New developments in EM Standard Electromagnetic Package

30 November 2005

V.M.Grichine, V.N.Ivanchenko, M.Maire, L.Urban

Otline

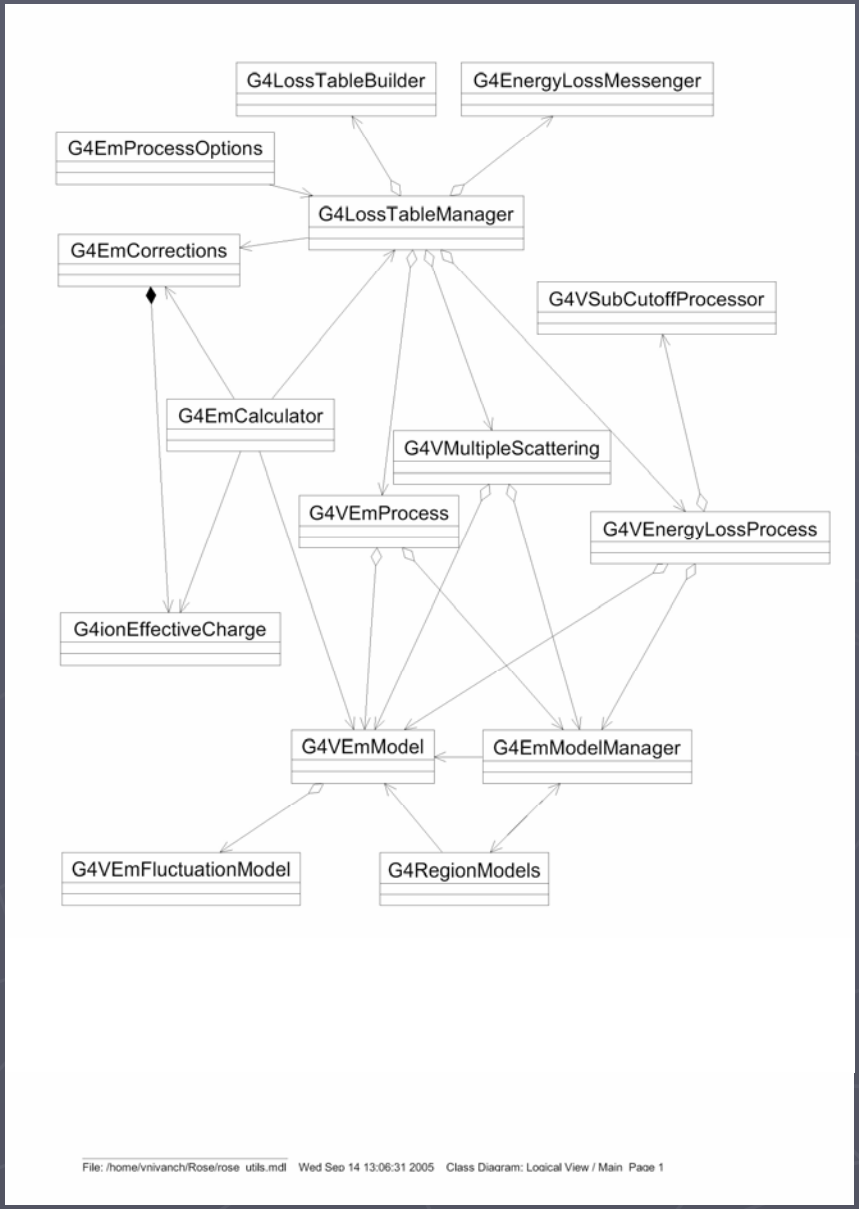
- Summary of main activity
- Ionization models upgrade
- Fluctuation model upgrade
- Extrapolator
- NIST materials
- Steering of EM Standard PhysicsList
- Acceptance suite
- Perspectives

Summary of Main Activities

- Photon processes migration to model design
- G4EnergyLossForExtrapolator – utility class to be used in event reconstruction
- Review and update ionization processes, new G4EmCorrection class
- NIST materials
- Update of the model of fluctuations
- Update of TRD processes
- Study on cut and step limit dependence of results
- Multiple scattering models update
- Acceptance suite for EM physics

