

Geant 4

Electromagnetic Physics

<http://cern.ch/geant4>

Electromagnetic packages in Geant4

- Standard
 - Low Energy
 - Optical
 - Muons
-
- Different modeling approach
 - Specialized according to particle type, energy scope

Electromagnetic physics

- electrons and positrons
- γ , X-ray and optical photons
- muons
- charged hadrons
- ions

- **High energy extensions**

- needed for LHC experiments, cosmic ray experiments...

- **Low energy extensions**

- fundamental for space and medical applications, dark matter and ν experiments, antimatter spectroscopy etc.

- **Alternative models for the same process**

- Multiple scattering
- energy loss { • Bremsstrahlung
- Ionisation
- Annihilation
- Photoelectric effect
- Compton scattering
- Rayleigh effect
- g conversion
- e+e- pair production
- Synchrotron radiation
- Transition radiation
- Cherenkov
- Refraction
- Reflection
- Absorption
- Scintillation
- Fluorescence
- Auger

All obeying to the same abstract Process interface: transparent to tracking

Geant 4

Low Energy Electromagnetic Physics

More information is available from the Geant4 Low Energy Electromagnetic Working Group web site

<http://www.ge.infn.it/geant4/lowE/>

What is

- A package in the Geant4 electromagnetic package
 - *geant4/source/processes/electromagnetic/lowenergy/*
- A set of processes extending the coverage of electromagnetic interactions in Geant4 down to “low” energy
 - 250 eV (*in principle even below this limit*)/100 eV for electrons and photons
 - down to the approximately the ionisation potential of the interacting material for hadrons and ions
- A set of processes based on detailed models
 - shell structure of the atom
 - precise angular distributions
- Complementary to the “standard” electromagnetic package

Overview of physics

- Compton scattering
- Rayleigh scattering
- Photoelectric effect
- Pair production

- Bremsstrahlung
- Ionisation

- Polarised Compton

- + atomic relaxation
 - fluorescence
 - Auger effect

following processes leaving a vacancy in an atom

- In progress

- More precise angular distributions (Rayleigh, photoelectric, Bremsstrahlung etc.)
- Polarised γ conversion, photoelectric

in two “flavours” of models:

- based on the **Livermore Library**
- à la **Penelope**

- Development plan

- *Driven by user requirements*
- *Schedule compatible with available resources*

LowE processes based on Livermore Library

Photons and electrons

different approach w.r.t.
Geant4 standard e.m.
package

- Based on evaluated data libraries from LLNL:
 - EADL (*Evaluated Atomic Data Library*)
 - EEDL (*Evaluated Electrons Data Library*)
 - EPDL97 (*Evaluated Photons Data Library*)especially formatted for Geant4 distribution (*courtesy of D. Cullen, LLNL*)
- Validity range: 250 eV - 100 GeV
 - The processes can be used down to 100 eV, with degraded accuracy
 - In principle the validity range of the data libraries extends down to ~10 eV
- Elements $Z=1$ to $Z=100$
 - Atomic relaxation: $Z > 5$ (*transition data available in EADL*)

Calculation of cross sections

Interpolation from the data libraries:

$$\log(\sigma(E)) = \frac{\log(\sigma_1)\log(E_2 / E) + \log(\sigma_2)\log(E / E_1)}{\log(E_2 / E_1)}$$

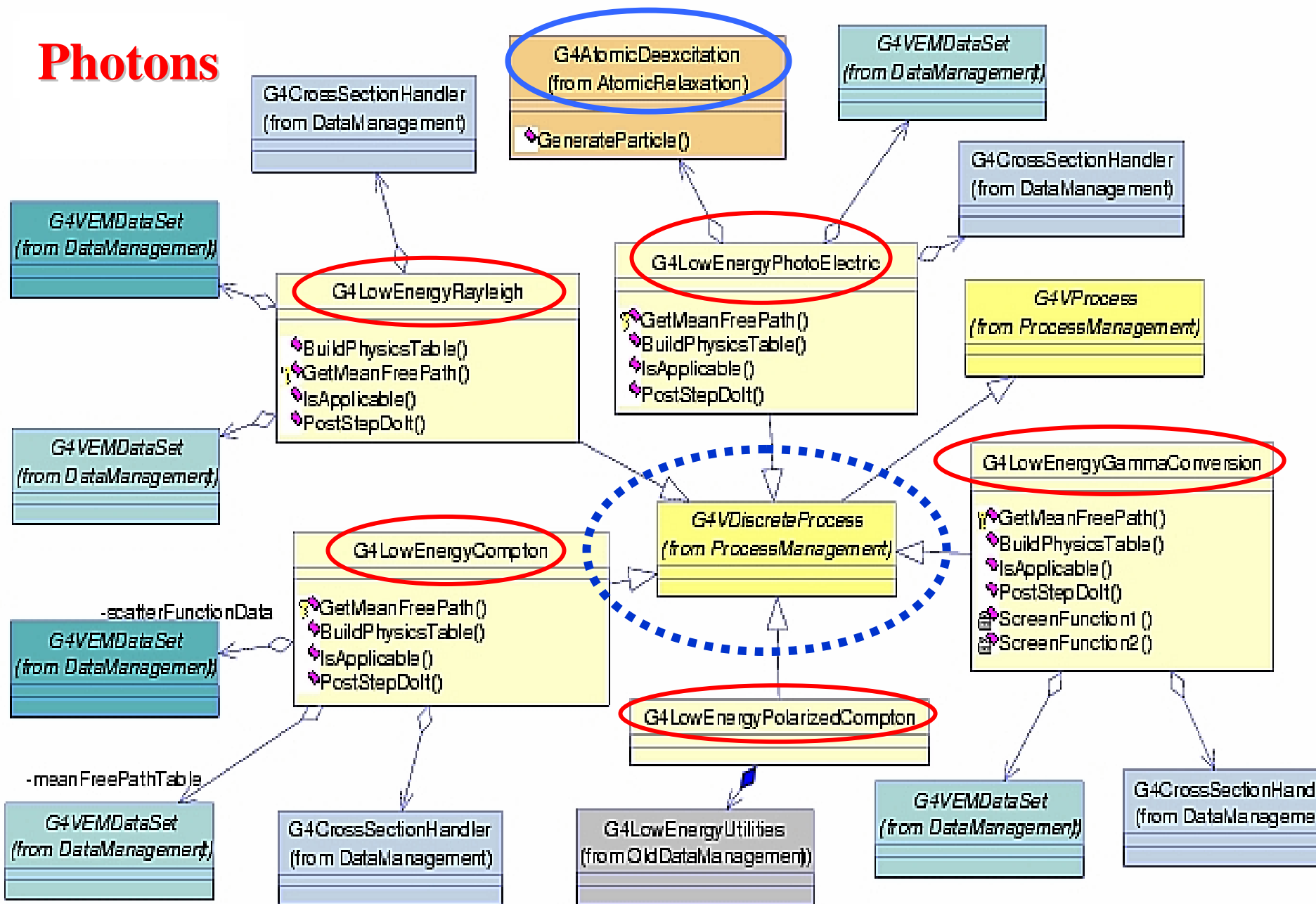
E₁ and E₂ are the lower and higher energy for which data (σ₁ and σ₂) are available

Mean free path for a process, at energy E:

$$\lambda = \frac{1}{\sum_i \sigma_i(E) \cdot n_i}$$

n_i = atomic density of the ith element contributing to the material composition

Photons



Compton scattering

Klein-Nishina
cross section:

$$\frac{d\sigma}{d\Omega} = \frac{1}{4} r_0^2 \frac{h\nu^2}{h\nu_0^2} \left[\frac{h\nu_0}{h\nu} + \frac{h\nu}{h\nu_0} - 2 + 4\cos^2\Theta \right]$$

- Energy distribution of the scattered photon according to the *Klein-Nishina formula*, multiplied by **scattering function** $F(q)$ from EPDL97 data library
- The effect of scattering function becomes significant at low energies
 - suppresses forward scattering
- Angular distribution of the scattered photon and the recoil electron also based on EPDL97

Rayleigh scattering

- Angular distribution: $F(E, q) = [1 + \cos^2(q)] \cdot F^2(q)$
 - where $F(q)$ is the energy-dependent **form factor** obtained from EPDL97
- This process is only available in the *lowenergy* package
 - Not available in the *standard* package

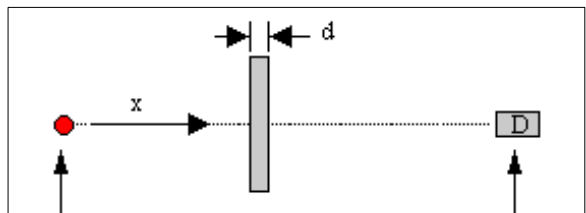
Photoelectric effect

- Cross section
 - Integrated cross section (over the shells) from EPDL + interpolation
 - Shell from which the electron is emitted selected according to the detailed cross sections of the EPDL library
- Final state generation
 - Various angular distribution generators (“naïve”, Sauter-Gavrila, Gavrila)
- Deexcitation via the atomic relaxation sub-process
 - Initial vacancy + following chain of vacancies created
- *Improved angular distribution in preparation*

γ conversion

- The secondary e^- and e^+ energies are sampled using Bethe-Heitler cross sections with Coulomb correction
- e^- and e^+ assumed to have symmetric angular distribution
- Energy and polar angle sampled w.r.t. the incoming photon using Tsai differential cross section
- Azimuthal angle generated isotropically
- Choice of which particle in the pair is e^- or e^+ is made randomly

