

# New Components in Standard EM Package and Verification Results

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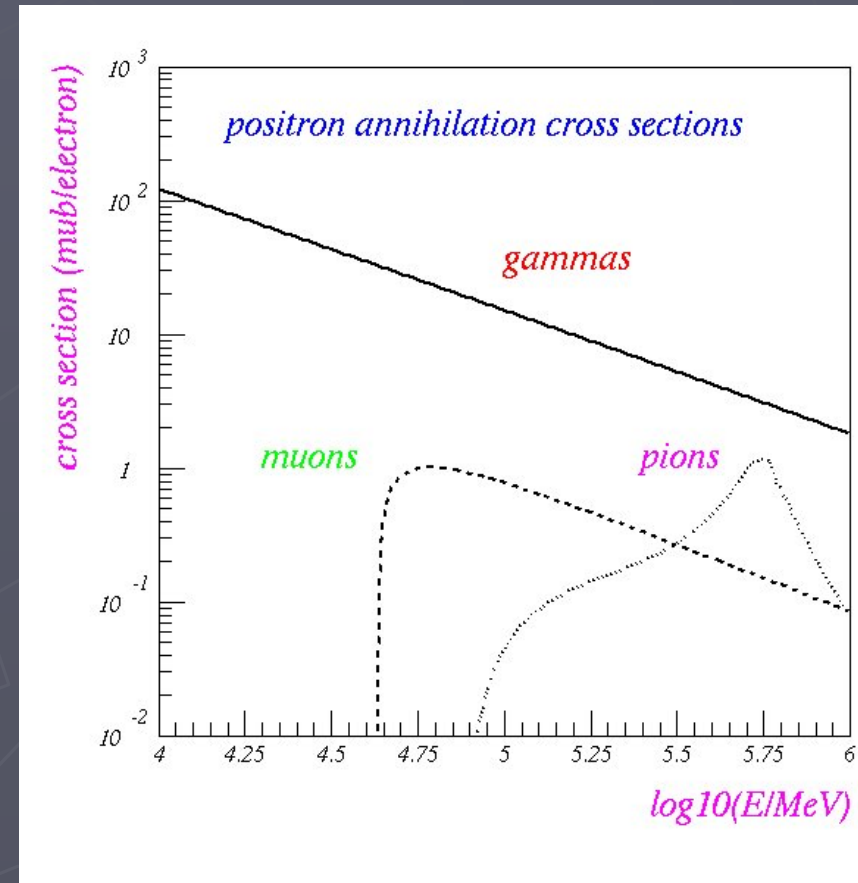
# G4EmCalculator class

## ► 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

- ▶ Analysis of current models in the Standard and Low-energy packages was done
- ▶ 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)
- $\delta$  – density correction
- F – finite size correction (new)
- $L_1$ - Barkas correction (was in Low-energy)
- $L_2$ - Bloch correction (was in Low-energy)

