Trasparenze : http://homepage.sns.it/rolandi/

Passaggio delle particelle nella materia:

Ionizzazione

– Bethe Bloch,

dE/dx,

caratteristiche della ionizzazione

scattering multiplo

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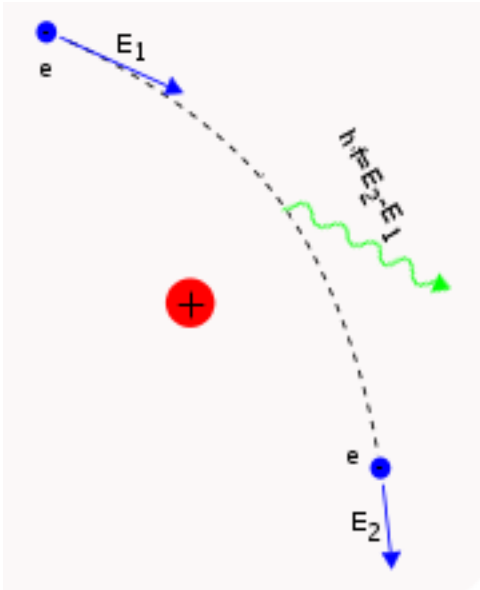
Passage of Particle through matter: bremsstrahlung

Charged particle interacting with the electric field of Nucleus may emit photons.

The probability to radiate is proportional to $(E/m)^4$ where E is the energy of the particle: this phenomenon will be more important for electrons than for any other particle.



One defines as critical energy Ec the energy at which the average energy loss due to Bremsstrahlung equates the average loss for ionization.

For electrons Ec = 6-100 MeV

Since Brm is proportional to Z^2 and ionization is proportional to Z, heavy materials have lower critical energy.

Electron energy loss

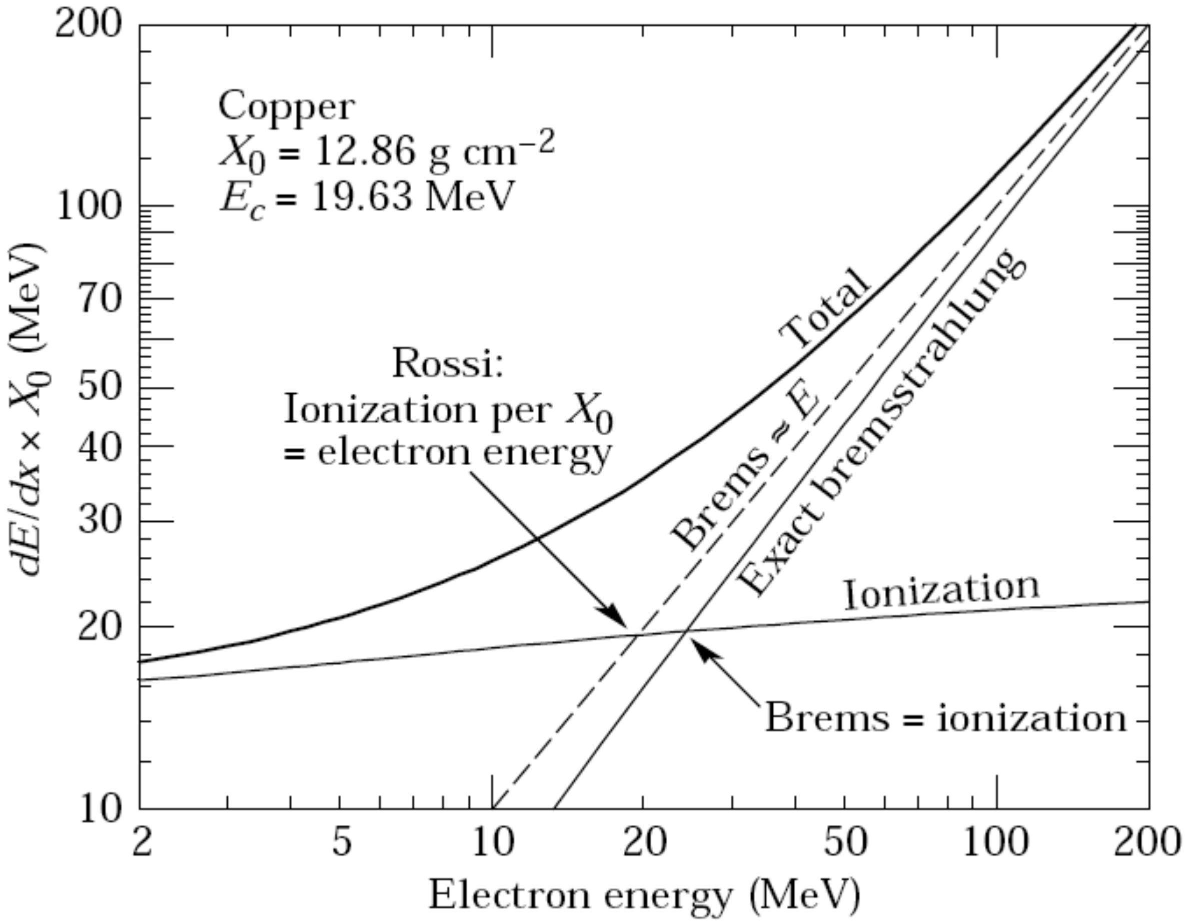


Figure 27.12: Two definitions of the critical energy E_c.

(There is no simple scaling of Ec with particle mass)

Radiation Length

The radiation length is the distance over which the electron looses 1/e of its energy.

$$E(x) = E(0) \cdot e^{-\frac{x}{X_0}}$$

This is the same quantity we have encountered when discussing the multiple scattering . Why ?

Radiation length in Lead is 0.5 cm and in Air 300 m. Since it depends ion the density of the material it is better expressed in gr/cm^2. In Lead it is 6 g/cm^2 and in Air 37 gr/cm^2. It scales roughly as Z^2. Verify how accurate is this approximation.