Status of Standard EM Package Design

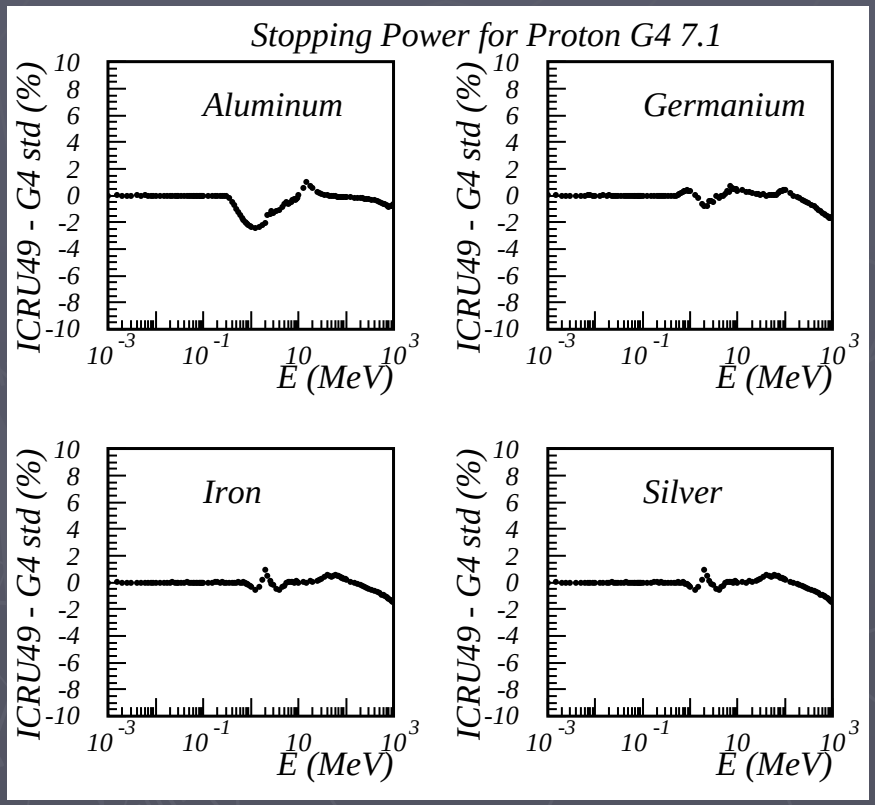
- Design iteration in EM package – refinements and optimization 2003-2005
- Migration of photon processes to model design for 7.1
- It will to be complete in general for G4 8.0 (Dec 2005)
- Move focus on updating physics model and on validation studies

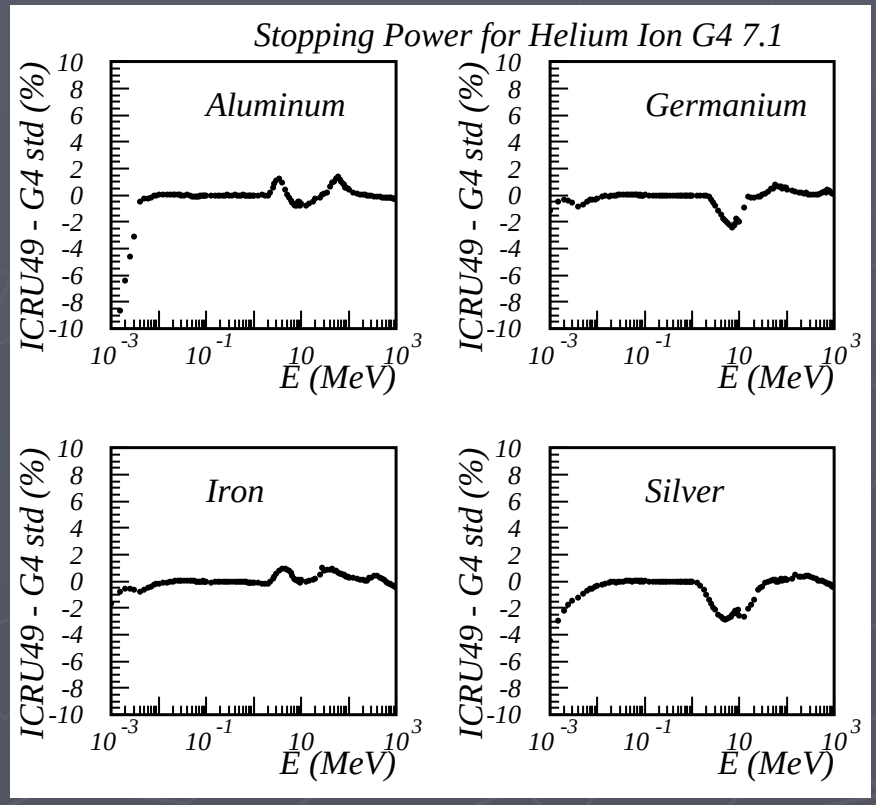


Hadron/ion ionization

- 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)