Photons: mass attenuation coefficient

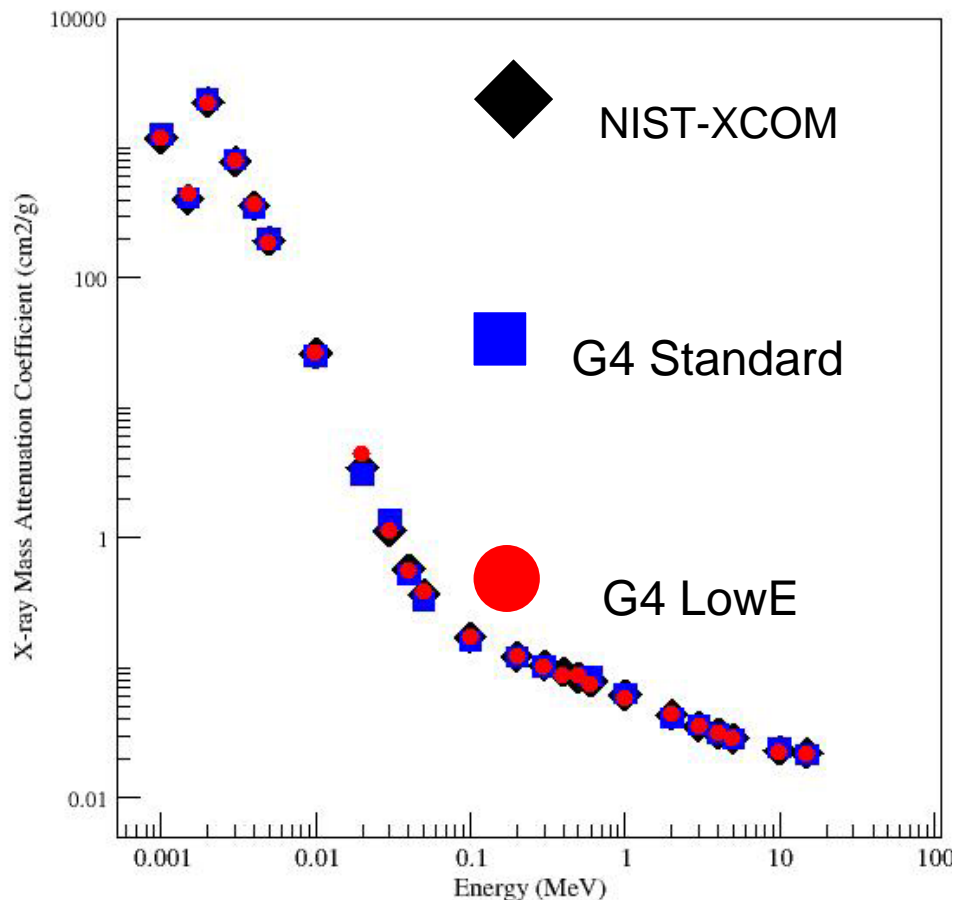


$$\chi^2_{N-L} = 13.1 - \nu = 20 - p = 0.87$$

$$\chi^2_{N-S} = 23.2 - \nu = 15 - p = 0.08$$

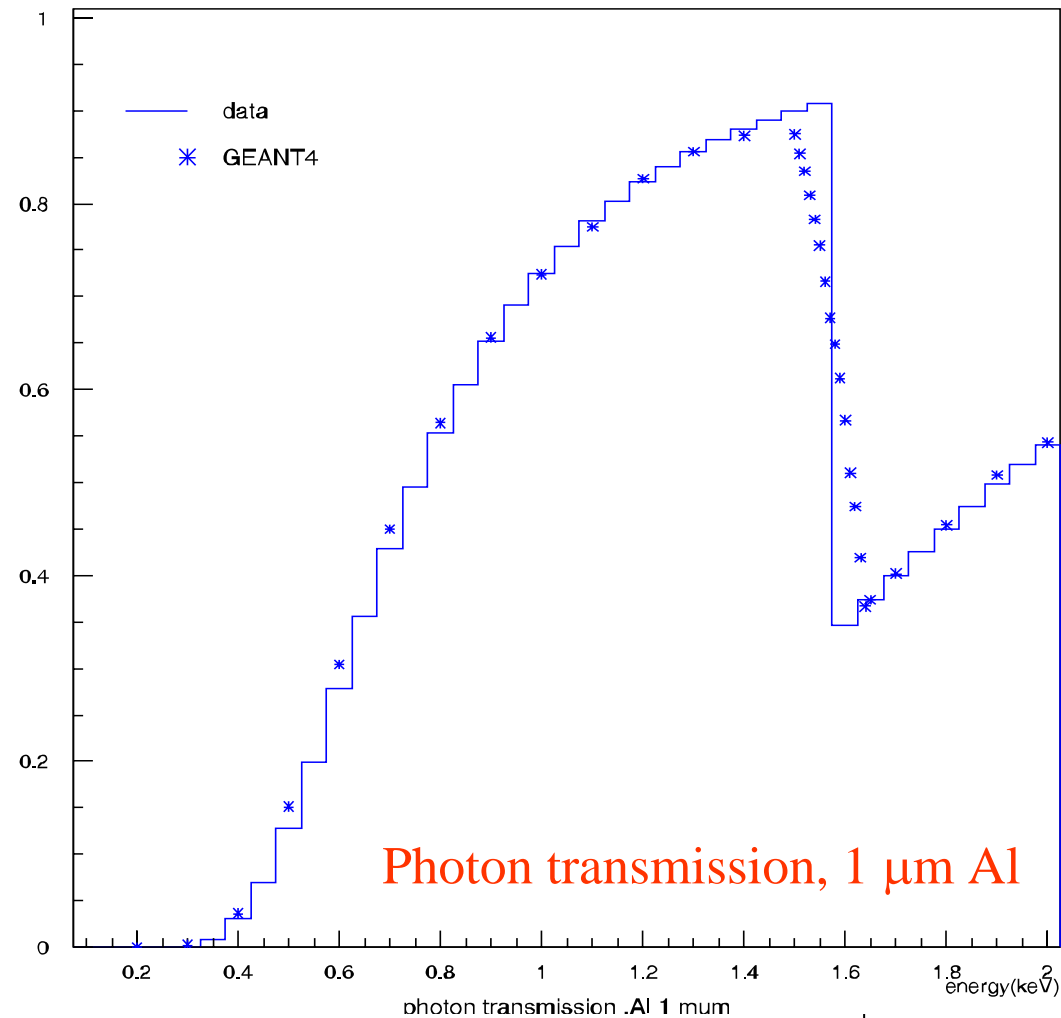
LowE accuracy ~ 1%

Comparison against NIST data

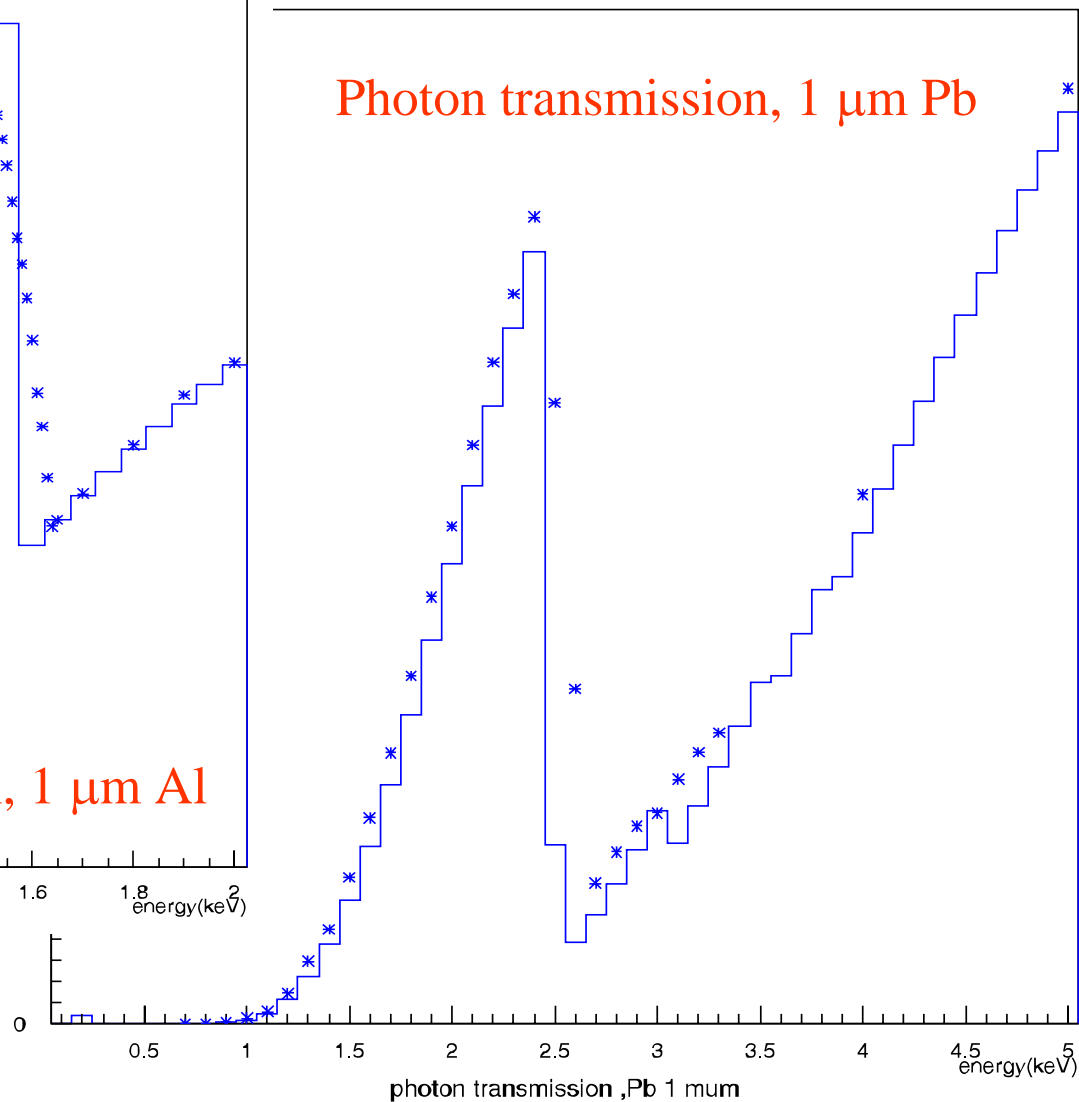


Photons, evidence of shell effects

photon transmission , Al 1 micrometer



photon transmission , Pb 1 micrometer



Polarisation

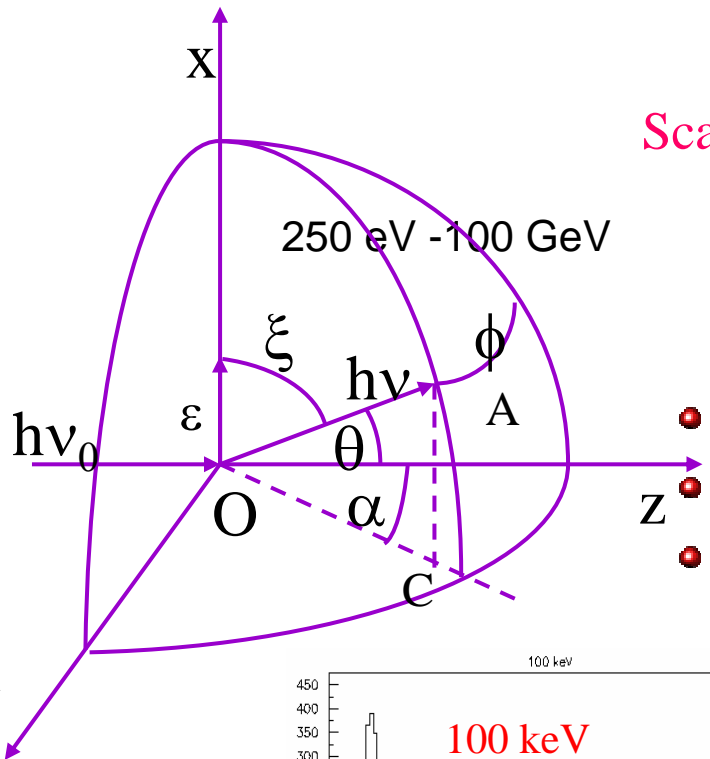
Cross section:

$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \frac{h\nu^2}{h\nu_0^2} \left[\frac{h\nu_0}{h\nu} + \frac{h\nu}{h\nu_0} - 2 \sin^2 \theta \cos^2 \phi \right]$$

$$\cos \xi = \sin \theta \cos \phi \Rightarrow \sin \xi = \sqrt{1 - \sin^2 \theta \cos^2 \phi} = N$$

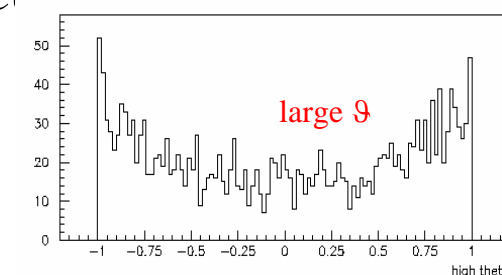
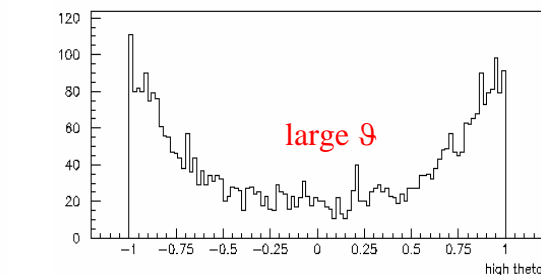
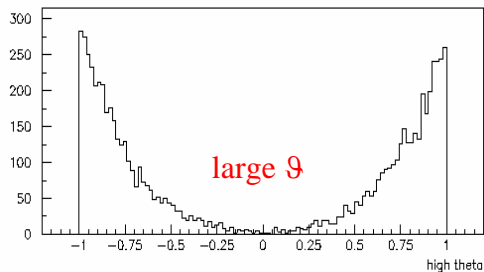
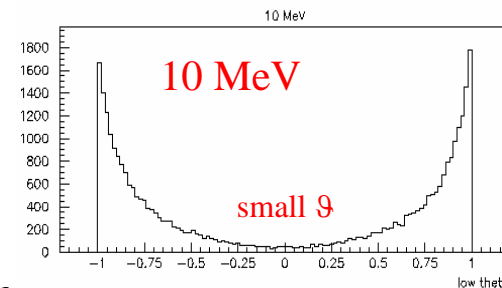
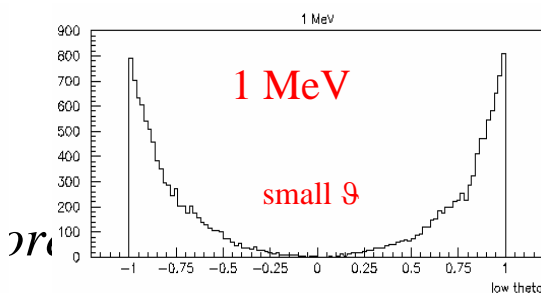
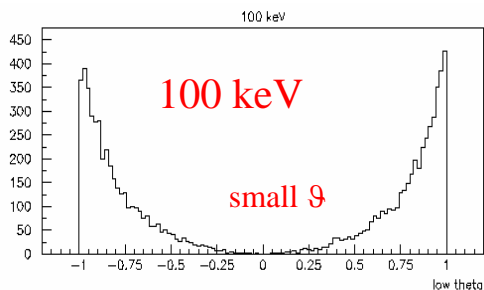
Scattered Photon Polarization $\bar{\varepsilon}_\perp = \frac{1}{N} (\cos \theta \hat{j} - \sin \theta \sin \phi \hat{k}) \sin \beta$

$$\bar{\varepsilon}_\parallel = \left(N \hat{i} - \frac{1}{N} \sin^2 \theta \sin \phi \cos \phi \hat{j} - \frac{1}{N} \sin \theta \cos \theta \cos \phi \hat{k} \right) \cos \beta$$

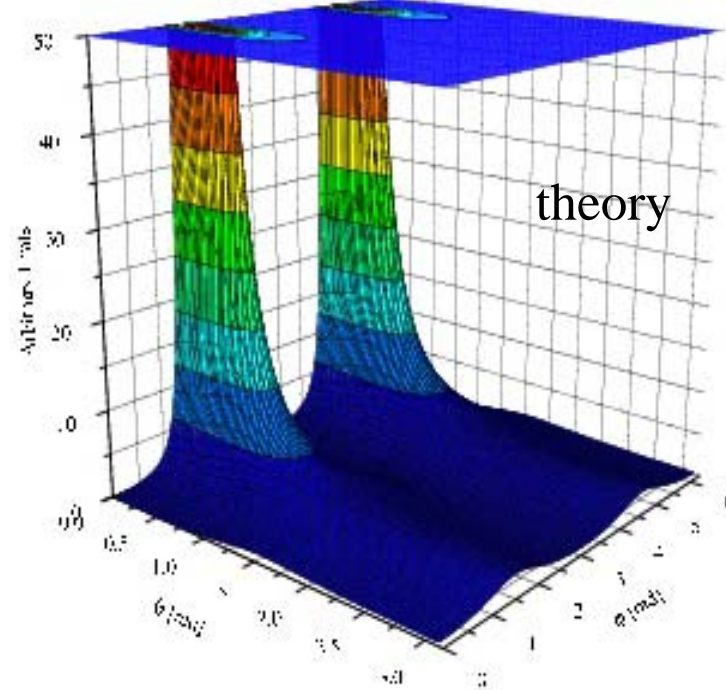
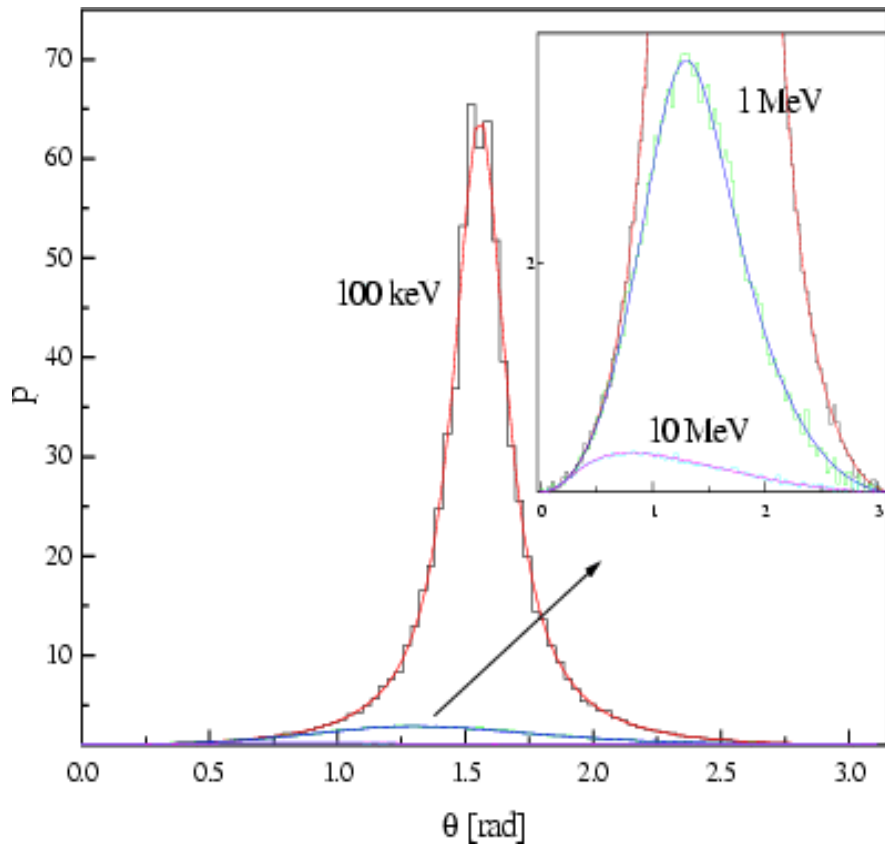


- θ Polar angle
- ϕ Azimuthal angle
- ε Polarization vector

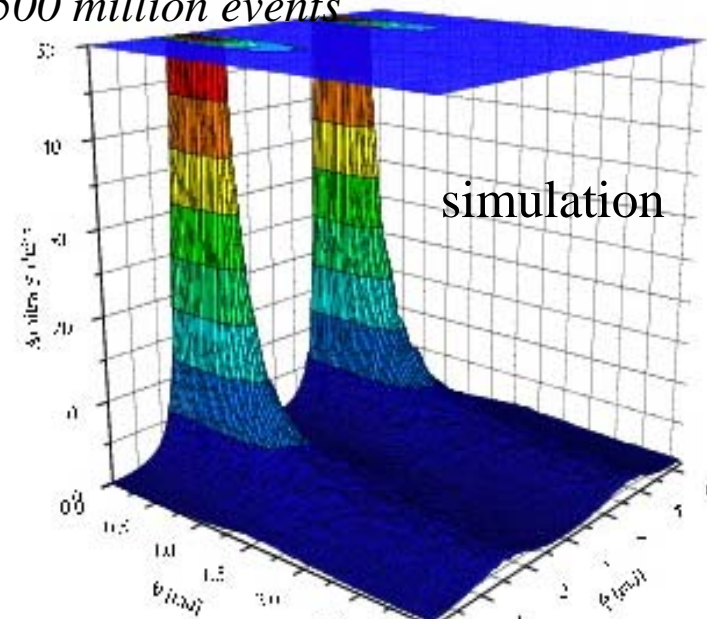
Low Energy
Polarised Compton



Polarisation



500 million events

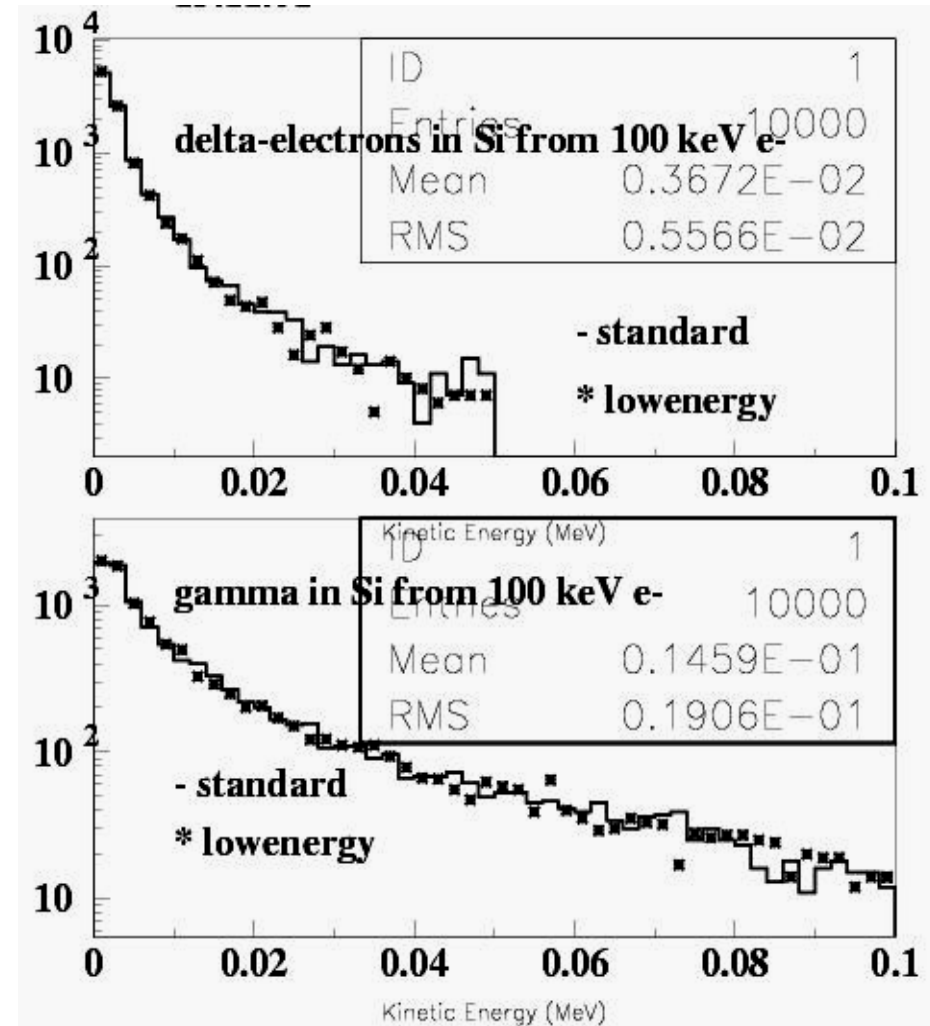


Polarisation of a non-polarised photon beam, simulation and theory

Ratio between intensity with perpendicular and parallel polarisation vector w.r.t. scattering plane, linearly polarised photons

Electron Bremsstrahlung

- Parameterisation of EEDL data
 - 16 parameters for each atom
 - At high energy the parameterisation reproduces the Bethe-Heitler formula
 - Precision is $\sim 1.5\%$
- Plans
 - Systematic verification over Z and energy

