The recent Upgrades in the Geant4 Standard Electromagnetic Physics Package

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Computing in High Energy and Nuclear Physics
13-17 February 2006,
T.I.F.R. Mumbai, India

Outline

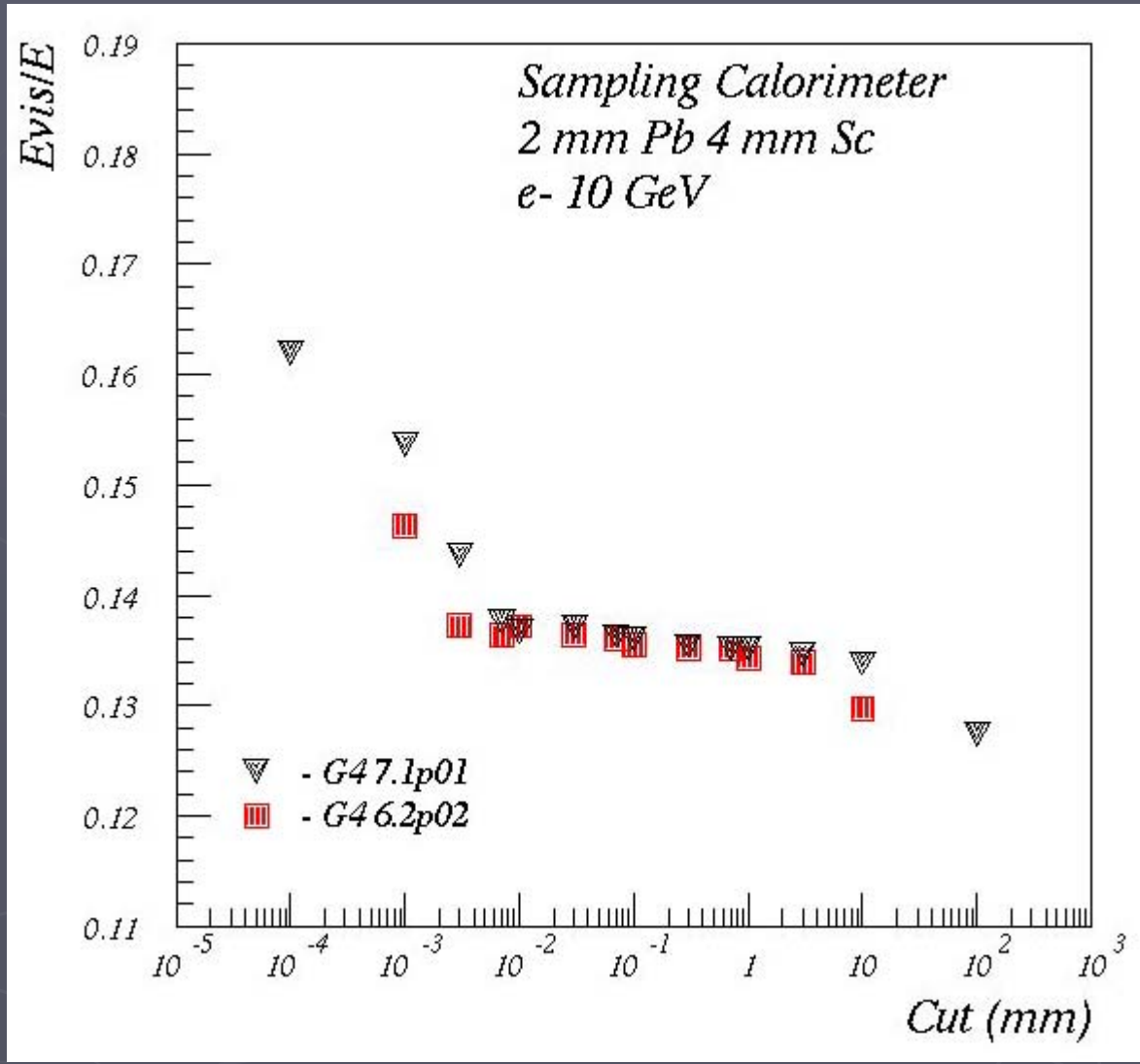
- Introduction to the ‘Standard’ EM package
- Stability of energy deposition
  - Issues reported with cuts
  - Multiple Scattering improvements in release 8.0
  - Result of improvement in calorimeters
- Other new developments
  - revised Physics models
  - materials
- Infrastructure
  - design and testing
- Conclusions

Standard EM Package: complete EM physics for HEP

- ***Standard***
  - basic EM processes for HEP: γ, e^-, e^+, charged leptons/hadrons
  - Cuts used for singularities, efficiency
    - A cut is production threshold,
      - Express in length – it is minimum value for range of produced particle
- ***Xrays***
  - Processes for producing xrays and optical photon
- ***Muons***
  - basic set of muon EM processes for HEP
- ***High-energy***
  - processes at high energy (new development relevant to LHC, Linear collider, astrophysics)

Issue with Stability of visible energy

- Users reported that results in some cases
  - depended on cuts
  - depended on step limits
- Precise simulation for thin layers (medical applications, shielding, fine granular calorimeters...)
  - could require simulation with very small cuts
- Investigated cut/step limit effects
  - concluded that Multiple Scattering process is key



