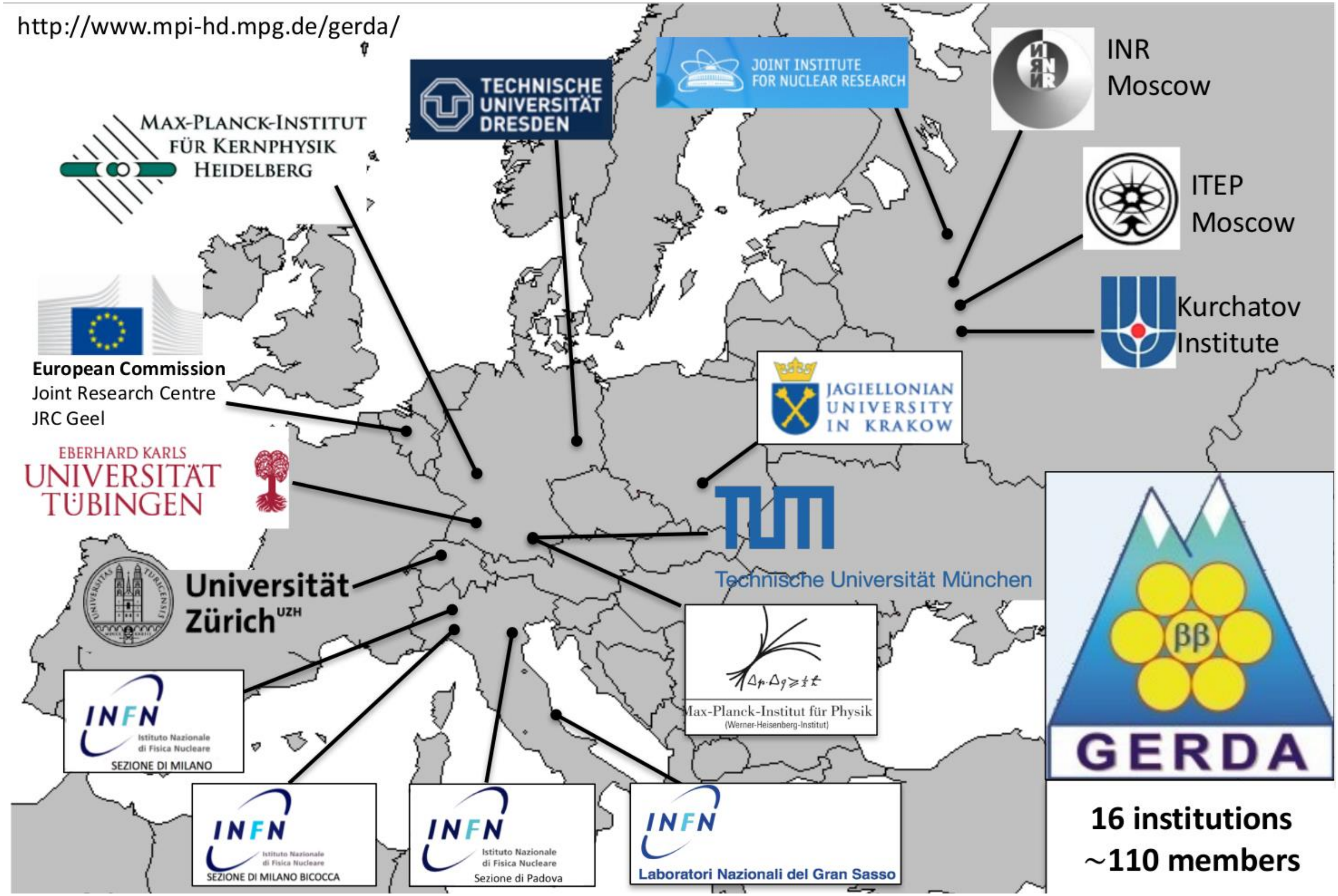
# Search for 0$\nu\beta\beta$-decay with GERDA Phase II

B. Majorovits (MPI für Physik) for the GERDA collaboration

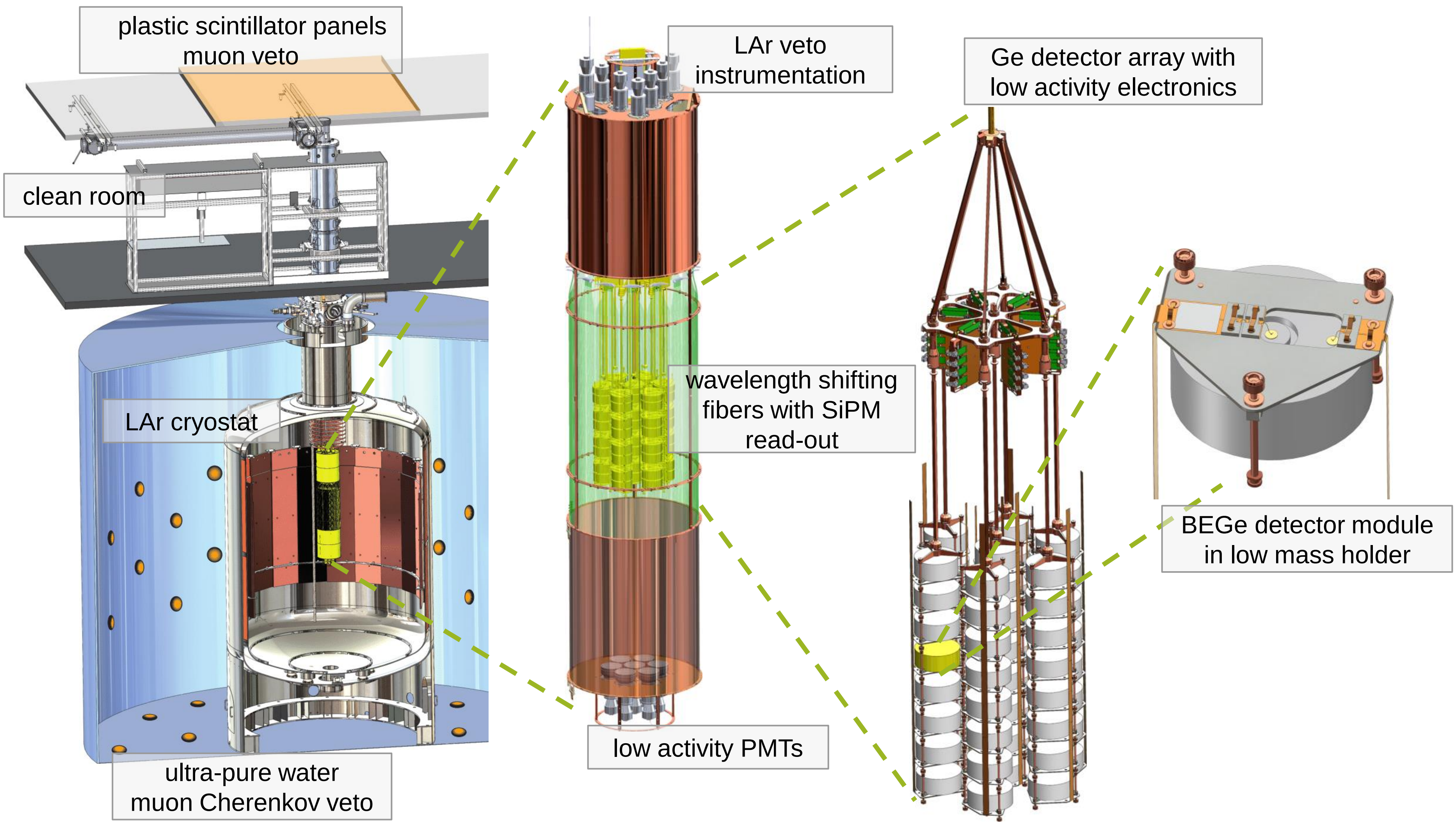
**OUTLINE:**

- GERDA
- Phase I background results
- Phase II data taking
- Phase II background \wo cuts
- LAr veto and PSD cuts
- 0$\nu\beta\beta$ result
- Phase II background after cuts

