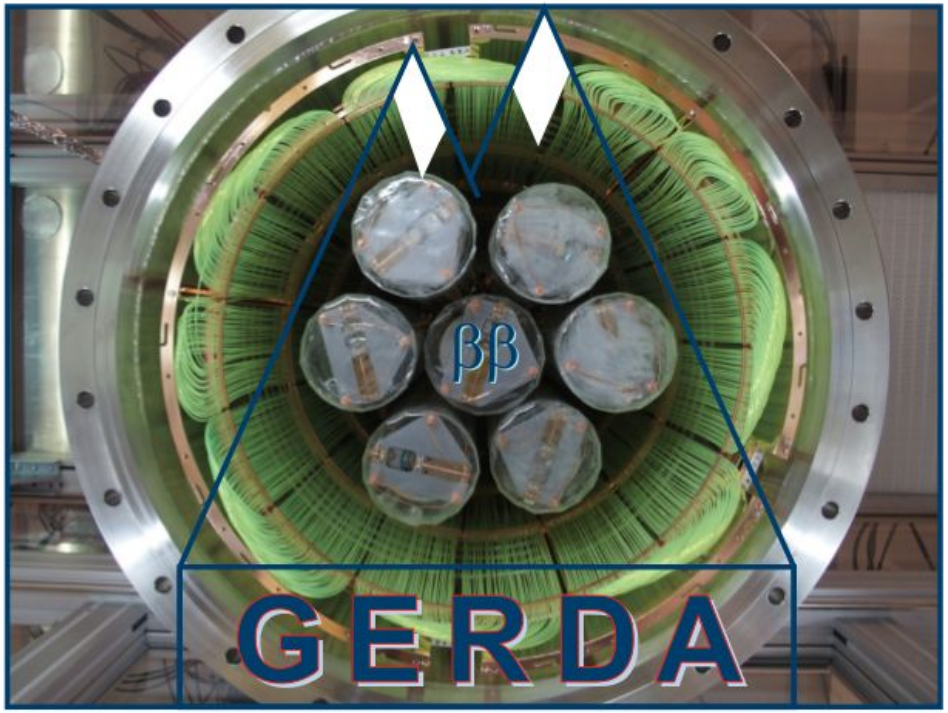
EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

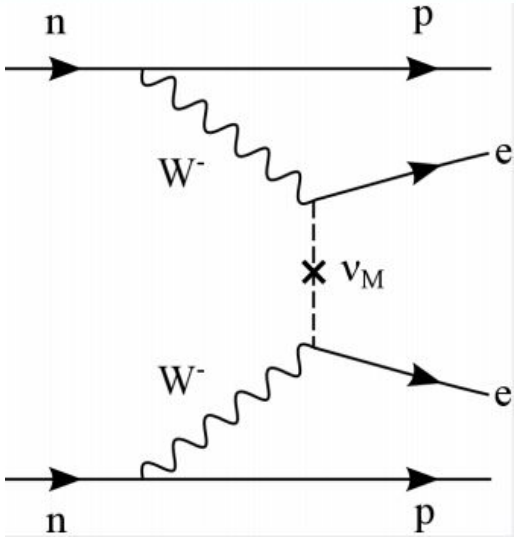


Neutrinoless double beta decay search with the "background-free" GERDA experiment

Ann-Kathrin Schütz
on behalf of the GERDA collaboration,
University of Tübingen, Germany

Neutrinoless Double Beta Decay

- process beyond SM
- lepton number violating $\Delta L = 2$
- in principle all 2νββ isotopes are candidates
- majorana mass component
- massive neutrino exchange
- constraints on lightest mass eigenstate
- neutrino mass hierarchy



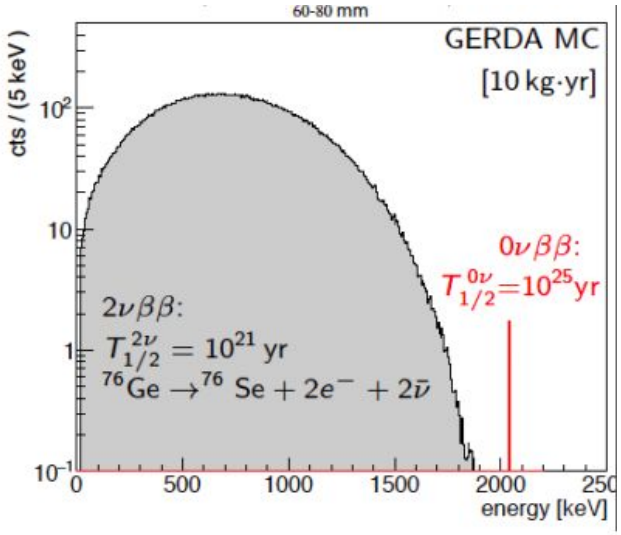
Search for neutrinoless double beta decay of ^{76}Ge:

$^{76}Ge \rightarrow {}^{76}Se + 2e^-$

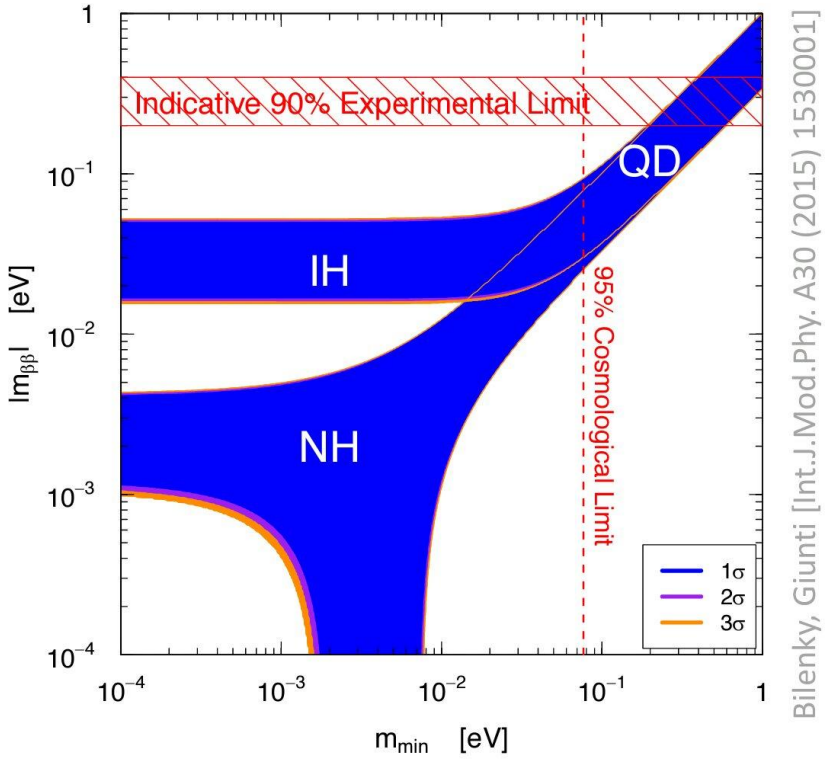
$\Rightarrow \Delta L = 2$

$\Rightarrow$ beyond Standard Model physics

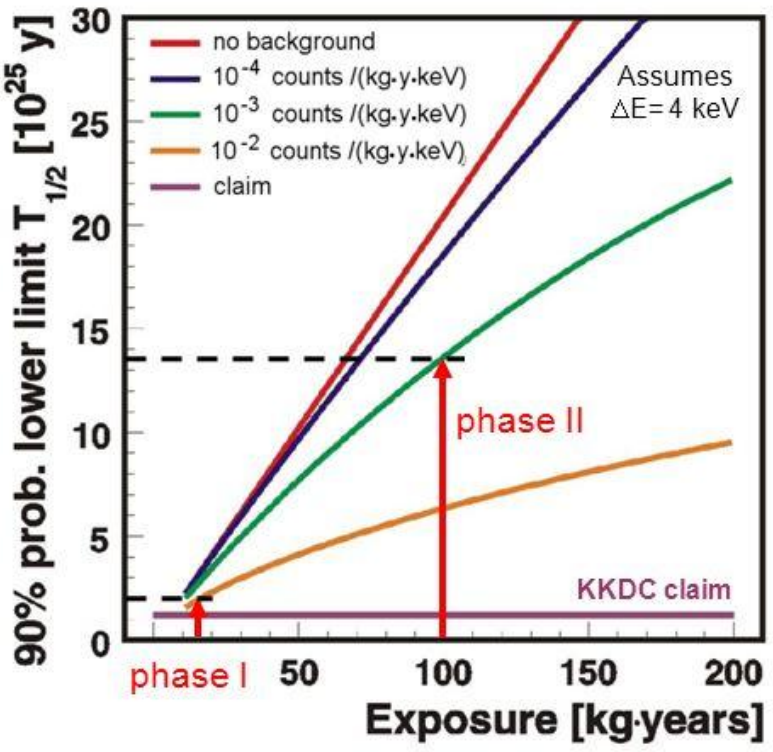
$\Rightarrow$ Majorana mass or other L-violating physics



