# Compton scattering on bound electrons

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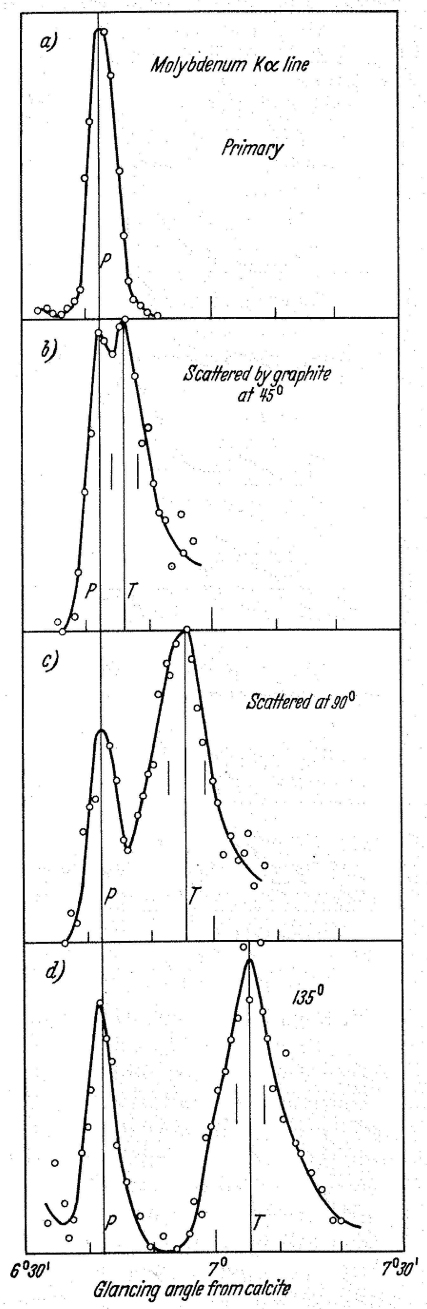
# Outline

# COMPTON SCATTERING IN MEDICAL IMAGING

- Compton scattering dominates the interaction of 511-keV gammas with the human body and still represents a sizable fraction of the energy deposition processes in the detectors.
- The effect of electron binding on Compton interaction is twofold:
  - the suppression of forward scattering angles is the most important consequence for image reconstruction algorithms,
  - the energy broadening $< 10$ keV is less important.
- Because Geant 4 has been used to generate the events for testing image reconstruction algorithms, it is the focus of the validation process.

# COMPTON SCATTERING

(A.H.Compton, PR 22 (1923) 409)



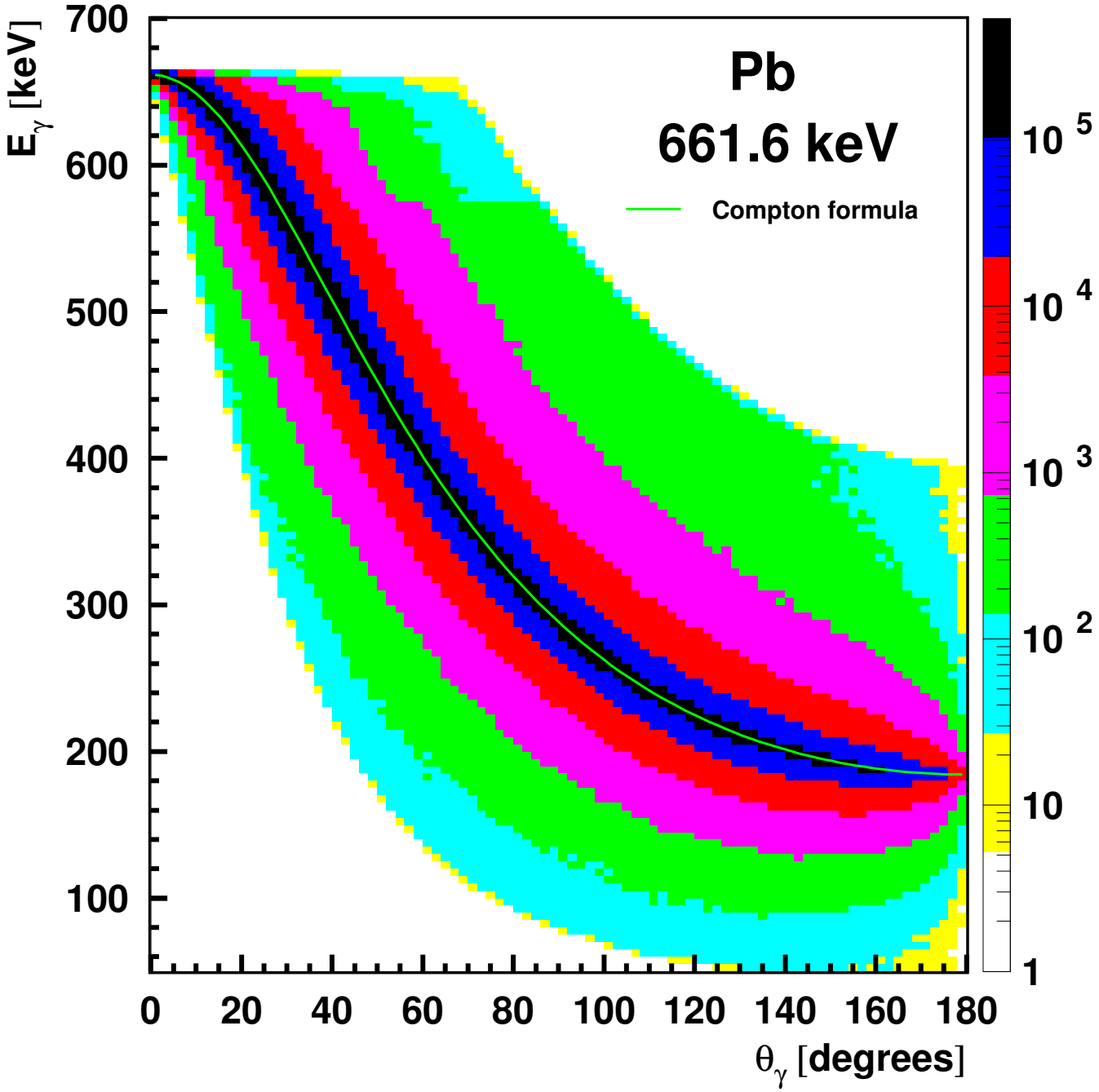

- Compton scattering is a textbook case for illustrating the corpuscalaur nature of light (A.H.Compton, PR 21 (1923) 483) and indeed played a fundamental role in establishing early quantum mechanics and Dirac's theory of the electron (O.Klein and Y.Nishina, ZP 52 (1929) 53).
- J.W.M. Du Mond first realised that the Compton profile contained information about the intrinsic linear momenta of electrons in matter (J.W.M. Du Mond, PR 33 (1929) 643).

# THE NAMITO ALGORITHM - EGS4

(Y.Namito et al., NIMA 349 (1994) 489)

1. As usual, the probability of the Compton interaction is determined by the total cross-section. If the process is selected to happen, then the final state has to be generated.
2. The photon scattering angle is sampled accordingly to the Klein-Nishina cross section multiplied by the incoherent scattering function (averaged over all atomic shells of the element).
3. The atomic shell is selected with a weight proportional to the number of contained electrons. Then the electron initial velocity component along the impinging gamma momentum is sampled accordingly to the so called Compton profile and the rest of the scattering kinematics, which is now fully fixed, calculated.

