The search for neutrino-less double beta decay with GERDA @ LNGS: status and perspectives

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On behalf of the GERDA collaboration
GDR Neutrino, Caen, 30/31. October 2012

GERDA general meeting and joint GERDA-Majorana workshop at TUM, June 2012

~ 100 members
19 institutions
6 countries

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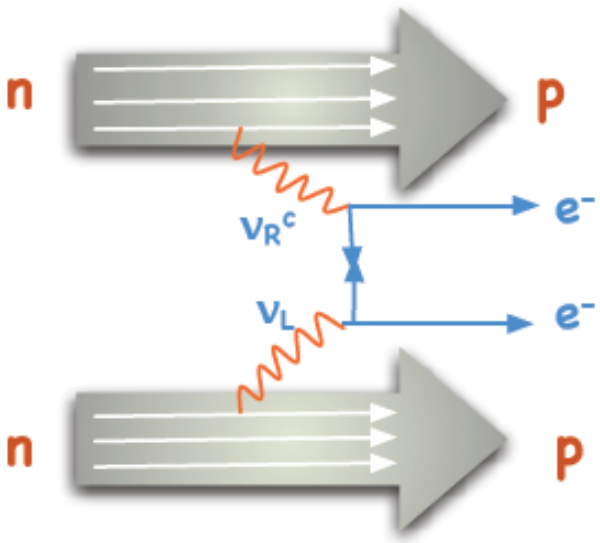
Groups from Germany:
Univ. Dresden, MPIK Heidelberg, MPP München, TU München, Univ. Tübingen

Introduction: 0νββ



Expected decay rate:

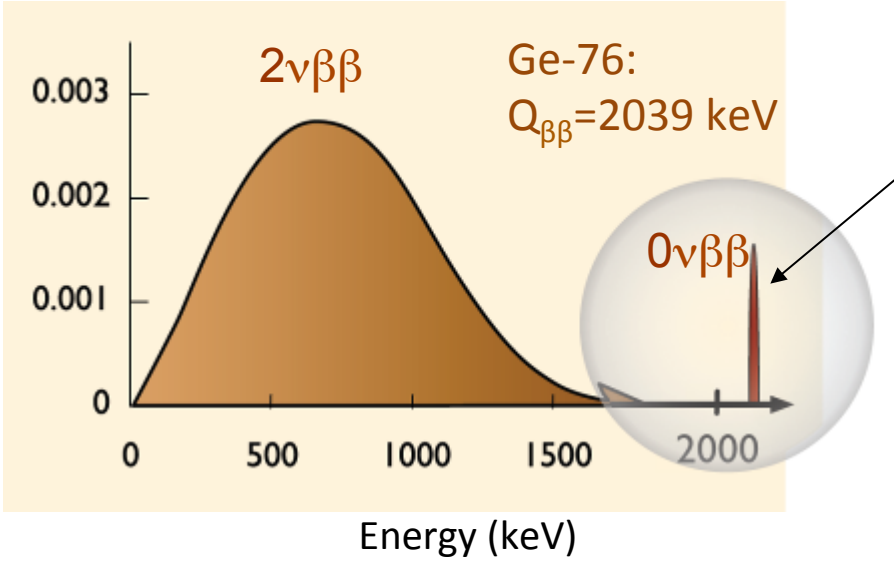
$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2\,\langle m_{ee}\rangle^2$$

Phase space integral — Nuclear matrix element

$$\langle m_{ee}\rangle = \left|\sum_i U_{ei}^2\, m_i\right|$$

Effective neutrino mass

U_{ei} Elements of (complex) PMNS mixing matrix



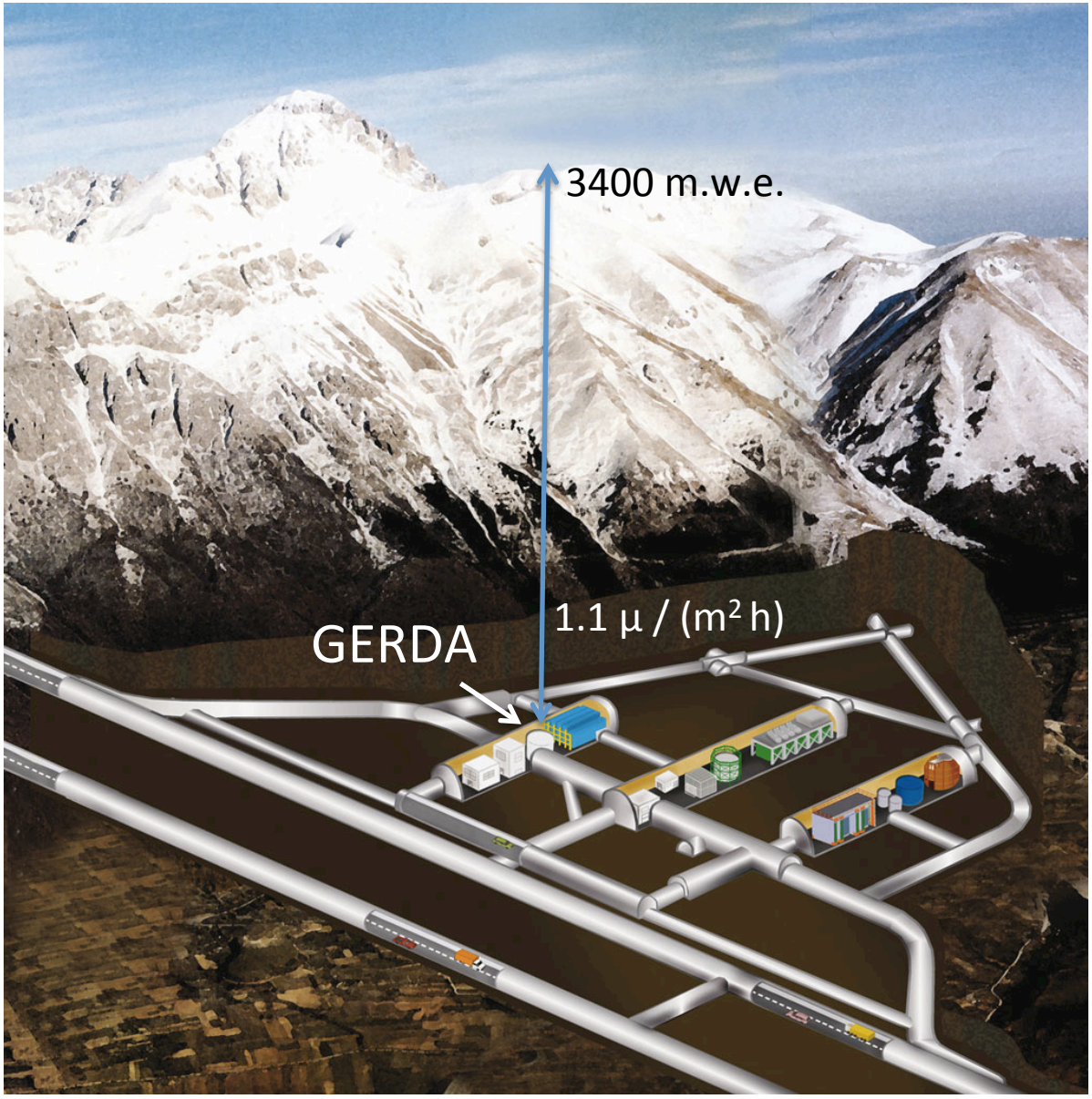
Experimental signatures:

- peak at $Q_{\beta\beta}$ = m(A,Z)-m(A,Z+2)-2m_e
- two electrons from vertex

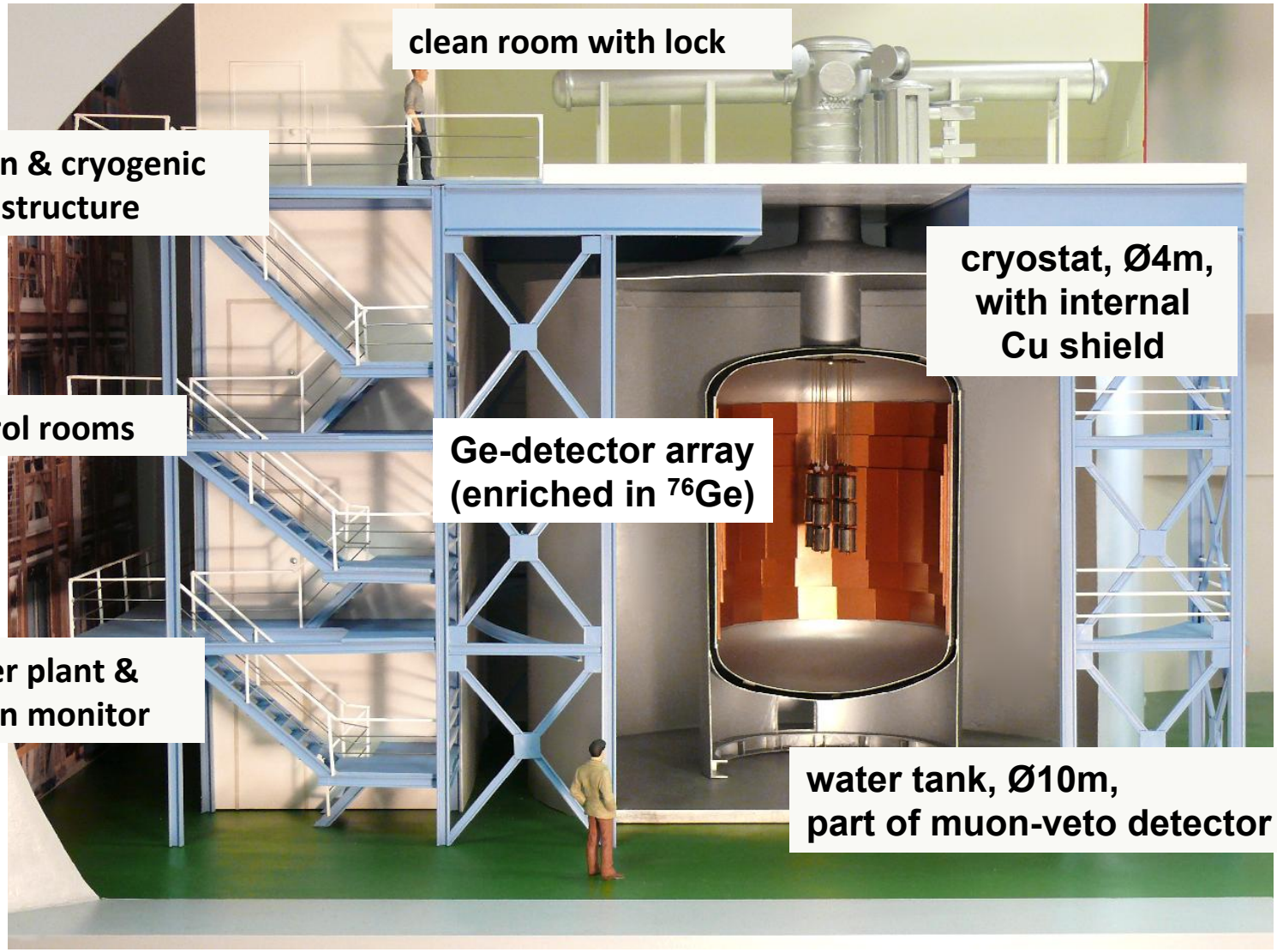
Discovery would imply:

- lepton number violation ΔL = 2
- ν's are Majorana type
- mass scale & hierarchy
- physics beyond the standard model

