What's new in 10.6: EM physics

V. Ivanchenko, CERN & Tomsk State University, Russia

for the Geant4 Collaboration

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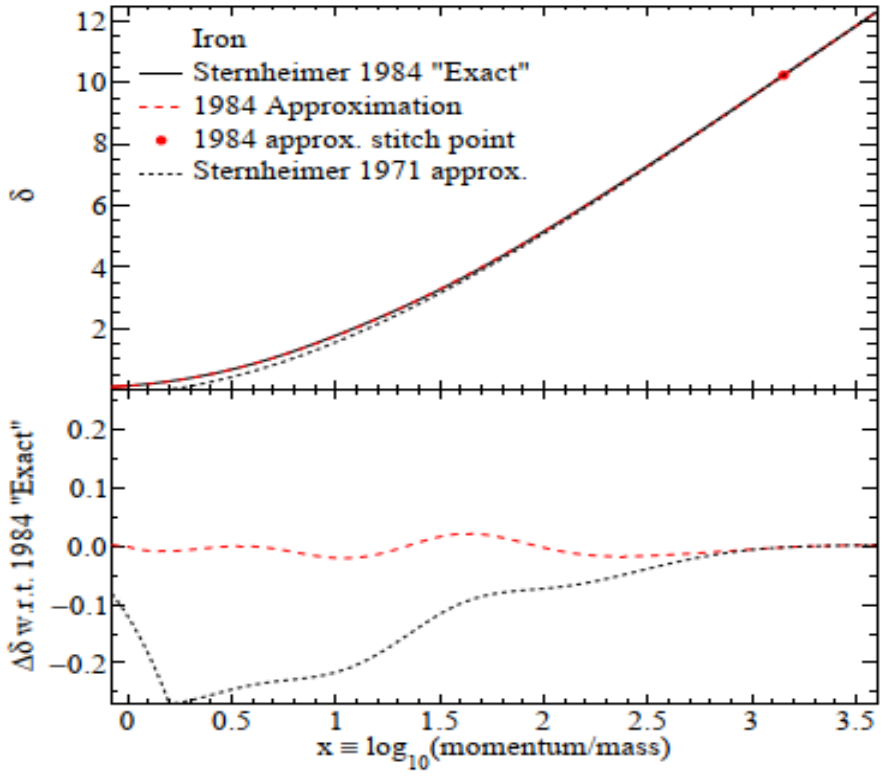
Outline

- Updates of Geant4 Materials
- EM Physics Developments for Geant4 10.6
- Geant4-DNA developments for 10.6
- Optimization and CPU speed-up for 10.6
- General gamma process
- Configuration of EM physics
- How to speed-up simulation of a concrete detector?

Updates of Geant4 Materials

- New static methods added – may be useful for HEP
  - *G4Material::GetMaterial(const G4String&, G4double density)*
  - *G4Material::GetMaterial(G4double Z, G4double A, G4double density)*
  - *G4Material::GetMaterial(size_t nComponents, G4double density)*
  - These methods may help to reduce duplicate material definitions in HEP detector descriptions
- New class G4DensityEffectCalculator (Matthew Strait, University of Minnesota, USA)
  - Based on R.M. Sternheimer publications as our default but do not use parameterisation, instead resolving non-linear equation
  - By user request compute density effect correction on fly without any parameterisation
    - New UI command "/material/g4/enableDensityEffOnFly material_name"
- For the default computation of the density correction for compounds the logic was changed
  - If a compound is not inside NIST materials DB but some element dominates in the mass fraction (>90 %), then density correction is based on parameterisation for this pure element available in Geant4

Accuracy of the new approach for Fe (M. Strait)



- Pure iron: 1984 approximation is quite close to the exact solution
- Impure iron (say, steel): 1971 approximation, up to 1.3% off

- Patch already used by NOvA to obtain improved $\mathrm{d}E/\mathrm{d}x$ in steel by up to 1.3%
  - Important because this difference cannot be calibrated out in a neutrino experiment
  - Same will be true for DUNE at the level of 0.6%

