online version

Compton Imaging with Pixelized Detectors and Applications

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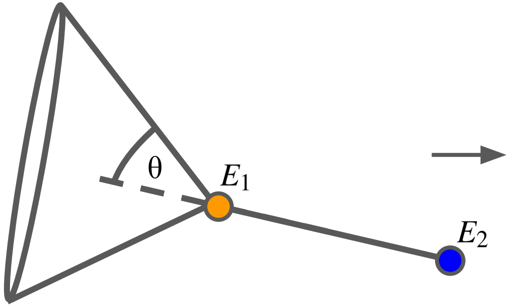
PIRE GEMADARC Summer School, Taiwan
May 27th, 2023

Solid State Detectors

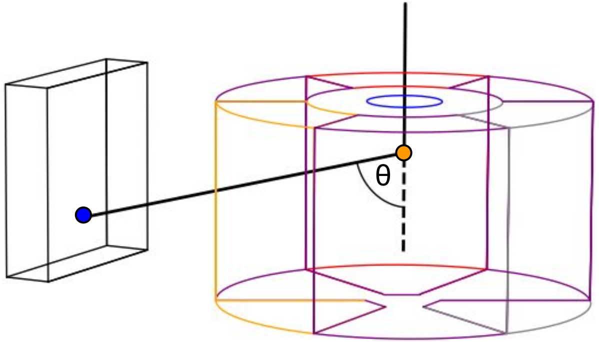
PIRE GEMADARC

MAX-PLANCK-INSTITUT FÜR PHYSIK

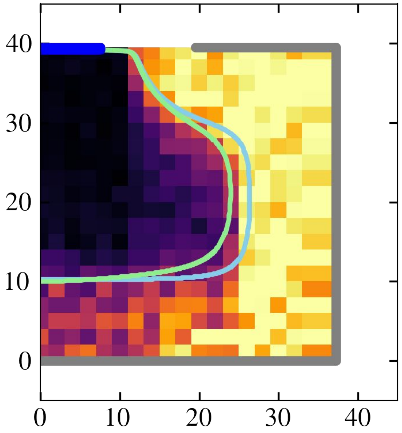
Outline



Compton imaging



Experimental setup:
Compton Scanner

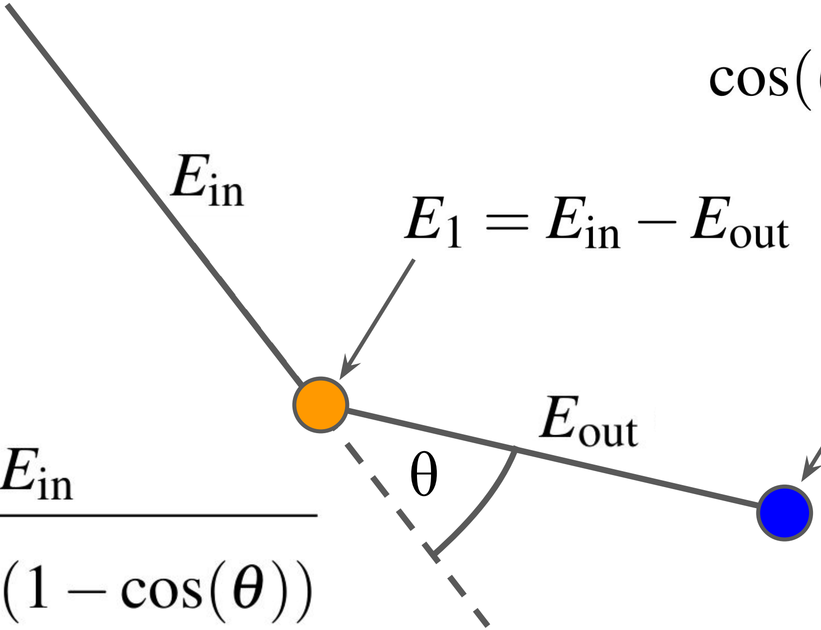


Compton imaging of
germanium detectors

Compton imaging

- Compton scattering
- Photoelectric absorption

$$\cos(\theta) = 1 - \frac{E_1 m_e c^2}{E_2(E_1 + E_2)}$$



$$E_1 = E_{in} - E_{out}$$

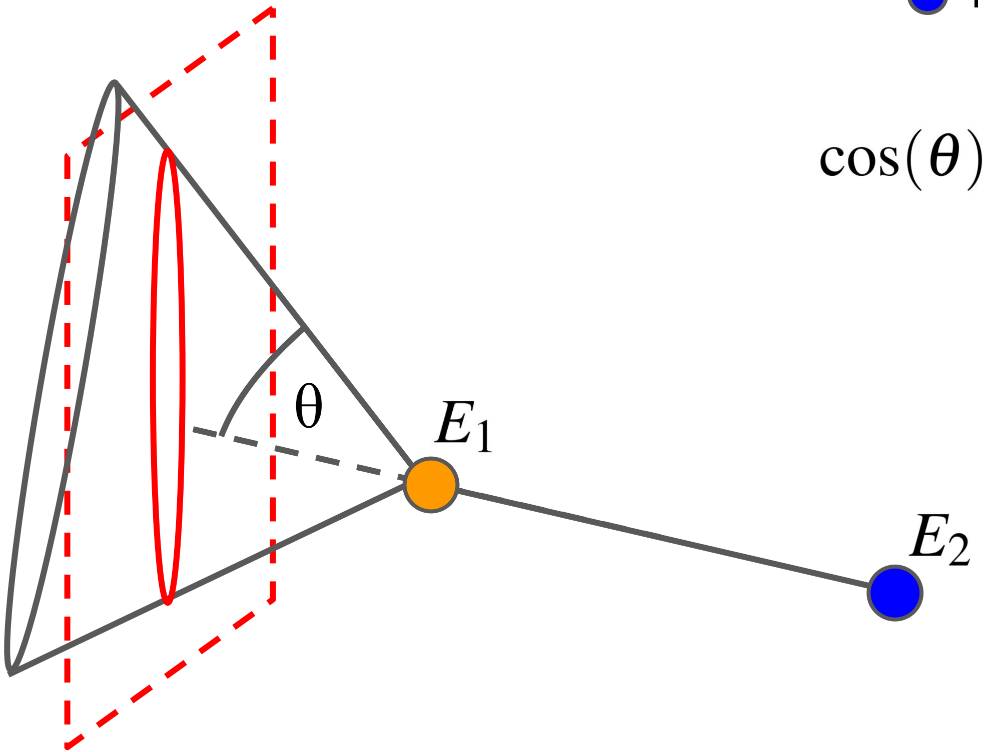
$$E_2 = E_{out}$$

$$E_{out} = \frac{E_{in}}{1 + \frac{E_{in}}{m_e c^2}(1 - \cos(\theta))}$$

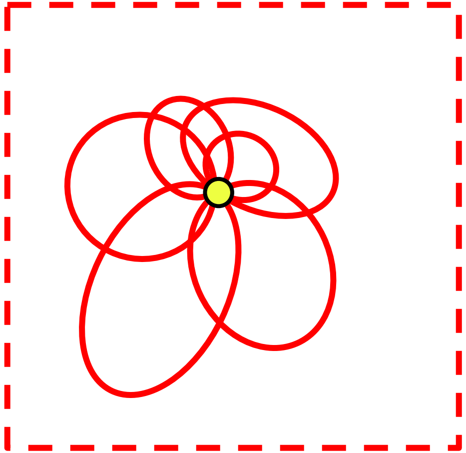
Compton imaging

Compton scattering

Photoelectric absorption



$$\cos(\theta) = 1 - \frac{E_1 m_e c^2}{E_2(E_1 + E_2)}$$



