BEGe Detector studies update

Performance and analysis

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GERDA

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Outline

1. BEGe publication
2. BEGe pulse-shape discrimination method
3. Update on recent results
4. Summary/Outlook

BEGe publication

Pulse shape discrimination studies with a Broad-Energy Germanium detector for signal identification and background suppression in the GERDA double beta decay experiment

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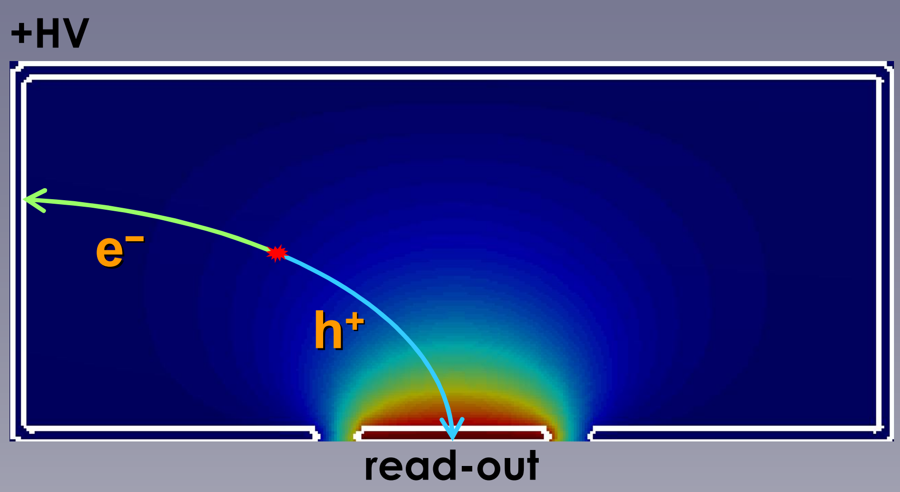
ABSTRACT: First studies of event discrimination with a Broad-Energy Germanium (BEGe) detector are presented. A novel pulse shape method, exploiting the characteristic electrical field distribution inside BEGe detectors, allows to identify efficiently single-site events and to reject multi-site events. The first are typical for neutrinoless double beta decays ($0\nu\beta\beta$) and the latter for backgrounds from gamma-ray interactions. The obtained survival probabilities of backgrounds at energies close to $Q_{\beta\beta}(^{76}Ge) = 2039$ keV are (0.93 ± 0.08)% for events from ^{60}Co, (21 ± 3)% from ^{226}Ra and (40 ± 2)% from ^{228}Th. This background suppression is achieved with (89 ± 1)% acceptance of ^{228}Th double escape events, which are dominated by single site interactions. Approximately equal acceptance is expected for $0\nu\beta\beta$-decay events. Collimated beam and Compton coincidence measurements demonstrate that the discrimination is largely independent of the interaction location inside the crystal and validate the pulse-shape cut in the energy range of $Q_{\beta\beta}$. The application of BEGe detectors in the GERDA and the Majorana double beta decay experiments is under study.

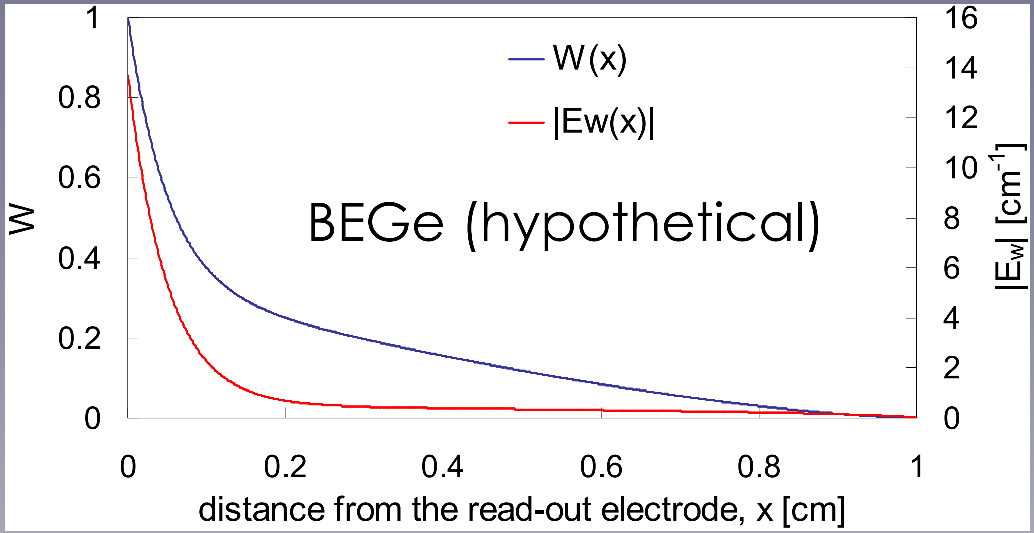
KEYWORDS: Gamma detectors; Particle identification methods.

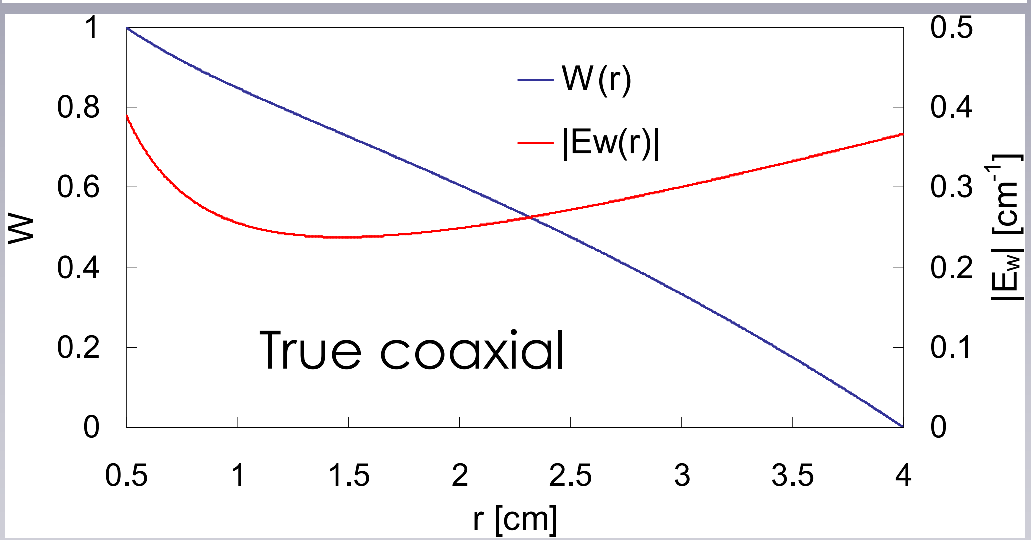
* Corresponding author.

- submitted to **JINST**
- **accepted for publication** after some minor corrections
- ArXiv: 0909.4044 [nucl-ex]
- Contents:
  - charge collection performance and stability
  - PSD method and its calibration
  - validation via coincident SCS and collimated 2.6 MeV beam
  - experimental PSD results
- also: proceedings from CIPANP 2009 (4 pages, submitted to AIP)
- previously: IEEE 2008 proceedings arXiv: 0812.1735v1[nucl-ex]

BEGe pulse shape discrimination method





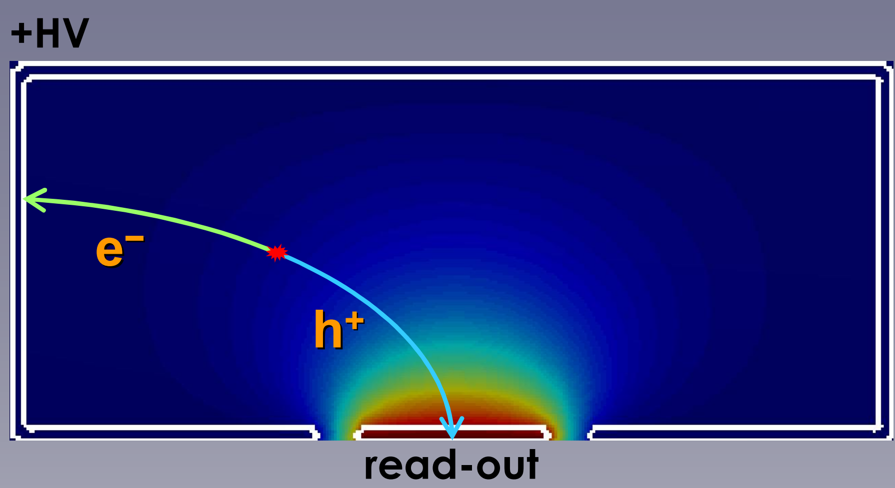


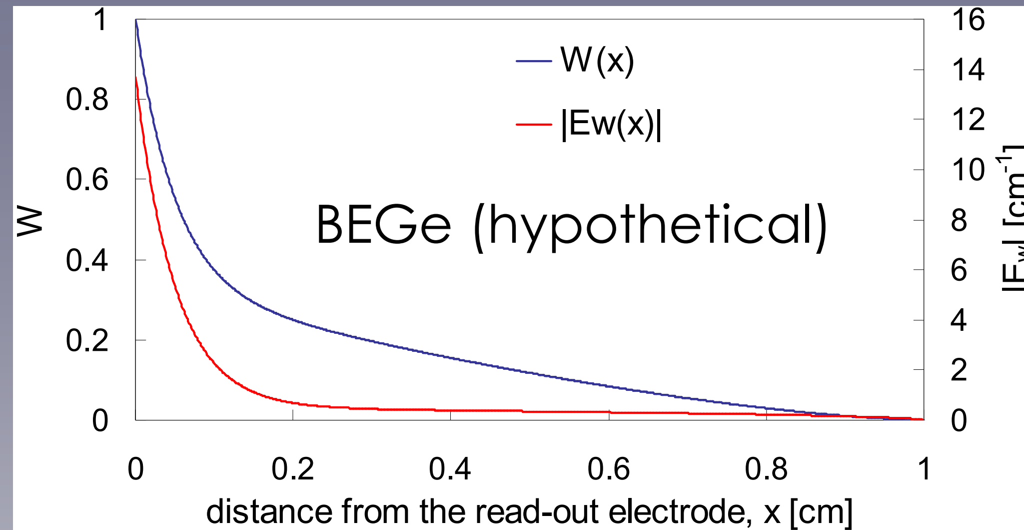
ref: Knoll

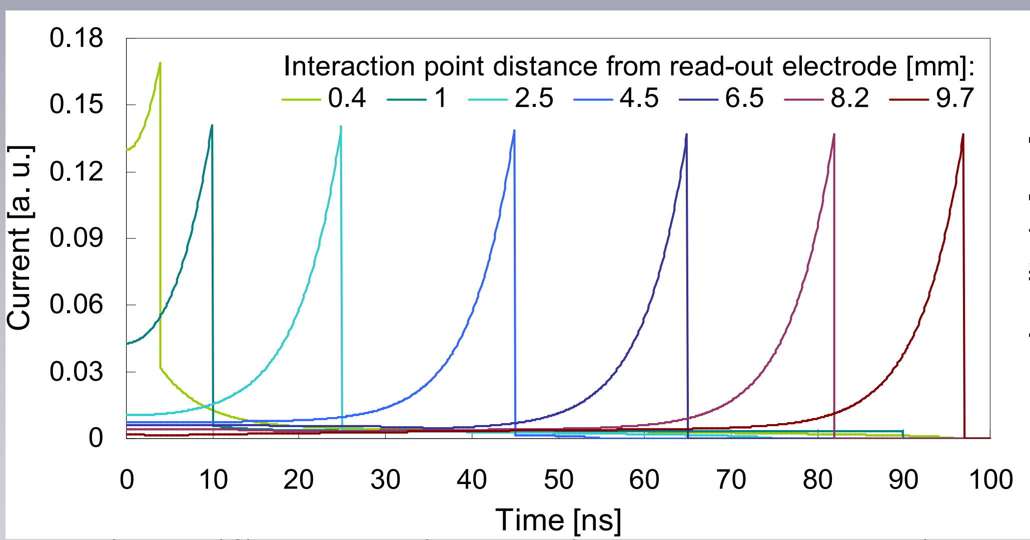
Ramo's theorem ⇒

$$I(t) = -q^e \cdot E_W\left(x^e(t)\right) \cdot v + q^h \cdot E_W\left(x^h(t)\right) \cdot v$$

