Background suppression by Pulse Shape Analysis with BEGe detectors

and their other features

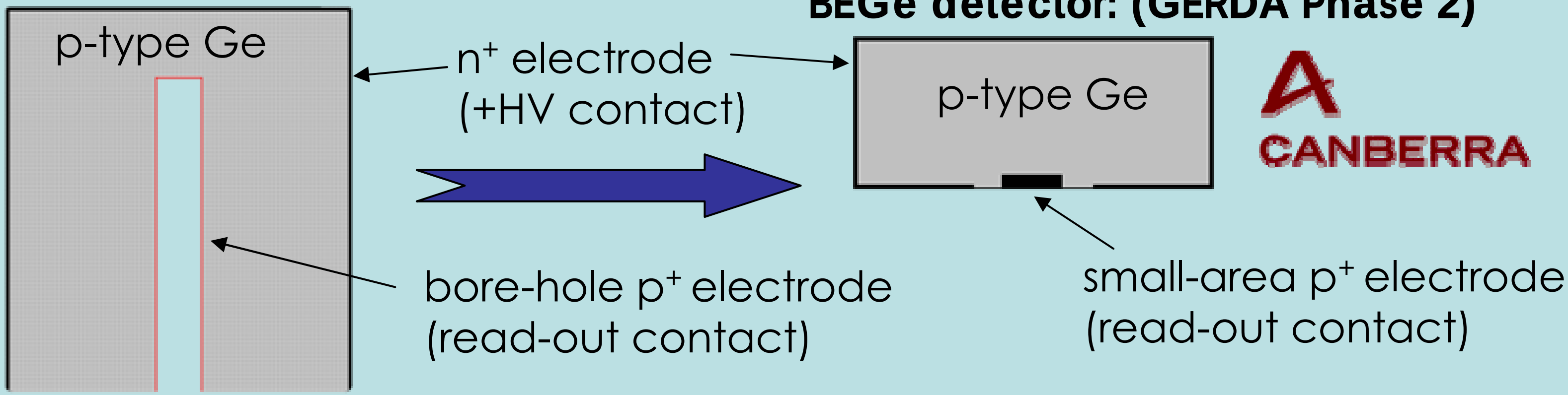
Dušan Budjáš
Max-Planck-Institut für Kernphysik, Heidelberg
(now at Institut E15, Technische Universität München)

on behalf of the BEGe group of GERDA
(INFN LNGS, INFN Milano Bicocca, INFN&University Padova, Universität Tübingen, Universität Zürich, Universität Dresden , INR Moscow)

Broad-Energy Germanium detector

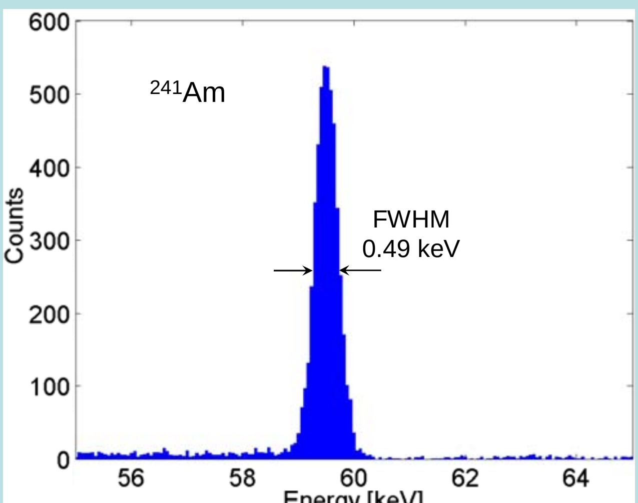
semi-coaxial Ge detector: (GERDA Phase 1)

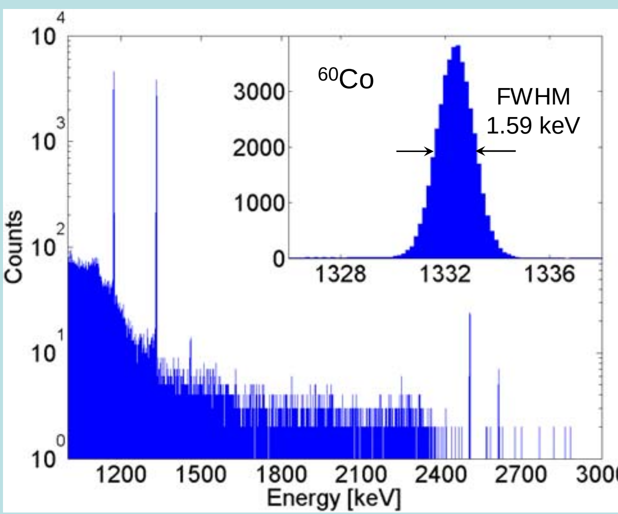
BEGe detector: (GERDA Phase 2)



small read-out electrode ⇒ low capacitance ⇒ low noise

BEGe: lower energy threshold (3 keV) and **better energy resolution**

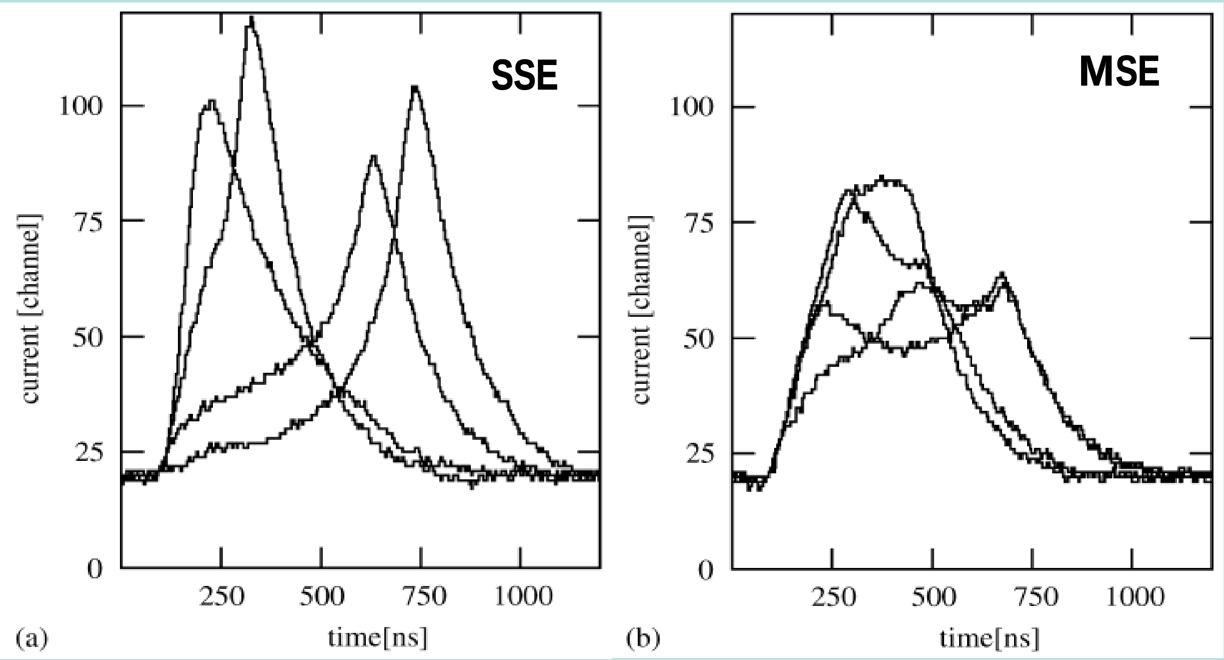




Multi-site event discrimination by pulse-shape analysis

1. semi-coaxial HPGe

Hellmig, Klapdor-Kleingrothaus,
NIM A 455 (2000) 638-644

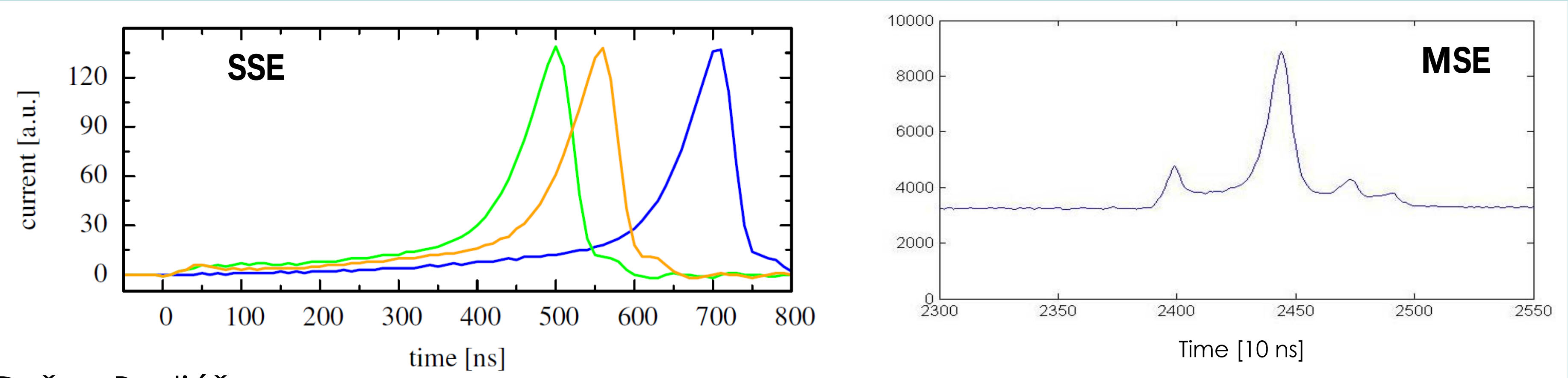


2. point-contact HPGe

P.S. Barbeau, J.I. Collar , O. Tench
JCAP 0709:009,2007

3. BEGe

D. Budjas et al., JINST 4:P10007,2009



Pulse shape discrimination with unsegmented detectors

Benefits of BEGe detectors:

- **simple, robust & powerful MSE discrimination** using a single read-out
- **reduced amount of contacts, cabling & front-end electronics**
  ⇒ avoids additional background sources
  ⇒ reduced complexity of electronic chain
- **p-type detector with thick surface dead-layer** (0.4 mm – 1 mm)
  ⇒ more robust for naked-detector handling
  ⇒ improved protection against surface beta-induced backgrounds
- **low energy threshold, superior energy resolution**
- **commercially produced**
  ⇒ high manufacturer expertise
  ⇒ cheaper than custom-designed detectors

Drawbacks:

- difficult to achieve detector mass >1 kg (0.9 kg demonstrated)
- PSD based on signal time-structure ⇒ only 1D hit-separation sensitivity

Pulse shape discrimination with BEGe detectors

1. how does it work?
2. why does it work?
3. how well does it work?
4. will it work for $0\nu\beta\beta$?
5. does it work in GERDA?
6. how robust is it?

Pulse shape discrimination with BEGe detectors

1. **how does it work?**
2. why does it work?
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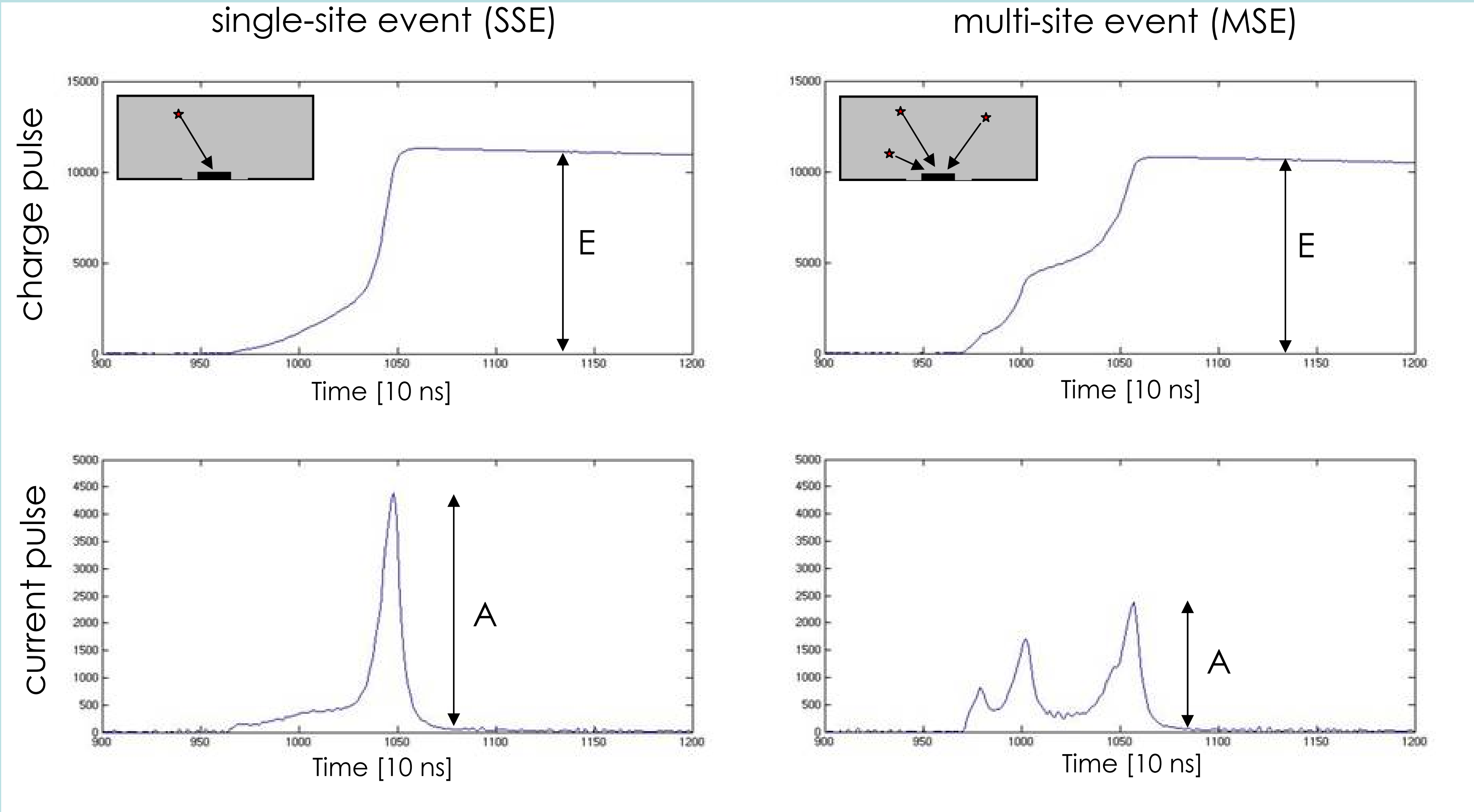
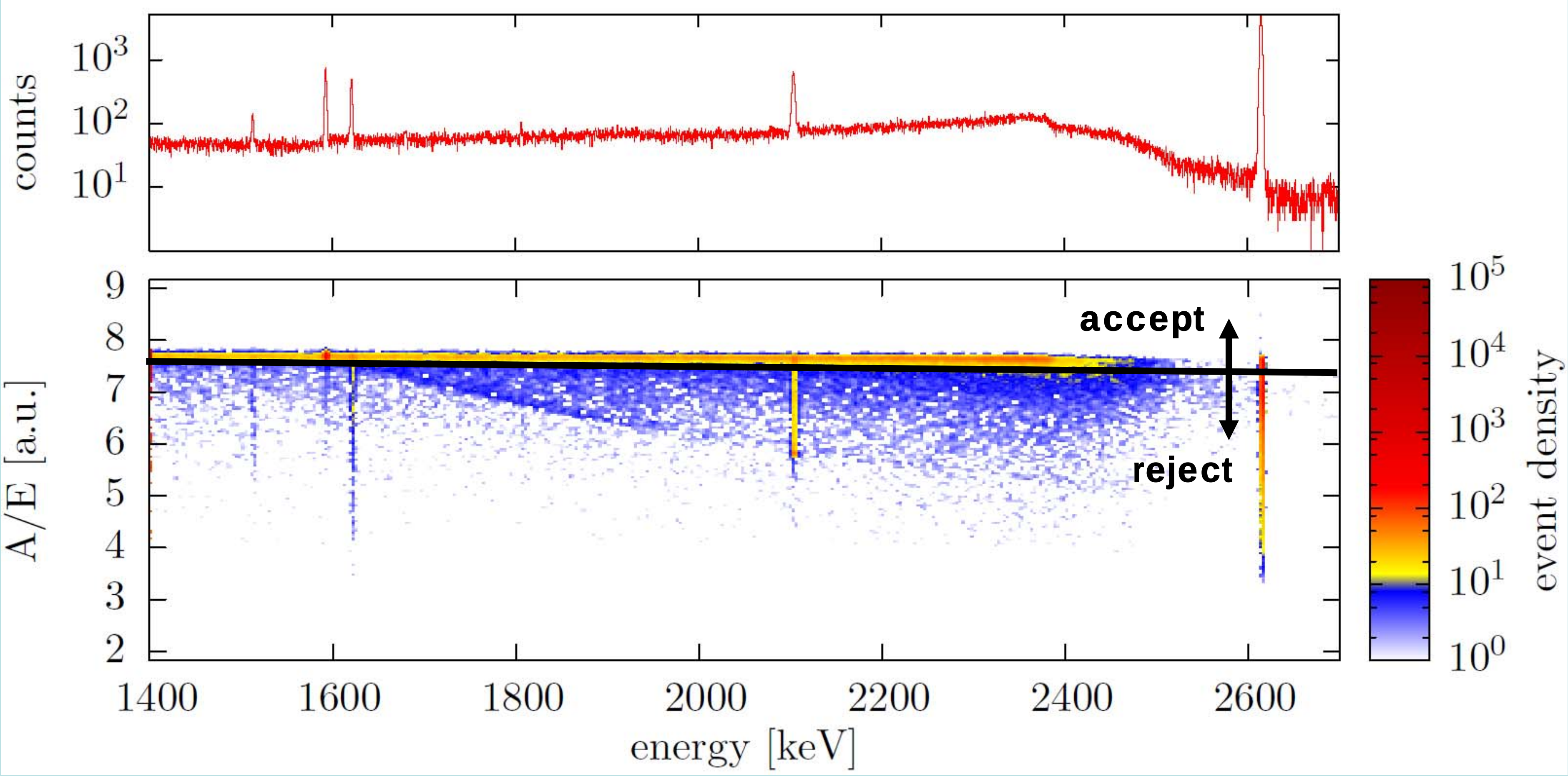
BEGe PSD: How does it work



