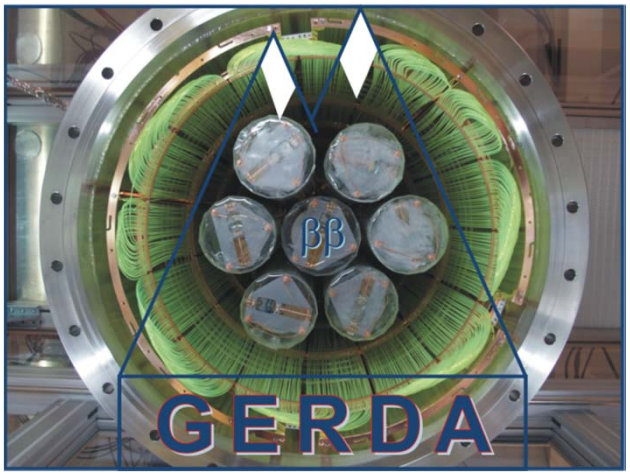
SEARCHING FOR THE NEUTRINOLESS DOUBLE BETA DECAY WITH GERDA



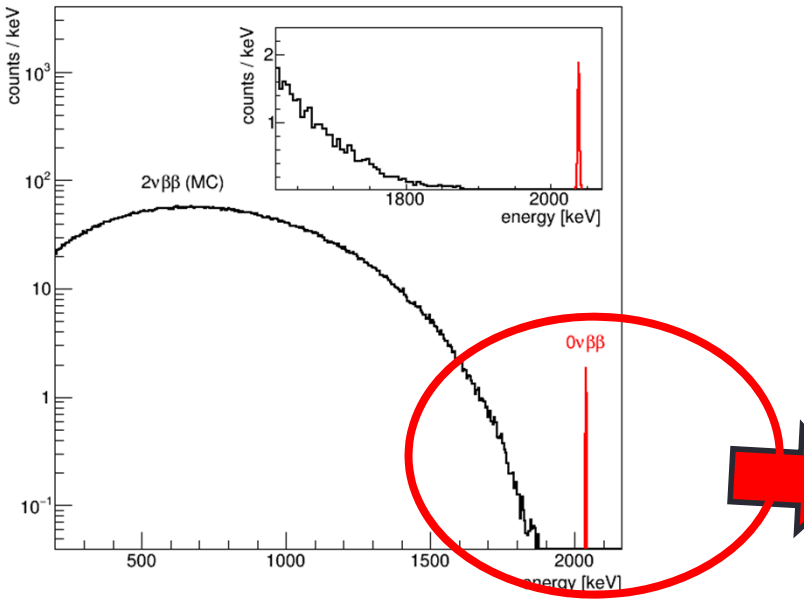
Luciano Pandola

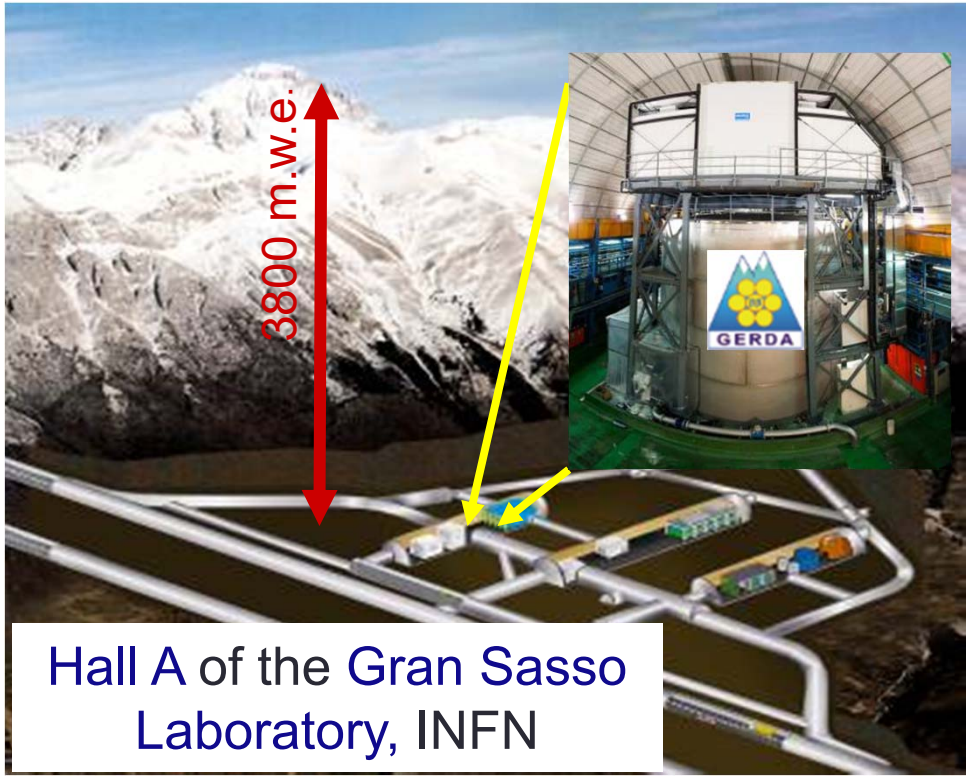
INFN – Laboratori Nazionali del Sud, Catania

on behalf of the GERDA Collaboration

Looking for ^{76}Ge decay with GERDA

GERmanium Detector Array (INFN-LNGS, Italy) searches for 0ν2β decay in ^{76}Ge using HPGe detectors enriched in ^{76}Ge

