Standard electromagnetic physics update

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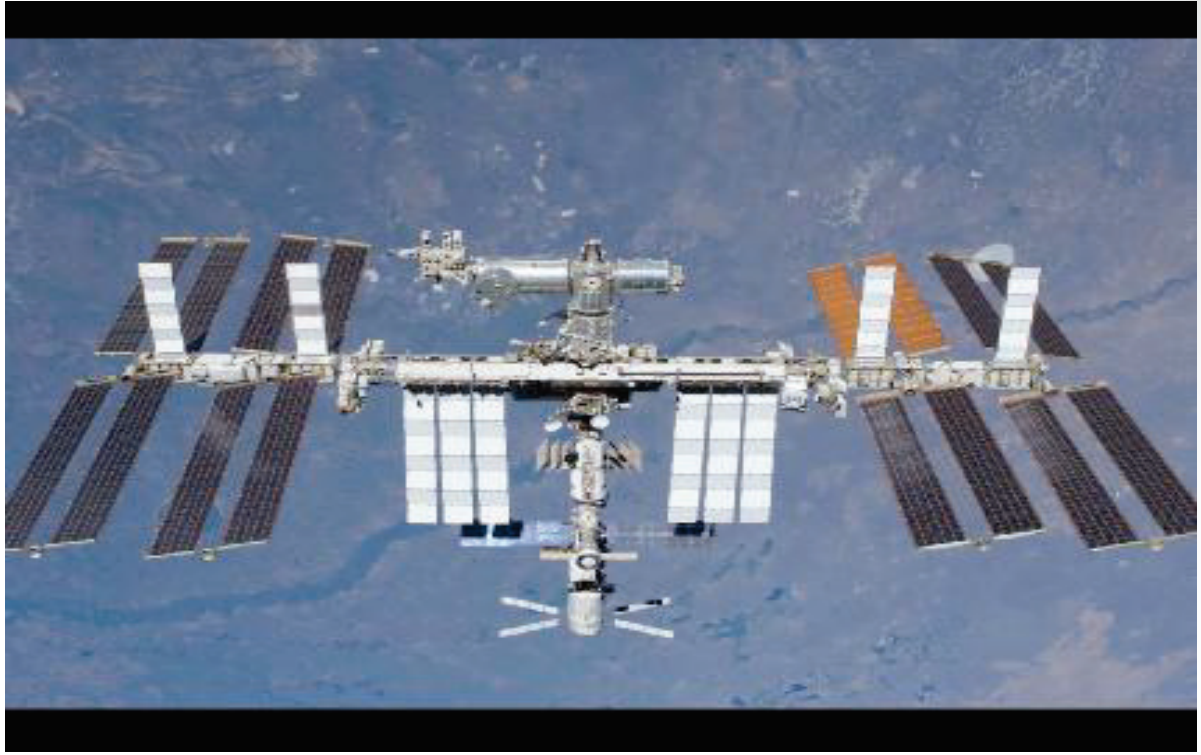
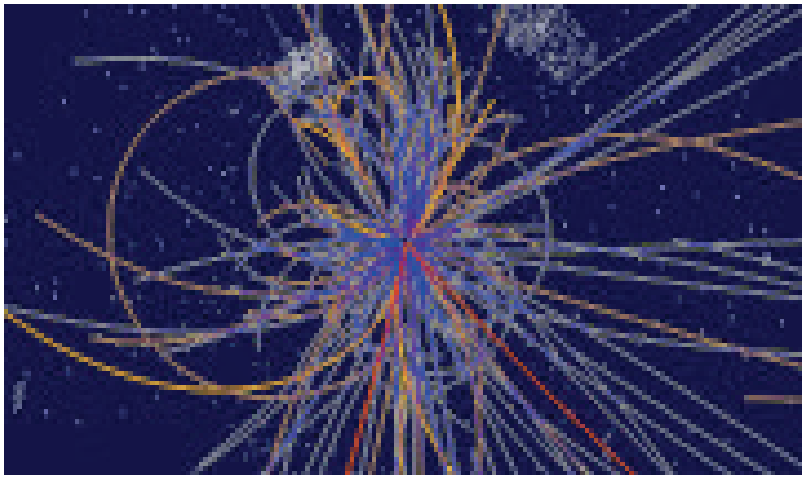
Outline

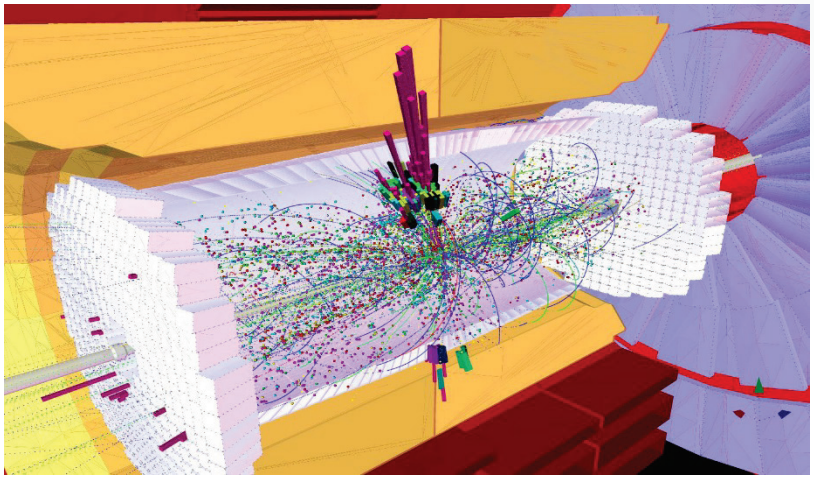


- Geant4 EM physics status
  - Consolidation of Geant4 EM physics
  - Multithreading mode
  - EM parameters
- Hightlight on selected developments for EM standard
  - Ionisation
  - Multiple scattering
  - EM physics Lists
- EM physics in Geant4 10.2
- Summary

- We will concentrate on the current Geant4 10.1patch02 and future 10.2

Standard EM physics





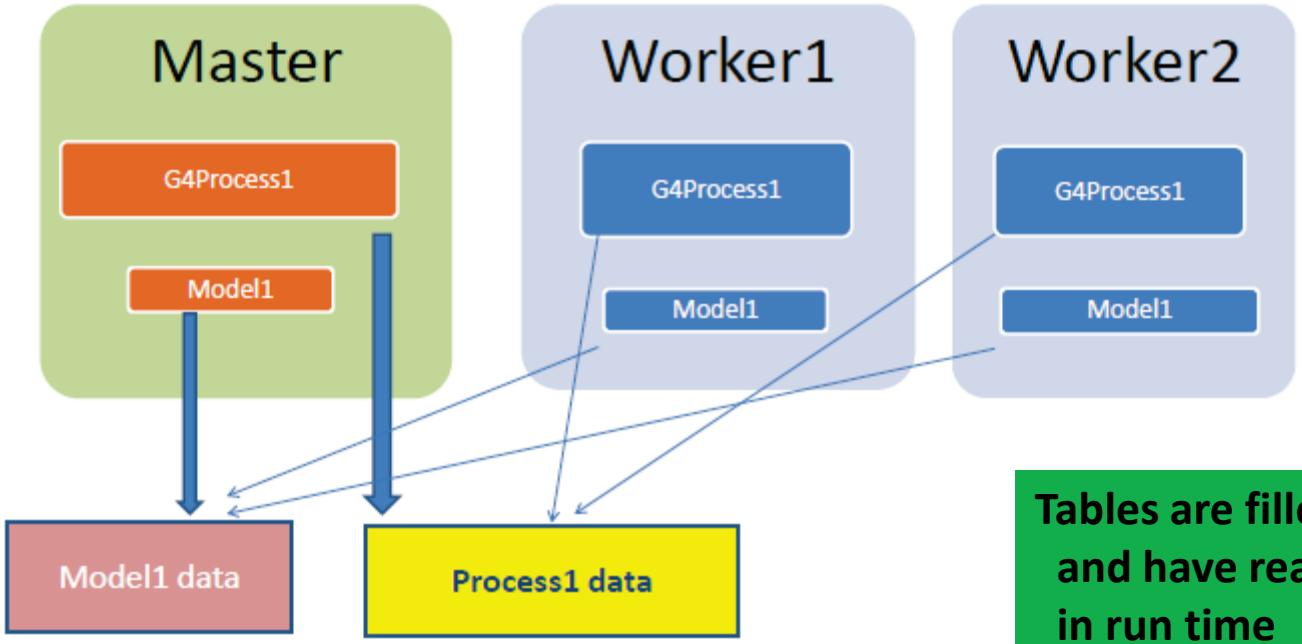
- First priorites – LHC requiremets
  - LHC run-1 was performed using simulation with Geant4 9.4
  - LHC run-2 is starting with Geant4 9.6 (ATLAS) and 10.0 (CMS)
    - Geant4 10.1 will be used in 2016 by ATLAS and CMS
- Main EM developments for LHC:
  - CPU performance improvements and memory reduction
    - About 10% overall speed-up from 9.6 to 10.1 in a good part due to EM physics speedup
  - Multi-threading will be used for 2016 production for CMS
  - Physics performance of Geant4 EM is fine for LHC applications in general
    - Improvements of the very high energy EM models are introduced recently
    - Some very high nergy models needs refinments

