GERDA & GeDet Project Review 2009

-Neutrinoless double-beta decay ($0\nu\beta\beta$)

-$0\nu\beta\beta$ experiment with HPGe detectors

-GERDA experiment

-GeDet group: segmented HPGe detectors

-GERDA group: cleanroom, matrix & cables,
commissioning lock, final lock

-Summary

Xiang Liu for GERDA & GeDet groups
Annual Project Review, MPI Munich
Dec. 14-15, 2009

GERDA & GeDet member

Director: Allen Caldwell

Project leaders: Béla Majorovits (GERDA), Iris Abt (GeDet)

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Daniel Lenz, Jing Liu (-03/09),
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Engineering: Karlheinz Ackermann, Stefan Mayer, Sven Vogt

Additional help: Hans Seitz

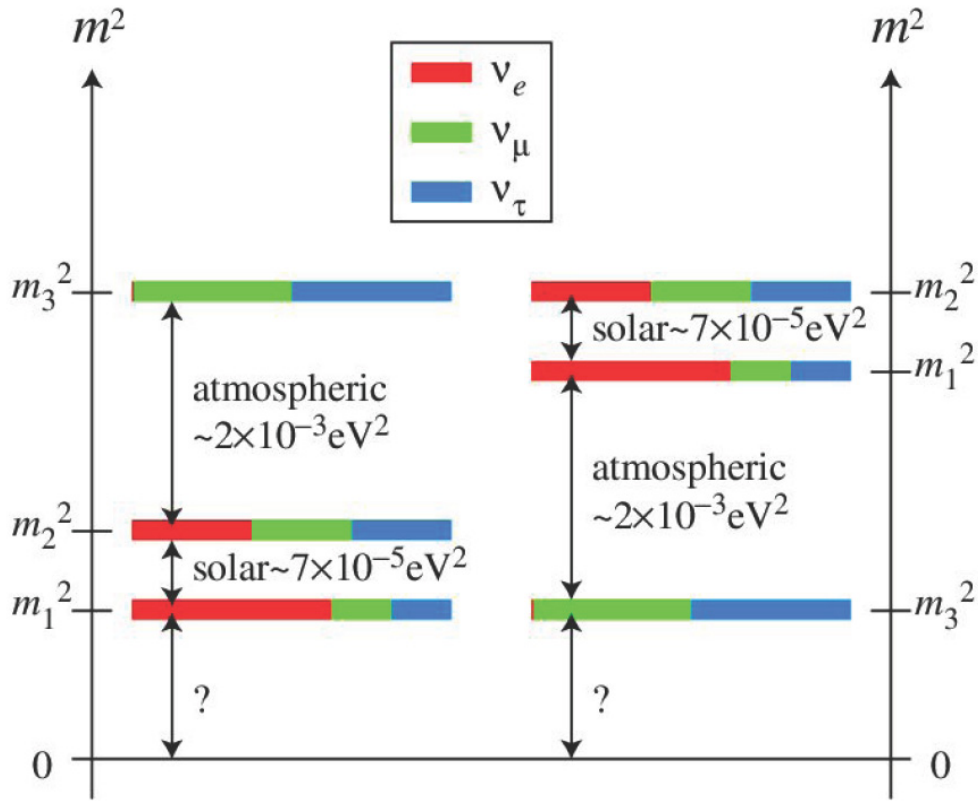
Many thanks to colleagues from electronic & mechanic departments!

Neutrino properties

ν oscillation observed → mν > 0
one of beyond-SM signals

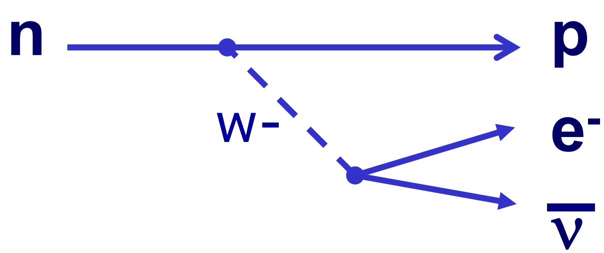
Still many questions:
1. mν = ?
2. normal or inverted
   mass hierarchy?
   ($m_3>m_2$ or not)
3. ν = $\bar{\nu}$?
4. Mixing angle θ13=?
5. CP-violation phase?
…

→neutrinoless
double-beta decay (0νββ)
can address first 3 questions.

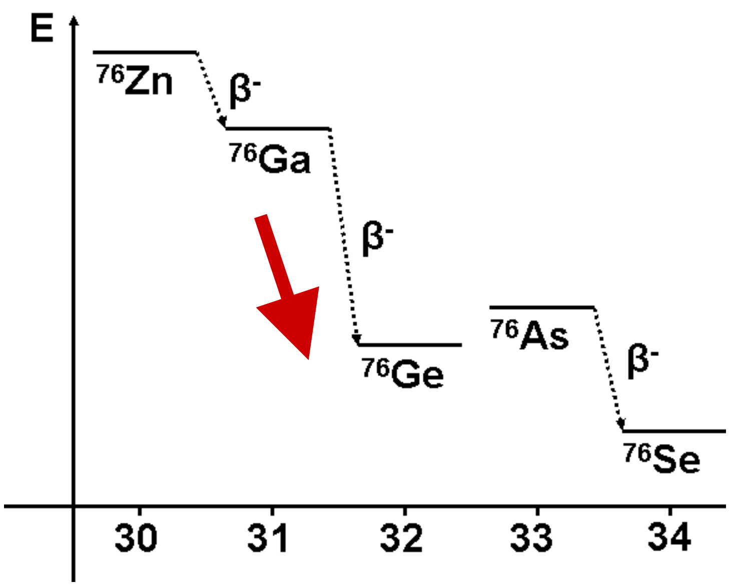


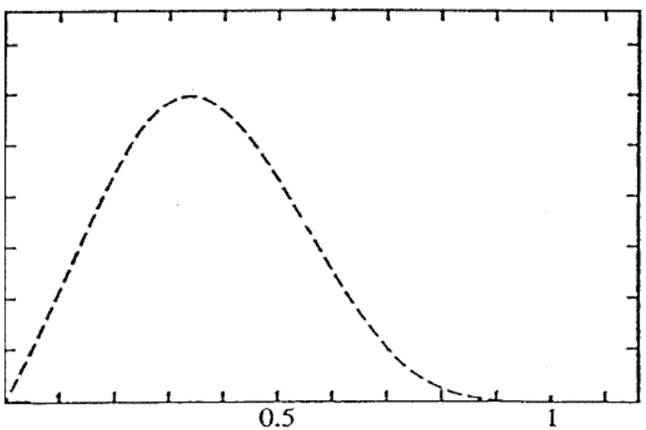
normal hierarchy $m_3>m_2$ or inverted hierarchy $m_3<m_2$

Normal beta decay



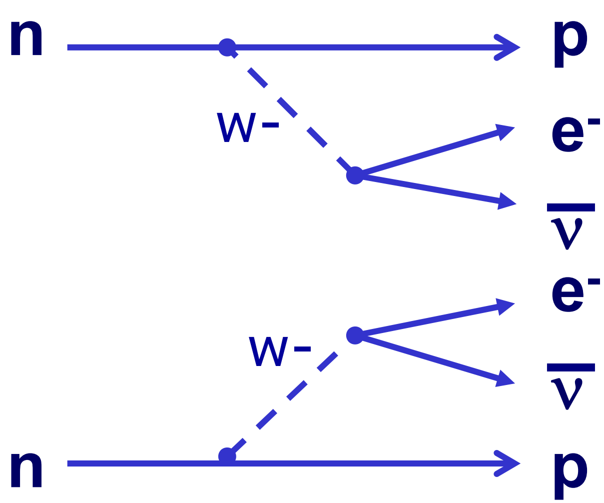
(A,Z)→(A,Z+1) + e + ν





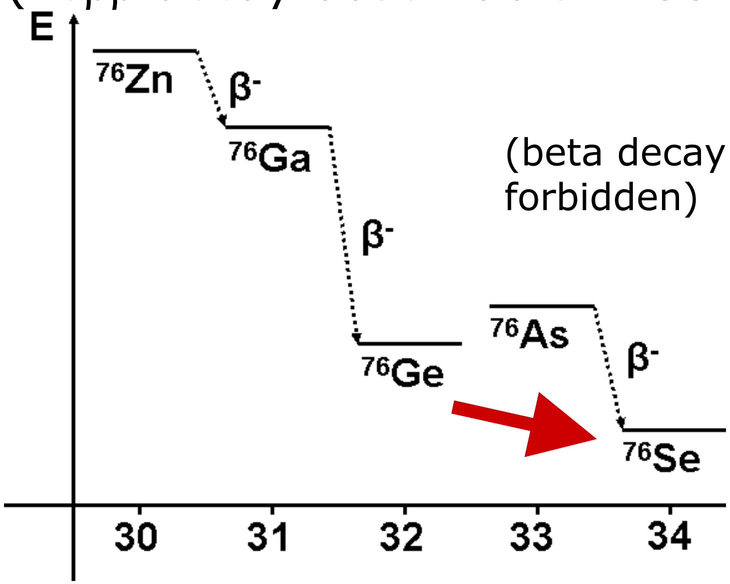
Electron energy/Q

Neutrino-accompanied double-beta decay (2νββ)

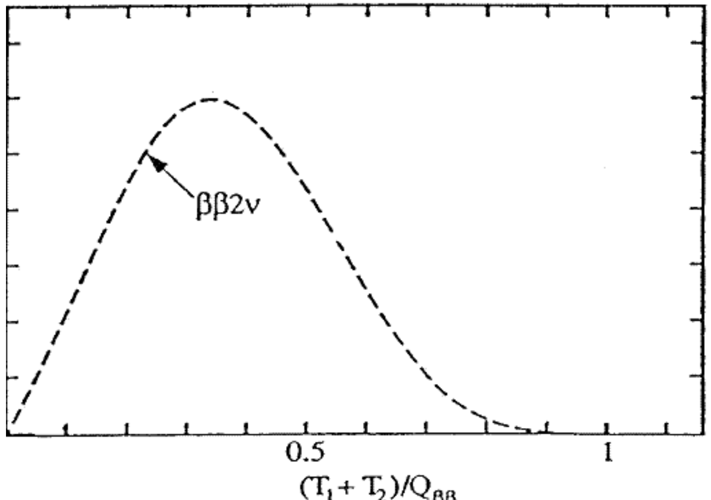


$(A,Z) \rightarrow (A,Z+2) + 2e + 2\nu$

(2νββ decay observable in 35 isotopes)

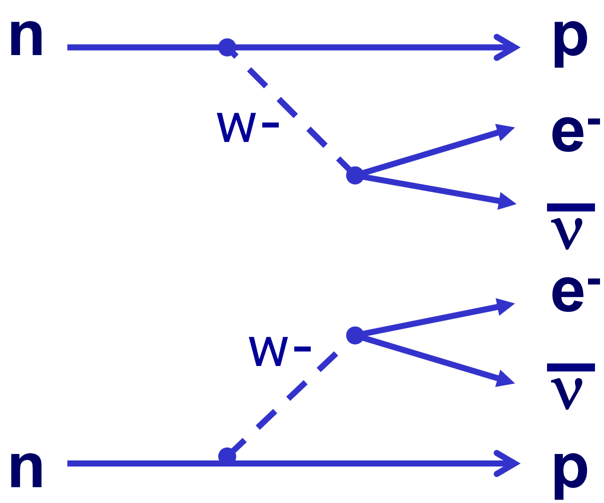


(beta decay forbidden)

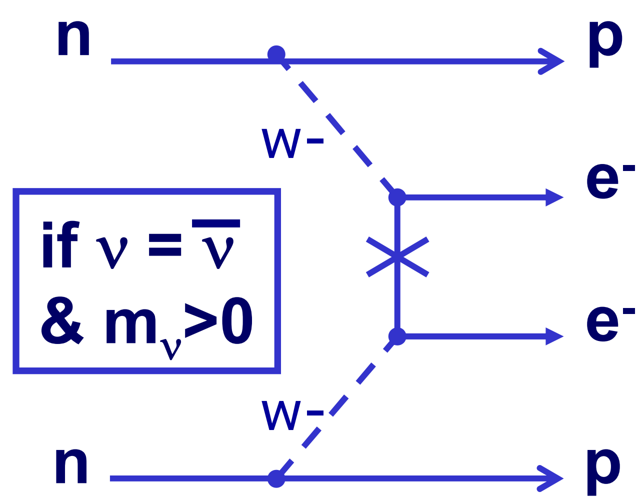


Esum of 2 electrons/Q

Neutrinoless double-beta decay ($0\nu\beta\beta$)

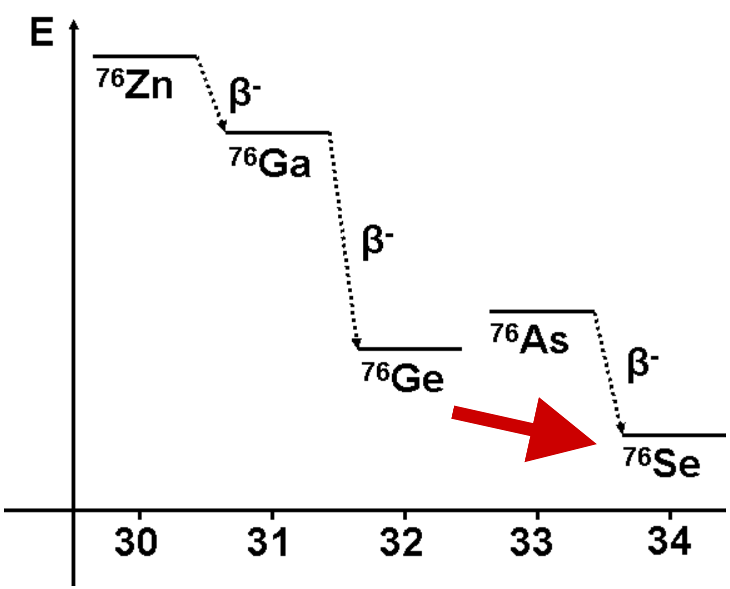


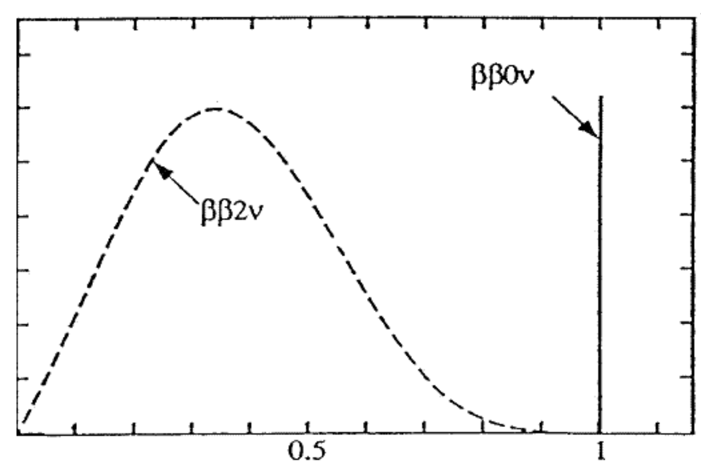
$(A,Z)\rightarrow(A,Z+2) + 2e + 2\nu$



$(A,Z)\rightarrow(A,Z+2) + 2e$

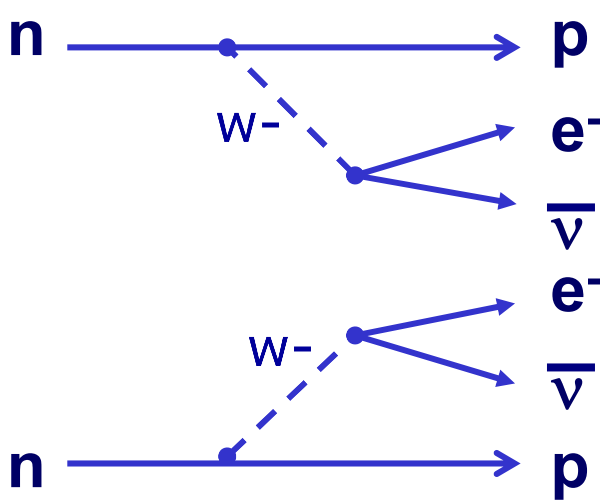
$\Delta L=2$, beyond SM



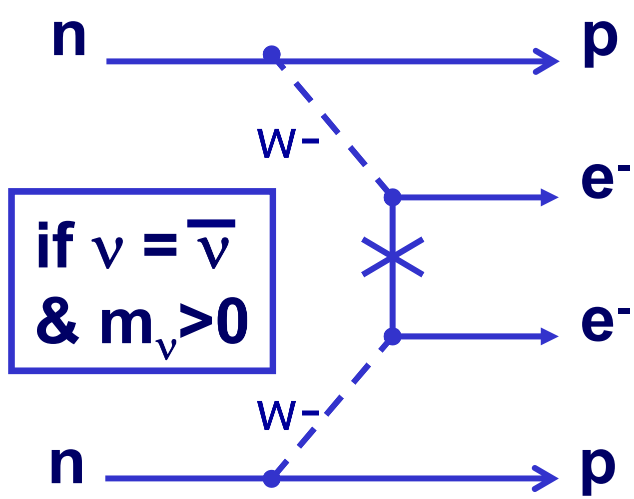


Esum of 2 electrons/Q

Neutrinoless double-beta decay ($0\nu\beta\beta$)

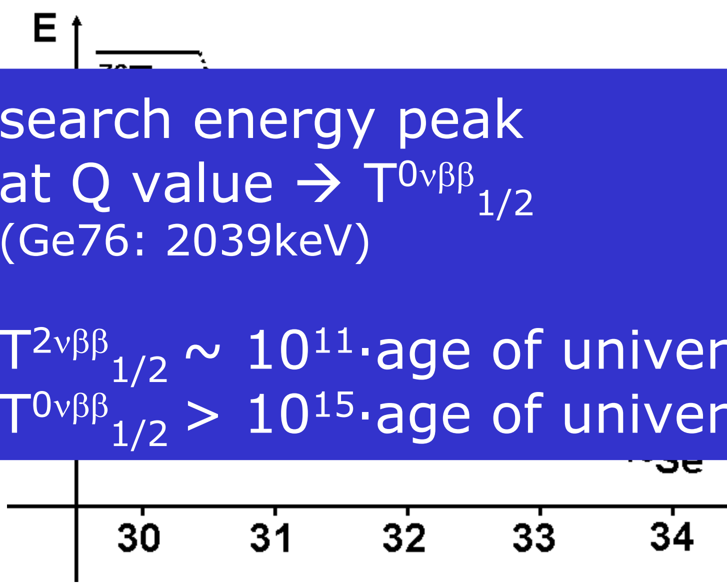


$(A,Z) \rightarrow (A,Z+2) + 2e + 2\nu$



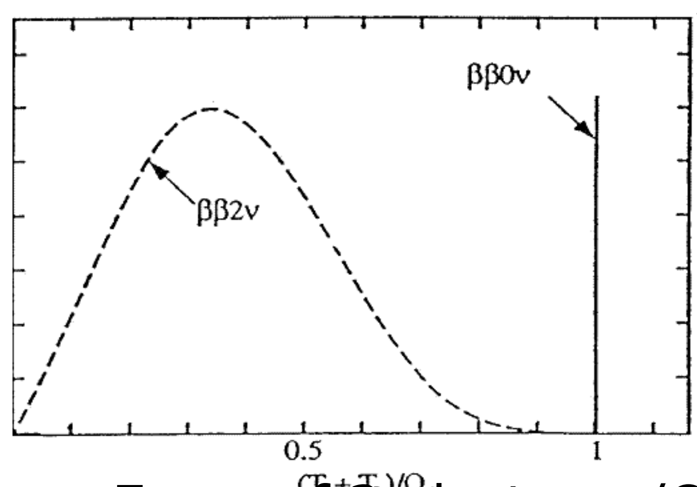
$(A,Z) \rightarrow (A,Z+2) + 2e$

$\Delta L=2$, beyond SM



search energy peak
at Q value → $T^{0\nu\beta\beta}_{1/2}$
(Ge76: 2039keV)