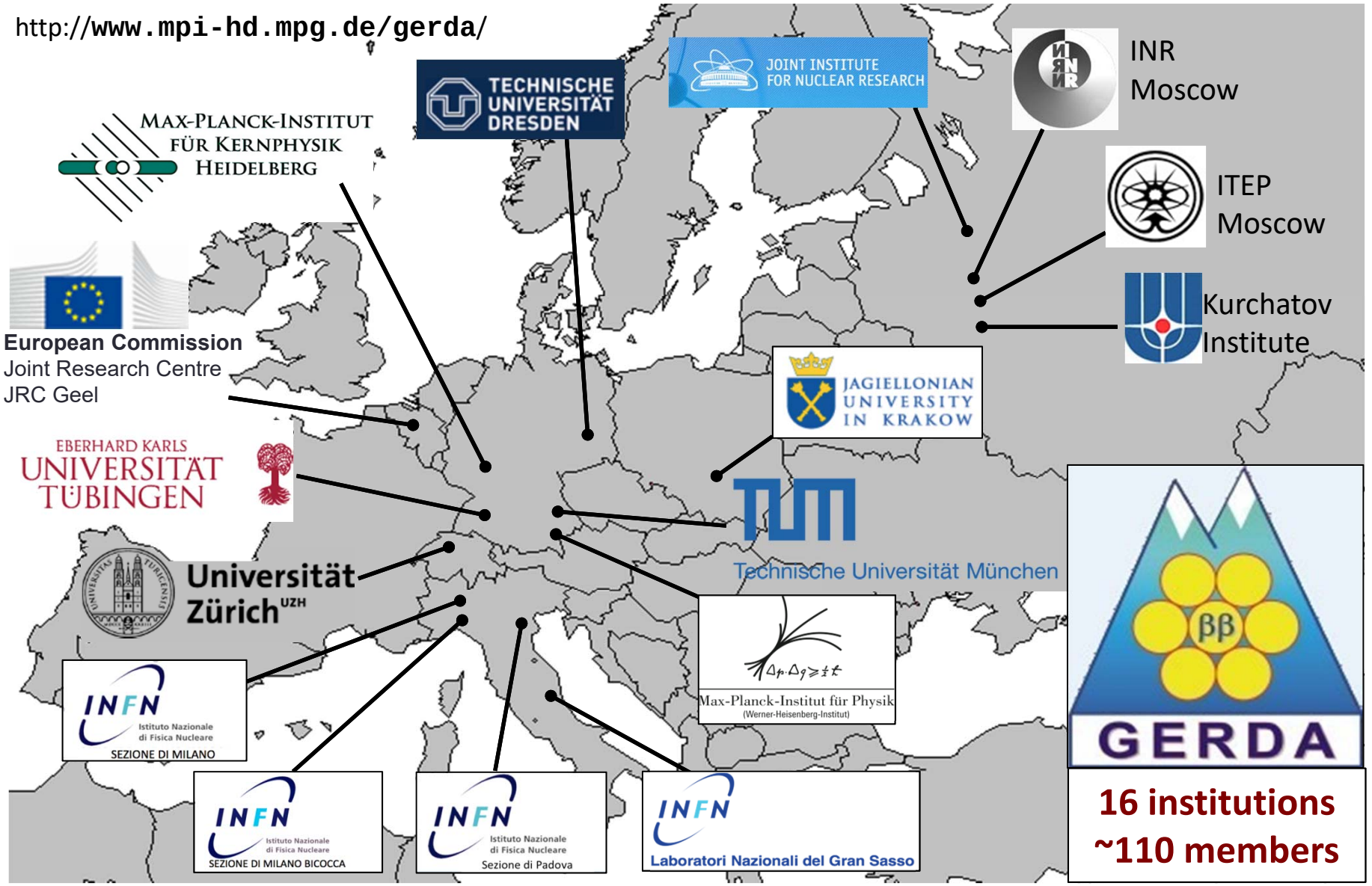




Hall A of the Gran Sasso Laboratory, INFN

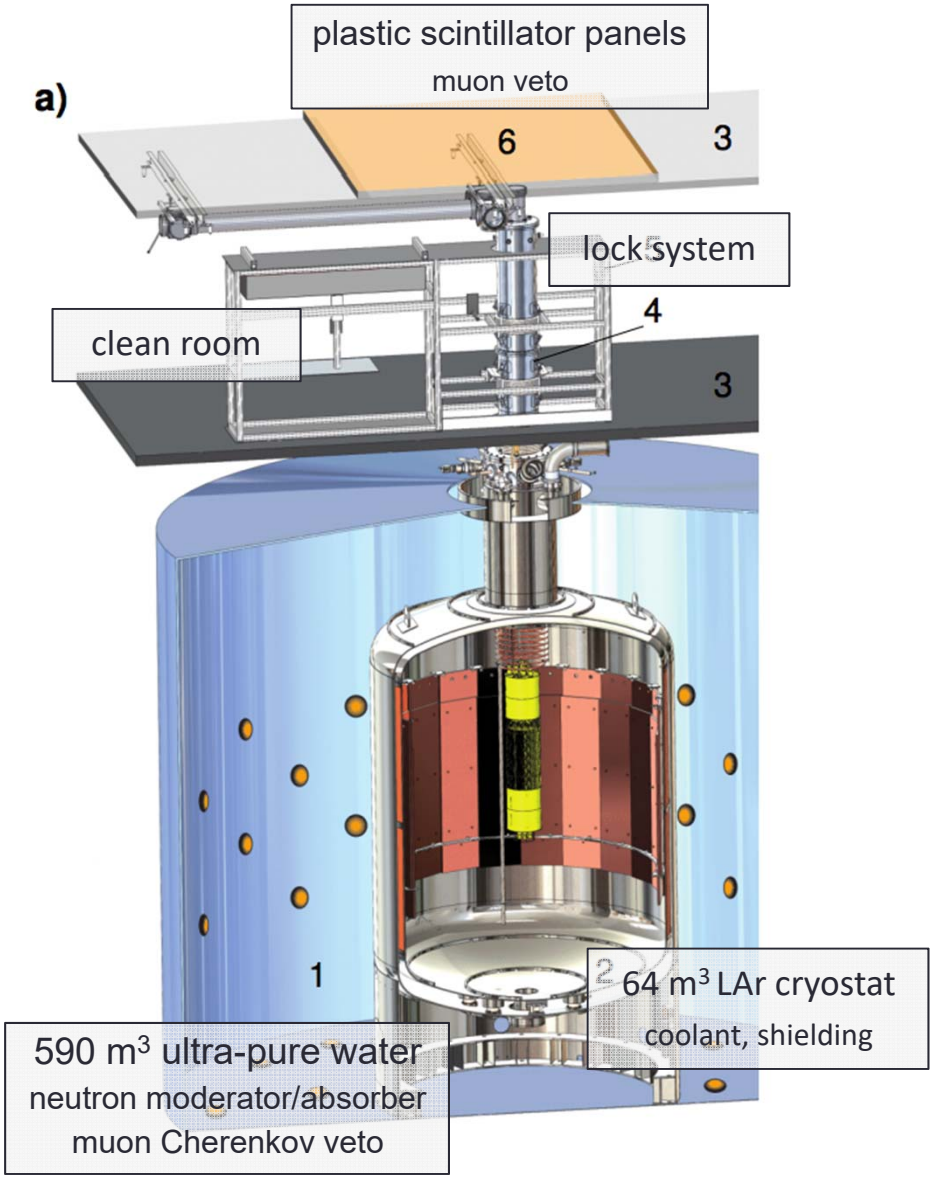
$Q_{\beta\beta}$-value = **2039 keV** in ^{76}Ge
Energy resolution <4 keV FWHM
→ important for discovery

GERDA: the Collaboration

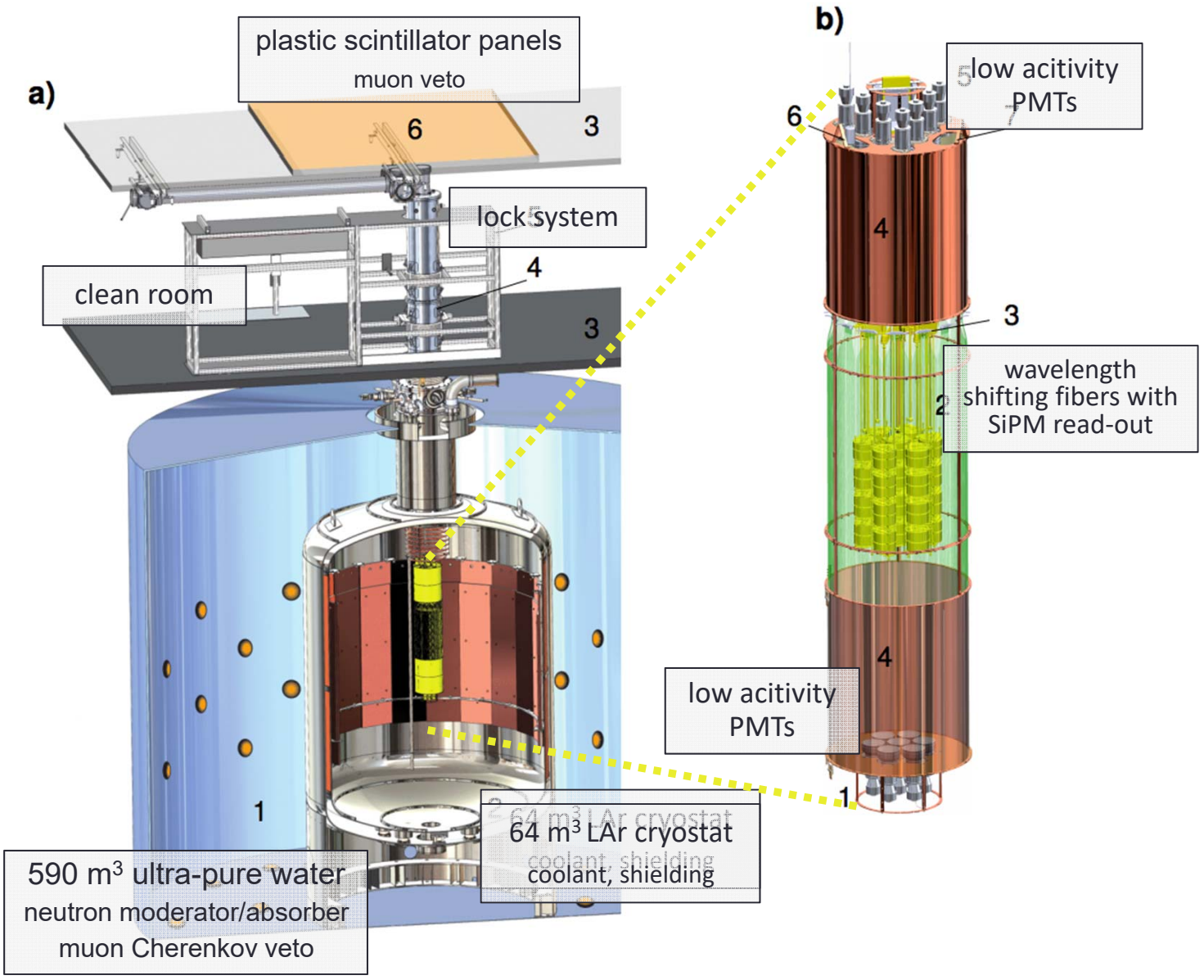


GERDA: the concept

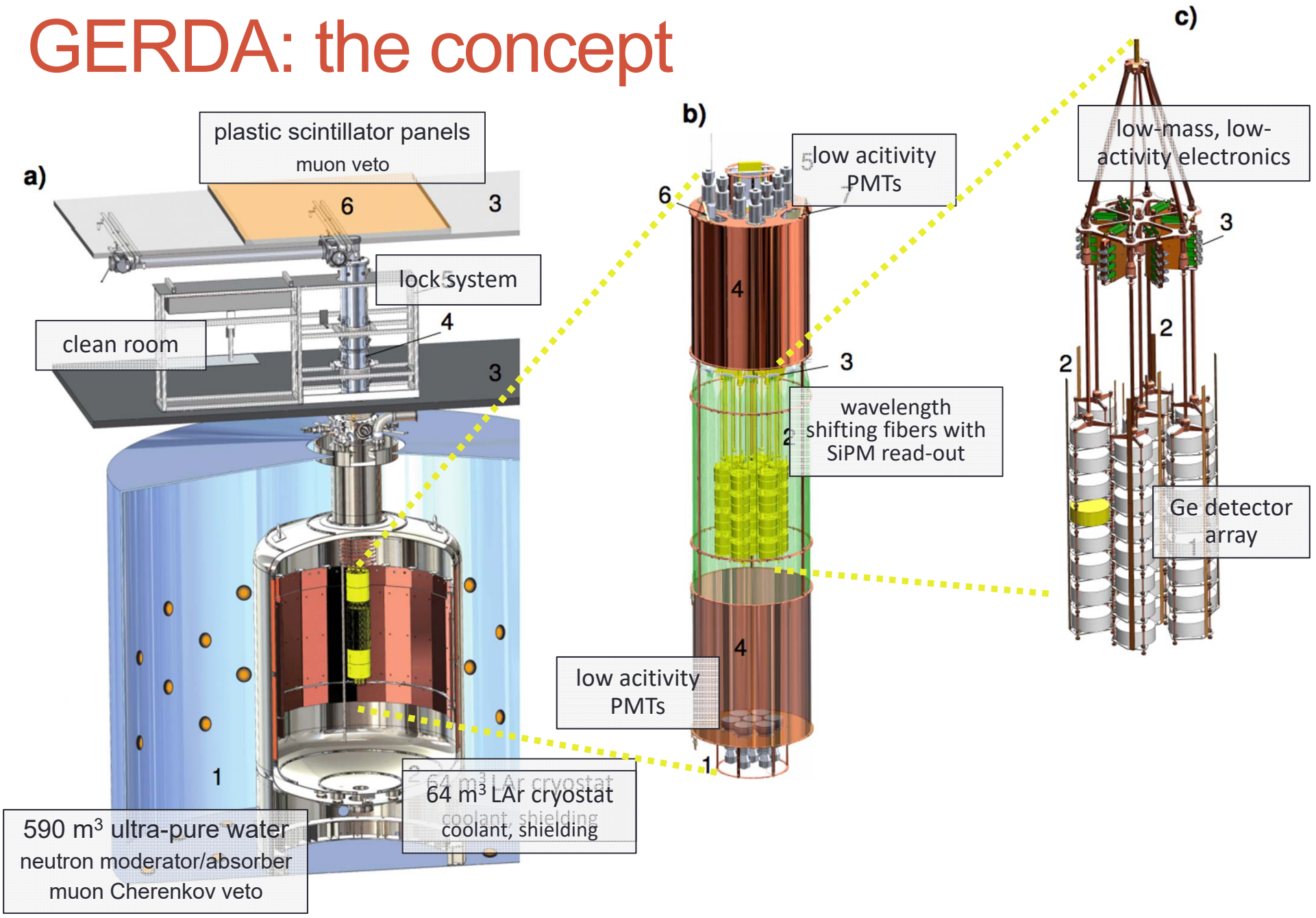
Eur. Phys. J. C 73 (2013) 2330
Nature 544 (2017) 47



