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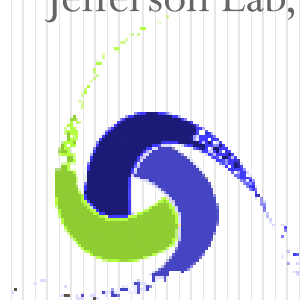
Highlights on EM physics for versions 10.5 and 10.6

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for Geant4 Collaboration

Jefferson Lab, Virginia (US), 24 September 2019



GEANT4
A SIMULATION TOOLKIT

Outline

- Developments for Geant4 10.5 and 10.6
 - Materials
 - EM infrastructure
 - EM standard
 - EM low-energy & DNA
 - EM physics constructors
- Summary



Materials modifications for EM

- `G4ICRU90StoppingData` added for 10.5, will be extended for 10.6:
 - Common project Geant4/GATE
- `G4AtomicShell_EADL` is replaced by the `G4AtomicShells_XDB_EADL` class
 - New data derived from X-Ray data book for binding energies
- `G4DensityEffectCalculator` – precise computation of the density effect corrections (by Matthew Strait) for 10.6
 - Enabled by C++ or UI command
 - Essential for accurate simulation of gaseous detectors

EM infrastructure updates for 10.5

- Extended user interface to EM physics
 - Added extra UI commands and C++ interface to EM parameters and fixed some problems
 - Improved online documentation for used EM processes and models
 - Improved dump of EM parameters
 - Added ICRU90 flag
- G4EmCalculator updated
 - Fixed computation of dEdx for ions
 - Fixed computation of transport cross section for multiple scattering
- G4VEmAngularGenerator
 - Added a new interface SamplePairDirection(..) used for sampling of conversion
- Implemented directional splitting option for biasing of final state
- Fixed problems #1992, #2045, #2056, #2084, #2089
- New data files are mandatory for Geant4 10.5 G4EMLOW7.7

