Finding the crystal axes

in an n-type segmented germanium detector

Oleksandr Volynets

Max-Planck-Institute for Physics

Particle Physics School Munich Colloquium

Munich, January Friday 13, 2012

Submitted to EPJ C
arXiv:1112.5291 [nucl-ex]

MAX-PLANCK-GESELLSCHAFT

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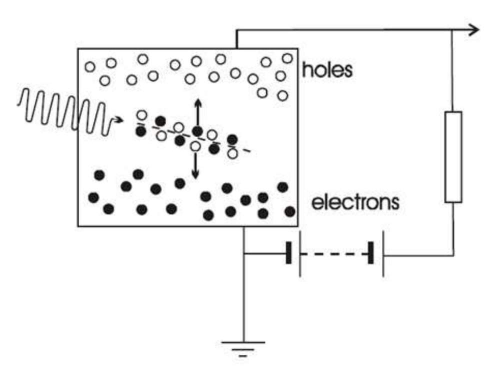
Outline

- Introduction: germanium detectors
- Anisotropy in germanium crystals
- Experimental setup and simulation
- The method to extraction the axes orientation
- Results, comparison and variations of the method
- Summary

Introduction

Semiconductor detectors are used to register radiation:



Germanium detectors

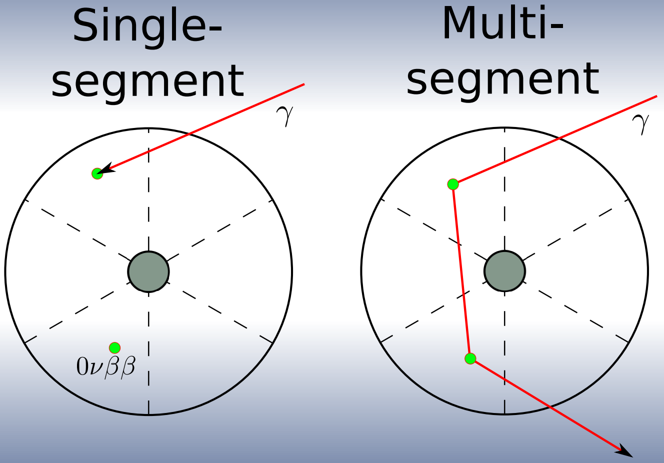
Germanium detectors have a very good energy resolution: 4-7 keV @ 2 MeV. They are used for:

- Spectroscopy, to measure low levels of radioactivity;
- Gamma ray tracking;
- $0\nu\beta\beta$ experiments: source=detector approach with detectors enriched in ^{68}Ge which $\beta\beta$ decays;
- ...

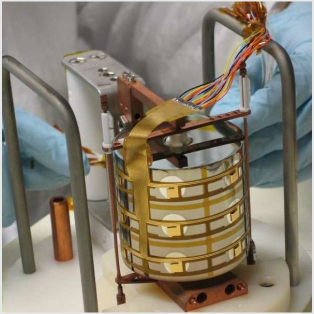
Analysis techniques for $0\nu\beta\beta$ with Ge detectors

- Detector granularity: segmentation helps to distinguish single-segment events (signal) from multi-segment events (background) and to localize events;
- Analysis of pulse shapes: collected charge pulses differ depending on event topology; simulation may be involved.

Segmentation: background rejection technique



Segmented germanium detectors

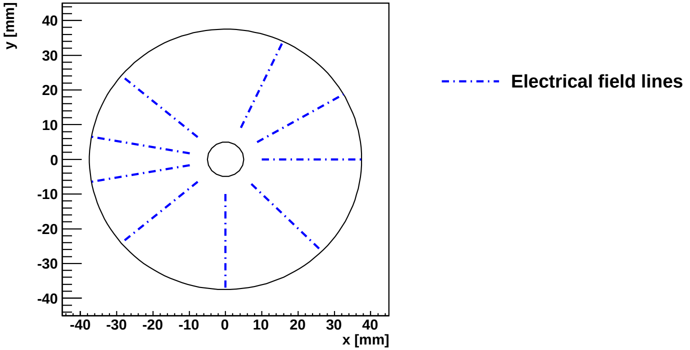


Siegfried-II detector:

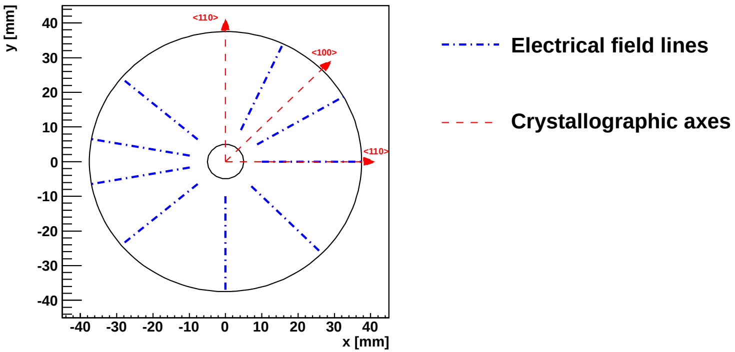
- Diameter 75 mm, height 70 mm;
- $3z \times 6\phi$-segmentation;
- High-purity: $\rho_{\text{imp}} \sim 0.45 \cdot 10^{10}/\text{cm}^3$: 1 ion per $\sim 10^{13}$ germanium ions.
- Operational voltage: 2000 V and higher.

Anisotropy

Effect of anisotropy



Effect of anisotropy



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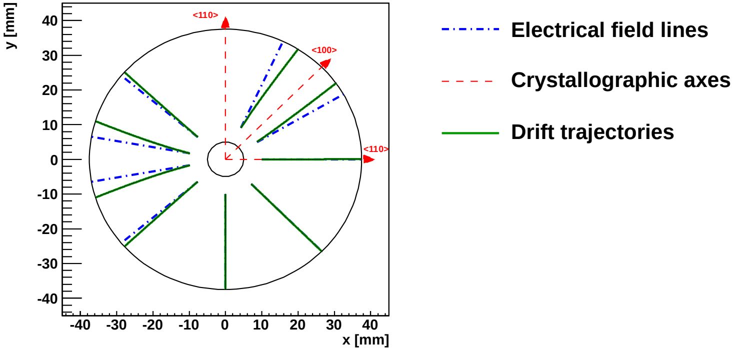

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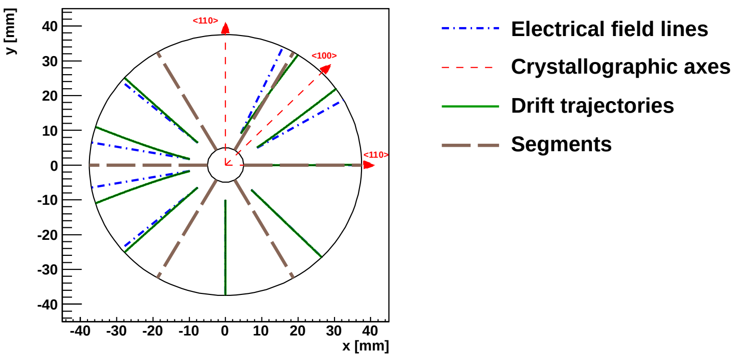

Effect of anisotropy: conclusion

Anisotropy “changes” segmentation!

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Drifting charge cloud of 2 mm at $r = 2.5$ cm has a spread of 5°.

A bit of theory: mobility

Drift velocity of charge carriers

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

Notations

- $\mathbf{v}$ - Velocity of charge carriers (electrons, holes)
- μ - mobility;
- $\mathcal{E}$ - electrical field;

A bit of theory: mobility

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

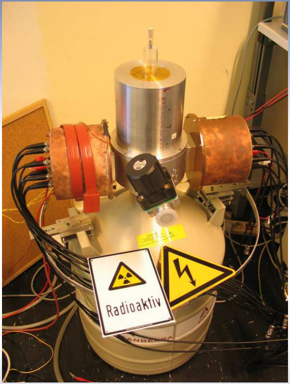
Drift component $\perp \mathcal{E}$

$\mathbf{v}_\phi \neq 0$,
$\mathbf{v}_\phi = f(v_{\langle 111 \rangle}, v_{\langle 100 \rangle})$

Notations

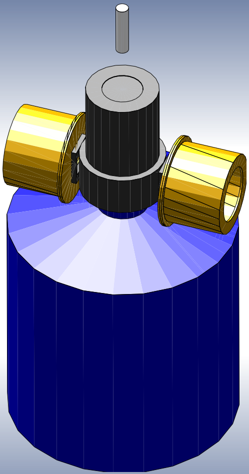
- $\mathbf{v}$ - Velocity of charge carriers (electrons, holes)
- μ - mobility;
- $\mathcal{E}$ - electrical field;
- $v_{\langle 111 \rangle}$, $v_{\langle 100 \rangle}$ - parameters; electron/hole velocities along axes.