# ENERGY ANGLE CORRELATION



# IMPLEMENTATION STATUS IN GEANT

| pakage | $\sigma_t$ | $d\sigma/d\theta$ | $d^2\sigma/d\theta dE$ |
|---|---|---|---|
| Geant 3.21 std. | yes | K-N | no |
| Geant 3.21 GLECS | yes | K-N*I.S.F. | Compton profile |
| Geant 4.9.4 std. | yes | K-N | no |
| Geant 4.9.4 Livermore | yes | K-N*I.S.F. | Compton profile |
| Geant 4.9.4 Penelope | yes | K-N*I.S.F. | analy. app. |

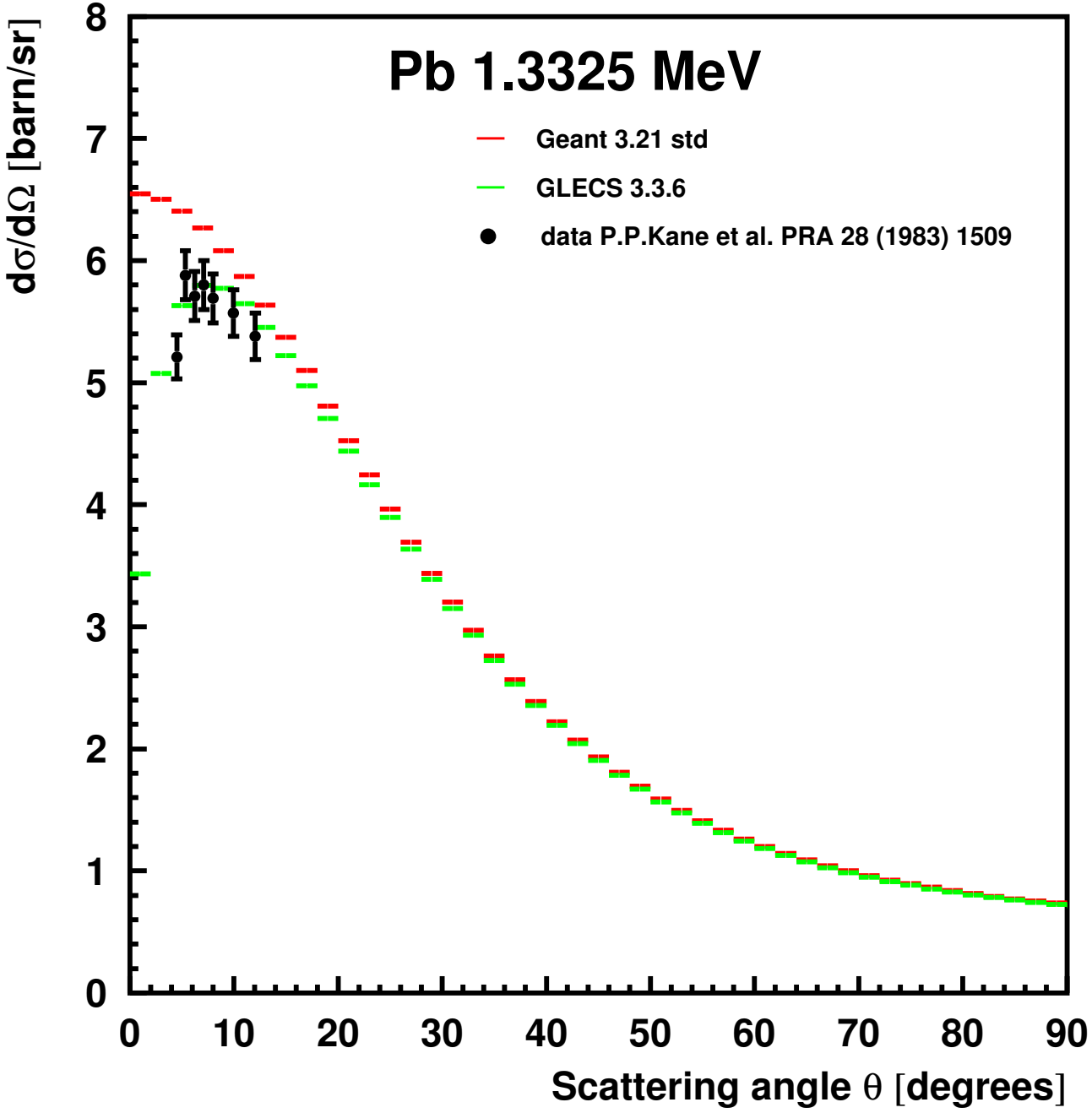
- The GLECS package (R.M.Kippen NAR 48 (2004) 221) is a full implementation of the Namito algorithm with the incoherent scattering functions (I.S.F) and the Compton profiles taken from the EPDL97 (E.Cullen et al., UCRL-50400, vol.6, rev.5). It has been developed at Los Alamos Nat. Lab. and used at NASA.
- The Geant 4 Livermore extension is also based on the EPDL97.
- The Geant 4 Penelope extension is based on Penelope 2001.

# VALIDATION WITH DATA

The search for experimental data in the literature met with two main difficulties (more than 200 papers were considered) :

- data measured to check theories of Compton scattering on bound electron are usually taken in coincidence with X-ray emission from the k shell to enhance the effects,
- whole atom data are usually taken on several targets with high precision, but measuring only one fixed angle.

# GLECS COMPTON VALIDATION



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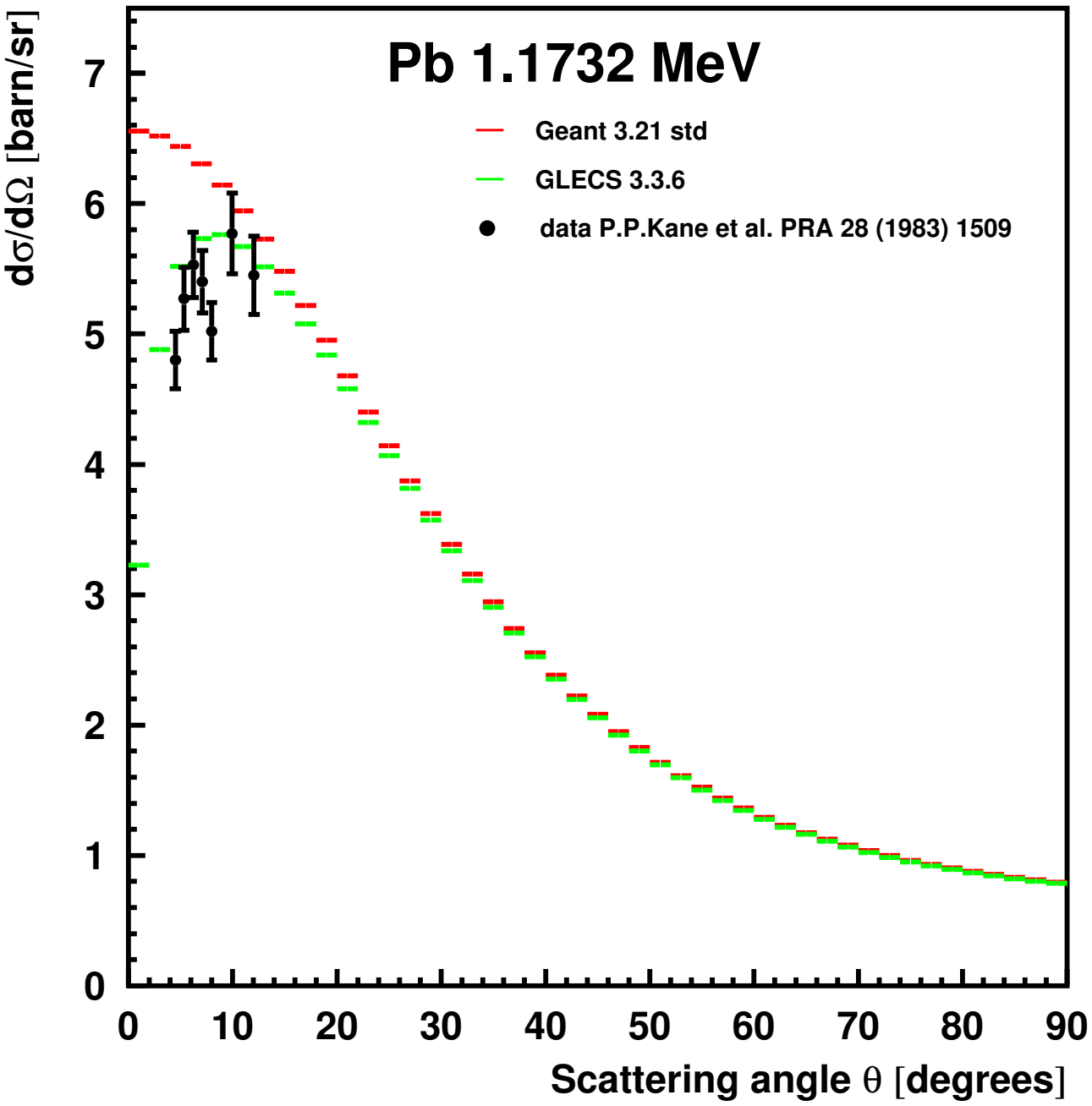

