Nick Speeney NPP Exam 2

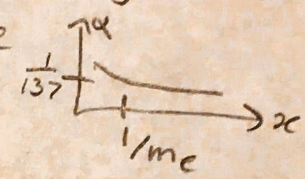
1. leptons: $\begin{pmatrix} e \\ \nu_e \end{pmatrix} \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$ } all spin $\frac{1}{2}$, have antiparticles too

Quarks: $\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$ } all spin $\frac{1}{2}$, have antiquarks too

Gauge Bosons: γ, 8 gluons, $W^{+/-}$, Z } all spin 1 +4

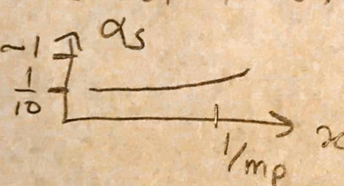
Higgs: H } spin 0 scalar

2. Due to vacuum fluctuations we get an effect of coupling rising or decreasing with distance. For example, α looks like



(scales a little with distance due to shielding effects from vacuum fluctuations)

But α_s looks like



→ as distances get larger we don't see strong force effects because quarks pairs just pop into existence instead (if we tried to pull a quark out of nucleus)

+2

weak force has massive force carrier, so distance $\sim \frac{1}{m_W}$ → limited range due to massive carrier.

3. W ——< $\begin{pmatrix} e \\ \bar{\nu}_e \end{pmatrix} \begin{pmatrix} \mu \\ \bar{\nu}_\mu \end{pmatrix} \begin{pmatrix} \tau \\ \bar{\nu}_\tau \end{pmatrix} \begin{pmatrix} u \\ \bar{d} \end{pmatrix} \begin{pmatrix} c \\ \bar{s} \end{pmatrix}$ ×3 colors ($\begin{pmatrix} t \\ b \end{pmatrix}$ too massive) +4

charged

Z ——< $\begin{pmatrix} e^- \\ e^+ \end{pmatrix} \begin{pmatrix} \mu \\ \mu^+ \end{pmatrix} \begin{pmatrix} \nu_e \\ \bar{\nu}_e \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \bar{\nu}_\mu \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \bar{\nu}_\tau \end{pmatrix} \begin{pmatrix} \tau \\ \bar{\tau} \end{pmatrix}$ + quarks

No charge

$$Br(Z \to \nu\nu) = \frac{3|M_0|^2}{\sum_f |M(Z \to f\bar{f})|^2} = \frac{3|M_0|^2}{6|M_0|^2} = \frac{1}{2}$$

$$Br(W \to e\nu) = \frac{|M_0|^2}{(3 + 2 \cdot 3)|M_0|^2} = \frac{1}{9}$$

⇒ How often $e\nu\nu\nu$ is $\sim \frac{1}{2} \cdot \frac{1}{9} = \frac{1}{18} \sim 5\%$ of the time

4. $WW \to \ell\nu\ell'\nu'$ $\quad W^{+/-} \longrightarrow \binom{e}{\nu_e}\binom{\mu}{\nu_\mu}\binom{\tau}{\nu_\tau}\overbrace{\binom{u}{d}\binom{c}{s}}^{\times 3\text{colors}}$ +5

ignore $\quad$ e or μ only

$Br(WW \to \ell\nu\ell'\nu') = Br(W \to \ell\nu)\,Br(W \to \ell'\nu') = \left(\frac{2|M_0|^2}{(3+2\cdot 3)|M_0|^2}\right)^2$

$= \left(\frac{2}{9}\right)^2 = \frac{4}{81} \sim 5\%$

$ZZ \to \ell\ell\ell'\ell' \to Z \longrightarrow \binom{e}{e^+}\binom{\mu}{\mu^+}\binom{\tau}{\tau^+}\binom{\nu_e}{\bar\nu_e}\binom{\nu_\mu}{\bar\nu_\mu}\binom{\nu_\tau}{\bar\nu_\tau}$ + quarks

$Br(ZZ \to \ell\ell\ell'\ell') = Br(Z \to \ell\ell)\,Br(Z \to \ell'\ell') = \left(\frac{2|M_0|^2}{6|M_0|^2}\right)^2 = \frac{1}{9}$ ← e or μ

