 meV

Claim of Evidence !

to test and to improve
- increase Mt
- reduce background B

⇒ 1 ton of isotopes and B <10^{-3} / (kg y)
for 10 meV scale

GERDA - *Idea*

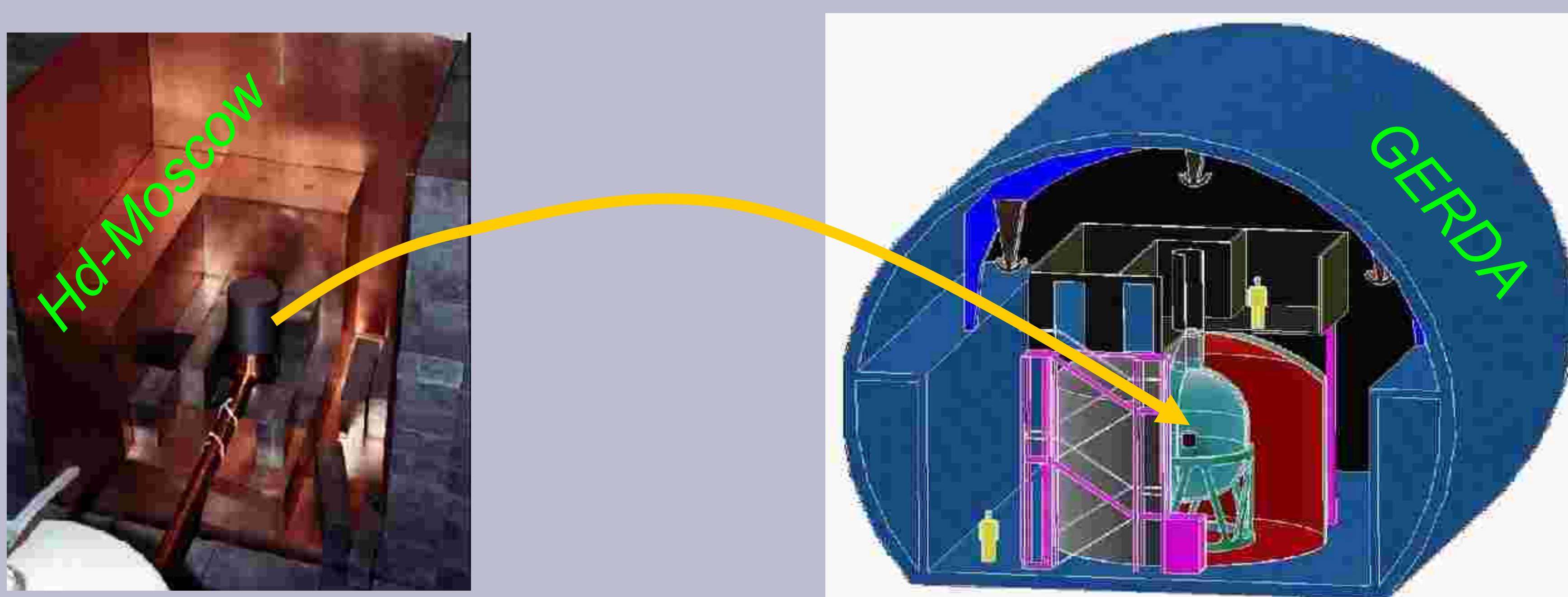
Hd-Moscow background given by:

- detectors surroundings
- cosmogenic activation of Ge

→

GERDA - Phase 1:

bare detectors
in purified liquid Argon
and low Z shield



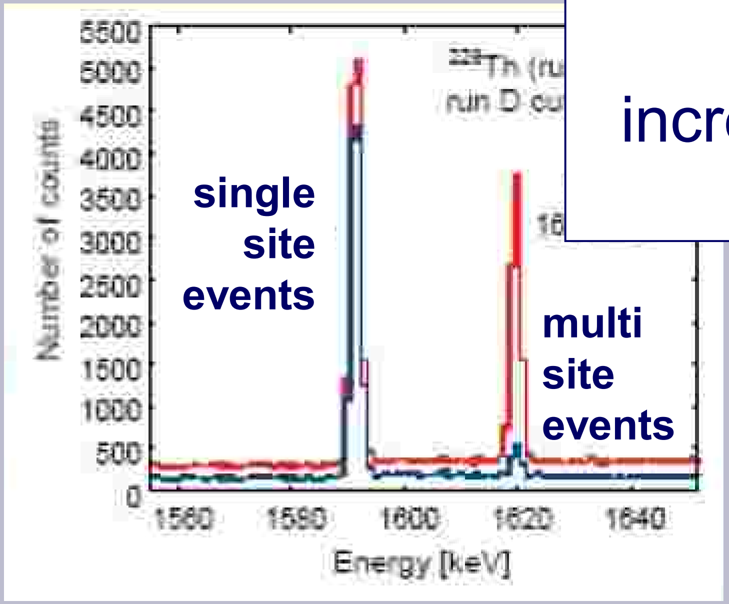
GERDA - *Idea*

Hd-Moscow background given by:

- detectors surroundings
- cosmogenic activation of Ge →

GERDA - Phase 2:

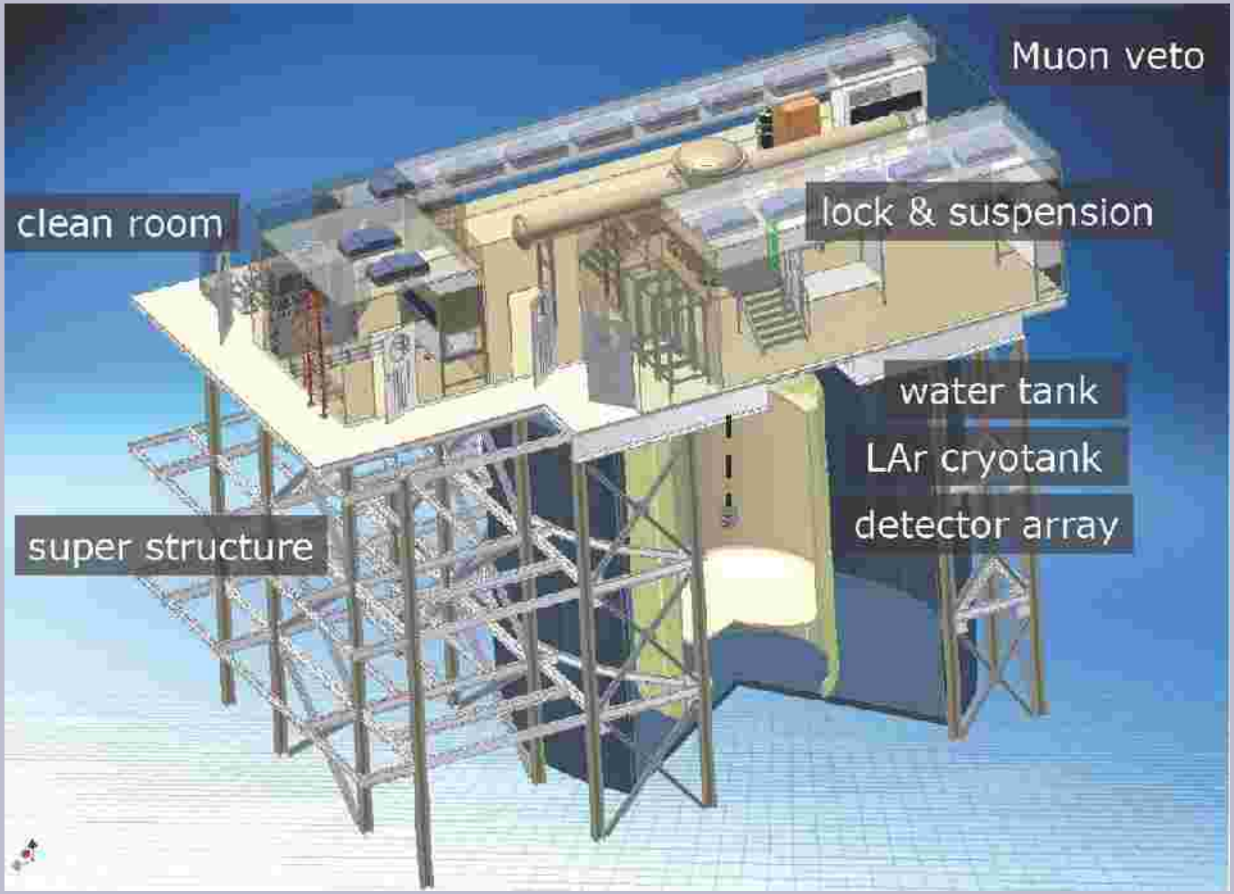
reduce cosmogenic background
by event recognition:
segmented detectors and/or pulse shape
+
increase ^{76}Ge-mass



$0\nu2\beta$ – events are single site

Co background are multiple site

GERDA - *set up at Gran Sasso*



from outside to inside

Water tank:
- Gamma shield
- Neutron shield
- Muon Veto

Cryostat:
- contains liquid Ar
- additional Cu shield inside

Liquid Argon provides:
- pure 'inner' shielding
- operating T for detectors

Bare Ge detectors
support structure as light as possible
detectors hold by strings

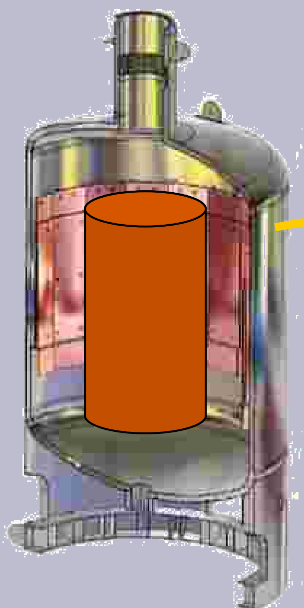
64 m^3 of liquid Ar, 650 m^3 of water,
4m Ø steel cryostat, 10 m Ø water tank

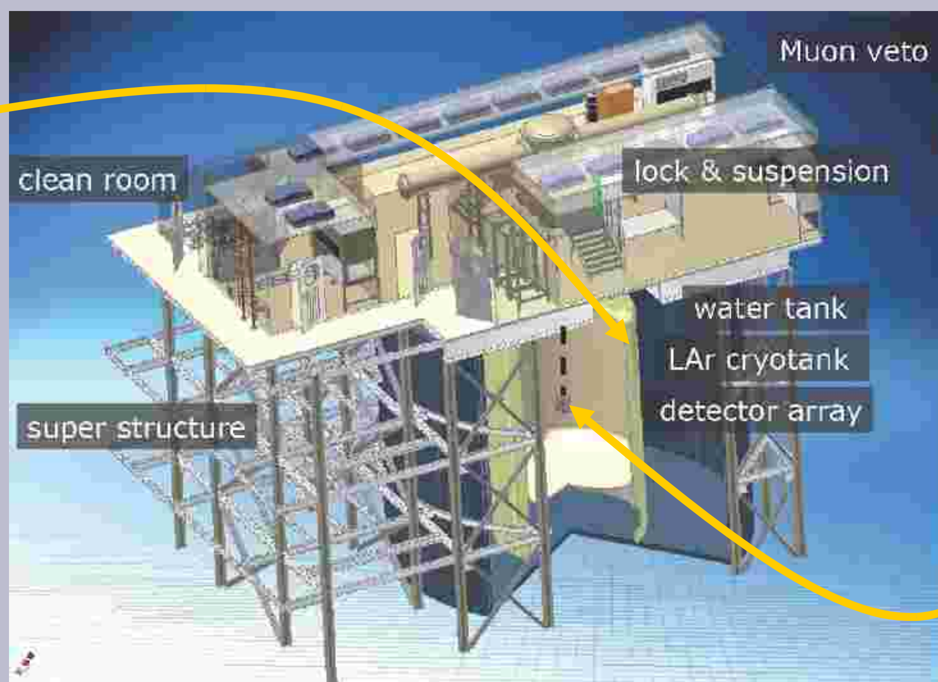
low Z materials, liquids can be purified, …

