Background rejection by Pulse Shape Discrimination in the LEGEND experiment

Raoul Cesarano
raoul.cesarano@gssi.it

TAUP XICHANG

On behalf of LEGEND — Large Enriched Germanium Experiment for Neutrinoless ββ Decay

The LEGEND collaboration is searching for **neutrinoless double beta (0νββ) decay** by operating **high-purity germanium detectors** (HPGe) enriched in ^{76}Ge in a low-background liquid argon environment. Building on key technological innovations from Gerda and the Majorana Demonstrator, LEGEND-200 has performed a first 0νββ decay search based on 61 kg yr of data [1].


Coax — GERDA · BEGe — GERDA · PPC · LEGEND IC

Detectors

- **Geometries**: Coaxial, BEGe, PPC, Inverted Coaxial (IC)
- **Backgrounds**: Surface α/β particles, bulk Compton scattering
- **Signal (0νββ)**: Bulk, single-site events (SSEs)
- **Pulse Shape Discrimination (PSD)**: Rejects multi-site events (MSEs) and surface backgrounds via signal profiles, preserving high signal efficiency
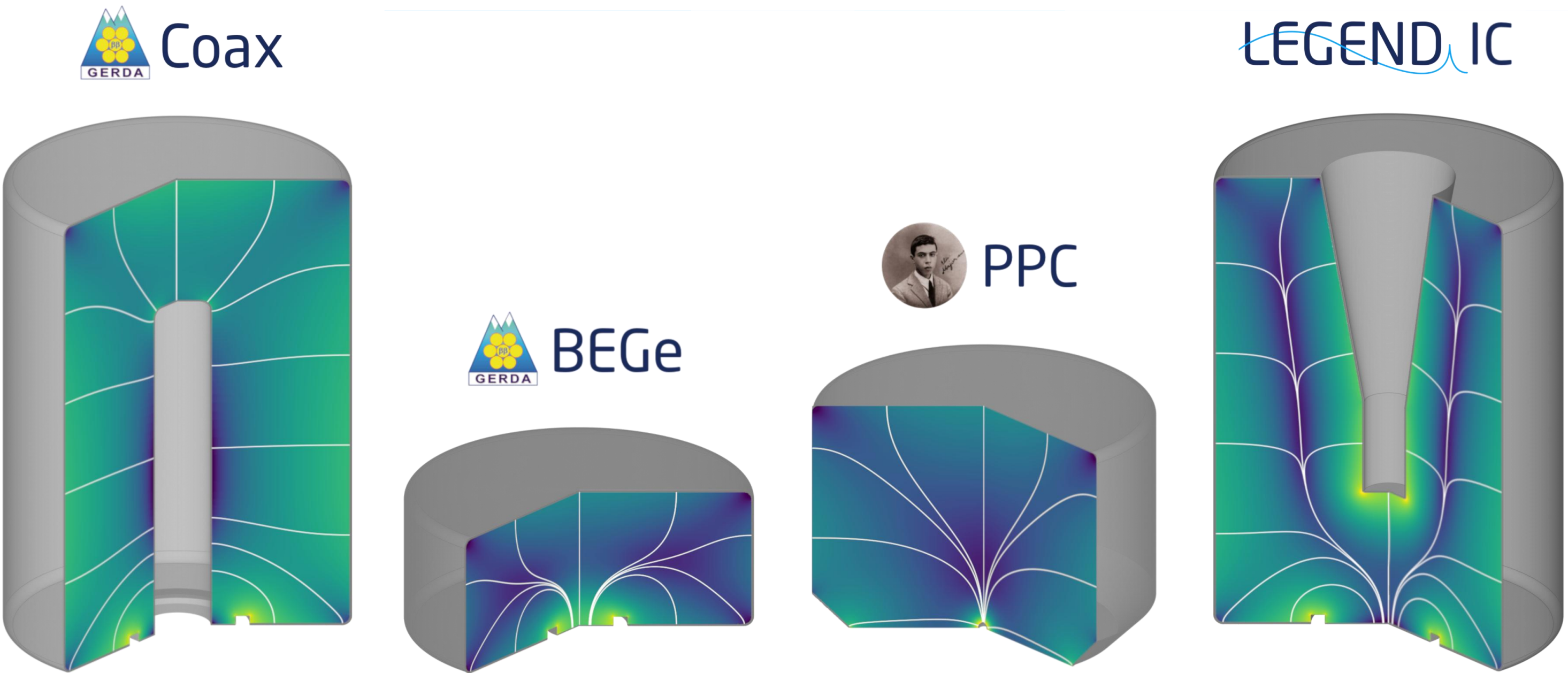
A/E Classifier