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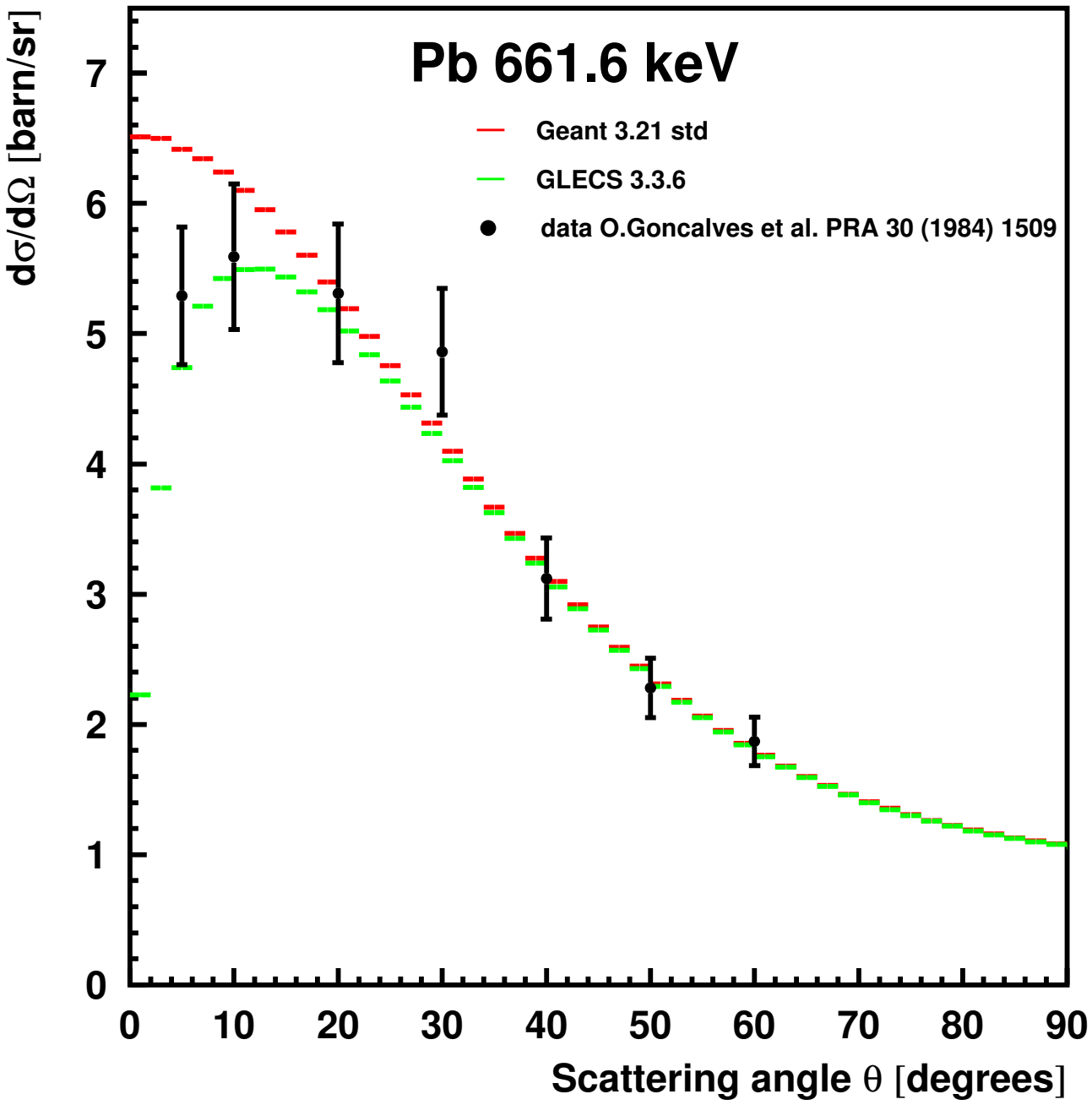

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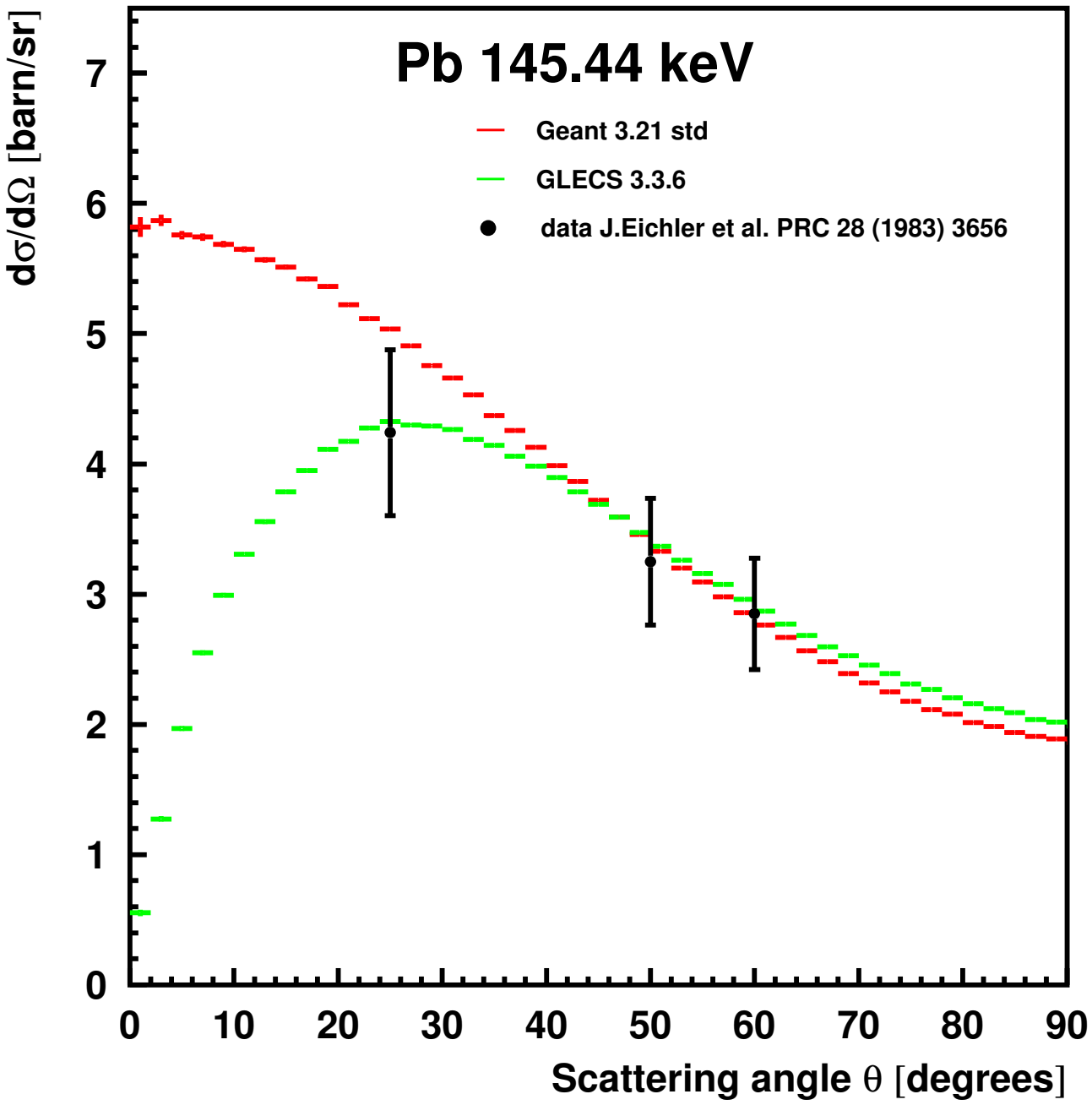

