Simulation of the Production of Secondary Particles from a Neutron Beam on Polyethylene Targets using the GEANT4 Simulation Tool

by

Christoph Ilgner (EST/LEA) and Oliver Link (EP/SFT)
C.E.R.N., Geneva, Switzerland

August 2003

Abstract

In view of a beam test of RadFET semiconductor detectors and optically stimulated luminescence (OSL) detectors as on-line dosimeters for radiation monitoring purposes in the caverns of the Large Hadron Collider (LHC) experiments, a simulation on the production of secondary particles from a neutron beam on a polyethylene target was carried out. We describe the yield of recoil protons, scattered neutrons as well as electrons, positrons and photons, when neutrons of an average energy of 20 MeV hit polyethylene targets of several thicknesses. The simulation was carried out using the latest release 5.2 of the GEANT4 detector description and simulation tool, including advanced hadron interaction models.

1 Scope of the Investigation

For on-line radiation monitoring purposes in the caverns of the Large Hadron Collider (LHC) experiments, several concepts are currently being considered. In the framework of the development of a state-of-the-art system beam tests will be performed on radiation-hard field effect transistors (RadFETs) and optically stimulated luminescence (OSL) detectors in order to determine their response to neutrons and secondary particles produced by neutrons in matter.

The setup will consist of the mentioned detectors closely attached to polyethylene blocks of several thicknesses, namely 2 mm, 5 mm and 10 mm, exposed to a neutron beam.

2 GEANT4 Model

According to the specifications of this setup, the simulated target was defined to be a polyethylene ($(CH_2)_n$) cuboid of 50×50 mm^2 surface, with the mentioned thicknesses in beam direction. The simulated sensitive area is another cuboid of $160\times160\times10$ mm^3, as shown in figure 1.

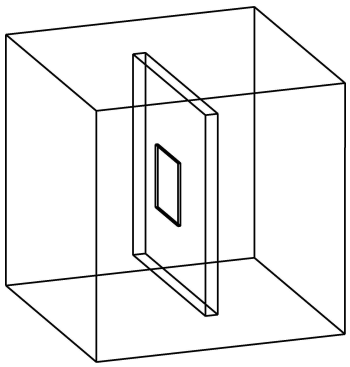

Figure 1: The simulated setup: the polyethylene target (50×50 mm^2 surface, several thicknesses, small cuboid) is closely attached to the sensitive volume ($160\times160\times10$ mm^2, larger cuboid).

The neutron beam itself has zero cross section, hitting the target under an angle of 90° in its center, with an average energy of 20 MeV, according to a Gaussian distribution of a width of 5 MeV (see figure 2). All angles in this report count from the axis of these incoming particles.

3 Results

As an overview, figure 3 shows secondary particles produced by 1000 incoming neutrons.

Based on 10^8 incoming neutrons, the forward distribution of secondary particles is summarized in table 1.

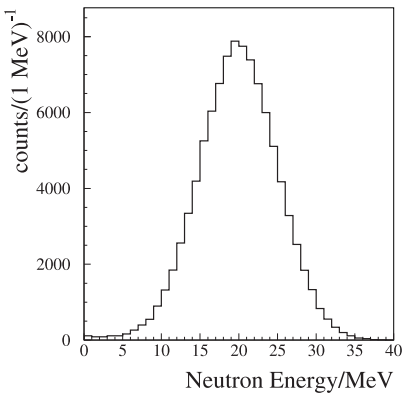

Figure 2: energy distribution of the incoming neutrons.

The angular distribution of the neutrons scattered in a 5 mm PE target displayed in fig. 4 shows that their interaction rate with the target material is 0.71 %/mm. This is based on a 10^5 neutrons simulation, considering only scattering angles larger than 1°.

Due to the fact that the simulation focused on the relevant solid angle covered by the sensitive volume, the significance of angular distributions of particles is limited to $\cos\theta \geq 0.12$, i.e. angles smaller than arctan(80 mm/10 mm)$\approx 85°$, corresponding to $\cos\theta \geq 0.12$.

