Geant4 electromagnetic physics for high statistic simulation of LHC experiments

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Abstract

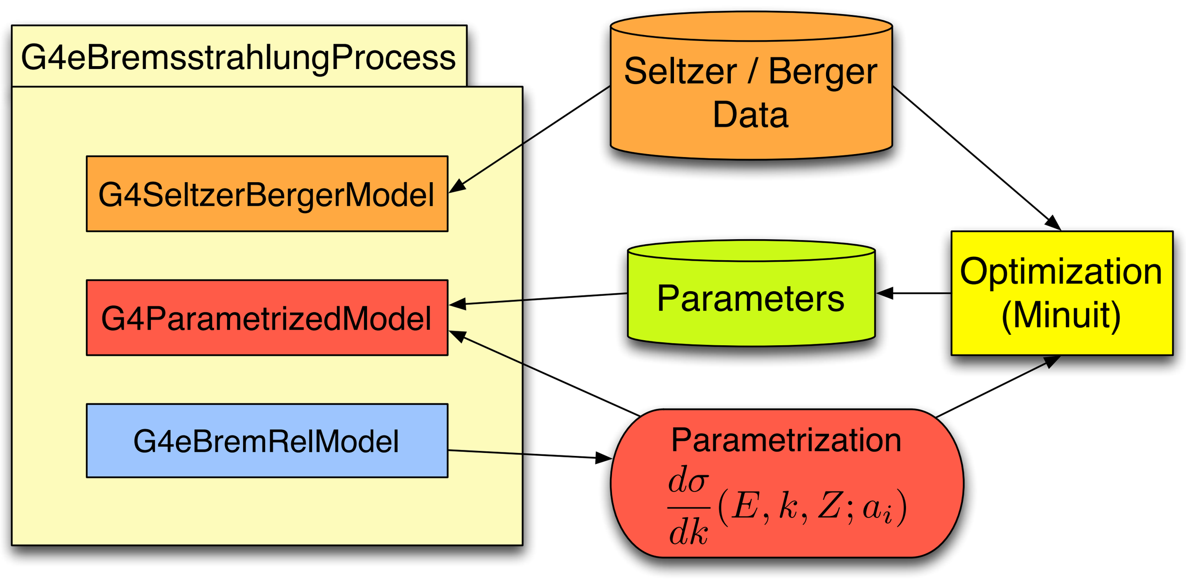
Geant4 is a toolkit for the simulation of the passage of particles through matter [1, 2]. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. An overview of the current status of electromagnetic (EM) physics is presented. Recent improvements focus on the performance of large scale production for LHC experiments and on the precision of simulation results over a wide energy range. Significant efforts have been made to improve the description of EM shower shapes in order to describe details of $H \to \gamma\gamma$ signal and other reactions. The Bremsstrahlung process and multiple scattering description were reviewed and improved, having been identified as key components in defining EM shower shapes. New biasing options for Geant4 EM physics have been introduced. The testing suite has been extended to allow high statistics validation of EM physics.

New Geant4 Bremsstrahlung Model

With the goal to to describe EM shower shape and high energy gamma emission with higher accuracy, the description of the Bremsstrahlung process in Geant4 has been improved for two main models:

- Seltzer-Berger model, new with Geant4 9.5;
- Relativistic model, available since Geant4 9.2 [3].

We report about recent upgrades in these models and a newly developed Parametrized model.



Seltzer-Berger model

A model based on theoretical data tables has been introduced in Geant4 version 9.5.

- it is based on tabulated single-differential cross-section from Seltzer & Berger [5], (31 points in electron and 14 in photon energies)
- it is available for all elements, and covers electron energies from 1 keV to 10 GeV
- it uses interpolation between data points.