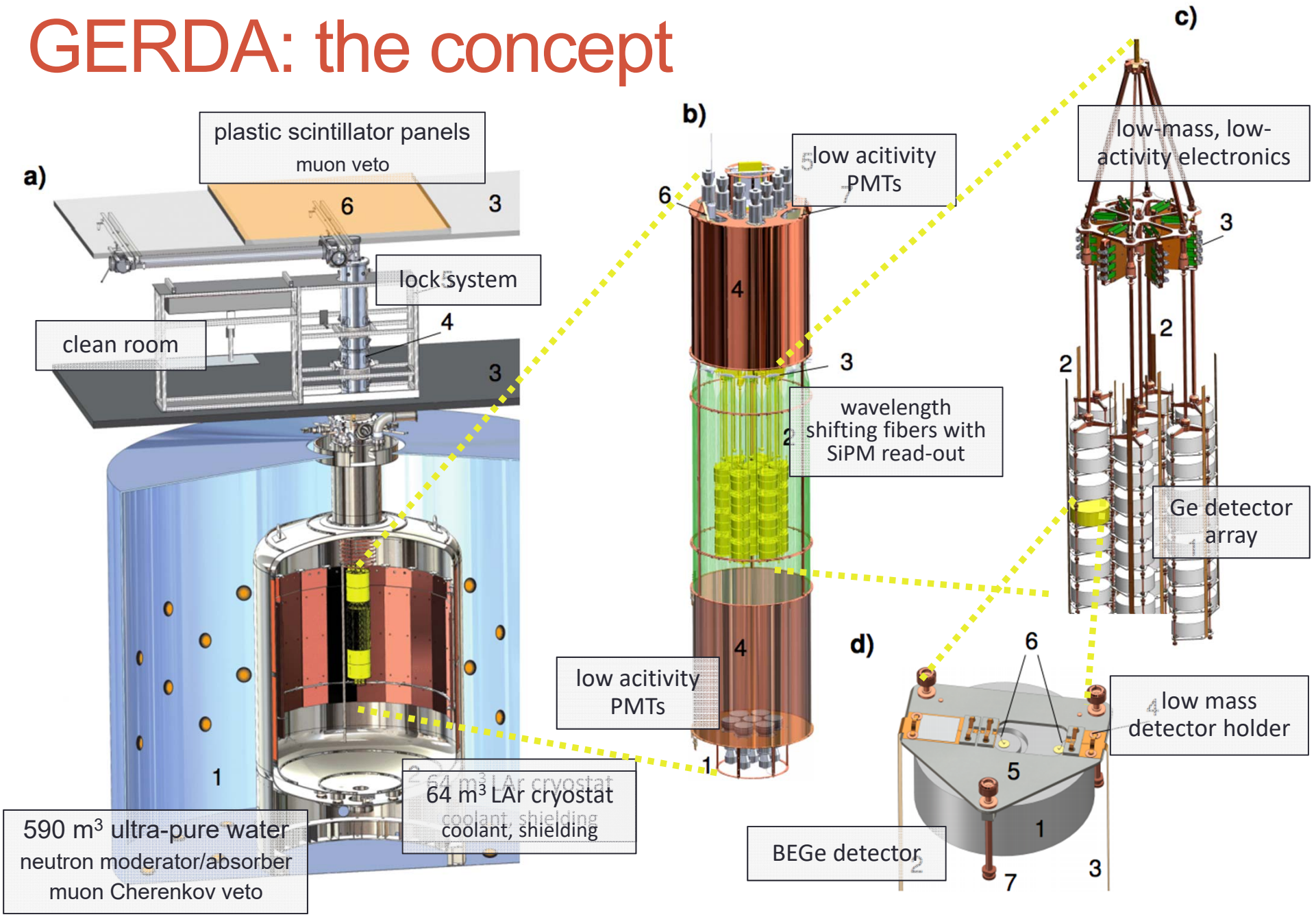
GERDA: the concept



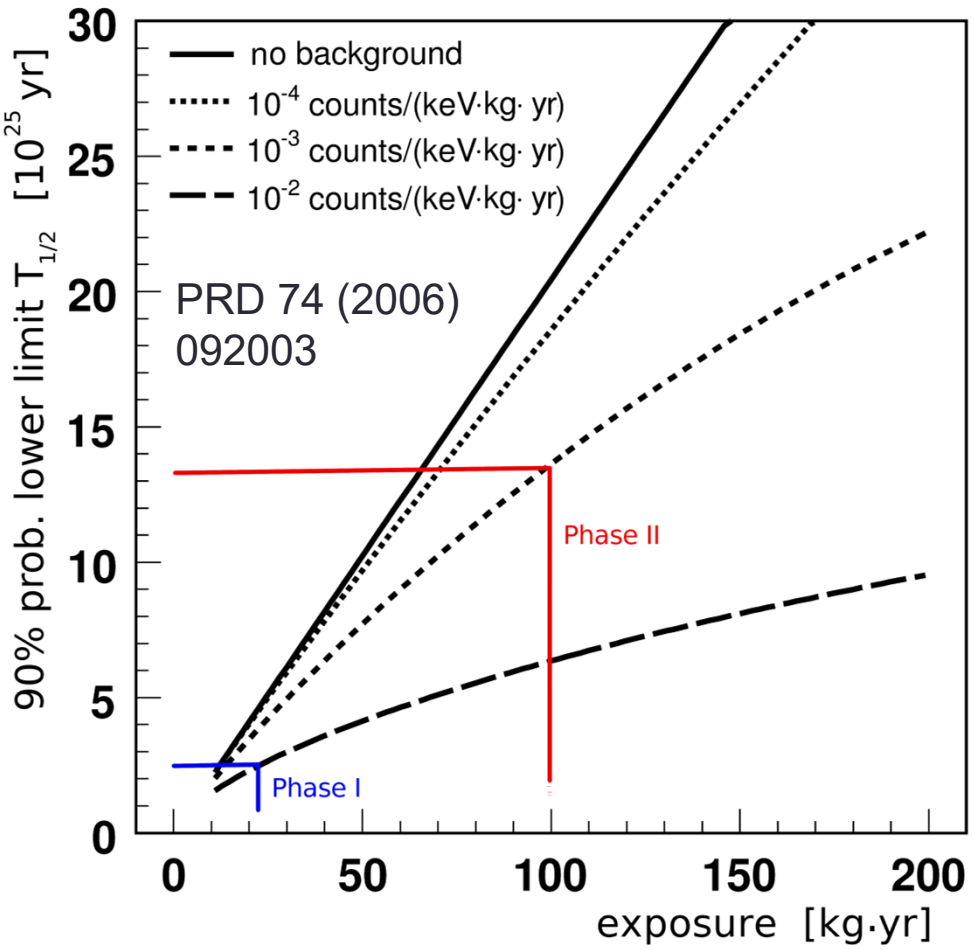
GERDA: the concept



GERDA: the concept



Strategy and phases



Phys. Rev. Lett. 111 (2013) 122503
Nature 544 (2017) 47

Phase I (Nov 2011- May 2013):
Completed
Use refurbished HdM and IGEX (18 kg) (+ new **BEGe** Phase II detectors)
B ≈ 0.01 cts / (keV kg yr)
No LAr readout (passive shield)
Accumulated 21 kg yr

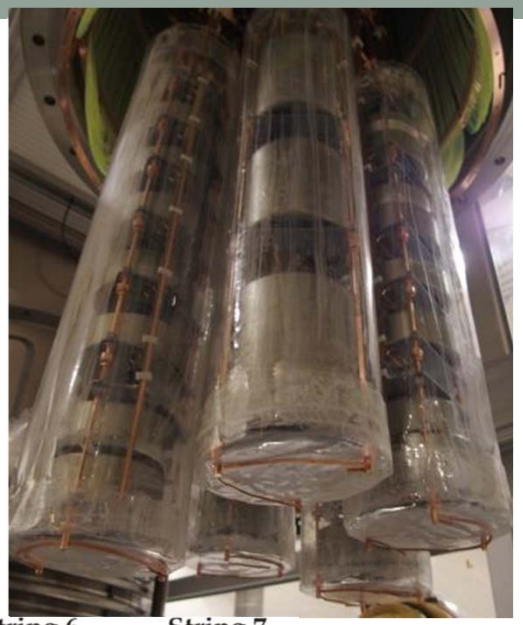
Phase II (Dec 2015- **ongoing**):
Add new ^{enr}BEGe detectors (20 kg)
BI ≈ 0.001 cts / (keV kg yr)
Goal: 100 kg yr
First data release on Jun 2016 (about 11 kg yr)

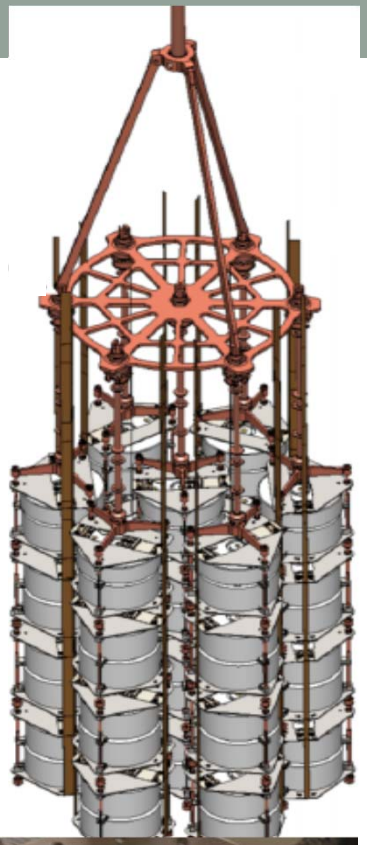
Blind analysis strategy
Events at $\mathbf{Q_{\beta\beta} \pm 25\ keV}$ in the blinding box
Open box when all cuts finalized

