JOINT INSTITUTE FOR NUCLEAR RESEARCH

GERDA

Status of the GERDA experiment: on the way to Phase II

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TAUP 2015

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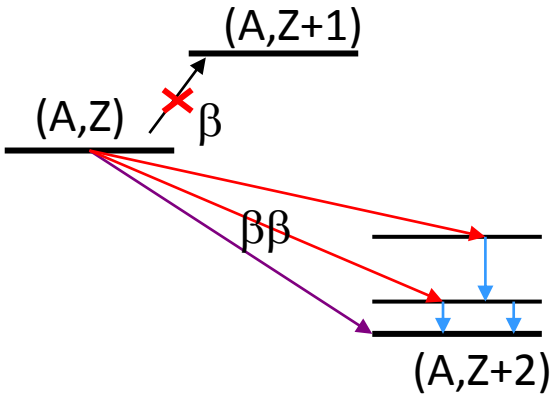
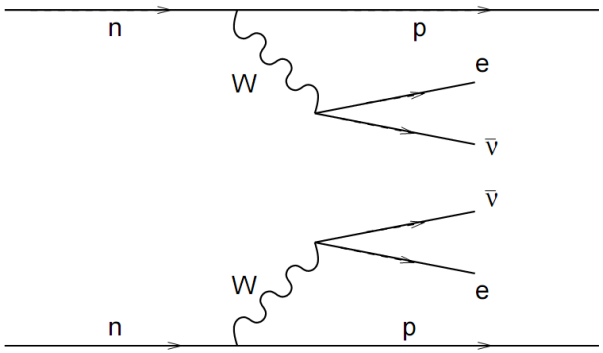
NATIONAL RESEARCH CENTRE "KURCHATOV INSTITUTE"

ββ-decay

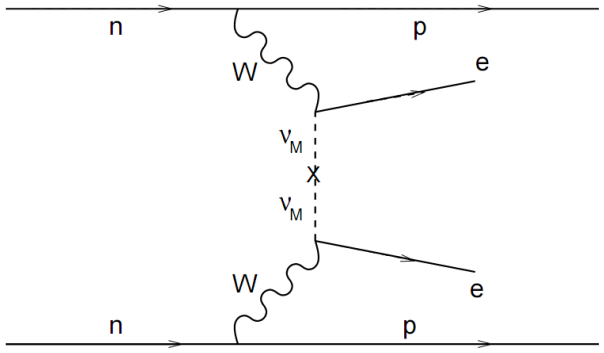


2νββ



- allowed in the SM
- conserves lepton number
- already observed

0νββ



- forbidden in the SM
- violates lepton number
- only if ν has Majorana mass component or other new ΔL = 2 operators exist

0νββ-decay

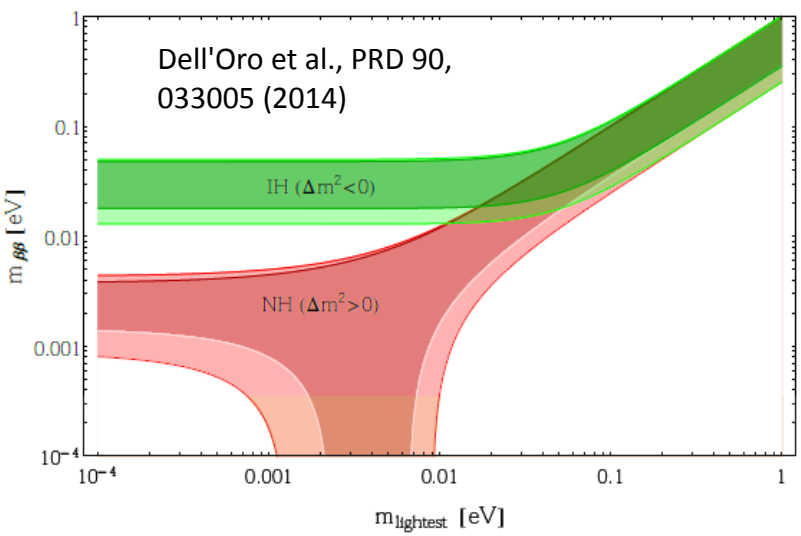
- Natural decay mechanism: exchange of massive Majorana neutrinos:

$$1/T_{1/2} = G(Q,Z)\ |M_{nucl}|^2\ \langle m_{ee}\rangle^2$$

0νββ decay rate — **Phase space factor** — **Matrix element** — **Effective Majorana neutrino mass**

