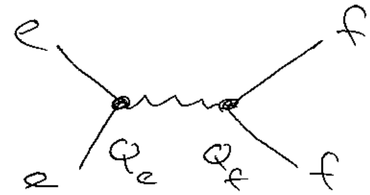
①

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

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



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

$$|M(ee \to \mu\mu)|^2 \equiv |M_0|^2$$

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

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

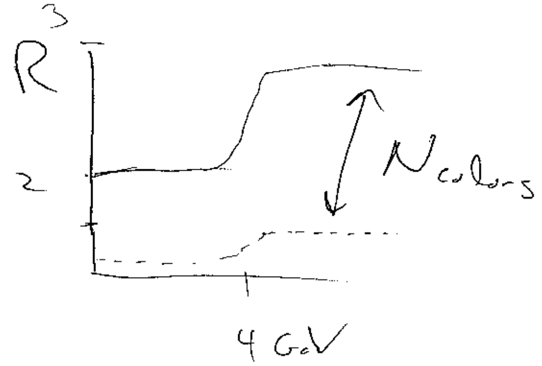
$\longrightarrow$ R sensitive to # of quarks (+ # of colors)

$R(E_{cm})$ @ 4 GeV only u, d, s can contribute

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

$$R(E_{cm} > 4\,\text{GeV}) = \sum_{q \in udsc} Q_q^2 = \frac{4}{9} + \frac{1}{9} + \frac{1}{9} + \frac{4}{9} = \frac{10}{9}$$

Problem, when you actually measure R you actually see



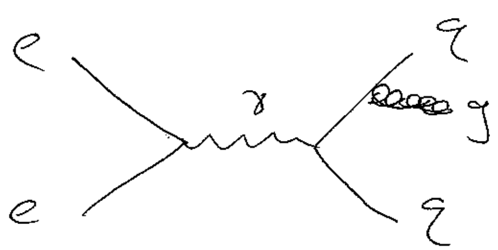
$\Rightarrow N_{colors} = 3$

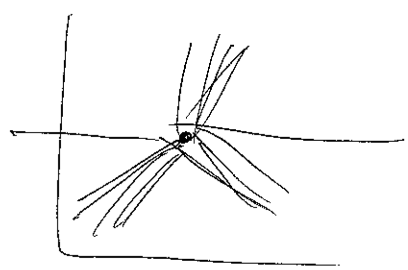
Measuring R determines N_{colors} & N_{quarks}

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

Discovery of the gluon

Can't produce gluons from e's, but you can radiate them from q's produced in $ee \to q\bar{q}$ collisions.





"Mercedes" events

smoking gun for gluons.

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

Now Collider Physics in some more detail.

σ - cross section characterizes the probability of interaction.

We've talked all about this.

$r_p \sim GeV^{-1} \sim 10^{-15}\,m$ $(10^{-13}\,cm)$ $10^{-26}\,cm^2 \equiv 0.01$ "barns"

→ Long Story ...

barn ~ size of uranium Atom

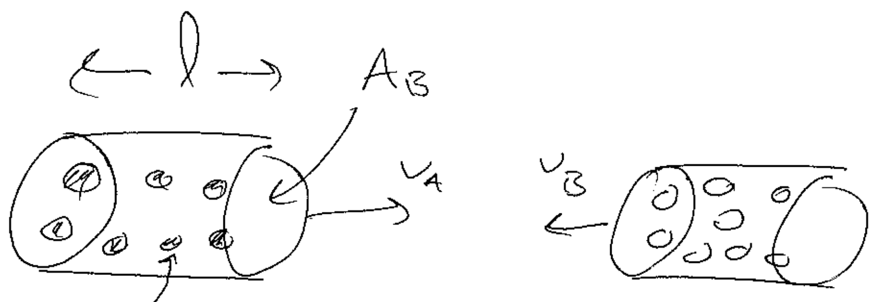
At the LHC interesting processes are

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 <u>hard</u>.

- 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 ~ 10^{11} protons (out of those ~20 collide)



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

number density Event rate

Think about a ~~proton~~ 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

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

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

F.F. depends on how the LHC was built, σ - intrinsic physical observable

Q: What is the flux factor @ the LHC?

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

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

$Vol \to$ ~~Vo~~ Volume of Bunch $= A_B \times l$

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

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

$|v_A - v_B| = 2c$ can't get much higher!

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

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

$\lambda \to$ 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 $10\ \mu m$! ~~B~~ width of human hair.

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