Electromagnetic physics (standard)

Mission and history

One of the RD44 objectives: provide a package of electromagnetic physics at least equivalent to GEANT3.

The Working Group started with two physicists coming from the GEANT3 team, plus one physicist in charge of the light propagation processes. Later on, an expert of the high energy muon physics joined us.

The RD44 objective was reached in time.
New concepts have emerged and have been implemented:

- the distinction between *tracking cut* and *production threshold*
- the idea to express this later in *range* rather than in energy
- the notion of coupling the effective production threshold to the distance to the *nearest geometrical boundary*

Today the group is $\sim$ 8 physicists, representing $\sim$ 3 fte.

It is responsible to maintain, develop and promote all the electromagnetic physics packages, other than the low energy extensions.

The activities of the group can be classified as follow:

- comparisons, tests and examples
- developments and refinements of models
- documentation
- QA and Design related matters

1. Common to all charged particles
   - ionization $(\sim keV \longrightarrow)$
   - Coulomb scattering from nuclei $(\sim keV \longrightarrow)$
   - Cerenkov effect
   - Scintillation
   - transition radiation
2. Muons
   - (e+,e-) pair production $(\sim 100GeV \longrightarrow)$
   - bremsstrahlung $(\sim 100GeV \longrightarrow)$
   - nuclear interaction $(\sim 1TeV \longrightarrow)$
3. Electrons and positrons
   - bremsstrahlung $(\sim 10MeV \longrightarrow)$
   - e+ annihilation

4. Photons
   - gamma conversion ($\sim 10MeV \longrightarrow$)
   - incoherent scattering ($\sim 100keV \longrightarrow \sim 10MeV$)
   - photo electric effect ($\longleftarrow \sim 100keV$)
   - coherent scattering ($\longleftarrow \sim 100keV$)
5. Optical photons
   - reflection and refraction
   - absorption
   - Rayleigh scattering

Total $:\sim 15$ processes $\longrightarrow \sim 40$ classes

$+ \sim 10$ classes for the materials category

Tests and comparisons

Primary and daily tasks of the group.

The set of tests used during RD44 was expanded, and new sets of comparisons with data were undertaken, and have been made public, together with their equivalent GEANT3 programs.

`geant4/examples/extended/electromagnetic`

They constitute our basic internal benchmark system.

Regular book keeping of results under CVS repository.

They are also included in the general GEANT4 system tests.

The group will participate in the creation of the regression suite, foreseen by the GEANT4 system testing working group.

Their results are published on a Web gallery accessible from the GEANT4 home page.

Making results and code public has a triple objective:

- serve as reference results
- provide additional, simple but real examples
- enable the user to reproduce these results by himself or herself

Validation Projects

Formal commitments have been agreed on a few projects with different experiments (see general GEANT4 milestones). They are going to compare their past and future beam test data with GEANT4 and GEANT3 simulations.

The EM working group is on first line in these Validation Projects.

In 2000 several regular meetings were held with Atlas and BaBar.

Atlas : Tracker, TRD, Ecal, Fcal, HEC, TileCal, Muon system

Cms : Tracker, Ecal

BaBar : global detector

Developments

In 1999/2000 developments and refinements of models include:

- continuous refinement of the Multiple Scattering model; this model is original to GEANT4.
- revision of the parmetrisation in Bremsstrahlung to ensure validity down to 1 keV.
- re-implementation of the LPM effect.
- extension of Ionization process for ions.
- generation of *sub-cutoff delta rays* : if a delta ray can reach a boundary, it is emitted, even if it is below the production threshold.
- development of the Photo-Absorption Ionisation (PAI) model (1 publication to NIM).

- development of several models of X-rays transition radiation radiators (1 publication to CPC).
- various (minor) refinements in optical processes.

Documentation and tutorials

Keep up to date the physics described in the Physics Reference Manual. In 2000, major revision has been made in the muon physics section.

A Cern preprint describes the mechanism of production of sub-cutoff delta rays

Seminars on EM physics have been given in Atlas and CMS collaborations

The examples in `geant4/examples/extended/electromagnetic` are permanently updated and documented; they represent our reference for education about EM physics

As a by-product of the tutorial given at CALOR2000, a set of exercises devoted to EM physics has been incorporated to the general GEANT4 toolkit tutorial

QA and Design

Minor reorganisations of directories and code, in order to allow independent development of Low Energy and Space Applications activities. This has not affected the basic design of the processes management, which has been stable.

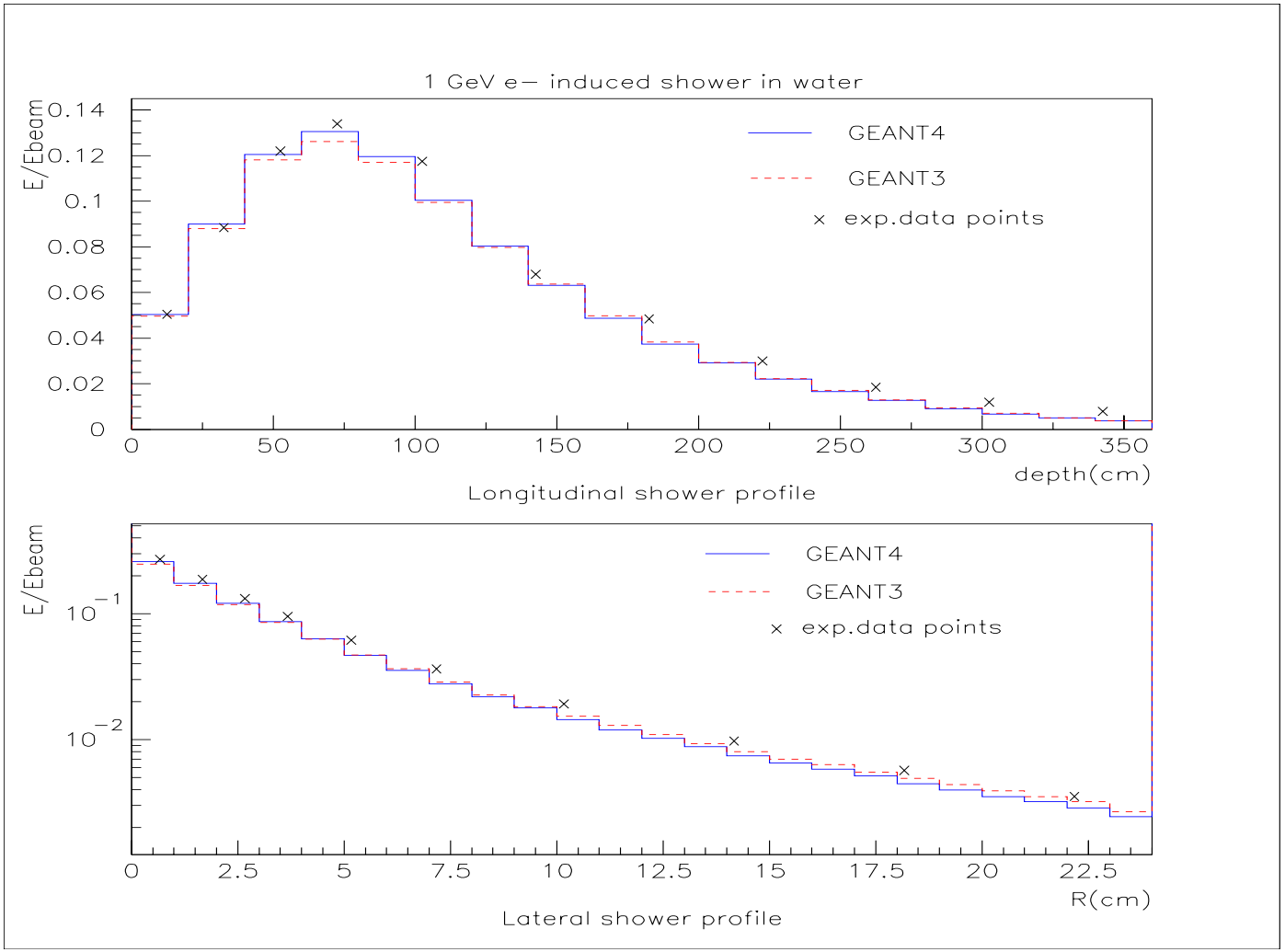
Migration to ISO C++ and STL, as part of the general GEANT4 migration.

Special care is taken in the working group to retain the independence from the system of units utilized. As a consequence the EM physics results has been demonstrated to be independent of the units, which is a contribution to the code quality assurance.

