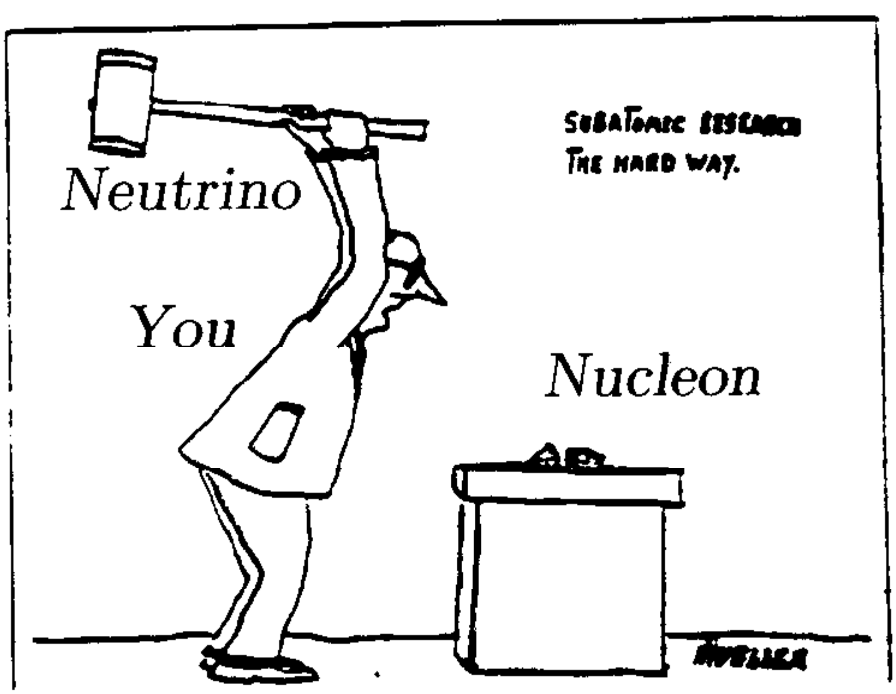
Bernstein

Structure Functions from CCFR

- Introduction
- What Does Neutrino DIS Measure?
- Results
  - Structure Functions
  - Charged-Lepton Comparisons
  - $x > 1$
- Future Prospects



DIS 97
Chicago,IL
15 April 1997

CCFR & NuTeV Collaborations

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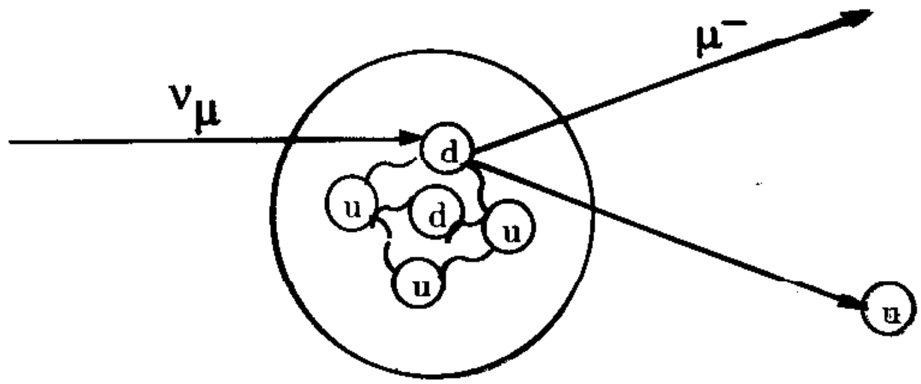
What Do We Need to Use Neutrinos?

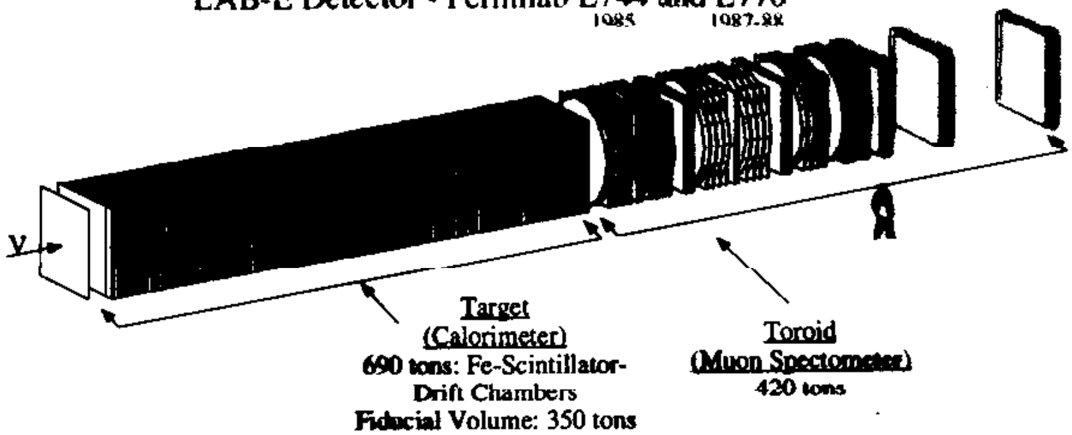


$$\sigma(\nu N) = 0.67 \times 10^{-38}\ \mathrm{cm}^2/\mathrm{GeV}$$

- Intense Neutrino Beam
- High Mass Target (hundreds of tons)
- Detector Which Measures Decay Fragments
  —hadron energy
- Something to Measure Muon Momentum

