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

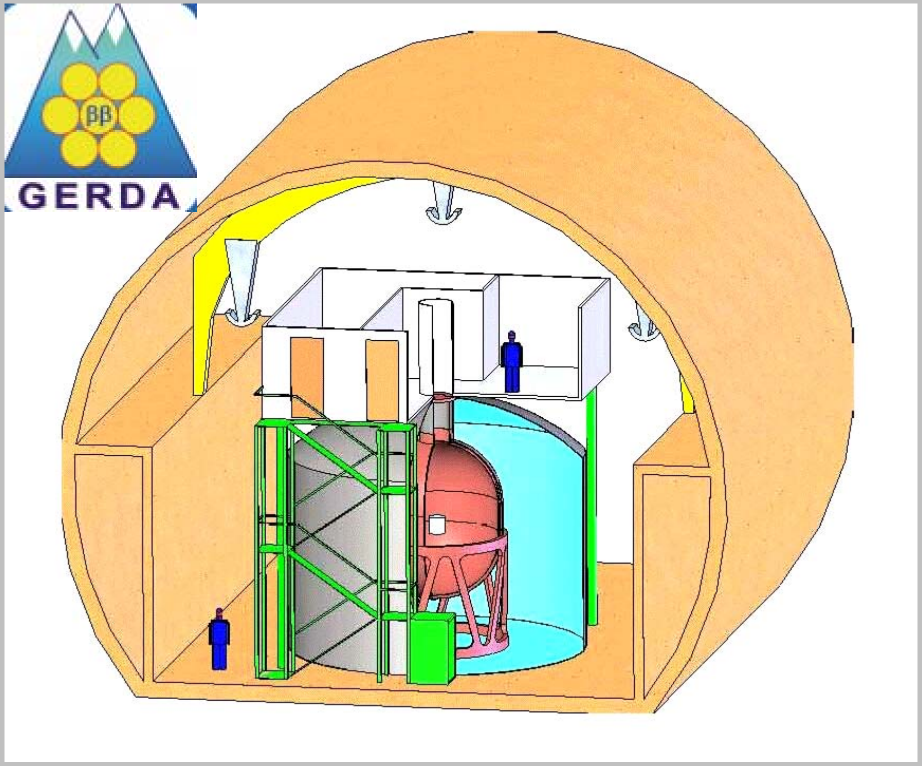
Experiment setup

Physics goal

Background reduction

Prototype detector R&D

Conclusion



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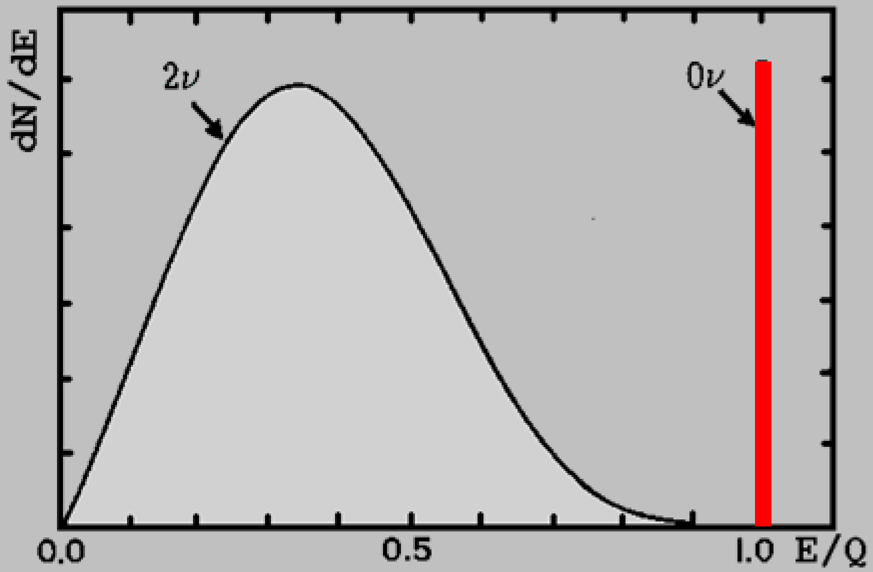
Fifth Annual Meeting of ENTApP N6/WP1
November 16-21,2008, Trento

Measure $T_{1/2}$ of $0\nu\beta\beta$ decay → effective Majorana neutrino mass $m_{\beta\beta}$



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

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

How to measure $T_{1/2}$
1st : count events in energy window $Q \pm 5\sigma$ (energy resolution).
2nd : remove background, count signal.

Why choose Ge76

$$\text{sensitivity on } T_{1/2} \propto \varepsilon \bullet A \bullet \sqrt{\frac{M \bullet T}{b \bullet \sigma}}$$

$$T_{1/2} \propto \varepsilon MTA \text{ if } b = 0$$

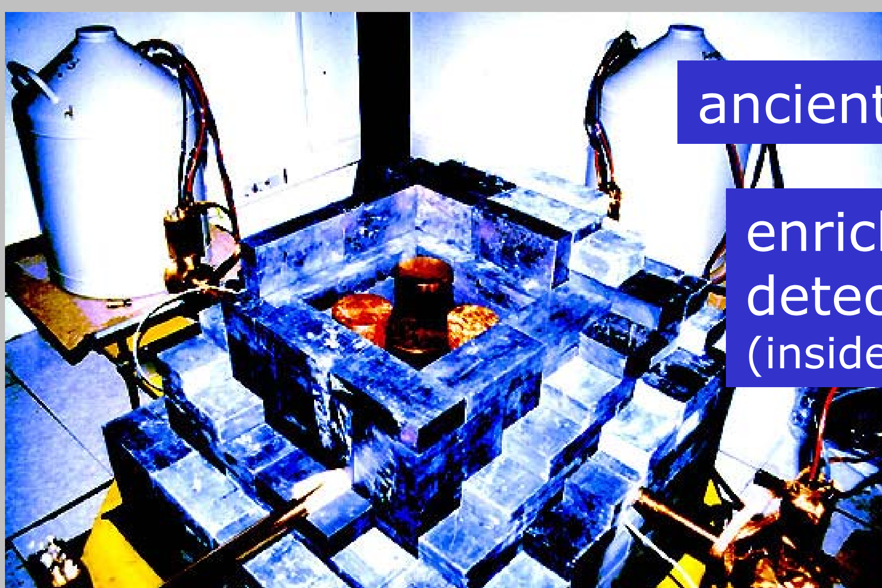
design focus	Ge76 advantage
large target mass **M** long exposure **T**	existing IGEX & HdMo detectors
high signal efficiency ε	source=detector, 85~95% ε
extremely low level background index b: background rate σ: energy resolution	ultrapure material (HPGe) excellent energy resolution → FWHM ~3keV at 2MeV, small search window → reduce background, including $2\nu\beta\beta$ new development → segmentation, new type of Ge detector etc…

☹need enrichment (A=7.6%, most bg scale with target mass)

☹$Q_{\beta\beta}$=2039keV (<2614keV)

Previous 0νββ Ge76 experiment: Heidelberg-Moscow

5 p-type Ge76-enriched detectors
- operated in Vacuum
- conventional shielding (Pb & Cu)
- underground (LNGS)



Previous Ge76 experiments

	HdMo	IGEX
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 0νββ" $1.2\cdot10^{25}$ (0.69-4.18 3σ)

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

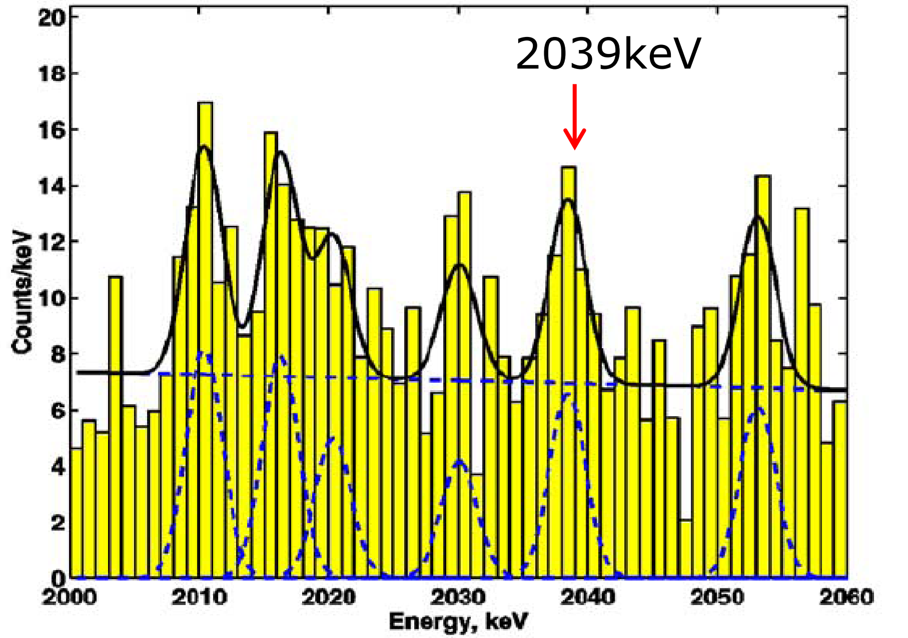
Background index B: counts/(kg·keV·y)

kg: Ge mass

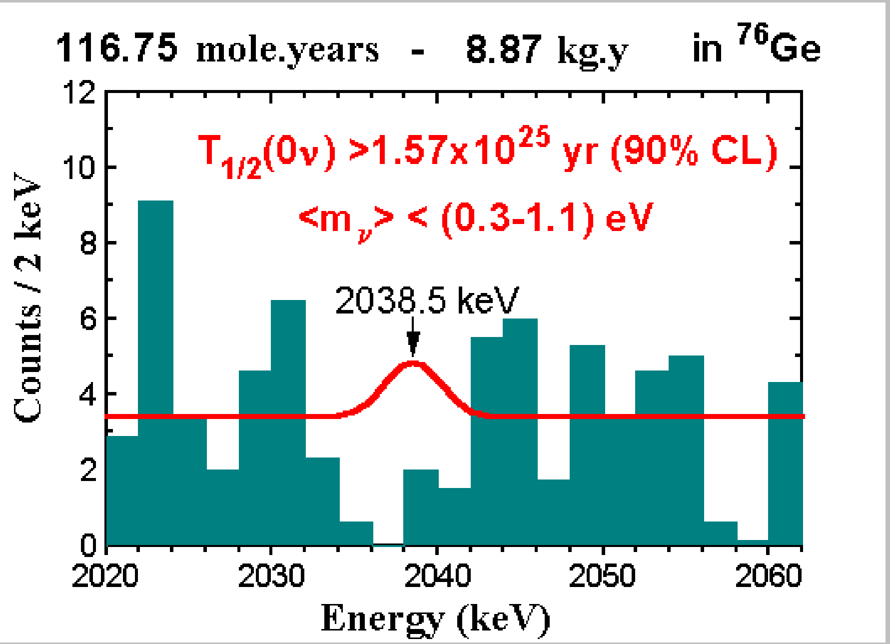
keV: energy window

year: exposure time

HdMo



IGEX



GERDA concept

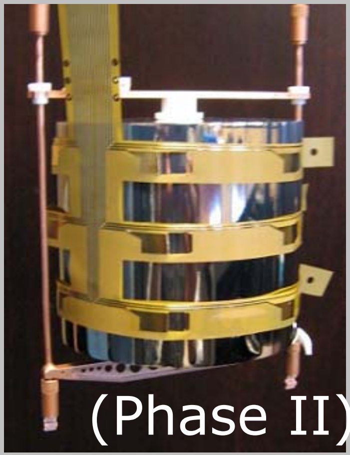
Ge detectors directly submerged in liquid Ar

