Computational studies of BEGe detectors

Presented by Marco Salathe, marco.salathe@mpi-hd.mpg.de

Max Planck Institute for Nuclear Physics, Heidelberg

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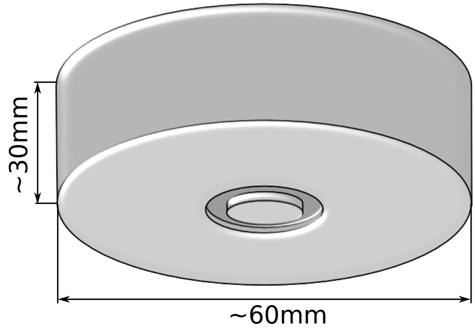
Introduction

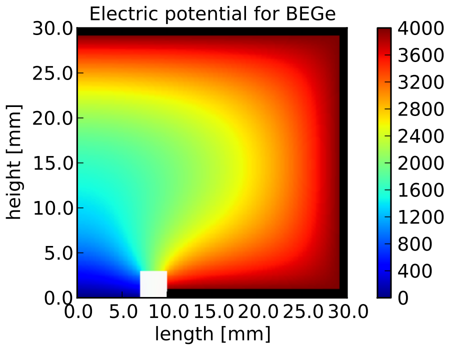


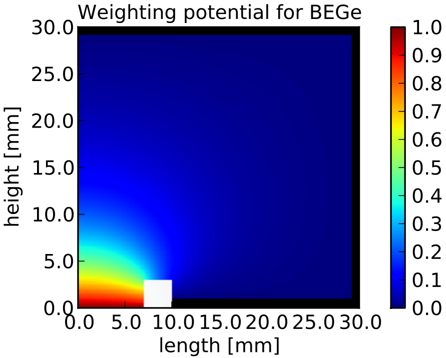
- BEGe: Broad Energy Germanium detector
  - Produced by Canberra Industries, Olen, Belgium
- GERDA: GERmanium Detector Array
  - Tues, 17:15, HSZ-401, GERDA status report, Mark Heisel
  - Thu, 16:45, WIL-A317, Gerda status report, Matteo Agostini
  - *GERDA Collaboration, Ackermann, K.-H., Agostini, M., et al. 2012, arXiv:1212.4067*
- HEROICA: Hades Experimental Research Of Intrinsic Crystal Appliances
  - Tues, 16:45, HSZ-101, HEROICA: a test facility for the characterization of BEGe detectors for the Gerda experiment, Raphael Falkenstein
  - *Andreotti, E., Garfagnini, A., Maneschg, W., et al. 2013, arXiv:1302.4277*

Pulse Shape Simulation

1) Calculate electric potential ϕ_E and weighting potential ϕ_W:

- Initial condition: potential on electrodes, detector dimensions, impurity gradient





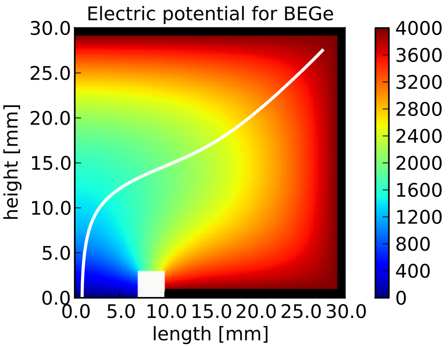
Pulse Shape Simulation

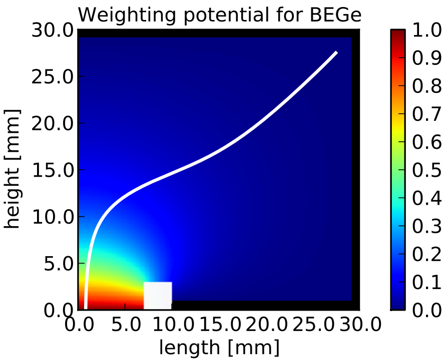
1) Calculate electric potential ϕ_E and weighting potential ϕ_W:

- Initial condition: potential on electrodes, detector dimensions, impurity gradient

2) Calculate the trajectory of the charge $\vec{x_{e/h}}$, which depends on:

- the point of charge deposition
- the electric field $\vec{E}$ defining the drift velocity
- specific mobility parameters for crystal axes





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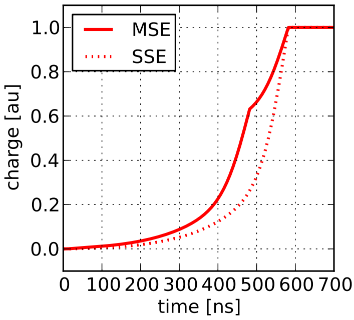
3) Calculate the induced charge at the electrode:

- Shockley–Ramo theorem : $Q(t) = -Q_0 \cdot [\phi_W(\vec{x}_h(t)) - \phi_W(\vec{x}_e(t))]$



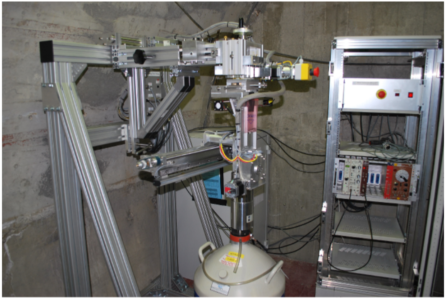
Pulse Shape Simulation

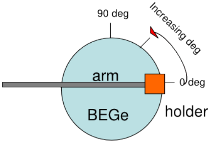
A few details and references:

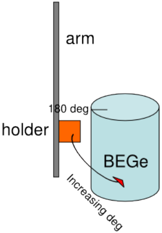
- Simulation is based on the ADL 3.0 (AGATA Detector simulation Library)
  - *http://www.ikp.uni-koeln.de/research/agata/download.php*
  - *B. Birkenbach - DPG 2011 / HK 54.2 : Characterisation of AGATA detectors*
- Calculation of potential:
  - Usually poisson equation: $\nabla^2\phi = \rho_f/\epsilon$
  - Not precise due to variable permittivity: $\nabla^2\phi(\vec{x}) \cdot \epsilon(\vec{x}) + \nabla\phi(\vec{x}) \cdot \nabla\epsilon(\vec{x}) = \rho_f(\vec{x})$
  - Solve in cylindrical (2D) or cartesian coordinates (3D) on a rectangular grid by *successive over relaxation*
  - *D. Radford, http://radware.phy.ornl.gov/MJ/m3dcr*
- Evaluation of charge trajectory:
  - *B. Bruyneel, et al. Nucl. Instr. and Meth. A (2006) 569, Issue 3, 764-773*
- Shockley-Ramo theorem:
  - *He, Z. 2001, Nuclear Instruments and Methods in Physics Research A, 463, 250*
- Pulse shape simulation with BEGe detectors:
  - *Agostini, M., Ur, C. A., Budjáš, D., et al. 2011, Journal of Instrumentation, 6, 3005P*

A few applications

^{241}Am scans in Heroica:





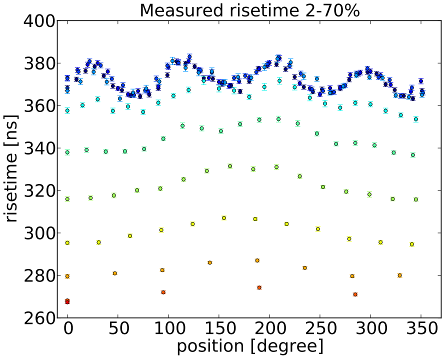


- Measurements of 30 detectors with collimated ^{241}Am source on up to three *Padova Scanning Tables* on up to 600 different points
- Analysis of data for each point: position of 60keV peak, FWHM, A/E peak, different pulse rise time

A few applications

^{241}Am scans in Heroica, $2-70\%$ rise time:

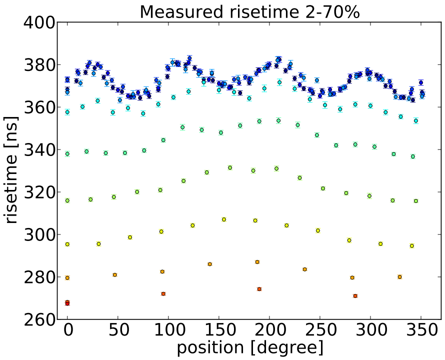
- Increasing risetime for large radius
- Fast oscillations for large radius
- Slow oscillations for small radius

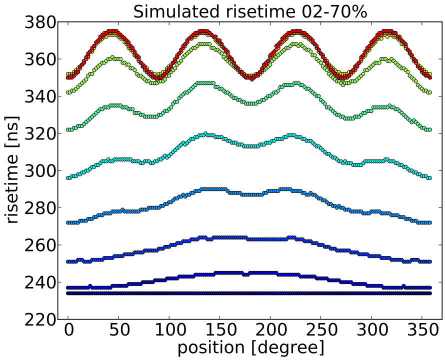


A few applications

^{241}Am scans in Heroica, $2 - 70\%$ rise time:

- Increasing risetime for large radius due to longer drift path
- Fast oscillations for large radius due to different mobilities along crystal axes
- Slow oscillations for small radius due to a misalignment of detector of up to 1mm