Consolidation of EM physics

- Since Geant4 9.6 the unification of all EM sub-libraries (standard, low-energy, highenergy, muons) has been completed
  - Common validation become possible
    - Applicability range of models is better defined
  - Reuse the same components in different sub-packages
    - Angular generators for sampling of final states
    - De-excitation module
    - Built-in biasing
    - G4EmCalculator and other helper classes
  - New sub-libraries (dna and adjoint) following the same design
- The unification help a lot for the development of the MT approach for EM sub-libraries
  - MT modifications were first introduced in common base clasess
  - Similar design solutions are used across EM sub-libraries to complete MT migration

EM data sharing for Geant4 MT

- The scalability of Geant4 application in the MT mode depends on how effectivly data management is performed
- Shared EM physics data:
  - tables for cross sections, stopping powers and ranges kept by process classes
  - Differential cross section data kept by models
  - Material propertes in material data classes
  - EM parameters established for Physics Lists



Tables are filled by Master and have read-only access in run time

Electromagnetic parameters

- In previous versions of Geant4 EM parameters were defined via UI commands and C++ interface G4EmProcessOptions
  - Via this class each EM process was accessed one by one in order to set parameter value
- Experience with Geant4 10.0 demonstrates some limitations of old methods:
  - G4EmProcessOptions class cannot be instantiated in any place of user code anymore as it was in sequential mode
    - This class is kept for backward compatibility but will be removed later (may be in 10.3)
  - Not all UI commands were normally executed
    - Parameters should be equivalently set in master and worker threads
    - User UI commands works without a gurantee

New EM parameters schema

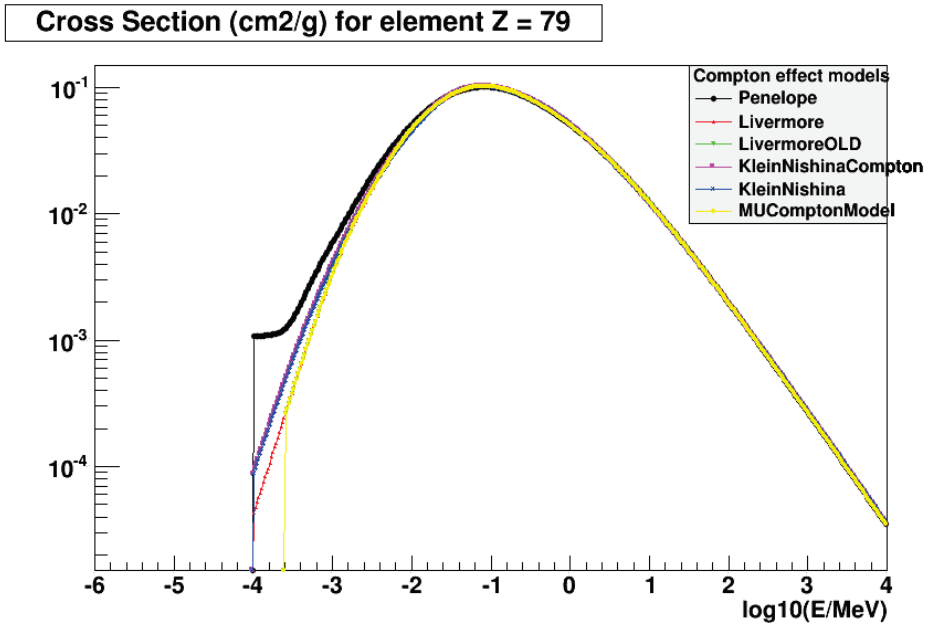
- Since Geant4 10.1 EM parameters are subdivided into two groups:
  - First group of static parameters is kept in the new pure singleton G4EmParameters class which is shared between all threads
    - They may be modified by user at any moment via UI command or C++ interface
    - EM processes/models access parameters at initialisation of a run
    - Changings parameters during the run are not applied until the next run starts
    - For 10.2 we may provide a «lock» mecanism allowing to fix parameter value per model/G4Region
  - Smaller group of parameters which are different for different particle type/process in the old way
    - Step function, number of bins, emin, emax, integral option
    - For the second group if a UI command is issued it will be applied to all particle/processes in all threads
      - We would not recommend use this method in production
- Adiabatically the old G4EmProcessOptions class is removed from examples/tests
  - Will still remain in part of examples in 10.2
- Please, make your validations of the new EM parameters schema and report problems

List of new UI commands

- New interfaces of G4EmParameters:
  - SetMuHadLateralDisplacement
  - SetMscMuhadRangeFactor
  - SetMscMuHadStepLimitType
- Corresponding UI commands:
  - /process/msc/MuHadLateralDisplacement
  - /process/msc/RangeFactorMuHad
  - /process/msc/StepLimitMuHad
  - Old commands are working only for e+-
- New UI commands:
  - /process/em/deexcitationIgnoreCut true
  - /process/eLoss/UseAngularGenerator true
  - /process/em/lowestElectronEnergy 50 eV
  - /process/em/lowestMuHadEnergy 100 keV
  - ....

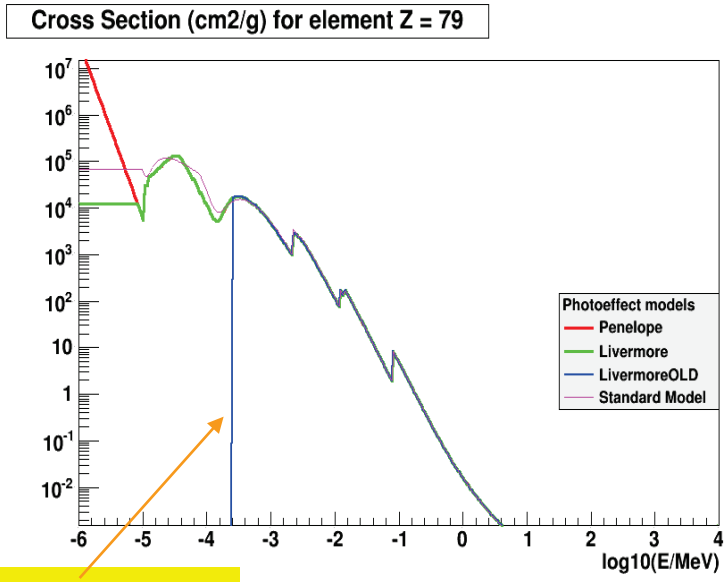
Cross sections for γ-rays in Geant4 10.1

common approach for all EM models



Compton scattering cross section now are forced to zero at low-energy limit – no Compton scattering below the limit

Photo-electric effect cross sections are now not zero below min ionisation potential: γ-rays always absorbed



Old Livermore

Plots from ESA project BIORAD-1

HIGHLIGHT ON SELECTED DEVELOPMENTS FOR EM

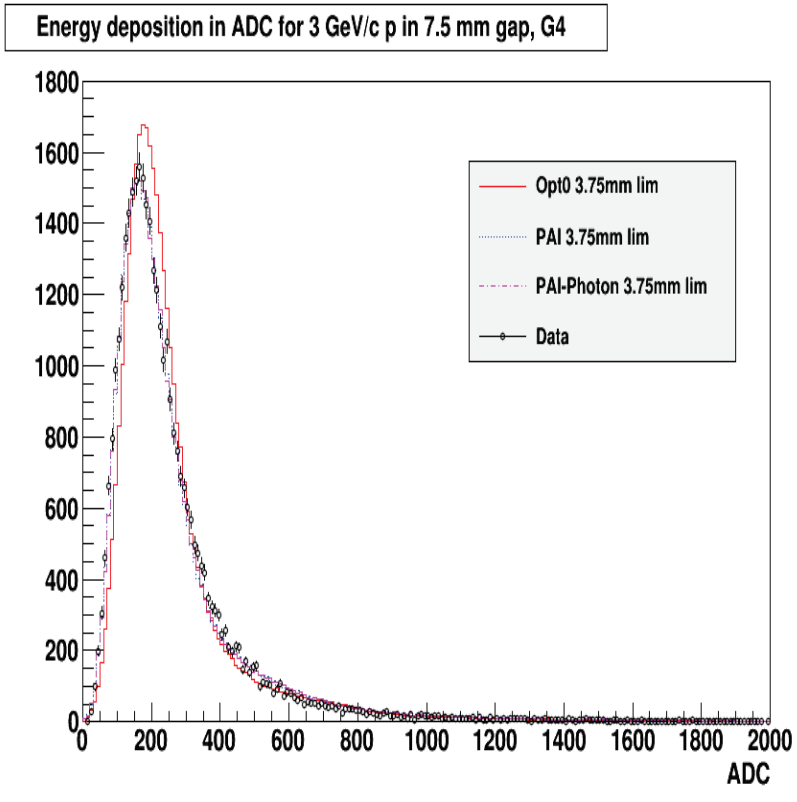
Ionisation processes/models improvements