In **point-contact** detectors, the A/E ratio (maximum current amplitude over energy) is used to classify backgrounds: MSEs and n$^+$ surface events have **wider pulses and lower A/E**, while p$^+$ surface events show **higher A/E**.
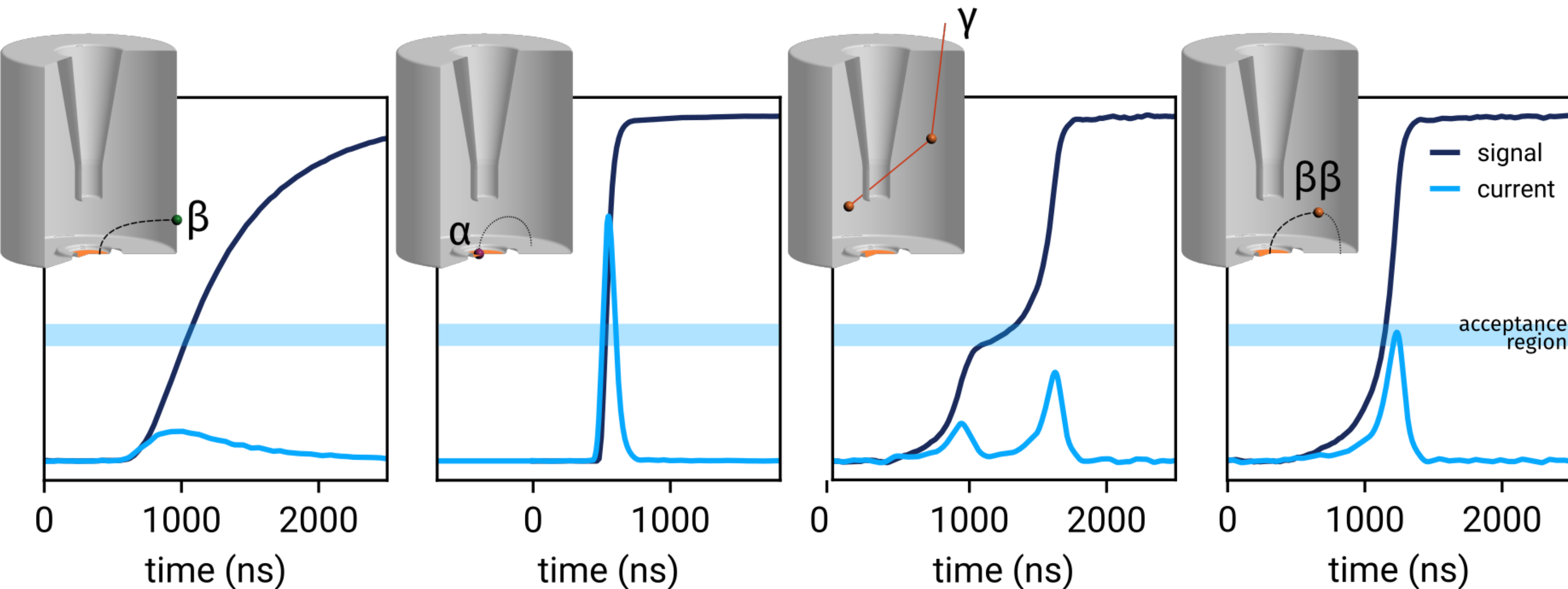
LQ Classifier

