Overview and new developments on Geant4 electromagnetic physics

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Outline

- Standard EM package
- Overview on major developments in 2003/2004
- Design iteration in the Standard package
- EM PhysicsLists
- Acceptance suite
- Conclusions and plans

Standard EM package

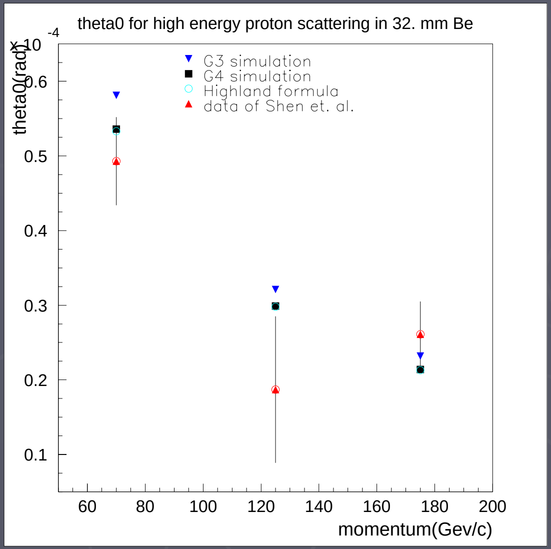
- Naturally continue Geant3 EM physics
- Include a complete set of models for simulation of electromagnetic processes in the energy range from 1 keV to 10 PeV
- Includes optical photons production and transport
- Focus on HEP experiments, well applicable for instrumentation, space, and medicine studies

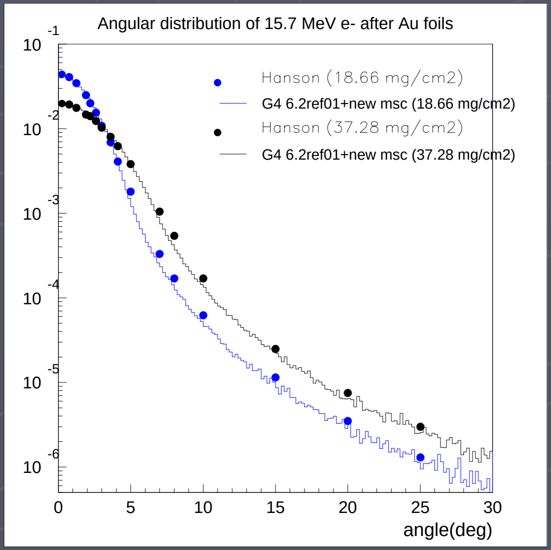
Major developments in 2003/2004

- Physics model improvements:
  - Evolutions of multiple scattering model
  - Hadron ionization was updated
  - New ion ionization & multiple scattering
  - Muon processes were updated
  - Updated cross section for Compton effect
  - Revised PAI models
  - New high energy processes
- Evolution in optical photons simulation
- Cut per region from G4 5.1

Multiple scattering model of L.Urban

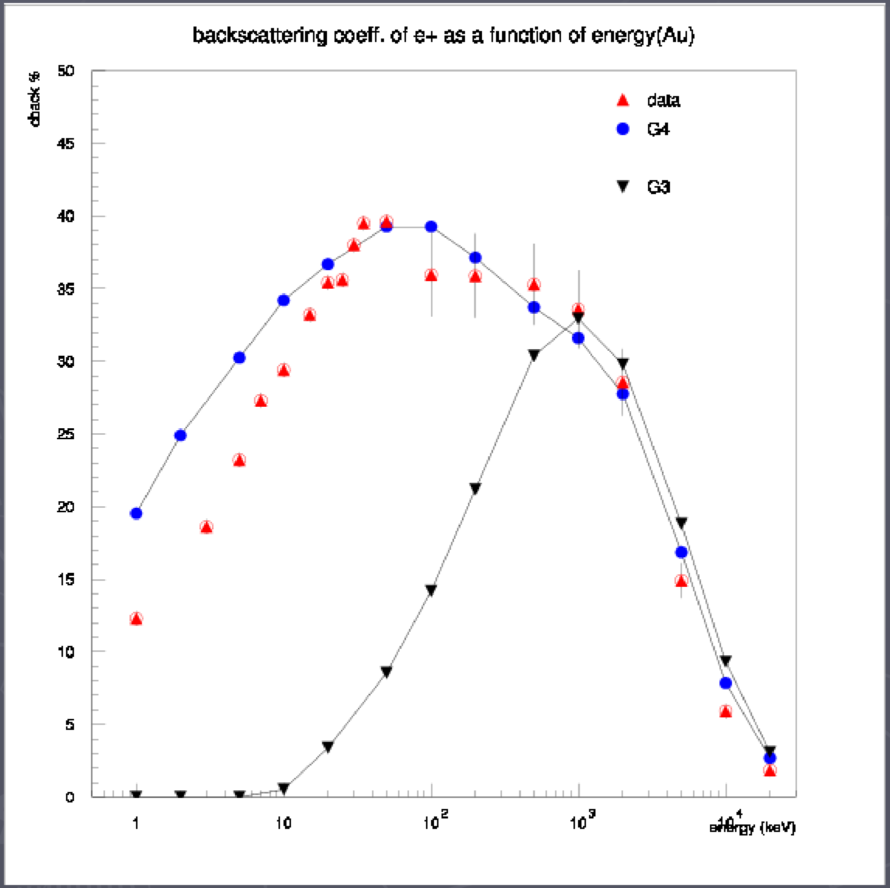
- Based on Lewis theory PR 78 (1950) 526
- Allows as small and large steps of particles
- Takes into account scattering on electrons and on nuclei
- Provides simulation of physical length of track
- Provides simulation of transverse displacement



