Temperature dependence of pulse properties

in an n-type germanium detector

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Application of Germanium Detectors in Fundamental Research

Beijing, China, March 26, 2011

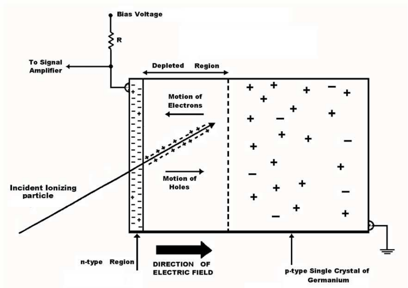
MAX-PLANCK-GESELLSCHAFT

Outline

- Introduction: germanium detectors
- Experimental setup
- Theoretical model
- Event selection
- Extraction of the rise time
- Summary

Introduction

Semiconductors detectors are used to register radiation:



Requirements for GeDes:

- cooled down ($T \sim 77\,\mathrm{K}$) to reduce thermal excitation.
- high voltage (few kV) applied to reduce the number of free charge carriers

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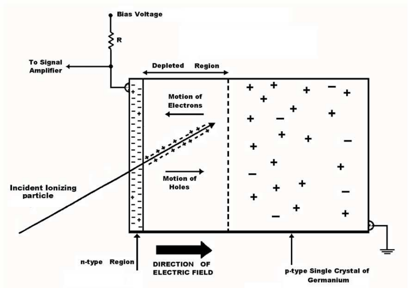
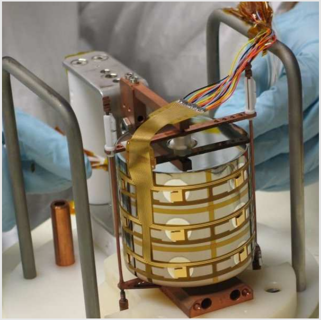


Requirements for GeDes:

- cooled down ($T \sim 77\,\mathrm{K}$) to reduce thermal excitation.
- high voltage (few kV) applied to reduce the number of free charge carriers

Created electrons and holes drift $\rightarrow$ induced signal is collected

Detector Siegfried-II



- Segmented 18-fold ($3z \times 6\phi$);
- High-purity detector (electrically active impurities concentration $0.35 - 0.55 \cdot 10^{10}/\text{cm}^3$);
- Operation voltage 2000+ V.

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  - Test stands
  - Temperature monitoring
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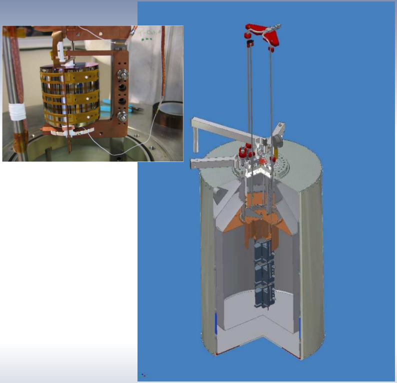
Test stands @ MPI

Two test stands were used:

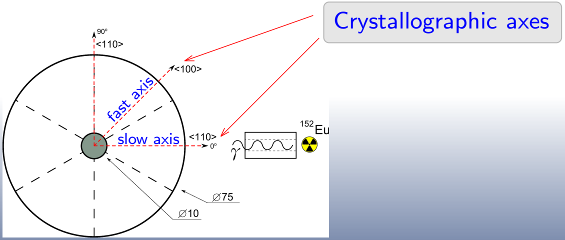


Gerdalinchen II, detectors submerged in LN2 at fixed $T = 77.4\,\mathrm{K}$;

K1 detector in vacuum cooled through a cooling finger at varying $T = 90$–$120\,\mathrm{K}$.

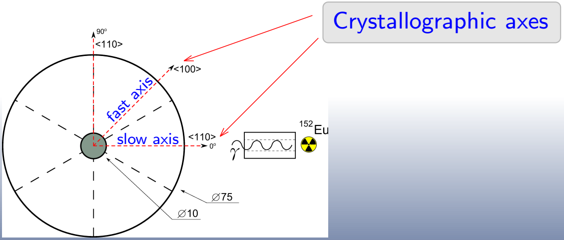
Collected datasets

Orientation	DS1@77 K	DS2@95–100 K	DS3@100–120 K
Along ⟨110⟩ axis	0°	0°	5°
Along ⟨100⟩ axis		45°	50°

