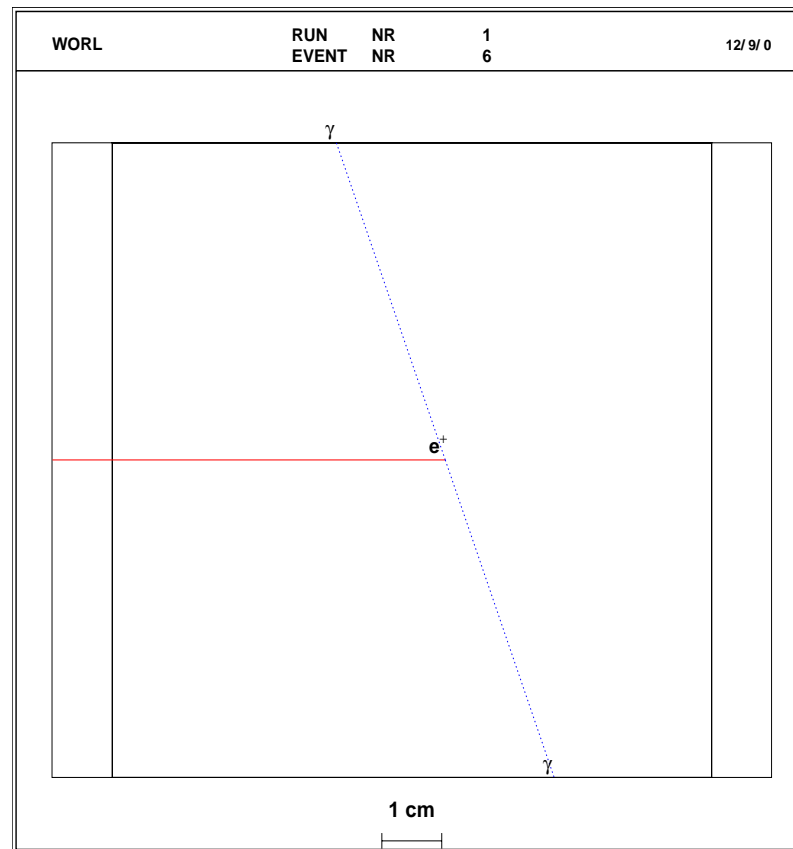
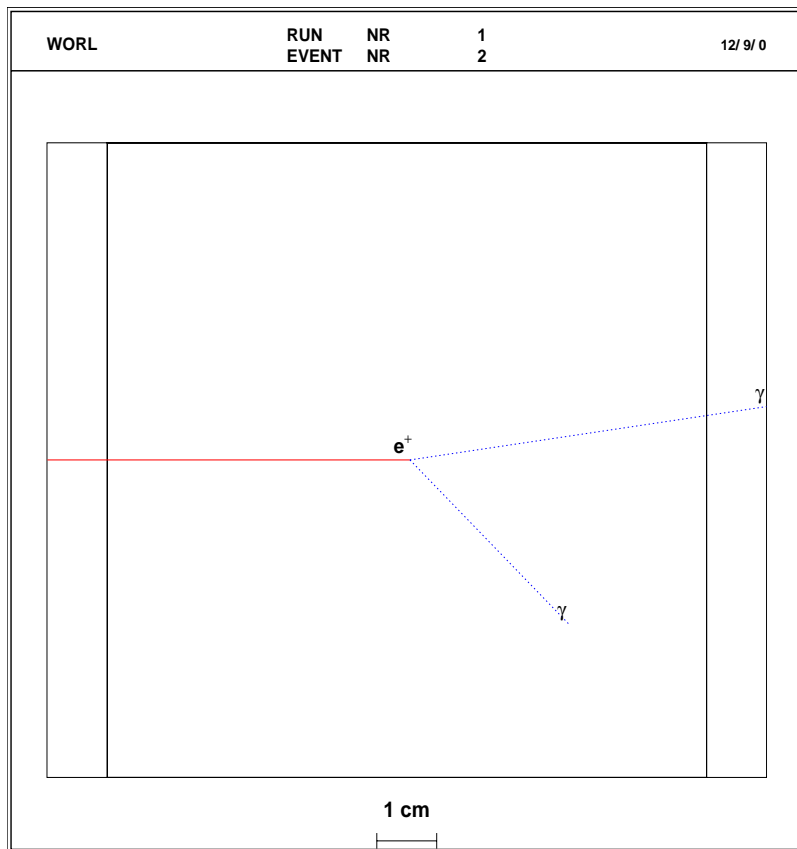


- **exercise 1** : annihilation of a positron
- **exercise 2** : attenuation of a beam of low energy photons
- **exercise 3** : electromagnetic cascades
- **exercise 4** : ionization
- **exercise 5** : multiple Coulomb scattering
- **exercise 6** : high energy muons

annihilation of a positron

(e^+, e^-) annihilation into two photons

this is the annihilation of a positron in fly (left), or at rest (right), within a given material.



Start from [examples/novice/N03](#)

- choose a material, a thickness absorber, an energy of the e^+
- play with the commands :

`/process/list`

`/process/(in)activate`

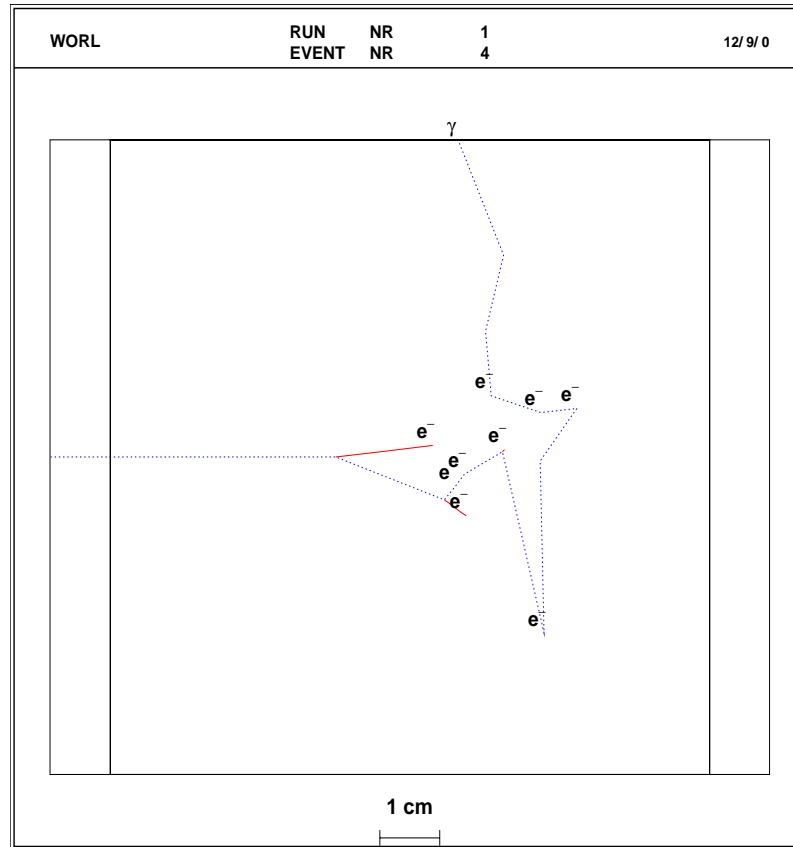
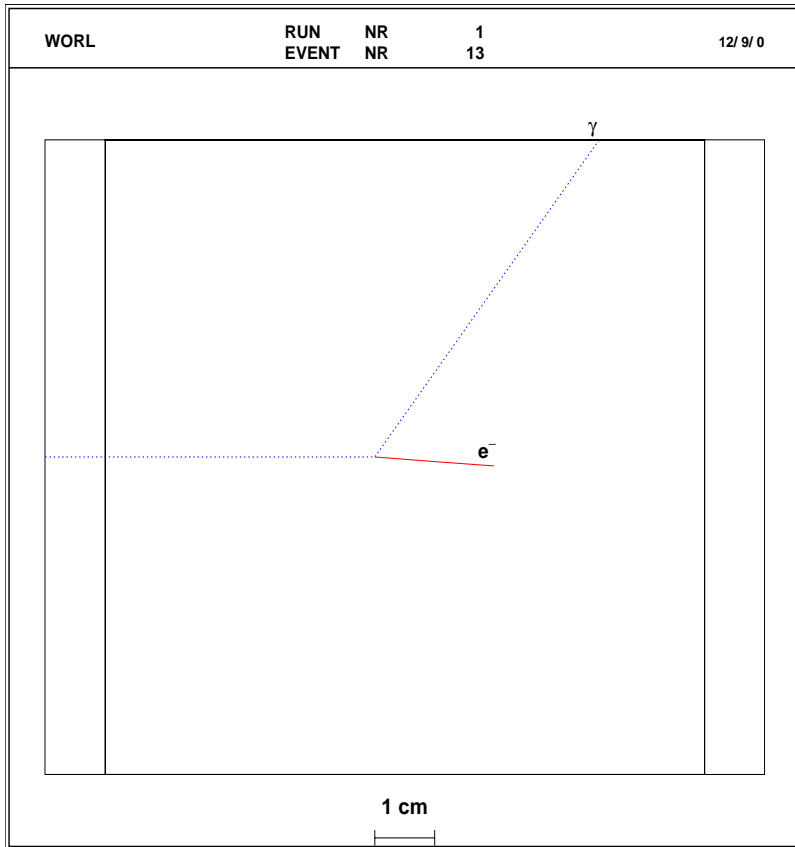
in order to produce similar pictures.