CCFR (Columbia-Chicago-Fermilab-Rochester)

LAB-E Detector - Fermilab E744 and E770



- 950562 ν_μ and 169114 $\bar{\nu}_\mu$ **After All Cuts**
- $\Delta p_\mu / p_\mu = 0.10$ Independent of Momentum
- $\sigma / E = 0.847/\sqrt{E_{\rm Had}} + 0.30/E$

How Are the Cross-Sections Expressed?

- Useful Because Universal and Easily Compared Among Probes: photons, muons, neutrinos
- "Lagrangian" Representation of What Neutrino Sees:

$$\sigma \propto L_{\mu\nu}W^{\mu\nu}$$
$$W^{\mu\nu} = (-g_{\mu\nu} + \frac{q_\mu q_\nu}{q^2})W_1 + \frac{1}{M}(p_\mu - \frac{p \cdot q}{q^2}q_\mu)(p_\nu - \frac{p \cdot q}{q^2}q_\nu)W_2 + i\epsilon_{\mu\nu\alpha\beta}\frac{p^\alpha q^\beta}{2M}W_3$$

with $F_1 = MW_1, F_2 = \nu W_2, F_3 = \nu W_3$.

- Parton Version of What Neutrino Sees:

$$2xF_1 = xq(x) + x\bar{q}(x)$$

$$F_2 = xq(x) + xq(x) + xk(x)$$

$$xF_3 = xq(x) - x\bar{q}(x)$$

(this definition depends on order of QCD calculation)

- And the Cross-Sections Become

$$\frac{d^2\sigma}{dx\,dy}|_{\nu,\bar{\nu}} = \frac{G_F^2 ME}{\pi}\left[(1 - y - \frac{Mxy}{2E})F_2 + \frac{y^2}{2}2xF_1 \pm (y - \frac{y^2}{2})xF_3\right]$$

What's So Special About xF_3?

- $xF_3 \propto q - \bar{q}$ Independent of Sea (well, almost)
- xF_3 Is Different for $\nu, \bar{\nu}$

$$xF_3(\nu) = x(u_v(x) + d_v(x)) + 2(s(x) - c(x))$$
$$xF_3(\bar{\nu}) = x(u_v(x) + d_v(x)) + 2(c(x) - s(x))$$

- We report

$$xF_3 = \frac{xF_3(\nu) + xF_3(\bar{\nu})}{2} = x(u_v(x) + d_v(x))$$

- Independent of Sea for Evolution Equations. But ...
- Dependent on AntiNeutrino Statistics

Experimental Method

- Determine the $\bar{\nu}/\nu$ Flux Ratio

$$N(\nu) \propto \int dE\Phi(\nu, E) \times \sigma(\nu, E)$$
$$N(\bar{\nu}) \propto \int dE\Phi(\bar{\nu}, E) \times \sigma(\bar{\nu}, E)$$

- But as $y = E_H / E_\nu \to 0$

$$\sigma(\nu, E) = \sigma(\bar{\nu}, E) \propto (q + \bar{q})$$

- *The Same!!*
- So

$$\frac{\Phi(\bar{\nu}, E)}{\Phi(\nu, E)} = \frac{\frac{N(\bar{\nu},E)}{\sigma(\bar{\nu},E)}}{\frac{N(\nu,E)}{\sigma(\nu,E)}} = \frac{N(\bar{\nu}, E)}{N(\nu, E)}$$

- Which Gives Us the "Relative" Flux
  - — Relative $\bar{\nu}/\nu$ vs. Energy
  - — Absolute Cross-Section from External Data

Extraction of Structure Functions

- Within an x, Q^2 bin

$$N^{\nu}(x, Q^2) = A_{\nu} F_2(x, Q^2) + B_{\nu}\, xF_3(x, Q^2)$$
$$N^{\bar{\nu}}(x, Q^2) = A_{\bar{\nu}} F_2(x, Q^2) + B_{\bar{\nu}}\, xF_3(x, Q^2)$$

- Where A, B are functions of
  - Relative Flux
  - Measured Kinematic Variables
  - R_{QCD}
- But Changing SFCNS changes Relative Flux, Through Resolution Smearing
- So Iterate:

$$\Phi \Leftrightarrow F_2, xF_3$$

Department of Corrections

- Physics Model Corrections

$$\text{corr} = \text{corr}^{\text{isoscalar}} \times \text{corr}^{\text{radiative}} \times \text{corr}^{\text{charmmass}} \times \text{corr}^{\text{propagator}}$$

- These do not use external parton distributions we iterate on F_2, xF_3 until changes are small

- Use LO Buras-Gaemers model

$$\frac{\sigma(\text{LO, physical Fe target})}{\sigma(\text{LO, bare proton})} \approx \frac{\sigma(\text{NLO, physical Fe target})}{\sigma(\text{NLO, bare proton})}$$

- Strange Sea Correction

So What Do We Report?

