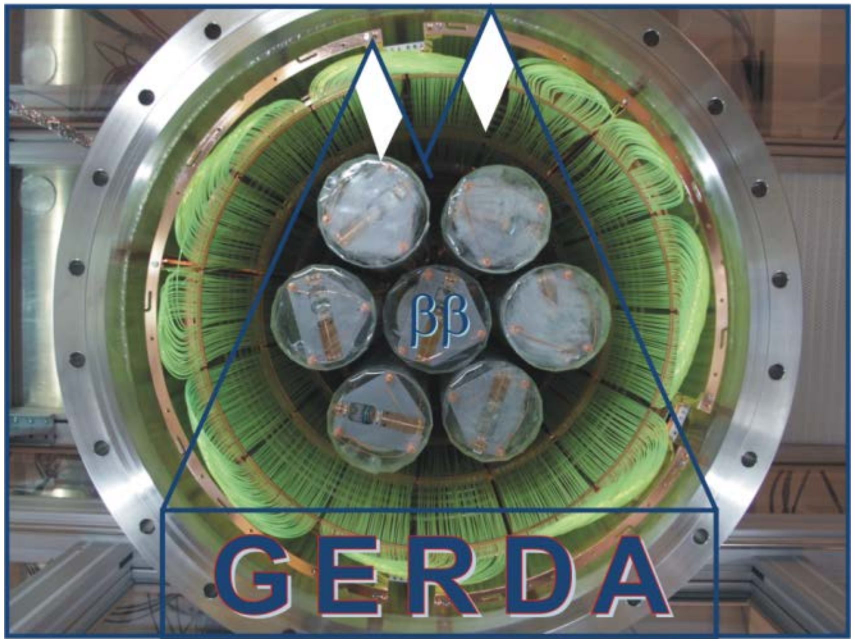
SEARCH FOR NEUTRINOLESS DOUBLE BETA DECAY WITH GERDA

Luciano Pandola

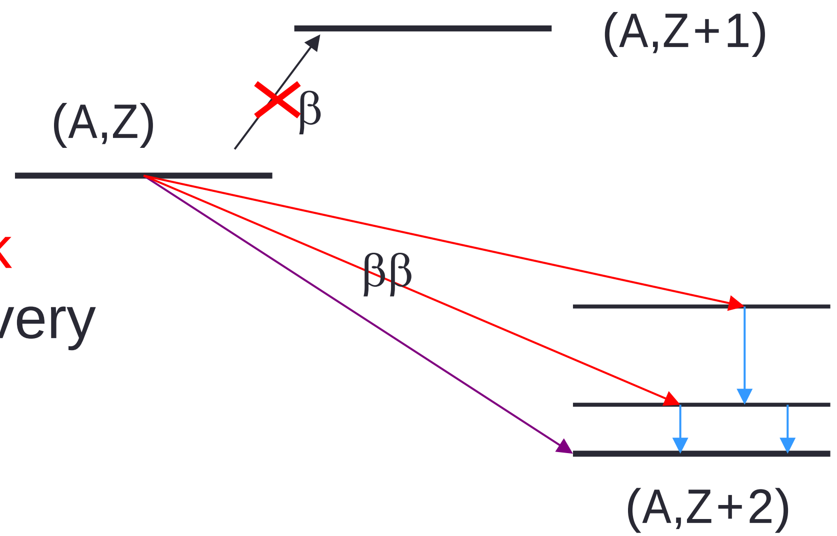
INFN, Laboratori Nazionali del Sud

IHEP, Beijing, May 17th, 2017



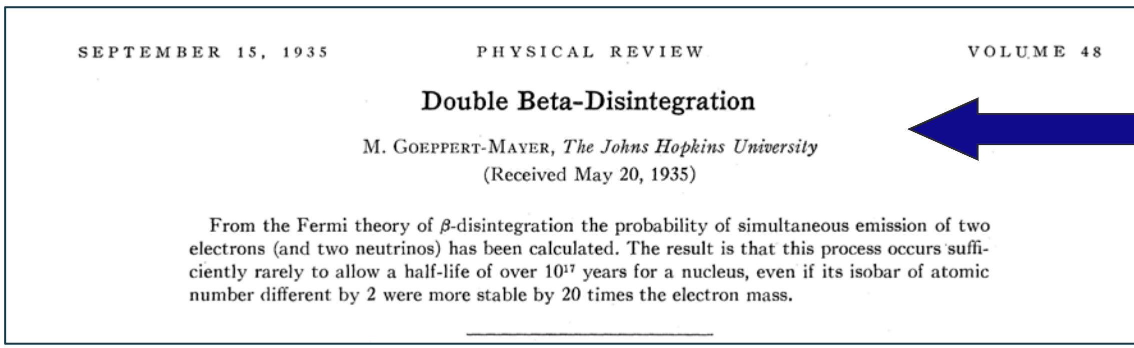
Neutrino-accompained double beta decay

$$(A, Z) \rightarrow (A, Z+2) + 2e^{-} + 2\overline{\nu}_{e}$$



Second-order process of the weak interaction in the Standard Model → very long half-life ($T_{1/2} \sim 10^{19} \div 10^{21}$ yr)

Conserves lepton number



SEPTEMBER 15, 1935 PHYSICAL REVIEW VOLUME 48

Double Beta-Disintegration

M. GOEPPERT-MAYER, *The Johns Hopkins University*
(Received May 20, 1935)

From the Fermi theory of β-disintegration the probability of simultaneous emission of two electrons (and two neutrinos) has been calculated. The result is that this process occurs sufficiently rarely to allow a half-life of over 10^{17} years for a nucleus, even if its isobar of atomic number different by 2 were more stable by 20 times the electron mass.

Described for the first time by M. Goeppert-Mayer (1935), based on the Fermi theory

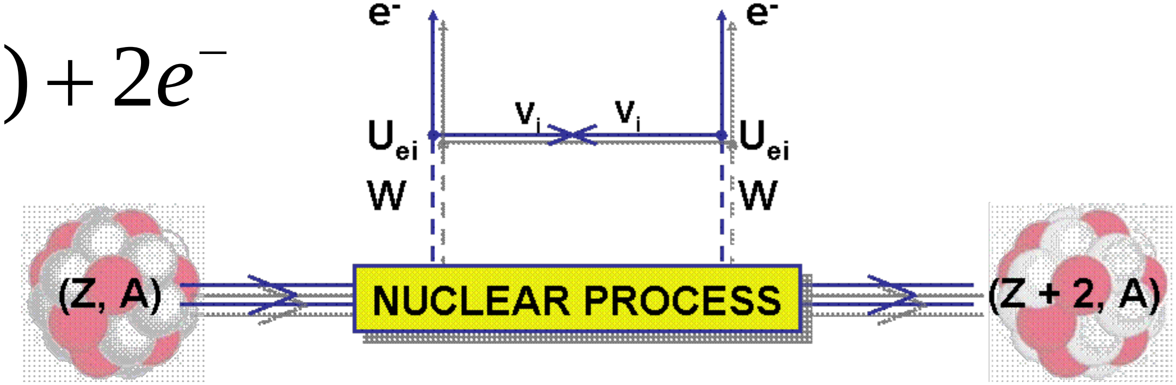
Observable when the (much faster) single-β decay is **forbidden** by energy conservation (e.g. in even-even nuclei)

Experimentaly seen in many nuclei (^{82}Se, ^{100}Mo, ^{48}Ca, ^{76}Ge, ...)

Neutrinoless double beta decay

$$(A,Z) \rightarrow (A,Z+2) + 2e^-$$

Violates lepton number conservation: ΔL=2



Forbidden in the SM → **new physics** (massive Majorana ν)

Very **rare process**: $T_{1/2}$ > **$10^{25\text{-}26}$ yr** → **< 1 event/(ton yr)**
requires unprecedented low-background conditions!

Explore **Dirac/Majorana nature** of neutrino and absolute **mass scale**

If leading mechanism = exchange of massive Majorana ν:

$$\boxed{1/\tau = G(Q,Z)\, |M_{nucl}|^2 <m_{ee}>^2}$$

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

0νββ Decay rate

Phase space ($\sim Q^5$)

Nuclear matrix element

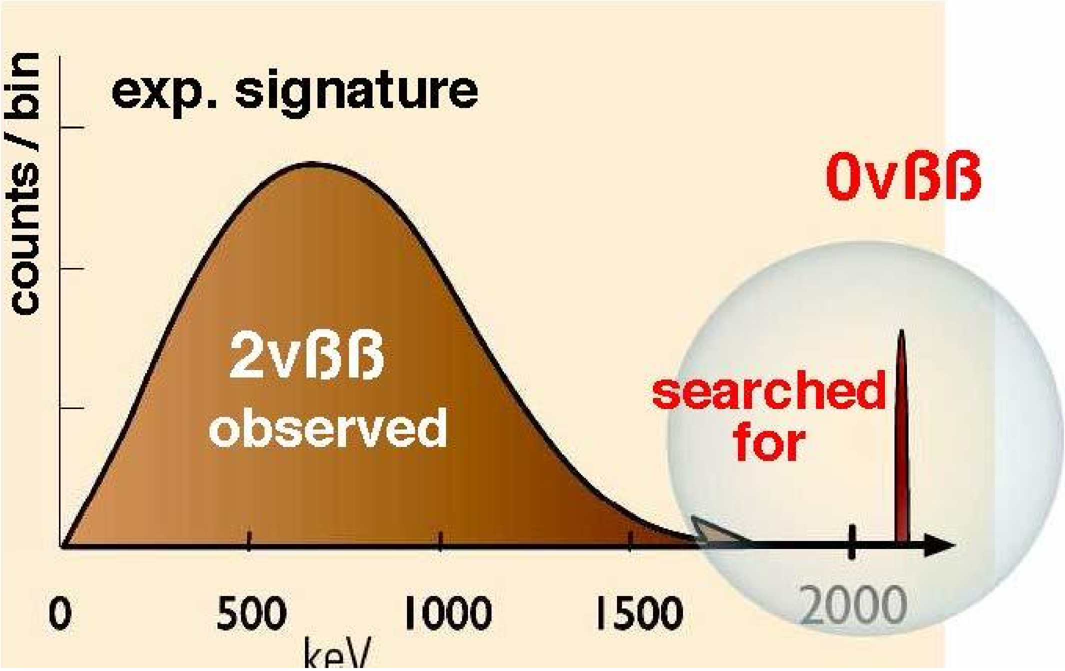
Majorana neutrino mass (coherent sum)

Neutrinoless double beta decay

Experimental **signature** of 0ν2β:

line in the energy spectrum, at the **$Q_{\beta\beta}$-value** of the decay

Neutrino-accompained decay
→ *continuous* spectrum

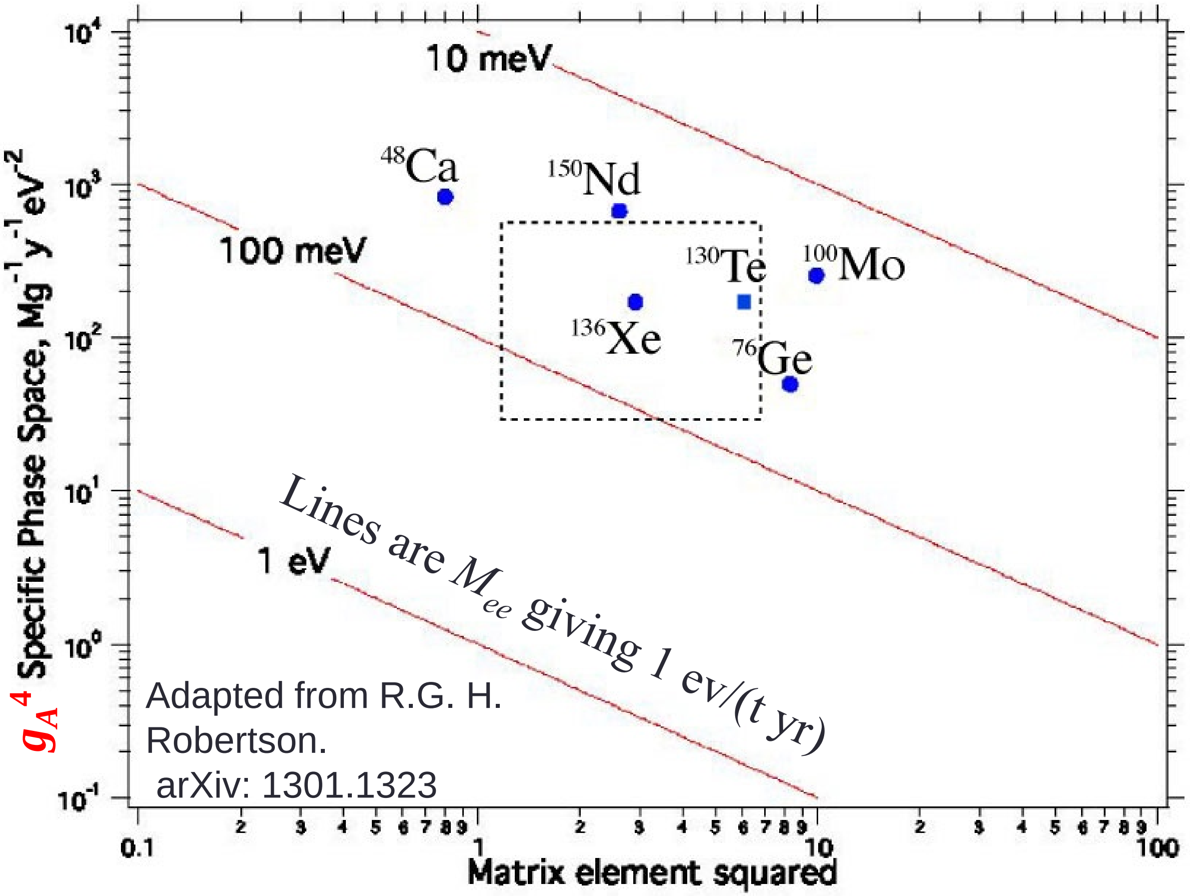


Other **key signatures** that can be exploited in experiments:

- mono-energetic event due to **electrons**, rather than γ (different topology: e^- are more localized)

- event having **two** particles, with characteristic distributions in energy and angle (→ shed light on the mechanism which generates 0ν2β)

Many 0ν2β candidates…



- Many different **candidate isotopes** available
  - no **clear** **"golden candidate"**
    - Similar specific rates (within a factor of two)
  - ^{76}Ge important also for historical reasons
- Choice on **practical** grounds
  - "Easy" **enrichment**
  - Energy **resolution**
  - $T_{1/2}$ of **2ν** decay
  - **Scalability**/modularity
  - **Cost**

Exposures of many **10's of kg·yr** achieved with ^{76}Ge, ^{130}Te, ^{100}Mo and ^{136}Xe → next round is scale up to 100's kg·yr

Why ^{76}Ge ?

- **HPGe technology**: commercial, reliable, well-known
  - Going to be a big "material screening" experiment
  - Very good (radio)purity
- Excellent **energy resolution** (< 4 keV FWHM at $Q_{\beta\beta}$)
  - No background from the 2ν2β decay
- **Source = detector**
- Handles for **background suppression**
  - Anti-coincidence, pulse shape discrimination
  - Low-background tecniques available
- Also **drawbacks**
  - $Q_{\beta\beta}$ relatively low, 2039 keV
    - below the 2614 keV line from ^{208}Tl (the highest-energy from environmental radioactivity) → sensitive to γ-induced background
  - Low isotopic abundance (7.8%)
    - Needs (expensive) **enrichment**: 50 $/g

GERDA experiment at LNGS

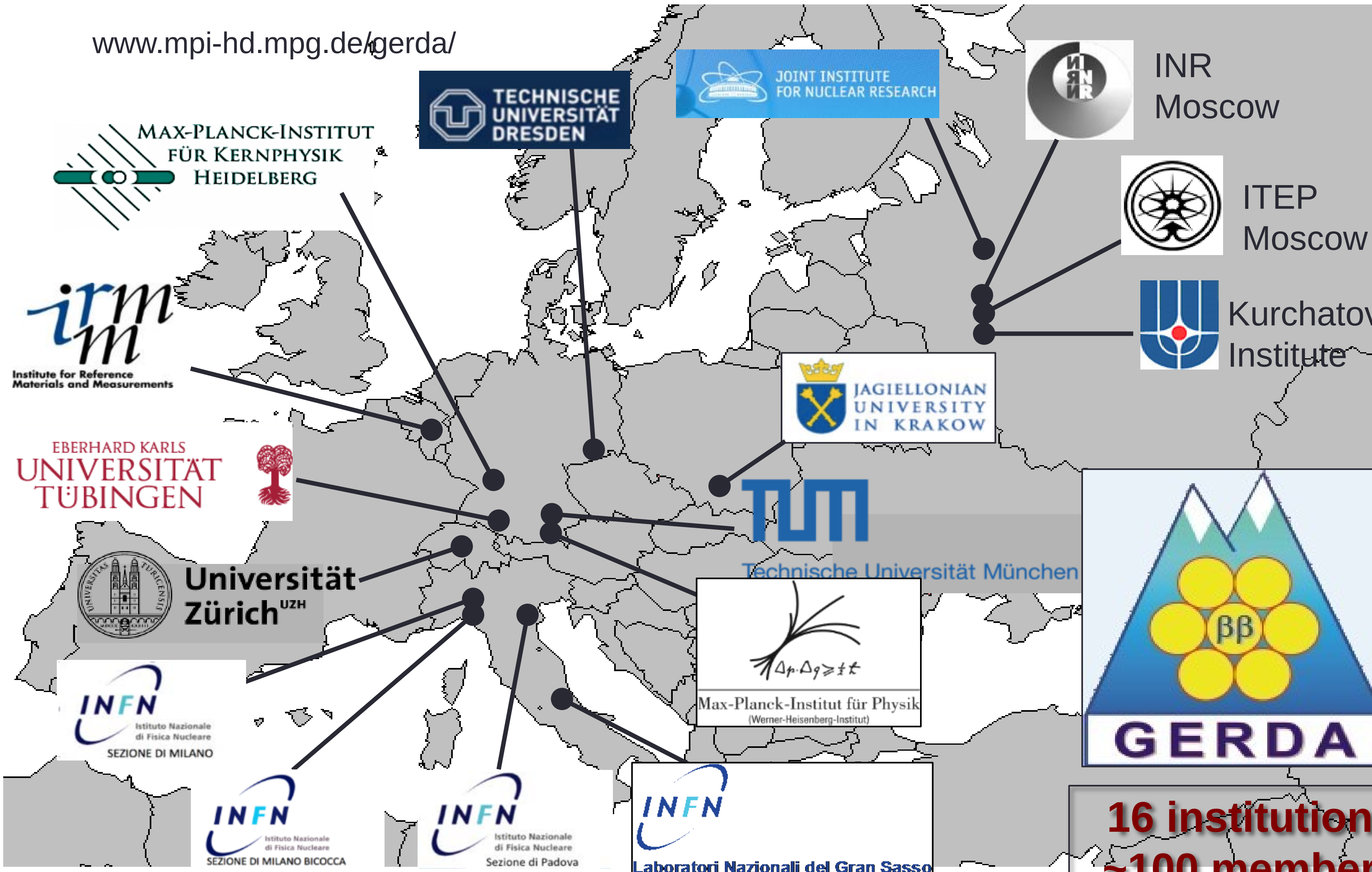
The **GERmanium Detector Array** experiment searches for 0ν2β decay in ^{76}Ge using HPGe detectors enriched in ^{76}Ge