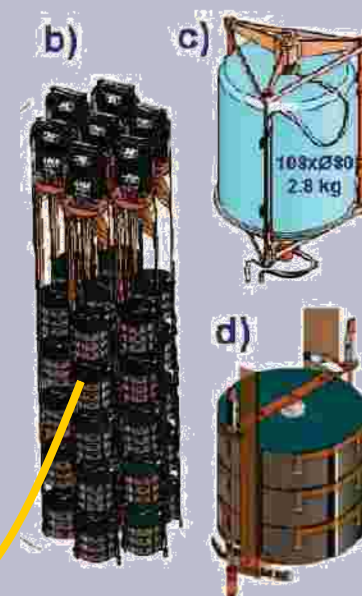
GERDA - *set up at Gran Sasso*

Stainless steel cryostat *25t, U/Th < 5mBq/kg*
Internal Cu shield *20t, U/Th < 16mBq/kg*
Radon Shroud inside Cryostate
to avoid Rn convection to Ge detectors

Ge detector array
- made up of detector strings
- in the center of the LAr-cryostat







GERDA - *Phases*

GERDA - Phase I:

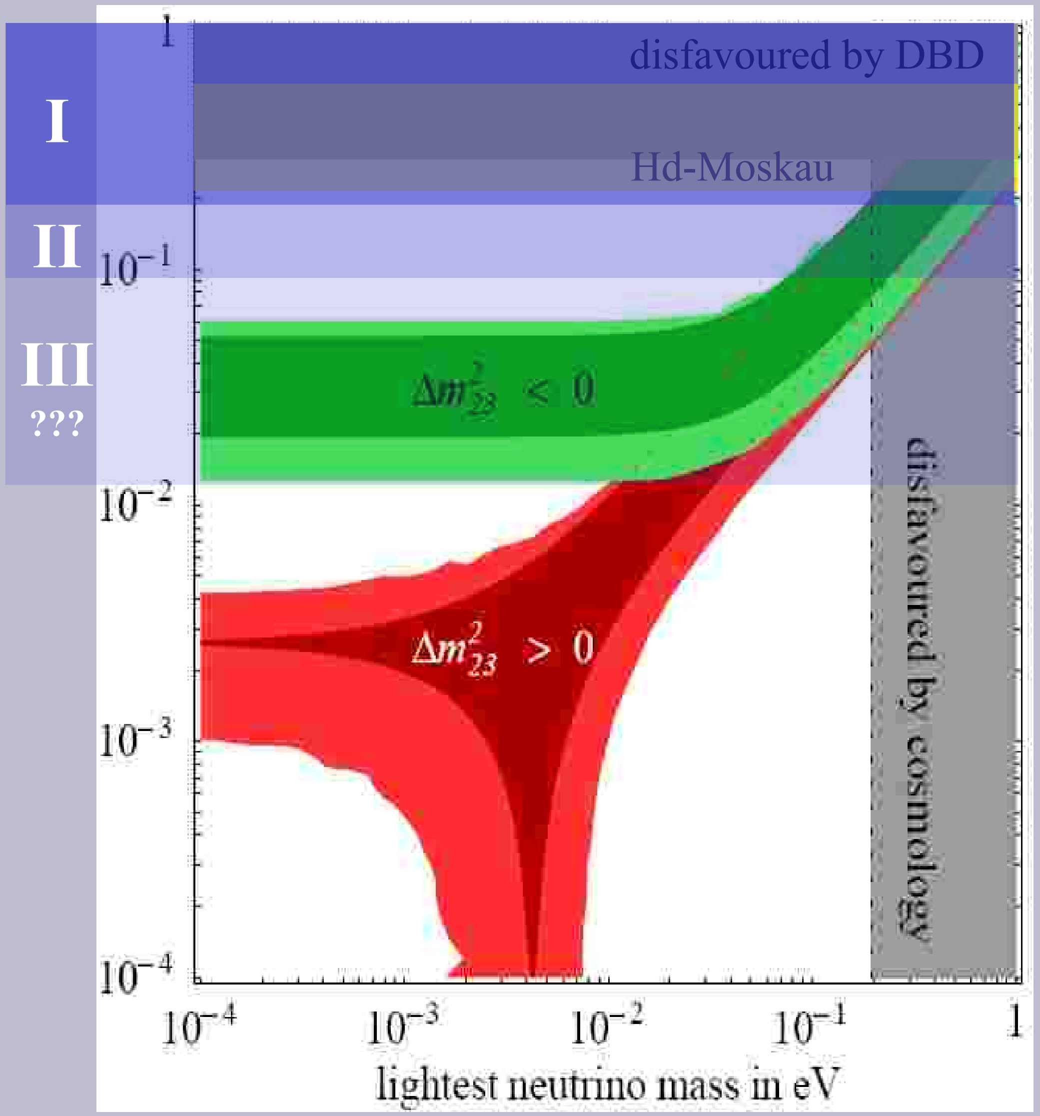
- 18 kg ^{76}Ge (existing from Hd-M and IGEX)
- 15 kg ^{Nat}Ge
- background 10^{-2} /(keV kg y)
- test claim within 1 year
  (6cts with 0.5 cts bckgrd)

GERDA - Phase II:

- new segmented or BeGe detectors
⇒ adds > 20kg ^{76}Ge
⇒ distinguish multi site / single site
- several detectors depleted in ^{76}Ge
- background 10^{-3} /(keV kg y)
  (= 1 count / (keV ton year) !!!)

