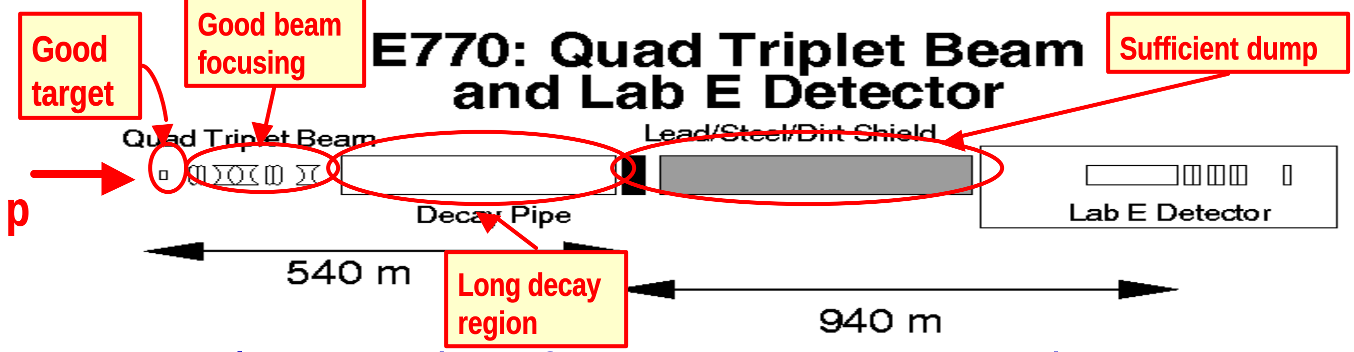
PHYS 5326 – Lecture #17

Monday, Mar. 24, 2003
Dr. Jae Yu

- Mid-term problem review
- Mass Terms in Lagrangians
- Spontaneous Symmetry Breaking

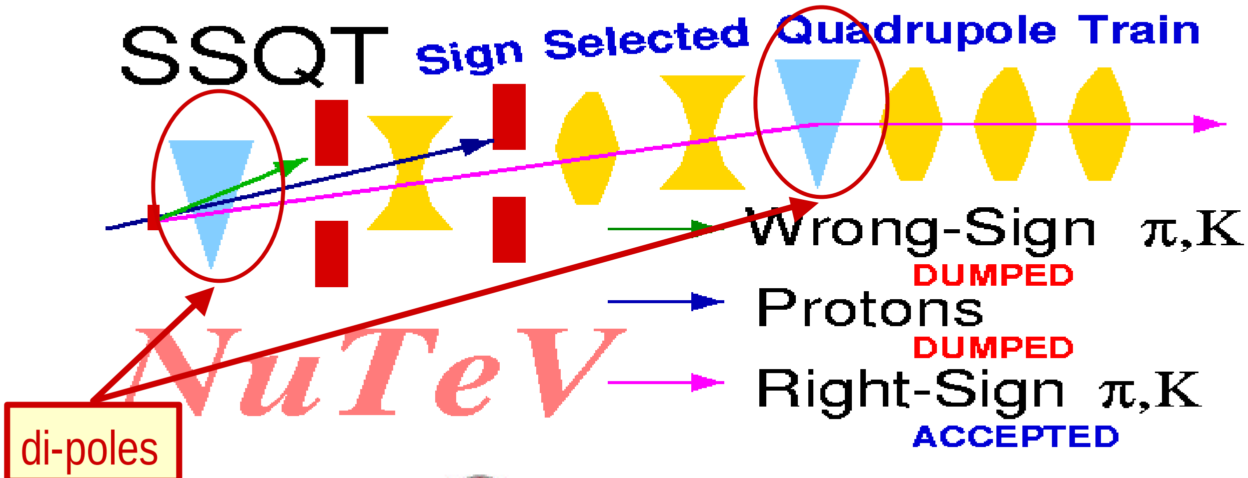
1. Conventional Neutrino Beam



- Use large number of protons on target to produce many secondary hadrons (π, K, D, etc) and focus as many of them as possible
- Let π and K decay in-flight for ν_μ beam in the decay pipe
  $\pi \rightarrow \mu + \nu_\mu$ (99.99%), $K \rightarrow \mu + \nu_\mu$ (63.5%)
- Let the beam go through shield and dirt to filter out μ and remaining hadrons, except for ν
  - Dominated by ν_μ