- F_2, xF_3 for
  - Isoscalar Target
  - No Strange Sea
  - Charm Mass = 0
    (no slow-rescaling correction)
  - Remove Physical Radiative Corrections
  - Remove Propagator Q^2 Dependence
- Each Correction is Explicitly Given in
  Seligman, PhD Thesis
  Down to Code – so you can take it out if
  you like

ftp://nevis1.nevis.columbia.edu/pub/.../selig...
or anonymous ftp

Errors

- Statistical
  - Since Data Are the Same, ΔF_2 is Correlated with $\Delta x F_3$
- Systematic

  Treated as Additional Term in χ^2
  - Hadron Energy Calibration

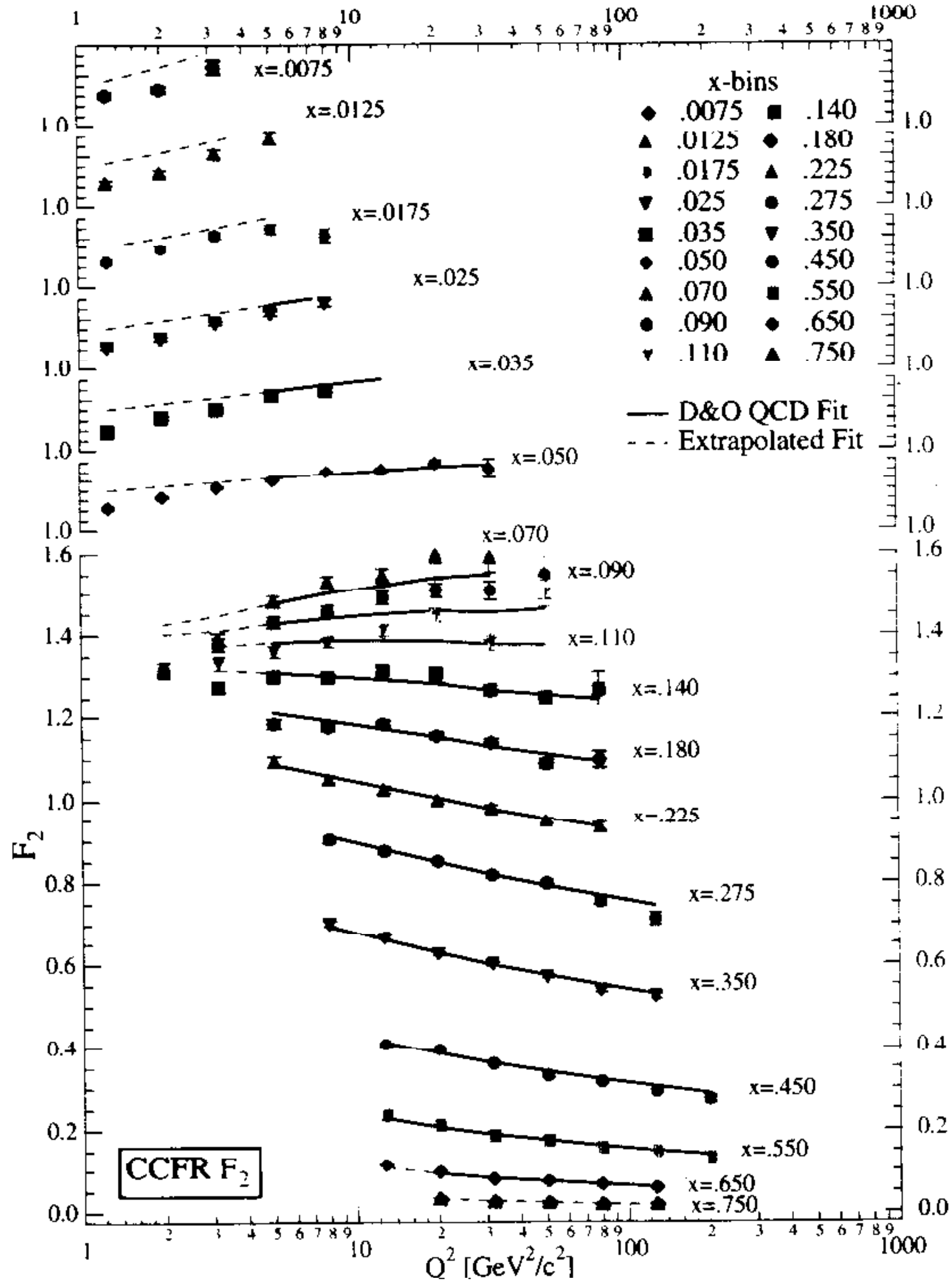
    — or more specifically, E_{Had}/p_μ
  - Flux Extraction

