JOINT INSTITUTE FOR NUCLEAR RESEARCH

GERDA

GERDA concept, design, status

Konstantin Gusev
for the GERDA collaboration

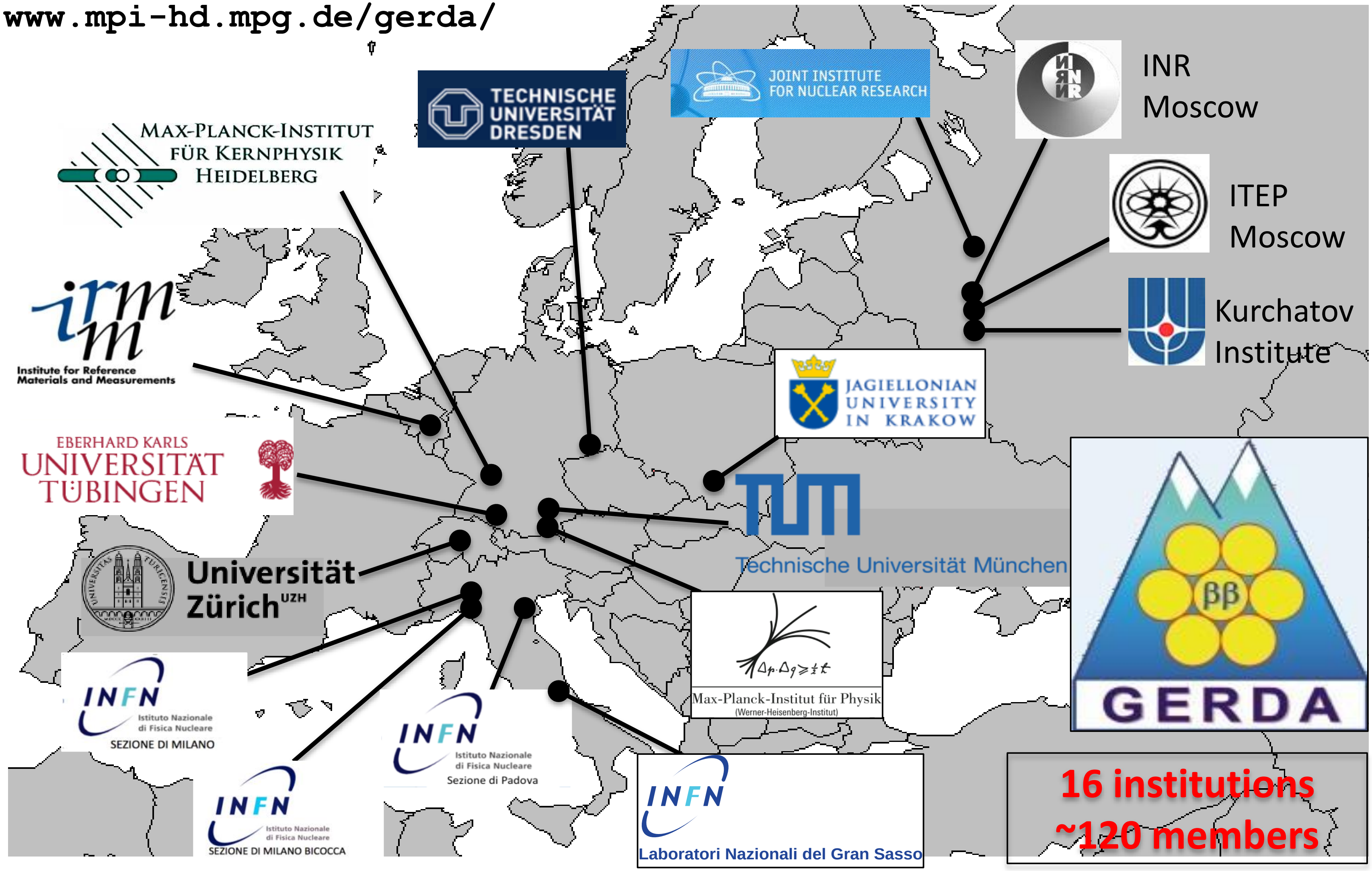
NG-Ge76 meeting
25-27 April 2016 – Munich

Technische Universität München

NATIONAL RESEARCH CENTRE
"KURCHATOV INSTITUTE"

Collaboration

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

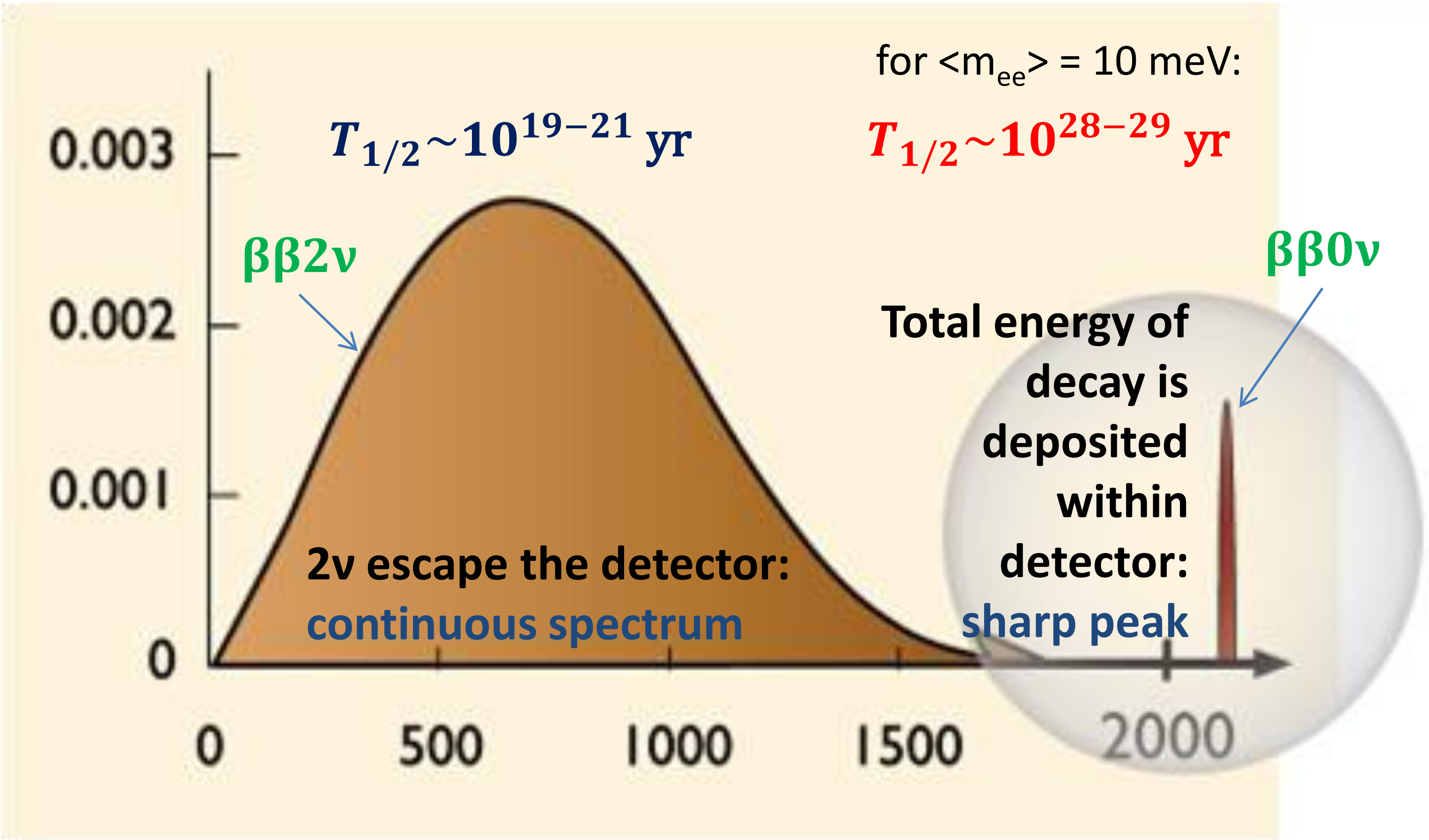


Collaboration

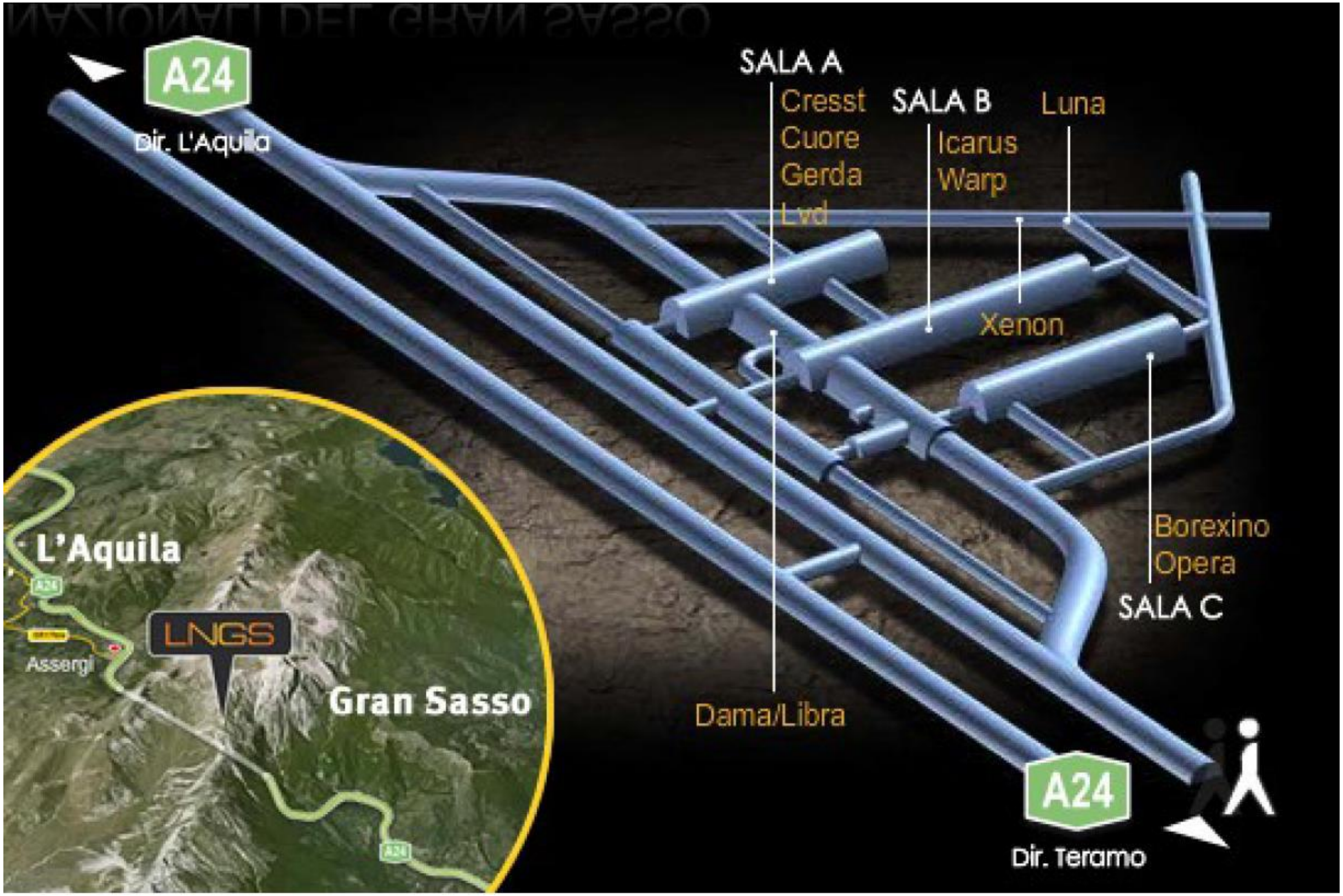
16 institutions
~120 members

0νββ-decay

Signature: sharp peak at Q-value of the decay

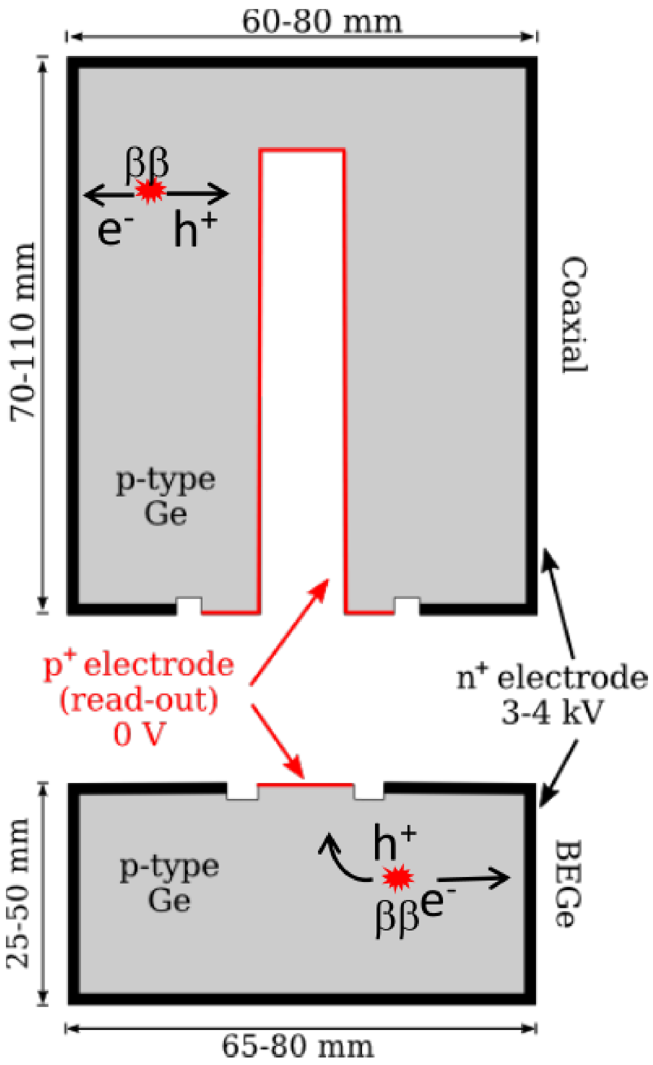


Location



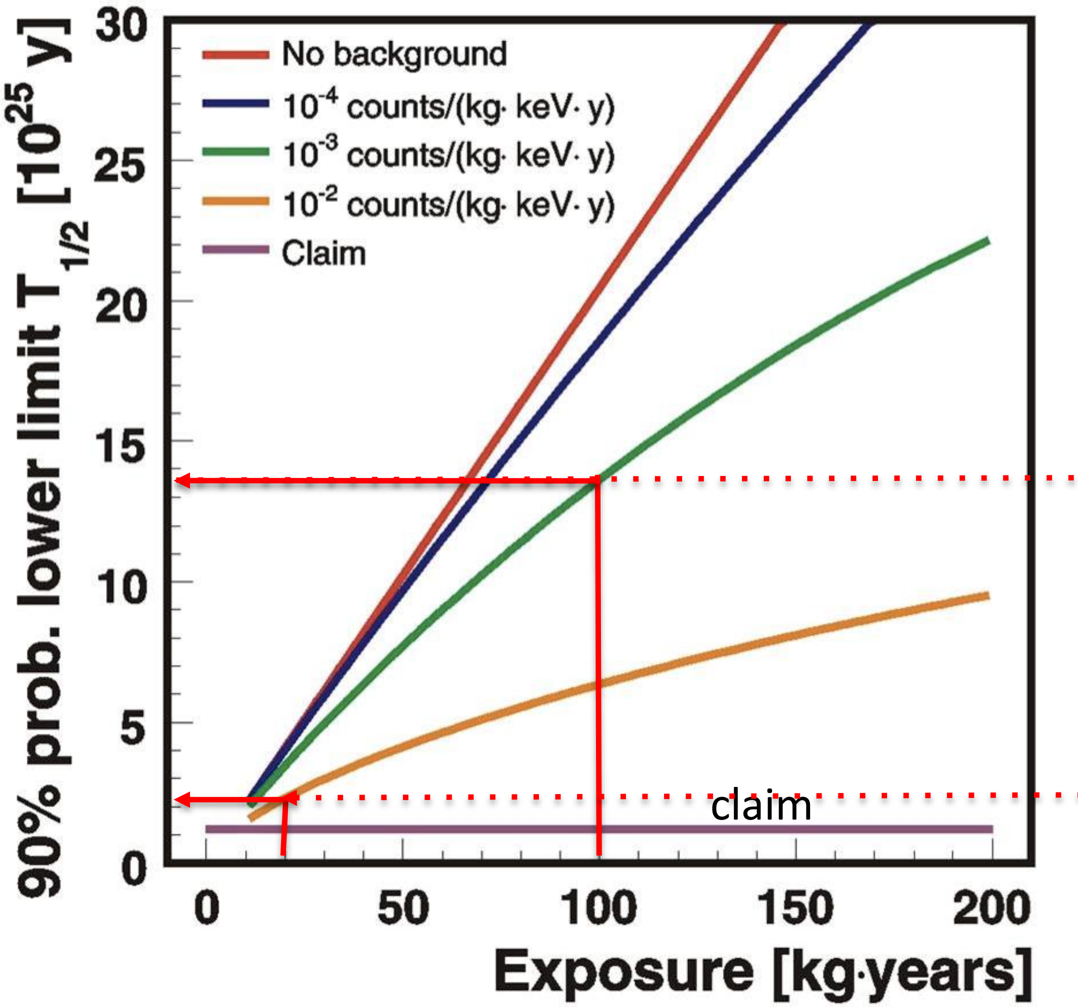
GERDA experiment located at LNGS underground laboratory, Gran Sasso, Italy (3400 m.w.e)

General concept
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

General concept
Phases of GERDA



<u>Phase II:</u>

Add new BEGe detectors (20 kg)

BI ≈ 0.001 cts / (keV kg yr)

Sensitivity after 100 kg yr

<u>Phase I:</u>

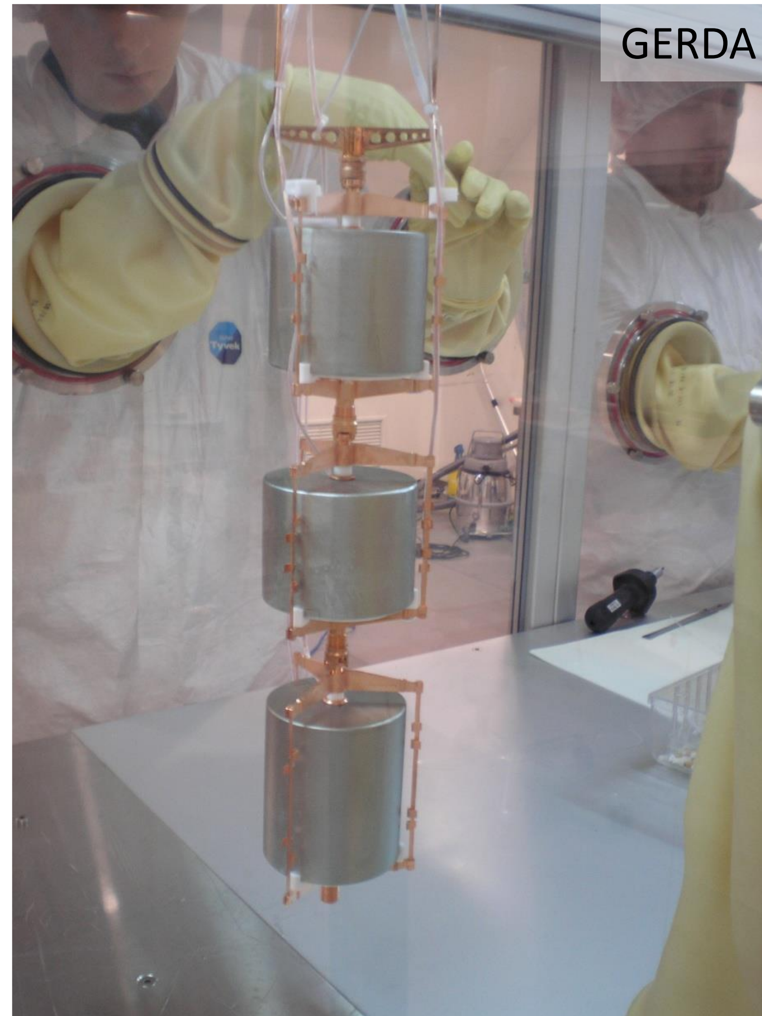
Use refurbished HdM & IGEX (18 kg)

BI ≈ 0.01 cts / (keV kg yr)

Sensitivity after 20 kg yr

General concept
Bare HPGe detectors in cryogenic liquid

Idea: G. Heusser, nnu.Rev. Nucl. Part. Sci. 45(1995) 543

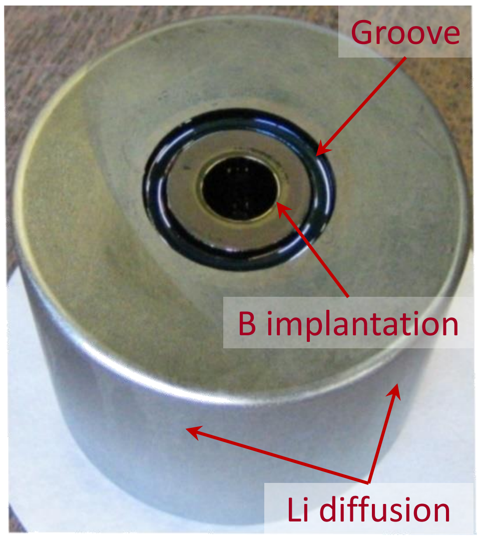


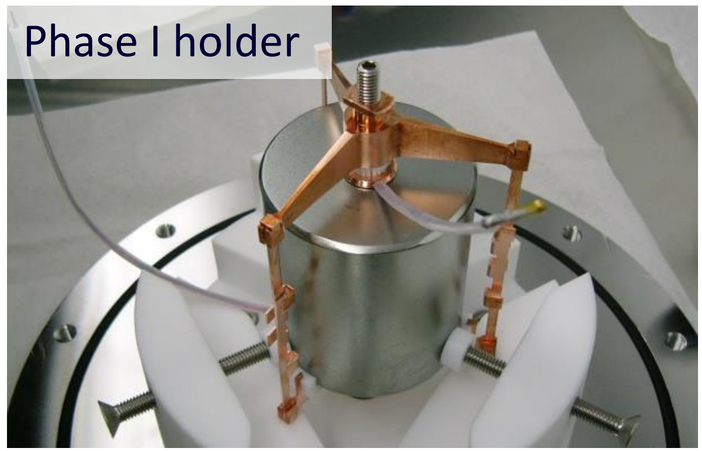
General concept

Prototype diodes (2006)

Prototype testing at GERDA Detector Lab

? Concept has not been proven by Genius TF – long term stability not established!