- ✓LAr as cooling and shielding
- ✓LAr purer than conventional Pb & Cu
- ✓minimum surrounding materials

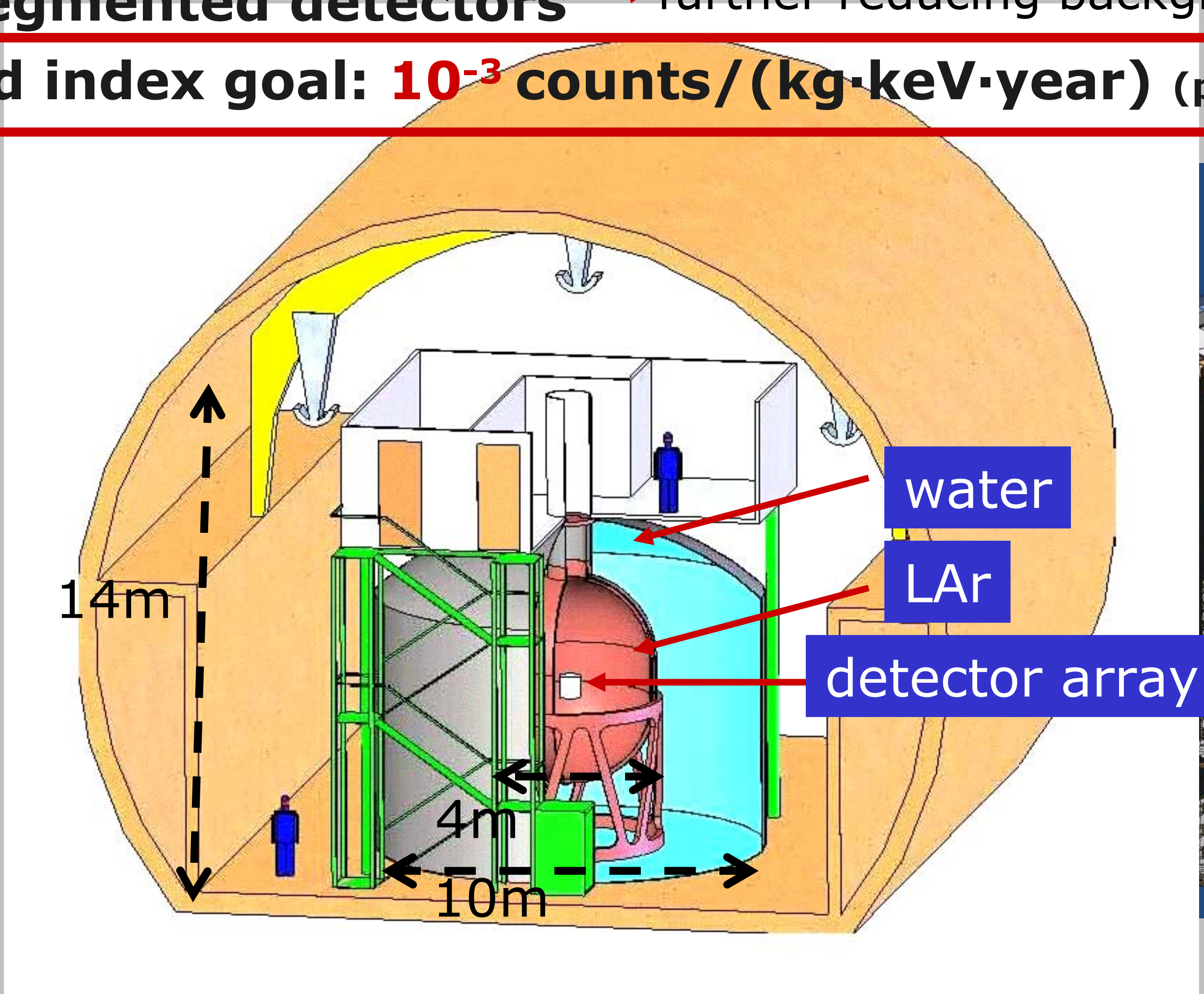
Phased approach with existing and new segmented detectors

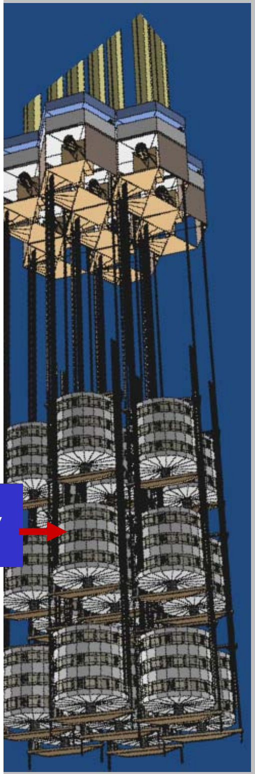
- ✓increase target mass
- ✓further reducing background