Hosted in the Hall A of the Gran Sasso Laboratory, INFN

Suppression of μ-flux > 10^6

GERDA: the Collaboration

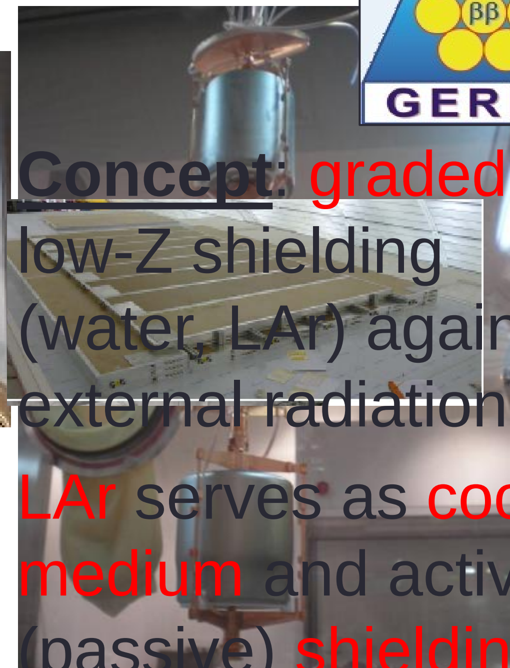
www.mpi-hd.mpg.de/gerda/

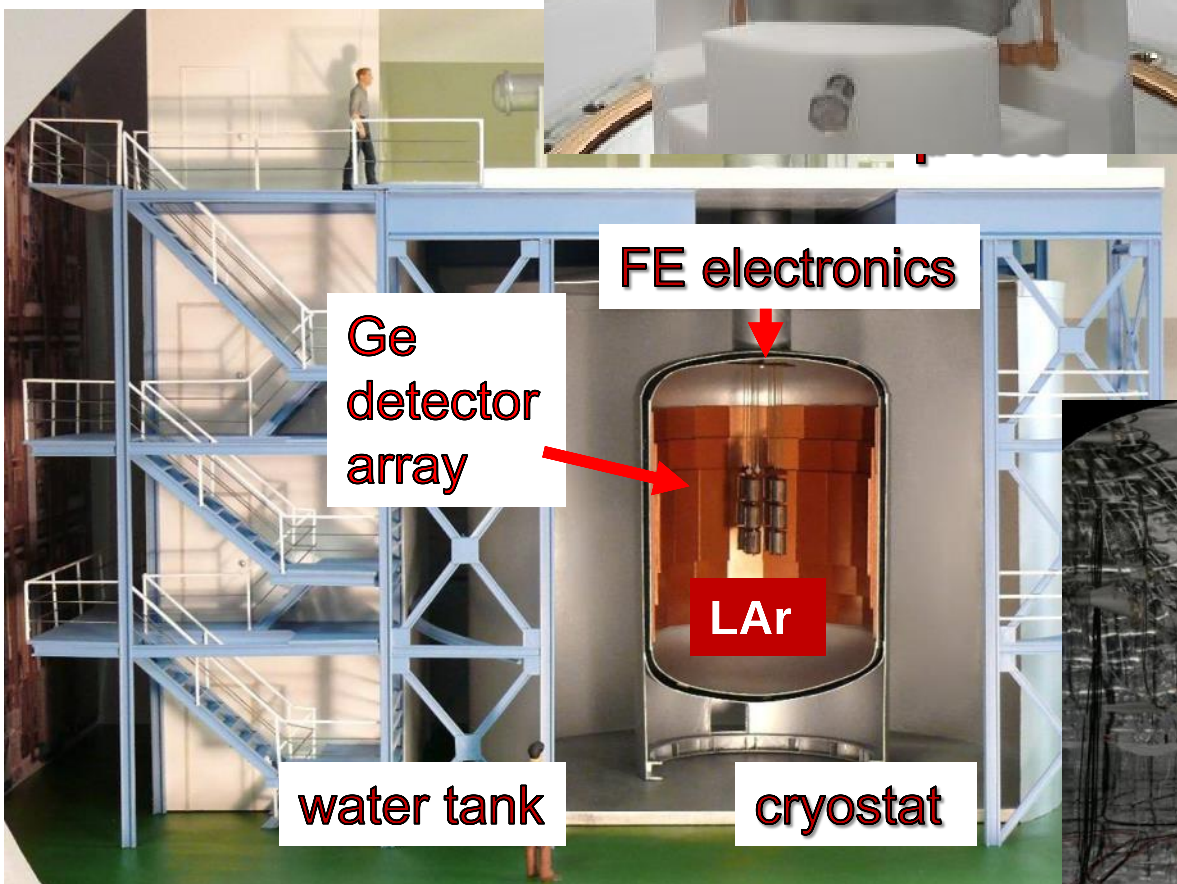


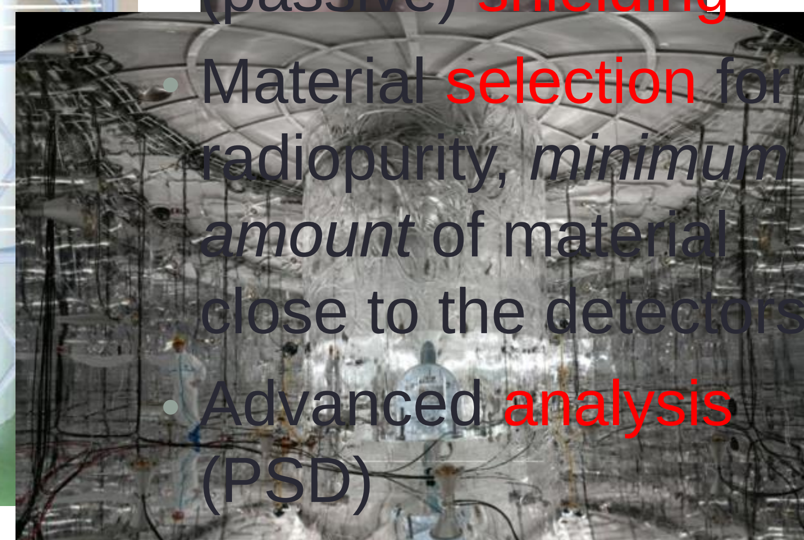
16 institutions
~100 members

GERDA concept

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

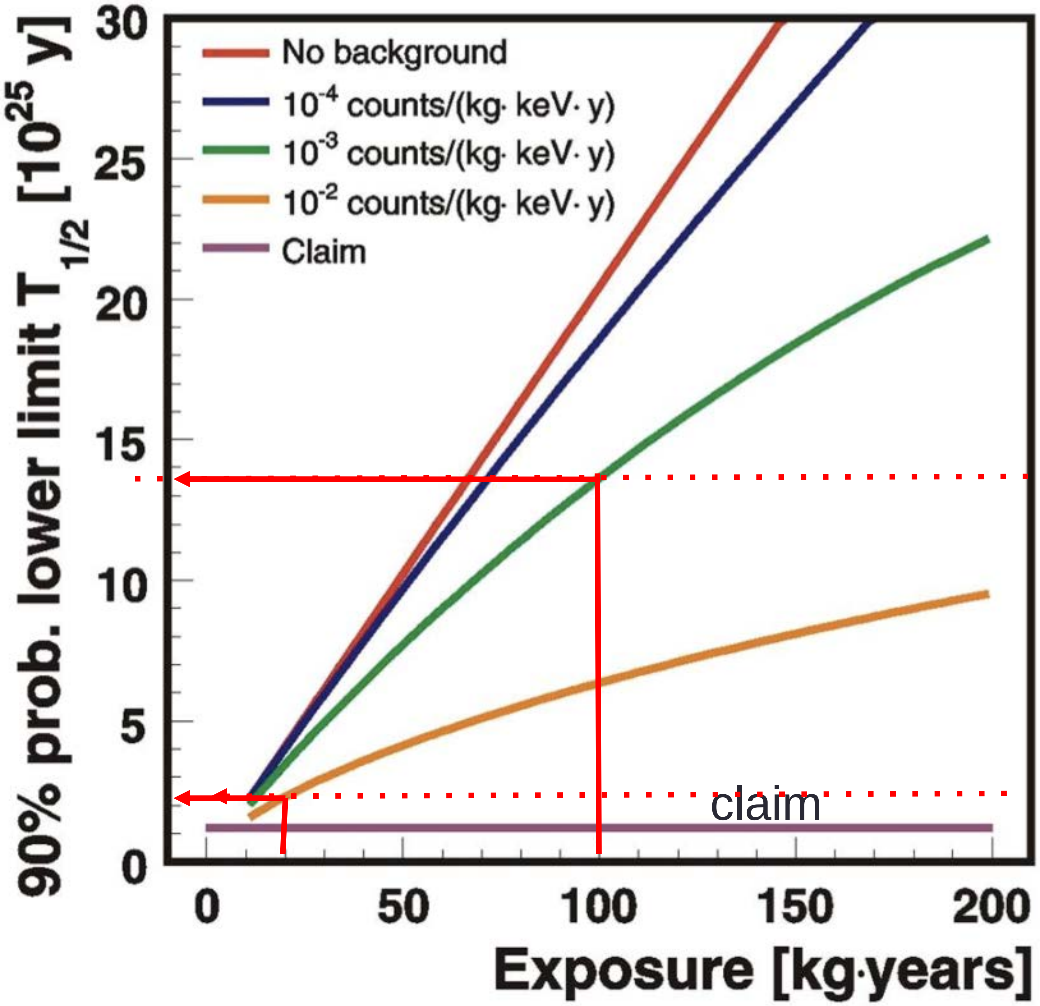






- **Concept**: graded low-Z shielding (water, LAr) against external radiation
- LAr serves as cooling medium and active (passive) shielding
- Material selection for radiopurity, *minimum amount* of material close to the detectors
- Advanced analysis (PSD)

Goals and phases



Phase I:

Completed (Nov 2011-May 2013)

Use refurbished HdM and IGEX (18 kg) (+new Phase II detectors, deployed Jun 2012)

B ≈ 0.01 cts / (keV kg yr)

No LAr readout (passive shield)

Accumulated 21 kg yr

Main purpose: test the KK claim

Phase II:

Add new ^{enr}Ge detectors (20 kg)

BI ≈ 0.001 cts / (keV kg yr)

Goal: 100 kg yr

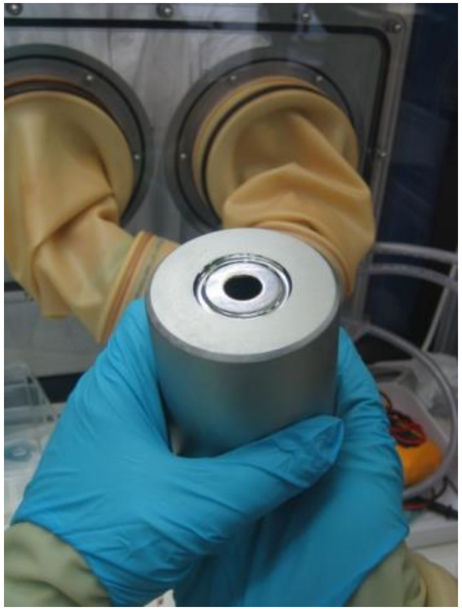
Started on **December 2015**

First data release on Jun 2016 (about 11 kg yr)

Background assessment

Data taking **ongoing** (> 30 kg yr)

The main actors: HPGe detectors



8 diodes (from HdM, IGEX)

- Enriched 86% in ^{76}Ge
- Total mass 17.7 kg
- Reprocessed by Canberra
- Resolution in LAr ~2.5 keV FWHM at 1333 keV

30 new Phase II detectors (custom-made)

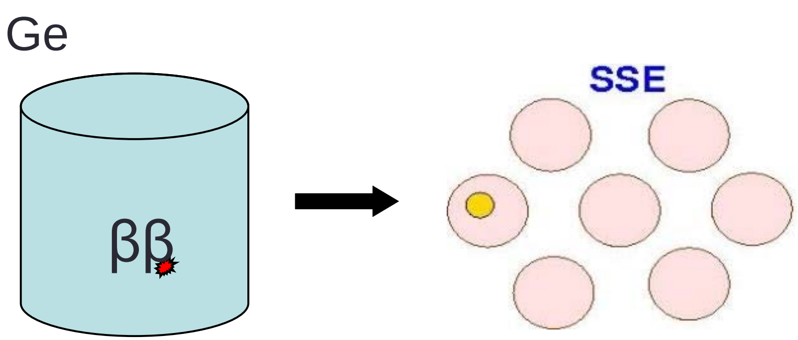
- **BEGe type** (allow for better PSD)
- Total mass: 20.0 kg
- Enriched 86% in ^{76}Ge
- Better resolution (~1.8 keV)
- 5 detectors from the first production batch used in Phase I

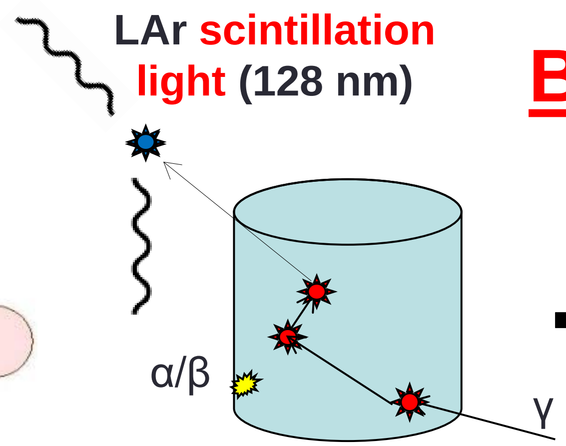
Eur. Phys. J. C 73 (2013) 2330
Eur. Phys. J. C 75 (2015) 39

Detectors arranged in **strings** and deployed in LAr

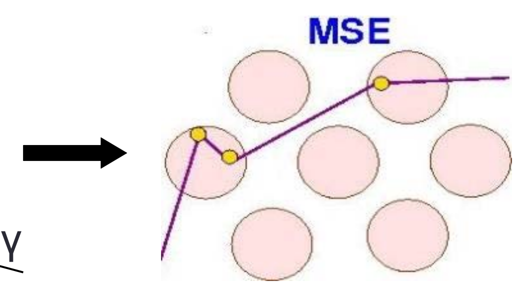
Background reduction tools

Signal





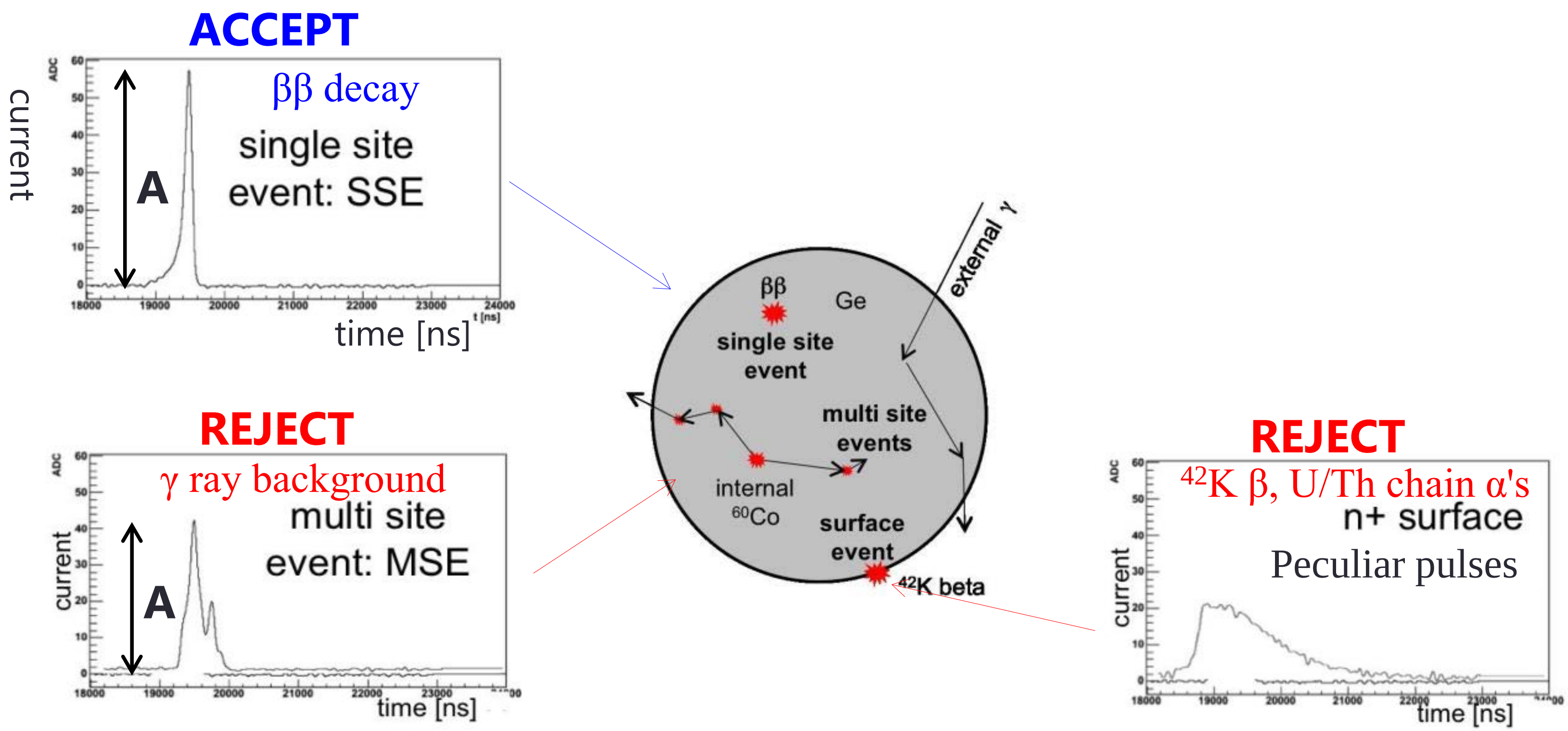
Backgrounds



Point-like (single-site) energy deposition inside one HP-Ge diode

Multi-site energy deposition inside HP-Ge diode (Compton scattering), or **surface** events

- **Anti-coincidence** with the **muon veto**
- Anti-coincidence **between detectors** (cuts MSE)
- **Active veto** using LAr scintillation (implemented in Phase II)



- **Anti-coincidence** with the **muon veto**
- Anti-coincidence **between detectors** (cuts MSE)
- **Active veto** using LAr scintillation (implemented in Phase II)
- **Pulse shape** discrimination (PSD)
  - MSE within one detector and surface events
  - Very efficient for the BEGe detectors
    - Accept **>90% of SSE**, while rejecting **90%** of MSE and surface events
  - Less efficient with coaxial detectors, but still doable (acc: 90%/ suppr: 50%)