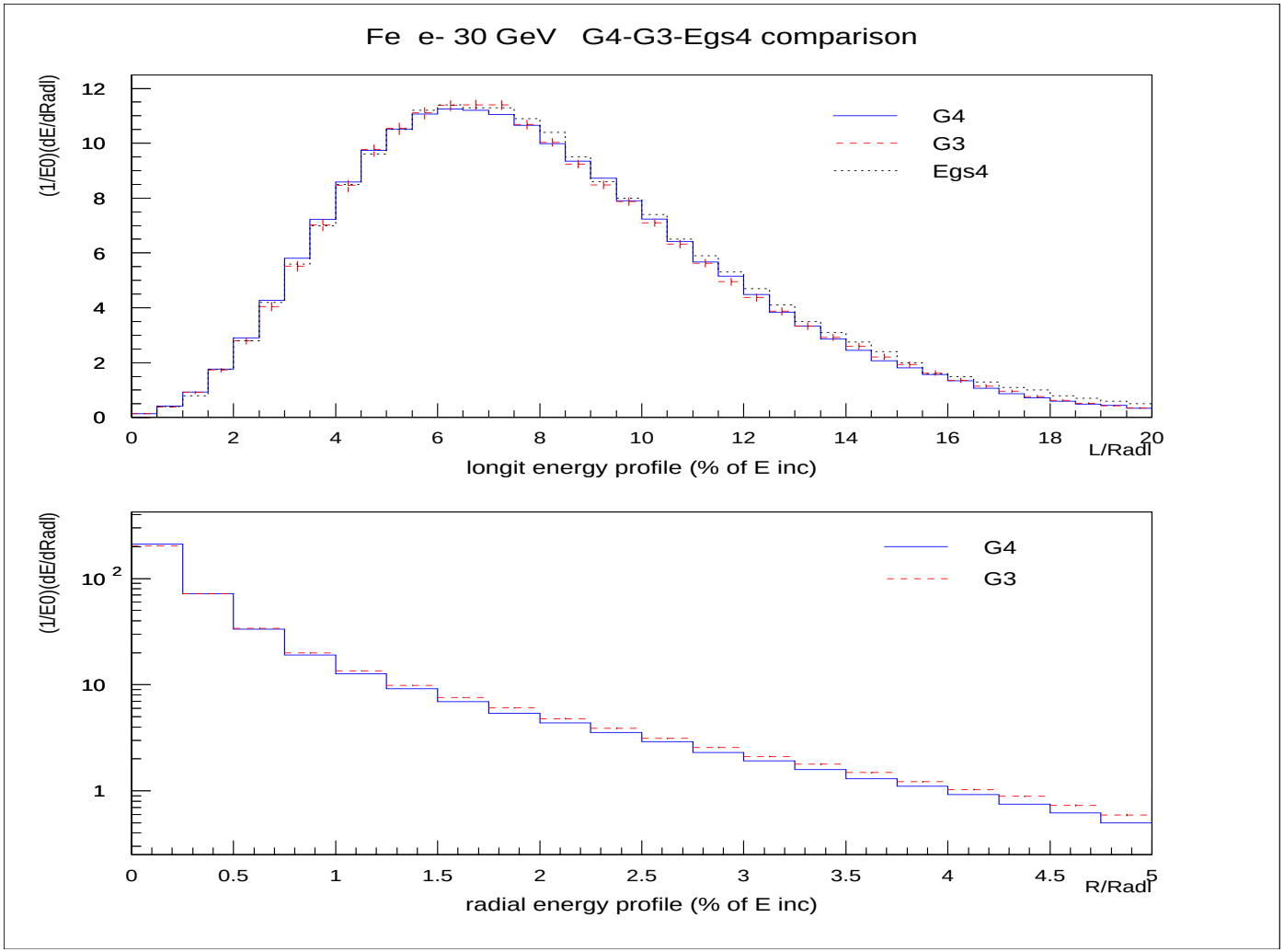
Web Gallery

shower profiles

profiles of the energy deposit by 1 GeV electrons in water



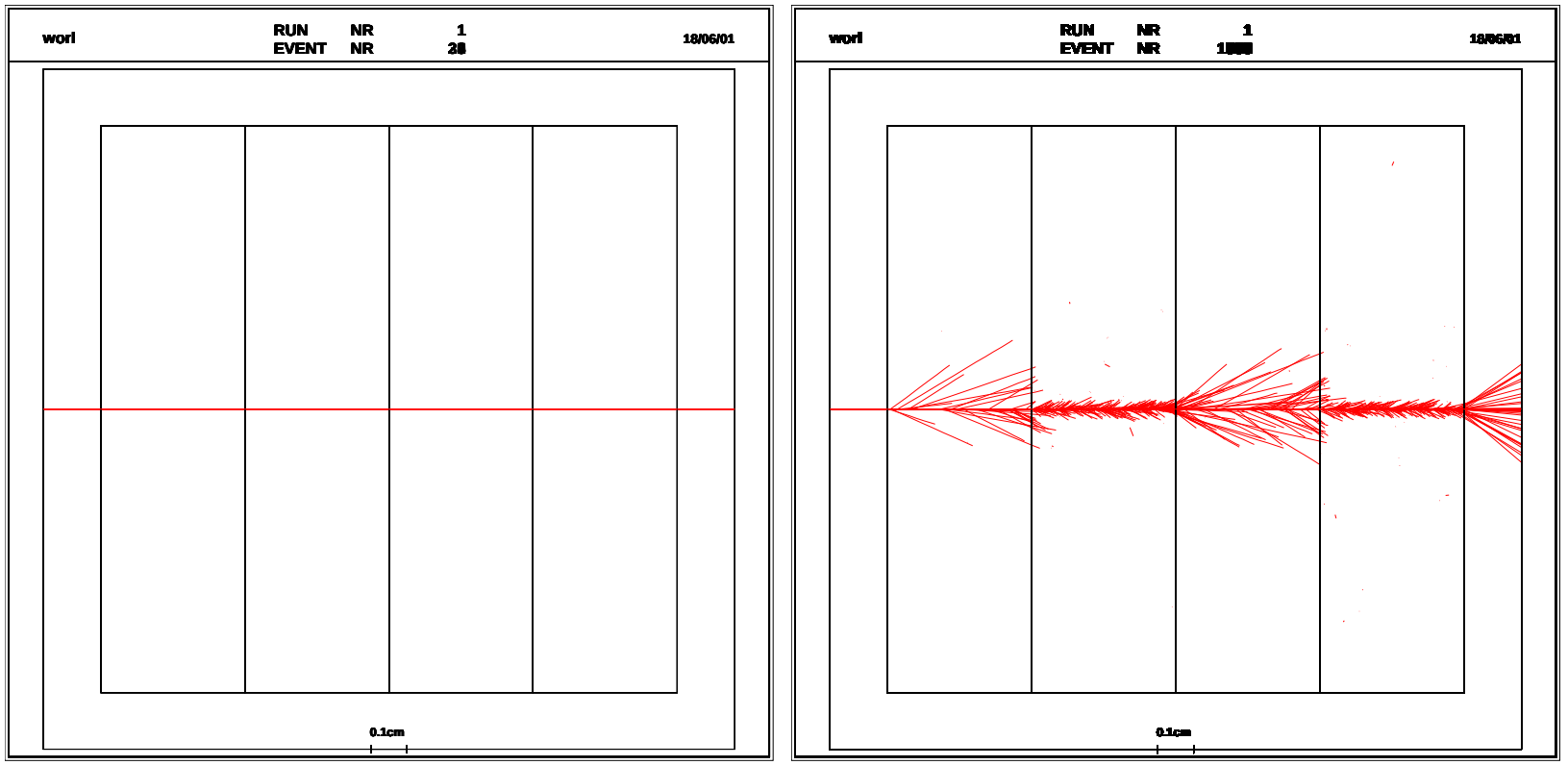
profiles of the energy deposit by 30 GeV electrons in iron



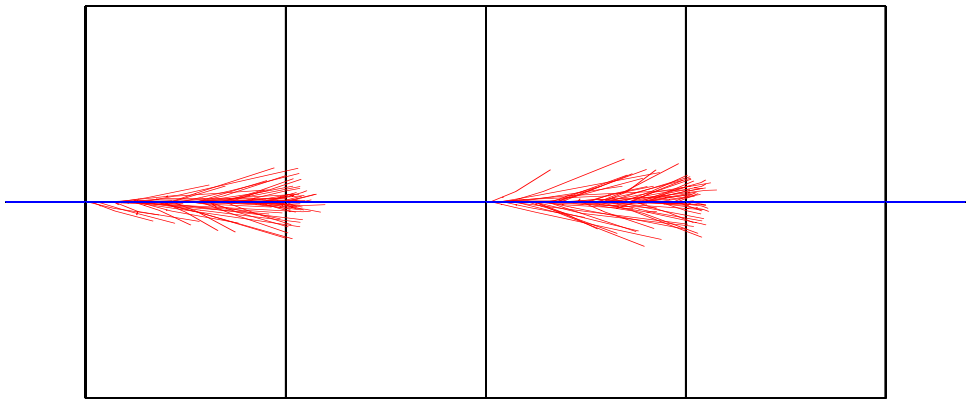
cut in range

sampling: LAr(4mm) Pb(4mm). Protons 500 MeV. GEANT3

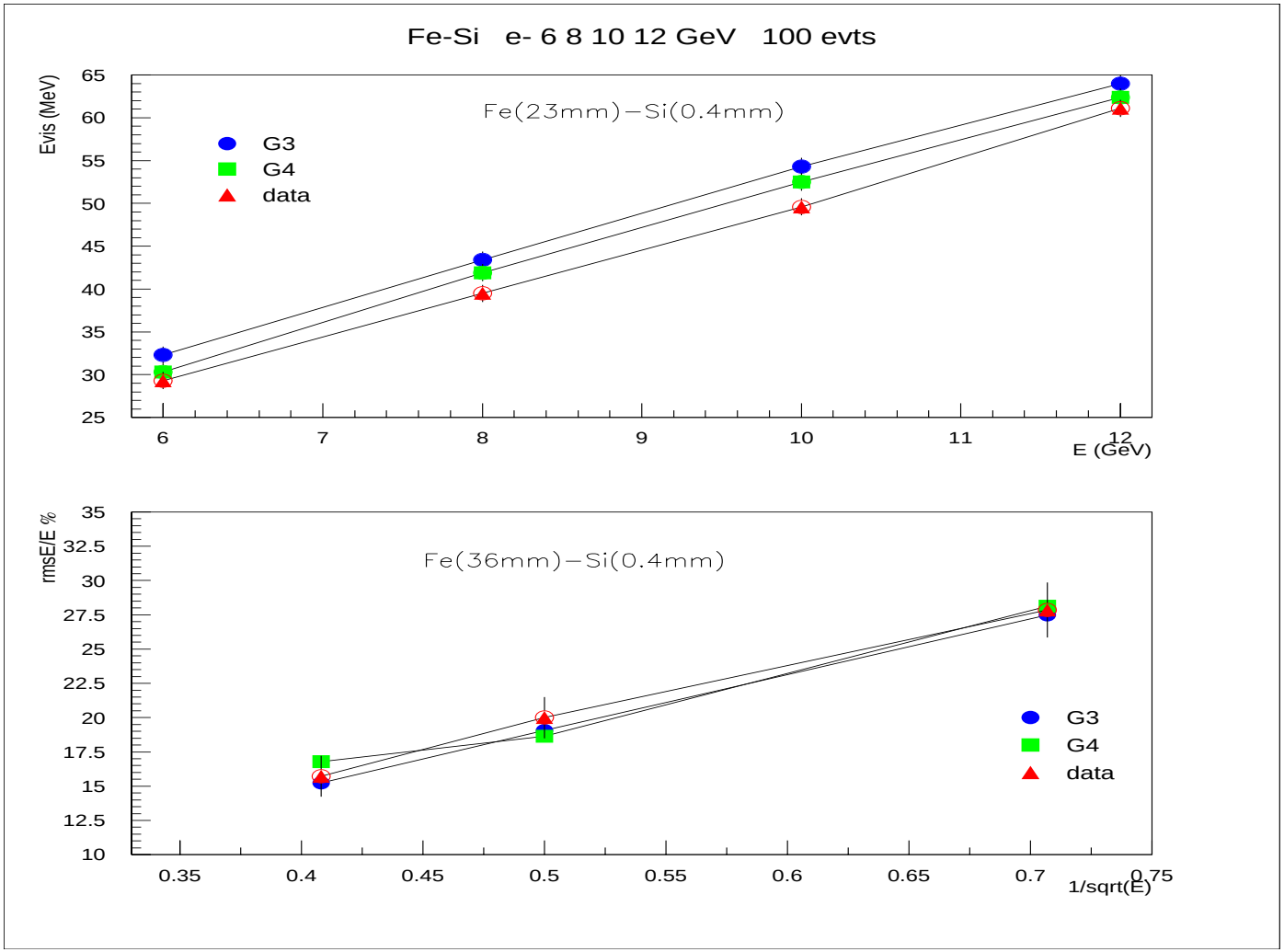
left: cut = 2MeV; right: cut = 450keV



Cut in range: sampling: LAr(4mm) Pb(4mm). Protons 500 MeV. Geant4 cut: 1.5mm =(450keV, 2MeV)