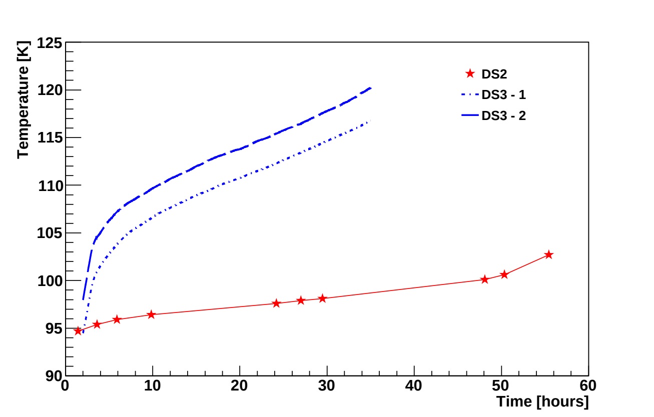


Collected datasets

Orientation	DS1@77 K	DS2@95–100 K	DS3@100–120 K
Along ⟨110⟩ axis	0°	0°	5°
Along ⟨100⟩ axis		45°	50°
⟨110⟩ + 5°	5°		5°
⟨110⟩ - 15°	-15°		-15°



Temperature monitoring in K1



DS2: One set of T measurements during data taking

DS3: Two sets of T measurements before and after data taking

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Theoretical model

Electrical field in a true-coax detector:

Poisson equation: $\Delta\phi(\boldsymbol{x}) = -\frac{1}{\epsilon_0\epsilon}\rho(\boldsymbol{x}) \Rightarrow$

$$E(r) = |\boldsymbol{E}(r)| = \frac{e\rho}{2\epsilon_0\epsilon} r + \frac{V - (e\rho/4\epsilon_0\epsilon)(r_2^2 - r_1^2)}{r\ln(r_2/r_1)}$$

$\mu_{e/h}^{\mathrm{eff}}$ - approximation for $\approx$ homogeneous EF;
μ_e^T - T-independent constant

Velocity: $v_{e/h} = \mu_{e/h}^{\mathrm{eff}} E(r)$

Theory*: $\mu_e^{\mathrm{eff}} = \mu_e^T \cdot T^{-3/2}$

$v = dr/dt = \mu_e^T \cdot T^{-3/2} \cdot \left(Ar + \frac{B}{r}\right) \Rightarrow$
|solve| $\Rightarrow$ For drift from the outside in:

$$t(r) = \frac{\ln\left(\frac{Ar_2^2+B}{Ar^2+B}\right)}{2A} \cdot \frac{T^{3/2}}{\mu_e^T};$$

Rise time: $t_{\mathrm{rise}} = C \cdot \frac{T^{3/2}}{\mu_e^T}$.

For Siegfried-II:

$r_1 = 5\,\mathrm{mm}$

$r_2 = 37.5\,\mathrm{mm}$

$\rho = 0.45 \cdot 10^{10}/\mathrm{cm}^3$

$V = 2000\,\mathrm{V}$

* Phys. Rev. **80** (1950) 72,

based on scattering off phonons

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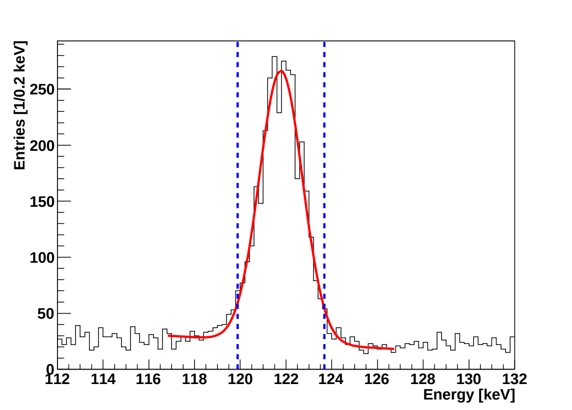
Event selection

- Only events induced by 122 $keV \pm 2\sigma$ photons from ^{152}Eu;
- Single segment event (only one segment above $E_{\text{threshold}} = 20\,keV$).



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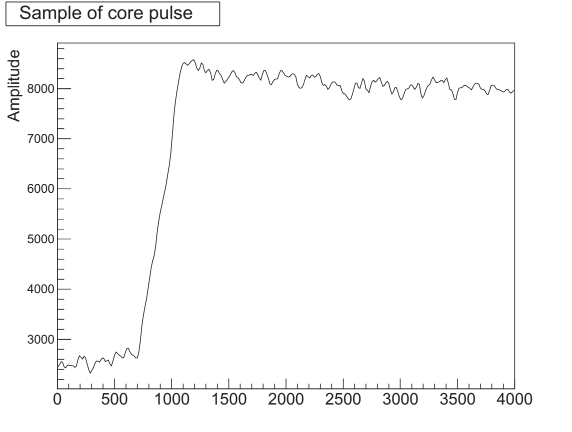
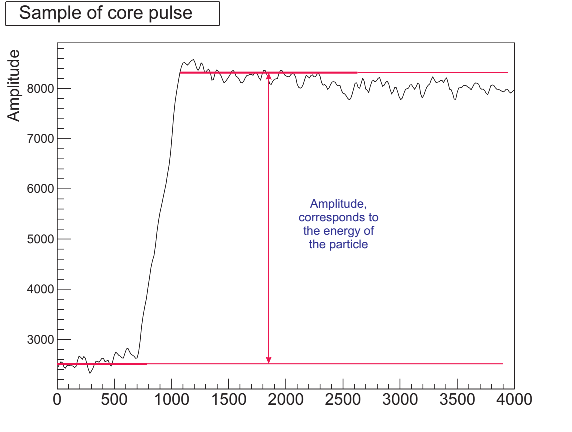
  - Pulse properties: amplitude, rise time
  - Fit with simulated pulses
- Summary

