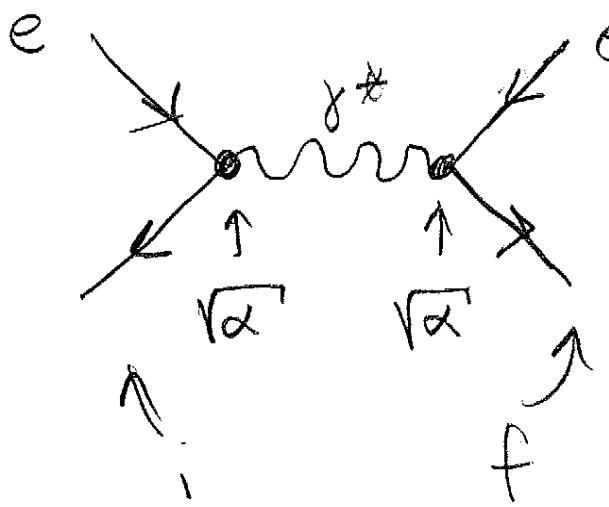
e^+e^- annihilation



Amplitude $\langle f | \hat{H}_{anni} | i \rangle$

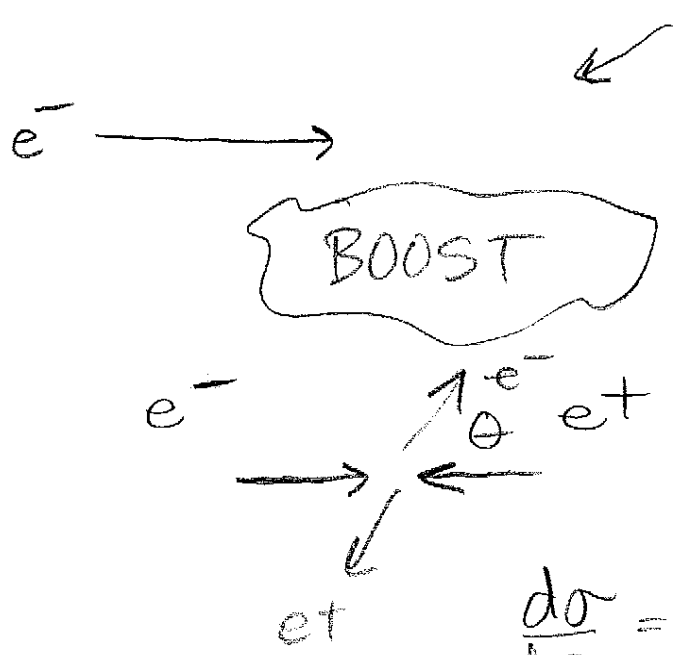
$\propto \alpha$

also a "tunneling" suppression factor.

$\rightarrow \frac{1}{(4\text{-momentum } Q)^2}$

↑ in γ^* line

How to think about this:

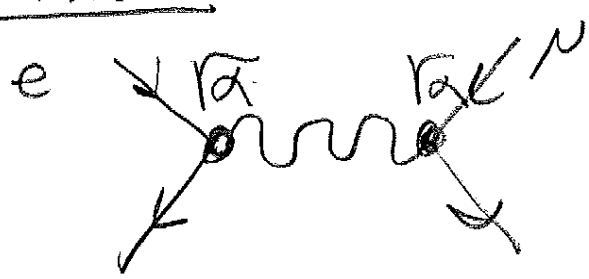


$\sum \vec{p}_i = 0$

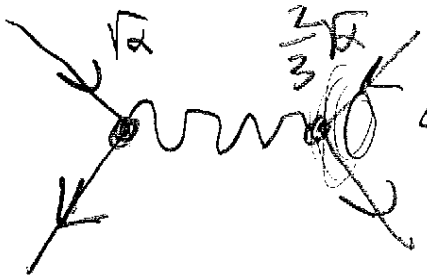
$\frac{d\sigma}{d\Omega} = f(E, \theta)$

4-momentum in γ

Famous:



→ NO t-channel



GLUE!
lots of
$u\bar{u}$, $d\bar{d}$

LOTS OF FINAL STATES POSSIBLE

→ Depends on Energy

→ Need at least $2m_{\pi^0}c^2$

→ When $E_{e^-} + E_{e^+}$ in their CM

$\gg 2m_{\pi^0}c^2$

OBSERVABLE STATE

"HADRONS" $n(\pi^+ + \pi^-) + m\pi^0$

also K^+, K^- ...

