GEANT4 simulations used in the search for tensor type weak currents

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Physics motivation

The general structure of the Weak Interaction Hamiltonian:

$$H_\beta = H_V(C_V, C'_V) + H_A(C_A, C'_A) + H_T(C_T, C'_T) + H_S(C_S, C'_S) + H_P(C_P, C'_P)$$

Standard Model:

$$H_\beta = H_V(C_V, C'_V) + H_A(C_A, C'_A)$$

Experimental limits:

$$|C_S/C_V| < 0.070 \qquad |C_T/C_A| < 0.090$$
$$|C'_S/C_V| < 0.067 \qquad |C'_T/C_A| < 0.089$$

β asymmetry parameter A

$$A_{GT} = A_{SM,\,GT} + \frac{\alpha Z m_e}{p_e}\,\Im\left(\frac{C_T + C'_T}{C_A}\right) + \frac{\gamma m_e}{E_e}\,\Re\left(\frac{C_T + C'_T}{C_A}\right)$$

Experimental observable?

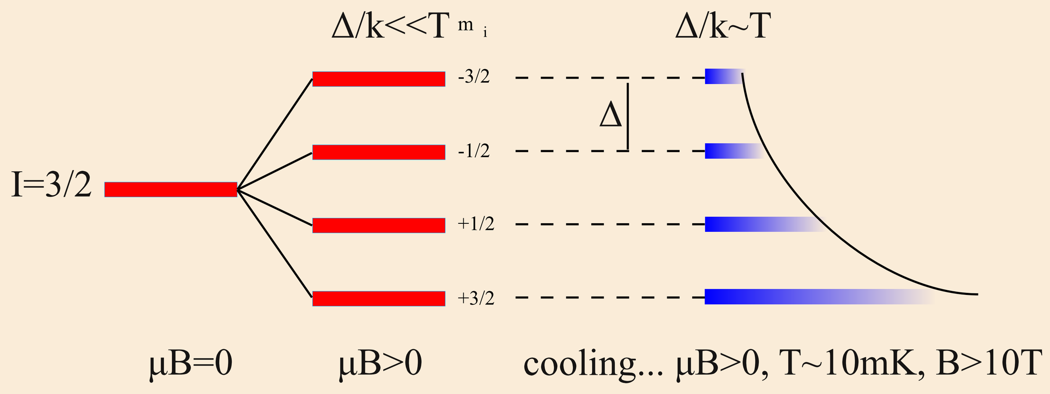
$$W(\Theta) = 1 + \tilde{A}\frac{\langle \vec{J}\rangle}{J}\frac{p_e}{E_e}; \qquad \tilde{A} = \frac{A}{1 + b_{Fierz}\frac{m_e}{E_e}}$$

To measure this parameter we need oriented nuclei!

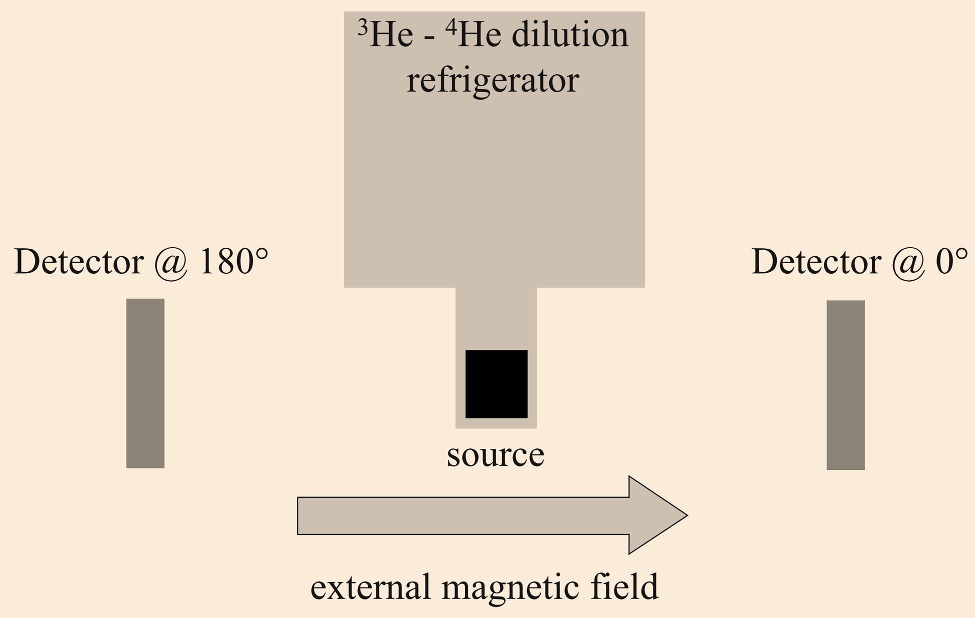
N. Severijns, M. Beck, O. Naviliat-Cuncic, Rev. Mod. Phys. 78 (2006) 991

