Geant4 Electromagnetic Physics for LHC Upgrade

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Abstract

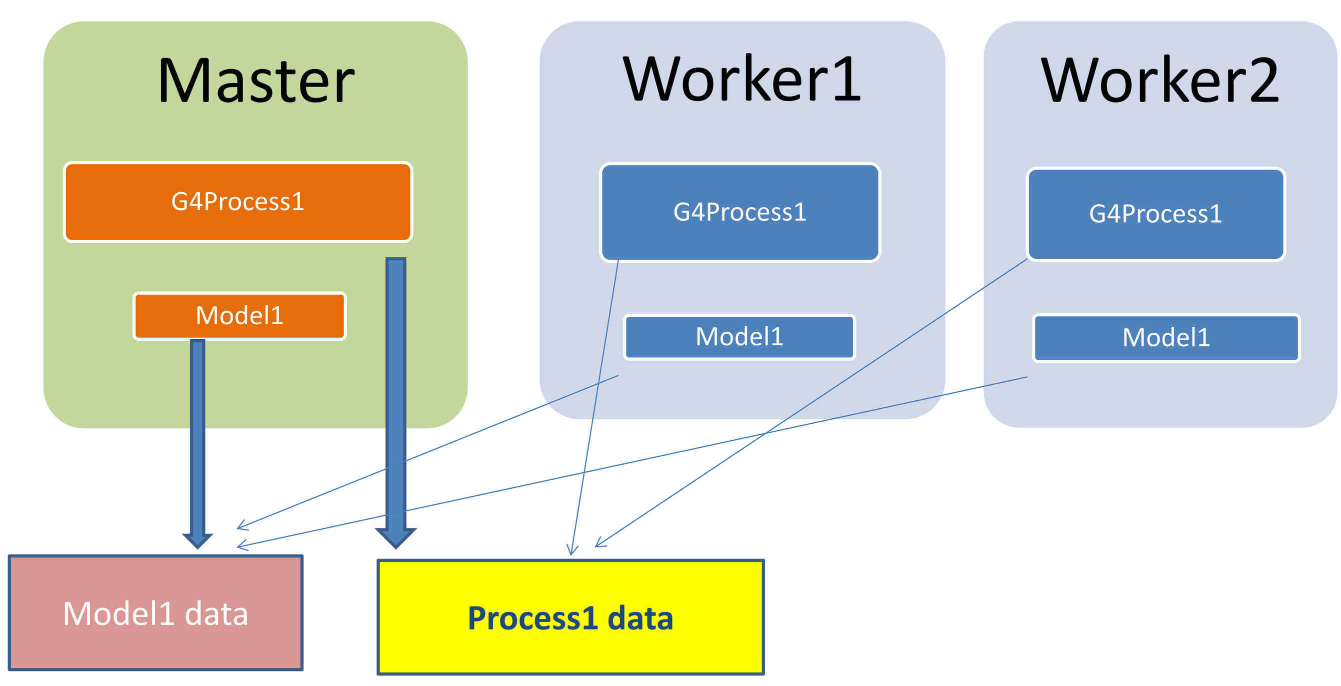
Electromagnetic (EM) physics sub-package of the Geant4 Monte Carlo toolkit is an important component of LHC experiment simulation and other Geant4 applications. In this work we present recent progress in Geant4 electromagnetic physics modeling, with an emphasis on the new refinements for the processes of multiple and single scattering, ionisation, high energy muon interactions, and gamma induced processes. These developments affect the results of ongoing analysis of LHC data, in particular, electromagnetic shower shape parameters used for analysis of H->γγ and Z->ee decays.

The LHC upgrade to future 14 TeV run will bring new requirements regarding the quality of electromagnetic physics simulation: energy, particle multiplicity, and statistics will be increased. To address new requirements high energy electromagnetic models and cross sections are improved. Geant4 testing suite for electromagnetic physics is extended and new validation results will be presented. An evolution of CPU performance and developments for Geant4 multi-threading connected with Geant4 electromagnetic physics sub-packages will also be discussed.

