Results of a PSA with a BEGe Detector for the GERDA $0\nu\beta\beta$-decay Experiment

Marik Barnabé Heider • Dušan Budjáš • Oleg Chkvorets[†]
Stefan Schönert • Nikita Xanbekov*

MPI für Kernphysik • Heidelberg
[†] now at: Laurentian University • Sudbury
* also: ITEP • Moscow

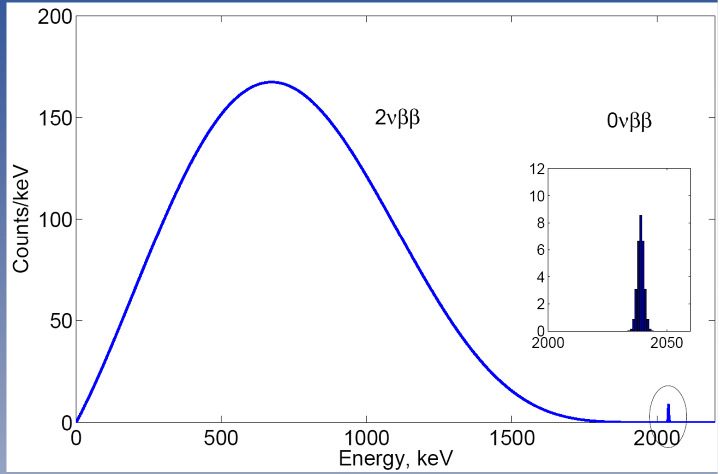
GERDA

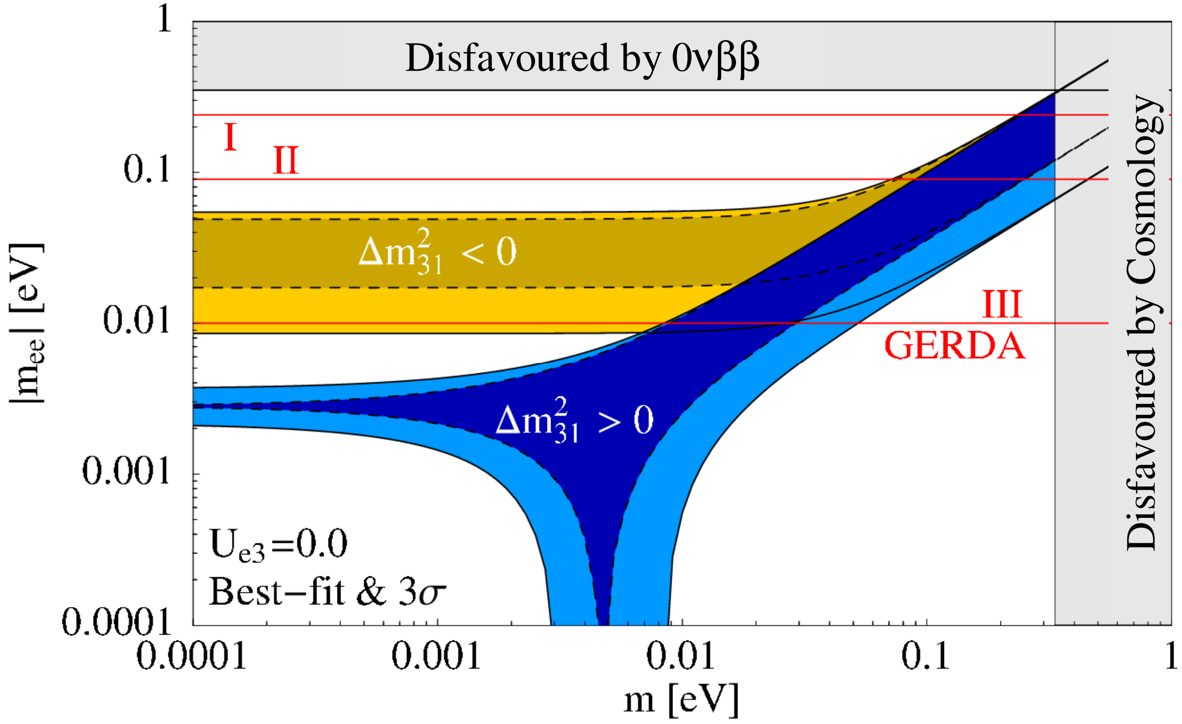
MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK

GERDA (GERmanium Detector Array)

Search for **0νββ decay** with **HPGe detectors**:

- 86% **enrichment in ^{76}Ge** (source = detector)
- HPGe is extremely pure (**low background**)
- very good **energy resolution** (~3 keV at $Q_{\beta\beta}$)
- existing technology, **substantial expertise**





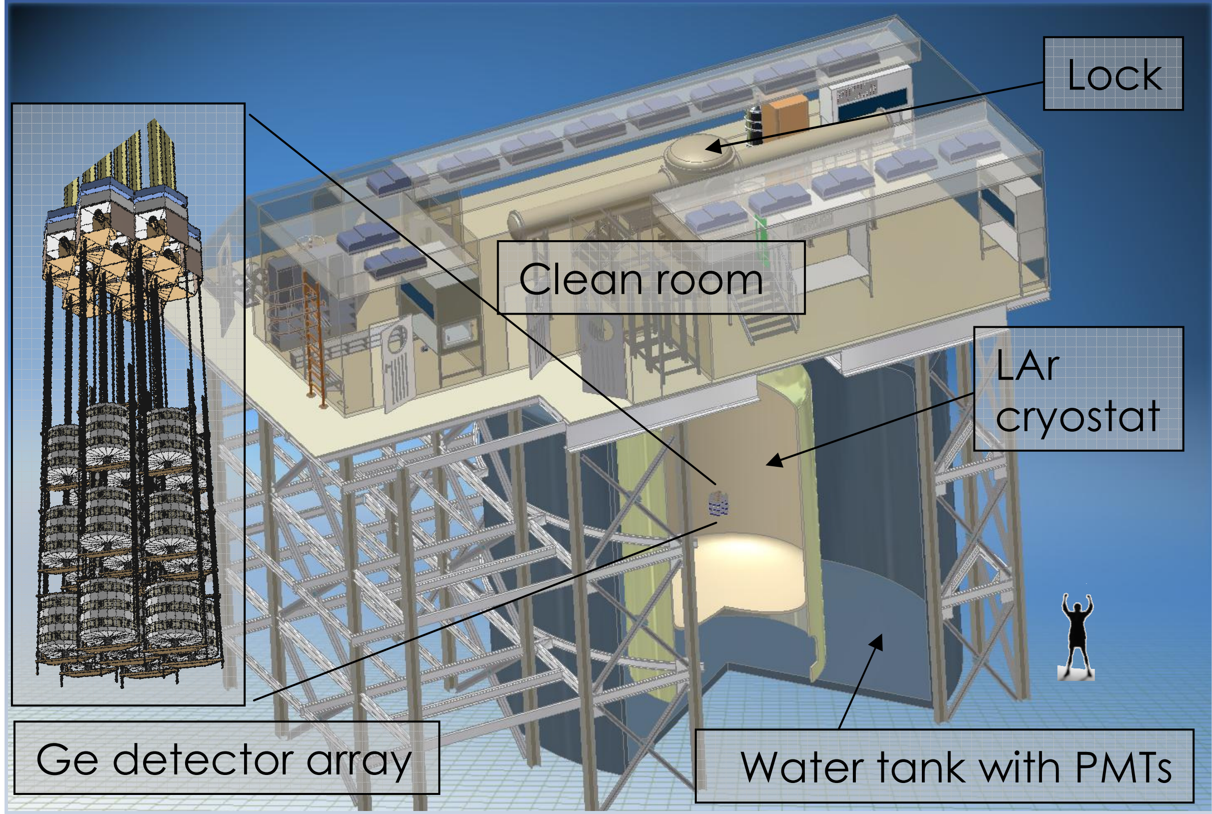
Phase I:

- 18 kg existing detectors
- background:
  <10^{-2} cts/(keV · kg · y)
  (10x improvement)

Phase II:

- 20 kg new detectors
- background:
  <10^{-3} cts/(keV · kg · y)
  (100x improvement)

GERDA design



Under construction at Gran Sasso Underground Lab, Italy (3800 m w.e.)

Design focused on background reduction:

- **bare HPGe detectors submersed in ultra-pure LAr**
- detector anticoincidence, passive shielding and μ-veto