A / E $\Rightarrow$ discrimination parameter

BEGe PSD: How does it work

^{228}Th measurement:



M. Heisel, Dissertation, University of Heidelberg (2011)

Pulse shape discrimination with BEGe detectors

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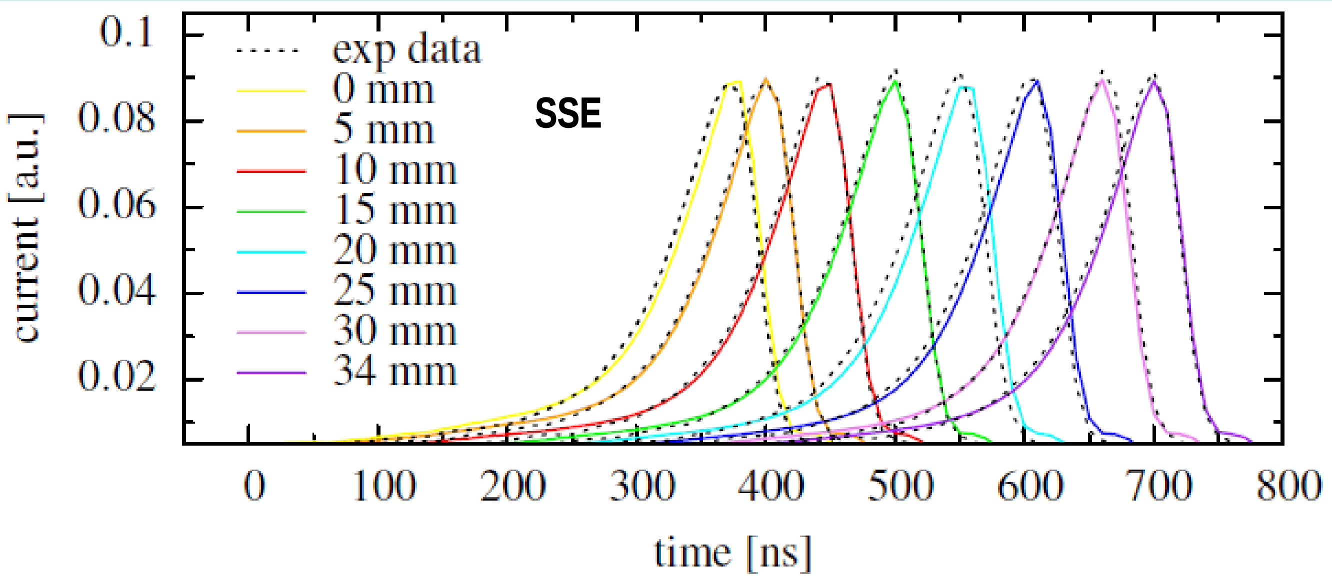
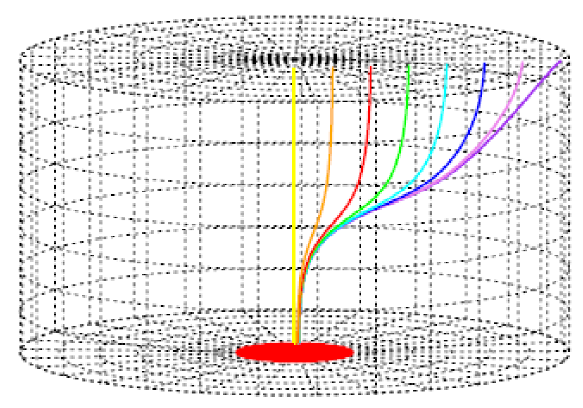
BEGe PSD: Why does it work





M. Agostini et al., JINST 6:P03005, 2011

- **signal shape independent of interaction position**
  ⇒ ~95% volumetric efficiency of A/E position independence
- **peak in current signal is narrow**
  ⇒ hit separation sensitivity: <10 ns ⇒ <1.2 mm (1D) *
- **current amplitude can be measured accurately**
  ⇒ ~0.6% A/E resolution ⇒ ~15 keV secondary hit sensitivity @ 2MeV

* using $12 \cdot 10^{-6}$ cm/s hole drift velocity [Bruyneel et al., NIM A 569 (2006) 764]

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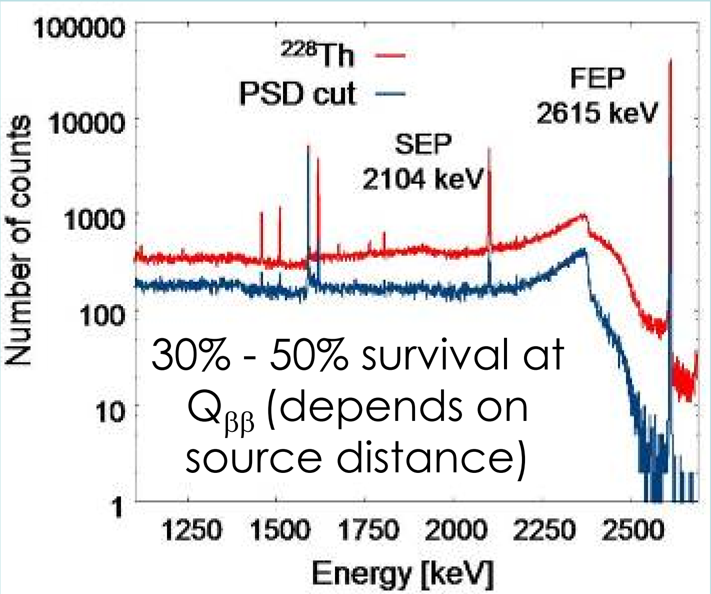
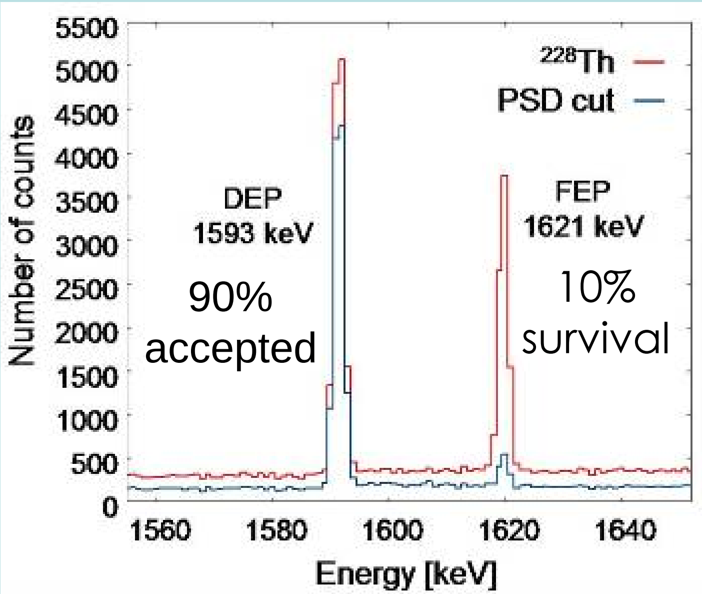
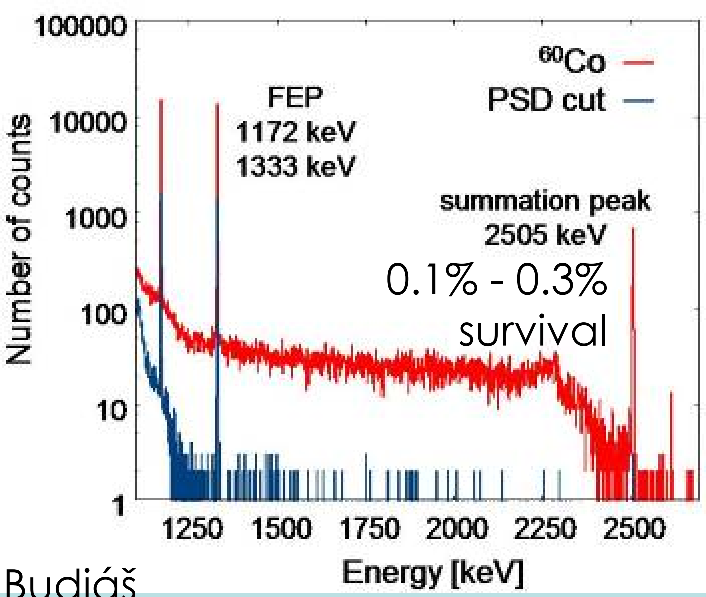
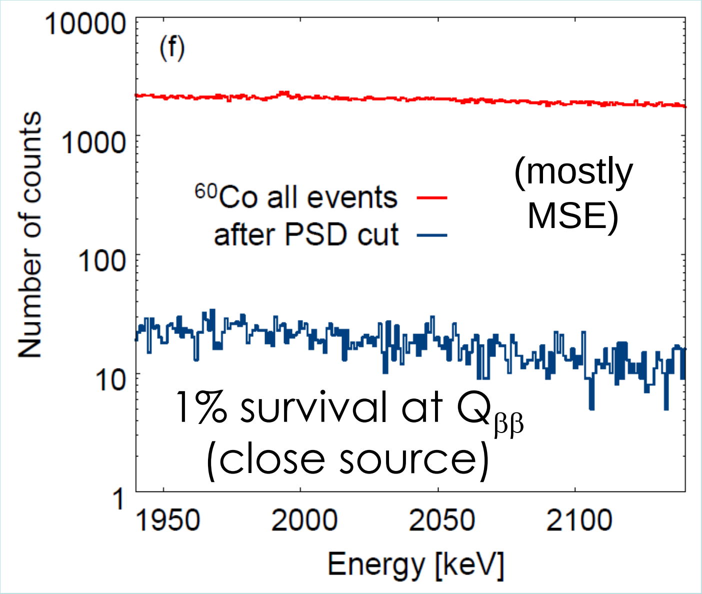
BEGe PSD performance





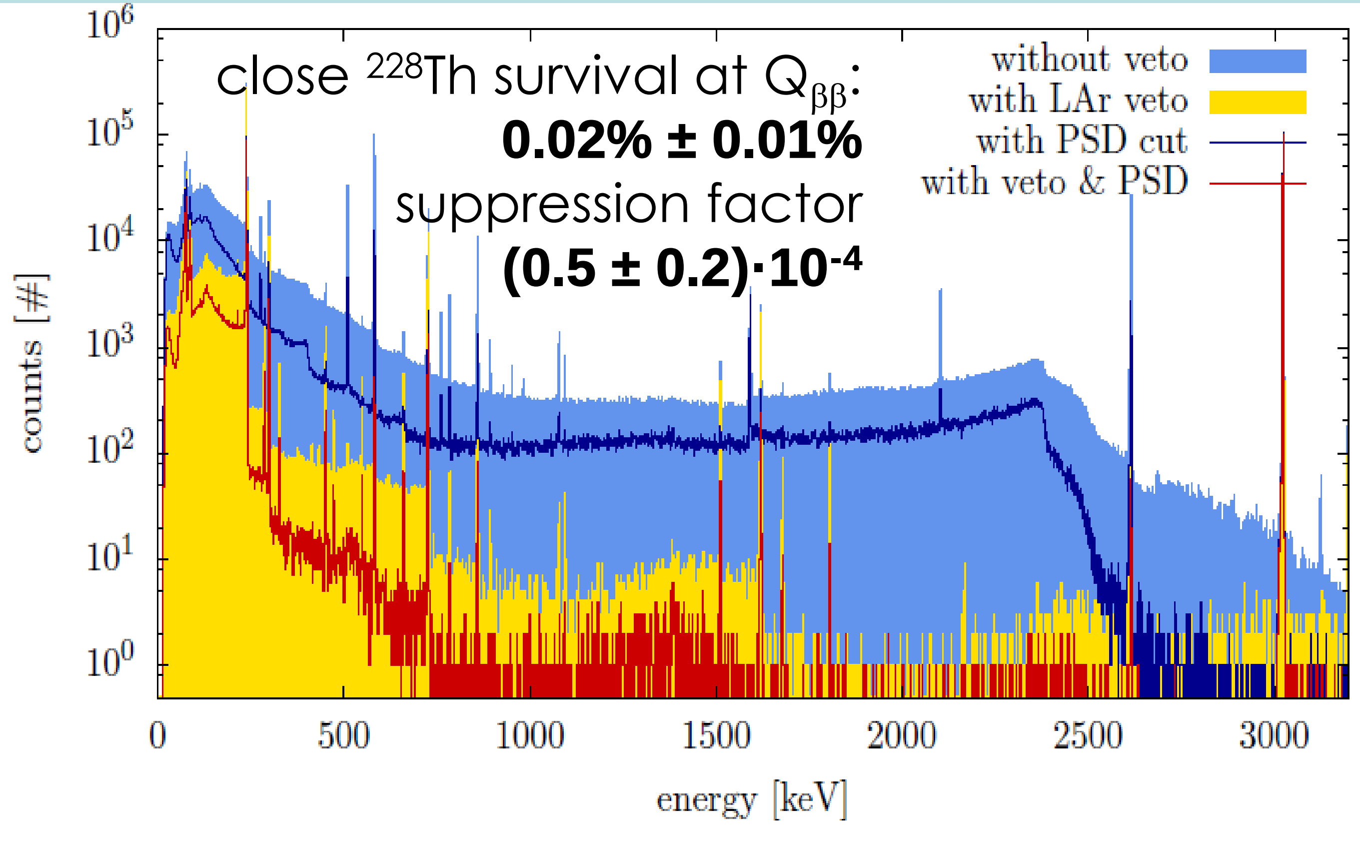


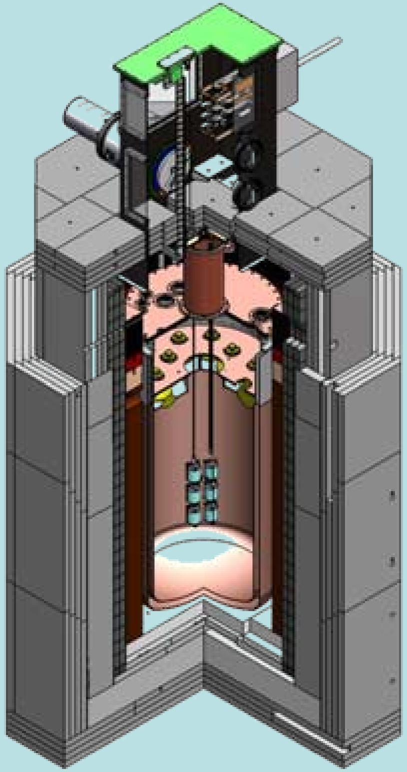


D. Budjas et al., JINST 4:P10007,2009
M. Agostini et al., JINST 6:P03005, 2011

BEGe detector in LArGe

Low background GERDA-LArGe test facility @ LNGS:
Detection of coincident liquid argon scintillation light to discriminate background





