Normalization procedure of Pulse Shape Discrimination for Broad Energy Germanium Detector

Outline:

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

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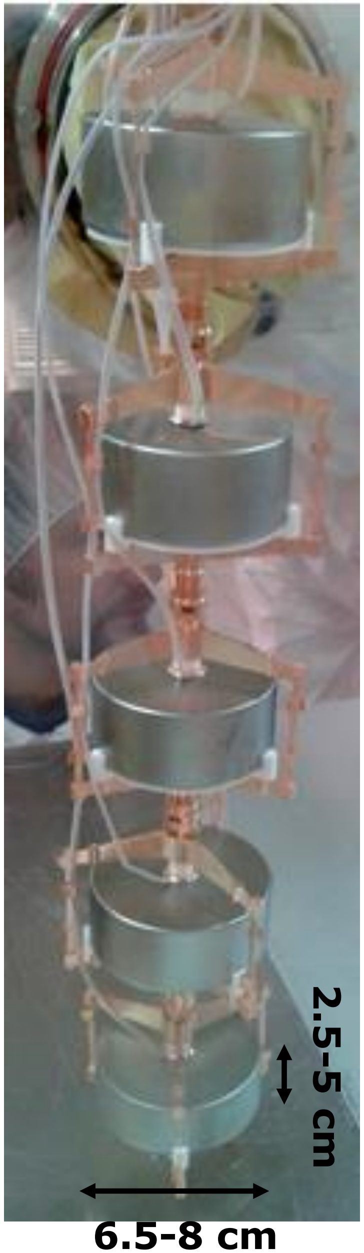
The GERDA Experiment

- **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[EPJ. A12 (2001)147-154]
    $> 1.6\cdot10^{25}$ yr @ 90% C.L. from IGEX[PRD65, 092007 (2002)]
  - **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 MeV:
    $\langle \Delta E_{coaxial} \rangle \sim 4.8$ **keV**
    $\langle \Delta E_{BEGe} \rangle \sim 3.2$ **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



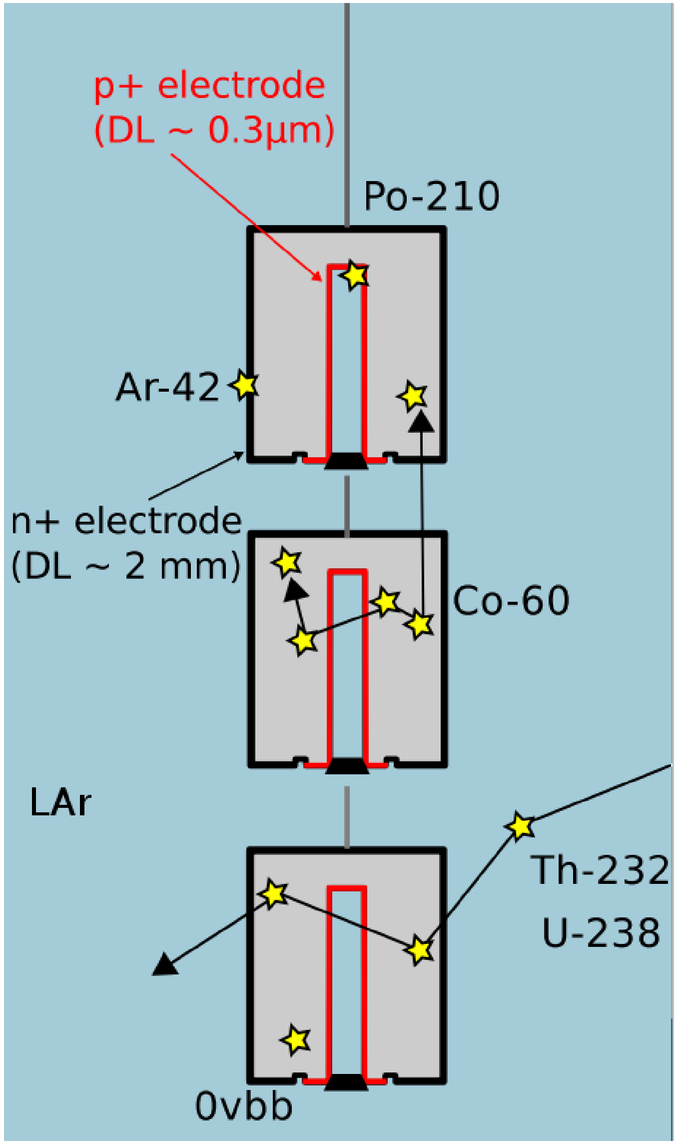
Backgrounds

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)