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Bremsstrahlung spectrum

The Bremsstrahlung spectrum has a simple form:

$$N(\omega)d\omega = A\frac{d\omega}{\omega}$$

Where A is a constant

$$\omega < E_{electron}$$

Show that the probability to emit a photon of energy ω in the interval $d\omega$ by an electron traversing a thin layer dx is

$$P(\omega)d\omega = \frac{dx}{X_o} \cdot \frac{d\omega}{\omega}$$

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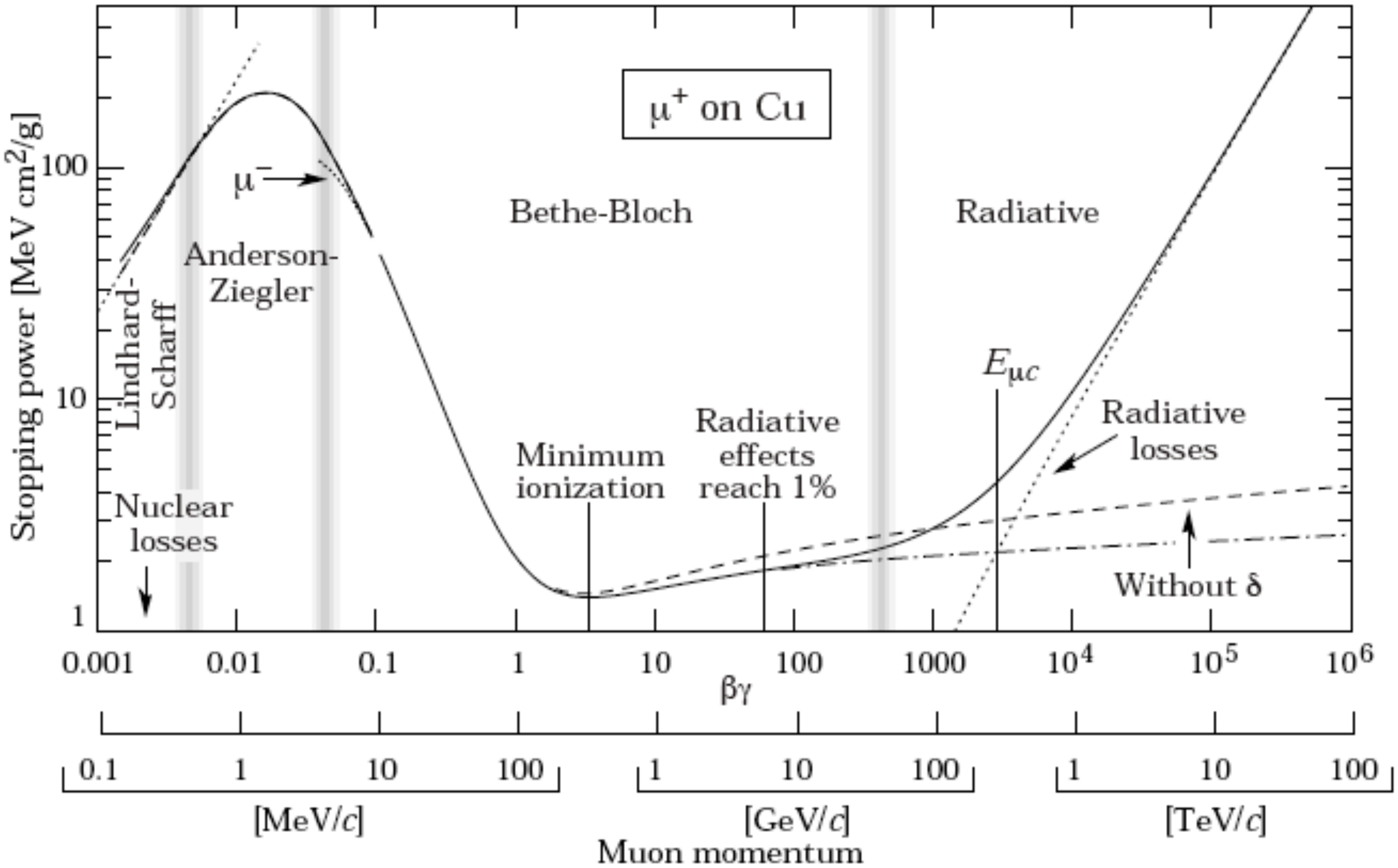
Muon Energy loss



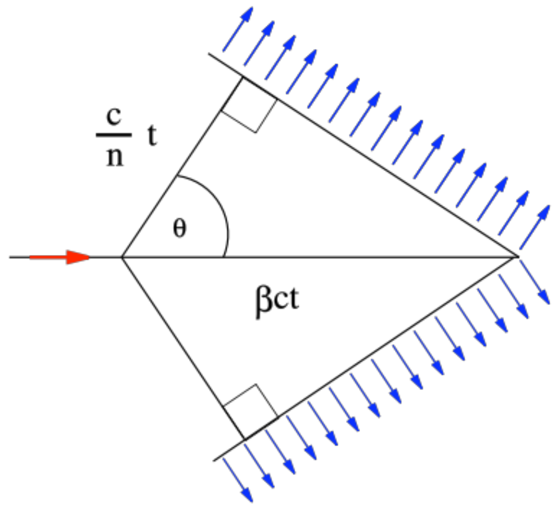
Cherenkov radiation

Shock wave emitted by a particle travelling at $\beta > 1/n$ in a dielectric medium.

It is a small effect compared to the loss by ionization. ~ 10^{-3} MeV/(gr/cm^2).

Its interest is more for particle identification as particles with different mass and same momentum have different β.

The spectrum is $dE/d\omega \sim \omega$



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Photons interactions in matter

Photons have three different interaction with matter:

- Photoelectric effect
  - one electron from the atom is ejected by the photon
- Compton effect
  - scattering of photons on electron
- Pair production
  - creation of an e+e- pair in the electric field of a nucleus

Neglecting the Compton effect (that is in any case quite small) the situation is similar to the “all or nothing” so we can define an absorption coefficient

