Geant4:
Electromagnetic Processes 2

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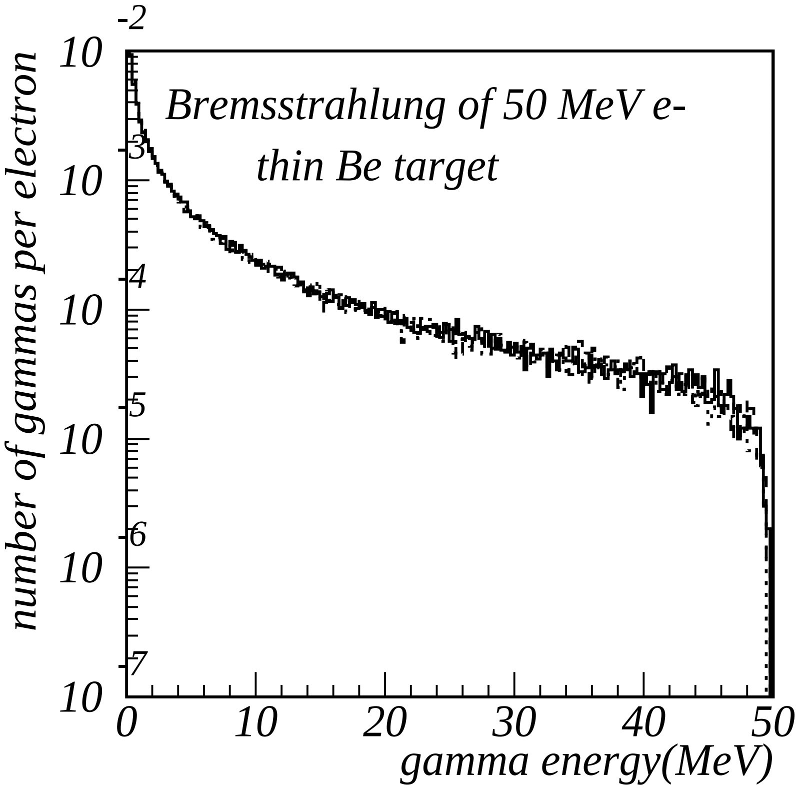
- Geant4 cuts
- Stopping powers and ranges
- Hadron and Ion ionization
- Fluctuations
- Multiple scattering
- G4 validation

Introduction remarks

- Energy spectrum of δ-electrons ~ $1/T^2$
- Energy spectrum of Bremsstahlung ~ $1/\omega$
- Huge number of low energy e- and gammas cannot be tracked by any Monte Carlo
- Cuts should be used



Geant4 cuts

- No tracking cuts, only production thresholds
- Cuts can be established now only for gamma, electrons, and positrons
- Thresholds for production of secondaries are expressed in range, universal for all media,
  - Range 10 keV gamma in Si ~ 2 cm
  - Range of 10 keV electron in Si ~ 2 microns
- Energy thresholds for a material is calculated from this cut in range.
- From G4 5.1 a possibility to set a cut by G4Region have been implemented

G4 cuts

- For a typical process G4Ionisation production threshold T_c subdivides continues and discrete part of energy loss:
- Energy loss
- δ-electron production
- By default energy is deposited at the step
- Energy loss can be used optionally for generation of δ-electrons under the threshold (subcutoff) and for fluorescence and Auger–electrons emission