- ▶ New class G4EmCorrections

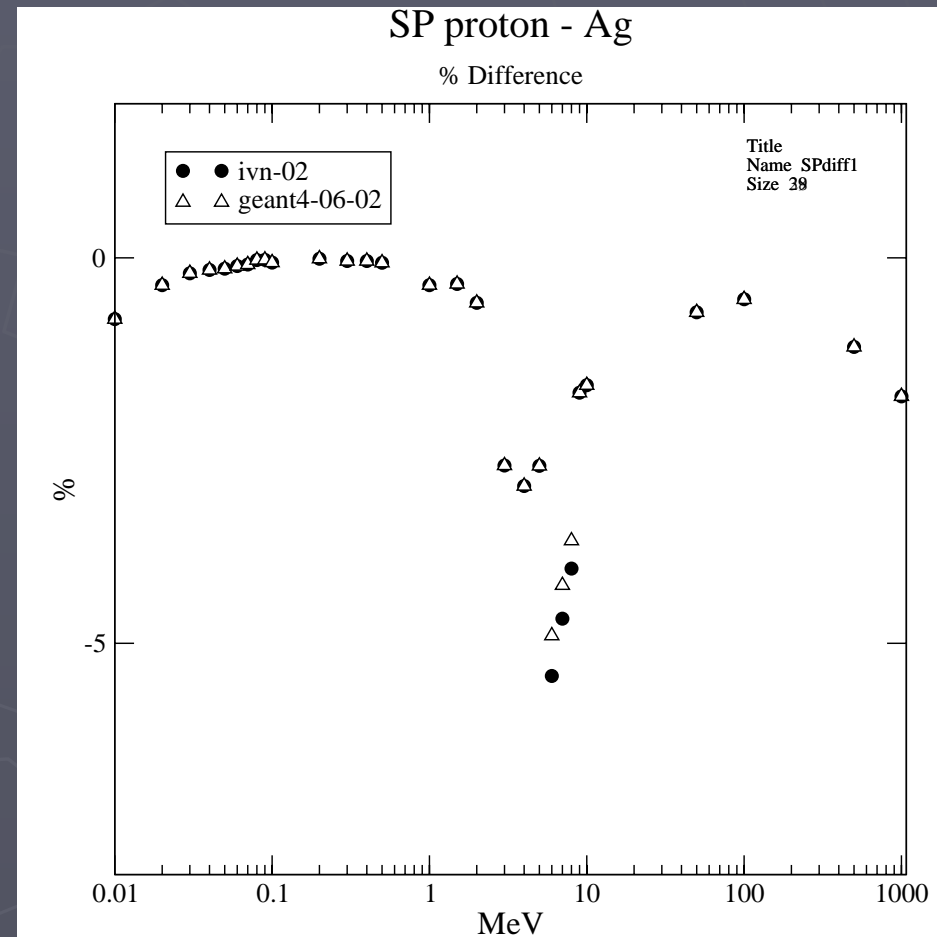
# Shell correction to hadron ionization

(NIST – G4 LE) G4 6.2p02

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

$$C = \sum_v C_v(\theta_v, \eta_v)$$

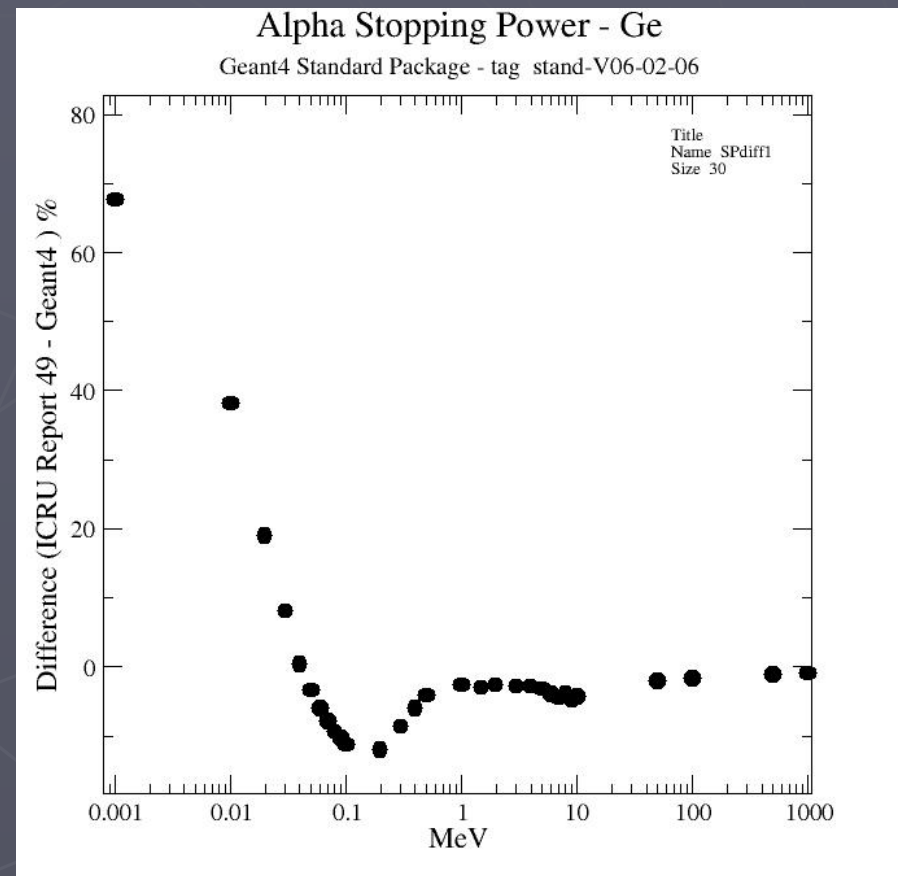
- ▶  $C_K$  and  $C_L$  are calculated using hydrogenic wave functions and effective nuclear charge for a shell
- ▶ For outer shells scaling relation is used