$$\mu = \mu_{photoelctric} + \mu_{compton} + \mu_{pair}$$

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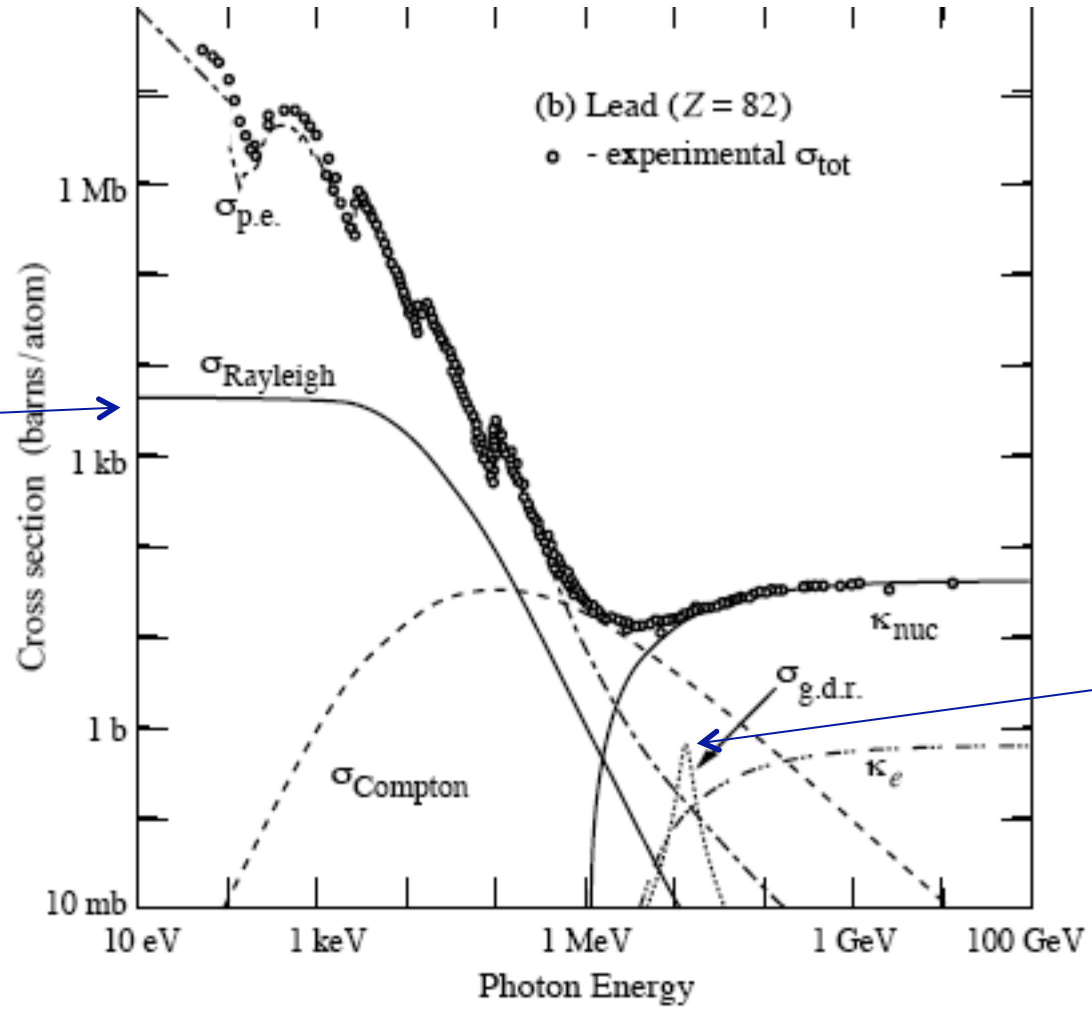
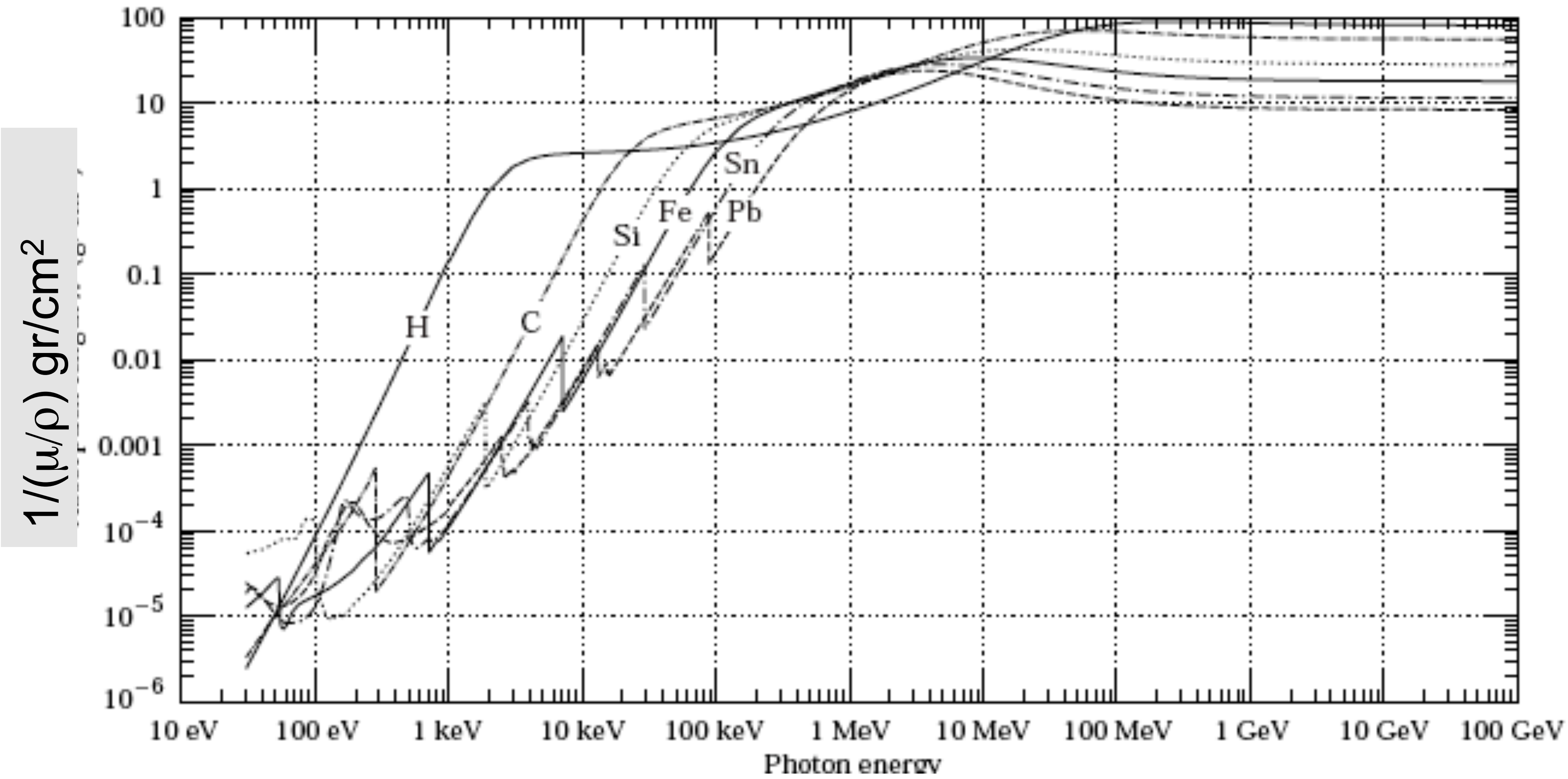
Photons interaction with matter