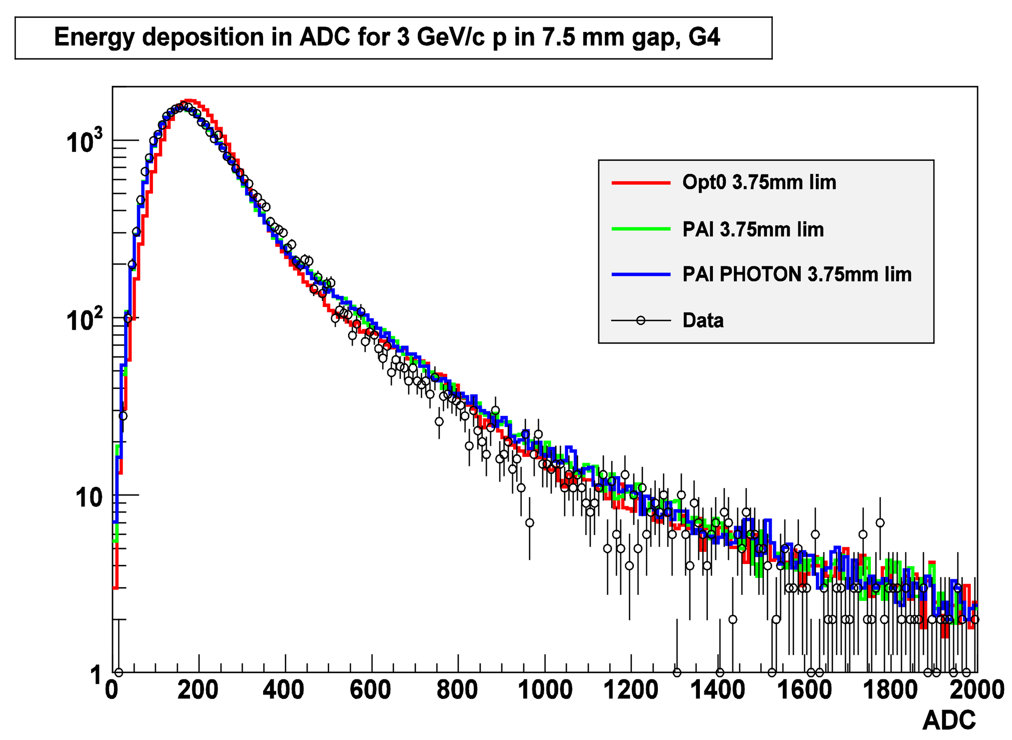
EM sub-packages are multi-threading capable

For the new Geant4 version 10.0 all EM Standard sub-packages have been fully adopted to multi-treading approach which is the main goal of Geant4 for this release. This migration of EM code is essential for LHC applications of Geant4 because EM physics processes and models uses large tables of cross sections, stopping powers, and ranges. These tables are created in master thread and shared by worker threads in run time. To achieve this goal material sub-library and Geant4 physics table classes have been updated:

- only *const* methods are used in run time;
- all these classes are initialized before event loop;
- new interfaces are added allowing data sharing.



Response of Silicon and gaseous detectors



Main Geant4 model of fluctuations of energy loss Urban (default), PAI and PAI-photon have been reviewed and updated. Dependences of peak position and width on cut value and step limit for the Urban model were reduced. It is recommended to use step limit of half size of sensitive area for this model. PAI models are stable and more accurate, so any cut or step limit may be used. In the plot Geant4 simulations are compared with ALICE test-beam data:

D. Antonchyk et al., NIMA, 565, 551-560 (2006).
P. Christiansen et al., Int. J. Mod. Phys. E, 16, 2457-2462 (2007).

Conclusions

EM physics of Geant4 was successfully used for LHC experiments. Recently consolidation of main EM models was achieved.
Physics performance of Geant4 EM for releases 9.6 and 10.0 is nearly the same. Some CPU speedup is expected for the version 10.0 (5 - 10 % for LHC experiments simulation).
Geant4 EM for the version 10.0 is fully multi-threading capable.