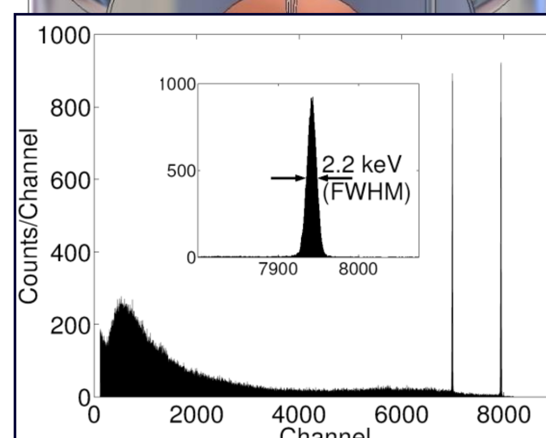
Low mass holder made of ultrapure materials: low-activity Cu (80 g), PTFE, Si

GERDA **D**etector **L**ab (GDL) @ LNGS:

- ✓ clean room underground
- ✓ test bench to mount and test Ge diodes

Non-enriched bare HPGe detectors operated in LAr/LN_2 to test:

- ✓ Phase I detector assembly – easy to mount/dismount
- ✓ detector handling – many cooling/warming cycles performed
- ✓ refurbishment technology
- ✓ long term stability – established
- ✓ spectroscopy performances – same FWHM (2.2 keV & 1.3 MeV) as in a test cryostat



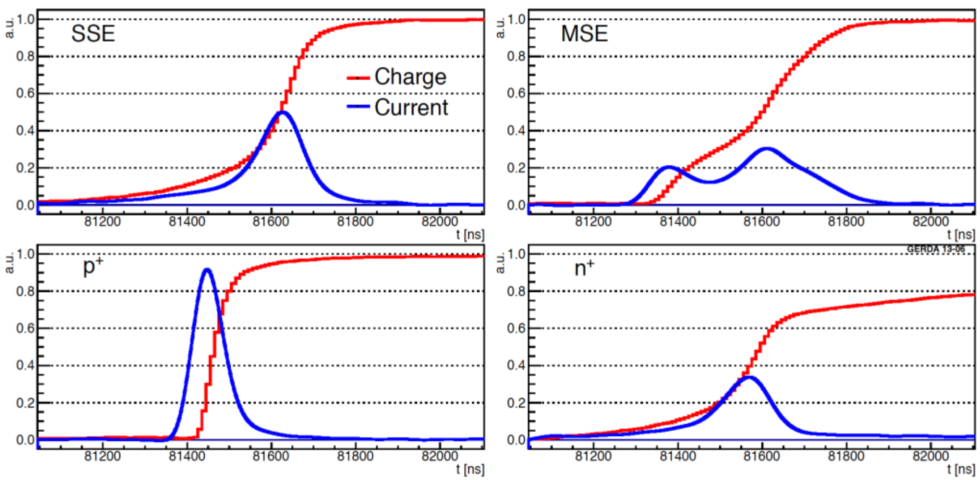
General concept
Pulse shape discrimination (PSD)

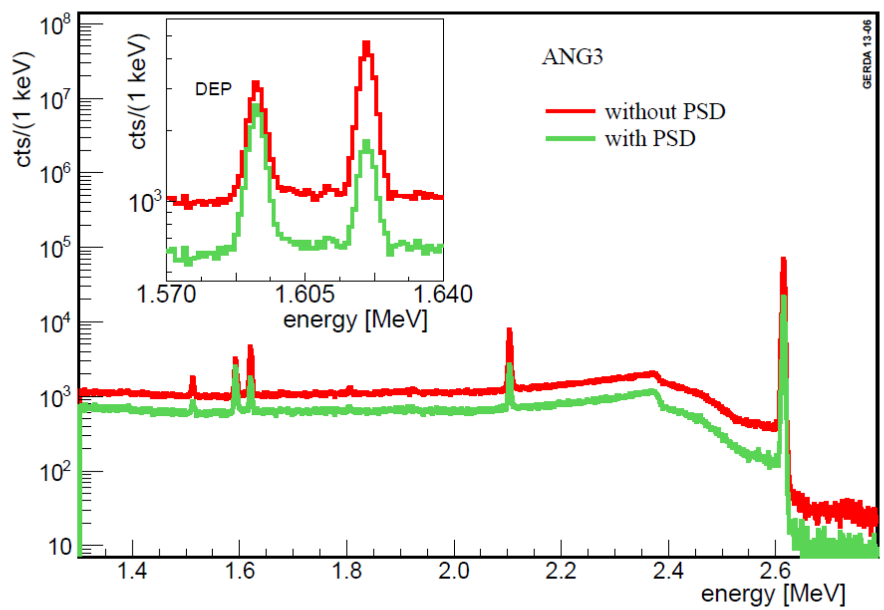
BEGes: Amplitude of Current/Amplitude of Charge Pulse **(A/E)**

- Easy and powerful, developed and tested since years, effective against multi-site and surface background
- "Loose" cuts: tuned to high signal efficiency (> 92%), bkg suppressed by a factor of 4
- used in Phase I and Phase II

Coaxial detectors: Artificial neural network (**ANN**)

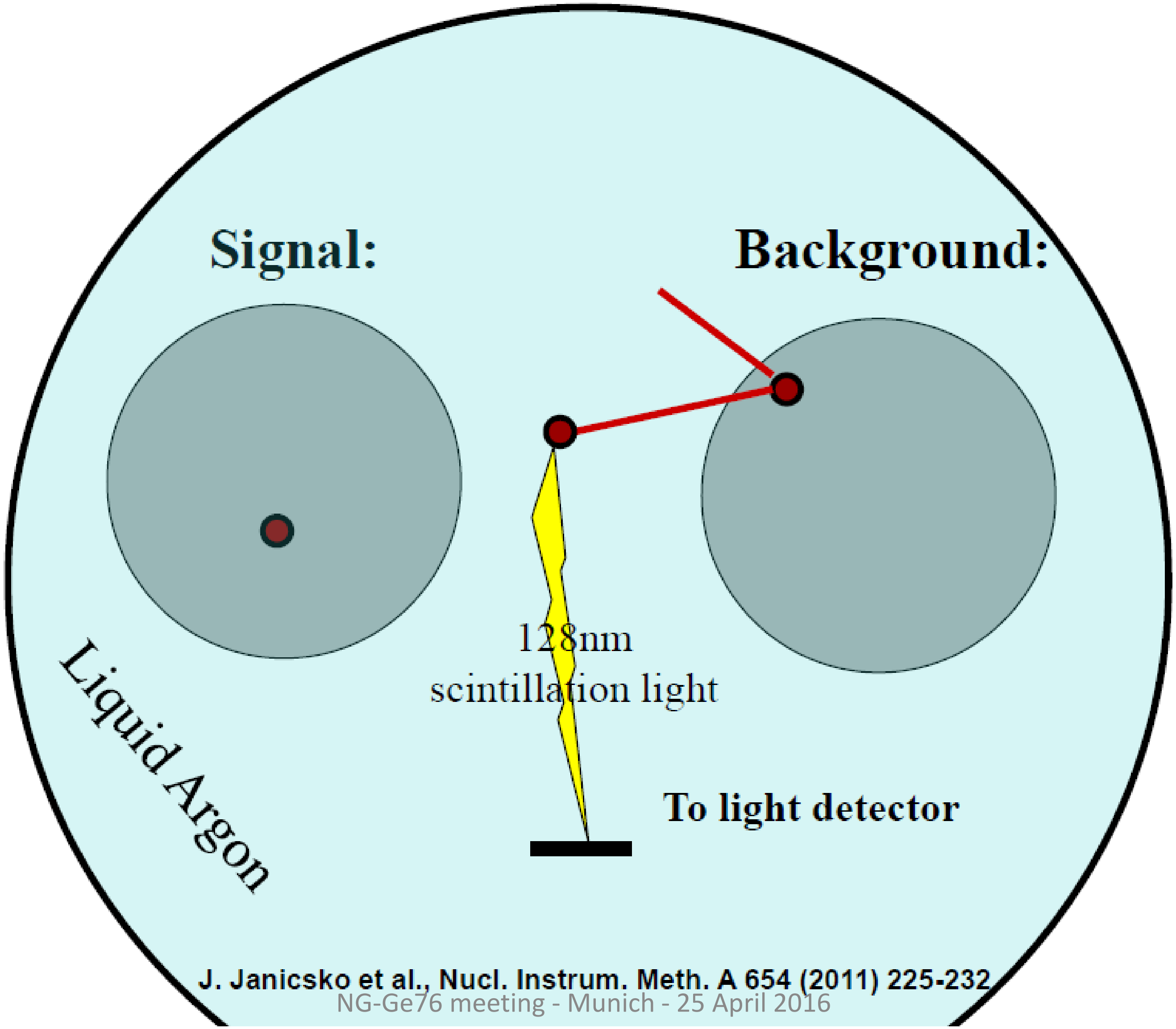
- Trained on signal (SSE) : ^{208}Tl (2614 keV) DEP at 1592 keV
- Background (MSE): ^{212}Bi @ 1620 keV γ-line
- used in both Phases





General concept

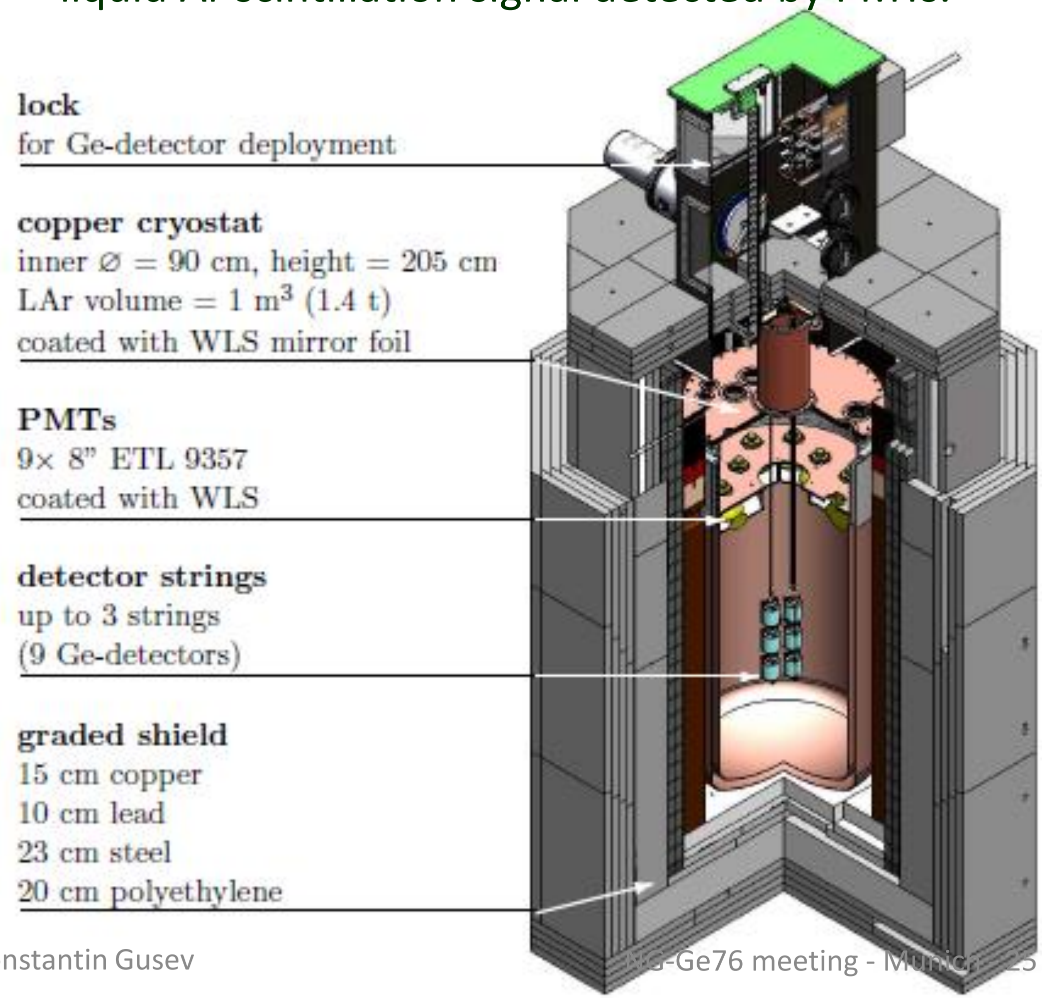
LAr instrumentation for Phase II



J. Janicsko et al., Nucl. Instrum. Meth. A 654 (2011) 225-232

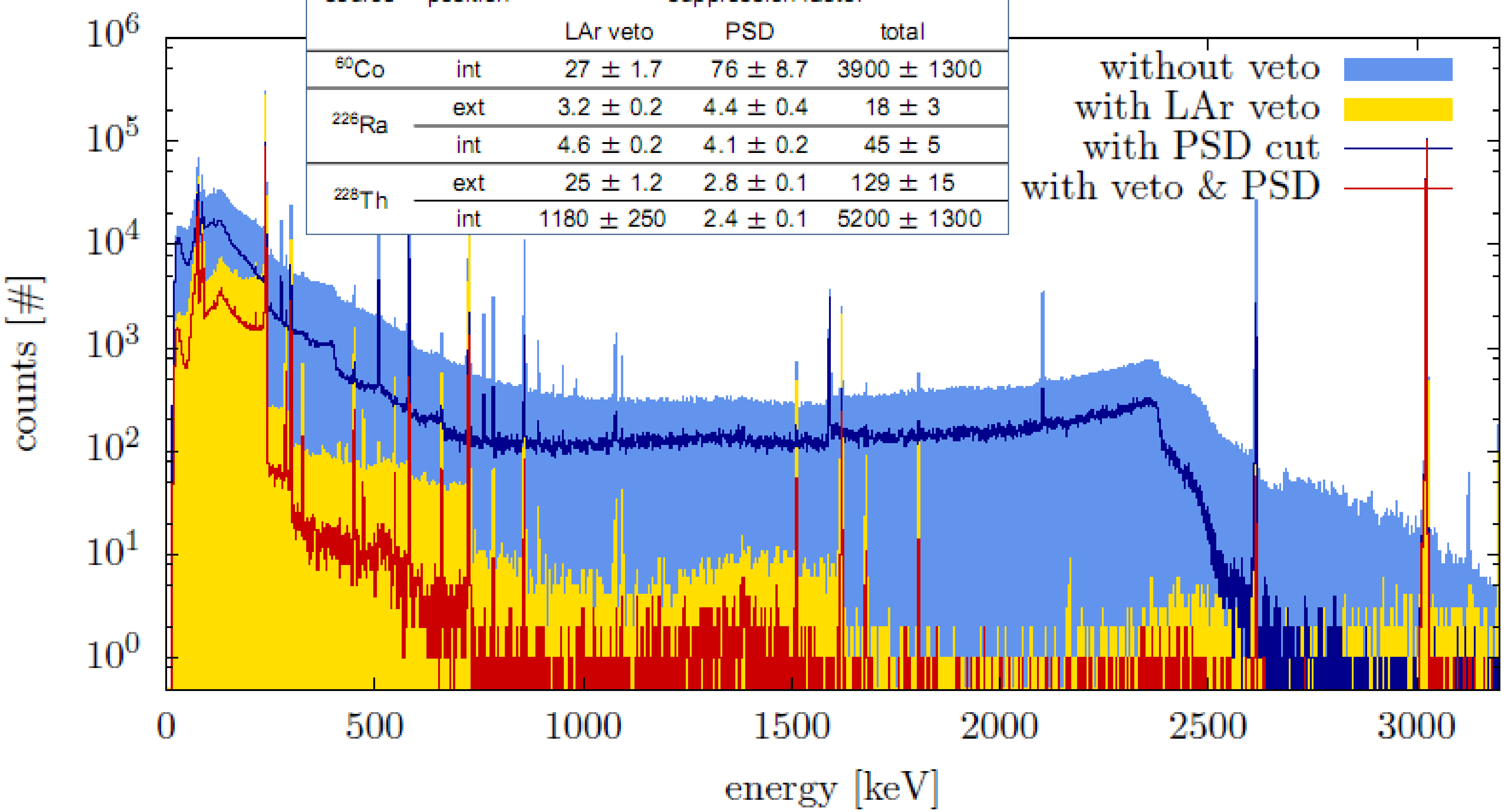
General concept
LAr instrumentation – LArGe test facility

LArGe is a low background test facility, also located at LNGS, which has been created in order to investigate possibility to suppress background by using anticoincidence with liquid Ar scintillation signal detected by PMTs.



