Simulating Particle Collisions

Particle physics masterclass, February 2016, University of Nottingham

To get started pick the **annihilation** option on the homepage and then click **next.**

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,

$$\mathrm{E}_{th} = 2\frac{(mc^2)^2}{m_e c^2} - m_e c^2$$

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	
pion π⁻/π⁺	139.6 MeV	magenta	
kaon K⁻/K⁺	493.7 MeV	yellow	
proton p+/p-	938.3 MeV	grey/dark grey	

* 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

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

_____

_____

_____

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

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?

_____

_____

*If you made it this far. Have a go at the **Higgs** option in the menu. This will show you how to use particle collisions to measure the mass of the Higgs boson. Call me or one of the helpers over if you need help getting started.*

What Particle Are You?

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

Color code:
elementary fermions
elementary bosons
composite particles

Start here!

How many smaller particles are you made of?

- **just a few** → Are your particles strongly-interacting?
  - **yes** → You are a **hadron!** A colorless collection of quarks and gluons.
  - **no** → I guess you are **positronium** or something? Weirdo.
- **many** → You might be an **atom** or a molecule or whatever. Too complicated for particle physics.
- **one** → Do you take up space, or pile on?

How many quarks are we talking?
- **zero** → You are a **glueball.** You are hypothetical at best.
- **more than three** → Probably a **nucleus,** although you could be a pentaquark (or worse).
- **three** → You are a **baryon!** Which is a kind of fermion.
  - Are you found in atomic nuclei?
    - **no** → You are some excited or strange or heavier baryon. Enjoy your brief lifetime!
    - **yes** → You are a **nucleon!** You are kind of a big deal.
      - What's your electric charge?
        - **0** → You are a **neutron!** Not bad!
        - **+1** → You are a **proton!** Go you!
- **one quark, one anti-quark** → You are a **meson!** Which is a kind of boson.
  - Yeah I'm not going to list all the mesons. Pions, kaons, etas, rhos, etc.

Do you take up space, or pile on?
- **take up space** → You are a **fermion!** A particle of matter.
- **pile on** → You are a **boson!** A force-carrying particle.

Is your field nonzero even in empty space?
- **yes** → You are a **Higgs boson!** You mysterious recluse, you.
- **no** → You are a **gauge boson!** You reflect a symmetry of Nature.

What force do you carry?
- **weak** → What's your electric charge?
  - **0** → You are a **Z boson!** Neutral currents for the win!
  - **+1 or –1** → You are a **W boson!** When fermions change flavor, it's your fault!
- **electro-magnetic** → You are a **photon!** From radio to gamma rays.
- **strong** → You are a **gluon!** In one of eight colorful hues.
- **gravity** → You are a **graviton!** And you exist. Ignore the haters.

You are a **fermion!** A particle of matter.

Do you feel the strong force?
- **yes** → You are a **quark!** You are stuck inside some hadron.
- **no** → You are a **lepton!** Light, but powerful!

What's your electric charge?
- **+2/3** → You are an **up-type quark!**
- **–1/3** → You are a **down-type quark!**
- **–1** → You are a **charged lepton!**
- **0** → You are a **neutrino!**

up	charm	top
down	strange	bottom

electron	muon	tau
electron neutrino	muon neutrino	tau neutrino

Sean Carroll 2012
http://preposterousuniverse.com/