The Performance of the Geant4 Standard EM Package for LHC and Other Applications

J. Apostolakis, A. Bagulya, S. Elles, V. Ivanchenko, O. Kadri, M. Maire, L. Urban

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Outline

- Recent upgrades for Geant4 satndard EM
  - EM physics and navigation
  - Updates provided with g4 8.3
  - Updates provided with g4 9.0
- Recent validation results
  - Electron transport
  - Heavy particle transport
  - LHC-type calorimeter response
- CPU performance
- Summary

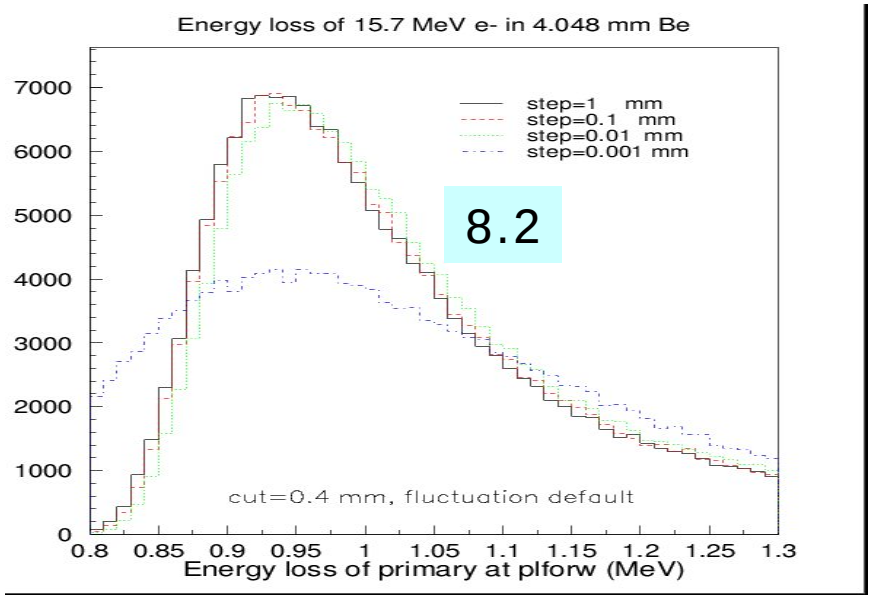
EM physics and Geant4 navigation

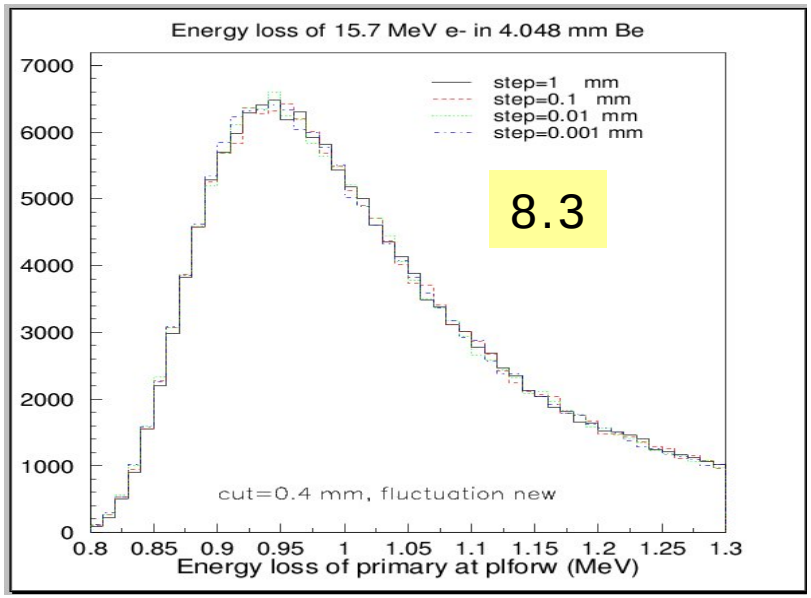
- Geant4 7.1p01 have been used in production for ATLAS, CMS, LHCb and other experiments
- Since then multiples scattering models was significantly upgraded
  - reduced dependence of detector response on production cuts for sampling calorimeters
- Sub-cutoff option restored – simulation with lower cuts in vicinity of geometry boundary
- Upgrades require access to geometry information from physics model to get
  - safety radius
  - distance to the next boundary
- Redesign of interfaces to navigator/transportation

Updates provided with Geant4 8.3

- G4SafetyHelper was introduced
- Single Coulomb scattering mode near geometry boundaries inside G4UrbanMscModel
  - do not use for simulation with strong magnetic field
- Multiple scattering angular distribution improved
  - both central part and tail
- G4hMultipleScattering process for heavy particles
  - the same model with options for faster computations
- Necessary protections were introduced to remove production job fail

Sampling of fluctuations in Geant4 8.3





- We cannot use Landau distribution which assumes no δ-rays production
  - Model of fluctuations is cut and material dependent **(L.Urban, NIM A362(1995) 416)**
- The model was improved for small steps or gas

Updates provided with Geant4 9.0

- Updated G4SafetyHelper
  - multiple scattering model
  - sampling of sub-cutoff option
- Provided alternative to continues multiple scattering G4CoulombScattering process
  - single scattering
- Optimized general interfaces for EM processes to be more fast
- Infrastructure updated
  - Renamed Physics Lists optional builders
  - Renamed EM standard components in examples
  - Renamed methods of G4EmProcessOptions
  - New UI commands
  - Removed 52-type processes