GERDA - Phase III:

- ~1 ton ^{76}Ge
- world wide GERDA-MAJORANA collaboration
- background 0.1 / (keV ton y)
- test inverted neutrino mass hierarchy
- $m_{\beta\beta}$ ~ (some) 10meV



GERDA – *Status – Phase I detectors*

Long term stability test of HPGe detectors in LAr **OK**

– ΔE ~ 2.5 keV, leakage current stable
- problems reported by GENIUS TF
  overcome by GERDA *(different detector types)*

IGEX and HdM crystals

- removed from vacuum cryostats
- refurbished by Canberra
- less than 1 week above ground
- new low mass holders
- now stored at LNGS
  in vacuum containers

GERDA – *Status – Phase II detectors*

Preparation of 18 fold segmented detectors

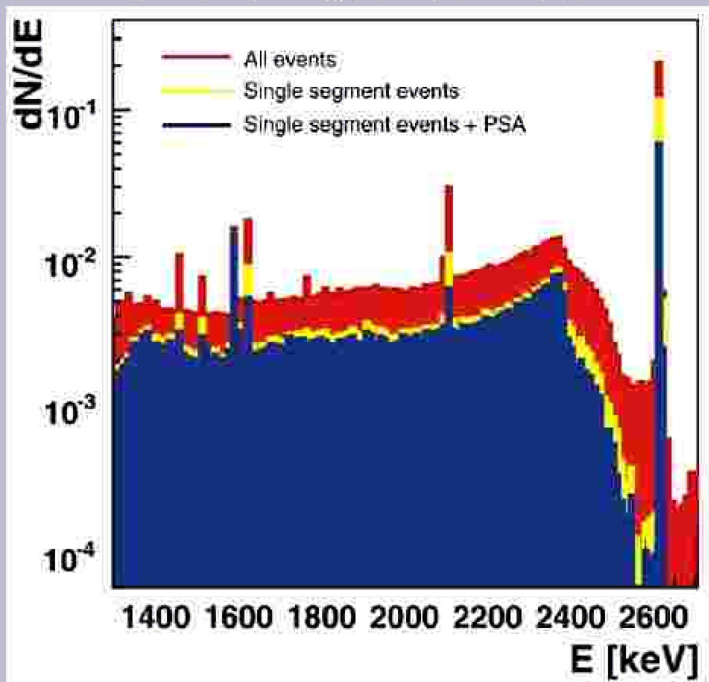
http://wwwgerda.mppmu.mpg.de/

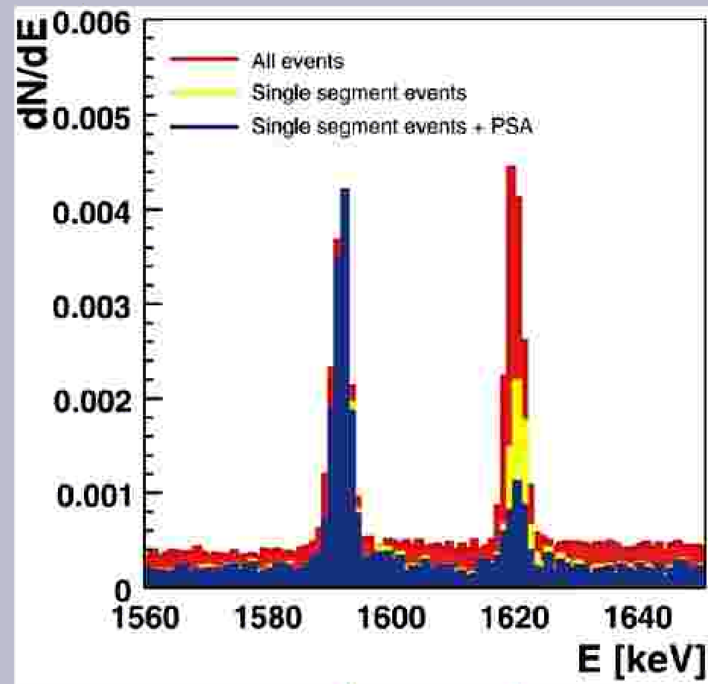
- novel ‘snap‘ contact
- only small amount of extra material (a few 10g / detector)
- successfully tested

Contact by mechanical pressure

GERDA – *Status – Phase II detectors*

Detector in vacuum exposed to Th228 source





Double-escape peak
(single-site dominant)

1620keV Bi212
(multi-site dominant)

segment reduction factor in RoI

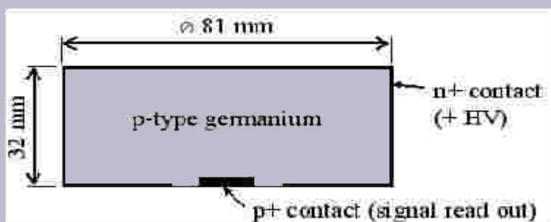
sample	data	MC
Co60	14.2 ± 2.1	12.5 ± 2.1
Th228	1.68 ± 0.02	1.66 ± 0.05

(depend on source position)