    — quality of fits to $\sigma_\nu = \sigma_{\bar{\nu}}$ at $y = 0$
  - Buras-Gaemers Model Parameterization

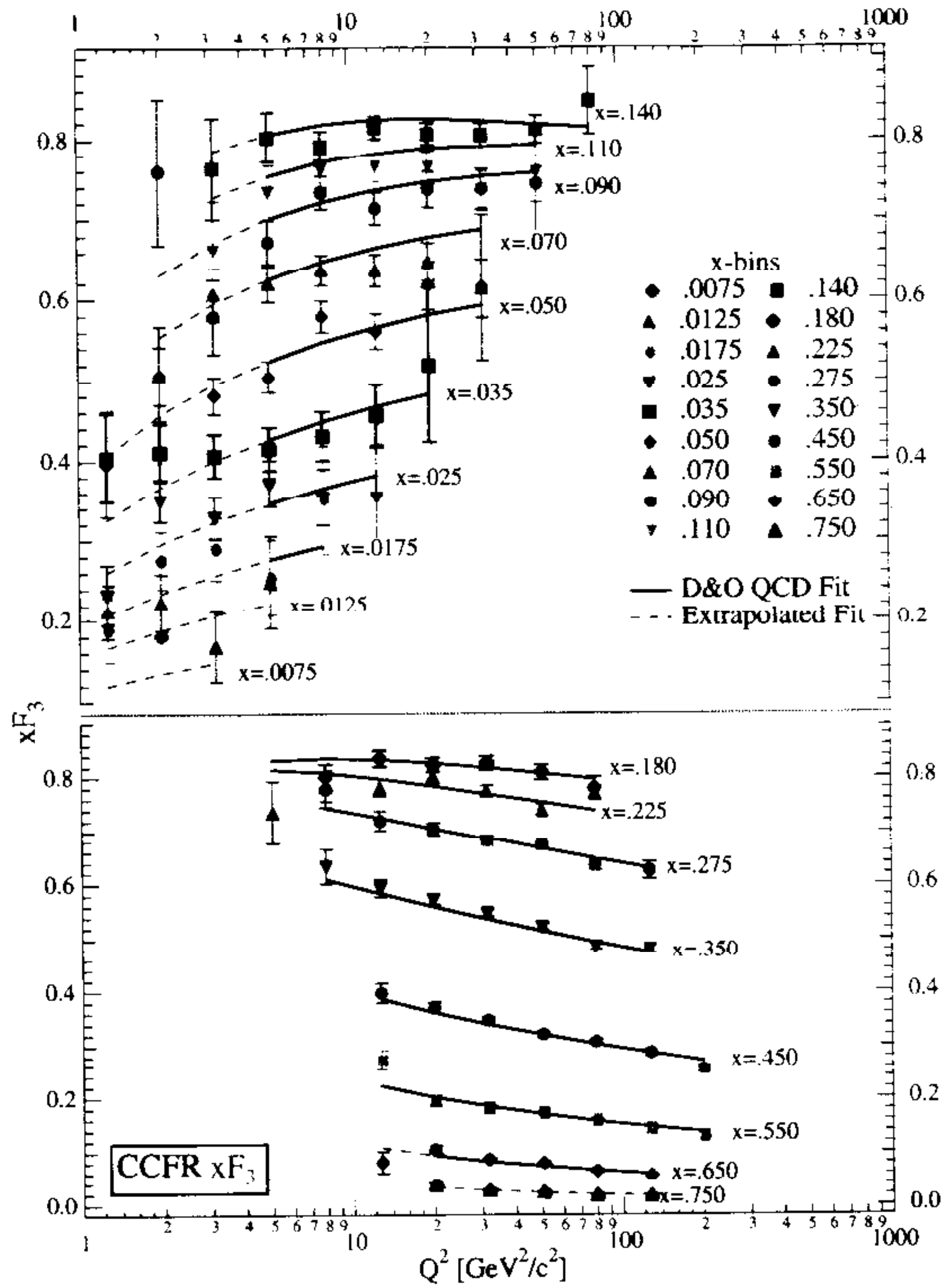
    — fits poorly at low x
  - R_{QCD}, m_c, strange sea, ...