Multiple scattering options

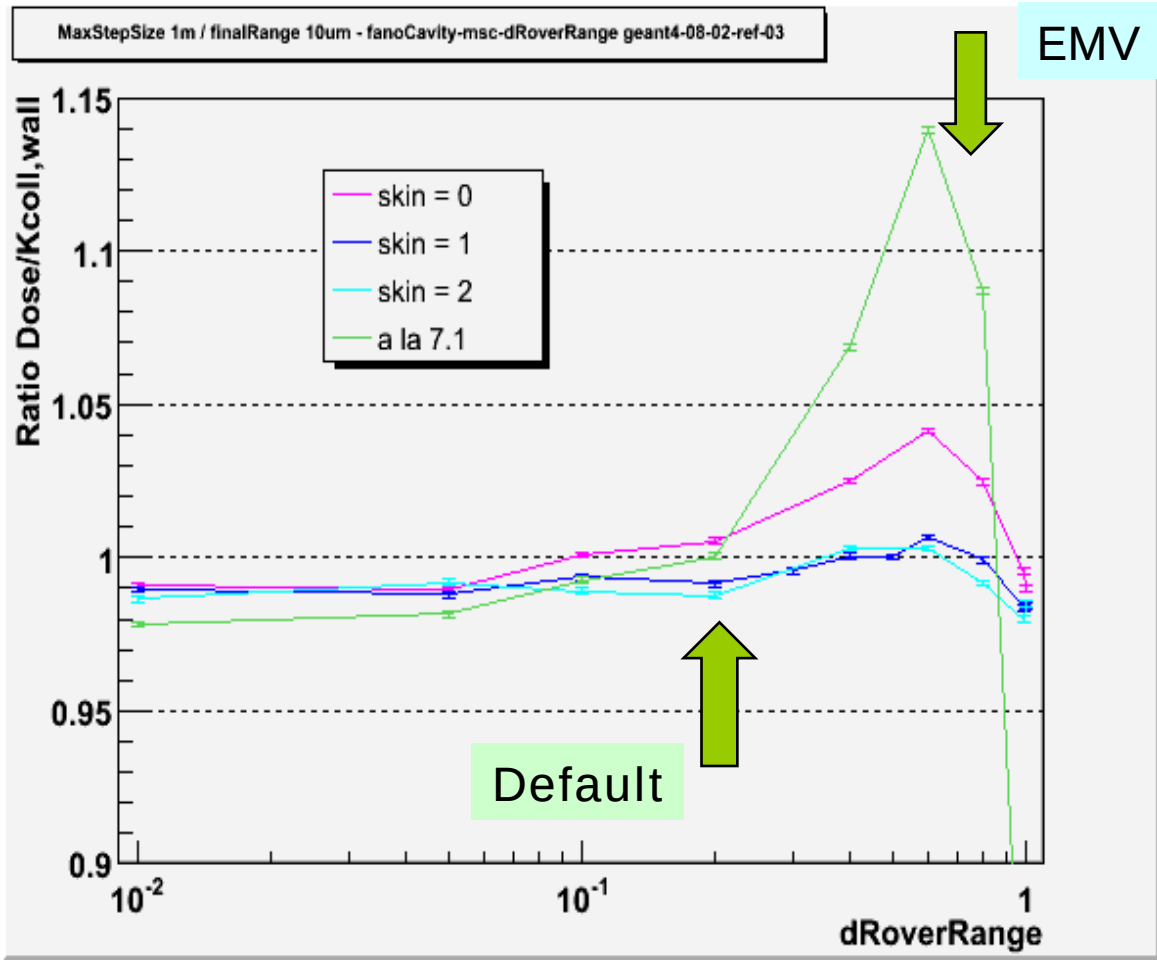
- G4MscStepLimitType
  - Minimal - equivalent to the algorithm of Geant4 7.1 and earlier releases (QGSP_EMV Physics Lists)
  - UseSafety - the current default, uses geometrical safety (QGSP and QGSP_EMX Physics Lists)
    - **QGSP_EMX includes sub-cutoff option**
  - UseDistanceToBoundary - the most advanced, recommended for accurate computations in the cases, where no magnetic field is set
- Multiple scattering options configurable via UI

Validation of MeV electron transport using Standard EM packages

Motivation: A significant part of LHC calorimeter response due to e^- with energy below 1 MeV

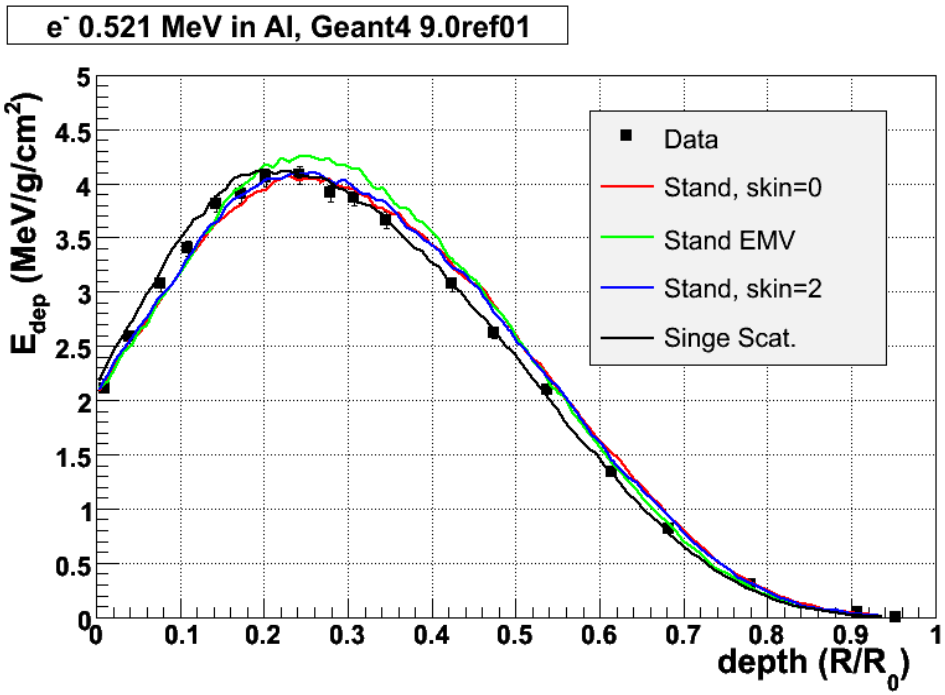
Fano Cavity test of e^- transport

- 1 MeV gamma beam in water with cavity of water-gas
- The absolute prediction of the dose deposition inside the cavity
- Significant deviation for EMV Physics List