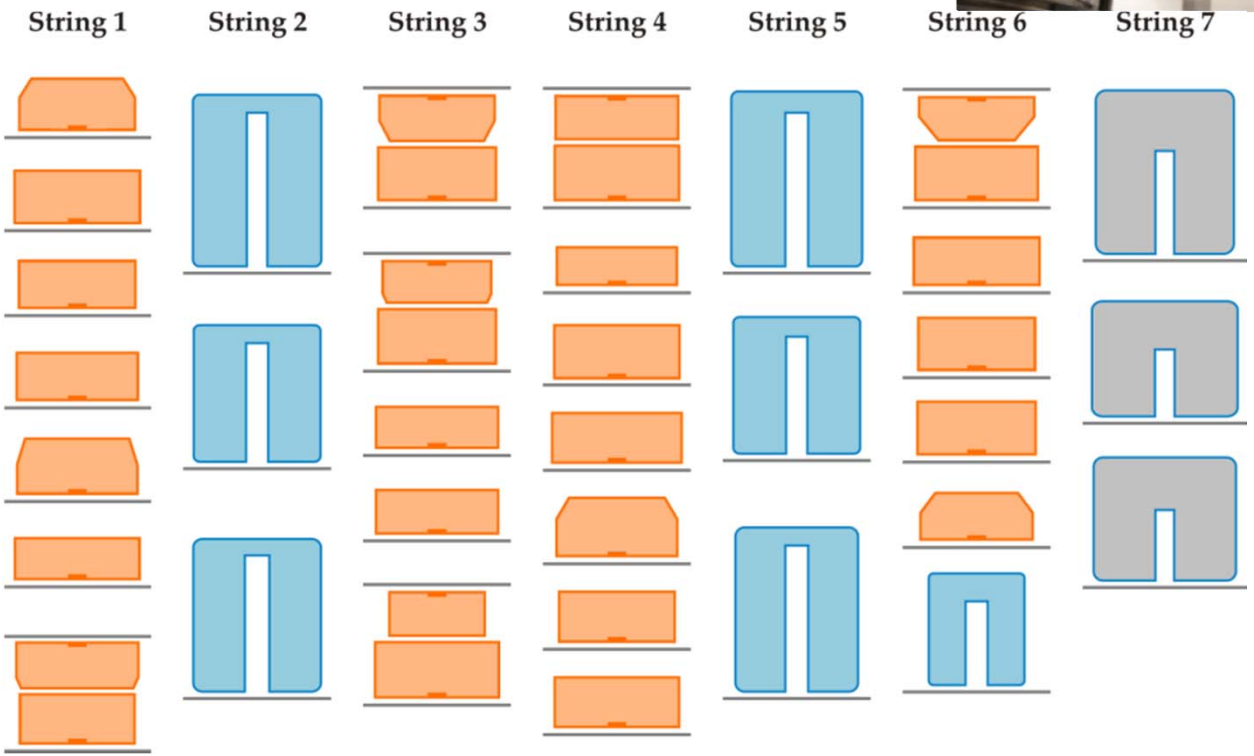
Phase II Array

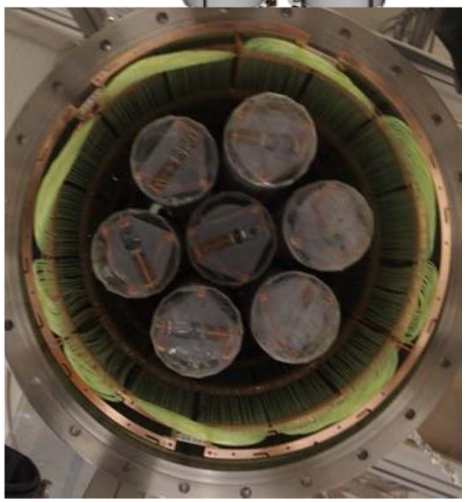
- Deployed in **December 2015**
- **40 channels**
  - 30 **enrBEGe** (20 kg)
  - 7 **enrCoax** (16 kg)
  - 3 **natCoax** (8 kg)

36 kg









Previous Phase II results

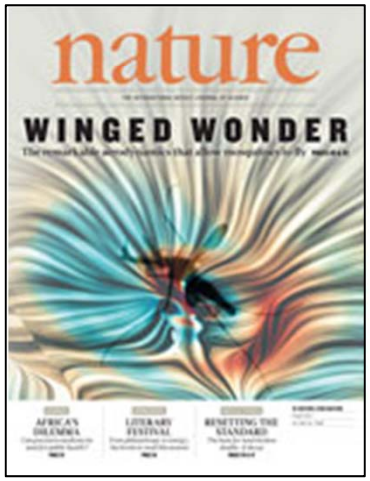
Nature 544 (2017) 47

ARTICLE

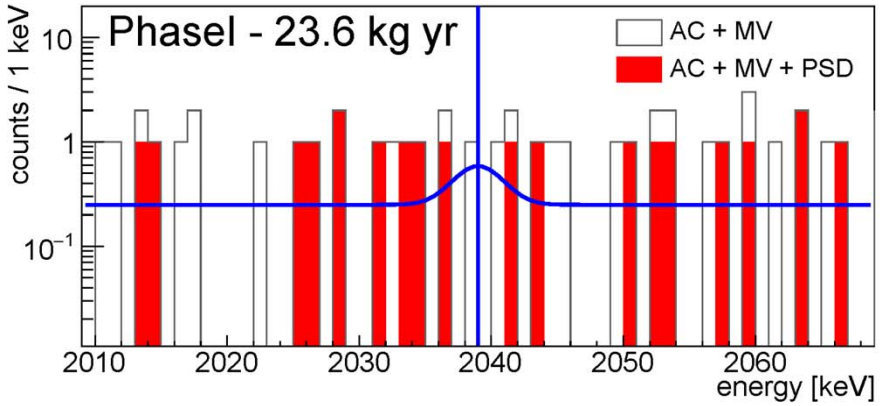
doi:10.1038/nature21717

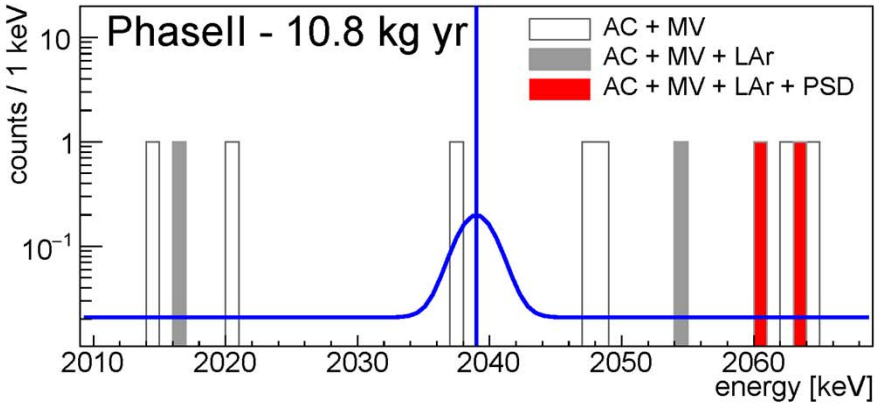
Background-free search for neutrinoless double-β decay of ^{76}Ge with GERDA

The GERDA Collaboration*



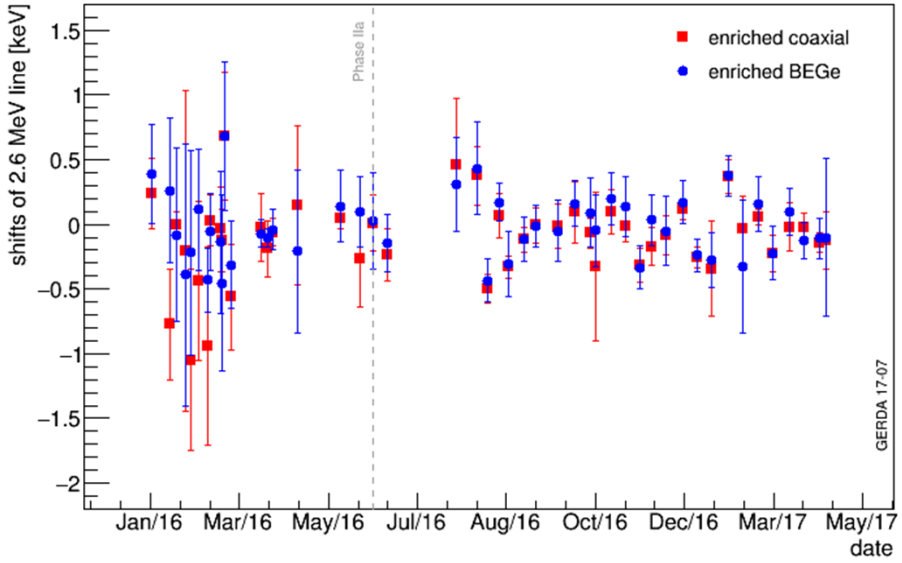
- New limit on ^{76}Ge $T_{1/2}$ (Phase I+II)
  - **$T_{1/2} > 5.3 \cdot 10^{25}$ yr @ 90% CL** (median sensitivity $4.0 \cdot 10^{25}$ yr)
- **Background < 1 cts** for the full **design exposure**
  - Coax: **$3.5^{+2.1}_{-1.5} \cdot 10^{-3}$** cts/(keV·kg·yr), FWHM: 4.0(2) keV
  - BEGe: **$7^{+11}_{-5} \cdot 10^{-4}$** cts/(keV·kg·yr), FWHM: 3.0(2) keV
- Bck/ε = 3.5 cts/(FWHM ton yr) [BEGe]