$$\frac{dE}{dx} = n \int_0^{Tc} t \frac{d\sigma(t)}{dt} dt$$

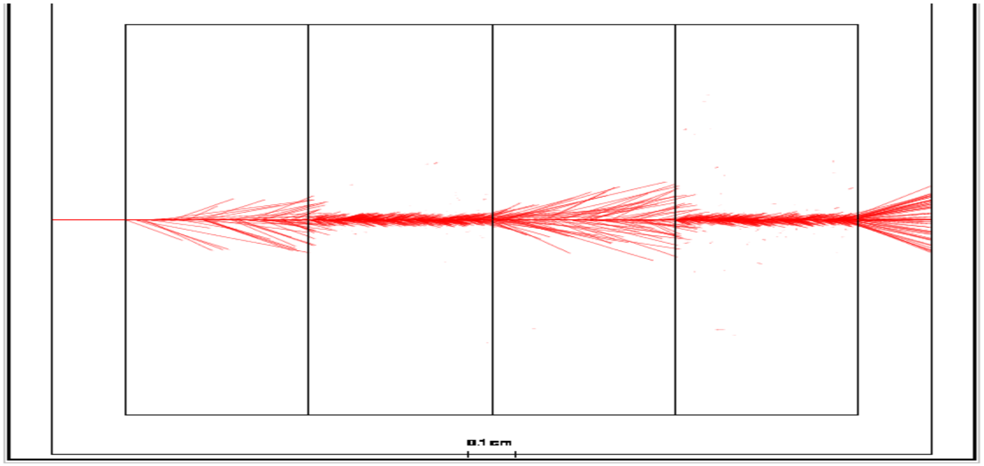
$$\sigma = \int_{Tc}^{T_{max}} \frac{d\sigma}{dt} dt$$

