Neutrinoless Double Beta Decay – Status of GERDA

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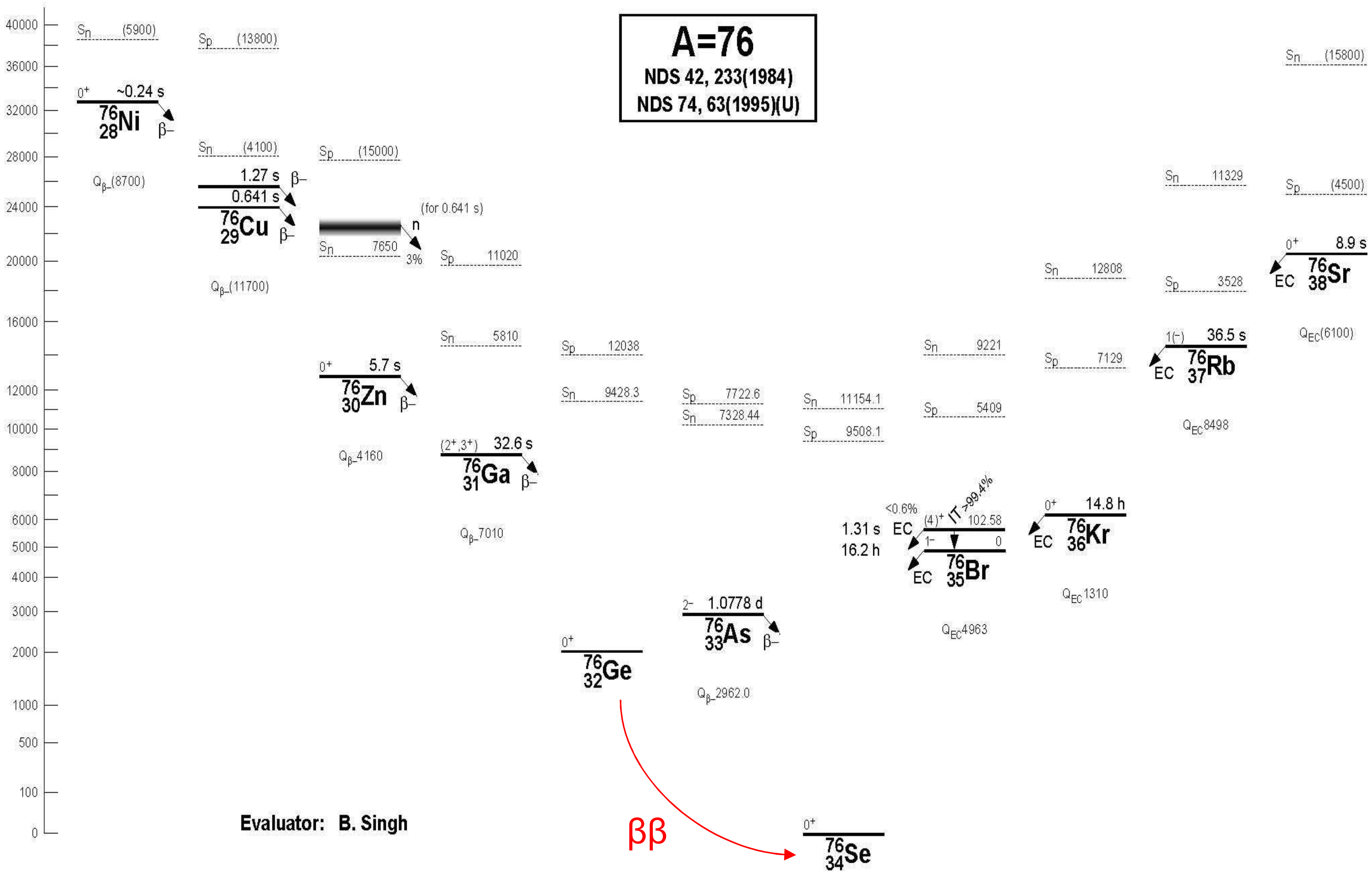
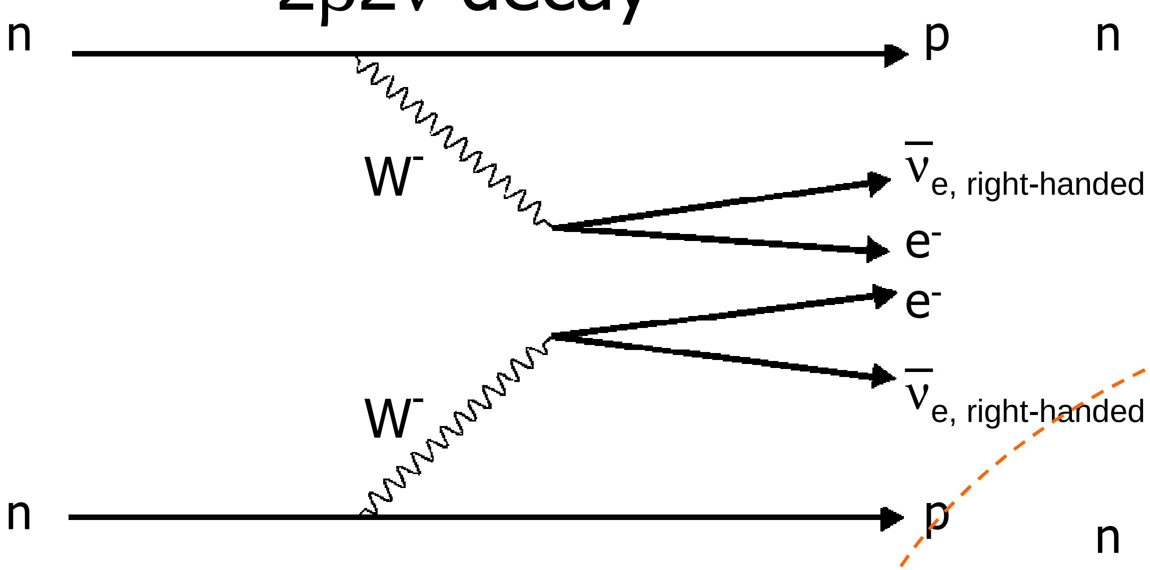
IDEA, Blaubeuren, 4.7.2007

Double Beta Decay

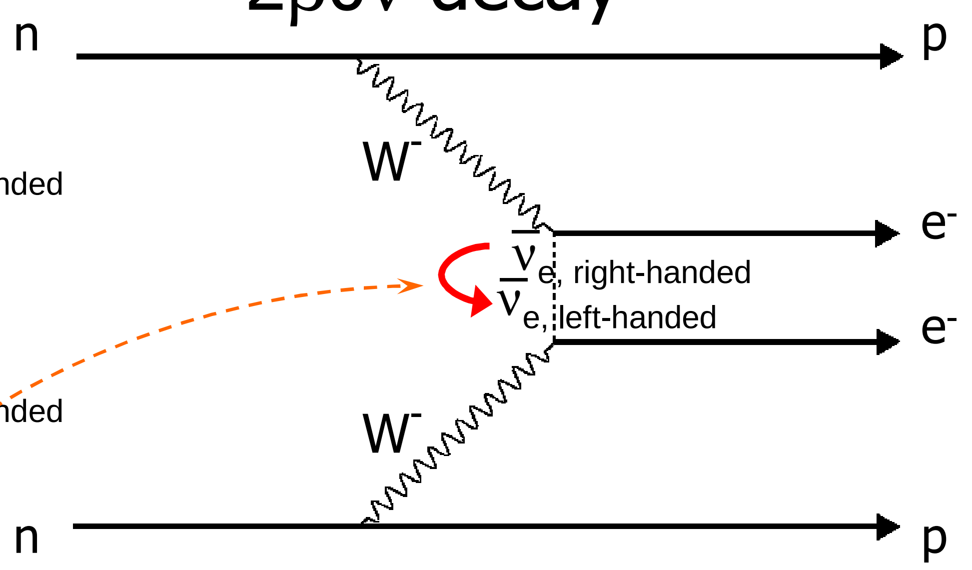


Neutrinoless Double Beta Decay

$2\beta2\nu$ decay



$2\beta0\nu$ decay

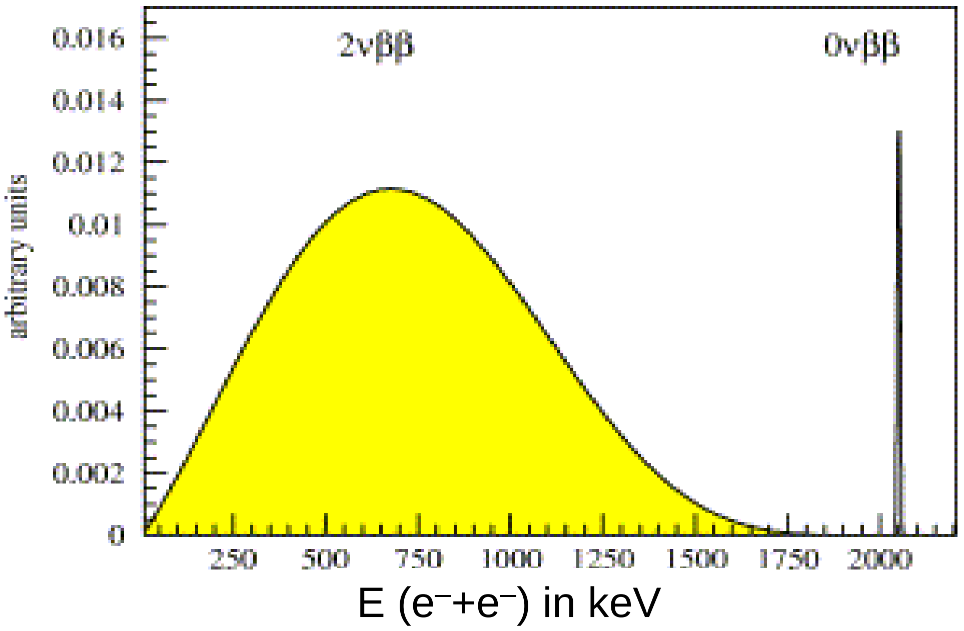


$2\beta0\nu$ conditions:

$\bar{\nu} = \nu$ **Majorana particle**

$\Delta L=2$ **Lepton number violation**

$P(\bar{\nu}_{e,\text{ left-handed}}) \sim (m/E)^2$ **for $m_\nu > 0$**



From 0ν2β to Neutrino Mass

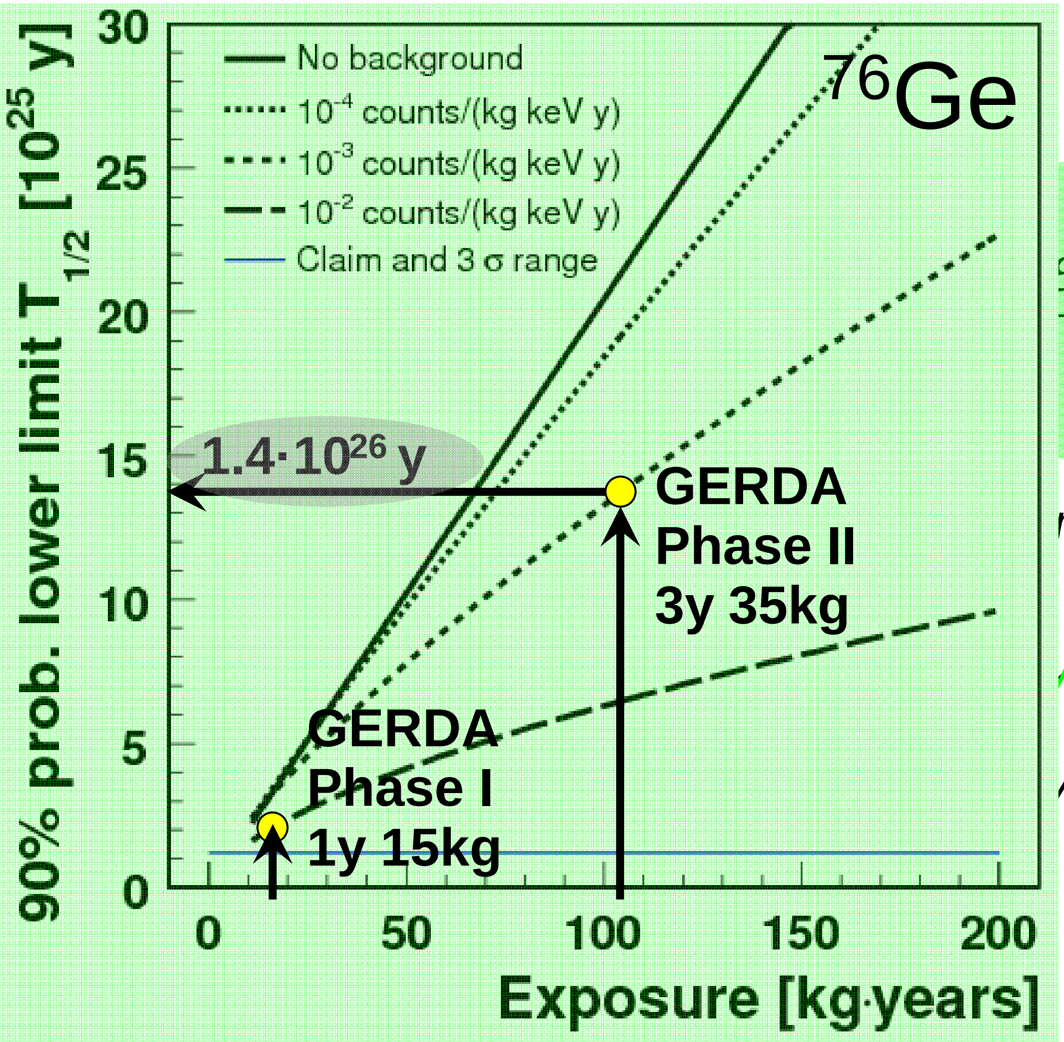
- Exp. deter

$$T^{0\nu}_{1/2} = \frac{N \ln 2}{S_{2\beta0\nu}/t\varepsilon}$$

$$\varepsilon\sqrt{\frac{m\,t}{b\,\delta E}}$$

with $T^{0\nu}_{1/2} = \frac{\;}{C}$

and $m_{ee} = \left|\sum_{n=1}^{3} U\right.$



ms

nals

$)^{-1}$

Number of Ge

$2\beta0\nu$ signal Background

Bgr. rate (kg s

Ge mass

Ge mol. weight

^{76}Ge enrichment

Detection efficiency

δE Energy binning

t Measurement time

BACKGROUND–FREE ($T_{1/2}$~t)

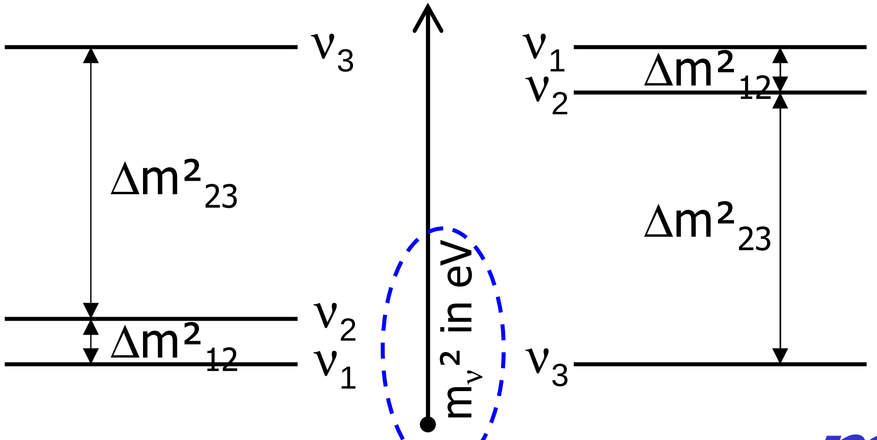
BACKGROUND >0 ($T_{1/2}$~√t)

Impact on Neutrino Physics

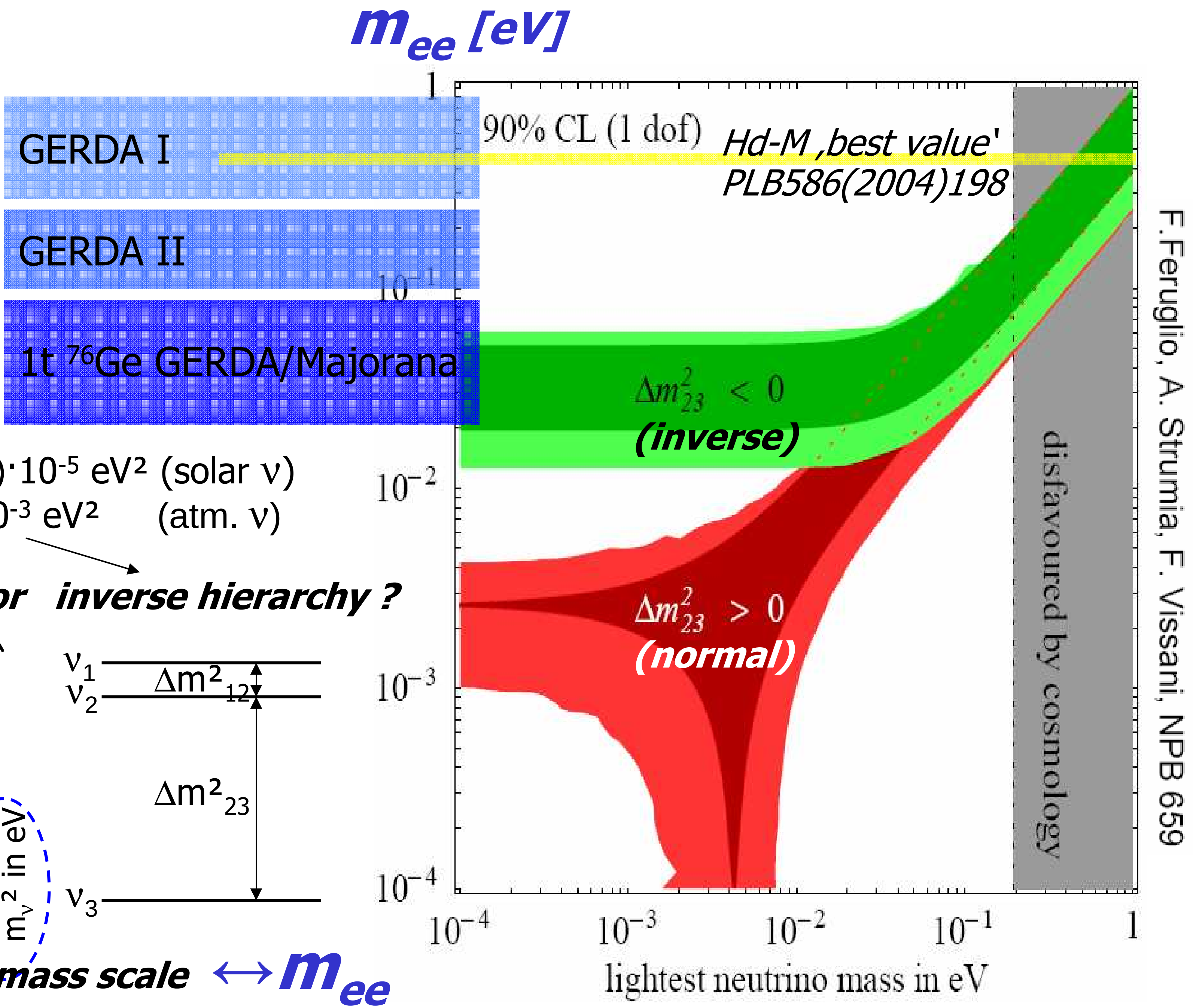
Current status:

$\Delta m^2_{12} = (7.92 \pm 0.07) \cdot 10^{-5}\ \mathrm{eV}^2$ (solar ν)
$\Delta m^2_{23} = (2.6 \pm 0.4) \cdot 10^{-3}\ \mathrm{eV}^2$ (atm. ν)

normal hierarchy or inverse hierarchy ?