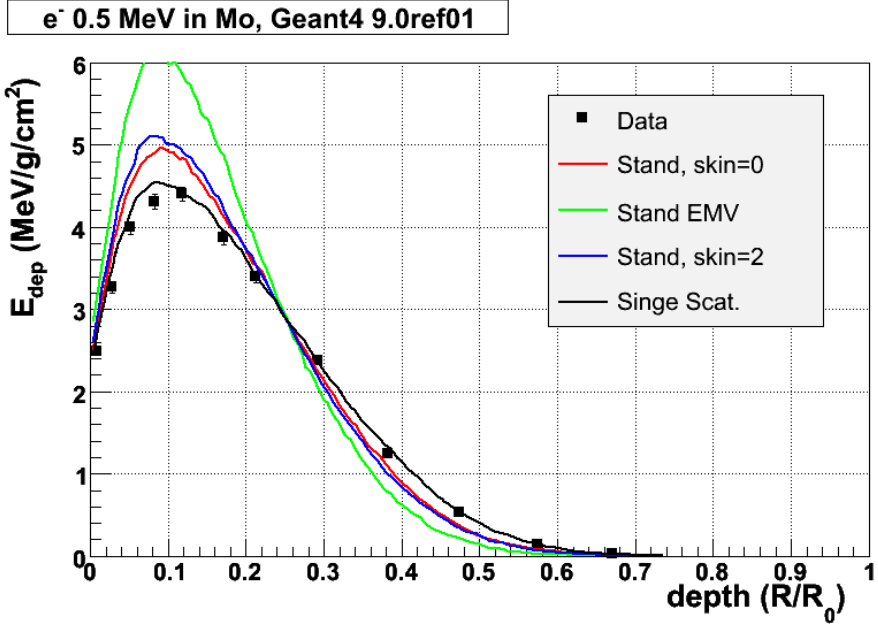


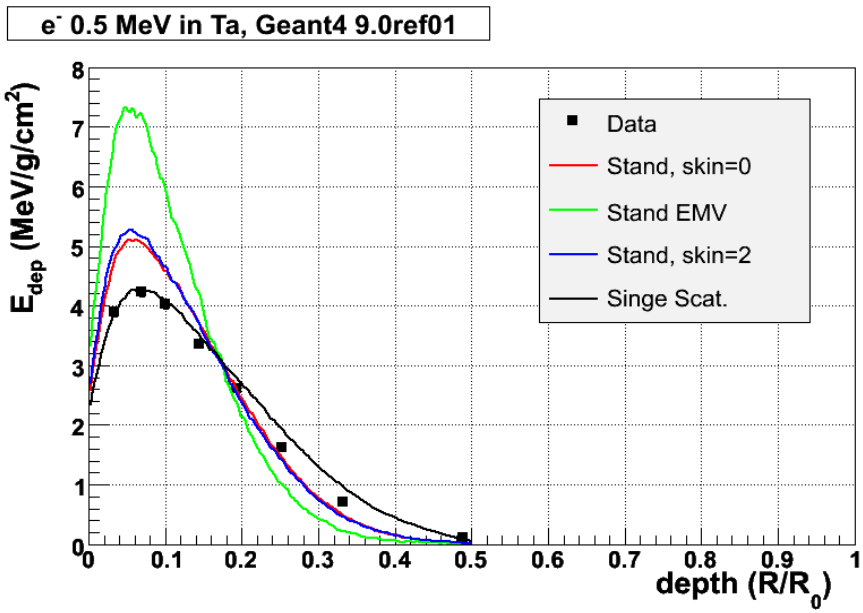
Sandia test of e⁻ transport (NIM B258 (2007) 358)

