Photon identification in double beta-decay experiments using segmented germanium detectors

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on behalf of the GERDA collaboration

- Motivation: neutrinoless double beta-decay
- Signal and background signatures
- Analysis chain: electron / photon distinction
- Test stand setup
- Results

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Motivation: Neutrinoless Double Beta-Decay

Motivation

- **Search for neutrinoless double beta-decay (0νββ)**
- Rare, second order weak process
- Information about the nature and mass of the neutrino
- **Low background requirement**
- High detection efficiency needed

The GERDA experiment

- Search for 0νββ-decay of Ge-76
- Source = detector
- Aim: background of 10^{-3} counts/(kg·keV·y)
- **Gamma-radiation is expected to dominate background**

Tool of choice:
Array of segmented germanium detectors

Signatures: Signal and Background (Photons)

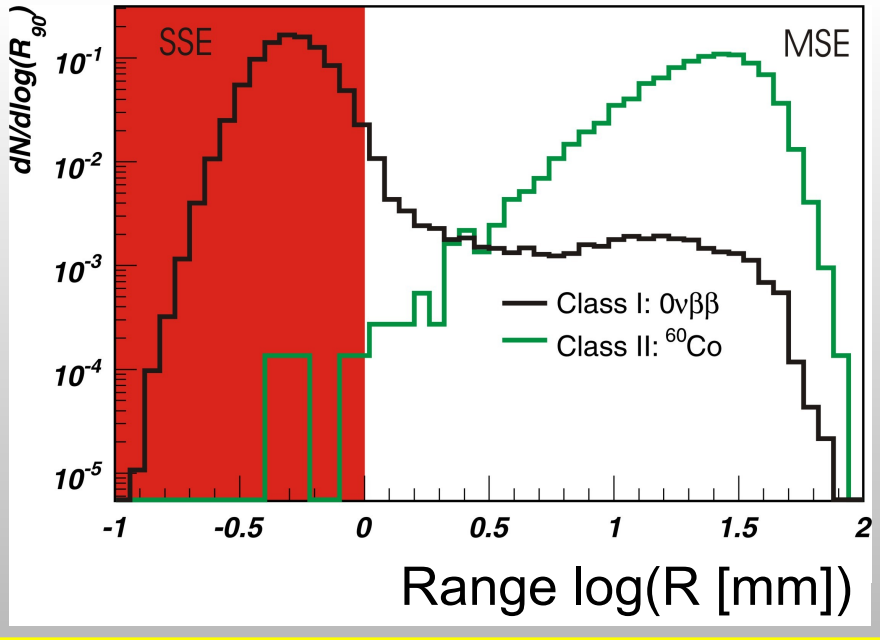
Signal

- 0νββ-decay has two electrons (only) in the final state
- Sum of the kinetic energies at Q-value (2 039 keV for Ge-76)
- Electrons of O(1) MeV have a range of ~ 1 mm in germanium
- **Single-site events**

Aim: Distinguish between single-site (electrons) and multi-site events (photons)

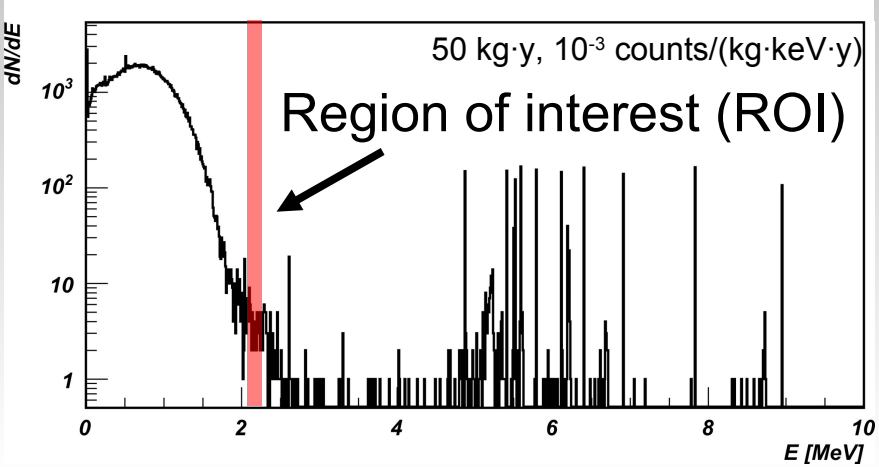
Background (photons)

