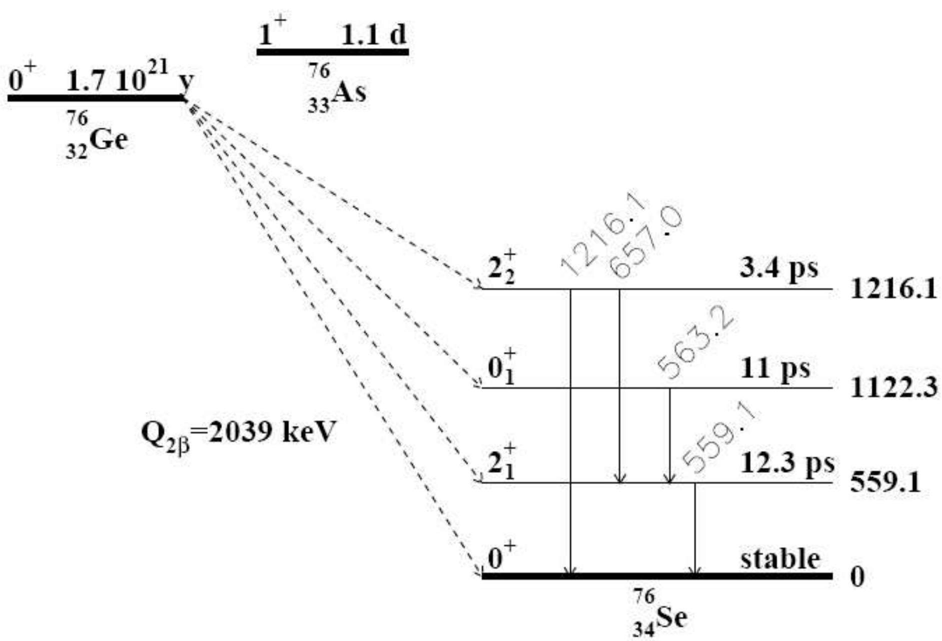
The GERDA scientific program

C. Cattadori INFN-Milano Bicocca

on behalf of GERDA collaboration



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Outline

- Known and Unknown about Neutrinos
- Double Beta Decay Physics and previous searches
- The GERDA experiment:
  - Discovery potential
  - Experimental approach
  - Features and challenges
- Conclusions

Neutrino in standard model

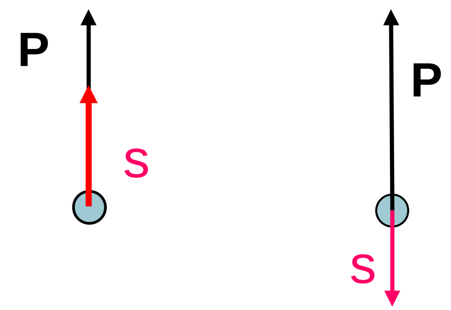
Quarks Leptons

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \text{V-A} \quad \begin{pmatrix} e^- \\ \nu_e \end{pmatrix}$$

$$\begin{pmatrix} c \\ s \end{pmatrix} \quad \quad \begin{pmatrix} \mu^- \\ \nu_\mu \end{pmatrix}$$

$$\begin{pmatrix} t \\ b \end{pmatrix} \quad \text{V+A} \quad \begin{pmatrix} \tau^- \\ \nu_\tau \end{pmatrix}$$

Handedness



Antineutrino is only right-hand $\bar{\nu}$

Neutrino is only left-hand ν

In Standard Model,

- νs come in doublets with their partner lepton
- they are massless, Dirac particles interacting by Weak Interactions,
- lepton number is conserved.

$$m_\nu = 0$$

Neutrino masses

$|\Delta m_{atm}{}^2|$=2.4 10^{-3} eV^2

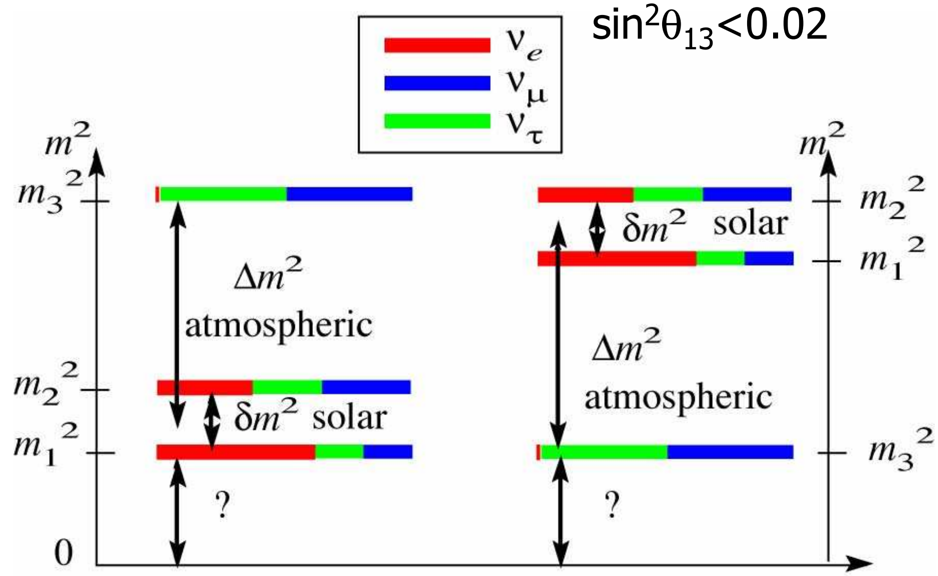
$\delta m_{sol}{}^2$=7.6 10^{-5} eV^2

$\sin^2\theta_{13}$<0.02

….in the last 20 years of neutrino physics experiments, we learned that:

- $\nu_e, \nu_\mu \nu_\tau$ neutrinos created in particle interactions, have finite mass.
- They are not the states of definite mass ν_1, ν_2, ν_3, but linear combinations of them
- They oscillate, i.e transform one into another along their path
- Lepton flavour is NOT conserved.