Signal and Sensitivity



Bilenky, Giunti [Int.J.Mod.Phy. A30 (2015) 1530001]



$$\frac{1}{T_{1/2}} = G^{0\nu} \left(\frac{g_A^{eff}}{g_A} \right)^2 \left| \mathcal{M}^{0\nu} \right|^2 \left| \frac{\langle m_{\beta\beta} \rangle}{M_e} \right|$$

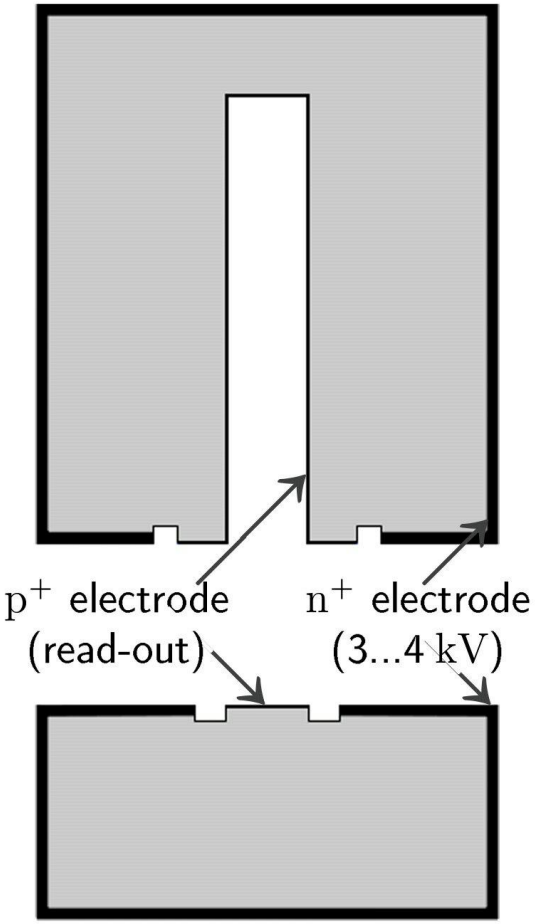
$$\langle m_{\beta\beta} \rangle = \left| \sum_{i=1}^{3} U_{ei}^2 m_i \right|$$

$$\text{with background} : T_{1/2} \sim \sqrt{\frac{M \cdot t}{BI \cdot \Delta E}}$$

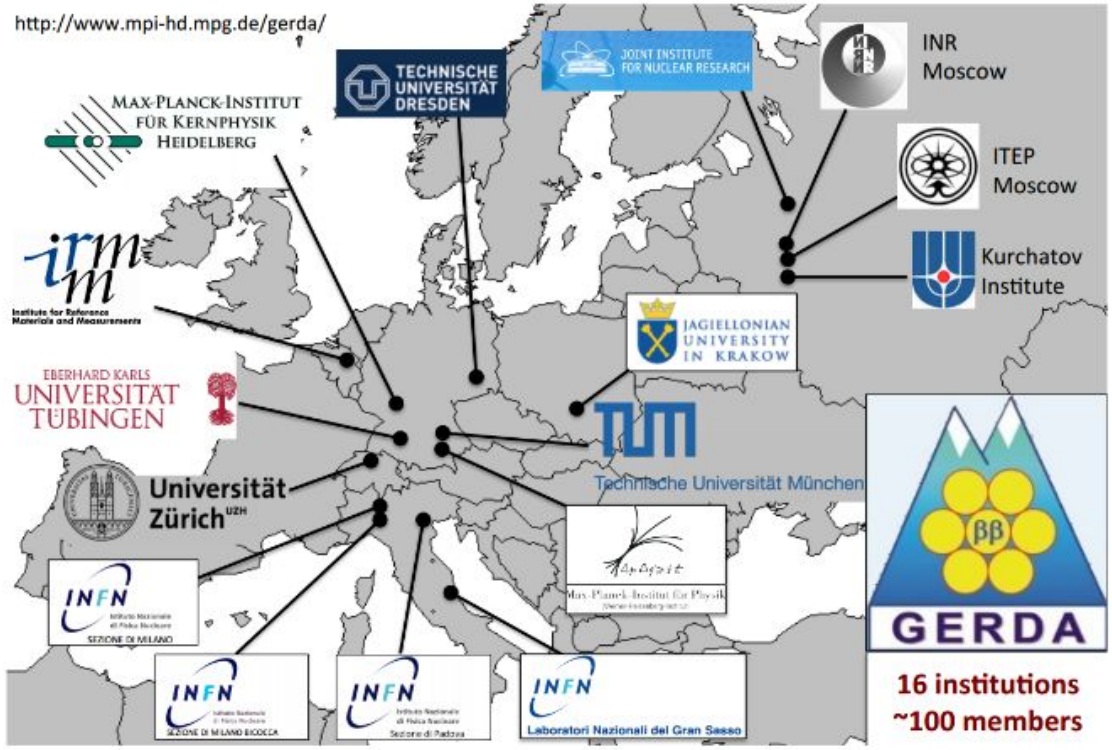
$$\text{background-free} : T_{1/2} \sim M \cdot t$$

Germanium Detectors

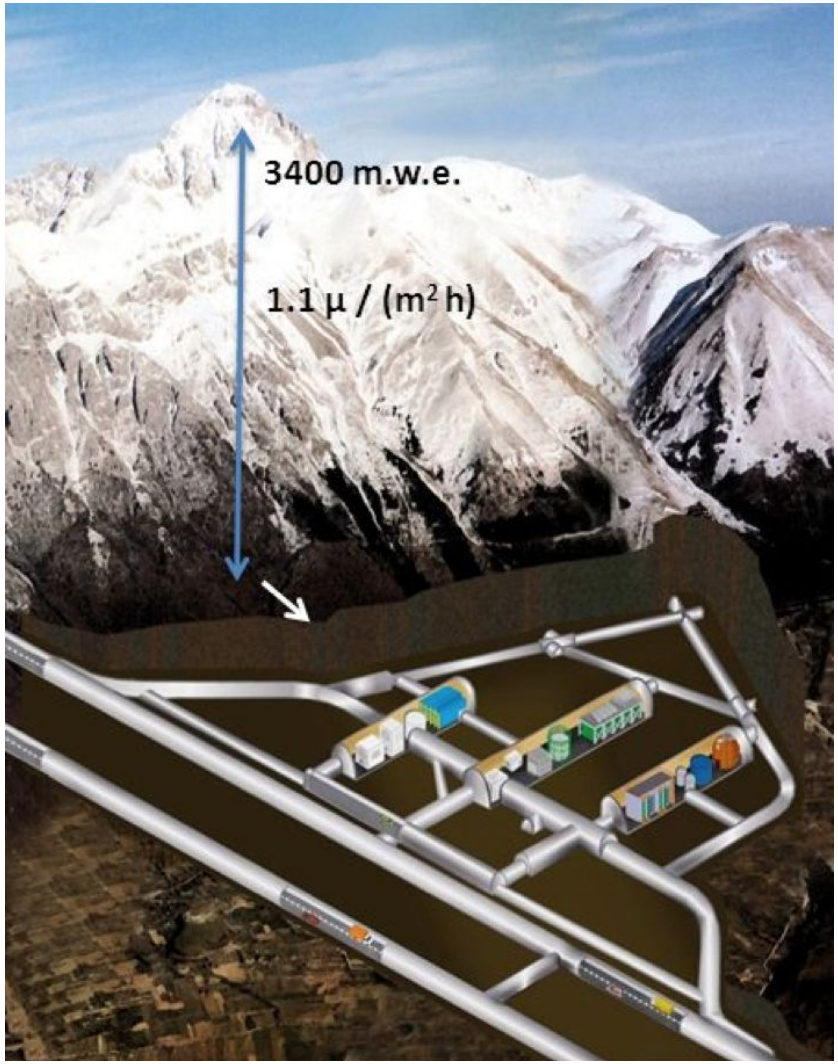
- Q-value of ^{76}Ge: $Q_{\beta\beta}$=2039 keV
- High purity Ge detectors (87% ^{76}Ge):
  - source=detector
  ⇒ high detection efficiency
  - ultra radio-pure
  ⇒ no intrinsic background
  - high density
  ⇒ 0νββ point like events
  - semiconductor ⇒ $\Delta E \approx 0.2\%$ at $Q_{\beta\beta}$
- 0νββ signature:
  - point-like energy deposition in detector bulk volume
  - sharp energy peak at 2039 keV (FWHM = 3-4 keV)