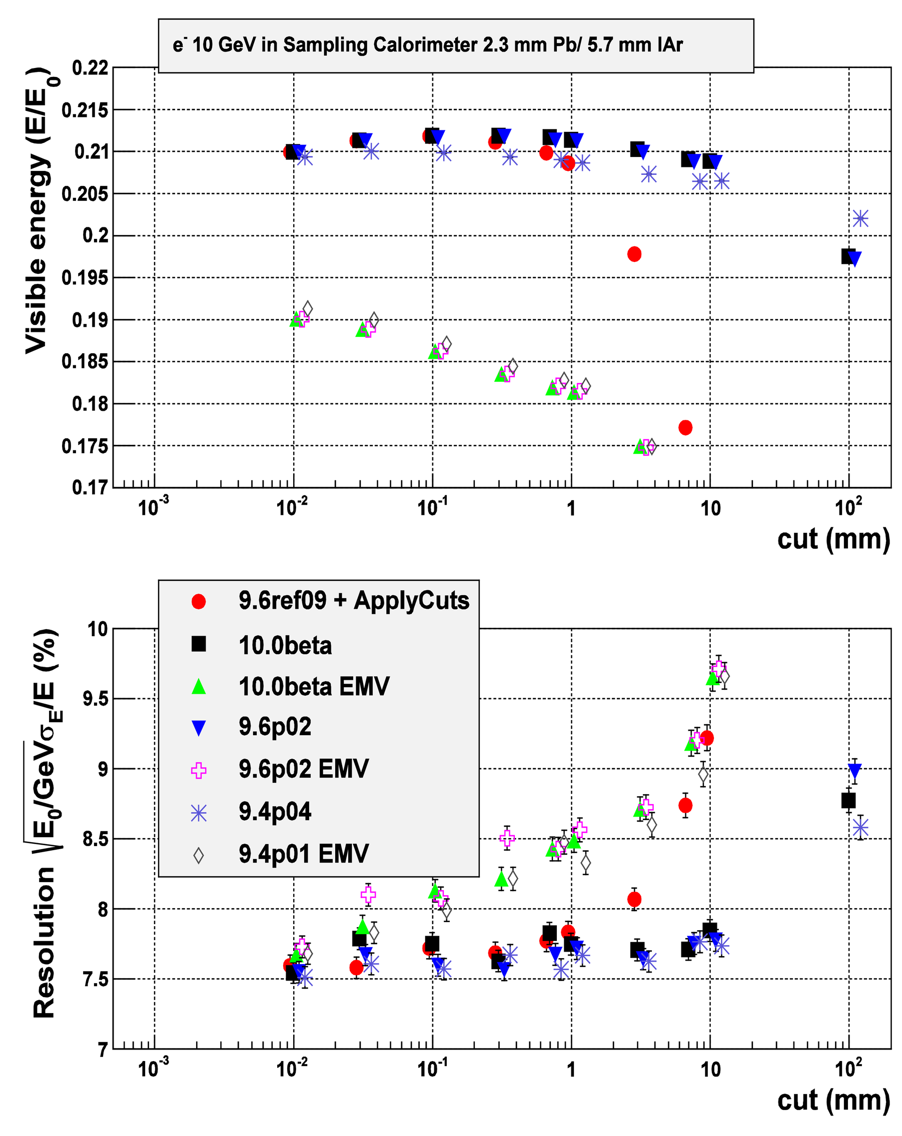
CPU performance improvements

EM physics sub-packages are CPU intensive, because ionisation, multiple scattering and other models are called at each step of a particle. CPU profiling shows that *G4PhysicsVector* run time methods and standard mathematical library functions are the most time consuming. For the new Geant4 release 10.0 *G4PhysicsVector* was significantly updated and new classes were introduced G4Pow, G4Exp, and G4Log. The last two are extracted from VDT library (see D. Piparo talk at this conference). CPU for 10^7 calls for different math-functions are shown in the table below.

Function	Std	G4 VDT	G4Pow
Log	8.97	4.91	5.19
Exp	13.93	1.95	1.34
$A^{1/3}$	20.46	7.03	0.77
$Z^{1/3}$	-	-	0.01