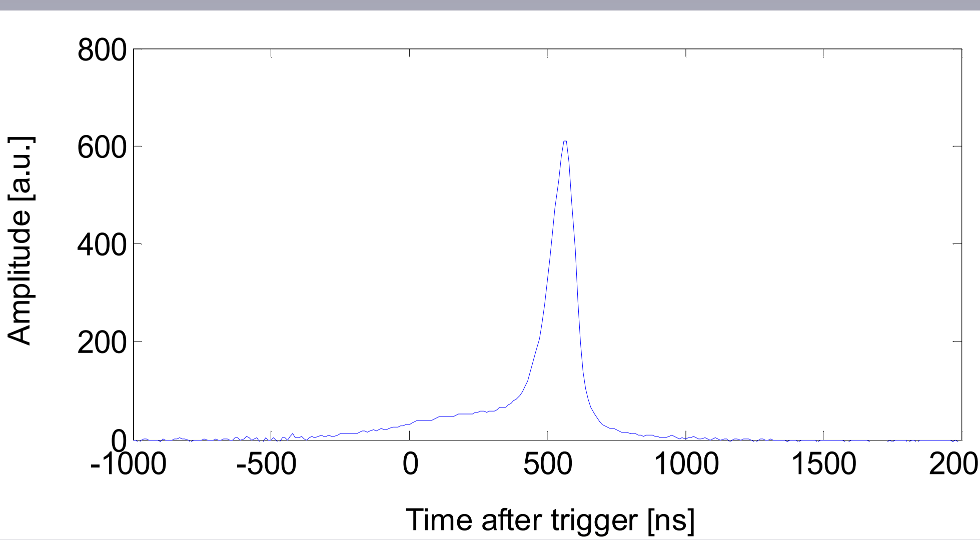
BEGe pulse shape discrimination method







simplified 1-dimensional calculation



real recorded signal

Ramo's theorem ⇒

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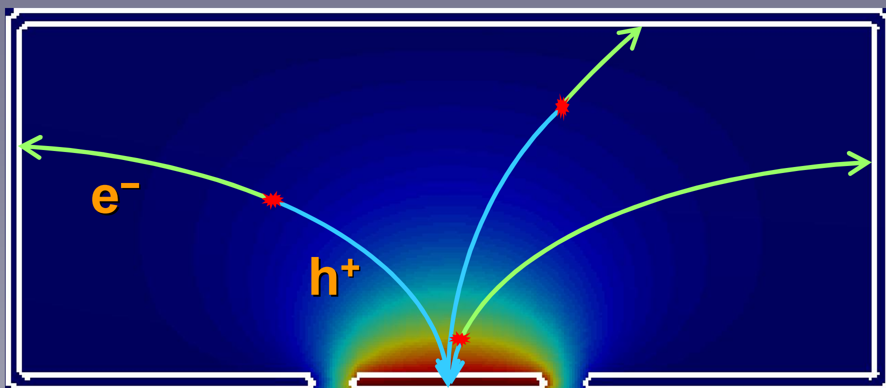
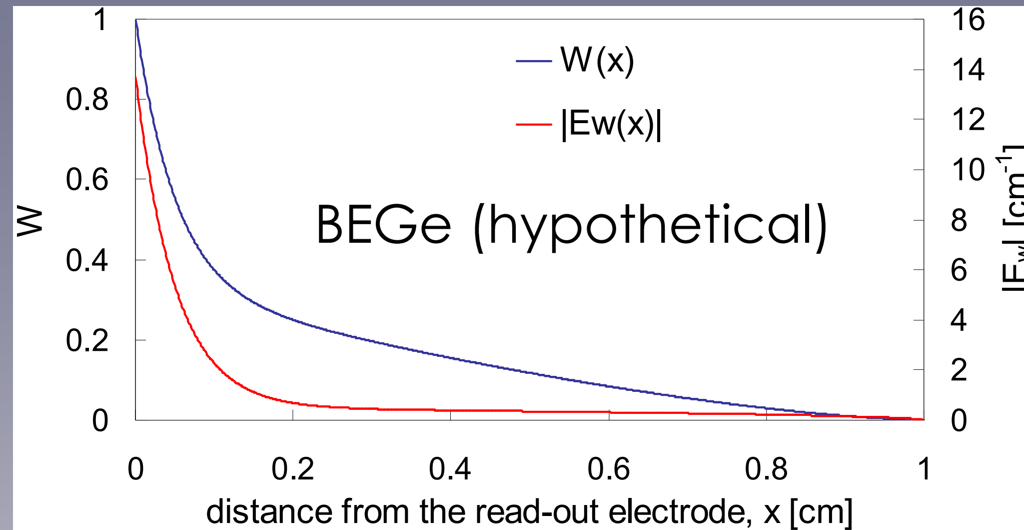
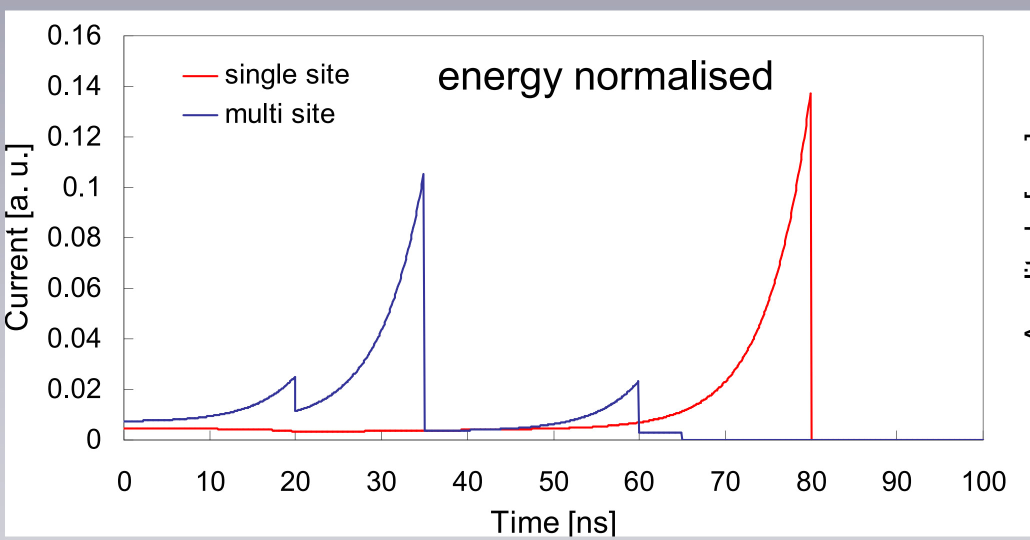
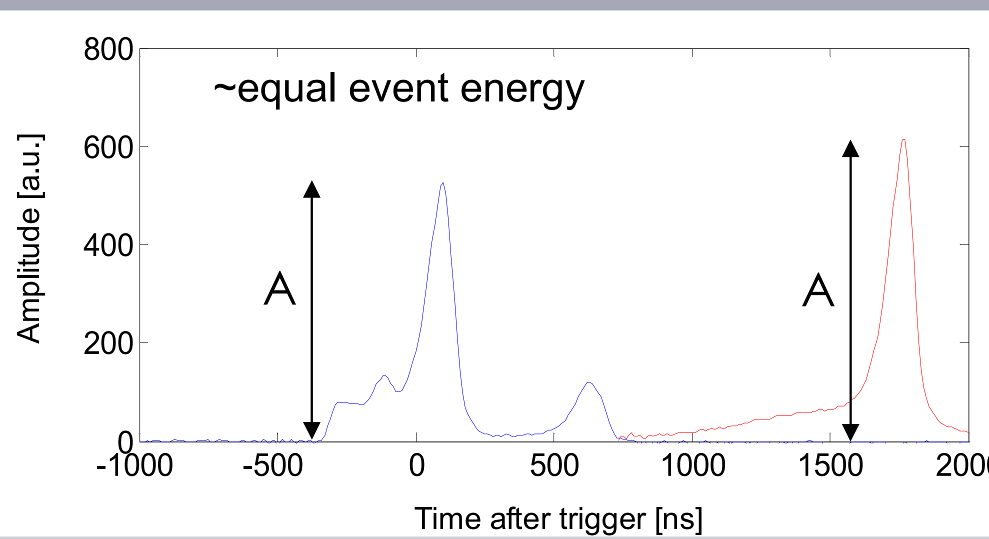
BEGe pulse shape discrimination method









simplified 1-dimensional calculation

real recorded signal

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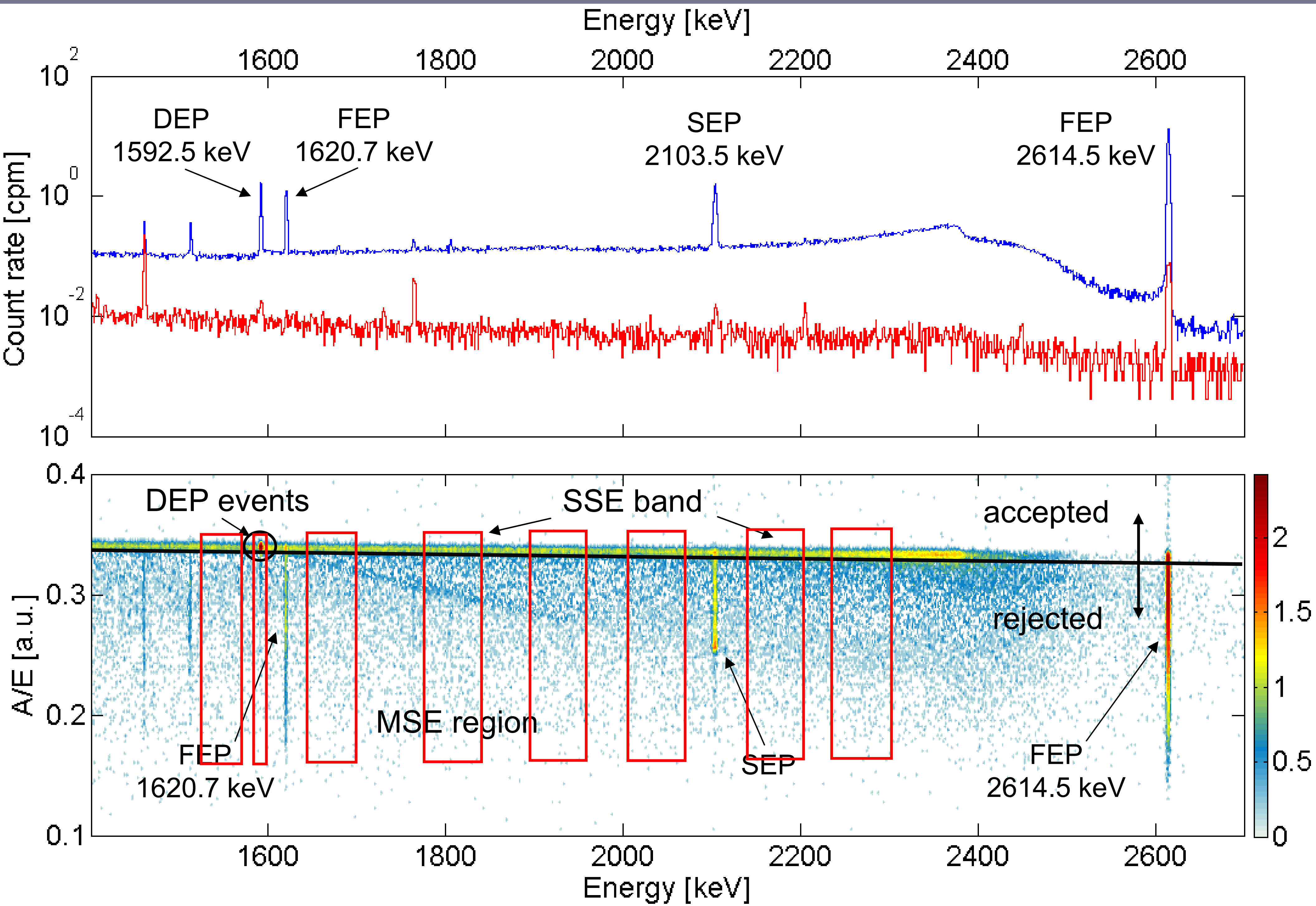
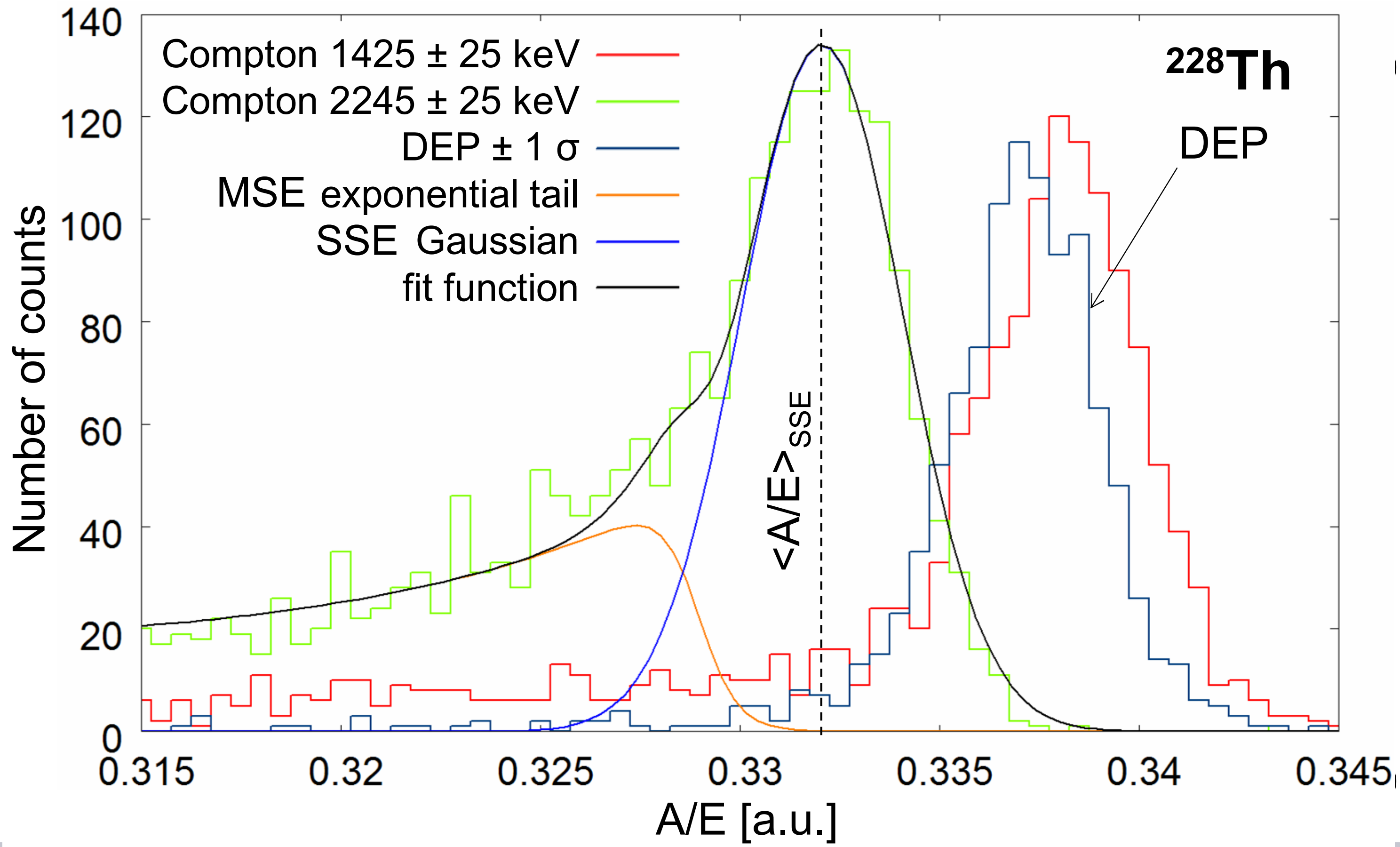
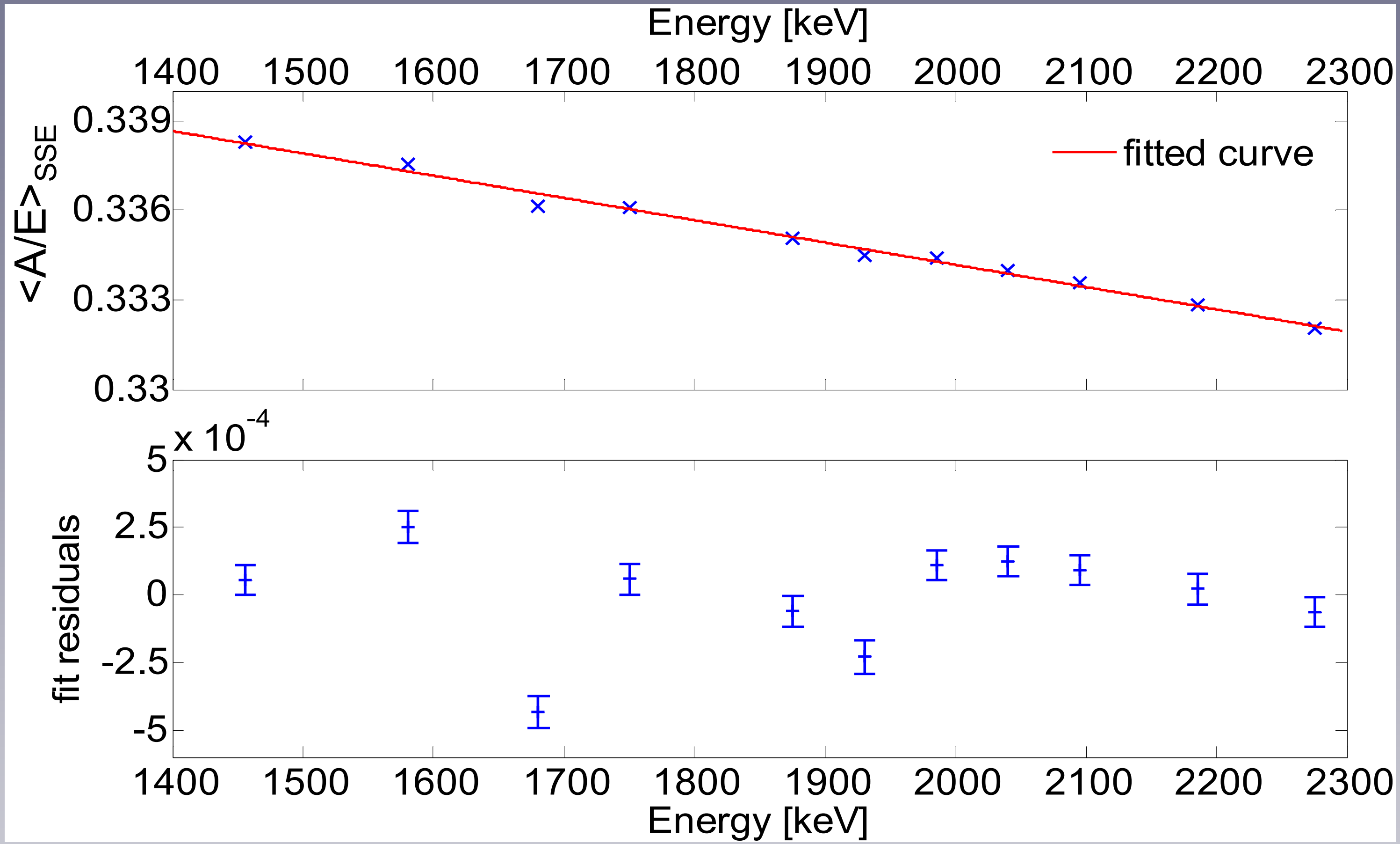
PSD parameter distribution



