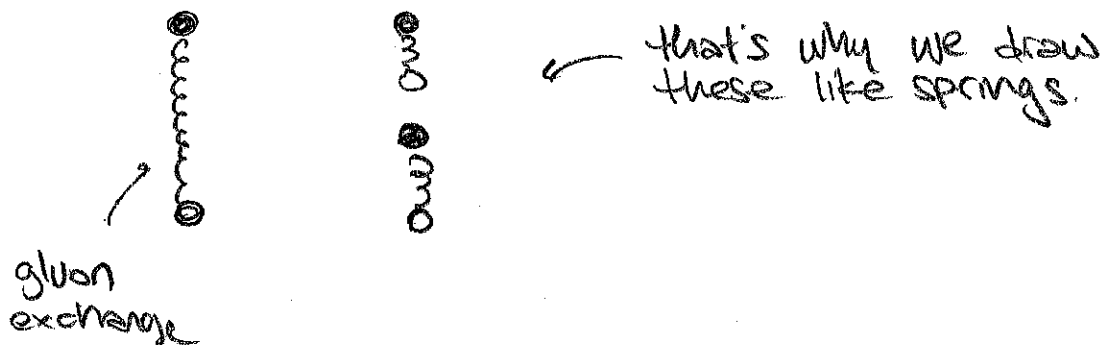


What's left in the SM?

↳ confinement in QCD: no free quarks

PULL 2 quarks apart \Rightarrow it becomes energetically favorable to create a $q\bar{q}$ pair



FREE PARTICLES: ~~OVER~~ NEUTRAL: all a, b, c INDICES MUST CONTRACT

eg. PION: $(u^a (u^\dagger)_a + (d)^a (d^\dagger)_a) \frac{1}{\sqrt{2}}$

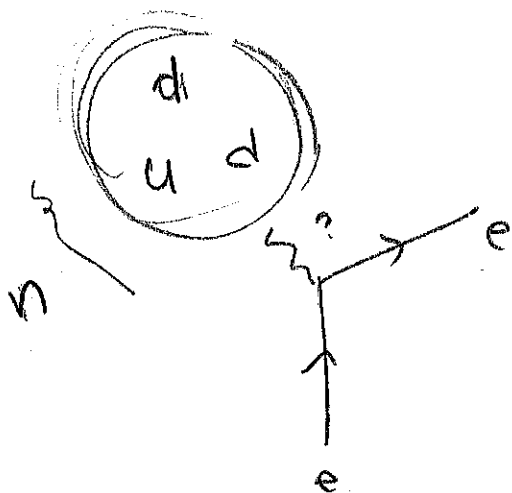
↑
itself a lin comb
of $u, d \Rightarrow \bar{u}^+ = u_R$

eg. neutron: $u^a d^b d^c \boxed{\epsilon_{abc}}$ "free" tensor that we have for $SU(3)$

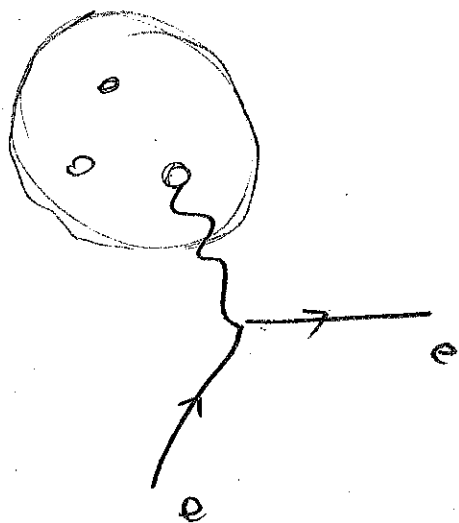
SO WE HAVE BOUND states: look like particles from far away, but you see substructure up close

↑
@ low E

↑
@ hi E



- ② low E (low momentum)
 compare Compton λ
 to characteristic
 binding
 n has no electric
 charge



