

Comparative study of the GEANT4, EGSnrc and PENELOPE Monte Carlo codes for efficiency calculations of a plastic scintillator

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The precision required when measuring the ft -values of superallowed β decays as a test of the unitarity of the Cabibbo-Kobayashi-Maskawa mass-mixing matrix is a demanding 0.1%. One of the crucial requirements of a branching ratio measurement to this level of precision is a detailed understanding of the response function of our β detector, specifically to determine its efficiency as a function of energy. This response function must be simulated using Monte Carlo (MC) techniques due to the unavailability of sources of monoenergetic low-energy β particles. In order to judge the reliability of our simulated response functions, we have undertaken a comparative study of three MC codes: EGSnrc [1], GEANT4 [2] and PENELOPE [3]. All three codes claim to be able to describe e^\pm interactions with matter from low energies (1 keV, 10 keV and 0.3 keV respectively) up to > 1 GeV, well above β -decay energies. The degree to which the three codes agree can be used to estimate the reliability of our simulated response functions and calculated β efficiency. In particular, EGSnrc and GEANT4 both use multiple scattering theories which rely on a judicious use of the step size for tracking the particles and are susceptible to spurious effects which may bias the results. PENELOPE on the other hand uses a mixed algorithm which is insensitive to the choice of step size, but which is significantly more CPU-time expensive.

The first comparison of the codes used the very simple geometry depicted in Fig. 1: a point-like source of positrons was set in the center of an infinitely long thin (76 μm) Mylar tape, positioned 4.92 mm in front of a 1 mm thick disk of BC408 scintillator with a diameter of 1.5 inches. Monoenergetic positrons were emitted isotropically with energies in the range of 200 keV to 20 MeV. The efficiency for

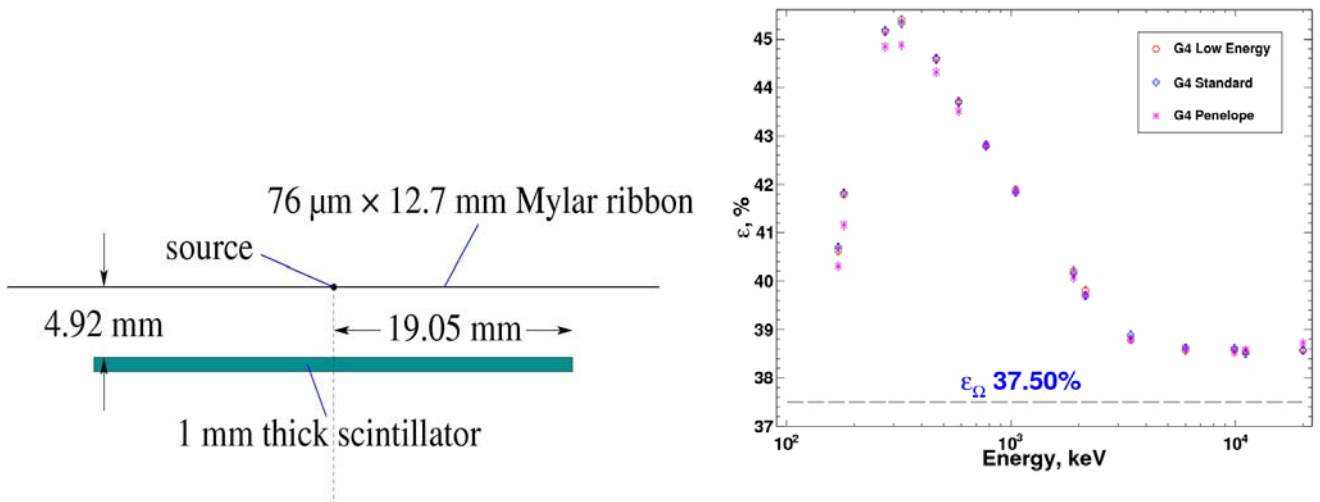


FIG. 1. Simplified geometry used in the MC simulations of the β -detector's efficiency (left) and results of a Geant4 simulations using the three different EM physics packages as compared to a purely geometrical calculation (right).

each incident energy was calculated as the ratio of the number of events where *any* energy was left in the scintillator to the total number generated. The results of GENT4 simulations using their “Low-energy”, “Standard” and “Penelope” electromagnetic (EM) physics packages are shown on the right panel of Fig.

1. The geometrical efficiency was calculated as $\varepsilon = \frac{\Omega}{4\pi} = \frac{1}{2} \left(1 - \frac{D}{\sqrt{R^2 + D^2}} \right)$ where Ω is the solid angle

defined by the cylindrical scintillator, D is the distance of the source from the front face of the scintillator, and R is the detector's radius. In our case, this leads to an efficiency of 37.5%. The deviation from the geometrical model is due to the effects of β scattering in the Mylar ribbon since results consistent with the geometrical efficiency were observed when the ribbon was not included in the geometry. Initially, this was a surprising effect since one might suppose that just as many positrons initially headed toward the scintillator get scattered away as those that get scattered into the direction of the scintillator. We found that the effect arises from positrons initially travelling along the plane of the Mylar ribbon; some of these events – which would not hit the scintillator if there was no Mylar foil – undergo scattering and are re-directed towards the scintillator resulting in an increased efficiency.

