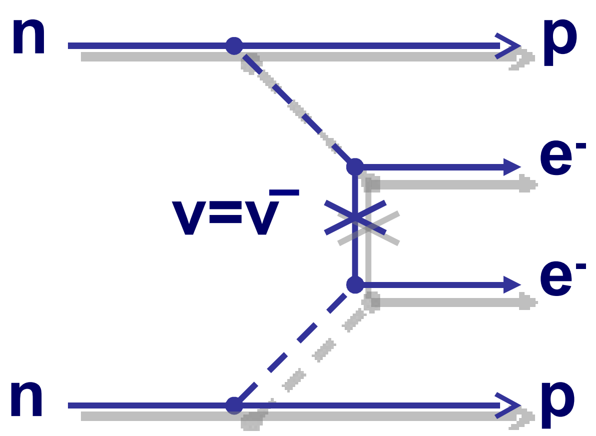
Pulse Shape Simulation for a GERDA Phase II Prototype Detector



Daniel Lenz

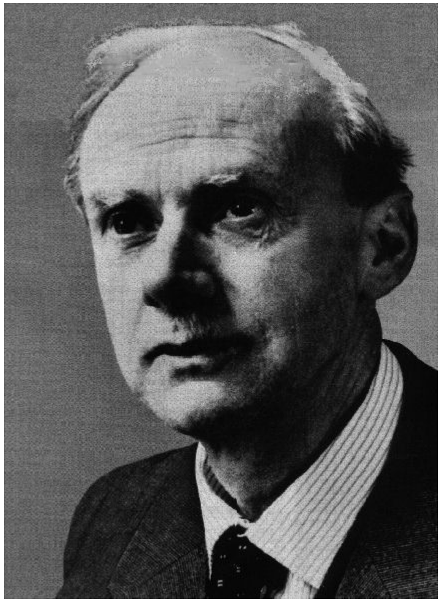
DPG Tagung - Teilchenphysik - München 2009

09. März 2009

Questions About to Being Answered

- What the GERDA-Experiment is About
- Why we Need a Pulse Shape Simulation
- How we Simulate Pulse Shapes
- How Simulation Compares to Data → **Jing Liu T 100.5**

Try to answer the question if neutrino is
Dirac- or **Majorana**-fermion



P. Dirac

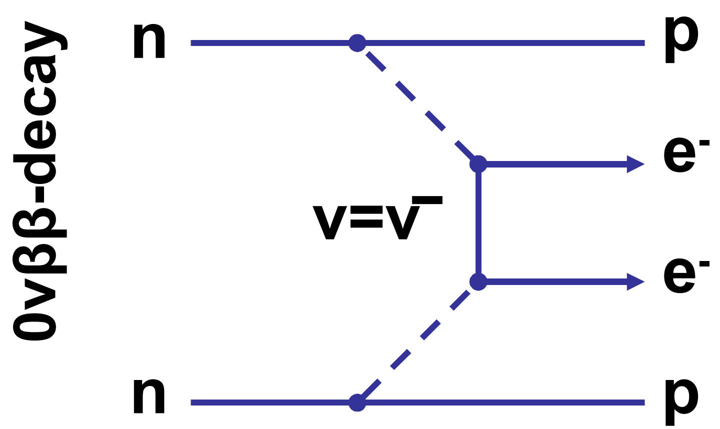
$\nu \neq \bar{\nu}$

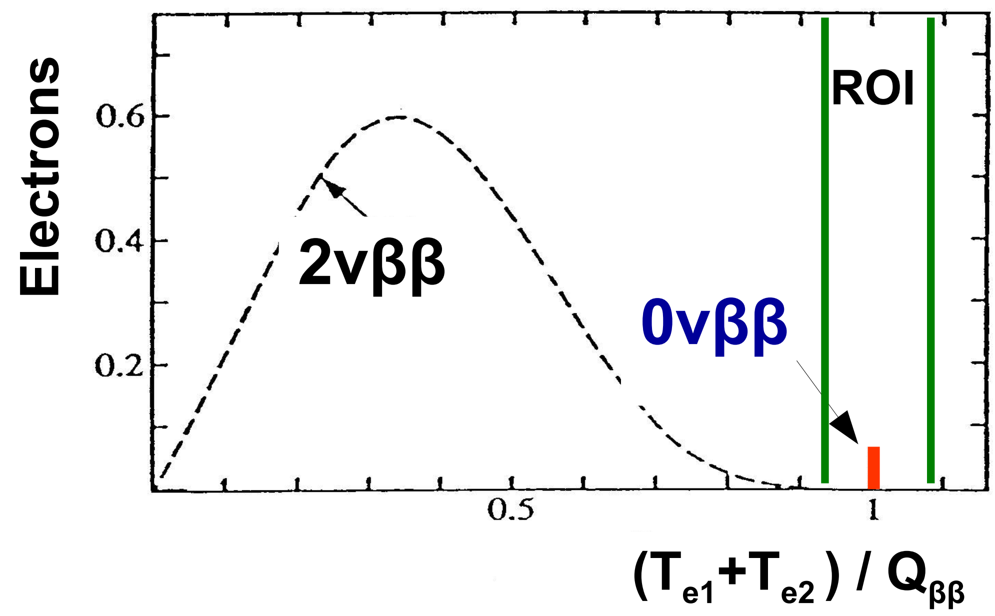
or

E. Majorana

$\nu = \bar{\nu}$

Try to find out using
neutrinoless double beta decay





- Neutrinoless double beta decay is **forbidden** in the **Standard Model** of Particle Physics

