HONORS 135 - Ideas in Honors - Week 4

Accelerators

Demo: Super conducting magnet

Overview: Start with cyclotron. Explain Lorentz and electrostatic forces. Talk about RF cavity and linear accelerator. Go on to collider, advantages and synchrotron radiation. Talk about the RHIC, LHC, SLAC. Add medical applications of colliders and detectors.

Class plan:

- 10min. Review material from last week. Methods of detection. Okay, now how do we create particles in the first place?
- 30min. Demo. 10min for setup, requires liquid nitrogen. Super conductor demo. Longer explanation for this - superconductivity, lorentz force, current loop.
- 10min. Discussion:
  - What is energy?
  - What does $E = mc^2$ mean?
  - Suppose you want to accelerate a particle... how?
  - What is the LHC?
- 30min Slides to cover accelerator physics.
  - Talk about energy: particles carry energy as both mass and momentum. The mass is constant, but momentum can change. Energy is measured in Electron Volts, Momentum in eV/c^2 - but the c is understood and left out. $E = mc^2 + pc$ becomes $E = m + p$. 1MeV=1 million eV mass of electron. 1 GeV=billion eV mass of proton. 1TeV=trillion eV. Human record is 7TeV.
  - Radioactive accelerators: Radon emits alpha particles. Rutherford used in gold foil experiment. Low energy and unfocused.
  - Cosmic rays: very high energy ($3 * 10^{20} eV$), but unpredictable location, quality, and composition.

- Cathode ray tube: 1897. The earliest artificial particle accelerator. Heat metal to boil off electrons. Accelerate via electrostatic forces. Creates beam of electrons that can be used for experiments.
- Van De Graaf generator: 1929. Uses a belt to physically carry charge to a reservoir. Example, ISNAP in Notre Dame, still in use. Can reach 1-10MeV energies.
- Cyclotron proposed by E.O. Lawrence in 1929 and built by Livingston in 1931. Uses vertical magnetic field to turn particle back to "Dees" voltage gap, driven by radio frequency. Particle starts in center and spirals out. $F = \frac{qB}{m}$ does not depend on radius! The short coming is that in relativity, fast moving particles gain mass, which puts a limit on the cyclotron energy: 500MeV. Cyclotrons are still in use in science: PSI, TRIUMF, RIKEN - show pictures. Also used in cancer treatment.
- Synchrotron: 1945 by Edwin McMillan. Synchrotron deals with changing mass by increasing magnetic field. Note $F = \frac{qB}{m}$.
- Once you have a synchrotron, you can build a collider. Take two beams, headed in opposite directions, and intersect them - collisions! This has been done many times over history: 1961 Ada, e+e-, 250MeV, 3m. 1971 - 1984: ISR (CERN), p+,p +, 31.5 GeV , 948 m. 1981: SPS p+p- 315 GeV , 6.9 km. 2008 - : LHC up to 14TeV, p+p+ 27km. RHIC in BNL
- Linear accelerator: the problem with circular accelerators is the circular beam loses energy due to Synchrotron radiation. A linear collider doesn't face this problem, and you don't need magnetics. However the particle only passes through the RF cavity once. SLAC in the US - 50GeV, 3.2km, electrons, positrons.
- Parts of the accelerator:
  * Klystron - creates microwaves to power RC cavities
  * RC cavity - Particle passes through metal cavities, charged via radio frequency. The timing is designed such that the RF accelerates bunches of particles. Automatically bunch beams into packets (phase stability).
  * Quadrupole - focusing beam, much like a convex optical lens.
  * Cryogenics - magnets must be cooled for superconductivity
  * Injectors - speed up beam first. Good example LHC complex

- Medical applications. Accelerators are used in cancer treatment, esp brain eye lung. X-rays burn a hole through a person, but proton/carbon ion beams deposit most of their energy after they slow down, giving good spacial resolution. Many commercial accelerators used in medical treatment: HIMAC (carbon), Hyogo, TERA, many others. Show pictures of equipment and treatment facilities.

References:

- Verena Kain: http://indico.cern.ch/event/316992/material/slides/1.pdf
- Verena Kain: http://indico.cern.ch/event/317006/material/slides/1.pdf
- Ugo Amaldi: http://indico.cern.ch/event/319538/