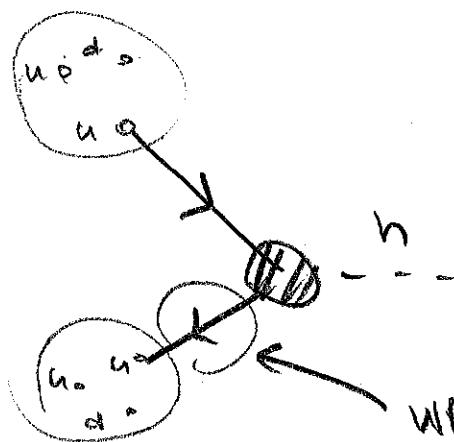
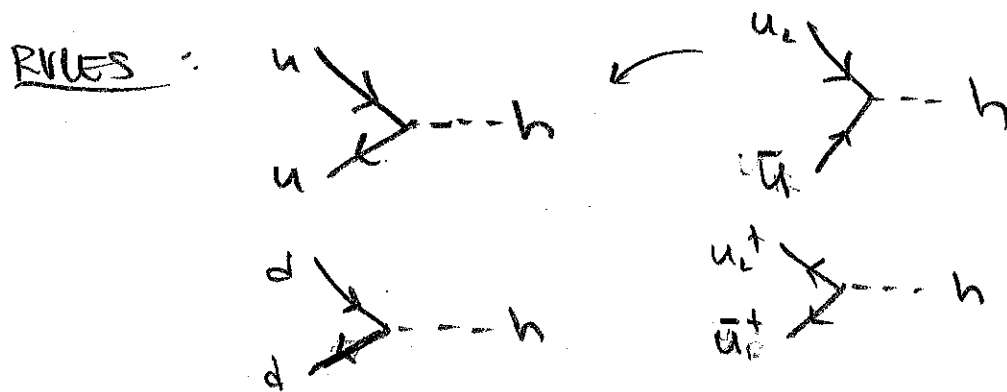
- ③ Hi E, see constituent
 quarks (w/ charge!)
 \rightarrow can recoil off these

\rightarrow DEEP INELASTIC SCATTERING

\uparrow
 analogy of
 Rutherford gold foil
 experiment!

@ hi-E proton colliders, you're colliding constituents \rightarrow each carrying a fraction of the proton's energy.

Q: how do protons collide to form Higgs bosons?



WRONG ARROW!

Need anti-up quark
BUT P only has up-quarks!

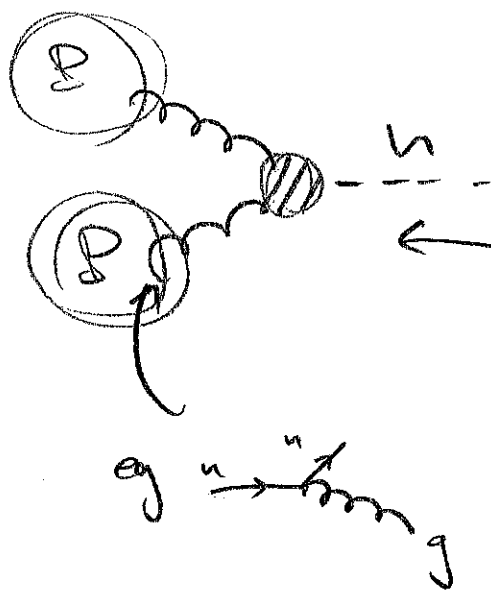
this is a puzzle!

SOLUTION: P^+ is more than its valence quarks

\uparrow full of quarks!

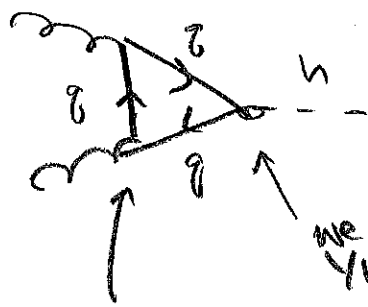
"PARTON DISTRIBUTION"

\uparrow q or \bar{q}



does higgs
talk to glue?

not directly. but it turns out:



we have this
YUKAWA interaction

standard
gluon interaction

WHICH SPECIES OF QUARK
CONTRIBUTES MOST?

↳ the triangle is purely VIRTUAL.

PUZZLES of SM

1. HOW DO NEUTRINOS GET MASS?

obvious choice: $y_\nu H L \bar{\nu}$

↳ gives ν mass upon $H \rightarrow \langle H \rangle$
↳ misalignment of flavor sym means you can have ν -oscillations

2. WHY IS THERE MORE MATTER than ANTIMATTER?
BARYOGENESIS

↳ has to do w/ C #s in our theory

3. WHY IS THE HIGGS SO LIGHT?

1. 'HAD' TO BE THERE

2. ... BUT NO REASON FOR THEORY TO DO THAT FOR US

↳ popular solutions: $\left\{ \begin{array}{l} \text{SUSY} \\ \text{XD} \\ \text{compositeness} \end{array} \right.$

4. why is $\Theta_{\text{em}} \approx 0$? ← neutron dipole moment is near zero

↳ BUT THERE IS A COMPLEX PHASE IN THE THEORY THAT COULD HAVE BEEN ANYTHING

→ popular solution: AXION / PQ MECHANISM

5. what is DARK MATTER? (DARK E?)

6. WHAT HAPPENS TO GRAVITY IN THE UV?