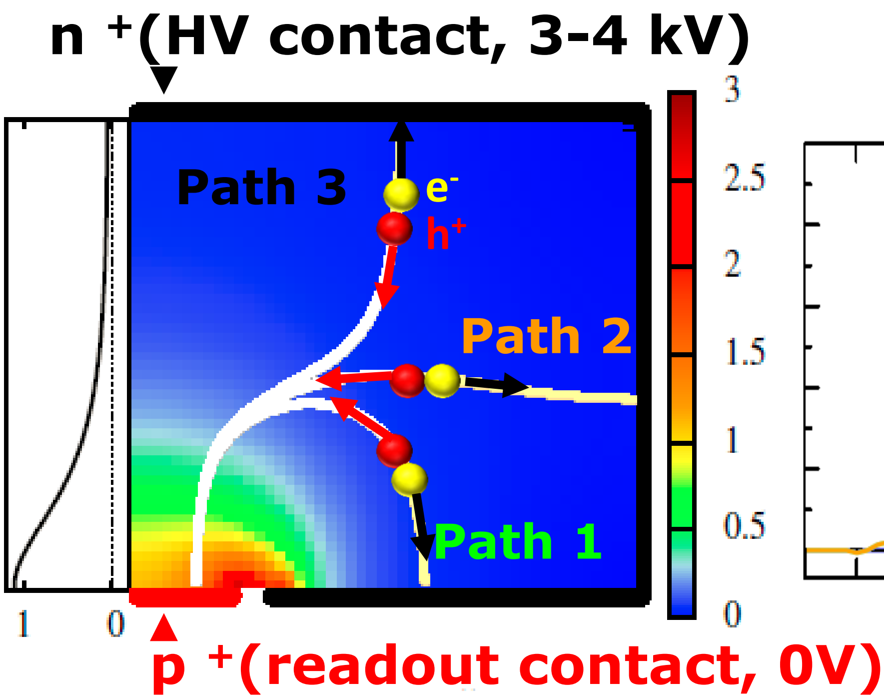
- **Cosmogenic isotopes in Ge decaying inside the detectors (^{68}Ge,^{60}Co)**
- **long-lived cosmogenic Ar isotopes (^{39}Ar,^{42}K)**

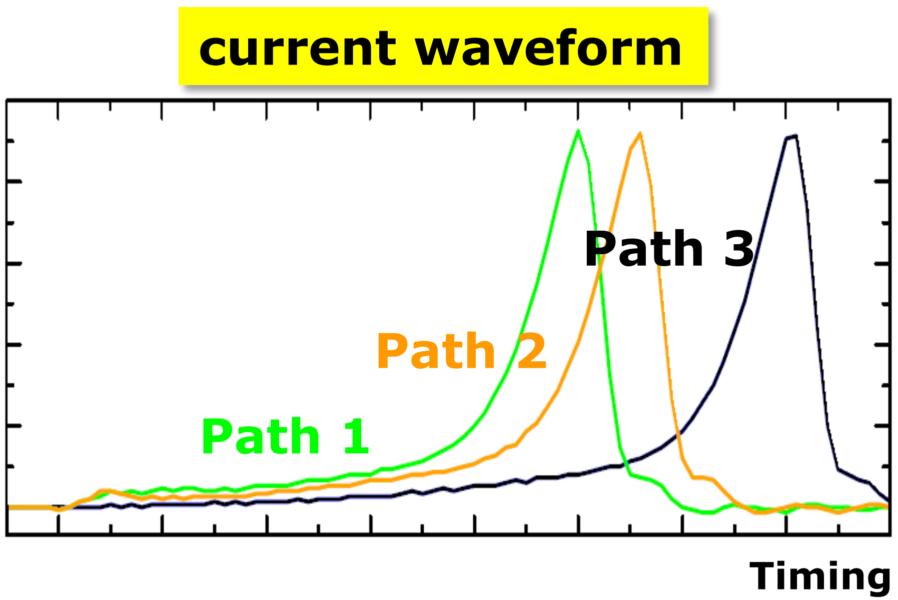


Background suppression:

- **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



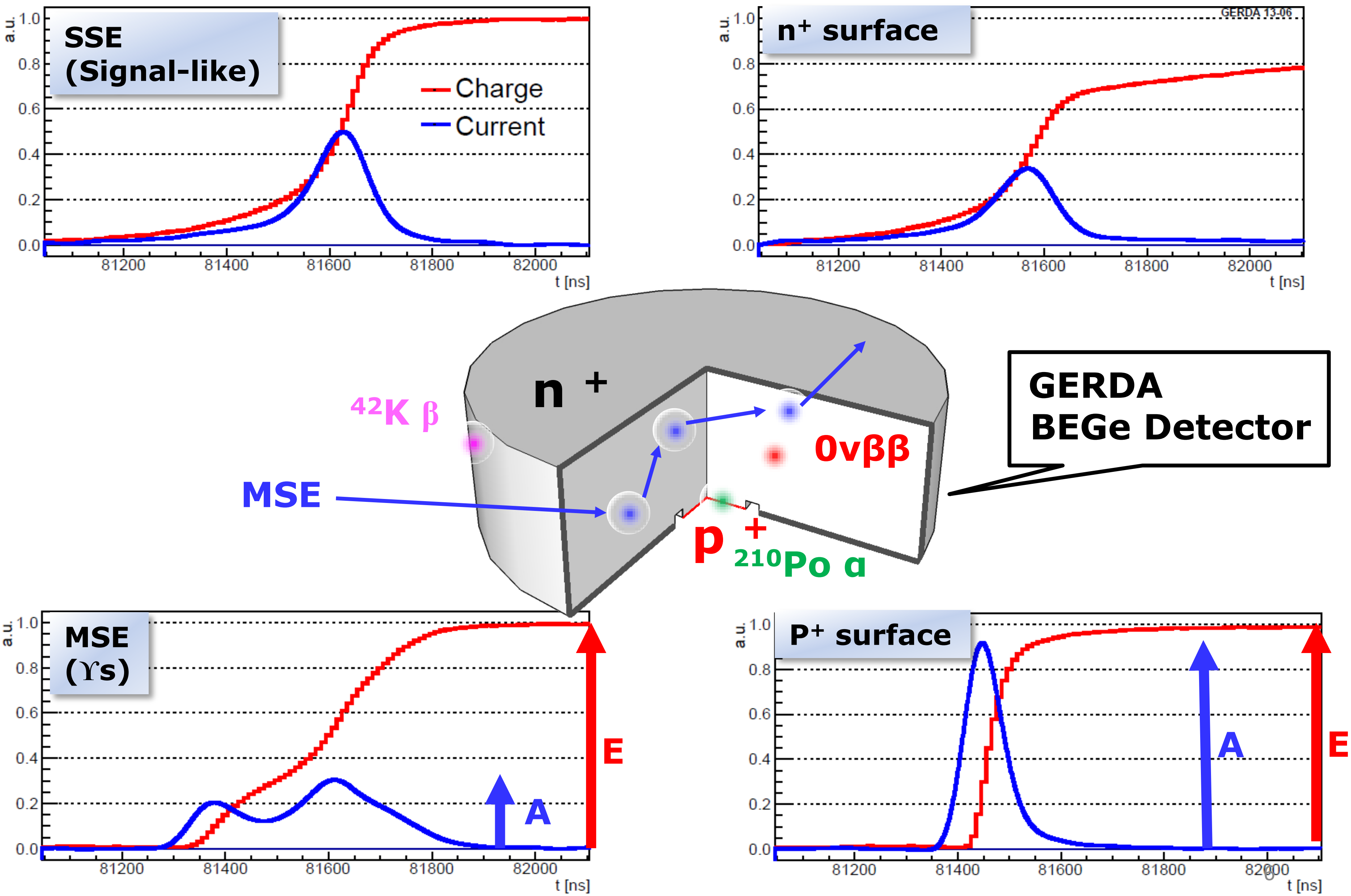


Properties of E-field of BEGe:

- **"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

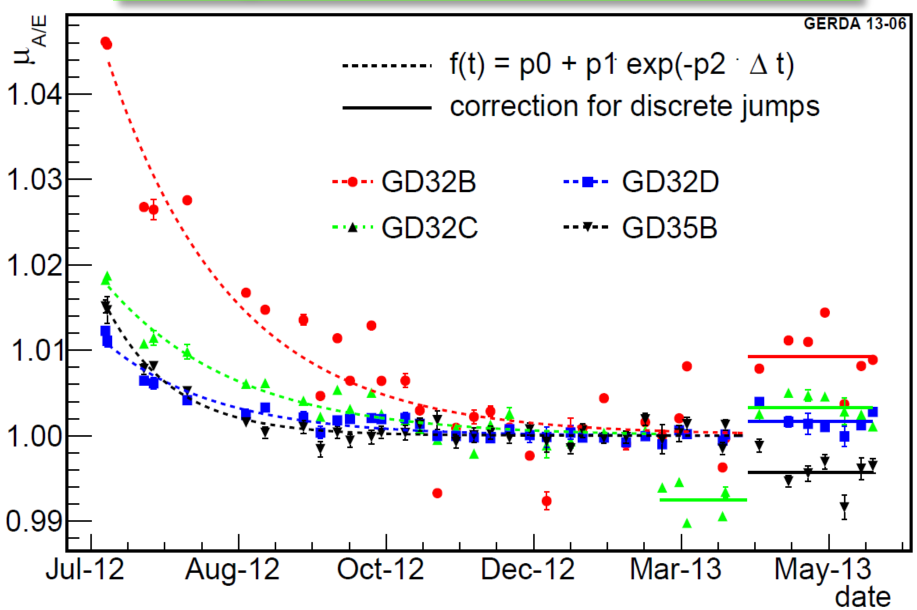


A/E PSD Normalization

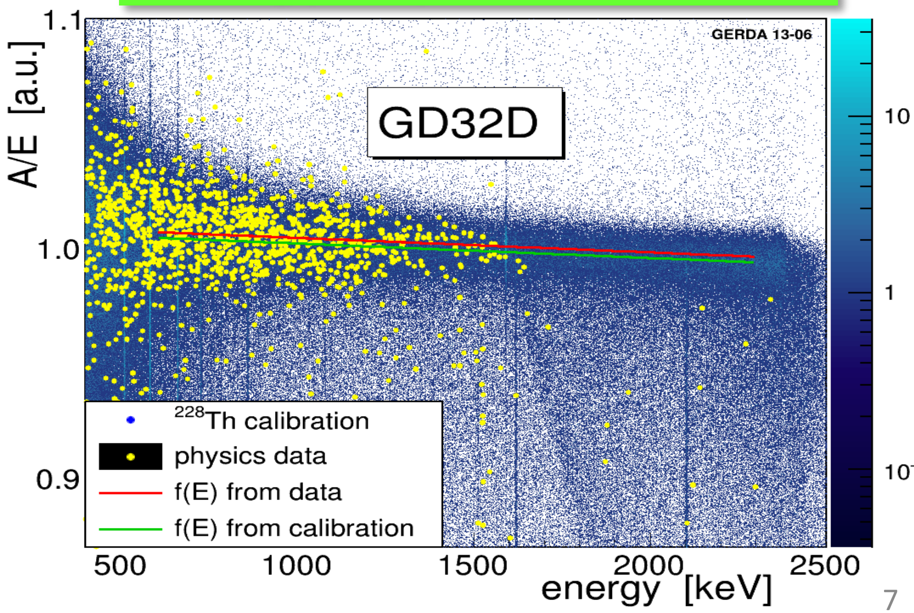
A/E PSD:

- **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

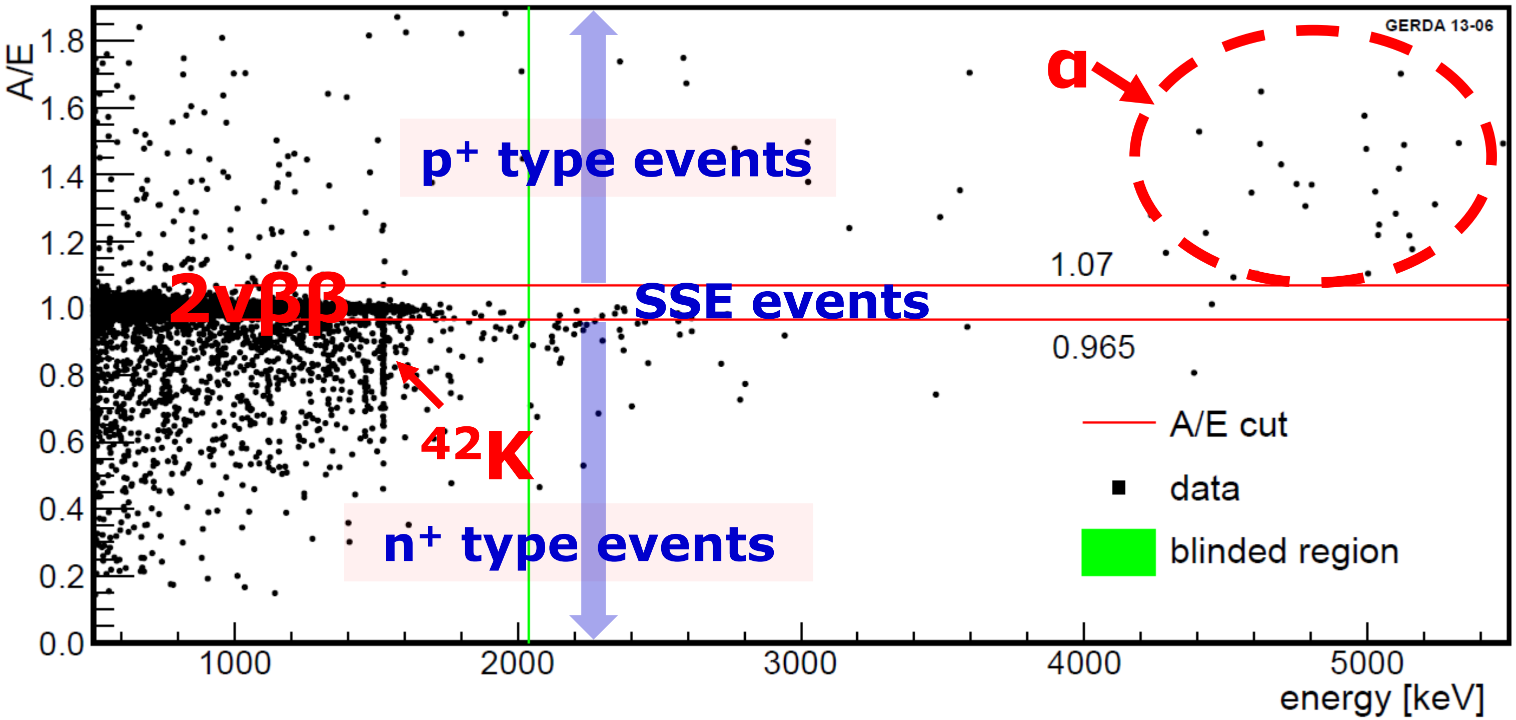
Long term drift correction



Energy dependence corr.