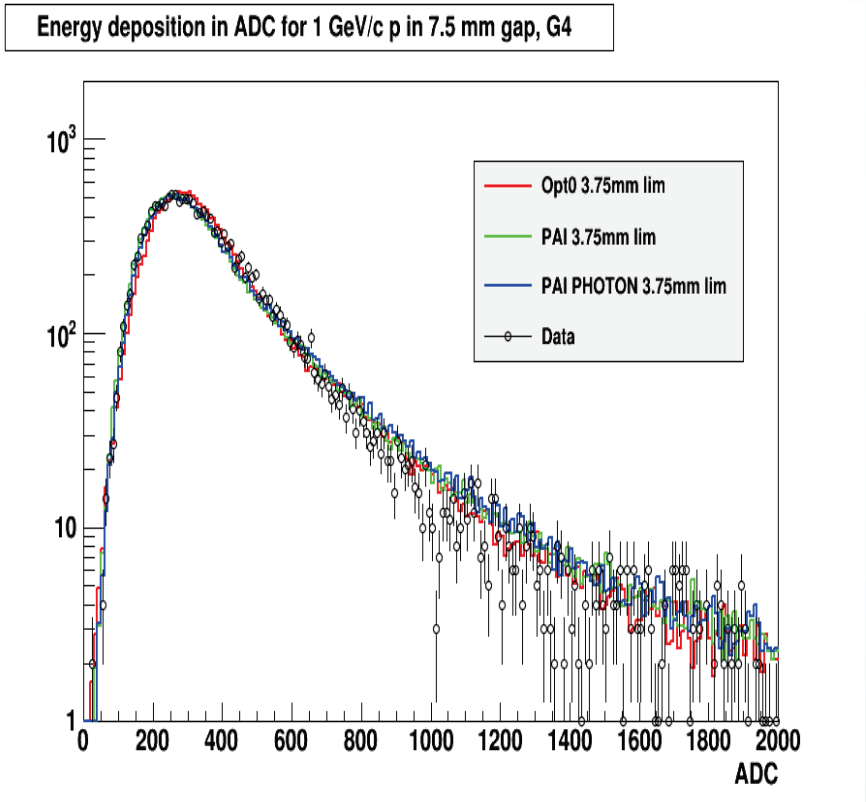
- Improved PAI models (G4PAIModel, G4PAIPhotModel)
  - Adding some CPU penalty compared with the Urban model, so should be applied only for specific sensitive volumes
  - in the MT mode can be applied now (10.2beta) for several G4Regions
  - PAI model provides stable energy deposition step independently on step size
- Improved Urban model (G4UniversalFluctuations)
  - Mainly CPU performance
- Fixed density effect parameterisation for gasses and mixtures
- Added angular generator for sampling of delta-electron angle taking into account electron PDF distribution
  - May be enabled for any ionisation model

Energy deposition in ALICE TPC Geant4

Nucl. Instr. Meth. A, 565, 551-560 (2006)

Int. J. Mod. Phys. *E*, **16**, 2457-2462 (2007)

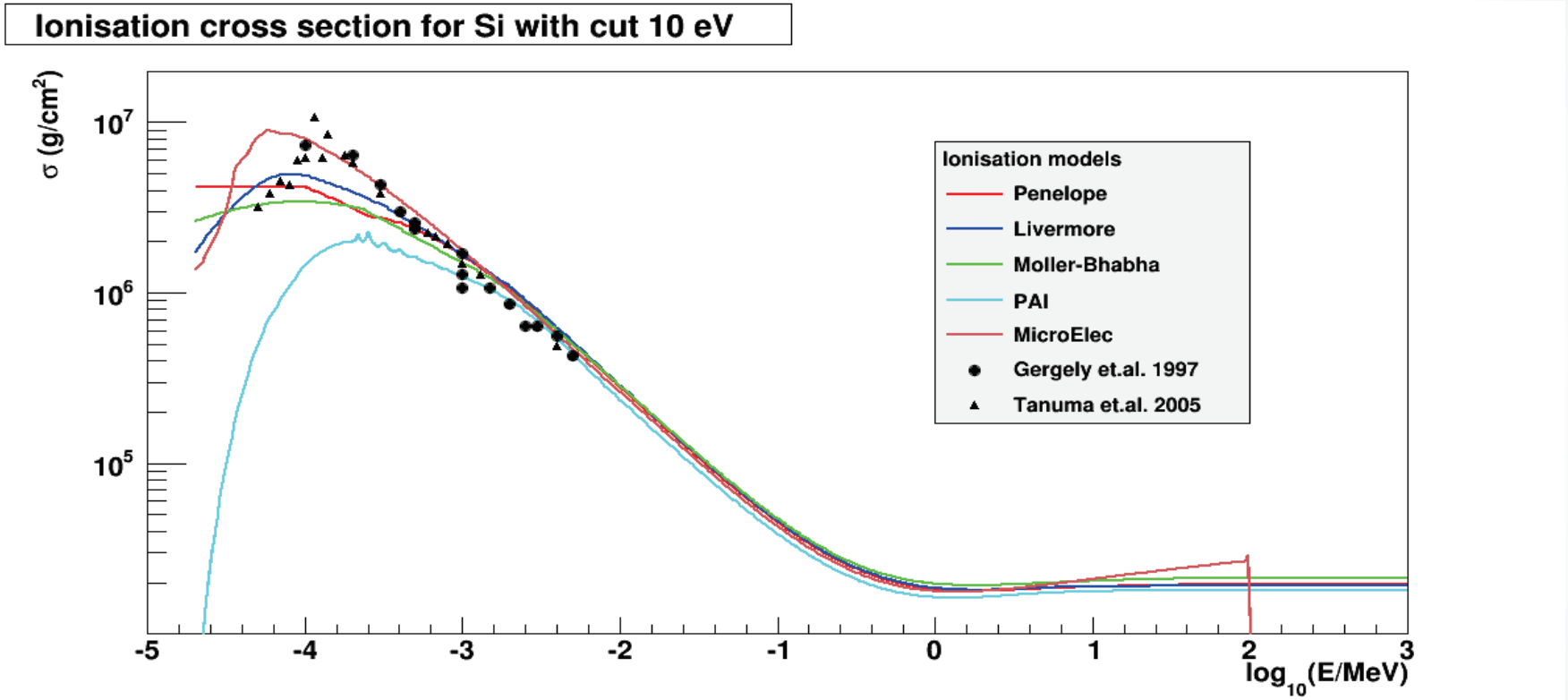




New features available for ionisation models

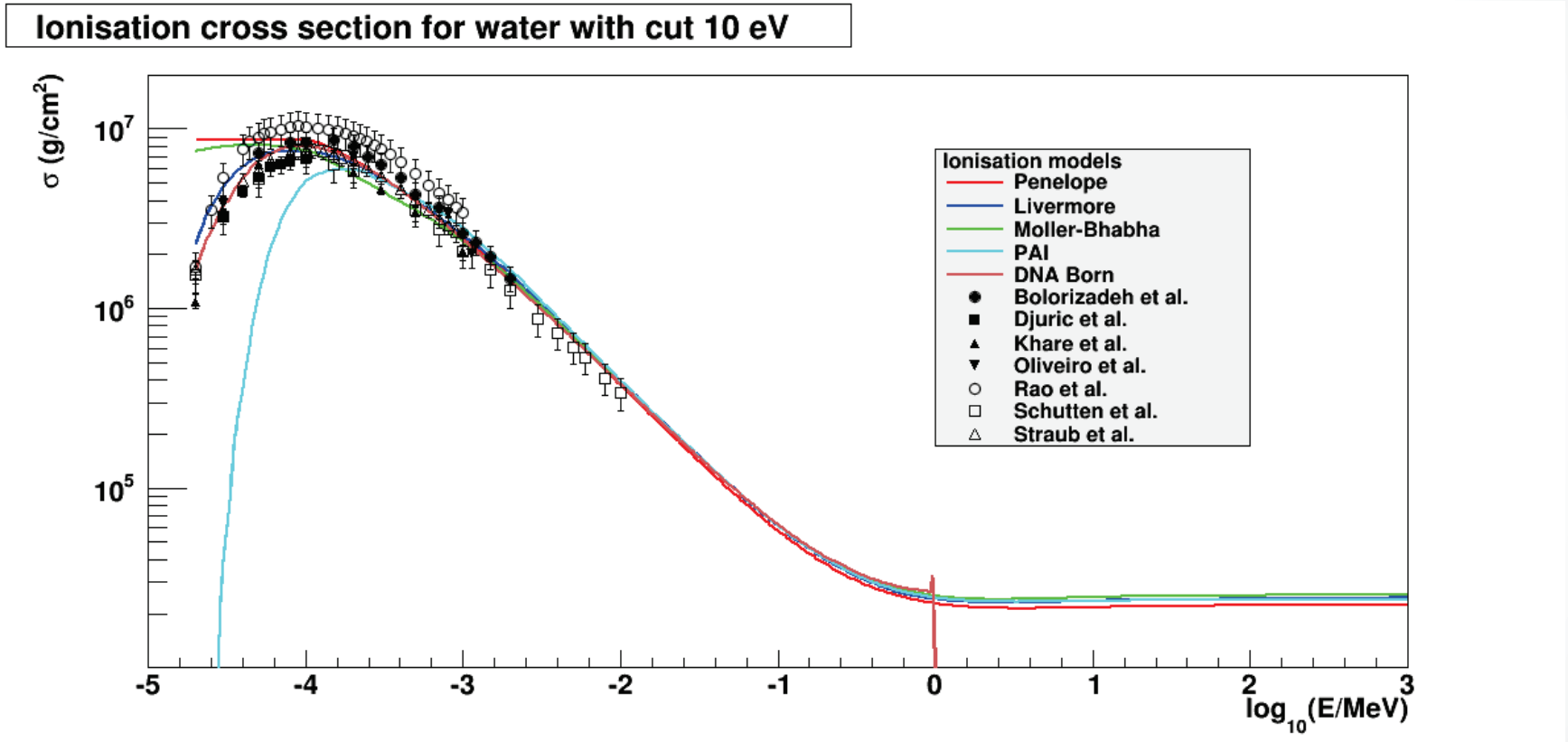
- Introduced lowest energy limit to all energy loss processes (10.2beta)
  - Separate values for e+- and muons/hadrons/ions
    - Can be defined via UI commands
  - Done for all sub-packages from standard to dna
    - If final energy after a step become below this limit then this energy is aded to the energy deposit at the step and the final energy is set to zero
  - Removed hidden lowest limits from ionisation and elastic scattering models
    - These limits were needed to avoid slow tracking of low-energy particles with many small steps in LHC simulations
- Introduced a new interface G4VSubcutProcessor which may be implemented by a user and added on top of any Physics List per G4Region (10.1)
  - Allowing production of secondary electrons below production threshold
  - This approach adresses long standing requirement from space users

