PHYS 5326 – Lecture #1

Monday, Jan. 22, 2007
Dr. Jae Yu

1. Class specifications and plans
2. What is a neutrino?
3. History of neutrinos
4. Neutrino cross section
5. Neutrino experiments

Class Specification

- Text Books
  - D. Griffiths, "Introduction to Elementary Particle Physics"
  - D. Perkins, "Introduction to High Energy Physics"
- Reading Assignments
  - Not just based on the books
  - Will have to rely on papers
  - Extra credit on presentations up to 5%
- Homework Assignments (20%):
  - There will be homework problems randomly assigned throughout the semester
- Two Written Term Exams (20%+20%)
- Semester Projects and Presentations (25+15%)
- Will be mixed theory + experimental techniques

Syllabus

- Neutrinos
  - Formalism
  - Neutrinos and proton structure functions
  - $\sin^2\theta_W$ measurements and its impact to Higgs
  - Neutrino Oscillation
- Electroweak Symmetry Breaking
  - Standard Model EWSB formalism & Higgs
  - Minimal Super-symmstric Extension of Standard Model
  - Other EWSB Theories (SUSY) & Other Types of Higgs
  - Strategy for Higgs search
- New Phenomena
  - SUSY Formalism and available models
  - Large Extra-dimension
  - Search strategy
- Will be mixed with appropriate experimental techniques
  - Detectors and Particle ID's, etc

Semester Projects

- ATLAS MC Data Analysis
  - Need to setup ATLAS Data Analysis systems
  - Get help from Arnap
  - Topics
    - H→$\gamma\gamma$
    - SUSY Higgs search w/ photons or electrons in the final state
    - Any other SUSY search channel w/ photons or electrons in the final state
- LC Detector Beam Test Data Analyses
  - Need to learn how to use root
- Consists of
  - A >=10 page report (must become a UTA-HEP note)
  - A 30 minute presentation on Mon. May 7, 2007

Semester Projects - Report

- Due: In electronic form by Mon. May 7, 2007
- Introduction
  - Provide physics and other motivations
- Apparatus
  - Describe the experimental setup
    - ATLAS detector description
    - LC Beam Test experiment setup
  - Must include accelerator and beams as well
- Signature and data selection
  - Describe and justify your cuts for selecting good data samples
- Data analysis technique and methods
- Results
  - Detailed description of what you have learned and the scientific justifications to support your results
- Conclusions

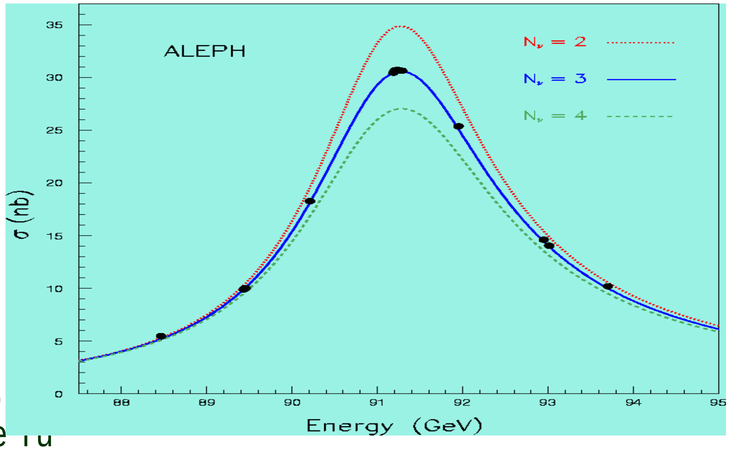
What are the current issues in HEP?

- Why are there 3 families of 6 quarks and 3 families of 6 leptons?
- Why are the masses of the quarks in such a wide range (0.1GeV – 175GeV)? ➔ Mass hierarchy
- How do particles obtain masses?
  - Higgs mechanism seems to work in the SM but haven't seen the Higgs particle yet
- Do neutrinos have mass?
- Why are there only four forces? Are there any other forces?
- Are there any other models that describes nature better?

What are neutrinos?