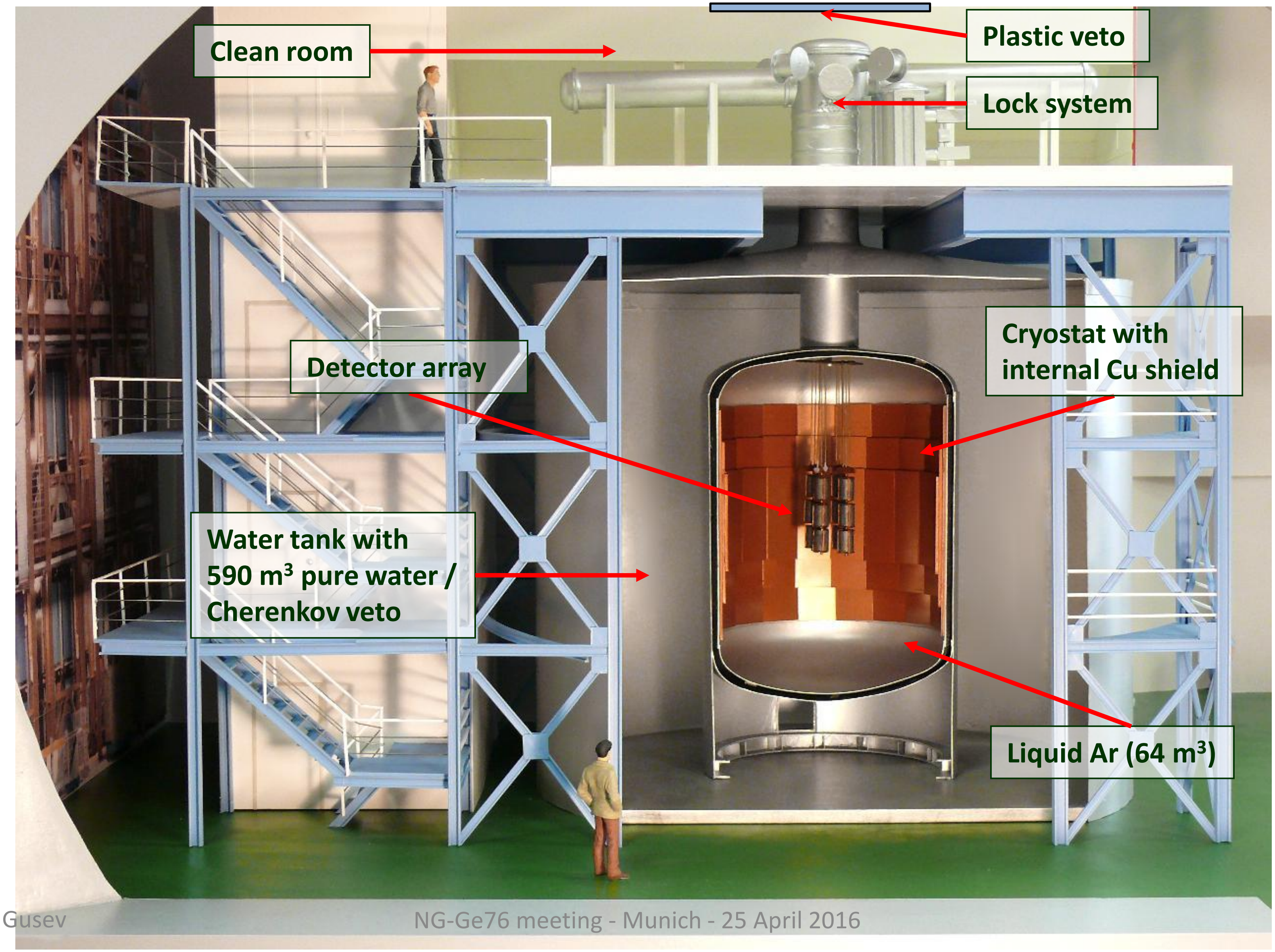
General concept
LAr instrumentation – LArGe

source	position	suppression factor		
		LAr veto	PSD	total
^{60}Co	int	27 ± 1.7	76 ± 8.7	3900 ± 1300
^{226}Ra	ext	3.2 ± 0.2	4.4 ± 0.4	18 ± 3
	int	4.6 ± 0.2	4.1 ± 0.2	45 ± 5
^{228}Th	ext	25 ± 1.2	2.8 ± 0.1	129 ± 15
	int	1180 ± 250	2.4 ± 0.1	5200 ± 1300



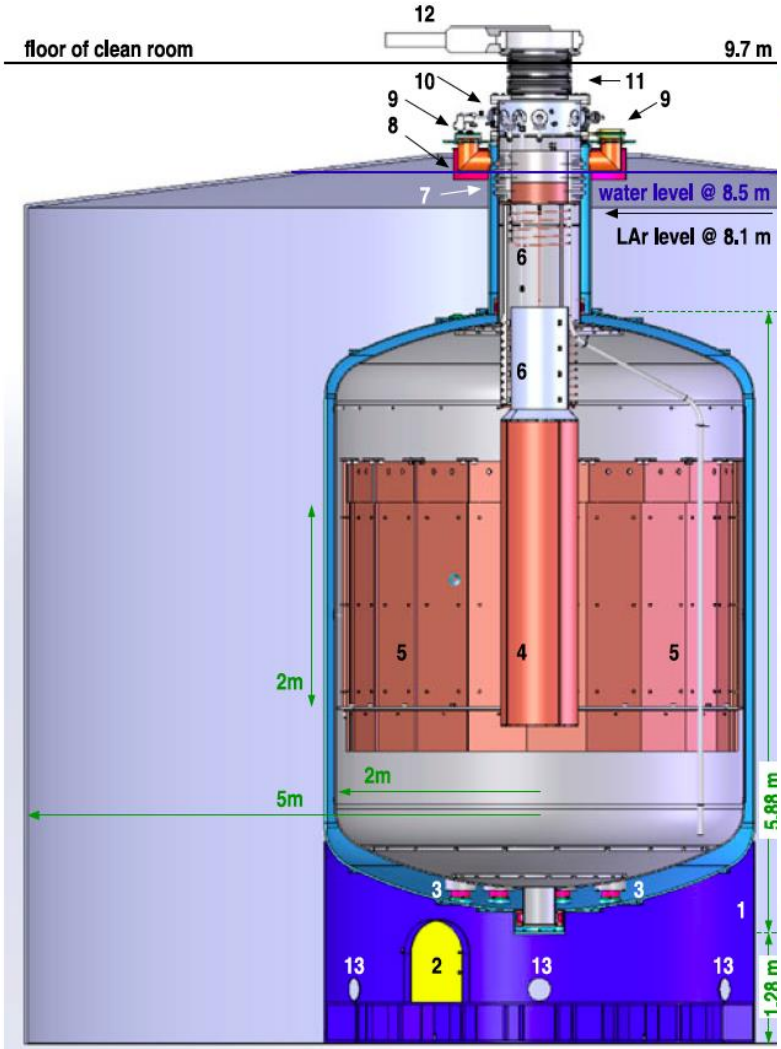
Measurements inside LArGe show very good suppression of background. As an example, for ^{228}Th inner source the suppression factor > 5000 has been obtained after applying LAr VETO and PSD.

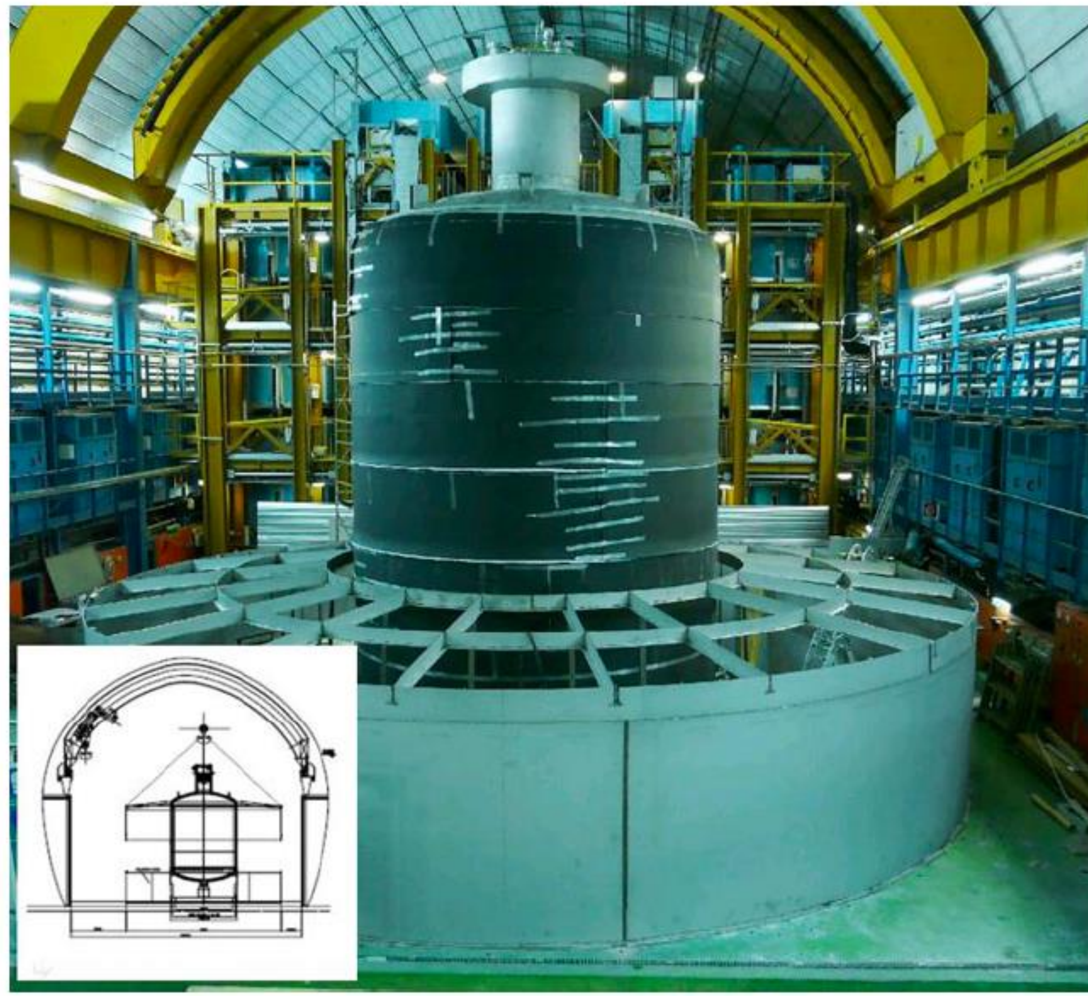
GERDA design



Cryostat and water tank

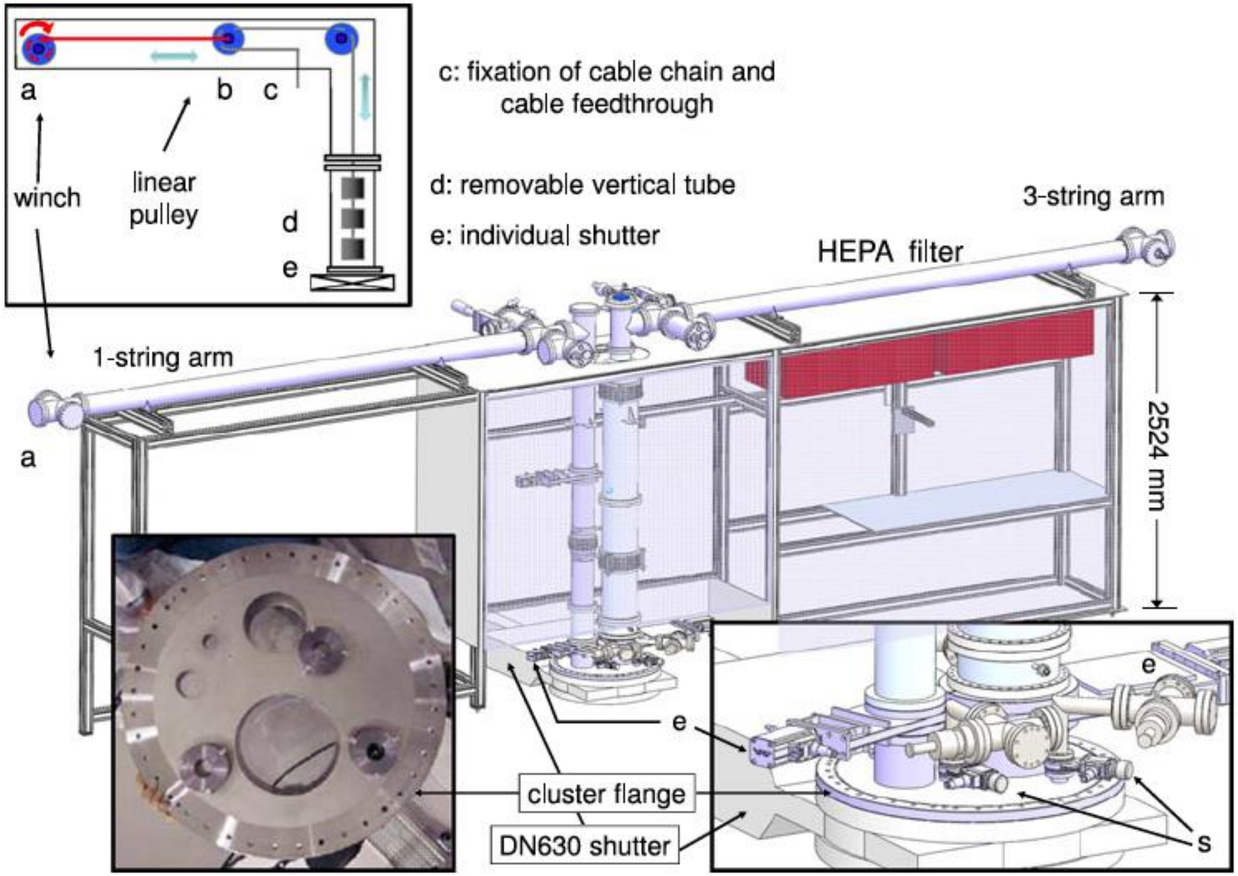
Eur. Phys. J. C (2013) 73:2330





Clean room
Phase I lock system

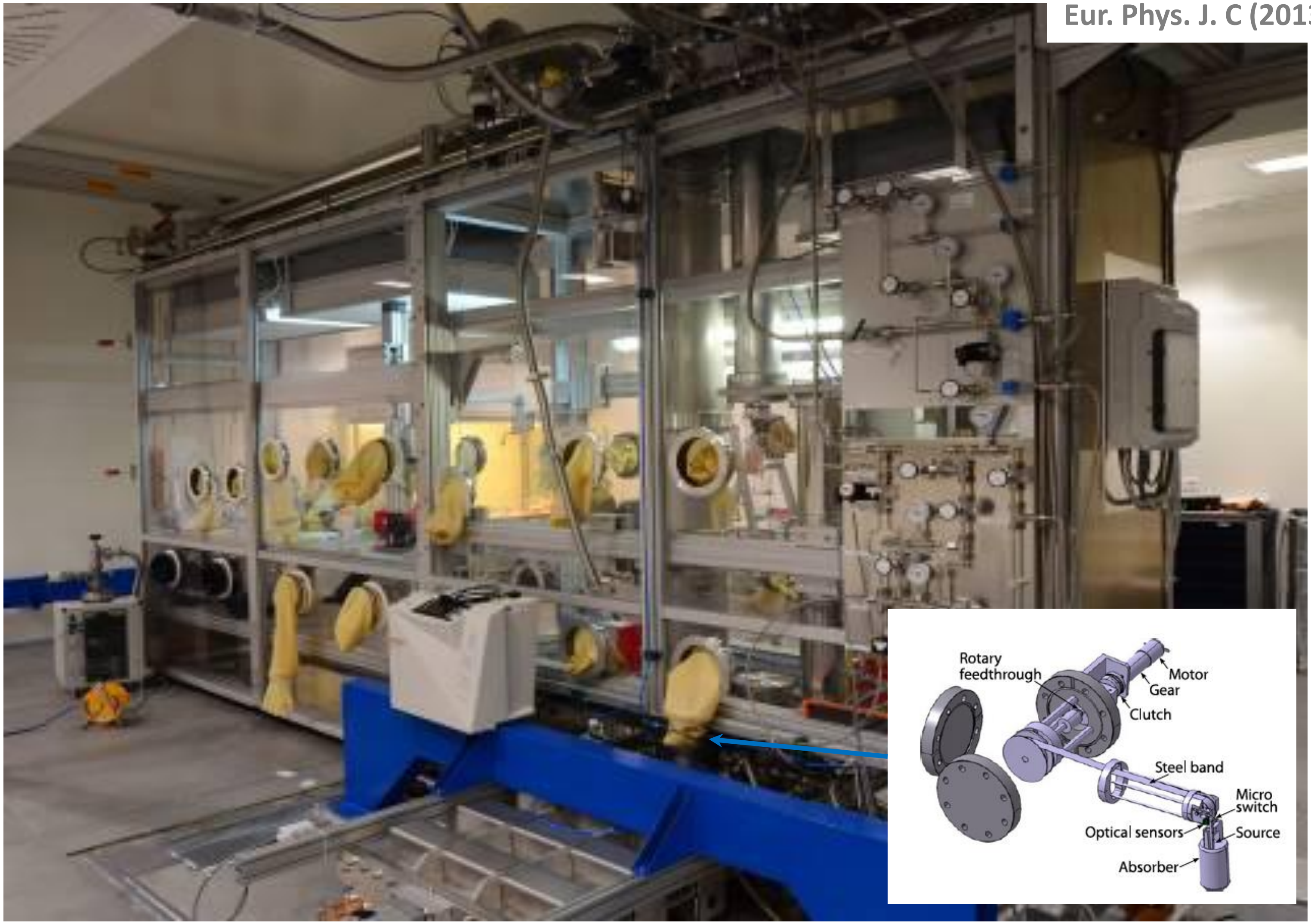
Eur. Phys. J. C (2013) 73:2330



Clean room

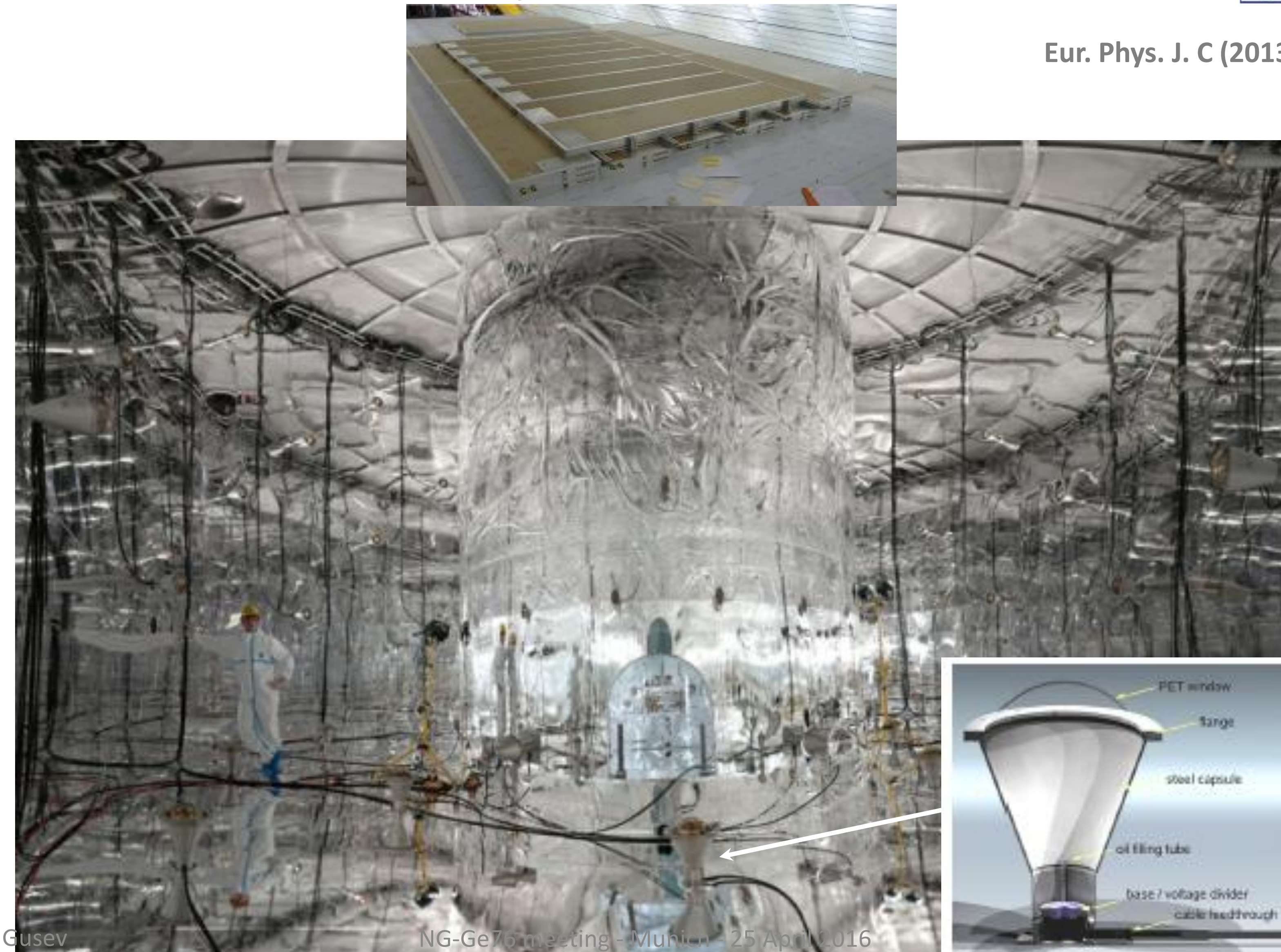
Glove box and Phase I calibration system

