Multiple scattering and EM builders

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Outline

- EM builders and general approach for EM Physics Lists
- Ionisation models in 9.4 EM builders
- Current status of MSC and single scattering models
- MSC in 9.4 EM builders

General approach: EM builders from physics_list sub-library

- The main advantages of using of EM builders:
  - Quality of results guaranteed by Geant4 testing
  - Testing suites can work only with well defined physics configuration which is known both for developers and users
- We need encourage users especially novice to use EM builders
- We need to migrate to EM builders in majority Geant4 examples and tests
  - N02 and N03 the most urgent
  - Further development of EM builders will be automatically used by examples
  - Example code become more compact
- Advanced users may create custom EM physics

EM Physics Builders for 9.4 (available since g4 9.3)

- G4EmStandardPhysics – default
- G4EmStandardPhysics_option1 – HEP fast but not precise
- G4EmStandardPhysics_option2 – Experimental
- G4EmStandardPhysics_option3 – medical, space
- G4EmLivermorePhysics
- G4EmLivermorePolarizedPhysics
- G4EmPenelopePhysics
- G4EmDNAPhysics

Combined Physics
Standard > 1 GeV
LowEnergy < 1 GeV

- We want to keep these 8 builders
  - Better do not extend this list
  - Difficult to reduce

Optional EM Builders for 9.4

- G4EmExtraPhysics:
  - G4SynchrotronRadiation by default disabled, may be enabled via UI command
- G4OpticalPhysics includes all optical processes

Ideal Approach to Change EM physics

- Main advice for majority of users:
  - Select EM builder
  - Define cut in range to be smaller than smallest size of the critical part of geometry
  - Use UI commands to change cut value
  - Establish step limit in volumes of interest
- Use UI command or G4EmProcessOptions helper class to change EM options
  - For example, max energy of EM tables and number of bins may be changed to reduce initilisation time and table size
- If we not yet have UI command let us discuus and establish one

How to change EM model in 9.4?

- In some cases default models should be substituted
  - In order to test a new model
  - In order to have specialized in some part of the setup
- G4EmConfigurator helper class – easy way to add a model
  - Should be applied on top of selected EM builder
  - Addition of a model for particle type, energy range and detector region
- TestEm8 showing how to add PAI model for gas volume
- Microdosimetry advanced example shows how to add DNA processes for a small region only

Ionisation models in standard EM constructors

New anti-particles in 9.4

- In EM builders EM processes are added explicitly for the defined list of particles
- When anti-deuteron, anti-triton, anti-alpha, anti-He3 will become Geant4 ‘stable’ particles they will be included in all EM builders

Ionisation in 9.4

- We propose to use G4ICRU73QOModel for all low-energy negatively charged hadrons and muons (A.Bagulya)
  - Used in 9.4beta
  - Minor improvement for ranges
- In Livermore Physics List low-energy ionisation model will be below 1 MeV (all other models below 1 GeV)
  - see M.Tsagri talk at 1-A
- We propose to use modified by L.Urban fluctuation model for all physics lists
  - No effect on calorimeter response
  - Significantly improved signal in gaseous detectors

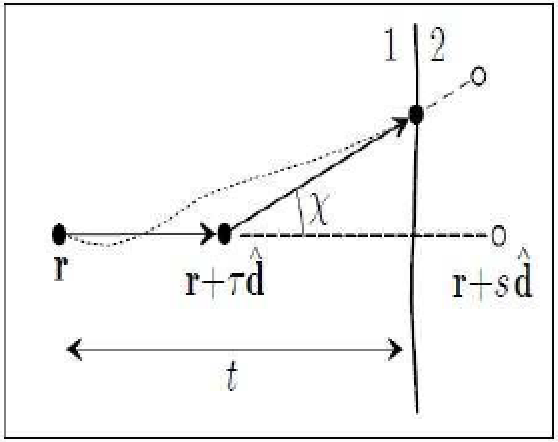
Status of multiple and single scattering