$$\Updownarrow$$

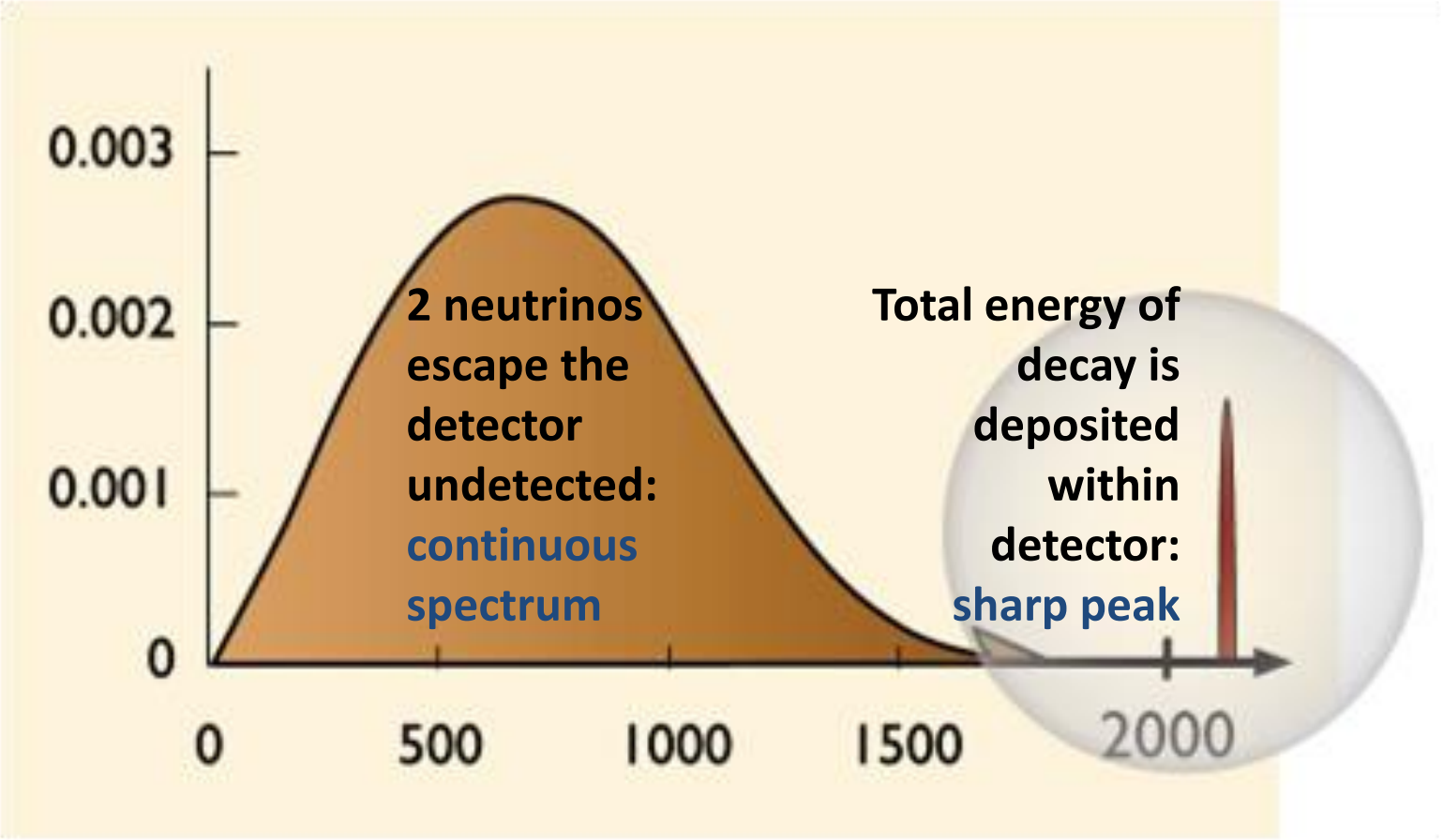
$$|\Sigma_i U_{ei}^2 m_i|$$



Neutrino is massive, but absolute mass scale and hierarchy still unknown

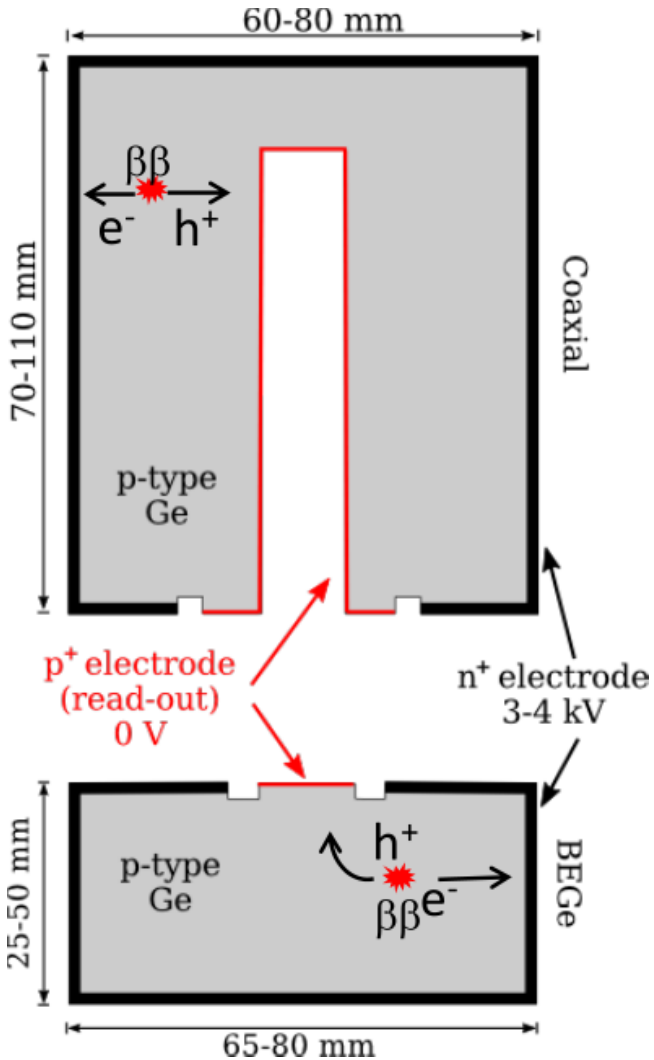
0νββ-decay – signature

Signature: sharp peak at Q-value of the decay



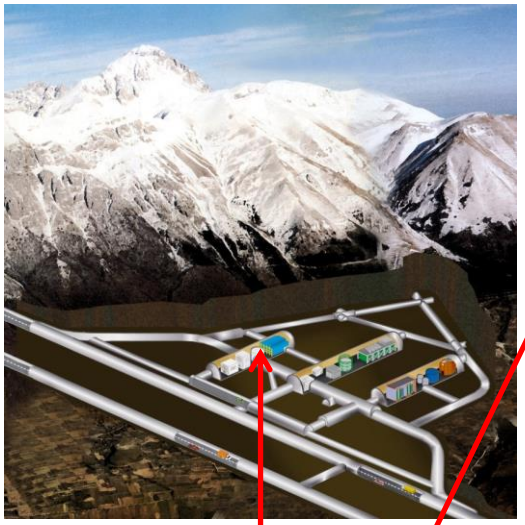
0νββ-decay:

HPGe detectors enriched in ^{76}Ge

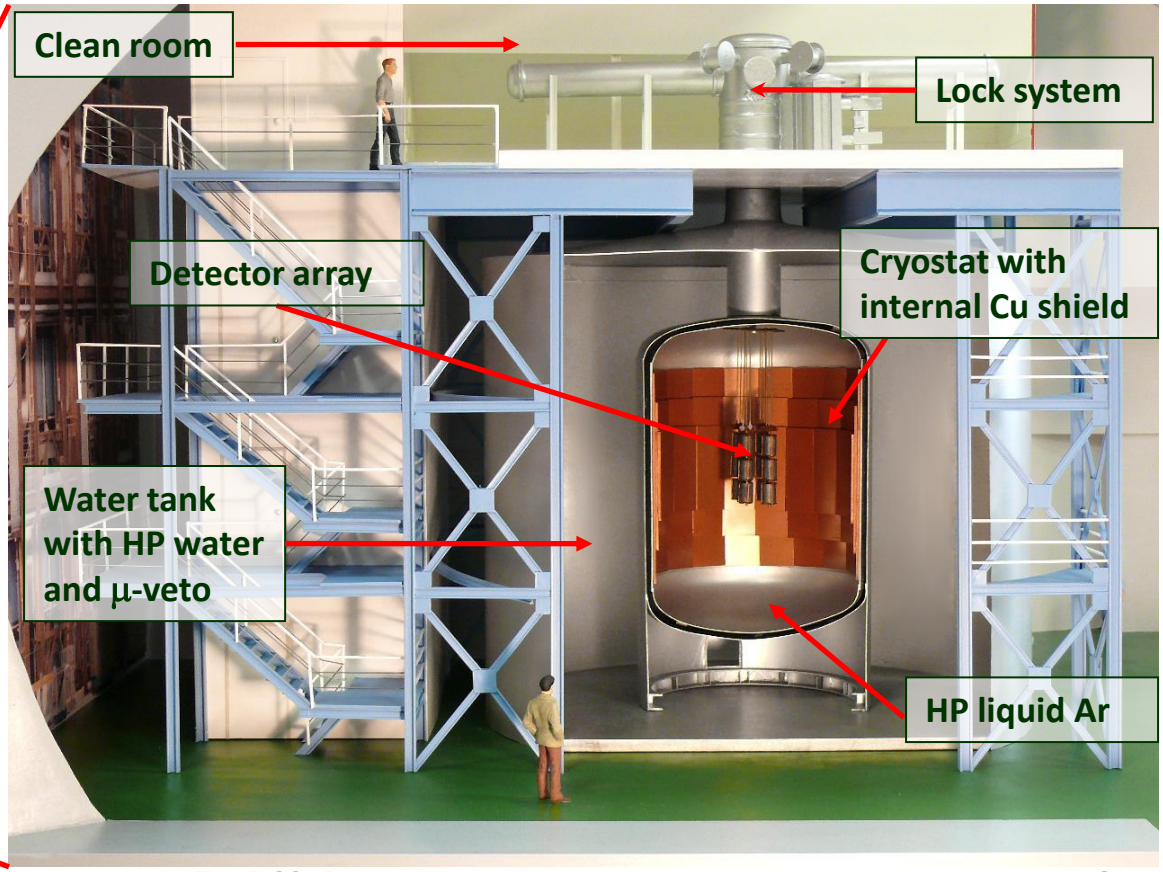


- detector-grade germanium is high-purity material
  $\Rightarrow$ low background
- established detector technology
  $\Rightarrow$ industrial support
- very good energy resolution
  ~0.1% at $Q_{\beta\beta}$
- high detection efficiency
  source = detector

GERDA experiment at LNGS

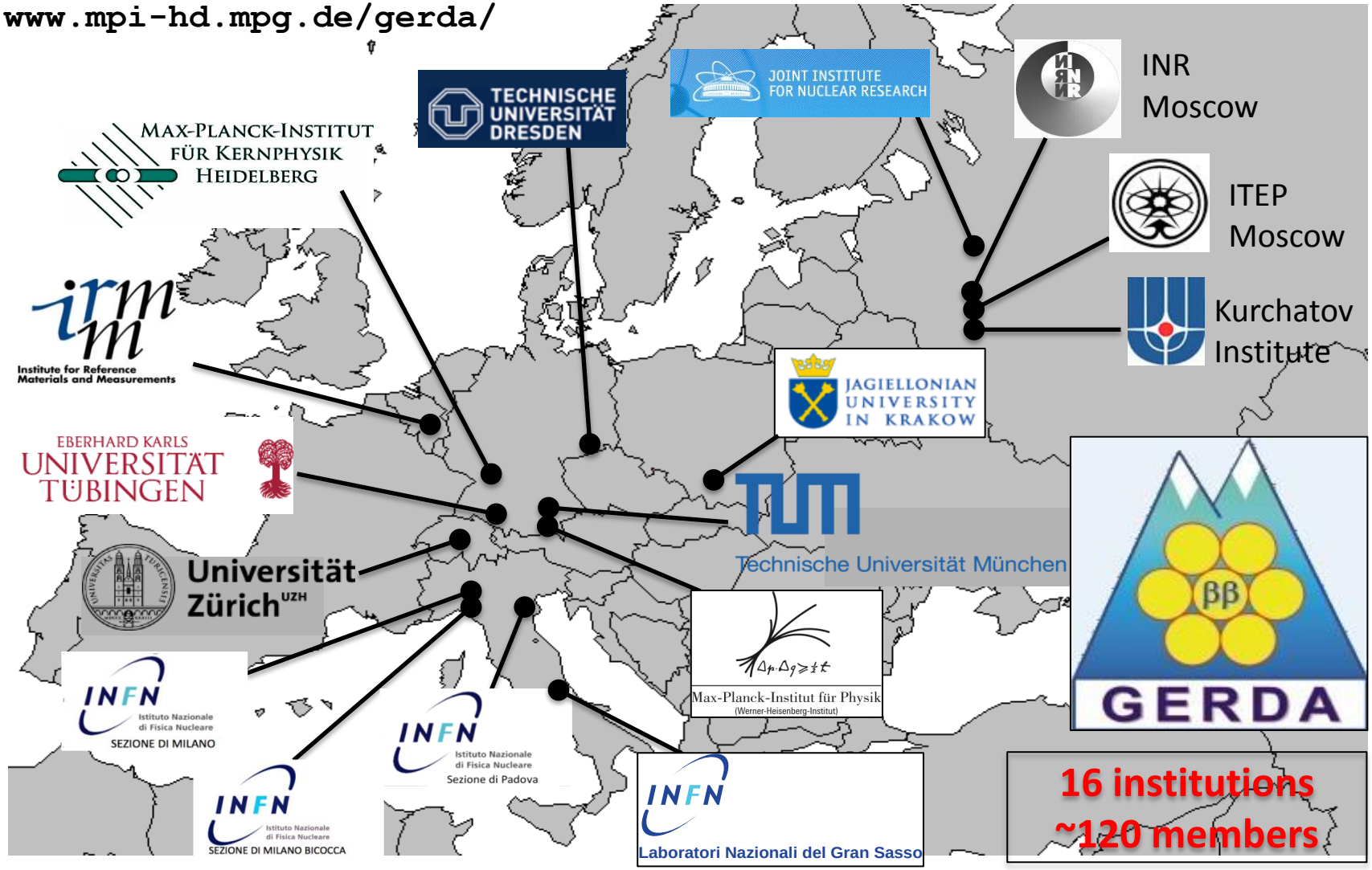


- bare HPGe detectors in LAr
- water and LAr – shield against external radiation
- deep underground – Hall A of LNGS, Italy (3400 m.w.e)

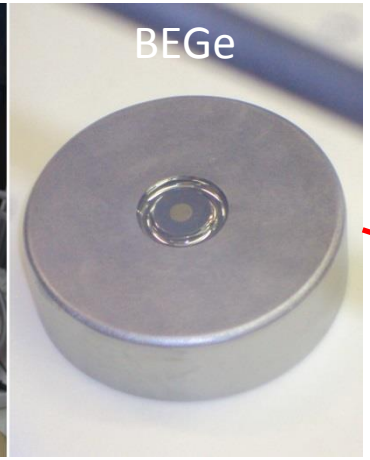


GERDA: the Collaboration

www.mpi-hd.mpg.de/gerda/



GERDA: Phase I



<u>Coaxial detectors (from HdM, IGEX)</u>

- Enriched 86% in ^{76}Ge
- Total mass 17.66 kg
- Reprocessed by Canberra
- Average FWHM 4.8 keV at $Q_{\beta\beta}$