Electron ionisation cross section in Silicon (BIORAD-2 ESA funded project)



- Ionisation cross section: $\sigma(E) = \sigma_R(E, T_c) + \frac{1}{\Delta_E}\frac{dE}{dx}(E, T_c)$, where Δ_E= 50 eV, T_c= 1 keV is cut independent

Electron ionisation cross section in liquid water (BIORAD-2 ESA funded project)



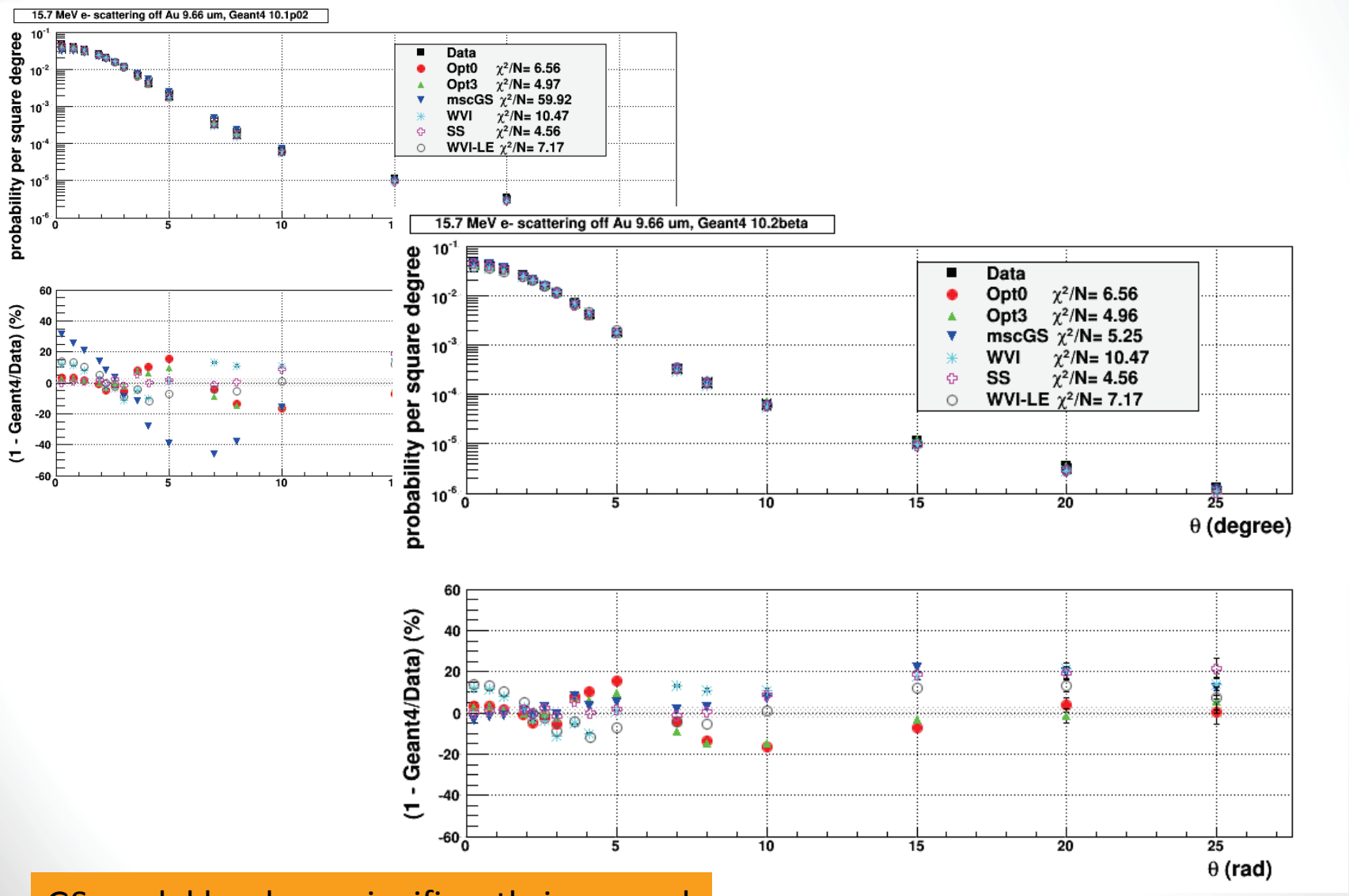
- Using this approach it is possible to define applicability range for DNA and standard/low-energy models and simulate full spectra of secondary electrons down to zero energy

Single and multiple scattering models evolution

- MultipleScattering models:
  - G4UrbanMscModel
    - Since 10.0 we have only one version of the Urban model
    - For 10.1 the model was updated to increase CPU performance
    - For 10.2 a new correction factor for positrons was added and improved mechanism of lateral displacement may be introduced
  - G4WentzelVIModel – minor tuning for 10.1
  - G4GoudsmithSoundersonModel
    - For 10.2 is completely rewritten (M. Novak, CERN)
    - Sampling according to EGSnrc prescriptions
    - Effective algorithms of sampling is introduced
    - CPU performance and accuracy become competative to other models
- Single scattering models:
  - G4eCoulombScatteringModel – minor tuning
  - G4hCoulombScatteringModel .- reviewed and updated for 10.2
  - G4IonCoulombScatteringModel – reviewed and fixed in 10.1.p02

Hanson data for e- scattering off thin foil

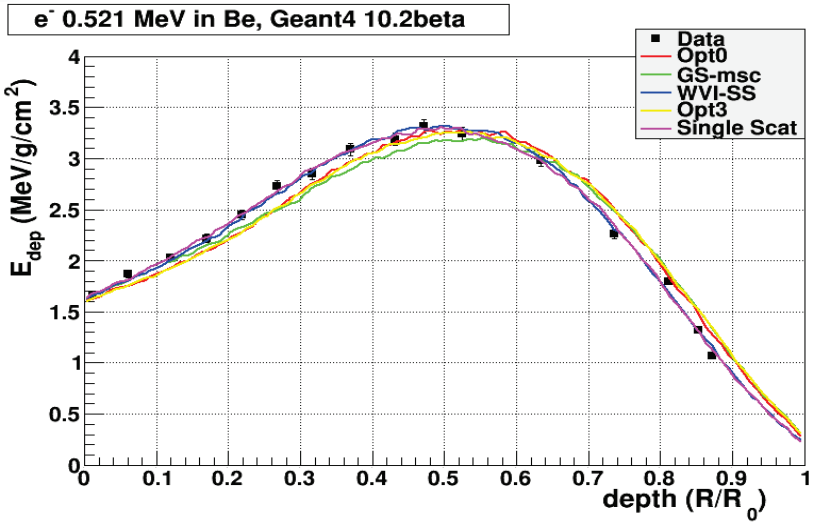
Phys. Rev. 84, p. 634-637, 1951.