# The GERDA Collaboration

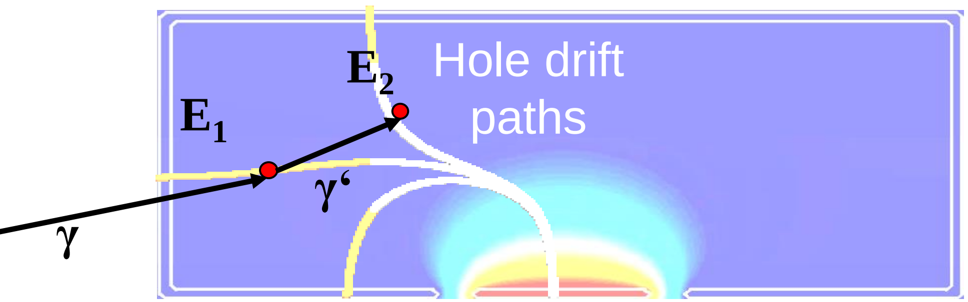


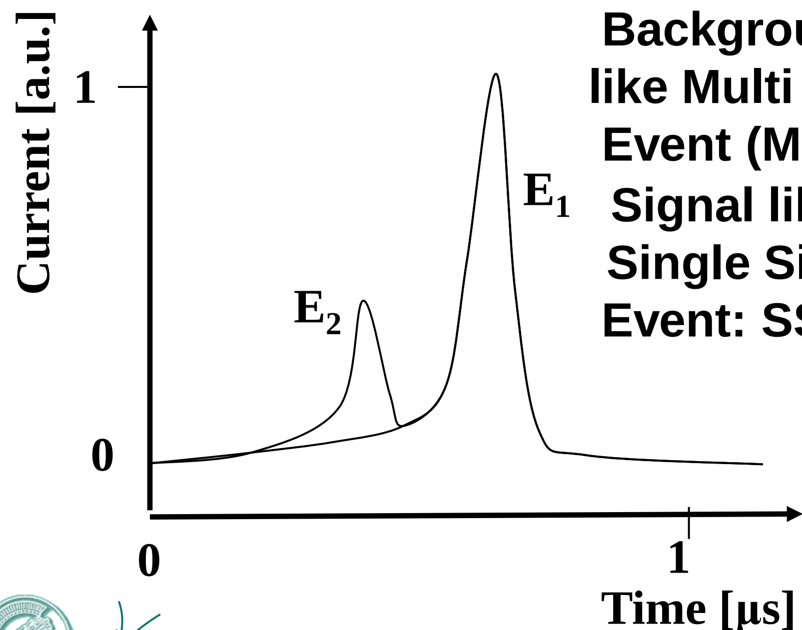
# GERDA Phase II: PSD and Lar veto



# GERDA Phase II: PSD and LAr veto

**Additional 20kg BEGe detectors with point like contact:**

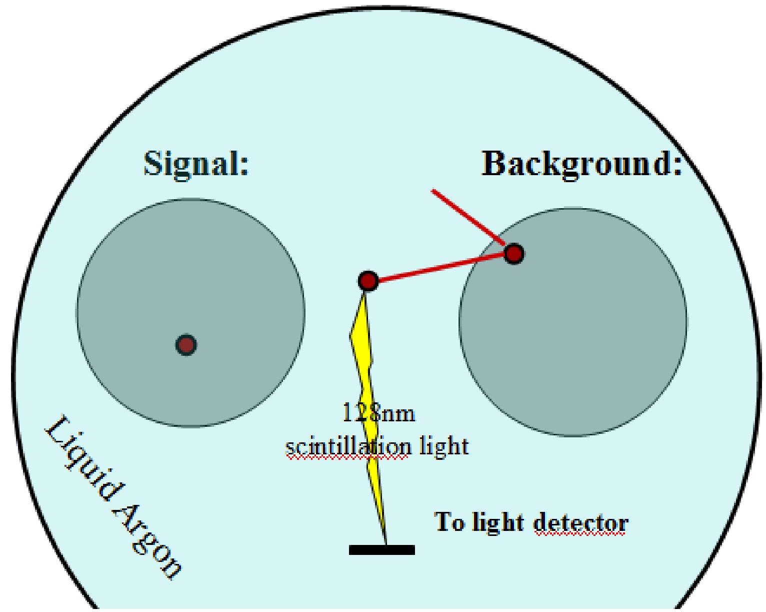



**Background like Multi Site Event (MSE)**

**Signal like Single Site Event: SSE**

**Use LAr veto:**



# GERDA Phase I: Results on Backgrounds

Astroparticle Physics 91 (2017) 15–21

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Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys

Limits on uranium and thorium bulk content in GERDA Phase I detectors

Analysis by searching for consecutive decays in $^{238}U/^{235}U/^{232}Th$ decay chains

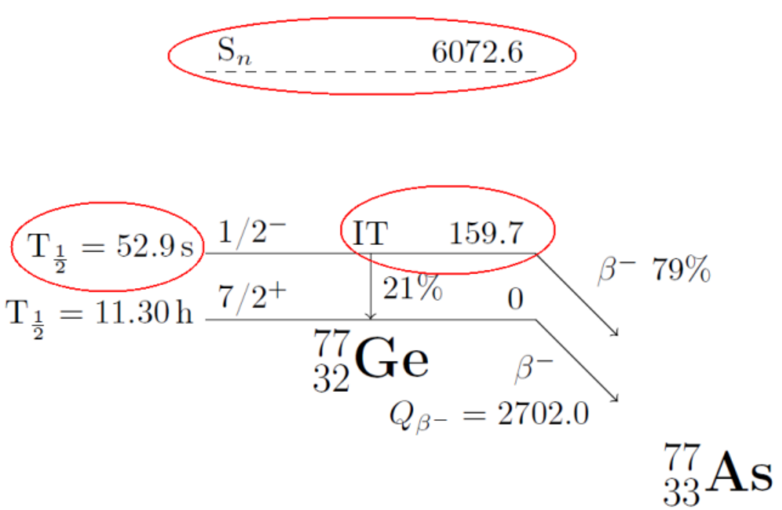
**90% C.I. upper limits on the concentration of $^{226}Ra$, $^{227}Ac$ and $^{228}Th$ bulk contamination in Gerda Phase I detectors**

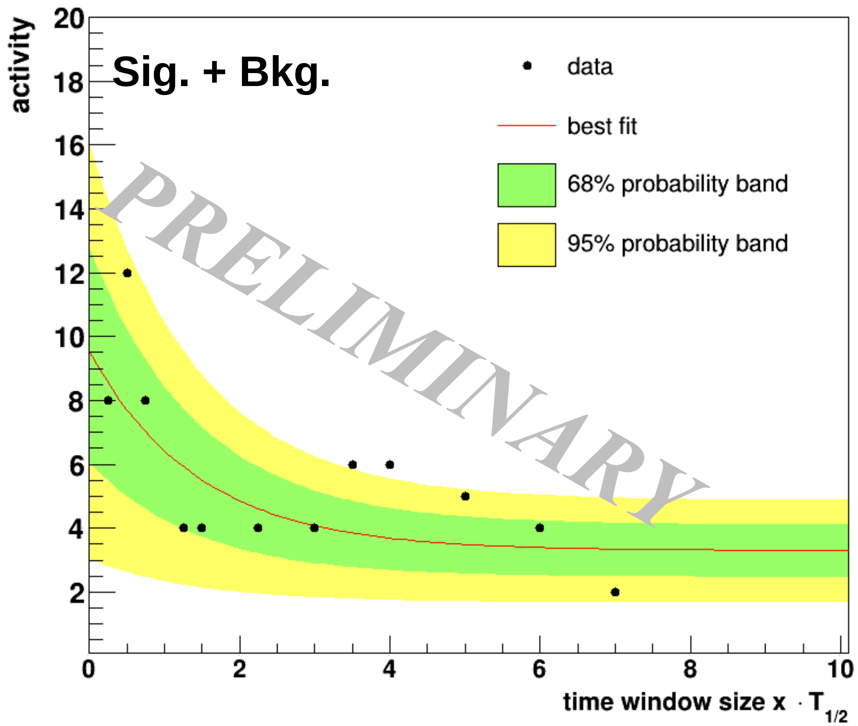
| Limits on | contamination [g/g] | activity [nBq/kg] |
|---|---|---|
| $^{226}Ra$ | $8.6 \cdot 10^{-23}$ | 3.1 |
| $^{227}Ac$ | $1.1 \cdot 10^{-24}$ | 3.0 |
| $^{228}Th$ | $1.0 \cdot 10^{-25}$ | 3.1 |

**→ Bulk HPGe is clean enough for ton scale experiment !**

# GERDA Phase I: Results on Backgrounds

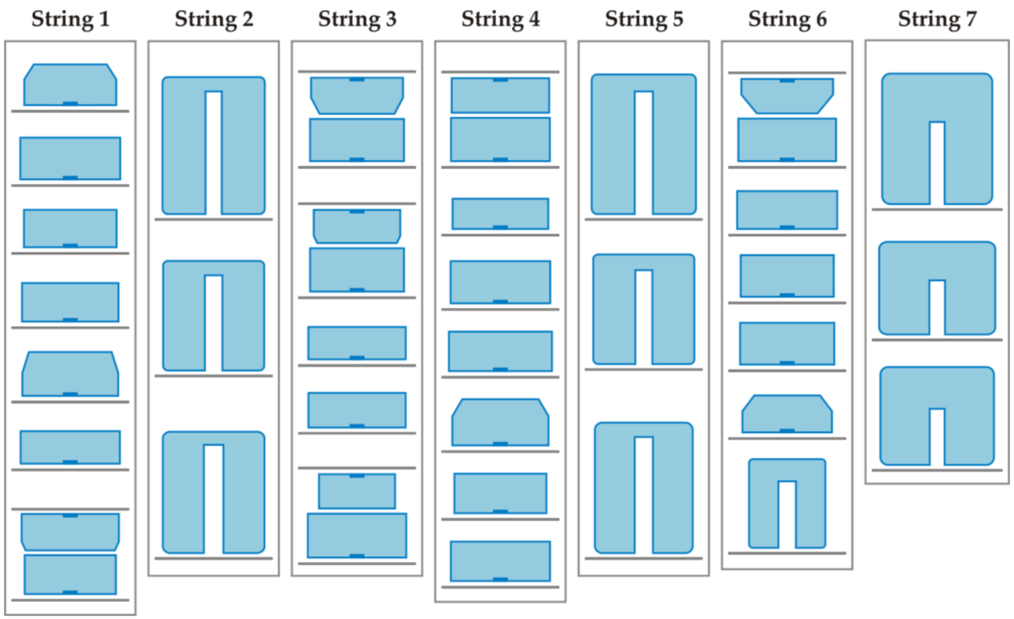
**Search for muon induced neutrons:**
**Signature: neutron capture on $^{76}$Ge followed by decay of meta-stable state $^{77m}$Ge ($T_{1/2}$=52.3s)**




**Signal plus background model fits data well**
**Need to understand efficiencies**
**→ Estimation of μ-induced Bkg. for ton scale experiment**

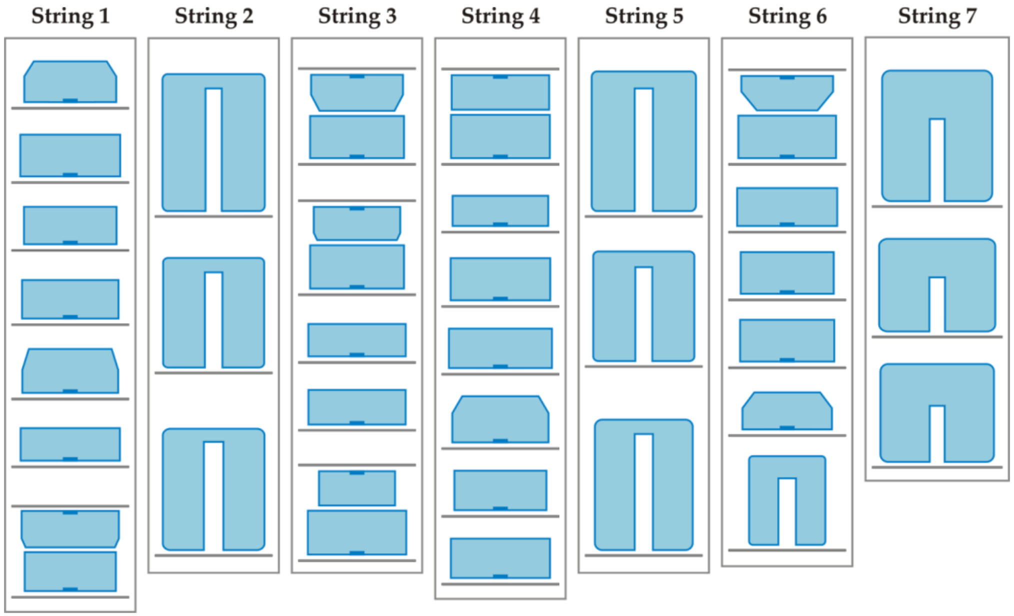
# GERDA Phase II: Detector array




7 strings with 40 detectors in total

- 7 enriched semi-coax (15.8 kg)
- 30 enriched thick window BEGe (20 kg)
- 3 natural semi-coax (7.6 kg)