background index goal: 10^{-3} counts/(kg·keV·year) **(phase-II)**

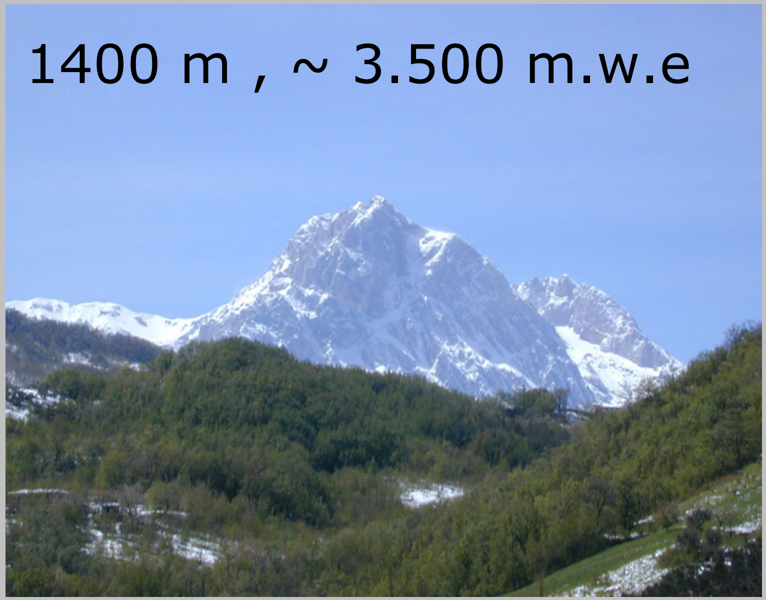


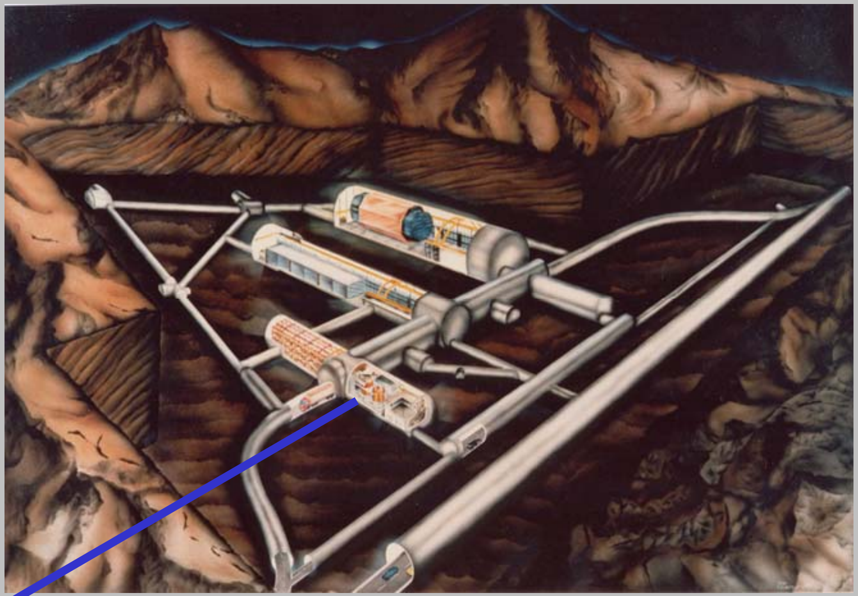
18 segments

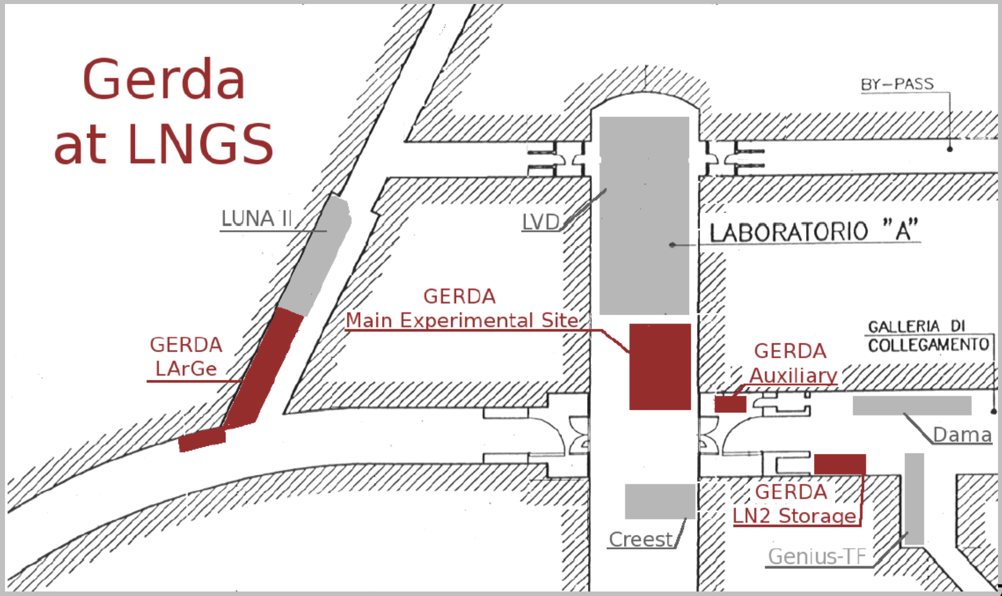




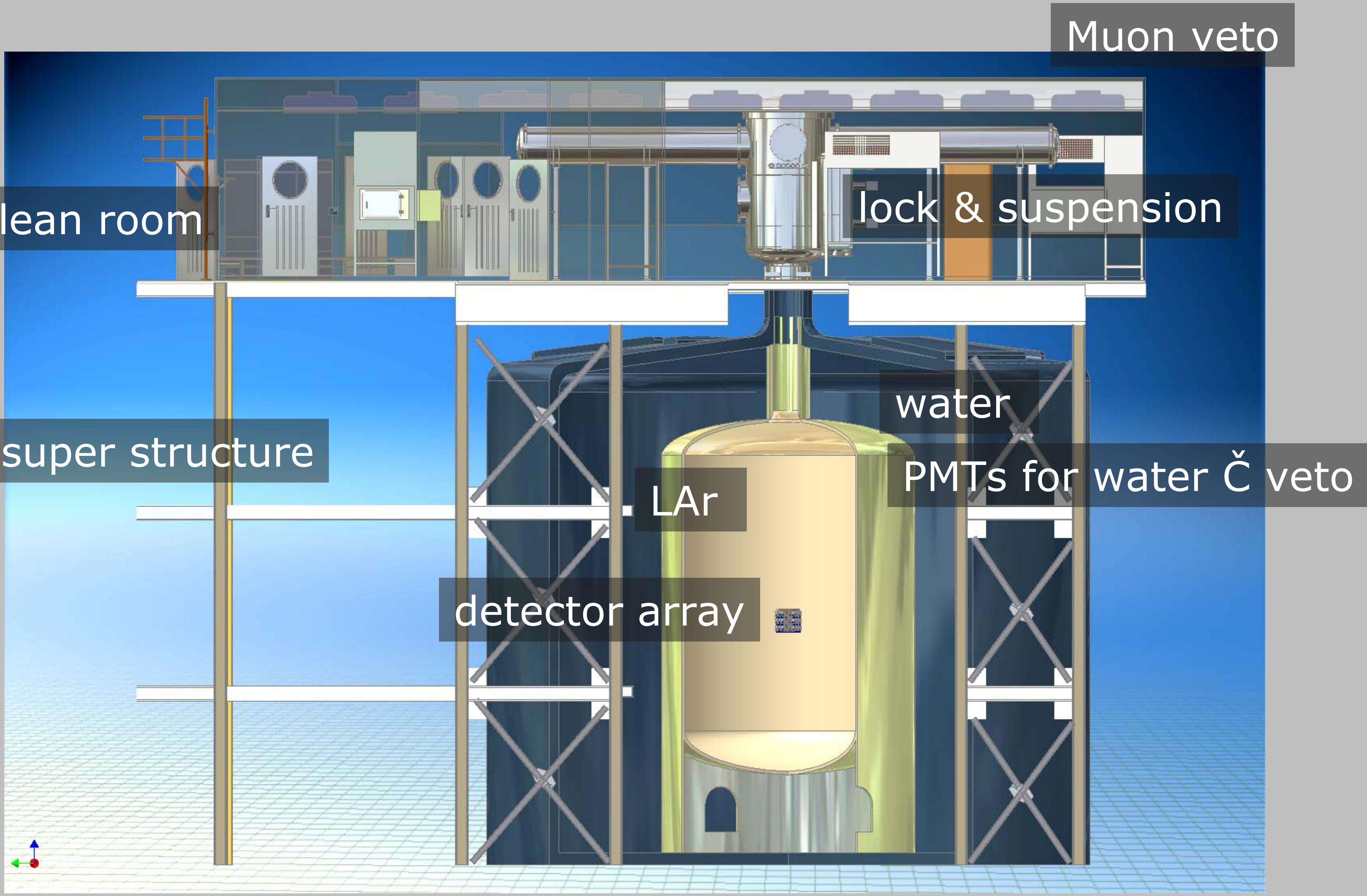
GERDA experiment at LNGS



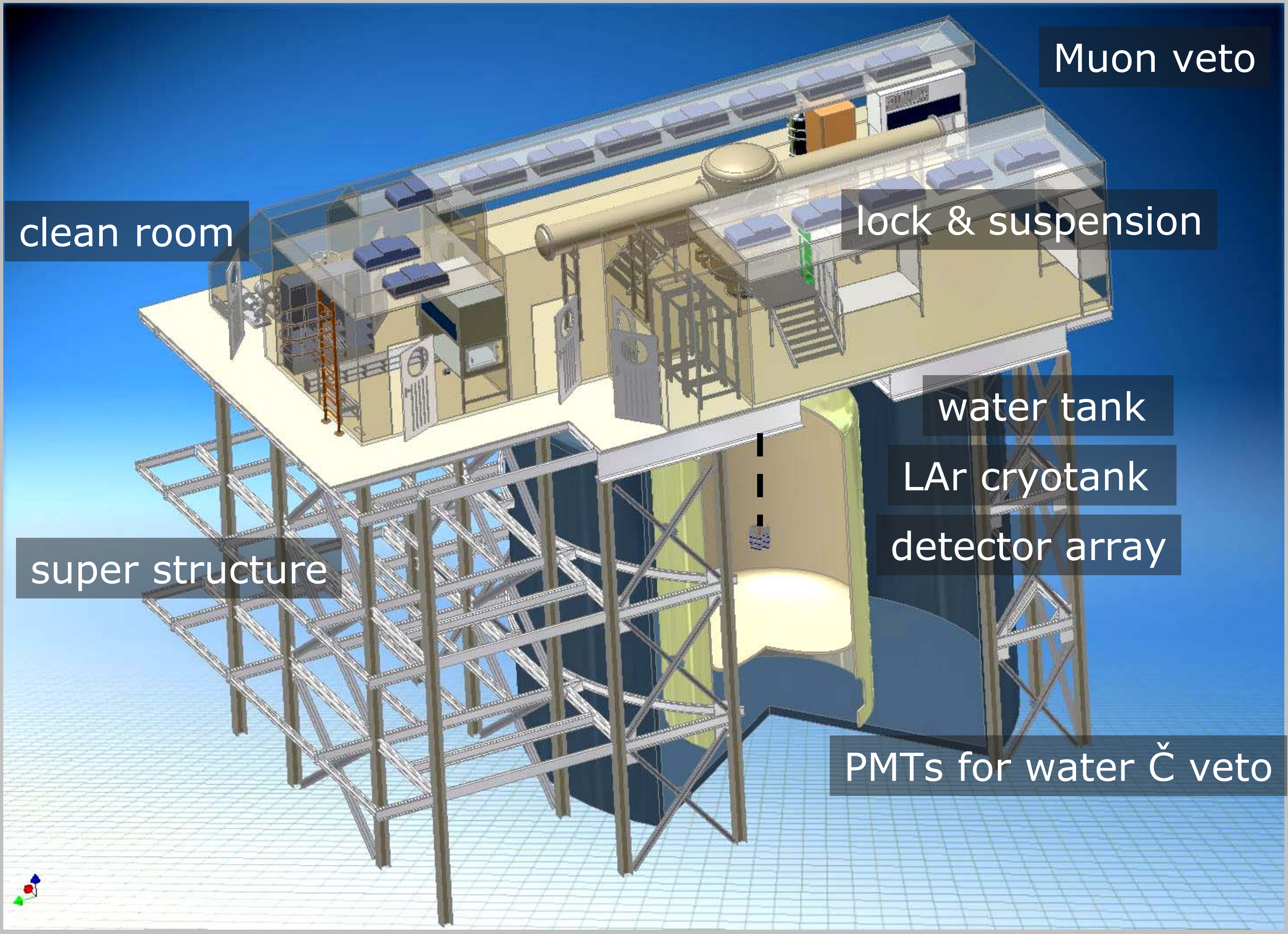




GERDA design

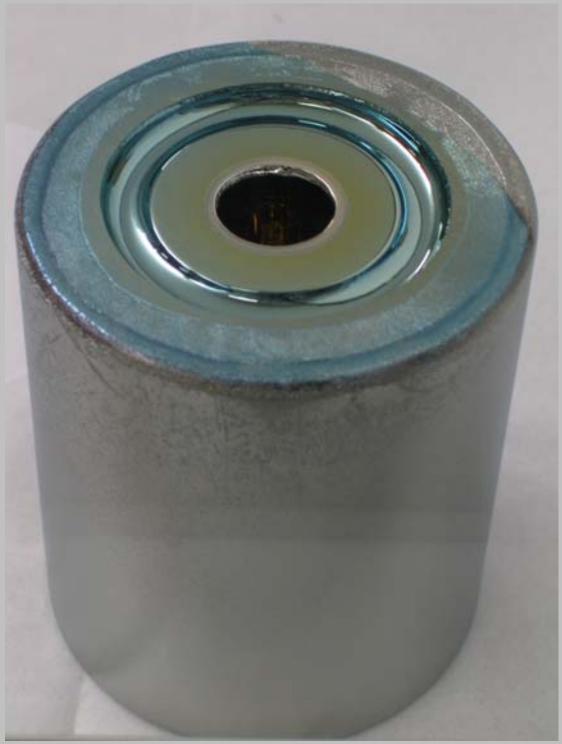


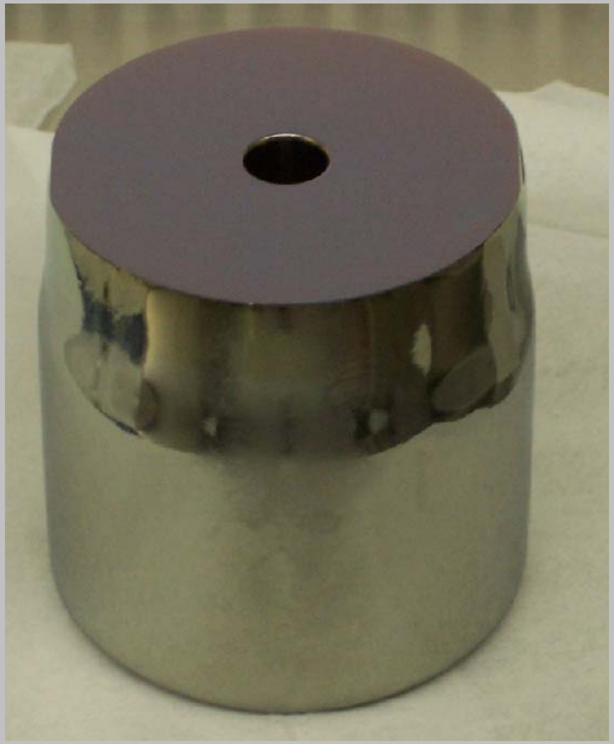
GERDA design



Phase-I detectors

Phase I: 3 IGEX & 5 HdMo detectors, in total 17.9 kg,
30g Cu, 6.3g PTFE, 1g Si per detector





Heidelberg-Moscow & IGEX (before processing)

All detectors reprocessed and tested in liquid Argon
FWHM ~2.5keV (at 1332keV), leakage current stable.

Phase-II detectors

expect ~25kg, ~15 detectors

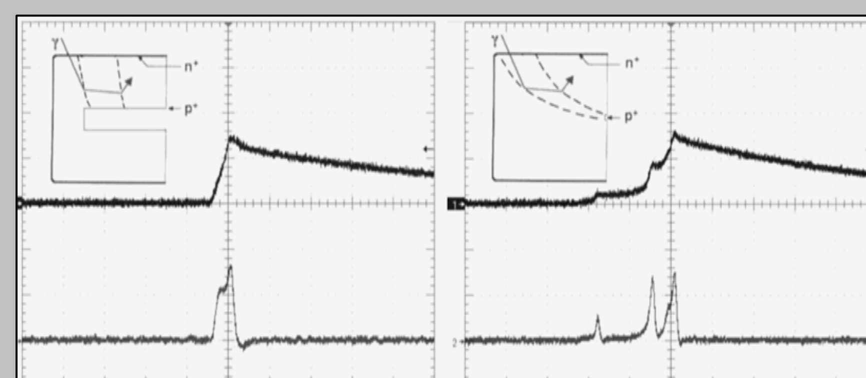
18-fold segmented detectors for Phase-II

✓novel contact method

✓small amount of extra material

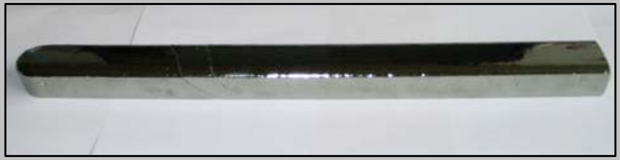
19g Cu, 7g PTFE, 2.5g Kapton per 1.62kg detector

Point-contact p-type detector: another option



Phase-II detectors

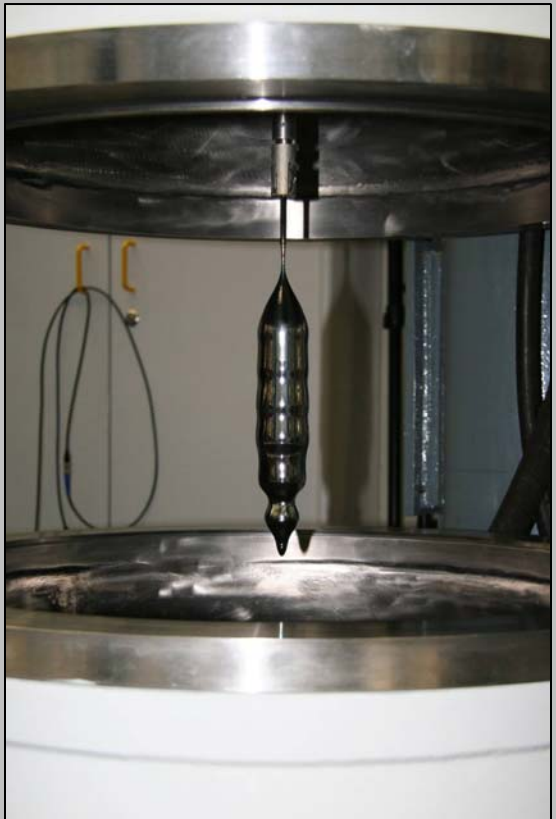
GeO_2 will be reduced to metal bars and purified to 6N material for Czochralski pulling.