absolute mass scale ↔ m_{ee}

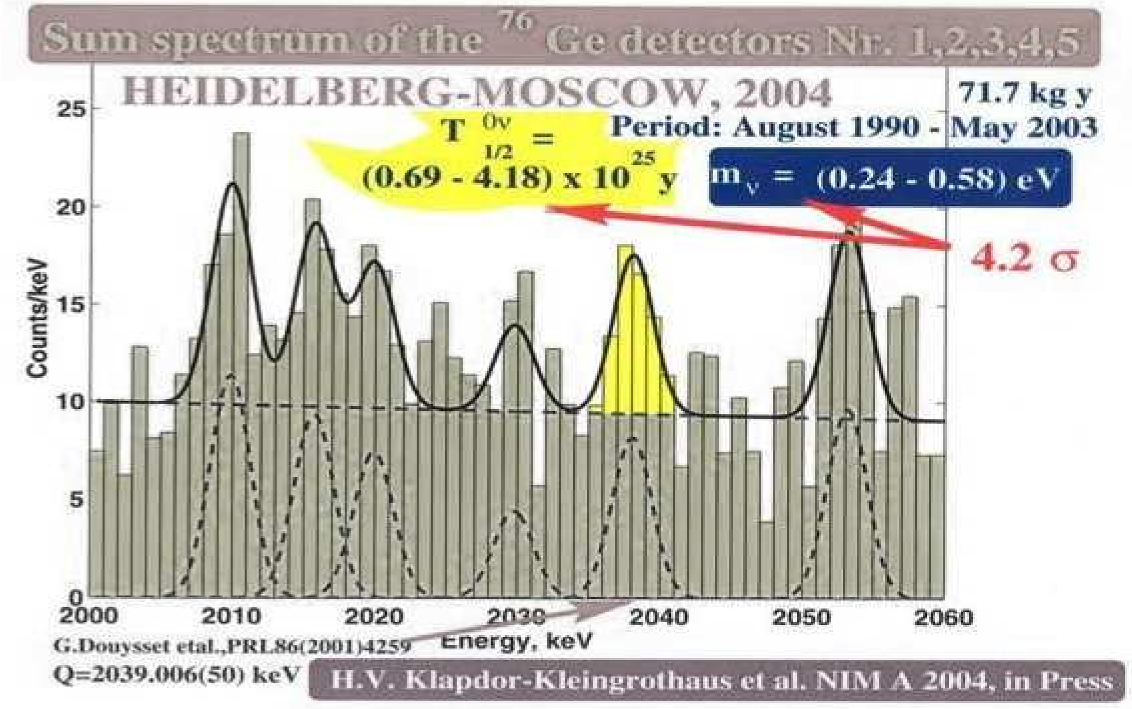


F.Feruglio, A. Strumia, F. Vissani, NPB 659

Two completed experiments

^{76}Ge

Heidelberg-Moscow



[Klapdor-K. et al, Phys.Lett. B586(2004)198]

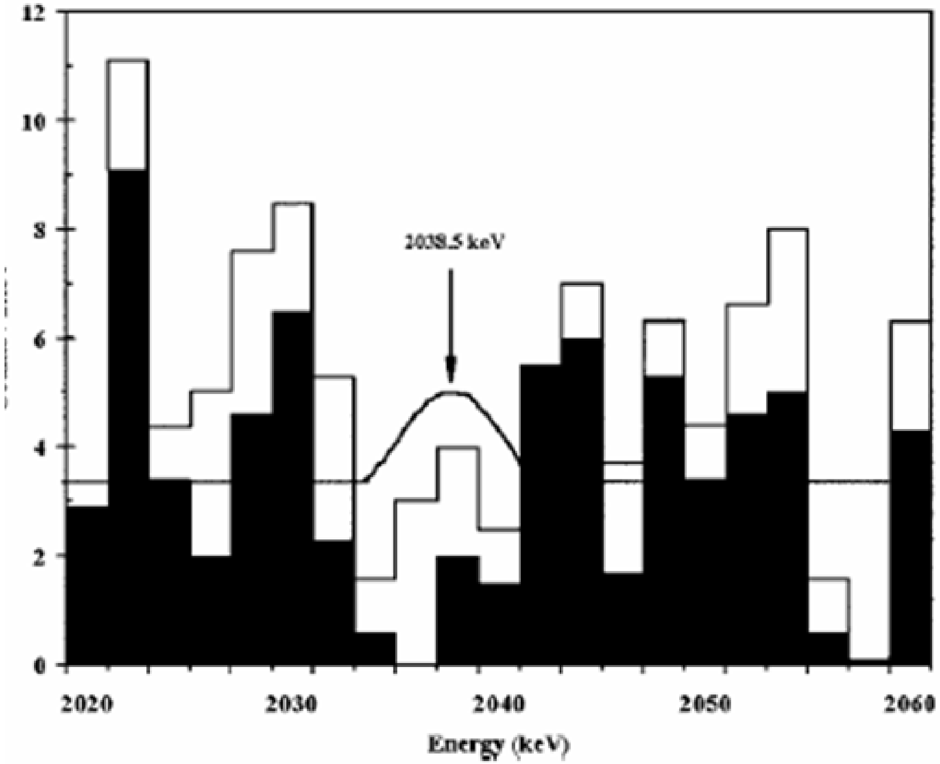
Best fit: $T_{2\beta0\nu} = 1.2 \cdot 10^{25}$ y

A.M. Bakalyarov, A. Ya. Balysh, S. T. Belyaev, V. I. Lebedev, S. V. Zhukov (Kurchatov Institute, Moscow)

$T_{1/2}(2\beta0\nu) > 1.55 \cdot 10^{25}$ y (90% C.L.)

[Письма в ЭЧАЯ. 2005. Т.2, No.2(125). С.21-28]

IGEX



[Phys.Rev.D65:092007,2002]:

Enriched Ge detectors (a=86%)

8.9 kg y of ^{76}Ge data

$T_{1/2}(2\beta0\nu) > 1.57\times10^{25}$ y

(90% C.L.)

Gerda - Motivation

- *Improvement of m_{ee} sensitivity*
- *Check of former publications*

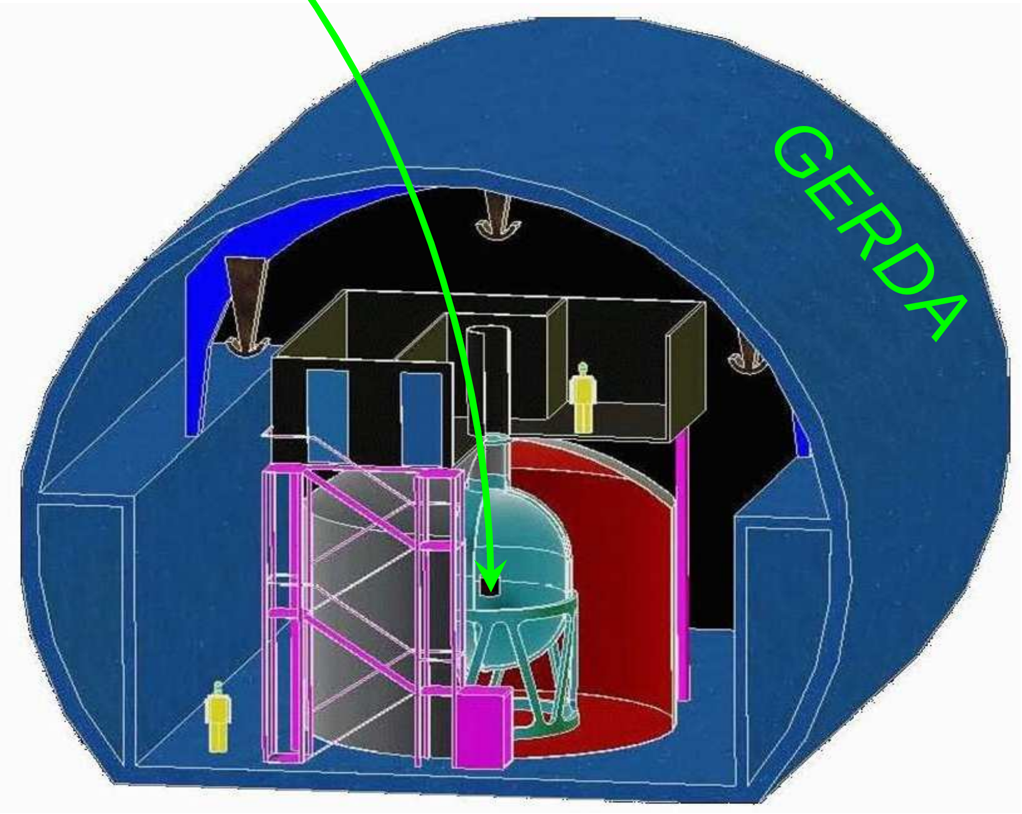
Improve Background by ultra-pure shielding

HPGe detectors in *Liquid Argon*

GERDA → 10^{-3} (kg·y·keV)$^{-1}$

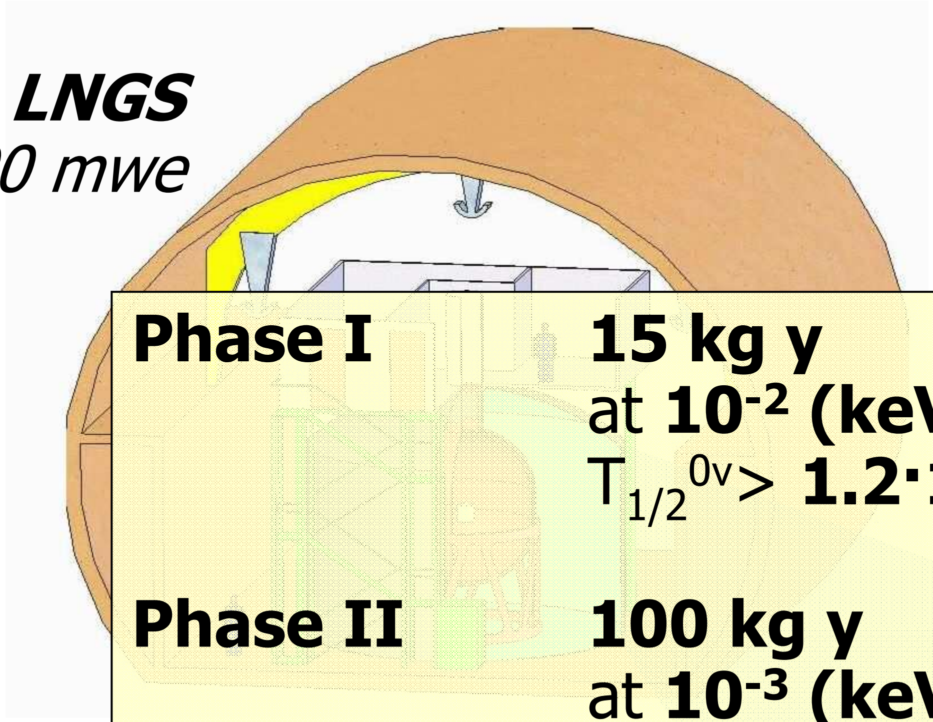
[IGEX 0.1–0.3 (kg·y·keV)$^{-1}$]