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

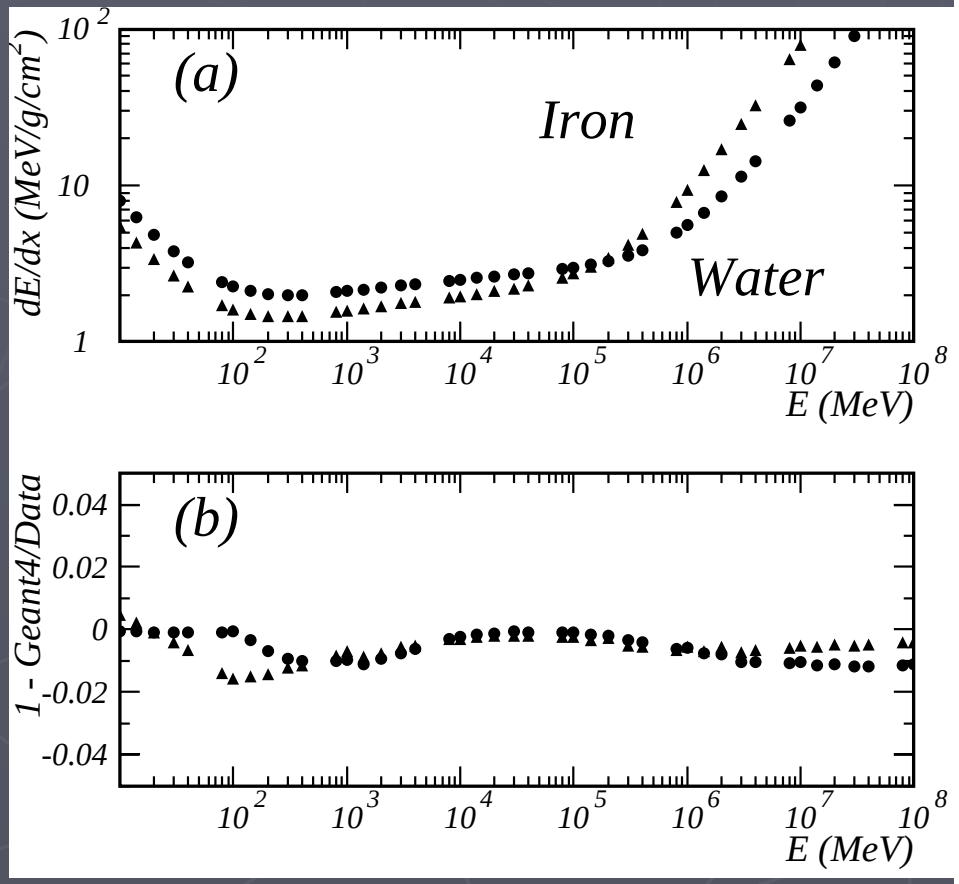




Hadron/ion ionization extension to low cuts and small steps

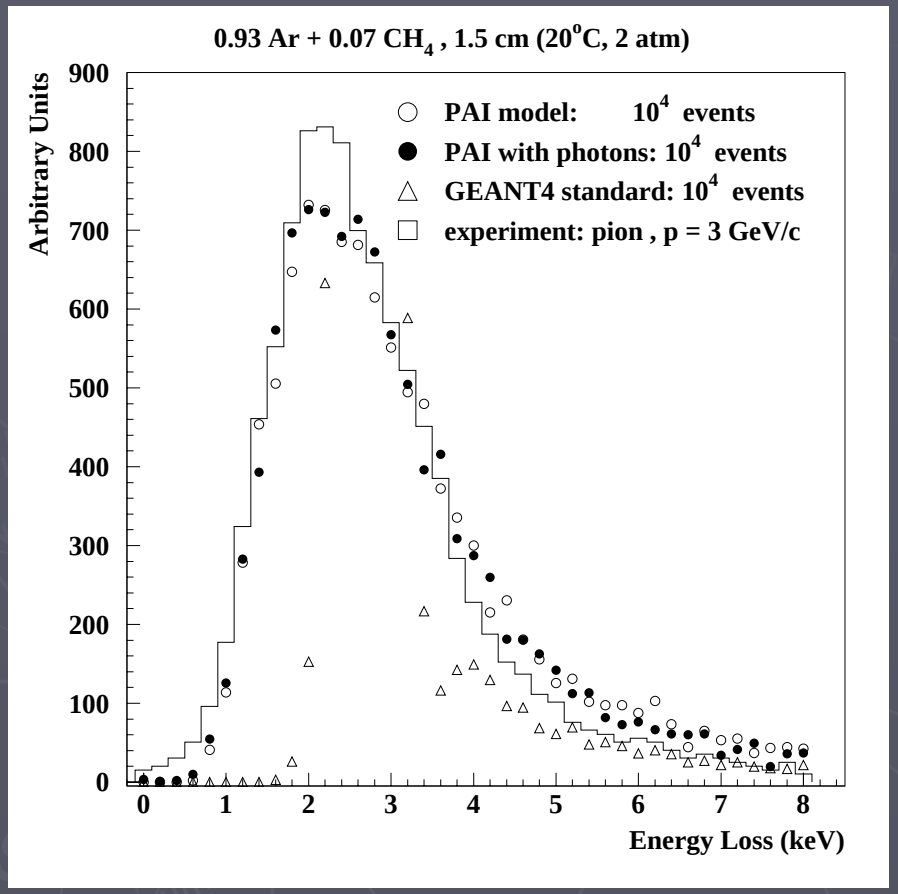
- Stopping powers and cross section are well validated
- Fluctuation model review
- PAI model refinement to model design and to low cut regime
- Utilization of model per region facility is required
- Multiple scattering model is a key process

Muon stopping power (7.1)