R.W. Todd *et al.*., Nature **251**: 132 (1974)
doi:10.1038/251132a0

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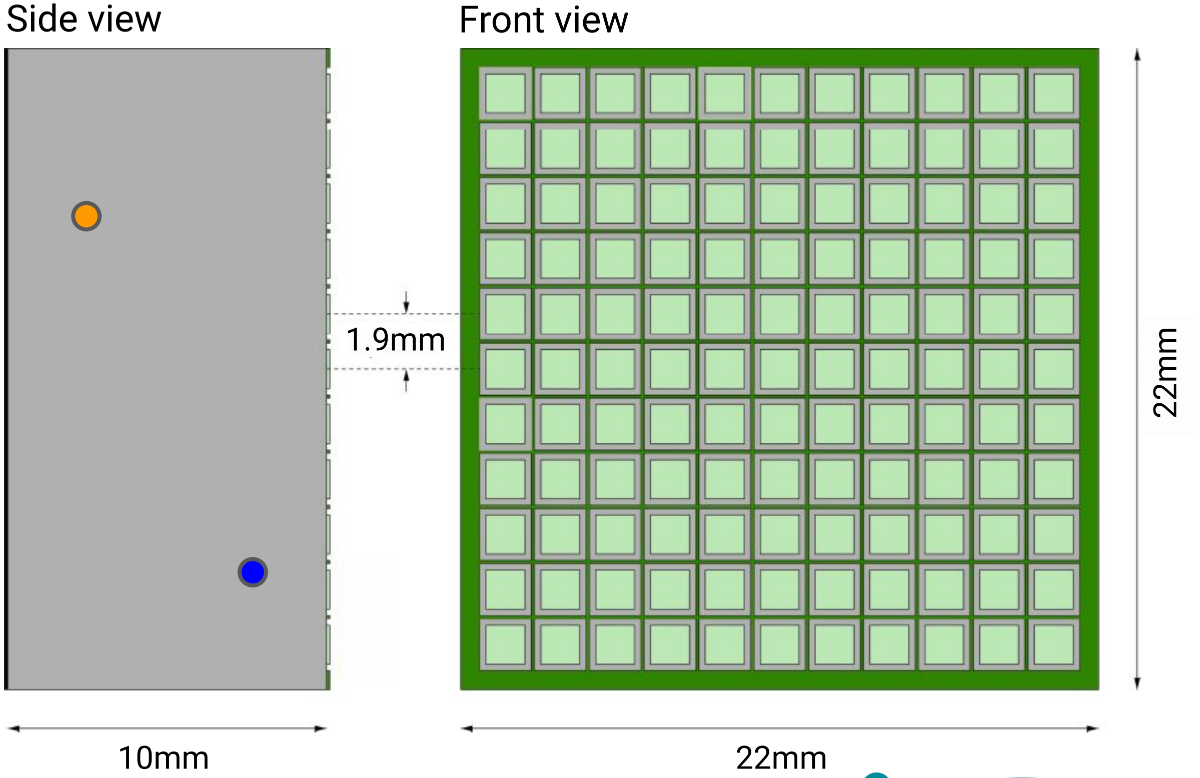
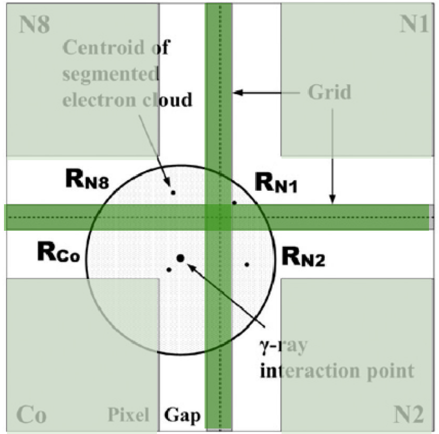
Pixelized Detectors



Single crystal CdZnTe

Cathode contact (covers whole back surface)

Anode pixels



J.C. Kim *et al.*., Nucl. Instr. Meth. A **651**: 233 (2011)
doi:10.1016/j.nima.2011.06.038

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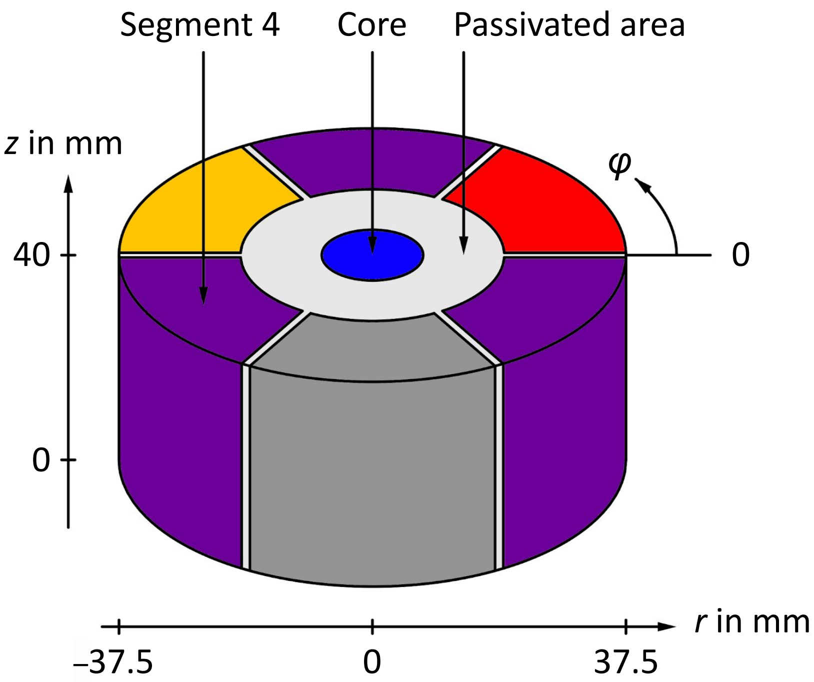
Segmented Broad Energy Germanium Detector



Values in the specification sheet of the detector:

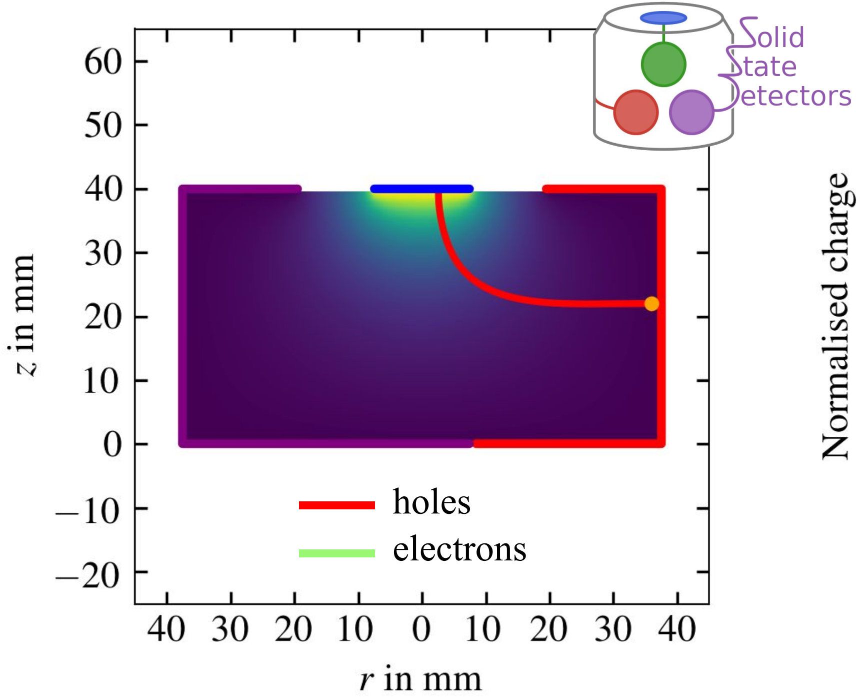
Net carrier concentration:

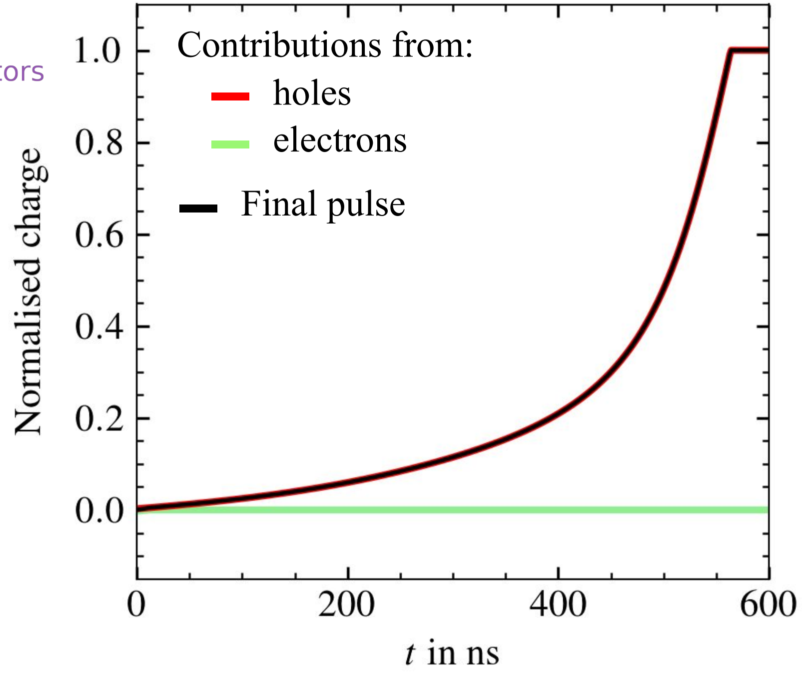
- Top surface: $6.5 \cdot 10^{9}$ cm^{-3}
- Bottom surface: $5.8 \cdot 10^{9}$ cm^{-3}

Note: The net impurity concentration is given by the crystal grower and could be different than the values calculated from depletion measurements.