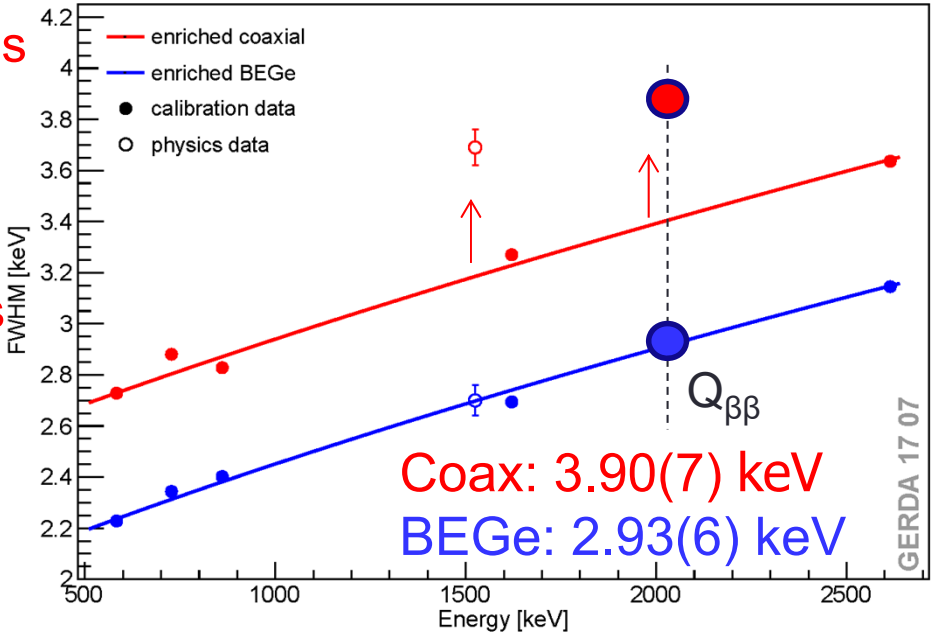




DAQ & energy resolution

- DAQ facts:
  - 14 bit, 25 MHz continuous running ADC (160 μs)
  - Leading edge of the pulse sampled at 100 MHz (10 μs)
- Energy scale
  - Offline, using optimized ZAC filter
    - Eur. Phys. J. C 75 (2015) 255
  - Weekly calibrations with ^{228}Th sources
  - Stability monitored online with Test Pulses, injected every 20 s
- Energy resolution
  - Profile derived from ^{228}Th calibrations
  - Correction (for coax) applied derived from the resolution of the ^{40}K and ^{42}K peaks in the physics data
    - Accounts for **instabilities** during the long-term data taking

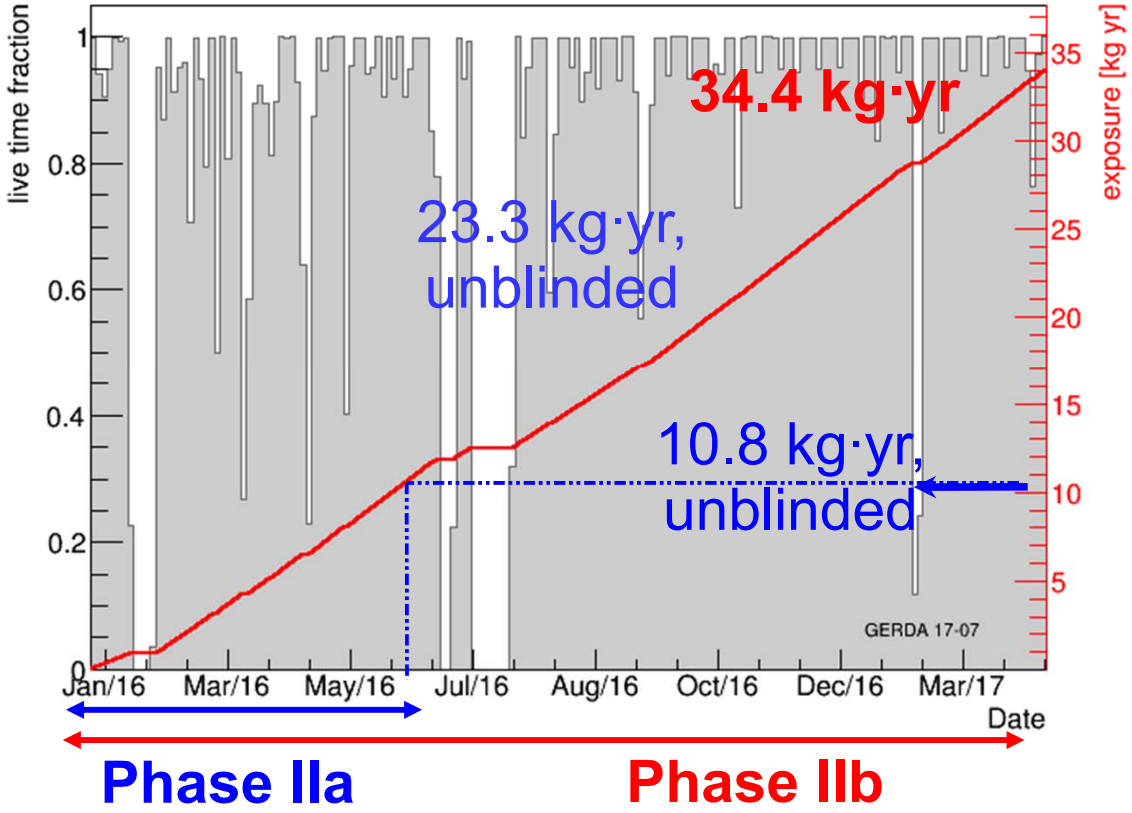




Current data taking

Nature 544 (2017) 47

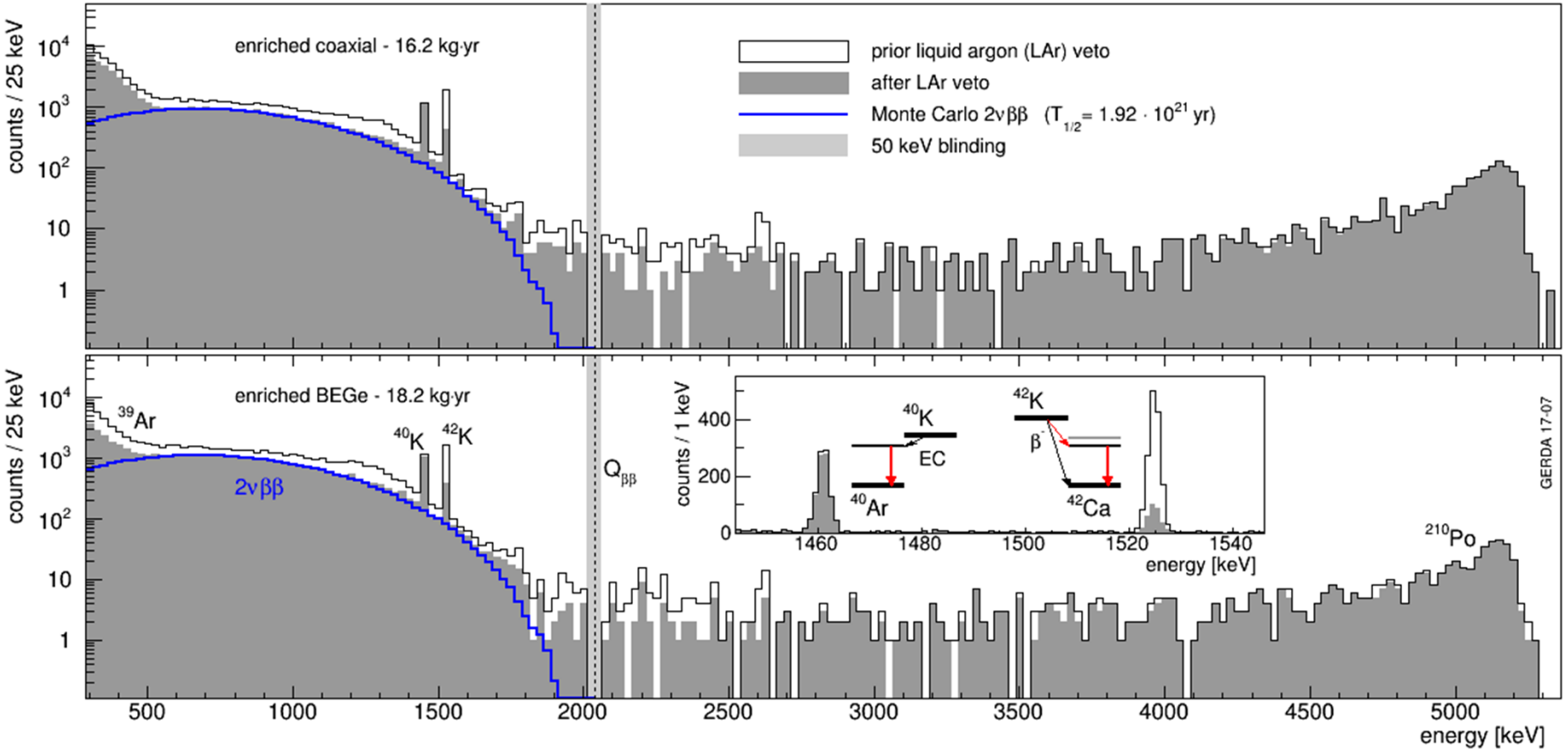
- Data taking in progress!
  - Phase II exposure increased by **x3** with respect to Nature paper (**Phasella**)
  - **Valid** exposure accumulated **34.4 kg·yr** up to Apr 15th (**Phasellb**)
    - 18.2 kg·yr of BEGe data and 16.2 kg·yr of ^{enr}Coax data
  - A few more kg·yr already in the bag (Apr-Jul)



