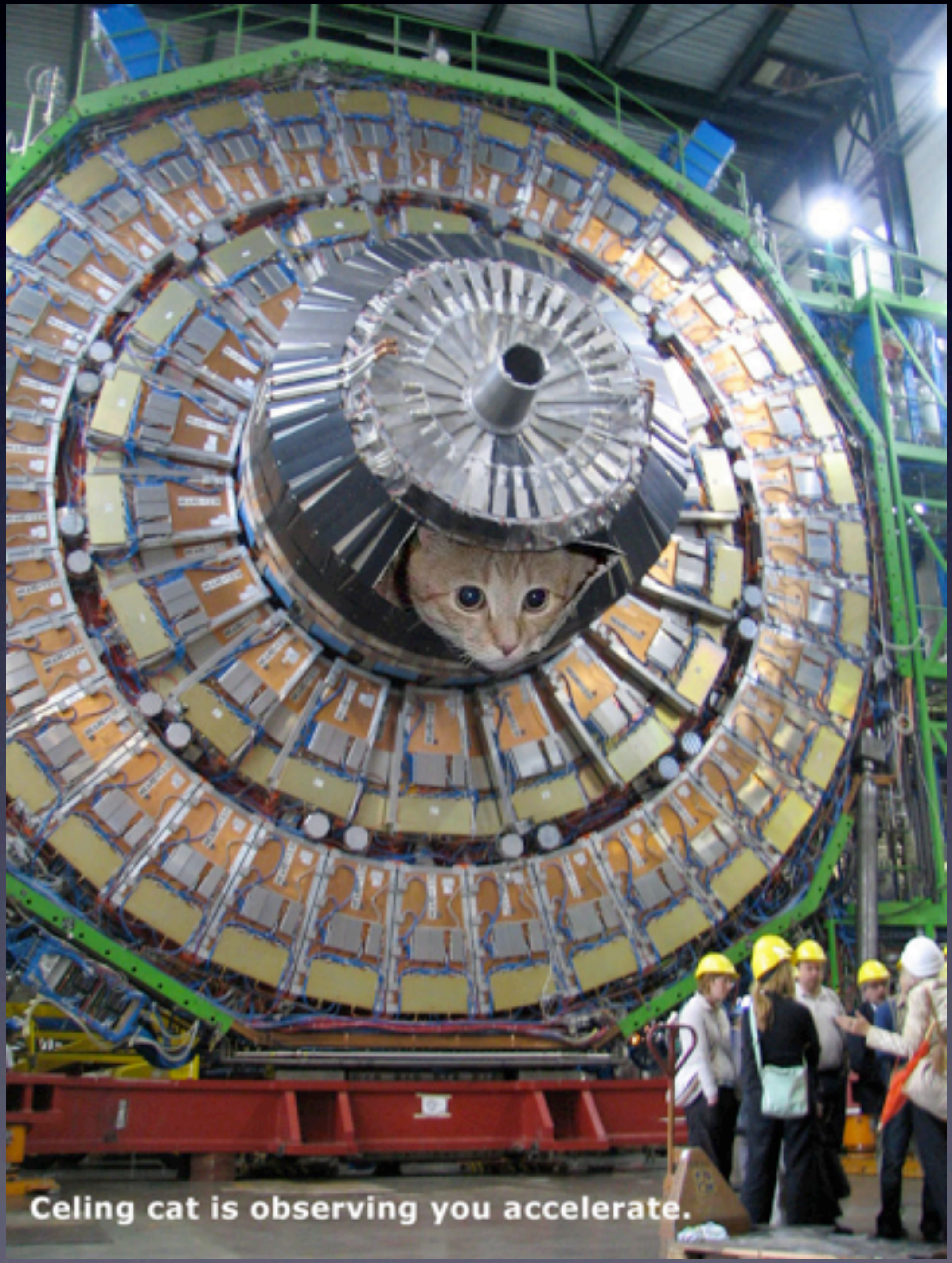
QuarkNet Data Workshop



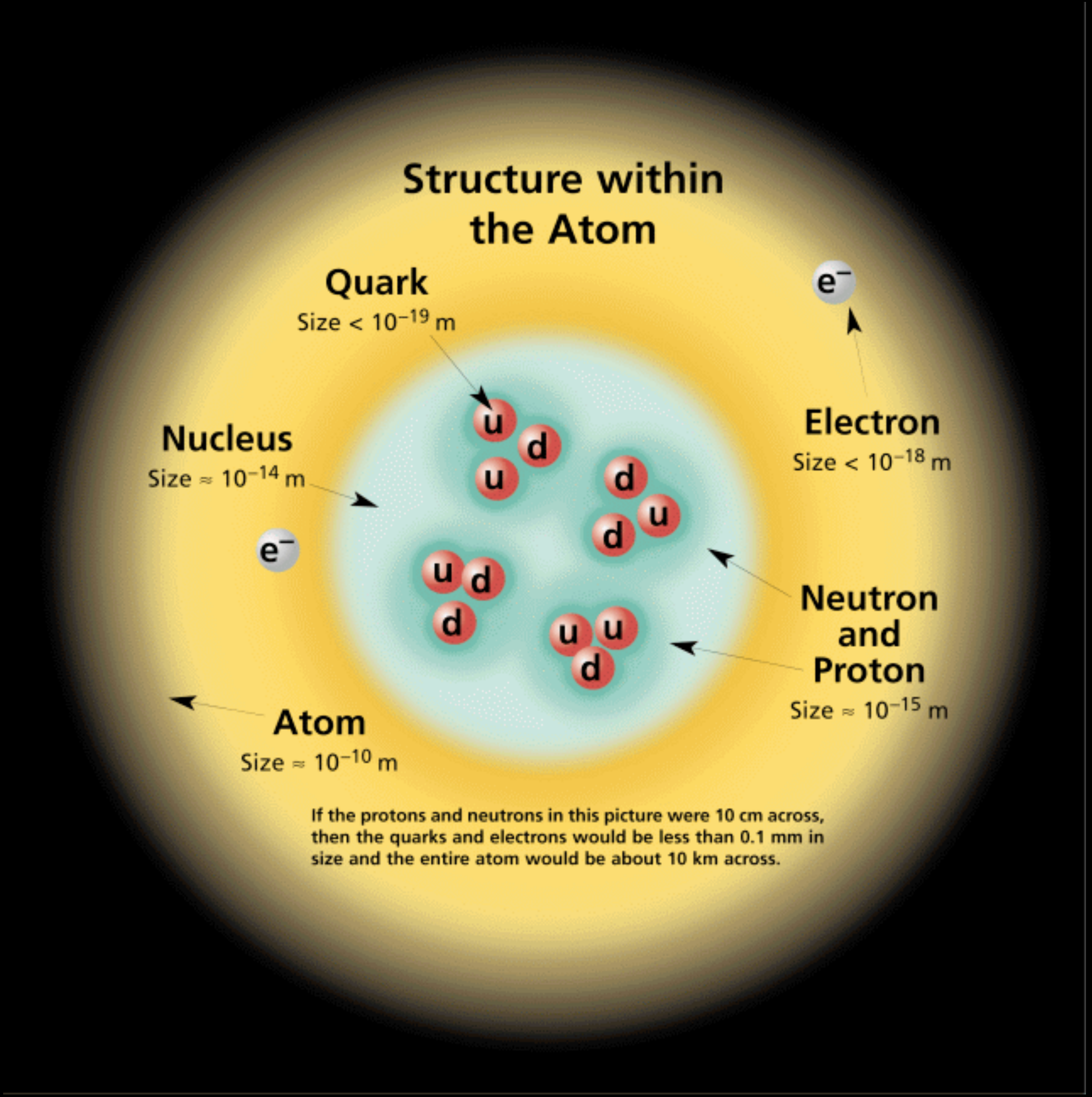
August 12, 2015

Feynman Diagrams:

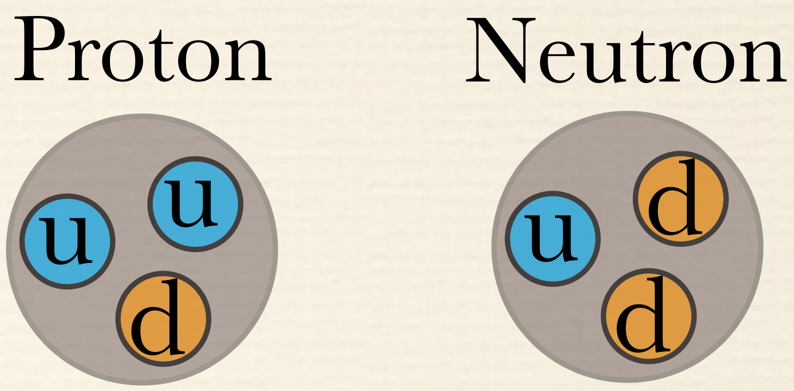
Introduction and Activities

First some useful material to introduce particle physics

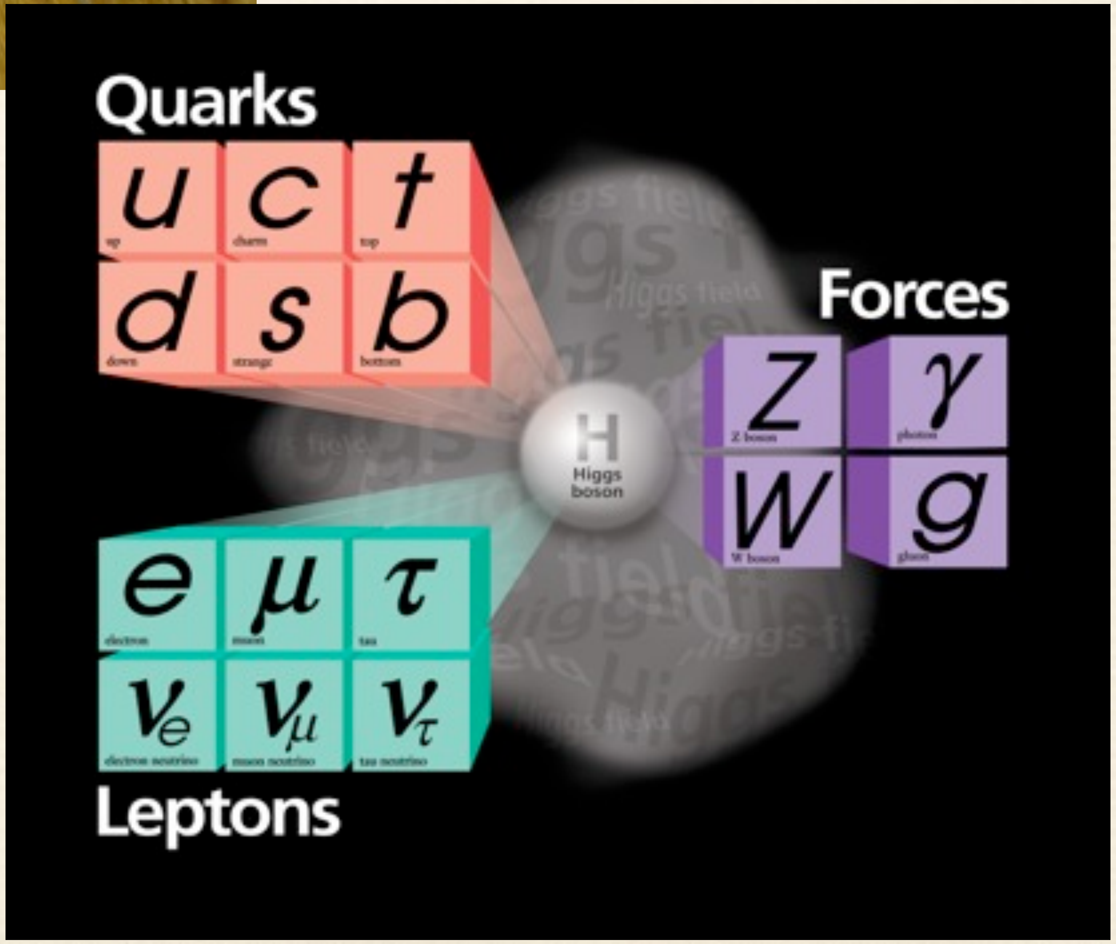
Inside the atom



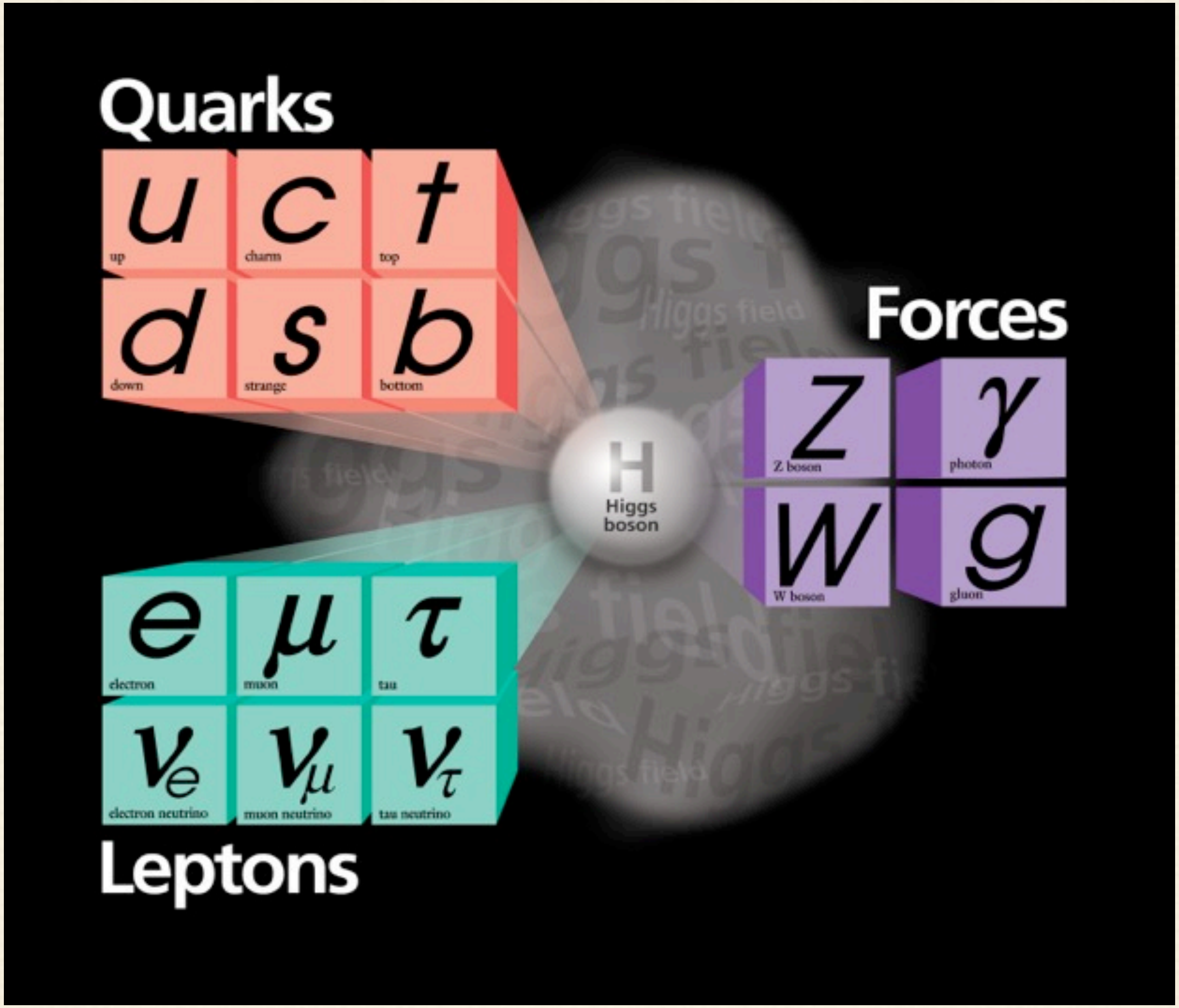
The Particle Zoo

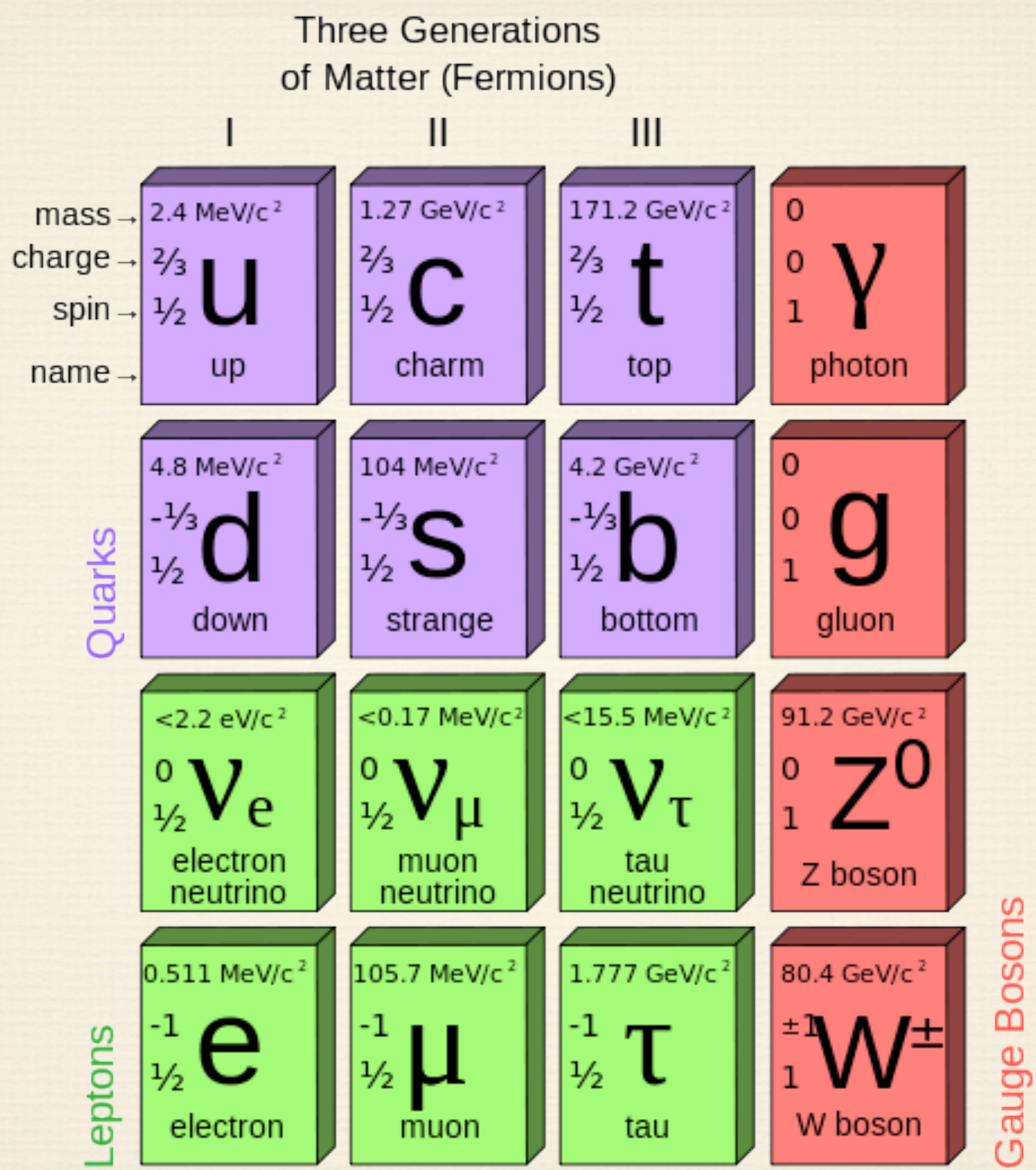


The Standard Model

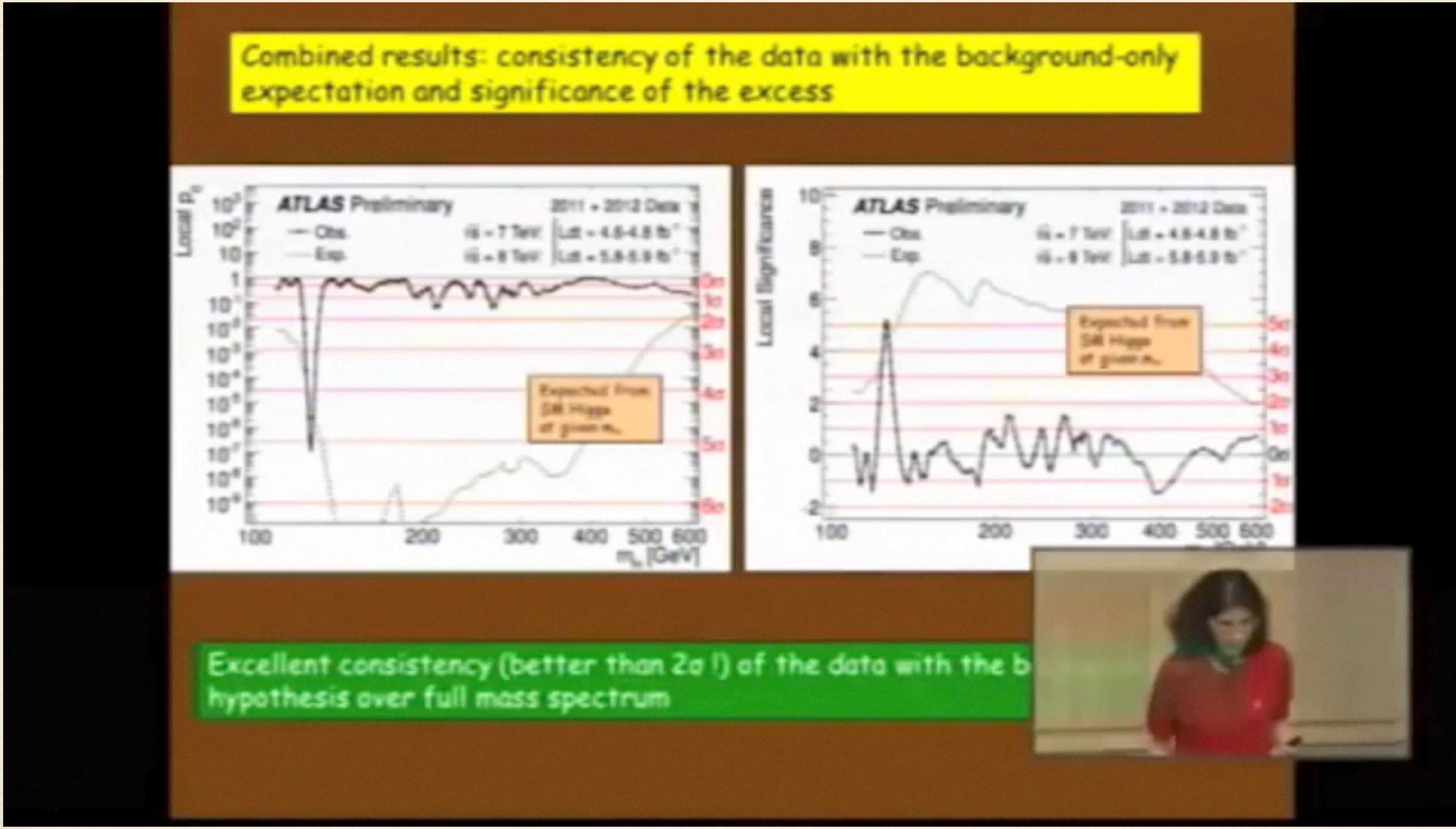



The PARTICLE ZOO
gluon


Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
H
Higgs
boson
e
electron
μ
muon
τ
tau
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
Leptons


Three Generations
of Matter (Fermions)
I
II
III
mass →
charge →
spin →
name →
2.4 MeV/c²
⅔
½
u
up
1.27 GeV/c²
⅔
½
c
charm
171.2 GeV/c²
⅔
½
t
top
0
0
1
γ
photon
4.8 MeV/c²
-⅓
½
d
down
104 MeV/c²
-⅓
½
s
strange
4.2 GeV/c²
-⅓
½
b
bottom
0
0
1
g
gluon
<2.2 eV/c²
0
½
νe
electron neutrino
<0.17 MeV/c²
0
½
νμ
muon neutrino
<15.5 MeV/c²
0
½
ντ
tau neutrino
91.2 GeV/c²
0
1
Z0
Z boson
0.511 MeV/c²
-1
½
e
electron
105.7 MeV/c²
-1
½
μ
muon
1.777 GeV/c²
-1
½
τ
tau
80.4 GeV/c²
±1
1
W±
W boson
Quarks
Leptons
Gauge Bosons

For a discussion of statistics, discoveries in physics



CERN, July 4, 2012.