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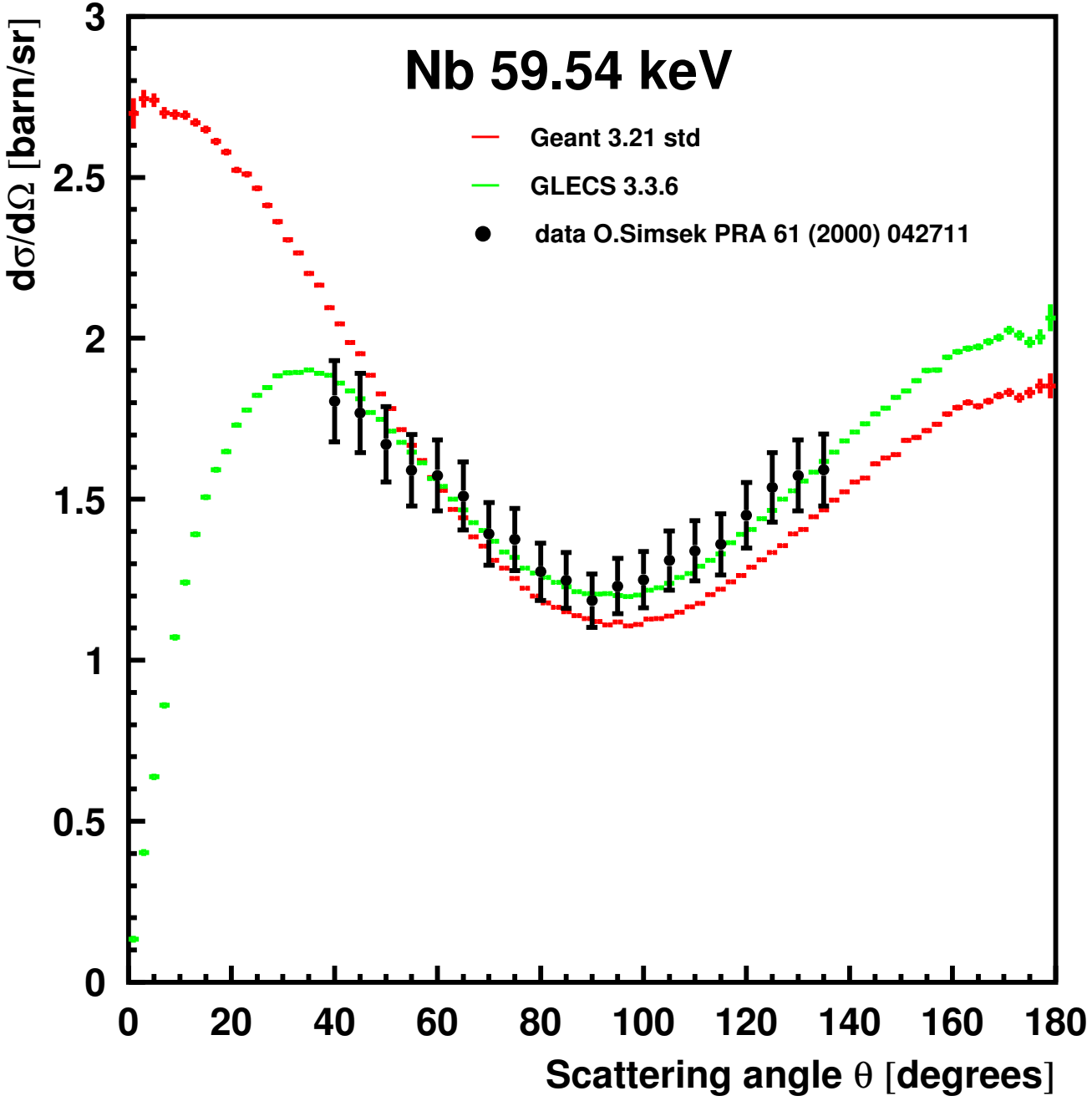
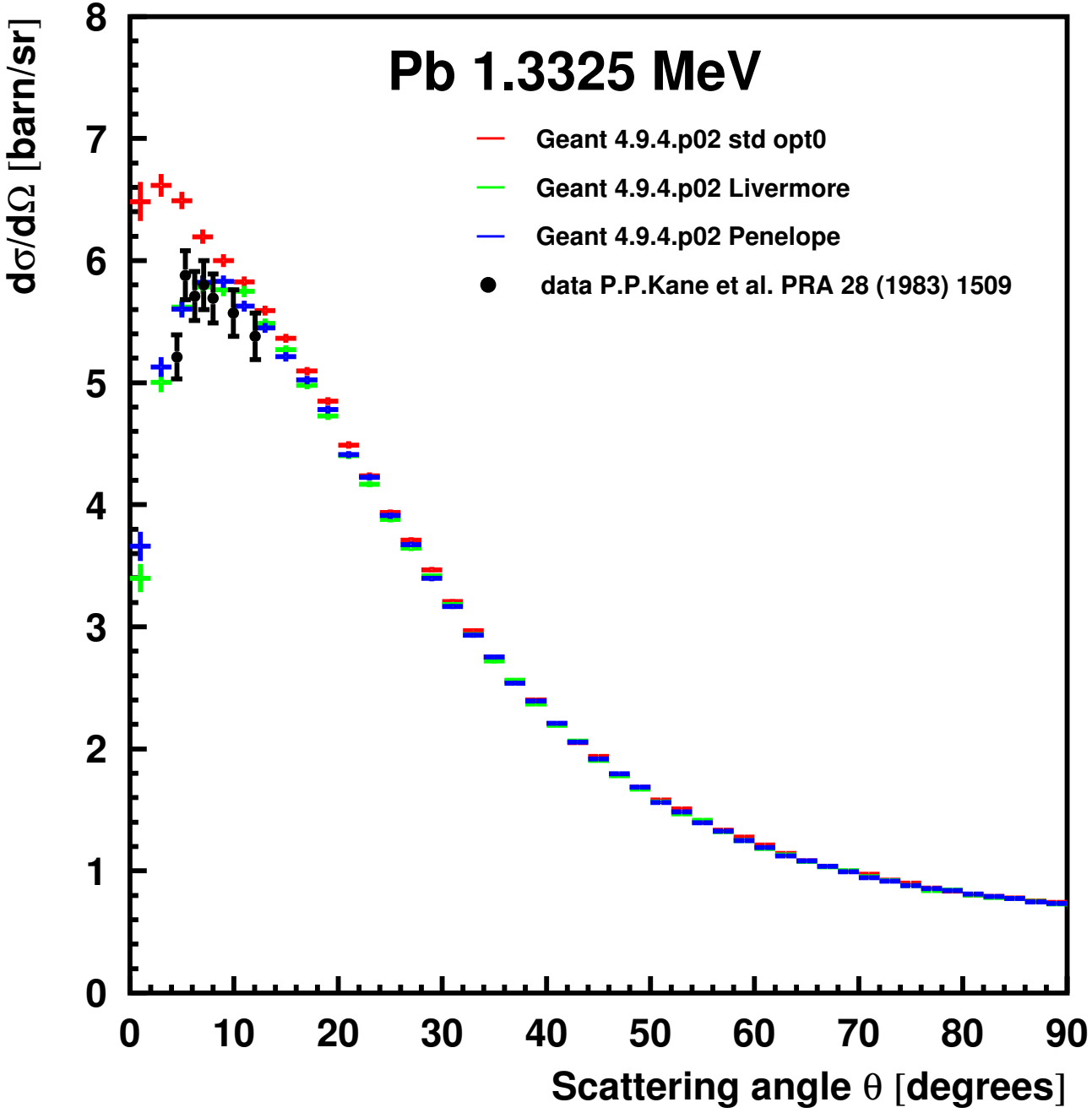