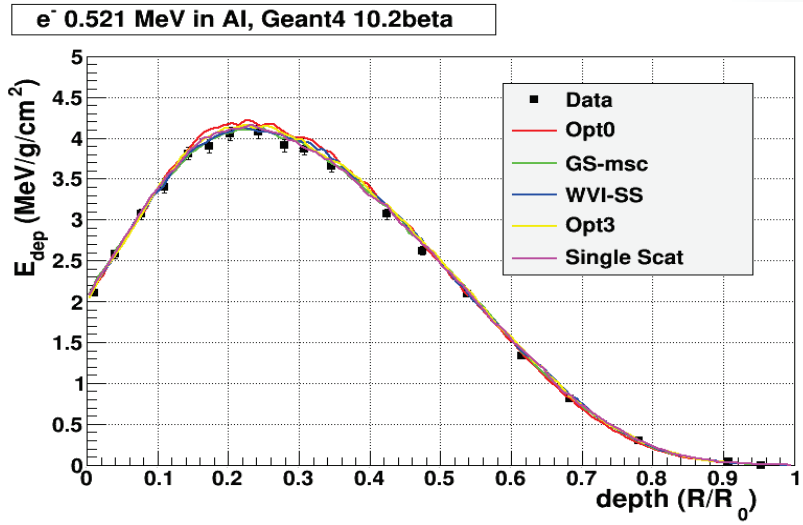


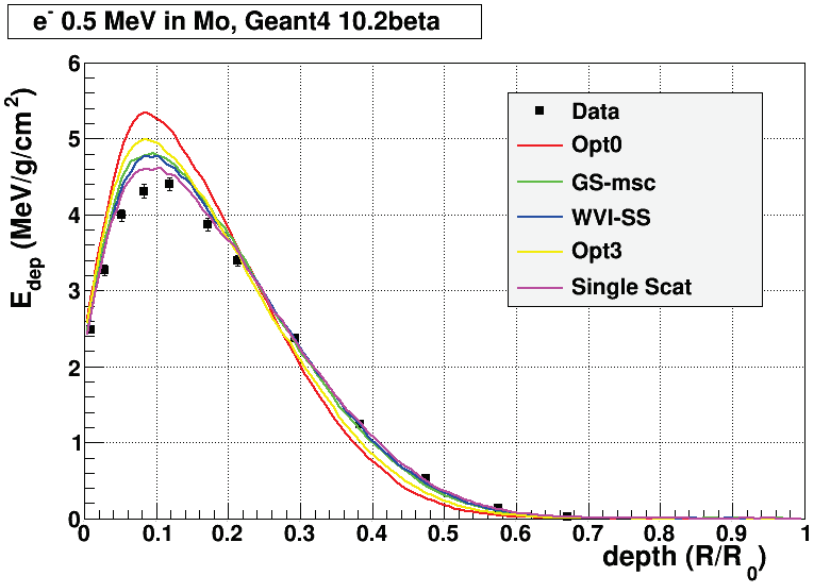
GS model has been significantly improved

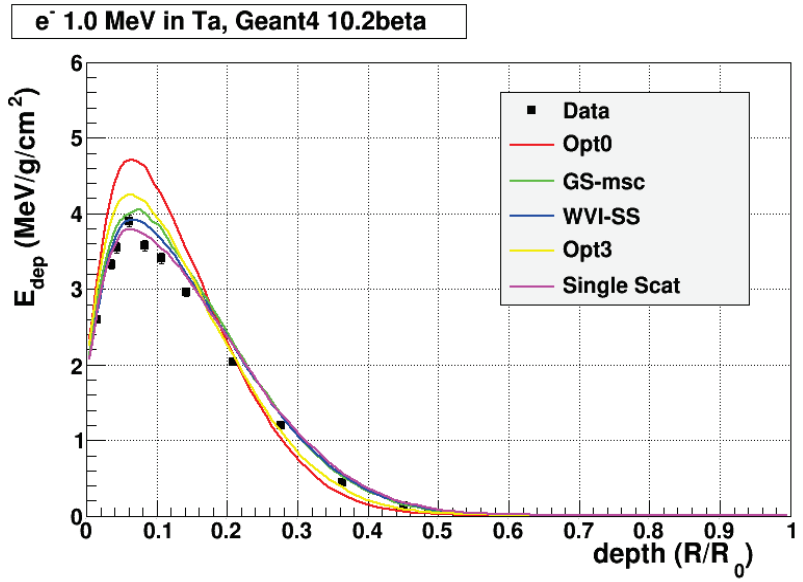
Sandia data – backscattering

NIM B 258 (2007) 381









Fano Cavity benchmark
(Sabine Elles)

Fano cavity test case

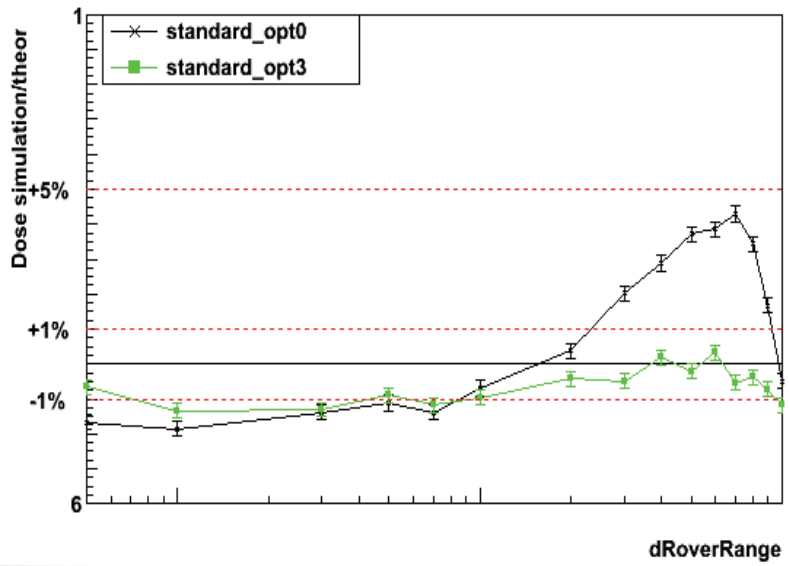
Ratio between simulated and theorical dose deposited by a 1.25 MeV photon beam crossing an ionization chamber

Geant4 release : 10-01-ref-07

Basic test (no fluct, no msc):

standard_opt0 : 0.9946 +/- 0.0002 for dRoverRange = 0.004
standard_opt3 : 0.9977 +/- 0.0002 for dRoverRange = 0.004

Full test (fluct & msc):



Fano cavity test case

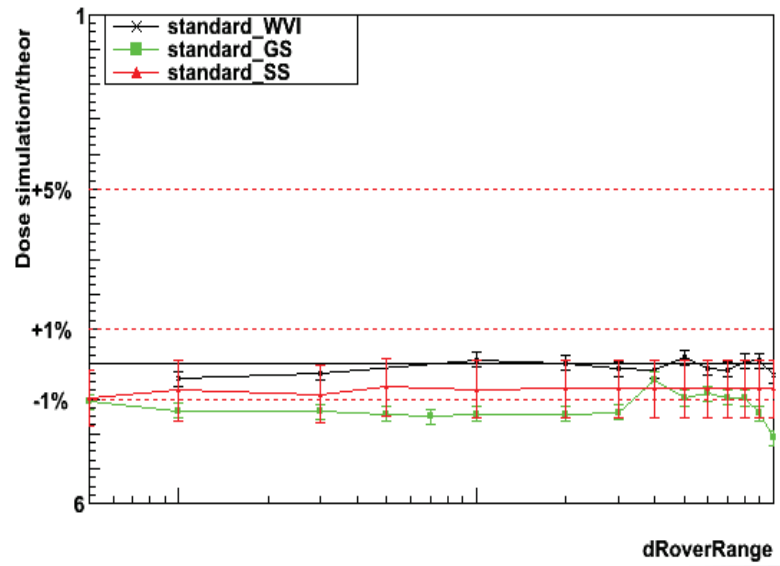
Ratio between simulated and theorical dose deposited by a 1.25 MeV photon beam crossing an ionization chamber

Geant4 release : 10-01-ref-07

Basic test (no fluct, no msc):

standard_WVI : 0.9993 +/- 0.0006 for dRoverRange = 0.004
standard_GS : 0.9977 +/- 0.0002 for dRoverRange = 0.004

Full test (fluct & msc):



Fano Cavity-2 benchmark
(Sabine Elles)

Fano2 cavity test case

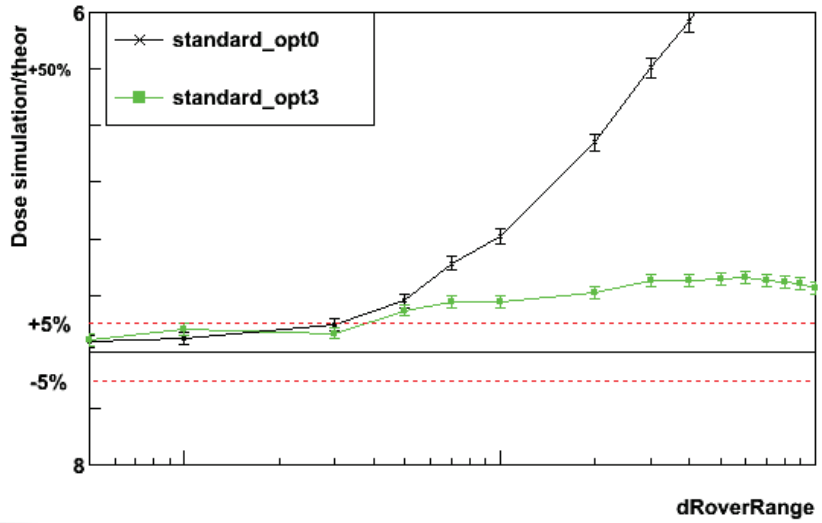
Ratio between simulated and theorical dose deposited by a 1.00 MeV electron beam crossing an infinite radius chamber

Geant4 release : 10-01-ref-07

Basic test (no fluct, no msc):

standard_opt0 : 1.0008 +/- 0.0009 for dRoverRange = 0.004
standard_opt3 : 0.9999 +/- 0.0009 for dRoverRange = 0.004

Full test (fluct & msc):



