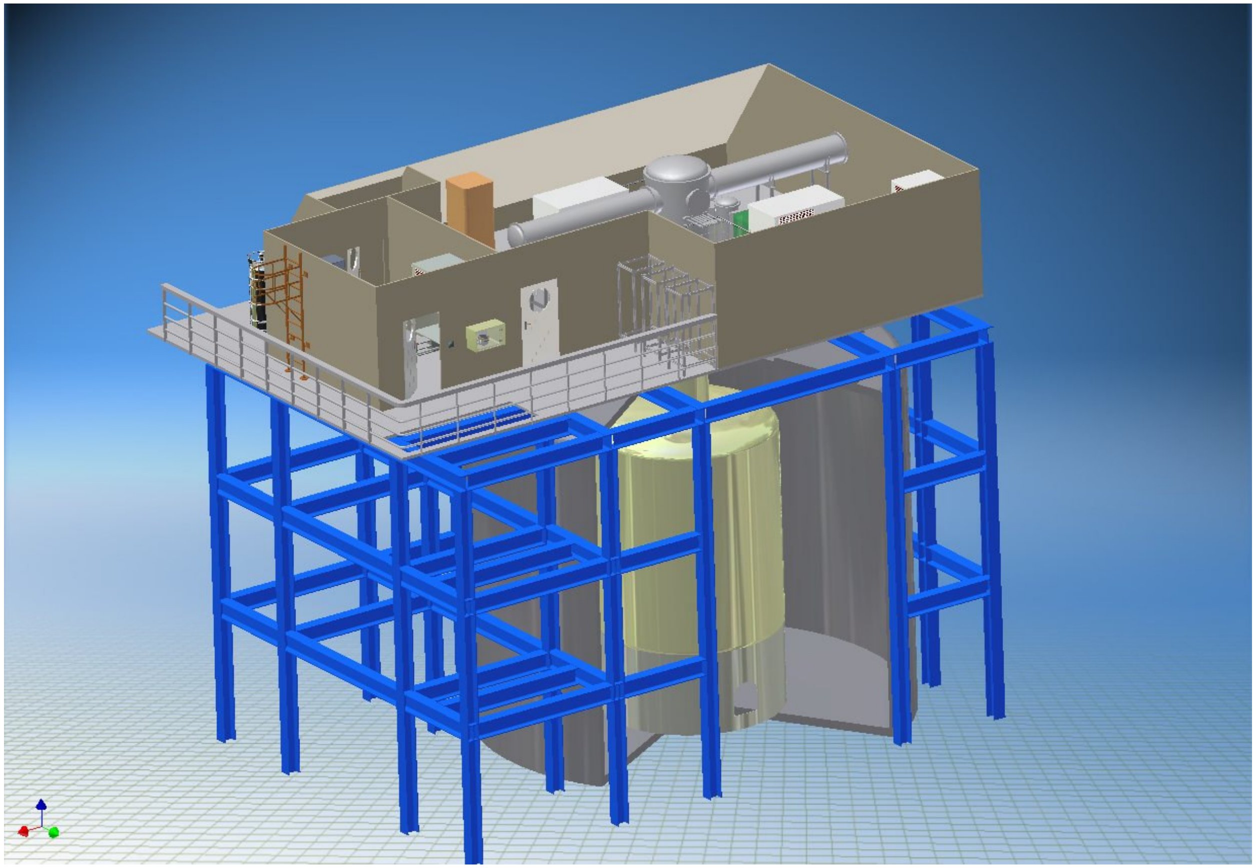
The GERDA Neutrinoless-Double-Beta-Decay Experiment



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OUTLINE:

- Introduction: Neutrino mass and Neutrinoless Double Beta Decay
- $0\nu\beta\beta$ of ^{76}Ge - HPGe experiments - status
- The GERDA experiment - principles
- Main background sources
- Status of GERDA

What we Know About Neutrino Masses:

Oscillation experiments have taught us:

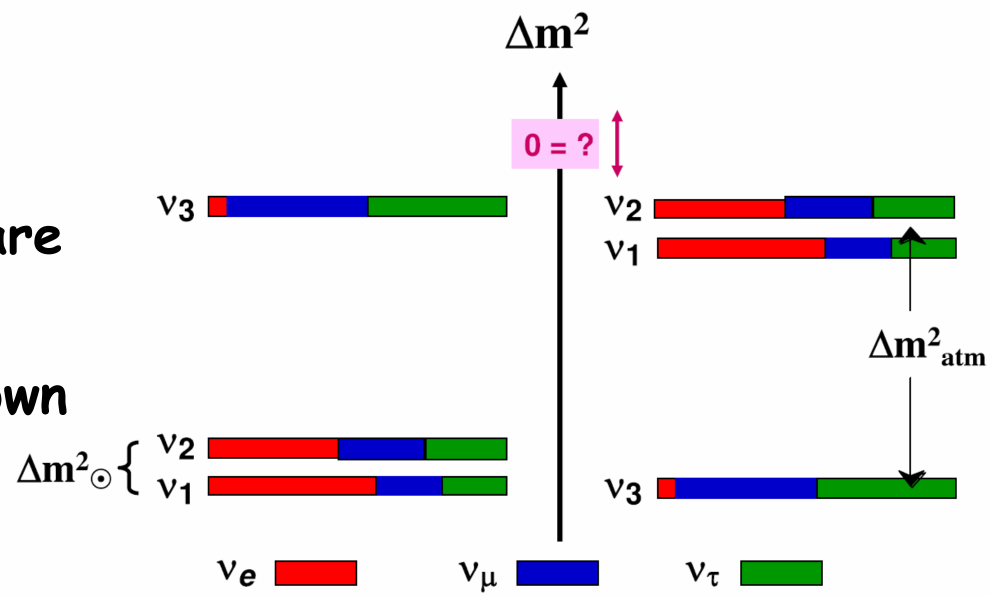
Neutrinos must have a mass!

