

A Computer Code Package for Monte Carlo  
Photon-electron Transport Simulation.  
Comparisons with experimental benchmarks

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## Abstract

A computer codes package for particle transport Monte Carlo simulation was developed using object oriented techniques of design and programming. A flexible system for simulation of coupled photon, electron transport, facilitating development of efficient simulation applications, was obtained. For photons: Compton and photo-electric effects, pair production and Rayleigh interactions are simulated, while for electrons, a class II condensed history scheme was considered, in which catastrophic interactions (Møller electron-electron interaction, bremsstrahlung, etc.) are treated in detail and all other interactions with reduced individual effect on electron history are grouped together using continuous slowing down approximation and energy straggling theories. Electron angular straggling is simulated using Molière theory or a mixed model in which scatters at large angles are treated as distinct events. Comparisons with experimentally benchmarks for electron transmission and bremsstrahlung emissions energy and angular spectra, and for dose calculations are presented.

**Keywords:** Monte Carlo, particle transport, photon, electron

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## 1. Introduction

A computer code package (PTSIM) for Monte Carlo particle transport simulation was developed. It includes specific techniques for coupled photon-electron/positron transport simulation, based on a more general object oriented framework for particle transport simulation.

A Monte Carlo simulation code has four major components: (1) the cross-section data for all processes being considered in the simulation, (2) the algorithms used for the particle transport, (3) the methods used for geometry representation and to handle particle passage from a volume to another and (4) methods to determine quantities of interest and analysis of the information obtained during the simulation. While the last two components has an important contribution to the complexity of computer code and running time, only first two are relevant form the point of view of the underlying physics of the simulation.

## 2. Coupled photon-electron transport simulation

The simplest approach of application of the Monte Carlo method to radiation transport problems is the analogue simulation in which random trajectories of the particles are generated according to the probability distributions governing each individual interaction with the medium. This analogue method to be desirable for computer simulation is required to have few interactions per particle history, that is the case for photons, but not for electrons. Due to the enormous number of collisions (long range Coulomb interactions) encountered by electrons, analogue simulation of electron transport is possible only in a few exceptional cases. Therefore condensed-history techniques are used, in which the electron is traced in a series of steps, and multiple-scattering theories are used to group individual scattering events which occur during each step. This makes electron transport more complex, first form the point of view of underlying physics of the simulations, and second from the point of view of the complexity of the algorithm

and computational aspects.

The photon transport simulations include simulation of photo-electric effect, Compton interaction, pair production and coherent scattering. For sampling these interactions general theoretical approaches are used (e.g. Klein-Nishina cross section for Compton interactions), but for the determination of the probability of occurrence of these interactions more accurate cross sections data is used [1], or from [2] where more detailed informations are necessary.

Details about electron transport simulation schemes and theories used are presented in [3]. The electron transport simulation algorithm is based on a condensed history class II scheme. According to the classification operated by Berger [4] in condensed history class II models the collisions in which the particle losses a large fraction of its energy, above certain energy thresholds, are simulated as individual interactions and only the remaining interactions are treated in a continuous manner.

Discrete events considered are production of knock-on electrons based on Møller cross section (or Bhabha cross section for positrons), and bremsstrahlung, where an improved cross section proposed by Al-Betery and Raeside [5] is used. Multi-scatter angular straggling is simulated using Molière theory [6, 7, 8]. In this enhanced version of the code, as an alternative, a refinement of class II condensed history scheme was introduced by treating separately the elastic scatters at large angles, above a certain threshold  $\theta_c$ , and considering for the remaining interactions a model based on a Gaussian distribution [9].

The Molière theory and the angular straggling mixed model are tested against results obtained with analog Monte Carlo based on the Rutherford cross section. As can be seen in figure 1 angular distributions predicted by these models are in a good agreement, the main improvements of the mixed model, compared with the complete grouping models (e.g. Molière theory) are revealed when comparisons of the spatial displacements distributions are made, due to the better consideration of the correlation between angular deflection and spatial displacement of the

electron during the simulation steps (see figure 1).

### 3. Comparisons with experimental benchmarks

Coupled photon-electron transport Monte Carlo codes are very complex and use a large amount of cross sections, stopping powers data. Simulation results are also influenced by different parameters, dependent on particles energies and materials, introduced in construction of algorithms to control the simulation of particle histories. Therefore it is essential to evaluate Monte Carlo codes by comparing calculated data with high-quality experimental data. In order to do the most meaningful comparisons it is preferable to have high-quality data in very simple geometries.

