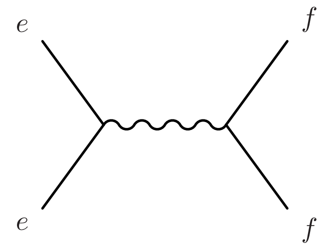
Lecture 22

Play same game as last lecture to calculate ratios of cross sections

$$\sigma = \frac{1}{2E_1}\frac{1}{2E_2}|M|^2 d\Pi_{LIPS}$$



$$\frac{\sigma(ee \to \text{“jets”})}{\sigma(ee \to \mu\mu)} = \frac{\sum_{\text{“quarks”}} \sum_{\text{“colors”}} |M(ee \to qq)|^2}{\underbrace{|M(ee \to \mu\mu)|^2}_{|M_0|^2}}$$

$$|M(ee \to qq)|^2 = Q_q^2 |M_0|^2$$

Define,

$$R \equiv \frac{\sigma(ee \to \text{“jets”})}{\sigma(ee \to \mu\mu)} = \sum_{\text{quarks}} Q_q^2$$

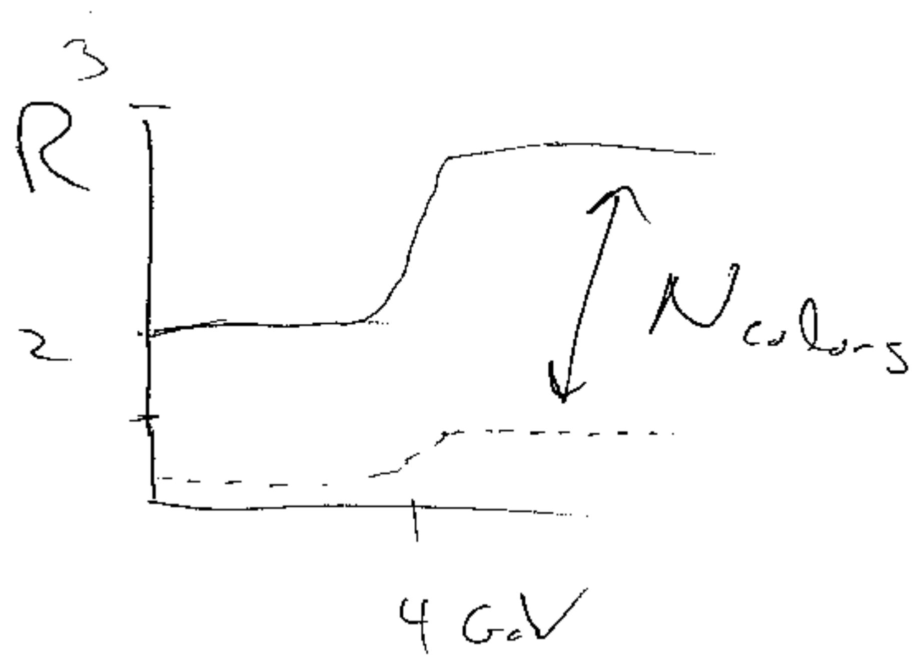
R is sensitive to the number of quarks.

$R(E_{CM})$ at 4 GeV only u,d,s can contribute.

$$R(E_{CM} < 4 \text{ GeV}) = \sum_{q \in u,d,s} Q_q^2 = \frac{4}{9} + \frac{1}{9} + \frac{1}{9} = \frac{2}{3}$$

$$R(E_{CM} > 4 \text{ GeV}) = \sum_{q \in u,d,s,c} Q_q^2 = \frac{4}{9} + \frac{1}{9} + \frac{1}{9} + \frac{4}{9} = \frac{10}{9}$$

Problem, when you measure R you actually see

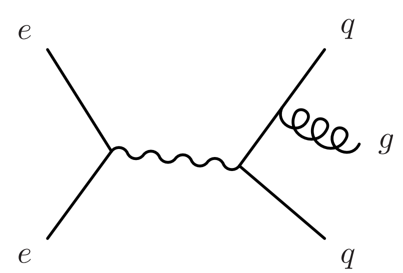


Measuring R determines N_{quarks} and N_{colors}.

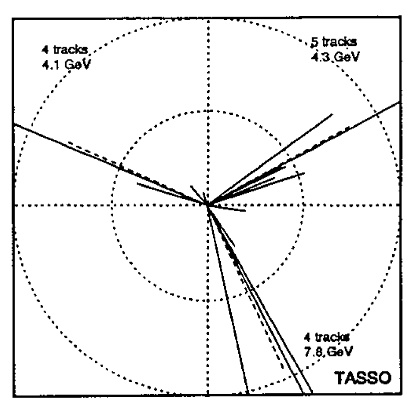
Scan E_{CM} measure R, changes at values of m_q.