An overall plot of the angular distribution of the ejected particles (except neutrons) is given in figure 5. The relative abundance of these particles is shown in figure 6. The complete set of plots on energy, angular and space distribution of the secondary particles is presented below.

References

[1] M. Asai et al., Geant4 User's Guide for Application Developers, Geant4 User's Documents, Version: Geant4 5.2, C.E.R.N., June 2003.

[2] D. Drakos, R. Moore, Physics Reference Manual, Geant4 User's Documents, Leeds 1996, Sydney 1999.

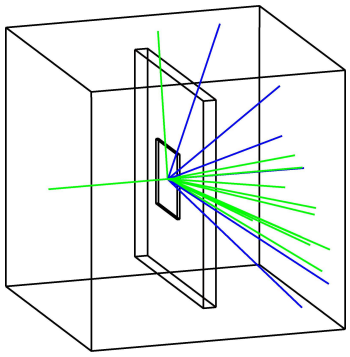

Figure 3: Secondary and scattered particles produced by 1000 neutrons (average energy: 20 MeV) after passage through a polyethylene target of 5 mm thickness. Green: neutrons, blue: protons.

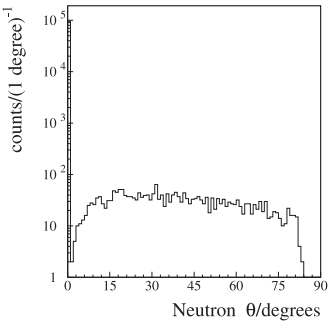

Figure 4: Angular distribution of 10^5 neutrons (20 MeV) after passage through 5 mm polyethylene.

Table 1: Relative particle yields in forward direction from 10^8 neutrons of 20 MeV (average) energy.

particles	thickness of PE target		
	2 mm	5 mm	10 mm
electrons	$2.68{\cdot}10^{-4}$ %	$1.17{\cdot}10^{-3}$ %	$3.39{\cdot}10^{-3}$ %
positrons	$4.3{\cdot}10^{-5}$ %	$1.5{\cdot}10^{-4}$ %	$4.61{\cdot}10^{-4}$ %
protons	0.637 %	0.999 %	1.02 %
photons	0.0346 %	0.085 %	0.167 %

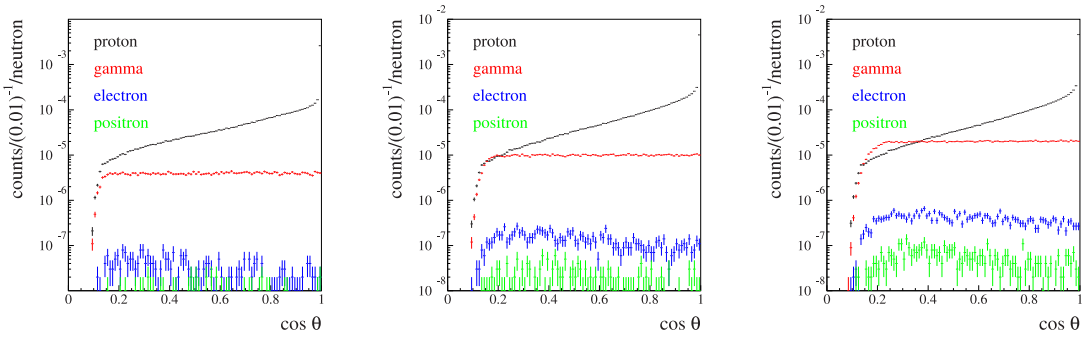

Figure 5: Angular distribution of all ejected particles except neutrons for several PE target thicknesses: left: 2 mm, center: 5 mm, right: 10 mm.