For a first series of comparisons were used measurements of Rester and Derrickson [10] of electron transmission energy spectra and angular distributions. Such comparisons are presented in figure 2 for electrons perpendicular on aluminum and gold at incident energies of 1.0 and 2.5 MeV respectively.

At high energies, the coupled transport of electrons and photons was tested against bremsstrahlung measurements. In figure 3 are shown bremsstrahlung energy spectra at near  $0^\circ$  and  $12^\circ$  emission angles from a thick tungsten radiator bombarded with 10 MeV electrons. This kind of comparisons are primarily a test for total and differential in energy bremsstrahlung cross sections and of the sampling routines.

Thick-target bremsstrahlung angular distributions data are a good test for the total production cross sections and the electron multiple-scattering model (since bremsstrahlung photons are emitted in nearly the same direction as the primary electrons). Such comparisons are plotted in figure 4 for 15 MeV electron beams perpendicular incident on beryllium and lead targets.

Another series of simulations were performed for comparisons with dose measurements. In figure 5 depth-dose measurements for 1 MeV electron beams per-

pendicular on beryllium and copper and for 10 MeV electrons on lead, taken from [11] are used for comparisons with Monte Carlo calculations. It is essential that a Monte Carlo code for radiation dosimetry applications be able to calculate dose in the vicinity of an interface between two media. Measurements near interface between high-Z and low-Z materials provide a good test, such an example is presented in figure 6. Given the scatter of the experimental data, calculated results match the experiment acceptably well.

## 4. Conclusions

A computer codes package for coupled photon-electron transport Monte Carlo simulation was developed using modern object oriented techniques of design and programming.

An improvement to standard electron condensed history class II scheme is introduced by simulating as discrete events elastic scatterings at large angles, in order to get better correlations between angular deflections and spatial displacements.

The theories used and the simulation techniques adopted were tested against simple configurations experimental benchmarks revealing a good agreement in the limits of experimental and statistical uncertainties.

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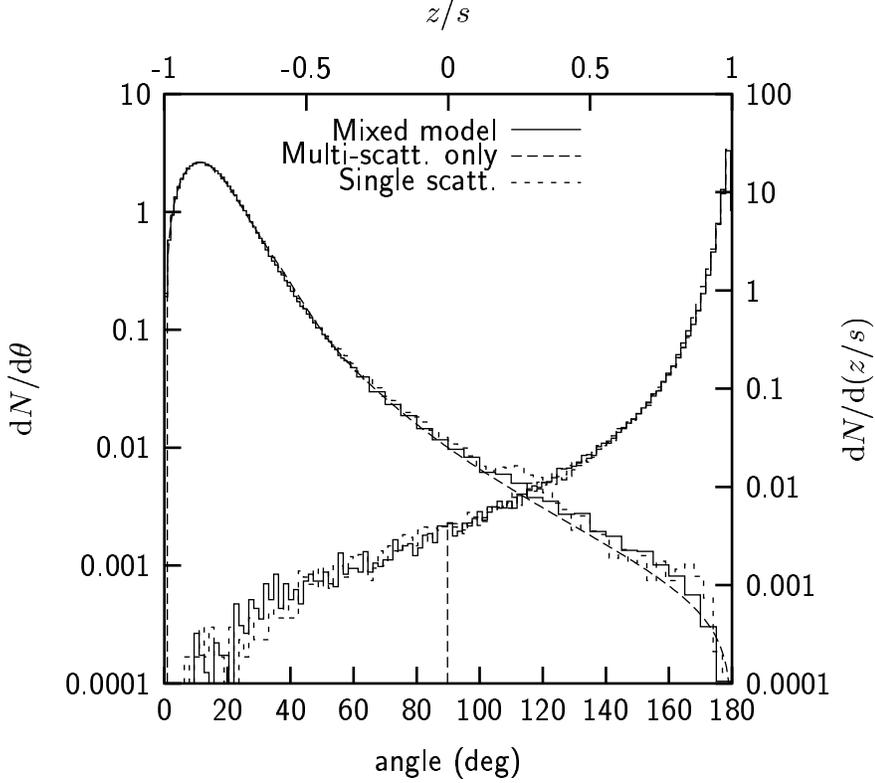