G3/G4 cuts in Pb/Ar calorimeter

Protons 500 MeV

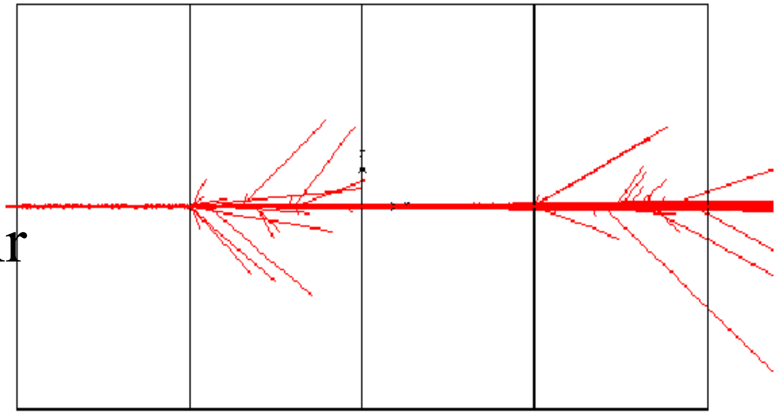
G3

Cut 450 keV



Ar Pb Ar

G4



1.5 mm - 450 keV LAr

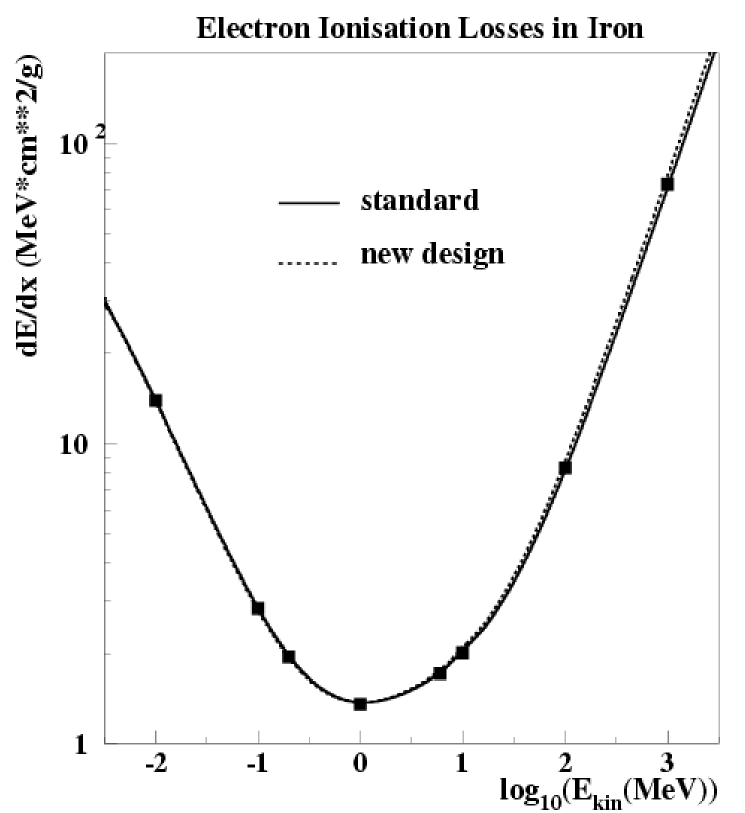
2 MeV Pb

Remarks about G4 cuts

- The use of production threshold is mandatory only for ionization and bremsstahlung processes
- Other processes can use or ignore G4 cuts
- Alternative mechanism is UserLimits, which can be defined in a given G4LogicalVolume:
  - Maximum step size
  - Maximum track length
  - Maximum track time
  - Minimun kinetic energy
  - Minimum range

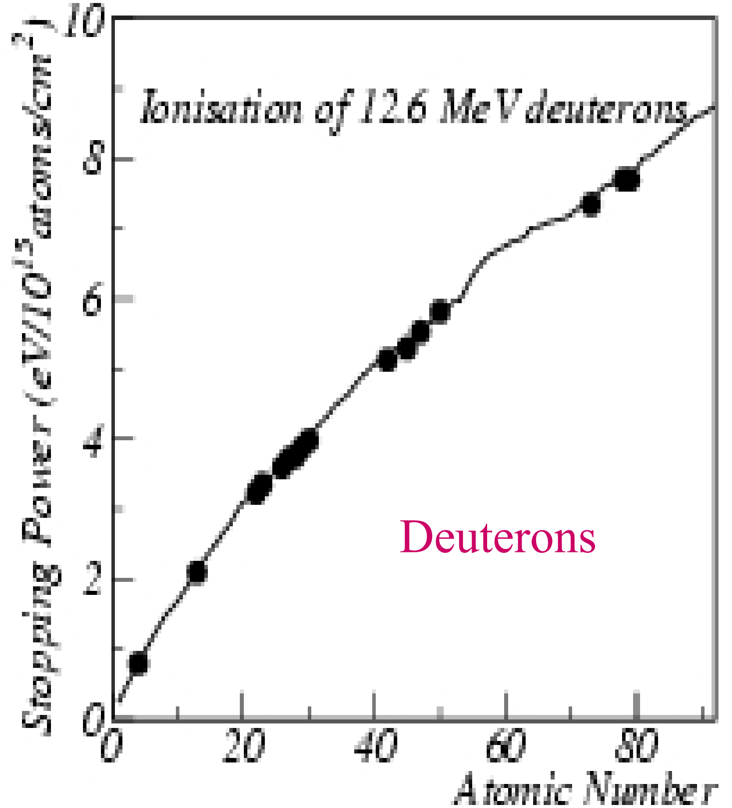
Energy loss and range tables

- 2 processes contribute to e^+ or e^- continues energy loss:
  - Ionization
  - Bremsstrahlung
- 3 process for $\mu^\pm$ energy loss:
  - Ionization
  - Bremsstrahlung
  - e^+e^- pair production
- To achieve CPU performance dE/dx tables are calculated as a sum of all contributed losses
- Range and inverse range tables are calculated from dE/dx tables



