Normalization procedure of Pulse Shape Discrimination for Broad Energy Germanium Detector

Outline:

- GERDA experiment
- BEGe detector
- PSD analysis & Results
- Outlook & Summary

Heng-Ye Liao

for the GERDA collaboration

Max-Planck-Institut für Physik

DPG-Frühjahrstagungen @ Mainz

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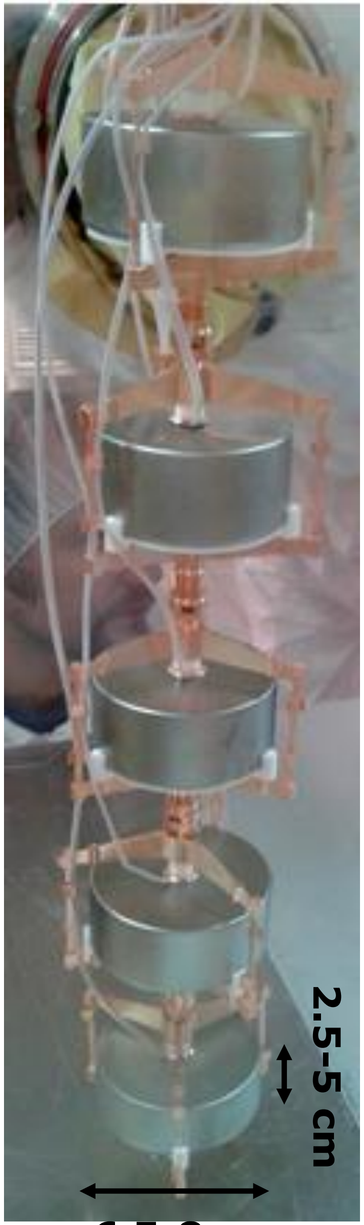
The GERDA Experiment

- **Search for 0vββ decay in ^{76}Ge @ $Q_{\beta\beta}$=2.039 MeV**
- **Previous results for ^{76}Ge 0vββ decay:**
  - **limit:** $T_{1/2}^{0\nu\beta\beta} > 1.9\cdot10^{25}$ yr @ 90% C.L. from HDM and IGEX [EPJ. A12 (2001)147-154]
  - **claim:** $T_{1/2}^{0\nu\beta\beta} = 1.19^{+0.37}_{-0.23}\cdot10^{25}$ yr Klapdor-Kleingrothaus et al., [PL B586 (2004) 198]

- **Phase-I:**
- Data taking: Nov. 2011 to Jun 2013, exposure: 21.6 kg·yr
- Detector:
  8 ^{enr}coax detectors(17.7 kg) from HDM & IGEX
  5 ^{enr}BEGe Phase-II detectors (3.6 kg) (started in May 2012)
  3 ^{nat}Ge coaxial detector (3.0 kg)
- BI: ~10^{-2} Cts/(keV·kg·yr)
- **Physics result:** $T_{1/2}^{0\nu\beta\beta} > 2.1\cdot10^{25}$ yr @ 90%C.L. [PRL 111 (2013) 122503]
  $T_{1/2}^{0\nu\beta\beta} > 3.0\cdot10^{25}$ yr [GERDA+HDM+IGEX results]
- **Phase-I successfully completed, Klapdor claim strongly disfavored**

GERDA Phase-I BEGe Detectors

- **Broad Energy Germanium Detectors**
- **Advantages of BEGe detectors:**
  - ✓ Low capacity → low noise
  - ✓ Very good energy resolution
    FWHM @ 2.6 MeV:
    $<\Delta E_{coaxial}> \sim 4.8$ keV
    $<\Delta E_{BEGe}> \sim 3.2$ keV
  - ✓ Powerful PSD to reject backgrounds
    → A/E method
- **Total Phase-I exposure for BEGes:**
  2.4 kg·yr
- **GERDA PSD paper has been published:**
  EPJC 73 (2013) 2583