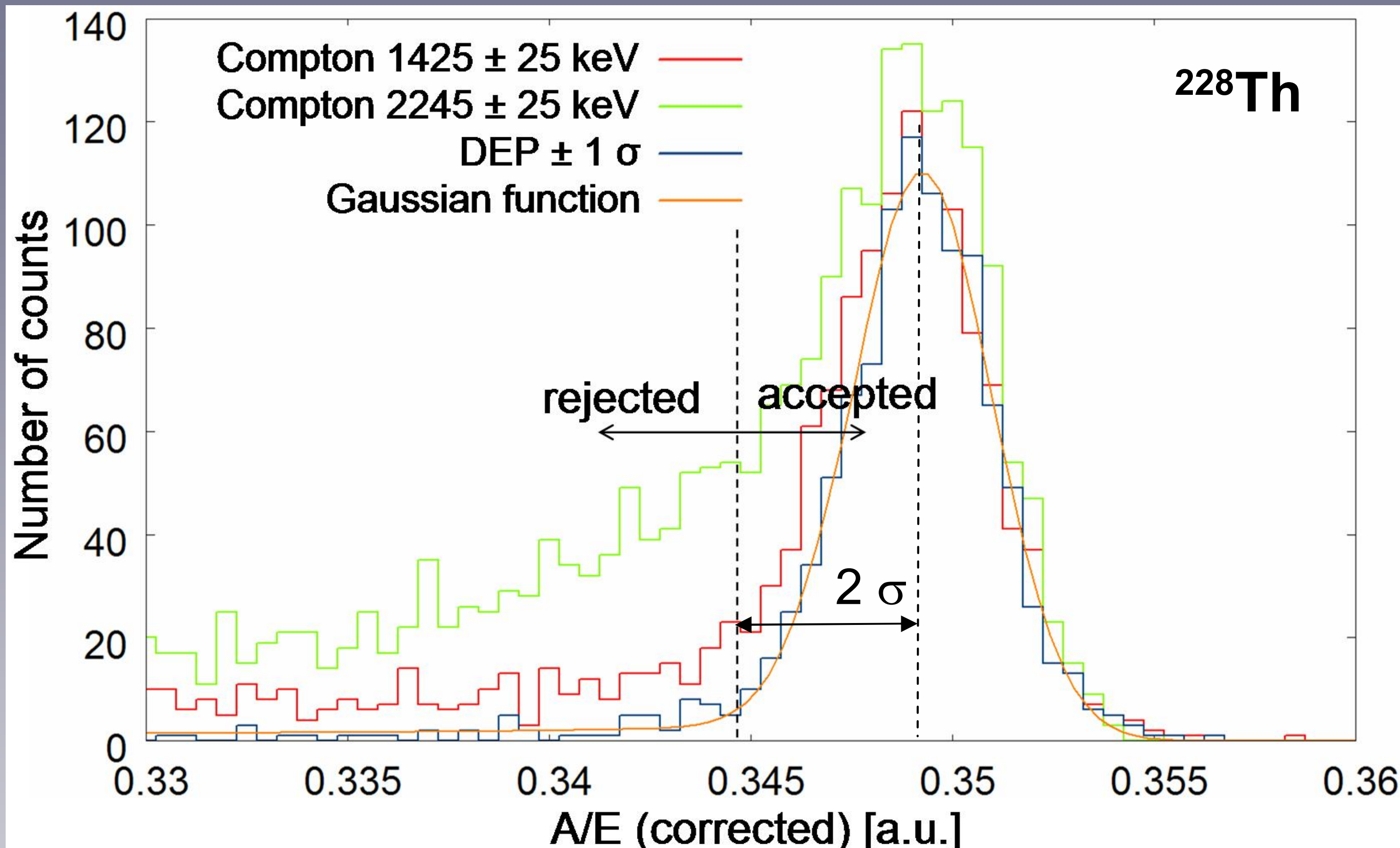
PSD calibration



PSD calibration



PSD calibration



Assuming **gaussian distribution** (resolution dominated by noise):

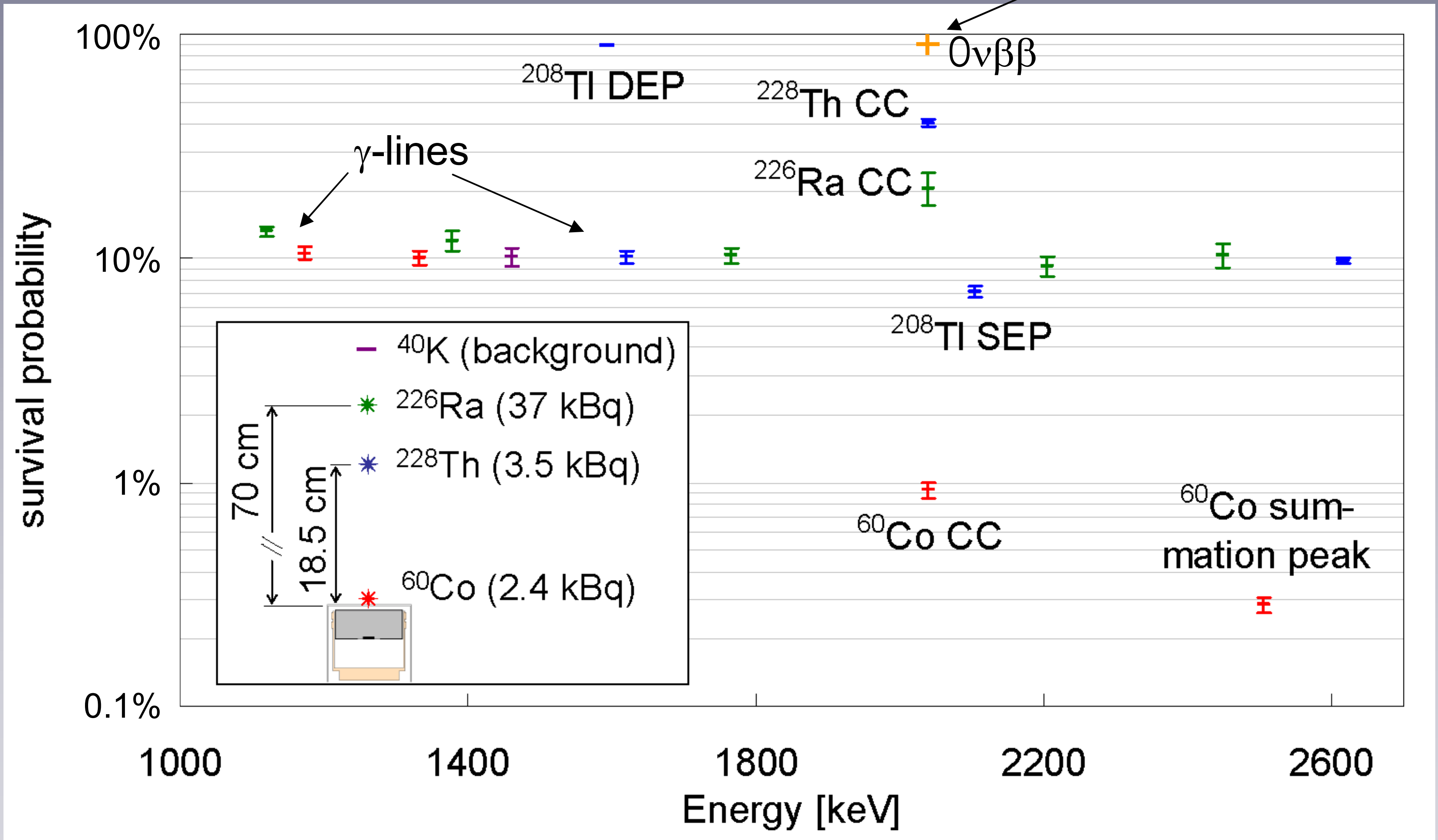
$2\sigma \Rightarrow$ 97.7% SSE acceptance

arbitrary choice of "SSE identification probability"

SSE defined as events with charge cluster extent so small that the electric field doesn't change significantly across it's width