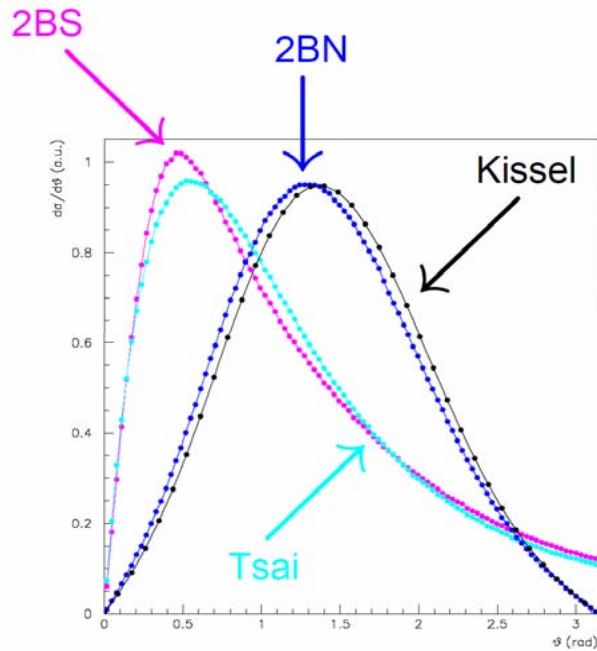


Bremsstrahlung Angular Distributions

Three LowE generators available in GEANT4 6.0 release:

G4ModifiedTsai, G4Generator2BS and G4Generator2BN

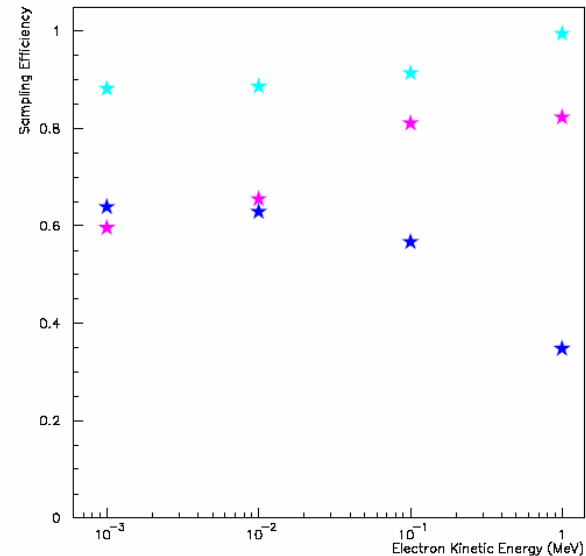
G4Generator2BN allows a correct treatment at low energies (< 500 keV)



T=10 keV (k/T=0.5)

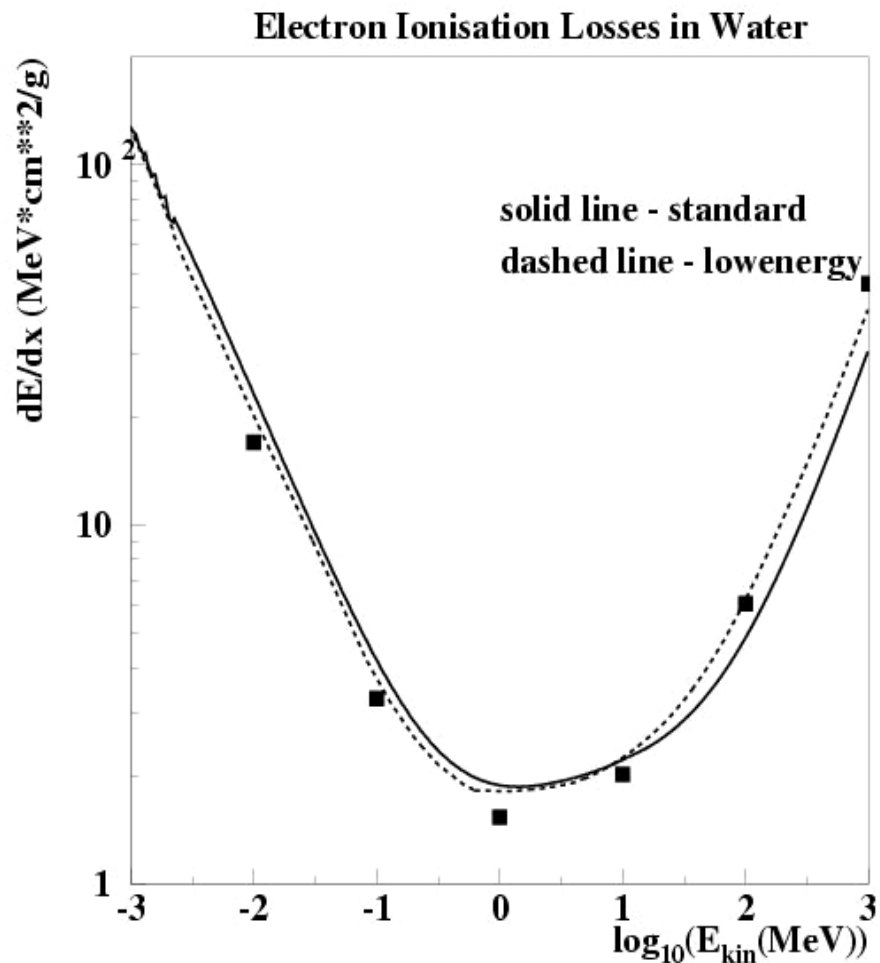
- ★ Tsai
- ★ 2BS (k/T=0.3)
- ★ 2BN (k/T=0.3)

Tungsten (W) - Z=74



Electron ionisation

- Parameterisation based on 5 parameters for each shell
- Precision of parametrisation is better than 5% for 50 % of shells, less accurate for the remaining shells
- Work in progress to improve the parameterisation and the performance



Electrons: range

Range in various simple and composite materials

Compared to NIST database

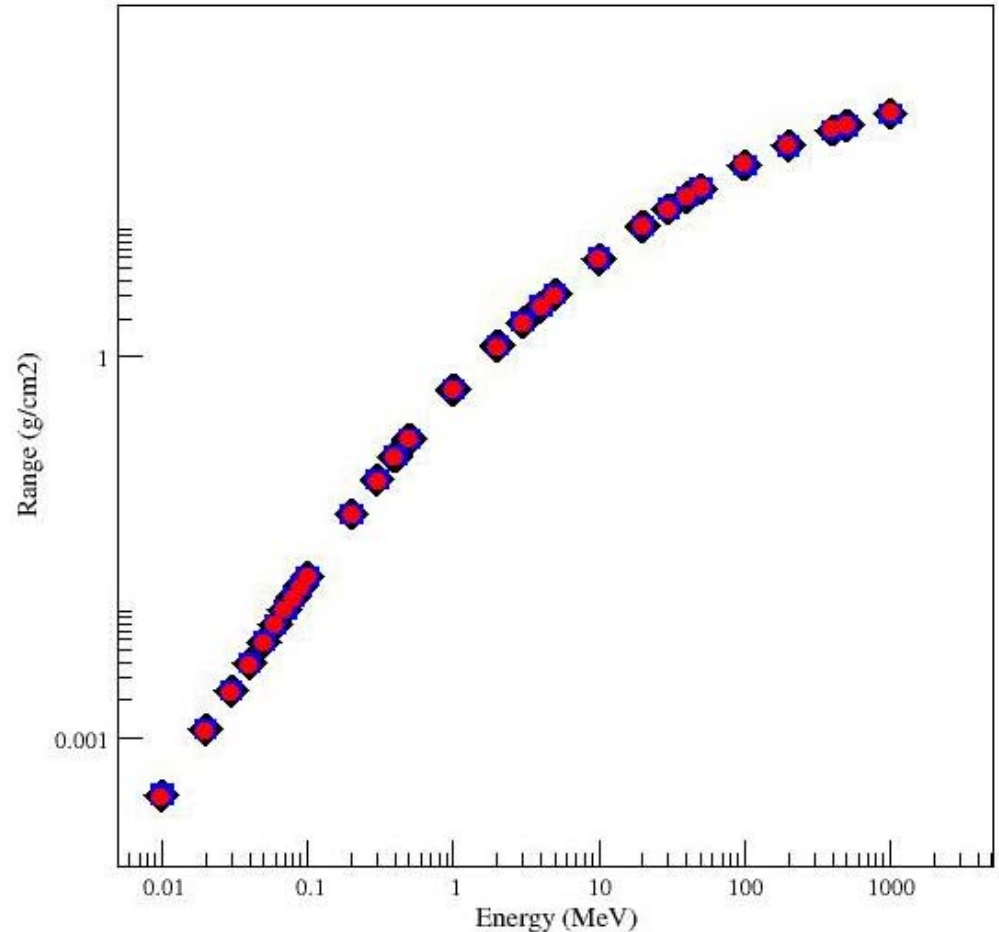
◆ NIST-ESTAR

■ G4 Standard

● G4 LowE

Electrons - CSDA Range - Aluminium

(Geant4-05-02)

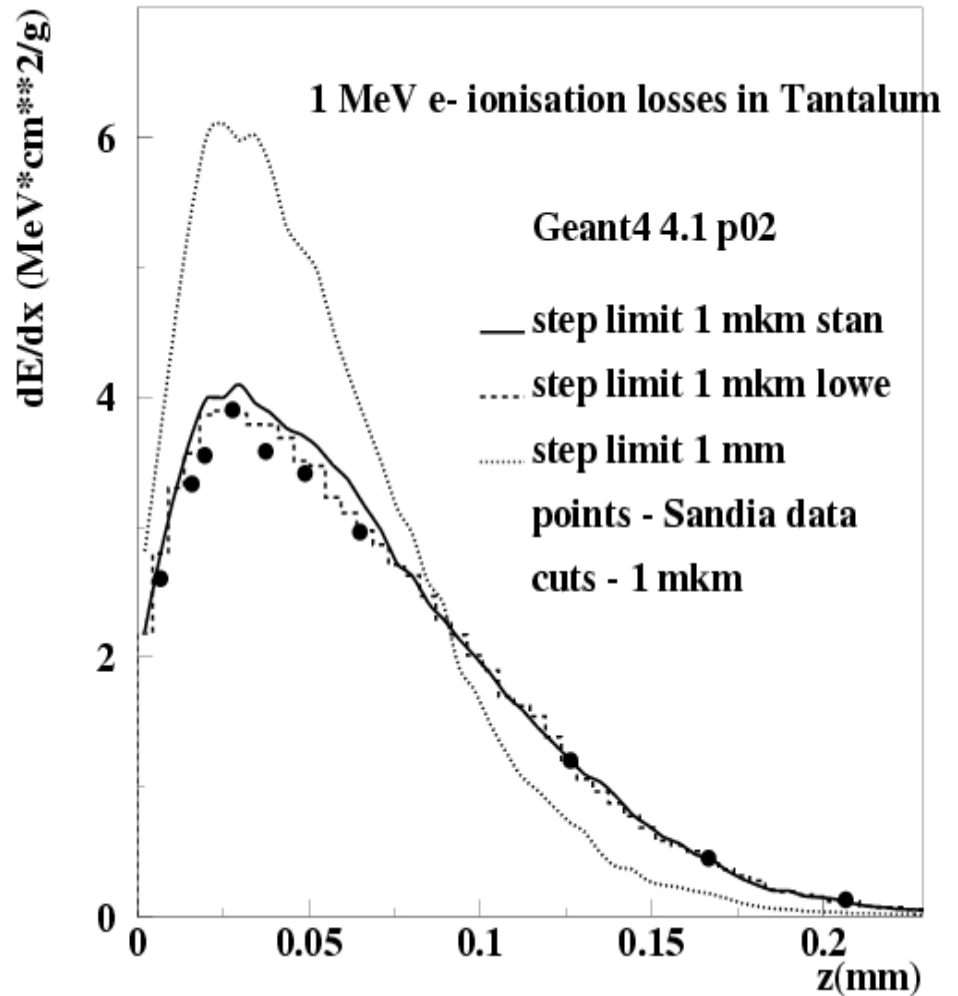


Electrons: dE/dx

Ionisation energy loss in various materials

Compared to Sandia database

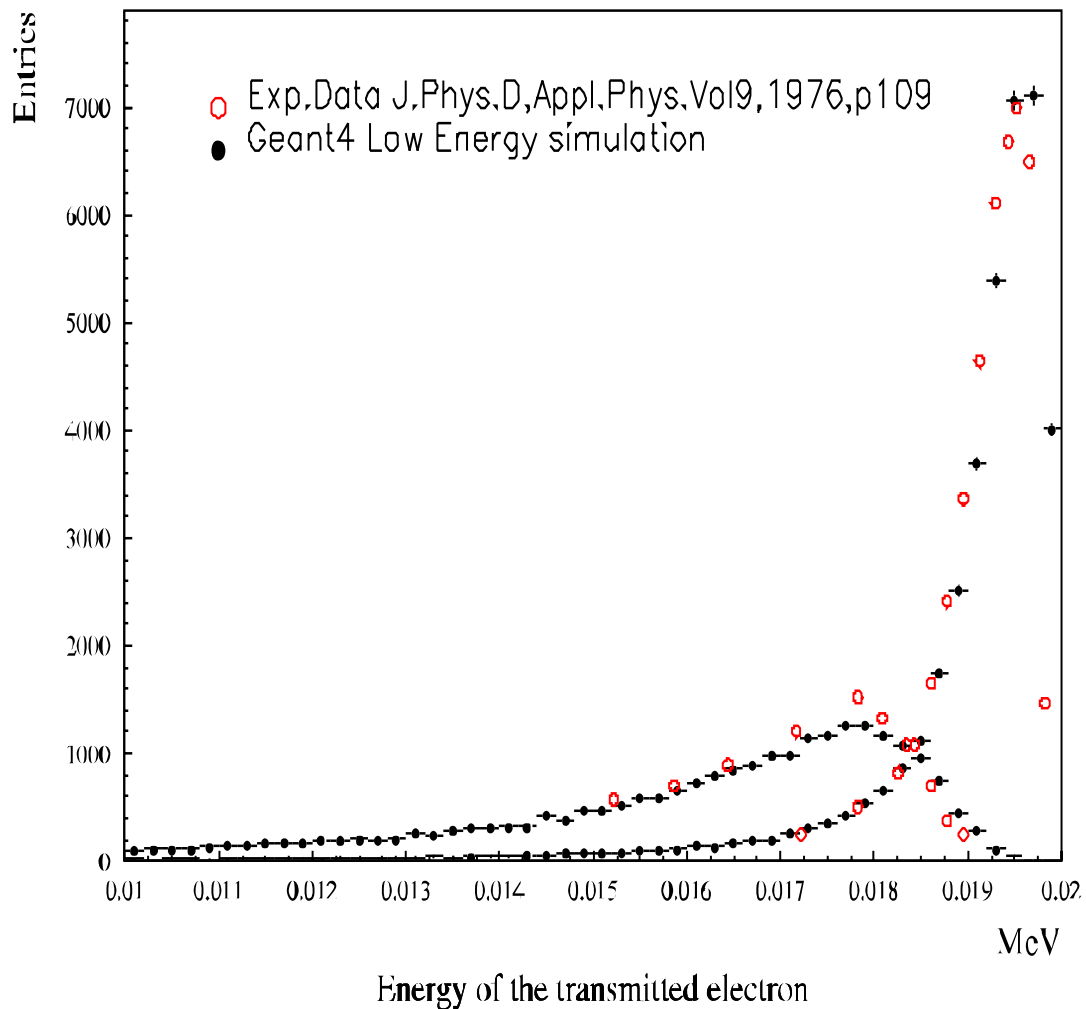
More systematic verification planned



Also Fe, Ur

Electrons, transmitted

20 keV electrons, 0.32 and 1.04 μm Al



Geant4 validation vs. NIST database

- All Geant4 physics models of electrons, photons, protons and α compared to NIST database
 - Photoelectric, Compton, Rayleigh, Pair Production cross-sections
 - Photon attenuation coefficients
 - Electron, proton, α stopping power and range
- Quantitative comparison
 - Statistical goodness-of-fit tests
- Other validation projects in progress

NIST Test

- Photon Mass Attenuation Coefficient
- Photon Partial Interaction Coefficient
 - related to the cross section of a specific photon interaction process
- Electron CSDA range and Stopping Power
- Proton CSDA range and Stopping Power
- α CSDA range and Stopping Power

Elements

Be, Al, Si, Fe, Ge, Ag, Cs, Au, Pb, U
(span the periodic element table)

Energy range

photon	1 keV – 100 GeV
electron	10 keV – 1 GeV
proton	1 keV – 10 GeV
α	1 keV – 1 GeV

Simulation configuration reproducing NIST conditions
(ionisation potential, fluctuations, production of secondaries etc.)

