Simulating Particle Collisions

Particle physics masterclass, February 2016, University of Nottingham

Answer for helpers

common problems

- **Use the 'next' and 'back' tabs at the top of the page to switch between animations**
- **When the security prompt comes up just press 'OK' to get the java animation working (annoyingly you have to do this every time)**
- **If they can't produce any new particles make sure they're on the higher energy slider (1 GeV- 1 Tev) not the lower energy slider (1 MeV – 1 GeV)**
- **If anyone gets to the Higgs boson section just tell them to read the instructions and call me over if they get stuck.**
- **The take home point is that they see that when you collide beams of particles head-on its much easier to make new heavy particles. This is why the LHC is designed to smash particles head-on.**

i) Stationary target

First we are going to collide a particle (an electron) against a stationary target (a positron). The aim here is to collide them hard enough for them to annihilate and create some new particles. The energy required to create a new pair of particles is called the threshold energy,

$$E_{th} = 2\frac{(mc^2)^2}{m_e c^2} - m_e c^2$$

where m is the mass of the particle that you want to create and m_e is the mass of an electron.

First we need to calculate the required energy for a few particles. Use the above formula to calculate the threshold energy and fill in this table. (If you are without a calculator, use the calculator program on the computer)

Particle/antiparticle	Rest mass energy (mc^2)	Colour* (particle/antiparticle)	Threshold energy (E_{th})
electron e^-/e^+	0.511 MeV	blue/red	----------
muon μ^-/μ^+	105.7 MeV	green/dark green	**44 GeV**
pion π^-/π^+	139.6 MeV	magenta	**76 GeV**
kaon K^-/K^+	493.7 MeV	yellow	**954 GeV**
proton p+/p-	938.3 MeV	grey/dark grey	**3.4 TeV**

* if you hover over the particle with the cursor it will also tell you what it is

Units: MeV = 10^6 eV
GeV = 10^9 eV
TeV = 10^{12} eV

Now use the program to collide your electrons around these threshold energies and see if you produce the particle you expect. Note: there are two slider settings a low energy one (1 MeV – 1 GeV) and a high energy one (1 GeV – 1 TeV). Make sure you're using the right one.

When you've got the hang of firing the particles try varying the energy and running the simulation multiple times (e.g. 5 runs) and record what particles you get out.

Incident beam energy	Particles: produced run 1	run 2	run 3	run 4	run 5
>44 GeV					
>76 GeV					
>954 GeV					
for example					

Q: Can you produce a proton/antiproton pair with colliding these two particles – if not, why not?

You can't produce protons because you need >3.4 TeV to do that which is more than the beam energy

ii) Colliding beams

Now we're going to collide beams of particles head-on rather than at a stationary target.

We have a new formula for the threshold energy in this case

$$E_{th} = mc^2$$

So the threshold energy is just the rest mass energy of the particle you want to create.

Particle/antiparticle	Rest mass energy (mc^2)	Colour (particle/antiparticle)
electron e^-/e^+	0.511 MeV	blue/red
muon μ^-/μ^+	105.7 MeV	green/dark green
pion π^-/π^+	139.6 MeV	magenta
kaon K^-/K^+	493.7 MeV	yellow
proton p+/p-	938.3 MeV	grey/dark grey

Now do the same thing as in part (i), pick a range of values of energy and run the simulation a few times. Record what particles you get in the table below.

Incident beam energy	Particles: produced run 1	run 2	run 3	run 4	run 5
>105.7 MeV					
>139.6 MeV					
>493.7 MeV					
>938.3 MeV					

Q: If you were designing a collider with the goal of making very heavy particles would you want to collide beams of particles head on, or collide particles at a stationary target?