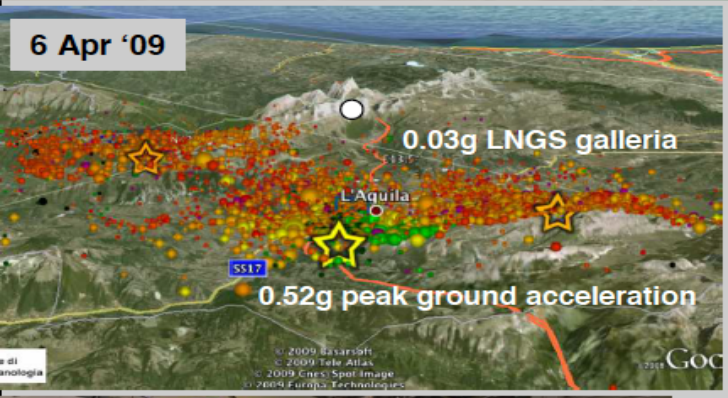
GERDA @ LNGS

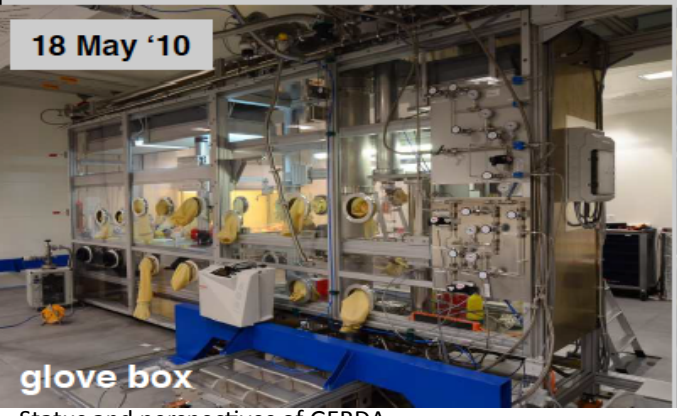


GERDA @ LNGS


plastic μ-veto
clean room with lock
muon & cryogenic infrastructure
cryostat, Ø4m, with internal Cu shield
control rooms
Ge-detector array (enriched in ^{76}Ge)
water plant & radon monitor
water tank, Ø10m, part of muon-veto detector

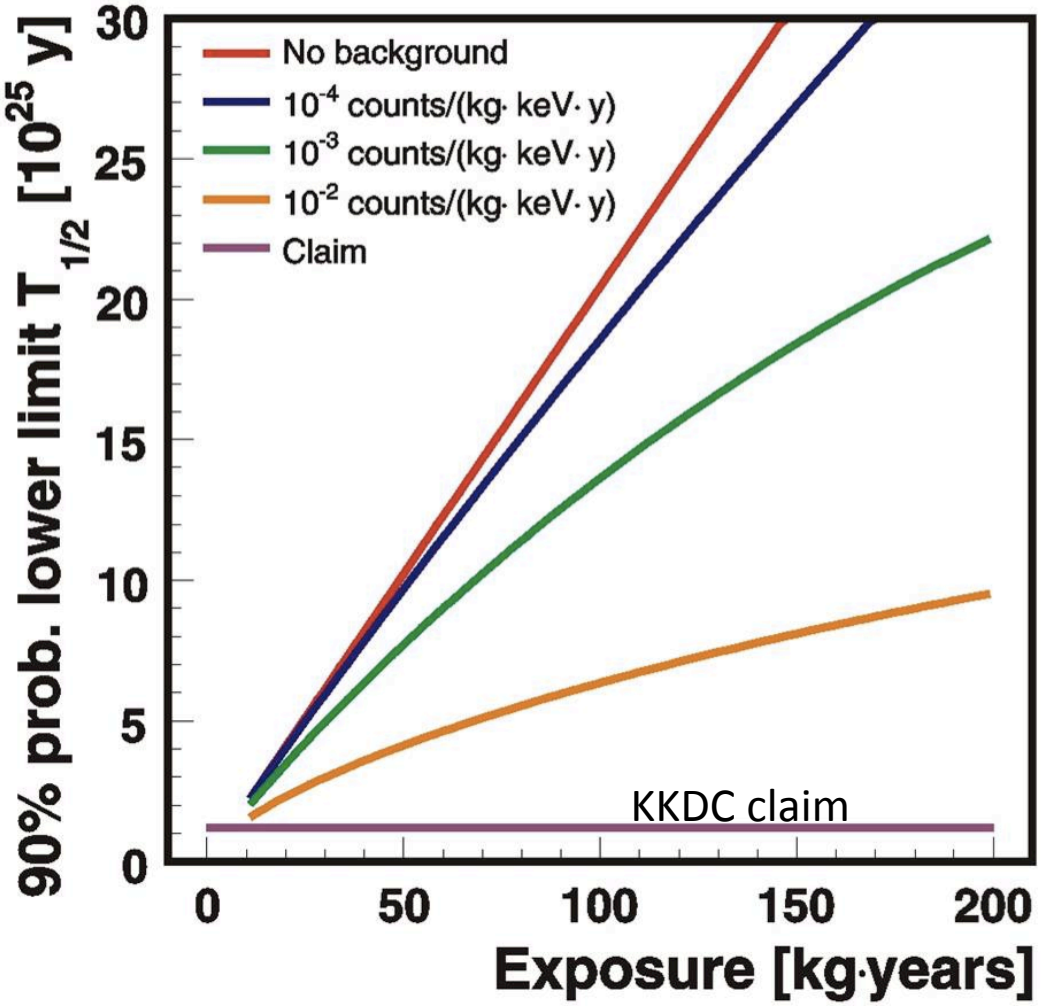
GERDA construction phase 2008-2010



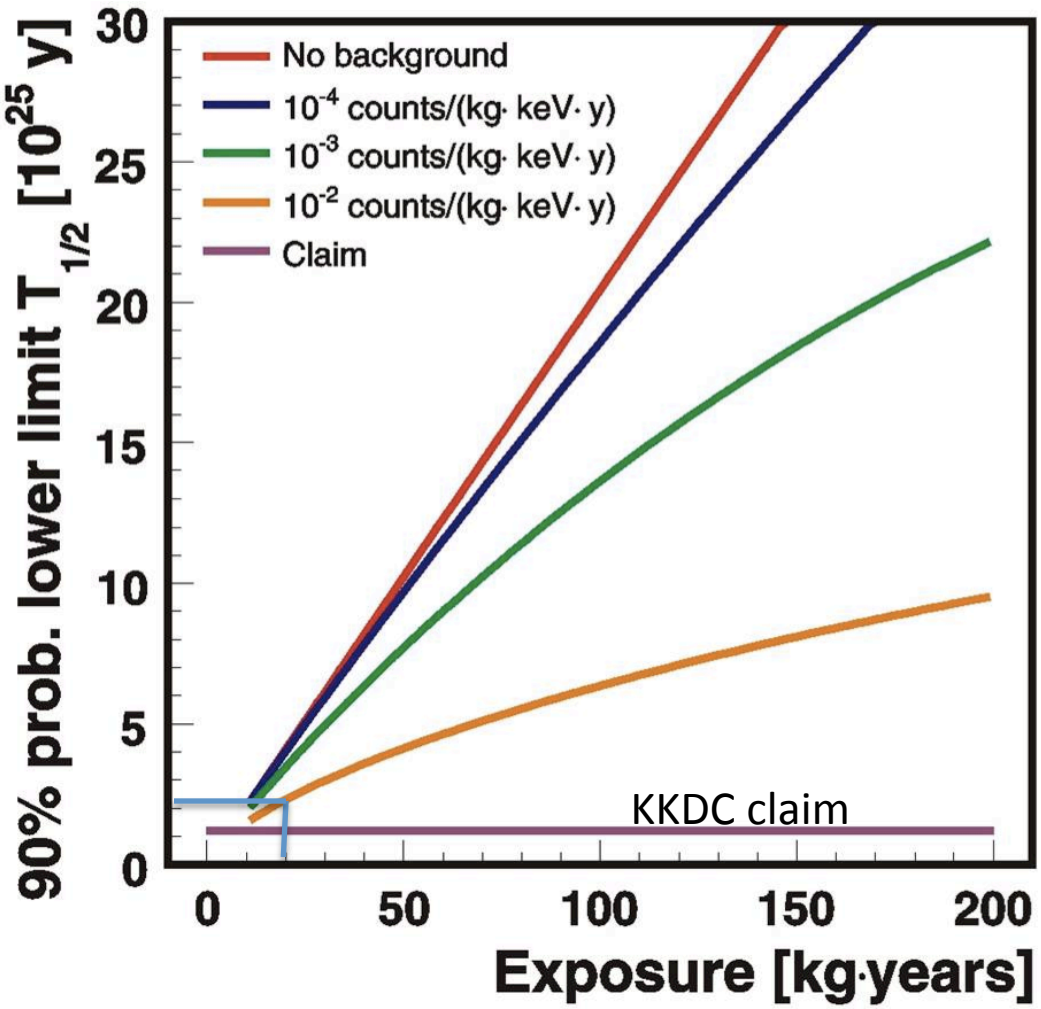


Cryostat filled since
December 2009

GERDA phased approach

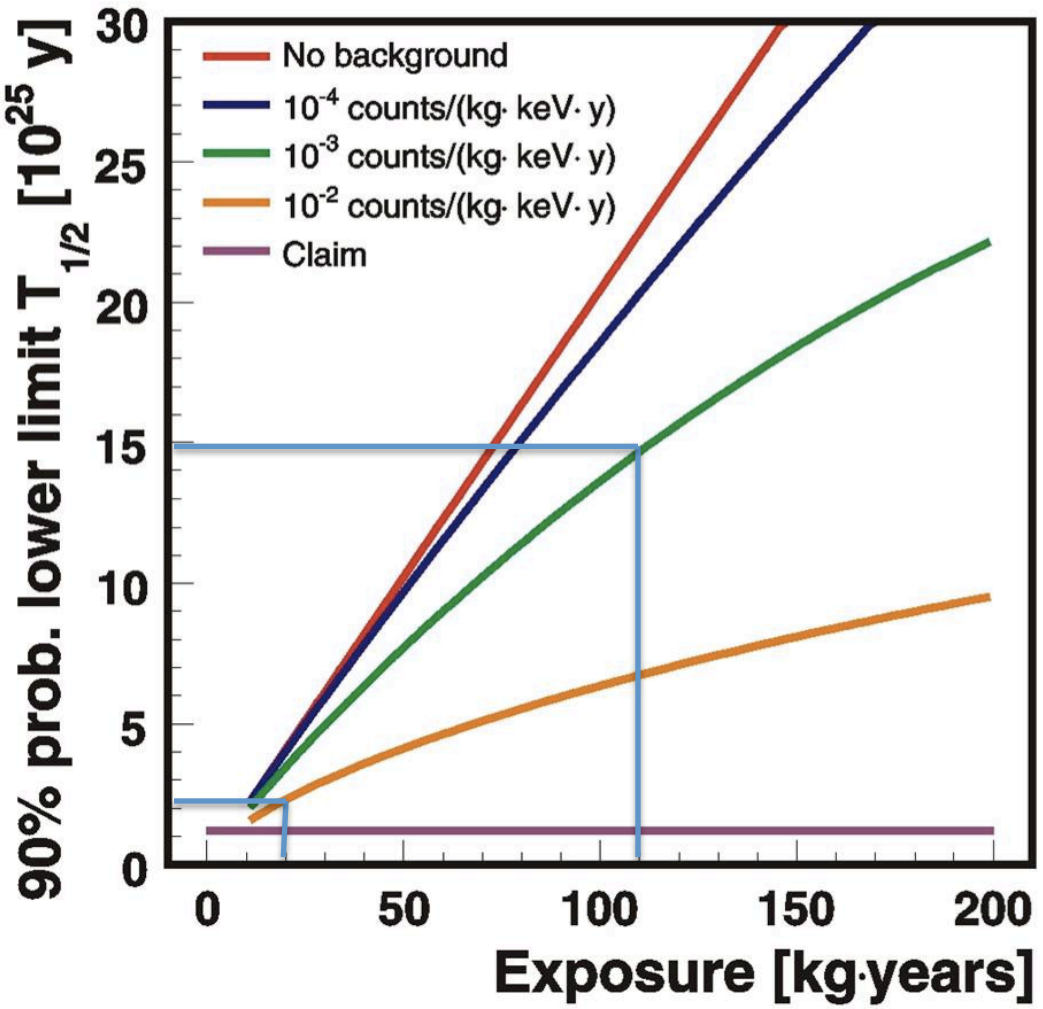


GERDA phased approach



phase I :
use Ge-76 diodes of HD-Moscow & IGEX
~18 kg
BI ~ 0.01 cts / (keV·kg·yr)
intrinsic background expected