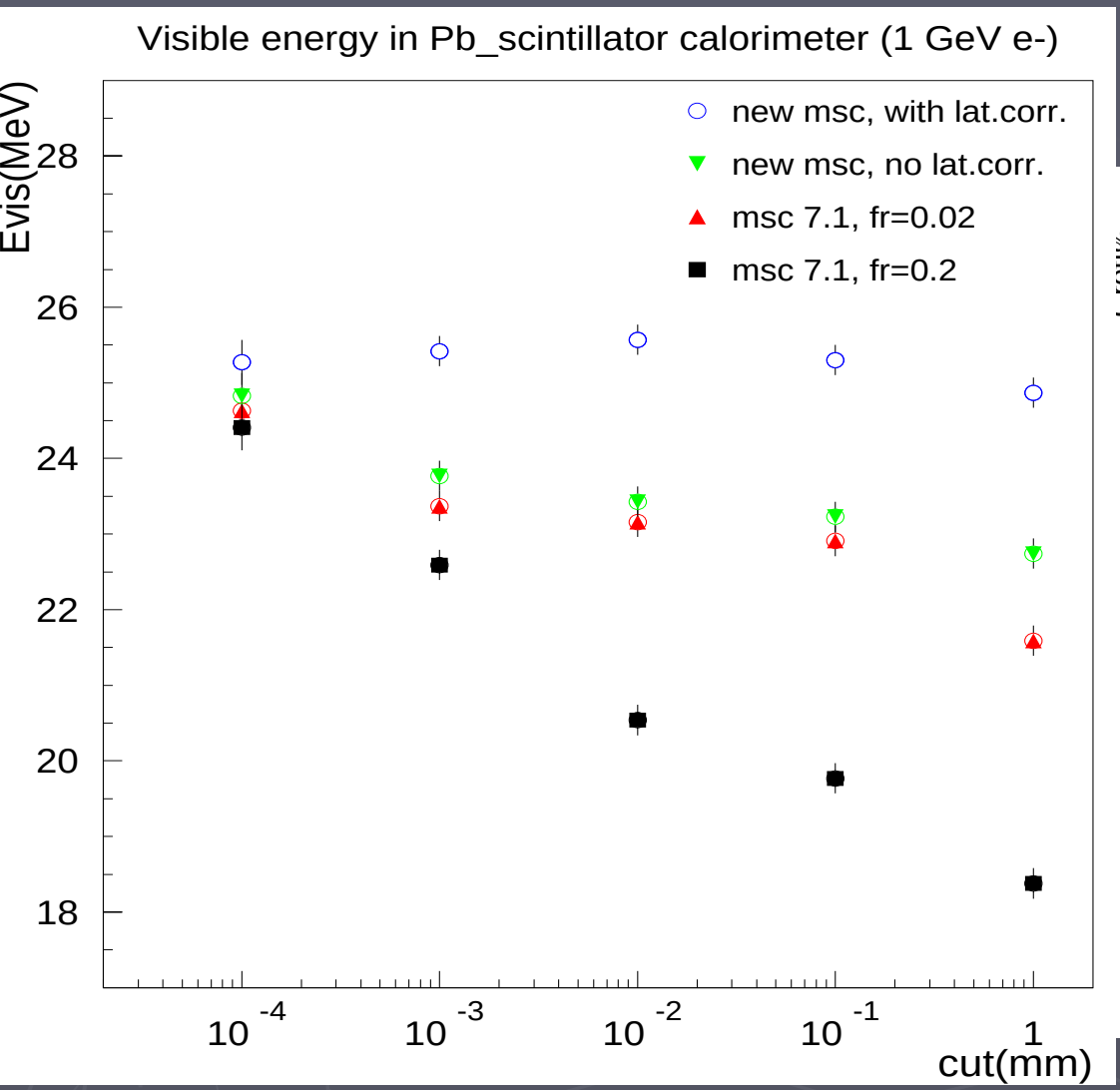
Multiple Scattering: duties, refinements

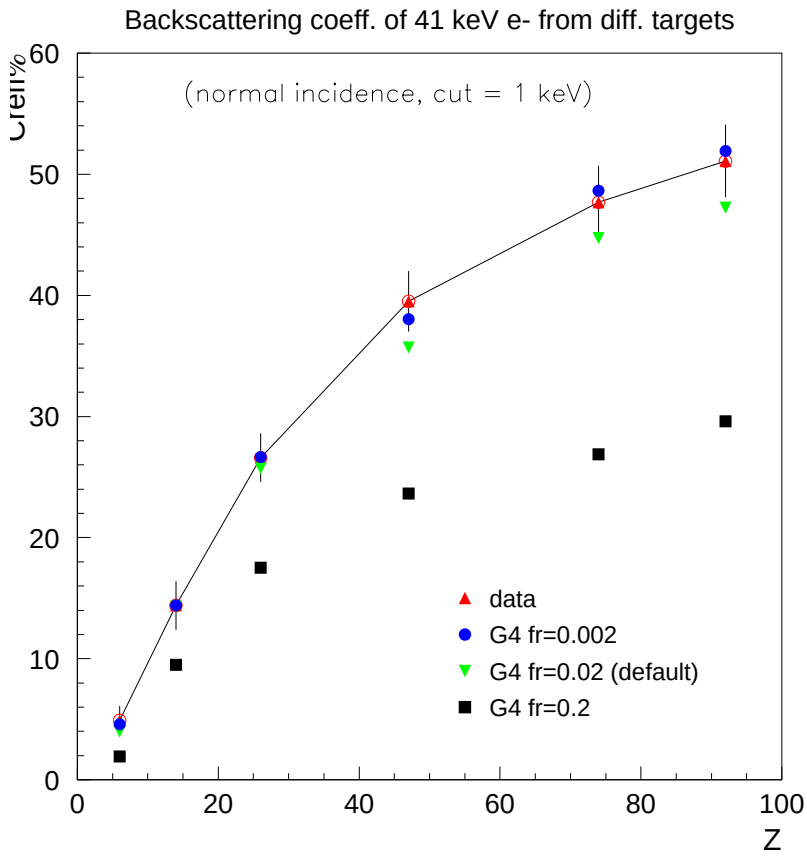
- In G4 the Multiple Scattering process performs these functions:
  - samples scattering angle after step
  - Samples lateral displacement
  - Step length transformations: Physical to/from geometrical
  - Step limitation
    - introduced in order to simulate boundary backscattering effects