The Standard Model Lagrangian (useful only to show that the Standard Model is described entirely by one equation)

$$\mathcal{L}_{GWS} = \sum_f (\bar{\Psi}_f (i\gamma^\mu \partial\mu - m_f)\Psi_f - eQ_f \bar{\Psi}_f \gamma^\mu \Psi_f A_\mu) +$$

$$+ \frac{g}{\sqrt{2}} \sum_i (\bar{a}_L^i \gamma^\mu b_L^i W_\mu^+ + \bar{b}_L^i \gamma^\mu a_L^i W_\mu^-) + \frac{g}{2c_w} \sum_f \bar{\Psi}_f \gamma^\mu (I_f^3 - 2s_w^2 Q_f - I_f^3 \gamma_5)\Psi_f Z_\mu +$$

$$-\frac{1}{4}|\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 - \frac{1}{2}|\partial_\mu W_\nu^+ - \partial_\nu W_\mu^+ +$$

$$-ie(W_\mu^+ A_\nu - W_\nu^+ A_\mu) + ig' c_w (W_\mu^+ Z_\nu - W_\nu^+ Z_\mu|^2 +$$

$$-\frac{1}{4}|\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w (W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 +$$

$$-\frac{1}{2} M_\eta^2 \eta^2 - \frac{g M_\eta^2}{8 M_W}\eta^3 - \frac{g'^2 M_\eta^2}{32 M_W}\eta^4 + |M_W W_\mu^+ + \frac{g}{2}\eta W_\mu^+|^2 +$$

$$+\frac{1}{2}|\partial_\mu \eta + i M_Z Z_\mu + \frac{ig}{2c_w}\eta Z_\mu|^2 - \sum_f \frac{g}{2}\frac{m_f}{M_W}\bar{\Psi}_f \Psi_f \eta$$

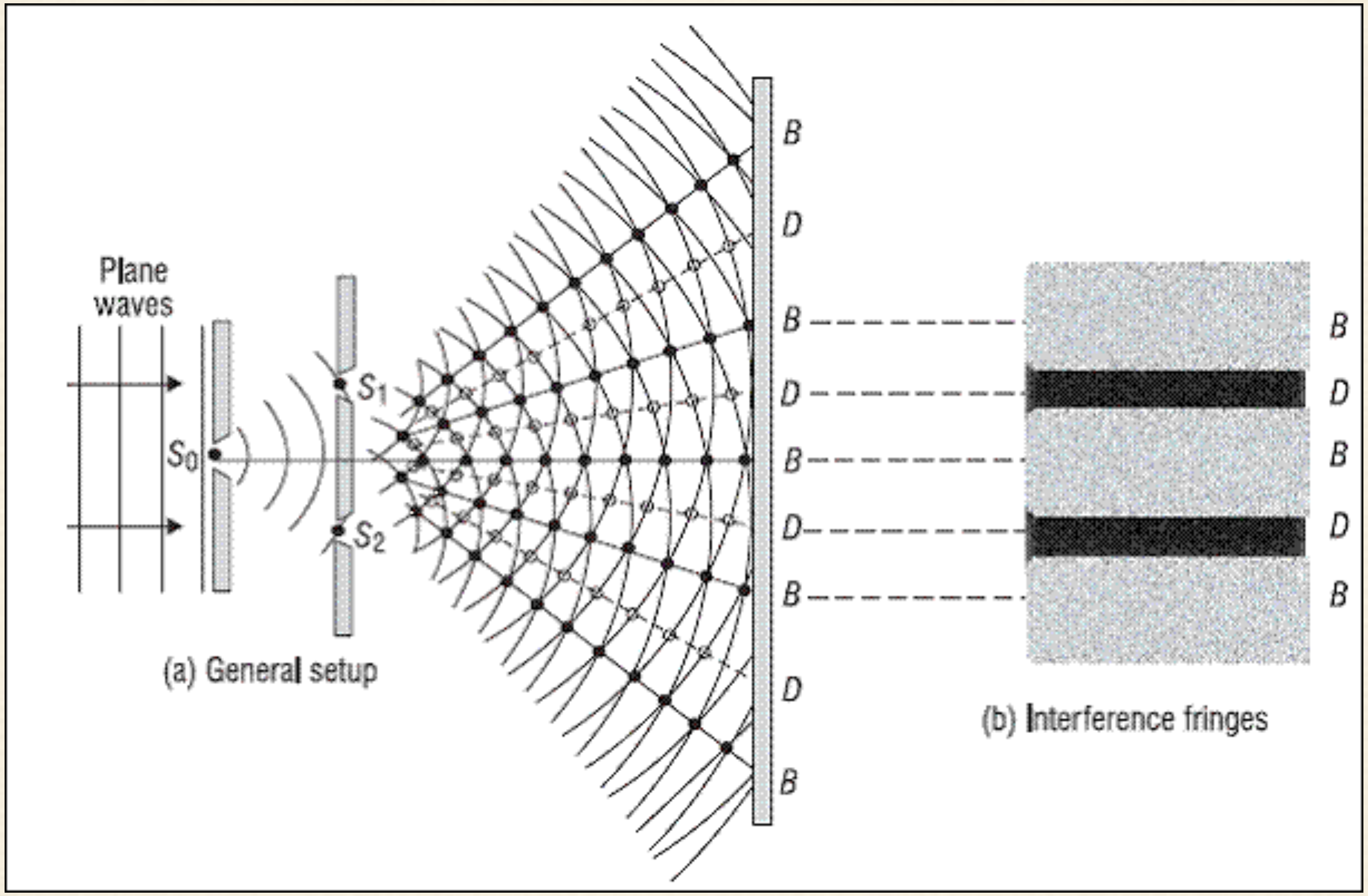
If you consider the amazing variety of living and nonliving things, you can’t help but be in awe of the fact that everything you have ever seen, smelled, and heard - people, birds, flowers; the clouds in the sky, and the moon and stars above; earth, wind, fire, and water - is ultimately described by a single beautiful equation.

The Standard Model

Feynman rules organize calculations of probabilities for initial states to evolve into specified final states.

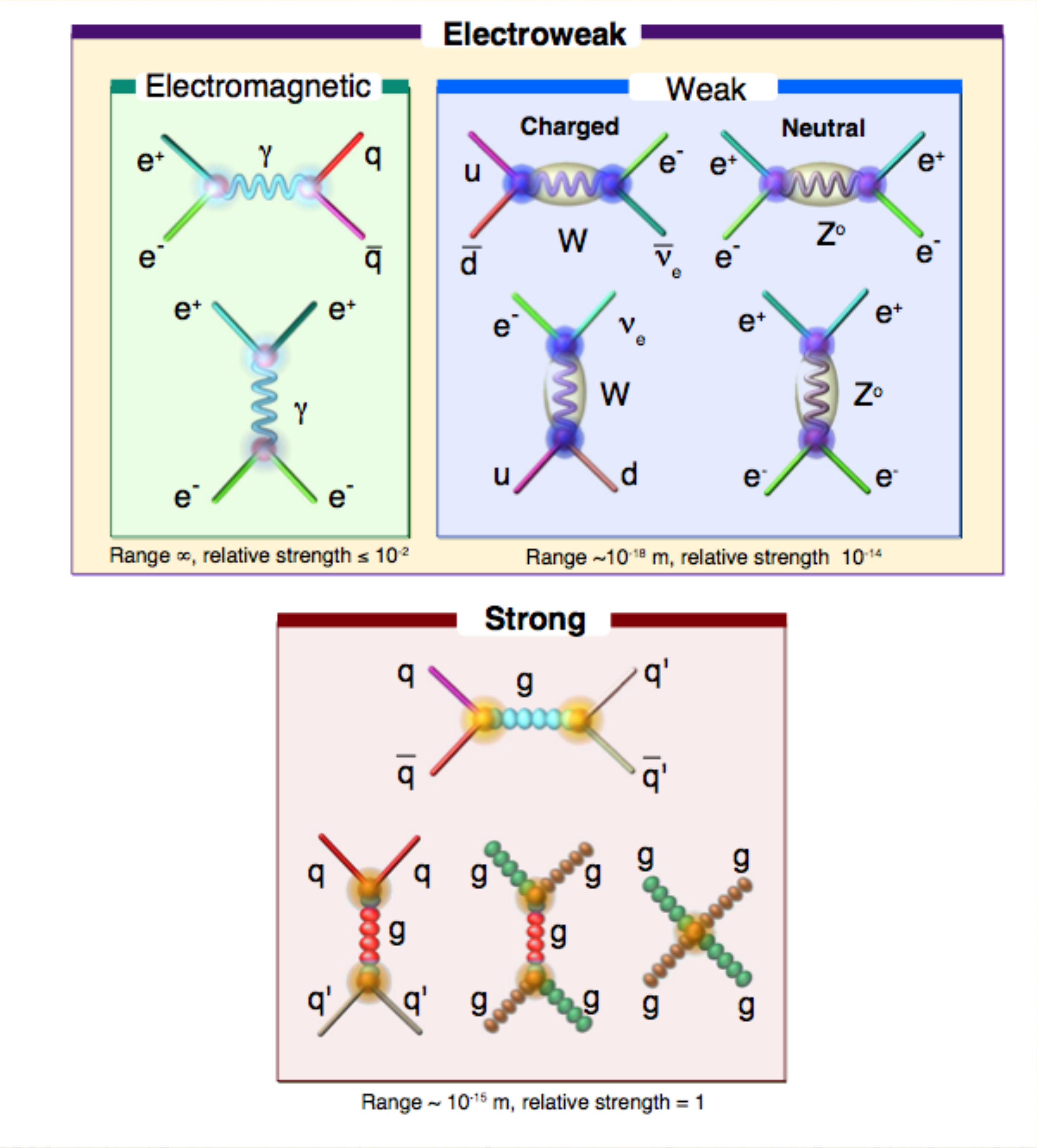
They also determine what types of interactions are allowed, and which are forbidden in the Standard Model.