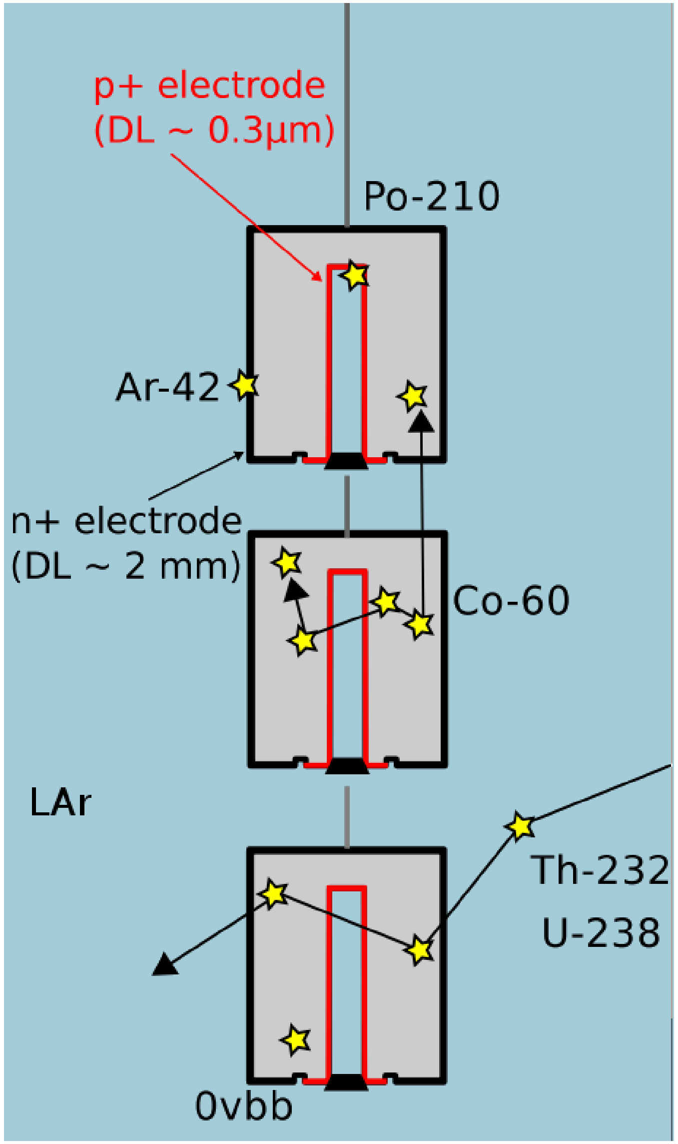
Backgrounds

Background sources:

- natural radioactivity(^{232}Th & ^{238}U chains):

  γ-rays (e.g. ^{208}Tl, ^{214}Bi)
  α-emitting isotopes from surface contamination (e.g. ^{210}Po or ^{222}Rn in LAr)

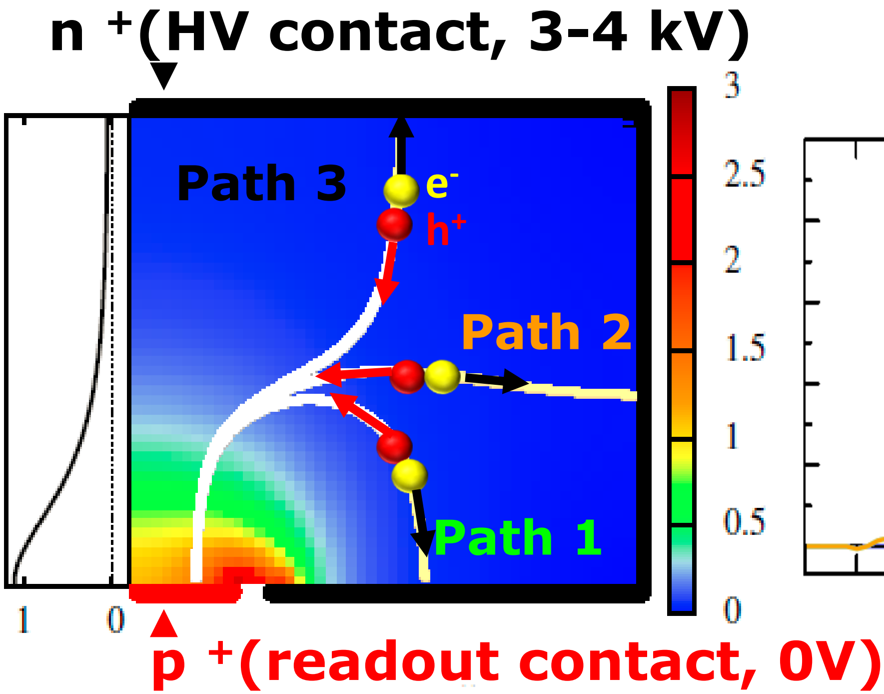
- Cosmogenic isotopes in Ge decaying inside the detectors (^{68}Ge,^{60}Co)
- long-lived cosmogenic Ar isotopes (^{39}Ar,^{42}K)

