Performance of Gerda Phase II BEGe Detectors

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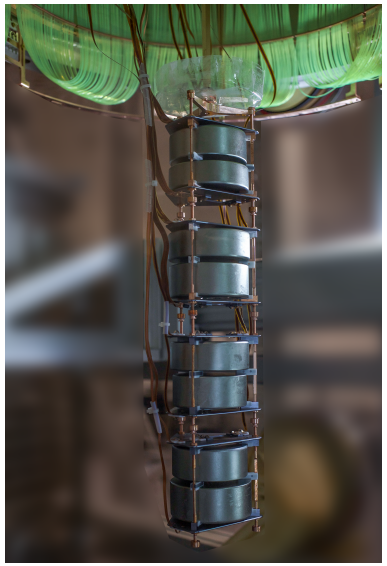
GERDA Phase II Upgrade

New **B**road **E**nergy **Ge**rmanium (BEGe) Detectors

- Additional 25 new BEGe detectors $\rightarrow \sim$ 20 kg target mass
- Better energy resolution and enhanced pulse shape discrimination compared to coaxial HPGe detectors



Low Mass Holders

- Goal is to reach background index (BI) 1×10^{-3} $\frac{\text{counts}}{\text{keV kg yr}}$
- Total mass of holder reduced and Cu replaced by Si
- 0.4 (0.3) μBq per kg BEGe (coaxial) detector mass (1 μBq/ kg detector mass in Phase I)

Phase II Electronics

- Less radioactivity
- Better match to low capacitance of BEGe detectors

Phase II Commissioning

First Commissioning

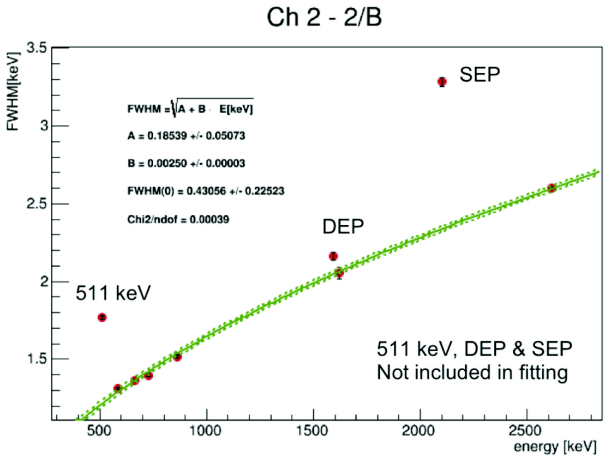
- Integration of **full string** with **8 detectors**
- **4 BEGe's isotopically enriched in ^{76}Ge**: GD61C, GD91C, GD02B, GD35B
- 4 BEGe's isotopically depleted in ^{76}Ge: 4/C, 1/D, 3/D, 2/B

Courtesy of Yura Suvorov

Phase II Commissioning: Preliminary Energy Resolution

Preliminary Energy Resolution with ZAC Filter

- New **Z**ero **A**rea **C**USP (ZAC) filter with an enhanced rejection of low frequency noise (for further details see arXiv:1502.04392)



Energy [keV]	FWHM [keV] 2/B	GD35B
583.2	1.31 ± 0.00	1.86 ± 0.01
1592.5	2.16 ± 0.02	2.49 ± 0.03
1620.5	2.06 ± 0.03	2.41 ± 0.05
2614.5	**2.60 ± 0.01**	**2.94 ± 0.01**

Analysis done by A. di Vacri, V. D'Andrea, F. Salamida, C. Cattadori

Average Energy Resolution in the 2614 keV line in GERDA Phase I

- Semi-coaxial detectors: 4.4 keV
- BEGe detectors: 2.8 keV

Discriminating Signal from Background Events

$0\nu\beta\beta$ Signal

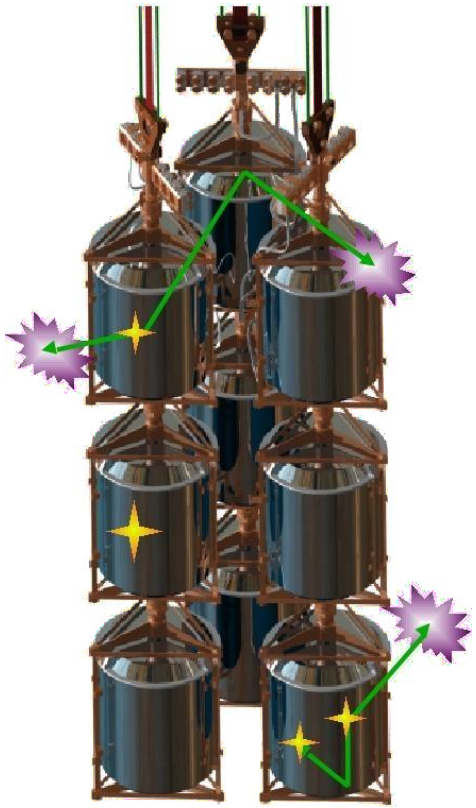
- Local energy deposition $\rightarrow$ single site event (SSE)

