

# **Incorporation of Goudsmit-Sounderson electron transport theory into Geant4**

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# Introduction

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Multiple scattering « process » of  $e^-/e^+$  through matter is mainly described with a group of theoretical models of :

- Angular distribution
- Displacement sampling
- Path length limitation

The G4GoudsmitSaunderson model use:

- Goudsmit-Saunderson → Angular distribution
- I. Kawrakow and A. Bielajew → Lewis moments → Displacement sampling
- L. Urban → Path length limitation
- L. Urban → Step limitation algorithm

As a first step the following energy-dependent parameters should be correctly implemented:

- Total elastic cross section
- First transport cross section

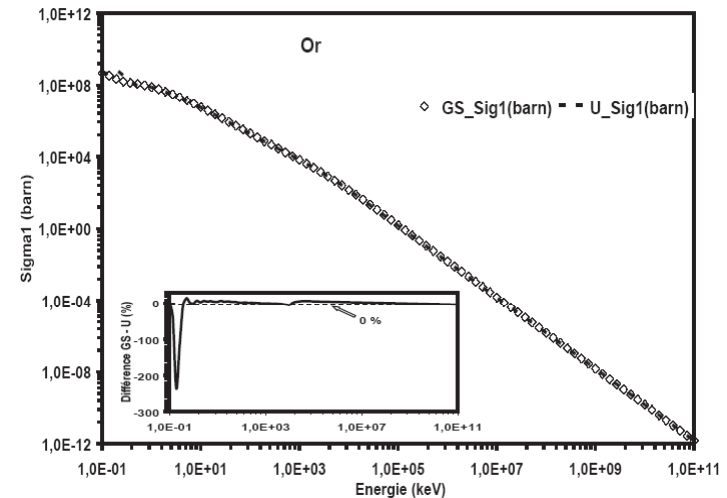
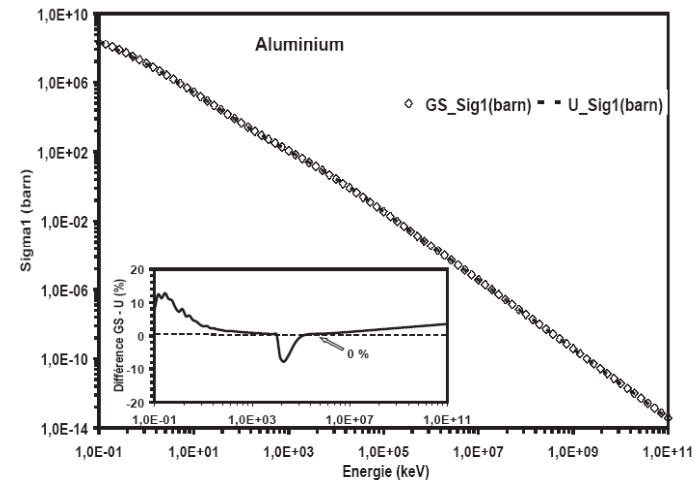
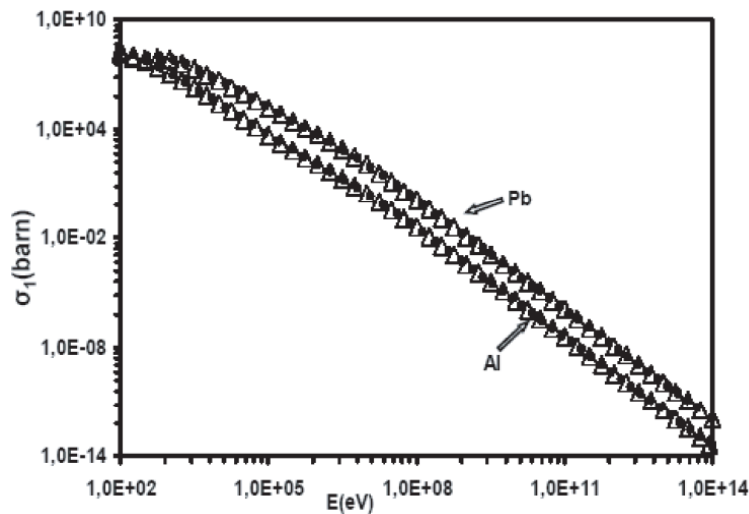