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

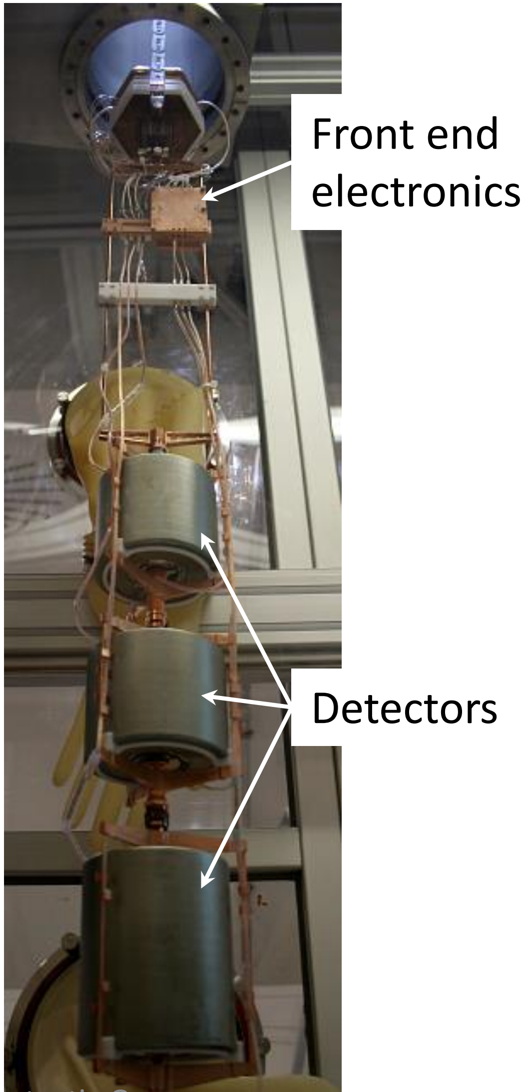


Muon veto
Water Cherenkov + plastic scintillators

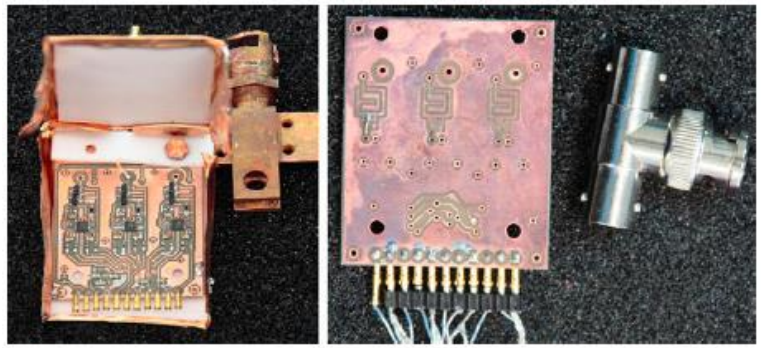
Eur. Phys. J. C (2013) 73:2330

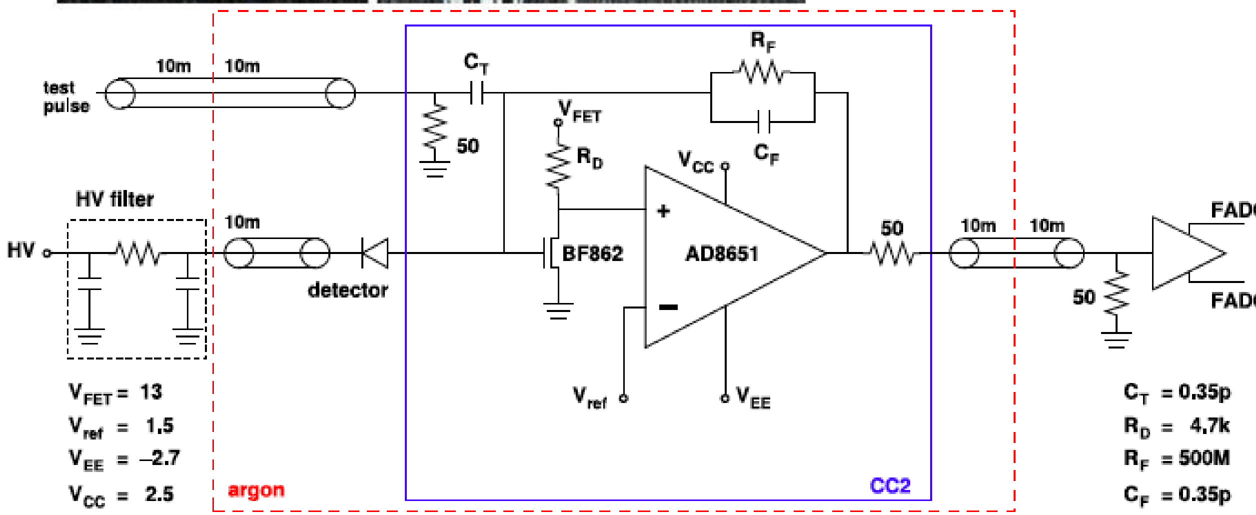


Phase I:
Front end electronics (CC2)



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





- ✓ whole preamplifier in LAr (at 87 K)
- ✓ > 35 cm from detectors to JFET

Phase I detectors:
Coaxial diodes

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

Diodes from predecessor experiments reprocessed at Canberra, Olen:

- ✓ optimized for LAr
- ✓ tested in GDL in 2008

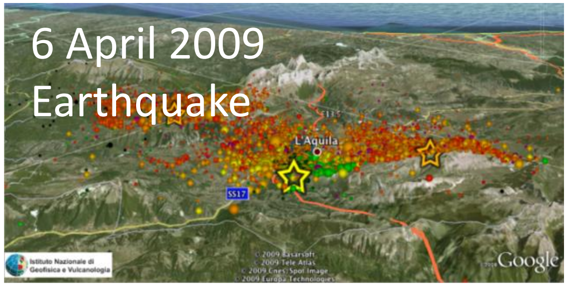
8 diodes (from HdM, IGEX):

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

6 diodes from Genius-TF:

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

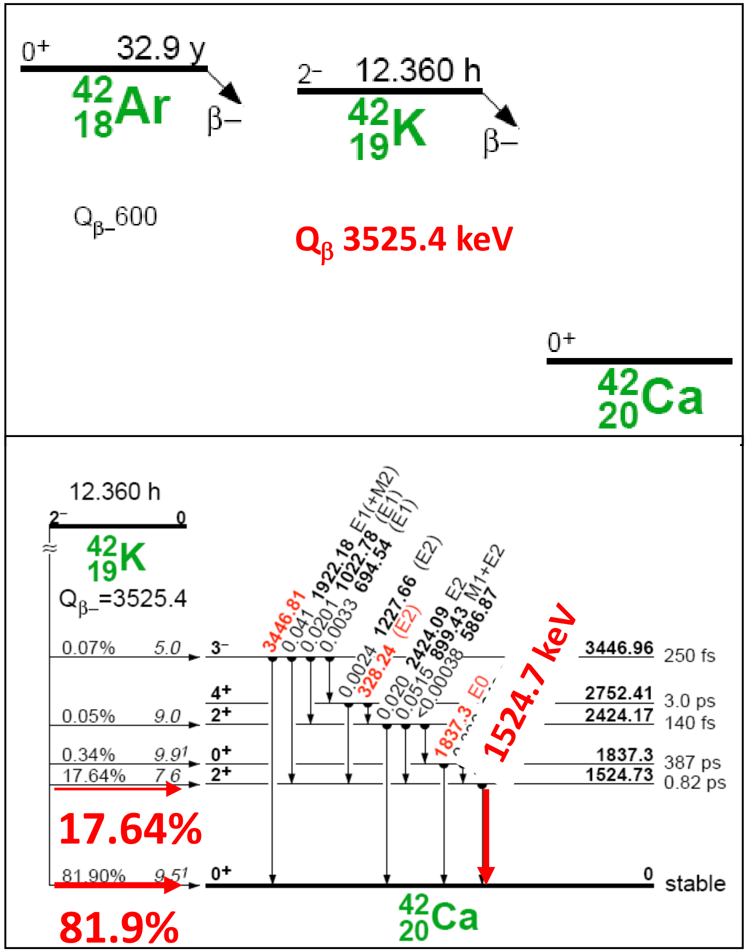
Installation of GERDA

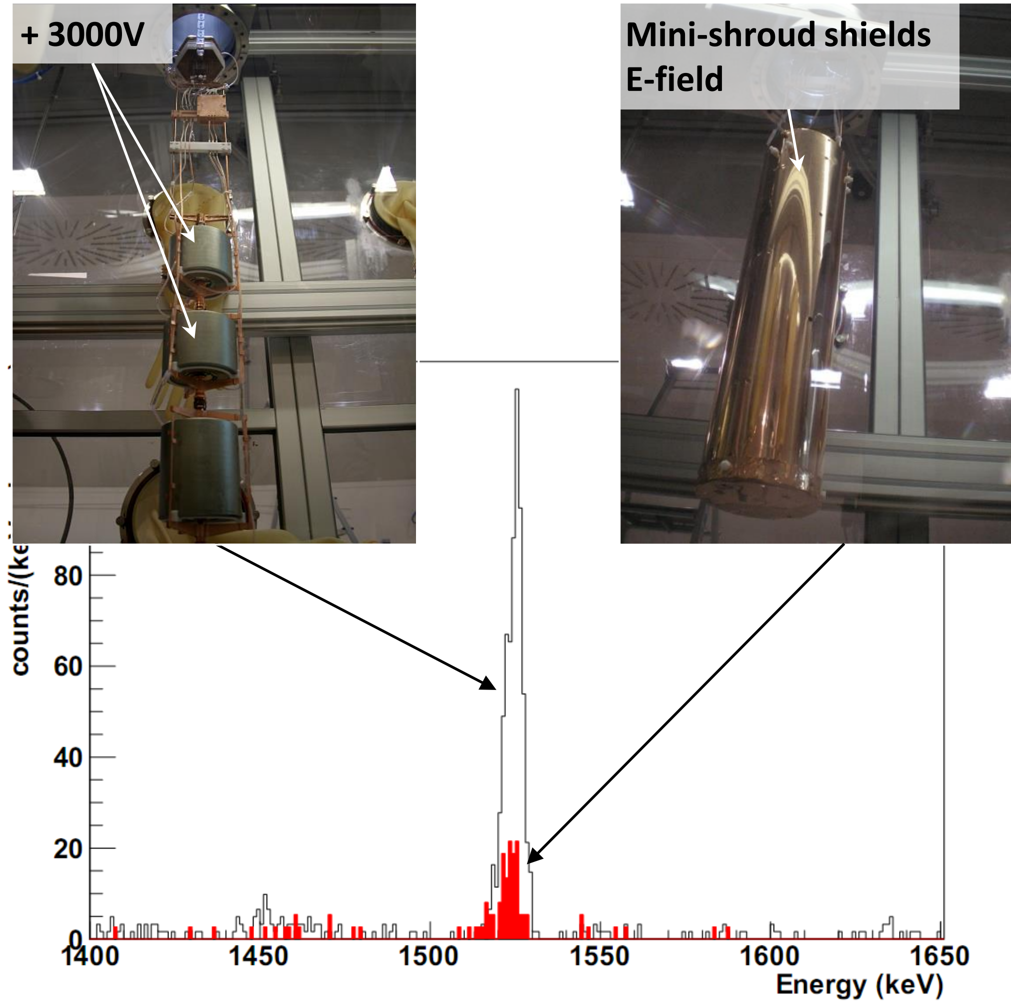


Cryostat filled in December 2009

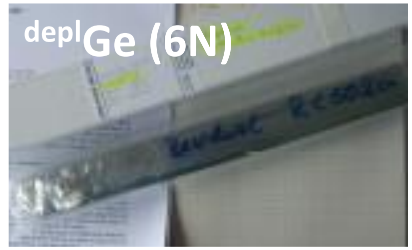
Inauguration at LNGS
November 2010

Phase I commissioning (from June 2010)
^{42}Ar (^{42}K) problem and solution (mini-shroud)

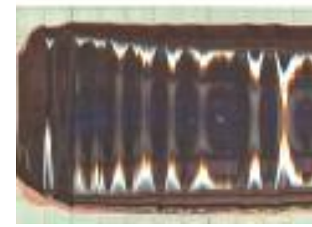




Phase II detectors
Production test of BEGes from depleted Ge

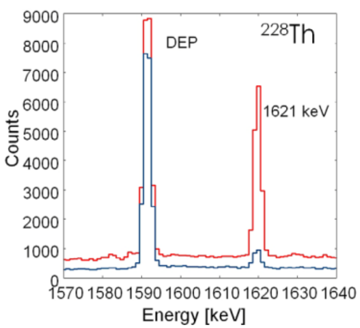


Crystal pulling



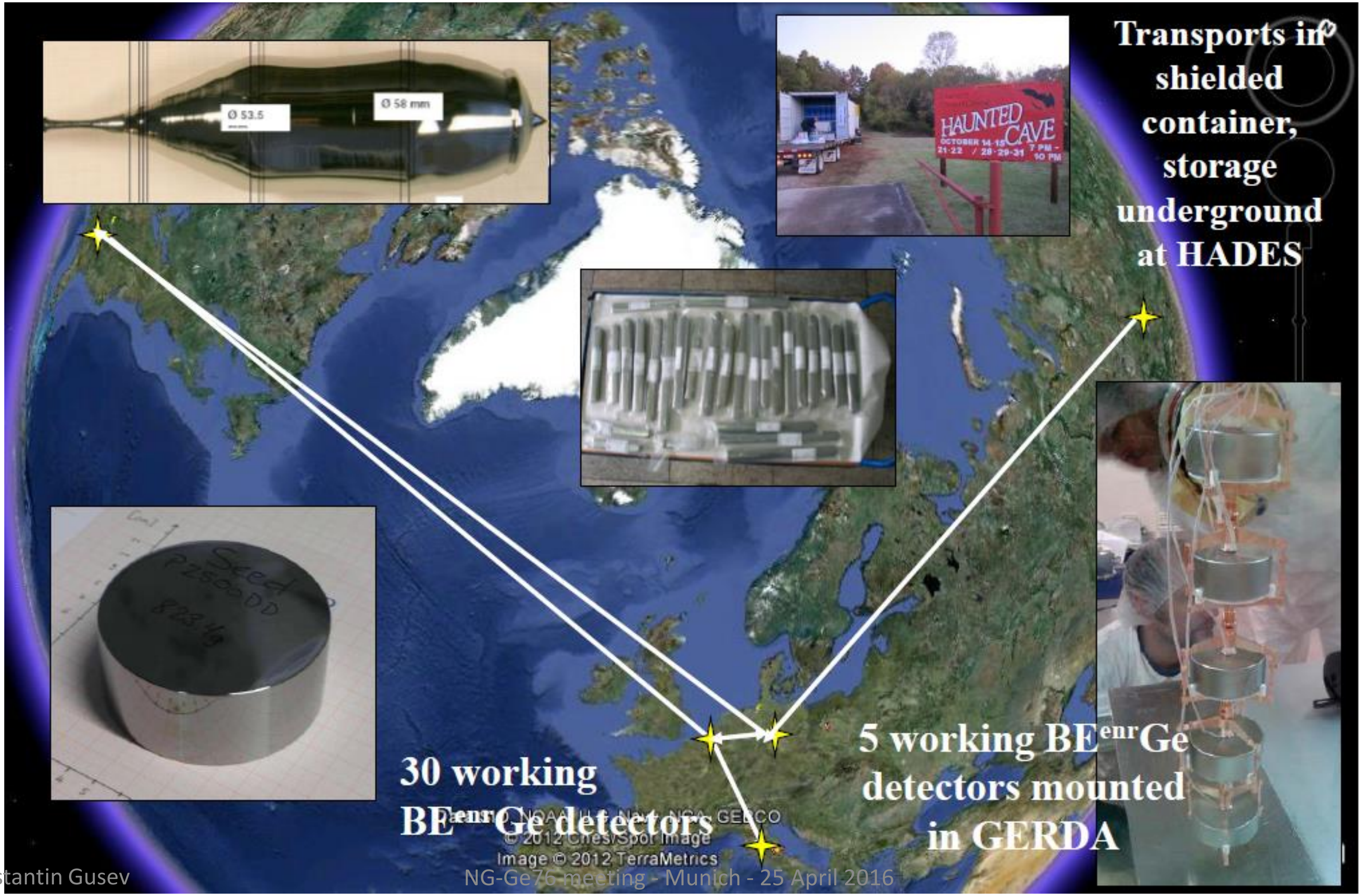
Crystal slice

Full production chain tested with isotopic depleted germanium

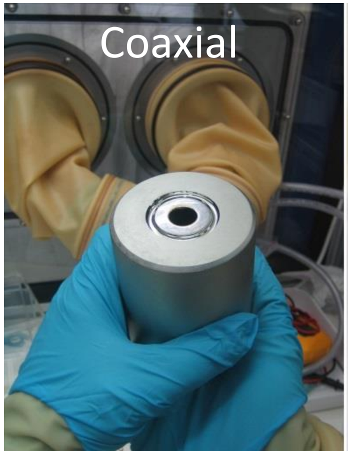


- ✓ Successful!
- ✓ Start production of BEGes from ^{enr}Ge

Phase II detectors
Enriched BEGes



Phase I
Installation of detectors



Coaxial:

- ✓ 3 strings (9 detectors) deployed
- ✓ Phase I data taking started in November 2011

BEGe:

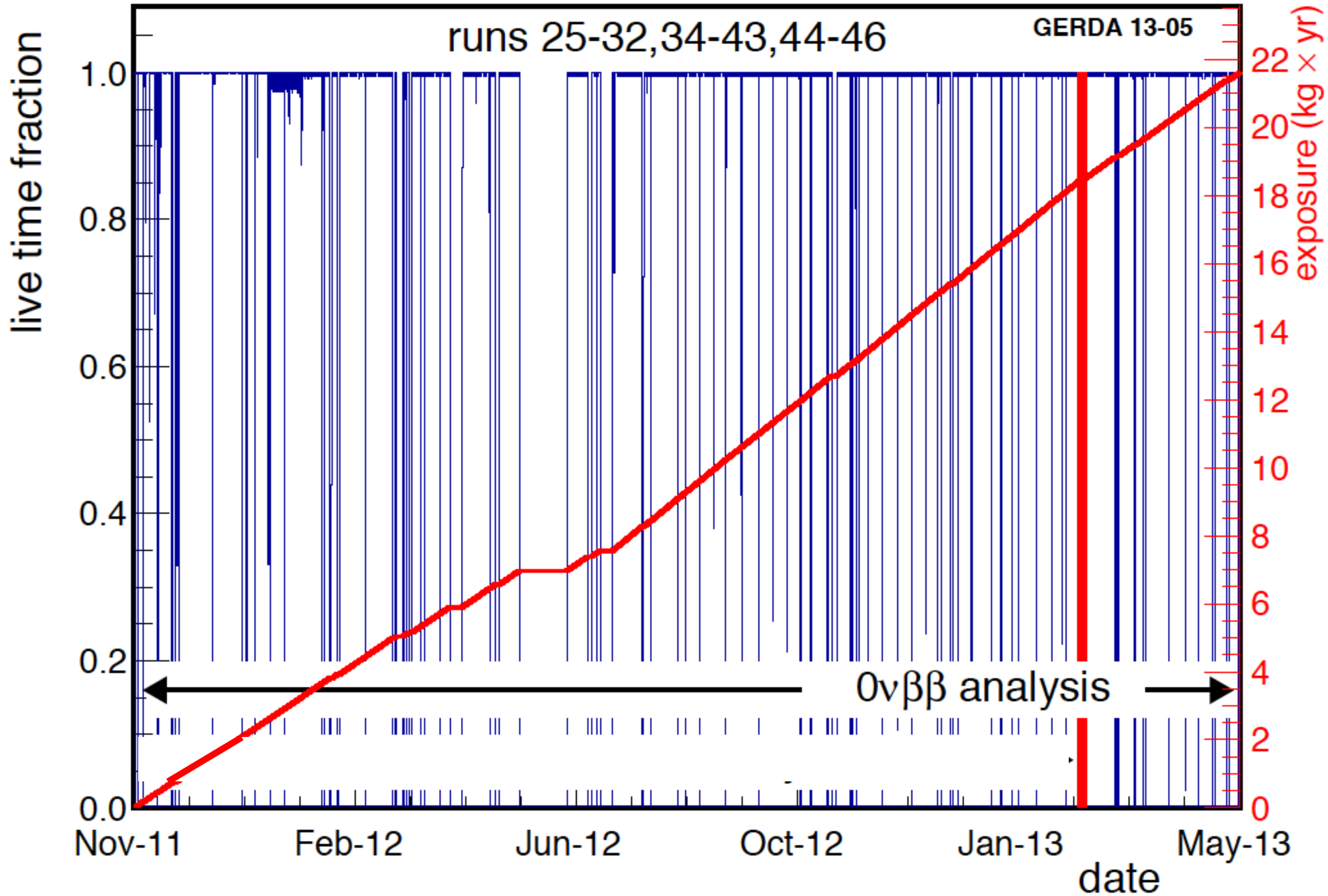
- ✓ 5 BEGe detectors in one strings deployed in June 2012

Phase I
Overview of data taking

<u>Total exposure</u>:

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

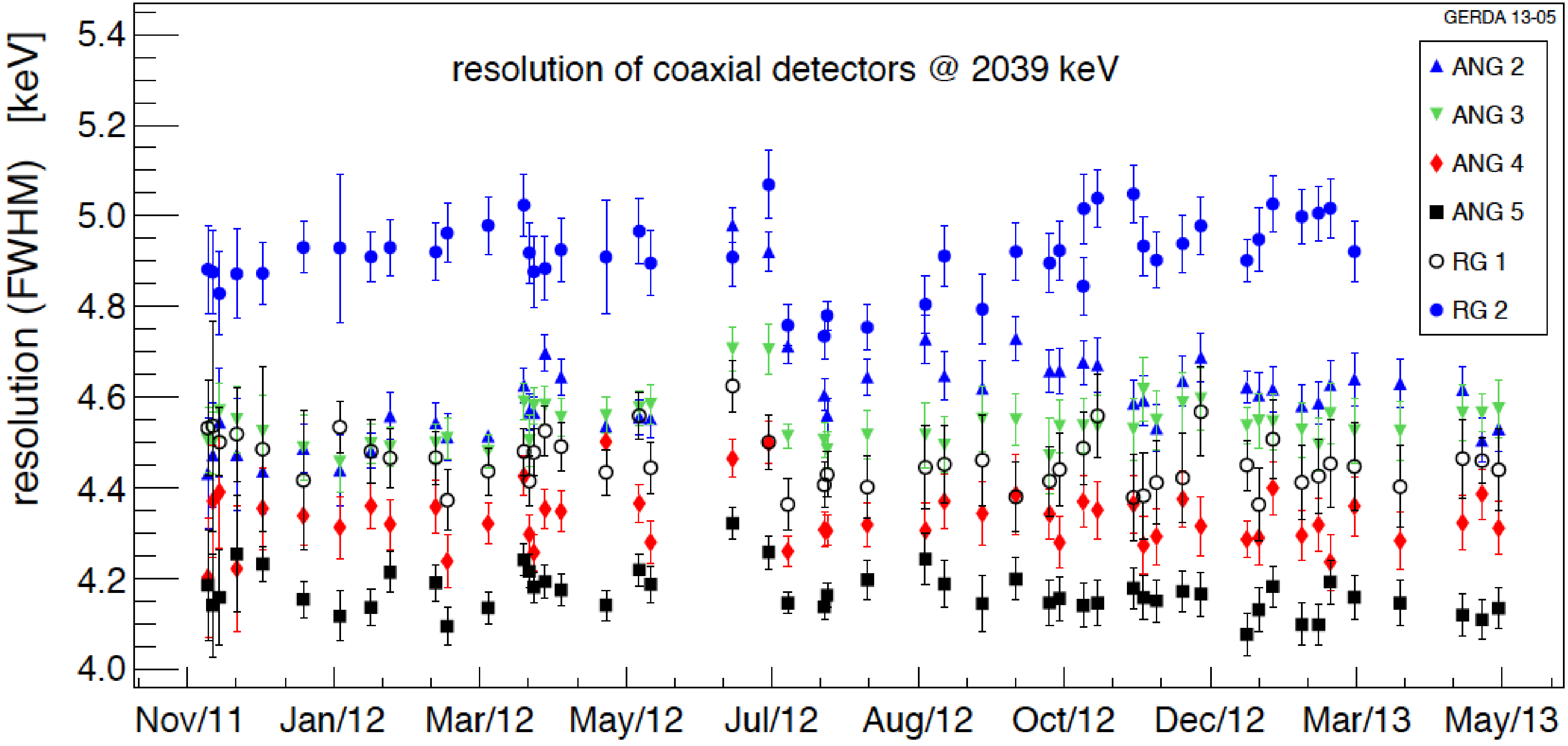
21.6 kg yr between Nov 2011 and May 2013 (492.3 live days, 88.1% duty factor)