- A lepton without electrical charge
- Only affected by weak interactions, no EM or strong
- Have one helicity
  - We have observed only left-handed neutrinos and right-handed anti-neutrinos
  - This property led Yang & Lee to parity violation and eventually theory of weak interactions
- No mass prescription in the SM ➔ Atmospheric and solar neutrino experiments seem to have provided direct evidence that challenges this hypothesis

•Measurements show three species only



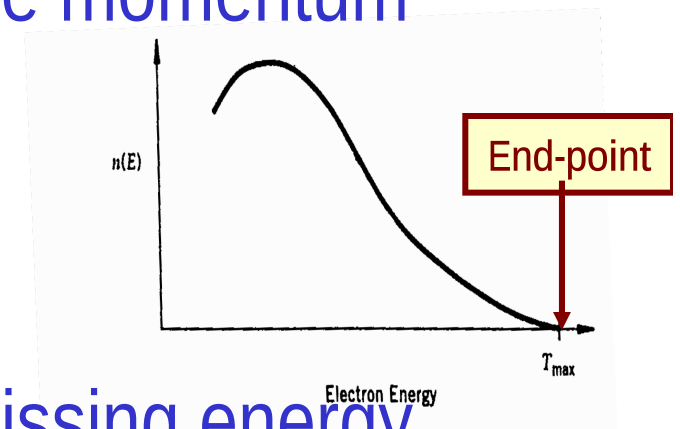
Properties of Neutrinos

Flavor	Spin	Masses	Magnetic Spin(MeV/T)	Total X-sec (cm^2)
ν_e	½	<2.8 ev	$<5.8\times10^{-20}$	$\sim10^{-38}$
ν_μ	½	<16~70KeV	$<4.3\times10^{-20}$	$\sim10^{-38}$
ν_τ	½	18.2 MeV	$<3.1\times10^{-17}$	$\sim10^{-38}$

History of neutrinos

- It was noticed at the end of 19th century that nuclear beta decays do not seem to conserve momentum and energy ➔ BIG problem!

$$n \to p + \bar{\nu}_e + e^-$$



- 1931: W. Pauli postulates that the missing energy may be carried by a neutral particle, as a “desperate remedy”.
- 1934: Fermi develops a theory of beta decay (four particle contact interaction) in which the inclusion of a neutral particle (neutrino) explains many experimentally observed results.

Neutrino history, cnt'd

- 1956: Cowen and Reines detects electron neutrinos from a reactor experiment by detecting photons (a few from neutron capture by Cd nucleus and two from positron annihilation with an electron) emitted as a result of an inverse beta decay, with a several μs time separation

$$\overline{\nu}_e + p \rightarrow n + e^+$$

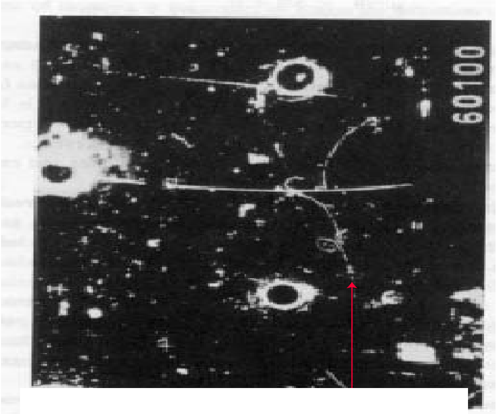
- 1956: Yang and Lee develops theory of parity violation of weak interactions based on Kπ2 and Kπ3 ➔ Existence of different types from lack of experimental observation of reactions like

$$\mu^- \rightarrow e^- + \gamma$$

Neutrino history, cnt'd

- 1962: BNL accelerator experiment proves the existence of muon neutrinos, by producing neutrinos from pion decays and determining the product of interaction to be muons ➔ No electrons above the background observed but muons
- Late 60': Proposal of Electroweak theory based on SU(2)xU(1) by Weinberg, Salam and Glashow (Weinberg, PRL 19, 1264 (1967))
- 1970:GIM model (Glashow, Iliopoulos & Maiani, PR D2, 1285 (1970)) of second quark family, confirmed experimentally in 1974

•1973: Experimental observation of neutral current interaction at the Gargamelle experiment (bubble chamber neutrino experiment)➔ Confirmation of electroweak theory



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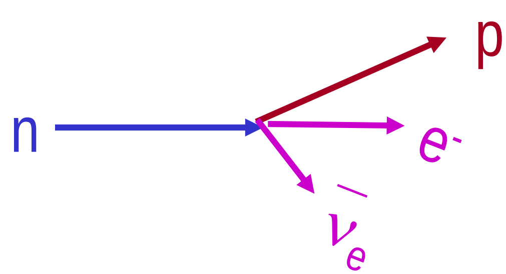
Weak Interaction Formalism

$$n \rightarrow p + \bar{\nu}_e + e^-$$

- Fermi 4-fermion contact interaction to describe nuclear β-decay (E. Fermi, Z. Physik 88, 161 (1934))



