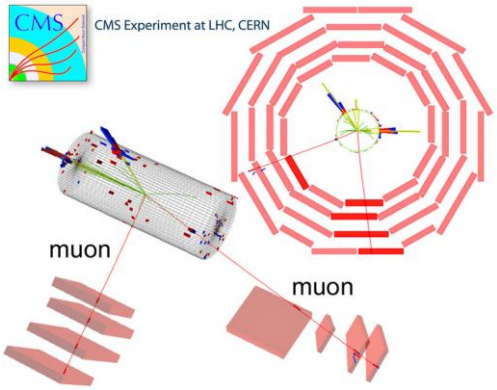
MASS CALC: Z

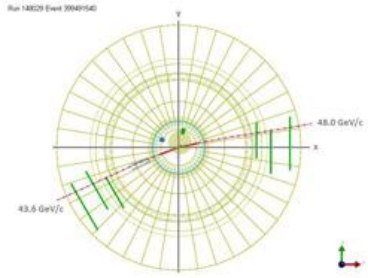
Relativity Used in the Creation of the Z Boson!
Analysis of LHC Data from CERN

Today you will use (a form of) Einstein's famous equation with experimental data collected in the ATLAS and CMS experiments at CERN to determine the mass of the **Z Boson**.

The image to the right shows what happens in one of these events. The tracks (at about 6 and 8 o'clock) are the paths of a muon and an anti-muon. These were created from the prompt decay of a Z boson (invisble here). The Z itself was created in the collision of two protons from the LHC beam.



You will receive a more detailed plot from data collected by the ATLAS or CMS detector. A sample of one of these "events" is below. You will need to determine the total energy of the muon anti-muon pair and their net momentum.



Data from LHC events are displayed in images like the one to the left. It shows the recorded momentum (in GeV/c) of the particle debris that came from the collision. Your class has eight event displays.

Can you identify the muons in this event? Physicists do not detect the Z boson directly but rather reconstruct it from the muon data. These muons carry the momentum and mass-energy of the Z boson parent.

What do we know?

1. Momentum is conserved. Energy is too.
2. Momentum is a vector. Energy is not.
3. The invariant mass and the momentum of the Z boson becomes the energies and momenta of the muon anti-muon pair.
4. The net momentum of the muon, anti-muon pair is the same as the net momentum of the Z boson.
5. Muons have small mass. In these events, we can say that their energy and momentum are equivalent.
6. Einstein really wrote $E^2=p^2+m^2$ (This requires using units that make the speed of light =1) This allows us to solve for energy, momentum or mass if we know the other two.

What tools do we need for our analysis?

Ruler, protractor, pencil to make a **momentum vector diagram**

What are your claims? What is your evidence?

Fill in a data table like this one for each event that you analyze. Note that muon 1 and muon 2 refer to the two tracks. One is a muon, the other an anti-muon *but you do not need to make this distinction for your calculations.*

Event Number	
x-momentum of muon 1*	
y-momentum of muon 2*	
Energy of muon 1	
x-momentum of muon 2*	
y-momentum of muon 2*	
Energy of muon 2	
Momentum of Z boson	
Energy of Z boson	
Mass of Z boson	

**These are for component addition of momentum vectors. You may choose instead to add the vectors graphically and then do not need to fill in these lines.*

In class, make a list of all of the Z boson masses calculated by you and your fellow students. Determine how to best find a consensus Z mass from these data and decide how much uncertainty there is in your result.