Several ^{nat}Ge crystals pulled with dedicated Czochralski puller at IKZ Berlin.

Charge carrier density at first try: 10^{11} cm^{-3} to 10^{13} cm^{-3}

(request: 10^{10} cm^{-3})



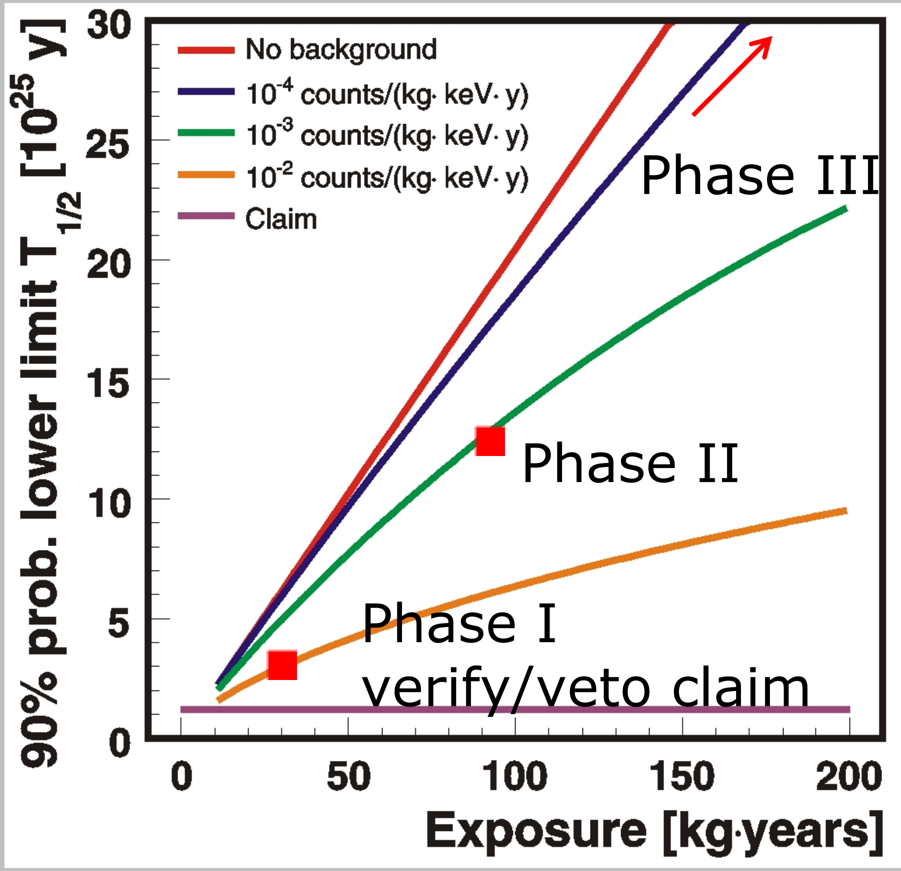
Cryotank and water tank constructed

cryotank (Mar.2008)
→ Phase-I start 2009!

water tank (Aug.2008)

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 $T_{1/2}$ [10^{25} y]	2	15	>280
Limit on $m_{\beta\beta}$ [eV]	0.27	0.13	<0.03

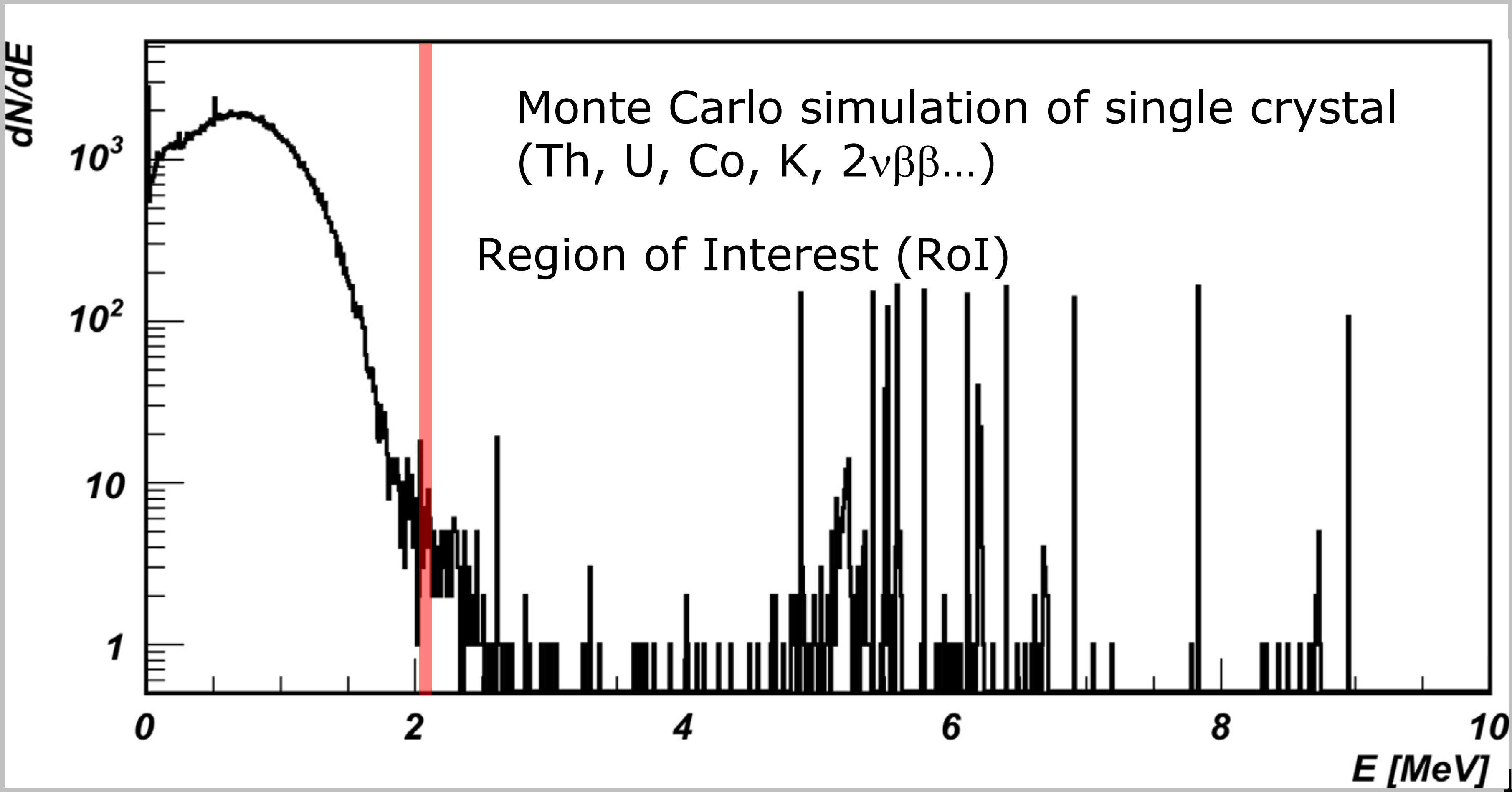


Claim of evidence
signal: 28.75±6.86 events
bg level: 0.11 cts/ kg·keV·y
H.V.Klapdor-Kleingrothaus, etc., Phys. Lett. B 586 (2004) 198-212

If claim true, phase-I will see:
signal: ~13 events
bg: 3 events in 10keV window at 2MeV
(assume 4keV FWHM at 2MeV)

Remove background

step 1: μ-veto (scintillator & water-č), energy window cut (2039±5keV)
step 2: single crystal cut (detector array)
step 3: single segment cut (segmented detector)
step 4: pulse shape analysis



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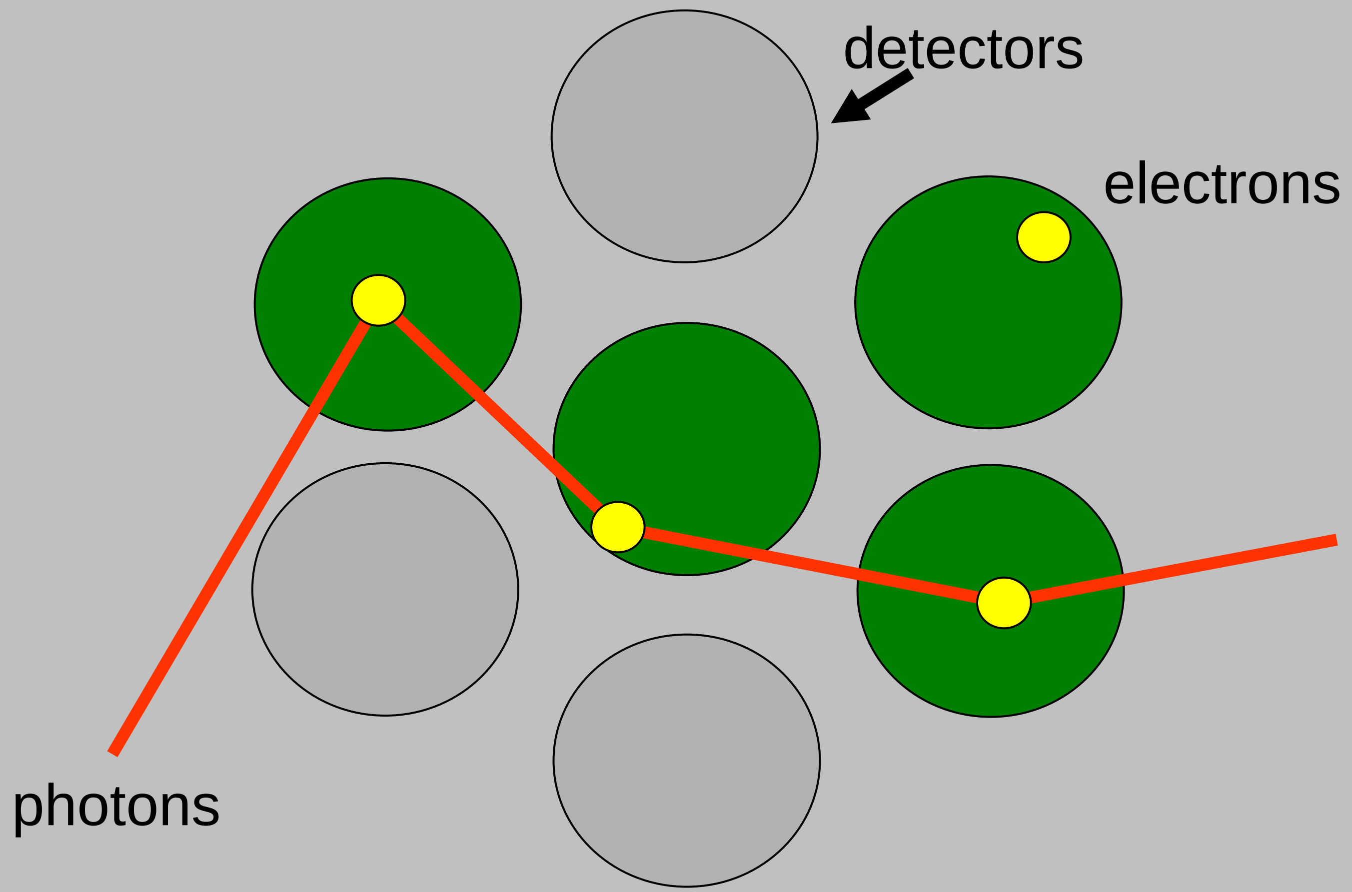