With Geant4 8.0 a number of changes were introduced:

- 'Model' Improvement:
  - Introduced correlation between scattering angle and lateral displacement
- Applying the displacement more frequently and 'further'
  - Recalculate geometry 'safety' before sampling the displacement
    - Since the safety limits this displacement

Result of Upgrades



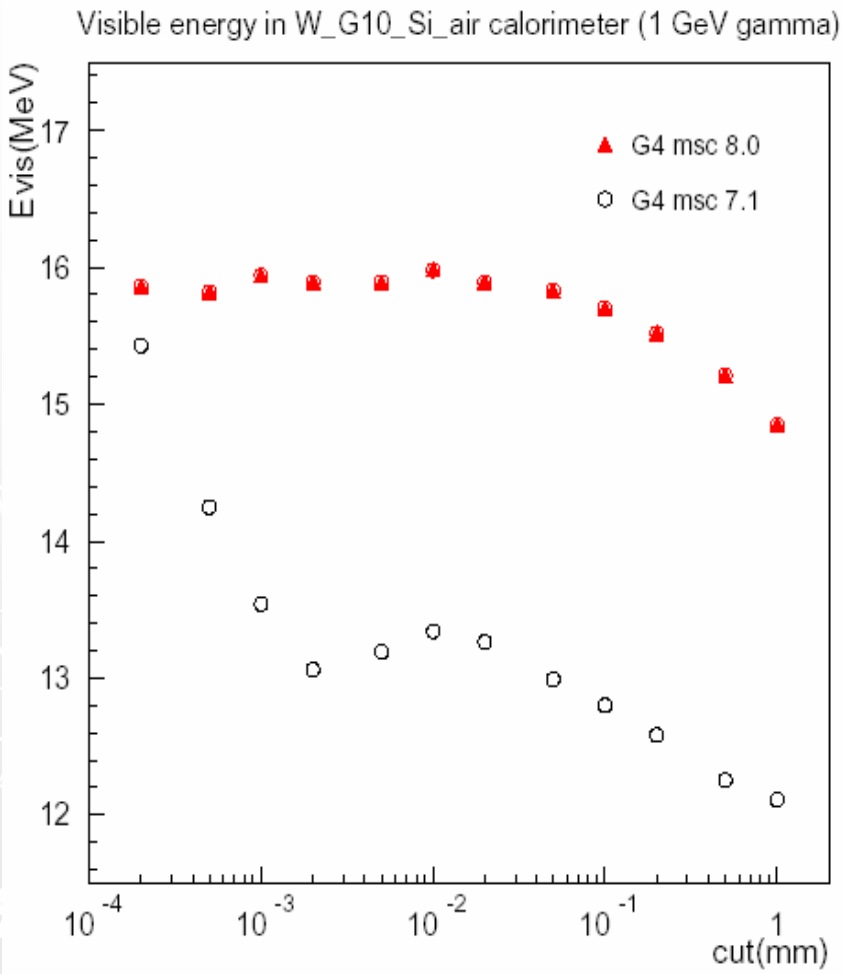


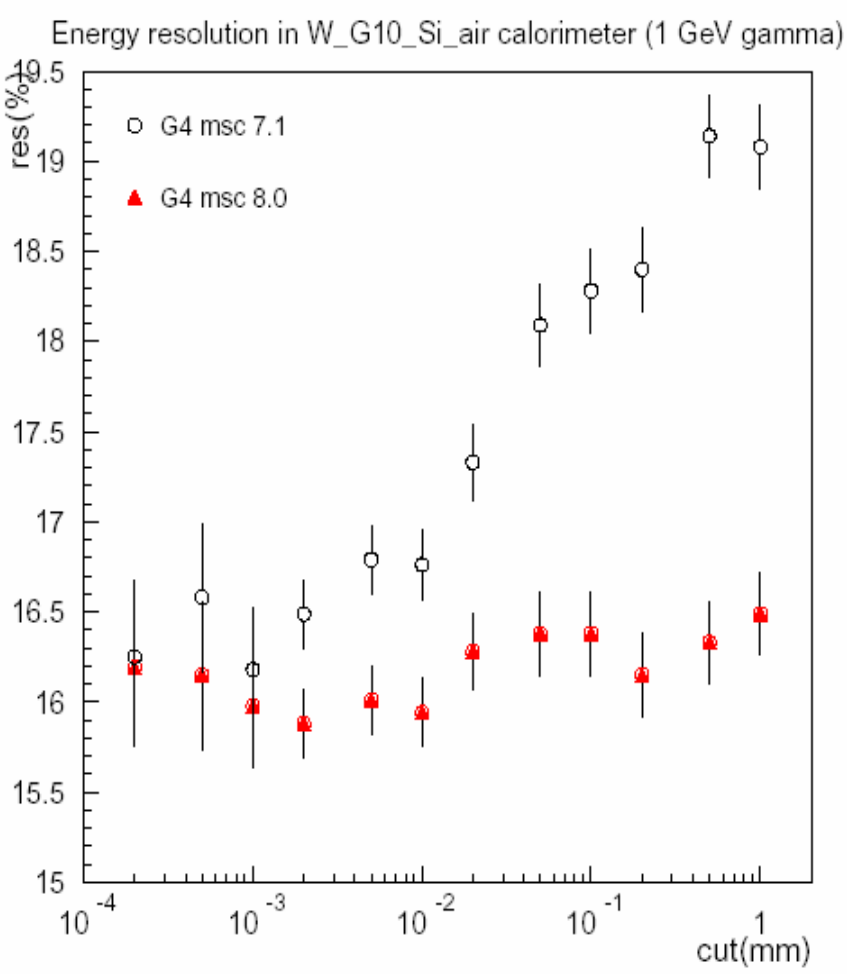
Multiple Scattering 'Process' updates

- 'Strict' step restriction and in all volumes