The experiments measured Δm^2 and the mixing angles (amplitude or probability)



…but didn't measure

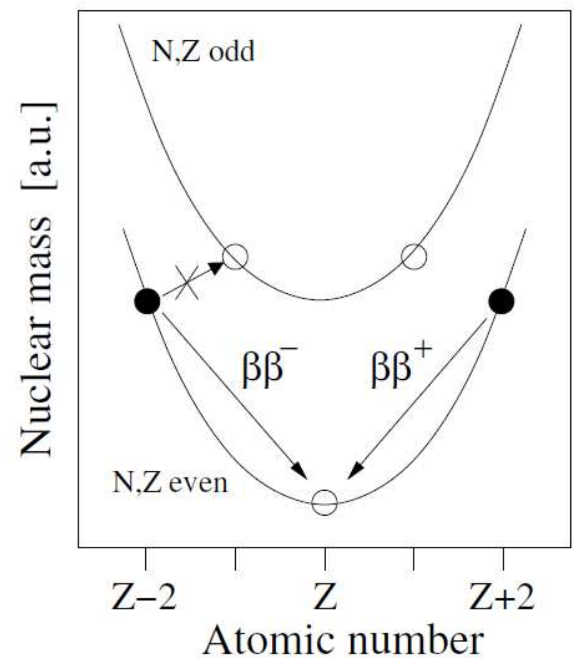
- **The absolute scale**
- **The sign of Δm^2 i.e. hierarchy**
- **CP phases**

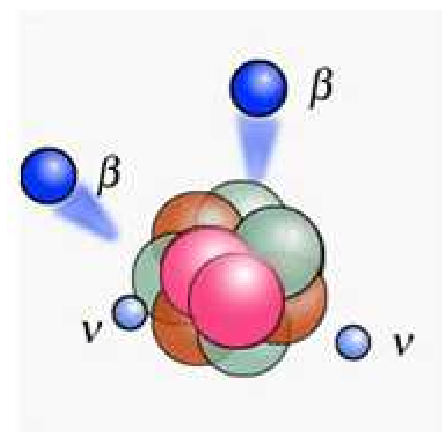
Cosmology provides limit

⇒ Σm_i< ~ 600meV model dependent

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

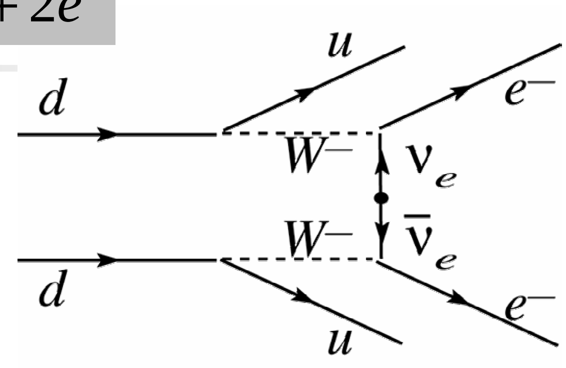
- It is a 2nd order process of weak interactions.
- Proposed in 1935 by the young M. Goeppert Mayer to explain the evidence that in even isobars multiplets (as in the 76) there is apparently more than one stable isobar, while in odd isobar multiplets there is only one.
- First evidence came from ^{130}Te geochemical experiments
- Since then observed for many isotopes (^{76}Se, ^{100}Mo, ^{48}Ca, ^{76}Ge ...). $T_{1/2}^{2n} \sim 10^{19} \div 10^{21}$ y.
- 2νββ of ^{76}Ge observed on ground state of ^{76}Se: $T_{1/2}^{2\nu}$: ~ 1.4 x 10^{21} y





@ $0\nu\beta\beta$

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



Feynman diagram of 0vbb

Proposed by Majorana (and Racah) in 1937:

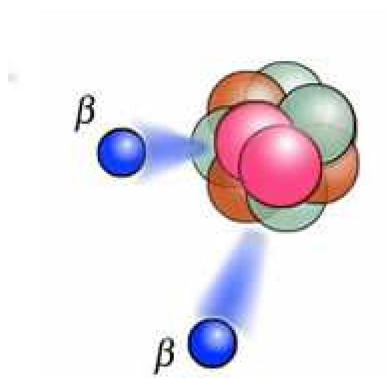
A $\nu=\bar{\nu}$ is exchanged between two neutrons

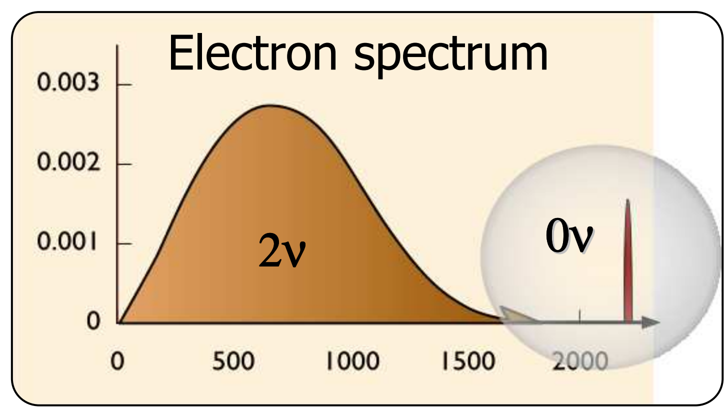
It is a forbidden process in SM and requires

