GERDA: GERmanium Detector Array searching for $0\nu\beta\beta$ decay

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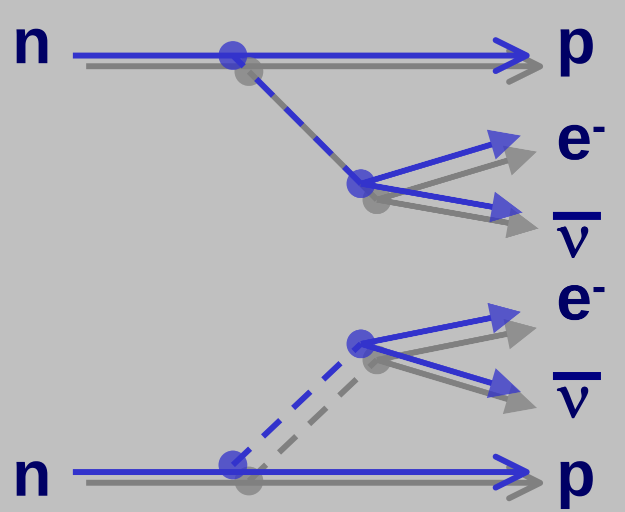
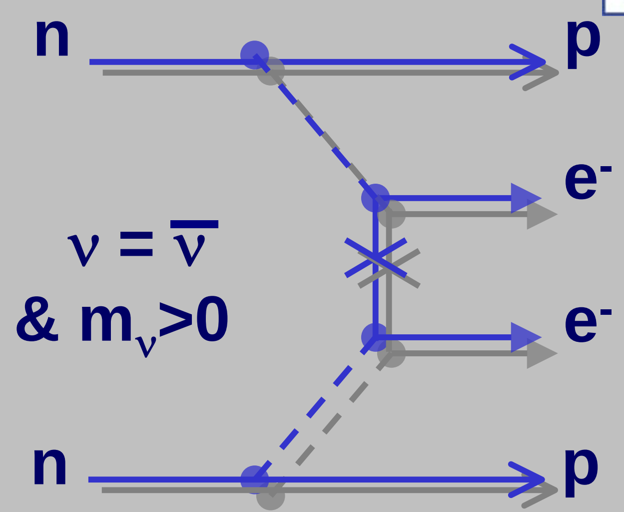




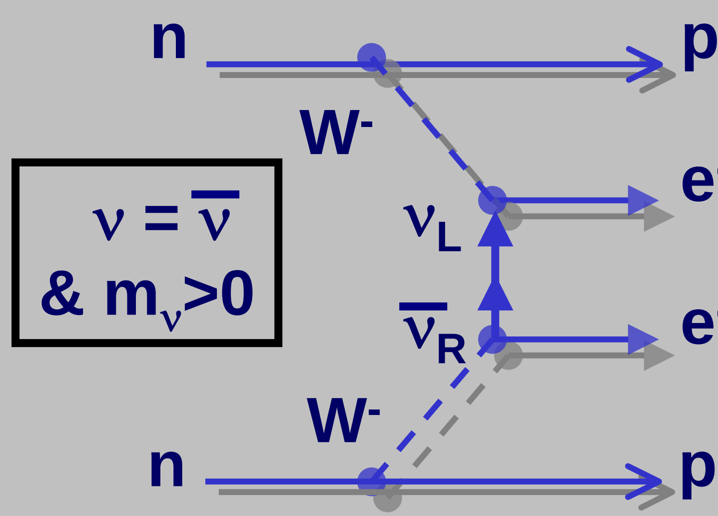
$2\nu\beta\beta$
$\Delta L = 0$

$0\nu\beta\beta$
$\Delta L \neq 0$

Baryon & Lepton Number Violation workshop
LBNL,Berkeley, 20-22/09/2007

$0\nu\beta\beta$ decay → effective Majorana neutrino mass $m_{\beta\beta}$

- $2\nu\beta\beta$ decay:
  (A,Z) → (A,Z+2) $+2e^{-}+2\bar{\nu}$
  SM allowed & observed.
- $0\nu\beta\beta$ decay: $\Delta L=2$
  (A,Z) → (A,Z+2) $+2e^{-}$
  if νs Majorana & have mass.

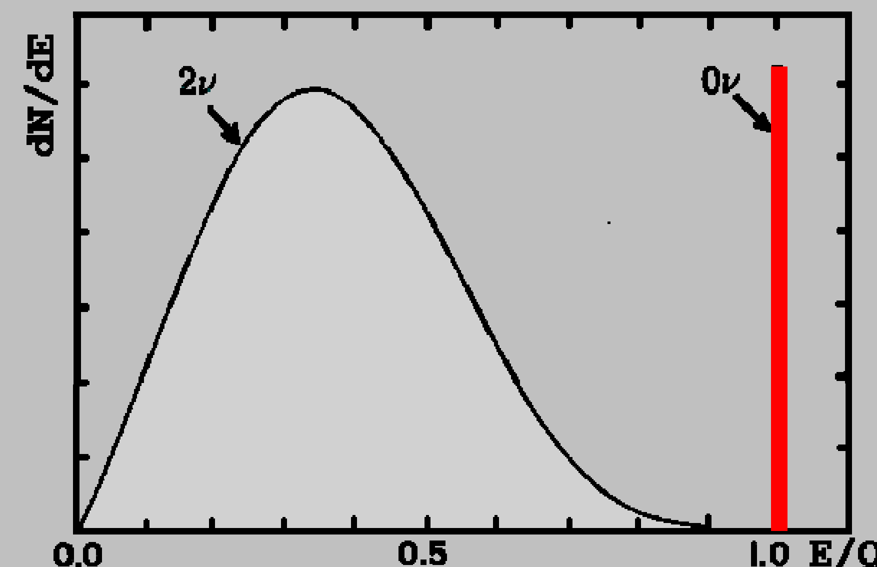


- many isotopes can be used
  to search for $0\nu\beta\beta$.

- measure half-life $T_{1/2}$:

$$T_{1/2}^{-1} = G^{0\nu}(E_0,Z)\left|M^{0\nu}\right|^2\left\langle m_{\beta\beta}\right\rangle^2$$

$G^{0\nu}$: phase space integral
$M^{0\nu}$: nuclear matrix element
$\langle m_{\beta\beta}\rangle = \left|\sum U_{ei}^2\, m_i\right|$
(U_{ei}: neutrino mixing matrix)



Search for 0νββ with Ge76

Rare process, focus of experiment design:
→ large target mass & long exposure **M·T**
→ high signal efficiency ε
→ extremely low level background

if $T_{1/2}=1.2\cdot10^{25}$ y,
expect 13 signal
in GERDA Phase-I
(~2 years running)

Why Ge76?