attenuation of a beam of low energy photons

Compton scattering

an incident photon scatters off an electron of the atom. The deviation of the photon may be large.

The photon can suffer several Compton scattering.



question 1

Start from [examples/novice/N03](#)

- choose a material, a thickness absorber, an energy of the incident photon
- play with the commands :

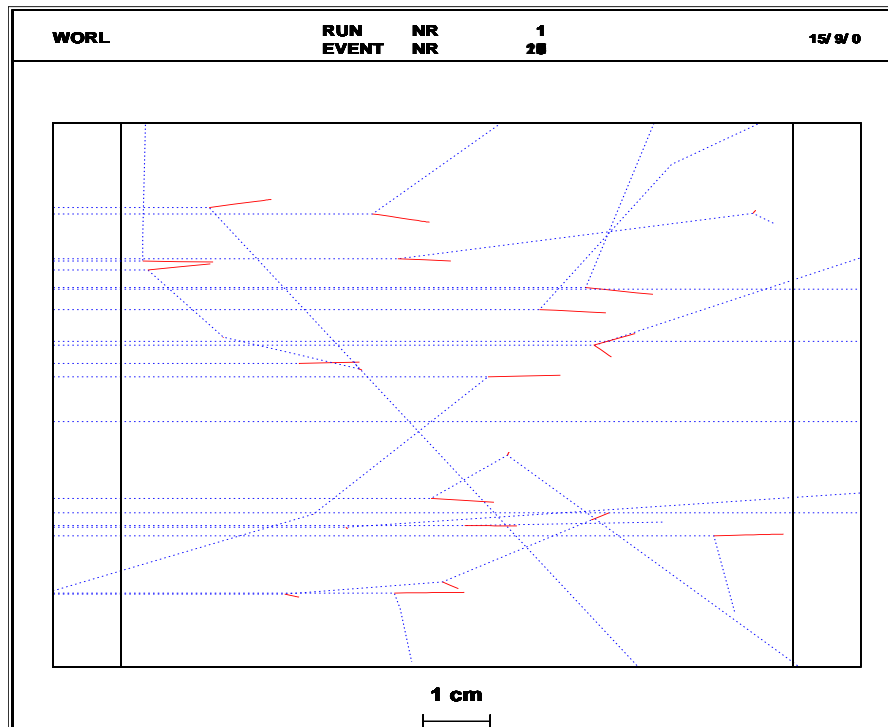
`/process/list`

`/process/(in)activate`

in order to produce similar pictures.

total photon attenuation

In addition, a low energy photon can also make a photo electric effect.
 Here, an incident beam a 20 monenergetic photons, randomly distributed.
 Only 4 **unaltered** photons exit the absorber.



question 2

with the same setup, use the commands :

```
/process/list  
/process/(in)activate  
/gun/random
```

in order to produce similar pictures.

What is the energy of the undeviated photons ?

(look in N03PrimaryGeneratorAction the implementation of the command /gun/random)

question 3

(need a histograming tool)

With high statistic, fill an histogram which illustrates the attenuation law:

$$\Phi(x) = \Phi(0) \exp(-x/\lambda)$$

where $\Phi(x)$ is the flux of the photon beam at thickness x .

(look at : examples/extended/electromagnetic/TestEm3 or TestEm4 for the examples of histograms. See readme.)

From the histogram, evaluate the **photon attenuation length** λ .

Check your result in the Particle Data Book, or at

<http://physics.nist.gov>

additional work

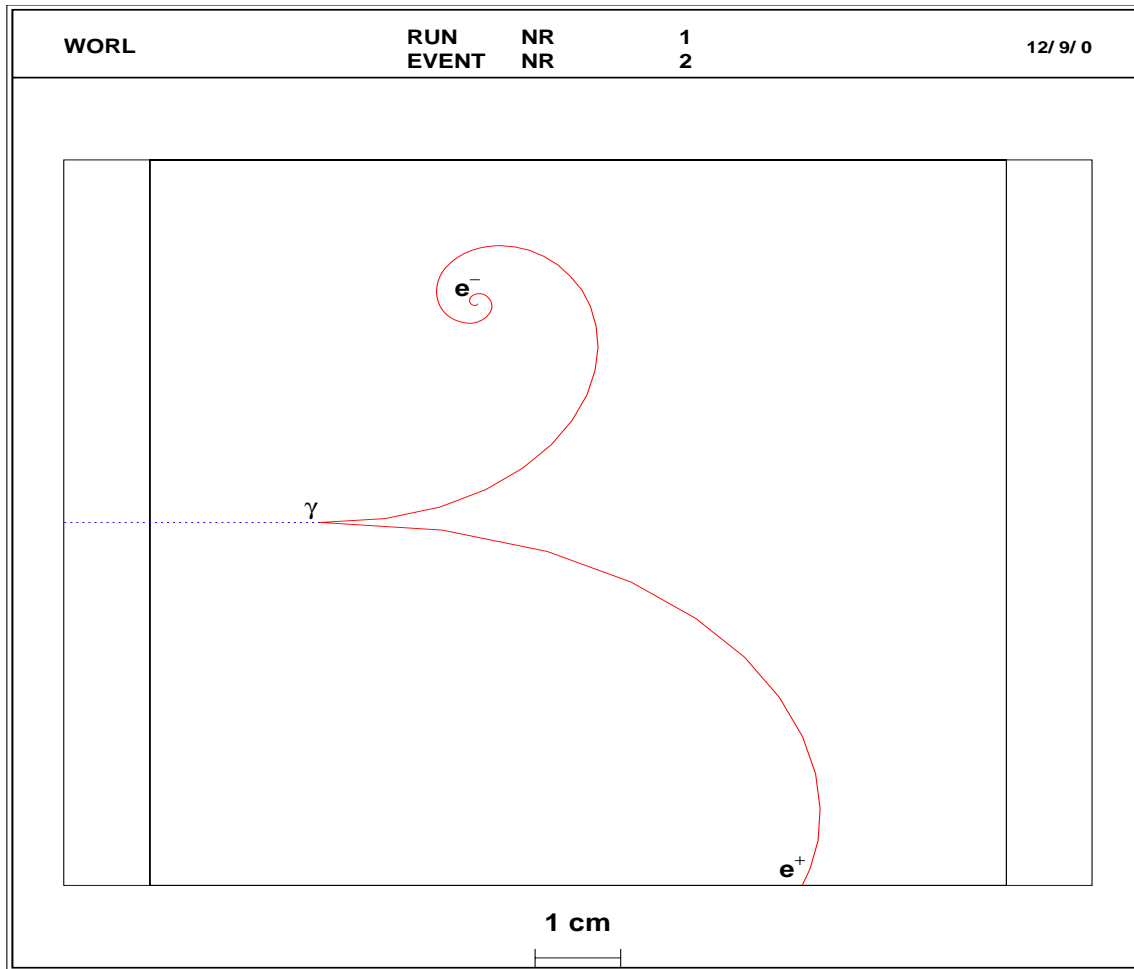
run `examples/extended/electromagnetic/TestEm4` both interactively (see readme) and in batch.