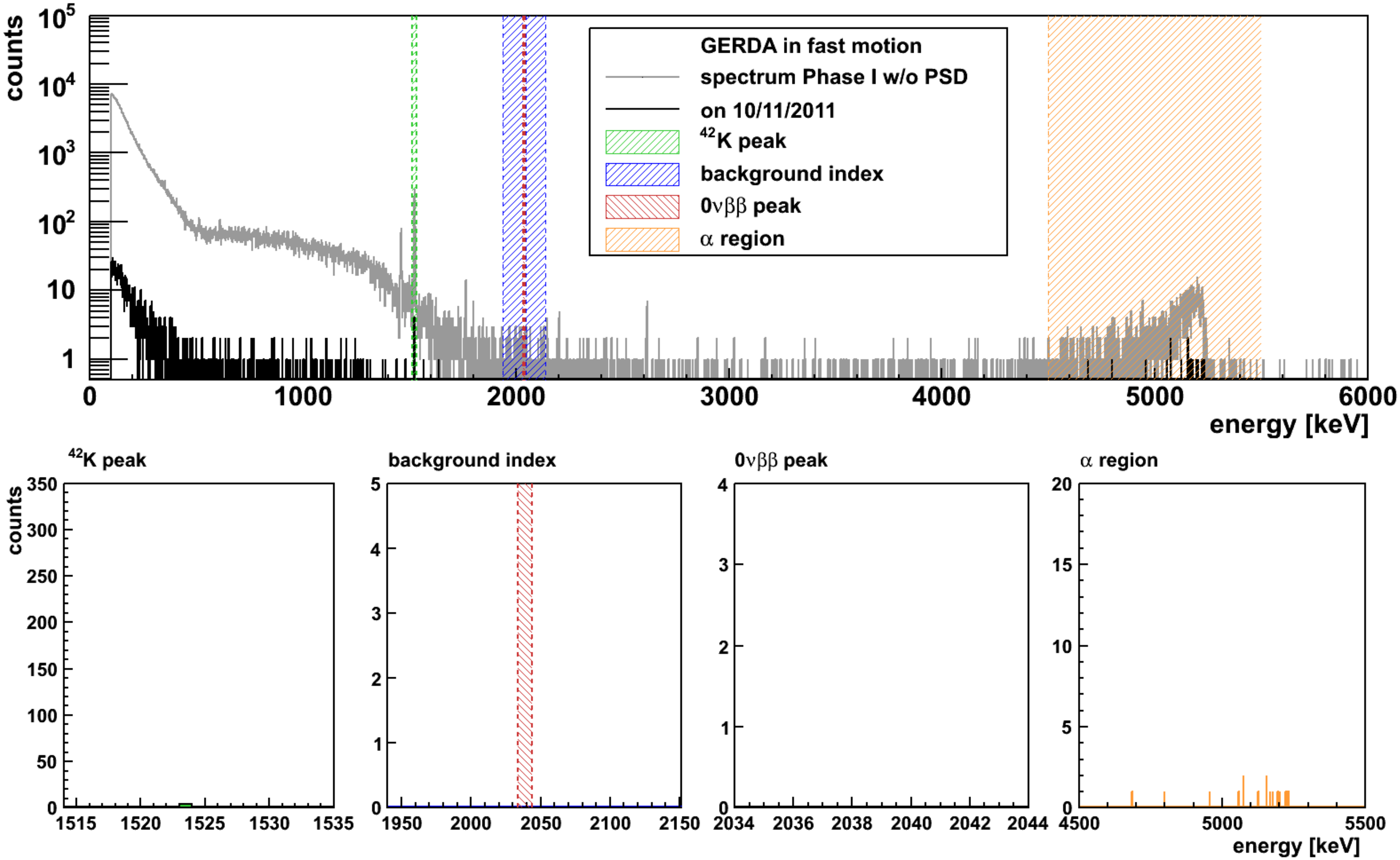
Phase I
Overview of data taking

Stable data taking during most of the time!

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

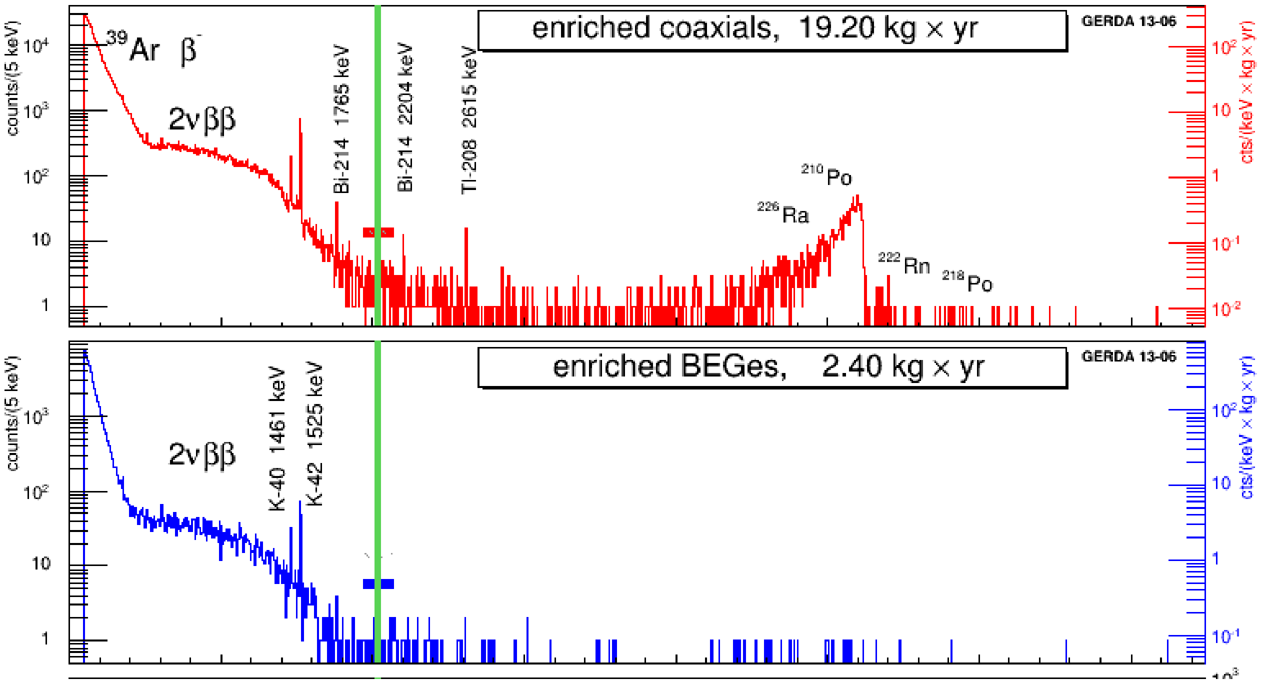


Phase I
Overview of data taking



Phase I results
Background

PRL 111 (2013) 122503



- Low-energy dominated by the β spectrum of ^{39}Ar (Q_β = 565 keV).
- Coaxial detectors show surface α (^{210}Po)
- Most intense γ-line: 1525 keV from ^{42}K (and 1460 keV from ^{40}K)
  - Only a few more γ-lines detected with statistical significance (^{214}Pb/^{214}Bi, ^{208}Tl, ^{228}Ac)

Backround after PSD: **10^{-2}** counts / (keV kg yr)

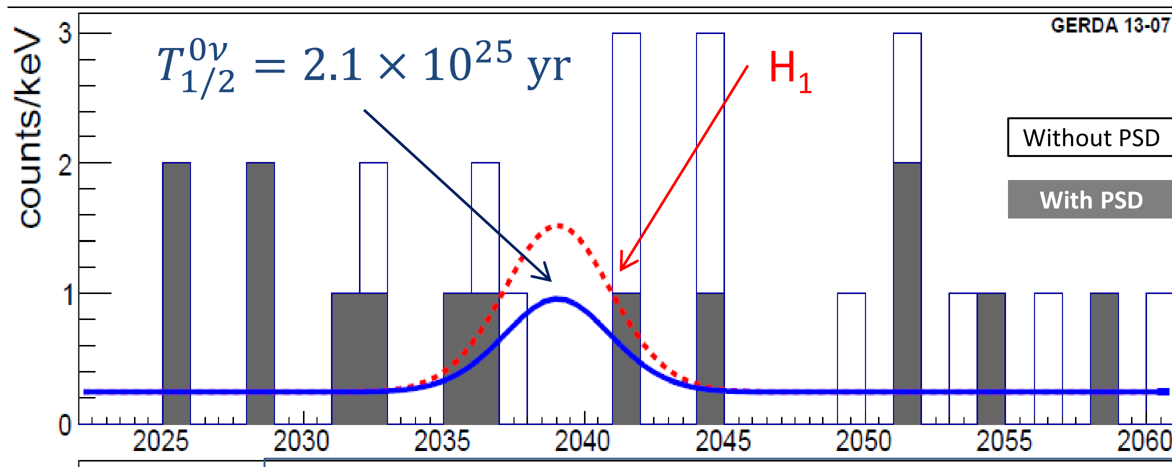
✓ design **goal reached**!

Phase I results
0νββ

PRL 111 (2013) 122503

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



Limit on the half-life:

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

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

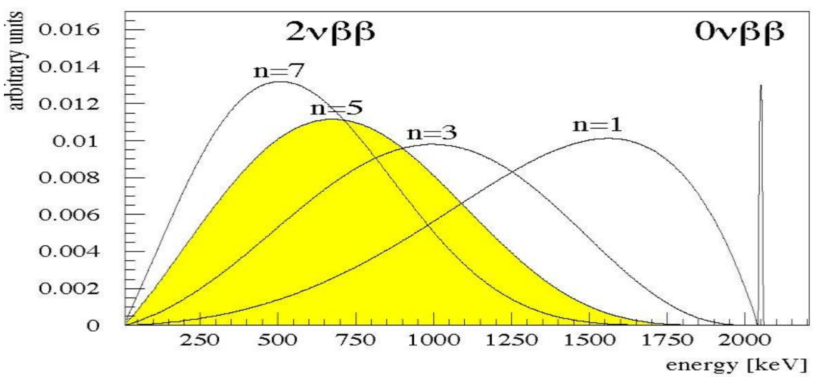
Observed: **3.0** in ±2σ (0 in ±1σ)

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

Phase I results
0νββχ(Majoron)

EPJC 75 (2015) 416

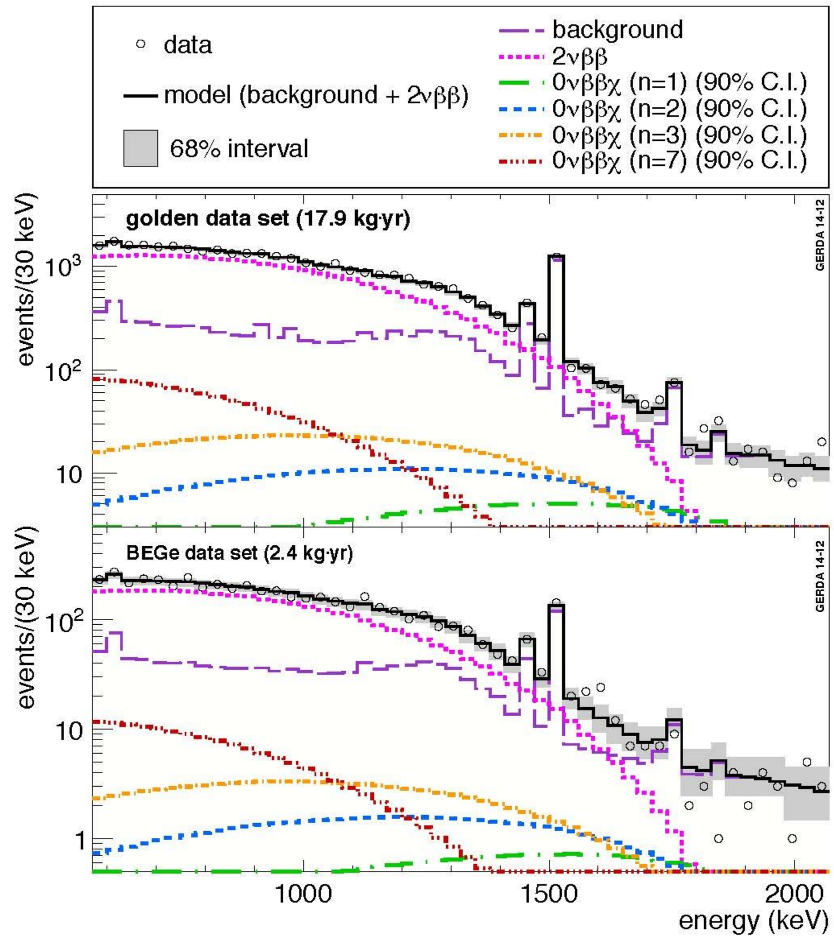
$$G \sim (Q_{\beta\beta} - K)^n$$



- 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

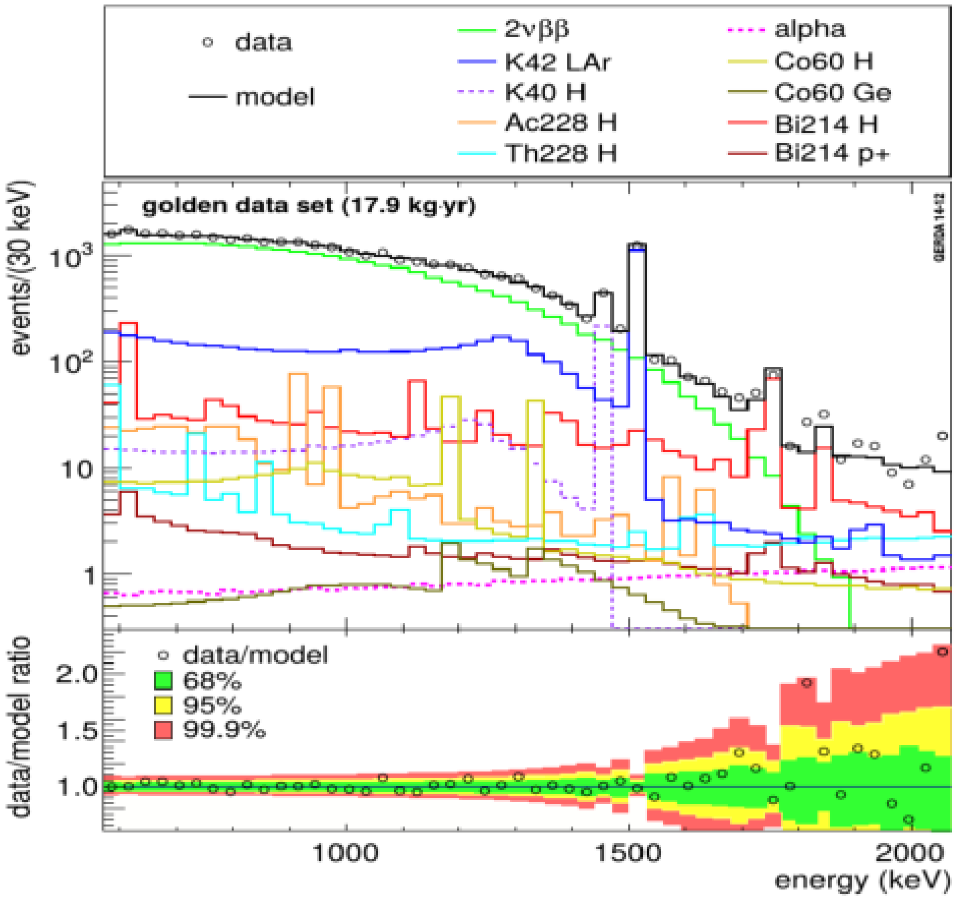
for n = 1: $\boldsymbol{T_{1/2}^{0\nu\chi} > 4.2 \times 10^{23}}$ **yr (90% CL)**

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



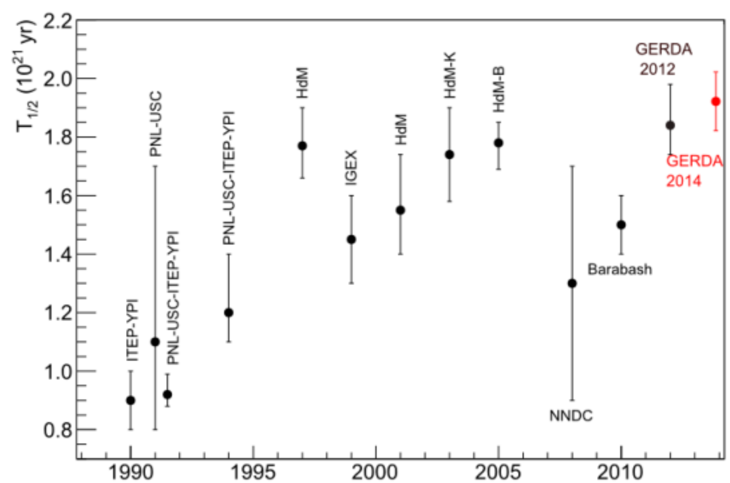
Phase I results
2νββ

EPJC 75 (2015) 416



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



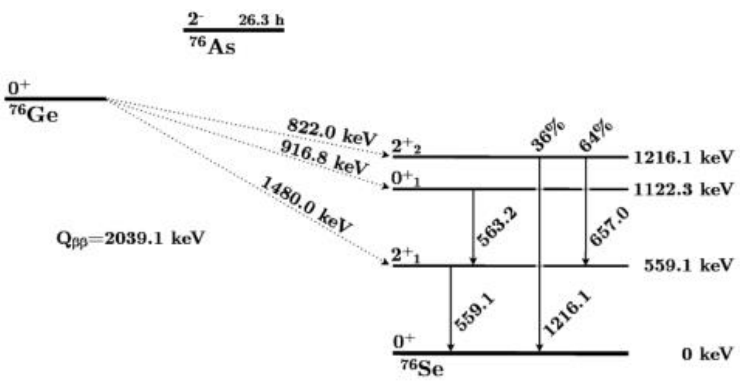
New result:

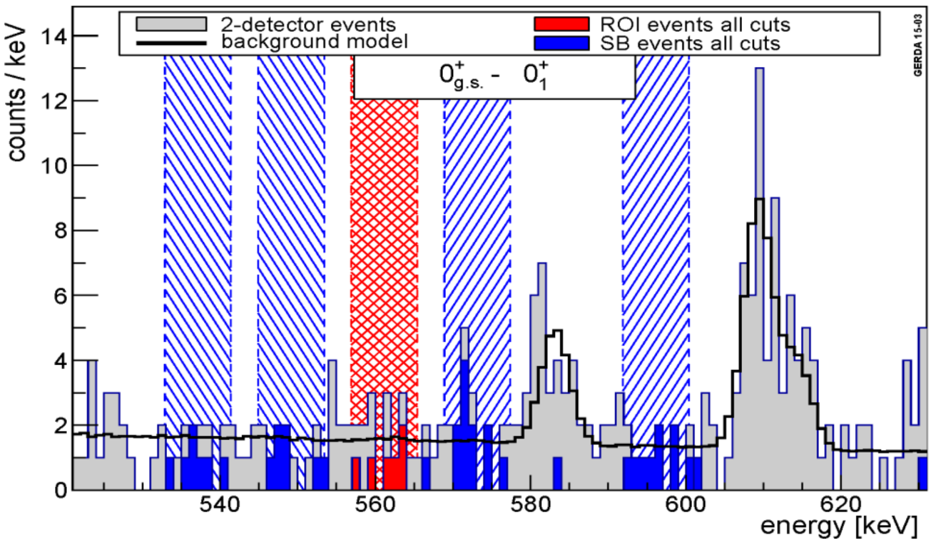
$$T_{1/2}^{2\nu} = (1.926 \pm 0.095) \times 10^{21}\ \mathbf{yr}$$