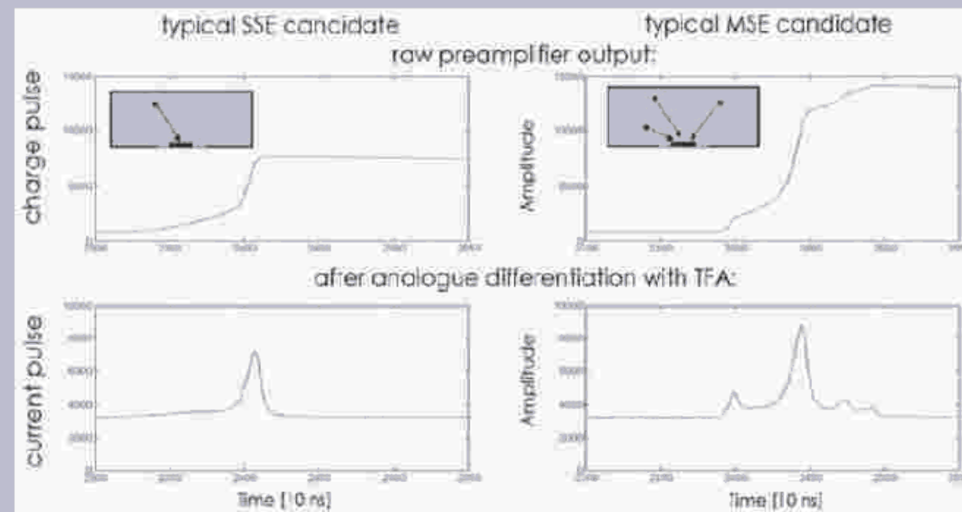
GERDA – *Status – Phase II detectors*

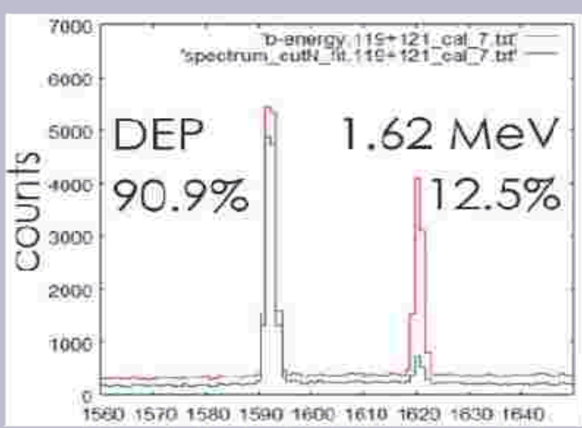
Phase-II detector candidate: point-contact detector

- enhanced efficiency for low-energy gammas (BeGe)
- low capacitance (⇒ low noise)
- position dependent pulse shape



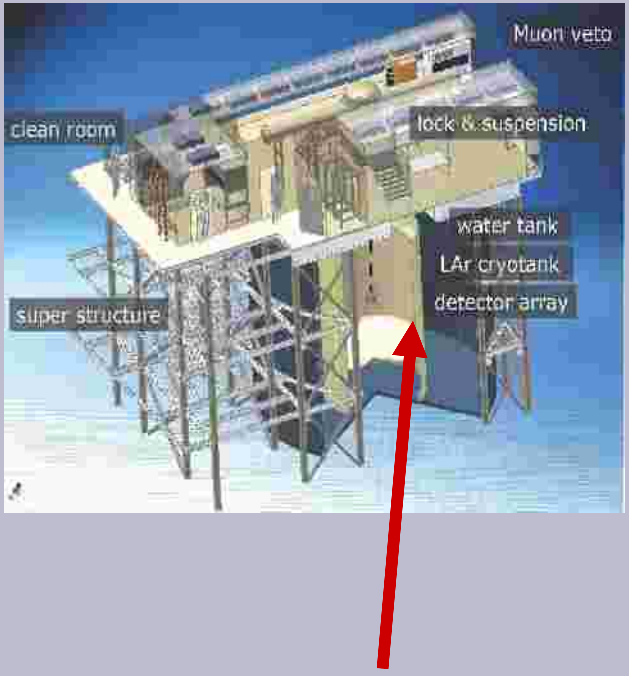
Canberra thick window broad energy detector (BEGe, 878g)