Other sources:	^{60}Co	0.03% ± 0.02%
	^{226}Ra	2.2% ± 0.3%

M. Heisel, Dissertation, University of Heidelberg (2011)

Pulse shape discrimination with BEGe detectors

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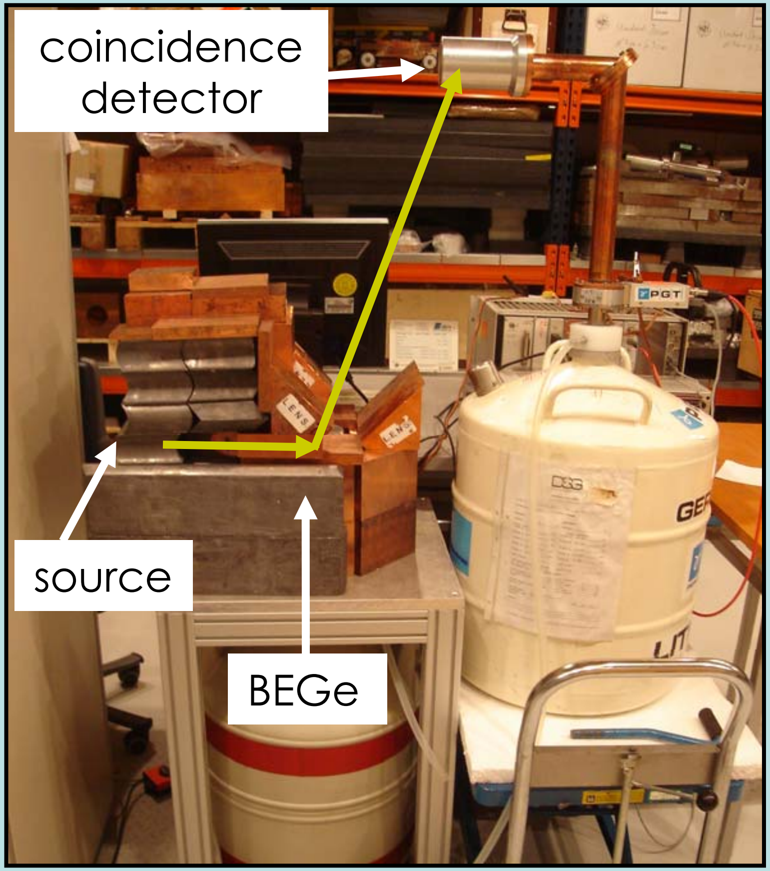
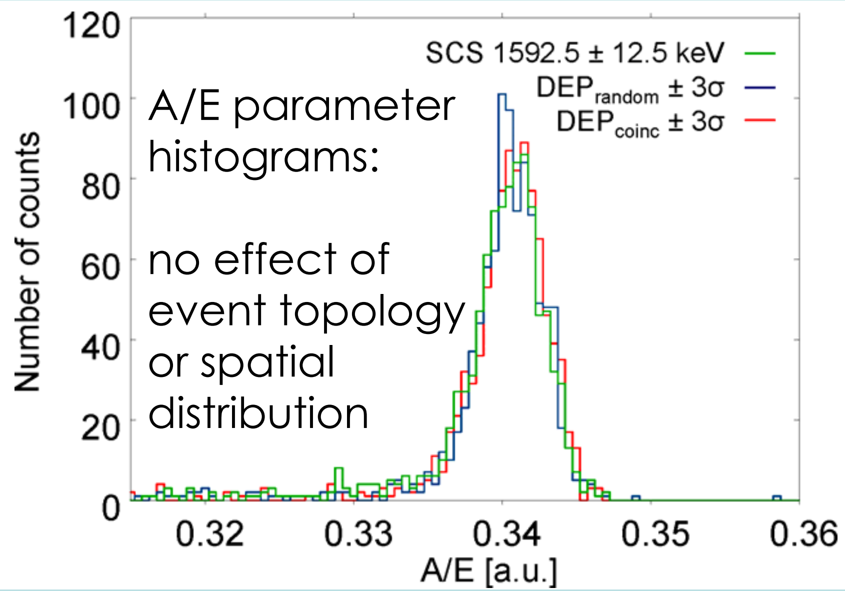
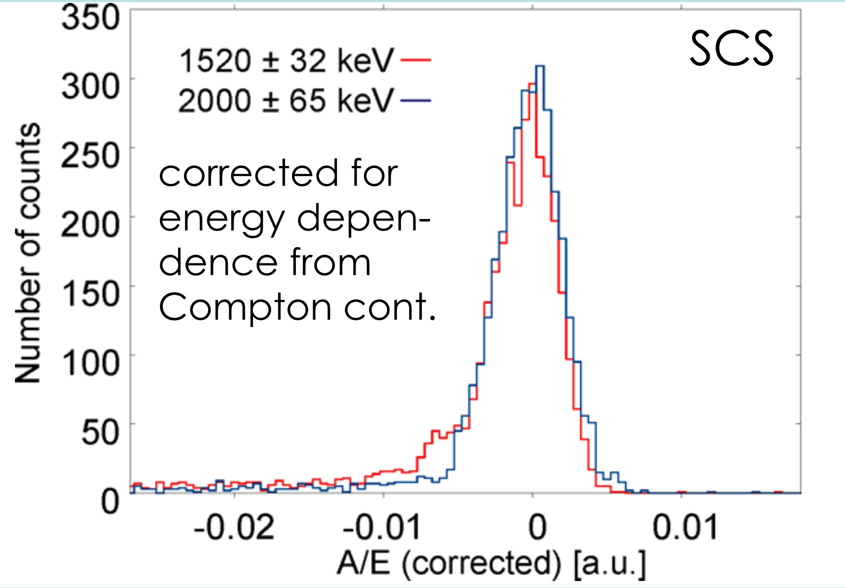
PSD validation via coincident single-Compton scattering







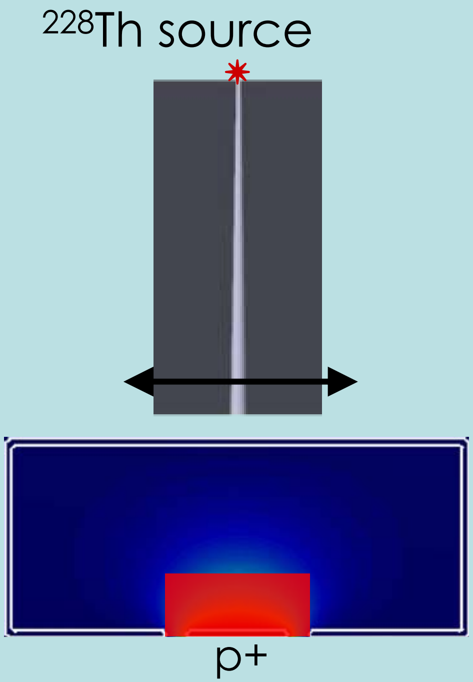
⇒ double-escape peak (DEP) is a good representation of ββ events

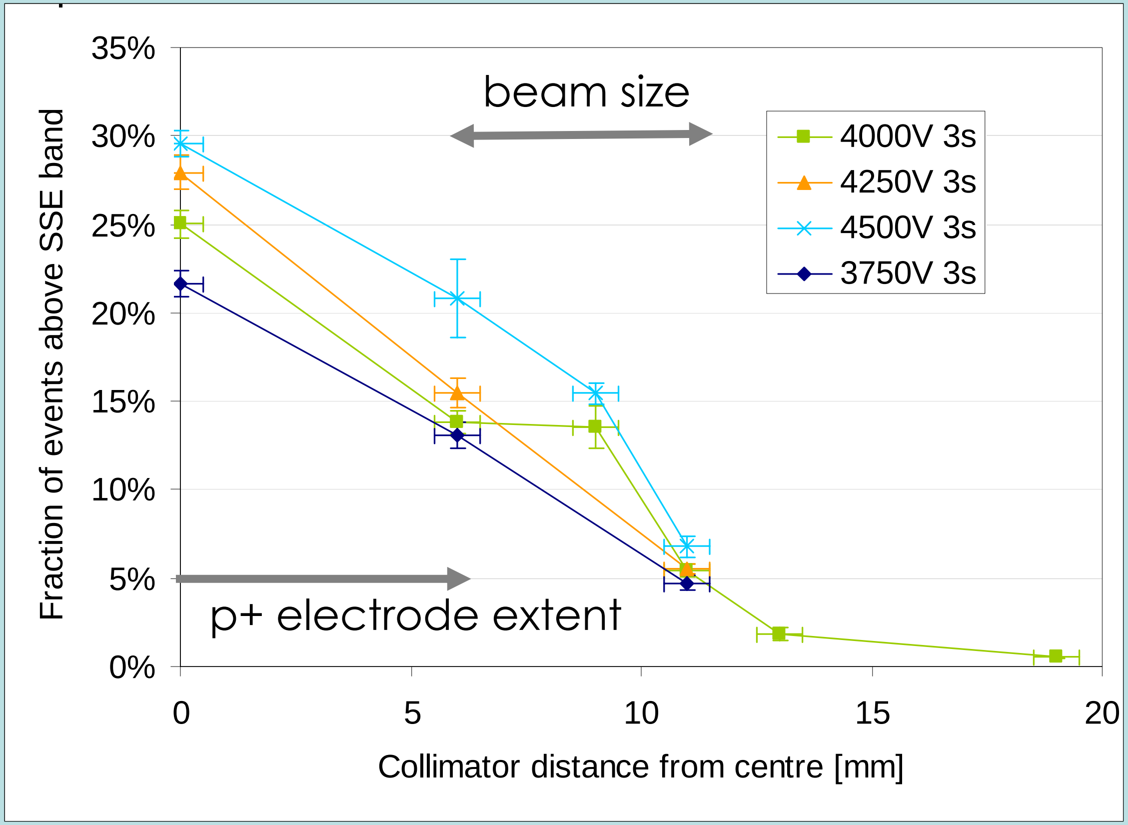
⇒ validated our PSD calibration using DEP and Compton continuum events

D. Budjas et al., JINST 4:P10007,2009

Spatial dependence of PSD: Experiment

Collimated beam measurements to study spatial dependence of PSD

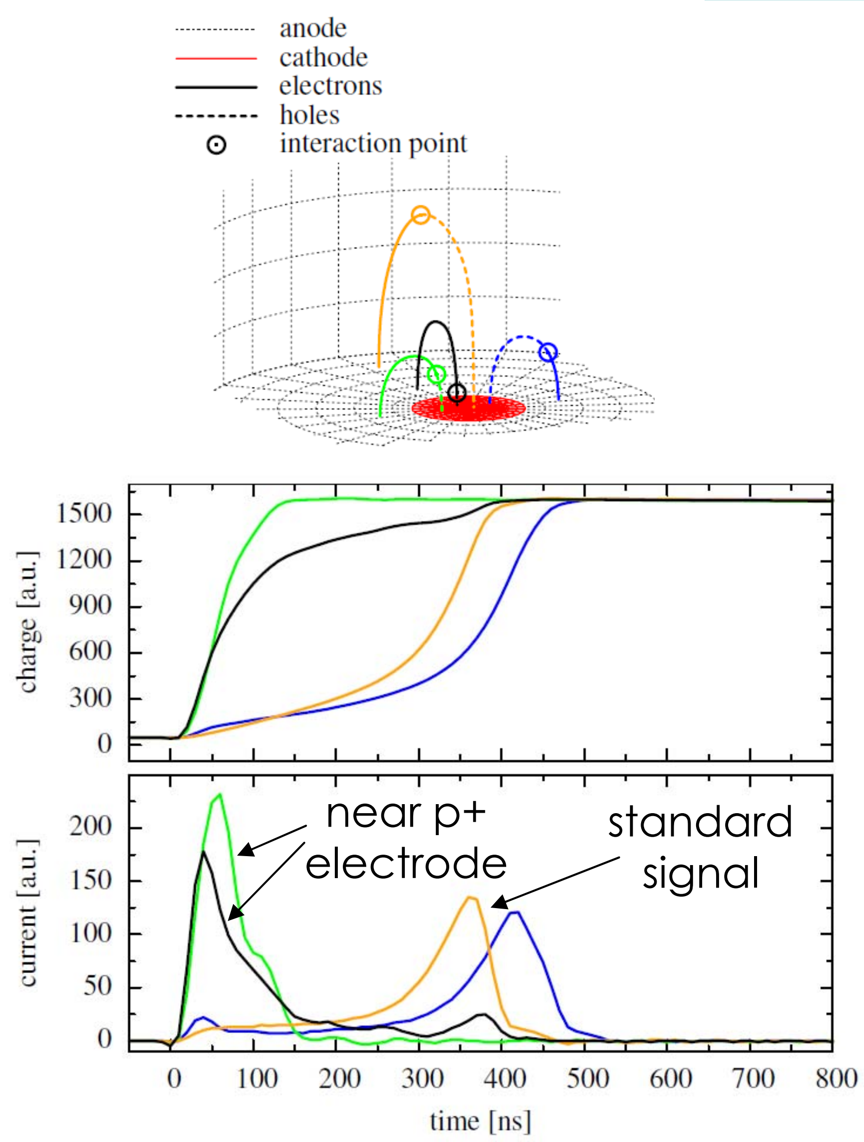




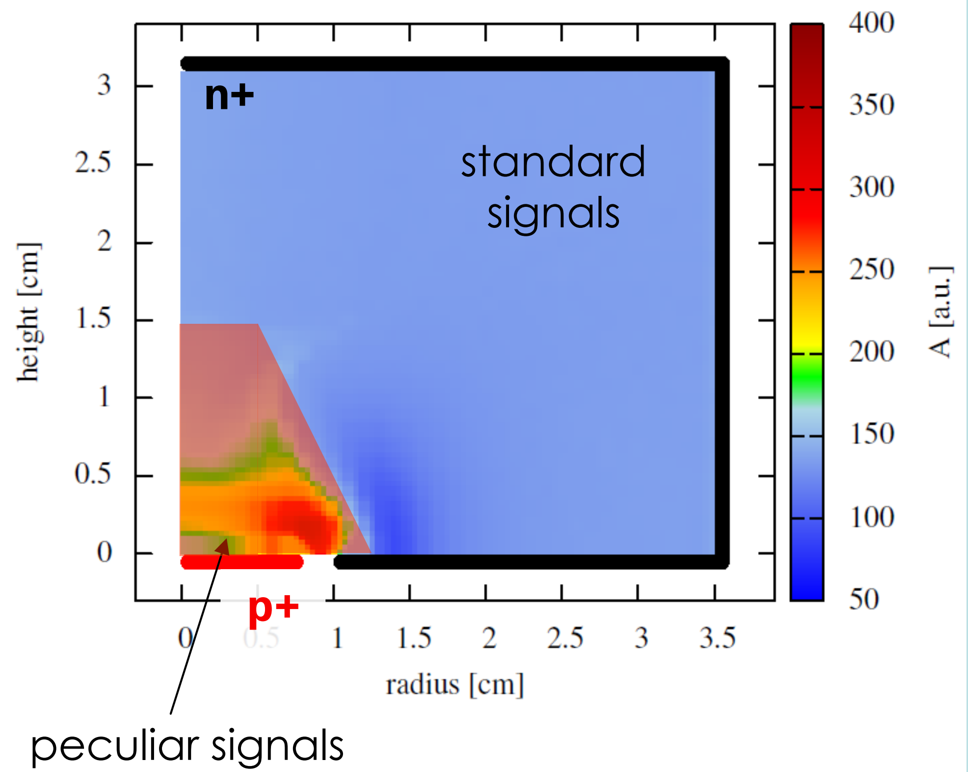
- ➢ peculiar pulses identified, occurring in ~3% of total detector volume
- ➢ in 97% of the volume PSD is uniform

D. Budjas et al., JINST 4:P10007,2009

Spatial dependence of PSD: Simulation



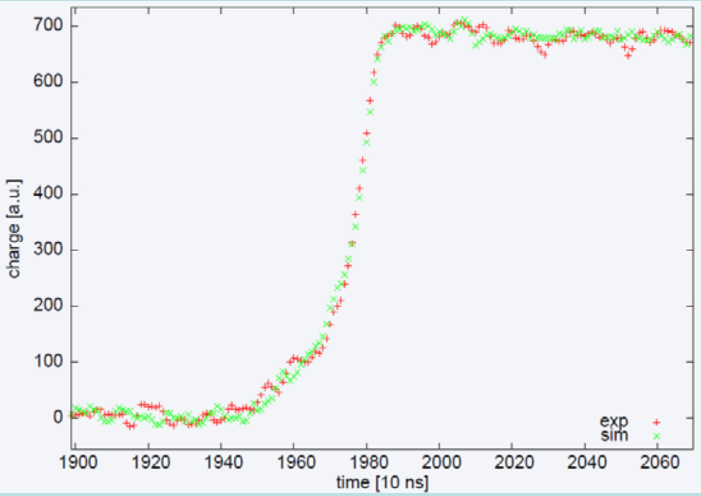
A/E vs. interaction position for SSE:
(detector half-section)

