# Plastic Scintillator Response Functions Simulated with the GEANT4 Code

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Precise $\beta^{\pm}$-branching-ratio measurements are required to determine *ft*-values as part of our program to test the Standard Model via the unitarity of the Cabibbo-Kobayashi-Maskawa matrix. For the measurements to be useful in this test, their precision must be close to 0.1%. This is a particularly demanding requirement for β-decay branching-ratio measurements.

In a typical branching-ratio measurement, we collect the radioactive species in mylar tape, and then move the tape to a shielded counting station, where the sample is positioned between a thin plastic scintillator used to detect β particles, and a HPGe detector for γ rays. The signals from both detectors are recorded for all events in which there is a β-γ coincidence. Although we obtain the β branching ratio from the absolute intensity of the coincident γ rays, the relative efficiency of the β-detector as a function of β energy is critical to our achieving a precise result since different γ-ray peaks correspond to β transitions with different end-point energies.

We have previously simulated β-response functions using Monte Carlo calculations produced by the EGS package of codes [1] but, since there are always questions about the validity of any particular simulation code, we have now made similar Monte Carlo calculations with the GEANT4 code [2]. GEANT4 allows for the transportation of both β and γ particles through matter with software that is modular and flexible, and accounts for low-energy electromagnetic processes down to 250 eV (see Ref. [3]). In addition, it accommodates rather complicated three-dimensional geometrical models and a wide variety of materials. It also allows the user to output the simulated data at different stages in the process and at different levels of detail and refinement.

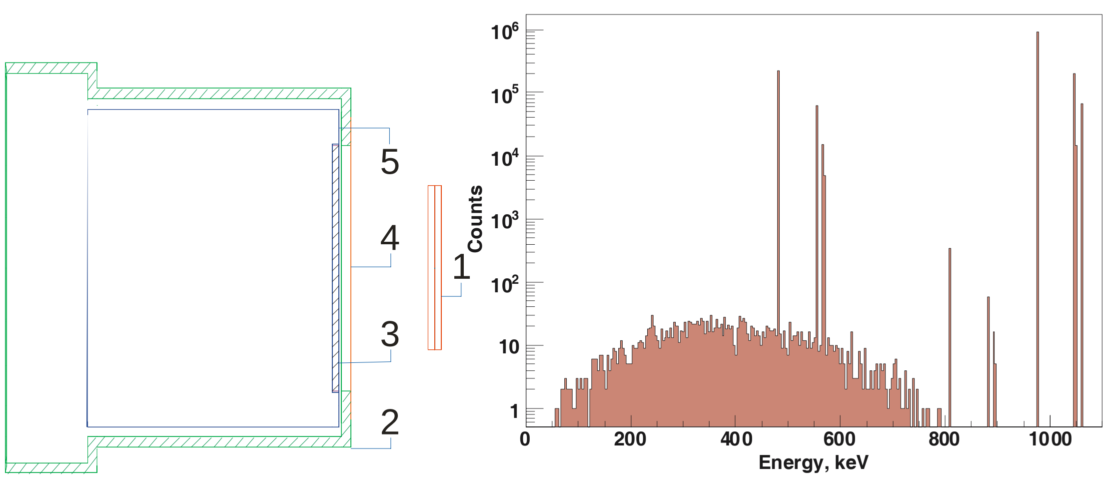


**Figure 1.** Left: Schematic drawing of the β-detector assembly (not exactly to scale). The radioactive source is contained in thin mylar foil (1), with emitted γ rays and electrons then passing through a havar foil (4) and into the plastic scintillator (3). The scintillator is optically coupled through the plastic light guide (5) to a photomultiplier tube. The scintillator and light guide are shielded from stray light by a cylindrical cover (2) made from PVC. Right: Decay spectrum of electrons for $^{207}$Bi generated by GEANT4 as input to the Monte Carlo simulations.

The geometric model we used for GEANT4 incorporates the essential features of our experimental test arrangement. It appears on the left side of Fig. 1. The β-detector consists of a 1-mm thick BC404 plastic scintillator coupled via plastic light guide to a photomultiplier tube (not shown in the figure). The scintillator and light guide are enclosed in a cylindrical shell made from 1.5-mm-thick PVC with a 5-μm-thick havar-foil window located directly in front of the scintillator. The whole assembly is light tight but allows electrons to pass through the havar window with negligible energy loss. In our simulation calculations, the various materials in this assembly were defined either as pure elements or as the appropriate chemical mixtures.