I. Abt et al., Nucl. Instr. Meth. A **925**: 172 (2019)
doi:10.1016/j.nima.2019.02.005, arXiv: 1810.10332

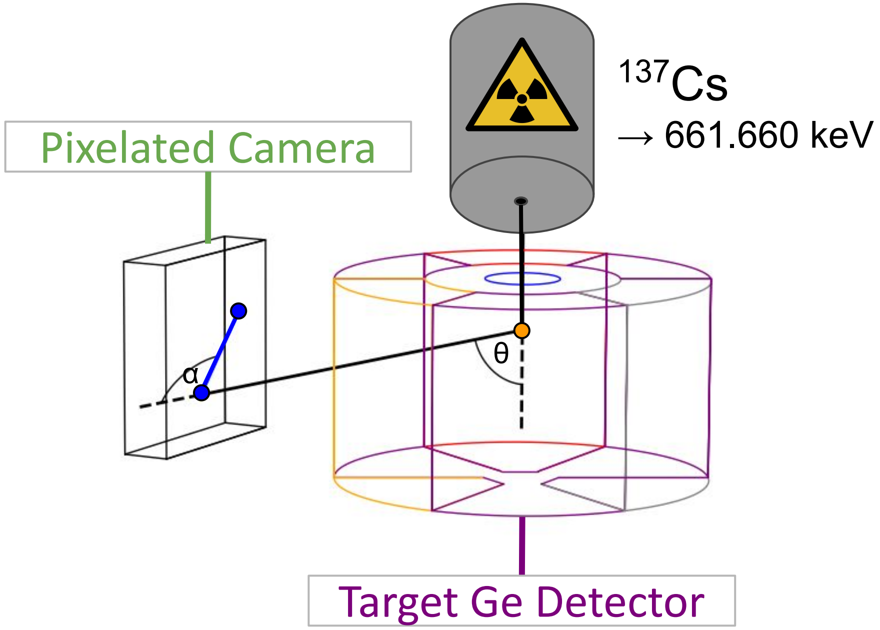
Signal Development in Germanium Detectors

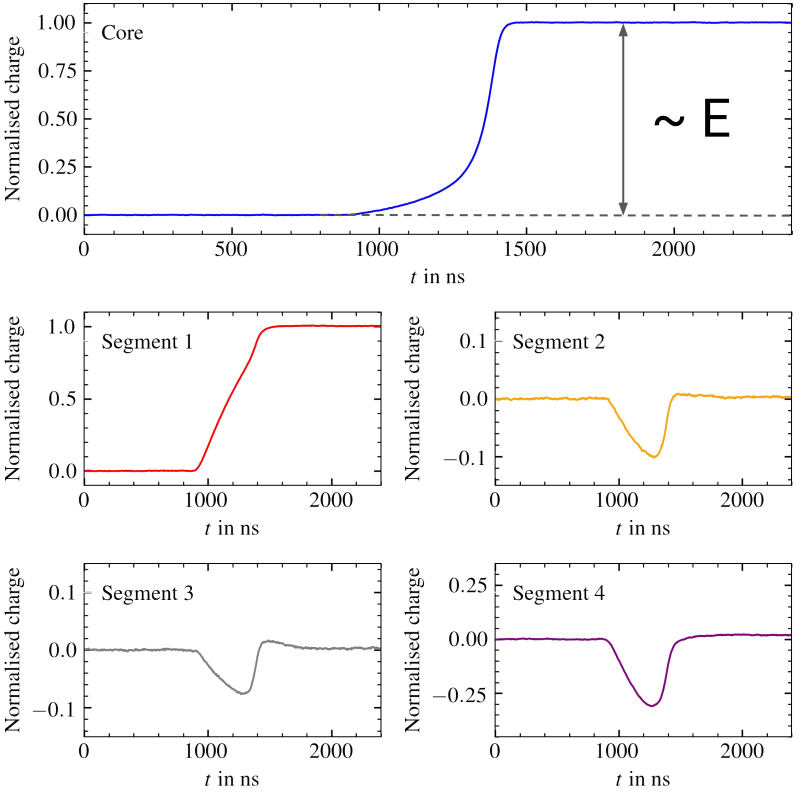




I. Abt et al., J. Instr. **16**: P08007 (2021)
doi:10.1088/1748-0221/16/08/P08007, arXiv: 2104.00109

Compton Scanner





I. Abt et al., Eur. Phys. J. C **82**: 936 (2022)
doi:10.1140/epjc/s10052-022-11064-8, arXiv: 2202.03116

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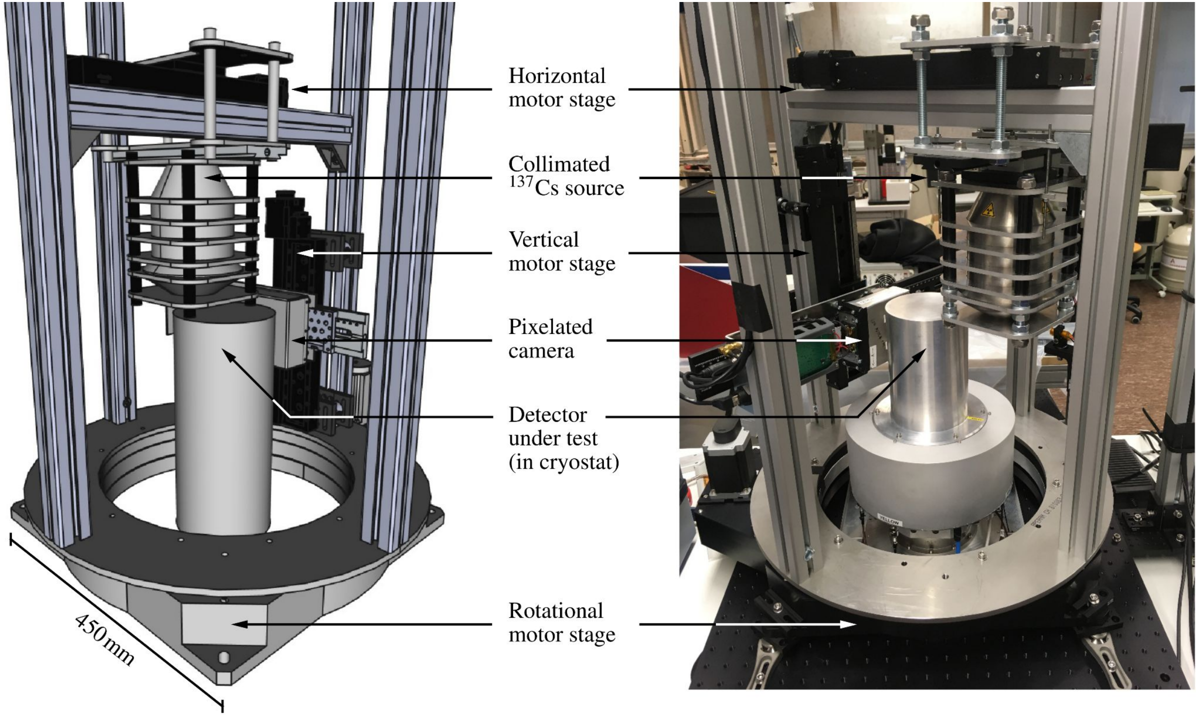
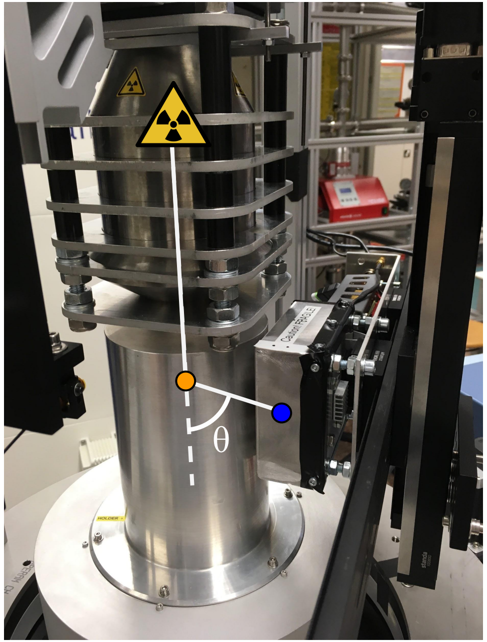
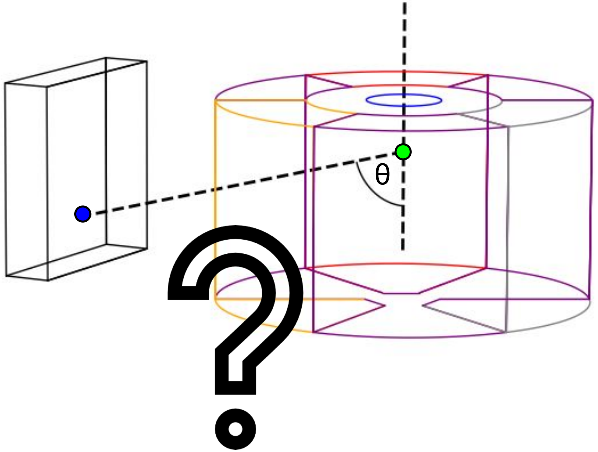
Compton Scanner Setup

