PHYS 3446 – Lecture #20

Monday, Apr. 18, 2005
Dr. Jae Yu

- The Standard Model
  - Gauge Bosons
  - Gauge boson decay and search strategy
  - Symmetry Breaking and the Higgs particle
  - Higgs Search Strategy
  - Issues in the Standard Model
  - Neutrino Oscillations

Announcements

- The final quiz this Wednesday, Apr. 20
  - At 1:05pm, in the class (SH200)
  - Covers: Ch 10 – what we cover today in the lecture
- Due for your project write up is THIS Friday, April 22
- How are your analyses coming along?
- Keep in mind the final, final homework due is THIS Wednesday, Apr. 20.

Quarks and Leptons

- In SM, there are three families of leptons

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix} \quad \begin{matrix} Q \\ 0 \\ -1 \end{matrix}$$

  - ➔ Increasing order of lepton masses
  - Convention used in strong isospin symmetry, higher member of multiplet carries higher electrical charge
- And three families of quark constituents

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix} \quad \begin{matrix} Q \\ +2/3 \\ -1/3 \end{matrix}$$

- All these fundamental particles are fermions w/ spin $\frac{1}{2}\hbar$

Quark Content of Baryons

- Baryon spins are measured to be ½ integer.
  - They must consist of an odd number of quarks
  - They can be described as bound states of three quarks based on the studies of their properties
- Quark compositions of some baryons
  - Nucleons — Strange baryons — Other Baryons
  - s=1 — s=2

$$p = uud \qquad n = udd$$

s=1:

$$\Lambda^0 = uds \qquad \Sigma^+ = uus \qquad \Sigma^0 = uds \qquad \Sigma^- = dds$$

s=2:

$$\Xi^0 = uss \qquad \Xi^- = dss$$

$$\Delta^{++} = uuu$$

- Since baryons have B=1, the quarks must have baryon number 1/3

Need for Color Quantum Number

- The baryon Δ^{++} has an interesting characteristics
  - Its charge is +2, and spin is 3/2
  - Can consists of three u quarks ➔ These quarks in the ground state can have parallel spins to give Δ^{++} 3/2 spin
  - A trouble!! What is the trouble?
    - The three u-quarks are identical fermions and would be symmetric under exchange of any two of them
    - This incompatible to Pauli's exclusion principle
  - What does this mean?
    - Quark-parton model cannot describe the Δ^{++} state
    - So should we give up?

Need for Color Quantum Number

- Since the model works so well with other baryons and mesons it is imprudent to give the model up
- Give an additional internal quantum number that will allow the identical fermions in different states
- A color quantum number can be assigned to the quark
  - Red, blue or green
  - Baryons and Mesons (the observed particles) are color charge neutral
- It turns out that the color quantum number works to the strong forces as the electrical charge to EM force
- The dynamics is described by the theoretical framework, Quantum Chromodynamics (QCD)
  - Wilcek and Gross ➔ The winners of last year's Nobel physics prize
- Gluons are very different from photons since they have non-zero color charges

Formation of the Standard Model

- Presence of global symmetry can be used to classify particle states according to some quantum numbers
- Presence of local gauge symmetry requires an introduction of new vector particles as the force mediators
- The work of Glashow, Weinberg and Salam through the 1960's provided the theory of unification of electromagnetic and weak forces (GSW model), incorporating Quantum Electro-Dynamics (QED)
  - References:
    - L. Glashow, Nucl. Phys. **22**, 579 (1961).
    - S. Weinberg, Phys. Rev. Lett. **19**, 1264 (1967).
    - A. Salam, Proceedings of the 8th Nobel Symposium, Editor: N. Svartholm, Almqvist and Wiksells, Stockholm, 367 (1968)
- The addition of Quantum Chromodynamics (QCD) for strong forces (Wilcek & Gross) to GSW theory formed the Standard Model in late 70's
- Current SM is U(1)xSU(2)xSU(3) gauge

Standard Model Elementary Particle Table

- Assumes the following fundamental structure:

- Total of 6 quarks, 6 leptons and 12 force mediators form the entire universe

Gauge Bosons

- Through the local gauge symmetry, the Standard Model employs the following vector bosons as force mediators
  - Electro-weak: photon, Z^0, W^+ and W^- bosons
  - Strong force: 8 colored gluons
- The electro-weak vector bosons were found at the CERN proton-anti proton collider in 1983 independently by C. Rubbia & collaborators and P. Darriulat & collaborators

Z and W Boson Decays

- The weak vector bosons couples quarks and leptons
  - Thus they decay to a pair of leptons or a pair of quarks
- Since they are heavy, they decay instantly to the following channels and their branching ratios
  - Z bosons: M_Z=91GeV/c^2
  - $Z^0 \rightarrow q\bar{q} \quad (69.9\%)$
  - $Z^0 \rightarrow l^+ l^-$ (3.37% for each charged lepton species)
  - $Z^0 \rightarrow \nu_l \bar{\nu}_l$ (20%)
  - W bosons: M_W=80GeV/c^2
  - $W^{\pm} \rightarrow q\bar{q}' \quad (68\%)$
  - $W^{\pm} \rightarrow l^{\pm} \nu_l$ (~10.6% for each charged lepton species)

Z and W Boson Search Strategy

- The weak vector bosons have masses of 91 GeV/c^2 for Z and 80 GeV/c^2 for W
- While the most abundant decay final state is qqbar (2 jets of particles), the multi-jet final states are also the most abundant in collisions
  - Background is too large to be able to carry out a meaningful search
- The best channels are using leptonic decay channels of the bosons
  - Especially the final states containing electrons and muons are the cleanest
- So what do we look for as signature of the bosons?
  - For Z-bosons: Two isolated electrons or muons with large transverse momenta (P_T)
  - For W bosons: One isolated electron or muon with a large transverse momentum along with a signature of high P_T neutrino (Large missing ET).

What do we need for the experiment to search for vector bosons?

- We need to be able to identify isolated leptons
  - Good electron and muon identification
  - Charged particle tracking
- We need to be able to measure transverse momentum well
  - Good momentum and energy measurement
- We need to be able to measure missing transverse energy well
  - Good coverage of the energy measurement (hermeticity) to measure transverse momentum imbalance well

Assignments

1. No homework today!!!