Normal hierarchy
$\Delta m_{32} > 0$ eV^2

Inverted hierarchy
$\Delta m_{32} < 0$ eV2

$\Delta m^2_{\odot} = 7.9 \cdot 10^{-5}$ eV^2

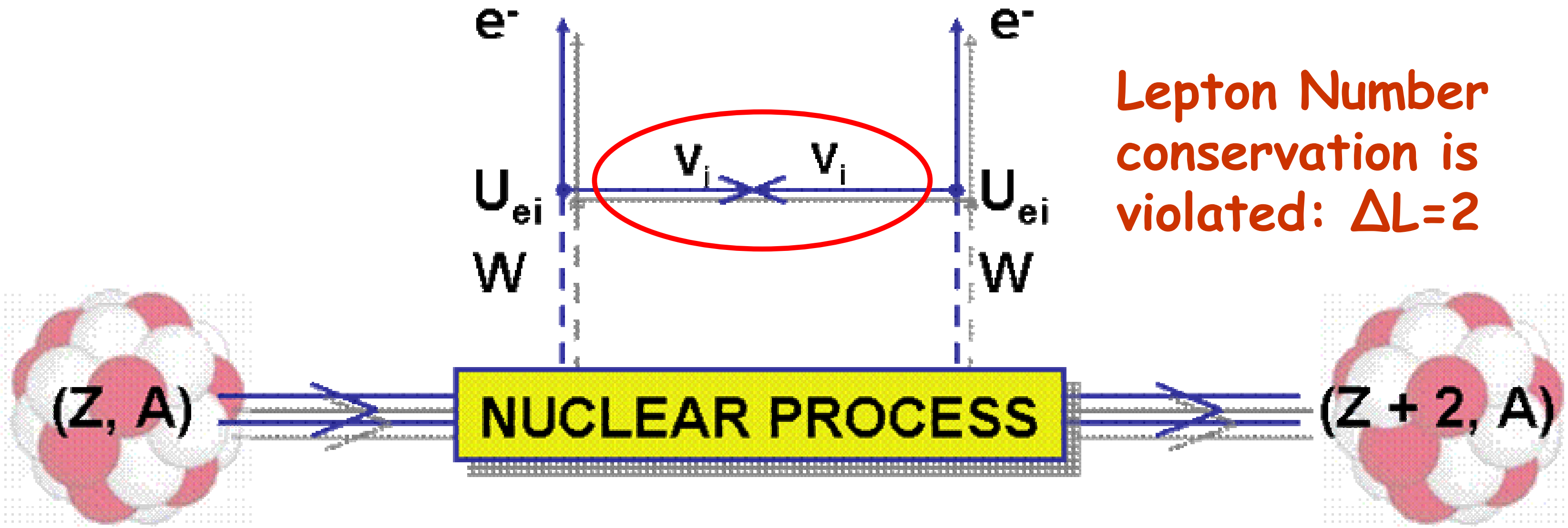
$\Delta m^2_{atm} = 2.4 \cdot 10^{-3}$ eV^2



But important information are missing:

- Absolute mass scale unknown
- Hierarchy unknown

Neutrinoless Double Beta Decay:



Lepton Number conservation is violated: ΔL=2

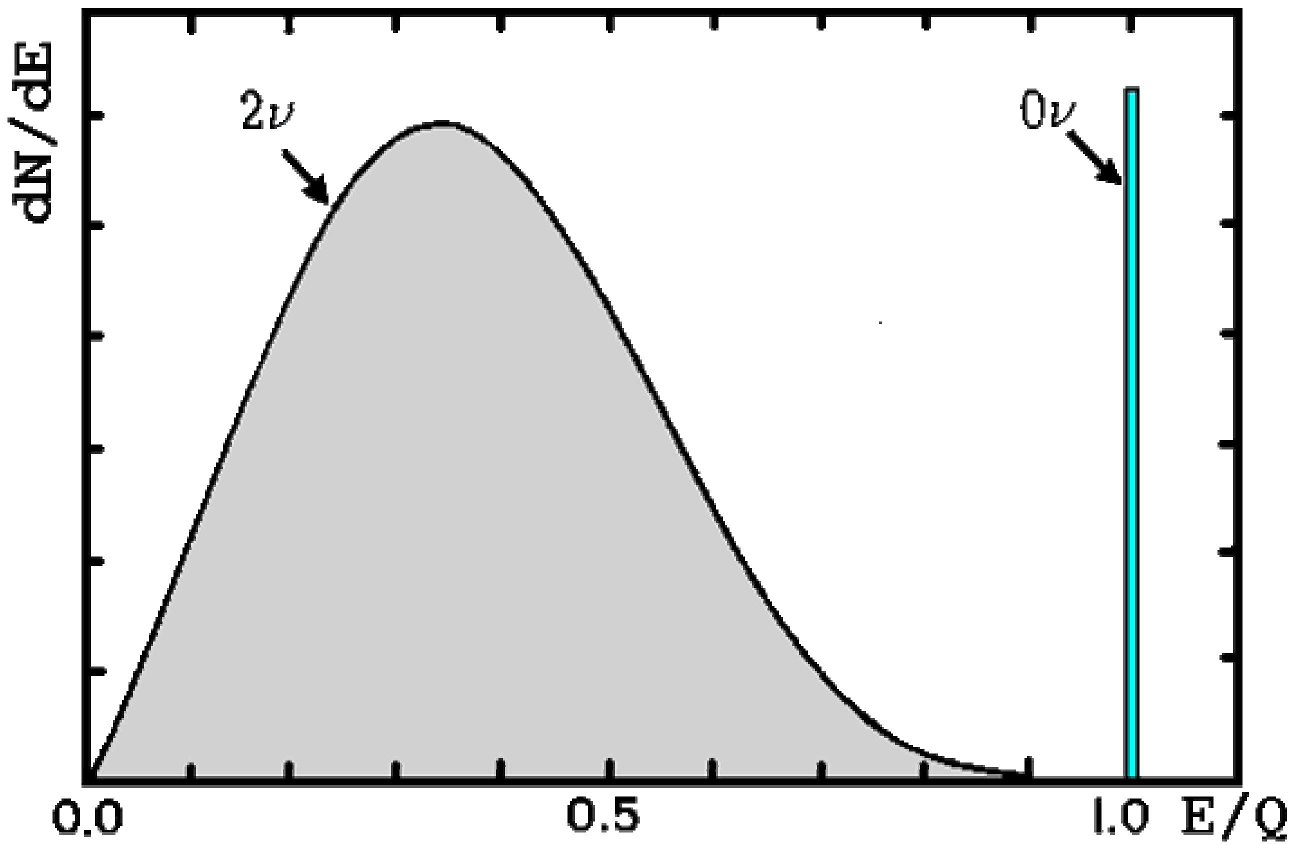
This process is only possible if:

- Neutrino is identical with its antiparticle (Majorana particle)
- Neutrino is massive