A pulse

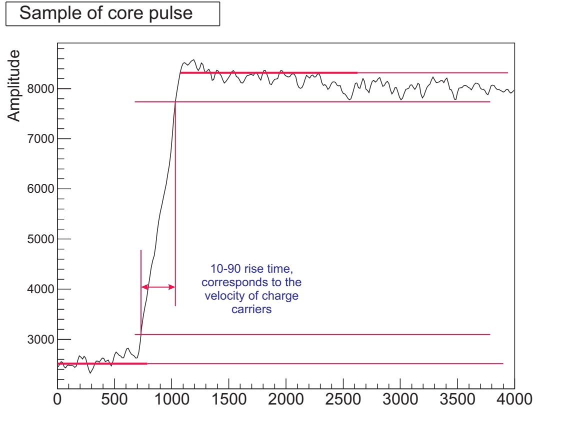


*DAQ had 75 MHz sampling frequency

Pulse properties: amplitude

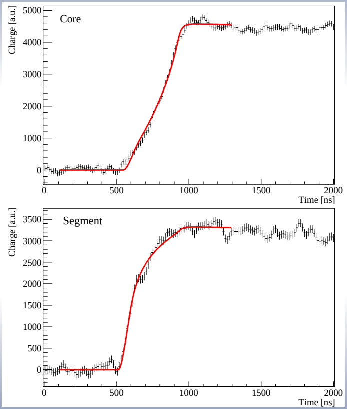


Pulse properties: rise time



Pulse fitting

Pulse example with the fit of simulated pulse:



Simulated pulse*:

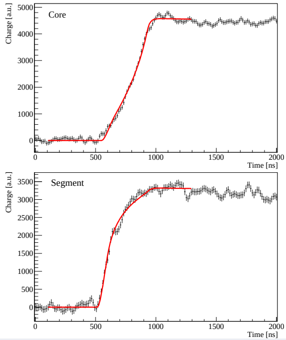
- 1 GHz sampling frequency
- Single hit at depth 5 mm and $\phi = 0^\circ \rightarrow$ axis $< 110 >$

Three parameters of the fit, one of which is $t_{\text{scale}} \propto \frac{1}{t_{\text{rise}}}$.

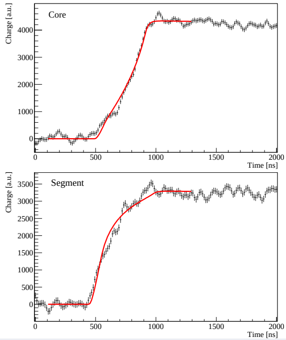
*Eur. Phys. J. C (2010) **68** 609

Pulse fitting

Pulse example with the fit of simulated pulse:



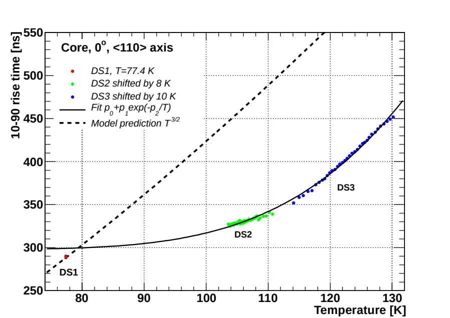
Good fit



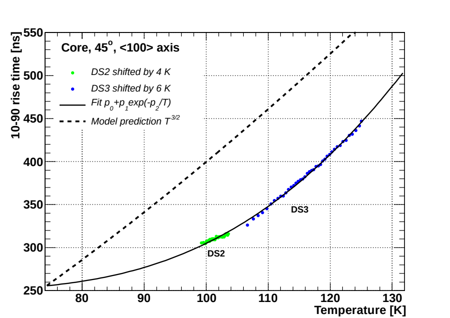
Bad fit

Only good fits were considered

Temperature dependence of pulse lengths: results



Slow axis $\langle 110 \rangle$

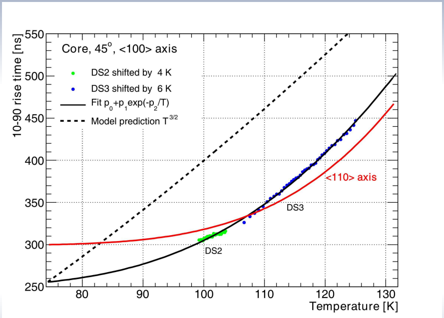


Fast axis $\langle 100 \rangle$

Fit: Boltzmann-like *ansatz* $p_0 + p_1 \cdot e^{-p_2/T}$

Temperature dependence of pulse lengths: results

Slow axis ⟨110⟩ becomes faster than the fast axis ⟨100⟩ at ∼ 107 K?



