Finding the crystal axes

in a segmented germanium detector

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Germanium detectors

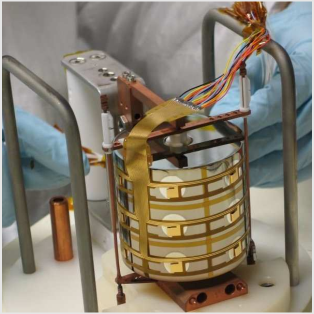
Germanium detectors have a very good energy resolution.

- Used in spectroscopy, gamma ray tracking, $0\nu\beta\beta$ experiments
- Segmentation provides granularity: helps to distinguish single-segment events (signal-like) from multi-segment events (background-like) and to localize events
- Analysis of pulse shapes: collected charge pulses differ depending on event topology; simulation may be involved

Features:

- Pulses and mirror pulses, talks by S. Irlbeck and B. Dönmez
- Crystallographic axes, this talk

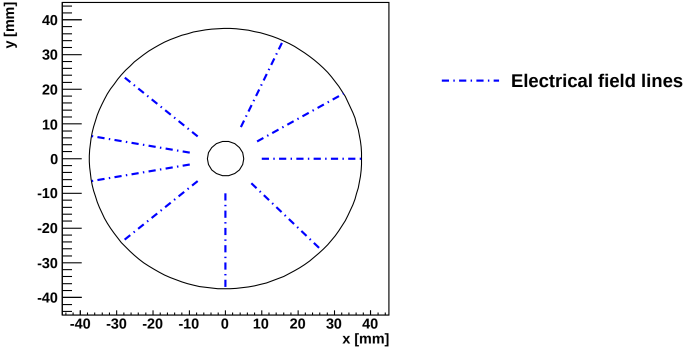
Segmented germanium detectors



Siegfried-II detector:

- Inner $\varnothing 10\,\mathrm{mm}$
  outer $\varnothing 75\,\mathrm{mm}$
  height $70\,\mathrm{mm}$;
- $3z \times 6\phi$-segmentation;
- High-purity:
  $\rho_{\mathrm{imp}} \sim 0.45 \cdot 10^{10}/\mathrm{cm}^3$:
  1 ion per $\sim 10^{13}$
  germanium ions.
- Radial electrical field
- Operational voltage:
  $2000\,\mathrm{V}$ and higher.

Effect of anisotropy



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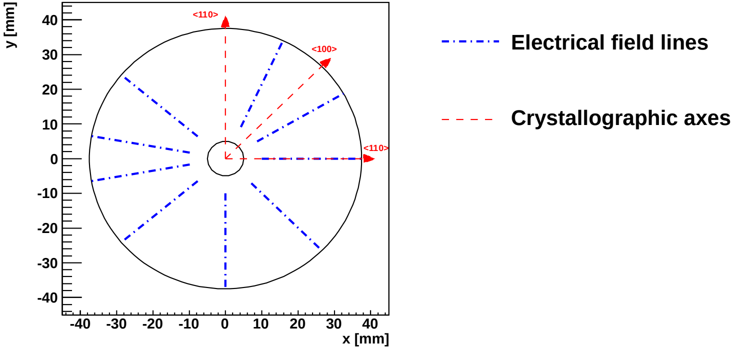

