Recent Progress of Geant4 Electromagnetic Physics and Readiness for the LHC Start

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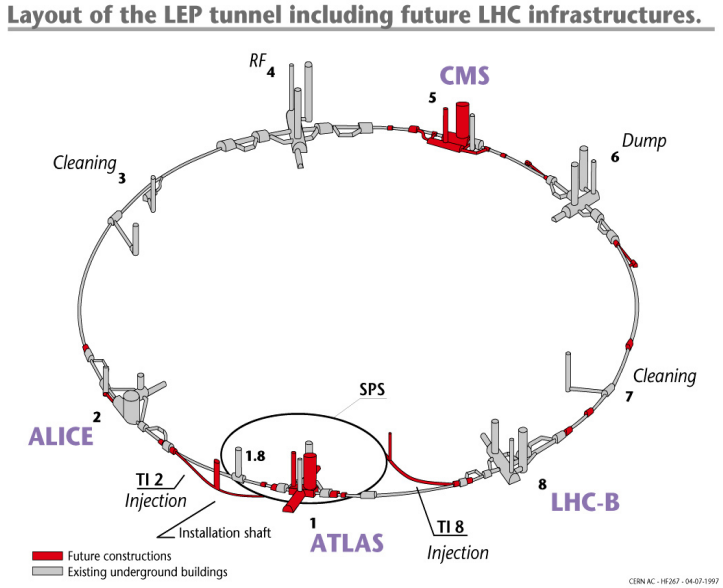
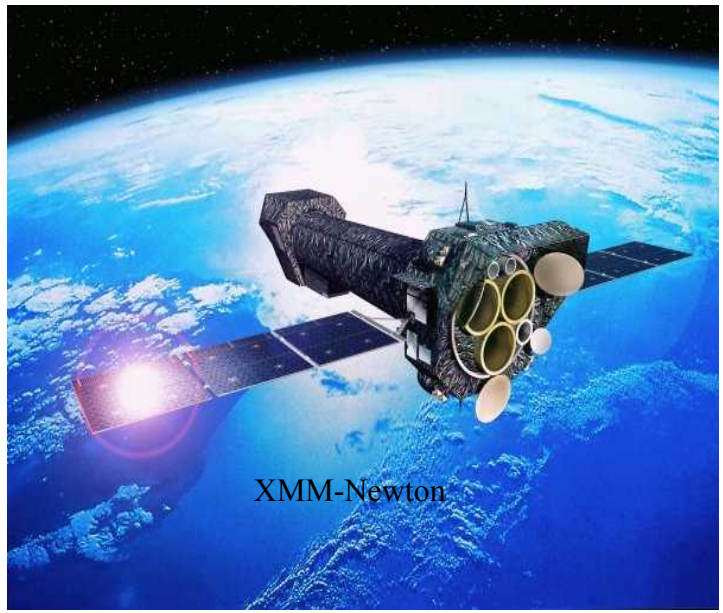
Outline

- Introduction
- Validation of EM physics
  - Infrastructure
  - EM Physics Lists
- Highlights of new developments and validations
  - High energy bremsstrahlung
  - Multiple and single scattering
- Infrastructure and performance upgrade
  - Spline option for physics tables
- Conclusions

Geant4

- Geant4 is a toolkit for simulation of particle transport and interaction with matter
- Includes components for LHC and other applications:
  - Geometry
  - Tracking in electromagnetic fields
  - Physics interactions
  - Scoring and interfaces
  - Visualization
- Geant4 is widely used:
  - HEP, space science, medicine, …
  - ATLAS, CMS, LHCb productions since 2004





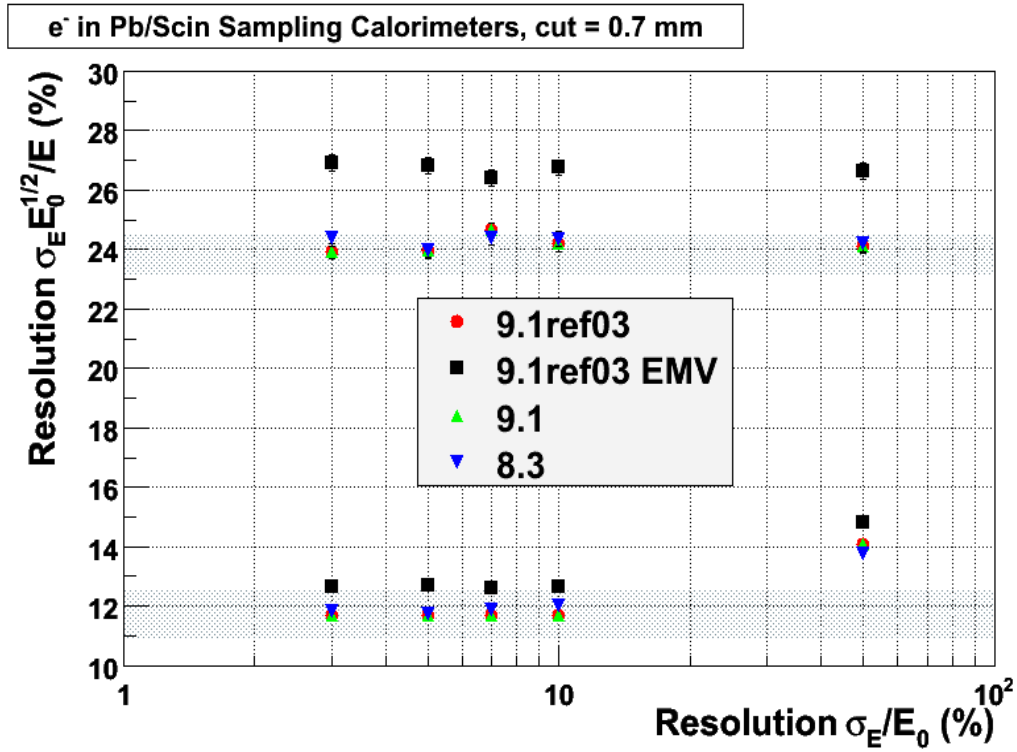
Electromagnetic physics sub-packages

- ***Standard***
  - γ, e up to 100 TeV
  - hadrons up to 100 TeV
  - ions up to 100 TeV
- ***Muons***
  - up to 1 PeV
  - Energy loss propagator
- ***Xrays***
  - X-ray and optical photon production
- ***High-energy***
  - Processes at high energy (E>10GeV)
  - Physics for exotic particles
- ***Polarisation***
  - Simulation of polarized EM interactions for γ and $e^{\pm}$ beams
- **Low-energy**
  - Livermore
  - Penelope
  - Deexcitation module
  - DNA processes
- ***Optical***
  - Optical photon propagation and interactions