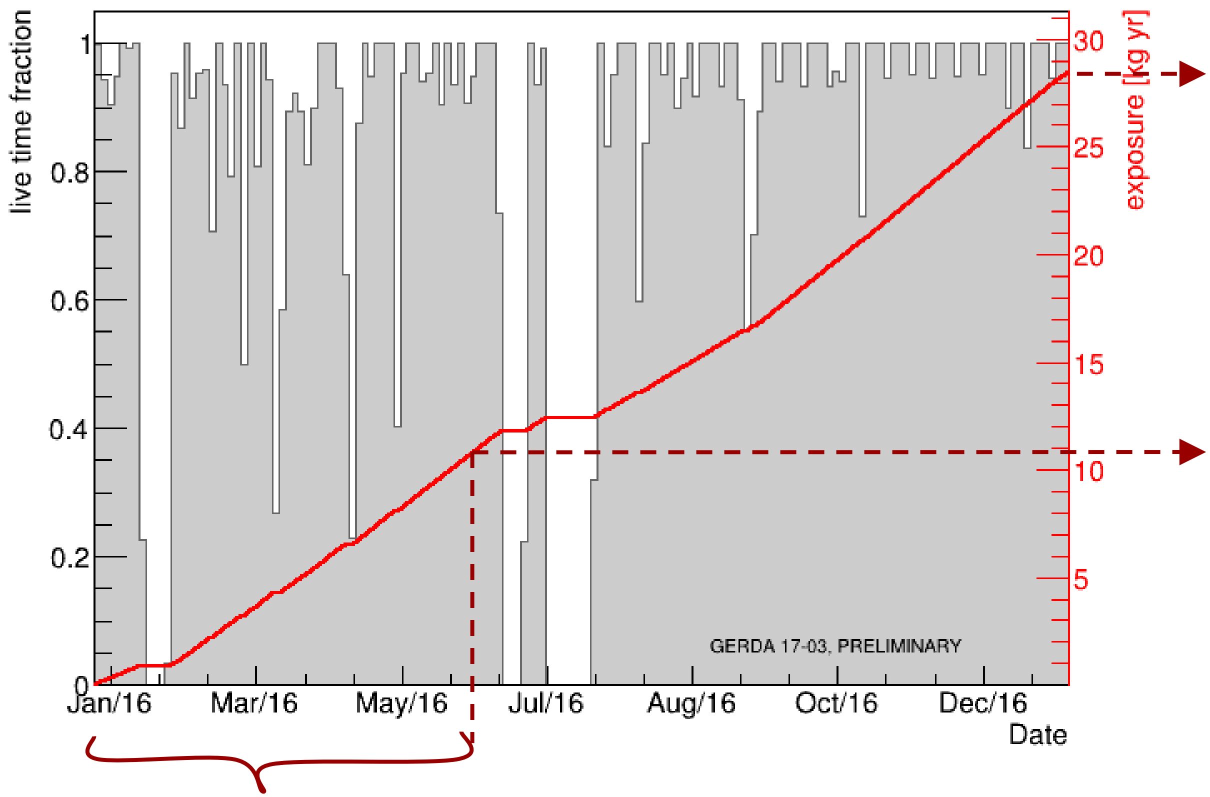
# GERDA Phase II: Detector array




**7 strings with 40 detectors in total**

- **7 enriched semi-coax (15.8 kg)**
- **30 enriched thick window BEGe (20 kg)**
- **3 natural semi-coax (7.6 kg)**

# GERDA Phase II: Data taking

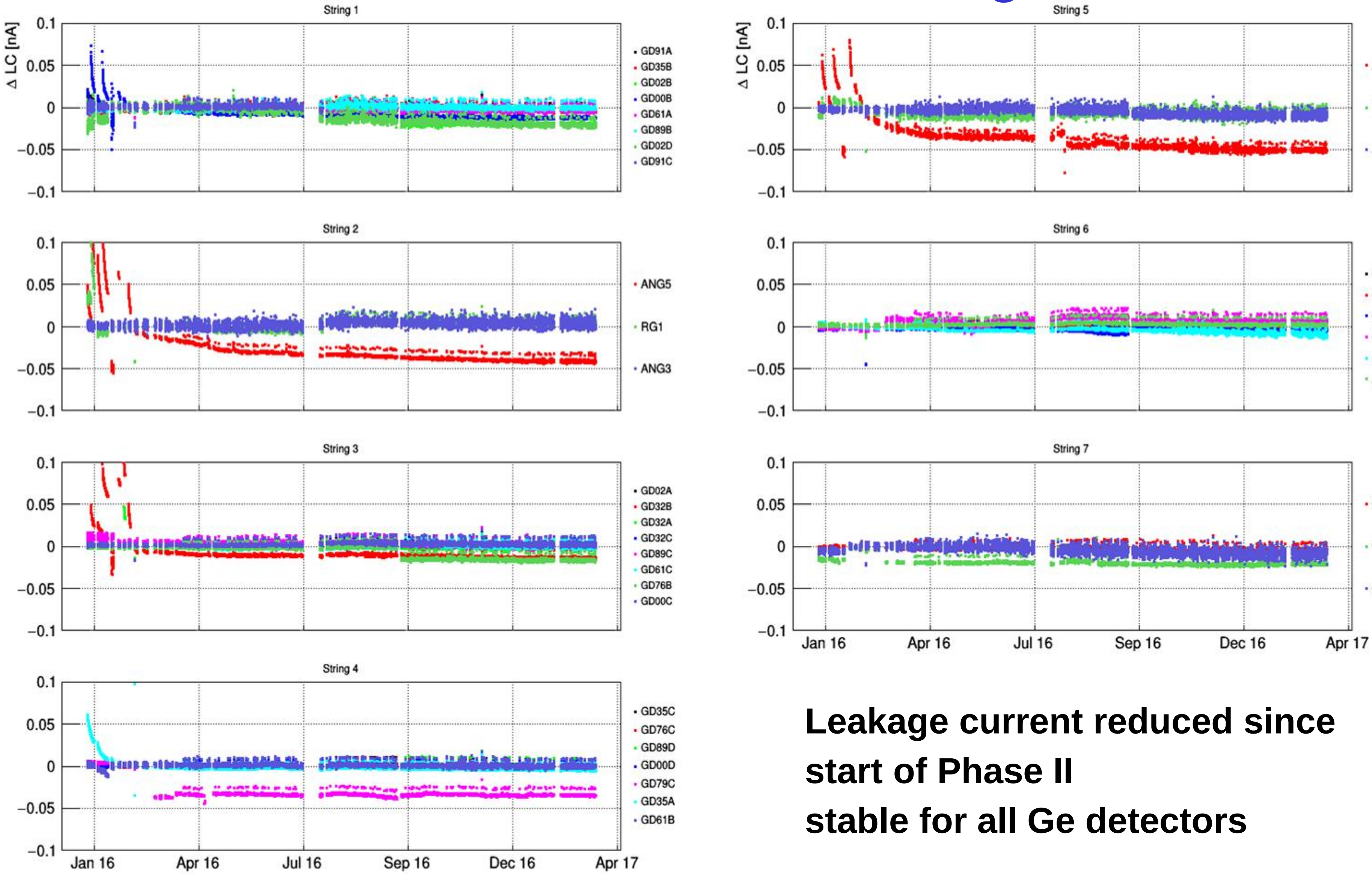



**PIIa**

**March 2017**
**28.5 kg yr**
**Qββ ± 25 keV**
**blinded**

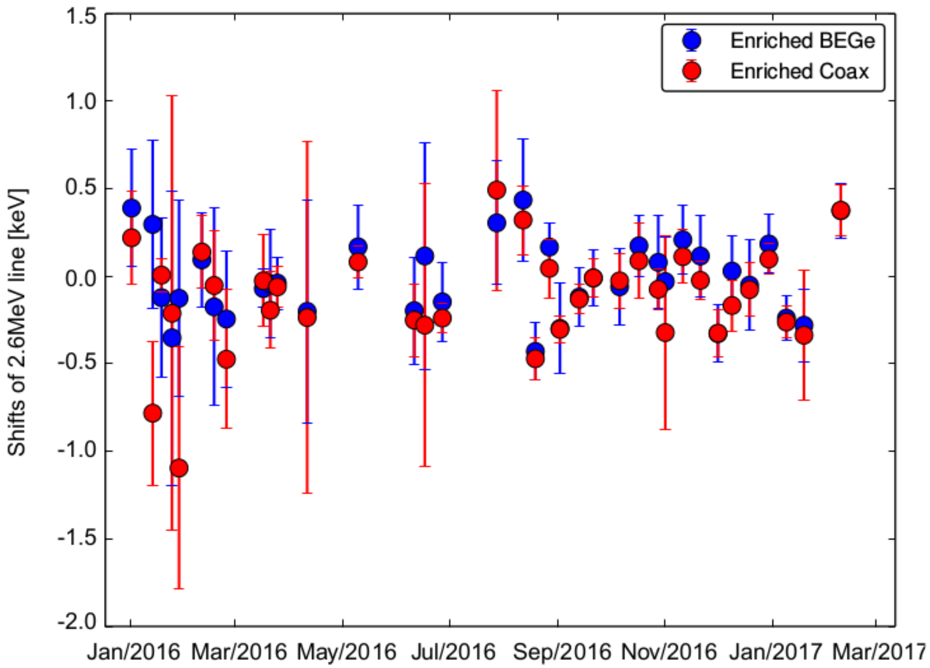
**June 2016**
**10.8 kg yr**
**first unblinding**
*Nature* **554** (2017) 47