$T^{2\nu\beta\beta}_{1/2} \sim 10^{11}$·age of universe
$T^{0\nu\beta\beta}_{1/2} > 10^{15}$·age of universe



Esum of 2 electrons/Q

Why Germanium

sensitivity on $T_{1/2} \propto \varepsilon \bullet \sqrt{\frac{MT}{B}}$

$T_{1/2} \propto \varepsilon MT \text{ if } B = 0$

design focus	
high signal efficiency ε	
large target mass & long exposure **M·T**	
extremely low level background B	

Why Germanium

$$\text{sensitivity on } T_{1/2} \propto \varepsilon \bullet \sqrt{\frac{MT}{B}}$$

$$T_{1/2} \propto \varepsilon MT \text{ if } B = 0$$

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

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

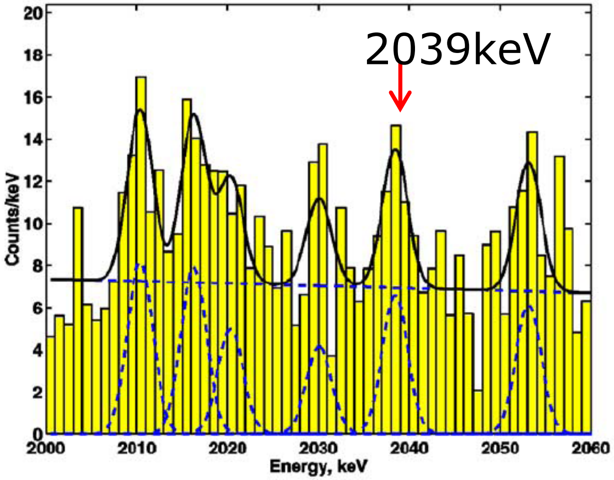
☹$Q_{\beta\beta}$=2039keV (<2614keV)

Heidelberg-Moscow experiment

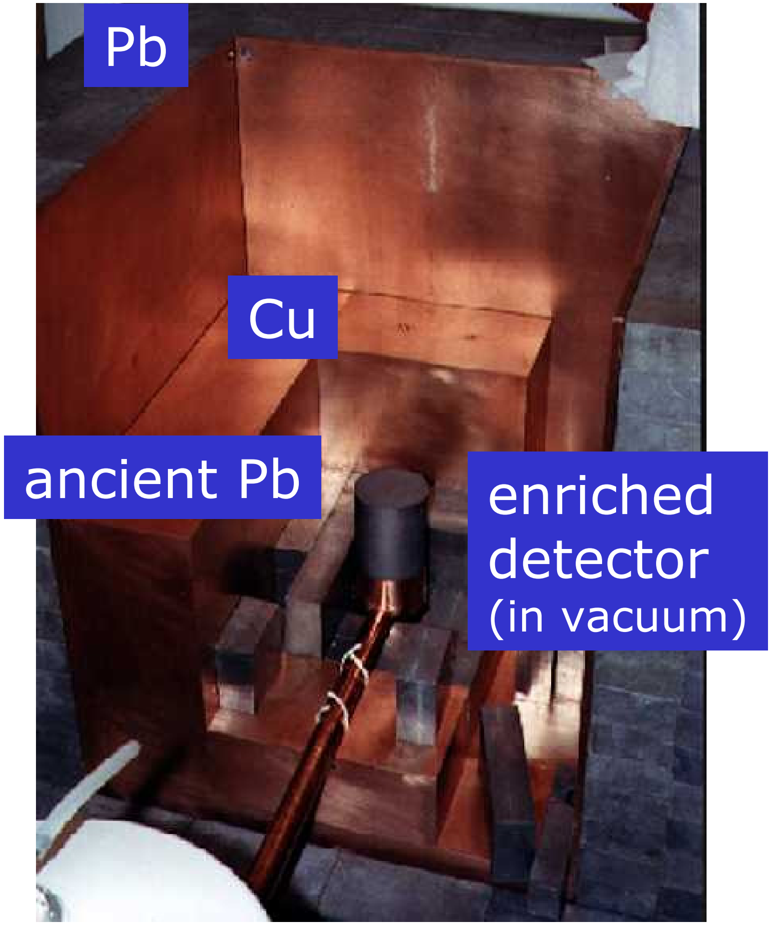
5 p-type Ge76-enriched detectors

exposure[kg·y]	71.1
B [counts/kg·keV·y]	0.11

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



0.11·71.1·10keV = ~70 bg events



conventional shielding

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

GERDA goal

phase	I	II	"III"
detector [kg]	17.9 existing	~20 more	ton-scale
exposure[kg·year]	30	100	>1000
bg [counts/(keV·kg·year)]	10^{-2}	10^{-3}	10^{-4}
limit on $T_{1/2}$ [10^{25} year](90%C.L.)	2	15	>280
limit on $m_{\beta\beta}$ [eV]*	0.27	0.13	<0.03

*Assuming $<M^{0\nu}>=3.92$ (Erratum: Nucl. Phys. A766 (2006) 107)

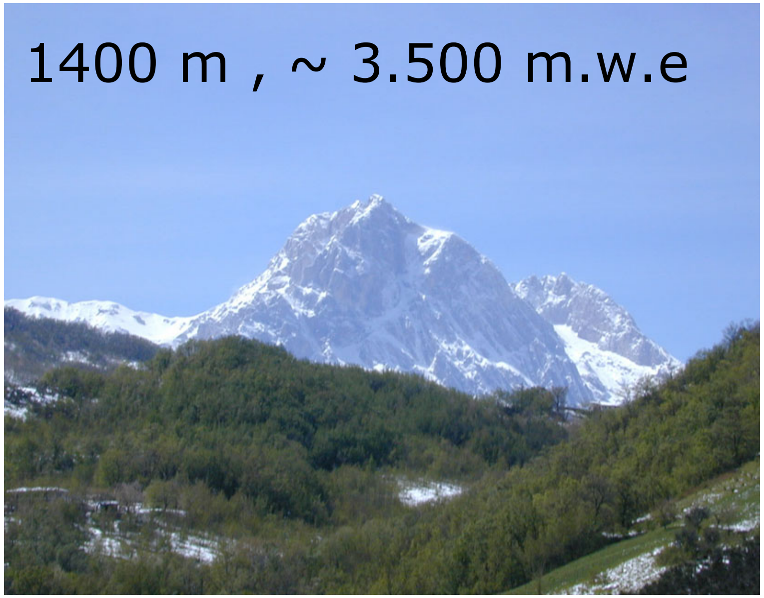
Phase-I

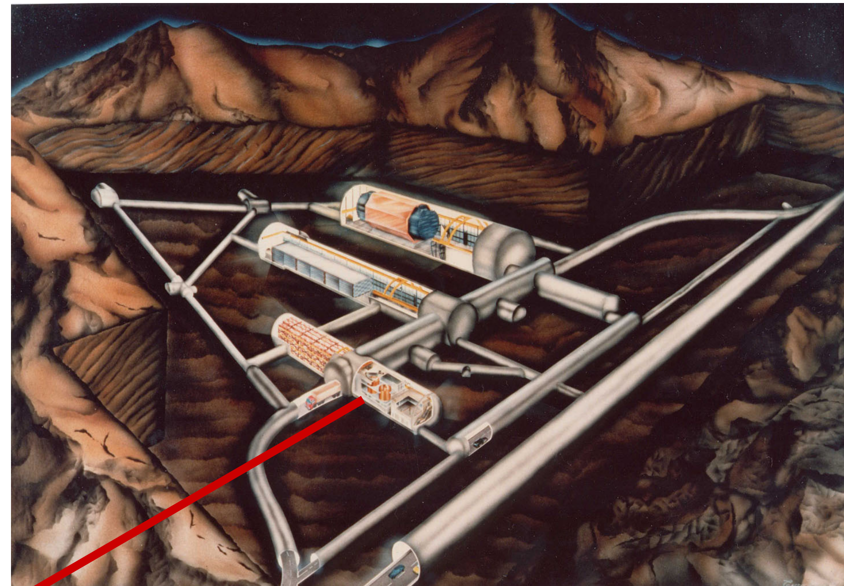
Claim of evidence
signal: 28.75±6.86 events
bg level: 0.11 counts/ keV·kg·year
H.V.Klapdor-Kleingrothaus, et al., Phys. Lett. B 586 (2004) 198-212

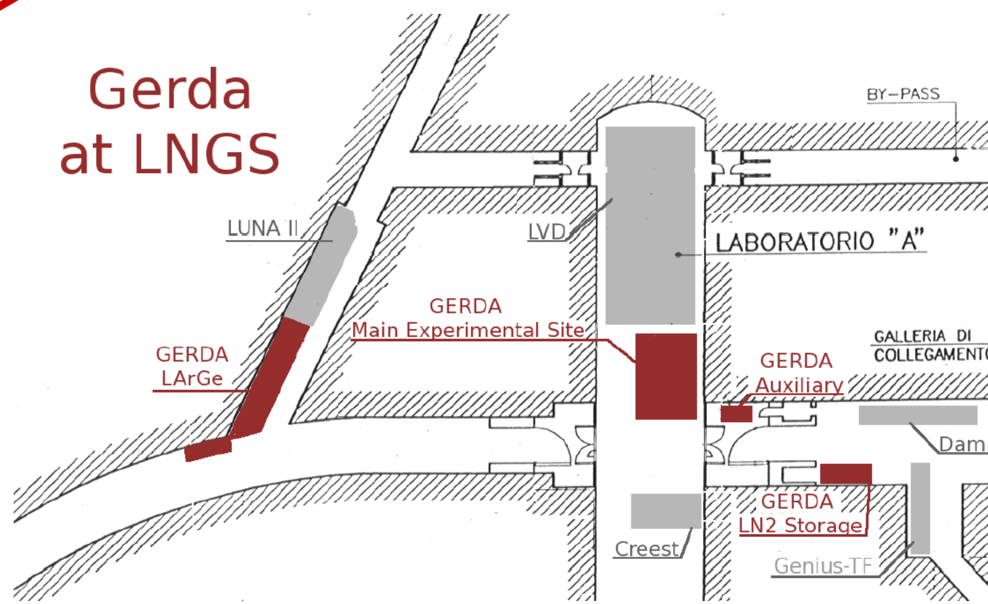
If claim true, phase-I will see:
signal: 13 events
bg: 3 events

in 10keV window at 2MeV
assume 4keV FWHM at 2MeV

GERDA experiment at LNGS

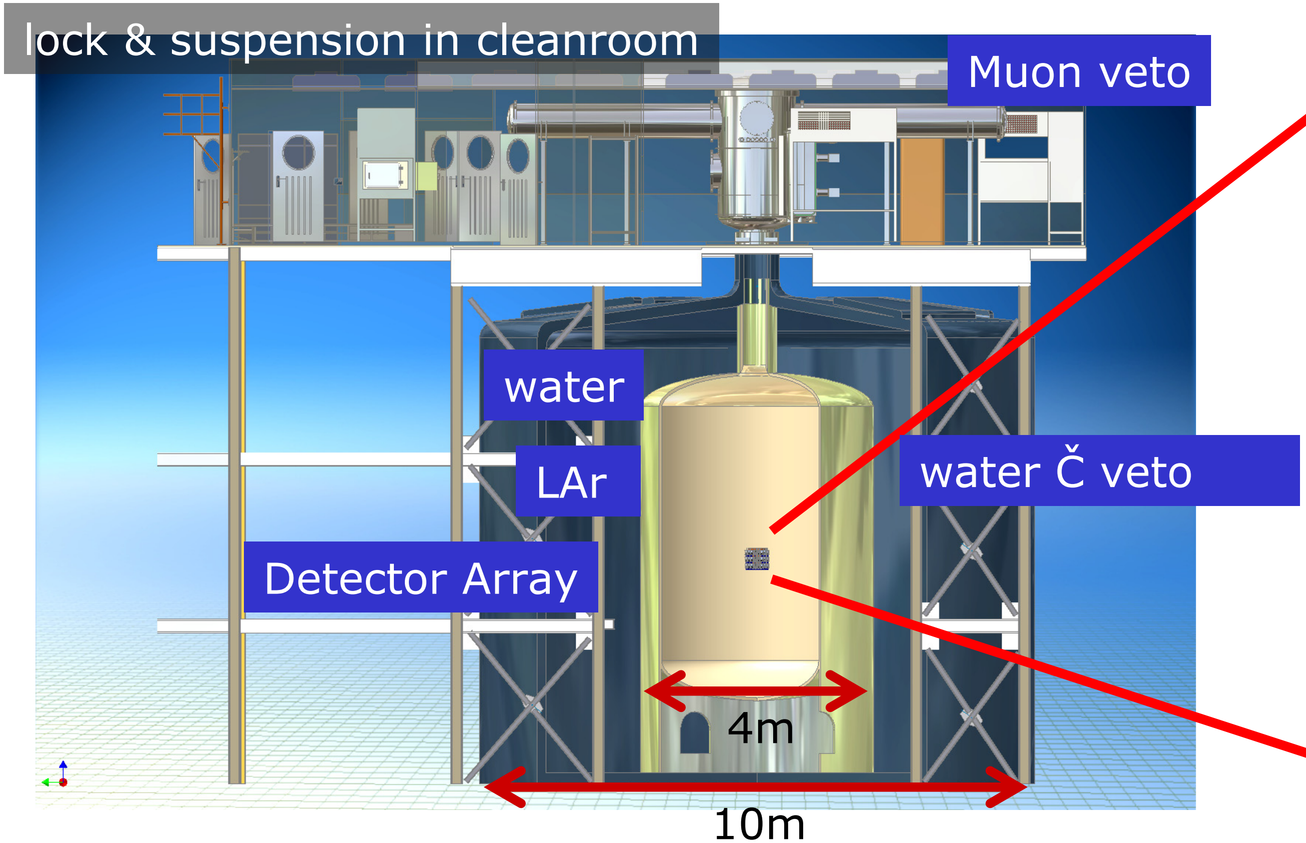






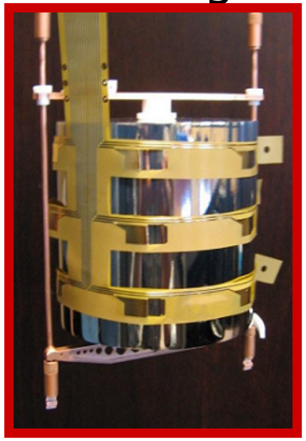
GERDA design concept

Ge detectors immersed in liquid argon	LAr as cooling and shielding* LAr >10^4 purer than Cu Pb (Th & U in LAr <$7\cdot10^{-4}$ μBq/kg)
phased approach with existing and new detectors	new bg-reduction techniques

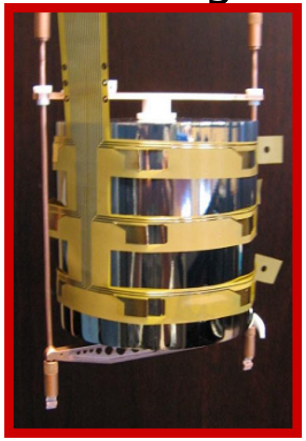


* G. Heusser, Ann. Rev. Nucl. Part. Sci. 45 (1995) 543.