Validation of EM physics

EM Standard

- Standard EM was focused on readiness to LHC start with goals:
  - Provide a stable version of EM physics for large scale productions
  - Extend existing EM models and develop alternative to reach maximum precision of simulation
- Validation is one of the key activity



- Two configurations:
  - 10 mm Pb/ 2.5 mm Scintillator (top)
  - 5 mm Pb/5 mm Scintillator (bottom)
  - Detector effects are excluded
    - Leakage at high energy

Geant4: main steps in validation

- Validation sequence:
  - Developer verification of model, process
    - **Compare with theory and/or data (thin-target, profiles, ..)**
  - High statistic tests by EM groups
    - **Simple setups**
    - **Calorimeter-like setups**
  - CPU benchmarks
  - User validation
    - **Experiment test beams, users from HEP, medical, space, …**

- Validation suite is constantly being extended
  - versus specific published data
  - versus evaluated data sets (NIST, Sandia, Livermore)
  - Long process required manpower

EM Physics Lists

Physics Lists	Builders	Names
QGSP_BERT	G4EmStandardPhysics	emstandard
QGSP_EMV	G4EmStandardPhysics_option1	emstandard_opt1
QGSP_EMX	G4EmStandardPhysics_option2	emstandard_opt2
-	G4EmStandardPhysics_option3	emstandard_opt3
-	-	standardSS, NR
-	-	Livermore, Penelope

- Default and opt1 for LHC – should be stable
- Opt2 – advance options can be used for LHC
- Opt3 for non-LHC applications – maximum precision

Highlights of new developments and validations

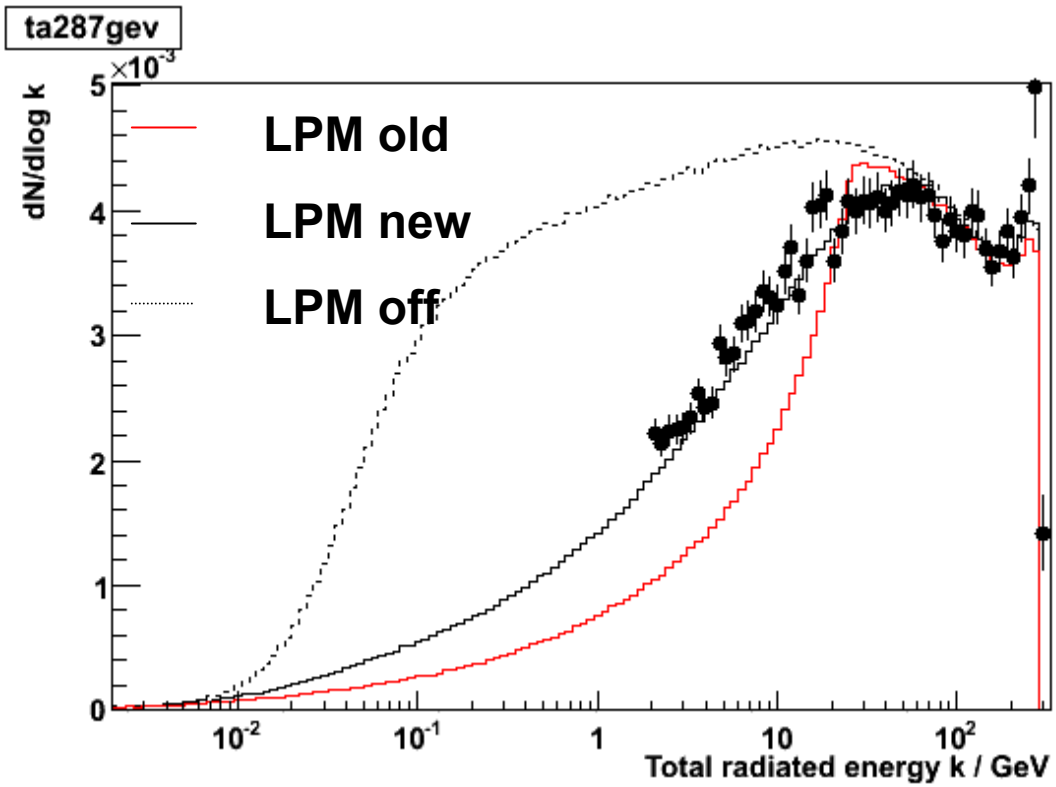
New EM physics available with G4 9.2

- Updated models for ionisation for hadrons/ions
- Relativistic bremsstrahlung model for electrons and positrons with E > 1 GeV
- Hadron induced bremsstrahlung and e^+e^- pair production
- Updated positron annihilation to hadrons
- Tuned model for electron multiple scattering
- Alternative model for muon multiple scattering

New relativistic bremsstrahlung model

- Bethe-Heitler formula with corrections
- Complete screening with Coulomb correction
  - Valid for E > 1 GeV
- **Density & LPM-Effect**
  - **consistent combination a'la Ter-Mikaelian**