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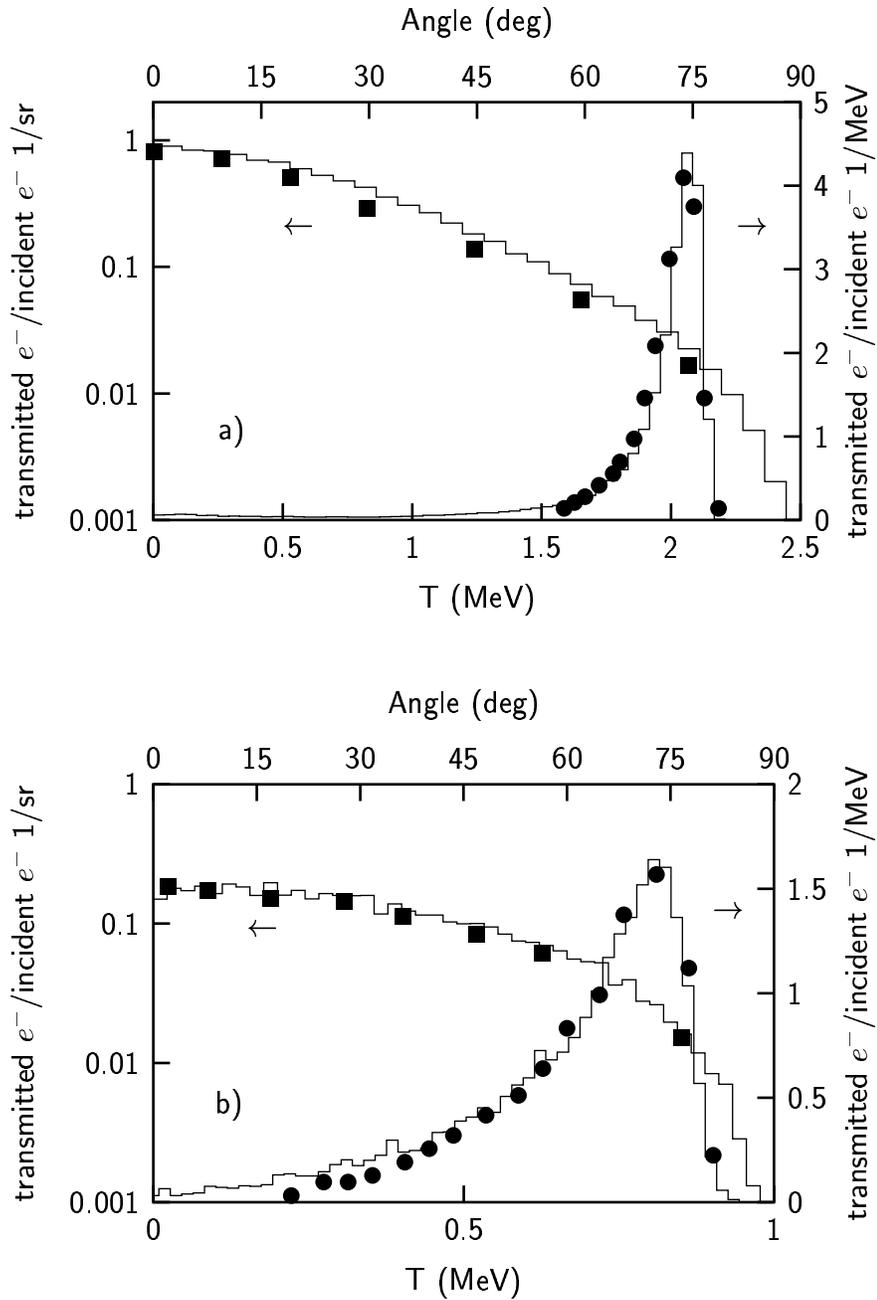