GERDA detectors

phase	I	II
detectors	5 Hd-Mo & 3 IGEX detectors, 17.9 kg  ready	~20kg, 18-fold seg. or BEGe  prototypes tested
exposure[kg·y]	30	100
bg [counts/kg·keV·y]	10E-2	10E-3

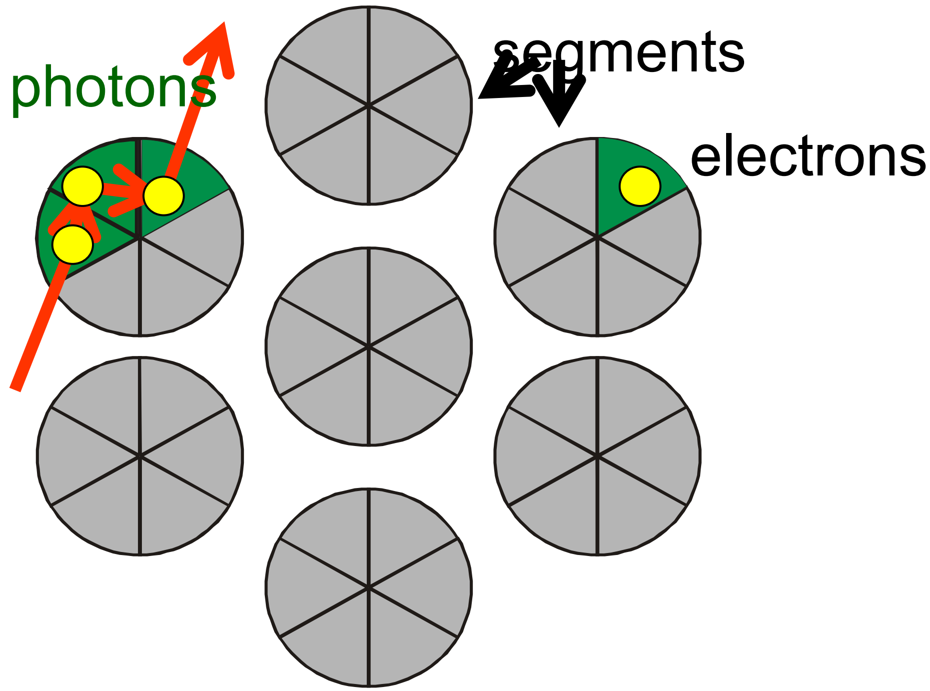
GERDA detectors

phase	I	II
detectors	5 Hd-Mo & 3 IGEX detectors, 17.9 kg  ready	~20kg, 18-fold seg. or BEGe  prototypes tested
exposure[kg·y]	30	100
bg [counts/kg·keV·y]	10E-2	10E-3

commissioning phase: first half of 2010
immerse 6 enriched detectors into LAr

Remove background

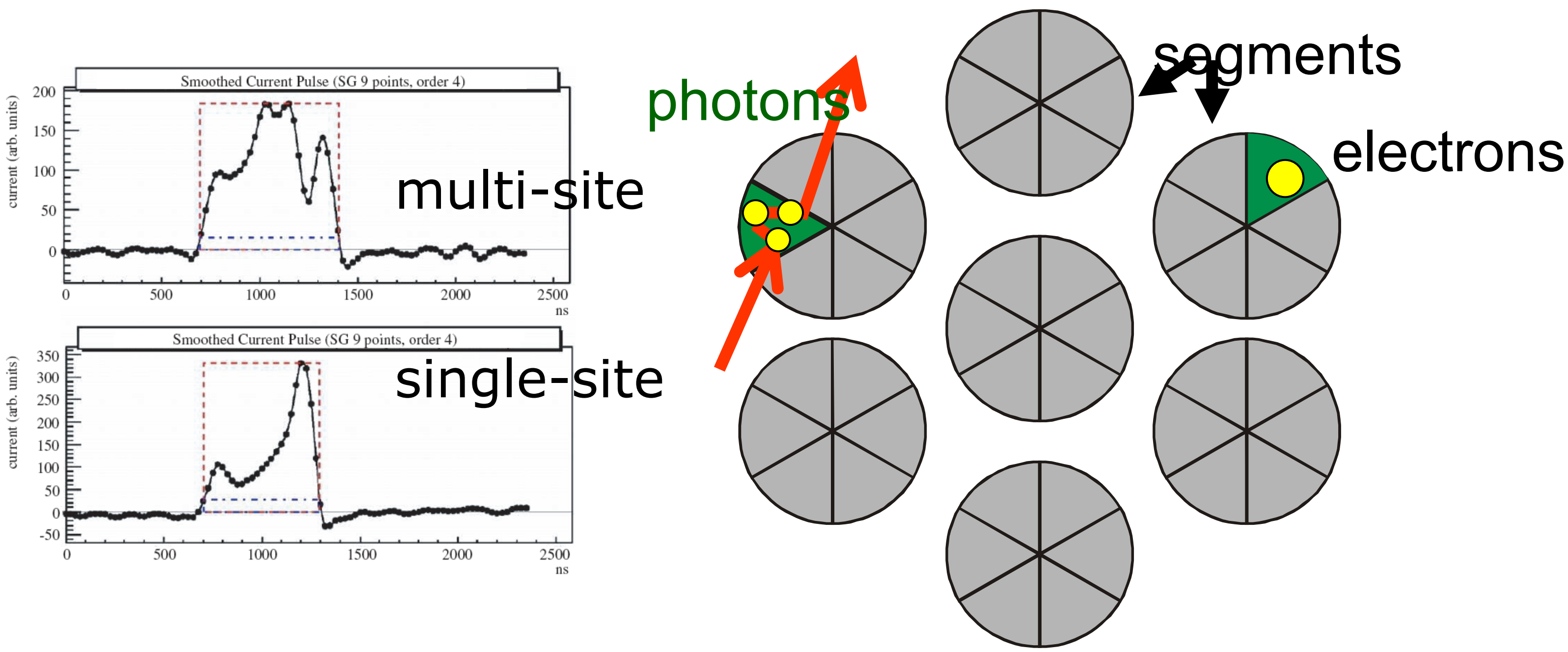
1. underground, shielding, energy window cut,
2. single detector & single segment cut,
3. pulse shape analysis.



Signal (2 electrons): single-segment event
Photon background: multi-segment event

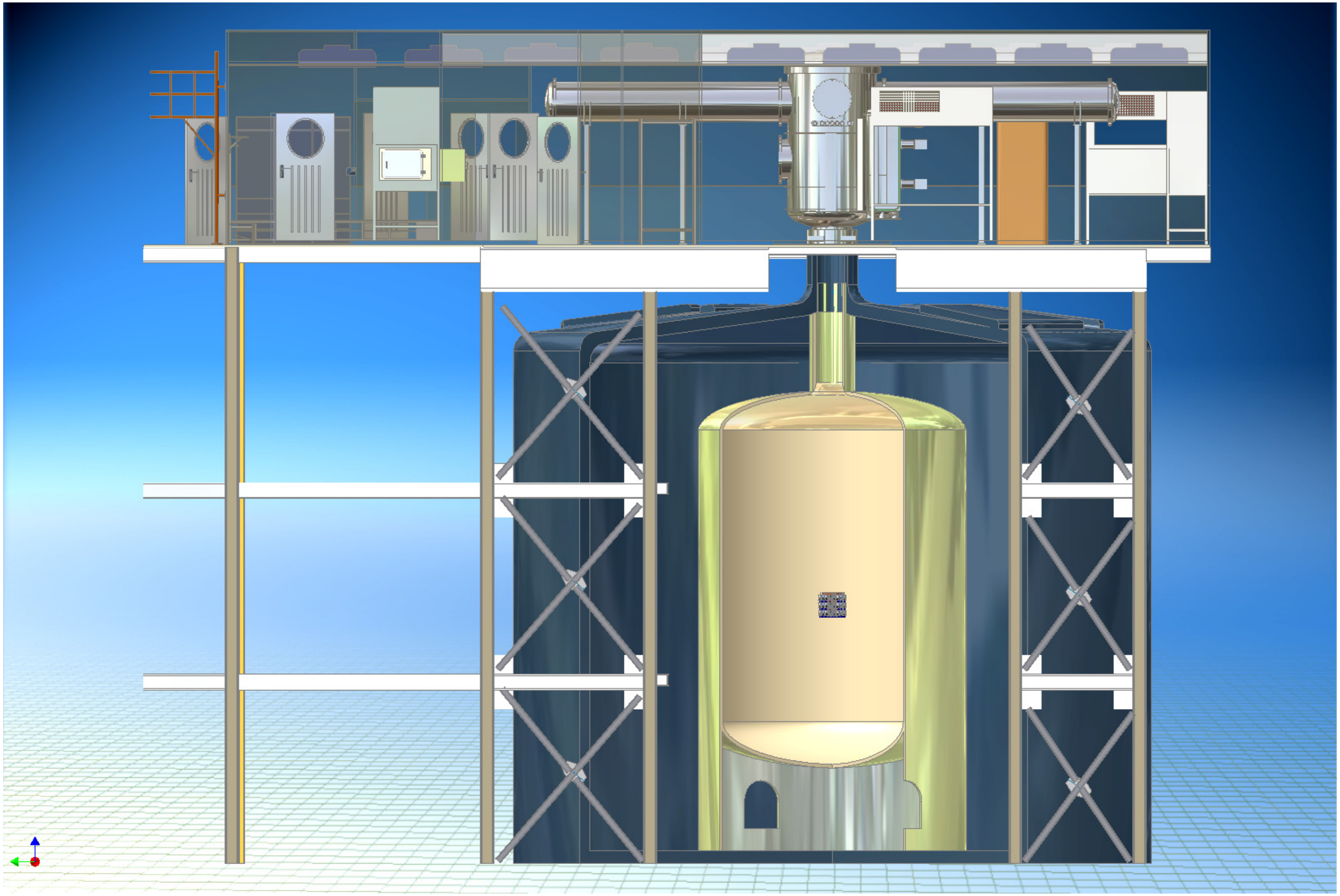
Remove background

1. underground, shielding, energy window cut,
2. single detector & single segment cut,
3. pulse shape analysis.

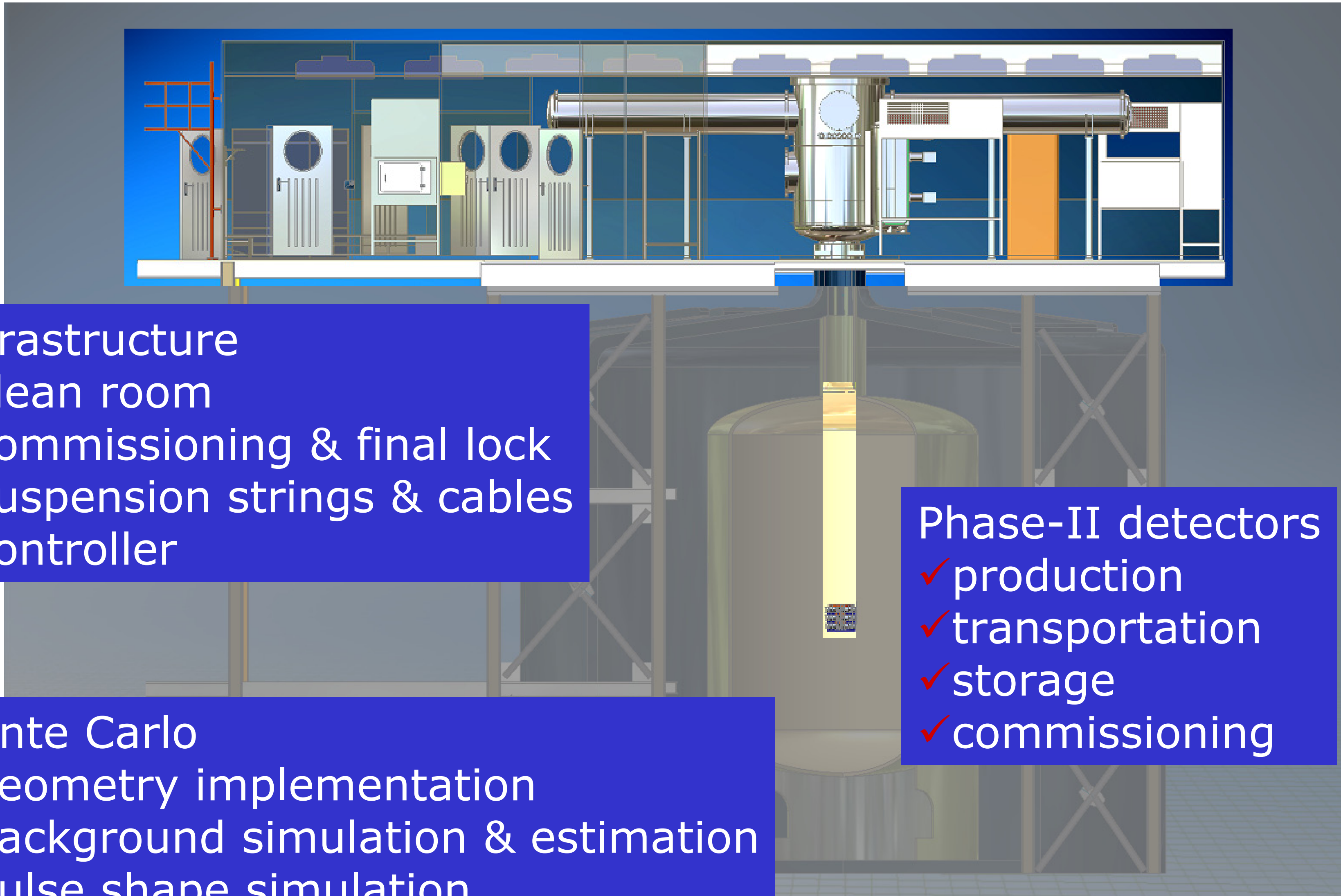


Signal (2 electron): single-site event
Photon background: multi-sit event

GERDA MPI Munich responsibilities



GERDA MPI Munich responsibilities



Infrastructure
- ✓clean room
- ✓commissioning & final lock
- ✓suspension strings & cables
- ✓controller

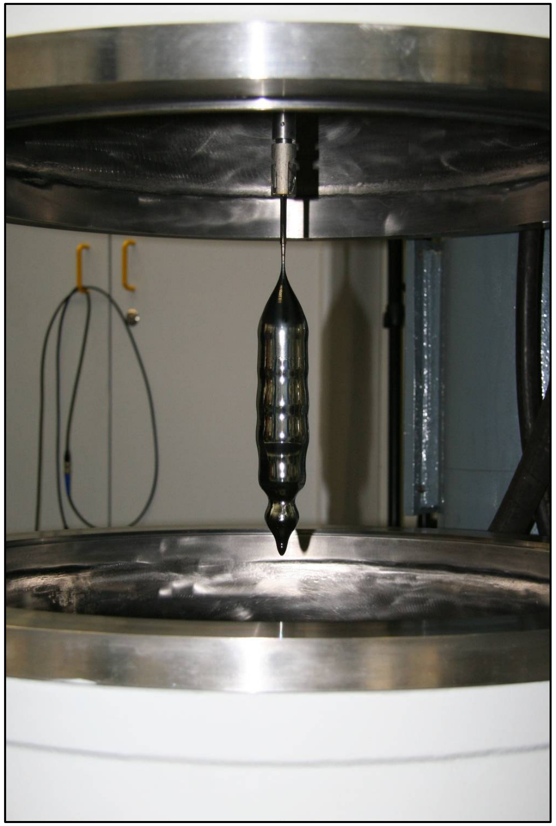
Phase-II detectors
- ✓production
- ✓transportation
- ✓storage
- ✓commissioning

Monte Carlo
- ✓geometry implementation
- ✓background simulation & estimation
- ✓pulse shape simulation

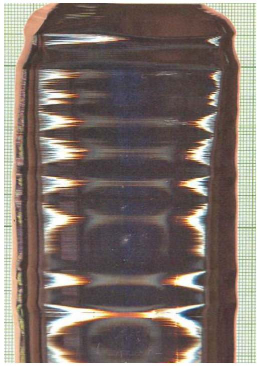
Analysis

Phase-II n-type segmented detector fabrication

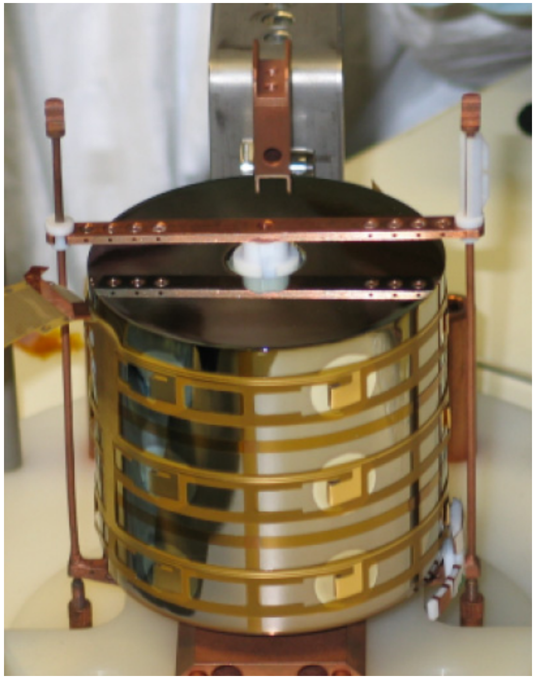
- 37.5 kg Ge with 88% enrichment, stored underground.
- 50kg ${}^{dep}GeO_2$ delivered, purified to >6N Ge metal successfully at PPM Pure Metals.
- n-type ^{dep}Ge crystals pulled with dedicated Czochralski puller at Institut für Kristallzüchtung (IKZ), Berlin.
- Net charge carrier density: 10^{11} cm^{-3} to 10^{13} cm^{-3} (required: 10^{10} cm^{-3})
- Puller components electropolished, restart soon.



- P-type crystal pulled at Canberra Oak Ridge.



GeDet: Ge detector development



true coaxial,
inner Φ 10mm,
outer Φ 75mm,
1.58kg,
18 segments,
  3-fold along z
  6-fold along ϕ

„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

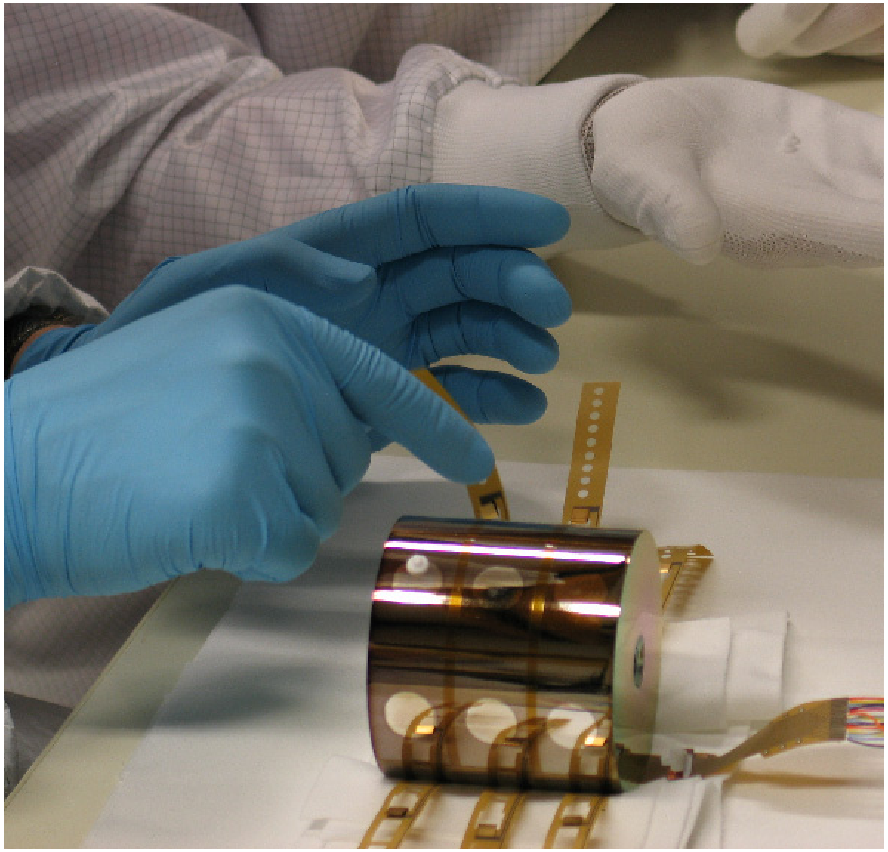
„Pulse shapes from electron and photon induced events in segmented high-purity germanium detectors“ Eur. Phys. J. C 52, 19-27 (2007)