# Nuclear stopping and ion ionization

G4 6.2p02

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



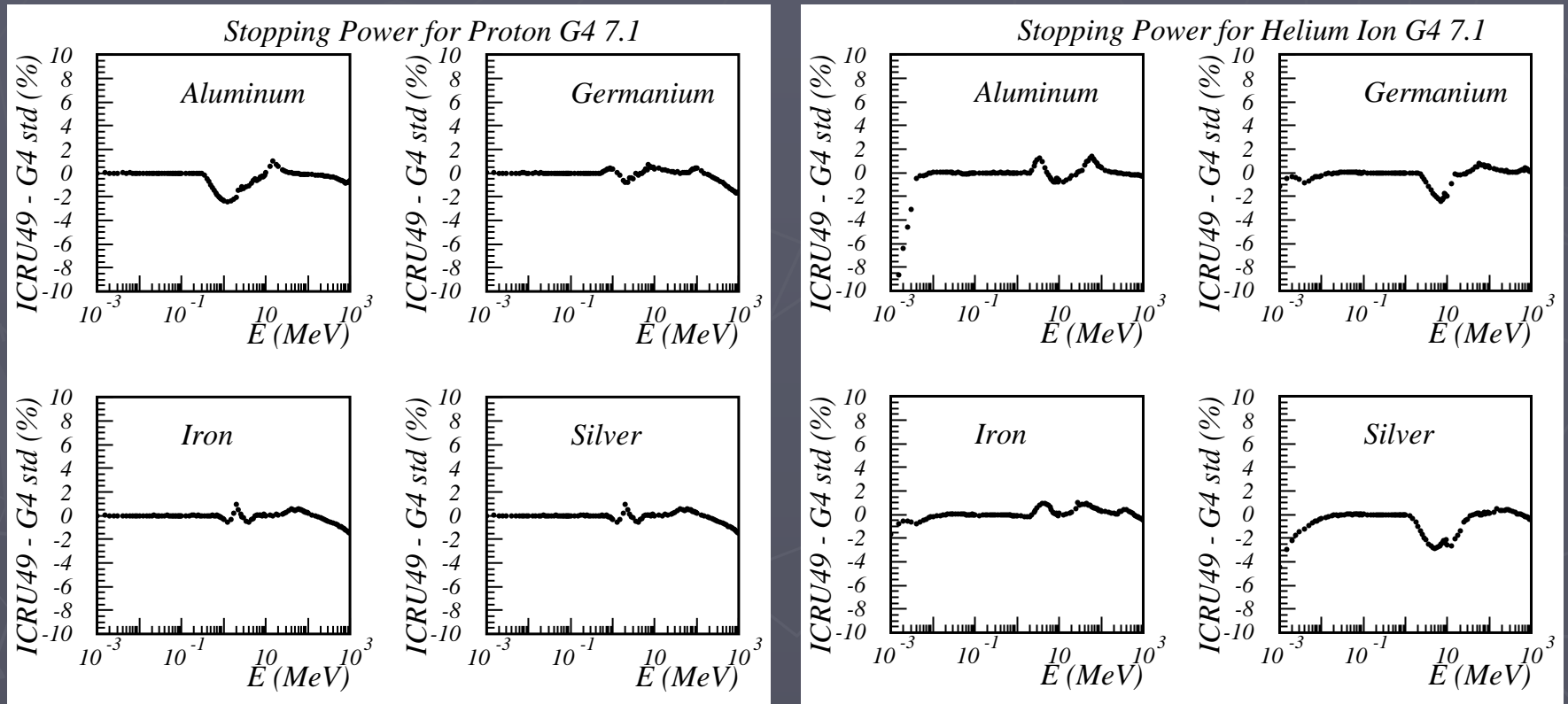
# High order corrections

- ▶ Are important at high energies
- ▶ Are important for ions
- ▶ Are implemented in G4EmCorrections class for Standard (can be used by Low-energy)