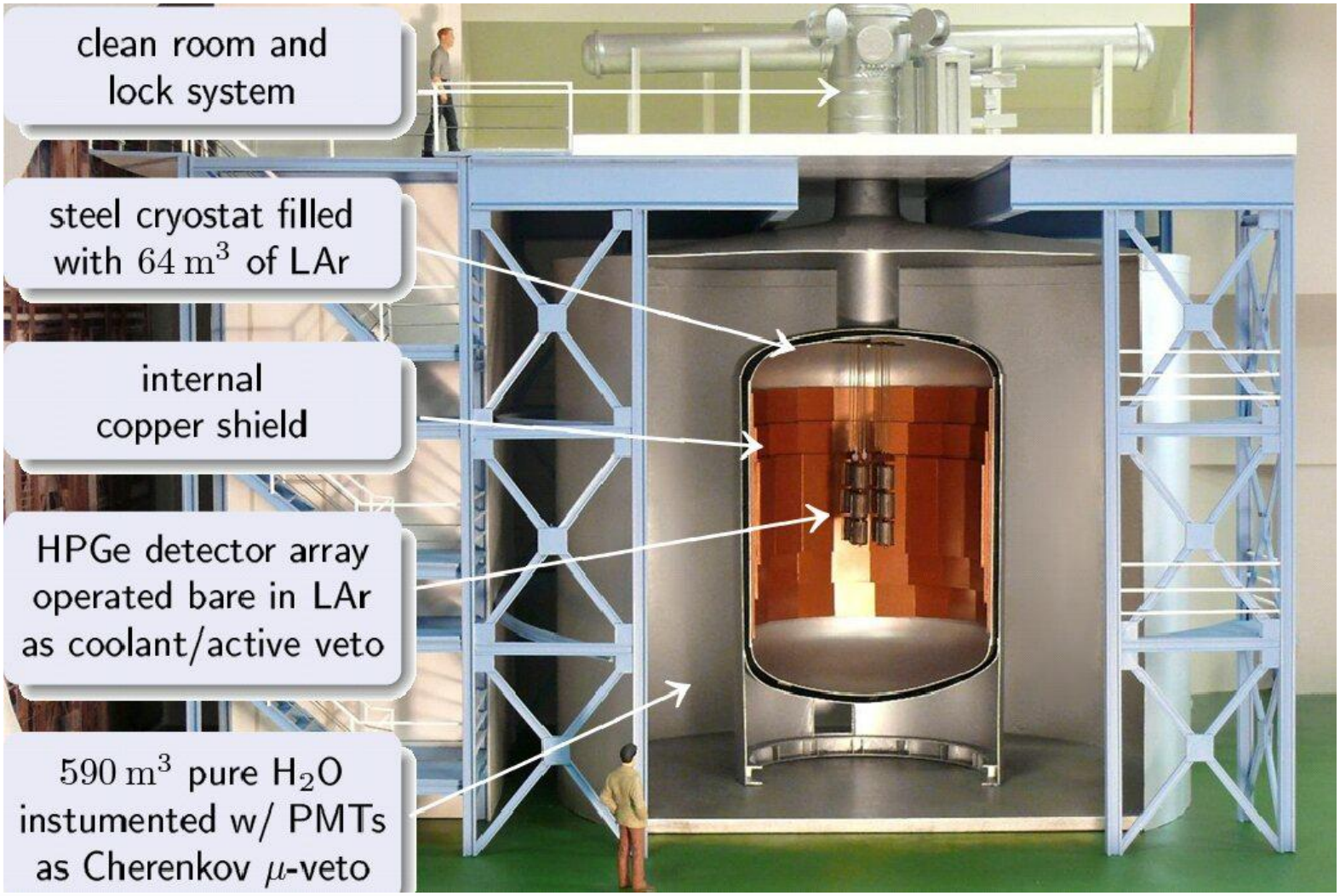
The GERDA Collaboration



GERDA @ LNGS



The GERDA Experimental Setup



Background Suppression

SIgnal events (0νββ/ 2νββ events)

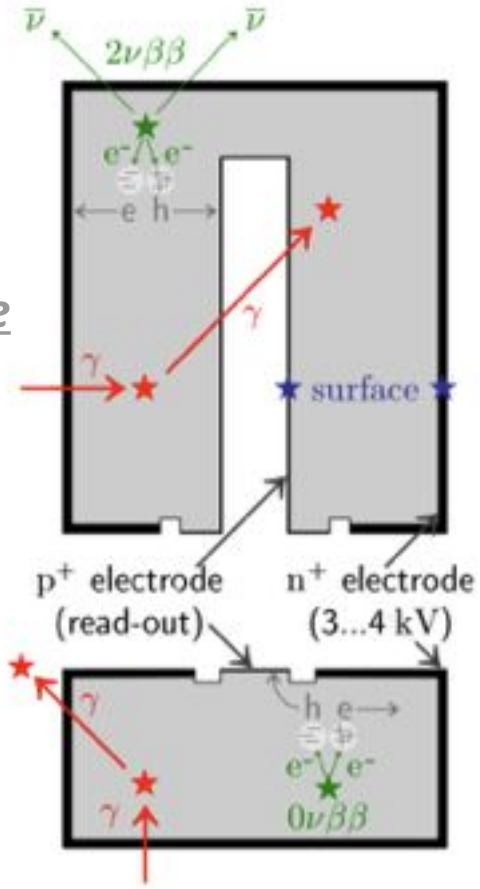
- local energy deposit in single detector

Background events (γ events)