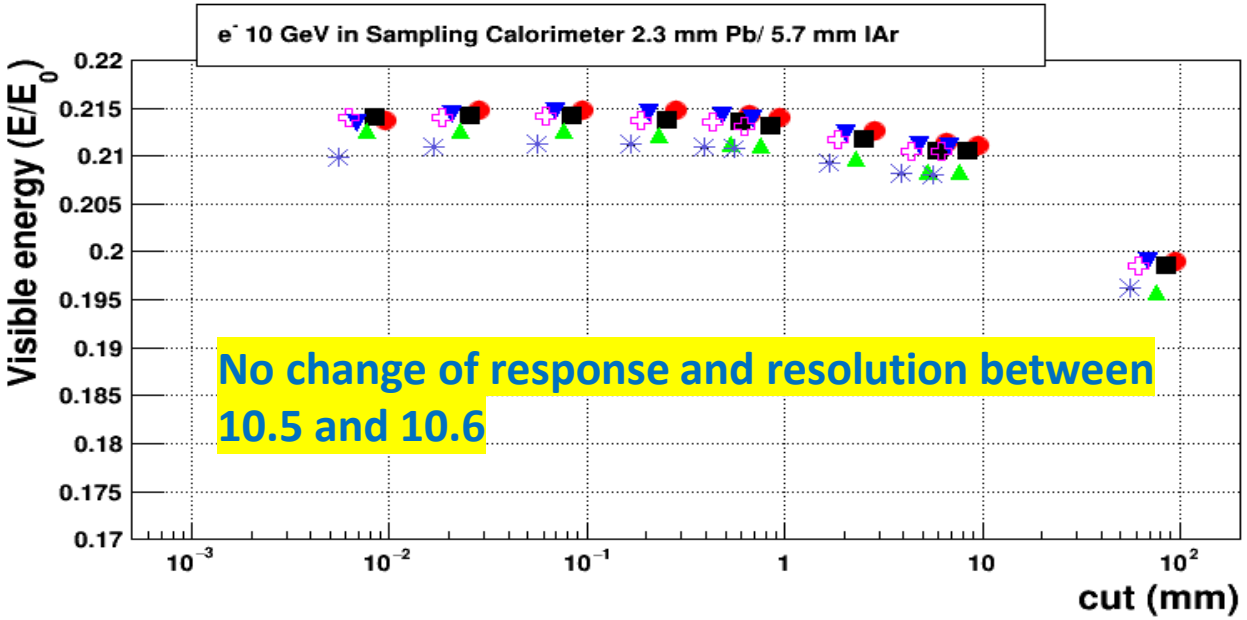
EM Physics Developments for Geant4 10.6

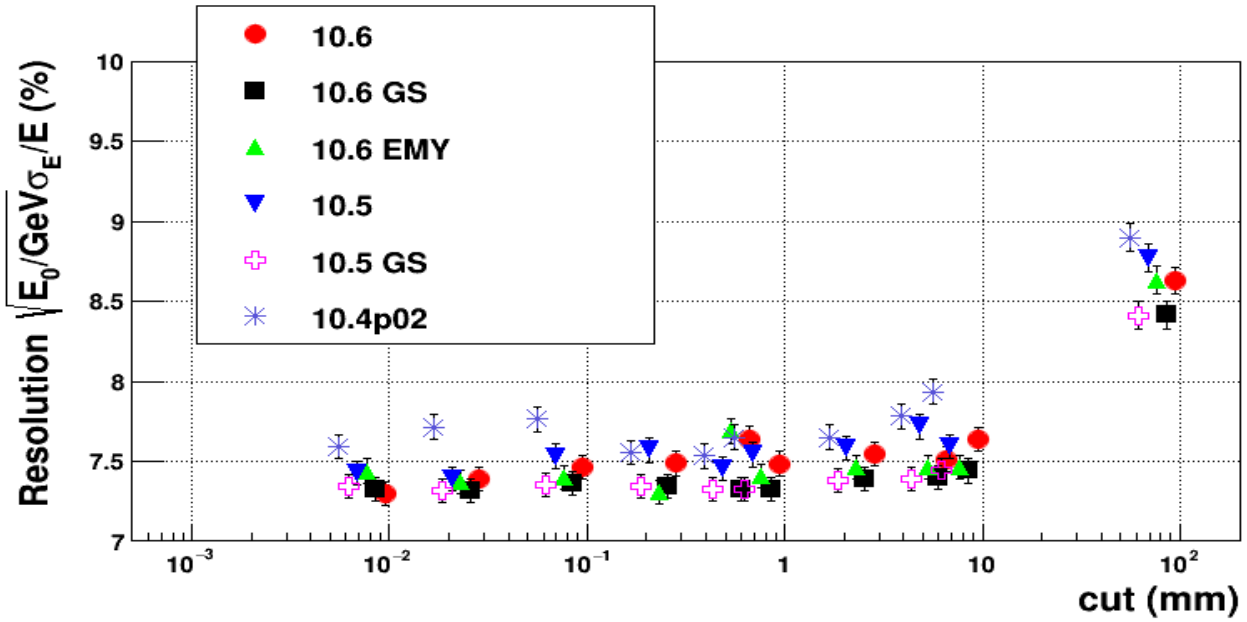
- Main updates for physics models, in particular, for multiple scattering were applied in Geant4 10.5
- Developments for 10.6 were focused on improvement of CPU performance
- Number of problem reports and requests were addressed for improvements for configuration of EM models and EM parameters
  - General process approach for gamma is available
  - New helper class *G4NIELCalculator*
  - Gamma conversion to muon pair process is extended down to production threshold (request from Gamma Factory R&D group)
- New data set is mandatory for Geant4 10.6 G4EMLOW7.9