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

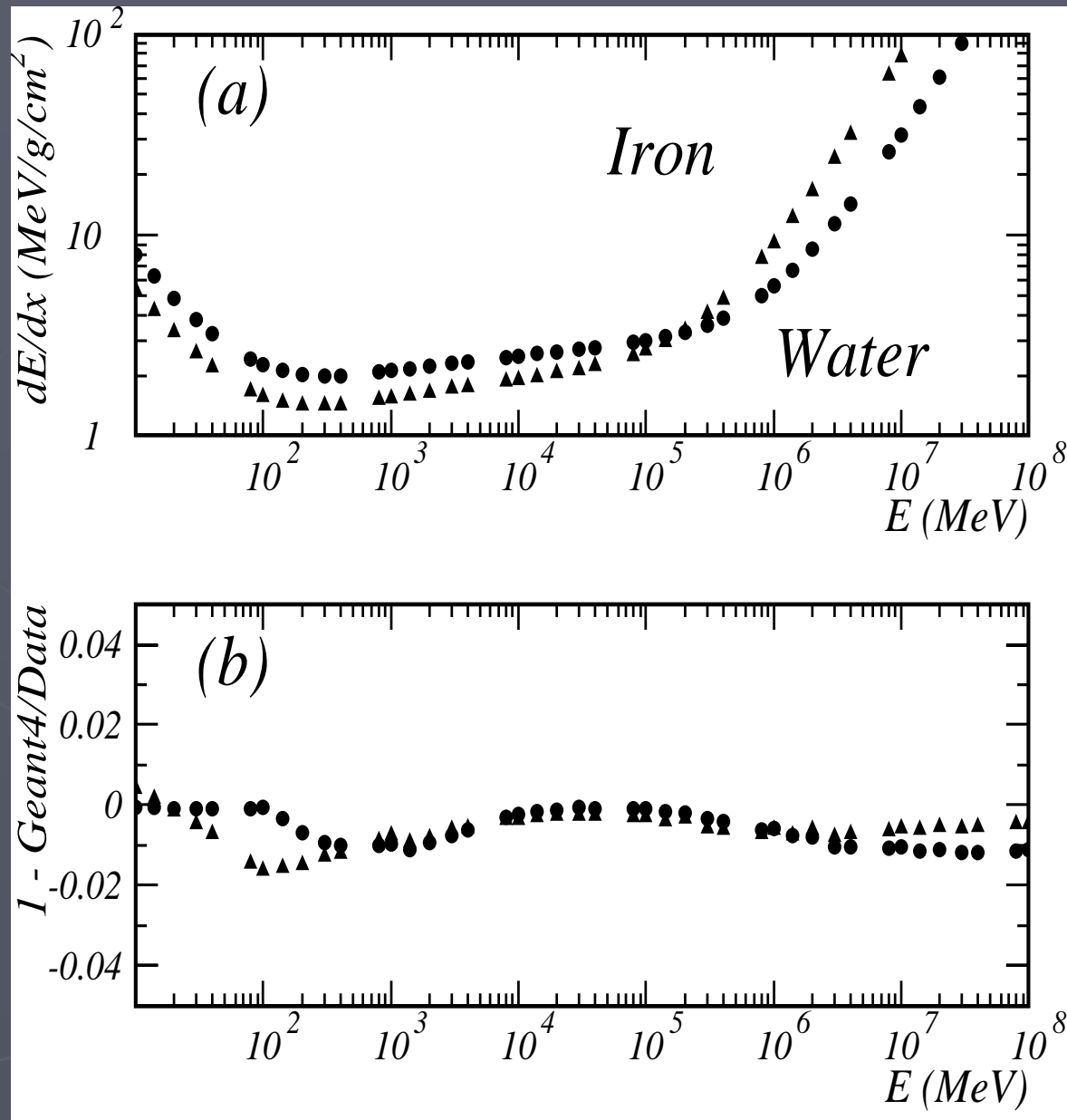
▶ Mott: 
$$G = z\alpha\beta \cdot \left(1.725 + \left(0.52 - 2\sqrt{\frac{I}{2m_e\beta^2\gamma^2}}\right)\pi \cos \chi\right) + (z\alpha)^2(3.246 - 0.451\beta^2) +$$
$$(z\alpha)^3\left(1.522\beta + \frac{0.987}{\beta}\right) + (z\alpha)^4\left(4.569 - 0.494\beta^2 - \frac{2.696}{\beta^2}\right) +$$
$$(z\alpha)^5\left(1.254\beta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

# Result of refinement of stopping power – Geant4 and NIST are within systematic uncertainty of the data



# Muon Energy Loss

- ▶ Comparisons with evaluated database on muon stopping powers
- ▶ G4 7.1
- ▶ An agreement within 2%