  - Now also in the first, starting volume of track
    - Previously only applied after first boundary
  - Again proportional to range
    - new stricter parameter (facrange=0.02, was 0.2)
- New restriction using information from geometry
  - Default step size restriction to obtain at least
    - 2 steps in the start volume
    - 4 steps in other volumes it crosses

Note: User can switch off new restrictions,
including the geometrical step limitation (for comparison)

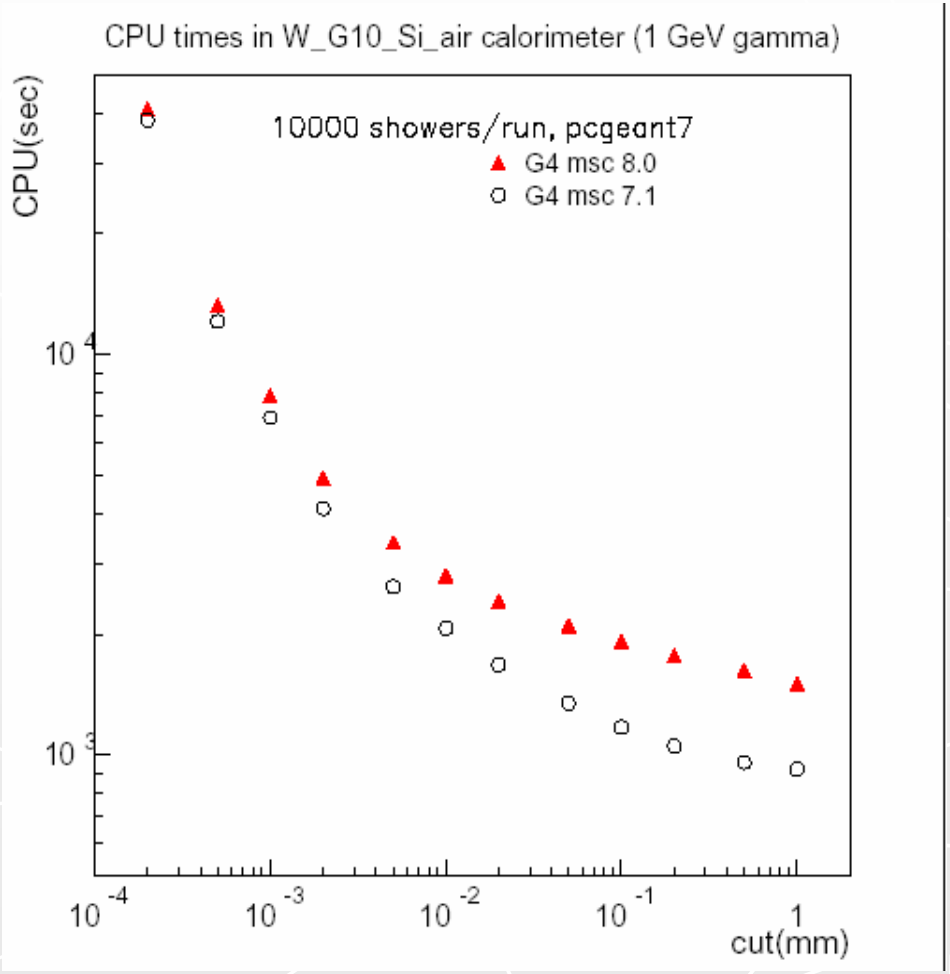
ILC-like setup : W(2.5mm)-Si(0.32mm)