Eur. Phys. J. C 73 (2013) 2583

A QUICK SUMMARY OF PHASE I

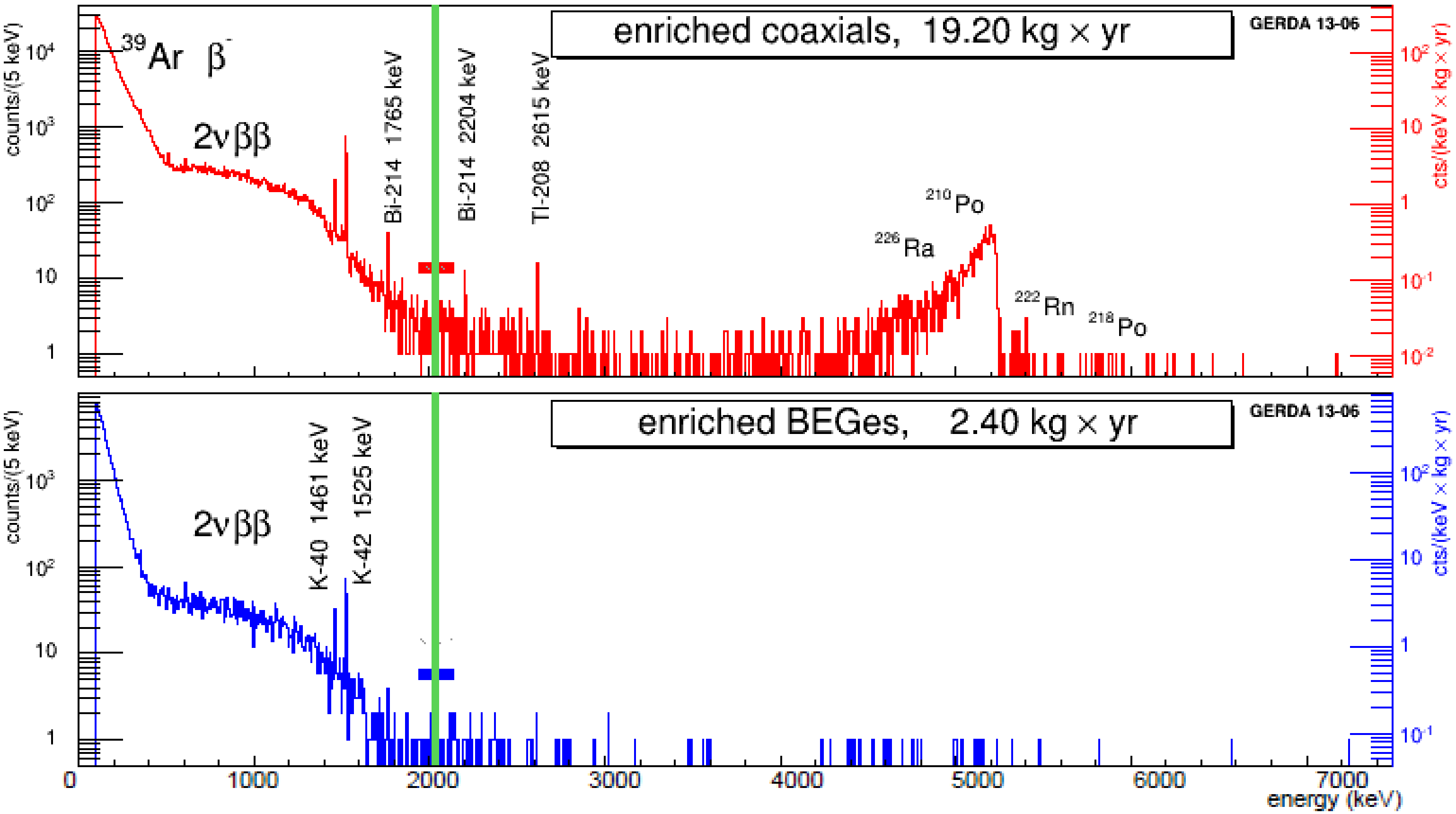
The GERDA datasets

EPJ. C 74 (2014) 2764

- Total exposure: **21.6 kg yr** (diodes) between Nov 9th, 2011 and May 21st, 2013 (492.3 live days, 88.1% duty factor)
  - 5% due to temperature-related instabilities of electronics
  - Five **Phase II** BEGe detectors deployed in **June 2012**
- Data are *not "homogeneous"* throughout the entire data taking
  - Higher background observed for the coaxial detectors for ~**20 days** after the deployment of BEGes (*silver dataset*). All the rest: *golden dataset*
  - BEGe detectors have better energy resolution than coaxials

- **Analysis strategy:**
  - **All data are taken**, but not summed up (separate analysis)
    - Maximizes information, avoids "worse data" to spoil better ones
    - Three datasets used ("golden coax", "silver coax", "BEGes"), with independent backgrounds and resolutions
  - **Blind analysis** (new in the field of $0\nu2\beta$ search)
    - Events in a 40 keV range around $Q_{\beta\beta}$ (energy & waveforms) are not made available for the analysis
    - Develop and validate the background model and the PSD cuts **before** the unblinding (all parameters frozen prior to unblinding)

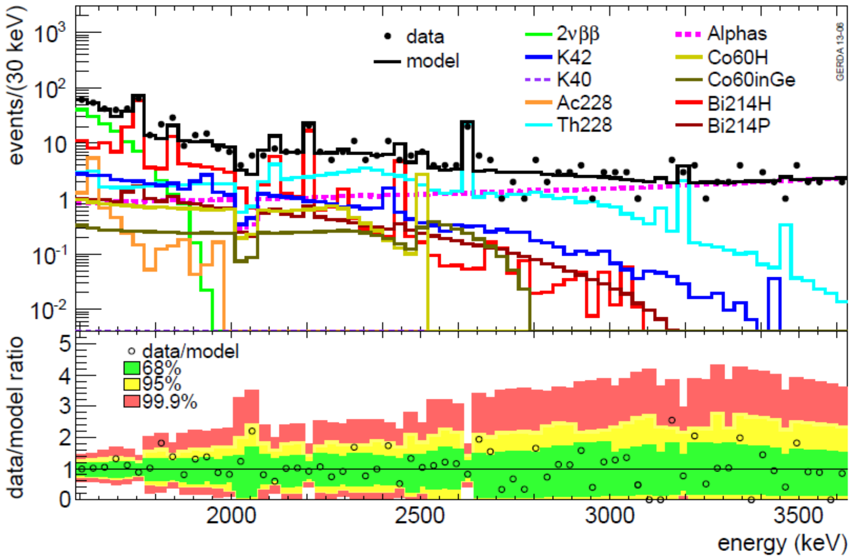
The energy spectrum



- 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)

EPJ. C 74 (2014) 2764

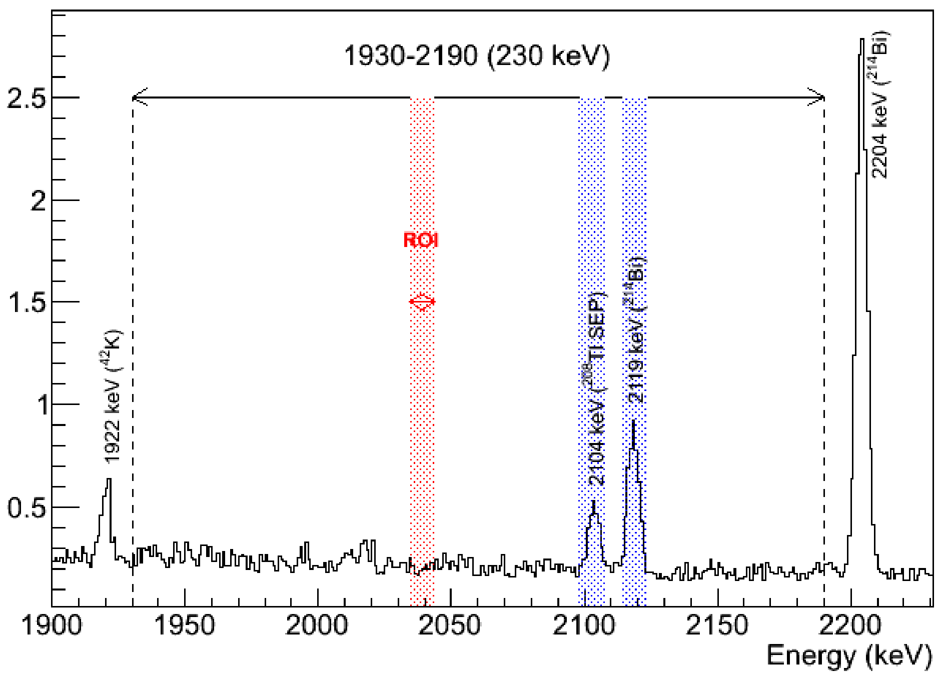
Identification of background components



- **Contributors at $Q_{\beta\beta}$ (for coax)**:
  - γ emitters (close): ^{214}Bi, ^{208}Tl (2/3)
  - surface contaminations: ^{42}K, and α (1/3)
- α contamination from ^{210}Po
  - ^{210}Po decaying away ($T_{1/2}$=138 d)
  - Large differences among detectors

- The model predicts a **flat background** around $Q_{\beta\beta}$
- No intense γ-lines expected around the $Q_{\beta\beta}$

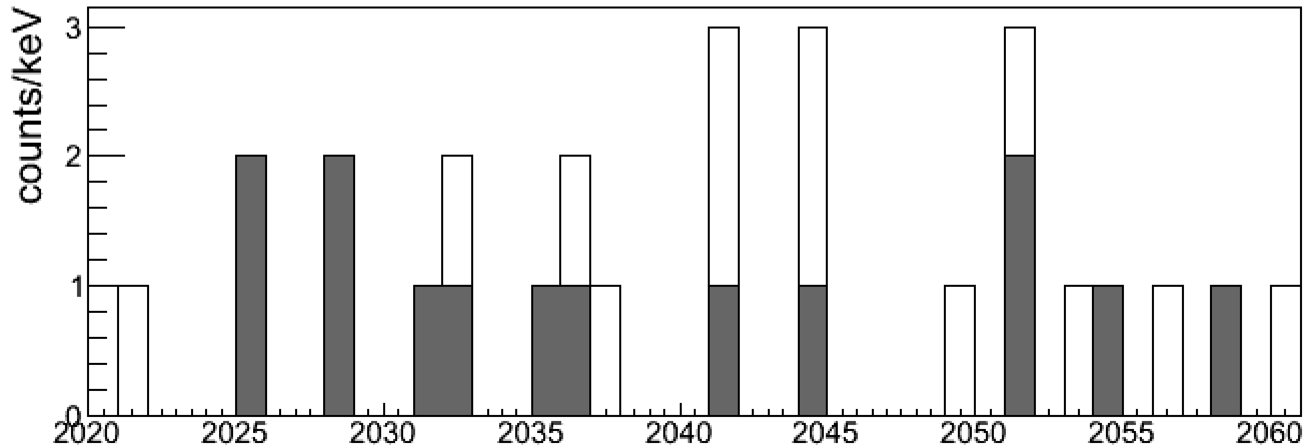
→ spectra can be **fitted with a flat background** apart from lines 2104 keV and 2119 keV



After the unblinding… the spectra

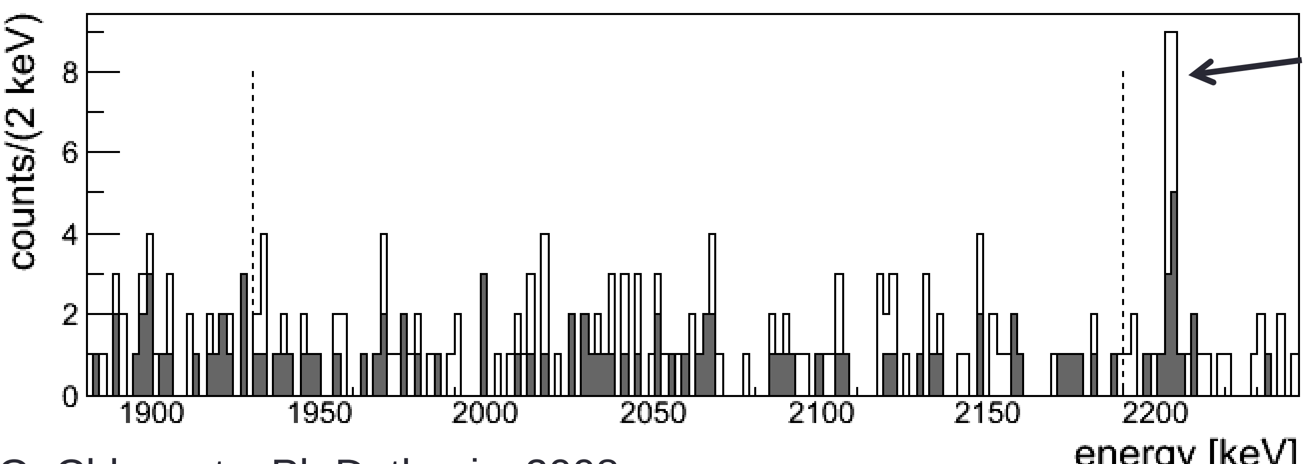
Phys. Rev. Lett. 111 (2013) 122503

- Sum spectrum, **21.6 kg·yr**
  - <u>Note</u>: Real analysis uses the three dataset spectra *separately*



Without PSD

With PSD



2204 keV from ^{214}Bi

~ 18 cts w/o PSD

→ 0.83 cts/(kg·yr)

~ 9 cts w/ PSD

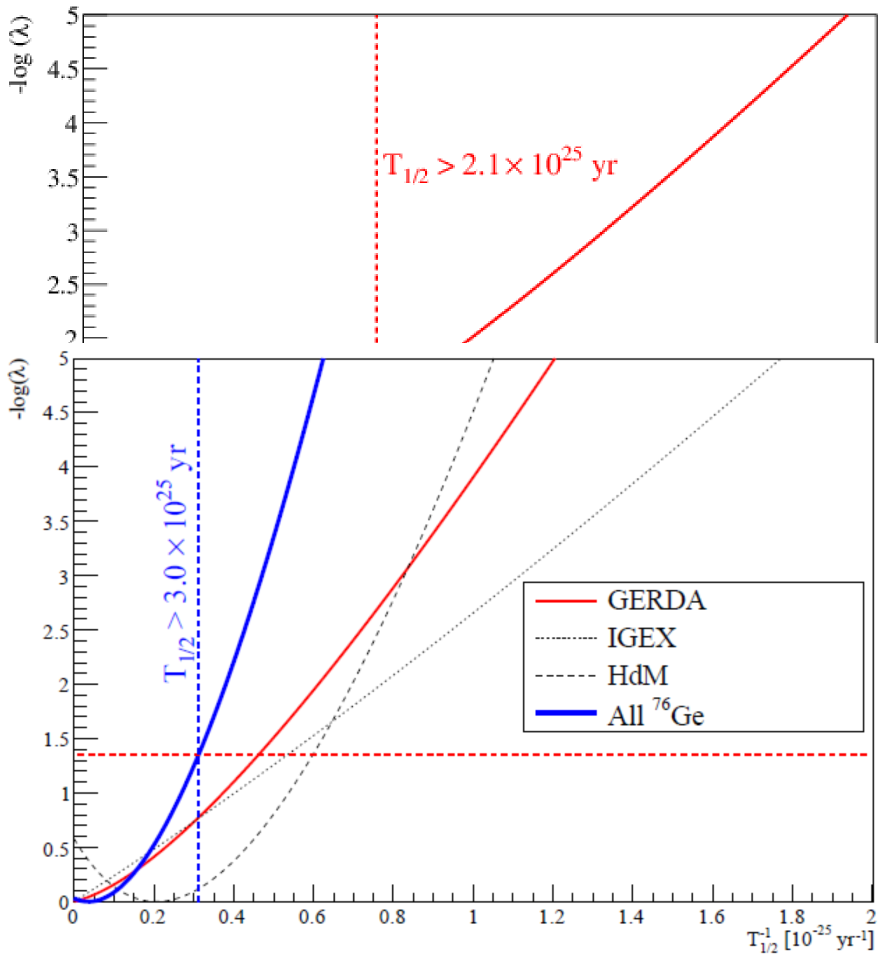
HdM w/o PSD [1]: (8.1±0.5) cts/(kg·yr)

[1] O. Chkvorets, Ph.D. thesis, 2008

The analysis

Phys. Rev. Lett. 111 (2013) 122503

- Baseline analysis with a frequentist approach (profile likelihood)
  - Maximum likelihood spectral fit (3 datasets, common $1/T_{1/2}$)
  - Bayesian version also available



Gerda only

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

$N^{0\nu} < 3.5$ cts @ 90% C.L.

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

MC Median sensitivity (for no signal):
$T_{1/2}^{0\nu} > 2.4 \times 10^{25}$ yr @ 90% C.L.

GERDA+HdM [1] +IGEX [2]

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

$T_{1/2}^{0\nu} > 3.0 \times 10^{25}$ yr @ 90% CL

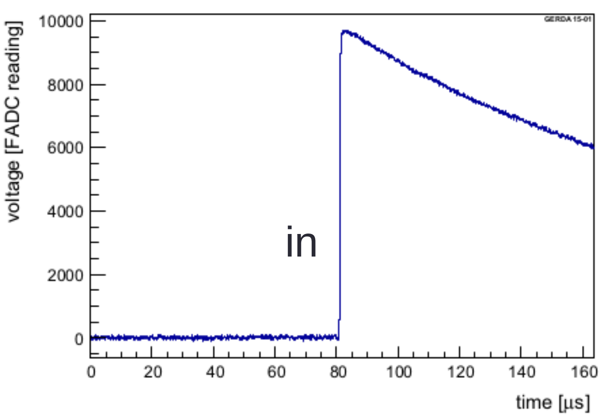
[1] Eur. Phys. J. A 12, 147 (2001)
[2] Phys. Rev. D 65, 092007 (2002),
Phys. Rev. D 70 078302 (2004)

Ge energy reconstruction: ZAC filter

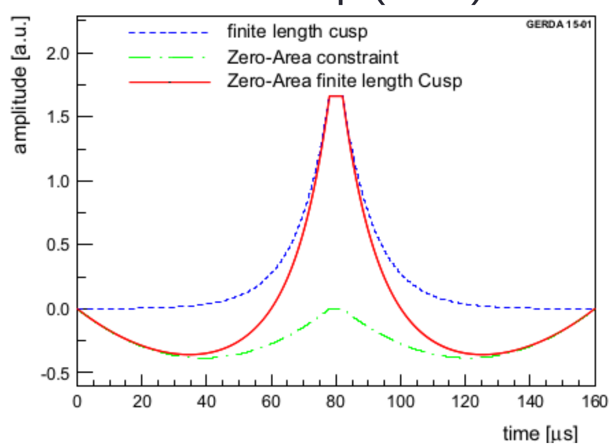
Eur. Phys. J. C 75 (2015) 255

- Development of a new filter for energy reconstruction
  - "Zero Area Cusp" (ZAC)
  - Better handling of low- and high-frequency noise than the Gaussian filter