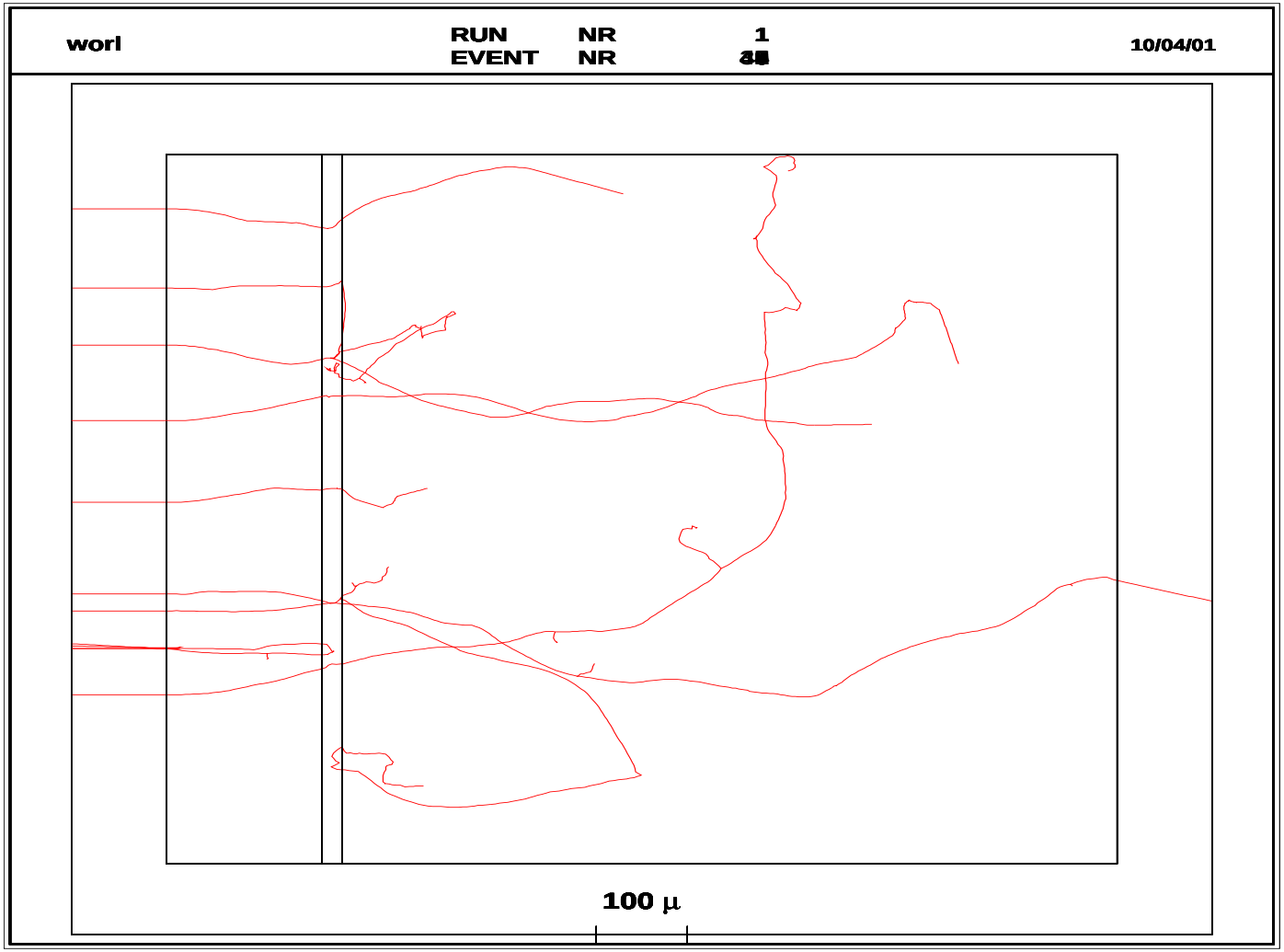


visible energy in sampling calorimeter

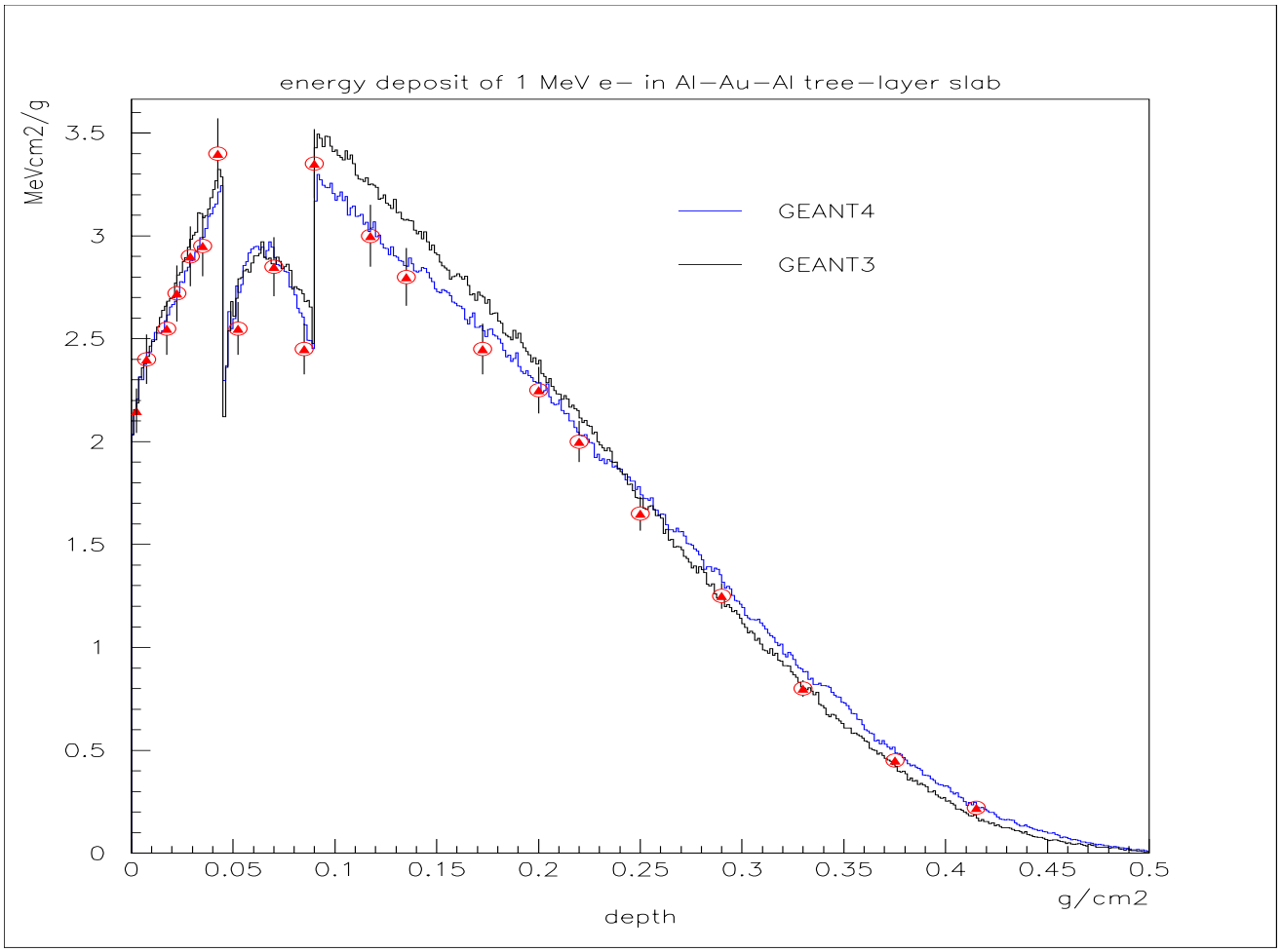


single thin layer

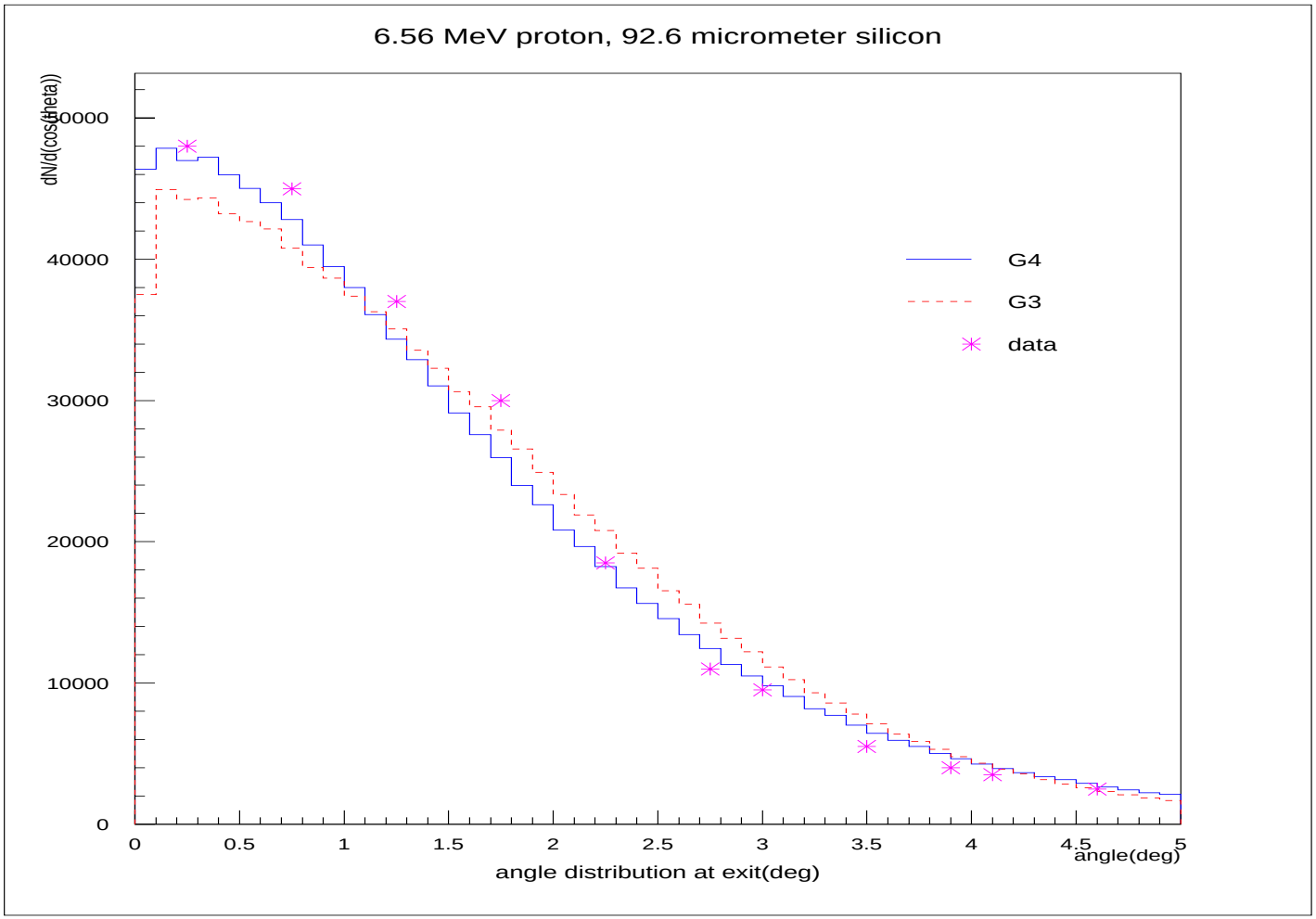
Distribution of energy deposit by1 MeV electrons in Al-Au-Al slab :
45 mg/cm2 - 45 mg/cm2 - 315 mg/cm2 (cut: 1 micron)



Distribution of energy deposit by1 MeV electrons in Al-Au-Al slab :
45 mg/cm2 - 45 mg/cm2 - 315 mg/cm2 (cut: 1 micron)
Data from a Sandia report: G.J.Lockwood et al. SAND79-0414 (1980)



6.56 MeV protons through 93 micron of silicon : angle distribution



Conclusions

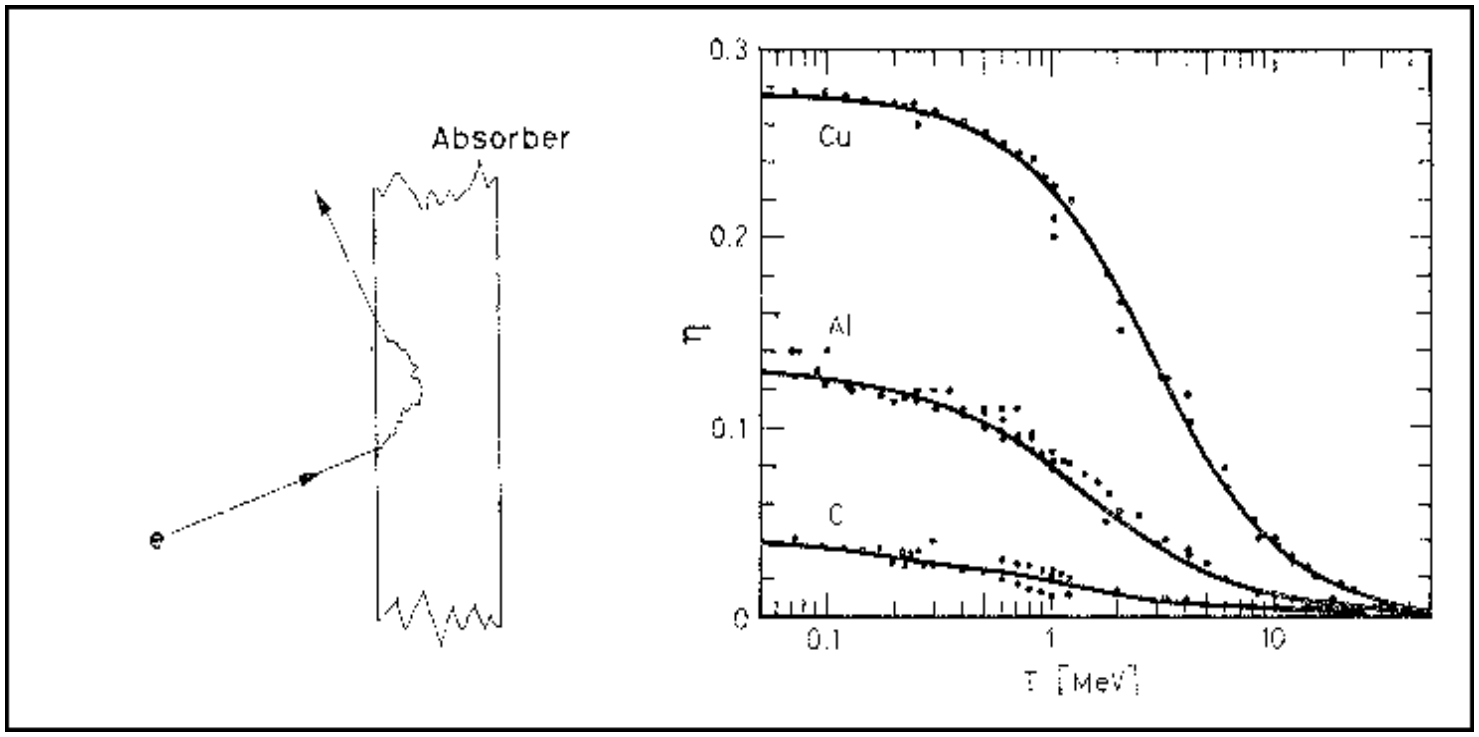
For energy deposited by low energy e-/e+ in single layers :

- ionization: G4 $\simeq$ G3 both for Em.p. and width
- differences (if any) come from multiple scattering. In favor of G4 when we can compare with data