- Photons in the MeV-energy region mostly Compton-scatter
- Mean free path of photons O(1-5) cm in germanium
- **Multi-site events**

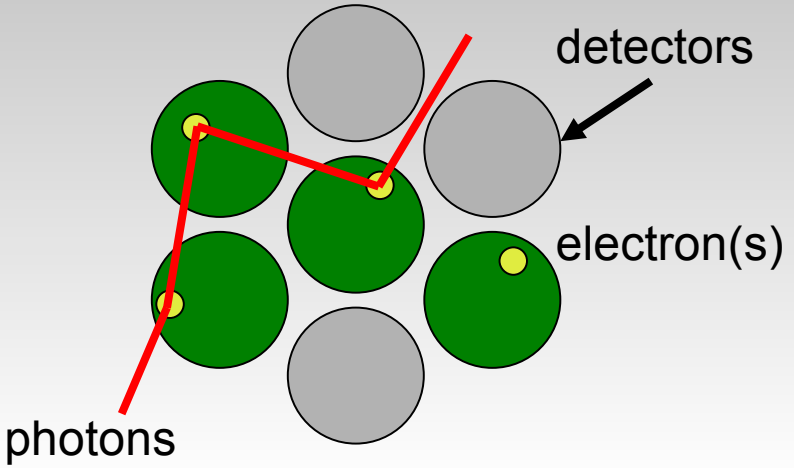


Analysis Chain: Electron / Photon Distinction

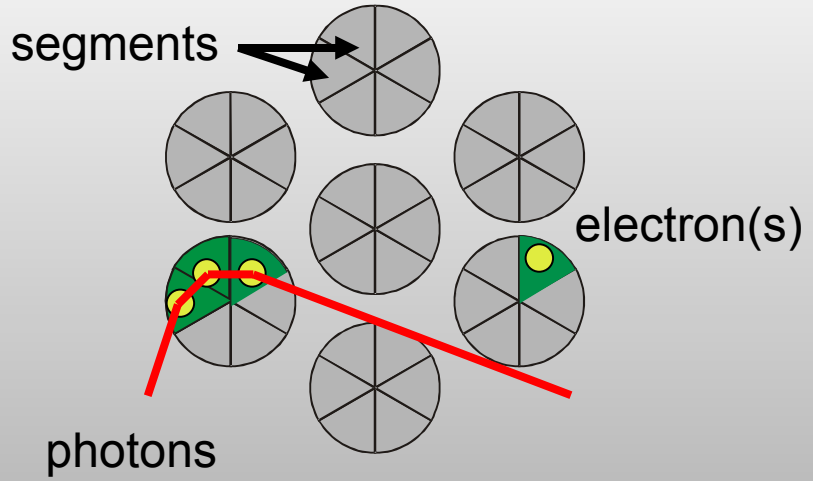