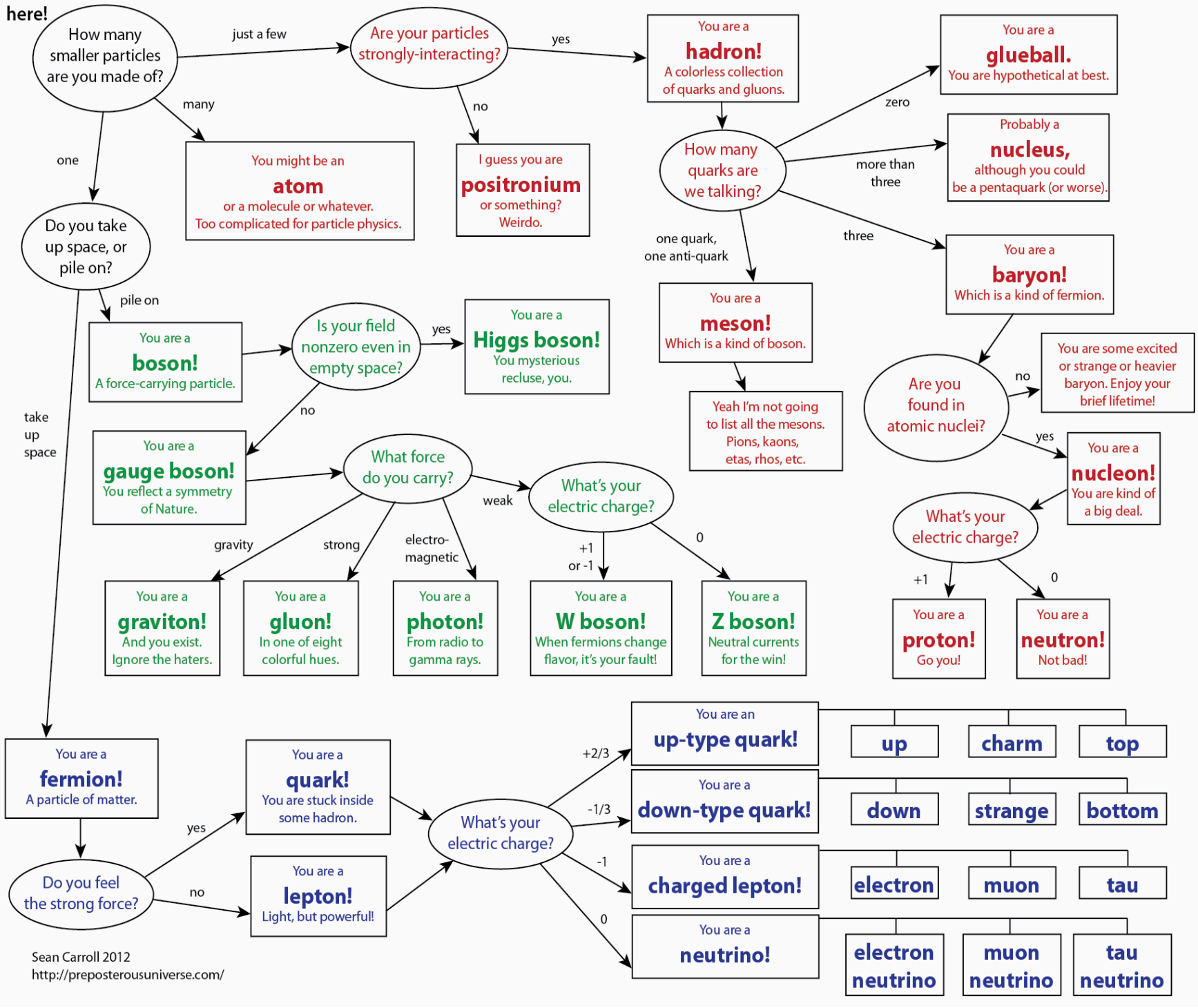
It is far easier to create heavy particle-antiparticle pairs with head on beams rather than a stationary target because all the energy in the collision goes into annihilating and creating new particles rather than having to conserve momentum.

The next part is doing the Higgs boson creation. It should be fairly self-explanatory but if they have any specific problems just let me know.

What Particle Are You?

(Standard Model particles only! Dark matter and other exotica not welcome.)

Color code:
elementary fermions
elementary bosons
composite particles



Sean Carroll 2012
http://preposterousuniverse.com/