EM infrastructure updates for 10.6

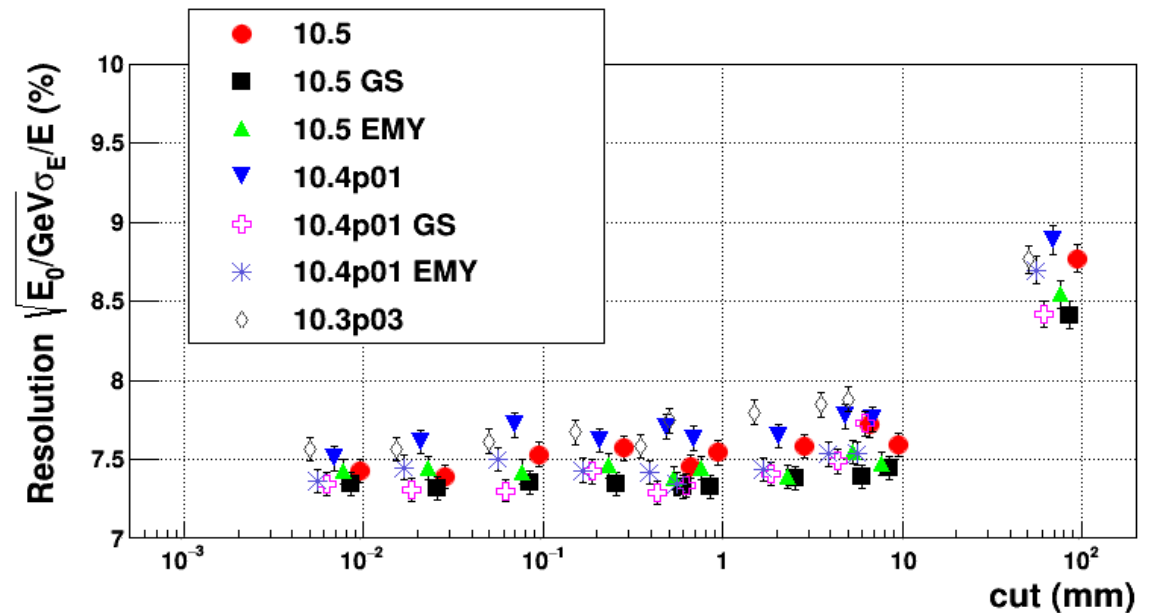
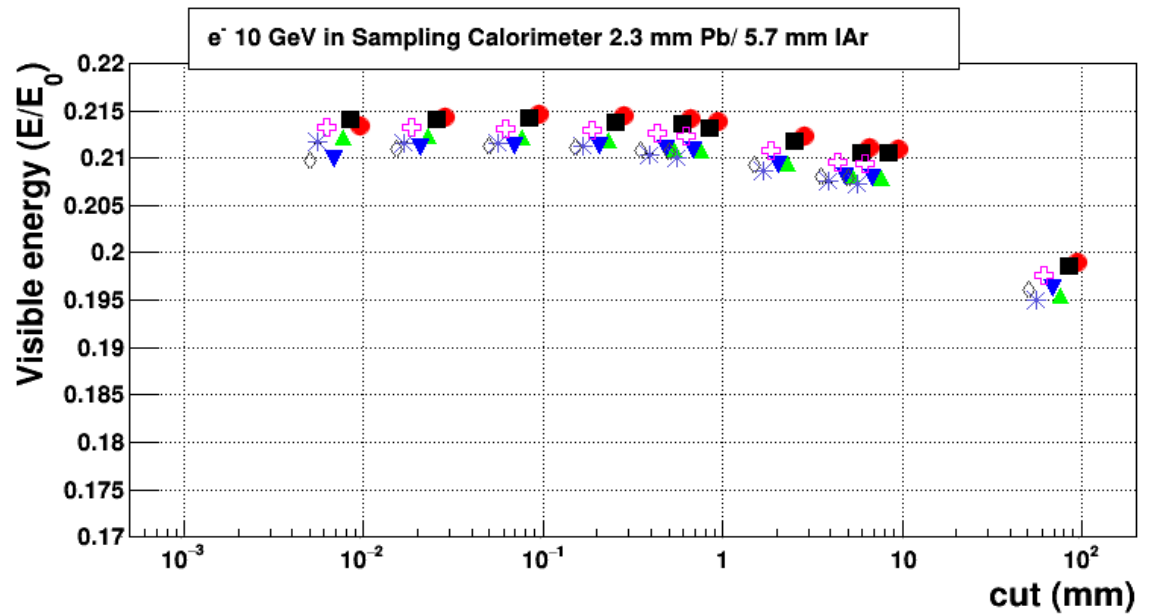
- Extension of EM testing
 - Migration of the EM testing suite from lxbatch to Condor
 - Added more tests for EM physics to Geant-Val grid based tool
 - Added extended EM test for sampling calorimeters into Geant-Val
 - Added full set of G4MSBG (medical physics benchmarks) into Geant-Val
- Code speed-up (M.Novak)
 - extension of **G4DynamicParticle** with logarithm of energy in order to reduce number of calls to logarithm
 - **G4PhysicsVector** code is revised (affect all EM processes and hadronic cross sections)
 - Evaluated "global process" approach for gamma, the option is available to users

Standard models updates for 10.5

- Models of single and multiple scattering for e^+ -
 - Improved sampling of displacement for the `G4UrbanMscModel`
 - Added Mott corrections to `G4WentzelVIModel` used for simulation of multiple scattering of e^+ - above 100 MeV
 - `G4ScreenedMottCrossSection` – use `G4MottData` shared between threads and implemented more optimal computations
 - `G4GoudsmithSoundersonMscModel` – fix initialisation and added extra access method to transport cross section
- Gamma models and bremsstrahlung
 - `G4ModifiedTsai` – use as a default for bremsstrahlung and pair production, added new method `SamplePairDirection`, improved performance
 - `G4BetheHeitlerModel`, `G4PairProductionRelModel` – improved screening function approximation, LPM function approximation, selection of elements in compounds
 - `G4SeltzerBergerModel` – added optional mechanism of sampling final state using sampling table