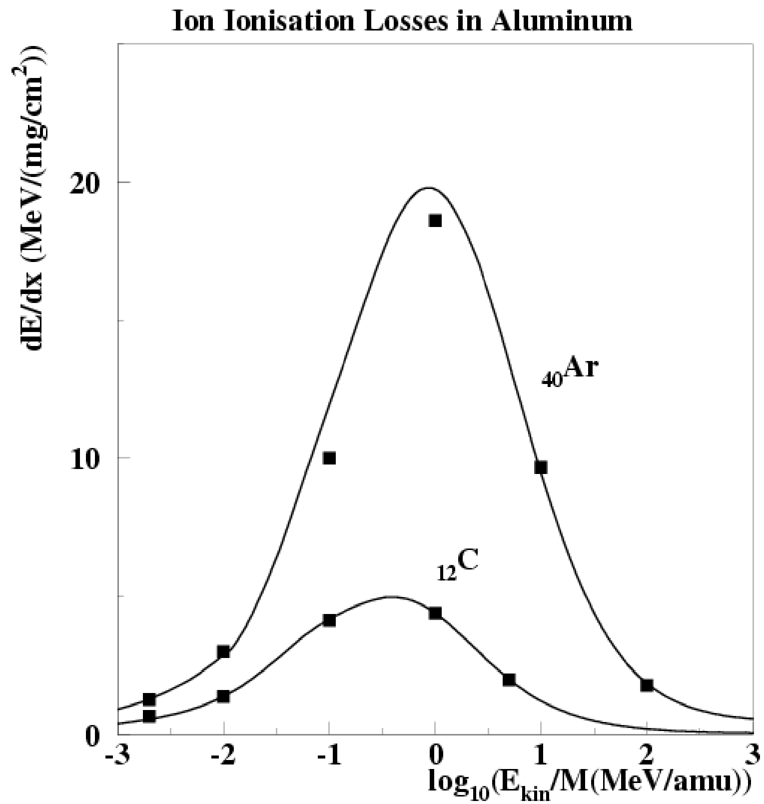
Stopping powers and ranges

- At initialization stage dE/dx, R(E), and E(R) tables are calculated for all materials and basic particles e^-, e^+, μ^-, μ^+, p, pbar
- For heavy particles ionization is a function of only velocity, so scaling relation is applicable
- At run time dE/dx, R(T), T(R) for hadrons and ions are calculated using scaling $T_p = T \cdot m_p / m$



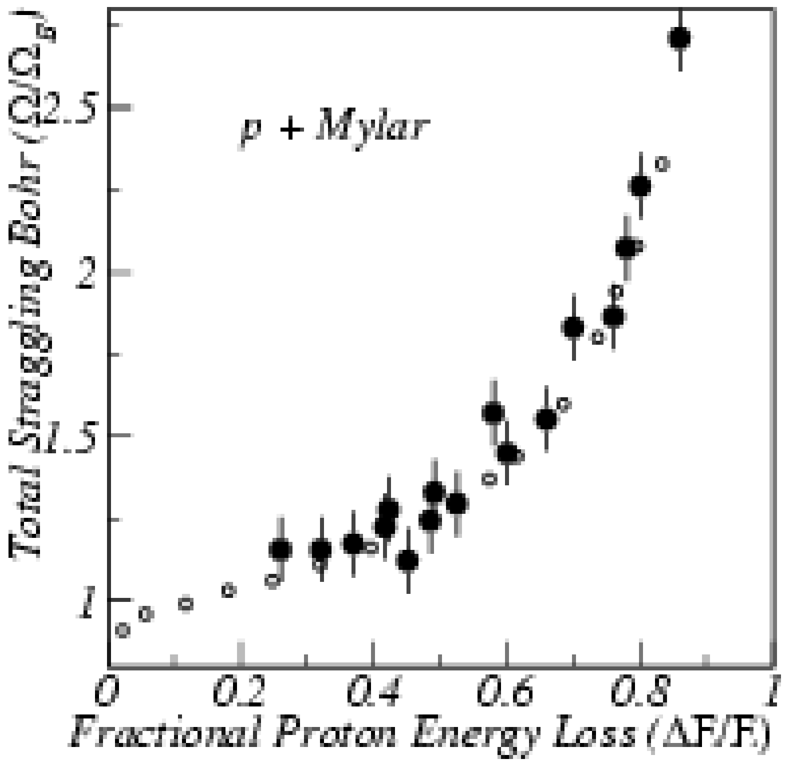
Stopping powers and ranges

- Scaling is applicable to all types of ions
- Initialization should be redone if run conditions are changed:
    - New basic particle
    - New material
    - New cut



