Study the PSD Performances of the PPCGe and BEGe detectors

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中国暗物质实验
China Dark matter EXperiment

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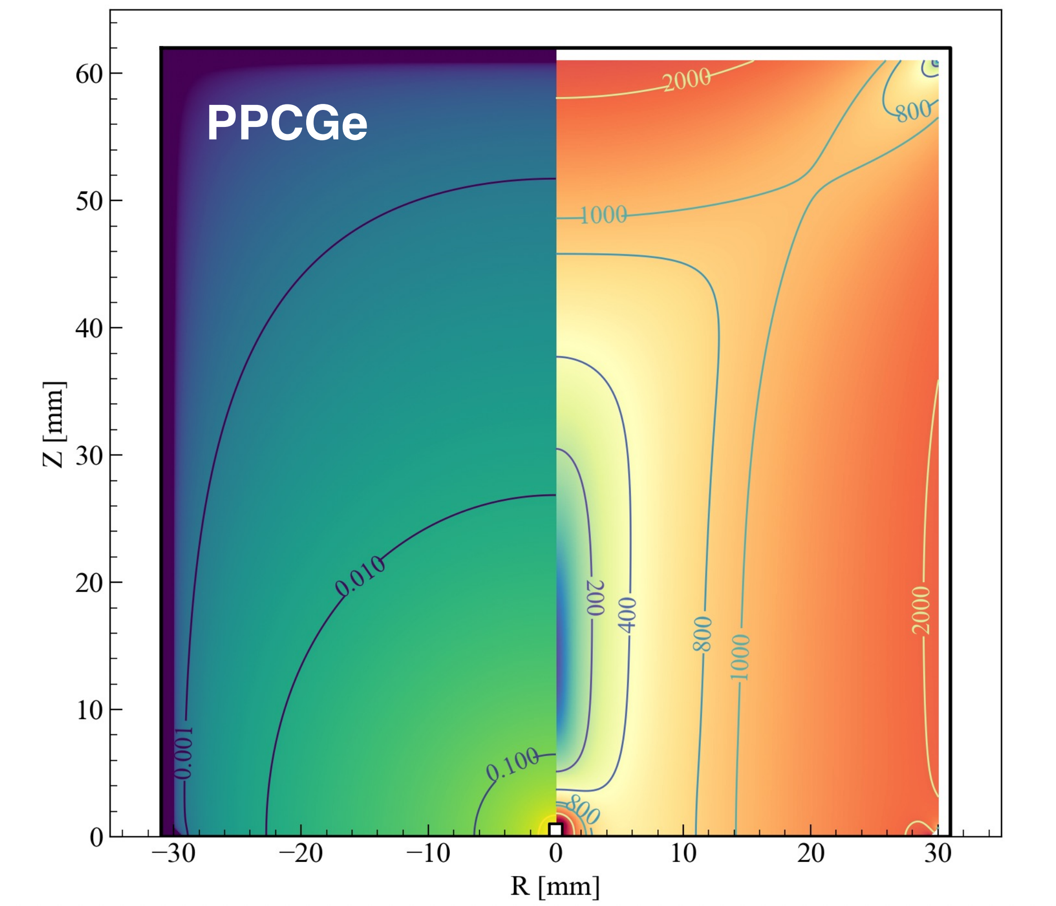
I. Introduction

I. Introduction

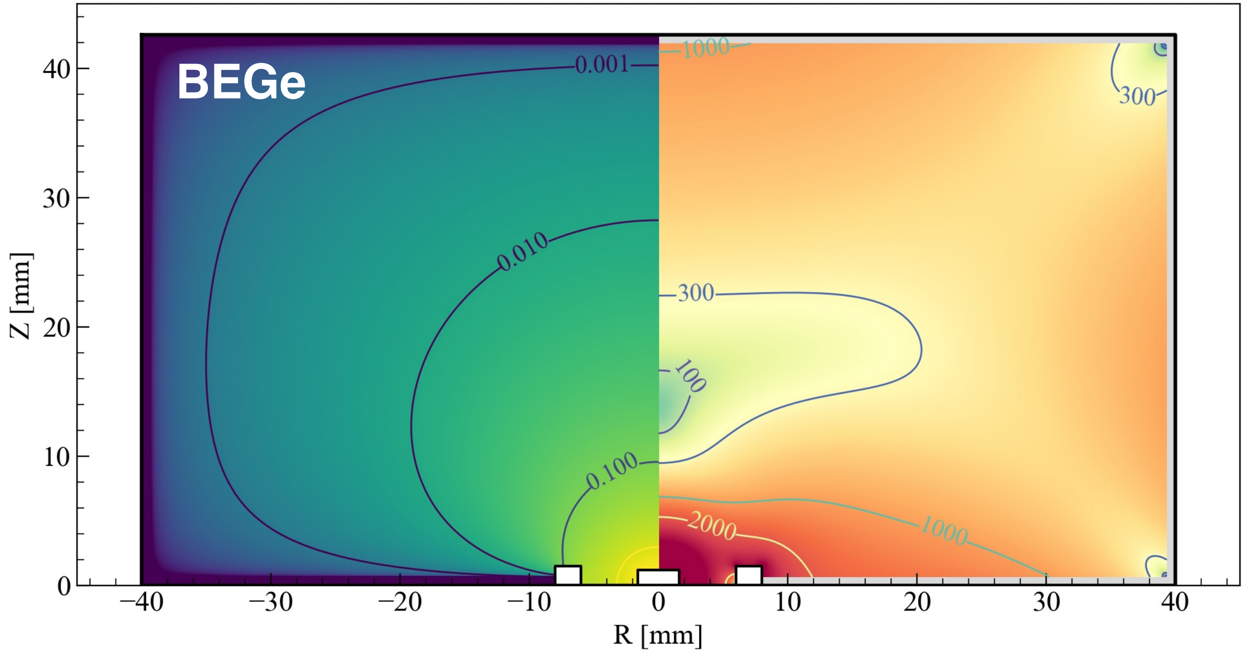
☐ Small contact HPGe detectors:

- PPCGe and BEGe detectors with millimeter-scale p+ contact are wildly used in rare event search experiments
- Small p+ contact leads to a weak electric and weight potential field in the bulk volume of the detector



☐ The weak field strength gives PPCGe and BEGe detectors pulse shape discrimination power

Weight potential field **Electric field**



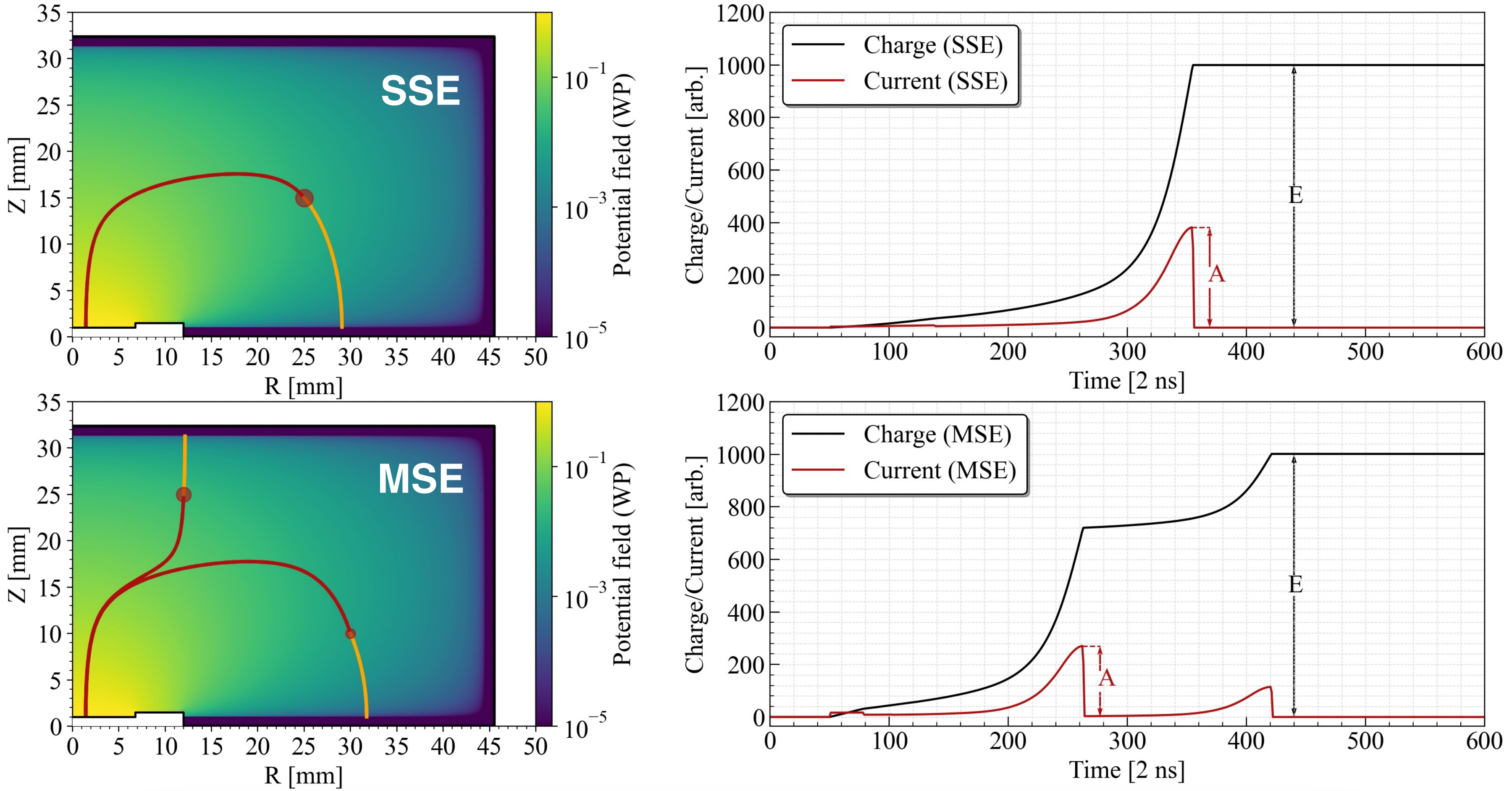
I. Introduction

☐ Pulse shape discrimination of PPCGe and BEGe: A/E method

- ➢ PPCGe and BEGe are capable of discriminating **single/multi-site events (SSE/MSE)** via the A/E parameter
- ➢ SSE/MSE discrimination serves as a background suppression technology in Ge-76 0νββ experiment

☐ Single-site event:
- ➢ **Single current peak**
- ➢ **A ∝ E**

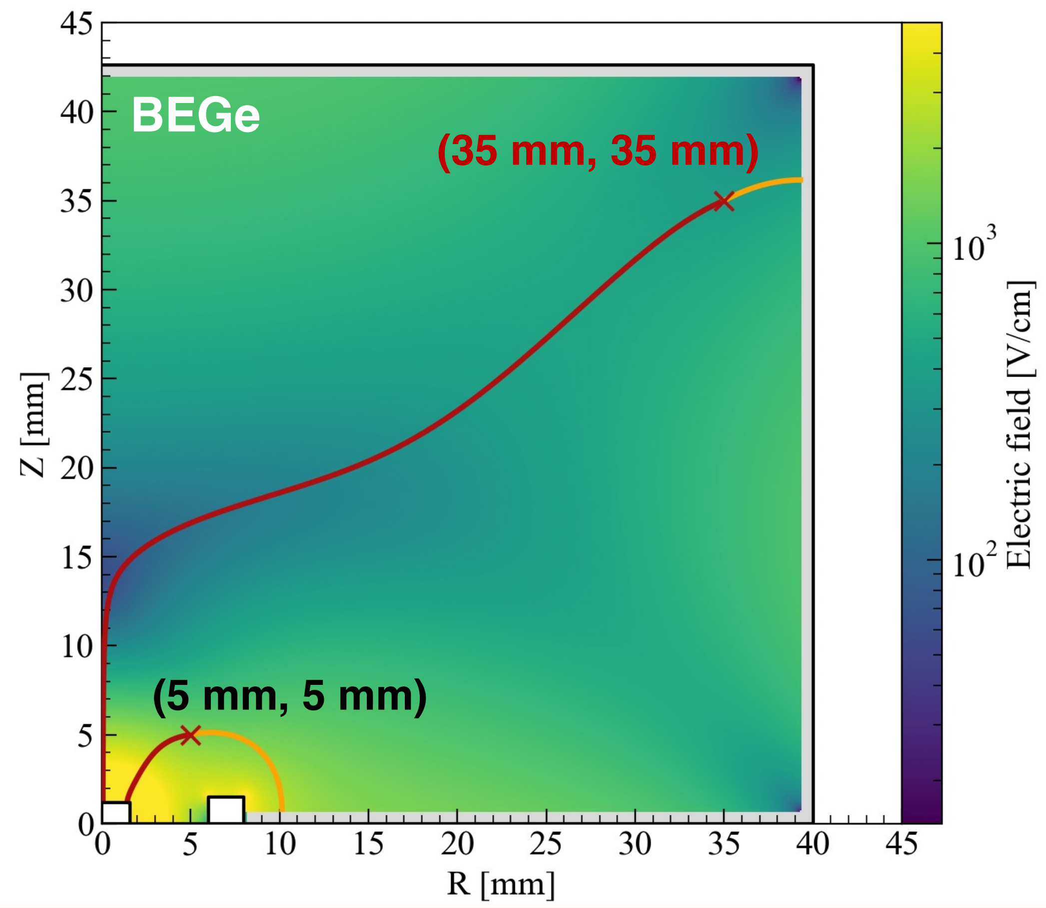
☐ Multi-site event:
- ➢ **Multi current peaks**
- ➢ **A/E < that of SSE**

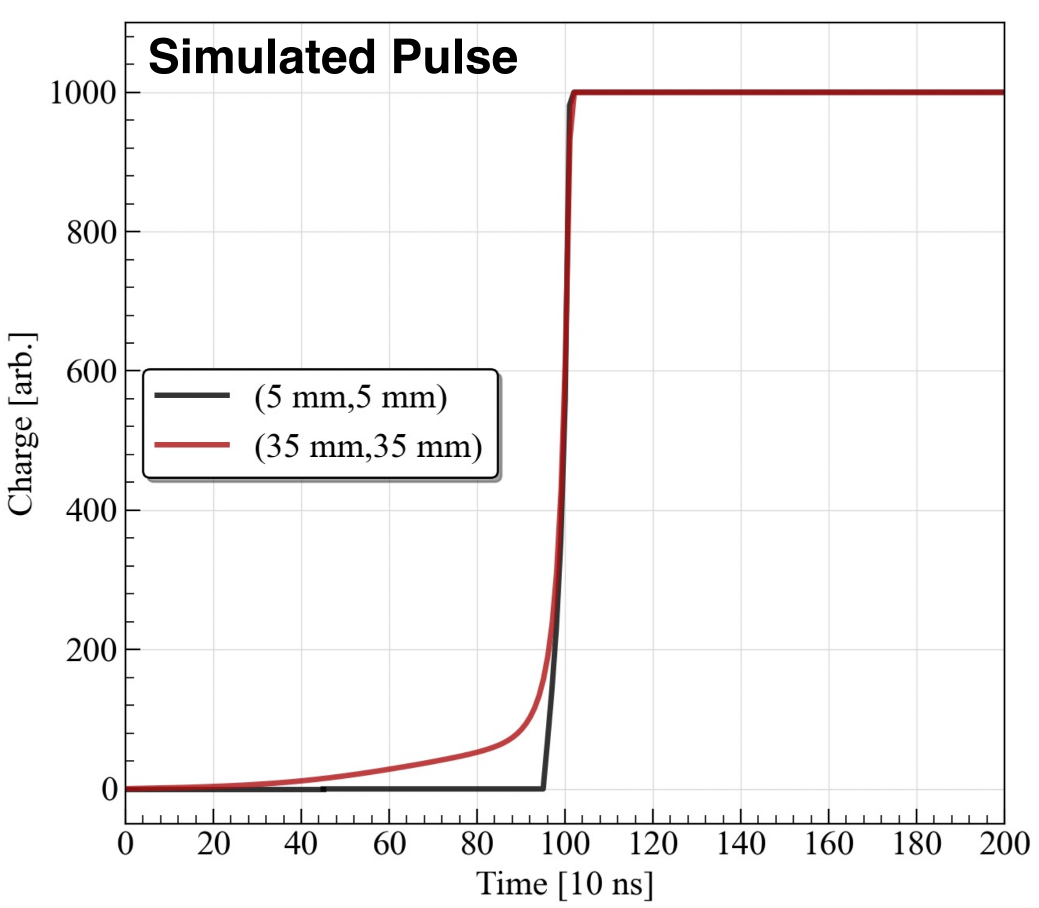


I. Introduction

☐ Pulse shape discrimination of PPCGe and BEGe: pulse matching

- The pulse shape also contains some spatial information on the hit position of the event
- Extract the spatial information via pulse matching can help understand the origin of the event





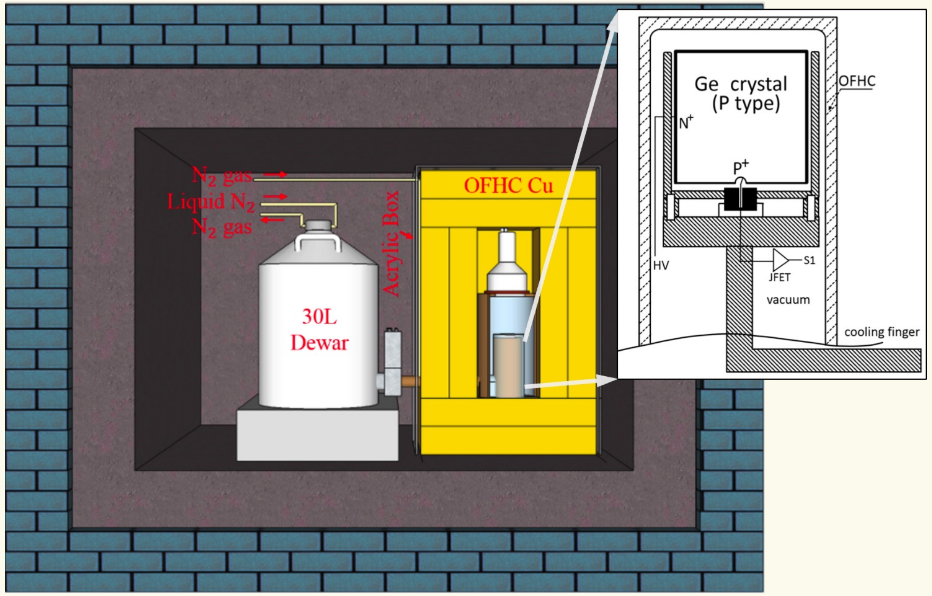
I. Introduction

☐ Pulse shape analysis of three HPGe detectors:

To assess the PSD performance of PPCGe and BEGe detectors and develop other PSA methods, we conducted PSA studies in three BEGe and PPCGe detectors:

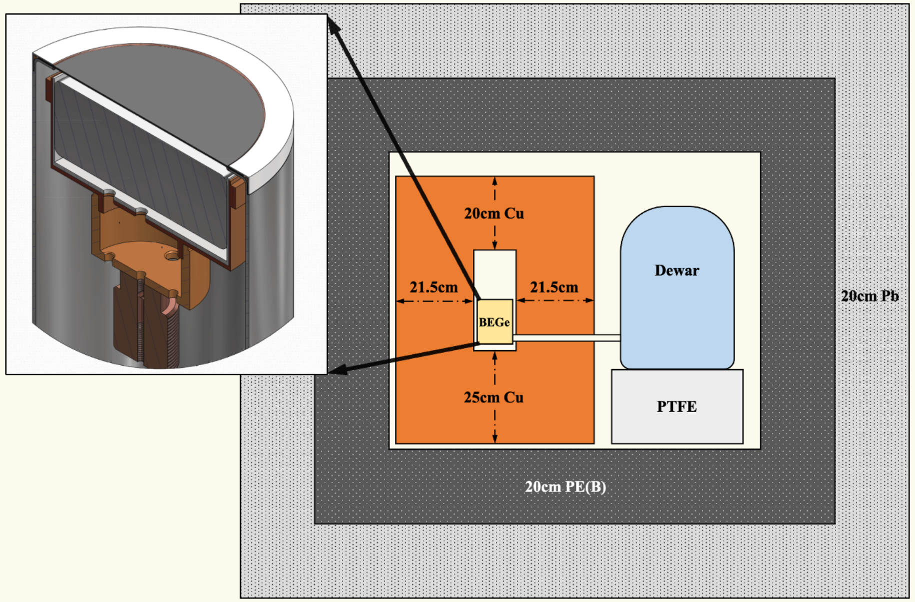
- **HPGe detectors:** one PPCGe and two BEGe detectors
- **PSA methods:** A/E method (SSE/MSE discrimination), Pulse matching (for spatial information)