1. Energy cut



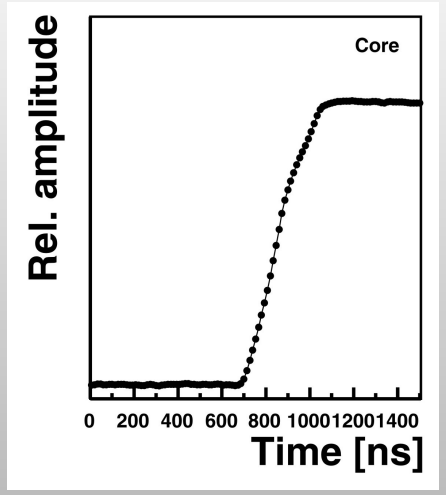
2. Crystal anti-coincidence

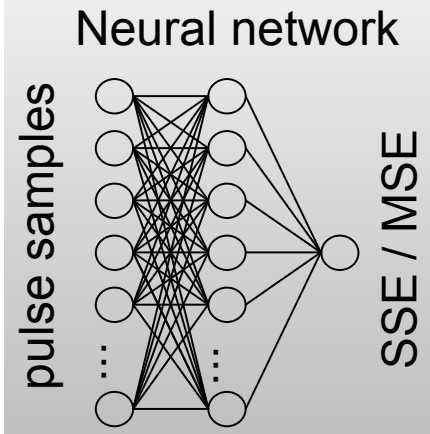


3. Segment anti-coincidence

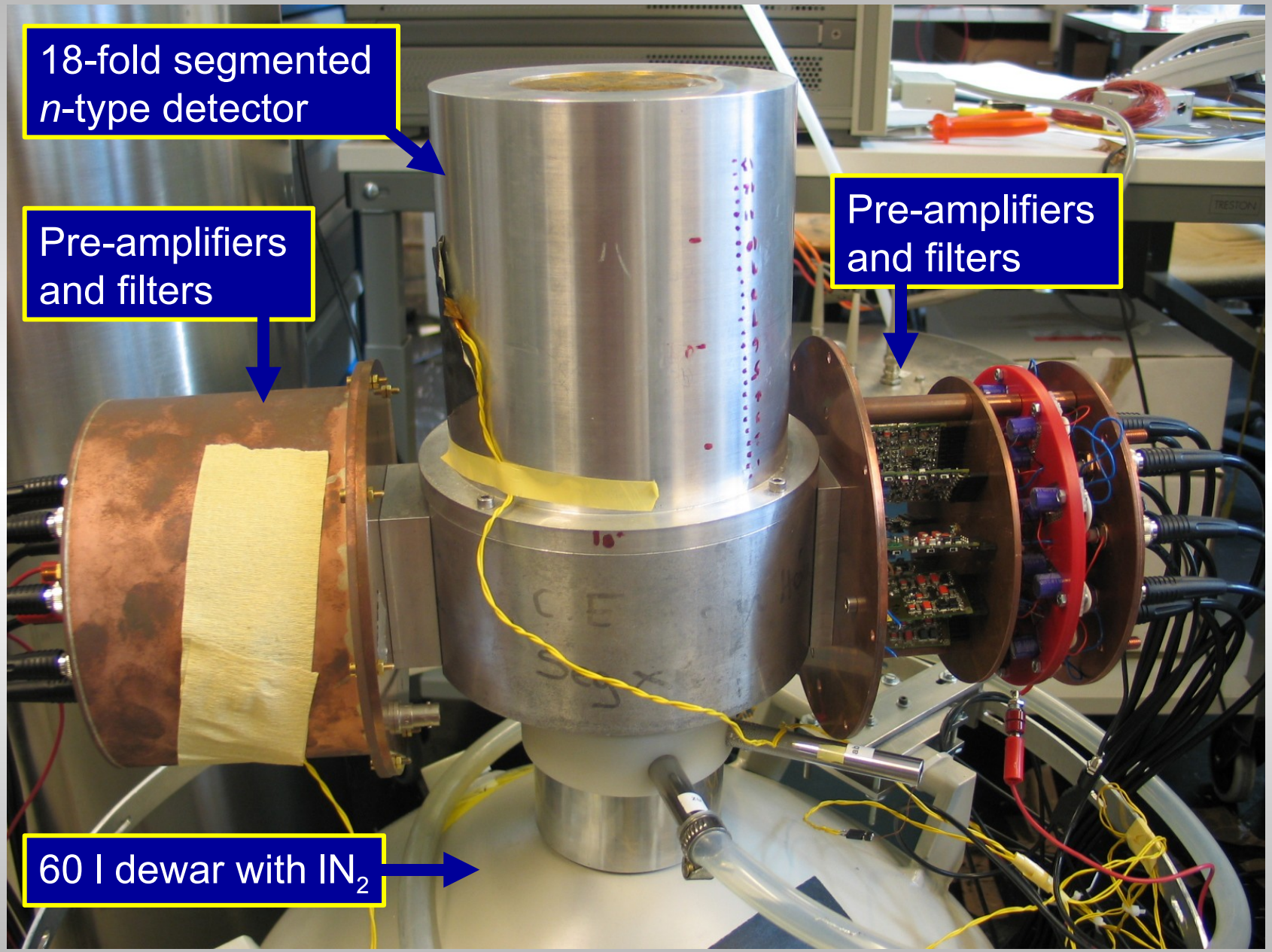


4. Pulse shape analysis