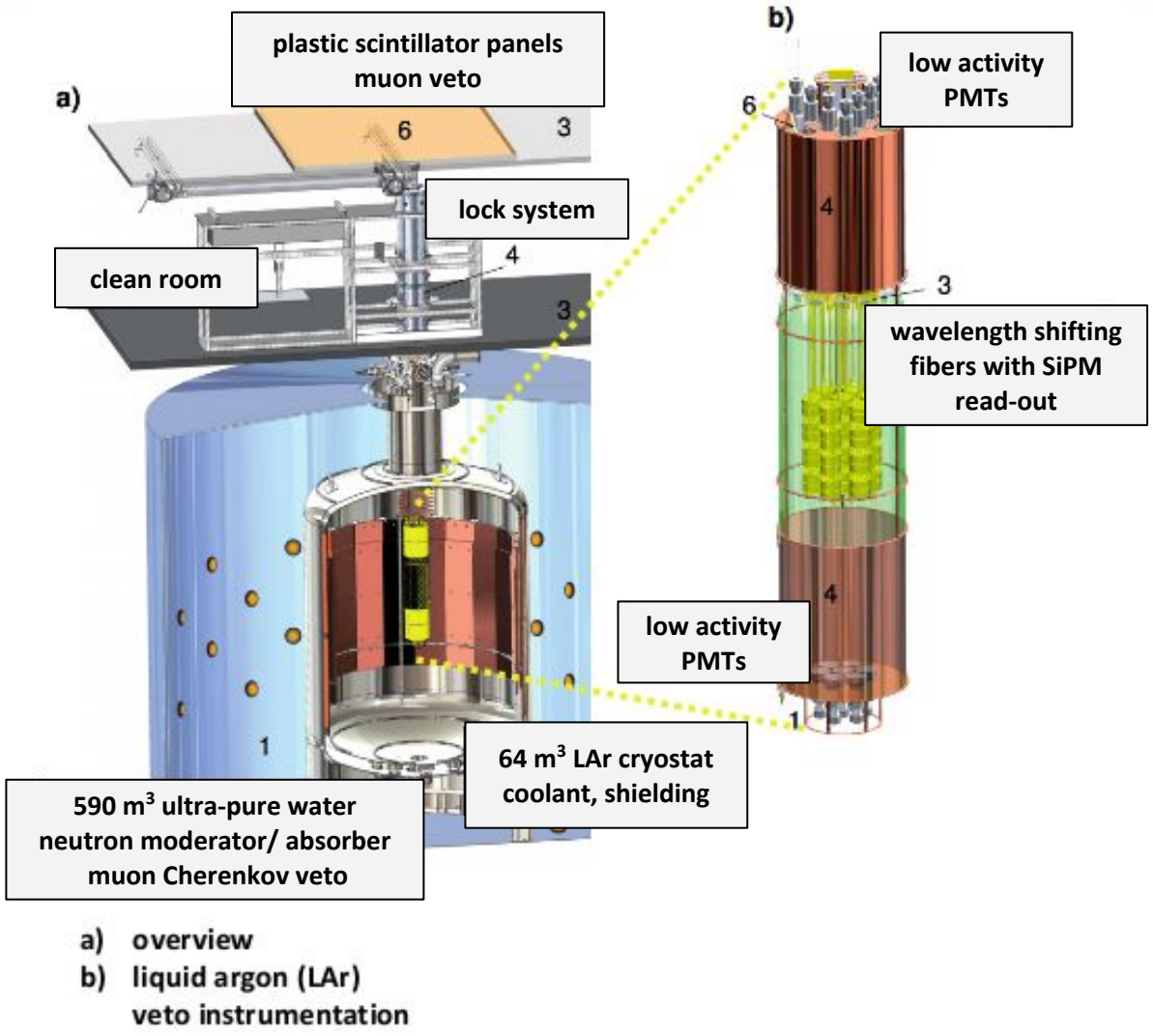
- energy deposition in multiple locations (MSE) in single detector
  → pulse shape discrimination (*analysis of time profile of current (integrated charge) signal*)
- coincident energy deposition in more than one detector
  → detector anti-coincindence
- additional energy deposition in LAr
  → LAr veto

Surface events (α/β events)

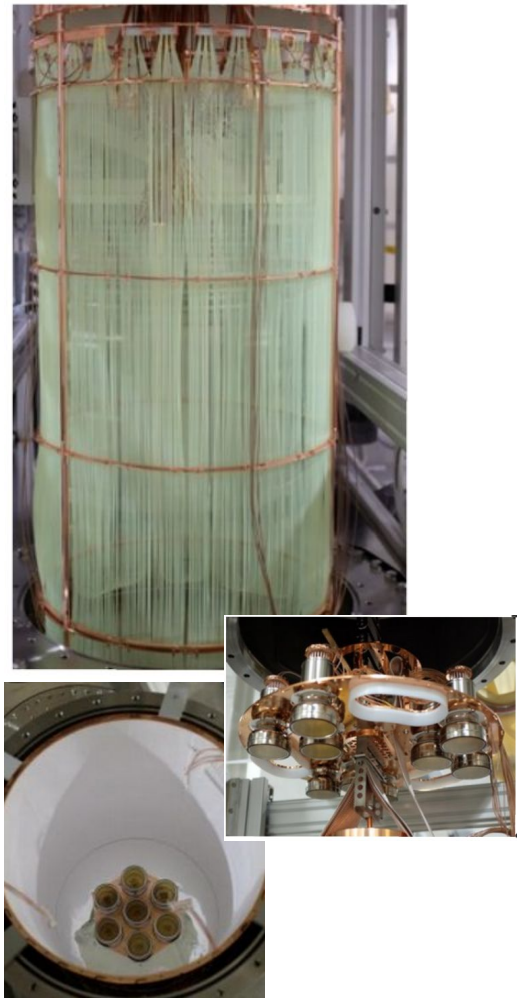
- energy deposited on or close by the detector contacts
  → short (p+) or long (n+) current pulse