Analyse the histogram of the energy deposition.

electromagnetic cascades

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

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



question 1

Start from [examples/extended/electromagnetic/TestEm3](#)

See readme for interactive run with visualisation.

- choose a material, a thickness absorber, an energy of the incident γ
- play with the commands :

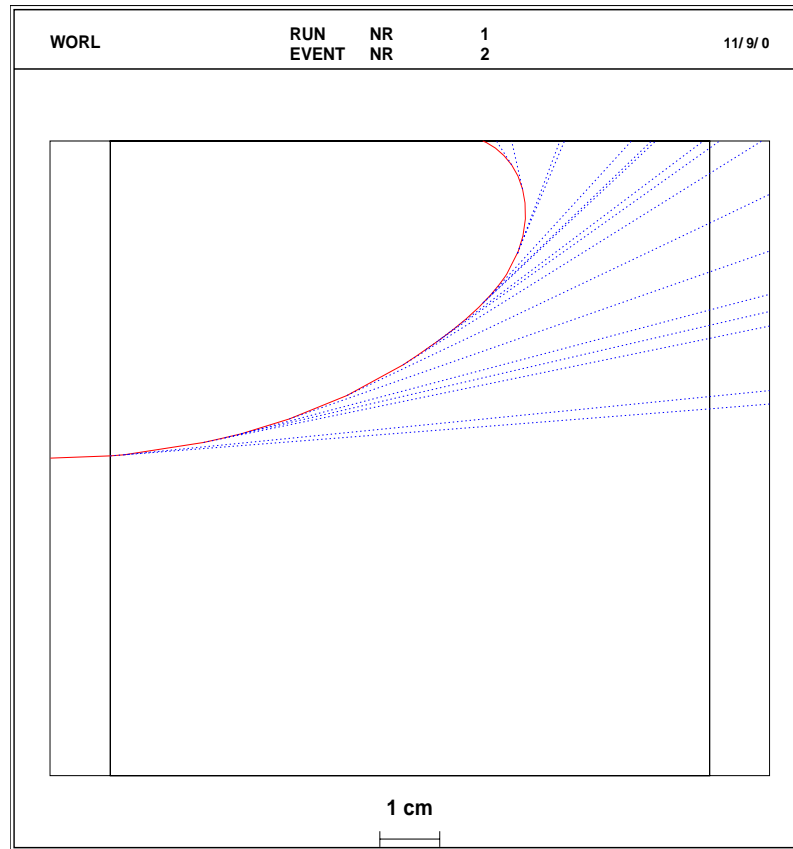
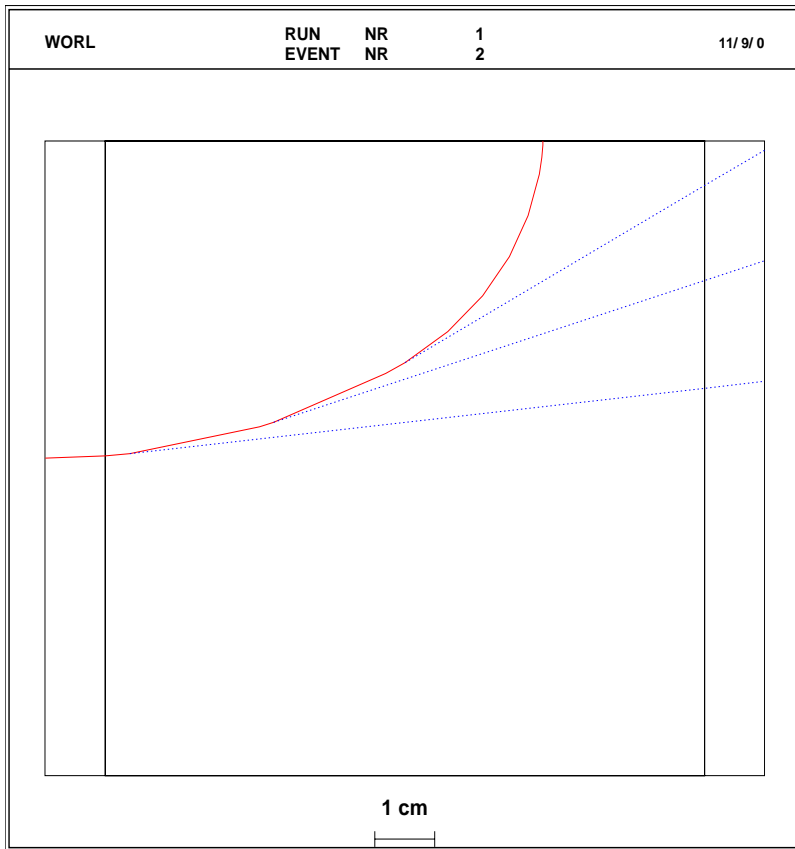
`/process/list`
`/process/(in)activate`

in order to produce similar picture.

Hint : see in `Em3DetectorMessenger` the list of available UI commands.

Bremsstrahlung

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



question 2

Start from `examples/extended/electromagnetic/TestEm3`

- choose a material, a thickness absorber, an energy of the e^-
- play with the commands :

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

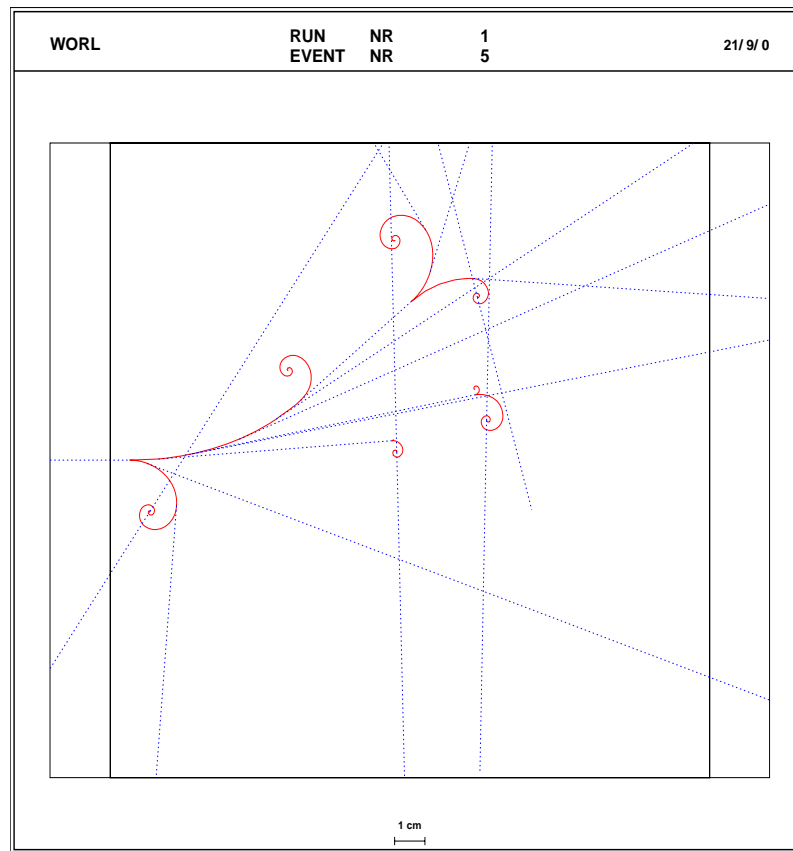
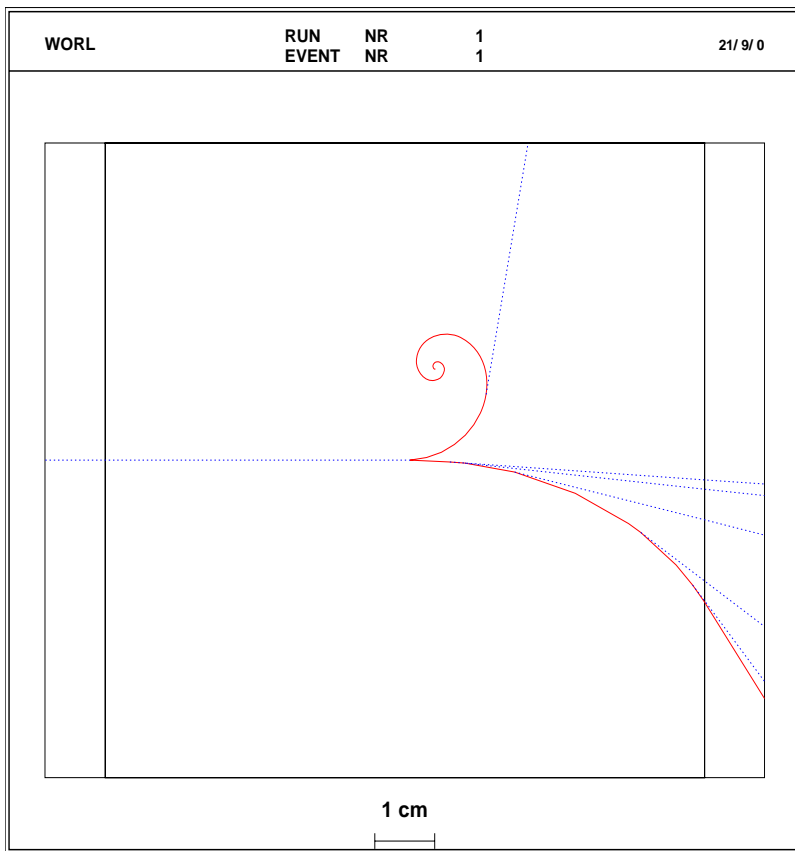
in order to produce similar pictures.