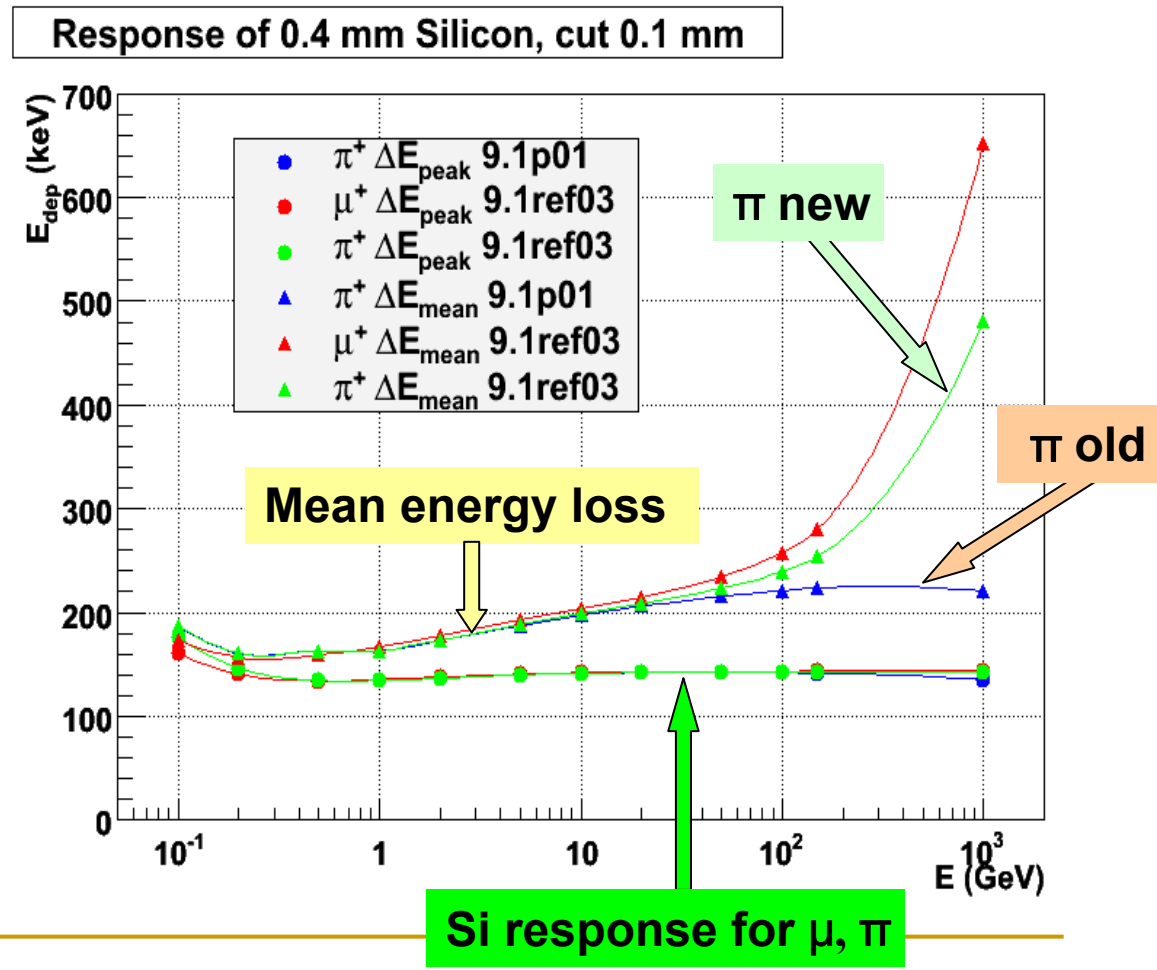
287 GeV e^- at Ta target ($4\%X_0$)



Data from the CERN experiment: H.D.Hansen et al, PR D 69, 032001 (2004)

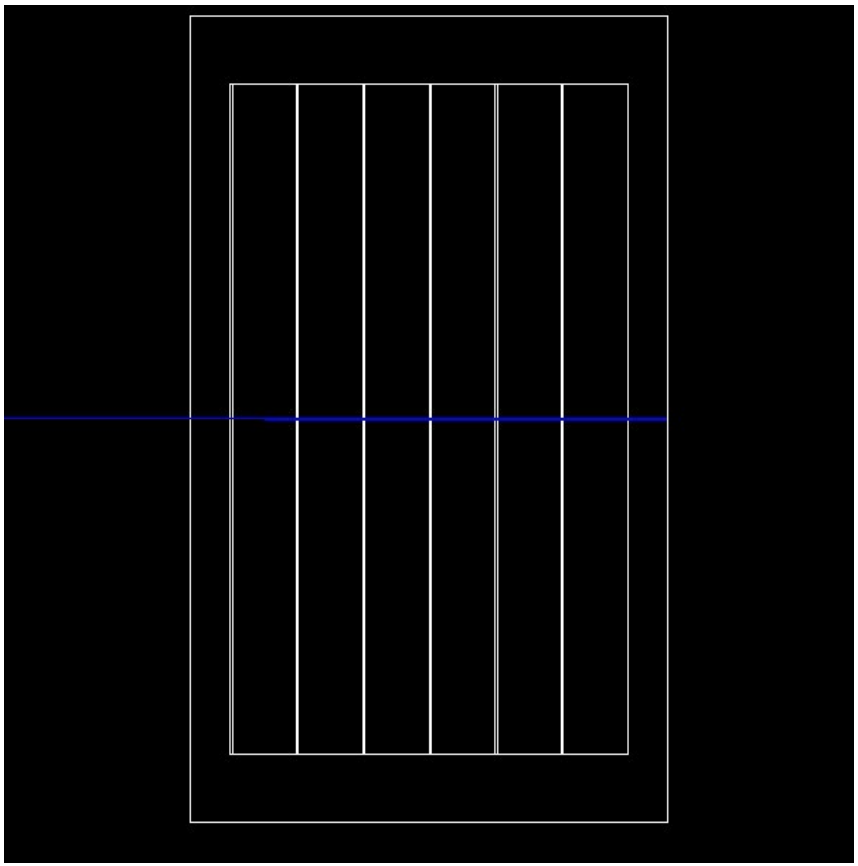
Tracking detector simulation, hadron bremsstahlung and e^+e^- pair production