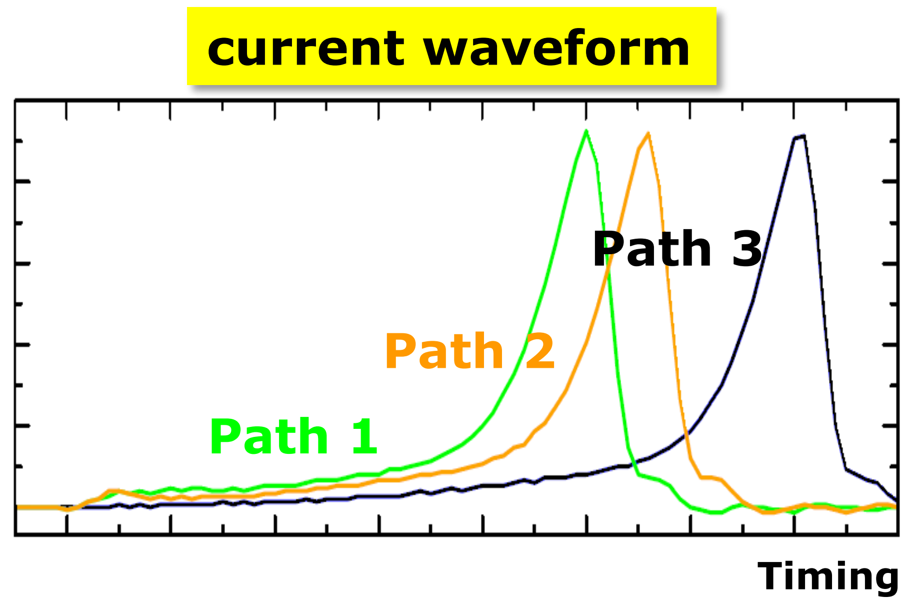


Background suppression:

- Gran Sasso μ flux reduction(10^6)
- Muon veto
- Detector anti-coincidence
- Pulse shape analysis
- LAr-scintillation (for phase II)

