New Monte Carlo Tool for polarimetry
Introduction of Polarization in Geant4

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Outline

Motivation

Polarization into Geant4

Existing Monte Carlo codes

Implementation

Stokes parameter

Matrix formalism

Implementation into Geant4

Applications

Compton scattering

Pair production

Summary

Motivation

Geant4:

- is a toolkit for the simulation of the passage of particles trough matter

Why do we study polarized interactions?

- Target studies
  i.e. if a polarized beam hits a target
- Polarimetry
  i.e. if polarization causes observable azimuthal correlations

Where can we study polarized processes?

- Polarized Positron source for an International Linear Collider
- Demonstration experiment E166 at SLAC

Existing Monte Carlo codes

- EGS, *polarization extension by K. Flöttmann*
  - considers polarization transfer only
  - simulates Pair production, Bremsstrahlung, Compton
  - suitable for target studies
- Geant3, *polarization extension by P. Schüler*
  - concentrates on asymmetries
  - simulates Bremsstrahlung, Compton (polarized target)
  - suitable for compton polarimetry
- Geant4
  - low-energy Compton scattering of linear polarized photons
- Geant4, *new polarization extension*
  - aim for a complete treatment polarization
  - polarization transfer and asymmeteries
  - suitable for polarimetry and target studies

TARGET

Gammas:

- GammaConversion
- ComptonScattering
- PhotoElectricEffect

Electrons and Positrons:

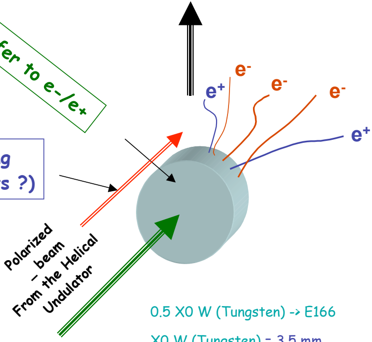
- MultipleScattering
- Ionization
- Bremsstrahlung

Polarization transfer to e-/e+

Diagnostics (Polarimetry)
Cross sections polarization dependent

- Compton Scattering
- Bhabha Scattering
- Moller Scattering
- Positron annihilation in Flight
- ....

Polarization tracking (depolarization effects ?)



0.5 X0 W (Tungsten) -> E166

X0 W (Tungsten) = 3.5 mm

MAGNETIC FIELD:

G. Stokes, Trans. Cambridge Phil. Soc. **9** (1852) 399

Stokes parameter

Wave function :

$$\Psi(\boldsymbol{x}, t) = a_1 \Psi_1 + a_2 \Psi_2$$

Jones vector :

$$|a_1|^2 + |a_2|^2 = 1 \qquad \boldsymbol{a} = \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

$$\sigma_1 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$\sigma_2 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$\sigma_3 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

Spin density matrix :

$$\rho = \boldsymbol{a} \otimes \boldsymbol{a}^* = \begin{pmatrix} a_1 a_1^* & a_1 a_2^* \\ a_2 a_1^* & a_2 a_2^* \end{pmatrix} = \frac{1}{2}(1 + \boldsymbol{\xi\sigma})$$

Stokes parameter :

$$\boldsymbol{\xi} = \begin{pmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \end{pmatrix} = \boldsymbol{a}^\dagger \boldsymbol{\sigma}\, \boldsymbol{a}$$

Matrix formalism

W. H. McMaster, Rev. Mod. Phys. **33** (1961) 8

$$\begin{pmatrix} I \\ \xi \end{pmatrix} = T \begin{pmatrix} I_0 \\ \xi_0 \end{pmatrix}$$

Transformation Matrix :

$$T = \begin{pmatrix} S & A_1 & A_2 & A_3 \\ P_1 & M_{11} & M_{21} & M_{31} \\ P_2 & M_{12} & M_{22} & M_{32} \\ P_3 & M_{13} & M_{23} & M_{33} \end{pmatrix}$$

- Differential cross section
- Asymmetry
- Polarization
- Depolarization and polarization transfer

Implementation into Geant4

`G4DynamicParticle`

`thePolarization`

`G4VPhysicalVolume`

Geant4 status:

- particle polarization exists
- no material polarisation
- no polarized processes

`G4VDiscreteProcess`

`PostStepDoIt()`

`G4VContinousDiscreteProcess`

`AlongStepDoIt()`

`PostStepDoIt()`

`G4VRestDiscreteProcess`

`AtRestDoIt()`

Implementation into Geant4

G4DynamicParticle
- thePolarization

G4VPhysicalVolume

G4VDiscreteProcess
- G4ComptonScattering
- G4GammaConversion

G4VContinousDiscreteProcess
- G4eIonisation
- G4eBremsstrahlung
- G4MultipleScattering

G4VRestDiscreteProcess
- G4eplusAnnihilation

Geant4 status:

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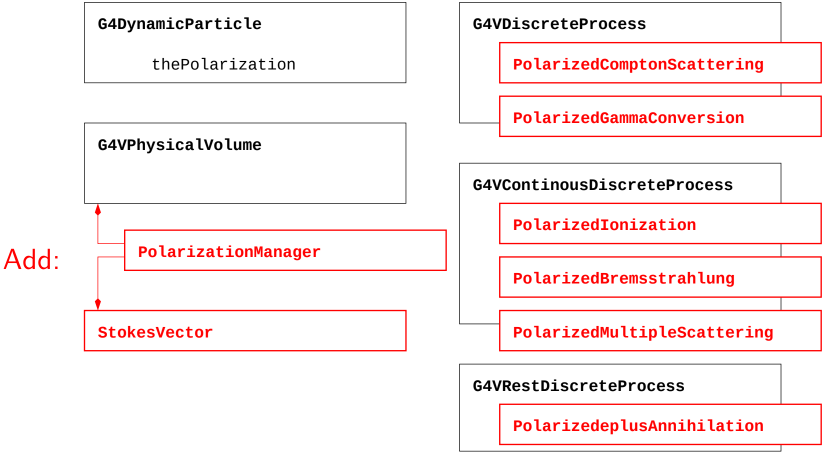
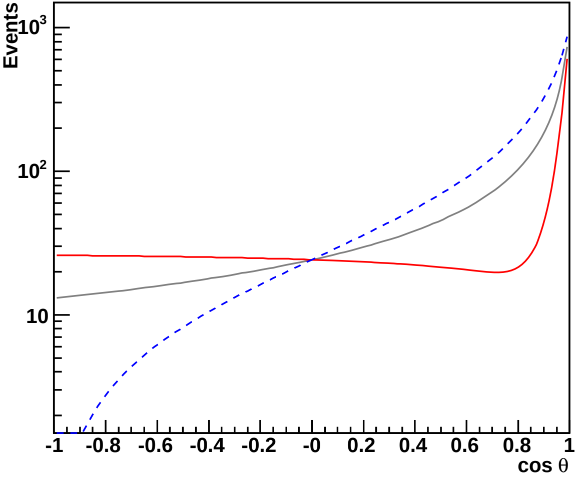
Implementation into Geant4



Compton scattering – Asymmetry

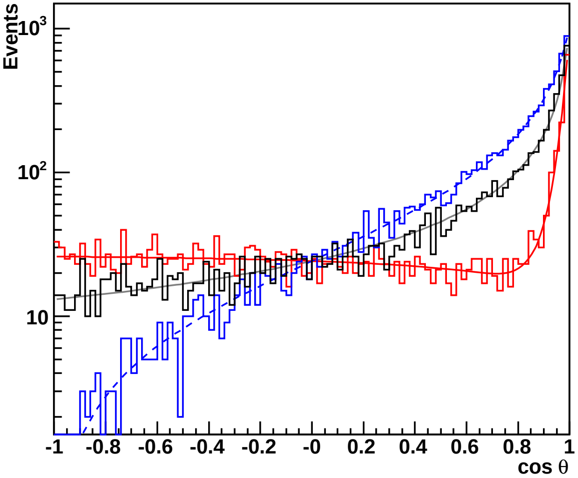


$P_\gamma \cdot P_e = +1$

$P_\gamma \cdot P_e = -1$

$P_\gamma \cdot P_e = 0$

Compton scattering – Asymmetry



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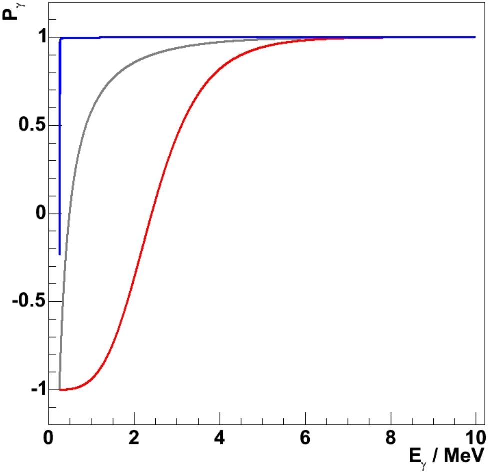
Compton scattering – Polarization transfer