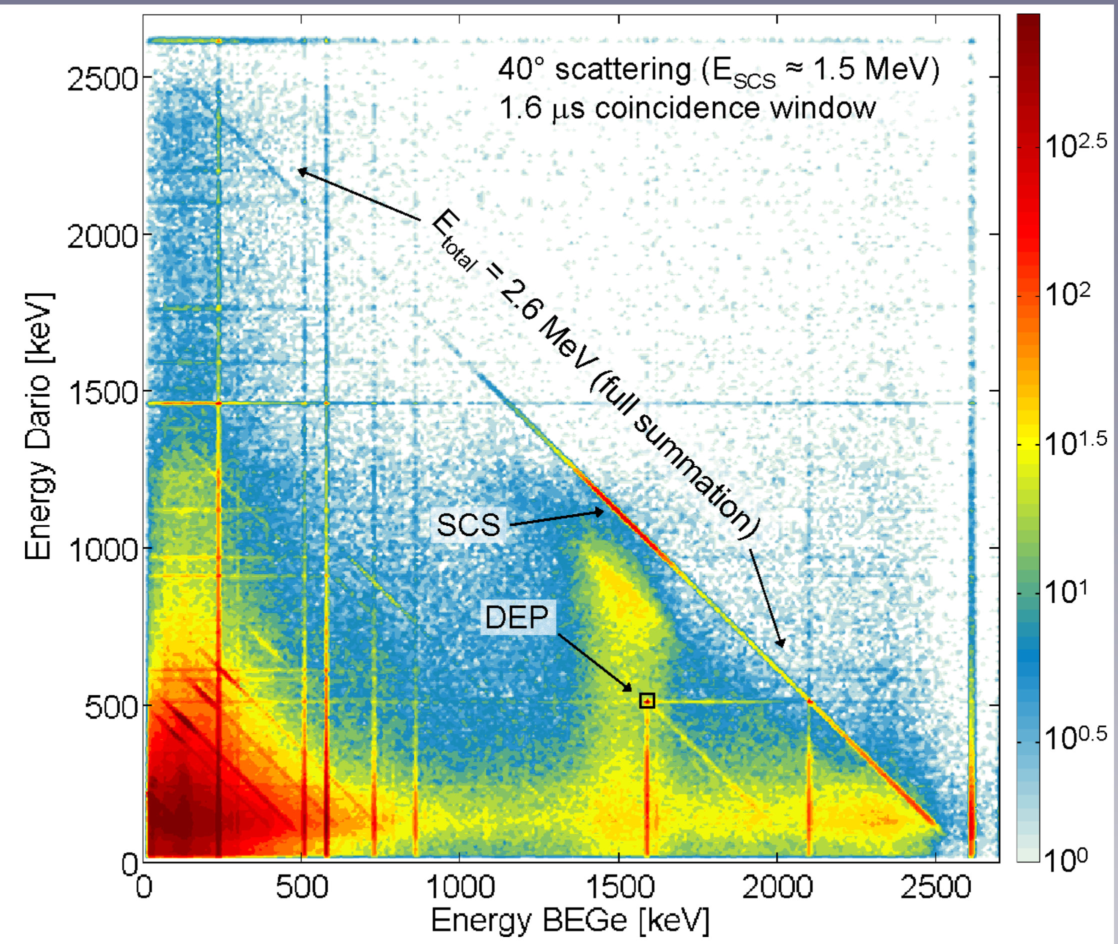
Updated experimental results

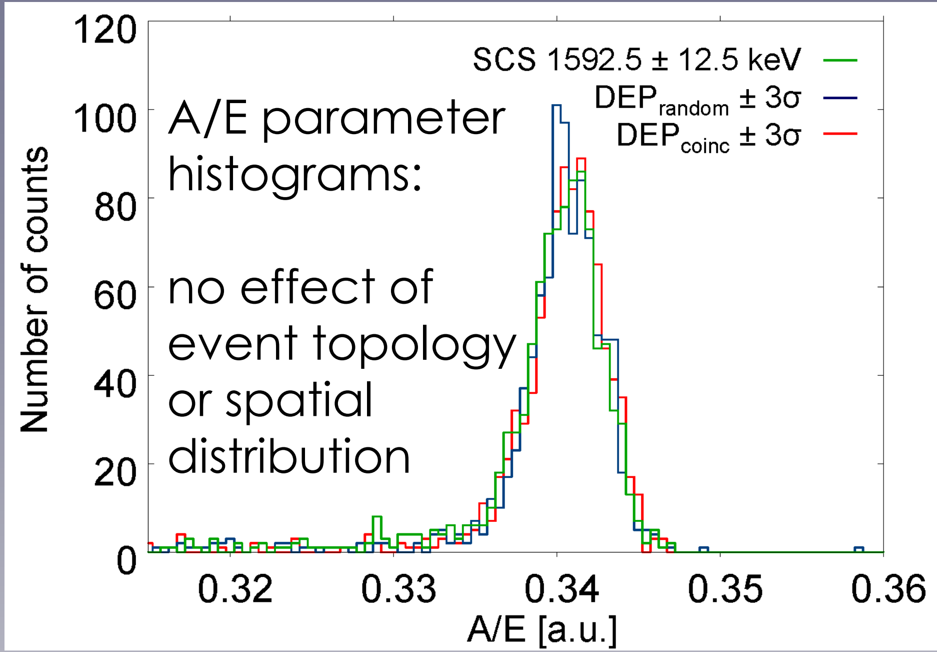
- cut at 2 σ from the SSE band mean
- simplified MC estimation of 0νββ acceptance: (89.4 ± 1.4)%

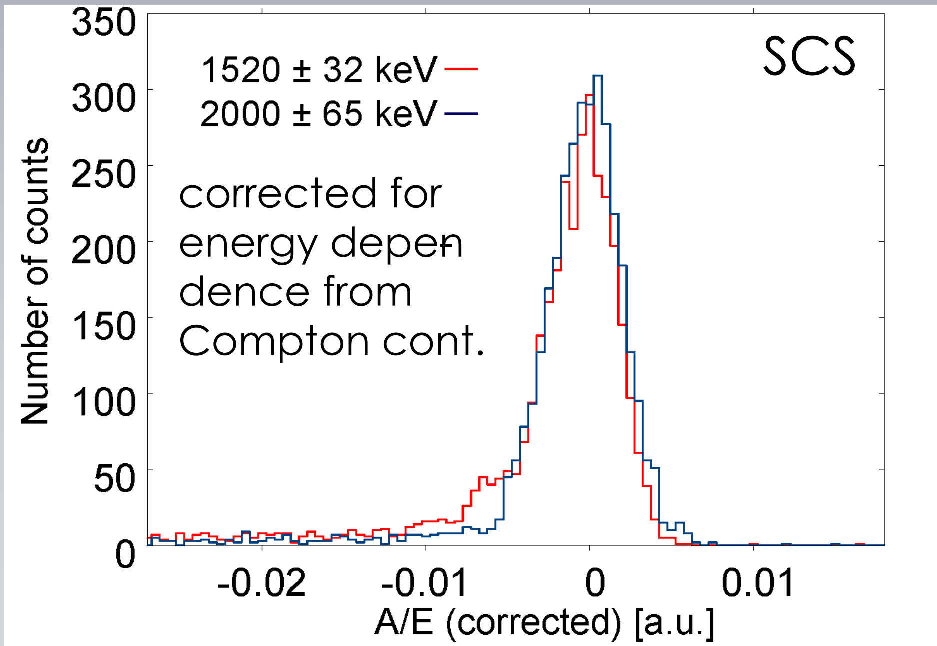


CC = Compton continuum (2039 ± 35 keV)

PSD validation via coincident single-Compton scattering



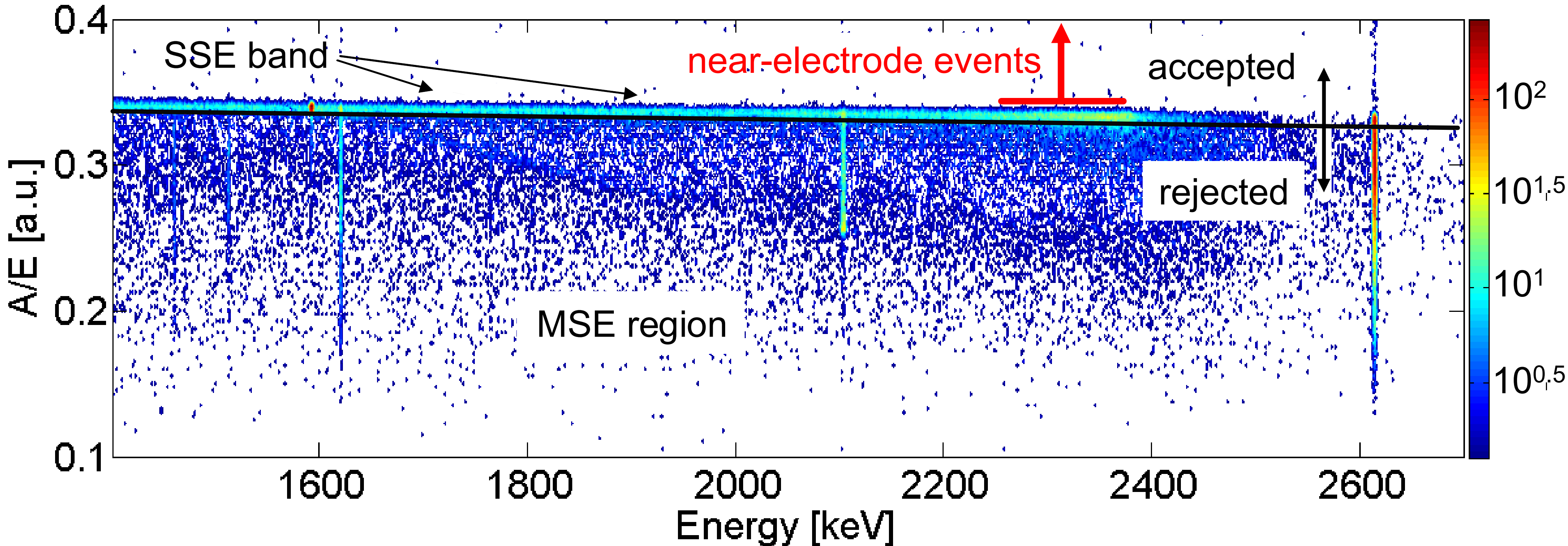


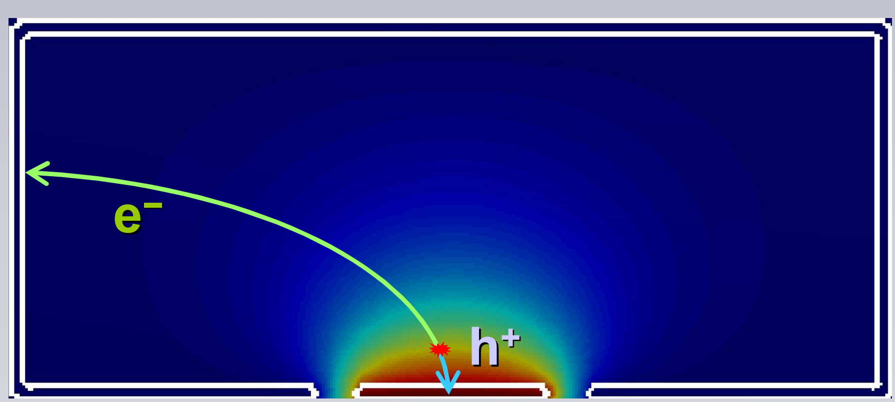


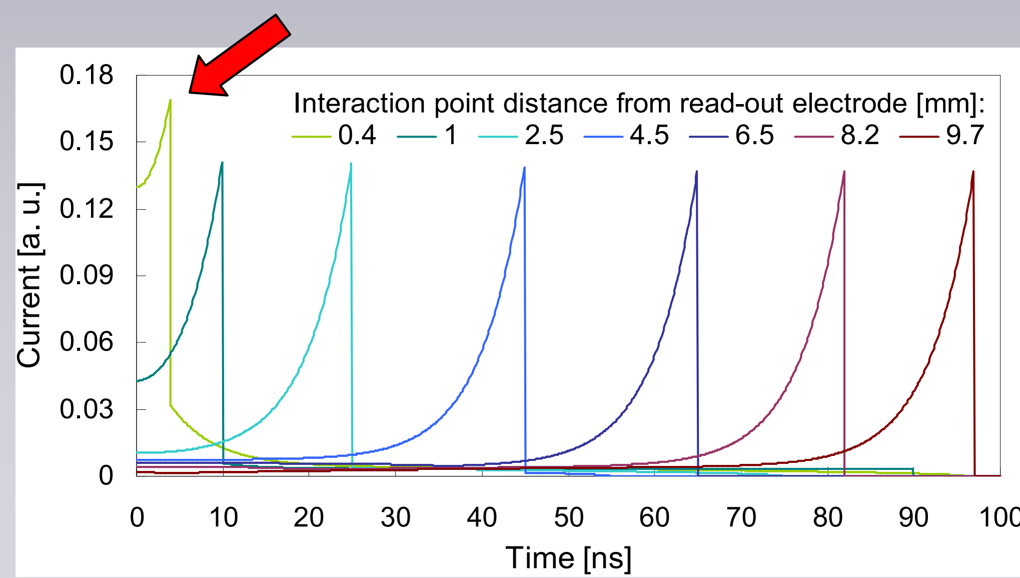
⇒ double-escape peak (DEP) is a good representation of ββ events