Late-charge (LQ) is the normalized **area above the last 20%** of the charge signal, used to tag **slow surface events**. The cut is used in detectors with large, thin passivated surfaces in place of high A/E.
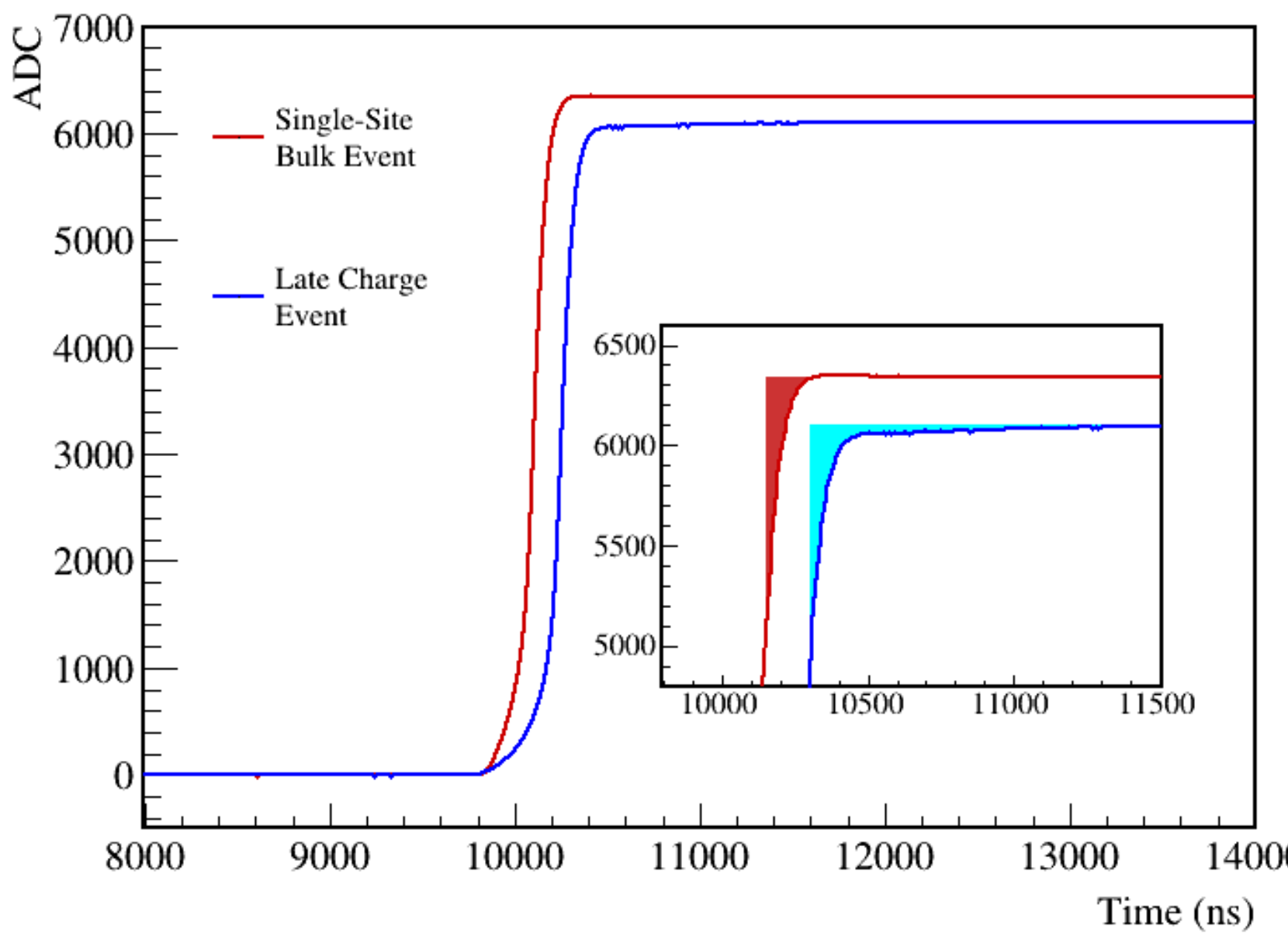

Coax

In Coaxial detectors, we apply an **Artificial Neural Network (ANN)** trained on ^{208}Tl DEP and ^{212}Bi FEP to distinguish SSEs and MSEs, then **cut on rise-time** to reject surface alphas.

Calibration

- PSD cuts are calibrated using **weekly ^{228}Th** gamma source runs
- A/E and LQ parameters are corrected for **drift time and energy dependence** to have normalized distributions centered at 0
- **^{208}Tl DEP** at 1593 keV: SSEs proxy (pair production electrons deposit locally while γ rays escape)
- **^{212}Bi FEP** at 1621 keV: MSEs reference (close in energy to DEP to avoid bias)
- Multi-site rejection performance is tested on SEP, FEP, and Compton continuum events

Cut thresholds:
- Low A/E: **90% DEP acceptance**
- High A/E: 3 sigma → >96% DEP acceptance
- LQ: 3 sigma → >98% DEP acceptance