<u>New Phase II BEGe detectors</u>

- Enriched 86% in ^{76}Ge
- Better pulse shape discrimination capability and FWHM (Phase I average: 3.2 keV at $Q_{\beta\beta}$)

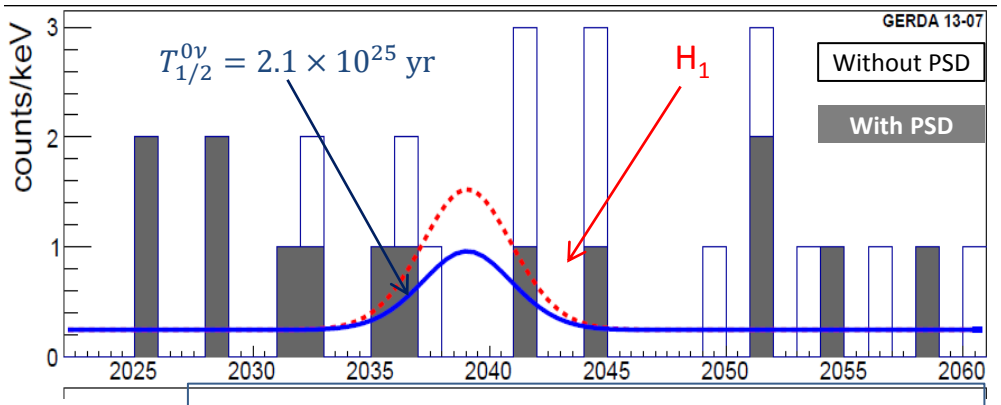
Phase I results: 0νββ

Total exposure:

21.6 kg yr between Nov 2011 and May 2013 (492.3 live days, 88.1% duty factor)

Prominent analysis feature: blind analysis!

- Events in a 40 keV range around $Q_{\beta\beta}$ are blinded
- Develop and validate the background model and the PSD cuts before the unblinding



H_1: $T_{1/2}^{0\nu} = 1.19^{+0.37}_{-0.23} \cdot 10^{25}$ yr (*) vs. H_0: background only

Expected Signal (w/ PSD): (5.9 ± 1.4) cts in ±2σ

Expected Bckgd (w/ PSD): (2.0 ± 0.3) cts in ±2σ

Observed: **3.0** in ±2σ (0 in ±1σ)

Backround after PSD:

10^{-2} counts / (keV kg yr)

✓ design **goal reached**!

Limit on the half-life:

$$T_{1/2}^{0\nu} > 2.1 \times 10^{25} \text{ yr } (90\% \text{ CL})$$

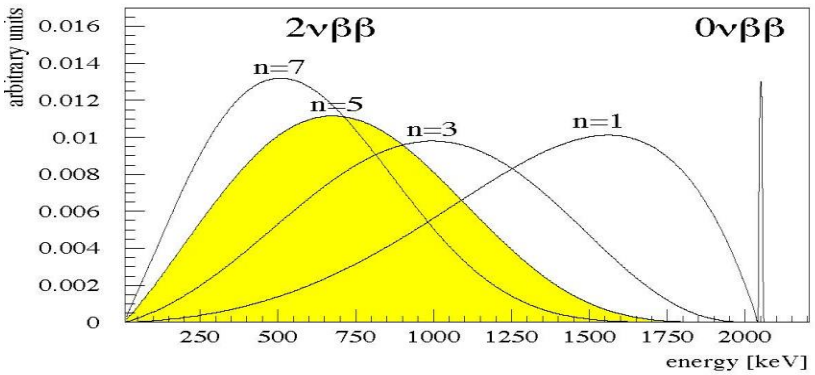
KK claim (Phys. Lett. B 586 198 (2004)) strongly disfavoured!

PRL 111 (2013) 122503

New Phase I results:

0νββχ(Majoron)

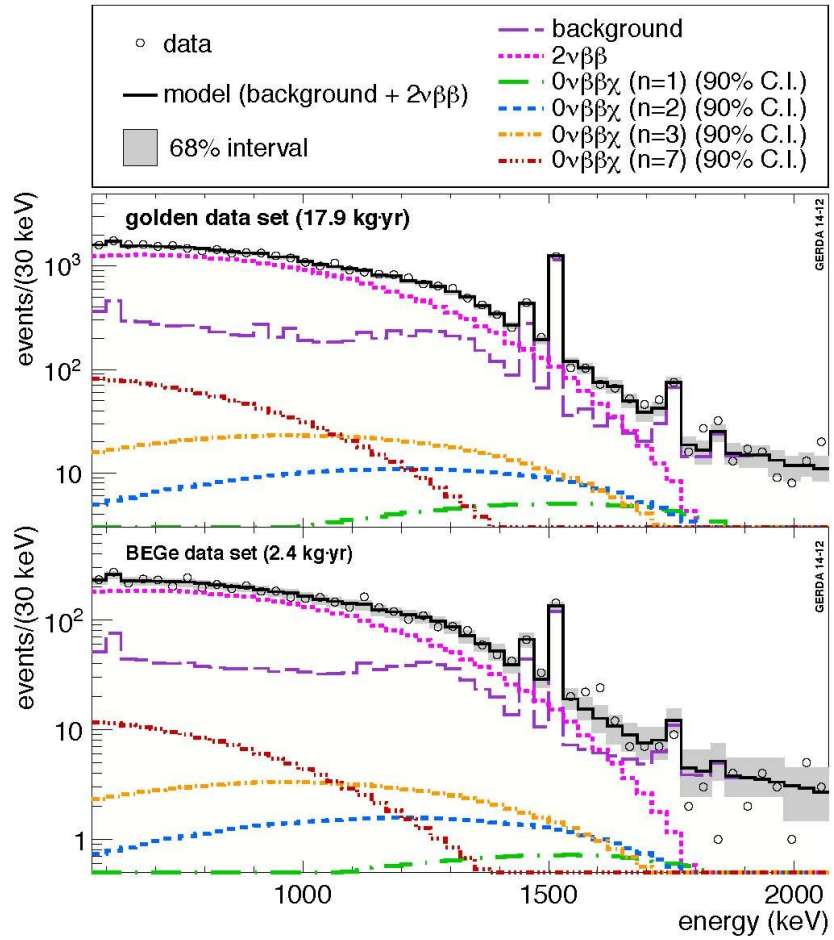
$$G \sim (Q_{\beta\beta} - K)^n$$



- Alternative mechanism of 0νββ : **Majoron(s) emission**
  - Many models/candidates available: ββχ, ββχχ
  - Continuous spectra, but different shape than 2νββ decay (n=5)
  - **Global fit** of the energy spectrum

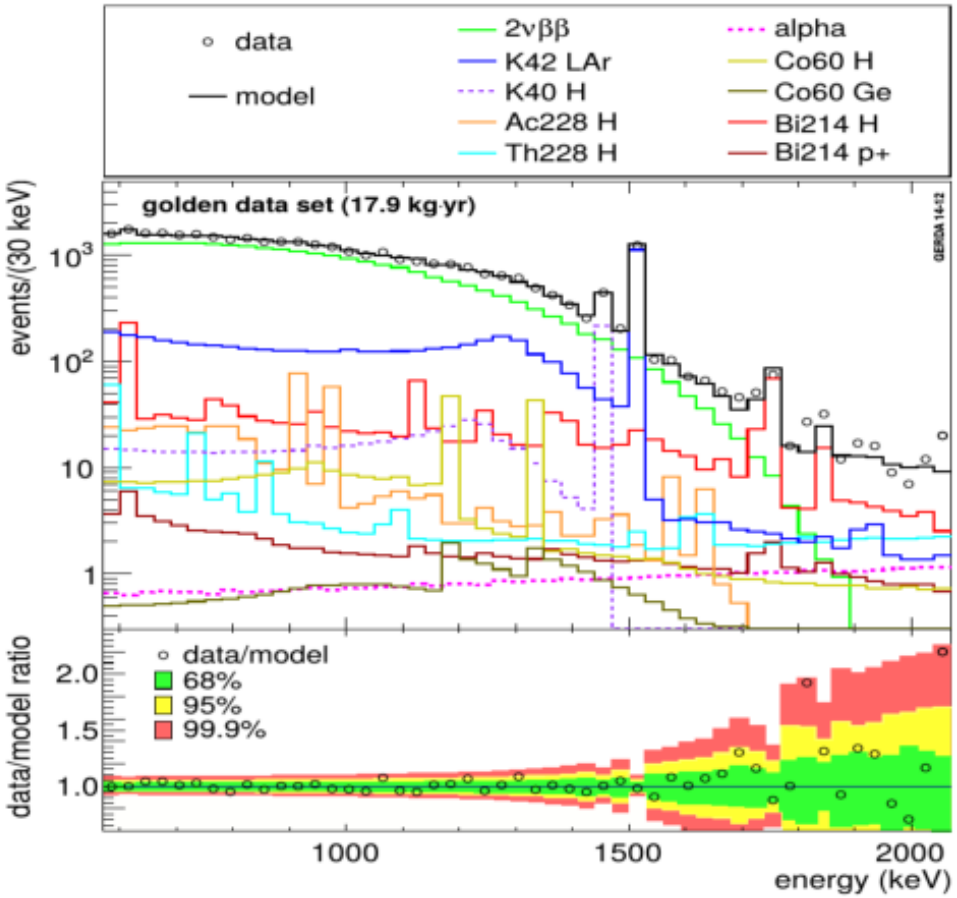
for n = 1: $T_{1/2}^{0\nu\chi} > 4.2 \times 10^{23}$ **yr (90% CL)**

Most stringent limits for ^{76}Ge, improvement by a **factor > 6**



arXiv:1501.02345 (in print at EPJC)