⇒ validated our PSD calibration using DEP and Compton continuum events

PSD performance in dependence on spatial event distribution



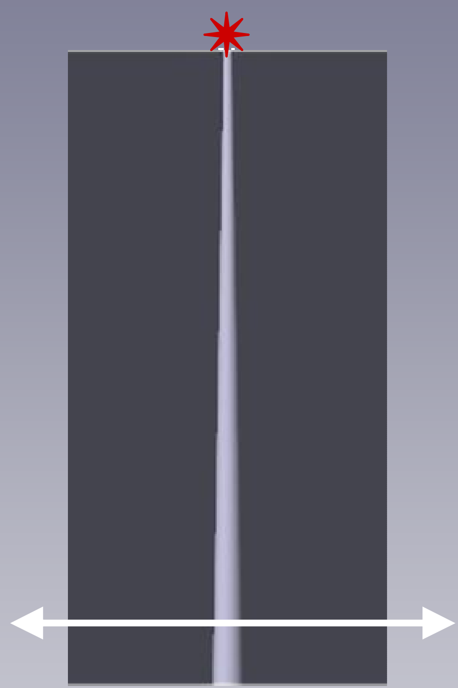


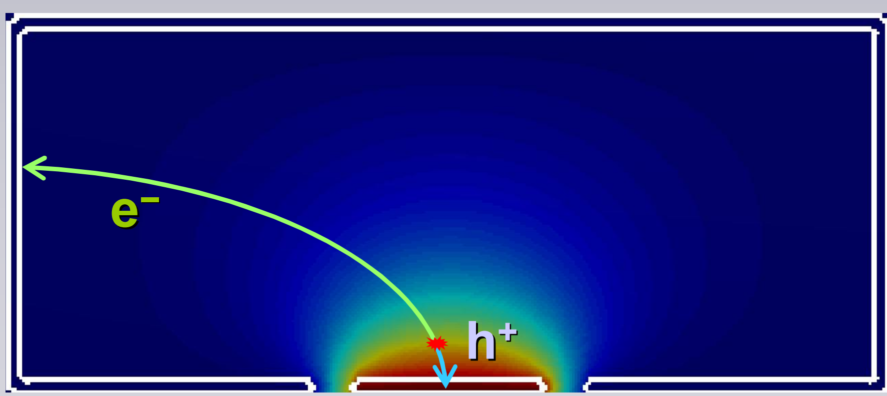


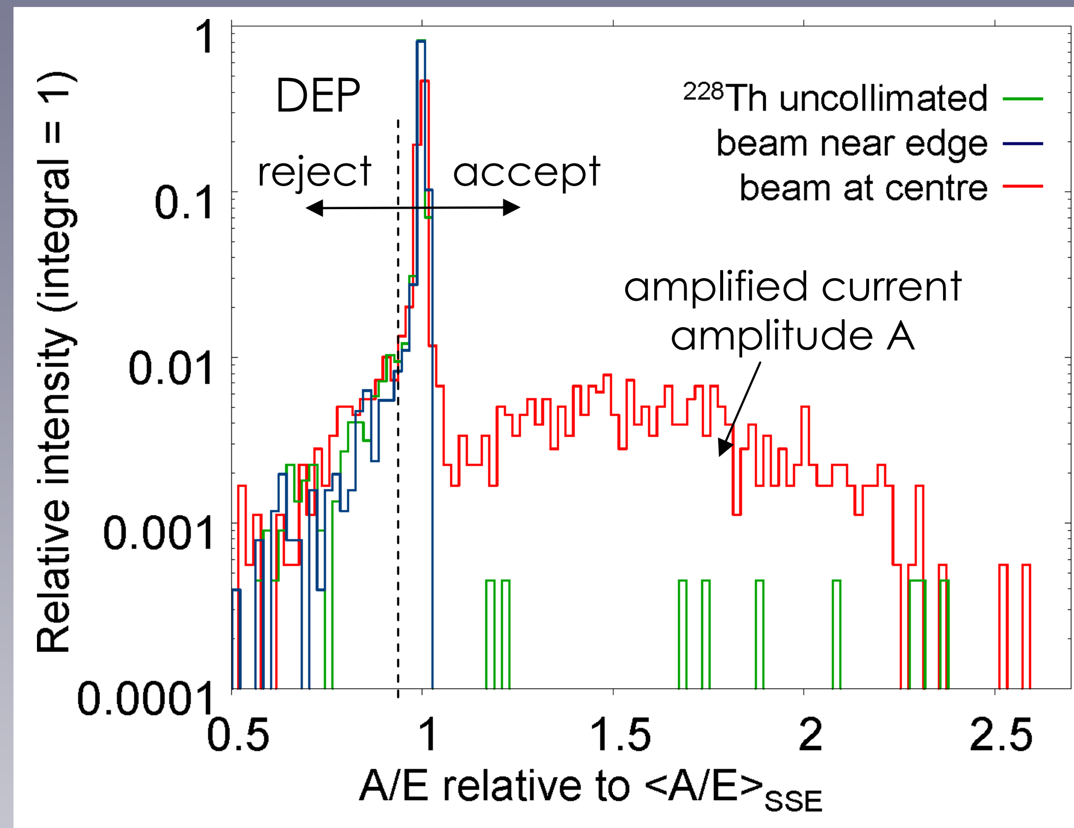
PSD performance in dependence on spatial event distribution

^{228}Th source

∅ 6 mm collimated beam

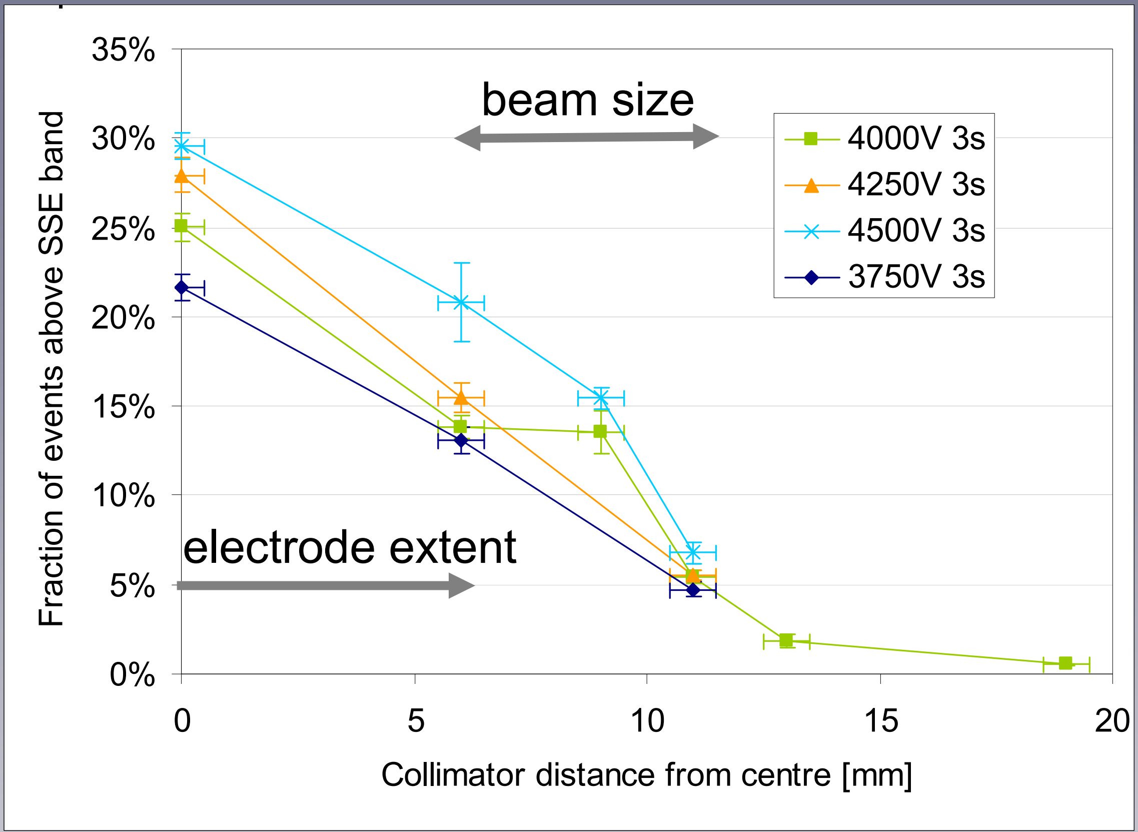


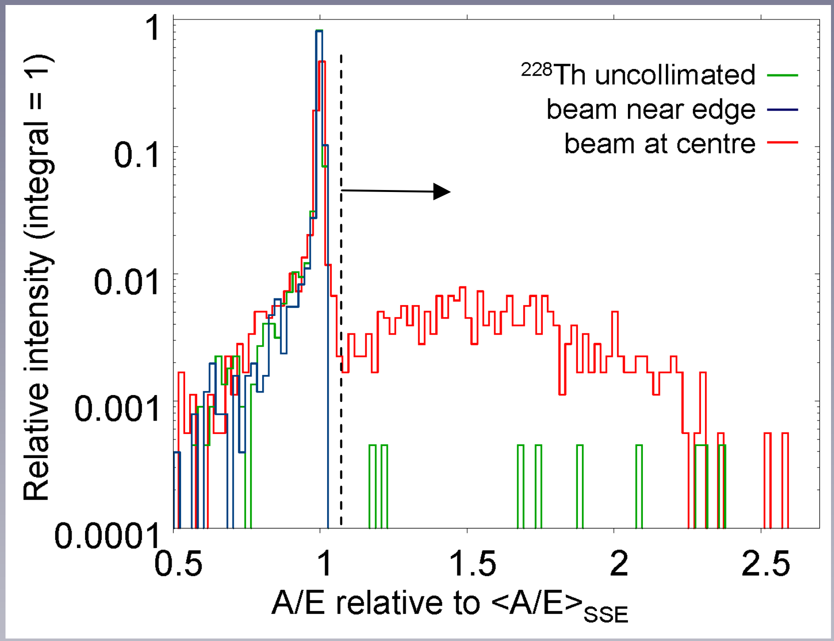


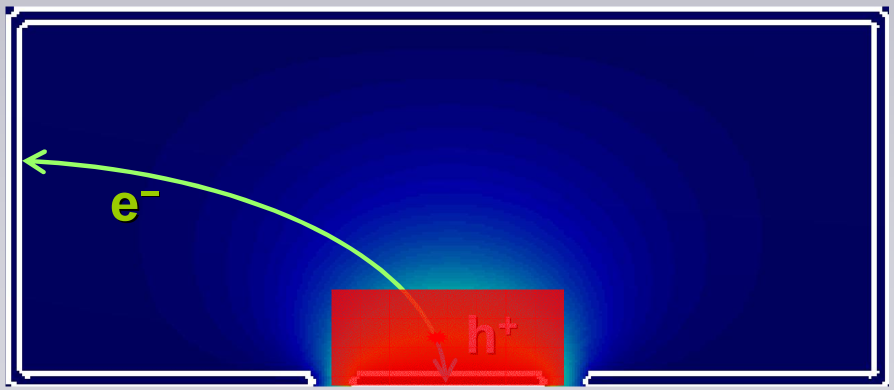


acceptance:	DEP	1621 keV
uncollimated:	89%	10%
collimated (centre):	88%	23%

HV dependence of PSD performance





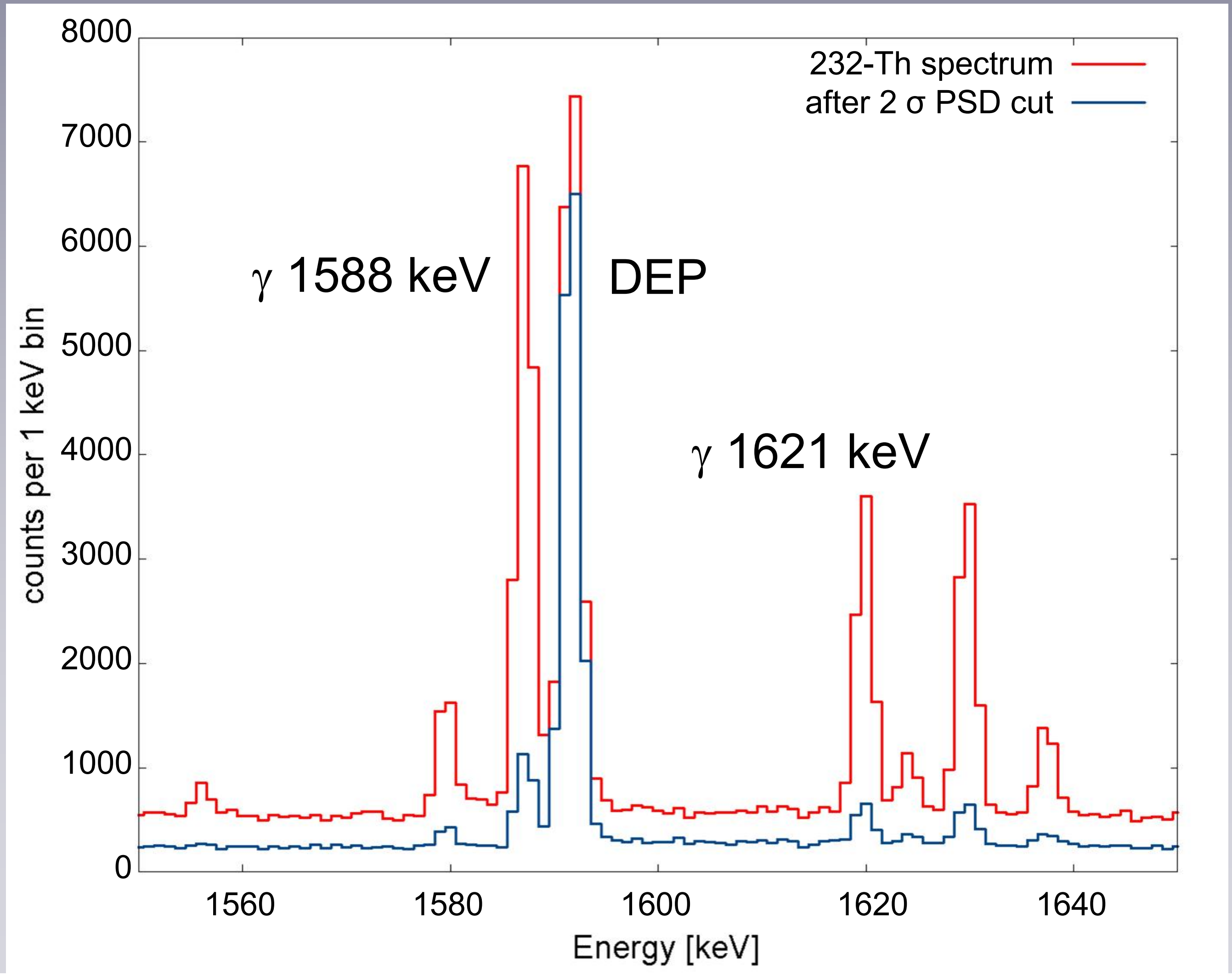


< 3% of total volume PSD ineffective
Complementary PSD techniques effective also in this region (e.g. rise-time based)

- the extent of the insensitive region grows with HV

PSD performance in dependence on crystal size

- PSD tested on ∅ 6 cm BEGe (at IRMM Geel, Belgium)
- results: SEP survival 9.2% (∅ 8 cm: 7.1%)
  FEP survival 13.5% (∅ 8 cm: 10.2%)
  at 89% DEP acceptance