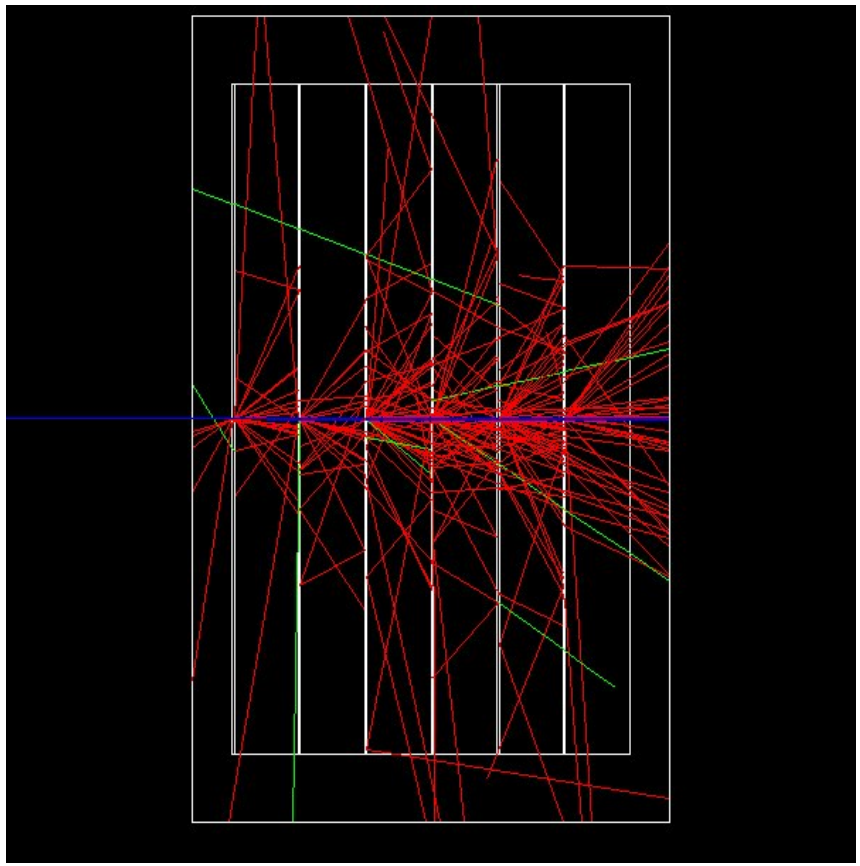
- Of concerns
  - Shower shape in calorimeters
  - Response of track detectors
- 9.1ref03 will be part of 9.2



100 GeV/c π^+ in vertex detector consisting of six 0.3 mm Si layers

Cuts 1 km **1000 events** **Cuts 0.02 mm**





Remarks

- Simulation with infinite cuts has limited scope
  - Should be used for consistency checks and not production
  - CPU optimisation should be done in a different way
- Geant4 default cut 1 mm
  - For thin layers cuts should be reduced
  - For thick layers cut should not exceed 10 cm
    - CPU between 1 mm – 10 cm does not change significantly
- For fast simulation of calorimeters G4FLASH approach is being developed
- Various other biasing approaches can be suggested
  - Tracking cuts

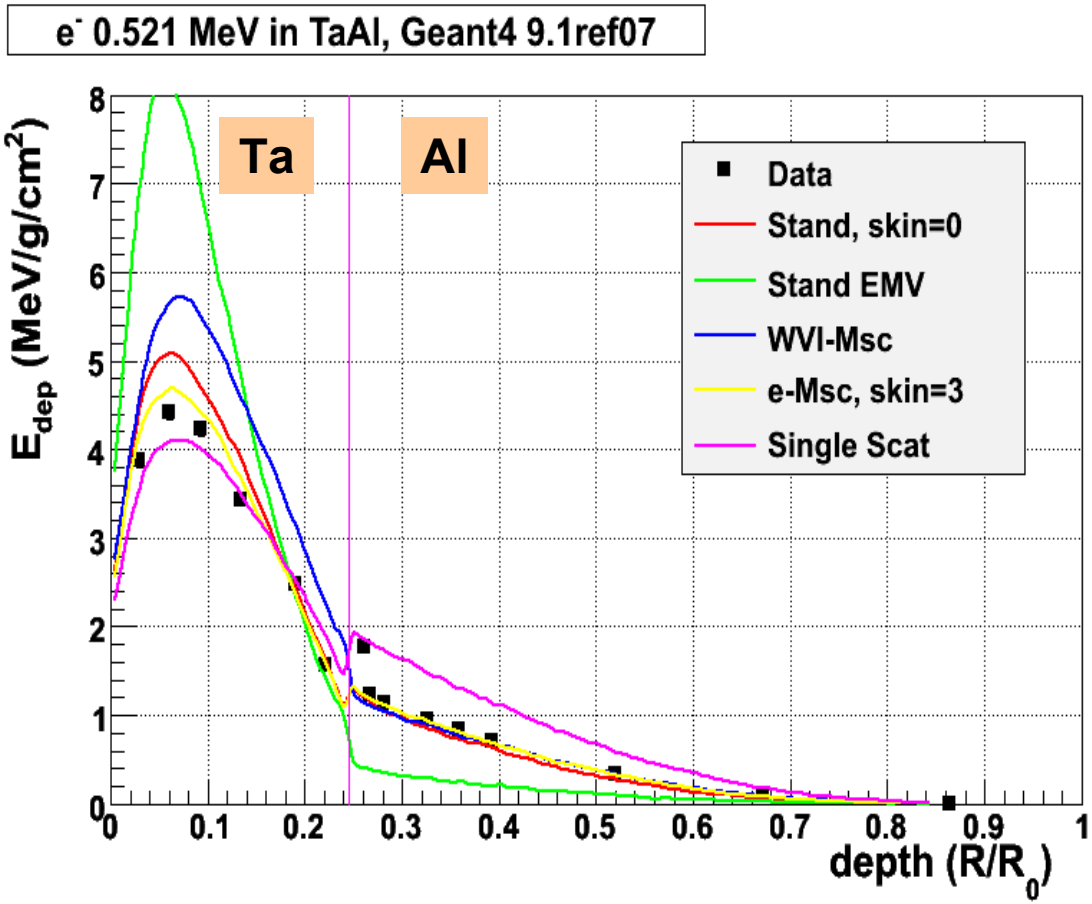
Multiple scattering – key process for particle transport

- Default msc model was frozen with g4 9.1
  - Backward compatibility
  - **LHC requirement – stability of calorimeters calibration**
- Several alternative models are under development:
  - Specialized per particle type and use case
    - G4UrbanMscModel2 focused on electron transport
    - G4WentzelVIModel focused on muon and hadron transport
  - Combined with single scattering processes
    - G4ScreenedNuclearRecoil
    - G4CoulombScattering
  - **Extended validation capabilities**