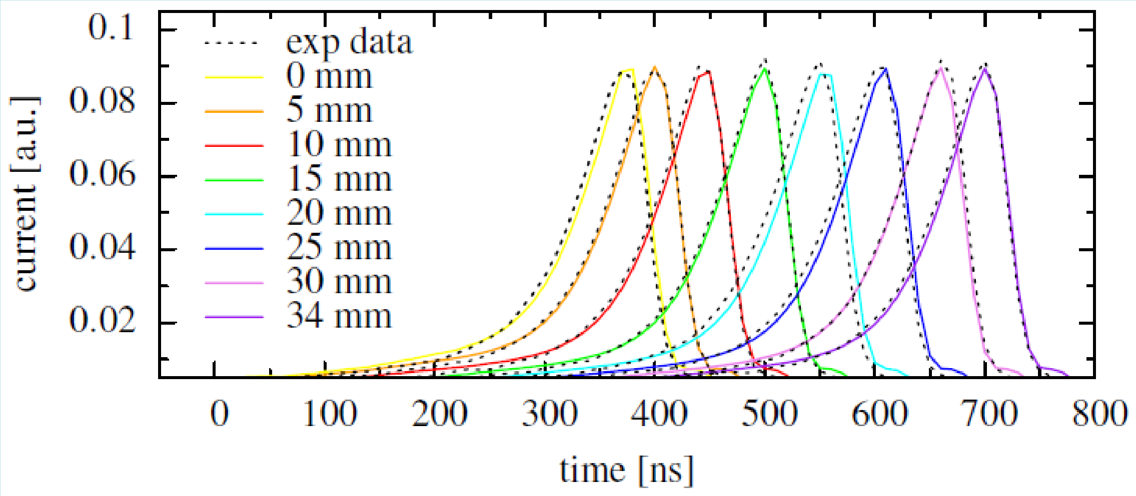


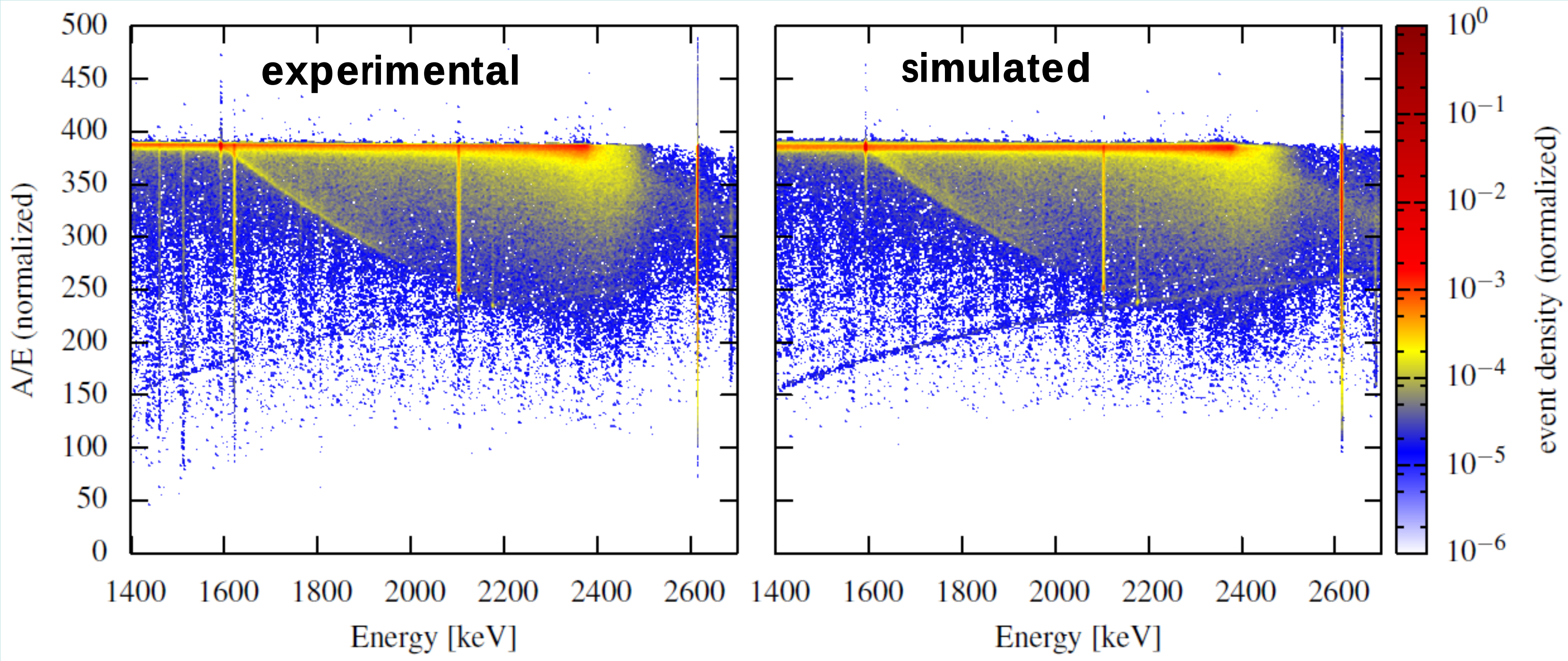
- 6% of total volume (different detector than on previous slide)

M. Agostini et al., JINST 6:P03005, 2011

Simulation: Validation

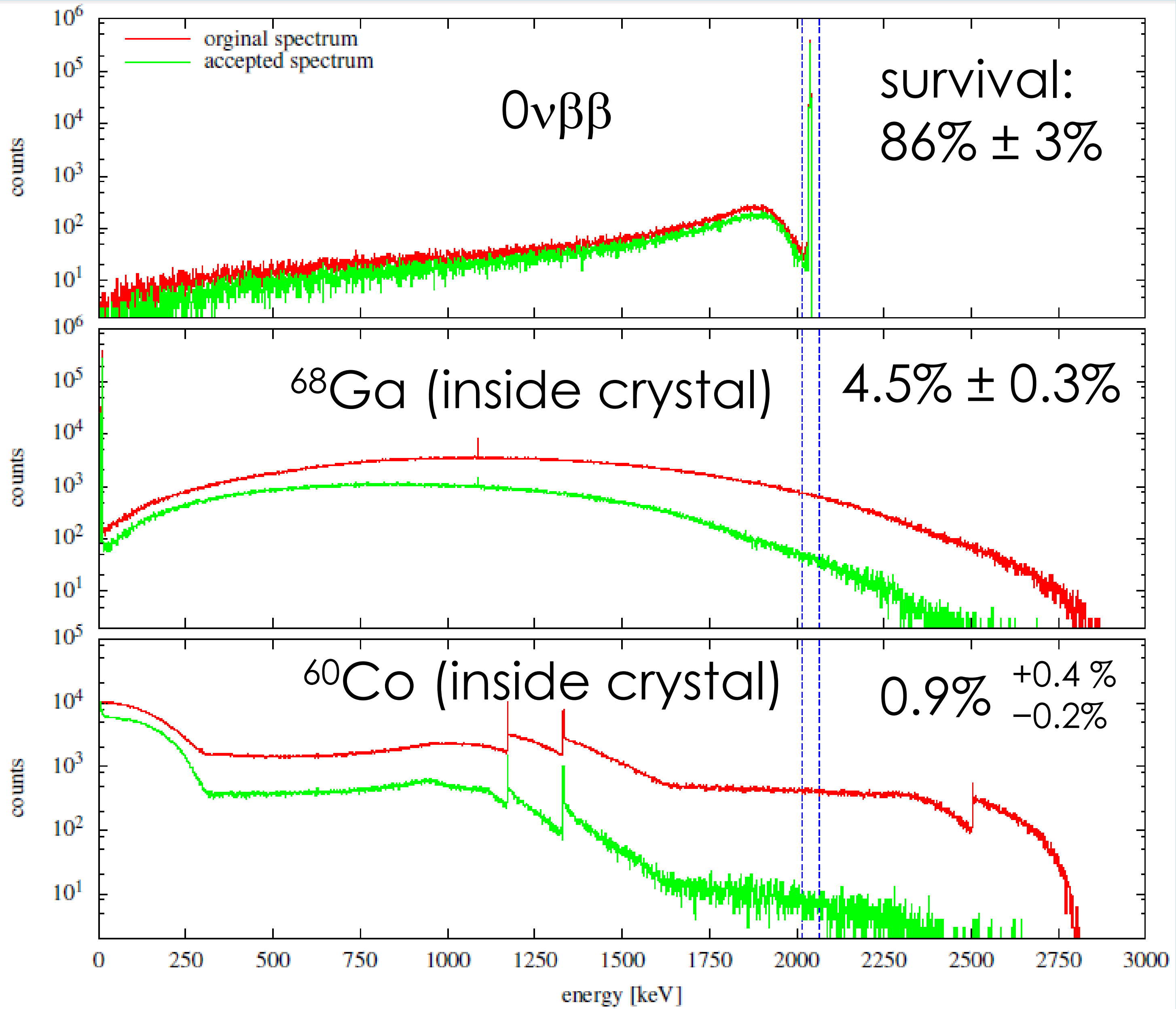






M. Agostini et al., JINST 6:P03005, 2011

Simulation: Predictions



M. Agostini et al., JINST 6:P03005, 2011

includes systematic error due to finite accuracy of the simulation

Pulse shape discrimination with BEGe detectors

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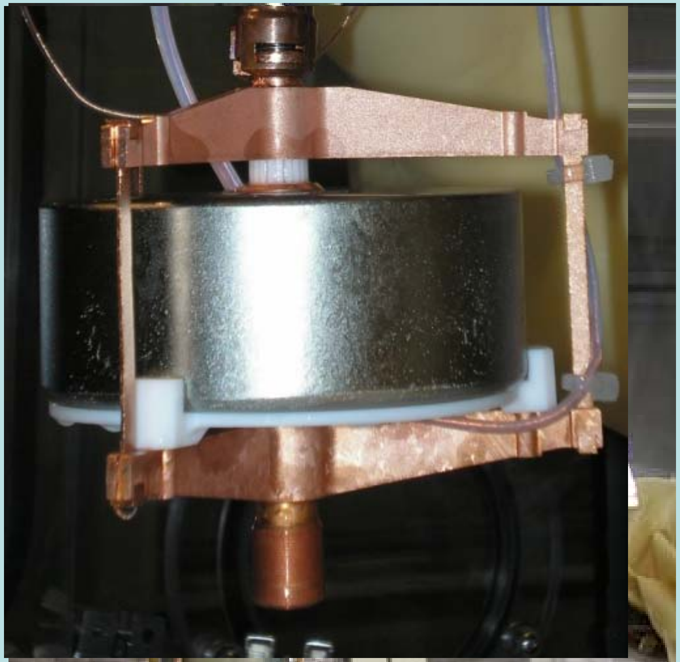
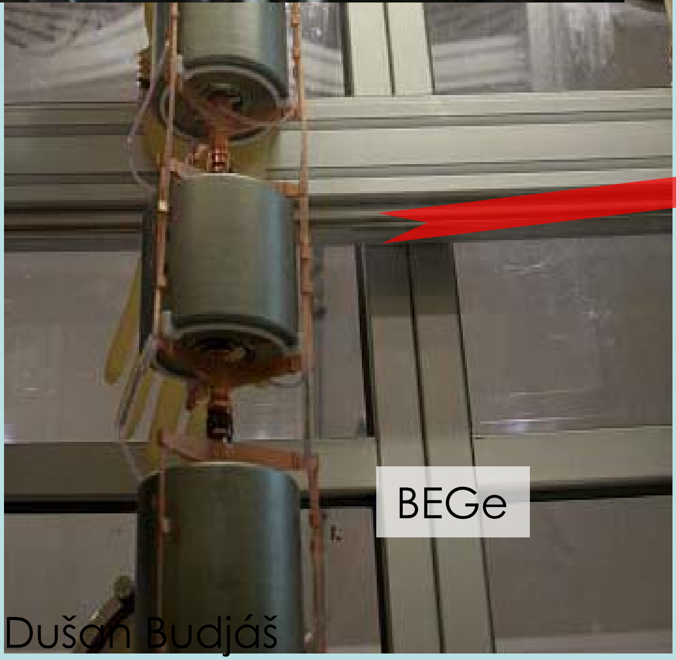
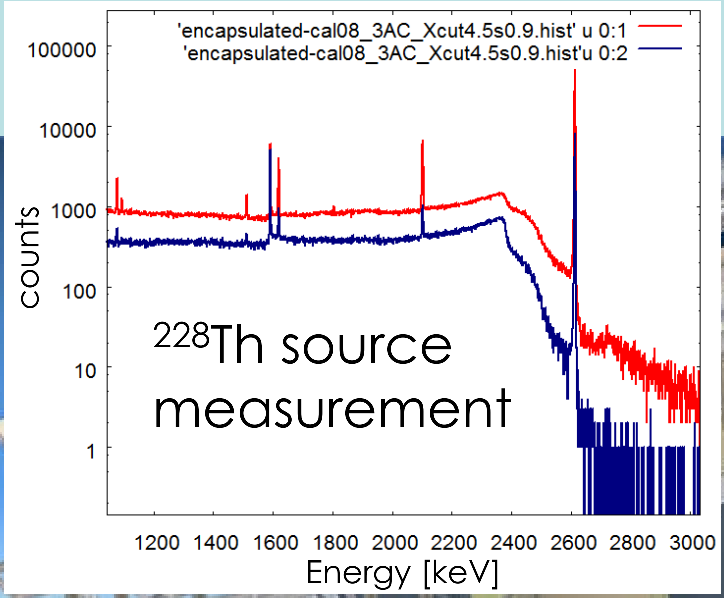
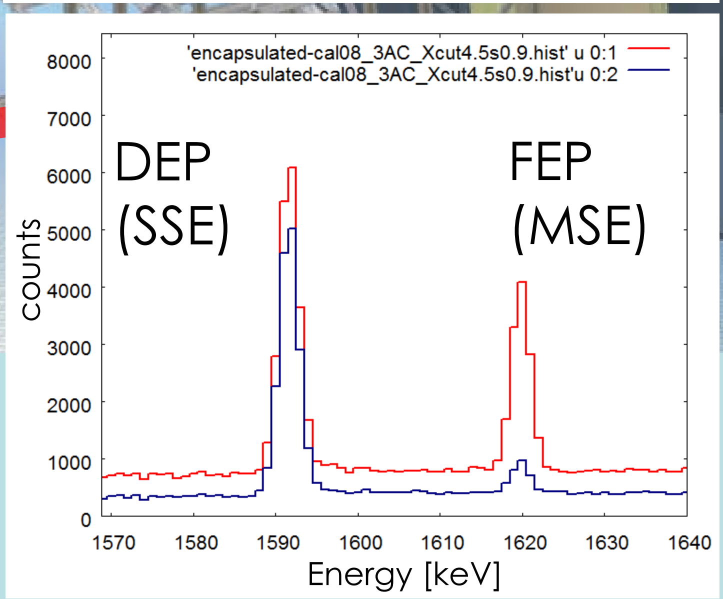
BEGe in GERDA

Preliminary analysis: shaping not optimised yet









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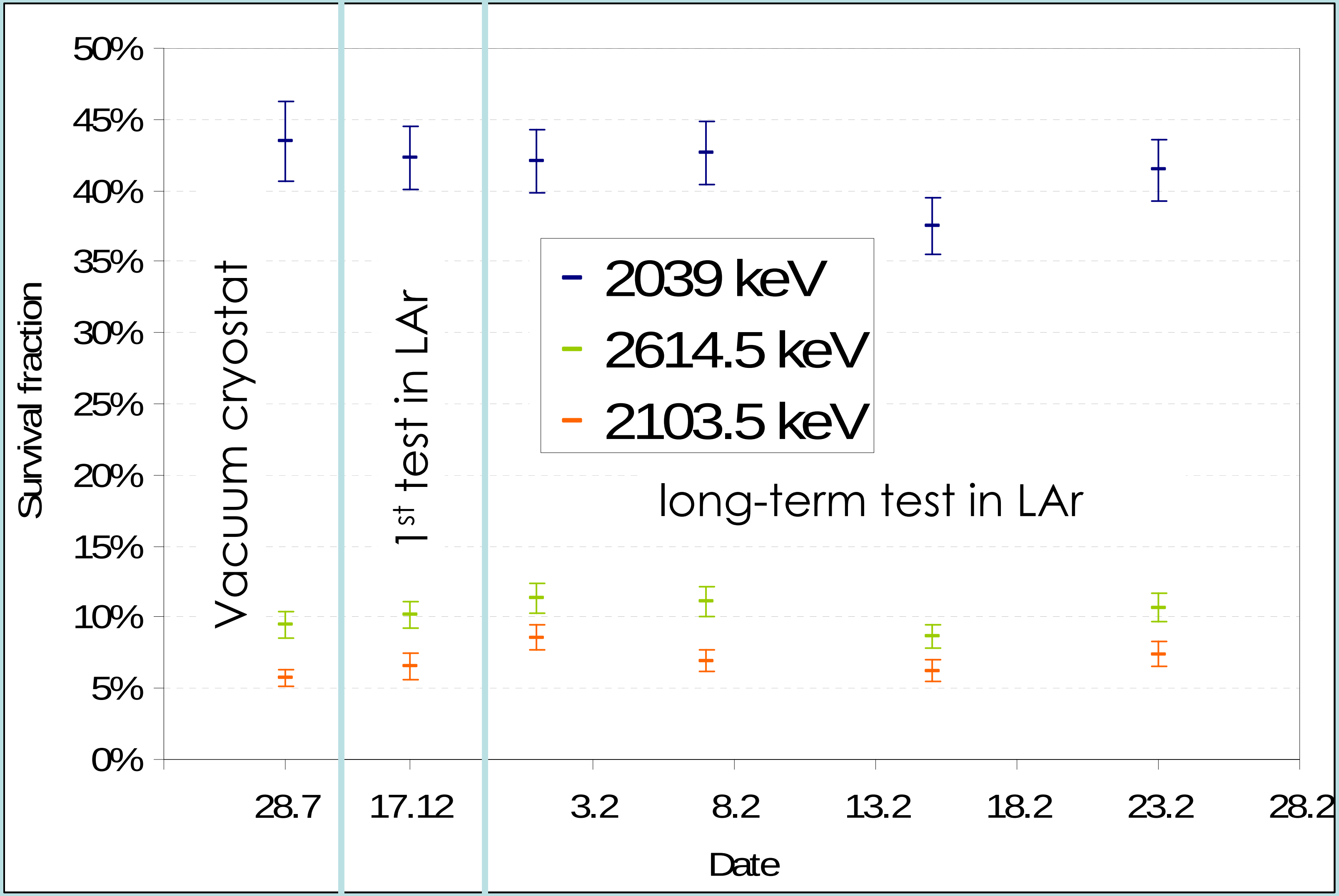
BEGe PSD stability in LAr