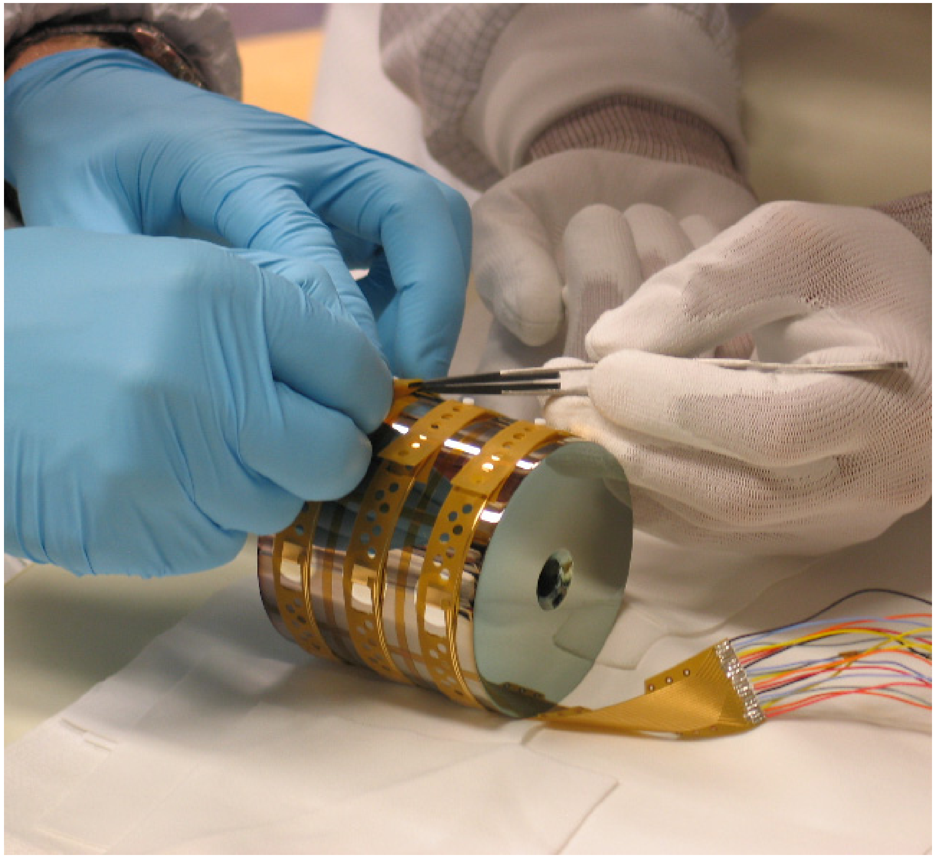
„Test of pulse shape analysis using single Compton scattering events“ Eur. Phys. J. C 54 425-433 (2008)

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

„Operation of an 18-fold segmented N-type HPGe detector in LN2“ 2009 JINST 4 P11008

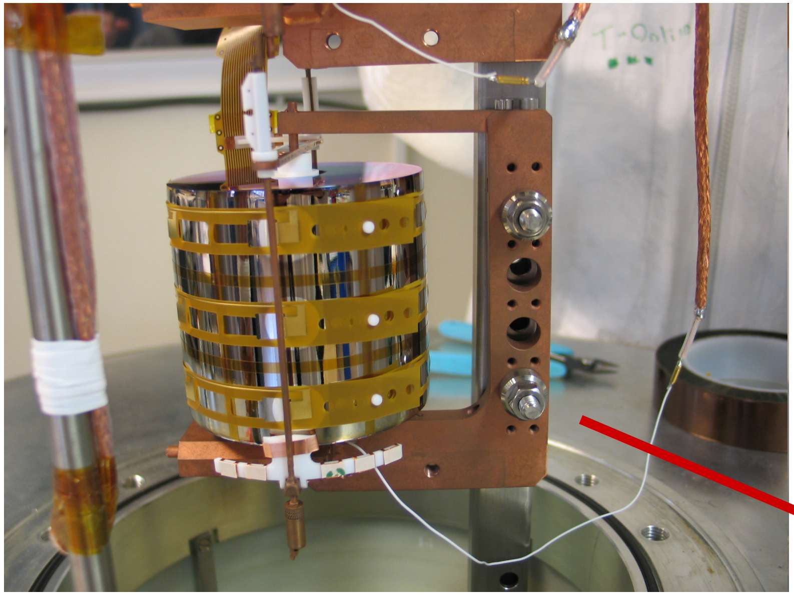
GeDet: Ge detector development

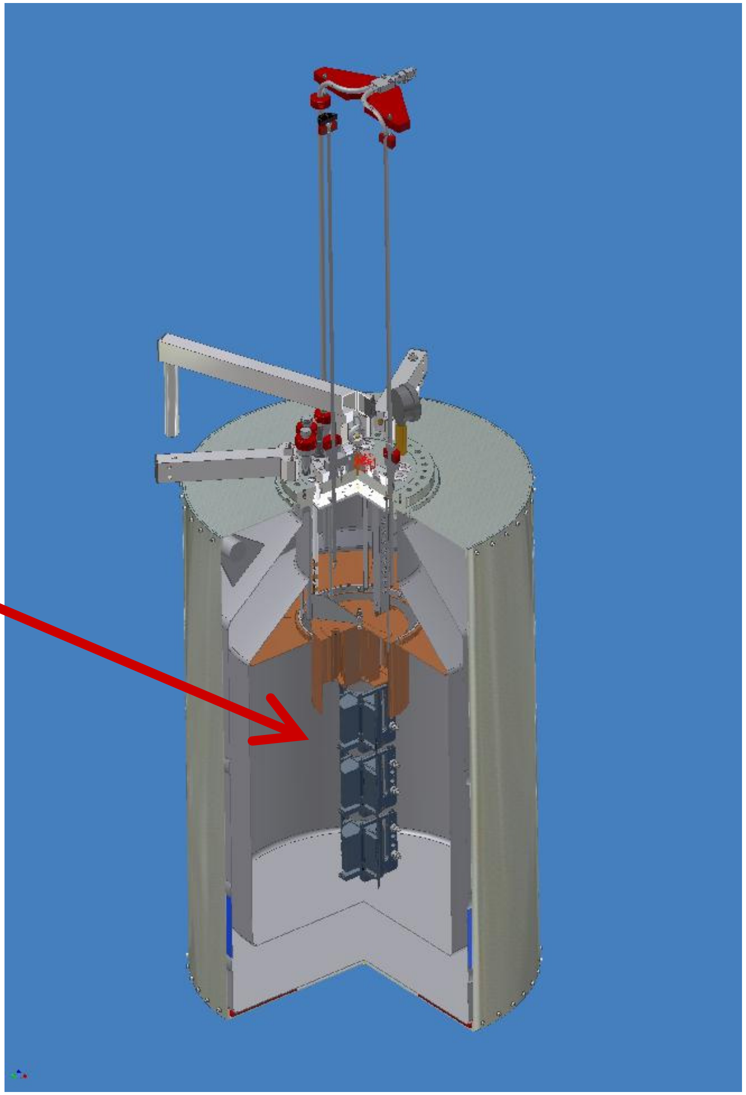




Replacing kapton cable,
able to operate detector with confidence.

GeDet: segmented detectors operated in LN_2 or LAr



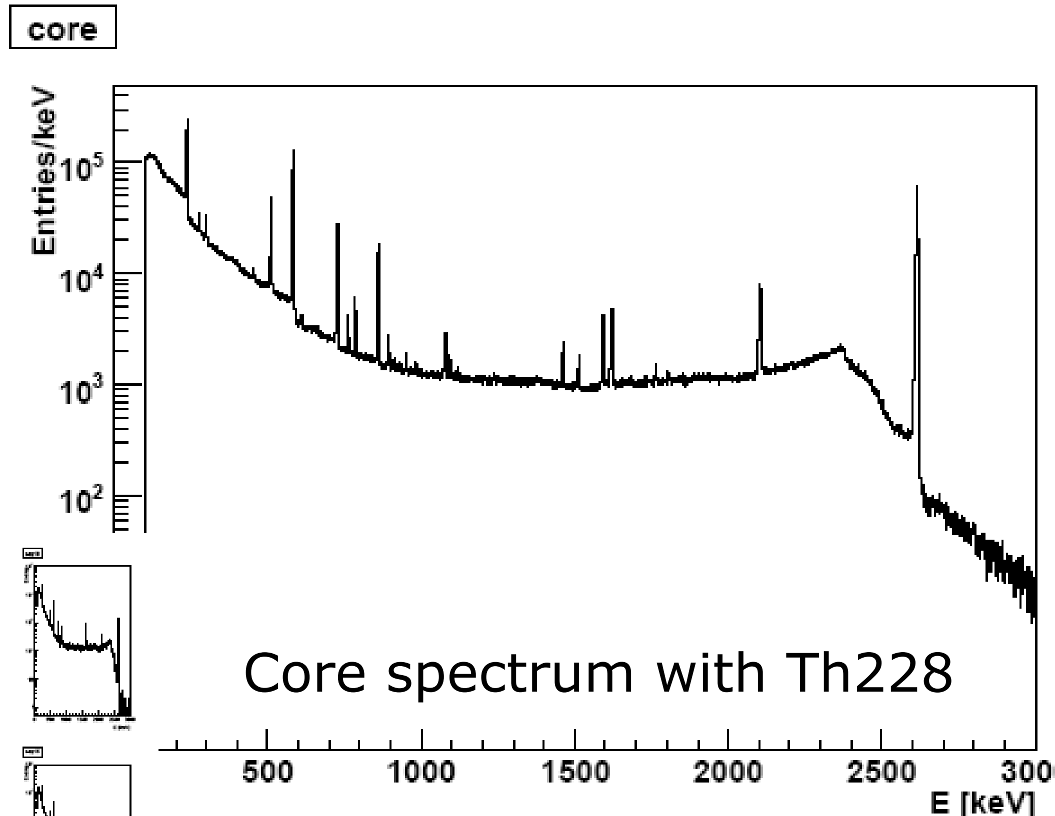


test stand able to handle
3 segmented HPGe in LN_2 or LAr

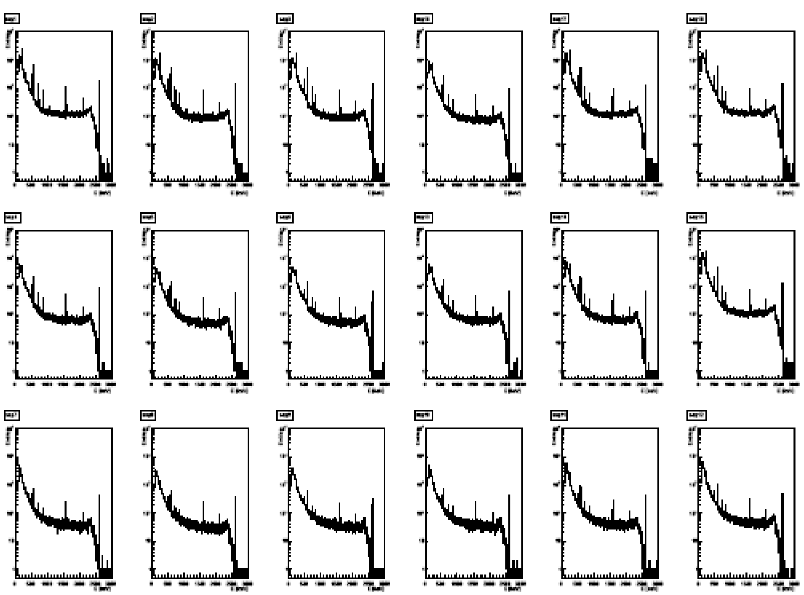
GeDet: segmented detectors in LN_2

FWHM at 1332keV:
core 4.1keV
segs 3.6-5.7keV
(all with warm FETs)

leakage current
35±5pA
stable for 5 months



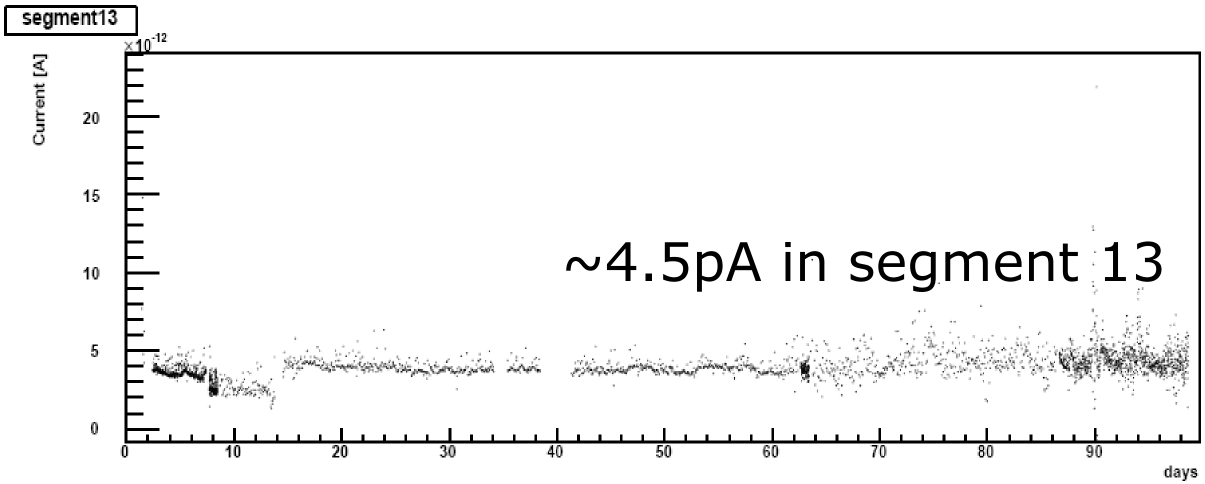
Core spectrum with Th228

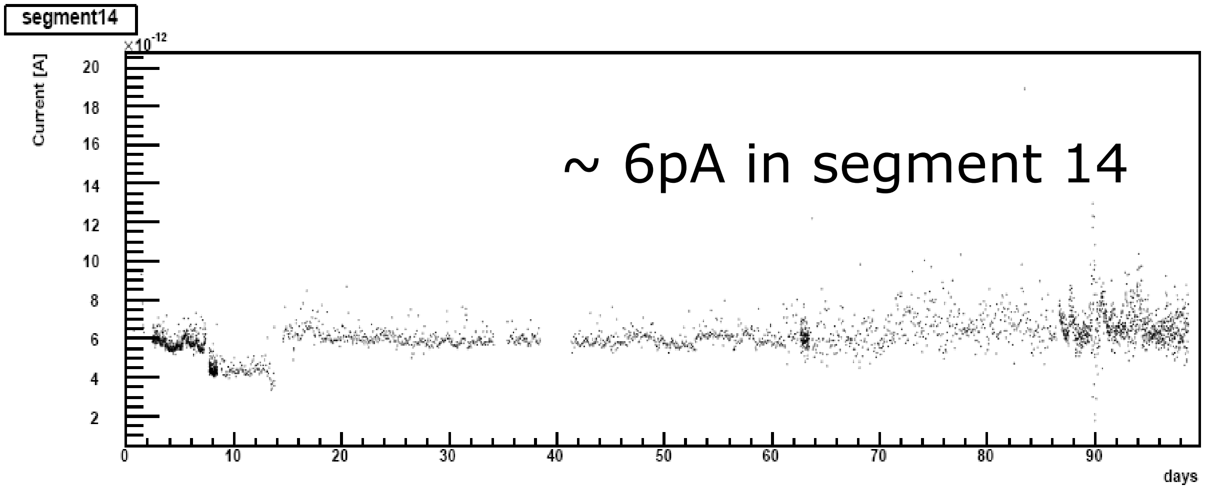

18 segment spectra

operation of an 18-fold segmented n-type HPGe detector in liquid nitrogen

I Abt *et al* 2009 JINST 4 P11008

GeDet: segmented detectors in LAr

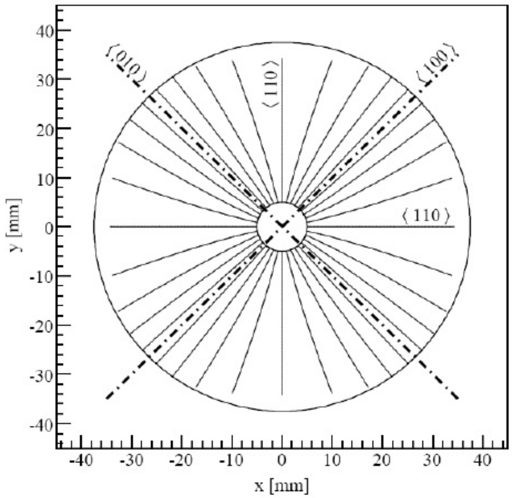


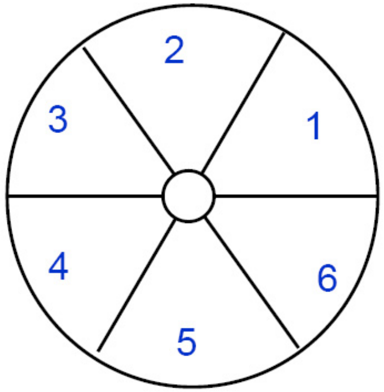


98 days in LAr with stable leakage current
(increase of LC observed with p-type, due to passivation layer).

GeDet: study electron/hole drift in segmented detectors

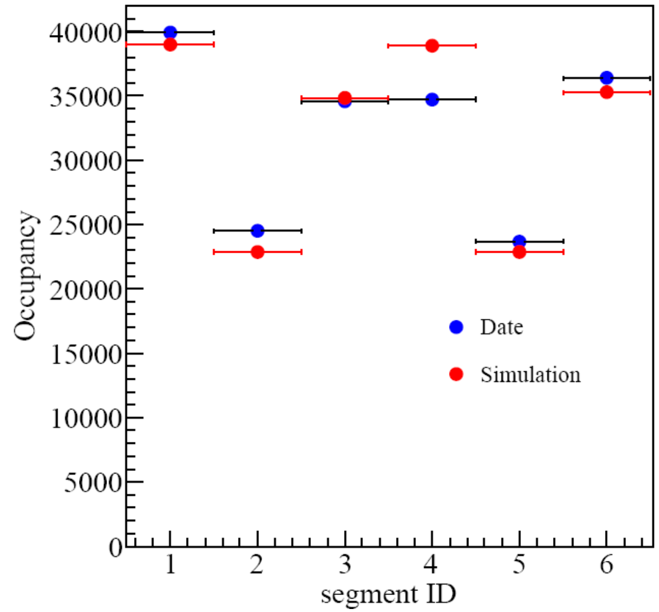
hole drift trajectory bended





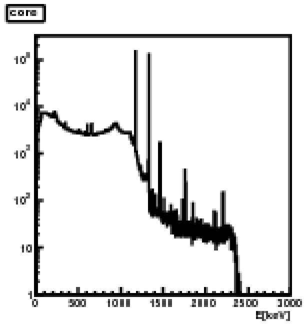
crystal anisotropy
→ different numbers of events
in segments with the same size.

assuming impurity $10^{10}/cm^3$
and 110 axis at $\phi=0$

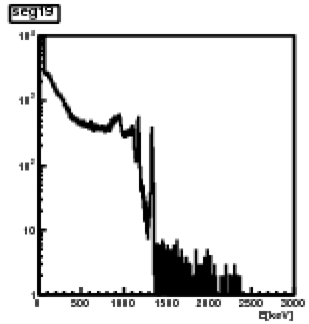


occupancy can be used to
→locate crystal axis,
→estimate impurity density.