Phase I results
$2\nu\beta\beta$ to excited states

J. Phys. G: Nucl. Part. Phys. 42 (2015) 115201

- $(2\nu)\beta\beta$ 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





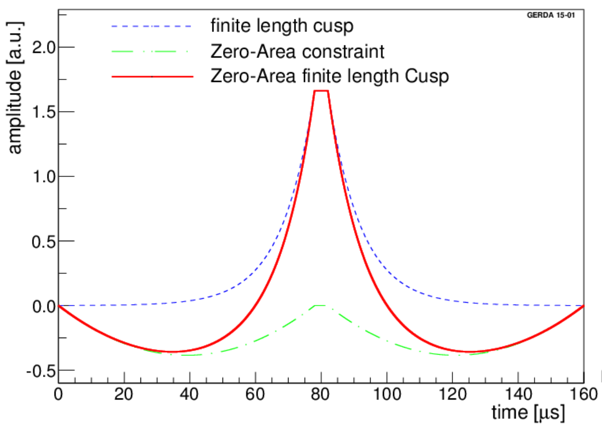
- Search for coincidence of $\beta\beta$-decay in one detector and 560 keV γ-ray in another
- NO evidence found
- Limits improved by ~100
- For 0^+_1 level:

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

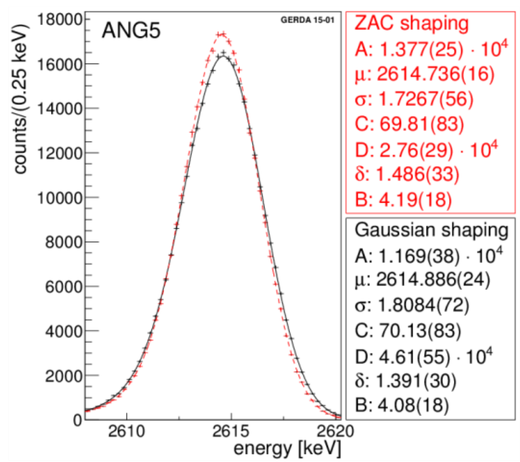
Phase I/II
Improvement in energy resolution

EPJC 75 (2015) 255

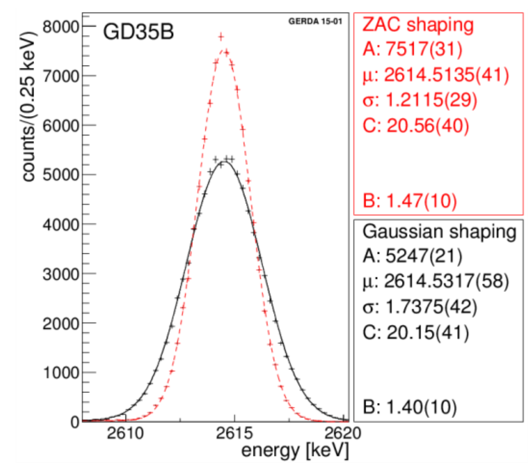
Zero Area Cusp (ZAC) filter: a novel filter for enhanced energy resolution



Coaxial detector



BEGe detector

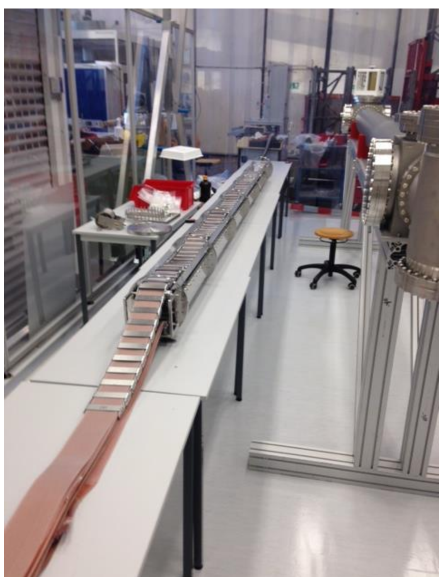


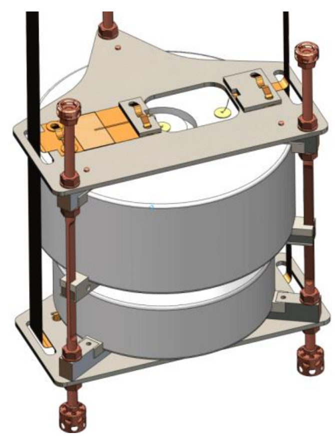
Detector	FWHM at 2614.5 keV (keV)		Improvement (keV)
	Gaussian	ZAC	
ANG2	4.712 (3)	4.314 (3)	0.398 (4)
ANG3	4.658 (3)	4.390 (3)	0.268 (4)
ANG4	4.458 (3)	4.151 (3)	0.307 (4)
ANG5	4.323 (3)	4.022 (3)	0.301 (4)
RG1	4.595 (4)	4.365 (4)	0.230 (6)
RG2	5.036 (5)	4.707 (4)	0.329 (6)
GD32B	2.816 (4)	2.699 (3)	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)

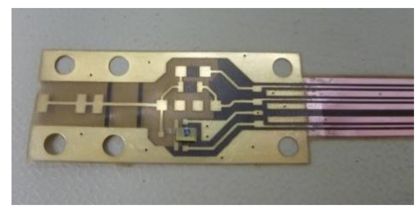
ZAC filter:
- ✓ Better low frequency rejection
- ✓ The energy reconstruction for Phase I/II can be improved (for both coaxial and BEGe detectors)

Phase II Upgrade

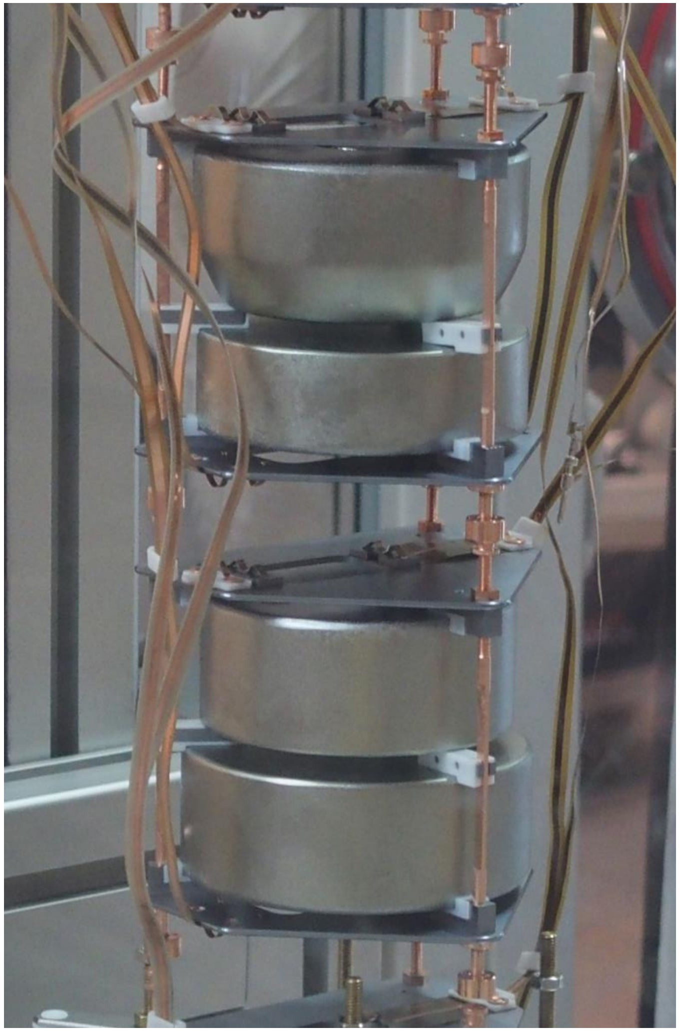
- 30 new BEGe detectors (produced and tested)
- New lock system (40 detectors + LAr veto – more channels needed)
- We had to reduce background by one order of magnitude!
    - New low mass holder
    - New front end readout close to detectors & new front end cabling
    - New HV and signal cabling
    - Liquid argon veto instrumentation

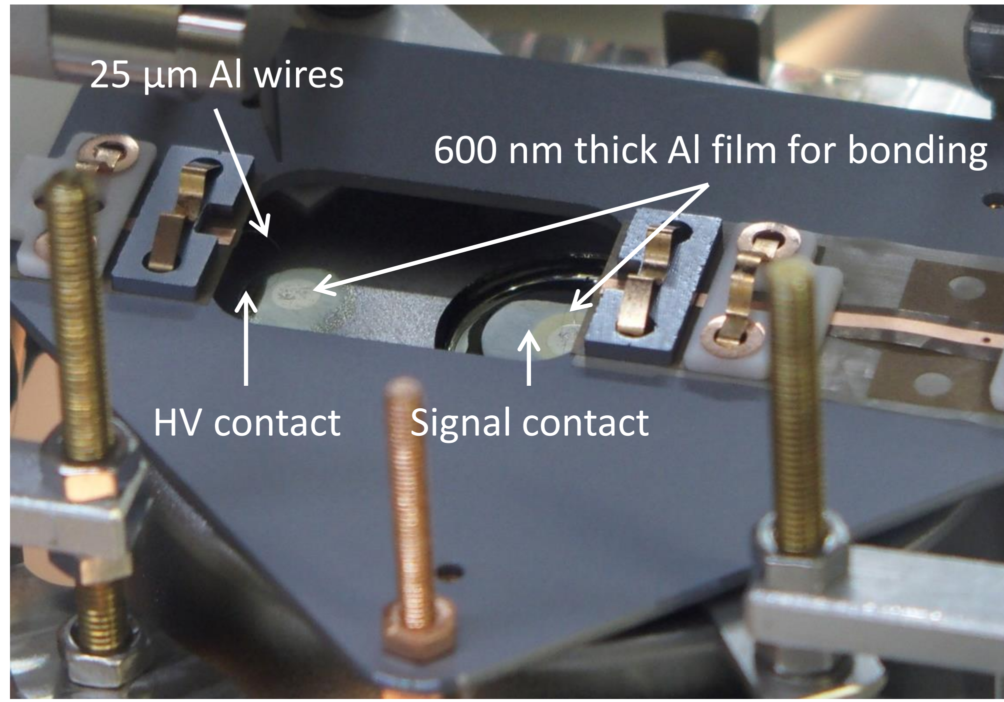






Phase II
New holders for new detectors

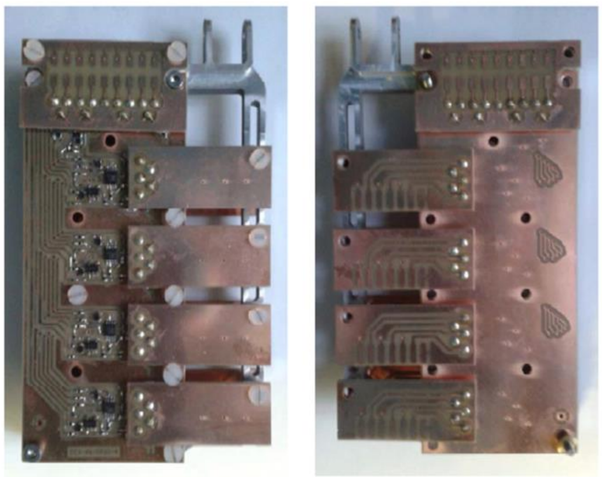


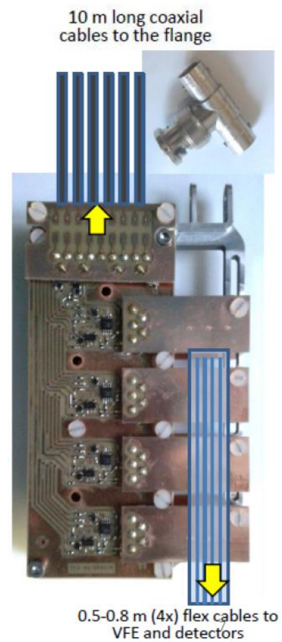


Phase II vs Phase I holder:
- Cu replaced by Si
- bonding instead of spring contacts

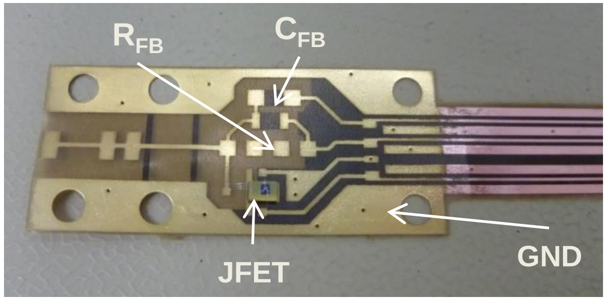
Phase II
new front end readout (CC3)

GERDA CC3 preamplifier





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



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

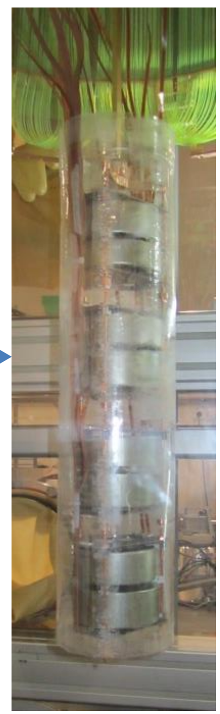
- Used at the beginning of Phase II commissioning:
  - High mortality of JFETs found

-> 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

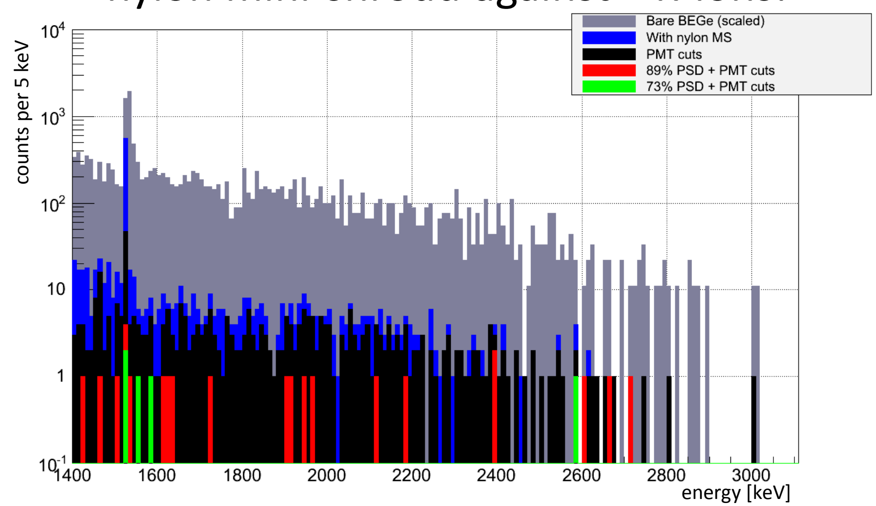
Phase II
detector array

- 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

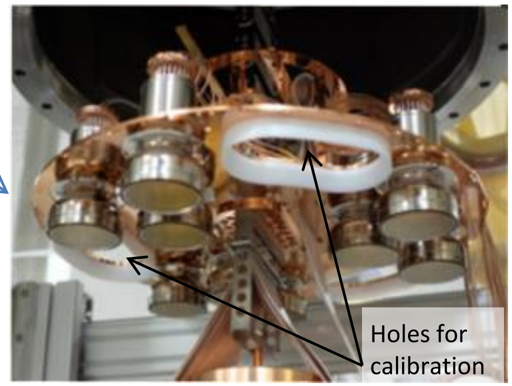
✓ Each string enclosed by transparent nylon mini-shroud against ^{42}K-ions:



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

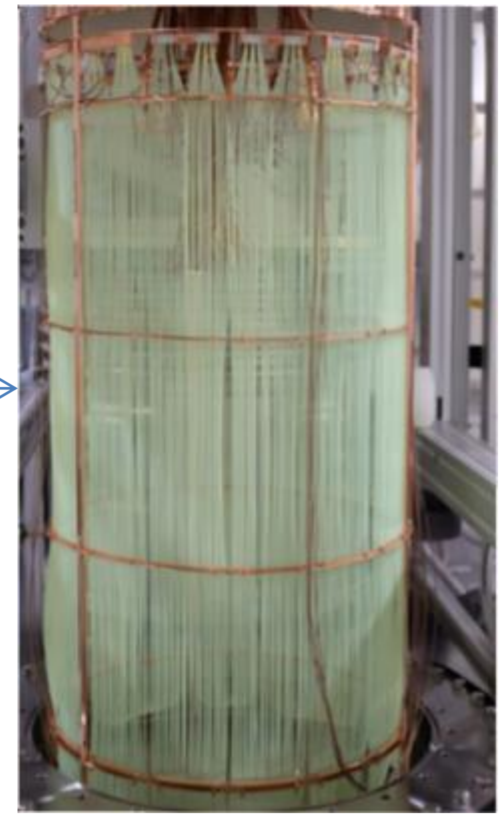
Phase II
LAr instrumentation

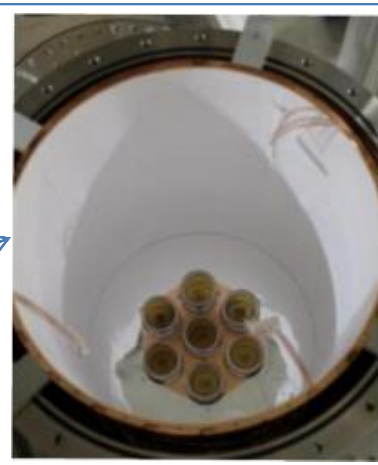
3” PMTs



Holes for calibration sources

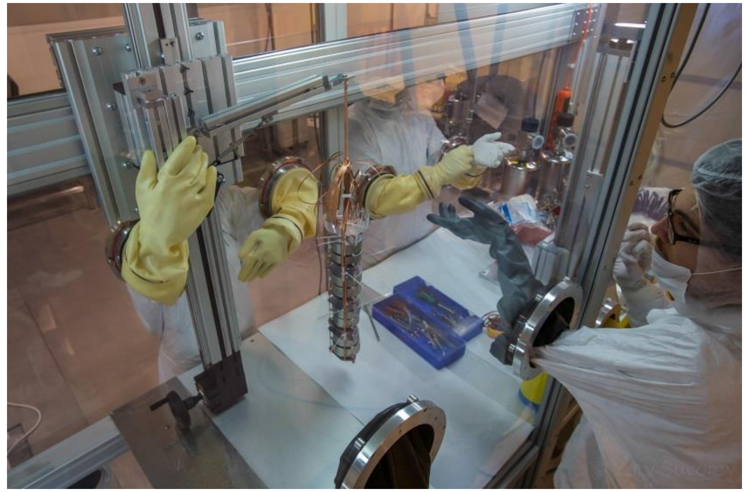
Fibers (coated with WLS) coupled to SiPMs



