

Models for low-energy gamma elastic scattering

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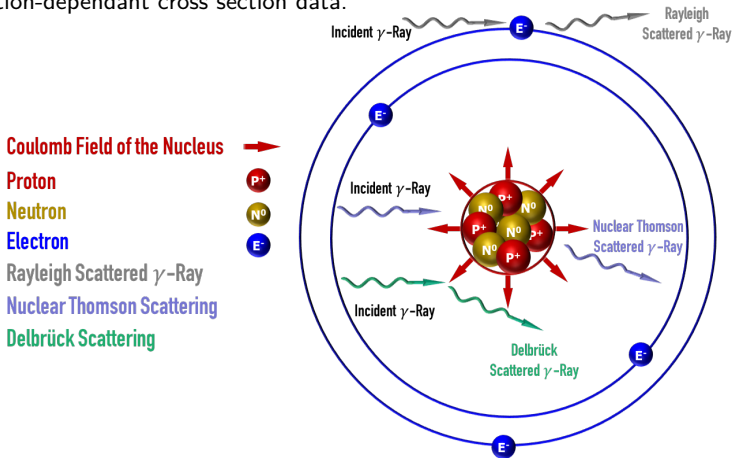
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Elastic Scattering of γ -rays

Elastic Scattering should:

- Include all effective contributing scattering processes.
- Superimpose the processes coherently.
- Polarization-dependant cross section data.



Differential Cross Section

Differential cross section:

- Differential cross section can be calculated from the scattering amplitudes:

$$\frac{d\sigma}{d\Omega} = |A|^2$$

Scattering amplitudes

- Rayleigh scattering amplitudes: calculated from scattering matrix for K-, L-, and M-shells.
- Delbrück scattering amplitudes: interpolated from lowest-order Born approximation data.
- Nuclear Thomson amplitudes: calculated from analytical form.

Superimposing Coherently:

- All amplitude (real and imaginary) are superimposed coherently.
- The whole angular domain is considered.

Polarization effects:

- Stokes parameter formalism with transformation matrix.

Transformation matrix

Stokes formalism requires transformation matrix. The differential cross section can be written in terms of transformation matrix \mathcal{T} as:

$$d\sigma = \xi'^T \mathcal{T} \xi$$

$$\text{with } \mathcal{T} = \frac{1}{4} \begin{pmatrix} (|A_{\parallel}|^2 + |A_{\perp}|^2) & (|A_{\parallel}|^2 - |A_{\perp}|^2) & 0 & 0 \\ (|A_{\parallel}|^2 - |A_{\perp}|^2) & (|A_{\parallel}|^2 + |A_{\perp}|^2) & 0 & 0 \\ 0 & 0 & (A_{\parallel} A_{\perp}^* + A_{\parallel}^* A_{\perp}) & i(A_{\parallel}^* A_{\perp} - A_{\parallel} A_{\perp}^*) \\ 0 & 0 & i(A_{\parallel} A_{\perp}^* - A_{\parallel}^* A_{\perp}) & A_{\parallel} A_{\perp}^* + A_{\parallel}^* A_{\perp} \end{pmatrix}$$

$$\xi = \begin{pmatrix} 1 \\ \xi_1 \\ \xi_2 \\ \xi_3 \end{pmatrix} \text{ normalized Stokes vector of the incident beam.}$$

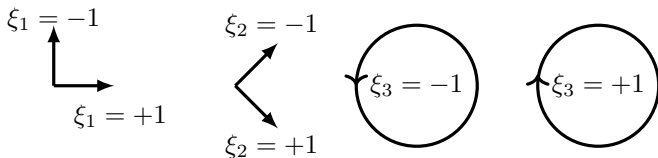
$$\xi' = \begin{pmatrix} 1 \\ \xi'_1 \\ \xi'_2 \\ \xi'_3 \end{pmatrix} \text{ normalized Stokes vector of the scattered beam.}$$

Convention of Stokes parameters

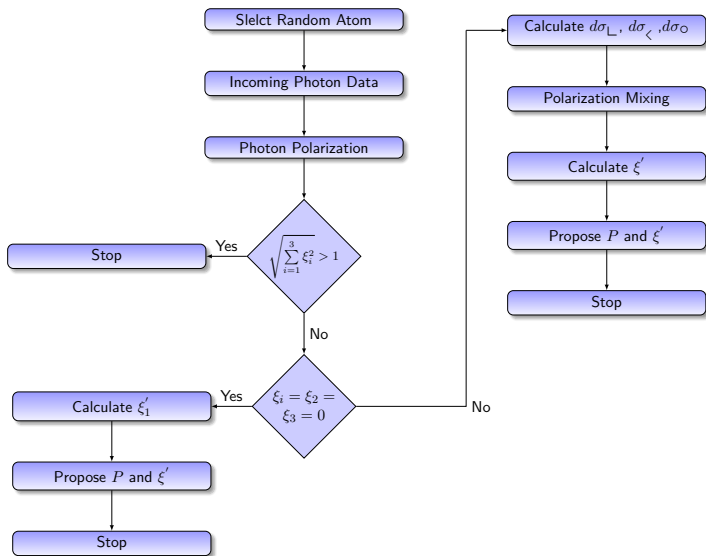
Physics Reference Manual, Release 10.6

	Photons	Electrons
ξ_1	linear polarization	polarization in x direction
ξ_2	linear polarization but $\pi/4$ to right	polarization in y direction
ξ_3	circular polarization	polarization in z direction