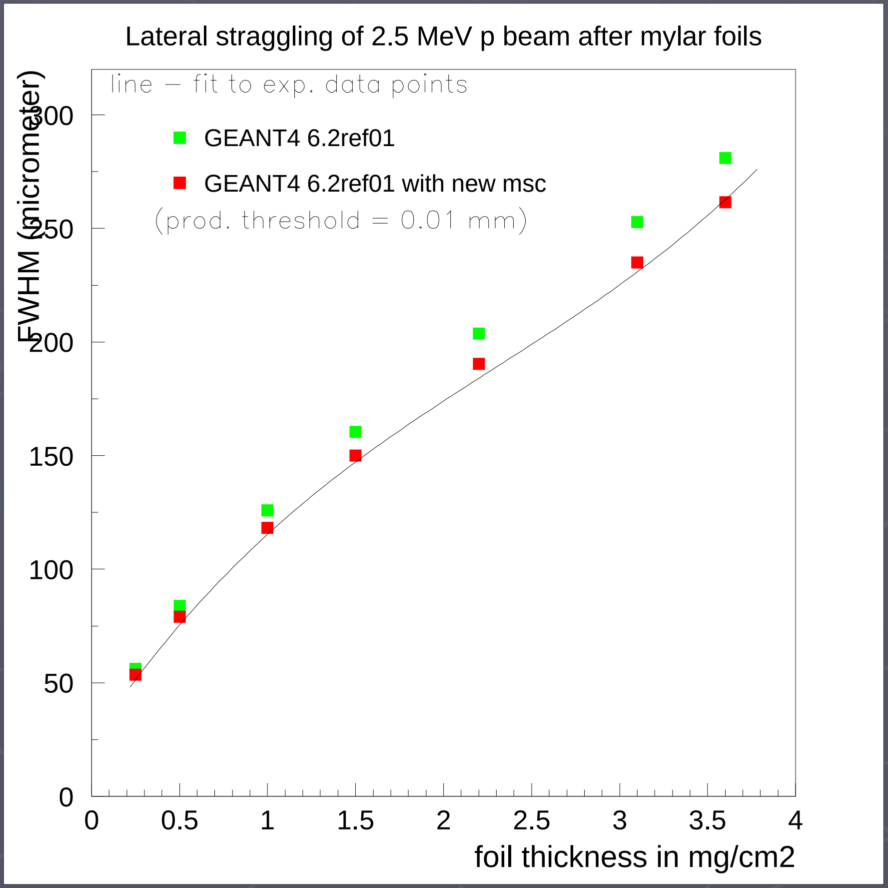


Multiple scattering model of L.Urban

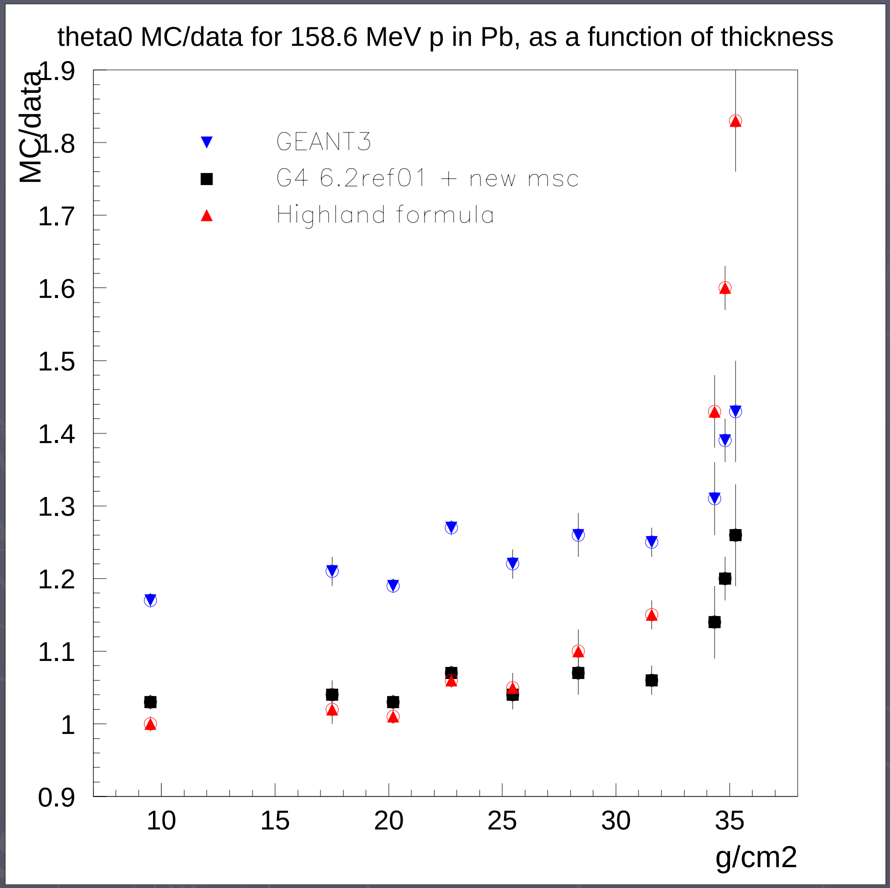
Back scattering

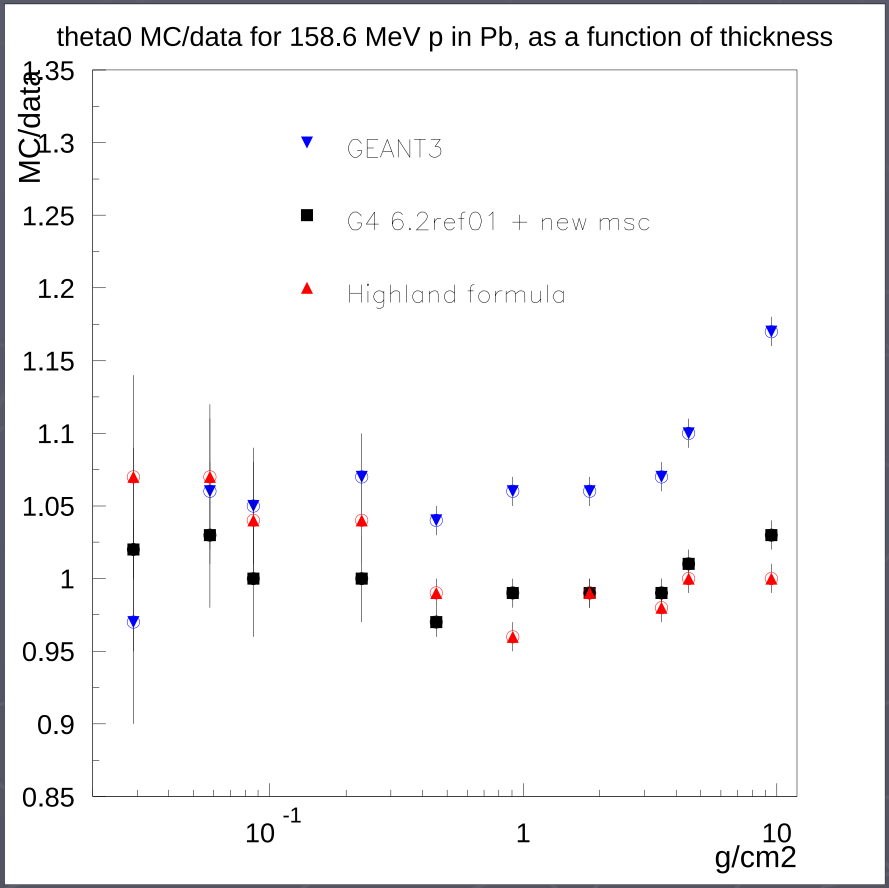


Will be in G4 7.0



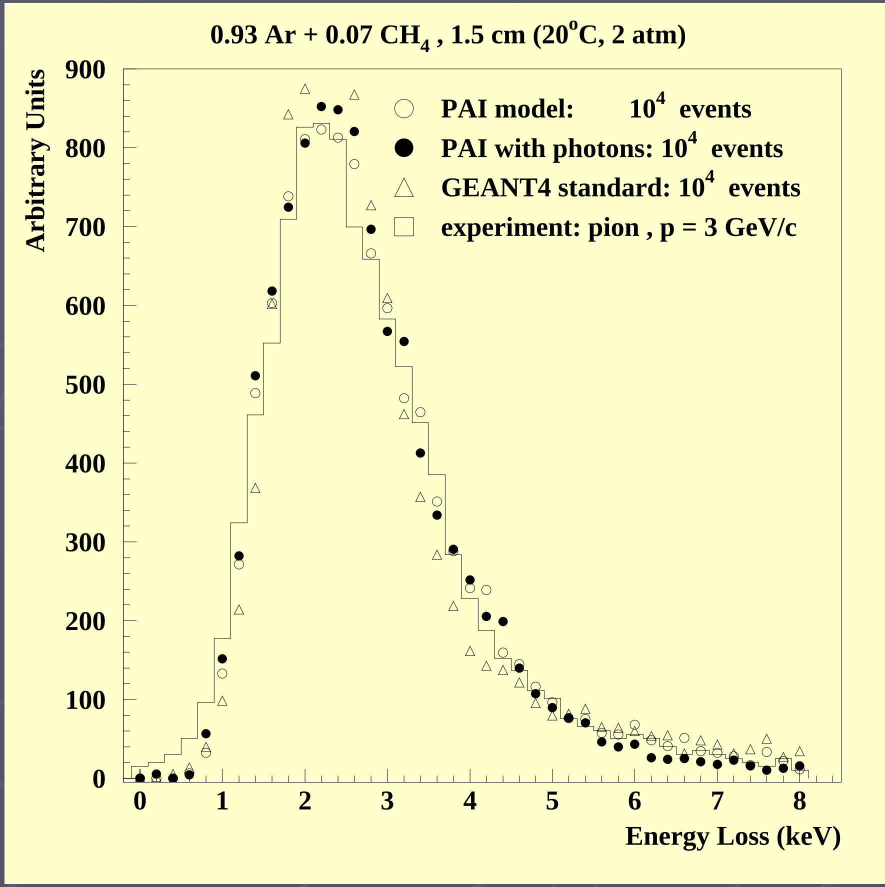
Geant4/Geant3/Data comparisons