☺source=detector, 85~95% signal efficiency

☺ultrapure material (HPGe)

☺excellent energy resolution (FWHM ~3keV at 2MeV, small search window)
→reduce background, including 2νββ

☺existing detectors & experiences from IGEX & HdMo

☺new development: segmentation, new type of Ge detector etc…

☹need enrichment (7.6% natural abundance, most bg scale with target mass)

Previous Ge76 experiments

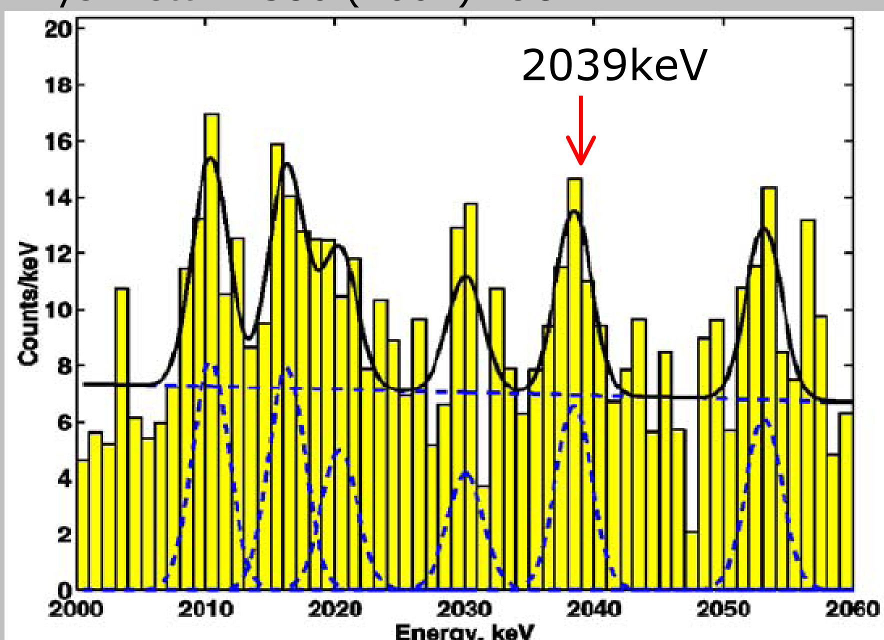
	HdMo	IGEX
location	LNGS	Canfranc
period	90-03	89-99
exposure[kg·y]	71.1	8.87
B [counts/kg·keV·y]	0.11	0.2
$T_{1/2}$ limit (90%CL)[y]	$1.9\cdot10^{25}$	$1.6\cdot10^{25}$

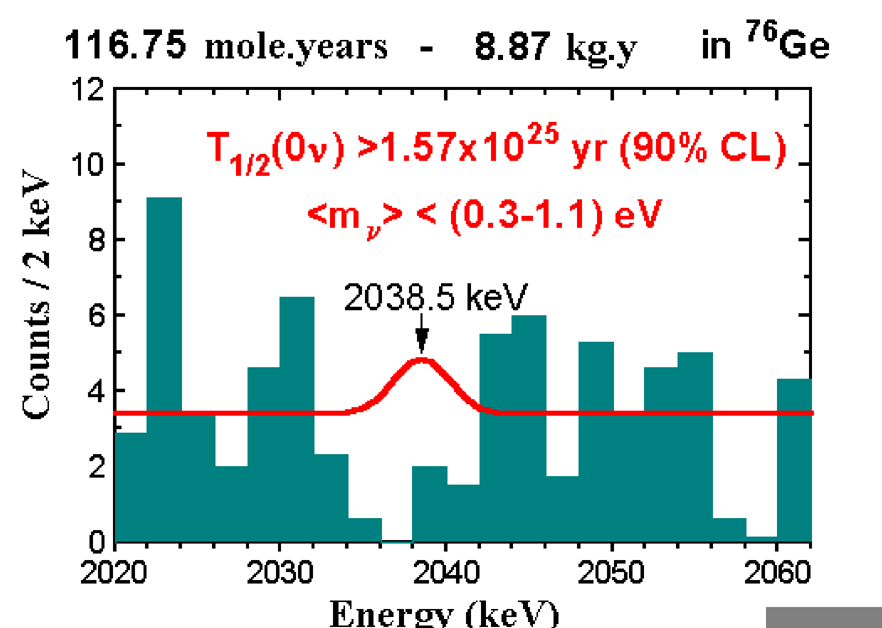
"Evidence for $0\nu\beta\beta$" $1.2\cdot10^{25}$ (0.69-4.18 3σ)