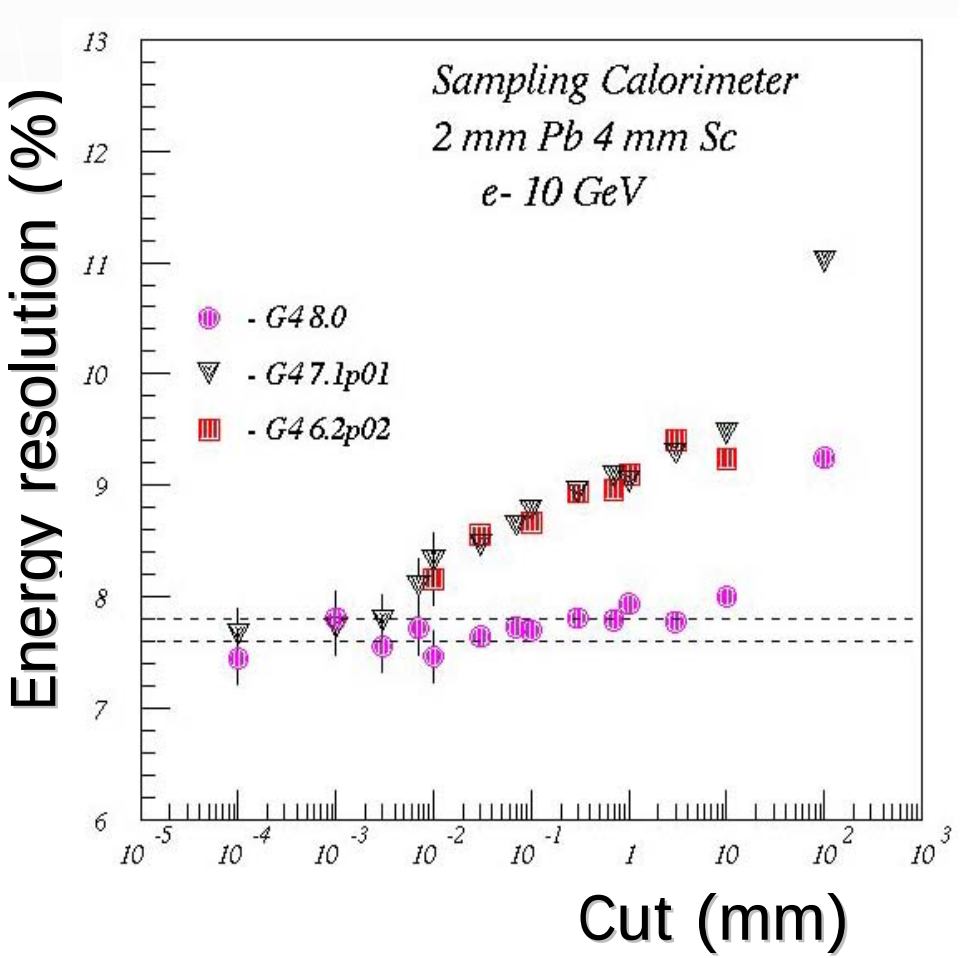


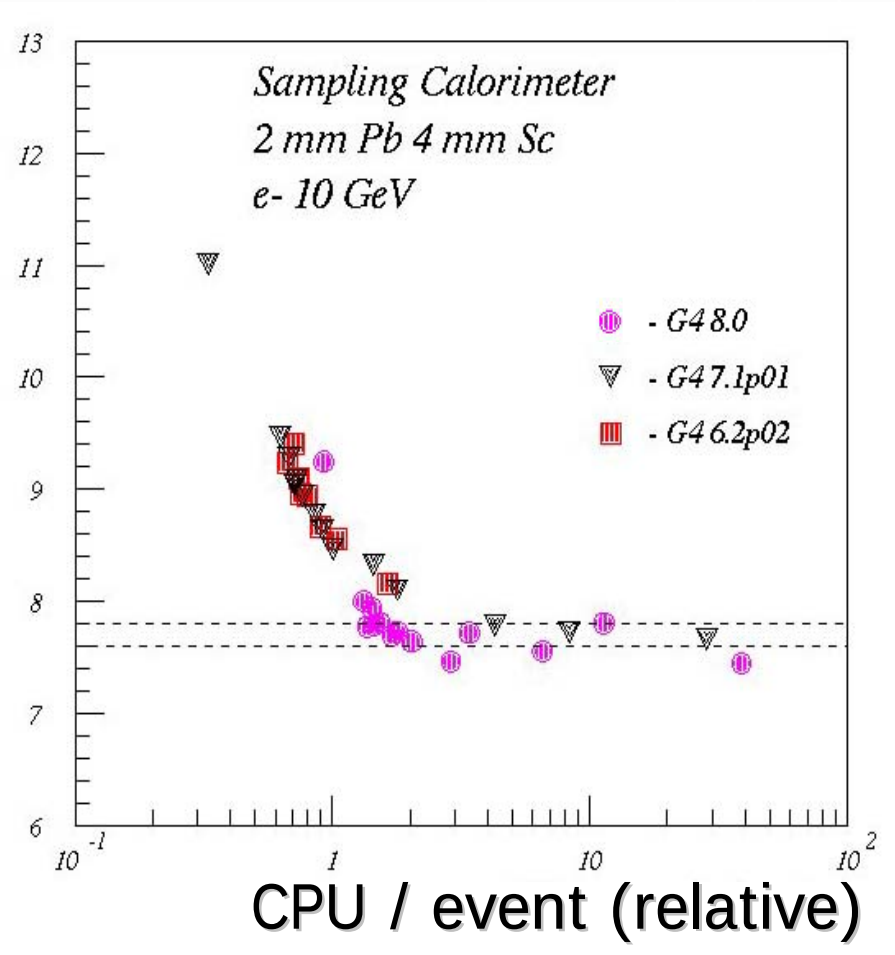
ILC-like setup : W(2.5mm)-Si(0.32mm)