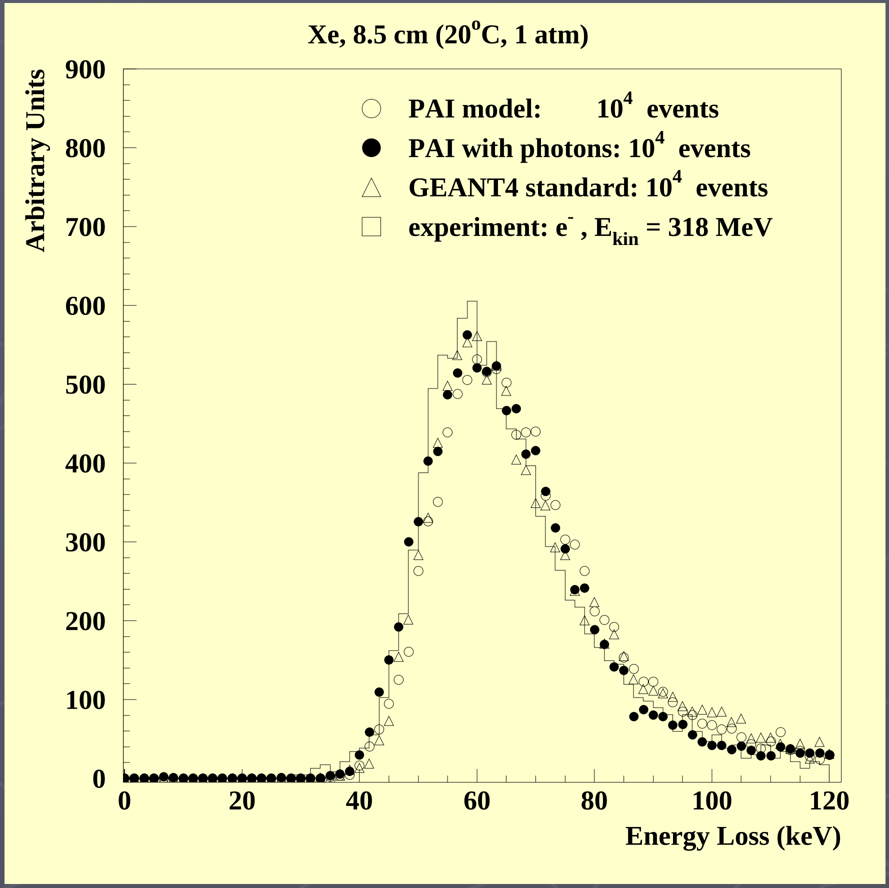
PAI model evolution

- 2 models in G4 6.2:
  - G4PAIModel
  - G4PAIPhotonModel
- Ionization in very thin absorbers
- Based on Sandia tables of photo-absorption
- Models can be defined for G4Region (TestEm8)



PAI model evolution