# Cross section DB

From the ELSEPA code (Salvat et al.),  
a cross section DB was generated covering:

- Z (1-103)
- E(0.1 keV – 1 GeV)
- e-/e+

- > Cubic spline for interpolation in log-log
- > linear log-log for extrapolation (E> 1GeV)



Figures show a comparison between Xsections of the GSModel and those of Urban → good agreement for E between (1 keV-1GeV) for all elements



# Angular sampling

**GS PDF**

**(probability density function)**



$$F_{GS}(\theta, s) = \sum_{l=0}^{\infty} (l + 1/2) e^{-sQ_l} P_l(\cos(\theta))$$

$$Q_l = 1 - y K_1(y) \left\{ 1 + 0.5y^2 \left\{ 1 + \frac{1}{2} + \dots + \frac{1}{l} - 0.5 \ln(l(l+1)) - 0.5772 \right\} \right\} \quad y = 2\sqrt{l(l+1)A}$$

**A: screening parameter**

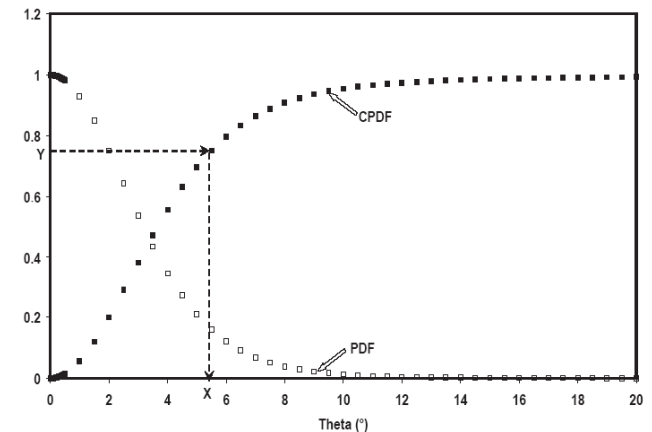
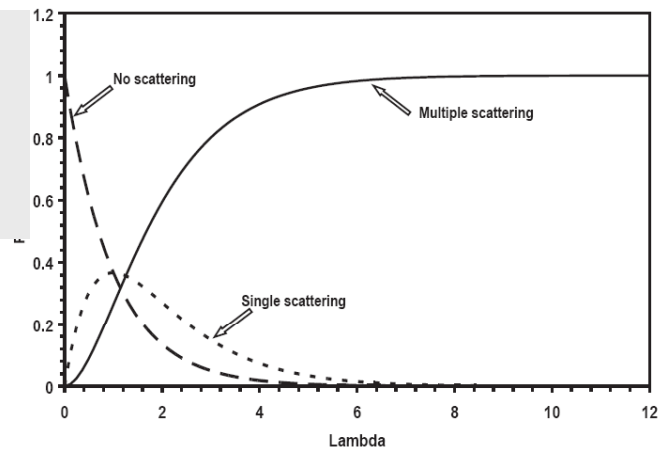
$$F_{GS}(\theta, s) = \exp^{-s} \delta(1 - \cos(\theta)) + s \exp^{-s} f_1(\theta)$$

$$+ (1 - s - s \exp^{-s}) \sum_{l=0}^{\infty} (l + 1/2) \frac{\exp^{-sQ_l} - [1 + s(1 - Q_l)] \exp^{-s}}{1 - (1 + s) \exp^{-s}} P_l(\cos(\theta))$$