- Lepton number violation $\Delta L=2$
- Neutrino is a Majorana particle having finite mass

$$\nu_e=\bar{\nu}_e$$

$$<m_\nu>\neq 0$$





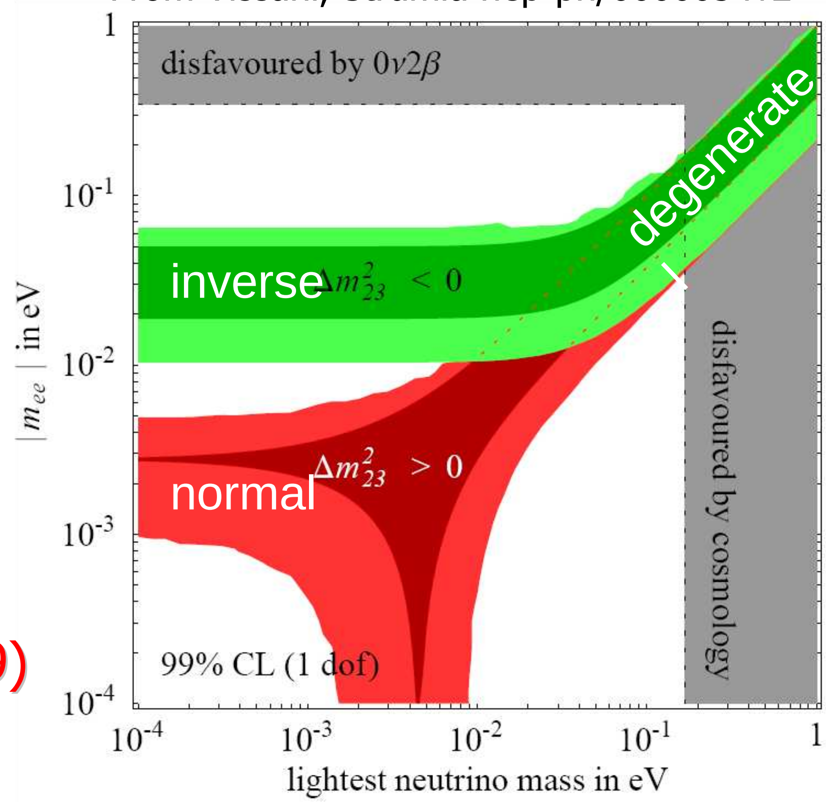
0νββ and the neutrino mass

$$(T_{1/2}^{\,0\nu})^{-1} \sim G_{0\nu}\,(Q,Z)\,|M_{0\nu}|^2\, m_{\beta\beta}^{\,2} / m_e^{\,2}$$

0νββ half-life — **Phase space…** — **Nuclear Matrix Elements** — **Effective Majorana neutrino mass**

- Rate is the measured quantity in ββ decay experiments. It is proportional to
  - **Effective neutrino mass $(m_{\beta\beta})^2$**
  - **Nuclear Matrix Element value**
- $Q_{\beta\beta}$=2039.06±0.05 keV
- $T_{1/2}^{0\nu} \sim 10^{26}$ y (for $<m_\nu>\sim$ 100 meV, and $M_{0\nu}^{nucl} = 3.9$)

From Vissani, Strumia hep-ph/0606054v2



GERDA @ LNGS

The real life: experimental sensitivity on $T^{0\nu}_{1/2}$

ε = detection efficiency

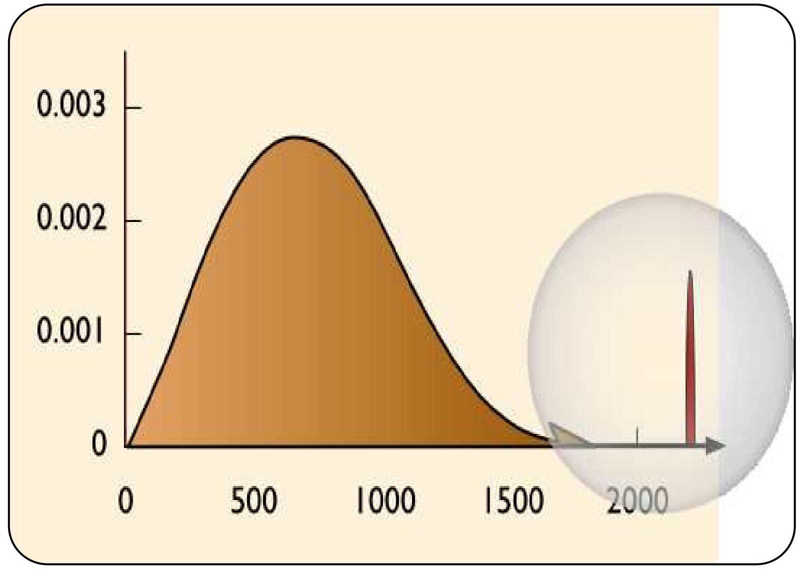
a = ββ isotope fraction → enrichment

M = mass of detector in kg

T = data taking time [y]

B = background index in cts/(keV kg y)