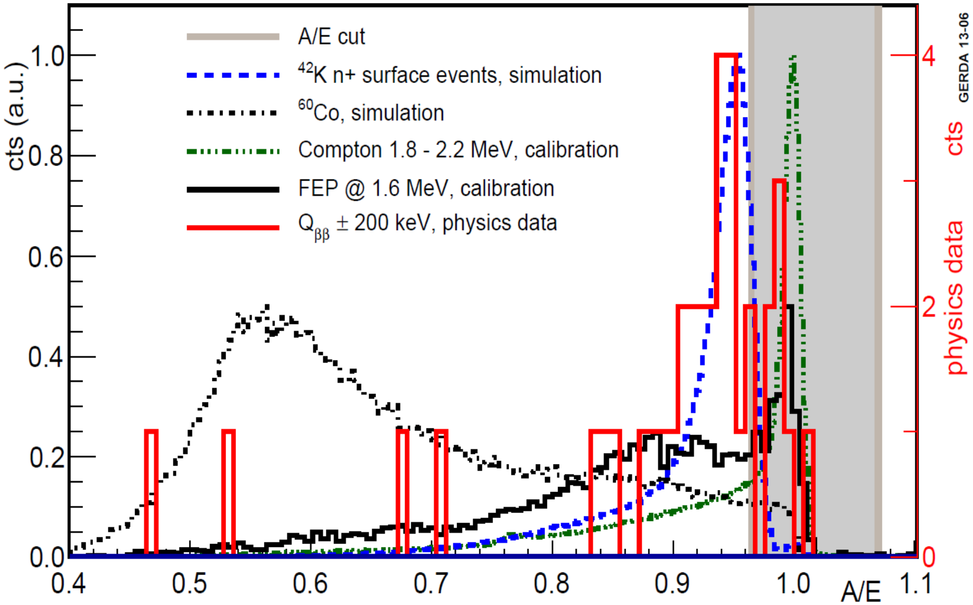


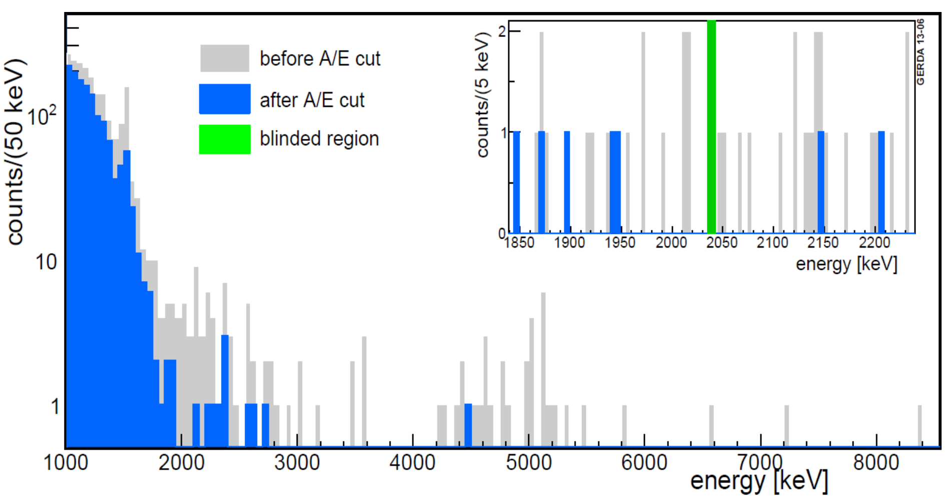
PSD for the GERDA Phase-I BEGe



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 (Proxy of 0νββ)
FEP 1620.7 keV	0.771 ± 0.008	0.009 ± 0.002	0.220 ± 0.008 (MSE)
SEP 2103.5 keV	0.825 ± 0.005	0.011 ± 0.001	0.165 ± 0.005 (MSE)
physics data			
FEP 1524.7 keV	0.69 ± 0.05	0.027 ± 0.015	0.29 ± 0.05 (^{42}K)
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 (ROI)
> 4 MeV (α at $p+$)	1/35	33/35	1/35 =0.028 (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**

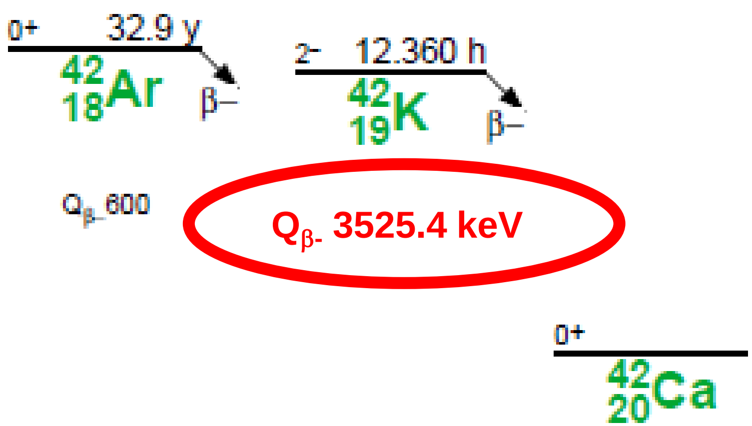
- **Physics result for GERDA phase I:**
  $T_{1/2}^{0\nu\beta\beta} > 2.1 \cdot 10^{25} yr$ **@ 90% C.L.**