H.V.Klapdor-Kleingrothaus, etc., Phys. Lett. B 586 (2004) 198-212

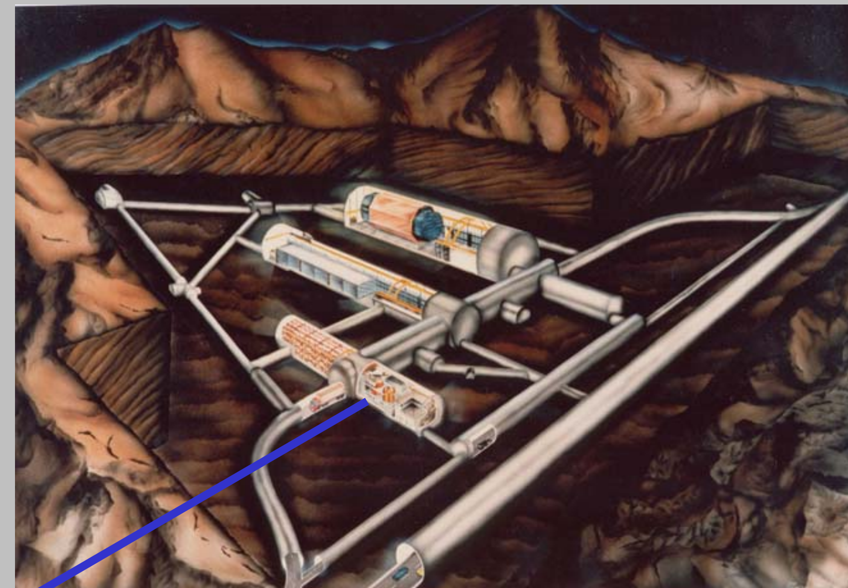
Background index B:
counts/kg·keV·y

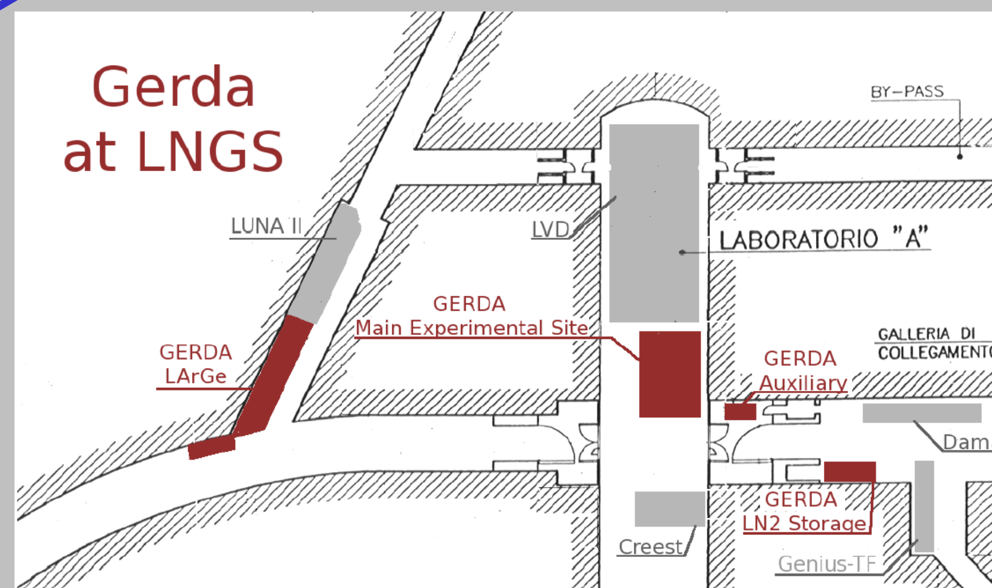
kg: Ge mass
keV: energy window
y: exposure time



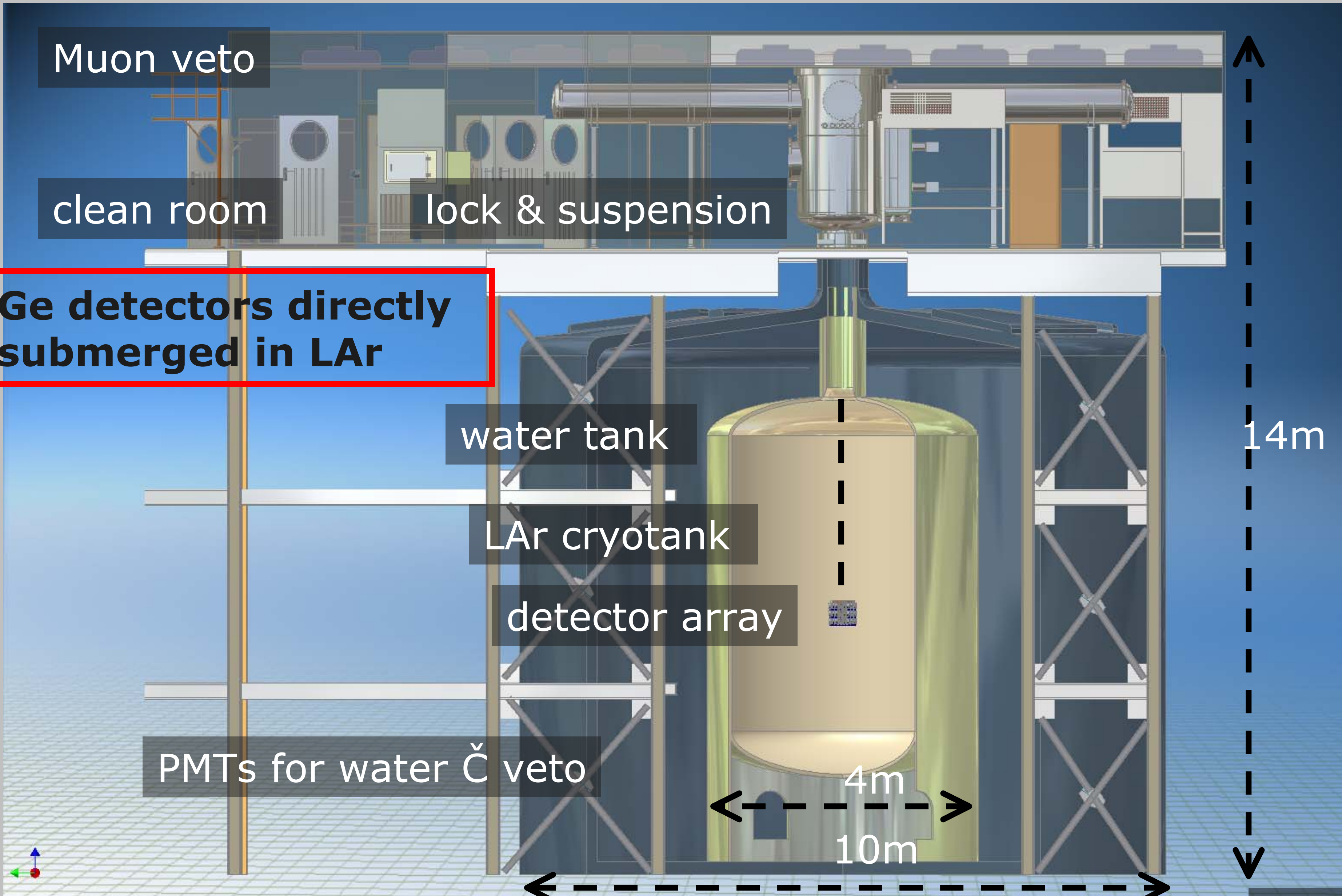


GERDA experiment at LNGS





GERDA design



Germanium detectors & holders

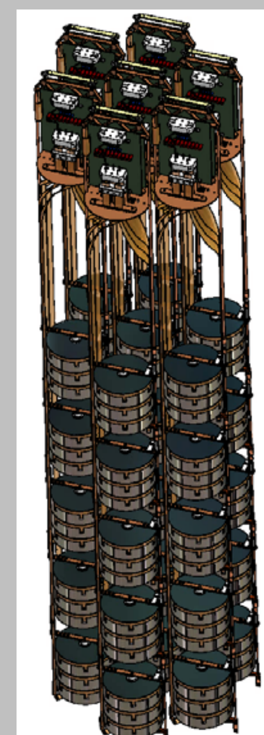
Phase I: 3 IGEX & 5 HdMo detectors, 17.9 kg, non-segmented