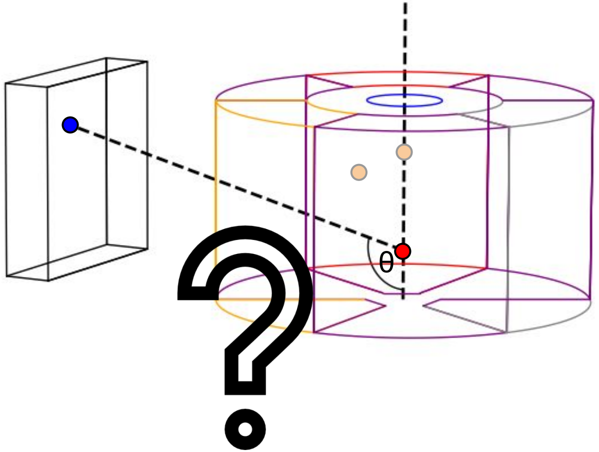




I. Abt et al., Eur. Phys. J. C **82**: 936 (2022)
doi:10.1140/epjc/s10052-022-11064-8, arXiv: 2202.03116

Background for Event Selection





I. Abt et al., Eur. Phys. J. C **82**: 936 (2022)
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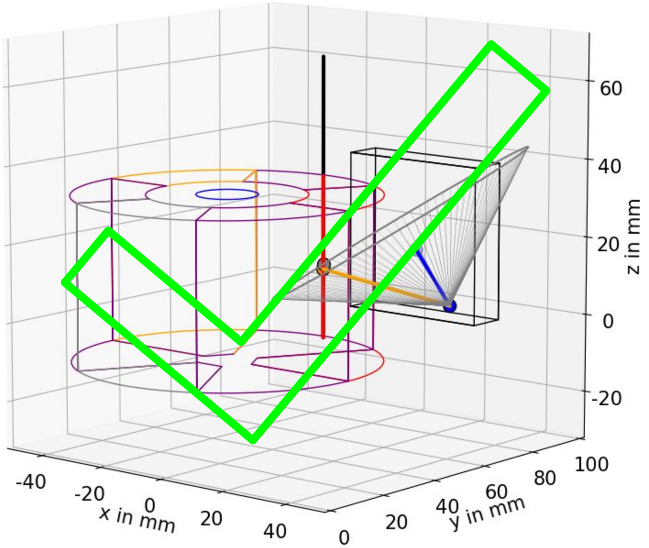
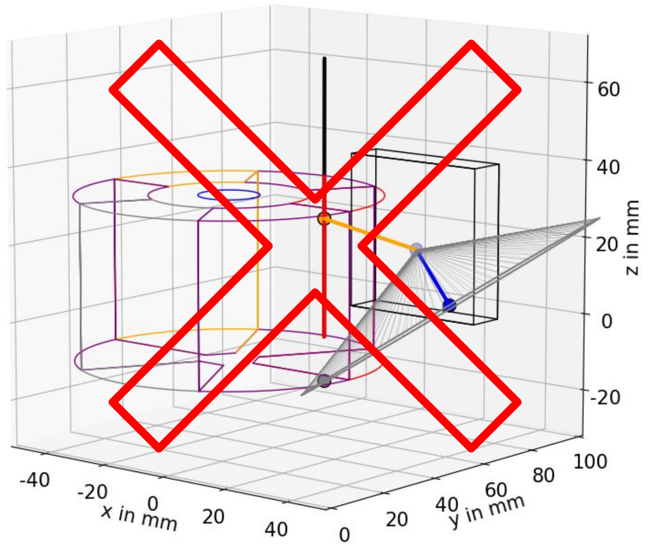
Reconstruction Algorithm





From energy ratio: $$\cos(\theta) = 1 - \frac{E_1 m_e c^2}{E_2(E_1+E_2)}$$

$$z_\theta = z + \sqrt{(x-x_0)^2 + (y-y_0)^2}\cot(\theta)$$

From hits in CZT: $$(H_z^2 - \cos^2(\alpha))\, z_\alpha^2 + 2(c_z\cos^2(\alpha) - (\vec{H}_0\cdot(\vec{c}_1-\vec{x}_0))\,H_z)\, z_\alpha + (\vec{H}_0\cdot(\vec{c}_1-\vec{x}_0))^2 - (\vec{c}_1-\vec{x}_0)^2\cos^2(\alpha) = 0$$

I. Abt et al., Eur. Phys. J. C **82**: 936 (2022)
doi:10.1140/epjc/s10052-022-11064-8, arXiv: 2202.03116

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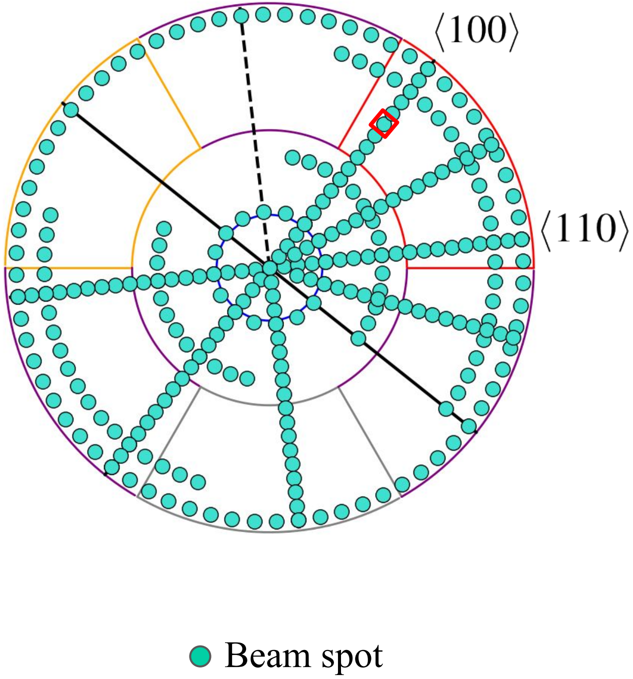
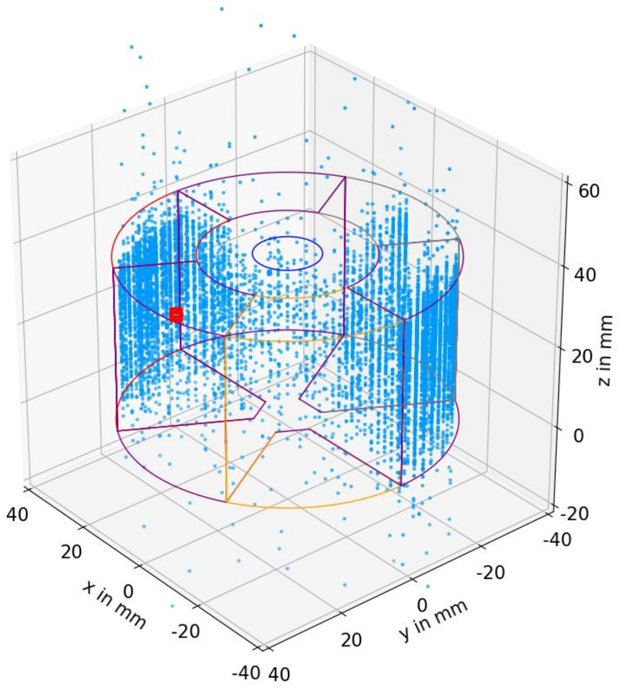
Reconstruction Algorithm Applied to Data



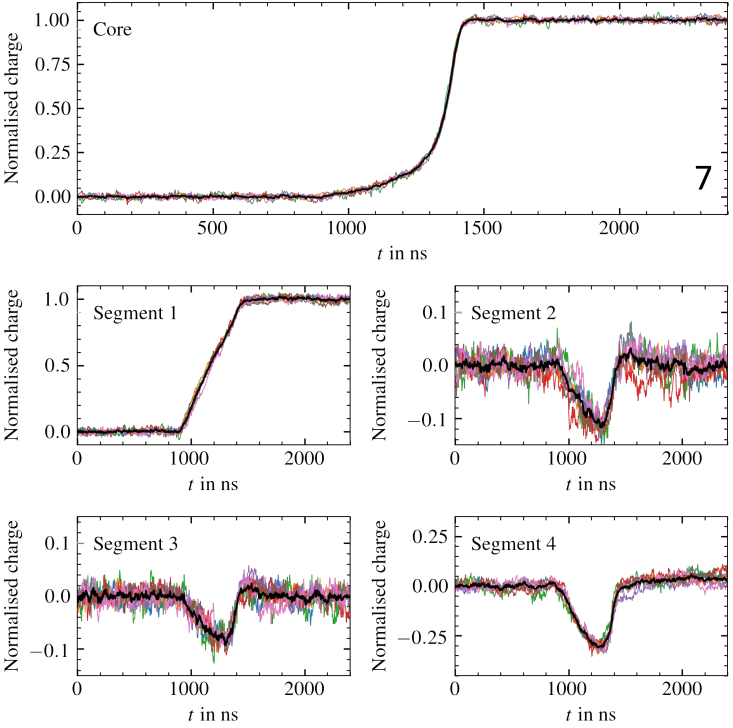


I. Abt et al., Eur. Phys. J. C **82**: 936 (2022)
doi:10.1140/epjc/s10052-022-11064-8, arXiv: 2202.03116

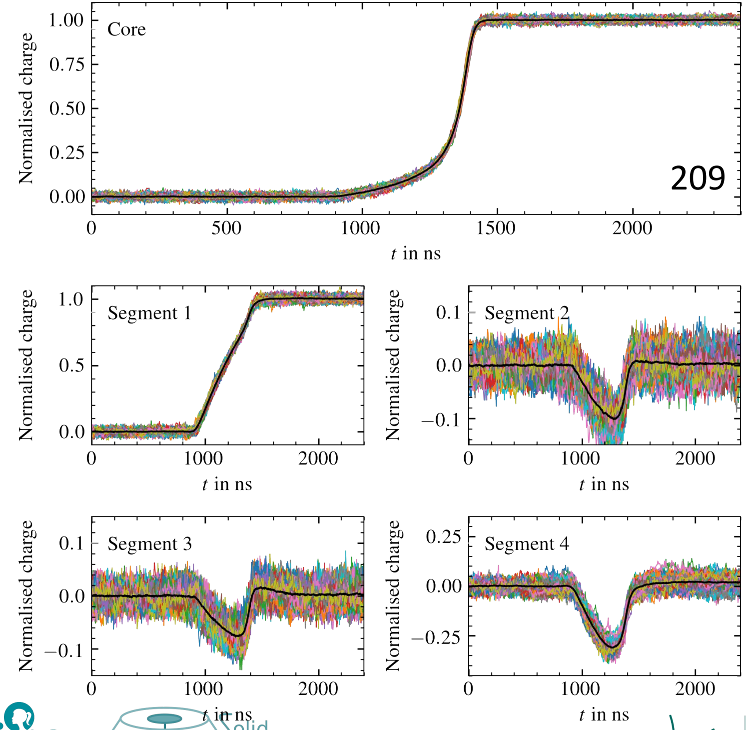
Pulse Shape Selection

→ similarity in core and collecting segment

From events with **2 hits** in the CZT camera:



From events with **1 hit** in the CZT camera:



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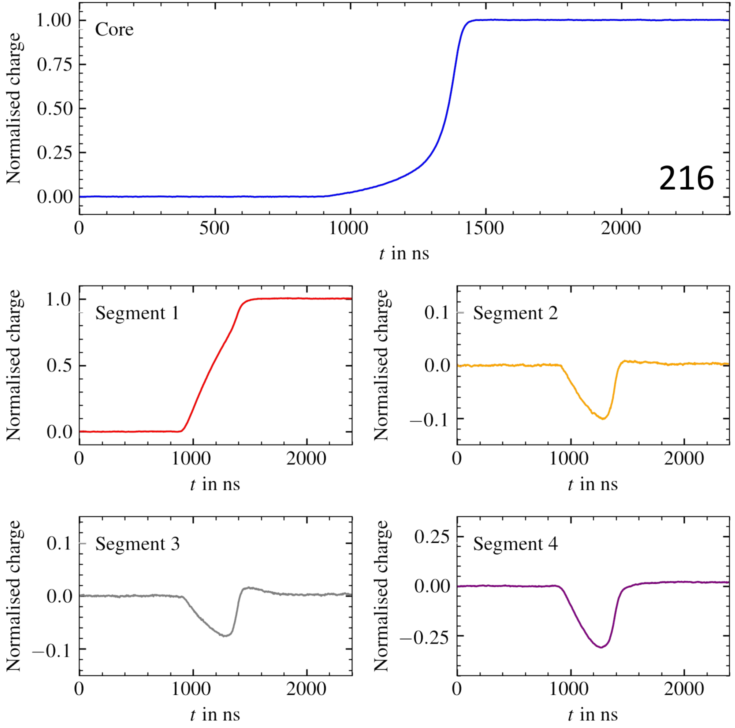
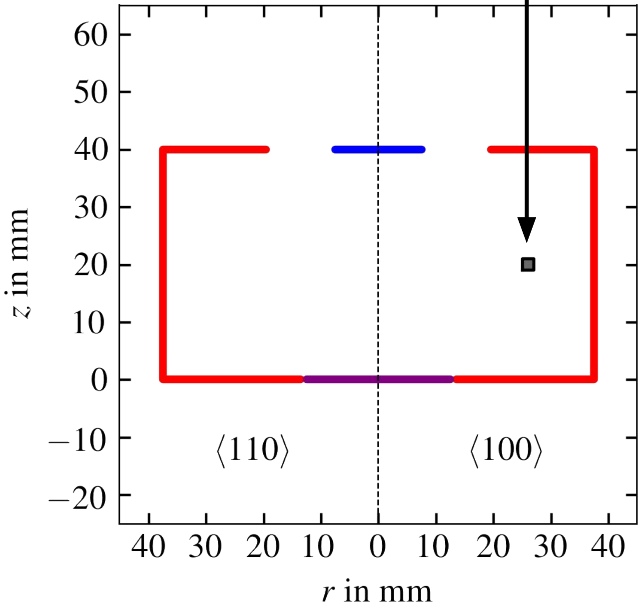
Pulse Shape Library

Waveforms from data at R = 25.5mm, φ = 50.8°, z = 20mm





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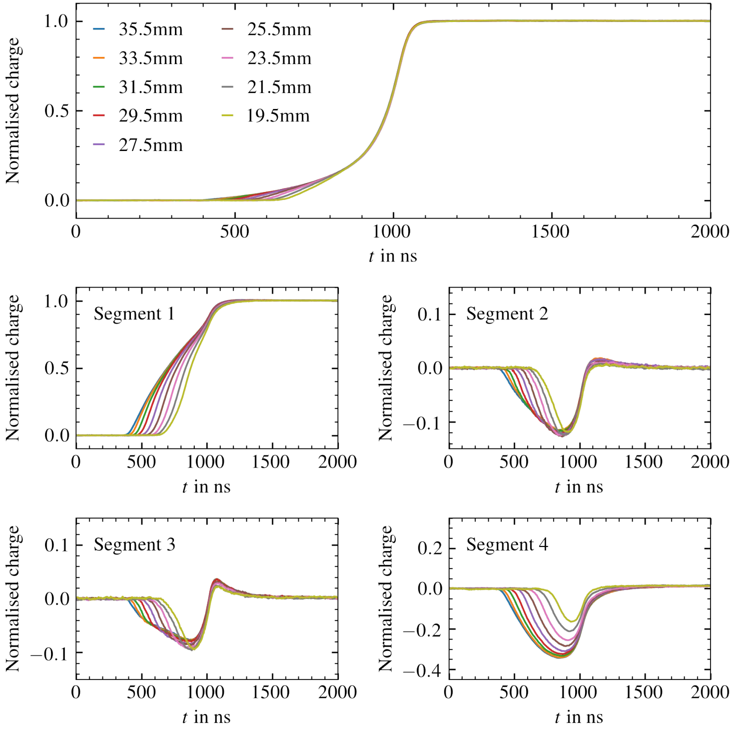
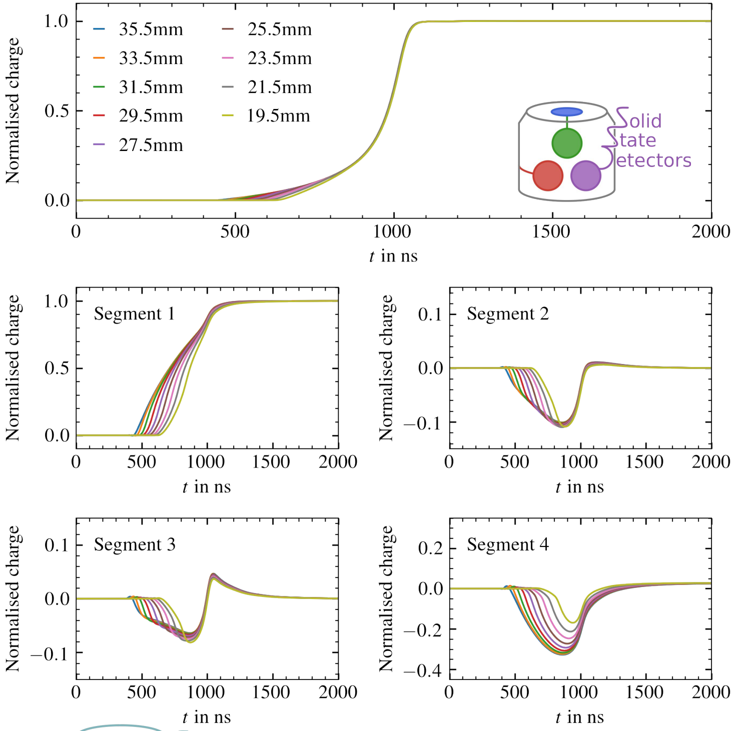
Comparison to Simulation





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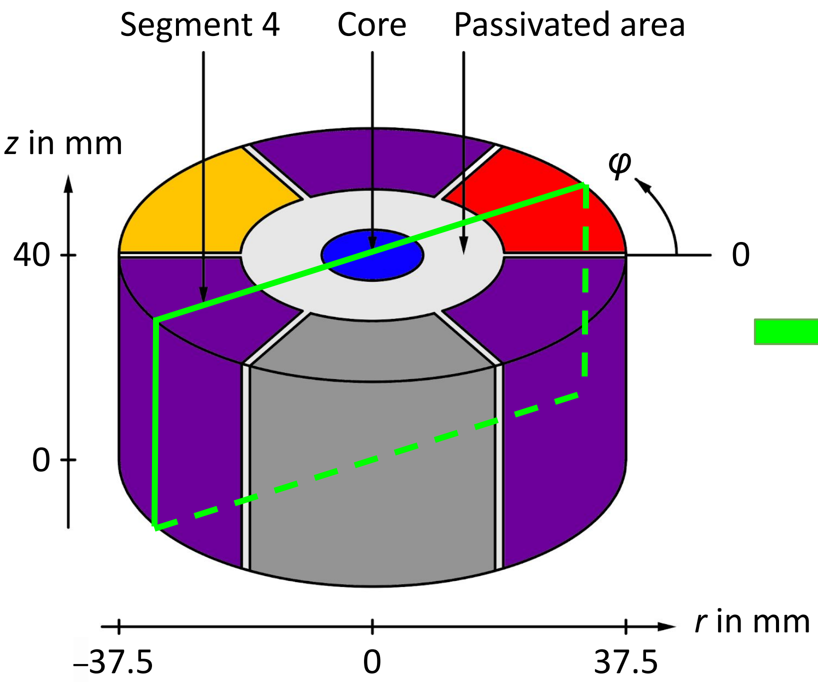
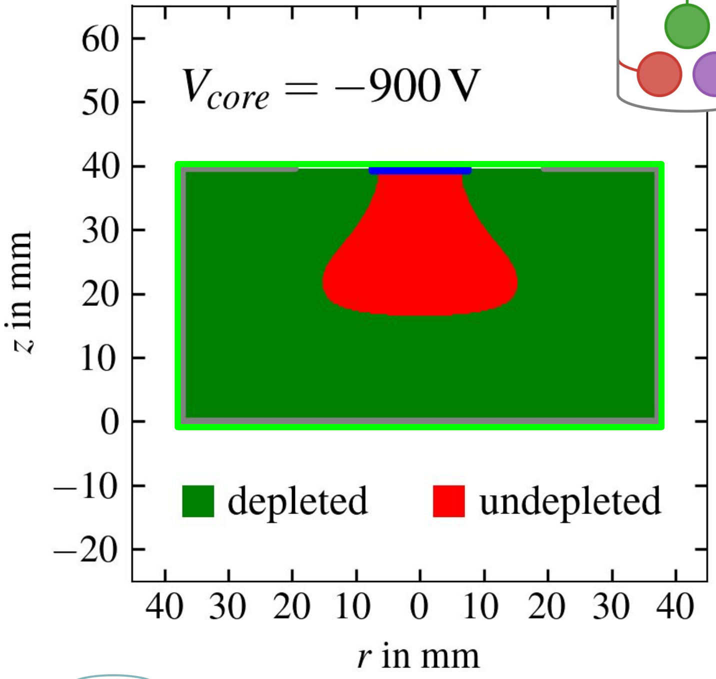
Simulated Depletion Behaviour of the segBEGe Detector