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 ?

cascade

beginning of a cascade induced by an incident γ , in 1 X0 and 2 X0 of a given material



question 3

Start from `examples/extended/electromagnetic/TestEm3`

- choose a material, an energy of the incident γ
- play with the commands :

`/process/list`
`/process/(in)activate`

in order to produce similar pictures.

additional work

run `examples/extended/electromagnetic/TestEm2` to visualize full shower development and to produce and analyse shower profiles.

ionization

Mean rate of energy loss

The Bethe-Bloch formula gives the mean rate of energy loss by moderately relativistic charged particles (other than electrons).

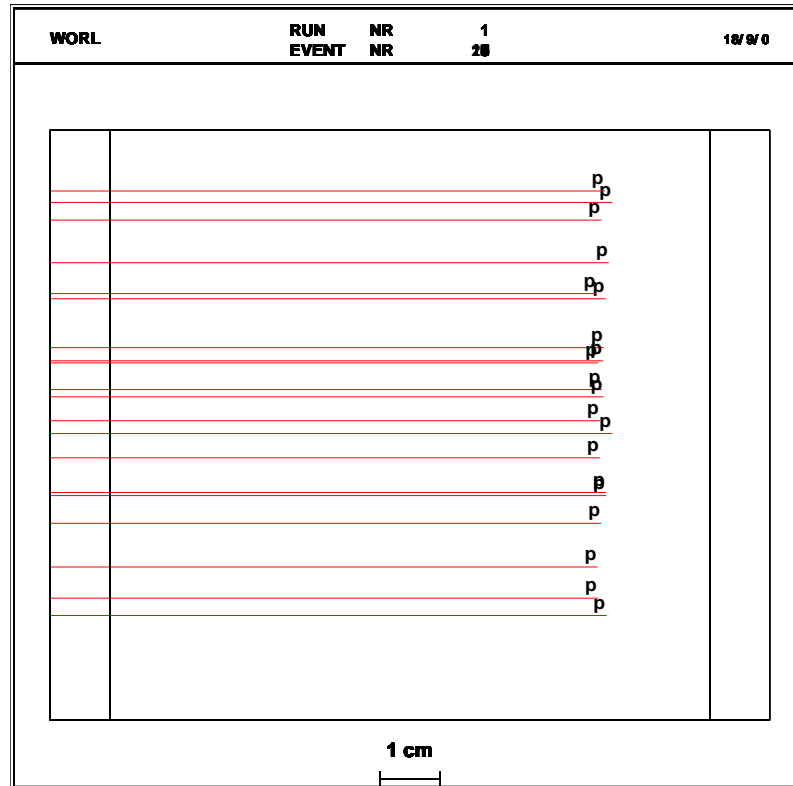
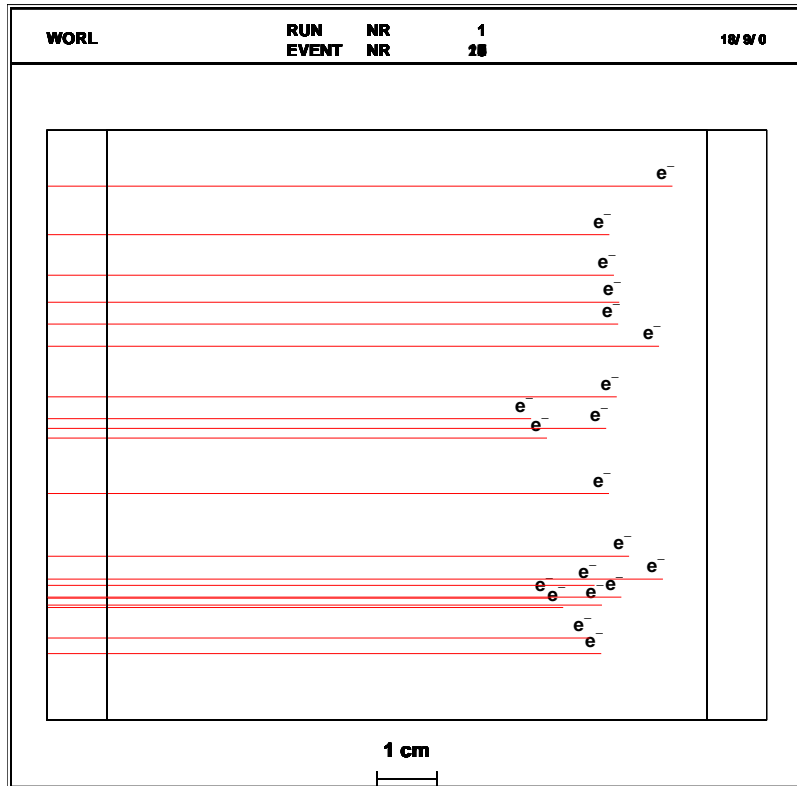
$\langle \Delta E \rangle = (dE/dx) \cdot \Delta x$ gives only the average energy loss by ionization. There are fluctuations. Depending of the amount of matter in Δx the distribution of ΔE can be strongly asymmetric (\rightarrow the Landau tail).

The large fluctuations are due to a small number of collisions with large energy transfers.