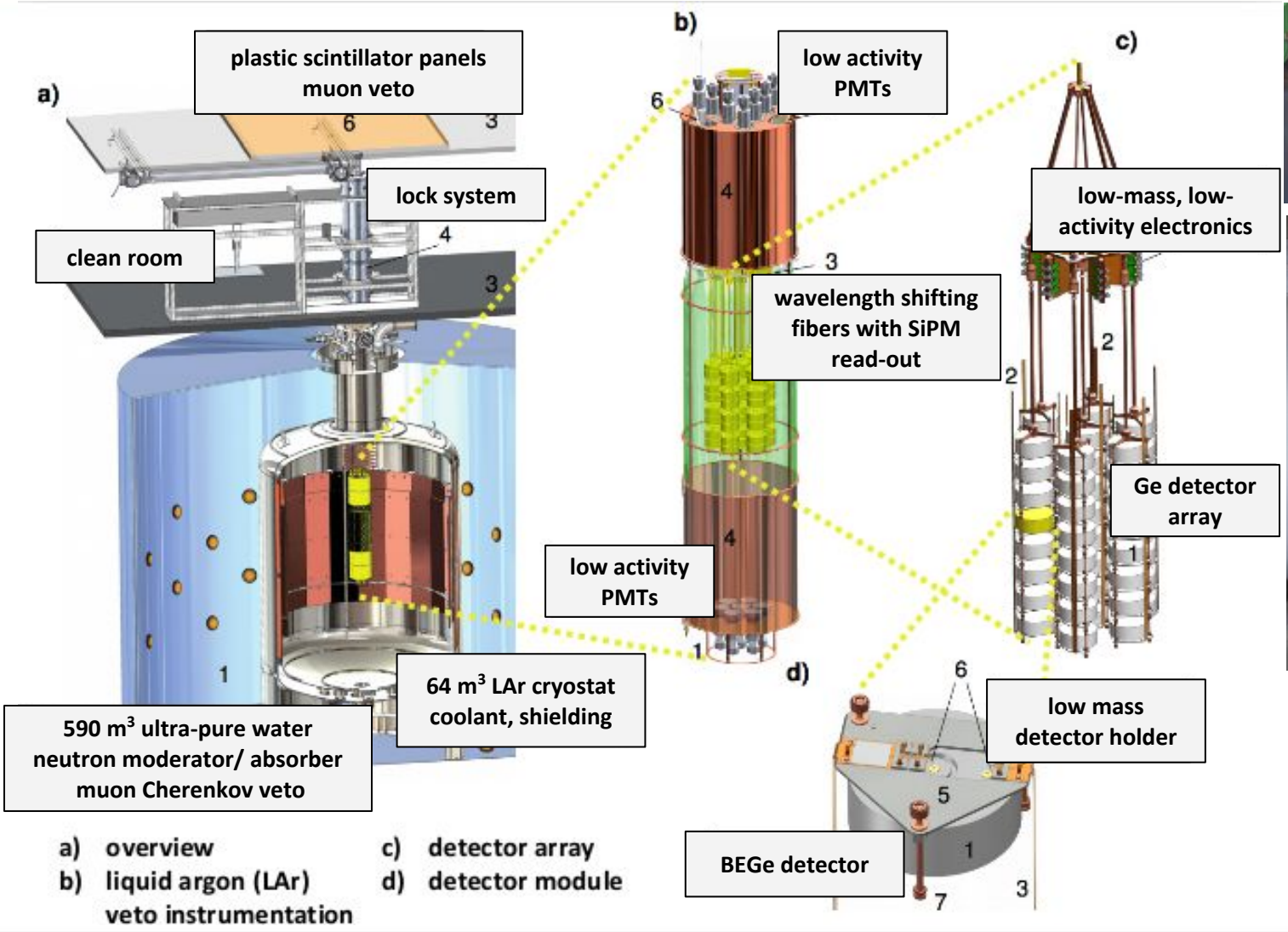
LAr Veto Insturmentation

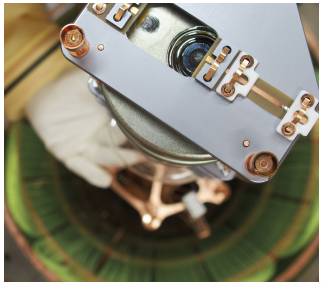


a) overview
b) liquid argon (LAr) veto instrumentation



The Detector Array





Phase II: Final Integration

Phase II: Final Integration in Dec 2015

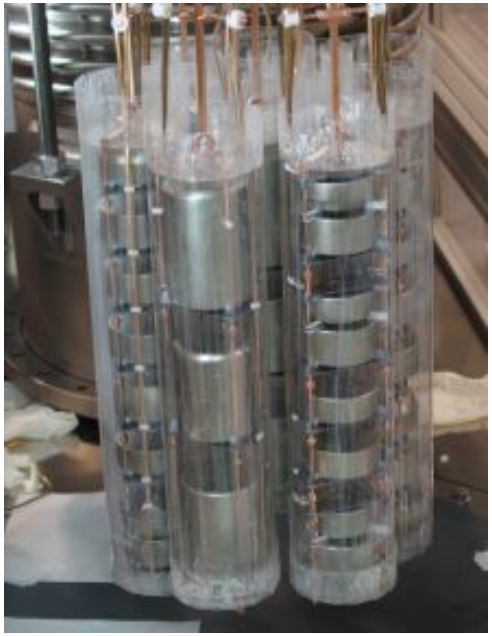
40 detectors in 7 strings:

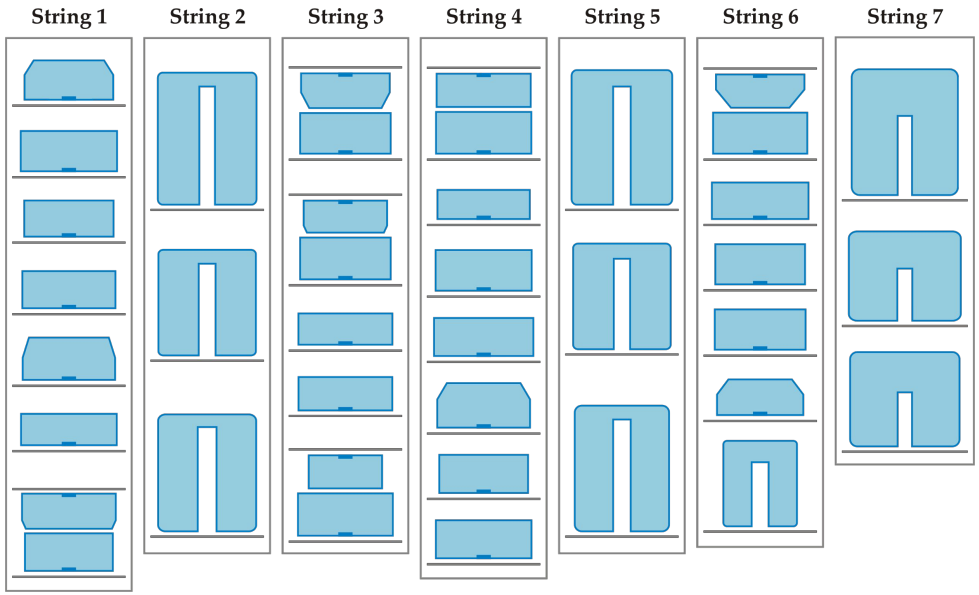
30 enrBEGe (20.0 kg)

7 enr semi-coaxial (15.8 kg)

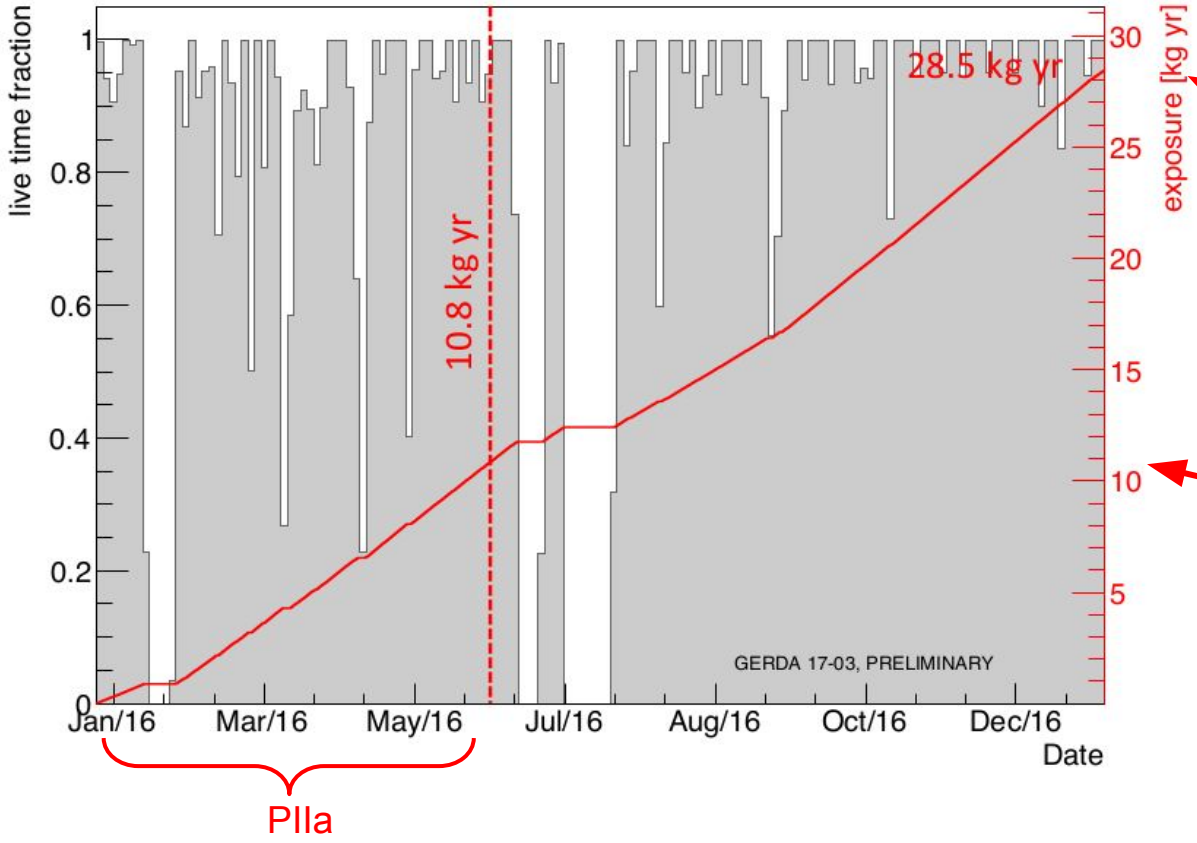
3 nat semi-coaxial (7.6 kg)