Low Temperature Nuclear Orientation

Obtainig an ensemble of oriented nuclei



Measuring the anisotropy



Analysis

Experimentally we measure the normalized angular distribution of electrons:

$$W(\Theta) = \frac{N(\Theta)_{COLD}}{N(\Theta)_{WARM}} = 1 + f\ \tilde{A}\left(P\ \frac{v}{c} Q\cos(\Theta)\right)$$

Effects that distort the recorded spectrum:
- electron scattering on the detector and the source
- magnetic focusing
- solid angle
- pile-up

Solution: use GEANT4 to address these effects!

With our GEANT4 based Monte Carlo simulation we simulate the whole experiment, thus obtaining the A parameter:

$$\frac{W(\Theta)^{SIM} - 1}{W(\Theta)^{EXP} - 1} = \frac{\tilde{A}^{SIM}}{\tilde{A}^{EXP}}$$

F. Wauters et al., NIM A 609 (2009) 563-567

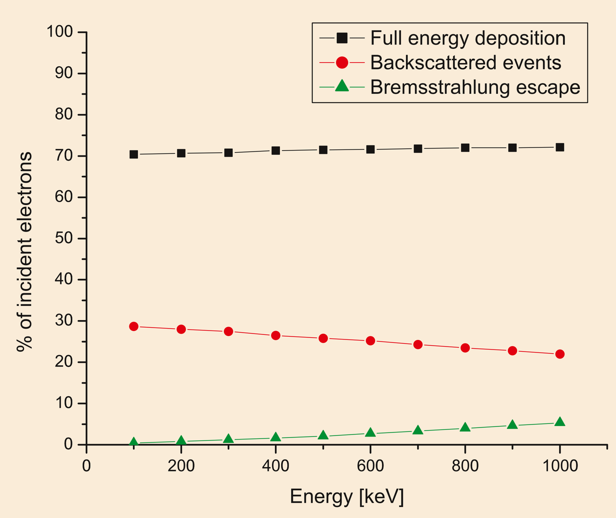
Response of the detectors to monoenergetic electrons

The simulation of the detector's response function is the easiest way towards a full understanding of the particle detectors.

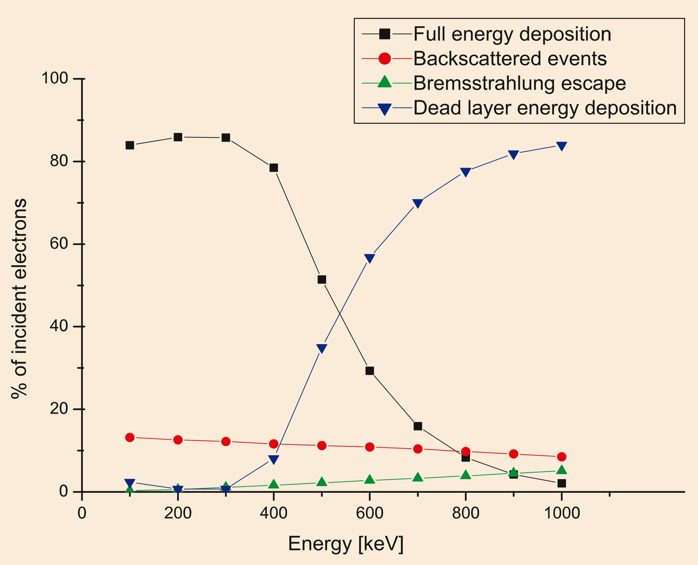
Monoenergetic electron beam on a slab of detector material.