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

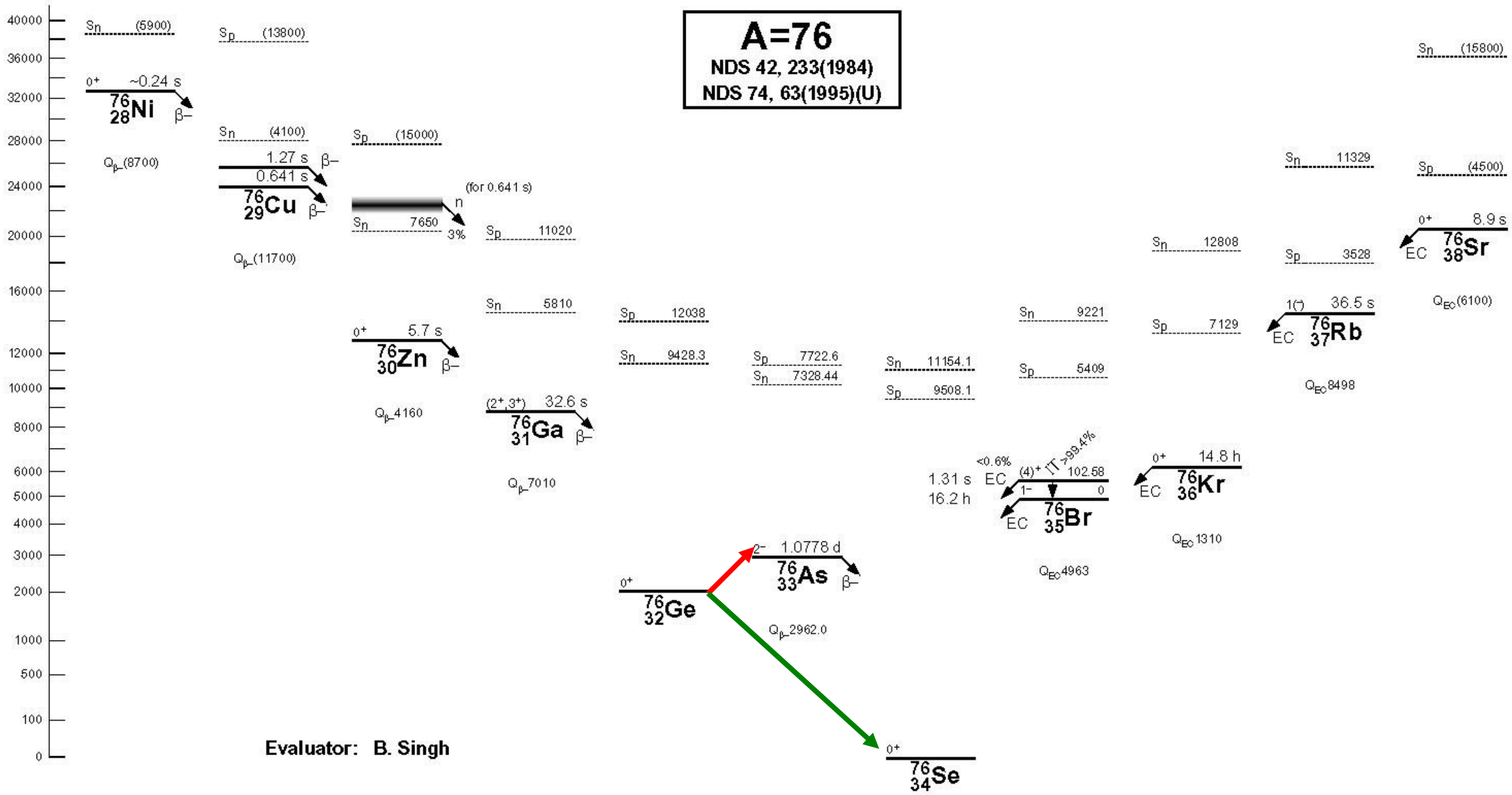
0νββ Decay rate — Phase space factor (~Q^5) — Matrix element — Effective Majorana Neutrino mass

Neutrinoless Double Beta Decay Signature:



Signature: Sharp peak at Q-value of the decay (2040 *keV* for ^{76}Ge)

Double Beta Decay of ^{76}Ge:

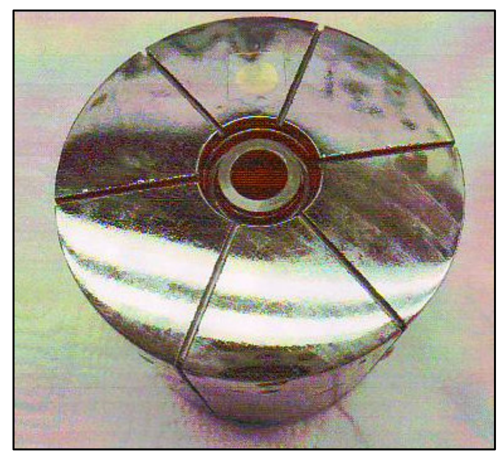


$^{76}Ge \rightarrow\ ^{76}As + e^- + \bar{\nu}_e$ energetically forbidden

$^{76}Ge \rightarrow\ ^{76}Se + 2e^- + 2\bar{\nu}_e$ 2nd order allowed weak process

High Purity Germanium detectors:

Very good energy resolution	Background due to $2\nu\beta\beta$ decay negligible
Source = Detector	High signal detection efficiency (95%)
Very high purity of detector material (zone refinement)	Very low intrinsic background
Considerable experience	Well known and reliable, improvements possible
Natural abundance of ^{76}Ge 7,44%	Enrichment necessary



Present Status:

E.L. Fireman, Phys. Rev. 1949 75:323

A Measurement of the Half-Life of Double Beta-Decay from $_{50}Sn^{124}$ *

E. L. FIREMAN
Department of Physics, Princeton University, Princeton, New Jersey
November 29, 1948

IF two isobars differ ... heavier may deca... decay.[1,2] This is the sin... if the heavier has lowe... emission of two posit... captures if the heavi... half-life depends markedly upon whether or not two neutrinos are emitted in the process. If no neutrinos are

TABLE I. Theoretical half-life for allowed double negaton emission.

Atomic mass difference	0	0.52 Mev	1.04 Mev	1.56 Mev	2.08 Mev	2.60 Mev
2 neutrinos	∞	$2.6\cdot10^{27}$ yr.	$2.4\cdot10^{25}$ yr.	$1.3\cdot10^{24}$ yr.	$2.1\cdot10^{23}$ yr.	$4.3\cdot10^{22}$ yr.
No neutrinos	∞	$2.1\cdot10^{16}$ yr.	$2.7\cdot10^{15}$ yr.	$6.5\cdot10^{14}$ yr.	$2.2\cdot10^{14}$ yr.	$8.3\cdot10^{13}$ yr.

specimens in the holder are interchanged every 20 hours. These data are summarized in Table II.

In all situations specimen A gives 2 coincidence counts/hr. more than specimen B. By repeating this type of

observations have been found to be plausible. This result would indicate that double beta-decay is unaccompanied by neutrinos. A further consequence of these results pointed out to the

decay from Sn^{124}, one obtains a half-life between $0.4\cdot10^{16}$ yr. and $0.9\cdot10^{16}$ yr. Other alternative explanations for these observations have been considered but none have been found to be plausible. This result would indicate that double beta-decay is unaccompanied by neutrinos. A further consequence of these results pointed out to the author by Professor J. R. Oppenheimer is that the neutron-proton charge difference is exactly equal to the electron charge.