Phase II: further **active background suppression** necessary

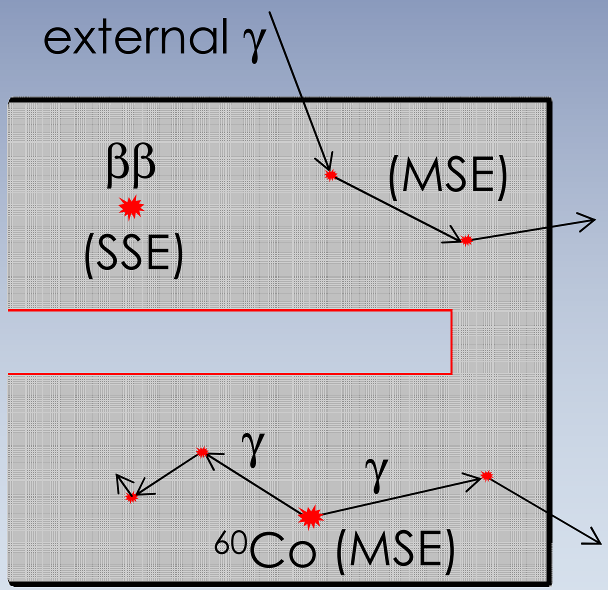
0νββ decay backgrounds

Most important backgrounds:

external: ^{228}Th and ^{226}Ra in materials around the detectors

intrinsic: ^{60}Co and ^{68}Ge cosmogenically produced in detectors

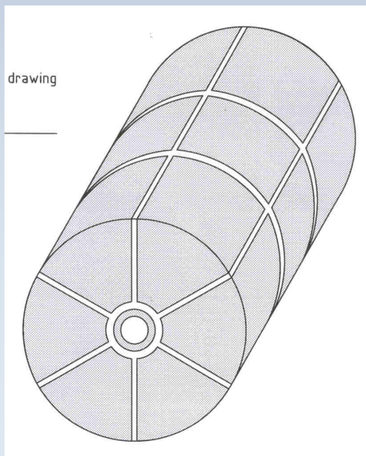
⇒ γ-ray emitters

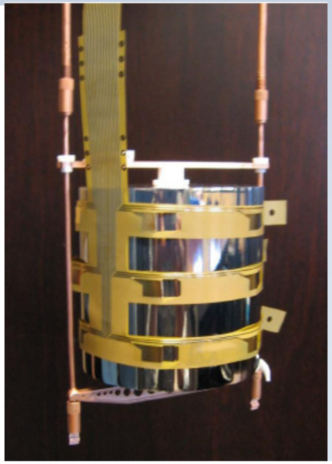


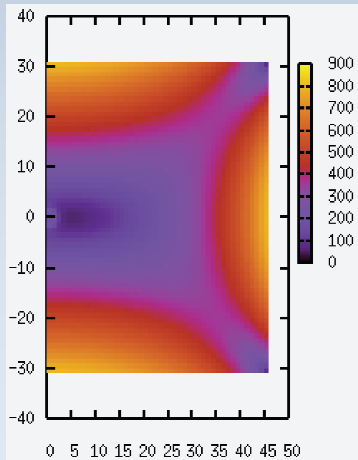
Distinguishing **single-site events (SSE)** and **multi-site events (MSE)** required for background suppression.

⇒ detector segmentation

⇒ signal time-structure analysis



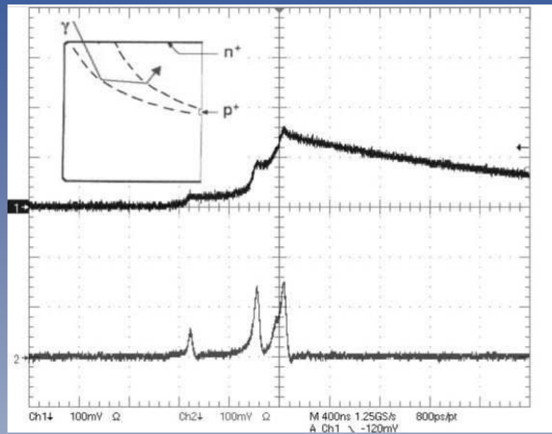




Modified-electrode detectors for $0\nu\beta\beta$ search

Majorana collaboration: detectors with **point-like contact** (custom made)

- have **excellent MSE / SSE discrimination** performance
- avoid **external background** from multiple contacts
- also: excelent energy resolution and low-energy treshold



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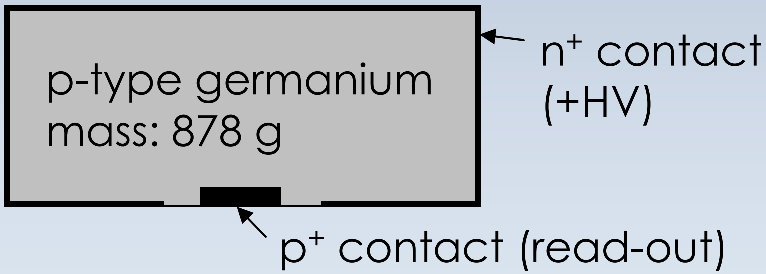
(Crystal mass: 475 g)

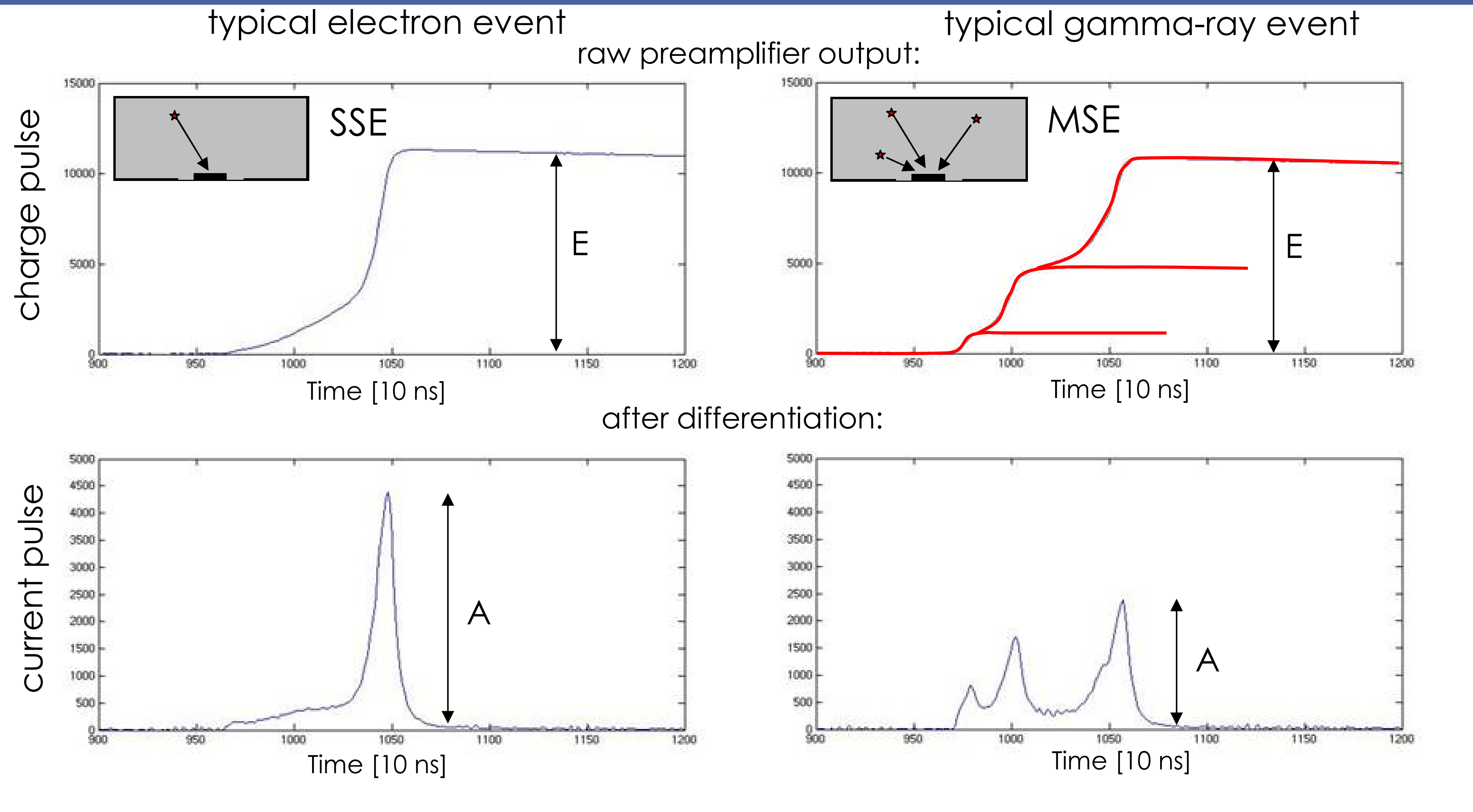
Standard commercial detector with similar features:

BEGe (Broad Energy Ge detector) from Canberra

⇒ research program within GERDA collaboration

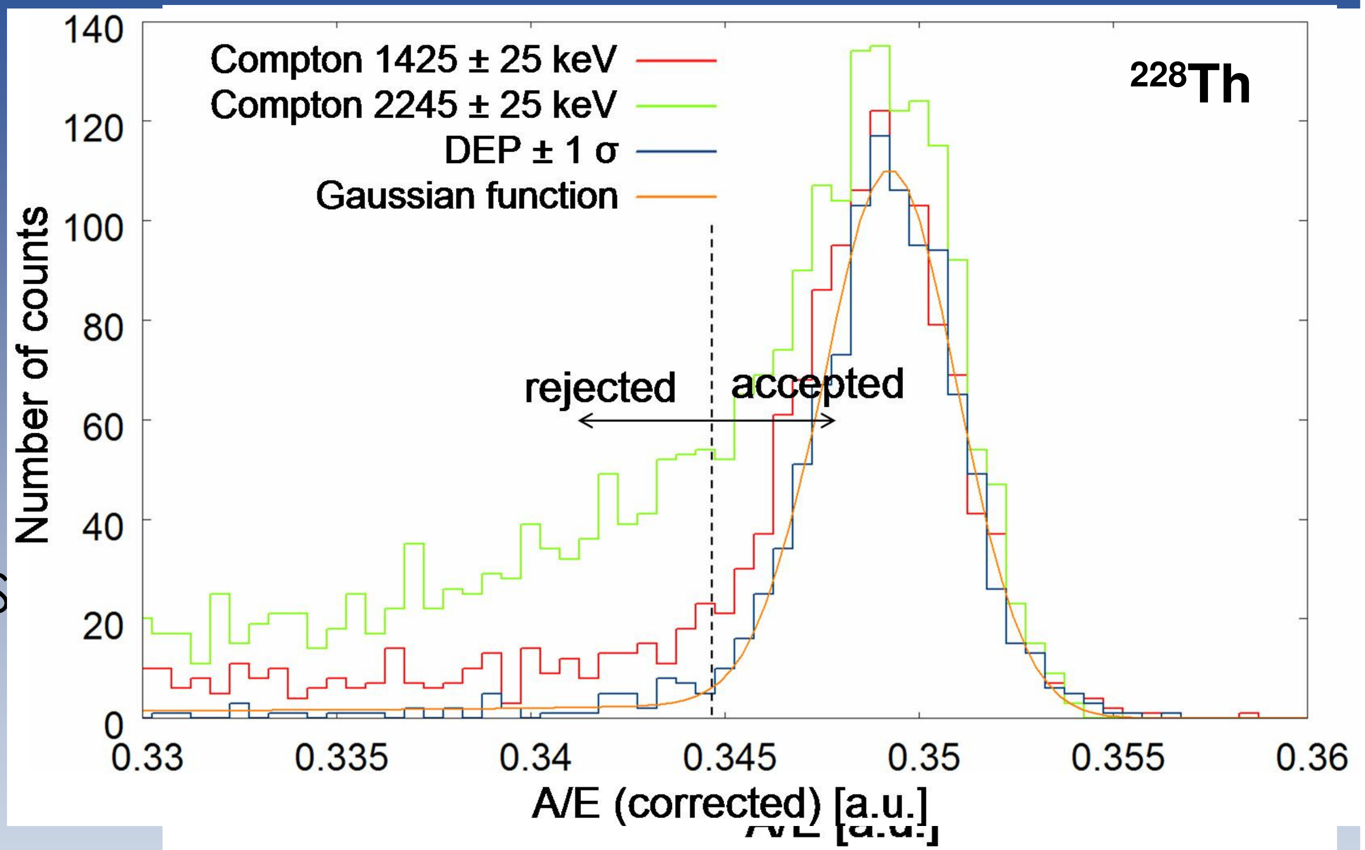


Pulse shape discrimination

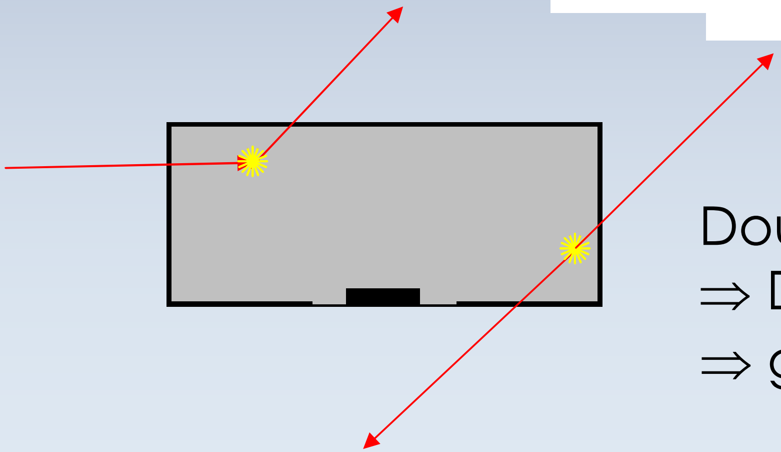


A / E $\Rightarrow$ discrimination parameter

PSD parameter distribution from SSE

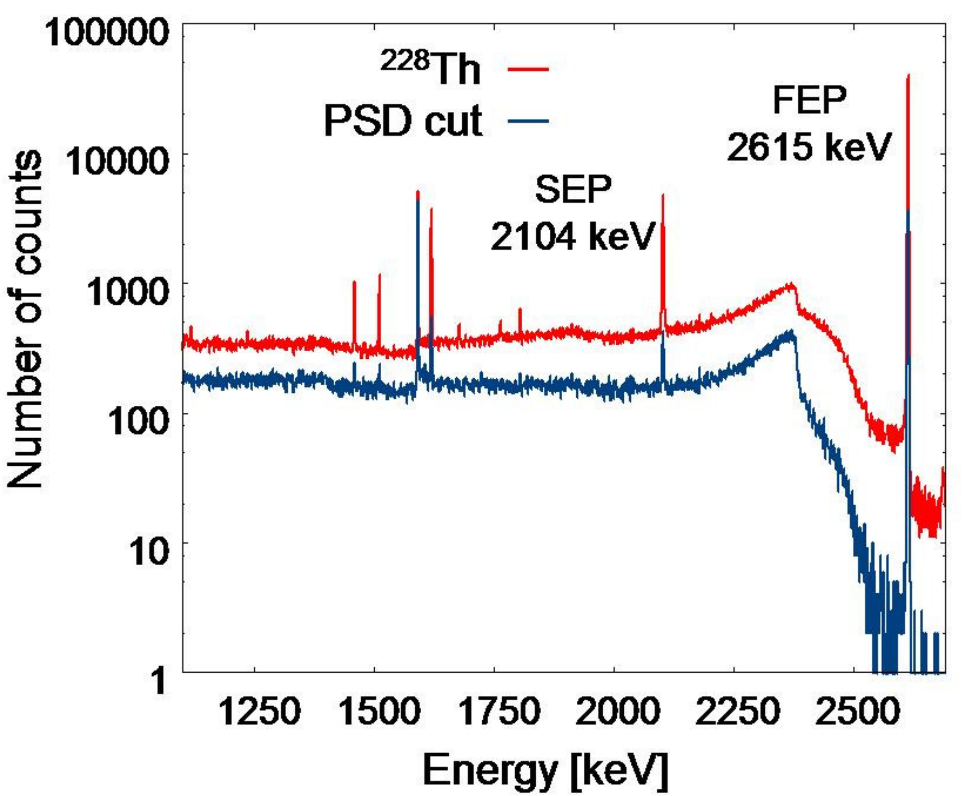


Single-Compton
scattering event (SCS
⇒ coincidence with
a second detector

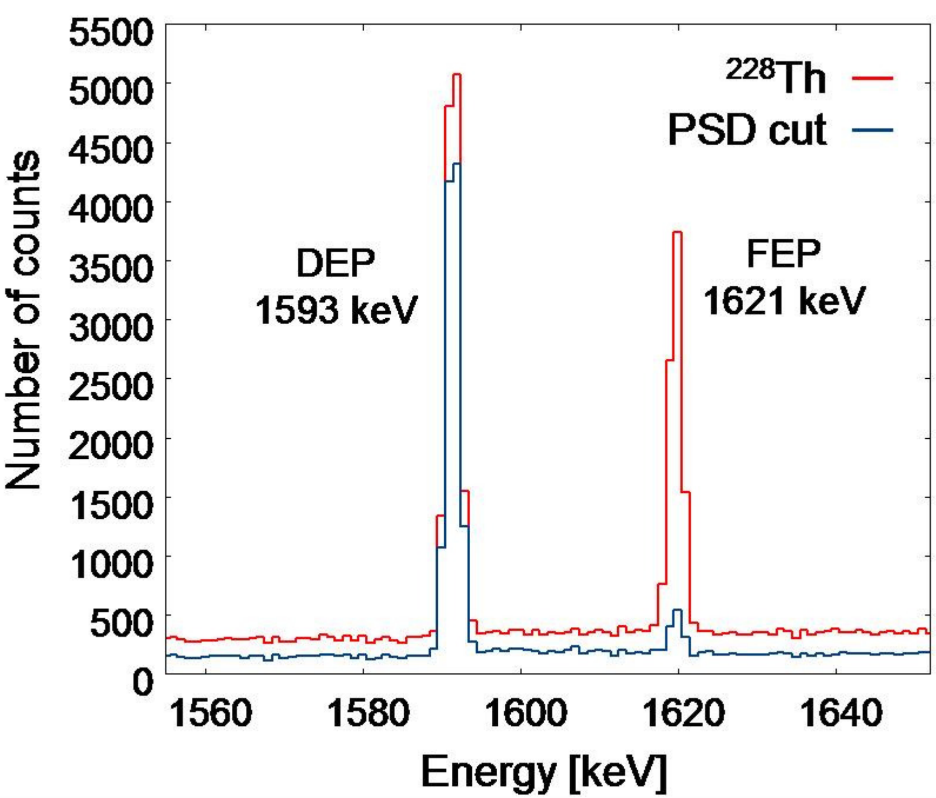


Double-escape event
⇒ DEP from ^{208}Tl (1592.5 keV)
⇒ good representation of ββ events

PSD results

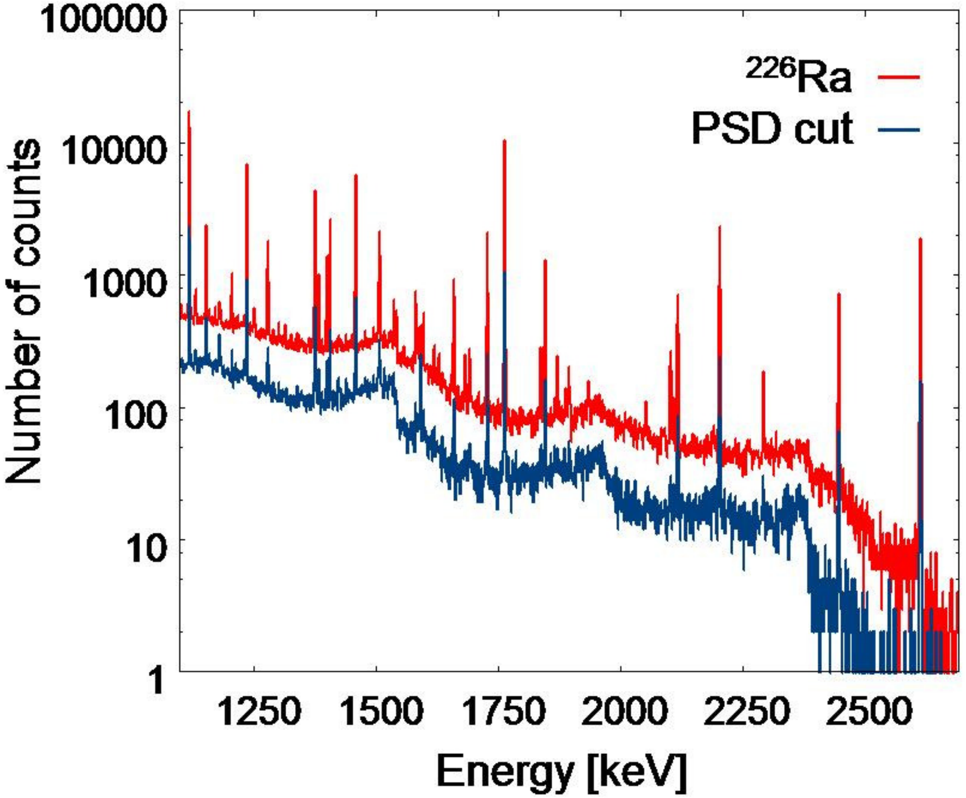


100000
10000
1000
100
10
1
Number of counts
^{228}Th
PSD cut
FEP
2615 keV
SEP
2104 keV
1250 1500 1750 2000 2250 2500
Energy [keV]