- If it exists it is very rare: $\tau(Ge^{76})$ 1($\gtrsim$ y

  need to have **extremely low background rate**

  need to **distinguish** between **background** and **signal** events

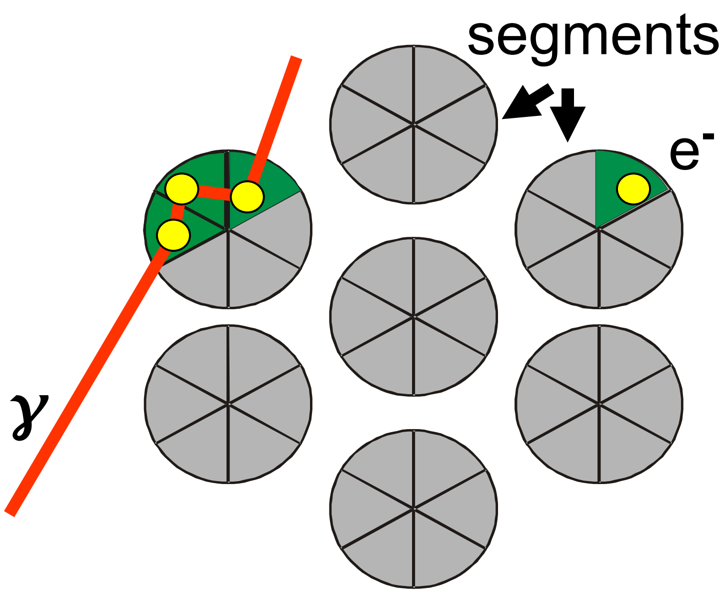
Background-like and Signal-like Events

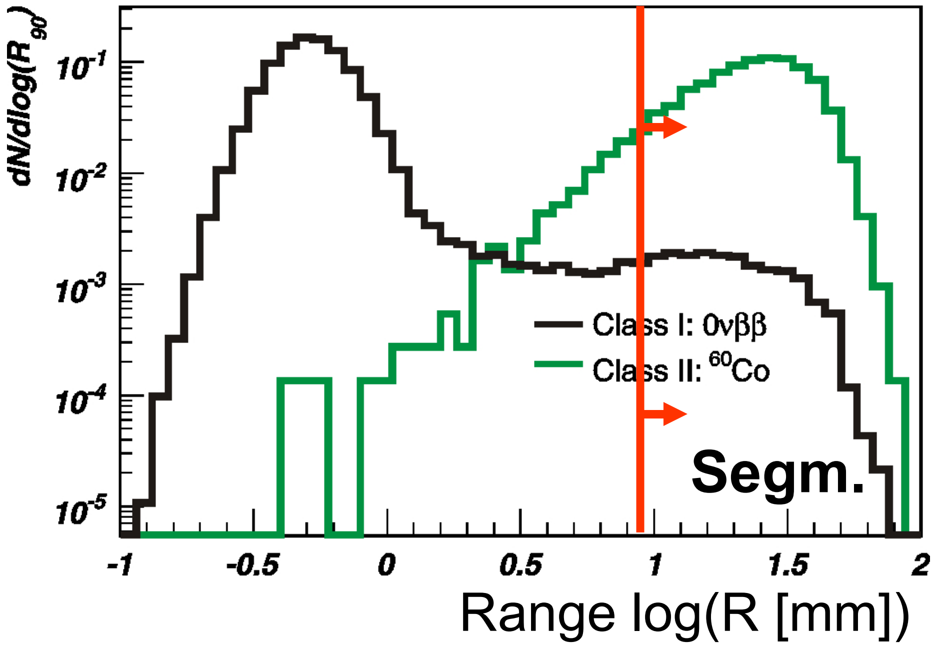
• typical background events deposit energy at multiple positions:

Multi Site Event (MSE)

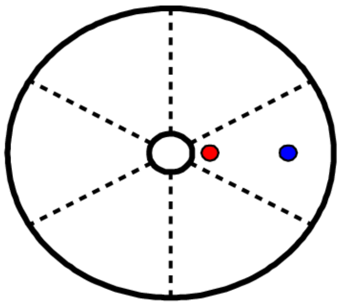
• typical signal events deposit energy locally, so called:

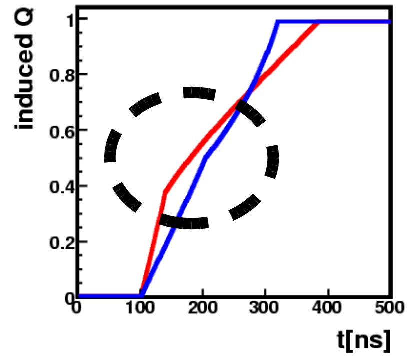
Single Site Event (SSE)

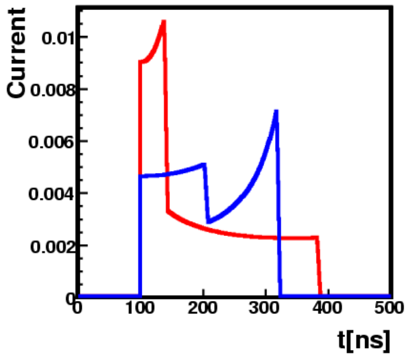




Single-site event (SSE):