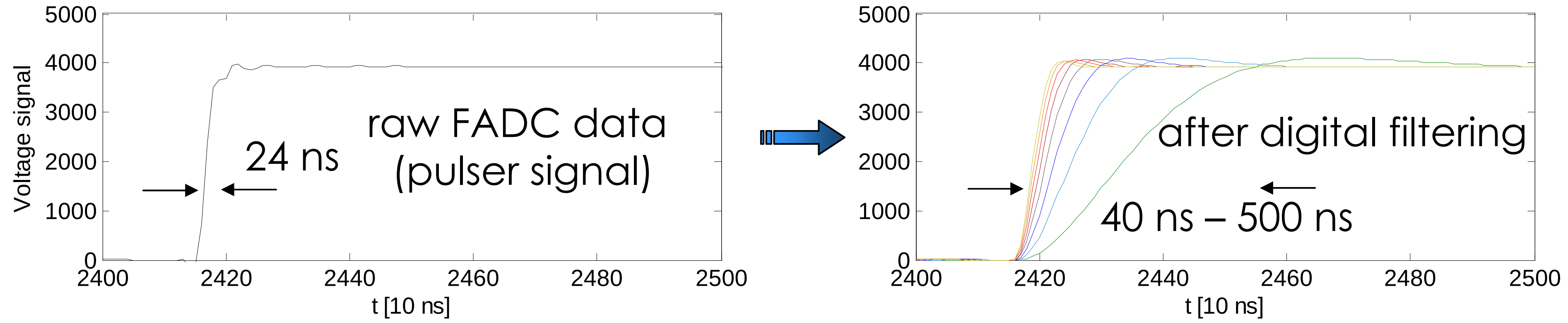
DEP acceptance fixed at 90%



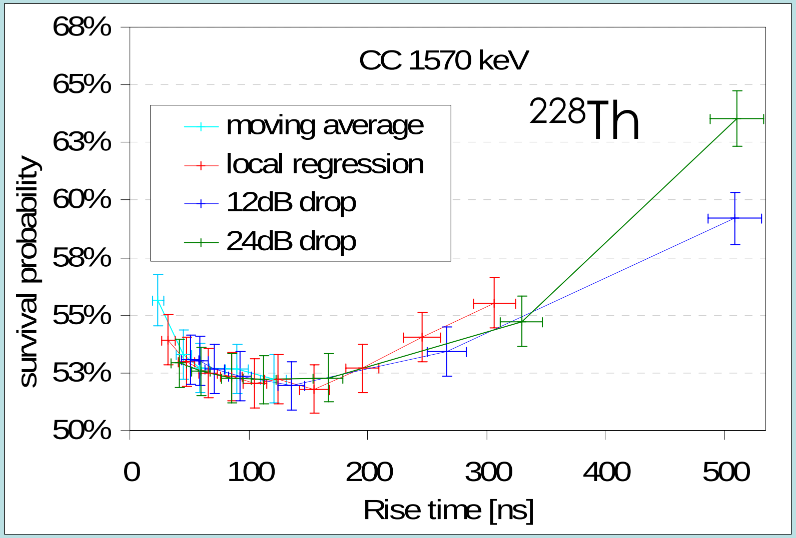
Barnabé Heider et al., JINST 5:P10007, 2010

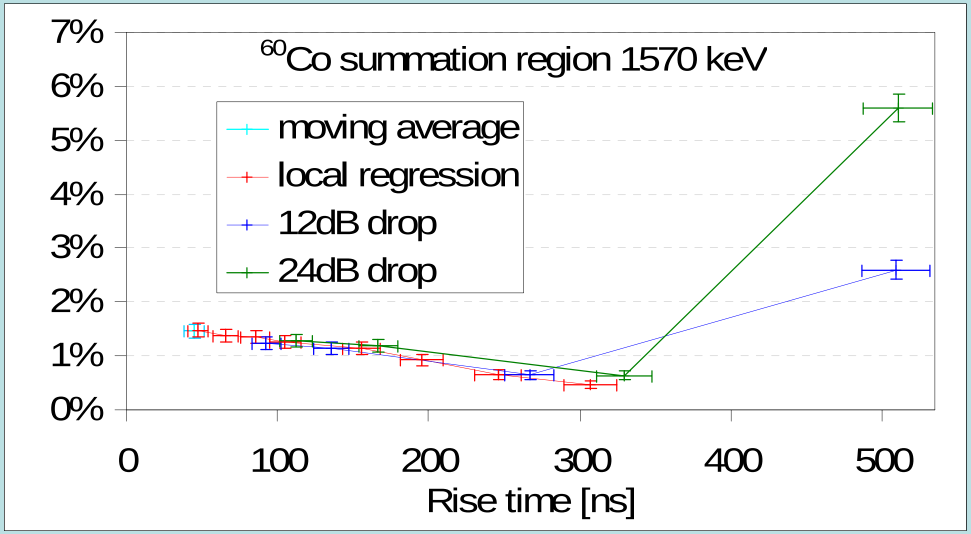
BEGe PSD in dependence on front-end bandwidth

- using recorded experimental pulse-data
- FE bandwidth restriction simulated by applying various off-line filters



- PSD on filtered pulses (DEP acceptance always fixed at 90%):





GERDA Phase II BEGe large-scale production test

- Ge material (21.5 kg) with the same chemical history as GERDA ^{enr}Ge used to perform a production test of GERDA Phase II BEGe detectors
- Four Ge crystals pulled (17.7 kg total mass)
- Five BEGe detectors manufactured, two in production, four tested

Det.	Diam. × length [mm × mm]	Mass [g]	Dead layer [mm]	FWHM @ 1.3 MeV [keV]	2.6 MeV peak PSD acc. [%]
Ref.	81 × 32	878	0.43	1.63	7.7 ± 0.4
1	74 × 33	760	0.7	1.61	6.1 ± 0.5
2	74 × 32	700	0.45	1.66	6.4 ± 0.5
3	75 × 31	730	0.5	1.6	7.4 ± 0.6
4	74 × 41	930	0.4	1.7	5.7 ± 0.5

Summary

Unsegmented BEGe detectors will provide excellent background rejection power for GERDA Phase II.

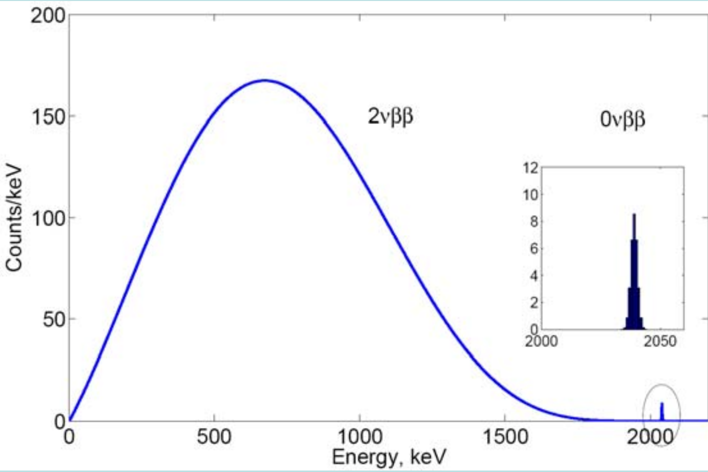
Confidence in BEGe PSD fully based on:

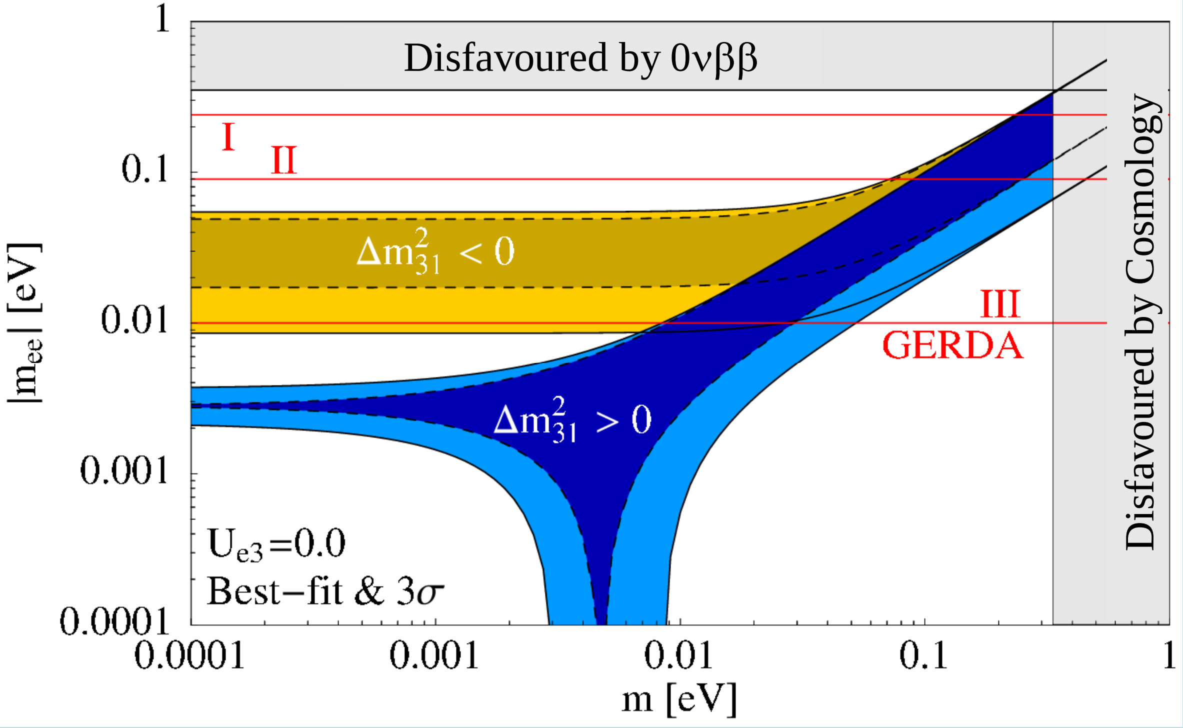
1. extensive experimental validation:
   - works well on 7 BEGe detectors available to GERDA
   - is stable in long-term operation in LAr
   - works in un-optimal noise environment of GERDA
   - works with preamp rise-times up to 150 ns
2. deep understanding of the detector signals
   - spatial and energy dependence of PSD

Back-up

GERDA (GERmanium Detector Array)

Search for **$0\nu\beta\beta$ 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**

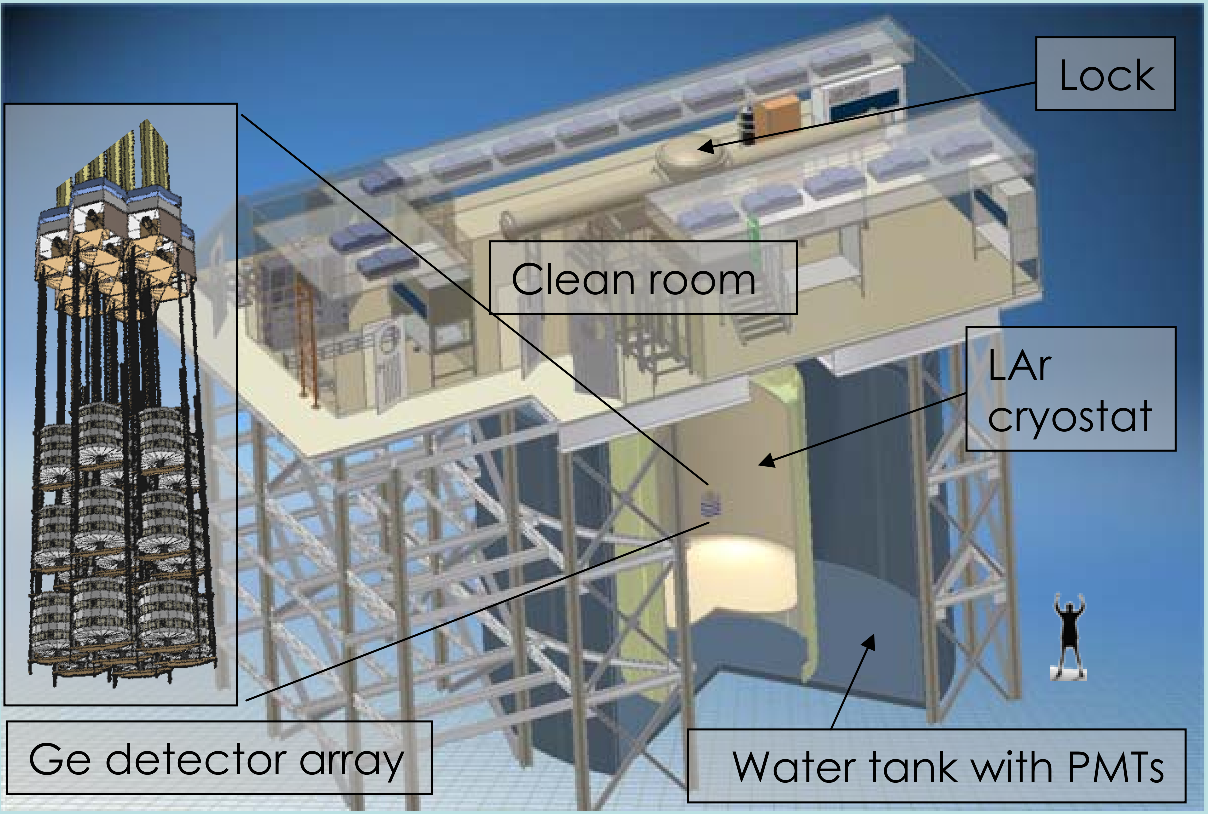




Phase I:
- 18 kg existing detectors
- background: $<10^{-2}$ cts/(keV· kg· y) (10x improvement)

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

GERDA design



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

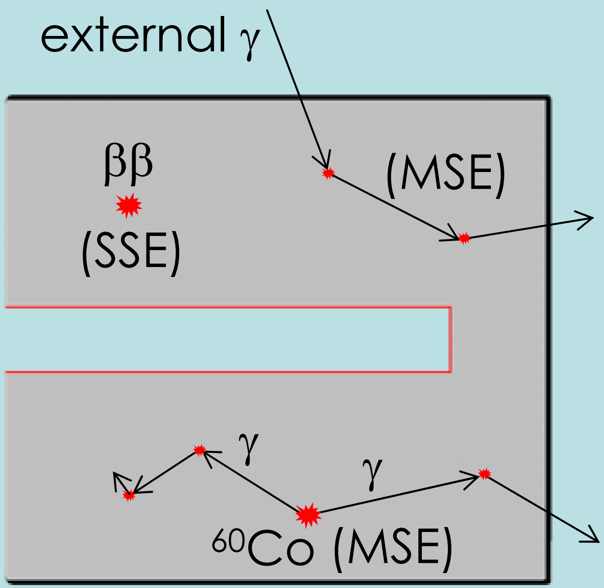
$0\nu\beta\beta$ decay backgrounds

Most important backgrounds:

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

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

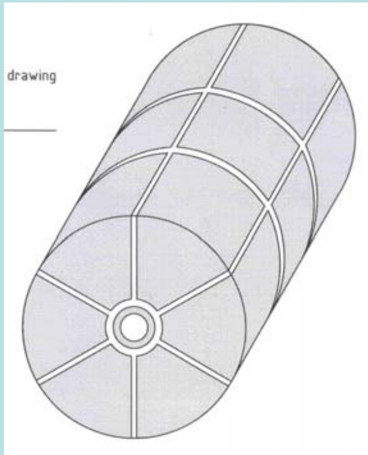
$\Rightarrow$ γ-ray emitters

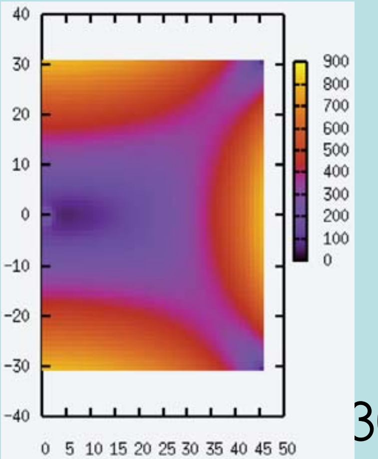


Distinguishing **single-site events (SSE)** and **multi-site events (MSE)** required for background suppression.