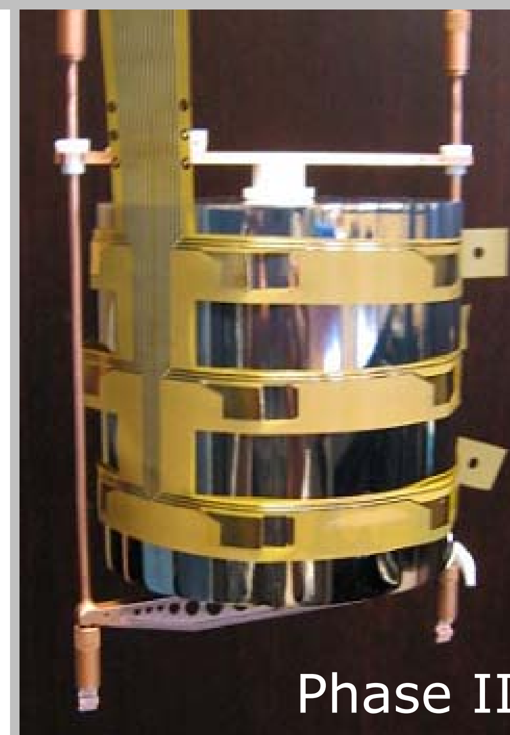
(6 non-enriched detectors from Genius-TF for reference)

Phase II: ~25kg, 18 segments ($3z \times 6\phi$)

Ultra-pure Cu & Teflon for holder
(19g Cu per Phase-II detector)

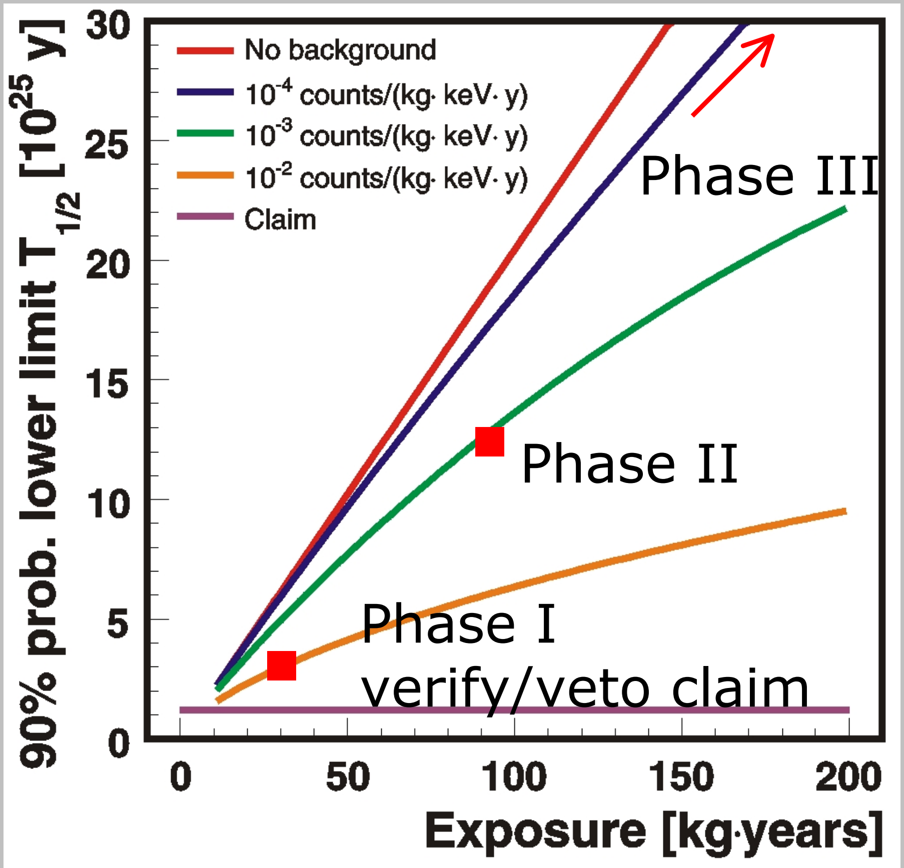
segmented detectors for Phase-II





GERDA physics goal

phase	I	II	III
exposure[kg·y]	30	100	>1000
bg [counts/kg·keV·y]	10^{-2}	10^{-3}	$<10^{-4}$
Limit on $m_{\beta\beta}$ [eV]	0.27	0.13	~0.05



(assume 4keV FWHM at 2MeV)

Claim of evidence
signal: 28.75±6.86 events
bg level: 0.11 cts/ kg·keV·y
H.V.Klapdor-Kleingrothaus, etc., Phys. Lett. B 586 (2004) 198-212

If claim true, phase-I will see:
signal: ~13 events
bg: 3 events in 10keV window at 2MeV

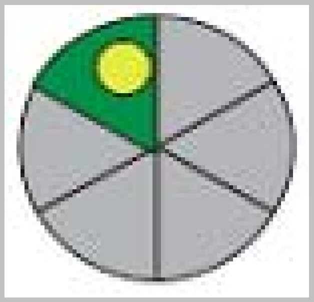
Background & its rejection

Cosmogenic production of radioactive isotopes (Co60 & Ge68)
→ minimize time above ground

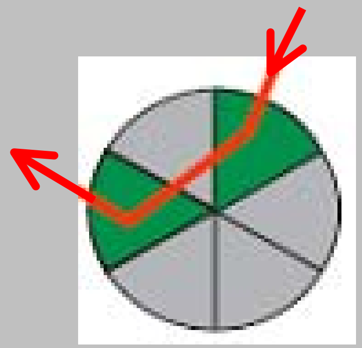
Cosmic muon & induced neutron
→ underground lab, muon veto and water C veto

Ambient neutron & photon → water & LAr shield

Radioactive contaminations of materials close to detectors, including detectors themselves (mostly photons)
→ rigorous material selection
→ use only screened materials
→ crystal anti-coincidence
→ segment anti-coincidence
(segmented detectors)
(signal: single-site, photon: multi-site)
→ pulse shape analysis



signal
2 electron



background
external photon

MC simulation of background (phase II)