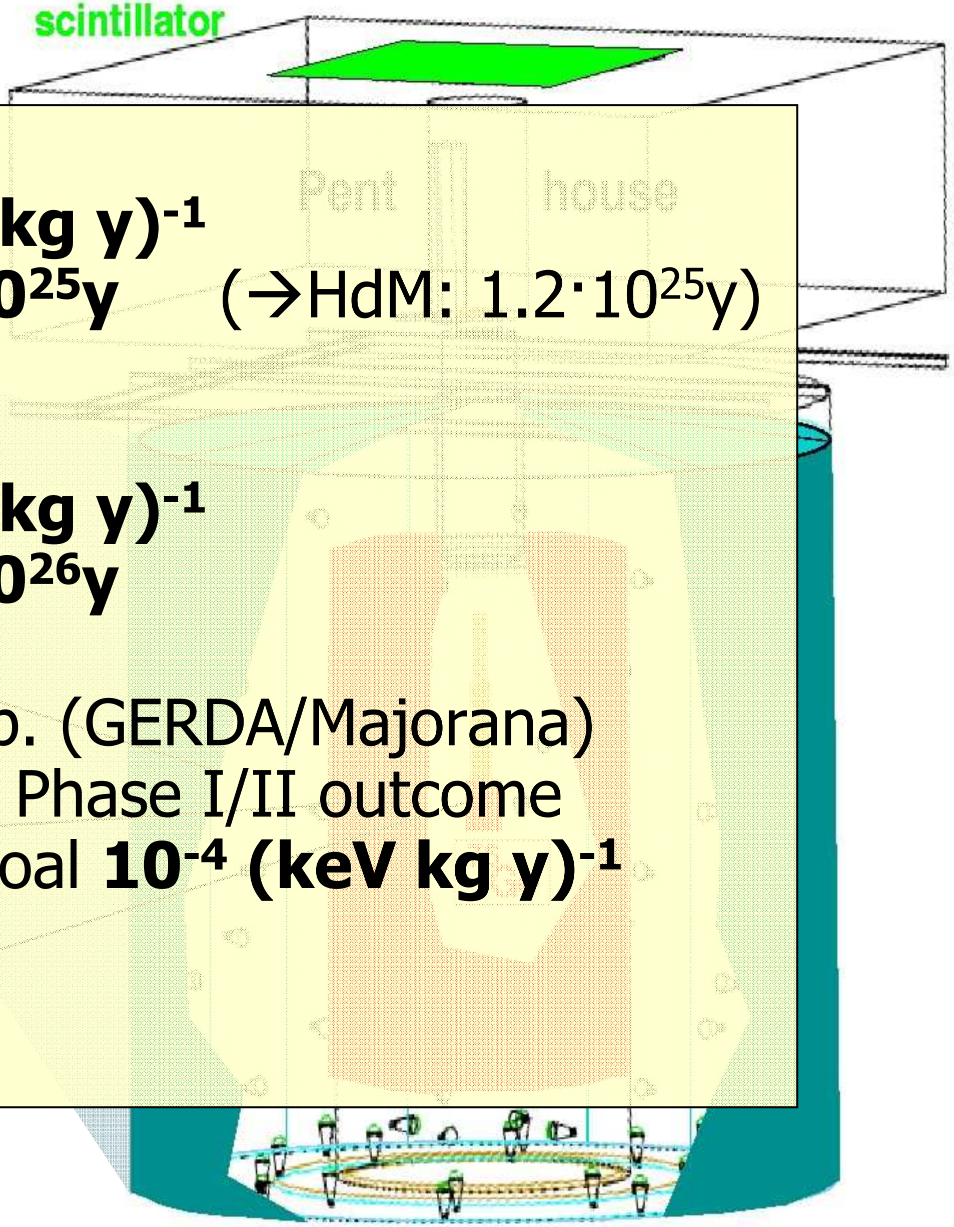
[Hd-M 0.17 (kg·y·keV)$^{-1}$]



Gerda - Detector Overview

LNGS
3600 mwe





Phase I	**15 kg y** at **10^{-2} (keV kg y)$^{-1}$** $T_{1/2}^{0\nu}>$ **$1.2 \cdot 10^{25}$y** (→HdM: $1.2 \cdot 10^{25}$y)
Phase II	**100 kg y** at **10^{-3} (keV kg y)$^{-1}$** $T_{1/2}^{0\nu}>$ **$1.4 \cdot 10^{26}$y**
Phase III	1 ton ^{76}Ge exp. (GERDA/Majorana) depending on Phase I/II outcome Background goal **10^{-4} (keV kg y)$^{-1}$**

Water shield
Cherenkov muon veto

LAr shield in steel cryostat

~20 Ge crystals on 7 Cu strings
~35kg of ^{76}Ge (a>85%)

$Q_{\beta\beta}$=2039 keV

Ge Detectors Phase

5 HdM HPGe: p-type 11kg, ΔE= 2–3 keV

3 IGEX HPGe: p-type 6.5kg

in Nov 05 from Canfranc to LNGS

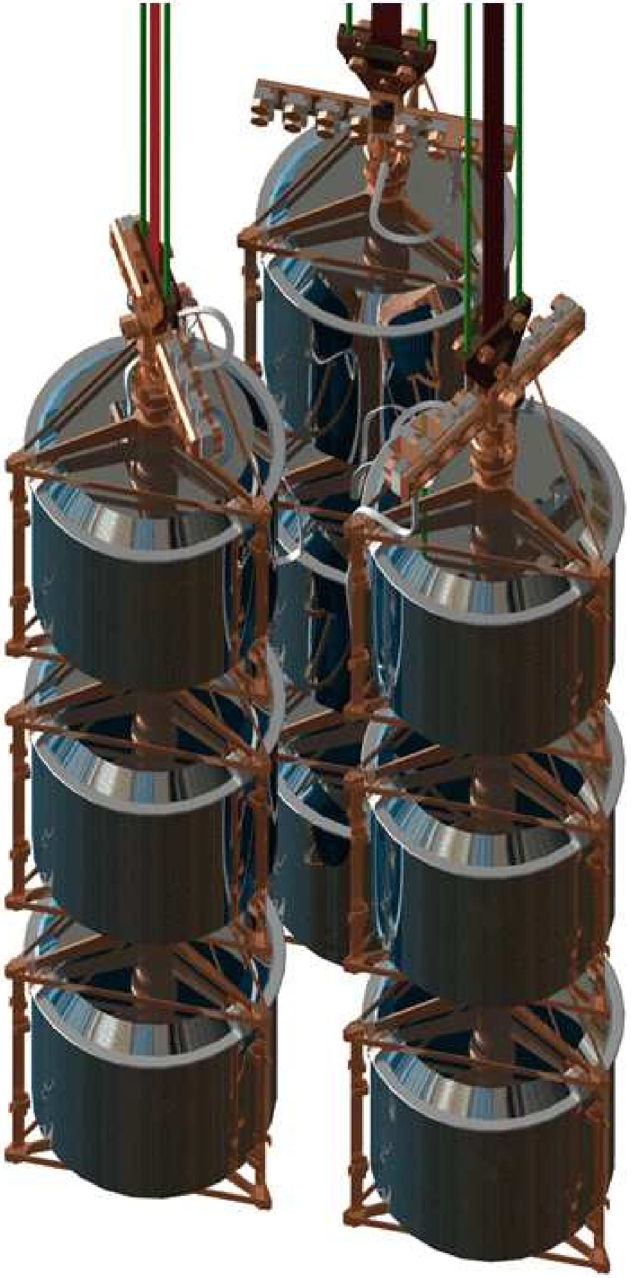
restored (cooled

→ ΔE≈2.3 keV

Refurbishment at Canberra/Olen into ultra-pure detector holders
(materials used: Copper, PTFE, silicon)

Underground storage possibility in Hades 500mwe

Tested at GDL@LNGS (former LArGe): resolution, efficiency, leakage current, cooling cycles



Internal background estimation:

^{60}Co 0.5y exposure history ~3·10^{-3} /(kg keV y)

Detector holders (Cu/PTFE): <1.5·10^{-3} /(kg keV y)

Ge Detectors Phase II

Available: GeO_2 with **37.5 kg of ^{76}Ge** (a=87%) → ~10 HPGe n-type (~20 kg) 3x6-fold segmented

Production: Purification → 6N (PPM Göttingen)

Monozone refinement → 8-9N (PPM) **First ^{dep}Ge (20kg) tests under way**

Crystal pulling (IKZ Berlin) **CZ puller installation, 1st crystals (Si, Ge)**

Detector production (Canberra)