Observe: full energy deposition, transmitted, backscattered, bremsstrahlung escape events

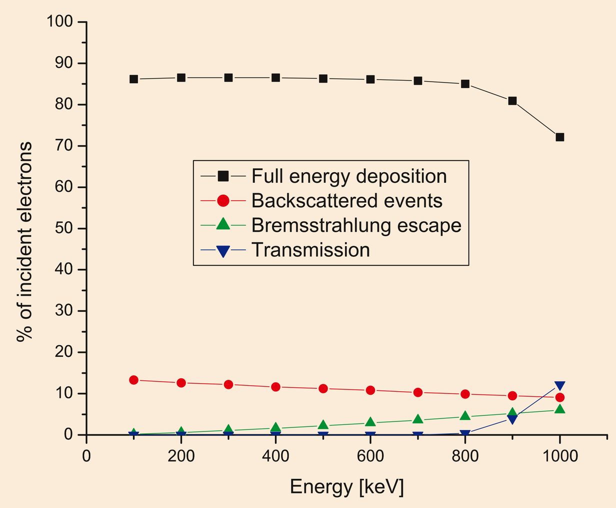
HPGe detector, 1 cm thick



Si PIN diode, 0.5 mm depletion thickness



Si PIPS detector, 1.5 mm thick

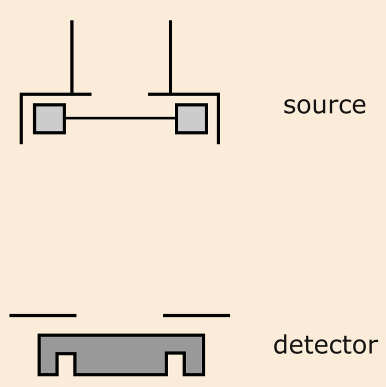


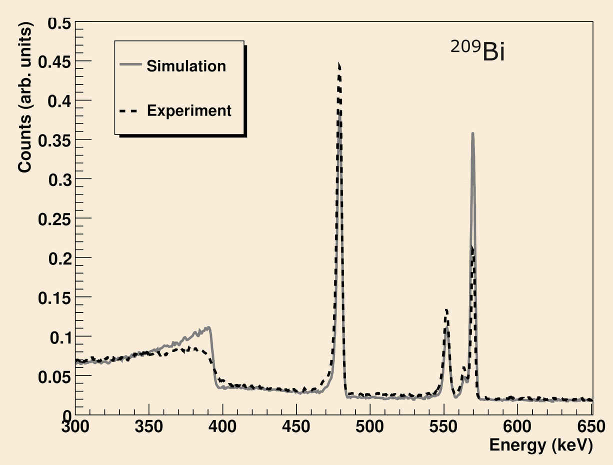
Validation of the GEANT4 code for particle detectors

Comparison of simulated and experimental spectra of HPGe and Si PIN diodes in simple source-detector geometries

Planar HPGe detectors

custom made HPGe detectors developed by the Nuclear Physics Institute in Rez, Czech Republic