# Model per G4Region

- ▶ Needed for PAI model (V. Grichine)
- ▶ Provided with design iteration of the Standard EM package
- ▶ Example/extended/electromagnetic/TestEm8
- ▶ Builder for the PAI:

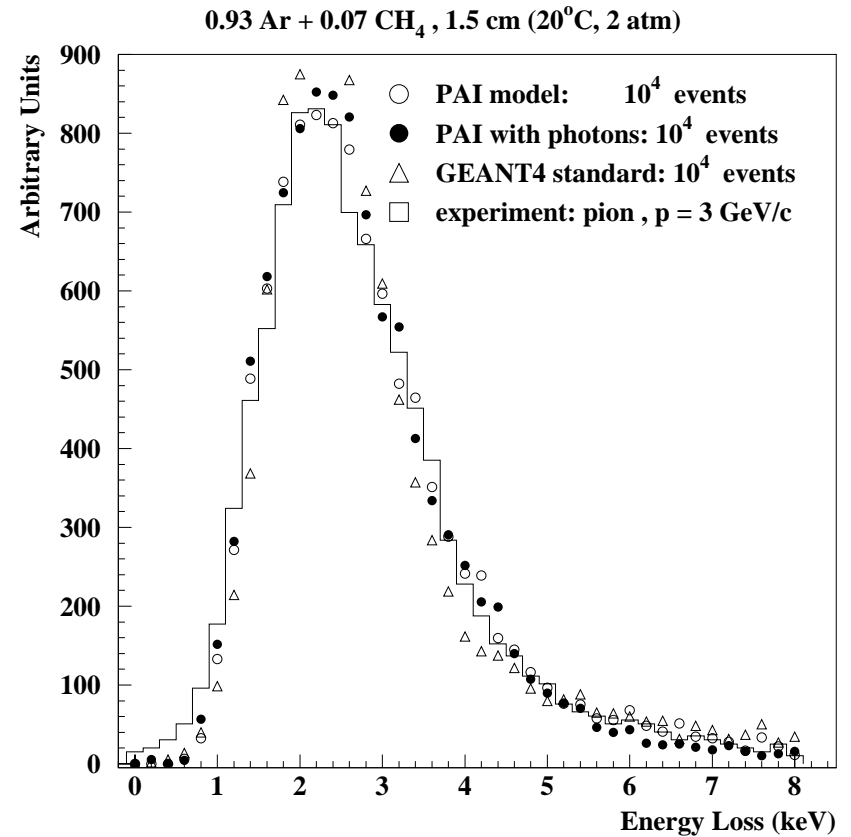
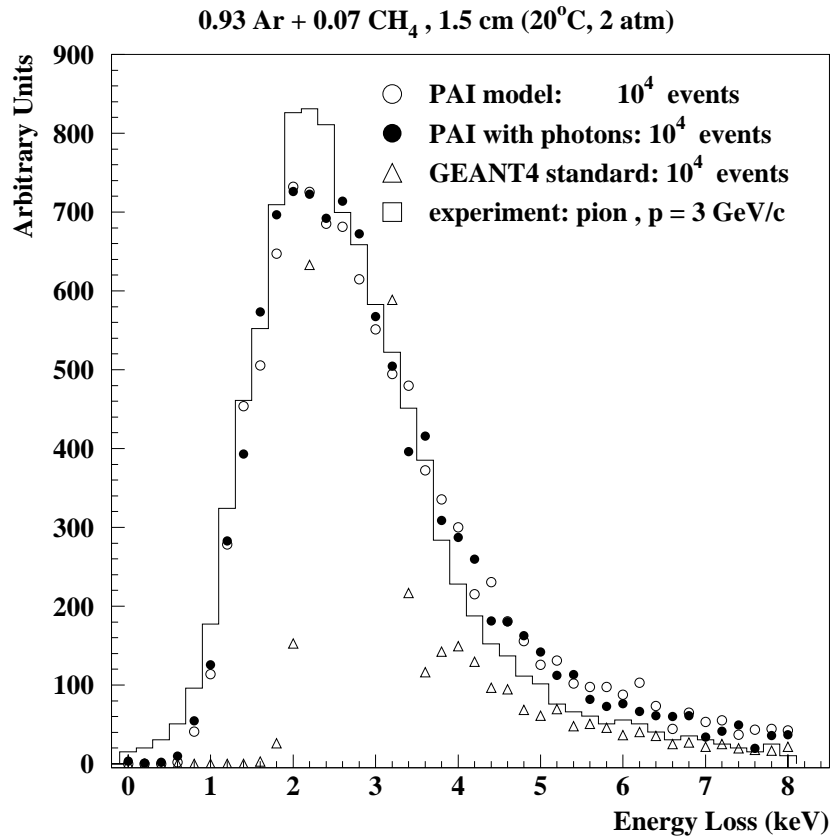
```
G4Region* gas = G4RegionStore::GetInstance()->GetRegion("VertexDetector");  
G4eIonisation* eion = new G4eIonisation();  
G4PAIModel* pai = new G4PAIModel(particle,"PAIModel");  
eion->AddEmModel(0,pai,pai,gas);
```