Fluctuations on ΔE give fluctuations on the actual range (straggling).

straggling

penetration of monoenergetic e^- and protons in 10 cm of water.



question 1

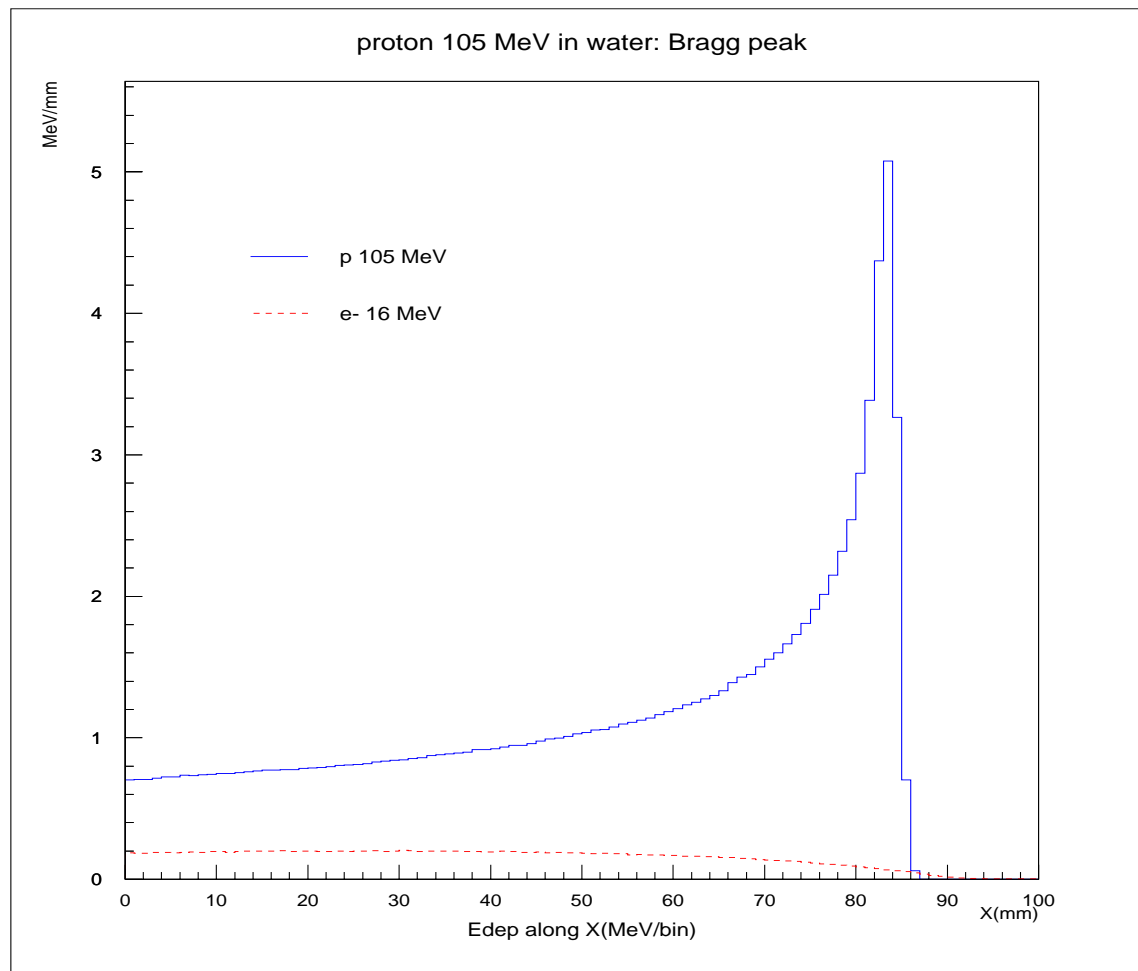
Start from [examples/extended/electromagnetic/TestEm3](#)

- choose the energies of electrons and protons in order to have approximatively the same range
- play with the commands :

/process/list
/process/(in)activate
/gun/rndm

in order to produce similar pictures.

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



question 2

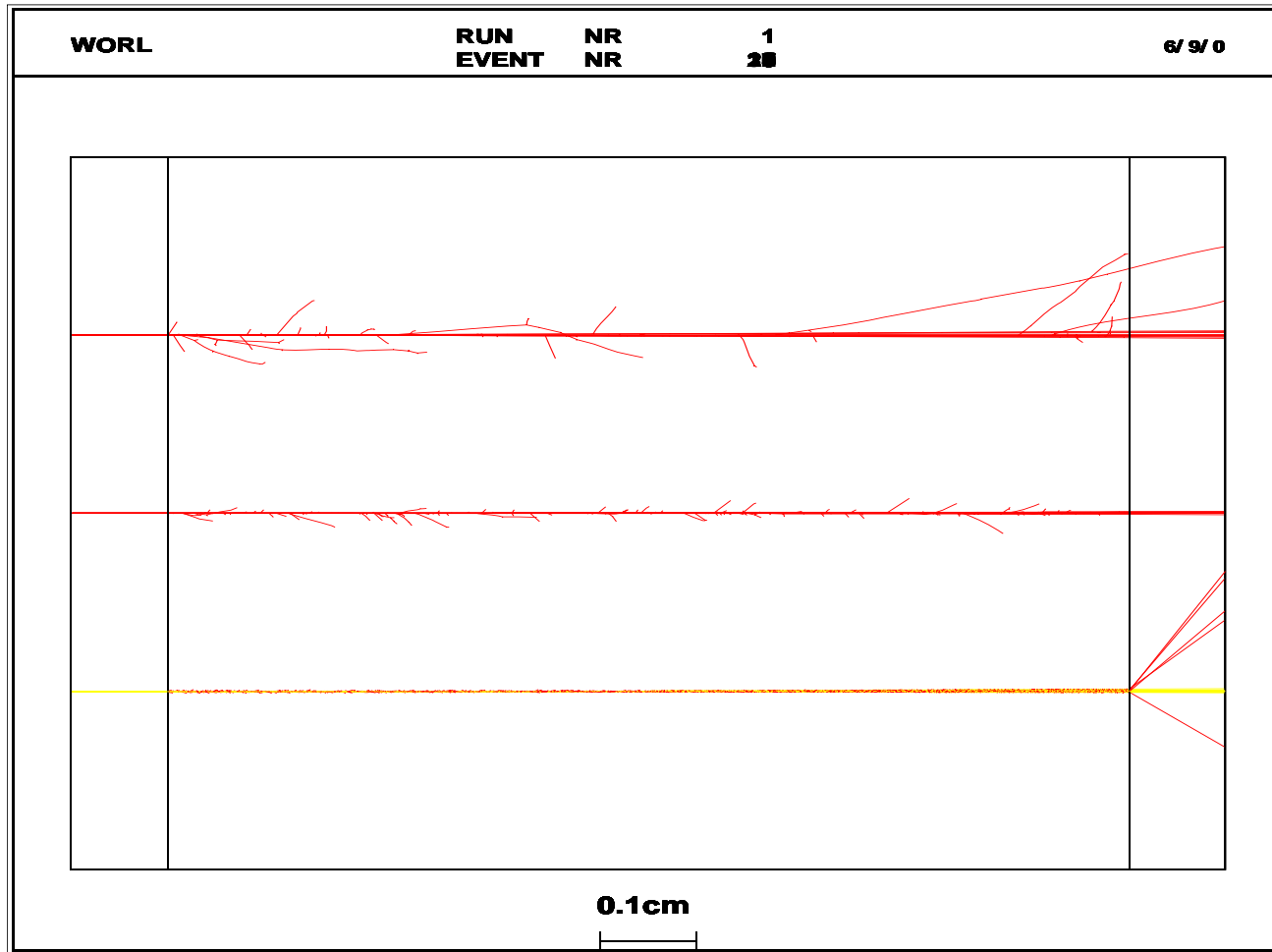
(need a histogramming tool)

With high statistic, fill an histogram which shows the Bragg peak.

hint: divide the absorber in a number of **replicas** equal to the number of bins of the histogram.

visualisation of the delta rays

electrons, protons, alphas of the same energy in a given absorber.



question 3

Start from [examples/extended/electromagnetic/TestEm3](#)

- choose a material, a thickness absorber, an energy of the incident electrons, protons and alpha
- play with the commands :

