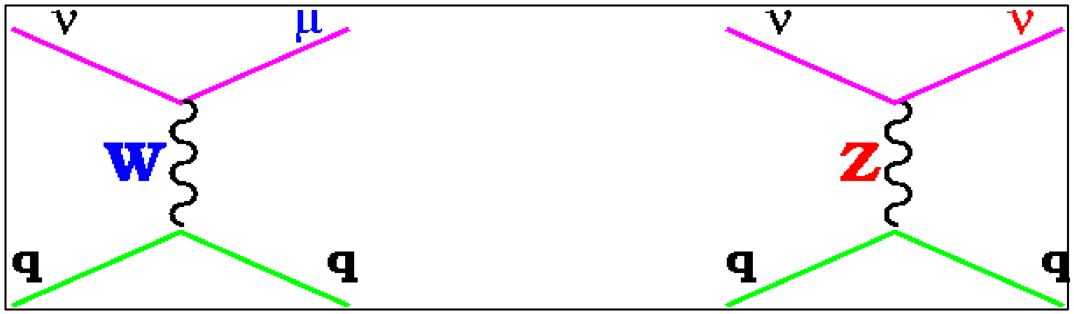
PHYS 5326 – Lecture #7

Monday, Feb. 10, 2003
Dr. Jae Yu

1. Improvements in $Sin^2\theta_W$
2. Interpretation of $Sin^2\theta_W$ results
3. The link to Higgs

No class this Wednesday → Will make up on Fridays.

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



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

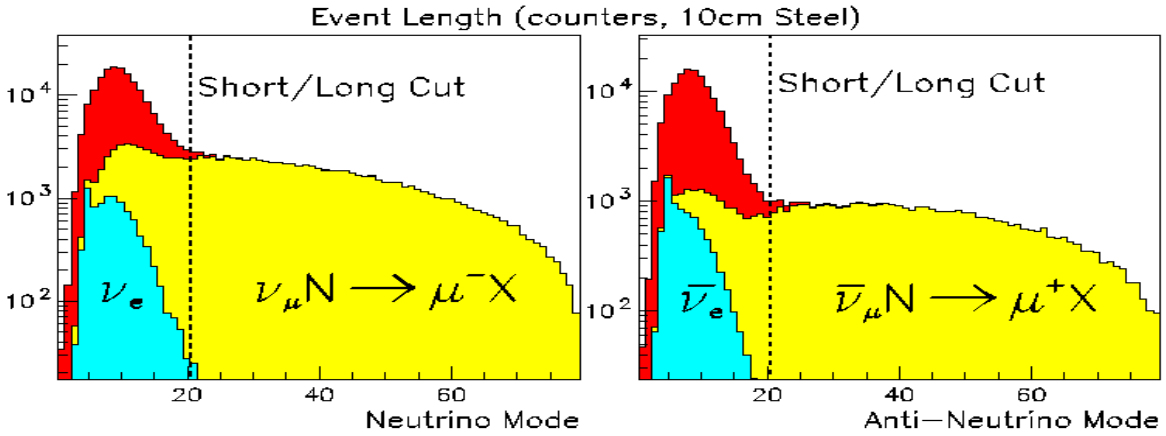
- Cross section ratios between NC and CC proportional to sin$^2\theta_W$
- Llewellyn Smith Formula:

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

Experimental Variable

Define an Experimental Length variable

➔Distinguishes CC from NC experimentally in statistical manner



Compare experimentally measured ratio

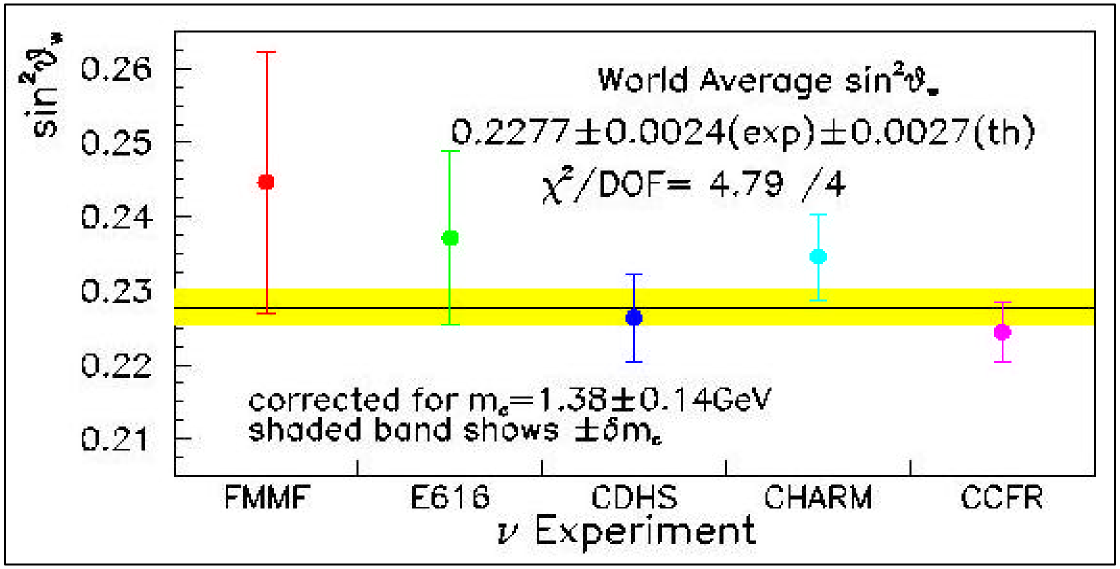
$$R_{Exp} = \frac{N_{Short}}{N_{Long}} = \frac{L < L_{Cut}}{L > L_{Cut}} = \frac{N_{NC\ Candidates}}{N_{CC\ Candidates}}$$

to theoretical prediction of R^ν

Past Experimental Results

$$\sin^2 ?_W^{On-Shell} = 1 - \frac{M_W^2}{M_Z^2} = 0.2277 \pm 0.0036$$

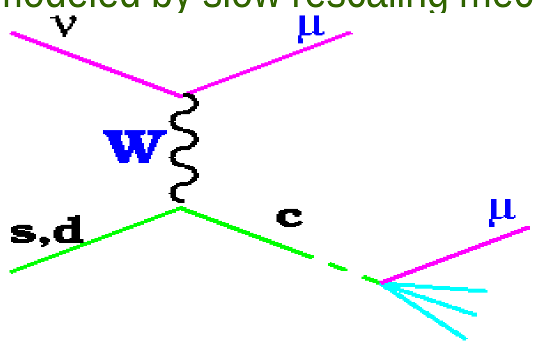
$$\Rightarrow M_W^{On-Shell} = 80.14 \pm 0.19 GeV/c^2$$

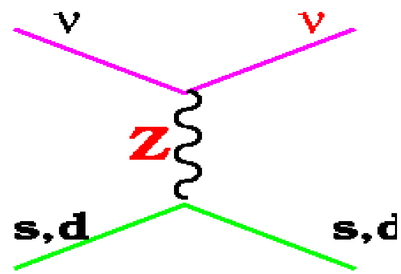


The yellow band represents a correlated uncertainty!!

$\sin^2\theta_W$ 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:

$$R^{-} = \frac{\sigma^{\nu}_{NC} - \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\bar{\nu}}_{CC}} = \rho^2\left(\frac{1}{2} - \sin^2\theta_W\right) = \frac{R^{\nu} - R^{\bar{\nu}}}{1 - r}$$