Integral dose is an important value for LHC – 3 % accuracy

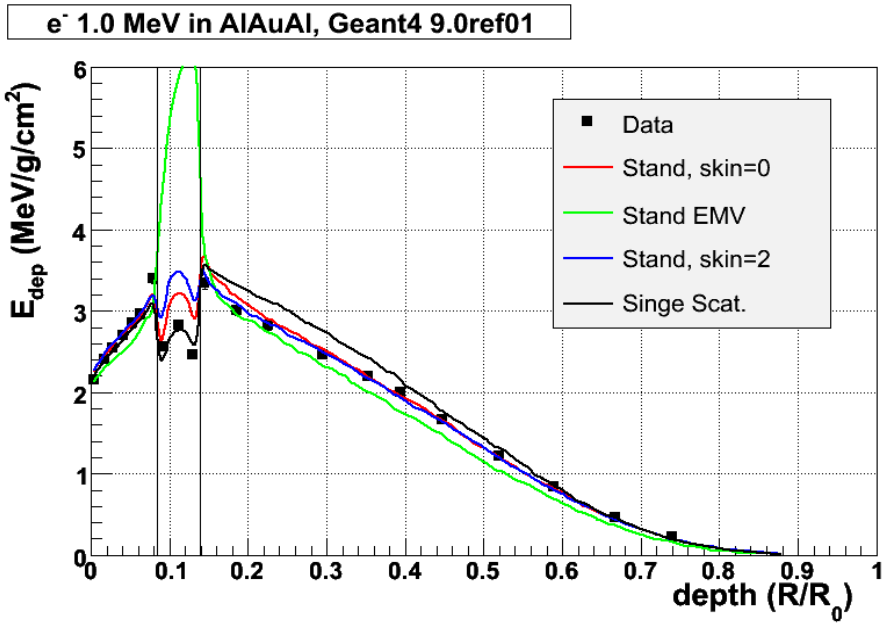


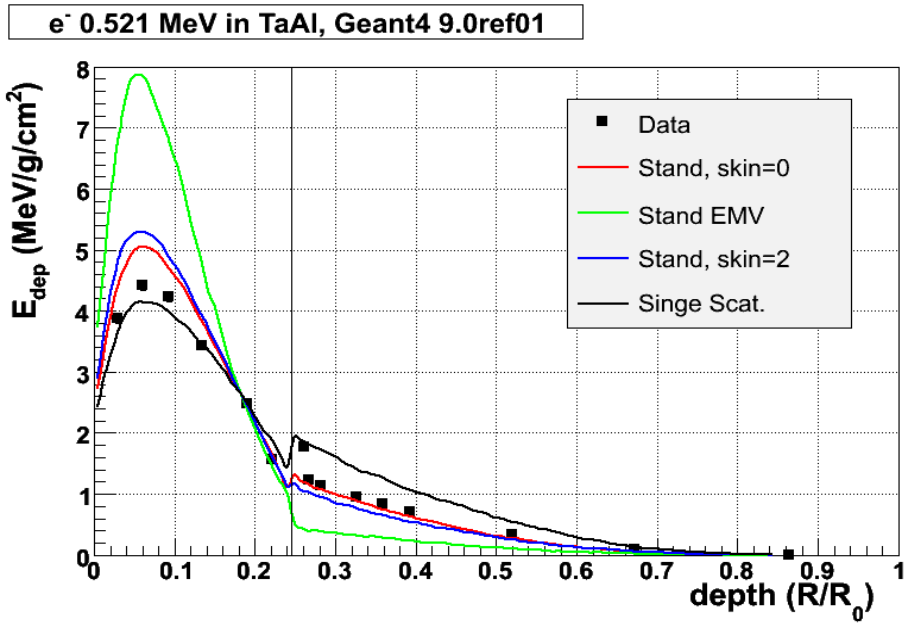
Standard cut 0.7 mm





Sandia test for multi-layer configurations

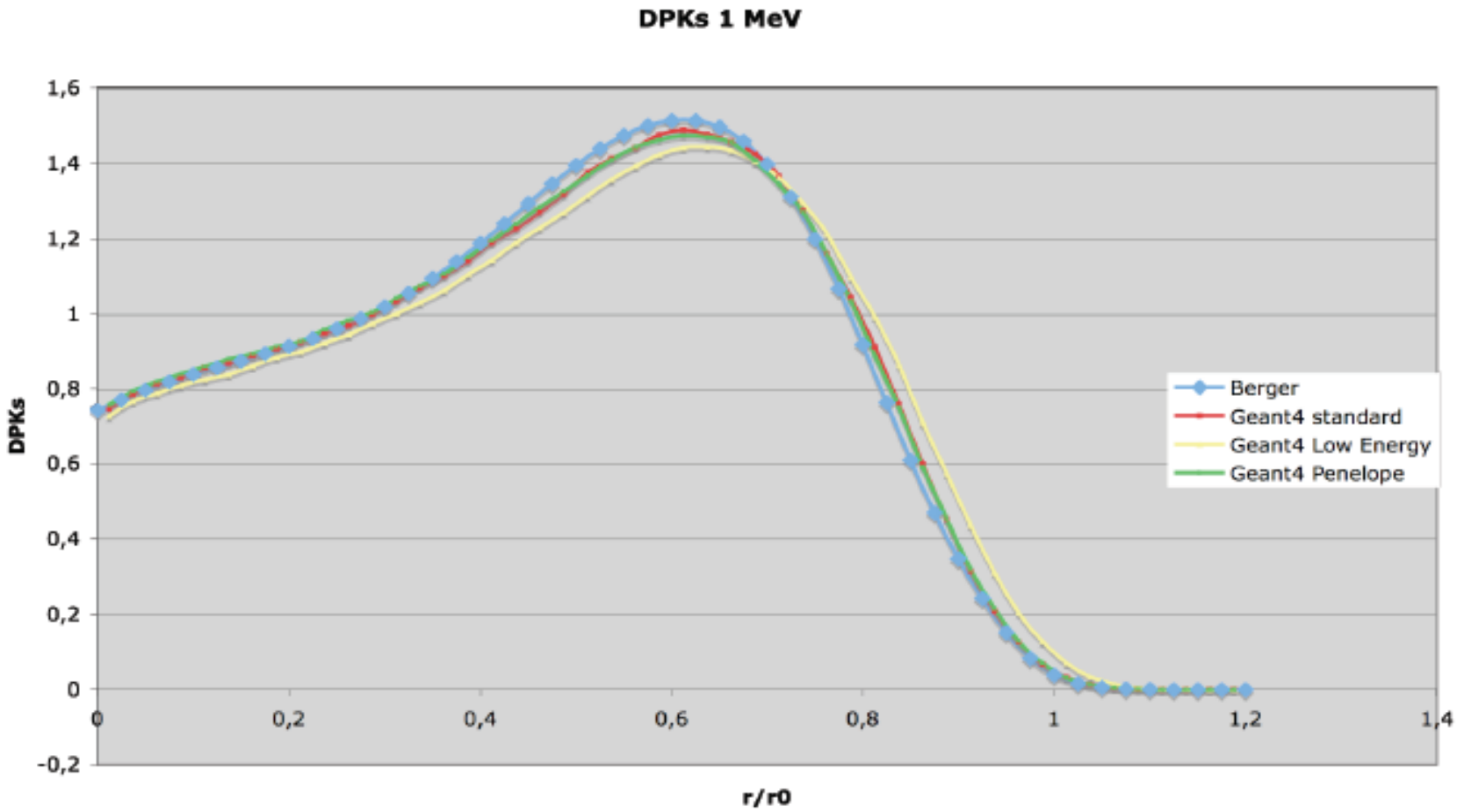




- EMV shows significant deviation from the data
- Single scattering model overestimates dose deposition in the last layer and provide slightly longer distribution in dense media