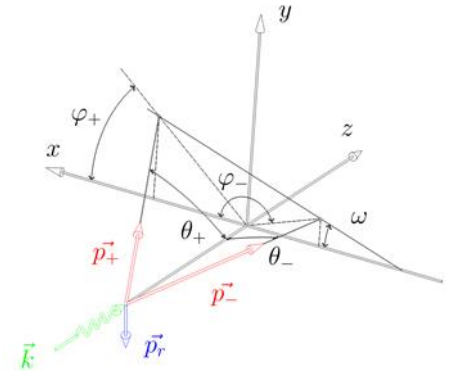
ATLAS barrel type simplified calorimeter

- In Geant4 10.5 Opt0 and GS provide the same visible energy 1% above 10.4p02
- Energy resolution for Opt0 is about 1.5% lower



New standard EM models for 10.5

- **G4BetheHeitler5DModel**
 - Accurate sampling of final state (~ 100 slower)
 - Nuclear recoil and polarisation are taken into account
- **Proton/hadron ionisation**
 - Added possibility to use ICRU90 data for stopping powers
 - Geant4/GATE project
- **Ion ionisation based on Lindhard-Sorensen theory**
 - **G4LindhardSorensenModel** – parameterisation above 10 MeV
 - **G4AtimaEnergyLossModel** – implementation of ATIMA code in C++
 - **G4AtimaFluctuations** – relativistic ion energy loss fluctuations
- **3-gamma annihilation model**
 - **G4eplusTo2GammaOKVIModel** and **G4eplusTo3GammaOKVIModel** implements 2-gamma and 3-gamma positron annihilation in fly and at rest
 - Using triplet interface introduced in 10.4
 - Probability of 3-gamma final state depends on cut to gamma energy



Standard models updates for 10.6

- **G4PairProductionRelModel** – M.Novak extended application area down to the process threshold
 - This model is based for G4BetheHeitler5DModel, the last now reuses LPM effect implementation from the base class
- **G4UrbanMscModel** – tuned step limit parameters
- **G4SeltzerBerger model** – initialized tables only for elements used in a particular run
- **G4ScreeningMottCrossSection** – revised memory usage and algorithm at low energies
- **G4GammaConversionToMuons** – extended down to production threshold (gamma factory requirement)
- Fixed problems #2105, #2152, #2169

Low Energy EM & DNA Physics in 10.5

- Added new JAEA model of [gamma elastic scattering](#) (M.Omer and R.Hajima)
- [G4PenelopeIonisationModel](#) – fixed rare energy non-conservation
- [Geant4-DNA](#)
 - Published [Special Report in Medical Physics](#) journal describing all physics models and applications for track structure simulations (covers 2008-2018 period)
 - [Med. Phys. 45, e722-e739 \(2018\)](#)
 - New constructors
 - Physics ([G4EMDNAPhysics_option8](#)) – electron elastic scattering based on CPA100 approach
 - Chemistry ([G4EmDNAChemistry_option1](#)) – alternative set of values (diffusion constants, reaction rates) from RITRACKS / NASA software
 - New examples
 - **splitting**: illustrating computing speedup in ionisation
 - Updated **svalue** example for the calculation of S values in nuclear medicine
 - Track structure models development on-going for liquid water and other biological materials

DNA Chemistry developments

- For 10.5:
 - chem5: extraction of radiochemical yields versus time using these new constructors
 - Updated other Chemistry examples
- Making chemistry more accurate and faster for 10.6:
 - Influence of physics models and chemistry parameters on the simulation of radiochemical yields Wook Geun Shin et al.
 - Porting of TOPASnBio IRT & alternative versions to Geant4 is on-going in collaboration with TOPAS developers
 - New constructor `G4EmDNAChecker_option2`