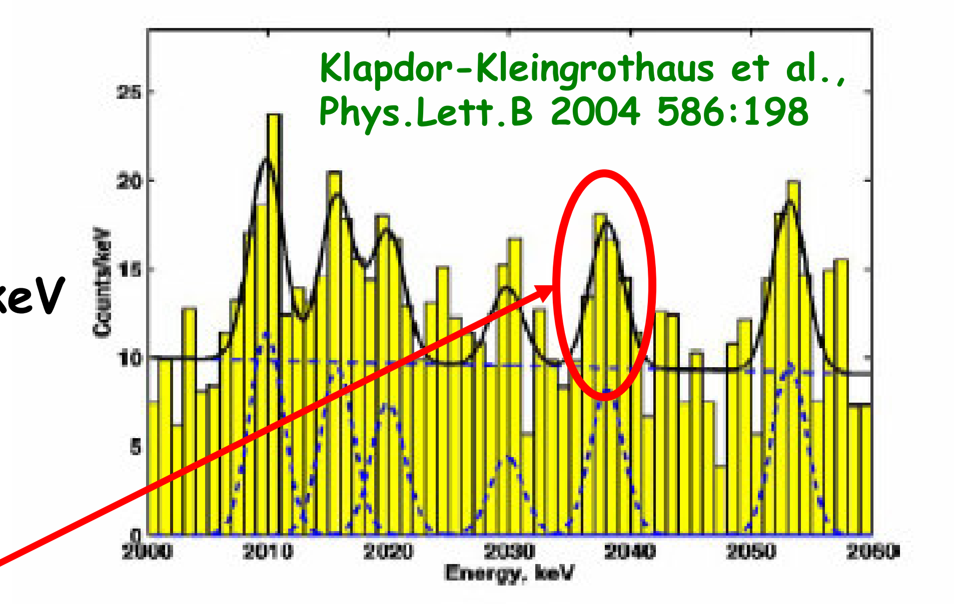
GOAL: Increase sensitivity in order to either confirm or refute claim

- Reduce bkg-index by two orders of magnitude to 10^{-3} Cts/(kg keV year)
- Increase exposure to 100 kg years --> improve limit

"One option for background reduction is to immerse the almost bare crystals in liquid N, which would serve as a shield."

(G. Heusser, Ann.Rev.Nucl.Part.Sci. 1995 45:543)

Results from HPGe experiments:



<u>Heidelberg-Moscow Experiment</u>:

11.5 kg of enriched Ge detectors

71.7 kg yrs of data

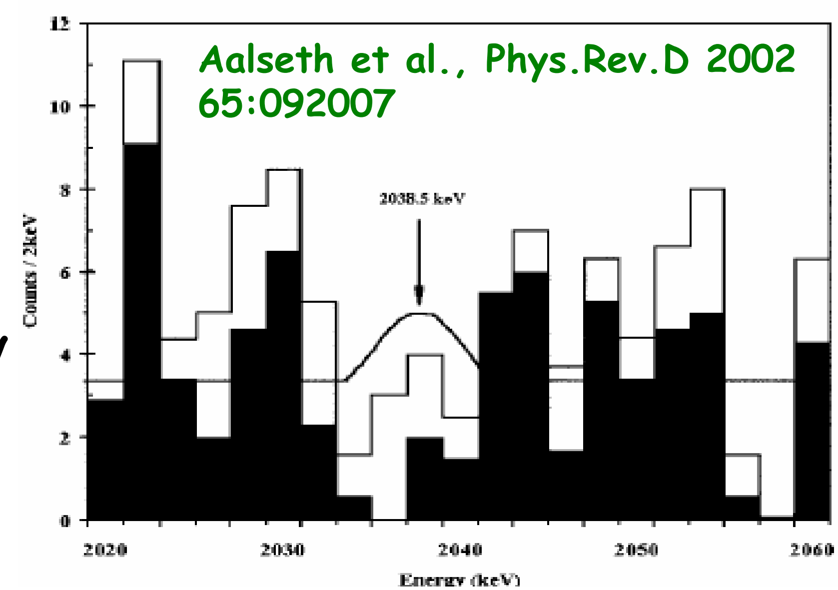
0.11 Counts/(kg keV y) around 2040 keV

--> Upper limit:

$T_{1/2} \geq 1.9 * 10^{25}$ years (90% C.L.)

4.2 σ claim: $T_{1/2} = 1.19 * 10^{25}$ years

--> $\langle m_{ee} \rangle$ = 440 *meV* (KK matrix el.)



<u>IGEX Experiment</u>:

6.8 kg of enriched Ge detectors

117 mol yrs of data

0.17 Counts/(kg keV y) around 2040 keV

--> Upper limit:

$T_{1/2} \geq 1.6 * 10^{25}$ years (90% C.L.)

GERmanium Detector Array: GERDA

Phase I: Use 5 Heidelberg-Moscow and 3 IGEX detectors

Estimated background: 0.01 Counts/(kg keV y) @ 2040 *keV*

Exposure: 15 kg years

The aim is to confirm/refute claim

~7 signal events and ~2 background events are expected after ~1 year of measuring time in a 10 *keV* signal window around 2040 *keV* in case of confirmation of claim.

Phase II: Plus 20 kg enriched material

Envisioned Background: 0.001 Counts/(kg keV y) @ 2040 *keV*

Exposure: 100 kg y

Discovery potential to $T_{1/2} \approx 5 \cdot 10^{25}$ yrs,

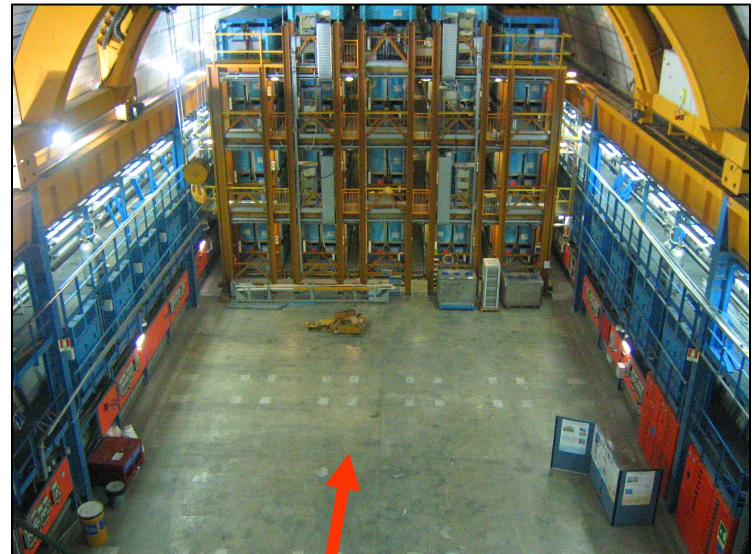
limit setting to $1.5 \cdot 10^{26}$ yrs.