Geant4-DNA developments for 10.6

- Physics
  - Atomic deexcitation & radioactive decay benchmarks
  - New models for electrons in gold
  - Checking and validation of sub-excitation electron thermalization models
  - New models for electrons in DNA material
  - Evaluation of proximity functions (extended example « microprox »)
- Chemistry
  - Influence of physics models and chemistry parameters on the simulation of radiochemical yields
  - Porting of TOPASnBio IRT & alternative versions to Geant4
- Geometries & damage
  - Evaluation of DNA damage in a fractal nucleus geometry
  - Dnadamage1 example

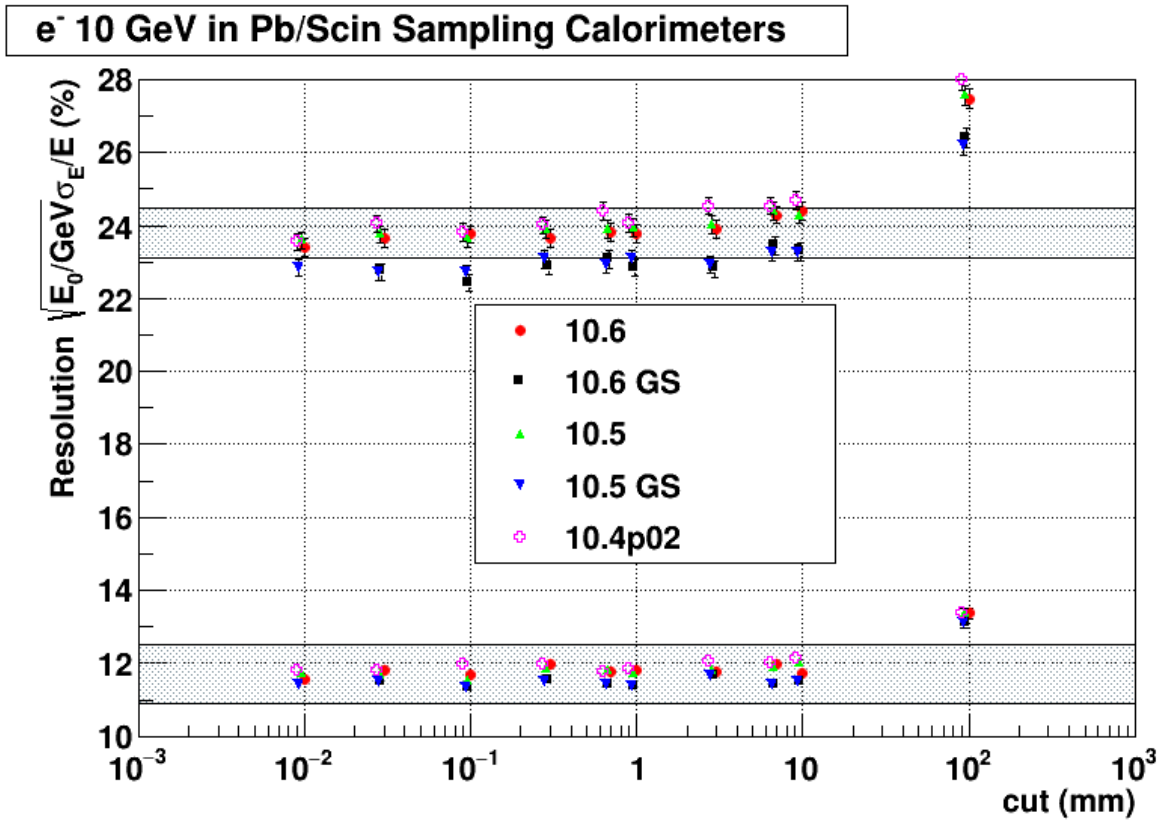
Cut dependence of ATLAS type simplified calorimeter response