2. How can we select sign of neutrinos?

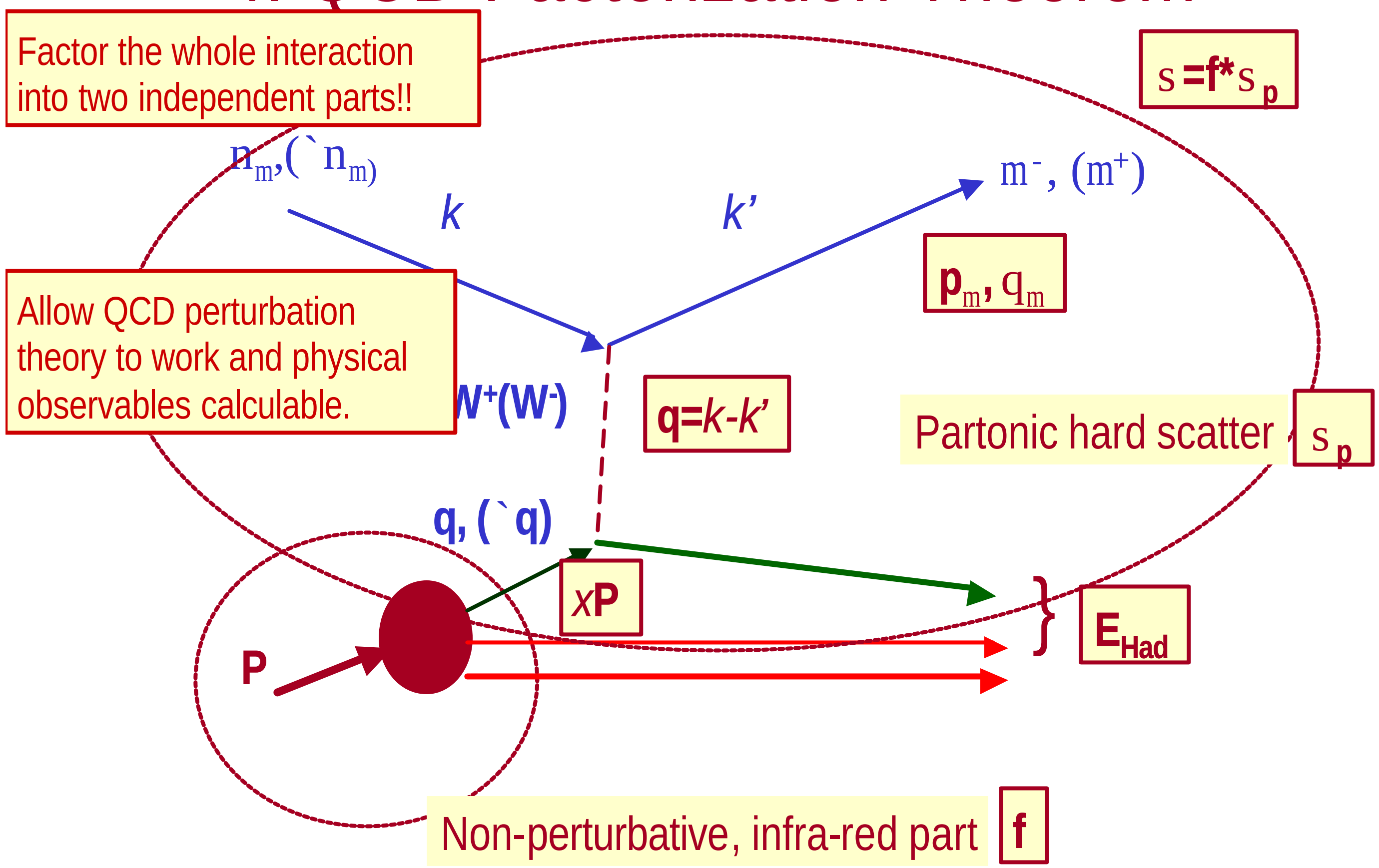
- Neutrinos are electrically neutral
- Need to select the charge of the secondary hadrons from the proton interaction on target
- Sets of Dipoles are used to select desired charges of the secondary hadrons