Coherent atomic scattering



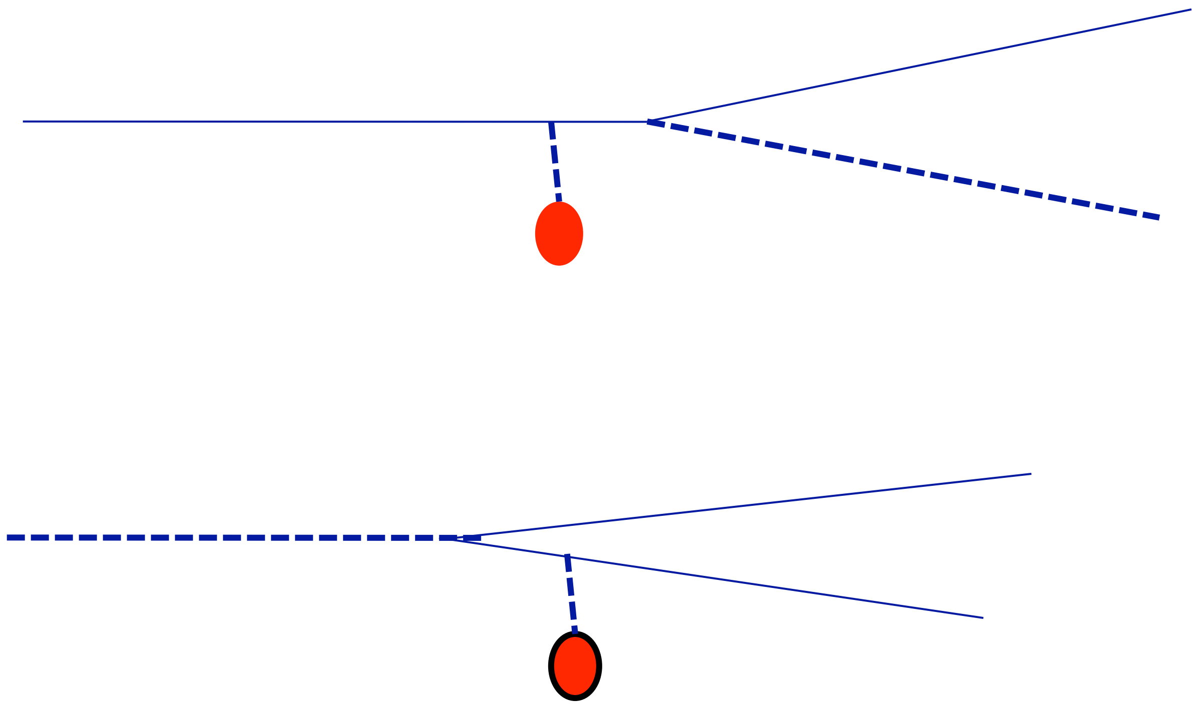
Nuclear absorption

Photons interactions with matter



Above few 10 MeV the only process is pair production with $1/\mu=7/9\ X_0$

Pair production and bremsstrahlung

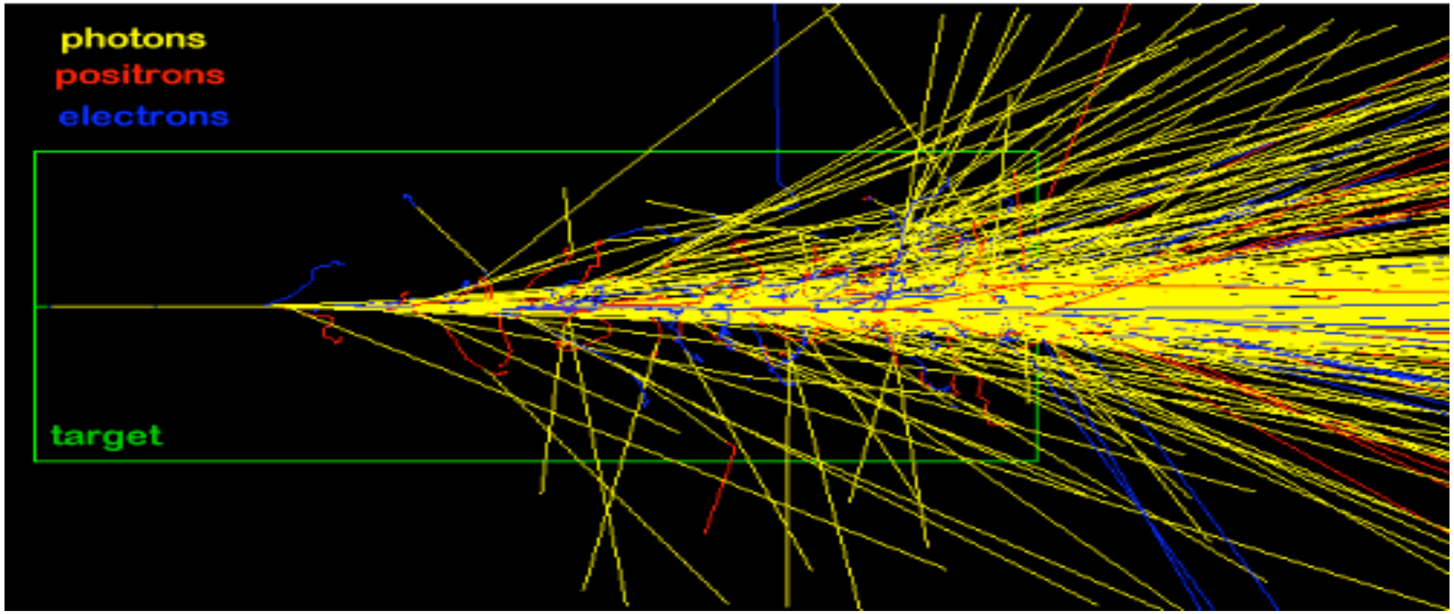


The two processes are very similar (look at the topology). No surprise if the have ~ the same absorption length.

Electromagnetic shower

When an electron or a photon above few 10 MeV interact with matter they produce a shower . The size is governed by the radiation length X_0 The process continues until the electrons energy falls below Ec.

Massive shower in a tungsten cylinder (outlined in green) produced by a single 10 GeV incident electron.



Is this picture a faithful representation of a shower ?