**No, simple and multiple scattering probabilities**

**Lambda (path length in terms of mean free path)**

**Illustrative example for the inverse cumulative method used to generate angular sampling**



# Angular sampling

The look-up table (angular distributions DB):

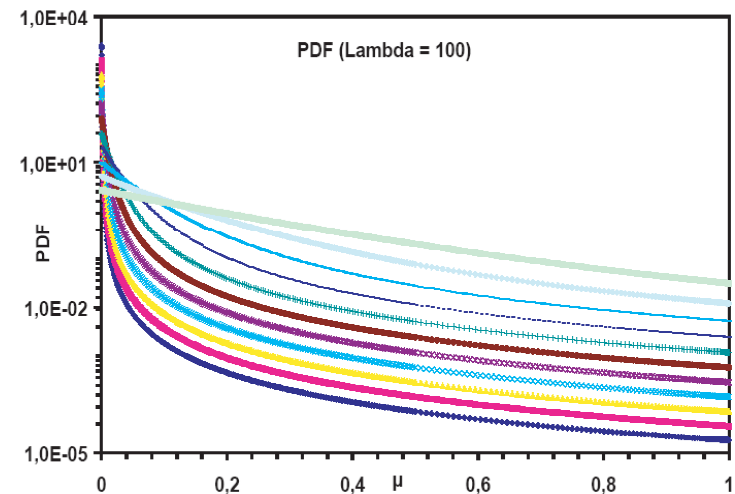
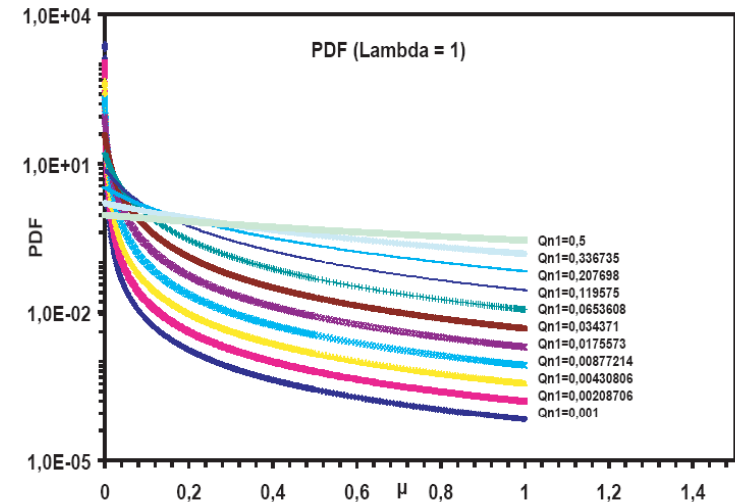
- 76 values of Lambda covering 1-  $10^5$
- 11 dynamic values of A
- 320 values of theta

→ Dynamic value: covering the range of Q1 from 0.001 to 0.5

$Q1 < 0.001$  → small angle approximation (exponential distribution)

