Recent Developments and Validation of the Geant4 Standard Electromagnetic Package

SPENVIS & Geant4 Workshop

5-7 October 2005, Leuven, Belgium

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Otline

- Status of EM package
- New Geant4 components for EM physics
- Material category upgrade
- Ionization models upgrade
- Prospects

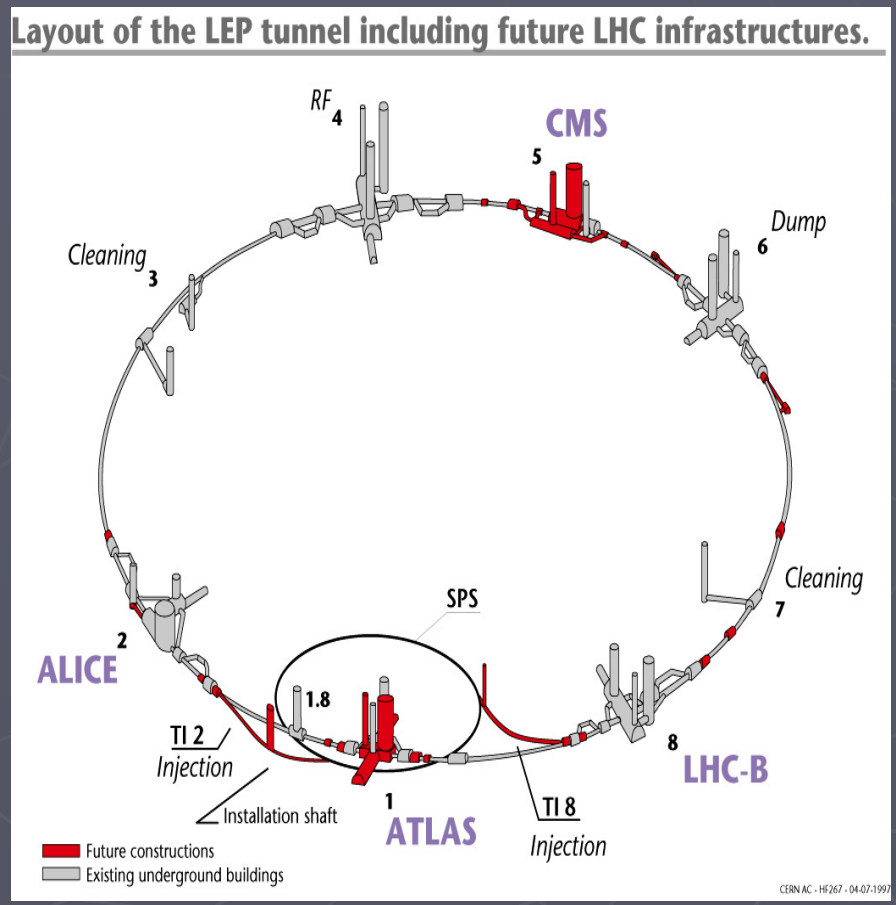
Introduction – Geant4 EM packages

- ***Standard*** – basic set of processes for HEP
- ***Muons*** – basic set of muon processes for HEP
- ***Xrays*** – xray and optical proton production
- ***Lowenergy*** – the alternative set of processes with low energy extensions of gamma, electron, and hadron EM physics
- ***Highenergy*** – EM processes important above 100 GeV
- ***Optical*** – Optical photon interaction
- ***Utils – common classes for other EM packages:***
  - ***Interfaces***
  - ***Energy loss and range table builders***
  - ***Useful utilities***

Introduction - History

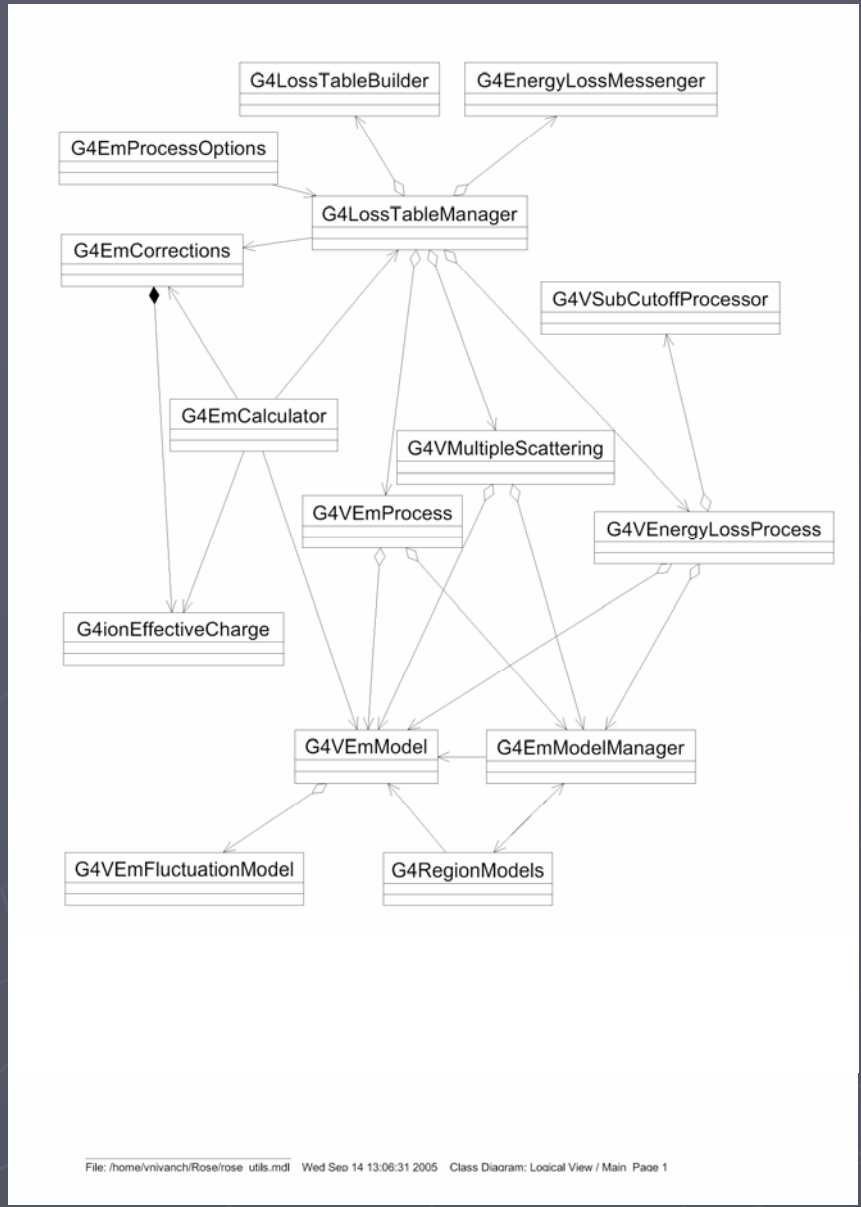
- EM package (Standard) was delivered with the 1st Geant4 release at 1998
- It is used practically in all Geant4 applications
- The most number of events are produced for BaBar experiment at SLAC
- However, internal problems were accumulated and new requirements appeared