3. How can there be wrong sign of neutrinos in a sign selected beam?

- Interaction of correct sign secondary hadrons with beamline elements, including dump and shields
  - Act as if a fixed target is hit by hadron beam
- Back-scatter of unused protons into the beamline
- CP violating neutrino oscillations

4. QCD Factorization Theorem



5. Structure Functions and PDF's

SF is the description of the collection of point-like particles that forms nucleons while PDF's provide momentum distributions of individual partons within the collection.

- Assuming parton model, n-N cross section can be rewritten in terms of point-like particle interactions

$$\frac{d^2 s^{nT}}{dxdy} = \frac{G_F^2 xs}{p\left(1+Q^2/M_W^2\right)^2}\left[q^{nT}(x)+\left(1-y^2\right)\bar{q}^{nT}+2(1-y)k^{nT}(x)\right]$$

$$\frac{d^2 s^{\bar{n}T}}{dxdy} = \frac{G_F^2 xs}{p\left(1+Q^2/M_W^2\right)^2}\left[\bar{q}^{\bar{n}T}(x)+\left(1-y^2\right)q^{\bar{n}T}+2(1-y)k^{\bar{n}T}(x)\right]$$

Spin 0 partons

- Comparing the parton-neutrino to proton-neutrino SF and PDF's are related as

$$2xF_1^{n(\bar{n})T} = 2\left[xq^{n(\bar{n})T}(x)+x\bar{q}^{n(\bar{n})T}(x)\right]$$

$$F_2^{n(\bar{n})T} = 2\left[xq^{n(\bar{n})T}(x)+x\bar{q}^{n(\bar{n})T}(x)+2xk^{n(\bar{n})T}\right]$$

$$xF_3^{n(\bar{n})T} = 2\left[xq^{n(\bar{n})T}(x)-x\bar{q}^{n(\bar{n})T}(x)\right]$$

Parity violating components

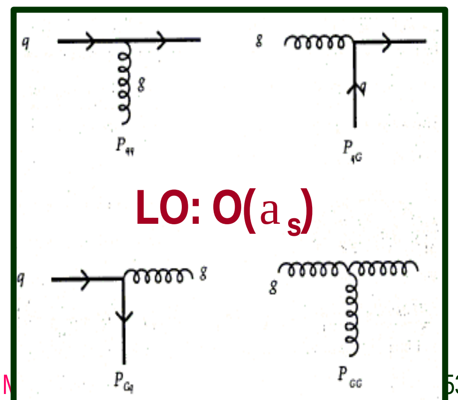
If no spin 0, 2xF1=F2

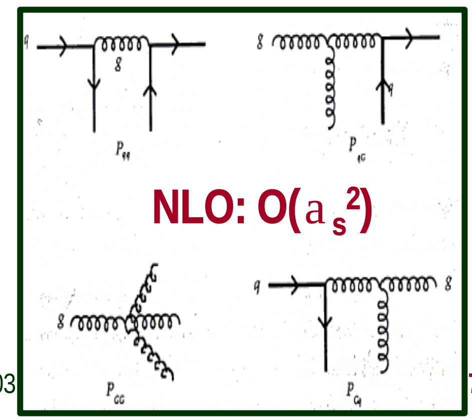
6. PDF Evolution: DGLAP Equations

- The evolution equations by **D**okshitzer-**G**ribov-**L**ipatov-**A**ltarelli-**P**arisi provide mechanism to evolve PDF's to any kinematic regime or momentum scale, as a function of momentum transfer scale of the interactions