multiple scattering again

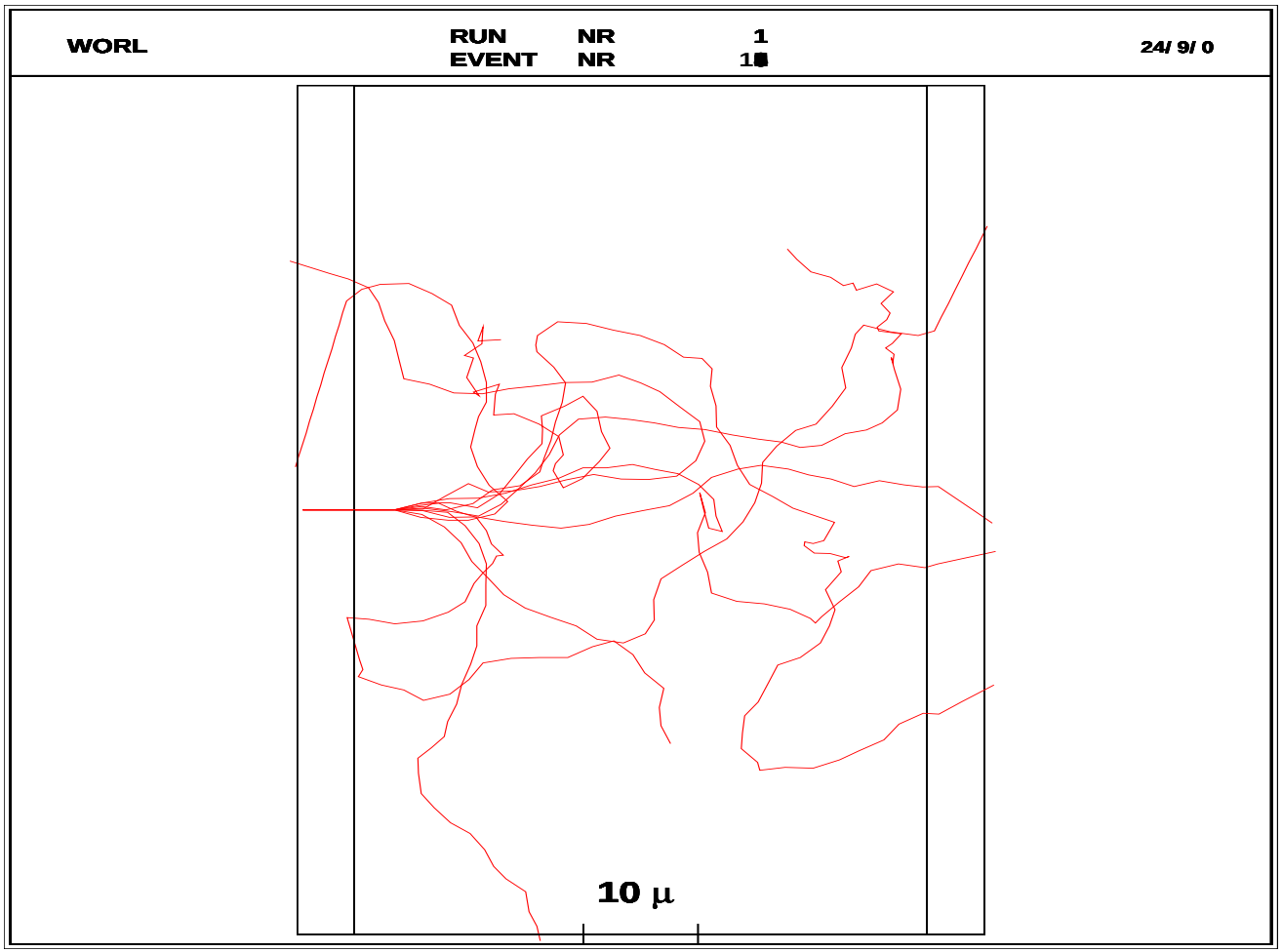
backscattering of low energy electrons

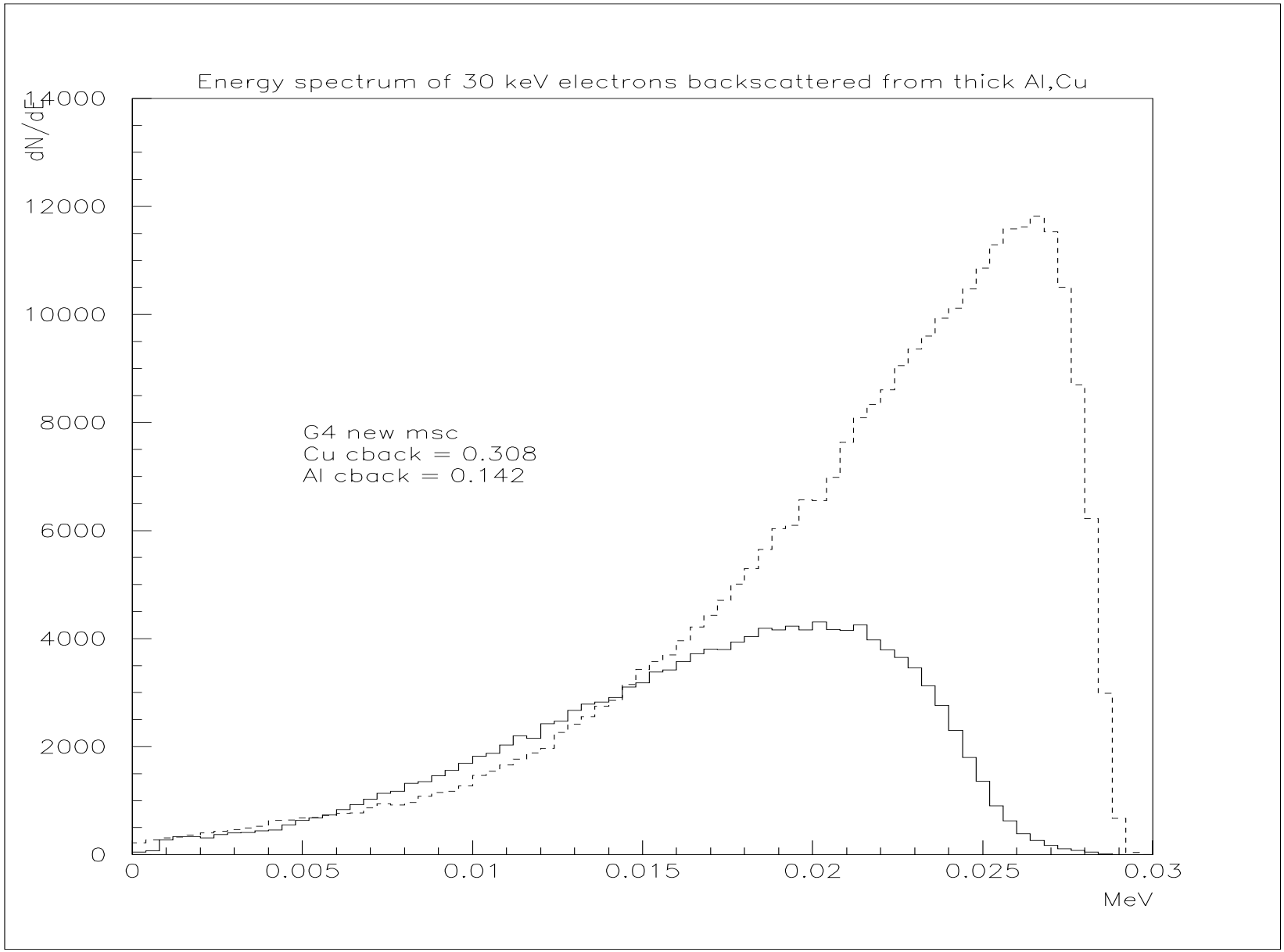
Because of its small mass, electron can have large deflection by scattering from nuclei.
For low energy incident electron beam, the ratio of electrons which are backscattered out of the detector may be important (*albedo*).



albedo : The incident beam is 10 electrons of 600 keV entering in 50 μm of Tungsten.

4 electrons are transmitted, 2 are backscattered.

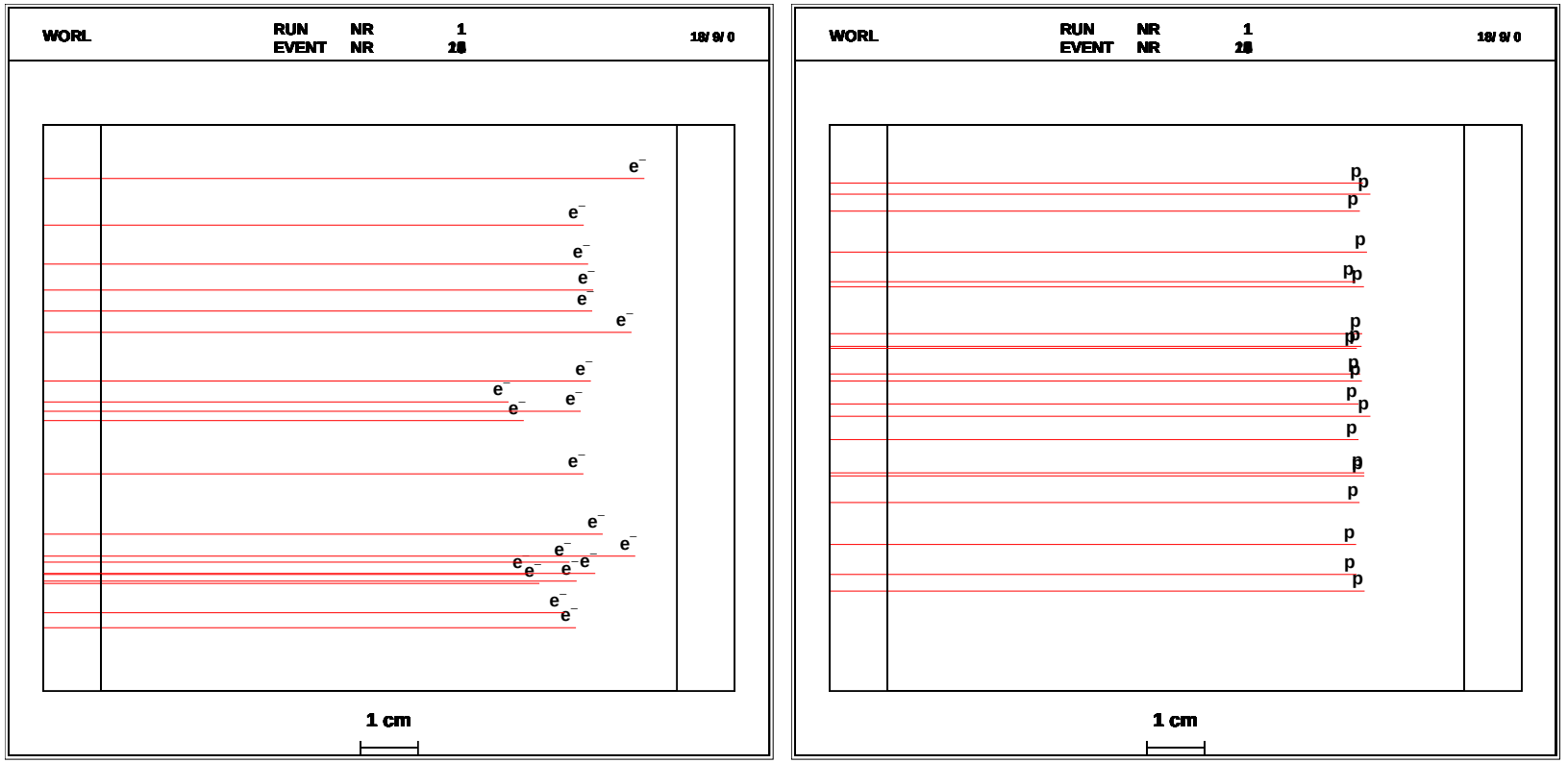



Energy spectrum of 30 keV electrons backscattered from thick Al,Cu
dN/dE
14000
12000
10000
8000
6000
4000
2000
0
G4 new msc
Cu cback = 0.308
Al cback = 0.142
0
0.005
0.01
0.015
0.02
0.025
0.03
MeV

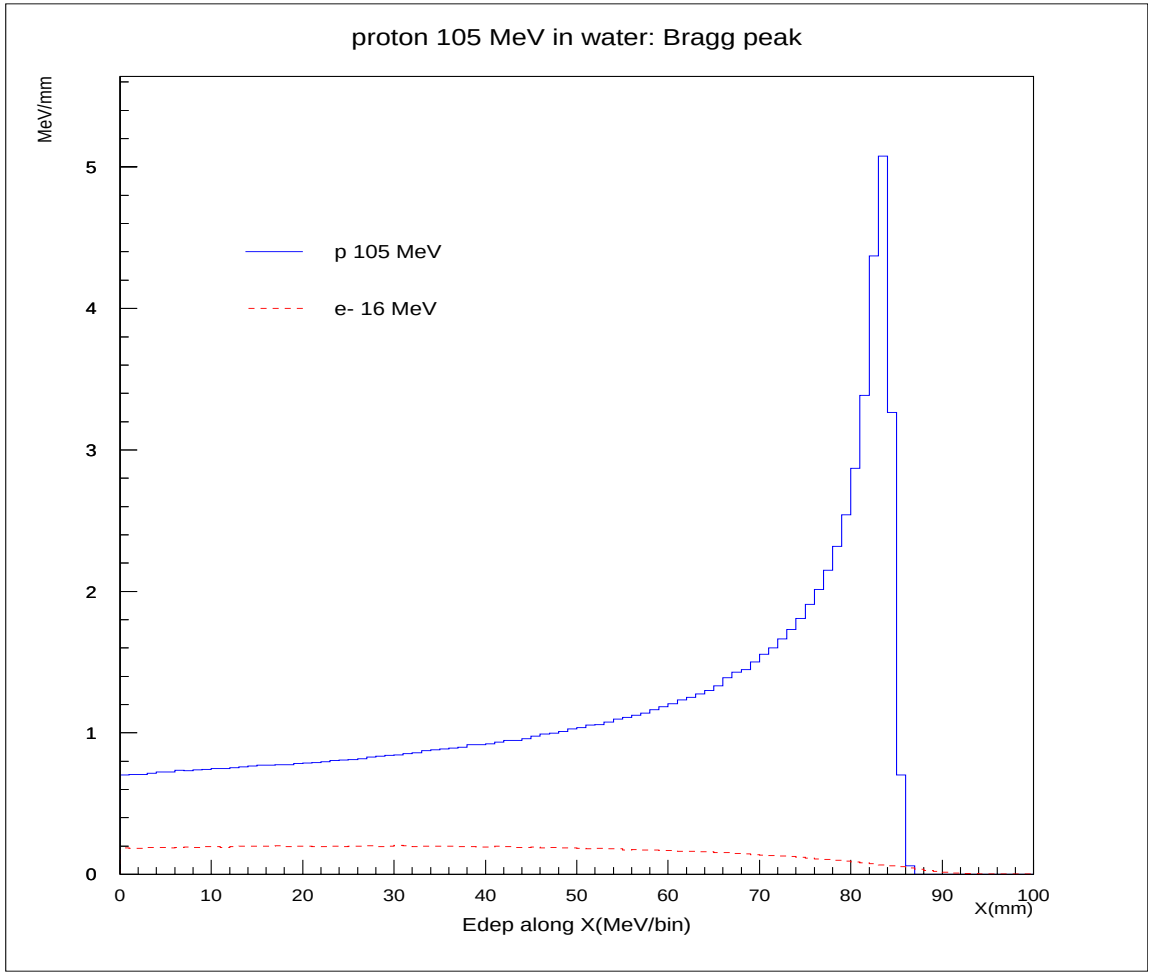
straggling

Fluctuations on ΔE lead to fluctuations on the actual range (straggling).