GeDet: 19-fold segmented detector



core

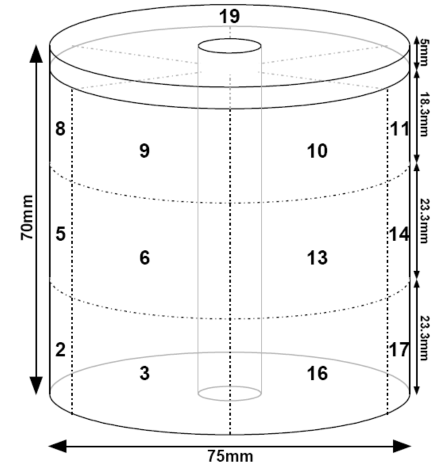


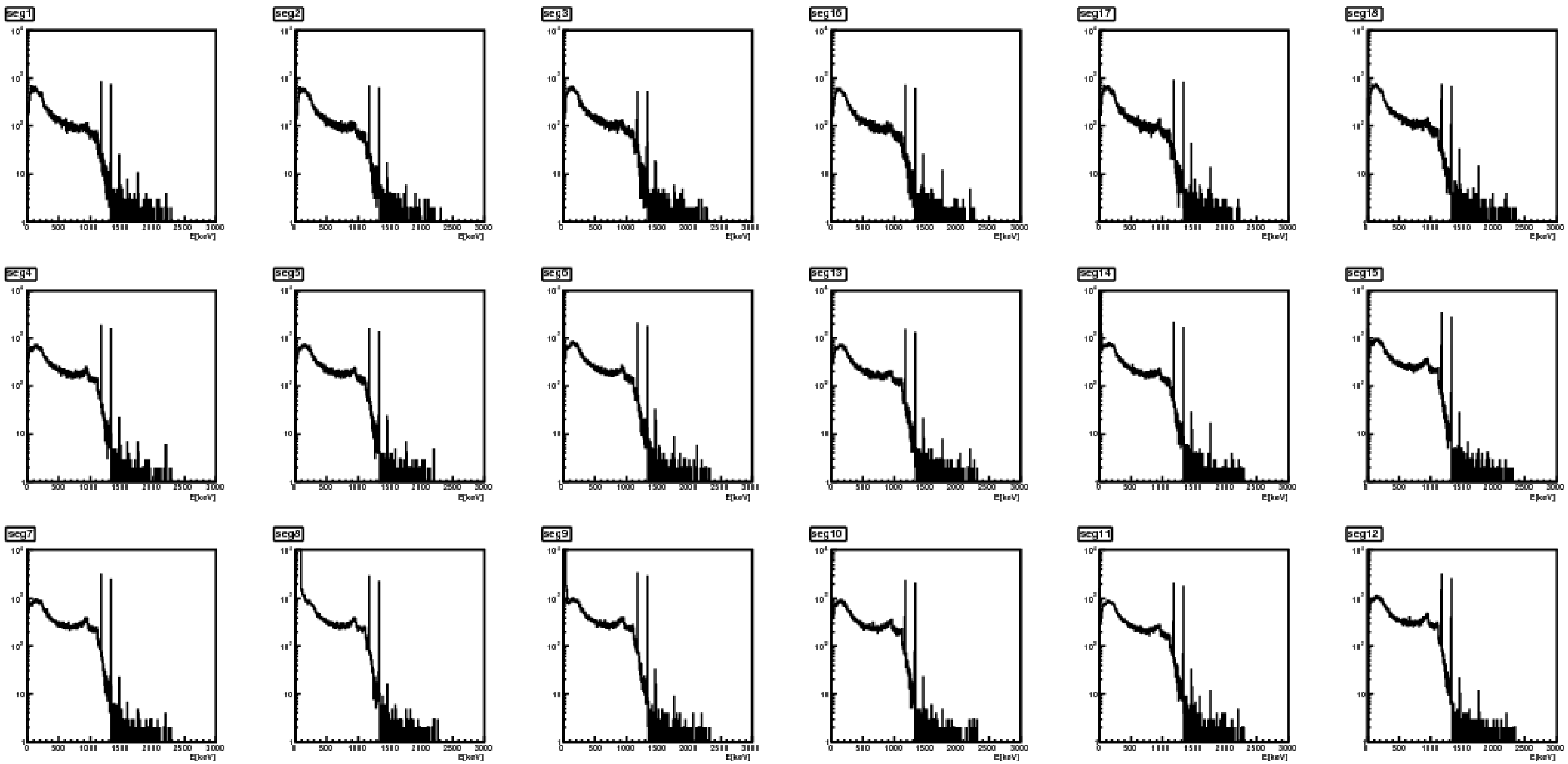
19th segment

detector operated in vacuum

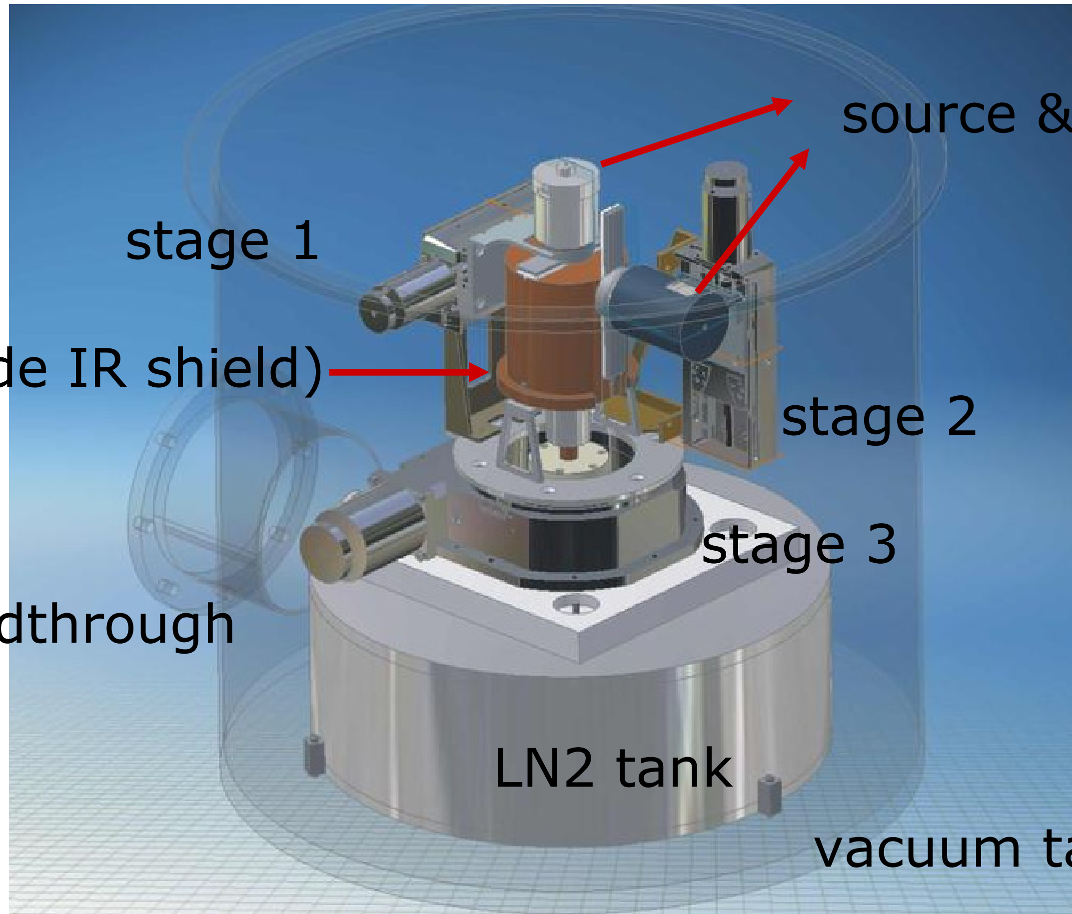
FWHM at 1332keV:

- core 2.7 keV
- segments 1-18: 2.4-2.9 keV
- 19th segment: 7.9 keV



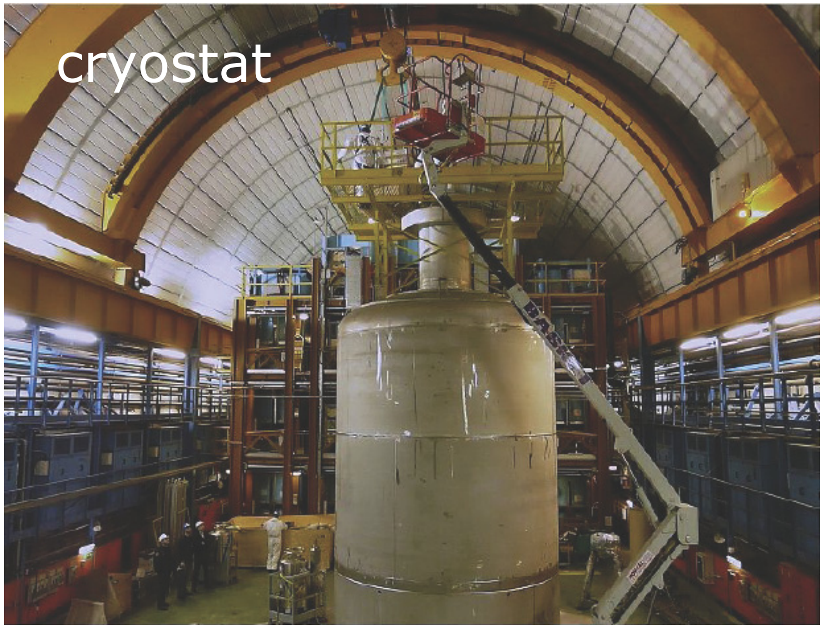


GeDet: one more new test stand under construction



3D scan with γ, α and laser.

GERDA status: cryostat & watertank

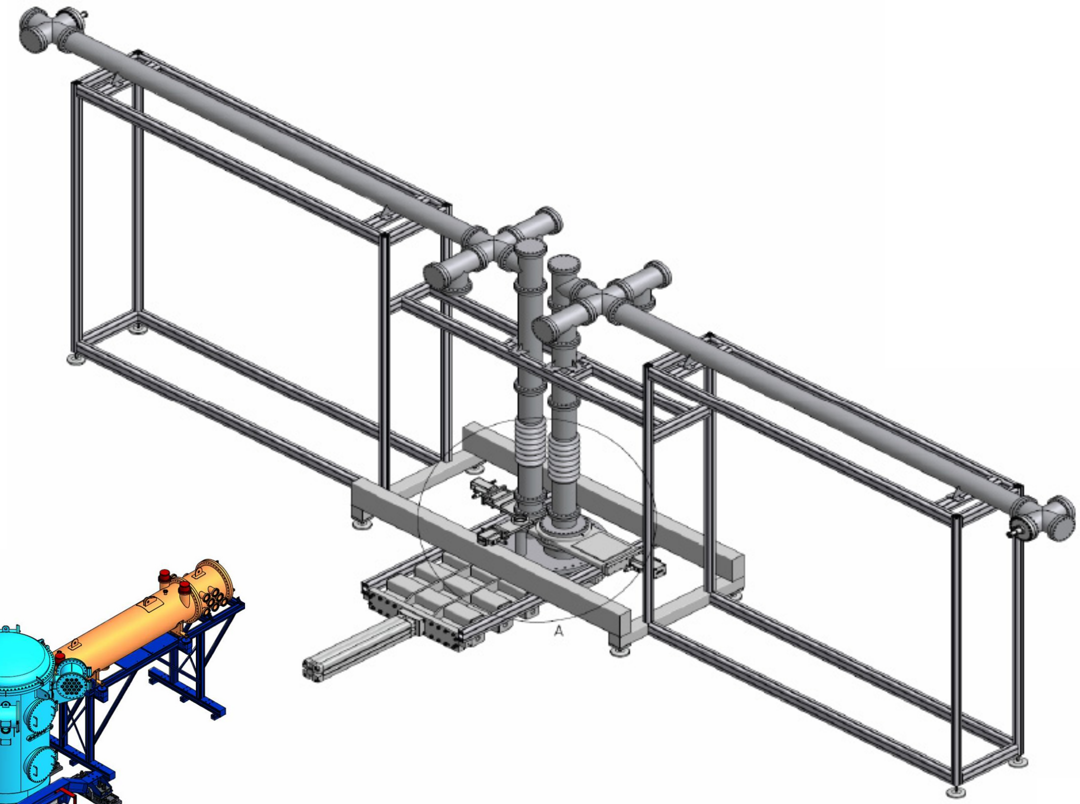


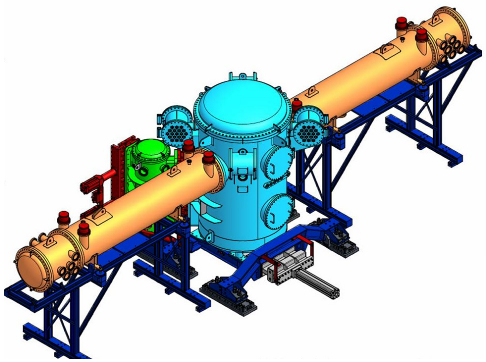
end 2008

GERDA status: cleanroom

May 2009

GERDA status: commissioning lock





(final lock)

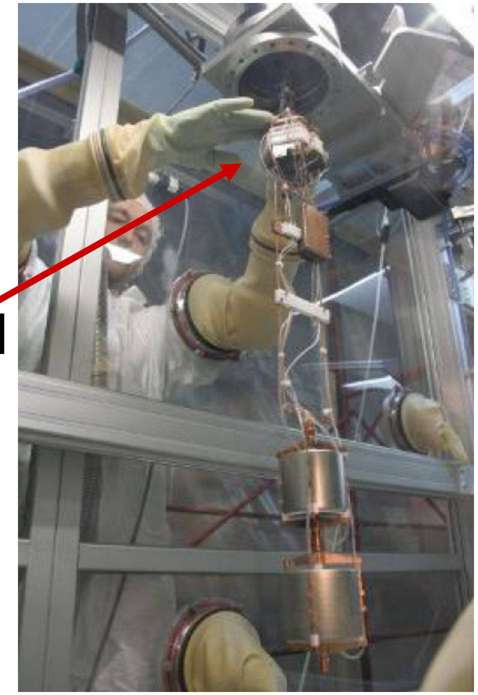
- can handle 2 strings with 6 detectors.
- goal: test whole GERDA setup, including detector operation.

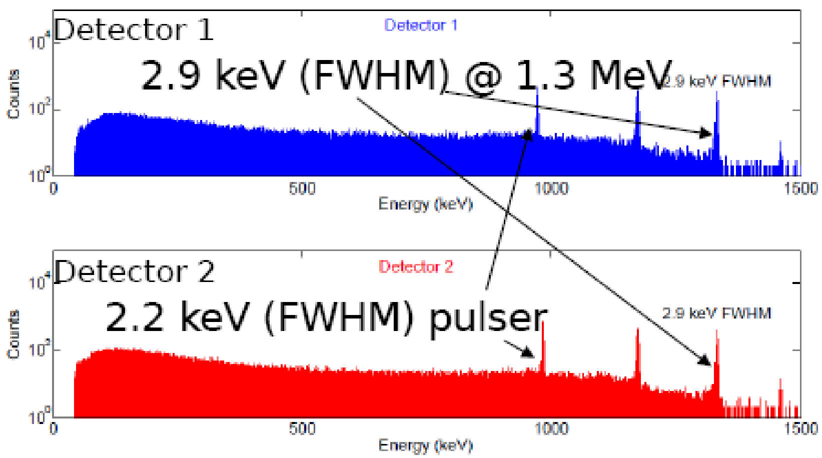
Commissioning locked tested aboveground at LNGS

mechanical shortfalls identified,
partially redesigned, new lock under construction,
will be delivered to LNGS early 2010.

Commissioning locked tested together with matrix & cables

matrix and cables

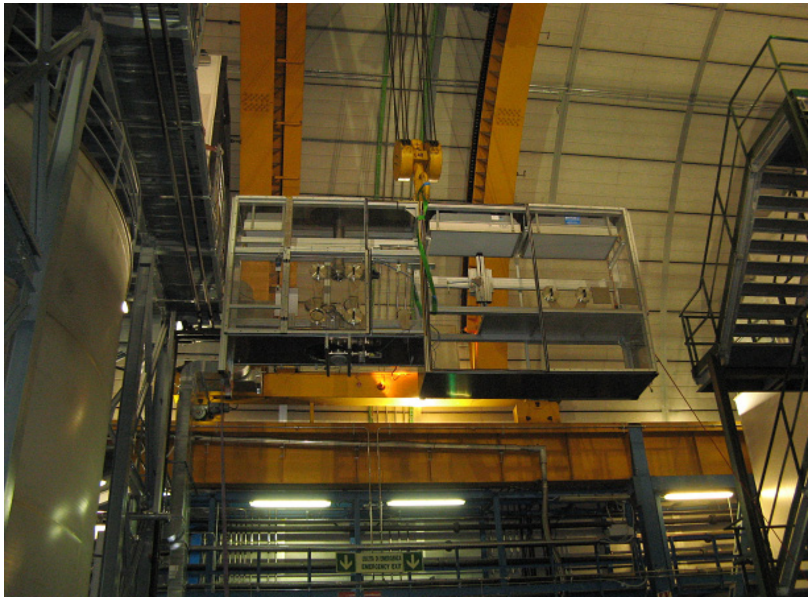




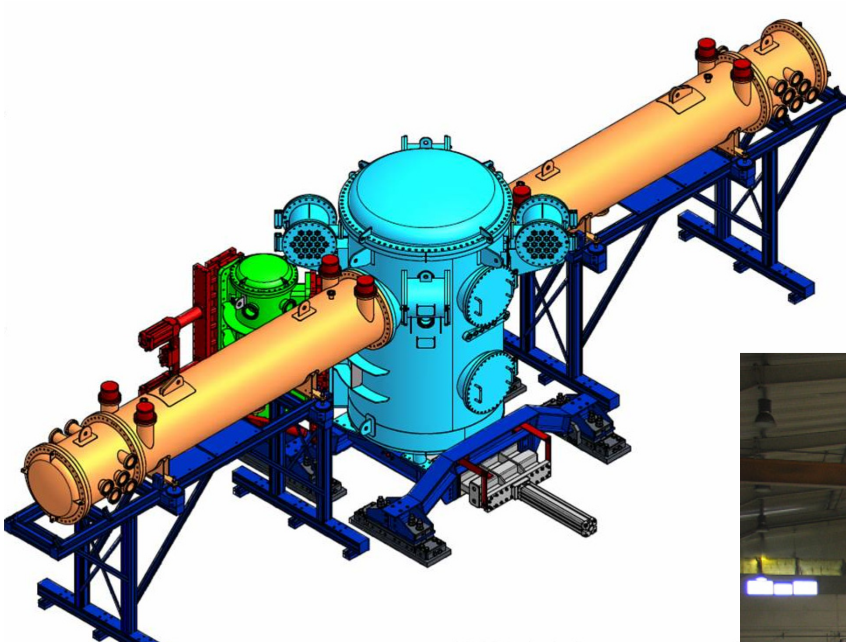
Best resolution achieved in setup: 2.7 keV (FWHM)

Signal transmission line satisfies requirement.

