HONORS 135 - Ideas in Honors - Week 2

History of Particle Physics

Demo: Cloud chamber

Overview: Follow Griffith's closely, in chronological order. Emphasize the search for underlying order. Explain the standard model particles, evidence for each.

Class plan:

- 10min. Meet in 4481 and walk over to demo lab.
- 20min. Cloud chamber is provided by demo lab. Explain the principle behind the cloud chamber. Have students observe charged tracks and categorize them. If there is a magnet, point out how it provides information about the particle. Have them speculate about the source of the charged particles. Remove the source and talk about cosmic rays. Segue into the history of particle discovery.
- 5min. Walk back to 4481.
- 45min. Slides on the history of particle physics. There should be a timeline at the bottom that gets filled in.
  - First particle discovered is the electron. 1897 by JJ Thomson. Thomson worked with a cathode ray tube. Thomson observed that electron beams could travel through air farther than expected, which suggests that the beam is made up of small particles. Further more, found that electrons were deflected by electric fields, which allowed him to measure their charge. Via magnetic, momentum.
  - Rutherford discovered nucleii by firing alphas at gold foil. If the foil was made of a homogenous material, alphas would have passed straight through. Instead, most passed through, but some shot off crazy like - these by chance had encountered a small massive object: the nucleus.
  - Bohr model in 1914.
  - Chadwick discovered the neutron in 1932, which explained why mass He = 4x mass H.

- Yukawa suggests strong force to hold neucleons together. The short range of the force implies the mediator is massive. Yukawa predicts the mass of this Meson. Pi meson discovered by Powell in 1947 in cosmic rays, up on mountain because of short decay time.
- Powel also discovers the long lived muon in cosmics at ground level, 1947
- $E^2 = m^2c^4 + p^2c^2$ has two soln: E. Dirac stuck with this interpretation, and suggested that the negative energies exist as particles. Anderson discovered the positron in 1931. Show famous cloud chamber picture.
- Positron discovered in Bevatron 1955. Photon is its own anti particle
- 1930, missing energy in neutron decays. Pauli suggested carried off by neutral particle, neutrino. (Two particle products cannot have varied energy! Require 3) Neutrino shares final energy with electron in beta decay, allows smeared electron energy distribution. Going back to cloud chamber tracks of pions, discover $\pi \to \mu + \nu$ (griffiths Figure 1.3). Neutrinos were finally observed directly in 50's from reactor ($\bar{\nu} + p^+ \to n + e^+$) by Cowan and Reines. Interacions in giant tank of water, detected outgoing positrons via annhiliation ($e^+ + e^- \to \gamma + \gamma$).
- Rochester and Butler discover K^0 from decay, $K^0 \to \pi^+ + \pi^-$ (griffiths fig 1.7) in 1947. 1949 Brown discoveres charged kaon meson (gfiffiths fig 1.8) decay to three pions $K^+ \to \pi^+\pi^+\pi^-$. Then many many more discovered. 1950 Anderson discovered the decay $\Lambda \to p^+ + \pi^-$. These dacays raised the question "why no decay of proton?" ie $p \to e^+ + \gamma$. Introduce conserved quantity "baryon number", which keeps proton from decaying to lighter particle. Now the particles are piling up- no elegant solution, no pattern.
- Baryons were produced rapidly, buy decayed rarely - long relatively lifetimes. Suggested different forces were involved in creation and decay - the strong and weak forces.
- Starting to organize particles. 1961 Gell-Mann proposed eightfold way, organized baryons based on charge and "strangeness". A similar octet for mesons. The eightfold way predicted the discovery of the Ω^- in 1964. Dectuplet for spin 3/2 baryons. Griffiths says this is the birth of modern particle physics. But the eightfold way suggested something else: quark theory. 1960 Gell-Mann and Zweig

suggested quark triplet, as a mathematical representation, not a physical one. Up Down Strange.

- Detail on Quark discovery: Hofstadter measured neucleon size 10^-15m in the 60's - hadrons assumed to be fundamental blobs. SLAC probed the proton with electron. At 20GeV, recoil was elastic, indicating no internal structure. At higher energies, however, electrons either kicked the proton into a more massive baryon, or distroyed it. This is called deep inelastic scattering (DIS). Bjorken thought this indicated proton structure. Later, 1968 Feynman looked at DIS, angle data and suggested the existance of constituents of the proton - called partons - which were later linked to quarks.
- There are 10 q/q/q combinations of u d s (order doesn't matter) - the baryon decuplet. There are 9 quark/antiquark combinations - makes up the octet (3 qqq in middle).
- But shouldn't there be direct observation for quarks? Quarks are confined to the meson or baryon - they can't propagate freely like an electron. They are stuck to groups of two or three, where their total color charge is white.
- From 64-74, no signifigant changes. The quark theory was ugly. Things changed when Ting discovered the J/ψ in 1974. It's a meson whose lifetime is 1000 times longer than expected, 3x massive as proton, and consists of a new quark: charm. The quark theory predicted a fourth quark, so this discovery brought new life into the model.
- The discovery of J/ψ kicked off the November Revolution in particle physics. Ting was working in Brookhaven National Lab. After his discovery, he waited to collect more statistics before announcing it publicly. Apparently, SLAC physicist Richter learned the mass of the J/ψ and tuned his machine to the proper energy to discover it. The two groups published at the same time, Richter picking ψ for the shape of the decay products, and Ting for after the character for his name. Ting, born in AA, is the best, so if you have to pick one, pick J. In the wake of the discovery, many charmed mesons were discovered.
- In 1975, the τ lepton was discovered. Then the b quark. The final quark, Top, is exceptionally massive. It wasn't produced until 1995 in Fermilab's Tevatron.

- The final piece of the standard model puzzle is bosons, the particles that carry forces from one particle to another. The first boson to be discovered was the photon, responsible for transmitting the electromagnetic force. Particle physics knows about three forces: EM, strong, and weak - so the bosons for the latter two were missing. The weak force is carried by three bosons: W and Z. They are quite heavy, 80 and 90 GeV each, discovered at CERN SPS in 1984. The mediator for the strong force is the gluon (there are 8), which carries two strong charges: one color and one anticolor. Gluons are detected in the jets produced in particle collisions, but due to confinement cannot exist naturally alone.
- Finally, in 2012 the Higgs boson was discovered at CERN LHC. The Higgs does not convey a force, but rather the interacts with certain particles. The interaction energy manifests itself as mass.
- The full standard model of particle physics - all known particles considered fundamental and without substructure - consists of 6 quarks, 6 leptons, (depending on how you count them) 4 gague bosons, 1 scalar boson. Quarks make up baryons and mesons; they carry electrical charge, strong charge, and weak charge. Leptons can be electron like - massive and charged, or neutrino like - very light and neutral. Gauge bosons carry forces, while the Higgs boson lends mass to quarks and leptons.

Refferences:

- Griffiths
- Quarks: http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-5724.pdf