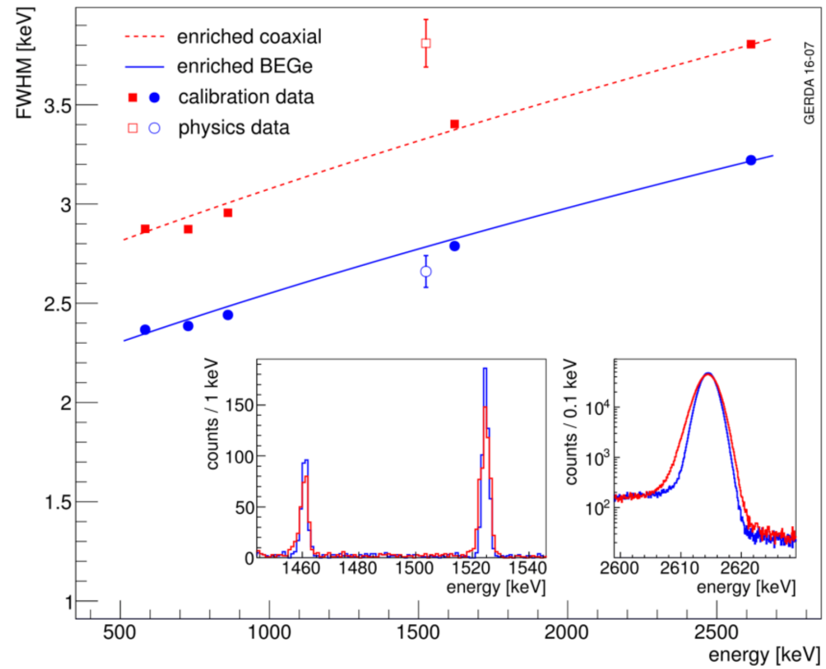
# GERDA Phase II: Data taking




**Leakage current reduced since start of Phase II**
**stable for all Ge detectors**

# GERDA Phase II: Data taking



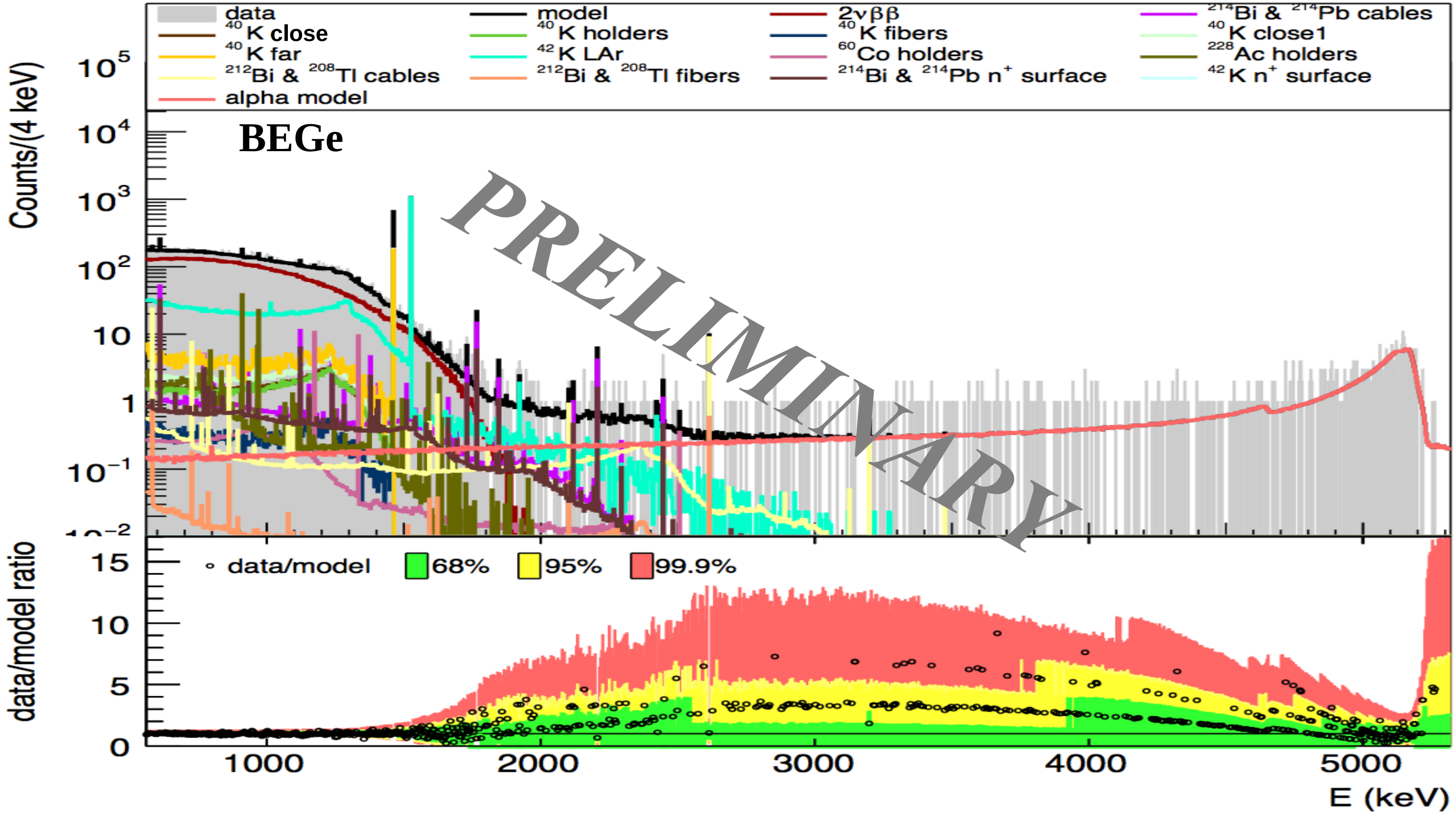




**PIIa** - - - - - - - - - - - - →

**Energy resolution FWHM at $Q_{\beta\beta}$ = 2039 keV**

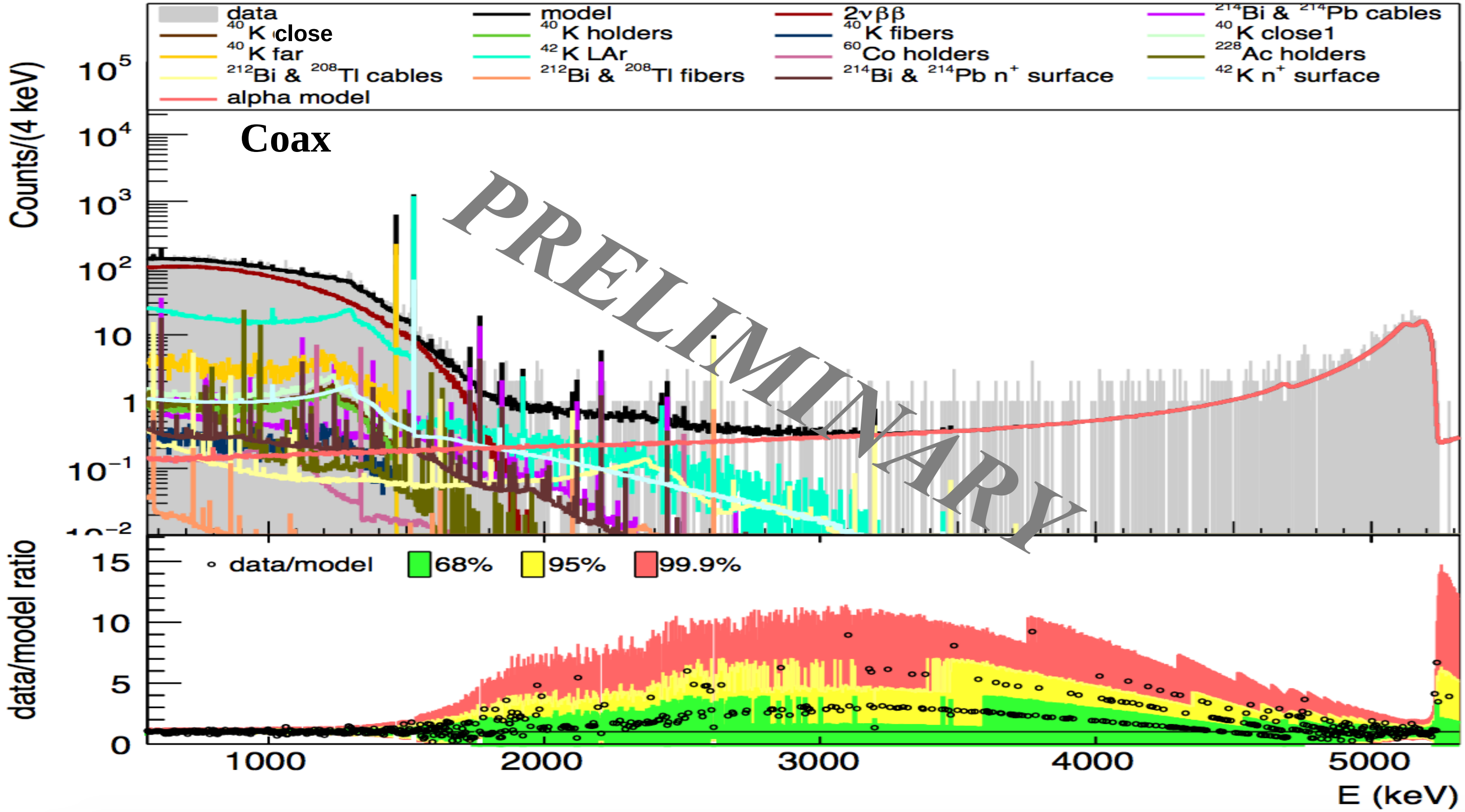
- **Coaxial 4.0 ± 0.2 keV**
- **BEGe 3.0 ± 0.2 keV**

# GERDA Phase II: Background decomposition




- Global model with different background components fitted to the data also taking into account the screening results
- Detector anti-coincidence cut and muon veto applied but no LAr veto or PSD cut