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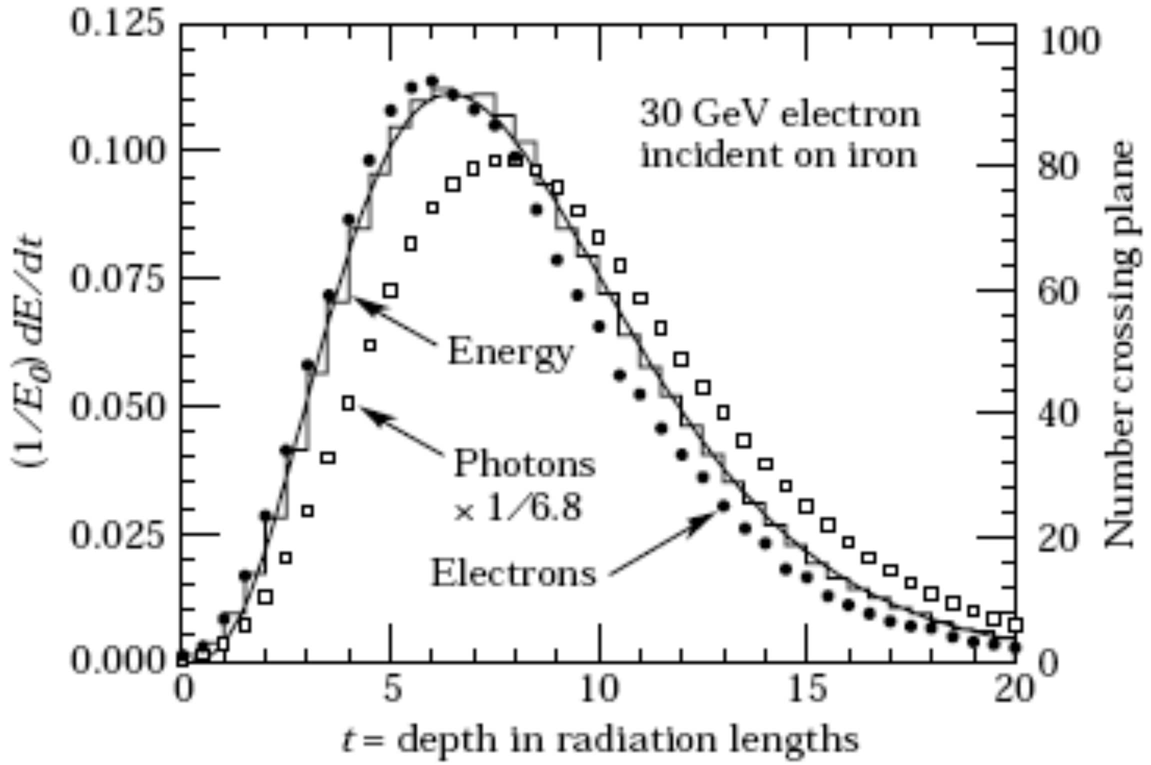
Electromagnetic showers



Simulation of 30 GeV Electron shower in Iron. The scale on the right gives the number of electron and photons above 1.5 MeV at a given depth. The shower “length” increases logaritmically while the transverse size.

Nuclear interactions

Up to now we have discussed only electromagnetic interactions.
Hadrons experience also strong interactions, that are similar to “all or nothing” interaction of a photon and are characterized by a “nuclear interaction length” that are longer that the radiation lengths.
Eg mean free path between inelastic hadronic interaction in Iron is 132 gr/cm^2 compared to the 14 gr/cm^2 of the radiation length.

Moreover the interaction length is energy dependent al low energy and the nuclear interaction produces typically charged and neutral pions and nucleons whose behavior in matter is quite different.

All this conspires to make the hadronic showers much more complex than the electromagnetic showers.