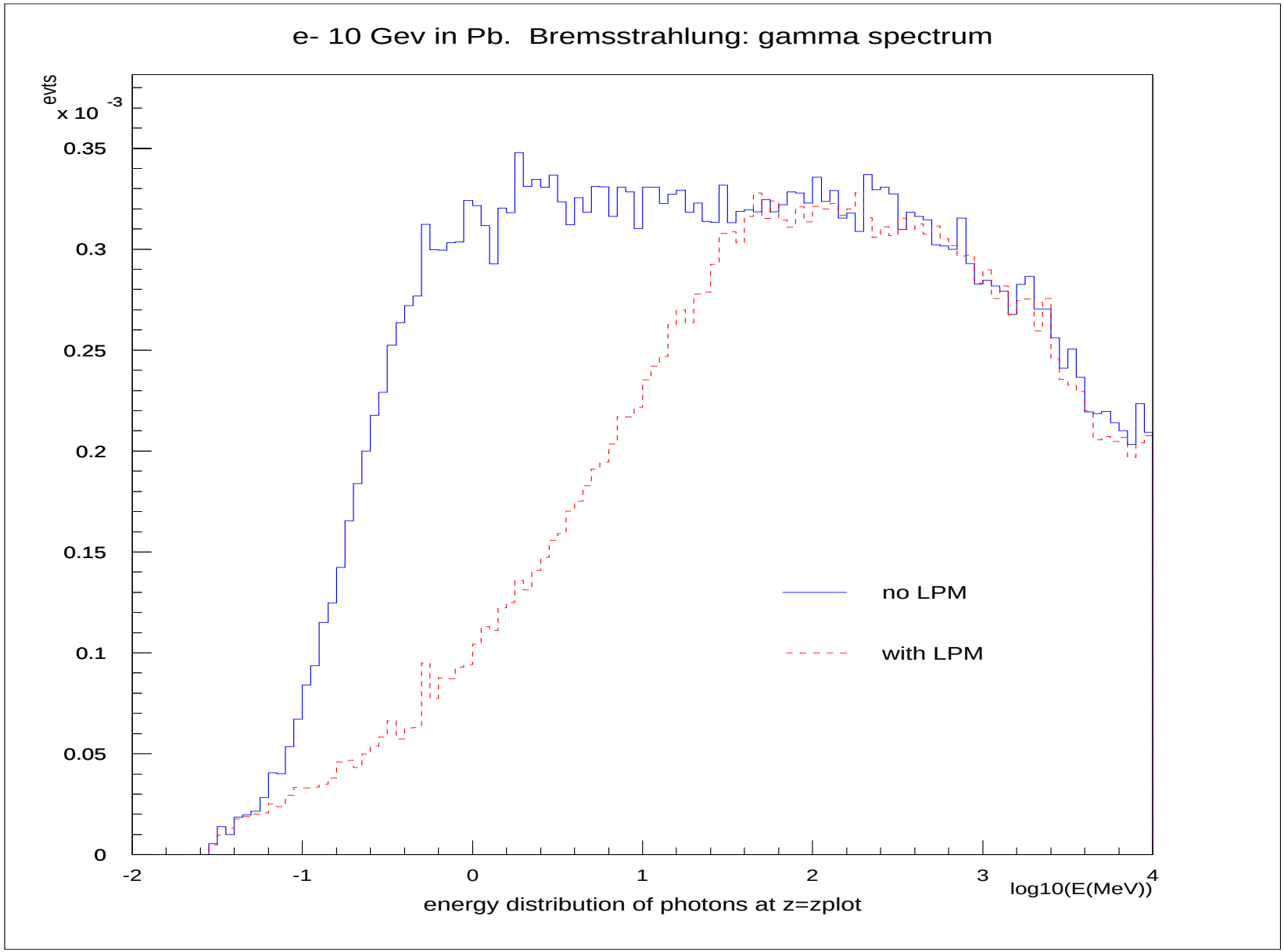
penetration of e^- (16 MeV) and proton (105 MeV) in 10 cm of water.



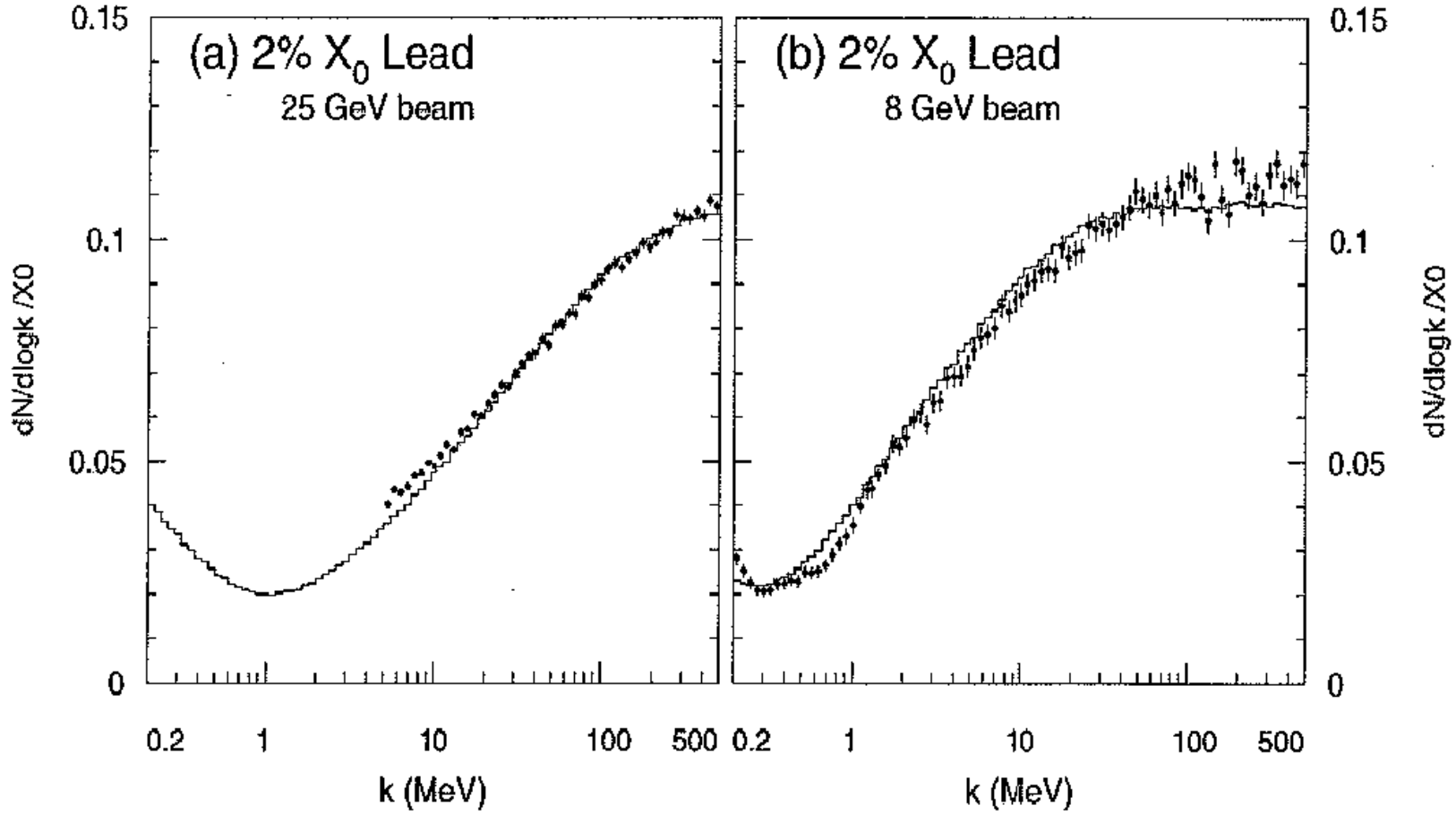
Bragg curve. More energy per unit length are deposit towards the end of trajectory rather at its beginning.



Bremsstrahlung

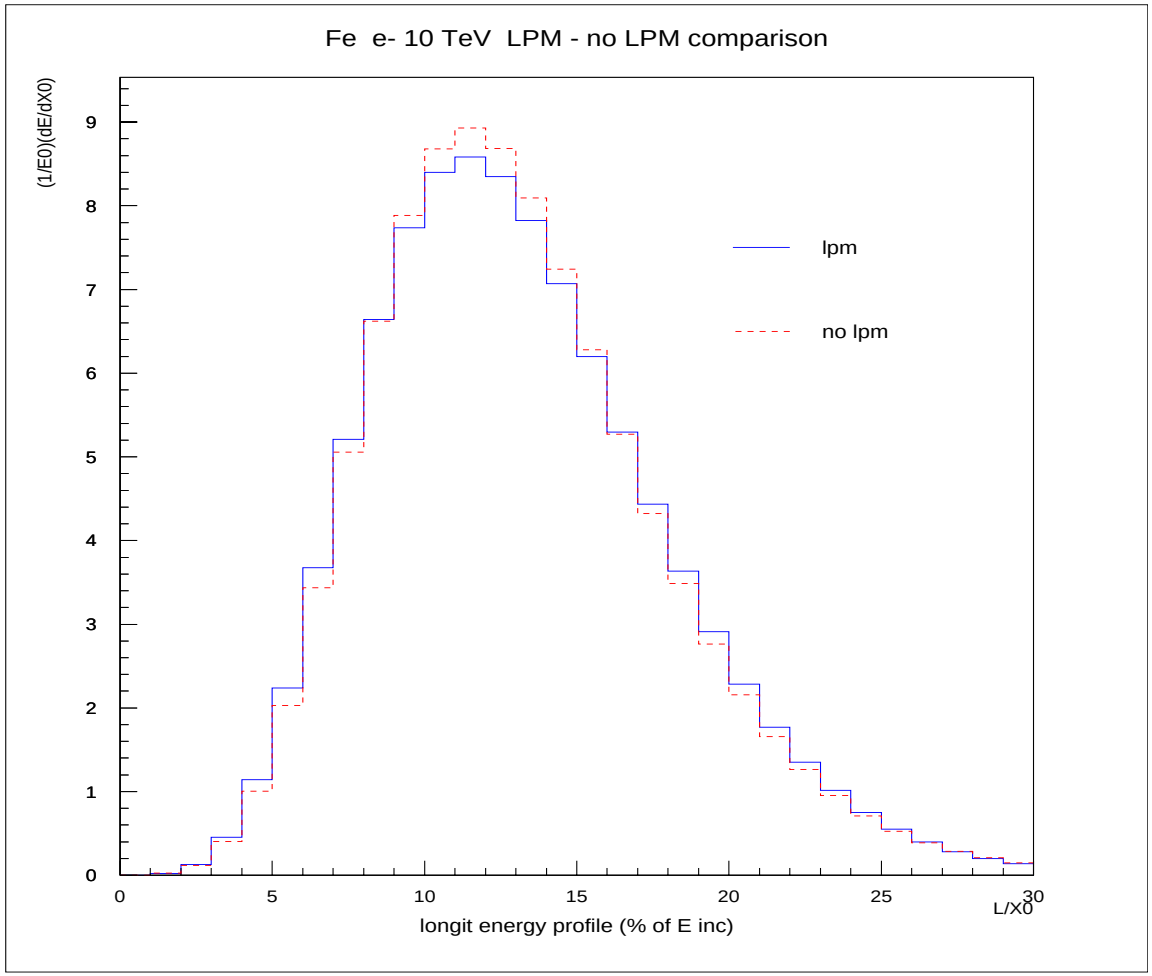

e- 10 Gev in Pb. Bremsstrahlung: gamma spectrum
evts
x 10 -3
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-2
-1
0
1
2
3
4
log10(E(MeV))
no LPM
with LPM
energy distribution of photons at z=zplot

E146 (SLAC) data

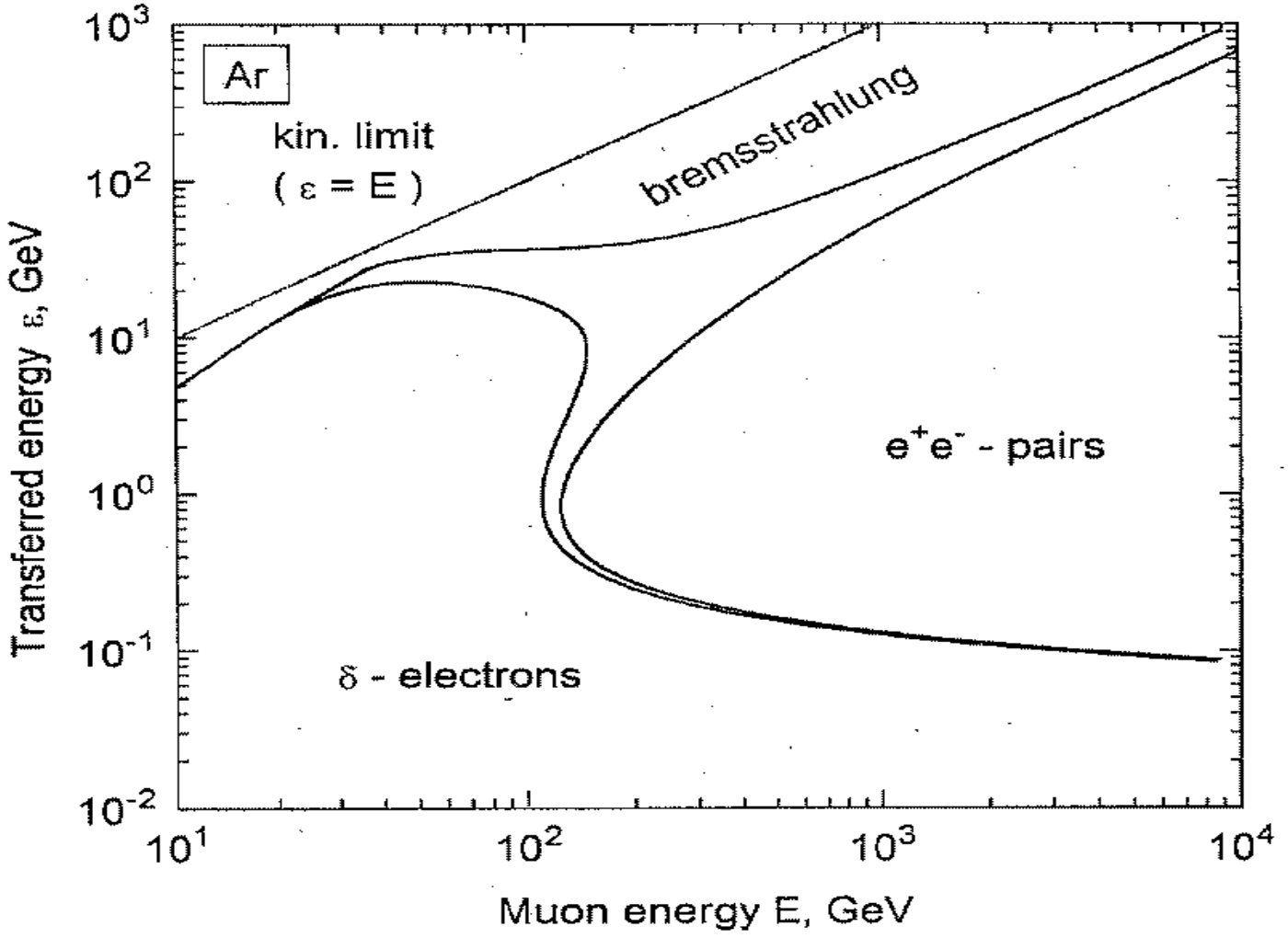


At high enough energies, the LPM effect can cause signifiant elongation of electromagnetic cascades ...

apparently, not yet at 10 TeV ...