Experiments will start in 2007



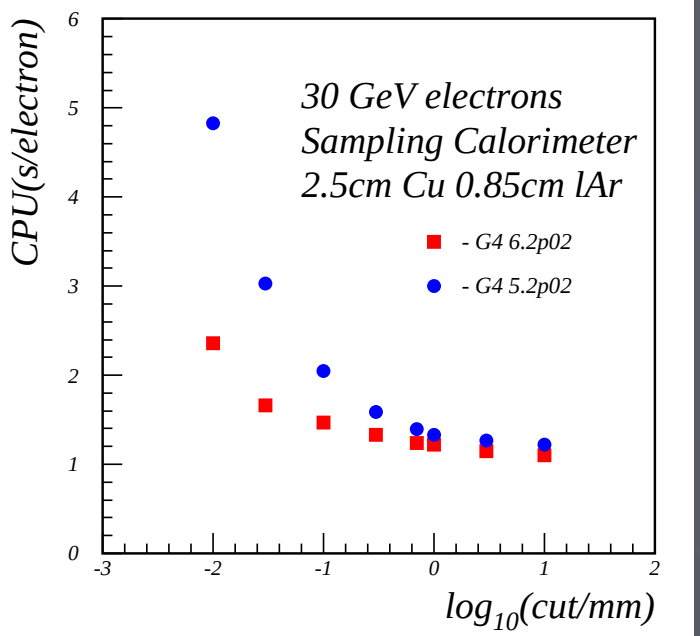
Status of Standard EM Package

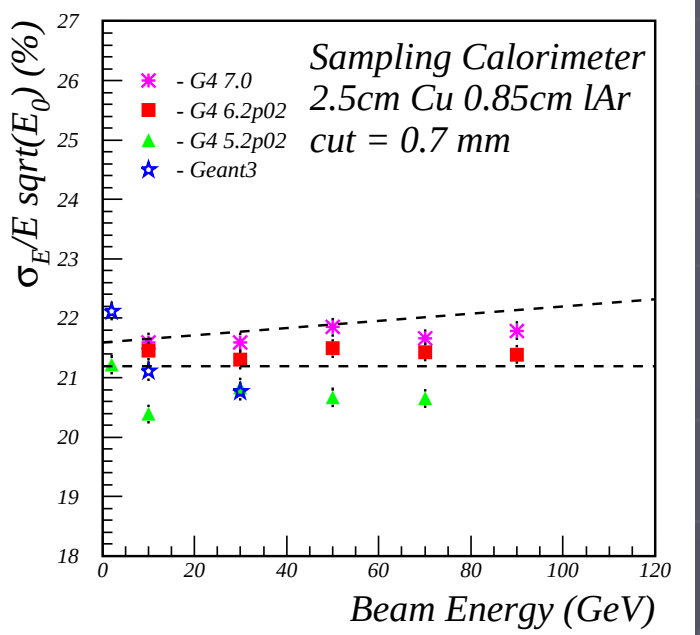
- Design iteration in EM package – refinements and optimization 2003-2005
- It will to be complete for G4 8.0 (Dec 2005)
- Move focus on updating physics model and on validation studies



New components for EM physics

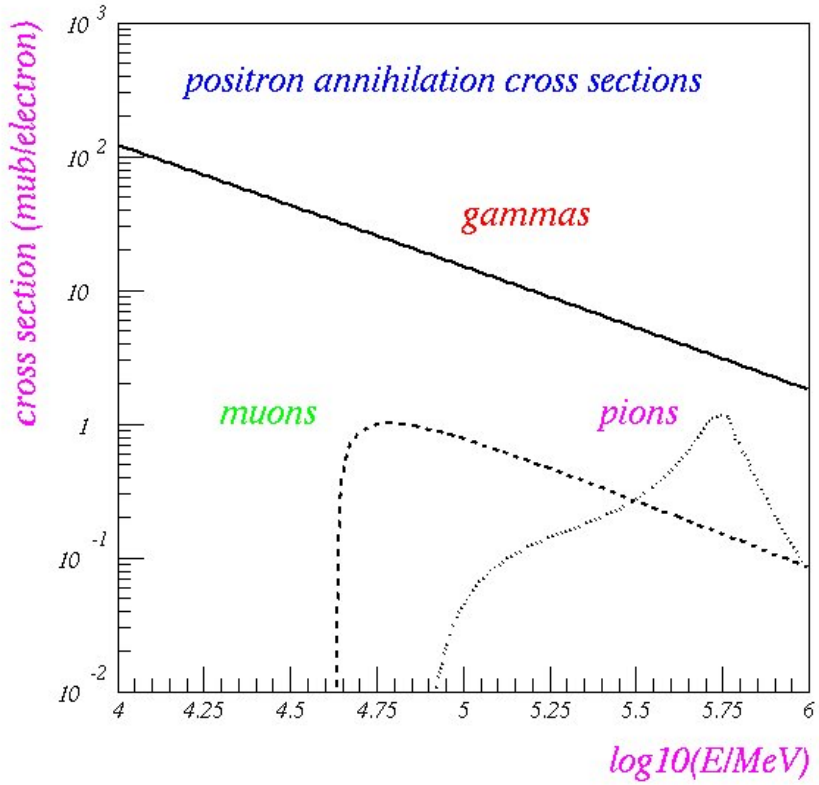
- Integral approach – more precise cross sections and straggling
- G4EmCalculator – access to cross sections and stopping power
- PhysicsList for EM use-cases released with G4 7.0
- G4EmProcessOptions – steering of the PhysicsList
- Acceptance suite is working





G4EmCalculator class

- Methods to get physics values
  - GetDEDX(kinEnergy, particle, material, region);
  - GetRange(kinEnergy, particle, material, region);
  - GetKineticEnergy(range, particle, material, region);
  - GetCrossSectionPerVolume(kinEnergy, particle, process, material, region);
  - GetCrossSectionPerAtom(kinEnergy, particle, process, material, region);
- Methods to recalculate physics values
  - ComputeDEDX(kinEnergy, particle, process, material, cut);
  - ComputeCrossSectionPerVolume(kinEnergy, particle, process, material, cut);
  - ComputeCrossSectionPerAtom(kinEnergy, particle, process, material, cut).



Hadron/ion ionization

- User requirements trigger analysis of ionization models in the Standard and Lowenergy packages
- Review of corrections to the Bethe-Bloch formula
- $$-\frac{dE}{dx} = 4\pi N_e r_0^2 \frac{z^2}{\beta^2}\left(\ln\frac{2m_e c^2\beta^2\gamma^2}{I} - \frac{\beta^2}{2}\left(1-\frac{T_c}{T_{\max}}\right) - \frac{C}{Z} + \frac{G-\delta-F}{2} + zL_1 + z^2 L_2\right)$$
  - C – shell correction (was asymptotic formula)
  - G – Mott correction (new)
  - δ – density correction
  - F – finite size correction (new)
  - L_1- Barkas correction (was in Lowenergy)
  - L_2- Bloch correction (was in Lowenergy)
  - Nuclear stopping (was in Lowenergy)
  - Ion effective charge (was in low energy)