# GERDA Phase II: Background decomposition

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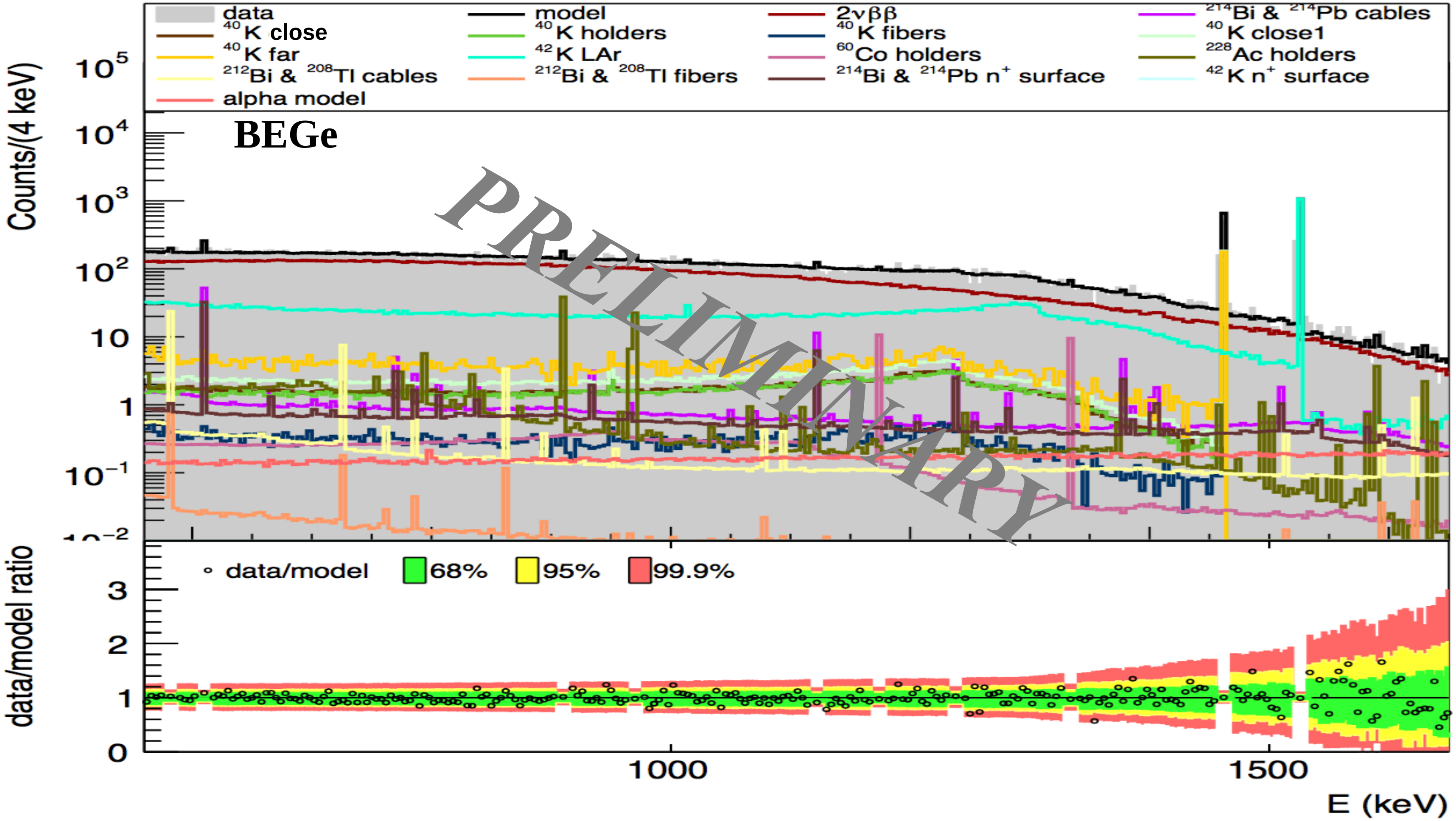
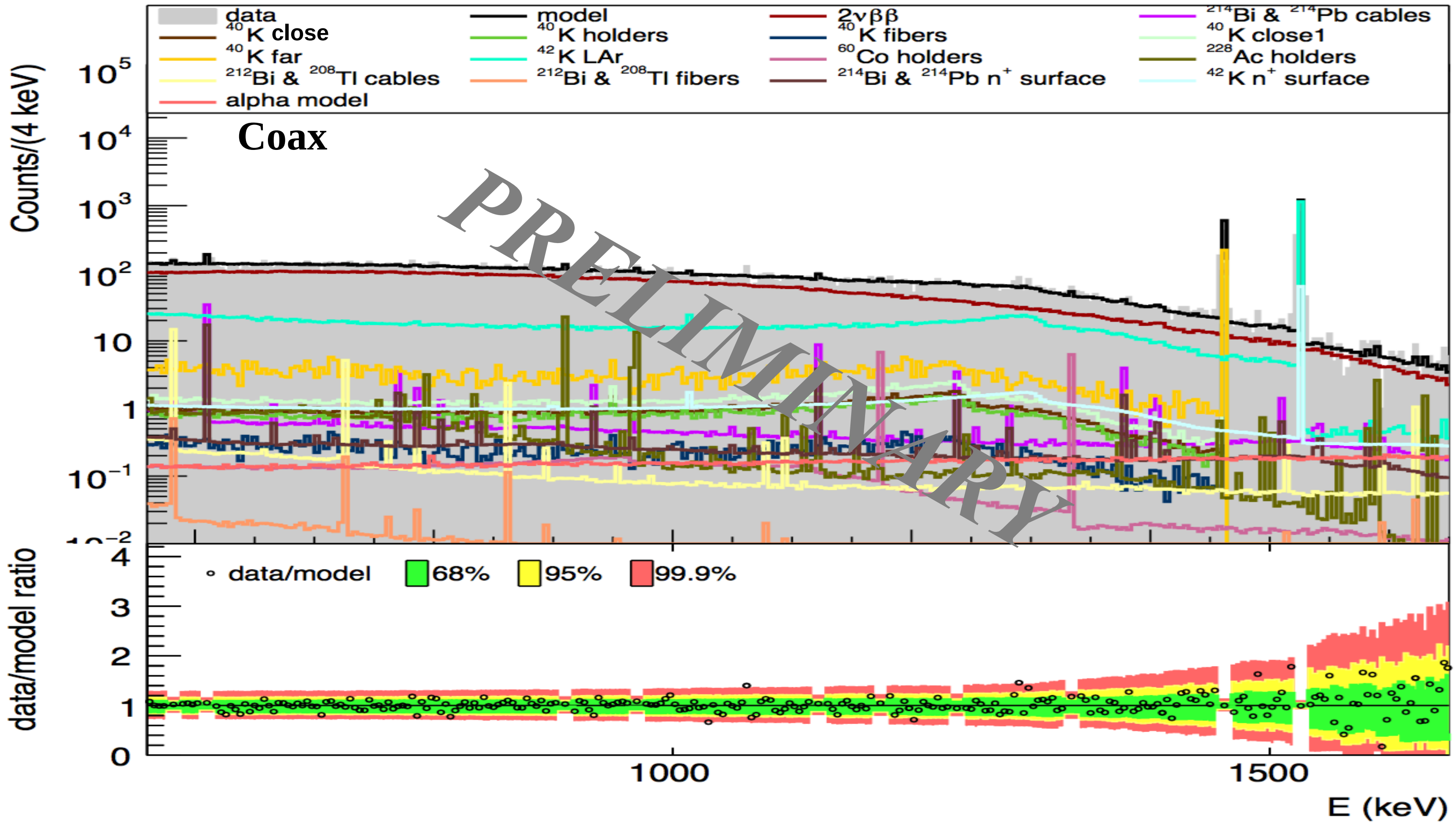
# GERDA Phase II: Background decomposition



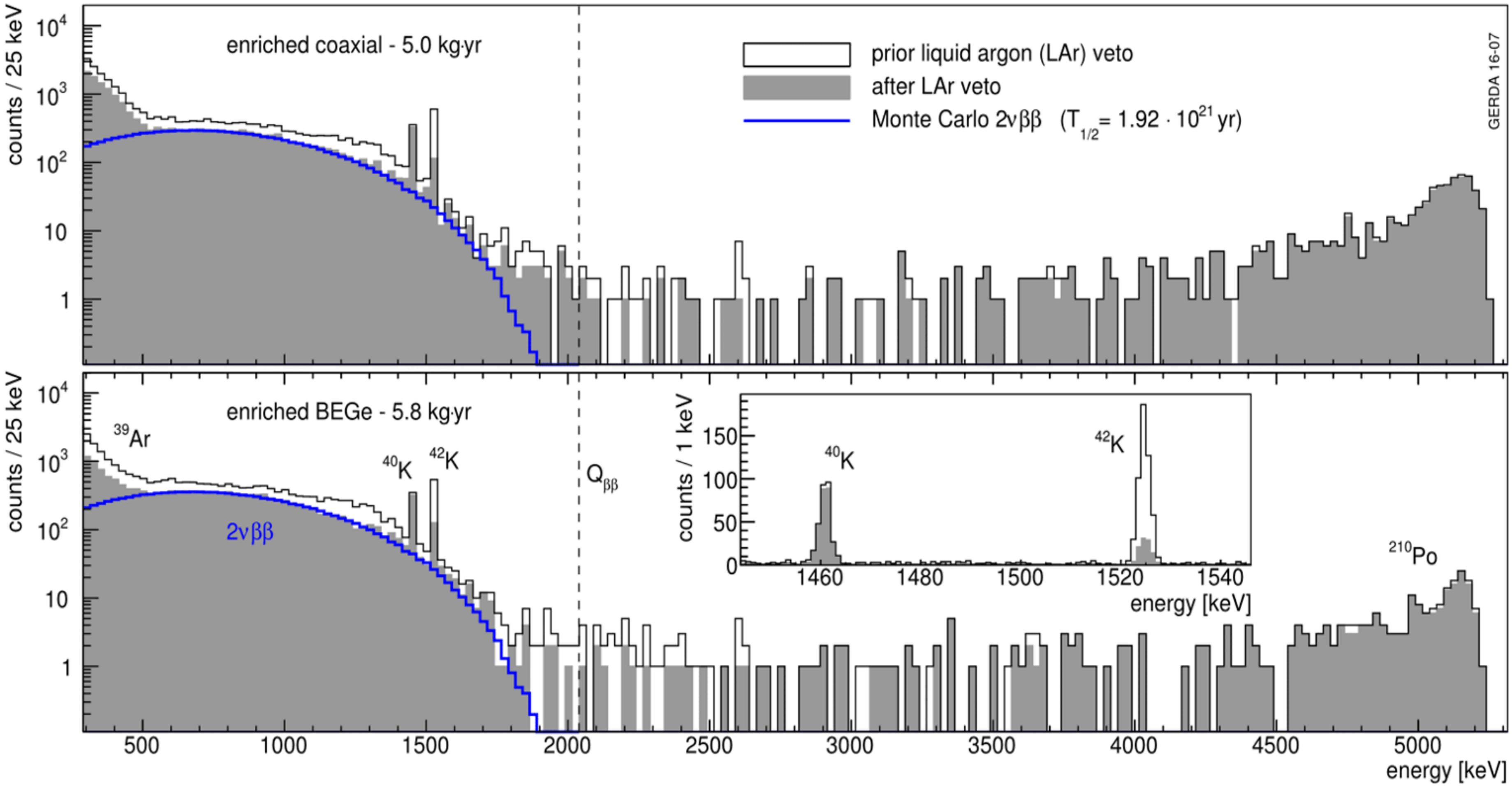

- **Main background components: $^{40}$K, $^{42}$K ($^{42}$Ar in LAr), 2νββ $^{76}$Ge, $^{226}$Ra ($^{232}$U series), $^{228}$Ac, $^{232}$Th series, $^{60}$Co**
- **Expected number of background events and spectral shape of background around $Q_{\beta\beta}$ can be derived**