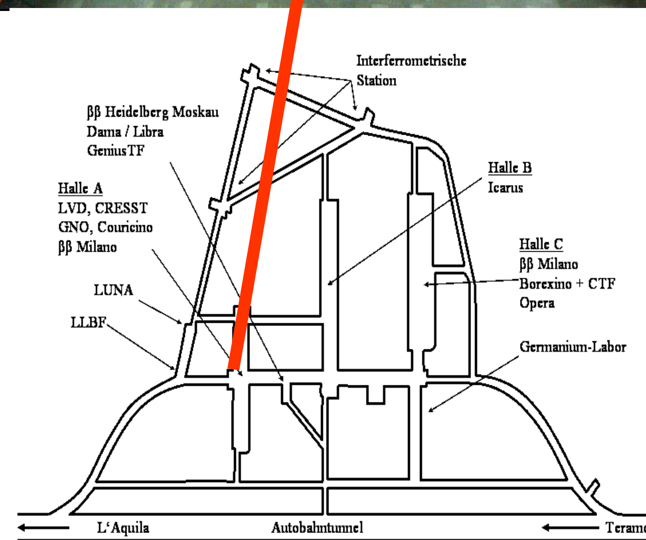
For Rodin et al. matrix element, mass sensitivity about 200 *meV*

GERDA location: Gran Sasso, Italy

1400 m rock overburden : 3800 mwe

View from the CRESST hut :





LNGS-INFN: Experiment approved

Construction will soon get underway (hall A)

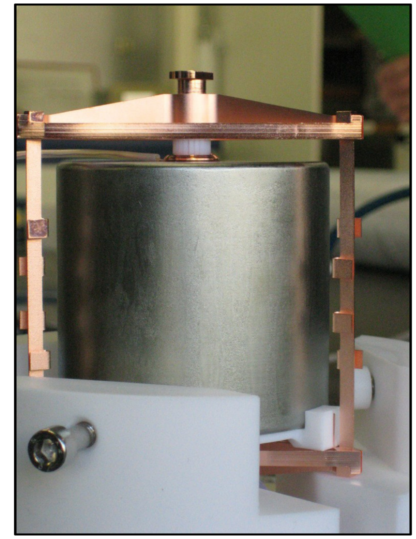
Expected background sources:

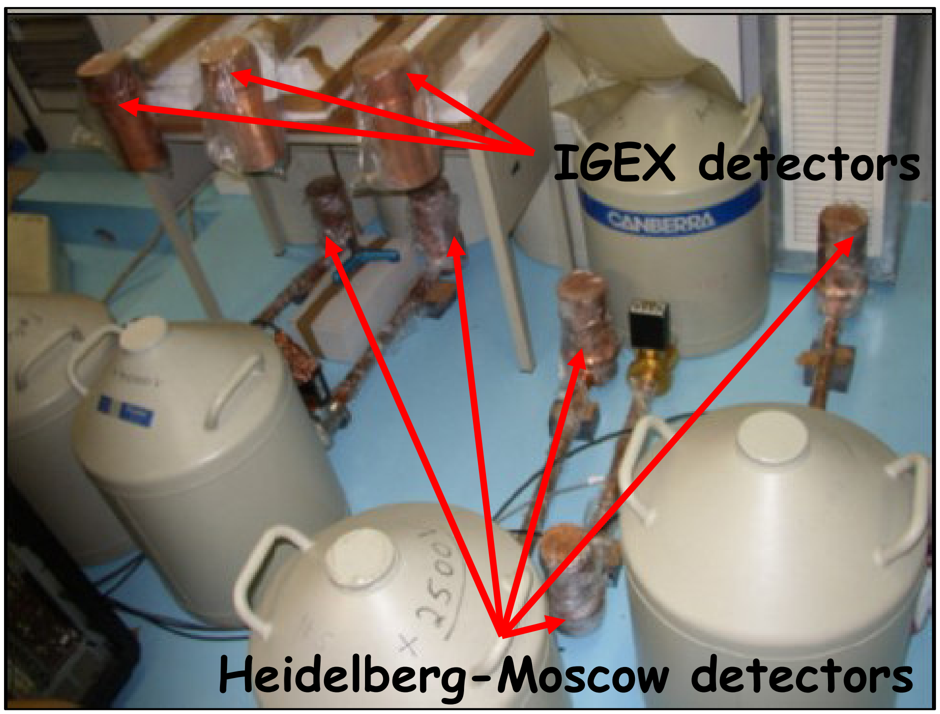
Source	Estimated Background* (MC) [10^{-4} *Counts/(kg keV y)*]	Means of background reduction
Holder, suspension, cabling, electronics (first shot design)	21	Minimize materials Screening and cleaning
Infrastructure	4	Segmentation of detectors Pulse shape analysis
Cosmogenics in Ge (^{60}Co, ^{68}Ge, etc.)	5	Store underground, in case of ^{68}Ge: wait
Neutrons from GS rock and muon induced	2	3800mwe at LNGS, Active muon veto Water buffer
TOTAL	32	--> Further R&D

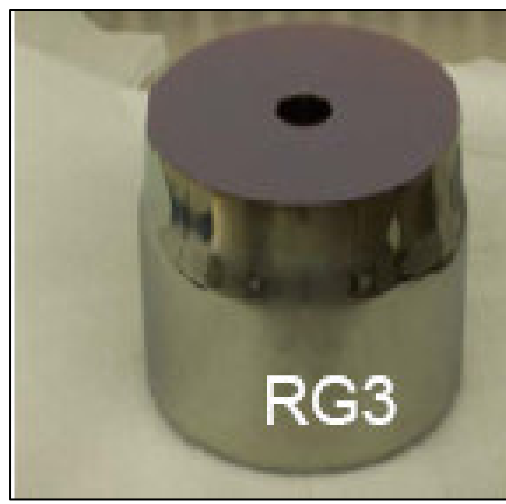
* Single segment cut taken into account, no PSA assumed

Phase I Detectors:

- 11 kg + 6 kg detectors enriched in 76Ge to 86% in GS
- Dismounting of first detectors from cryostats without problem
- Prototype (nat.) detector works well in LAr