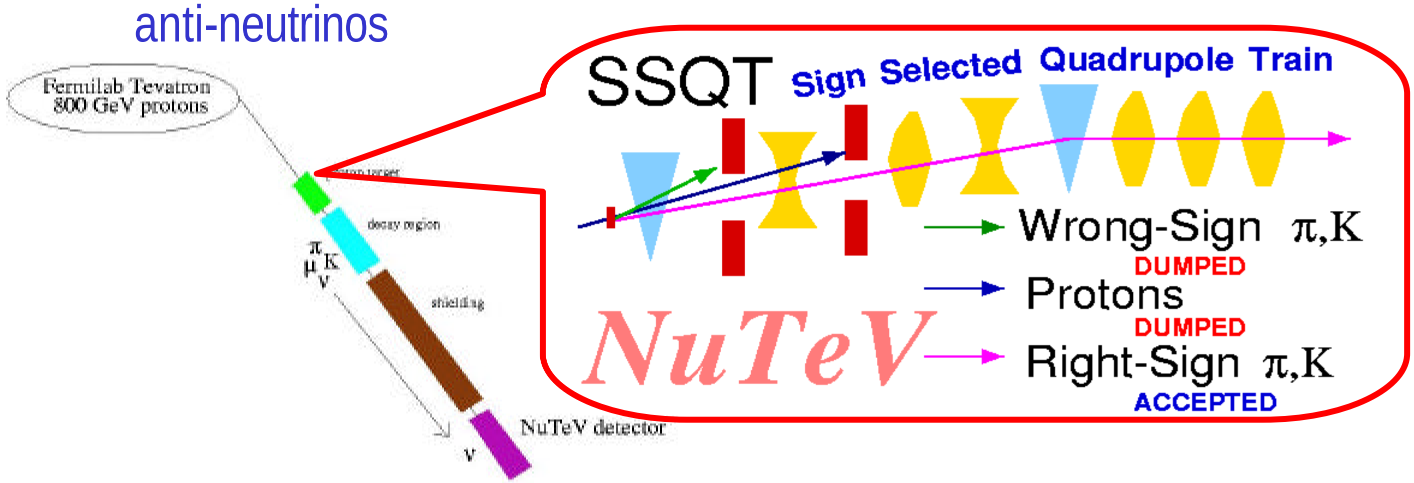
➔Reduce charm CC production error by subtracting sea quark contributions

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

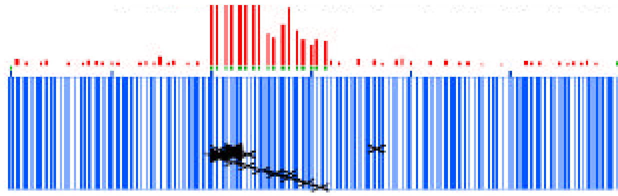
➔Massive quark production through Cabbio suppressed d_v quarks only

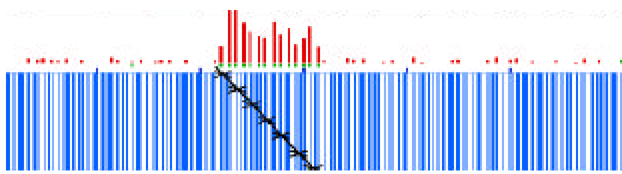
Improving Experimental Uncertainties

- 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
- Need to come up with a beamline that separates neutrinos from anti-neutrinos

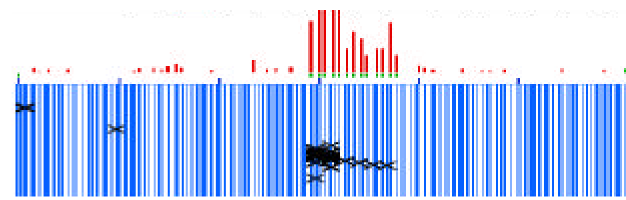


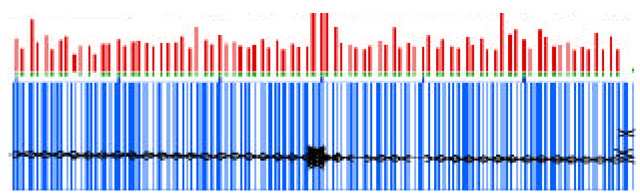
Event Contamination and Backgrounds





- **SHORT** n_m **CC's (20%** n, 10% `n **)**
  μ exit and rangeout
- **SHORT** n_e **CC's (5%)**
  $\nu_e N \rightarrow eX$
- **Cosmic Rays (0.9%)**