External Background

- α or β decays, e.g. ^{210}Po or ^{42}K, on detector surface $\rightarrow$ surface events
- γ background, e.g. ^{208}Tl, ^{214}Bi: often multiple Compton scattering with energy deposition in several locations in and outside the crystal $\rightarrow$ multi site event (MSE)

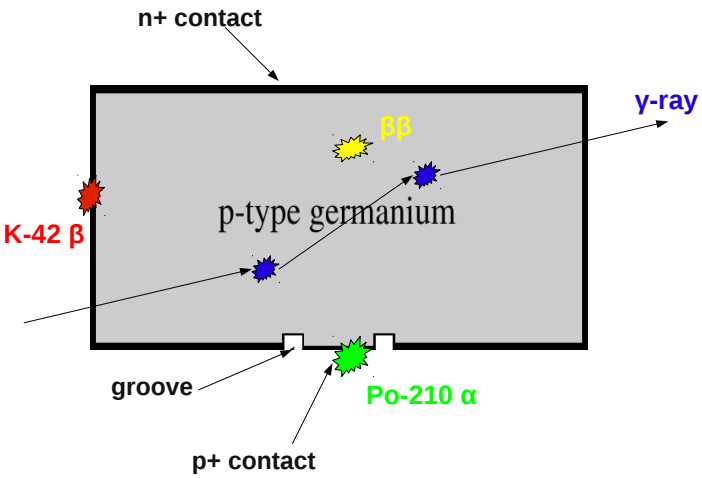
Internal Background at $Q_{\beta\beta} = 2039$ keV

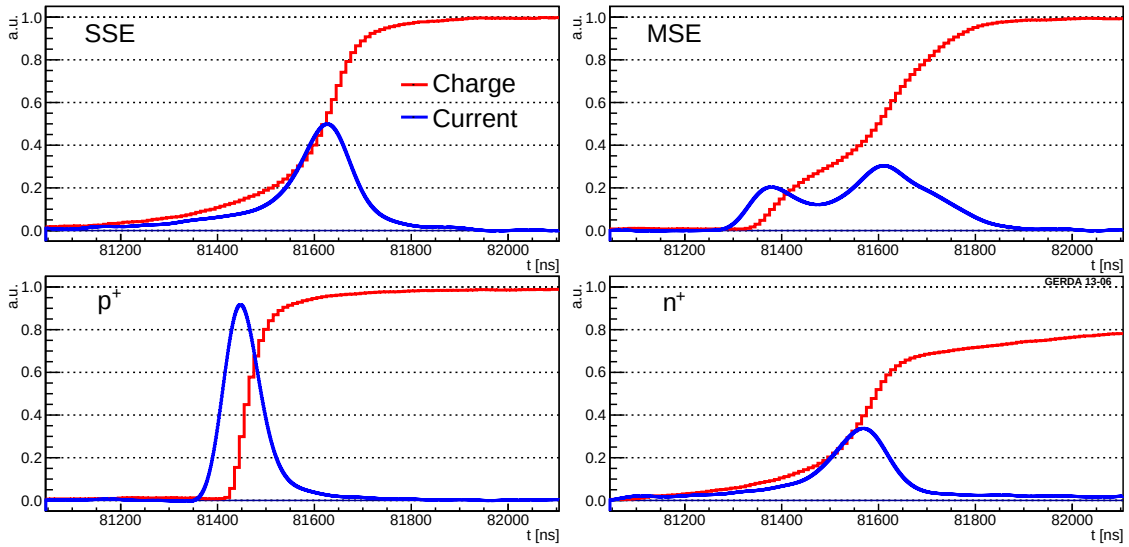
- Events from cosmogenic isotopes, e.g. ^{60}Co or ^{68}Ga, in Ge deposit energy in several locations $\rightarrow$ MSE



The A/E Parameter

Pulse shape discrimination (PSD) method based on a single parameter:
Ratio of the maximum current amplitude **A** over the energy **E**→ **A/E**