- Any cut can be used
- Sampling of single clusters in gaseous detectors
- TRD detectors simulation
- NIM A453 (2000) 597
- PL B525 (2002) 225
- Space and medical applications



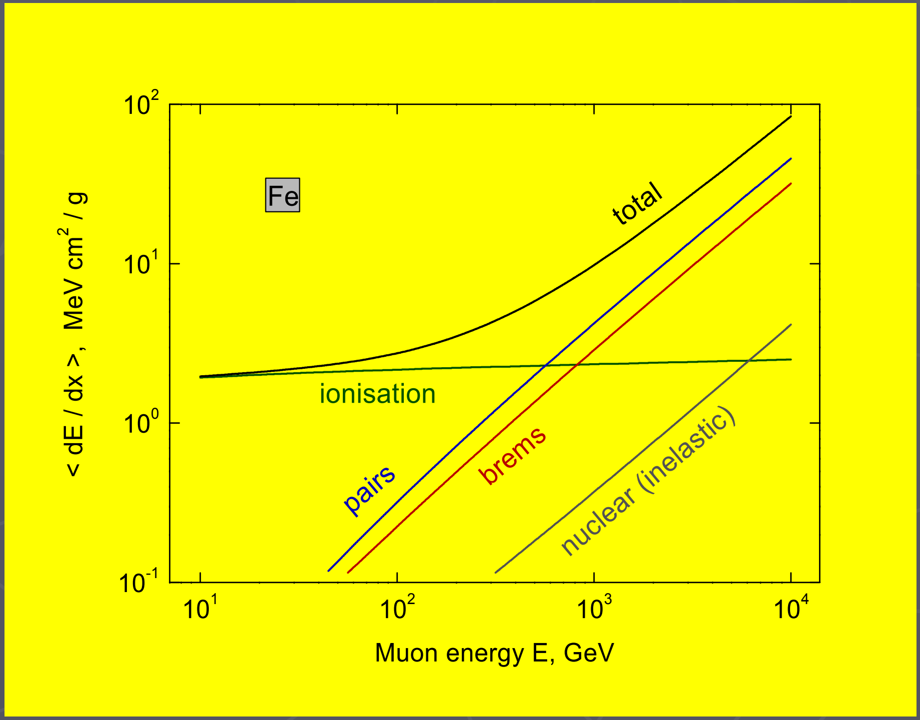
Muon energy loss

- Continuous energy loss in Geant4:

$$\frac{dE}{dx} = n\sum_i \left(\int_0^{Tcut} T \frac{d\sigma}{dT} dT \right)$$

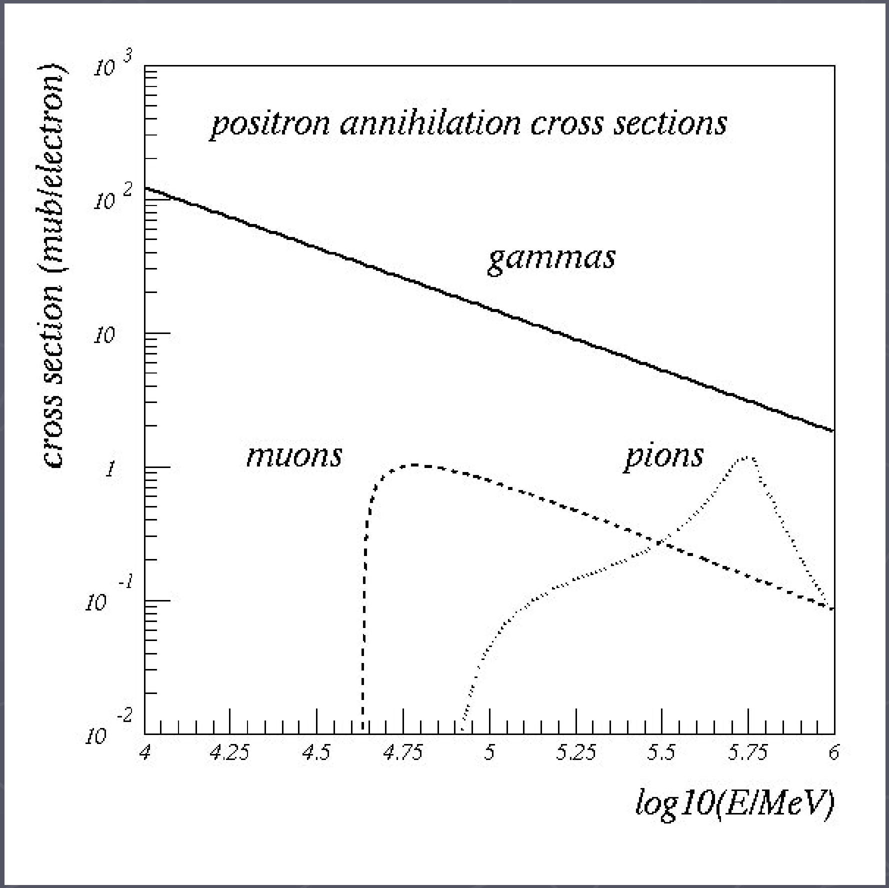
- Contribution from processes:
  - Ionization
  - Bremsstrahlung
  - Production of e^+e^-
- T_{cut} – cut energy
- Transfers above T_{cut} are sampled
- Recent upgrade:
  - Radiative corrections to ionization at E > 1 GeV
  - Improve precision of double differential cross section for pair production (biases reduced from 30% to 5%)
  - Initialization time decreased

Total muon energy loss

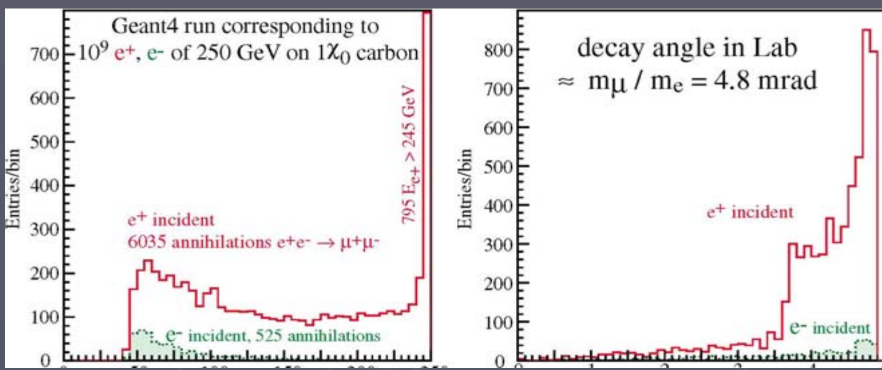


New High energy EM processes

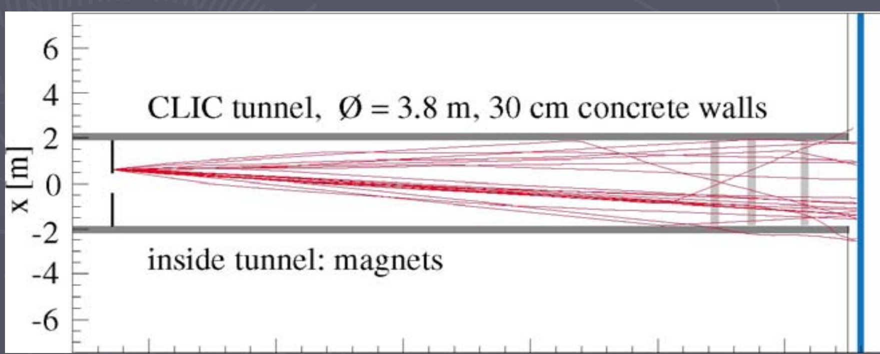
- EM background due to high energy EM interaction with media:
  - $\gamma \rightarrow \mu^+\mu^-$ ($\sigma \sim Z^2$)
  - $e^+ \rightarrow \mu^+\mu^-$ ($\sigma \sim Z$)
  - $e^+ \rightarrow \pi^+\pi^-$ ($\sigma \sim Z$)
- Visible at LEP and High at SLC
- Of concern for linear colliders