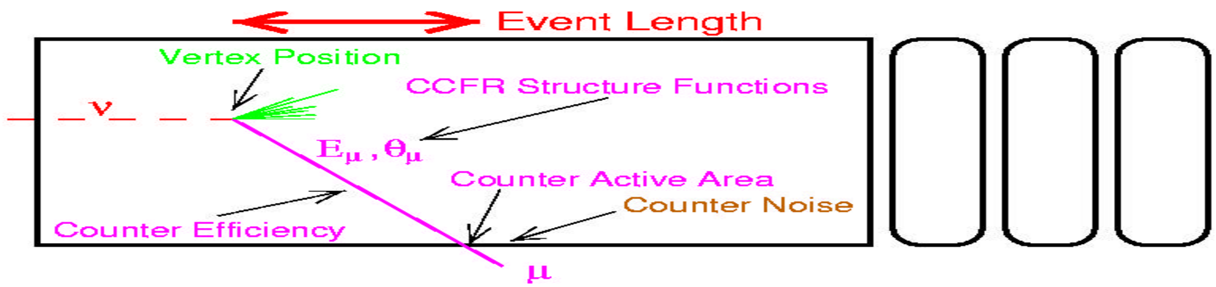




- **LONG** n_m **NC's (0.7%)**
  hadron shower
  punch-through effects

- **Hard** m **Brem(0.2%)**
  Deep μ events

Other Detector Effects

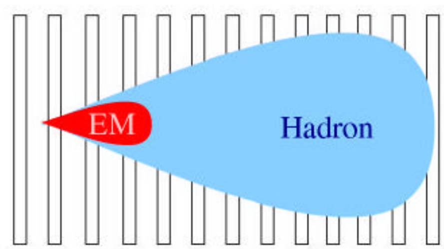


Sources of experimental uncertainties kept small, through modeling using n and TB data

Effect	Size(d sin^{2}q$_W$)	Tools
Z_{vert}	0.001/inch	$\mu^+\mu^-$ events
X_{vert} & Y_{vert}	0.001	MC
Counter Noise	0.00035	TB μ's
Counter Efficiency	0.0002	ν events
Counter active area	0.0025/inch	ν CC, TB
Hadron shower length	0.0015/cntr	TB π's and k's
Energy scale	0.001/1%	TB
Muon Energy Deposit	0.004	ν CC

Measurements of ν_e Flux

- Use well known processes (Ke3: $K^{\pm} \to \pi^{0} e^{\pm} \overset{(-)}{\nu}_{e}$)
- Shower Shape Analysis can provide direct measurement ν_e events, though less precise