New Phase I results: 2νββ



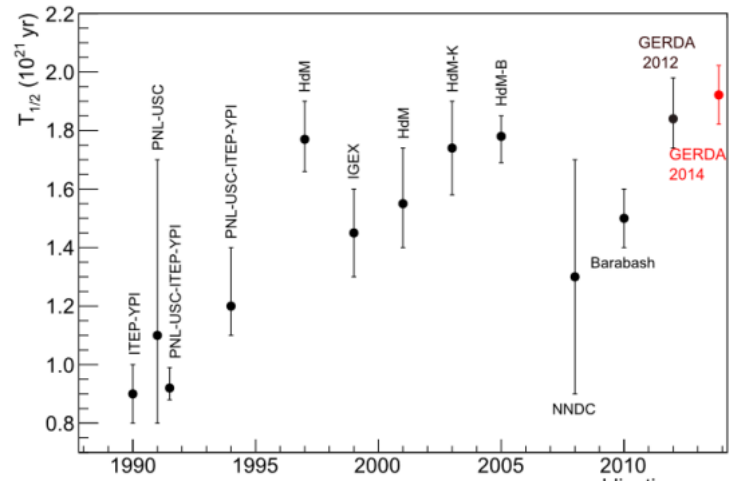
Old GERDA result (5 kg yr):

$T_{1/2}^{2\nu} = (1.84^{+0.14}_{-0.10}) \times 10^{21}$ yr

J. Phys. G: Nucl. Part. Phys. 40, 035110 (2013)

New:

- exposure 17.9 kg yr
- uncertainties on background model reduced



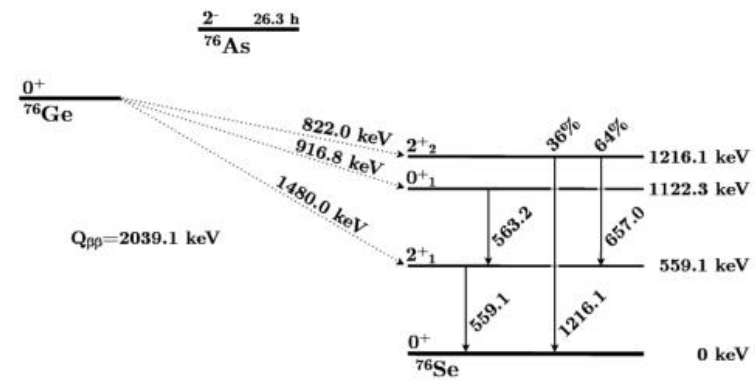
New result:

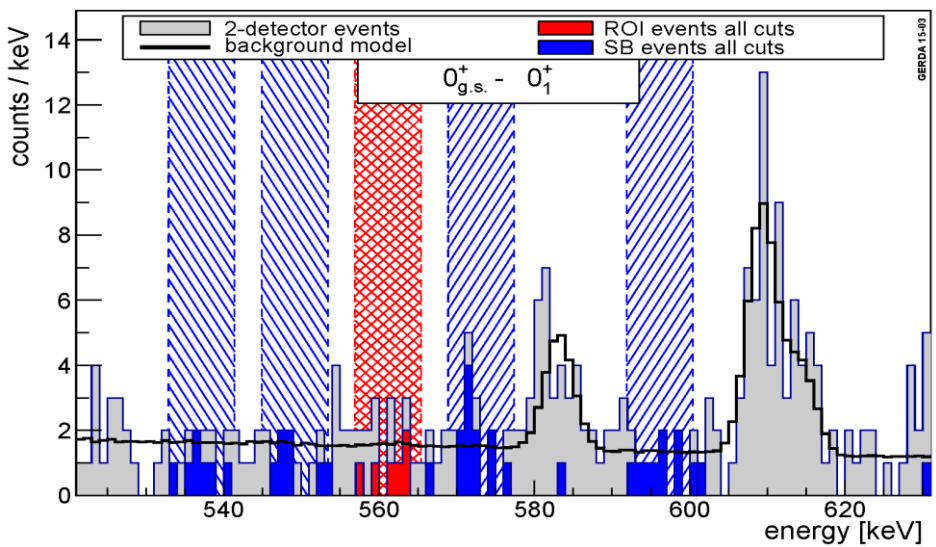
$$\boldsymbol{T_{1/2}^{2\nu} = (1.926 \pm 0.095) \times 10^{21}\ \mathrm{yr}}$$

arXiv:1501.02345 (in print at EPJC)

New Phase I results:
2νββ to excited states

- (2ν)ββ of ^{76}Ge can occur into excited states of ^{76}Se
  - Not observed by now.
    Previous limits for $T_{1/2}$ in the range of few 10^{21} yr.
  - Most probable: 0^+_1 level at 1122 keV.
    Predictions 10^{21}-10^{24} yr for $T_{1/2}$
  - Benchmark for NME calculations





- Search for coincidence of ββ-decay in one detector and 560 keV γ-ray in another
- NO evidence found
- Limits improved by ~100
- For 0^+_1 level:

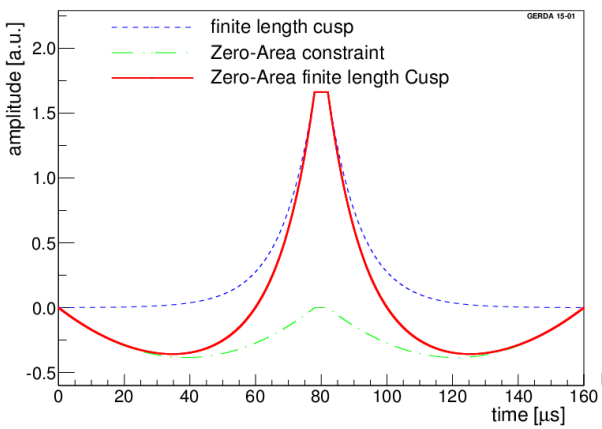
$$T_{1/2} > 3.7 \times 10^{23}\ \mathrm{yr}\ (90\%\ \mathrm{CL})$$

arXiv:1506.03120 (in print at J.Phys G)

Phase I/II:

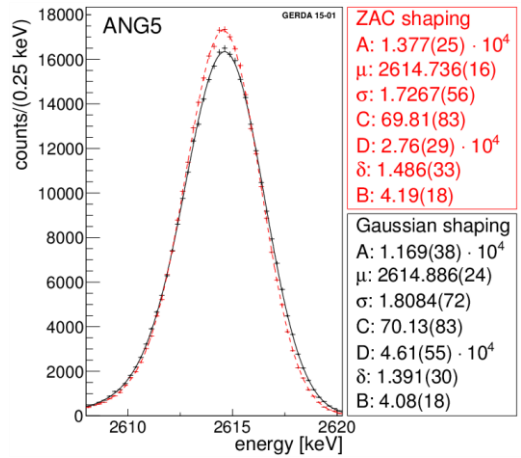
Improvement in energy resolution

Zero Area Cusp (ZAC) filter: a novel filter for enhanced energy resolution

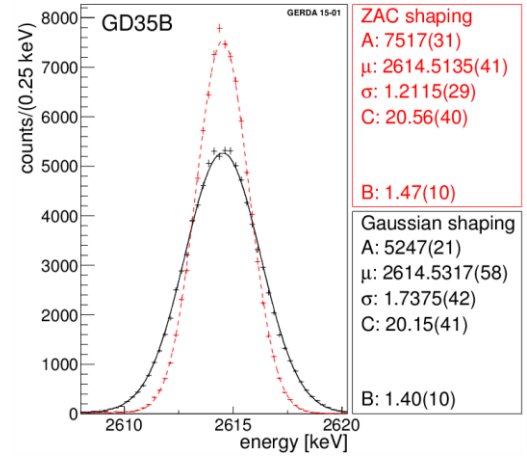


Detector	FWHM at 2614.5 keV (keV)		Improvement (keV)
	Gaussian	ZAC	
ANG2	4.712 (3)	4.314 (3)	0.398 (4)
ANG3	4.658 (3)	4.390 (3)	0.268 (4)
ANG4	4.458 (3)	4.151 (3)	0.307 (4)
ANG5	4.323 (3)	4.022 (3)	0.301 (4)
RG1	4.595 (4)	4.365 (4)	0.230 (6)
RG2	5.036 (5)	4.707 (4)	0.329 (6)
GD32B	2.816 (4)	2.699 (3)	0.117 (5)
GD32C	2.833 (3)	2.702 (3)	0.131 (4)
GD32D	2.959 (4)	2.807 (3)	0.152 (5)
GD35B	3.700 (5)	2.836 (3)	0.864 (6)

Coaxial detector



BEGe detector

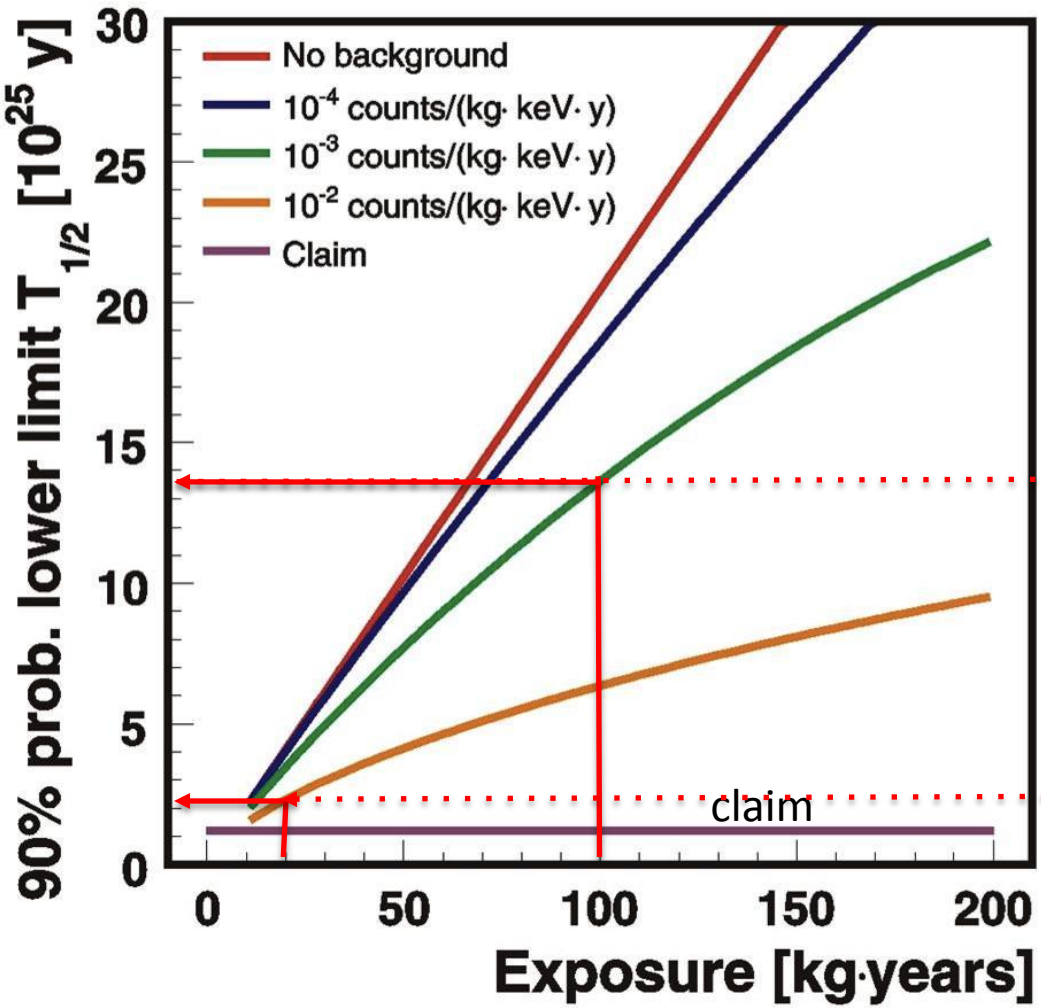


ZAC filter:

- ✓ Better low frequency rejection
- ✓ The energy reconstruction for Phase I/II can be improved (for both coaxial and BEGe detectors)

EPJC 75 (2015) 255

GERDA: on the way to Phase II

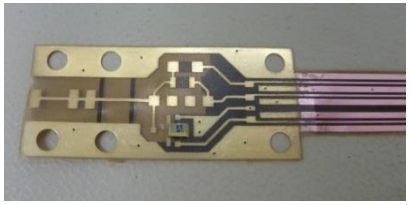


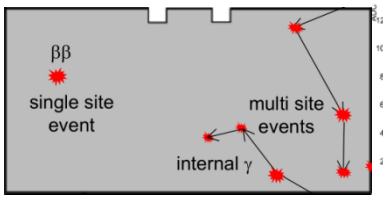
Phase II:
Add new BEGe detectors (20 kg)
BI ≈ 0.001 cts / (keV kg yr)
Sensitivity after 100 kg yr

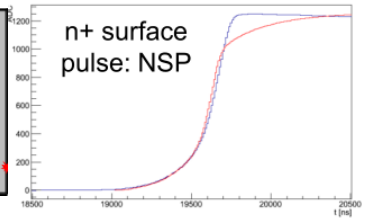
Phase I:
Use refurbished HdM & IGEX (18 kg)
BI ≈ 0.01 cts / (keV kg yr)
Sensitivity after 20 kg yr

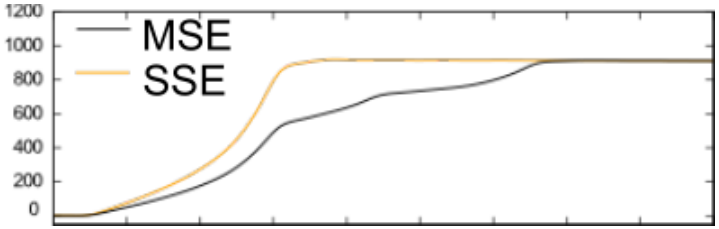
GERDA: on the way to Phase II

- 30 new BEGe detectors (produced and tested)
- We have to reduce background by one order of magnitude!
  - New low mass holder
  - New front end readout close to detectors & new front end cabling
  - New HV and signal cabling
  - Pulse shape discrimination (PSD) with BEGes
    (more details in the poster from Bjoern Lehnert)
  - Liquid argon veto instrumentation

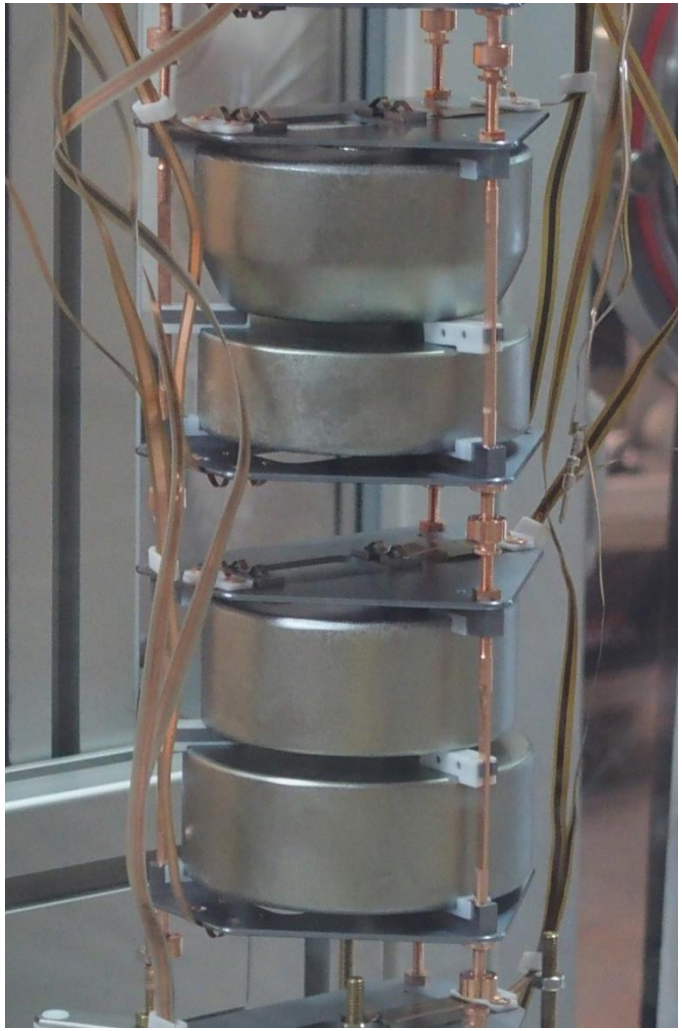


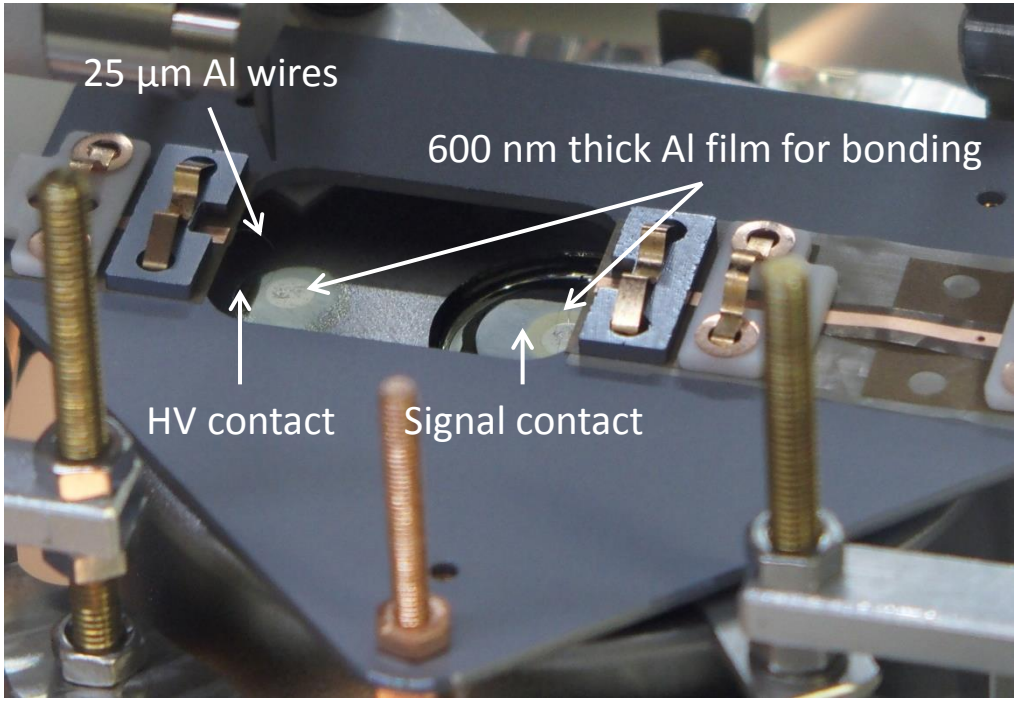






Phase II: new holders for new detectors

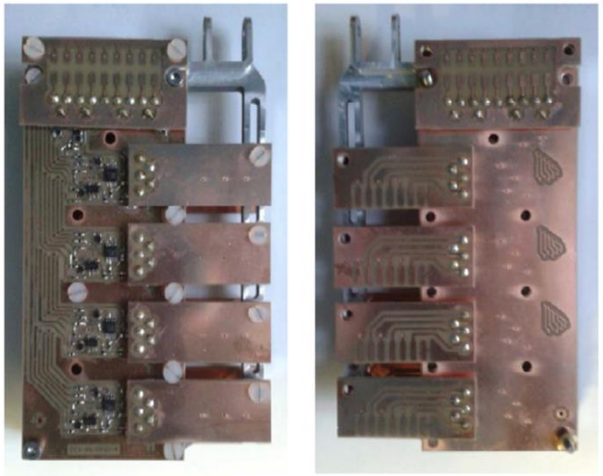


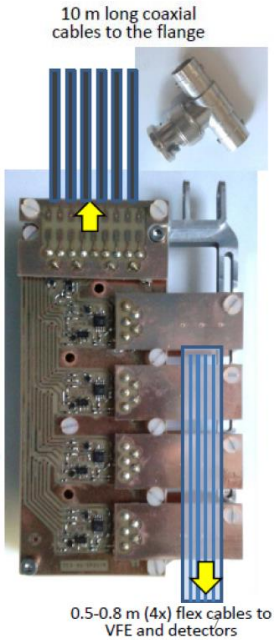


- ✓ 28 out of 30 BEGe detectors mounted in Phase II holders and tested in LAr/LN_2