# GEANT 4 COMPTON VALIDATION



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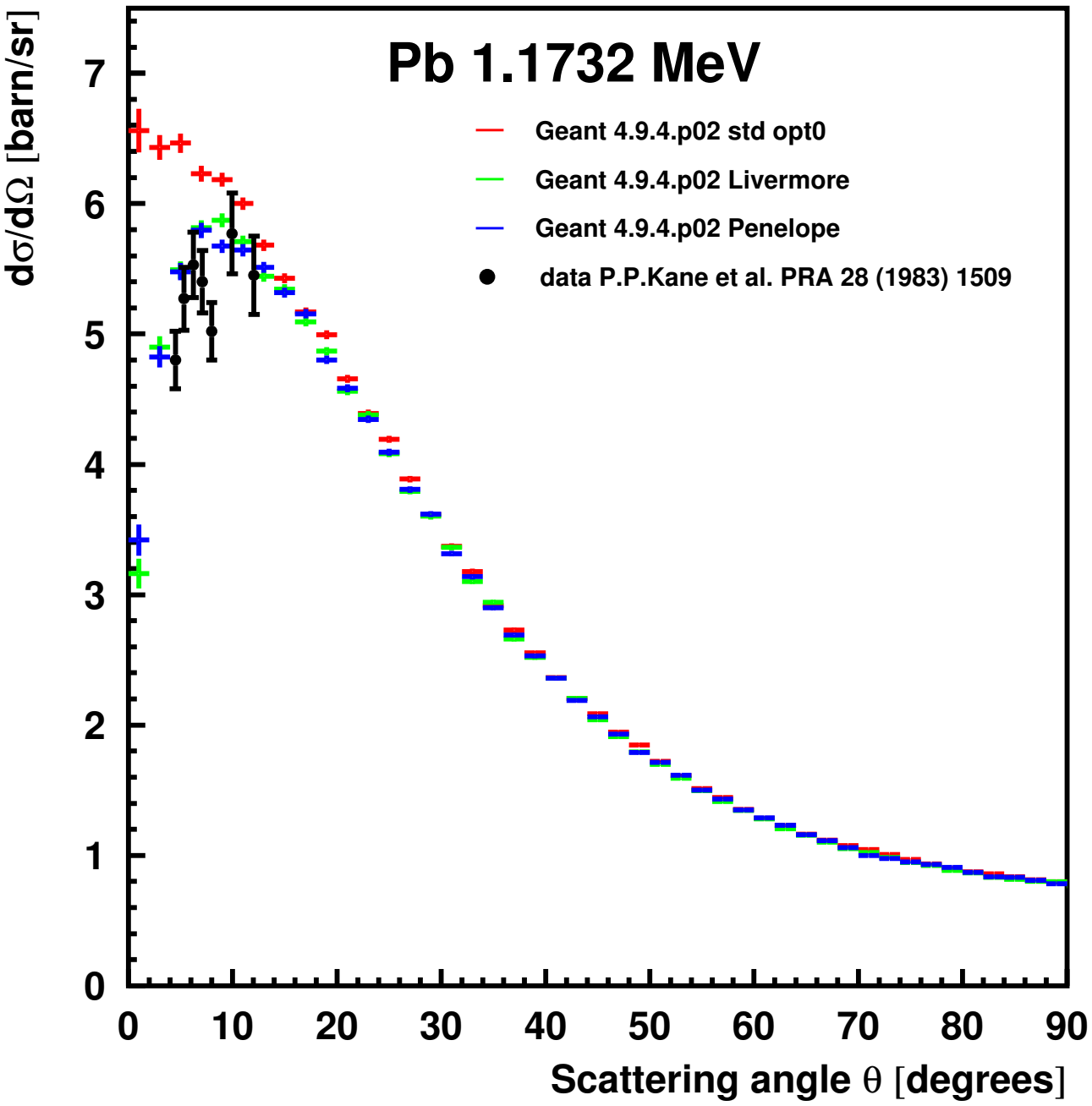

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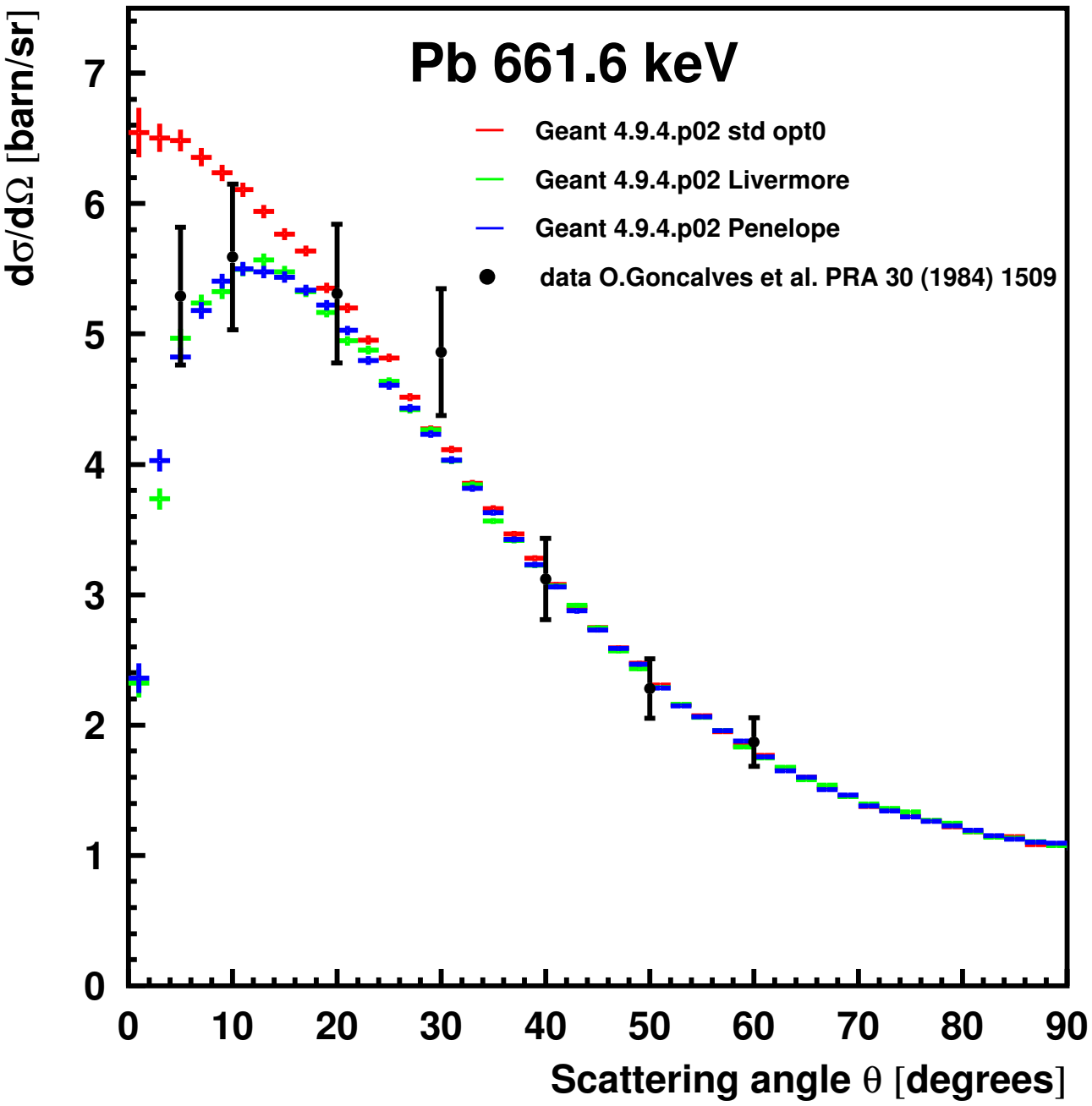