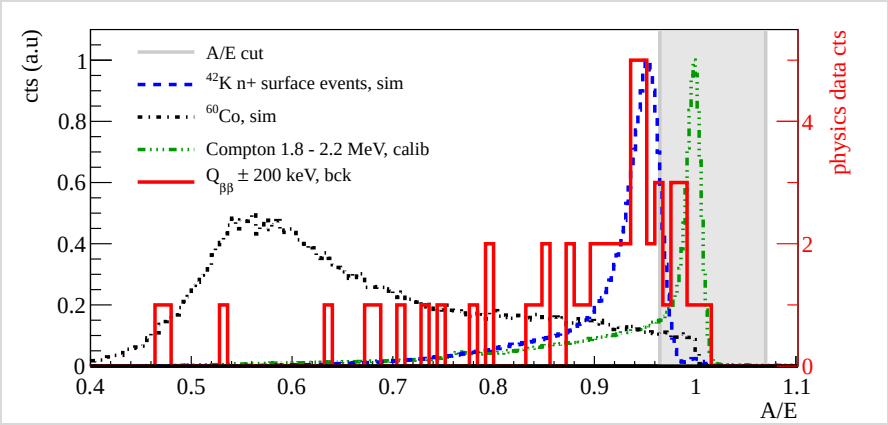


The Different Event Topologies

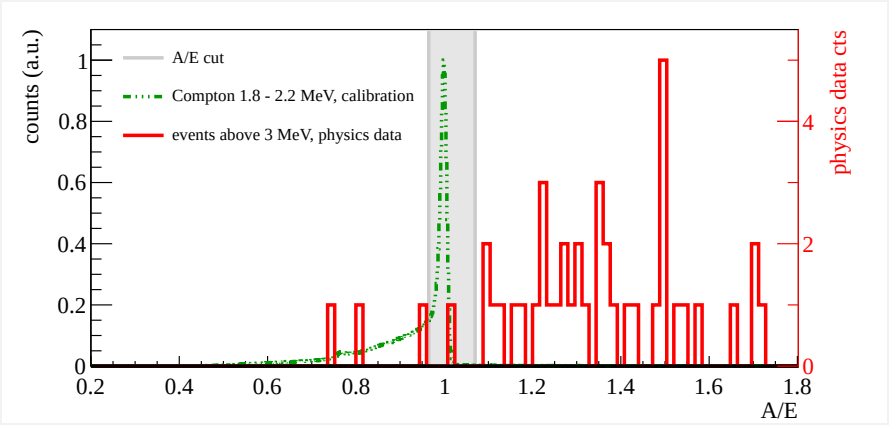
- Most **SSE** (e.g. $\beta\beta$) have similar pulse shapes independent from the interaction point
- **MSE** are a superposition of SSE → **smaller A/E**
- **p^+ contact events**: In a small volume around the read-out electrode signals have high rise time → **larger A/E**
- **n^+ surface events**: Signals from events penetrating from the outer surface have long rise time → **smaller A/E**