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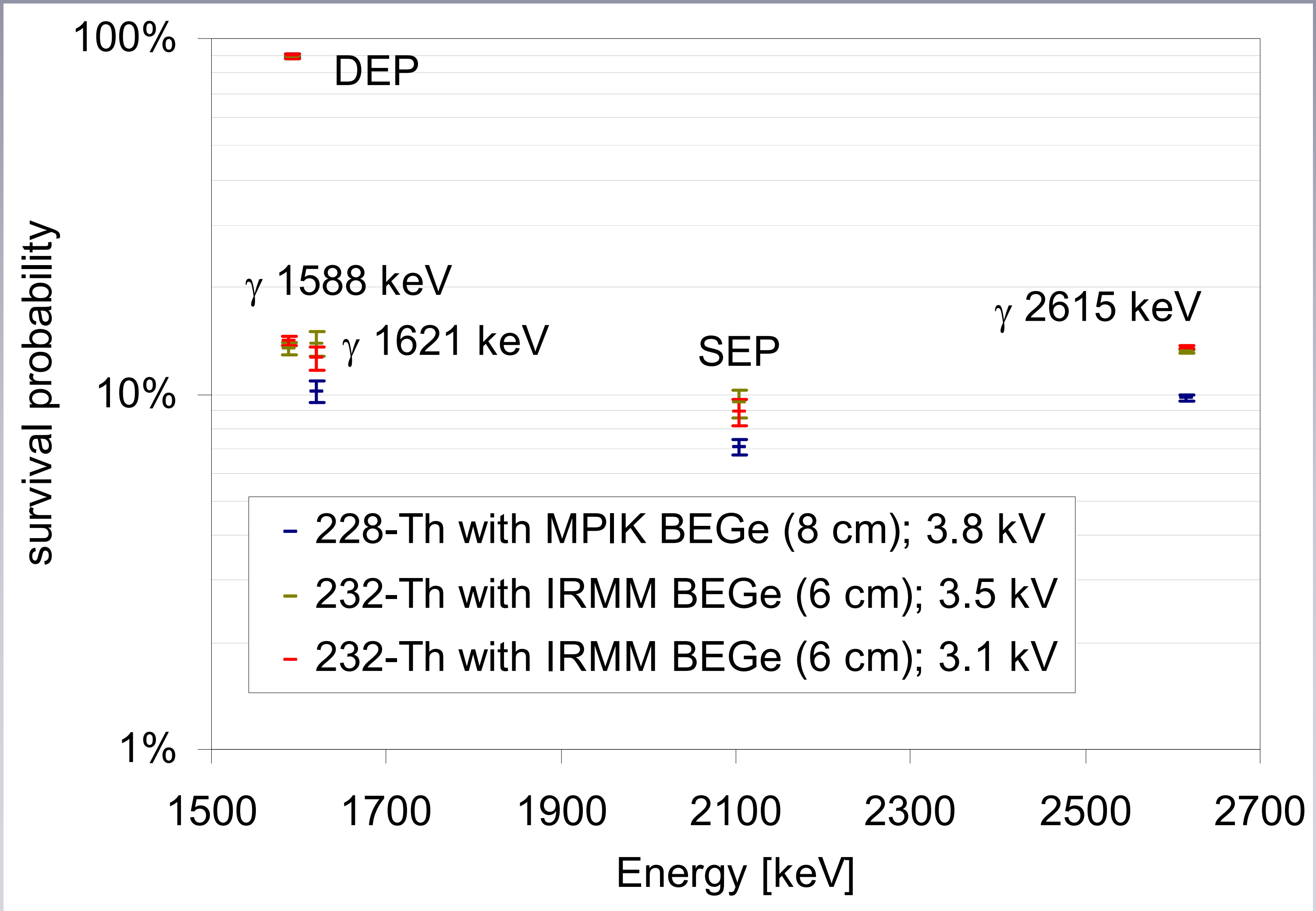


Summary and conclusions

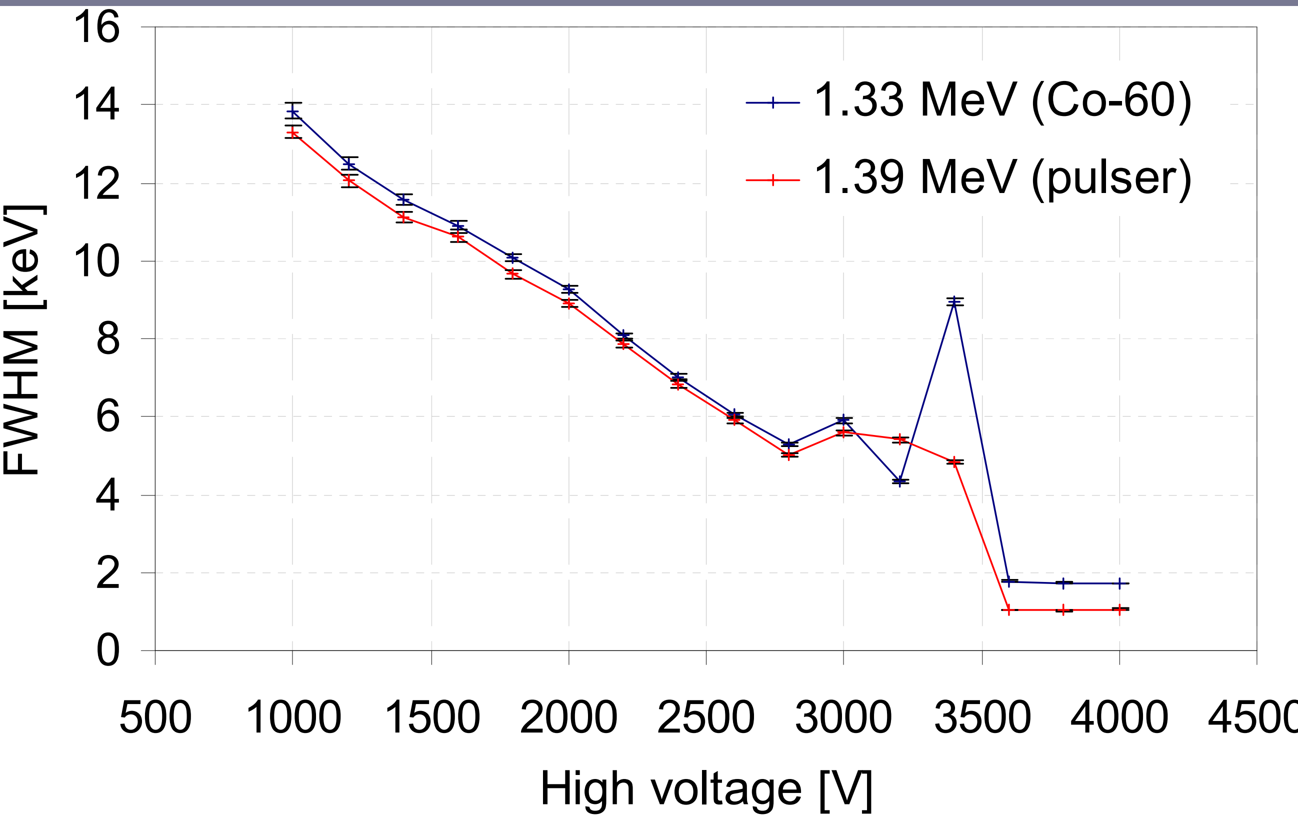
- PSD validated with SSE events of different topology (DEP vs. SCS), spatial distribution, and energy
- discovered < 3% loss of MSE rejection sensitivity near the read-out electrode (specific to our PSD method)
- no spatial dependence of SSE acceptance found
- no change of PSD sensitivity in dependence on HV (except for a slight growth of the MSE-insensitive volume)
- PSD performance in smaller crystals likely different only due to lower γ-ray absorption efficiency

Outlook

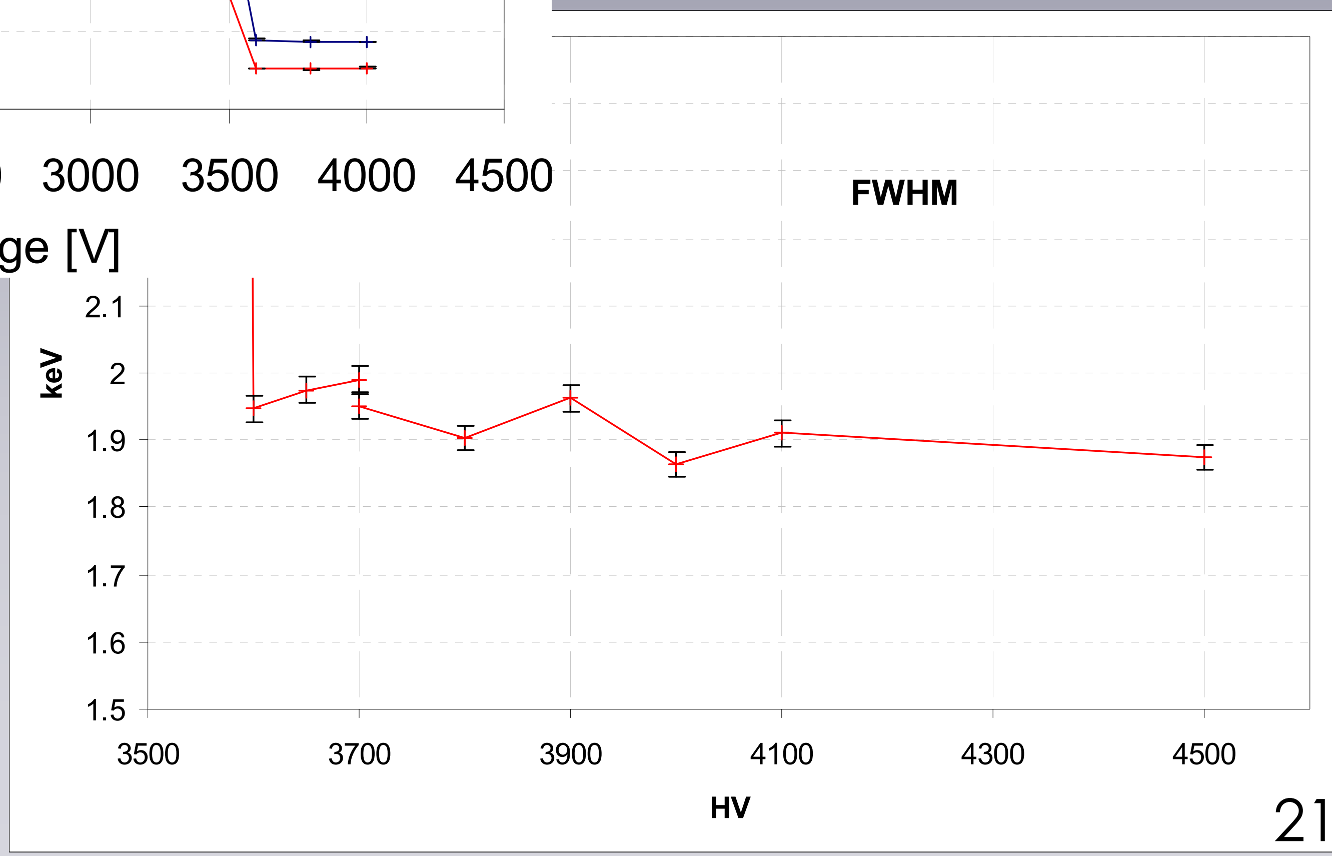
- tests of FE electronics for bare BEGe operation in LAr
- optimisation of the PSD procedure and coordination with LNGS BEGe team in advance of acceptance testing of new BEGe's from ^{dep}Ge
- coordination with Zürich group (Francis) on definition of the Phase 2 calibration source from the point of view of PSD calibration requirements

