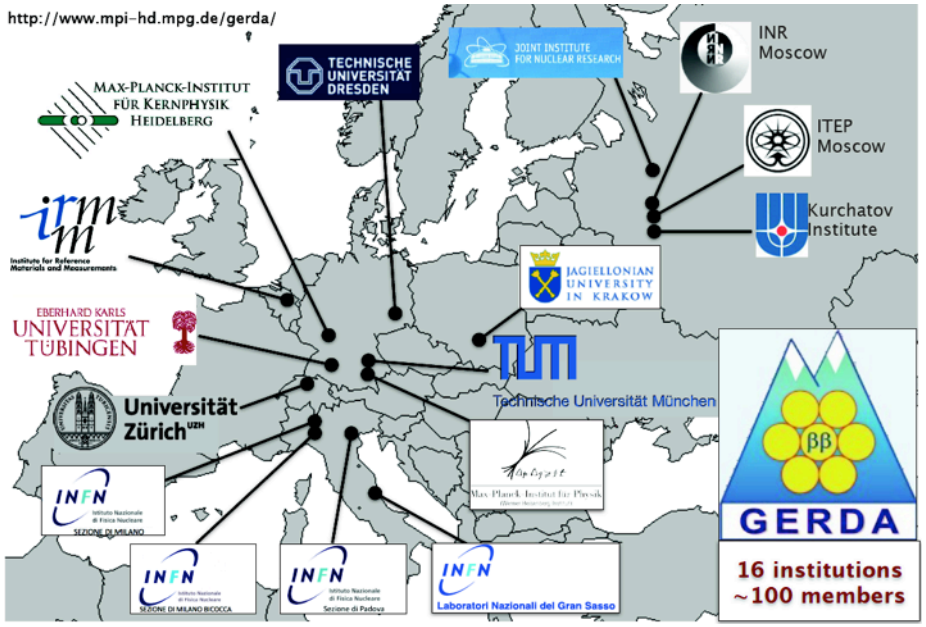


NEUTRINO2014

XXVI International Conference on Neutrino Physics and Astrophysics

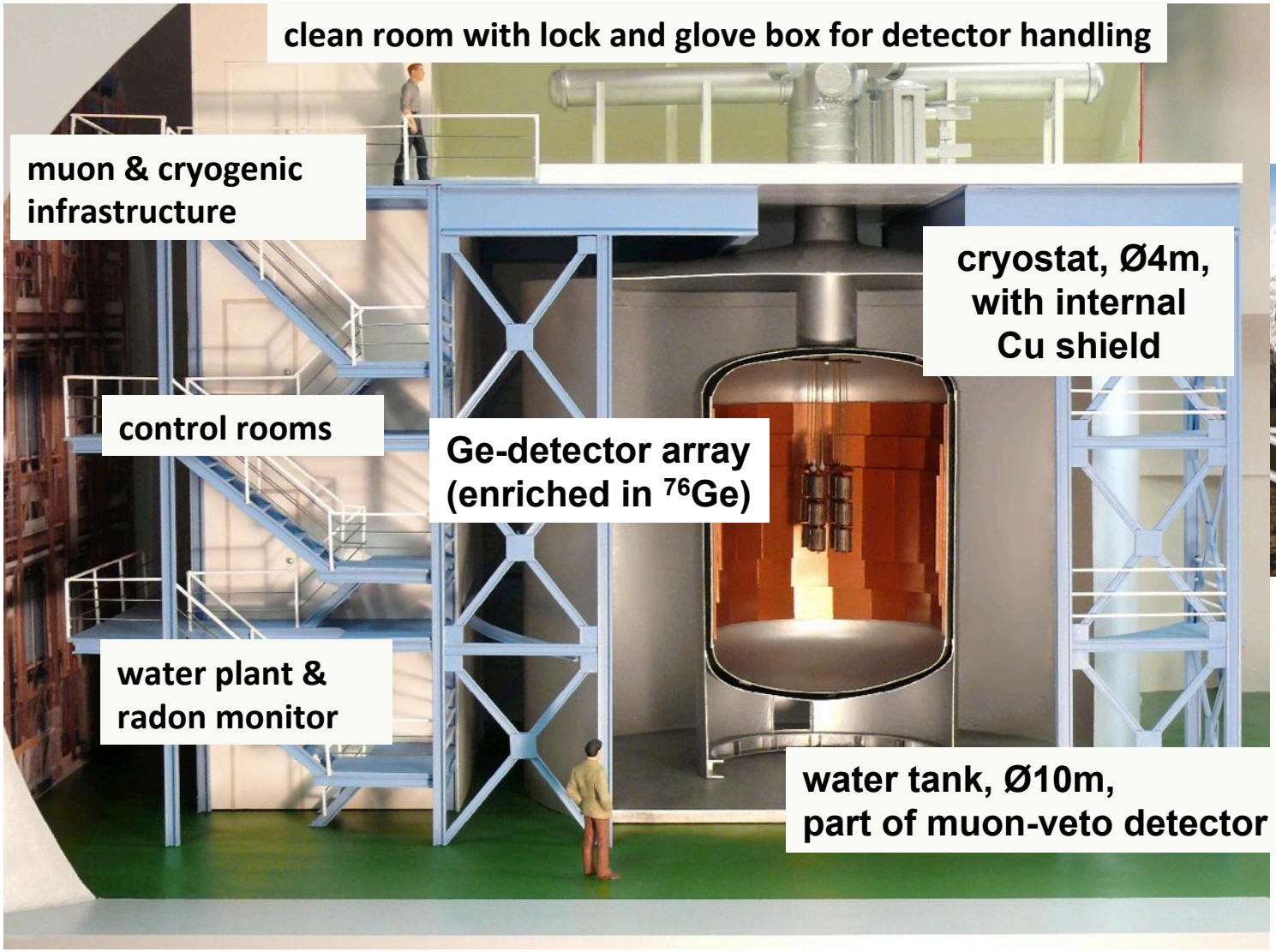
June 2-7, 2014, Boston, U.S.A.

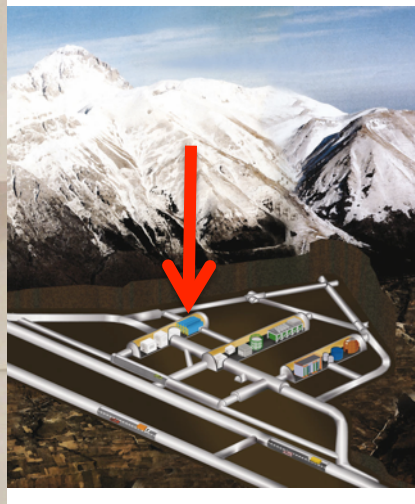
Results from **GERDA Phase I** and **status** of the upgrade to **Phase II**

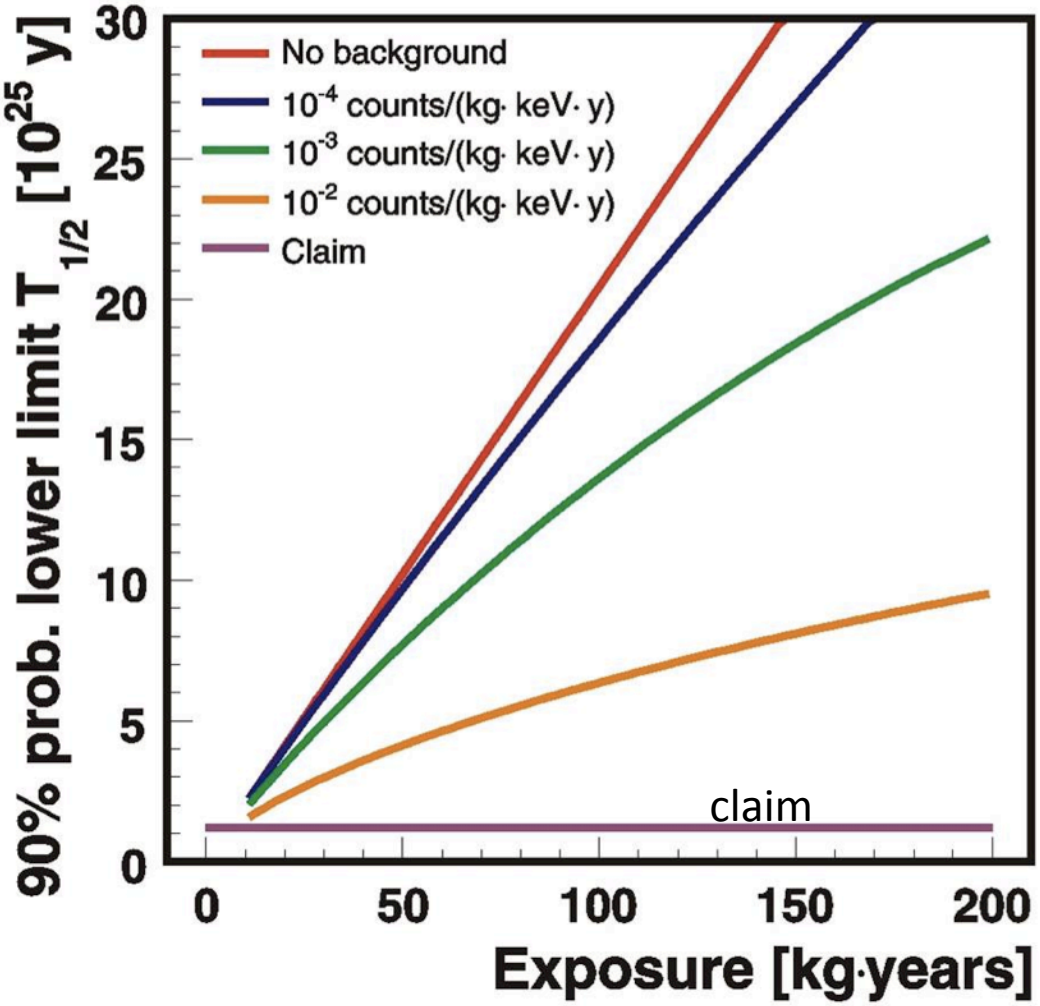
Stefan Schönert (TU München)
on behalf of the GERDA collaboration

The GERDA experiment @ LNGS

Eur. Phys. J. C (2013) 73:2330
arXiv:1212.4067



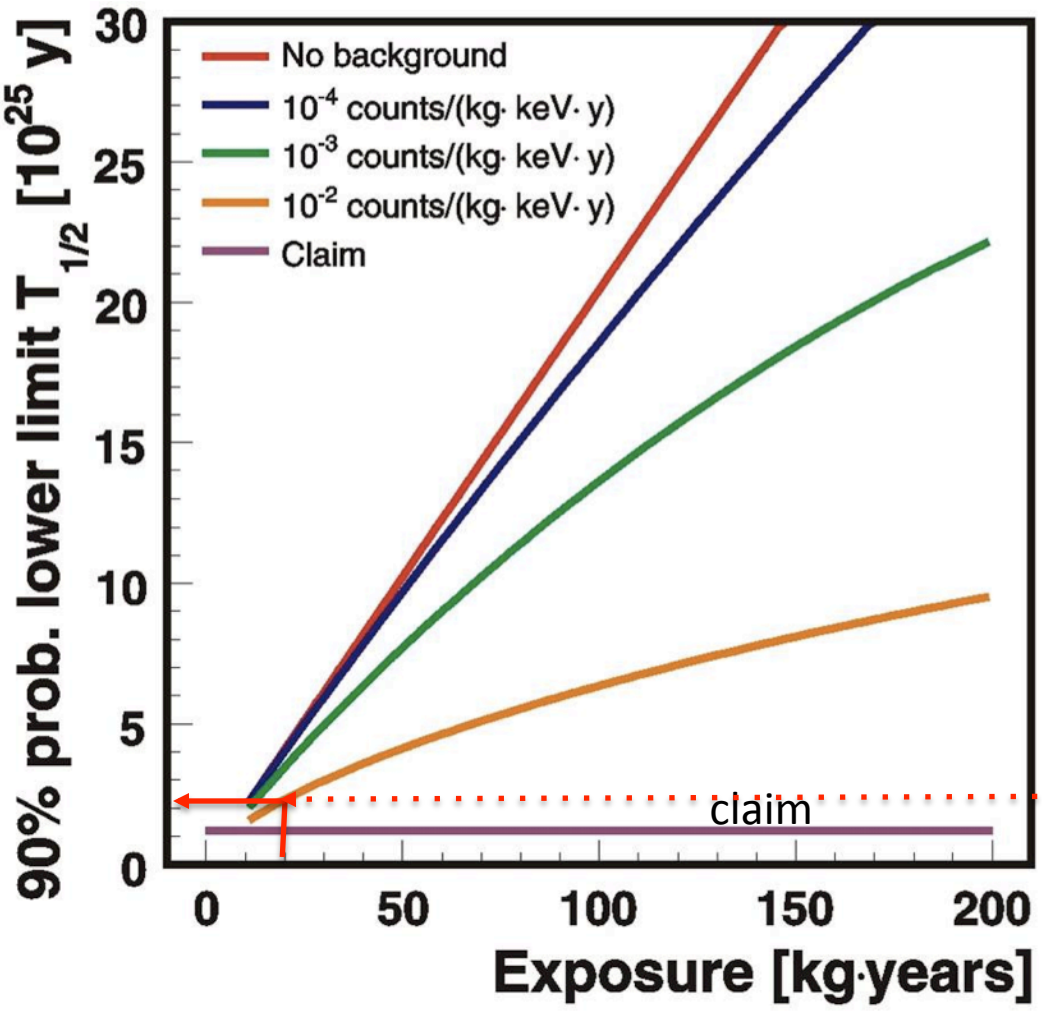




Goal:

'background free' operation

$T^{0\nu}_{1/2}$ scales with exposure



Goal:

'background free' operation

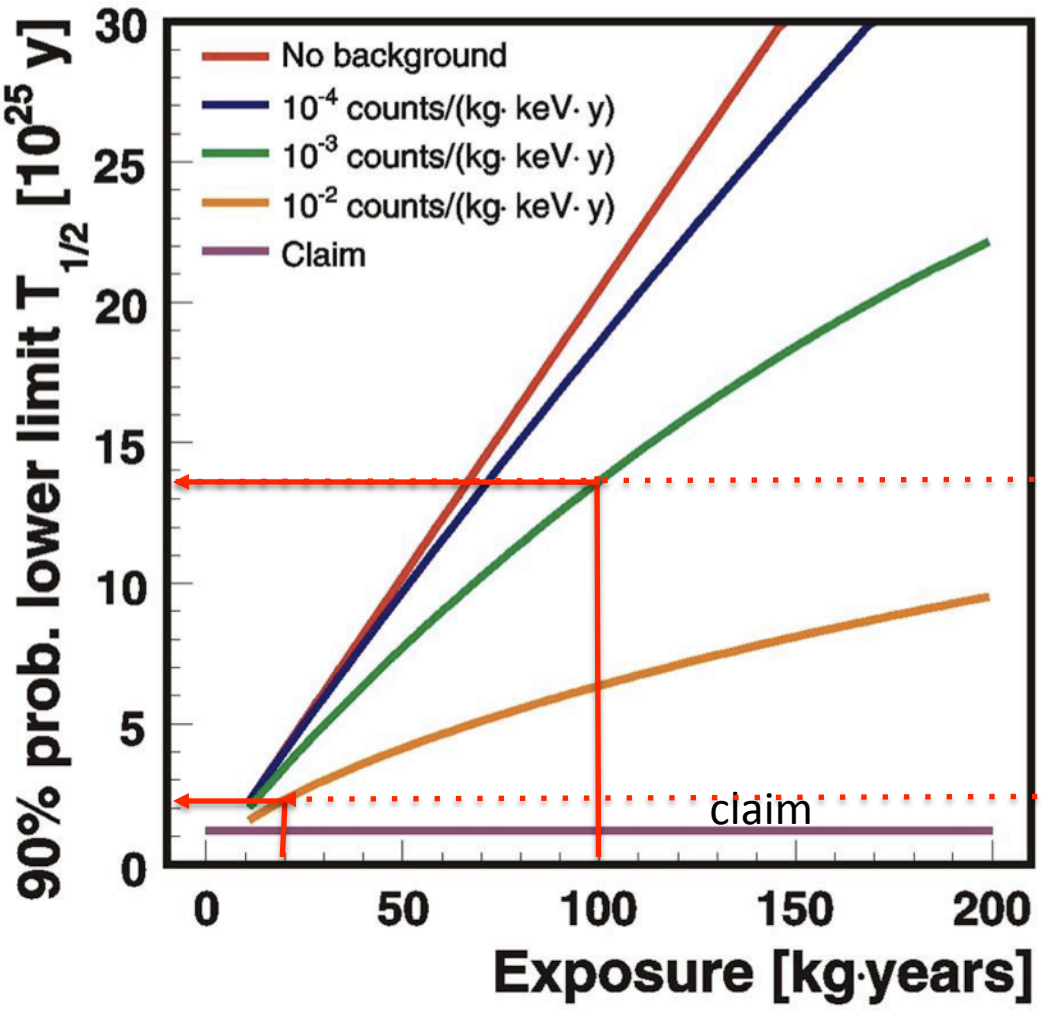
$T^{0\nu}_{1/2}$ scales with exposure

Phase I:

Use refurbished HdM & IGEX (18 kg)

BI ≈ 0.01 cts / (keV kg yr)

Sensitivity after 20 kg yr

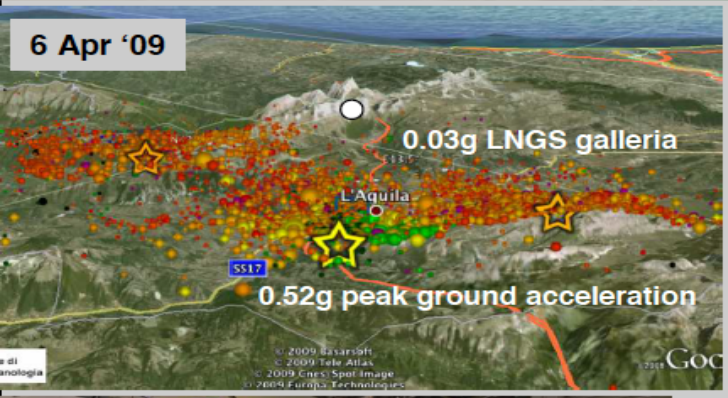


Goal:
'background free' operation
$T^{0\nu}_{1/2}$ scales with exposure

Phase II:
Add new enr. BEGe detectors (+20 kg)
BI ≈ 0.001 cts / (keV kg yr)
Sensitivity after 100 kg yr

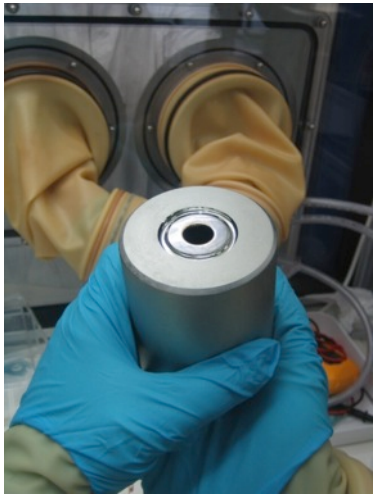
Phase I:
Use refurbished HdM & IGEX (18 kg)
BI ≈ 0.01 cts / (keV kg yr)
Sensitivity after 20 kg yr

The GERDA construction 2008-2010



Cryostat filled since December 2009

Nov 2011: deployment of 3-string & start of Phase I physics runs



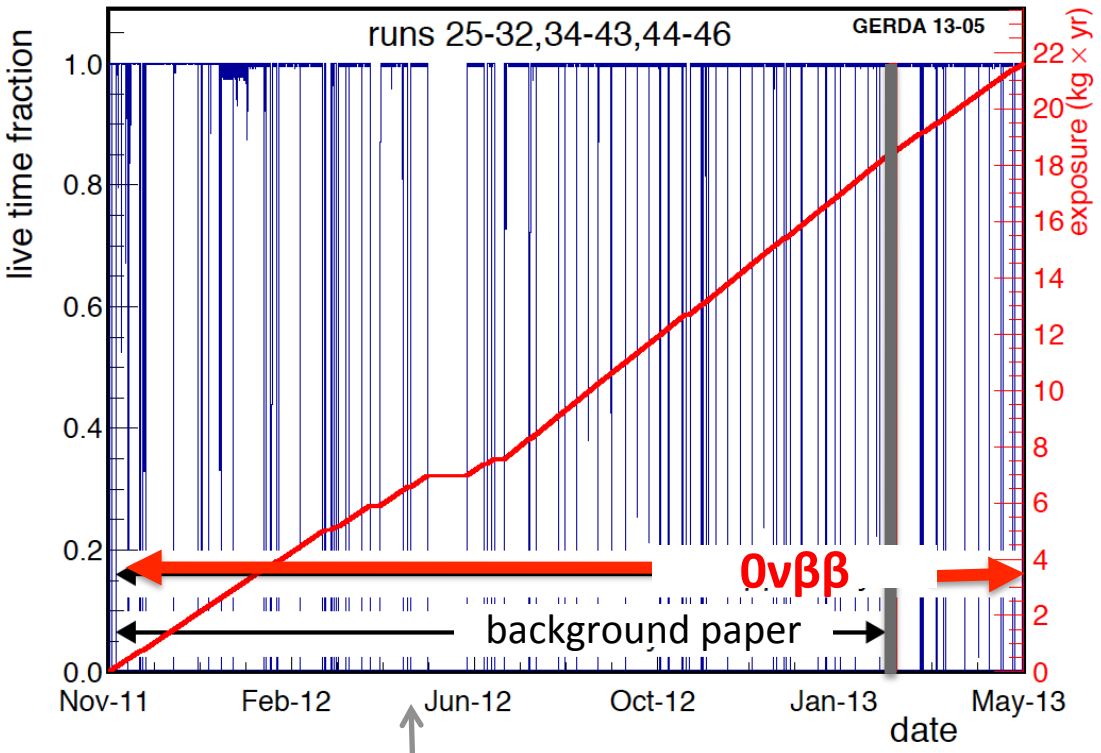
8 refurbished enriched diodes from HdM & IGEX
- 86% isotopically enriched in Ge-76
- 17.66 kg total mass
- plus 1 natural Ge diode from GTF

2 diodes shut off because leakage current high:
- total enriched enriched detector mass 14.6 kg

Overview of data taking

Eur. Phys. J. C (2013) 73:2330
arXiv:1212.4067

Total exposure for 0νββ analysis: 21.6 kg yr
(bi-)weekly calibration runs ('spikes')

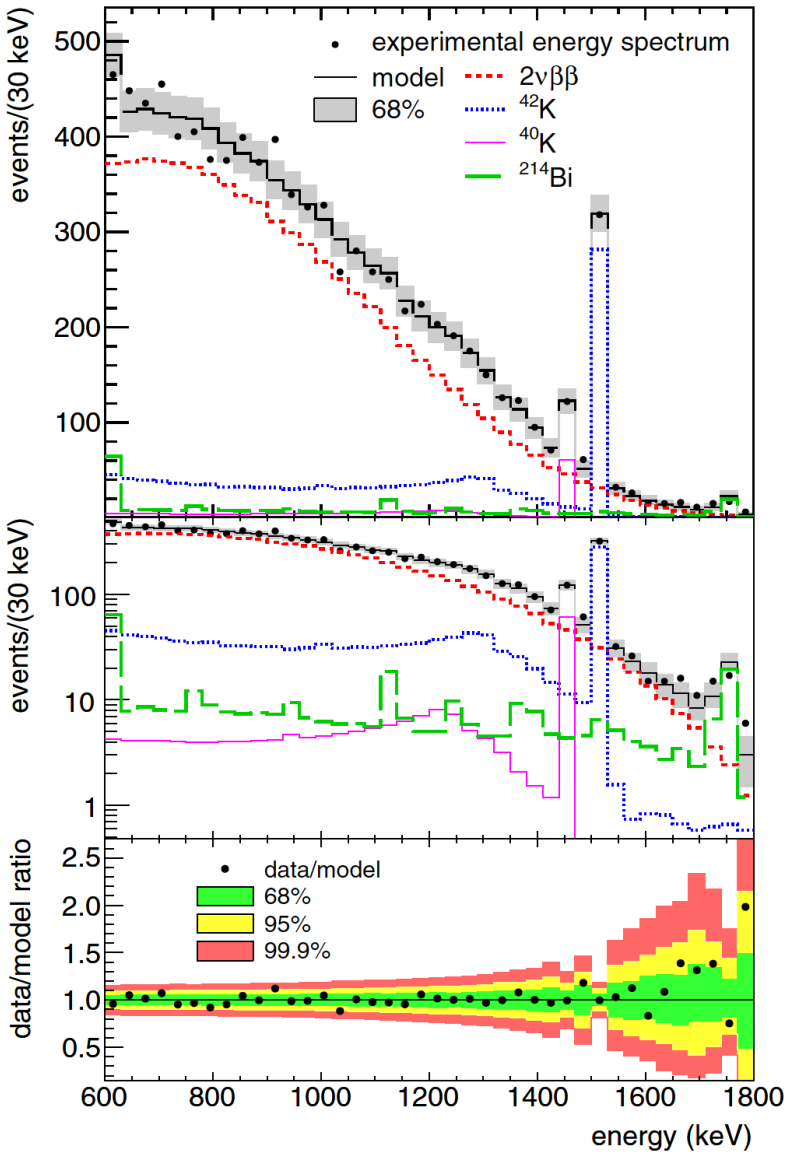


1st physics: 2νββ analysis (5.04 kg yr)

Data blinding:

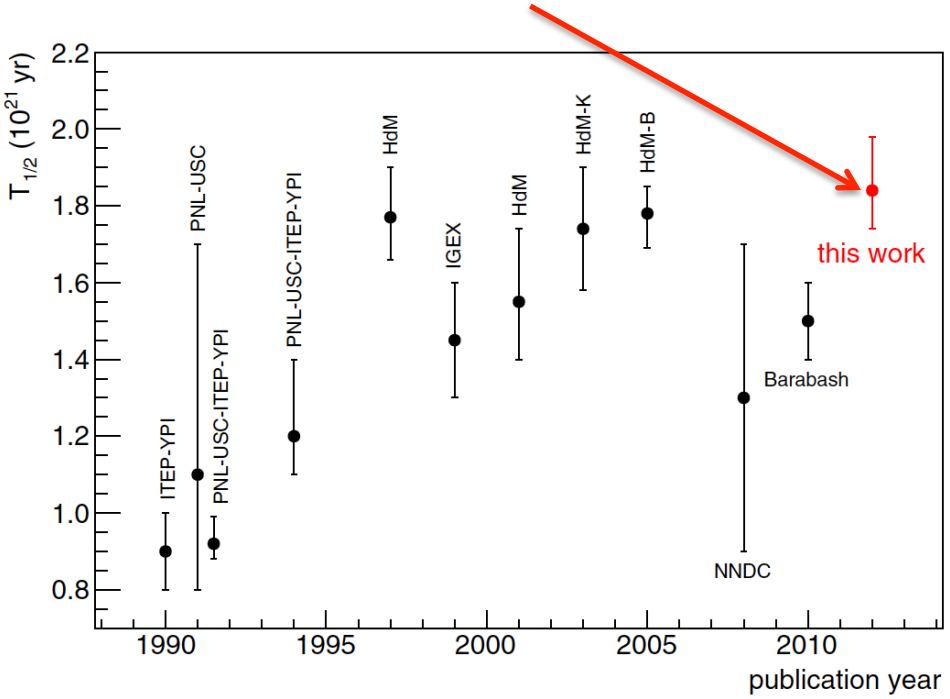
- All events in $Q_{\beta\beta}$±20 keV removed in Tier 1
- 2 copies of raw data kept for processing after unblinding

Measurement of $T^{2\nu}_{1/2}$ (^{76}Ge)



After only 5.04 kg yr exposure:

$T^{2\nu}_{1/2}(^{76}\mathrm{Ge}) = (1.84^{+0.14}_{-0.10}) \cdot 10^{21}$ yr



Overview of data taking

Eur. Phys. J. C (2013) 73:2330
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Total exposure for 0νββ analysis: 21.6 kg yr