Total effect for LHC simulations is expected on level 5-10%

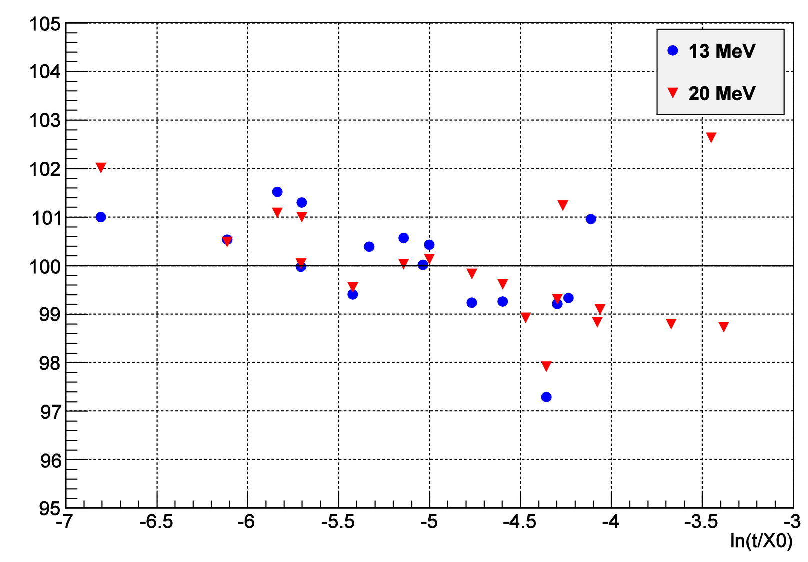
Sampling calorimeter response



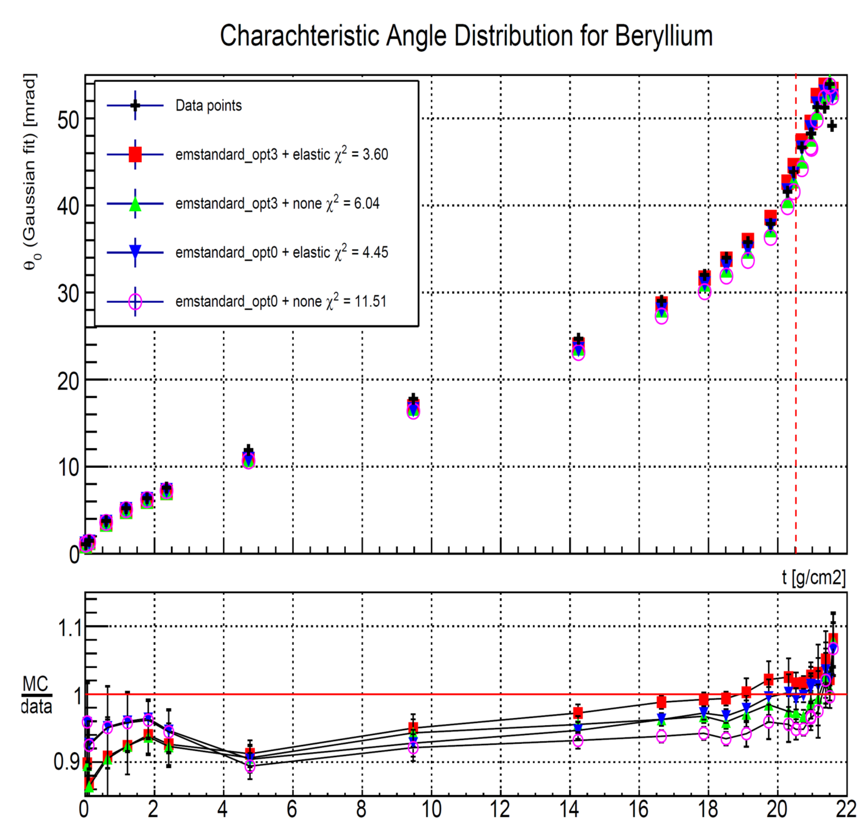
In the plot above response and resolution of simplified Cu/liquidAr (ATLAS-barrel type) sampling calorimeter as a function of cut in range for different Geant4 versions and EM Physics Lists. For the version 9.6p02 it is expected 0.2% increased response compare to the 9.4p04 version. No difference between 9.6 and 10.0 is expected.
Accurate stable response of sampling calorimeter can be obtained if step limitation is applied when electrons are closed to a geometry boundary between absorber and sensitive volumes. In the case of weak step limitation (EMV) both response and resolution are biased.
Red circles shows results for the case when *"ApplyCuts"* option is enabled. This option establish production thresholds to all EM processes cutting out all low-energy secondaries. This provides about 30% speedup of simulation for the cut = 1 mm but more strong dependence of the results on cut value.

Multiple scattering models upgrade

Urban model for multiple scattering is the Geant4 default. Recent tuning of the model provides the best accuracy for all low-energy benchmarks. In the plot below the ration of Data/MC (%) are shown for the set of materials (Be, C, Al, Ti, Cu, Ta, Au)of the electron scattering benchmark (*C. Ross et al., Med. Phys., 35, 4121, 2008*). Accuracy of the data ~1%.



For high energy charged particles a combination of WentzelVI and single scattering models provides the most accurate results. This combination is based on theory, so applicable for wide areas of target thicknesses, densities, and energies. Rutherford tail of scattering naturally described by the single scattering model. Stability versus step size is an important advantage for simulation of vertex reconstruction.
This choice is supported by several benchmarks versus data for muon scattering from MuScat experiment data for 172 MeV/c (*D. Attwood et al,. NIMB , 251, 41, 2006*) to L3 detector data for muons from the decay Z->μ+μ− (*P. Arce et al. MC-2000 Conference, EXP CERN-LEP-L3, 2000*). In all these benchmarks the combined model is more accurate than the Urban model.
For Geant4 9.6 a design iteration was introduced allowing to combine different multiple scattering models for different energy range. This allows to use the Urban model below 100 MeV for electrons and positrons where this model has significant advantage in accuracy and CPU speed.



New proton scattering benchmark includes data for 14 different materials and different target thickness (*B. Gottschalk et al., NIMB 74, 467, 1993*). The effect of hadron elastic scattering on characteristic angle can be seen. Agreement data/MC is improved when more strong step limitation is applied.