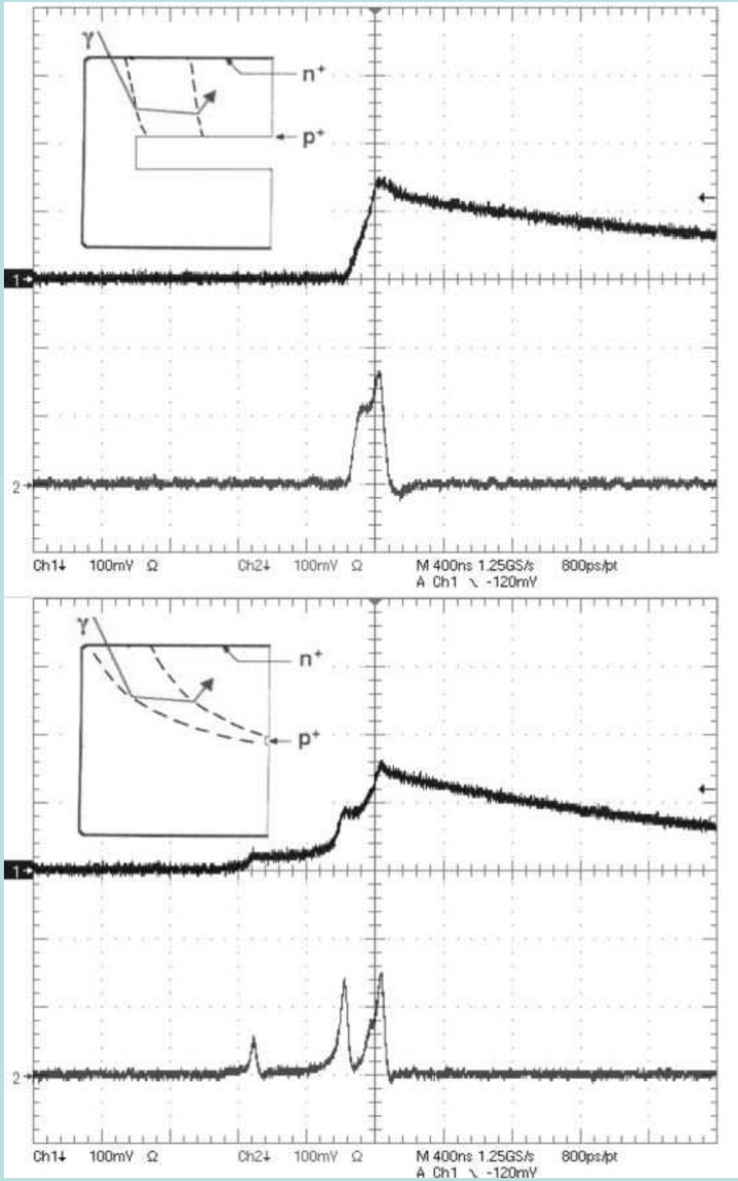
$\Rightarrow$ detector segmentation

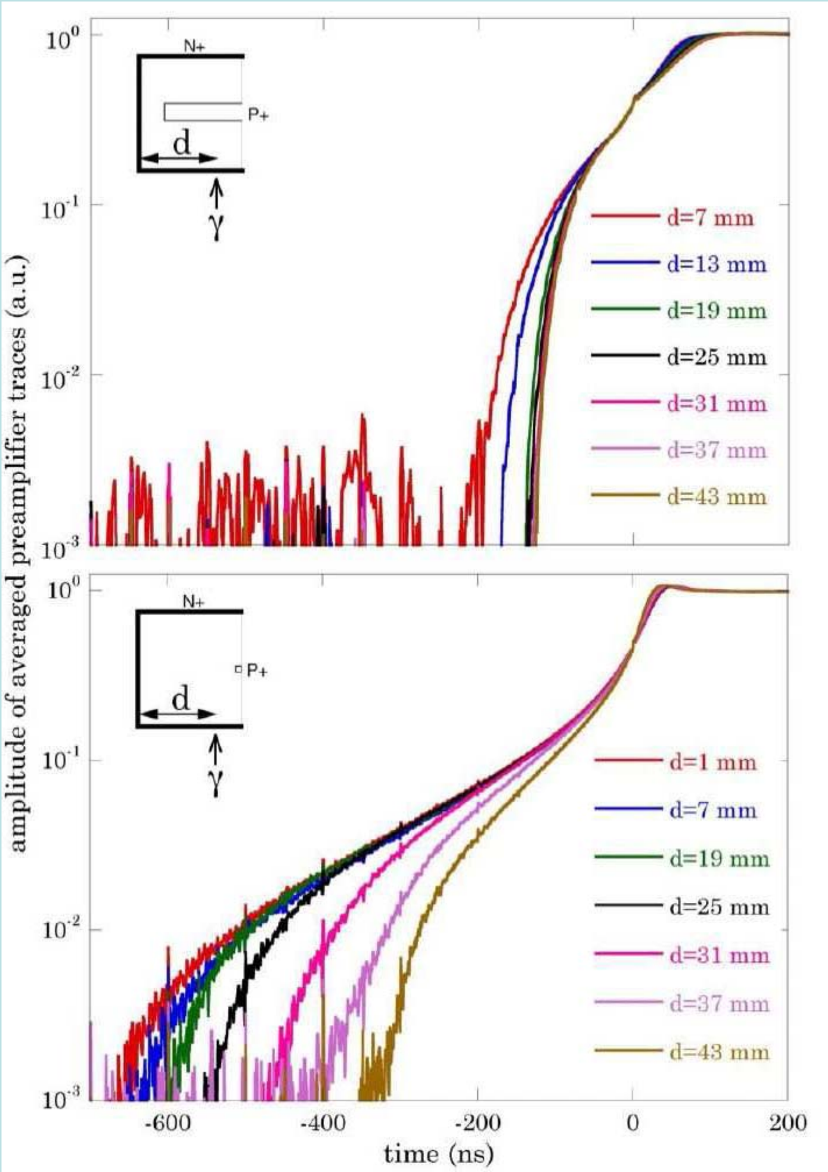
$\Rightarrow$ signal time-structure analysis





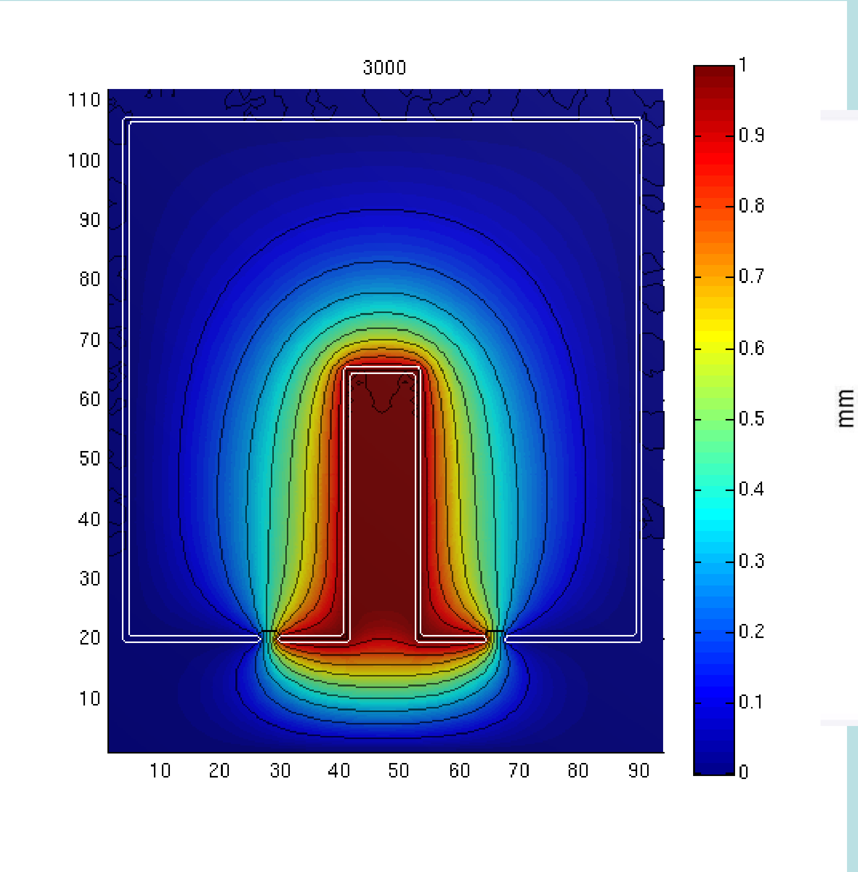
Coax vs. ppc pulse-shapes

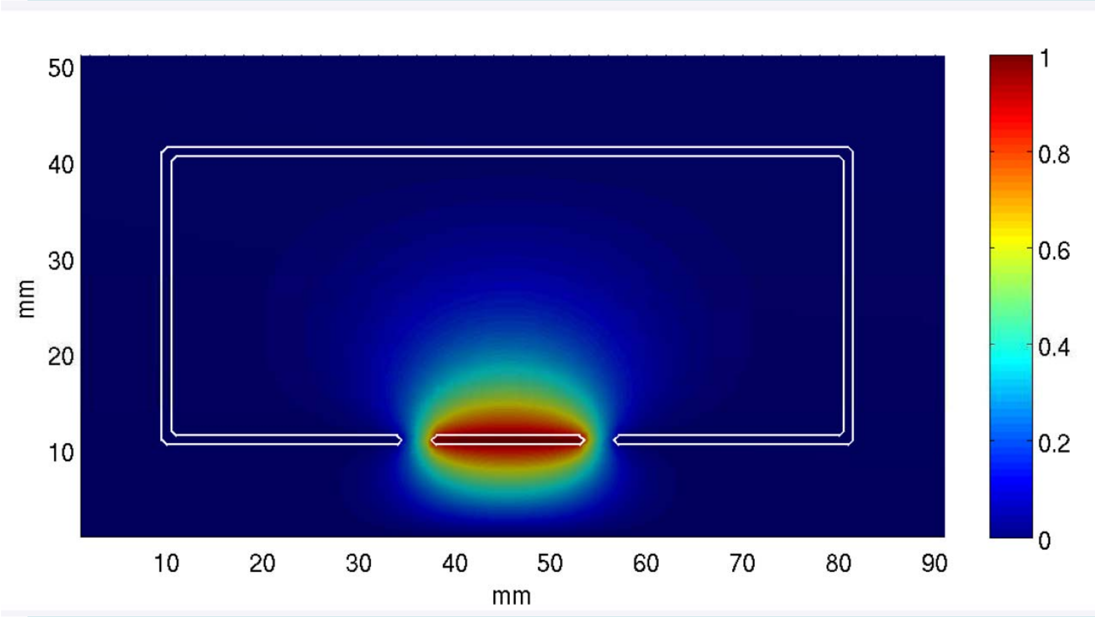




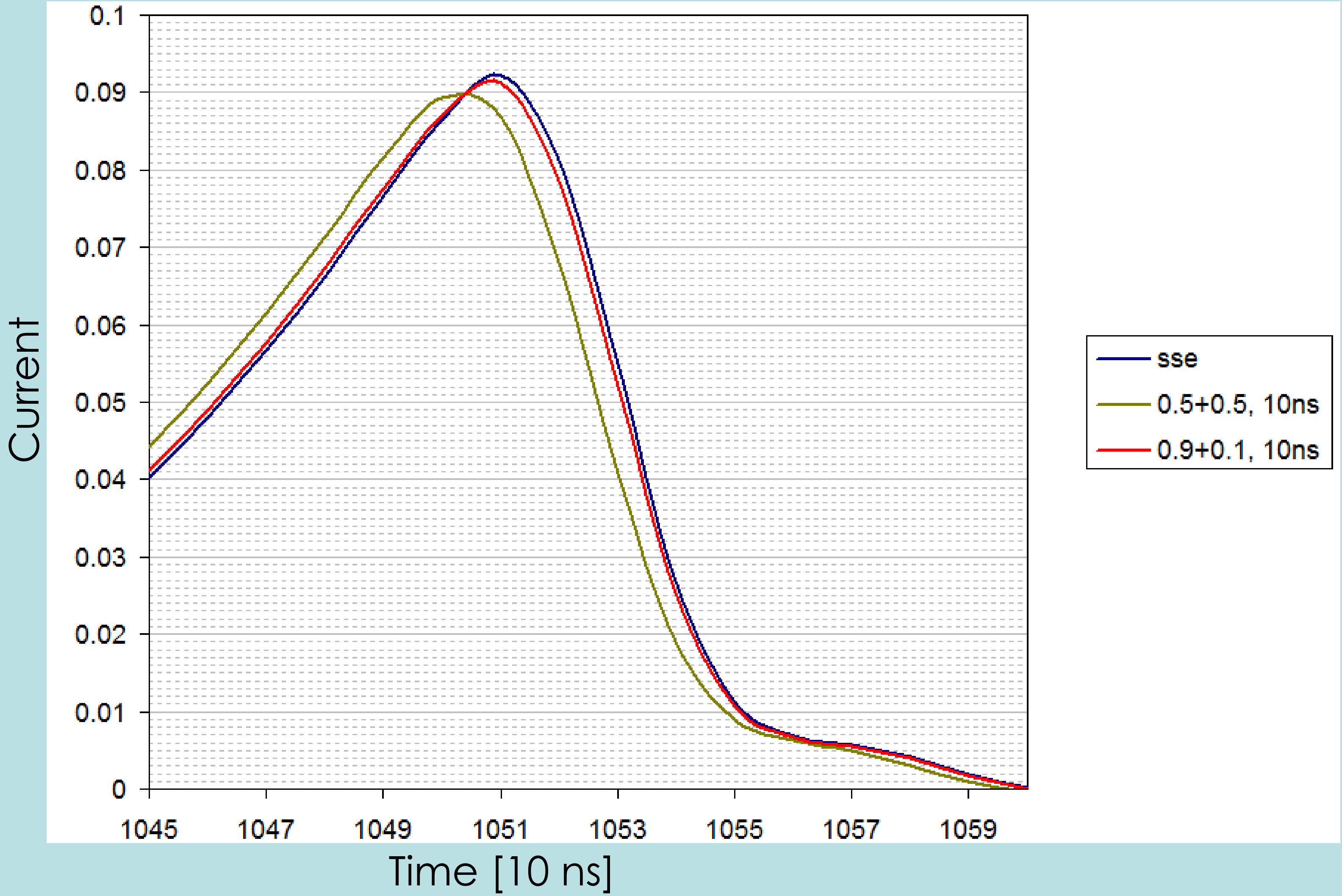
P. S. Barbeau, J. I. Collar, O. Tench arXiv:nucl-ex/0701012v1