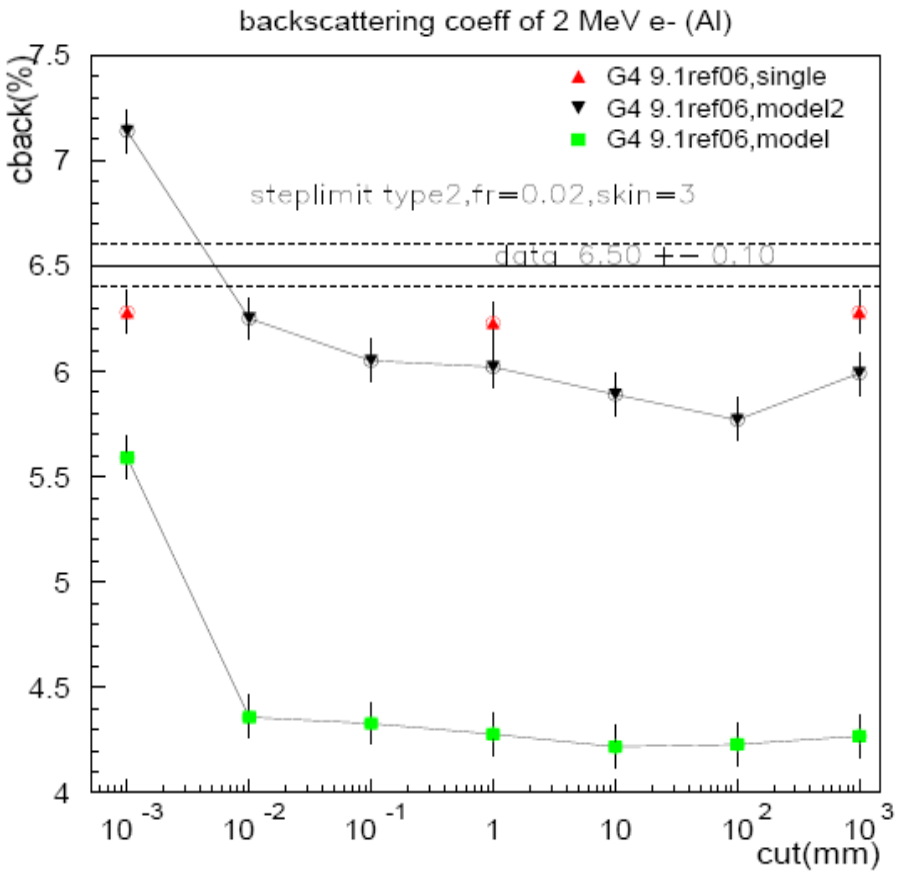
Test of e⁻ transport versus Sandia data

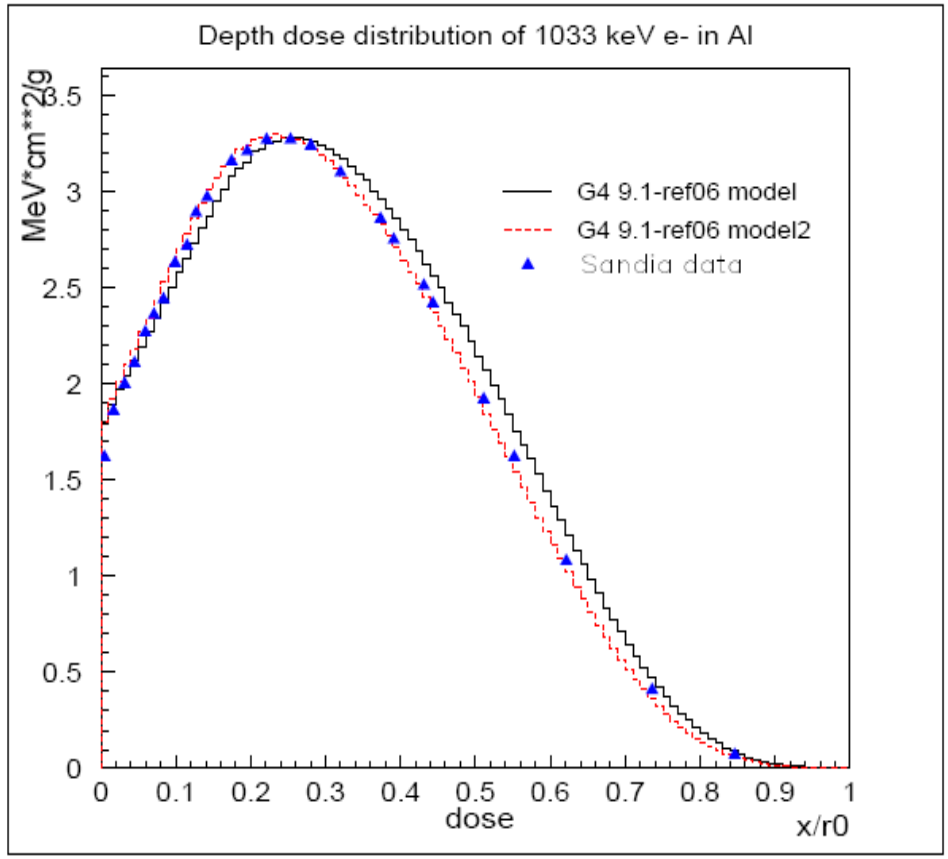
(details in O.Kadri et al, NIM B258 (2007) 358)

- Sensitive to multiple scattering
- Directly connected with LHC calorimeters results
- Tuned Urban's msc model#2
  - is best in describing data
    - Label e-Msc, skin=3