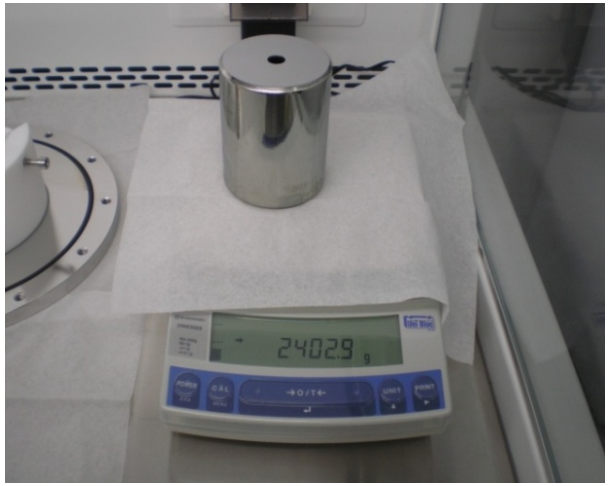
GERDA phased approach



phase II :
add new enriched Ge-76 detectors, 20 kg
BI ~ 0.001 cts / (keV·kg·yr)
► 37.5 kg enriched Ge-76 bought
35 kg · 3 yr exposure

phase I :
use Ge-76 diodes of HD-Moscow & IGEX
~18 kg
BI ~ 0.01 cts / (keV·kg·yr)
intrinsic background expected

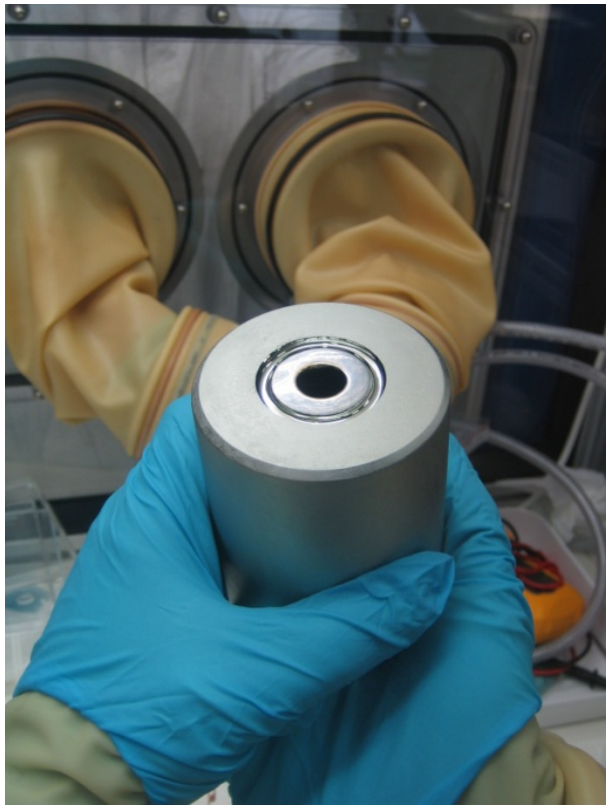
GERDA phase I detectors



- All diodes reprocessed and optimized for LAr
- Well tested procedure for detector handling
- Long term stability in LAr established
- Energy resolution in LAr: ~2.5 keV (FWHM) @1.3 MeV

8 diodes (from HdM, IGEX):

- Enriched 86% in ^{76}Ge
- Total mass 17.66 kg

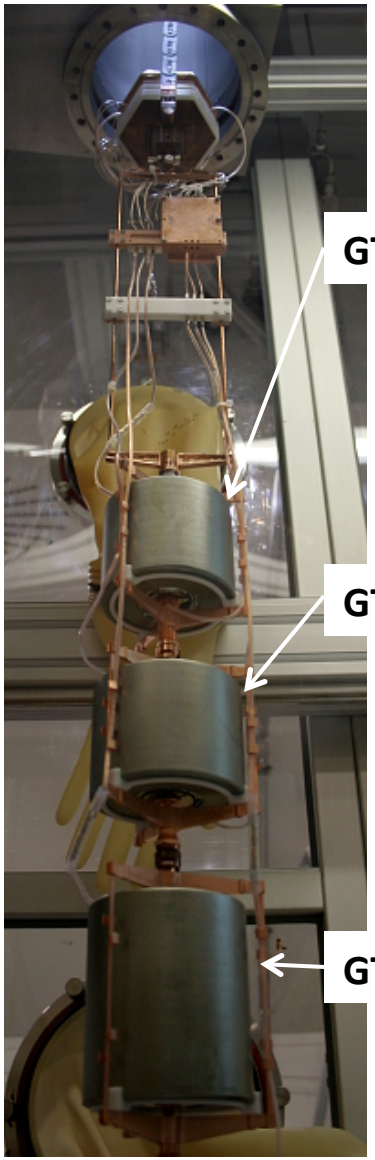


6 diodes from Genius-TF:

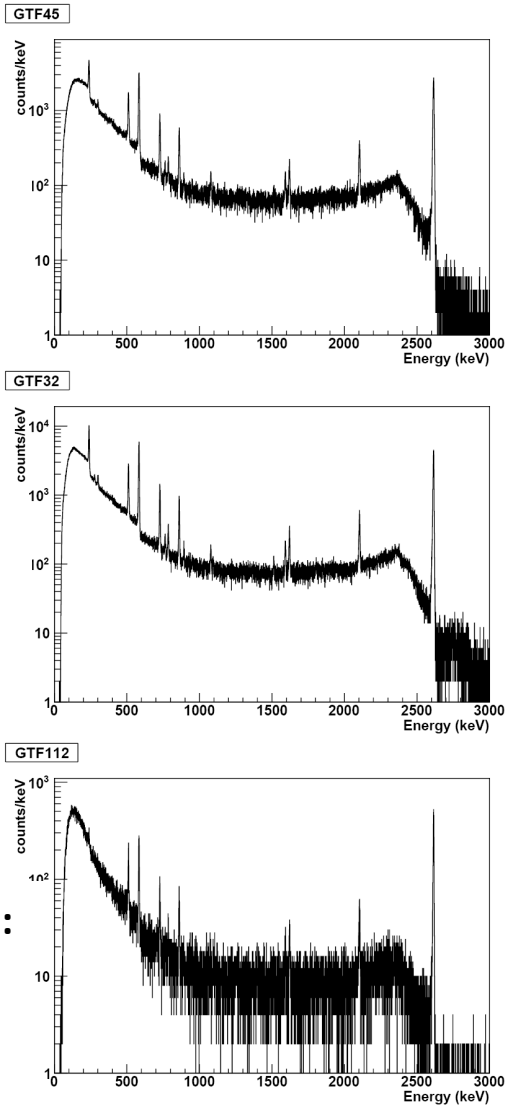
- ^{nat}Ge
- Total mass: 15.60 kg

1-string assembly for commissioning

started June 2010



Calibration with ^{228}Th:



Commissioning runs with **non-enriched low-background detectors** to study performance and backgrounds
(June 2010 – Mai 2011)

Energy resolutions during commissioning:
dependent on chosen detector configuration:

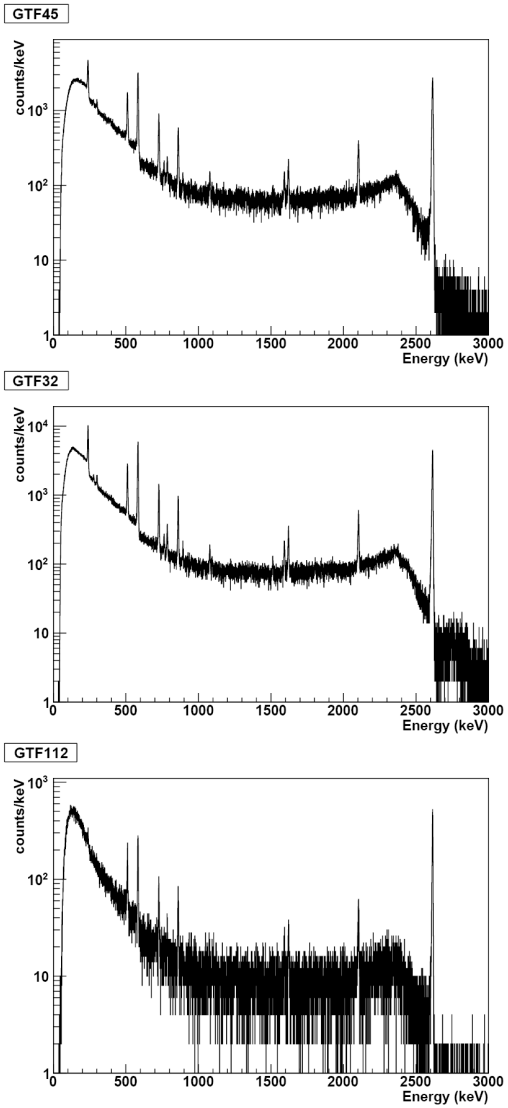
- Coaxial (Phase I): 4-5 keV (*FWHM*) @ 2.6 MeV
- BEGe (Phase II): 2.8 keV (*FWHM*) @ 2.6 MeV

1-string assembly for commissioning

started June 2010

65µm Cu cylinder ('mini-shroud') to shield E-field

Calibration with ^{228}Th:



Commissioning runs with **non-enriched low-background detectors** to study performance and backgrounds
(June 2010 – Mai 2011)

Energy resolutions during commissioning:
dependent on chosen detector configuration:

- Coaxial (Phase I): 4-5 keV (*FWHM*) @ 2.6 MeV
- BEGe (Phase II): 2.8 keV (*FWHM*) @ 2.6 MeV