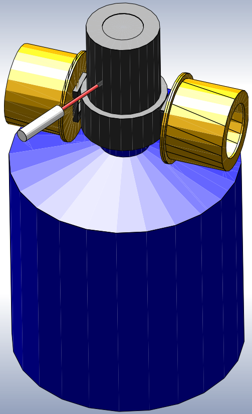
Vacuum cryostat K1



Detector in vacuum cooled through a cooling finger at $T = 90 - 120\,\mathrm{K}$.

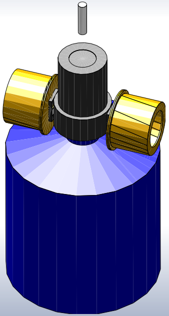
Vacuum cryostat K1 in simulation

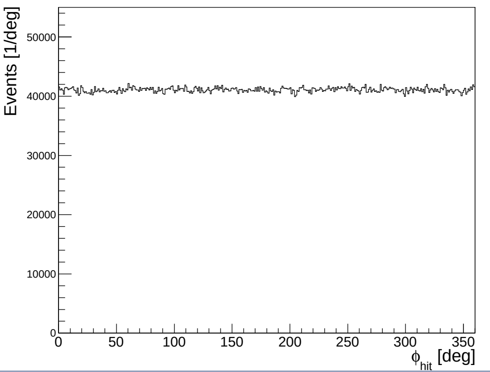




Effect of anisotropy

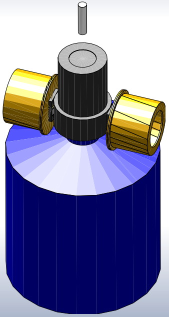
Energy deposits from a γ source located homogeneous in ϕ, Cobalt-60:

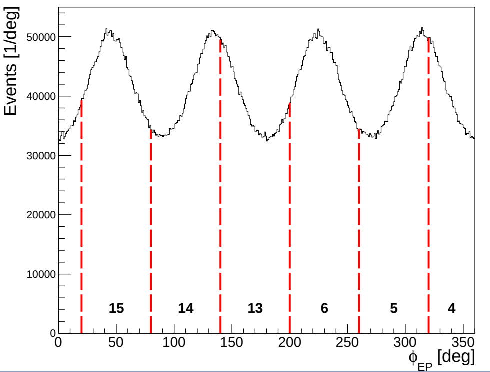




Effect of anisotropy

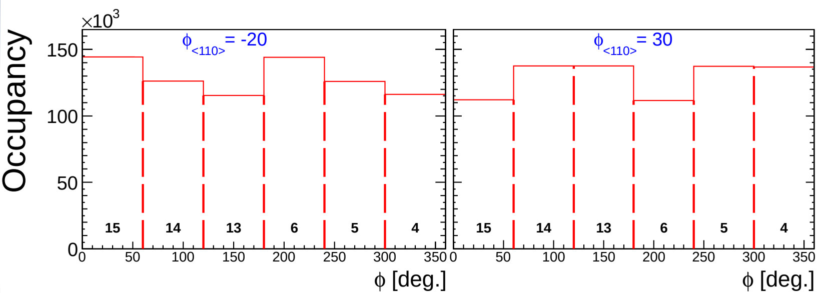
Charge carriers as they reach the contacts
at the outer surface:





Effect of anisotropy: occupancy

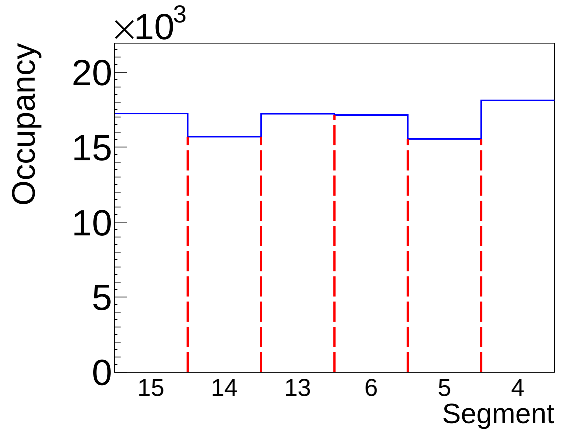
Number of events in segments, 1.33 MeV line, single segment cut:



Simulation

Measurements

Number of events in segments, 1.33 MeV line, single segment cut:



Extraction method: idea

- Simulation has a free parameter: axes orientation angle, $\phi^{sim}_{\langle 110 \rangle}$;