Remove background (Phase-II segmented detector)

step 1: μ-veto (scintillator & water-č), energy window cut (2039±5keV)
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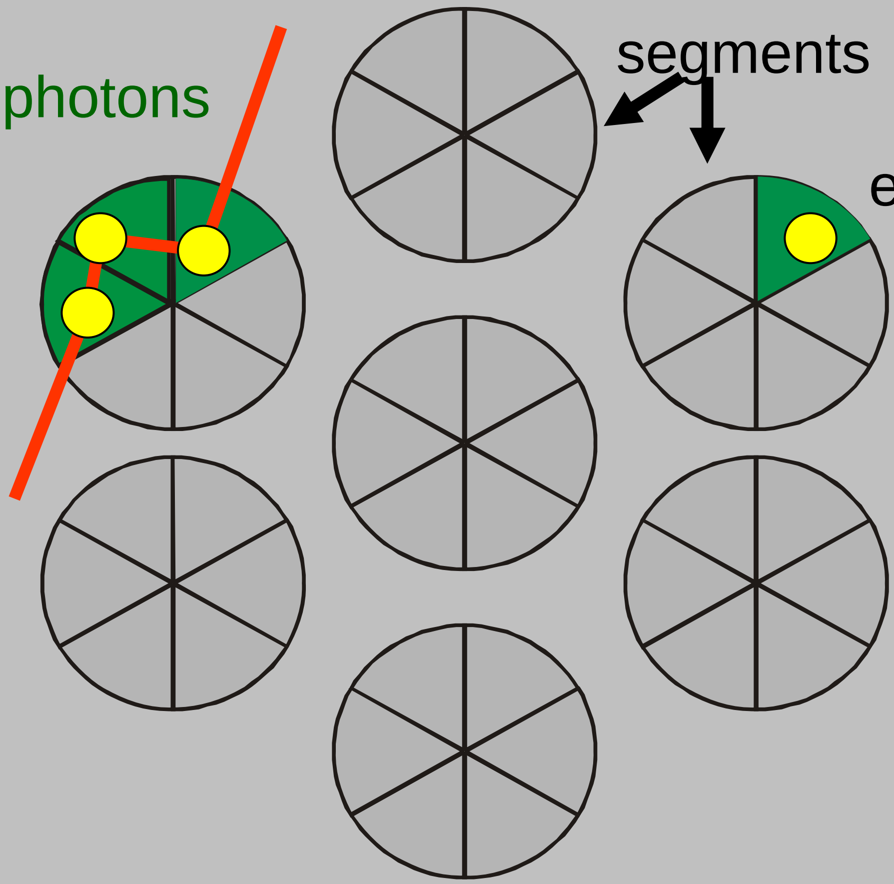
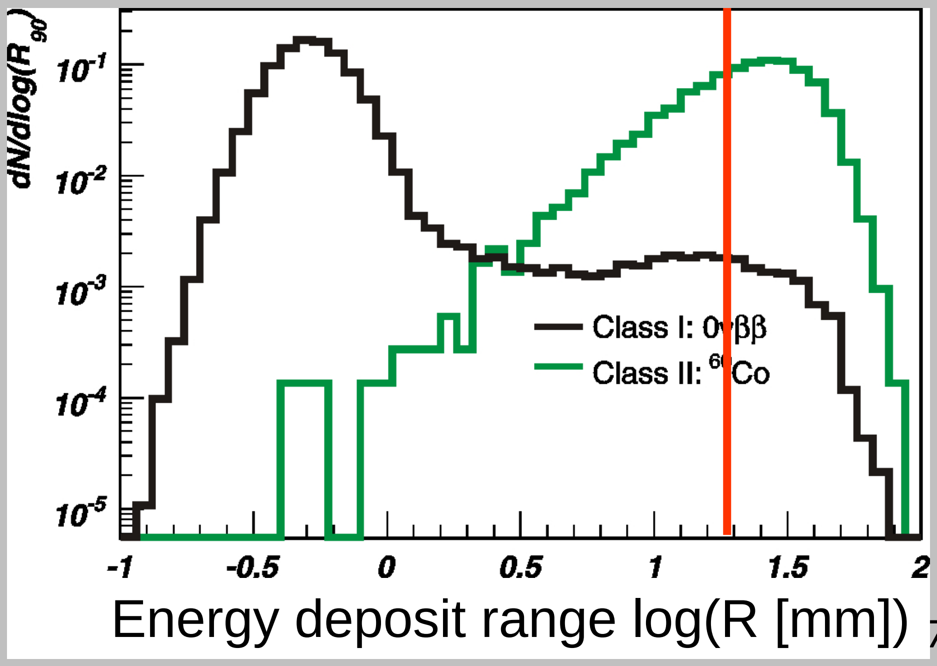


~segment size



Remove background

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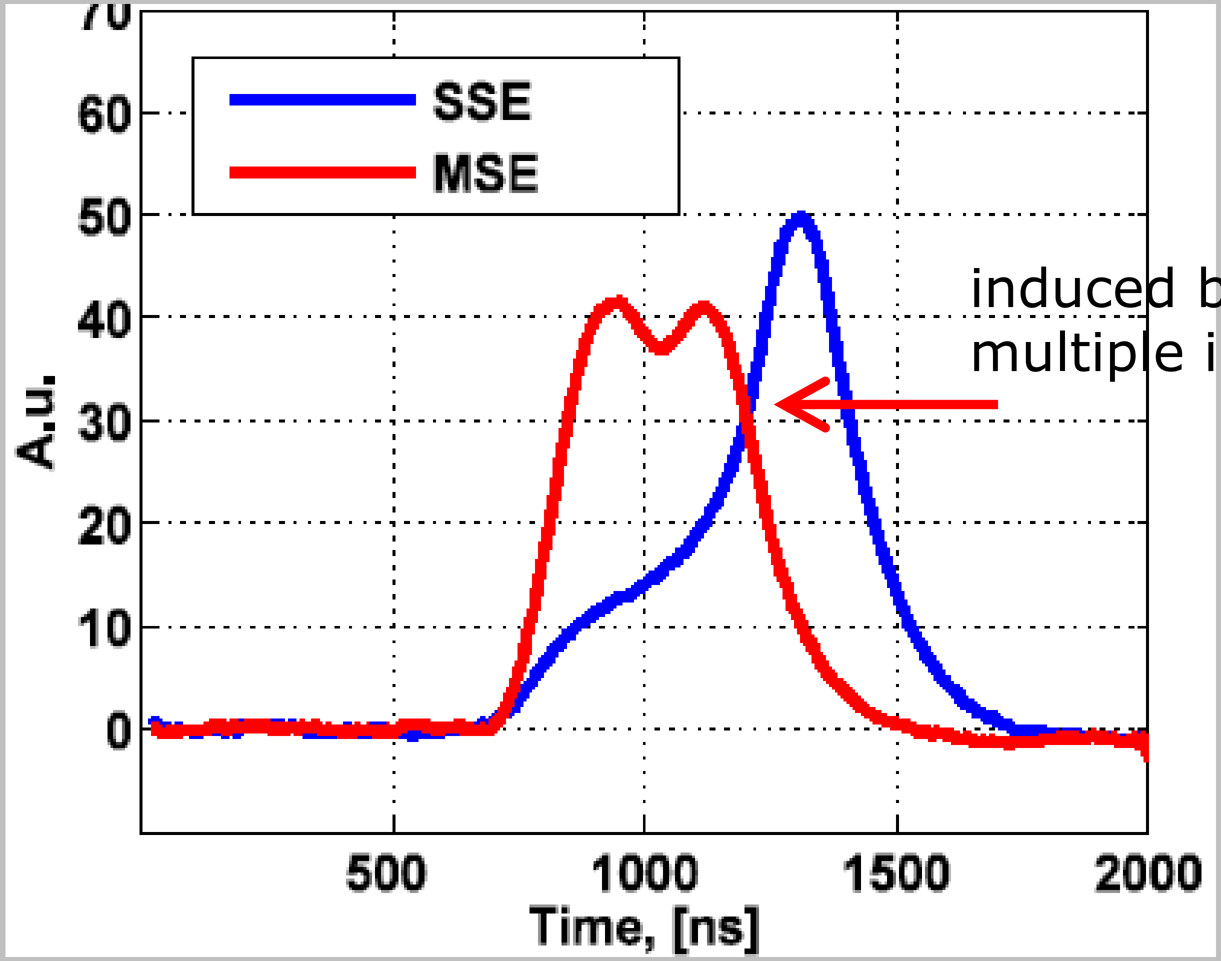
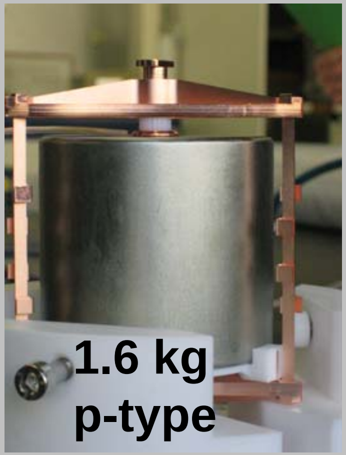
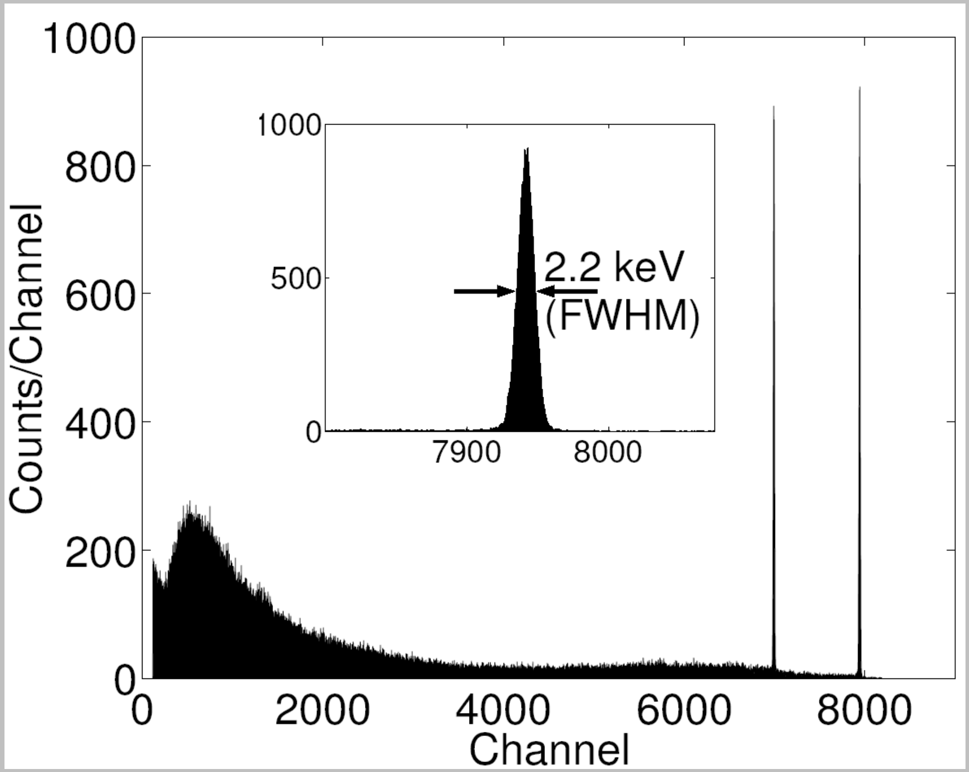


induced by
multiple interactions

R&D: Phase-I prototype detector

- ✓Prototype p-type detector (non-enriched) tested in liquid Nitrogen & Argon.
- ✓Good resolution achieved, leakage current stable.
- ✓Stable performance over long time scale.