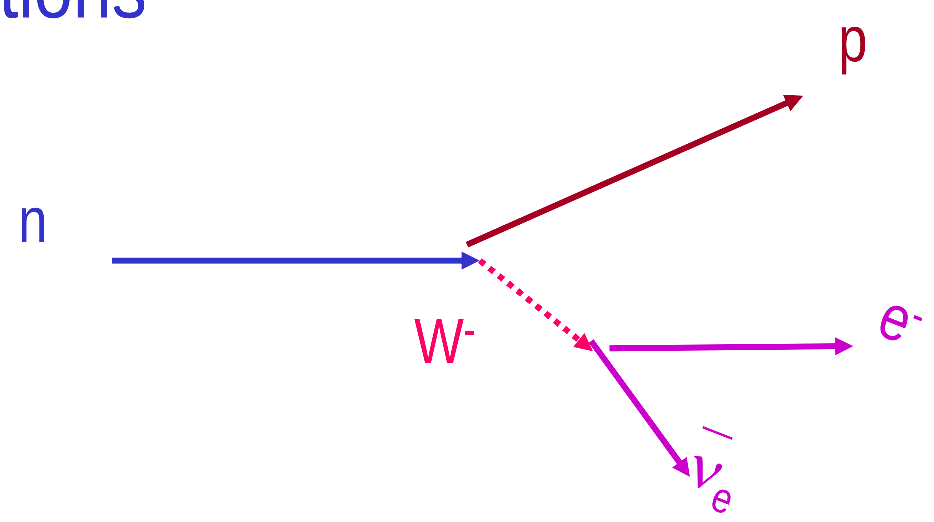
$$\mathcal{L}_{Fermi} = -\frac{4G_F}{\sqrt{2}} J_\alpha^{CC+} J_\alpha^{CC-}$$

$$G_F = 1.16639 \times 10^{-5} \text{ GeV}^2$$

- The theory begins to violate unitarity at about the momentum transfer scale 100GeV ➔ Cross section becomes larger than that from optical theorem

Introduction of IVB's and EW Unification

- Inspired by the failure of Fermi contact interaction and QED, Weinberg, Salam and Glashow introduced Intermediate Vector Boson (IVB) exchange to replace Fermi contact interactions



EW Formalism

- Lagrangian for EW interactions by GSW:

$$-\mathcal{L}_{EW} = \frac{g}{2}\left(J_\alpha^{CC+}W_\alpha^- + J_\alpha^{CC-}W_\alpha^+\right) + \frac{g}{\cos\theta_W} J_\alpha^{NC} Z_\alpha^0 + g\cos\theta_W J_\alpha^{EM} A_\alpha$$

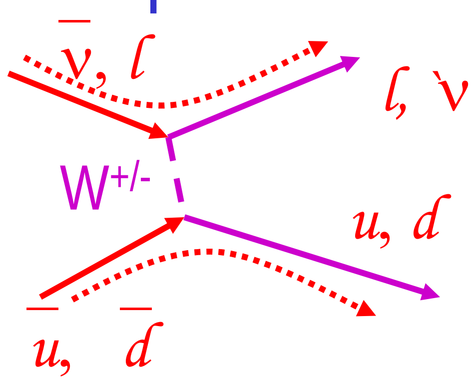
Charged Weak

Neutral Weak

EW Mixing Angle

EM

- Leptonic currents (J's) couple to vector bosons



$$J_\alpha^{CC+} = \bar{\nu}_i \gamma_\alpha \frac{1-\gamma_5}{2} l_i + \bar{u}_i \gamma_\alpha \frac{1-\gamma_5}{2} d_i$$

$$J_\alpha^{CC-} = \bar{l}_i \gamma_\alpha \frac{1-\gamma_5}{2} \nu_i + \bar{d}_i \gamma_\alpha \frac{1-\gamma_5}{2} u_i$$

EW Formalism cnt'd

- EM current $J_{\alpha}^{EM} = q_j \overline{f}_i \gamma_\alpha f_j$
- Weak Neutral Current

$$J_{\alpha}^{NC} = \overline{f}_j \gamma_\alpha \frac{V_j - A_j \gamma_5}{2} f_j$$