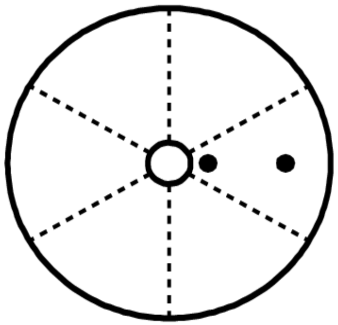


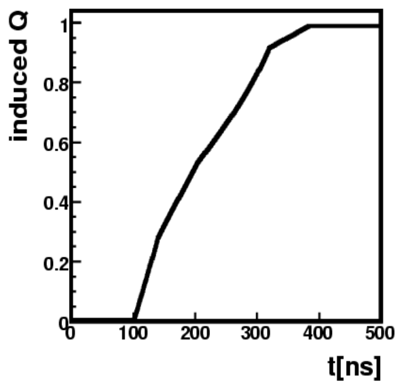


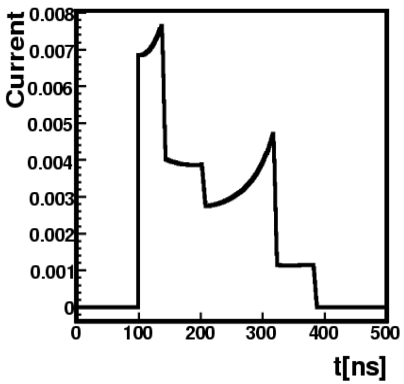


Knee indicates that one charge carrier reaches electrode and stops drifting

Multi-site event (MSE):







MSE tends to have more complicated pulse structures.

Pulse Shape Simulation needed:

- to gain **detailed** understanding of **pulse development**
- to **understand signal efficiency** and **background rejection power** in detail!

1. Simulated energy deposit using Monte Carlo Framework MaGe

2. Group hits according to position, bandwidth and sampling rate of DAQ

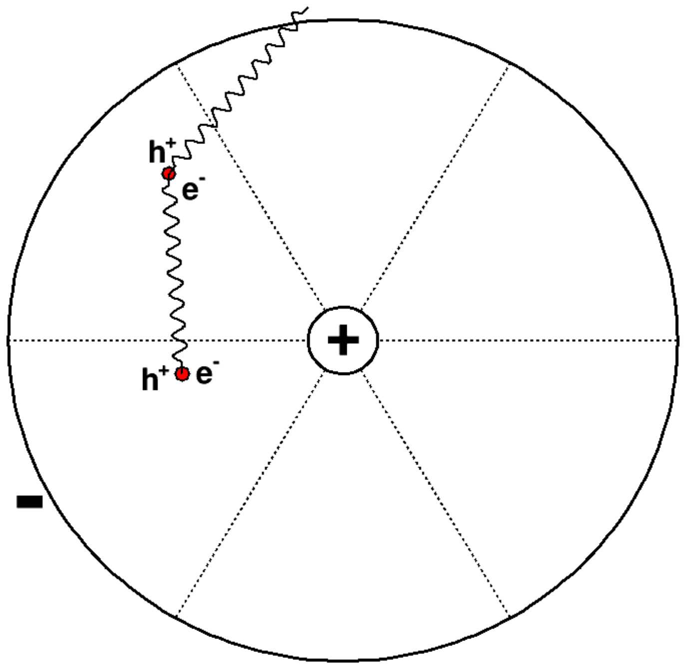
3. Determine e-h pairs and their position

4 Calculate E-Field inside detector

5 Calculate drift of charge carriers

6 Calculate induced signals on electrodes, according to drift trajectories and weighting potentials

7 Take into account electronics effects, such as noise, bandwidth,...



How we Simulate Pulse Shapes

1. Simulated energy deposit using Monte Carlo Framework MaGe

2. Group hits according to position, bandwidth and sampling rate of DAQ

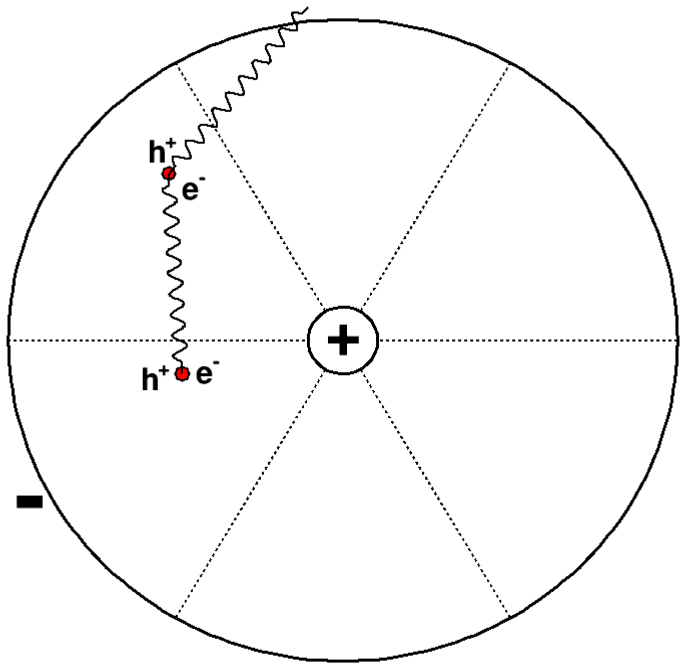
3. Determine e-h pairs and their position