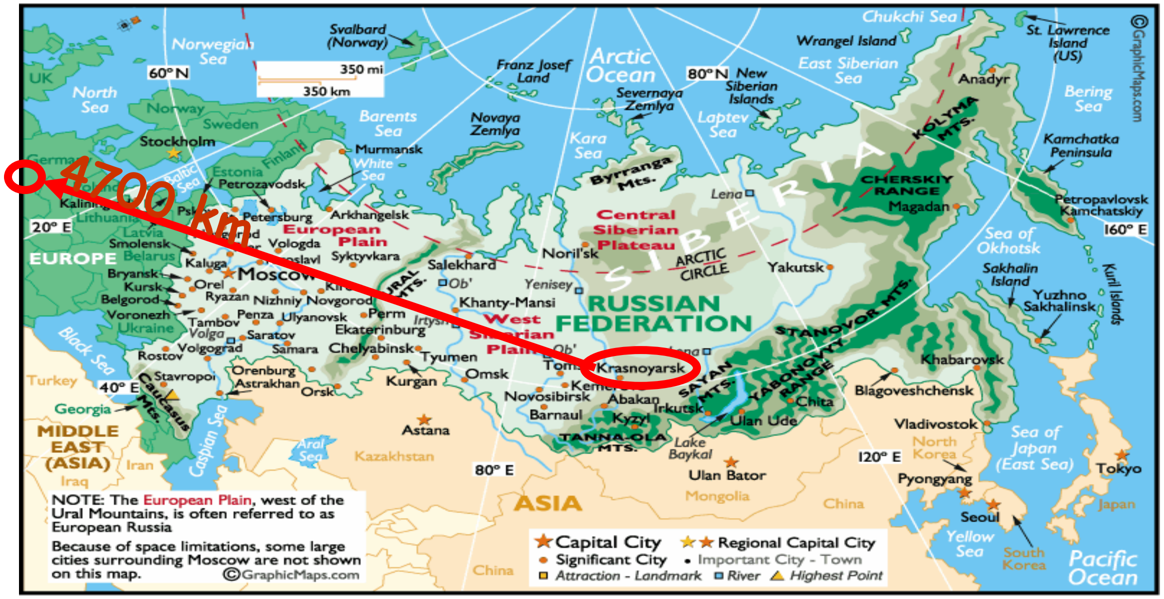






Phase II: 37.5 kg of enriched ^{76}Ge

37,5 kg of enriche ^{76}Ge have been shipped to Munich
and are now stored underground

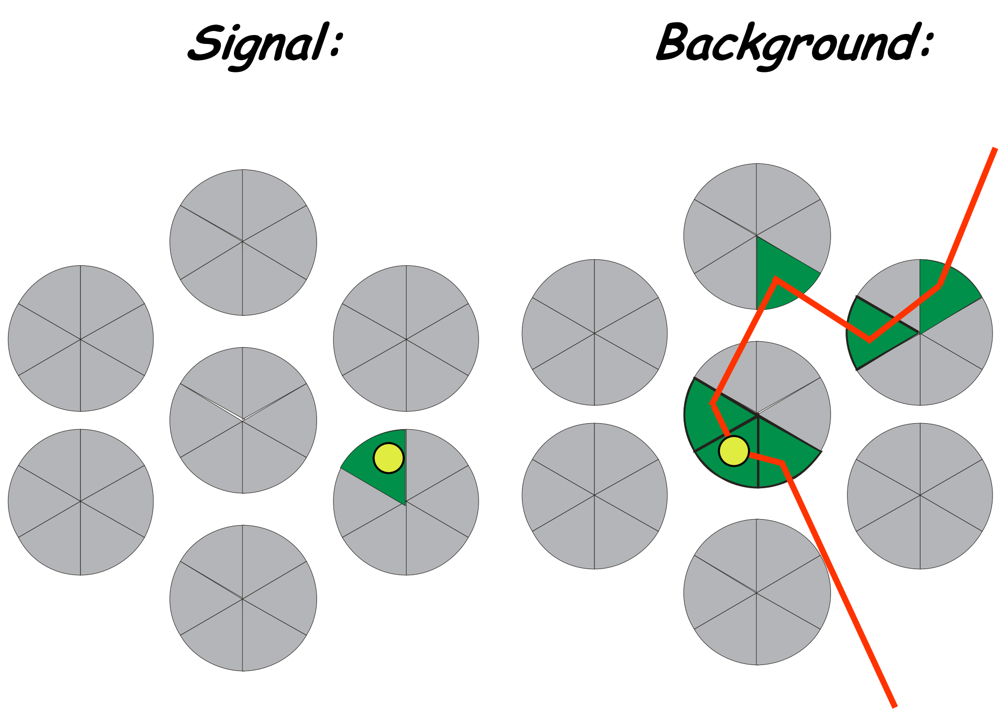


PhaseII: Segmentation of detectors

Germanium detectors can be segmented -->

Identify multiply Compton-scattered photons by coincidences

18 fold segmentation: 3-fold in height, 6-fold in φ



Source	Reduction
^{208}Tl (in Ge)	13
^{60}Co (in Ge)	38
^{68}Ge (in Ge)	18
^{210}Pb (α on Ge surface)	1
^{208}Tl (in holder)	5
^{60}Co (in holder)	157
^{208}Tl (in cable)	5

Reduction factors estimated using a GEANT4 Monte Carlo simulation

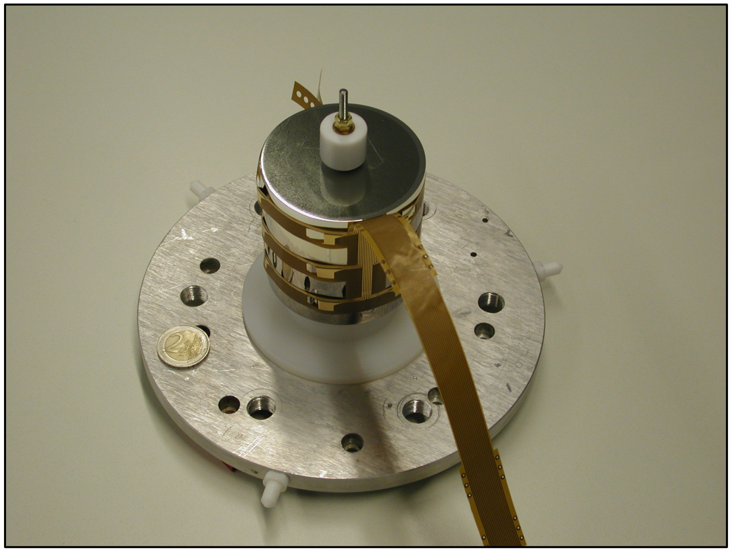
Phase II Detectors: Contacts and Holder

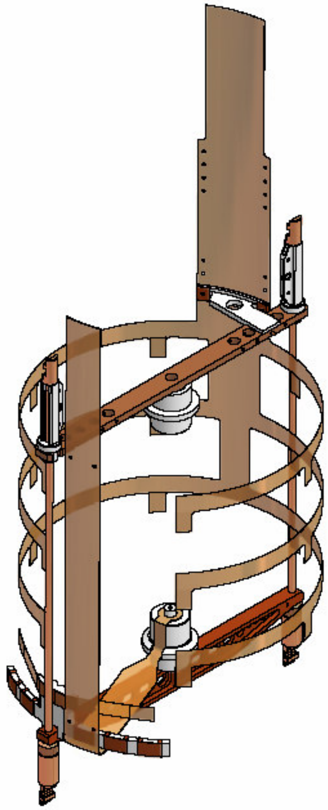
Very little material used for detector holder and contacts:

31g of copper + 7g of PTFE + 35µm Cu on 50µm Kapton

In the meantime: Reduction of Kapton surface and mass by factor 2 and 4 ,respectively with respect to earlier one