Weighing potential

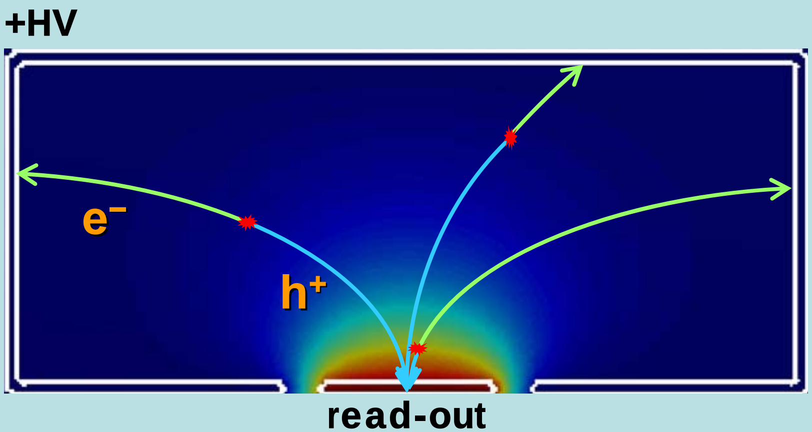


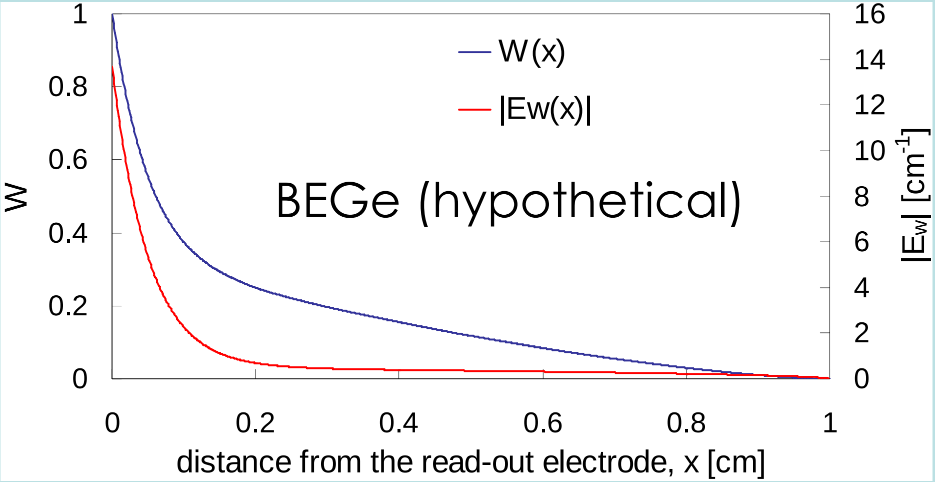


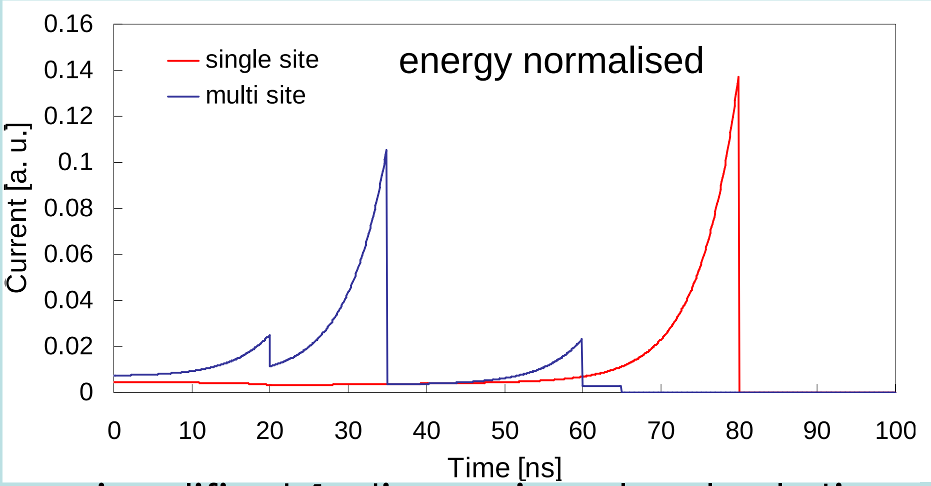
Hit separation resolution



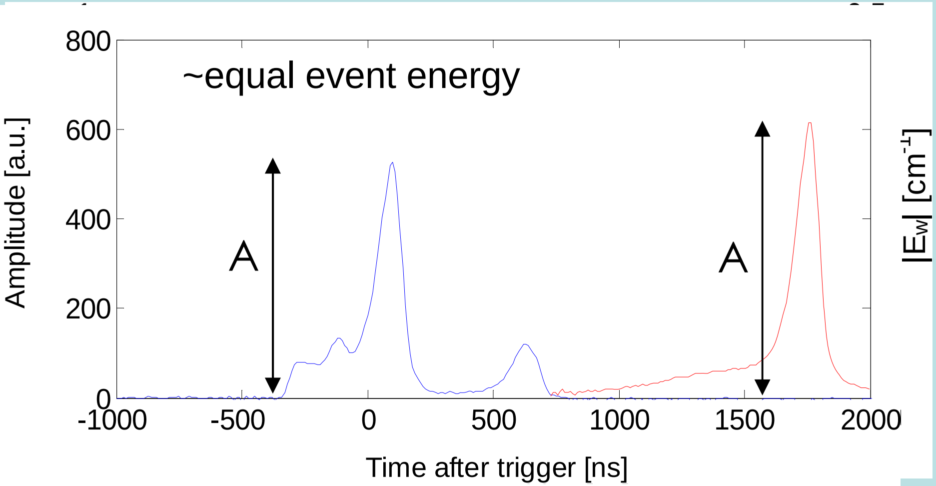
BEGe Pulse Shape Discrimination method







simplified 1-dimensional calculation

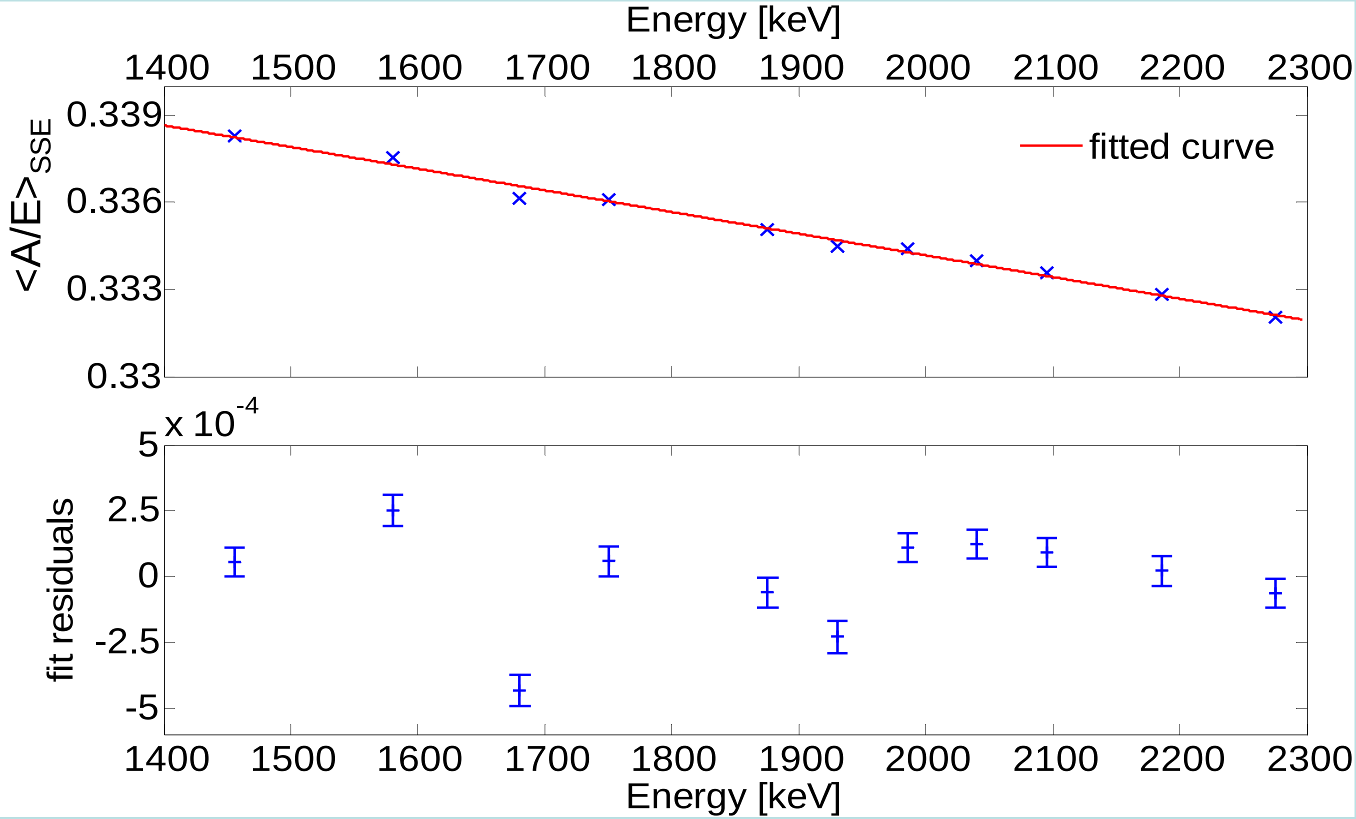


real recorded signal ref: Knoll

Ramo's theorem ⇒

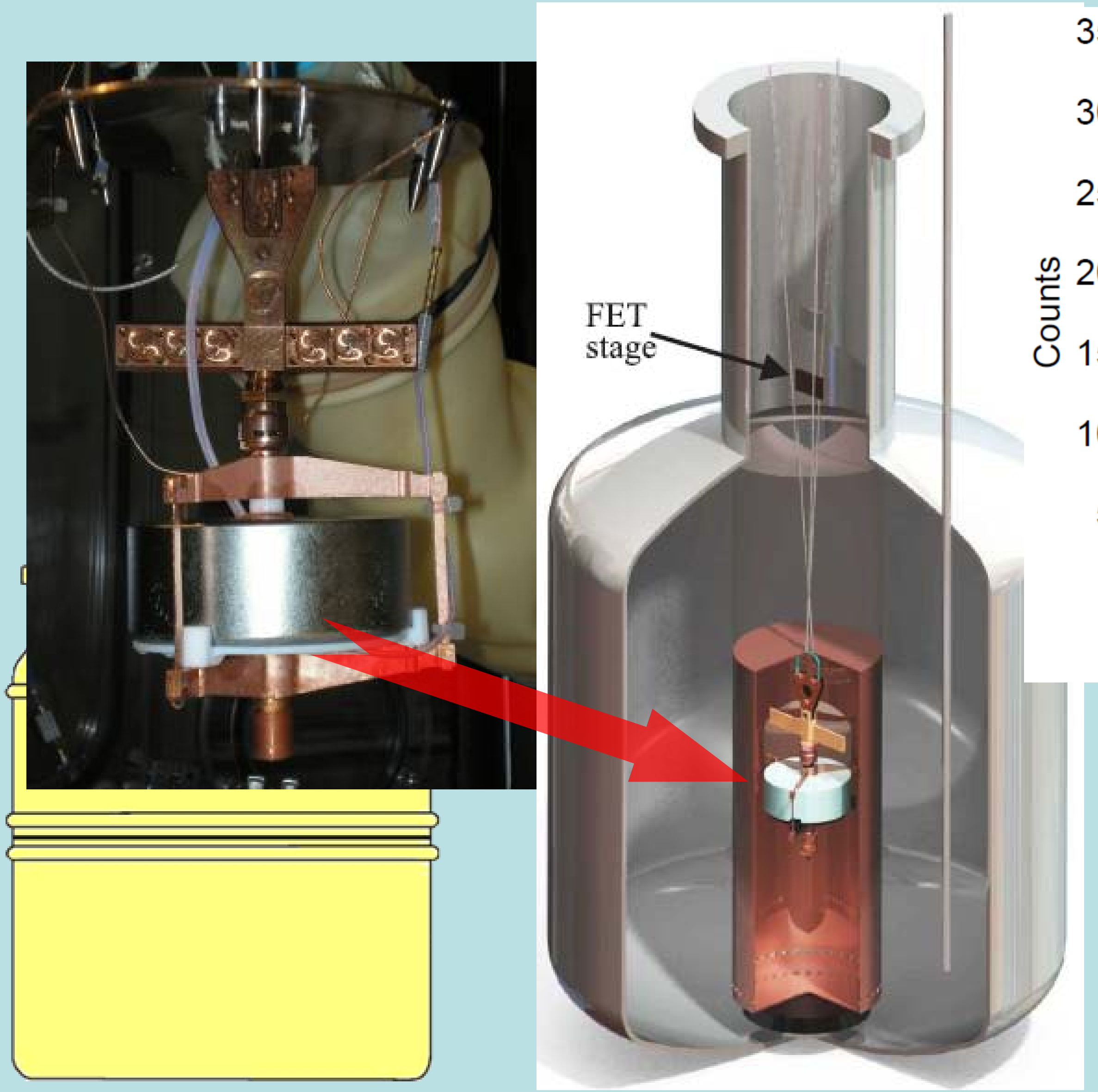
$$I(t) = -q^e \cdot E_W\left(x^e(t)\right)\cdot v + q^h \cdot E_W\left(x^h(t)\right)\cdot v$$

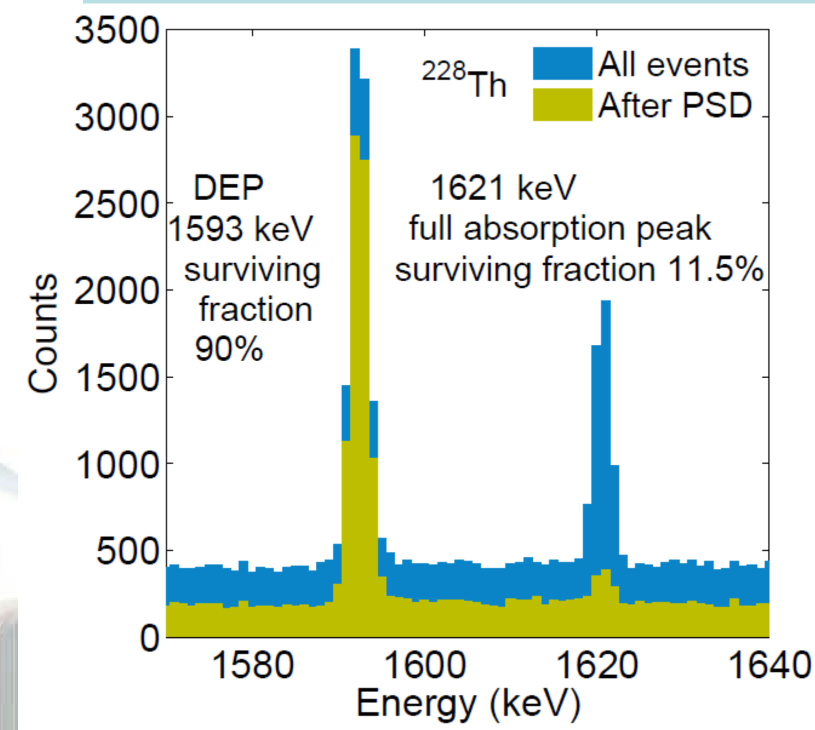
PSD calibration

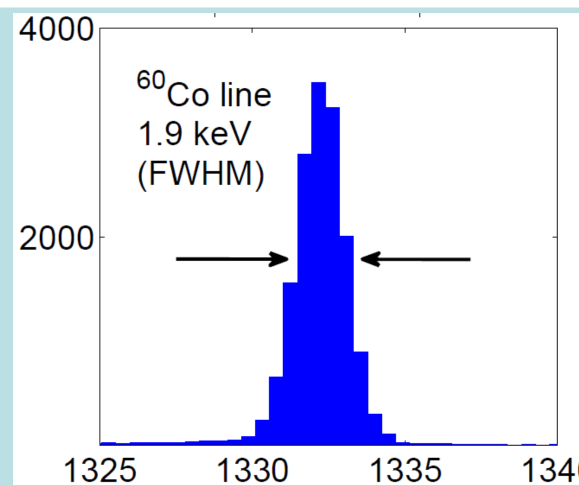


Energy dependance of A/E → likely an electronic effect
(observed with a pulser)