CDEX-1B (PPCGe)



Phys. Rev. Lett. 123, 221301, 2019
arXiv:2305.00894v2, 2023

0νββ prototype (BEGe#1)



Phys. Rev. D, 106, 032012, 2022

BEGe#2

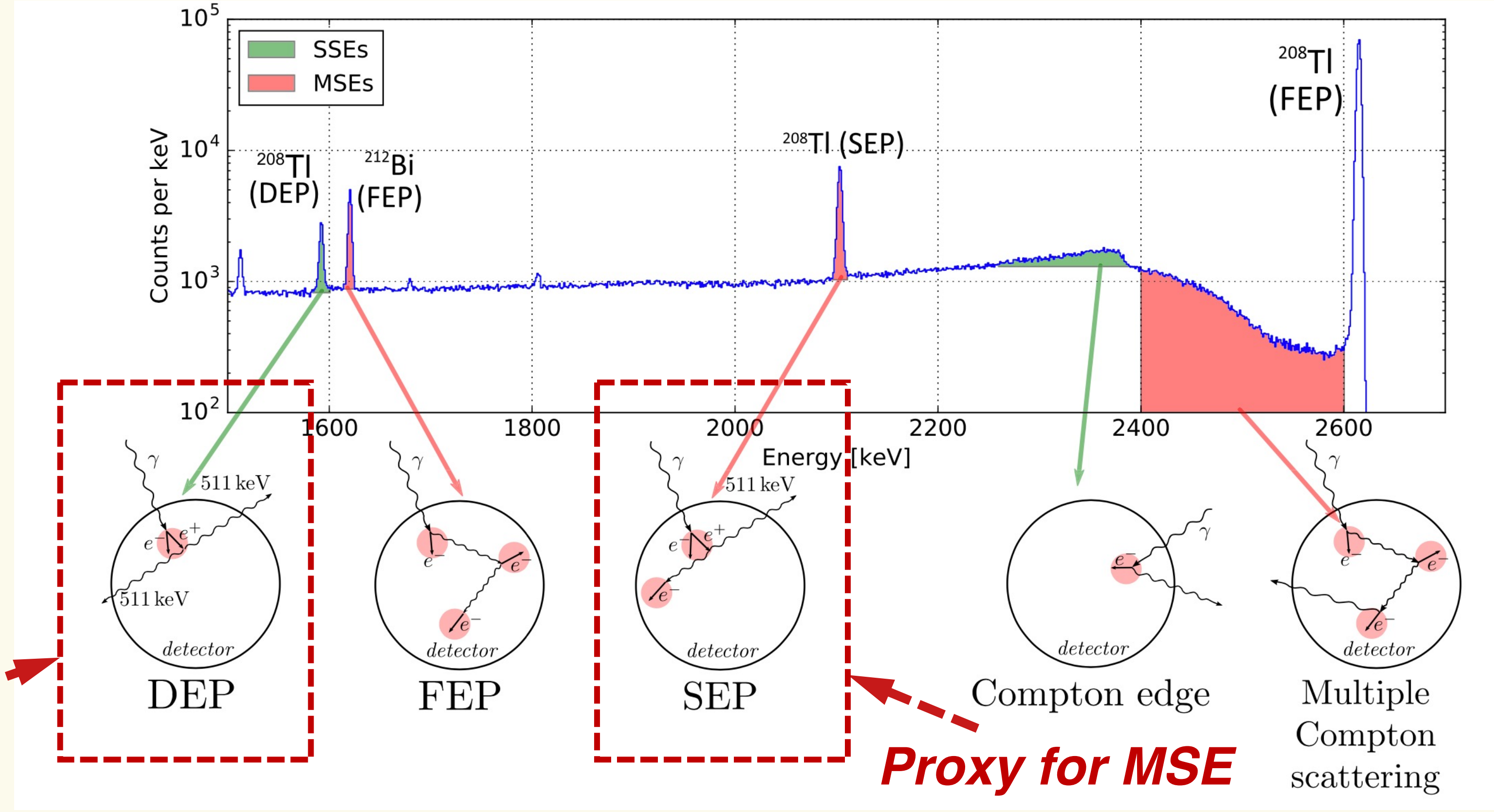
II. SSE/MSE discrimination of BEGe and PPCGe

II. SSE/MSE discrimination of PPCGe and BEGe

☐ Test method:

Calibration experiments using the Th-228 source are conducted to produce SSEs and MSEs for testing:

- **1592.5 keV DEP events:** Typical SSEs, use to determine the A/E cut region
- **2103.5 keV SEP events:** Typical MSEs, use to assess the A/E rejection power of MSEs



Proxy for SSE

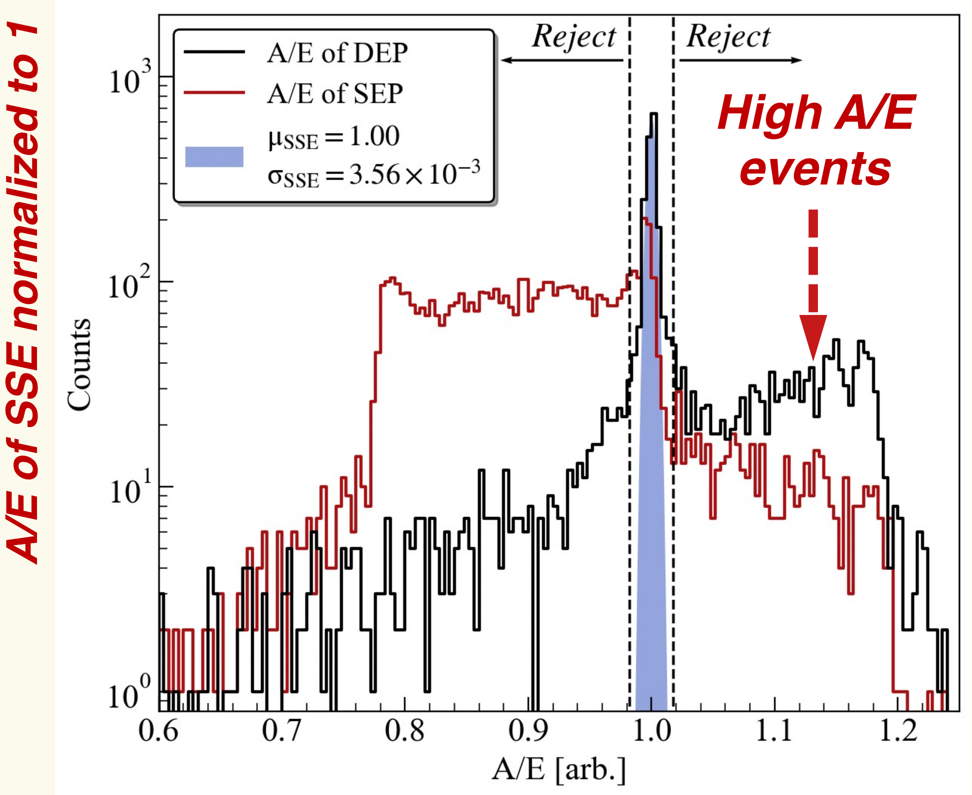
Proxy for MSE

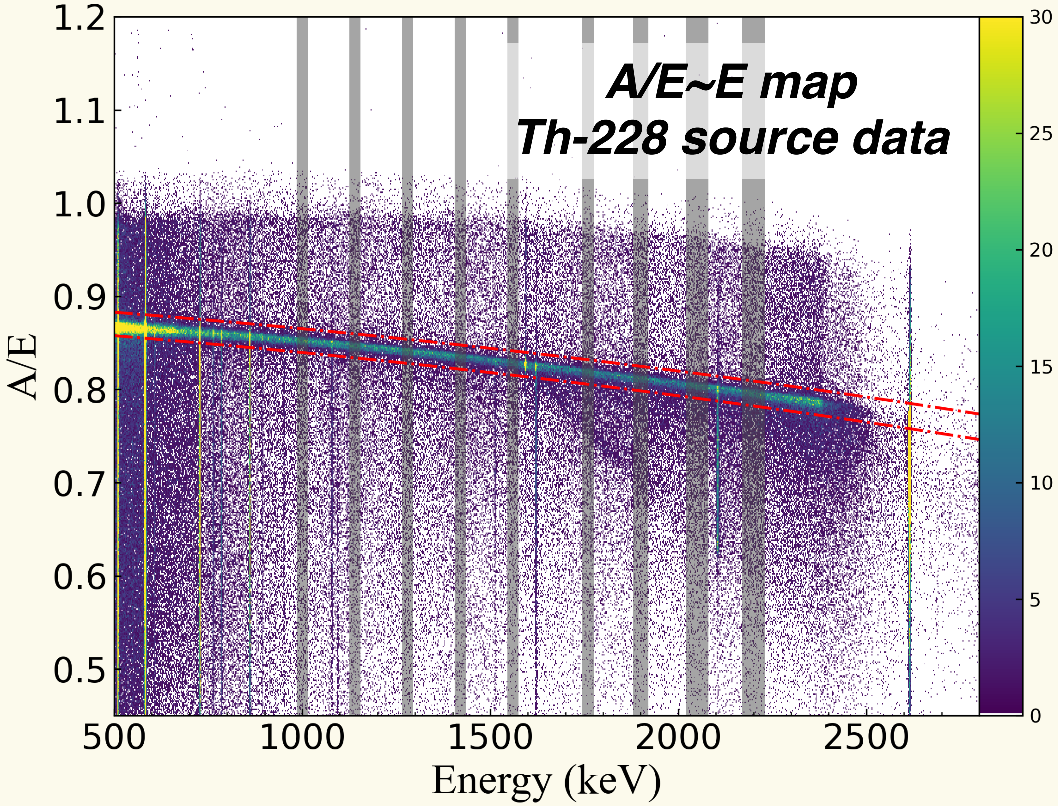
II. SSE/MSE discrimination of PPCGe and BEGe

☐ SSE/MSE discrimination power of a PPCGe (CDEX-1B) detector:

A/E acceptance region: $(A/E)_{SSE} \propto (\mu_{DEP} \pm 5\sigma_{DEP})$

- Survival fraction of DEP events: (50.6±2.3)% ***~42.6% high A/E events removed***
- Reject fraction of SEP event: (90.1±1.4)% ***~5.3% high A/E events removed***



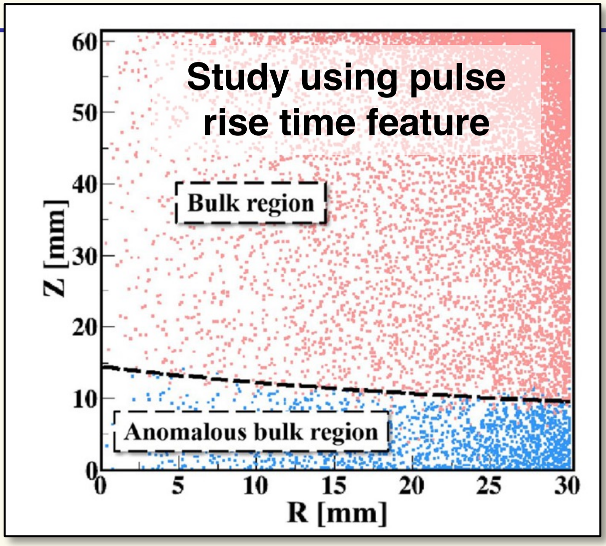


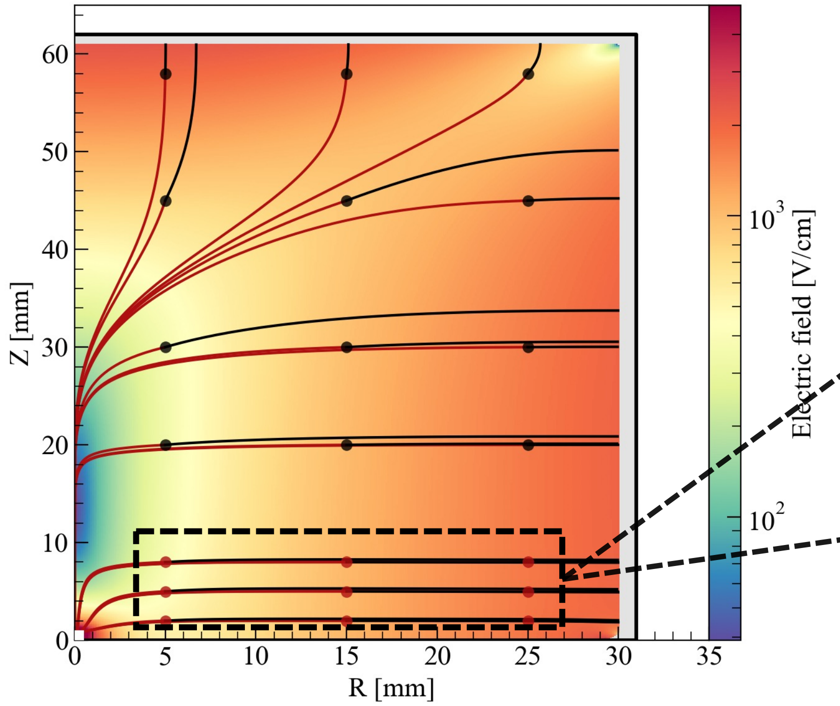
II. SSE/MSE discrimination of PPCGe and BEGe

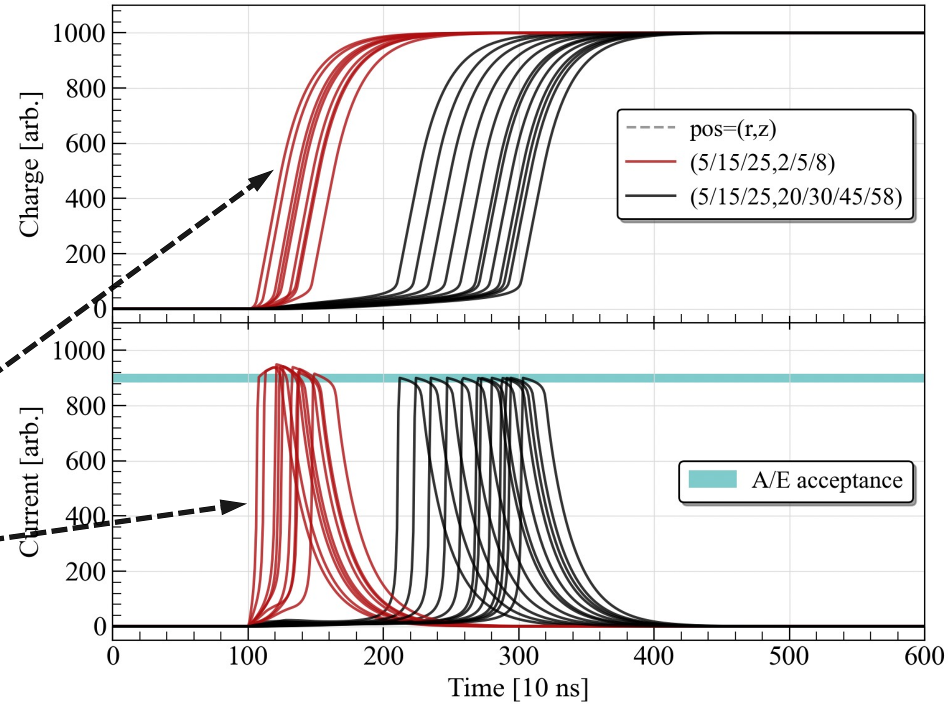
☐ High A/E events in CDEX-1B PPCGe detector:

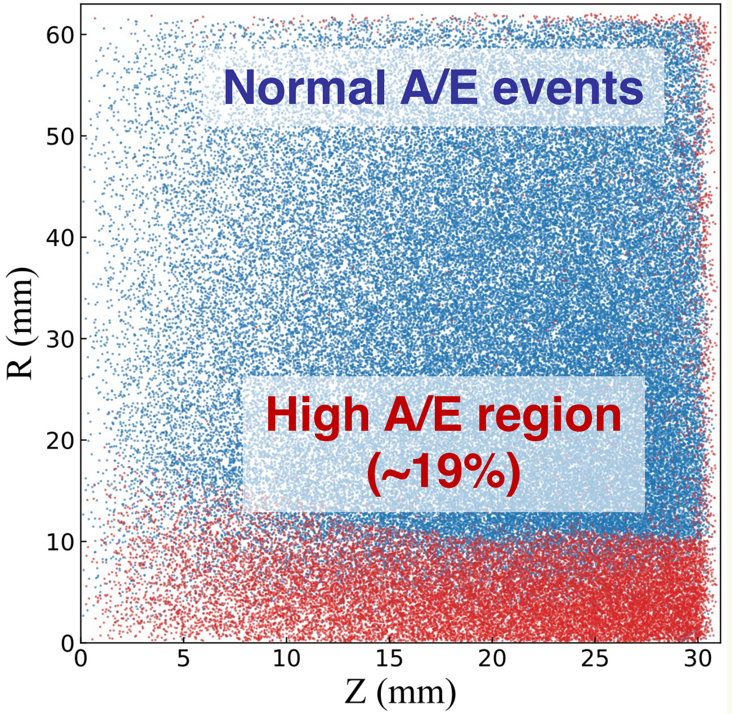
Infer the origins of the high A/E events in the CDEX-1B by PSS:

- ➢ Those events are mainly located at the bottom of the detector
- ➢ The high A/E region is about 19% of the total detector volume
- A study using pulse rise time feature is in line with this simulation









II. SSE/MSE discrimination of PPCGe and BEGe

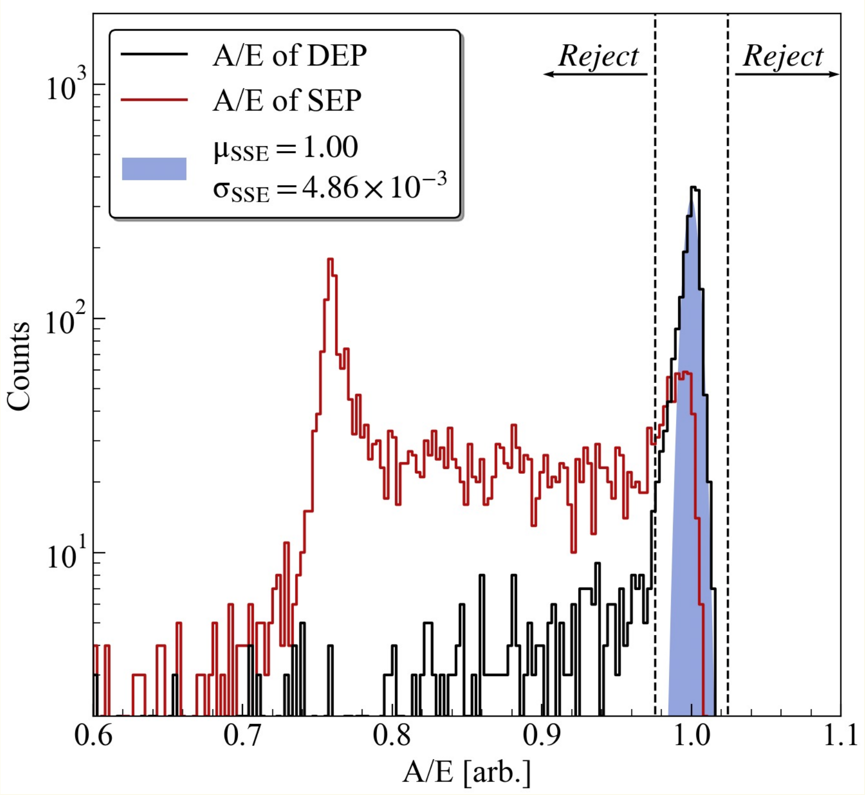
□ SSE/MSE discrimination power of a BEGe (0νββ prototype, BEGe#1) detector:

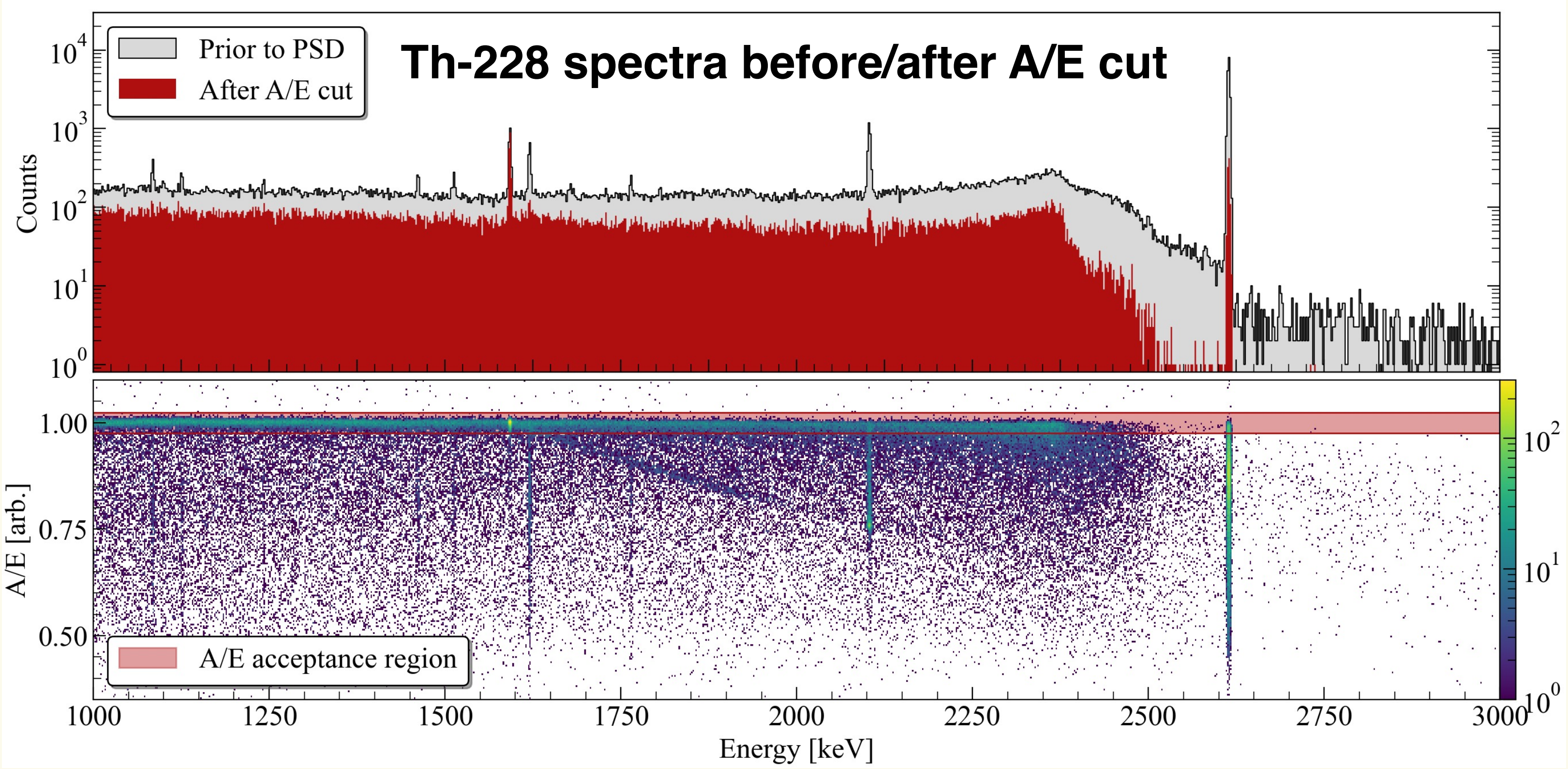
A/E acceptance region: $(A/E)_{SSE} \propto (\mu_{DEP} \pm 5\sigma_{DEP})$

- Survival fraction of DEP events: (93.1±3.3)%
- Reject fraction of SEP event: (95.1±0.5)%

Φ×H = 91.1 mm × 31.4 mm

No significant amount of high A/E events in BEGe#1





II. SSE/MSE discrimination of PPCGe and BEGe

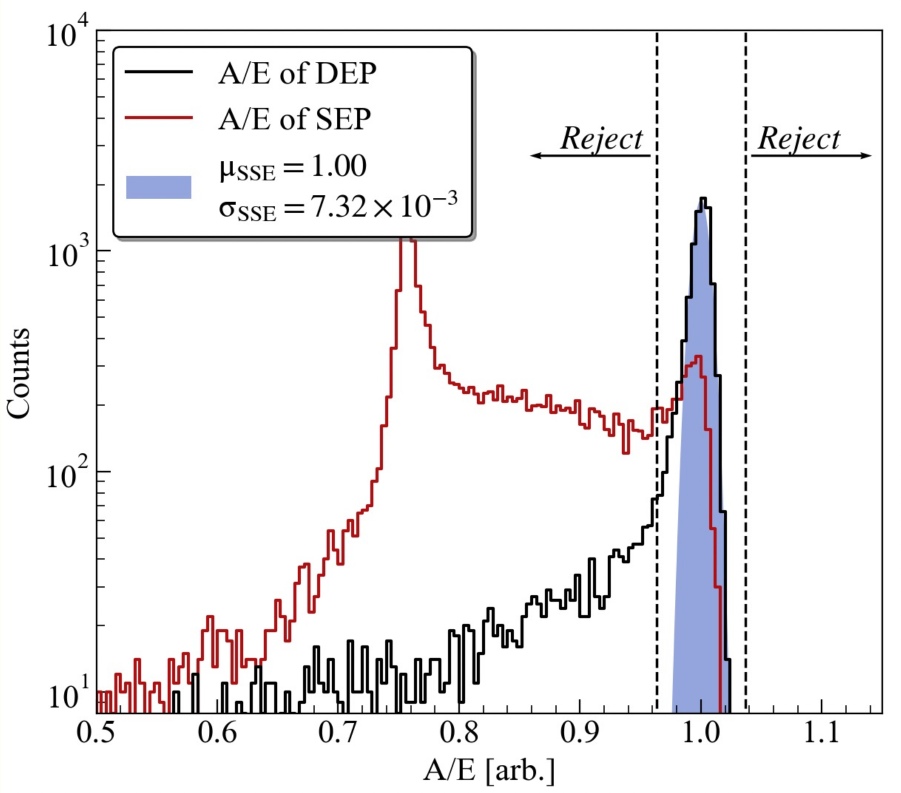
◻ SSE/MSE discrimination power of another BEGe detector (BEGe#2):

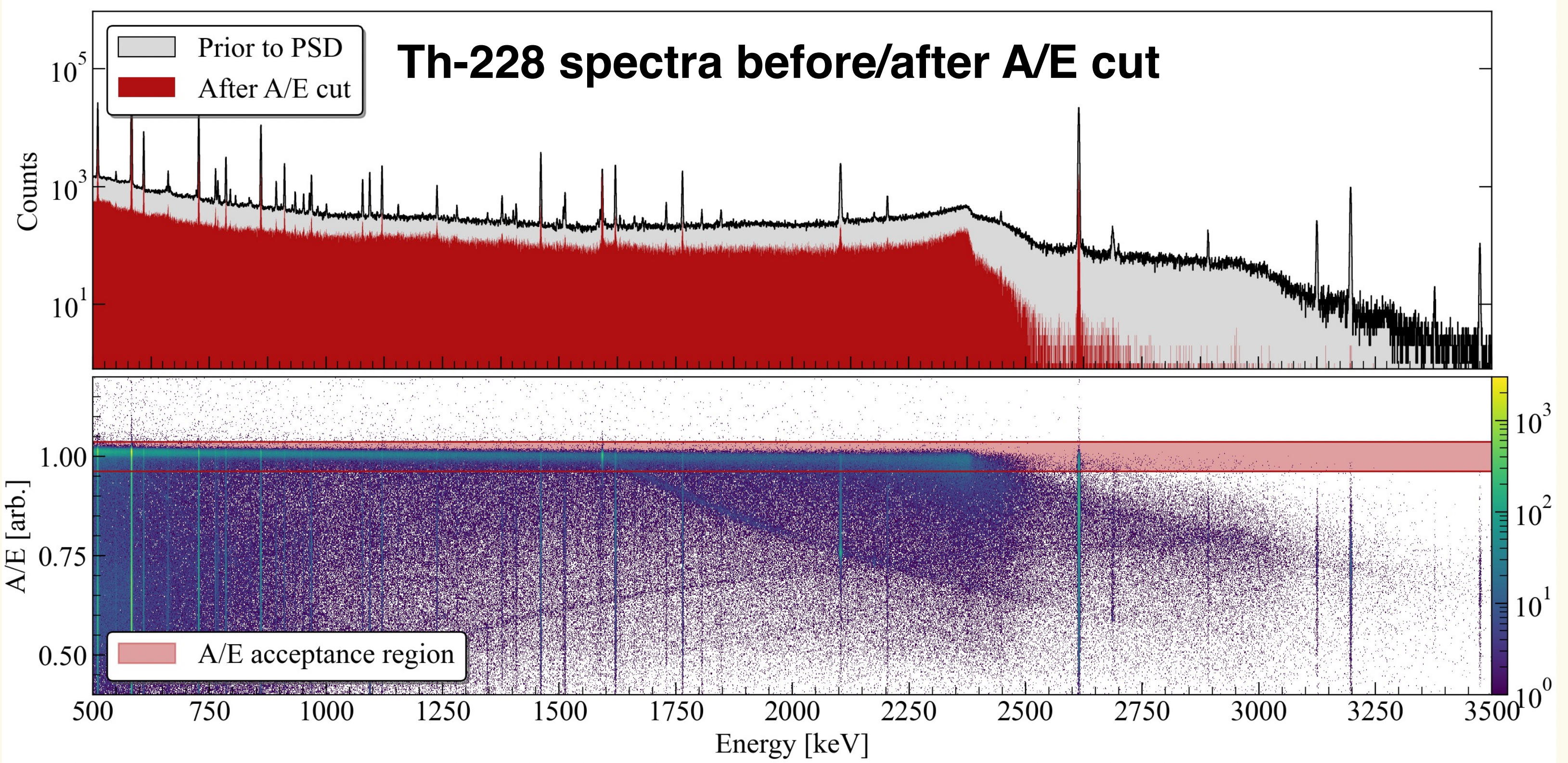
A/E acceptance region: $(A/E)_{SSE} \propto (\mu_{DEP} \pm 5\sigma_{DEP})$

- Survival fraction of DEP events: (94.8±2.7)%
- Reject fraction of SEP event: (94.2±0.3)%

Φ×H = 80 mm × 42.6 mm

No significant amount of high A/E events in BEGe#2





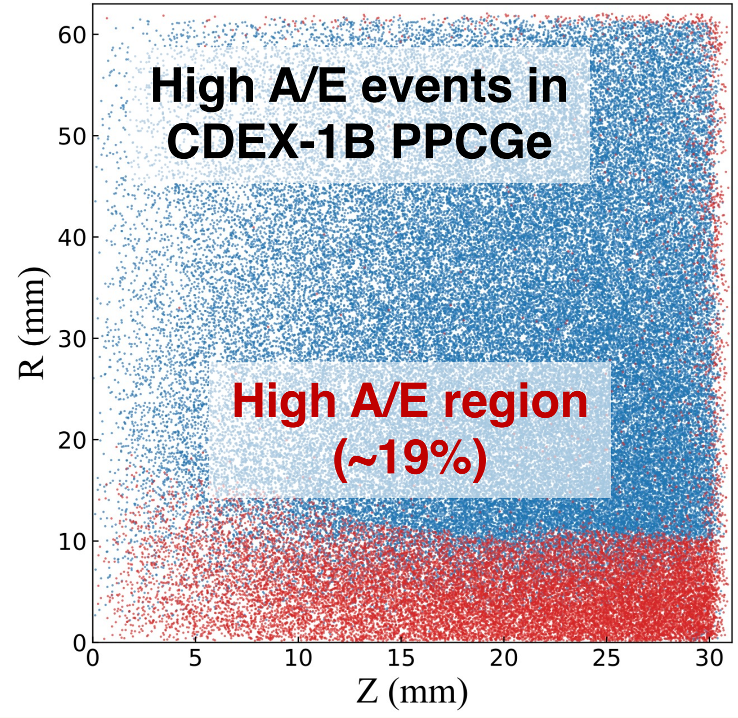
II. SSE/MSE discrimination of PPCGe and BEGe

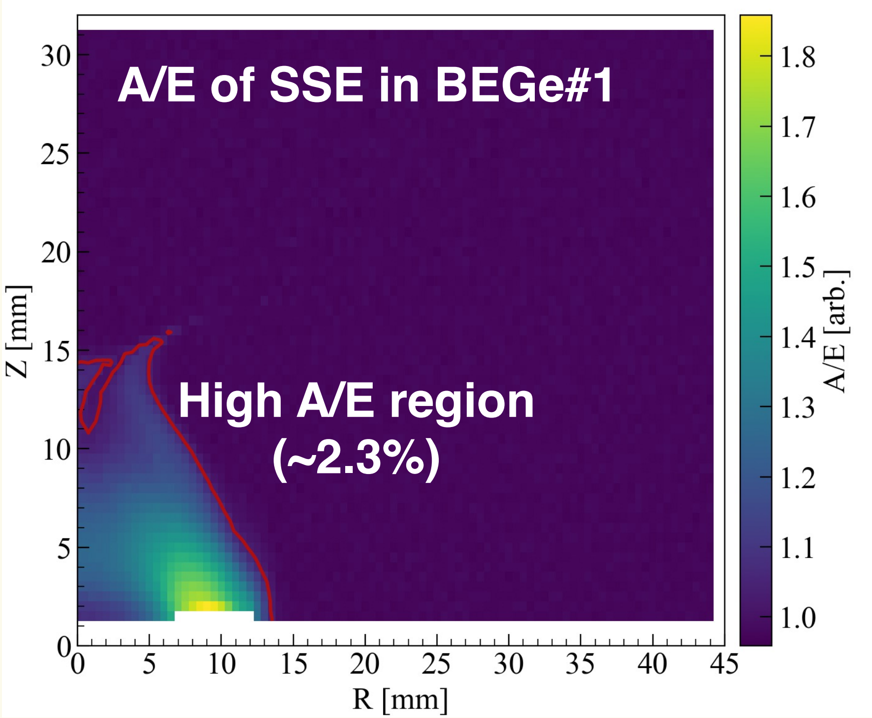
◻ High A/E events in the PPCGe and BEGe detectors:

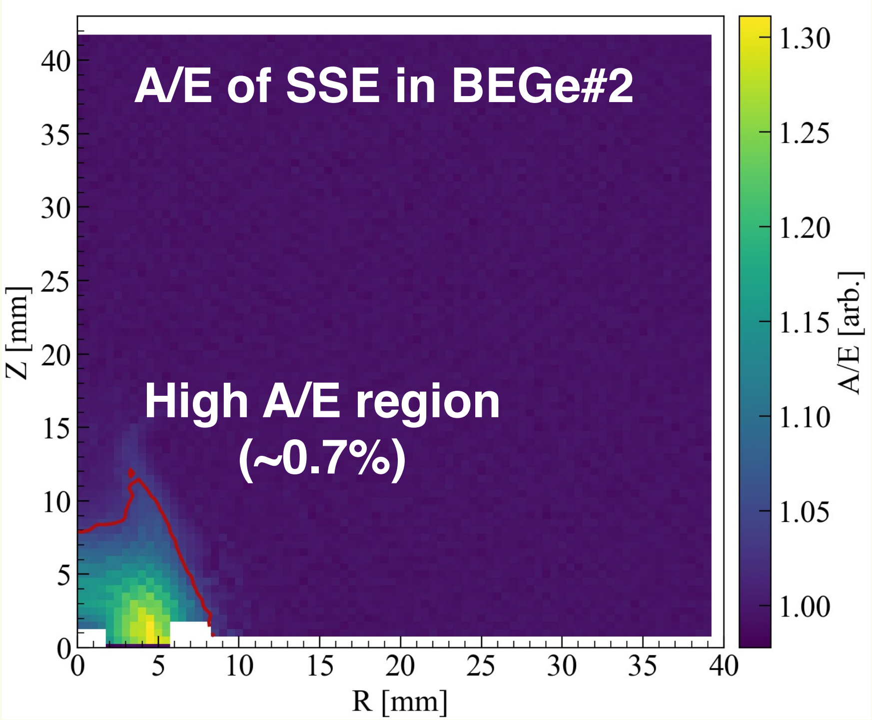
SSEs are placed in different positions of the detector to assess their A/E values via PSS

- For the CDEX-1B PPCGe: high A/E events originate at the bottom of the detector (~ 19% volume)
- For two BEGe detectors: high A/E events originate at a small region near the p+ contact (0.7~2.3% volume)

The volume of the high A/E region mainly depends on detector geometry and the size of the p+ contact







II. SSE/MSE discrimination of PPCGe and BEGe

□ Comparison of SSE/MSE discrimination power in PPCGe and BEGe:

- The A/E cut performances of two BEGe detectors are similar

The low DEP survival fraction of the CDEX-1B is mainly due to large amounts of high A/E events

	PPCGe (CDEX-1B)	BEGe (#1)	BEGe (#2)
Geometry (Φ×H)	62.2 mm × 62.3 mm	91.1 mm × 31.4 mm	80 mm × 42.6 mm
Survival of DEP	50.6±2.3 %	93.1±3.3 %	93.0±0.5 %
Rejection of SEP	90.1±1.4 %	95.1±0.5 %	94.5±0.1 %

II. SSE/MSE discrimination of PPCGe and BEGe

☐ Comparison of SSE/MSE discrimination power in PPCGe and BEGe:

- The A/E cut performances of two BEGe detectors are similar

If keep high A/E events, CDEX-1B has a similar DEP survival rate and a lower rejection rate with BEGe

	PPCGe (CDEX-1B) (keep high A/E event)	BEGe (#1)	BEGe (#2)
Geometry (Φ×H)	62.2 mm × 62.3 mm	91.1 mm × 31.4 mm	80 mm × 42.6 mm
Survival of DEP	93.2±3.8 %	93.1±3.3 %	93.0±0.5 %
Rejection of SEP	84.8±2.3 %	95.1±0.5 %	94.5±0.1 %