Glovebox transported to cleanroom underground



Final lock status

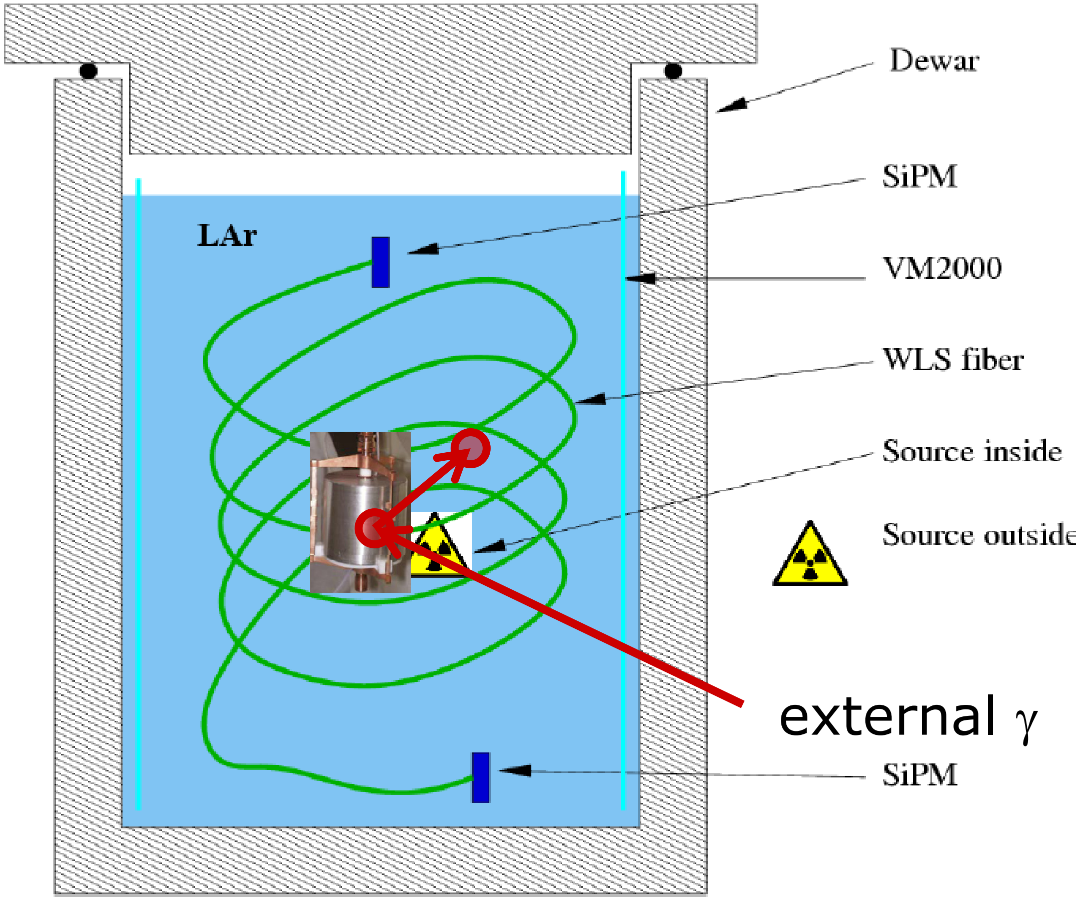


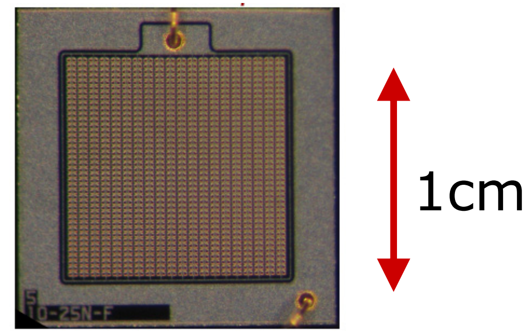
- to operate all Phase-I & -II detectors,
- design finished, under construction, installation at MPI early 2010.

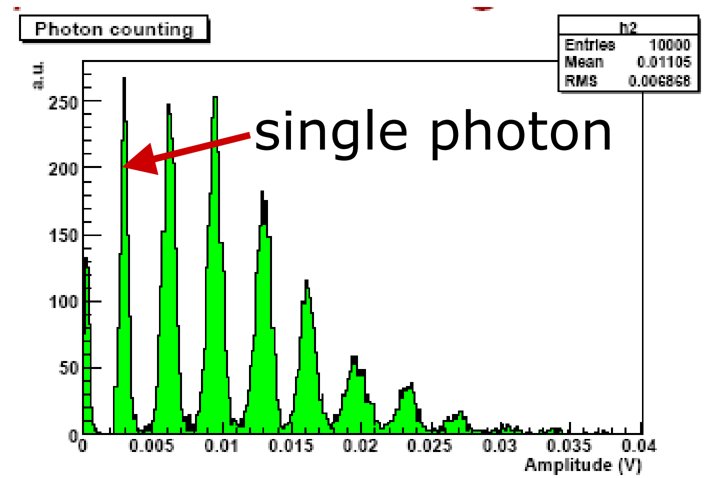
Bg reduction R&D: use liquid argon scintillation as veto

veto background by tagging extra energy in LAr

SiPM: array of Geige-mode APD, dark rate reduced by 10E6 in LAr

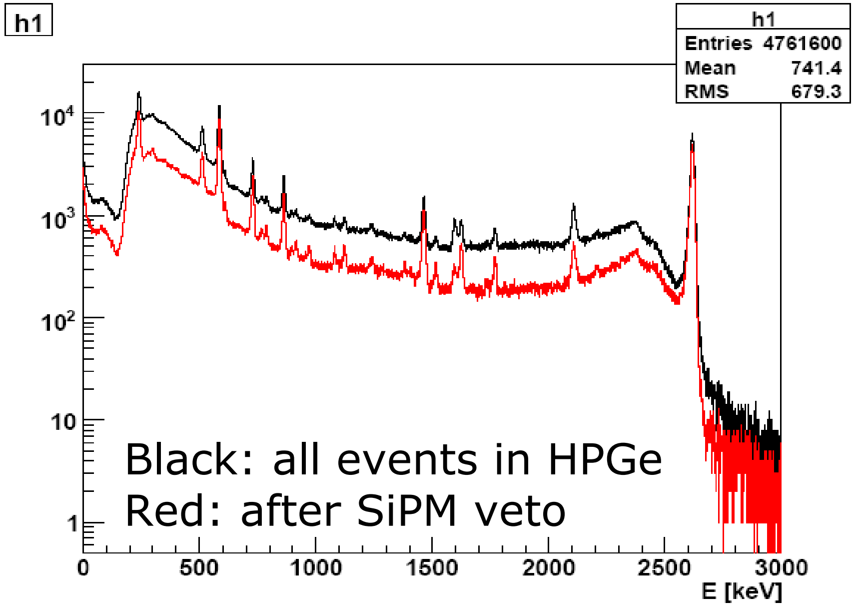


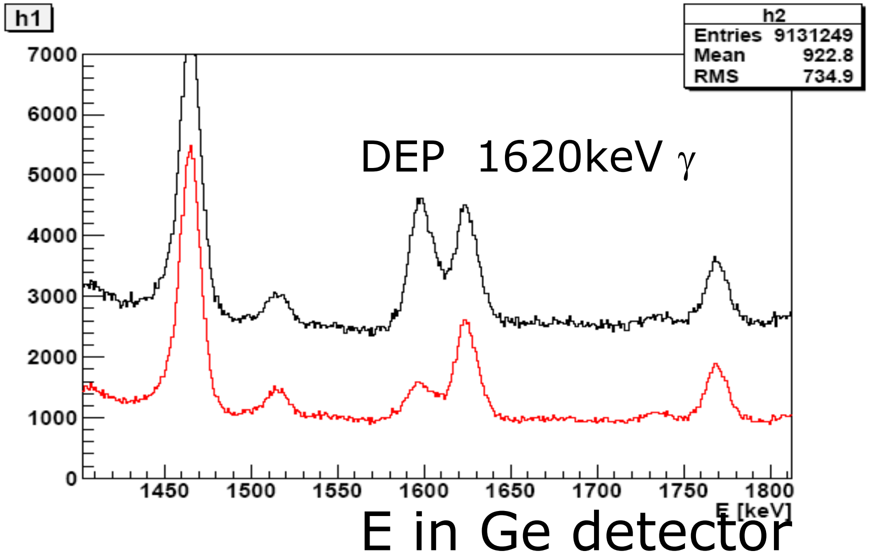




energy in liquid argon → 128nm scintillation light
→ shift to ~400nm by VM2000 & WLS-fiber → detected by SiPM

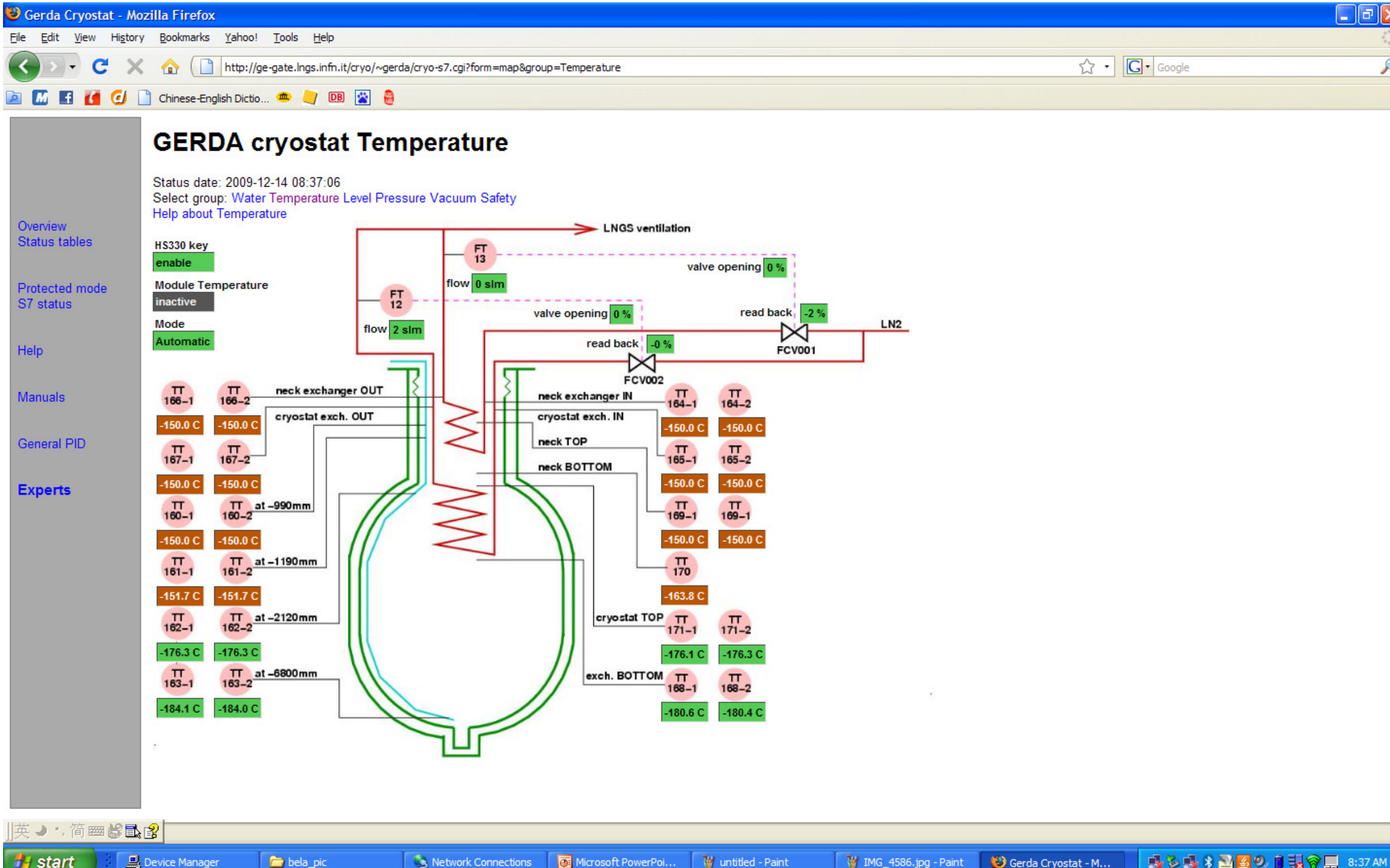
Detect liquid argon scintillating light with SiPM





- operate SiPM together with HPGe,
- suppression factor 2 at 2MeV,
- next: focus on scintillation light collection efficiency

Current GERDA status at 8:30am today



filling liquid argon now,
will fill to full before Christmas.

Summary

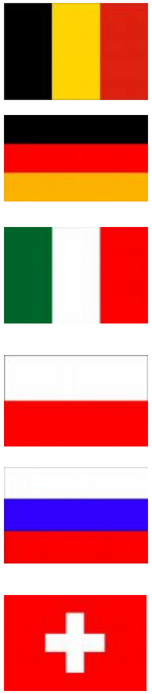
GERDA well progressing
- cleanroom ready,
- commissioning lock tested,
- filling LAr,
- install modified commissioning lock at LNGS Mar. 2010,
- start commissioning phase,

- Phase-II detector: segmented or BEGe ?

GeDet with many studies
- 18-fold segmented stable operation in LN2/LAr,
- 19-fold segmented studied,
- pulse shape simulation on the way,
- “super” test stand under construction.
- SiPM for LAr scintillation promising.

stay tuned

GERDA collaboration



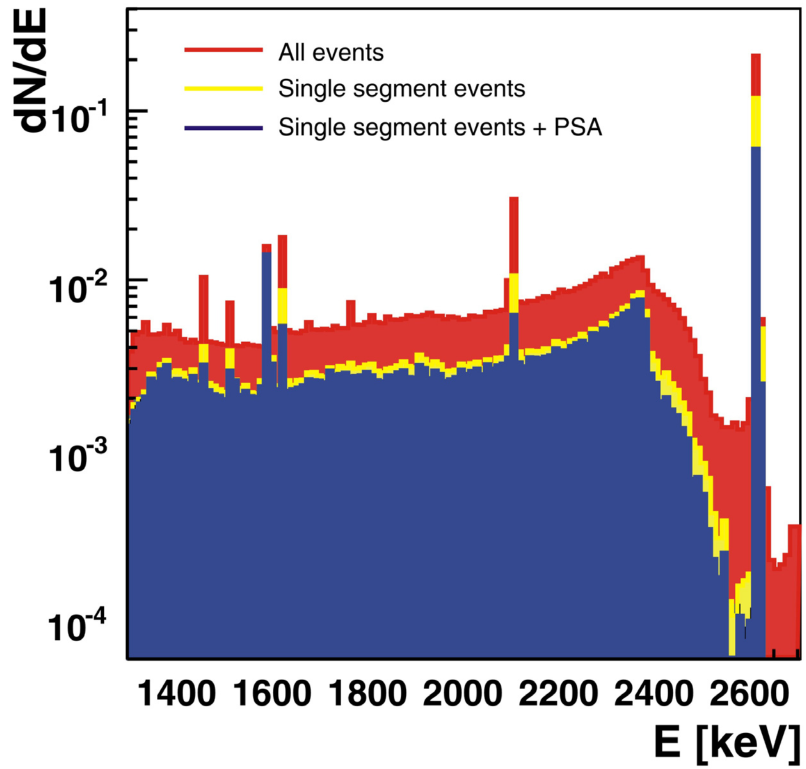
Institute for Reference Materials and Measurements, Geel, Belgium
Institut für Kernphysik, Universität Köln, Germany
Max-Planck-Institut für Kernphysik, Heidelberg, Germany
Max-Planck-Institut für Physik (Werner-Heisenberg-Insititut), München, Germany
Physikalisches Institut, Universität Tübingen, Germany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

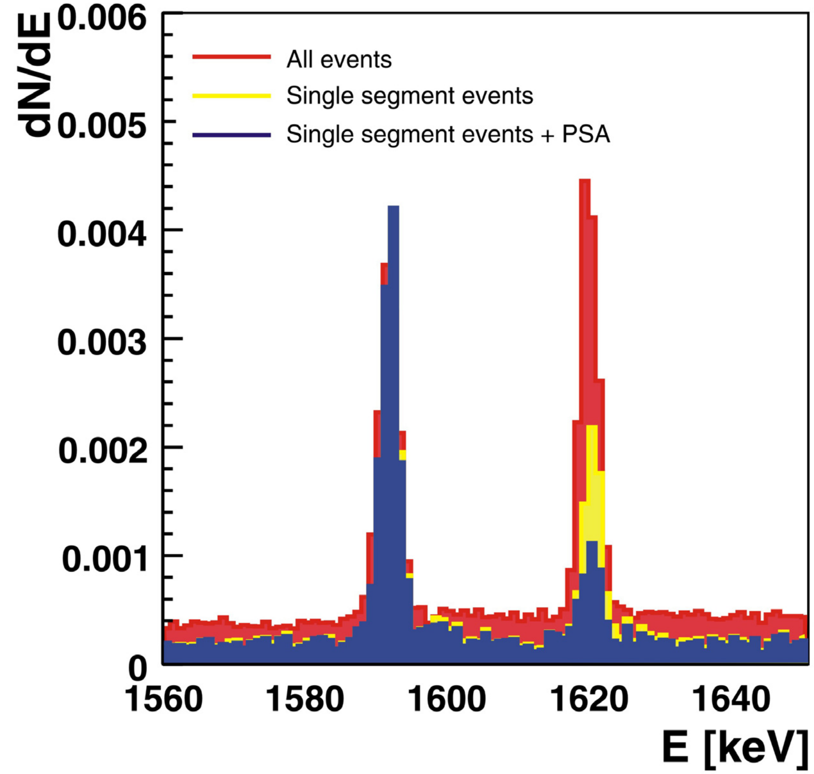
~97 scientists.