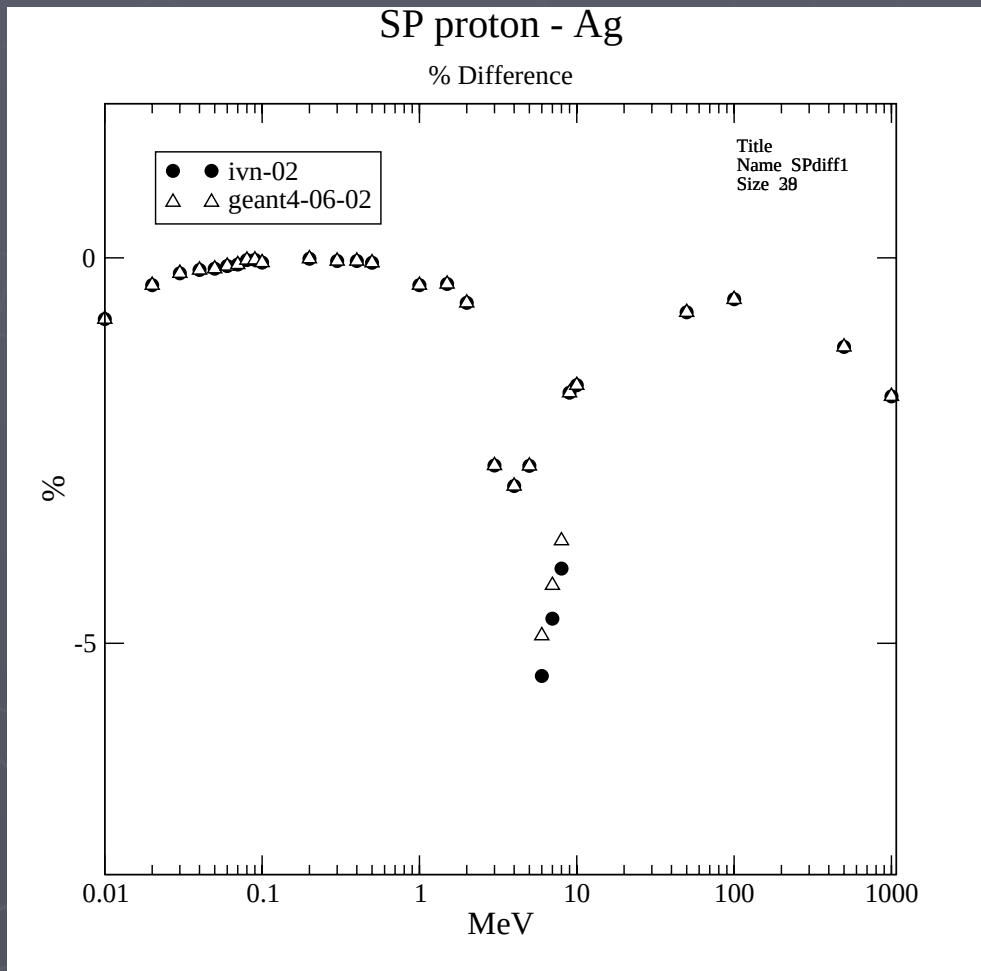
Shell correction to hadron ionization

(NIST – G4 LE) G4 6.2p02

- Both Standard and Low-energy had problem in the energy range 1-10 MeV

$$C = \sum_{\nu} C_{\nu}(\theta_{\nu}, \eta_{\nu})$$

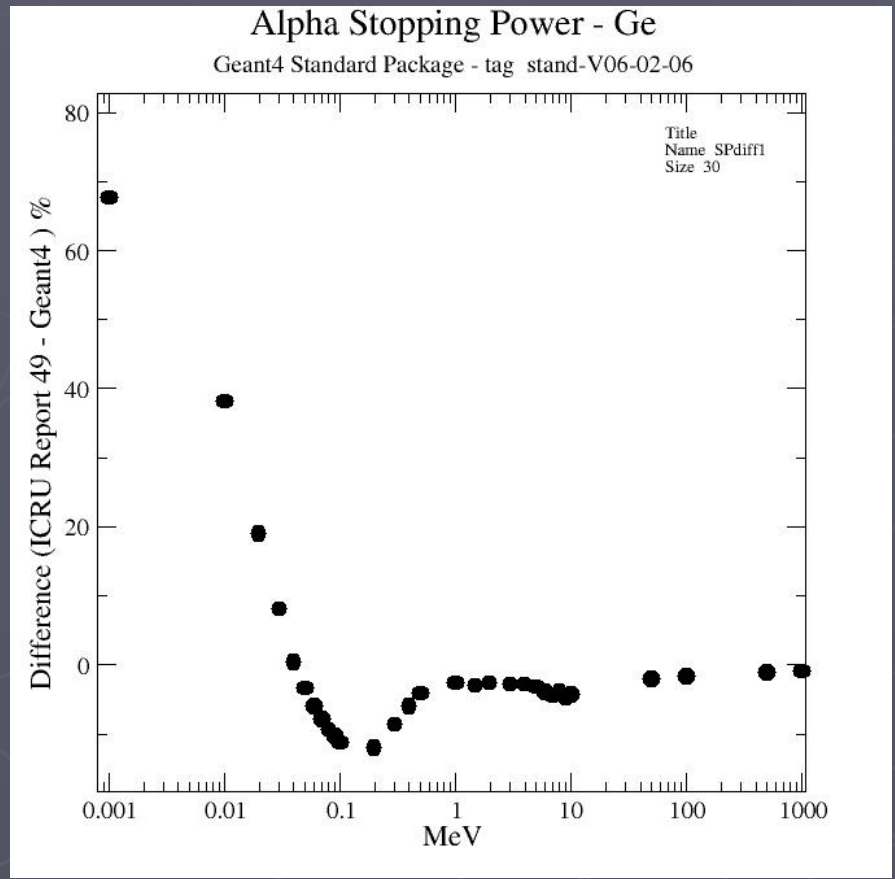
- C_K and C_L are calculated using hydrogenic wave functions and effective nuclear charge for a shell
- For outer shells scaling relation is used



Nuclear stopping and ion ionization

G4 6.2p02 - Standard

- At low energies some problem were observed in parameterization of both electronic and nuclear stopping power
- Parameterizations were reviewed
- Proton parameterizations is used for hadrons
- Helium ion parameterizations for ions



High order corrections

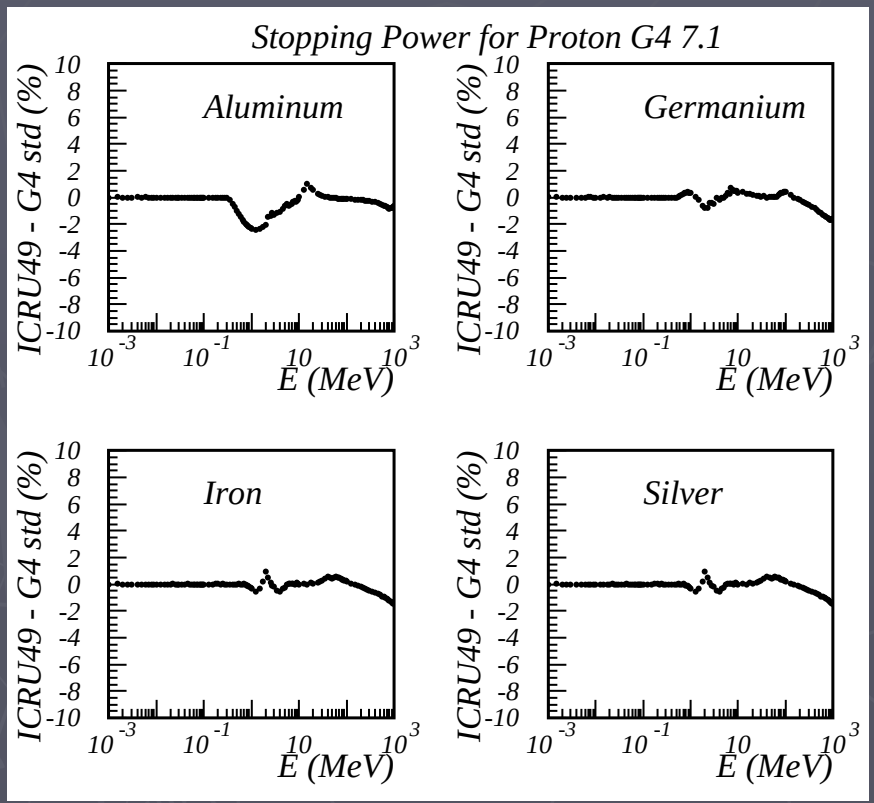
- Are important at high energies
- Are important for ions
- Finite size:

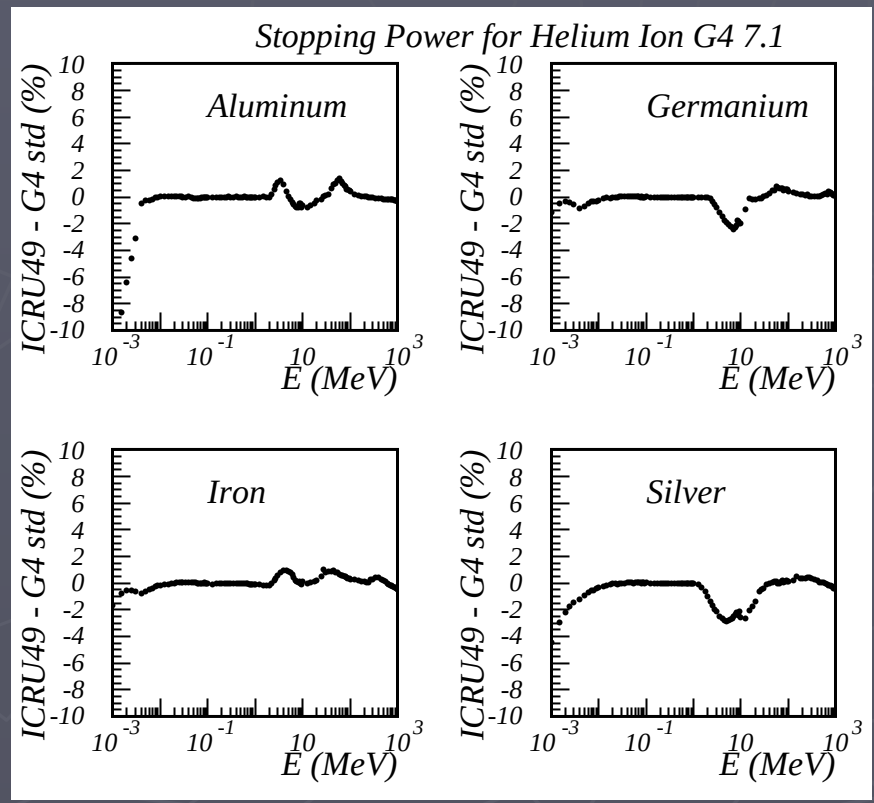
$$F = \ln\left(1 + x_{\max}^2\right) = \ln\left(1 + \frac{4m_e^2\beta^2\gamma^2}{\mu^2}\right)$$

- Mott:

$$G = z\alpha\beta \cdot \left(1.725 + \left(0.52 - 2\sqrt{\frac{I}{2m_e\beta^2\gamma^2}}\right)\pi\cos\chi\right) + (z\alpha)^2\left(3.246 - 0.451\beta^2\right) +$$
$$(z\alpha)^3\left(1.522\beta + \frac{0.987}{\beta}\right) + (z\alpha)^4\left(4.569 - 0.494\beta^2 - \frac{2.696}{\beta^2}\right) +$$
$$(z\alpha)^5\left(1.254\beta + 0.222/\beta - \frac{1.17}{\beta^3}\right),$$

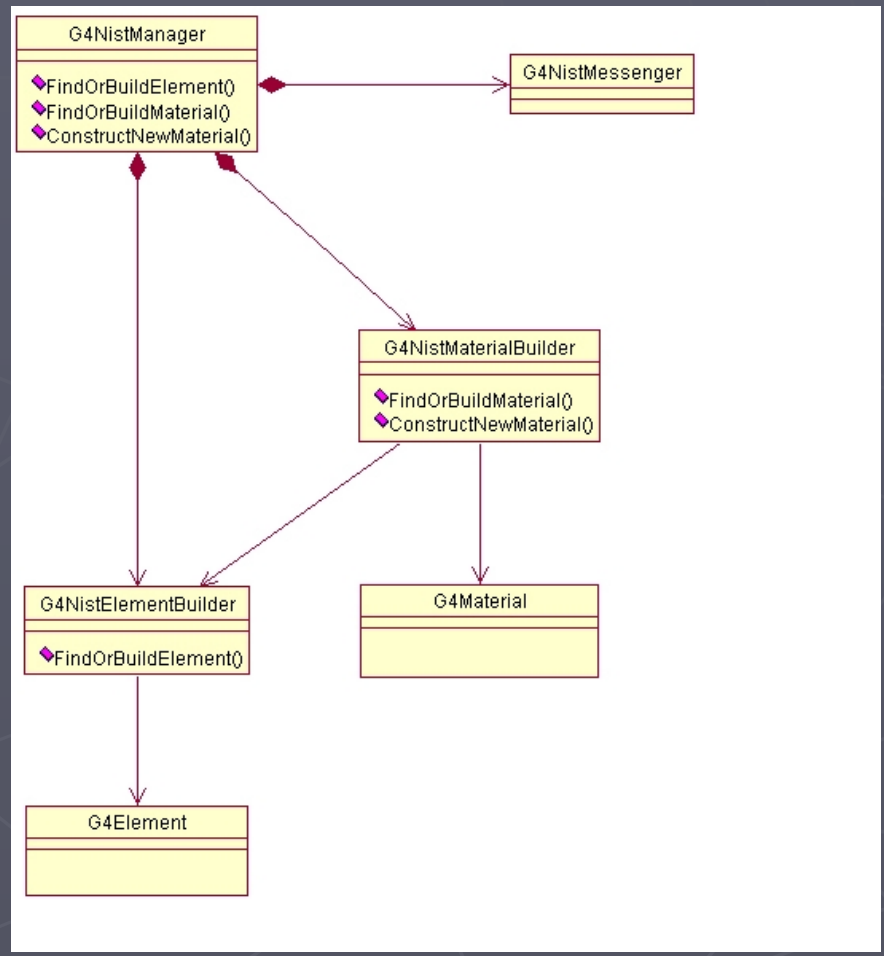
Result of refinement of stopping power – Geant4 and NIST are within systematic uncertainty of the data (G4 7.1)





Material category upgrade

- NIST database for materials is imported inside Geant4 (http://physics.nist.gov/PhysRefData)
- New interfaces are added, old are kept
- UI commands for material category
- Guarantee the best accuracy for major parameters:
  - Density
  - Mean excitation potential
  - Chemical bounds
  - Element composition
  - Isotope composition
  - Various corrections



NIST Element and Isotopes

Z		A	m	error	(%)	A_{eff}
14	Si	22	22.03453	(22)		28.0855(3)
		23	23.02552	(21)		
		24	24.011546	(21)		
		25	25.004107	(11)		
		26	25.992330	(3)		
		27	26.98670476	(17)		
		28	27.9769265327	(20)	92.2297 (7)	
		29	28.97649472	(3)	4.6832 (5)	
		30	29.97377022	(5)	3.0872 (5)	
		31	30.97536327	(7)		
		32	31.9741481	(23)		
		33	32.978001	(17)		
		34	33.978576	(15)		
		35	34.984580	(40)		
		36	35.98669	(11)		
		37	36.99300	(13)		
		38	37.99598	(29)		
		39	39.00230	(43)		
		40	40.00580	(54)		
		41	41.01270	(64)		
		42	42.01610	(75)		

NIST materials in Geant4

```
=====================================
###   Elementary Materials from the NIST Data Base
      =====================================
 Z Name  ChFormula       density(g/cm^3)  I(eV)
=====================================
1   G4_H    H_2             8.3748e-05       19.2
2   G4_He                   0.000166322      41.8
3   G4_Li                   0.534            40
4   G4_Be                   1.848            63.7
5   G4_B                    2.37             76
6   G4_C                    2                81
7   G4_N    N_2             0.0011652        82
8   G4_O    O_2             0.00133151       95
9   G4_F                    0.00158029       115
10  G4_Ne                   0.000838505      137
11  G4_Na                   0.971            149
12  G4_Mg                   1.74             156
13  G4_Al                   2.6989           166
14  G4_Si                   2.33             173
```