How did Feynman think about quantum mechanics?

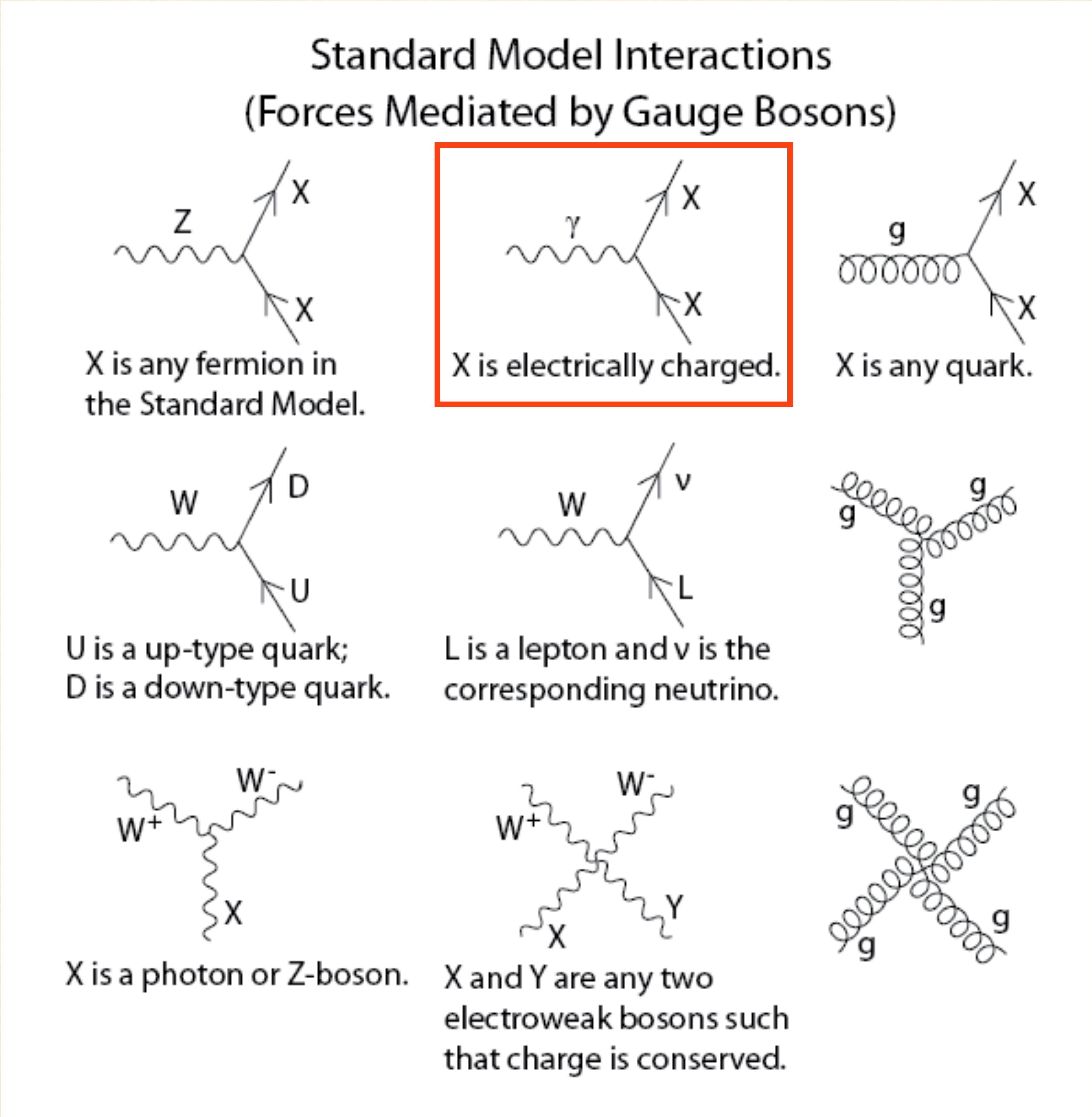


Now add more slits.

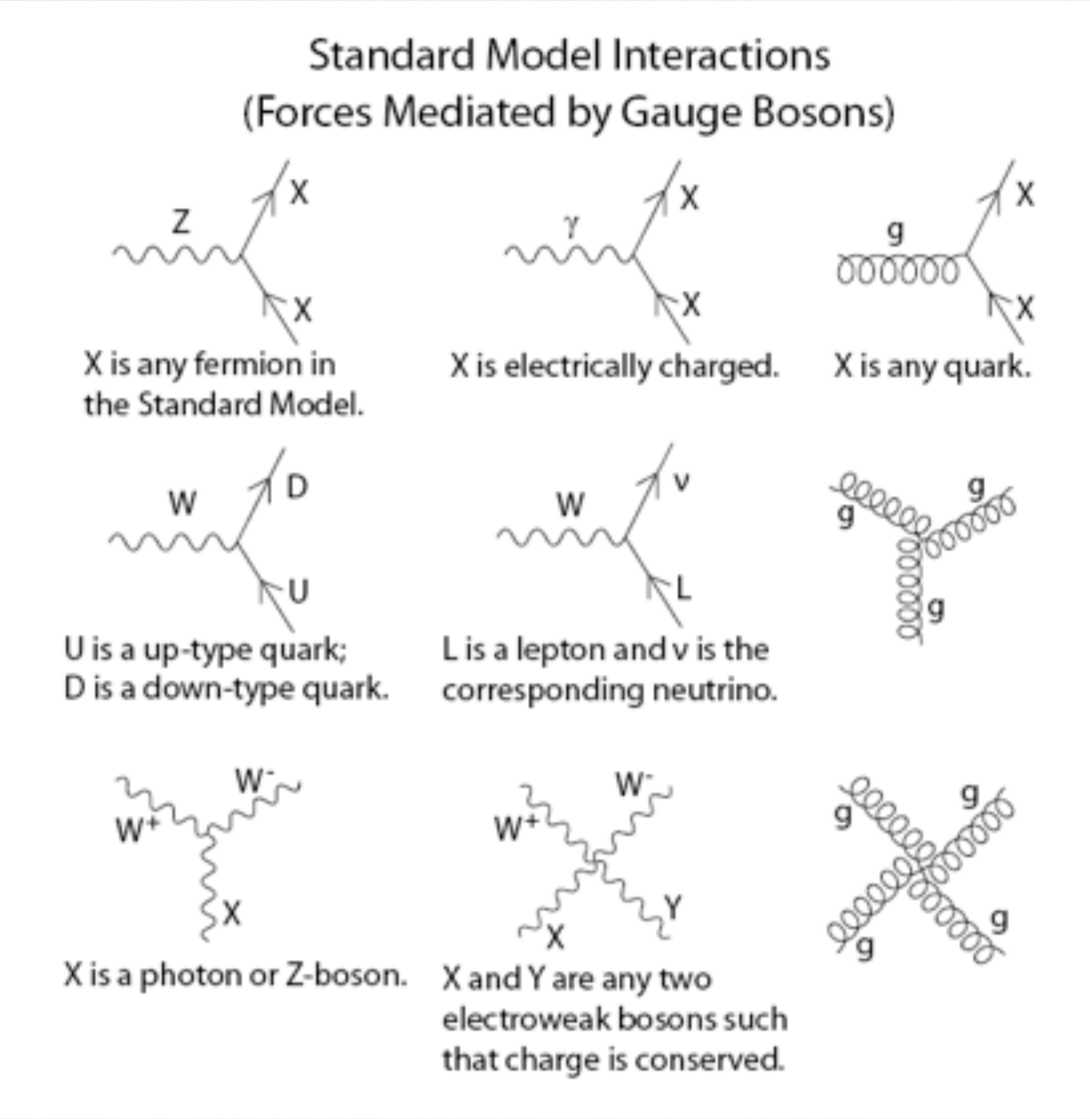
Types of Particle Interactions



Feynman Vertices



The Standard Model



Rules:

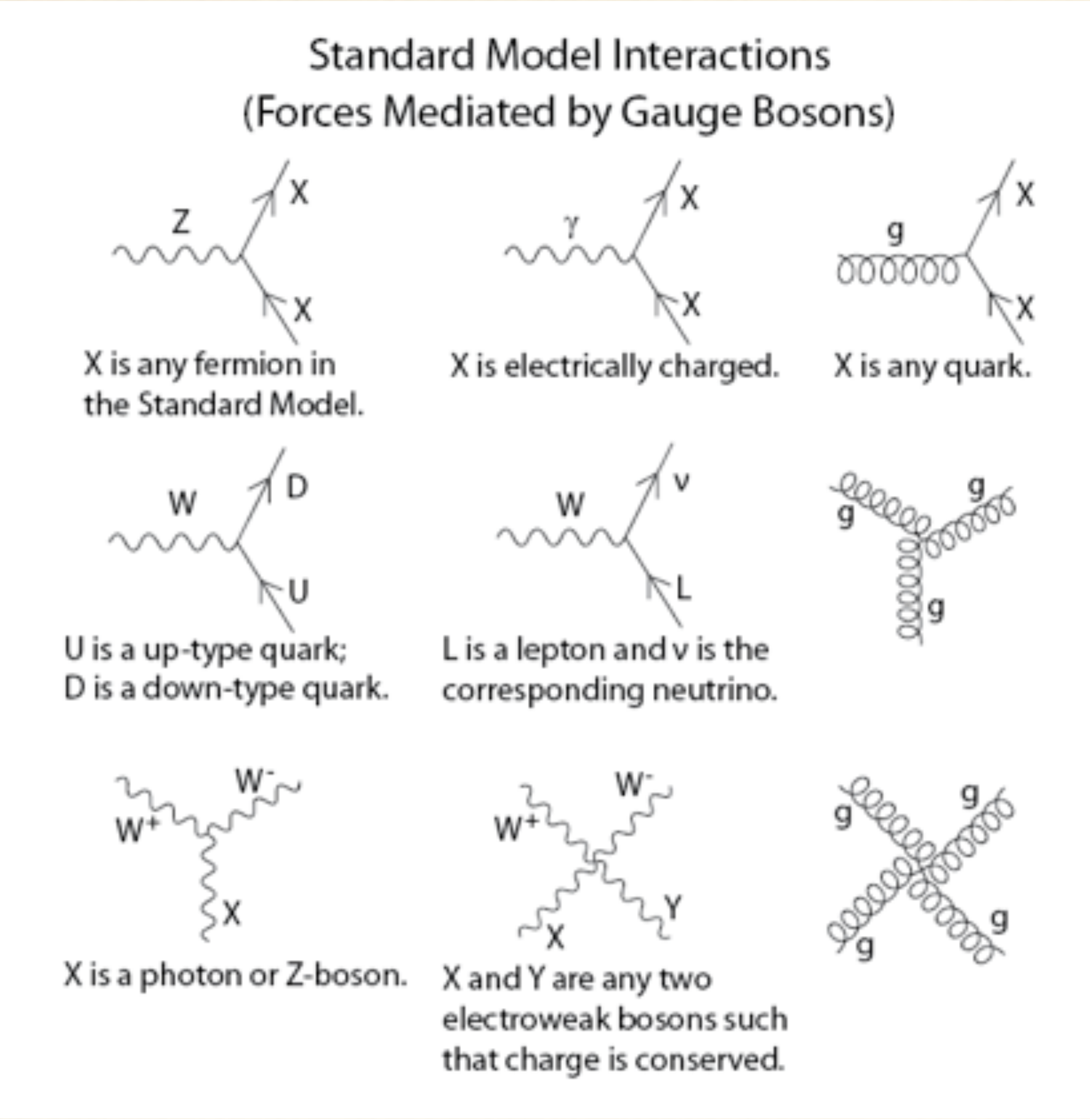
1. Arrows that follow the direction of time are particles; arrows that oppose the direction of time are antiparticles.

2. Lines of similar type can be connected to one another, with arrows flowing continuously.

3. Loops are okay.

4. Energy and momentum are conserved (so light things can't decay into heavier things, even if there's a Feynman diagram for such a process).

The Standard Model



Activity:

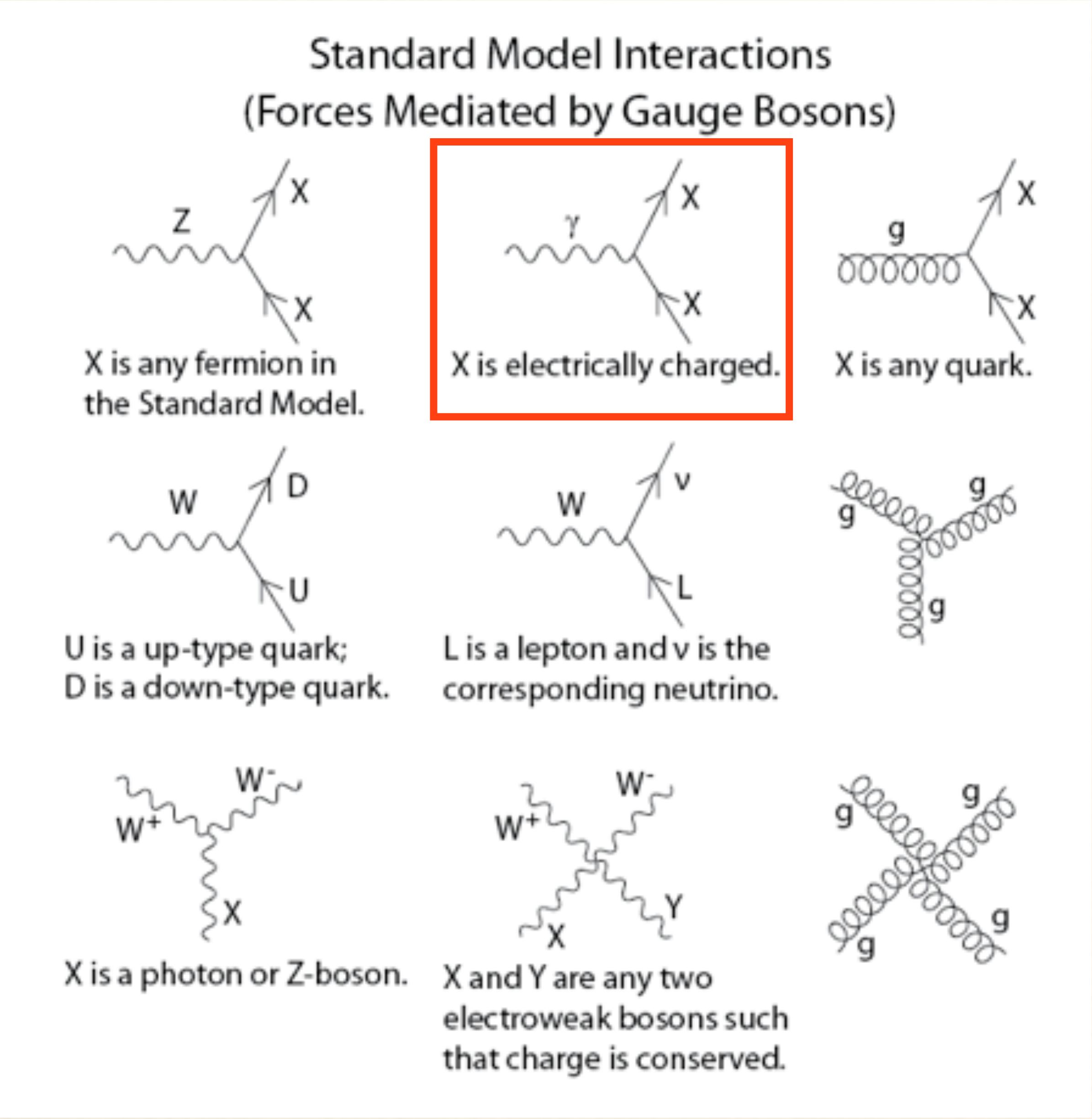
Draw a bunch of Feynman diagrams, and describe the particles in the initial and final states.