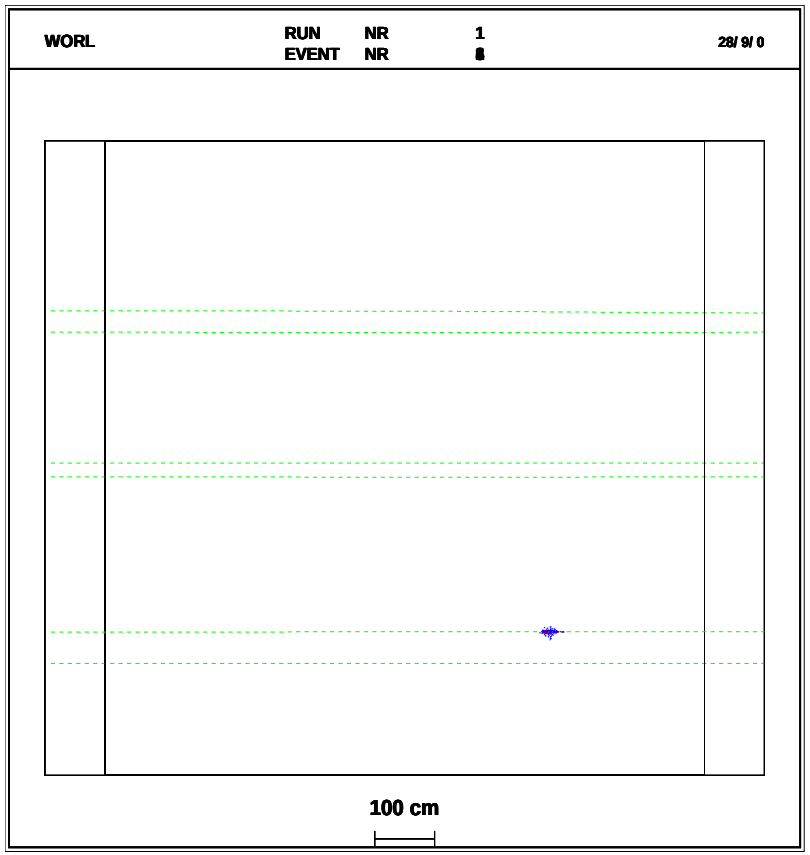
high energy muons

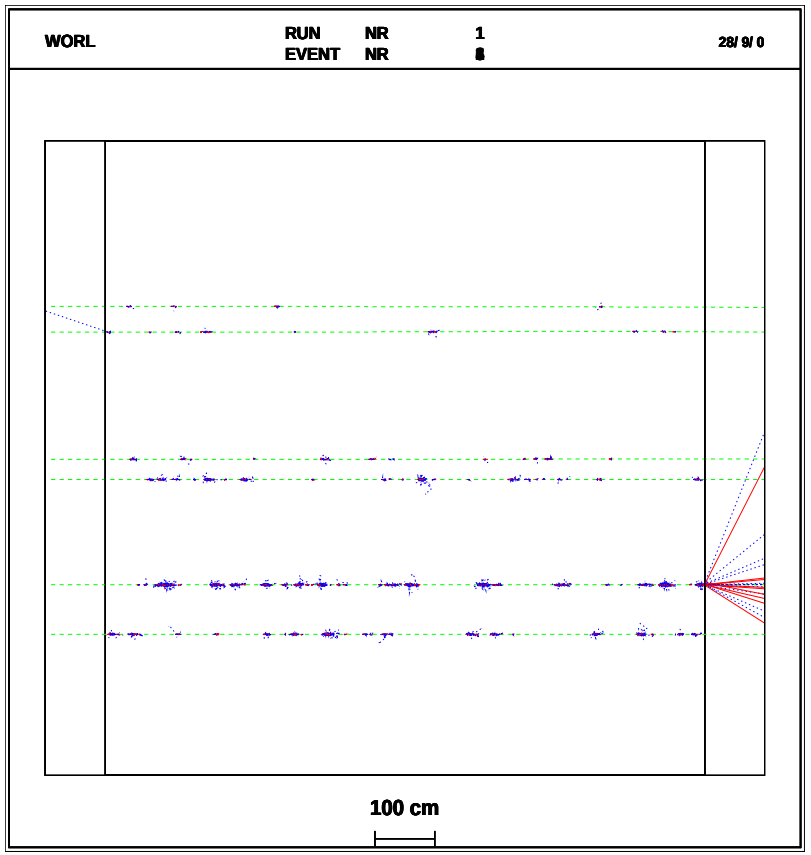

Ar
kin. limit
(ε = E)
bremsstrahlung
e+e- - pairs
δ - electrons
Transferred energy ε, GeV
Muon energy E, GeV
10^3
10^2
10^1
10^0
10^-1
10^-2
10^1
10^2
10^3
10^4

10 meter of Fe : muons 100 GeV, 1 TeV, 5 TeV.