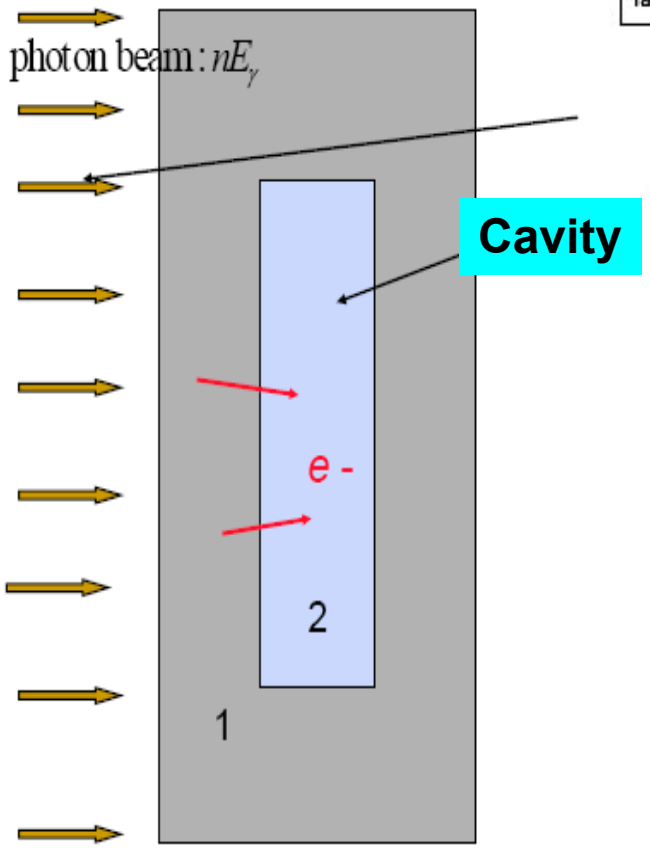
Upgrade of multiple scattering model

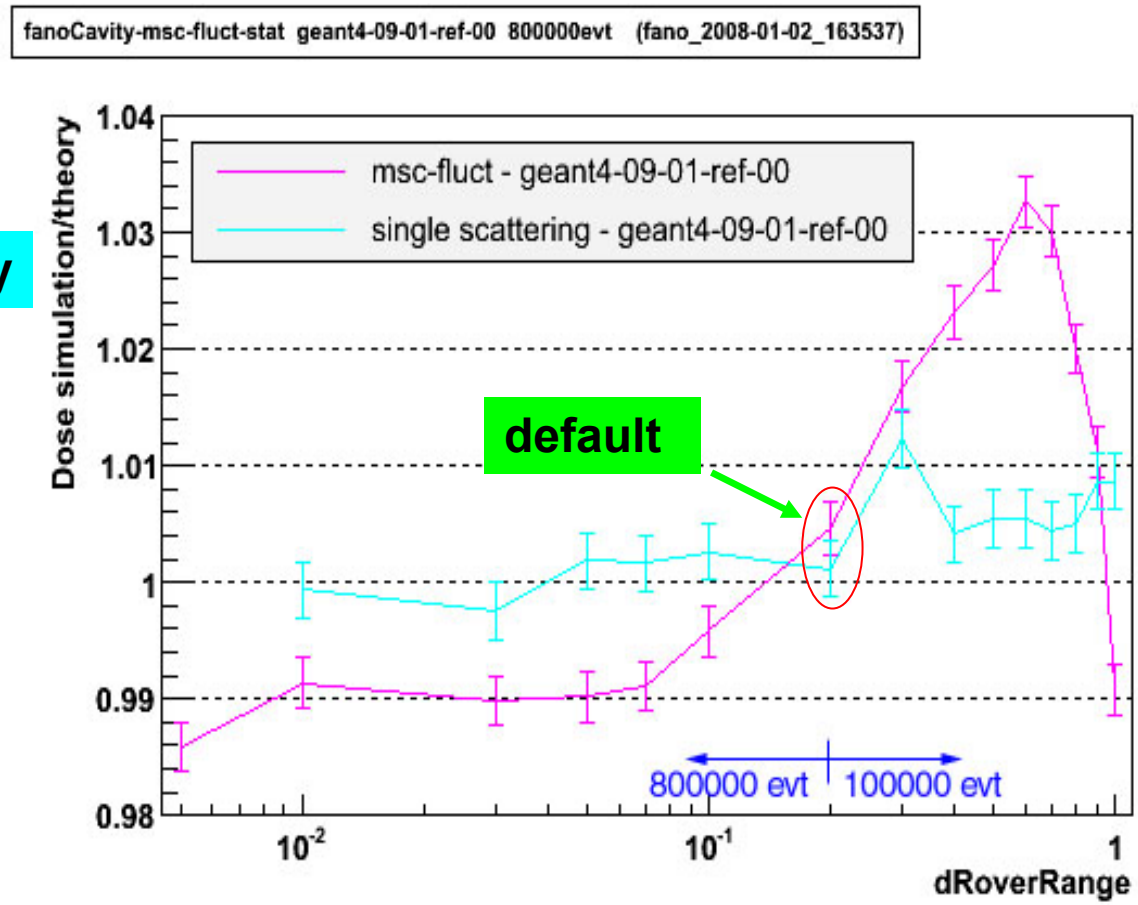




Old default version will be kept for backward compatibility

Fano cavity benchmark for e- transport (9.1)