4 Calculate E-Field inside detector

5 Calculate drift of charge carriers

6 Calculate induced signals on electrodes, according to drift trajectories and weighting potentials

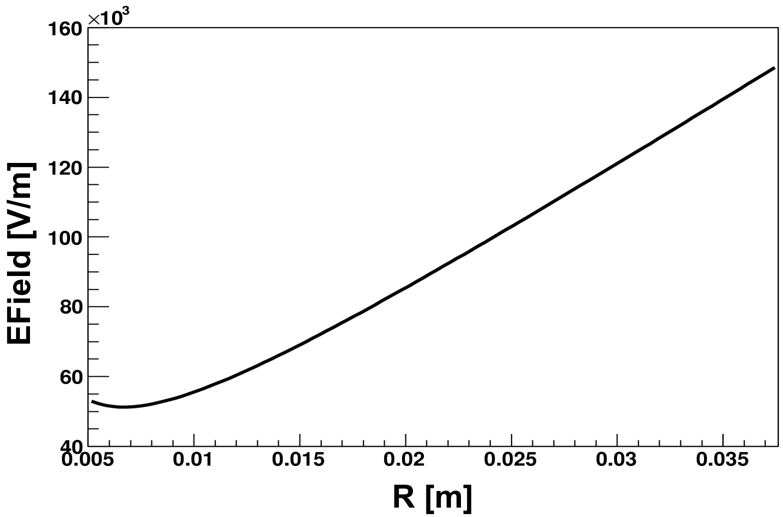
7 Take into account electronics effects, such as noise, bandwidth,...



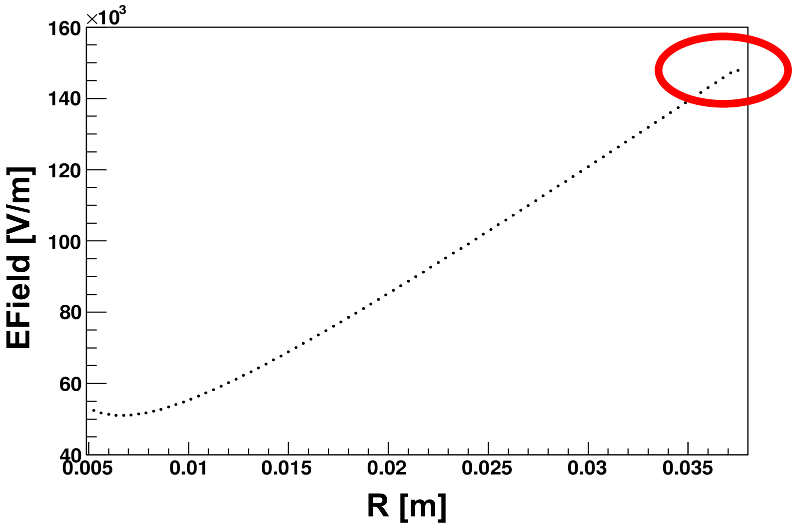
Solve Laplace-equation: $$\nabla \varphi(\vec{r}) = \frac{1}{(\epsilon_0 * \epsilon_R)} * \rho(\vec{r})$$

use iterative, numerical procedure:

Successive Overrelaxation (SOR)



