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C++ implementation of Bethe-Heitler, 5D, Polarized, $\gamma \rightarrow e^+e^-$ Pair Conversion Event Generator

I. Semeniouk[1,*], D. Bernard[1,*]

LLR, Ecole Polytechnique, CNRS/IN2P3, 91128 Palaiseau, France

Abstract

We present the C++ implementation of an event generator for linearly-polarized gamma-ray conversions to e^+e^- pairs. The generator uses the full 5D Bethe-Heitler probability density function for the generation of the e^+e^- pair and for the recoil of the target nucleus. The same code is used for triplet generation. We present a verification of the model by comparing sample distributions with theoretical predictions.

Keywords: gamma rays, pair conversion, event generator, polarized, Bethe-Heitler, Geant4

None of the existing event generators for gamma-ray conversions to e^+e^- pairs present in the packages used to simulate the interactions of high-energy particles in a detector actually simulate the 5D (five-dimensionnal) Bethe-Heitler [1] differential cross-section [2]. The reason is that a number of divergences (e.g. forward lepton emission at high energy or at low values of the momentum, q, transferred to the target) make the sampling of the probability density function (pdf) difficult [2]. A consequence is that the available physics models generate the electron and the positron in a plane that contains the photon direction, without any transverse recoil [2], an issue which is critical to the simulation of modern high-performance gamma-ray telescopes. Furthermore the polar angles of the electron and of the positron are generated independently, so energy-momentum is not conserved. Additionally, existing polarized conversion models were not verified successfully [2].

In the context of the HARPO project [3], an initial version of a full 5D generator was written using the BASES/SPRING implementation of the VEGAS method and was verified by the confrontation of 1D distributions with available published expressions [4, 5]. A new version without BASES/SPRING and therefore potentially usable in a Geant4 context was then obtained; a Fortran standalone generator is documented at [6]. We present in this poster a C++ version of the generator that we have carefully verified with respect to the Fortran version (plots not shown). The C++ version was implemented as Geant4 [7] gamma conversion model (G4BetheHeitler5DModel). The Geant4 local physics list (G4Em5DStandard) was added to some Geant4 examples.

The main features of the code are the same as that of the previous versions:

- Exact sampling down to threshold, i.e. without any low-energy or small-angle approximations;
- Generation of nuclear or electron ("triplet") conversions;
- Strict energy-momentum conservation;
- Linearly-polarized or non polarized gamma-rays.

The generator is found to simulate electromagnetic showers with profiles identical to those from other physics models, as shower shapes are not mainly determined by the details of the primary interaction (Fig. 1).

The distribution of the pair opening angle is found to scale as the inverse of the photon energy and to peak at 1.6 (MeV · radian) as computed [8] in the high-energy approximation (Fig. 2).

The polarization asymmetry for the conversion of fully linearly polarized photons is computed with the moments method [4, 5] using the correct definition of the event azimutal angle [5]. In that case, the polarization asymmetry of the simulated

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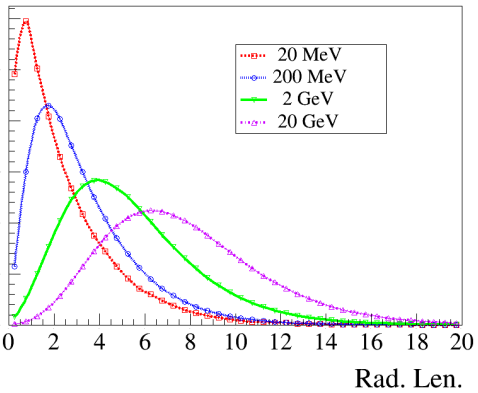

Figure 1: Longitudinal shower profiles for incident photons of various energies in Argon.

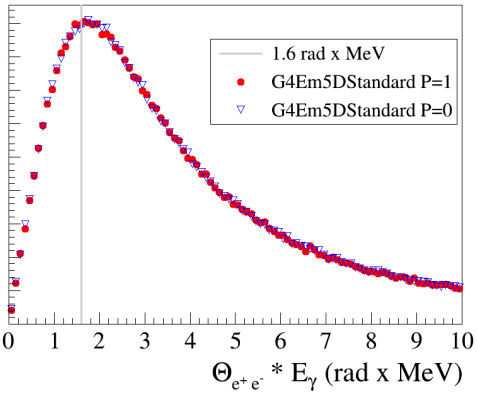

Figure 2: Distribution of the pair opening angle normalized to the inverse of the photon energy, $\Theta_{e^+e^-} \cdot E_\gamma$, for 640 MeV gamma in Argon gas. The vertical line at 1.6 (MeV · radian) is the high-energy prediction of the most probable value [8].

samples is found to be compatible with the published high-energy [9] and low-energy [5] asymptotic expressions (Fig. 3).

Figure 4 shows the agreement of the distribution of the recoil momentum of the generated samples with the high-energy calculation of [10].

The code (G4BetheHeitler5Dmodel) was submitted to the Geant4 EM group as a possible physics model of polarized gamma conversion in the Geant4 framework [7] and will be available in a future release.

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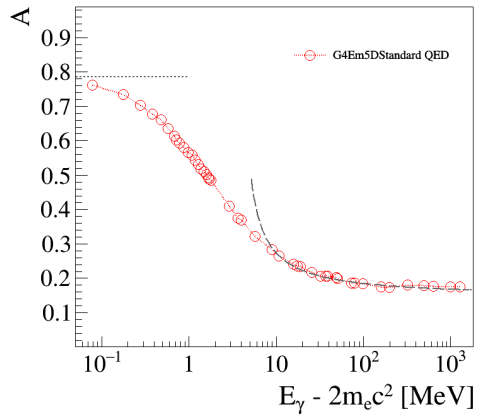

Figure 3: The polarization asymmetry of the conversion of linearly polarized photons on Argon as a function of the available energy (photon energy minus threshold). The horizontal line denotes the low-energy asymptotic value $\pi/4$ [5]. The dashed curves denote the Boldyshev - Peresunko high-energy asymptotic expression [9].

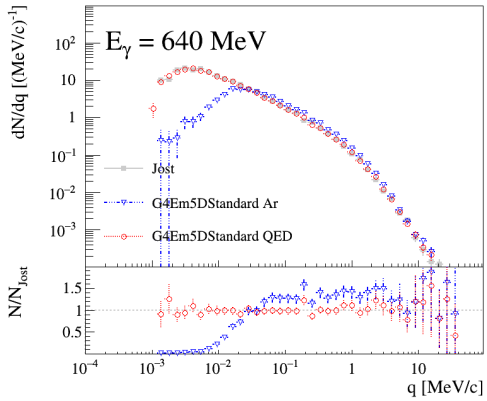

Figure 4: Distribution of the recoil momentum for nuclear conversions on argon. The simulated values for isolated nuclei (circles) are compared to the high-energy analytical calculation of [10] (squares). Triangles are for conversions on nuclei inside atoms. The lower plot shows the ratio to the analytical calculation of [10].

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