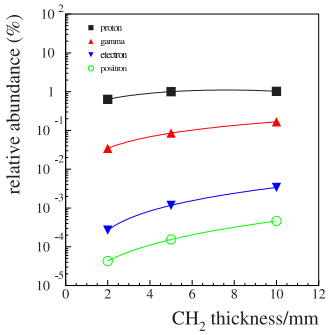

Figure 6: Relative abundances of all ejected particles except neutrons, as a function of target thickness.

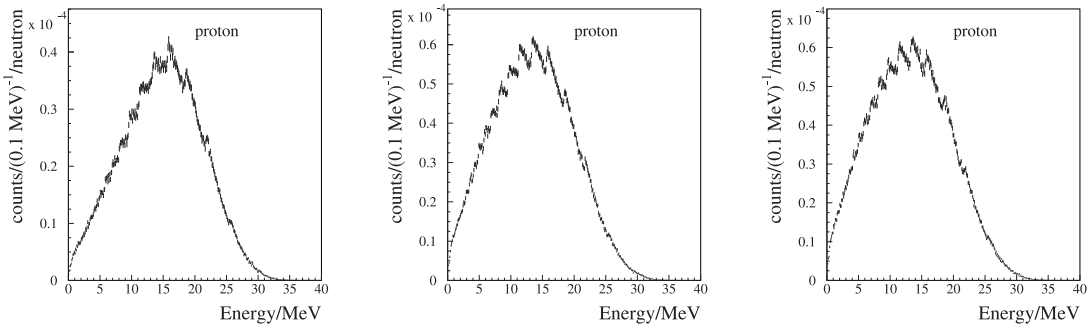

Figure 7: Proton-energy distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.

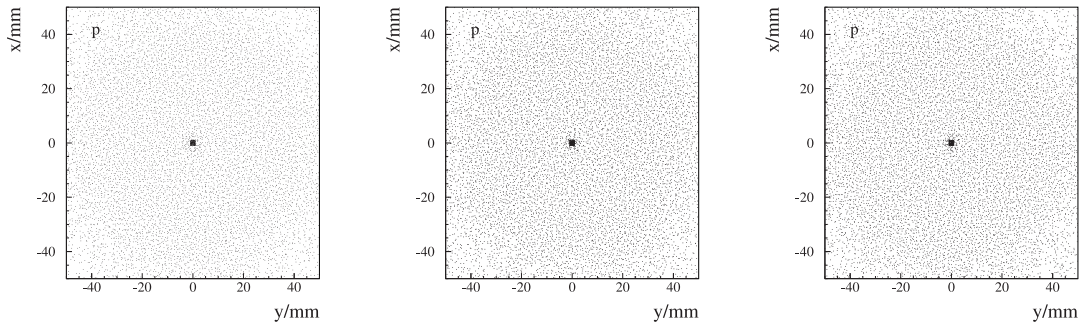

Figure 8: Proton space distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.

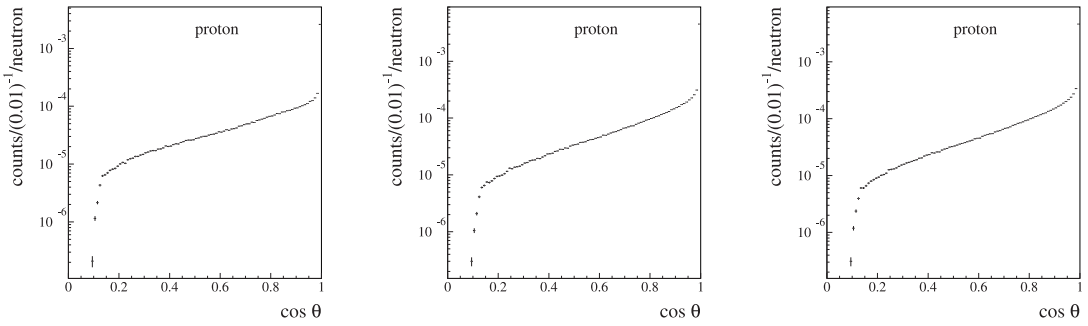

Figure 9: Proton angular distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.