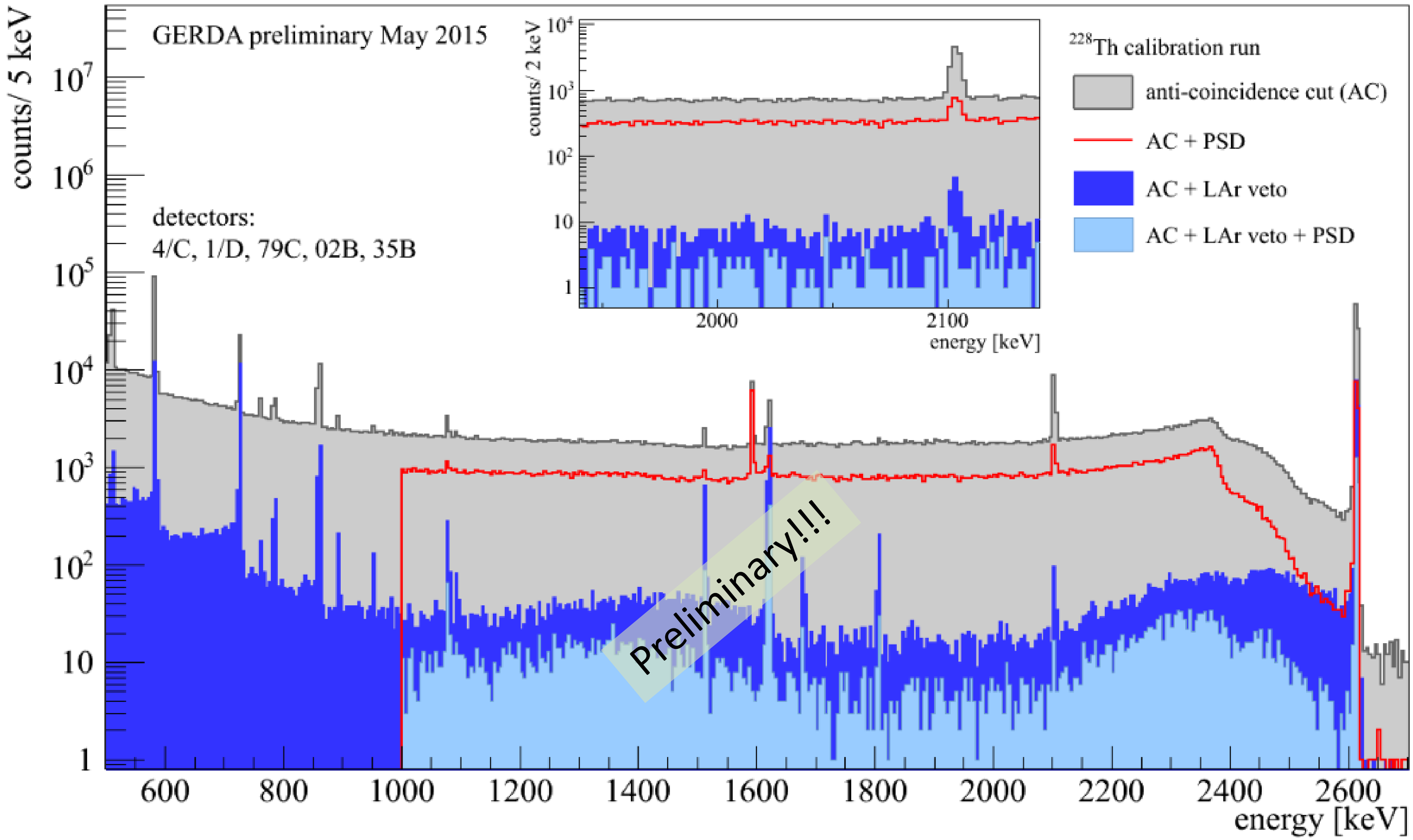


Cu cylinders with WLS foil

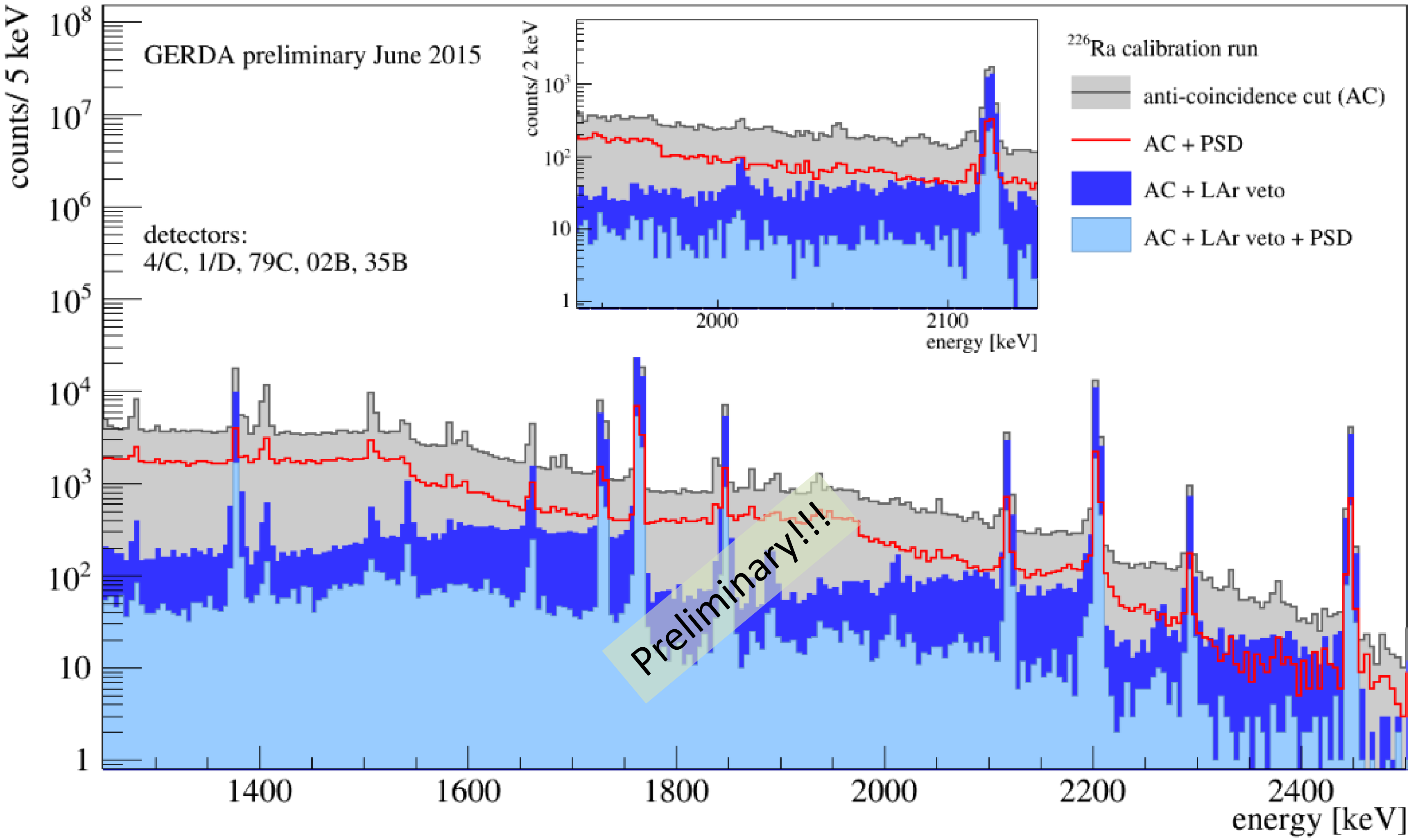
Phase II
commissioning 1st step (pilot string)



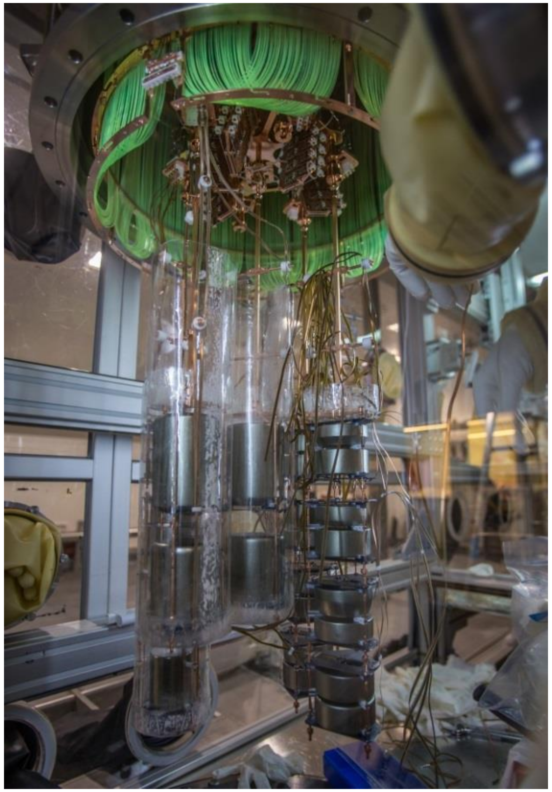
Phase II
commissioning 1st step (pilot string) – ^{228}Th

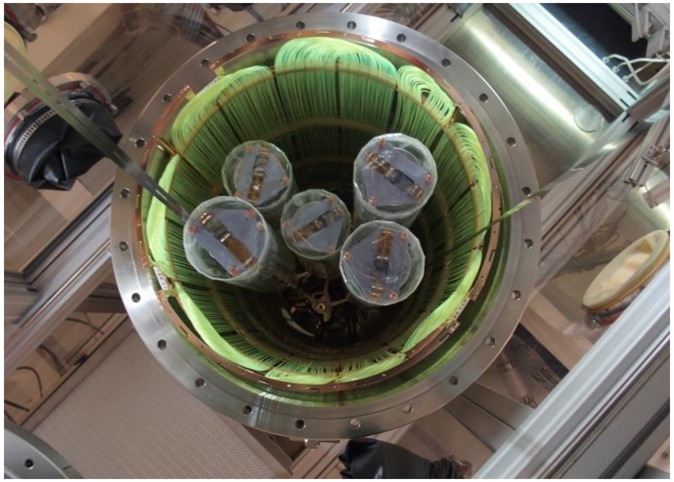


Phase II
commissioning 1st step (pilot string) – ^{226}Ra



Phase II
commissioning 2nd step (5 string assembly)





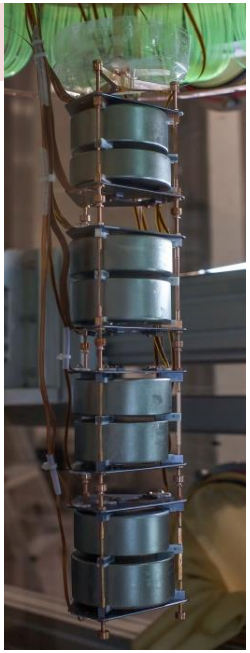

Phase II
lessons from commissioning – dark current

Problems:
- 18 out of 27 diodes were working
- most of problematic BEGe detectors were top detectors in pairs (groove faced up)

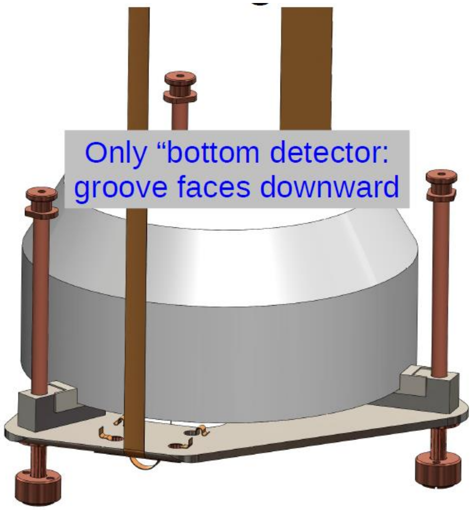
Solution:

✓ new single BEGe holder (bottom faced groove)

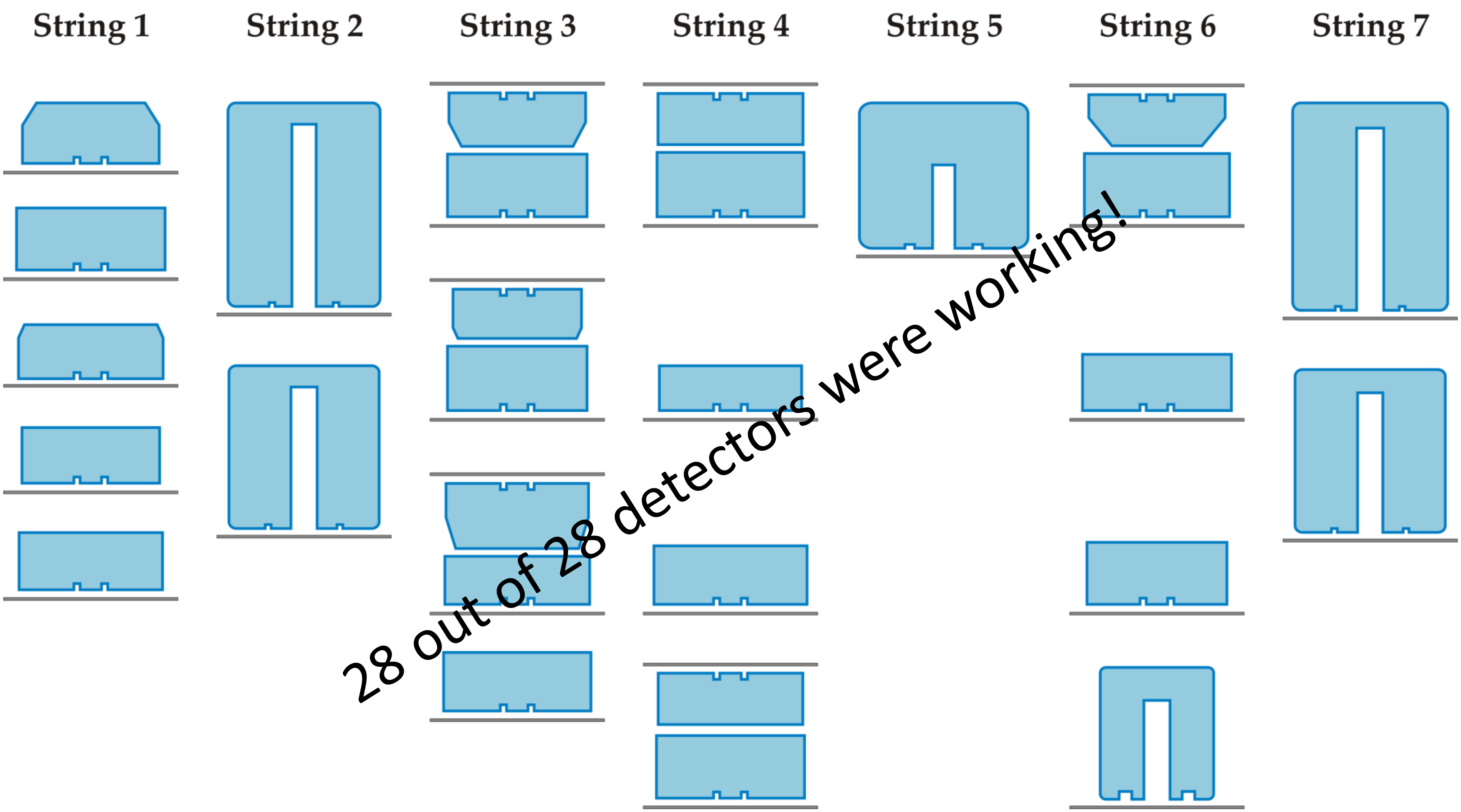
Paired BEGes ('old' holder):



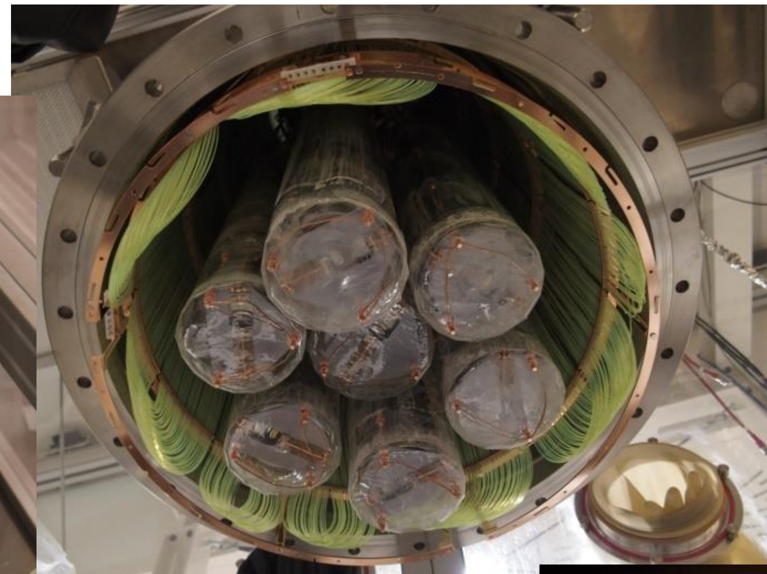
Single BEGe (new holder):

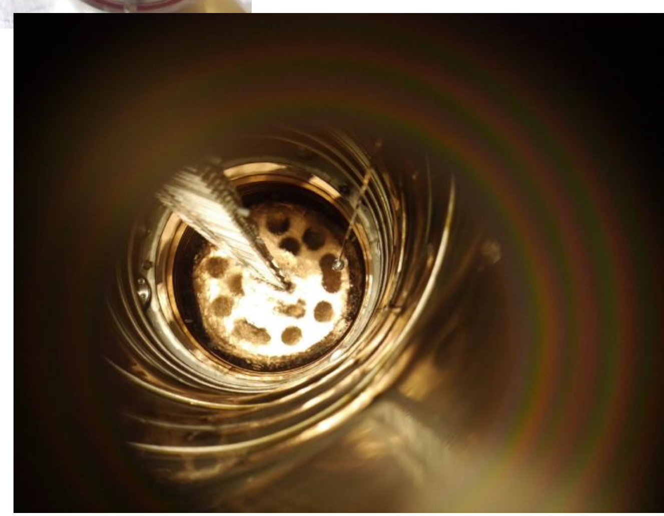


Phase II
commissioning 3rd step (7 string assembly)

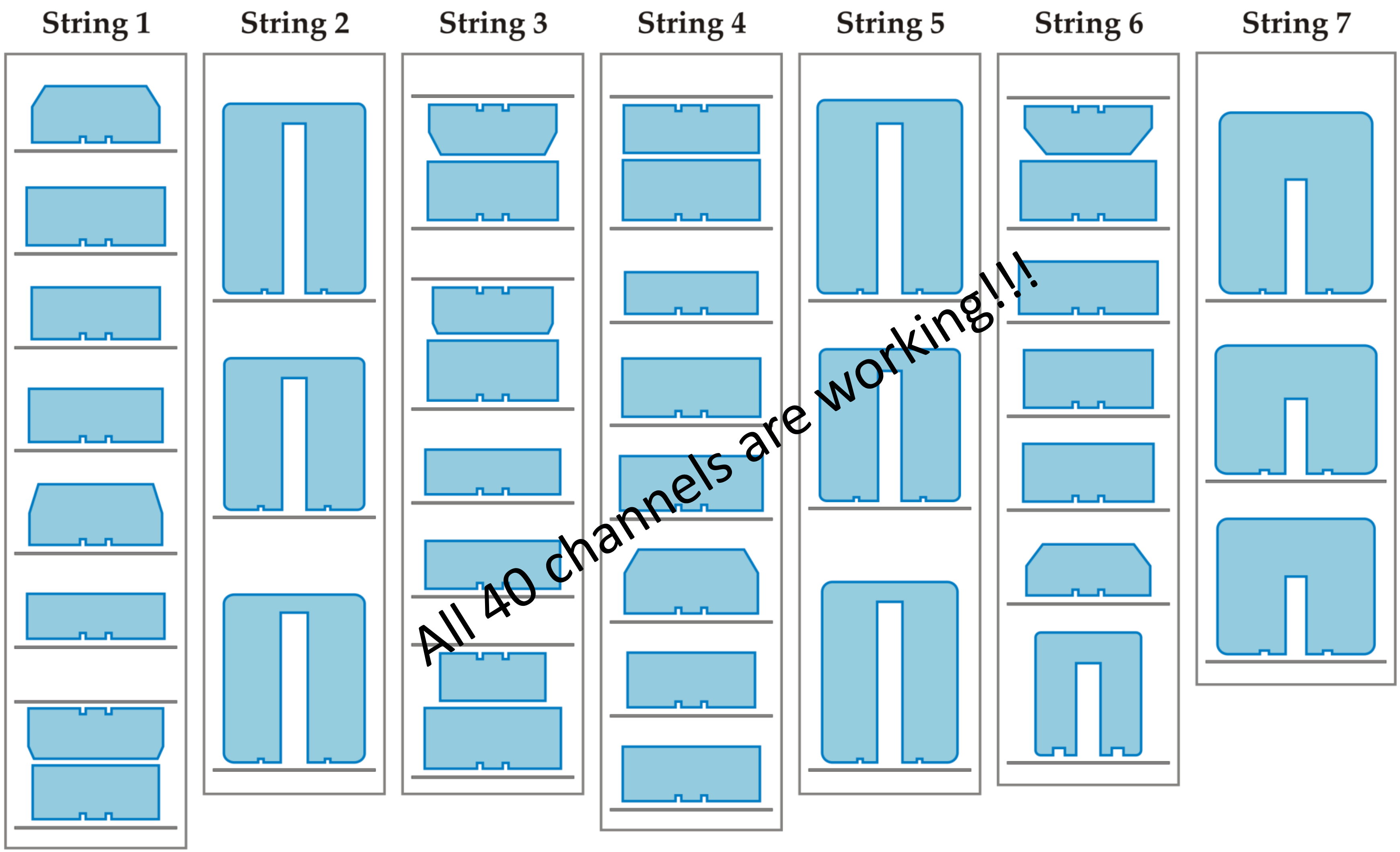


Phase II
Final Integration (December 2015)





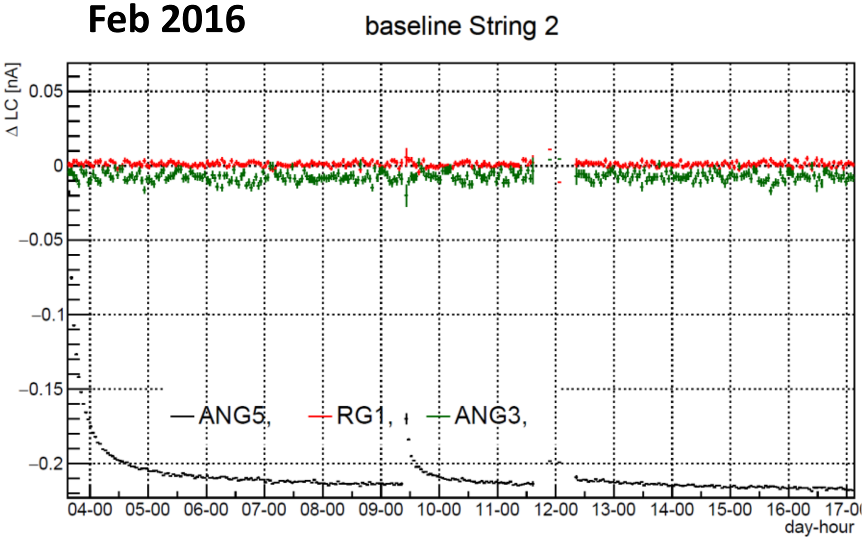
Phase II
Final Integration (December 2015)