/process/list
/process/(in)activate
/process/setCut
/gun/position

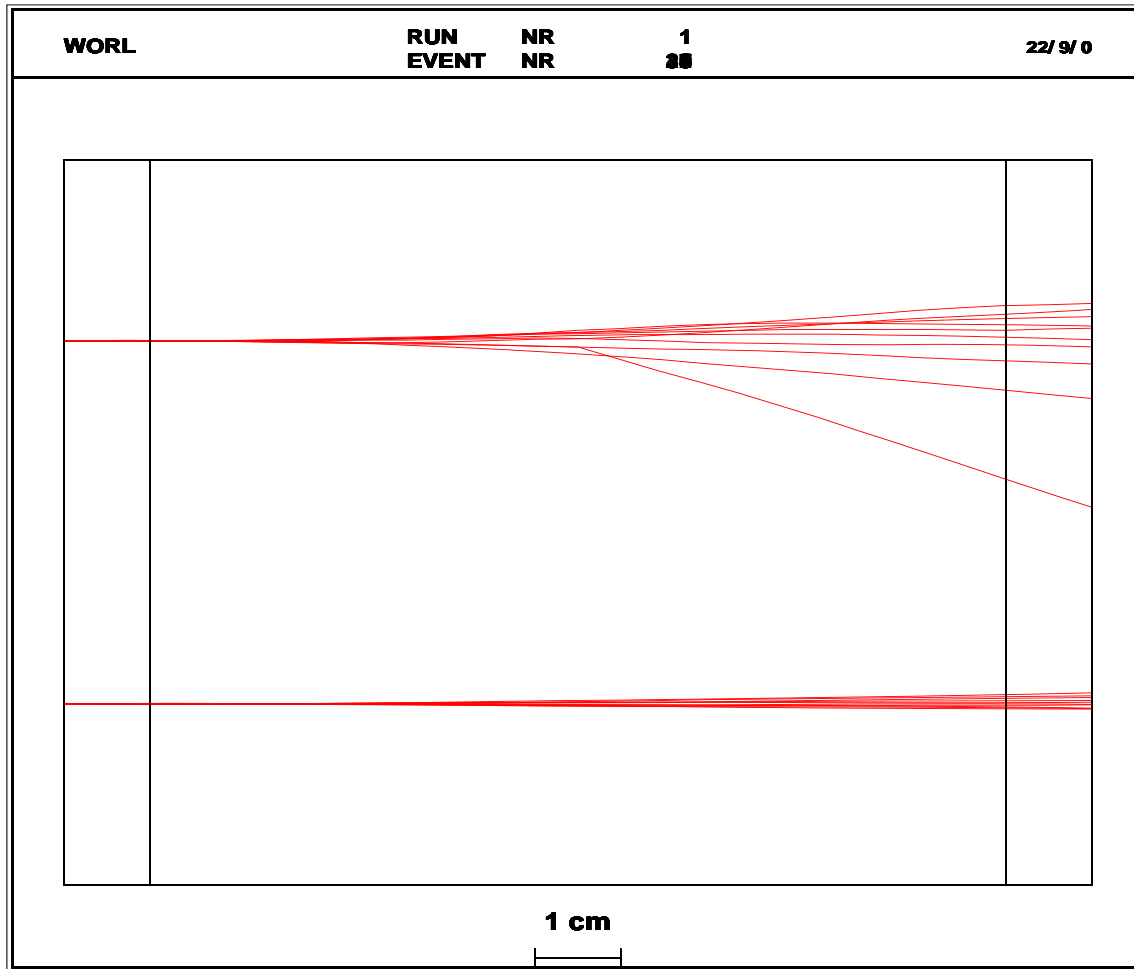
in order to produce similar picture.

What is the value of the maximum transferable energy T_{max} in the 3 cases ?

multiple Coulomb scattering

energy dependence

ponctual beam of $10 \pi^+$, at two different energies



question 1

Start from [examples/extended/electromagnetic/TestEm3](#)

- choose a material, a thickness absorber, two energies of the incident π^+
- play with the commands :

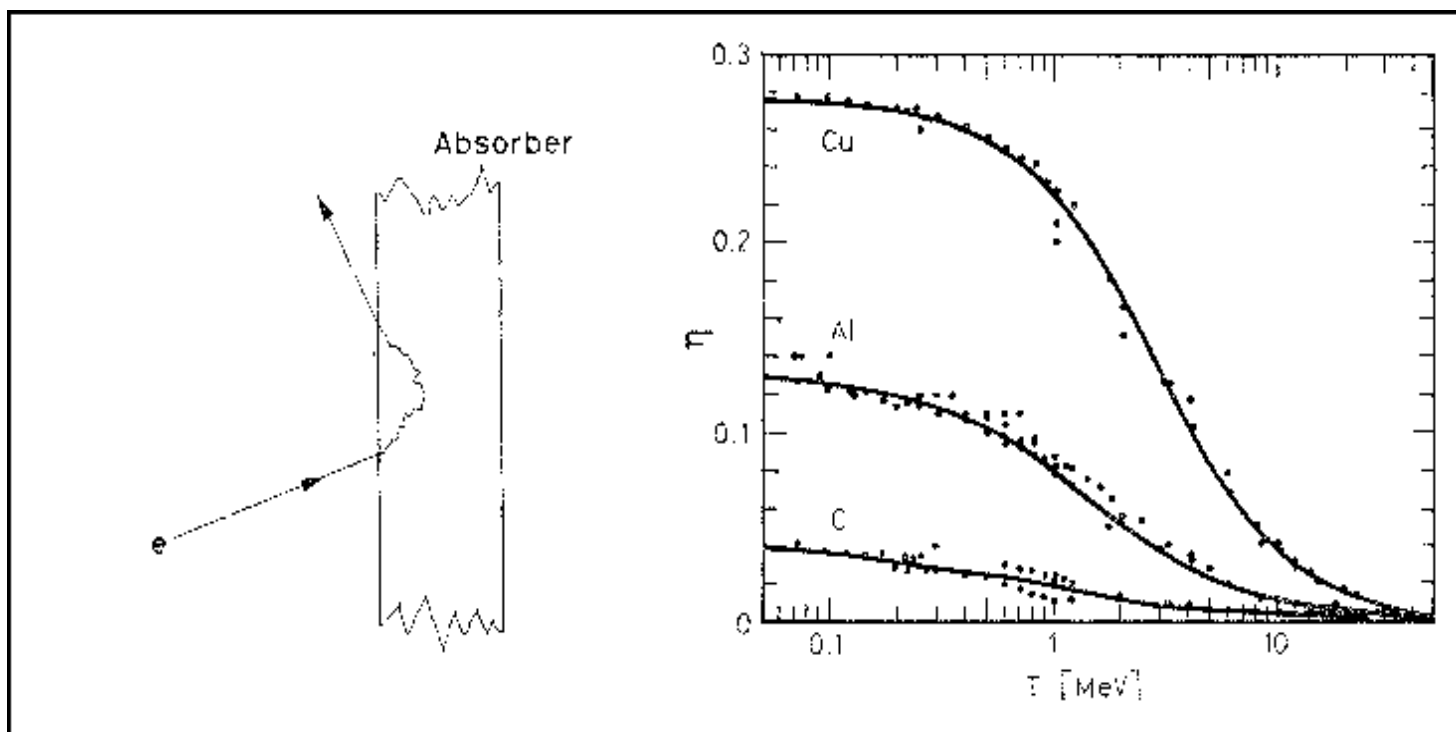
/process/list
/process/(in)activate
/gun/position

in order to produce similar picture.