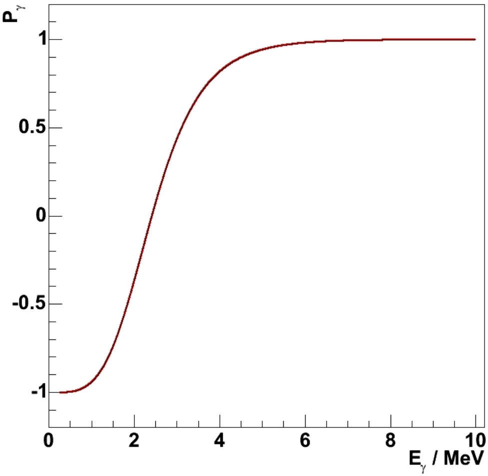


$P_1 \cdot P_2 = +1$

$P_1 \cdot P_2 = -1$

$P_1 \cdot P_2 = 0$

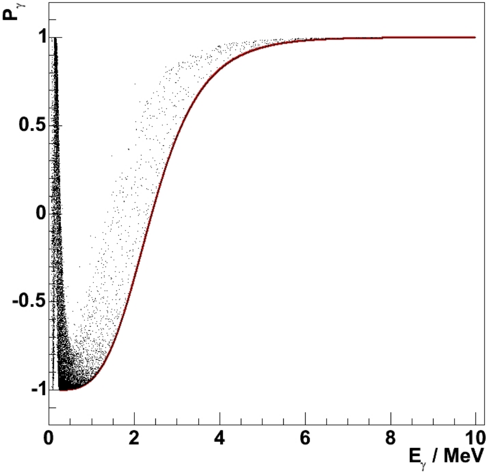
Compton scattering – Polarization transfer



$P_1 \cdot P_2 = +1$

single scattering

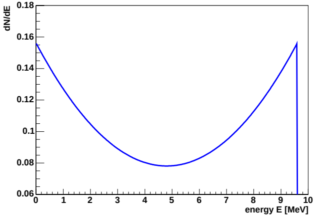
Compton scattering – Polarization transfer

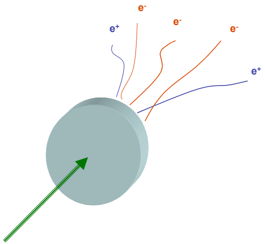


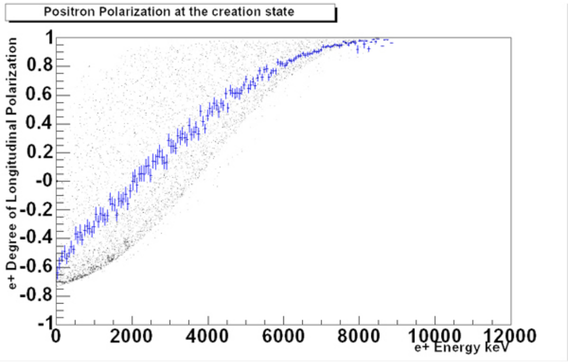
$$P_1 \cdot P_2 = +1$$

multiple scattering

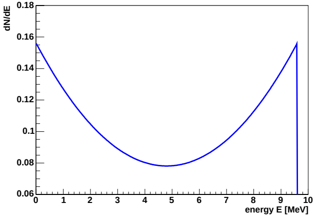
Pair production

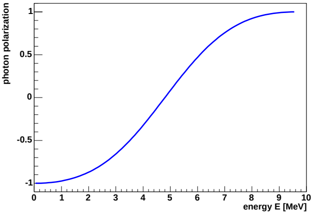


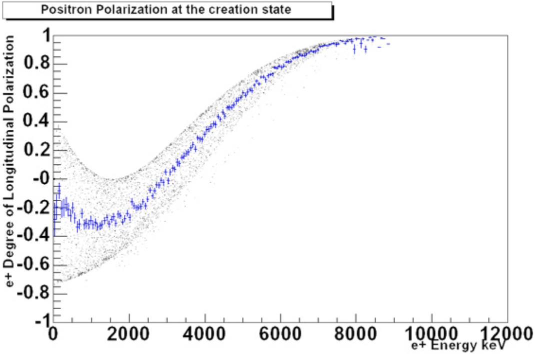




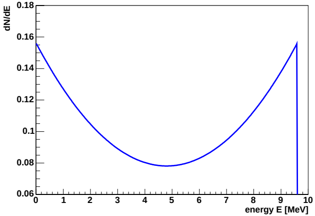
Pair production

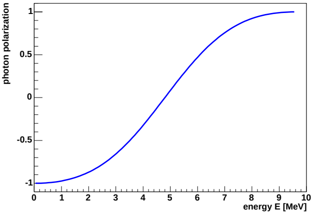


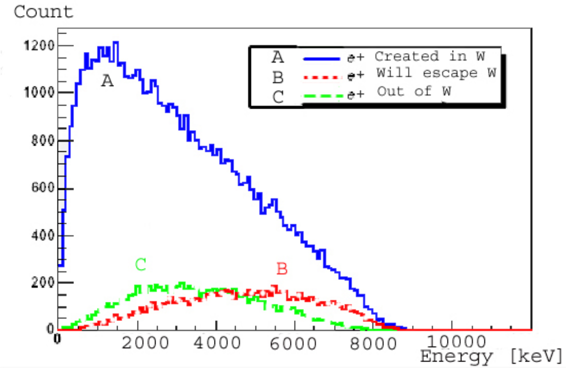




Pair production







Summary & Outlook

- Continue the implementation in Geant4
  - using matrix formarlism
  - first concentrate on E166 needs
- Carefull test of routines
  - checks with analytic formulas
  - comparison with EGS (polarisation transfer)
- Application to physics studies
  - analysis of E166 data
  - study of ILC polarimetry

G4 polarization group:

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