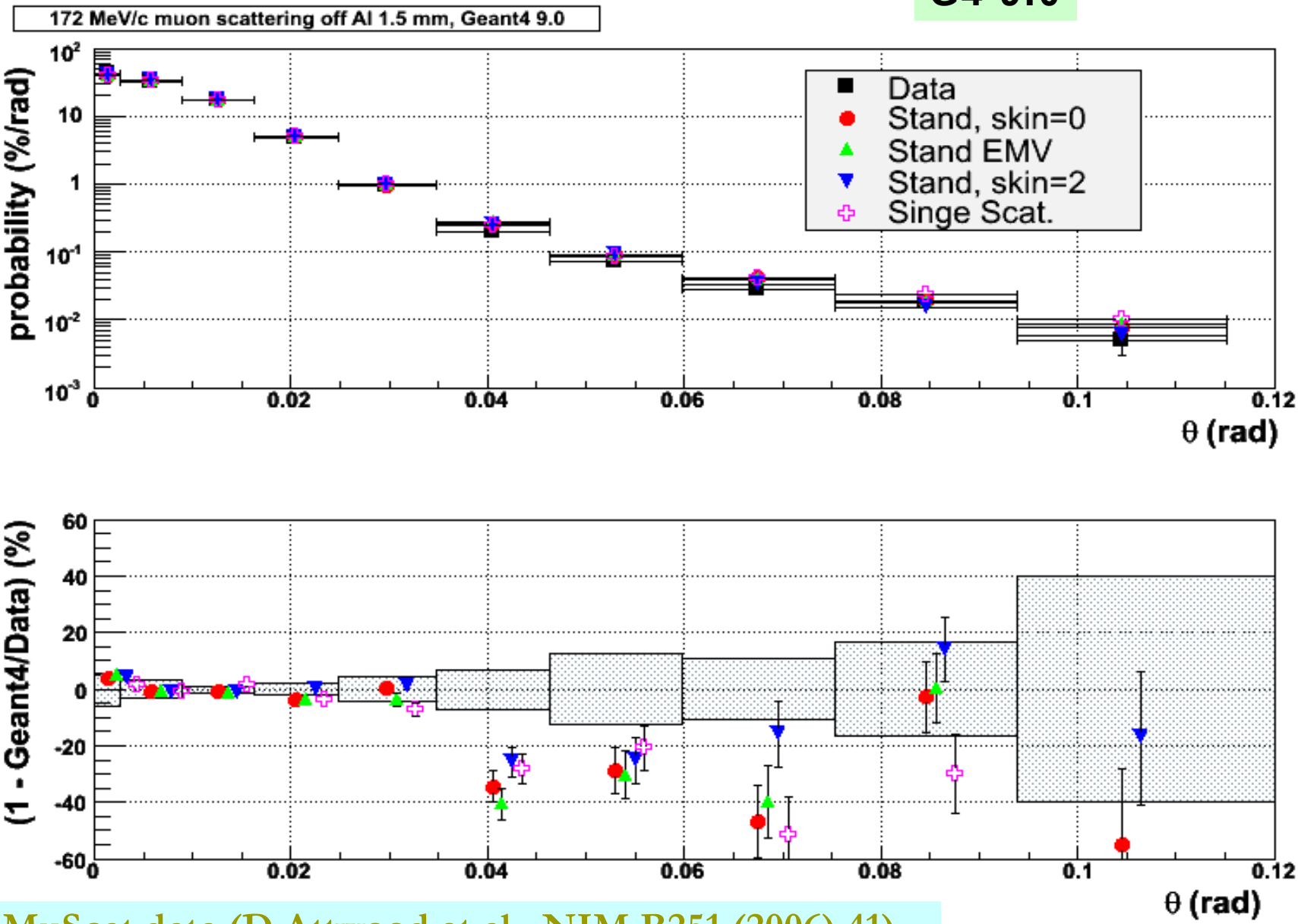
Similar test versus other MC codes

(L. Ferrer et al., Cancer Biotherapy & Radiopharmaceutical, 22 (2007))



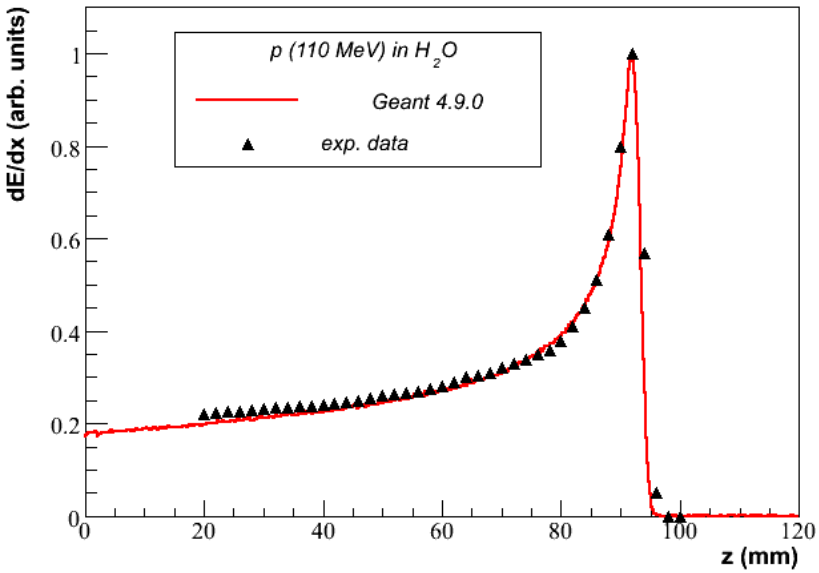
Validation on heavy particle transport using Standard EM packages

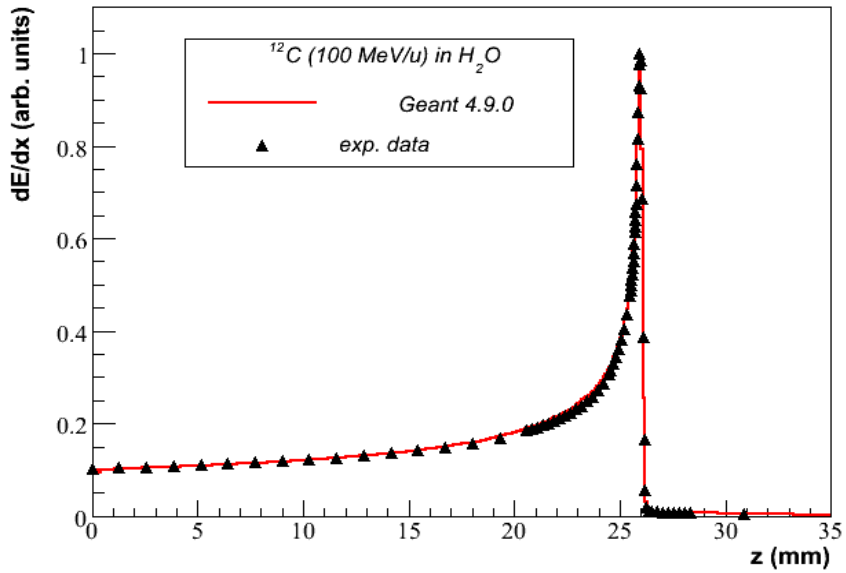
G4 9.0



MuScat data (D.Attwood et al., NIM B251 (2006) 41)

Proton and ion stopping in water
(QBBC Physics List)