In Fig. 2, we show the comparison of the calculated efficiencies using GEANT4 to PENELOPE. Since EGSnrc gave results in complete agreement with PENELOPE, it is not included in this plot. One can see that the three different physics packages in GEANT4 agree with each other, but that there are

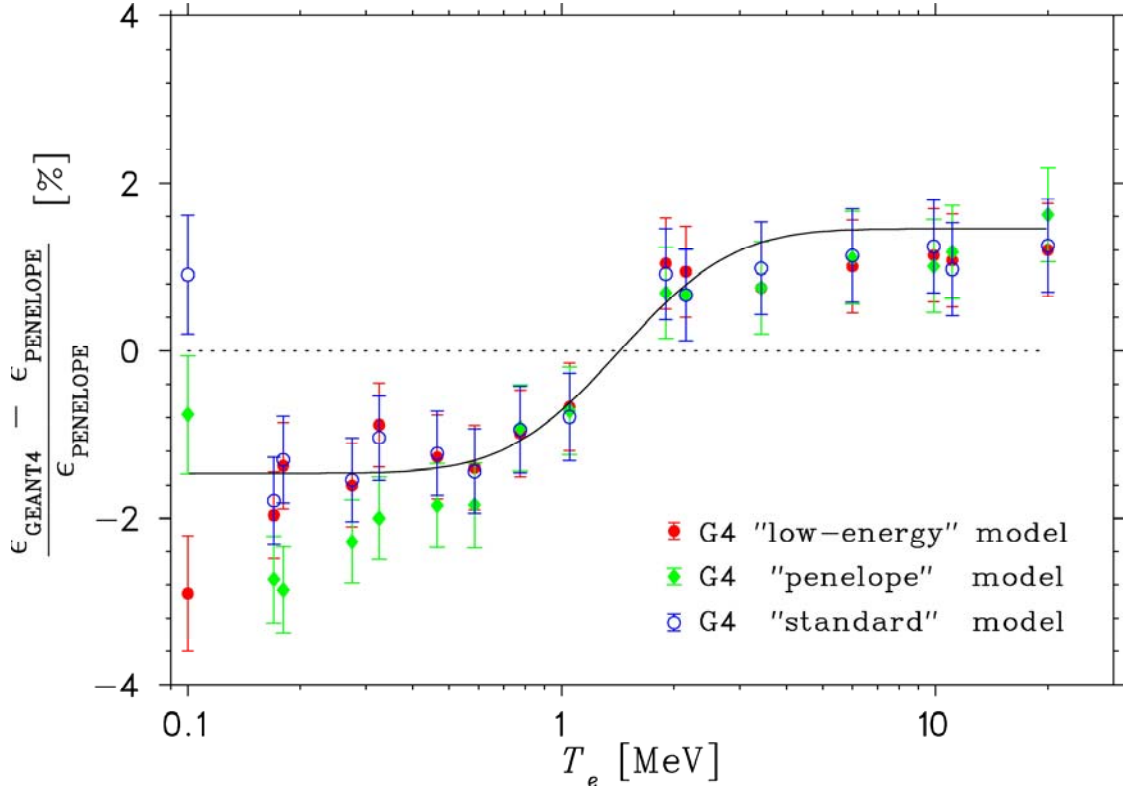


FIG. 2. The difference in scintillator efficiencies between PENELOPE and the various EM physics packages using Geant4. The EGSnrc code produced results in complete agreement with PENELOPE and so are not shown for clarity.

$\approx 3\%$ differences from the PENELOPE (and EGSnrc) predictions. The “Penelope” package of GEANT4, it should be pointed out, is *not* the same as PENELOPE itself because the algorithm used to describe multiple scattering remains the same regardless of which physics package is used in GEANT4. The different models used to describe multiple scattering gives rise to the small deviations observed in Fig. 2.

We have also performed simulations of the β decay of ^{207}Bi , ^{22}Na and ^{60}Co , and compared them to observed spectra where the absolute activity of the source was known to better than 1%. In all cases, agreement between the Geant4 and EGSnrc MC codes and the measured efficiency are in agreement. Simulations of these sources using PENELOPE are nearly completed, and preliminary results continue to indicate good agreement.

- [1] NRCC Report PIRS701 and <http://www.irs.inms.nrc.ca/inms/irs/EGSnrc/EGSnrc.html>.
- [2] S. Agostinelliae *et al.*, Nucl. Instrum. Methods Phys. Res. **A506**, 250 (2003).
- [3] J. Sempau *et al.*, Nucl. Instrum. Methods Phys. Res. **B207**, 107 (2003).