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

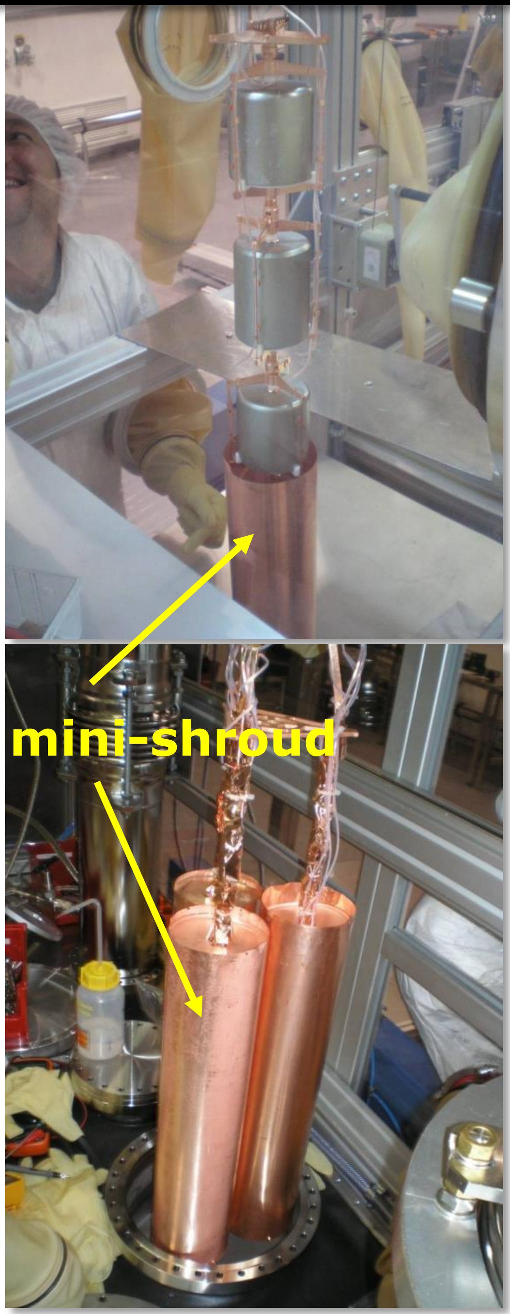
Backup Slides

^{42}K Background in GERDA

- **^{42}Ar: Isotope of Ar created by cosmic-ray activation**
- **Decay chain:**
  ^{42}Ar → ^{42}K → ^{42}Ca



- **^{42}K ions get attracted by detector HV**
- **GERDA Phase I approach:**
  Installation of mini-shroud
  → Keep ions away from detectors



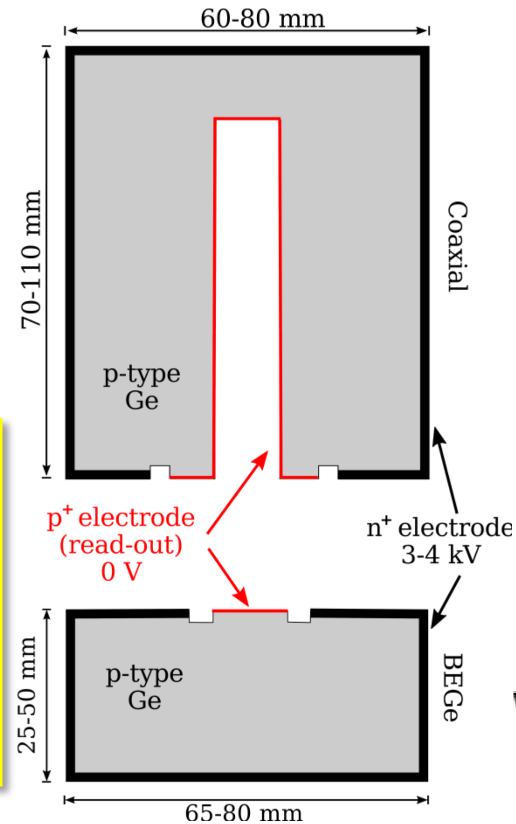
α-induced events in GERDA

- **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. when the decays:
- **on the p+ surface**
- **in LAr very close (<100 μm) to p+ surface**
- **in the groove)**



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)