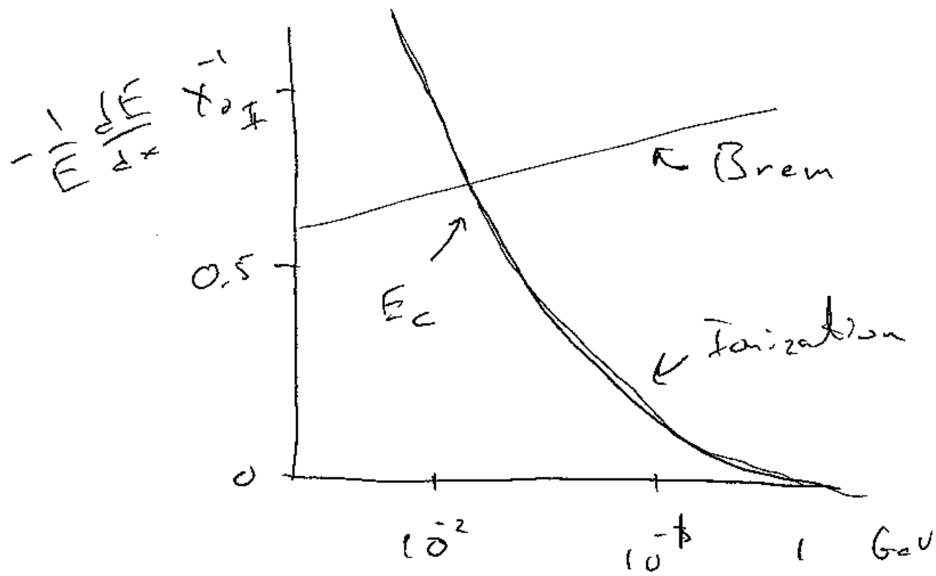
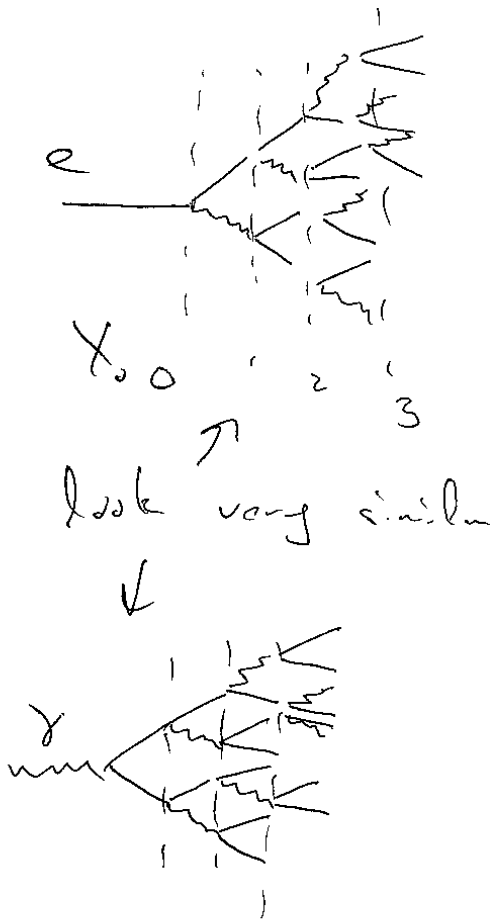
Lecture 24



Similar story for photons.

E_c - critical energy O(10^{-2} – 10^{-1} GeV)



"Electromagnetic Shower"

-) For each e (or γ) with $E > E_c$ travels $\sim 1x_0$ then gives up 1/2 energy to γ (or ee).

-) e's, γ's with energy $< E_c$ get absorbed via ionization

If initial energy $E_0 >> E_c$ then after t-radiation lengths there will be 2^t particles. Approximately equal e's and γ's each with energy $E(t) \sim \frac{E_0}{2^t}$.

Shower will stop growing when

$$E(t) \simeq E_c \equiv E(t_{max})$$

t_{max} is point in shower with max particles

$$t_{max} = \frac{\ln \frac{E_0}{E_c}}{\ln 2}$$

$\Rightarrow$ shower depth grows as ln

N_{max} given by E_0/E_c

For heavier particles, Brem does not kick in until much higher energies.

eg: $E_c \sim 3000$ GeV for a muon in lead.

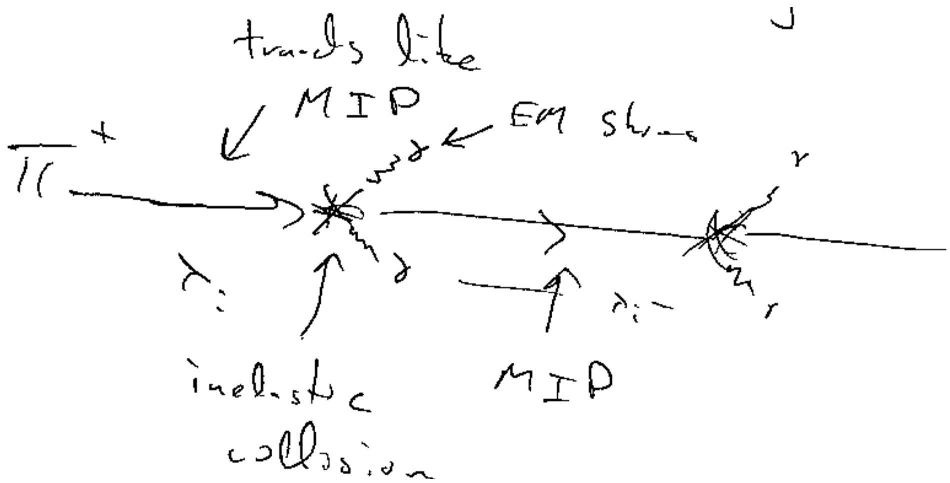
Nuclear Interactions

If the particle traversing the medium is a hadron, can interact via the strong interaction.