Backup slides

HV scan

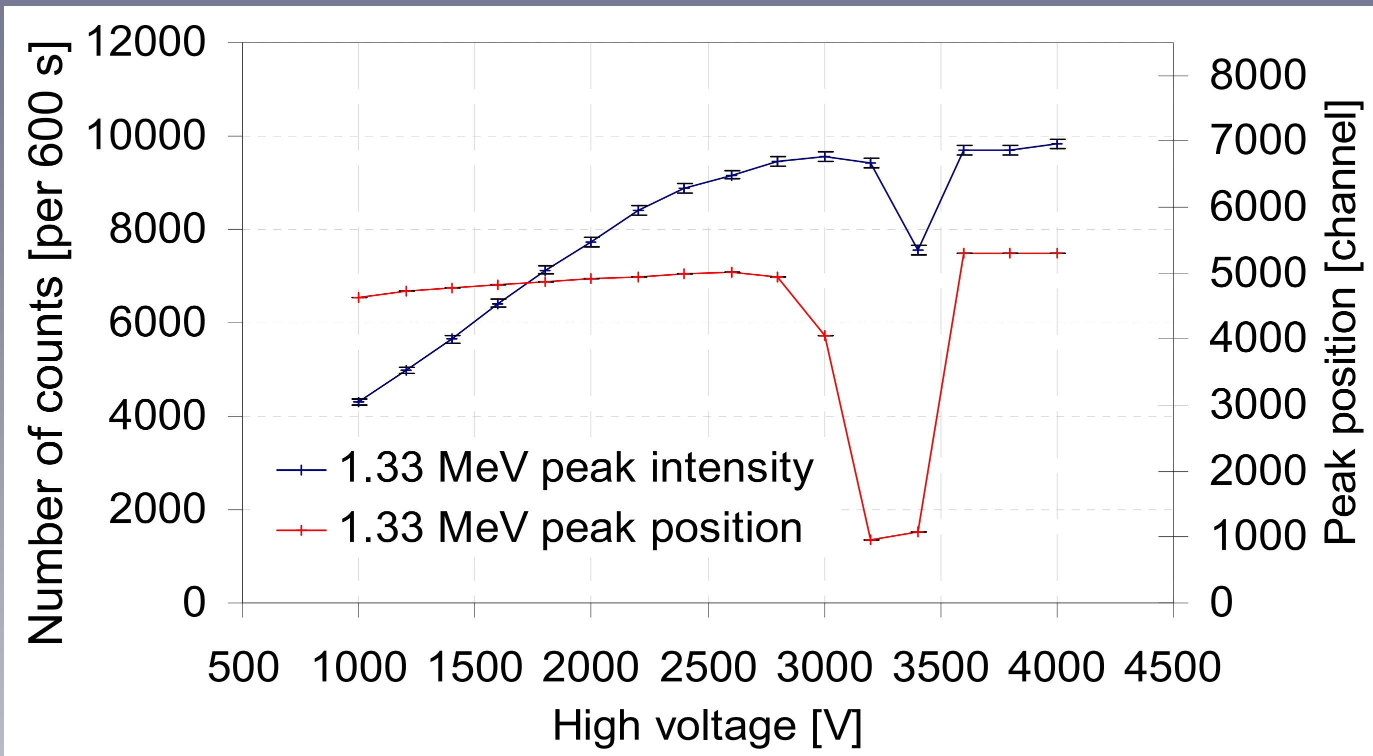


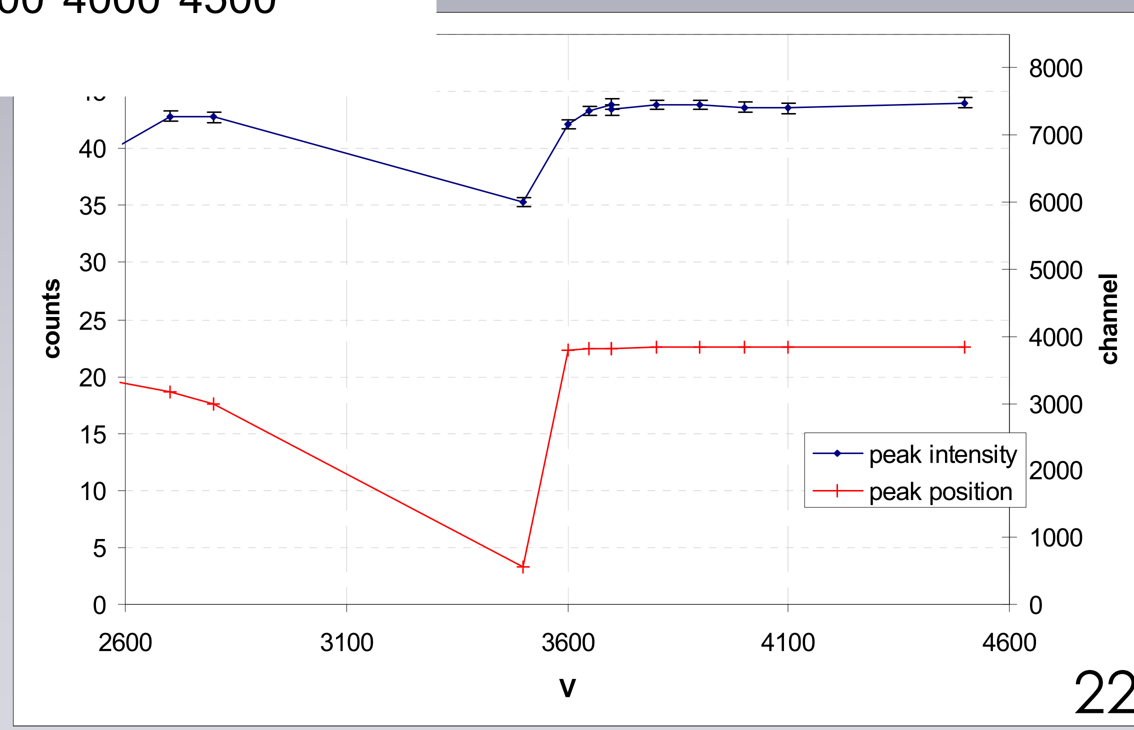
1.33 MeV (Co-60)
1.39 MeV (pulser)
FWHM [keV]
High voltage [V]
0
2
4
6
8
10
12
14
16
500
1000
1500
2000
2500
3000
3500
4000
4500



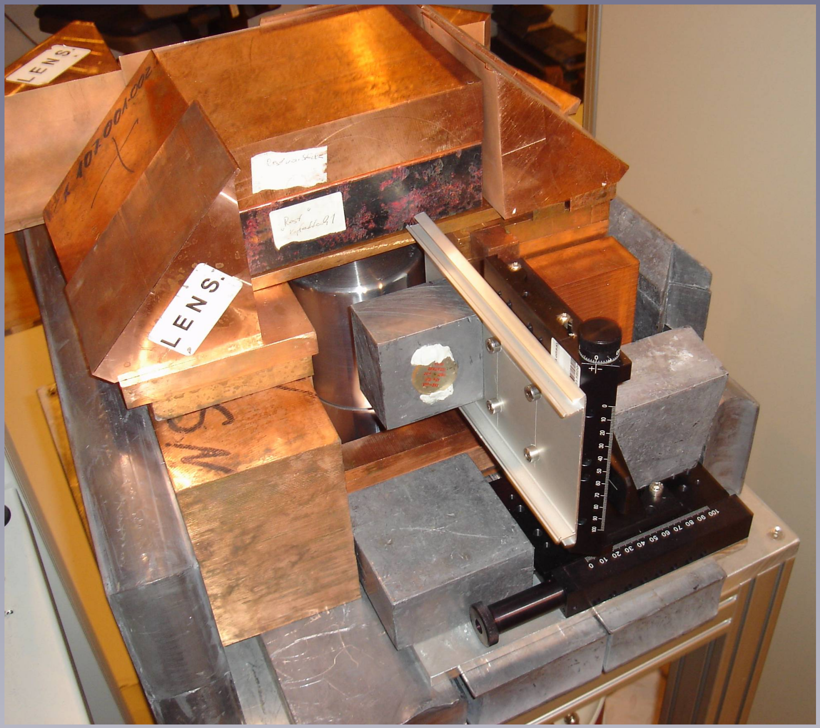
FWHM
keV
HV
1.5
1.6
1.7
1.8
1.9
2
2.1
3500
3700
3900
4100
4300
4500

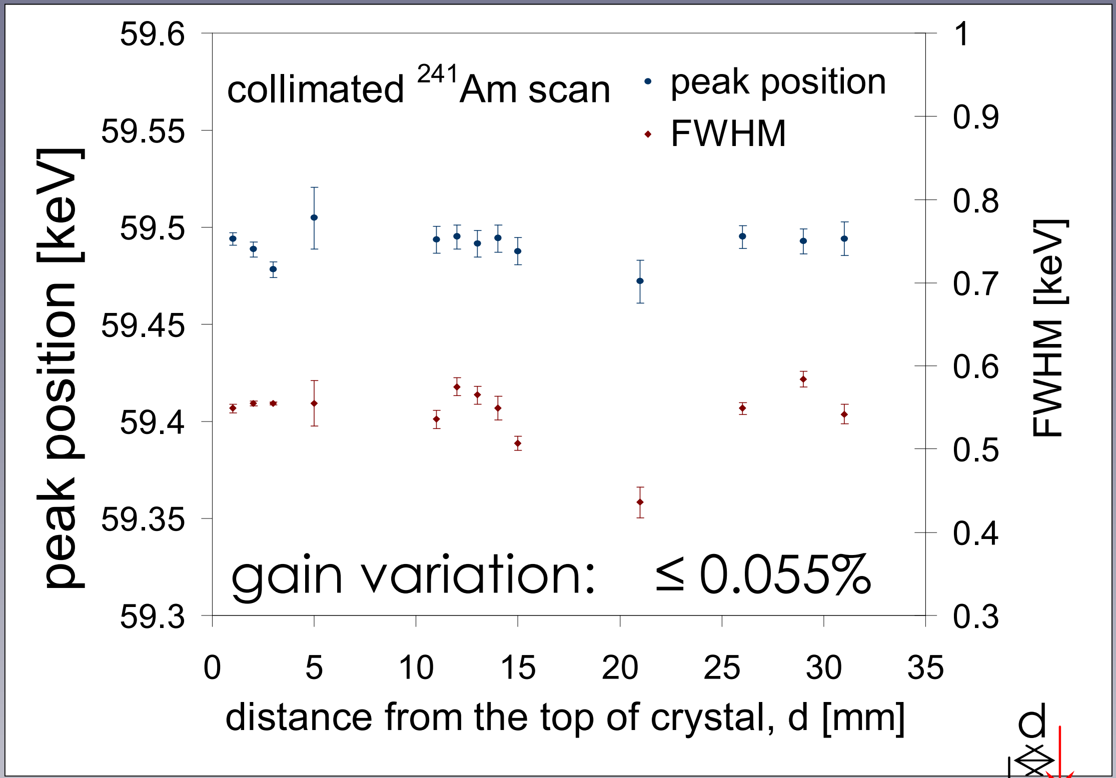
HV scan

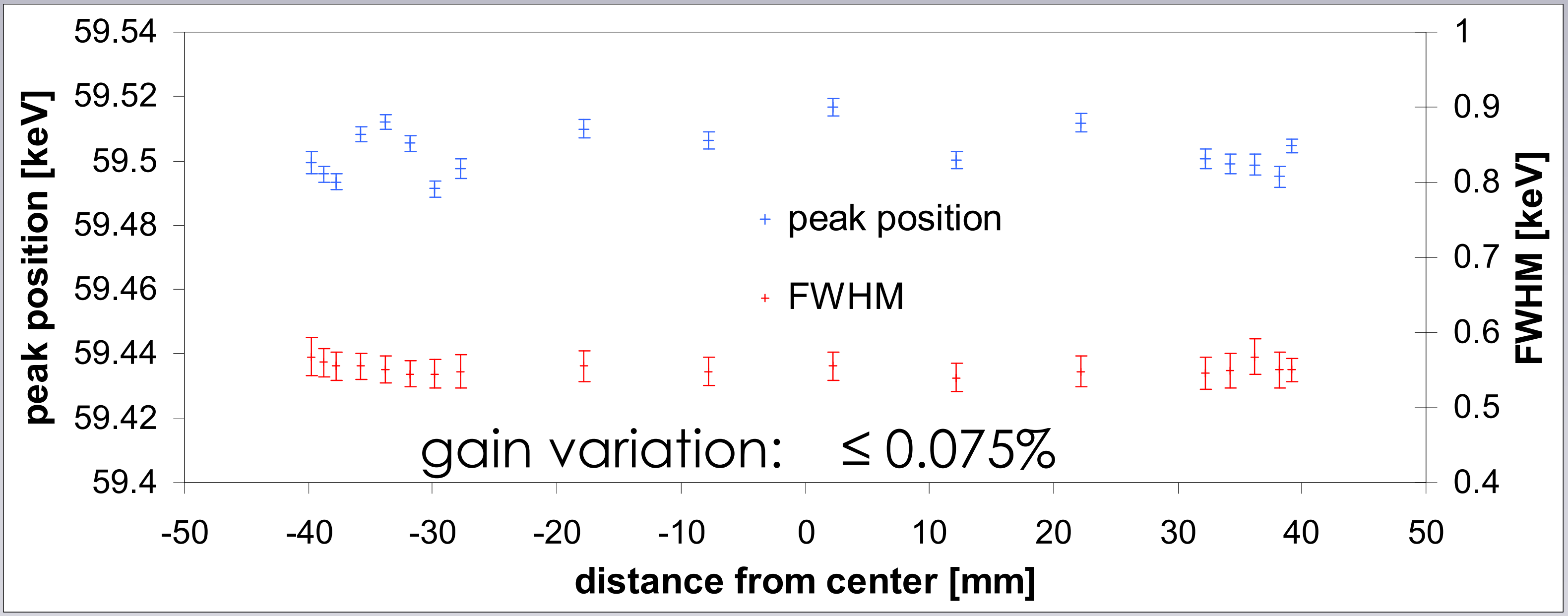

Number of counts [per 600 s]
12000
10000
8000
6000
4000
2000
0
Peak position [channel]
8000
7000
6000
5000
4000
3000
2000
1000
0
500 1000 1500 2000 2500 3000 3500 4000 4500
High voltage [V]
1.33 MeV peak intensity
1.33 MeV peak position

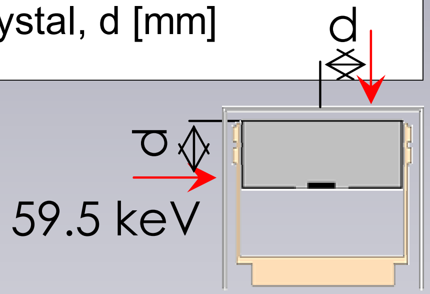

counts
40
35
30
25
20
15
10
5
0
channel
8000
7000
6000
5000
4000
3000
2000
1000
0
2600 3100 3600 4100 4600
V
peak intensity
peak position