Pulse Shape Properties of BEGes

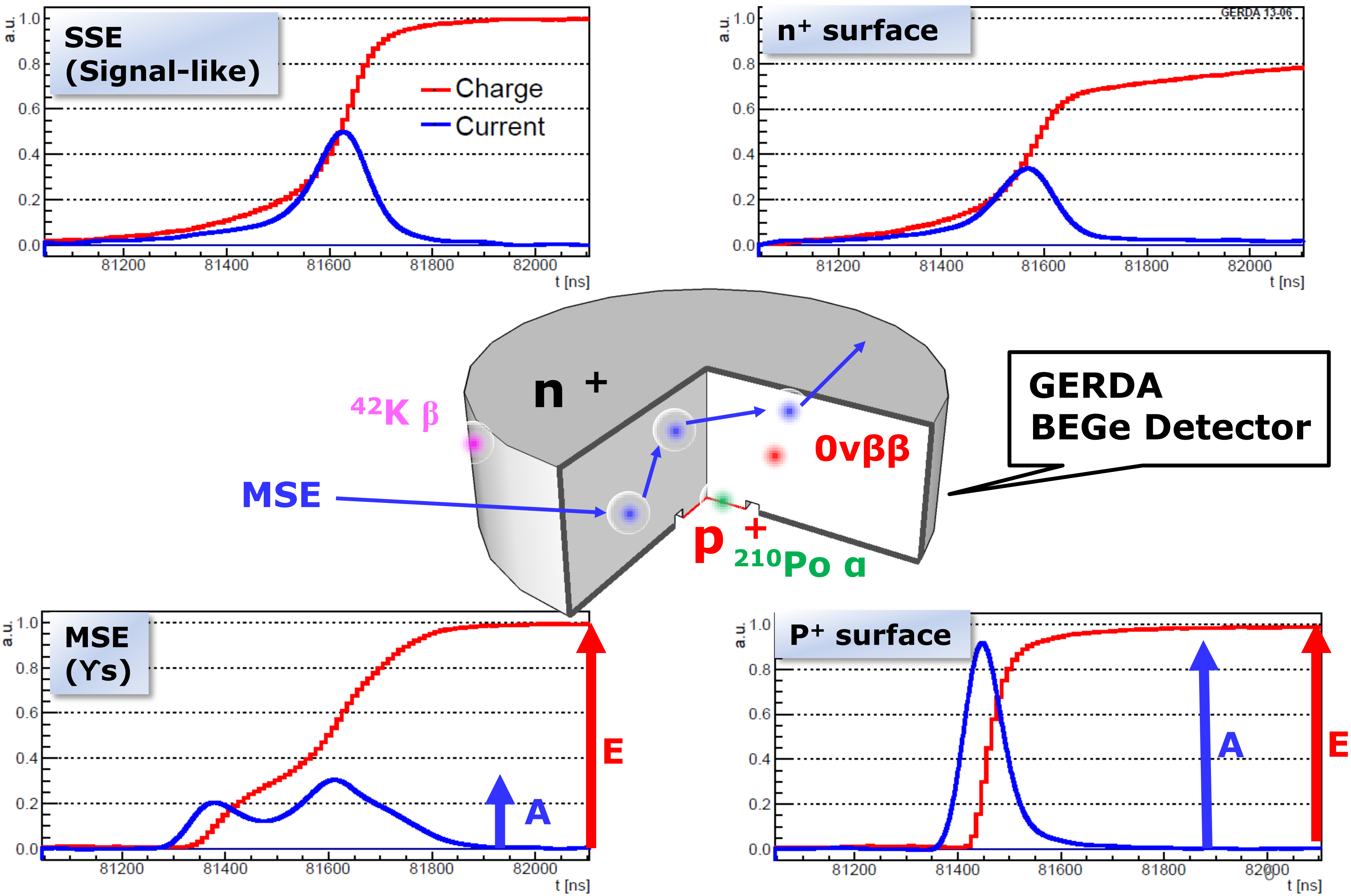




Properties of E-field of BEGe:

- **"Funneling effect"**
  Last part of the drift is the same for where the charge carriers created for individual depositions
- **Different interaction positions**
  ➡ **the same pulse height**