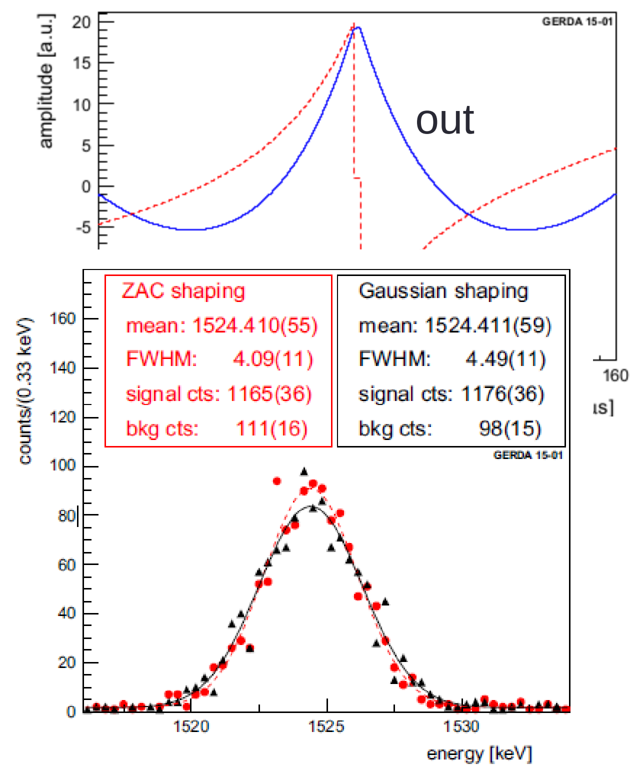
digitized input trace



digital filter constants
zero area cusp (ZAC)



convoluted trace
max = uncalibrated energy

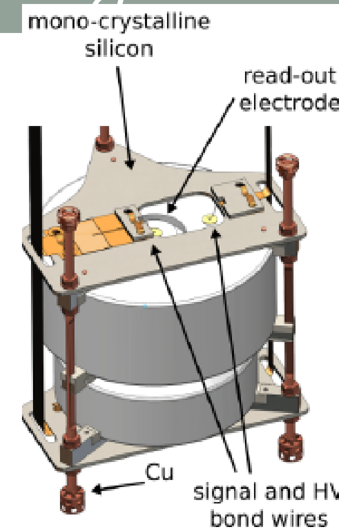


- Meant to replace the Gaussian filter

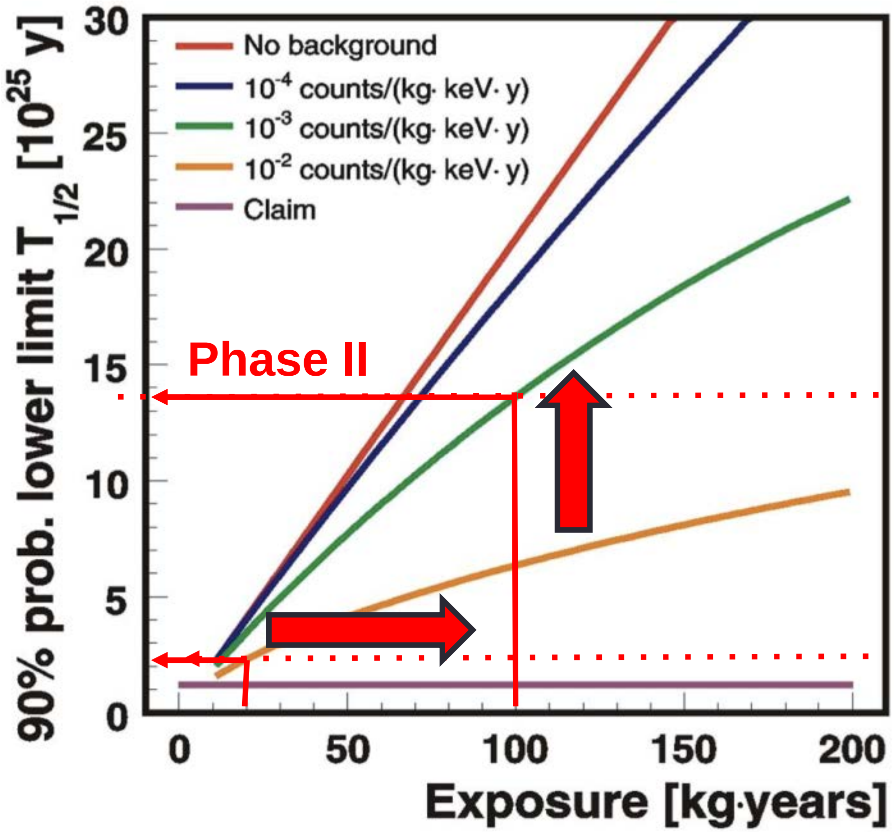
- Phase I: average FWHM coax detectors **4.8 keV →4.25 keV** at $Q_{\beta\beta}$

GERDA PHASE II

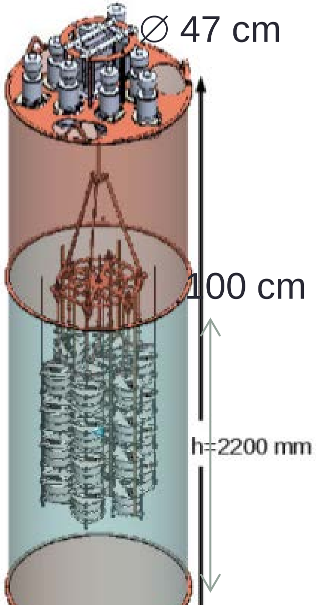
Transition to Phase II (2013-2015)



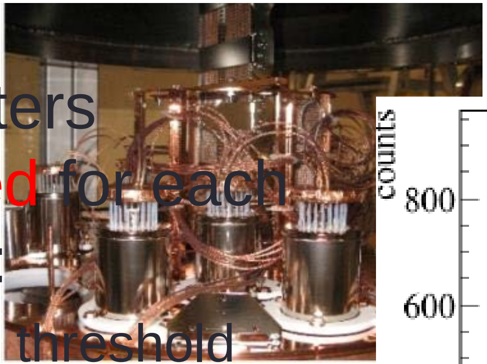
- **Target**: push $T_{1/2}$ sensitivity into the **10^{26} yr range**
  - Increase exposure : 20 kg yr → 100 kg yr
  - Reduce background 10^{-2} → 10^{-3} counts/(keV kg yr)
- Mass increase: +30 enriched BEGe detectors (~ **20 kg**)
  - produced by Canberra Olen and completely tested at Hades (Belgium)
  - first BEGe sample already tested in the data chain of the Phase I
- x10 background reduction
  - **PSD** with the BEGe's
  - **Liquid argon veto instrumentation** to detect scintillation light
  - New lower mass holders and contacting solution (wire bonding)



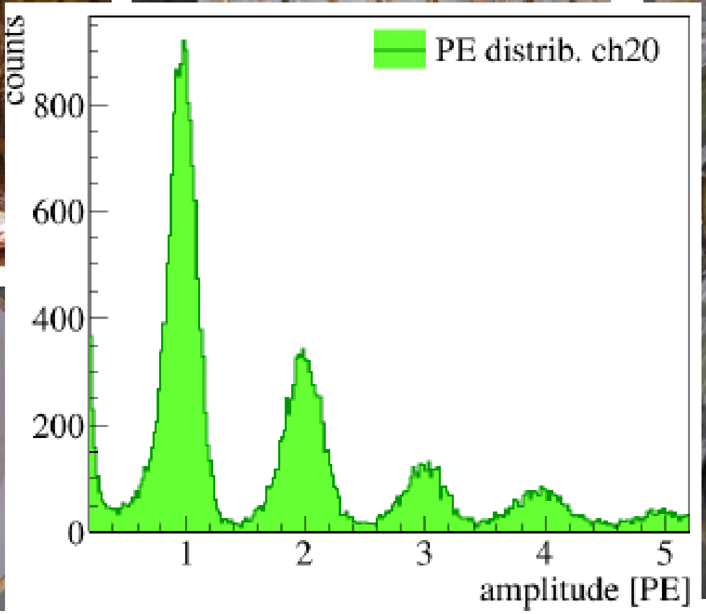
Liquid Argon veto of Phase II

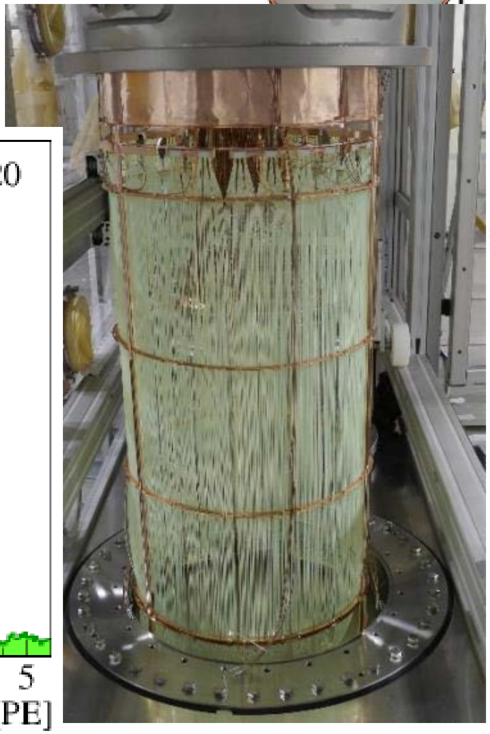


- **Hybrid system** to detect LAr scintillation light
  - Curtain of scintillating fibers (800m fibers coated with wave-length-shifter), 90 SiPMs (grouped x6)
  - 3"-PMTs on the top and on the bottom of the array (9+7)
  - Nylon mini-shroud around each string coated with wave-length-shifting



- Parameters optimized for each channel:
  - 0.5 phe threshold
  - 5-6 µs a
    coincide

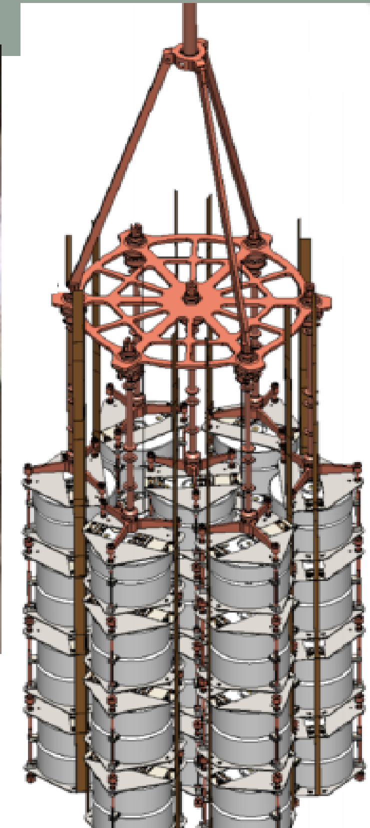




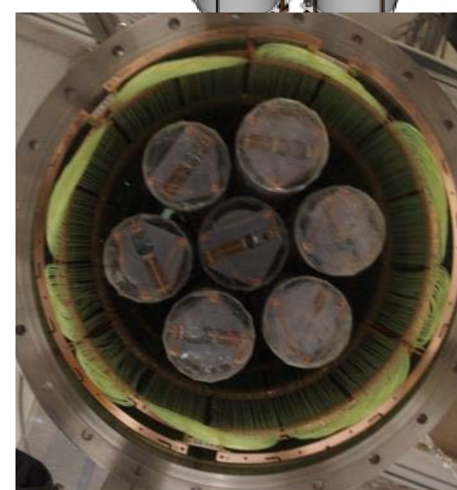
Phase II Array

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

36 kg

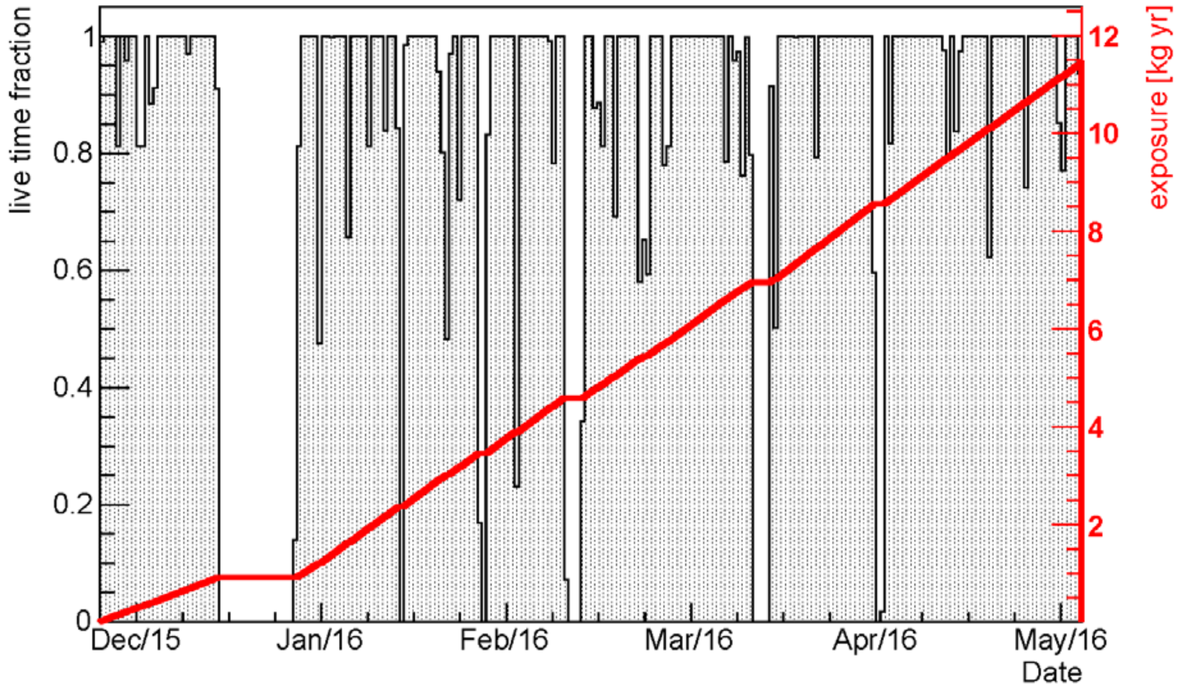


All channels working



Phase II data taking – first release

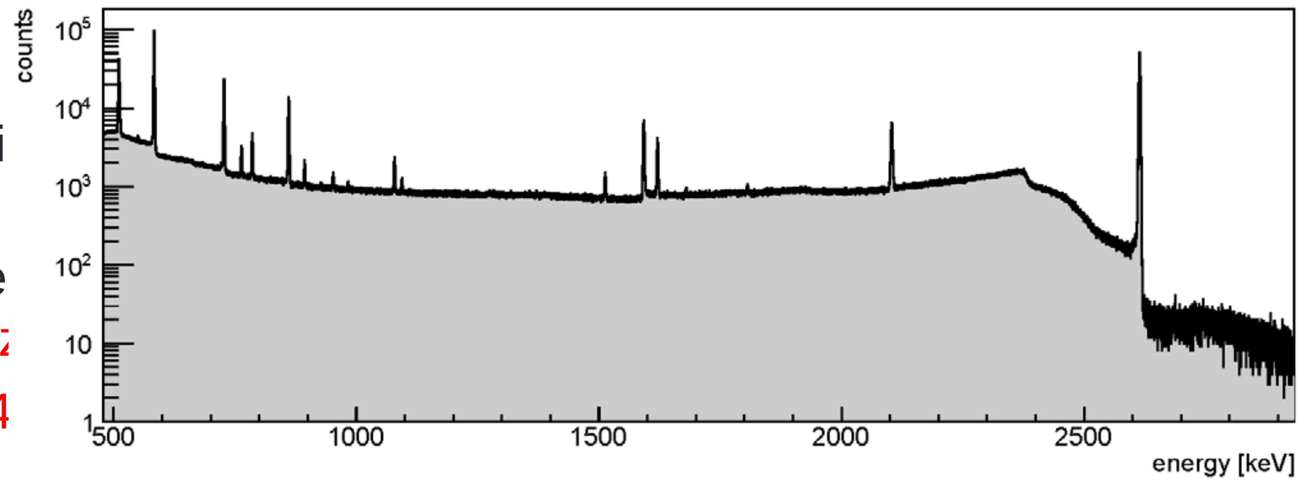
- Data taking between Dec 25th, 2015 and Jun 1st, 2016 (130.7 live days)
- 82.0% duty factor
- **Blinding** applied at **$Q_{\beta\beta}$ ± 25 keV**

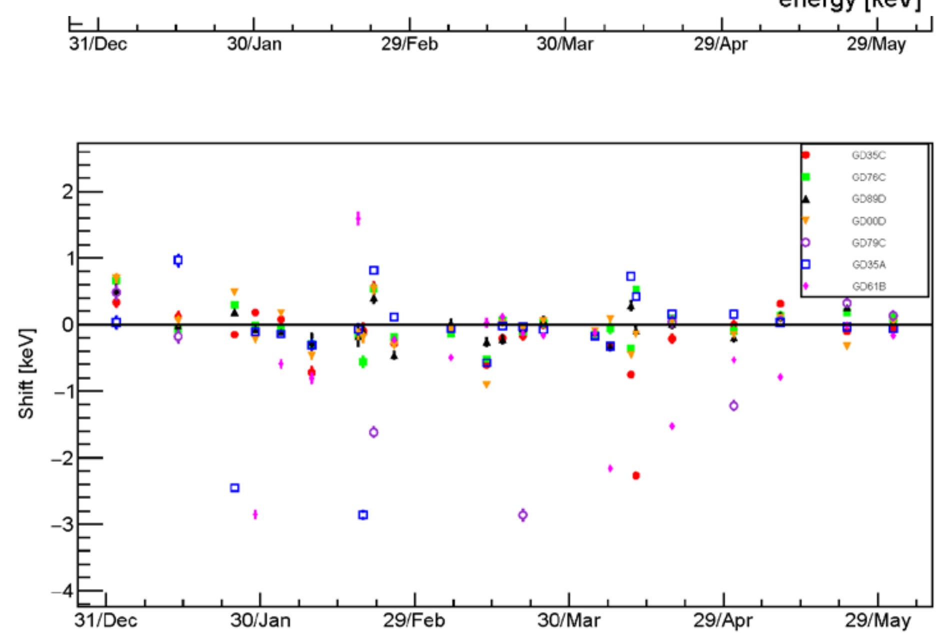


- Usable for analysis **10.8 kg·yr**
  - 5.8 kg·yr BEGe and 5.0 kg·yr coax, plus 2.8 kg·yr ^{nat}Ge
  - About 0.4 kg·yr of BEGe data not considered due to poor PSD
- Additional **unpublished data** from Phase I (**1.9 kg·yr**)
  - Taken after the freezing of the Phase I release dataset (Jul-Sep 2013)
  - Still blinded since 2013

Energy scale and stability

- DAQ facts:
  - 14 bit, 25 MHz conti ADC (160 μs)
  - Leading edge of the sampled at 100 MH
  - Trigger threshold ~4
- Energy scale
  - Offline, using optimized ZAC filter
  - Calibrations with ^{228}Th source every 1-2 weeks
  - Position of the 2614 keV line from ^{208}Tl between successive calibrations **stable** (Δ < **1 keV**)
- Stability monitored online with Test Pulses, injected every 20 s