$Q1 > 0.5$  → isotropic distribution

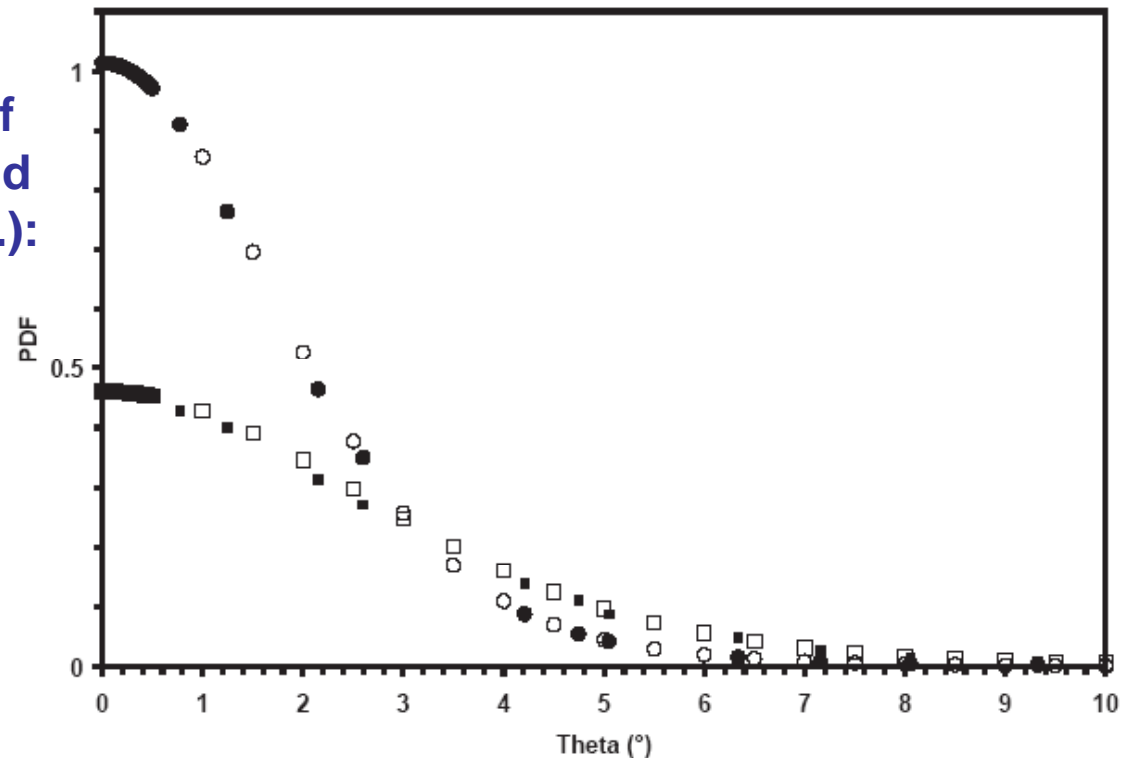
Figures are part of the DB  
For lambda=1 and 100 as examples



# Angular sampling

Using a correct interpolation (Benedito et al.) method for a given lambda, screening parameter and a random number  
→ generate the angle of distribution

Example: angular distribution of 15.7 MeV/e- two thin foils of Gold compared to data (Hanson et al.): empty circle and square for the current model and filled circle and square for Hanson data