Resolution of Pb/Sc calorimeters

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

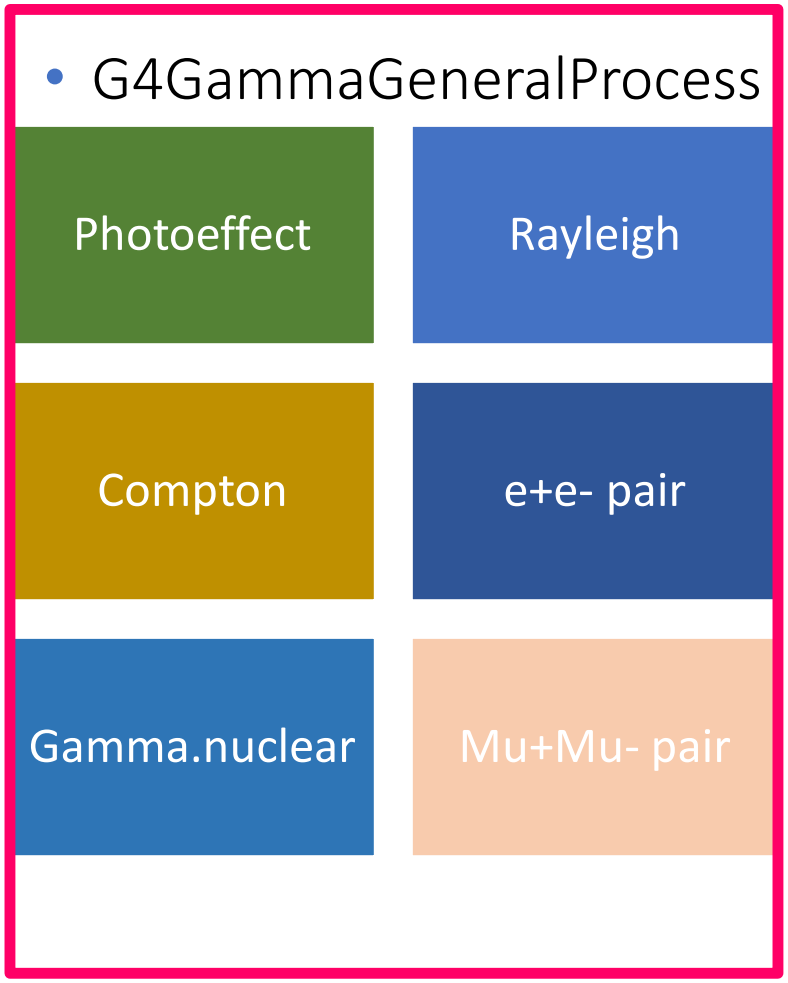


- Resolution for 10.5 and 10.6 is lower but within data errors
  - Effect is visible for high sampling fraction (thicker scintillator)

Optimization and CPU speed-up for 10.6
by Mihaly Novak (CERN)

- EM physics software was reviewed, and several optimizations were introduced into the toolkit:
  - At any step of each track EM energy loss, ranges, cross sections are recomputed using internal tables
  - Energy scales of tables are logarithmic over particle kinetic energy
    - Main optimization is in computing logarithm only once if the energy is the same
    - This also allows substantial simplify interpolation code reducing number of lines of code used at a step practically by 10 times
- Benchmark results for CMS geometry without hit creation:
  - ~8% for Mac Book Pro (Mac OS 10.13.2) 2.8 GHz i7
  - ~5 % for AMD (SLC6 gcc8.2.0) 3.5 GHz

General Gamma Process



- SteppingManager sees only 1 physics process
  - Only 1 mean free path
  - Plus transportation
- Enabled via UI command
  - In 10.6 it is optional in general, UI command may be used to enable it
  - /process/em/UseGeneralProcess true
  - Is the default for Opt1 EM physics
- Reduced number of instructions
  - Advantage in CPU ~5%
  - Extra PhysicsTables shared between threads – a bit more memory
- Final numbers for CPU/memory should be checked by users

Configuration of EM physics

- A set of EM physics constructors are provided together with each recent Geant4 version
  - The default (Opt0) EM physics is optimized for use in HEP
  - There are variants Opt1 (EMV) and Opt2 (EMX) with simplified multiple scattering and other options
  - The alternative Opt4 (EMZ) physics is a combination of the most accurate EM models
    - Is recommended for R&D and detector performance studies
    - For 10.6 will use 5D gamma conversion model
    - It is substantially shower than the default EM physics
- On top of any EM physics configuration it is possible to customize EM parameters via UI commands and C++ interface
  - G4EmParameters class may be called
  - EM physics configuration and PAI ionization model may be defined for one or more G4Region(s)
    - This feature is used already by ALICE and CMS

How to speed-up simulation of a concrete detector?

- In Geant4 10.6 following customization options for EM physics are recommended:
  - Production thresholds (cuts in range) per G4Region
  - Tracking cuts per particle type
  - General process for gamma may be enabled
- Different multiple scattering parameters may be tuned per G4Region (per sub-detector)
  - Range Factor, Geom Factor, Stepping algorithm, Lateral displacement
  - New in 10.6: Safety Factor , Lambda Limit
- User may design EM physics constructor with multiple scattering models separately defined per G4Region or use G4EmConfigurator interface