Elastic scattering models

- In EM standard sub-library there are G4CoulombScattering process and two models (E > 1 keV):
  - G4eCoulombScattering – simplified nuclear recoil
  - G4CoulombScattering – Lorentz invariant nuclear recoil
- In TestEm7 there is Vanderbilt process for low-energy ion (<100MeV/u) scattering
  - G4ScreenedNuclearRecoil

Multiple scattering – effective simulation of particle transport

- Many elastic scatterings sampled at the particle step
- Theory was developed more than 80 years ! (Wentzel paper 1928)
- Step limitation increase precision
  - CPU performance penalty
  - Effect of step limitation is clearly seen in LHC experiments
- Path length correction
- Sampling of scattering angle
  - Central part and the tail
- Displacement of end point
  - Gaussian part and tail



Geant4 multiple scattering models

- All MSC models (G4, EGS, Penelope…) use the same base theory of screened Rutherford scattering
  - The difference only in implementation details
- Urban model – significantly used empirical parameterisations in order to optimise precision and CPU performance
- Goudsmit-Saunderson model is based on the well established theory
  - Is focused on electrons and positrons
- WentzelVI combines single scattering for large angles and multiple scattering at small angles, also based only on theory
  - Initially was focused on muons and hadrons
  - Can be applied to other particles

Theory based MSC model of O.Kadri

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

-Angular distribution

-Displacement sampling

-Path length limitation

The G4GoudsmitSaunderson model use:

-Goudsmit-Saunderson ➔ Angular distribution (F.Salvat provided ELSEPA code)

-I. Kawrakow and A. Bielajew ➔ Lewis moments ➔ Displacement sampling

-L. Urban ➔ Path length limitation

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

- Total elastic cross section
- First transport cross section

Overview of GS model (O.Kadri)

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

$$Q_l = 1 - yK_1(y)\left\{1 + 0.5y^2\left\{1 + \frac{1}{2} + \ldots + \frac{1}{l} - 0.5\ln(l(l+1)) - 0.5772\right\}\right\} \quad y = 2\sqrt{l(l+1)A}$$