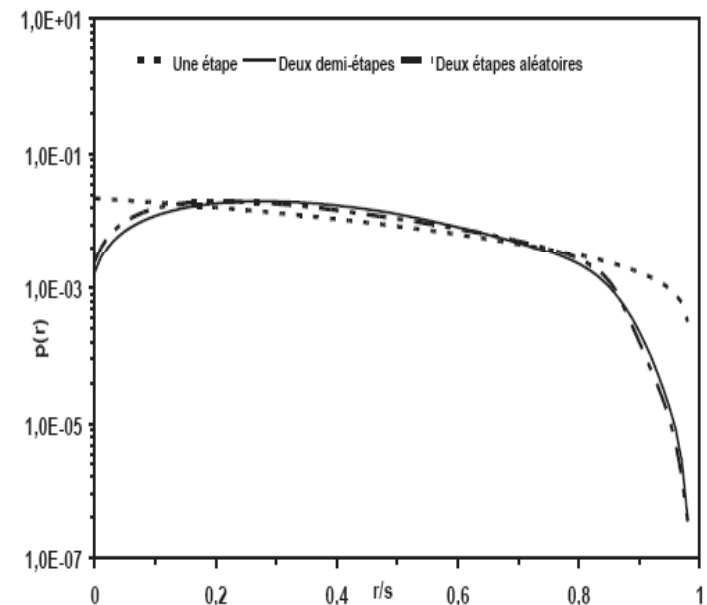
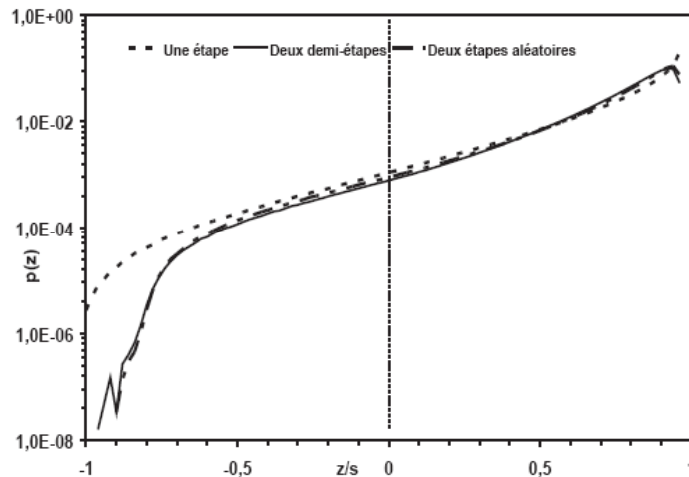
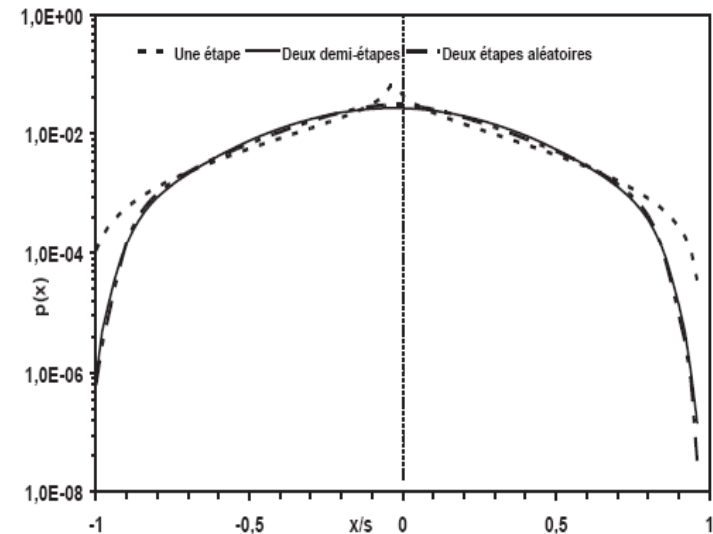
# Displacement sampling

In the MSC regime, each step was subdivided into two equal sub-steps (I.Kawrakow et al.)

Figures show a comparison if using:

- One step
- two equal sub-steps
- two randomly sub-steps,

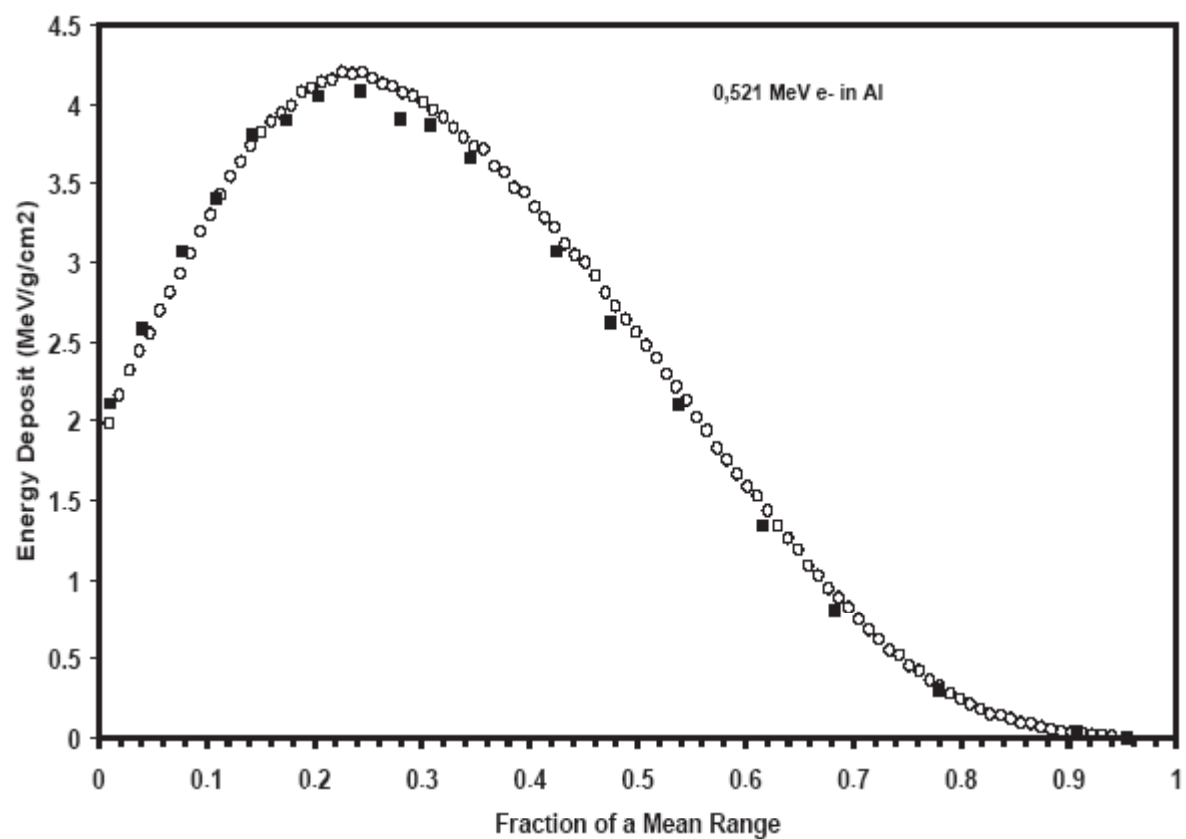
In the case of (100keV e-/Pb), for longitudinal, transversal and radial distributions





# Results

0.521 MeV/e- through Al:  
Sandia data (filled square) compared to current calculations



# Results

Benchmarks against Seltzer data: S: Seltzer data; T: this work; TN (RN), transmission (reflection) coefficient number; TE (RE), transmission (reflection) energy coefficient ; PhiA, energy absorption coefficient. Cases of electrons with kinetic energy of 100, 150, 200, 300 and 400 keV normally incident on slabs of Al and Ti.

		100		150		200		300		400	
	Param	S	T	S	T	S	T	S	T	S	T
Al	TN	0.602	0.607	0.918	0.924	0.968	0.980	0.997	1.001	1.004	1.006
	TE	0.393	0.403	0.766	0.772	0.880	0.883	0.949	0.949	0.969	0.968
	RN	0.124	0.126	0.070	0.075	0.031	0.037	0.010	0.011	0.005	0.005
	RE	0.071	0.072	0.045	0.046	0.022	0.025	0.007	0.007	0.002	0.003
	PhiA	0.536	0.532	0.189	0.188	0.098	0.096	0.044	0.045	0.029	0.029
Ti	TN	0.105	0.082	0.597	0.565	0.808	0.812	0.957	0.969	0.985	0.996
	TE	0.050	0.039	0.419	0.394	0.662	0.660	0.873	0.878	0.931	0.936
	RN	0.224	0.186	0.213	0.209	0.161	0.168	0.053	0.054	0.024	0.024
	RE	0.142	0.118	0.133	0.129	0.107	0.111	0.039	0.040	0.018	0.018
	PhiA	0.808	0.847	0.448	0.489	0.231	0.243	0.088	0.089	0.051	0.051



# Conclusion

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- Until now, a good satisfaction is seen (at least for the studied cases)
- CPU time consuming will be improved
- The plural scattering regime will be improved using the forced interacting technique

## THANK YOU