III. Pulse matching via pulse shape simulation

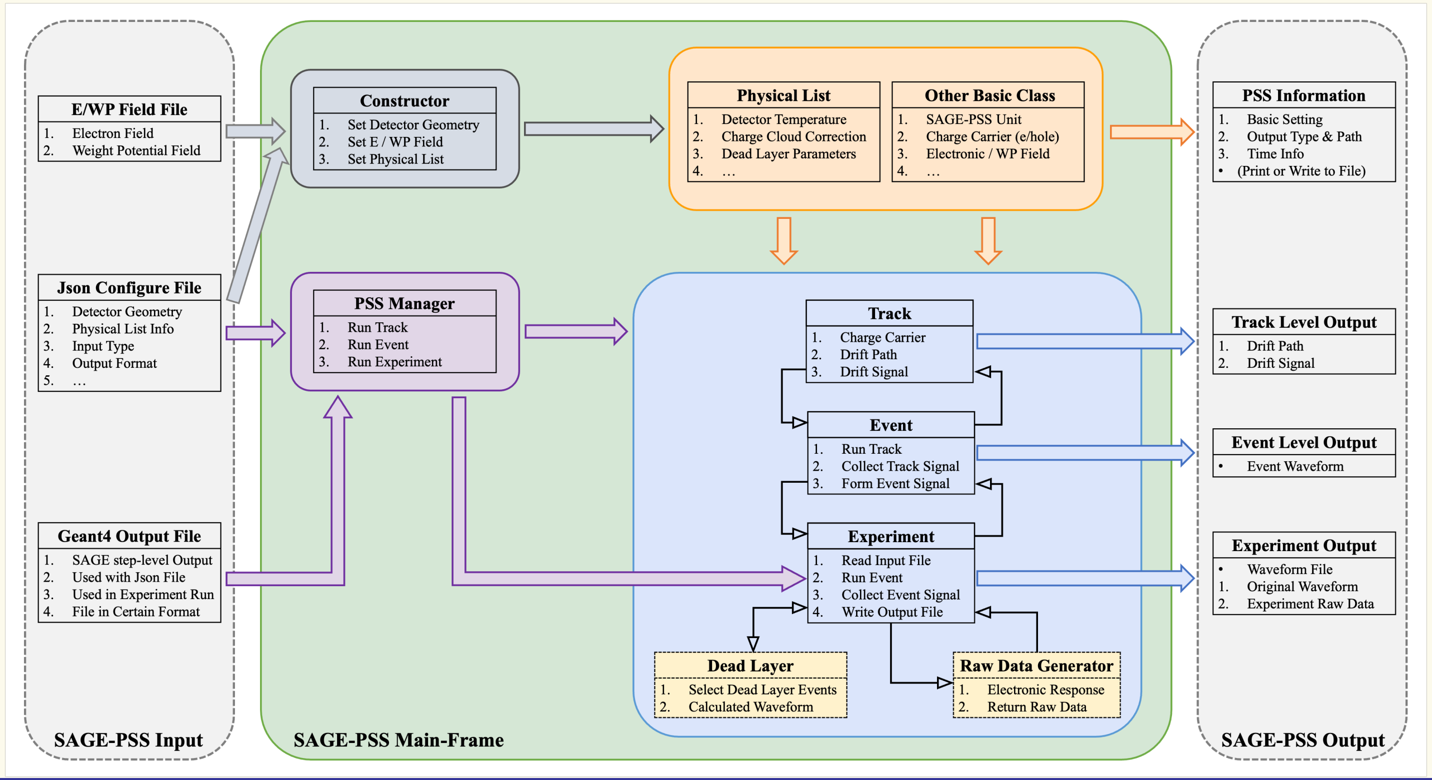
III. Pulse matching via PSS

❑ The basic idea of pulse matching:

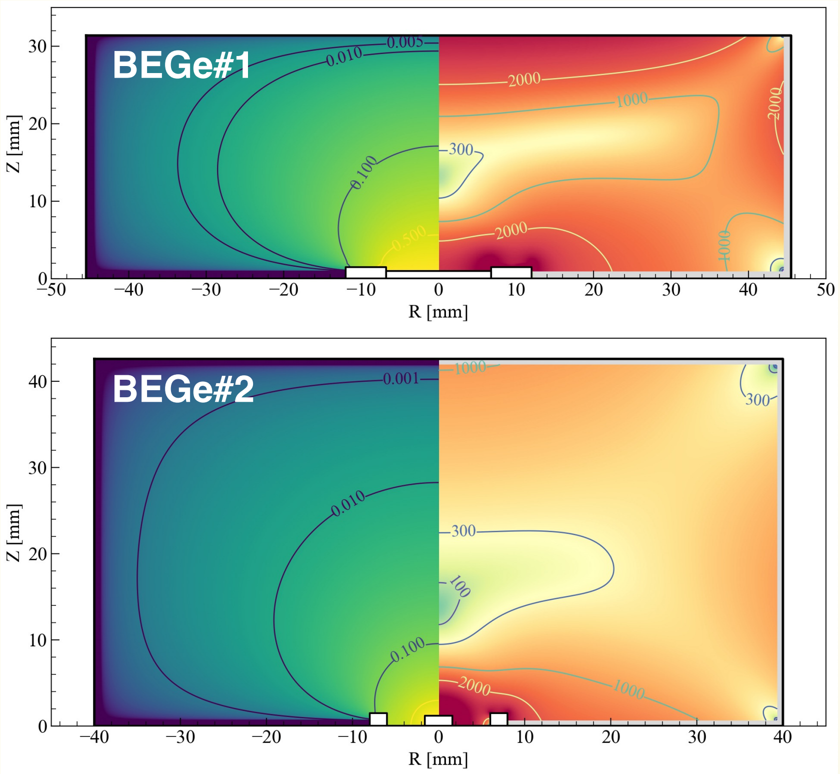
- ➢ Pulse library: simulate output pulses for SSEs in different positions of the detector @ SAGE-PSS
- ➢ Compare the measured pulse with simulated pulses and select the best match result

The position of the best-match pulse can be used to infer the position of the measured pulse

SAGE-PSS simulation toolkit



Electric / Potential Fields



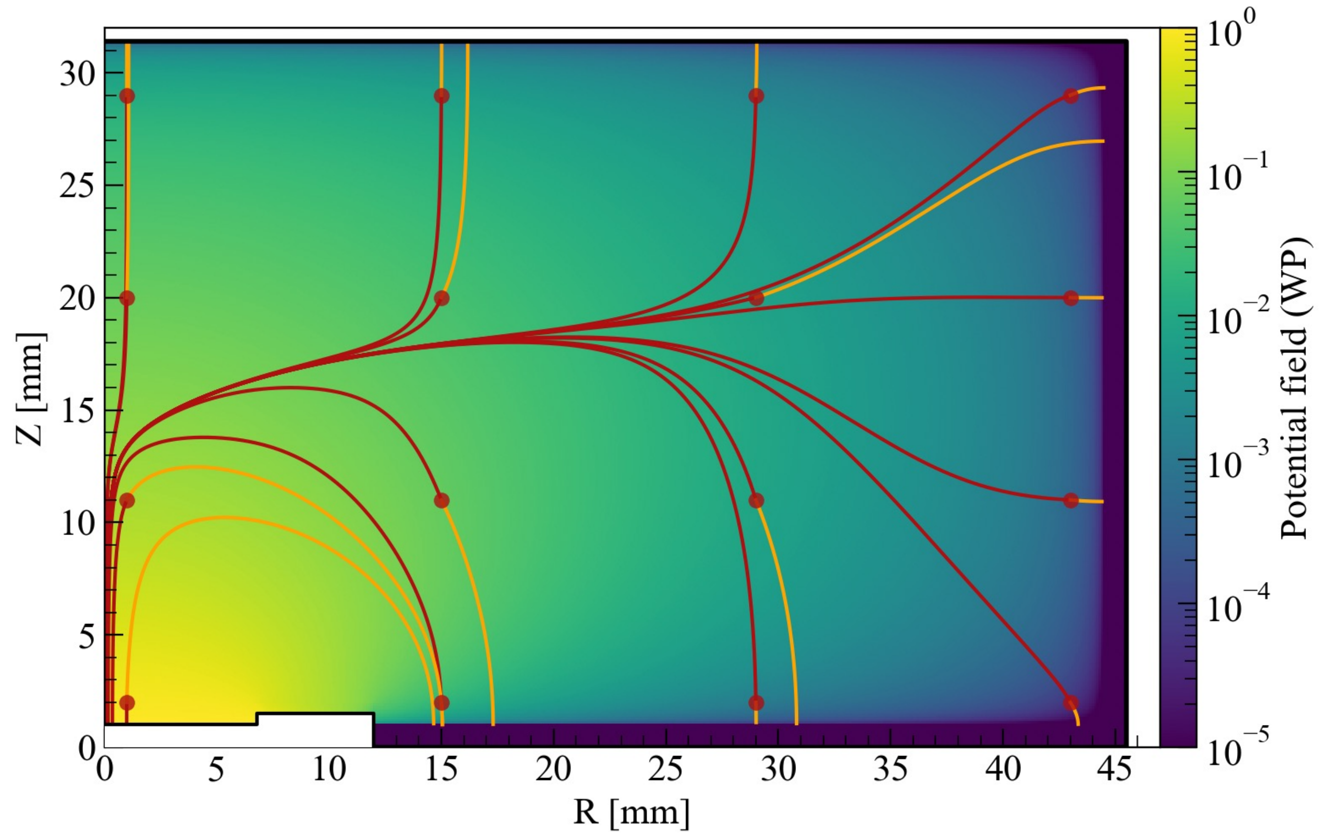
III. Pulse matching via PSS

☐ Apply pulse matching in BEGe detectors: (BEGe#1)

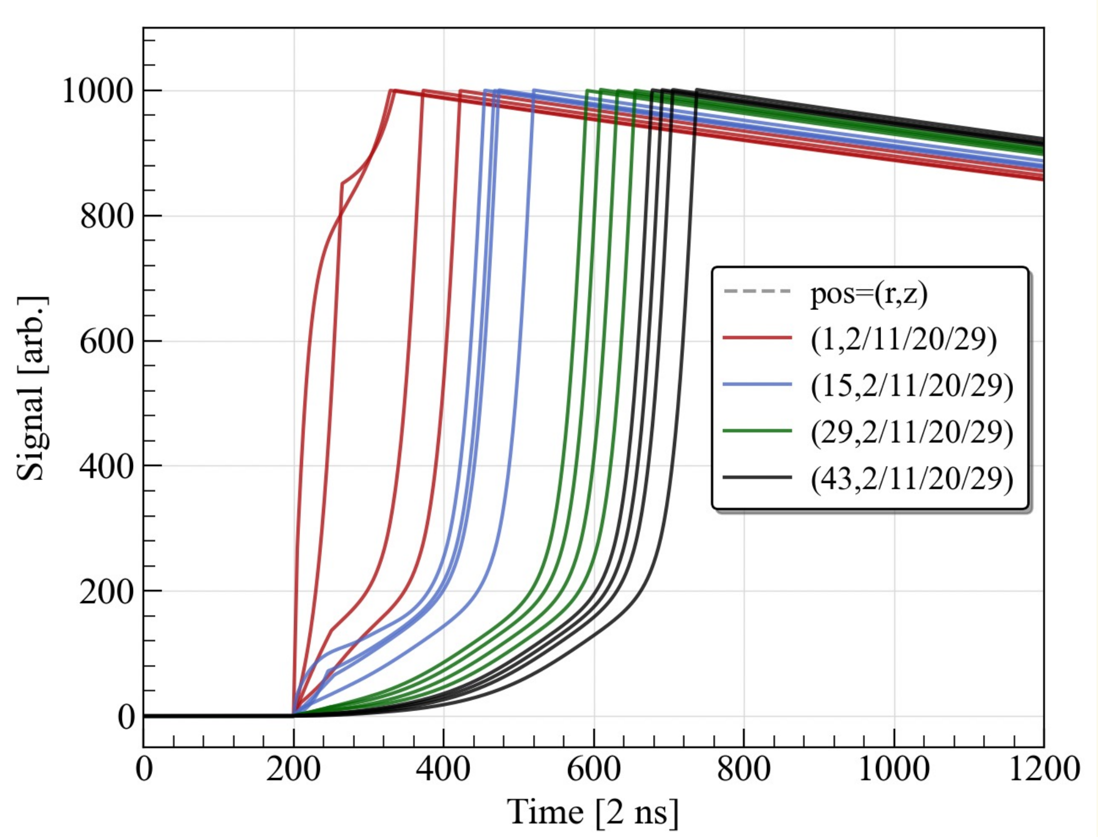
- ➢ Construct pulse library: simulate SSE pulses in different positions (0.5 mm step in R and Z directions)

Figure below demonstrates pulses selected from the library and their corresponding charge carrier draft paths

Charge carriers drift path of SSE in the library

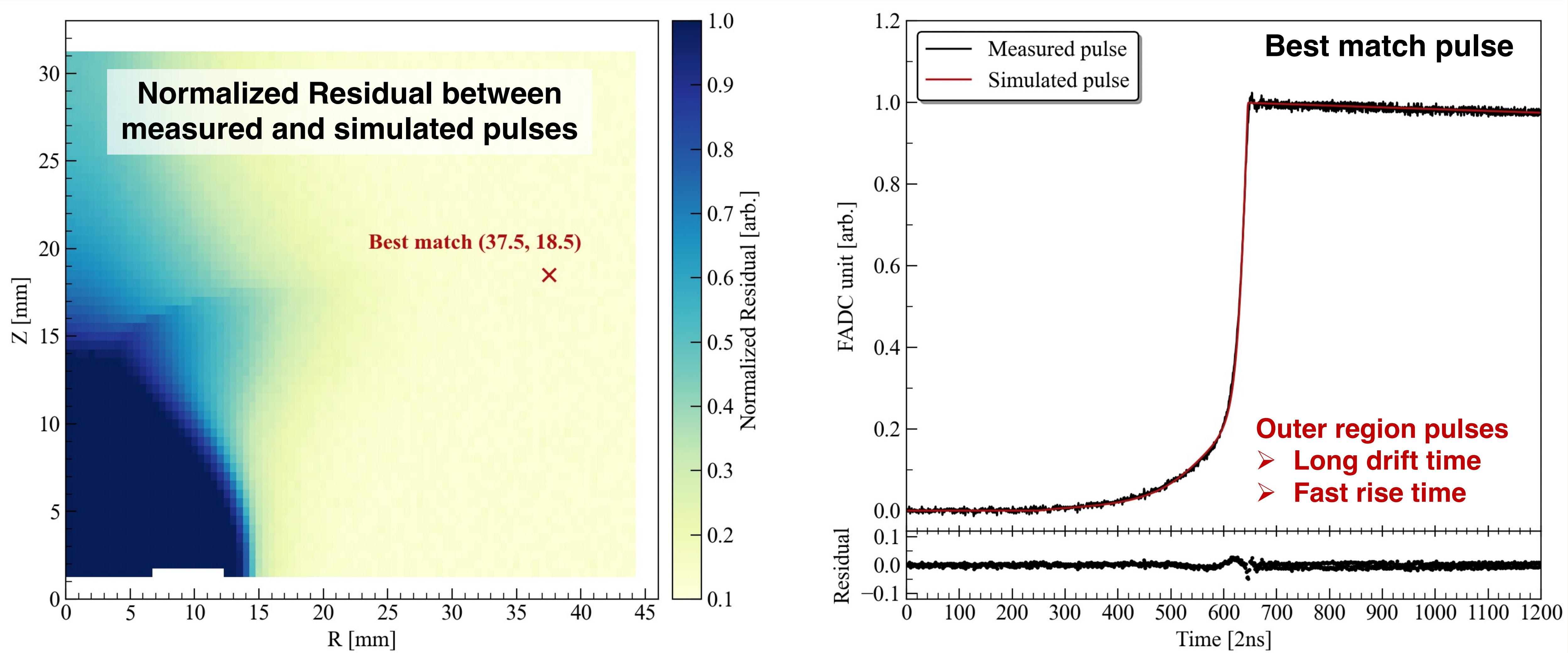


Simulated pulse in the library



☐ Match measured pulses with simulated pulses in the library: (BEGe#1)

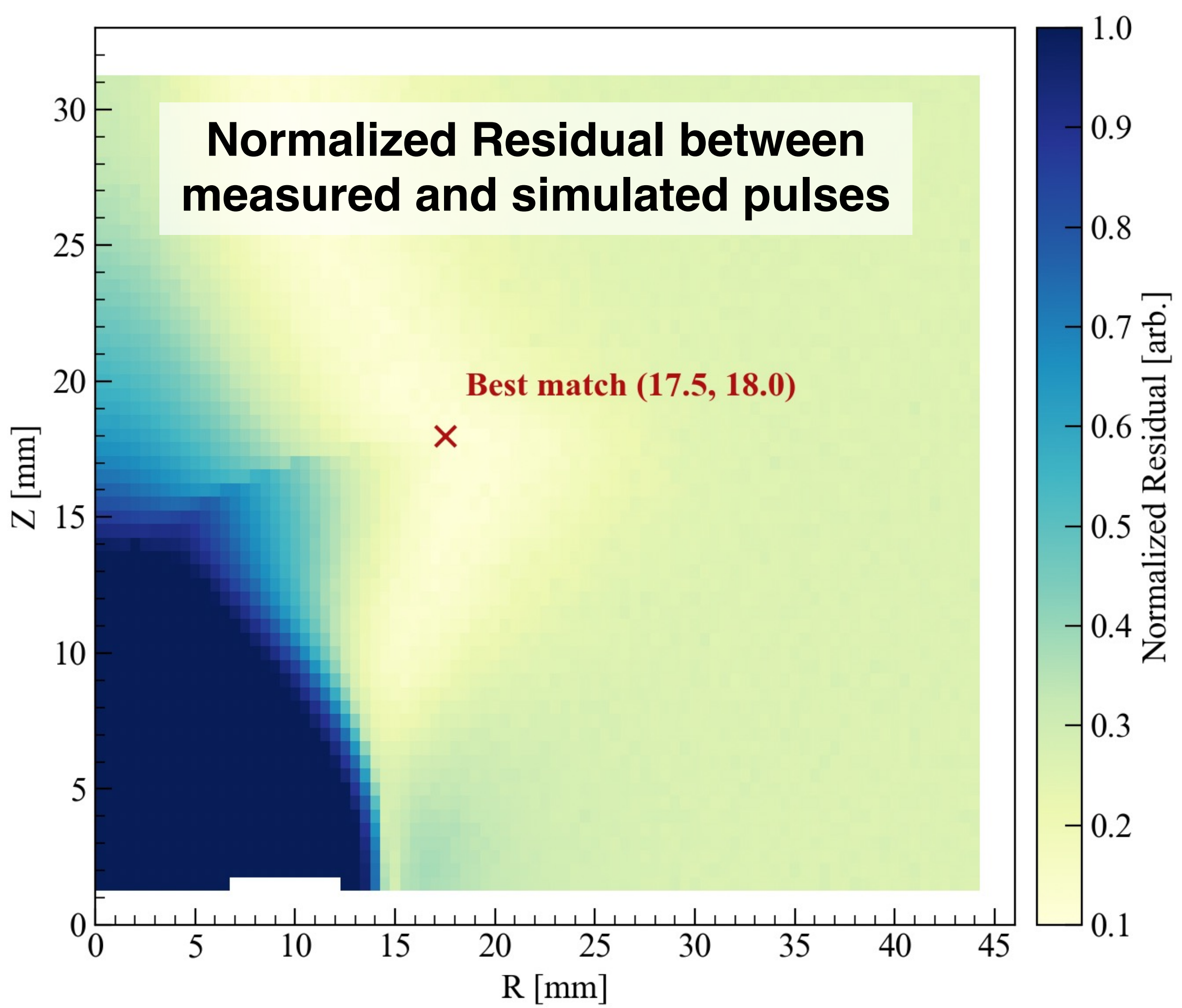
- ➢ **Type-I pulses: pulses origin in the outer region of the detector**