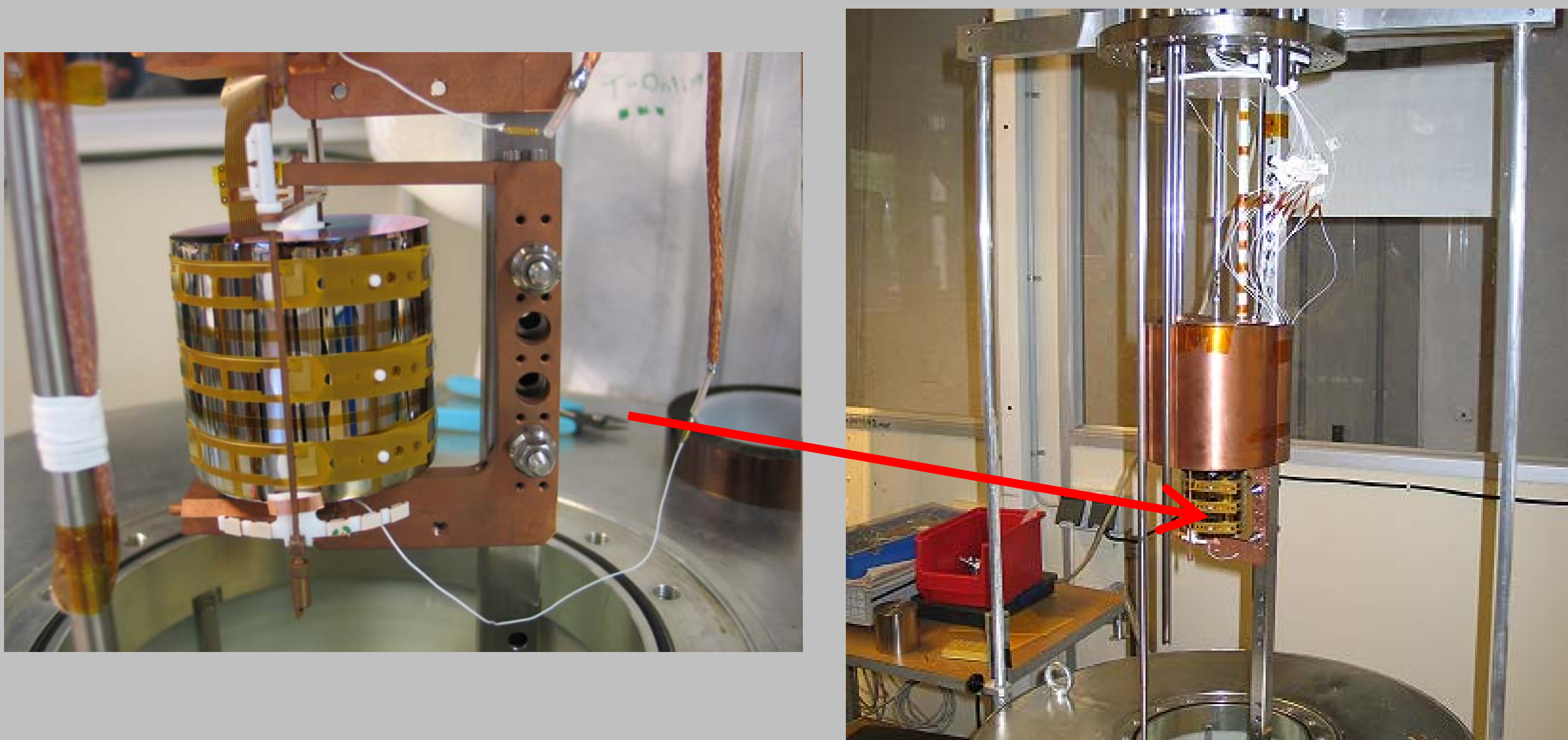




R&D: Phase-II prototype detector

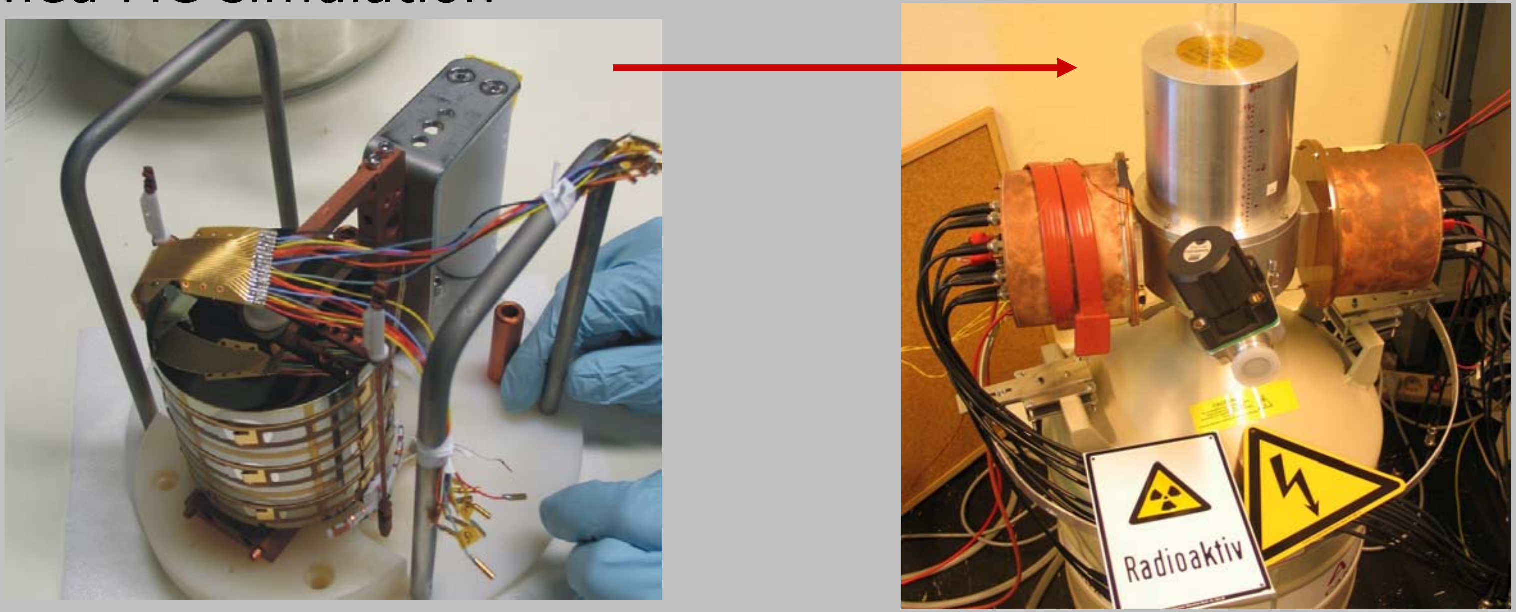
Prototype detector works in liquid Nitrogen!

FWHM core 4.1 keV, segments 3.6 - 5.7 keV
Leakage current < 6 pA



R&D: Phase-II prototype detector

exposed to γ and neutron sources
→confirmed segmentation cut, pulse-shape cut
→verified MC simulation



„Characterization of the true coaxial 18-fold segmented n-type detector" NIM A 577 (2007) 574

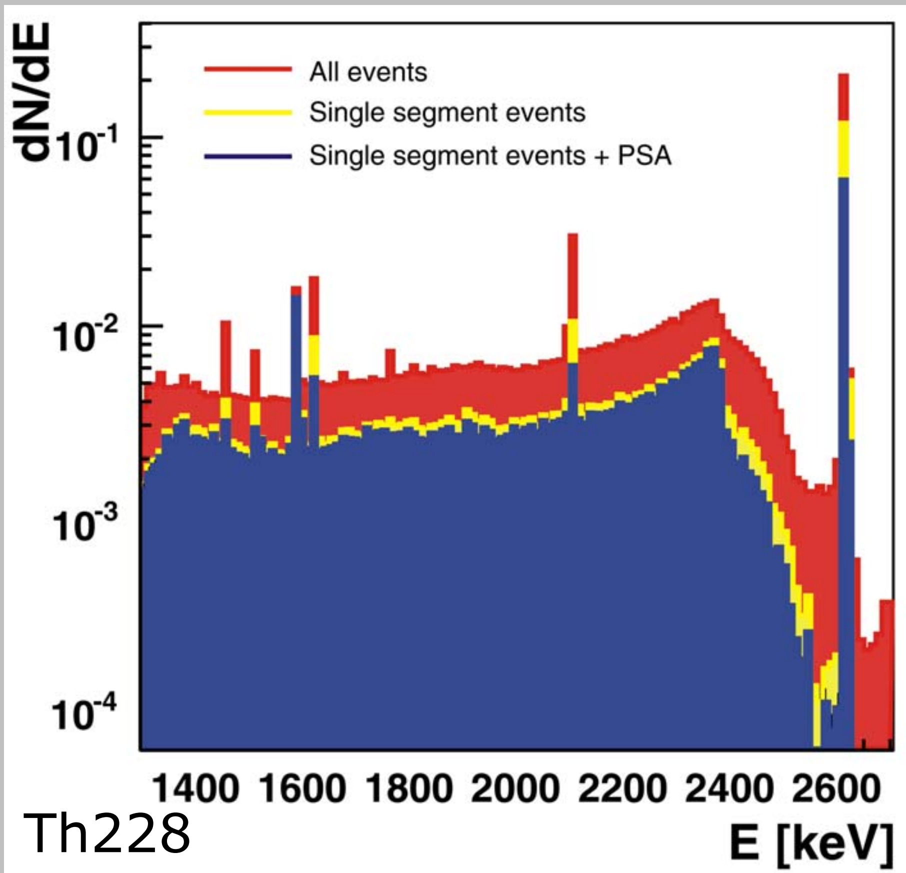
„Identification of photons in double beta-decay experiments using segmented detector – studies with a GERDA Phase II prototype detector" NIM A 583 (2007) 332-340