Part		Background contribution [10^{-4} counts/(kg·keV·y)]
Detector	**^{68}Ge**	**10.8**
	^{60}Co	0.3
	Bulk	3.0
	Surf.	**3.5**
Holder	Cu	0.9
	Teflon	1.4
Cabling	**Kapton**	**7.5**
Electronics		**3.5**
Infrastructure		1.0
Muons and neutrons		2.0
Total		32

cosmogenic production (Ge68: $T_{1/2}$=271days)

further reduction expected from PSA

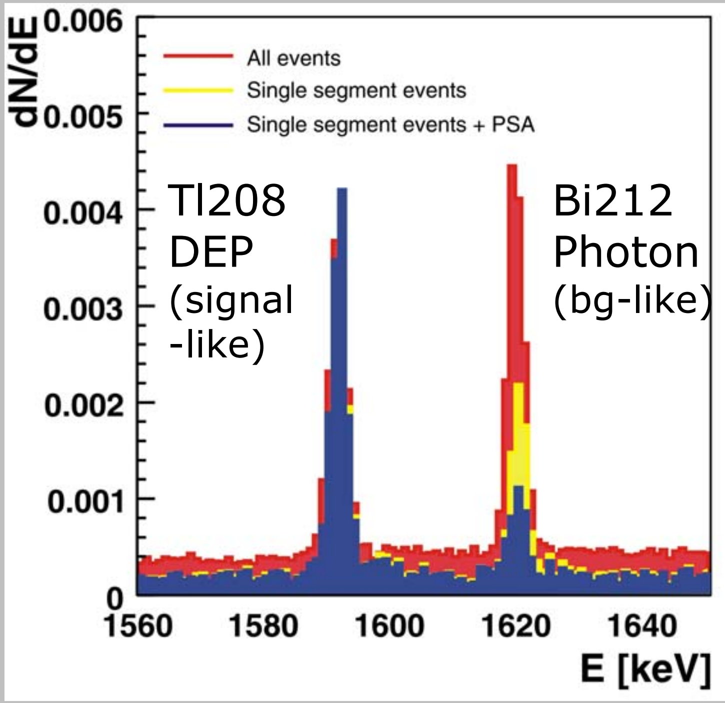
new design with reduced material

results with LN2, will reduce with LAr

(MaGe MC package developed together with Majorana)

R&D: Phase-II prototype detector for γ rejection

One 18-fold segmented n-type detector exposed to γ and n sources
→ Confirmed segmentation technique & MC simulation



„Characterization...“ I. Abt *et al.* NIM A **577** (2007) 574

„Identification of photon events...“Abt *et al.*
arxiv:nucl-ex/0701005 (sub. to NIM A)

„PSA...“ I. Abt *et al.* arXiv:0704.3016
(accepted by EPJC 53, 19-27(2007)

„Test of PSA...“ I. Abt *et al.* arXiv:0708.0917

„Neutron interaction...“ (coming soon)

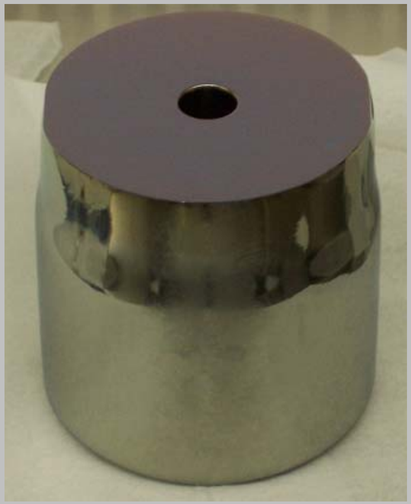
energy region	segment suppr.
1.3MeV [Co60]	2.6
2.6MeV [Tl208]	3.0
2.0MeV [Co60]	14.2
2.0MeV [Tl208]	1.7

Phase-I & II detector status

Phase-I:
- All detectors tested, FWHM 2-3keV at 1.3MeV
- Now taken out from cryostat & being refurbished.

Phase-II:
- 37.5kg Ge enriched in 76 (88%) delivered & stored underground
- Next step: purification, crystal pulling, detector fabrication.