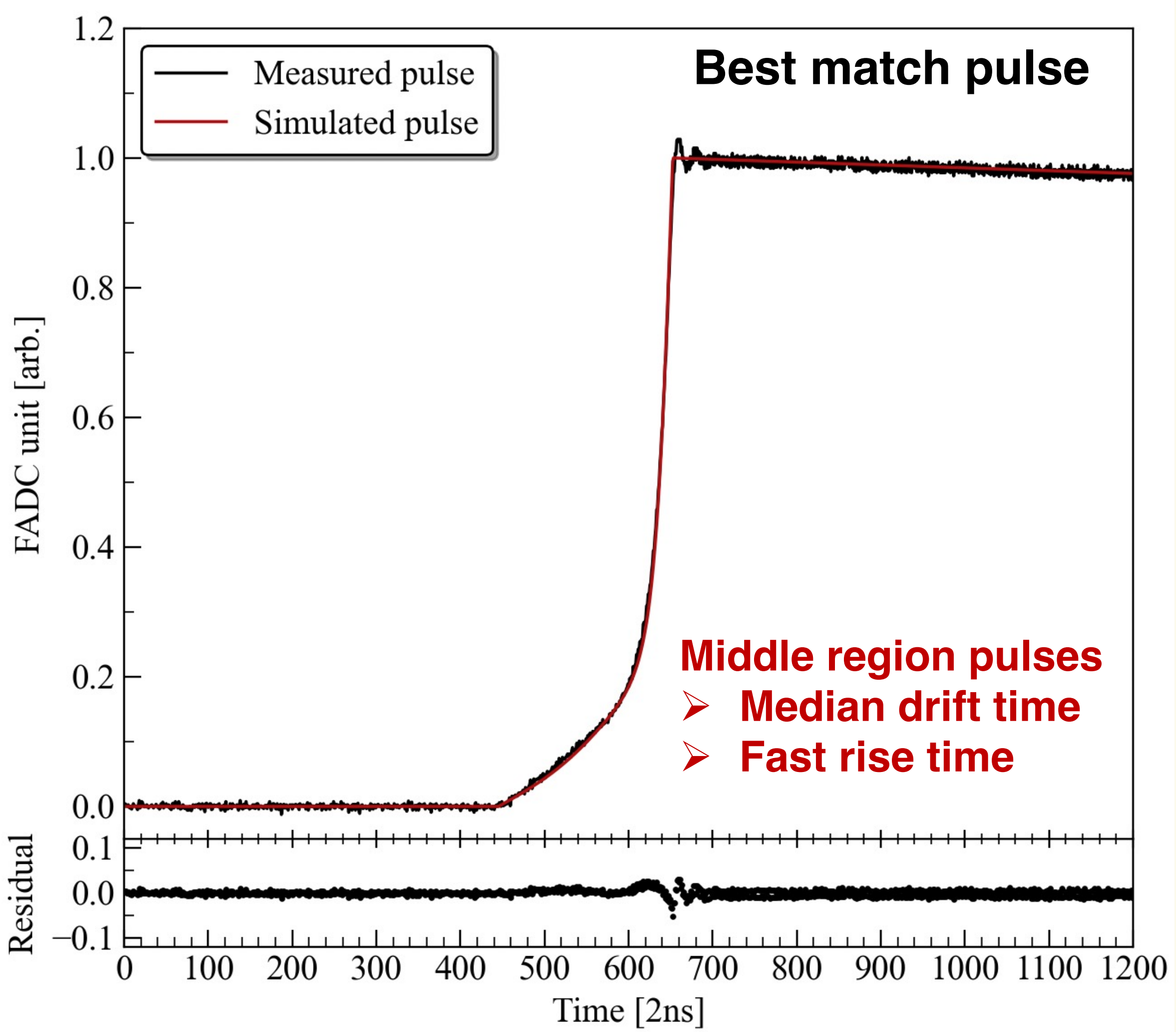


III. Pulse matching via PSS

☐ Match measured pulses with simulated pulses in the library: (BEGe#1)

- ➢ **Type-II pulses: pulses origin in the middle region of the detector**

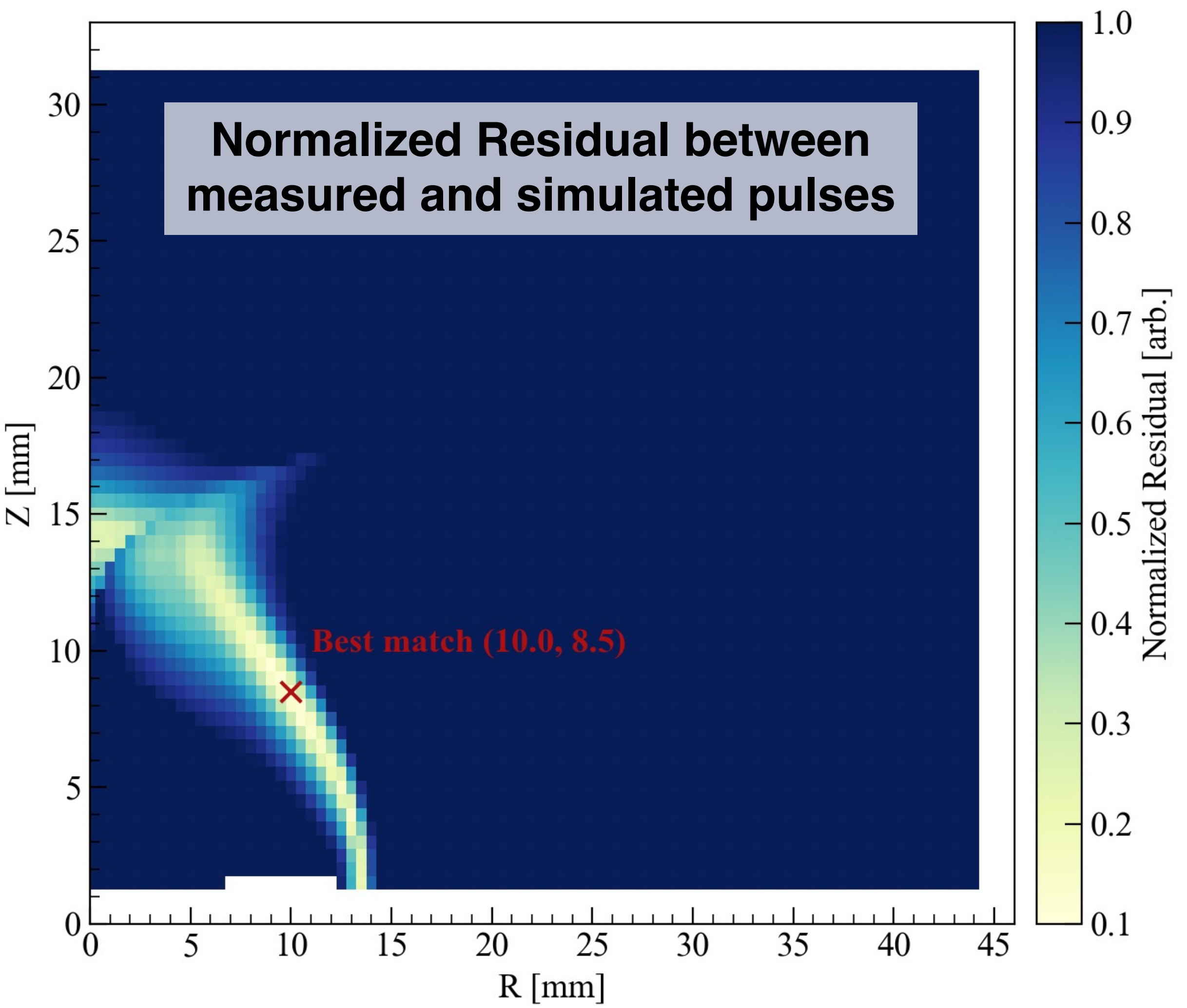


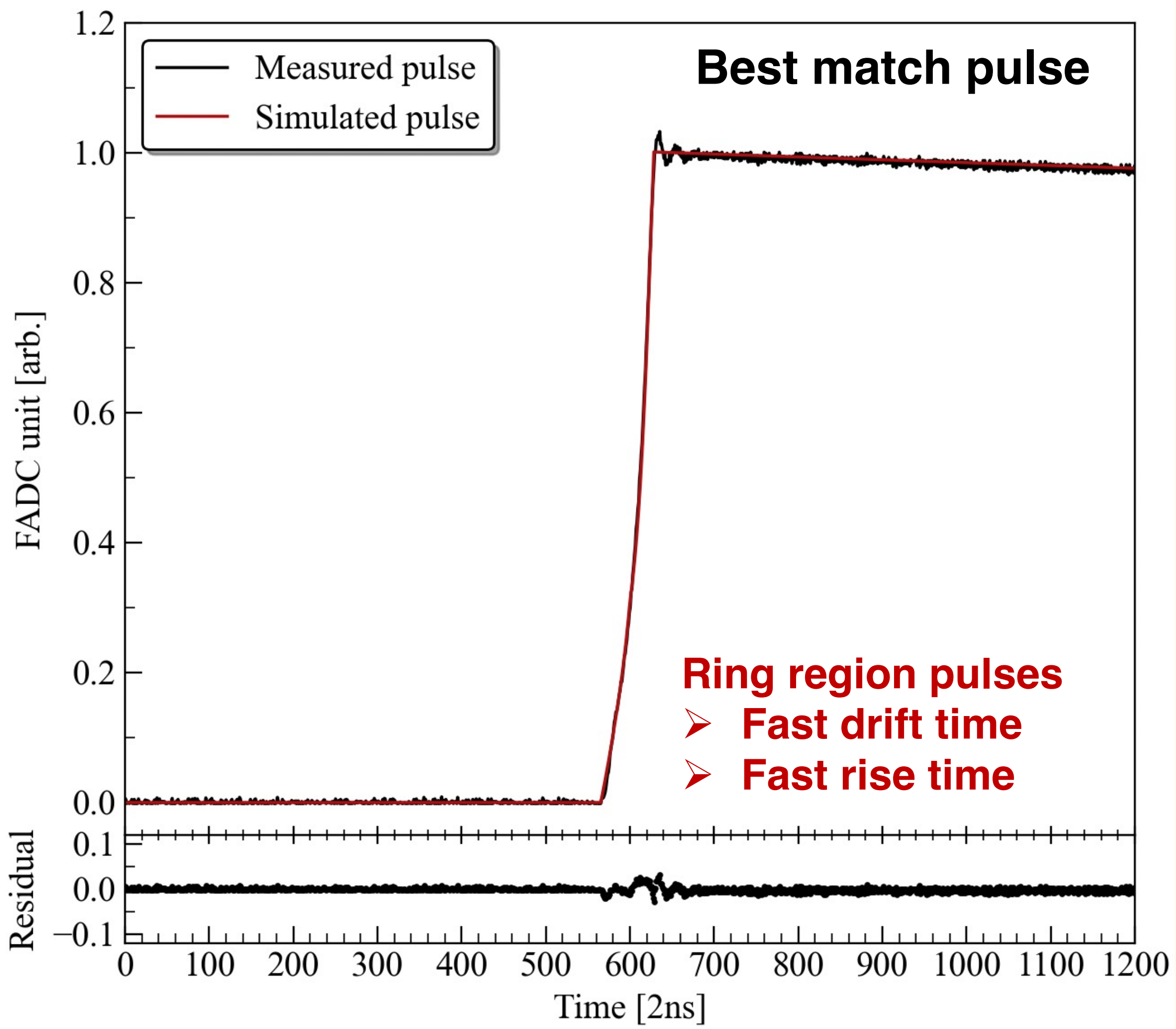


III. Pulse matching via PSS

☐ Match measured pulses with simulated pulses in the library: (BEGe#1)

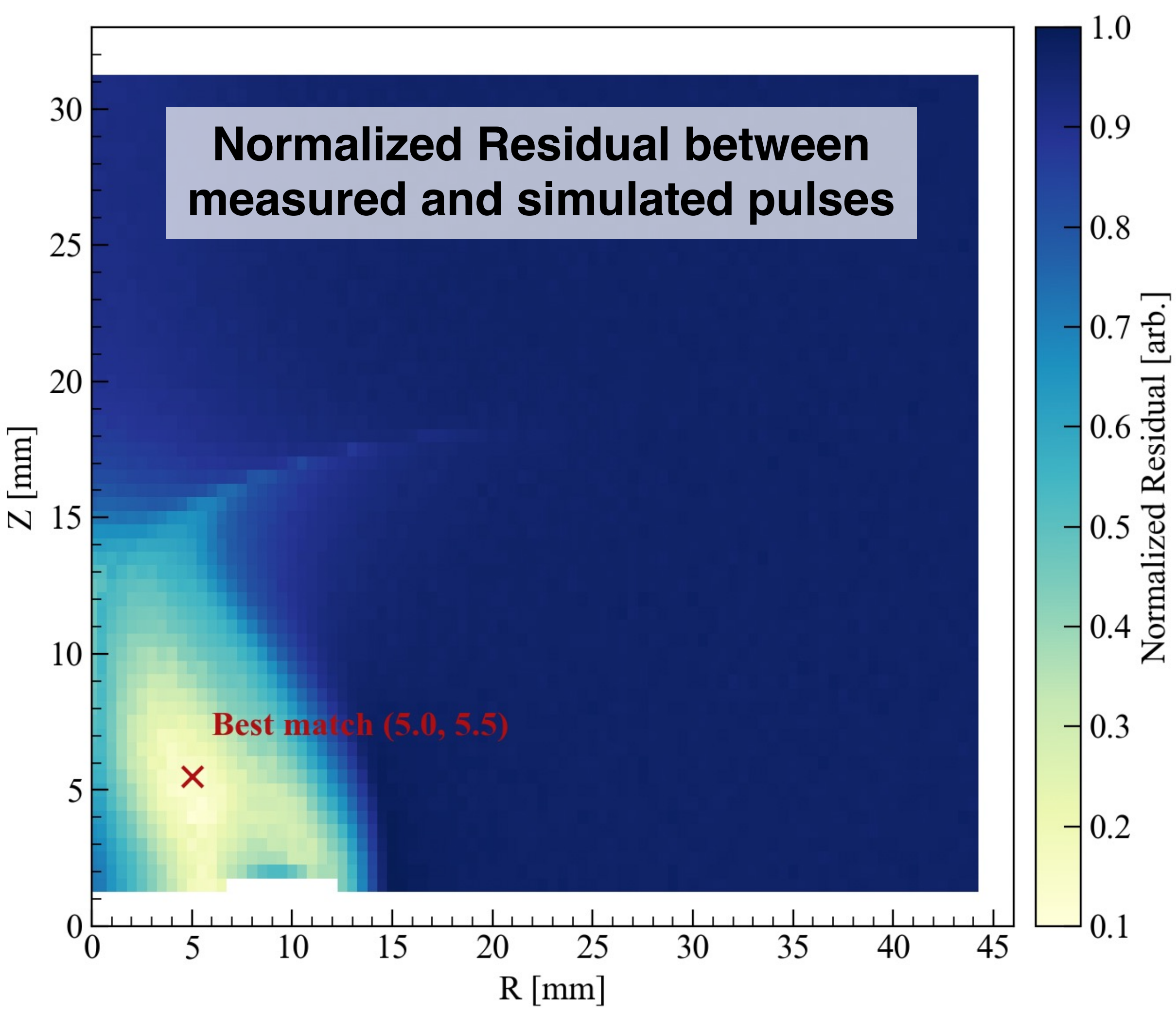
- ➢ **Type-III pulses: pulses origin in the inner ring region near the p+ contact**

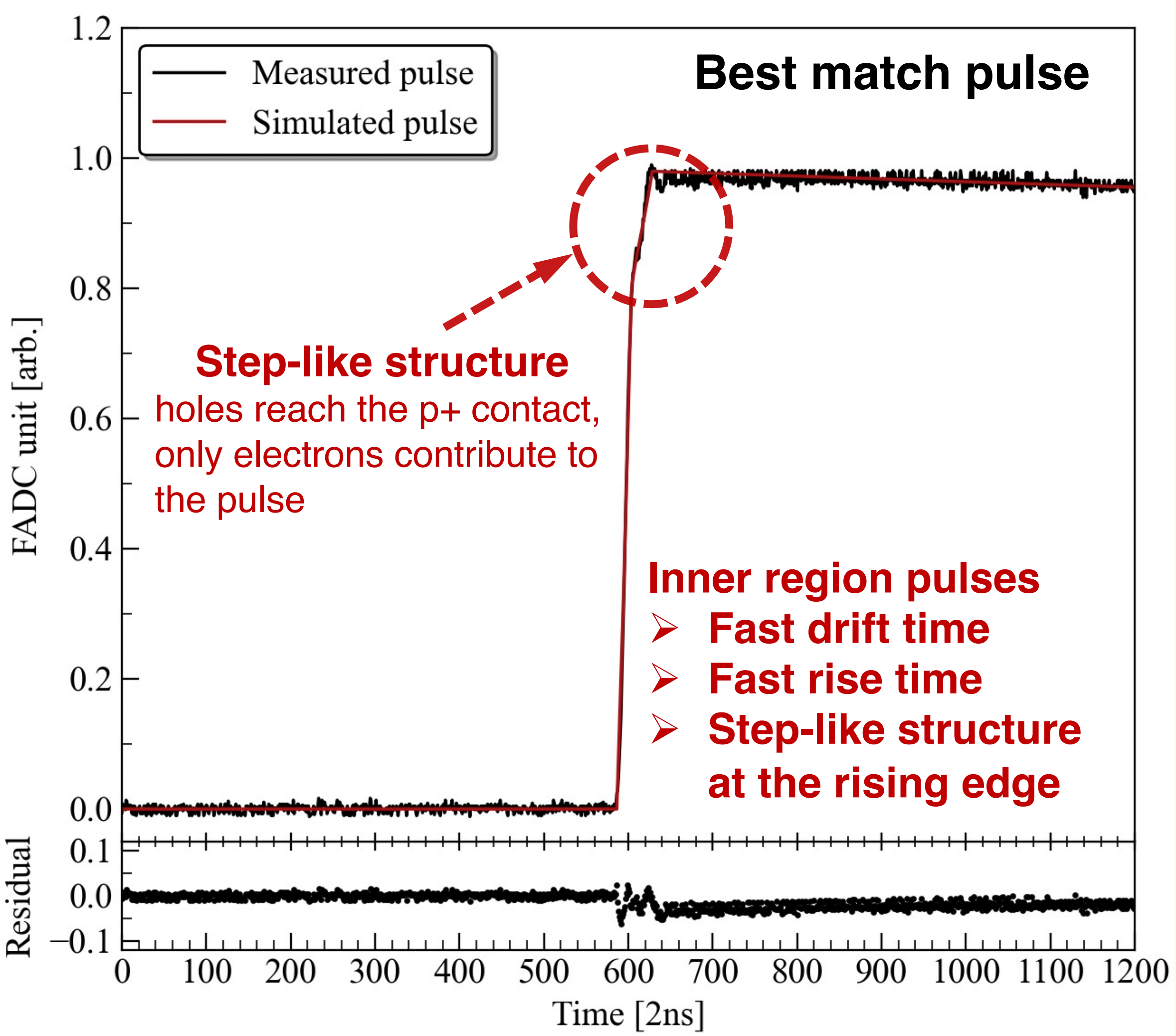




III. Pulse matching via PSS

- Match measured pulses with simulated pulses in the library: (BEGe#1)
  - Type-IV pulses: pulses origin in the inner region near the p+ contact





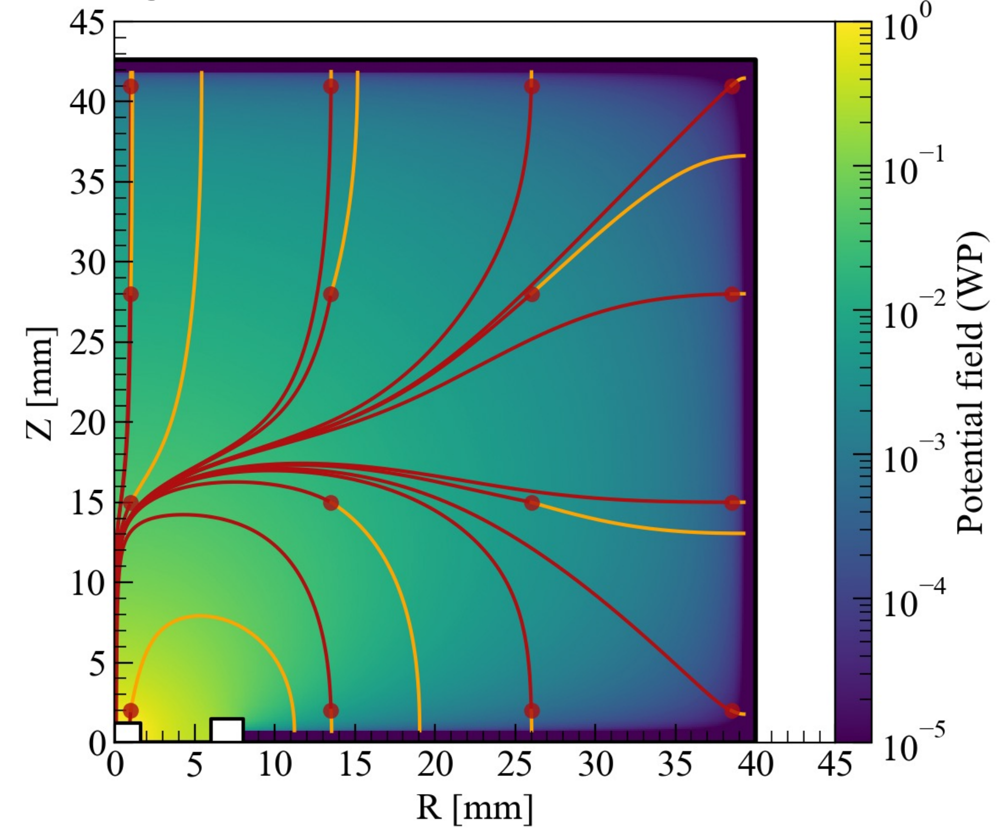
III. Pulse matching via PSS

☐ Apply pulse matching in BEGe detectors: (BEGe#2)