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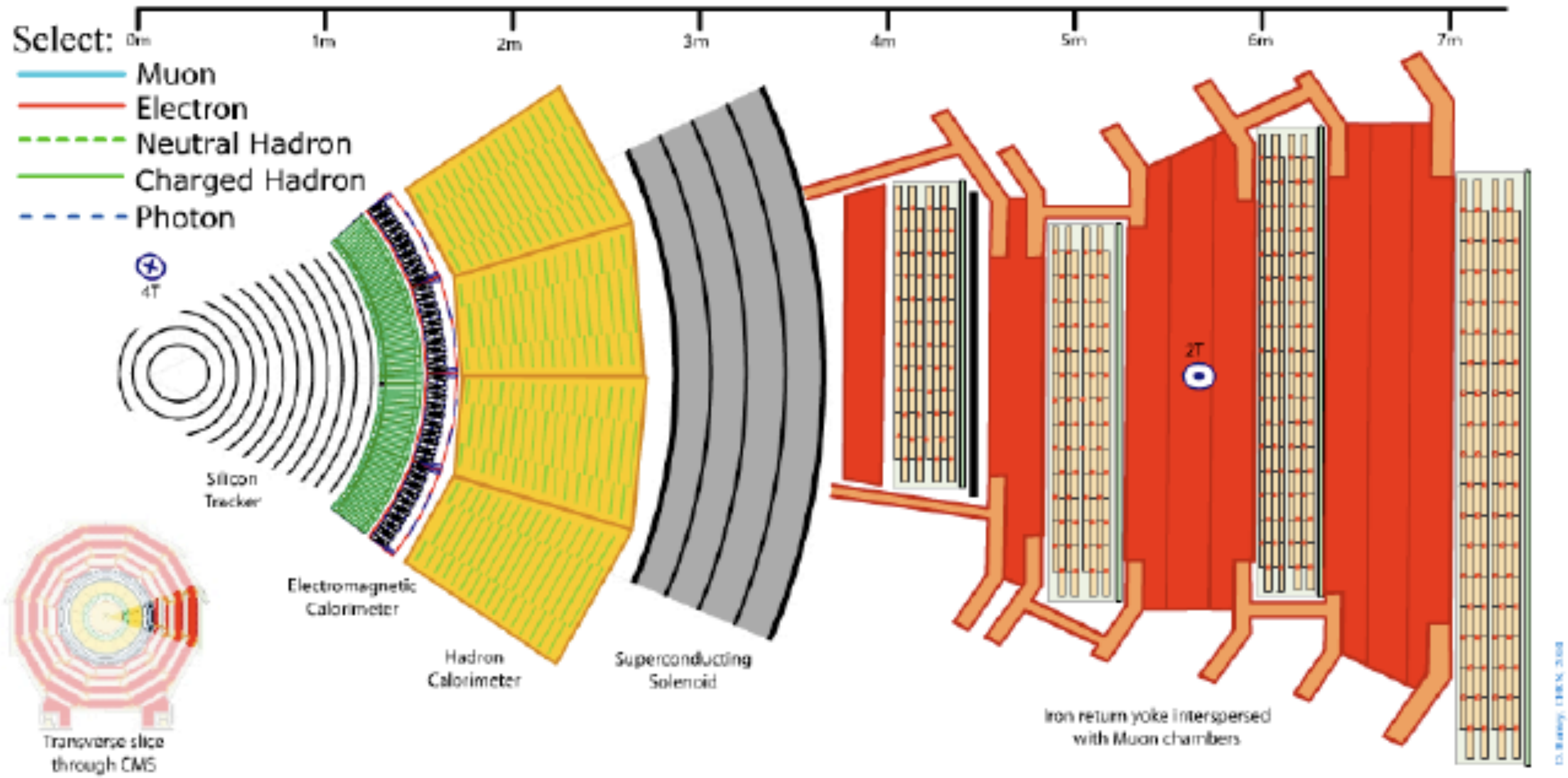
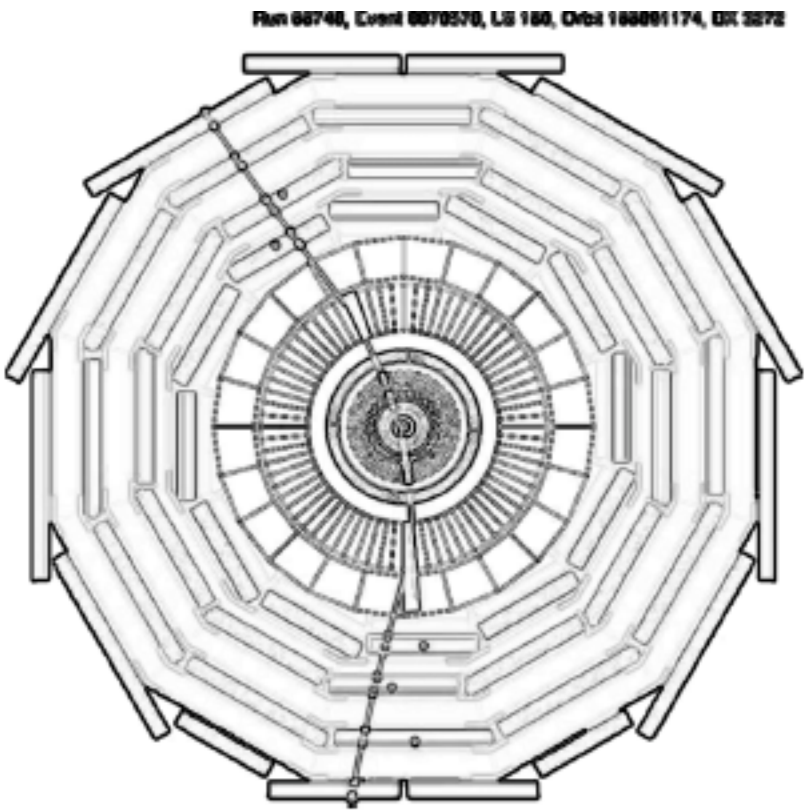
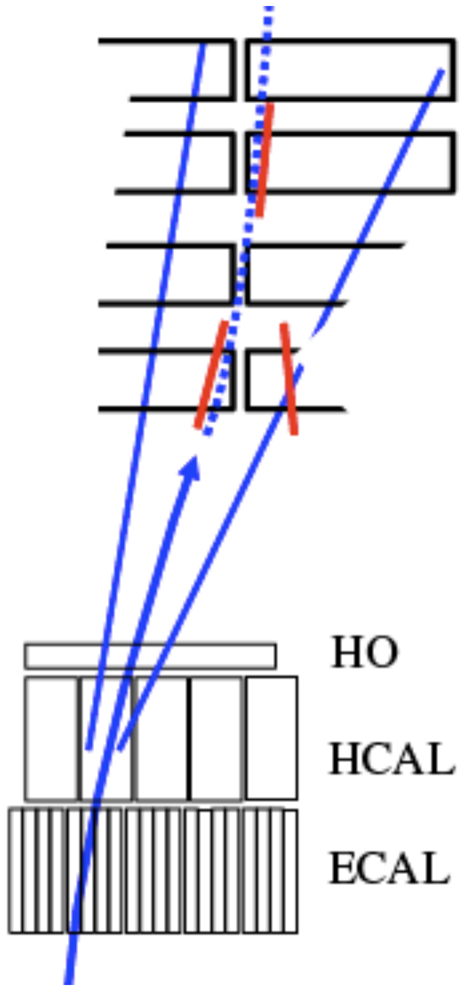
CMS



Select:
0m
1m
2m
3m
4m
5m
6m
7m
Muon
Electron
Neutral Hadron
Charged Hadron
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

Cosmic Rays in CMS (1)





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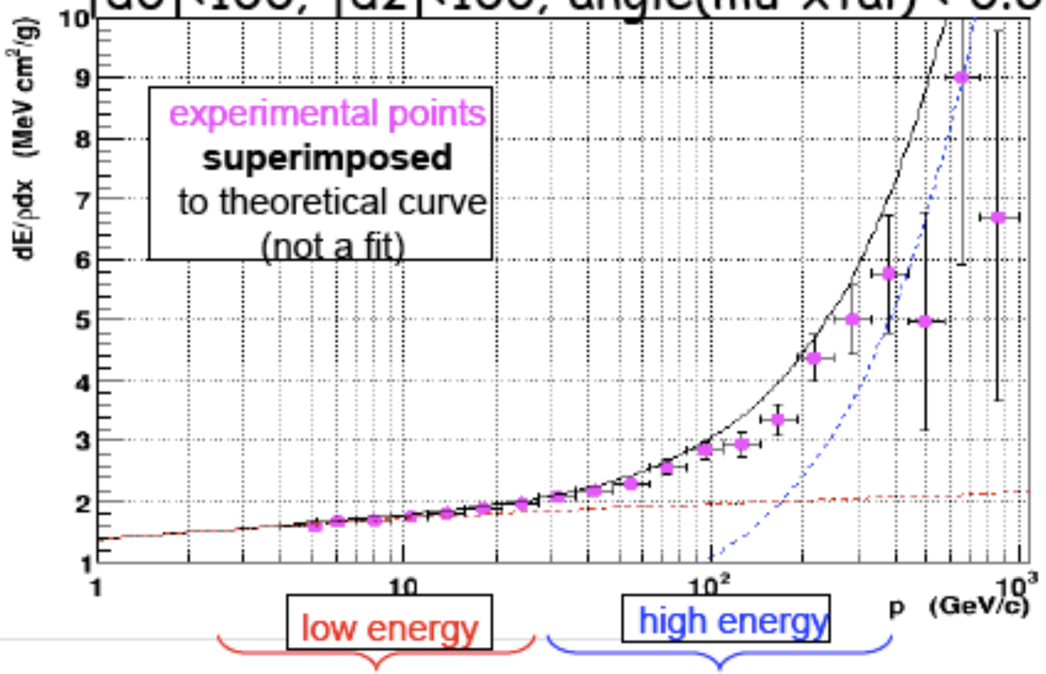
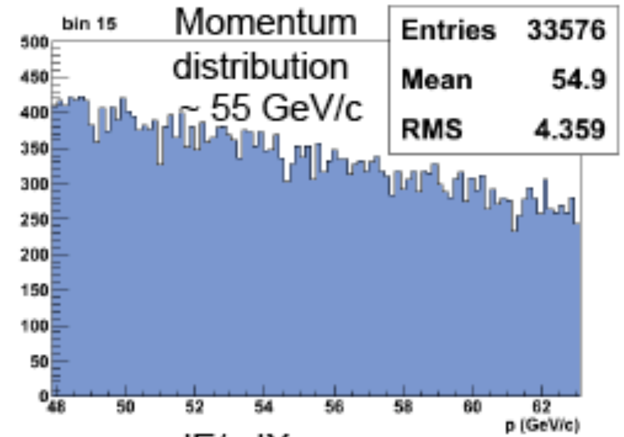
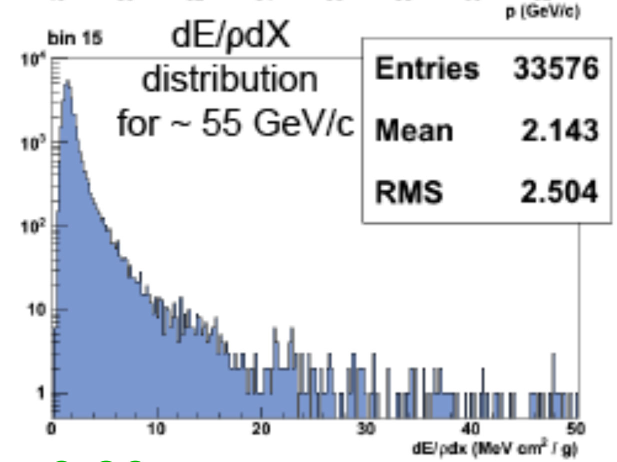
Cosmic Rays in CMS (2)