Charge collection characterisation



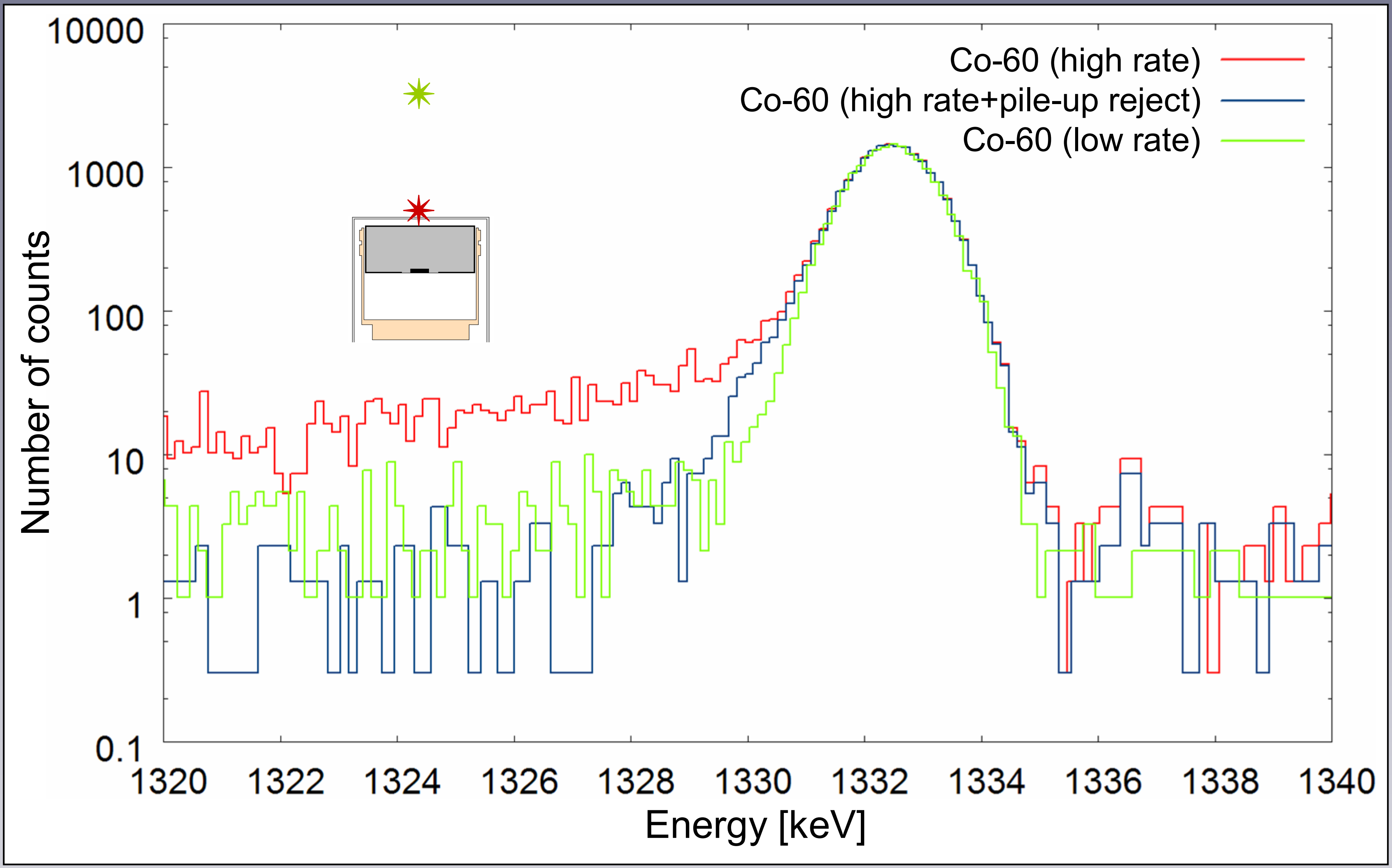




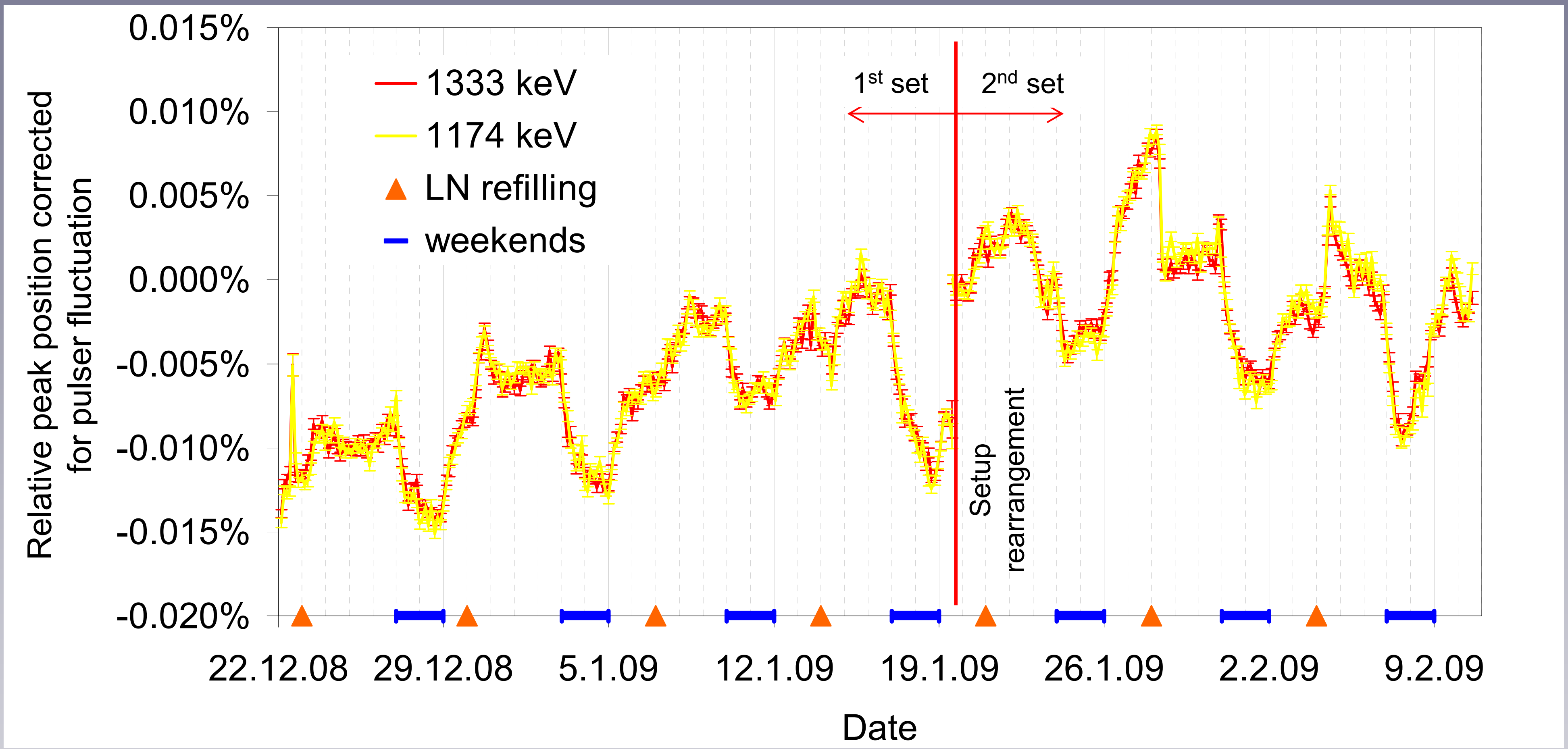


- active mass: **836 g** (95 % of total mass)
- dead layer: **0.43 mm**

Charge collection losses: peak tails

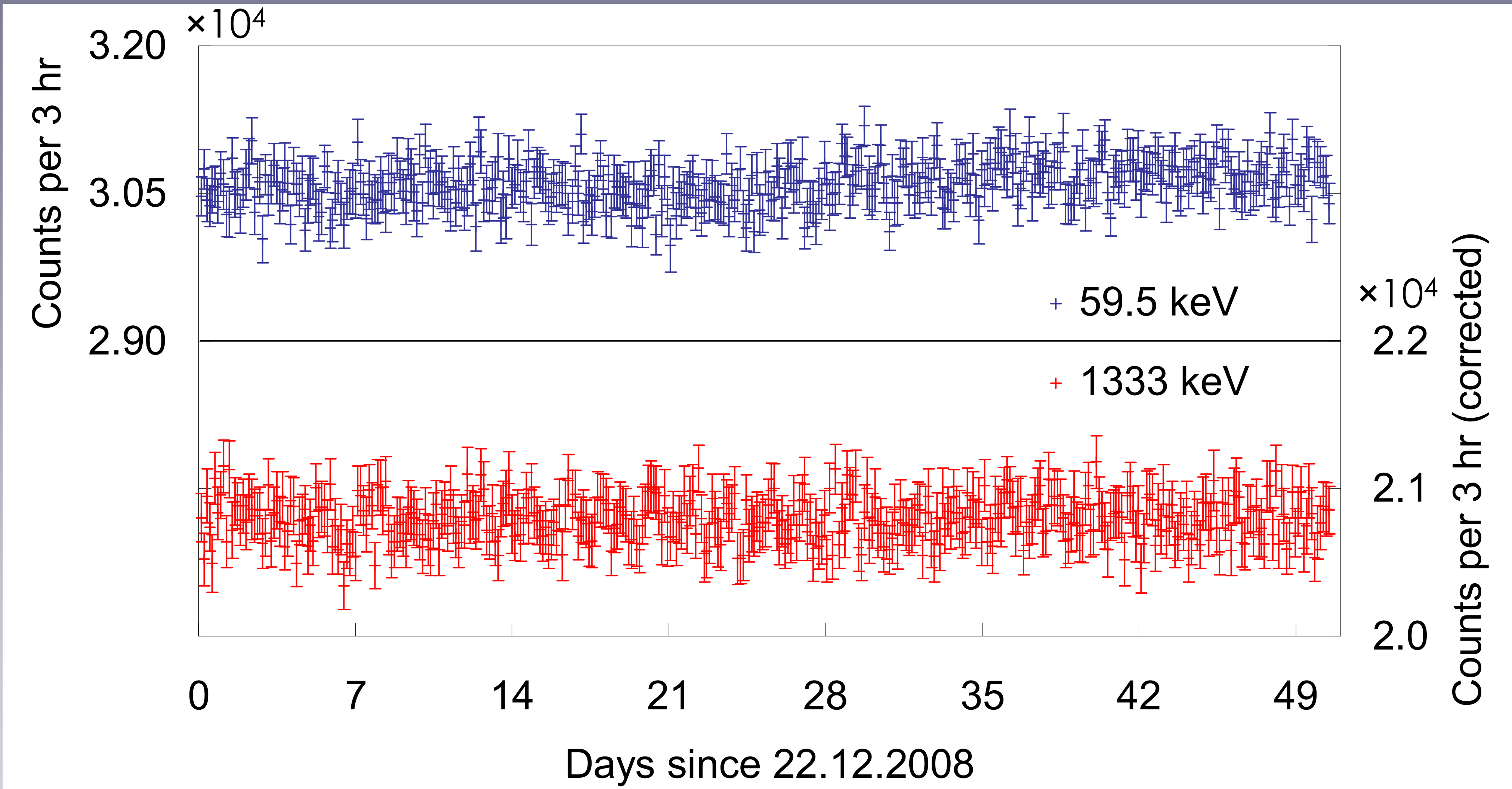


Charge collection stability

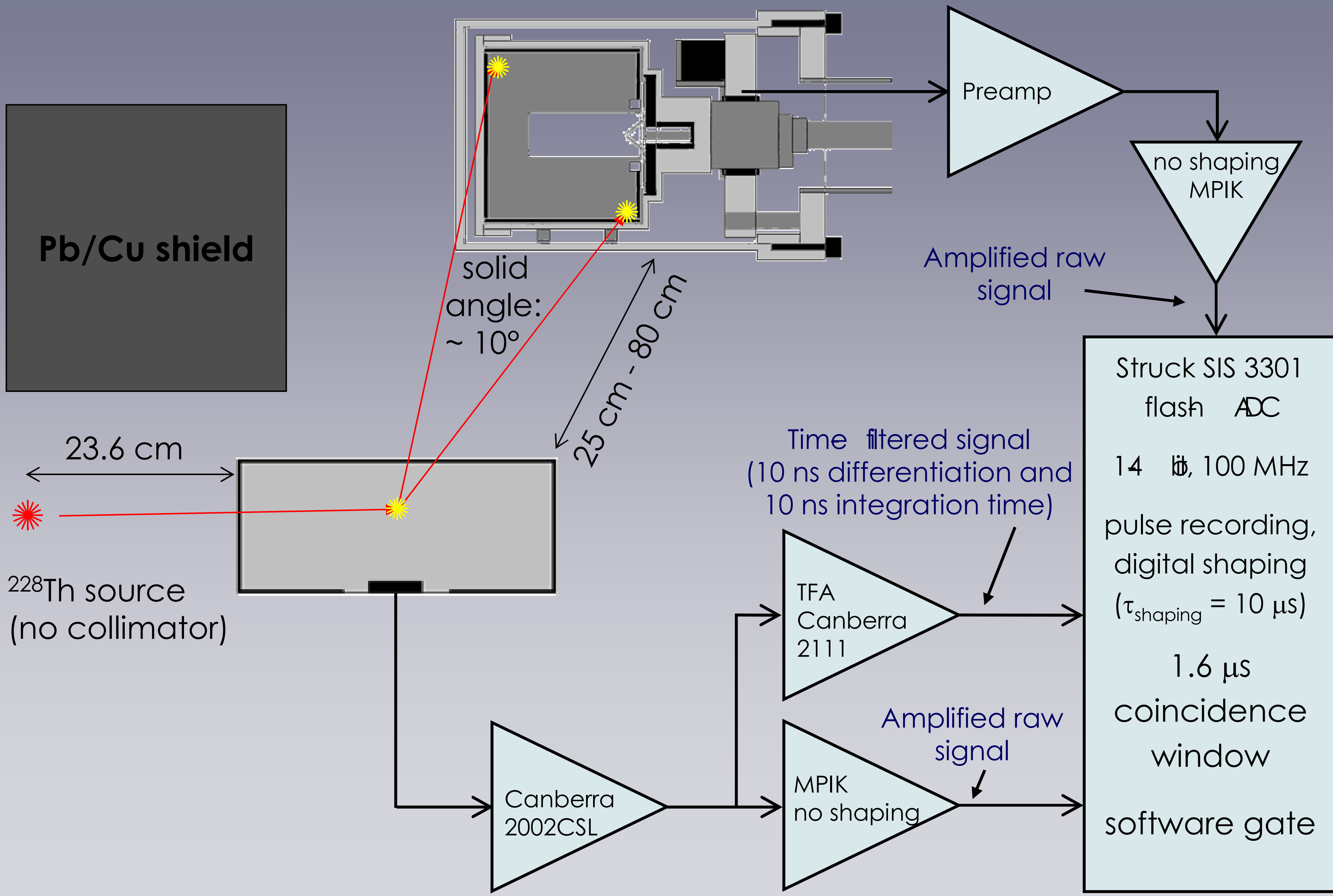


Maximal variation: ≤ 0.015% ≈ 0.2 keV @ 1332.5 keV

Charge collection stability: count rate



Coincident recording



HV dependence of PSD performance

- current signal amplitude grows with HV => weighing field shape changes
- (the width of the SSE band seems to slightly increase with HV)