N_{meas}/N_{MC}

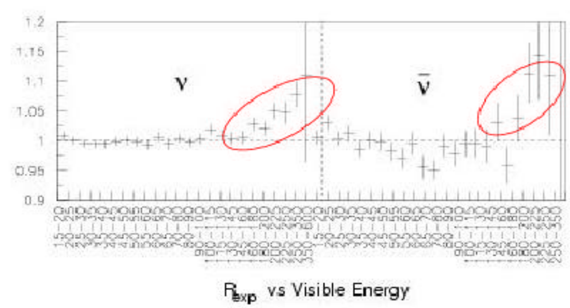
$1.05 \pm 0.03\ (\nu_e)$

$1.01 \pm 0.04\ (\bar{\nu}_e)$

Weighted average used for ν_e
➔ δR_{ν}^{exp}~0.0005

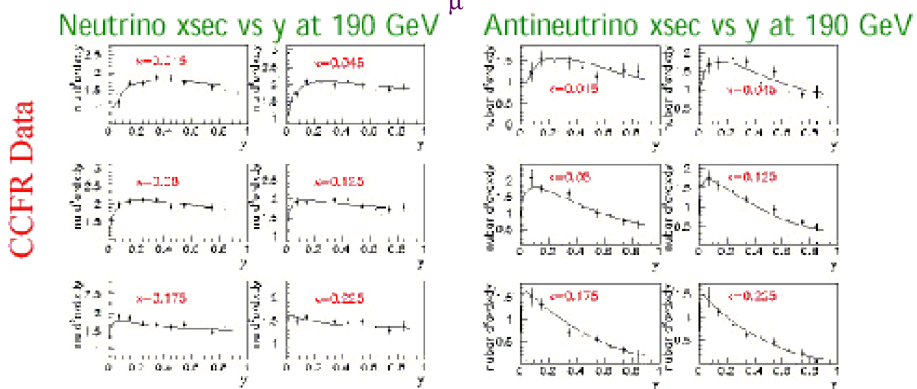
- ν_e from very short events (E_ν>180 GeV)
  - Precise measurement of ν_e flux in the tail region of flux ➔ ~35% more $\bar{\nu}_e$ in $\bar{\nu}$ than predicted
  - Had to require (E_{had}<180 GeV) due to ADC saturation

Results in $\sin^2\theta_W$ shifts by +0.002

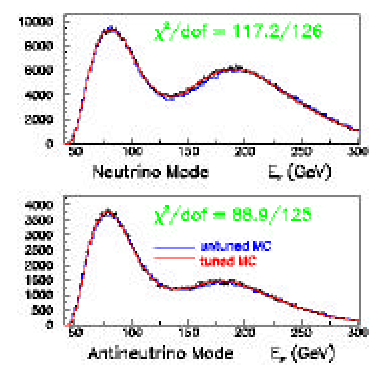


MC to Relate R_ν^{exp} to R^ν and $\sin^2\theta_W$

- Parton Distribution Model
  - Correct for details of PDF model ➔ Used CCFR data for PDF
  - Model cross over from short ν_μ CC events



- Neutrino Fluxes
  - $\nu_\mu, \nu_e, \bar{\nu}_\mu, \bar{\nu}_e$ in the two running modes
  - ν_e CC events always look short
- Shower length modeling
  - Correct for short events that look long
- Detector response vs energy, position, and time
  - Continuous testbeam running minimizes systematics



$\sin^2\theta_W$ Fit to R_ν^{exp} and $R_{\bar\nu}^{exp}$

- Thanks to the separate beam ➔ Measure R^ν's separately
- Use MC to simultaneously fit $\mathbf{R}_n^{exp}$ and $\mathbf{R}_{\bar n}^{exp}$ to $\sin^2\theta_W$ and m_c, and $\sin^2\theta_W$ and ρ

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

- R^ν Sensitive to $\sin^2\theta_W$ while $R^{\bar\nu}$ isn't, so R^ν is used to extract $\sin^2\theta_W$ and $R^{\bar\nu}$ to control systematics
- Single parameter fit, using SM values for EW parameters (ρ_0=1)

$$\sin^2\mathbf{?}_W = \mathbf{0.2277} \pm \mathbf{0.0013}\ \mathbf{(stat)} \pm \mathbf{0.0009}\ \mathbf{(syst)}$$

$$m_c = 1.32 \pm 0.09\ \text{(stat)} \pm 0.06\ \text{(syst) w/ } m_c = 1.38 \pm 0.14\ \text{GeV/c}^2 \text{ as input}$$

