Models for low-energy gamma elastic scattering

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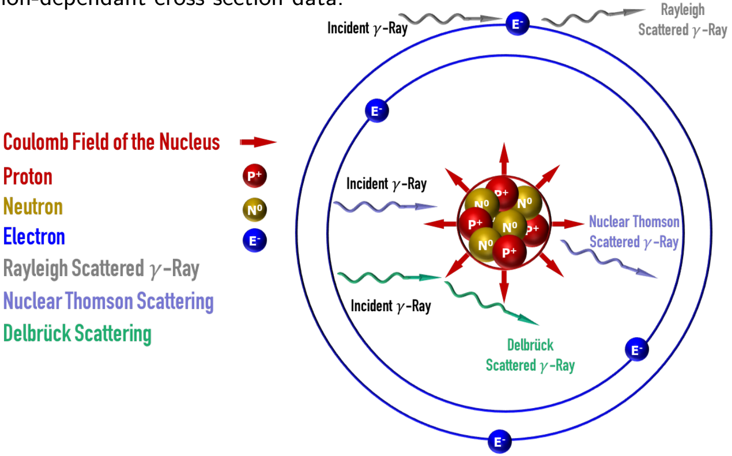
Elastic Scattering of γ-rays

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:

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

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

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

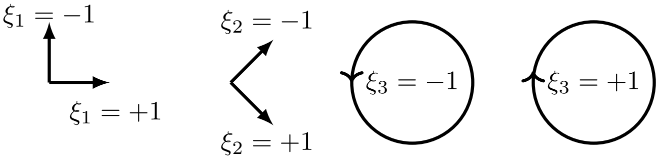
$$\xi^{'} = \begin{pmatrix} 1 \\ \xi_1^{'} \\ \xi_2^{'} \\ \xi_3^{'} \end{pmatrix}$$ normalized Stokes vector of the scattered beam.

Convention of Stokes parameters

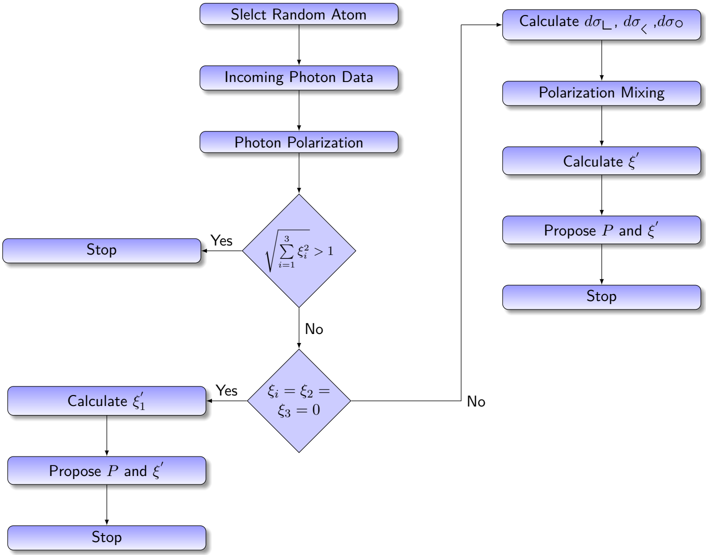
Physics Reference Manual, Release 10.6

	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.



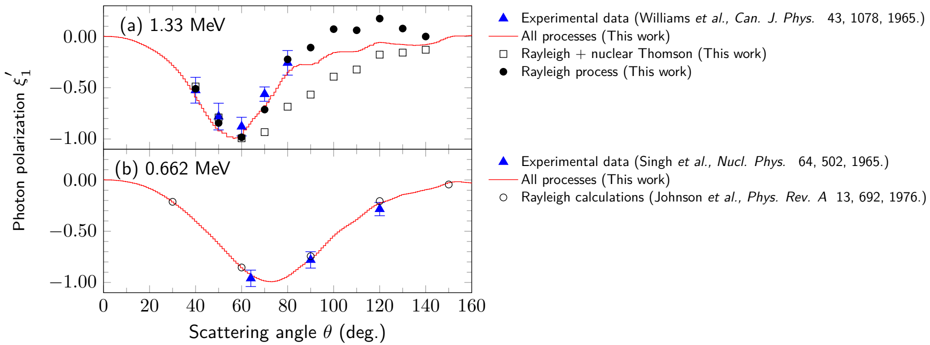
Sampling secondaries



Scattered Photon Polarization

Polarization caused by elastic scattering:

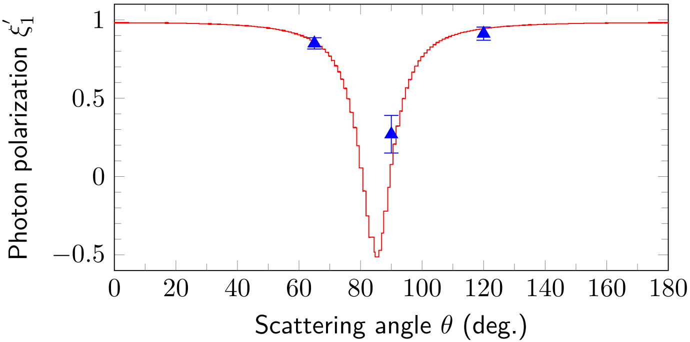
- Elastic scattering works as a perfect polarizer for γ-rays $\left(\xi' = -1\right)$.
- At lower energy (0.662 MeV), Rayleigh scattering is dominant.
- At higher energy (1.33 MeV), Delbrück and nuclear Thomson must be included.
- The simulation model results agree with the measured polarization of the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



Polarization transfer

Strong depolarization:

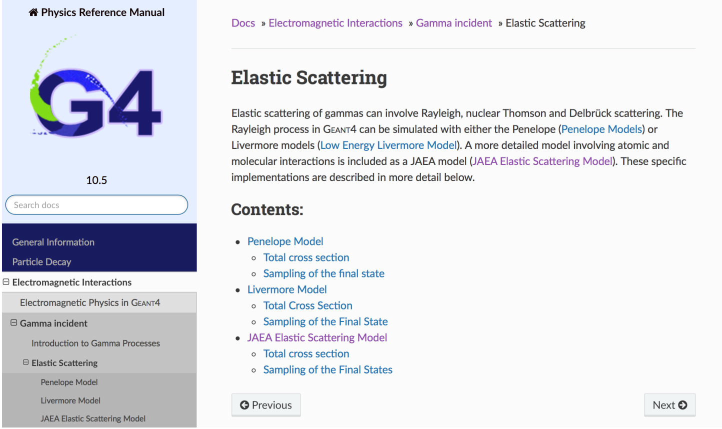
- Strong depolarization is obtained when the incident photon has $(\xi = 0.9802)$.
- Polarization transfer makes the scattered photon having $\left(\xi^{'} = -0.27\right)$ at 90°.
- Again, the simulation model results agree with the measured polarization of the scattered photons, reported by Blumenhagen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



Geant4 Releases

Tow 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).



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.