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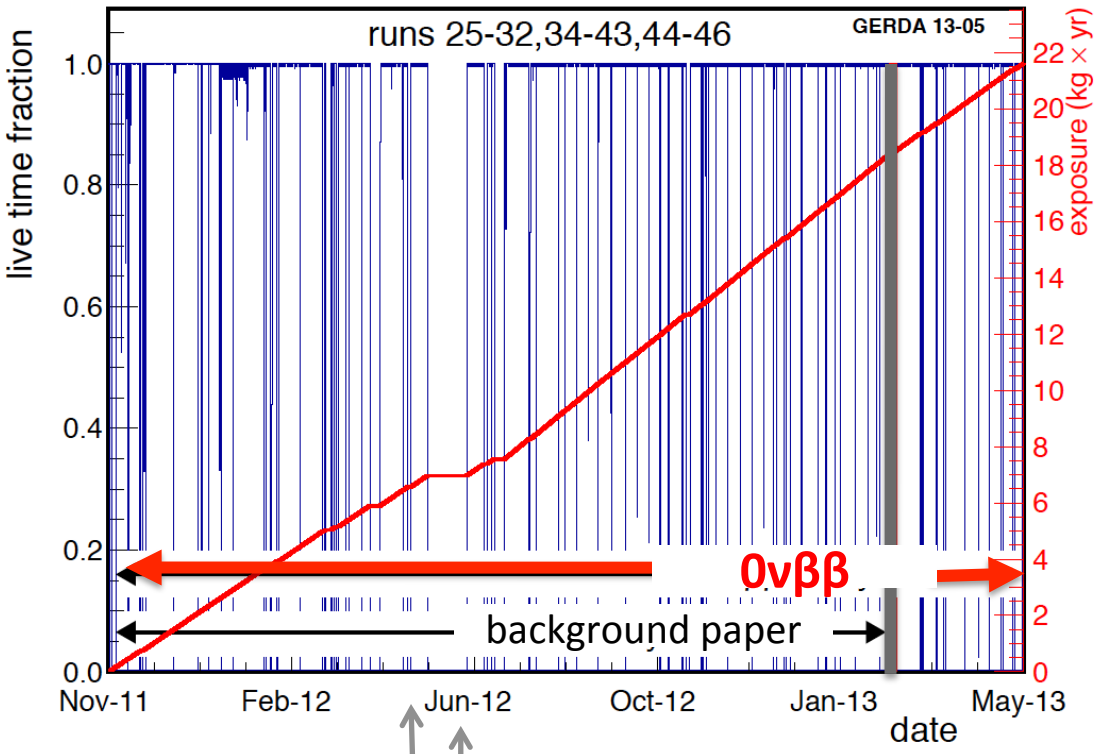


Insertion of 5 Phase II ^{enr}BEGe

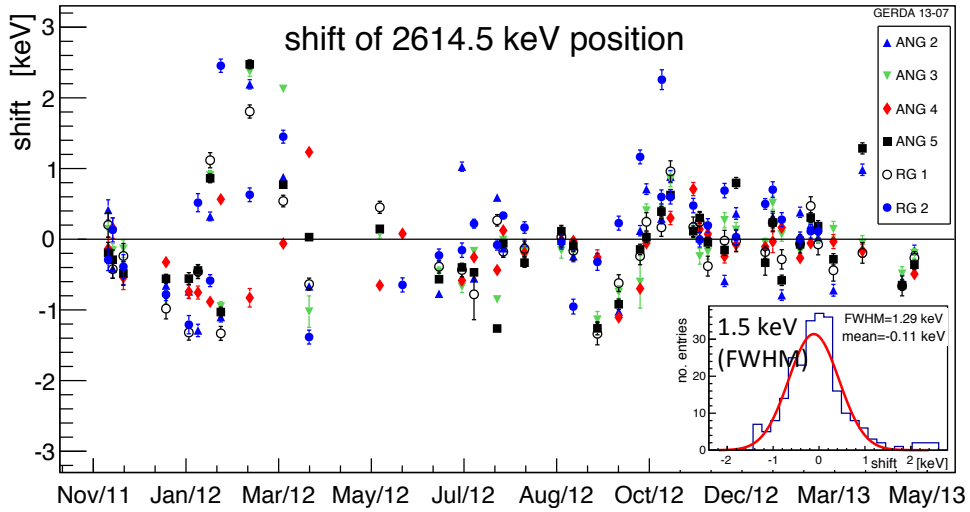
1st physics: 2νββ analysis (5.04 kg yr)

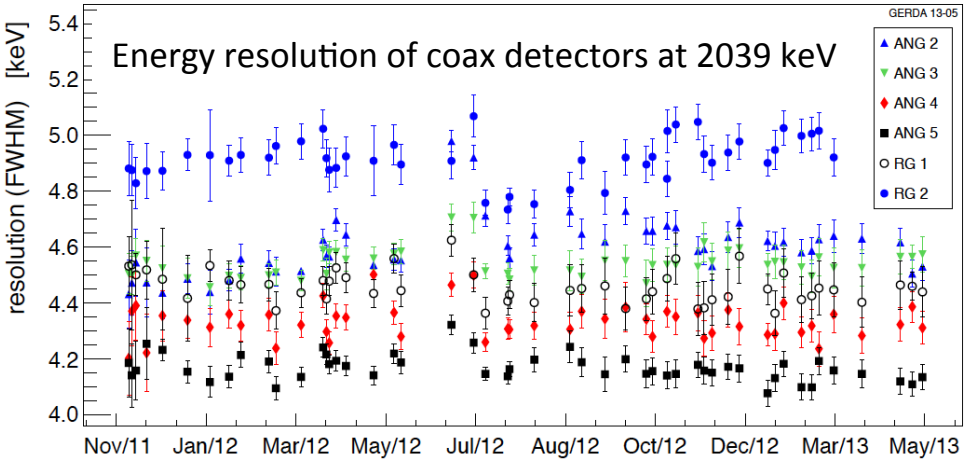
Data blinding:

- All events in $Q_{\beta\beta}$±20 keV removed in Tier 1
- 2 copies of raw data kept for processing after unblinding

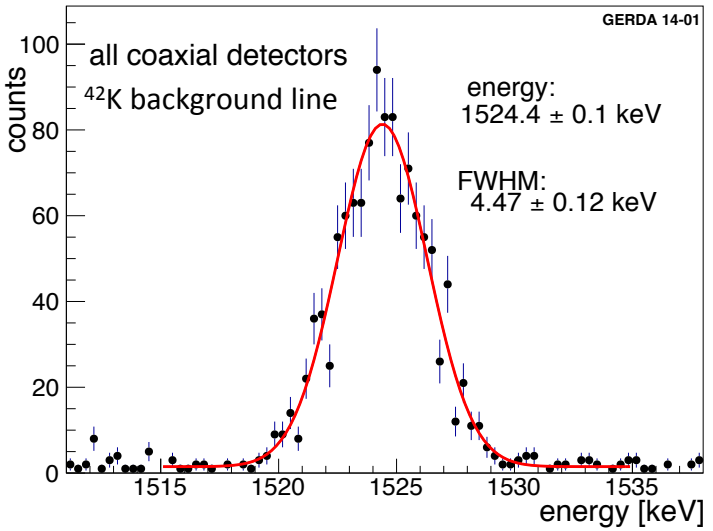
Calibration: stability of HPGe detectors

Peak position stability of 2614.5 keV calibration line:
coax: 1.5 keV / BEGe: 1.0 keV (FWHM)





Summing all runs: Eur. Phys. J. C (2013) 73:2330

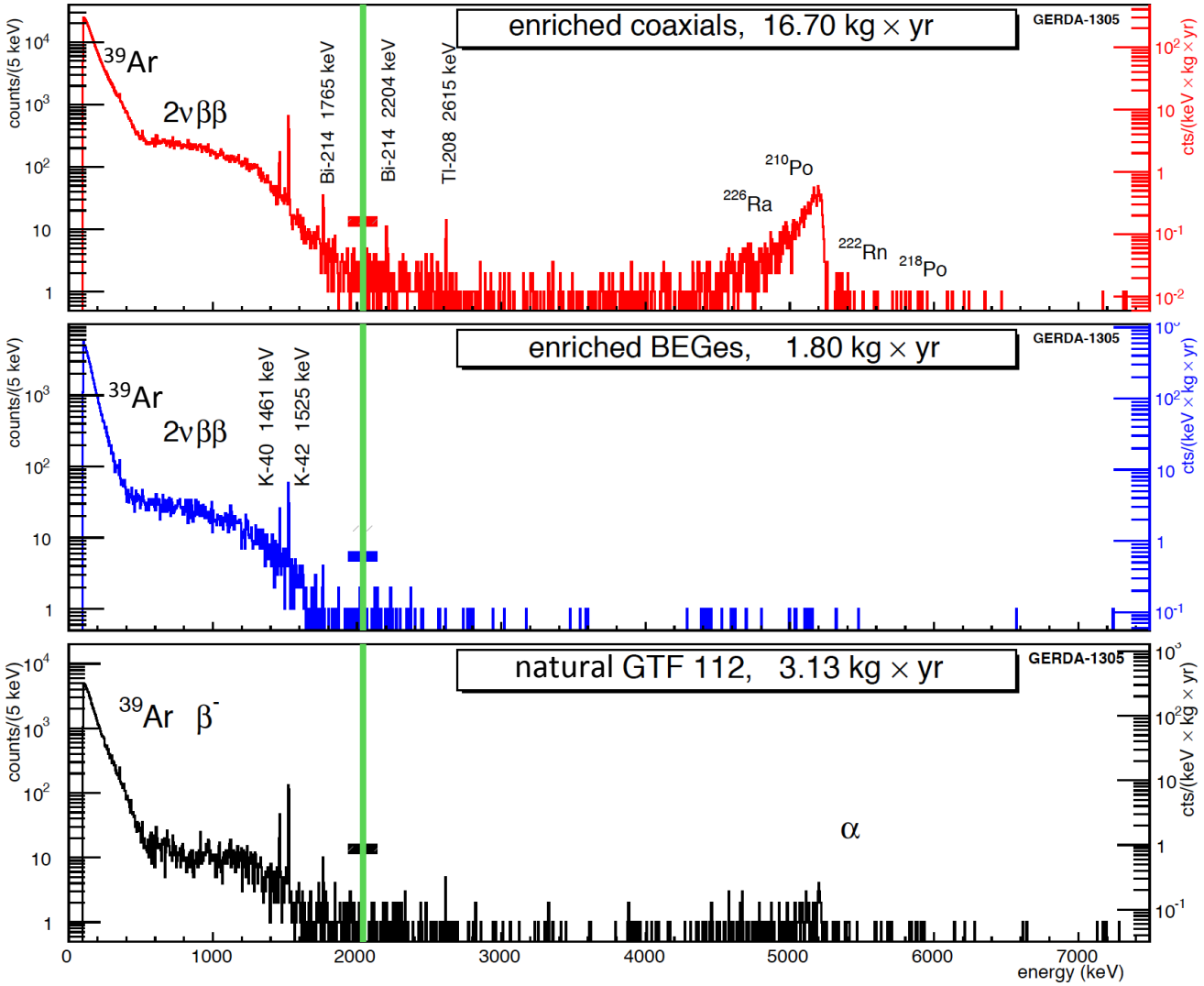


Mean energy resolution at $Q_{\beta\beta}$=2039 keV:

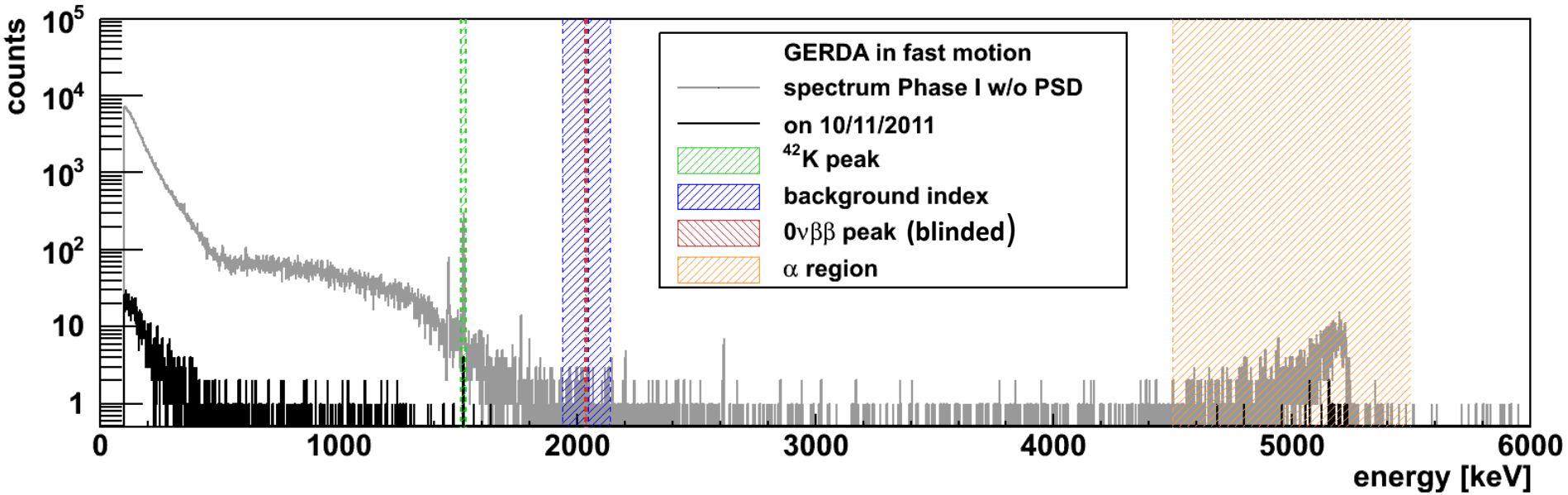
- Coax: 4.8 keV (FHWM)
- BEGe: 3.2 keV (FWHM)