3-string assembly for phase I run

started Nov 2011

8 refurbished enriched diodes from HdM & IGEX

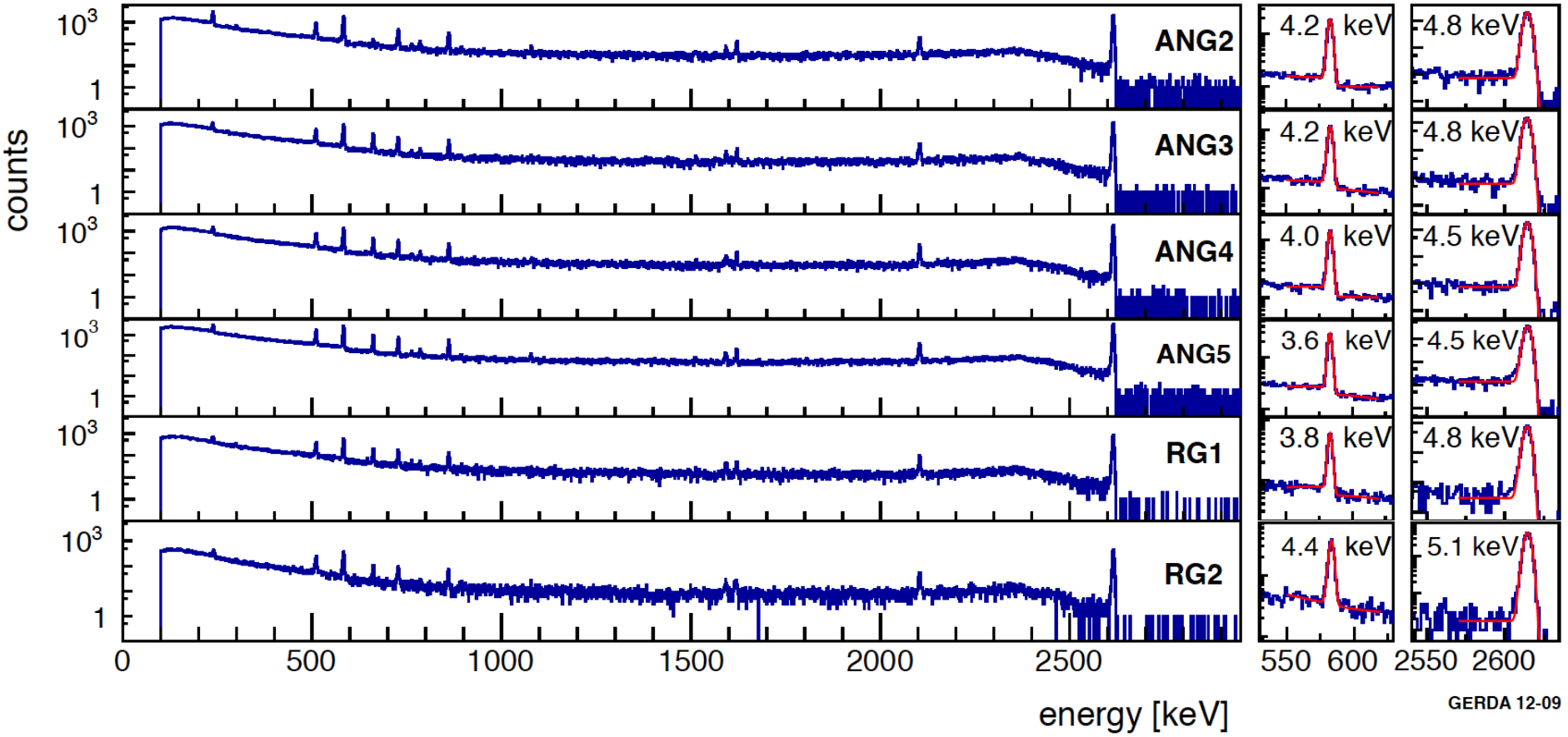
- 86% isotopically enriched in Ge-76
- 17.66 kg total mass
- plus 1 natural Ge diode from GTF

2 diodes shut off because leakage current high:

- total enriched enriched detector mass 14.6 kg

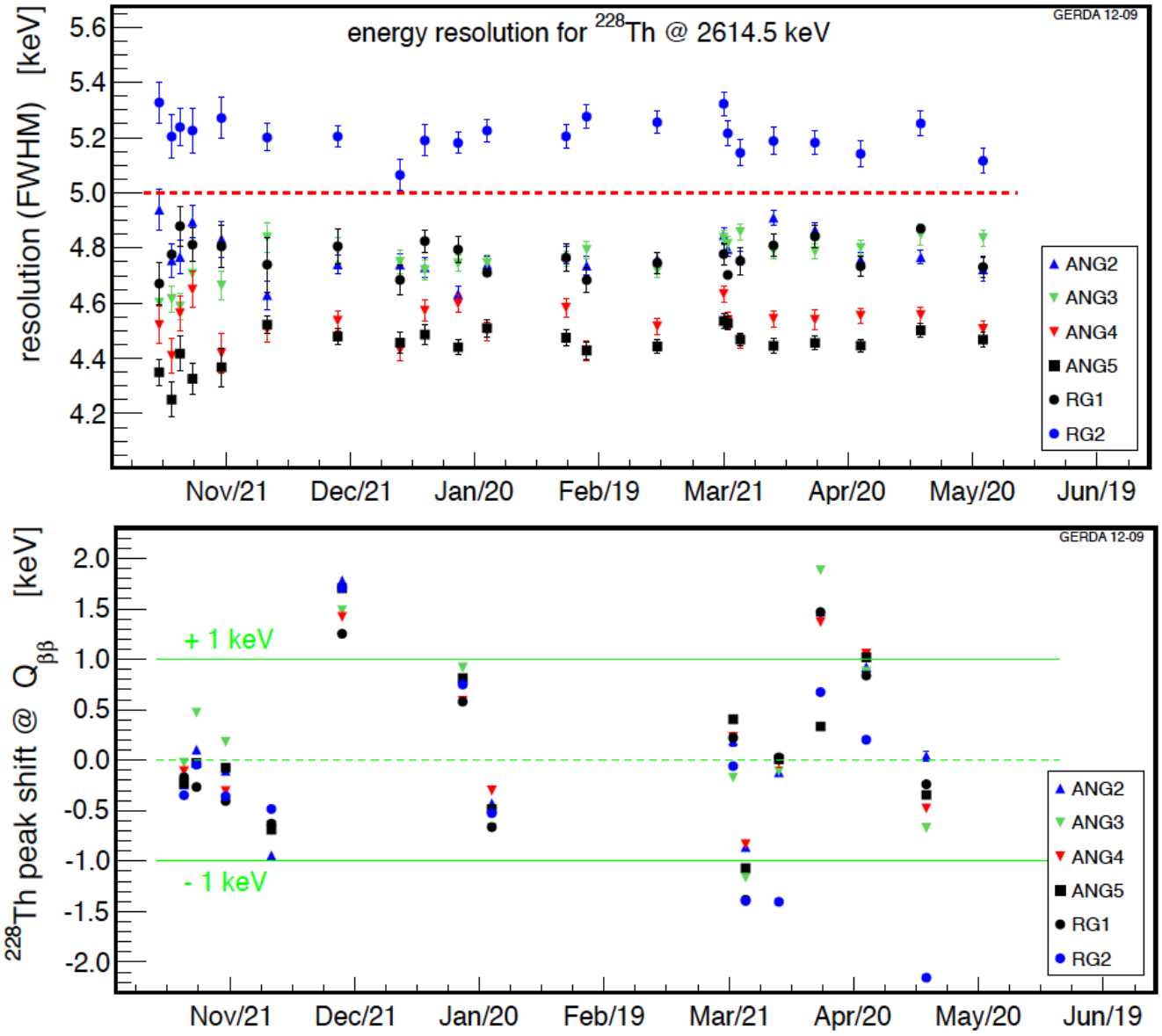
calibration spectra

energy resolution



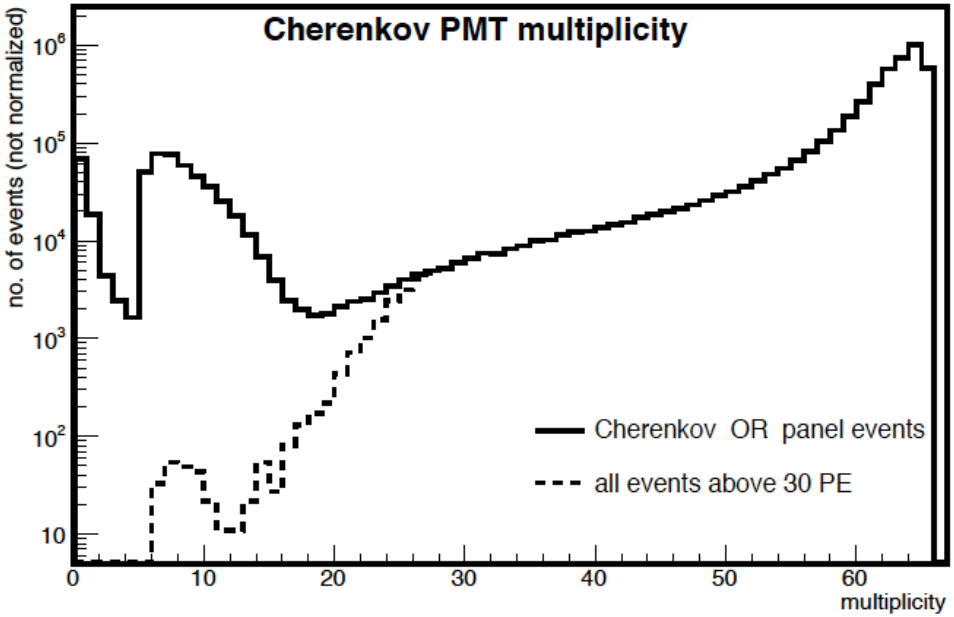
^{228}Th calibration once every one to two weeks; stability continuously monitored with pulser

calibration spectra



muon veto

threshold, efficiency & stability

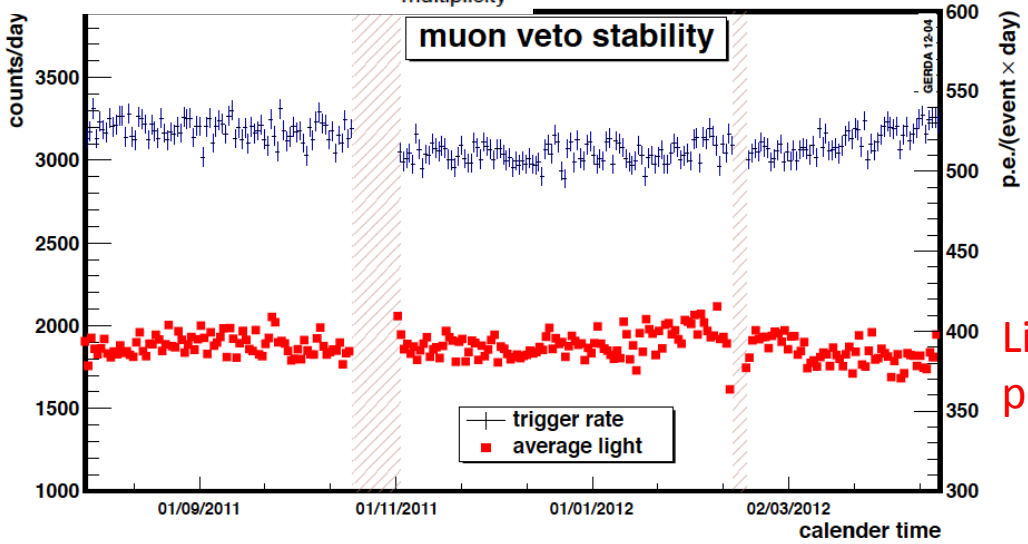


Measured PMT multiplicity w/o and with cut (>30) on number of detected p.e.

Veto efficiencies (threshold: 30 p.e.)