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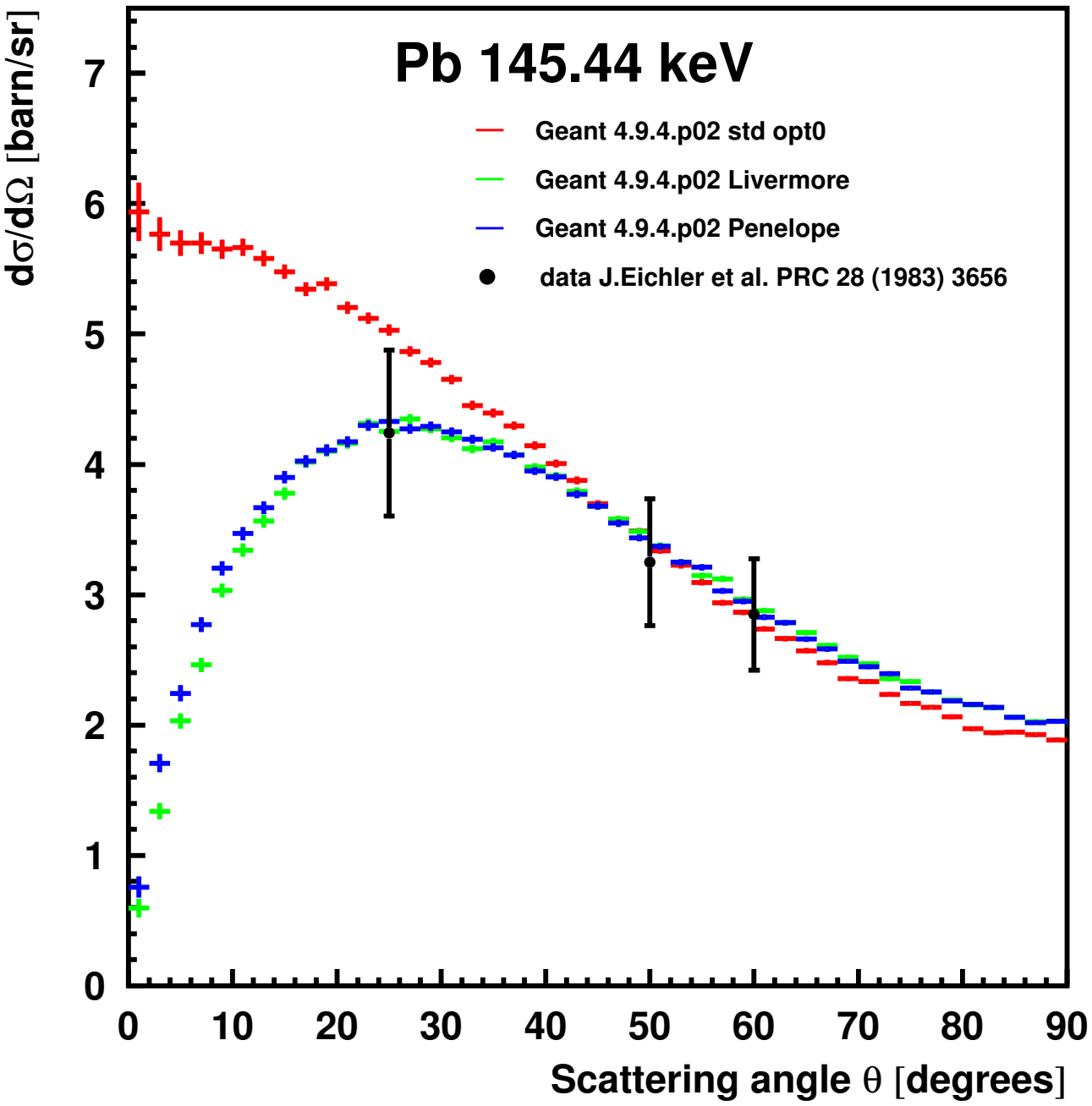