	$\Delta\Lambda_{\overline{\mathrm{MS}}}$ (MeV)
Statistical	42
Calibration/Energy Scale	64
Flux	21
Cross-Section	31
Buras-Gaemers "Model"	41
Remaining	21

F_2


x=.0075
x=.0125
x=.0175
x=.025
x=.035
x=.050
x=.070
x=.090
x=.110
x=.140
x=.180
x=.225
x=.275
x=.350
x=.450
x=.550
x=.650
x=.750
x-bins
.0075
.0125
.0175
.025
.035
.050
.070
.090
.110
.140
.180
.225
.275
.350
.450
.550
.650
.750
D&O QCD Fit
Extrapolated Fit
CCFR F2
F2
Q2 [GeV2/c2]

xF_3


x=.140
x=.110
x=.090
x=.070
x=.050
x=.035
x=.025
x=.0175
x=.0125
x=.0075
x-bins
.0075 .140
.0125 .180
.0175 .225
.025 .275
.035 .350
.050 .450
.070 .550
.090 .650
.110 .750
D&O QCD Fit
Extrapolated Fit
x=.180
x=.225
x=.275
x=.350
x=.450
x=.550
x=.650
x=.750
CCFR xF3
xF3
Q2 [GeV2/c2]

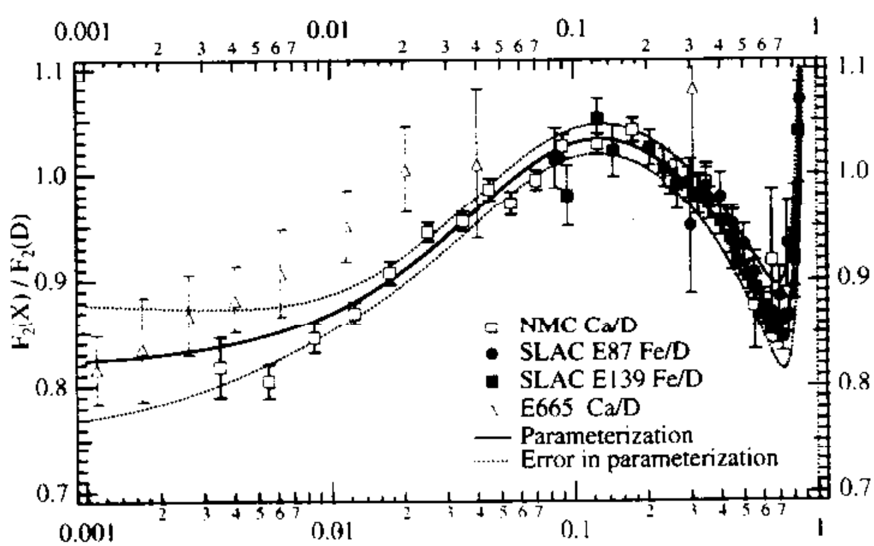
Comparison to ChargedLepton Experiment

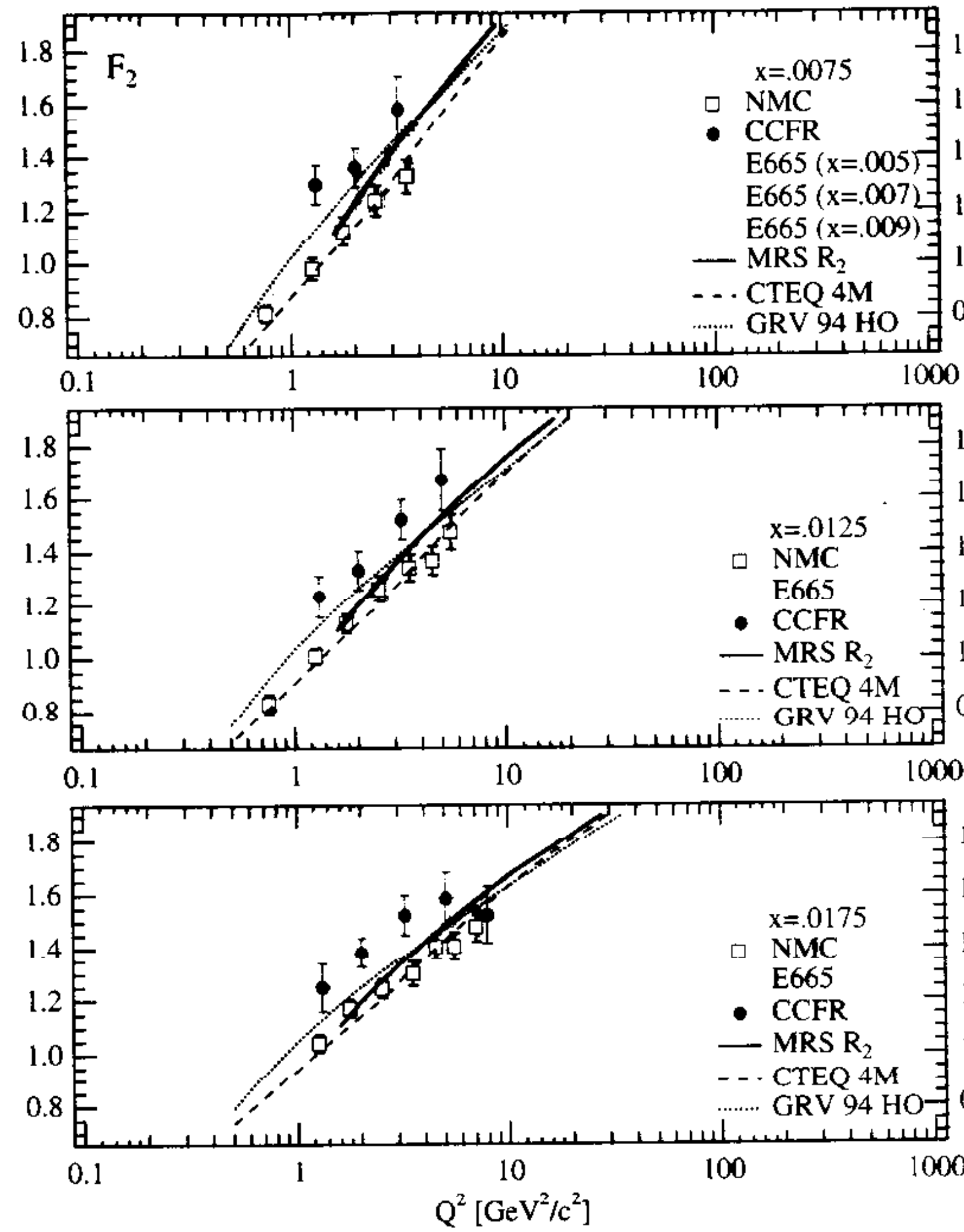
- Heavy Target Correction
- "5/18"ths Rule

