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Electron backscattering simulation in Geant4

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ABSTRACT

The backscattering of electrons is a key phenomenon in several physics applications which range from medical therapy to space including AREMBES, the new ESA simulation framework for radiation background effects. The importance of properly reproducing this complex interaction has grown considerably in the last years and the Geant4 Monte Carlo simulation toolkit, recently upgraded to the version 10.3, is able to comply with the AREMBES requirements in a wide energy range. In this study a validation of the electron Geant4 backscattering models is performed with respect to several experimental data. In addition a selection of the most recent validation results on the electron scattering processes is also presented. Results of our analysis show a good agreement between simulations and data from several experiments, confirming the Geant4 electron backscattering models to be robust and reliable up to a few tens of electronvolts.

1. Introduction

Scattering of particles is a critical component of every Monte Carlo transport code, being one of the fundamental processes to represent the particle evolution within matter. The ESA AREMBES (ATHENA Radiation Environment Models and X-ray Background Effects Simulators) consortium aims to develop a new space radiation background effects simulator for the ATHENA [1] X-ray telescope. The AREMBES simulator is based on Geant4 [2–4], a Monte Carlo track-structure toolkit designed for the simulation of particle transport through matter. Geant4 addresses the scattering process with different approaches, accuracy, and CPU usage [5]. The version 10.3 of Geant4, released in December 2016, includes several improvements as well as new developments in hadronic and electromagnetic physics interactions.

Within the AREMBES framework the simulation of low-energy electron scattering is fundamental. Secondary electrons are produced by proton scattering on the materials surrounding the X-ray instruments. These particles can be completely absorbed by the detectors or can backscatter on their surfaces, avoiding de facto any means of detection by anti-coincidence techniques and leading to a dominant contribution to the overall background of both ATHENA focal plane detectors [6,7]. Given the relevance of the subject a detailed study, reported in this paper, was carried on by a synergy of AREMBES and Geant4 Collaboration members in order to evaluate the real capability of Geant4 to accurately reproduce the electron backscattering process.

In the first part of this paper an overview of electron scattering models and Geant4 internal validation will be presented. In the second part the electron backscattering process will be addressed by comparing the simulation with respect to a collection of experimental datasets available in literature for a variety of materials and energy regimes.

2. Electron scattering in Geant4

2.1. Scattering models

The Geant4 toolkit offers several scattering models applicable to different particles in a wide energy range. In the following paragraphs those models are briefly discussed, focusing on their applicability to electrons.

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2.1.1. Urban multiple scattering model

The multiple scattering model (MSC in the following) developed by Laszlo Urban [8] based on the Lewis theory [9] has been the Geant4 default model of multiple scattering for a long time. The function describing the scattering distribution shape has been tuned on the basis of various electron scattering datasets. The Urban model is applicable to any particle, but in recent Geant4 versions it is used only for electrons, positrons, and ions. In particular for electrons and positrons this model is exploited for energies below 100 MeV since the parametrisations used by the model are optimized for this energy range. The only exception is represented by the emstandard-opt3 (opt3 in the following) electromagnetic physics configuration, where the Urban model is used for all particles and all energies.

2.1.2. Combined multiple and single scattering model

In the recent Geant4 versions including 10.3 a model that combines multiple and single scattering, called Wentzel-VI, is provided [4,5]. This combined model can be used with low CPU usage for all charged particles and all energies, except electron and positron below 100 MeV.

2.1.3. Goudsmit-Saunderson multiple scattering model

This model is based on Goudsmit-Saunderson theory [10,5] and use some algorithms of the EGSnrc multiple scattering model developed by Kawrakow and Bielajew [11]. In this model at each step a sampling of