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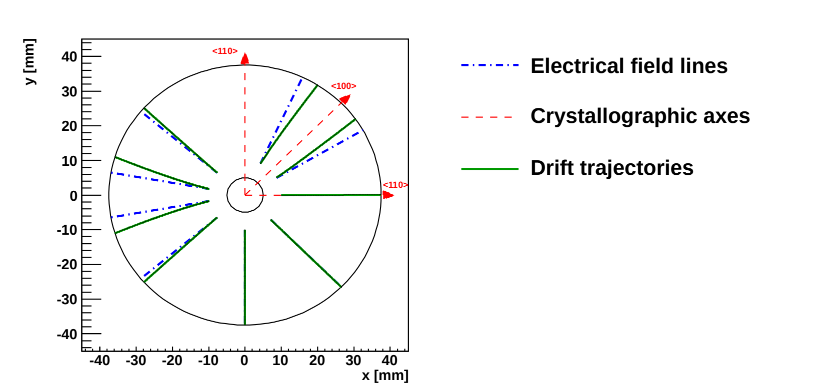
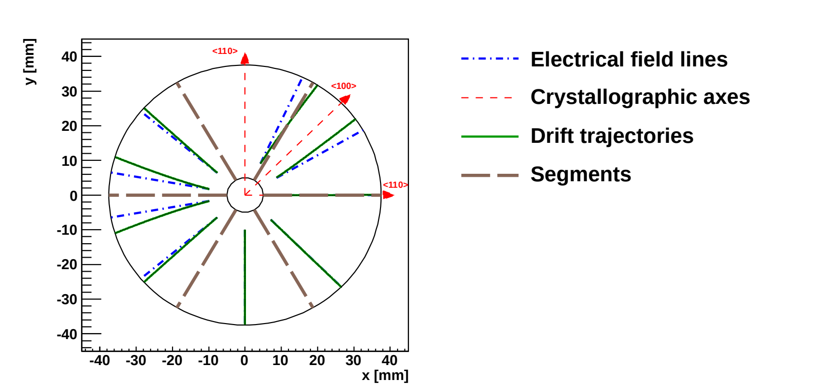


Drift velocity of charge carriers

$\mathbf{v} = \mu \cdot \mathcal{E}$

Mobility μ is a tensor, drift does not follow $\mathcal{E}$

Effect of anisotropy



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Effect of anisotropy: conclusion

Segmentation: physical $\neq$ geometrical.
Blame anisotropy!

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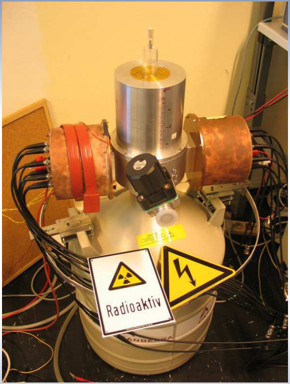
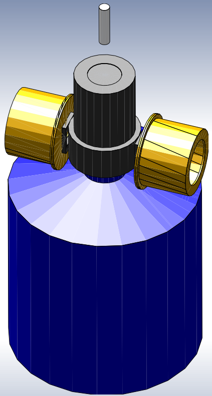
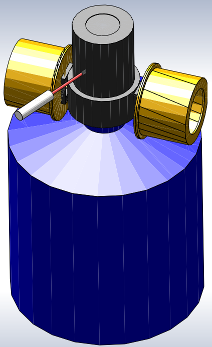
Drifting charge cloud of $0\nu\beta\beta$ event has $\varnothing \simeq 2$ mm: spread at $r = 2.5$ cm is 5°.

Vacuum cryostat K1



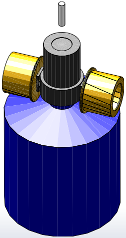


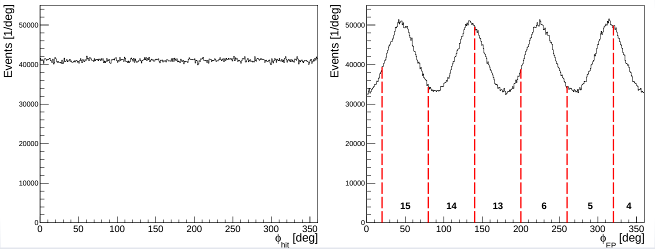


Detector in vacuum cooled through a cooling finger at $T \simeq 90\,\mathrm{K}$.

Effect of anisotropy

Energy deposits from a γ source located homogeneous in ϕ, Cobalt-60:

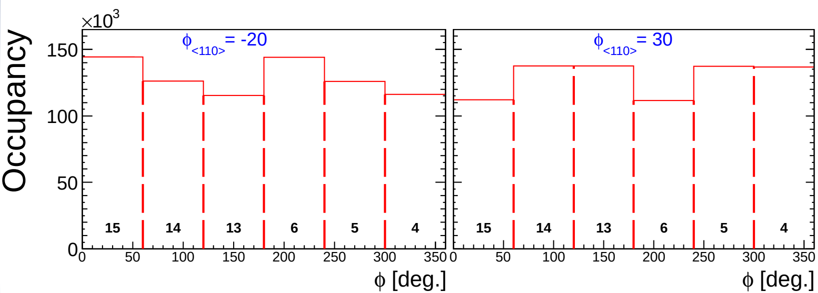




Before drift $\Longrightarrow$ After drift

Effect of anisotropy: occupancy

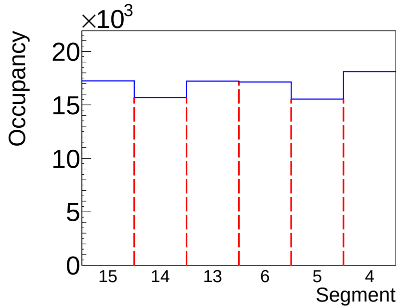
Number of events in segments under the 1.33 MeV peak



Simulation

Measurements

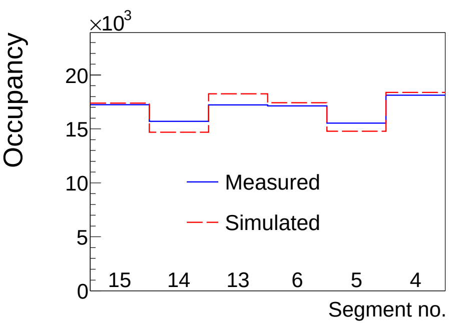
Number of events in segments under the 1.33 MeV peak



Extraction method: procedure

1. Vary $\phi^{sim}_{\langle 110\rangle}$ in 1°steps;
2. For each $\phi^{sim}_{\langle 110\rangle}$ a test statistic ϵ is calculated;
3. Dependence of ϵ on $\phi^{sim}_{\langle 110\rangle}$ is a smooth function;
4. $\epsilon\left(\phi^{sim}_{\langle 110\rangle}\right)$ is fitted with a second order polynomial;
5. The minimum of the fit $= \phi_{\langle 110\rangle}$.

Test statistic



Test statistic

$$\sum_{\text{segments}} \frac{(\text{Data}_i - \text{MC}_i)^2}{\text{Data}_i^2}$$

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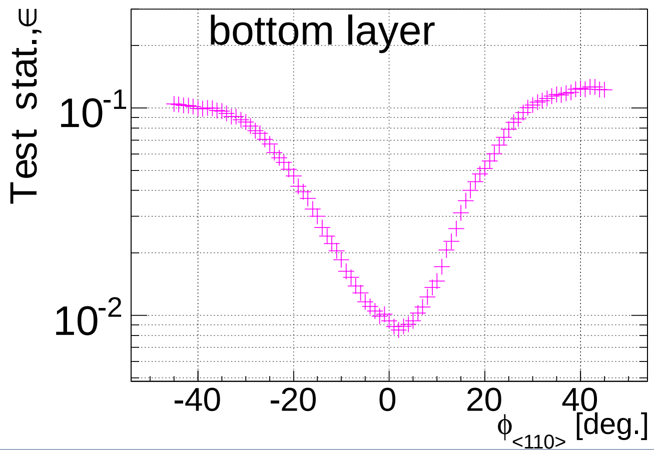
Dependence of ϵ on angle parameter $\phi^{sim}_{\langle 110\rangle}$



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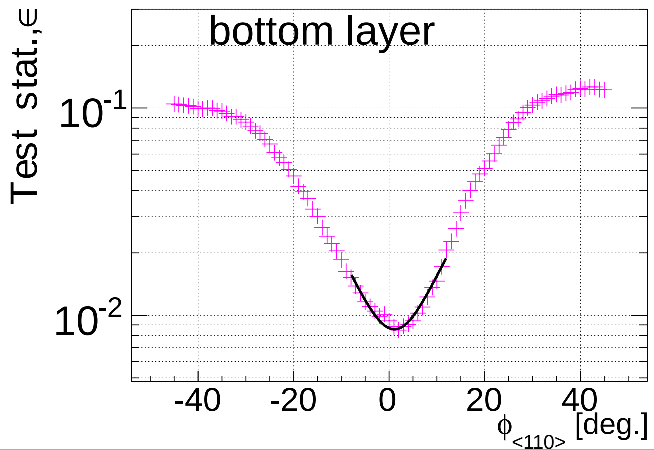
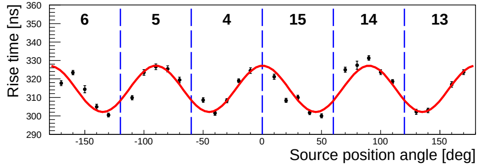
Fit on test statistic