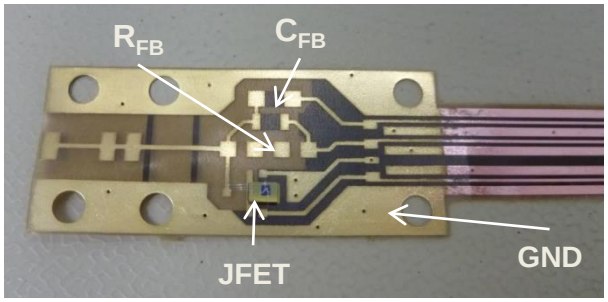
Phase II: new front-end readout

GERDA CC3 preamplifier





Resistive feedback circuit of FE electronics (very front-end, VFE)



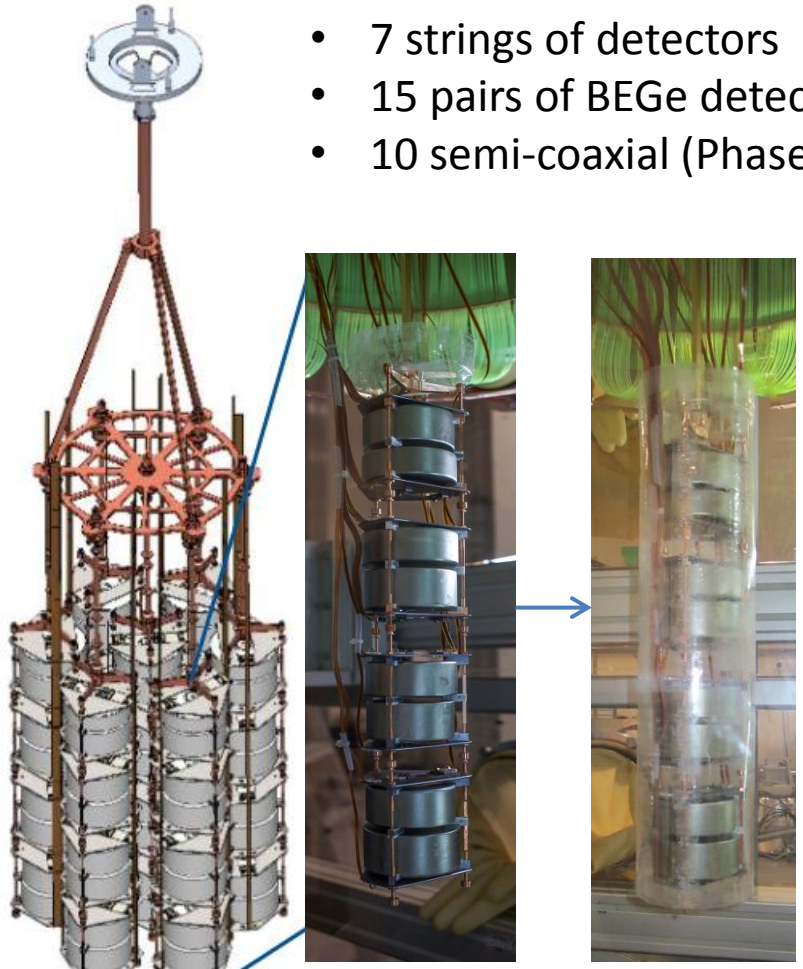
situated on the Si plate close (~1 cm) to the detector

- Used at the beginning of Phase II commissioning:
  - High mortality of jFETs found

-> decision: **start** with Phase I like readout (**VFE** at CC3 level (> **40 cm** from detectors))

- ✓ Tested with 5 BEGes during Phase I
- ✓ FWHM was fine (≤ 3 keV at $Q_{\beta\beta}$)
- ✓ PSD was also acceptable

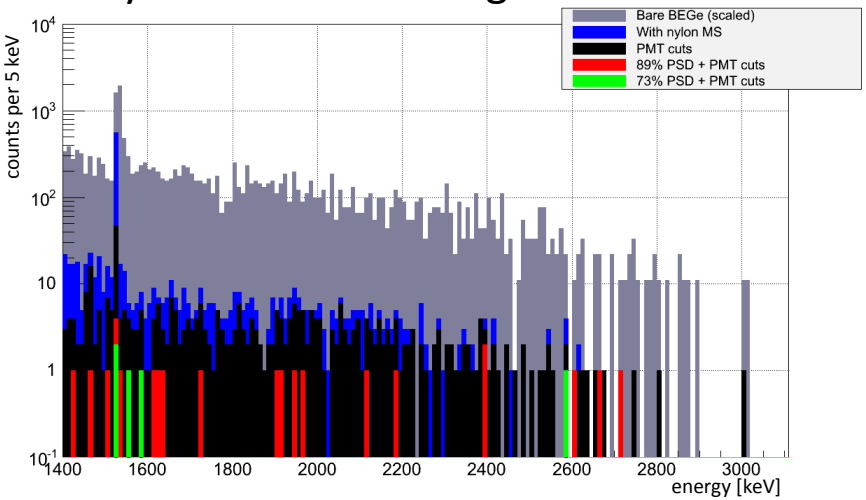
Phase II: detector array



- 7 strings of detectors
- 15 pairs of BEGe detectors mounted back-to-back
- 10 semi-coaxial (Phase I) detectors: 7 enriched + 3 non-enriched

✓ Dense packing of detectors allows better anti-coincidence cut

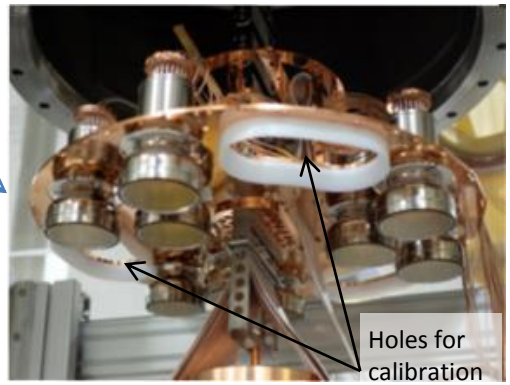
✓ Each string enclosed by transparent nylon mini-shroud against ^{42}K-ions:



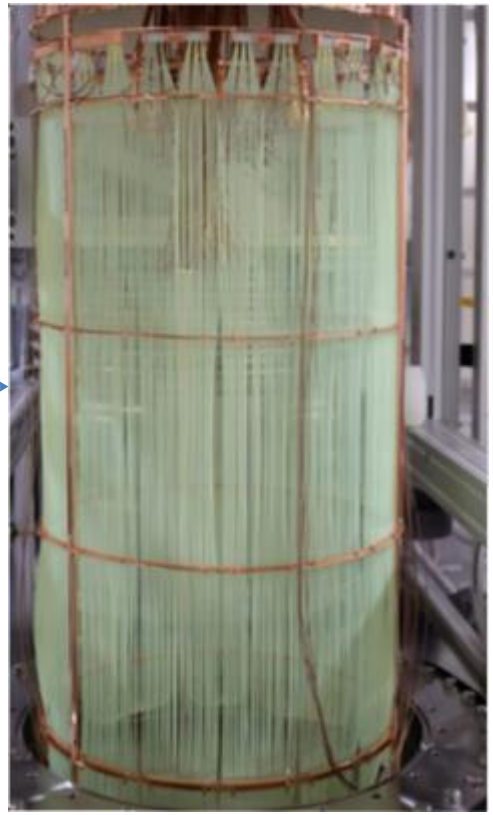
Suppression factor > 1000 for ^{42}K bkg has been demonstrated in LArGe test facility (nylon mini-shroud + PSD + LAr veto)

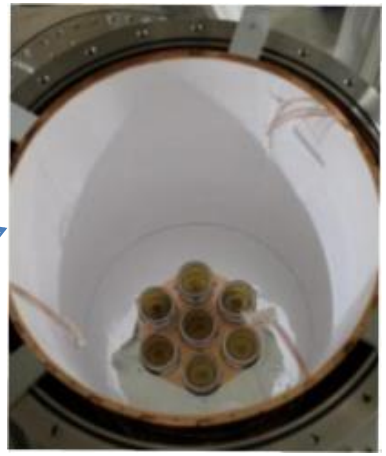
Phase II: LAr veto

3” PMTs



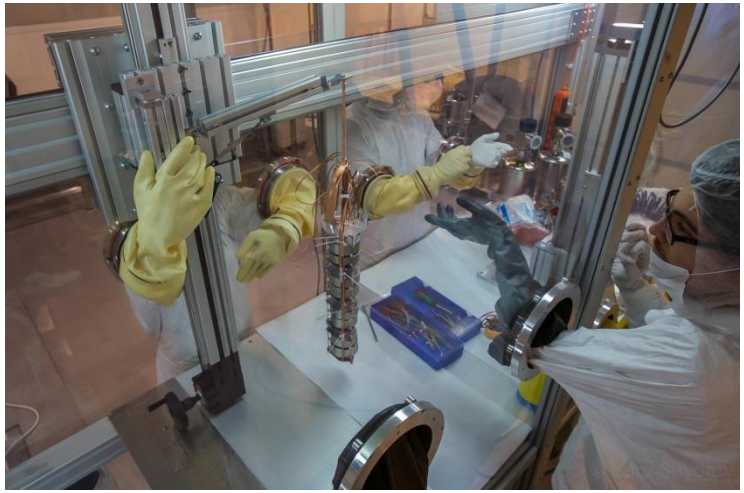
Fibers (coated with WLS) coupled to SiPMs