PSD with BEGe Detectors in GERDA Phase I

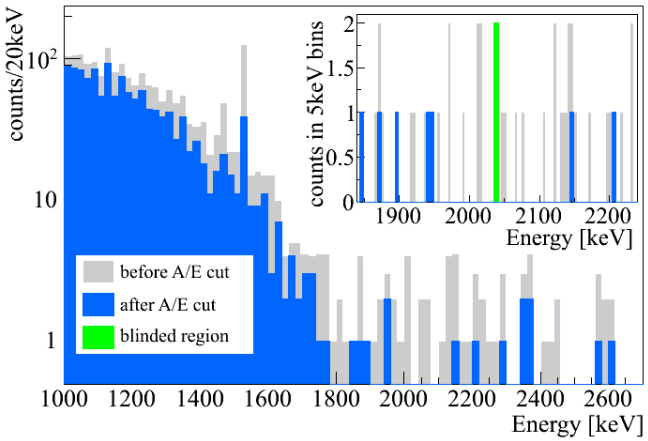
Background at 2039 ± 200 keV



Background above 3 MeV

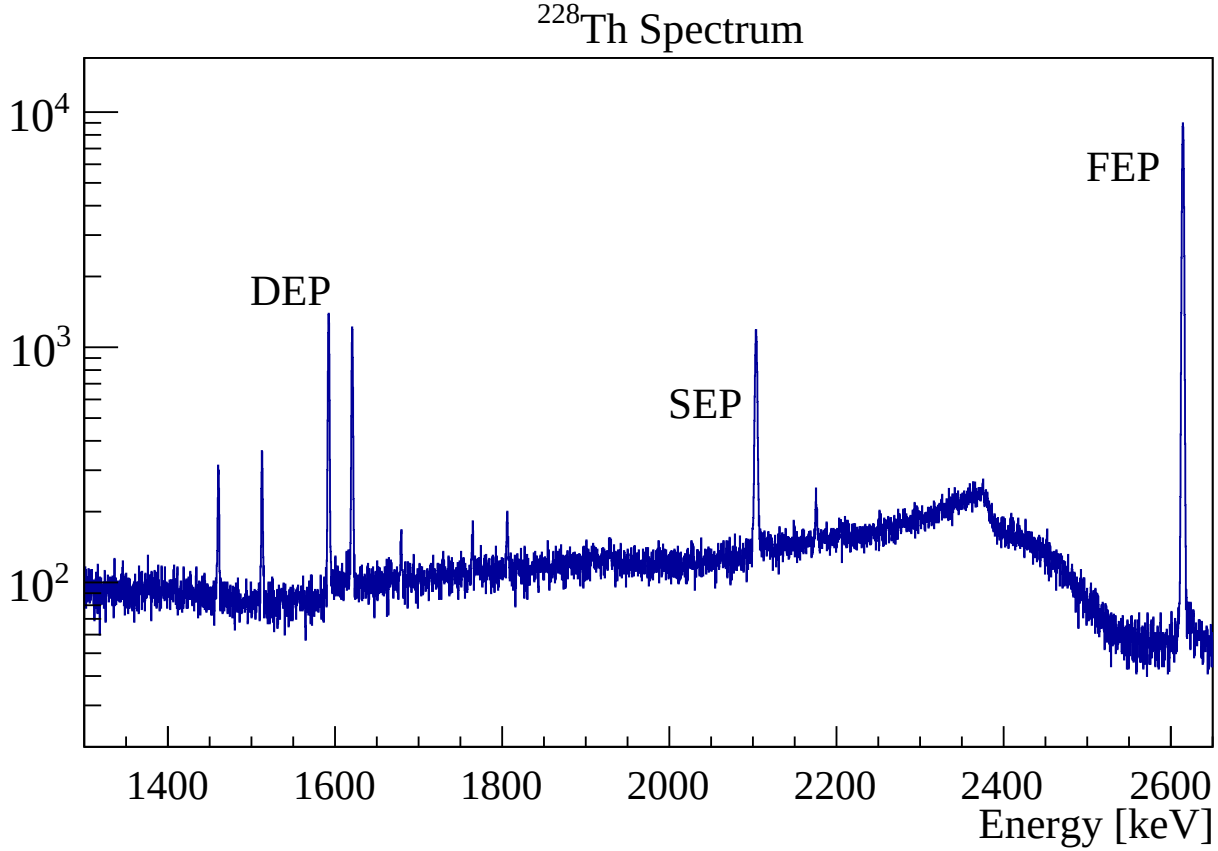


Background Reduction in Phase I



- More than 80% of the background events are rejected
- The $0\nu\beta\beta$ decay detection efficiency is 92 ± 2 %