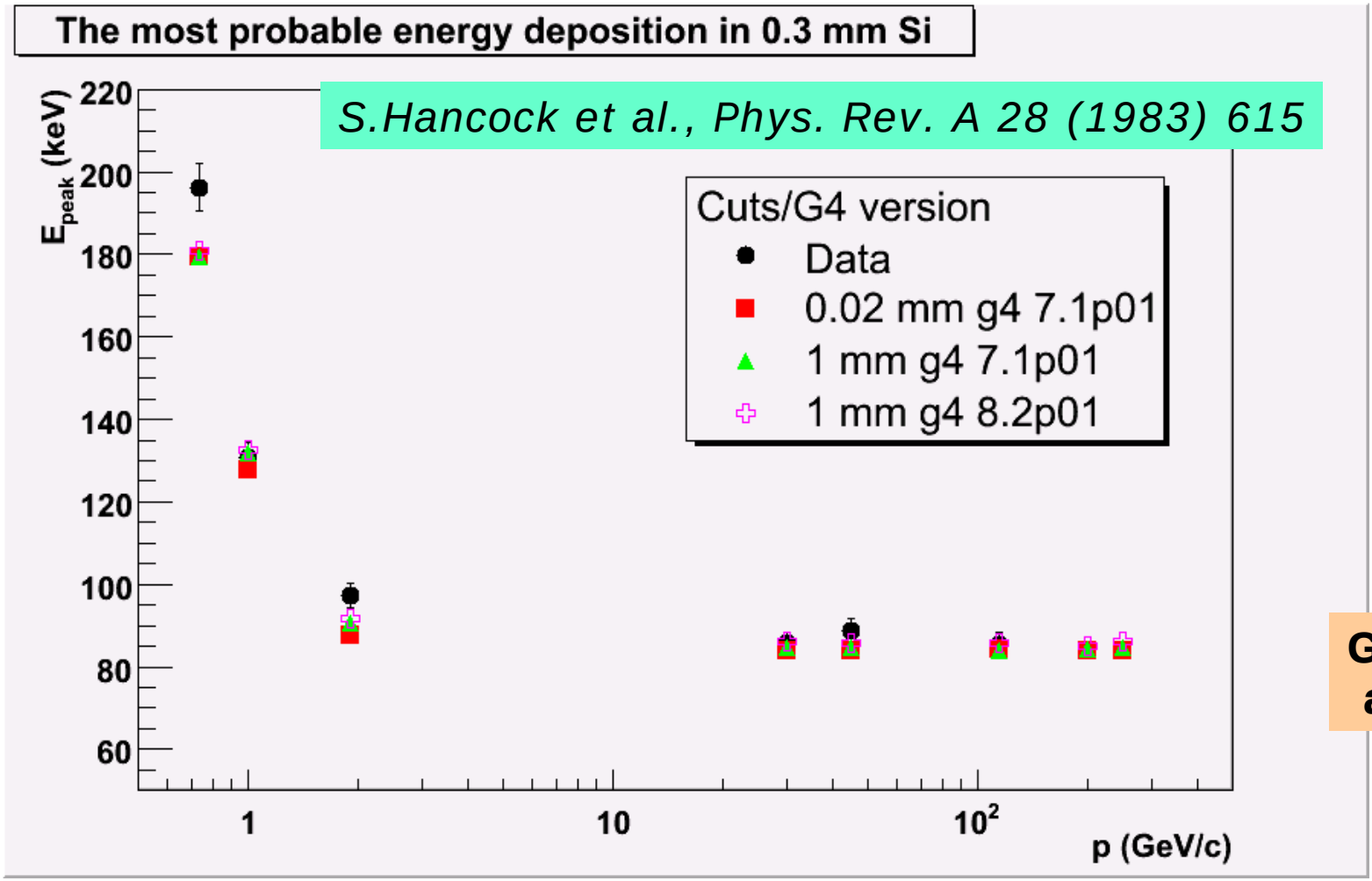




A.Bagulya et al., 11th Geant4 workshop, Lisbon, 2006

- The data for medical proton and carbon-ion beams in water are well reproduced by the Standard package
- Binary Cascade is used for sampling of inelastic interactions
- QElastic model is used for sampling of elastic scattering