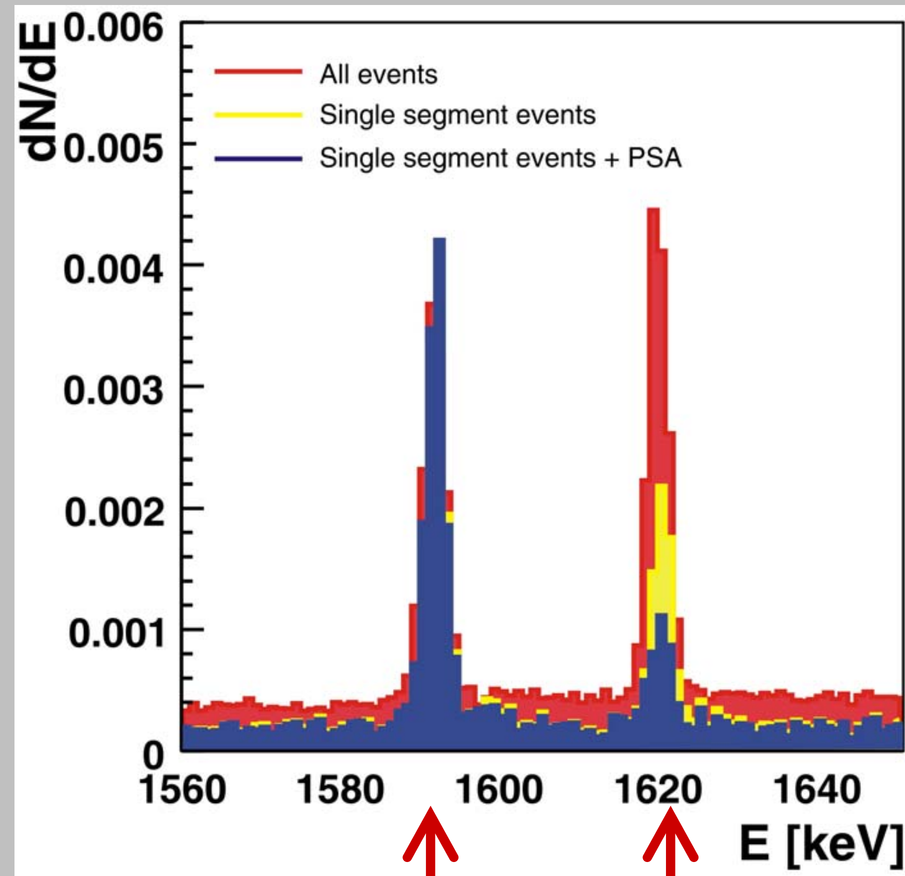
„Pulse shapes from electron and photon induced events in segmented high-purity germanium detectors" Eur. Phys. J. C 52, 19-27 (2007)

„Test of pulse shape analysis using single Compton scattering events" Eur. Phys. J. C 54 425-433 (2008)

„Neutron interactions as seen by a segmented Ge detector" Eur. Phys. J. A 36, 139-149 (2008)

R&D: Phase-II prototype detector





Double-escape peak
(single-site dominant)

1620keV Bi212
(multi-site dominant)

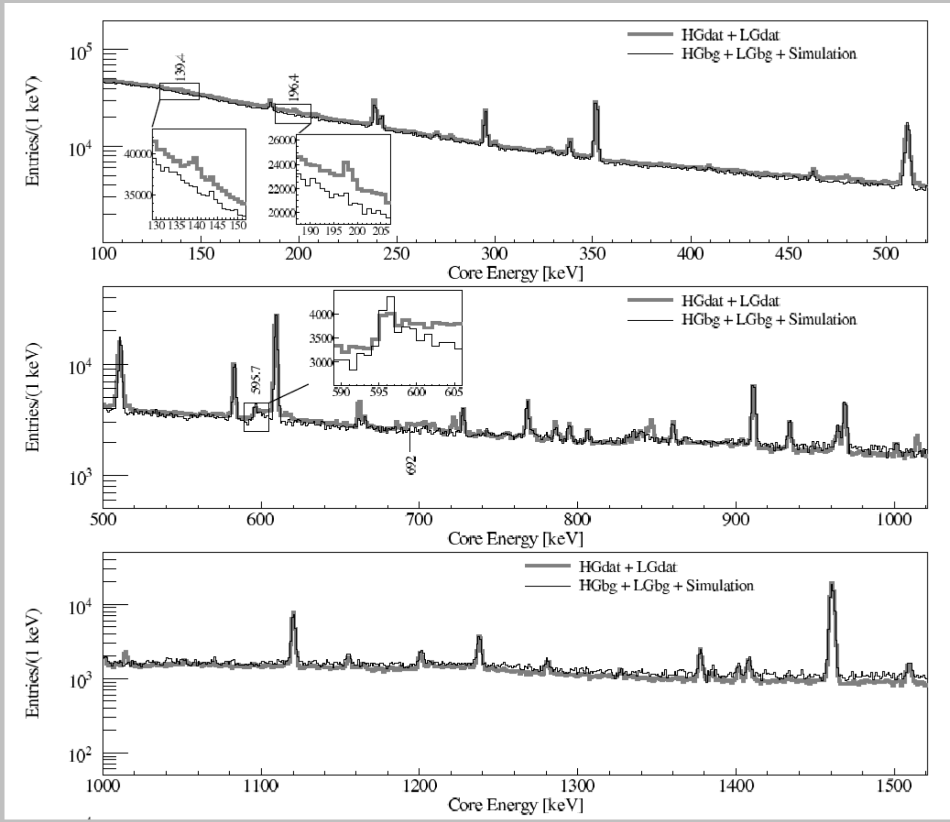
Reduction factor in RoI

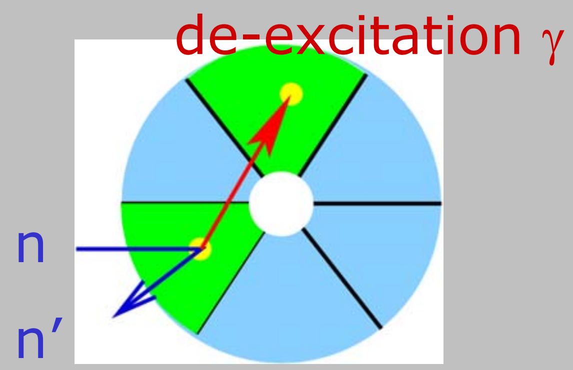
sample	data	MC
Co60	14.2 ± 2.1	12.5 ± 2.1
Th228	1.68 ± 0.02	1.66 ± 0.05

R&D: segmentation for neutron interaction measurement

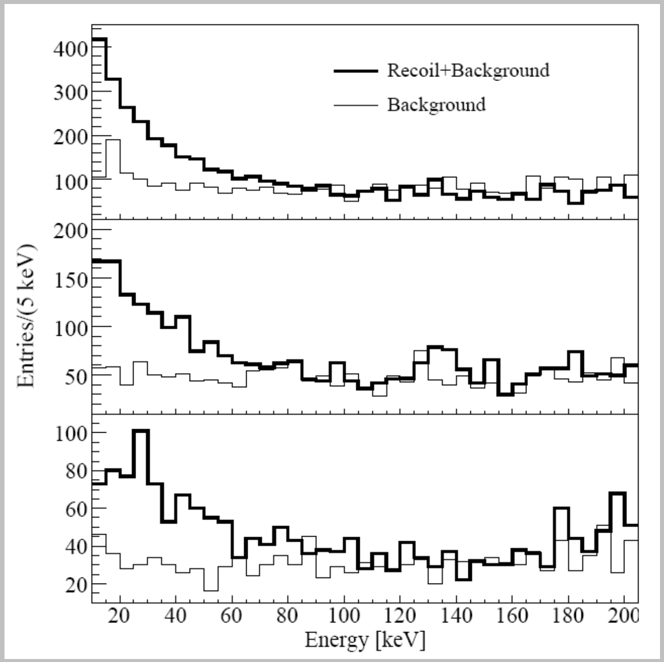
- study neutron interaction with Ge
- check Geant4 MC simulation

energy spectrum from AmBe source





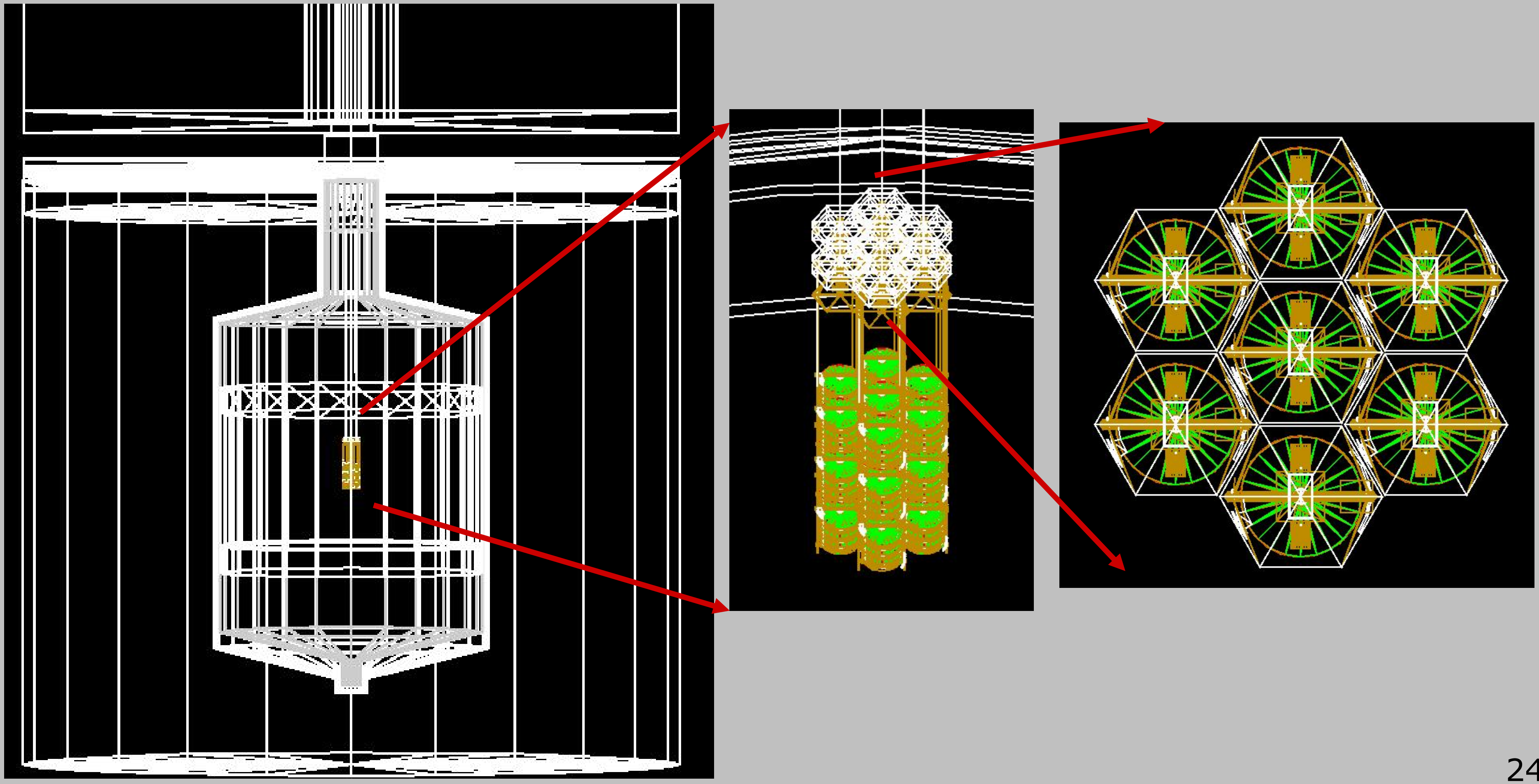
inelastic scattering (n, n′γ)



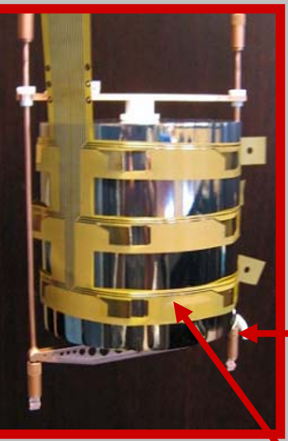
Direct measurement of recoil energy

Monte Carlo package MaGe (Majorana-Gerda)

- Geant4-based, developed together with Majorana.
- optimized for low energy & low bg.
- code sharing & physics verification.