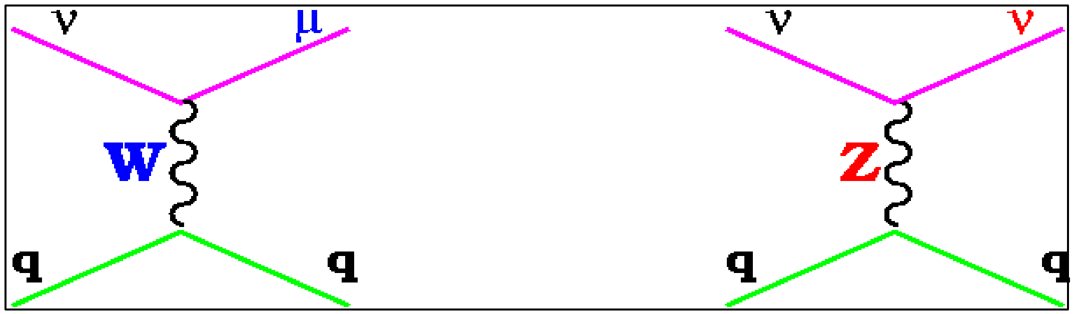
$$\frac{dG(x,M^2)}{d\ln M^2}=\frac{a_s(m^2)}{2p}\int_x^1\frac{dy}{y}\left[q^S(y,M^2)P^s_{Gq}\left(\frac{x}{y}\right)+G(y,M^2)P_{GG}\left(\frac{x}{y}\right)\right]$$

$P_{ij}(x/y)$: Splitting function that is the probability of parton i with momentum y get resolved as parton j with momentum x<y





7. How is sin^{2}q$_W$ measured?



$$coupling \propto I_{weak}^{(3)} \qquad\qquad coupling \propto I_{weak}^{(3)} - Q_{EM}\sin^2 q_W$$

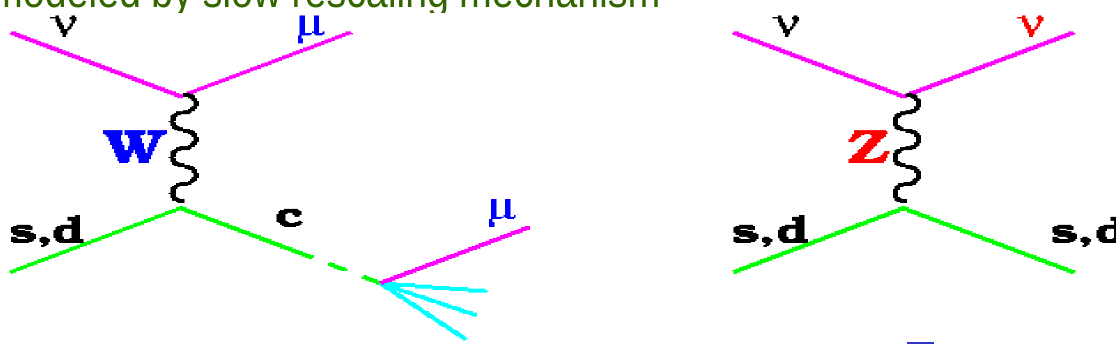
- Cross section ratios between NC and CC proportional to sin$^2\theta_W$
- Llewellyn Smith Formula:

$$\mathbf{R}^{n(\bar{n})} = \frac{\mathbf{s}_{\mathbf{NC}}^{n(\bar{n})}}{\mathbf{s}_{\mathbf{CC}}^{n(\bar{n})}} = ?^2\left(\frac{1}{2} - \sin^2 ?_W + \frac{5}{9}\sin^4 ?_W\left(1 + \frac{\mathbf{s}_{\mathbf{CC}}^{\bar{n}(n)}}{\mathbf{s}_{\mathbf{CC}}^{n(\bar{n})}}\right)\right)$$

- Define experimental variable to distinguish NC and CC
- Compare the measured ratio with MC prediction

8-1. $\sin^2\theta_W$ Theoretical Uncertainty

- Significant correlated error from CC production of charm quark (m_c) modeled by slow rescaling mechanism



- Suggestion by Paschos-Wolfenstein by separating ν and $\bar{\nu}$ beams:

$$R^{-} = \frac{s^{n}_{NC} - s^{\bar{n}}_{NC}}{s^{n}_{CC} - s^{\bar{n}}_{CC}} = ?^{2}\left(\frac{1}{2} - \sin^{2}?_{W}\right) = \frac{R^{n} - R^{\bar{n}}}{1-r}$$