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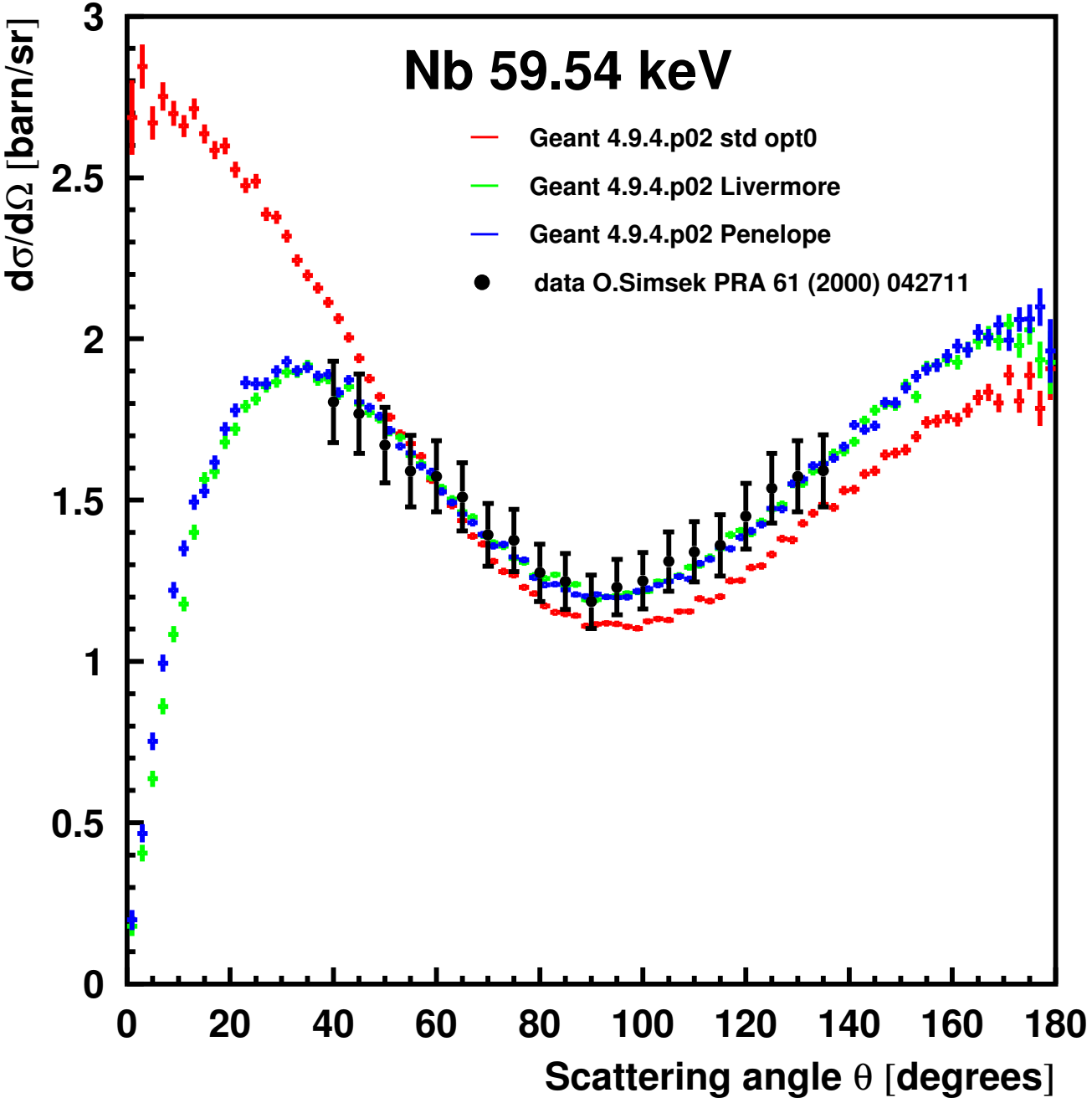
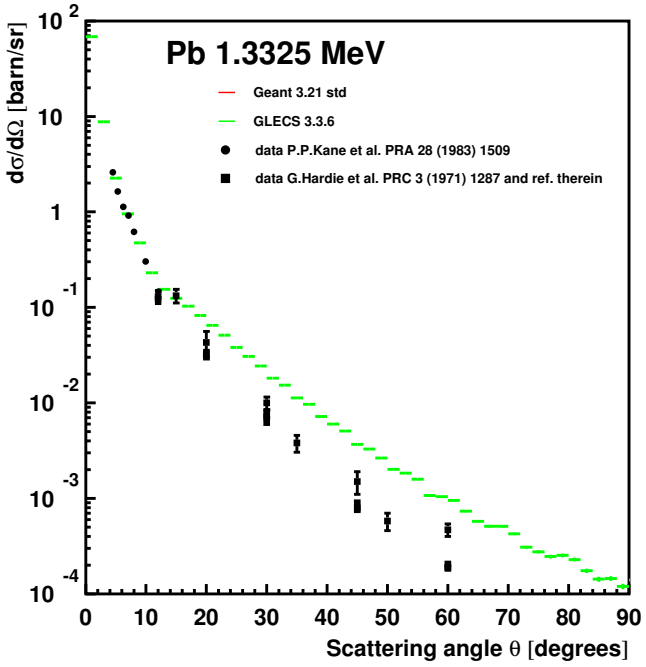
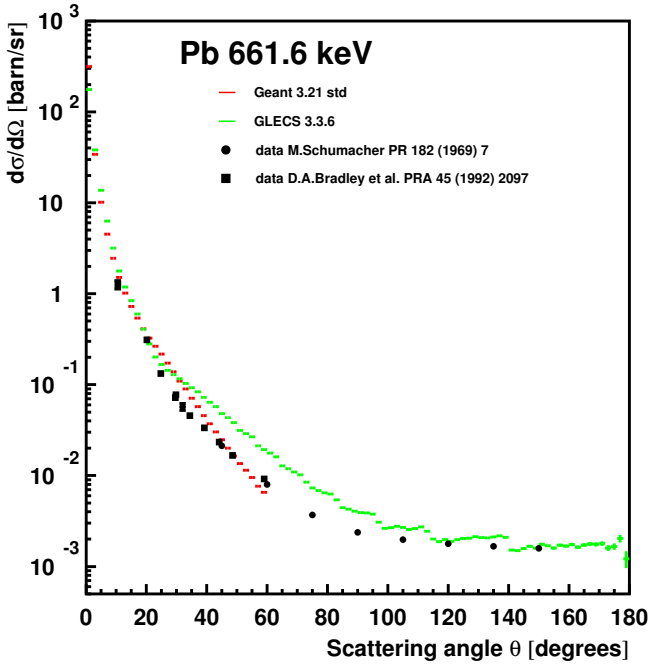
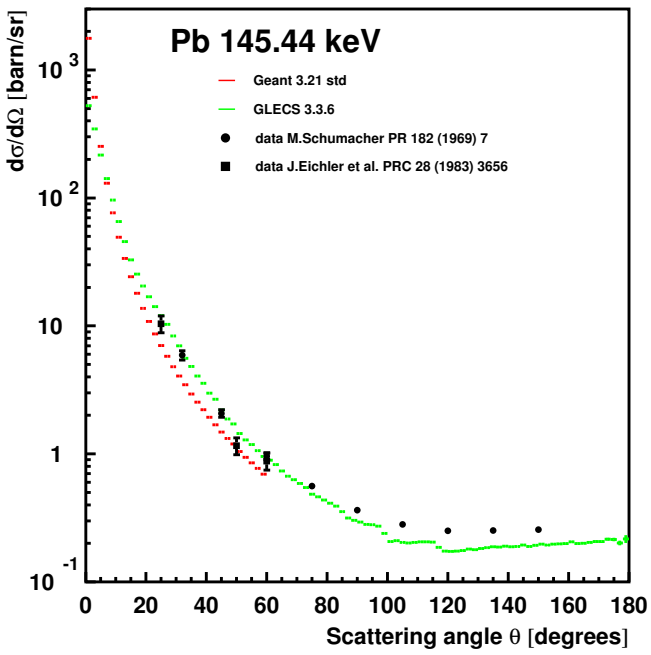
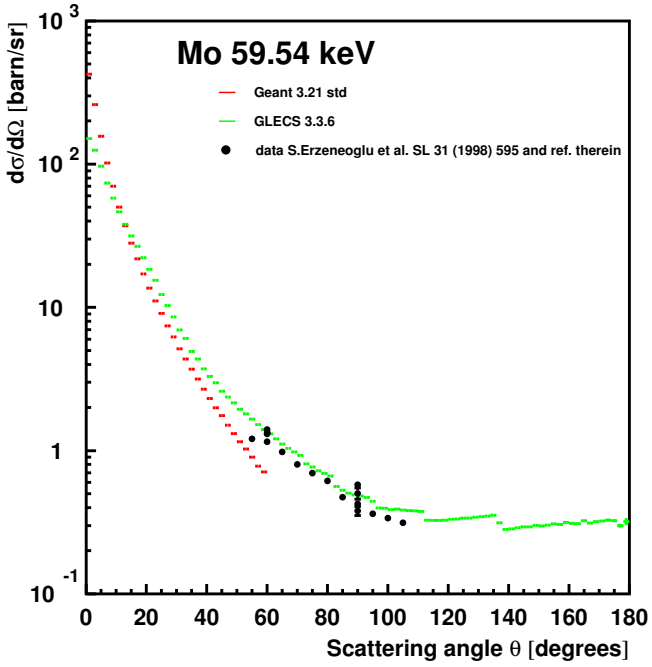


# GLECS RAYLEIGH VALIDATION



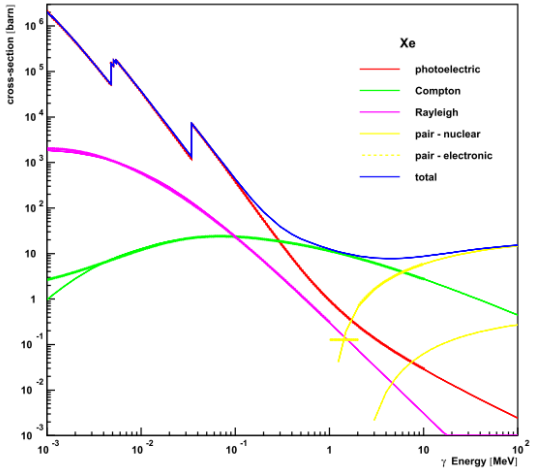
# CONCLUSIONS

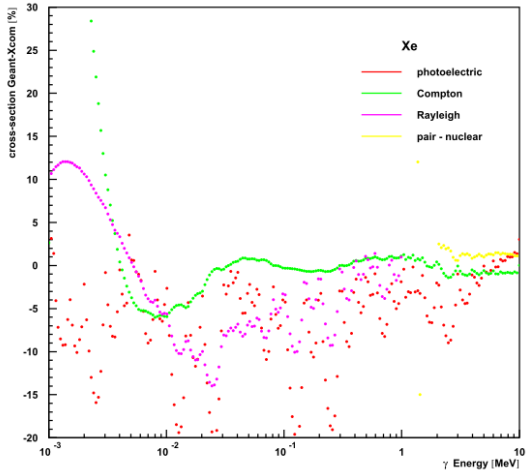
- The validation of the total cross-section with XCOM (not shown) did not reveal particular surprises: the standard versions can not be used below 10 keV and there is a disagreement between Penelope and XCOM below 10 keV.
- The validation of $d\sigma/d\theta$ with ALL AVAILABLE DATA in the literature (only a small selection has been shown) indicates that the suppression of small scattering angles is well reproduced by GLECS and by the Livermore and Penelope extensions of Geant 4.
- The validation of $d^2\sigma/d\theta dE$ (much less available data) and of Rayleigh scattering are in progress.
- The effect of the electron binding on the development of the Compton cascade in several materials and on point kernels in water have been investigated in detail (not shown).