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

# Refinement of the fluctuation model (L.Urban)

6.2p02

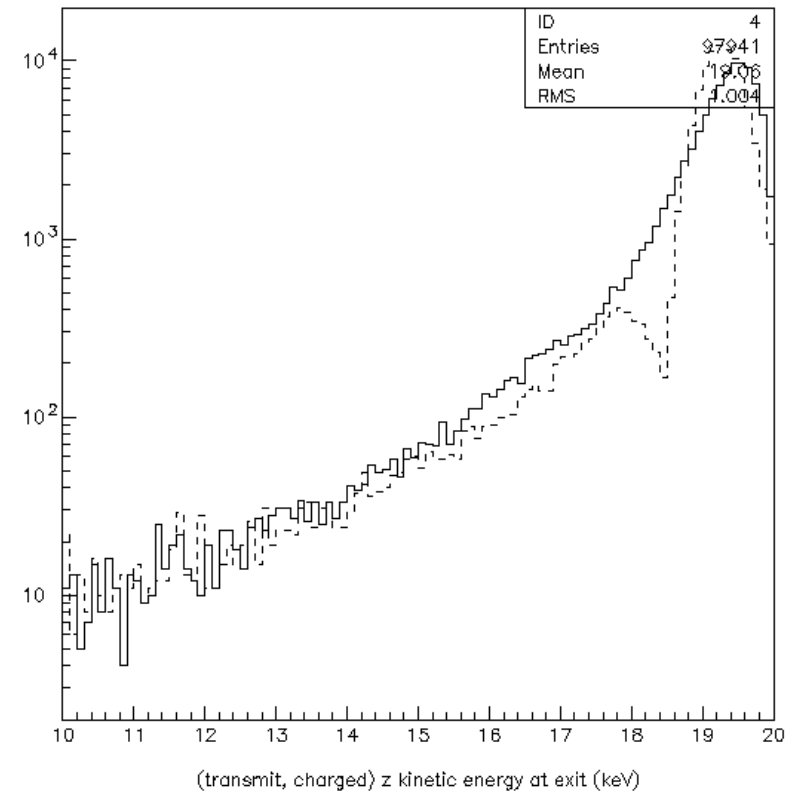
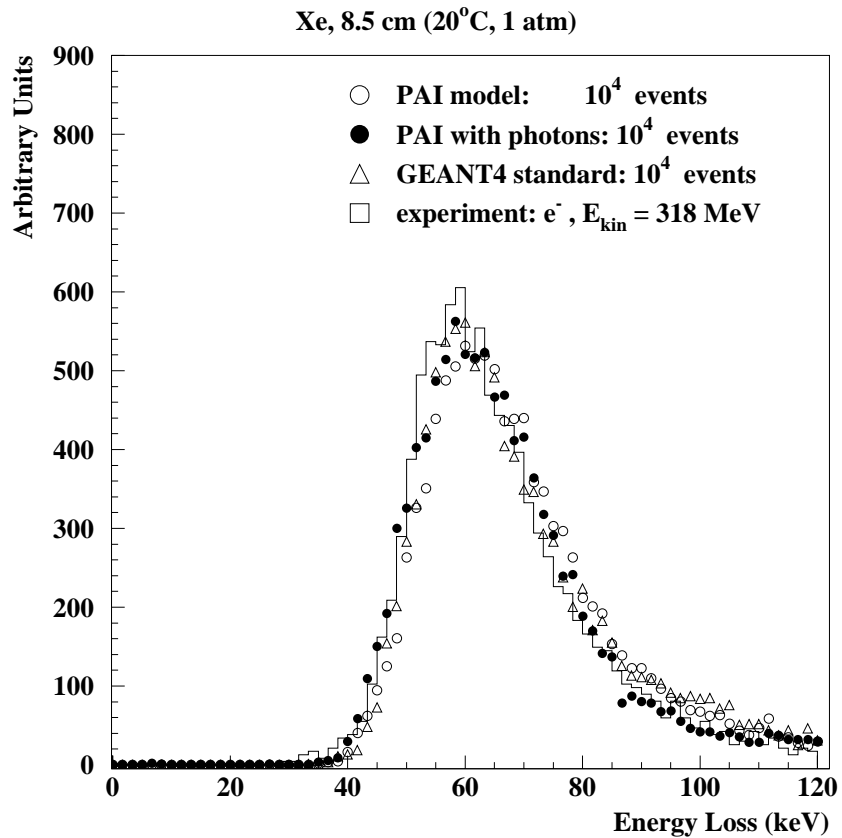
7.0