- 97.2% for all muons
- (99.1±0.4)% for muons with energy deposition in Ge

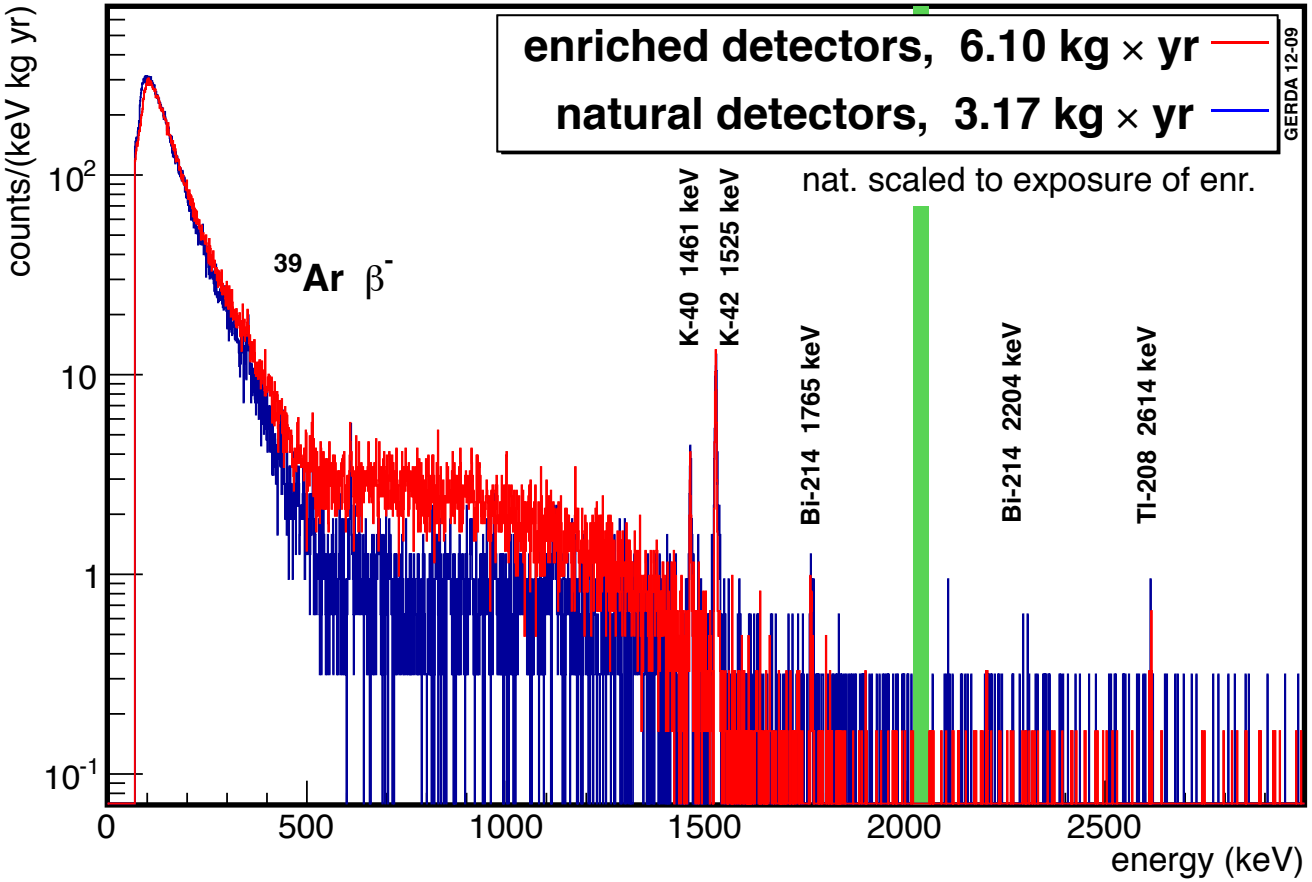
Daily rates



Light out put per event

preliminary results

total energy spectrum



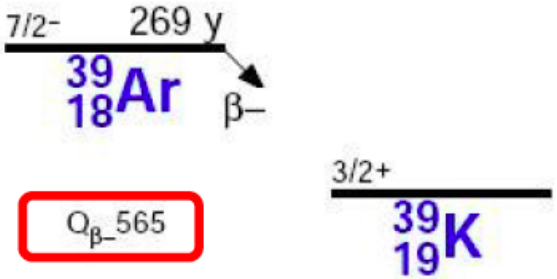
Cuts applied:

- Data quality (noise)
- Muon-veto
- Ge-Ge anti-coincidenc

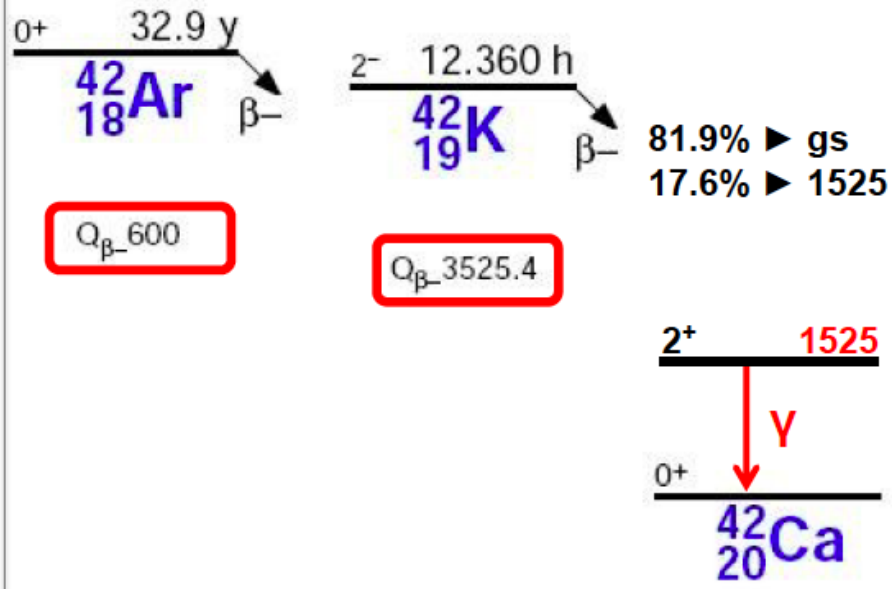
Blinded region: ($Q_{\beta\beta}$±20) keV

Visible backgrounds:

- Ar-39
- Alphas
- Indicated isotopes
- 2νββ decay of Ge-76



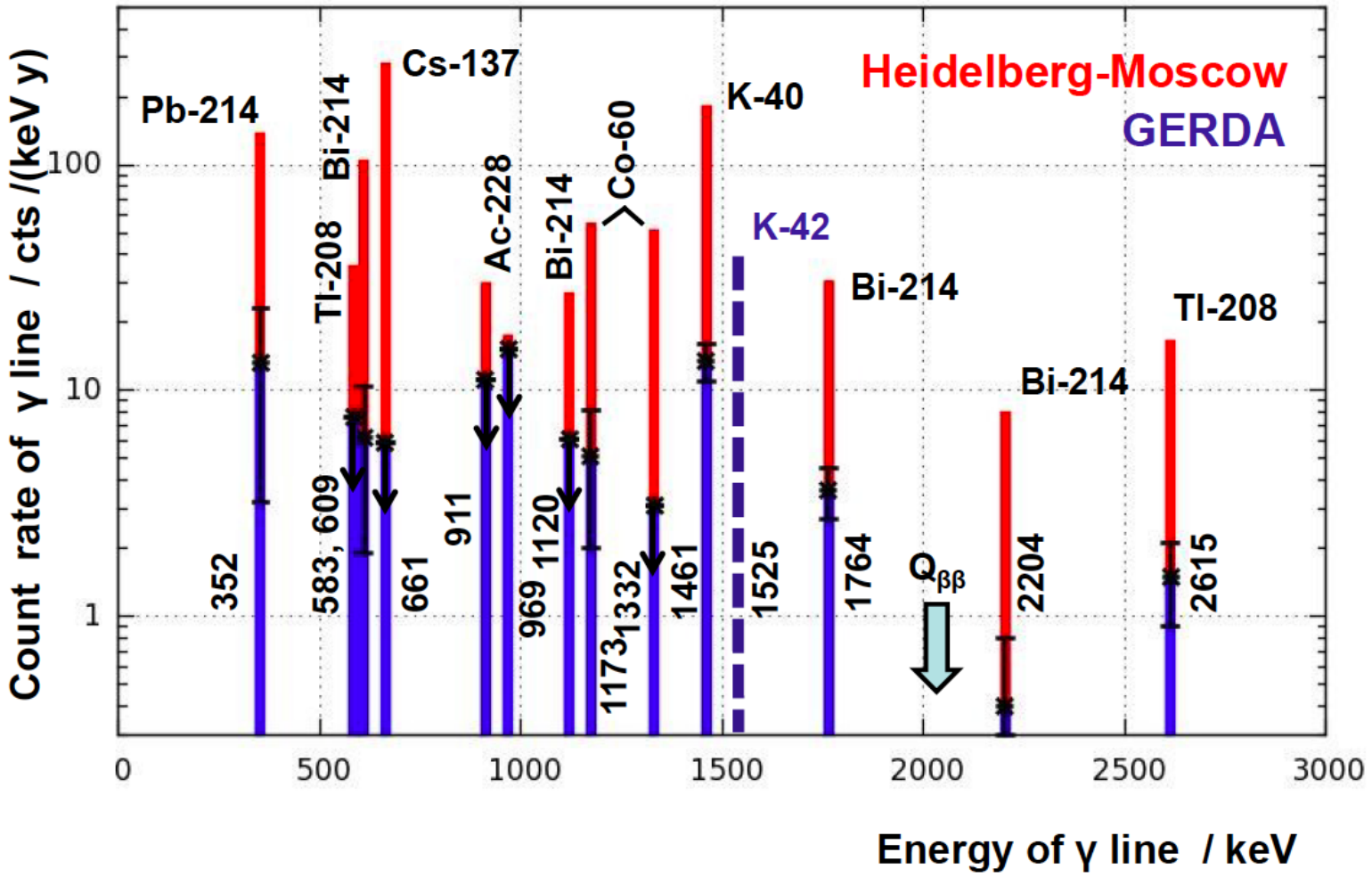
Published activity of (1.01±0.08) Bq/kg (Benetti et al., NIM A574 (2007) 83) fully compatible with our data



Limit <41 µBq/kg (90% CL) (Ashtikov et al., arXiv:nucl-ex/0309001) NOT compatible with our data

Intensity of 1525 keV line in E-field free setup indicates Ar-42 activity to be more than twice the value of avove limit

