Introduction to Accelerator Physics

The last two weeks you heard that Particle and Nuclear physics are about looking inside of things to see their underlying structure. How do we do this?

Basically we act like very small children and try to smash things we know, study the pieces flying out, and see if we can find patterns that tell us about the building blocks and forces that make up the smashed thing.

The tools that provide the energy to smash things we know (electrons, protons, their anti-particles, ions) are called Accelerators and the branch of physics that studies their design, construction, and operation is called Accelerator physics.
Accelerator Physics by Steps

I  Particle Sources: Hammer
II  Acceleration: Force
III  Focus and Store: Aim
IV  Collisions: Target
Particle Sources

Electrons are pretty easy. A hot conductor has only a weak hold on the flowing electrons. Induce them to flow away by attracting them.
Protons are also not so difficult. Start with Hydrogen, heat it up enough to get the electrons to be weakly held, and pull the two charged constituents different directions.
Heavy Ions are hard. Start like protons, but lots of electrons are tightly bound, and more has to be done to strip them off to get the naked nucleus. Do this by sending them through thin plates. The electrons get knocked off while the big, heavy nucleus goes straight through.
Antiparticles are even harder. There is no convenient source of them. The usual approach is to start with the particle, accelerate them, slam them into a heavy metal plate, and use a magnetic field to pick the antiparticles out of the debris.

Very inefficient and have to accumulate and store the antiparticles to get enough to do experiments.
Particle Acceleration

Now get them to go fast. Well that is pretty simple. Accelerate them with an electric field. (Also makes their energy easy to figure using Particle Physicists Units. Energy = Voltage through which they are accelerated.)

Can get to 100's of MeV ($10^6$ eV) this way.
But we want to smash protons (Mass = 1 GeV \(10^9\) eV) and make bottom quarks (Mass = 5 GeV) and top quarks (Mass = 175 GeV) so we have to repeatedly accelerate the particles.

Use EM waves (RF):

Can get to 20 TeV \(10^{12}\) eV this way.
A bunch of energetic particles all going different directions is not very useful. Need to focus them with magnetic fields. Can build a magnetic lens:

**Focus**

Magnetic Field Up

Focal Point

Magnetic Field Down
Store

It is difficult and time consuming to get the beam, and can be more efficient by reusing acceleration over and over if the beam is stored in a circular path. How? Dipole magnetic fields:
Beams travel in vacuum. They would quickly disappear if they were interacting with the air. Accelerators have some of the worlds largest vacuum systems.

Synchronization between the acceleration and bending magnetic fields to keep the particles traveling in the same circle as their energy goes up. Most modern accelerators are called Synchrotrons.

Charged particles radiate energy as they are accelerated. Synchrotrons are used to produce x-rays to do all sorts of physics of materials, etc. Accelerators produce lots of undesired radiation.

Magnets and accelerating systems can be superconducting to be more efficient. Accelerators have large cryogenic plants.
Collisions

Two choices:
Slam the beam into a wall (Fixed Target). This wastes some of the energy that has been put into the beam as the total collision energy is simply the beam energy.

Bring the beam into collision with a beam going the opposite way. Total collision energy is two times the beam energy. A new set of problems:
But the biggest headache is actually getting the collision to happen. This is measured by the Luminosity

\[ \mathcal{L} = f \frac{N_1 N_2}{A} \]

where \( f \) is the frequency of the collisions, \( N_1 \) and \( N_2 \) are the number of particles in the colliding bunches, and \( A \) is the cross sectional area of the collision. Multiply by a cross section to get a rate and integrate over time to get numbers of events produced.

The implications are clear. Want \( N \) as big as possible which means very high beam currents (Amps) and \( A \) as small as possible which means very powerful focusing.
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FRR N Bursts / Pattern: 799 6:1582:4;1706:3318:4 26 1594:1694:4

Last Owl/Day/Swing/24hr: 88 5 90.2 98.1 271.8 Shift: 13.59 /pb

Peak Luminosities: 4184 4223 4253 4134

**PEP-I: Luminosity and Currents**

![Graph showing luminosity and currents over time](image-url)
Laboratories

Thus accelerator physics labs are giant complexes consisting of multiple accelerator and their support equipment:
What is there for you to do?

Lots! At Cornell we have had REU/RET work on:

1. Muon cooling via ionization - Forget

2. Beam motion monitoring - DeMarco

3. Niobium crystals - Cates

4. Higher Order Mode Absorbers - Gillet

5. Beamstrahlung Detector - Wisnewski

6. CESR Lattice Optimization - Darland
7. Ion Clearing Electrodes - Rupasinghe

8. Bunch-by-Bunch Instrumentation - Vyas
Accelerator Physics Web Sites

1. CESR at Cornell:
   http://w4.lns.cornell.edu/public/CESR/

2. RHIC at Brookhaven:
   http://www.bnl.gov/rhic/RHIC_complex.htm

3. Fermilab’s Chain of Accelerators:

4. The Particle Adventure on tools:

5. The World of Beams:
   http://cbp-1.lbl.gov/

6. Stanford Linear Accelerator:
   http://www2.slac.stanford.edu/vvc/accelerator.html