eg: $\pi^{\pm}$ moving through detector material will suffer an inelastic collision in distance λ_i

This collision takes energy from π and converts it to additional hadrons (charged and neutral)

Leads to what is called "Hadronic Shower" - same basic idea as an EM shower, but much more complex. Involves a variety of processes at different length scales



At the inelastic collision, typically produce

$\pi^+ \sim 1/3$ of the time. Travels like a MIP w/scale λ_i

$\pi^0 \sim 1/3 \leftarrow Br(\gamma\gamma) \sim 100\%$ travels 10nm $\Rightarrow$ EM shower w/ scale X_0

$\pi^- \sim 1/3$

Both $\pi^{\pm}$ travel like MIPs of order λ_i. $\Rightarrow$ Hadronic showers develop over larger distances and contain much more fluctuations.

Trackers

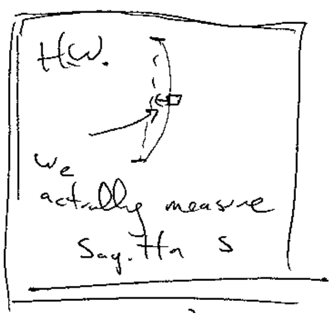
Ionization detectors in a magnetic field.

Charged particles traveling in a magnetic field move in circles.

$$\frac{1}{R[\mathrm{m}]} = Q \cdot B[T] \cdot \frac{0.3}{p_T[\mathrm{GeV}]}$$

Particle positions are measured by finely etched silicon sensors.
$\sim 10\mu$m resolution

We measure the curvature $\sim \frac{1}{R} \sim \frac{1}{p_{\mathrm{T}}}$



$$s = \frac{qBL^2}{8p_{\mathrm{T}}}$$

(More important to have bigger length than larger B)

$$\Rightarrow \Delta\frac{1}{p_{\mathrm{T}}} = \frac{\Delta p_{\mathrm{T}}}{p_{\mathrm{T}}^2}$$

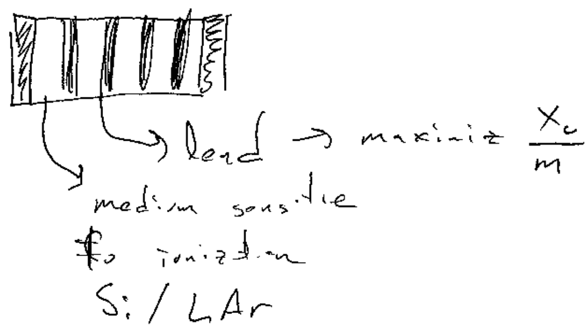
So the relative uncertianty in p_{T} degrades with p_{T}.

LHC typical performance

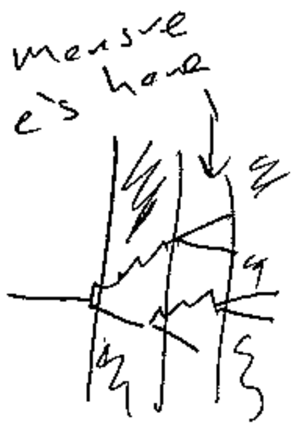
$$\frac{\Delta p_{\mathrm{T}}}{p_{\mathrm{T}}} \sim (\text{few }\%)\frac{p_{\mathrm{T}}}{100\ \mathrm{GeV}}$$

EM Calorimeter

Contains and measures e's γ's and $\pi^0 \rightarrow \gamma\gamma$.



Total depth ~ $20X_0$ (Enough to contain high p_{T} showers)



Only energy deposited in Si/LAr is measured.
Rest is lost in uninstrumented lead.

So only a small fraction of the total EM shower energy is collected (measured).

$E \sim N_c$ amount collected scales like the number of electrons produced

$$\frac{\Delta E}{E} \sim \frac{\Delta N_c}{N_c} \sim \frac{1}{\sqrt{N_c}} \sim \frac{1}{\sqrt{E}}$$

At the LHC typical performance

$$\frac{\Delta E}{E} \sim \frac{10\ \%}{\sqrt{E}}$$

Unlike trackers the relative energy measurement improves with E.

Hadronic Calorimeter

Compare shooting a $\pi^{\pm}$ in the detector instead of an electron.

- π will travel further because it has to interact via the strong force (shorted range than EM)
- π will make other $\pi^{\pm}$ and π^{0}
- Compared to electrons, make less particles (fewer at fixed E) b/c π mass is bigger.
- More varied showers depending on what particles are produced $\pi^{\pm}$ vs π^{0}.

$\Rightarrow$ hadronic calorimeters need to be bigger, and will measure showers that have more fluctations.

At the LHC typical performance worse than for EM calorimeters

$$\frac{\Delta E}{E} \sim \frac{50\ \%}{\sqrt{E}}$$

Relative energy measurement also improves with E.

Muon Detectors

Put tracking detectors outside of the calorimeters.

If any charged particle makes it through $\sim$ 3m of lead it has to be a muon.

$$\mu \left| \begin{array}{l} \text{no strong interaction} \\ \text{only rarely radiate } \gamma\text{s (below} \sim 3\text{ TeV)} \end{array} \right.$$