Prototype Detector Setup



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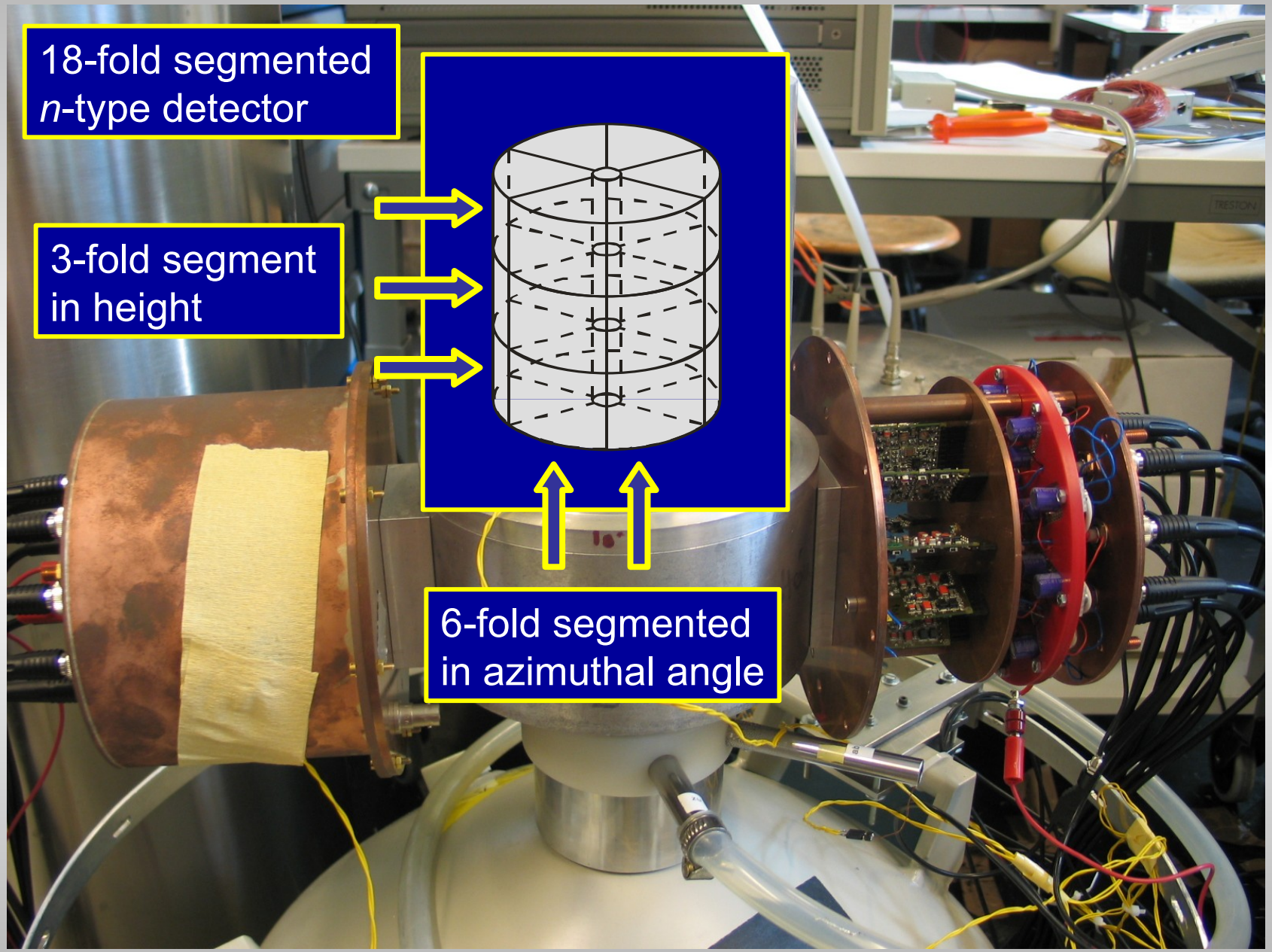
Prototype Detector Setup



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Prototype Detector Specifications