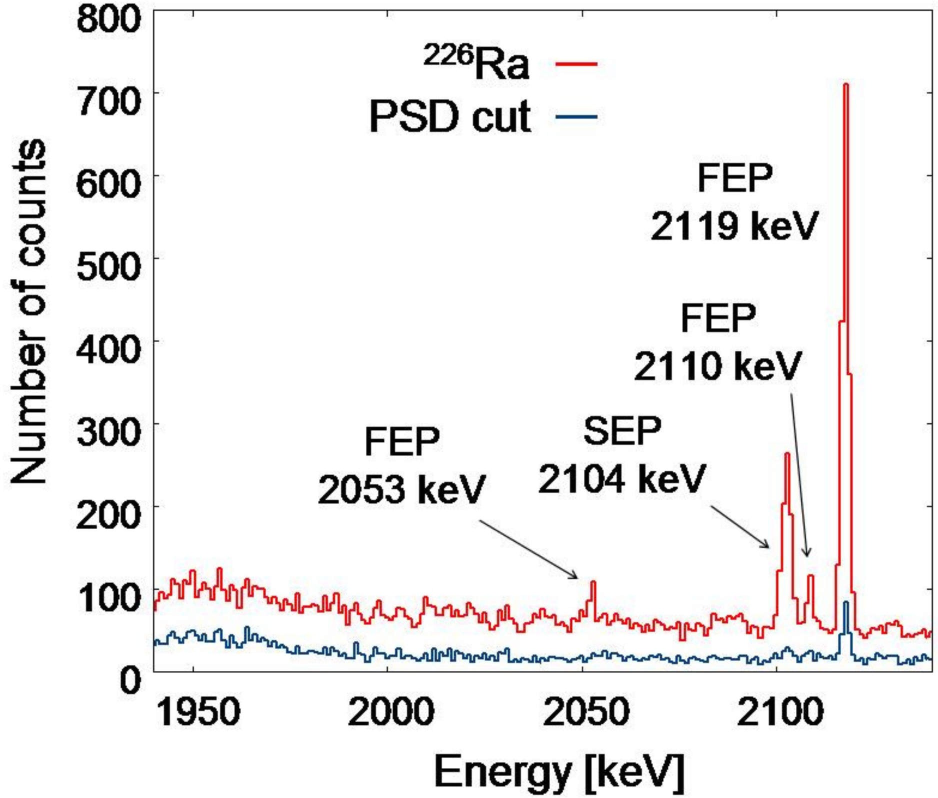


5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Number of counts
^{228}Th
PSD cut
DEP
1593 keV
FEP
1621 keV
1560 1580 1600 1620 1640
Energy [keV]

PSD results

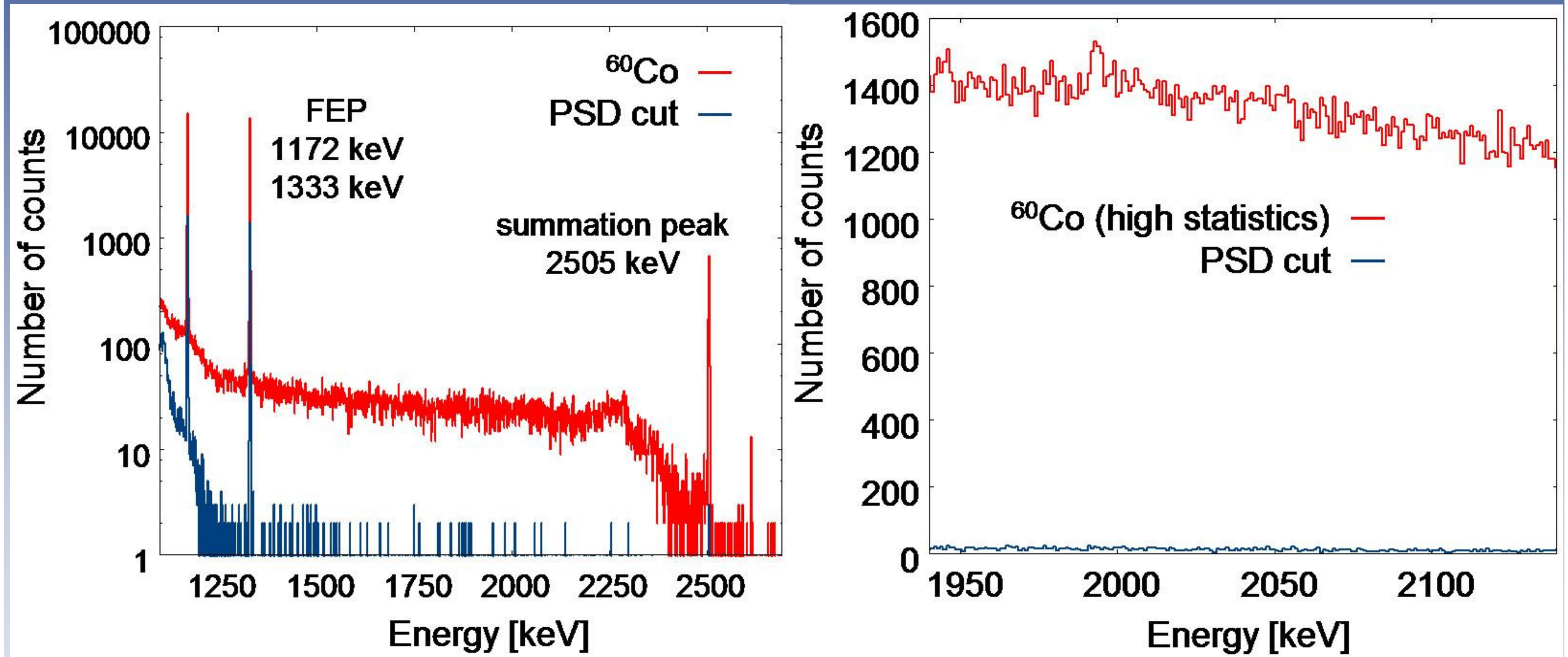


100000
10000
1000
100
10
1
Number of counts
1250 1500 1750 2000 2250 2500
Energy [keV]
226Ra
PSD cut