backscattering of low energy electrons

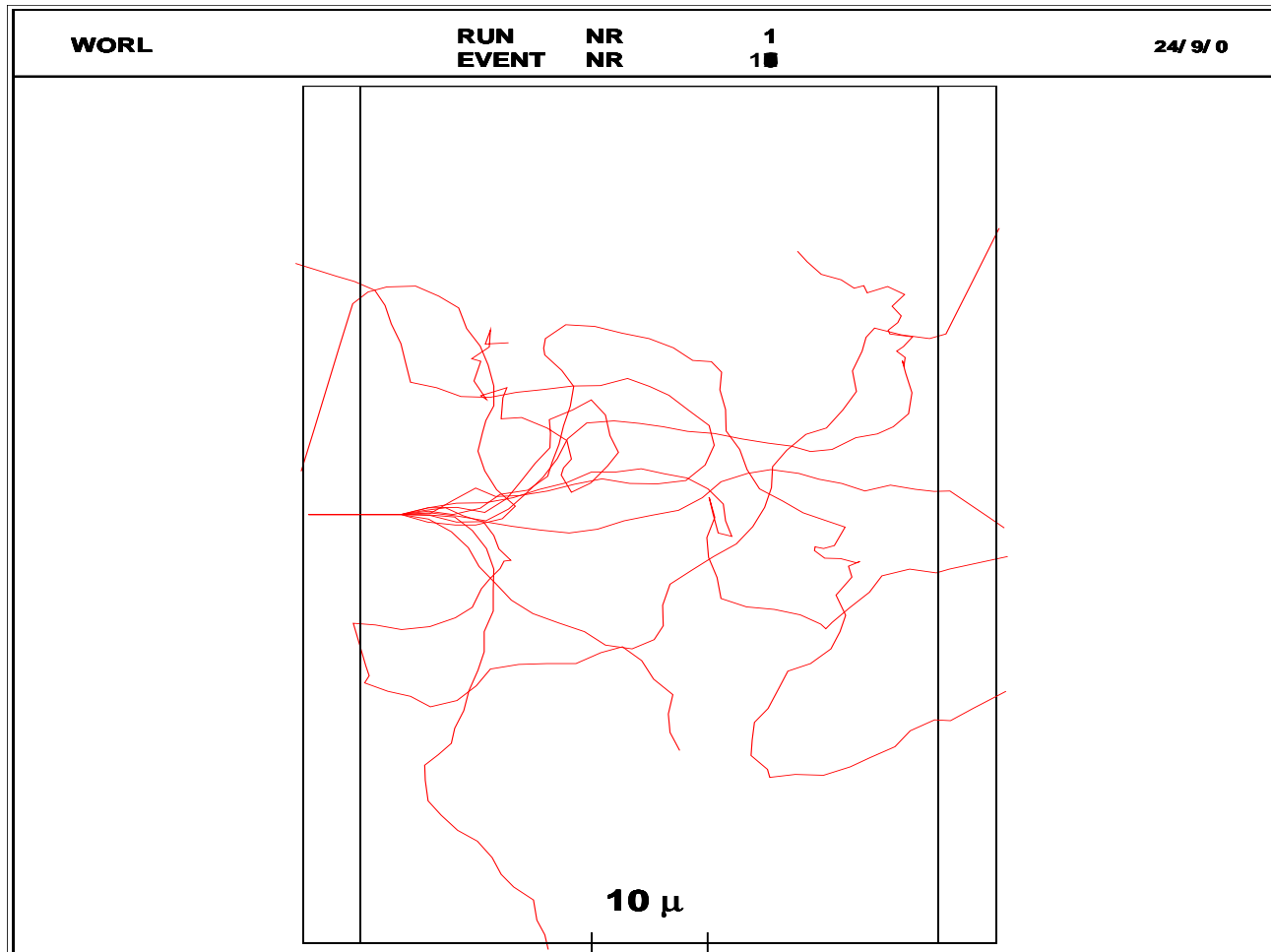
Because of its small mass, electron can have large deflection by scattering from nuclei.

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.



question 2

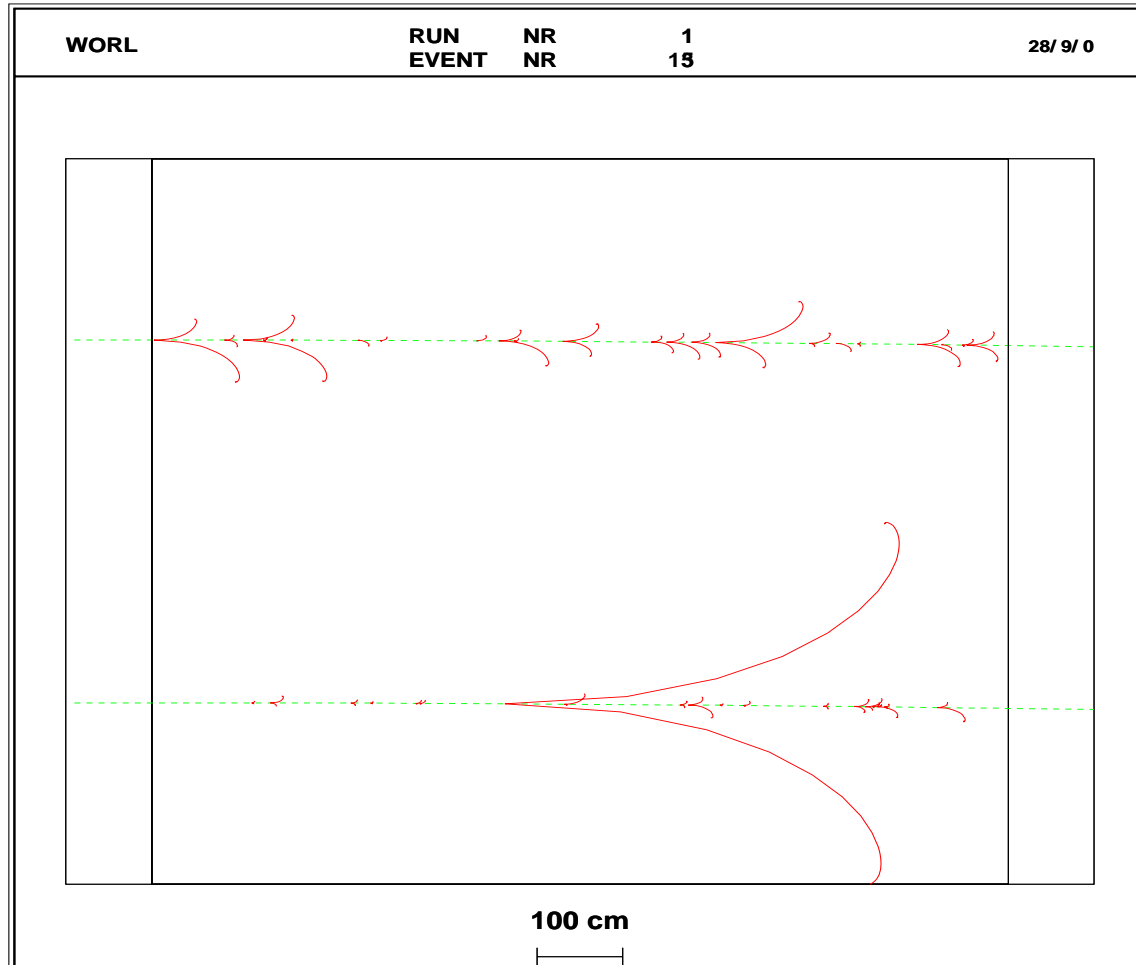
With examples/extended/electromagnetic/TestEm3 try to produce similar picture.

N.B. to get the correct number of backscattered electrons, one may have to limit 'by hand' the step length to a small value compared to absorber thickness.