--> Background reduction close to envisioned level





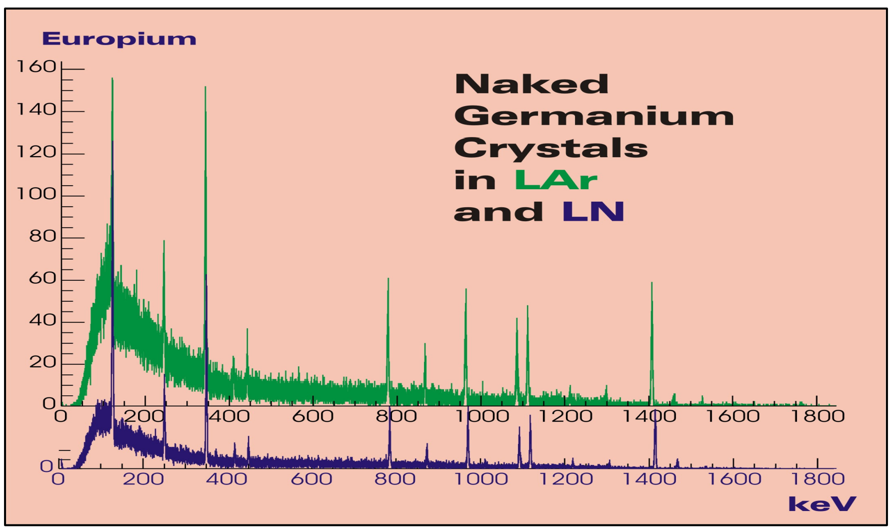
Prototype-detector performance:

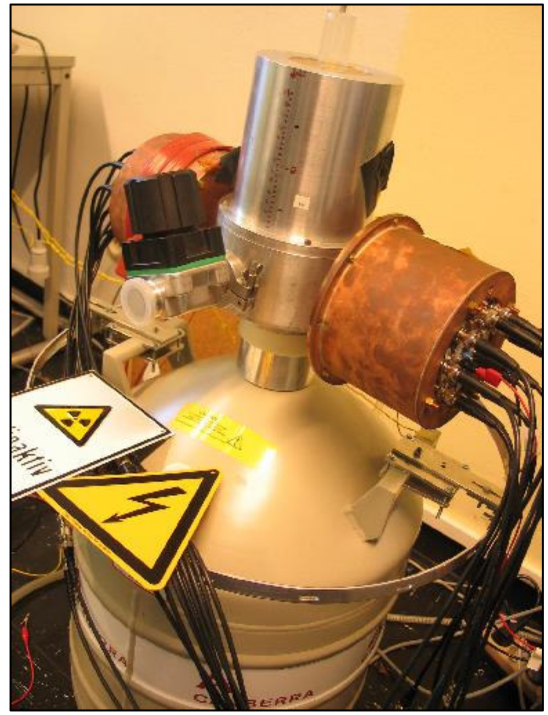
Prototype detectors work well in cryogenic liquid:

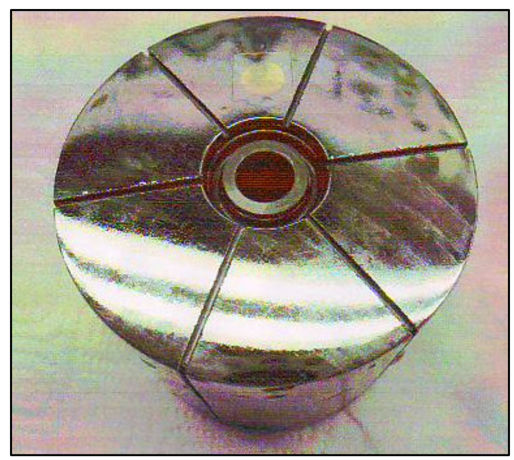
• prototype detectors (n-type as well as p-type) were cycled > 20 times in LN without problem

• Performance for LAr as good as with LN

• 18-fold segmented n-type detector works fine. New contacting scheme verified in conventional surrounding