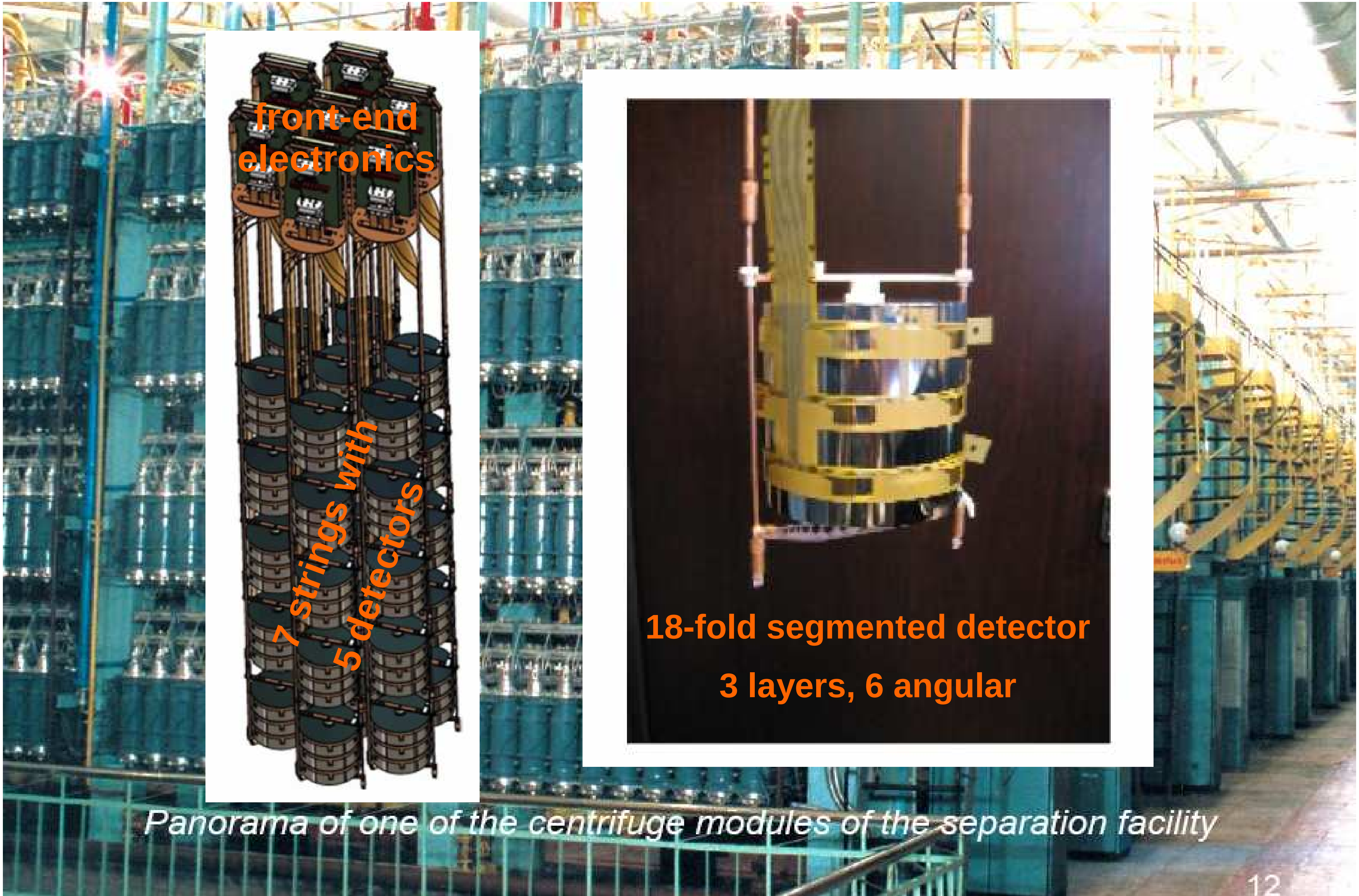
Internal background estimation:

^{60}Co ~40d exposure during fabrication 3.5·10^{-5} /(kg keV y) **(with segment anticoinc.)**

^{68}Ge ~40d exposure during fabrication 1.3·10^{-3} (1st) ~5·10^{-4} (2nd y)

Suspension+cabling+electronics: <2·10^{-3} /(kg keV y)