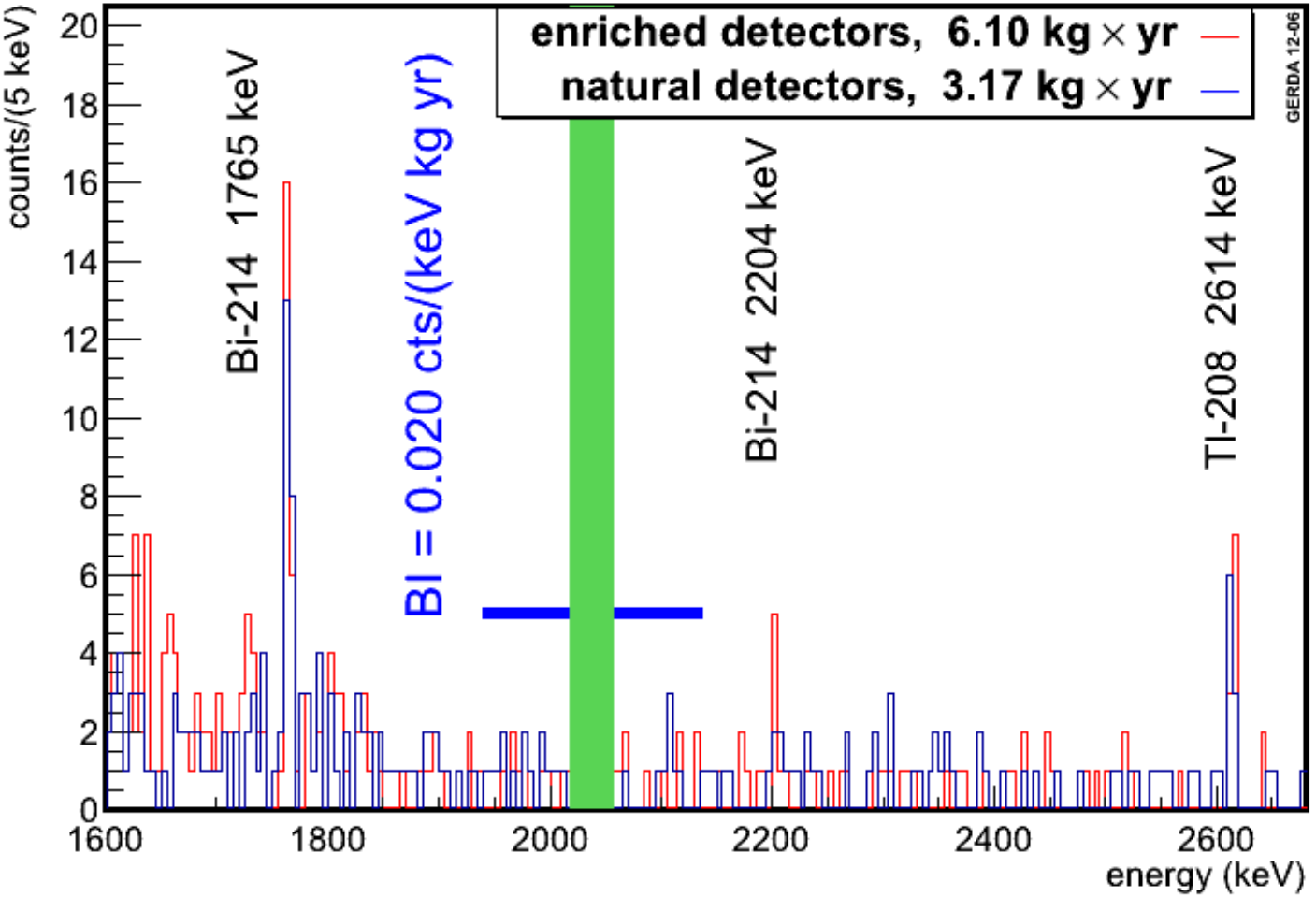
Evidence that charge K-42 ions drift in electic field of Ge-diodes.
Minishroud as shield against E-field



GERDA /HdM intensity ratio typically 1/10

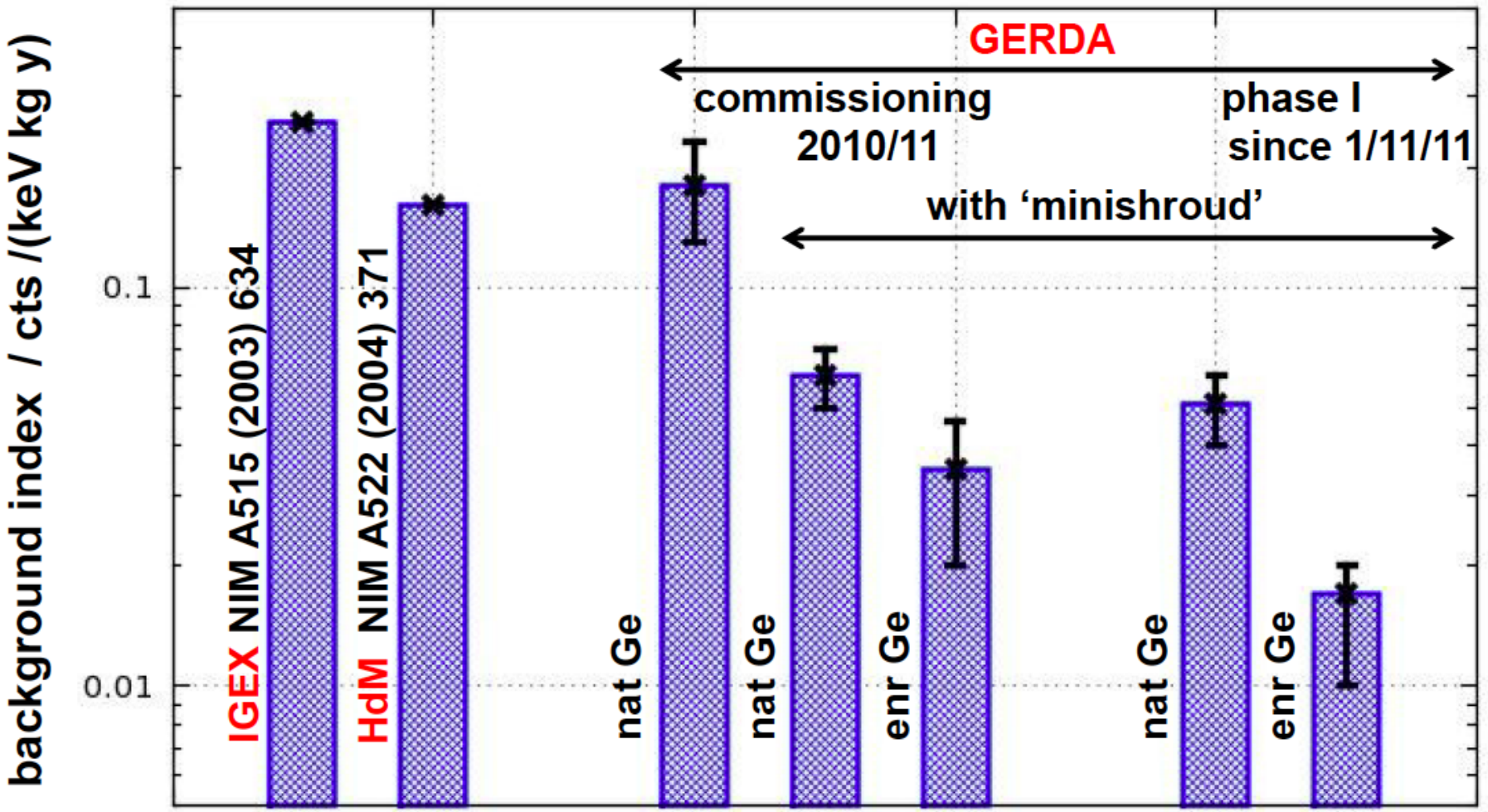
preliminary results

energy spectrum: zoom to ROI



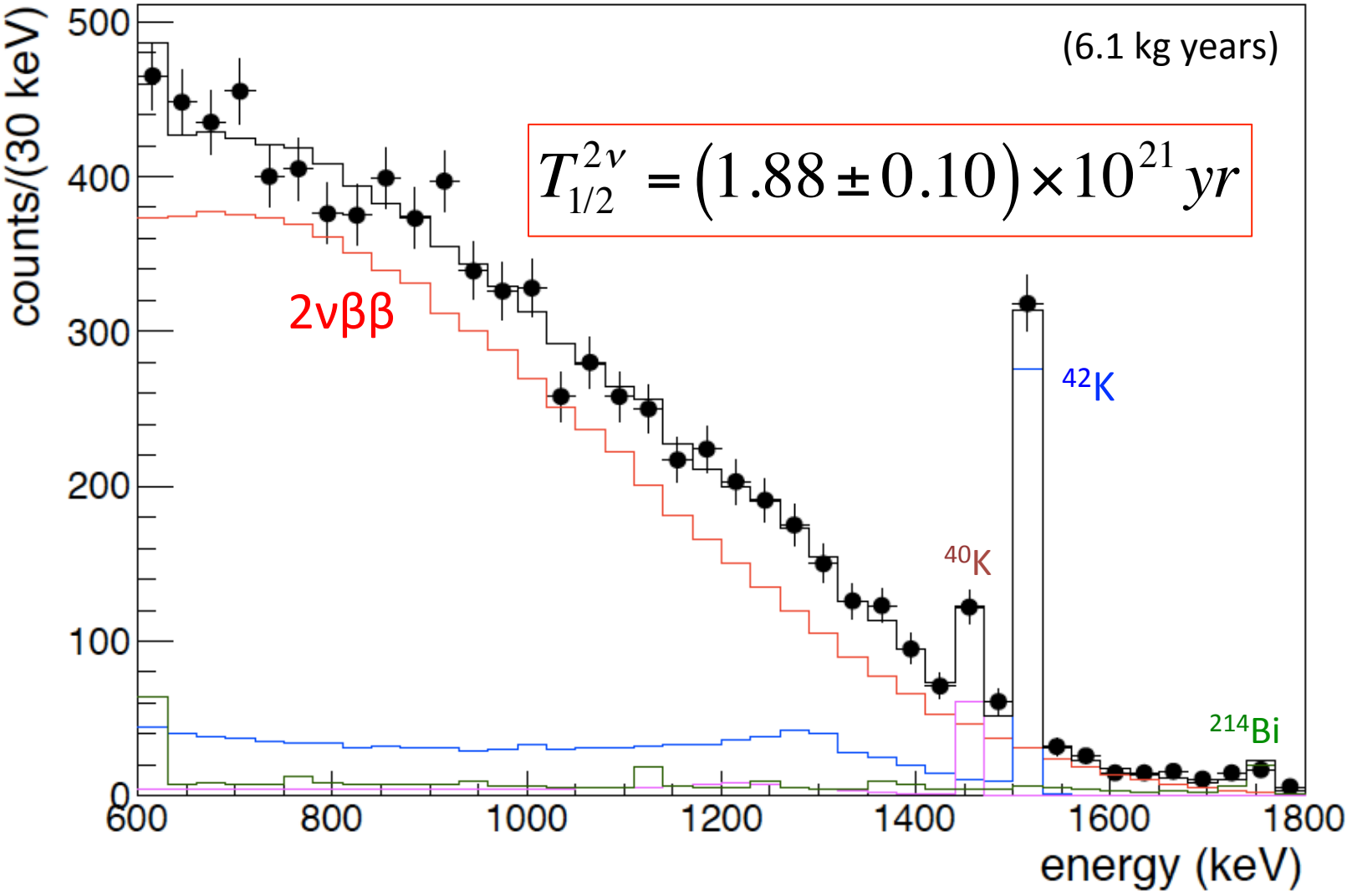
Background index usually evaluated in ($Q_{\beta\beta}$± 100) keV (excluding blinded region of ($Q_{\beta\beta}$±20) keV)