A:screening parameter

s/Lambda : path length in terms of mean free path

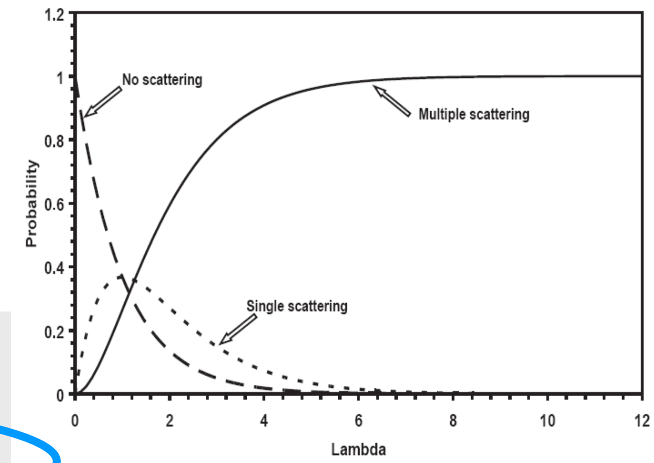
No scattering

Single scattering

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

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

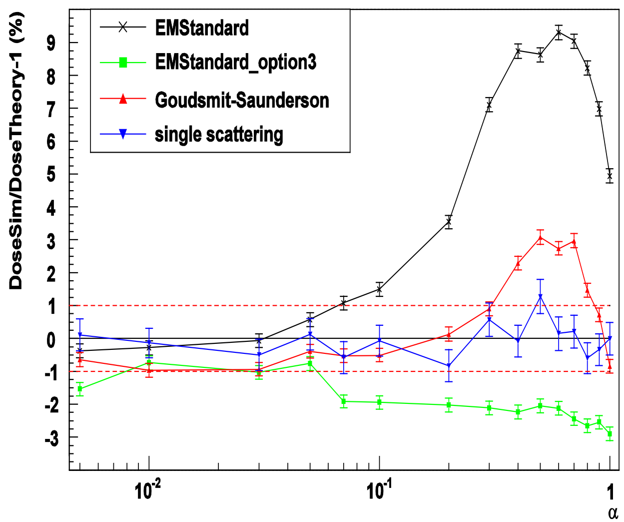
Multiple scattering

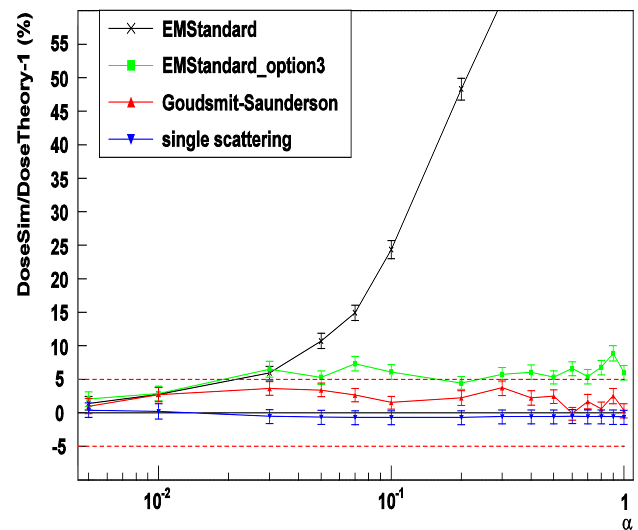


WentzelVI model

- Is much more simple but fully theory based
- Dynamically (depending on momentum) the angular limit for single scattering is selected
  - May be applied for transportation in vacuum or low-density media
- Has original step limitation
- Can be used together with hadronic diffuse elastic model developed by V.Grichine

Recent Fano Cavity validation results (S.Elles)