Backup slides

GeDet: photon background reduction with segmented detector

Detector in vacuum exposed to Th228 source





Double-escape peak
(single-site dominant)

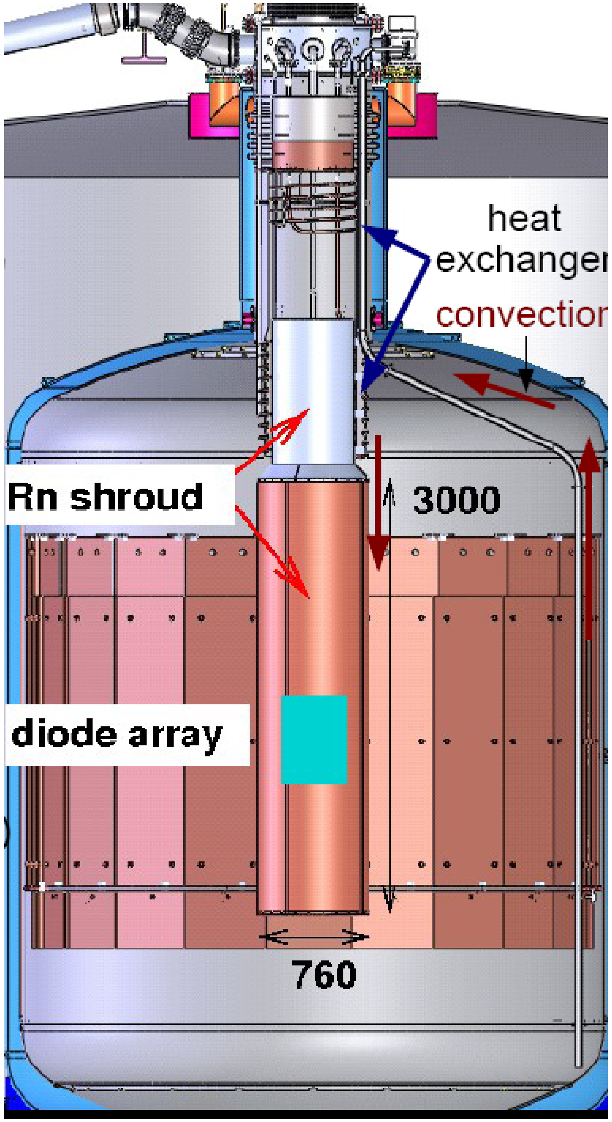
1620keV Bi212
(multi-site dominant)

segment 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

(depend on source position)

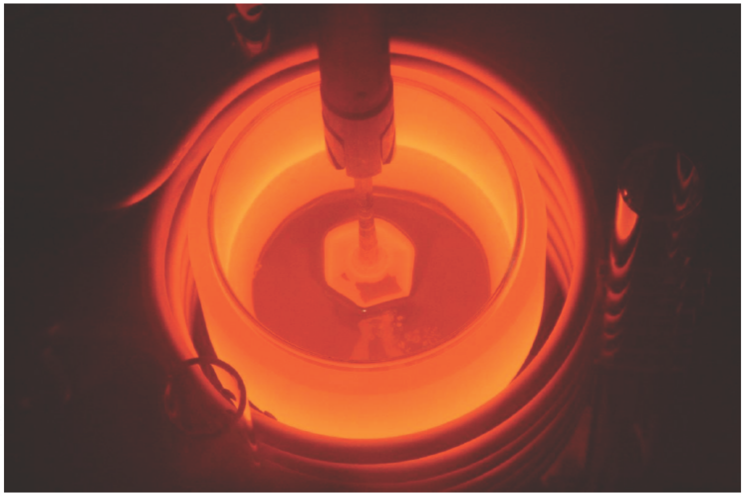
GERDA status: shroud to avoid convection & Rn contamination

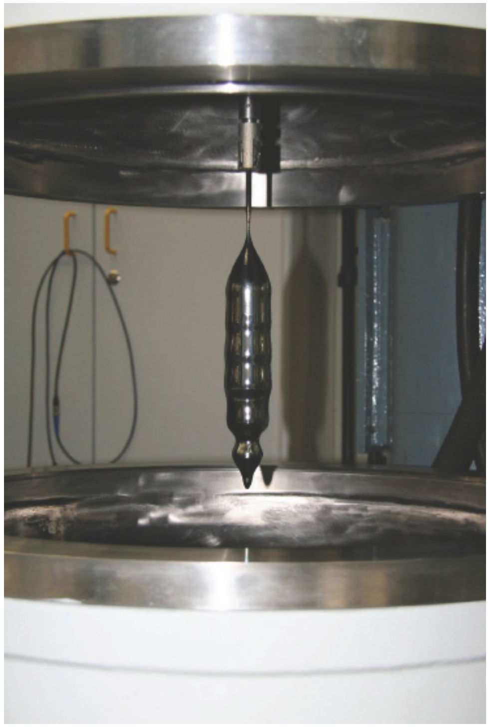


Phase-II segmented detector production

Ge enrichment	53kg enriched GeO_2 & 50kg depleted GeO_2 purchased from Russia. ✓
metal reduction and purification	PPM Pure Metals, Langelsheim, Germany, tested with dep. GeO_2, reached >6N, contract for purifying enriched GeO_2 signed. ✓
crystal pulling	n-type crystal pulling at Institut für Kristallzüchtung (IKZ), Berlin, testing with dep. GeO_2, net charge carrier concentration $4 \times 10^{11}/cm^3$?
detector production	n-type 18-fold at Canberra Lingolsheim, 4 prototype detectors (natural Ge) delivered. ✓

Phase-II segmented detector fabrication

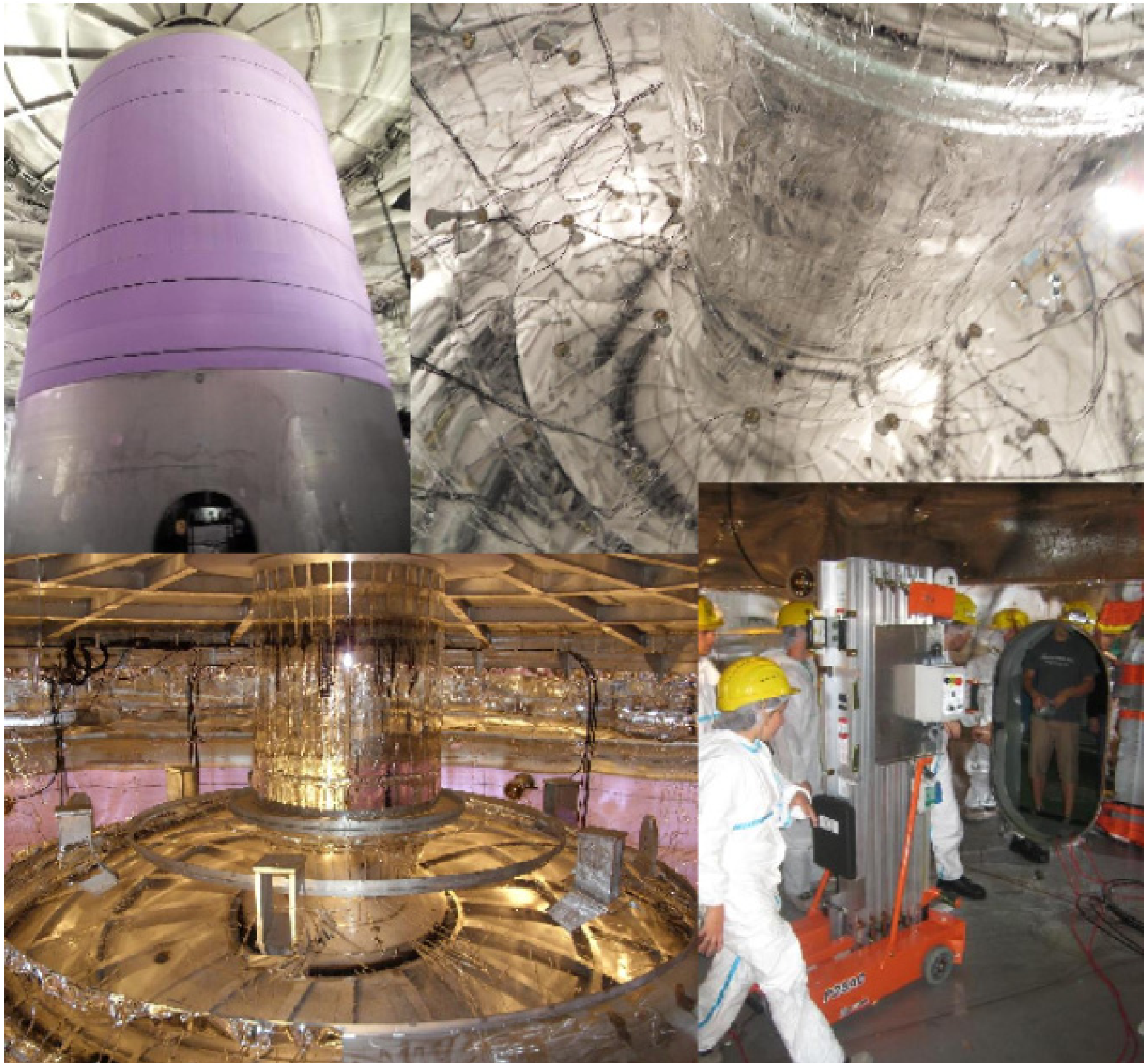




- 30kg dep. Ge from PPM.
- best net impurities $4x10^{11}/cm^3$, Arsenic dominate, from puller itself

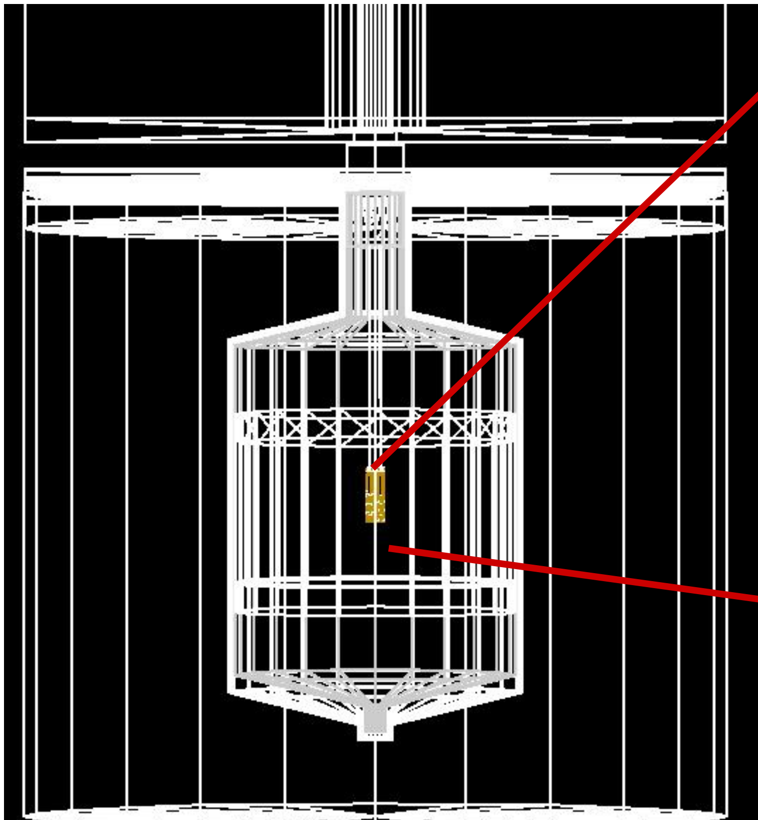
- puller dismantled, electropolished, seals replaced, reassembled, restart pulling end of 2009.

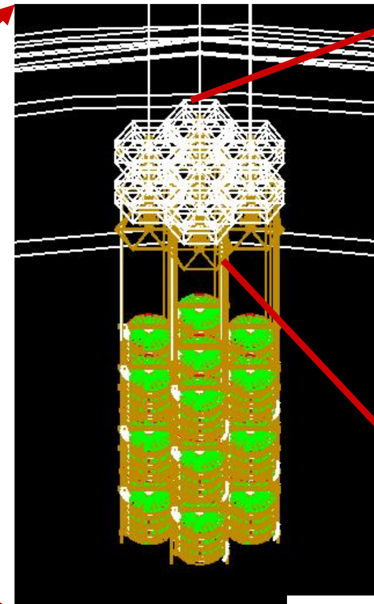
GERDA status: muon veto inside water tank

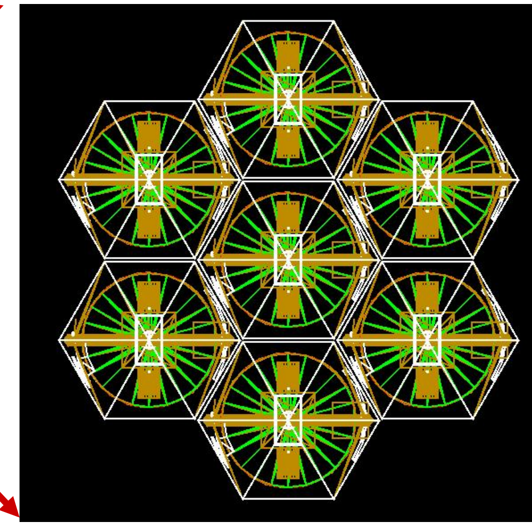


Simulation campaign with Monte Carlo package MaGe

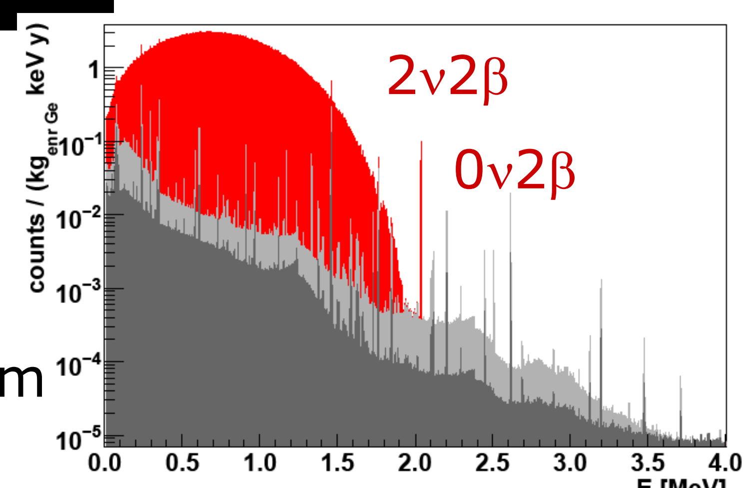
- Geant4-based, developed together with Majorana.
- optimized for low energy & low bg.
- code sharing & physics verification.







background from
detector holder



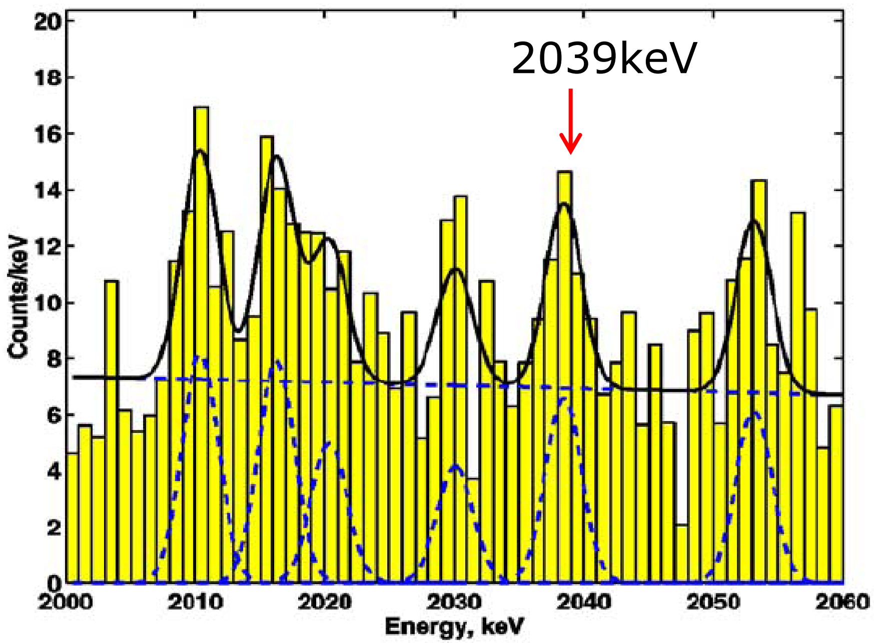
Heidelberg-Moscow experiment

exposure[kg·y]	71.1
B [counts/kg·keV·y]	0.11
$T_{1/2}$ limit (90%CL)[y]	$1.9 \cdot 10^{25}$
"Evidence for $0\nu\beta\beta$" H.V.Klapdor-Kleingrothaus, etc., Phys. Lett. B 586 (2004) 198-212	$1.2 \cdot 10^{25}$ (0.69-4.18 3σ)

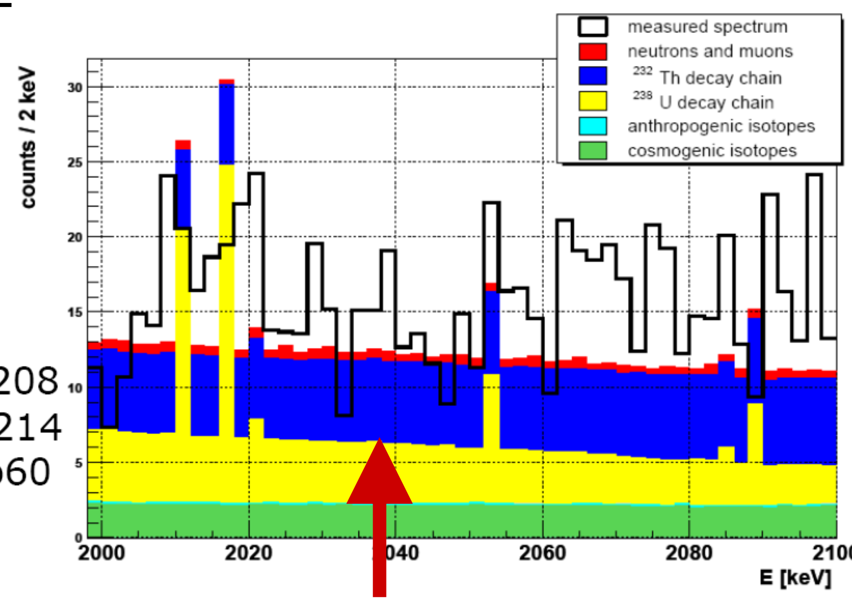
Background index B:
counts/kg·keV·y

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

0.1·10keV·71.1 = ~70 bg



Tl208
Bi214
Co60



background, dominated by γ from shielding

Effective majorana neutrino mass by $0\nu\beta\beta$

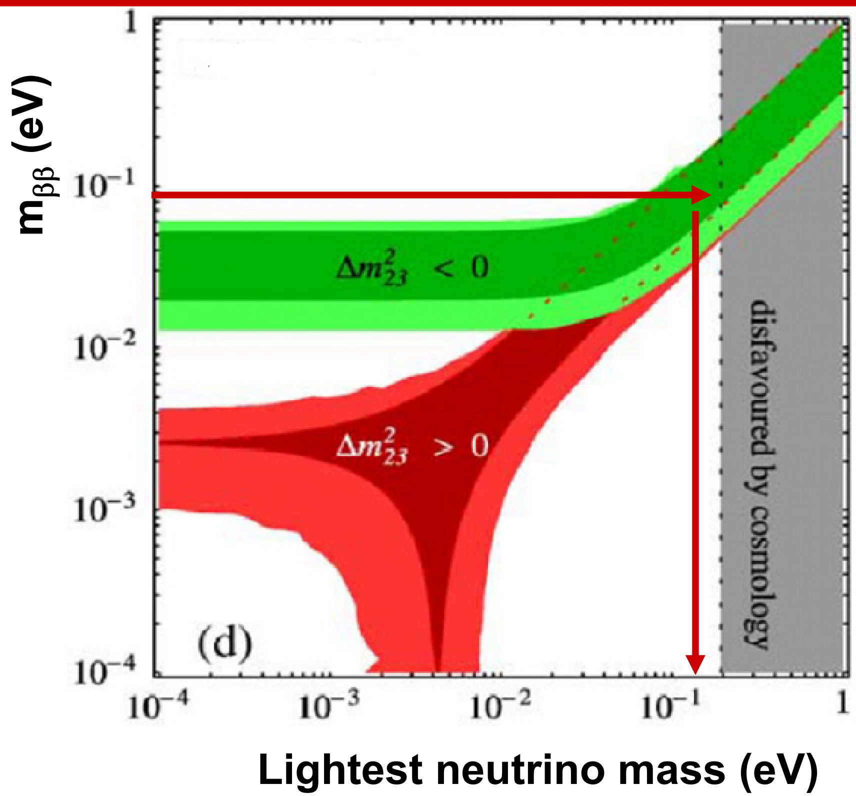
half life $\left[T_{1/2}\right]^{-1} = G(^{2}Q,Z)\cdot\left|M^{GT} - \frac{g_V^2}{g_A^2}M^F\right|\cdot\langle m_{\beta\beta}\rangle^2$