- NIST Elementary Materials
- NIST Compounds
- Nuclear Materials
- Space Materials?

```
=====================================
###   Compound Materials from the NIST Data Base
=====================================
 N Name     ChFormula       density(g/cm^3)  I(eV)
=====================================
13  G4_Adipose_Tissue              0.92          63.2
              1     0.119477
              6     0.63724
              7     0.00797
              8     0.232333
             11     0.0005
             12     2e-05
             15     0.00016
             16     0.00073
             17     0.00119
             19     0.00032
             20     2e-05
             26     2e-05
             30     2e-05
4   G4_Air                         0.00120479    85.7
              6     0.000124
              7     0.755268
              8     0.231781
             18     0.012827
2   G4_CsI                         4.51          553.1
             53     0.47692
             55     0.52308
```

How to use

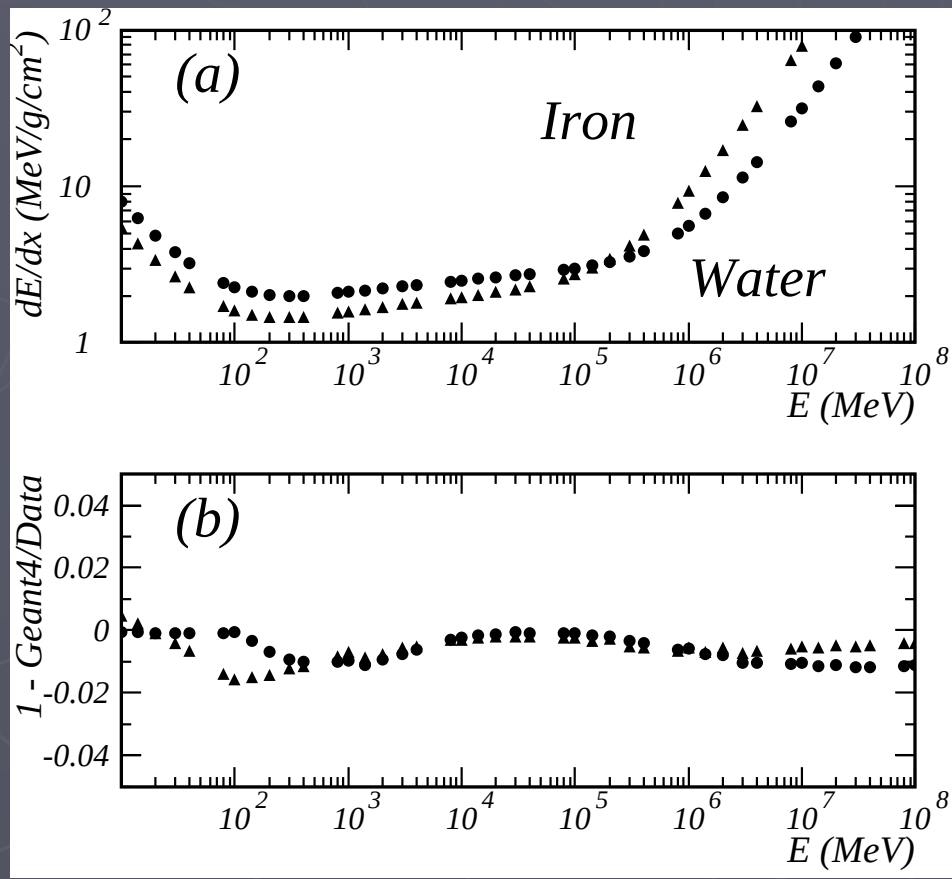
- Do not need anymore to predefine elements and materials
- Main new user interfaces:

```
G4NistManager* manager = G4NistManager::GetPointer();
G4Element* elm = manager->FindOrBuildElement("symb", G4bool iso);
G4Element* elm = manager->FindOrBuildElement(G4int Z, G4bool iso);
G4Material* mat = manager->FindOrBuildMaterial("name", G4bool iso);
G4Material* mat = manager->ConstructNewMaterial("name",
                        const std::vector<G4int>& Z,
                        const std::vector<G4double>& weight,
                        G4double density, G4bool iso);
G4double isotopeMass = manager->GetMass(G4int Z, G4int N);
```

Hadron/ion ionization extension to low cuts and small steps

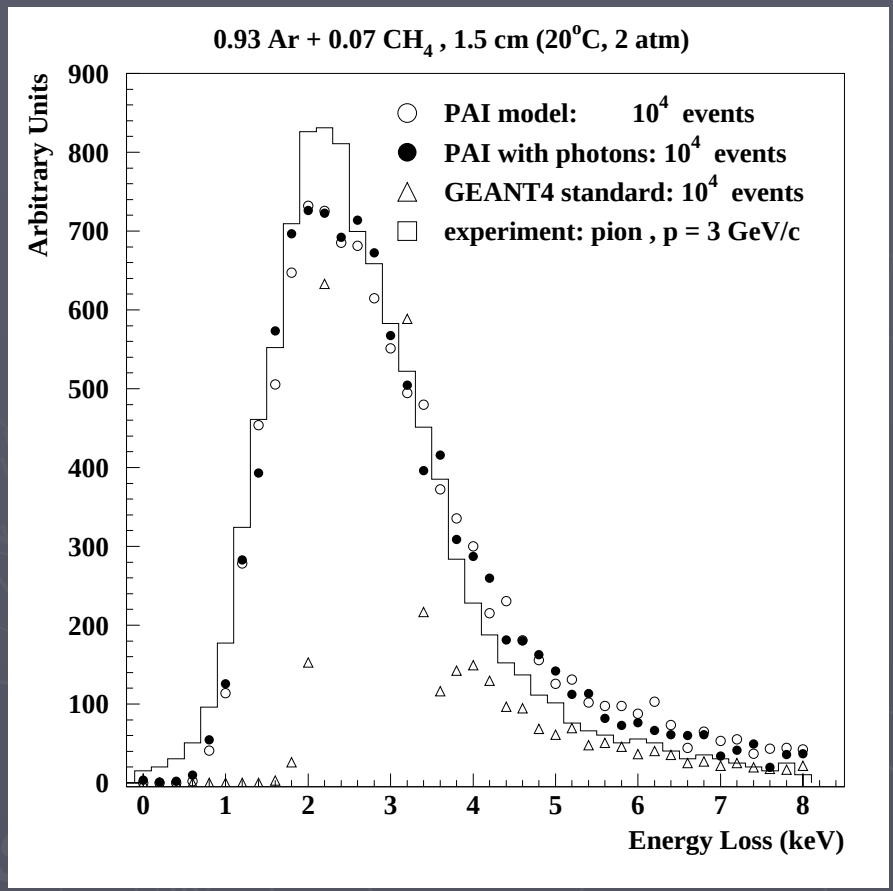
- Stopping powers and cross section are well validated
- Fluctuation model review
- PAI model refinement to model design and to low cut regime
- Utilization of model per region facility is required