Fano2 cavity test case

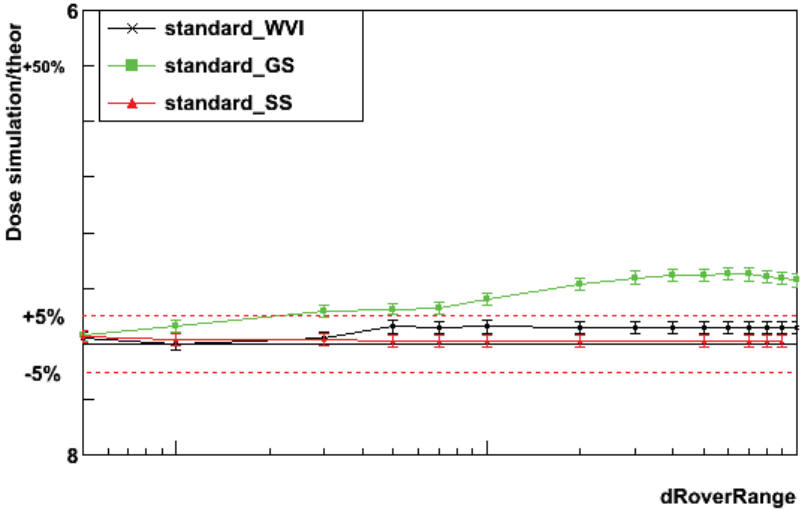
Ratio between simulated and theorical dose deposited by a 1.00 MeV electron beam crossing an infinite radius chamber

Geant4 release : 10-01-ref-07

Basic test (no fluct, no msc):

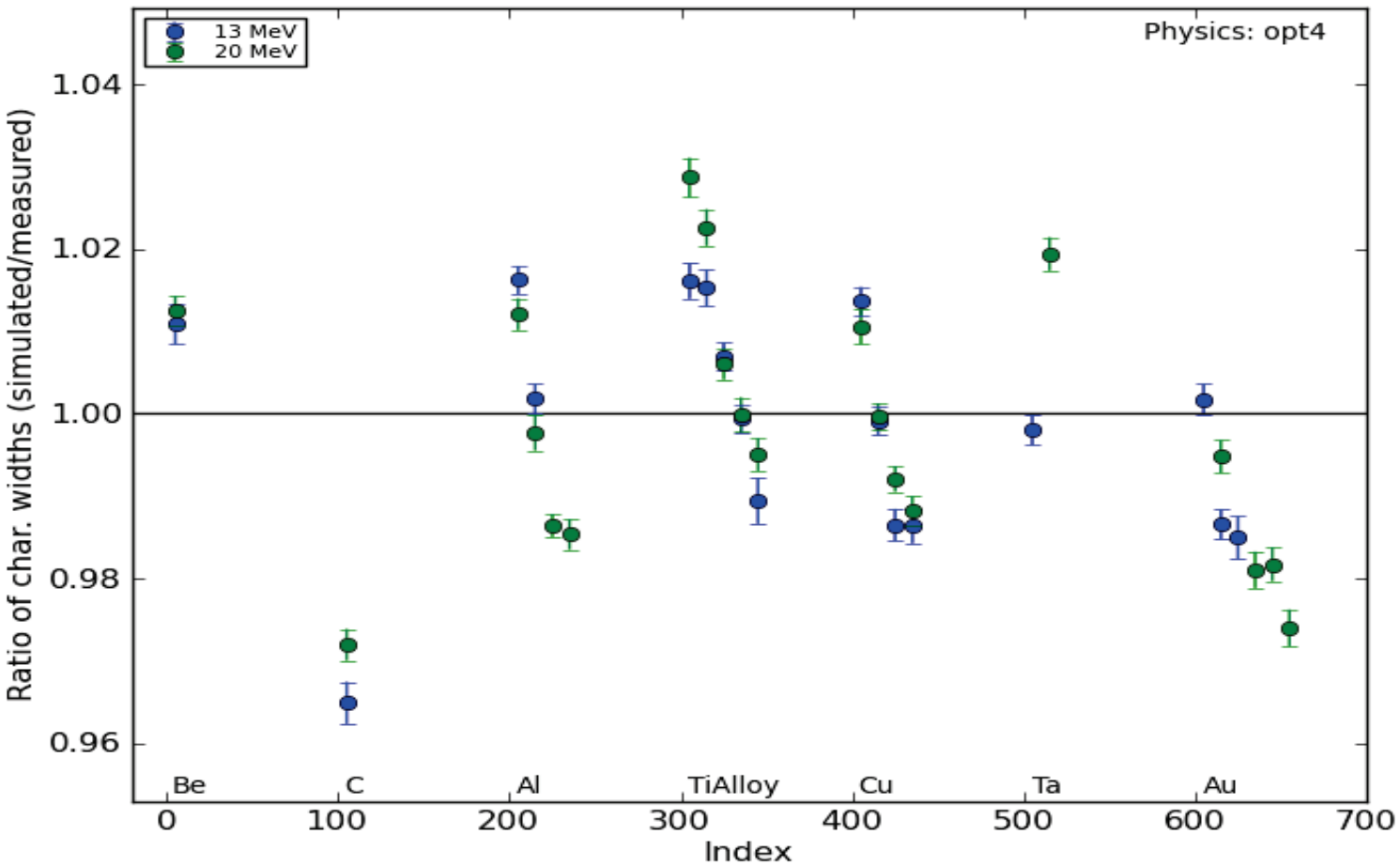
standard_WVI : 0.9981 +/- 0.0033 for dRoverRange = 0.004
standard_GS : 0.9999 +/- 0.0009 for dRoverRange = 0.004

Full test (fluct & msc):

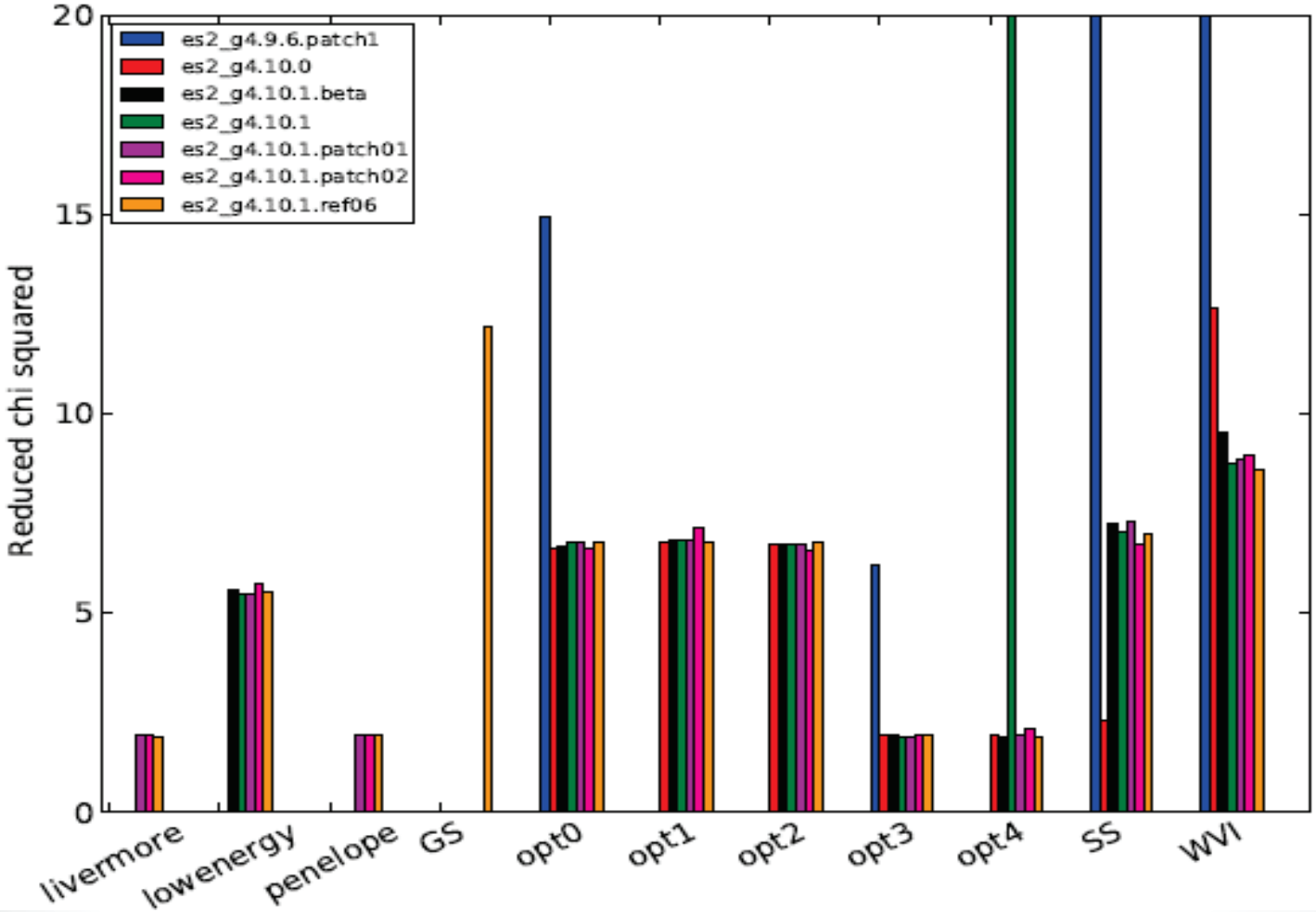


Electron scattering benchmark

Ross et al., Med. Phys. 35, (2008) 4121 (Daren Sawkey)



Electron scattering benchmark for 10.2beta (Daren Sawkey)