➔Reduce charm CC production error by subtracting sea quark contributions

➔Only valence u, d, and s contributes while sea quark contributions cancel out

➔Massive quark production through Cabbio suppressed d_v quarks only

8-2. Experimental Uncertainties from ν_e

- Electron neutrinos, ν_e, in the beam fakes NC events from CC interactions
  - If the production cross section is well known, the effect will be smaller but since majority come from neutral K (K_L) whose x-sec is known only to 20%, this is a source of large experimental uncertainty
- Using tilted incident proton beam to eliminate neutral hadrons from the secondary beam.

9. Neutrino Oscillation & Its importance

- Caused by the fact that there are two different eigenstates for mass and weak flavors
- The weak eigenstates are expressed as a linear combination of mass eigenstates with time phase and mixing angle

- Neutrinos are one of the fundamental constituents in nature
  - Three weak eigenstates based on SM
- Left handed particles and right handed anti-particles only
  - Violates parity ➔ Why only neutrinos?
  - Is it because of its masslessness?
- SM based on massless neutrinos
- SM inconsistent

10. Atmospheric Neutrinos & Their Flux

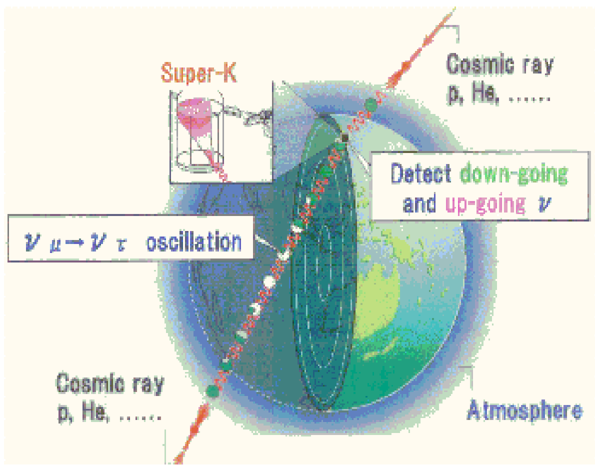
- Neutrinos resulting from the atmospheric interactions of cosmic ray particles
  - He, p, etc + N → π,K, etc

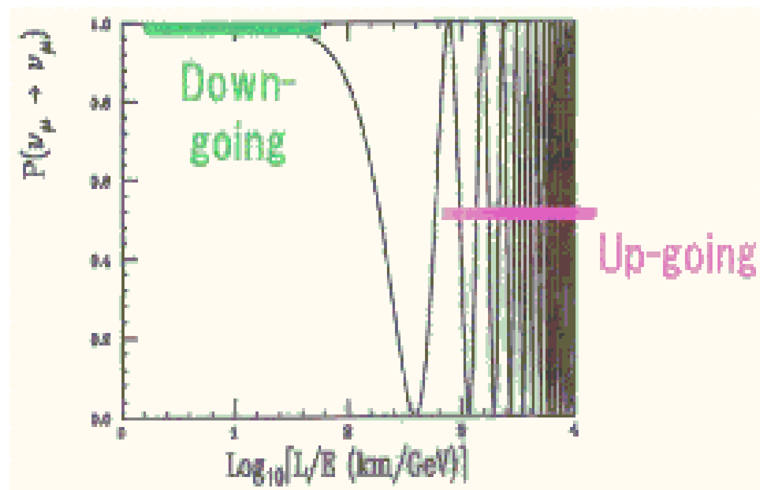
    $\pi \rightarrow \mu+\nu_\mu$

    $\mu \rightarrow e+\nu_e+\nu_\mu$
  - This reaction gives 2 ν_μ and 1 ν_e
- Expected flux ratio between ν_μ and ν_e is 2 to 1
- Give a predicted ratio of $\boxed{\left(\frac{N_{\nu_e}}{N_{\nu_\mu}}\right) \approx \frac{1}{2}}$