June 2017 unblinding

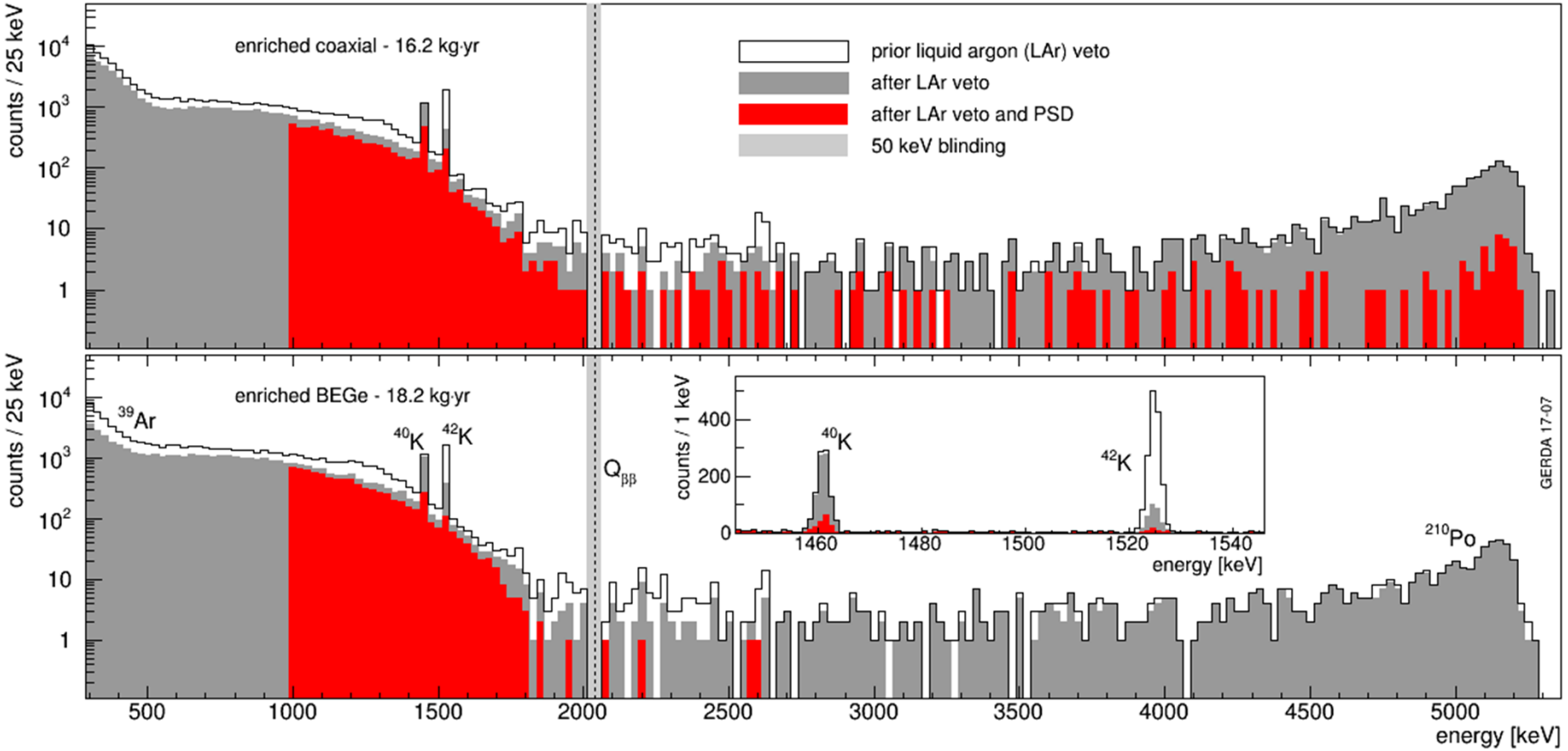
- Box opened for the BEGe dataset only (12.4 kg yr)
- New ^{enr}Coax data (11.2 kg yr) still in the box
  - **Background** comparable (slightly better) to Phase IIa
  - Confident to **improve it further** by better rejection of **α** events from the **groove**
  - Rejection *"a posteriori"* would spoil the concept of blinding
- Total unblinded exposure: **23.3 kg yr**

GERDA spectra



- Most prominent features: ^{39}Ar β (< 500 keV), 2νββ, ^{42}K and ^{40}K γ-rays, α

GERDA spectra

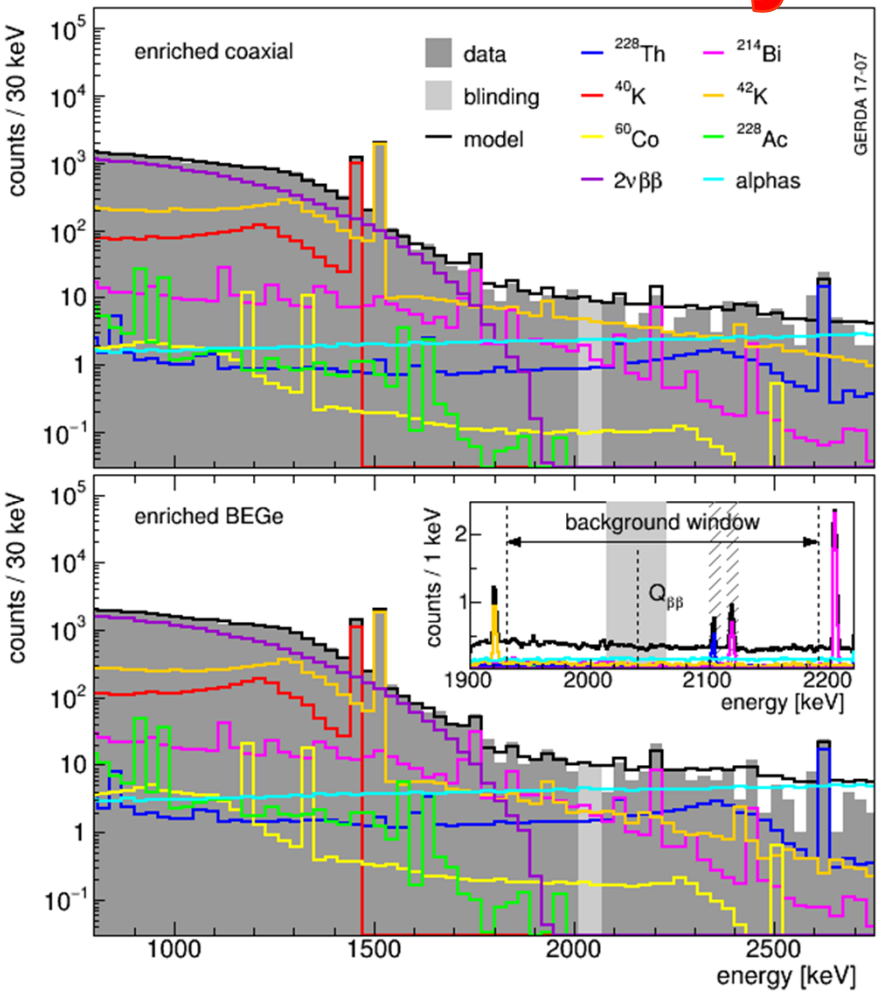


- Most prominent features: ^{39}Ar β (< 500 keV), 2νββ, ^{42}K and ^{40}K γ-rays, α
- PSD clears completely the α region
- LAr and PSD **complementary**
- Final background at $Q_{\beta\beta}$ O(10^{-3} cts/(keV kg yr))
  - PSD for coaxials to be further optimized (groove α) → background will decrease