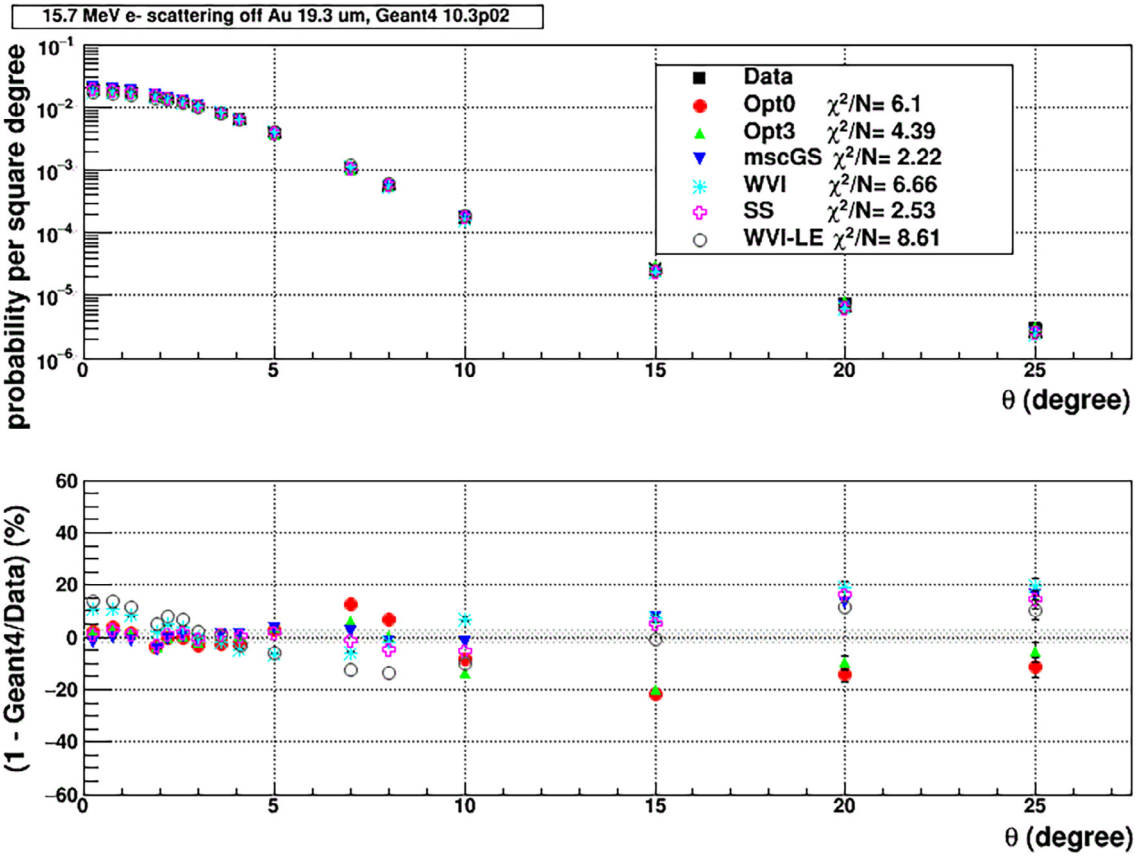

Fig. 1. Scattering angle of 15.7 MeV electrons by Au nuclei. Experimental data [15] (black dots) are compared with respect to Geant4 10.3 simulation using standard EM physics lists (coloured dots) for 19.3 μm target thickness. Image is taken from [16]. In the upper plot the scattering probability per square degree is reported in function of the scattering angle θ. In the lower plot the deviation between data and simulation in percentage is reported in function of the scattering angle θ.

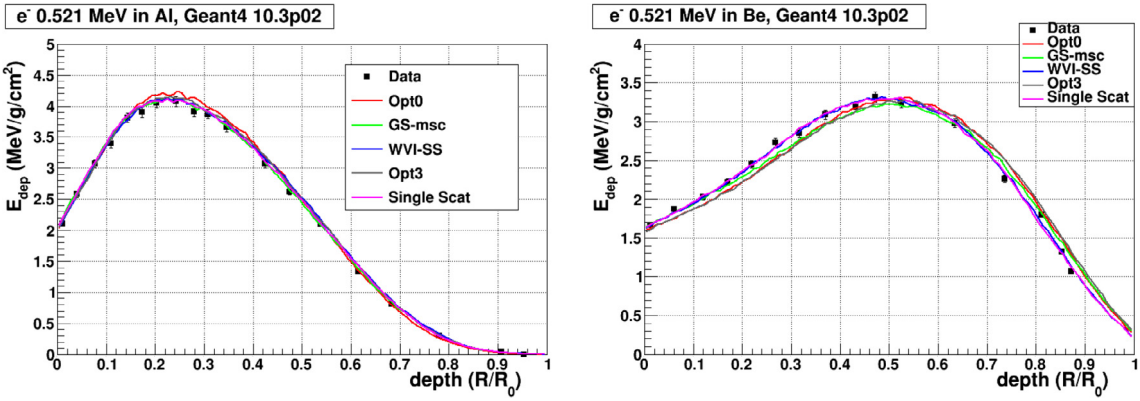

Fig. 2. Dose deposition of 0.5 MeV electron beam in Al (left plot) and Be (right plot) as a function of depth in the unit of electron range. Black points are experimental data from [17]. Colored curves are the simulation results obtained with Geant4 10.3 using various standard electromagnetic physics lists. Image is taken from [5].