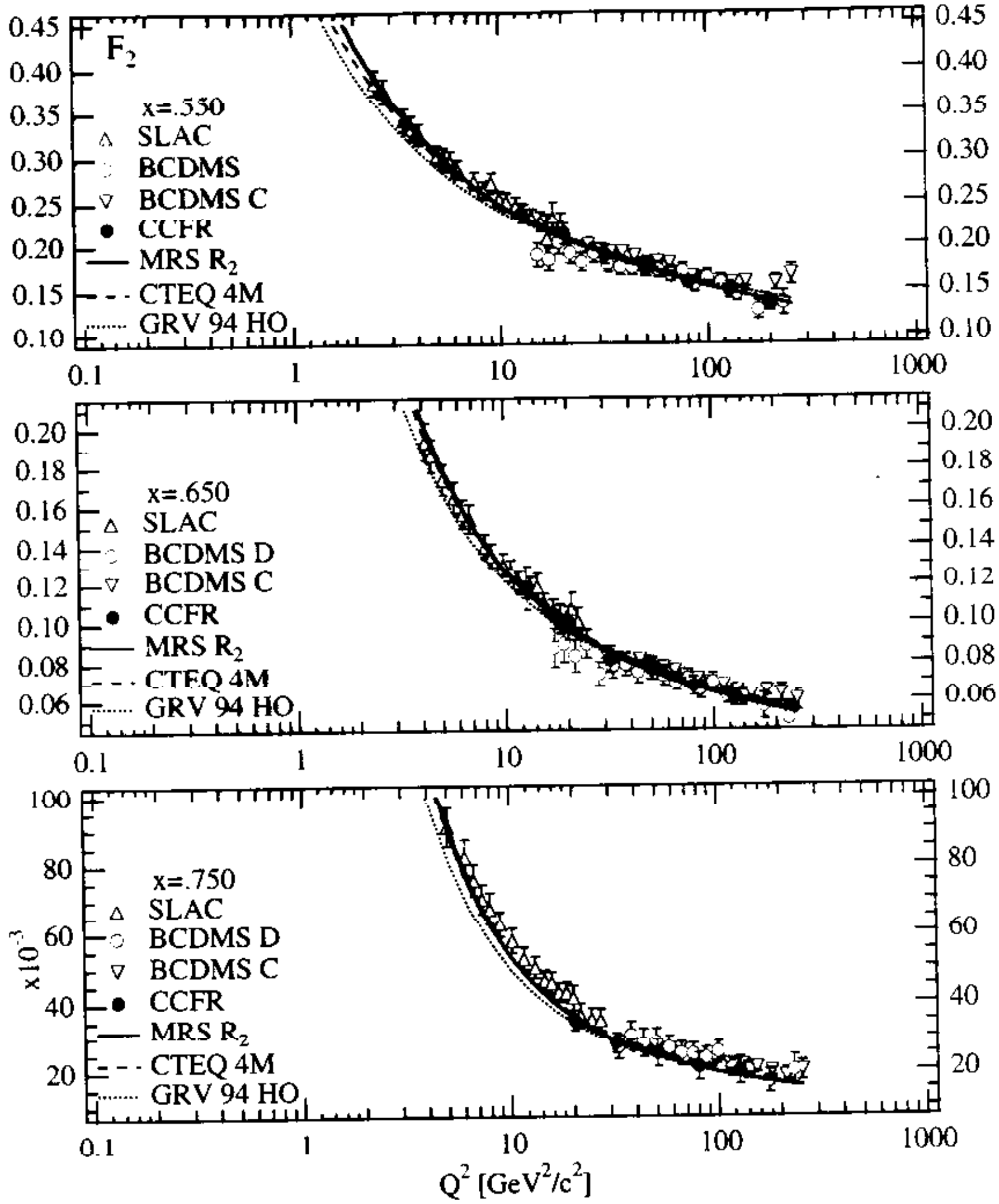
$$\frac{F_2^{\text{lepton}}}{F_2^{\nu}} = \frac{5}{18}\left[1 - \frac{3}{5}\left(\frac{s + s - c - \bar{c}}{q + \bar{q}}\right)\right]$$