Muon stopping power

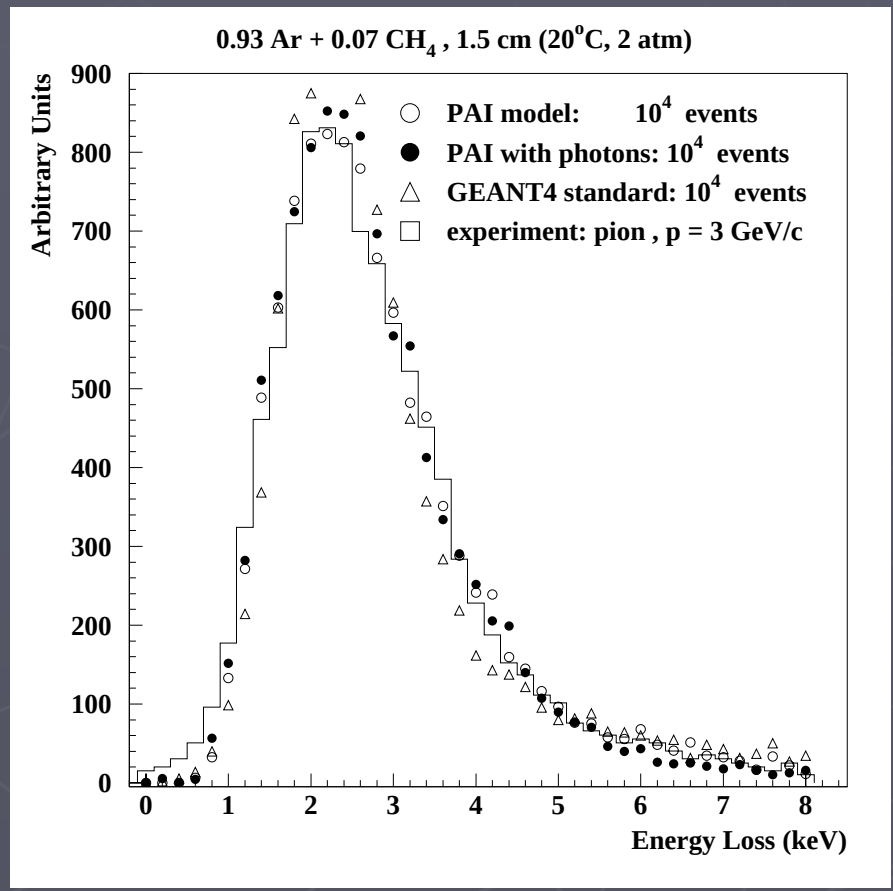


Refinement of the fluctuation model

6.2p02



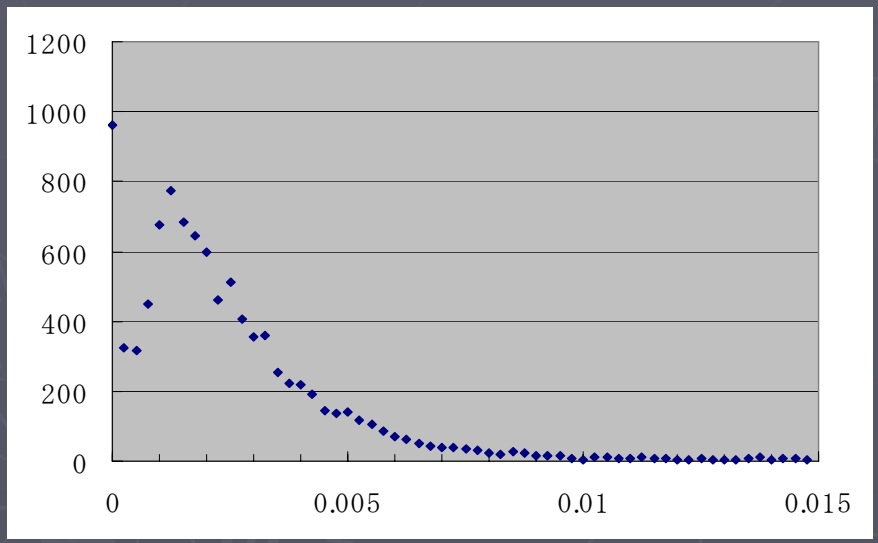
7.0



Argon gas thickness of 2mm electron 235 keV (γ=1.5)

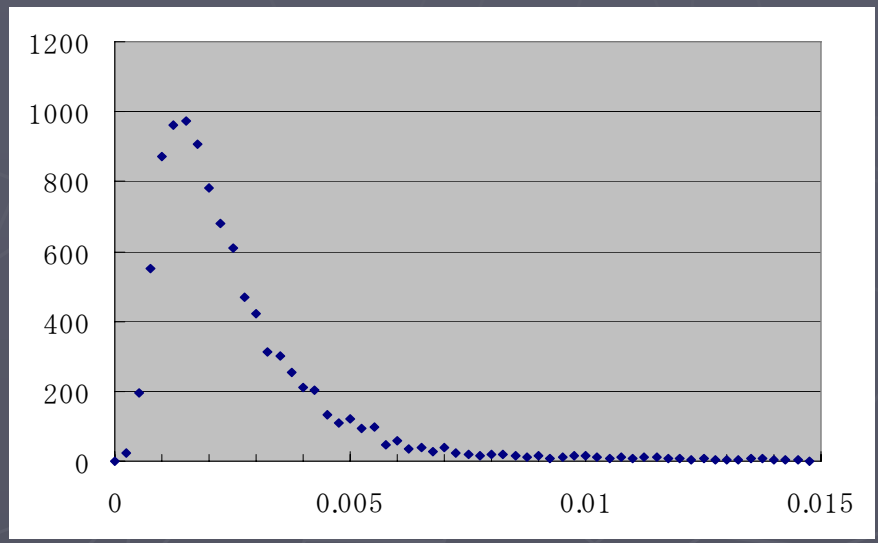
T. Koi (SLAC)

Geant4 v7.0



Energy loss [MeV/cm]

Geant4 v7.0p01



Energy loss [MeV/cm]

Model per G4Region

- PAI model is slow – need to be applied for specific part of a setup
- Example/extended/electromagnetic/TestEm8
- Builder for the PAI:

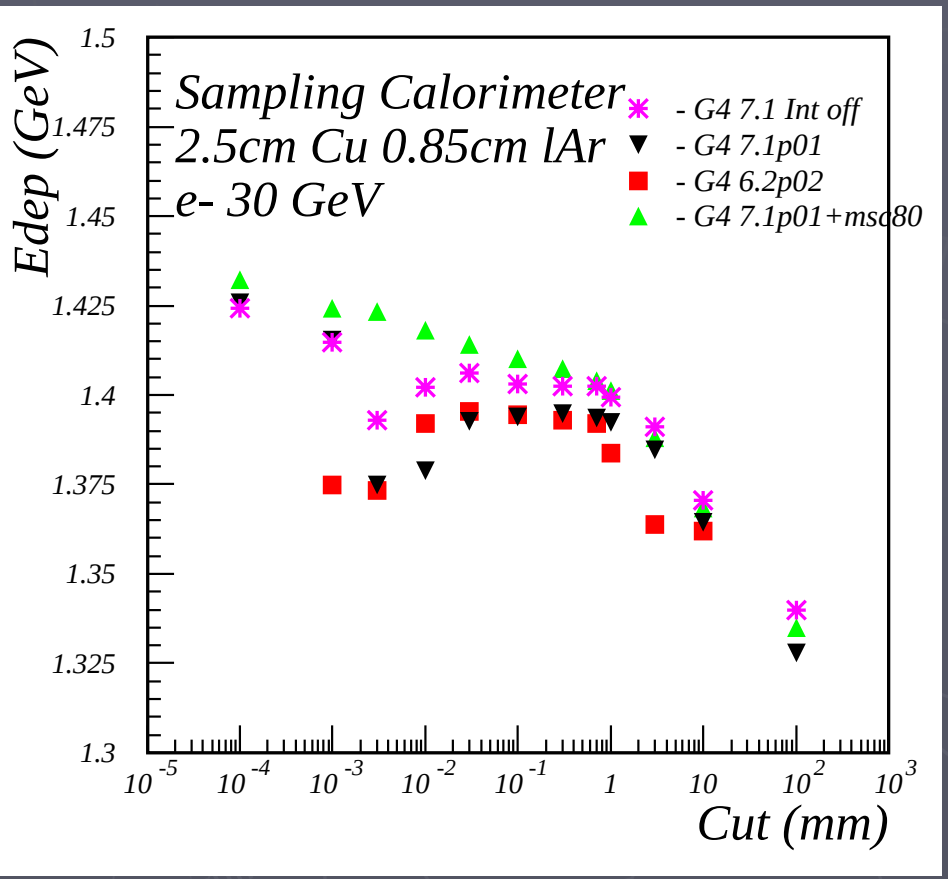
```
G4Region* gas = G4RegionStore::GetInstance()->GetRegion("VertexDetector");
G4eIonisation* eion = new G4eIonisation();
G4PAIModel*     pai = new G4PAIModel(particle,"PAIModel");
eion->AddEmModel(0,pai,pai,gas);

pmanager->AddProcess(new G4MultipleScattering, -1, 1,1);
pmanager->AddProcess(eion,-1, 2, 2);
pmanager->AddProcess(new G4eBremsstrahlung,-1,-1,3);
```