A/E Pulse Shape Discrimination Method

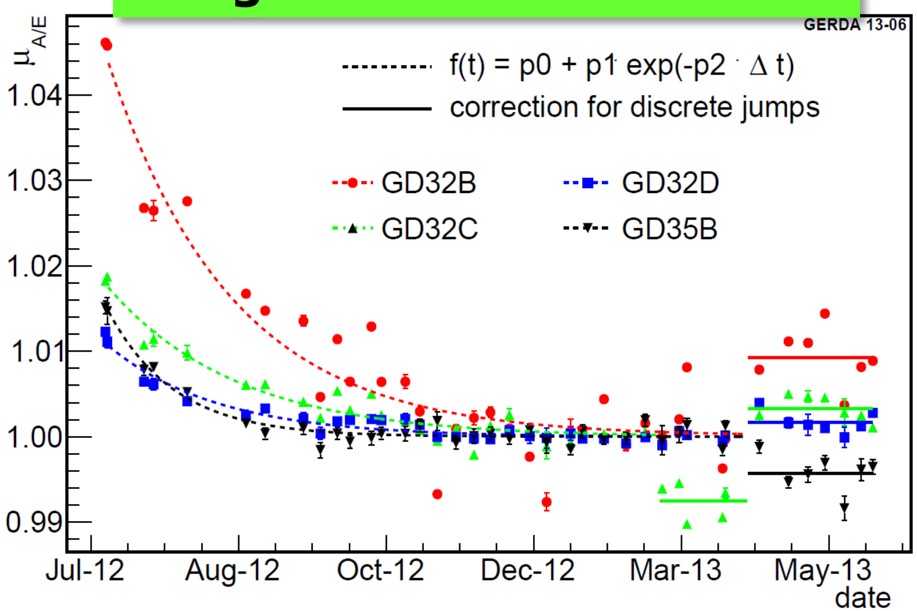


A/E PSD Normalization

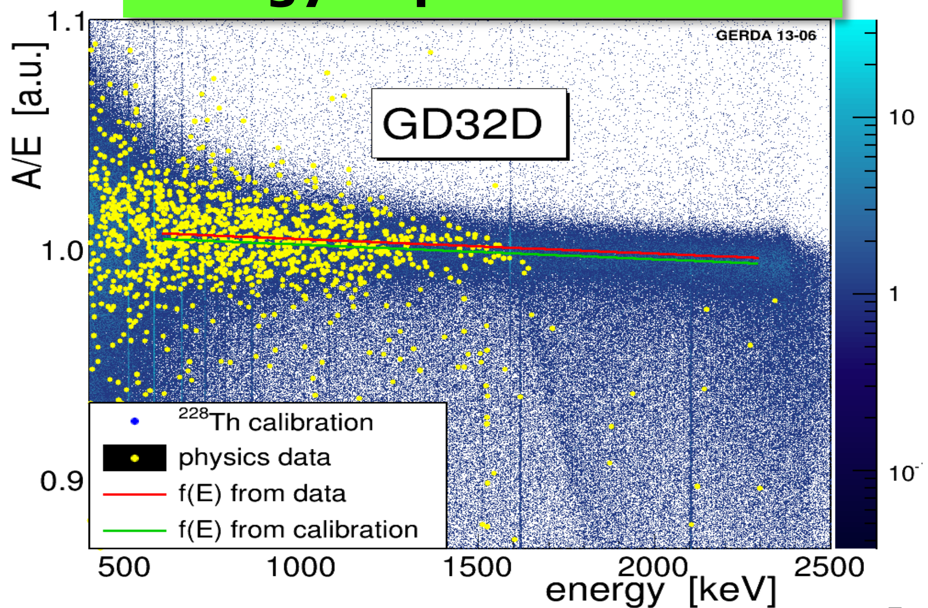
A/E PSD:

- **Develop PSD method with ^{228}Th calibration data ⇒ apply it on physics data**
- **Calibration using ^{228}Th external source for every one/two weeks**
  ⇒ Monitor PSD stability over time
- **Optimization of PSD/Global PSD cut:**
  Investigate normalization schemes:
  raw A/E → time dependence → energy dep. → Normalized A/E