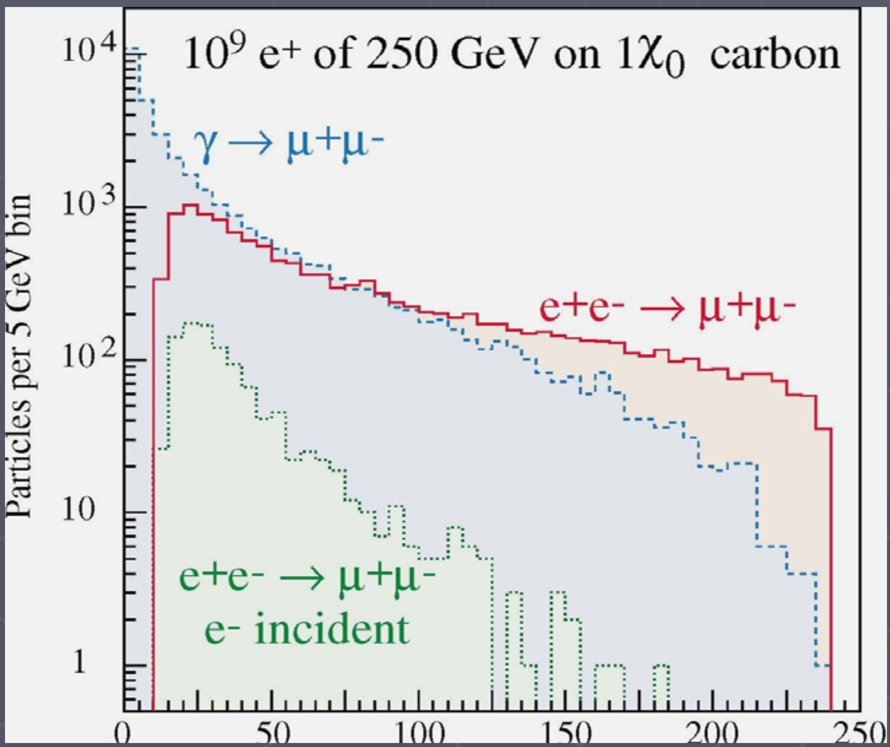


Background for linear collider



High energy e⁺, e⁻, and γ can produce μ⁺μ⁻ pair





E(GeV)

10^{10} e / bunch
After collimator ~ 10^3 μ⁺μ⁻

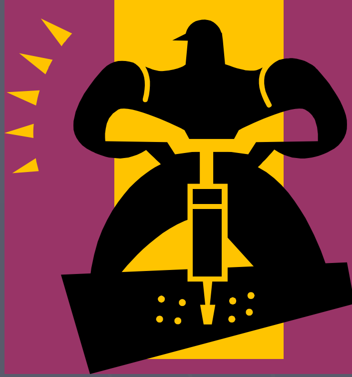
Design iteration in Standard EM package

- Standard EM package was one of physics package working from 1st Geant4 release
- Created using Geant3 expertise
- Used practically in all Geant4 applications
- Used in production for BaBar for many years
- Some architecture problems were accumulated
- In 2003 the package were redesigned
- New developments were enabled

Requirements to model design of standard EM package

- **Physics should be unchanged**
- **The same user interface as before should be available**
- **High energy and low energy models should work together for any particle**
- **Performance should be at least the same**
- **Ionization and Bremsstrahlung should be decoupled**
- **Different physical models for different regions and energy ranges**
- **Different models of energy loss fluctuations for different particles**
- **Integral approach as an alternative**

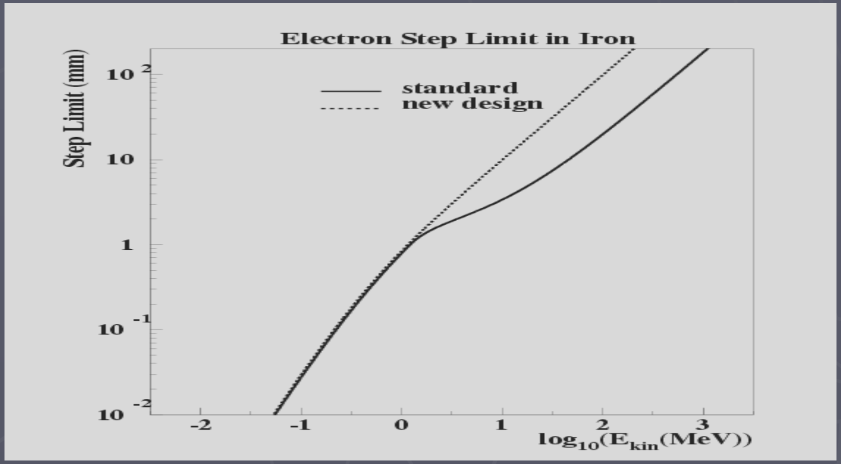
Design and implementation (released in G4 6.0)