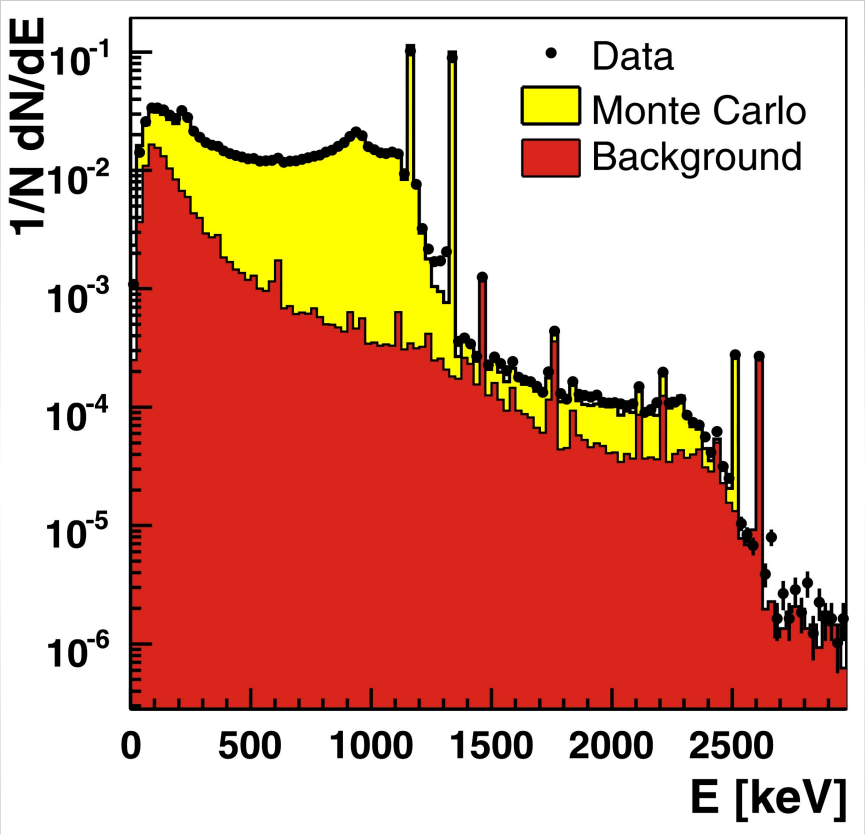
Test stand / detector characteristics

- 18-fold segmented *n*-type detector (Canberra-France)
- 19 pre-amplifiers (PSC-823C)
- PIXIE-4 read-out and analysis (14-bit, 75 MHz)

Size	70 mm height, 10 mm / 75 mm inner / outer radius
Mass	1.6 kg
Active volume	302 cm^3
Segments	6-fold in φ, 3-fold in z
Operating V	(+)3000 V
Peak to Compton	75.7
FWHM (1.3 MeV)	1.99 keV