- where Vector and axial-vector couplings are

$$V_j = I_j - 2Q_j \sin^2 \theta_W$$

$$A_j = I_j$$

- with propagator terms

$$\text{W or Z propagator} = \frac{-i\left(g_{\mu\nu} - q_\mu q_\nu / M^2\right)}{q^2 - M^2}$$

Some properties of GSW

- GSW model is SU(2)xU(1) gauge group theory with the specified relative coupling strength in the Lagrangian. EM coupling is $g\sin\theta_W = e$.
- GSW Prediction of IVB mass from spontaneous symmetry breaking mechanism, that gives masses to IVB and leptons, is

$$\sin^2\theta_W = 1 - \frac{M_W^2}{\rho M_Z^2}$$

- SM Predicts one Higgs boson, giving ρ=1

Linking Fermi to GSW

- Using the two Lagrangians of Fermi and GSW and CC propagator

$$\mathcal{L}_{Fermi} = -\frac{4G_F}{\sqrt{2}} J_\alpha^{CC+} J_\alpha^{CC-}$$

$$-\mathcal{L}_{EW} = \frac{g}{2}\left(J_\alpha^{CC+} W_\alpha^- + J_\alpha^{CC-} W_\alpha^+\right) + \frac{g}{\cos\theta_W} J_\alpha^{NC} Z_\alpha^0 + g\cos\theta_W J_\alpha^{EM} A_\alpha$$

- The coupling g can be written ($q^2 \ll M^2$)

W or Z propagator for $q^2 \ll M^2 = \frac{-ig_{\mu\nu}}{M^2}$

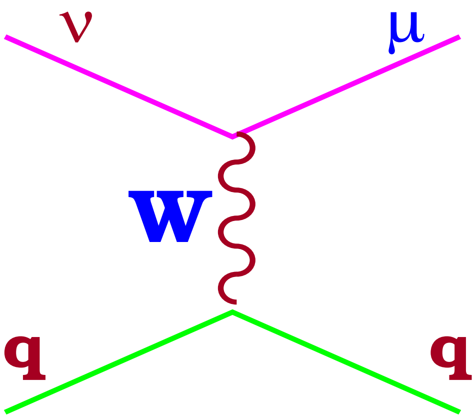
- Effective coupling strengths can be related

$$\frac{4G_F}{\sqrt{2}} = \left(\frac{g}{2}\right)\frac{1}{M_W^2}$$

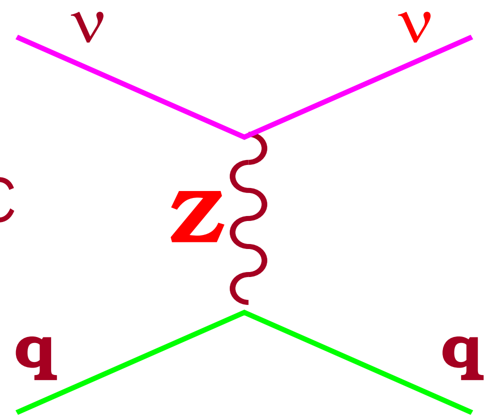
$$G_F = \frac{g}{4\sqrt{2}M_W^2}$$

Neutrino Cross Sections

CC



NC



$$coupling \propto I^{(3)}_{weak}$$

$$coupling \propto I^{(3)}_{weak} - Q_{EM}\sin^2\theta_W$$

$$\frac{d^2\sigma}{dxdy} = \frac{2G_F ME}{\pi}\left[\left(1 - y - \frac{Mxy}{2E}\right)F_2\left(x,Q^2\right) + \frac{y^2}{2}2xF_1\left(x,Q^2\right) \pm y\left(1-\frac{y}{2}\right)xF_3\left(x,Q^2\right)\right]$$

$$\sigma_{\nu N} / E_\nu \approx 0.68\times10^{-38}\ \mathrm{cm}^2/\mathrm{GeV}$$

$$\sigma_{\bar{\nu} N} / E_\nu \approx 0.35\times10^{-38}\ \mathrm{cm}^2/\mathrm{GeV}$$

Assignments

- Reading assignments
  - S. Weinberg on Electroweak theory
    - S. Weinberg, PRL **19**, 1264 (1967)
  - S. Weinberg paper on Standard Model:
    - S. Weinberg, Rev. Mod. Phys. **52**, 515 (1980)
- Homework assignment: due Monday, Jan. 27
  - Find a way to create a neutrino beam at an accelerator
  - Find a method of distinguishing neutrino signs (neutrinos from anti-neutrinos) in an accelerator based neutrino experiment.