→ **35.8 kg of enr detector mass**





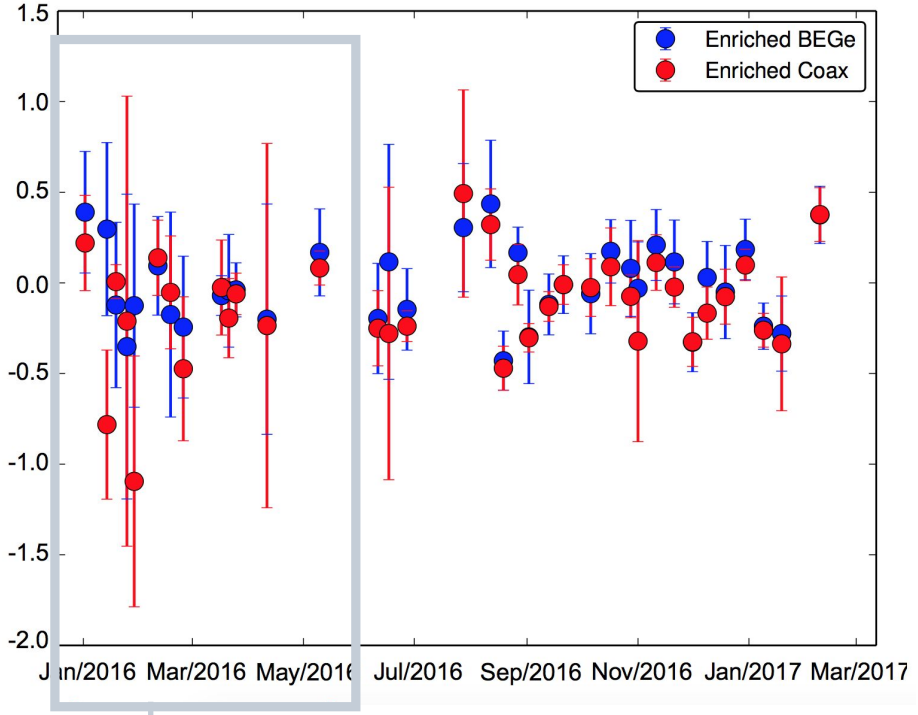
Data Taking & Duty Cycle

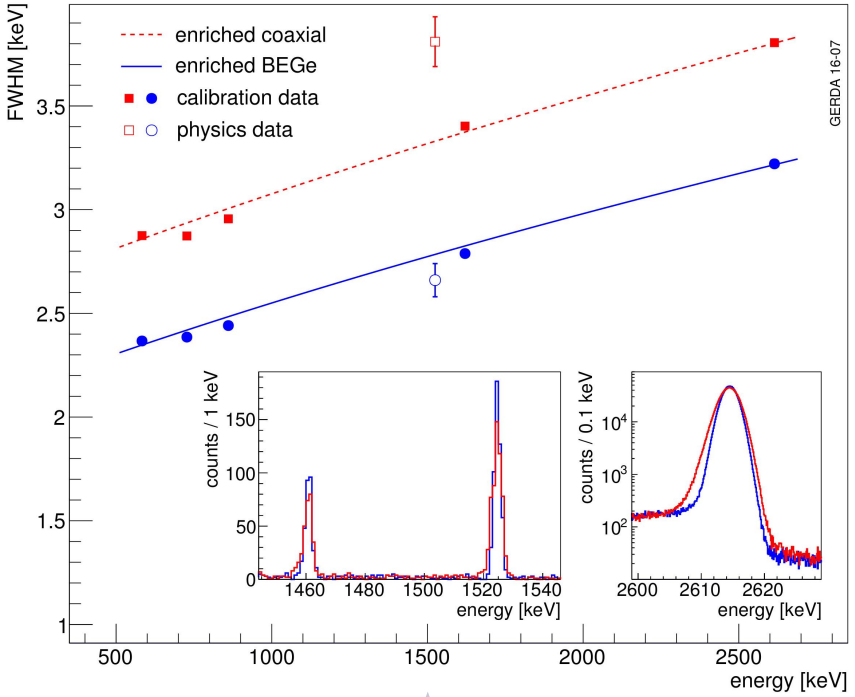


February 2017: 28.5 kg yr

Neutrino 2016: 10.8 kg yr
1st unblinding
arXiv:1703.00570, publ. in Nature 2017

Stability and Energy Resolution





Weekly calibrations with ^{228}Th

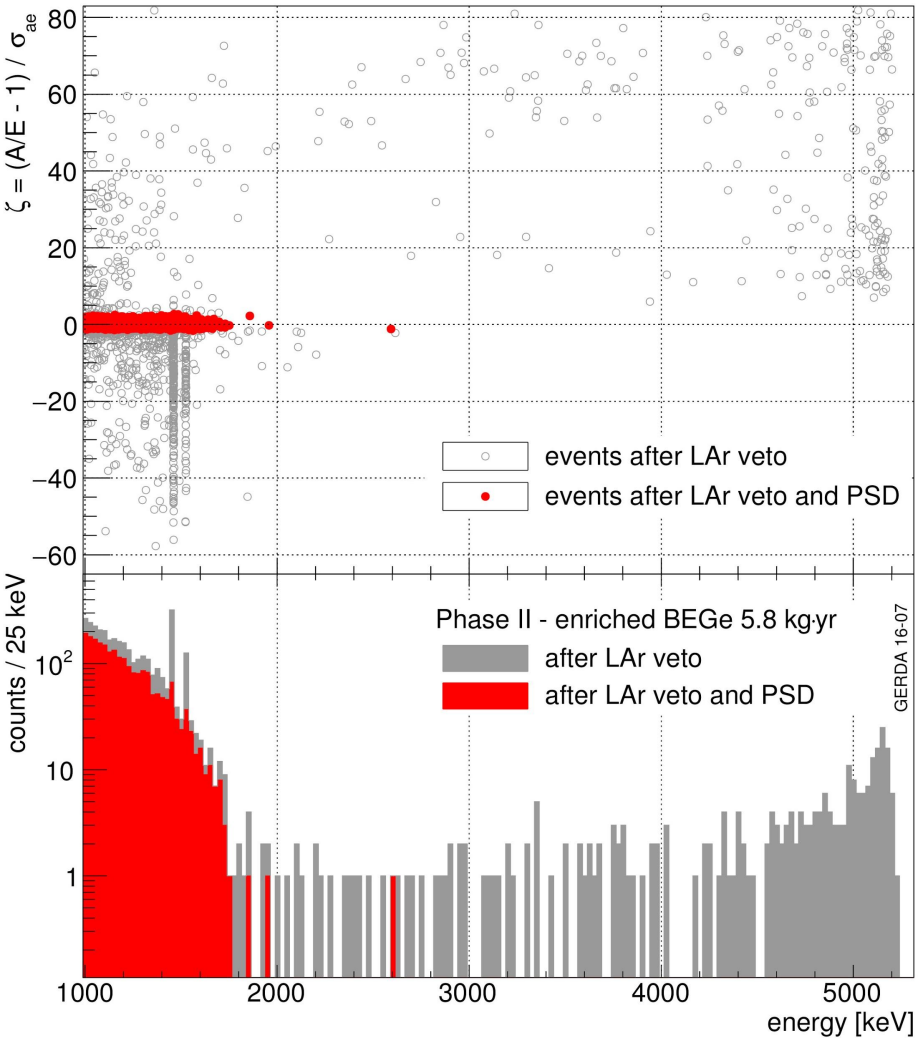
Energy Resolution FWHM @ $Q_{\beta\beta}$ = 2039 keV