- Feature driven design
- Physics is decoupled from management
- Number of static objects very limited
- No repeated software
- Old interfaces are kept
- Old messenger is used
- New (default) and old (serial 52 and LowEnergy) processes can be used in the same Physics List
- Fine steps (~20) implementation at 2003
- About 15 different tests were running after each iteration
- Tests against results with old standard processes and/or data
- Code review is done
- Performance optimization is on the way

Integral approach

- EM cross sections strongly depend on energy
- Precision of interaction probability depends on step size and energy change
- Integral approach: interaction probability is sampled using integral method (MC'91 Proceedings)
- Integral approach allows to have any step size



standard

$$p = \exp\{-\sum_i \sigma(E_i) n \Delta s_i\}$$

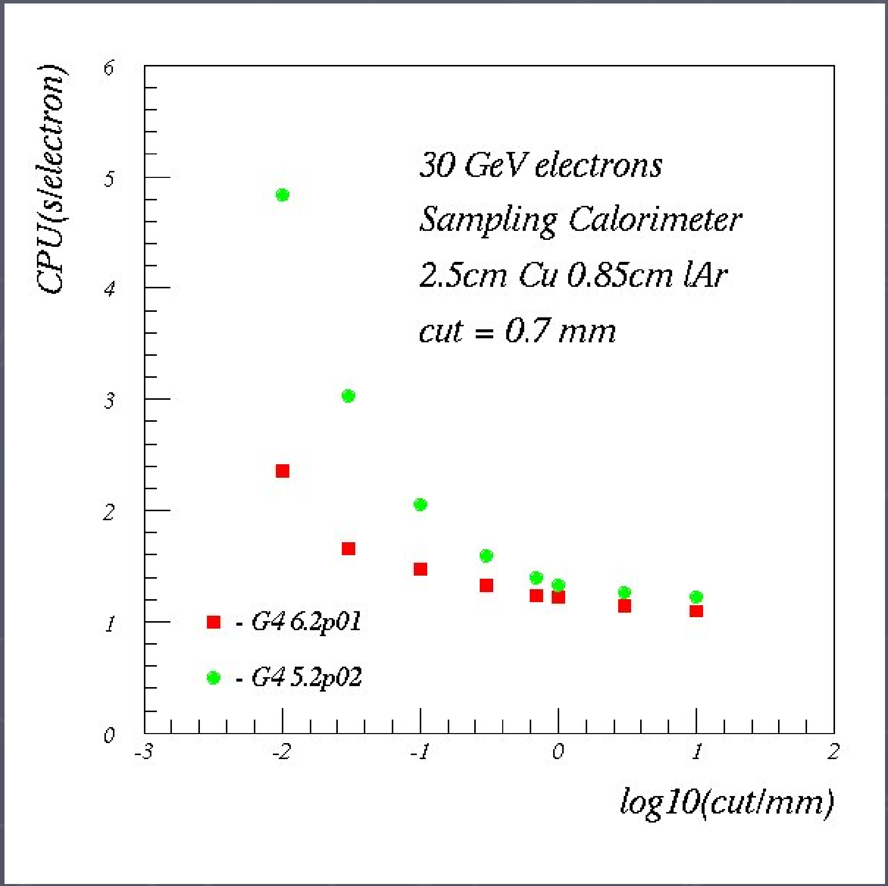
integral

$$p = \exp\{-\int \sigma(E) n ds\}$$

Performance comparison 5.2/6.2

- Performance improved after design iteration
- Initialization time smaller by 2 times or more
  - 15s for 43 materials (HARP)
- Size of EM tables smaller by 2 times or more
- CPU per event less at least by 10%
- Higher quality for large cuts, higher performance for low cuts