Discovery of the gluon

Cant produce glues from e's, but you can radiate them from q's produced in $ee \to qq$ collisions. "Mercedes" events smoking gun for gluons.



$$\frac{\sigma(ee \to \text{3-jets})}{\sigma(ee \to \text{2-jets})} \sim \alpha_s N_{\text{gluons}}$$



Now collider physics in more detail.

Collide protons / Measure how often a certain type of interaction occurs.

(Weve already talked about this...)

$$r_p \sim GeV^{-1} \sim 10^{-15} m$$

$$r_p^2 \sim 10^{-26} cm^2 = 0.01 \underbrace{\text{“barns”}}_{\text{Long story}}$$

barn is about the size of a Uranium atom.

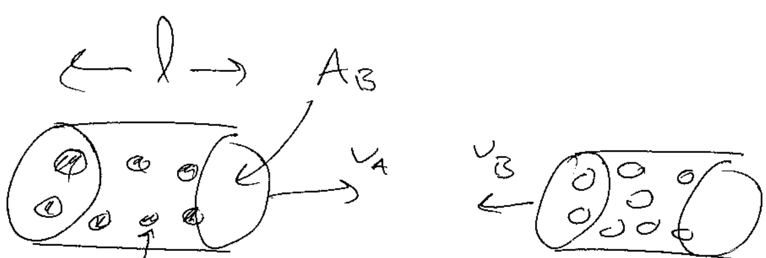
At the LHC, interesting processes are

- nanobarns ($\sim 10^{-9}$ b)
- picobarns ($\sim 10^{-12}$ b)
- femptobarns ($\sim 10^{-15}$ b)

One of the few units in particles physics not in natural units.

Now, colliding protons is <u>hard</u>.

- In order to get two protons to interact need to get them with an $fm \sim 10^{-15} m$ of each other. - To get around this, we collide bunches of protons
Bunch is $\sim 10^{11}$ protons



Protons $n_A = \frac{10^{11} p}{V_A}$ Relevant quantity $\frac{\# \text{ collisions}}{s}$

number density Event rate

Think about a slice of bunch “B”.

The number of protons in bunch A that it sees per time is

$$\frac{N_A}{t} = n_A \cdot \underbrace{A_B \cdot |v_A - v_B|}_{\frac{\text{Volume}}{\text{time}}\text{of A that passes through B}}$$

Now the number of protons in B that could interact is

$$N_B^{\text{eff}} = n_B \cdot \underbrace{l \cdot \sigma}_{\text{Volume of the protons}}$$

$\Rightarrow$

$$\frac{\text{Events}}{\text{Time}} = \frac{N_A N_B^{\text{eff}}}{t} = \underbrace{n_A n_B A l |v_A - v_B|}_{\text{flux factor we thought about before}} \quad \sigma$$

- Flux factor depends on how the LHC was build
- σ is an intrisic physical observable

Integrated Luminosity L = $\int dtL$

Number of events is given by $N = \text{L} \times \sigma$

Q: What is the flux factor at the LHC ?

Flux Factor also called L "instantaneous luminosity" or just "luminosity"

$$L = n_A n_B A l |v_A - v_B| = \frac{N_A N_B |v_A - v_B|}{\underbrace{Vol}_{\text{Vol. of bunch} = A_B \times l}}$$

Now σ is fixed, so to maximize number of events collected, need to maximize L

- $N_A = N_B = N = 10^{11}$ (fixed)
- $|v_A - v_B| = 2c$ can get much higher!
- Vol $\sim A_B \cdot l$

At the LHC, acceleration is done with radio-frequency EM feild that fixes l (Protons ride in the troughs of this feild) The wavelength of this feild sets $l \sim \frac{c}{2\times 400\text{ MHz}} \sim \frac{3}{4}m$ The one handle we have is A_B, focusing magnets (quadruples) act like a lens near the collision points to squeeze the beam. So far focusing magnets have achieved squeezing down to the radii of 10 μm! Width of a human hair.

$$A_B \sim 10^{-10}\, m^2$$

$\Rightarrow$

$$L = 2c\frac{N^2}{lA} \sim 10^{-36} cm^{-2} s^{-1}$$