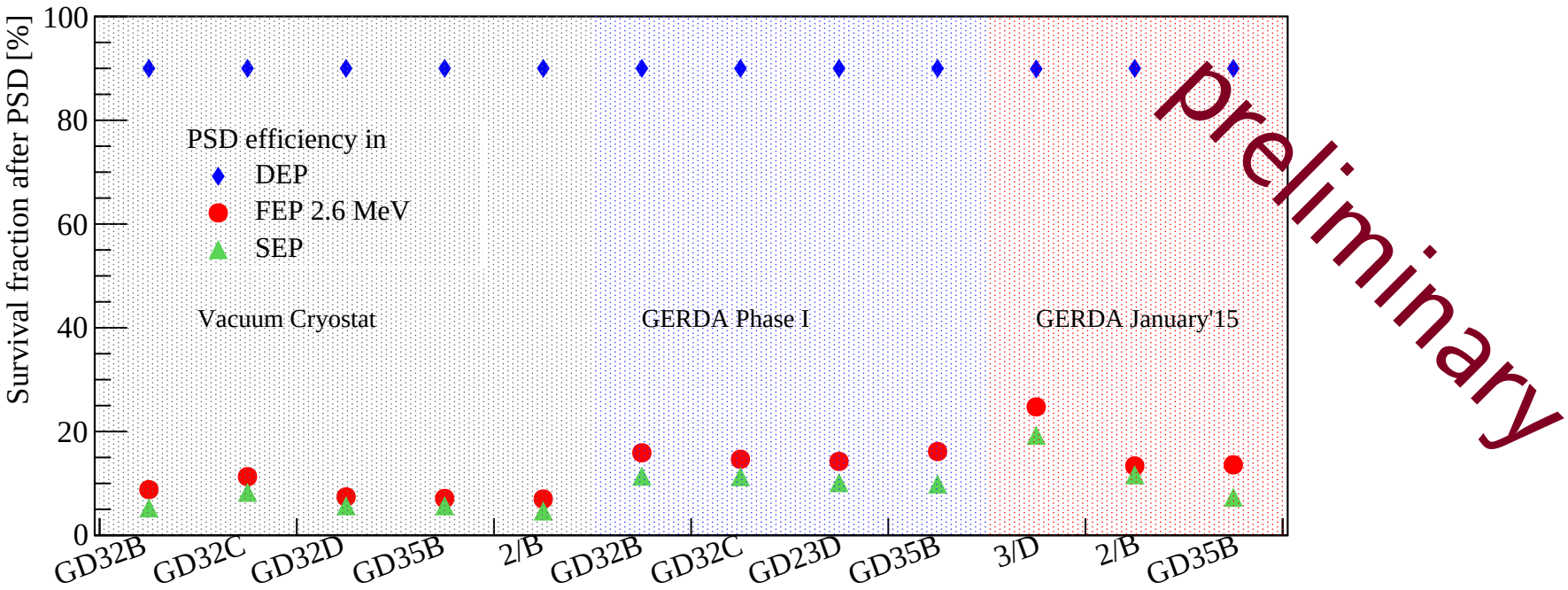
Calibration of A/E



^{228}Th Spectrum for A/E Calibration

- Double escape peak (**DEP**) events are used as a **proxy for $0\nu\beta\beta$ events**
- Single escape peak (**SEP**) and full energy peaks (**FEP**) contain a **high fraction of MSE**