- CPU penalty :
  - 70 % at 1mm
  - 10 % at 1um
- More simulation steps
  - due to extra step limitation (mul. sc.)
- Yet best to compare physics quality vs CPU



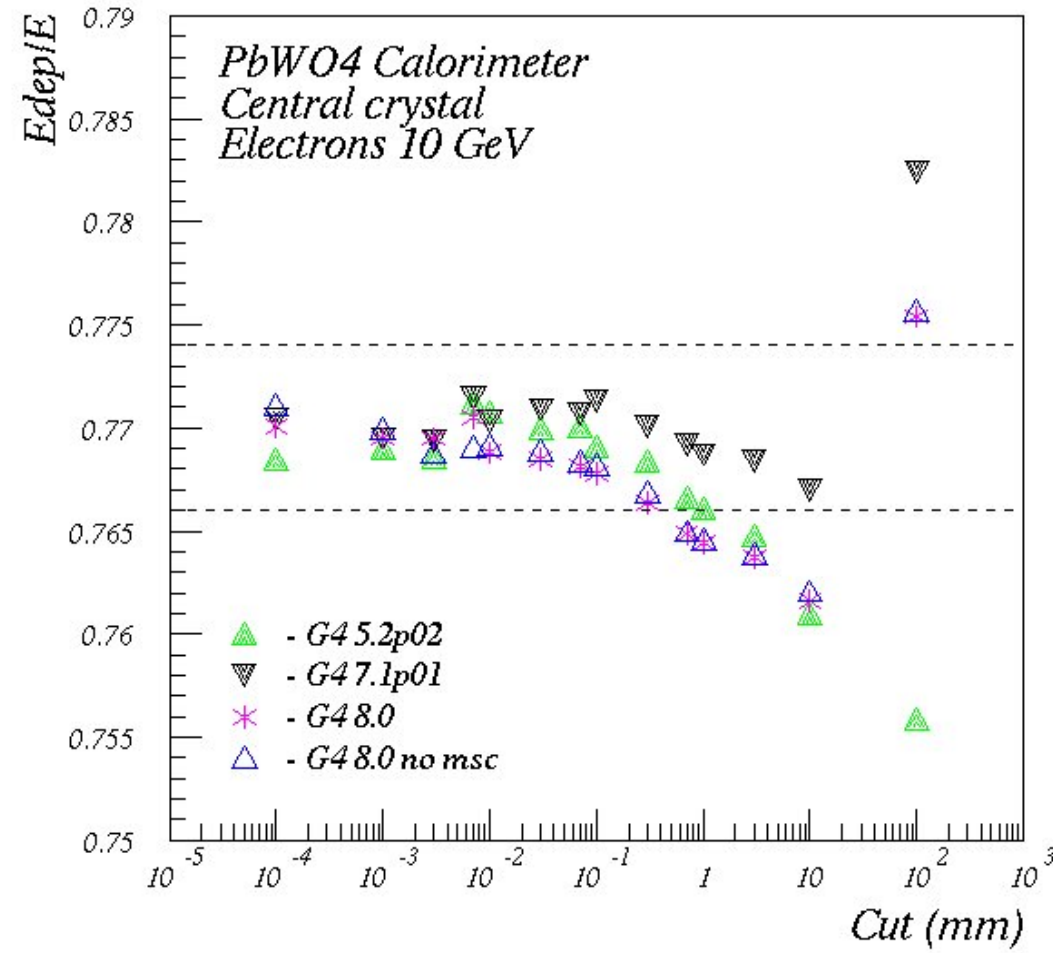
Multiple Scattering model upgrade LHCb type calorimeter