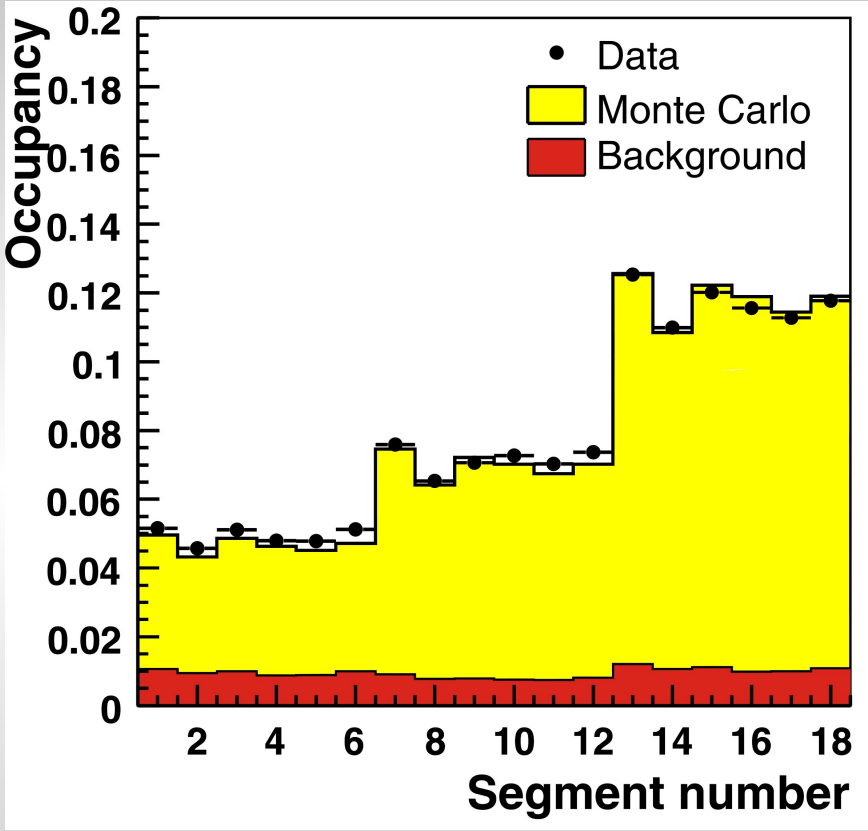
Data to Monte Carlo Comparison

Spectrum of Co-60 source



- Core electrode spectrum
- **Average deviation ~5%**
- Some features not in MC

Segment occupancy



- Substructure due to drift anisotropy of charge carriers