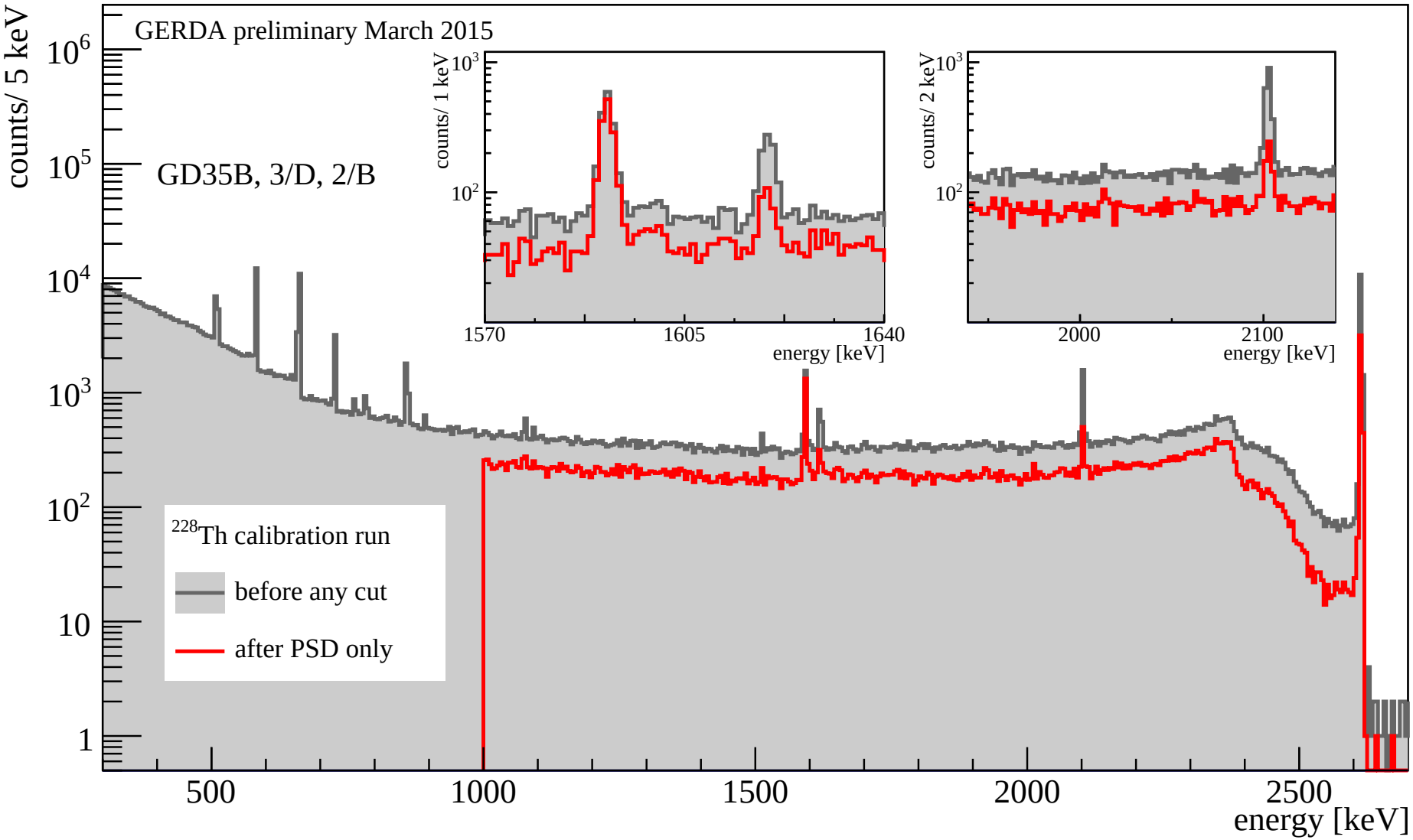
PSD of ^{228}Th Calibration



Survival Fractions

- 2/B and GD35B reach similar survival fractions like in Phase I:
  - 2/B: 11.7% (SEP) and 13.4% (FEP)
  - GD35B: 7.4% (SEP) and 13.6% (FEP)
  - Phase I: 10.7% (SEP) and 15.0% (FEP) on average
- Aim to reach similar PSD performance like in vacuum cryostat – 5.9% (SEP) and 8.3% (FEP) on average

Energy Spectrum before and after PSD



Summary

In Phase I the BEGe detectors showed

- stable performance over 10 months in liquid argon (LAr),
- good energy resolution and
- enhanced pulse shape discrimination (PSD)

In first Commissioning of GERDA Phase II we reach

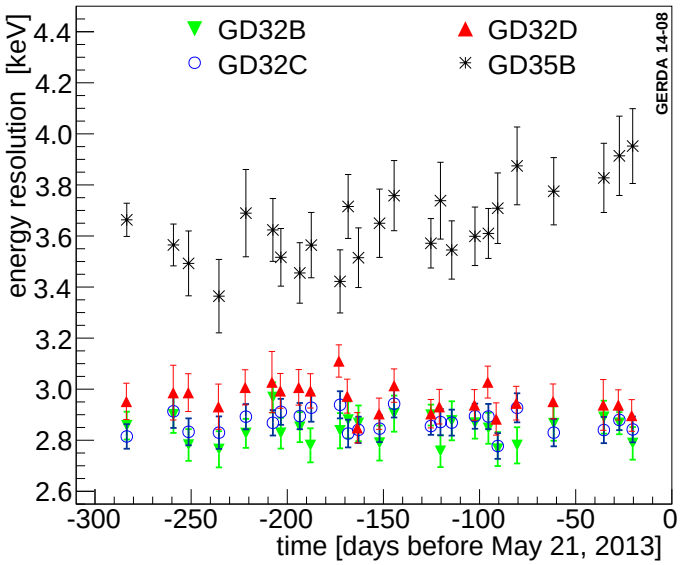
- similar energy resolution like in GERDA Phase I and
- similar PSD like in GERDA Phase I

On-going Commissioning

- Commissioning very promising
- Aim to reach similar performance like in vacuum cryostat
- More commission data these days

Bonus Slides

Energy Resolution in GERDA Phase I



FWHM of the ^{208}Tl γ-line at 2615 keV

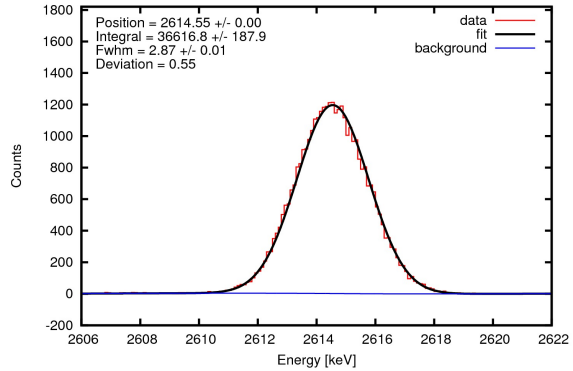
Detector (Semi-coax)	FWHM [keV]	Detector (BEGe)	FWHM [keV]
ANG2	4.712(3)	GD32B	2.816(4)
ANG3	4.658(3)	GD32C	2.833(3)
ANG4	4.458(3)	GD32D	2.959(4)
ANG5	4.323(3)	GD35B	3.700(5)
RG1	4.595(4)		
RG2	5.036(5)		