Possible explanation:

- measurements of two germanium samples* showed conductivity change with temperature: electrical field is temperature dependent?

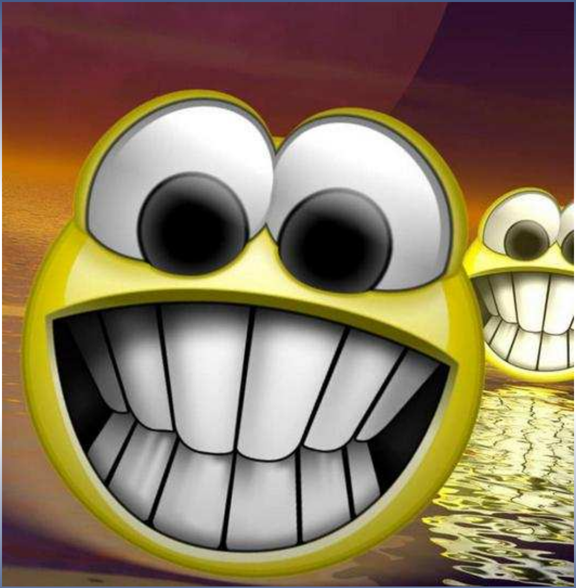
*IKZ, K. Irmscher, private communication

Summary and conclusions

- Measurements do not agree with the simple model predictions (theoretical $T^{3/2}$, experimental $T^{1.66}$ and $T^{1.6}$);
- Boltzmann-like ansatz works fine;
- The old measurements of mobilities* are precise, therefore some detector-specific effects affect the results;
- Note: pulse amplitudes were stable for T range 95–120 K $\rightarrow$ the detector can be stably operated well above 100 K.

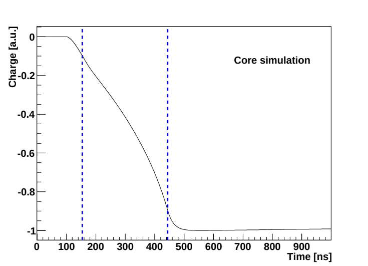
*Nucl. Instrum. Meth. A **569**, 764(2006)

Thank you for your attention!

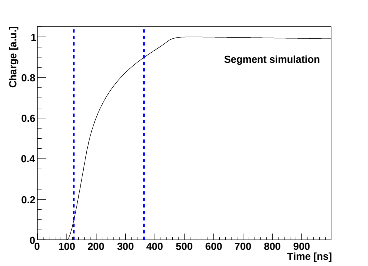


Backup

Simulated pulse



Core pulse



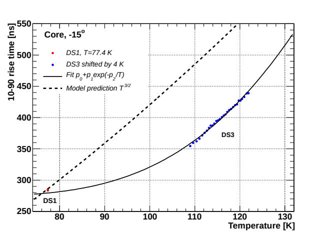
Segment pulse

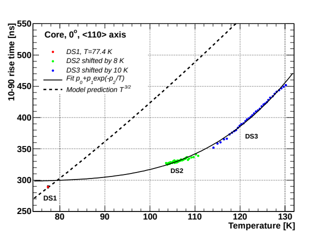
Simulated pulse

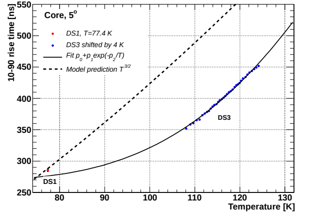
Properties:

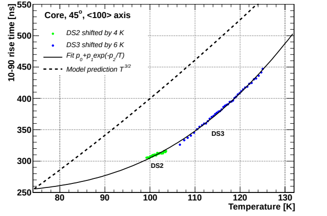
- single hit at depth 5 mm and $\phi = 0^\circ \rightarrow$ axis $< 110 >$;
- impurity level $0.45 \cdot 10^{10}/\text{cm}^3$;
- electron mobility constant 38609 (38536) mm^2/Vs for $\langle 100 \rangle$ ($\langle 111 \rangle$) axis;
- grid for numerical calculation $32(r) \times 180(\phi) \times 70(z)$;
- 1 GHz sampling frequency, corresponding to 1 ns step;
- bandwidth of ≈ 10 MHz;
- amplifier decay time 50 μs;
- no noise.

Temperature dependence of pulse lengths: Core









Temperature dependence of pulse lengths: Segment