Assumptions (LOTS)

$$\frac{\sigma(e^+e^- \to \text{Hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)} \simeq \frac{\left(\frac{2}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2}{1^2}$$

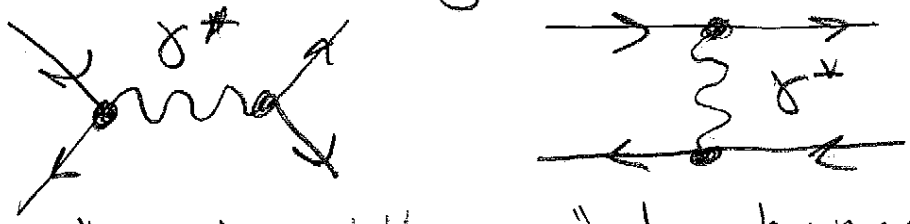
$$\simeq \frac{\frac{4}{9} + \frac{2}{9}}{1^2} = \frac{2}{3}$$

Measure ... 2! (p. 280 fig 8.4) COLOR

Technically:

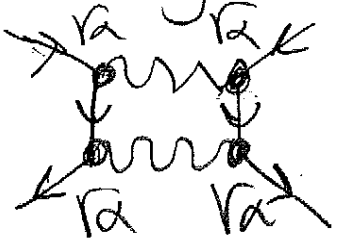
- Draw all diagrams that lead from $|i\rangle$ to $|f\rangle$
- Sum amplitudes that are indistinguishable
- Square $\propto$ Rate, Cross Section
  "decay" "scattering"

$e^+e^- \to e^+e^-$ Has Two, Lowest Order Diagrams ($O(\alpha)$)



"s-channel" "t-channel"

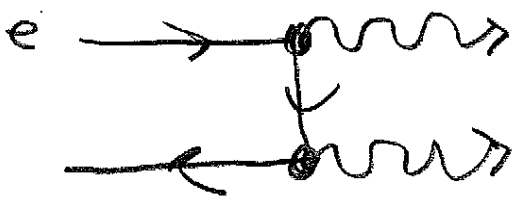
→ Indistinguishable
→ Q of γ^* Causes Differences
→ t-channel .. loves small angles
→ "Rutherford"
→ s-channel .. nearly uniform
⇒ Higher order too ...



$O(\alpha^2) \simeq \frac{1}{137} O(\alpha)$

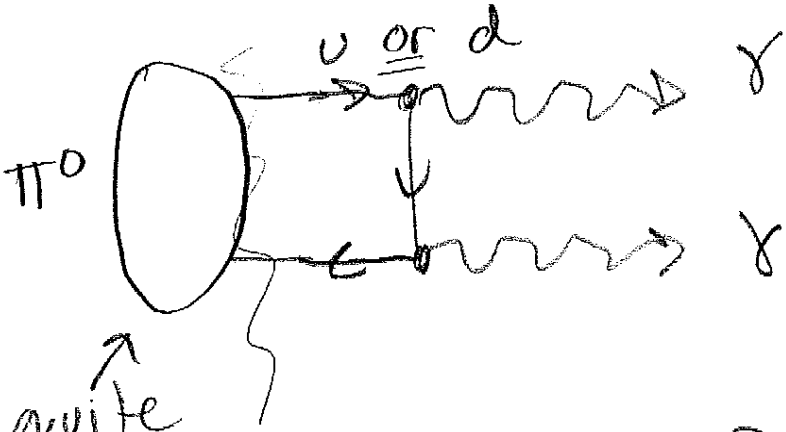
neglect! (E+M)

$O(\alpha)$ ..



$e^+e^- \to \gamma\gamma$

Most Important Historically



Rate 3x the tost Calc

$\pi^0 \to \gamma\gamma$

or $n \to \gamma\gamma$

Decay of an Eigenstate

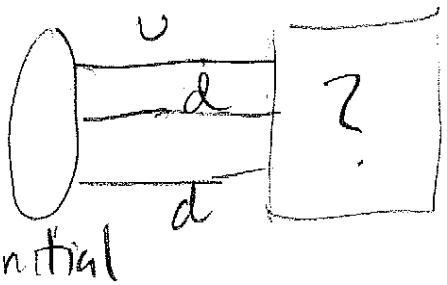
Electromagnetic Transitions ..

→ γ in final state

→ (isospin violated).

HADRONS Quarks not simple!

Inductive: Charge, Baryon #, Lepton #.



---- Final

net # quarks

leptons conserving

$n \to p\, e^-\, \bar{\nu}_e$ ← −1 unit of e-ness

charge 0 → +1 must be −1 ← $\bar{\nu}_e$ actually not an eigenstate of full 比

+1 unit of electron-ness

Baryon 1 1

$\bar{\nu}_e = a_1\nu_1 + a_2\nu_2 + a_3\nu_3$!

$n \to \bar{p}\, e^+\, \nu_e$ ← e-ness OK

charge 0 −1

Baryon 1 −1

↑ 3 quarks ↖ 3 antiquarks

VIOLATES BARYON #

GUTS strong, weak, E+m } do this -- experimentally nothing.

$p\bar{p} \to \pi^+\pi^0$ $(q + \bar{q})$

B 1 −1 0 0

Q 0 +1 1. No go.

$p\bar{p} \to \pi^+\pi^-$ OK (iso spin).