Average Energy Resolution

- Average energy resolution of semi-coaxial detectors:
- Average energy resolution of BEGe detectors:

Energy Resolution in Integration Tests

preliminary



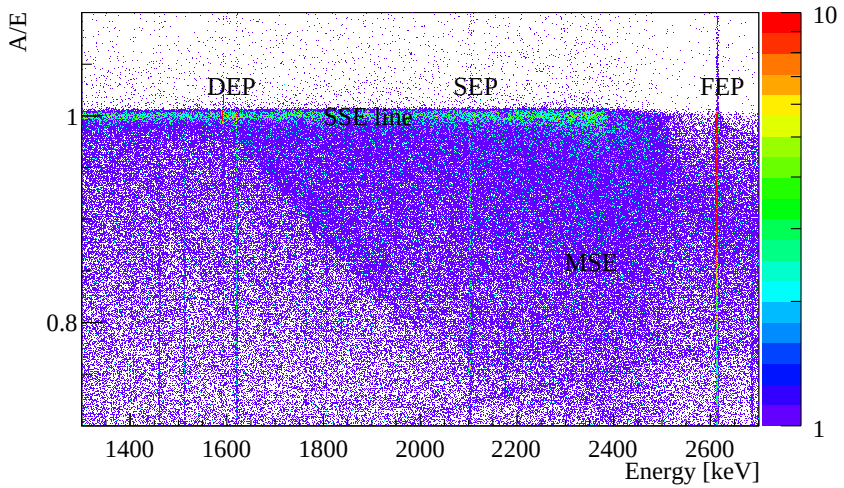
Energy Resolution with Standard Gaussian Filter

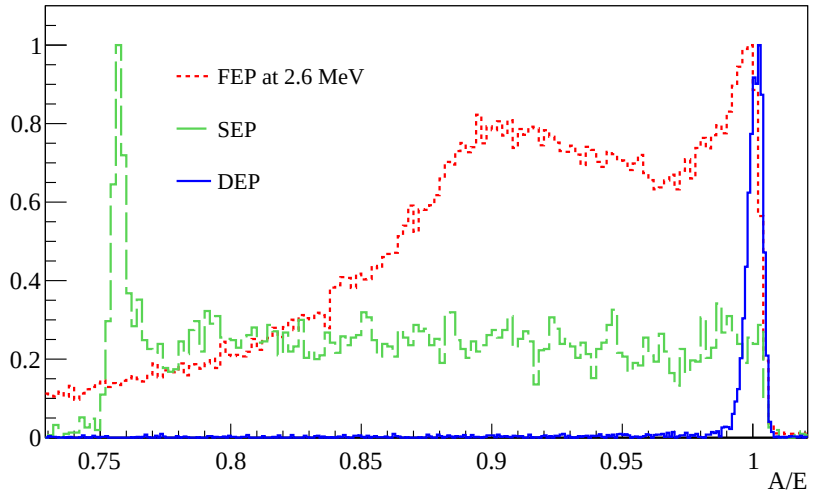
Energy [keV]	FWHM [keV] 3/D	2/B	GD35B
583.2	1.85 ± 0.02	1.53 ± 0.01	2.09 ± 0.01
1592.5	2.69 ± 0.08	2.37 ± 0.05	2.71 ± 0.06
1620.5	2.53 ± 0.19	2.27 ± 0.09	2.83 ± 0.15
2614.5	**3.41 ± 0.03**	**2.87 ± 0.01**	**3.38 ± 0.06**