Geant 4

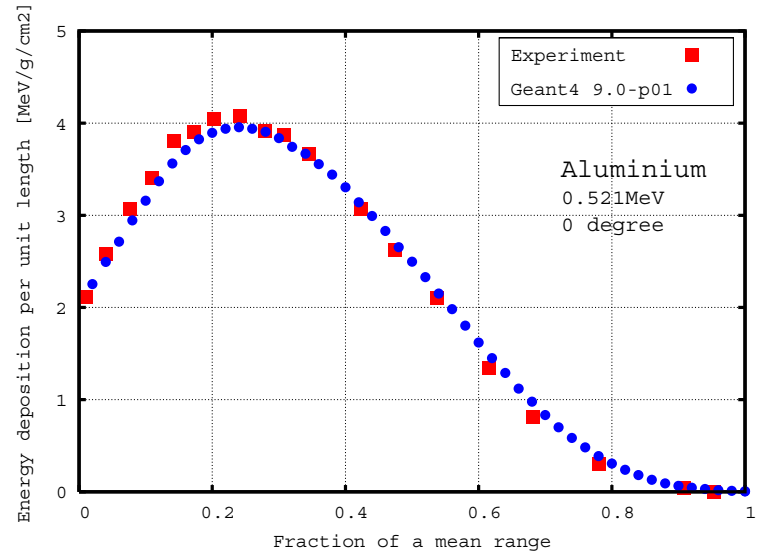
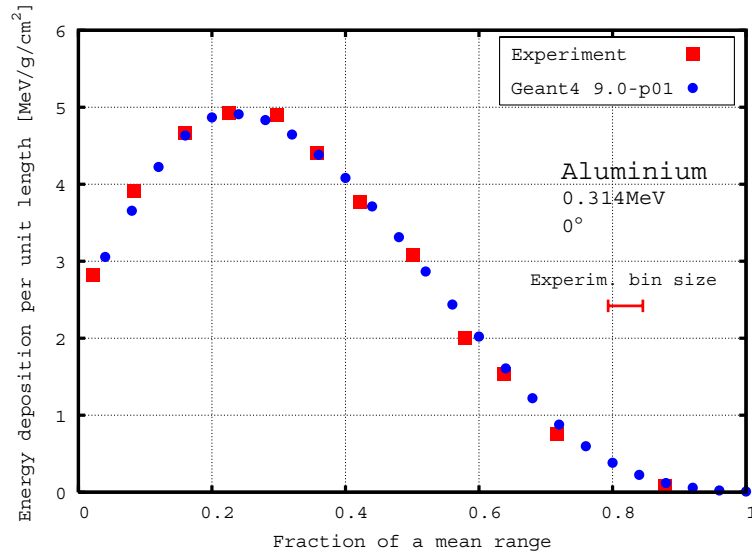
Geant4 models: electrons and photons

Standard
Low Energy EEDL/EPDL
Low Energy Penelope

Geant4 models: protons and α

Standard
Low Energy ICRU49
Low Energy Ziegler 1977
Low Energy Ziegler 1985
Low Energy Ziegler 2000
(Low Energy: free electron gas +
parameterisations + Bethe-Bloch)

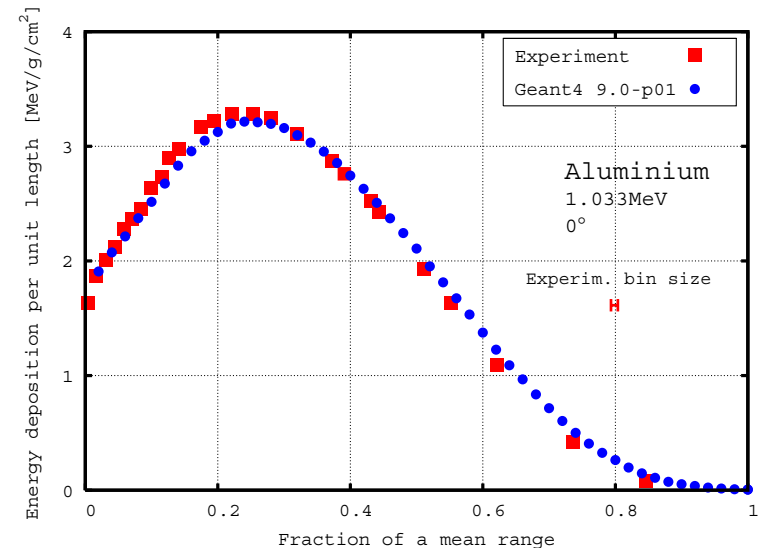
Dosimetry with Geant4 LowE EM package



Energy deposit in calorimeter

Experimental data

G.J. Lockwood et al.,
“Calorimetric Measurement of Electron
Energy Deposition in Extended
Media - Theory vs. Experiment”,
SAND79-0414 UC-34a, 1987.



A. Lechner, M.G. Pia, M. Sudhakar

IEEE NSS 2007 Conf. Rec. - IEEE NPSS Best Student Paper Award

Effect of secondary production threshold

Geant4 Low Energy
Electromagnetic

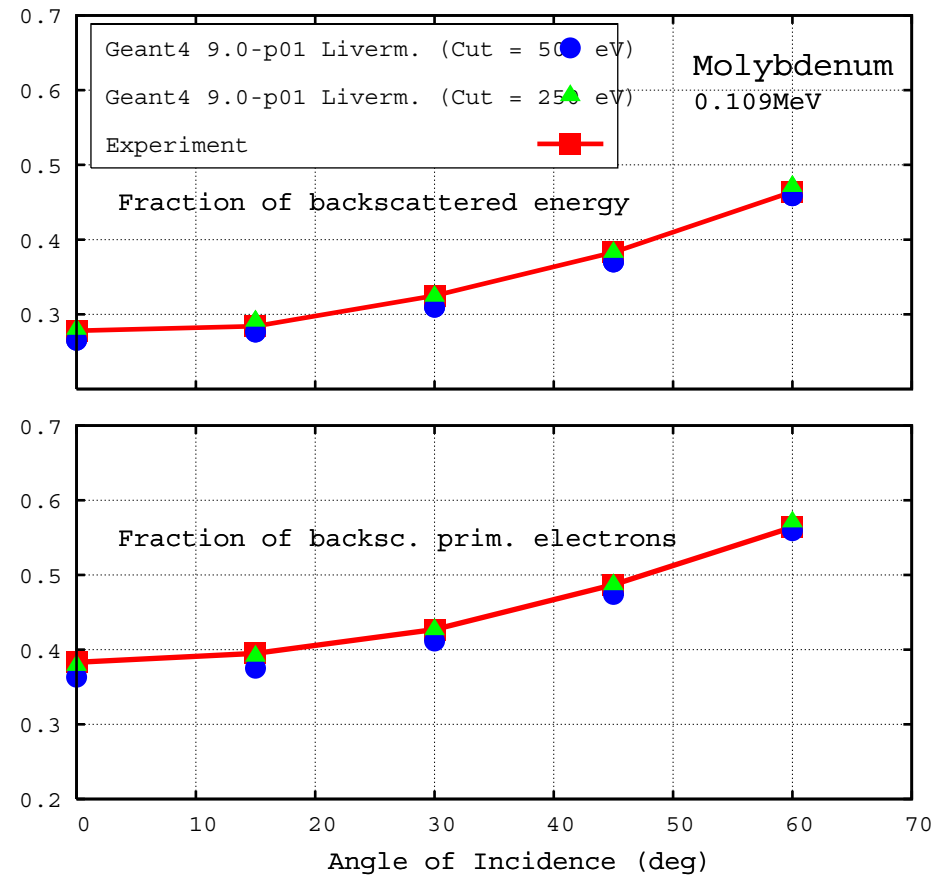
250 eV

EGS

Geant4 Standard
Electromagnetic

MCNP

1 keV



Example 5.2. Registration of electromagnetic low energy electron/photon processes.

```
void LowEnPhysicsList::ConstructEM()
{
    theParticleIterator->reset();

    while( (*theParticleIterator)() ){

        G4ParticleDefinition* particle = theParticleIterator->value();
        G4ProcessManager* pmanager = particle->GetProcessManager();
        G4String particleName = particle->GetParticleName();

        if (particleName == "gamma") {

            theLEPhotoElectric      = new G4LowEnergyPhotoElectric();
            theLECompton             = new G4LowEnergyCompton();
            theLEGammaConversion    = new G4LowEnergyGammaConversion();
            theLERayleigh           = new G4LowEnergyRayleigh();

            pmanager->AddDiscreteProcess(theLEPhotoElectric);
            pmanager->AddDiscreteProcess(theLECompton);
            pmanager->AddDiscreteProcess(theLERayleigh);
            pmanager->AddDiscreteProcess(theLEGammaConversion);

        }
        else if (particleName == "e-") {

            theLEIonisation = new G4LowEnergyIonisation();
            theLEBremsstrahlung = new G4LowEnergyBremsstrahlung();
            theeminusMultipleScattering = new G4MultipleScattering();

            pmanager->AddProcess(theeminusMultipleScattering,-1,1,1);
            pmanager->AddProcess(theLEIonisation,-1,2,2);
            pmanager->AddProcess(theLEBremsstrahlung,-1,-1,3);

        }
    }
}
```

Processes à la Penelope

- The whole physics content of the Penelope Monte Carlo code has been re-engineered into Geant4 (*except for multiple scattering*)
 - processes for photons: release 5.2, for electrons: release 6.0
- Physics models by F. Salvat et al.
- Power of the OO technology:
 - extending the software system is easy
 - all processes obey to the same abstract interfaces
 - using new implementations in application code is simple
- Profit of Geant4 advanced geometry modeling, interactive facilities *etc.*
 - same physics as original Penelope

Hadrons and ions

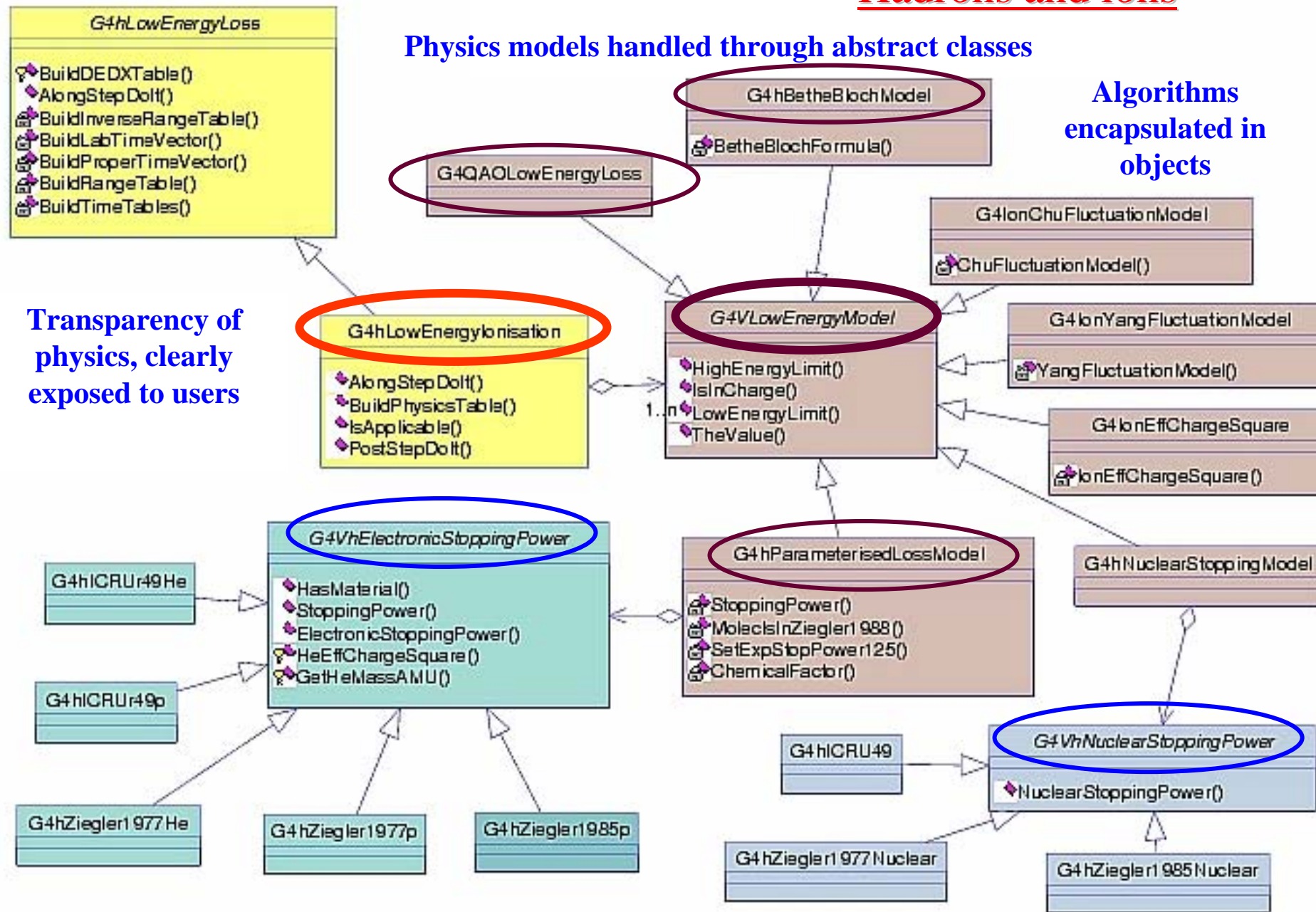
- Variety of models, depending on
 - energy range
 - particle type
 - charge
- Composition of models across the energy range, with different approaches
 - analytical
 - based on data reviews + parameterisations
- Specialised models for fluctuations
- Open to extension and evolution

Hadrons and ions

Physics models handled through abstract classes

Algorithms encapsulated in objects

Transparency of physics, clearly exposed to users



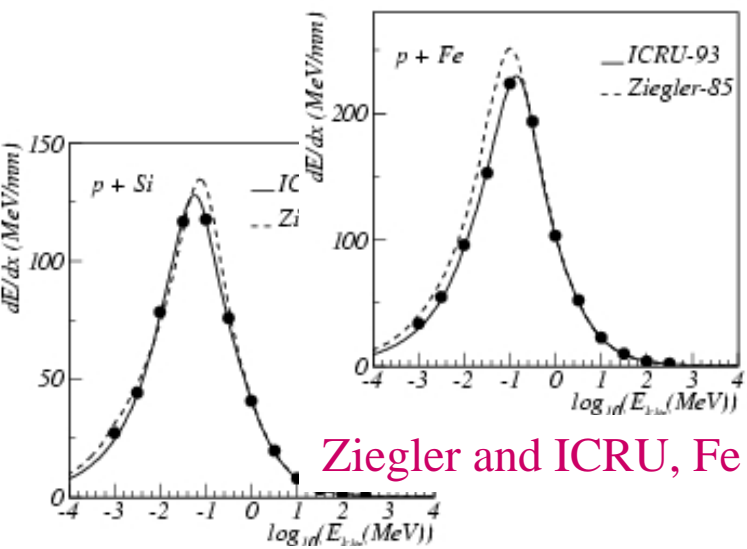
Interchangeable and transparent access to data sets

Positive charged hadrons

- Bethe-Bloch model of energy loss, $E > 2 \text{ MeV}$
- 5 parameterisation models, $E < 2 \text{ MeV}$
 - based on Ziegler and ICRU reviews
- 3 models of energy loss fluctuations

- Density correction for high energy
- Shell correction term for intermediate energy

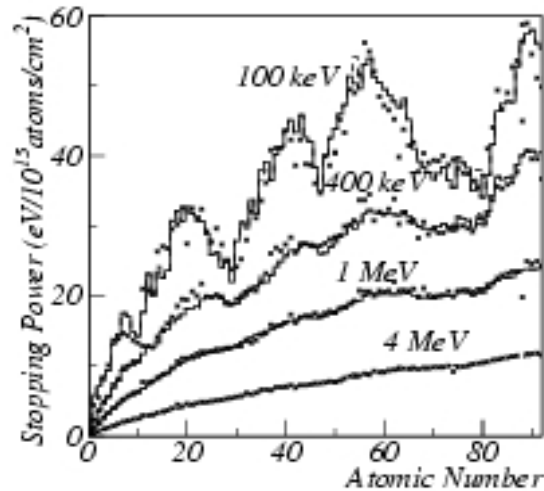
- Chemical effect for compounds
- Nuclear stopping power
- PIXE included



Ziegler and ICRU, Fe

Ziegler and ICRU, Si

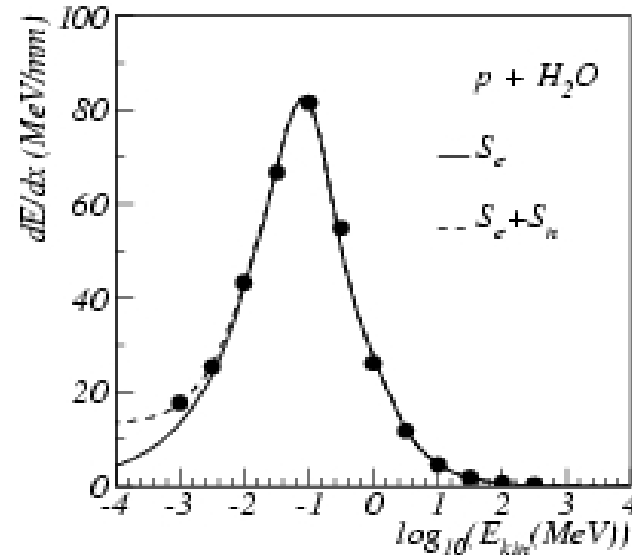
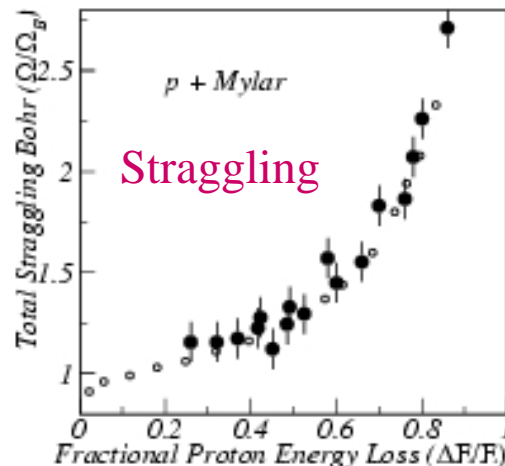
- Spin dependent term
- Barkas and Bloch terms