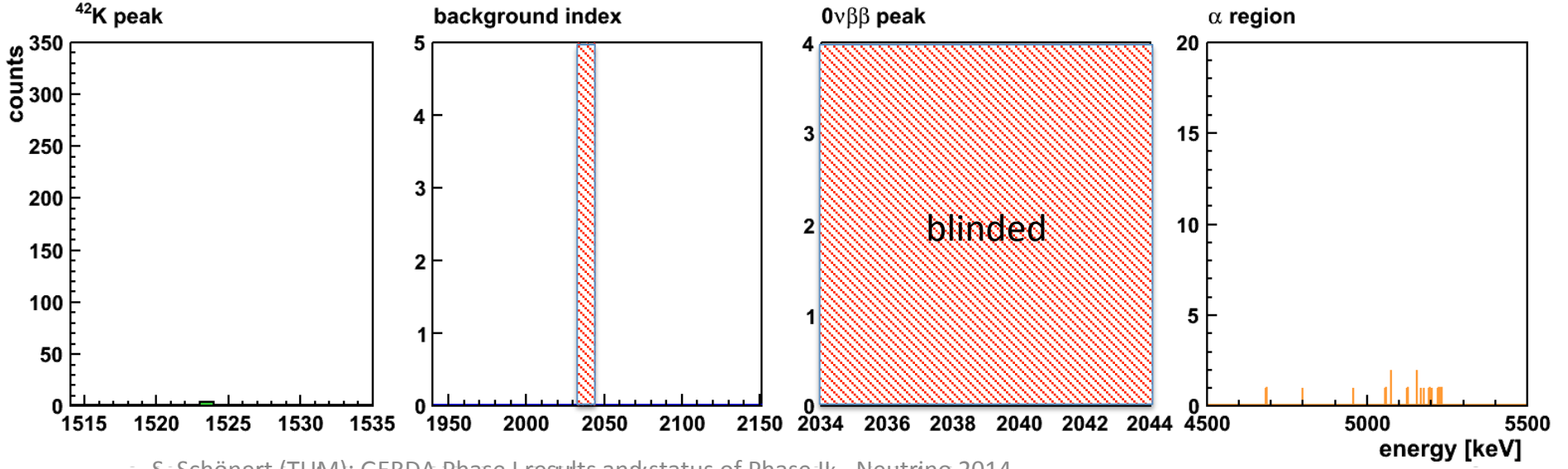
Physics run: energy spectra

arXiv:1306.5084
Eur. Phys. J. C (2014) 74:2764

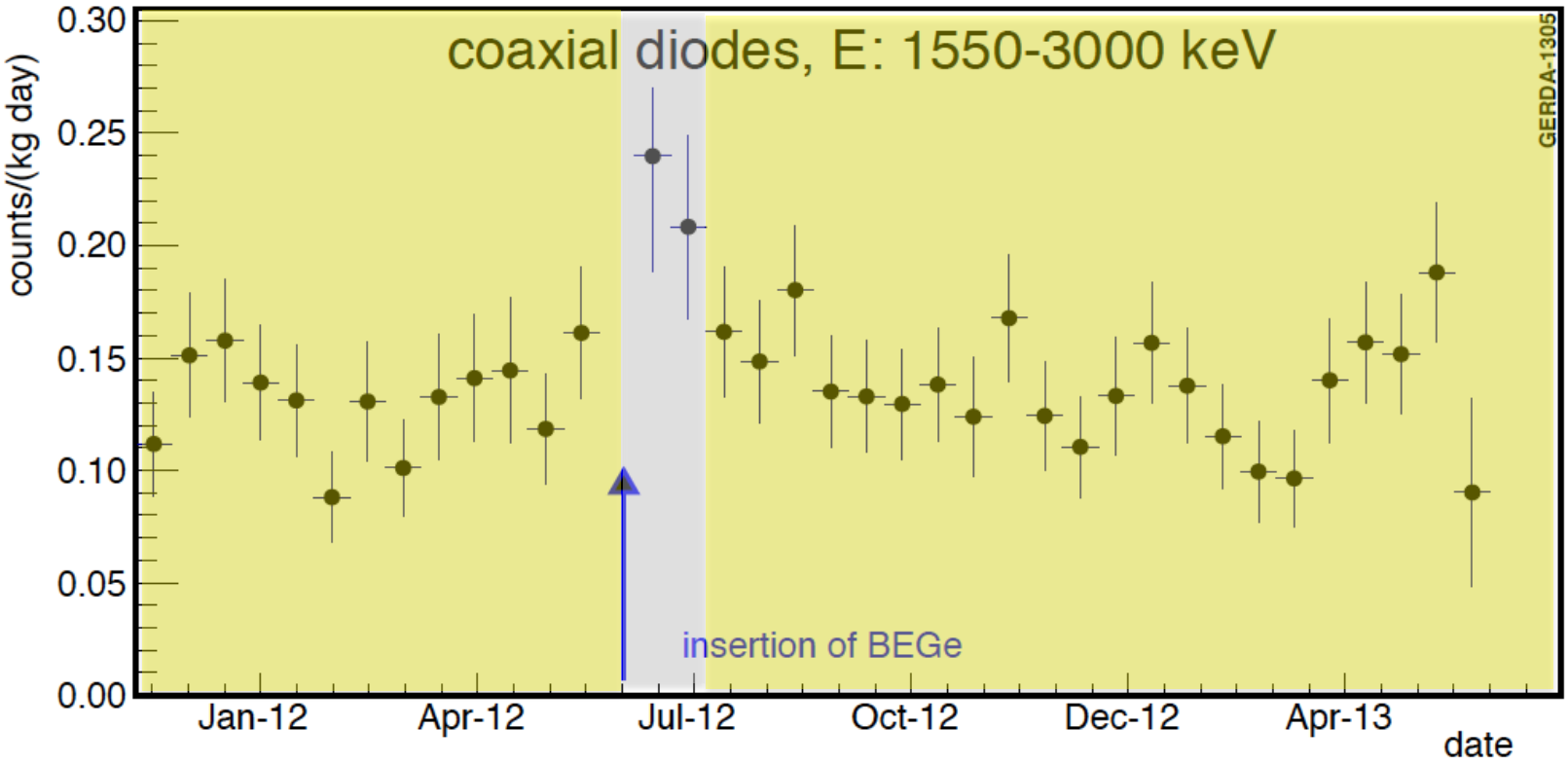


Physics run: energy spectra as function of time





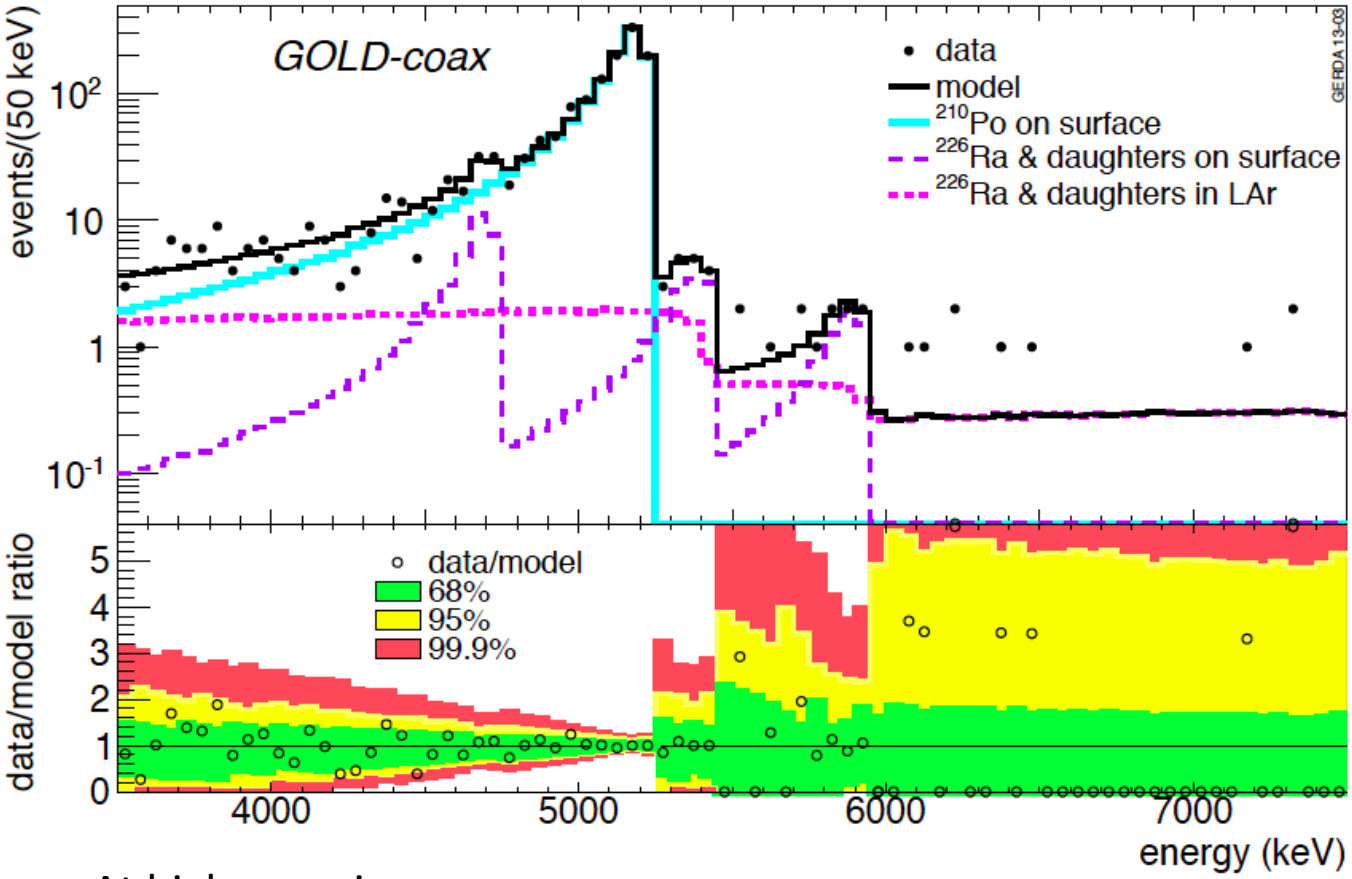
Physics run: background rate as function of time

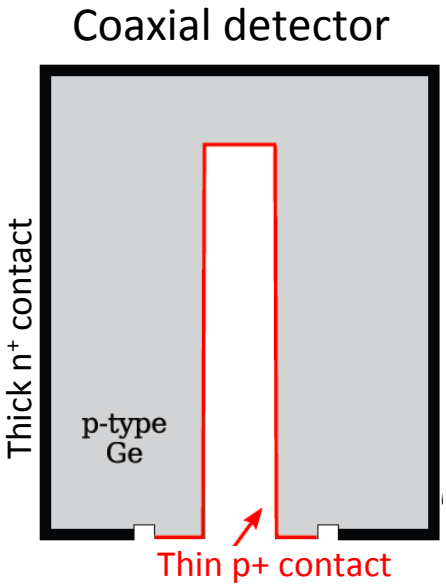


Coax-detector data set split in 'Gold' and 'Silver' (30 d)

Physics run: background decomposition

arXiv:1306.5084
Eur. Phys. J. C (2014) 74:2764



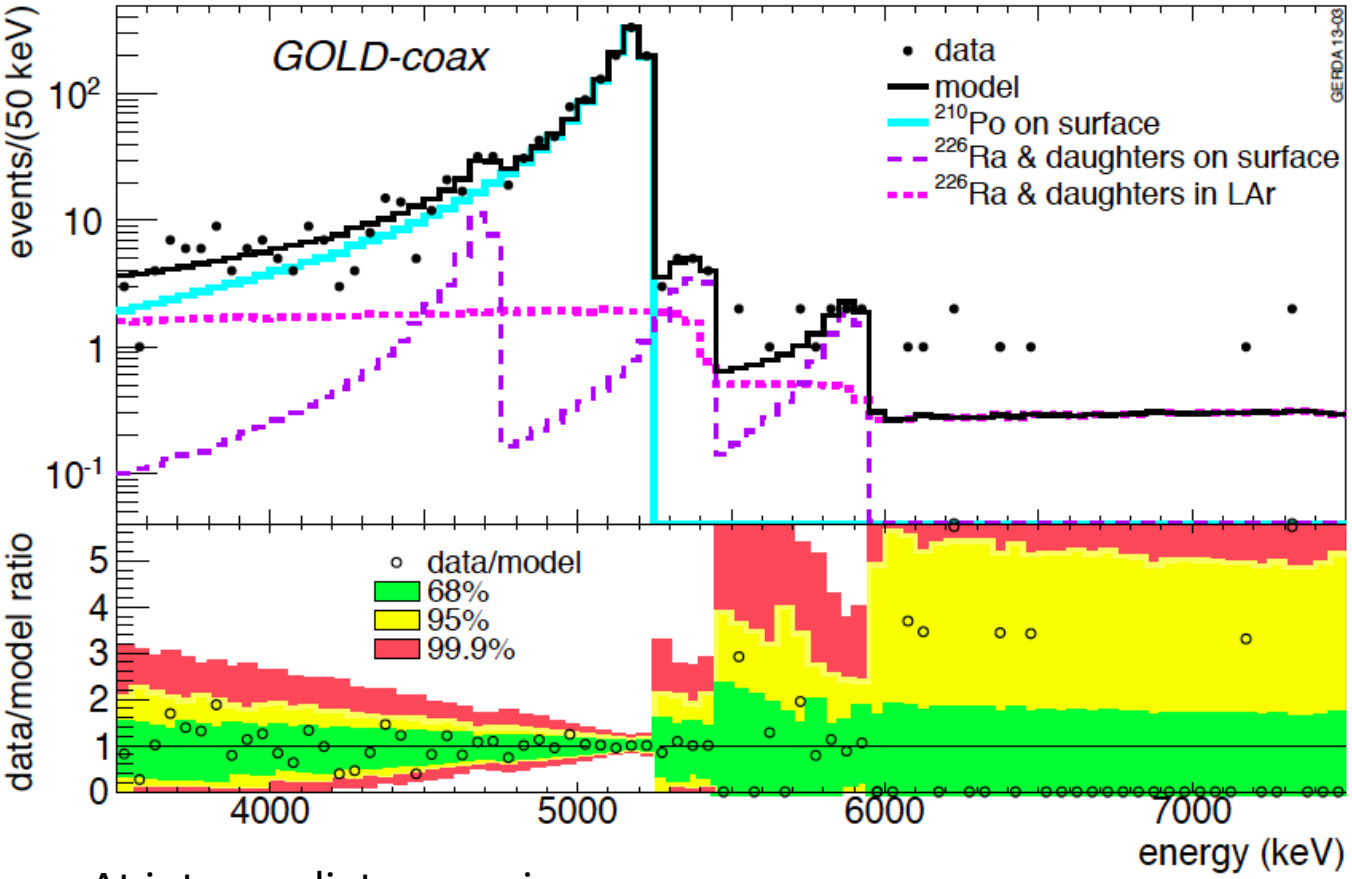


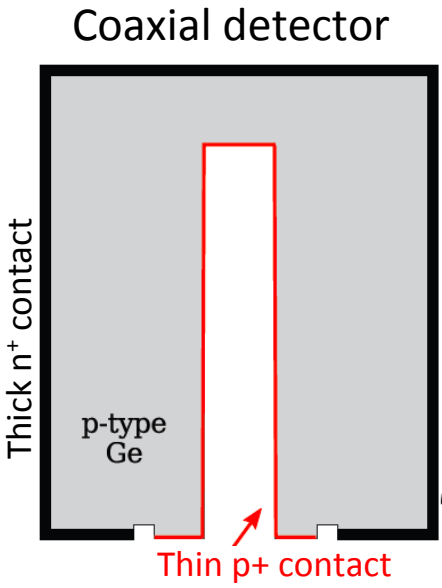
At high energies:

- dominated by (unsupported) **^{210}Po** ($T_{1/2}$=138 d)
- also contributions of **^{226}Ra** and progenies
- located on thin p+ contact; confirmed by pulse shape analysis

Physics run: background decomposition

arXiv:1306.5084
Eur. Phys. J. C (2014) 74:2764



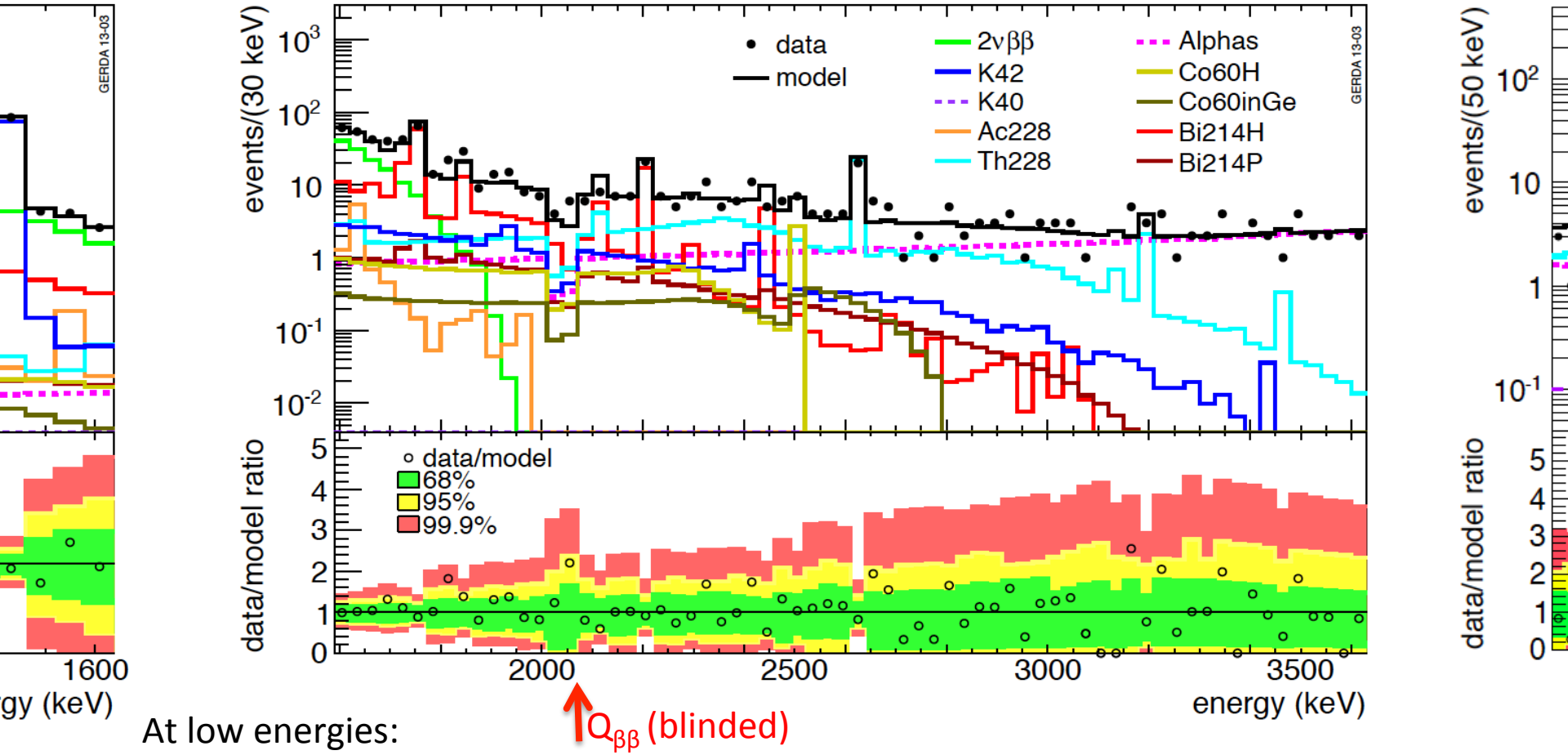


At intermediate energies:

- **Coax:** no single dominant component at $Q_{\beta\beta}$ for coax detectors
- BEGe: ^{42}K at n+ surface dominate because of thinner dead layer

Physics run: background decomposition

arXiv:1306.5084
Eur. Phys. J. C (2014) 74:2764



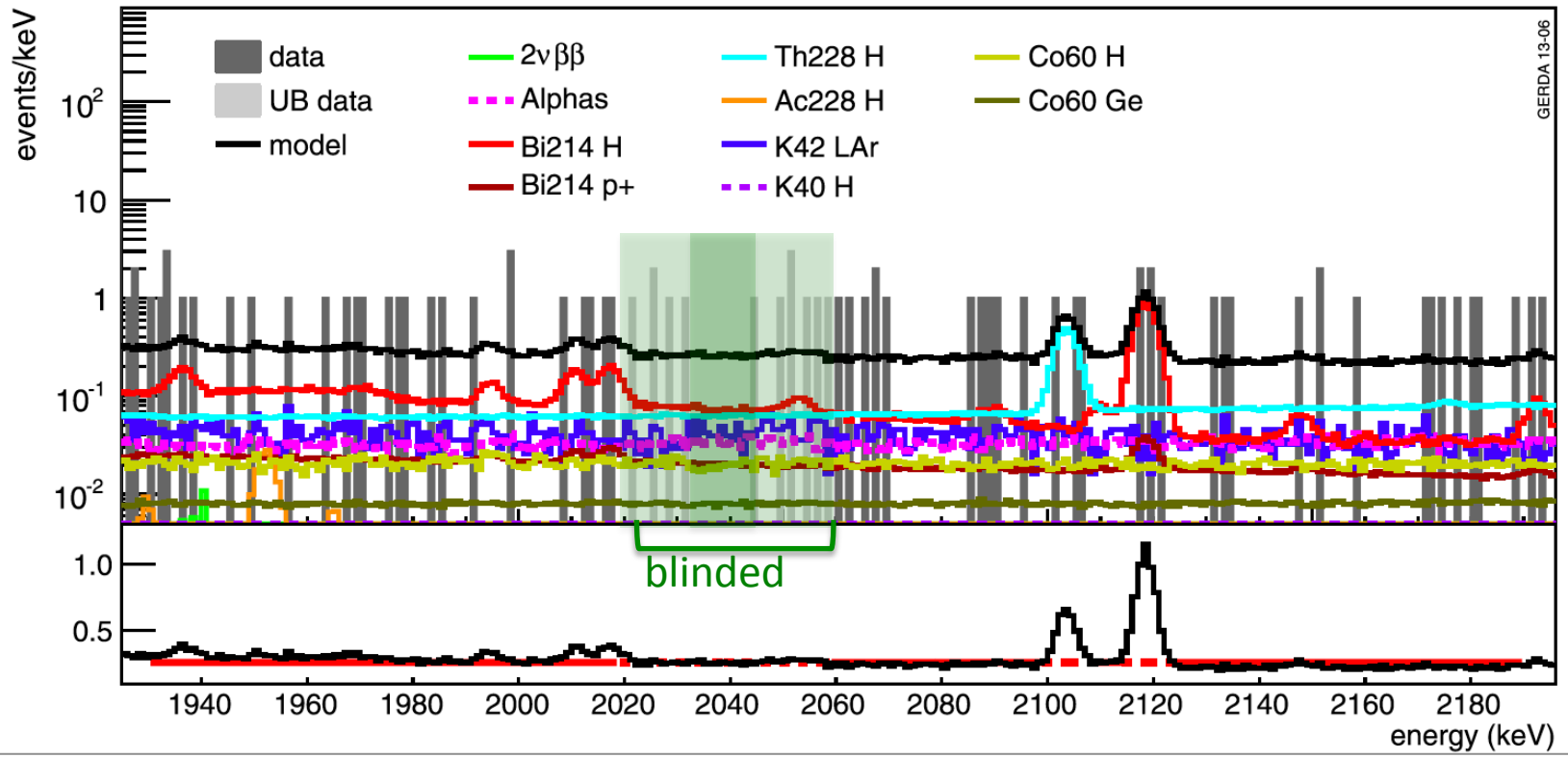
$Q_{\beta\beta}$ (blinded)

At low energies:

- 2νββ decays (>0.6 MeV)
- ^{39}Ar (<0.6 MeV)

Physics run: background model and prediction of BI at $Q_{\beta\beta}$

Eur. Phys. J. C (2014) 74:2764



- **No background peaks** expected around $Q_{\beta\beta}$ expected
- BI at $Q_{\beta\beta}$ **(17.6-23.8) x 10^{-3} cts/(keV kg yr)** depending on assumptions for location of sources
- Spectrum can be modeled with **flat background** (red line) in 1930-2190 keV excluding known peaks at 2104 and 2119 keV
- **Statistical uncertainty** of BI from interpolation **coincides** numerically **with systematic** uncertainty from model
- Prediction for 30 keV blinded side wings: Min./Max Mod: 8.2-9.1 / 9.7-11.1 observed.: 13

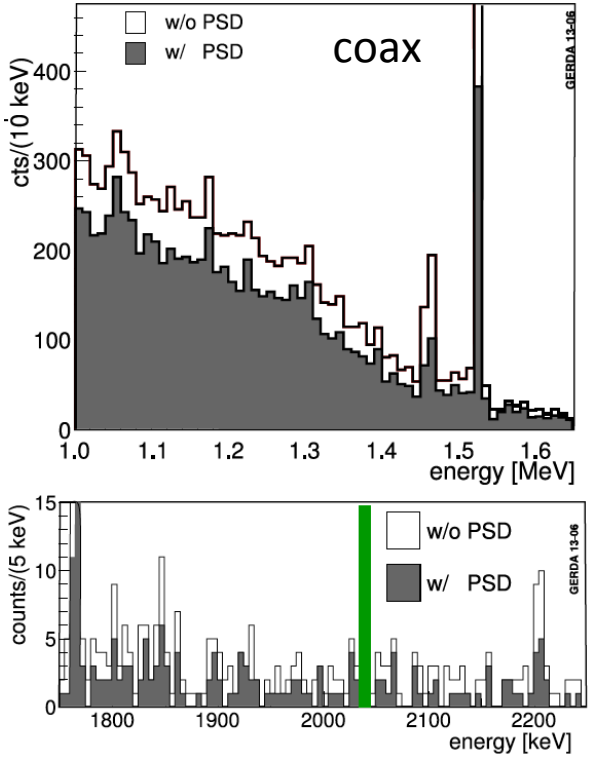
Pulse shape discrimination: method and cuts fixed prior unblinding

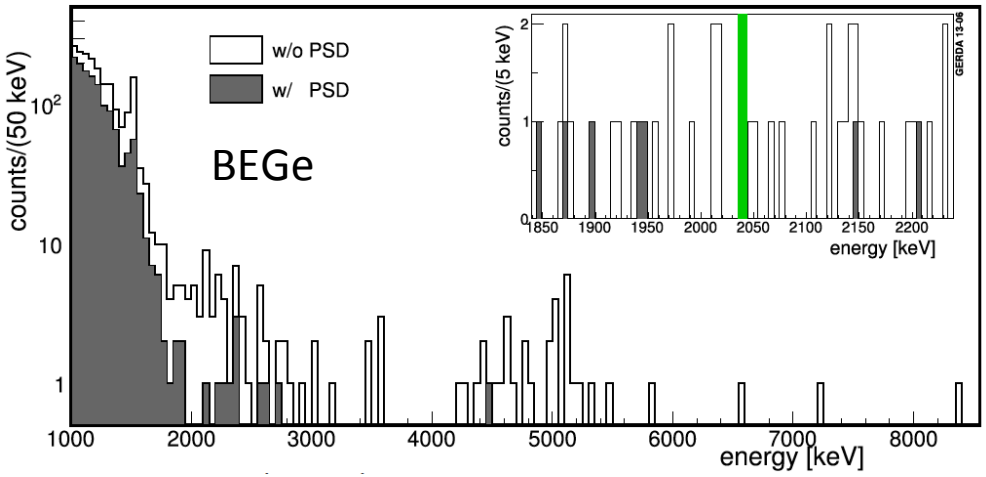
Coaxial detectors:

- artificial neural network TMlpANN
- cut defined using ^{228}Th calibration data
  cut fixed to 90% acceptance of 2.6 MeV DEP
- cross checks:
  - $2\nu\beta\beta$ acc. = (85±2)%
  - 2.6 MeV γ-line compton-edge acc. = 85-94%
  - Co-56 DEP (1576 & 2231 keV) acc. = 83-95%