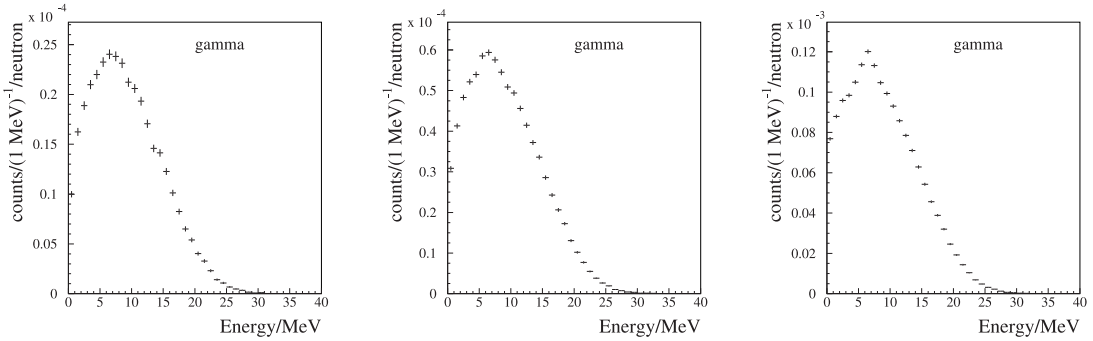

Figure 10: Photon-energy distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.

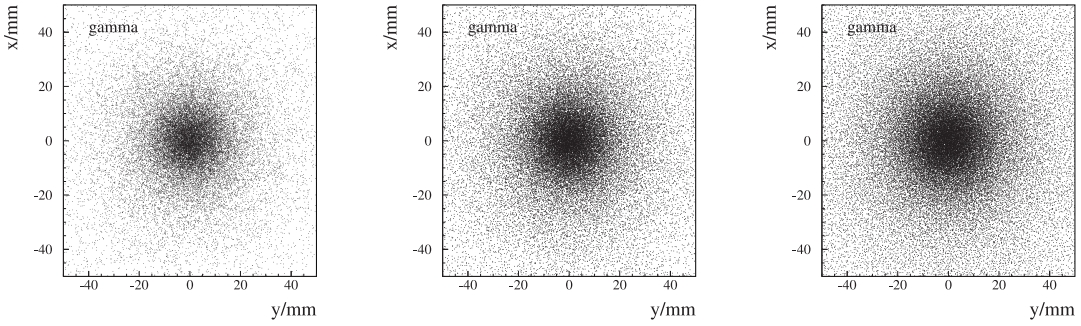

Figure 11: Photon space distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.

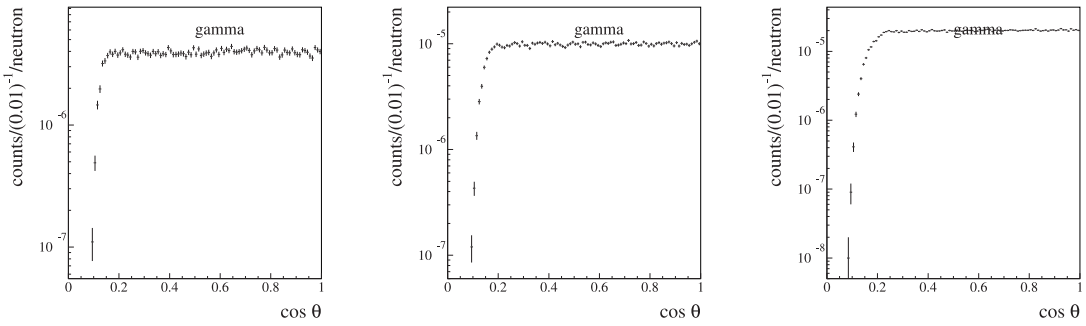

Figure 12: Photon angular distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.