Stopping power

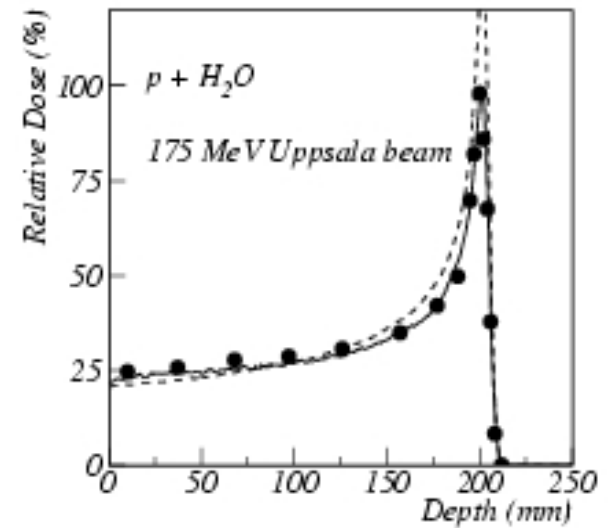
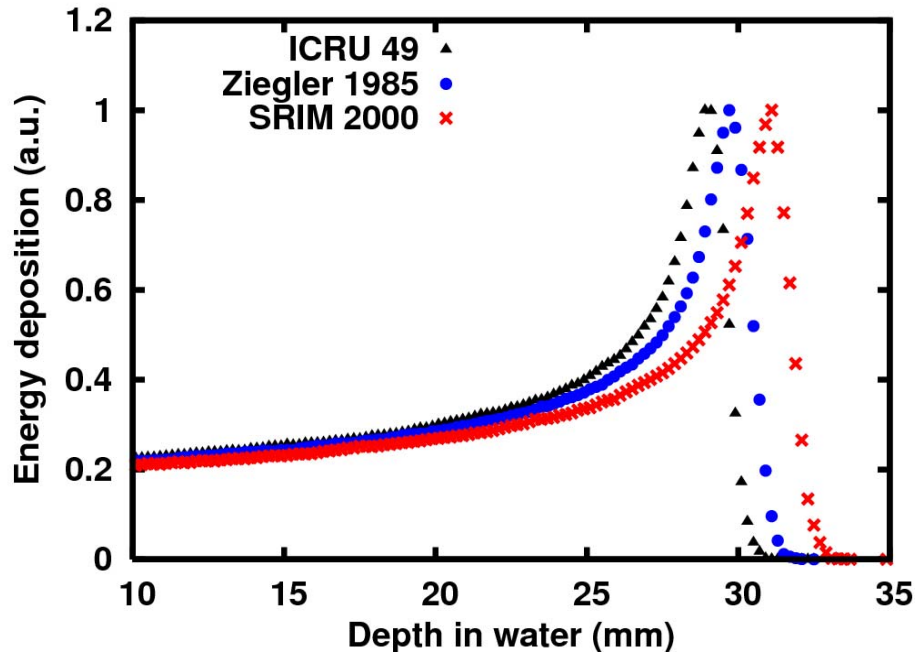
Z dependence for various energies

Ziegler and ICRU models

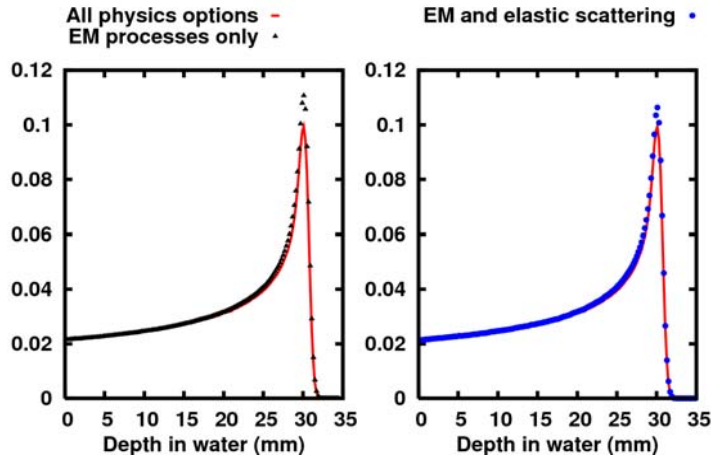


Nuclear stopping power

Further activity in progress



Bragg peak
(with hadronic interactions)



Positive charged ions

- Scaling: $S_{ion}(T) = Z_{ion}^2 S_p(T_p), T_p = T \frac{m_p}{m_{ion}}$
- $0.01 < \beta < 0.05$ parameterisations, Bragg peak
 - based on Ziegler and ICRU reviews
- $\beta < 0.01$: Free Electron Gas Model

- Effective charge model
- Nuclear stopping power

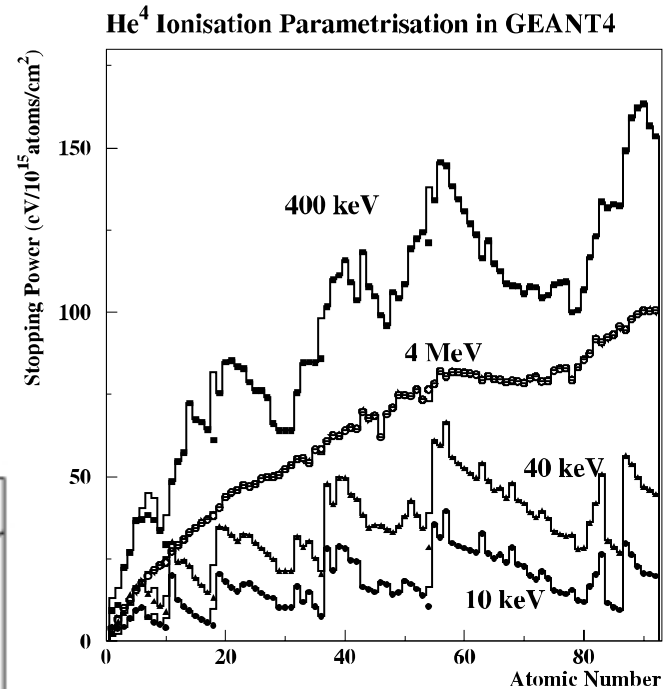
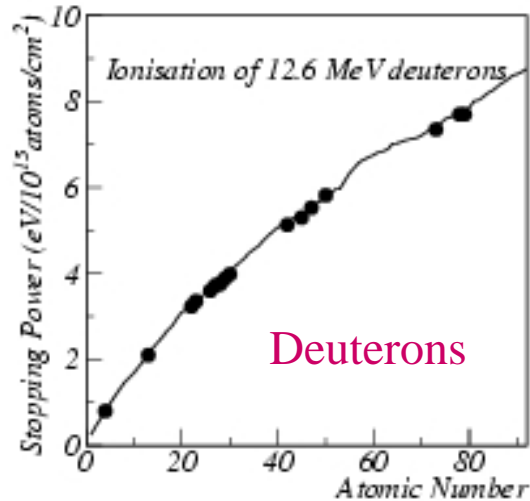
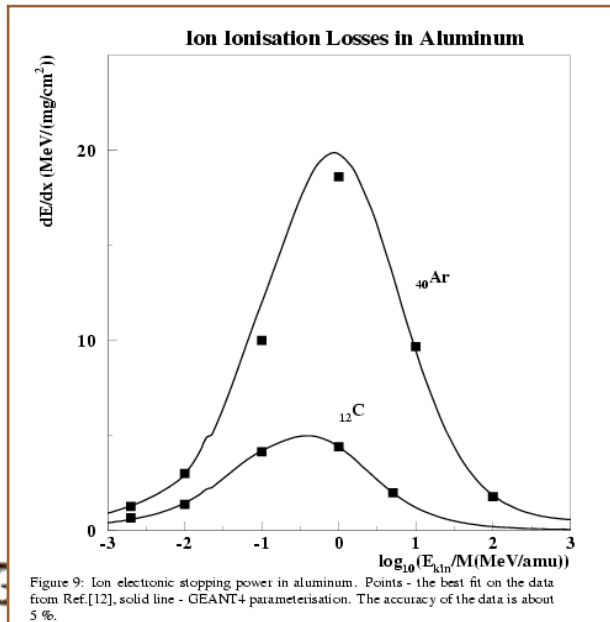


Figure 9: Ion electronic stopping power in aluminum. Points - the best fit on the data from Ref.[12], solid line - GEANT4 parameterisation. The accuracy of the data is about 5 %.

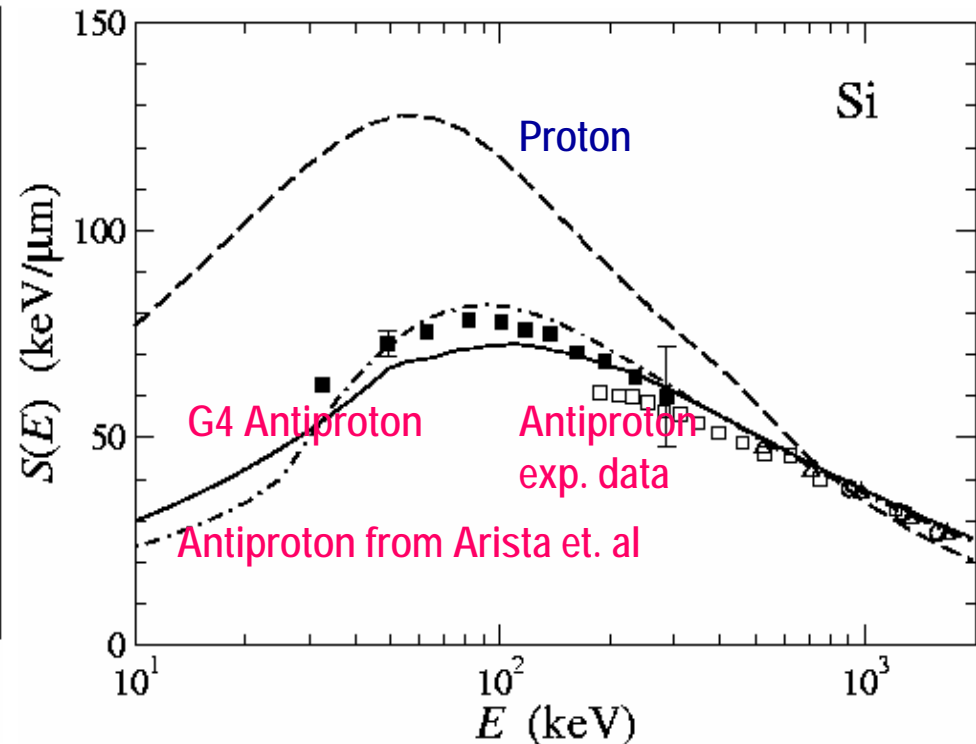
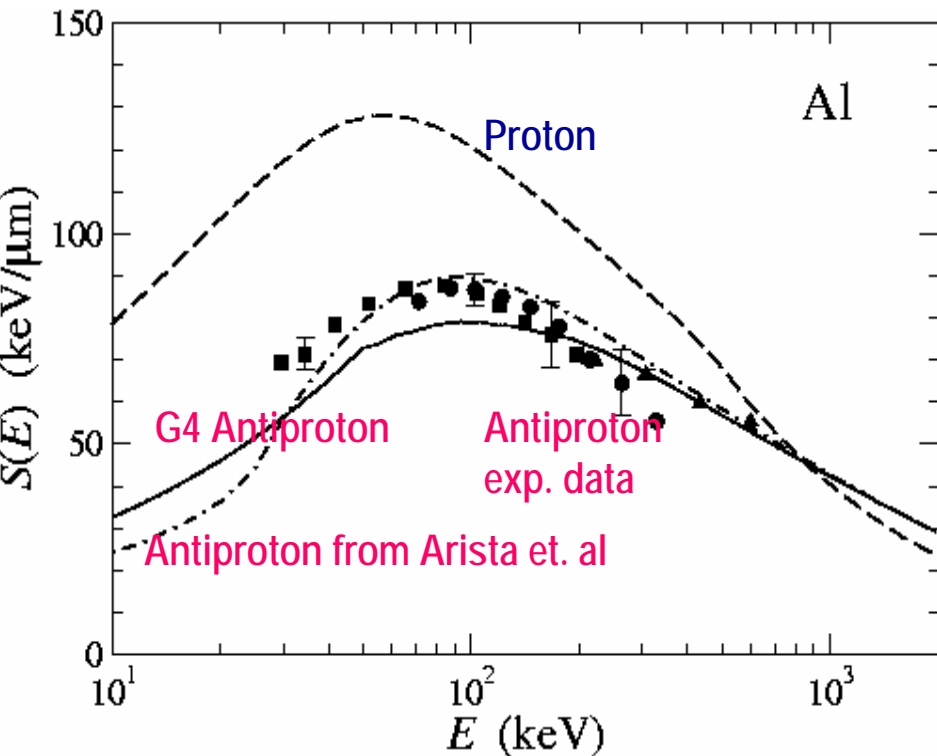
Models for antiprotons

- $\beta > 0.5$
- $0.01 < \beta < 0.5$
- $\beta < 0.01$

Bethe-Bloch formula

Quantum harmonic oscillator model

Free electron gas mode

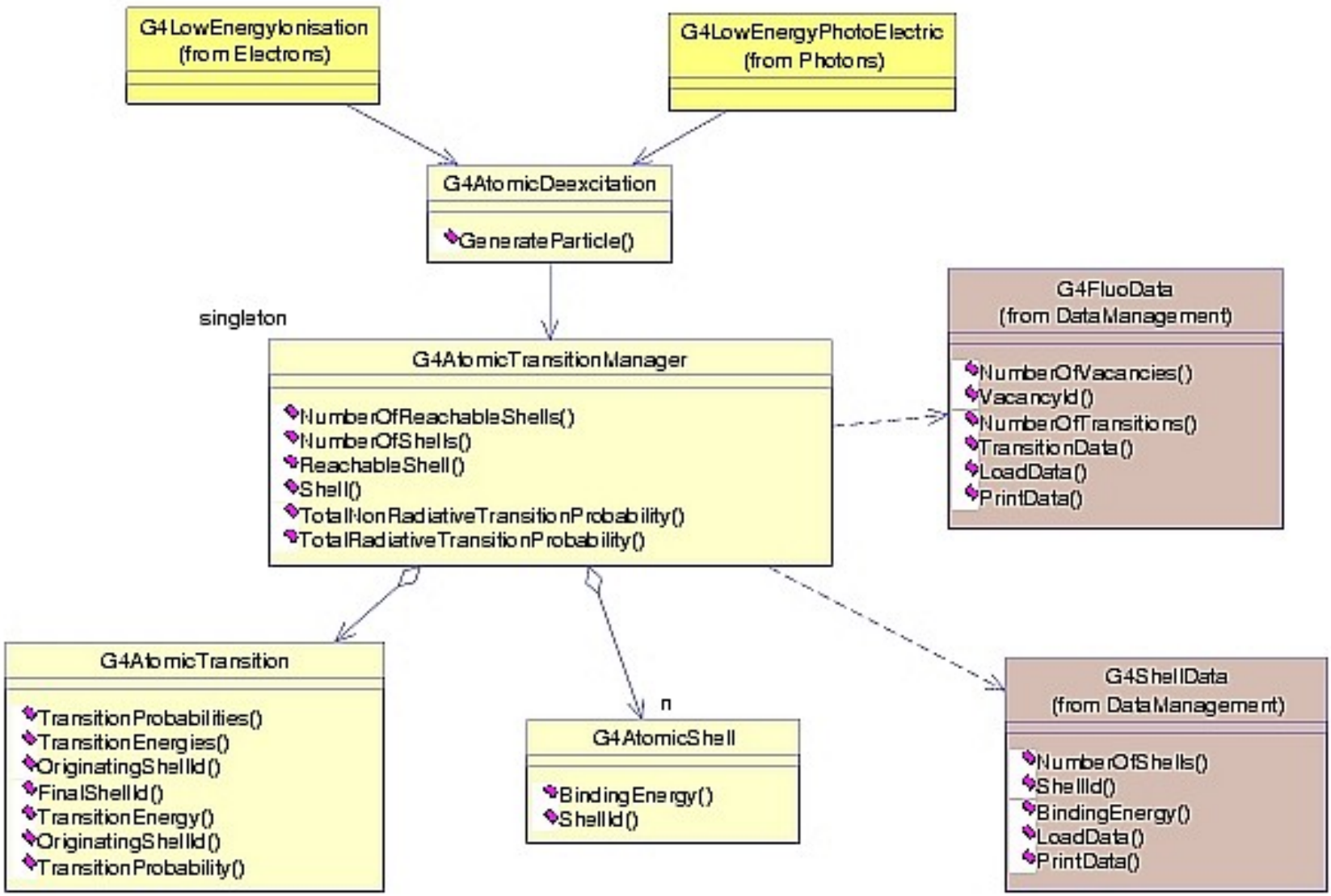


Options for G4hLowEnergyIonisation

G4hLowEnergyIonisation hIonisation = new G4hLowEnergyIonisation;
hIonisation->Set...();*