$0\nu\beta\beta$ acceptance = 90^{+5}_{-9}%

background acc at $Q_{\beta\beta}$= ~45%





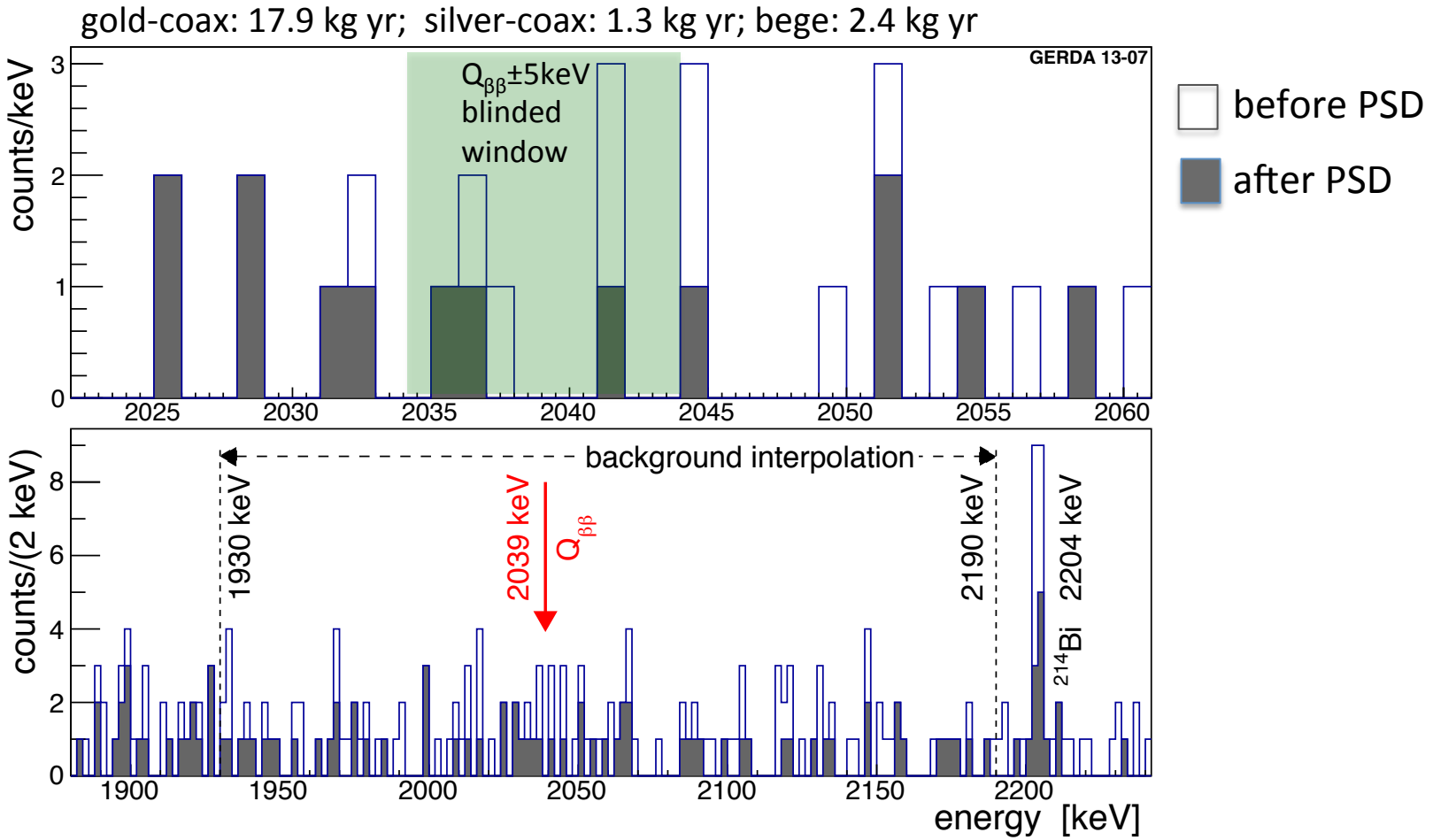
BEGe detectors:

- A/E method (mono-parametric PSD)
- $0\nu\beta\beta$ acc (DEP and simulations) (92±2)%
- $2\nu\beta\beta$ acc (91±5)%
- background acc at $Q_{\beta\beta}$≤20%

more details in [Eur.Phys.J C73 (2013) 2583]

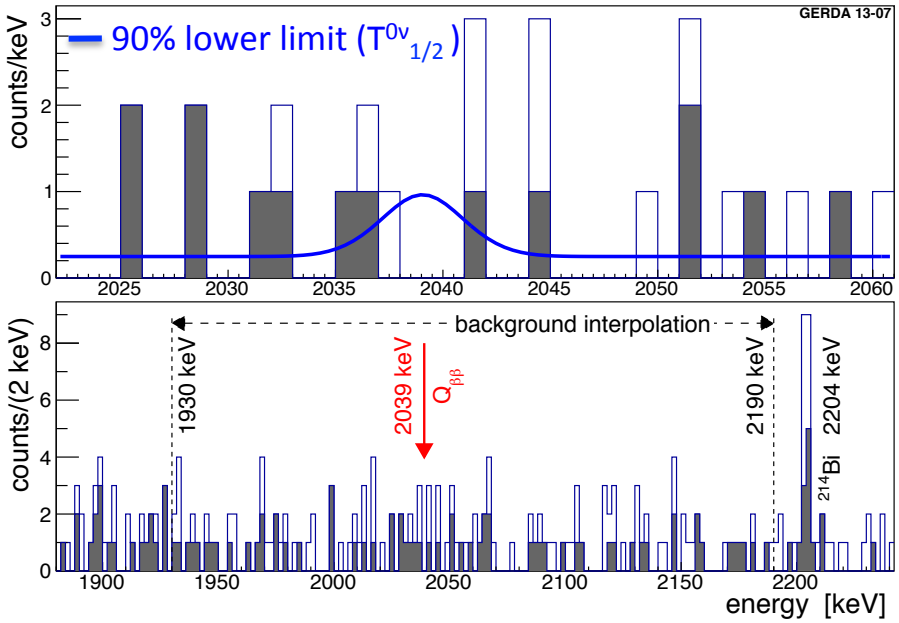
Unblinding: full data set (21.6 kg yr)

PRL 111 (2013) 122503



Full data set:	7 events obs. in blinded window	vs. 5.1 expected for bgd only
	3 events survive PSD cut	vs. 2.5 expected for bgd only

Profile likelihood fit to 3 data set (21.6 kg yr)
Frequentist and Bayesian limits & median sensitivities



PRL 111 (2013) 122503

Frequentist limit:

- 90% lower limit derived from profile likelihood fit to 3 data sets (constraint to physical 1/T range; excluding known γ-lines from bgd model at 2104±5 and 2119±5 keV)
- Best fit: **$N^{0\nu}=0$**
- **No excess** of signal counts above the background
- 90% C.L. lower limit:

$$T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}\ \text{yr}$$

- Limit on half-life corresponds **to $N^{0\nu}<3.5$ cts**
- Median sensitivity (90% C.L.): $>2.4\times10^{25}$ yr

Bayesian:

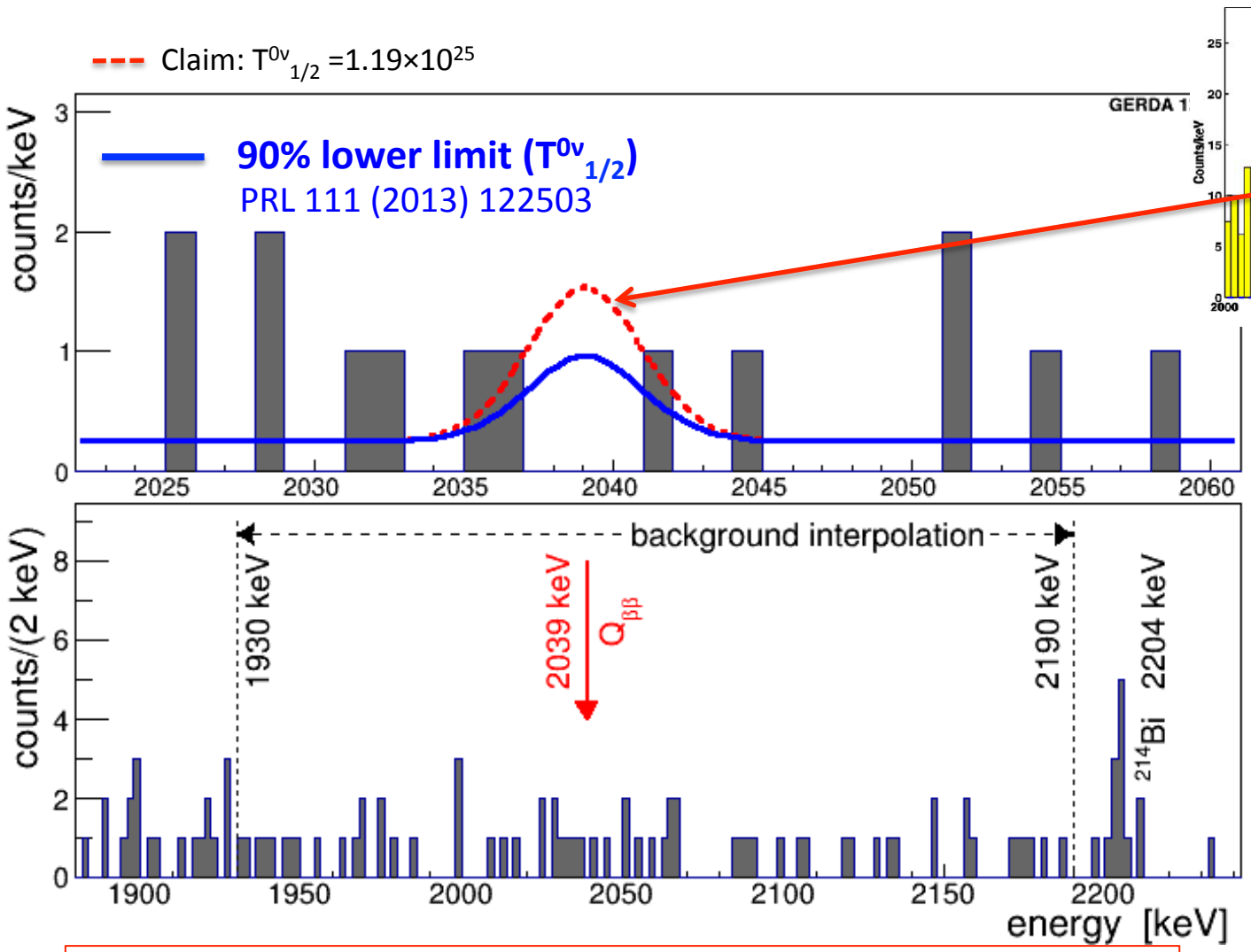
- Flat prior for 1/T
- Posterior distribution for $T^{0\nu}_{1/2}$
- Best fit: **$N^{0\nu}=0$**
- 90% credibile interval: $T^{0\nu}_{1/2} > 1.9 \cdot 10^{25}\ \text{yr}$
- Median sensitivity: (90% C.I.): $>2.0\times10^{25}$ yr

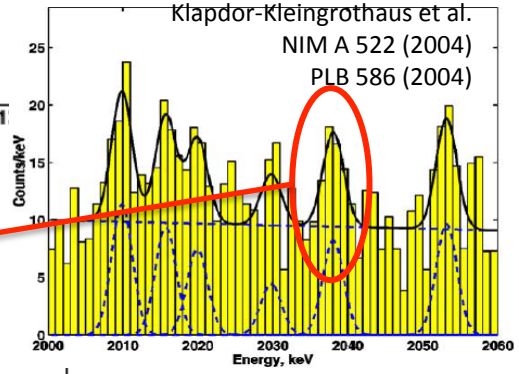
Systematics folded: limit weakened by 1.5%

Systematics:

Parameter	Det./Set	Value	Uncertainty
<ε> w/o PSD	Coax	0.688	0.031
	BEGe	0.720	0.018
Energy res.	Golden	4.83 keV	0.19 keV
	Silver	4.63 keV	0.14 keV
	BEGe	3.24 keV	0.14 keV
Energy scale (keV)		N.A.	0.2 keV
ε_{PSD}	Coax	0.90	+0.05/-0.09
	BEGe	0.92	0.02

Comparison with Phys. Lett. B 586 198 (2004) 0νββ claim in ^{76}Ge





H0: background only
H1: claimed signal plus background

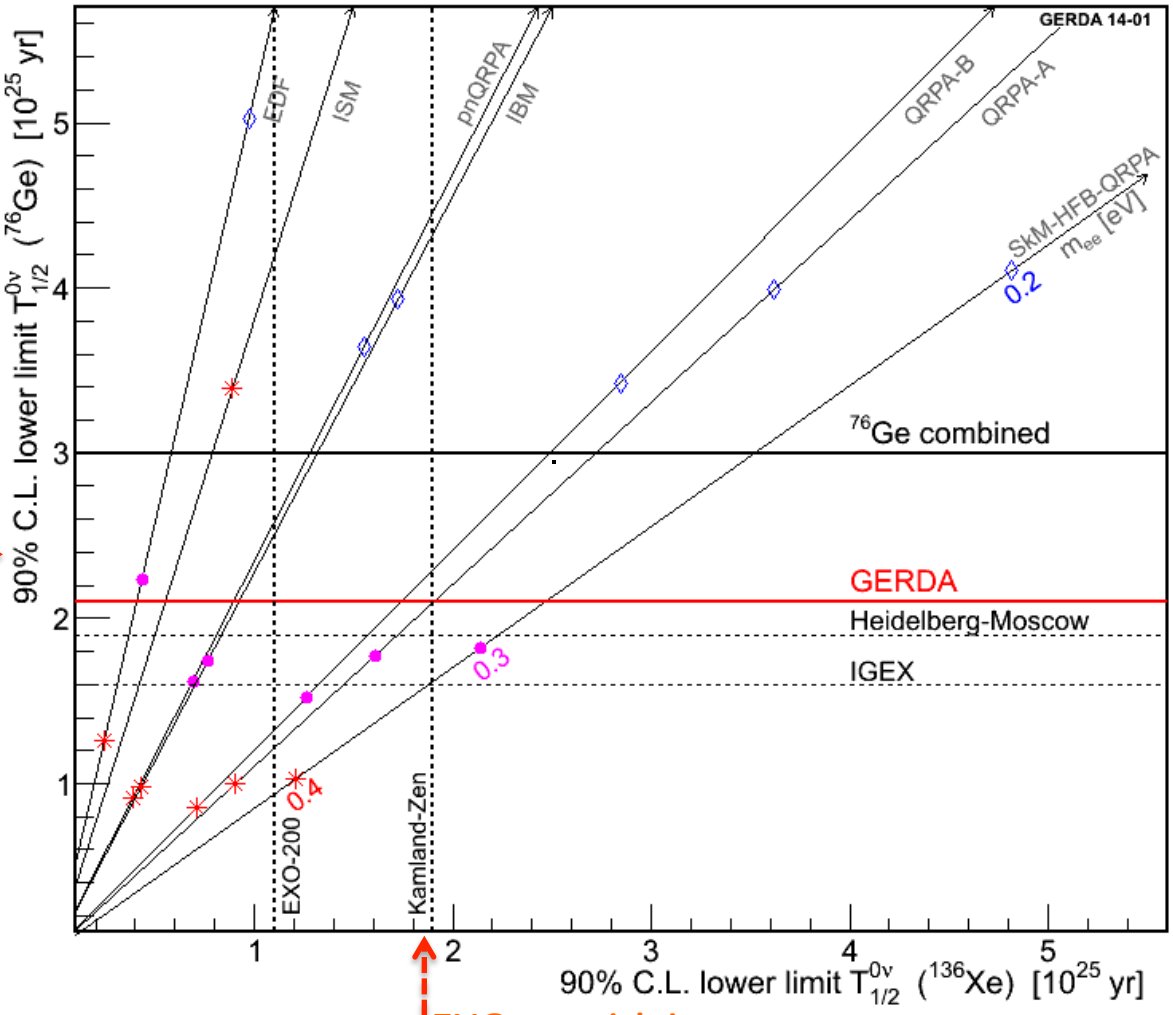
p-value from profile likelihood
P(N=0|H1) = 0. 01
(0.006 if 1/T unconstrained)