- Two parameter fit for $\sin^2\theta_W$ and ρ_0 yields

$$\sin^2\mathbf{?}_W = \mathbf{0.2265} \pm \mathbf{0.0031}$$

$$\mathbf{?}_0 = \mathbf{0.9983} \pm \mathbf{0.040}$$

Syst. Error dominated since we cannot take advantage of sea quark cancellation

NuTeV $\sin^2\theta_W$ Uncertainties

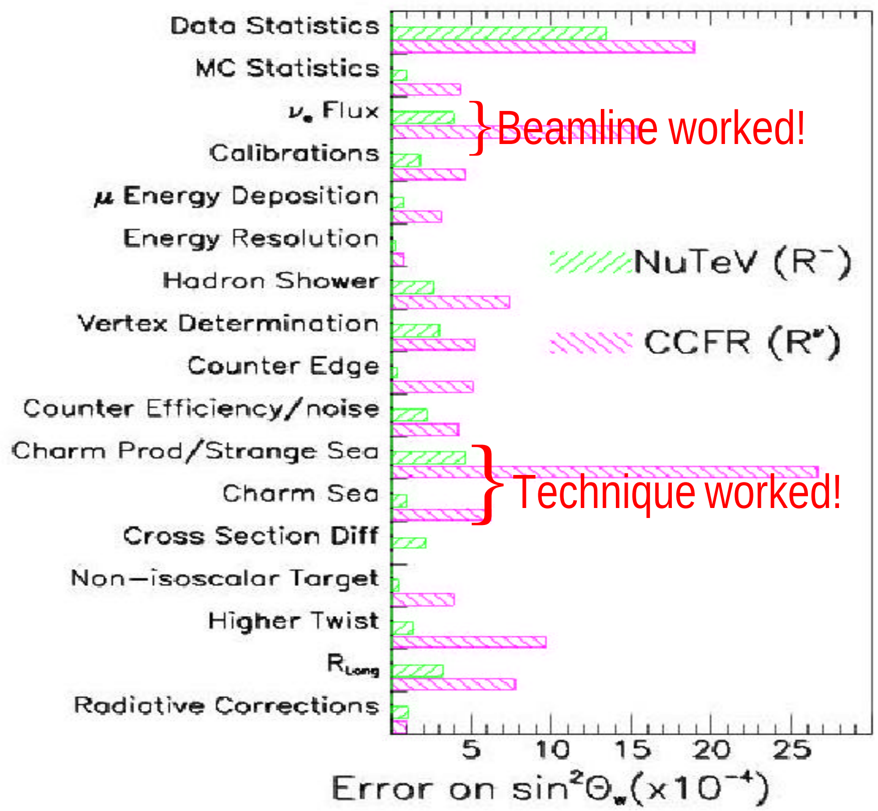
Source of Uncertainty	$\delta \sin^2\theta_W$
Statistical	**0.00135**
ν_e flux	0.00039
Event Length	0.00046
Energy Measurements	0.00018
Total Experimental Systematics	**0.00063**
CC Charm production, sea quarks	0.00047
Higher Twist	0.00014
Non-isoscalar target	0.00005
$\sigma^{\bar{\nu}} / \sigma^{\nu}$	0.00022
RadiativeCorrection	0.00011
R_L	0.00032
Total Physics Model Systmatics	**0.00064**
Total Systematic Uncertainty	**0.00162**
ΔM_W (GeV/c²)	**0.08**

Dominant uncertainty

1-Loop Electroweak Radiative Corrections based on Bardin, Dokuchaeva **JINR-E2-86-2 60 (1986)**

$$\delta\sin^2\theta_W^{(On-shell)} = -0.00022 \times \left(\frac{M_t^2 - (175\,GeV)^2}{(50\,GeV)^2} \right) + 0.00032 \times \ln\left(\frac{M_H}{150\,GeV} \right)$$

NuTeV vs CCFR Uncertainty Comparisons



Homework Assignments

- Process the transferred TMB data files and convert them into TMBtree for root analysis
  - You can work together on this one
  - One person can produce TMBtree for all
  - Due next Monday, Feb. 17
- Produce an electron E_T spectrum of the highest E_T electrons in your samples
  - Due next Wednesday, Feb. 19