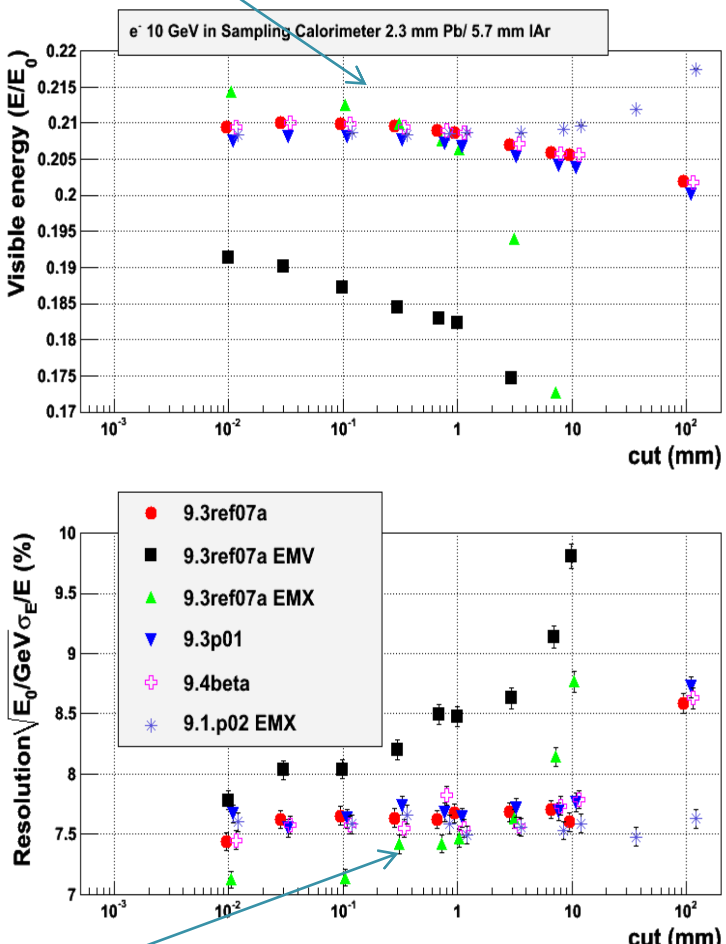


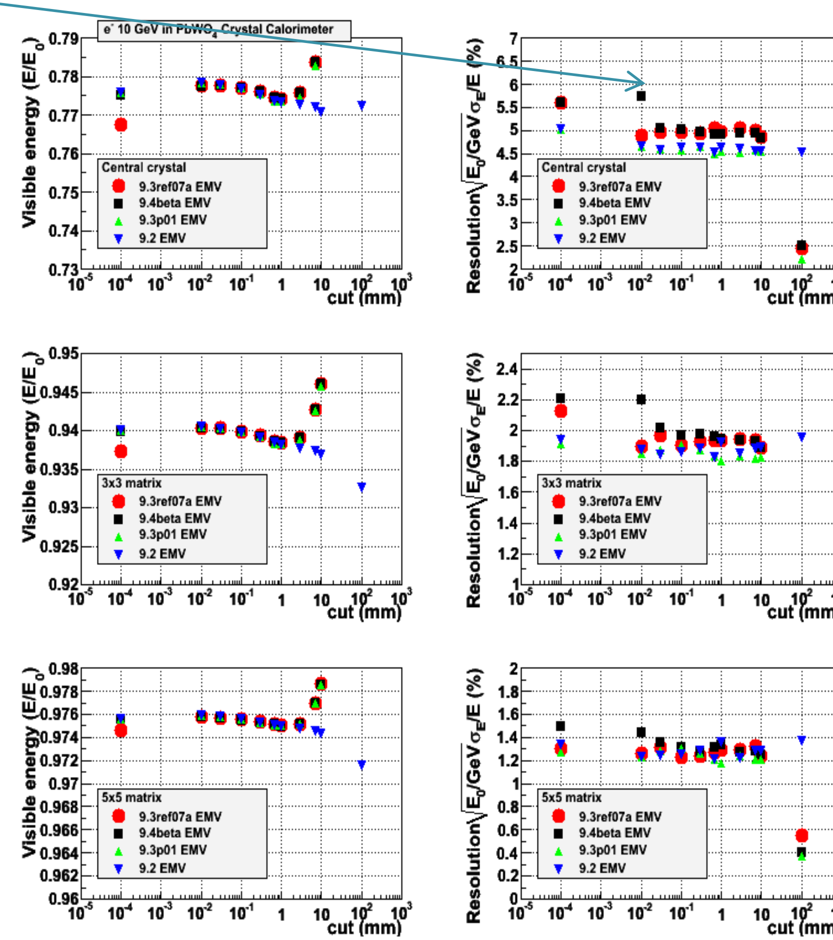


- Dependence of ionisation dose inside the cavity demonstrates precision of MeV electron transport