IGEX



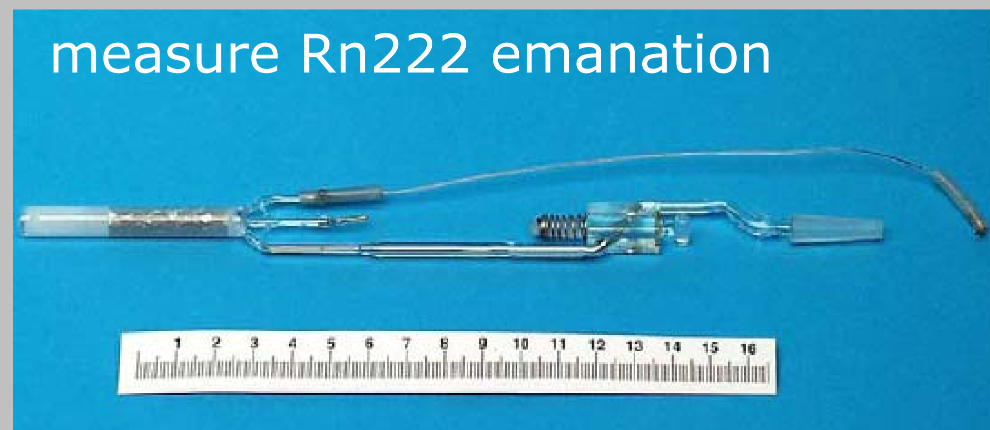
HdMo

enriched Ge transportation

Construction at LNGS started

Ground level for water tank & cryostat, August 2007

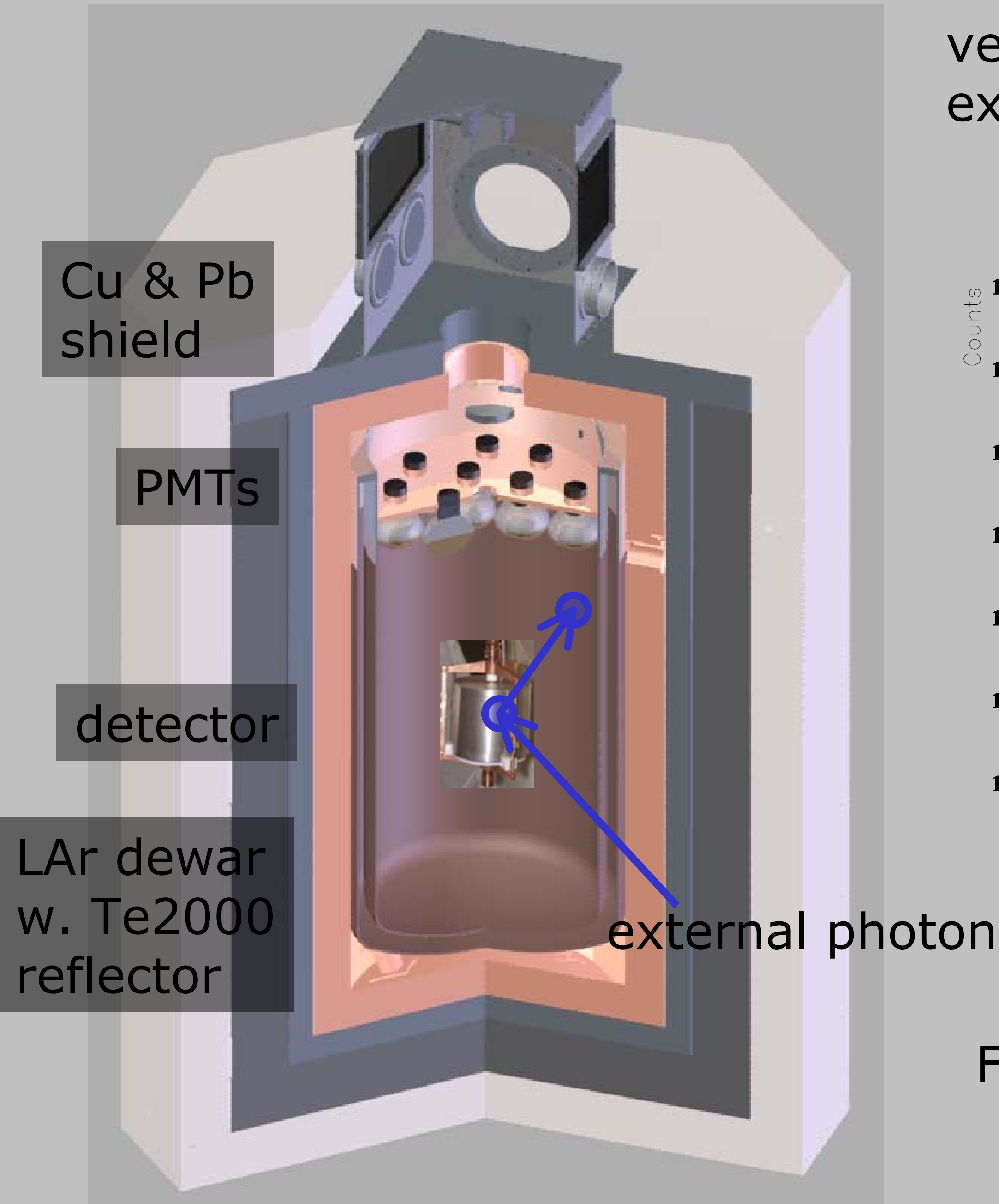
Status



Impurity measurement (phase-II)

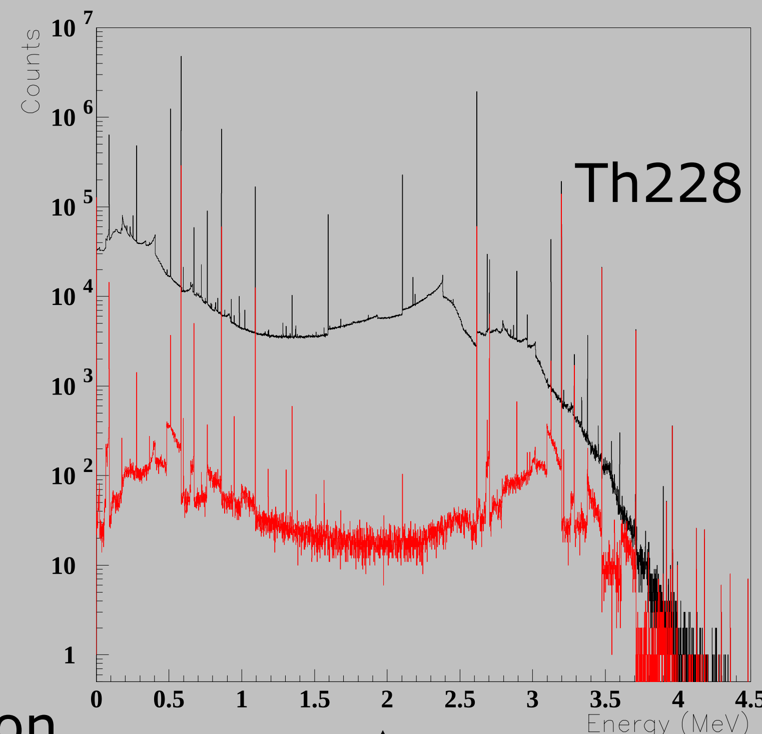
- End 2007, water tank & cryostat installing at LNGS.
- Summer 2008, cleanroom & suspension.
- Afterwards, detector commissioning.

R&D for future: LArGe at GDL (liquid Argon scintillation veto)



veto background by tagging extra energy in LAr

P. Peiffer *et al.*, Nucl. Phys. B. Proc. Supp. **143** (2005) 511



Factor 300 reduction in ROI

Summary

Open questions in ν : absolute mass? hierarchy? Majorana or Dirac?
$0\nu2\beta$ might answer all these questions.

- GERDA searches for $0\nu2\beta$ decay in ^{76}Ge.
- Experiment design driven by background reduction.
- Ge detectors submerged directly in LAr (cooling & shielding).
- Phase-I verify/veto the claim.
- Phase-II (segmented detectors) reaches sensitivity on $m_{\beta\beta}$ 120meV.

- Construction work at LNGS started.
- Cryostat & water tank, end 2007.
- Suspension & clean room, summer 2008.
- Detector commissioning.