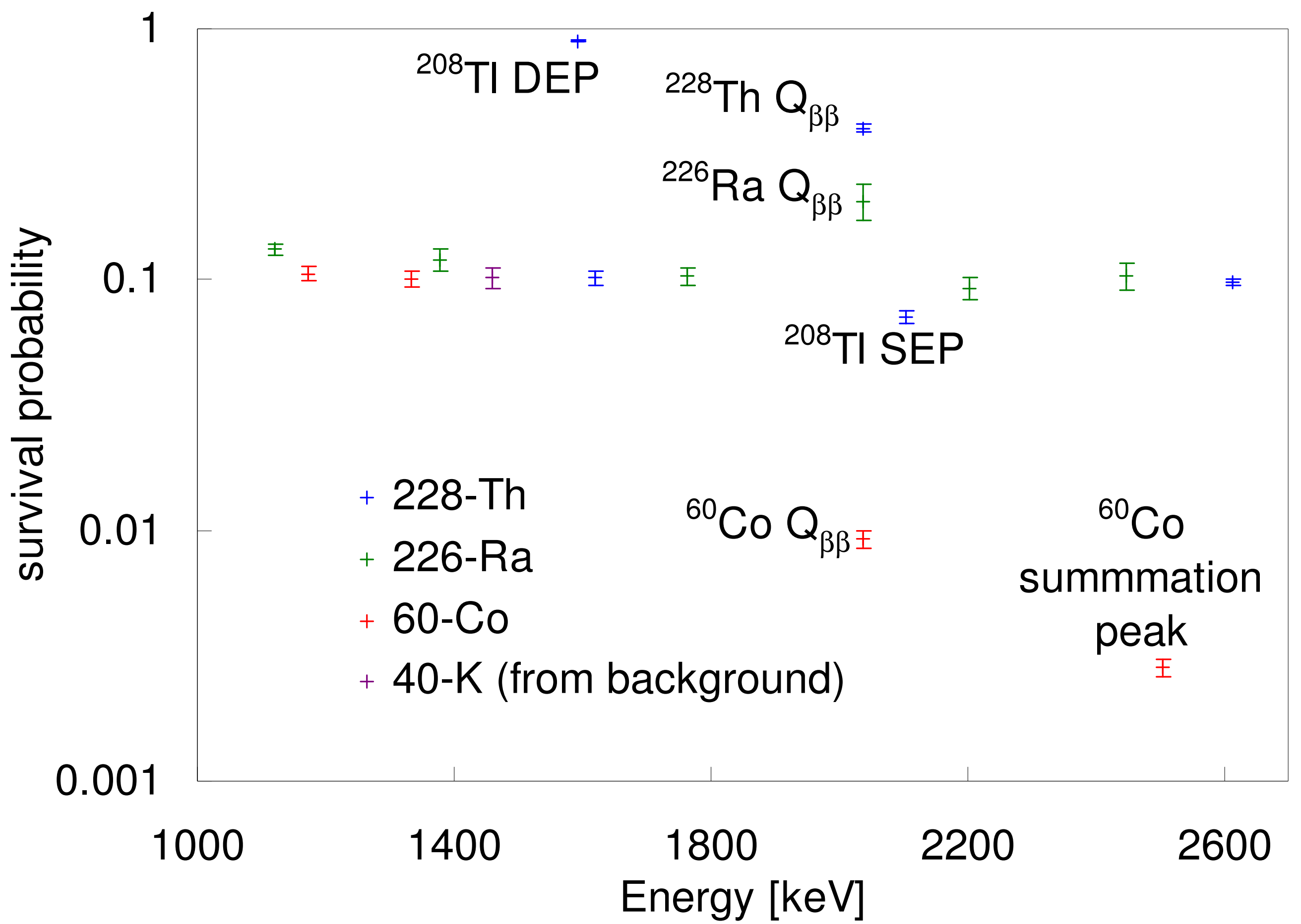


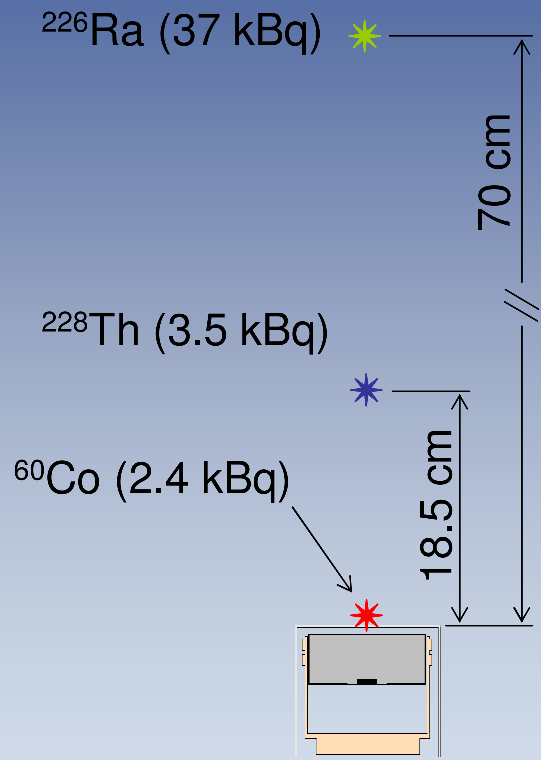
800
700
600
500
400
300
200
100
0
Number of counts
1950 2000 2050 2100
Energy [keV]
226Ra
PSD cut
FEP
2119 keV
FEP
2110 keV
SEP
2104 keV
FEP
2053 keV

PSD results


100000
10000
1000
100
10
1
Number of counts
^{60}Co
PSD cut
FEP
1172 keV
1333 keV
summation peak
2505 keV
1250 1500 1750 2000 2250 2500
Energy [keV]
1600
1400
1200
1000
800
600
400
200
0
Number of counts
^{60}Co (high statistics)
PSD cut
1950 2000 2050 2100
Energy [keV]

PSD results summary





PSD results summary

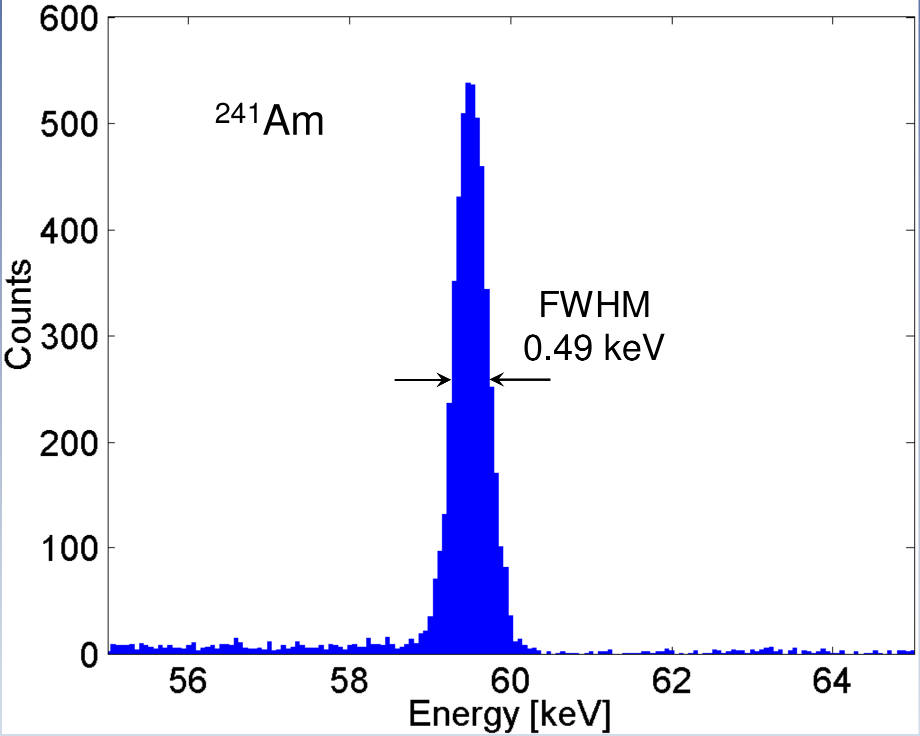
- acceptance of **$0\nu\beta\beta$ decay** events is (89.2 ± 0.9)% (determined by DEP measurements, validated by coincident single-Compton scattering)
- survival probability of **external background** events:
  ^{228}Th (40.2 ± 1.6)%
  ^{226}Ra (20.6 ± 3.4)%
- survival probability of **intrinsic background** events:
  ^{60}Co (0.93 ± 0.08)%
  ^{68}Ge is expected to be also strongly suppresed (creates background at $Q_{\beta\beta}$ via the summation of a β^+ energy loss and an interaction of the annihilation γ-rays => strong MSE signature)

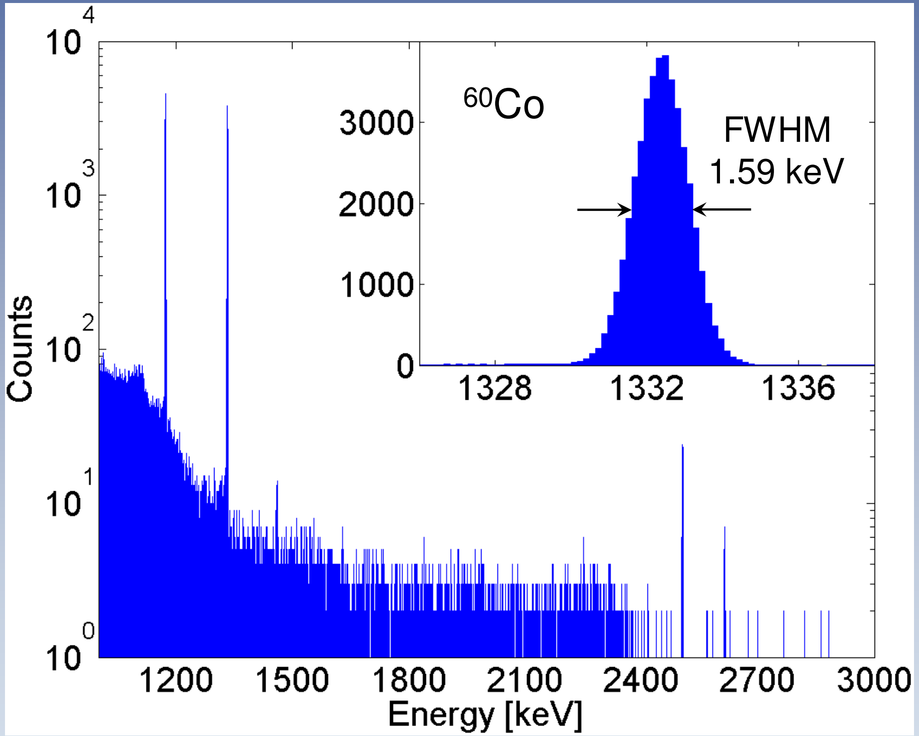
Conclusions

- the PSD properties of BEGe detector allow strong suppresion of main external and intrinsic backgrouds in $0\nu\beta\beta$ decay experiments
- results comparable to highly segmented detectors
- potentially lower background coming from signal contacts compared to segmented detectors
- BEGe is in standard commercial production
- as a consequence, the GERDA collaboration has included BEGe in the R&D for Phase II