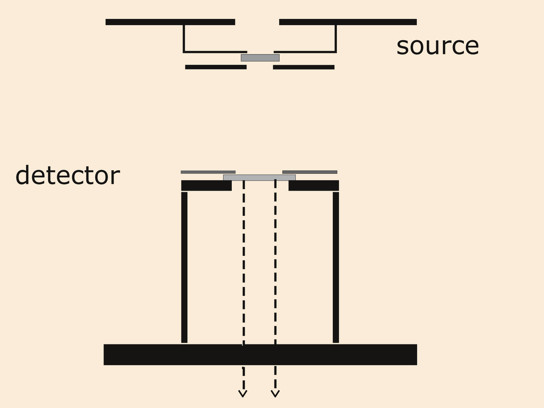


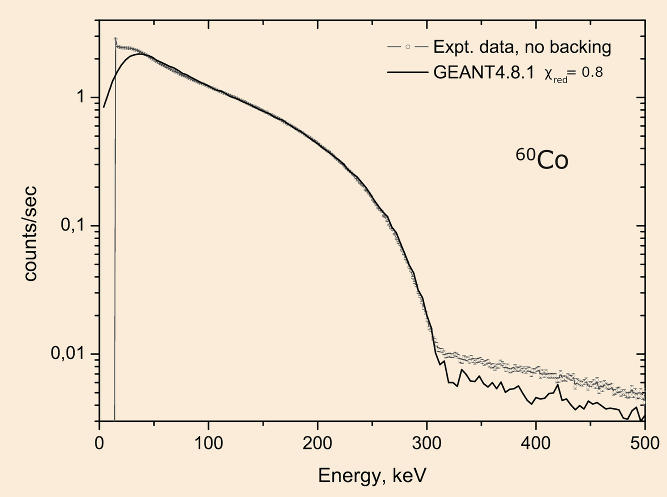


D. Venos et al., NIM A 365 (1995)
D. Venos et al., NIM A 454 (2000)

Hamamatsu Si PIN diodes

500 μm thick depleted layer, 81 mm² sensitive area





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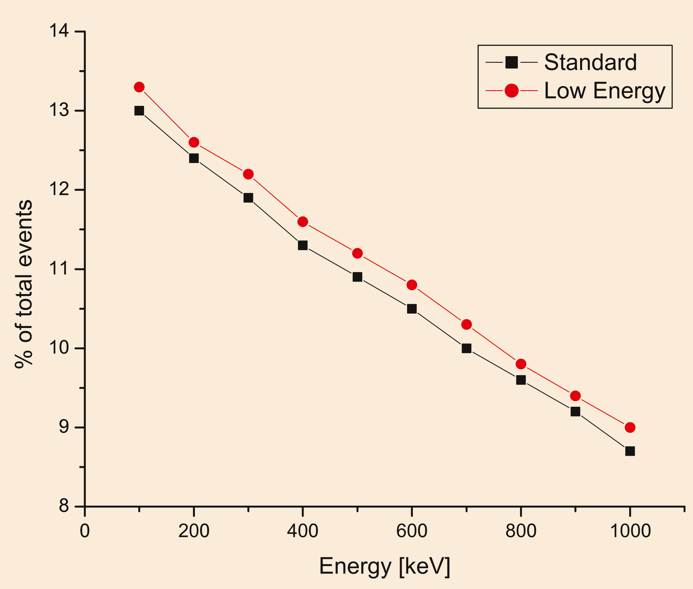
The GEANT4 physics models

In version 9.0 and earlier there were two Electromagnetic Physics packages: *Standard* and *Low Energy* (also called Livermore). In version 9.3 the Livermore package was redesigned and also the Penelope package was fully implemented, giving in total three different packages to choose from: *Livermore*, *Penelope*, and *Standard EM*.