# GERDA Phase II: Background decomposition




- Main background components: $^{40}$K, $^{42}$K ($^{42}$Ar in LAr), 2νββ $^{76}$Ge, $^{226}$Ra ($^{238}$U series), $^{228}$Ac, $^{232}$Th series, $^{60}$Co
- Expected number of background events and spectral shape of background around $Q_{\beta\beta}$ can be derived

# GERDA Phase II: LAr veto




**Almost pure 2νββ after LAr veto cut (600-1300 keV)**

**Background reduced by factor 2 around $Q_{\beta\beta}$**

**LAr veto cut signal acceptance (97.7 ± 0.1)%**

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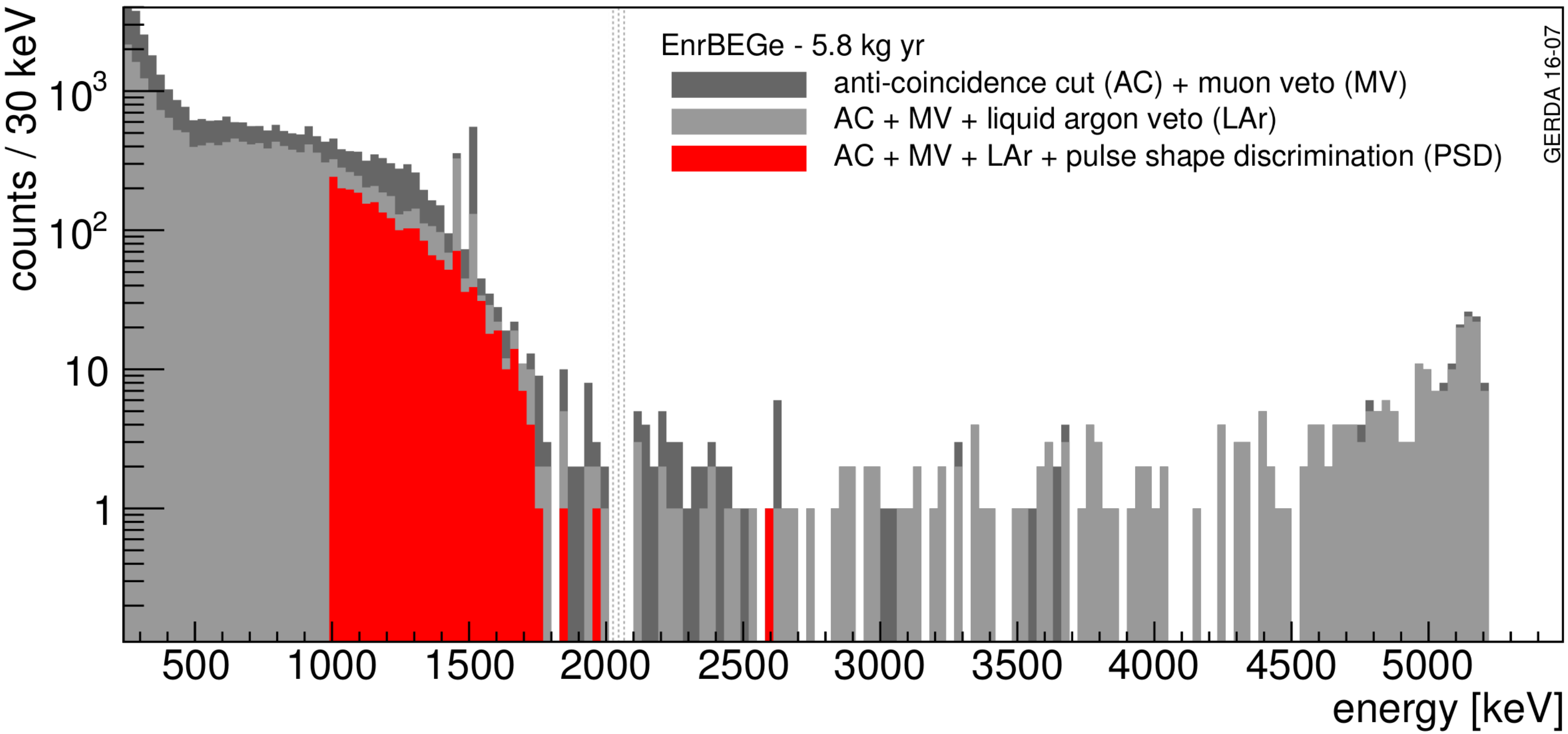
# GERDA Phase II: Pulse Shape Discrimination

## BEGe → A/E parameter

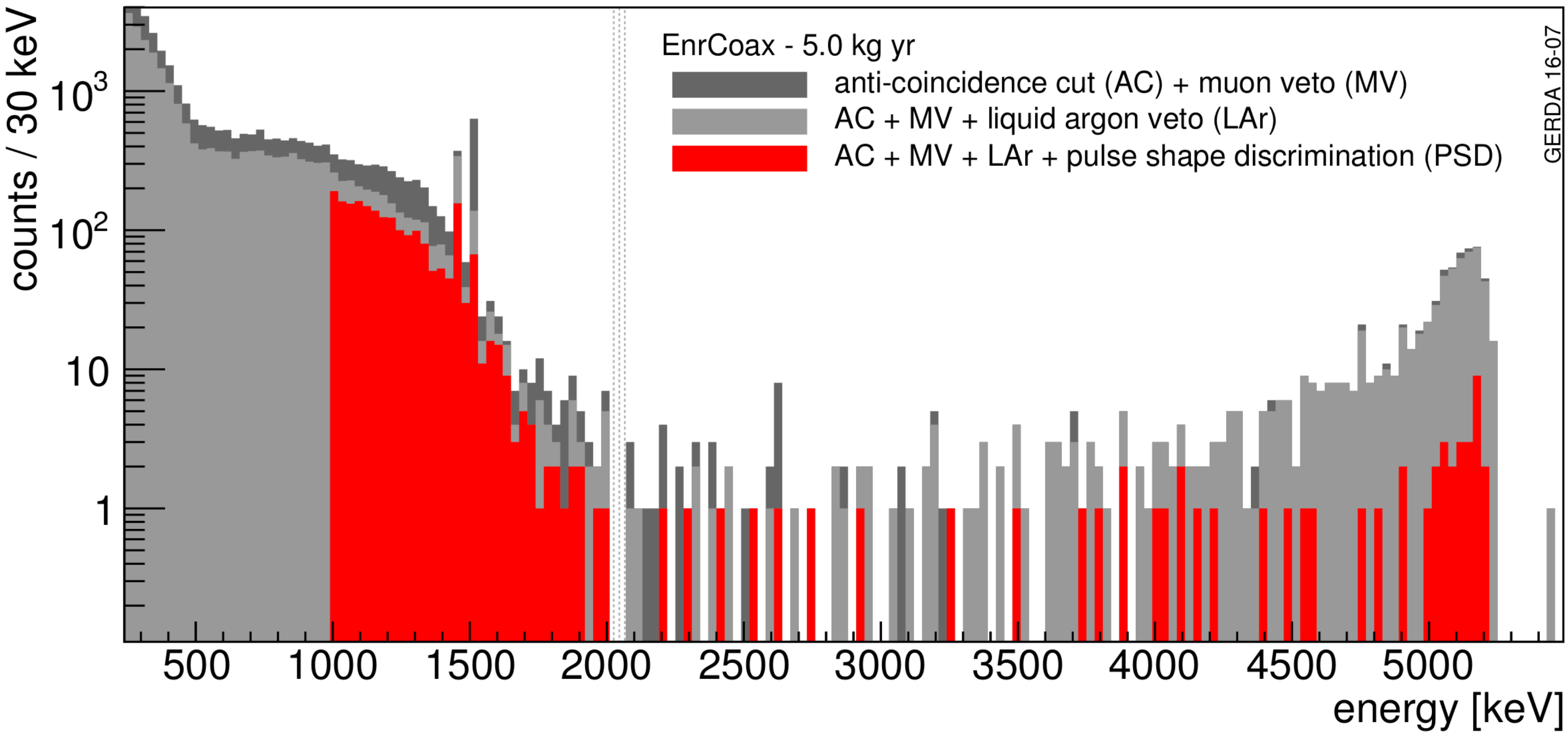
- 0νββ acceptance (87 ± 2)%
- removes all high energy α events