Geant4 simulation and data for signal in a vertex detector



TestEm3

π^+ or p beam

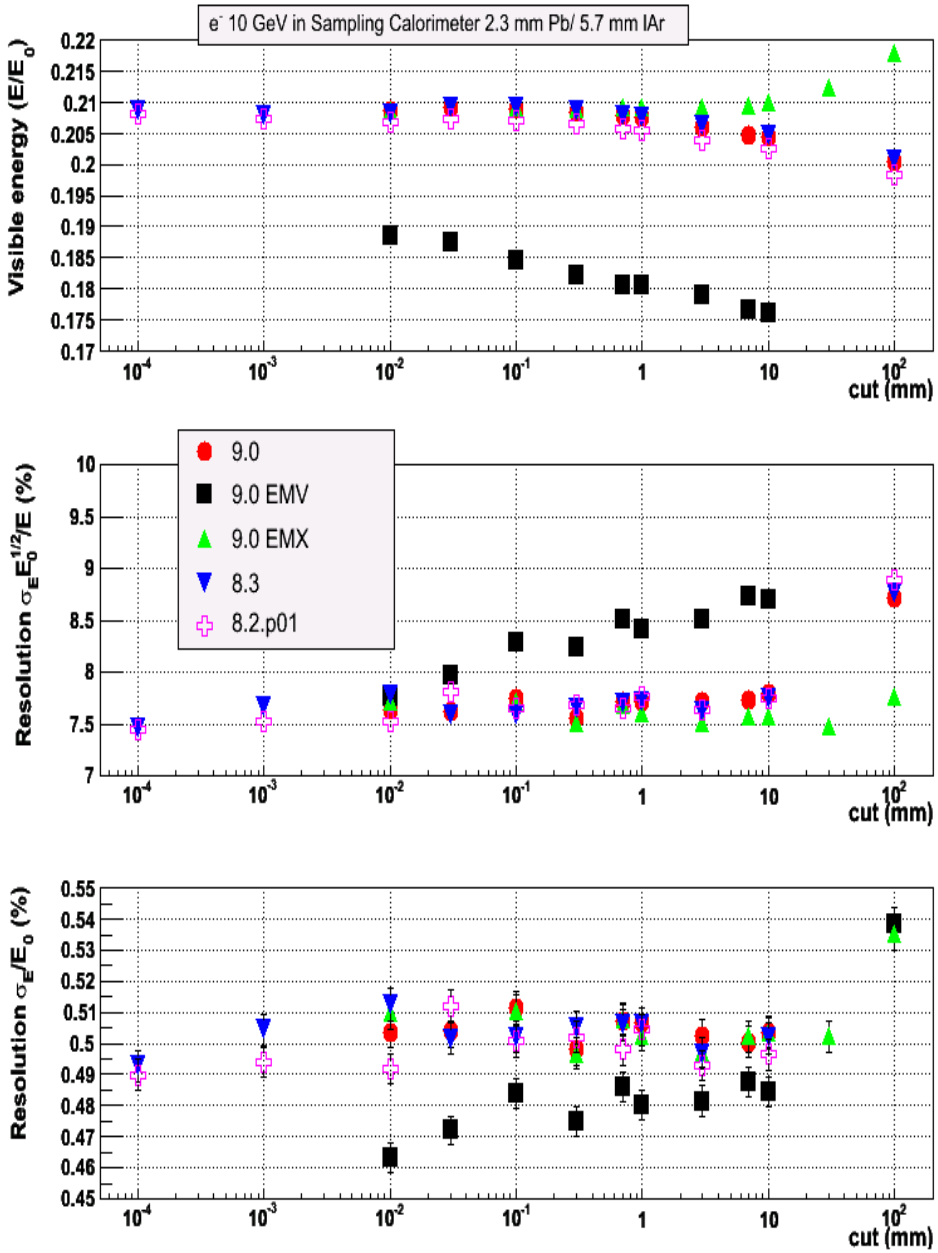
G4 results are stable

LHC-type Calorimeter Responses

Regular tests of ATLAS barrel, ATLAS HEC, CMS, LHCb simplified calorimeters

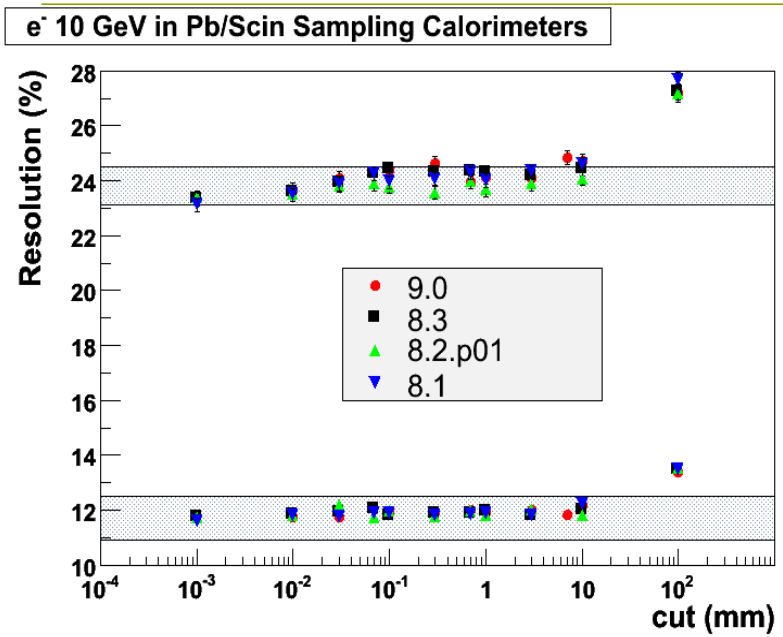
Calorimeter tests ATLAS barrel type

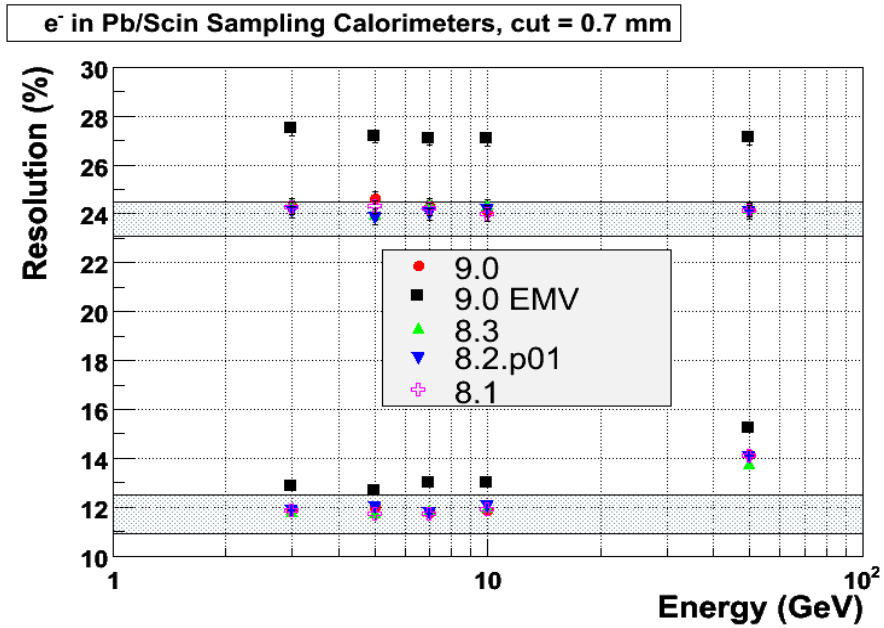
- Practically no difference between 8.3 and 9.0
- EMV results are the same as for 7.1p01
- Sub-cutoff option (EMX) was optimized



Pb/Scintillator sampling calorimeter

(NIM A262 (1987) 229; NIM A274 (1989) 134)