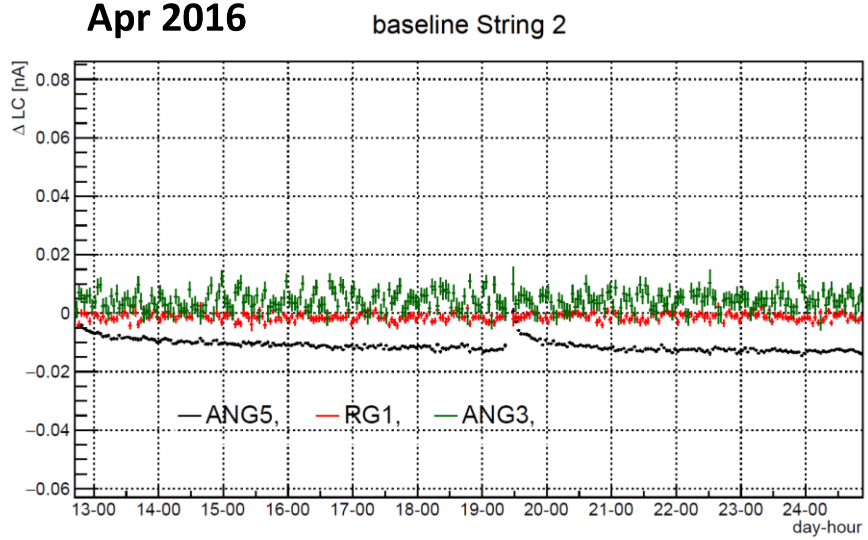
Phase II
Status of Ge detectors

- 39 out of 40 detectors are at operational voltages
  - ✓ leakage currents are low and stable
- 1 BEGe diode just at the depletion voltage – has bad FWHM, but still usable
- new Phase II effect – small increase of leakage current during calibrations
  - exists for several detectors
  - ✓ seems to become smaller vs time

Feb 2016



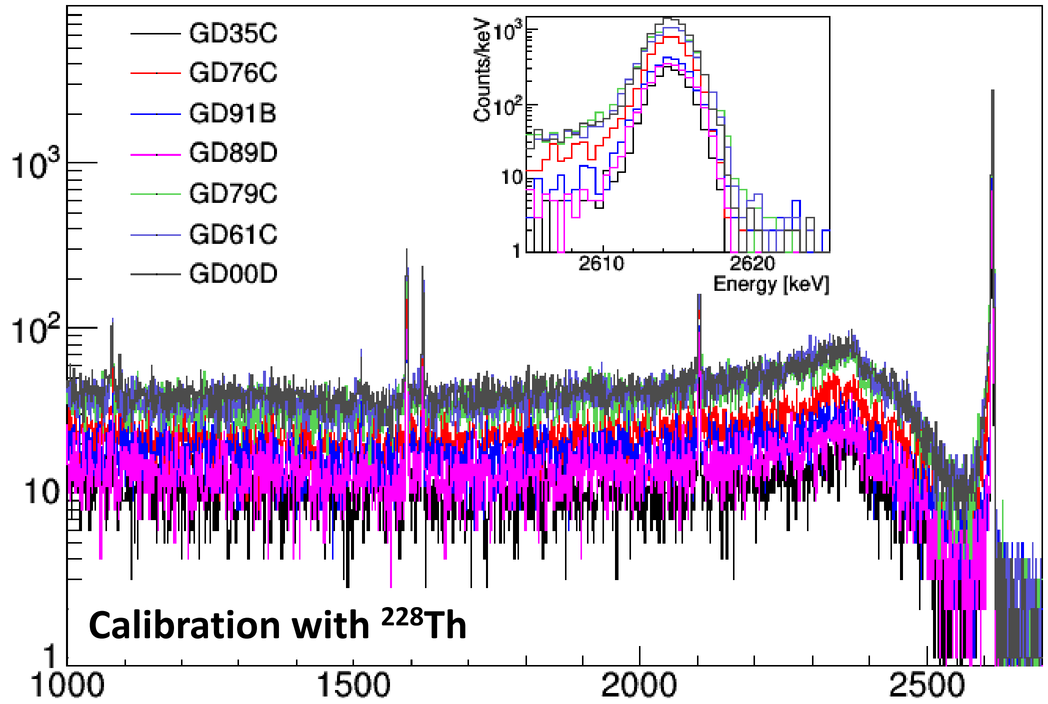
Apr 2016



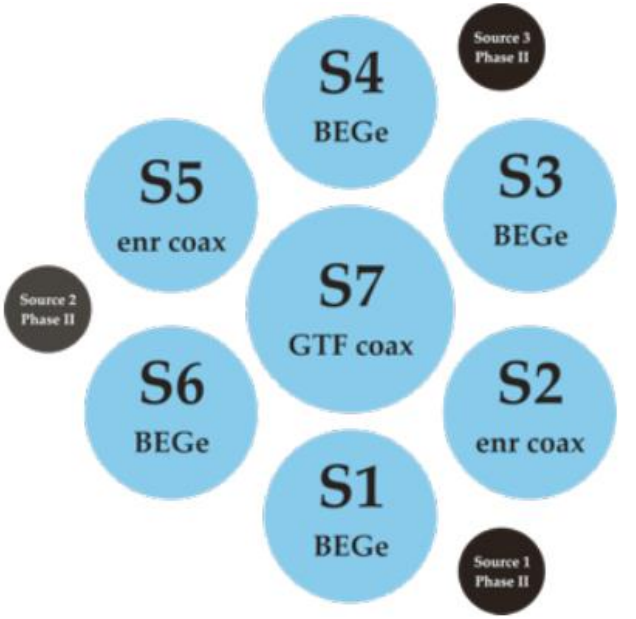
Phase II
Start data taking

Data taking started in December 2015

- blinding applied on raw data: ±25 keV around $Q_{\beta\beta}$ (2039 keV)
- weekly calibration with ^{228}Th sources
- first data release expected for summer conferences

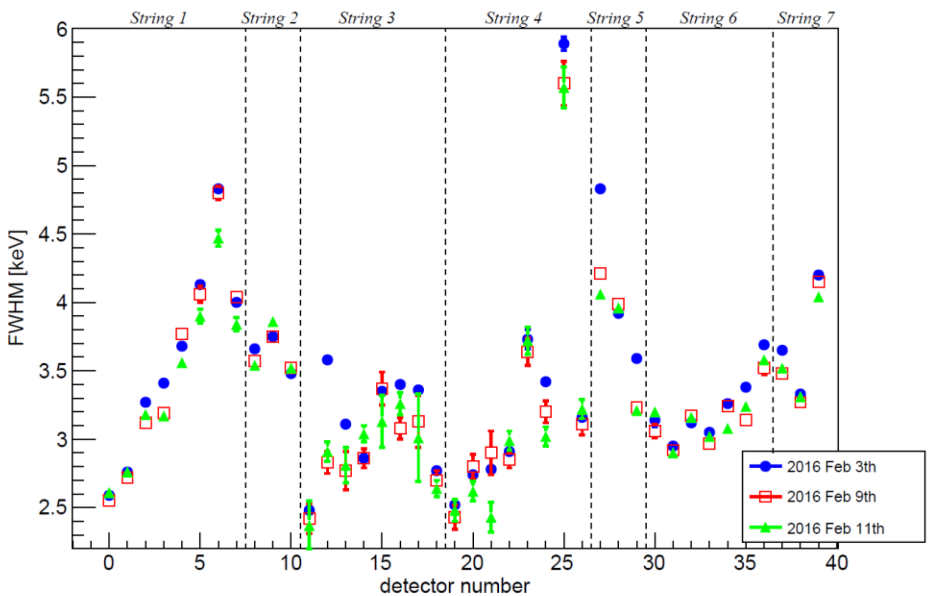


Top view of GERDA setup

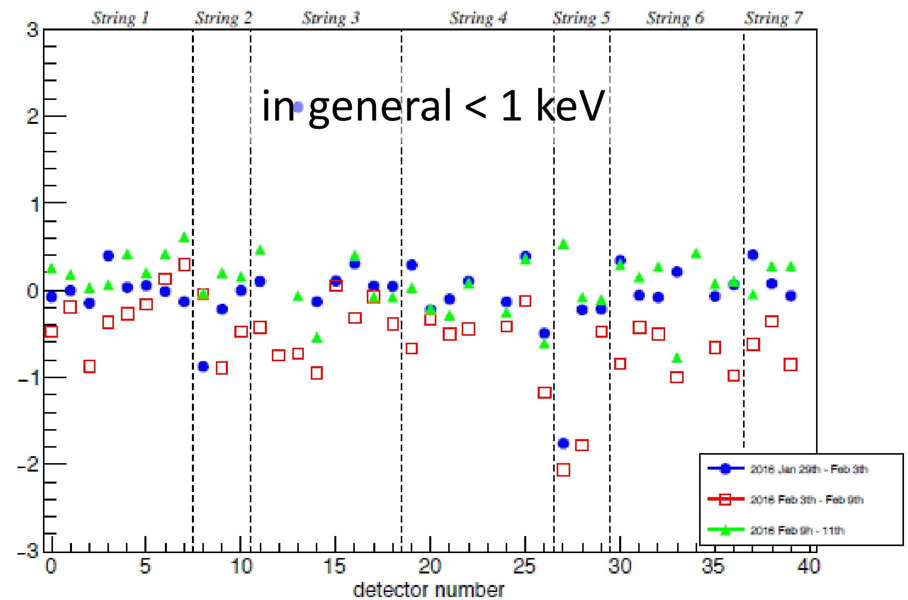


Phase II
Start data taking

FWHM of 2.6 MeV peak



Shift of 2.6 MeV peak between calibrations



FWHM of coaxial detectors: in the range 3.2 – 4.1 keV

✓ better resolution compared to Phase I (avg. ~4.3 keV)

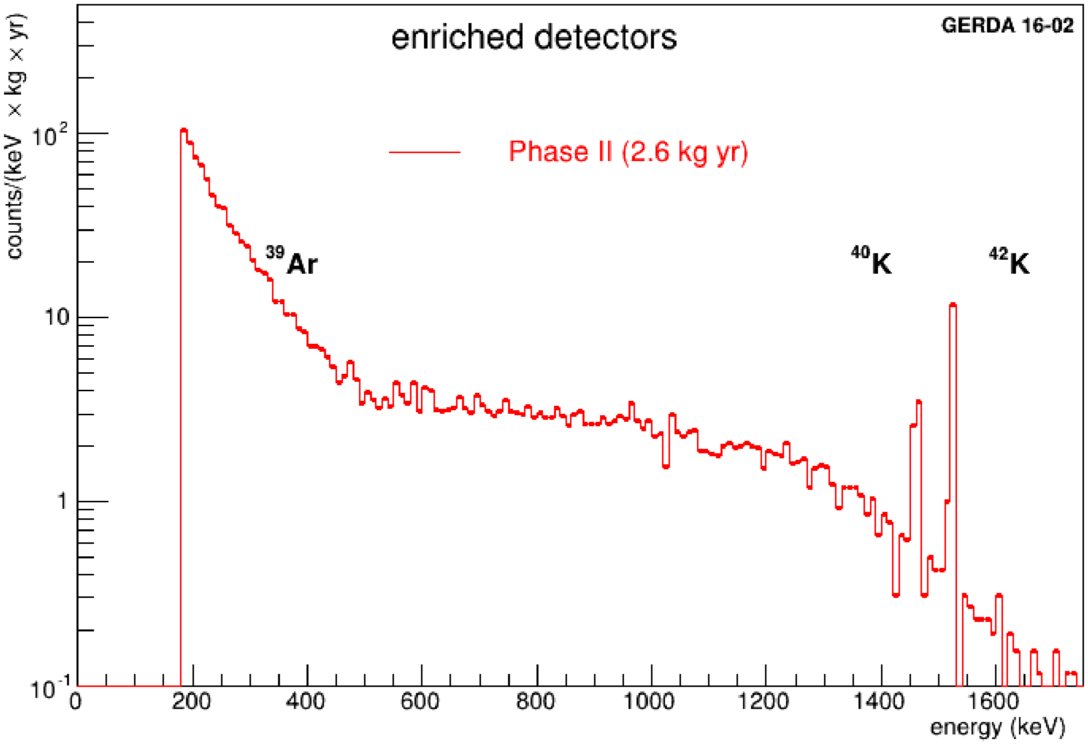
FWHM of BEGes: in the range 2.4 – 4.0 keV

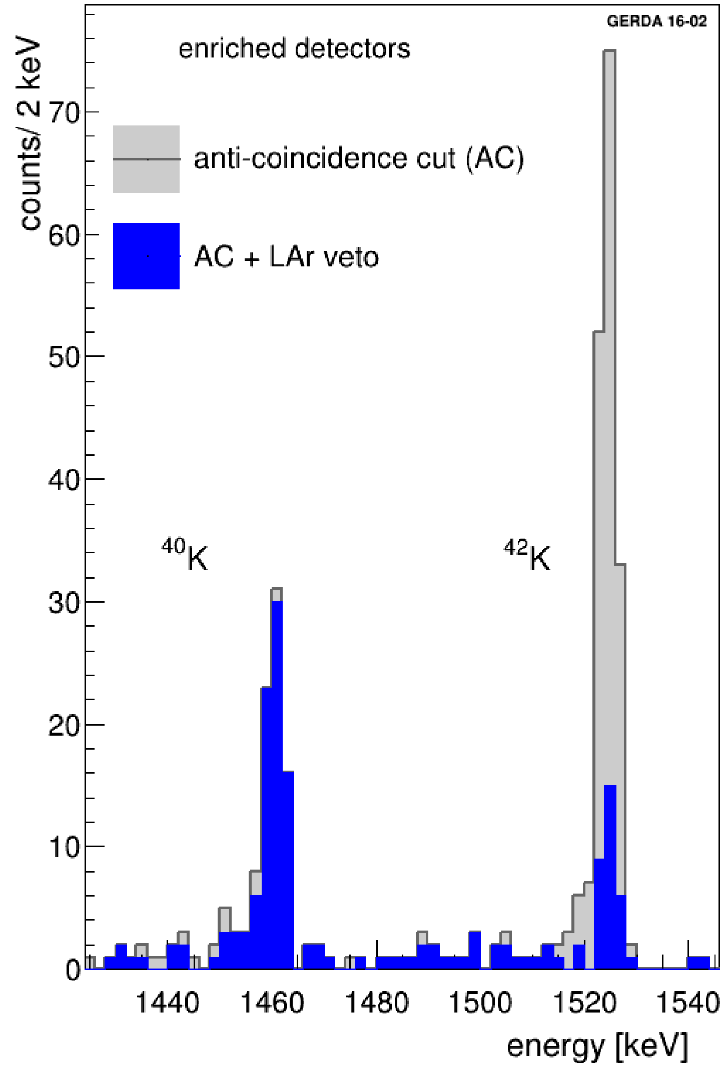
- resolution is worse than in Phase I (~ 2.8 keV)

? due to excess of series white noise: under investigation

Phase II
First look at the data

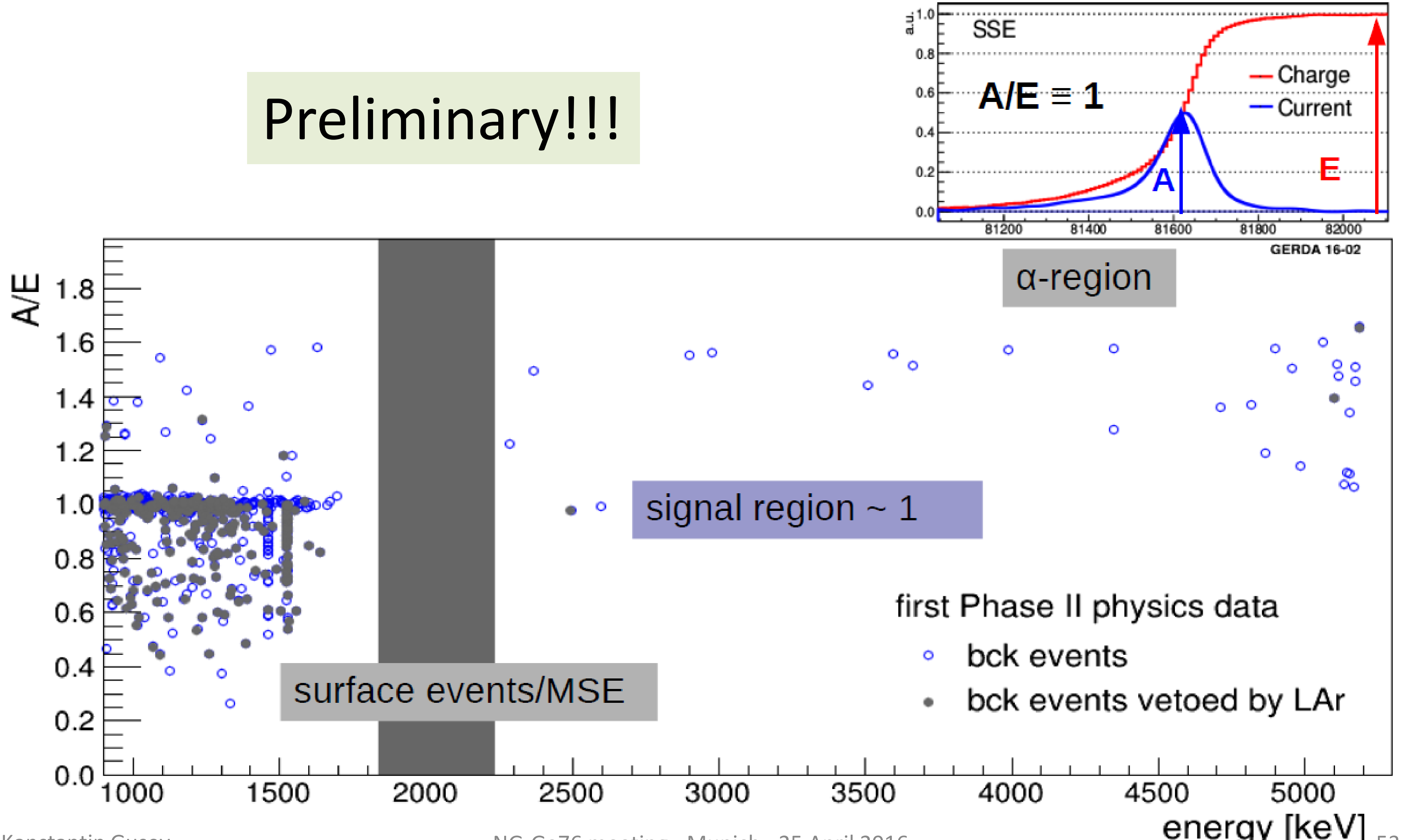
Preliminary!!!





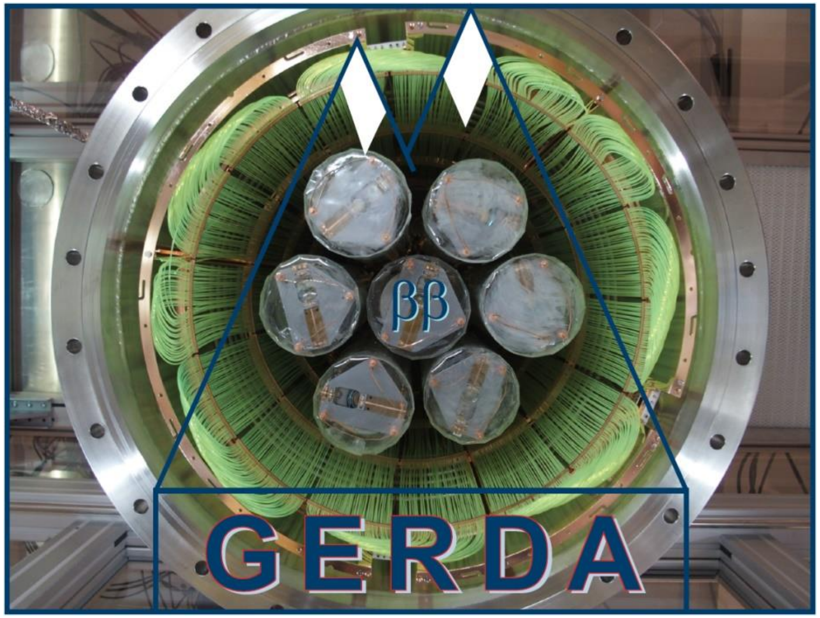
Phase II
PSD for BEGe detectors

Preliminary!!!



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
- Phase II data taking started in **December 2015**!



✓ 7 strings of HPGe detectors deployed:
  - 37 detectors enriched in ^{76}Ge (**35.8 kg**)
  - 3 natural detectors (7.6 kg)

✓ All 40 detectors and LAr veto work well

✓ First data release expected this summer

Goal:

- Reach background index of 10^{-3} counts / (keV kg yr) and explore

$$T_{1/2}^{0\nu} \geq 10^{26} yr$$