# Refinement of the fluctuation model

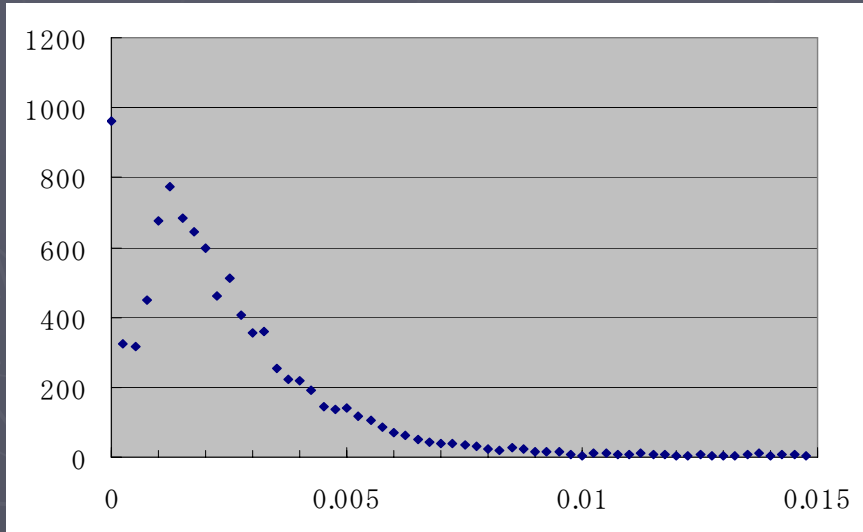
7.0

6.2p02/7.0



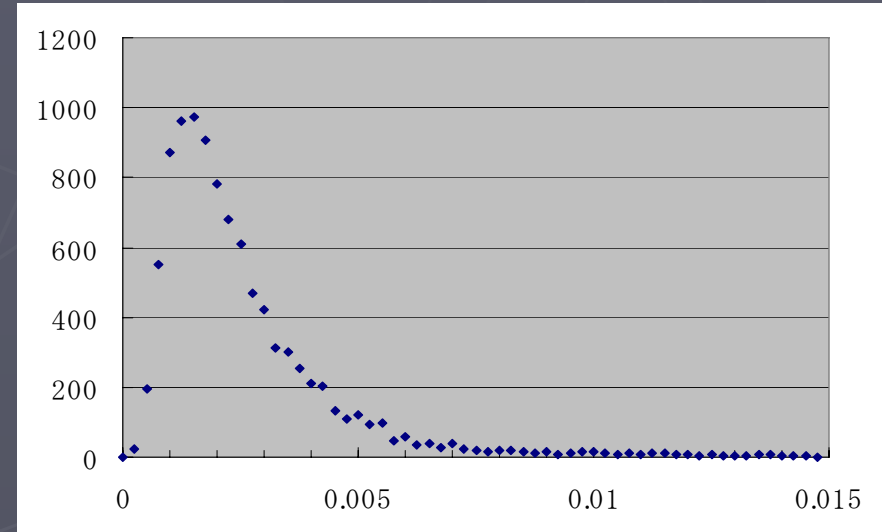
# Argon gas thickness of 2mm electron 235 keV ( $\gamma=1.5$ ) T. Koi (SLAC)

Geant4 v7.0



Energy loss [MeV/cm]