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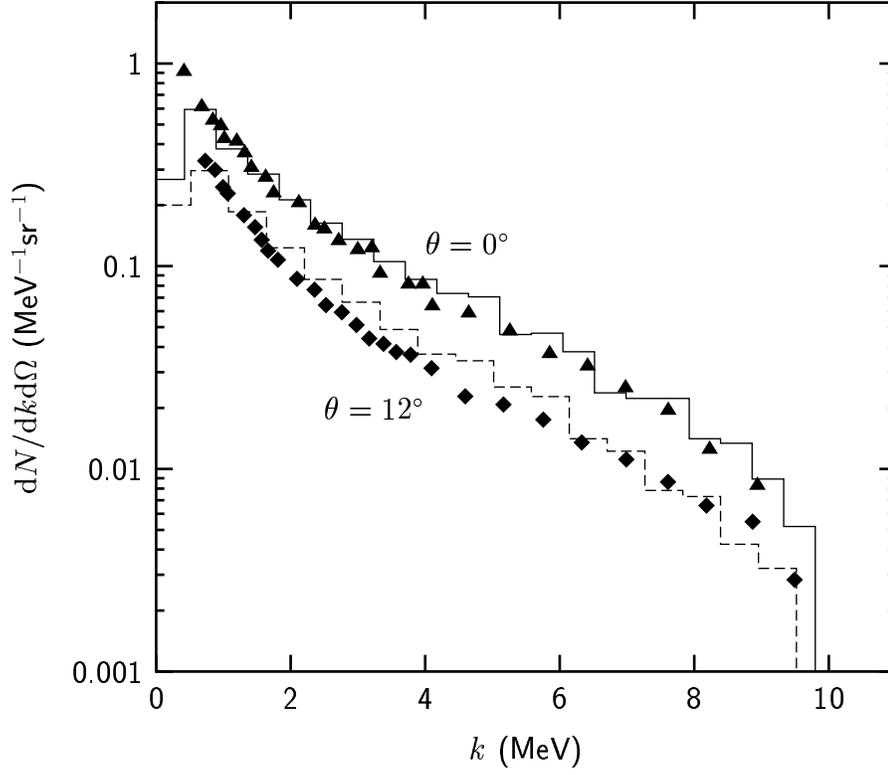


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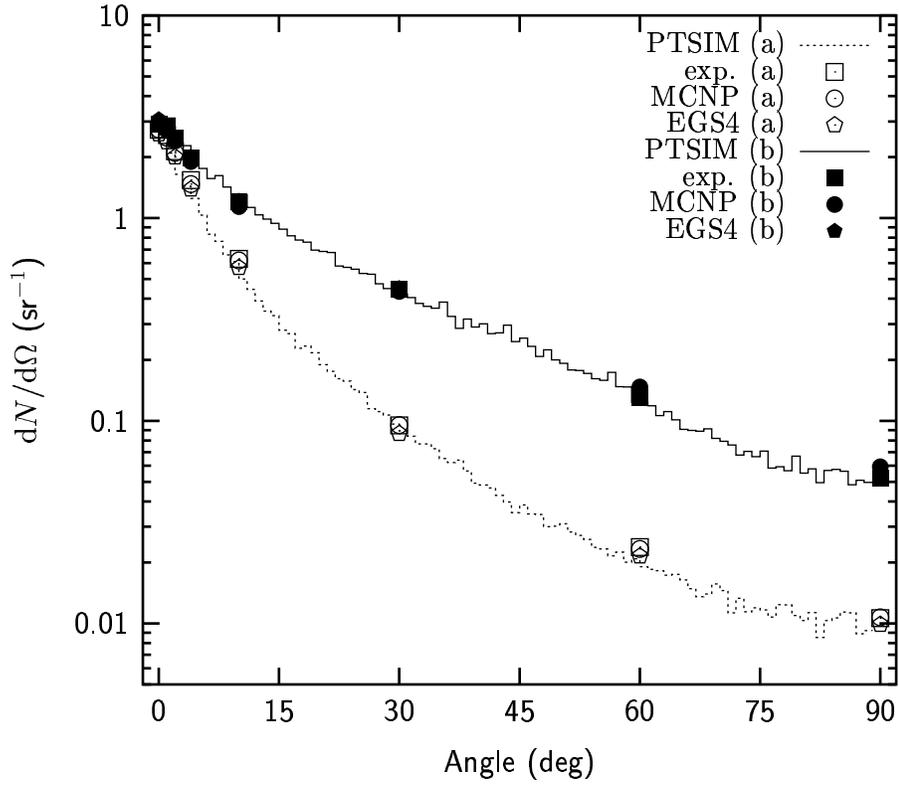