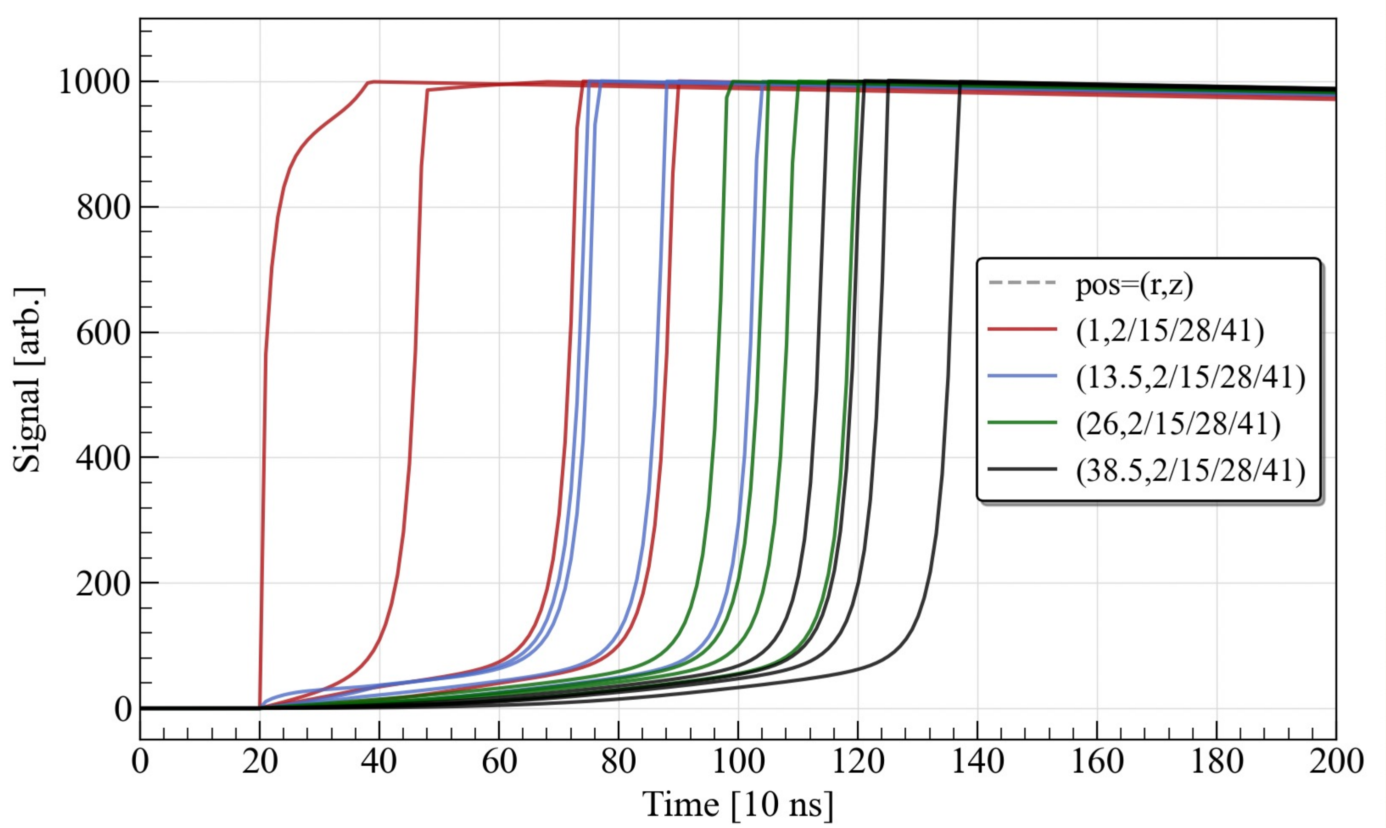
- Construct pulse library: simulate SSE pulses in different positions (0.5 mm step in R and Z directions)

BEGe#2 has a smaller p+ contact and different R/H ratio compare to BEGe#1

Charge carriers drift path of SSE in the library

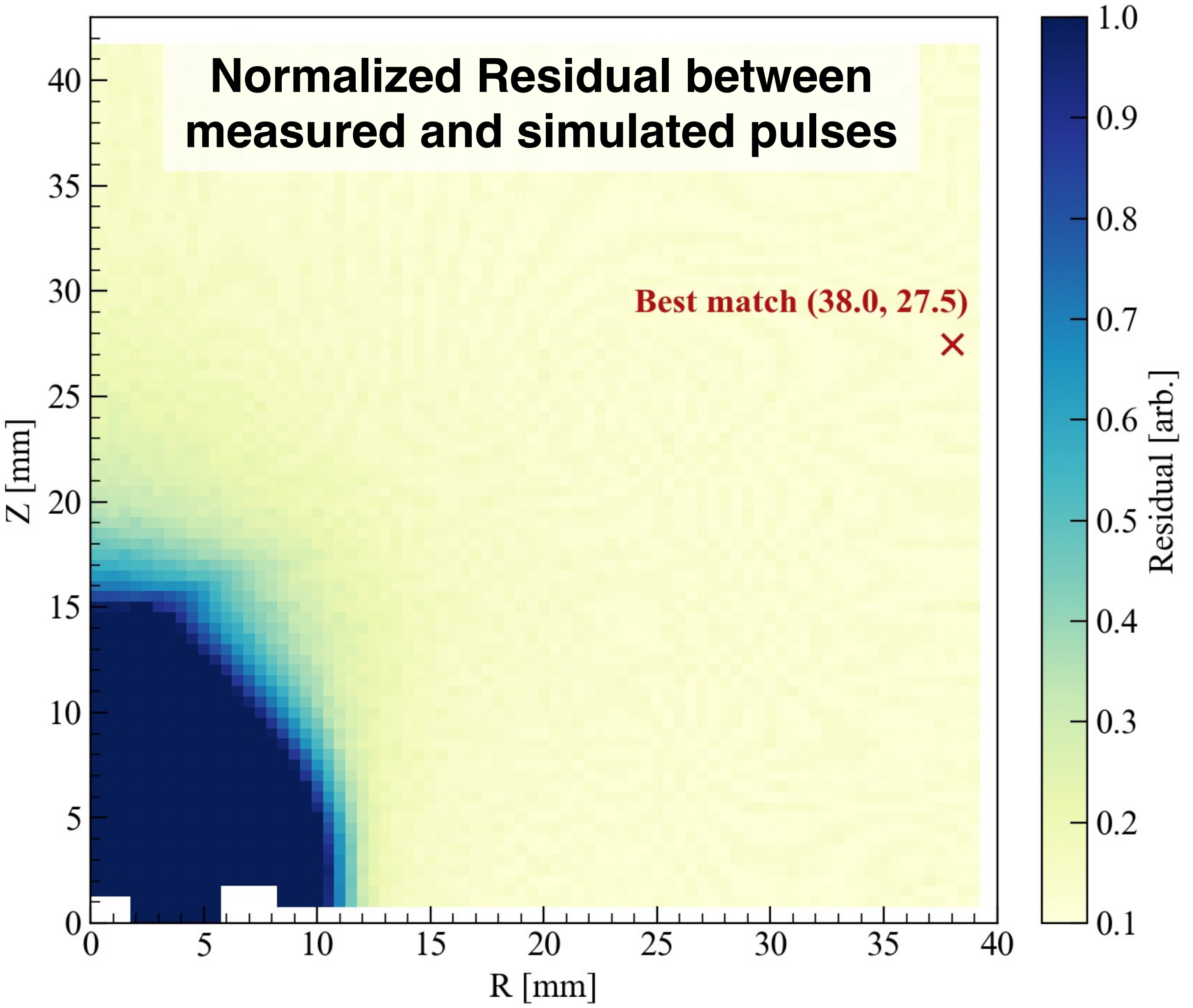


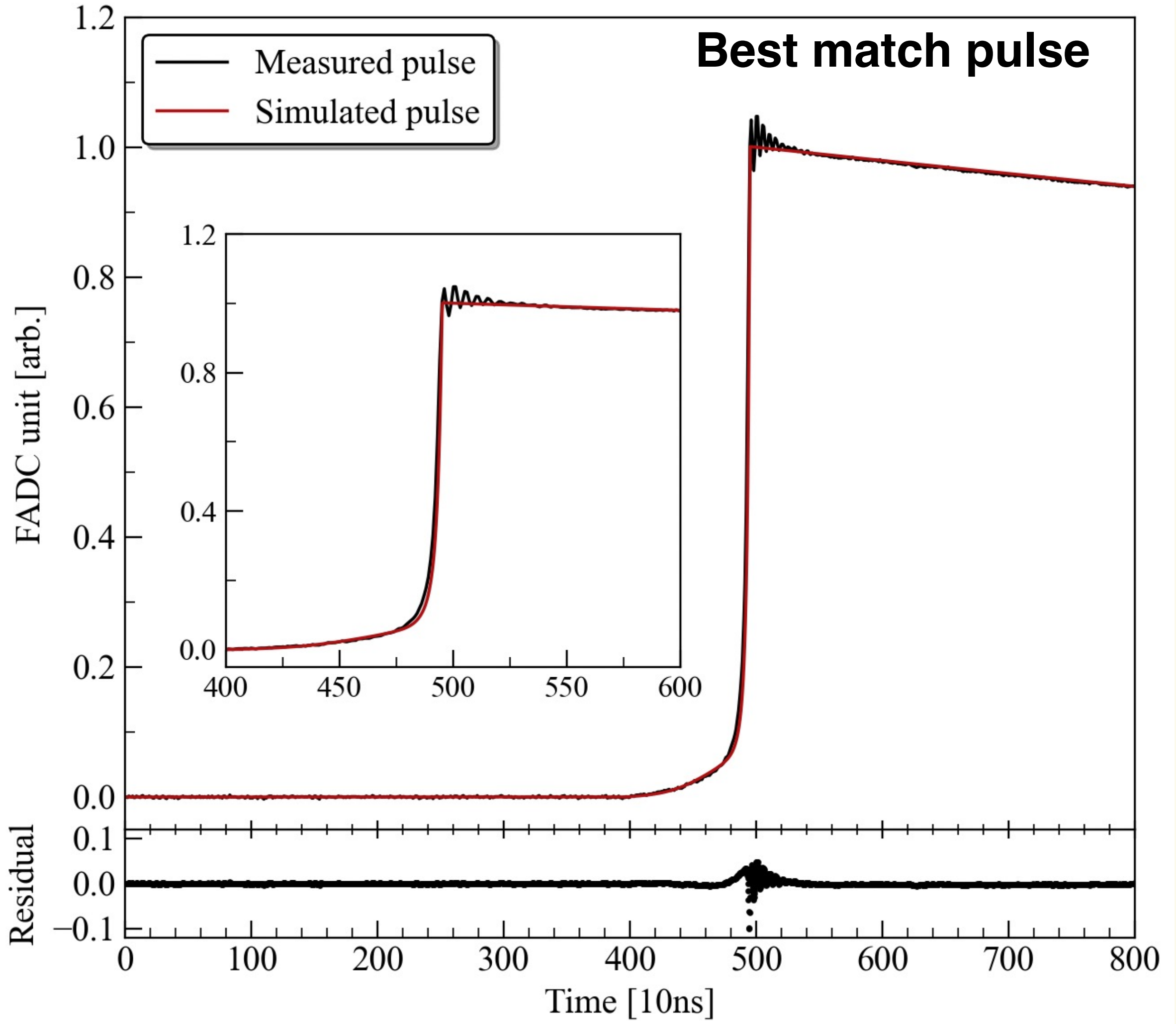
Simulated pulse in the library



III. Pulse matching via PSS

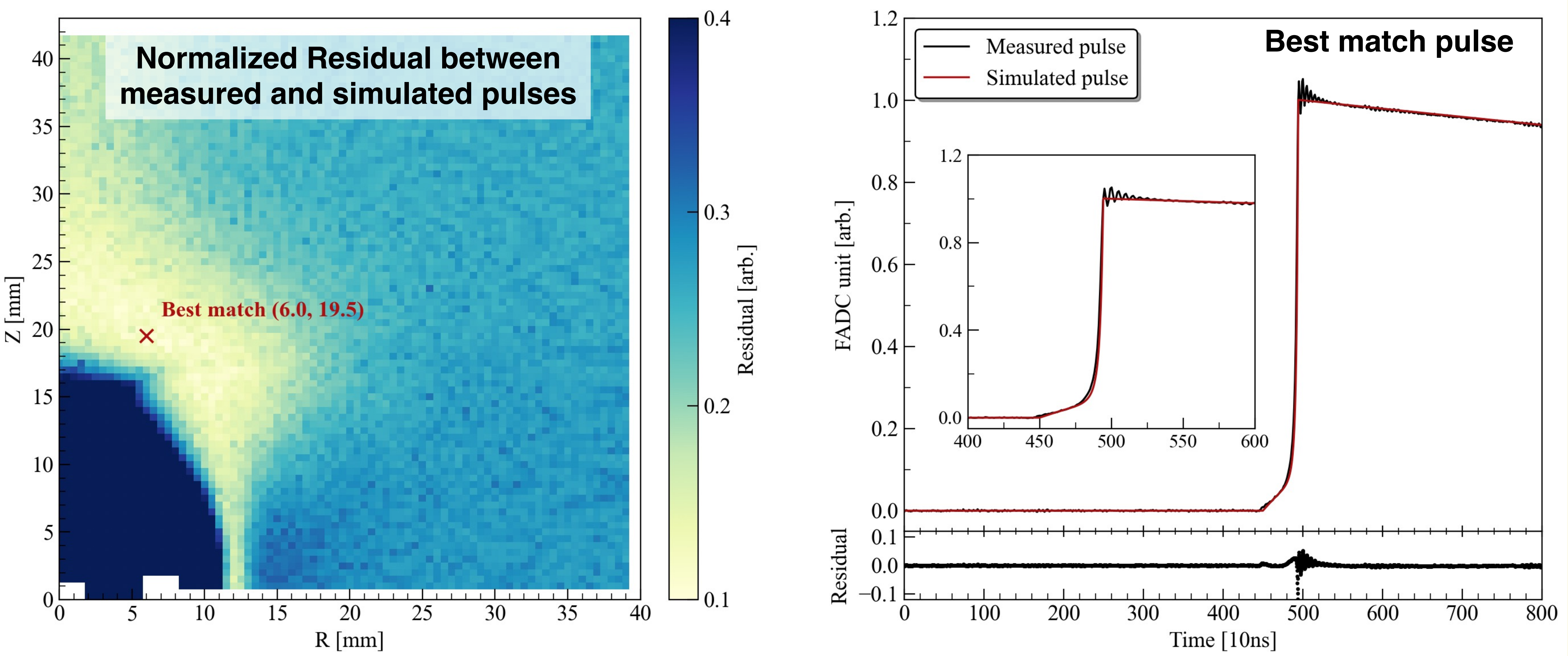
- **Match measured pulses with simulated pulses in the library: (BEGe#2)**
  - **Type-I pulses: pulses origin in the outer region of the detector**