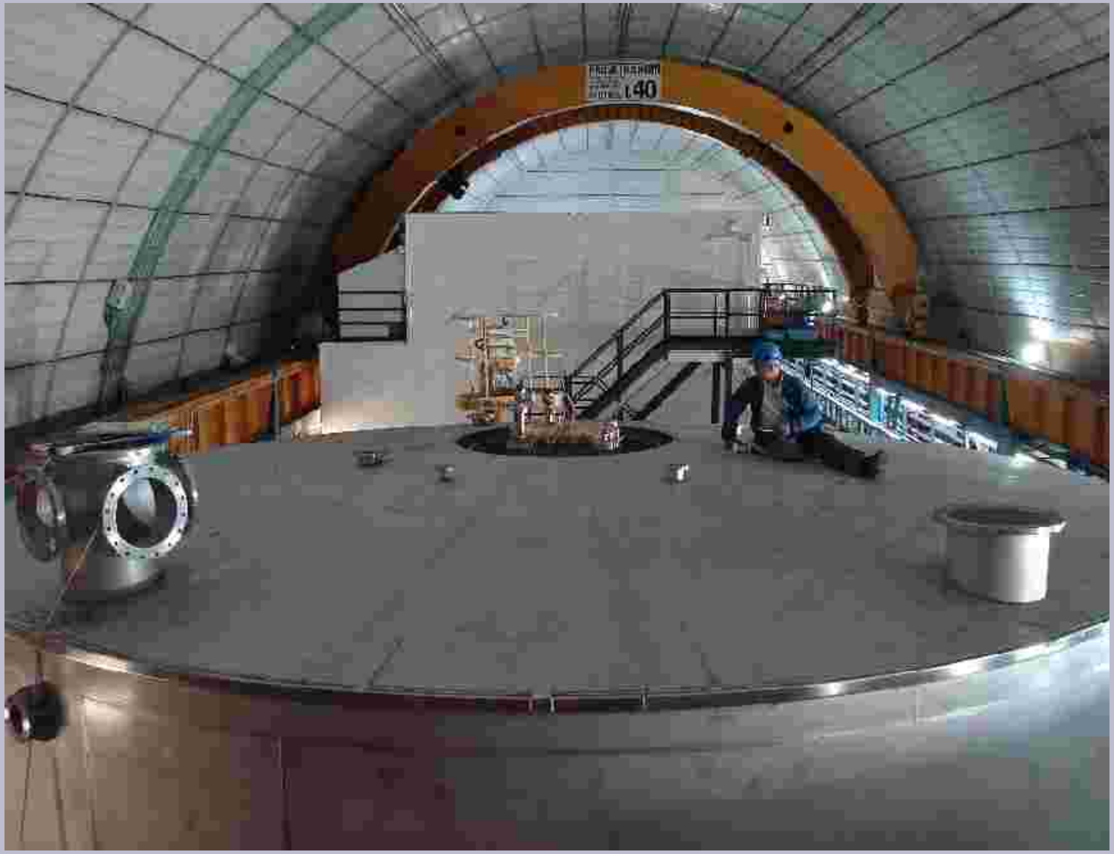


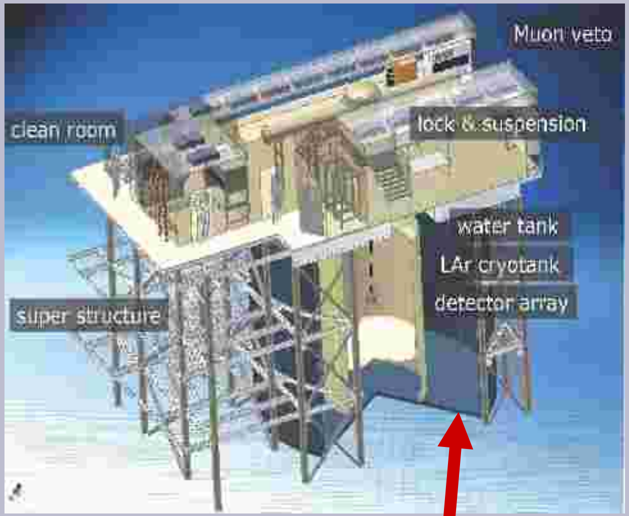
- Successful R&D
  - ✓Observed complete charge collection from full detector volume.
  - ✓No position dependence of pulse heigh and resolution.
  - ✓Similar reduction factor achieved.
- BEGe production yield under investigation.

GERDA – *Set up at Gran Sasso – Cryostat 03/08*

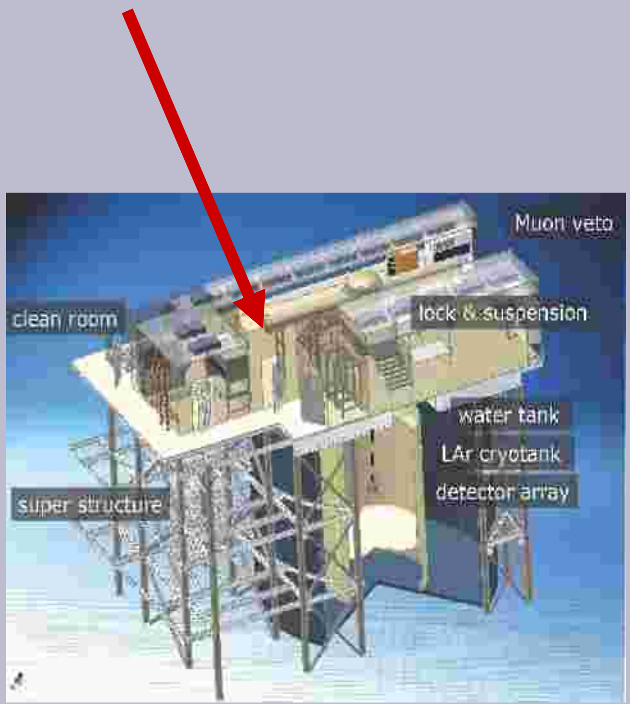


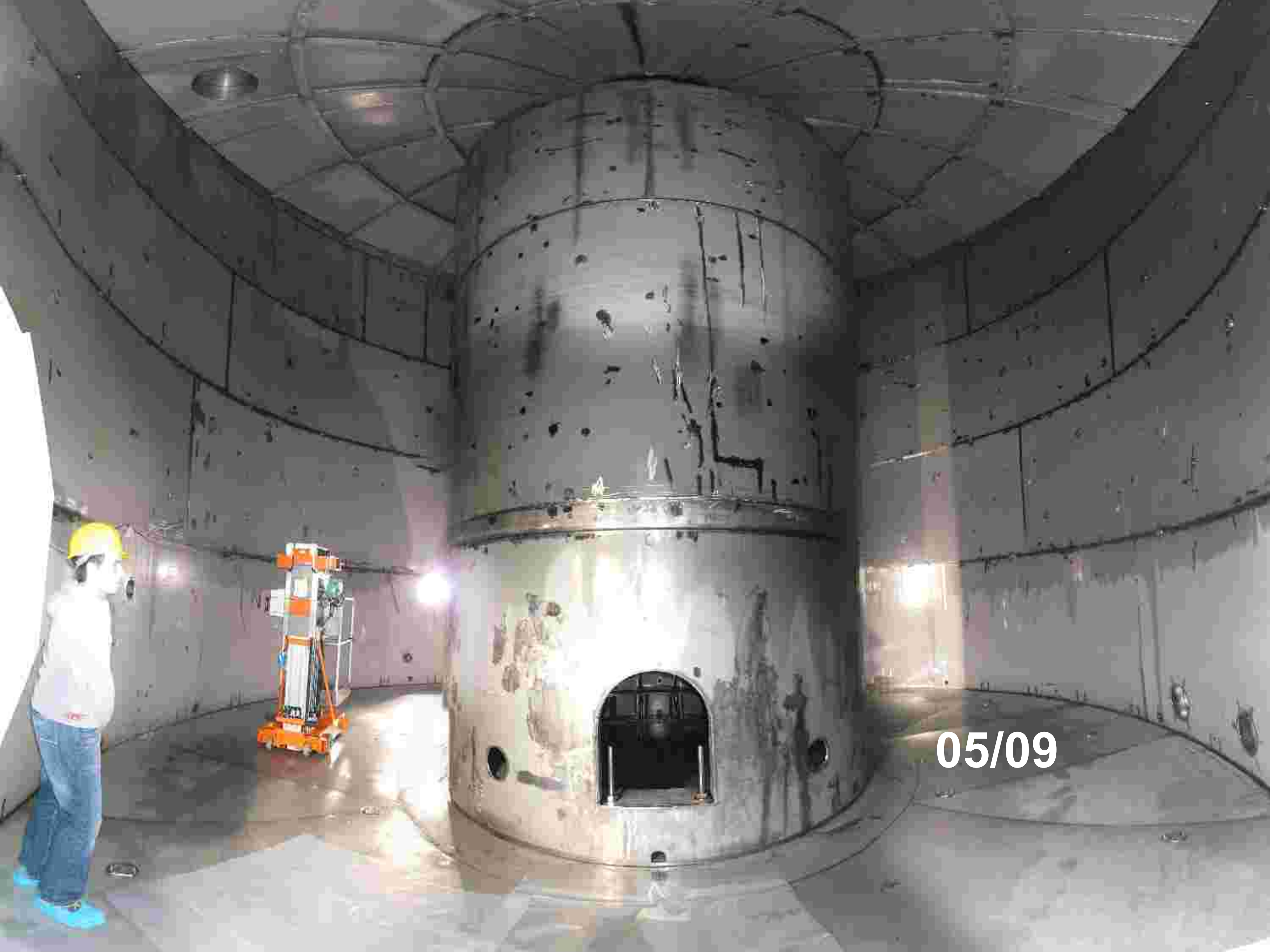
GERDA – *Set up at Gran Sasso – Water Tank 06/08*