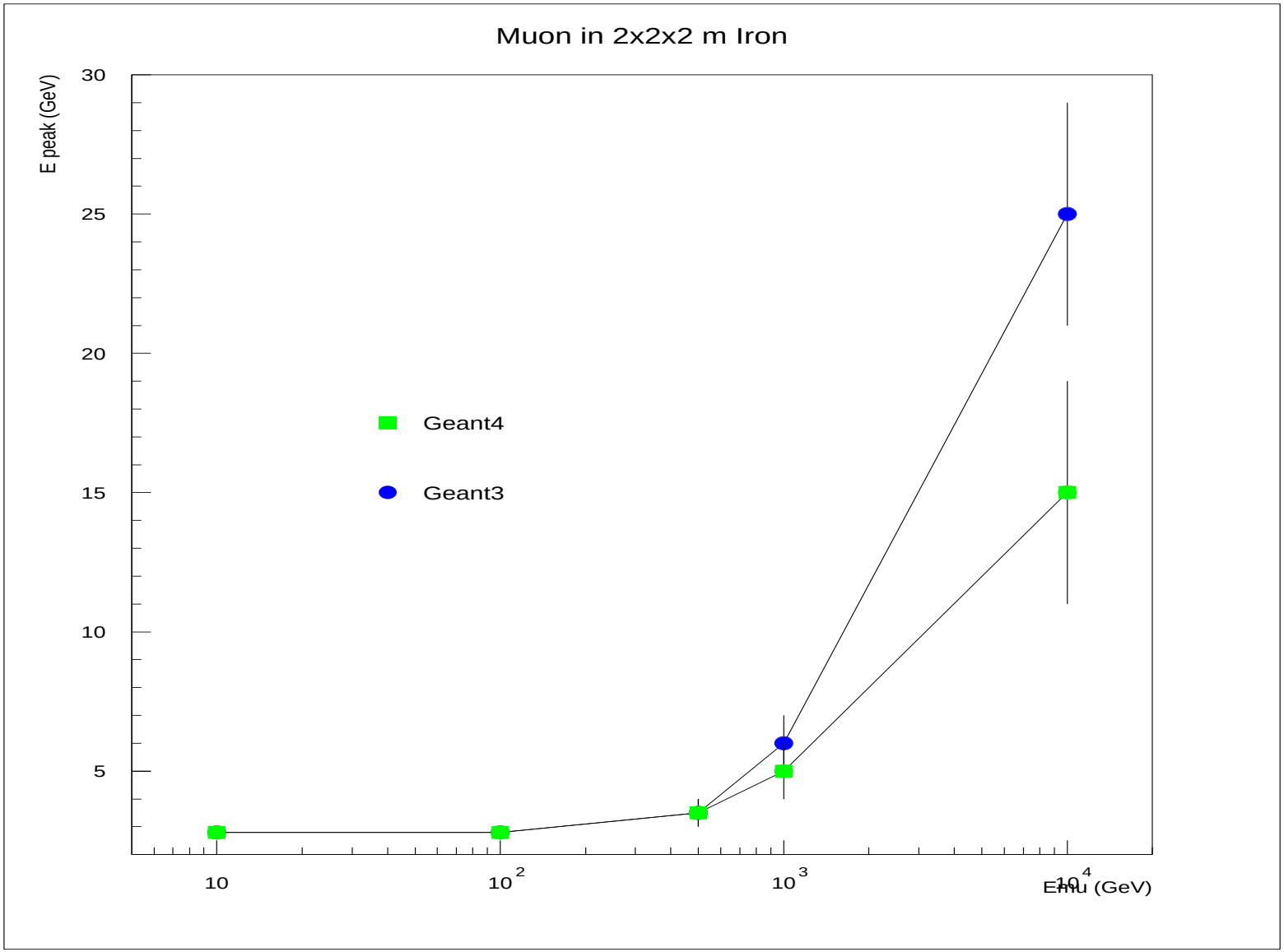
left : brems only

right : brems + direct pair creation

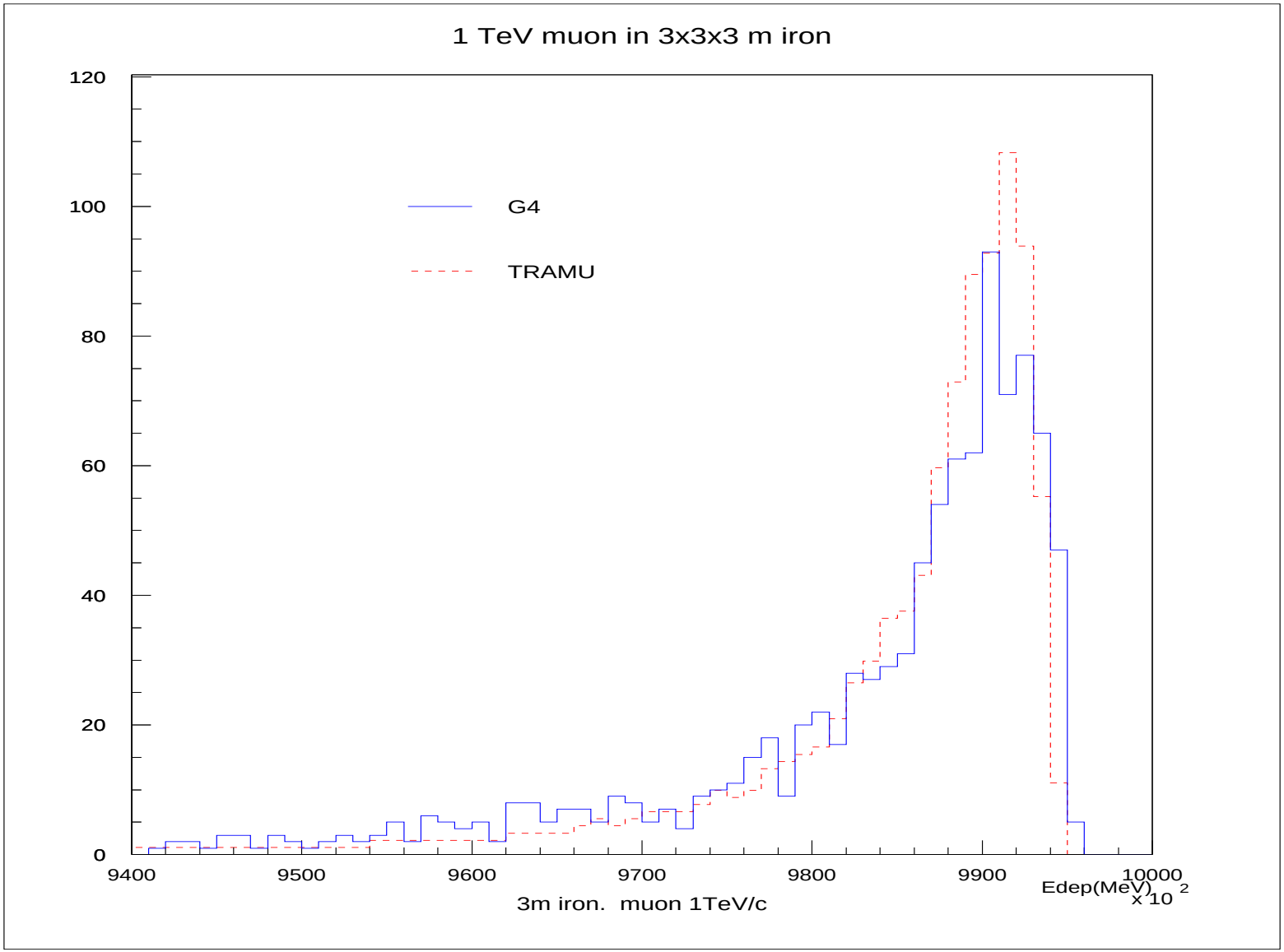




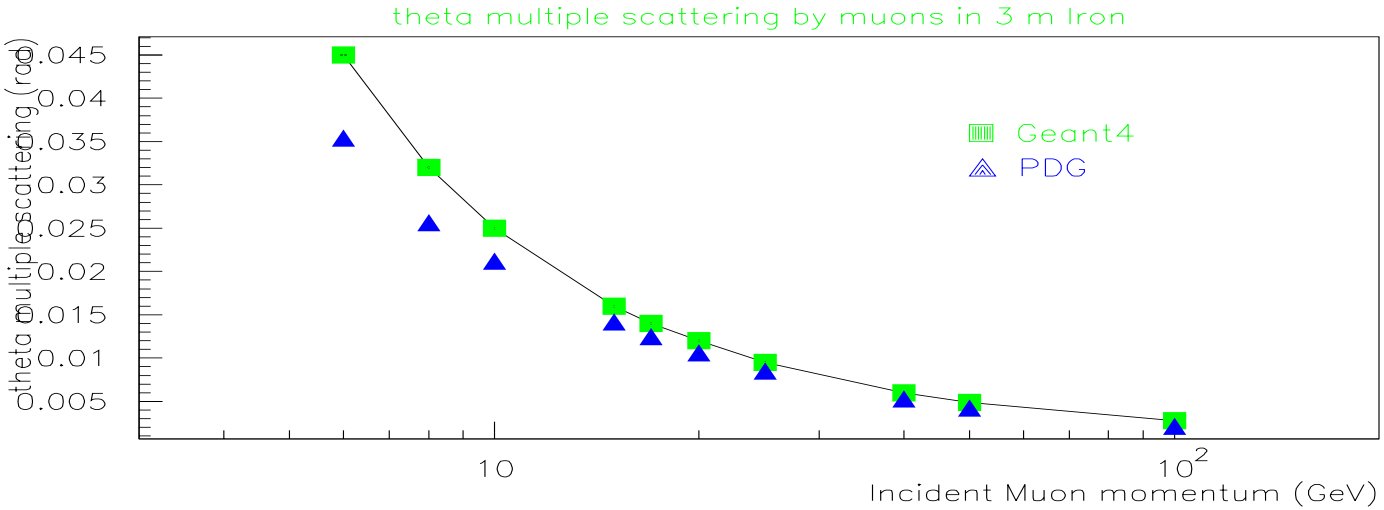
energy deposited by high energy muons in a bloc of Iron

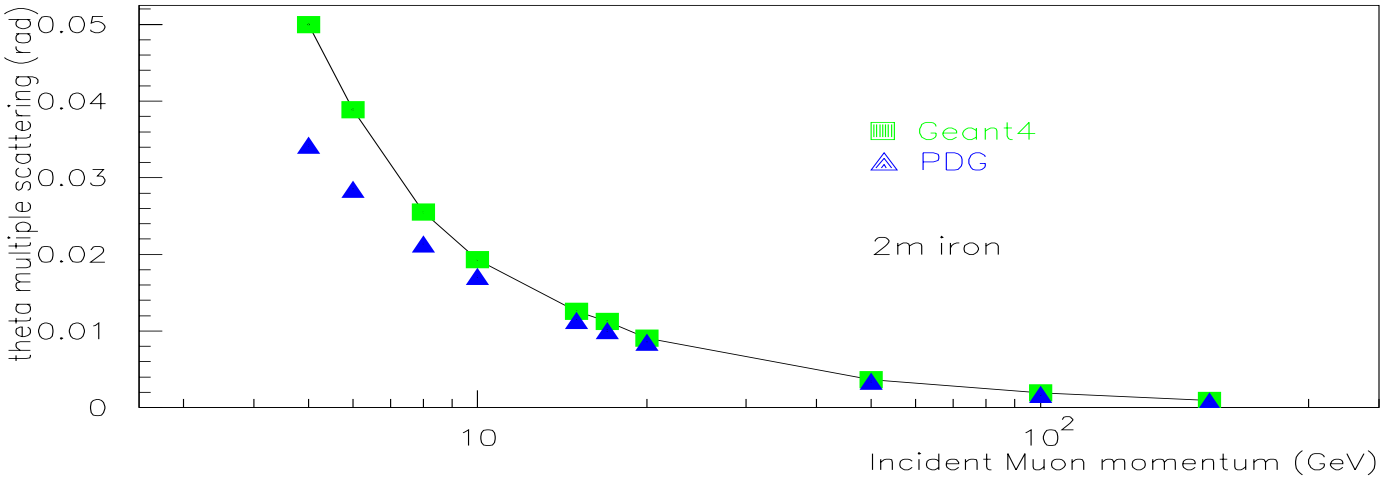


energy spectrum of 1 TeV muons after 3 m of iron



scattered angle of muons through a bloc of Iron





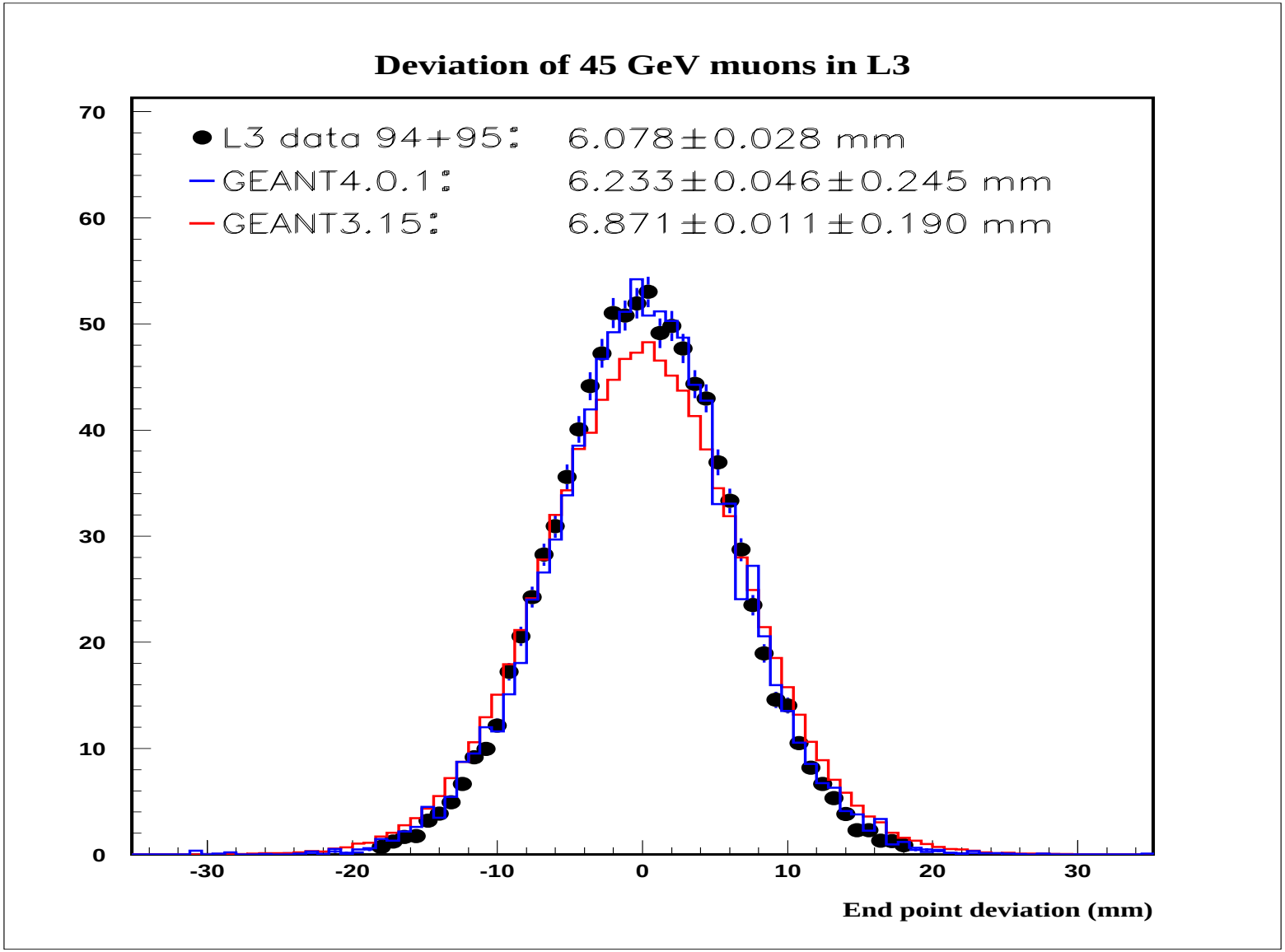
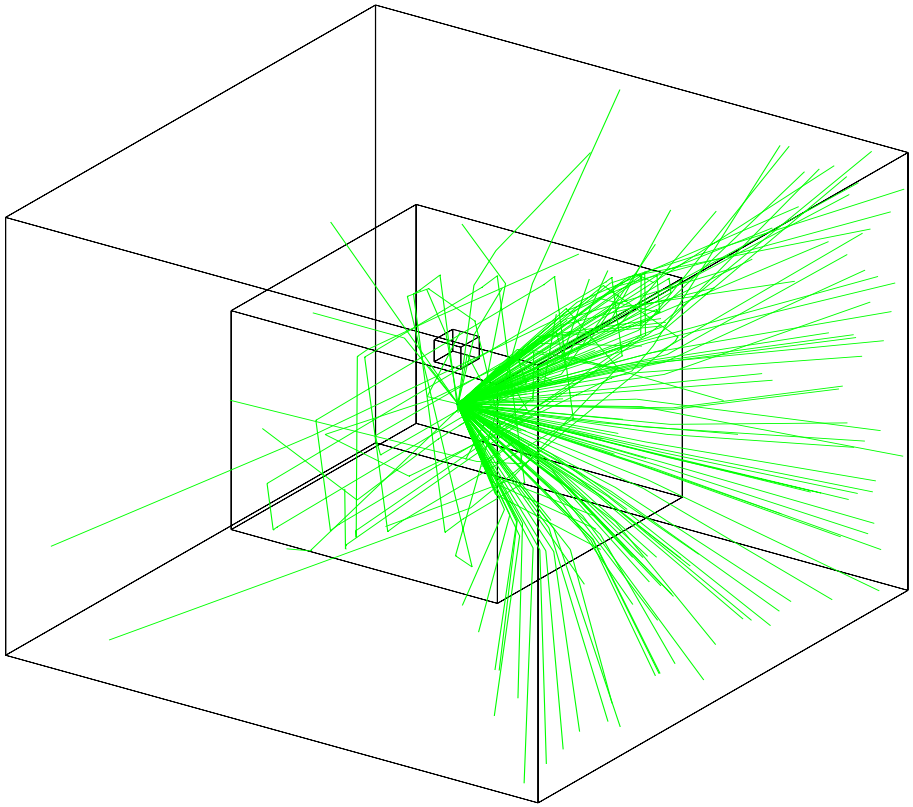