Background modeling

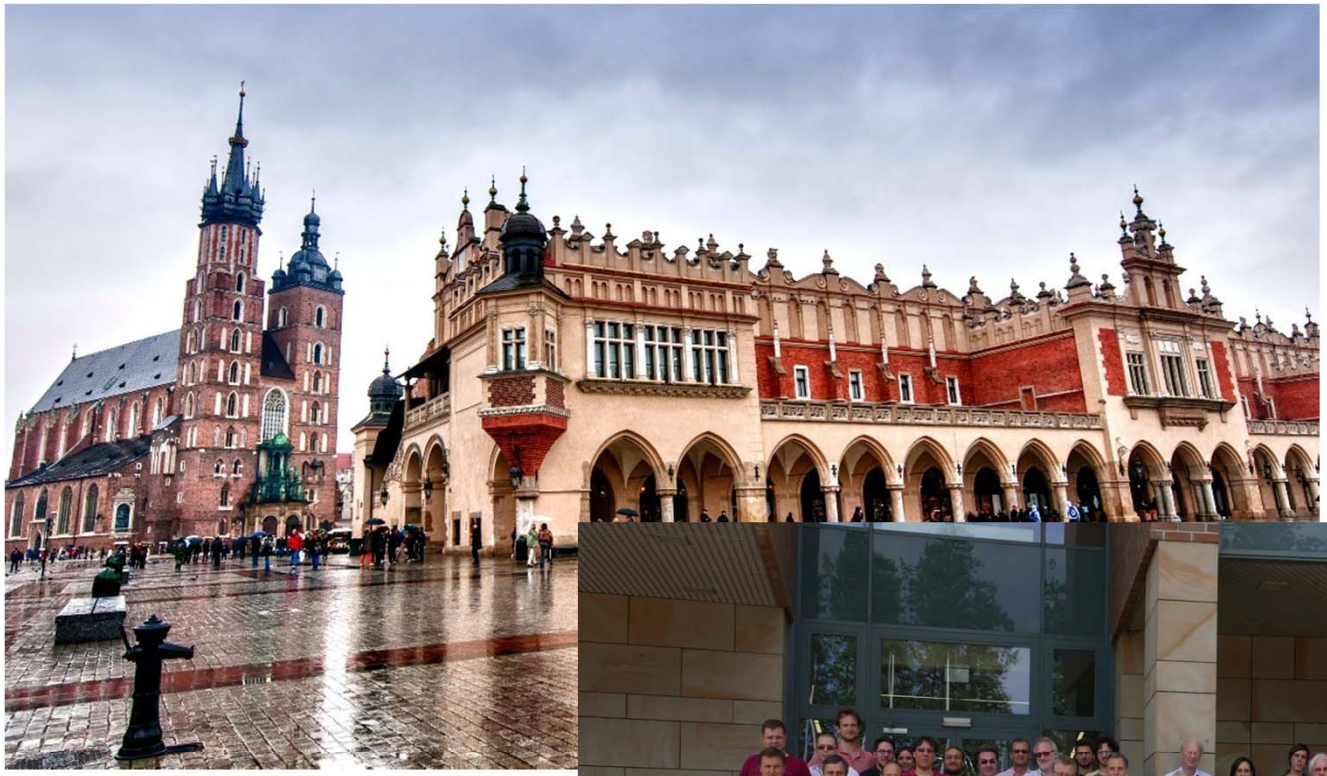
Preliminary

- Very same approach as in Phase I
  - EPJ. C 74 (2014) 2764
  - Mostly, same components considered
  - Also same problem: **poor statistics** makes difficult to disentangle components
  - Simultaneous fit of multiple data sets and external constraints
  - Screening results used as priors
- Consider the spectrum before LAr and PSD cuts
  - Work in progress to have a full combined fit including LAr, PSD and multi-detector events
  - PDFs being derived by MC
- Established **γ-lines** from ^{42}K, ^{40}K, Th chain (^{228}Ac, ^{208}Tl), U chain (^{214}Bi and ^{214}Pb), ^{85}Kr NEW



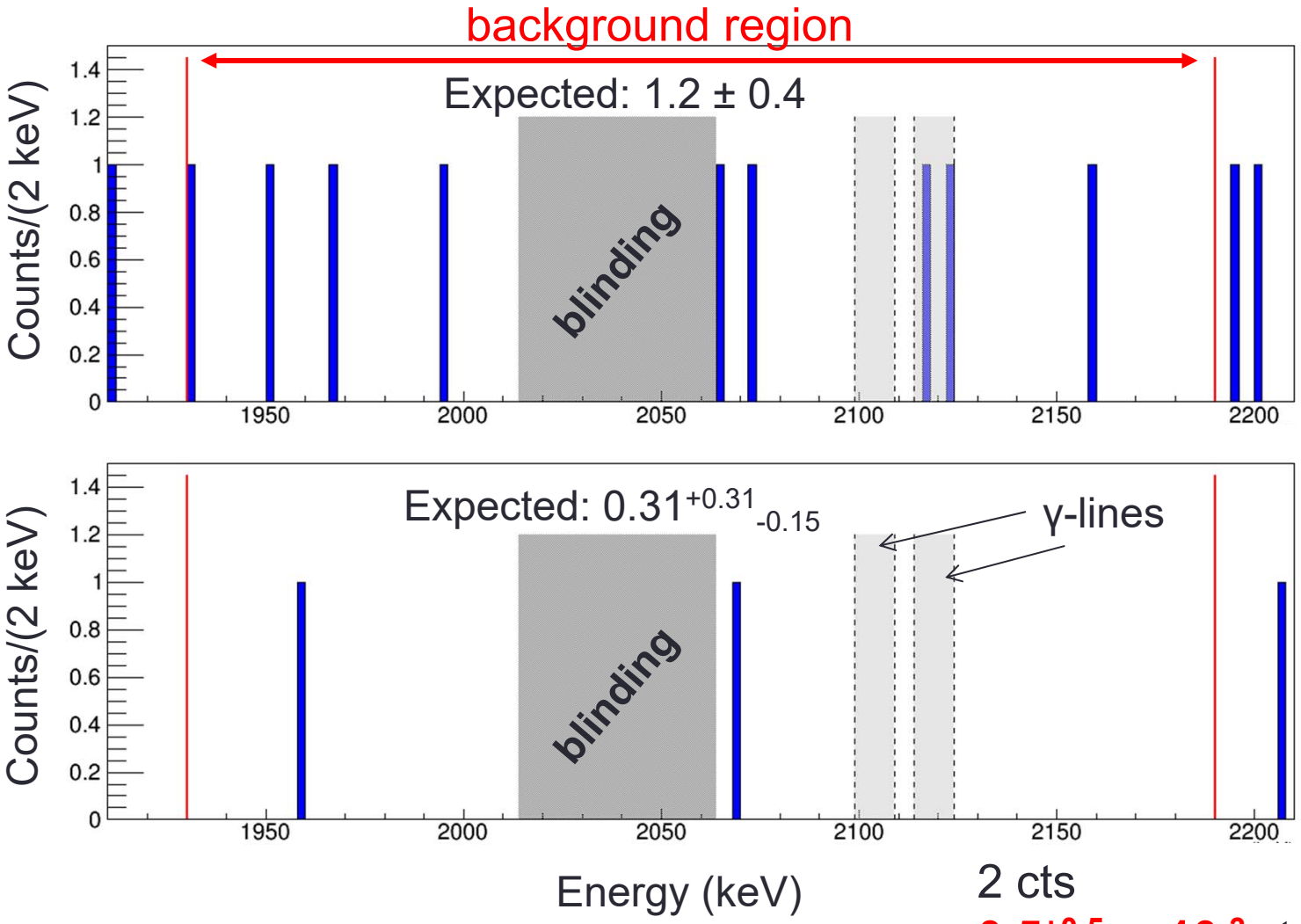
- Use the same analysis window as Phase I
  - 1930-2190 keV, excl. ±5 keV around two known γ lines

GERDA Meeting in Cracow (Jun 28th-30th)



Spectra in the ROI

7 cts (+2 known in blinded box)
$\mathbf{2.7^{+1.0}_{-0.8}\ 10^{-3}}$ cts/(keV kg yr)



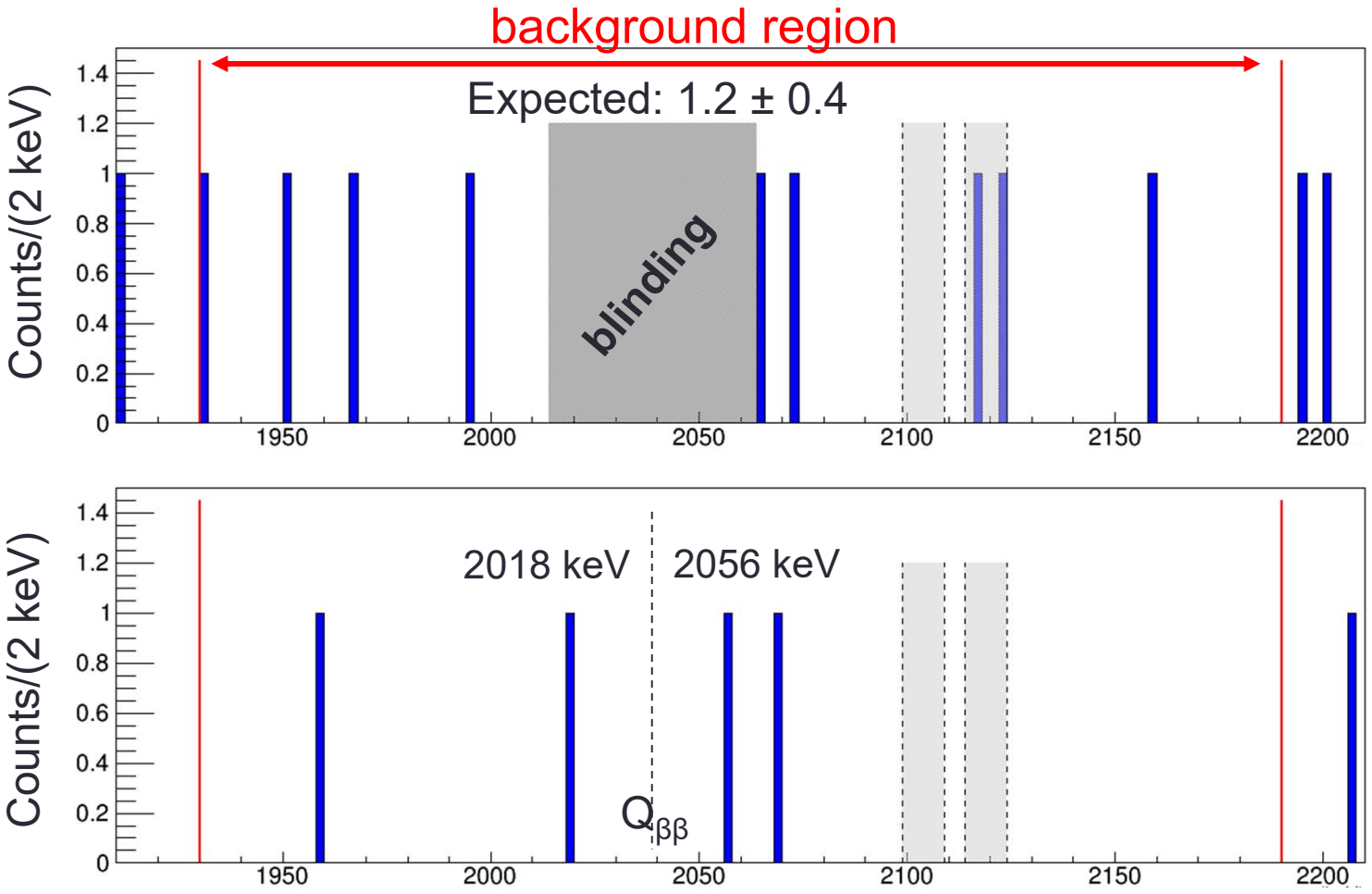
^{enr}Coax
16.2 kg·yr
(all cuts)

^{enr}BEGe
18.2 kg·yr
(all cuts)

2 cts
$\mathbf{0.5^{+0.5}_{-0.3}\ 10^{-3}}$ cts/(keV kg yr)

Spectra in the ROI

7 cts (+2 known in blinded box)
$2.7^{+1.0}_{-0.8}\ 10^{-3}$ cts/(keV kg yr)