—note this is *exact* in DIS scheme
—use CTEQ4D, determined in DIS
(and CTEQ charm sea)

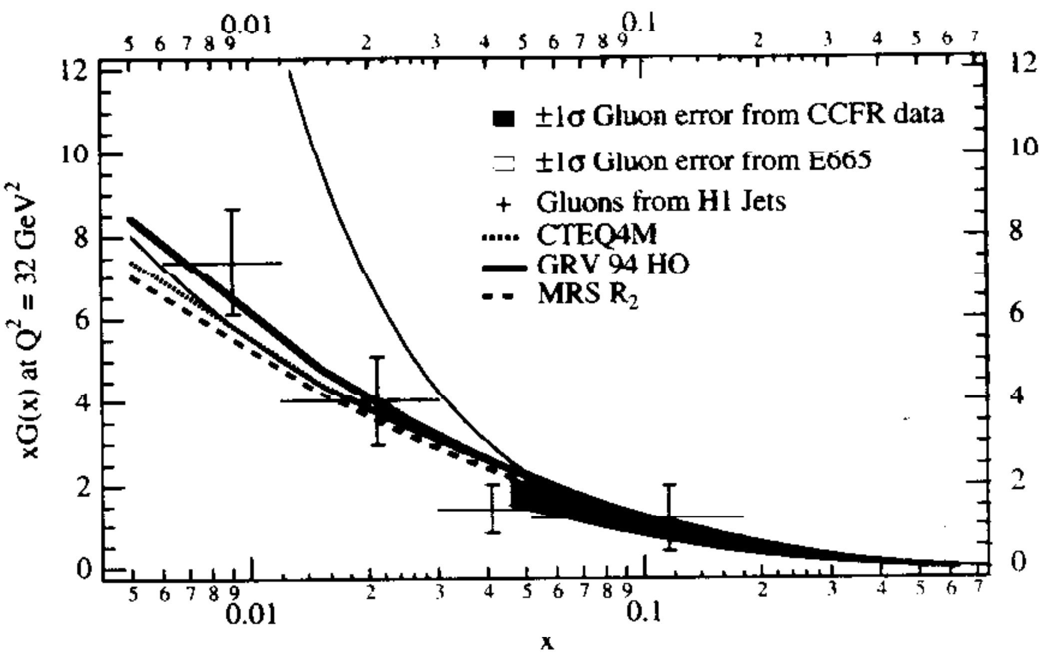
- Deviation at low-x, not Understood
- Small Deviation from SLAC/BCDMS at $x = 0.75$, probably Fermi motion




F2
x=.0075
NMC
CCFR
E665 (x=.005)
E665 (x=.007)
E665 (x=.009)
MRS R2
CTEQ 4M
GRV 94 HO
x=.0125
NMC
E665
CCFR
MRS R2
CTEQ 4M
GRV 94 HO
x=.0175
NMC
E665
CCFR
MRS R2
CTEQ 4M
GRV 94 HO
Q2 [GeV2/c2]

