#### Momentum and Relativity

Watch the first 9½ minutes of **Approaching the Speed of Light**. <http://www.triumf.ca/home/multimedia/videos/speed-light>

1. The video mentions a number of particles.
2. What particles can be found in the nucleus? Protons, neutrons and pions.
3. What particles are produced when the proton hits the carbon atom? Pions.
4. What particles are produced when these decay? muons, pions and electrons
5. The electromagnets select particles with equal charge and momentum

p

v

1. You will be graphing momentum against velocity for subatomic particles.
2. Sketch the graph that you expect.
3. Give reasons for your predictions.

Most students will predict a straight line because p = mv.

However, some will recall hearing that nothing with mass can go at the speed of light. This suggests a curve with an asymptote at c.

1. Each histogram shows the time of flight for the particles of equal momentum to travel 4.4 m. Each graph has two and possibly three peaks. The peaks are due to the three different particles present; electrons, muons and pions. The electrons move fastest and the pions move the slowest.
2. Which particle produces the peak that is furthest to the left? Electrons
3. Which particle is heaviest? Pion

Note: The twelve different histograms are available at the same address as the video.

1. Use your histogram to get the speed as a fraction of c for each particle. Show your steps below.
2. Electron b) Muon c) Pion

v = 4.4/ct

1. Look at the class`s data. We can’t use the electrons’ velocities. Why not?

The velocities are all almost c. Some may even be over.

1. Graph p (units of MeV/c) vs. v (in units of c) for the muons and pions.
2. Sketch the results on the right. See graph above

b) Does p = mv at high speeds? Explain. No. It increases more rapidly with v than that.

5) Guess what you need to graph p against to get a straight line and test it.

a) How can you straighten the line? Hint: What should you graph on the horizontal axis instead of v?

Graph p vs. mv

b) What is the value of the slopes of your two straight-line graphs?

c) What is the physical meaning of the slopes on your graph?

Mass of the pion and muon in units of MeV.

d) Calculate the % difference of your slopes and the accepted values.

Mass of muon (105.7 MeV), mass of pion (139.6 MeV)

e) What do you think the major source of error was?

The time could only be measured to two digits. It was +/- 0.2 ns, which for small times like the electrons there was an error of close to 15%. The distance was given as just two digits - 4.4 m - but they could have easily measured it to the nearest mm or 4 digits.

f) Why do the histogram peaks have a spread to them?

The particles don not all have exactly the same momentum nor speed.

1. The formula p = mv can be interpreted as the mass increasing or the momentum increasing. Which should it be? Why? This relativistic change has a direction unlike mass. It is almost impossible to speed up the electron further but it is possible to turn it. Also, mass can be defined as F/a (inertial mass) or F/g (gravitational mass). A relativistic mass would make them different.
2. Your friend thinks that it is just a matter of time before we have rockets that can go faster than the speed of light. How would you try to convince them that this will not happen?

As we can see from the graph and the equation, as the speed increases it gets harder and harder to increase it further. There is an asymptote at v = c, so an object with mass cannot go at the speed of light let alone faster. This is not a technical limit like the speed of sound was – but a theoretical limit like absolute zero**.**