$\sim 10\%$

$WW (Br \sim 20\%) \to \ell\nu\ell'\nu'$ ~5% of time → $H \to \ell\nu\ell'\nu'$

$\sim .2 \cdot 0.05 \sim 1\%$

$ZZ (Br \sim 3\%) \to \ell\ell\ell'\ell'$ ~10% of the ⇒ $H \to \ell\ell\ell'\ell'$

$\sim 0.03 \cdot .1 \sim 0.3\%$

⇒ $H \to \ell\nu\ell'\nu'$ has ~1% ← 1

$H \to \ell\ell\ell'\ell'$ has ~0.3% ← 2

$H \to \gamma\gamma$ has ~0.2% ← 3

+4

5. a. Mostly the strength of B field, since synchrotron radiation is lesser

b. Mostly the synchrotron radiation due to e− small mass

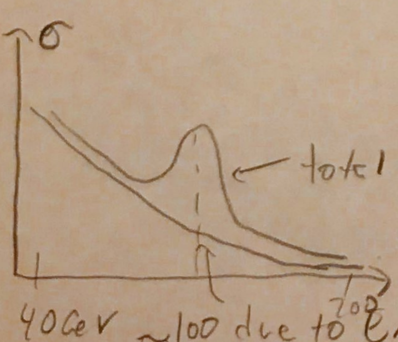
6. a. $R(E_{cm})$ grows larger as E_{com} is increased beyond $2m_{charm}$

→ $R(<2m_{charm}) = \sum Q_q^2 = Q_u^2 + Q_d^2 + Q_s^2 = \frac{4}{9} + \frac{1}{9} + \frac{1}{9} = \frac{2}{3}$

→ $R(>2m_{charm}) = \sum Q_q^2 = Q_u^2 + Q_d^2 + Q_s^2 + Q_c^2 = \frac{4}{9} + \frac{1}{9} + \frac{1}{9} + \frac{4}{9} = \frac{10}{9}$

× colors

b.



+5

7a. Both e's and μ's leave tracks since they are charged in the inner tracker. e's stop in the EM calorimeter however, and deposit their energy there. μ's continue through all the way to the outermost muon detector

+4

b. Both leave energy traces in the EM calorimeter, but electrons leave tracks in the inner tracker, whereas γ does not (it isn't charged)

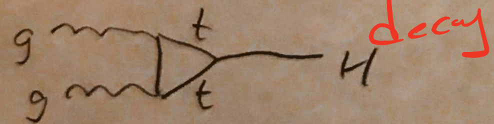
8. Hadronic showers since they are full of very complicated processes, and so accurate measurement is harder. EM showers are a more straight forward process with well defined energies and time scales

+4

9. $X \to \mu\mu$, since μ's are heavier than e's there is less uncertainty in the origin of μ's and so detectors could more easily confirm that the μ's were indeed coming from this particle X. +2

$m_\mu - m_e \ll$ TeV

10. ν's are detected by looking at the other particles and seeing whether energy is being unaccounted for. Also, seeing if there is momentum being unaccounted for (i.e. $p_i \neq p_f$ and $E_i \neq E_f$, indication that ν was involved) +2

11. a. 

b. produced ~~through strong~~ coupling rather than ~~weak~~ +1

12. $\mu\mu$, since μ's are easy to detect and should be yielded highly compared to others (also e^+e^- signals could be confused with other things) +3

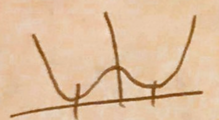
13. a. # of generators is = number of particles

b. $SU(2)_L \times U(1)$ +5

c. $SU(2)_L$ has 3 generators (σ's) $\to$ 3 particles $W^{+/-}, Z$ 8

$U(1)_Y$ has 1 generator → get Higgs

14. a. SSB is the broken symmetry of $\phi \to -\phi$ by choosing a mass term $\mu^2 < 0$, which gives potential in Lagrangian like this:



$-v$ $+v$

Since we expand about the minimum, we choose to expand around $\phi = v$ → the $\phi \to -\phi$ symmetry is broken by this

b. This is responsible for describing the mass

c. relations between Z and $W^{+/-}$ particles, we have detected the Higgs also, and confirmed the predicted masses of $W^{+/-}$ and Z

+6