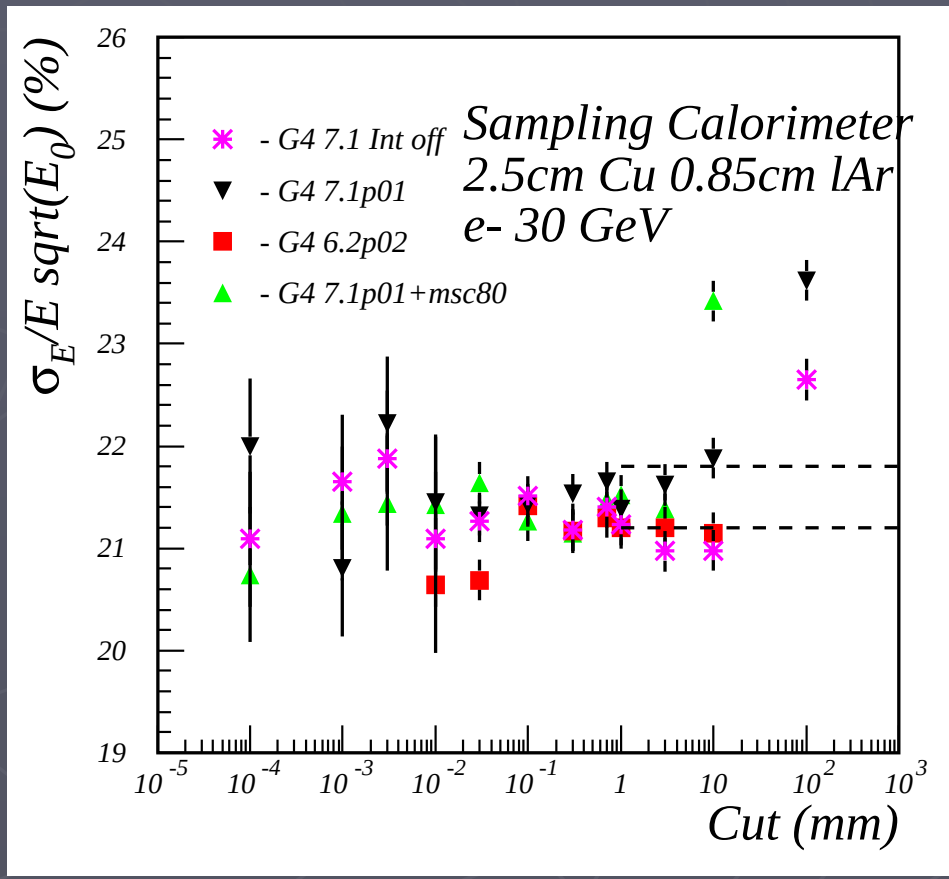
Review on Multiple Scattering

- Simulation for thin layers requires precise simulation with small cuts (medical applications, shielding, fine granular calorimeters…)
- Cut dependence of the results and dependence of results from step limits were reported by users
- The investigation of cut/step limit effects have been carried out and the conclusion was following:

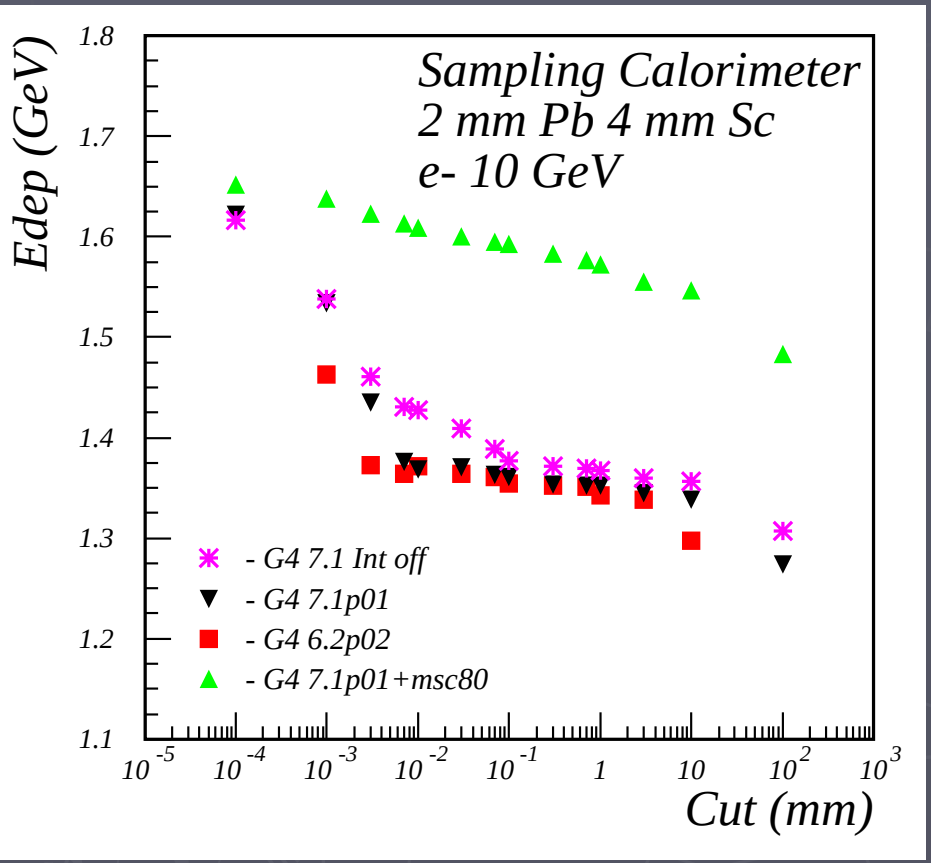
  MultipleScattering process is very important