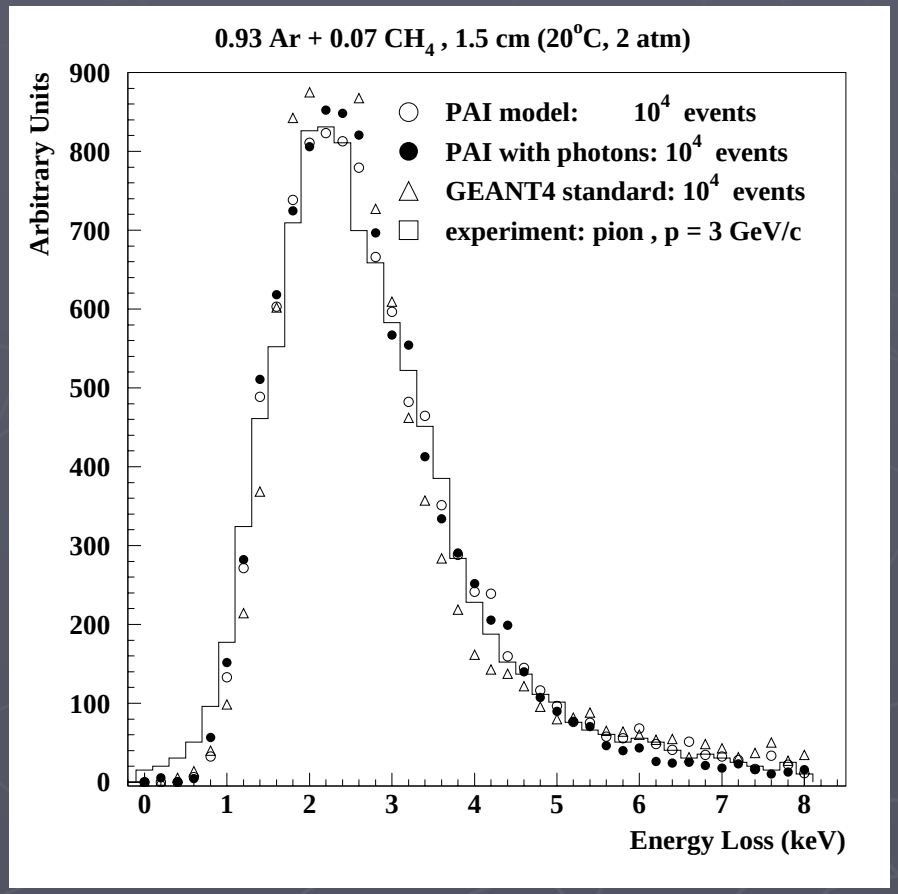


Refinement of the fluctuation model

6.2p02



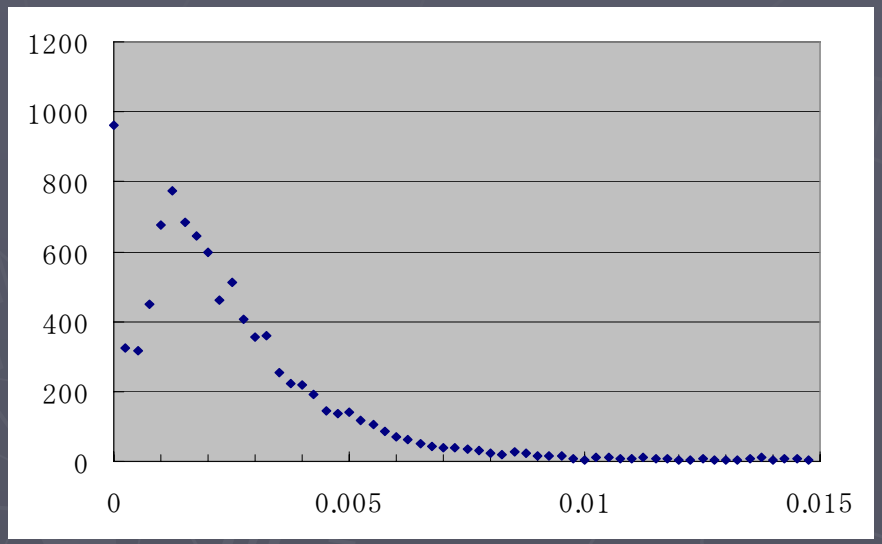
7.0



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

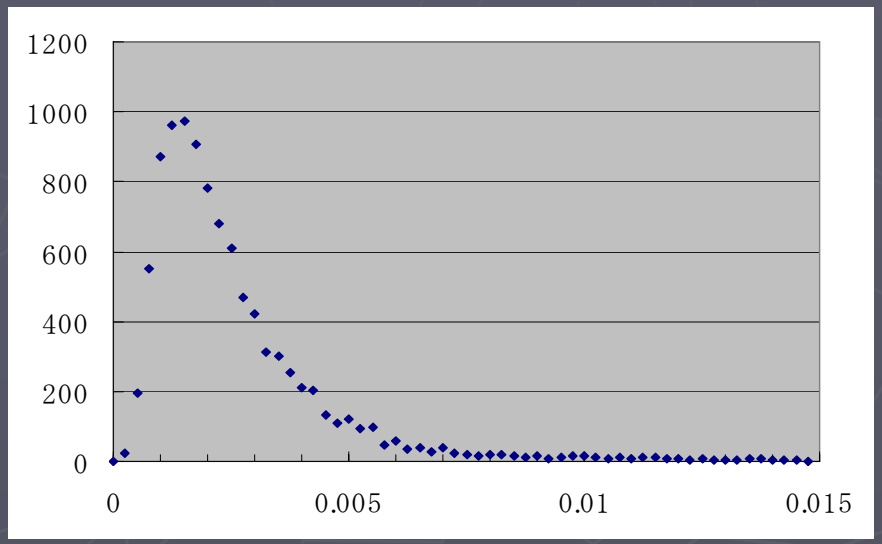
T. Koi (SLAC)