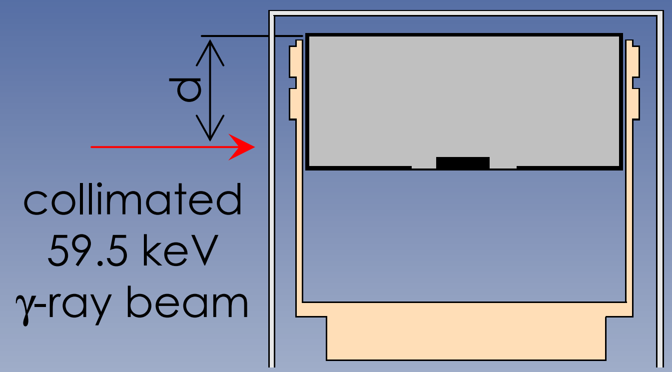
Backup slides

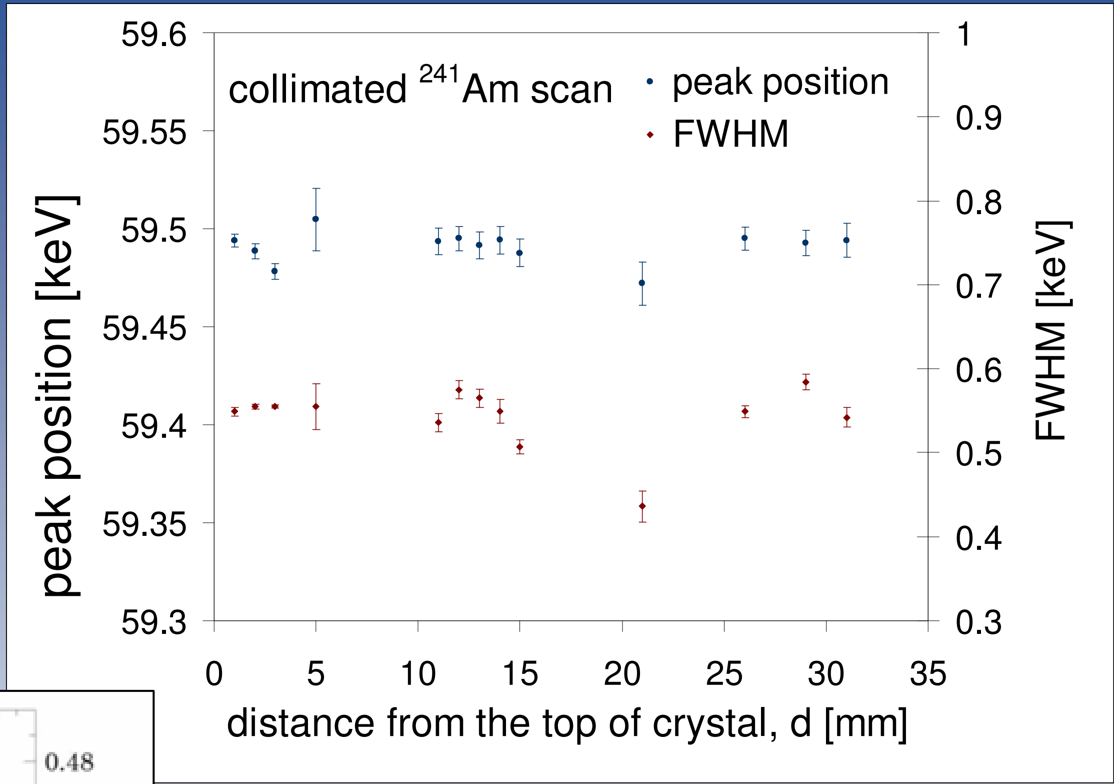
Energy resolution

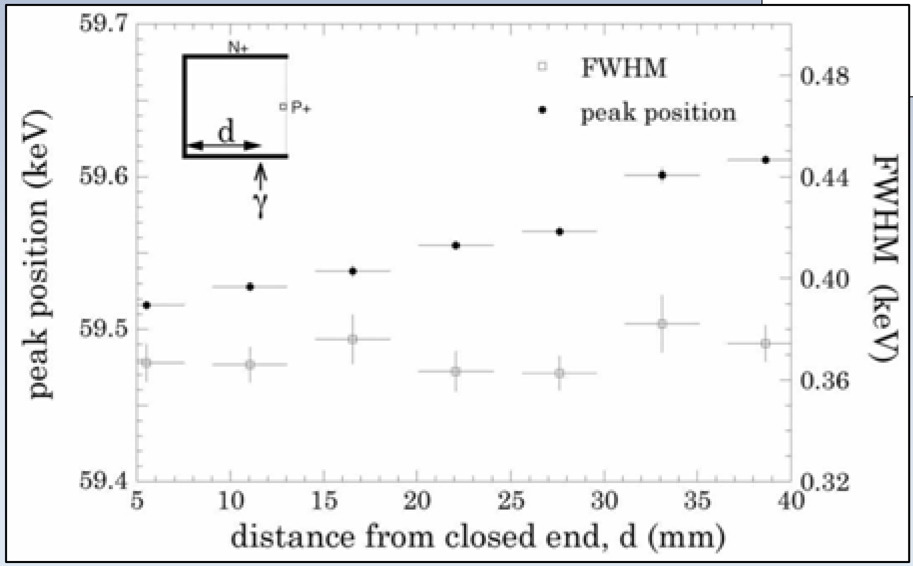




Surface variation of charge collection







Gain variation: ≤ 0.055%

Majorana PPC detector:
Gain variation: ≤ 0.15%

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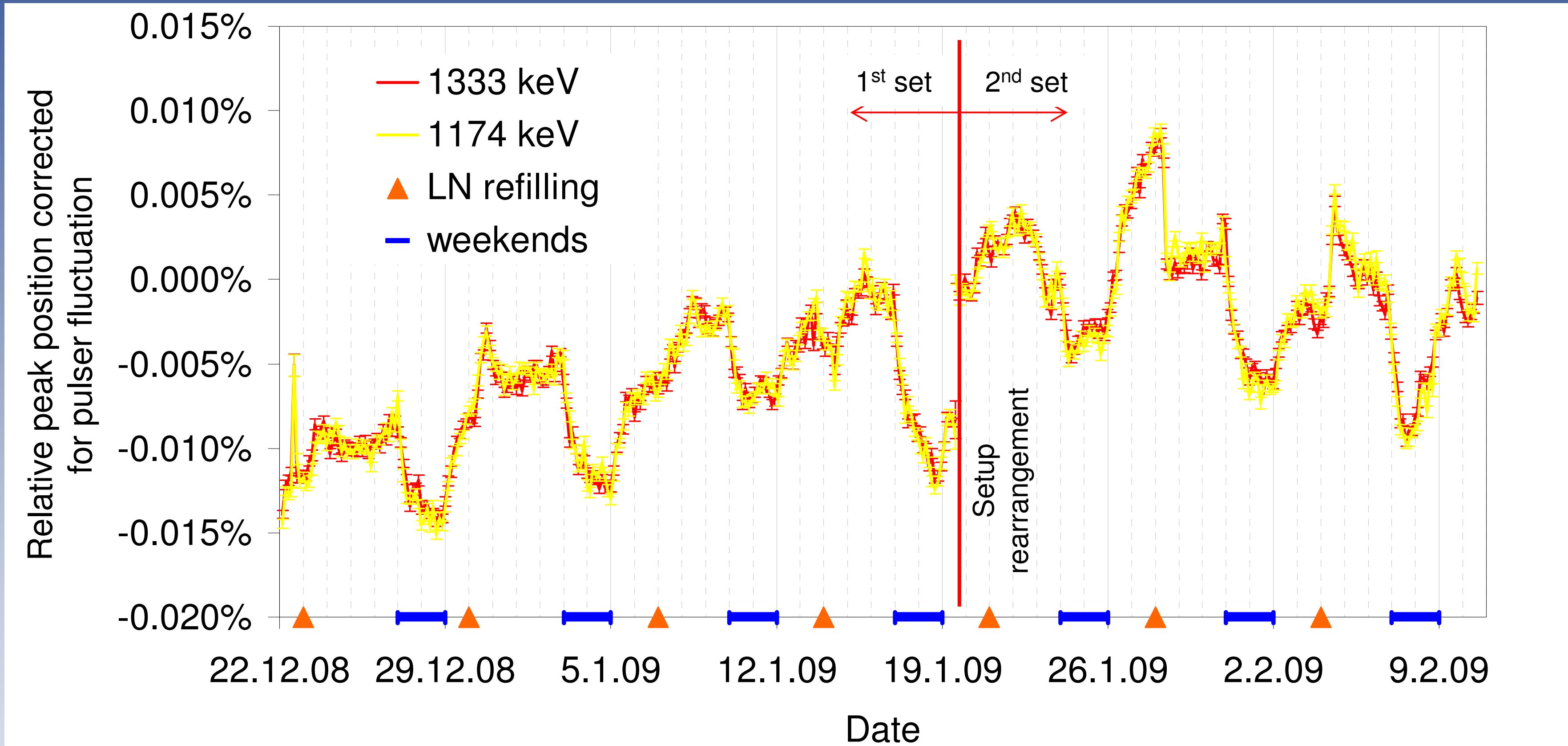
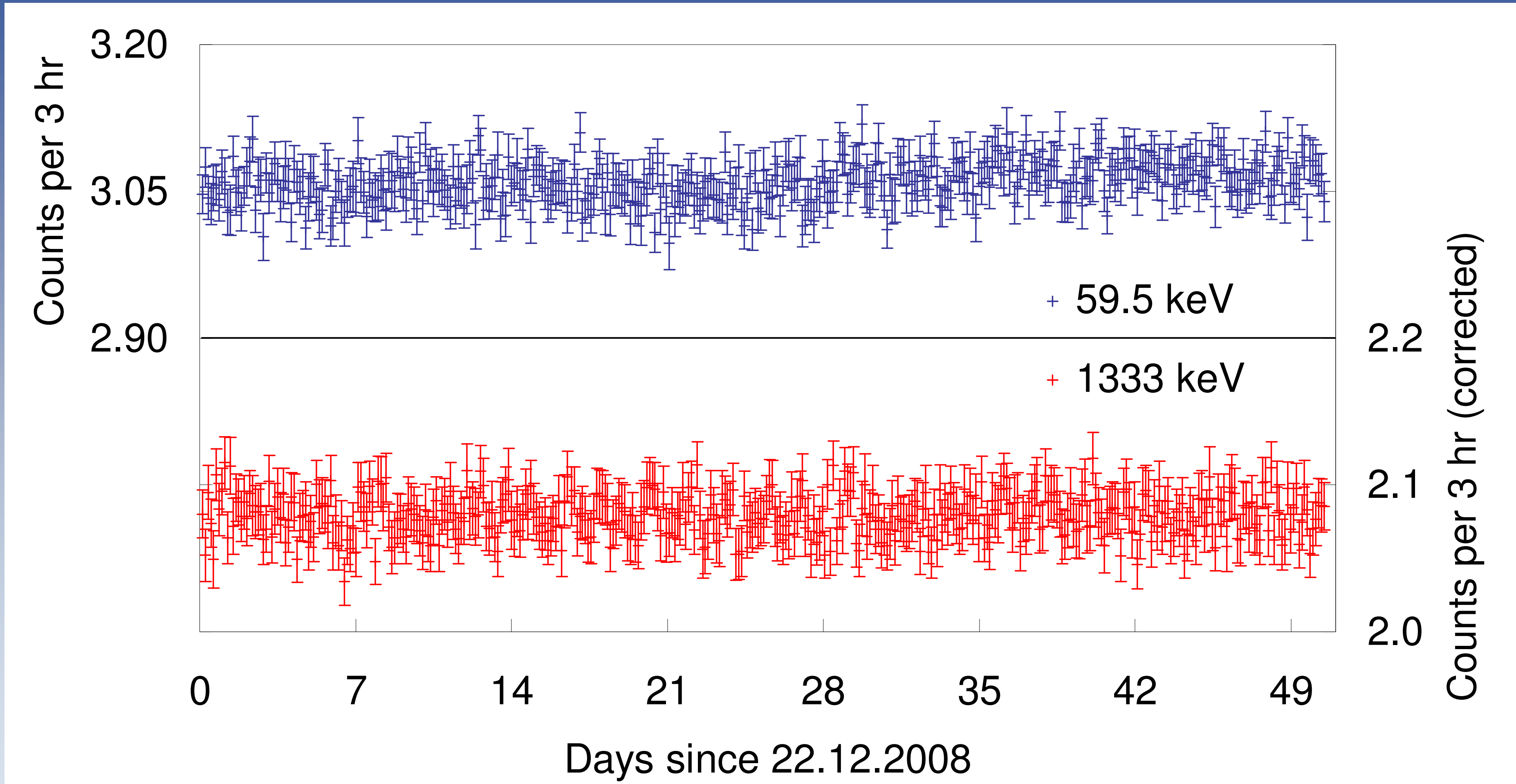
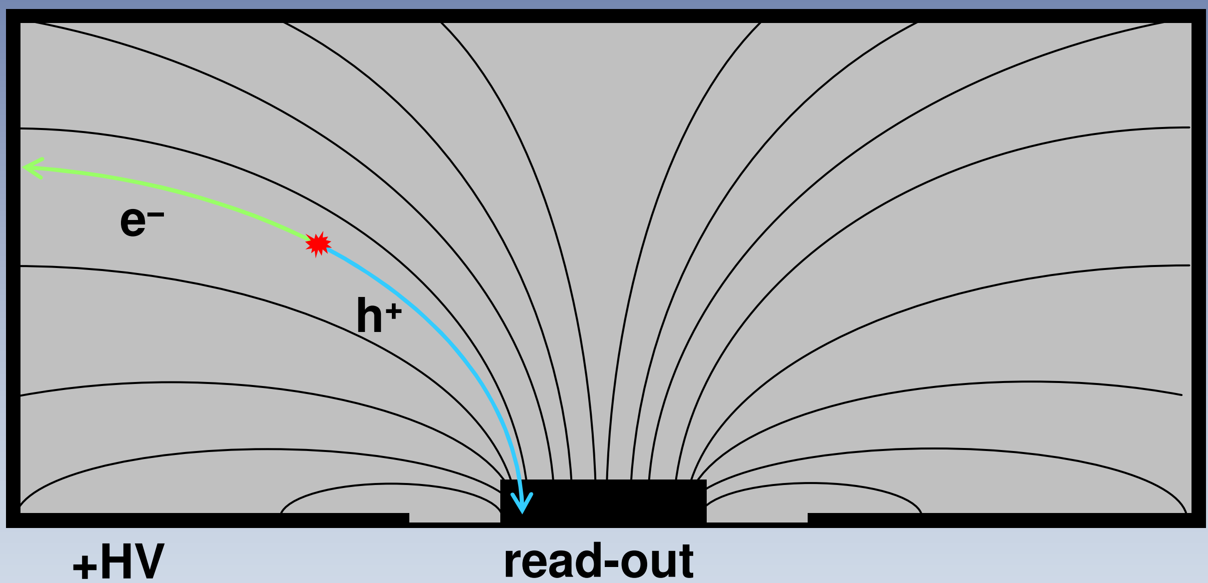
Charge collection stability