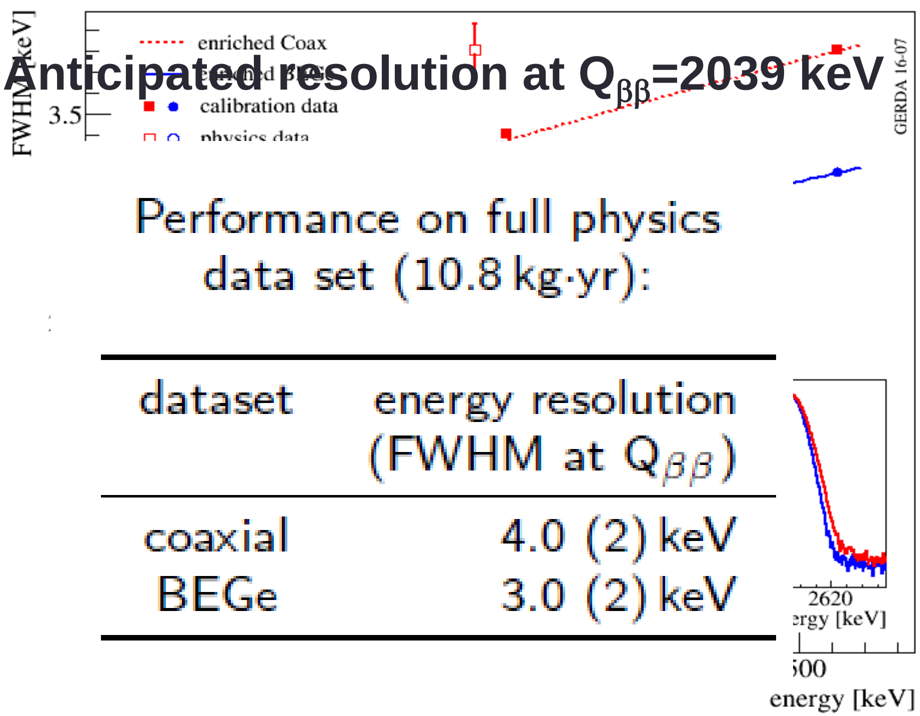




Energy resolution

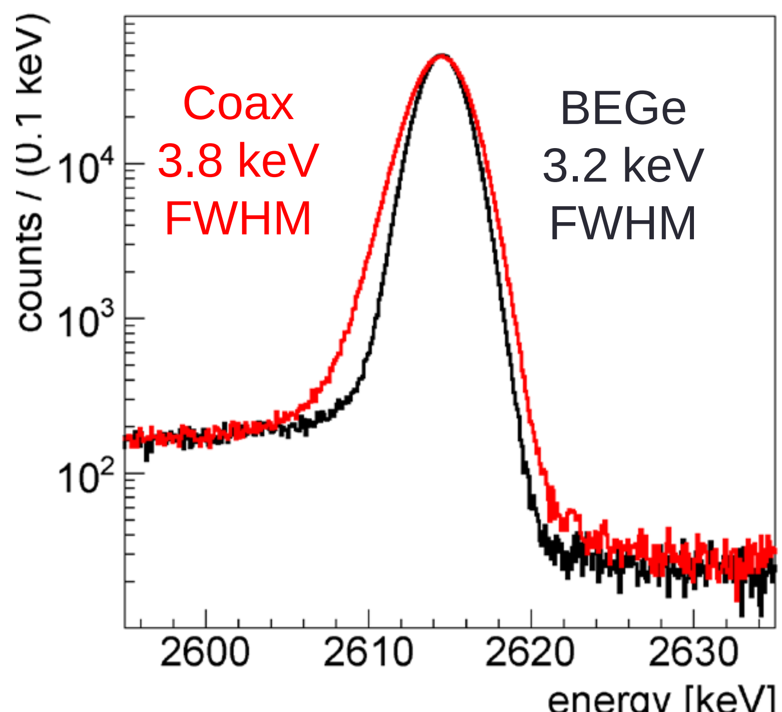
- Resolution profile derived from ^{228}Th calibrations
- Correction applied derived from the resolution of the ^{40}K and ^{42}K peaks in the physics data
  - Accounts for **instabilities** during the long-term data taking
- Data with unreliable energy scale not considered for analysis

Anticipated resolution at $Q_{\beta\beta}$=2039 keV

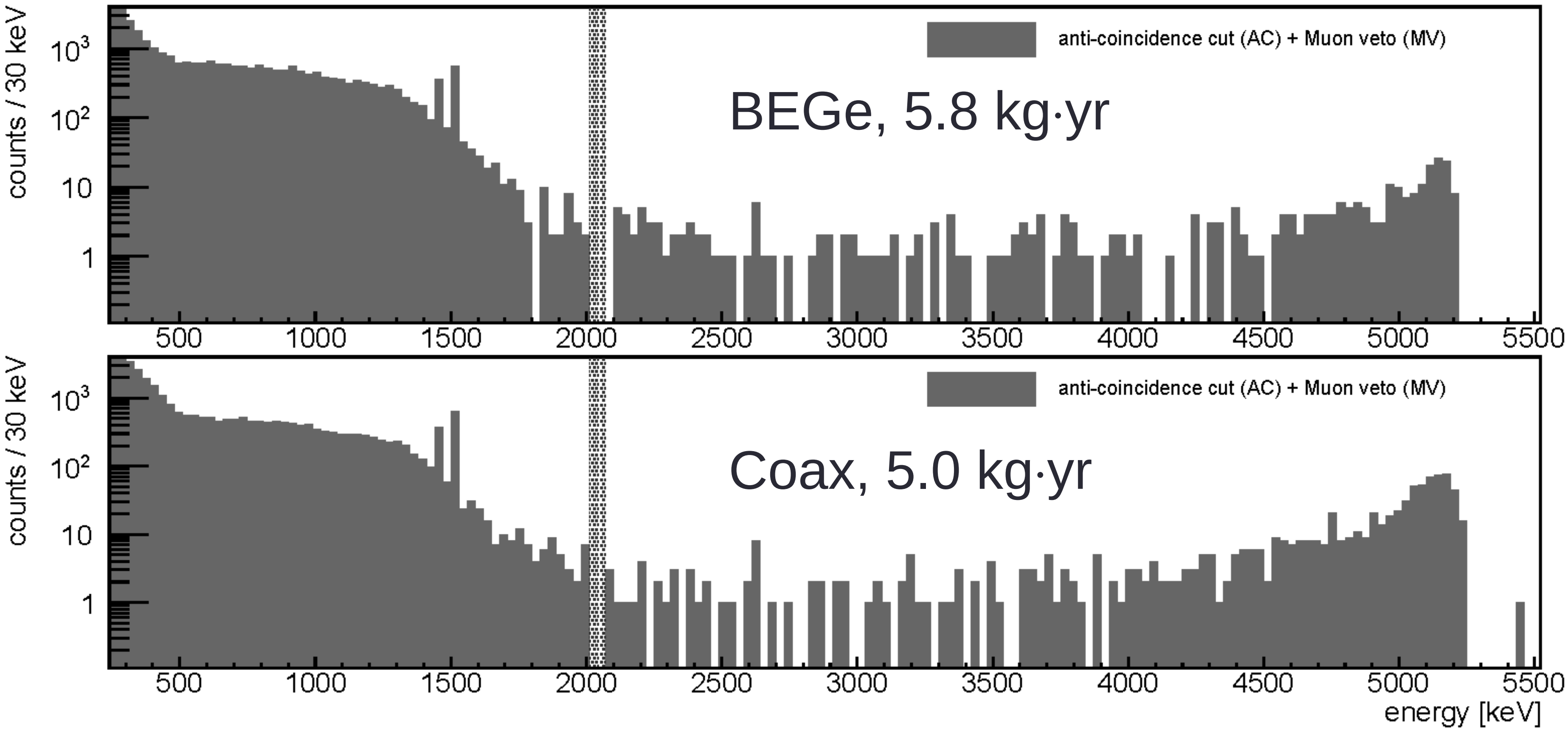


Performance on full physics data set (10.8 kg·yr):

dataset	energy resolution (FWHM at $Q_{\beta\beta}$)
coaxial	4.0 (2) keV
BEGe	3.0 (2) keV

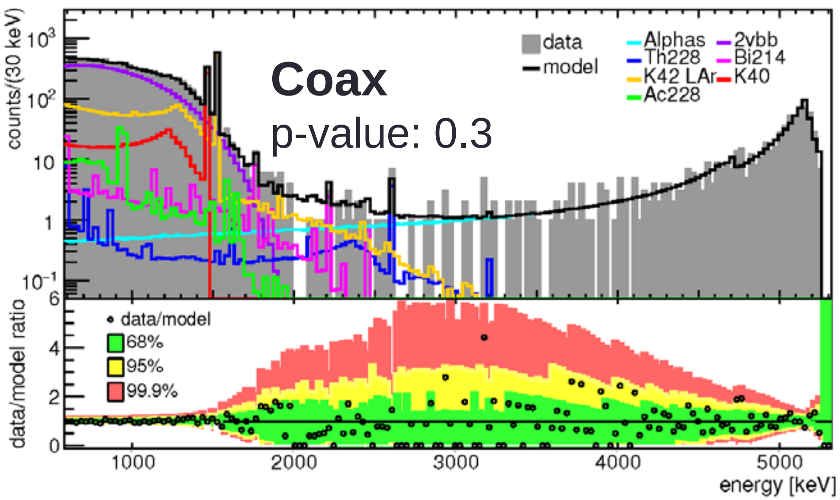


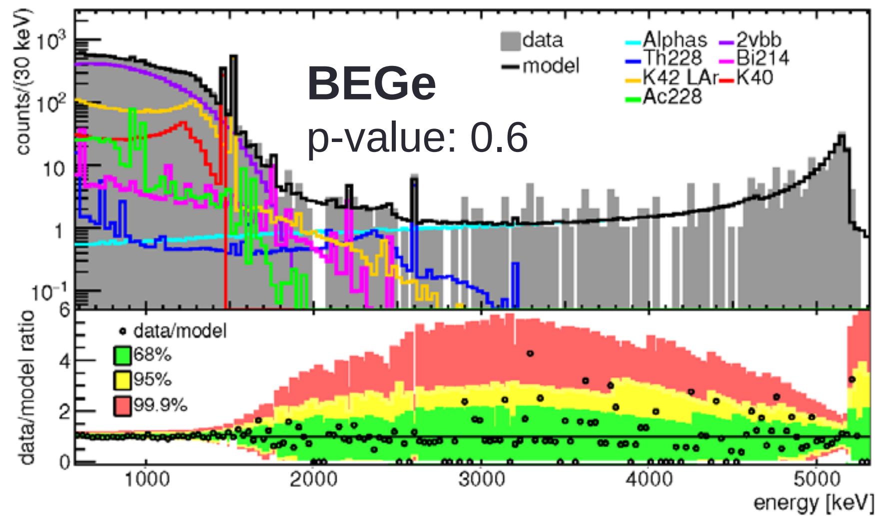
Phase II (raw) energy spectrum



- Only a few γ-lines observed (^{40}K, ^{42}K)
  - **Consistent** with Phase I
- Coax detectors have higher α rate

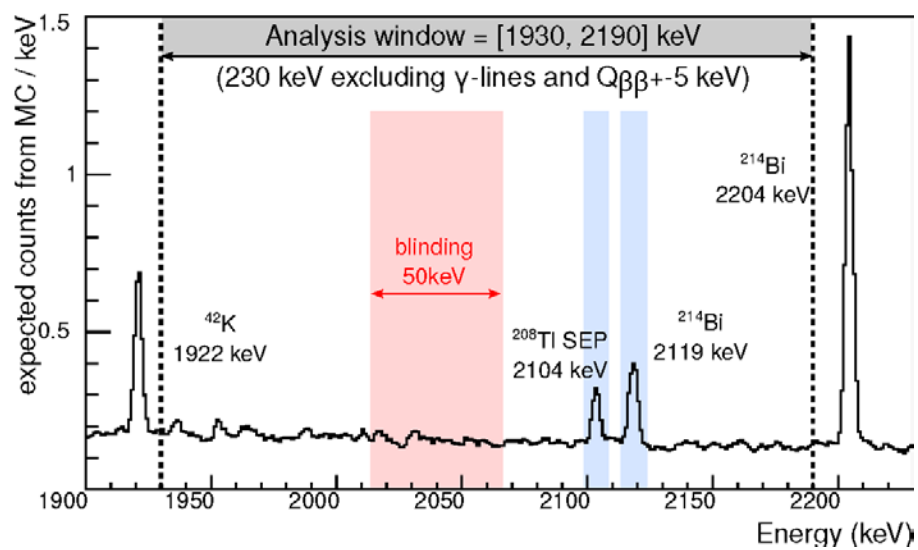
Background modeling





- Very same approach as in Phase I
  - Mostly, same components considered
  - Fit range 570-5300 keV
- Results for ^{228}Th and ^{226}Ra consistent with screening results
- Use the same analysis window as Phase I
  - 1930-2190 keV, excl. ±5 keV around two known γ lines

EPJ. C 74 (2014) 2764



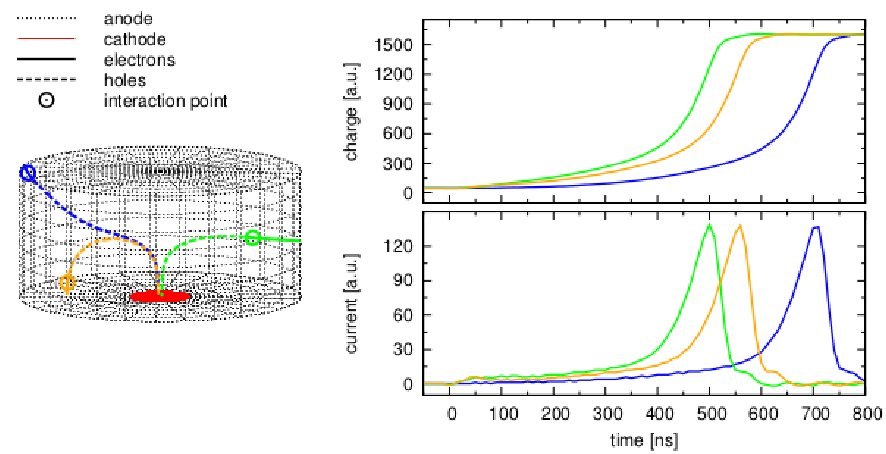
PSD for BEGe detectors

Eur. Phys. J. C 73 (2013) 2583

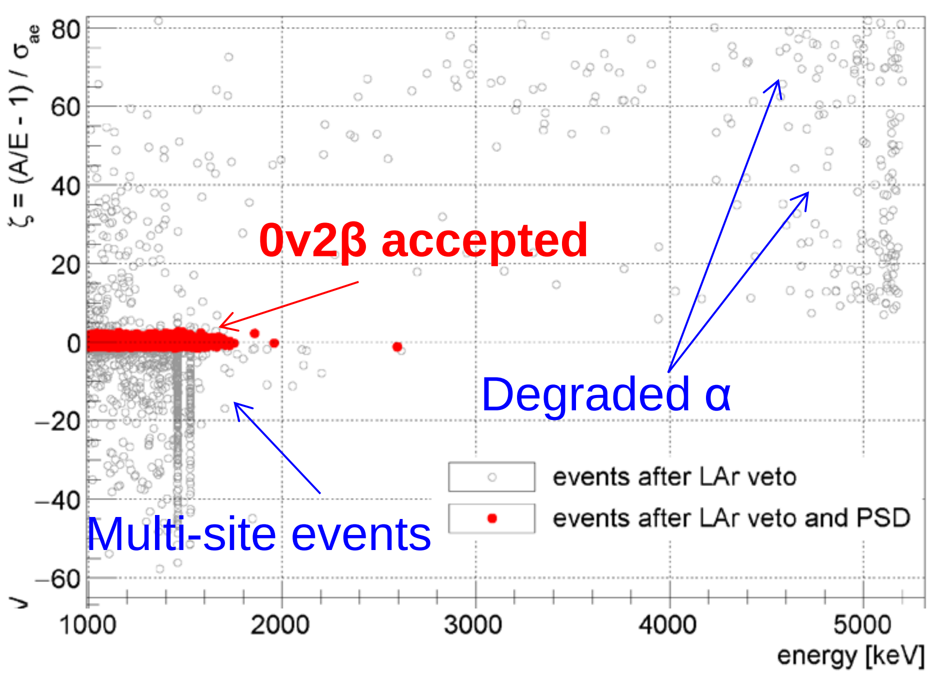
- **A/E**: single parameter
  - Amplitude of Current/Amplitude of Charge Pulse
- *Event-per-event* selection
  - **Above band**: events on p+ electrode (e.g. α's from ^{210}Po)
  - **Below band**: events on n+ electrode, multiple scattering

Acceptance for 0ν2β events: **(87 ± 2)%**

- Estimated from ^{208}Tl DEP
- Double-check at low energy with 2ν2β events (LAr cut)



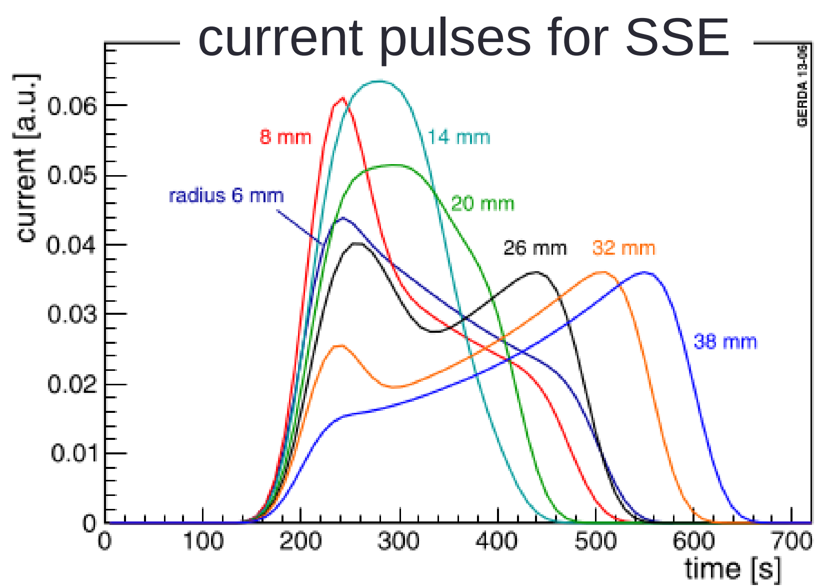
(a) Trajectories (b) Charge and current pulses

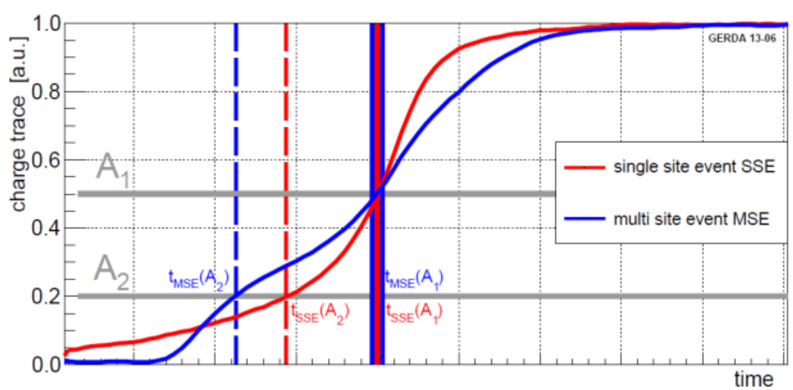


PSD for coaxial detectors

Eur. Phys. J. C 73 (2013) 2583

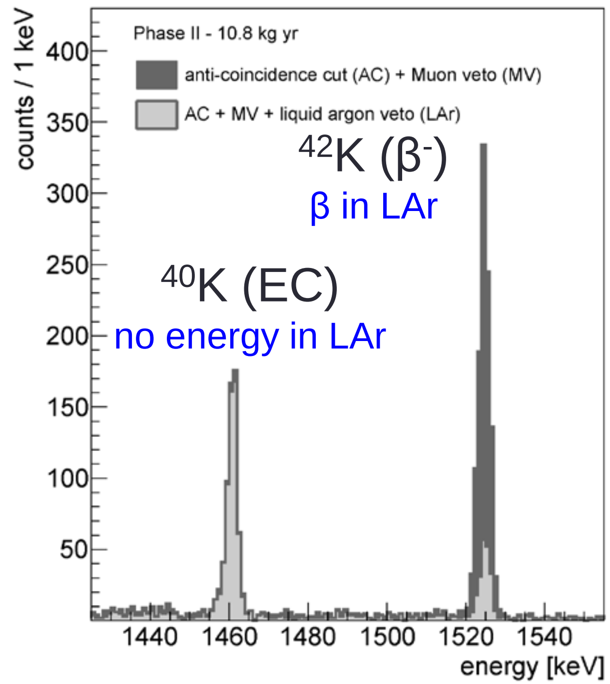
- PSD for coax detectors less effective than for BEGes
- Artificial neural network (**ANN**), as in Phase I
  - Trained on signal (SSE) : ^{208}Tl (2614 keV) DEP at 1592 keV
  - Background (**MSE**): ^{212}Bi @ 1620 keV γ-line
  - Acceptance for 0ν2β events: **(85±5)%**
    - Double check with Compton edge and 2ν2β
    - MC simulation of waveforms
- NEW **ingredient**: dedicated **ANN for α**
  - Test/train sample from data
  - Acceptance for 0ν2β events: **(93±1)%**
- Combined acceptance (79±5)%