- **Effective model in MC**

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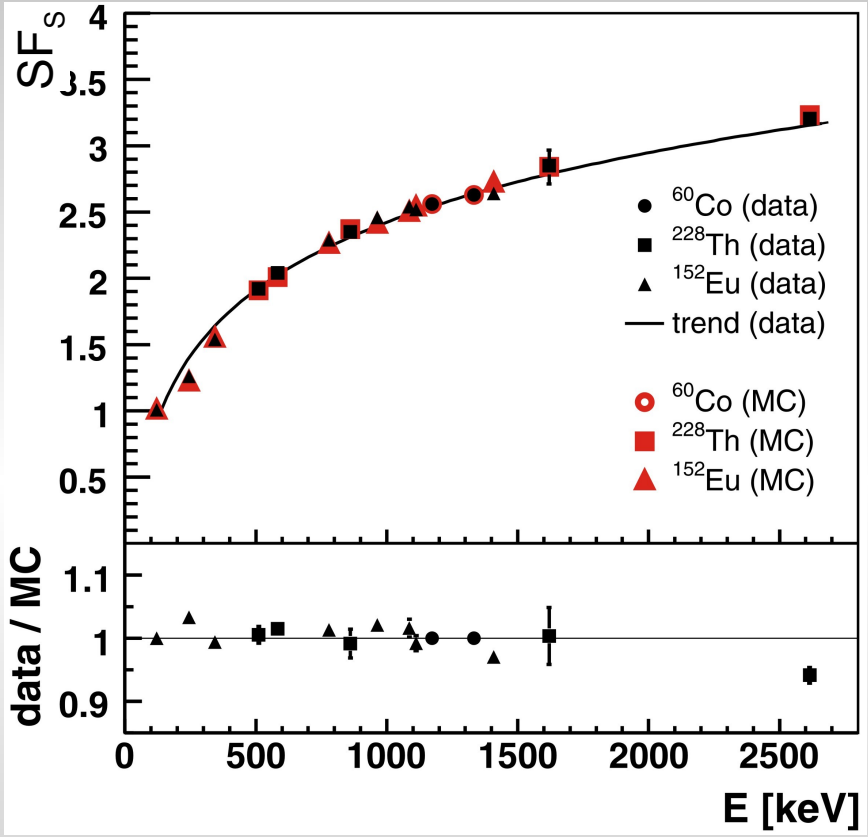
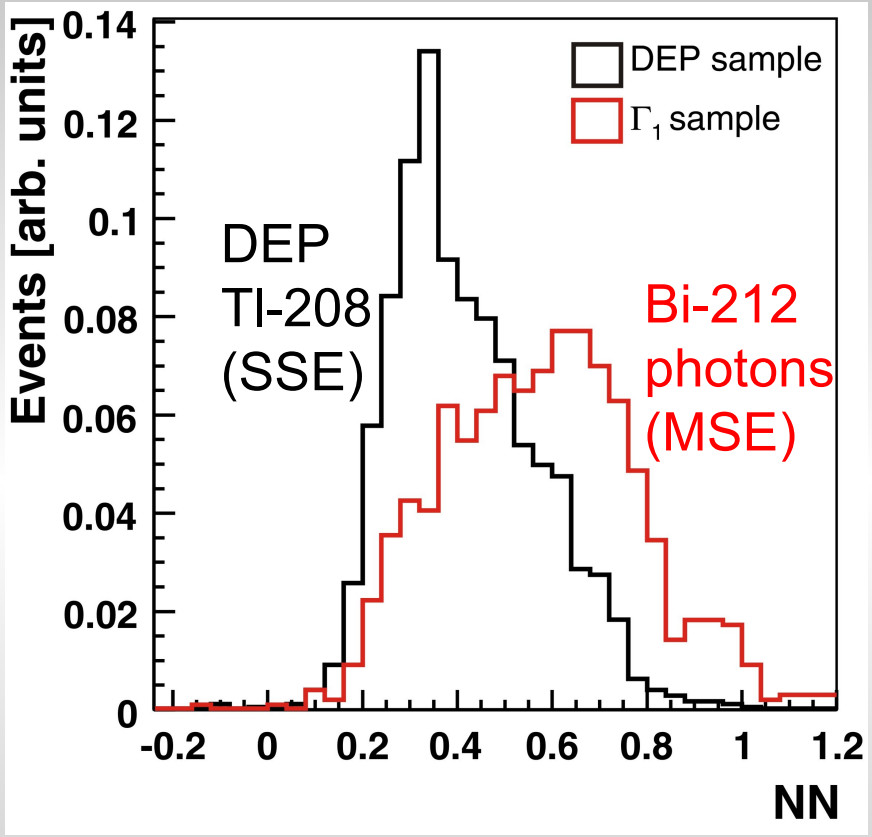
Results I: Photon Event Discrimination