EM physics constructors

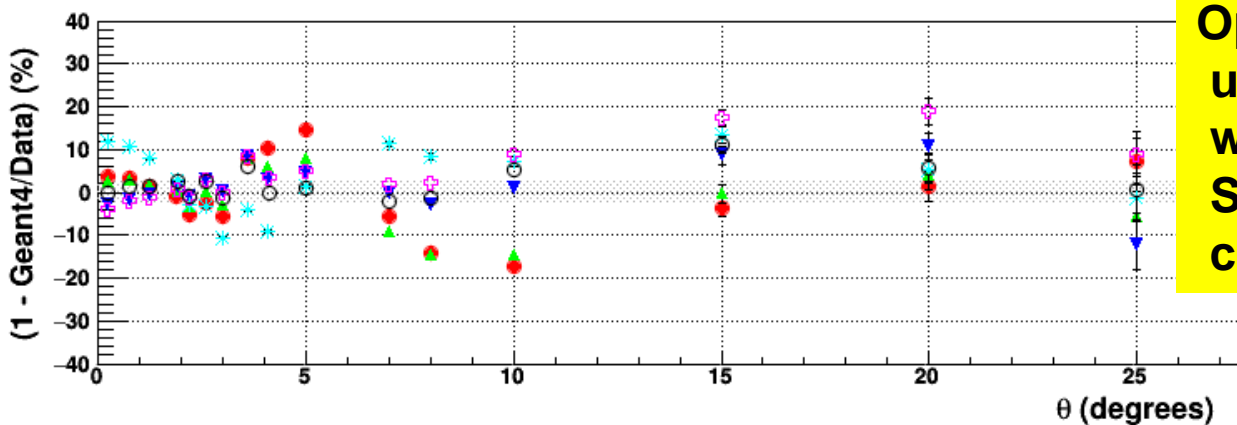
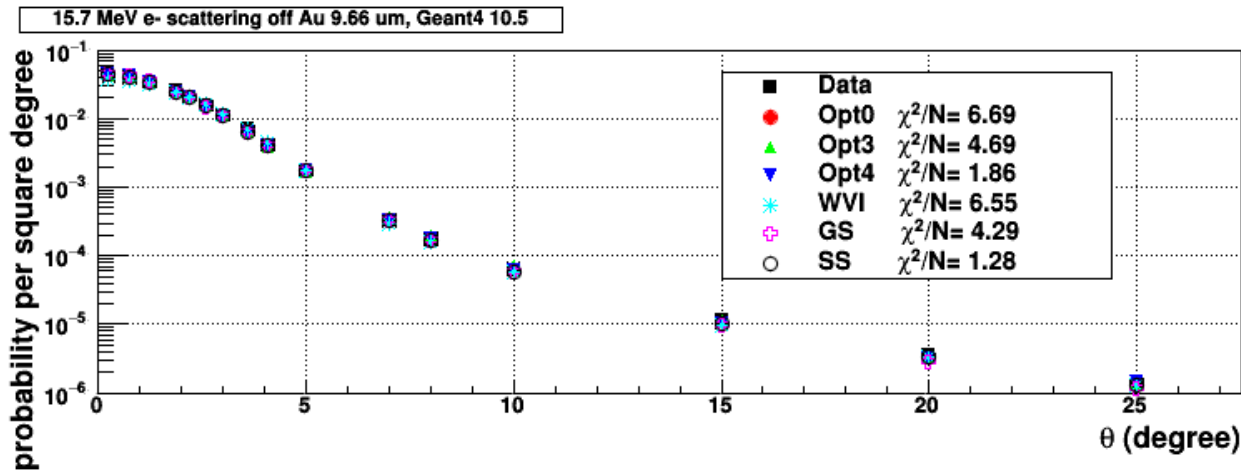
- Default EM physics (Opt0)
 - New lateral displacement for the Urban model
 - G4ModifiedTsai for angular distribution of bremsstrahlung and gamma conversion
- LHCb type of EM physics (Opt2)
 - Check of options was done and tuned to be the same as in LHCb
- Accurate EM physics (Opt4)
 - Use GS model of multiple scattering below 100 MeV with “error free” stepping option
 - MscRangeFactor changed from 0.2 to 0.08
 - Used 5D model of gamma conversion
- Livermore and Penelope physics
 - Use GS multiple scattering as in Opt4 EM physics
- Experimental EM configurations (WVI and LE)
 - New standard models are included
- EM physics configuration via UI commands is improved
 - Still work in progress

Summary

- Due to modifications in Urban msc model we can expect shift of calorimeter results for $\sim 1\%$ in 10.5 compared to 10.4
 - EM constructors Opt0, Opt4, Liv, Pen ... provide calorimeter results more closed to each other
 - Opt2 constructor now is equivalent to the LHCb configuration
- Several new models are provided
 - They are not included into production constructors but to experimental only
- We do not expect change of CPU performance in a significant way for Geant4 10.5 due to EM physics
 - In 10.6 we expect some speedup on level of few %