Results and comparison

Method	Value [degree]
True value *	$\phi_{\langle 110 \rangle} = -0.2^\circ \pm 0.4^\circ(\text{stat.}) \pm 3^\circ(\text{syst.})$
Source on top	$\phi^{\text{top}}_{\langle 110 \rangle} = -1.8^\circ \pm 1^\circ(\text{stat.}) \pm 6^\circ(\text{syst.})$

* Obtained using a reference method



Extraction method: variations

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  - Different layers of the detector (top, middle, bottom);
  - Different lines of a source:
    1. ^{60}Co: 1.17 MeV; 1.13 MeV;
    2. ^{208}Tl: 0.58 MeV; 2.61 MeV;
  - Different source positions: top, side.

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  - Different lines of a source:
    1. ^{60}Co: 1.17 MeV; 1.13 MeV;
    2. ^{208}Tl: 0.58 MeV; 2.61 MeV;
  - Different source positions: top, side.
- Cobalt lines, 1.17 MeV and 1.33 MeV seem to be best suited:
  1. High probability of emission from the source;
  2. High enough probability to be fully absorbed in a single segment.

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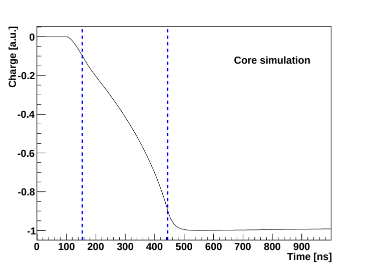
Summary

- In some cases a precise knowledge of the crystallographic axes orientation in a Ge-detector is required
- A new method to determine the axes orientation was developed and tested
- Very sensitive to any imperfection of setup representation in simulation
- The more data is available, the better: enough data is required to get satisfactory accuracy
- No need to move the source, wait and see: much faster than the reference ϕ-scanning method

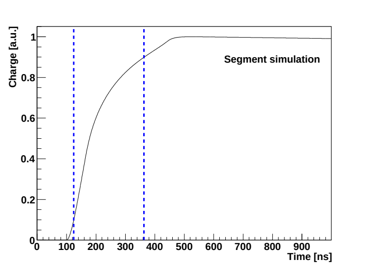
More details: arXiv:1112.5291 [nucl-ex]

Backup

Simulated pulse



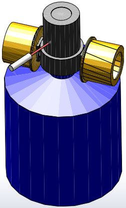
Core pulse

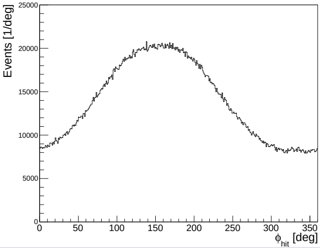


Segment pulse

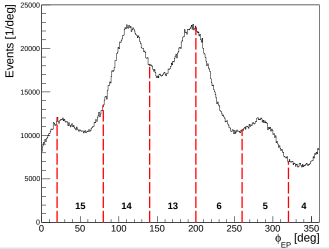
Effect of anisotropy

Energy deposits from a γ source located in front of a segment, Thalium-208 (Thorium-228):





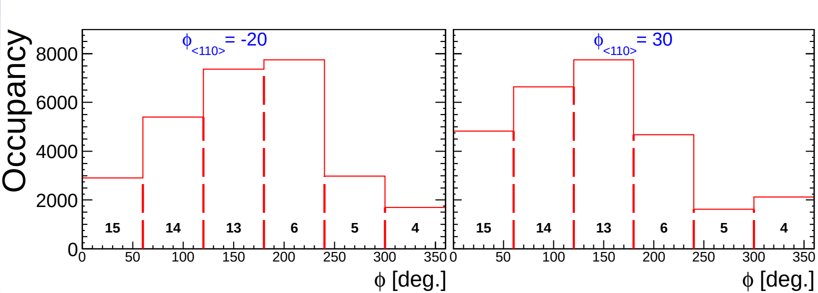
Before drift $\Longrightarrow$



After drift

Effect of anisotropy: occupancy

Number of events in segments under the 2.61 MeV peak



Simulation