- <dE/ρdX> computed with: muonP from the tracker +
  dE from super clusters (0.97 factor applied) +
  dx from track length in ECAL
- CMS lower part considered
- |d0|<100; |dz|<100; angle(mu-xtal) < 0.6







ρ=8.3 g/cm^3 l=22 cm section 2.9x2.9 cm^2 X_0=0.89 cm

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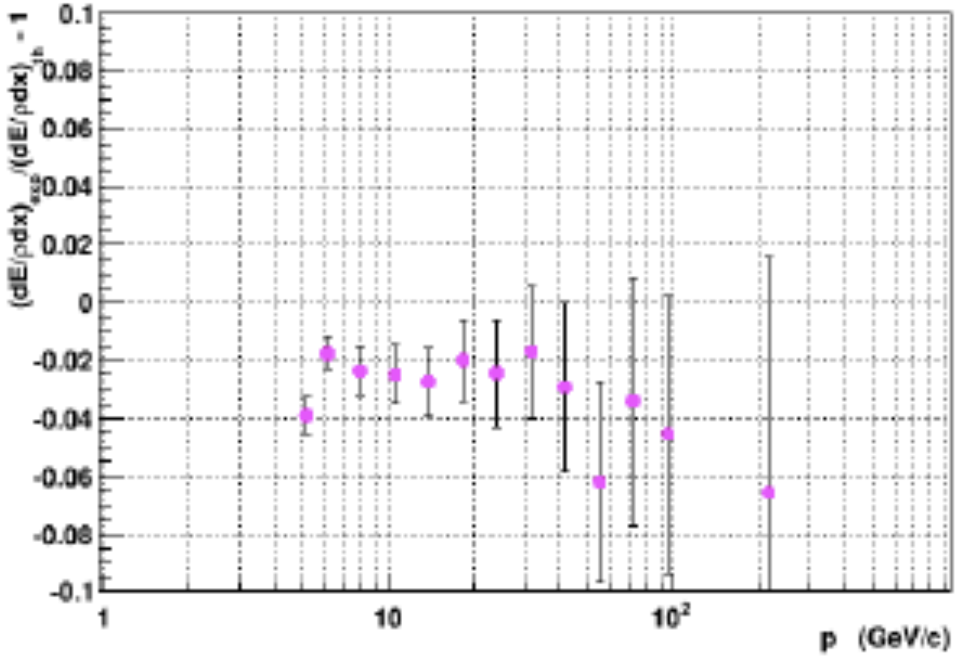
Cosmic Rays in CMS (3)

- p < 50 GeV/c range:
  - all energy lost is collected in the calorimeter
  - error on track length measurement is negligible
- <dE/dx> studies allow for:
  - check of the absolute calibration scale

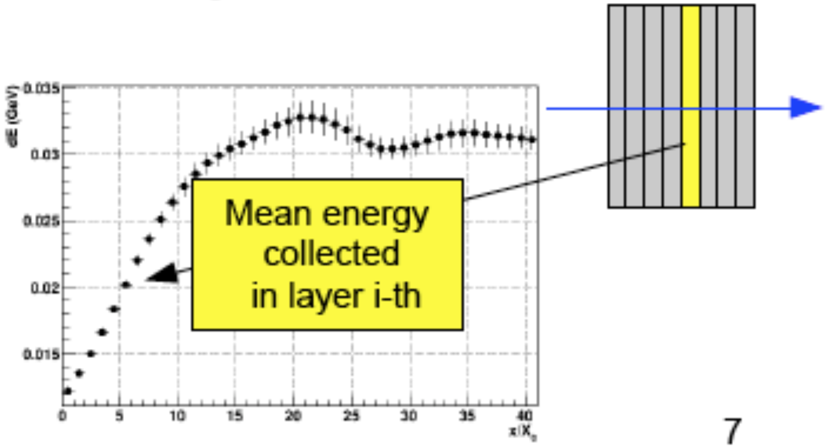


Cosmic Rays in CMS (4)

- p > 50 GeV/c range:
  - irradiation is a non-continuous process
  - irradiated energy is not locally collected
- Equilibrium condition between irradiated and converted energy is required

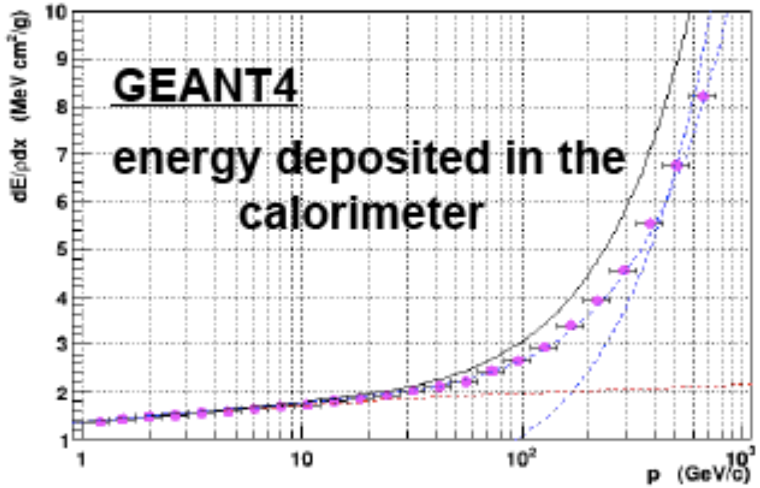
- A geometry of consecutive $PbWO_4$ slices (1 X_0 thickness) considered