Phase space

nuclear matrix element

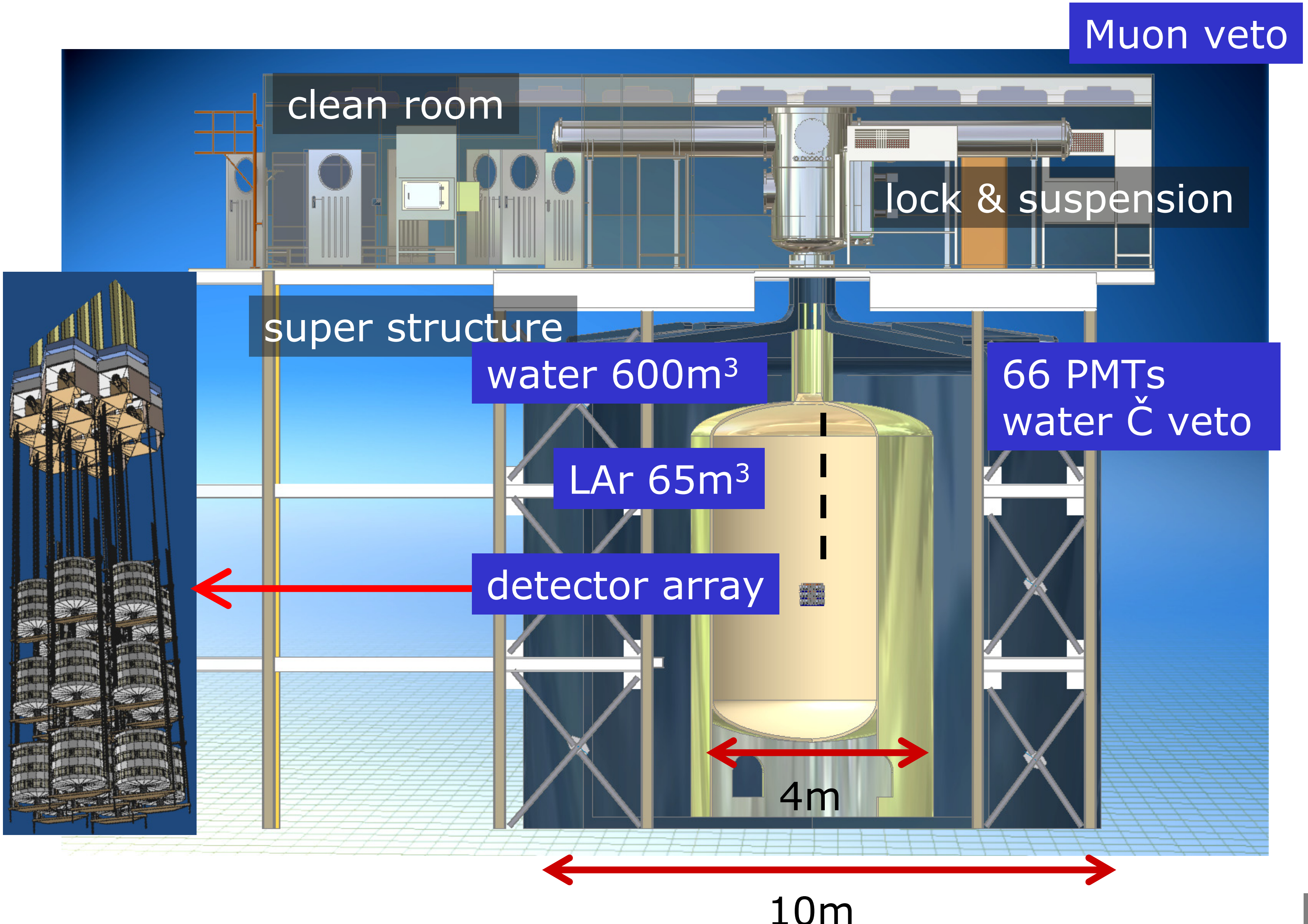
effective mass $m_{\beta\beta}$

$$\langle m_{\beta\beta}\rangle = \left|\sum_j m_j U_{ej}^2\right| = \left|m_1\cdot|U_{e1}|^2 + m_2\cdot|U_{e2}|^2 e^{i(\alpha_2-\alpha_1)} + m_3\cdot|U_{e3}|^2 e^{i(-\alpha_1-2\delta)}\right|$$

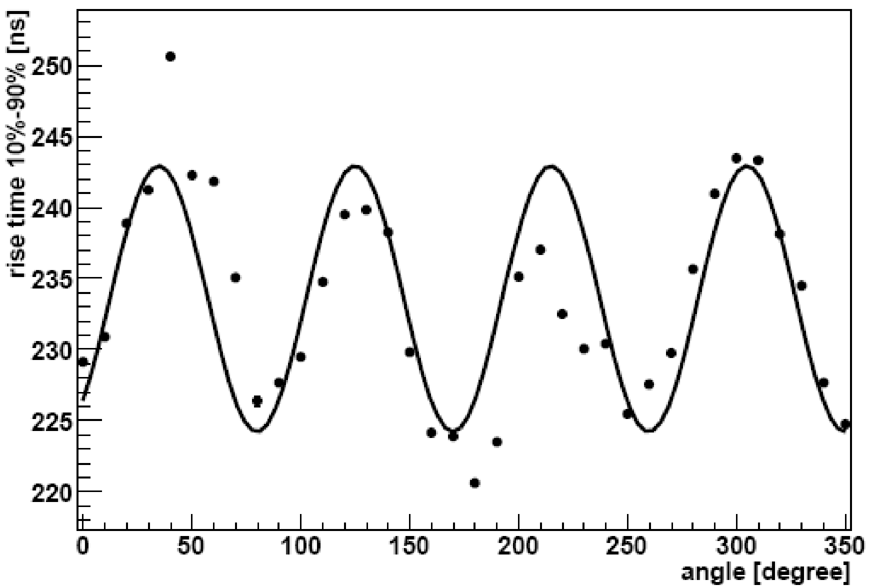


$0\nu\beta\beta$ $T_{1/2}$ >
10^{15} x age of Universe

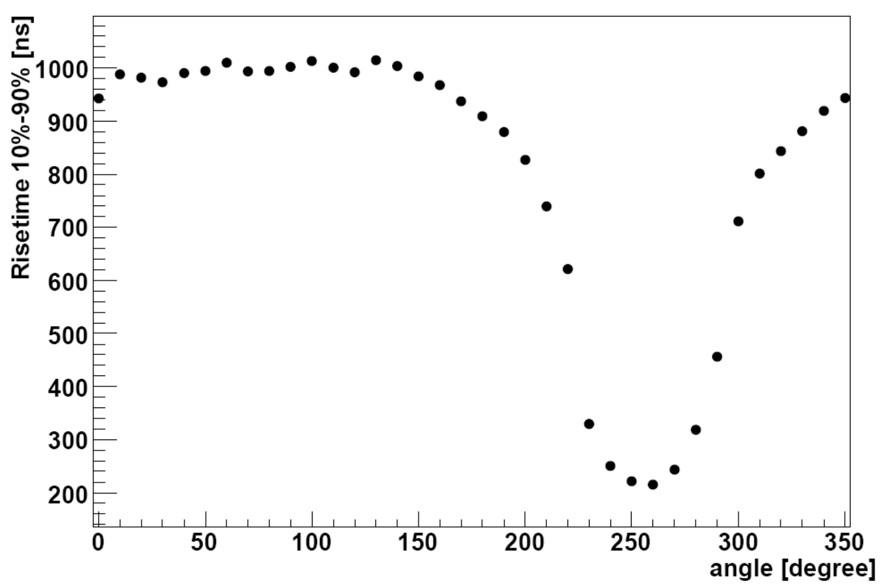
GERDA design



GeDet: 19-fold segmented detector



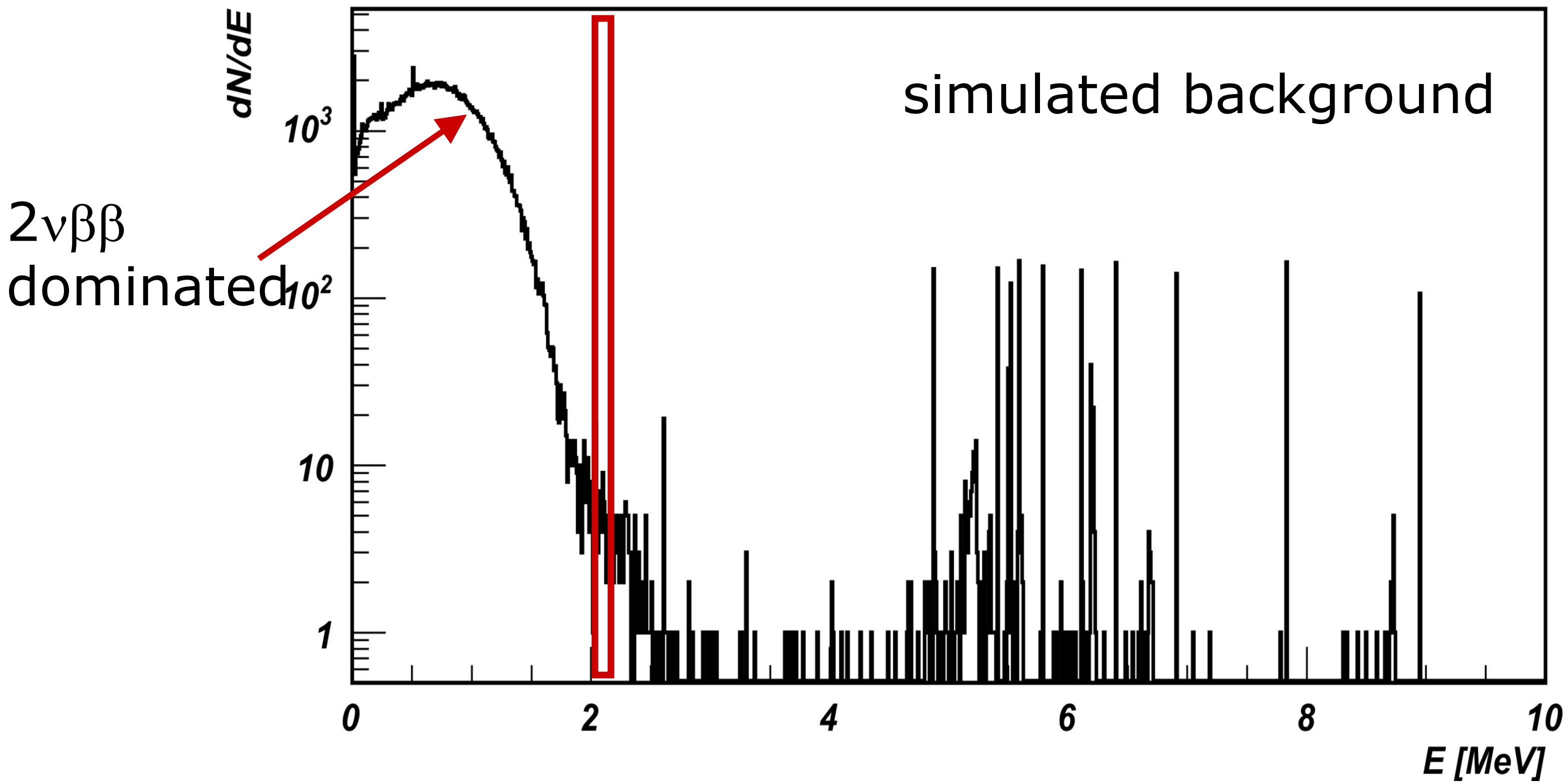
Rise time along ϕ in middle seg, oscillation due to crystal axis,



Rise time along ϕ in segment 19, possible electric field distortion?

Remove background

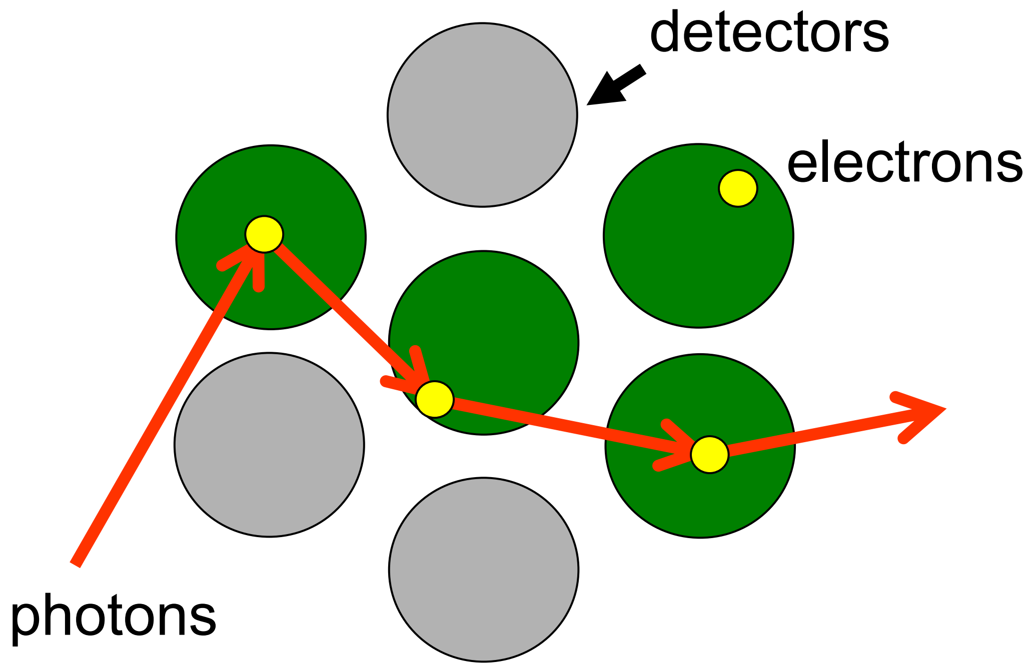
1. underground, shielding, energy window cut,
2. single detector cut, 3. single segment cut,
4. pulse shape analysis.



0νββ signal search window: 2039 ± 5keV

Remove background

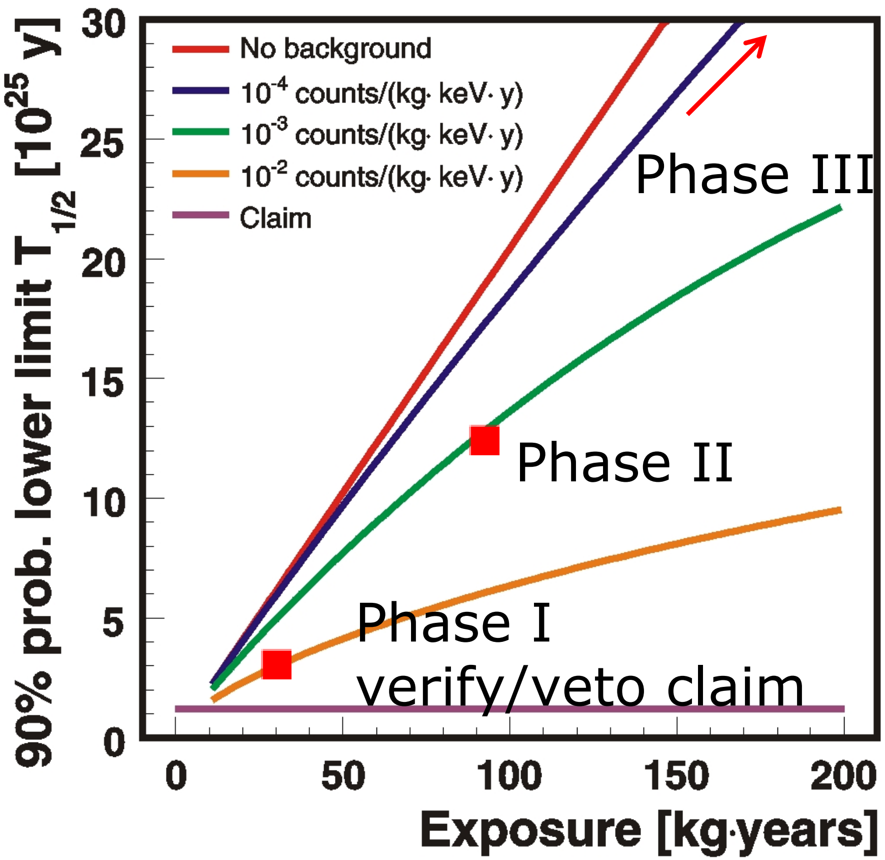
1. underground, shielding, energy window cut,
2. single detector cut, 3. single segment cut,
4. pulse shape analysis.



2 electrons : energy deposit range in germanium <1mm
2MeV photon: several Compton scattering, >cm range

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)

Phase-II p-type BEGe detector fabrication

- 34kg ${}^{dep}GeO_2$ purified.
- 4 p-type ${}^{dep}Ge$ crystals pulled at Canberra Oak Ridge.
- net charge carrier density: $\sim 4 \cdot 10^{10}\ cm^{-3}$.
- will cut to slices and make BEGe detectors.

→ Purification at PPM successful.