# GERDA Phase II: Pulse Shape Discrimination

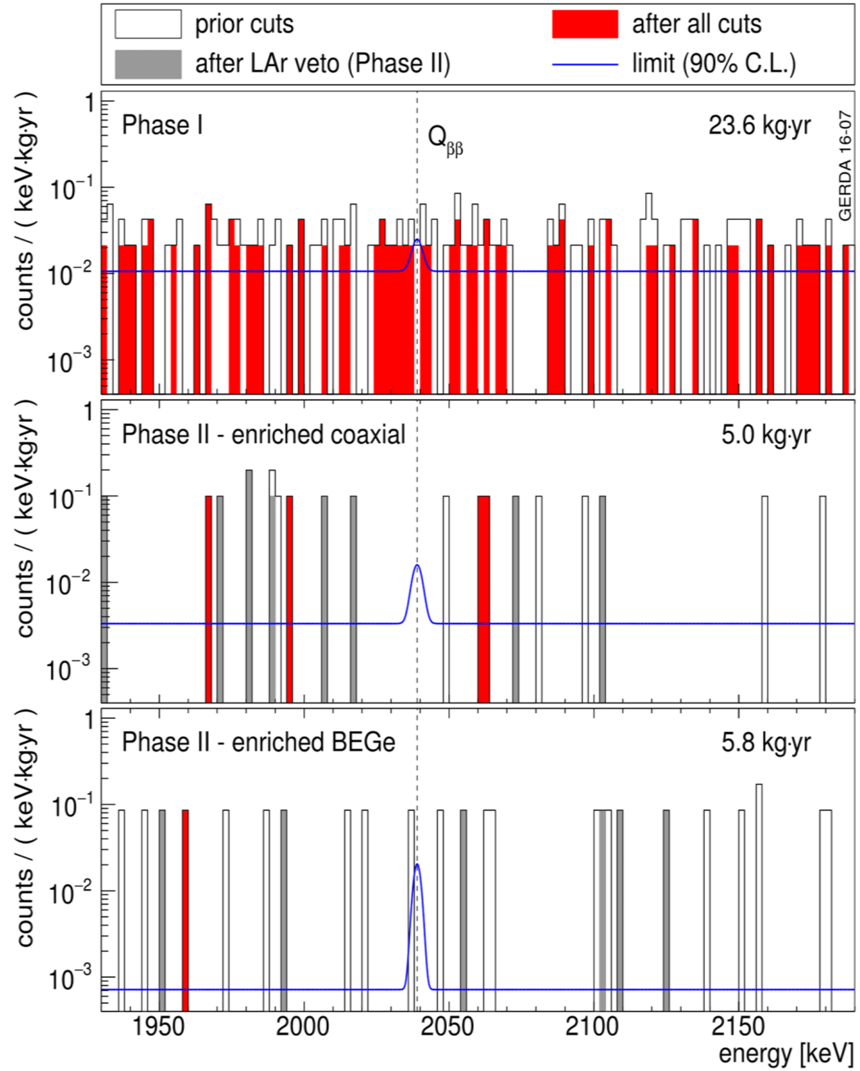
## Coax → Neural network

- $0\nu\beta\beta$ acceptance (79 ± 5)%
- removes 90% of α events



# GERDA Phase II: Bkg in RoI and first 0νββ results:

| Dataset | Exposure [kg yr] | FWHM [keV] | Corrections | BI [$10^{-3}$ cts/(keV kg yr)] |
|---|---|---|---|---|
| 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) | $5^{+4}_{-3}$ |
| 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) | **$0.7^{+1.1}_{-0.5}$** |




**Unbinned profile likelihood fit with flat background and Gaussian signal on combined data from Phase I (new energy reconstruction, extra data) and Phase II**

**Limit: $T_{1/2} > 5.3 \times 10^{25}$ yr (90% C.L.)**

**Sensitivity: $T_{1/2} > 4.0 \times 10^{25}$ yr (90% C.L.)**

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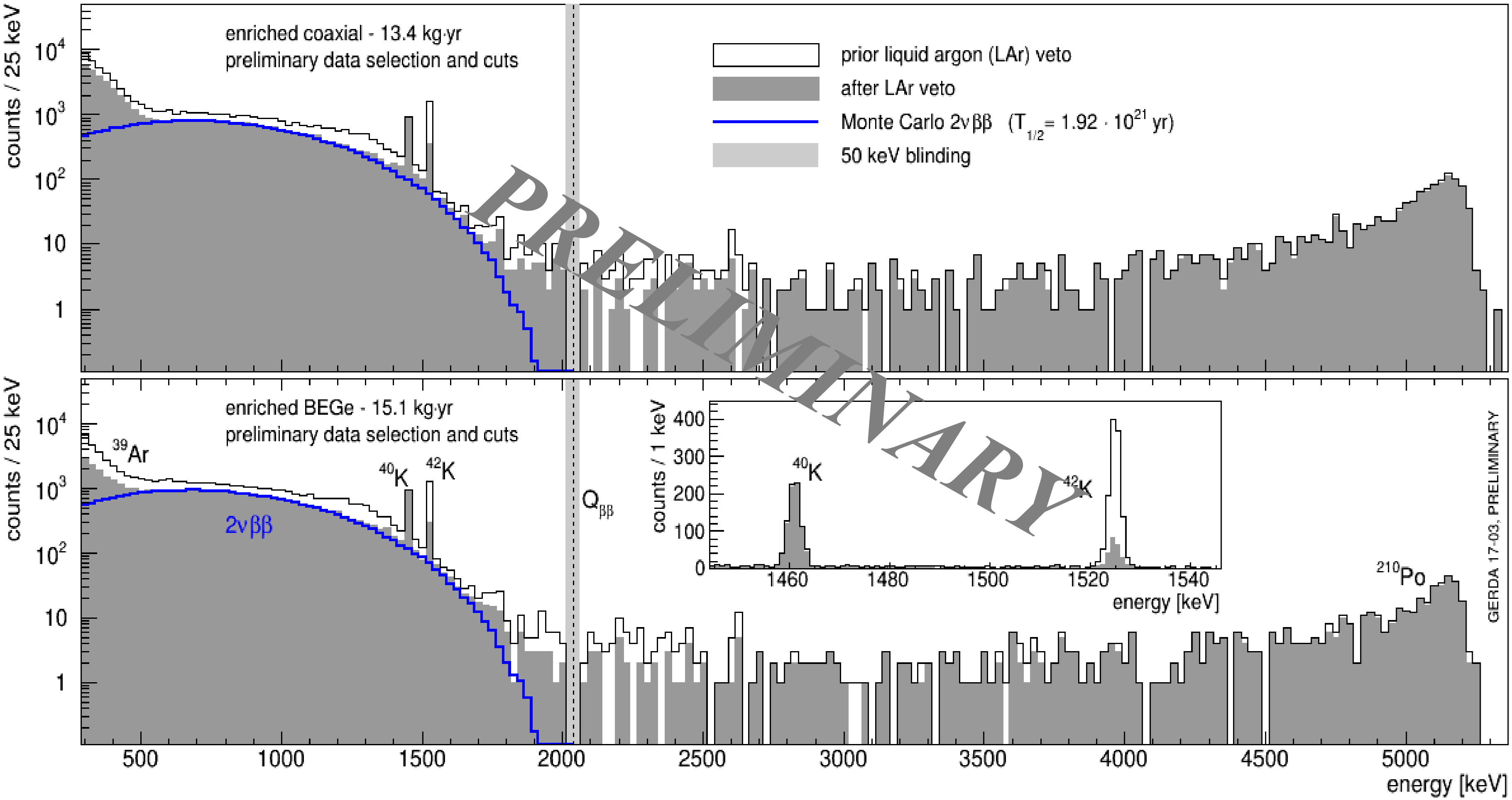
# GERDA Phase II: After 28.5 kg yr

