Brief Description:

Since the 1930s, scientists have been using particle accelerators to make beams of protons, electrons and ions. These have been used in practically every scientific field, from colliding particles in the LHC to measuring the chemical structure of drugs and even treating cancer. We have made a major step in building an accelerator for an entirely different sort of particle, a muon. A muon accelerator could replace the LHC, providing dramatically improved performance.

Muon beam production:

Muons can be produced by smashing a beam of protons into a target. The debris from the collisions include particles known as pions. The pions are separated from the other particles produced in the collision and directed along a series of magnetic lenses where they decay into muons.

Because of the rough-and-ready production mechanism, these muons form a diffuse cloud that that occupies a large volume. This means we need big magnets to contain the beam. It also means that when we eventually collide the muons, the chances of them hitting each other and producing interesting physics is really low. We want them all close together and moving in the same direction and to do this we need beam cooling.

Cooling:

The process of getting the beam all going in the same direction is known as ‘cooling’. This is because we are literally removing energy (i.e. “heat”) of the beam particles relative to the centre of the beam.

A major problem is that muons only live for 2 millionths of a second. This means that methods previously developed to cool beams and which take hours to achieve an effect are not going to work with muons, so we use a new method.

In our experiment, we cooled the muons by putting them through some energy-absorbing material (the 'absorber') while the beam was very tightly focussed by magnetic lenses. This reduced the energy of the beam in all directions. The beam energy can then be put back in by accelerating the muons using a normal particle accelerator, but this only puts energy back in the direction the beam is going.

Special materials had to be used for the absorber. We tried a few different materials, including cryogenically-cooled liquid hydrogen and lithium metal with hydrogen embedded in it. We had to devise special safety systems because hydrogen is explosive when it mixes with air.

We built special high aperture, high field superconducting magnets to focus the beam strongly enough to get the cooling to work. The magnets used superconducting wires carrying hundreds of amps. They had to be cooled to just a few kelvin above absolute zero using liquid helium to make such a strong field. The magnets were powerful enough that they exerted a force of tens of tonnes on each other, as much as a fully loaded lorry.

This is the first time that a beam has been 'cooled' by passing particles through an absorber under these conditions.

What can we do with cool beams?

A muon collider is one of the favourites to be the big machine to follow the LHC. The LHC has many advantages, but the protons it accelerates are large complex objects. When they collide the really interesting particles are obscured by the fragments the protons produce as they break up. Protons themselves are made up of lots of different sorts of particles, so they don't collide very well. Protons are like grapeshot while muons are like a cannon ball.

The accelerator which preceded the LHC, LEP (Large Electron-Positron), used electrons and their anti-particles which are simple; but no one has been able to come up with a way to accelerate electrons up to the sorts of energies that the protons have in the LHC.

A muon is simple like an electron, so the fragments they produce are easy to understand; but, if we can collect a dense enough beam of muons, we do know how to accelerate them up to high energy like in the LHC.

Muons have lots of other uses. For example, they can be used to study materials, they can be used as a catalyst for fusion and they can be used to see through really dense, thick materials which x-rays can't get through. We hope that this technology can help produce really good quality muon beams for these applications too.