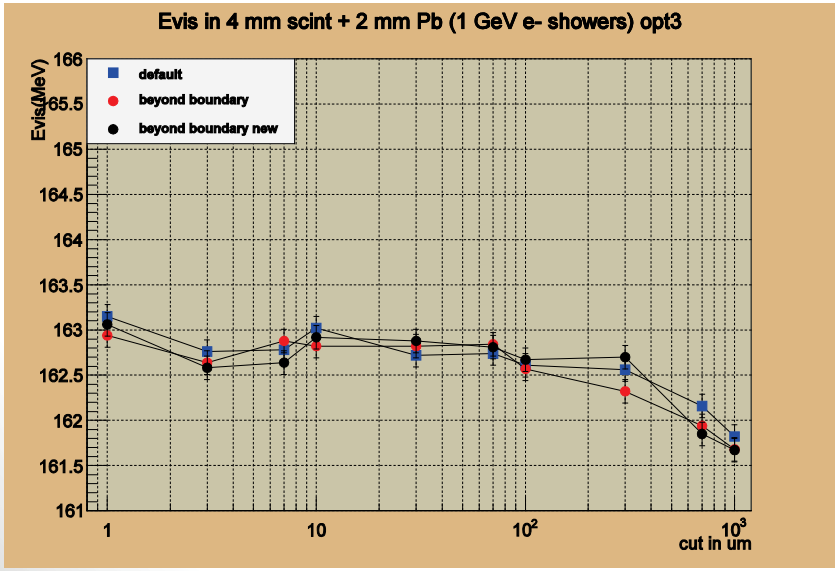
Lateral displacement at geometry boundary for multiple scattering

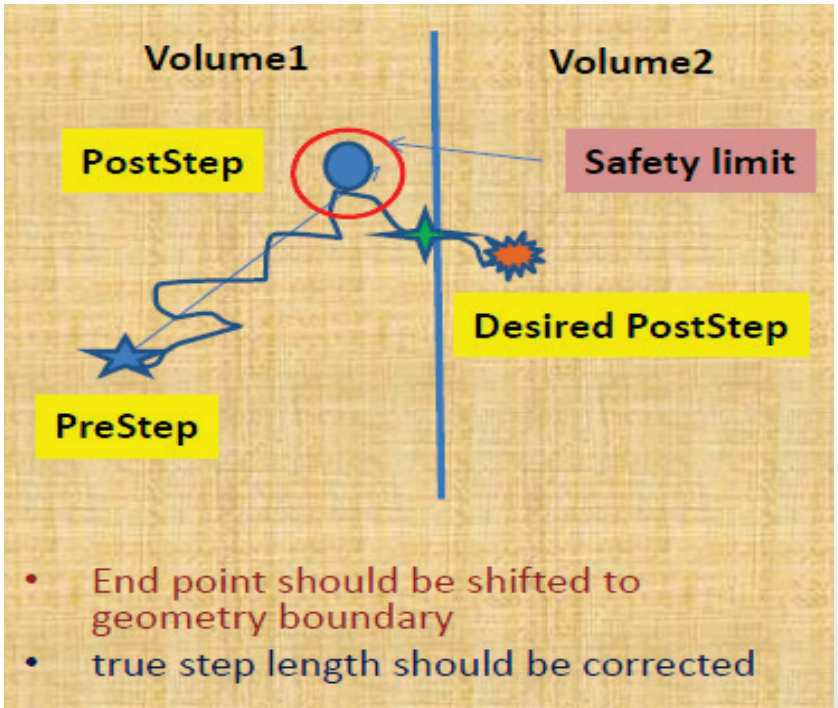
- To provide correct response of sampling calorimeters a sophisticated method of step limitation based on F_R, F_S, skin parameters has been developed
  - Many small steps of e- in vicinity of a boundary
  - Safety limit on the displacement radius
  - No displacement if end point is at a boundary
- The problem is fully solved by addition of a correction to step length and pushing end point of the track to the boundary.
- This feature may be enabled via UI command:

/process/msc/DisplacementBeyondBoundary true

- We suggest also to try out other new options:

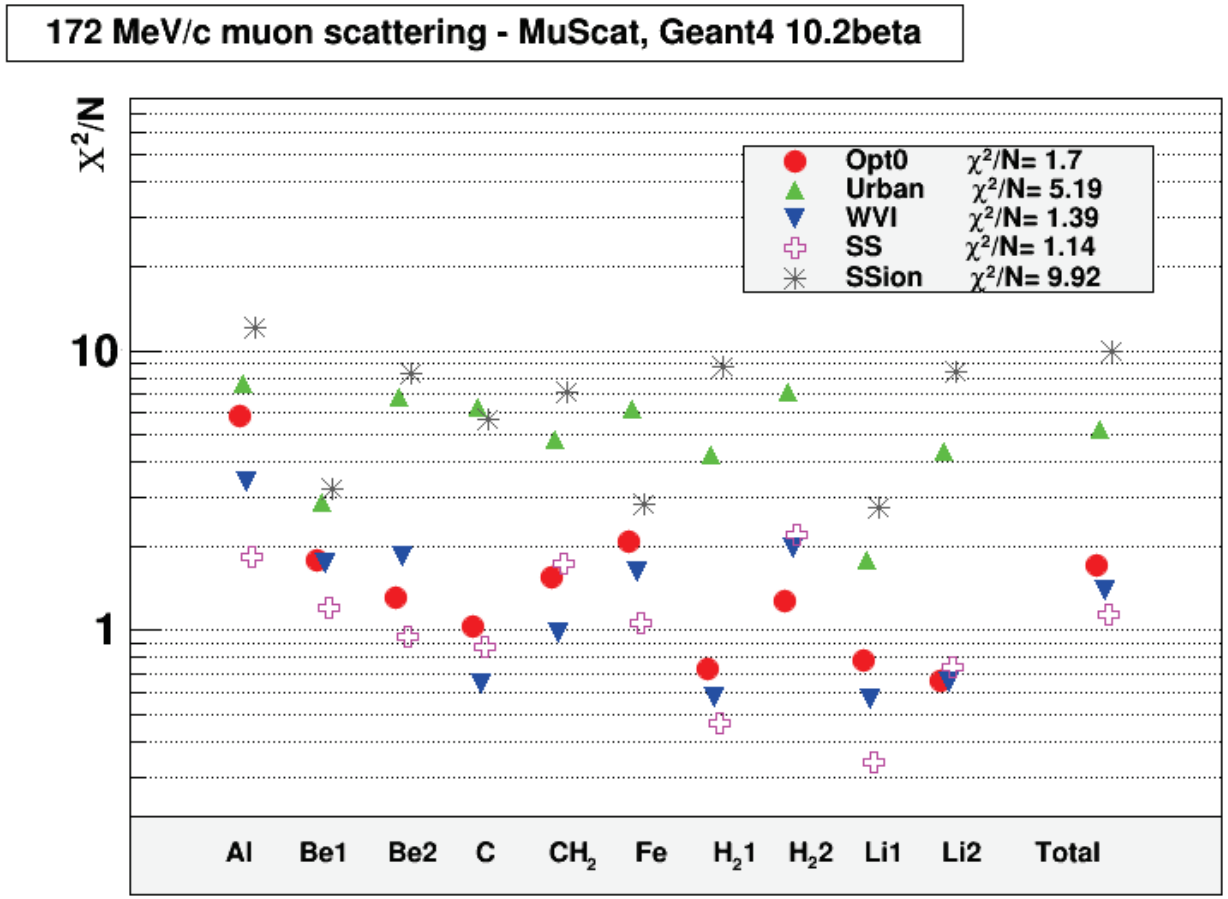
/process/msc/MuHadLateralDisplacement false
/process/msc/StepLimit UseSafety