Geant4 v7.0



Energy loss [MeV/cm]

Geant4 v7.0p01



Energy loss [MeV/cm]

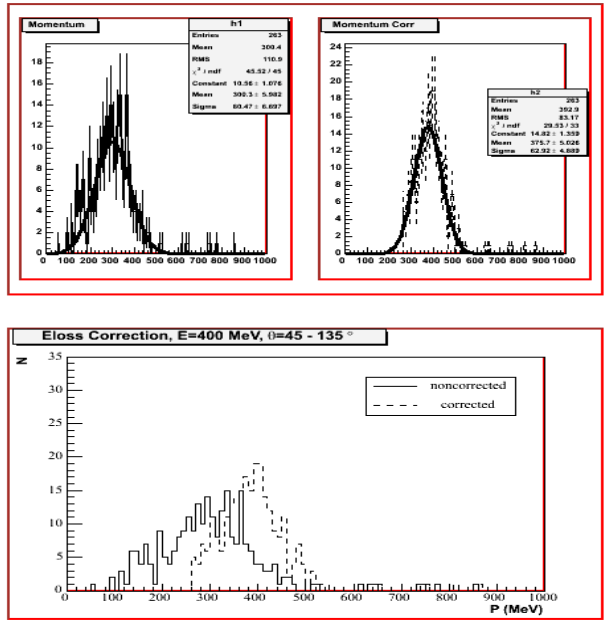
Model per G4Region

- PAI model is slow – need to be applied for specific part of a setup
- examples/extended/electromagnetic/TestEm8
- TRD: examples/extended/electromagnetic/TestEm10
- Builder for the PAI:

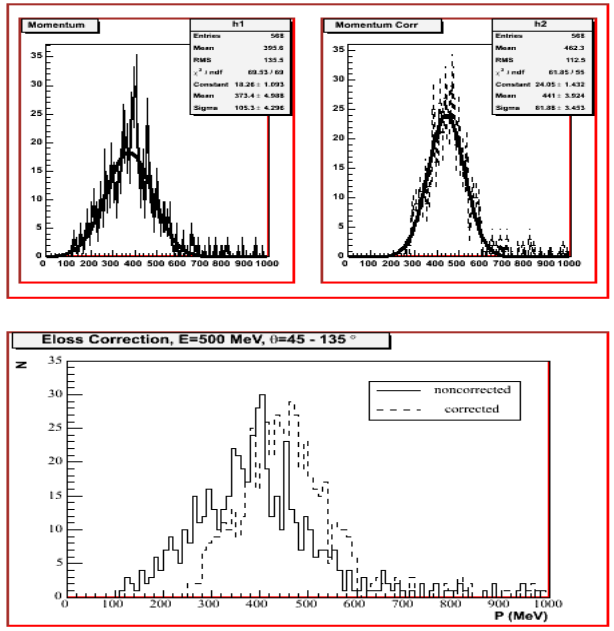
```
G4Region* gas = G4RegionStore::GetInstance()->GetRegion("VertexDetector");
G4eIonisation* eion = new G4eIonisation();
G4PAIModel*     pai = new G4PAIModel(particle,"PAIModel");
eion->AddEmModel(0,pai,pai,gas);

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

G4EnergyLossForExtrapolator class (HARP)

400 MeV/c



500 MeV/c




```
double e2 = eloss->EnergyAfterStep(e1,step_length,material,particle);
double e1 = eloss->EnergyBeforeStep(e2,step_length,material,particle);
double D = eloss->EnergyDispersion(e, eloss, step_length,material,particle);
double theta = eloss->AverageScatteringAngle(e, step_length, material,particle);
double dedx = eloss->ComputeDEDX(e, material, particle);
double range = eloss->ComputeRange(e, material, particle);
double e = eloss->ComputeEnergy(range, material, particle);
```

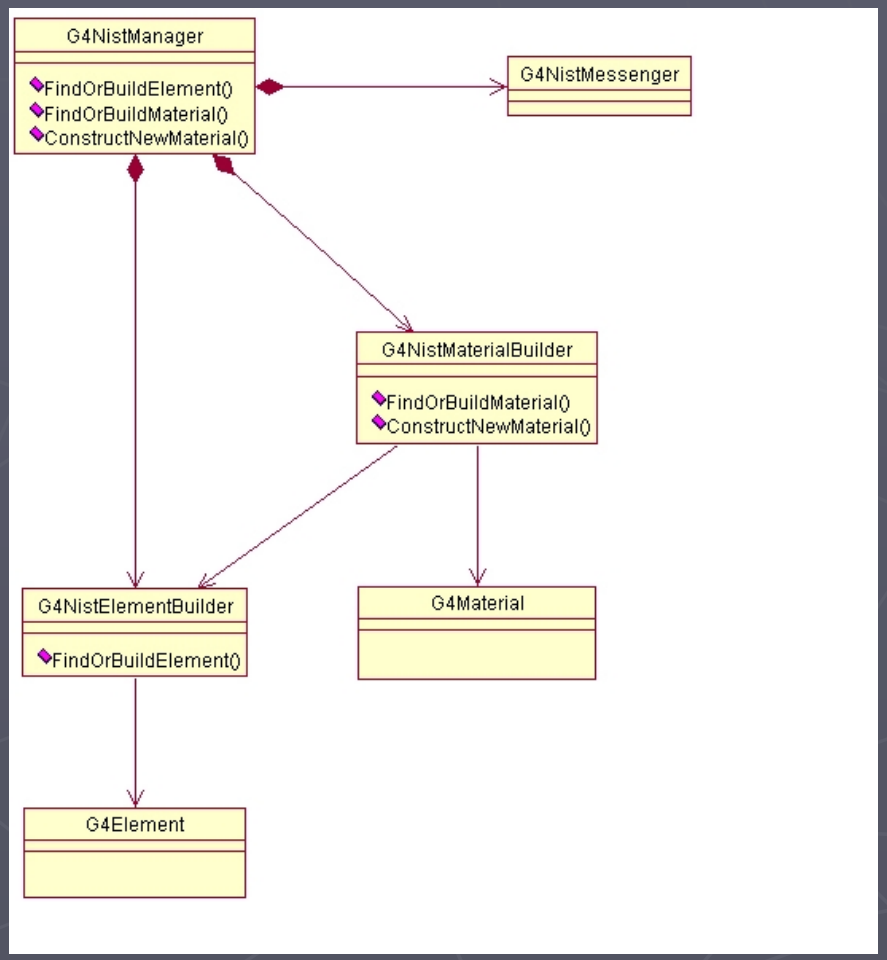
Does not need G4RunManager and Physics List

NIST materials: Motivation

- There hundreds (?) Geant4 users
- There are only ~100 elements, which in case of the natural isotope composition are the same for any user
- There are many common materials for different applications
- Geant4 is working on precise validation against NIST
- Why not to take NIST DB on elements and materials?

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
```