R = energy resolution at $Q_{\beta\beta}$ [keV]



Ideal case:
no bckgd

$$T^{0\nu}_{1/2} \propto a\varepsilon MT$$

Real case: with bkgd →

$$T^{0\nu}_{1/2} \propto a\varepsilon\sqrt{\frac{MT}{BR}}$$

The challenge of ββ decay experiments is to minimize background, expose large mass of candidate decay isotope, improve the resolution

^{76}Ge ββ searches: the pre-history

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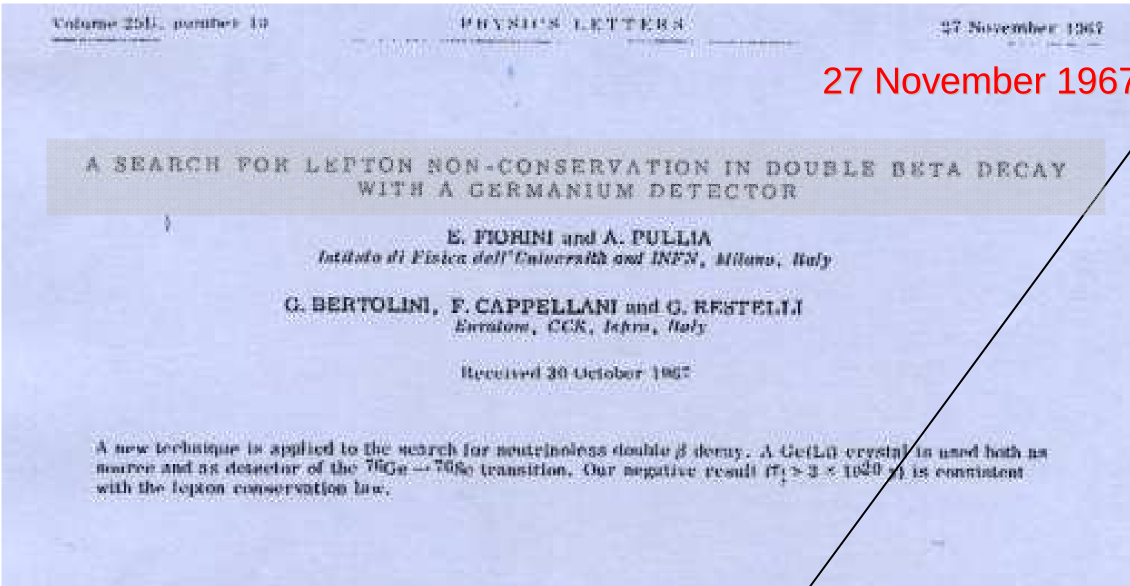

Volume 25B, number 10 PHYSICS LETTERS 27 November 1967

A SEARCH FOR LEPTON NON-CONSERVATION IN DOUBLE BETA DECAY WITH A GERMANIUM DETECTOR

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Euratom, CCR, Ispra, Italy

Received 30 October 1967

A new technique is applied to the search for neutrinoless double β decay. A Ge(Li) crystal is used both as source and as detector of the ^{76}Ge → ^{76}Se transition. Our negative result ($T_{\frac{1}{2}} > 3 \times 10^{20}$ y) is consistent with the lepton conservation law.

27 November 1967

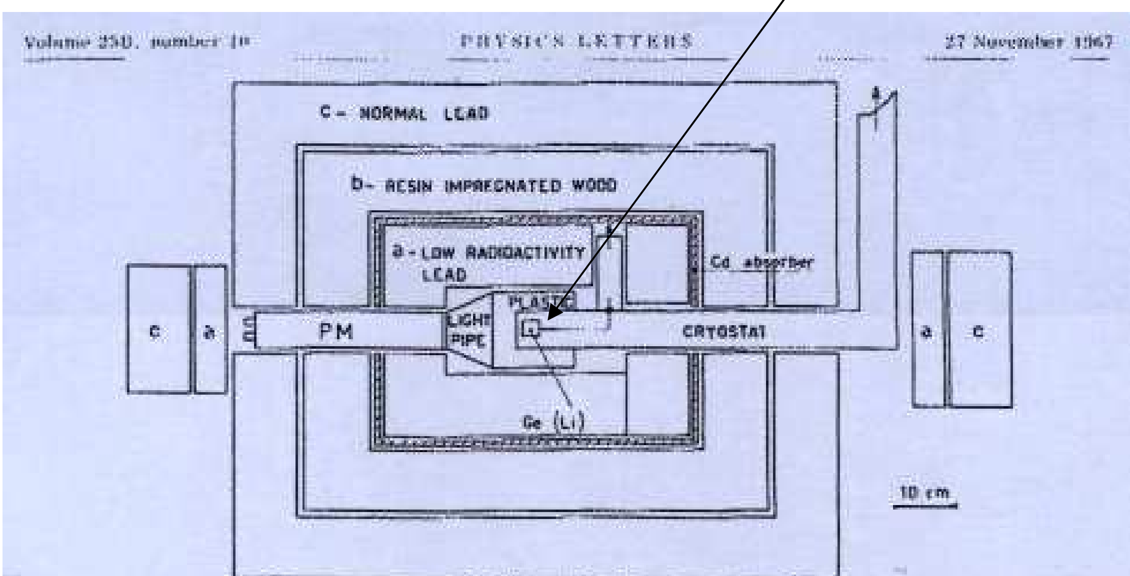

Fig. 1. Experimental setup.