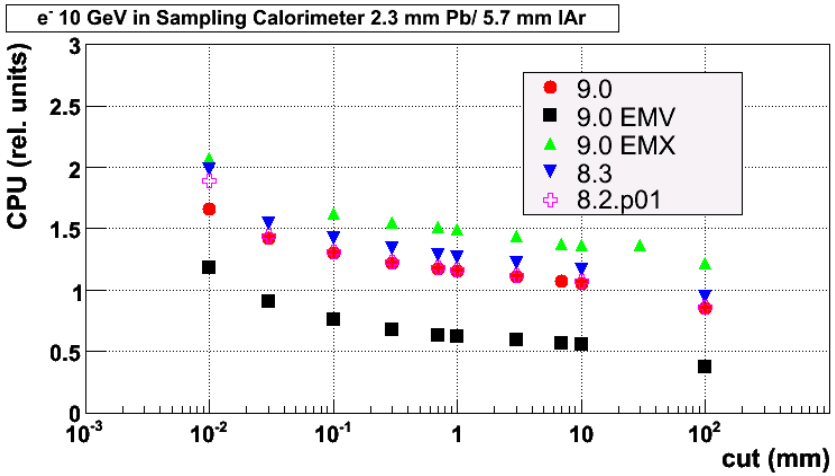


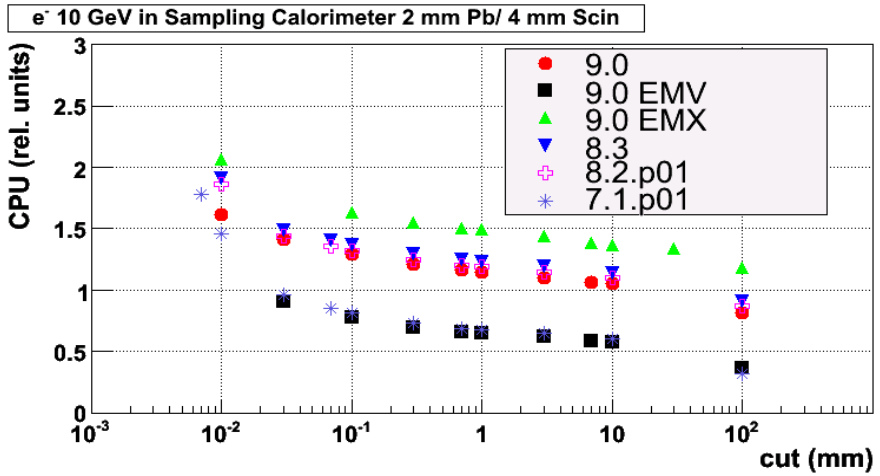


- Two configurations:
  - 5 mm Pb/5 mm Scintillator
  - 10 mm Pb/ 2.5 mm Scintillator
- Default Geant4 (QGSP) within experimental uncertainty
  - At 50 GeV a special cut was applied for data analysis to reduce leakage
- QGSP_EMV version provides biased results
  - Less precise for small sampling fraction

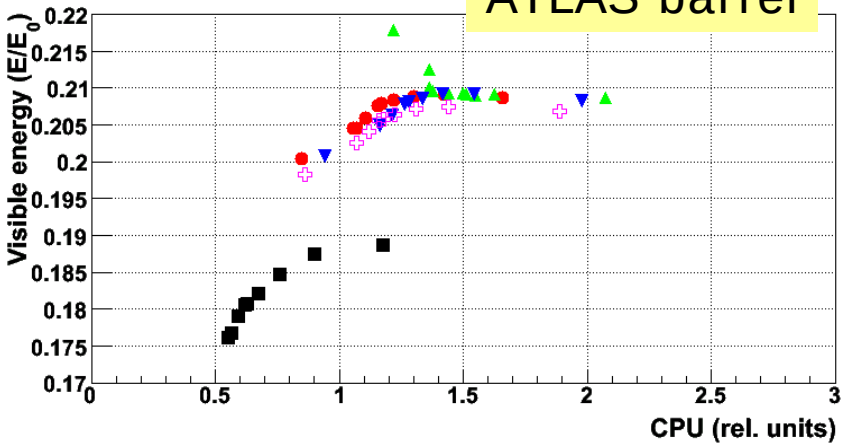
CPU performance

Visible energy and CPU performance

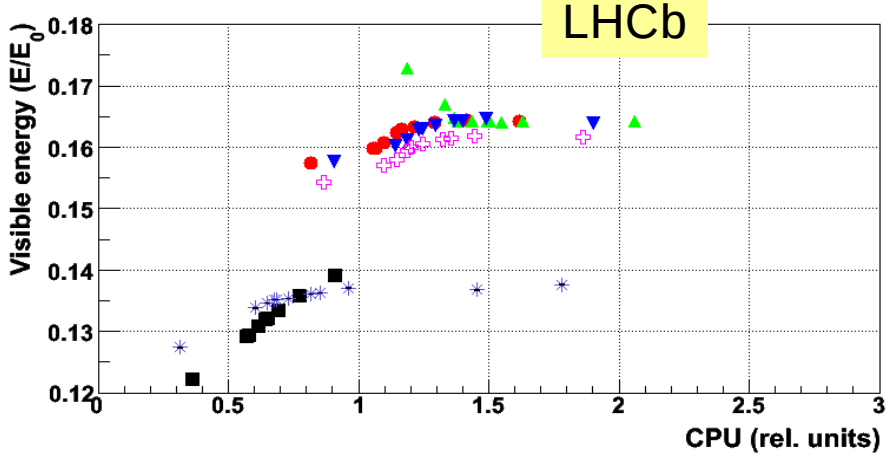




ATLAS barrel



LHCb



CPU optimization for Geant4 9.0

- The review and optimization of interfaces have been performed
  - G4VEmModel
  - G4VEnergyLossProcess
  - G4VEmProcess
  - G4VMultipleScattering
  - Modifications were provided for all derived classes
- Reduction of usage of virtual methods
- Reuse stl vectors - reduced calls to *new* and *delete* for intermediate vectors
- Minor optimization of G4UrbanMscModel code

CPU benchmark

Electromagnetic physics

EM-1 : 10 GeV e- in matrix 5x5 of PbWO4 crystals (CMS-type);
cut = 0.7 mm, 1000 events.

EM-2 : 10 GeV e- in ATLAS barrel type sampling calorimeter;
cut = 0.7 mm, 1000 events.

EM-3 : 10 GeV e- in ATLAS barrel type sampling calorimeter;
cut = 0.02 mm, 100 events.

	QGSP			QGSP_EMV		
Release	**EM-1**	**EM-2**	**EM-3**	**EM-1**	**EM-2**	**EM-3**
5.2.p02	1.03	0.99	1.59			
6.2.p02	0.89	0.98	0.97			
7.1.p01	1.00	1.00	1.00			
8.0.p01	1.33	2.24	2.26			
8.1.p01	1.37	2.43	2.01	1.06	1.08	1.07
8.2.p01	1.27	2.03	1.73	1.03	1.09	1.06
8.2.ref02	1.29	2.14	1.79	1.03	1.08	1.06
8.2.ref03	1.28	2.08	1.78	1.04	1.04	1.05

All numbers with Geant4 CERN afs installation for SLC3 and shared libraries

CPU benchmark upgrade

- Static build on dedicated SLC4 PC
  - no libraries from afs
- SLC3 to SLC4 migration slightly change ratio between CPU of different tests

	EM1	EM2	EM3	EM1_EMV	EM2_EMV	EM3_EMV
8.3 SLC4	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
9.0ref01	1.17	2.07	1.66	0.91	0.92	0.91

- Possible further CPU improvements:
  - more efficient computation of safety
  - more efficient sub-cutoff sampling
  - reducing of number of steps

Summary

- With Geant4 8.3 and 9.0 EM standard is capable to provide results on level of accuracy ~2 %
  - EMV Phys List is kept to be the same as default physics of Geant4 7.1p01
- 0.7 mm cut is the today default
  - Lower cuts not needed for LHC calorimeters!
  - Lower cuts may be useful for tracking detectors
- Sub-cutoff option (EMX) provides stable results up to cut 10 mm
  - CPU performance of sub-cutoff needs to be upgraded
- There is a visible speed up for Geant4 9.0