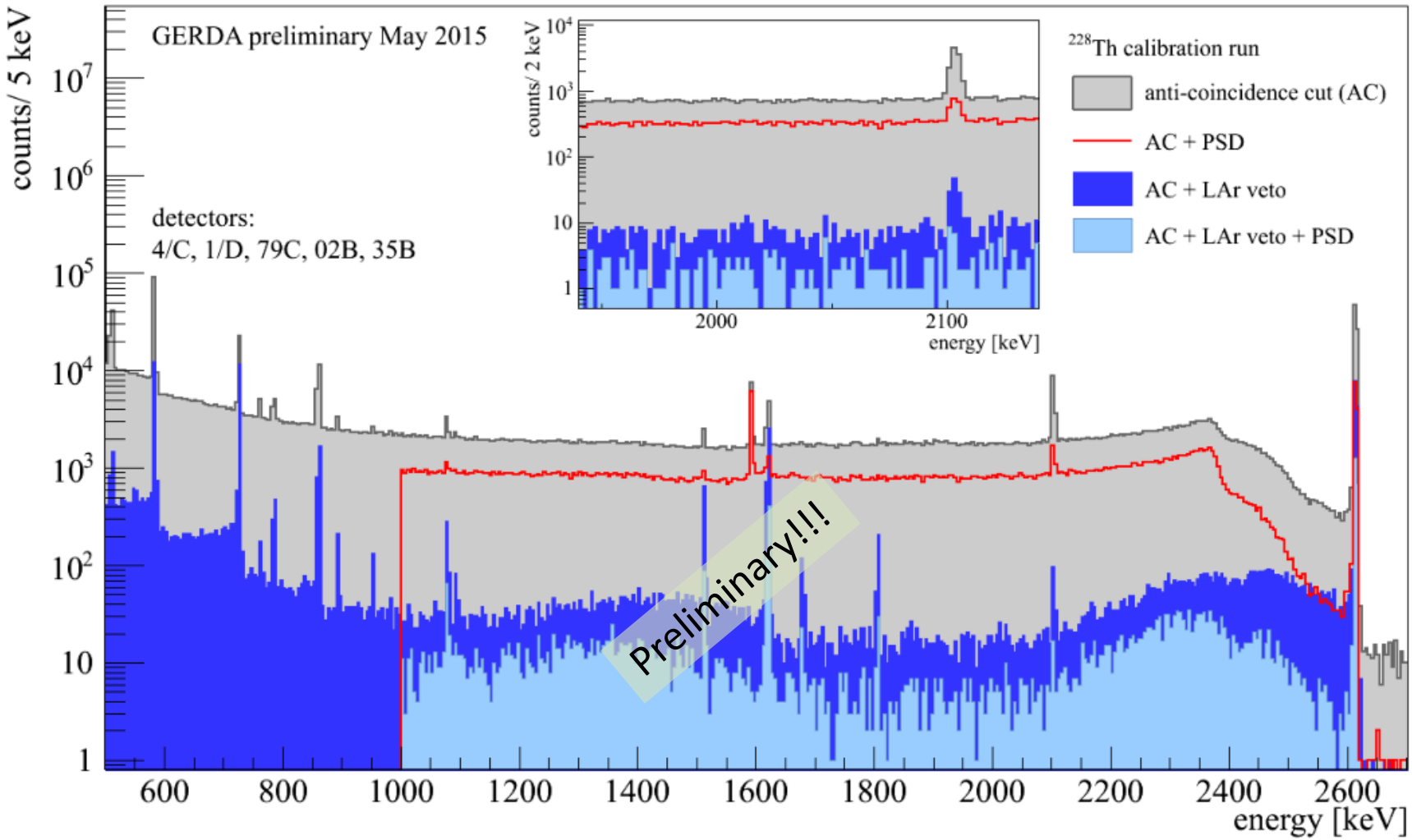
Cu cylinders with WLS foil

Phase II:
commissioning 1st step (pilot string)



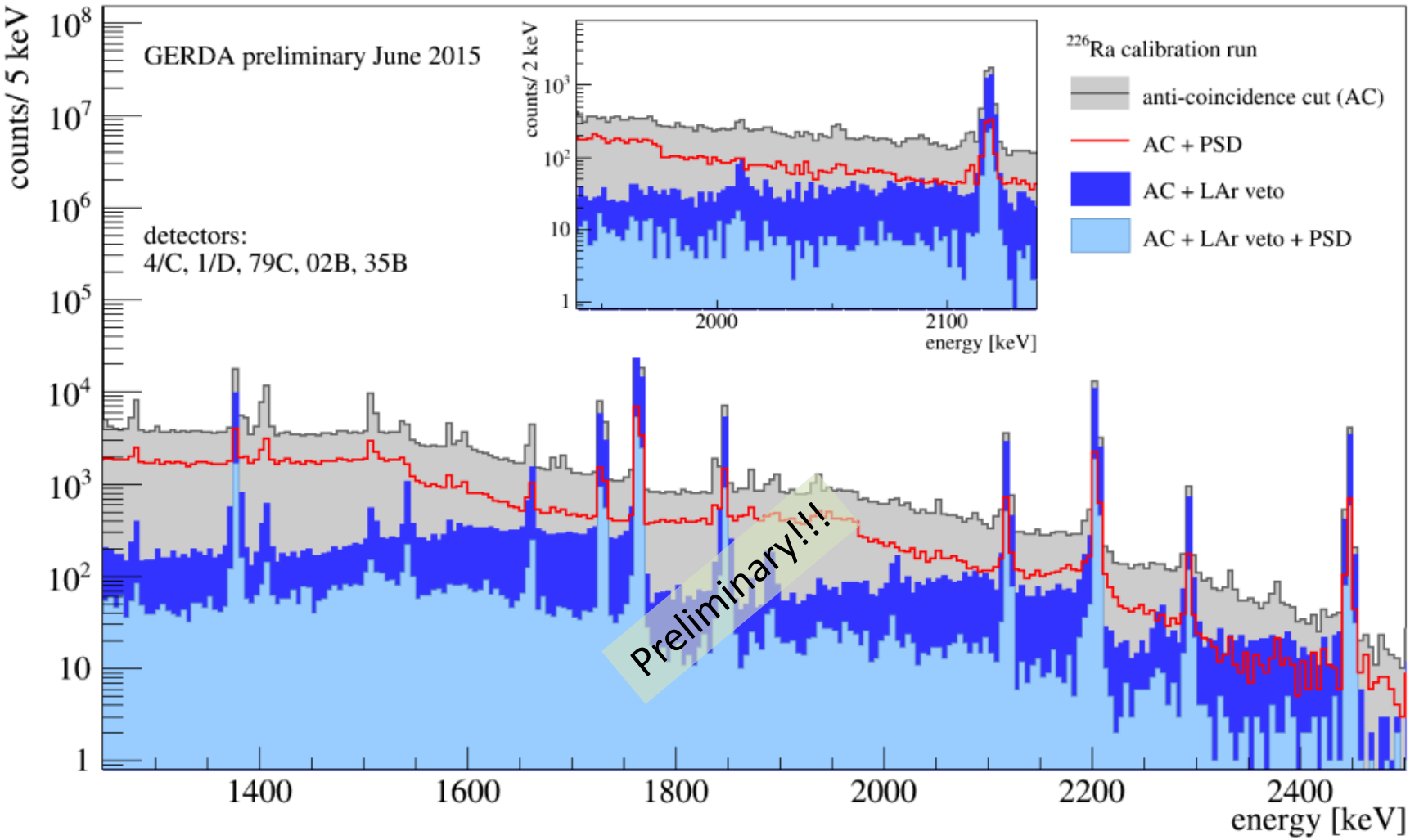
Phase II:

commissioning 1st step (pilot string) – ^{228}Th

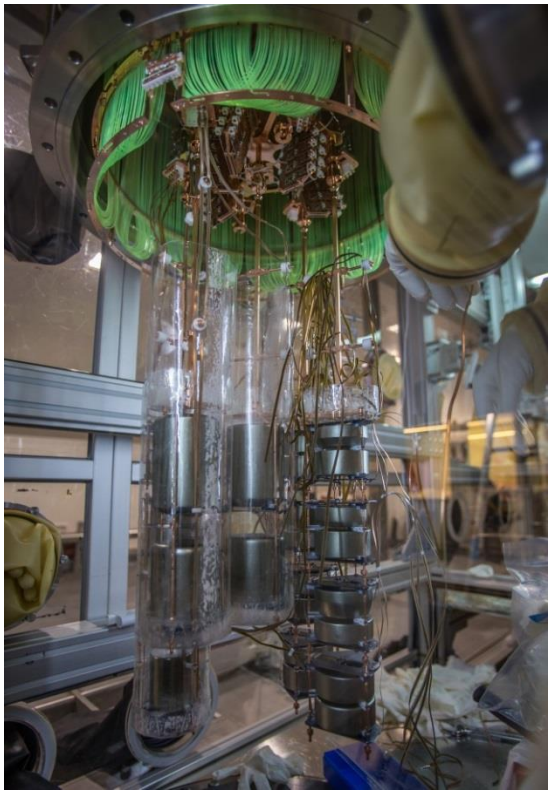


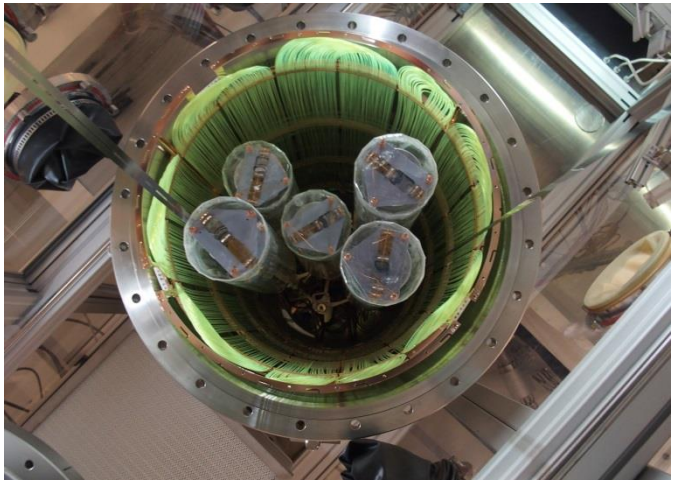
Phase II:

commissioning 1st step (pilot string) – ^{226}Ra



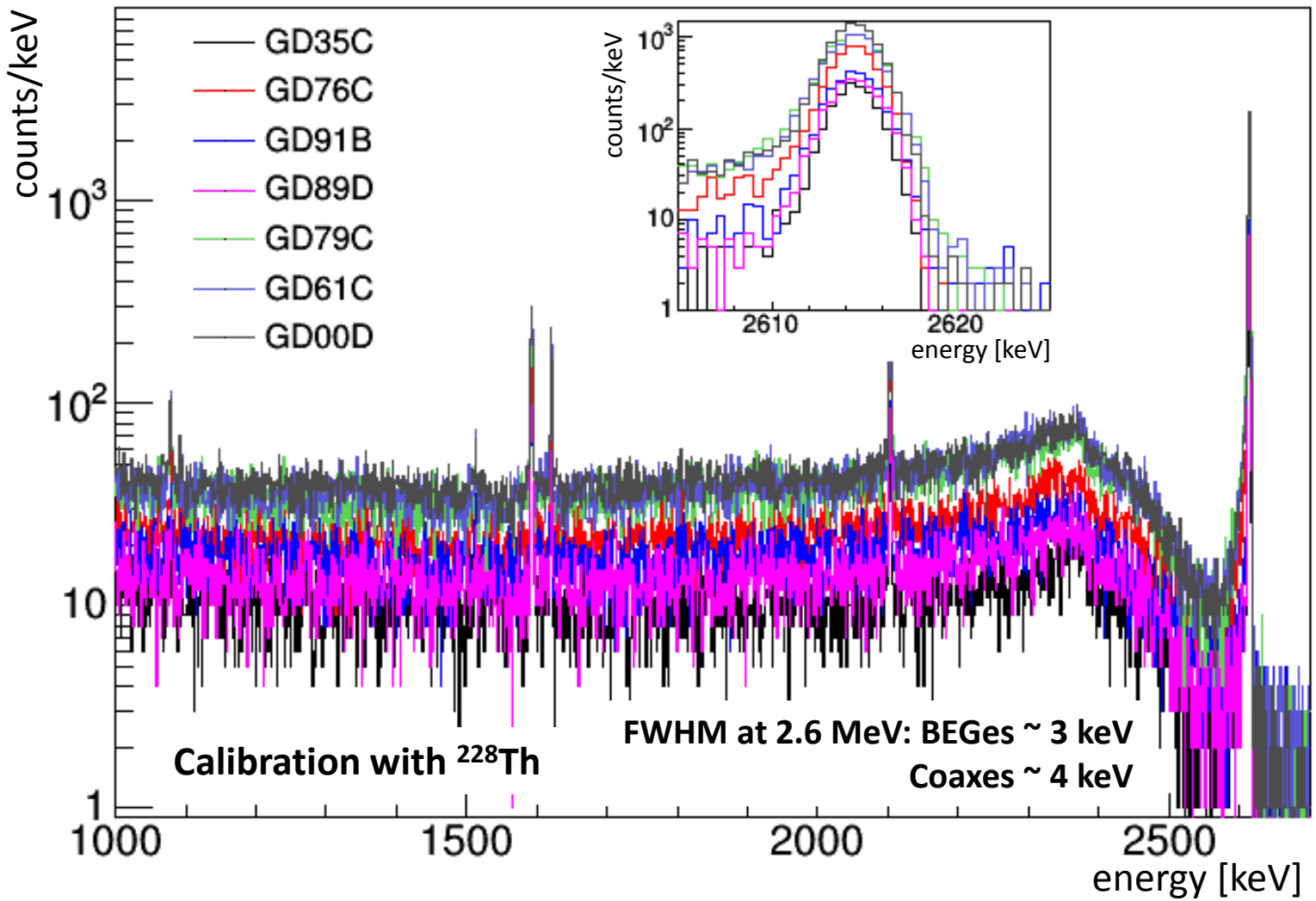
Phase II:
commissioning 2nd step (5 string assembly)



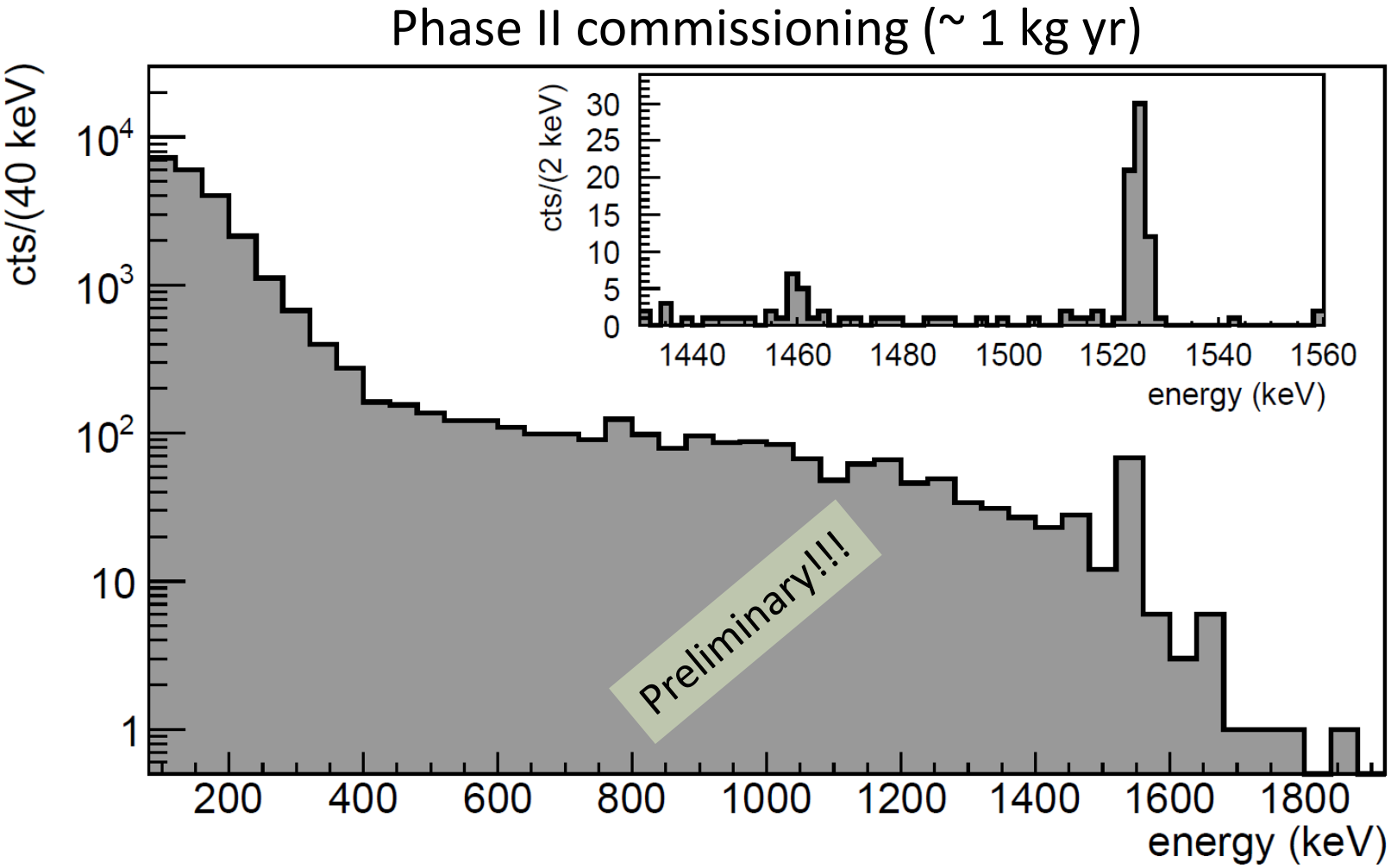


Phase II:

commissioning 2nd step (5 string assembly)



Phase II:
commissioning 2nd step (5 string assembly)



GERDA status

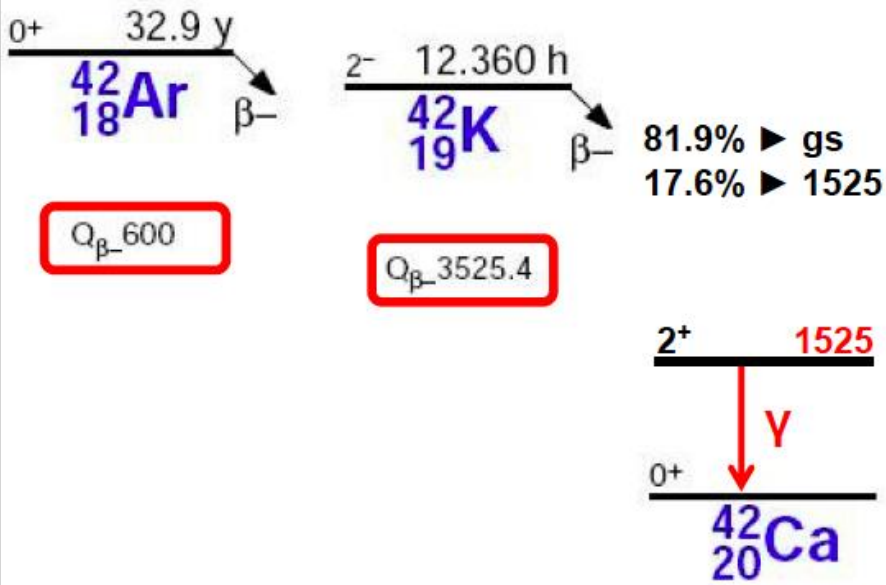
- Phase I finished in 2013 but still providing new results:
  - Most stringent limit for Majoron(s) emission in ^{76}Ge
  - New analysis for 2νββ of ^{76}Ge: $T_{1/2}^{2\nu} = (1.926 \pm 0.095) \times 10^{21} yr$
  - New limits for 2νββ to excited states (improvement ~ 100)
- Phase II commissioning is ongoing:
  - LAr veto fully installed and operational
  - 27 out of 40 detectors installed
  - Unexpected problem with LC for some detectors found
    - ✓ will be solved soon by producer
  - Working diodes show stable behaviour
  - Energy resolutions of working diodes are good (as in Phase I)
    - ✓ Phase I like readout is fine to start physic data taking
  - bkg run with 1 kg yr exposure: background fits our expectation

→ Final Phase II installation will require more steps

- Fall 2015: full array in GERDA

Additional slides

GERDA:
^{42}Ar concentration



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

Intensity of 1525 keV line in *E*-field free setup indicates ^{42}Ar activity is significantly higher than the limit above

Evidence that charge ^{42}K ions drift in electric field of HPGe detectors.

GERDA/LArGe measurement: 70-90 µBq/kg