- SetHighEnergyForProtonParametrisation(G4double)
- SetLowEnergyForProtonParametrisation(G4double)
- SetHighEnergyForAntiProtonParametrisation(G4double)
- SetLowEnergyForAntiProtonParametrisation(G4double)
- **SetElectronicStoppingPowerModel**(const G4ParticleDefinition*,const G4String&)
- **SetNuclearStoppingPowerModel**(const G4String&)
- **SetNuclearStoppingOn**()
- **SetNuclearStoppingOff**()
- SetBarkasOn()
- SetBarkasOff()
- SetFluorescence(const G4bool)
- ActivateAugerElectronProduction(G4bool)
- SetCutForSecondaryPhotons(G4double)
- SetCutForSecondaryElectrons(G4double)

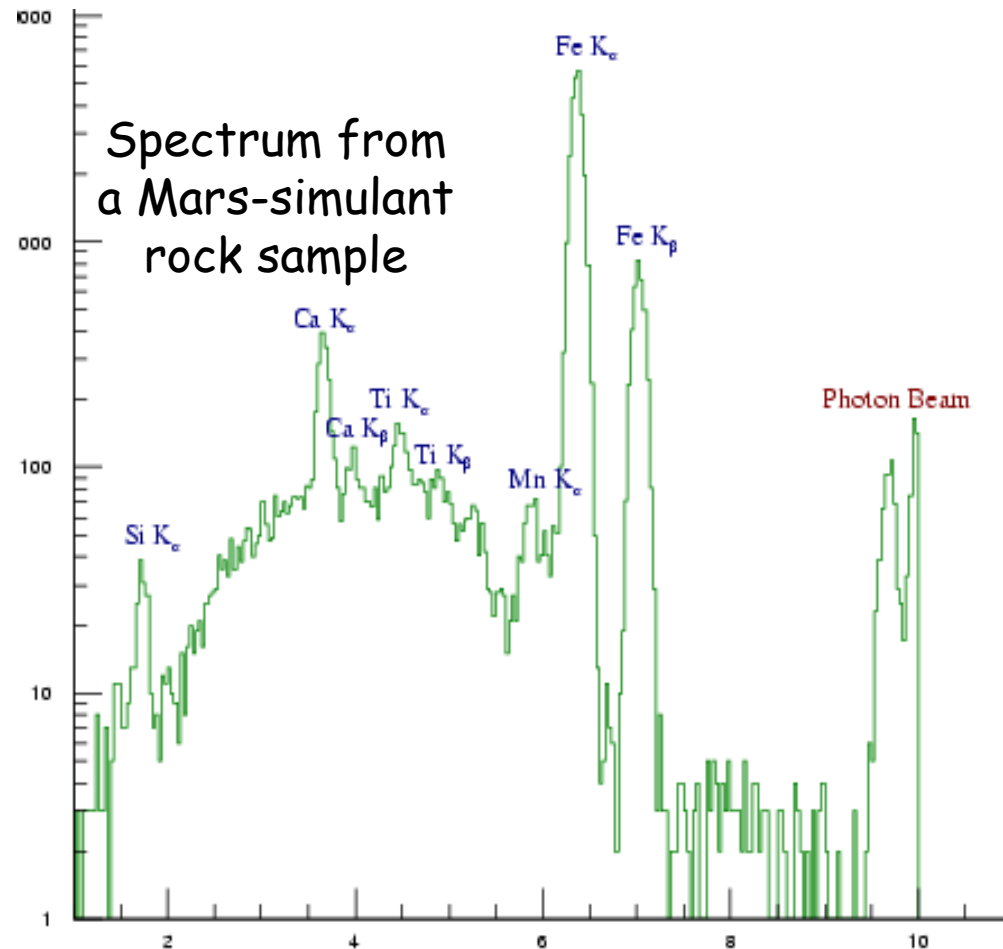
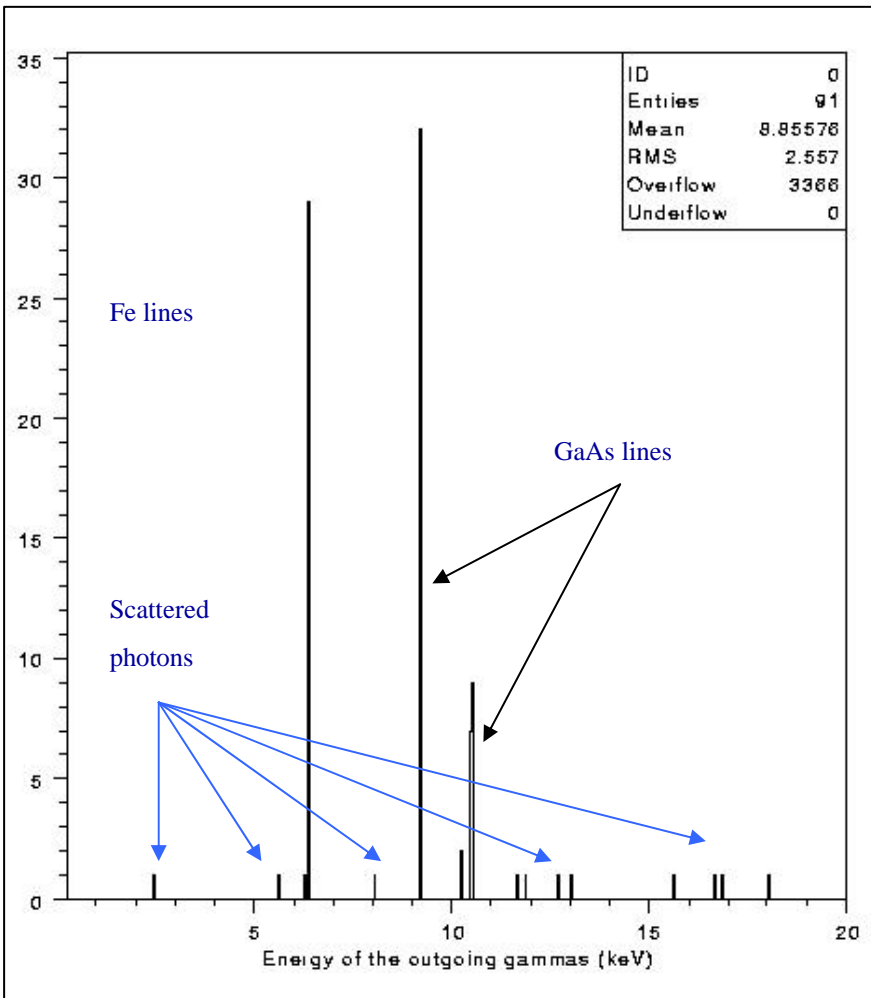
Atomic relaxation



Fluorescence

Microscopic validation:
against reference data

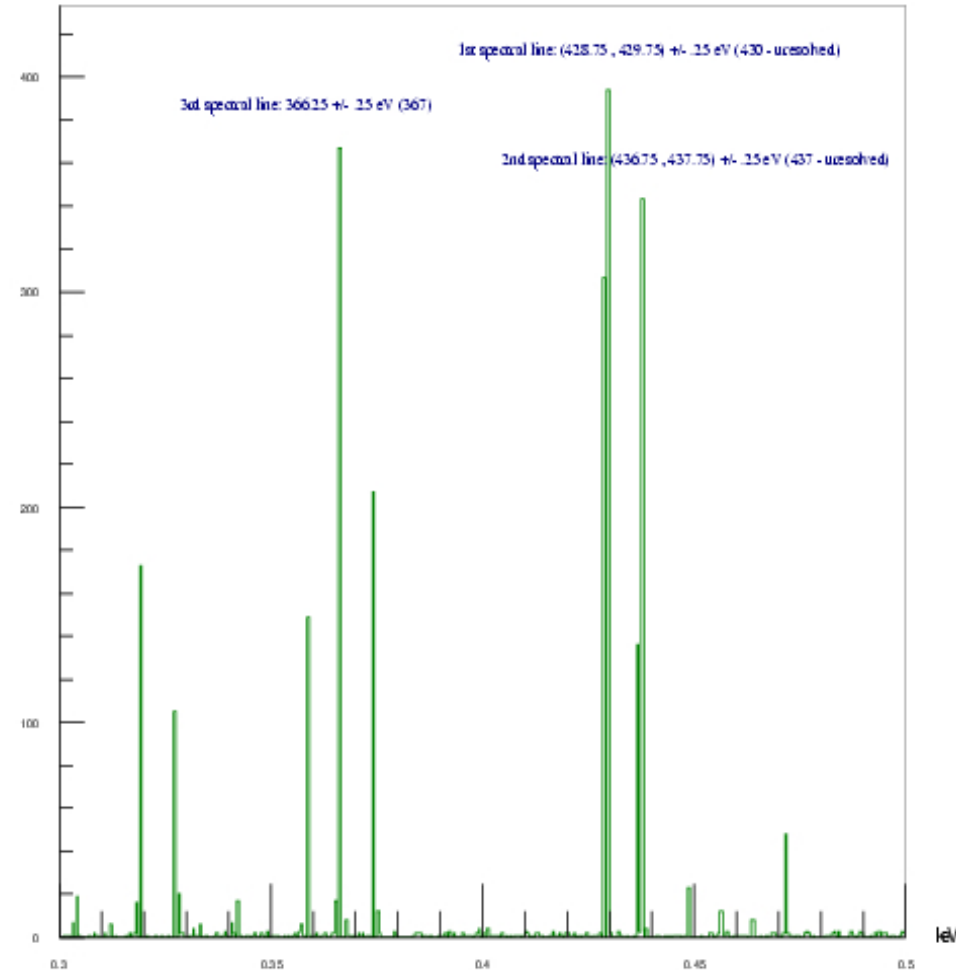
Experimental validation:
test beam data, in collaboration with
ESA Advanced Concepts & Science
Payload Division



Auger effect

Sn, 3 keV photon beam,
electron lines w.r.t. published
experimental results

Electron emission from Sn - 3 KeV photon Beam



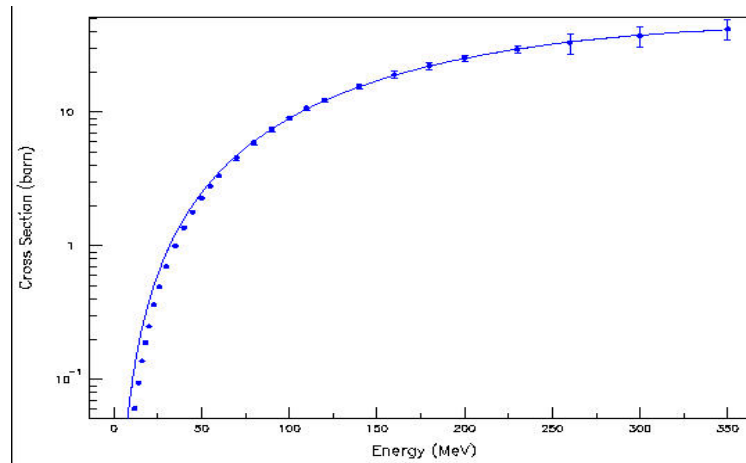
PIXE

- Model based on experimental data
 - Parameterisation of Paul & Sacher data library for ionisation cross sections
 - Uses the EADL-based package of atomic deexcitation for the generation of fluorescence and Auger secondary products
- Current implementation: protons, K-shell

Example of p ionisation cross section,
K shell

Geant4 parameterisation (solid line)

Experimental data



Further documentation on Geant4 Atomic Relaxation

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 54, NO. 3, JUNE 2007

585

Geant4 Atomic Relaxation

2007

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594

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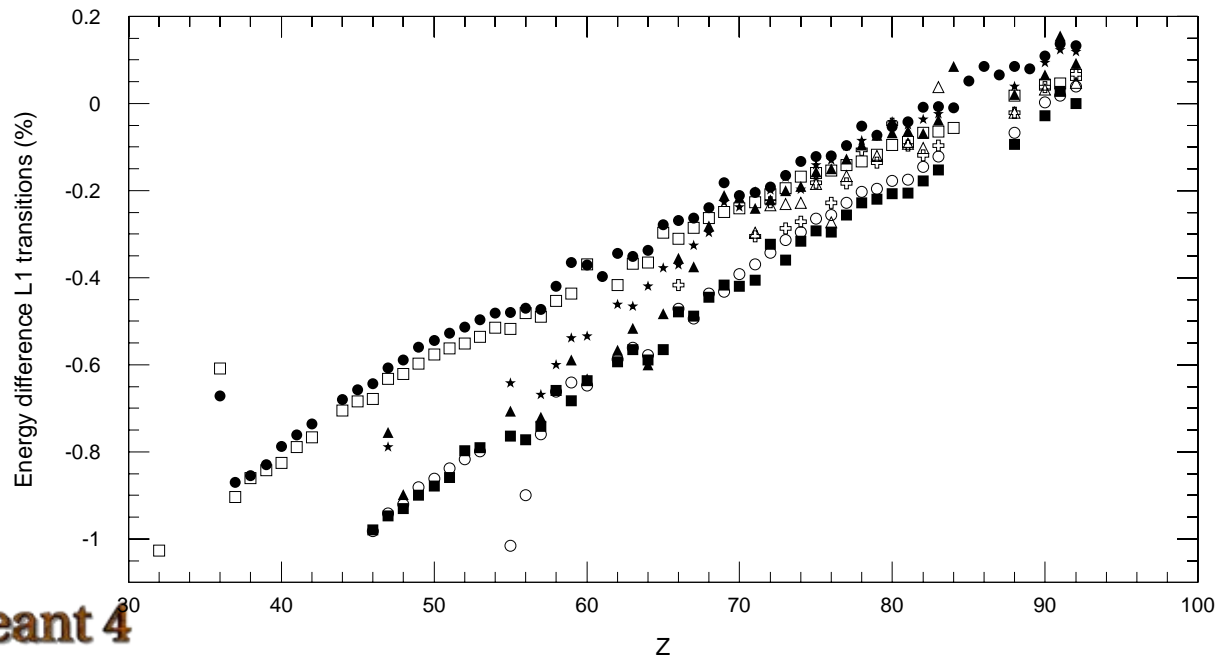
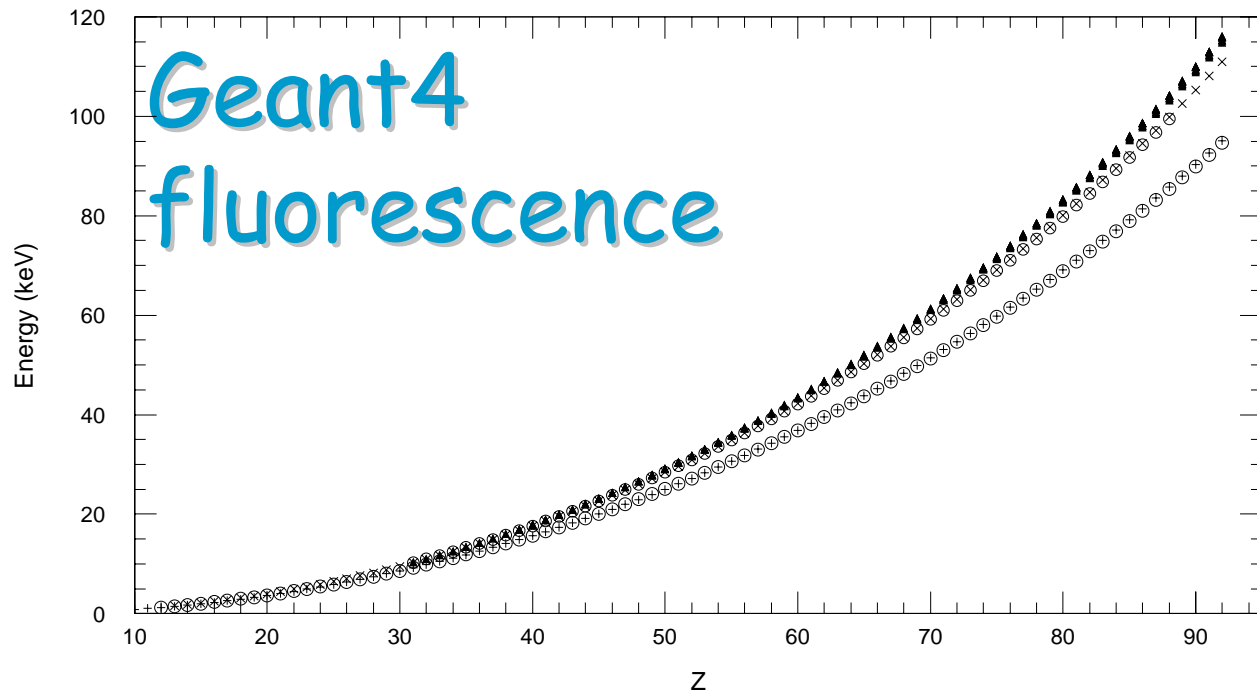
Validation of Geant4 Atomic Relaxation Against the NIST Physical Reference Data

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S. Guatelli, A. Mantero, B. Mascialino, M. G. Pia, and V. Zampichelli

More in preparation (M.G. Pia et al.)