Geant4 v7.0p01

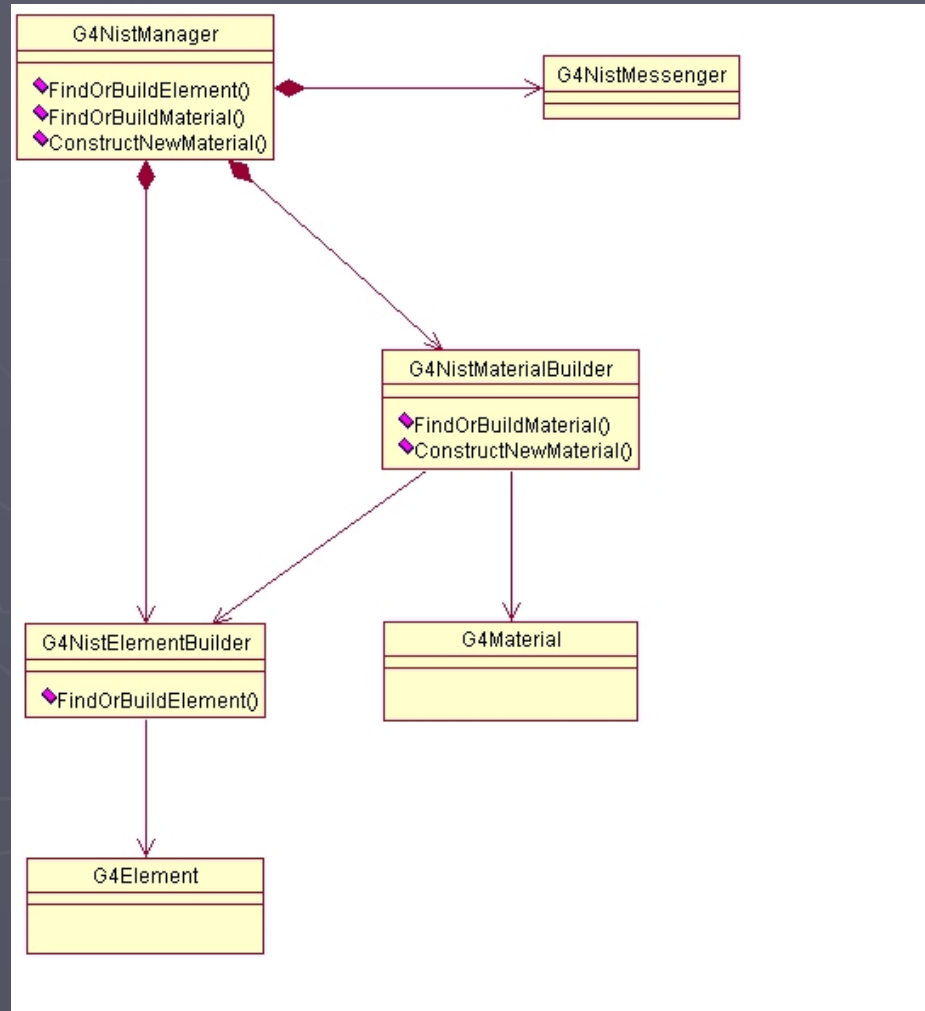


Energy loss [MeV/cm]

# Material category upgrade

- ▶ NIST database for materials is imported inside Geant4
- ▶ 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

# Design of new classes (G4 7.1)



# NIST Element and Isotopes

Z	A	m	error (%)	$A_{\text{eff}}$	
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 <sup>3</sup> )	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

## Compound Materials from the NIST Data Base

N	Name	ChFormula	density(g/cm <sup>3</sup> )	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		

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



# Conclusion remarks

- ▶ NIST data base on materials is implemented inside Geant4
- ▶ Old interfaces in the material category are kept
- ▶ Open an opportunity to simplify and improve many G4 application
- ▶ **Geant4 takes responsibility for providing all parameters of these materials, including parameters for different atomic shell corrections**
- ▶ **Main new user interfaces:**

```
G4Material* mat = manager->FindOrBuildMaterial("name", G4bool iso);  
G4Element* elm = manager->BuildOrFindElement(Z, G4bool iso);  
G4double mass = manager->GetMass(Z, N);
```

# Conclusion

- ▶ The review of Geant4 ionization for hadrons/ions is done
- ▶ G4EmCorrection class provides necessary correction functions
- ▶ Ion ionization is scaled from He ion ionization in Standard
- ▶ Corrected stopping power is in agreement with the NIST data within systematic uncertainty of the data
- ▶ It is a result of joint activity on validation of EM physics between Standard and Low-energy groups