Bayes factor:
P(H1)/P(H0)=0. 024

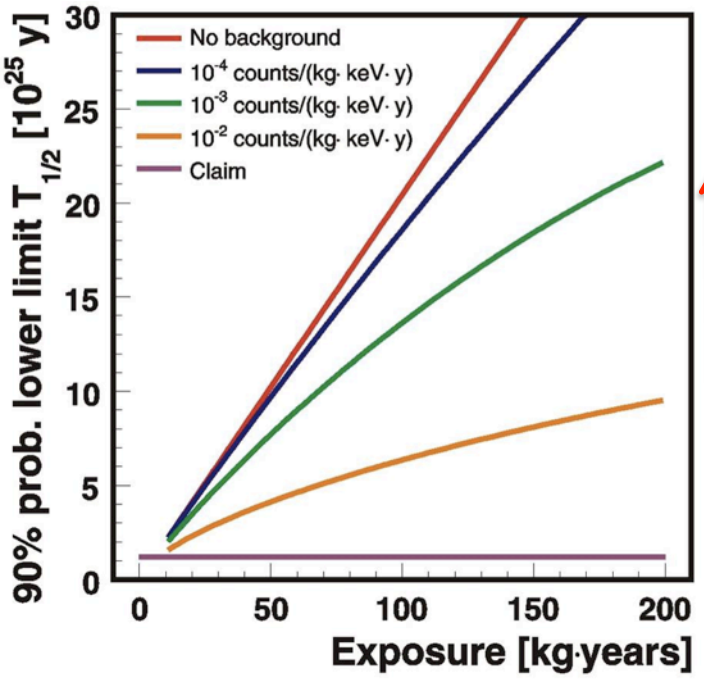
➔Claim refuted with high probability independent of NME and lepton number violating mechanism

Comparison with the Xenon DBD experiments

Sensitivity
GERDA Phase I



Reducing background further for GERDA Phase II



Phase II:
10^{-3} cts/(kg keV yr)

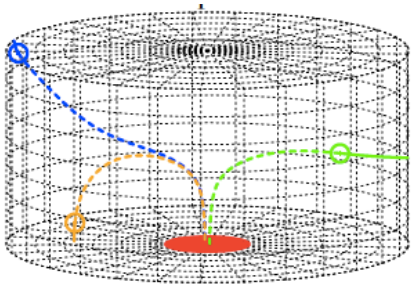
1/10

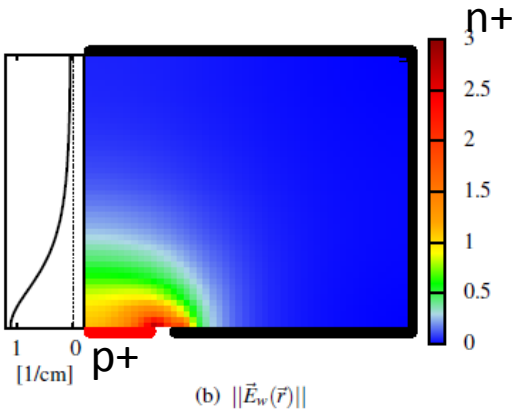
Phase I:
10^{-2} cts/(kg keV yr)

<u>Major hardware upgrade:</u>

- Novel detectors with advanced pulse shape discrimination (BEGe's)
- Improved detector assembly & electronics
- Liquid argon instrumentation (veto system)

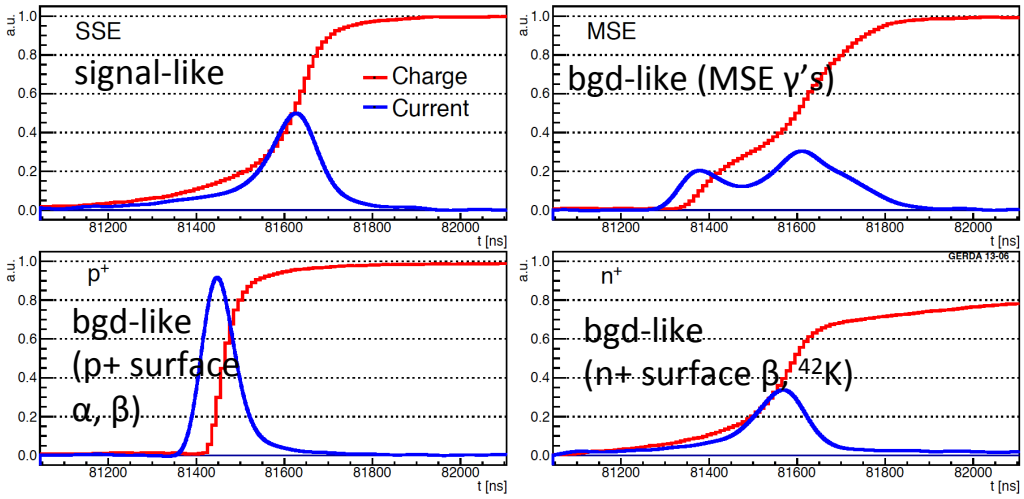
Thick window BEGe's with advanced pulse shape performance

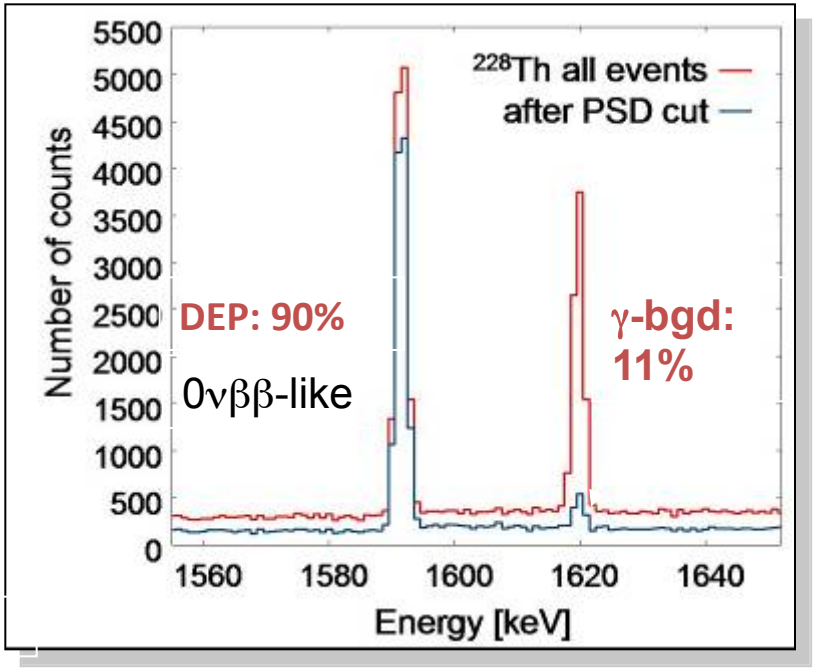




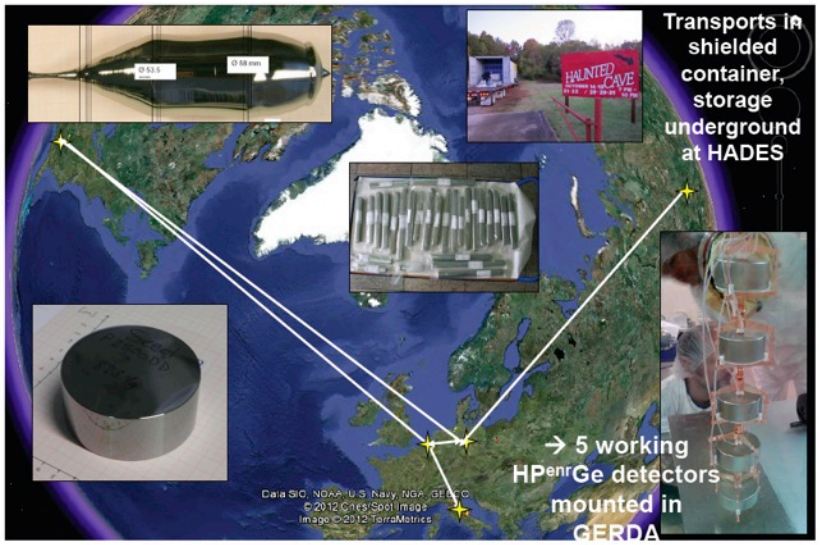
Signal shape provides clear topology for event-by-event signal ID / bgd discrimination:

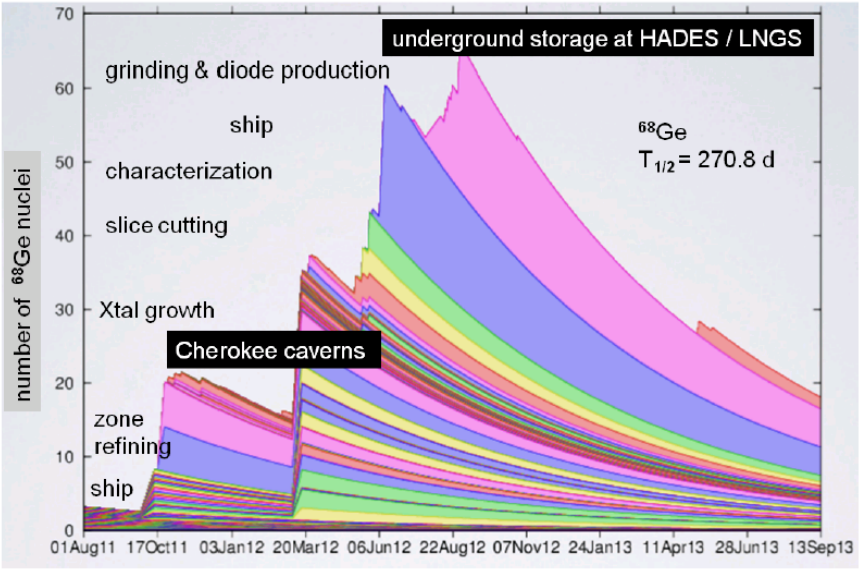
- **SSE/MSE** discrimination
- **Surface** events:
  - n+ slow pulses
  - p+: 'amplified' current pulses

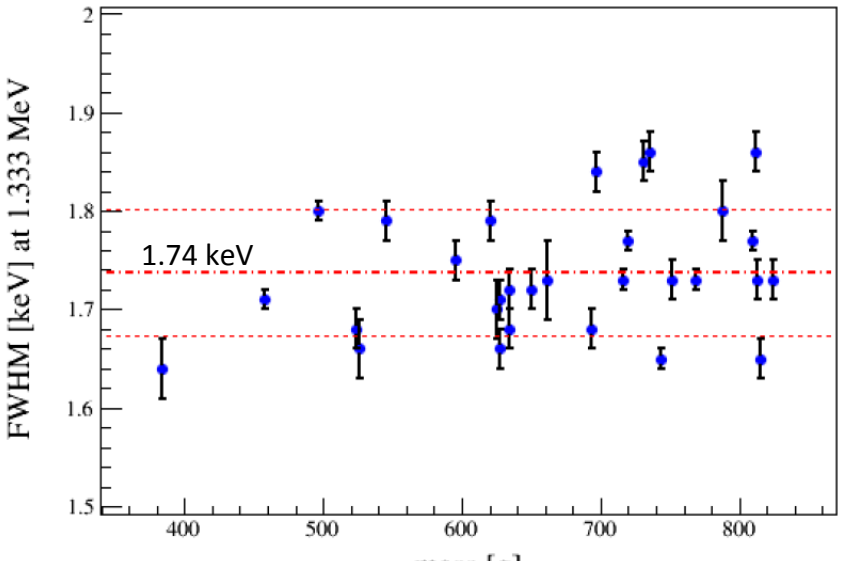




Phase II enriched BEGe detector characteristics







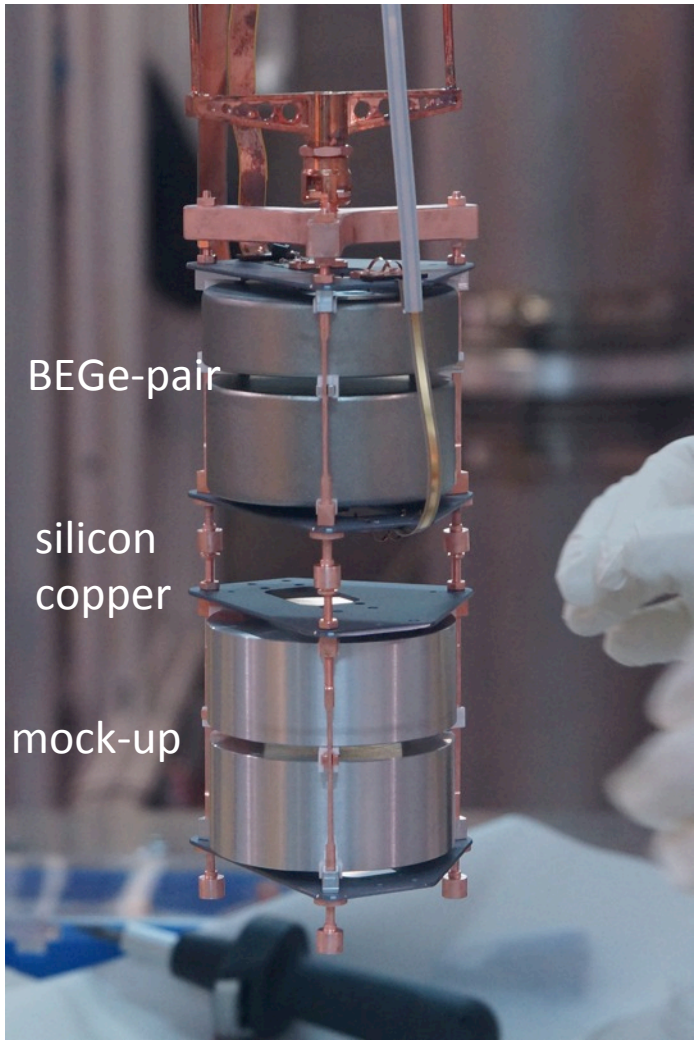
- Background index due cosmogenic activation(w/o PSD):