Ge(Li) mass 90 g.

Resolution 4.7 keV @ 1.32 MeV

Running time = 712 h

Result:

$T_{1/2} > 3.1 \times 10^{20}$ y (68%C.L.)

Bkgd = 1.1×10^{-2} (h keV)$^{-1}$

Lepton no. is conserved.

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Evolution over 5 decades of the sensitivity on ^{76}Ge 0νββ half-life

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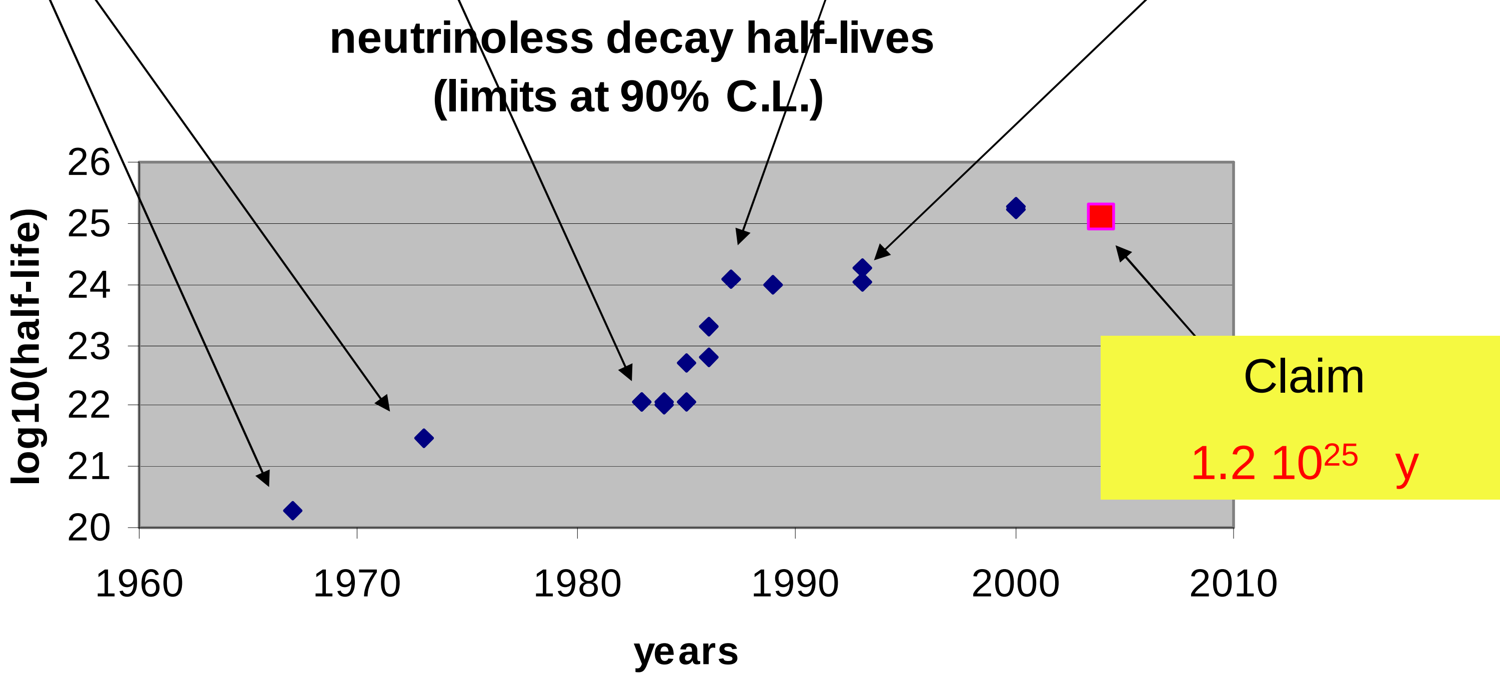
Pioneer era:

17 cm^3 home made crystal

Deep underground; ^{nat}Ge but material selection

Enriched detectors

Large mass enriched detectors: HdM and IGEX; p.s.a. implemented



Sensistivity improved a factor 10 in ~ 10 years

GERDA: Sensitivity

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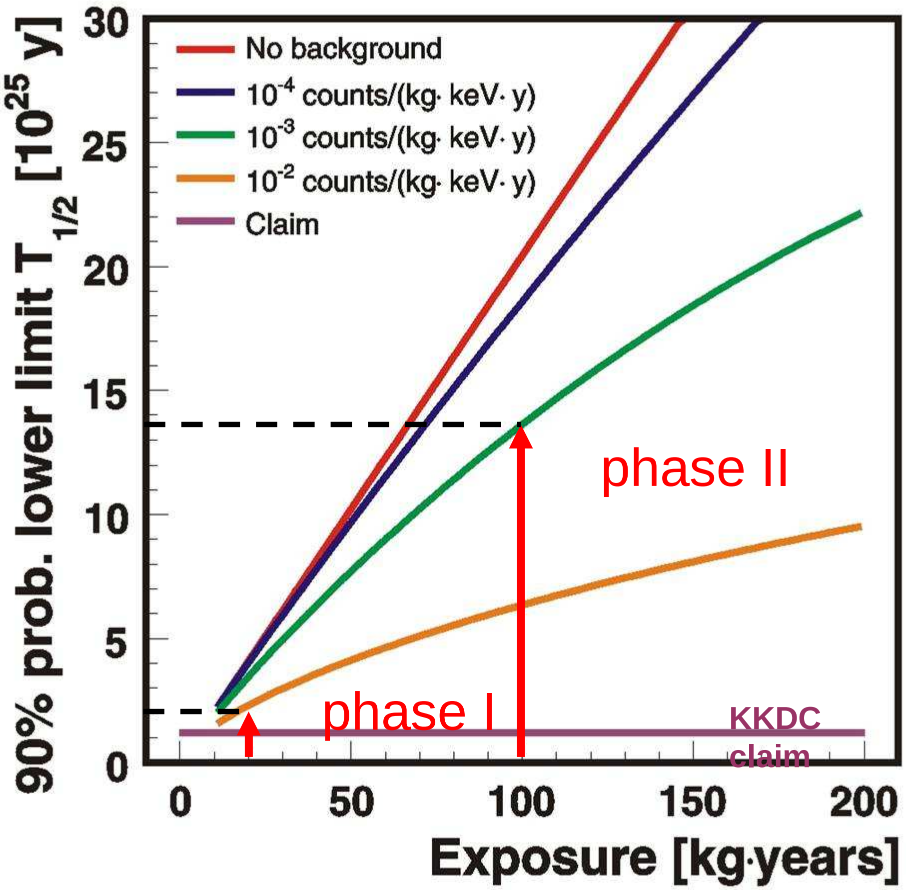
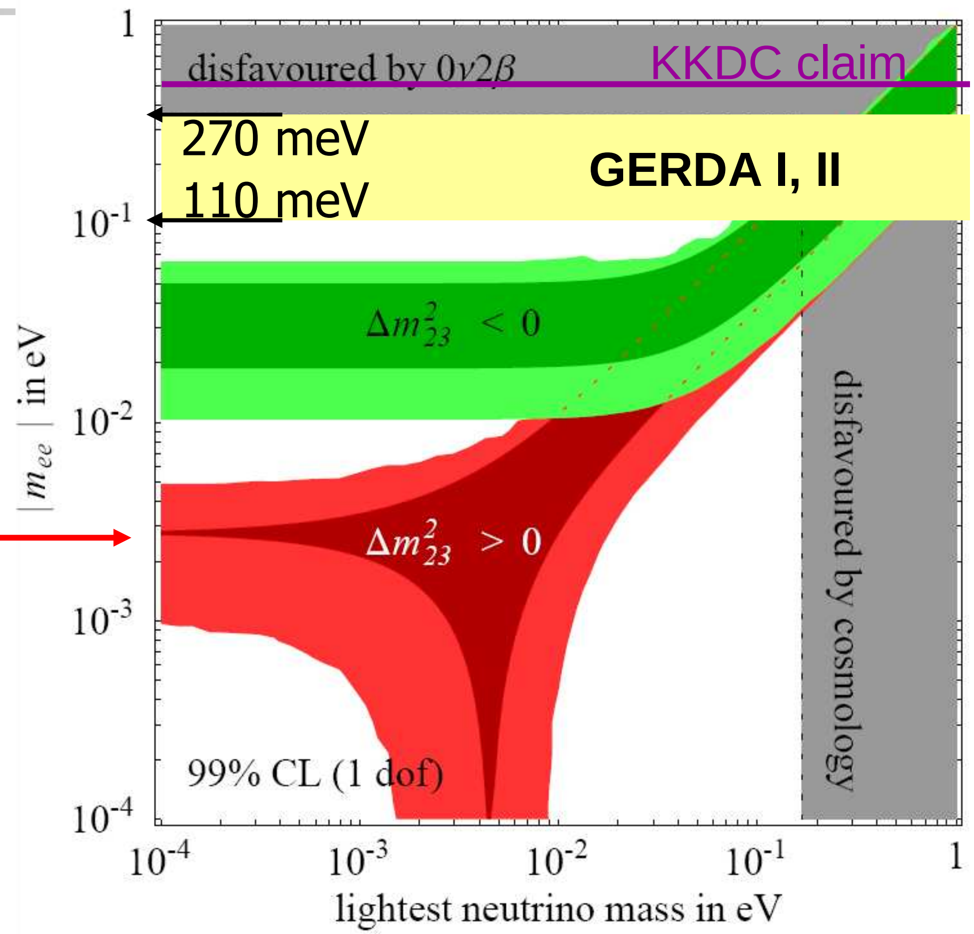
Assumed E resolution: ΔE = 4 keV

From Vissani, Strumia hep-ph/0606054v2





→ if signal found in HdM by KK is true ββ decay, this would produce in ~ 1 year GERDA I data taking (assuming 18 kg y exposure) 7 cts, above bckg of ~ 1 count

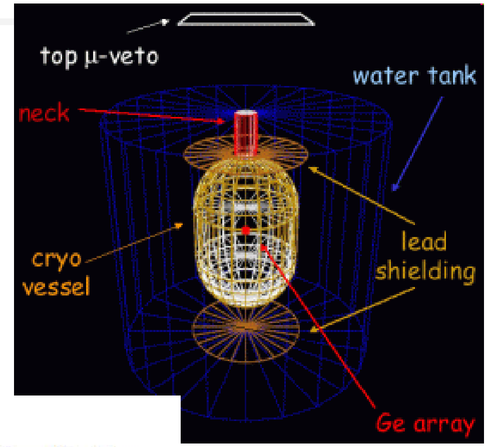
→ probability that bkgd simulate signal ~ 10^{-5}