1st time bare BEGe detector in LAr

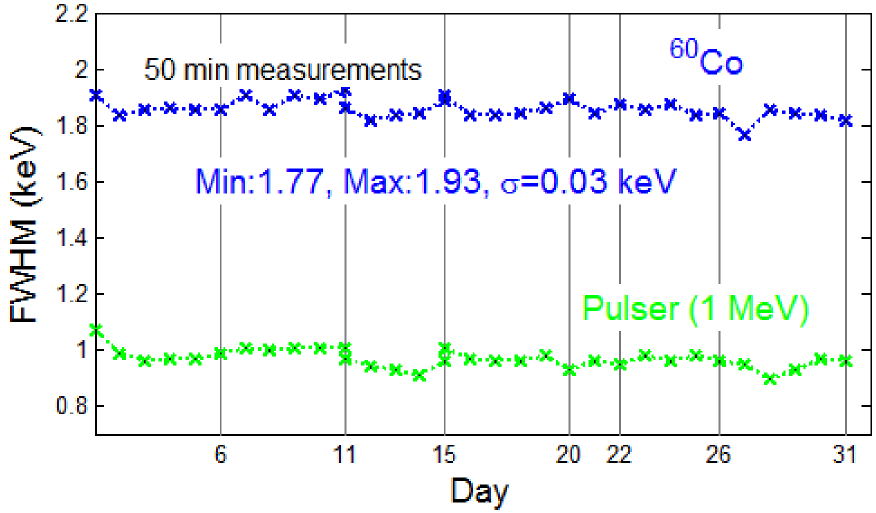


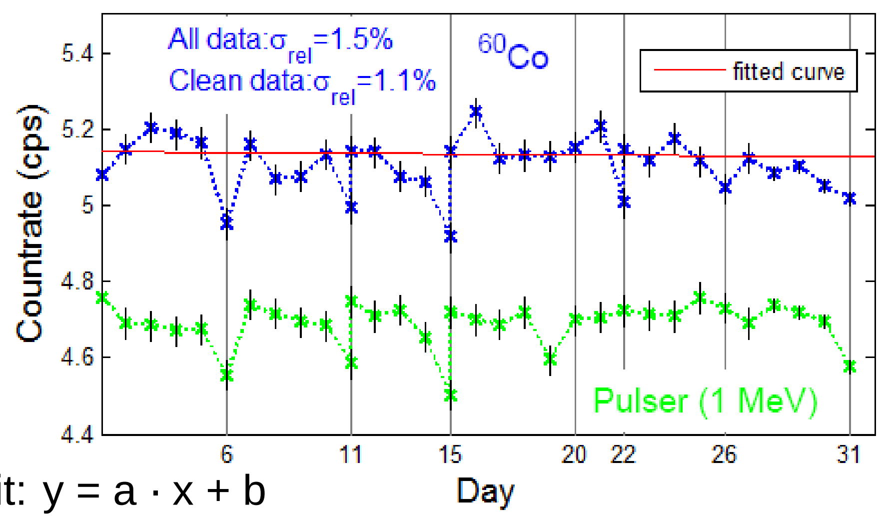




 Barnabé Heider et al., JINST 5:P10007, 2010

BEGe in LAr: long term test 2. 2010



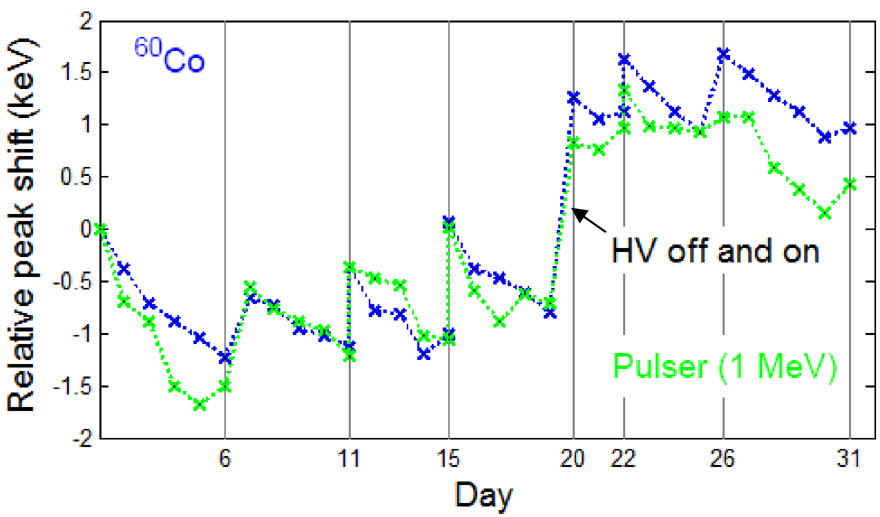


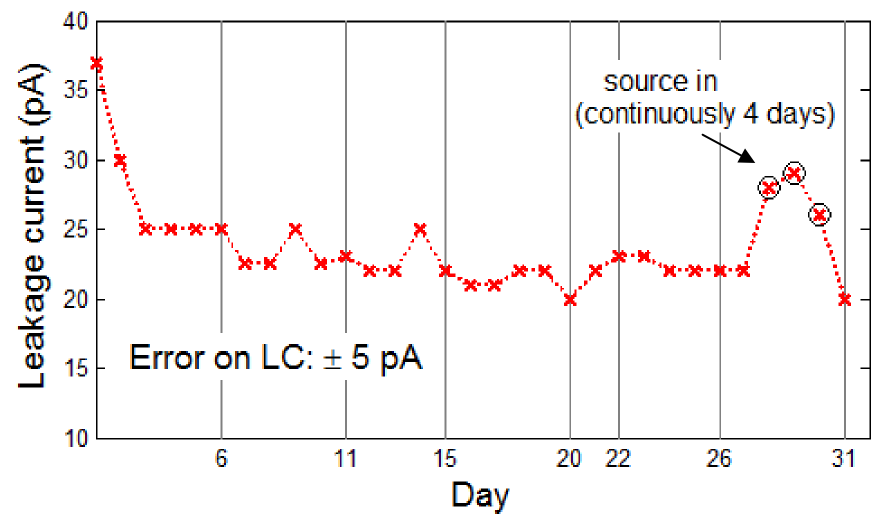
LAr refillings

Fit: $y = a \cdot x + b$

$a = (-0.5 \pm 2.5)\cdot 10^{-3}$

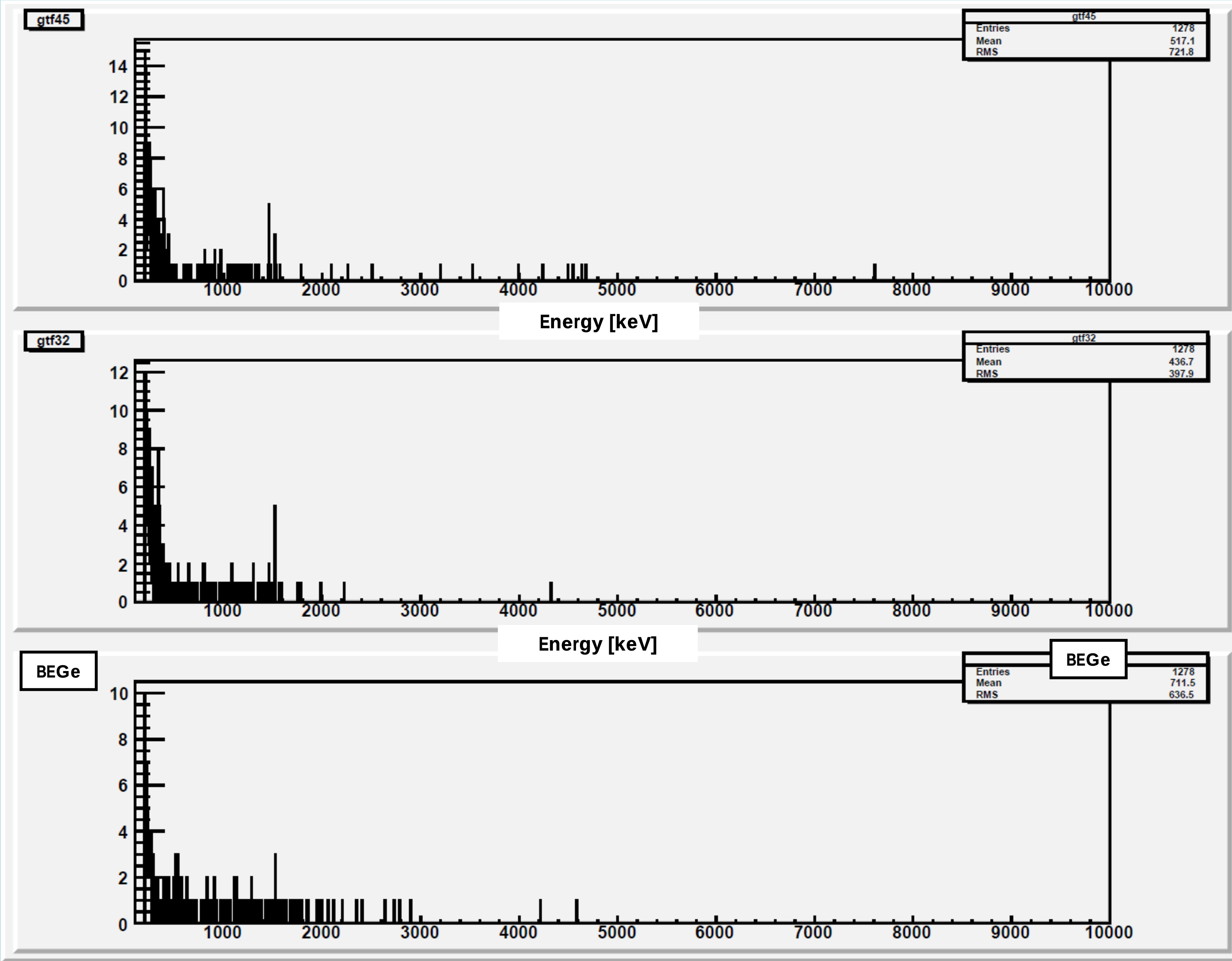
$b = 5.14 \pm 0.04$



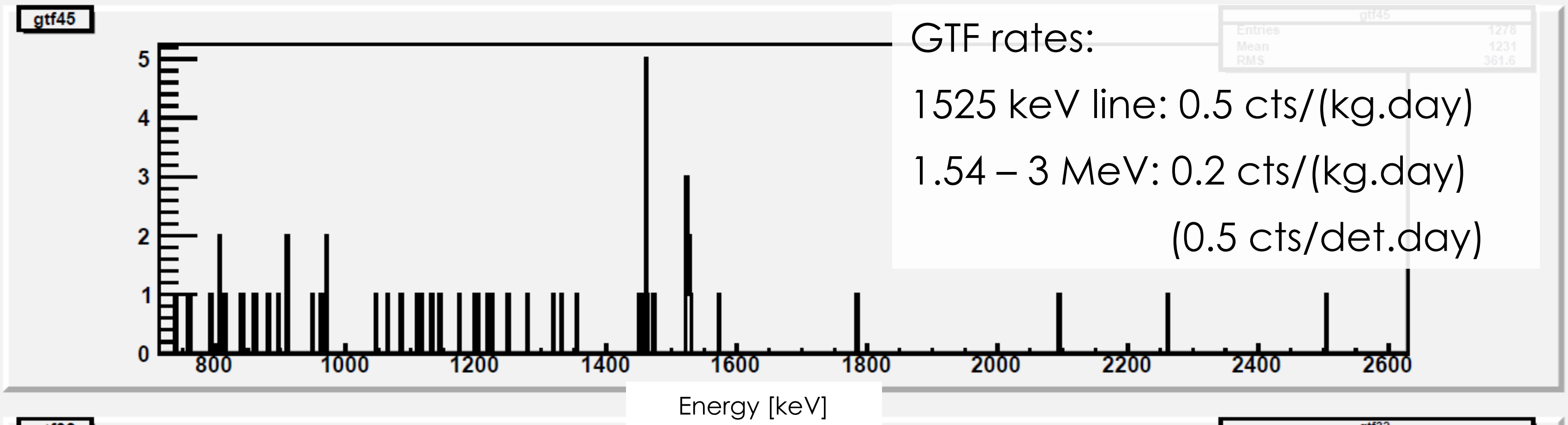


detector performance stable over 1 month period

Background spectrum



Background spectrum

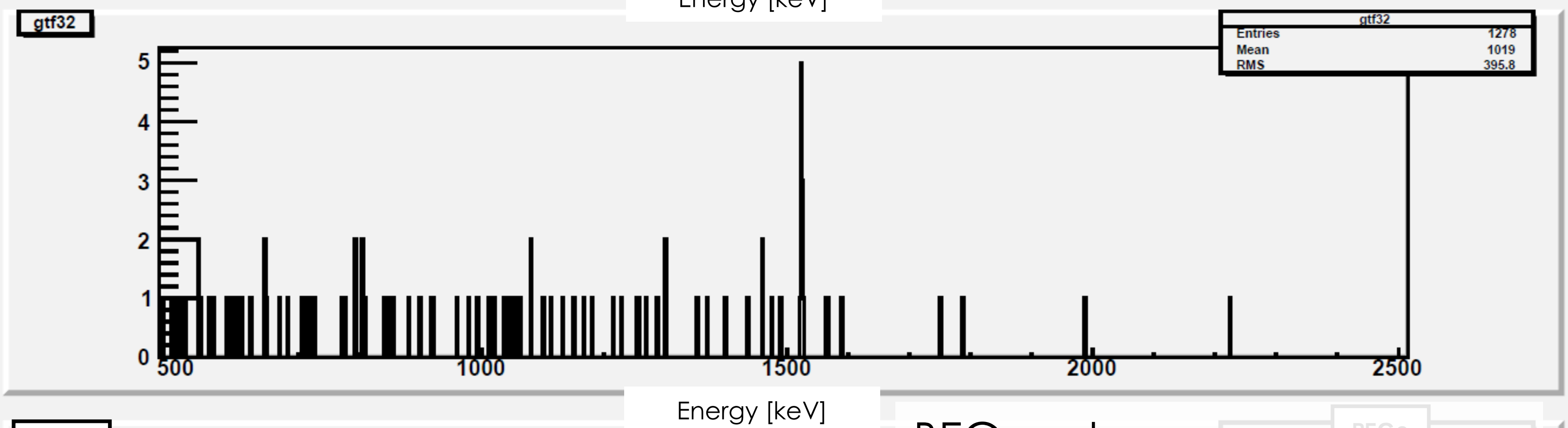


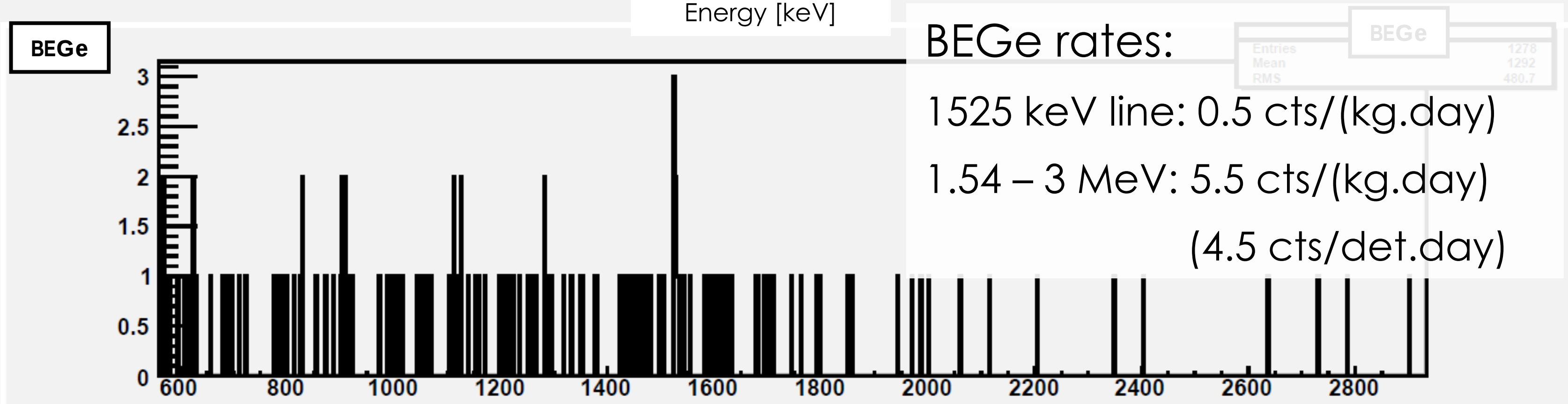
GTF rates:

1525 keV line: 0.5 cts/(kg.day)

1.54 – 3 MeV: 0.2 cts/(kg.day)

(0.5 cts/det.day)





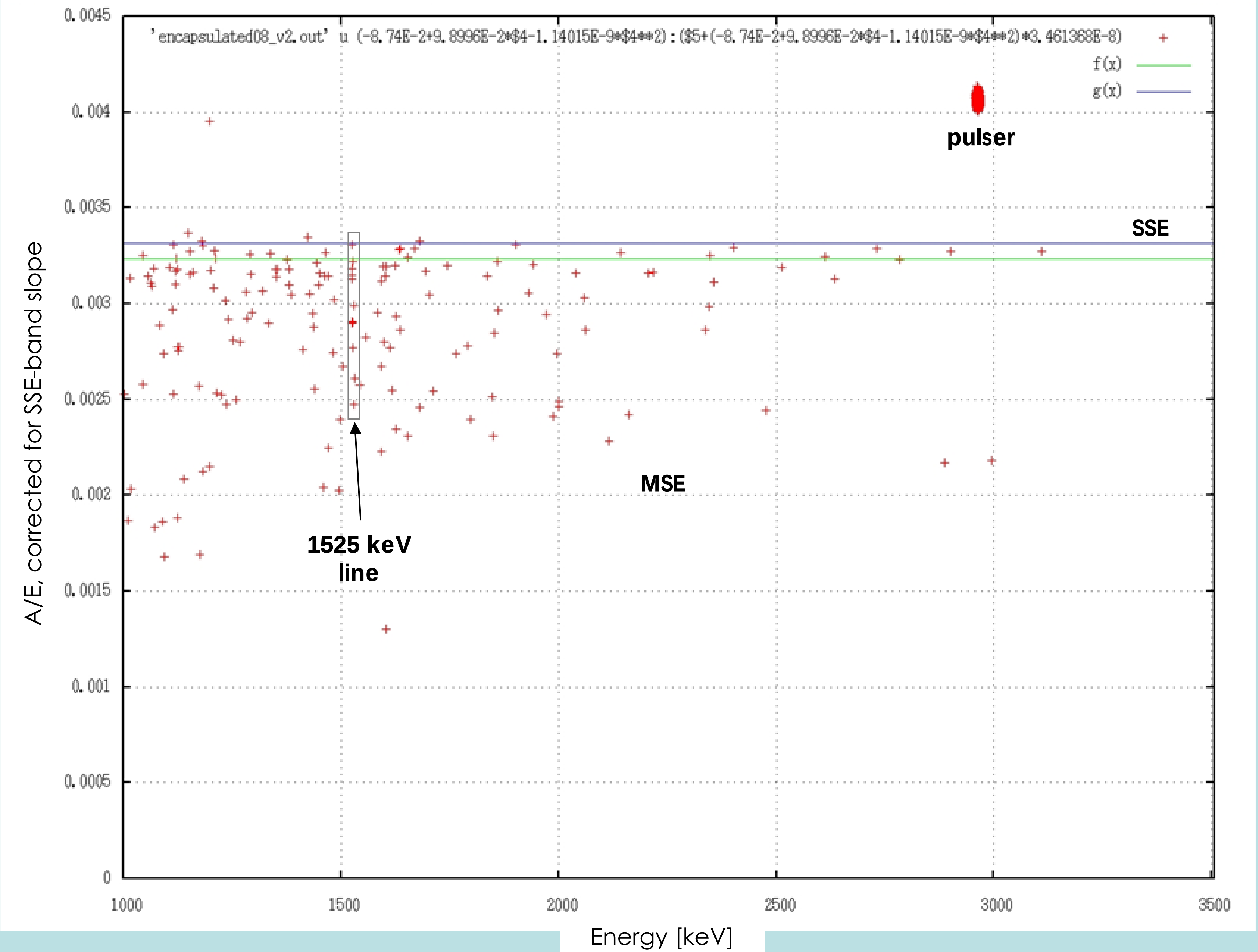
BEGe rates:

1525 keV line: 0.5 cts/(kg.day)

1.54 – 3 MeV: 5.5 cts/(kg.day)

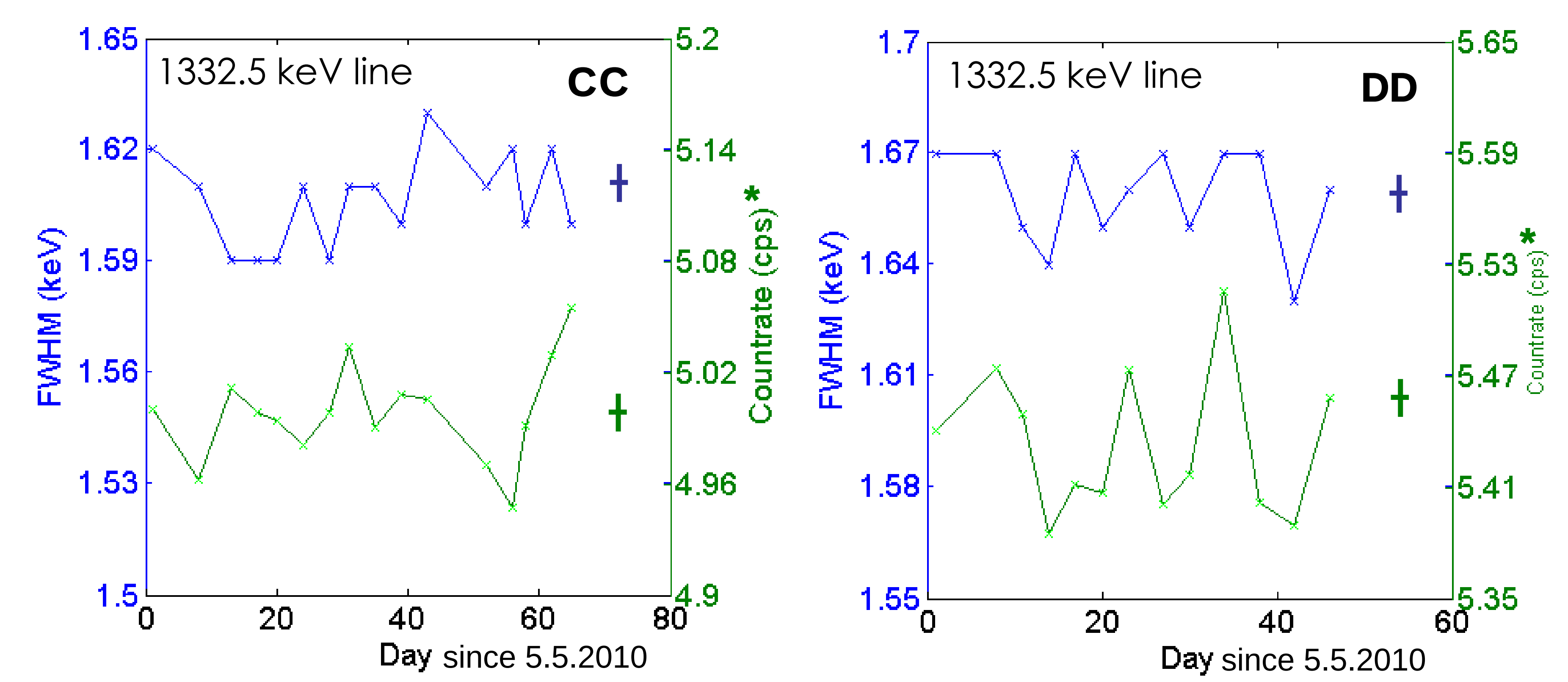
(4.5 cts/det.day)

Background analysis



Results: Stability

- measurement ongoing at LNGS underground in Ge-spectrometry lab since the beginning of May
- preliminary analysis:



* count rate corrected for ^{60}Co decay