^{228}Th cal data — before PSD / after PSD
^{208}Tl (DEP) · ^{212}Bi (FEP)
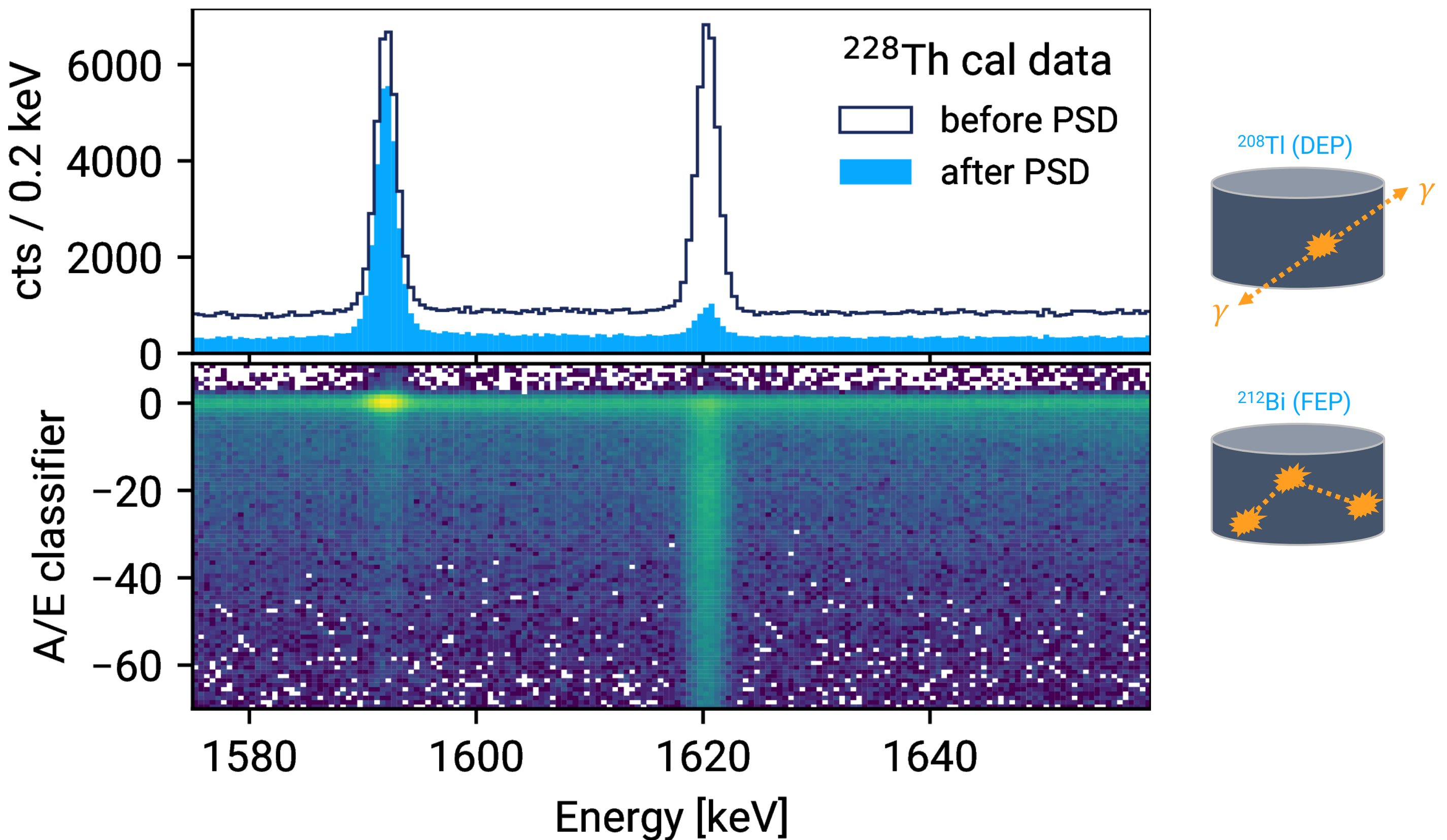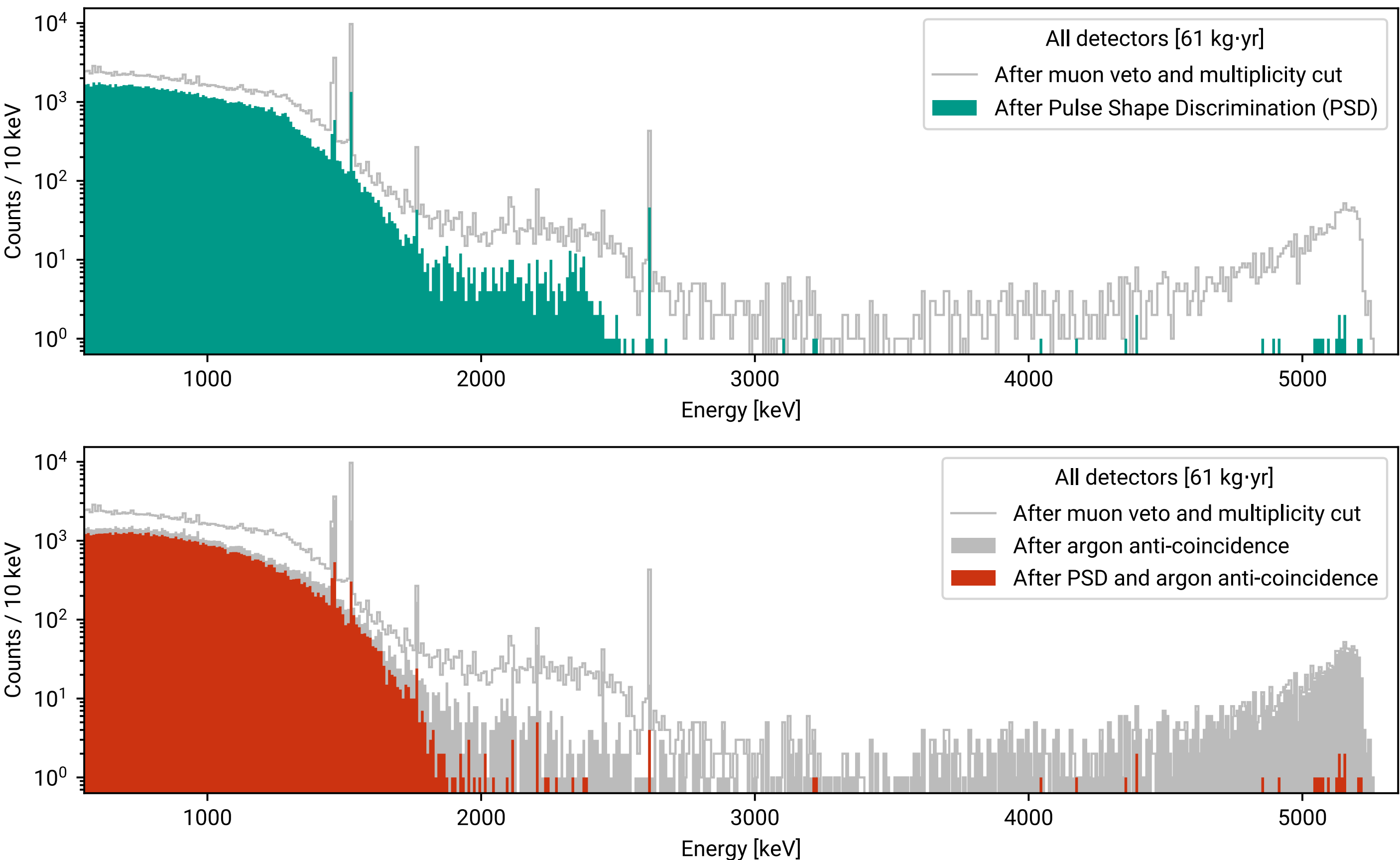
PSD at Q$_{\beta\beta}$ is corrected by several **systematic effects** as: energy dependence (using ^{60}Co source), spatial distribution (using 2νββ), time variability.

Thanks to the powerful PSD capabilities and a **strong anti-correlation with Liquid Argon** anticoincidence, LEGEND observed a background index* of:

$$0.5^{+0.3}_{-0.2} \text{ cts / (keV ton yr)}$$ in the 0νββ decay signal region [1]

*Only point contact IC

	BEGe	PPC	Coax	IC
Exposure (kg yr)	10,9	4,2 kg yr	7,8 kg yr	38,2 kg yr
PSD at Q$_{\beta\beta}$ (%)	81.1 ± 3.9	85.0 ± 4.5	76.0 ± 5.7	84.3 ± 3.0

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[1] https://doi.org/10.48550/arXiv.2505.10440