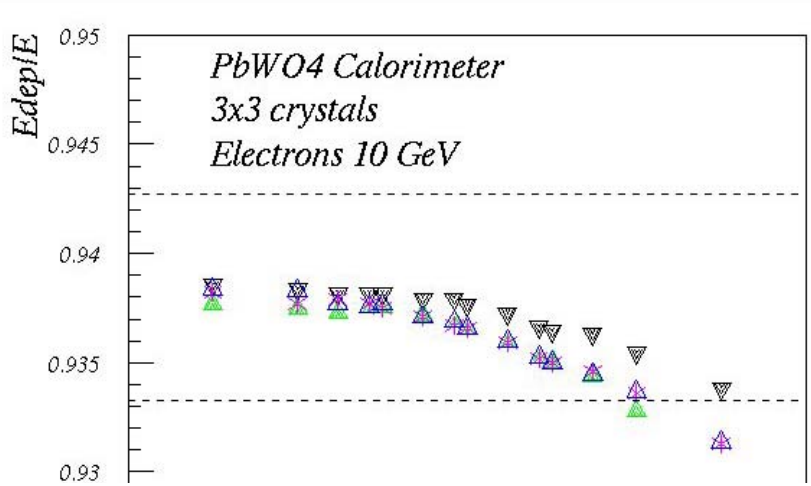


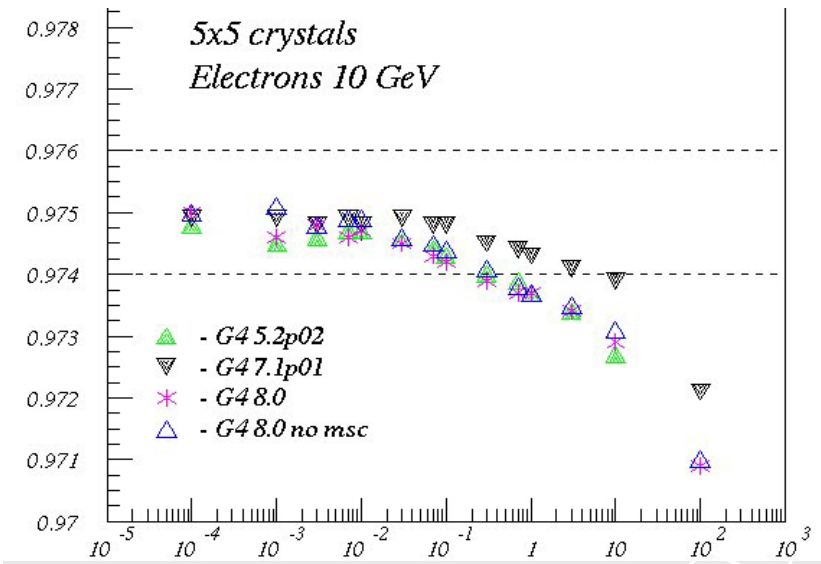


Crystal calorimeter of CMS type

Effect of MSC update is small







Test suite for EM physics

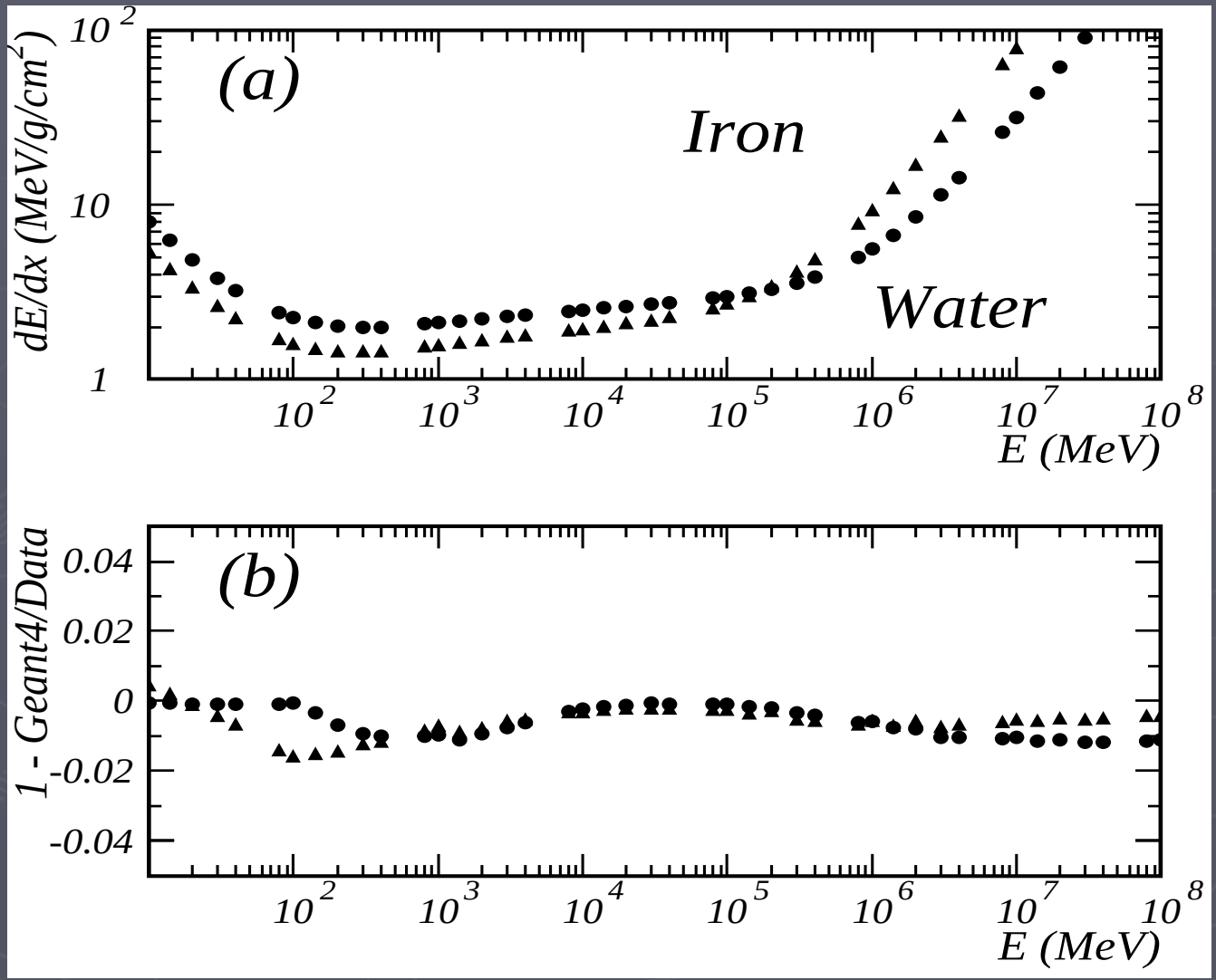
- The test suite
  - covers 120 test cases from single material to model calorimeter
  - uses the 16 'extended' EM examples
  - 23 key test cases run in regression
- Large statistics tests for simplified LHC calorimeters:
  - ATLAS Barrel Pb/lAr
  - ATLAS HEC Cu/lAr
  - CMS crystal calorimeter $PbWO_4$
  - LHCb Pb/Sc calorimeter
- Results for key test cases kept for each G4 version
  - from Geant4 release 5.1 (April 2003)

In addition these setups serve as starting points for user applications.