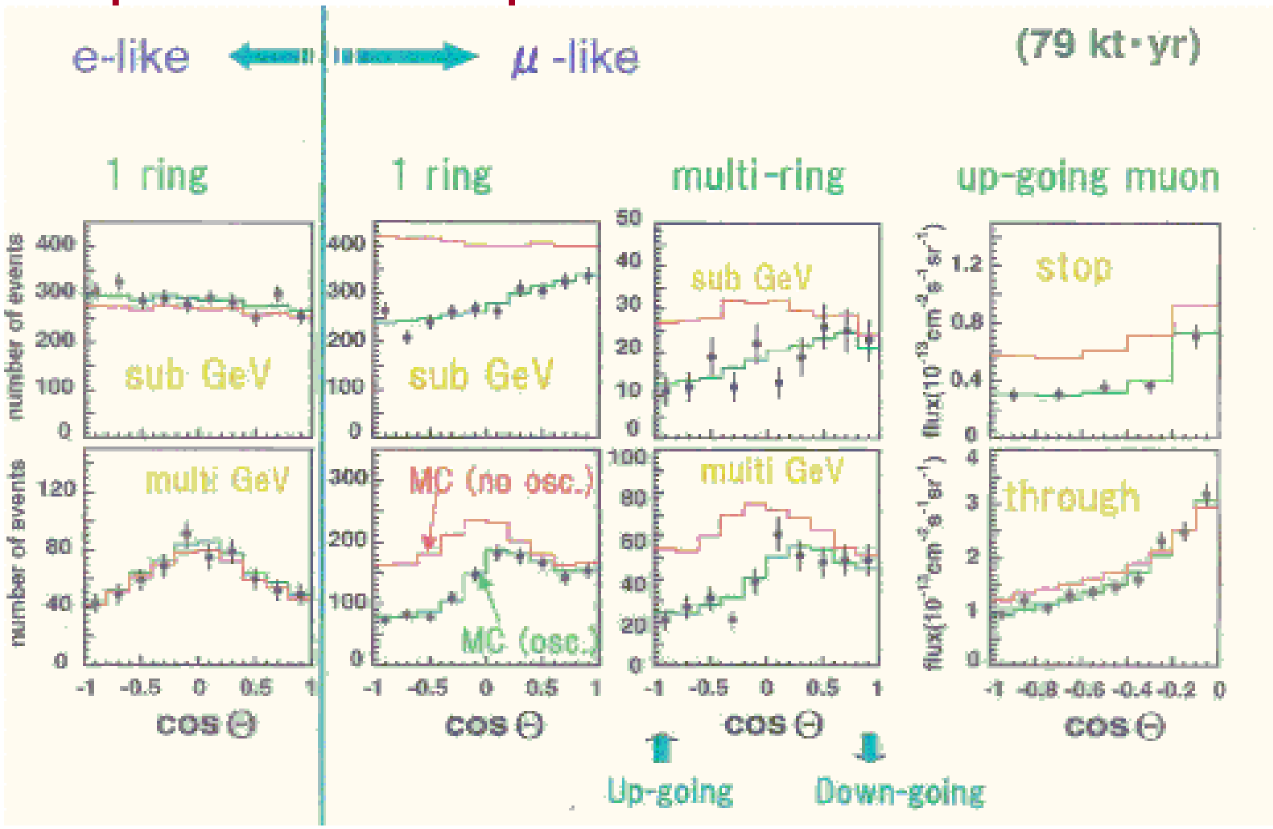
11. Importance of Zenith Angle

- The Zenith angle represents the different distance the neutrinos traveled through the earth
- The dependence to the angle is a direct proof of the oscillation probability $\boxed{P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta \, \sin^2\left(\frac{1.27\Delta m^2 L}{E_\nu}\right)}$





Super-K Atmospheric Neutrino Results



12. Local Gauge Invariance

Physical meaning of local gauge invariance is the preservation of energy-momentum conservation and the physical law governing the interactions.

Requiring local gauge invariance forces the L to accept new vector fields which are massless to preserve the invariance and introduces interactions between the vector field and the field currents.

Homework

- Presentation of detailed cuts used in data selection
  - Next Monday, Mar. 31