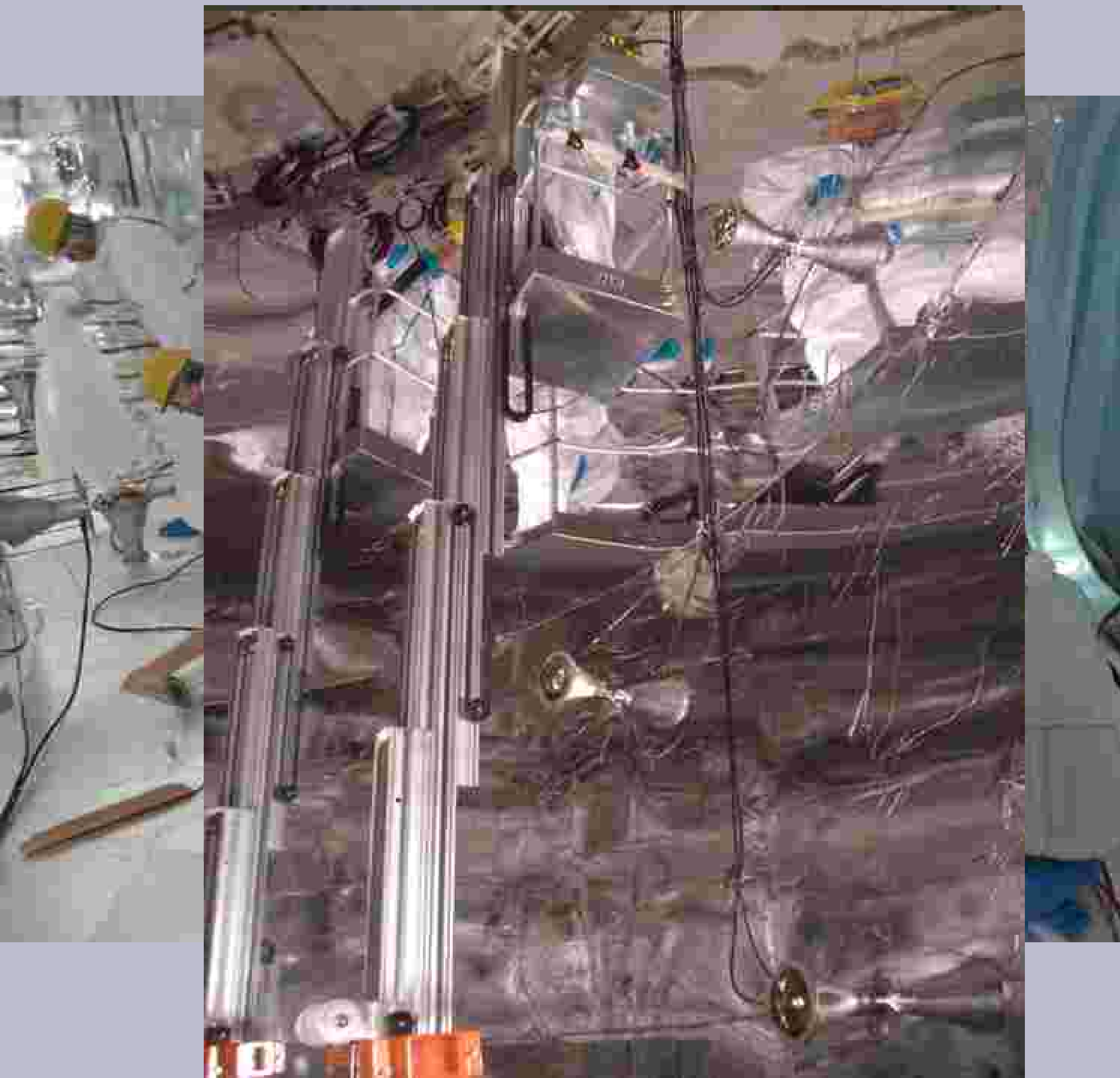


GERDA – *Set up at Gran Sasso – Clean Room 05/09*

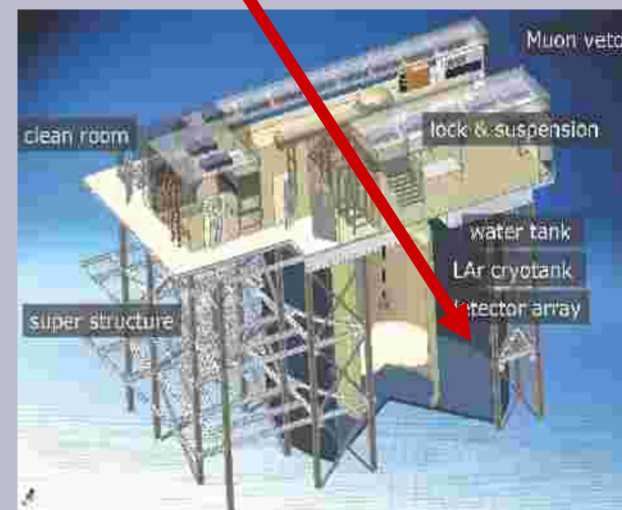


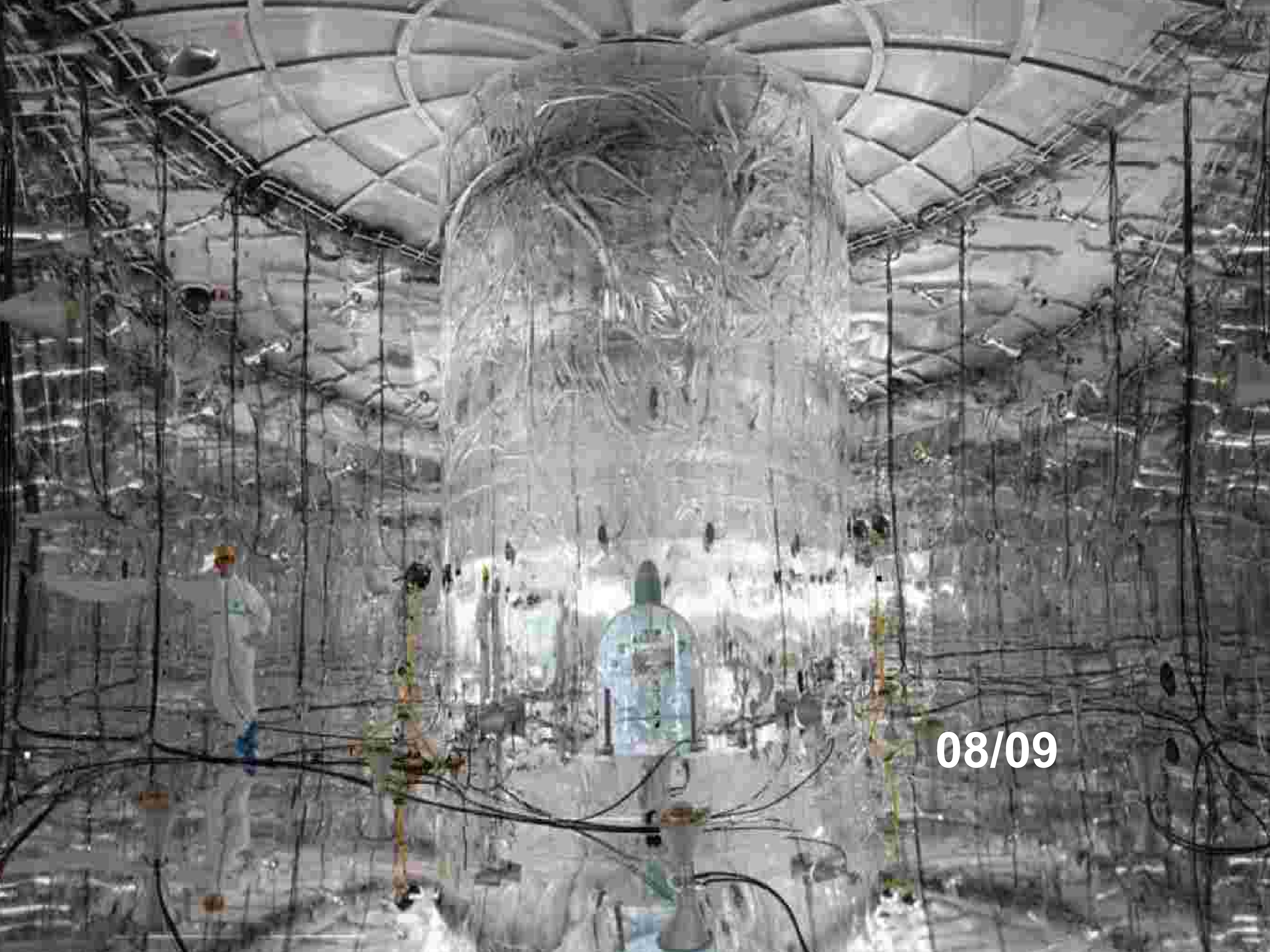

05/09

GERDA – *Set up at Gran Sasso – Muon Veto 06/09*



Inside the water tank




08/09

GERDA – *Outlook*

Commissioning of GERDA set up at Gran Sasso will start in 2009

Phase I (2009-2011):

After 1 year data taking (~ 15 kg y) with background 10^{-2} / (keV kg y)

⇒ GERDA can confirm or refute claim of $0\nu2\beta$ observation

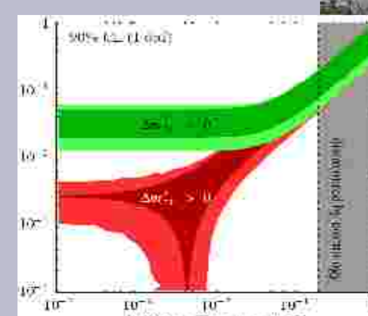
Limit: half live $T_{1/2}(0\nu) > 3\times10^{25}$ y, $m_{\beta\beta} < (0.2 – 0.5)$ eV
QRPA. SM

Phase II (starting 2011):

-Total ^{76}Ge mass of 40kg
-Background reduction by segmented detectors and/or PSA
-After exposure of 100 kg y with background 10^{-3} / (keV kg y)
⇒ test degenerate neutrino mass regime

Limit: half live $T_{1/2}(0\nu) > 1.5\times10^{26}$ y, $m_{\beta\beta} < (0.1 – 0.2)$ eV
QRPA. SM

Phase III (proposed to start 2014):



- GERDA – MAJORANA collaboration
- mass of ^{76}Ge at 1 ton scale
- background reduction to 10^{-4} / (keV kg y)

⇒ test inverted neutrino mass regime

GERDA – *Collaboration*

Institute for Reference Materials and Measurements, Geel, Belgium
Institut für Kernphysik, Universität Köln, Germany
Max-Planck-Institut für Kernphysik, Heidelberg, Germany
Max-Planck-Institut für Physik (Werner-Heisenberg-Insititut), München, Germany
Physikalisches Institut, Universität Tübingen, Germany
Technische Universität Dresden, Germany
Dipartimento di Fisica dell'Univeristá; di Padova e INFN Padova, Padova, Italy
INFN Laboratori Nazionali del Gran Sasso, Assergi, Italy
Universitá; di Milano Bicocca e INFN Milano, Milano, Italy
Jagiellonian University, Cracow, Poland
Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
Institute for Theoretical and Experimental Physics, Moscow, Russia
Joint Institute for Nuclear Research, Dubna, Russia
Russian Research Center Kurchatov Institute, Moscow, Russia
University Zurich, Switzerland

~97 scientists.