Ge Detectors Phase II



front-end electronics

7 strings with 5 detectors

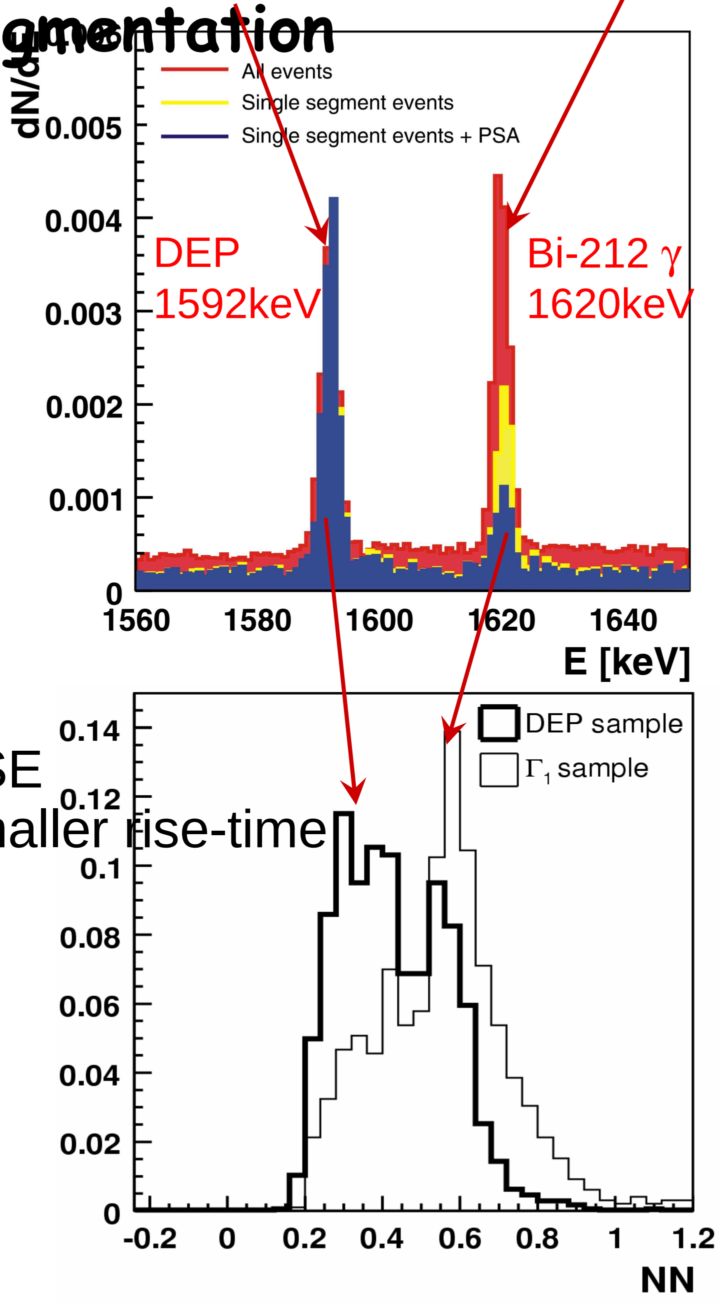
18-fold segmented detector

3 layers, 6 angular

Panorama of one of the centrifuge modules of the separation facility

GERDA – Suppression Methods

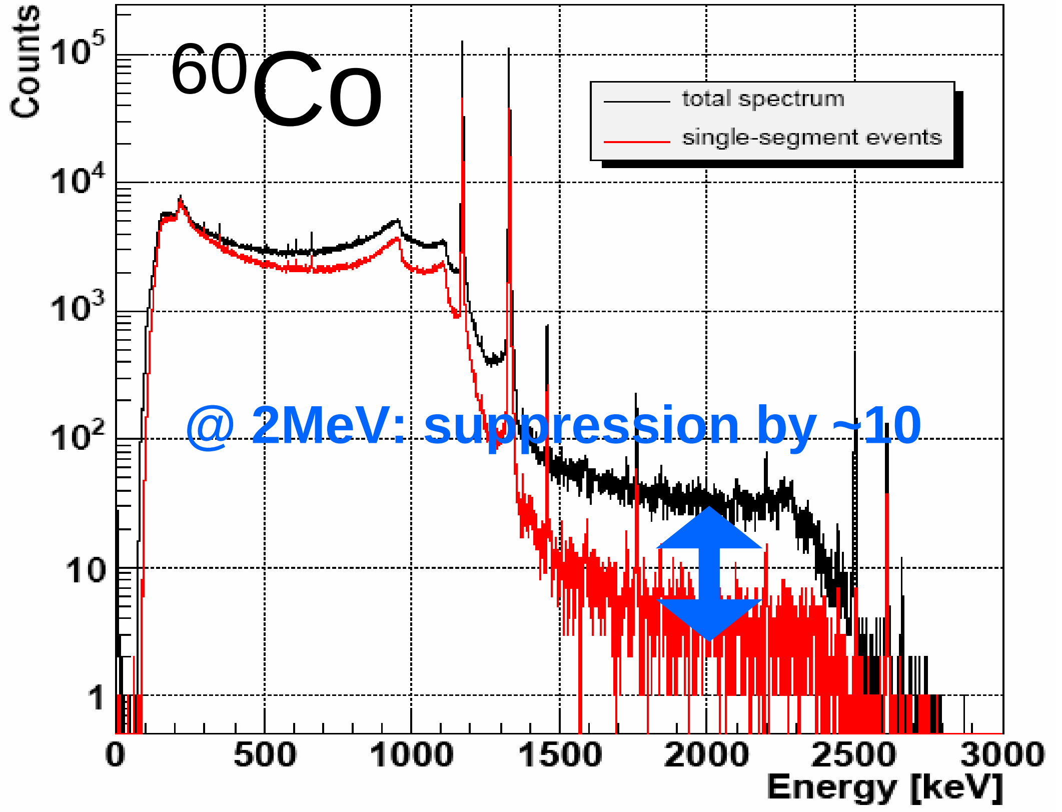
PSA: Single Site ↔ Multi Site



SSE

smaller rise-time

Crystal Segmentation



@ 2MeV: suppression by ~10

Tests (MPI): 1.6kg n-type

HPGe 3x6-fold

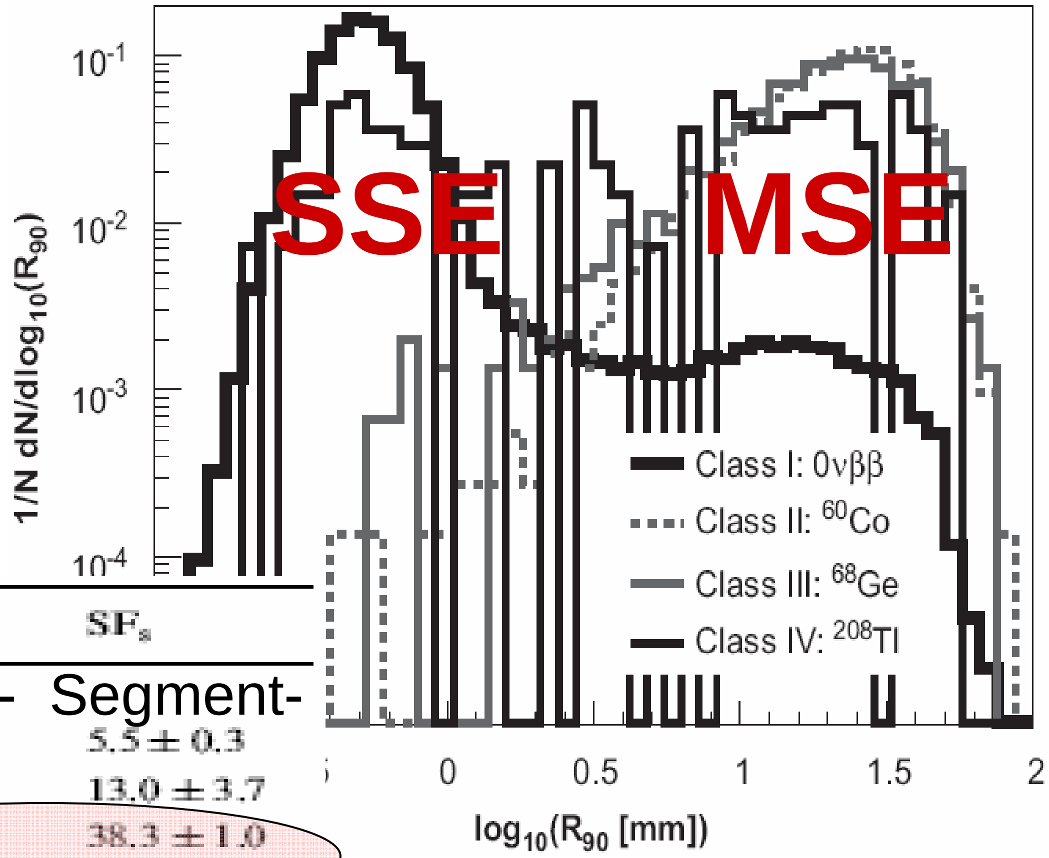
segments:

E resolution of

2.3–4.0 keV @

Crystal Segmentation

Suppression factors simulated [NIMA 570 (2007) 479]

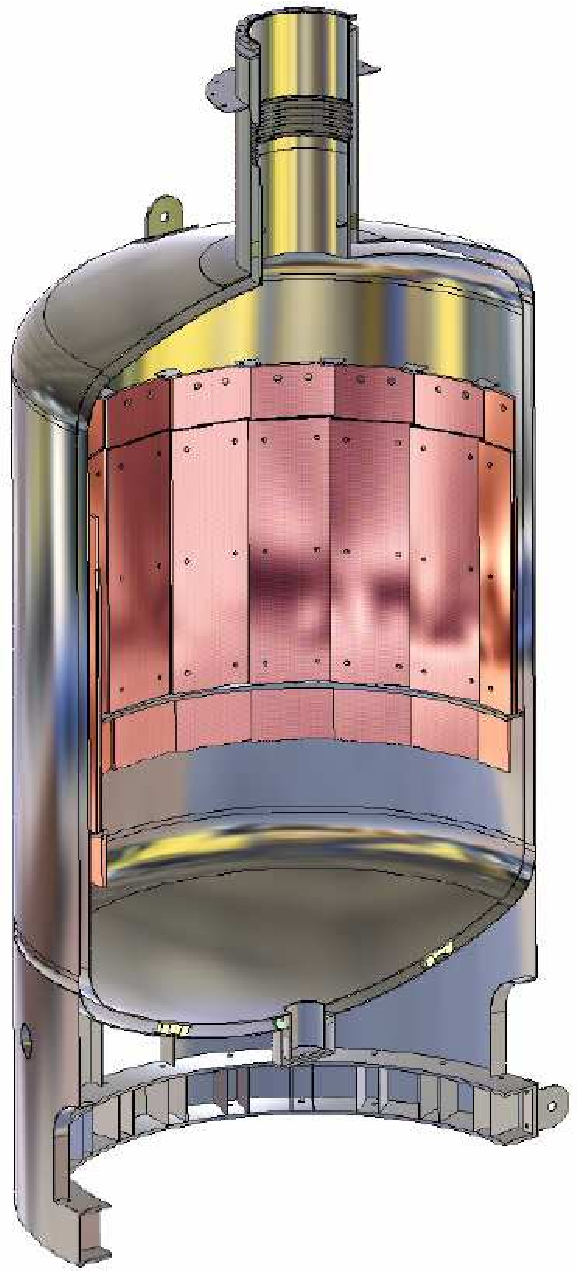


anticonicidence: Crystal- Segment-

Material	Source	Class	SF_c	SF_s
Crystal				
Germanium	^{214}Bi	II ($e^- + \gamma$)	1.8 ± 0.1	5.5 ± 0.3
	^{208}Tl	II ($e^- + \gamma$)	2.6 ± 0.4	13.0 ± 3.7
	^{60}Co	II ($e^- + \gamma$)	3.2 ± 0.1	38.3 ± 1.0
	^{68}Ge	III ($e^+ + \gamma$)	2.4 ± 0.1	18.0 ± 1.4
Surface	^{210}Pb	V (α)	$1.0^{+0.4}_{-0}$	$1.0^{+0.4}_{-0}$
Detector holder				
Copper	^{214}Bi	IV (γ)	2.8 ± 0.5	6.0 ± 1.4
	^{208}Tl	IV (γ)	2.2 ± 0.4	4.6 ± 0.9
	^{60}Co	IV (γ)	6.7 ± 0.2	157.2 ± 26.7
Teflon	^{214}Bi	IV (γ)	2.2 ± 0.3	12.8 ± 3.7
	^{208}Tl	IV (γ)	2.5 ± 0.3	10.0 ± 2.1
	^{60}Co	IV (γ)	3.8 ± 0.1	106.3 ± 7.6
Cables				
Kapton	^{214}Bi	(II) IV (γ)	3.3 ± 0.5	7.4 ± 1.3
	^{208}Tl	(II) IV (γ)	3.1 ± 0.7	4.7 ± 1.2
Electronics				
Miscellaneous	^{208}Tl	IV (γ)	1.5 ± 0.3	2.9 ± 0.6

→ talk of
Kevin Kröninger

GERDA – Cryostat



Stainless steel cryostat (3cm double wall)

^{228}Th <830 µBq/kg ^{226}Ra <810 µBq/kg
<1.7·10^{-5}/kg keV y <2.3·10^{-6}/kg keV y

Inner Cu shield 3 – 6cm

^{228}Th <39 µBq/kg ^{226}Ra <50 µBq/kg
(negligible compared to steel)

Superinsulation

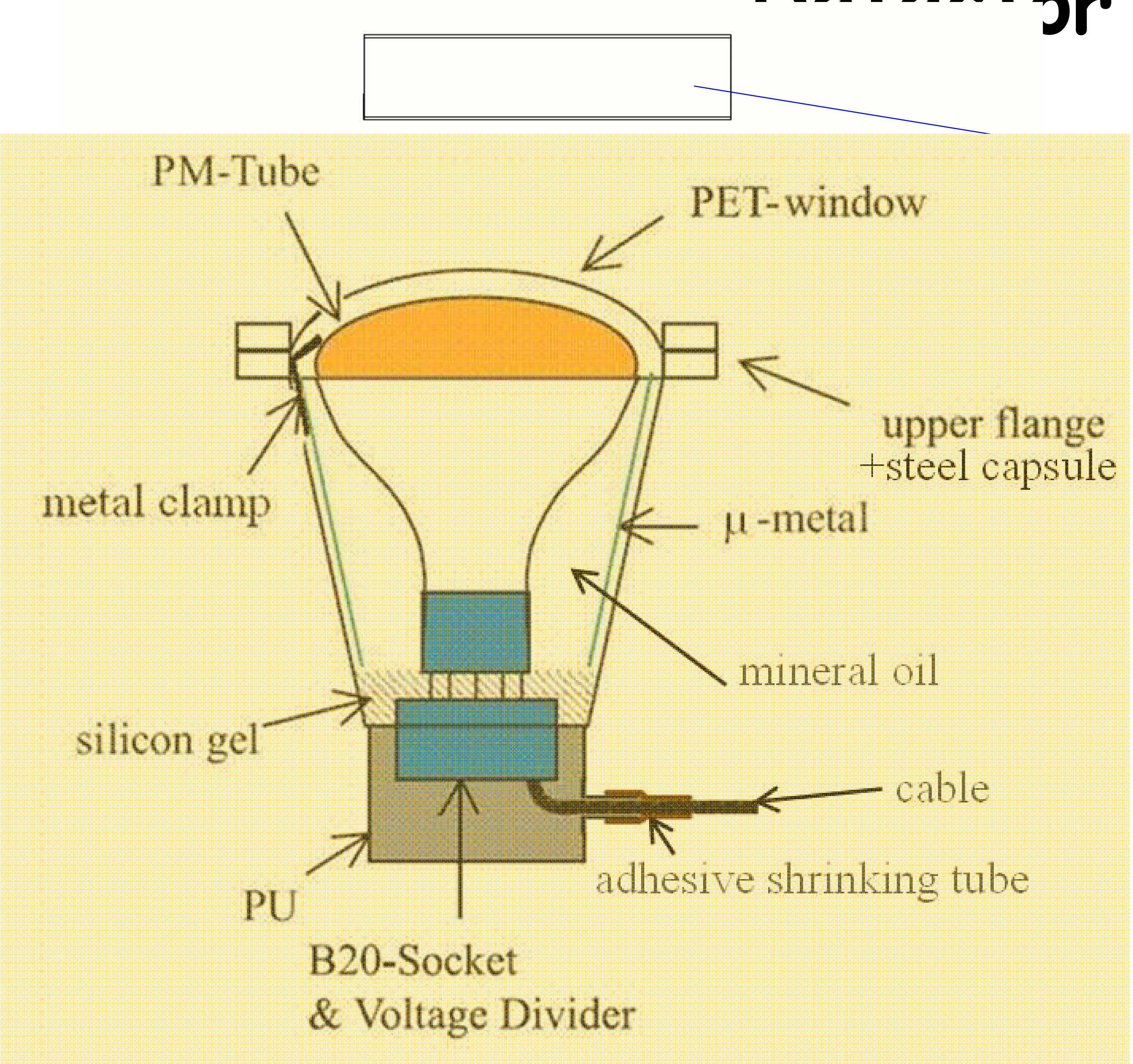
^{228}Th <2.2·10^{-6}/kg keV y ^{226}Ra <1.4·10^{-6}/kg keV y