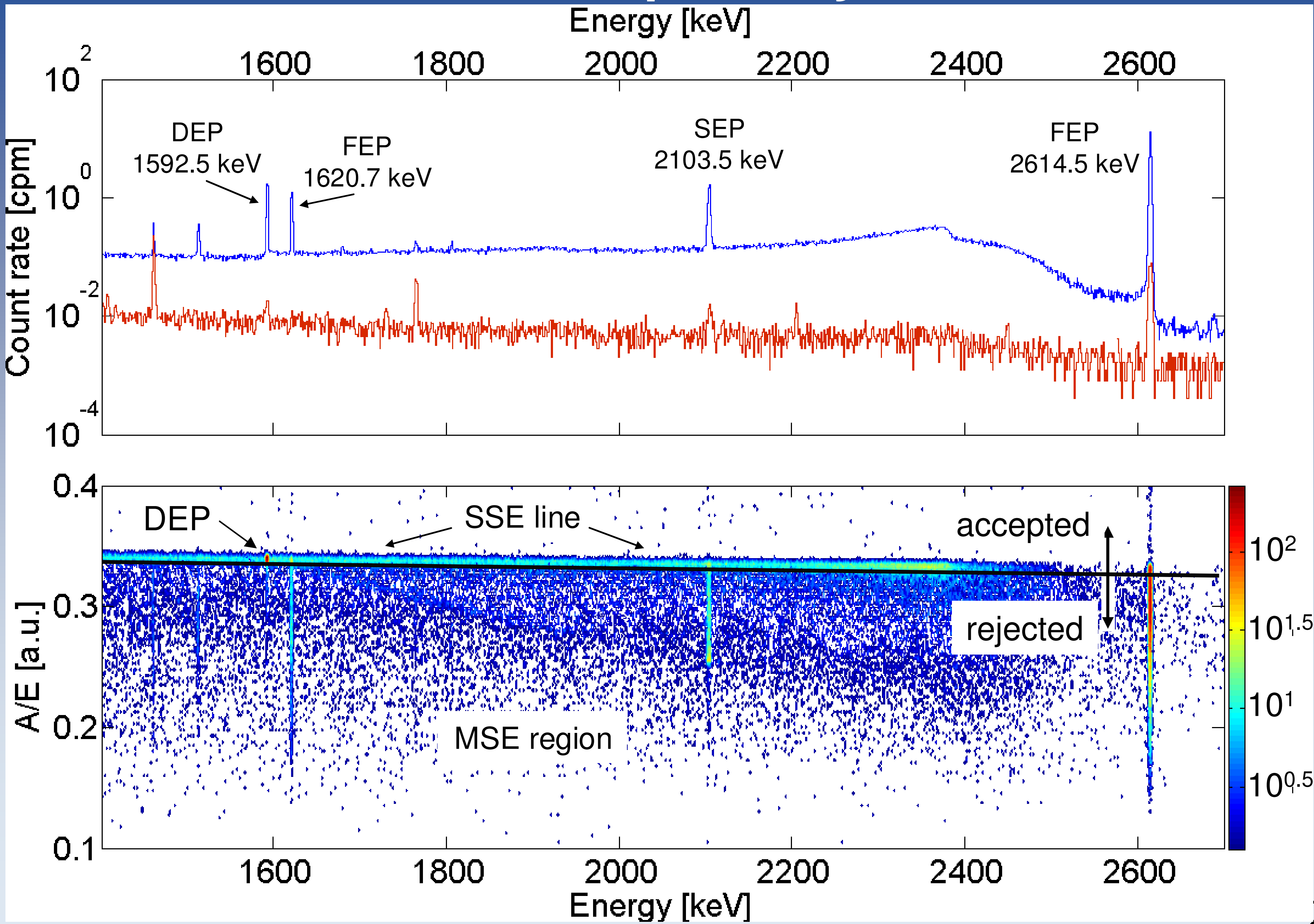


Charge collection stability

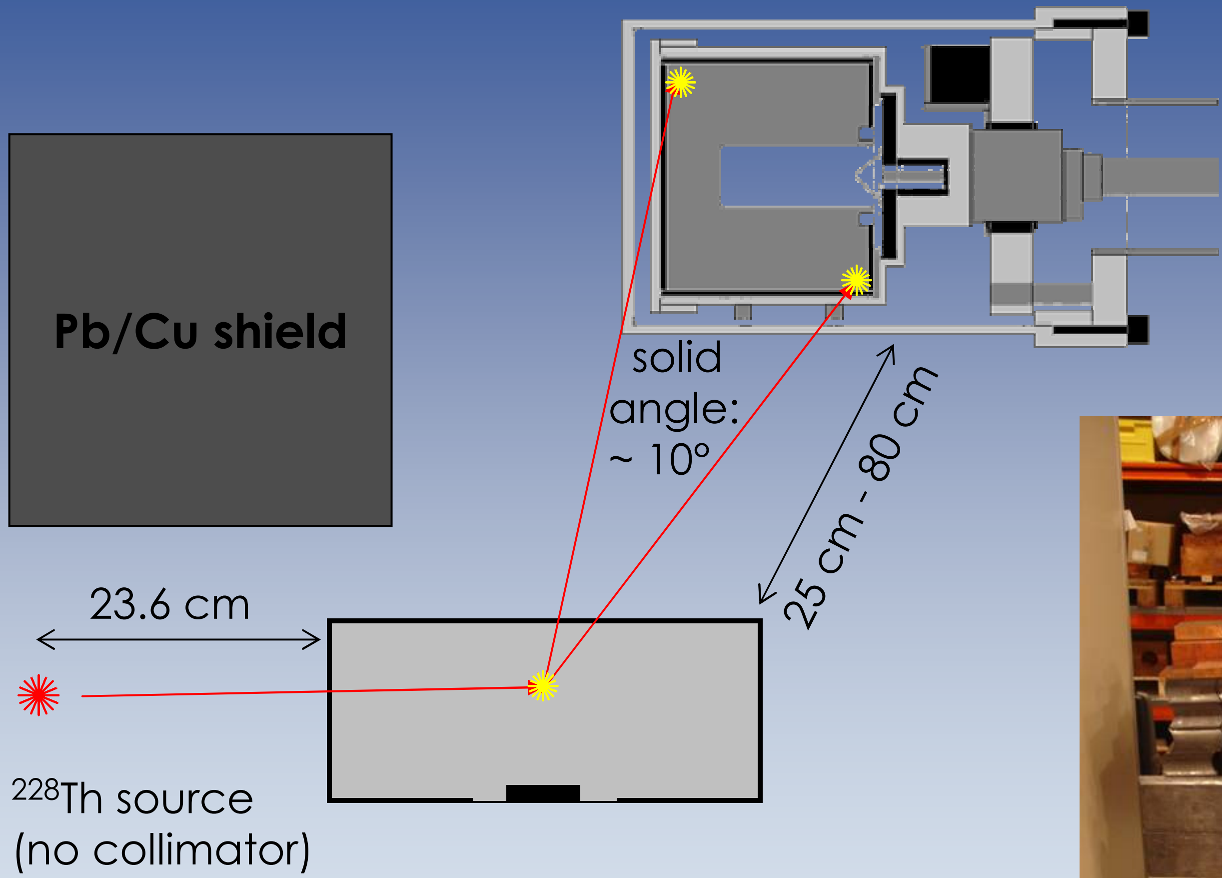


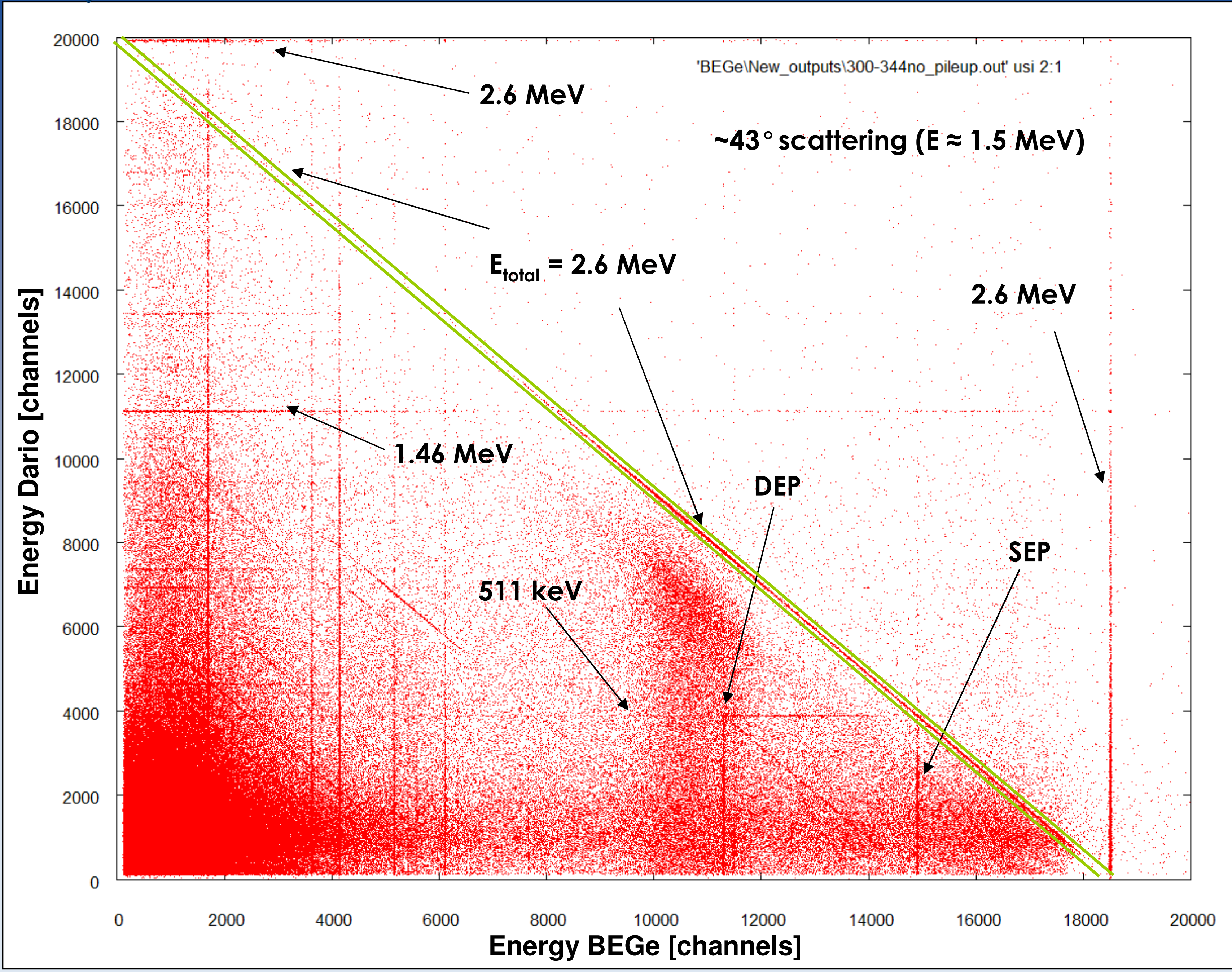

e−
h+
+HV
read-out

Pulse shape analysis

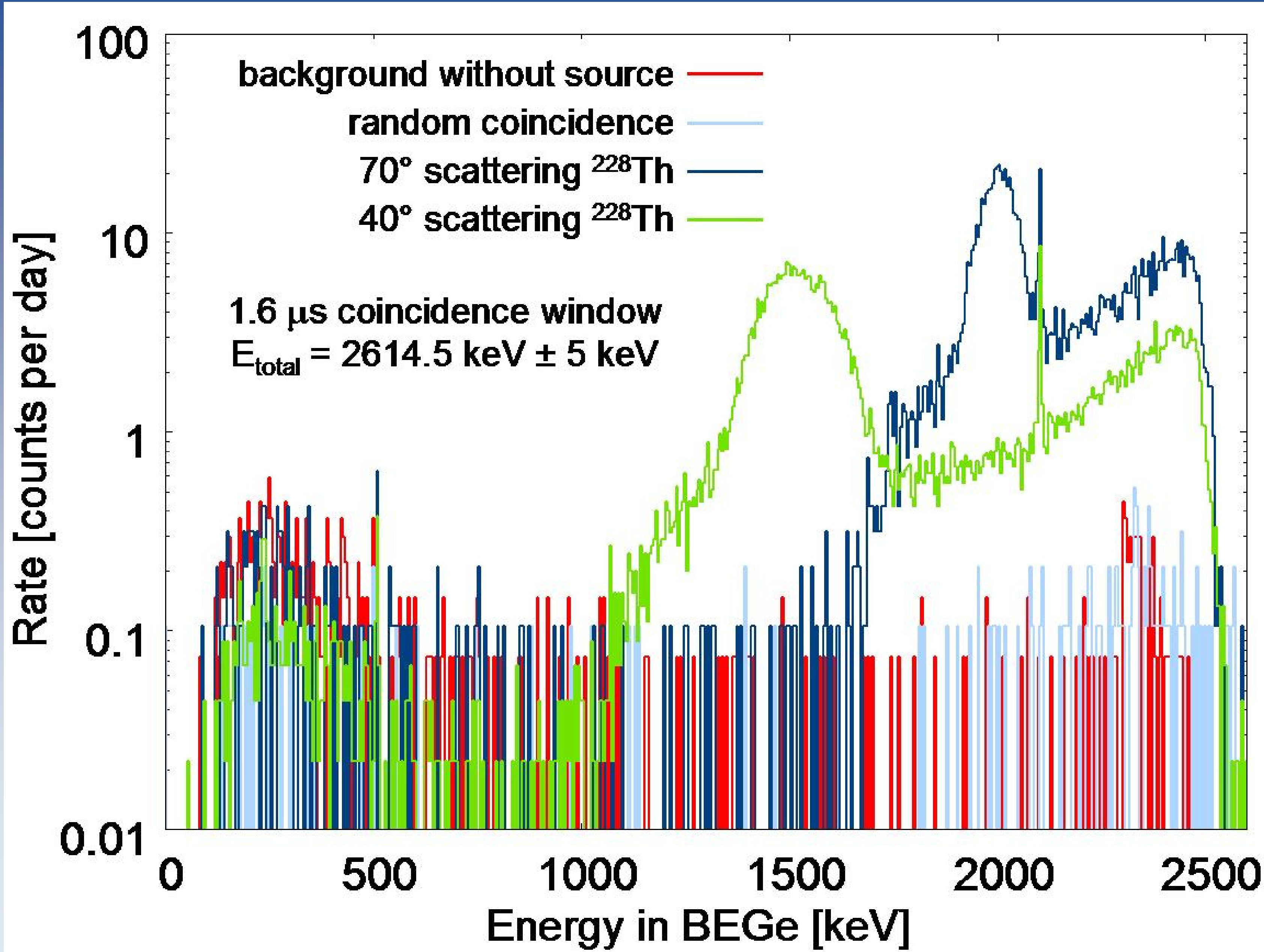


Coincident Compton scattering




'BEGe\New_outputs\300-344no_pileup.out' usi 2:1
2.6 MeV
~43° scattering (E ≈ 1.5 MeV)
E_total = 2.6 MeV
2.6 MeV
1.46 MeV
DEP
SEP
511 keV
Energy Dario [channels]
Energy BEGe [channels]
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000

Coincident backgrounds



Compton scattering events