2008

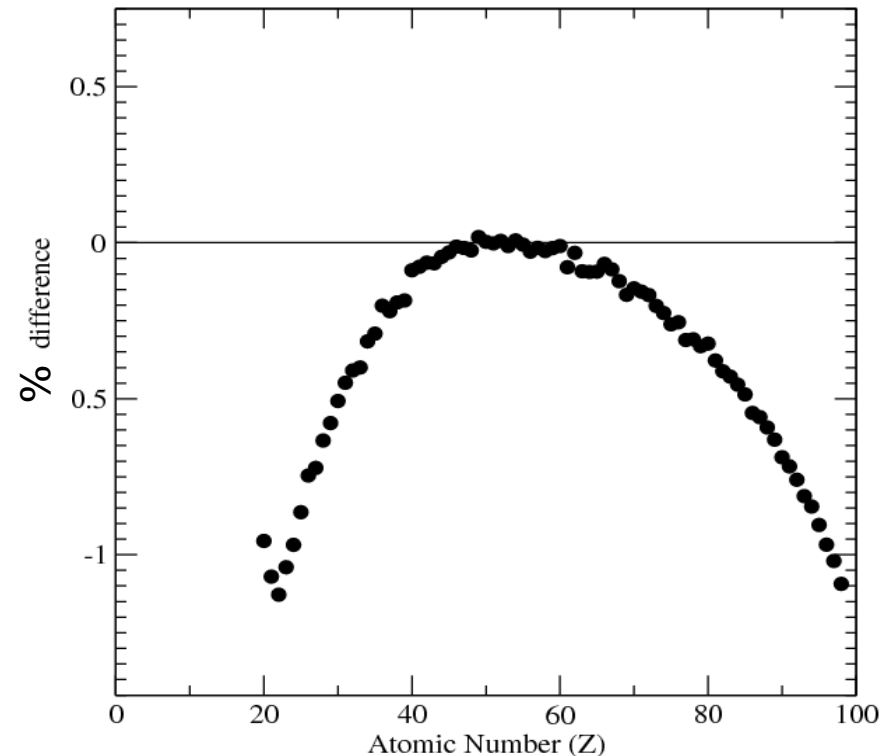
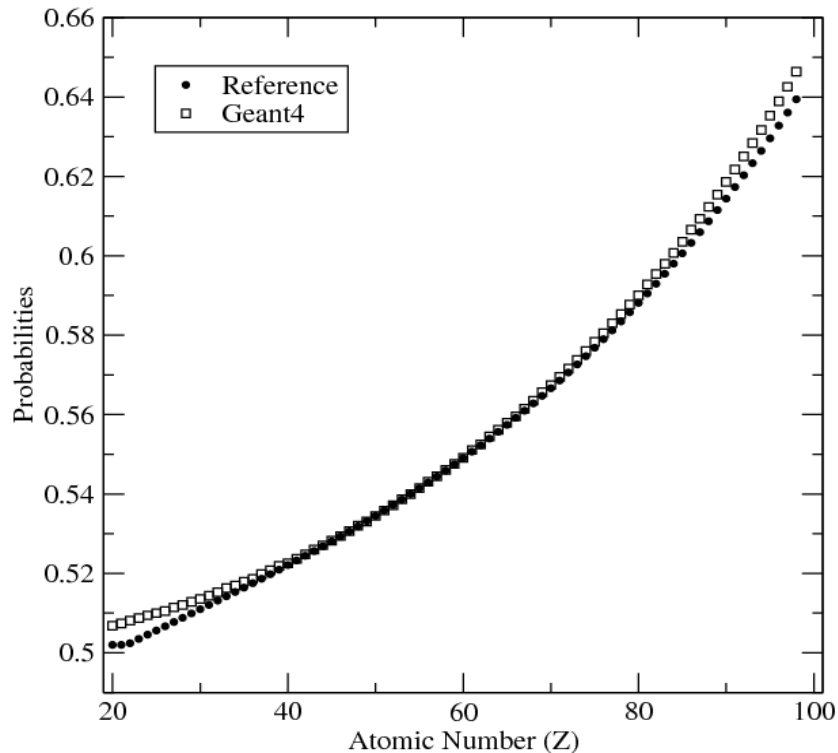


Goodness of fit test

Transition	p-value
KL ₂	1
KL ₃	1
KM ₂	1
KM ₄	1
KM ₅	1
KN ₂	1
KN ₃	1
L ₁ M ₂	1
L ₁ M ₃	1
L ₁ M ₄	1
L ₁ M ₅	1
L ₁ N ₂	1
L ₁ N ₃	1
L ₁ N ₄	0.997
L ₁ N ₅	1
L ₂ M ₁	1
L ₂ M ₃	1
L ₂ M ₄	1
L ₂ N ₂ or L ₂ N ₃	1
L ₂ N ₃	1
L ₂ N ₄	1
L ₂ N ₆	1
L ₃ M ₁	1
L ₃ M ₂	1
L ₃ M ₃	1
L ₃ M ₄	1
L ₃ M ₅	1
L ₃ N ₂ or L ₃ N ₃	1
L ₃ N ₂	1
L ₃ N ₃	1
L ₃ N ₄	1
L ₃ N ₅	1

Goodness-of-fit test	p-value
Anderson-Darling	1
Cramer-von Mises	1
Kolmogorov-Smirnov	1
Kuiper	1
Watson	1

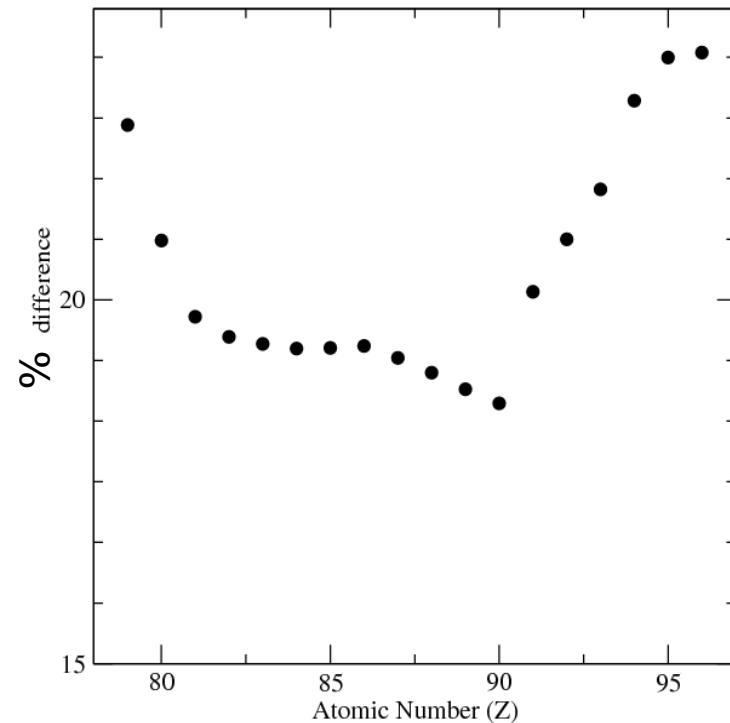
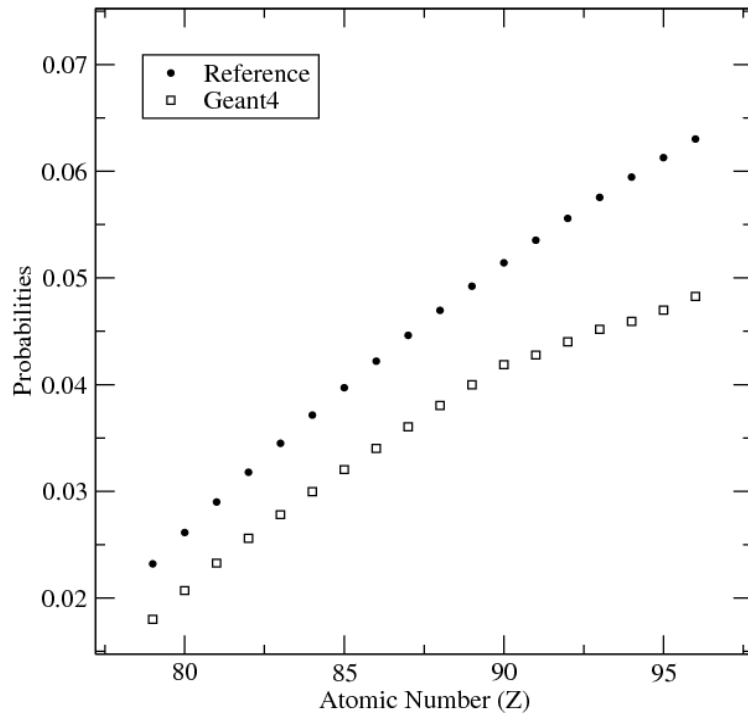
Fluorescence transition probabilities



Experimental reference:

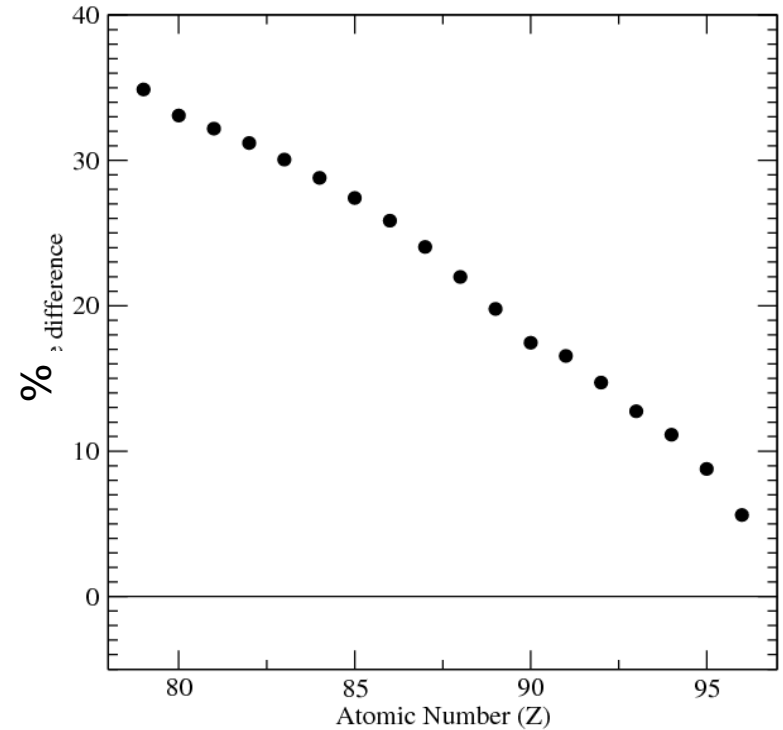
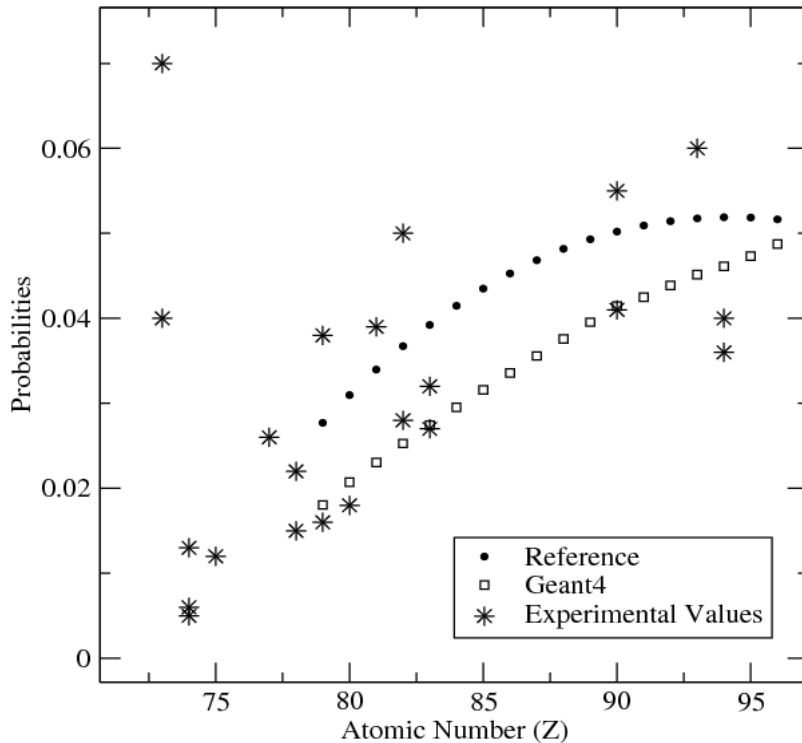
W.T. Elam, B.D. Ravel, J.R. Sieber, *A new atomic database for X-ray spectroscopic calculations*, Radiat. Phys. Chem. 63 (2002) 121–128

Bad but harmless...



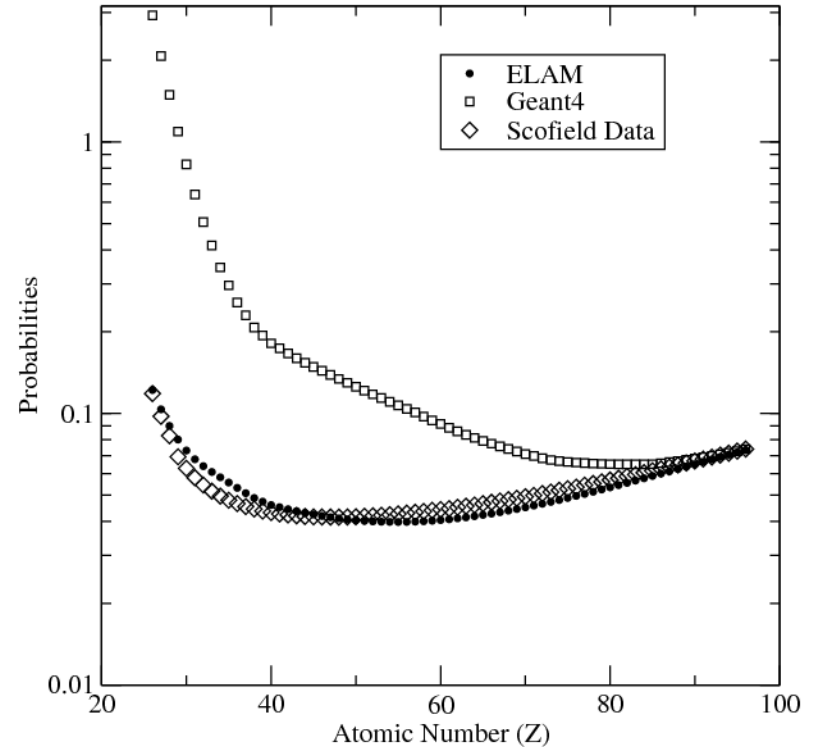
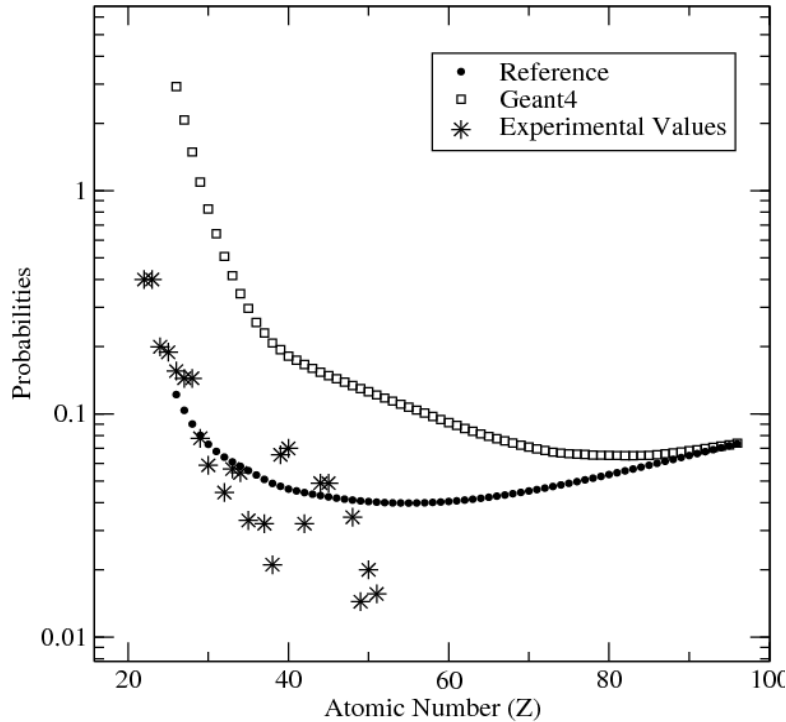
25% absolute error \Rightarrow 0.04% error in an experimental use case

Hard to say...



Controversial experimental data

Hidden for 17 years...



The error is in EADL!

Easy to put a remedy in Geant4
Replace EADL data with Scofield data directly
in Geant4 Low Energy data file G4EMLOW

In progress

- Extensions down to the eV scale
 - In water (for radiobiology studies)
 - Other materials (gas, solids)
- Difficult domain
 - Models must be specialised by material
 - Cross sections, final state generation, angular distributions

1st development cycle: Very-low energy extensions

Physics of interactions in water down to the eV scale

- **Complex domain**

- **Physics:** collaboration with theorists
- **Technology:** innovative design technique introduced in Geant4 (1st time in Monte Carlo)

- **Experimental complexity as well**

- Scarce experimental data
- Collaboration with experimentalists for model validation
- Geant4 physics validation at low energies is difficult!

