Scattering Summary/Review

Spring 2009 Compton Lecture Series:
From Quantum Mechanics to the String

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- The best way to study objects too small to see is to examine the results of their interactions with other objects
  - A particle approaching a target will be deflected off the target at some angle. This angle will depend on how the potential energy of the particle changes with position (what the potential hill is shaped like) and how far off center the particle is when it approaches the hill (what its impact parameter is).
  - A beam of particles consists of particles approaching the target with an evenly distributed range of impact parameters.
  - This beam is scattered into a distribution of angles.
  - The number of particles scattered into a given angular range depends on the shape of the potential hill. This is what experimentalists actually observe and from this they must reconstruct the shape of the potential hill.
- New particles are produced when the scattering event has enough energy to produce them
  - This event can be detected because the decay products may be different from the initial particles being scattered, and also because the decay products come off with equal probability in all directions.
  - If the scattering comes from two beams aimed at each other with equal and opposite momentum, then a produced particle must be a rest, with energy mc^2
  - In order for it to be produced, classically we expect that the particles in the incident beams must together have exactly this much energy
  - Since this particle typically decays before we can measure it directly, quantum mechanically there is some uncertainty in the energy (mass) of the particle. This uncertainty is related to the lifetime of the particle by

$$\Delta E \approx \frac{h}{4\pi \Delta t}.$$

- Electric and magnetic fields are used to get particles up to high energies and to direct them
  - Charged particle speed up or slow down when subjected to an electric field.
  - Charged particles change their direction when subjected to a magnetic field. They move in circles; the radius of the circle grows if the momentum of the particle grows. For a magnetic field strength B, charge q, and momentum p, the radius R is

$$R = \frac{p}{qB}.$$

  - In a cyclotron, charged particles travel in a spiral. A magnetic field causes the circular motion, but every half-circle they pass a region with an electric field, causing the particle to speed up and the radius of the circle to increase. Even though they are moving faster, the circle is now bigger; these effects cancel out so that the particle reaches the next electric field region in the same amount of time. This only works for non-relativistic particles.

  - In a linear accelerator, particles travel down a pipe where there is an alternating electric field. During the times the electric field points in the wrong direction, they are in shielded regions of the pipe. This allows them to get faster and faster. While they are non-relativistic, the shielded and unshielded regions must grow. As they approach the speed of light, the region lengths also approach a constant
  - In a modern accelerator, the particles are accelerated in different stages. At the LHC, they are eventually inserted into a huge ring where the shielded and unshielded region lengths are constant. In this ring we can have bunches of particles traveling in opposite directions in the ring, just by timing their insertions correctly.

- Detectors at particle accelerators measure the momenta and energies of particles coming out of interactions
  - The momenta of particles coming out of an event are measured by subjecting the particles to a magnetic field and observing the radius of curvature of the track the particle leaves
  - The energies of particles coming out of an event are measured in calorimeters. Different types of particles are detected in different calorimeters. Inside the calorimeter the particle passes through slabs of material (like lead or uranium) which causes it to deposit energy. This energy is recorded by scintillators as flashes of light.
  - Not all particles can be detected. Generally, neutrinos pass right through the detectors. Their momenta and energy must be reconstructed later from the momenta and energy of the other particles.
  - From this resultant particles the event which caused them can be pieced together.
  - At an accelerator like the LHC, there are too many events per second for the equipment to record all of them. The detectors must have "triggers" built into them which decide which events are interesting enough to keep. In order to design the trigger, the experimentalist must have some idea of what they are looking for. Unfortunately, it is always possible that something new and unexpected might be missed because the trigger is not designed to look for it.