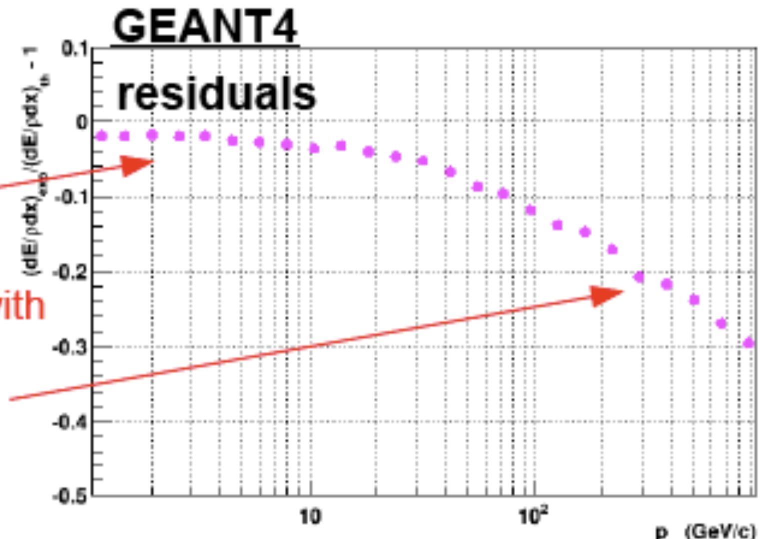
The mean energy deposited in each slice is represented as a function of the total length crossed by the muon



Cosmic Rays in CMS (5)

- Experimental measurement is affected by containment effects
- Dedicated Geant4 simulation:
  - simple plain matrix of 81 xtals
  - B_y = 3.8 T
  - random energy muon gun along the central xtal axis



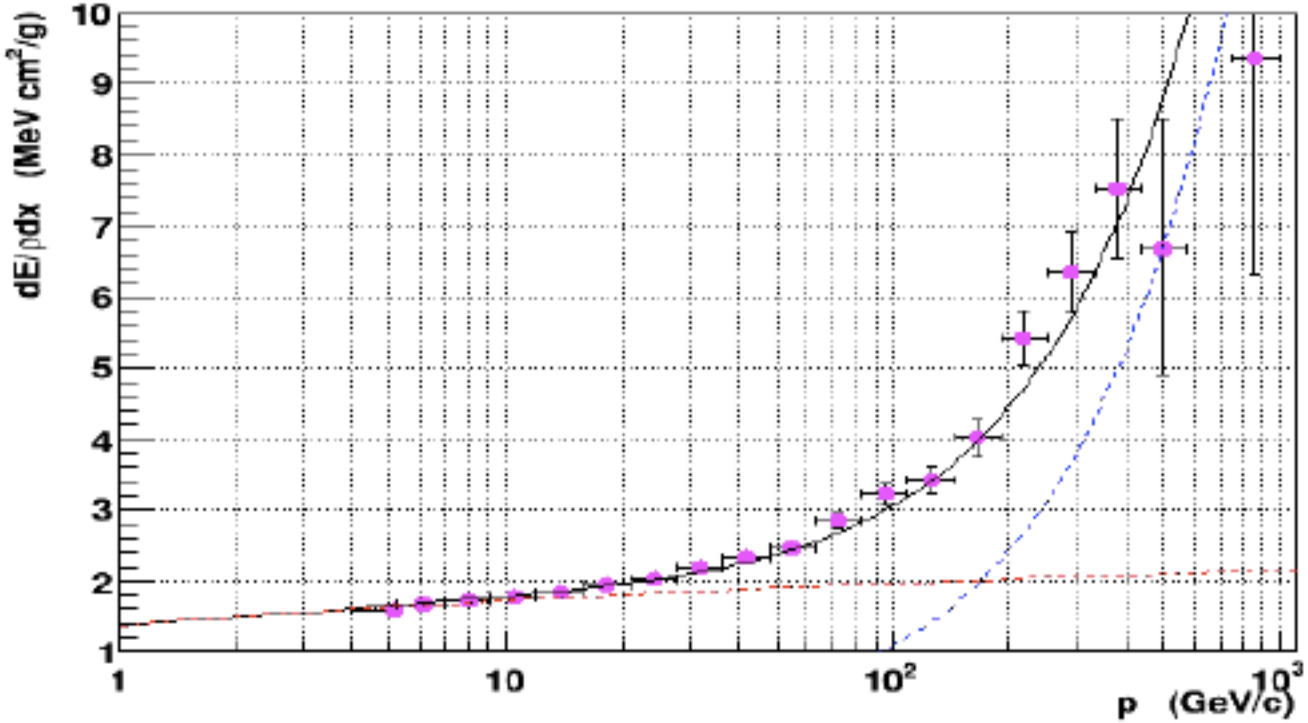


2% effect at low energy

High-energy behaviour compatible with a 35% leakage of energy lost by irradiation processes

Cosmic Rays in CMS (6)

- MC correction factor applied to data
- Over-estimated correction:
  - simulation with particles in a 81xtals matrix
  - data can recover some high energy photons from upper CMS part



Exercises

- A radioactive source emits photons of 1.1 MeV energy. Compute the thickness of Lead to reduce the rate by a factor 10^4
- A source emits 14 and 6 KeV gamma. Select an absorber that absorbs as much as possible the 6 KeV and as little as possible the 14 KeV photons
- What is the energy of an electron that has the same path length of a 10 MeV proton ?
- A 10 GeV electron passes through a 1 cm aluminum plate how much energy is lost ?

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Discussions

Explain qualitatively and possibly quantitatively why there is so large non containment of muon energy lost in the CMS electromagnetic calorimeter when E> few hundred GeV.

The inner part of CMS (tracker) can be schematized as a cylinder 1.2 m radius and 6 t length of ligth material with an (average) density of 0.1 gr/cm^3 . Outside the cylinder here is very high density material. The magnetic field of 4 T is along the axis of the cylinder. Consider a muon of momentum p produced at t=0 in the center of the tracker. Discuss what is the fate of this pion as a function of its momentum and angle wrt the magnetic field. Relevant values of p are 300 MeV 700 MeV and 10 GeV. Once discussed the muon case consider the pion case.