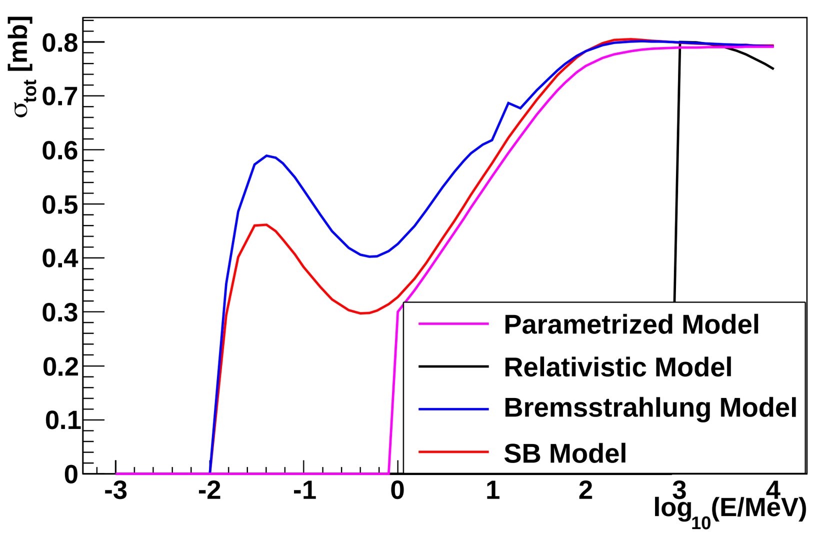


Figure 1: Total cross section comparison between models.

Parametrized Bremsstrahlung model

Until Geant4 version 9.4, the standard EM model used independent parametrizations for total cross-section, energy-loss, and differential cross-section.

- the newly proposed model uses one parametrization for the differential cross-section[b];

$$F(x) = c[(1 - ax)F_1(\delta) + bx^2F_2(\delta)]$$

- total cross-section and energy-loss are evaluated by numerical integration [6];
- this model guarantees a smooth transition to the relativistic model;
- has a good description of Seltzer-Berger data;
- applicable from 1 MeV to 10GeV.

[b]Where $x = k/T$. k and T are photon and electron energy resp., $F_1(\delta)$ and $F_2(\delta)$ the Thomas-Fermi screening functions, and a, b and c the parameters of the model.

Relativistic Bremsstrahlung Model

Bethe-Heitler cross-section, complete screening approximation

- includes Landau-Pomeranchuk-Migdal effect (LPM);
- consistent combination with polarization effect;
- good description of SLAC and CERN LPM experimental data [3].

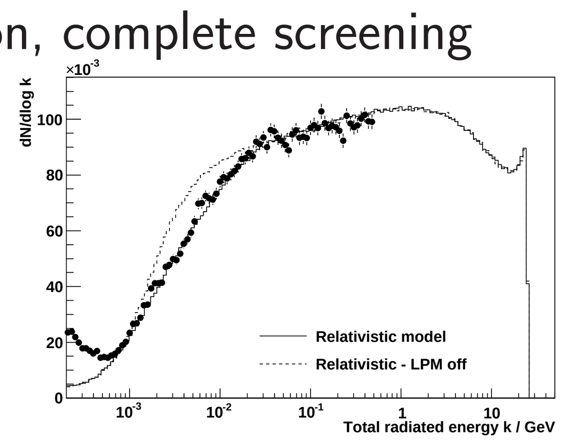


Figure 2: Relativistic model vs exp. data for 25GeV electron on Aluminum (SLAC E-146 data).

Model is currently being improved to use Thomas-Fermi screening functions.