analytical calculation



numerical calculation

agreement **better than 1%**

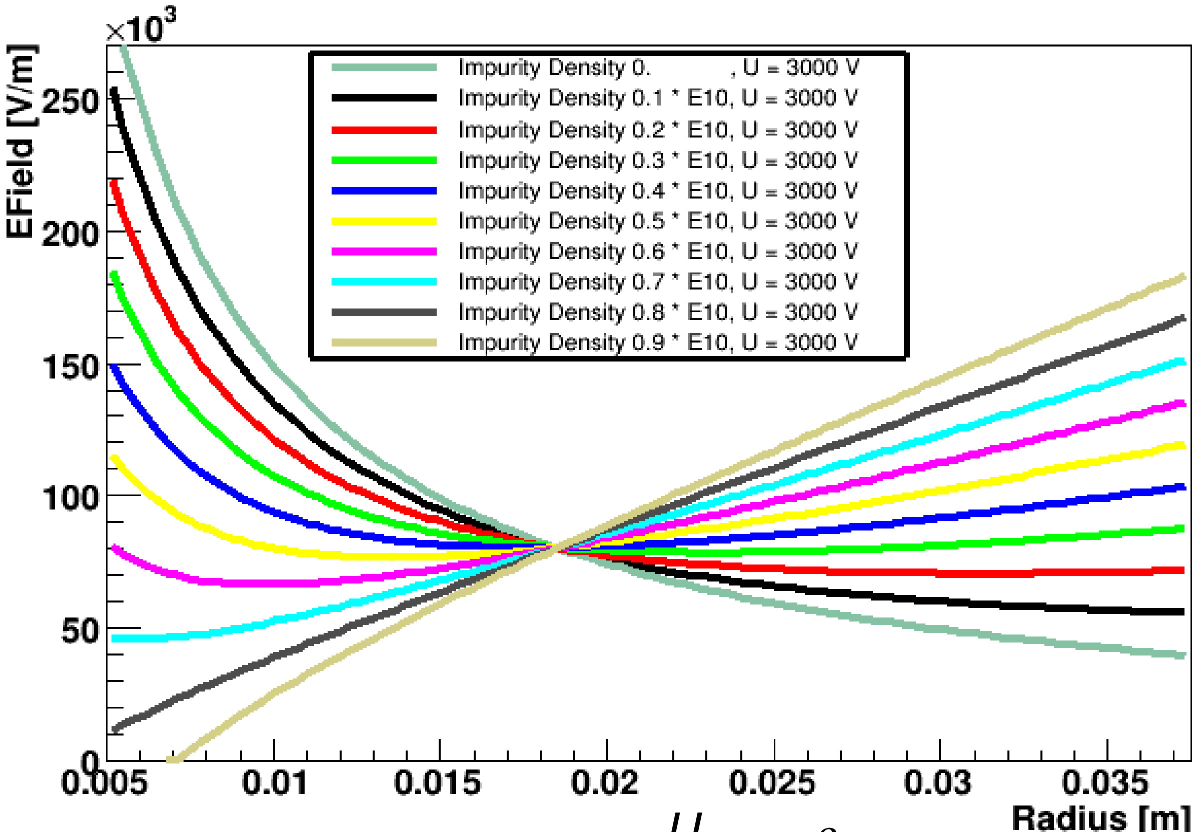
numerical calculation works

Calculate E-Field Inside Detector

4

Solve Laplace-equation: $\nabla \varphi(\vec{r}) = \frac{1}{(\epsilon_0 * \epsilon_R)} * \rho(\vec{r})$

ρ dominates E-Field



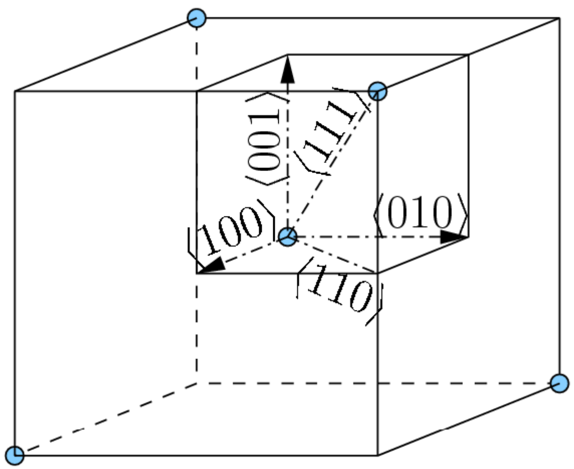
$$E \propto C_1 \rho \cdot r + C_2 \frac{U}{r} + C_3 \frac{\rho}{r}$$

Understanding impurity distribution **crucial** for correct **E-Field**

Drift:

$$v(\vec{r}) = \mu_{e,h} \vec{E}(\vec{r})$$

with $\mu_{e,h}$ depends on temperature, electric Field and **structure** of **germanium crystal**



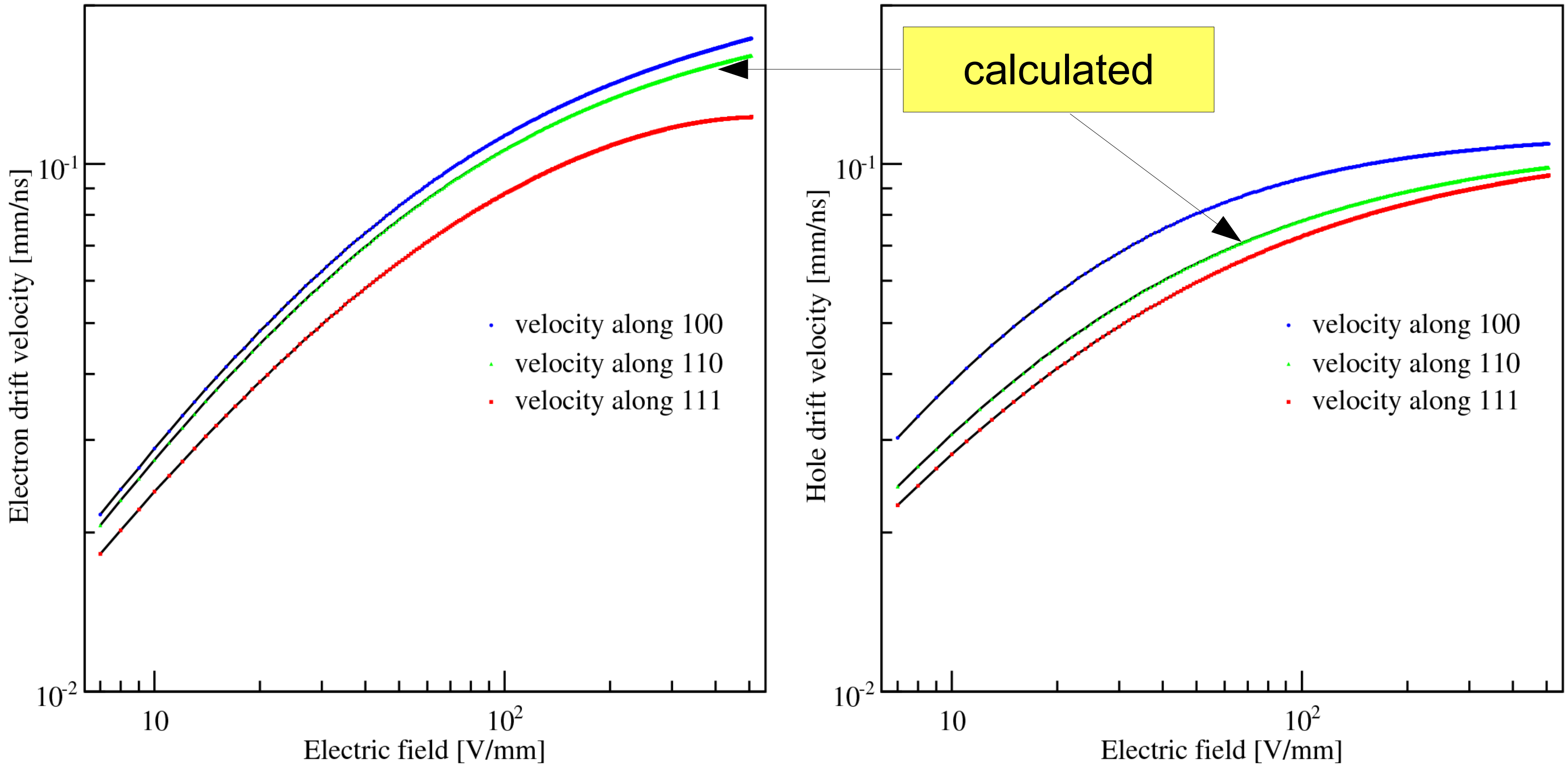
- in direction
  $\langle 100 \rangle$, $\langle 110 \rangle$ and $\langle 111 \rangle$
  mobility aligned with EField