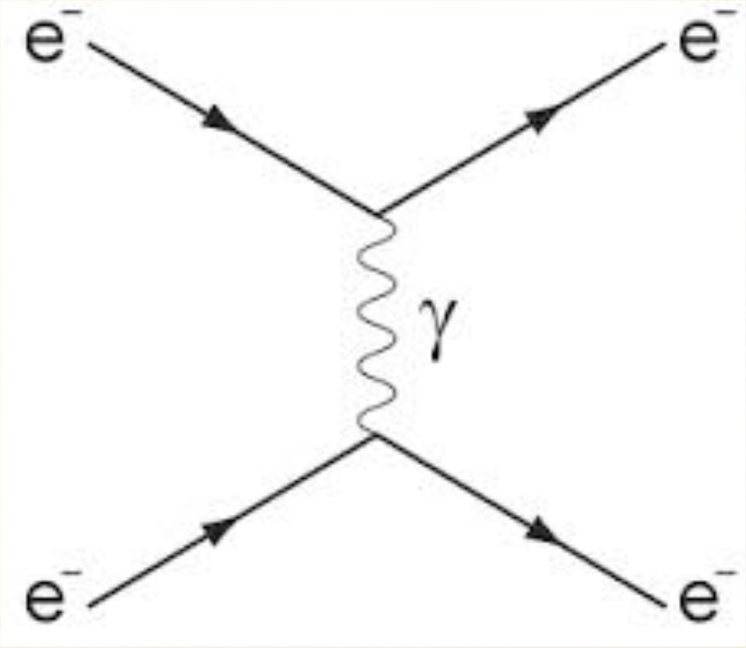
Questions (after the activity):

1. What particle properties are conserved (necessarily the same before and after an interaction)?

2. How are the weak interactions and the strong interactions different than the electromagnetic interaction?

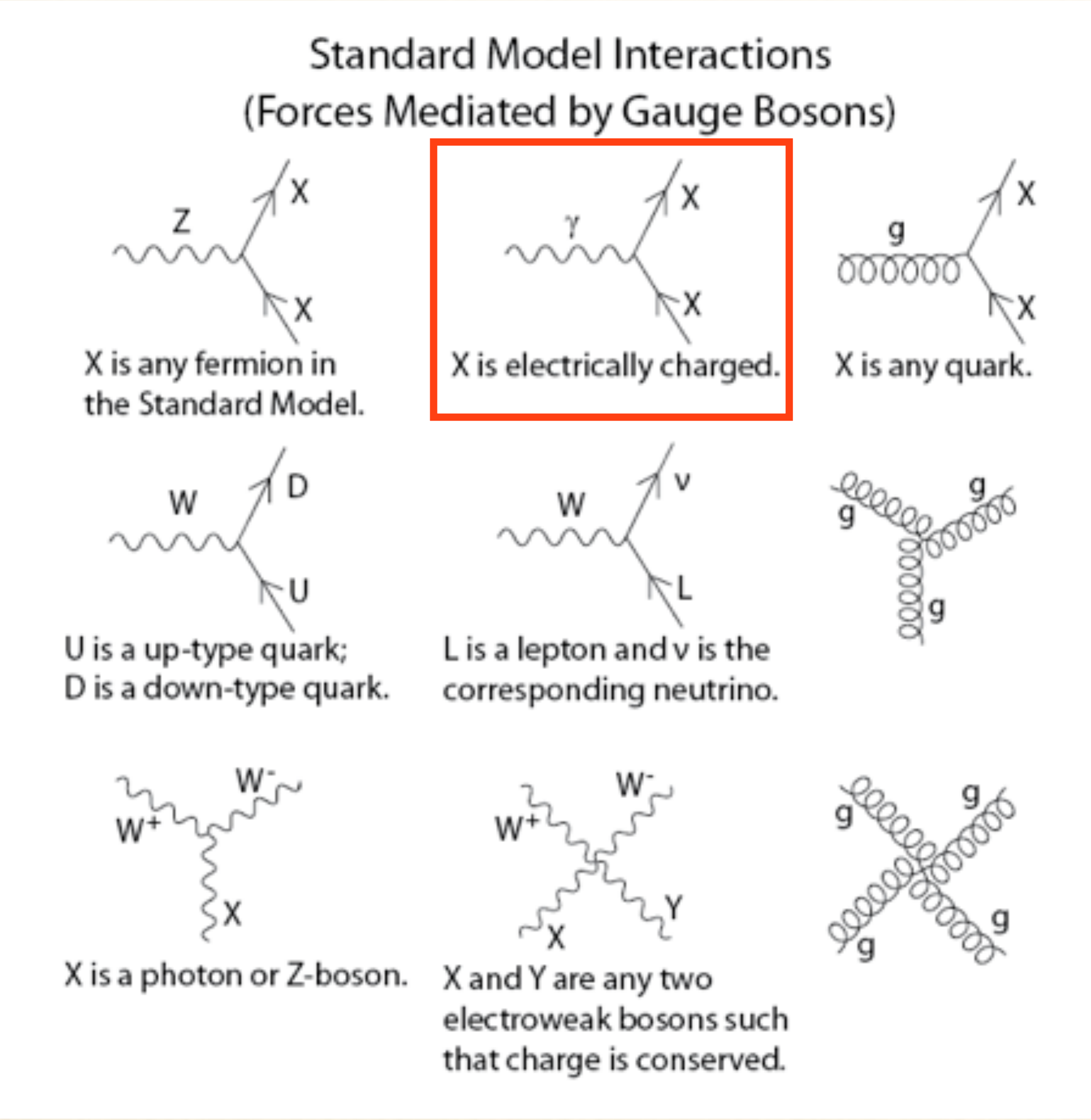
Electron Scattering

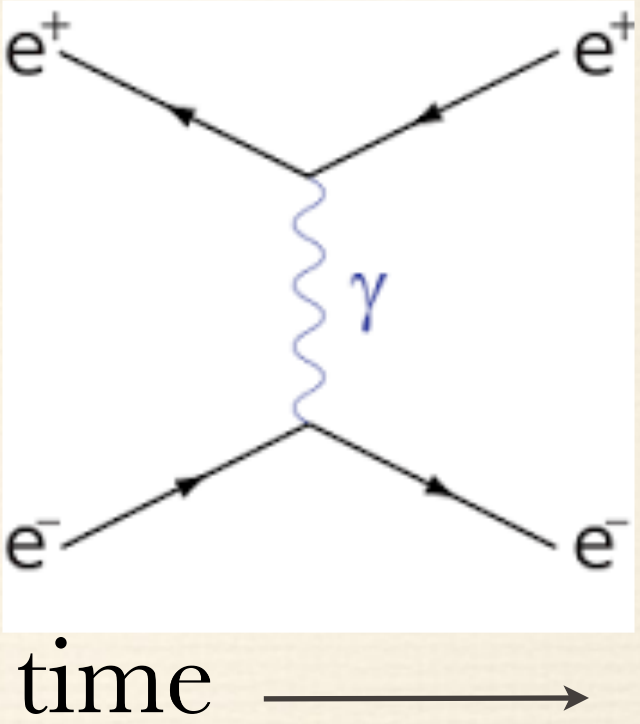




time →

Electron-Positron Scattering





total electric charge = conserved

#leptons - #antileptons = conserved

Activity: Interactions and the Direction of Time

Activity:

1) Draw a Feynman diagram representing scattering of electrons. Label the direction of time with an arrow near the Feynman diagram.