MuScat benchmark

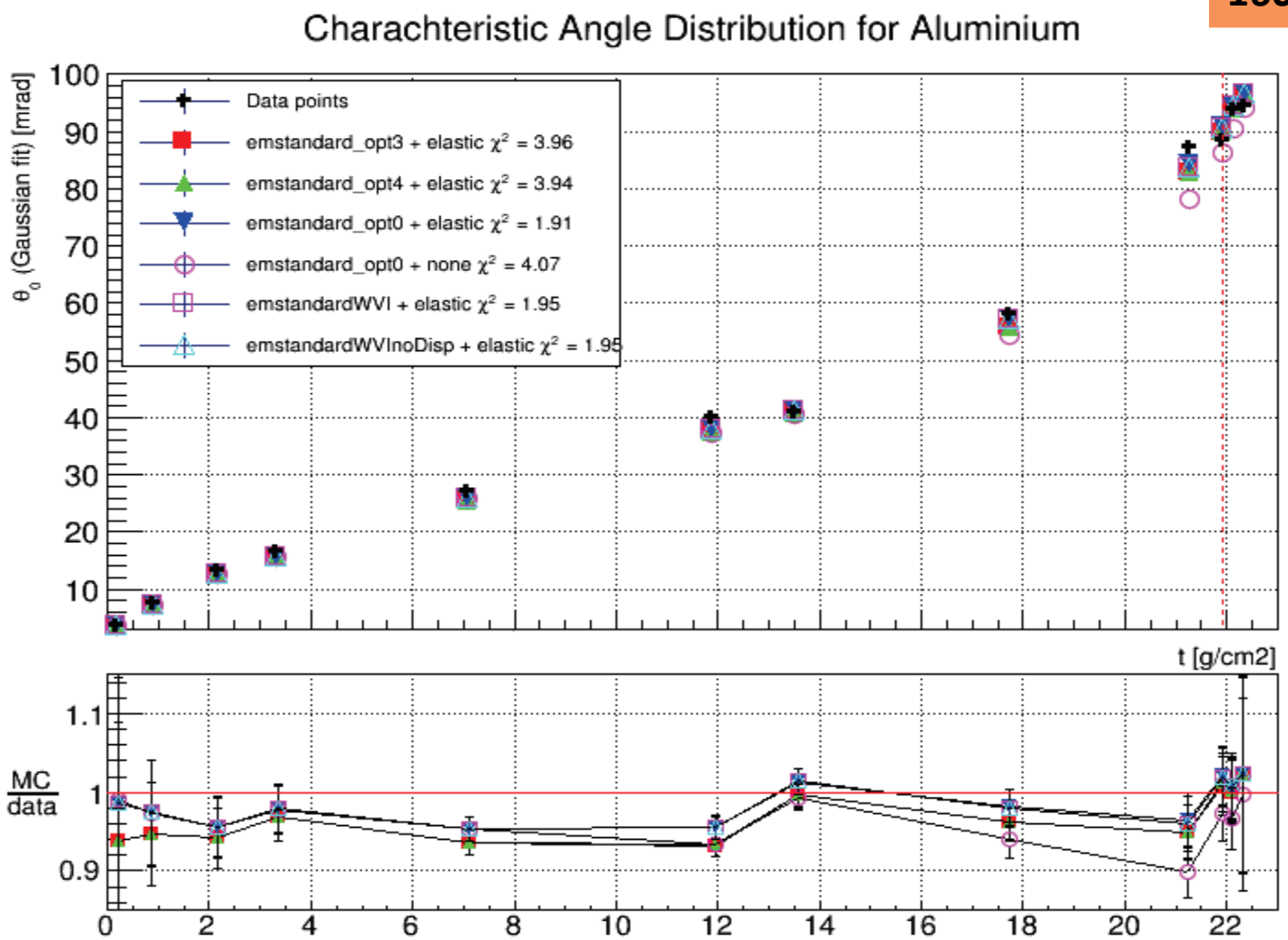
Nucl. Instr. Meth. B 251 (2006) 41



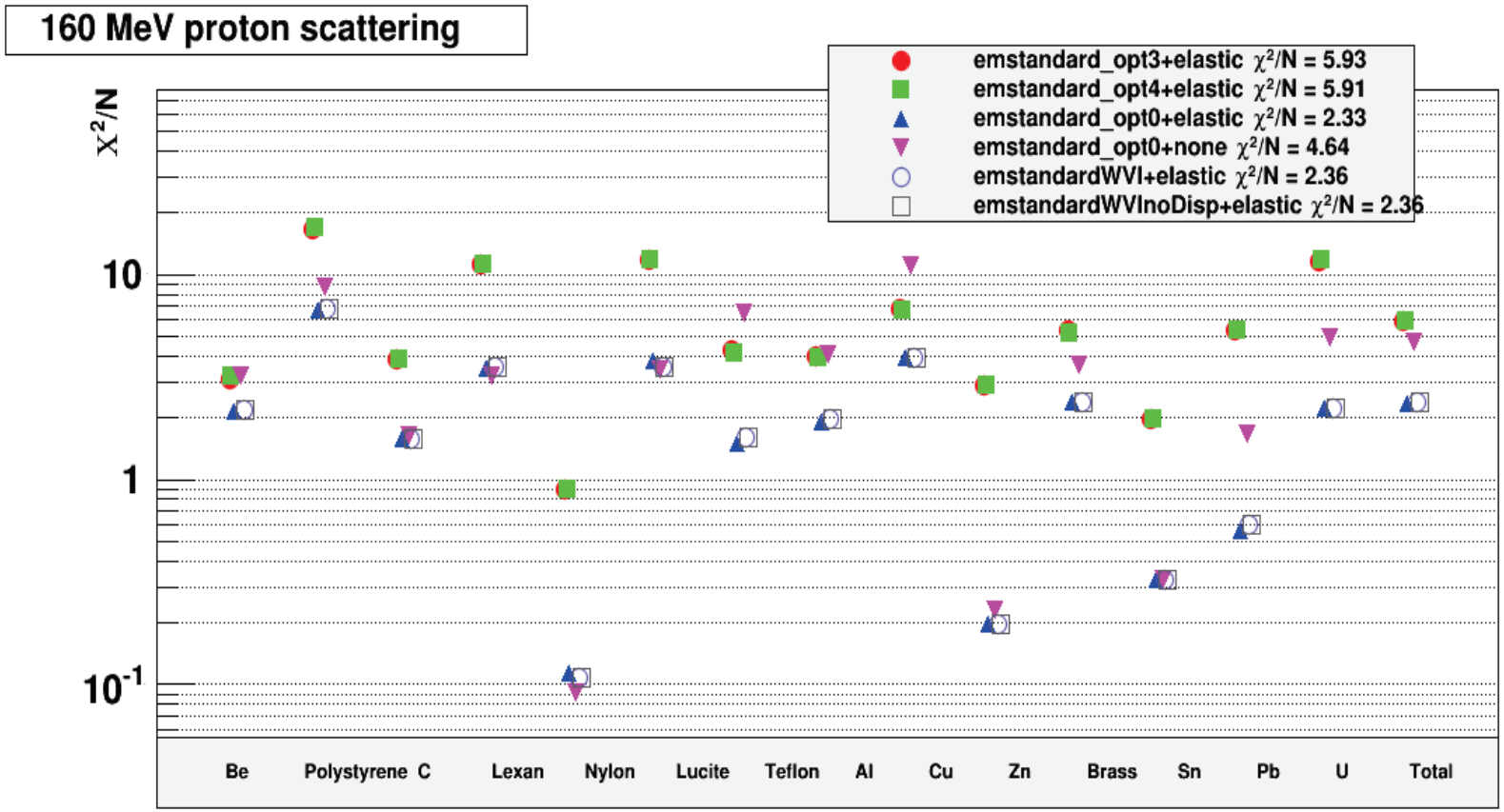
Single scattering and WentzelVI models are closer to the data than Urban models

Thick target proton scattering benchmark (B. Gottschalk et al., NIM B 74 (1993) 467)

160 MeV protons



Thick target proton scattering benchmark (B. Gottschalk et al., NIM B 74 (1993) 467)



WentzelVI model with hadron elastic describe well data for all targets
we will switch in Opt4, Liv and Pen Physics list to these models

EM PHYSICS IN GEANT4 10.2

EM Physics builders for HEP

- Urban multipe scattering for e+- below 100 MeV only
- WentzelVI + single scattering for muons and hadrons
- Urban model for ions

Constructor	Components	Comments
G4EmStandardPhysics	Default (QGSP_BERT, FTFP_BERT…)	ATLAS, and other HEP productions, other applications
G4EmStandardPhysics_option1	Fast due to simple step limitation, cuts used by photon processes (FTFP_BERT_EMV)	Similar to one used by CMS, good for crystals, not good for sampling calorimeters
G4EmStandardPhysics_option2	Experimental: updated photon models and bremsstrahlung on top of Opt1	Similar to one used by LHCb

Combined EM Physics List constructors

- Focus on accuracy instead of maximum simulation speed
- Ion stopping model based on the ICRU'73 data
  - Step limitation for multiple scattering using distance to boundary
- Strong step limitation by the ionisation process defined per particle type
- Recommended for hadron/ion therapy, space applications

Constructor	Components	Comments
G4EmStandardPhysics_option3	Urban MSC model for all particles	Proton/ion therapy
G4EmStandardPhysics_option4	The combination of models per particle type and energy range	Goal to have the most accurate EM physics
G4EmLivermorePhysics	Livermore models for γ, e^- below 1 GeV, Standard models above 1 GeV	Livermore low-energy electron and gamma transport
G4EmPenelopePhysics	Penelope models for γ, $e^\pm$ below 1 GeV, Standard models above 1 GeV	Penelope low-energy $e^\pm$ and gamma transport

Experimental EM Physics List constructors to be used only for validation

Constructor	Components	Comments
G4EmStandardPhysicsGS	SG model for e+- below 100 MeV	Electron/gamma transport
G4EmStandardPhysicsWVI	WVI + SS combination	Is good for high energy interactions
G4EmStandardPhysicsSS	Single elastic scattering for all particles	Mainly for validation and verification
G4EmLowEPPhysics	Monarsh University Compton scattering model, WVI-LE model, potentially GS model	Used new low-energy models

The most recent development

- Implementing UI commands allowing to configure PAI, MicroElec, or DNA models per G4Regions (10.2beta)
  - Done on top of any EM physics constructor
  - Number of G4Regions is not limited
  - This method of PAI models configuration is used in TestEm8 (10.2beta)
  - New UI commands:
    - /process/em/AddPAIRegion proton MYREGION pai
    - /process/em/AddMicroElecRegion MYREGION
    - /process/em/AddDNARegion MYREGION opt0

Summary

- Standard EM physics of Genat4 is well established
- LHC and other experments are satisfied in general by Geant4 EM
  - New requirements are not excluded – we are trying improve accuracy whenever is possible
- Number modifications are introduced in 10.2beta
  - For effitient running in the MT mode
  - Improving accuracy of muliple stcattering
  - Improving high energy models
  - New UI commands and helper classes