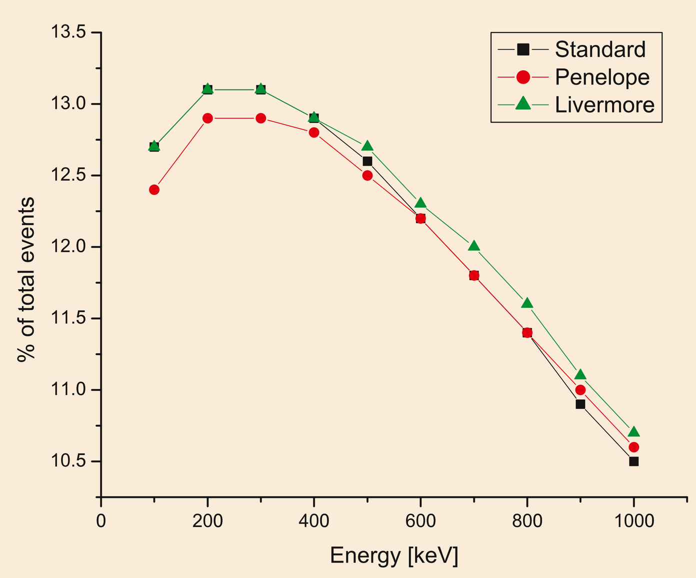
On the following figures comparisons of the various physics models are shown. We simulated monoenergetic electron beams hitting a piece of detector material (Si), and recording the backscattered events. The electron beam's initial kinetic energy varied in the range of 100 keV and 1 MeV.

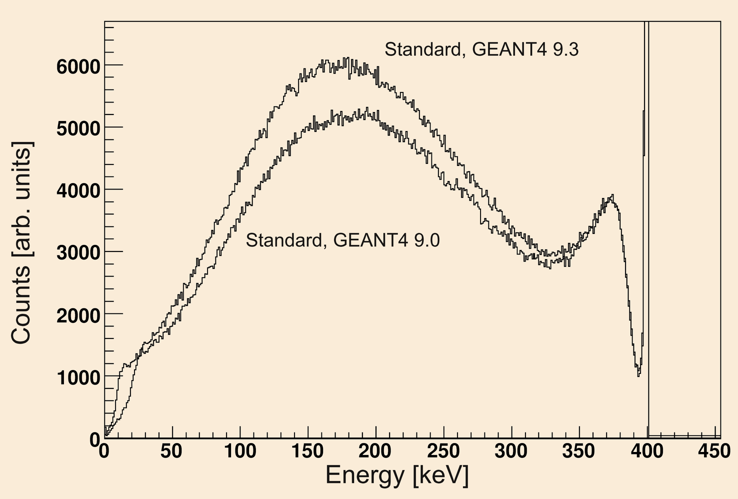
Backscattering coefficients

GEANT4 9.0



GEANT4 9.3





The backscattering coefficients from the two versions of GEANT4 are in disagreement. The left figure shows the spectrum of 400 keV electrons recorded with the Si detector. In order to emphasize the backscattered events, the full energy peak is partially omitted. According to this figure the bremsstrahlung model (the small peak next to the full energy peak) for the two versions works the same. The reason of the difference between the backscattering doefficients is not clear yet, further tests are required.

https://twiki.cern.ch/twiki/bin/view/Geant4/LowEnergyElectromagneticPhysicsWorkingGroup

Outlook

GEANT4 9.3

We still need further testing before we decide which one of the new GEANT4 physics models works the best for our experiment. Simulations of our new Si PIPS detectors and of the whole experiment will show us which model performs better in describing our experiment.

Scattering of electrons

The comparisons between experimental and simulated spectra show that the GEANT4 multiple scattering model still can be improved. Our group is currently working on a β-spectrometer coupled to a multi wire drift chamber. With this one can record individual paths of electrons and it can be used to measure the backscattered events with high precision, providing calibration data for the GEANT4 multiple scattering model.

Coming experiments

We are preparing 2 new experiments. The one in ISOLDE, CERN will be measuring the β-asymmetry of the ^{133}Xe nucleus. With the endpoint energy of 346 keV and no higher energy γ-rays we expect a clean spectrum where the corrections coming from simulations can be smaller, thus the error associated with them will be smaller.
The second experiment, to be conducted in Leuven, Belgium, will be a second measurement of the 60Co nucleus. By preparing a well defined neutron activated radioactive sources and new, fully digital data acquisition system we expect to further reduce the uncertainty on the β asymmetry parameter.

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