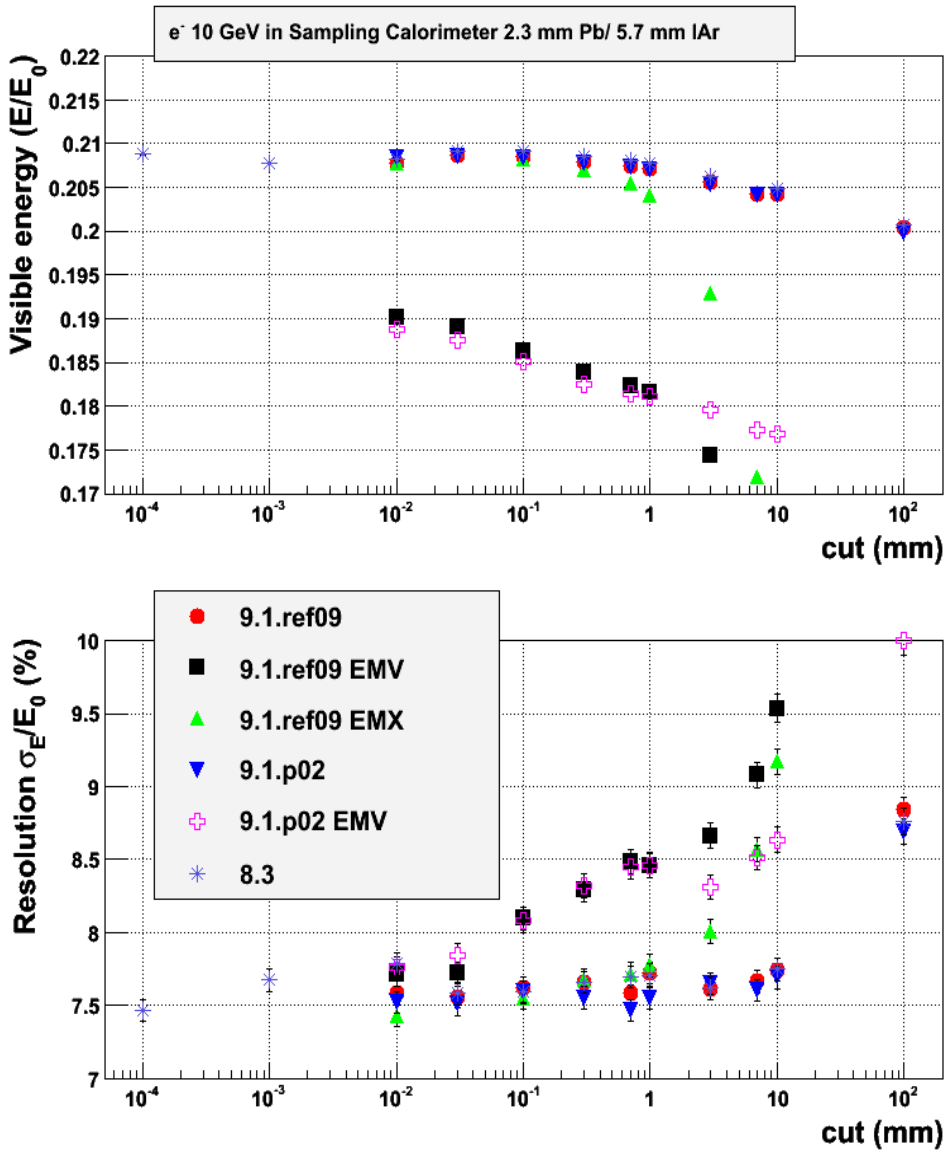




Multiple scattering now more stable. Working point at 0.2.
Note: Single scattering simulation requires more than 10 times of CPU

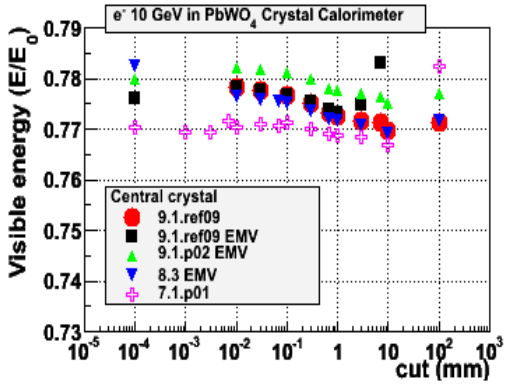
ATLAS barrel type calorimeter

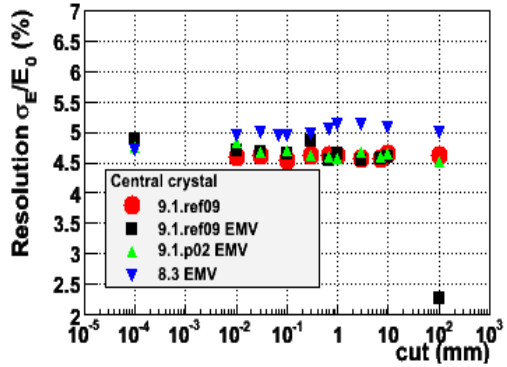
- 9.1ref09 – pre-release version of EM physics
- Default Physics List results unchanged
- Cut on gamma processes (EMX) reduces accuracy of energy response but has no effect on EMV

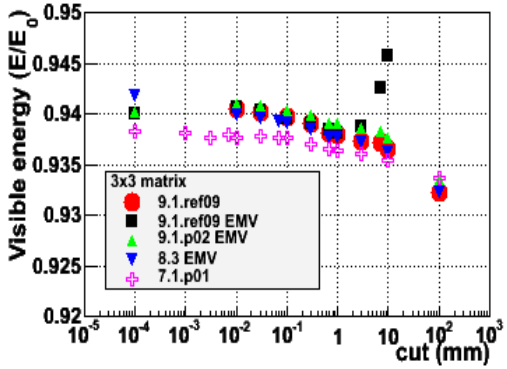


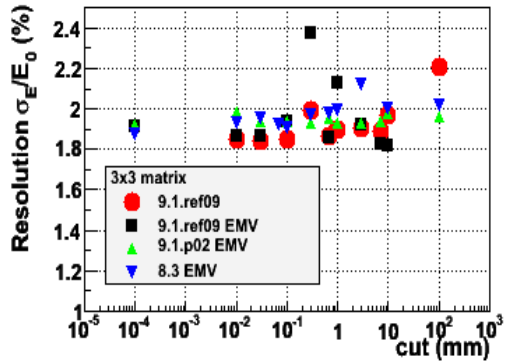
CMS ECAL type calorimeter

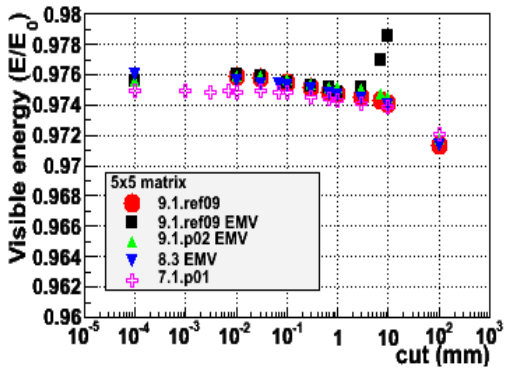
- 5x5 matrix of $PW0_4$ crystals
- Reduced (~0.5%) energy deposition in central crystal both for the default and EMV Physics Lists
  - Result of upgrade of Urban multiple scattering model