^{enr}Coax
16.2 kg·yr
(all cuts)

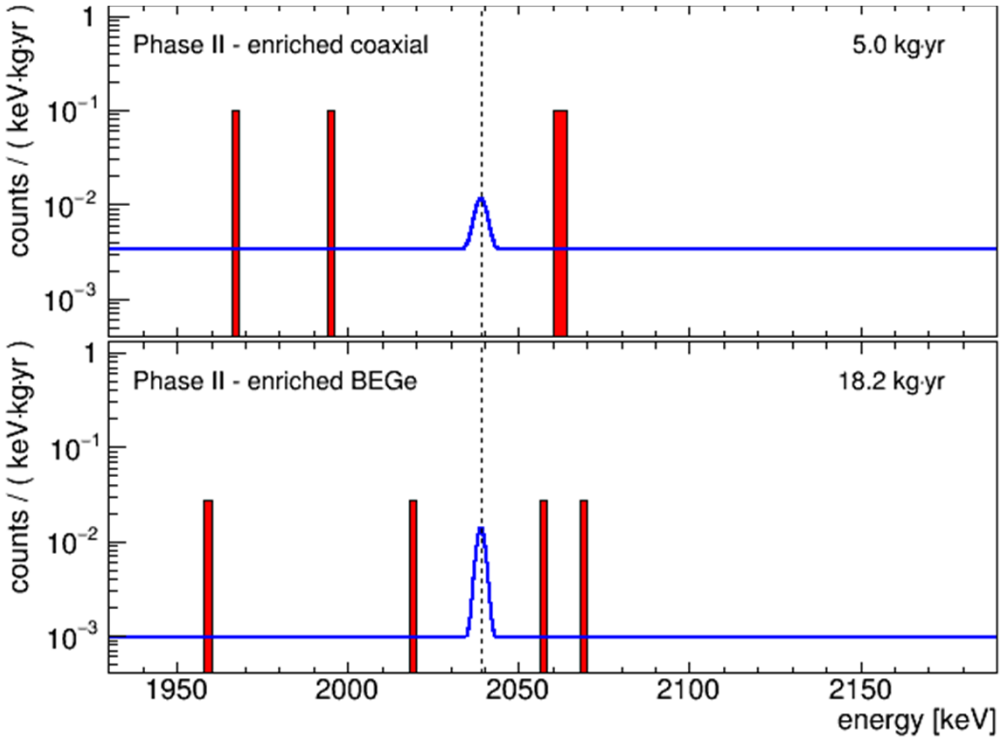
Previously unblinded: 5.0 kg yr

^{enr}BEGe
18.2 kg·yr
(all cuts)

2 cts **+ 2 new** (>10σ from $Q_{\beta\beta}$)
$1.0^{+0.6}_{-0.4}\ 10^{-3}$ cts/(keV kg yr)

Statistical analysis

	Exposure (kg·yr)	
Phase I (4 sets)	**23.5**	Same as Nature 544 (2017) 47
Phase II – coax	**5.0**	
Phase II – BeGe	**5.8+12.4 = 18.2**	
	46.7 kg· yr	



- Combined unbinned **maximum likelihood fit** of the six spectra
  - **Frequentist**: test statistics and method after Cowan et al., EPJC 71 (2011) 1554
  - **Bayesian**: flat prior on $1/T_{1/2}$ between 0 and 10^{-24} yr^{-1}
  - Systematic uncertainties folded as pull terms or by Monte Carlo

Preliminary

- Frequentist:

Best fit: $N^{0\nu} = 0$

$T_{1/2} > 8.0 \cdot 10^{25}$ yr @ 90% CL

It was $5.3 \cdot 10^{25}$ yr in Phasella

MC Median sensitivity (no signal):

$5.8 \cdot 10^{25}$ yr (for 90% C.L.)

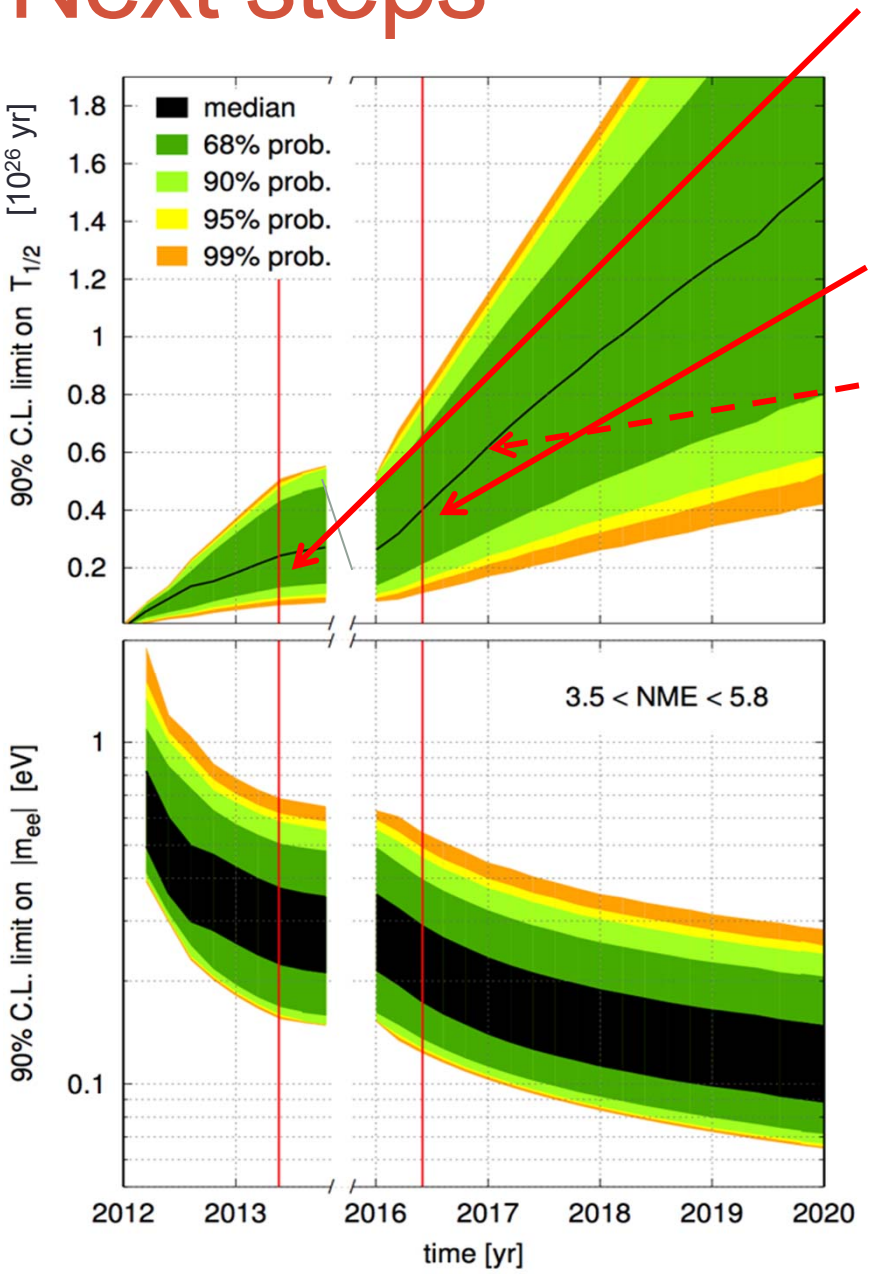
30% chance to have a better limit

- Bayesian:

$T_{1/2} > 5.1 \cdot 10^{25}$ yr @ 90% CI

Median sensitivity $4.5 \cdot 10^{25}$ yr

Next steps



- **Phase I** (23.5 kg yr)
  - Sensitivity: 2.4·10^{25} yr
  - Limit: $T_{1/2}^{0\nu}$ > 2.1·10^{25} yr (90%CL)
- **Phase IIa** (PhI + 10.8 kg yr)
  - Sensitivity: 4.0·10^{25} yr
  - Limit: $T_{1/2}^{0\nu}$ > 5.3·10^{25} yr (90%CL)
- This release (PhIIa + 12.4 kg yr)
  - Sensitivity: **5.8·10^{25} yr**
  - Limit: $T_{1/2}^{0\nu}$ > 8.0·10^{25} yr (90%CL)
- Already in the bag:
  - 11.2 kg yr of **validated** ^{enr}Coax data
    - Median sensitivity → 7.1·10^{25} yr
  - ~ 4 kg yr taken after Apr 15th
- Break **10^{26} yr** wall (sensitivity) in mid-**2018**
- Design exposure 100 kg yr
  - Background-free
  - Final sensitivity **1.3·10^{26} yr** (for limit) or **~ 8 10^{25} yr** (50% for 3σ discovery)

Conclusions

- **GERDA Phase II** taking data since 1.5 years
  - Valid exposure of **34 kg·yr** accumulated (analysis cutoff: Apr 15th)
  - A few more kg yr available in the recent runs
- Very good **background level** at $Q_{\beta\beta}$ confirmed
  - $2.7^{+1.0}_{-0.8}$ (^{enr}Coax) and $1.0^{+0.6}_{-0.4}$ (^{enr}BEGe) [10^{-3} cts/(keV kg yr)]
  - Will allow to achieve **O(< 1 count) in the ROI** for the full design exposure
- Lowest background (~10x) in ROI wrt other isotopes
- Unblinding of **12.4 kg·yr** of best-quality data
  - **$T_{1/2} > 8.0 \cdot 10^{25}$ yr @ 90% CL** ($m_{\beta\beta}$ < 0.12-0.27 eV)
  - Median sensitivity: **$5.8 \cdot 10^{25}$ yr** (~ KamLAND-Zen 2016)
  - 11.2 kg yr of valid ^{enr}Coax data *still blinded*

Preliminary

- For full **100 kg·yr exposure**: sensitivity to a signal up to $T_{1/2}$ **~$8\ 10^{25}$ yr** (or limit $T_{1/2}$ > **$1.3\ 10^{26}$ yr** at 90%CL)