Average Energy Resolution at $Q_{\beta\beta} = 2039$ keV in GERDA Phase I

- Semi-coaxial detectors: 4.8 keV
- BEGe detectors: 3.2 keV

Calibration of A/E

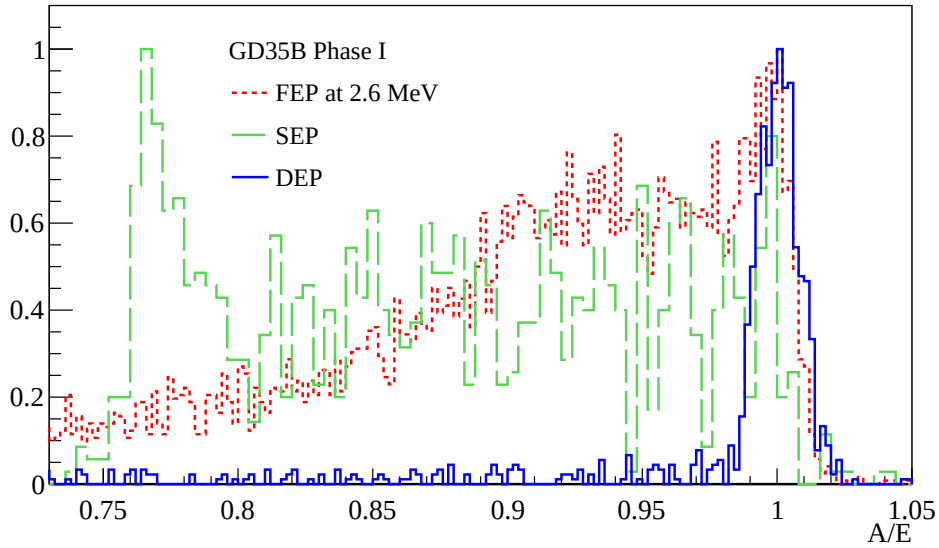




^{228}Th Spectrum for A/E Calibration

- double escape peak (DEP) events are used as a proxy for $0\nu\beta\beta$ events
- single escape peak (SEP) and full energy peaks (FEP) contain a high fraction of MSE

PSD Efficiencies in GERDA Phase I

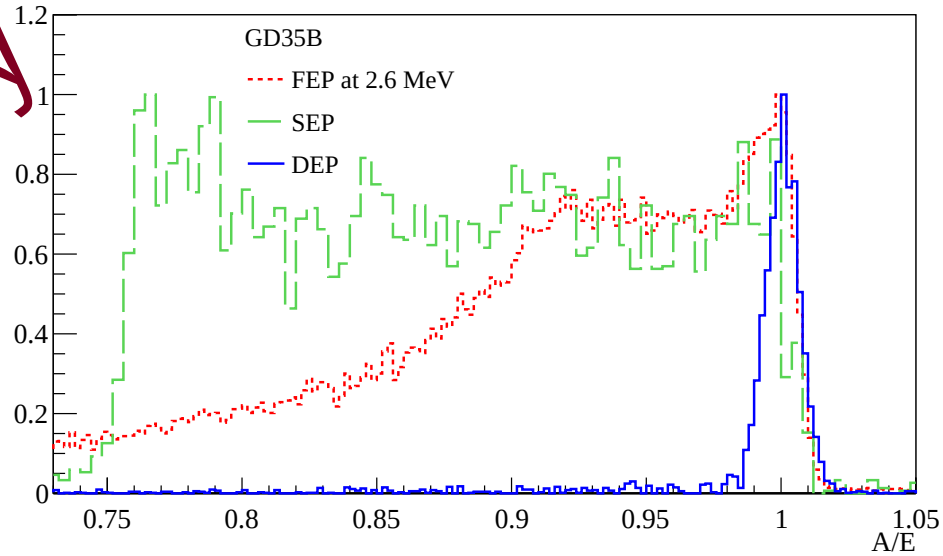


Survival Fraction after PSD Cut

Energy region	GD32B	GD32C	GD32D	GD35B
DEP	89.99 ± 0.91	89.99 ± 0.79	90.00 ± 1.07	90.00 ± 1.54
FEP 1620.5 keV	13.42 ± 1.45	16.23 ± 1.31	15.78 ± 1.59	11.68 ± 2.70
SEP	11.41 ± 0.67	11.32 ± 0.70	10.17 ± 0.69	9.88 ± 1.29
FEP 2614.5 keV	15.09 ± 0.95	14.66 ± 0.92	14.24 ± 0.90	16.15 ± 1.47

PSD Efficiencies Commissioning

preliminary



Survival Fraction after PSD Cut[1] [2]

Energy region	3/D	2/B	GD35B
DEP	89.91 ± 1.43	90.03 ± 1.27	89.99 ± 1.25
FEP 1620.5 keV	22.74 ± 3.08	10.60 ± 2.11	11.49 ± 2.06
SEP	19.29 ± 1.22	11.68 ± 0.96	7.35 ± 1.01
FEP 2614.5 keV	24.75 ± 0.25	13.37 ± 0.15	13.58 ± 0.15

[1] statistical uncertainties only
[2] subset of commissioning data