I. Abt et al., Nucl. Instr. Meth. A **925**: 172 (2019)
doi:10.1016/j.nima.2019.02.005, arXiv: 1810.10332

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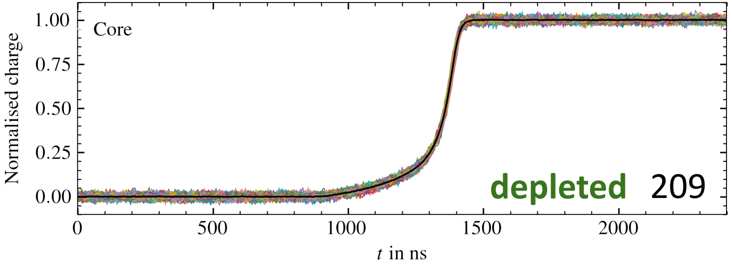
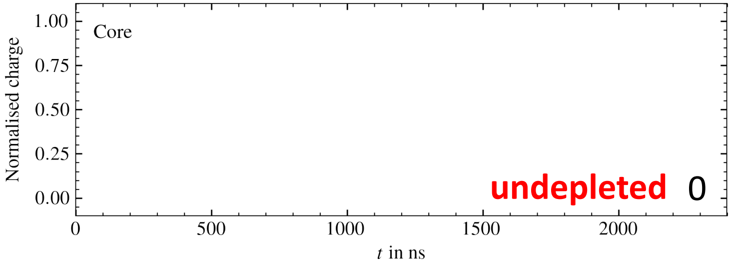
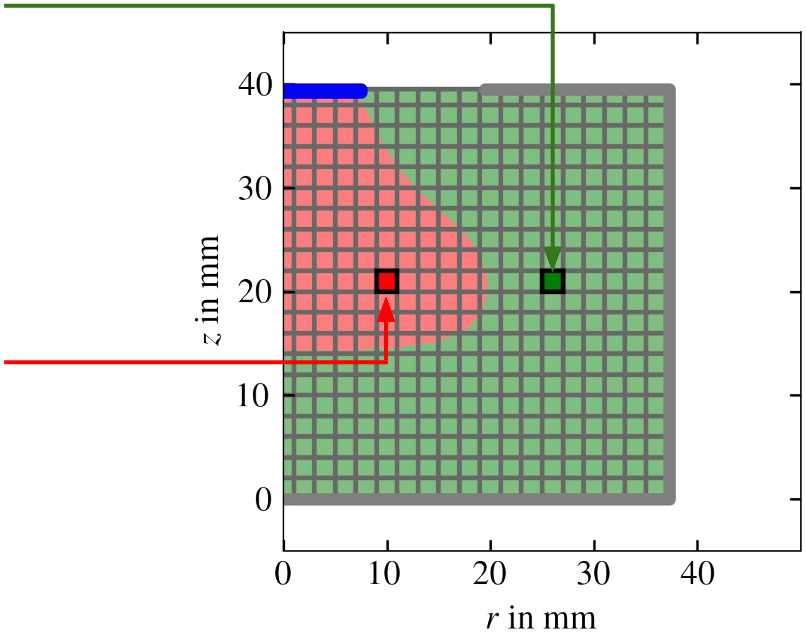
Compton Imaging of Undepleted Regions

From events with **2 hits** in the camera:

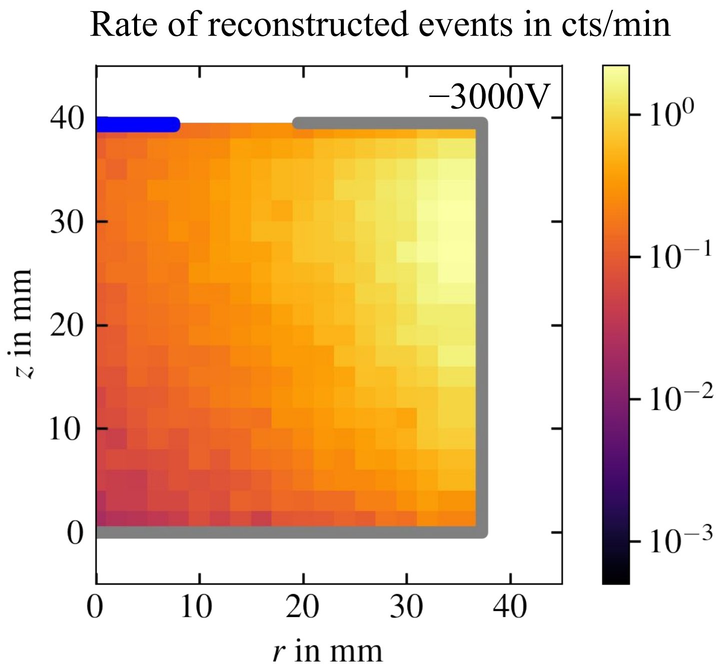


From events with **2 hits** in the camera:

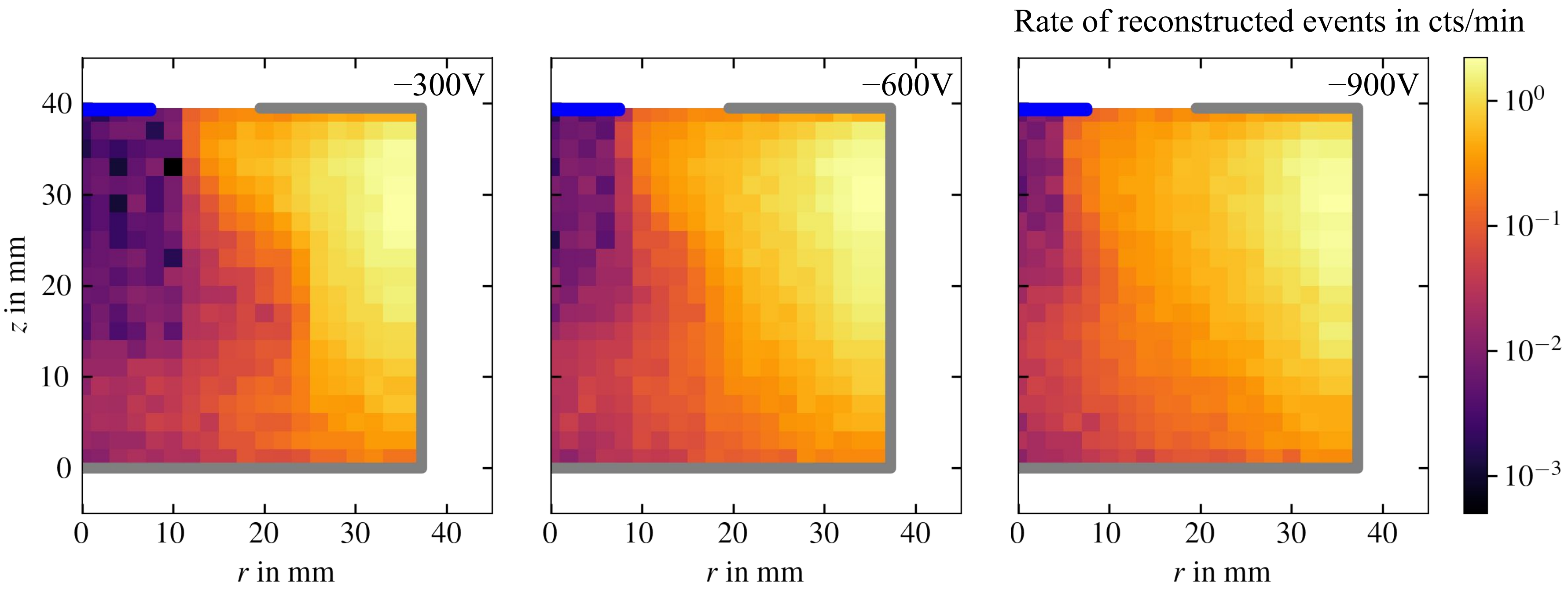




Rates of Compton Reconstructed Events



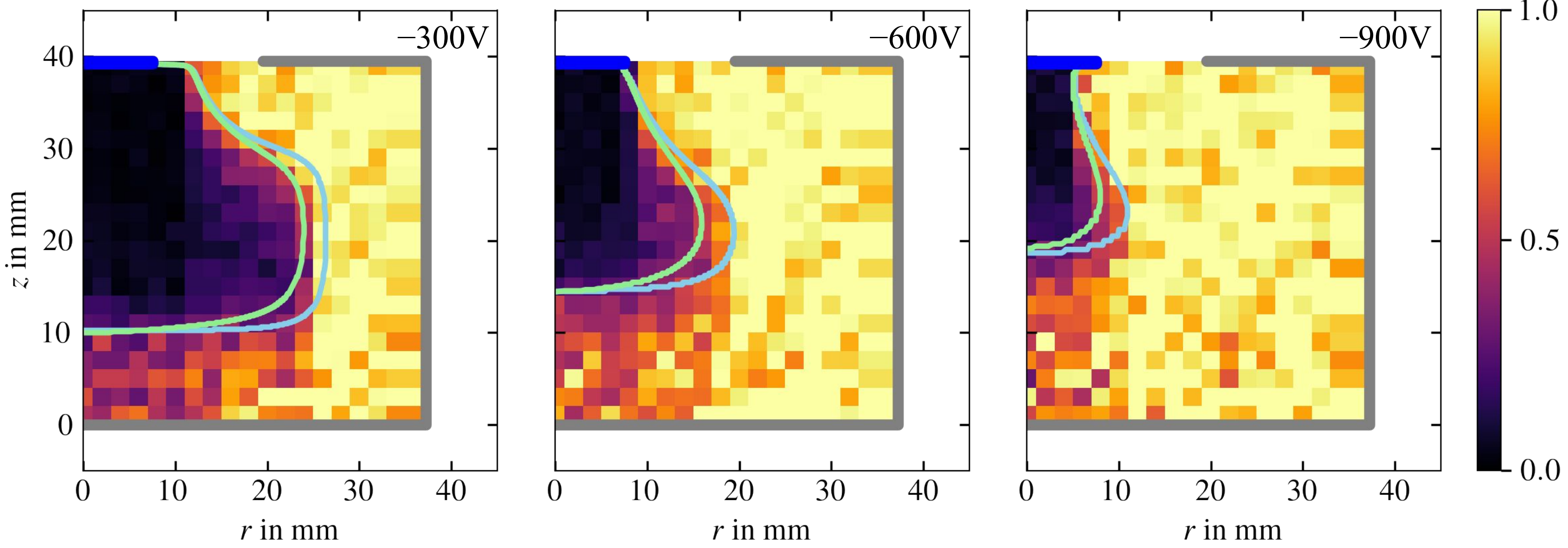
Rates of Compton Reconstructed Events



Comparison to Simulation

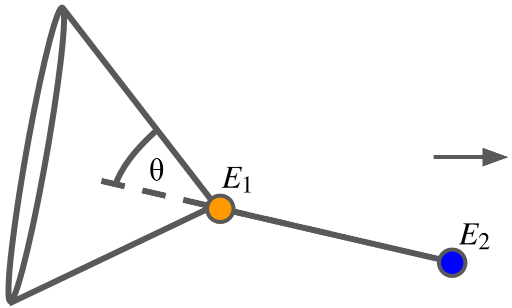
— Simulated undepleted region using the manufacturer values (scaled by a factor to match the measured depletion voltage)

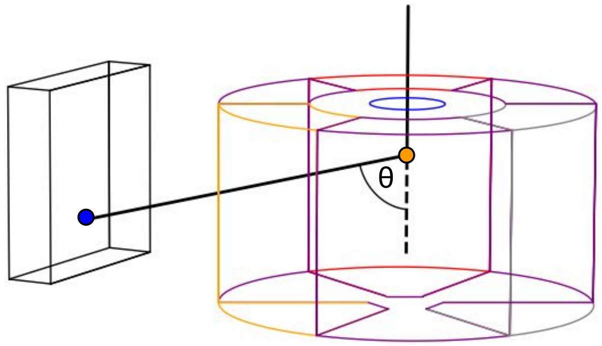
— Simulated undepleted region using an impurity profile with a linear radial dependence: $\rho(r) = \rho_0 \cdot (1 - r/R)$

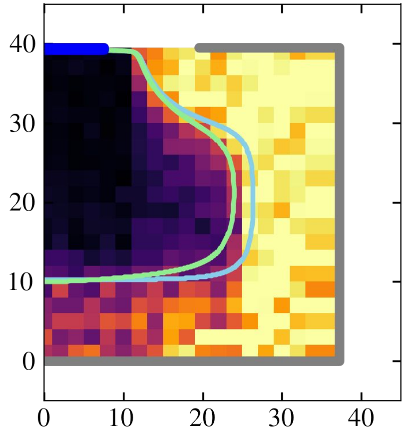


I. Abt et al., J. Instr. **16**: P08007 (2021)
doi:10.1088/1748-0221/16/08/P08007, arXiv: 2104.00109

Summary







Compton imaging

Experimental setup:
Compton Scanner

Compton imaging allows to study pulse shapes and depletion behavior

R.W. Todd *et al.*., Nature **251**: 132 (1974)
doi:10.1038/251132a0

I. Abt et al., Eur. Phys. J. C **82**: 936 (2022)
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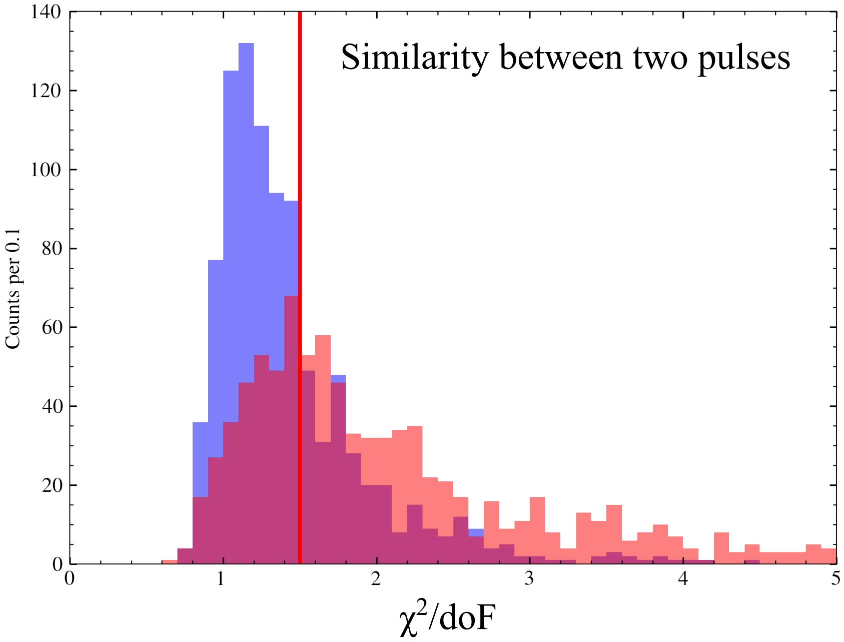
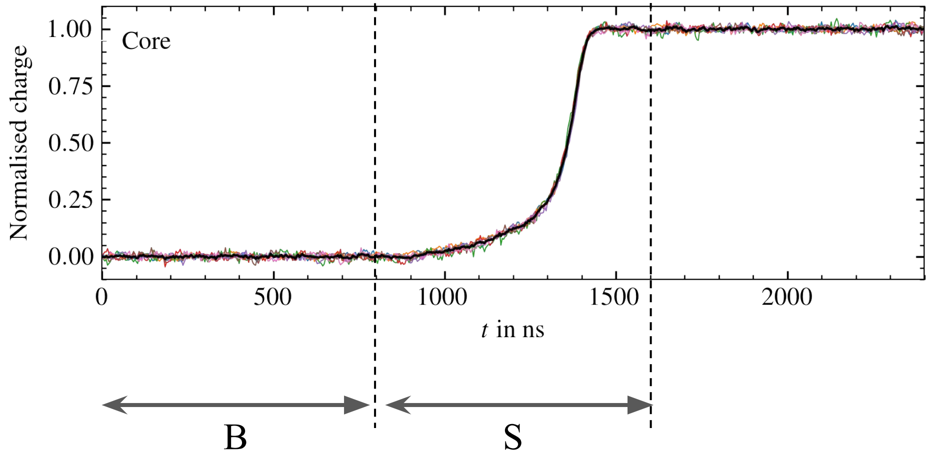
Backup

Similarity cut





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Contributions to the Electric Potential