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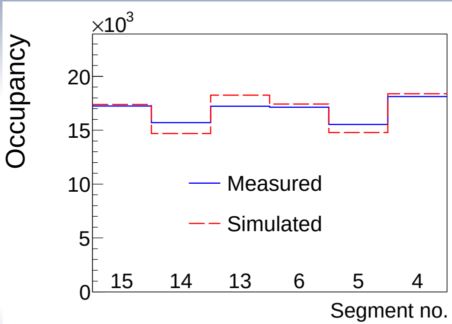
- Simulation has a free parameter: axes orientation angle, $\phi^{sim}_{\langle 110 \rangle}$;
- For varied $\phi^{sim}_{\langle 110 \rangle}$ compare simulated and measured occupancies - a test statistic is needed;
- The best fit gives a hint about axes orientation.

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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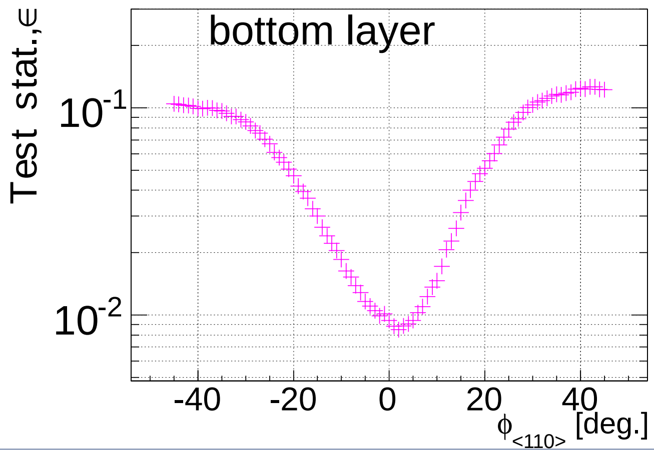
5. The minimum of the fit $= \phi_{\langle 110 \rangle}$.

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



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1. Vary $\phi^{sim}_{\langle 110 \rangle}$ in 1° steps;
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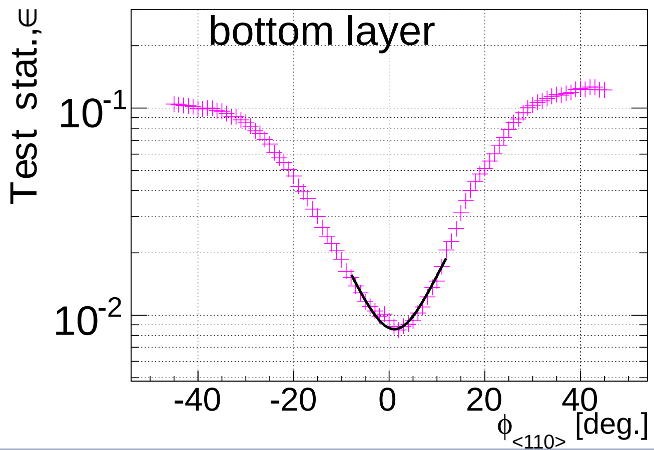
Fit on test statistic



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	$\phi^{\text{top}}_{\langle 110\rangle} = -1.8^\circ \pm 1^\circ(\text{stat.}) \pm 6^\circ(\text{syst.})$
Source at the side **	$\phi^{\text{side}}_{\langle 110\rangle} = -11.5^\circ \pm 3^\circ(\text{stat.}) \pm 7^\circ(\text{syst.})$

*Obtained using a reference method

**The source was misaligned by ≈5°

Extraction method: variations

- Various alternatives may have different qualities of the result:

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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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- Various alternatives may have different qualities of the result:
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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.

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

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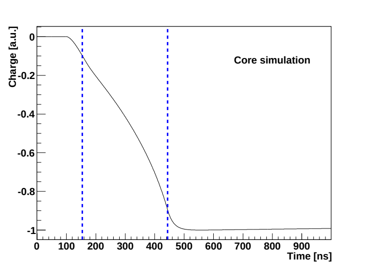
- Very sensitive to any imperfection of setup representation in simulation
- The more data is available, the better: enough data is required to get satisfactory accuracy

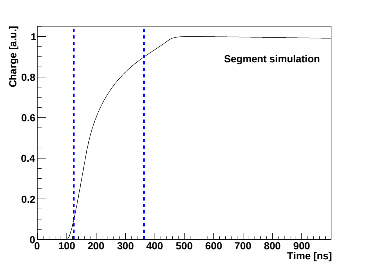
Summary

- 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

Backup

Simulated pulse





Core pulse

Segment pulse

Pulse length as function of source position