Results

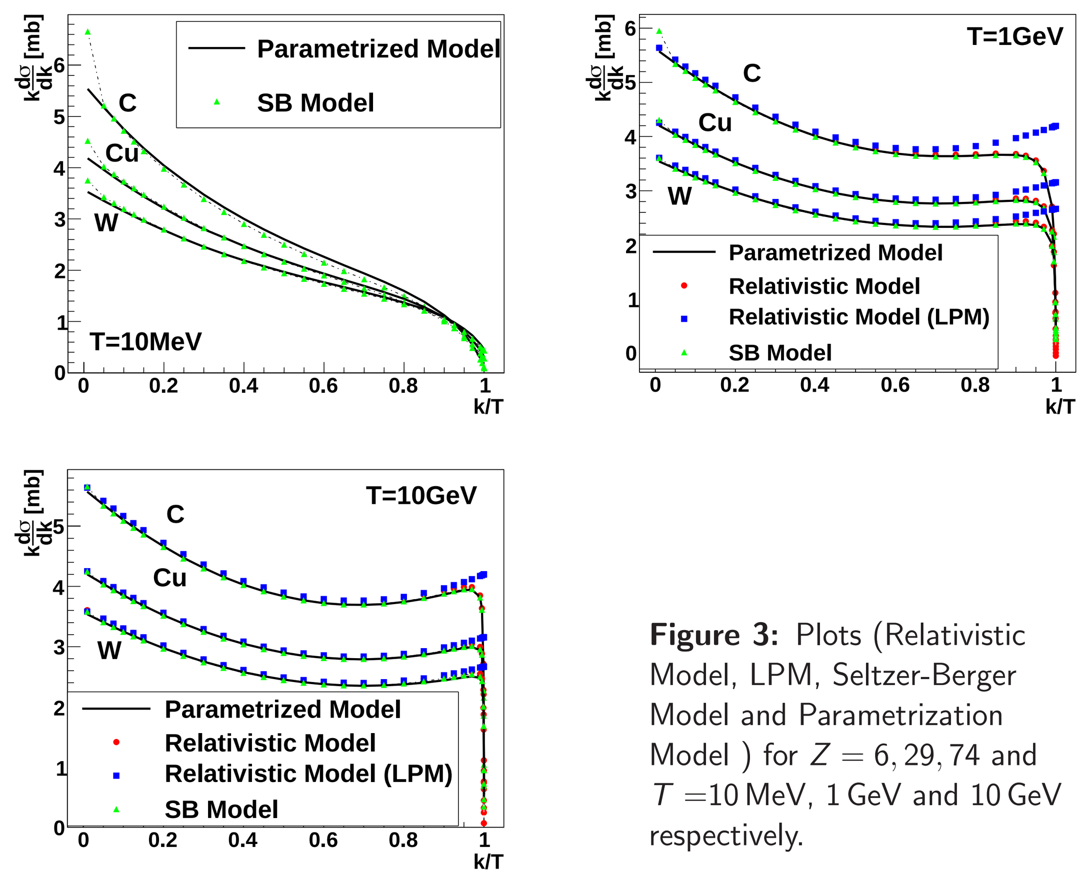


Figure 3: Plots (Relativistic Model, LPM, Seltzer-Berger Model and Parametrization Model) for $Z = 6, 29, 74$ and $T = 10$ MeV, 1 GeV and 10 GeV respectively.

Multiple Scattering

The Geant4 toolkit offers several models of multiple scattering (MSC). G4UrbanMscModel95 provides better agreement with the scattering data for electrons than previous versions of the model.

The list of upgrades includes:

- new tuning of tail of scattering function;
- added sampling of correlations between scattering angle and lateral displacement at a step;

This new variant of MSC model is the default for Geant4 9.5.

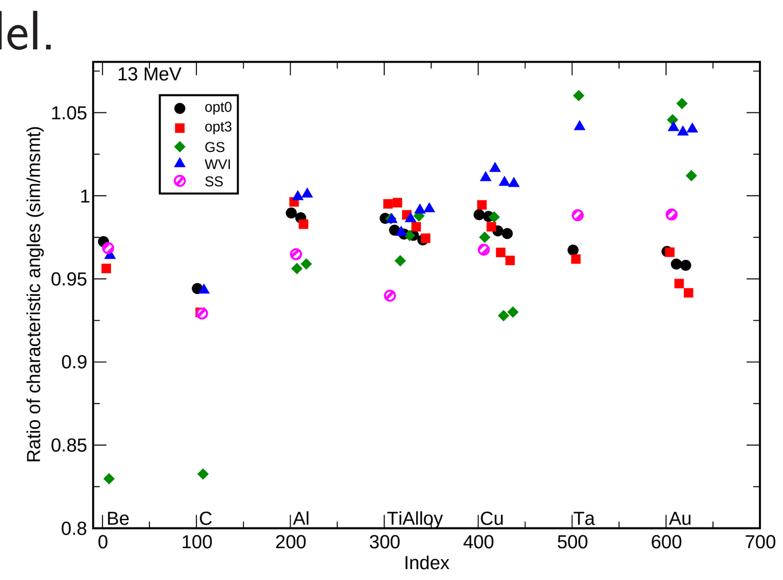


Figure 4: Characteristic angle compared to data.