Backup

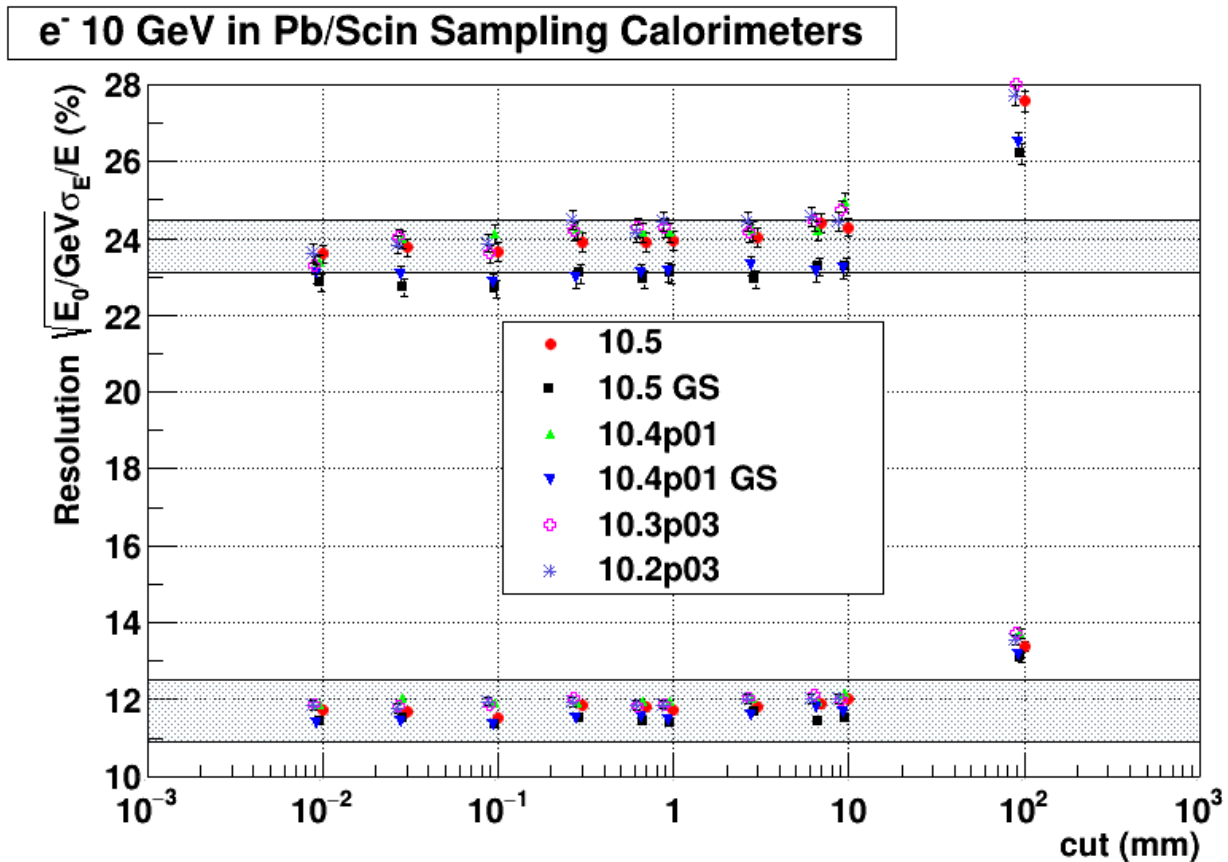
Hanson data for electron scattering off Gold target (*Phys. Rev.* 84, 634-637, 1951)



**Opt4 Physics List
uses the GS model
with Mott corrections
SS also uses Mott
corrections**

Resolution of Pb/Sc calorimeters

Bernardi E. et al. 1987 Nucl. Instrum. Meth. A 262, 229



- Resolution for 10.5 is lower but within data errors
 - Effect is larger for high sampling fraction (thicker scintillator)