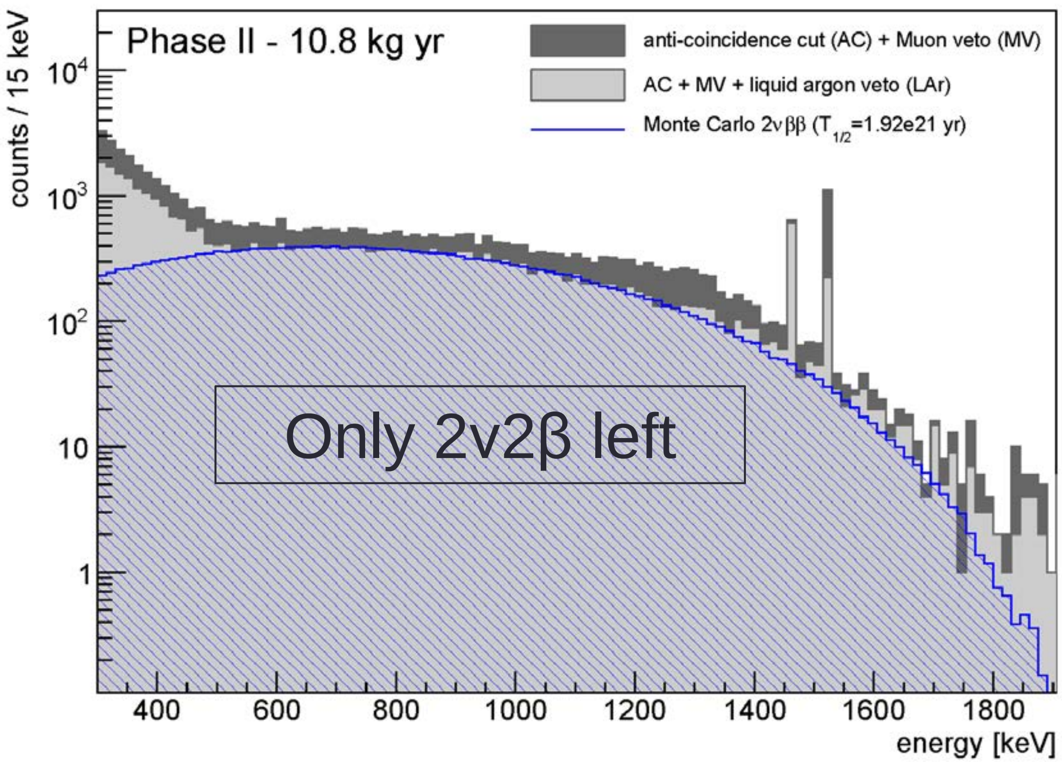




LAr performance with physics data

- LAr readout only when there is a trigger in Ge
  - **Dead time 2.3%**
- Very different suppression for the γ-rays of ^{40}K (EC) and ^{42}K (β-decay)



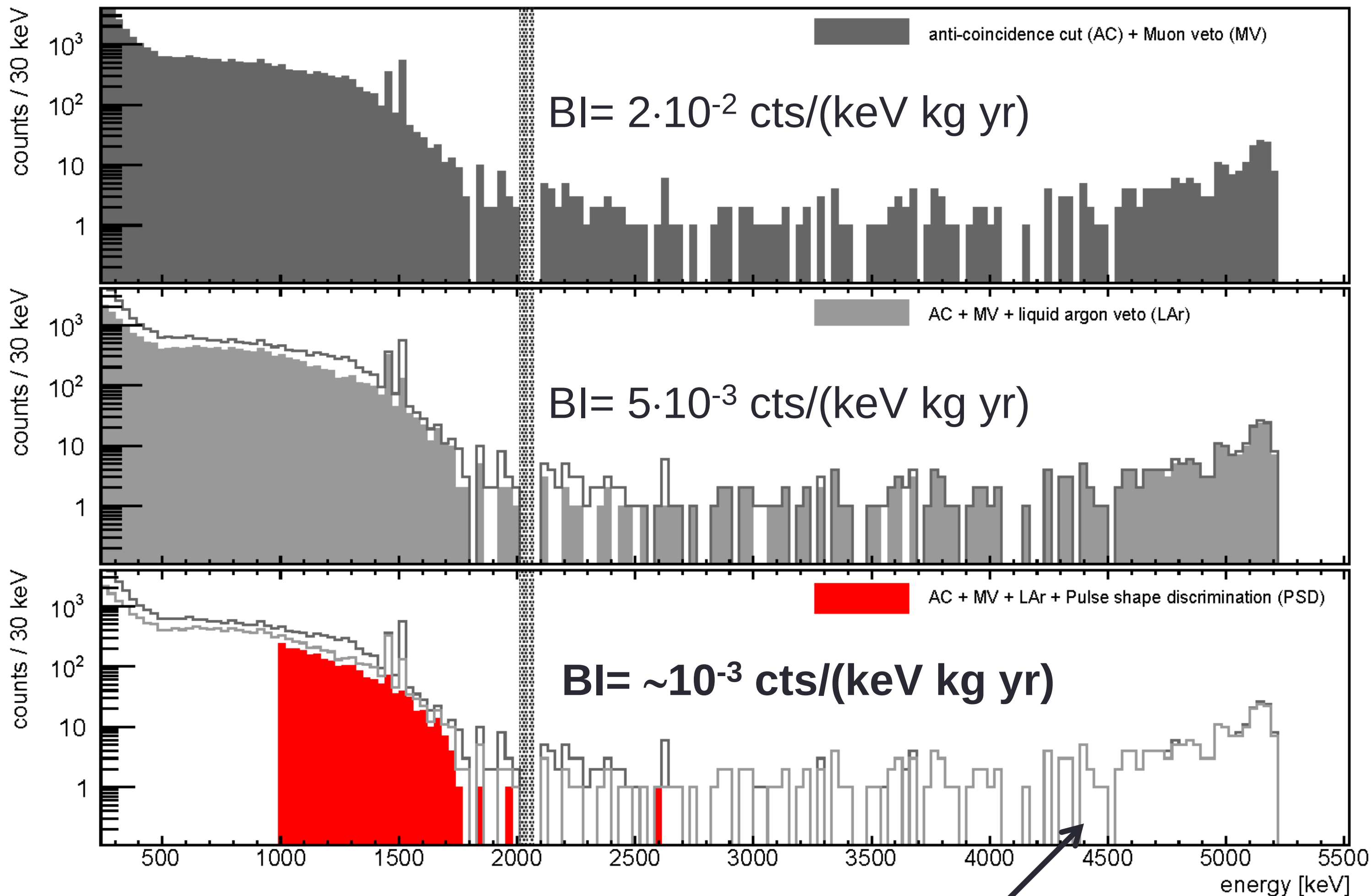


Survival fraction between 0.6 and 1.3 MeV:

(70.4 ± 0.3)%

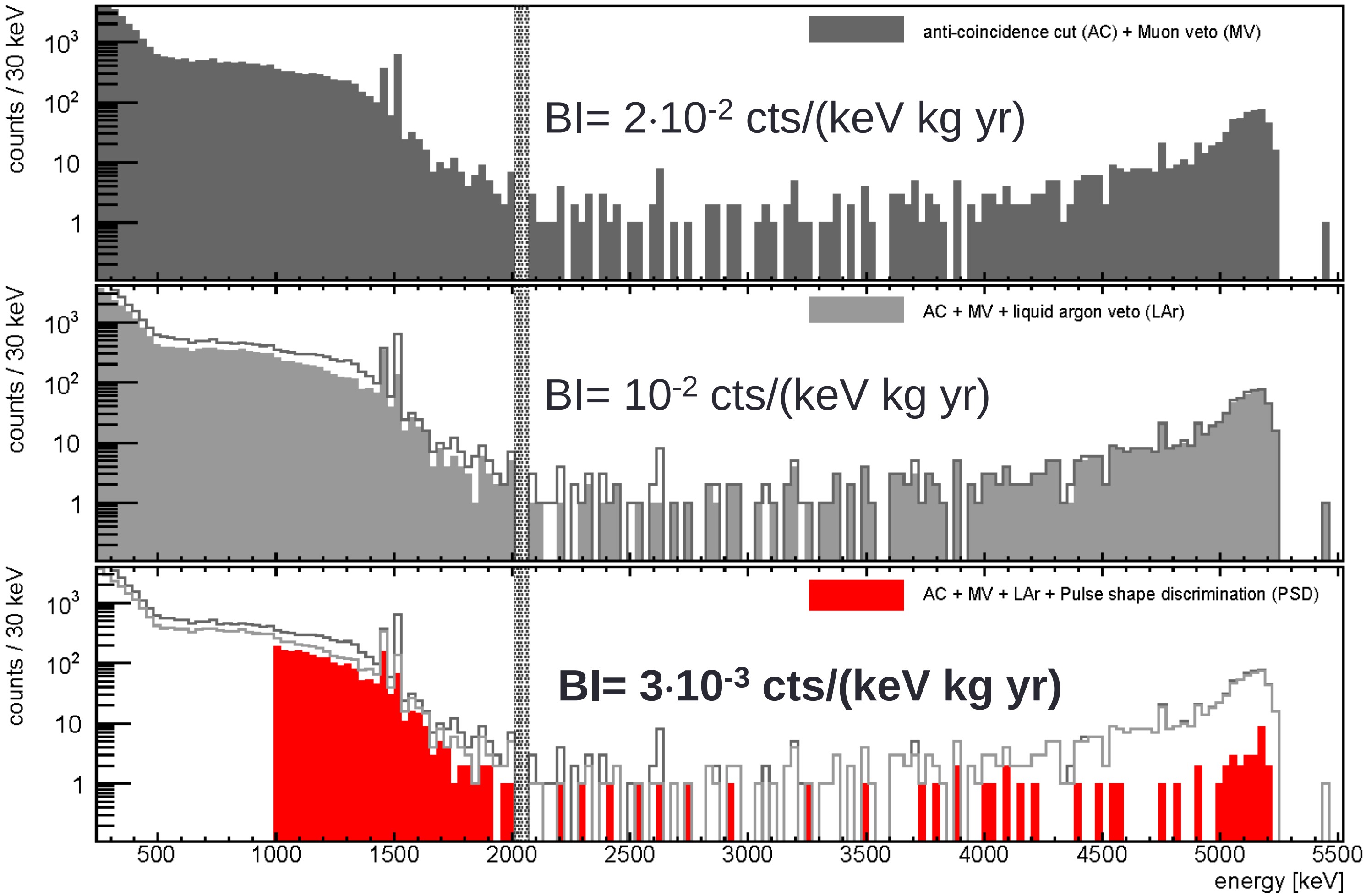
- $T_{1/2}$(2ν2β) **fixed** as 1.92 10^{21} yr (Phase I)
- ^{40}K and ^{42}K continua completely suppressed

Putting all together: BEGe (5.8 kg·yr)



- PSD clears completely the α region
- LAr and PSD **orthogonal**

Putting all together: coaxials (5.0 kg·yr)

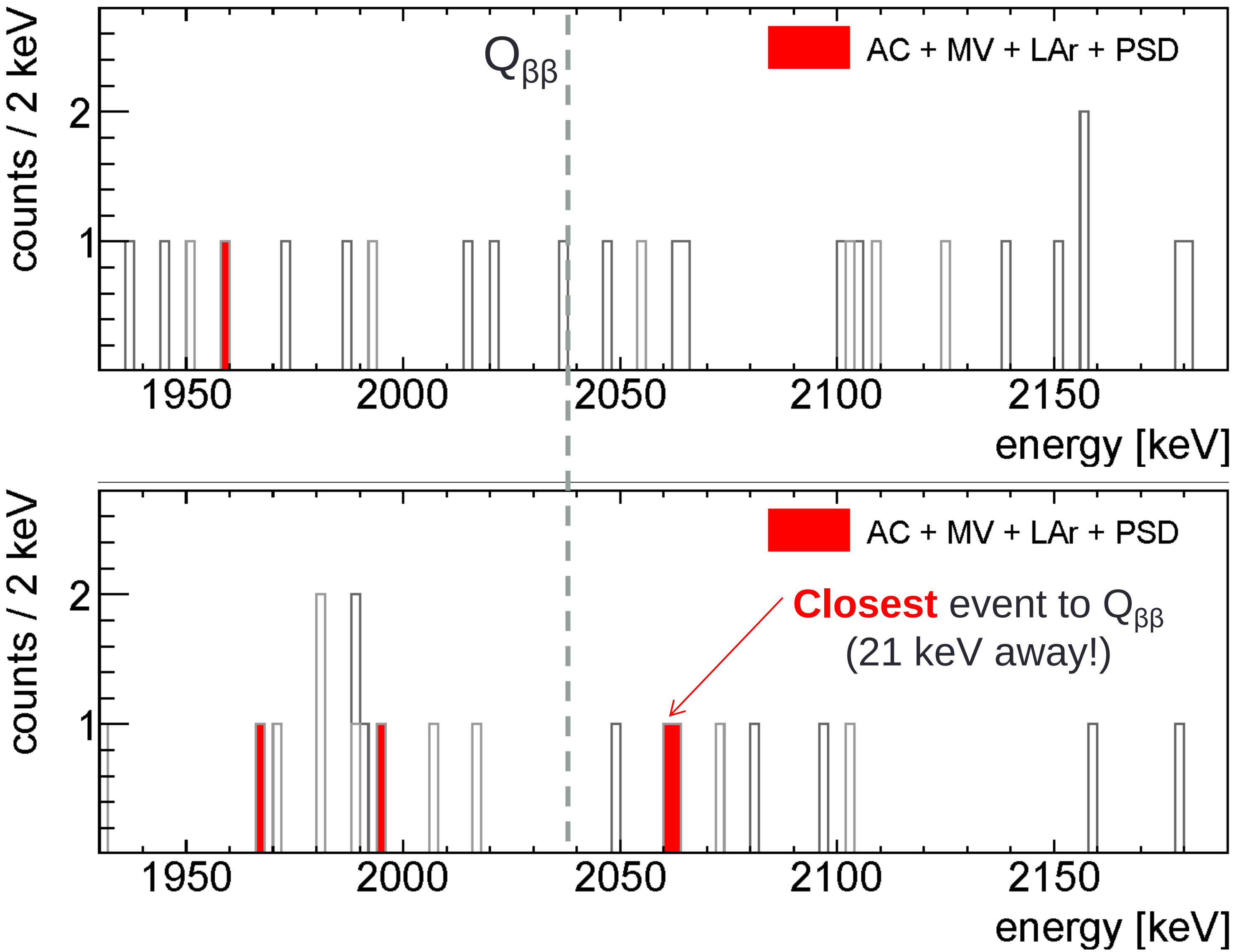


- PSD *less effective* than for BEGe
- New α-ANN critical to remove events in the α region

Unblinding at Ringberg castle

GERDA collaboration meeting at Ringberg
17 June 2016: **unblinding** of $\pm$ 25 keV around $Q_{\beta\beta}$

A closer look at $Q_{\beta\beta}$: the unblinding



BEGe (5.8 kg·yr)

Coax (5.0 kg·yr)

Event counts

	BEGe (5.8 kg · yr)	Coax (5.0 kg · yr)
Before unblinding 1930-2190 keV (190 keV)	**1**	**3**
Expected after unblinding $Q_{\beta\beta}$±25 keV	**0.3**	**0.78**
Expected after unblinding 1930-2190 keV, excl. $Q_{\beta\beta}$ (230 keV)	**1.2**	**3.6**
Observed after unblinding $Q_{\beta\beta}$±25 keV	**0**	**1**
Observed after unblinding 1930-2190 keV, excl. $Q_{\beta\beta}$ (240 keV)	**1**	**4**
Background (counts/keV kg yr)	$\mathbf{7^{+11}_{-5} \cdot 10^{-4}}$	$\mathbf{35^{+21}_{-15} \cdot 10^{-4}}$

Projection to the design Phase II exposure (100 kg yr)

	Exposure	FWHM (keV)	Bck counts in $Q_{\beta\beta}$± 0.5 FWHM
BEGE	~50 kg yr	3.0	**0.10**
Coax	~50 kg yr	4.0	**0.70**

Less than **1 background count** expected in the **full** exposure

ARTICLE

doi:10.1038/nature21717

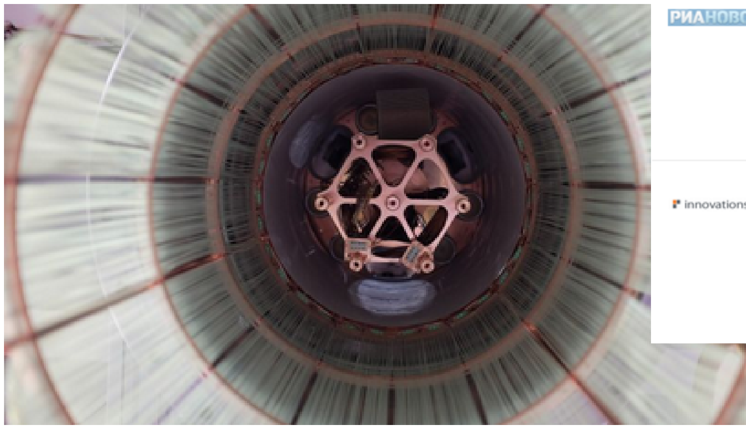
Background-free search for neutrinoless double-β decay of ^{76}Ge with GERDA

The GERDA Collaboration*

- First experiment in the field which is basically **background-free** for the entire **design exposure**
  - Nature **544** (2017) 47
- BI/ε = 3.5 counts/(ROI ton yr) [BEGe]
  - ROI: ± 0.5 FWHM
- **World record** (!)
  - Phase I: 80 counts/(ROI ton yr) [Coax]

Some traffic of news and press releases

SCIENCE



Scientists Are Getting Closer to Understanding Where All the Antimatter Has Gone

By Ryan F. Mandelbaum on 05 Apr 2017 at 10:00PM

R.it Scienze

Fisica: entra nel vivo la "caccia" al neutrino di Majorana

L'esperimento Gerda (foto: ufficio comunicazione Infn)

РИА НОВОСТИ

Ученые не нашли следов новой физики в "самоуничтожении" нейтрино

РИА Новости, 06 Apr 2017

МОСКВА, 6 апр – РИА Новости. Физикам из коллаборации GERDA не удалось зафиксировать "безнейтринных" вариантов распада материи, чт...

innovations report

GERDA-Experiment: Beste Aussichten für den Nachweis eines extrem seltenen radioaktiven Zerfalls

Innovations Report, 06 Apr 2017

06.04.2017 Warum gibt es im Universum mehr Materie als Antimaterie? Die Ursache dafür vermuten Physiker in den Eigenschaften...