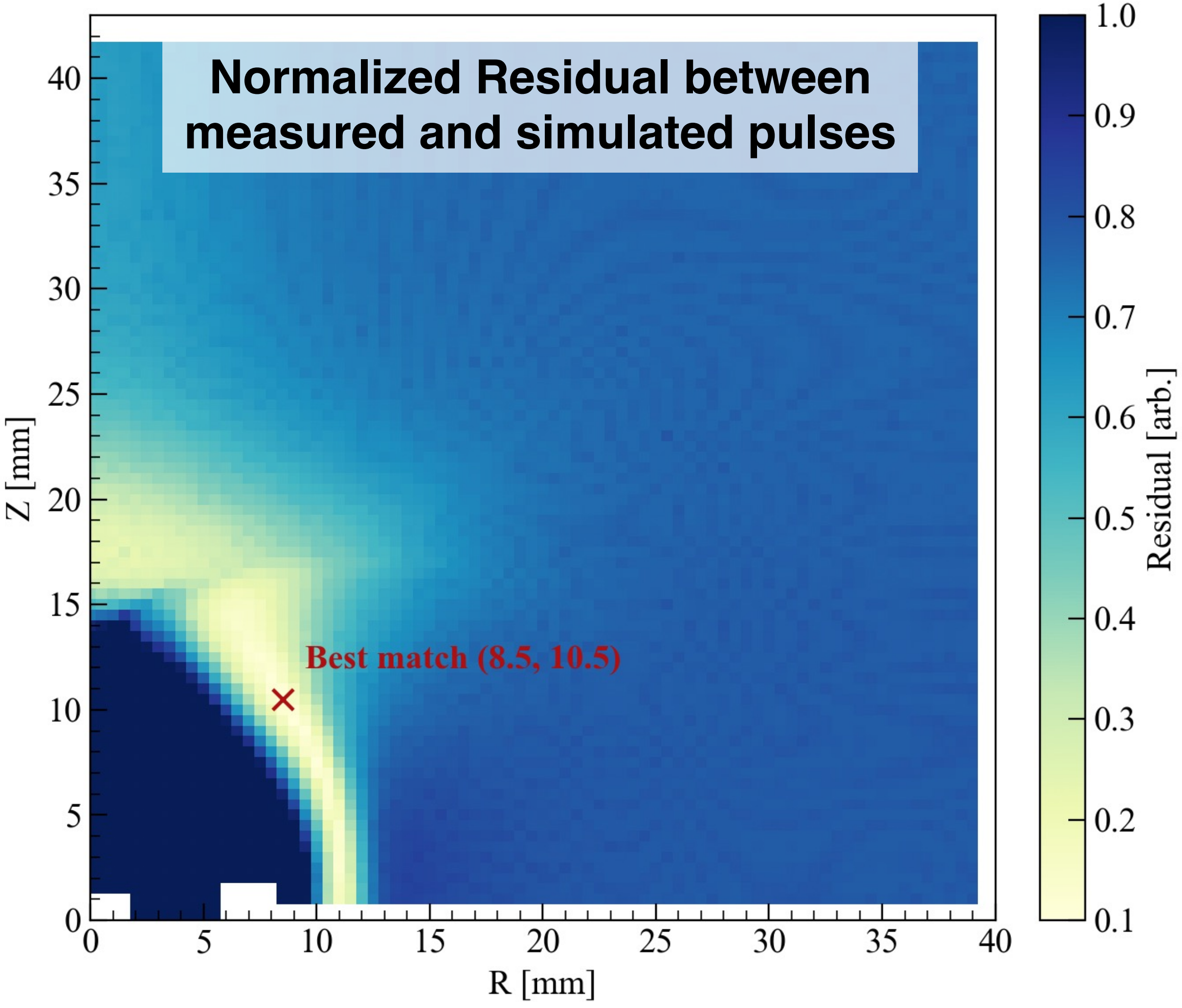
III. Pulse matching via PSS

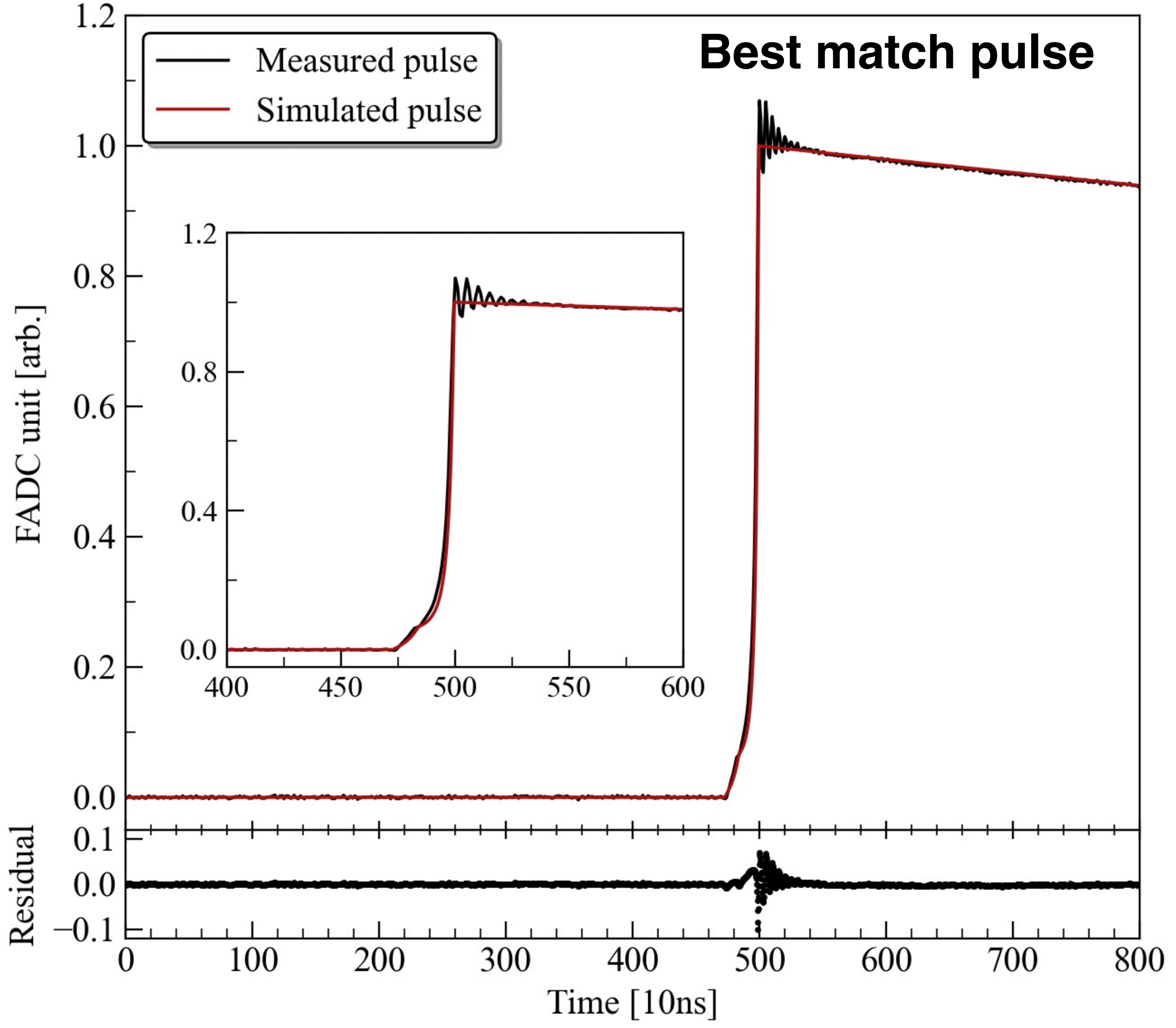
- **Match measured pulses with simulated pulses in the library: (BEGe#2)**
  - **Type-II pulses: pulses origin in the middle region of the detector**



III. Pulse matching via PSS

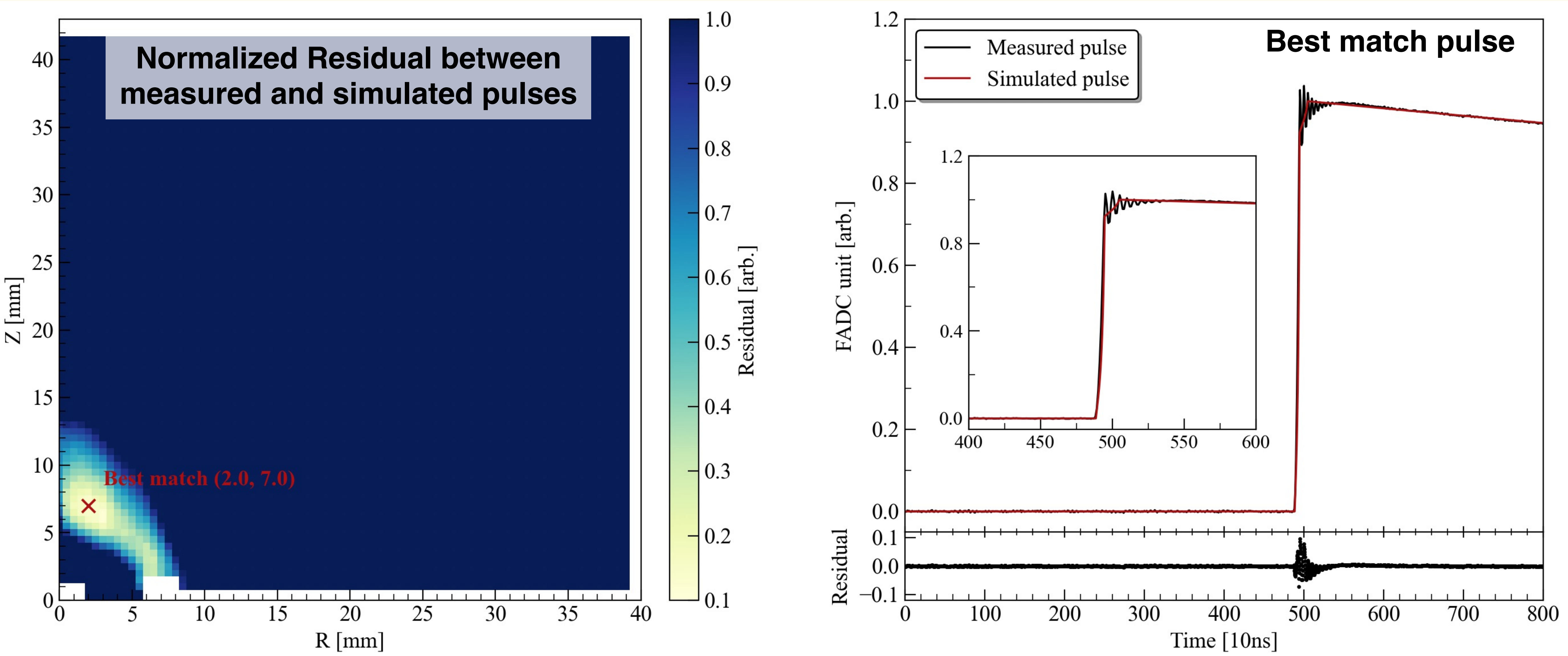
- **Match measured pulses with simulated pulses in the library: (BEGe#2)**
  - **Type-III pulses: pulses origin in the Inner ring region of the detector**





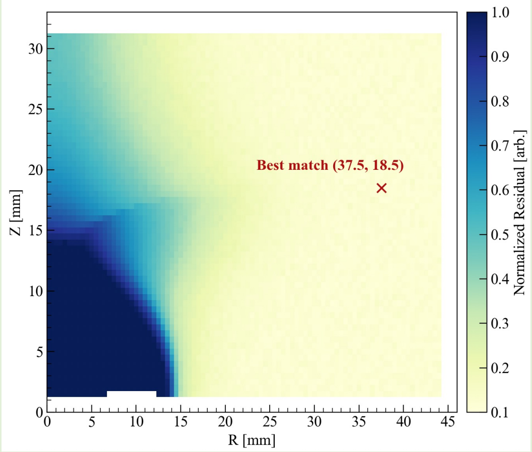
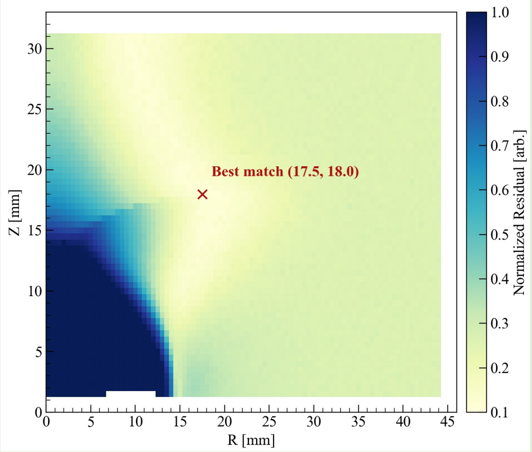
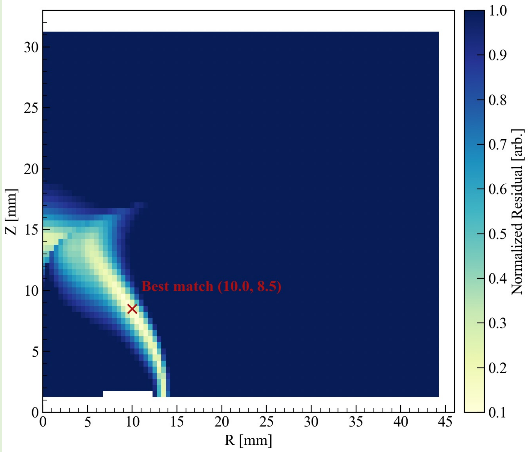
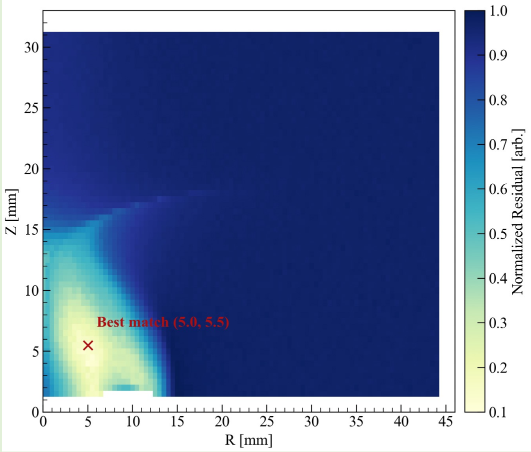
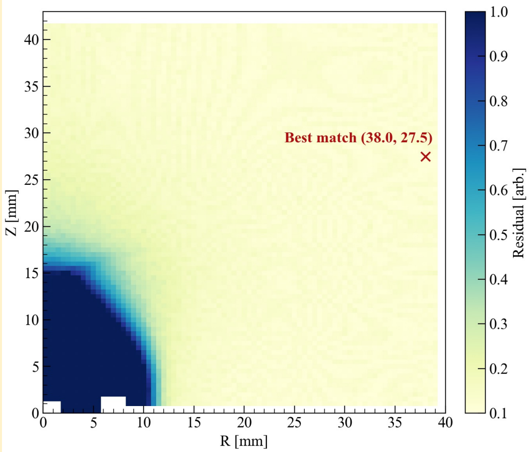
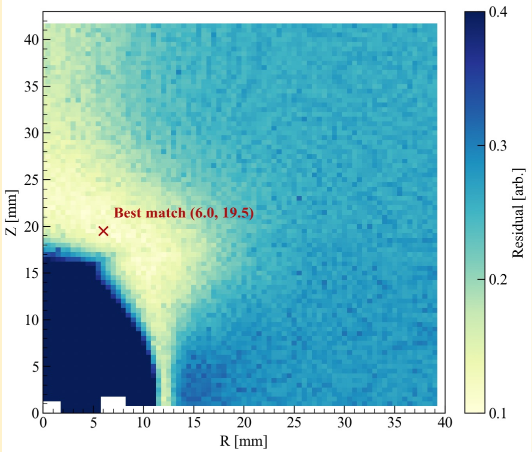
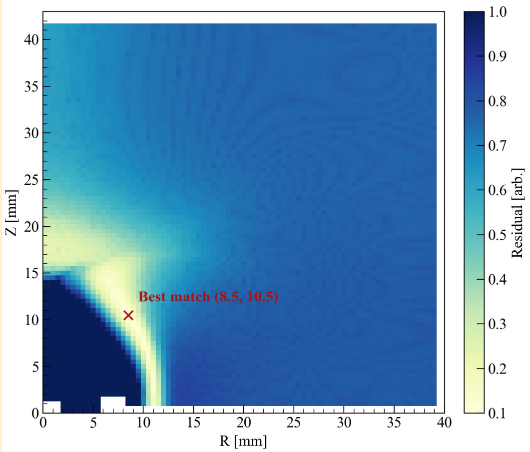
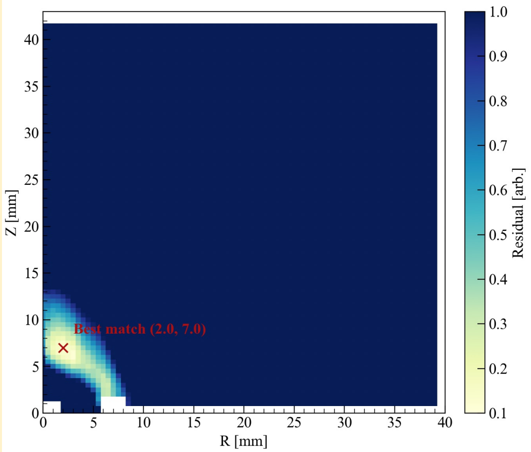
III. Pulse matching via PSS

- **Match measured pulses with simulated pulses in the library: (BEGe#2)**
  - **Type-IV pulses: pulses origin in the inner region near the p+ contact**



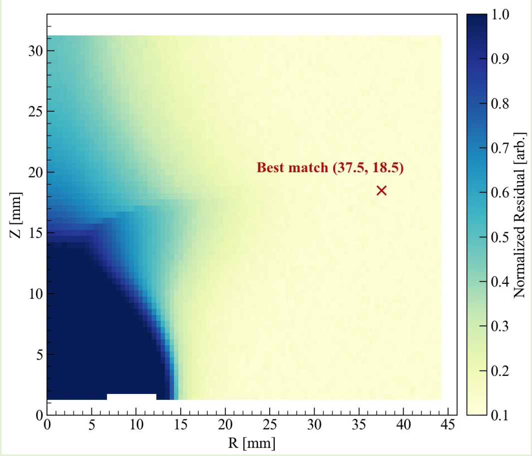
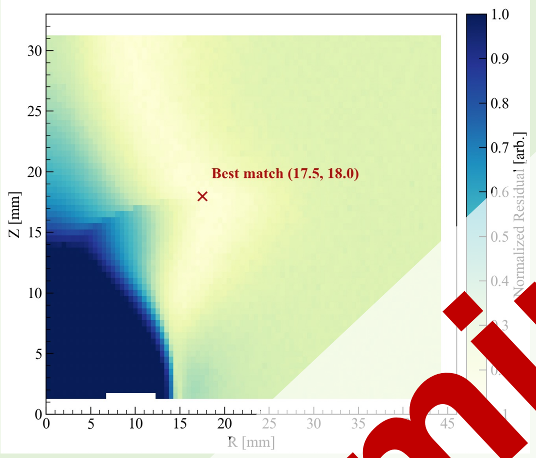
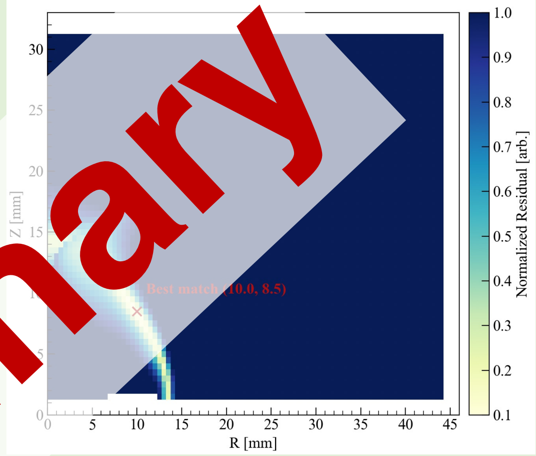
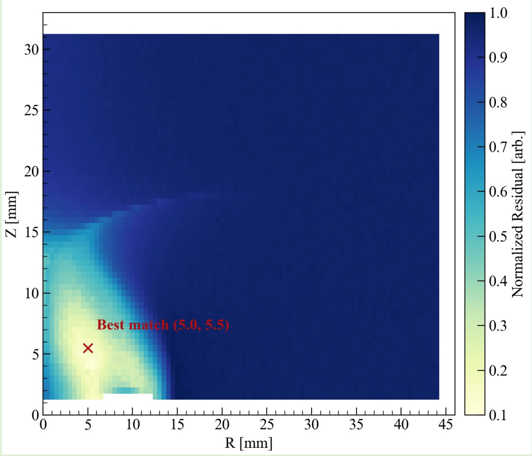
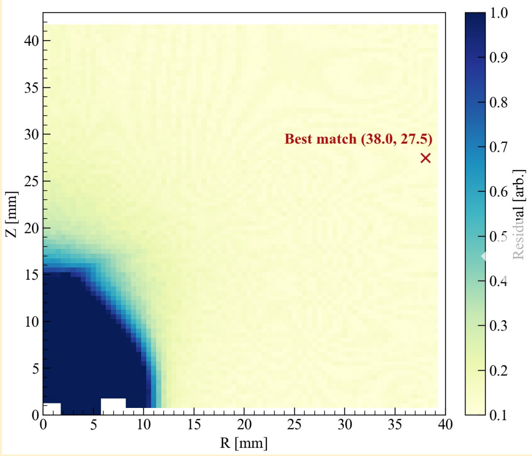
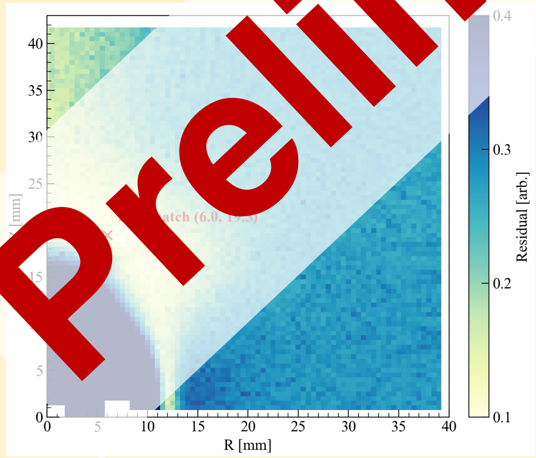
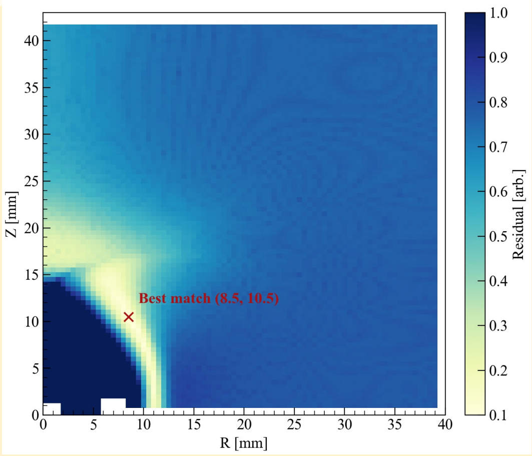
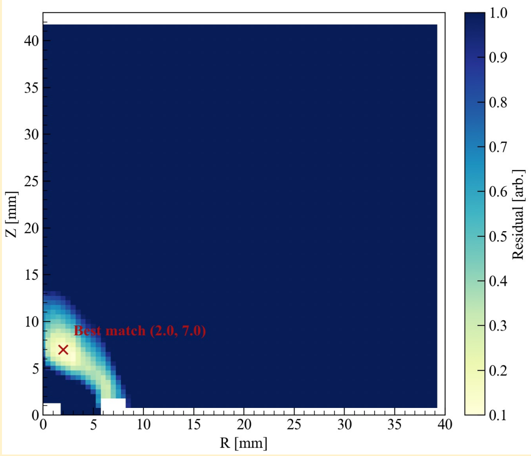
III. Pulse matching via PSS

◻ Both BEGe#1 and BEGe#2 could identify SSE in 4 regions via pulse matching:

Det.	Outer region	Middle region	Inner ring region	Inner region
BEGe#1 Φ×H (mm) 91.1×31.4				
BEGe#2 Φ×H (mm) 80×42.6				

III. Pulse matching via PSS

☐ Both BEGe#1 and BEGe#2 could identify SSE in 4 regions via pulse matching:

Det.	Outer region	Middle region	Inner ring region	Inner region
BEGe#1 Φ×H (mm) 91.1×31.4				
BEGe#2 Φ×H (mm) 80×42.6				

IV. Conclusion

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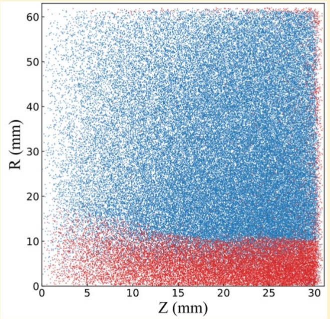
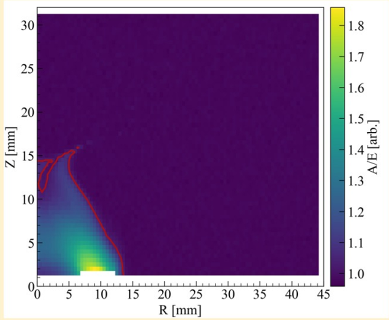
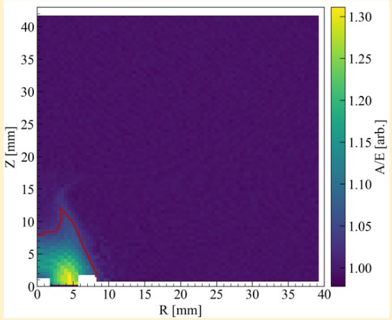
☐ The A/E cut performance in one PPCGe and two BEGe detectors:

- ➢ The CDEX-1B PPCGe has a large high A/E region of ~18.8% total detector volume

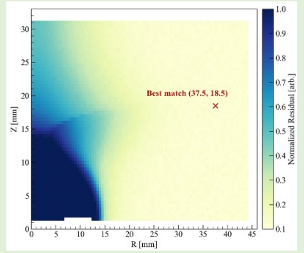
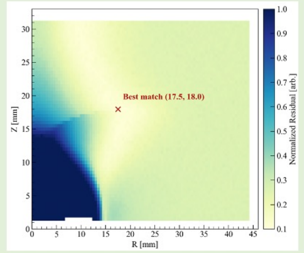
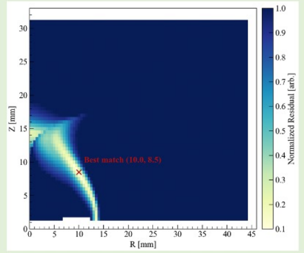
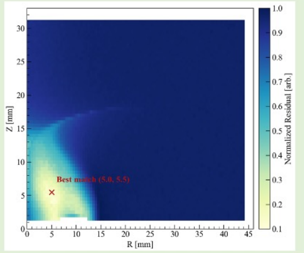
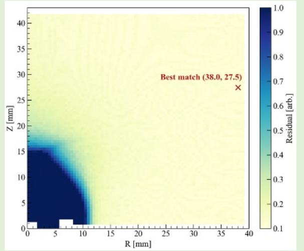
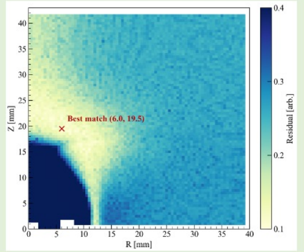
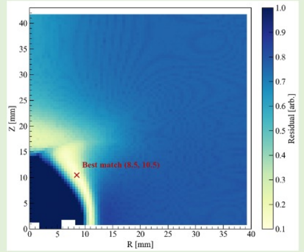
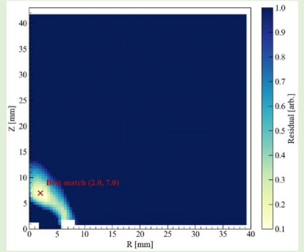
☐ Apply the pulse matching method in two BEGe detectors:

- ➢ Both BEGe#1 and BEGe#2 could identify SSE in 4 regions via pulse matching

High A/E region in the three detectors

PPCGe (CDEX-1B)	BEGe#1	BEGe#2
ΦxH (mm) = 80×42.6 High A/E region ~18.8%	ΦxH (mm) = 91.1×31.4 High A/E region ~2.3%	ΦxH (mm) = 80×42.6 High A/E region ~0.7%
		

SSE regions identified by pulse matching in BEGe

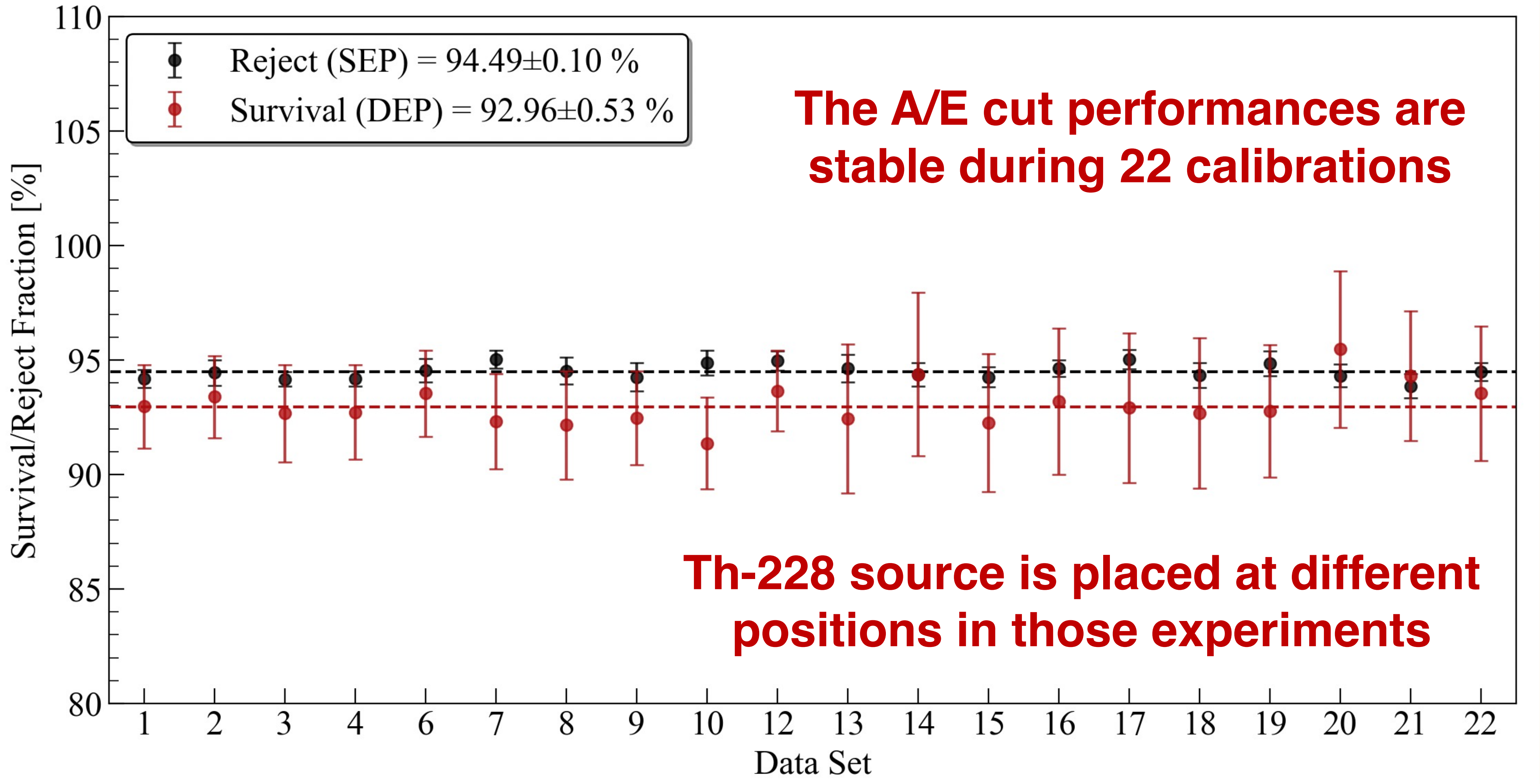
Det.	Outer region	Middle region	Inner ring region	Inner region
BEGe#1 ΦxH (mm) 91.1×31.4				
BEGe#2 ΦxH (mm) 80×42.6				

Thanks

II. SSE/MSE discrimination of PPCGe and BEGe

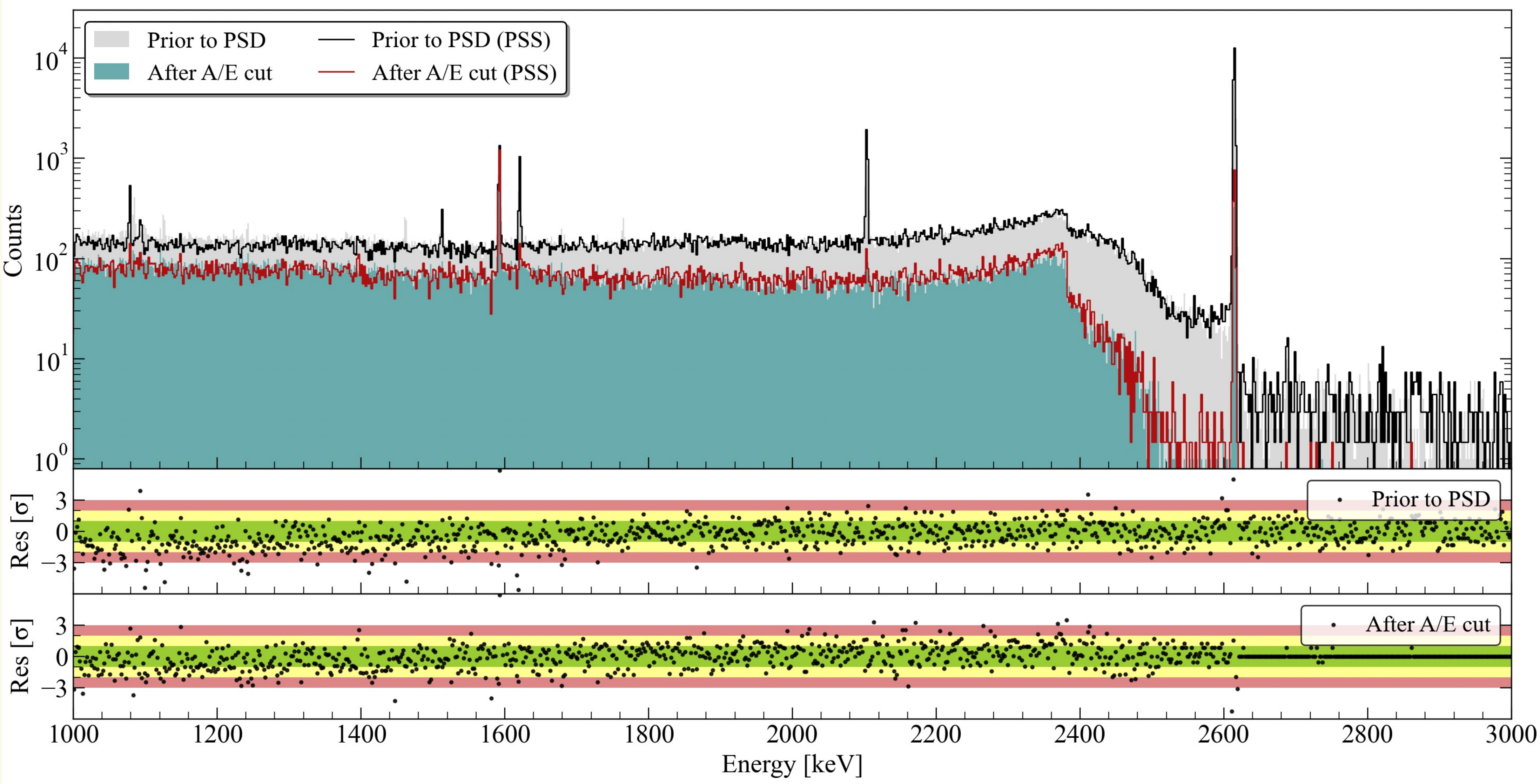
☐ SSE/MSE discrimination power of another BEGe (BEGe#2) detector:

We also monitor the A/E cut performance in BEGe#2 over 22 calibration experiments (during ~ 1 month)



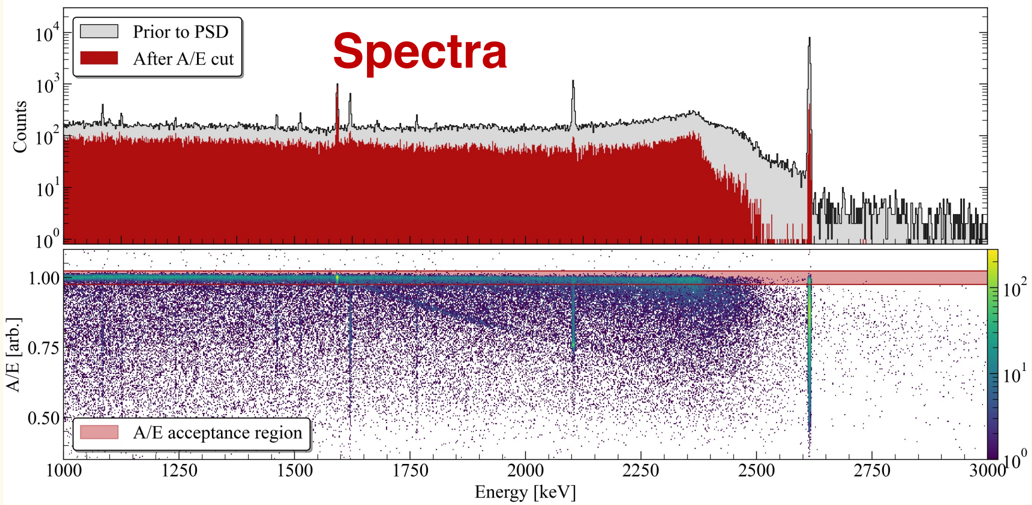
BEGe#1 PSS vs. Experiment

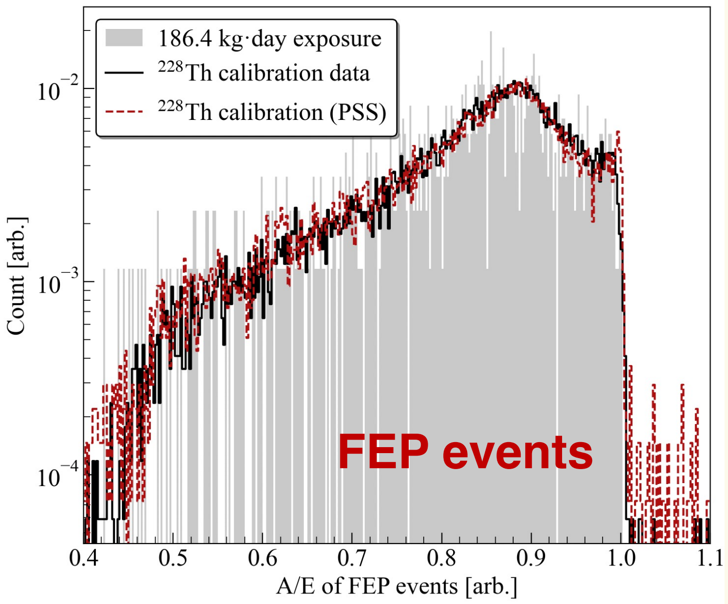
- Comparison of spectra using Th-228 calibration data

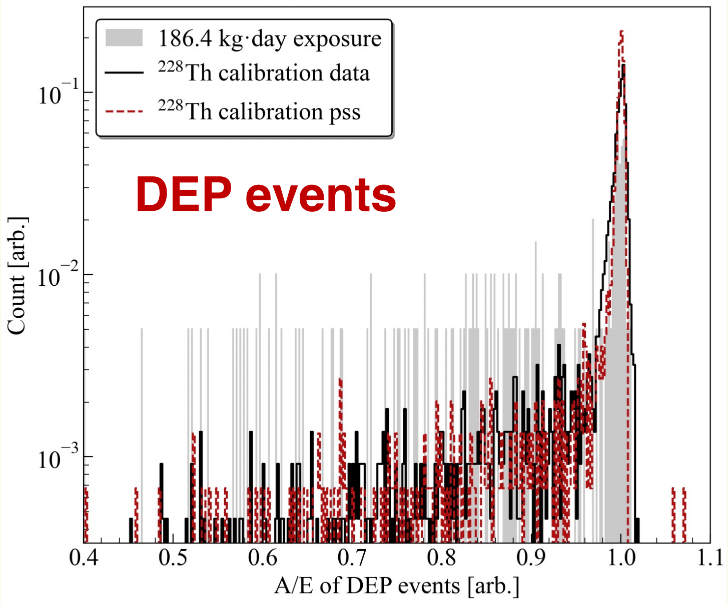


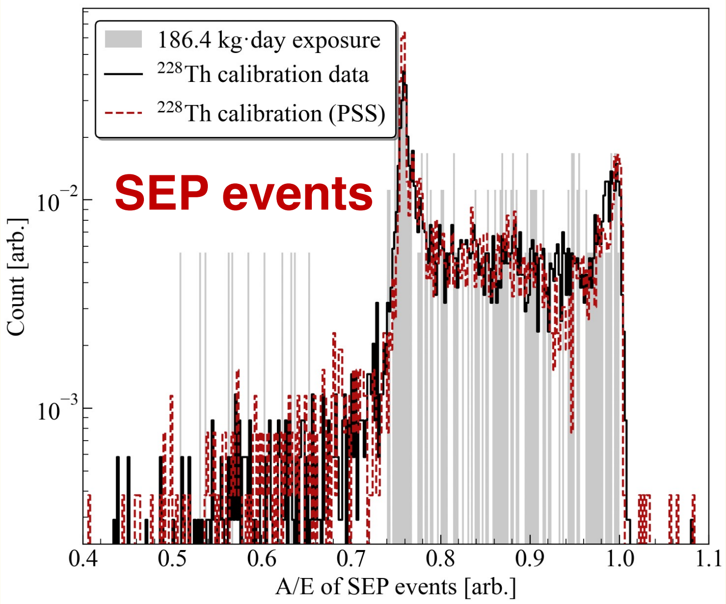
BEGe#1 PSS vs. Experiment

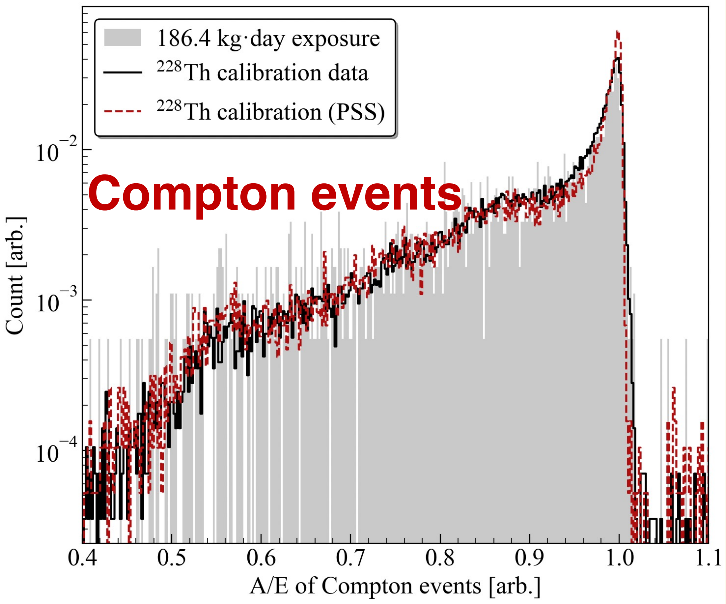
□ Comparison of A/E using Th-228 calibration data











BEGe#2 PSS vs. Experiment

□ Comparison of A/E using Th-228 calibration data