- BEGe 3.0 ± 0.2 keV
- Coax 4.0 ± 0.2 keV

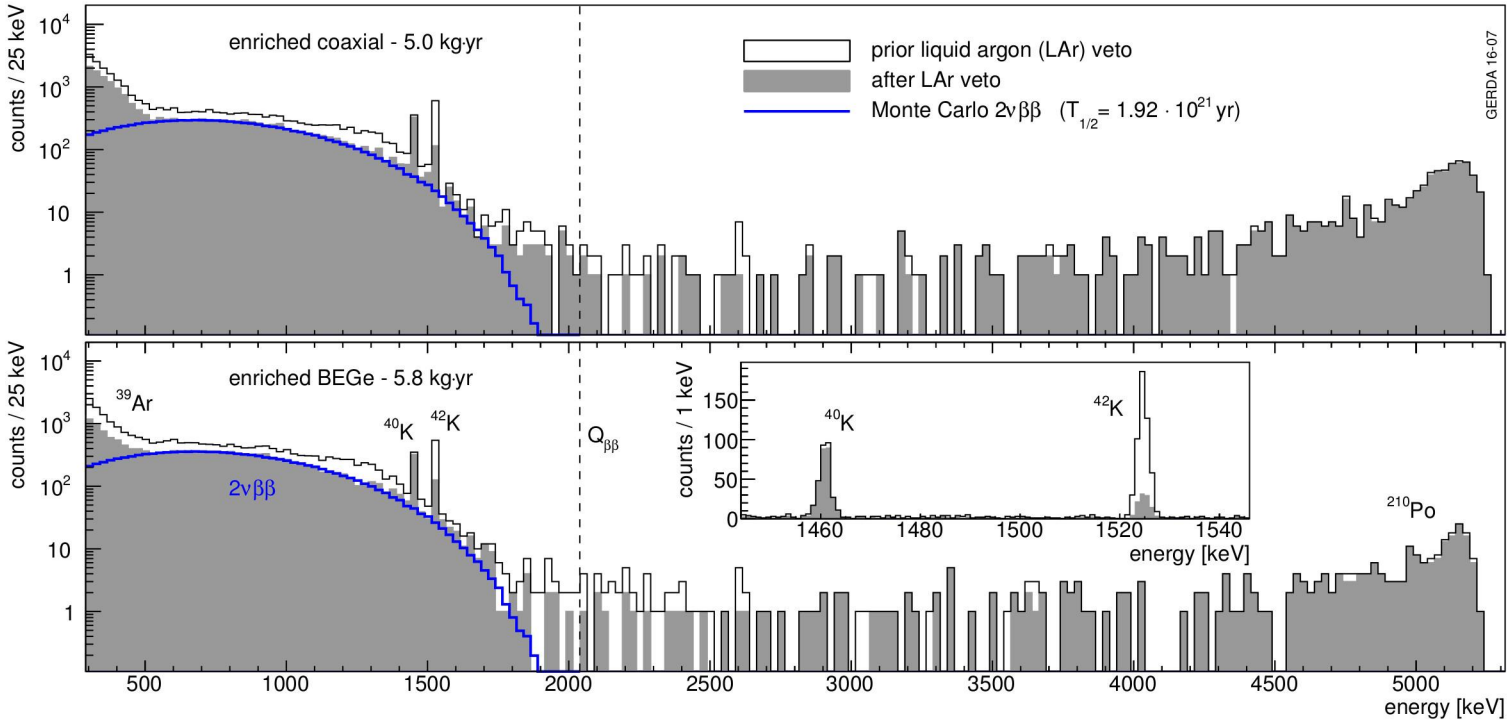
PSD Performance - BEGe

“A/E cut “
single parameter based on current amplitude A and event energy E

- tuned by DEP of 2615 keV from calibration data
- 80 % of background events rejected at $Q_{\beta\beta}$
- 2νββ acceptance 85.4±0.8±1.7 %
- all surface alpha events removed
- γ-lines suppressed by factor of 6
- **0νββ acceptance (87 ± 2)%**



LAr Veto Performance



- Almost pure 2νββ after LAr cut (97%, 600-1300 keV)
- LAr cut signal acceptance: (97.7 ±0.1)%

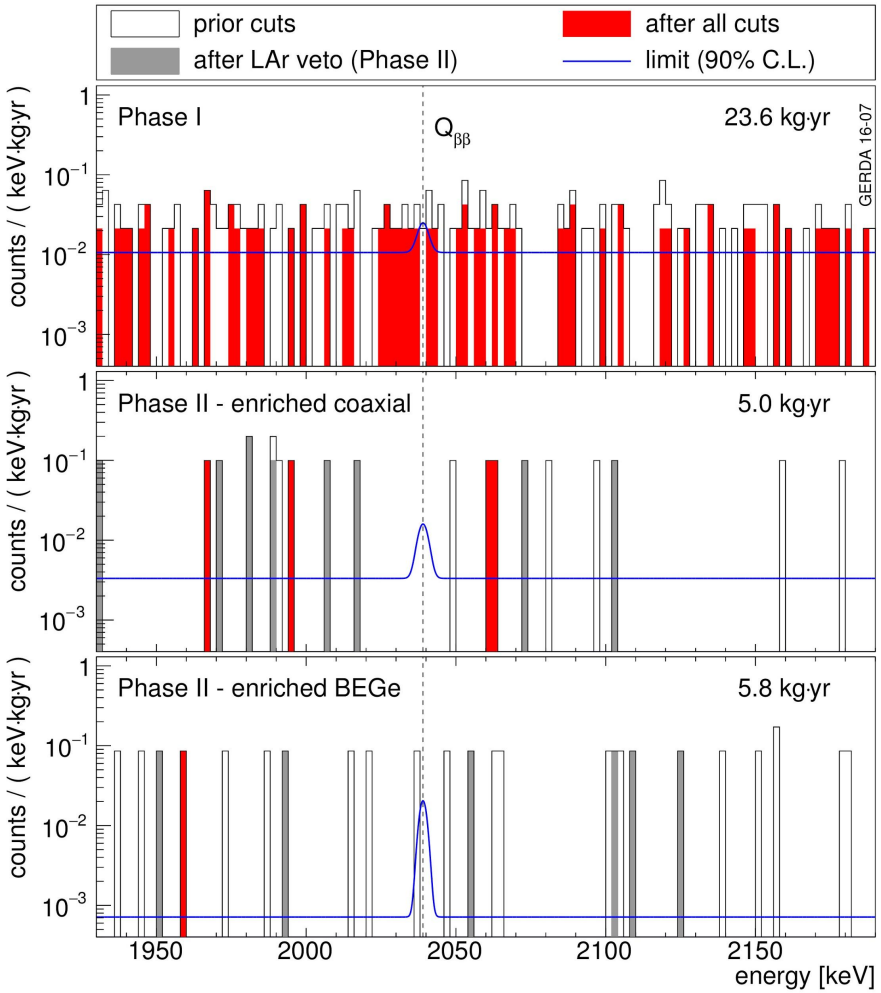
- Background at $Q_{\beta\beta}$ reduced by factor 2
- No reduction of α
- Compton continuum strongly suppressed

Phase IIa Results (10.8 kg yr)

data set	exp [kg·yr]	FWHM [keV]	ϵ	BI $\left[10^{-3}\ \frac{cts}{keV \cdot kg \cdot yr}\right]$
PI golden	17.9	4.3(1)	0.57(3)	11 ± 2
PI silver	1.3	4.3(1)	0.57(3)	30 ± 10
PI BEGe	2.4	2.7(2)	0.66(2)	5^{+4}_{-3}
PI extra	1.9	4.2(2)	0.58(4)	5^{+4}_{-3}
PI	23.5			
PIIa Coax	5.0	4.0(2)	0.53(5)	$3.5^{+2.1}_{-1.5}$
PIIa BEGe	5.8	3.0(2)	0.60(2)	$0.7^{+1.1}_{-0.5}$
PIIa	10.8			