Calorimeter response

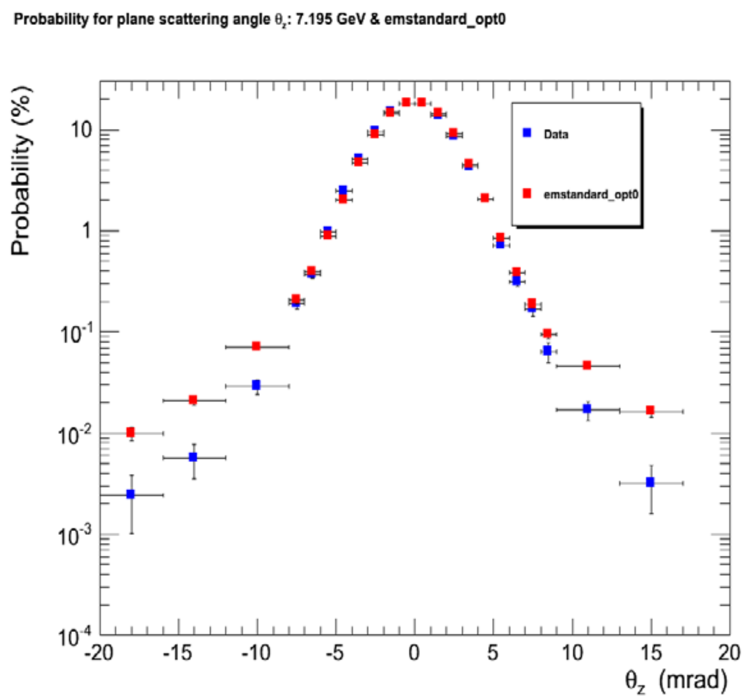
Effect of MSC

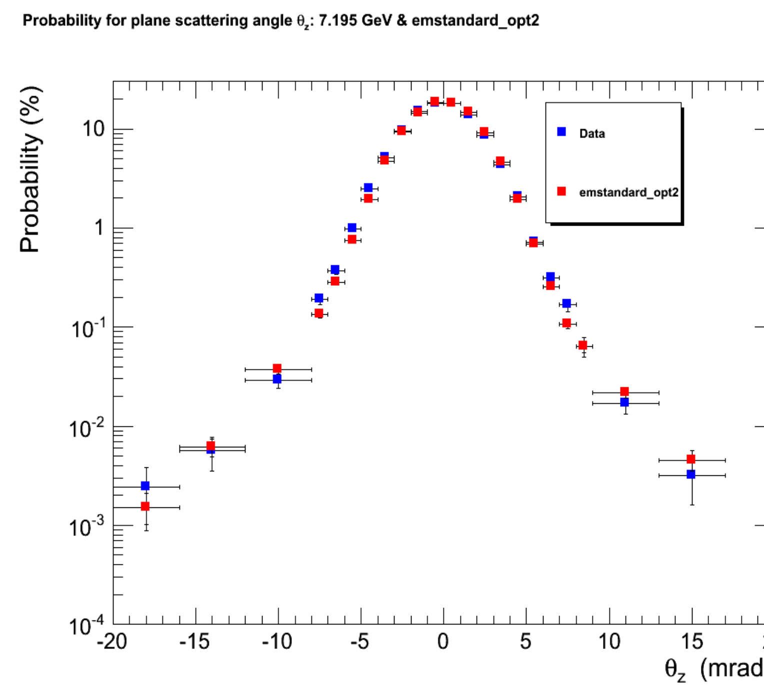




WentzelVI problem

New test of high energy MSC CERN summer student (O.Dale)





- Urban model overestimates tail,
- WentzelVI and Colomb scattering model s more close to the data
- See today parallel session

Proposal for configuration of MSC models for 9.4

Default EM constructor

- Use UrbanMscModel93 for electrons and positrons by default instead of G4UrbanMscModel92
  - Tuning to electron data for light media
- Sampling calorimeters (ATLAS, LHCb):
  - 0.5% increased visible energy
  - Relative resolution unchanged
- CMS-type calorimeter crystal calorimeter:
  - 5% increase of relative width of energy deposition in central crystal
  - Peak position of the signal unchanged

Default EM constructor

- Proposal to use G4WentzelVI + G4eCoulombScattering models for muons instead of G4UrbanModel90
  - The best results for all muon data

Standard EM constructor Option2,3

- Proposal to use G4WentzelVI + G4eCoulombScattering models for muons instead of G4UrbanModel90
  - The best results for all muon and hadron data
- Proposal to use G4WentzelVI without single scattering assuming that hadron elastic will be active instead of G4UrbanModel90
  - This option is not well tested yet
- Is there any sense to leave WentzelVI for electrons – quality is not good for today?

Combined EM constructors standard + low-energy

- Proposal to use GS model for electrons and positrons
  - Very good results for number of tests
- Proposal to use G4WentzelVI + G4eCoulombScattering models for muons instead of G4UrbanModel90
  - The best results for all muon and hadron data
- Proposal to use G4WentzelVI without single scattering assuming that hadron elastic will be active instead of G4UrbanModel90
  - This option is not well tested yet