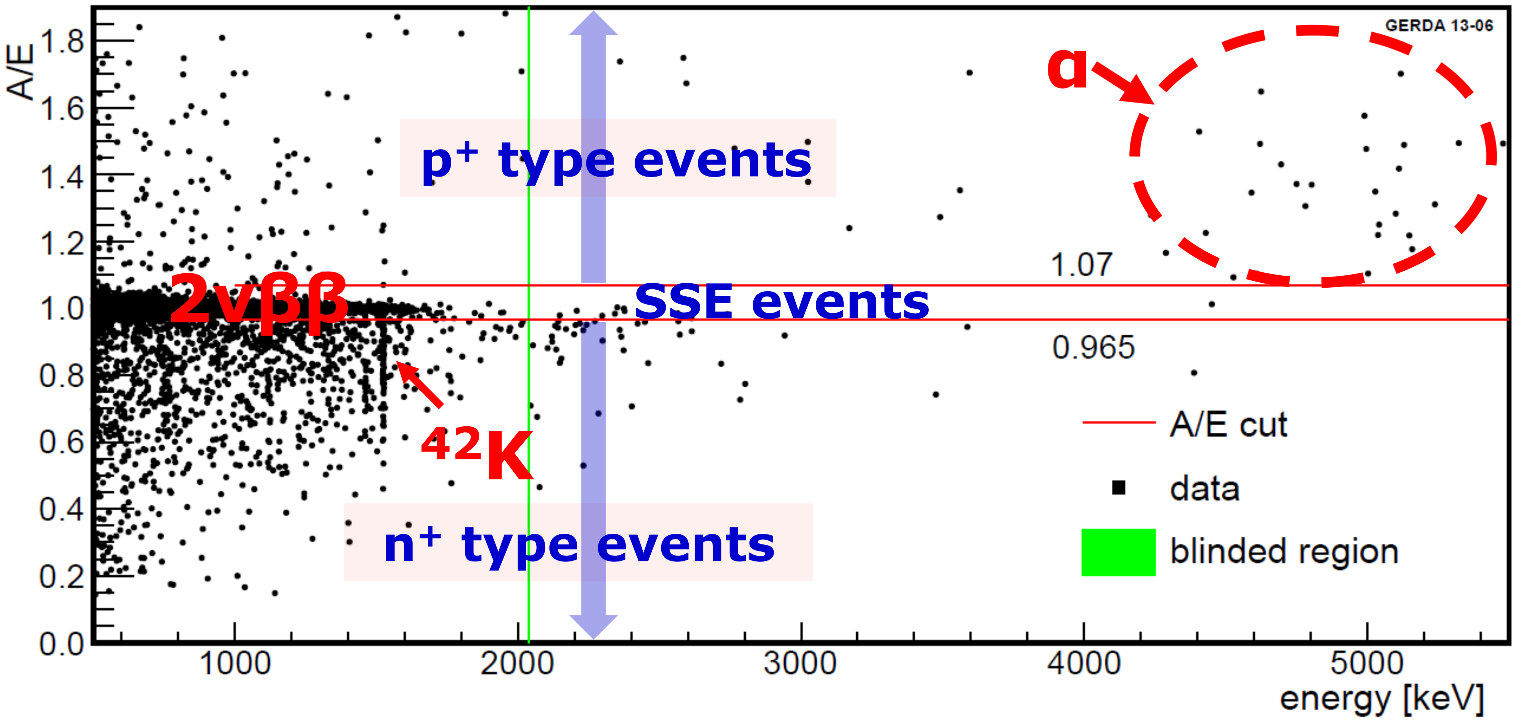
Long term drift correction



Energy dependence corr.



PSD for the GERDA Phase-I BEGe



region	low A/E cut $A/E < 0.965$	high A/E cut $A/E > 1.07$	surviving fraction $0.965 < A/E < 1.07$
^{228}Th calibration			
DEP 1592.5 keV	0.054 ± 0.003	0.015 ± 0.001	0.931 ± 0.003
FEP 1620.7 keV	0.771 ± 0.008	0.009 ± 0.002	0.220 ± 0.008
SEP 2103.5 keV	0.825 ± 0.005	0.011 ± 0.001	0.165 ± 0.005
physics data			
FEP 1524.7 keV	0.69 ± 0.05	0.027 ± 0.015	0.29 ± 0.05
1000 - 1450 keV	0.230 ± 0.011	0.022 ± 0.004	0.748 ± 0.011
1839 - 2239 keV	30/40	3/40	7/40 =0.175
> 4 MeV (α at $p+$)	1/35	33/35	1/35 =0.028

