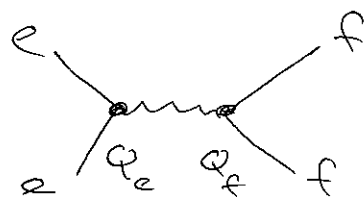


Play same game as last lecture to calculate ratios of cross sections

①

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



$$\frac{\sigma(ee \rightarrow \text{"jets"})}{\sigma(ee \rightarrow \mu\mu)} = \frac{\sum_{\text{quarks}} \sum_{\text{colors}} |M(ee \rightarrow q\bar{q})|^2}{|M(ee \rightarrow \mu\mu)|^2}$$

$\rightarrow \equiv |M_0|^2$

$$|M(ee \rightarrow q\bar{q})|^2 = Q_q^2 |M_0|^2$$

$$\Rightarrow R \equiv \frac{\sigma(ee \rightarrow \text{"jets"})}{\sigma(ee \rightarrow \mu\mu)} = \sum_{\text{quarks}} Q_q^2$$

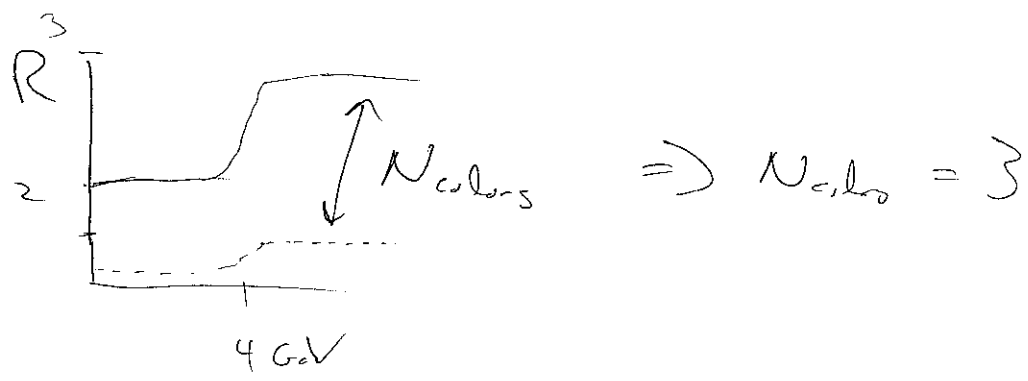
$\rightarrow R$ sensitive to # of quarks (+ # of colors)

$R(E_{cm})$ @ 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 ^{actually} measure R you [^] see

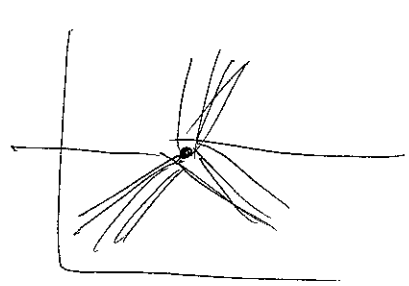
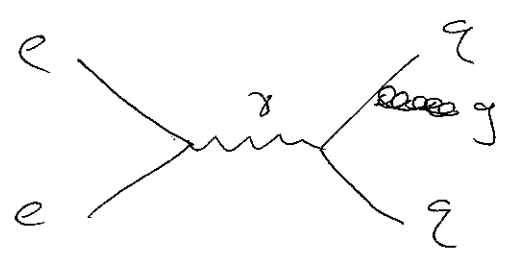


Measuring R determines N_{colors} + N_{quarks}

So can E_{cm} measure R , changes @ values of m_q .

A Discovery of the gluon

Can't produce gluons from e 's, but you can indicate their from q 's produced in $ee \rightarrow eeq$ collisions.



"multiple" events
smoking gun
for q 's.

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

Now Collision Physics in some more detail.

(3)

$\equiv \bigcirc \equiv$ σ - cross section characterizes
the probability of interaction.

We've talked all about this.

$$r_p \sim \text{GeV}^{-1} \sim 10^{-15} \text{ m} \quad 10^{-26} \text{ cm}^2 \approx 0.01 \text{ "barns"}$$

(10^{-13} cm)

Long Strung ...
barn \sim size of uranium
Atom

At the LHC interesting processes are

nanobarns 10^{-9} b

pico " 10^{-12} b

femto " 10^{-15} b

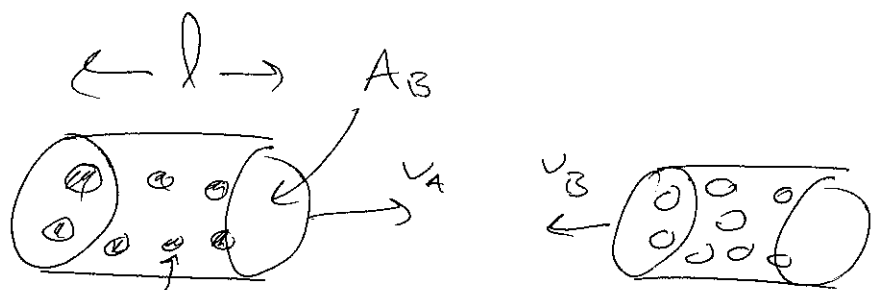
One of few units
in particle physics
not in natural units.

Now, colliding protons is hard.

- In order to get 2 protons to interact need
to get them within a fm of each other.

- To get around this we collide bunches of protons
Bunch $\sim 10^{11}$ protons (out of these ~ 20 collide)

(4)



Protons $n_A = \frac{10^{11} P}{V_A}$

↑
number density

Relevant quantity $\frac{\# \text{ - coll. } \sigma \text{ buns}}{s}$

Event rate

Think about a ~~part~~ slice of bunch "B",
the number of protons in bunch A that it sees
per time is

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

Now the number of protons in B that could interact
is

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

$$\Rightarrow \frac{\text{events}}{\text{time}} = \frac{N_A N_B^{\text{eff}}}{t} = \underbrace{n_A n_B A l |v_A - v_B| \sigma}_{\substack{\text{exactly flux factor talked about} \\ \text{before}}}$$

EF depends on how the LHC was built
 σ - intrinsic physical observable

Q: What is the flux factor @ the LHC?

(5)

FF also called \mathcal{L} "instantaneous luminosity"
"luminosity"

$$\mathcal{L} = n_A n_B A_B |v_A - v_B| = \frac{N_A N_B |v_A - v_B|}{\text{Vol}}$$

\hookrightarrow Volume of Bunch
 $= A_B \times l$

Now v is fixed, so to ~~maximize~~ maximize Events collected,
Need to maximize \mathcal{L} .

$$N = N_A = N_B = 10^{11} \text{ fixed}$$

$$|v_A - v_B| = 2c \text{ can't get much higher!}$$

$$\text{Vol} \sim A_B \cdot l \quad \text{@ LHC acceleration w/ RF EM field that fixes } l \text{ (Particles ride the troughs of this field)}$$

$$\Rightarrow \lambda \text{ sets } l. \left(\approx \frac{c}{2 \times 400 \text{ MHz}} \right) \sim \frac{3}{4} \text{ m}$$

\hookrightarrow wavelength

One handle is A_B , focusing magnets (quadrupoles) act like a lens near the collision points to squeeze the beam. So far focusing magnets have achieved squeezing down to radii of 10 μm ! \approx width of human hair.

$$A \approx 10^{-10} \text{ m}^2$$