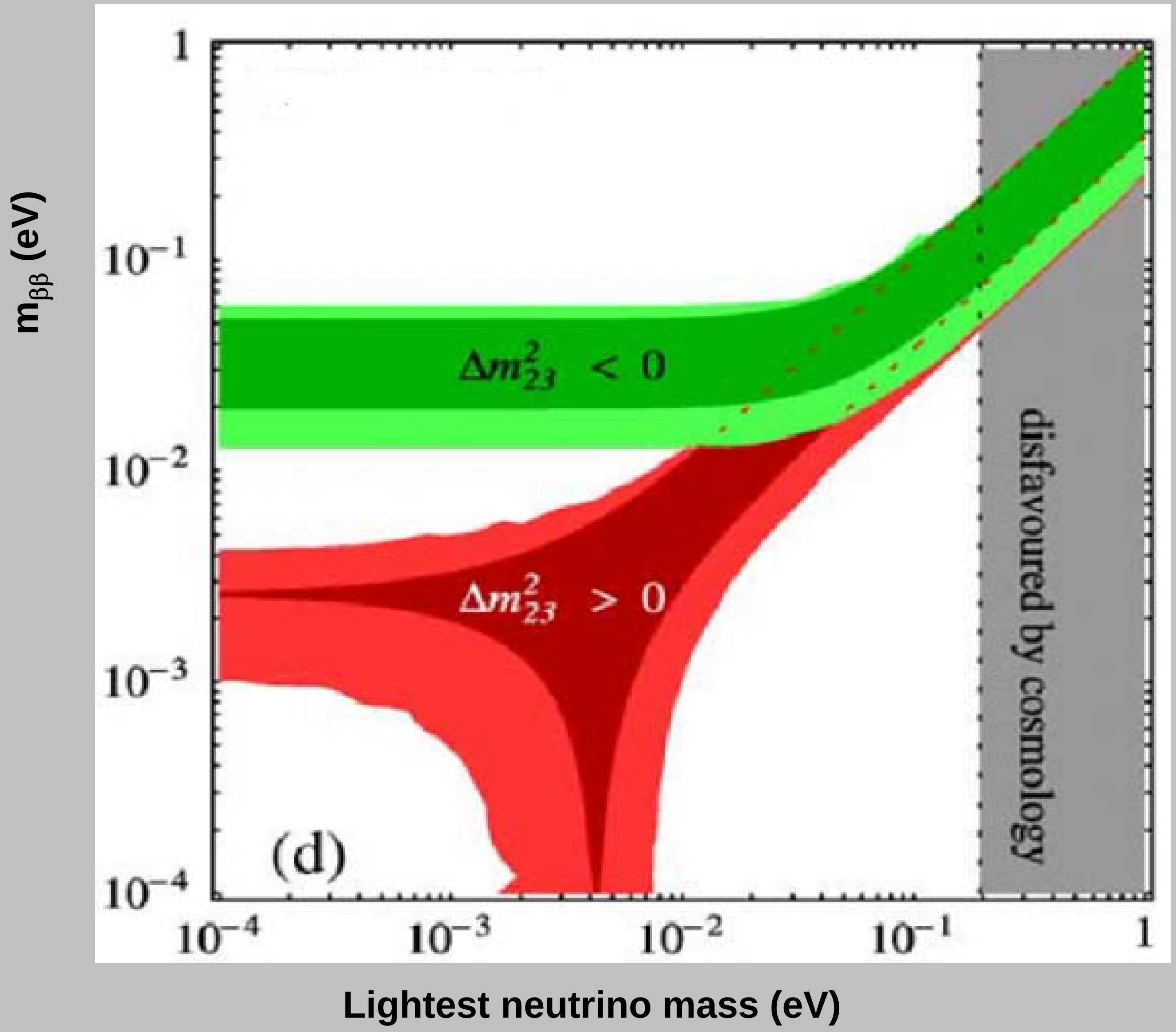
Once the GERDA concept is proven, global experiment with 1ton Ge might be pursued (MoU with Majorana exists).

GERDA collaboration

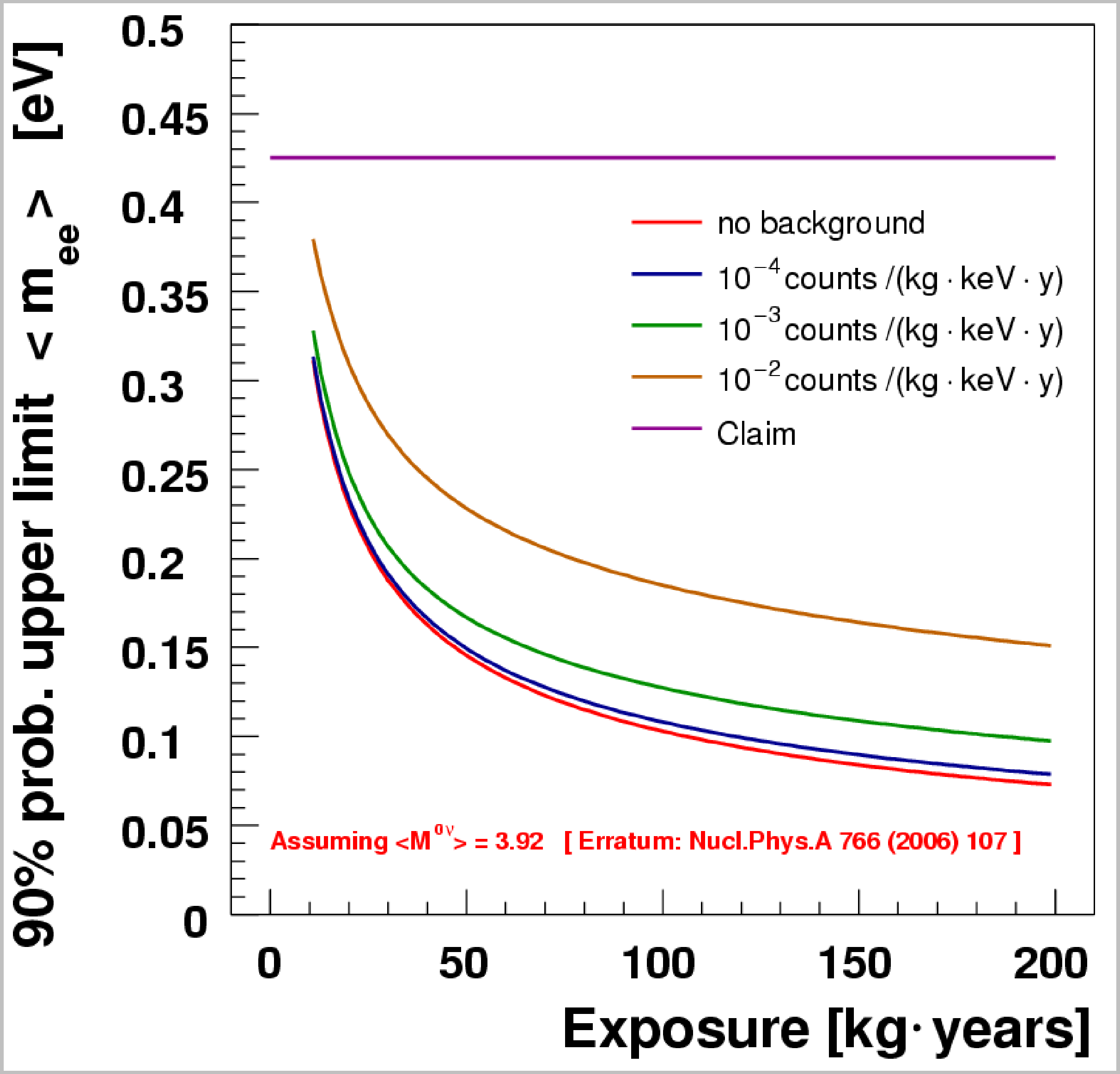
Institute for Reference Materials and Measurements, Geel, Belgium
Institut für Kernphysik, Universität Köln, Germany
Max-Planck-Institut für Kernphysik, Heidelberg, Germany
Max-Planck-Institut für Physik (Werner-Heisenberg-Insititut), München, Germany
Physikalisches Institut, Universität Tübingen, Germany
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

backup

effective Majorana neutrino mass vs neutrino mass



Sensitivity on effective Majorana neutrino mass



$$T_{1/2} \propto \varepsilon \cdot \sqrt{\frac{M \cdot T}{\Delta E \cdot B}}$$

B: background index
ΔE: energy resolution

Co60 & Ge68 background index for Phase-I detectors

Results of the calculations.