Other states of polarization can be realized by combining the three parameters.



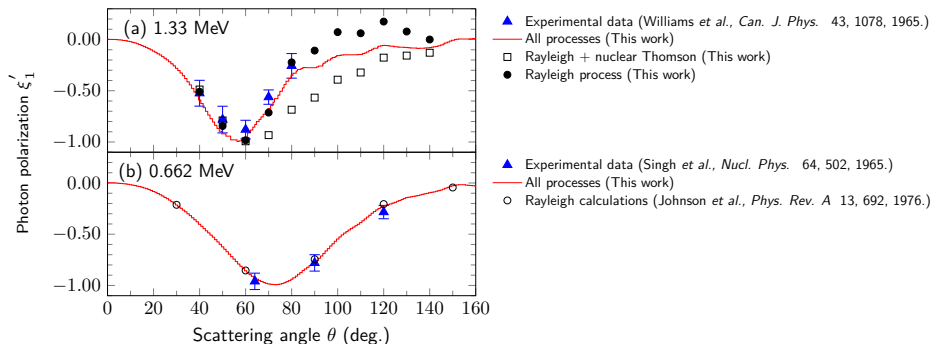
Sampling secondaries



Scattered Photon Polarization

Polarization caused by elastic scattering:

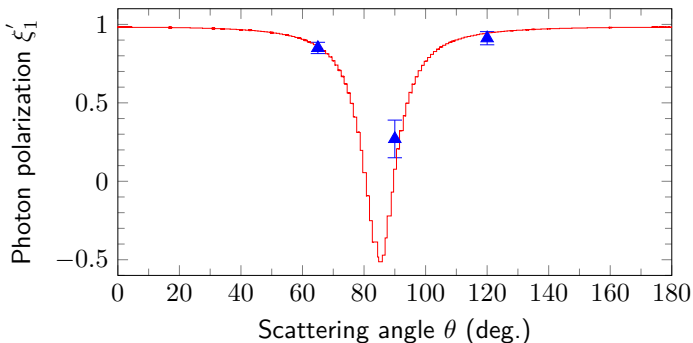
- Elastic scattering works as a perfect polarizer for γ -rays ($\xi' = -1$).
- At lower energy (0.662 MeV), Rayleigh scattering is dominant.
- At higher energy (1.33 MeV), Delbrück and nuclear Thomson must be included.
- The simulation model results agree with the measured polarization of the scattered photons.



Polarization transfer

Strong depolarization:

- Strong depolarization is obtained when the incident photon has ($\xi = 0.9802$).
- Polarization transfer makes the scattered photon having ($\xi' = -0.27$) at 90° .
- Again, the simulation model results agree with the measured polarization of the scattered photons, reported by Blumenhagen *et al.*, *New J. Phys.*, 18, 103034, 2016.



Geant4 Releases

Two simulation models of elastic scattering have been included in Geant4 Official Release:

- G4JAEAElasticScatteringModel: From Geant4-10.5 (December 2018).
- G4JAEAPolarizedElasticScatteringModel: From Geant4-10.7-beta (June 2020).

Physics Reference Manual

G4

10.5

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Elastic Scattering

Elastic scattering of gammas can involve Rayleigh, nuclear Thomson and Delbrück scattering. The Rayleigh process in GEANT4 can be simulated with either the Penelope ([Penelope Models](#)) or Livermore models ([Low Energy Livermore Model](#)). A more detailed model involving atomic and molecular interactions is included as a JAEA model ([JAEA Elastic Scattering Model](#)). These specific implementations are described in more detail below.

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Summary and Outlook

- Summary
 - A new EM process accounting for polarization effects of γ -ray elastic scattering was implemented.
 - The process can handle an arbitrary state of polarization of the incident beam and correspondingly transfer polarization to the scattered beam.
 - Validation of the process using experimental data was realized.
- Outlook
 - Extending validation over different Z and E (new experiments).
 - Extending the energy range of the process (new calculations).
 - Take the target polarization into account (new physics).
- Notice: Some events of Polarized Compton Scattering resulted in non-unit polarization vectors.