LUNEDÌ SICILIANO

LA STORIA. Ricerca all'Infn

Un catanese a caccia del neutrino di Majorana

NINO ARENA PAGINA 9

Le Scienze

Quel decadimento senza neutrini che non si trova - Le Scienze

Le Scienze, 06 Apr 2017

La collaborazione GERDA non ha trovato traccia di un elusivo decadimento radioattivo previsto dai fisici teorici per spiegare l'a...

madrid

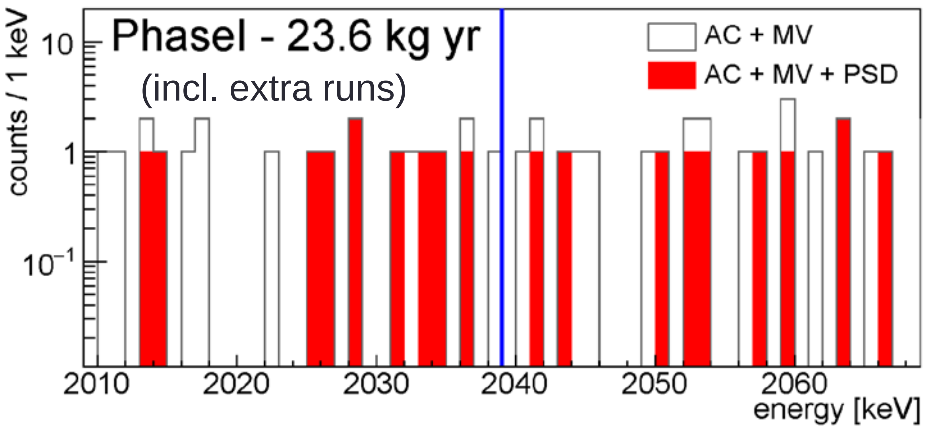
La desintegración radiactiva que elude a los físicos

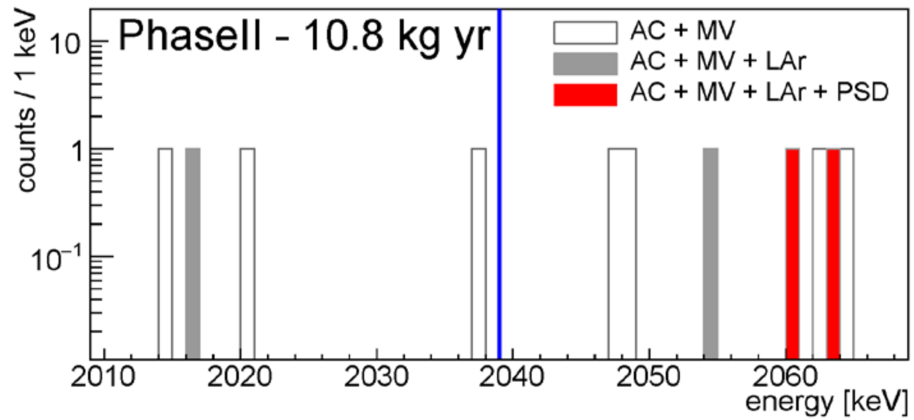
Madrid , 06 Apr 2017

Esta semana se publica en la revista Nature un nuevo avance en la búsqueda de la llamada desintegración doble beta sin...

Combined analysis – the datasets

Nature 544 (2017) 47





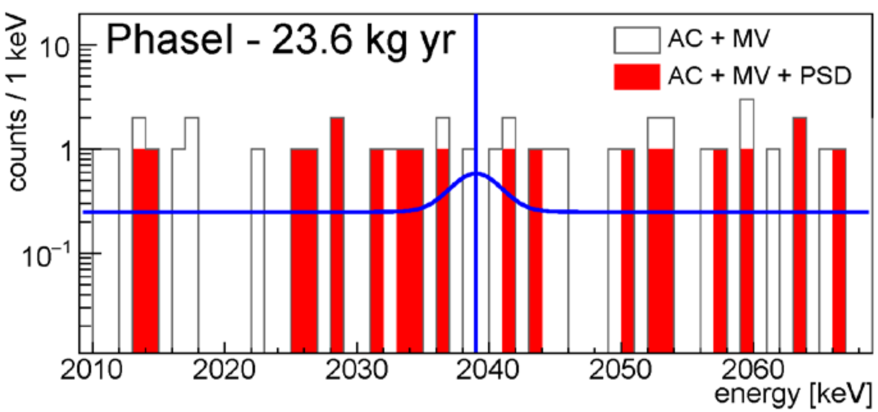
data set		exposure [kg·yr]	signal eff	background [cts/(keV·kg·yr)]	resolution [FWHM]
Phase I	golden	17.9	0.57 (3)	$11 \pm 2 \cdot 10^{-3}$	4.3 (1)
Phase I	silver	1.3	0.57 (3)	$30 \pm 10 \cdot 10^{-3}$	4.3 (1)
Phase I	BEGe	2.4	0.66 (2)	$5^{+4}_{-3} \cdot 10^{-3}$	2.7 (2)
Phase I	extra	1.9	0.58 (4)	$5^{+4}_{-3} \cdot 10^{-3}$	4.2 (2)
Phase II	coaxial	5.0	0.51 (7)	$35^{+21}_{-15} \cdot 10^{-4}$	4.0 (2)
Phase II	BEGe	5.8	0.60 (2)	$7^{+11}_{-5} \cdot 10^{-4}$	3.0 (2)
		34.3			

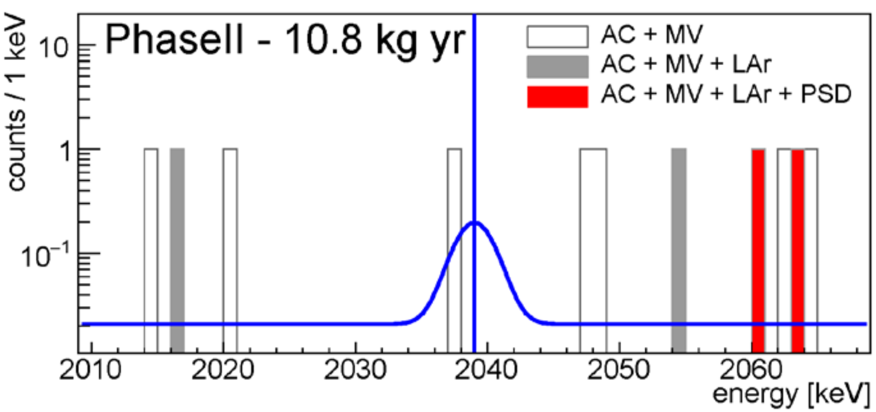
PRL 111 (2013) 122503, but for **ZAC energy reconstruction** and **revised ε_{PSD}**

Nature 544 (2017) 47

Combined analysis – statistical analysis

- **Combined** unbinned **maximum likelihood fit** of the six spectra
  - Independent constant terms plus **common signal** Gauss($Q_{\beta\beta}$,σ_E)
  - Free parameters: six backgrounds, $1/T_{1/2}$ ($T_{1/2}$ constrained to be >0)
- Fit, same strategy as for Phase I: two sets of praescriptions
  - **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 on ε and resolution folded as pull terms (frequentist) or by Monte Carlo (Bayesian)





Statistical analysis

Nature 544 (2017) 47

Frequentist

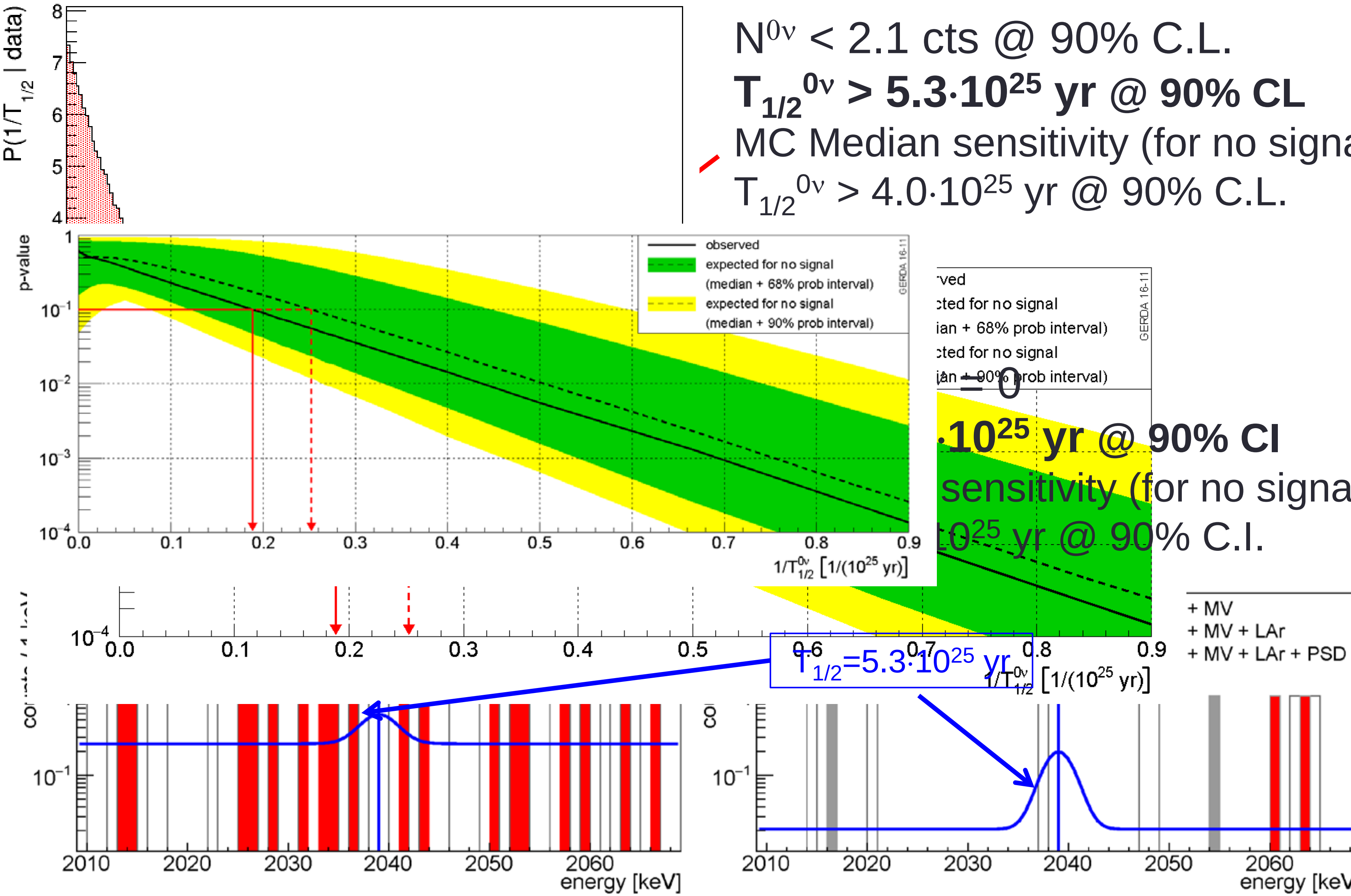
Best fit: $N^{0\nu} = 0$

$N^{0\nu} < 2.1$ cts @ 90% C.L.

$T_{1/2}^{0\nu} > 5.3 \cdot 10^{25}$ yr @ 90% CL

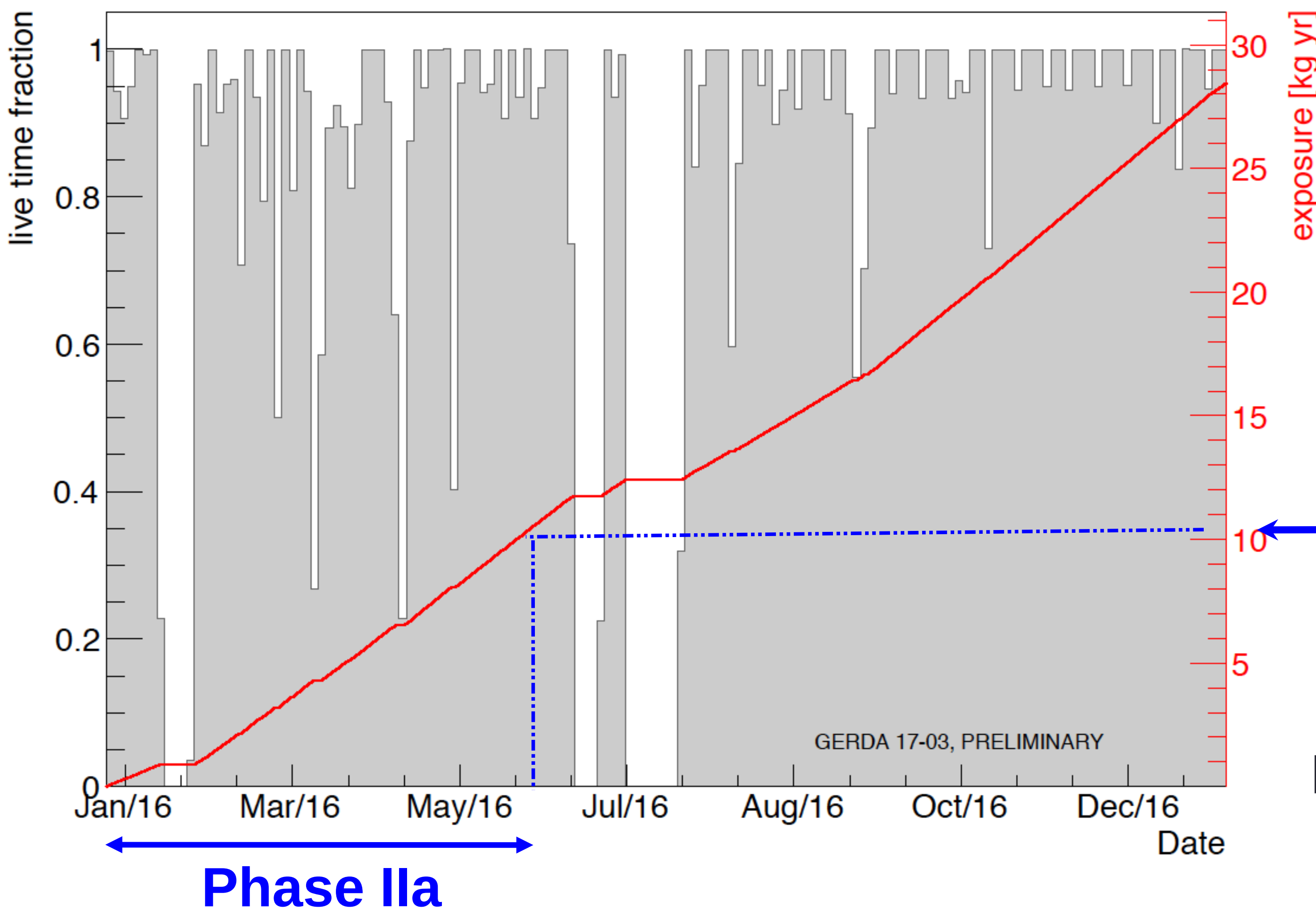
MC Median sensitivity (for no signal):

$T_{1/2}^{0\nu} > 4.0 \cdot 10^{25}$ yr @ 90% C.L.



Current data taking…

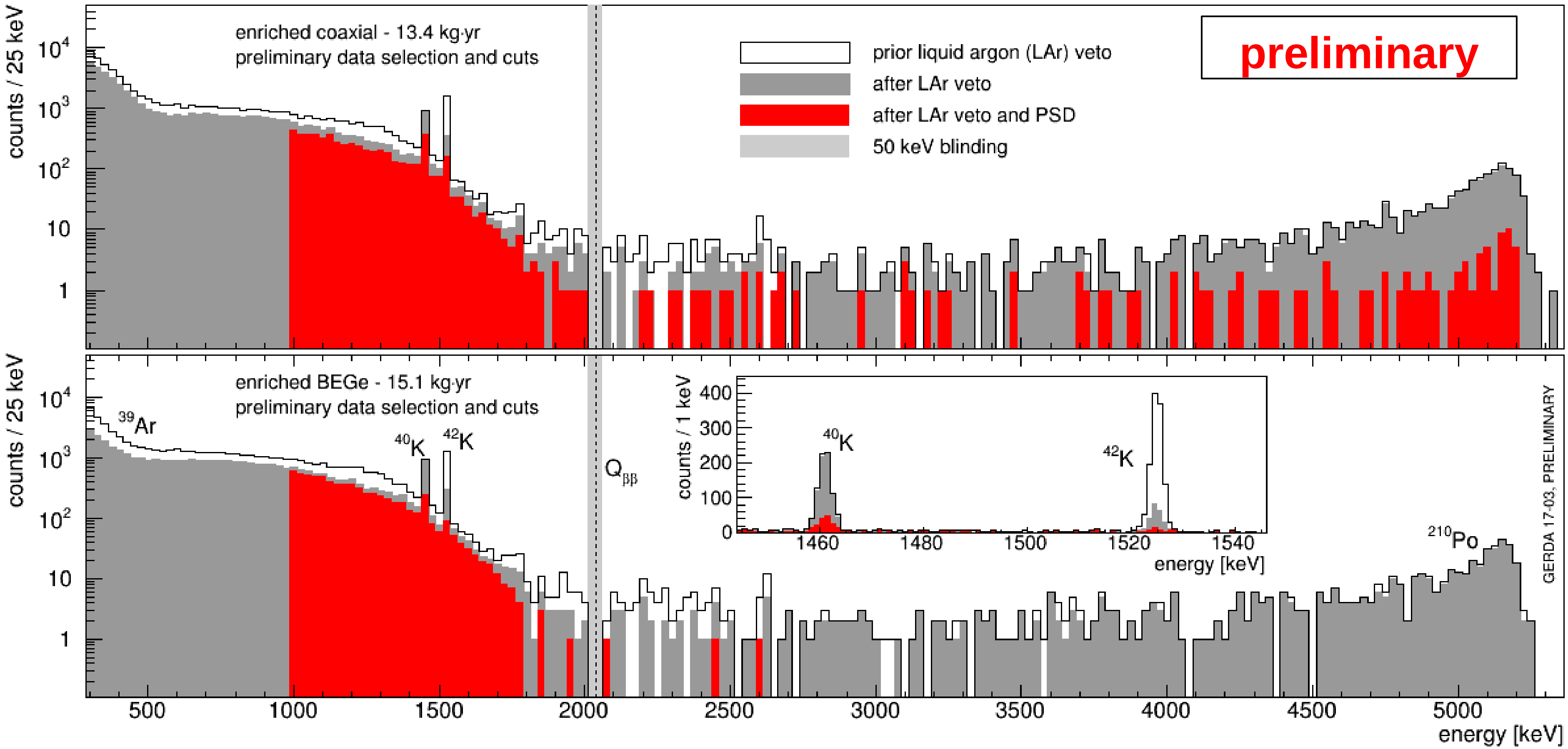
- Data taking in progress!
  - Phase II exposure increased by **x3**



XVII Neutel 2017
(March 2017)
28.5 kg·yr
(Blinding in $Q_{\beta\beta} \pm$ 25 keV)