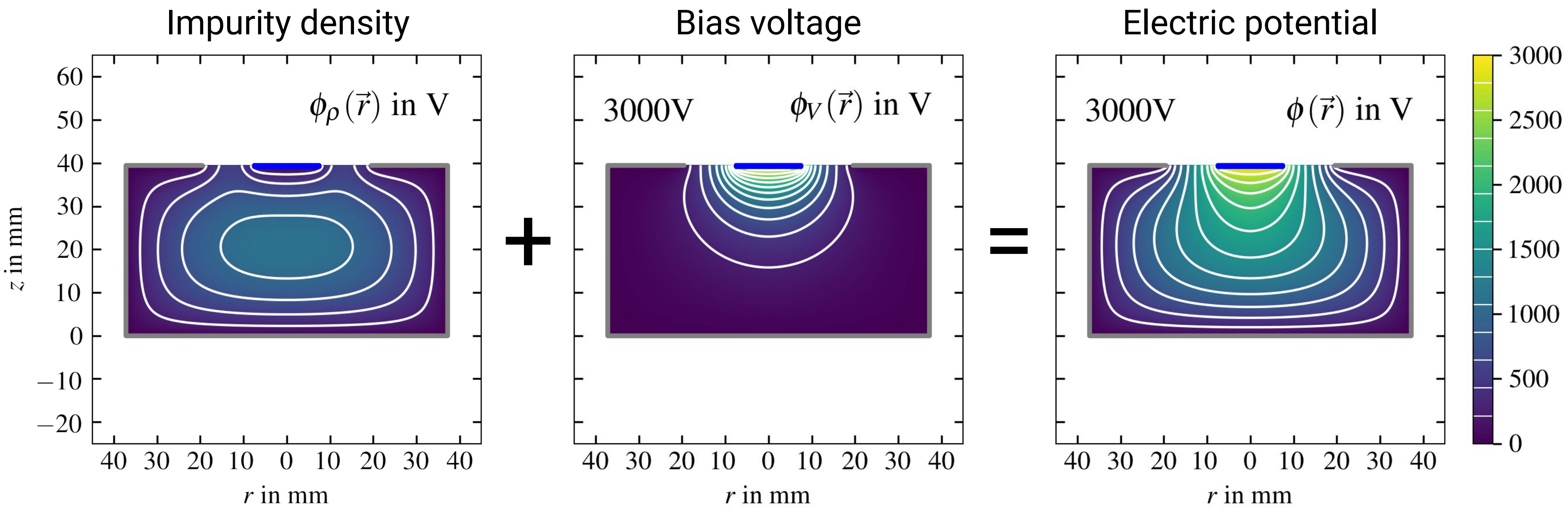
$$\nabla^2 \phi(\vec{r}) = -\frac{\rho(\vec{r})}{\varepsilon} \qquad \phi(\vec{r})|_{S_i} = V_{B,i}$$

$$\phi_\rho(\vec{r}) \quad + \quad \phi_V(\vec{r}) \quad = \quad \phi(\vec{r})$$

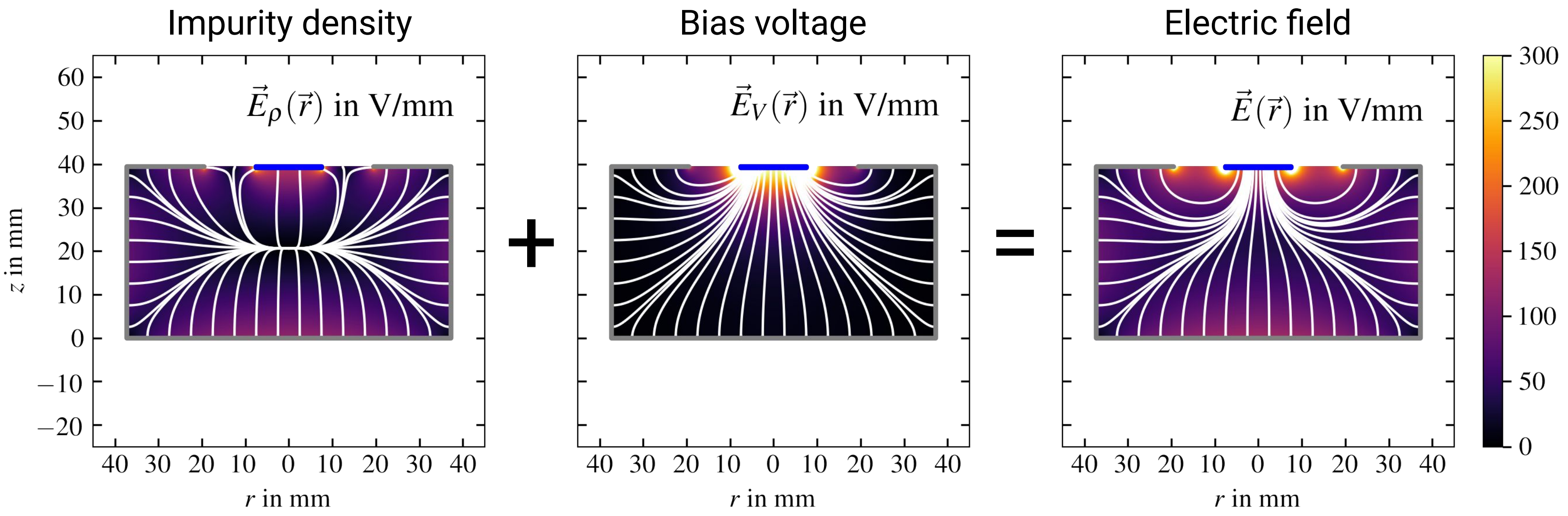
$$\nabla^2 \phi_\rho(\vec{r}) = -\frac{\rho(\vec{r})}{\varepsilon} \qquad \nabla^2 \phi_V(\vec{r}) = 0$$

$$\phi_\rho(\vec{r})|_{S_i} = 0 \qquad \phi_V(\vec{r})|_{S_i} = V_{B,i}$$

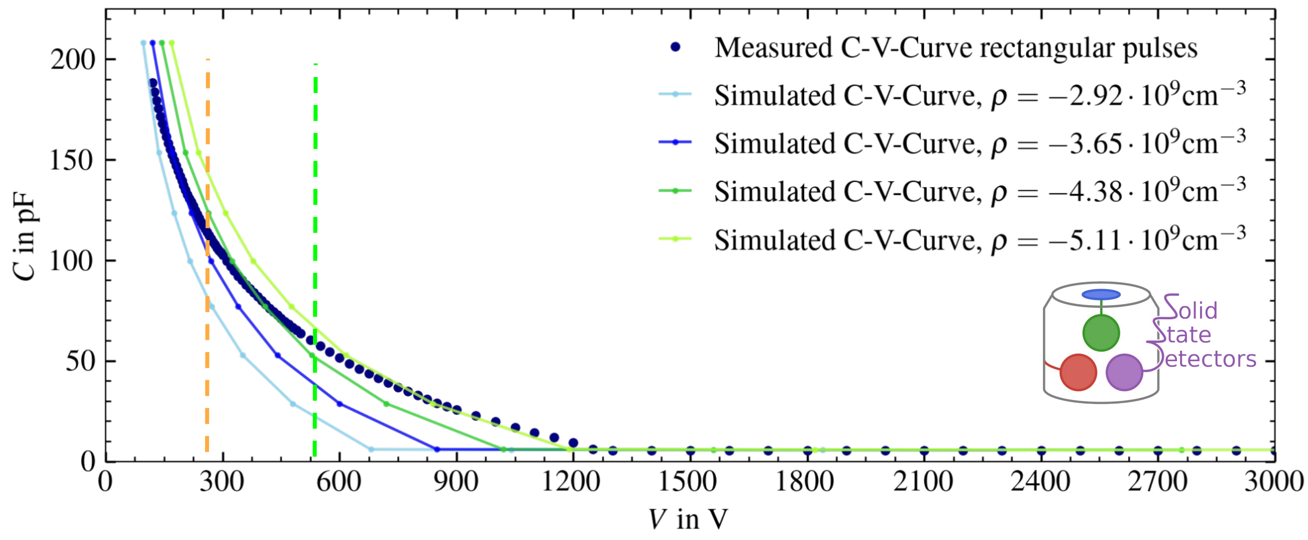
Contributions to the Electric Potential

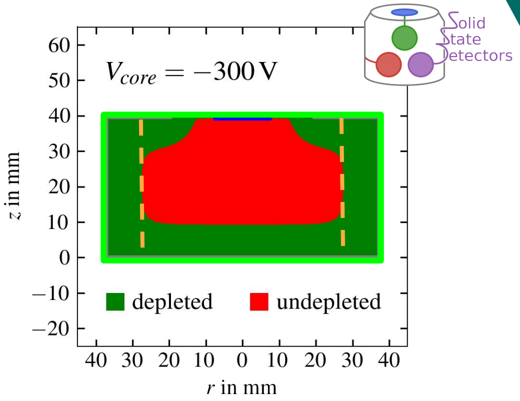


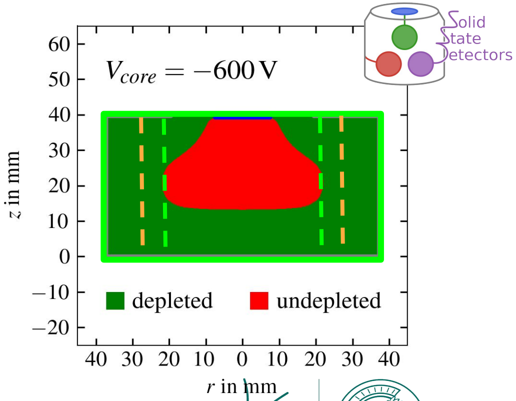
Contributions to the Electric Field



Estimating the Radial Component from CV Measurements







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Estimating the Radial Component from CV Measurements