Stopping powers validation for muons against evaluated data from *Atomic and Nuclear Data Tables 78, 183 (2001)*

G4 7.1

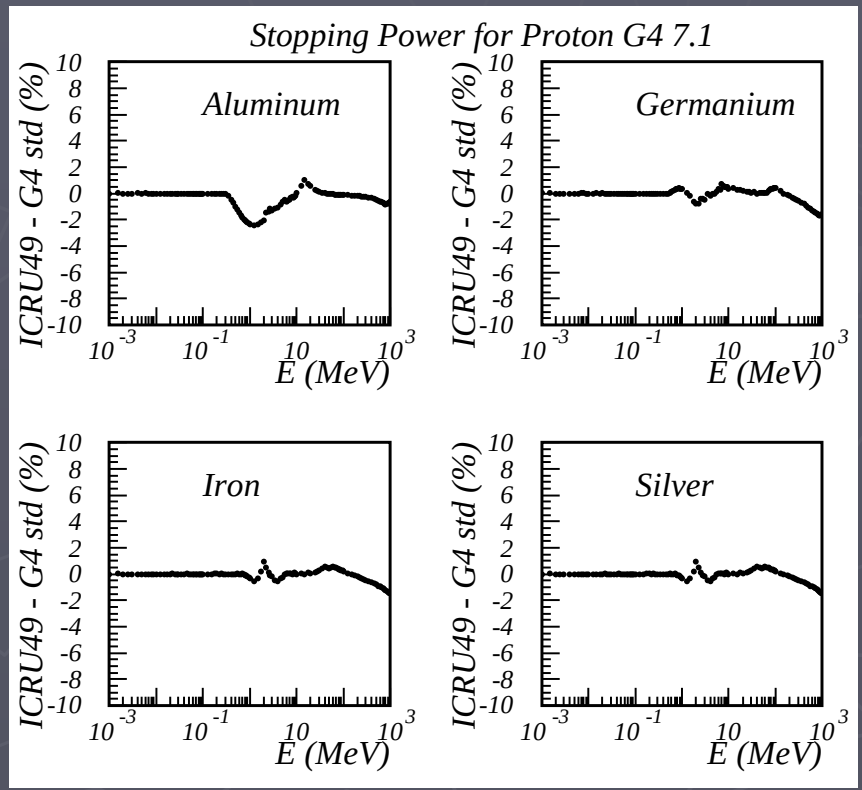
MC/Data
Within 2%



Physics models improvements

- Revision of corrections to hadron/ion ionization
- TRD models
  - specialised models for key LHC use cases
  - Key change
  - X-rays generated as a collective effect at a point in the TR volume
- New process for ionization of exotic hadrons
  - G4hhIonisation

Stopping power within 2%



‘Infrastructure’: Design Iterations

- The goals of the design iterations:
  - Enable extensions (eg with high energy models)
  - Ability to trigger special models per ‘Geometrical Region’
  - Improved bookkeeping, maintenance
- New components and user interfaces:
  - G4EmProcessOptions – enable common options
  - G4EmCalculator – access cross sections
  - G4EnergyLossForExtrapolator – average effects for ‘swimming’ tracks
- Completes design evolution started in release 5.1

‘Infrastructure’: Database of materials, elements, and isotopes

- Ensure accuracy for key properties of materials:
  - Values from NIST
  - Density
  - Mean excitation potential (I)
  - Chemical formula
  - Element composition
- and (for hadronic processes):
  - Natural isotope composition
- New interfaces
  - Old constructors kept
- Can also access via UI commands

```
#    Elementary Materials from the NIST Data Base
 Z  Name  ChemFormula  density(g/cm^3)   I(eV)
---------------------------------------------------------------
1    G4_H    H_2              8.3748e-05        19.2
...
6    G4_C                     2                 81
7    G4_N    N_2              0.0011652         82
8    G4_O    O_2              0.00133151        95

#    Compound Materials from NIST Data Base
 N Name     ChFormula       density(g/cm^3)
     I(eV)
---------------------------------------------------------------
95  G4_Air                   0.00120479        85.7
            6     0.000124
            7     0.755268
            8     0.231781
           18     0.012827
96  G4_CsI                   4.51              553.1
           53     0.47692
           55     0.52308
```

Summary

- The Geant4 Multiple Scattering was significantly revised
  - More precise and more stable results for different use cases
  - In typical cases achieves high-quality physics results for less CPU
- A physics testing suite has been deployed
  - 120 cases, 20 used monthly, 4 in high-statistics regression
- Models, infrastructure improved
  - Improvements in high-energy, TRD physics models
  - Cycle of design revision of Std EM package is complete
  - NIST materials database with density, ionisation potential, ...
- Standard EM group continues to
  - focus on validation / verification, and model updates
  - be open to user feedback and new requirements