Geant4-DNA physics processes

Specialised processes for low energy interactions with water

- **Models in liquid water**
 - More realistic than water vapour
 - Theoretically more challenging
 - Hardly any experimental data
 - New measurements needed
- **Status**
 - 1st β -release Geant4 8.1 2006
 - Full release December 2007
 - Further extensions in progress
- **Current focus**
 - Experimental comparisons

Toolkit: offer a wide choice among available alternative models for each process

Particle	Processes
e^-	Elastic scattering Excitation Ionisation
p	Charge decrease Excitation Ionisation
H	Charge increase Ionisation
He $^{++}$	Charge decrease Excitation Ionisation
He $^+$	Charge decrease Charge increase Excitation Ionisation
He	Charge increase Excitation Ionisation

(Current) Physics Models

	e	p	H	α He ⁺ He
Elastic	> 7.5 eV Screened Rutherford + empirical <i>Brenner-Zaider</i>			
Excitation	7.5 eV – 10 keV A ₁ B ₁ , B ₁ A ₁ , Ryd A+B, Ryd C+D, diffuse bands	10 eV – 500 keV <i>Dingfelder</i> 500 keV – 10 MeV <i>Emfietzoglou</i>	100 eV – 10 MeV <i>Dingfelder</i>	Effective charge scaling from same models as for proton <i>Dingfelder</i>
Charge Change		100 eV – 10 MeV <i>Dingfelder</i>	100 eV – 10 MeV <i>Dingfelder</i>	
Ionisation	7 eV – 10 keV <i>Emfietzoglou</i> 1b ₁ , 3a ₁ , 1b ₂ , 2a ₁ + 1a ₁	100 eV – 500 keV <i>Rudd</i> 500 keV – 10 MeV <i>Dingfelder (Born)</i>	100 eV – 10 MeV <i>Dingfelder</i>	

No emotional attachment to any of the models

Toolkit: offer a wide choice among many available alternatives

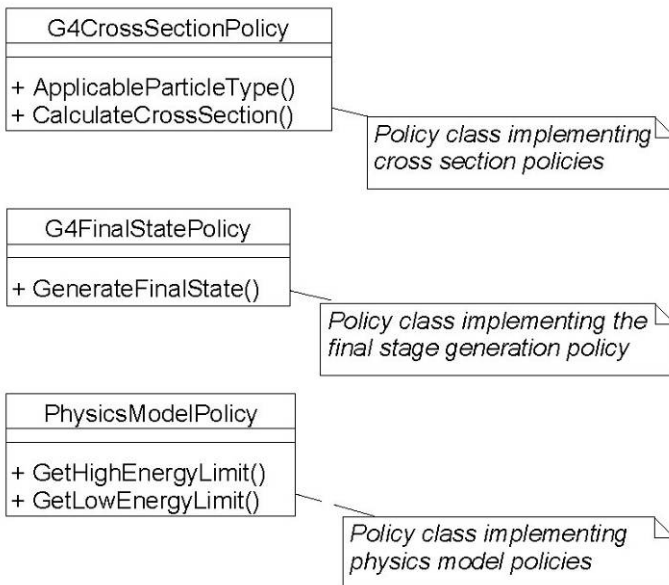
What is behind...

Policy-based class design

- A policy defines a class or class template interface
- Policy host classes are parameterised classes
 - classes that use other classes as a parameter
- Advantage w.r.t. a conventional strategy pattern
 - Policies are not required to inherit from a base class
 - The code is bound at compilation time
 - No need of virtual methods, resulting in faster execution

New
technique

1st time
introduced
in Monte
Carlo



Weak dependency of the policy and the policy based class on the policy interface

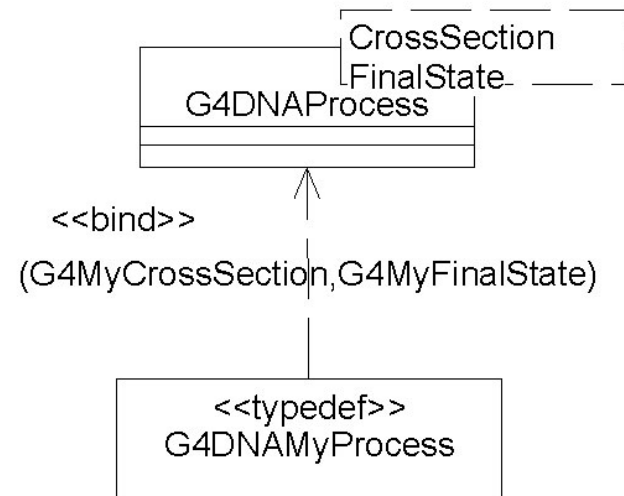
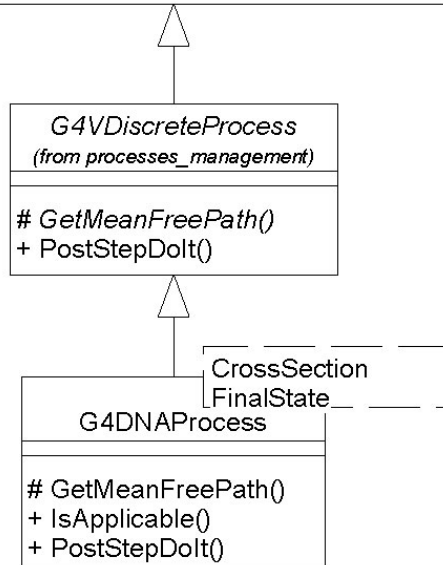
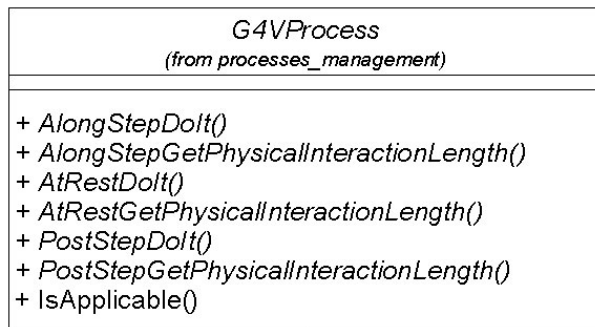
Highly customizable design
Open to extension

Geant4-DNA physics process

Handled transparently
by Geant4 kernel

Deprived of any intrinsic
physics functionality

Configured by
template specialization
to acquire physics properties



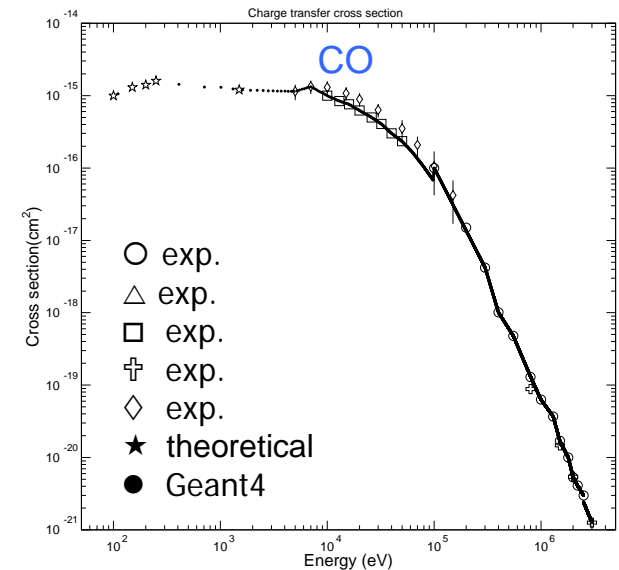
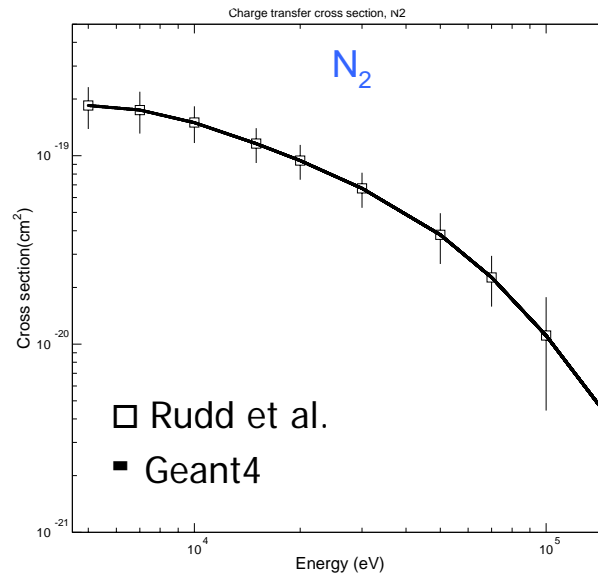
From cells to plasma...

Proton **charge transfer** processes for 12 materials

(He, water vapour, N₂, CO, CO₂, hydrocarbons)

Relevant to astrophysics and fusion reactor design

Development
metrics
in Easter egg



Design investment
pays back!

- M.E. Rudd et al., *Phys. Rev. A* 28, 3244-3257, 1983
L.H. Toburen et al., *Phys. Rev.* 171, 114 - 122, 1968
S.L. Varghese et al., *Phys. Rev. A* 31, 2202-2209, 1985
M.B. Shah and H.B. Gilbody, *J. Phys. B* 23, 1491-1499, 1990
R.S. Gao et al., *Phys. Rev. A* 41, 5929-5933, 1990
M. Kimura et al., *Phys. Rev. A* 61, 032708, 2000

How to use policy-based processes

// Definition

```
typedef G4DNAProcess<G4CrossSectionElasticScreenedRutherford,G4FinalStateElasticScreenedRutherford> ElasticScreenedRutherford;  
typedef G4DNAProcess<G4CrossSectionElasticScreenedRutherford,G4FinalStateElasticBrennerZaider> ElasticBrennerZaider;  
typedef G4DNAProcess<G4CrossSectionExcitationEmfietzoglou,G4FinalStateExcitationEmfietzoglou> ExcitationEmfietzoglou;  
typedef G4DNAProcess<G4CrossSectionExcitationBorn,G4FinalStateExcitationBorn> ExcitationBorn;  
typedef G4DNAProcess<G4CrossSectionIonisationBorn,G4FinalStateIonisationBorn> IonisationBorn;  
typedef G4DNAProcess<G4CrossSectionIonisationRudd,G4FinalStateIonisationRudd> IonisationRudd;  
typedef G4DNAProcess<G4CrossSectionExcitationMillerGreen,G4FinalStateExcitationMillerGreen> ExcitationMillerGreen;  
typedef G4DNAProcess<G4CrossSectionChargeDecrease,G4FinalStateChargeDecrease> ChargeDecrease;  
typedef G4DNAProcess<G4CrossSectionChargeIncrease,G4FinalStateChargeIncrease> ChargeIncrease;
```

// Registration

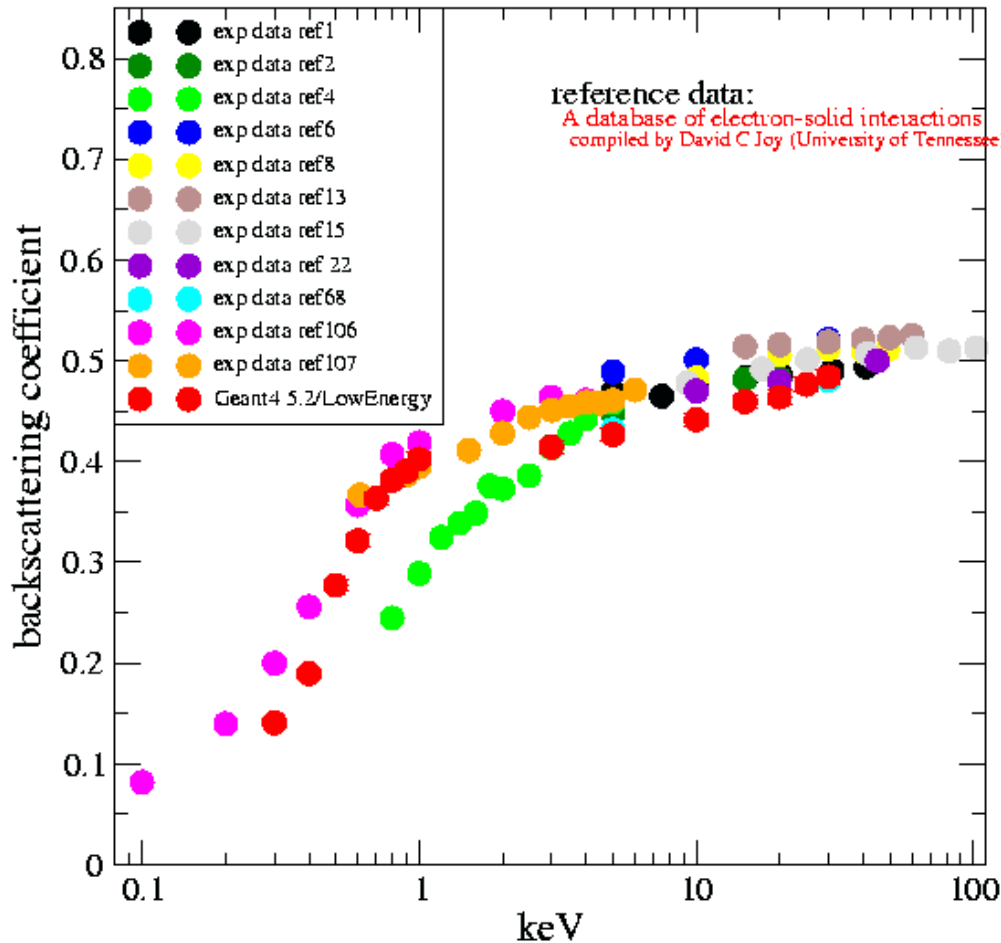
```
...  
if (particleName == "e-")  
{  
    processManager->AddDiscreteProcess(new ExcitationEmfietzoglou);  
    processManager->AddDiscreteProcess(new ElasticScreenedRutherford);  
    processManager->AddDiscreteProcess(new ElasticBrennerZaider);  
    processManager->AddDiscreteProcess(new IonisationBorn);  
}
```


Physics models and their validation

- S. Chauvie et al.,
Geant4 physics processes for microdosimetry simulation: design foundation and implementation of the first set of models
IEEE Trans. Nucl. Sci., vol. 54, no. 6, Dec. 2007
- S. Chauvie, P. Nieminen, M. G. Pia
Geant4 model for the stopping power of low energy negatively charged hadrons
IEEE Trans. Nucl. Sci., vol. 54, no. 3, pp. 578-584, Jun. 2007
- S. Guatelli, A. Mantero, B. Mascialino, P. Nieminen, M. G. Pia
Geant4 Atomic Relaxation
IEEE Trans. Nucl. Sci., vol. 54, no. 3, pp. 585-593, Jun. 2007
- S. Guatelli, A. Mantero, B. Mascialino, P. Nieminen, M. G. Pia, V. Zampichelli
Validation of Geant4 Atomic Relaxation against the NIST Physical Reference Data
IEEE Trans. Nucl. Sci., vol. 54, no. 3, Jun. 2007, pp. 594-603
- K. Amako et al.,
Comparison of Geant4 electromagnetic physics models against the NIST reference data
IEEE Trans. Nucl. Sci., vol. 52, no. 4, pp. 910-918, Aug. 2005

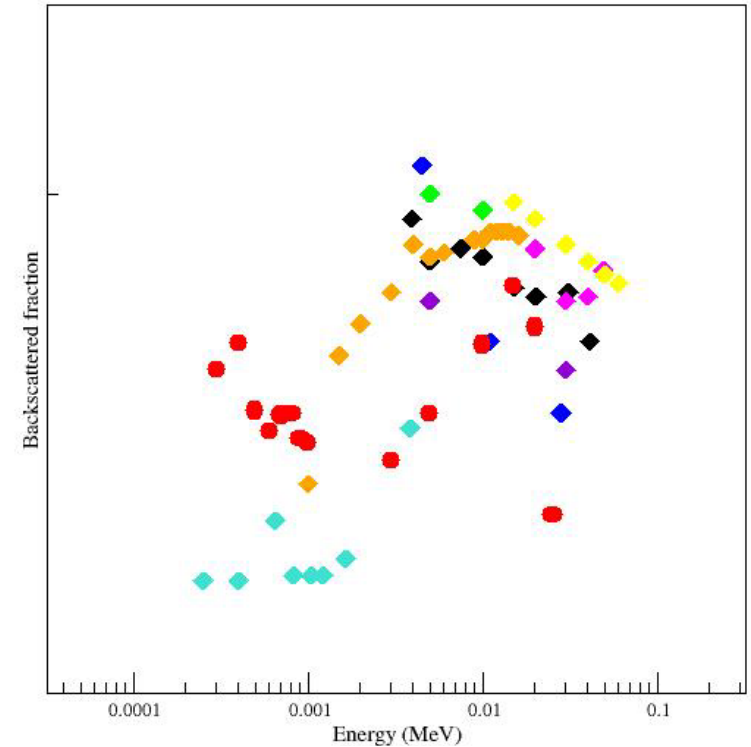
The problem of validation: finding reliable data

backscattering for e-
e- energy range: 0.1 keV -> 102. keV



Backscattering low energies - Au

Electrons - Backscattering - Iron
(Geant4-05-02 LowE)



Note: Geant4 validation is not always easy

experimental data often exhibit large differences!

To learn more

- Geant4 Physics Reference Manual
- Application Developer Guide
- <http://www.ge.infn.it/geant4/lowE>

Summary

- OO technology provides the mechanism for a rich set of electromagnetic physics models in Geant4
 - further extensions and refinements are possible, without affecting Geant4 kernel or user code
- Two main approaches in Geant4:
 - Standard package
 - Low Energy package

each one offering a variety of models for specialised applications
- Extensive validation activity and results
- More on Physics Reference Manual and web site