Deviation of 45 GeV muons in L3
L3 data 94+95: 6.078±0.028 mm
GEANT4.0.1: 6.233±0.046±0.245 mm
GEANT3.15: 6.871±0.011±0.190 mm
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
End point deviation (mm)

photo absorption ionization and X-ray transition radiation

Optical photons

Cerenkov emission and optical photons in water

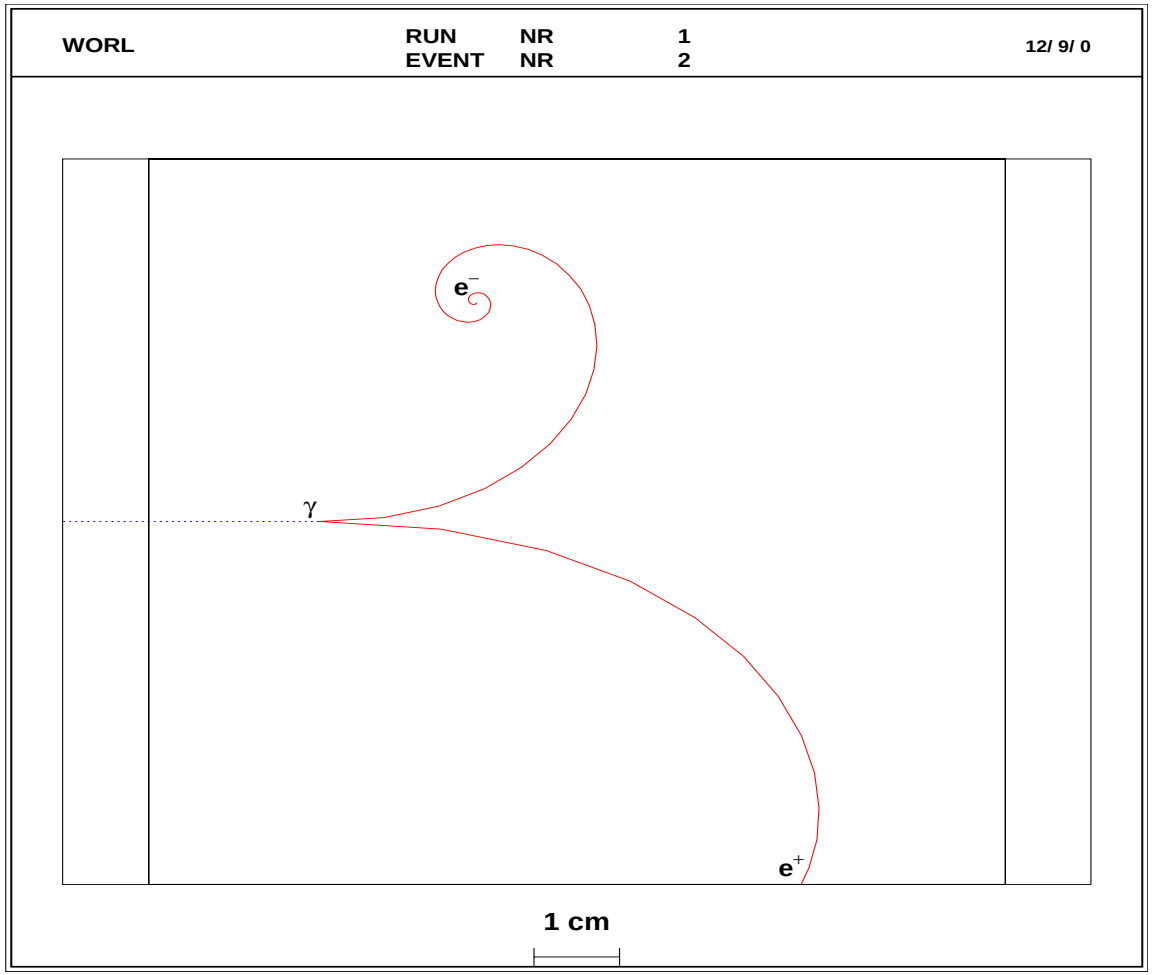


exercices

- **exercise 1 :** annihilation of a positron
- **exercise 2 :** attenuation of a beam of low energy photons
- **exercise 3 :** electromagnetic cascades
- **exercise 4 :** ionization
- **exercise 5 :** multiple Coulomb scattering
- **exercise 6 :** high energy muons

gamma conversion in (e^+, e^-)

this is the gamma conversion into (e^+, e^-), within a given material



question 1 : Starting from examples/novice/N03 :

$\longrightarrow$ choose a material, a thickness absorber, an energy of the incident γ,

$\longrightarrow$ and play with the commands :

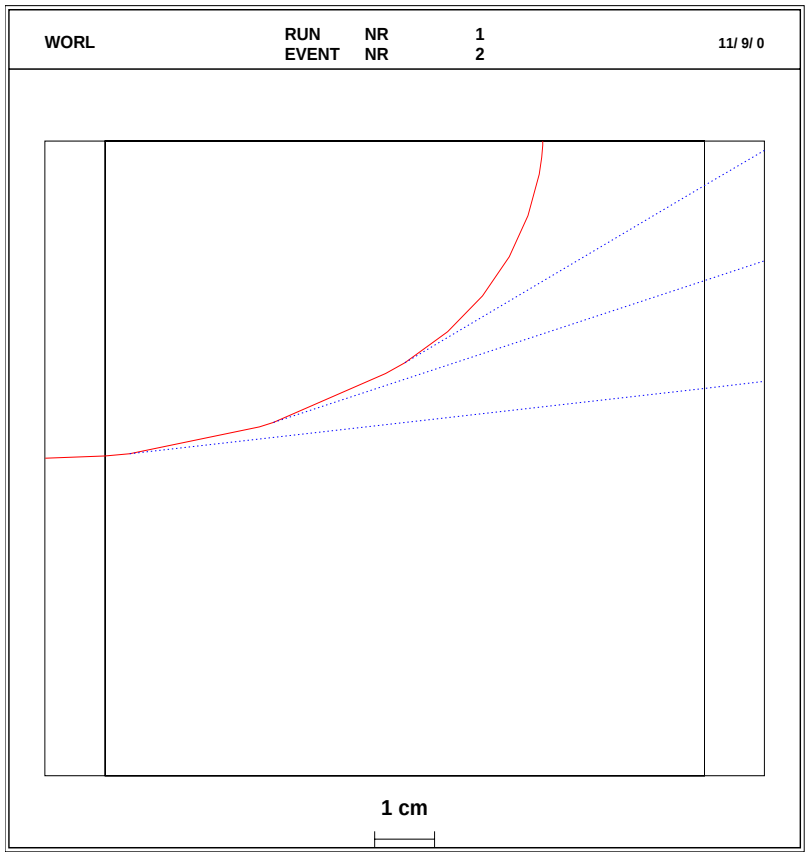
/process/list

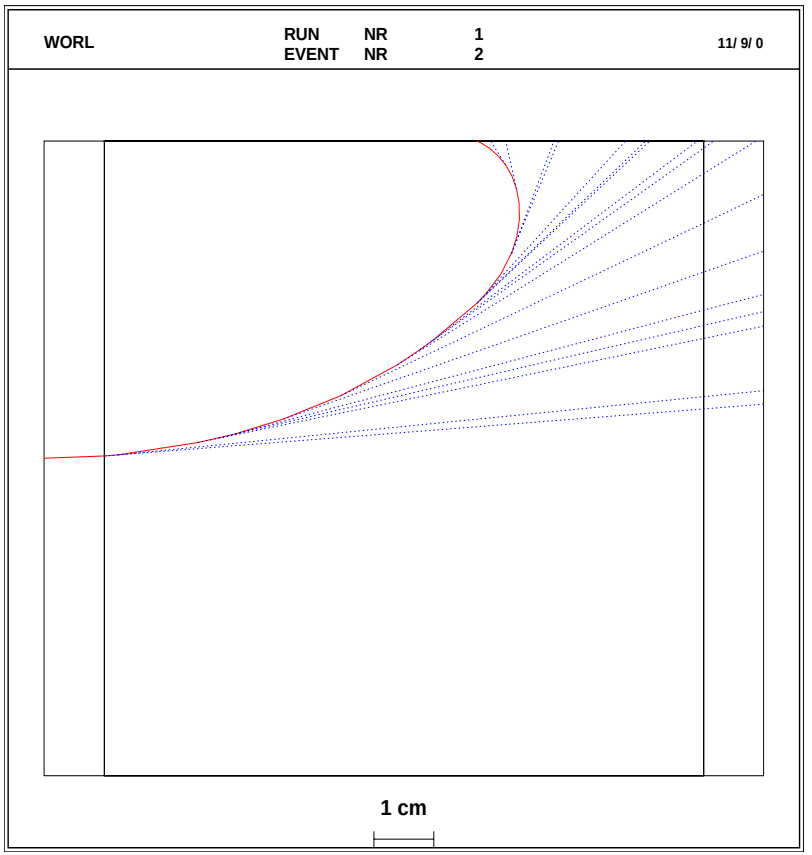
/process/(in)activate

in order to produce similar picture.

Bremsstrahlung

emission of photons bremsstrahlung by an incident e^- in a given material, with two different production cuts.





question 2 : Starting from examples/novice/N03 :
$\longrightarrow$ choose a material, a thickness absorber, an energy of the e^-,
$\longrightarrow$ and play with the commands :

/process/list
/process/(in)activate
/run/particle/setCut

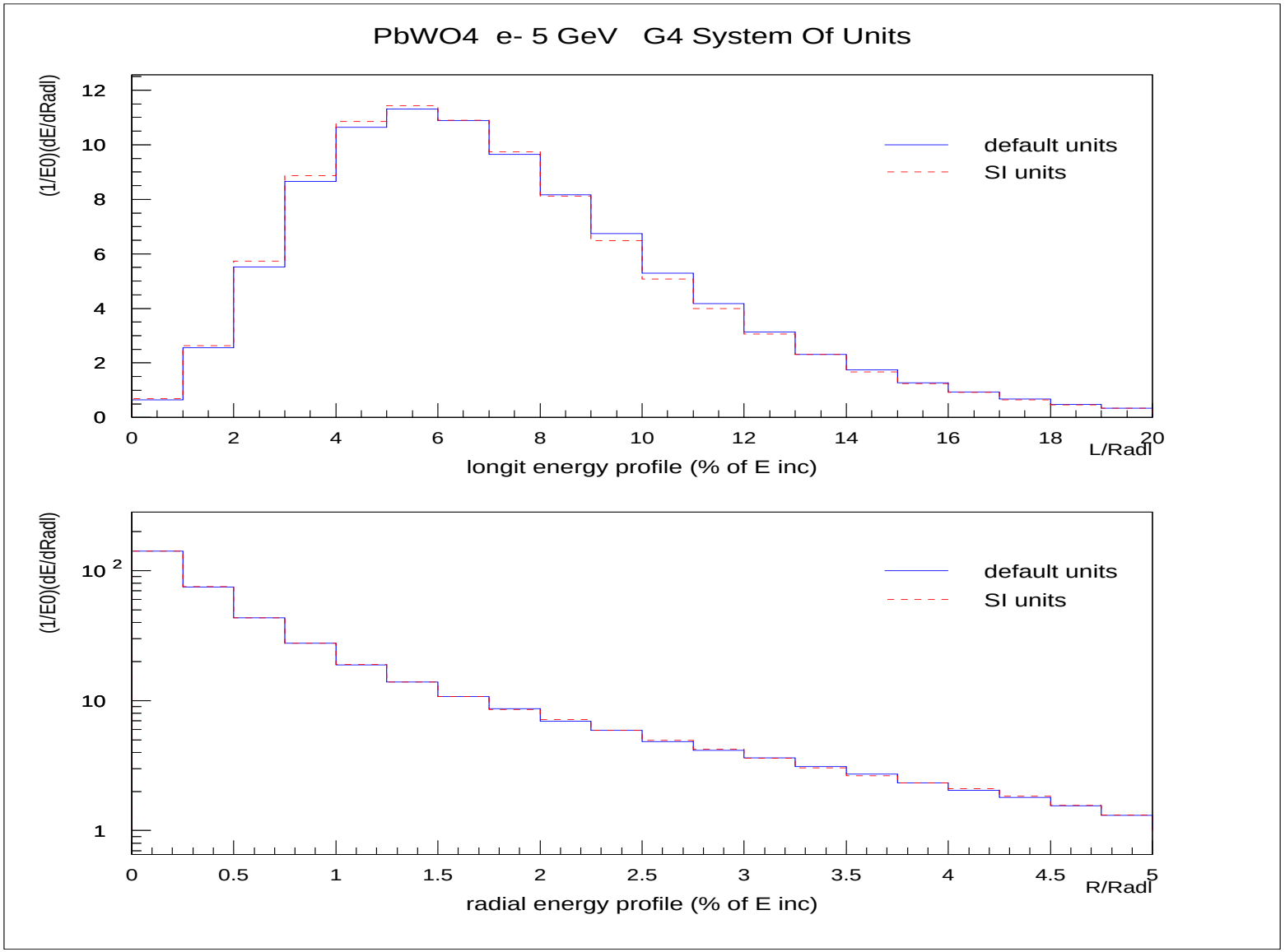
in order to produce similar pictures.

nota bene : after changing the production threshold cut, one must recompute some cross section tables with /run/initialize

What is the radius of the electron track ?

system of units

shower profiles: independence from the system of units



Conclusions

Summary

1999

- suite of public benchmarks-examples
- web gallery dedicaced to EM physics and results
- development : subcutoff δ-rays

2000

- first feedback from users. Beginning of comparison projects
- Calor2000
  - first results from Collaborations (Atlas, CMS)
  - talk on EM physics $\longrightarrow$ exercices as part of the general GEANT4 tutorial

- developments
  - multiple scattering
  - revision of Bremsstrahlung : 10 $keV \longrightarrow 1\ keV$
  - LPM effect
  - Photo Absorption Ionisation process
  - X-rays transition radiation models, in connection with Atlas
- documentation : deep revision of the muon section of the physics reference manual

Prospective : near and far future

- feedback from users + comparison projects ..etc.. :
  wait and see ..
- deep understanding of the implications of the new concepts :
  - cut in range : only one ?
  - subcutoff δ rays : generalisation to photons from Bremsstrahlung ?
  - multiple scattering model
- completion of the photo electric effect : $10keV \longrightarrow\sim 1keV$
- astro-particles : coherent physics scheme above $\sim PeV$ (?)
- develop an interactive course on particle-matter interactions ...

Contributors (past,present)

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- Rostislav Kokoulin (MEPhI, Moscow)
- Veronique Lefebure (CMS, Cern)
- Vincente Lara (Valencia University)
- Vladimir Grichine (Lebedev Institute, Moscow)
- Vladimir Ivantchenko (Budker Institute, Novosibirsk)