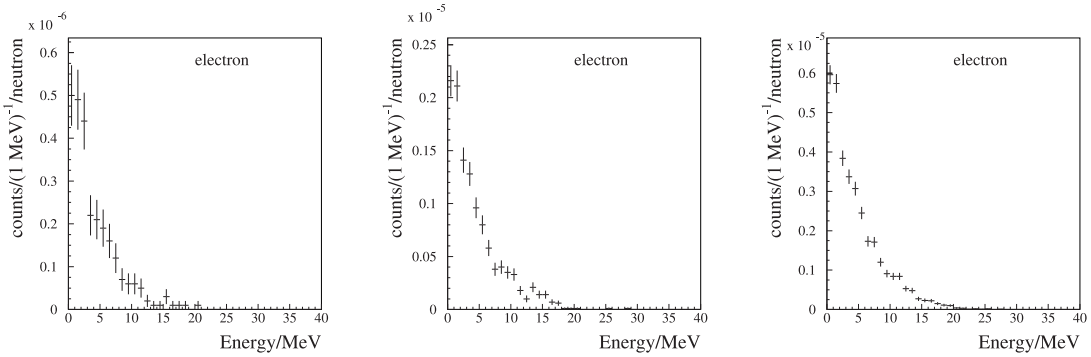

Figure 13: Electron-energy distribution for several PE target thicknesses: left: 2 mm, center: 5 mm, right: 10 mm.

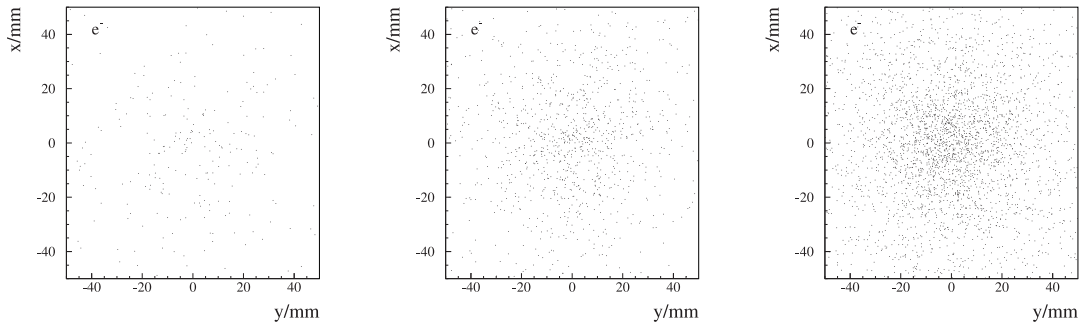

Figure 14: Electron space distribution for several PE target thicknesses: left: 2 mm, center: 5 mm, right: 10 mm.

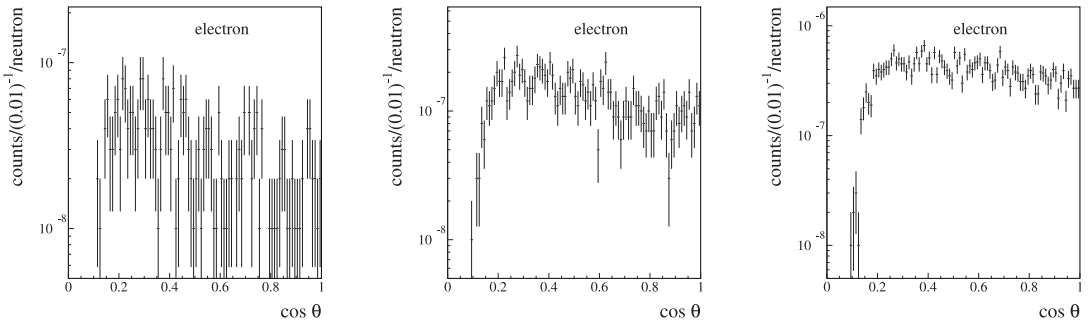

Figure 15: Electron angular distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.