Proxy of 0νββ

MSE

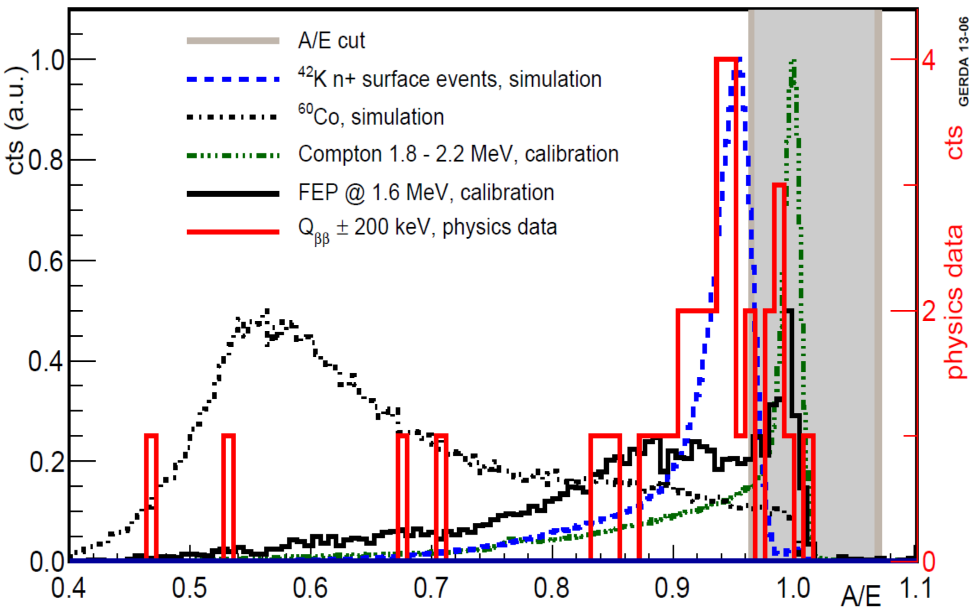
^{42}K

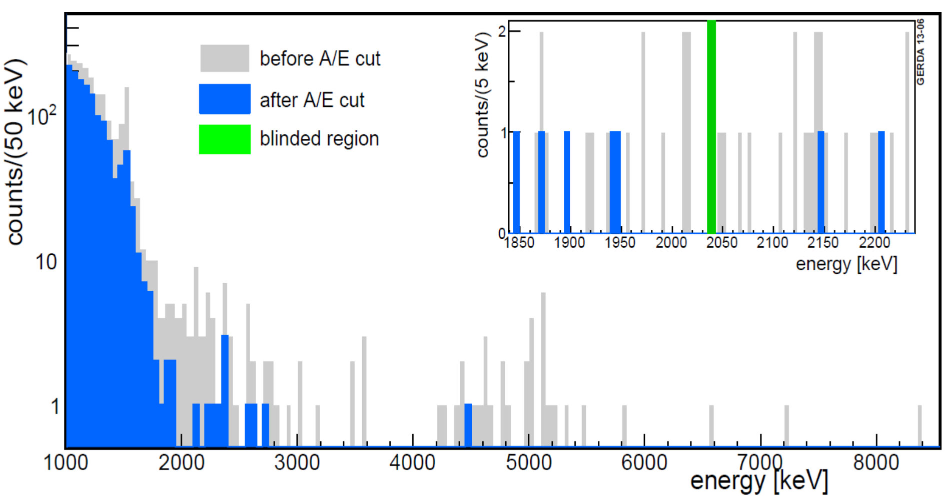
2νββ

ROI

α

PSD Results for the GERDA Phase-I BEGe





- **A/E PSD:**
  Supports the GERDA background model that most of the BEGe background is from
  ^{42}K on n+ contact

- **BI in ROI:**
  - **After PSD:**
    0.007 Cts/(kg·yr·keV)
  - **Suppression factor:**
    > 80% of bkg events
  - **Signal efficiency:**
    (92 ± 2) %

- **After unblinding:**
  0/1 event after/before PSD cut

Outlook & Summary

- **A/E PSD of BEGes demonstrates powerful SSE/MSE pulse shape recognition efficiency**

- **Normalization procedure improves PSD recognition efficiency**

- **Physics result for GERDA phase I:**
  $T_{1/2}^{0\nu\beta\beta} > 2.1 \cdot 10^{25} yr$ **@ 90% C.L.**

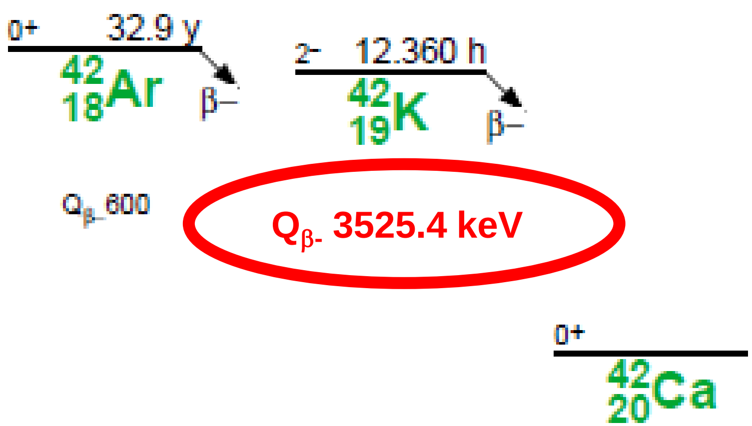
- **GERDA phase II will go beyond:**
  Increase total detector mass &
  lower background index & Improved PSD