GERDA: challenges
A novel approach to the background issues

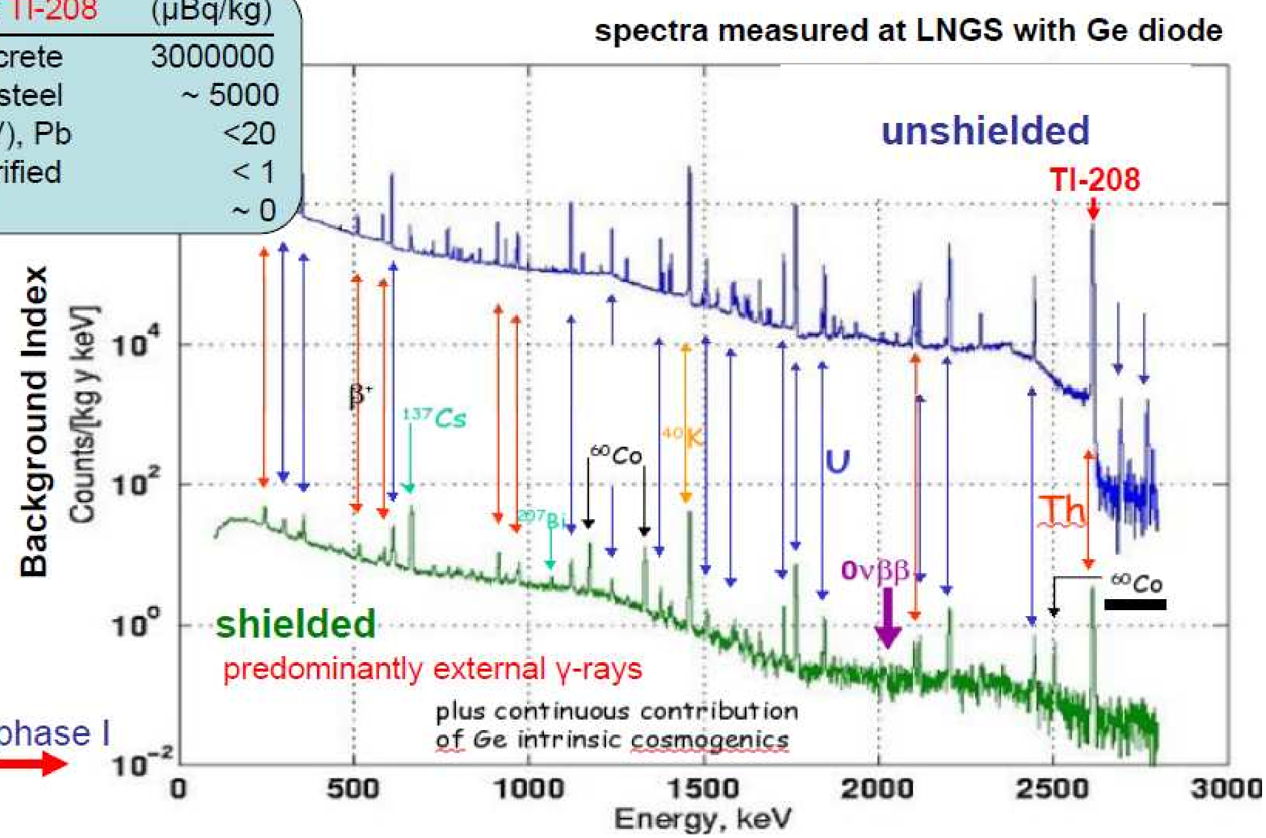
GERDA goal: build a setup with a B ≤ 10^{-3} @ $Q_{\beta\beta}$

GERDA distinctive features to reduce bkgnd of 10^{-6}

- Ge diodes operated naked in LAr
- Ge diodes with enhanced PSD features (Phase II)