We describe here the first results of simulations we have made for the decay of $^{207}$Bi. In principle, it is possible to input each individual γ-ray and conversion-electron group in this decay into GEANT4, one by one. However the code includes a radioactive-decay module that derives for itself the full spectrum of particles emitted in the decay from the data available in the current ENSDF files. We followed the latter, much simpler approach. The primary spectrum of emitted electrons derived by the radioactive-decay module for the decay of $^{207}$Bi is shown on the right side of Fig. 1. It, together with the equivalent spectrum of primary γ rays, was what we used as input for the GEANT4 Monte Carlo calculation.

In any Monte Carlo simulation the desired physical quantity is the energy deposited into the scintillator. However, in order to compare the calculated and experimental spectra it is necessary to simulate the statistical fluctuations in the process of charge carrier production and pulse electronic analysis. It is these fluctuations that lead to a finite peak width. For this purpose, we applied a Gaussian distribution with parameters (mean $\bar{x}$ and standard deviation σ) extracted from experimental data as a function of the deposited energy $E_0$. This is known in the energy region 0.8-3.8 MeV (see Ref. [4]) and we extrapolated these data to lower energies assuming that the Gaussian width, $\sigma_{exp}$, is linearly dependent on the energy of the incident electrons. First, we computed the experimental resolution (FWHM) at a particular deposited energy, $E_0$. Next, we generated a random energy, $E_r$, using a Gaussian distribution with $\bar{x} = E_0$ and $\sigma = \sigma_{exp}(E_0)$. Finally, the modeled spectrum obtained from GEANT4 was thus processed at all energies by a randomization algorithm written in C++ in the ROOT [5] analysis framework. In Fig. 2, the results are compared with data that we obtained experimentally with a $^{207}$Bi conversion-electron source that we purchased from Isotope Products Laboratories.

The simulation is in good agreement with the measured spectrum. All features of the latter are present in the former. However, the experimental spectrum is not independently energy calibrated. Our next goal is to compare simulations with experimental data for several other conversion-electron sources, and from these comparisons derive a consistent energy calibration as well as the energy dependence of detector efficiency. We also plan to investigate the influence of peripheral objects located around the source and detector, and to examine systematically the differences between GEANT4 and EGS simulations.

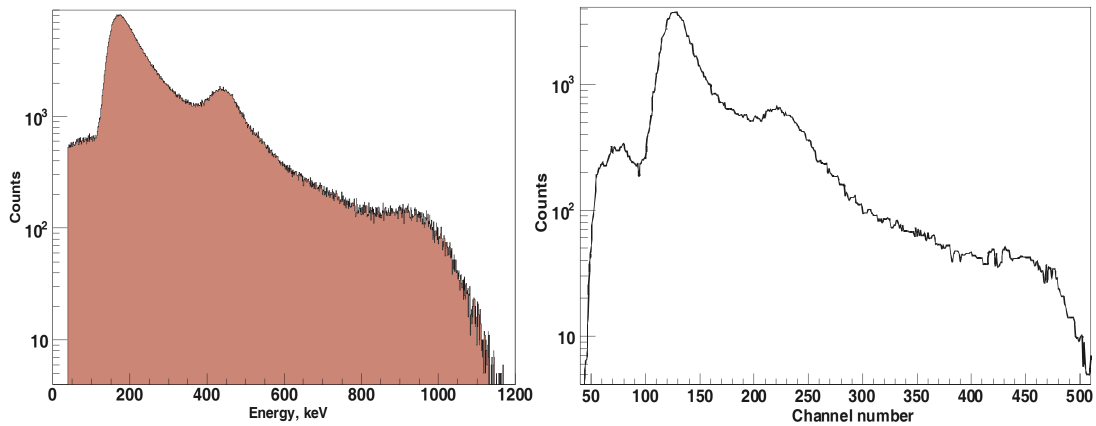


**Figure 2.** Deposited energy from β-particles that have been simulated by GEANT4 (left) and measured (right) for a $^{207}$Bi source located 40 mm from the front face of the β-detector. The simulated spectrum incorporates the finite resolution of the detector.

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