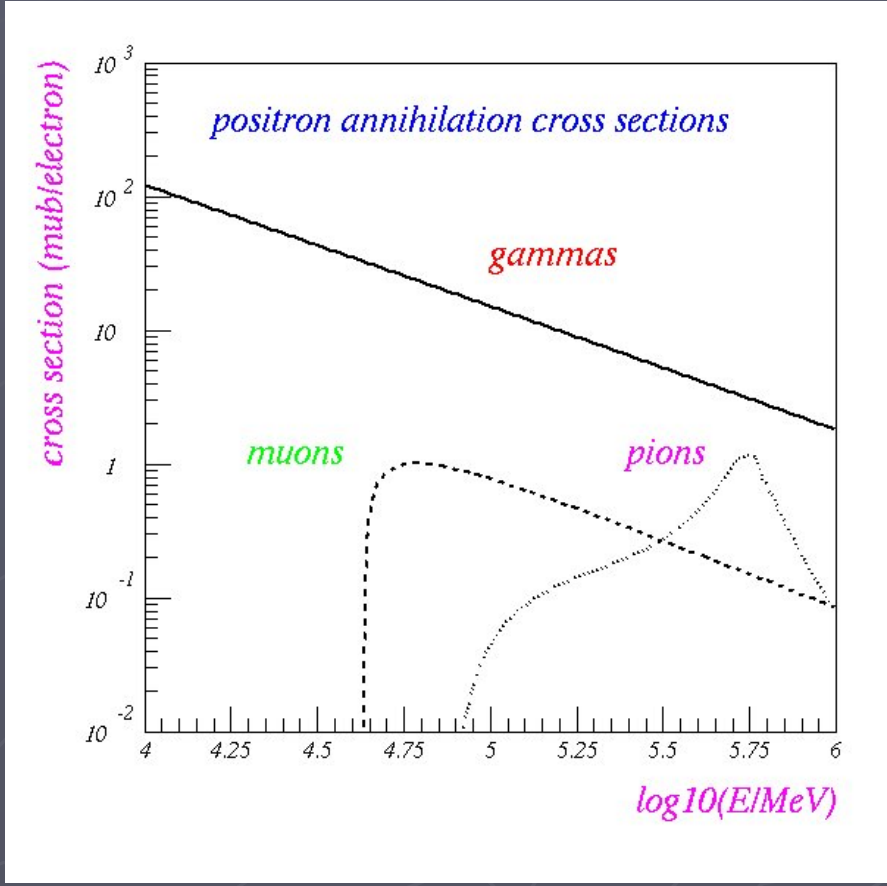
How to use NIST DB?

- 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);
```

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).



G4EmProcessOptions class

- An alternative to UI messenger
- Steering of EM Standard processes
- Should be used at initialization
- Main user interfaces:

```
G4EmProcessOptions  EmOpt;
EmOpt.SetVerbose(0);                    // reduce verbosity
EmOpt.SetMscStepLimitation(false);      // simplified MSC
EmOpt.SetMaxEnergy(maxKinEnergy);       // size of tables
```

Standard EM Test Strategy

- Private tests by developers
  - Necessary but not enough
- Fast automatic test on main platform
  - SLC3 now
  - Low statistic
  - 16 macro out of 116
  - Comparison with previous version
- Stt test integration
- Large statistic tests for major use cases
- Other tests by G4 Collaboration and user groups

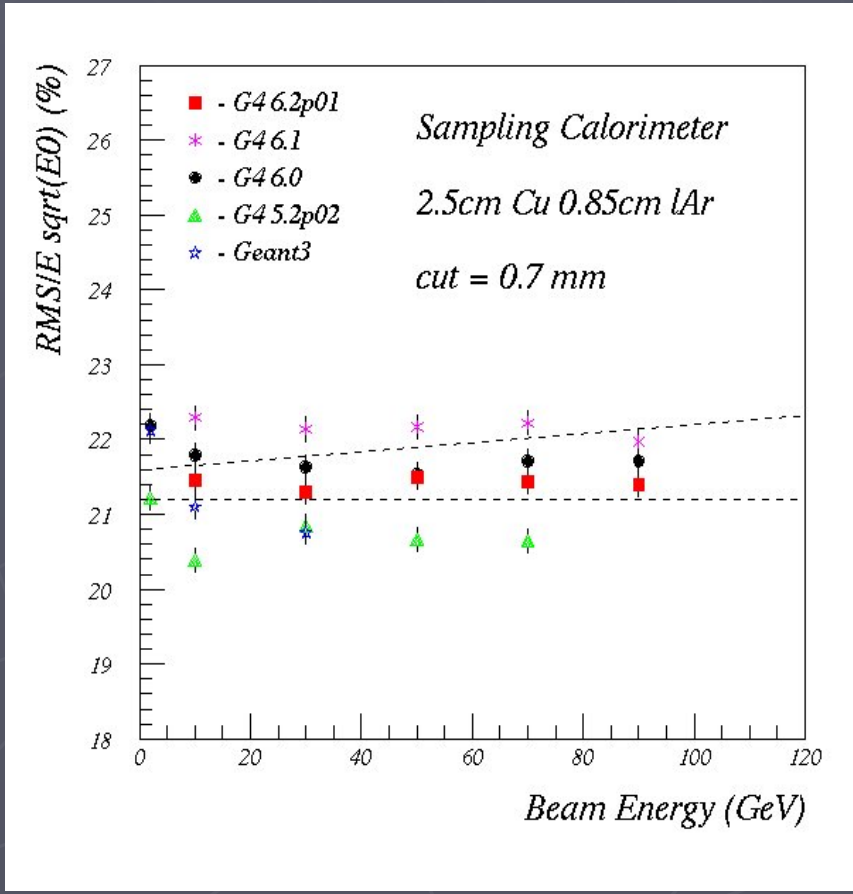
Test	Purpose	Author	N macro	G3
TestEm1	Tracking and EM physics in semi infinite media	M.Maire	15	+
TestEm2	EM shower in homogeneous media	M.Maire	7	+
TestEm3	Sampling calorimeter	M.Maire	23	+
TestEm4	Gamma interactions	M.Maire	3	+
TestEm5	Multiple scattering	L.Urban	18	+
TestEm6	High energy muons	H.Burtkard	6	
TestEm7	Bragg peak	M.Maire	6	
TestEm8	PAI models	V.Grichine	2	

TestEm9	Crystal Calorimeter	V.Ivanchenko	5	
TestEm10	TRD models	V.Grichine	2	
TestEm11	Deep dose profile (plane)	M.Maire	5	+
TestEm12	Deep dose profile (spherical)	M.Maire	4	
PhotonProcesses	Gamma interactions	M.Maire	6	+
MuonProcesses	Muon processes	R.Kokoulin, A.Bogdanov	6	
GammaTherapy	Bremsstrahlung beam	V.Ivanchenko	5	
test31	Sliced media	V.Ivanchenko	5	

Atlas HEC Calorimeter

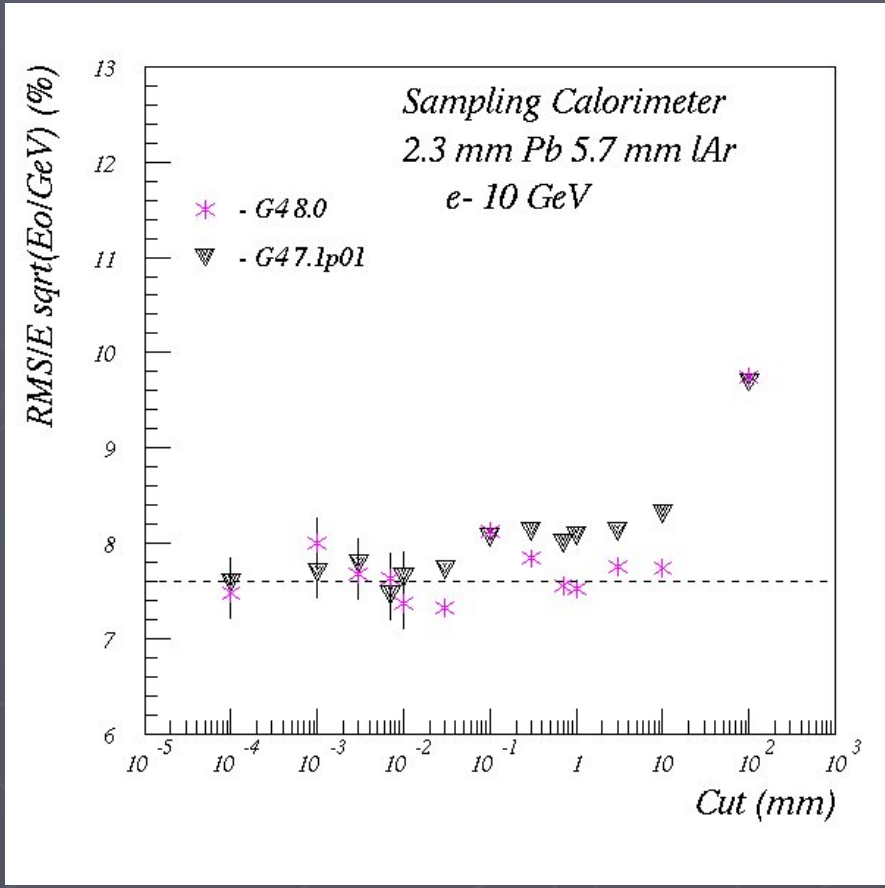
- The first setup for the suite
- ATLAS HEC structure is used as a reference since release 5.2
- Based on TestEm3
- Resolution is compared with the data
- 30 GeV e^- were chosen (Gaussian spectrum)
- Results are shown by Michel

Default EM physics