Neutrino 2016
10.8 kg·yr
(First unblinding)
Nature 544 (2017) 47

Spectra and background index



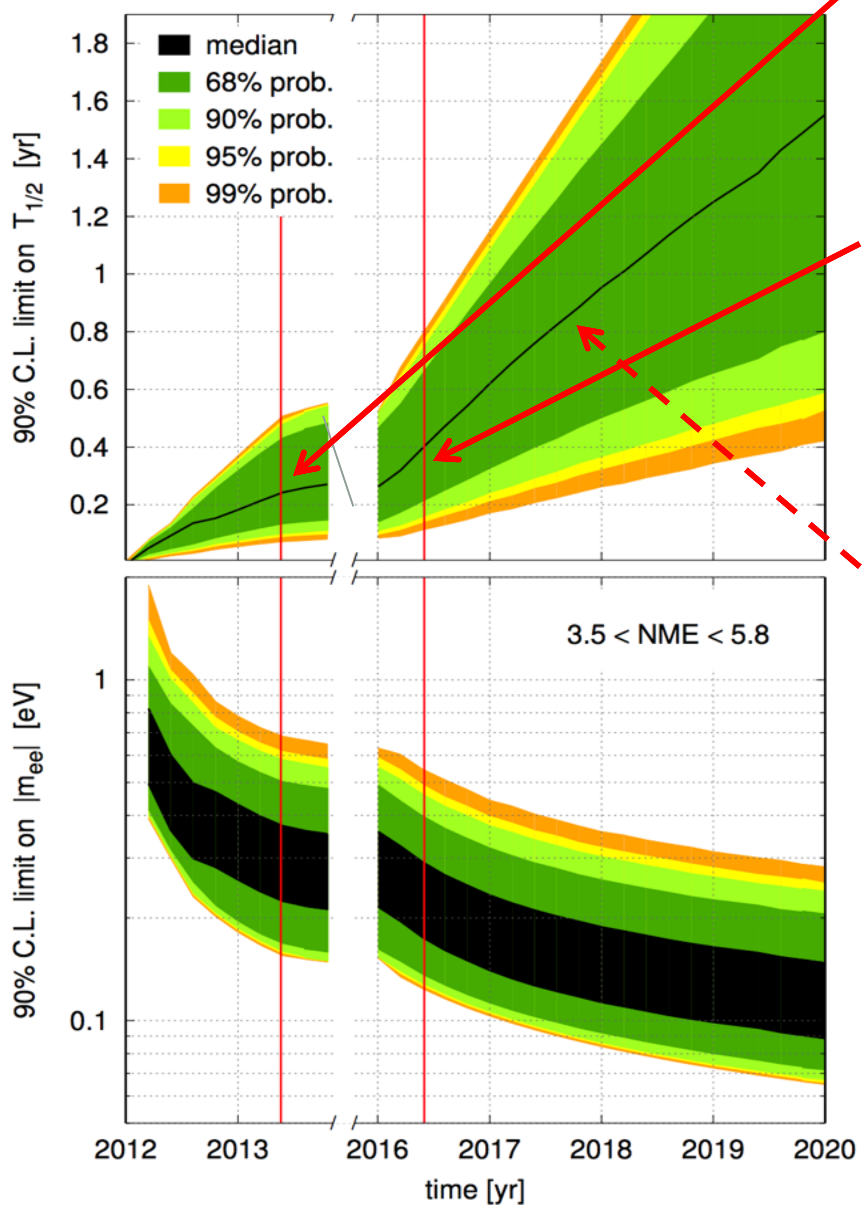
- Background performance **confirmed** (1930 → 2190 keV)
  - Smaller statistical uncertainty for BEGe
  - Even a little bit improved for Coax
  - Mix unblinded/blinded ROI

$\boxed{7^{+11}_{-5} \rightarrow 6^{+6}_{-4} \cdot 10^{-4}}$ 2 cts

$\boxed{35^{+21}_{-15} \rightarrow 22^{+11}_{-8} \cdot 10^{-4}}$ 6 cts

(counts/keV kg yr)

Next steps



- **Phase I** (21 kg yr)
  - Sensitivity: $2.4 \cdot 10^{25}$ yr
  - Limit: $T_{1/2}^{0\nu} > 2.1 \cdot 10^{25}$ yr (90%CL)
  - PRL **111** (2013) 122503
- **Phase IIa** (PhI + 10.8 kg yr)
  - Sensitivity: $4.0 \cdot 10^{25}$ yr
  - Limit: $T_{1/2}^{0\nu} > 5.3 \cdot 10^{25}$ yr (90%CL)
  - Nature **544** (2017) 47
- In the bag: >25 kg yr more of Phase II data (background-free)
  - Open the blinding box in **July 2017** (TAUP2017), sensitivity ~$8.0 \cdot 10^{25}$ yr
- Break the **10^{26} yr** wall (sensitivity) in early **2018**
- Design exposure 100 kg yr
  - Background-free
  - Final sensitivity **$1.4 \cdot 10^{26}$ yr**

Conclusions and perspectives

- **0ν2β decay** actively searched for by **many experiments** worldwide
- **GERDA** experiment at LNGS
  - **Phase I completed** (2011-2013), 21.6 kg·yr of exposure, **blind** analysis**,** $T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}$ yr @ 90% CL
- **Phase II ongoing (stable data taking!)** since December 2015
  - Deployed ^{enr}Ge mass doubled
  - Validated background suppression tools (LAr and PSD)
- First results, with **34.4 kg·yr total** (10.8 kg·yr Phase II)
  - $T^{0\nu}_{1/2} >$ **$5.3 \cdot 10^{25}$ yr** @ 90% CL (median sensitivity: $4.0 \cdot 10^{25}$ yr)
  - **Lowest background** in ROI ever achieved, Nature 544 (2017) 47
- > 25 kg yr of Phase II data already **available**
  - Blind analysis in $Q_{\beta\beta} \pm$ 25 keV. Box to be opened in the summer
  - Very good **background performance confirmed**, < 1 count/(keV ton yr)
- Plan to accumulate 100 kg·yr within 3 years
  - Expected to be background free
  - Break the wall of **10^{26} yr** (*median sensitivity*) in 2018

BACKUP

LUNEDÌ 24 APRILE 2017

TESTATA INDIPENDENTE CHE NON PERCEPISCE CONTRIBUTI PUBBLICI COME PREVEDE LA LEGGE N° 250/90

ANNO 73 - N. 112 € 1.30
(+0.70 "La Verità" in abbinamento facoltativo)

LA SICILIA del lunedì

quotidiano fondato nel 1945

www.lasicilia.it

SPED. IN ABB. POSTALE - DL 353/2003 CONV. L. 46/2004 ART. 1, C. 1

Catania
LUNGOMARE LIBERATO: RIPULITA LA SCOGLIERA
FOLLA ALL'ISOLA PEDONALE E CONTROLLI ANTIABUSIVI
PAGINA 13

Stazzo
ONDA ANOMALA COLPISCE PICCOLA BARCA IN TRE SOCCORSI IN MARE
ANTONIO CARRECA PAGINA 13

Macron e Le Pen duello di Francia Spariti i socialisti fuori i neogollisti

Presidenziali. Un sondaggio dà il 62% al ballottaggio al candidato di En Marche, con la rivale al 38%. Fuori per la prima volta i grandi partiti della V Repubblica

TULLIO GIANNOTTI, ENRICO TIBUZZI PAGINE 2-3

LUNEDÌ SICILIANO

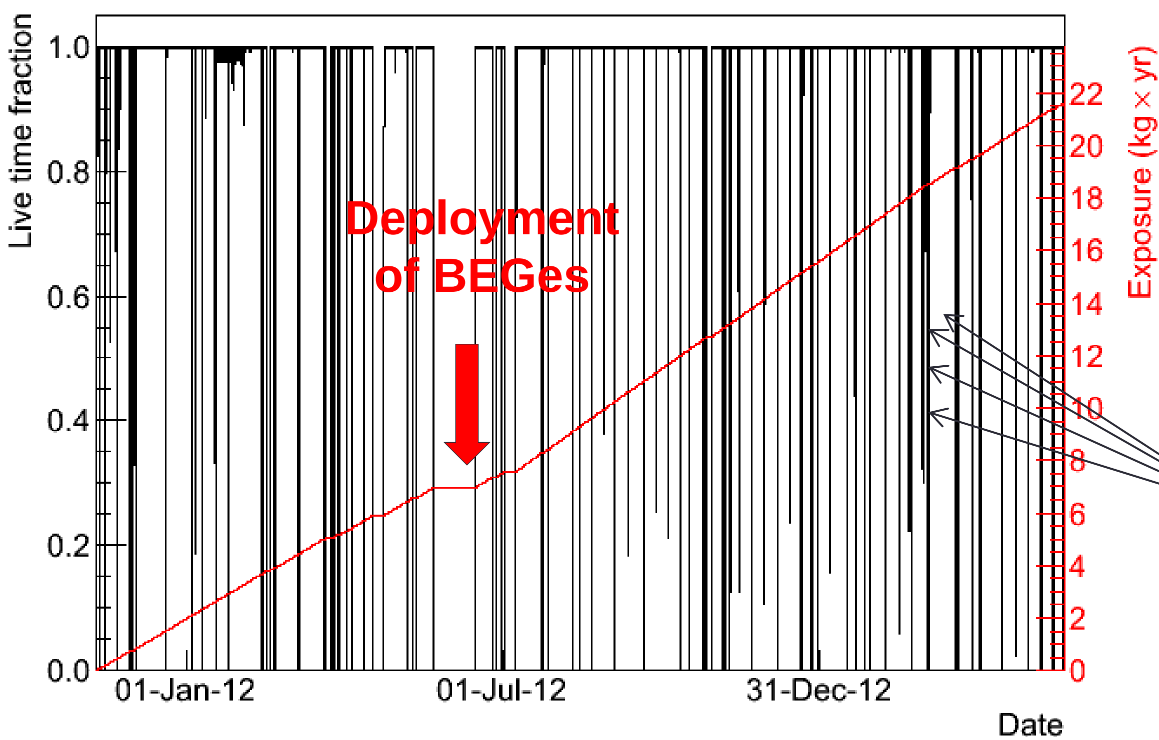
LA STORIA. Ricerca all'Infn

Un catanese a caccia del neutrino di Majorana

NINO ARENA PAGINA 9

GERDA Phase I data taking

- Total exposure: **21.6 kg yr** (diodes) between Nov 9th, 2011 and May 21st, 2013 (492.3 live days, 88.1% duty factor)
  - 5% due to temperature-related instabilities of electronics
- Used for analysis: 6 ^{enr}Ge coaxial detectors (4 from HdM + 2 from IGEX)
  - Data from two other deployed detectors not used in analysis because of high LC
  - Usable mass: **14.62 kg**



- Five **Phase II** BEGe detectors deployed in **June 2012**
  - One detector showed instabilities
  - Extra **3.0 kg**
- Stability monitored by
  - Weekly calibrations with ^{228}Th
  - Test pulses (0.05 Hz)

Physics observables

Quantity of physical interest

Measured quantity

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

- The calculation of m_{ee} from $T_{1/2}$ requires the **knowledge** of the **nuclear matrix element**
  - **Complex theoretical** calculations, and not so many groups working on it worldwide
  - Different approaches (flavours of QRPA, Shell Model, etc.) can differ by a **factor of 2-10**
- Systematic uncertainty on m_{ee} → difficult to compare experiments carried out with different nuclei
  - It is important to have *many experiments running*: if the effect is observed, needs **confirmation** by at least two isotopes

The events

Phys. Rev. Lett. 111 (2013) 122503

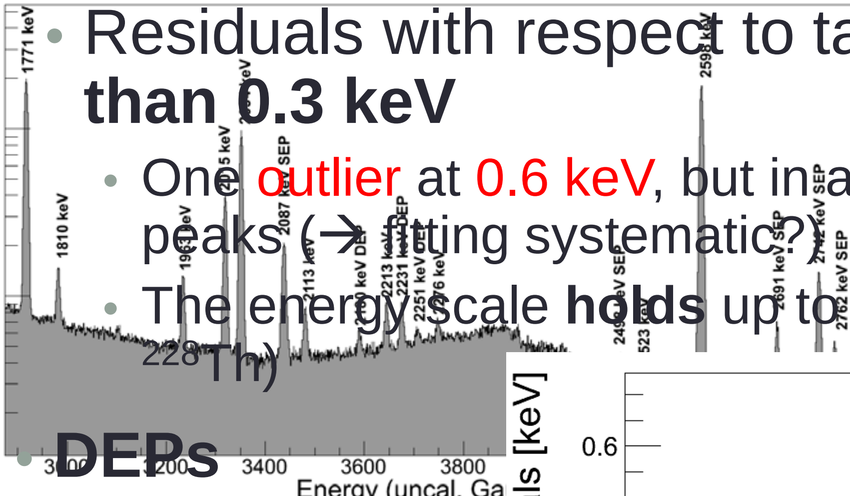
Table 1: List of all events within $Q_{\beta\beta} \pm 5$ keV

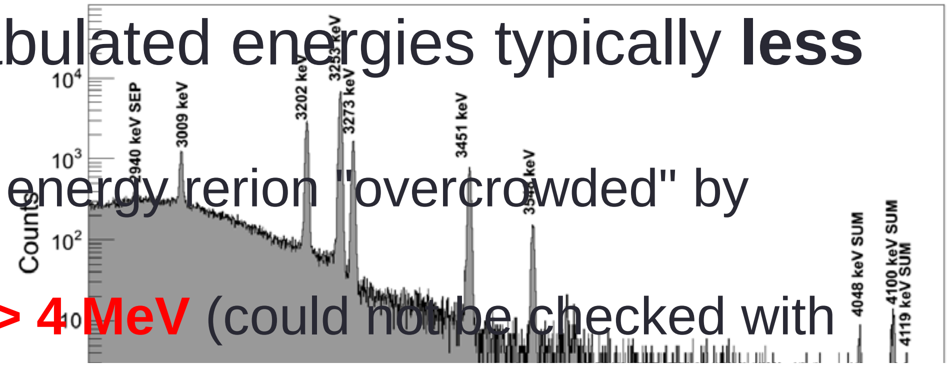
data set	detector	energy [keV]	date	PSD passed	ANN	A/E	Cut Threshold
golden	ANG 5	2041.8	18-Nov-2011 22:52	no	0.344		0.366
silver	ANG 5	2036.9	23-Jun-2012 23:02	yes	0.518		0.366
golden	RG 2	2041.3	16-Dec-2012 00:09	yes	0.682		0.364
BEGe	GD32B	2036.6	28-Dec-2012 09:50	no		0.750	0.965÷1.070
golden	RG 1	2035.5	29-Jan-2013 03:35	yes	0.713		0.372
golden	ANG 3	2037.4	02-Mar-2013 08:08	no	0.205		0.345
golden	RG 1	2041.7	27-Apr-2013 22:21	no	0.369		0.372

data set	$\mathcal{E}$[kg·yr]	$\langle\epsilon\rangle$	bkg	BI †)	cts	Expected from background only
without PSD						
golden	17.9	0.688 ± 0.031	76	18 ± 2	5	3.3
silver	1.3	0.688 ± 0.031	19	63^{+16}_{-14}	1	0.8
BEGe	2.4	0.720 ± 0.018	23	42^{+10}_{-8}	1	1.0
with PSD						
golden	17.9	$0.619^{+0.044}_{-0.070}$	45	11 ± 2	2	2.0
silver	1.3	$0.619^{+0.044}_{-0.070}$	9	30^{+11}_{-9}	1	0.4
BEGe	2.4	0.663 ± 0.022	3	5^{+4}_{-3}	0	0.1

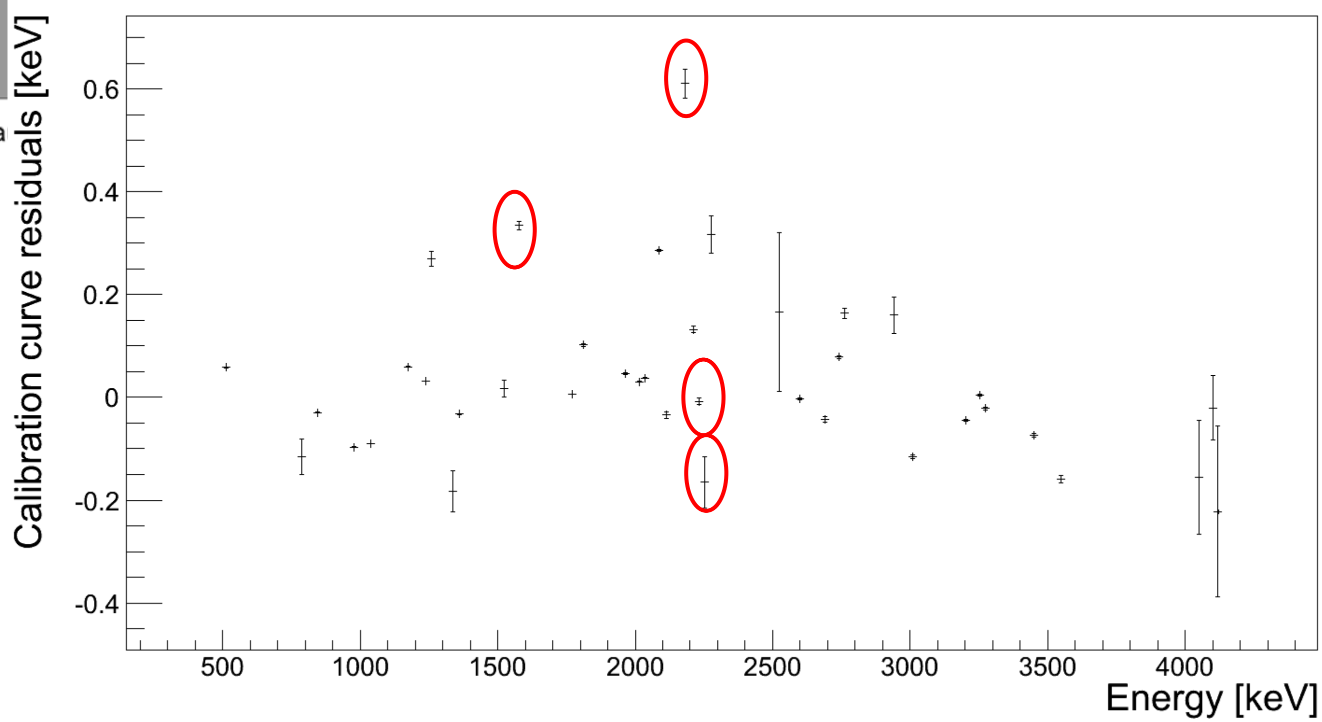
†) in units of 10^{-3} cts/(keV·kg·yr).

^{56}Co calibration and position of the DEPs





- Residuals with respect to tabulated energies typically **less than 0.3 keV**
  - One outlier at 0.6 keV, but in a energy rerion "overcrowded" by peaks (→ fitting systematic?)
  - The energy scale **holds** up to **> 4 MeV** (could not be checked with ^{228}Th)
- **DEPs** reconstructed at the **proper energy**
  - Kinematically similar to the DBD
  - **No** hints of ballistic deficit



Background modeling - 2

- Background in the ROI (before LAr and PSD)
  - α from ^{210}Po and ^{222}Rn daughters
  - β from ^{42}K
  - γ from ^{214}Bi and ^{208}Tl
- Flat background expected at $Q_{\beta\beta}$
- Use the same analysis window as Phase I
- 1930-2190 keV, excl. ±5 keV around two known γ lines