Segment anti-coincidence



- SF_S = N (all) / N (single segment)
- Geometry dependent

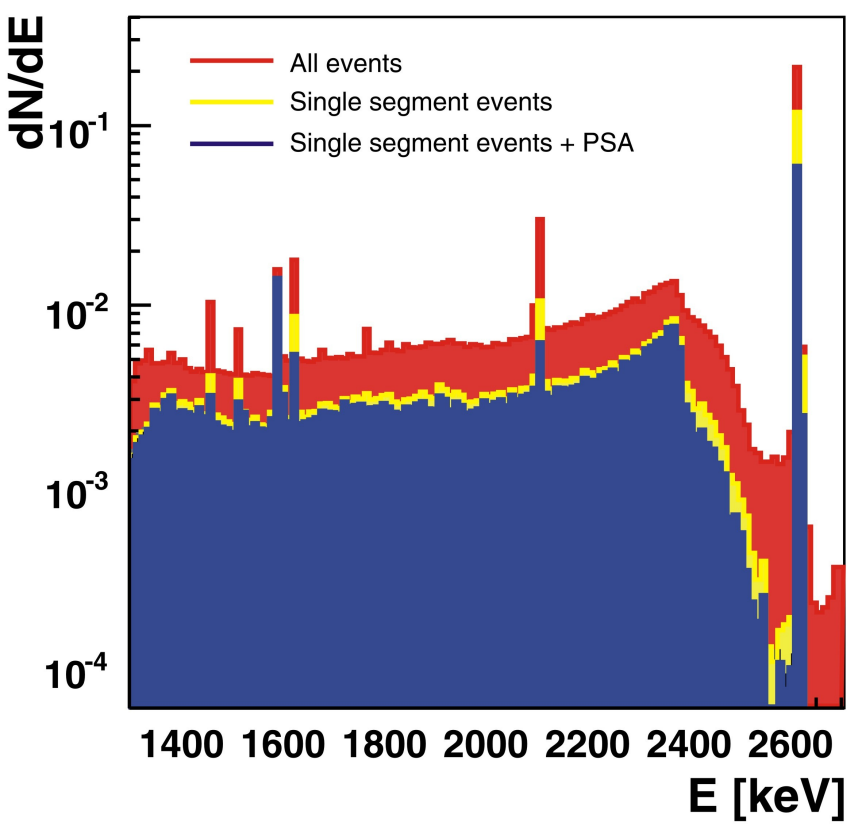
Pulse shape analysis



- Neural network output
- Distinction between single-site and multi-site events

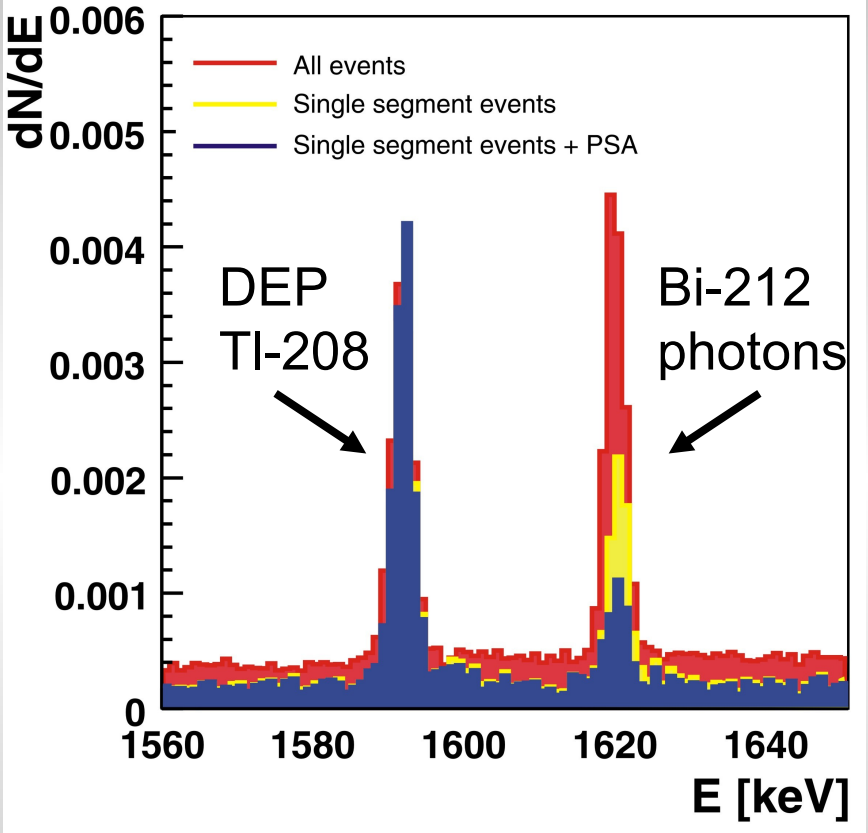
Results II: Th-228 Spectrum

Spectrum of Th-228 source



- Core energy spectrum
- **Segmentation reduces Compton-background in ROI**

Spectrum (close-up)



- Correct identification of electrons and photons
- **PSA confirms signal**

Results III: GERDA Background

Background reduction

Part	Source	SF_C	SF_S
Detector	Co-60	3.2 ± 0.1	38.3 ± 1.0
	Ge-68	2.4 ± 0.1	18.0 ± 1.4
Holder	Tl-208	2.2 ± 0.4	4.6 ± 0.9
	Bi-214	2.8 ± 0.5	6.0 ± 1.4
	Co-60	***6.7 ± 0.2***	***157 ± 27***
Electronic	Tl-208	1.5 ± 0.3	2.9 ± 0.6

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Expected background

Part	10^{-4} counts/(kg·keV·y)
Detector	*5*
Holder (Cu + Teflon)	***12***
Cabling	***6***
Electronics	*3*
Infrastructure	*4*
Muon, neutron & co.	*2*
GERDA	32

- Significant background reduction predicted
- Monte Carlo is proven reliable
- MC triggered redesign of suspension
- New results are pending

Conclusions

- **Double beta-decay opens a window to neutrino properties**
- Experiments place emphasis on background reduction
- Segmented germanium detectors have great potential for distinguishing between electron and photon induced events:
  - **Segment anti-coincidences → background reduction**
  - **Pulse shape analysis → signal confirmation**
- Prototype detector operational
- **Monte Carlo simulations are reliable**
- Predictions for GERDA background are promising