ATLAS Barrel

- The most recent test
- 1–dimensional sampling calorimeter
  - Lead 2.3 mm, lAr 5.7 mm
- Not accordion
- Based on TestEm3
- 10 GeV e-

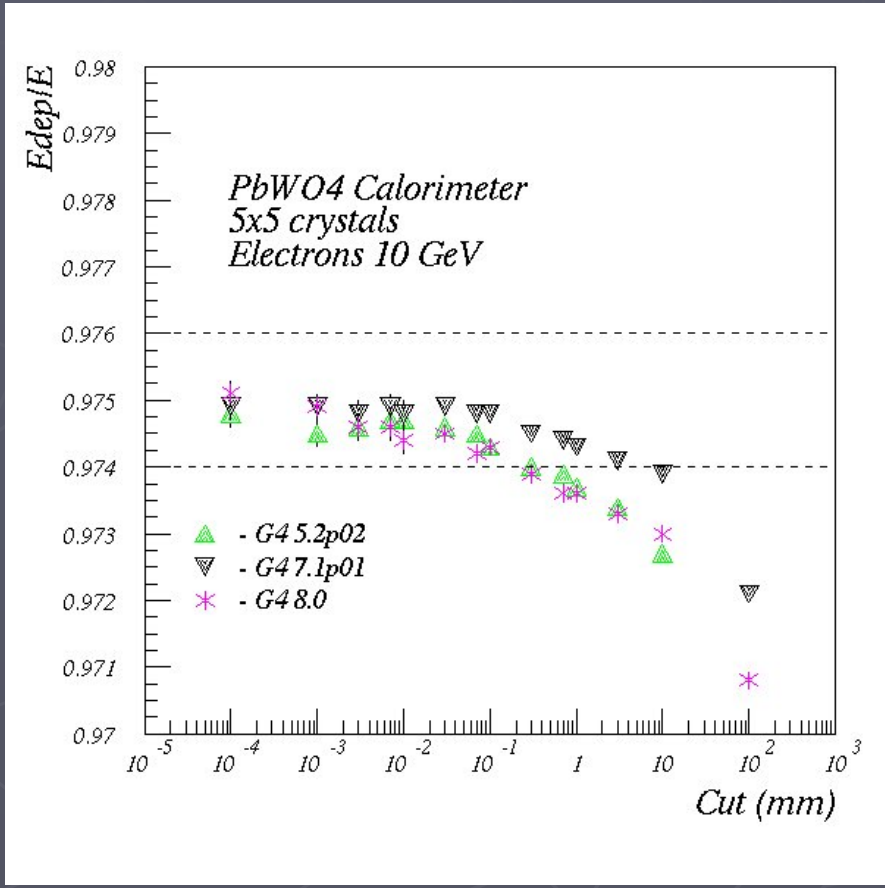


LHCB Calorimeter

- Based on TestEm3
- Lead/scintillator structure
- Higher sampling fraction than ATLAS HEC
- Larger difference in Z between sensitive material and absorber
- 10 GeV e^- were chosen – Gaussian response

CMS Crystal Calorimeter

- Based on TesEm9
- Matrix of 5x5 crystals
- Energy deposition inside
  - central crystal
  - 3x3 matrix
  - 5x5 matrix
- 10 GeV e^- were chosen



Comments

- Testing requires stability in order to have a possibility to compare different releases/tags
- Number of tests need to be adequate
  - cover important use-cases
  - compact – possibility to control results
- Candidates for large statistic tests:
  - Babar setup need to be discussed
  - Specialized msc tests
  - Bragg peak test

Standard EM Testing

- There are a significant number of examples
  - If there is new user request/problem EM group can provide a feedback promptly
  - Debugging of known bugs is fast
  - Still there are cases when bugs are identified by user not by the suite
- PhysicsList from EM examples
- Not all use cases are covered
  - We are open to comments suggestions

Conclusions

- Revision of Standard EM package was carried out
- Hadron/ion stopping have been improved
- NIST material included inside Geant4
- Ionization in thin layers was improved
- MultipleScattering is updated significantly
- Standard EM group is now concentrated on model upgrade and validation
- We are open for new requirements