# GLECS VALIDATION

## Xe

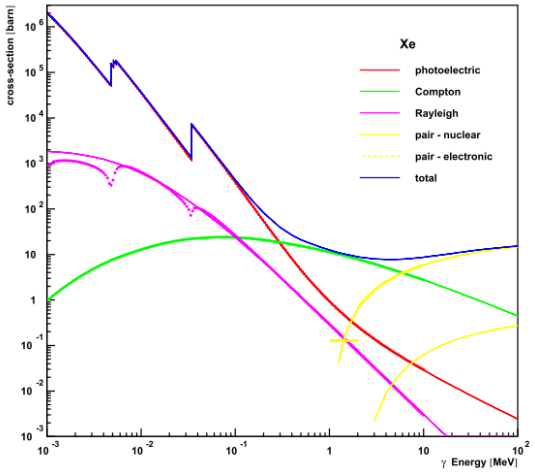
GEANT3

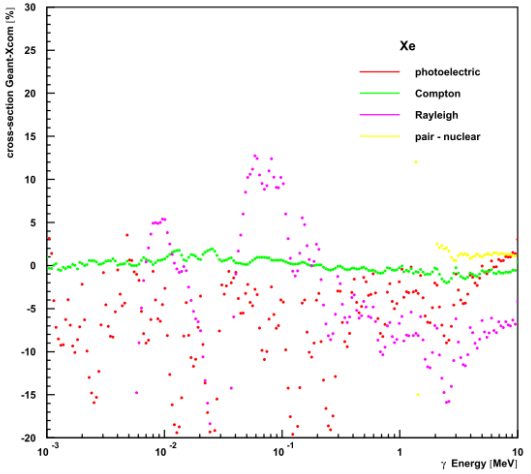


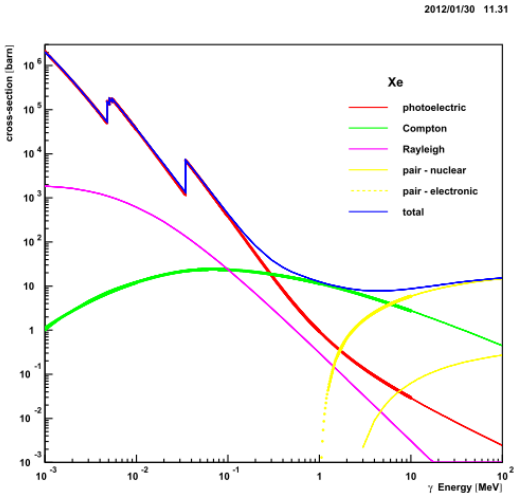



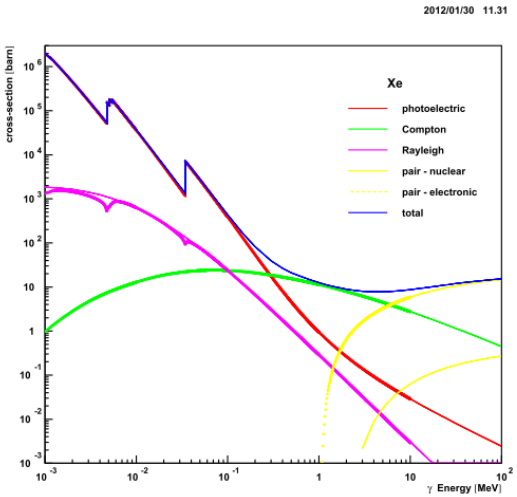

## Xe

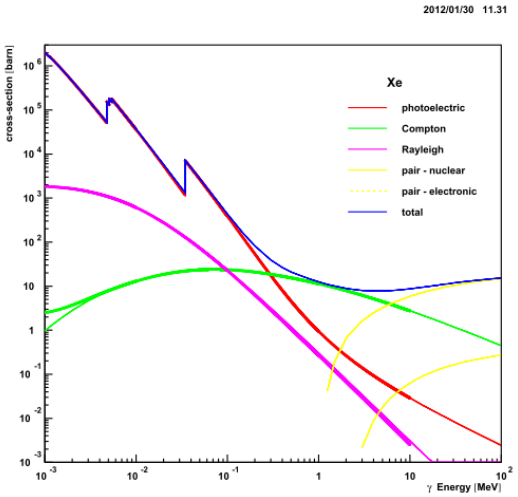
GEANT3 + GLECS

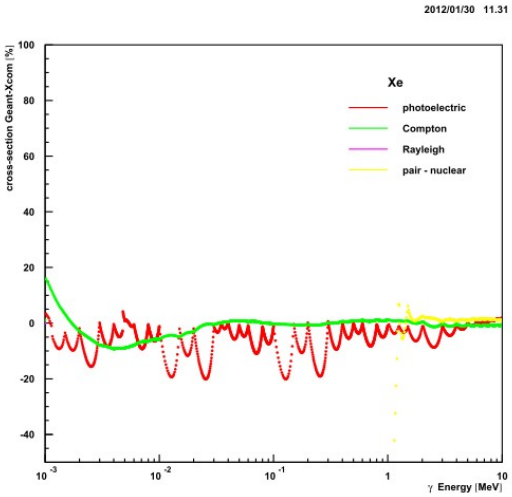


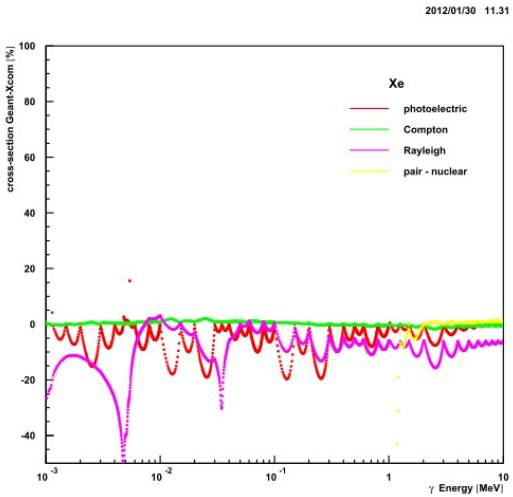



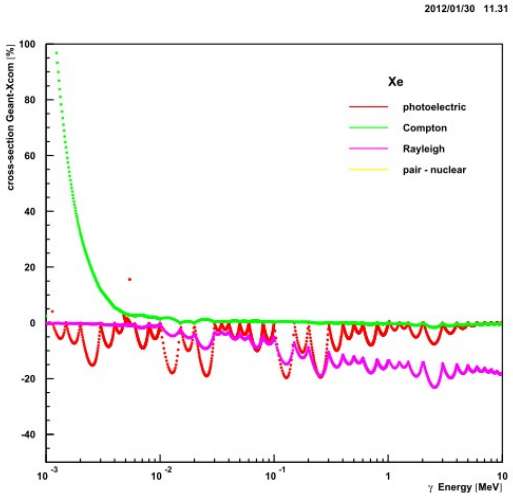












# GEANT 4 VALIDATION

**Xe** Standard_opt0 Livermore Penelope **Xe**

# GEANT 4 VALIDATION

**Pb**

**Pb**

Standard_opt0

Livermore

Penelope