preliminary results

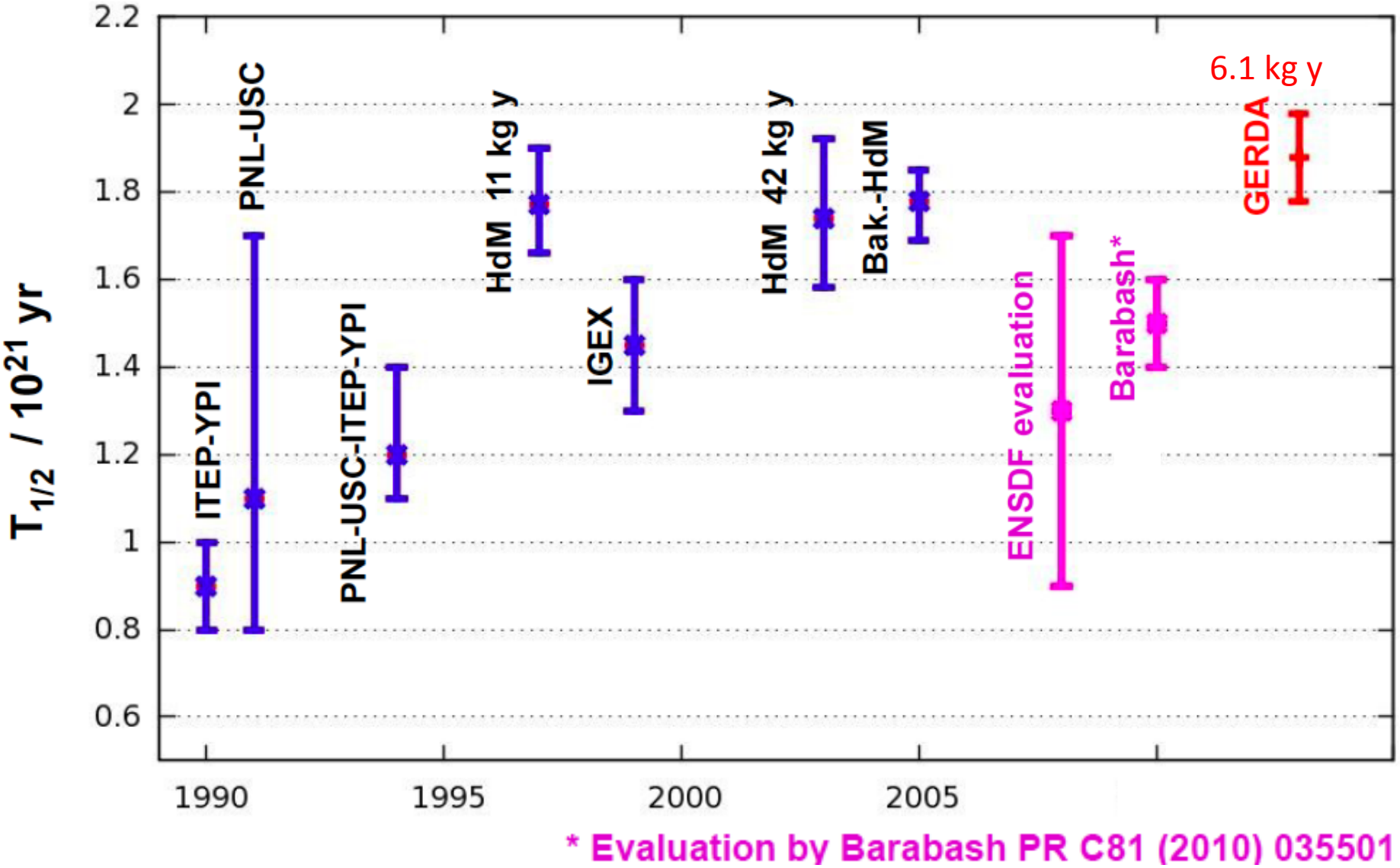


GERDA / HdM BI ratio about 1/10

preliminary results



preliminary results



From GERDA phase I to II

Approximately 10 kg × years of data acquired until Sept. 2012

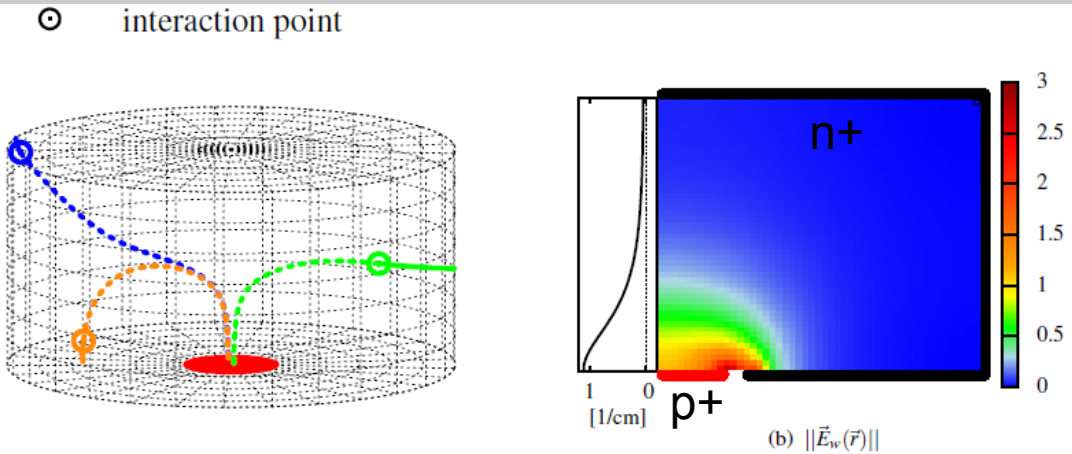
- GERDA Phase I expected completion in spring 2013: Unblinding & physics analysis

Subsequently start of GERDA Phase II:

- Goal: reduce background by factor >10 -- (BI: 0.001 cts/(keV kg year)
- Up to additional 30 enriched BEGe detectors (20 kg)
- Liquid argon veto instrumentation

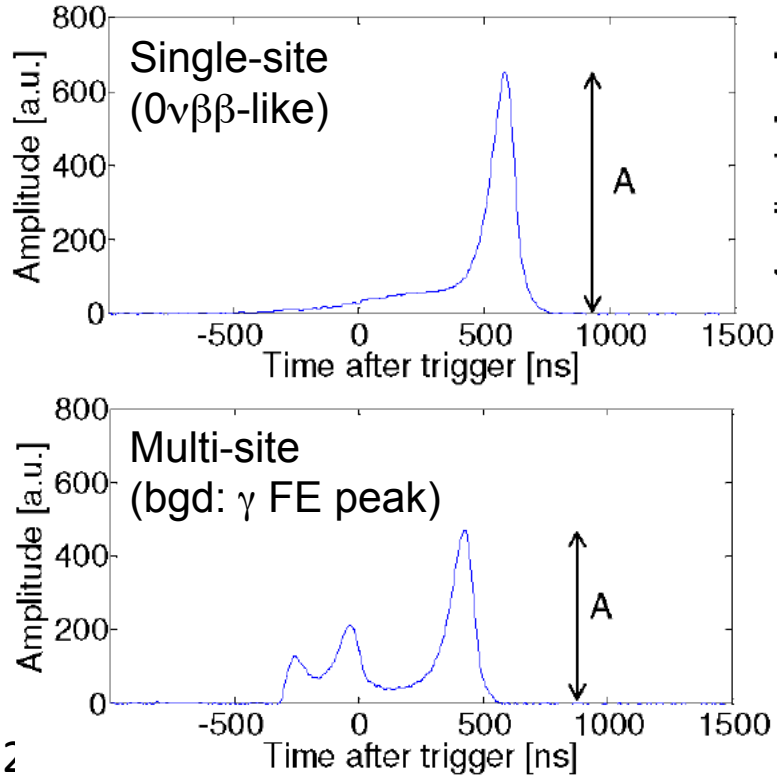
Phase II detectors

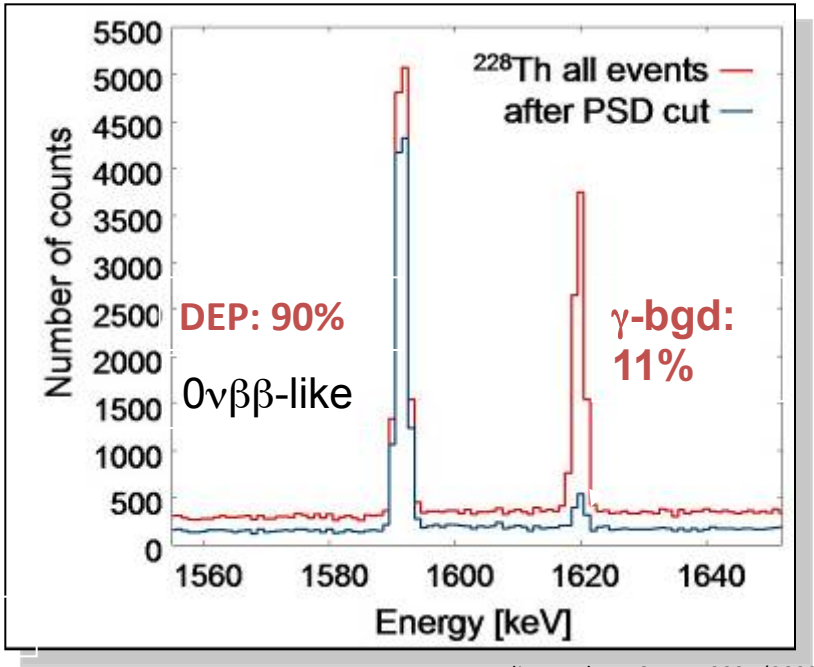
novel thick window BEGe's with advanced pulse shape performance



Signal shape provides clear topology for event-by-event signal ID / bgd discrimination:

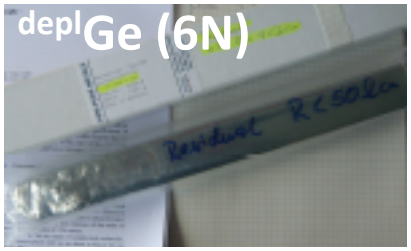
- **SSE/MSE** discrimination
- **Surface** events:
  - n+ slow pulses
  - p+: 'amplified' current pulses



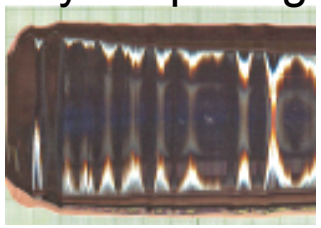


Budjas et al., JINST 4 P10007 (2009)
M. Agostini et al., JINST 6P03005 (2011)

Production test of BEGe detectors from depleted Ge for GERDA Phase II

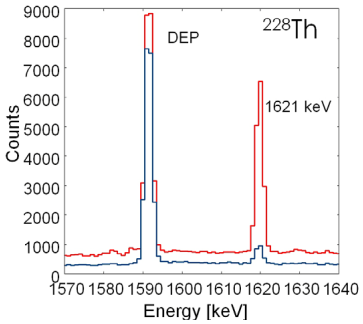


Crystal pulling



crystal slice

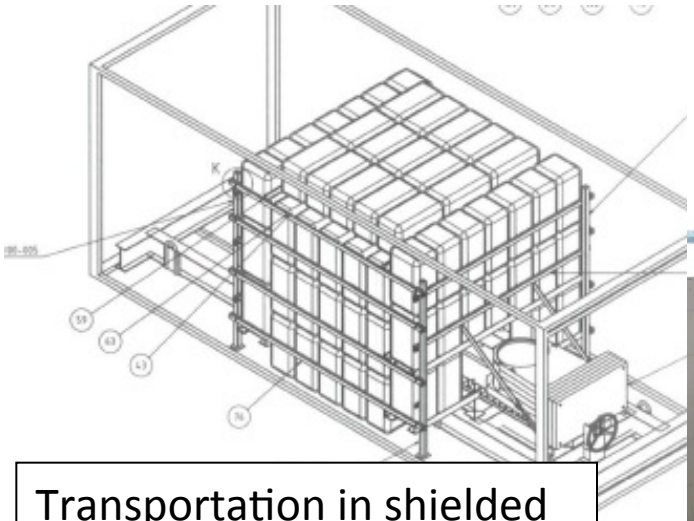
Full production chain tested with isotopic depleted germanium



After successful test of production production chain with ^{depl}Ge:

- **37.5 kg of 86% ^{enr}Ge** (in form of GeO2) purified to **35.4 kg (94%) of 6N** (+ 1.1 kg tail = 97%);

Production of ^{enr}Ge crystals at Oak Ridge (USA) October, 2011 – August 2012 completed