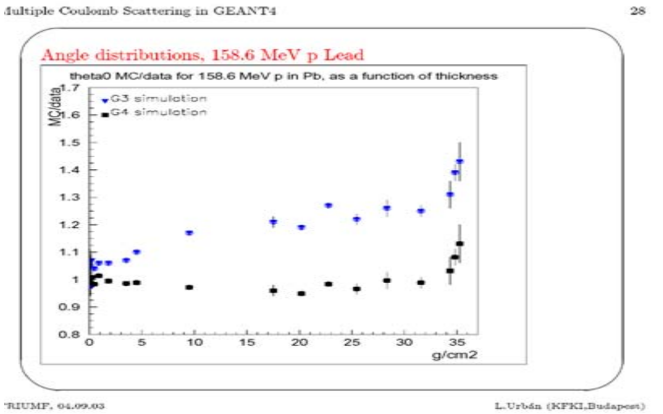
Straggling

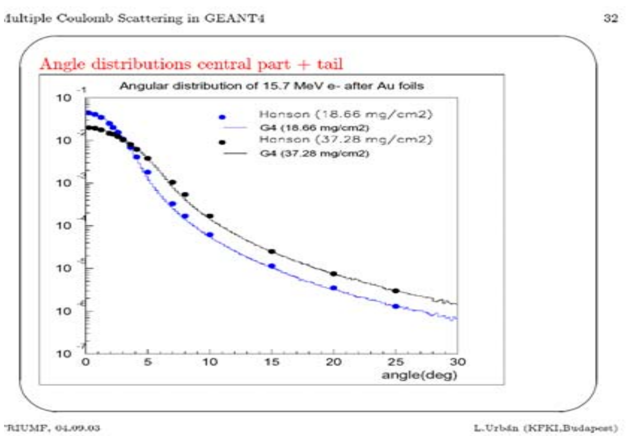
- At each step of charged particle after calculation of average energy deposition the sampling of energy is performed
- Two fluctuation models are used
  - Bohr fluctuations for “thick” absorber regime
  - Urban fluctuations for “thin” absorber regime
- Small cut – Bohr fluctuations



Multiple Scattering

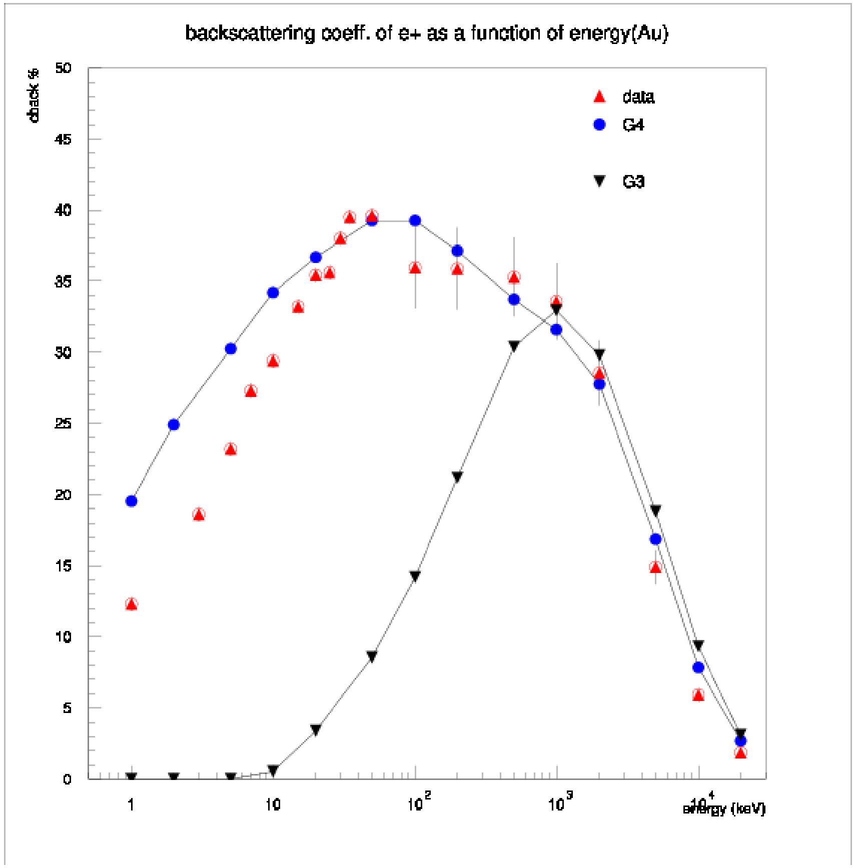
- Long evolution from G4 3.2 to G4 5.2
- L.Urban is developing a combine model which applicable for case of big scattering angles
- Both multiple Coulomb scattering and hard Rutherford scattering
- Boundary algorithm for backscattering