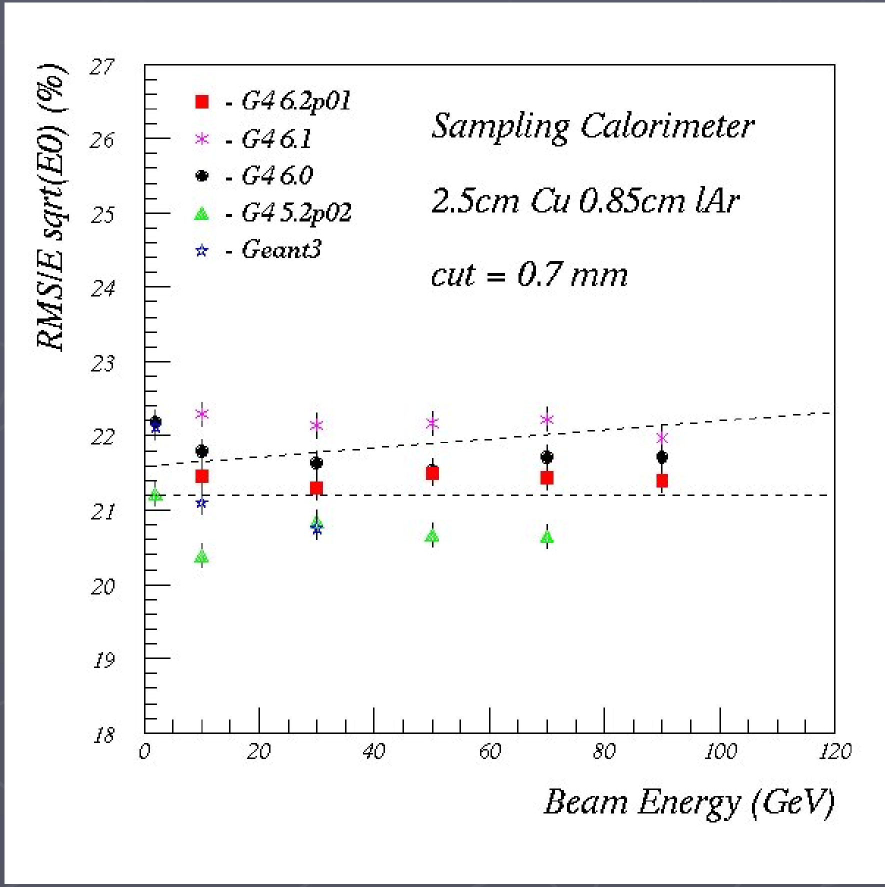
Intel 2.4GHz 512 KB



Sampling calorimetry

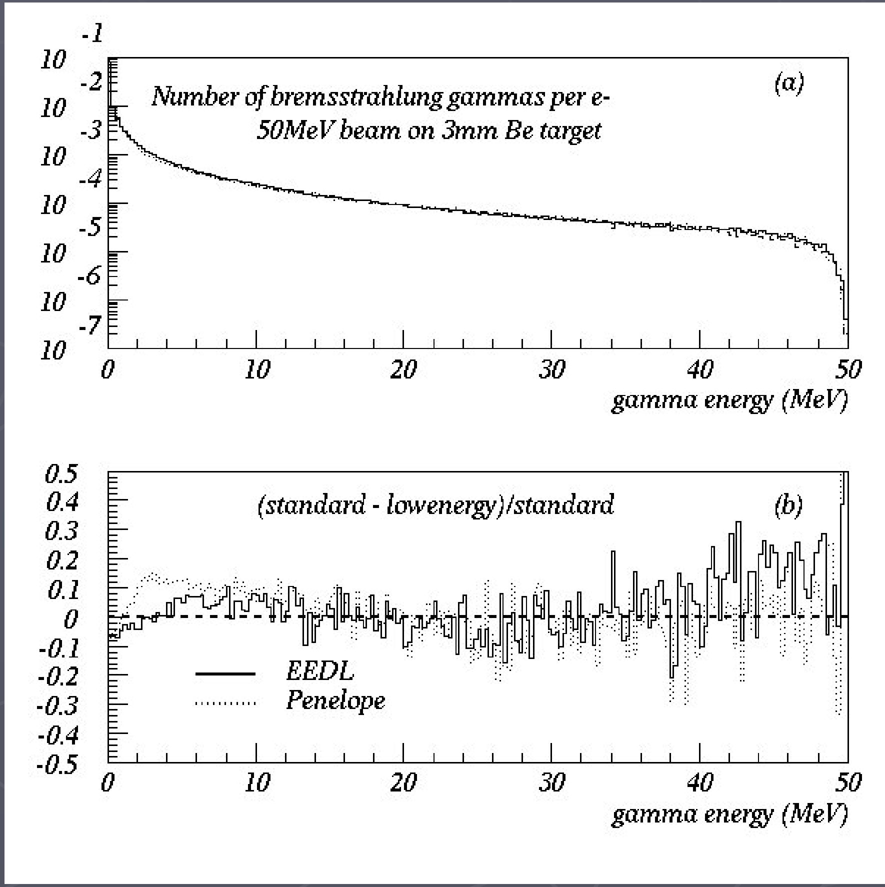
Default EM physics

- ATLAS HEC structure is used as a reference
- Some instability observed in 6.0 → 6.1 → 6.2 transitions
  - Fixes in integral mode
  - Fixes in multiple scattering model
- In PhysicsList distributed via G4 web page the optimal combination of processes are provided, so results are stable



PhysicsList for EM use-cases

- First release G4 6.2
- Use modular structure with different builders:
  - QED (γ, e^+, e^-)
  - Muons (μ^+, μ^-)
  - Hadrons/ions
  - Decay
  - Step Limiter
  - High energy
  - Limited hadron physics
- Builders for G4 6.2 and G4 5.2
- No precompiled library
- Are tested inside EM examples
- G4EmOptions for steering
  - Min, max energies
  - Cuts
  - Step limits



Acceptance suite for Standard EM package

- To insure stability of results with time
- To control performance
- Is based on extended electromagnetic examples
- G4EmCalculator is an interface to dE/dx and cross sections
- Control on summary numbers:
  - Average energy deposition
  - Shower shape
  - Scattering angles
- Tests on cross sections and dE/dx
- Comparison of histograms (in project)

Conclusions and plans

- Standard EM package have been redesigned
- Physics was extended and improved
- Performance was improved
- Main short-term goals:
  - Achieve stability of simulation of sampling calorimeters to level 0.1% (ATLAS requirement)
  - Comparisons/validation
- Long-term prospects:
  - Physics model on level of theory/experiment for all processes
  - High energy extensions
  - Further performance improvement
  - Complete automatic acceptance suite