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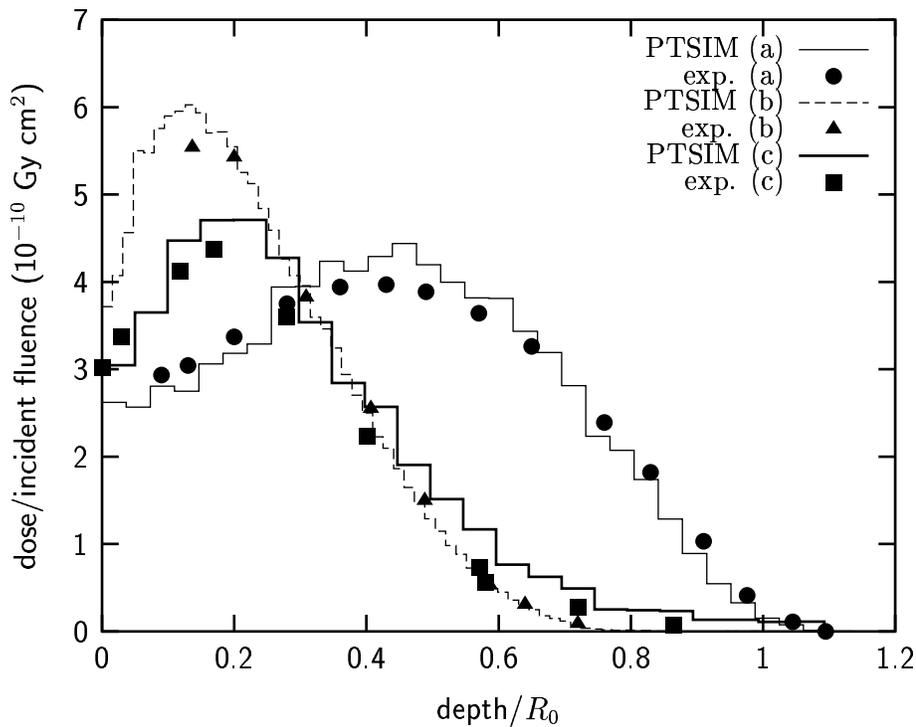


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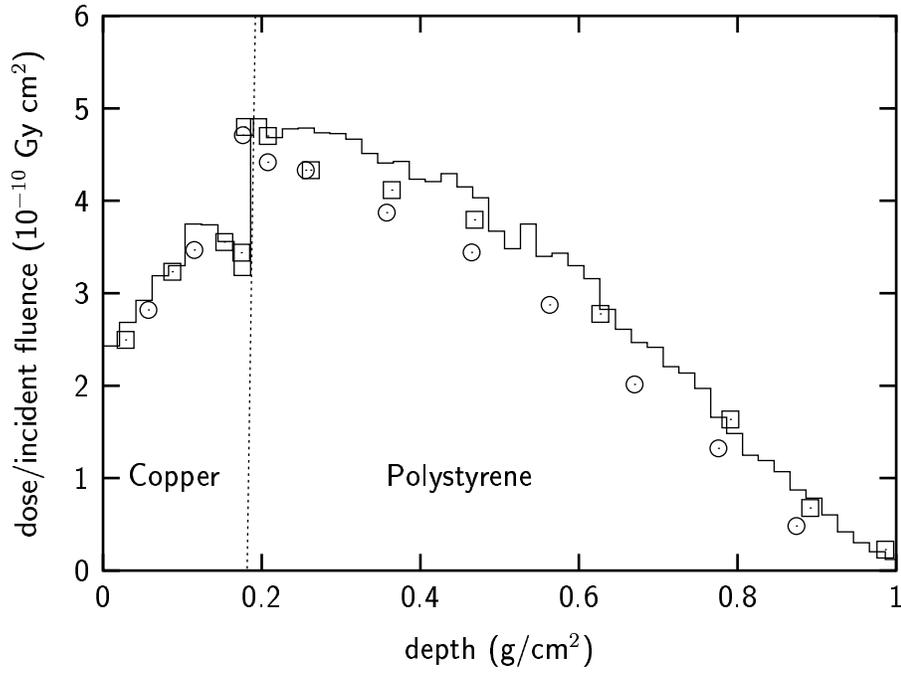


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