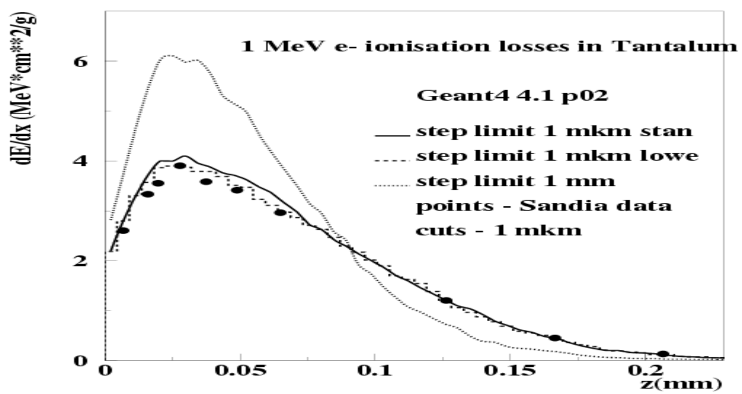
Multiple Scattering

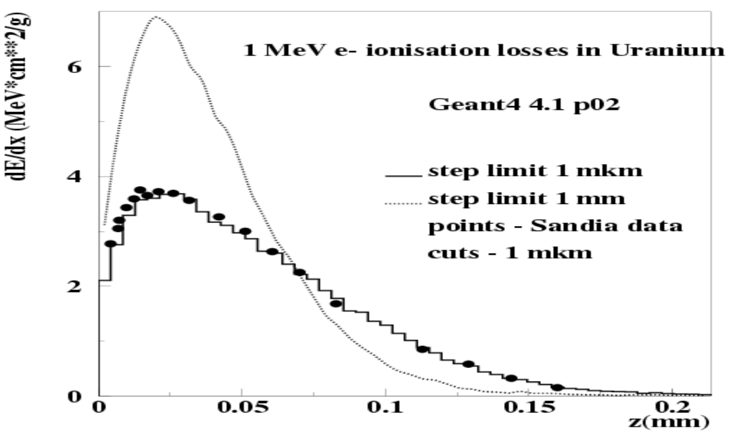
- Provides step limit near the boundary of the volume
- Sample transverse displacement at end point of the step
- Sample scattering angle