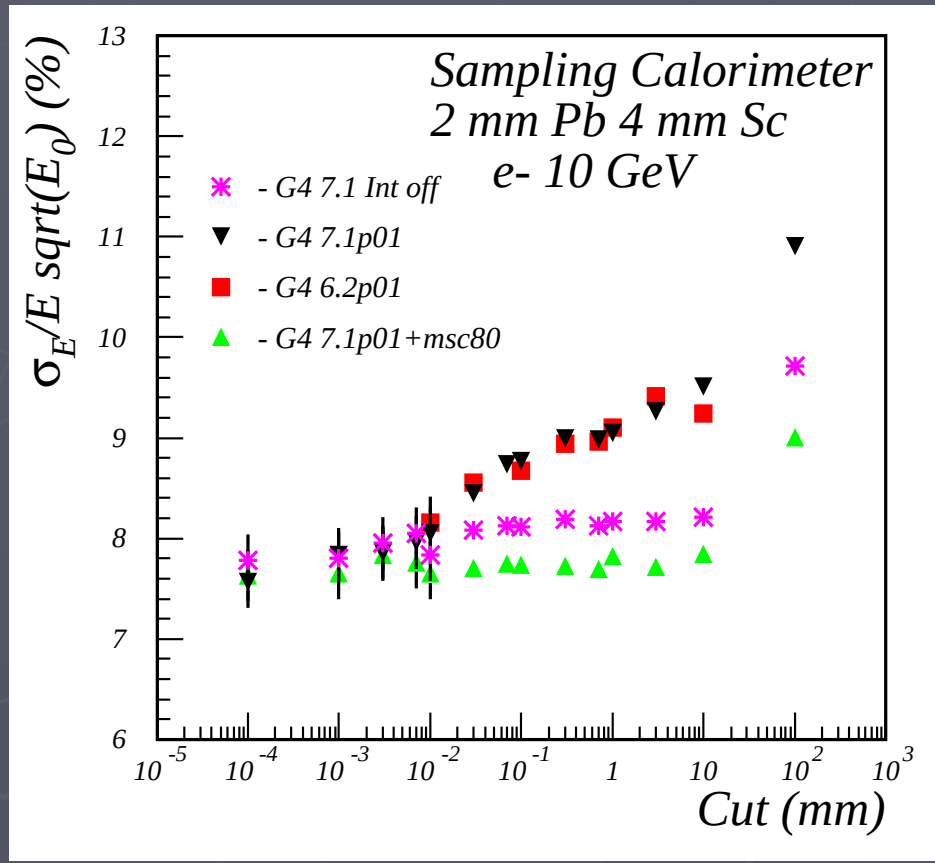
Multiple Scattering model upgrade (Preliminary Plots!)





Multiple Scattering model upgrade
(Preliminary Plots!)





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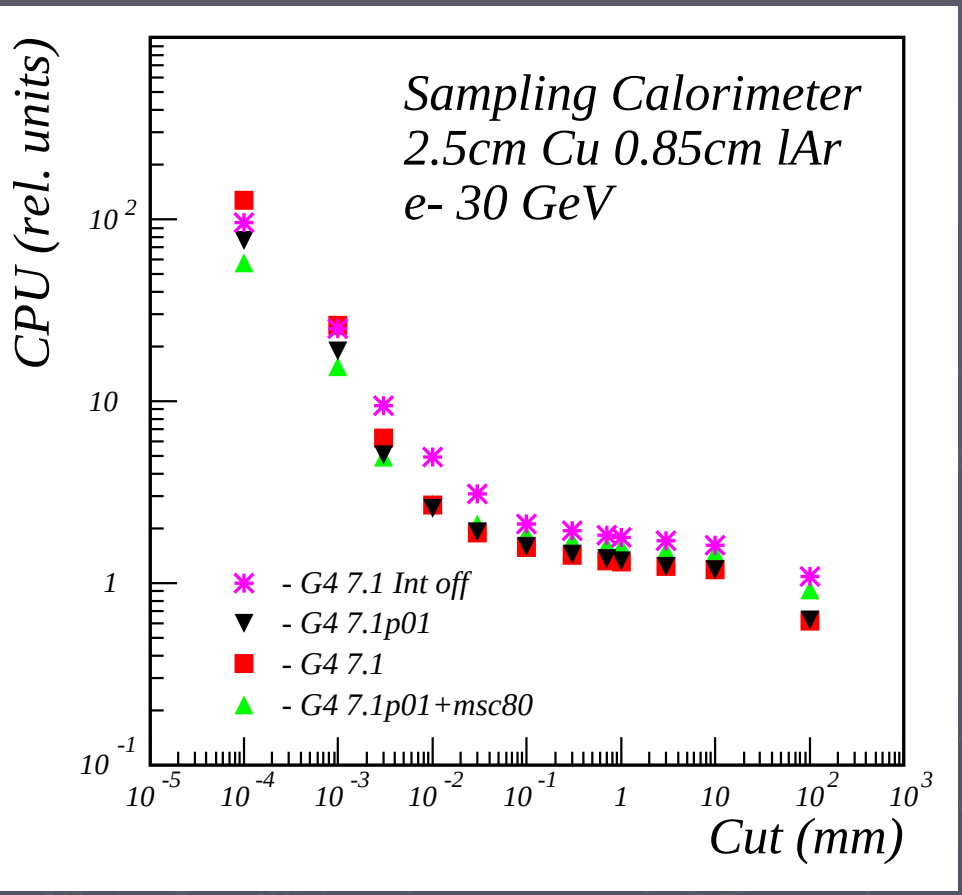

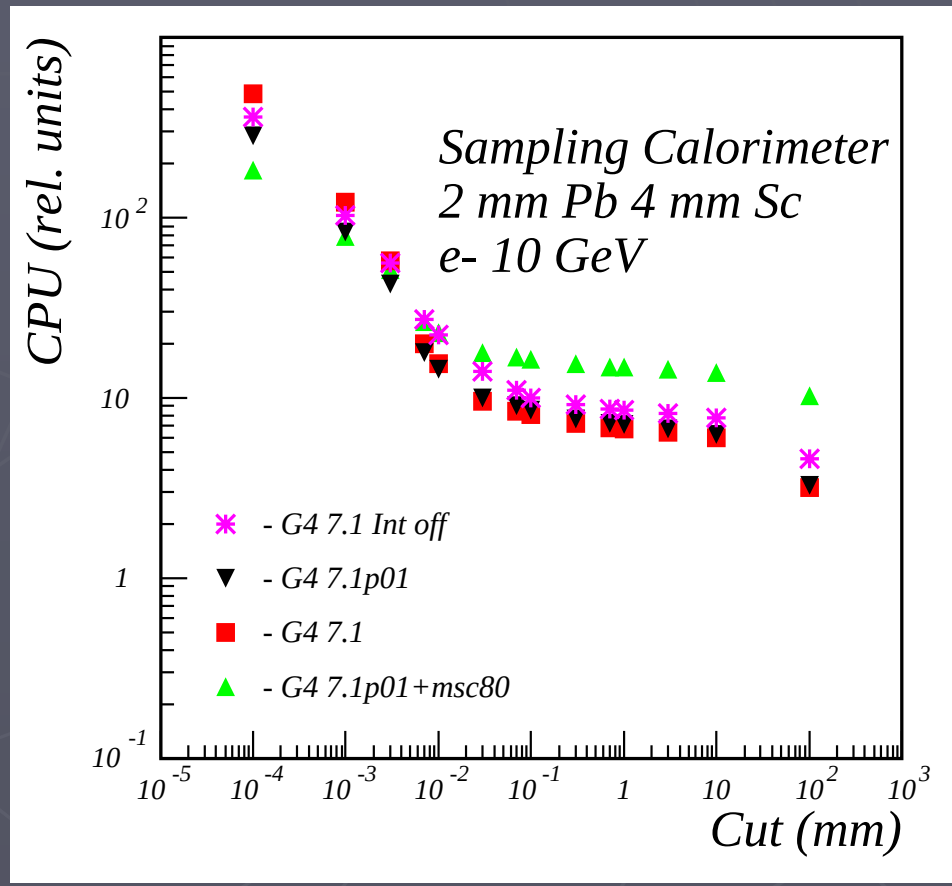

Conclusions

- Revision of Standard EM package was carried out
- New Geant4 components were introduced
- Hadron/ion stopping have been improved
- NIST material included inside Geant4
- Ionization in thin layers was improved
- MultipleScattering is under review – December 2005 will be released
- Standard EM group is now concentrated on model upgrade and validation
- We are open for new requirements