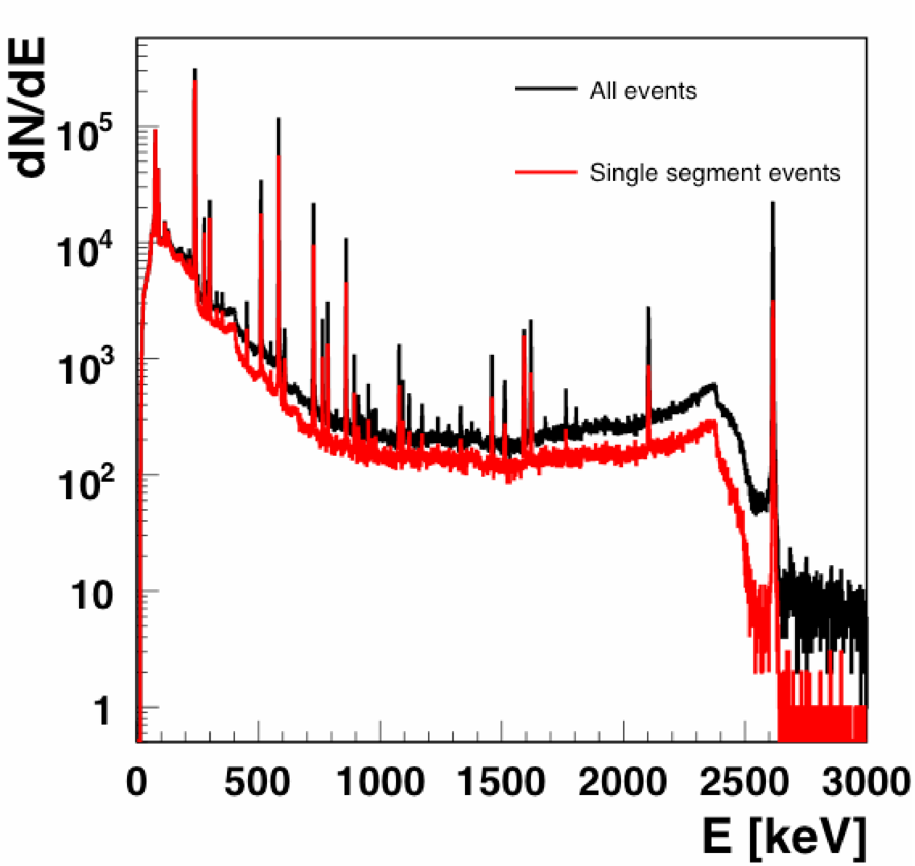


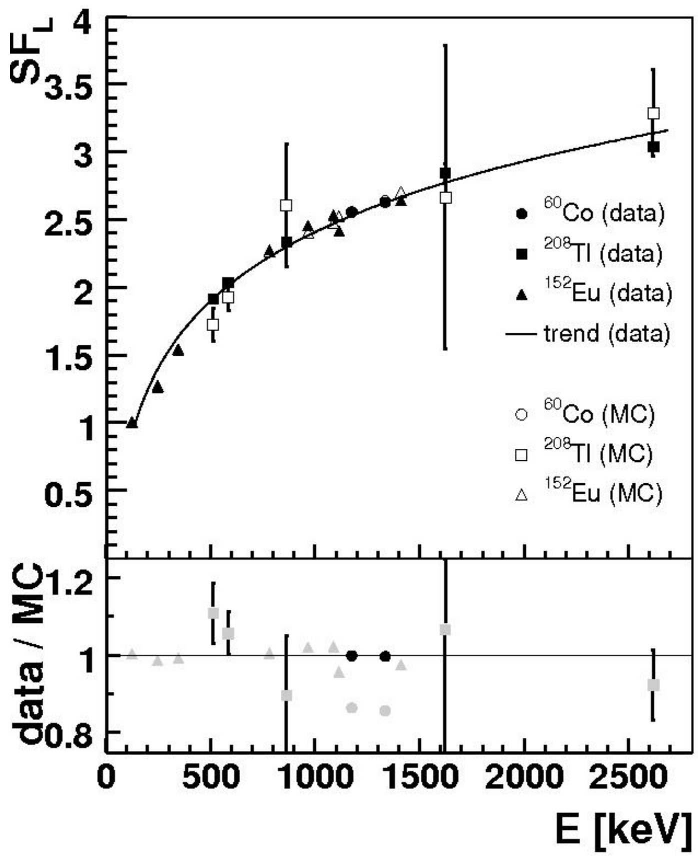


Phase II: Results with prototype detector

Prototype detector works well in conventional cryostat:

- Core and segment resolutions around 3~*keV* @ 1.3 *MeV*
- Compton Background recognition works as expected

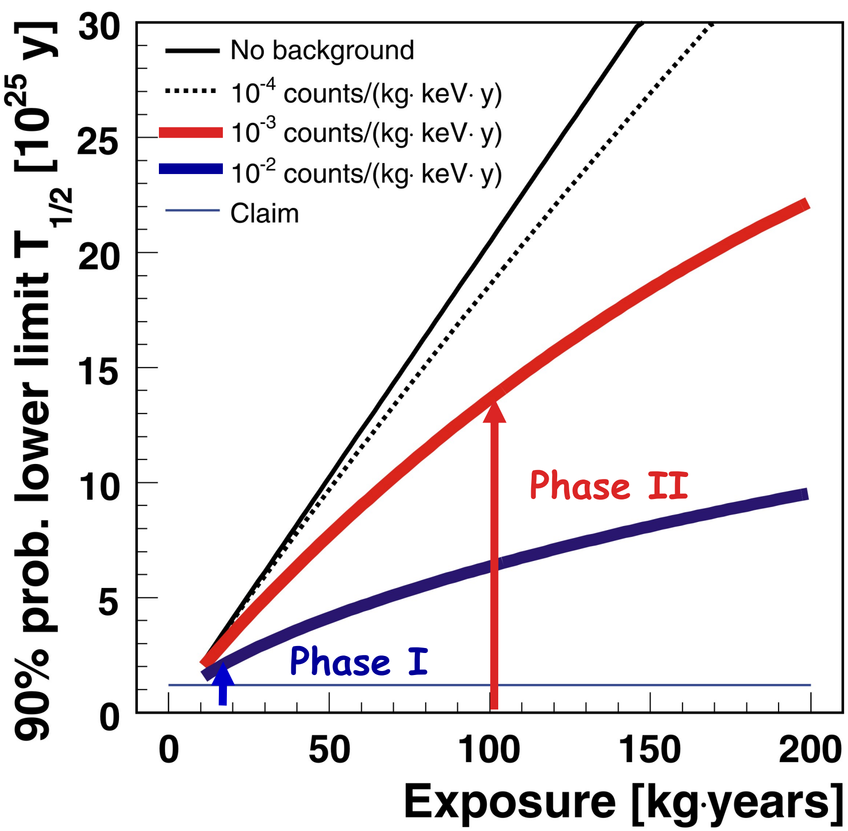


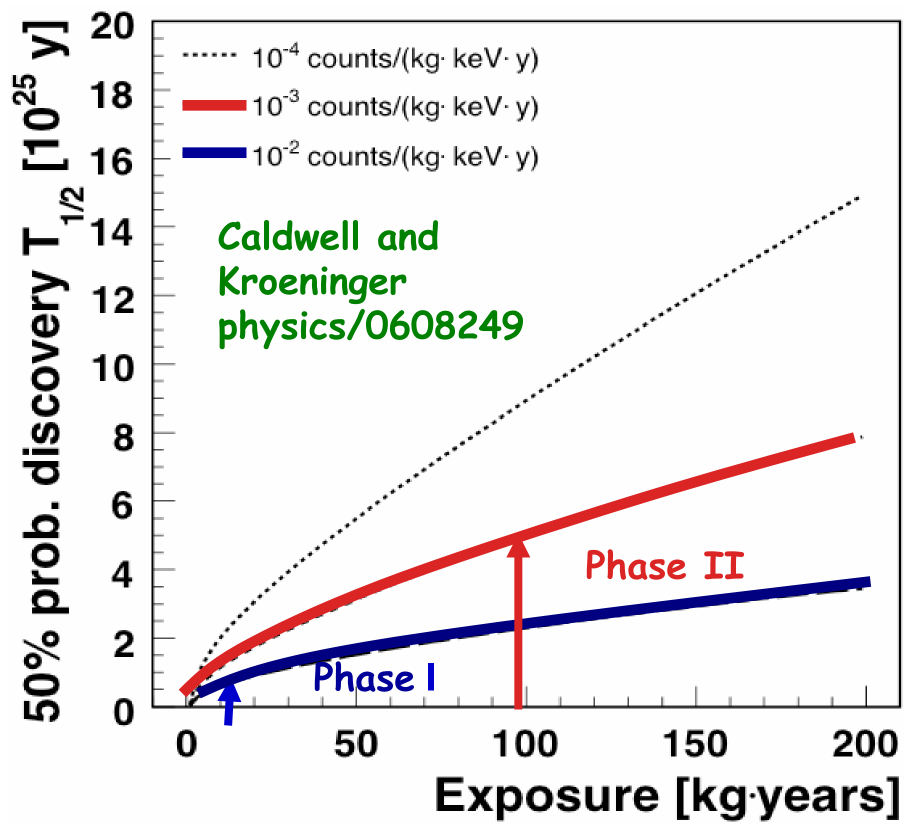


Conclusions:

- Measurement of $0\nu\beta\beta$ has very high priority.
- HPGe experiments have very high discovery potential.
- The GERDA experiment will use new technique of using naked HPGe detectors in cryo liquid.
- Sensitivty of GERDA Phase I will be sufficient to confirm or refute claim.
- GERDA phase II will further improve limits in case of a negative result.
- GERDA will start construction of experiment at Gran Sasso laboratory very soon.
- World wide effort needed to probe $\langle m_{ee} \rangle$ down to 10 *meV*.

GERDA sensitivity:





Phase I: ~7 signal events and ~2 background events are expected after ~1 year of measuring time in a 10 *keV* signal window around 2040 *keV* in case of confirmation of claim.