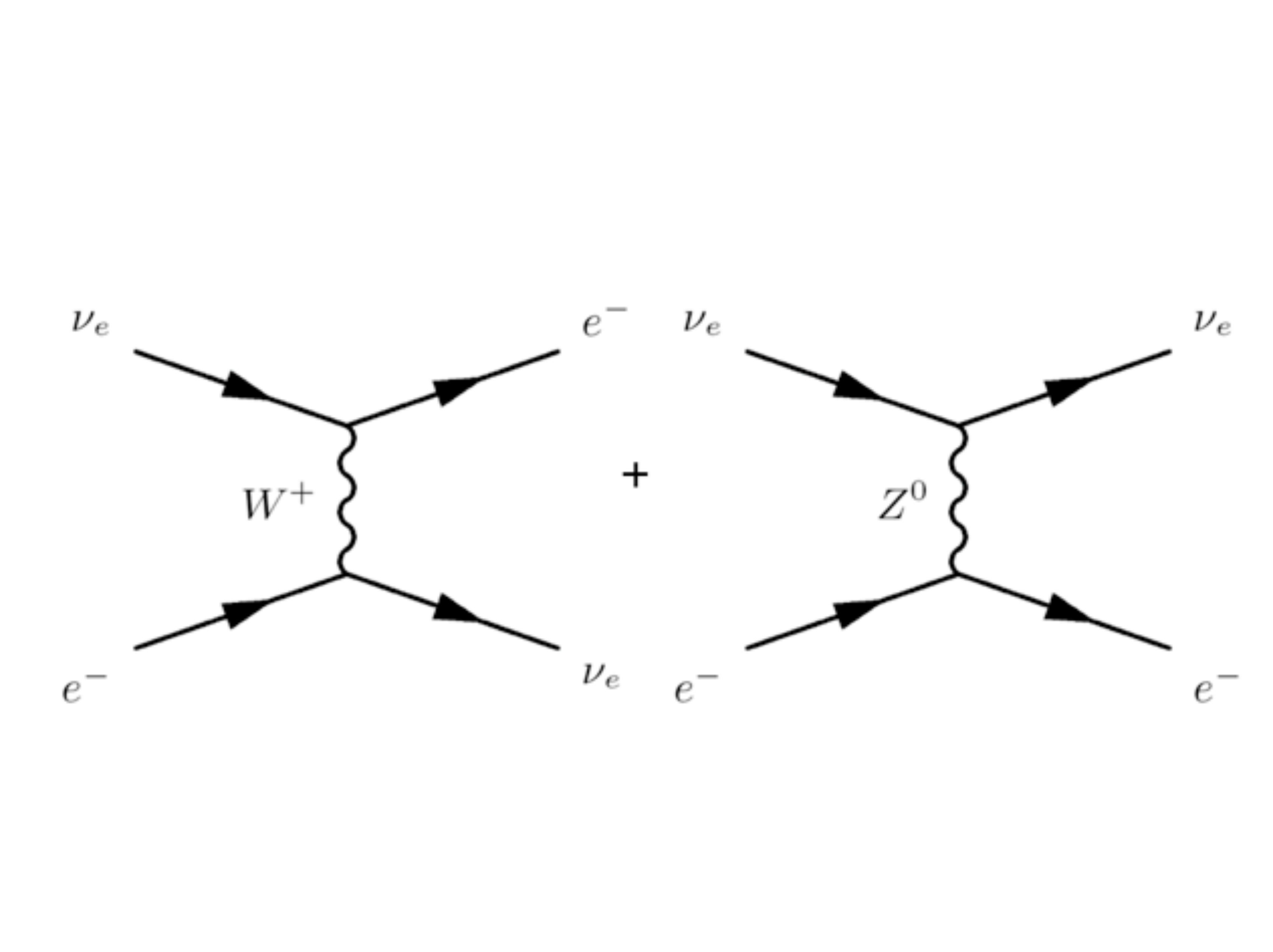
2) Draw the same Feynman diagram again, but this time reverse the direction of time, indicated with an arrow pointing opposite the direction of the original arrow. What interaction does this correspond to?

3) Repeat with the two other orientations of time relative to the Feynman diagram.

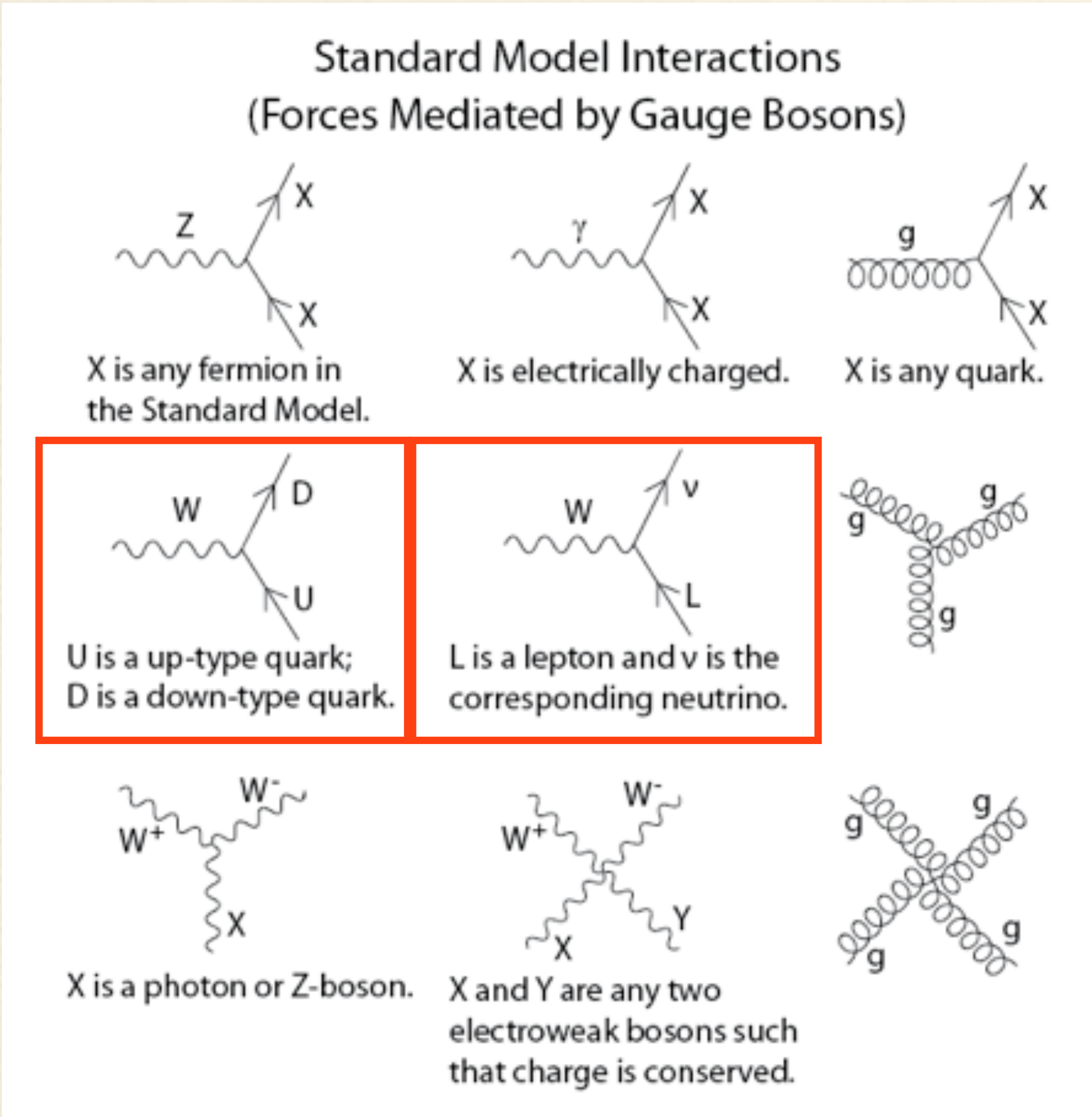
Discuss:

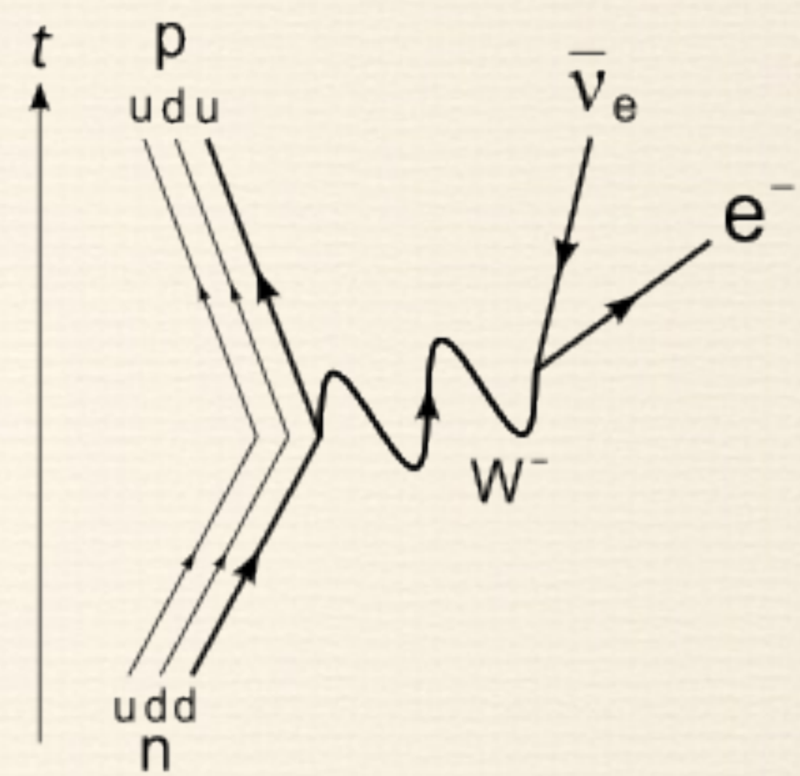
1) How are the various process described by the same Feynman diagram related to one another?

Note: There are many ways to skin a cat!



Neutron Beta Decay





total electric charge = conserved

#leptons - #antileptons = conserved

#quarks - #antiquarks = conserved

Activity: List a number of interactions that may or may not be possible.

For interactions that are not possible, why not? What conservation rules are violated?

For interactions that are possible, draw a Feynman diagram for that interaction.

Can a pion (or Kaon) decay to a muon and neutrino? If so, draw a Feynman diagram for that process.