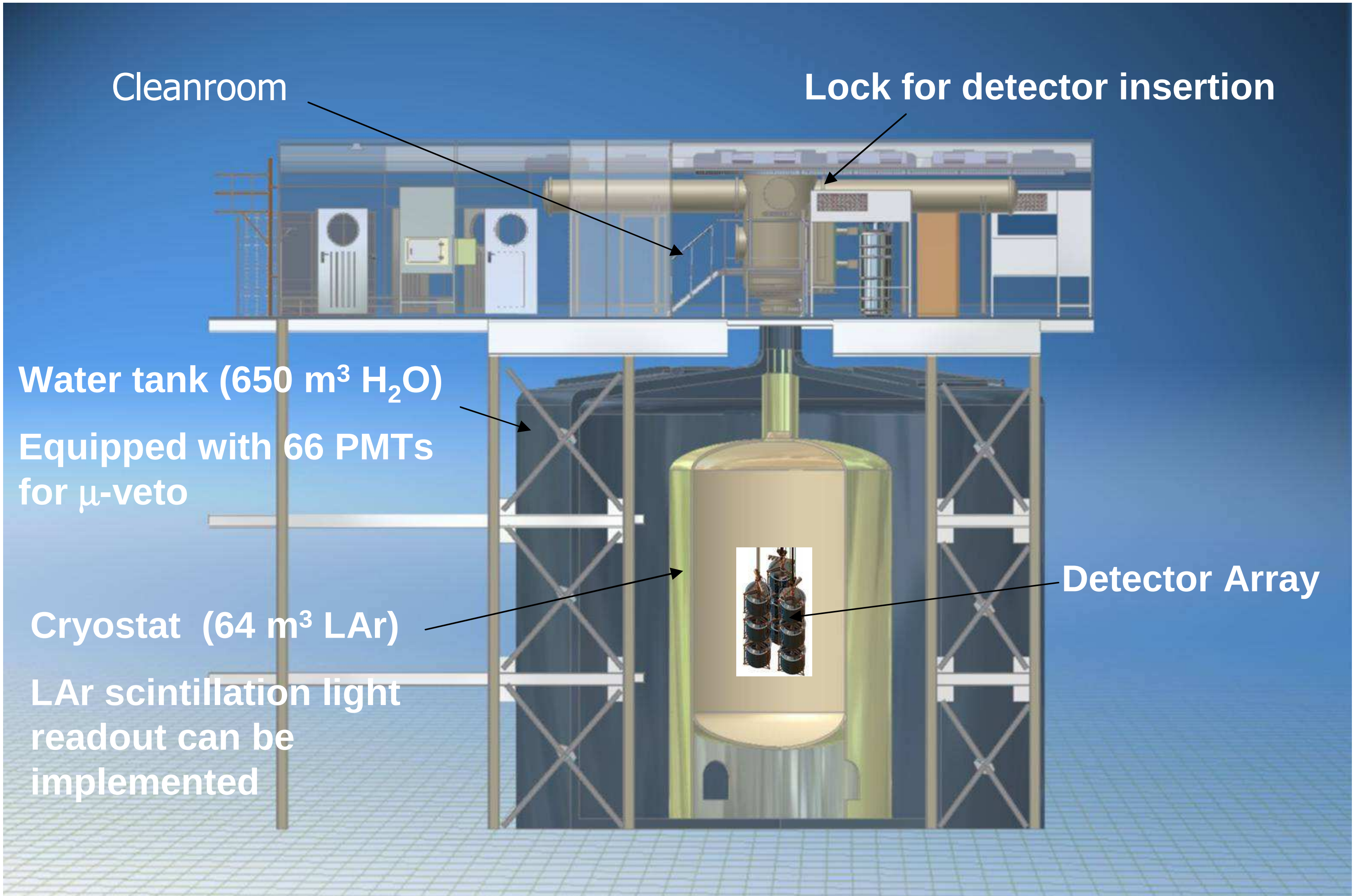


Activity of Tl-208	(μBq/kg)
rock, concrete	3000000
stainless steel	~ 5000
Cu(NOSV), Pb	<20
water, purified	< 1
LN2, LAr	~ 0



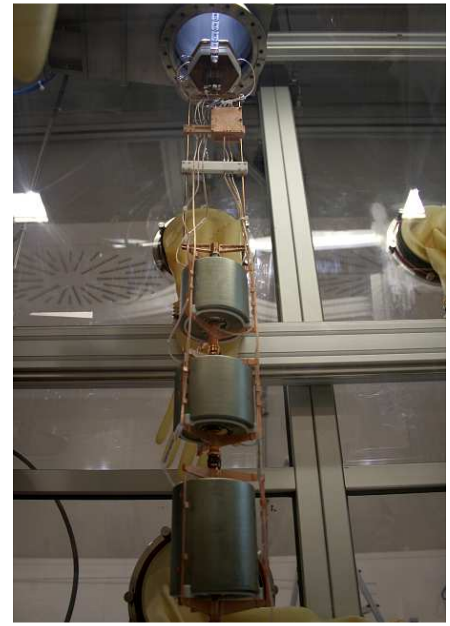
GERDA phase I

GERDA design



Detector deployment: a staged approach

- Phase I:
  - Use of existing ^{76}Ge-diodes refurbished for our experimental needs
  - 8 detectors for 17.9 kg of ^{enr}Ge
  - Expected Background ~ 10^{-2} count/(kg·keV·y) dominated by crystal internal bkgd
  - ➢ Verify HdM claim in an external background-free setup.



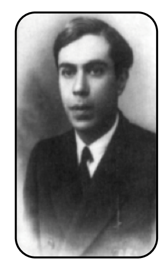
The ^{nat}Ge pilot string

- Phase II:
  - Add new diodes (+22 kg, total ^{enr}Ge) of novel type able to discriminate SSE/MSE. (see V. Kornoukhov talk)
  - Demonstration of bkgd-level <10^{-3} count/(kg·keV·y)

Conclusions

- GERDA experiment has been fully constructed; it adopts a novel technique to
  - operate Ge detectors and
  - reduce 10^{-2} the background, compared to previous experiments.
- GERDA is in the commissioning phase since june 2010.
- In one year of real data taking, GERDA should provide results on $0\nu\beta\beta$ decay and scrutinize the HdM claim
- When the full detector array (Phase II) will be deployed, while matching the bkgd specifications, GERDA should be able to investigate the degenerate ν_{mass} region

ν



Impact of neutrino mass on particle physics and cosmological models

- Once the mass operator is introduced, neutrino is naturally a Majorana particle; *seesaw (a mechanism within GUT)* produces a light neutrino, corresponding to the three known neutrino flavors, and a very heavy, undiscovered sterile neutrino (N).
- In primordial Universe, N then decayed into lepton/antilepton (leptogenesis) with some unbalance towards leptons, i.e. CP violating
- This would have generated the observed baryonic asymmetry (baryogenesis).

…. Therefore the experimental determinations of the neutrino mass scale, pattern and nature

- Are crucial bench tests for predictive particle physics models, and for the improvement of our understanding of the basic theory of fundamental interactions.
- The neutrino mass value will as well impact on early universe evolution and on astrophysical (e.g. supernova) models.