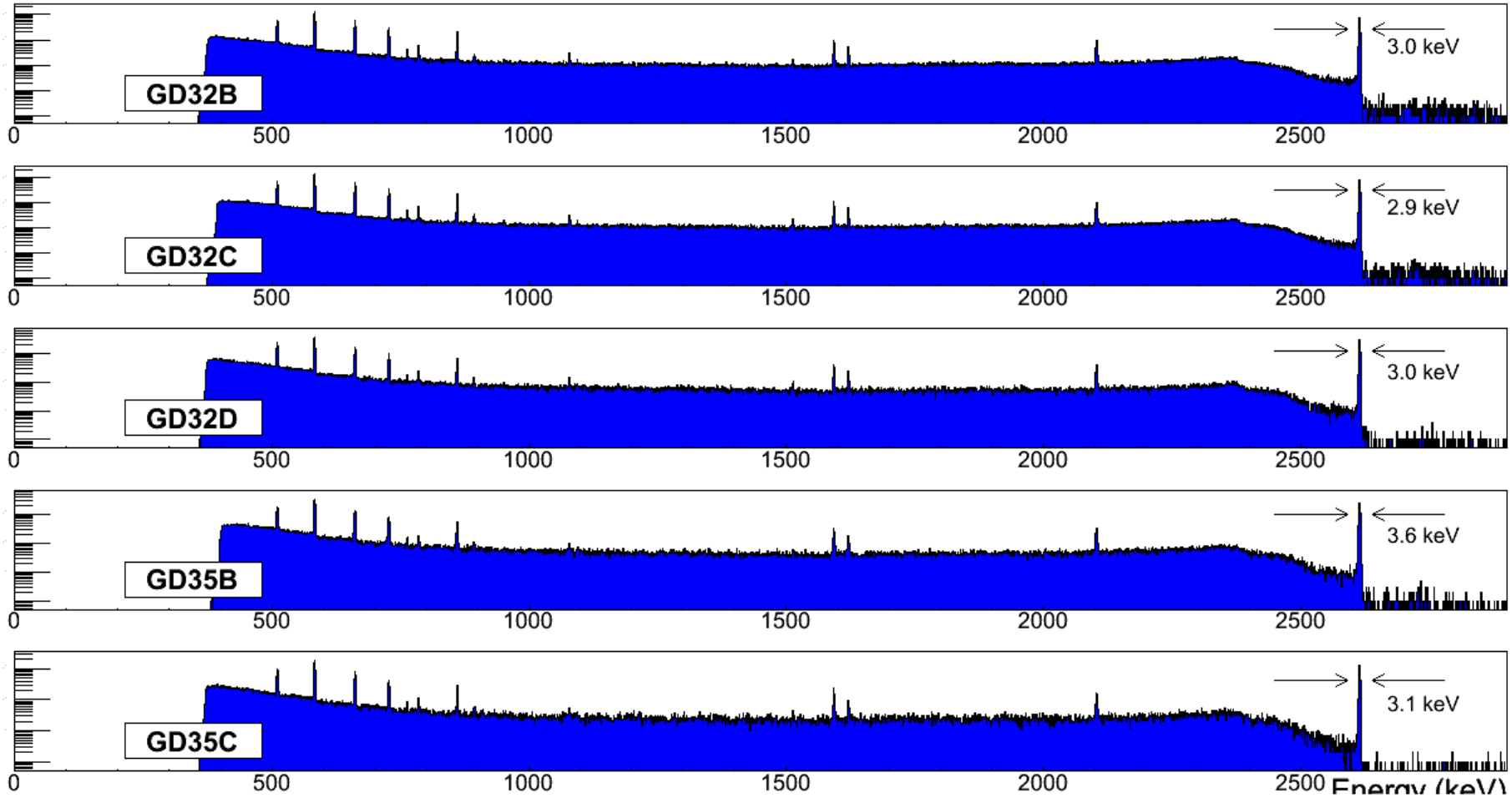


Transportation in shielded container to minimize cosmic ray activation

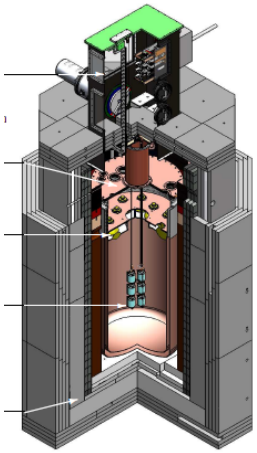
Ge stored underground storage when not processed

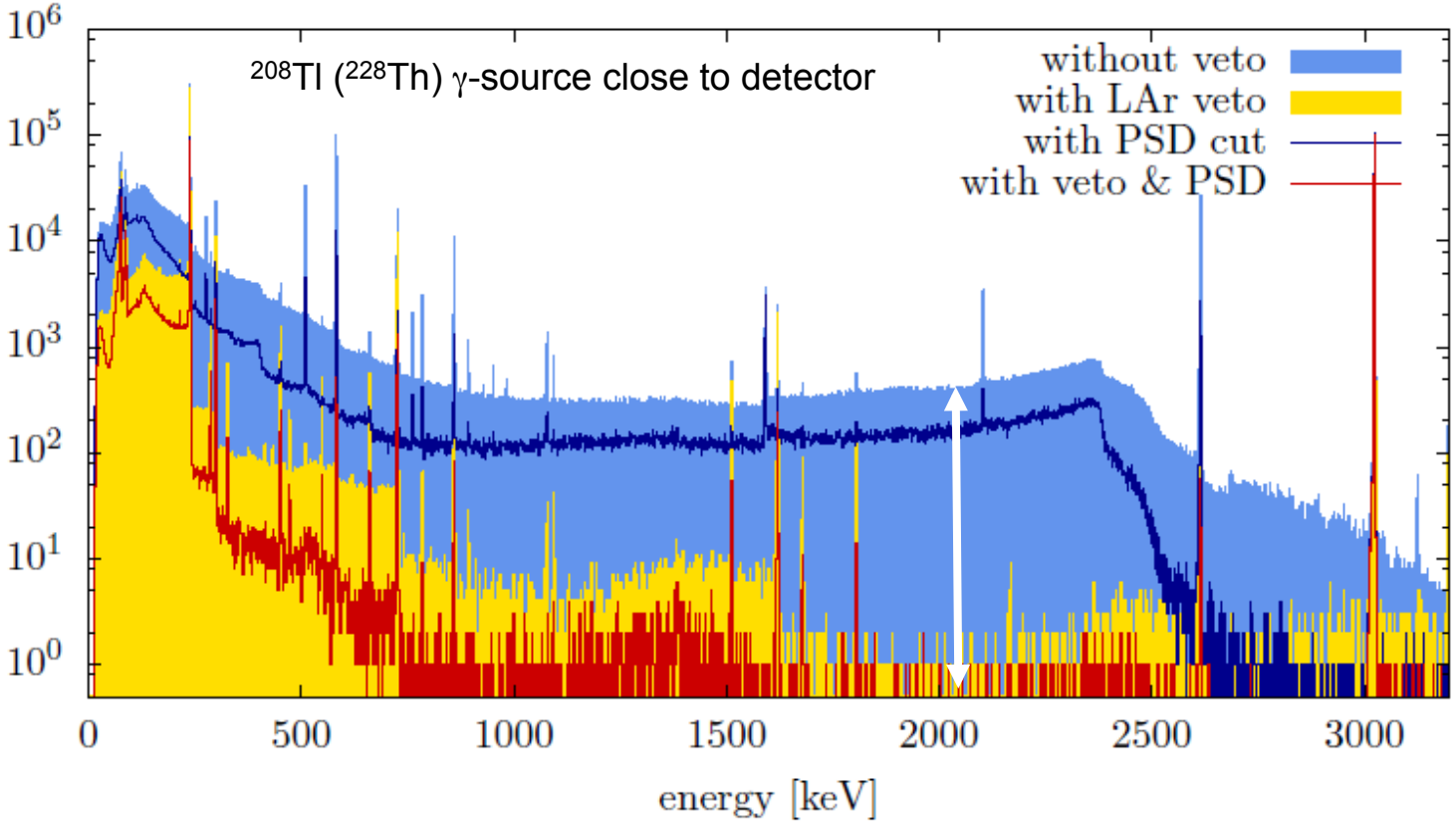
- 30 crystal slices (20.5 kg) produced and shipped
- Diode production on-going: 18 from 30 diodes produced
- End of 2012: up to 30 phase II (20 kg) detectors available
- Up to 15 kg residual ^{enr}Ge material which needs chemical purification; production of 3rd batch considered

June: 5 ^{enr}BEGe Phase II detectors deployed in GERDA



R&D liquid argon instrumentation

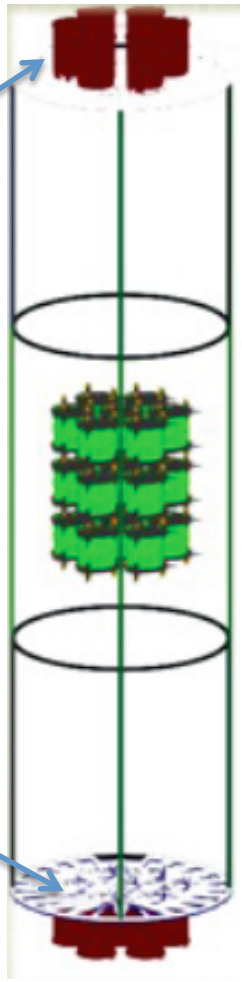




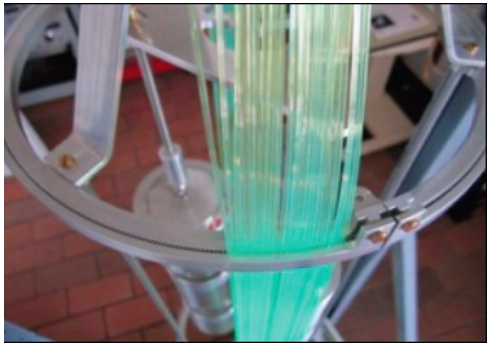
Operation of Phase II detector prototype in LArGe:
Measured suppression factor at $Q_{\beta\beta}$: **~0.5·10^4** for a ^{228}Th calibration source
Also: successful read out scintillation light with fibers coupled to SiPMs

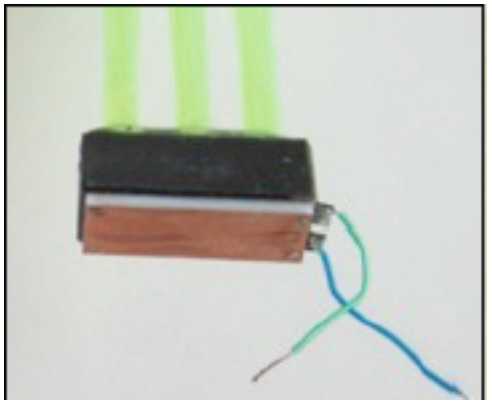
Liquid argon instrumentation for Phase II

Top/bottom: PMTs



Central cylinder:
SiPM/Fiber readout





- Also: R&D on large area avalanche photodiodes and UV sensitive SiPMs to detect light inside MS

Summary & outlook

- Novel cryogenic/water shield realized
- All subsystems running smoothly
- Phase I physics run started Nov 2011
- Region of interst (Qββ±20 keV) blinded
- BEGe string since June
- Total data acquired up to date: ca. 10 kg years

Preliminary results with 6 kg years exposure:

^{42}Ar abundance factor >2 larger than 90% published limit
Best value for 2νββ decay of Ge-76 to be published soon
Best background index at $Q_{\beta\beta}$ of all Ge experiments so far
BI ≈ 0.02 cts / (keV×kg×yr) w/o pulse shape analysis
Goal: un-blind data spring next year and scrutinize KKDC result

Perspectives for Phase II

Approx. 20 kg (30 pcs) new enriched Ge diodes of BEGe type produced by end of year; superior PSA properties
Installation of LAr sintillation veto
Goal BI ≤ 0.001 cts / (keV×kg×yr)
$T_{1/2} > 1.5\times10^{26}$ yr, $0.09 < \langle m_{ee} \rangle < 0.15$ (PRC81 (10) 028502)

Contingent on results: world wide collaboration with Majorana for 1 ton experiment to explore few 10 meV mass range