Liquid Ar (~50m³)

Initial: ^{222}Rn ~ 0.4 – 4 mBq/m³ (STP)
Required: 0.5 µBq/m³ [→ <10^{-4} /(kg keV y)]

→ LAr Purification of f~1000 needed
Proven for gas phase
Achievable for liquid phase

Gerda Muon Veto – A Water Cherenkov Detector



plastic scintillator

66 PMTs

cryostat

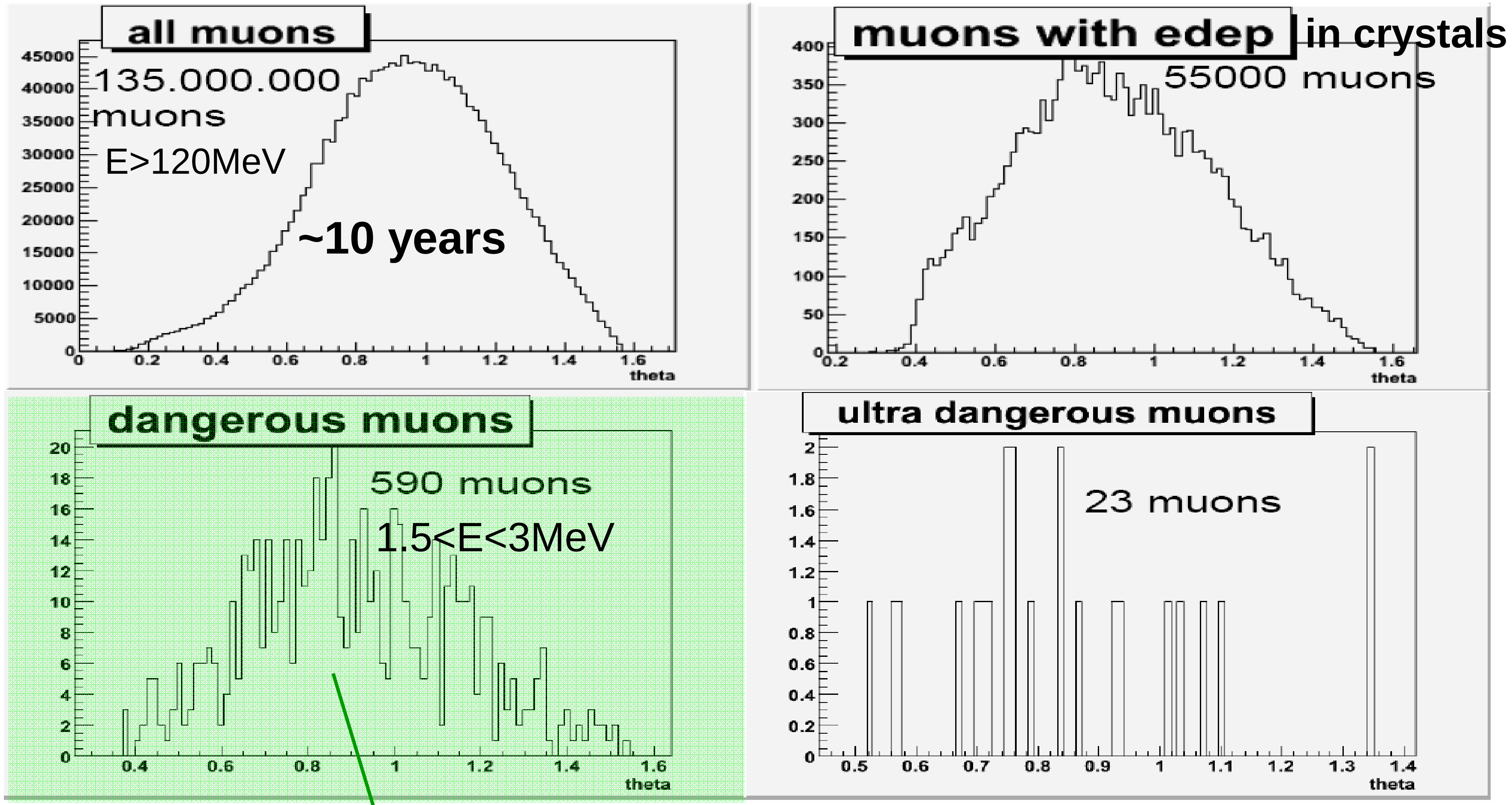
Ge detectors

water tank

reflector VM2000

‚lower pillbox‘

Simulations – Muon distribution



135.000.000 muons E>120MeV

~10 years

55000 muons

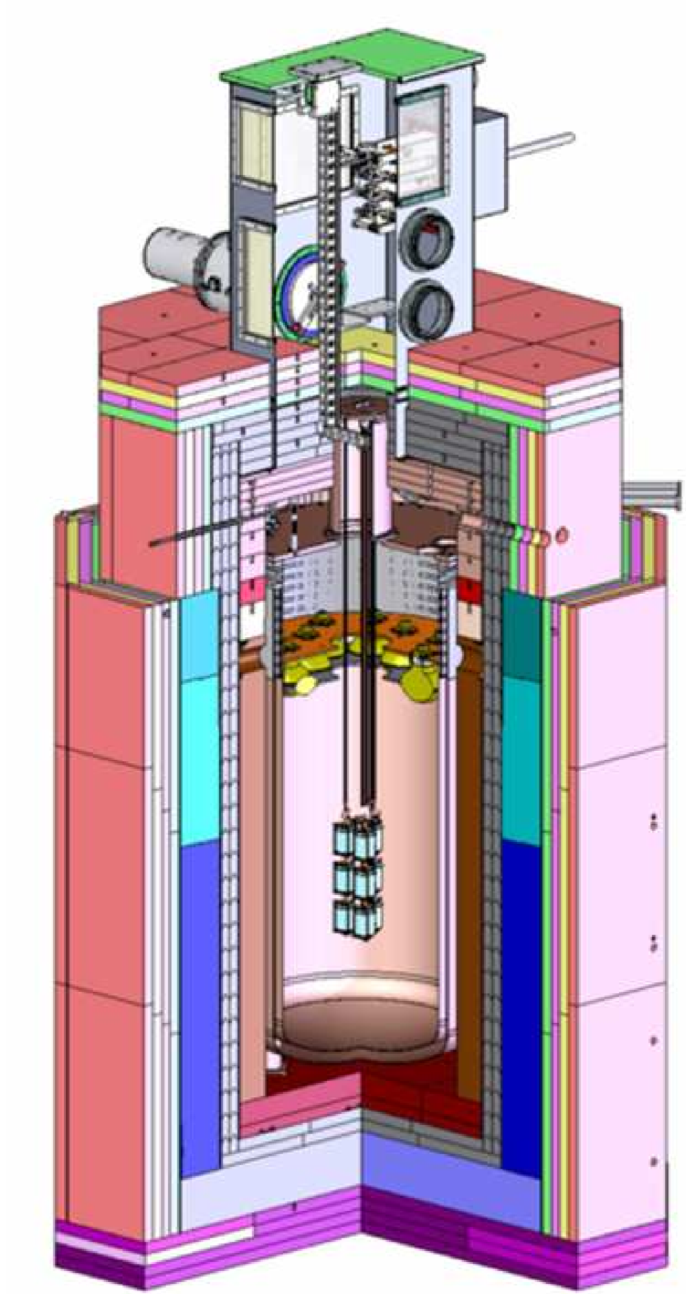
590 muons 1.5<E<3MeV

23 muons

[cts/(kg keV y)]		det. anticoinc Phase I	segm. antico Phase II	with 95% veto
direkt μ	$\sim 2 \cdot 10^{-3}$	$\sim 2 \cdot 10^{-4}$		$\sim 10^{-5}$
μ-induced [NIMA570(2007)149]	$(1.89 \pm 0.04) 10^{-2}$	$(1.6 \pm 0.1) 10^{-3}$	$(4.0 \pm 0.4) 10^{-4}$	$\sim 2 \cdot 10^{-5}$

→ talk about n-induced ^{77}Ge/^{77m}Ge (Georg Meierhofer)

GDL (Gerda Detector Laboratory) LArGe
h Dewar



Cryostat (1.3m³)

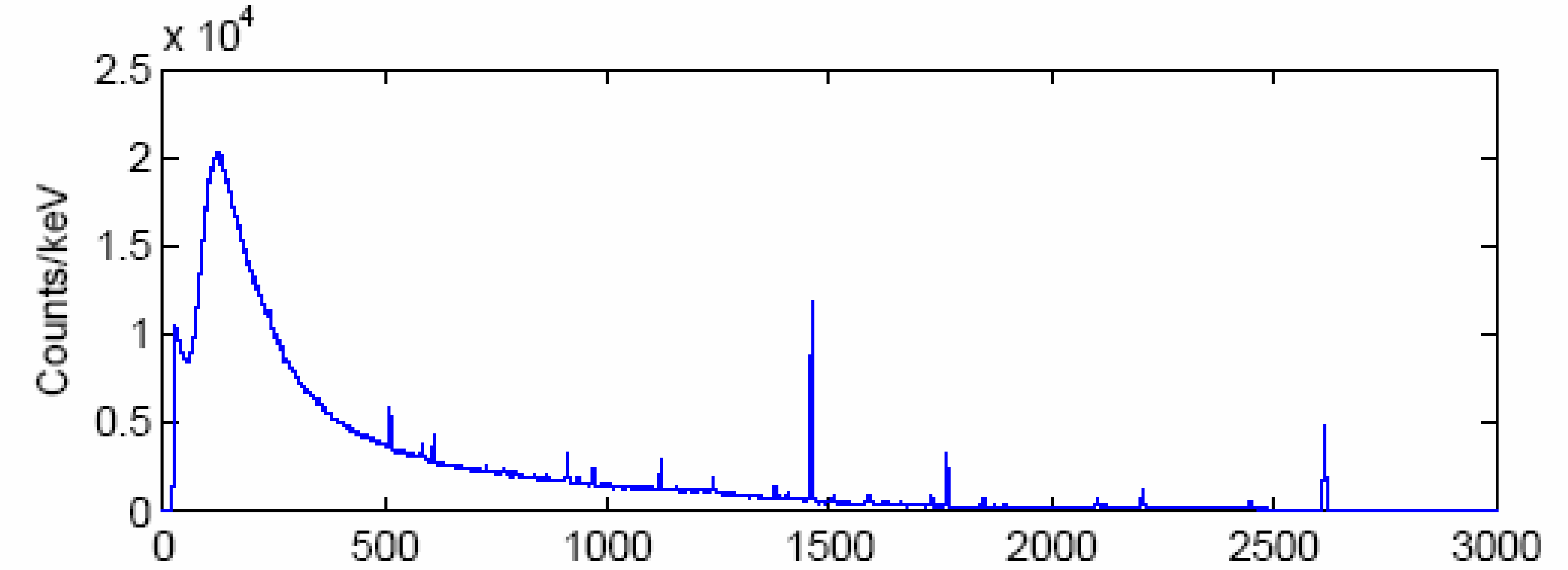
Pb, Cu -shielded

In construction until end of 2007

Volume 70 l
Cu infrared shield
Now: Liquid Ar 5.0
1.6kg, p-type

Tests of prototype Ge detectors in LAr

With Phase I prototype: ^{36}Ar 0νECEC



Examination of **0νECEC** : **$^{36}Ar + 2e^- \rightarrow {}^{36}S + \gamma(431keV)$**