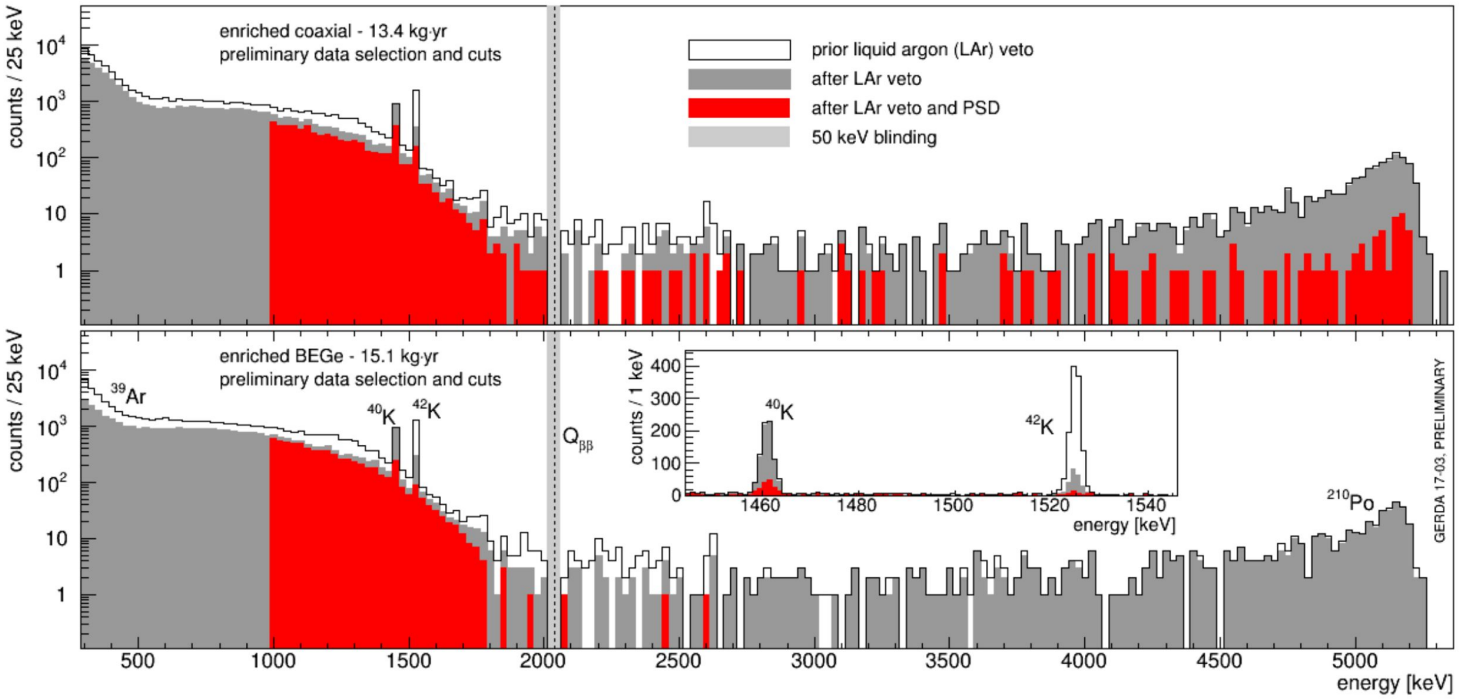
	profile-likelihood 2-sided	Bayesian flat prior
$0\nu\beta\beta$ best fit value [cts]	0	0
$T^{0\nu}_{1/2}$ **lower limit [10^{25}yr]**	**5.3 (90% C.L.)**	3.5 (90% C.L.)
$T^{0\nu}_{1/2}$ **median sensitivity [10^{25}yr]**	**4.0 (90% C.L.)**	3.1 (90% C.L.)

frequentist test-statistics and methods [EPJC 71 (2011) 1554]



Current Background (28.5 kg yr)

- since summer 2016 additional (blinded) data



(cts)	exposure [ky·yr]	BI* [10^{-3} cts/(keV kg yr)]	LAr cut	PSD cut	LAr + PSD cuts
enrBEGe	15.1	$12.3^{+2.3}_{-1.8}$ (38)	$3.9^{+1.3}_{-1.0}$ (12)	$3.2^{+1.2}_{-0.9}$ (10)	$0.6^{+0.6}_{-0.4}$ (2)
enrCoax	13.4	$16.7^{+2.7}_{-2.3}$ (46)	$8.0^{+1.9}_{-1.6}$ (22)	$8.0^{+1.9}_{-1.6}$ (22)	$2.2^{+1.1}_{-0.8}$ (6)

*background windows weighted by exposure (≈205keV)

Summary & Outlook

- GERDA Phase II is running stable
- 3-4 keV energy resolution @$Q_{\beta\beta}$
- blind analysis on first 10.8 kg yr of data
- published in Nature 544 (2017)

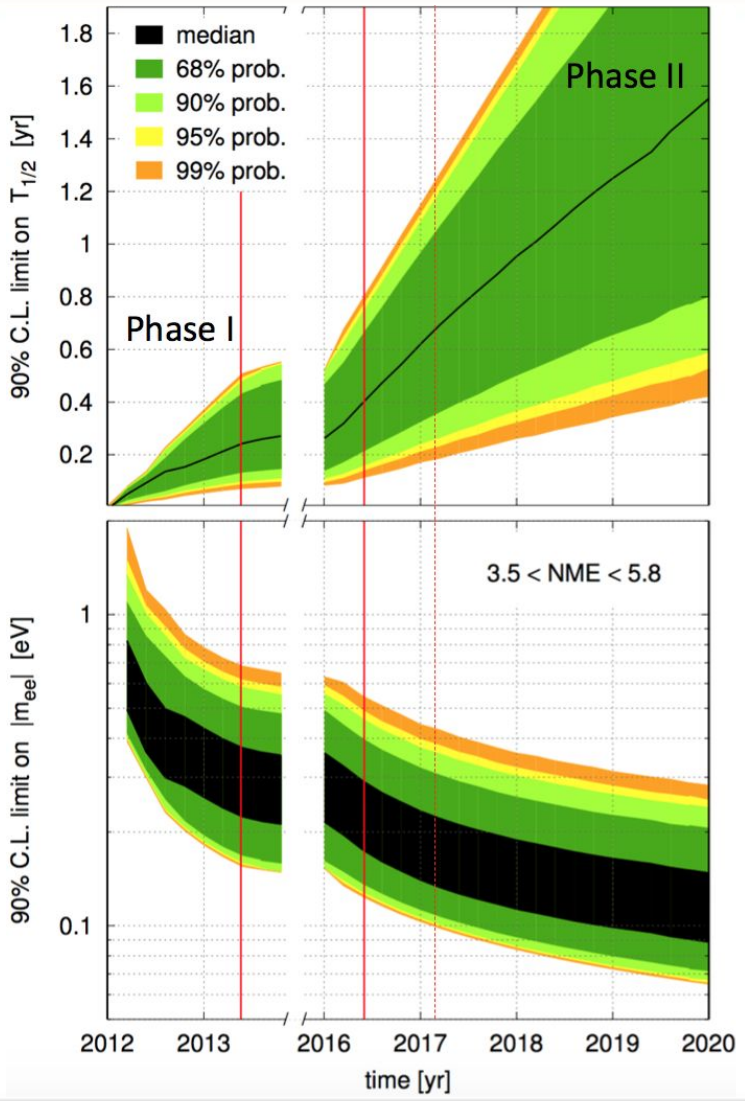
Phase IIa achievements

background	~10^{-3} cts/(keV·kg·yr)
exposure	10.8 kg·yr
limit	$T^{0\nu}_{1/2}$ > $5.3 \cdot 10^{25}$ yr (90%CL)
	$m_{\beta\beta}$ < (0.15-0.33) eV (90%CL)

GERDA Phase II is the high-resolution and background-free 0νββ experiment

Phase II goals

background	~10^{-3} cts/(keV·kg·yr) ✓
exposure	≳ 100 kg·yr
limit	$T^{0\nu}_{1/2}$ > 10^{26} yr



Outlook – Beyond GERDA

LEGEND (Large Enriched Germanium Experiment for Neutrinoless Double Beta Decay)

new collaboration formed in Oct 2016
(=GERDA+Majorana+new groups)

Goals:
- 1 t enriched Ge
- first phase: 200 kg in existing infrastructure @ LNGS
- reduce background with respect to GERDA
→ remain background-free
→ best discovery potential