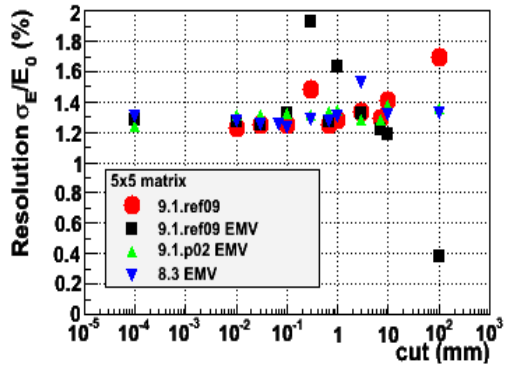








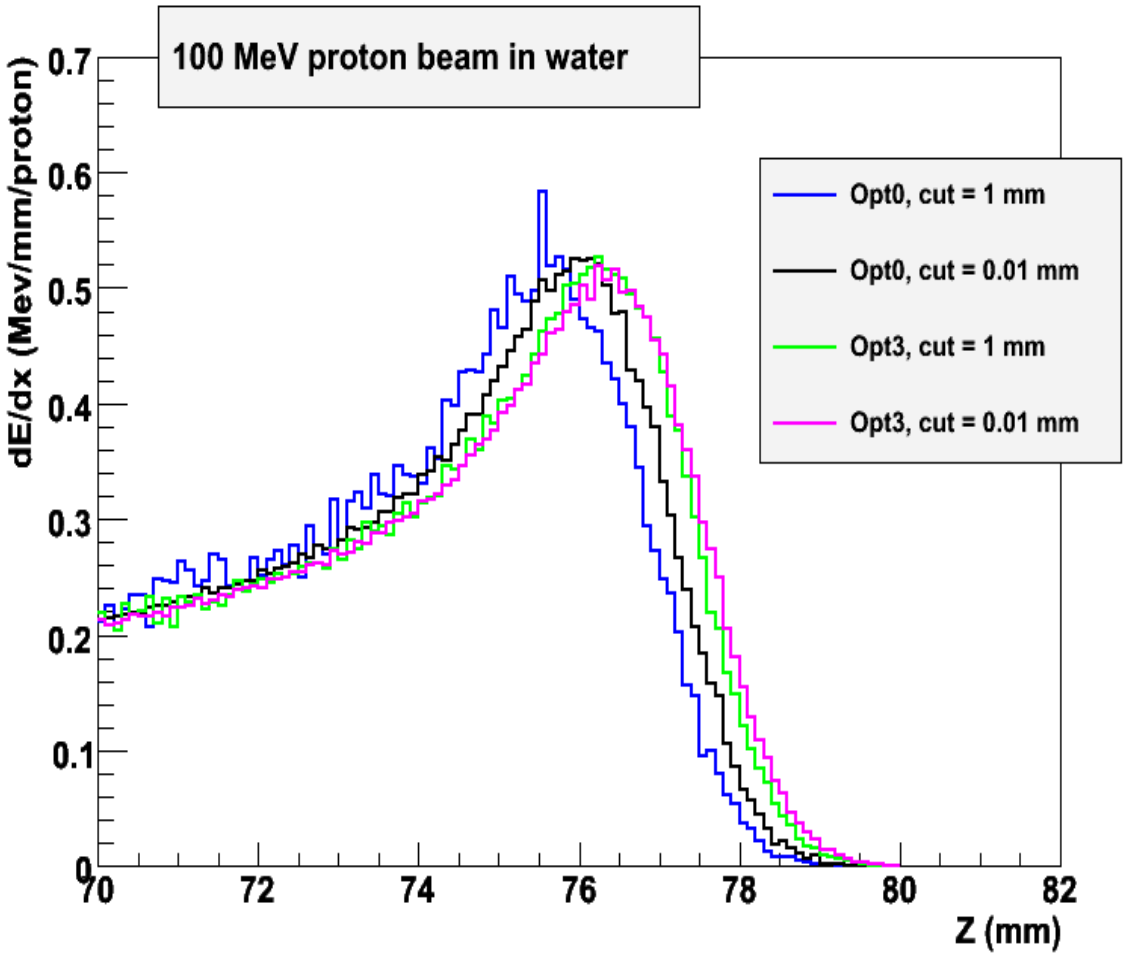




Infrastructure and performance upgrade

Spline option for Physics Tables

- Spline interpolation of dEdx, range and other tables
- Zoomed Bragg peak
- Default EM physics without spline (Opt0)
  - strong cut dependence
  - Non-statistical variations due to numerical instability
- Advanced EM physics (Opt3)
  - Stable result



Cerenkov and Scintillation processes: Recent improvements

- Photon emissions now stop where particle drops below Cerenkov threshold
  - Step also limited by maximum allowed change in β = v/c
- Lateral displacement due to Multiple scattering affects photon origin
- Biasing method for Cerenkov process have been studied
  - number of photons in heavy crystals ($PbWO_4$) could be reduced in 10^2-10^3 times without appreciable change of energy resolution
- G4Scintillation process Birks effect
  - Uses new helper class G4EmSaturation
  - Birks constants for G4 or defined by user

CPU benchmarking

- Static build on dedicated SLC4 PC
  - no libraries from afs

	EM1	EM2	EM3	EM1_EMV	EM2_EMV	EM3_EMV
8.3	1.33	2.30	1.84	1.0	1.0	1.0
9.0	1.21	2.05	1.65	0.92	0.93	0.94
9.1p02	1.16	2.05	1.64	0.92	0.94	0.93
9.2 (prospect)	1.11	1.84	1.49	0.72	0.81	0.87

- CPU gain with 9.0 mainly due to c++ software cleanup
- CPU gain with 9.2 due to optimization of physics
  - step limitation by multiple scattering
  - energy threshold for gamma processes

Conclusions

- Standard EM packages are used in many applications
  - ATLAS, CMS, LHCb productions for LHC
- New Geant4 release 9.2 planned for December 2008 will include number of improvements
  - New relativistic bremsstrahlung model
  - Specialized electrons multiple scattering model
  - Spline option for tables of dEdx, range, cross sections
  - New functionality
- Better CPU performance is expected

Validation of muon scattering

- **MuScat data (D.Attwood et al., NIM B251 (2006) 41)**
  - **10 different targets**
- **Hashed area – one standard error of the measurement**
- **Single scattering model and WentzelVI msc model better describe the tail**