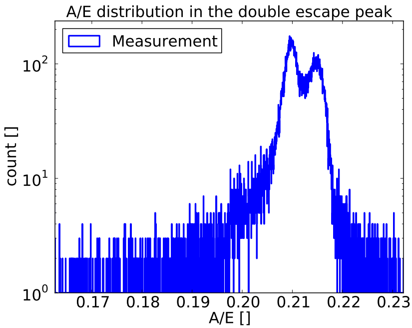


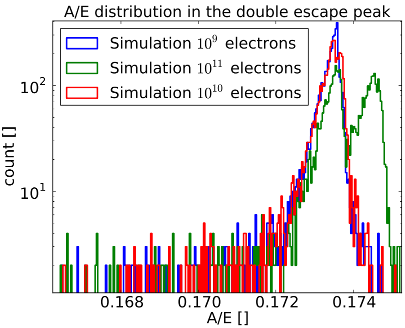


A few applications

Double peak structure in A/E in ^{228}Th measurement in Heroica:

- A/E is used for pulse shape discrimination:
  - E: energy (moving window average filter)
  - A: amplitude of weakly smoothed current pulse
- A double peak structure was observed in double escape peak of ^{228}Th for many dectectors
  - *Tues, 17:05, HSZ-101, Pulse Shape Analysis of Enriched BEGe Detectors in Vacuum Cryostat and Liquid Argon, Victoria Wagner*
- Idea: Inhomogeneous charge within the groove

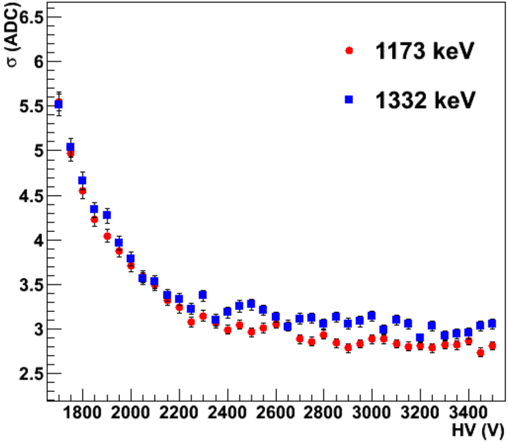




A few applications

High voltage scans in Heroica:

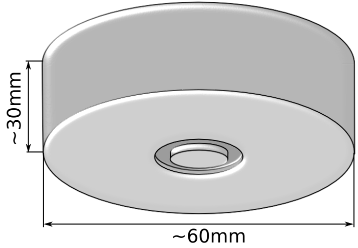
- Measuring peak count rate and resolution of ^{60}Co peaks for different applied high voltage
- Evaluation of depletion voltage
- Sensitive to detector parameters (especially impurity gradient)

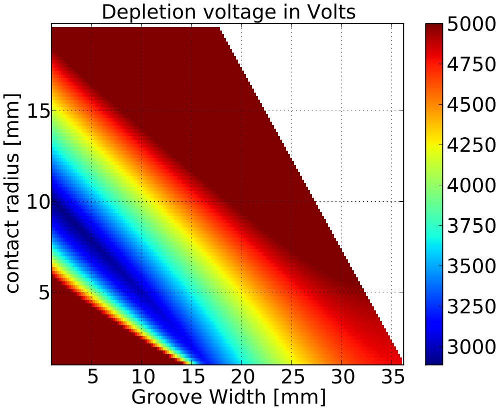


A few applications

Detector optimization:

- For a crystal slice many fixed parameters: Impurity gradient, height, radius
- There are a few free parameters: size of point contact, groove width
- Depletion voltage as a function of the free parameters
- A compromise between values of free parameter and depletion voltage can be found





Thanks for your interest

Backup slide

Extended ADL 3.0:

- Many detectors implemented: coaxial, BEGe, planar
- Field calculation in cylindrical and cartesian coordinates
  - Fields of 0.1mm resolution can be calculated in roughly 1min on a single core (1.5GB/field for 3D structure)
- Crystal effects (axes, trapping) are included
- Electronic response can be implemented
- Implemented in C: Library can be used with ROOT, etc.

Validation of electric field simulation:

- Field solving with successive over-relaxation (SOR), a widely used method
- Comparison between cylindrical and cartesian method: Excellent agreement
- Comparison between different programs: In agreement

Validation of pulse simulation:

- Previous validation by AGATA collaboration
- Continues use by AGATA for position reconstruction within their germanium array
- Ongoing investigation together with HEROICA ^{241}Am surface scans

Backup slide

Capacitance of detectors:

- The definition of the capacitance is given by:

$$C = Q_f / V \tag{1}$$

  with Q_f the amount of free charge in the electrodes and V the potential difference between the electrodes

- Maxwells equations can be used to calculate the amount of charge in the electrodes:

$$\int_{\partial\Omega} \mathbf{D} \cdot \mathrm{d}\mathbf{S} = Q_f \tag{2}$$

- The potential difference is simply the applied voltage
- Hence the capacitance can be calculated from the calculated fields