Signal Generation & Simulations

Software Working Group Meeting
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Overview

Pulse Shape Calculations

- Electric Field Calculations (Maxwell 3D)
- Signal Generation
- Factors to be taken into account: Anisotropy in Ge, impurity concentration, radiation damage

Gamma-ray interactions (Geant 4)

- Array geometry and performance
- Packing scheme (3-crystals or 4-crystals in 1 cryostat)
Why Signal Calculations?

- Calculated signals provide the basis for the signal decomposition algorithm (David Radford)

- Signal Decomposition is based on the comparison between the observed charge pulse and linear contribution of pre-calculated signals

\[ q(t) = e_i q_i(t) + e_j q_j(t) + \ldots \]

- The accuracy of the method relies on the accuracy of the basis signals.
Pulse Calculation Ingredients

- Detector geometry
- Electric Field
  - Impurity concentration
- Drift velocity magnitude and direction of electrons and holes
- Charge carriers path
- Weighting potential
- Mobility of carriers
- Interaction position
- Neutron damage
- Pulse Shape Calculations

* Maxwell 3D
* Signal generation

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Gamma Ray Energy Tracking Array
June 22, 2004
Electrostatic Calculation: Maxwell 3D

- Modeler: geometrical model from a 3D structure
- Material Manager: assign material properties to objects in model
- Boundary / Source Manager: applied potential, charge distributions (impurity concentration profiles, both r- and z- variations)
- Executive parameters: enables capacitance calculations
- Solution option: specify convergence criteria, manually create finite element mesh
- Post processor: plot field quantities, analyze and view field solutions
- Electric field & weighting potential are written out on 1 mm grid.
• Weighting potential is calculated by applying 1 V on the segment collecting the charge and 0 V to all the others (Ramo’s Theorem).
• It measures the electrostatic coupling between the moving charge and the sensing contact.
Signal Generation Program

- LBNL-developed programs:
  - `genps1` by Greg Schmidt and Kai Vetter
  - `m3d2s` by I-Yang Lee (more accurate Energy, more stable)

- **Trajectory** of e & h is calculated at a given time interval ($\Delta T=1 \text{ ns}$)
- **Charge** induced at the outer contacts are calculated using Ramo’s theorem for the weighted potential

- **Anisotropy** of drift velocity of e & h in Ge is reproduced

- **Improvements**: Finite range of the primary electron in the crystal, finite size of the e-h distribution.
Anisotropy of Drift Velocity

Velocity of electrons and holes in germanium is anisotropic in:

1) **Magnitude** (Electric Field strength, temperature, crystal orientation)
2) **Angle** between the drift velocity and the electric field directions

In the signal generation code this anisotropy is implemented through interpolation.

Knowing velocity at <100>, <110> and <111> directions, a 3-term function is used for interpolation. Since velocity is irrotational, it can be derived from a potential.
REFERENCES:

- Angular dependence of the electron drift velocity on the electric field direction [L. Mihaielsecui et al. NIM A 447 (2000) 350]

- EXPERIMENT for measuring angular dependance of hole velocity at LBNL (Paul Luke)
Interpolation Results

* Interpolation - velocity is irrotational (by I-Yang Lee)
Calculated Pulse Shapes

Pulse shapes corresponding to interactions in segment A3, 2mm apart

\[ P1 = (20, 0, 26) \]
\[ P2 = (20, 2, 26) \]
Recent Results: Neutron Damage

- Fast neutrons degrade energy resolution of germanium detector, by creating hole traps.
- Hole trapping can be parameterized through the trapping length $\lambda$, which depends on neutron flux and on electric field [T.W. Raudorf, R.H. Pehl, NIM A255 (1987) 538].

$$n = n_0 \cdot \exp \left( - \frac{r - r'}{\lambda_h} \right)$$

- Do neutrons degrade position resolution?
Recent Result: Neutron Damage (cont)

Pulse Shape have been calculated for different $\lambda$ and corresponding energy and position resolution have been extracted.

Neutrons degrade E & P resolution. Degradation depends on distance traveled by holes. Energy is corrected for the position of the interaction.

- Neutron damage has more effect on energy than on position resolution
- The detectors will be annealed before the position resolution will be affected.

$10 \text{ keV } \sim 1 \text{ mm}$
Recent Results: Impurity Concentration

- Why is impurity concentration an important factor?
  Impurity conc. => Space Charge => Electric Field => Drift velocity => Pulse shape

- Impurity concentration is not constant in the crystal.

From the manufacturer:
- Crystal 1: \( \rho = (0.76 - 1.2) \times 10^{10} \text{ a/cm}^3 \)
- Crystal 2: \( \rho = (0.45 - 1.5) \times 10^{10} \text{ a/cm}^3 \)
- Crystal 3: \( \rho = (0.83 - 1.8) \times 10^{10} \text{ a/cm}^3 \)

Pulse shape simulations:
- Impurity concentration from no charge up to \( \rho = 1.4 \times 10^{10} \text{ a/cm}^3 \).
- Calculated position resolution.

- If the impurity concentration in the program is more accurate than:

  \[ \Delta \rho = 0.75 \times 10^{10} \text{ atoms/cm}^3 \Rightarrow 1 \text{ mm} \]

Capability of reconstructing the interaction position is not affected.
Monte Carlo simulations: Geant 4

Geant 4 simulations:
- Geometry of the array (packing scheme)
- Performance (efficiency and peak-to-total)

Why Geant 4?
- The code is well maintained and in widespread use
- C++ based => Object-oriented

A Monte Carlo code based on Geant 4 has been developed for the AGATA array by Dino Bazzacco and Enrico Farnea (The University of Padova, Italy)

Documents and information: http://agata.pd.infn.it

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Characteristics of the code

- User has to specify: geometry, event generation and read out.
- **Geometry**: coordinates of the corner of crystals, encapsulation and cryostat and the $\theta$ and $\phi$ rotation angles to locate detectors.
- Parameters are calculated (by I-Yang) based on the array geometry.
- C- program for optimizing geometry (David Radford and John Pavan).
- **Event generation**: gammas and neutrons (optional)
  - source type, position, energy, recoil velocity
- **Event analysis**: Different tracking methods
- **Event read-out**: (list-mode files) detector and cluster number, track number, energy released, position of the interaction, initial direction of the particle and volume’s name.
Array geometry is reproduced including:

- 2 irregular hexagonal shapes
- Canning of 3 crystals in 1 cryostat
- Exact inter-crystal gap, Al thickness for encapsulation and cryostat

Total Ge Volume = 47488 cm$^3$
Solid Angle = 71.3%

Solution with 4 crystals in 1 cryostat has to be investigated.
Simulation Results (Geant 3)

Phot. Eff. & P/T ratio vs. E

4 stages of GRETA

Gretina compared to Gammasphere

Events M=1
- no tracking
- maximum performance

Geant 3 limits:
Geometry
- The packing in triple clusters was not reproduced
- Average inter-crystal gap and Al can thickness

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Topics for discussion

- Pulse shape simulation
  - Improvements in the signal generation code:
    - Understand limitation in data analysis
    - Anisotropy in direction of holes drift velocity.
    - Temperature dependence of drift velocity

- Geant 4 simulations
  - Independent geometry input program
  - Packing 4 crystals in 1 cryostat
  - Geometry optimization code
I-Yang Lee, Paul Fallon, Austin Kuhn, Augusto Macchiavelli, Mario Cromaz, Marie-Agnes Deleplanque, Frank Stephens, Dick Diamond, Rod Clark, David Ward, Elena Rodriguez-Vieitez, Hassan Mahmud

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