- experimental data along these directions can be found
  ⇒ mobility can be fitted along these axis

$$v = \frac{\mu_0 E}{\left[1 + \left(\frac{E}{E_0}\right)^{\beta}\right]^{1/\beta}} - \mu_n E$$

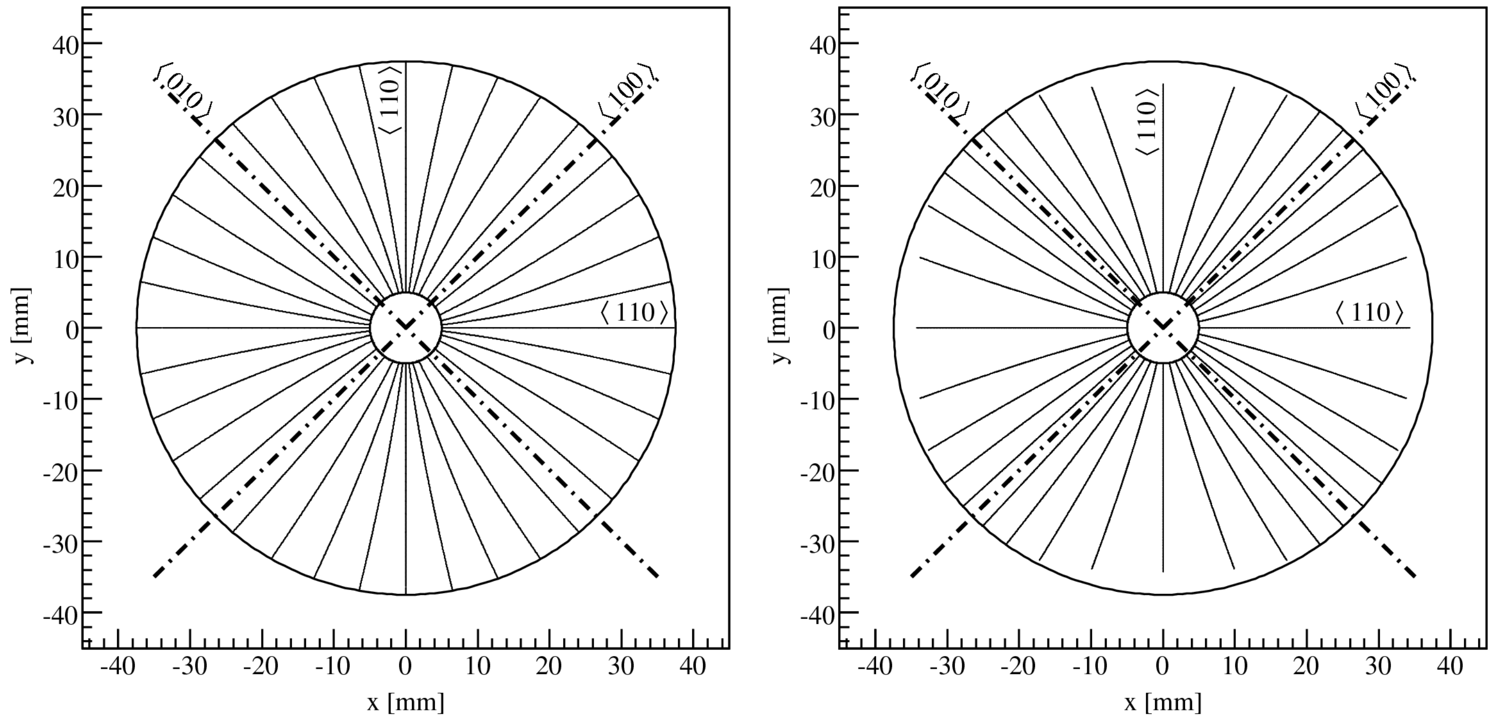
5

Charge carrier drift in any direction can be computed using mobilities along ⟨100⟩ and ⟨111⟩ directions



e^- drift faster than holes along ⟨110⟩

5



e⁻
drift from outside in

h⁺
drift from inside out

Path of charge carriers inside the Germanium crystal depends on crystal axis

e⁻ drift faster than holes along ⟨110⟩

Weighting Potential:

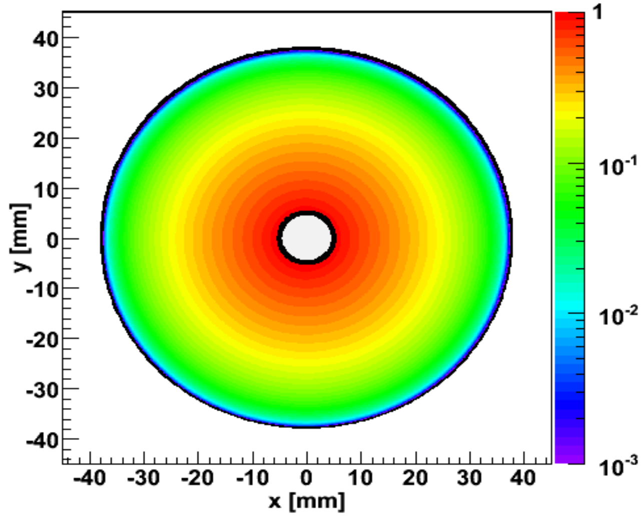
Need to solve Laplace equation: $\nabla \varphi_0(\vec{r}) = 0$

Boundary conditions: potential on electrode = 1

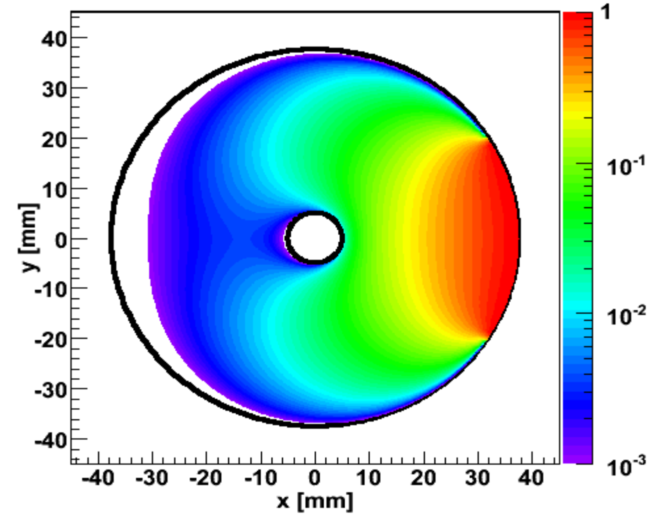
all other = 0

no analytical calculation possible

Need numerical calculation (SOR)



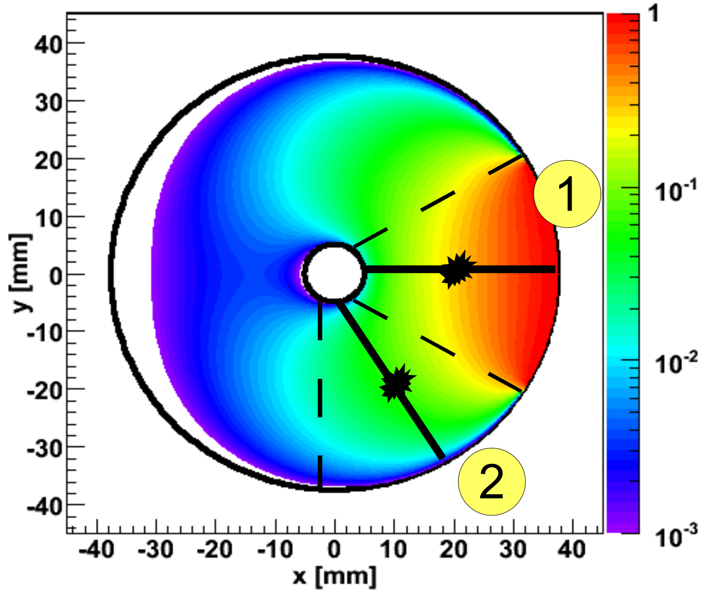
core weighting potential

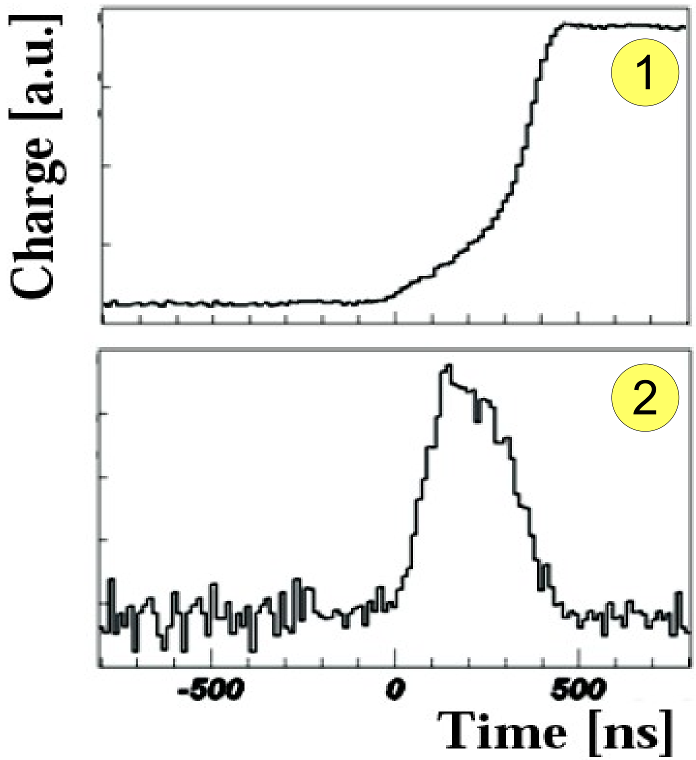


segment weighting potential

Shockley-Ramos Theorem:

$$Q^{i}_{induced}(t) = q_e \cdot \phi^{i}_W(\vec{r}(t)) + q_h \cdot \phi^{i}_W(\vec{r}\,'(t))$$



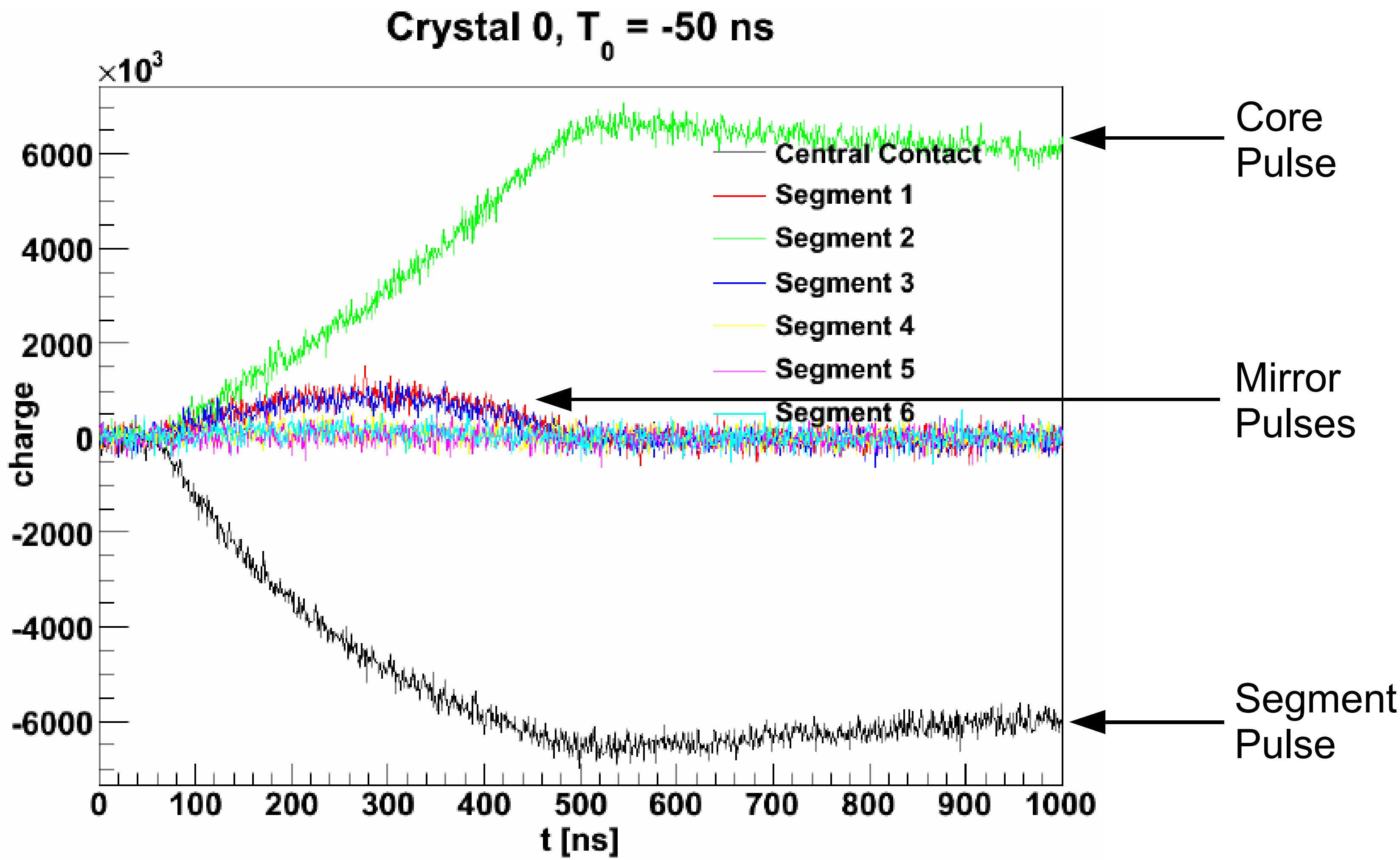


Segment Pulse

Mirror Pulse

7

Take into account: **noise**, **bandwidth**, preamplifier **decay time**,...



... and we have a **fully simulated Pulse Shape!**

We Learned

that the **GERDA**-Experiment is used to search for
neutrinoless double beta decay

That we **need** a **Pulse Shape Simulation**:

- to understand Pulse formation process in Germanium detectors
- to understand **signal efficiency** and **rejection power** of **PSA**

How the signal is formed

that the **impurity density dominates** E-Field

that the charge carrier **drift** takes into account **crystal axis effects**

We have a **working** Pulse Shape Simulation