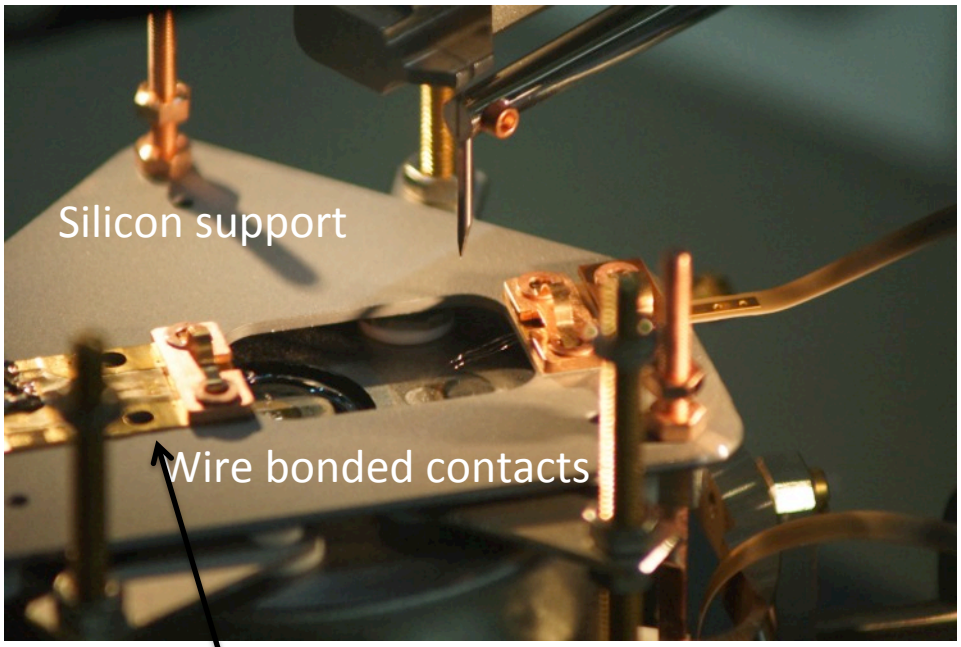
  ^{60}Co: $< 0.7 \cdot 10^{-4}$ cts/(keV·kg·yr)

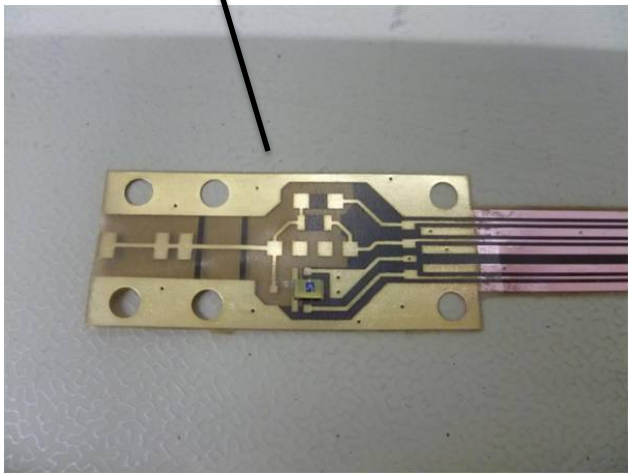
  ^{68}Ge: $< 4 \cdot 10^{-6}$ cts/(keV·kg·yr)
- 30 detector slices with 20.8 kg total
- Energy resolution in vacuum cryostats <1.9 keV (FWHM) @ 1.3 MeV

Phase II enriched BEGe detector assembly and VFE electronics

Phase II detector assembly



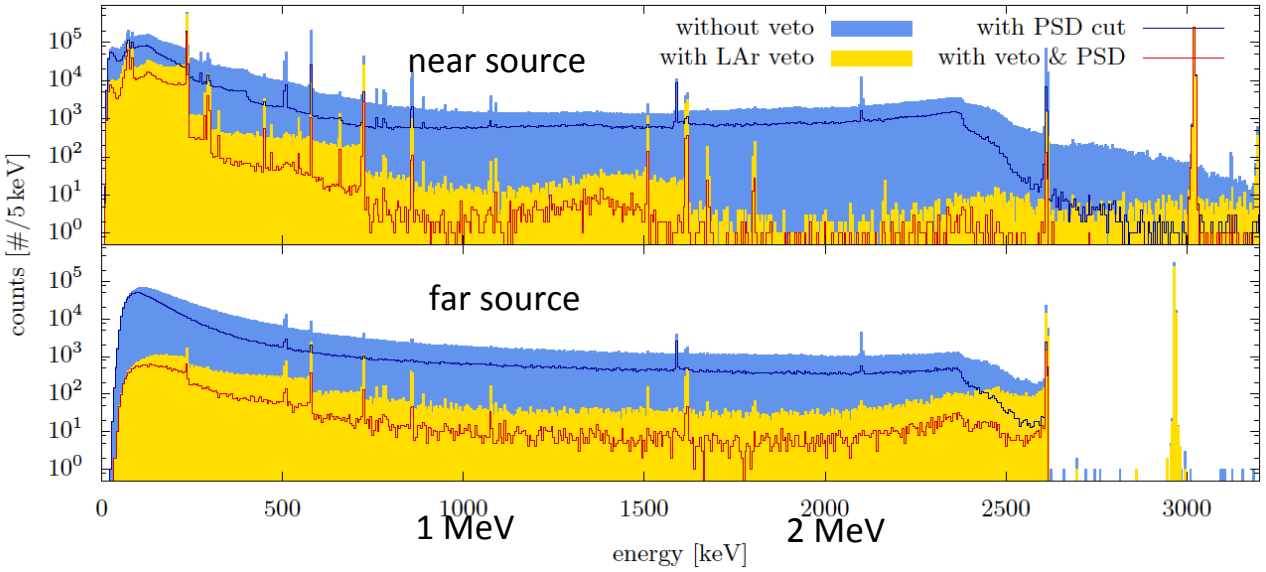


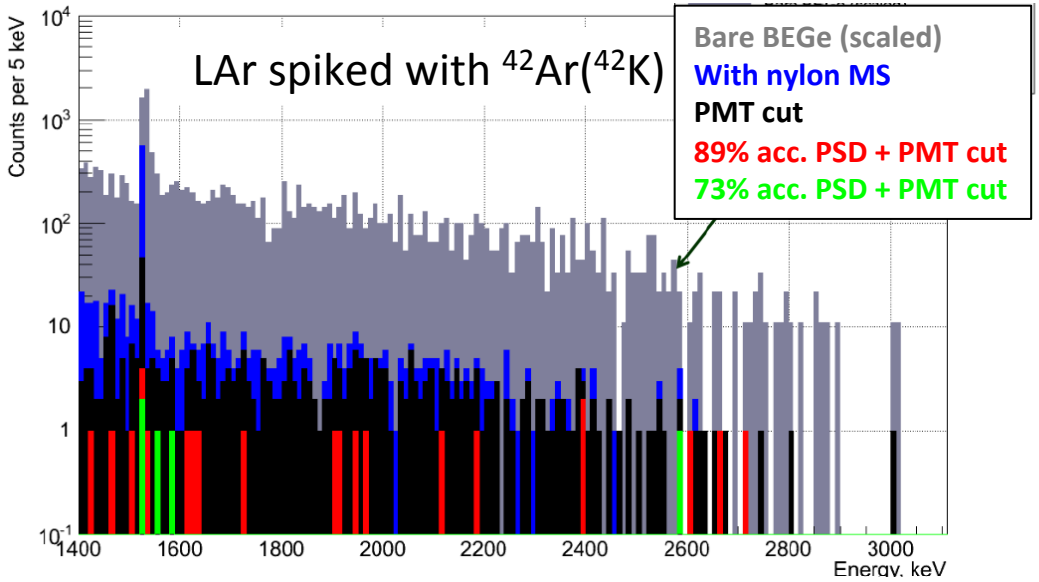


flex cables with
JFET and feedback
resistor/capacitor

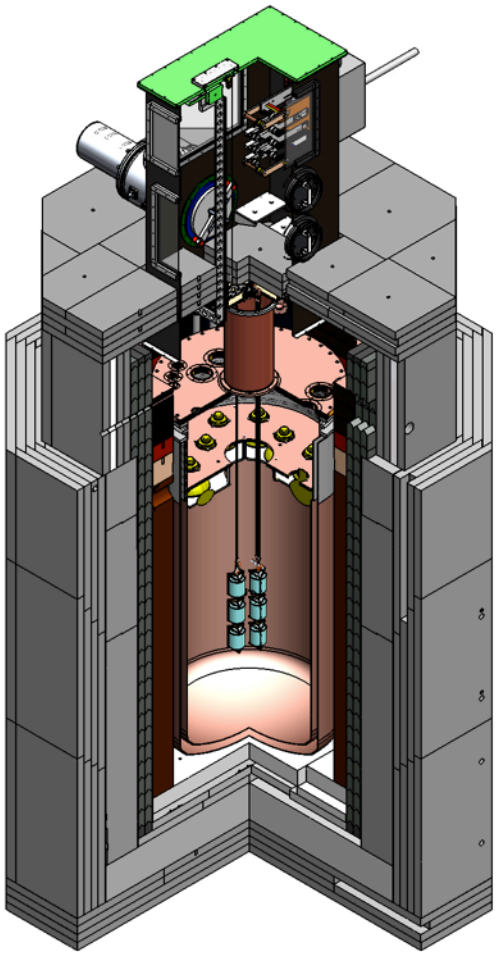
Suppression of bgd by PSD & liquid argon scintillation veto

Calibration with ^{228}Th source

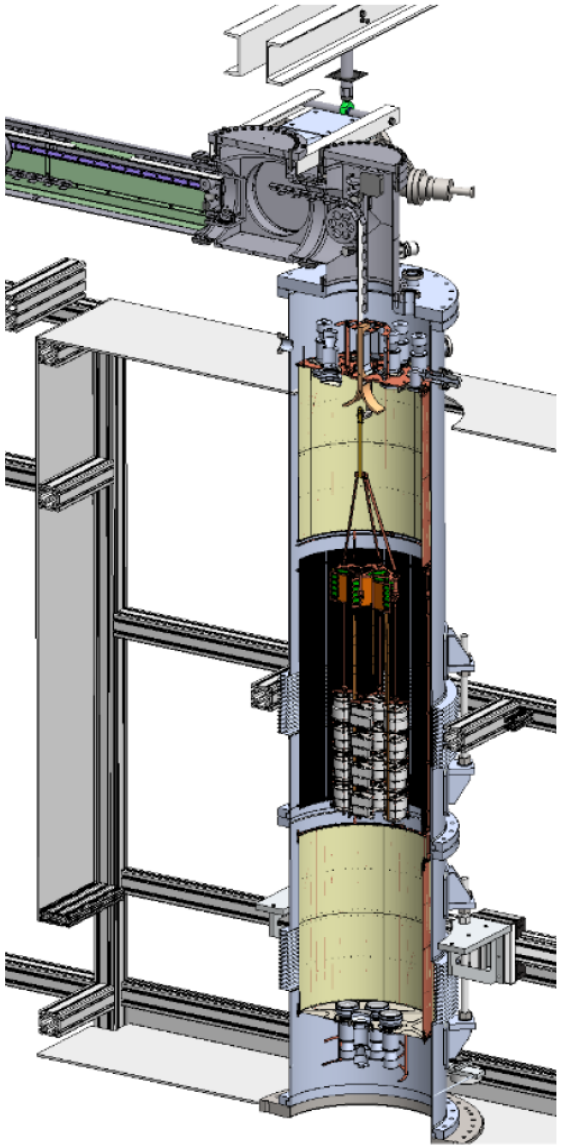


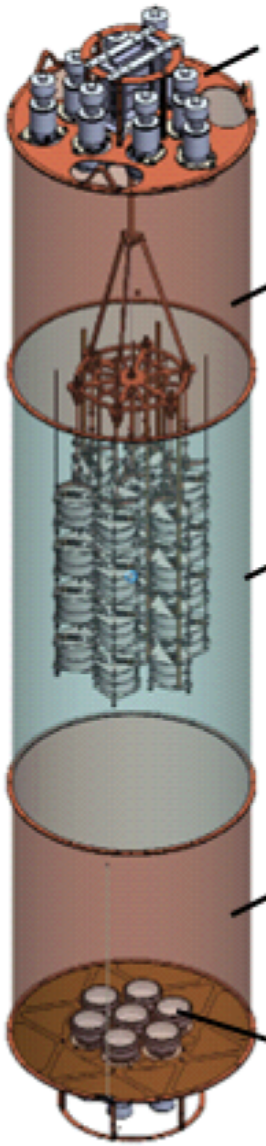


LArGe test stand @ LNGS



Liquid argon instrumentation for Phase II





Summary & outlook

- **GERDA Phase I design goals reached:**
  - Background index after PSD: 0.01 cts / (keV kg yr)
  - Exposure 21.6 kg yr

- **No 0νββ-signal observed at $Q_{\beta\beta}$ = 2039 keV; best fit: $N^{0\nu}=0$**
  - Claim strongly disfavored (independent of NME and of leading term)

- **Limit on half-life:**

  GERDA: $T^{0\nu}_{1/2} > 2.1\times10^{25}$ yr (90% C.L.)

  GERDA+IGEX+HdM: $T^{0\nu}_{1/2} > 3.0\times10^{25}$ yr (90% C.L.) ($\langle m_{ee}\rangle < 0.2$-$0.4$ eV)

- Results reached after only 21.6 kg yr exposure because of **unprecedented low background:** bgd expectations after analysis cuts and correcting for efficiencies:
  0.006 cts /(mol yr FWHM)
- Analysis in pipeline: 2νββ to excited state (poster #136), 0νββ exc. state, Majoron
- **Transition to Phase II ongoing:**
  - Increase of target mass (+20 kg; total ≈40 kg of Ge detectors)
  - New custom made BEGe detectors with enhanced pulse shape discrimination
  - Liquid argon instrumentation
  - Background ≤ 10^{-3} cts /(keV kg yr)
  - Explore $T^{0\nu}_{1/2}(0\nu)$ values in the 10^{26} yr range