Photo-electric effect

A new photo-electric effect model with fluorescence which uses implementation of atomic de-excitation *G4UAtomicDeexcitation* has been developed.

- all models provide better than 5% accuracy on average in the photon energy range 1 keV - 10 MeV;
- speed of the new model is similar to the previous one, but faster than Livermore or Penelope models.

This model is default for production physics lists since Geant4 9.5.

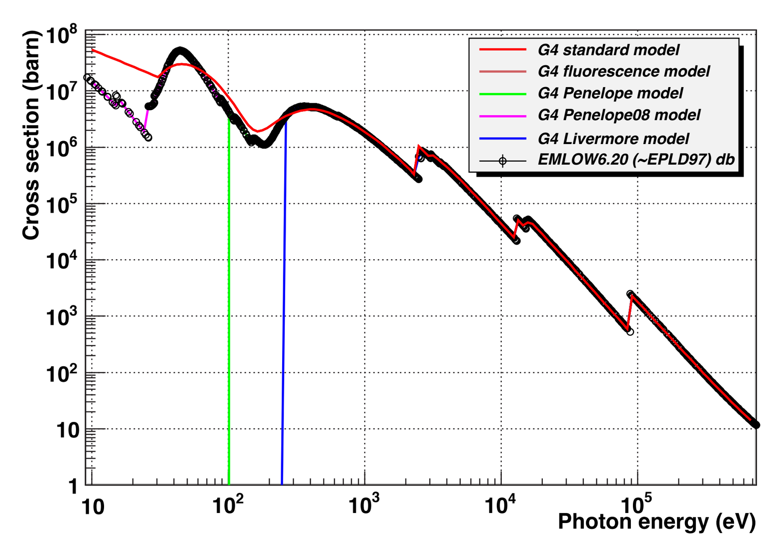


Figure 6: Comparison of G4 photo-electric cross section models versus EPLD97.

Validation

Geant4 EM physics is validated on a regular basis using an extensive validation suite. Results are stored for each subsequent Geant4 release, and are available on a web interface.

The test suite includes among others:

- resolution and visible energy in simplified calorimeter tests with different setups (Atlas LAr, Atlas Tile, CMS crystal);
- Bremsstrahlung distributions of different Geant4 models.
- electron scattering benchmarks including back scatter fractions and differential cross-section.

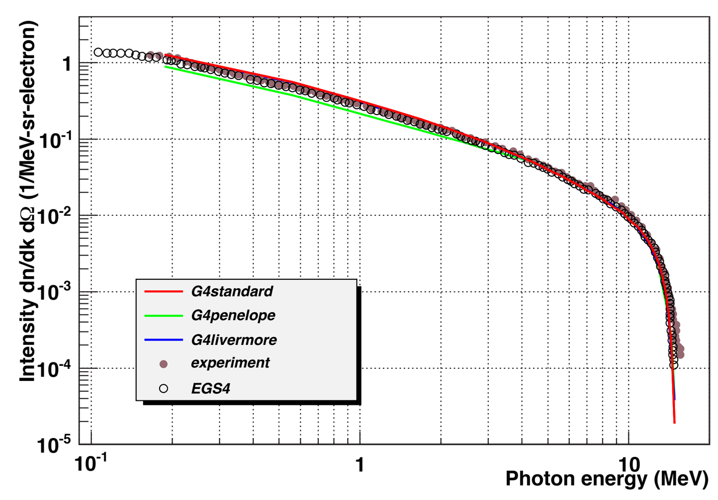


Figure 5: Comparison of Bremsstrahlung spectrum at an angle of 10° between different models and data.

References

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