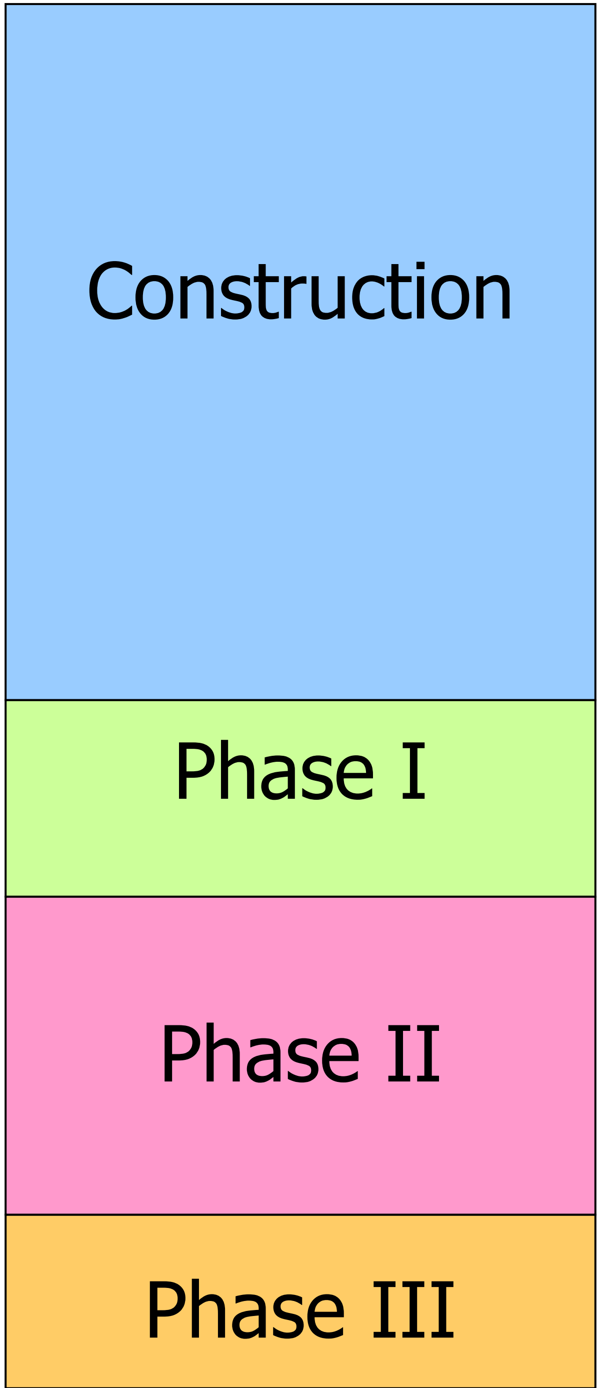
- 1.6kg HPGe in 70l dewar with natural liquid Ar (0.336% ^{36}Ar)
- 2.5cm passive lead shield

$T_{1/2}^{0\nu ECEC} > 1.9 \cdot 10^{18}$ y (68% C.L.)

LArGe (~15kg y) → $10^{22} - 10^{23}$ y

Gerda – Schedule

- Safety concept approved by LNGS
- HPGe prototype testing in GDL ongoing
- Water tank bottom plate in construction
- Cryo tank: installed by end of 2007
- Water tank completion: first half of 2008
- Muon veto & Infrastructure
  (building, clean room, lock): fall 2008
- Commissioning: beginning of 2009
- Insertion of Phase I detectors
  and data taking (1 year): 2009
- Insertion of Phase II detectors
- Data taking Phase II (~3 years)
- 1 ton ^{76}Ge exp. GERDA+Majorana
  depending on Phase I+II outcome



Construction

Phase I

Phase II

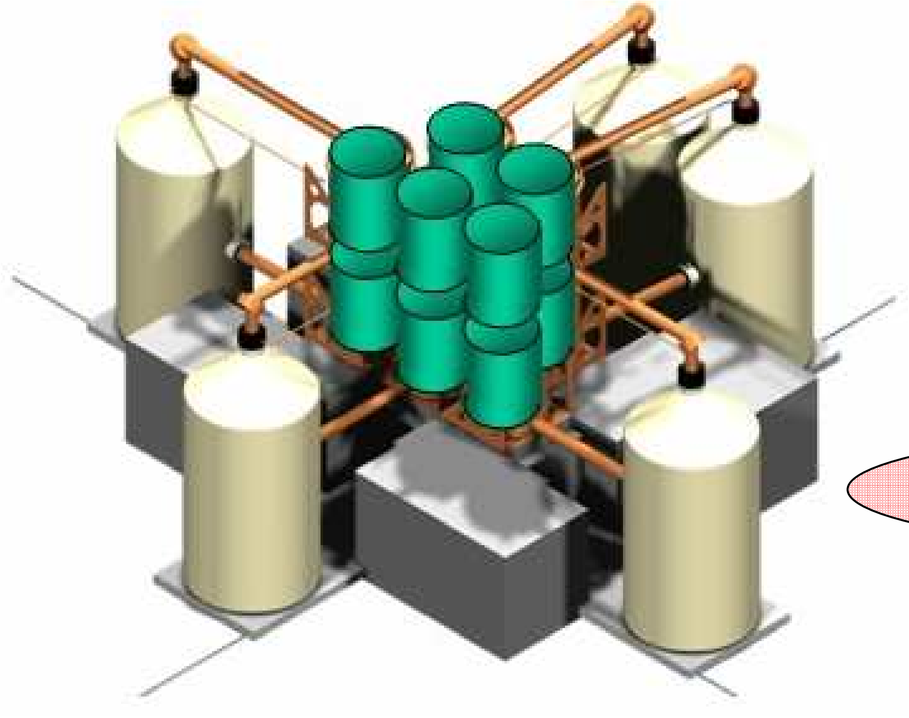
Phase III

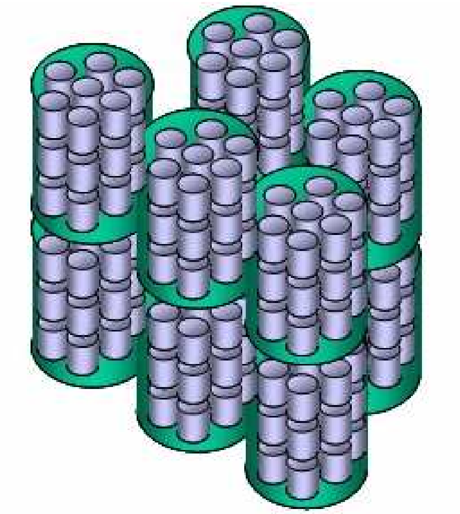
Gerda Collaboration

- INFN Laboratori Nazionali del Gran Sasso, Assergi, Italy
- Joint Institute for Nuclear Research, Dubna, Russia
- Max-Planck-Institut für Kernphysik, Heidelberg, Germany
- Jagellonian University, Krakow, Poland
- Università di Milano Bicocca e INFN Milano, Milano, Italy
- Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
- Institute for Theoretical and Experimental Physics, Moscow, Russia
- Russian Research Center Kurchatov Institute, Moscow, Russia
- Max-Planck-Institut für Physik, München, Germany
- Dipartimento di Fisica dell'Università di Padova e INFN Padova, Padova, Italy
- Physikalisches Institut, Universität Tübingen, Germany
- EC-JRC-IRMM, Geel, Belgium

Outlook: Majorana

Ultra-large Ge detector array, m(^{76}Ge) ~ 1 ton





Proposed (2003)

500 kg · 5 y
a = 86% →
$T_{1/2}^{0\nu} = 10^{27}$ y
b = 10^{-3}/(kg·ROI·y) m_{ee} ~ 0.04 eV

Passive shielding: 10cm of old Pb
(High Z !!) 40cm of common Pb
Active shielding: μ veto (10cm plastic sc.)

investigate secondary n
Depth required: 4500 mwe

Internal bgr estimated to
1–10 ·10^{-3}/(kg keV a) from ^{68}Ge, ^{60}Co

Outlook: Majorana

2007 Submission of R&D for **1 ton detector** and for **prototype**

2007-2011 60 kg Ge prototype det. (‚Majorana Demonstrator‘)
= 30 kg of ^{76}Ge (86%), 30 kg of natural Ge
(40 kg p-type, 20 kg n-type)

n-type, 6x6 segm.
pos. reconstr. 1-2mm
PSA f=3 for ^{60}Co

↔

p-type, point contact det.
low threshold 0.3 keV
highly sensitive PSA

→ 120 kg y at 10^{-3} /(kg·ROI·y)

$T_{1/2}^{0\nu} > 1.6 \cdot 10^{26}$ y $m_{ee} < 0.19$ eV (90% C.L.)

2009-2011 Majorana Demonstrator construction

2011-2013 Operation, analysis

Outlook:

Gerda and Majorana

Low Z inner shielding (ultra-pure LAr)	High Z inner shielding (ultra-pure Pb)
LNGS 3600 mwe	Deep underground >4500 mwe
Water Cherenkov muon veto	Plastic scintillator muon veto

Valuable Exchange between GERDA and Majorana