Try the command /tracking/stepMax

high energy muons

1 TeV muon in a thick absorber.
direct pair creation only



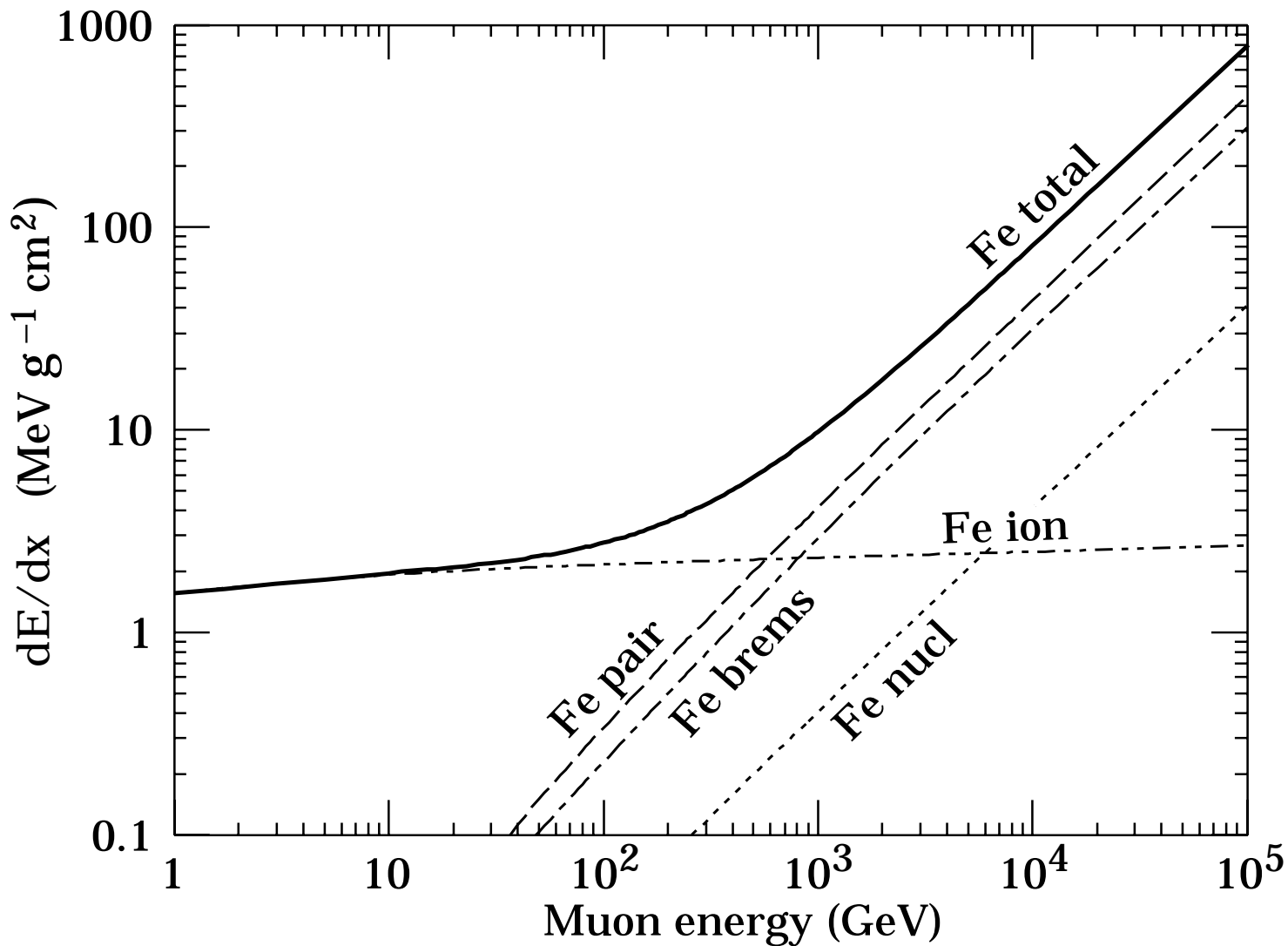
question 1

Start from [examples/extended/electromagnetic/TestEm3](#)

- choose a material, a thickness absorber
- play with the commands :

`/process/list`
`/process/(in)activate`
`/process/setCut`
`/gun/position`

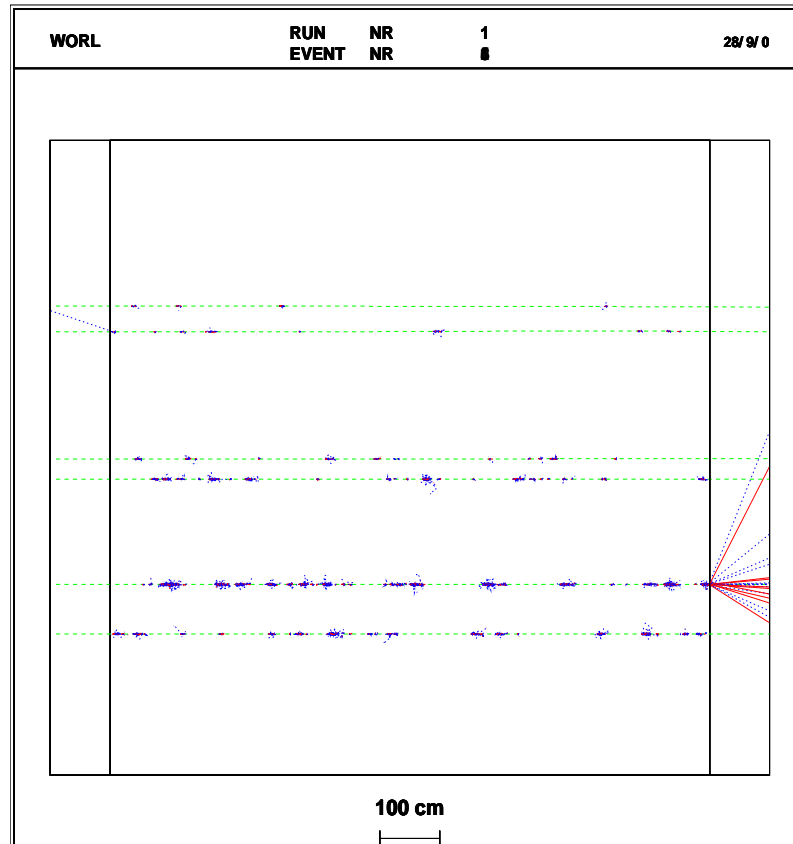
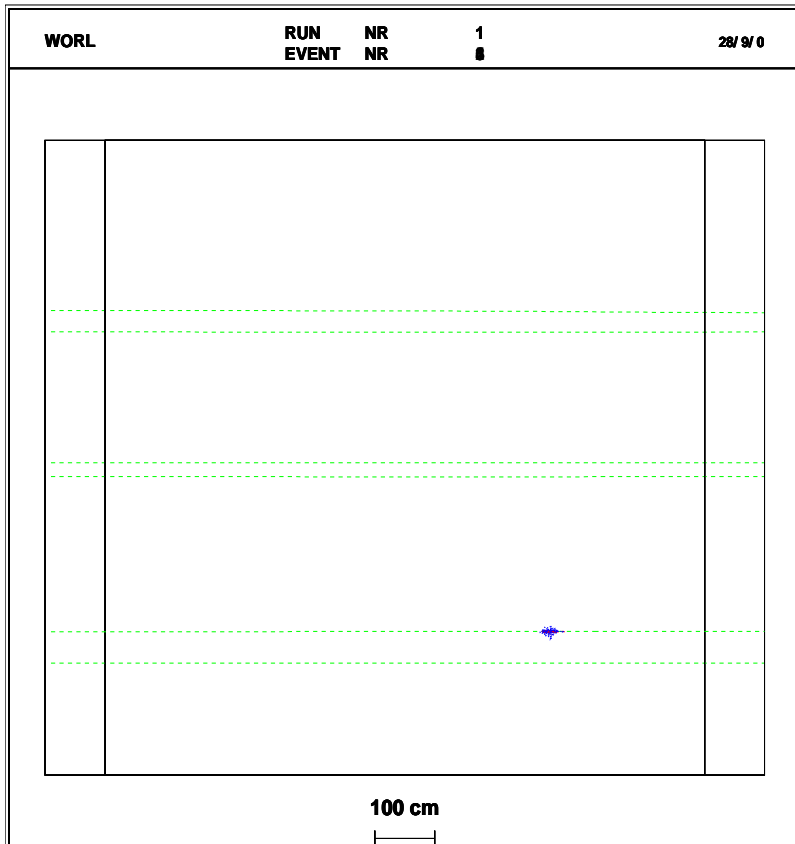
in order to produce similar picture.



same absorber : muons 100 GeV, 1 TeV, 5 TeV.

left : brems only

right : brems + direct pair creation



question 2

In the same setup, play with the commands :

```
/process/list  
/process/(in)activate  
/process/setCut  
/gun/position
```

in order to produce similar pictures.