Backup Slides

^{42}K Background in GERDA

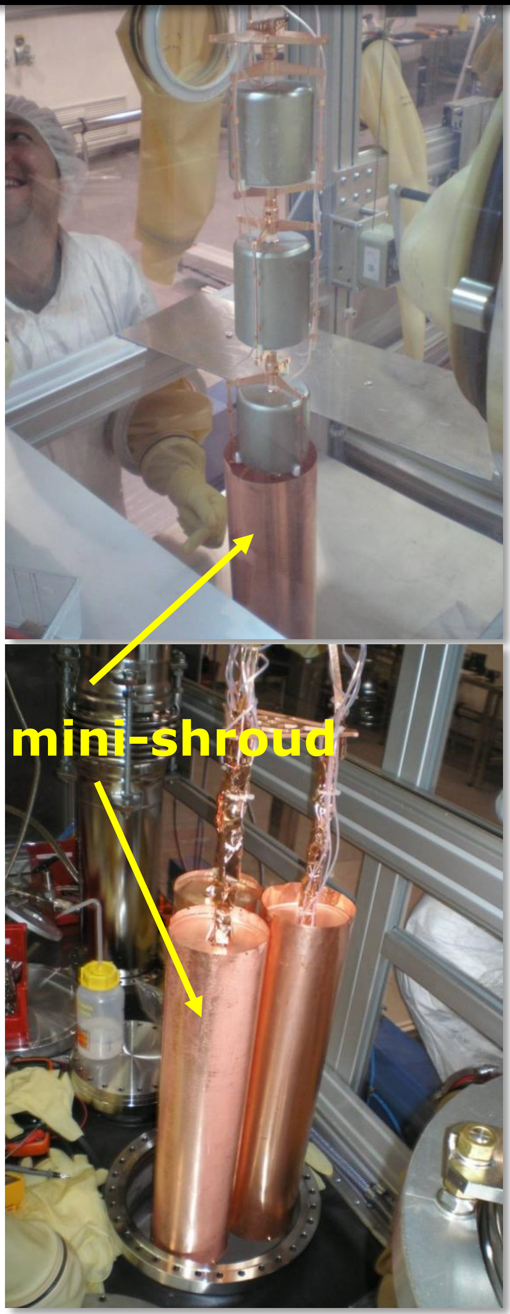
- **^{42}Ar: Isotope of Ar**
  created by cosmic-ray activation

- **Decay chain:**
  $^{42}Ar \longrightarrow {}^{42}K \longrightarrow {}^{42}Ca$



- **^{42}K ions get attracted by detector HV**

- **GERDA Phase I approach:**
  Installation of mini-shroud
  ⟶ Keep ions away from detectors



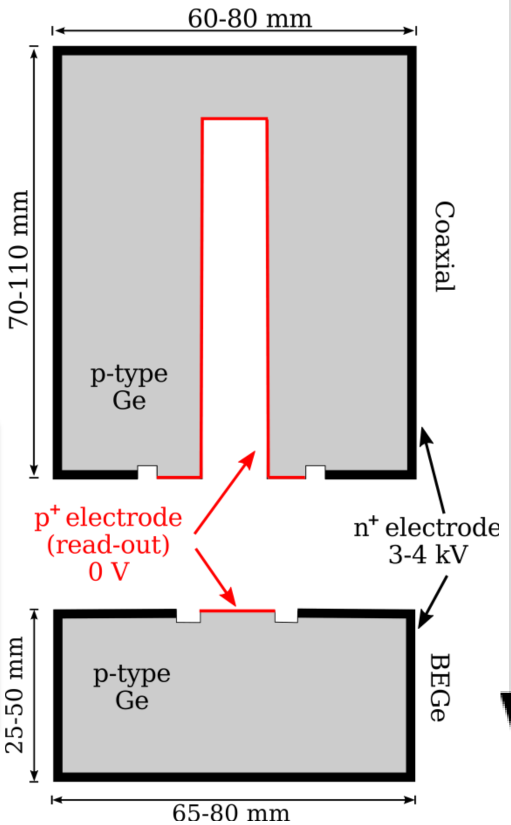
α-induced events in GERDA

- **Range of α particles(4MeV-9MeV):**
  34 μm - 113 μm in Lar
  14 μm - 41 μm in Ge

- **Thickness of surface is different for p⁺ & n⁺ contacts.**

  p^+(B) < 1 μm
  n^+(Li) ~ 2 mm for coax
  n^+(Li) ~ 1 mm for BEGe

α contributes to bkg. only when the decays on the p+ surface or in LAr very close (<100 μm) to p+ surface



- Ra-226 (E_α = 4.8 MeV, $T_{1/2}$ = 1600 y)
- Rn-222 (E_α = 5.5 MeV, $T_{1/2}$ = 3.8 d)
- Po-218 (E_α = 6.0 MeV, $T_{1/2}$ = 183 s)
- Pb-214 ($T_{1/2}$ = 0.45 h)
- Bi-214 ($T_{1/2}$ = 0.33 h)
- Po-214 (E_α = 7.7 MeV, $T_{1/2}$ = 164 μs)
- Pb-210 ($T_{1/2}$ = 22.3 y)
- Bi-210 ($T_{1/2}$ = 5.01 d)
- Po-210 (E_α = 5.3 MeV, $T_{1/2}$ = 138.4 d)
- Pb-206 (stable)