Table 4. Co60 data

Det. Type	Total Mass, kg	Average ncl/kg	Final Average Detector				
			Mass, kg	Pr. rate, ncl/d/kg	Average ncl/kg	Decays, 1 /y /kg	BI, 10^{-3} cpy/keV/kg
HD-M	11.5	205	18.1	6.6	**231**	**30**	**3.3**
IGEX	6.6	277					

For HD-M detectors Ge68 contribution is negligible

Table 5. Ge68 data

Det. Type	Total Mass, kg	Pr. rate, ncl/d/kg	Average Ncl/kg	Decays, 1 /y /kg	BI, 10^{-3} cpy/keV/kg
IGEX	6.6	5.6	**4.5**	**4.2**	**0.8**

HdMo: 0.11 cts/[keV kg year]

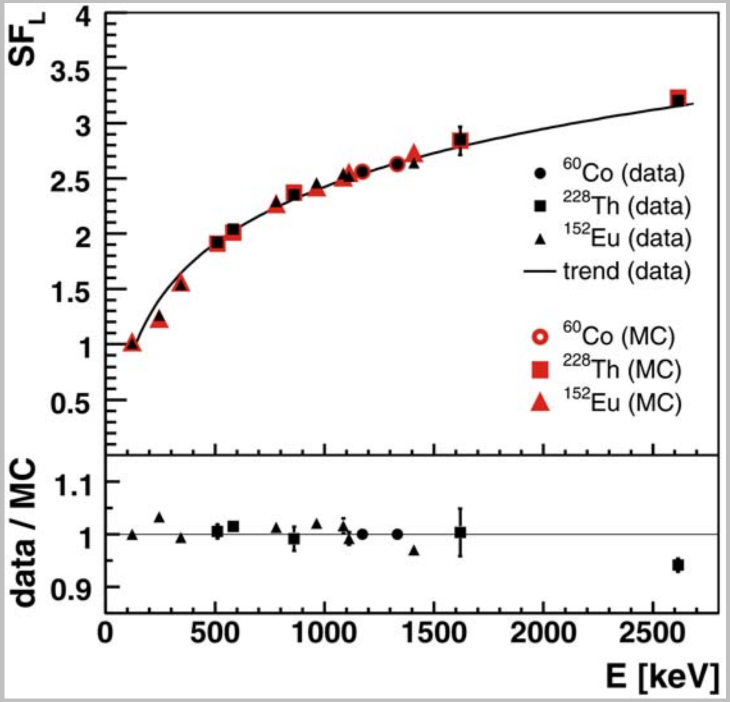
→ 60Co contribution 0.03 (during operation)

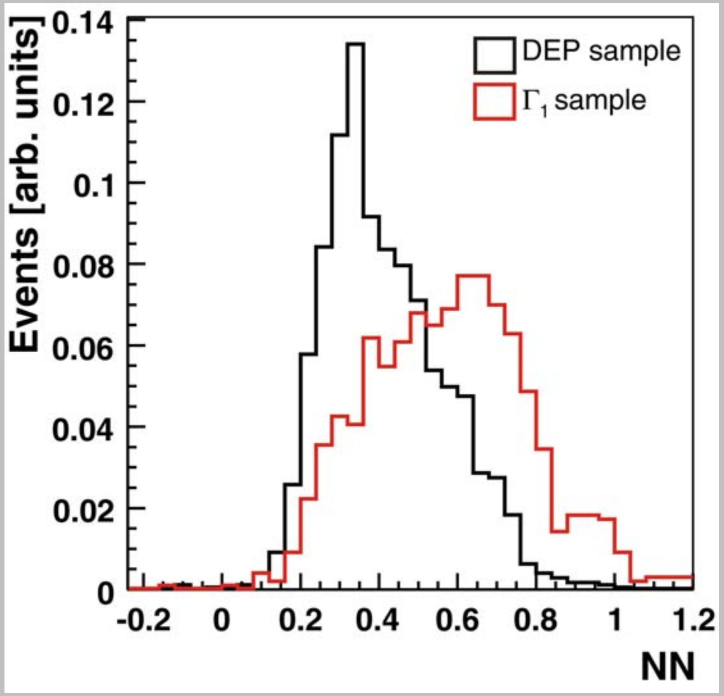
→ contribution now, ~0.01

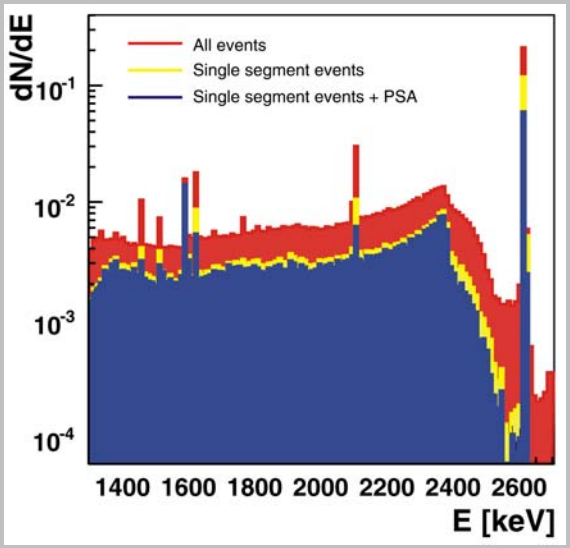
MC simulation of background (phase II)

Part	Material	Contamination level [μBq/kg]	Background contri. [10^{-4} cts/(kg·keV·y)]
Detector		Ge68	**10.8**
		Co60	0.3
	Bulk	0.1[^{238}U & ^{228}Th]	3.0
	Surf.	0.3[^{210}pb]	**3.5**
Holder	Cu	16[^{238}U] 19[^{228}Th]	0.9
	Teflon	160[^{238}U & ^{228}Th]	1.4
Cabling	Cu	16[^{238}U] 19[^{228}Th]	0.1
	Kapton	2000[^{238}U & ^{228}Th]	**7.5**
Electronics		10^5 [^{238}U & ^{228}Th]	**3.5**
Liquid nitrogen		0.5 μBq/m3	<0.1
Infrastructure			1.0
Muons and neutrons			2.0

R&D: 18-fold segmented Ge detector







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