MC simulation of background (phase II)



Part		Background contribution [10^{-4} counts/(kg·keV·y)]
Detector	**^{68}Ge**	**4.3** → after 2 years
	^{60}Co	0.3
	Bulk	3.0
	Surf.	**3.5** → further reduction expected from PSA
Holder	Cu	1.4
	Teflon	0.3
Cabling	Kapton	1.5
Electronics		**3.5**
LAr		1.0
Infrastructure		0.2
Muons and neutrons		2.0
Total		21.0

Summary

Open questions about neutrino :

absolute mass? hierarchy? Majorana or Dirac?

→ GERDA (searching $0\nu\beta\beta$ in Ge76) might address all.

- Phase-I detectors (unsegmented) ready.
- Successful R&D with Phase-II prototype segmented detector.
- R&D on crystal pulling & detector production.

- Shielding structure finished.
- Phase-I commissioning early 2009!

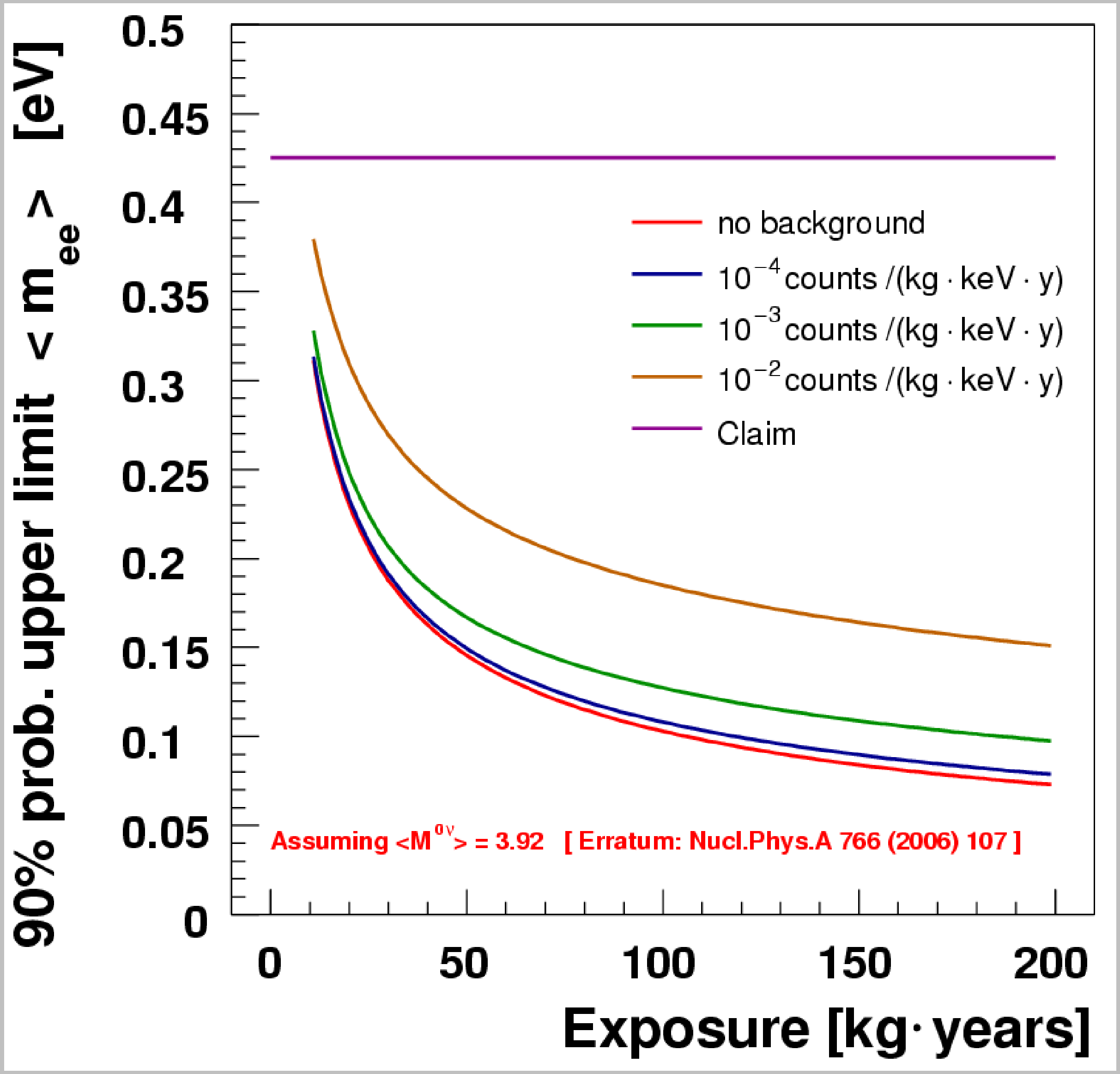
GERDA collaboration

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

97 scientists.

Backup

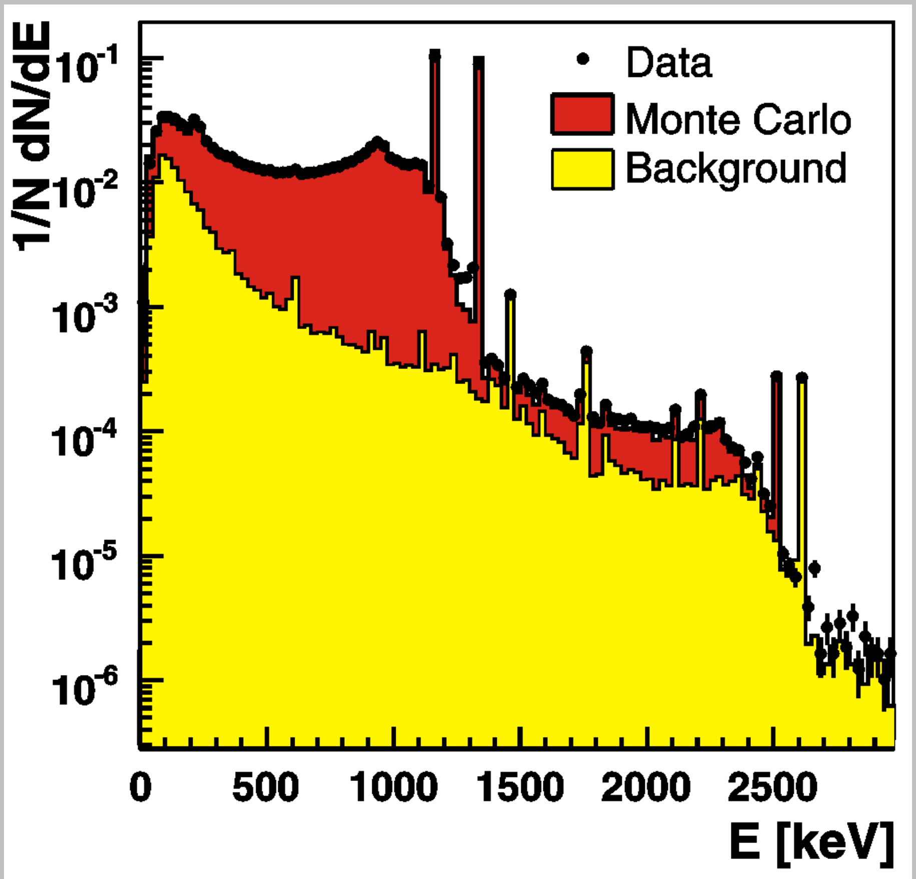
Backup: Sensitivity on effective Majorana neutrino mass



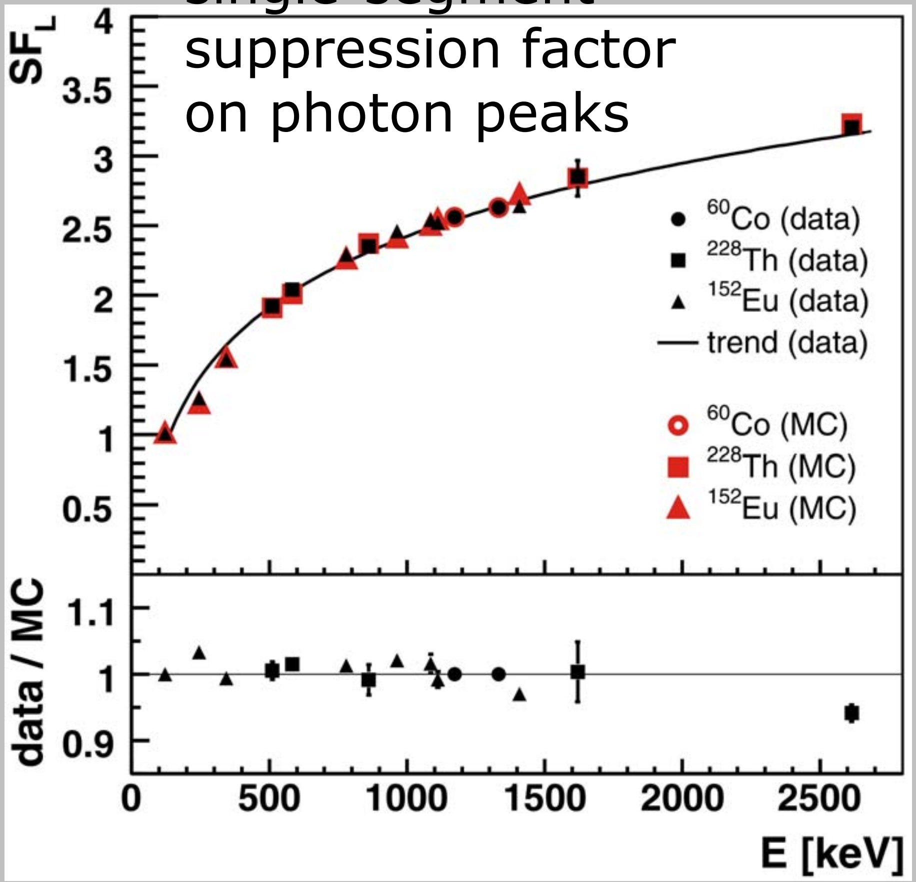
$$T_{1/2} \propto \varepsilon \cdot \sqrt{\frac{M \cdot T}{\Delta E \cdot B}}$$

B: background index
ΔE: energy resolution

R&D: Phase-II prototype detector



single-segment suppression factor on photon peaks



Data agrees with MC within 5%.

data sample	segmentation reduction in RoI
Co60	14.2 ± 2.1
Th228	1.68 ± 0.02

GERDA physics goal

Phase I
Phase II

Phase III