Electron ionization in media
Geant4/Sandia data

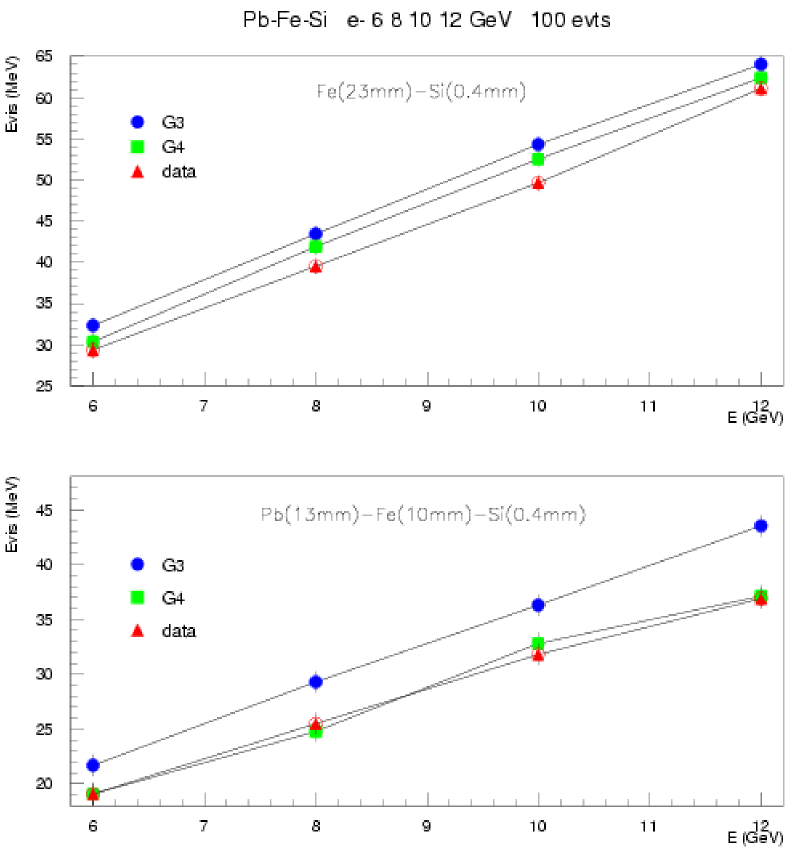
- Backscattering and energy deposition profiles in semi-infinite media are directly connected
- Correct energy profile and backscattering are achieved when boundary algorithm is applied





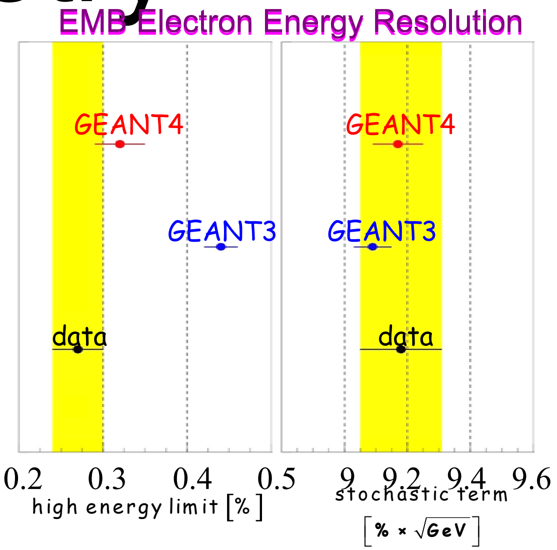
G3/G4 data comparisons

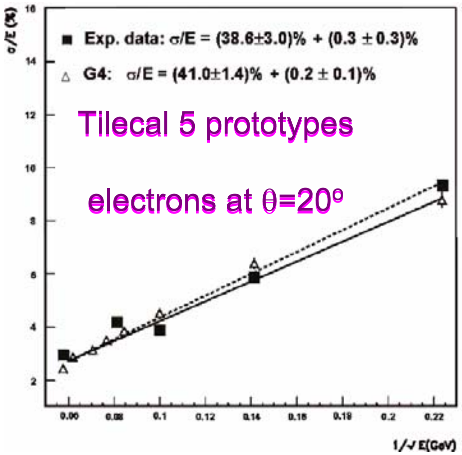
- From the beginning of G4 the comparisons G3/G4 have been doing permanently
- Usually G4 is close to the data or is close to G3 predictions
- Currently focus on comparison with the data



Geant4 electron response in ATLAS calorimetry

- Geant4 reproduces the average electron signal in all ATLAS calorimeters very well (±1%)
- Signal fluctuations are very well simulated
- stochastic term: G4 and data similar





Conclusion remarks

- Geant4 electromagnetic model based on new conception: *universal cut in range*
- Geant4 is not a frozen program – it is a free toolkit, which allows to implement any new model or alternative process
- Geant4 electromagnetic physics is well tested and demonstrates a good quality for HEP applications
- In some cases Geant4 provide physics which is absent in Geant3, in others – more precise models