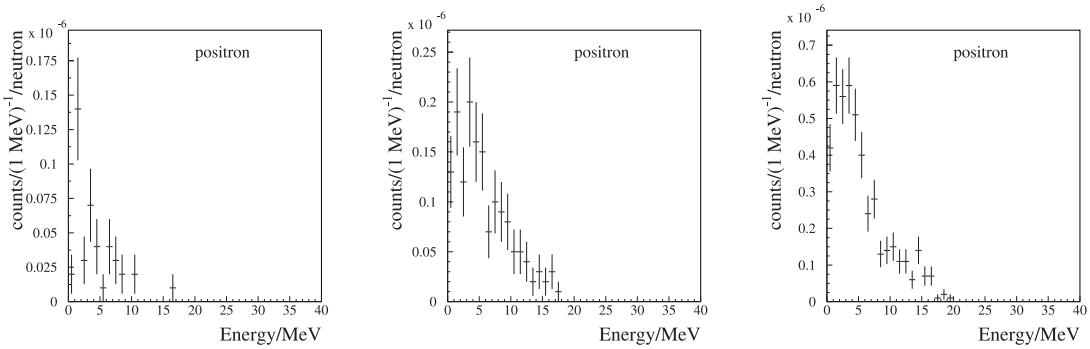

Figure 16: Positron-energy distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.

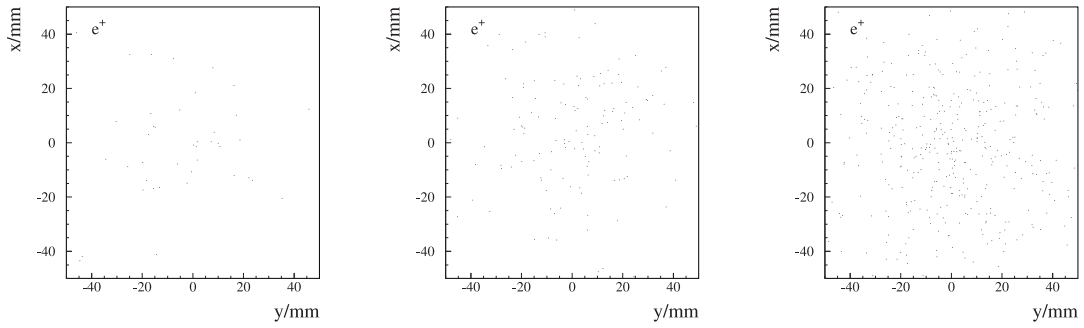

Figure 17: Positron space distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.

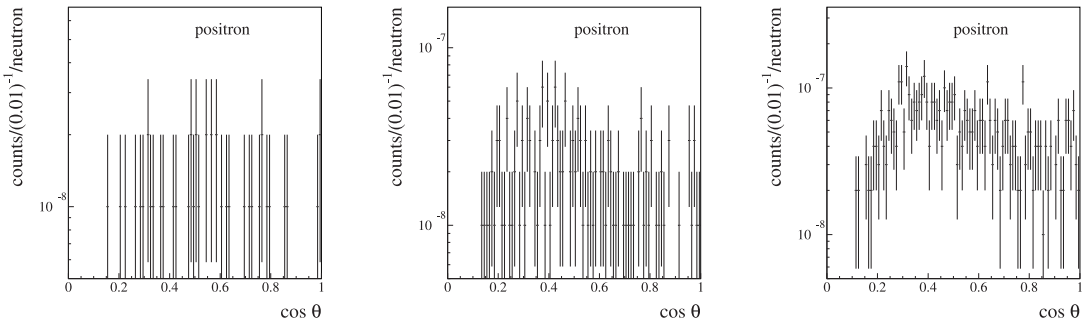

Figure 18: Positron angular distribution for several PE target thicknesses: top left: 2 mm, center: 5 mm, right: 10 mm.