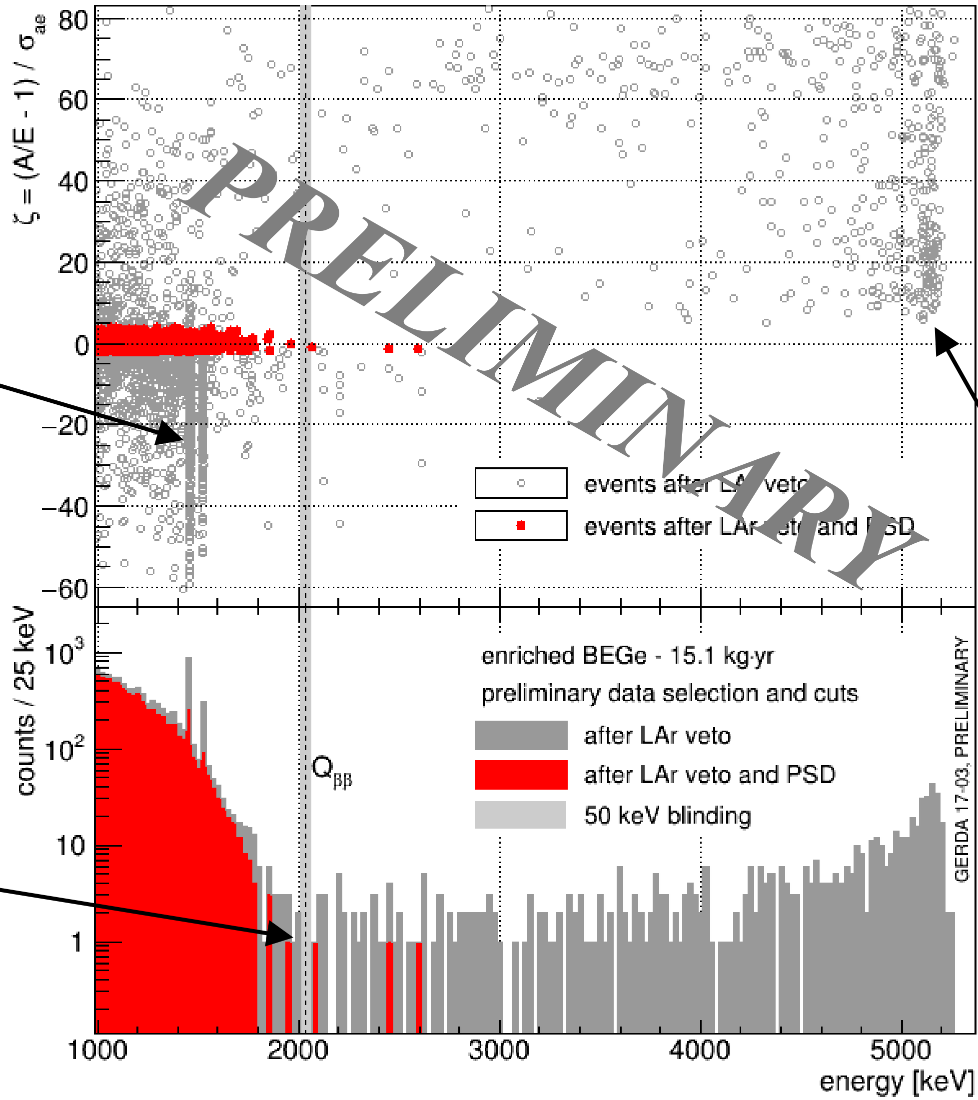



**Same background contributions as with 10.8 kg yr**

**Main contributions around $Q_{\beta\beta}$ from nearby sources: U/Th progenies, $^{42}$K, surface α events**

# GERDA Phase II: After 28.5 kg yr

$^{40}$K and $^{42}$K γ lines suppressed

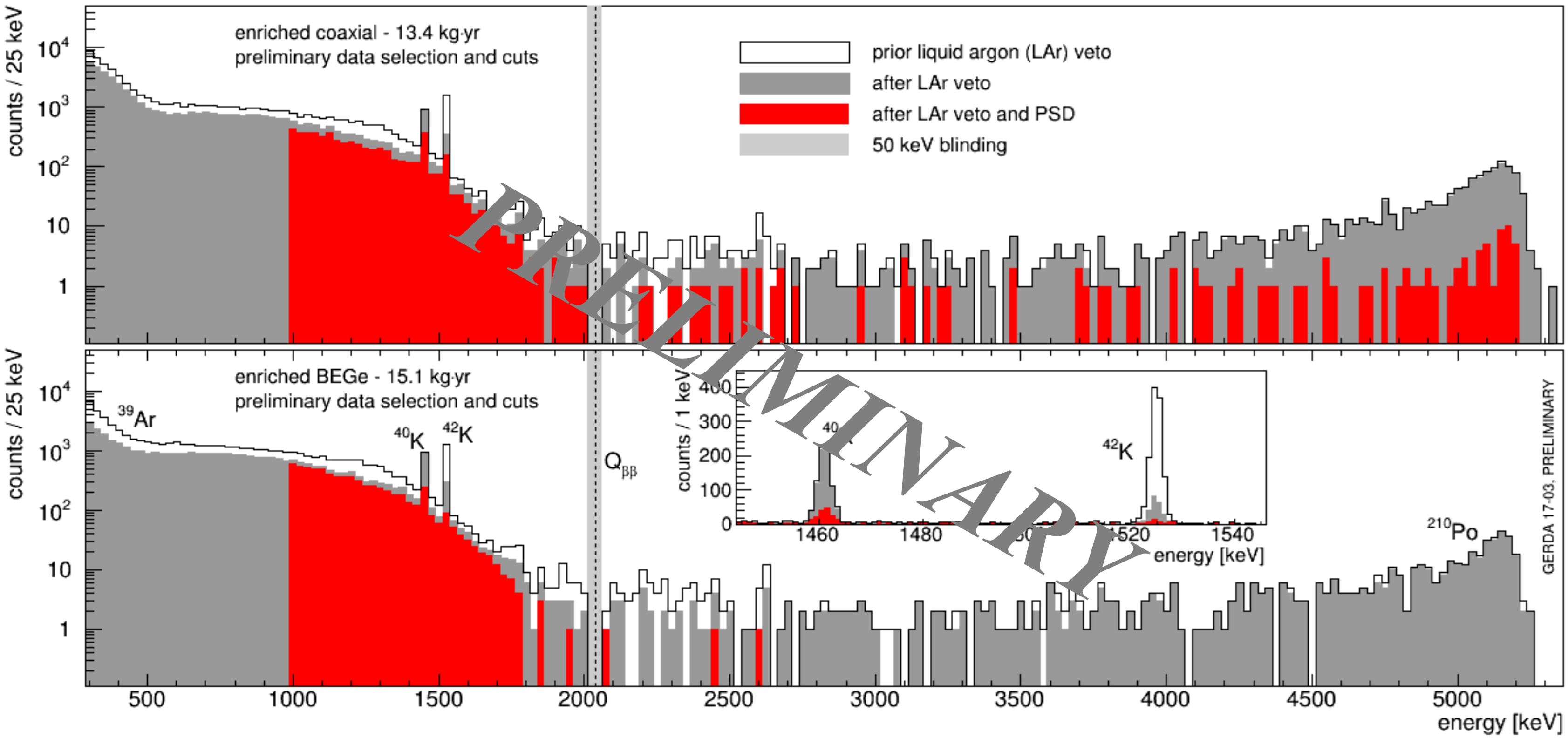



α events on detector surface all cut by PSD

Dominated by $^{210}$Po

2 counts around $Q_{\beta\beta}$ = 2039 keV

# GERDA Phase II: After 28.5 kg yr

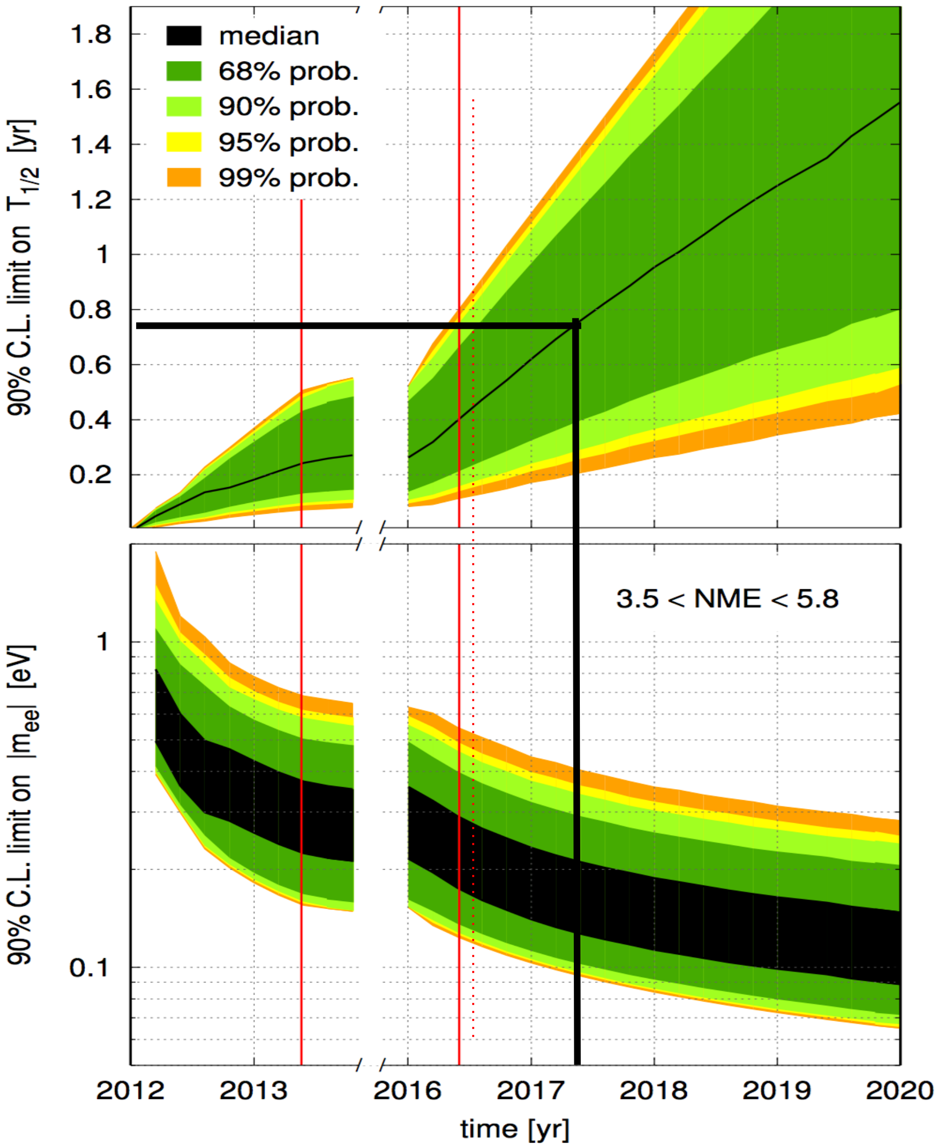



| | exposure [kg · yr] | BI* $\left[10^{-3} \cdot \frac{\text{cts}}{\text{keV·kg·yr}}\right]$ | (cts) | ...after LAr veto | | ...after PSD | | ...after LAr veto + PSD | |
|---|---|---|---|---|---|---|---|---|---|
| **EnrBEGe** | 15.1 | $12.3^{+2.3}_{-1.8}$ | (38) | $3.9^{+1.3}_{-1.0}$ | (12) | $3.2^{+1.2}_{-0.9}$ | (10) | $\mathbf{0.6^{+0.6}_{-0.4}}$ | (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) | $\mathbf{2.2^{+1.1}_{-0.8}}$ | (6) |

**BI for BEGes, ϵ - corrected** (enrichment, active mass, efficiencies) **:**

**With 3keV FWHM @ $Q_{\beta\beta}$ : BI = $3.0^{+3.0}_{-2.0}$ Cts/RoI/t/yr**

# CONCLUSION:




## Phase I analysis:

- Measured μ-induced n-flux
- HPGe bulk contamination

→ BI for ton scale Germanium

## Phase II achivements

- BEGe Background ~2 cts/(RoI t yr)
- 0νββ decay limits:
  $T_{1/2} > 5.3 \times 10^{25}$ yr (90% C.L.)
  $m_{\beta\beta} < 0.15 - 0.33$ eV (90% C.L.)
- ~1/3 of design exposure 100 kg yr
- In RoI: GERDA will likely stay **background free**

→ **Linear sensitivity increase**

# Large Enriched Germanium Experiment for Neutrinoless ββ Decay – LEGEND

## 47 Institutions, 219 Scientists


Univ. New Mexico
L'Aquila Univ. and INFN
Gran Sasso Science Inst.
Lab. Naz. Gran Sasso
Univ. Texas
Tsinghua Univ.
Lawrence Berkeley Natl. Lab.
Leibniz Inst. Crystal Growth
Comenius Univ.
Lab. Naz. Sud
Univ. of North Carolina
Sichuan Univ.
Univ. of South Carolina
Jagiellonian Univ.
Banaras Hindu Univ.
Univ. of Dortmund
Tech. Univ. – Dresden
Joint Inst. Nucl. Res. Inst.
Nucl. Res. Russian Acad. Sci.

Joint Res. Centre, Geel
Chalmers Univ. Tech.
Max Planck Inst., Heidelberg
Dokuz Eylul Univ.

Queens Univ.
Univ. Tennessee
Argonne Natl. lab.
Univ. Liverpool

Univ. College London
Los Alamos Natl. Lab.
Lund Univ.
INFN Milano Bicocca
Milano Univ. and Milano INFN
Natl. Res. Center Kurchatov Inst.
Lab. for Exper. Nucl. Phy. MEPhI
Max Planck Inst., Munich
Tech. Univ. Munich
Oak Ridge Natl. Lab.
Padova Univ. and Padova INFN
Czech Tech. Univ. Prague
Princeton Univ.
North Carolina State Univ.
South Dakota School Mines Tech.
Univ. Washington
Academia Sinica
Univ. Tuebingen
Univ. South Dakota
Univ. Zurich