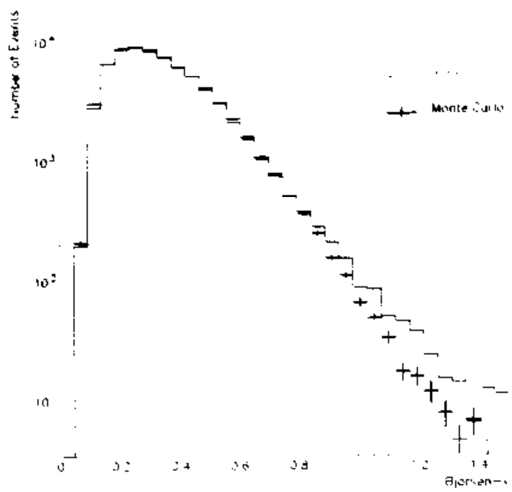

F2
x=.550
SLAC
BCDMS
BCDMS C
CCFR
MRS R2
CTEQ 4M
GRV 94 HO
x=.650
SLAC
BCDMS D
BCDMS C
CCFR
MRS R2
CTEQ 4M
GRV 94 HO
x=.750
SLAC
BCDMS D
BCDMS C
CCFR
MRS R2
CTEQ 4M
GRV 94 HO
x10^-3
Q^2 [GeV^2/c^2]

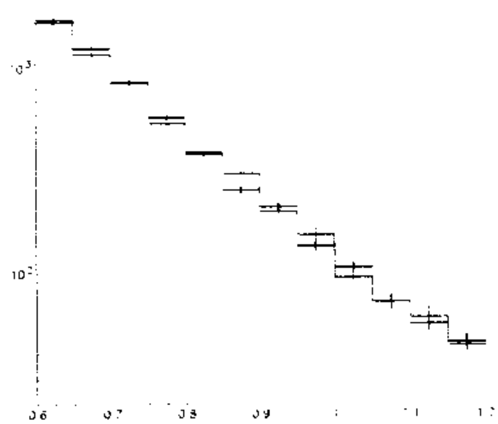
Gluon Distribution



- Cut so that $x > 0.045$ (best fit)
- Evolved or Extracted at $Q^2 = 32\ \mathrm{GeV}^2$
- E665 Evolved from $Q^2 = 8\ \mathrm{GeV}^2$

Collective Effects and $x > 1$





- Difference is Collective Effects from *Strikman and Frankfurt, Phys.Rep. 160, 25(1988), Nikiforov Phys.Rev. C22 700, (1980)*
- $s = 7.7 \pm 0.6$ CCFR Prelim (M. Vakili)
- SlacE133 s =7-8, BCDMS $S = 16.5 \pm 0.5$

"S" from different sources:

$$F_2(x, Q^2) = F_2^f(.75; Q^2) \times \exp[-S(x - .75)]$$

$S \approx 8-9$ FNCM Strikman & Frankfurt
Phys. Rep. 160 1988 325

$S \approx 7-8$ Al (e e') SlacE133
S. Rock

$S \approx 6$ Nikiforov
Phys. Rev. C22 1980 700

$S = 16.5 \pm .5$ BCDMS μC
Z. Phys. C63 29-36 1994

$S = 7.7 \pm 0.6$ CCFR preliminary

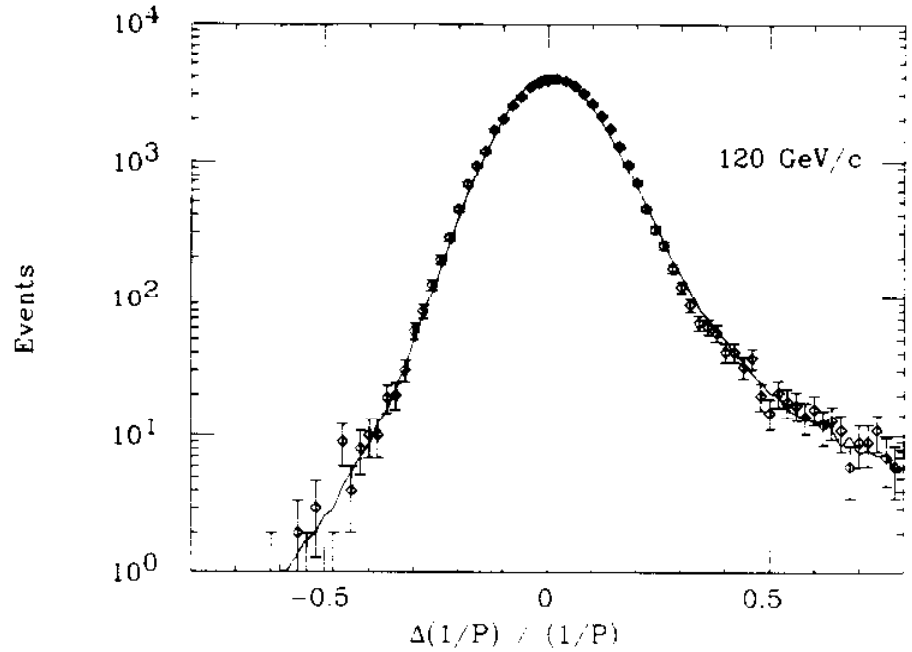
Conclusions

- New νN DIS Structure Function Determination
- Improved Systematic Errors on Muon Calibration $\Rightarrow$ Changed Results
- Charged-Lepton Discrepancy
- $x > 1$ Results

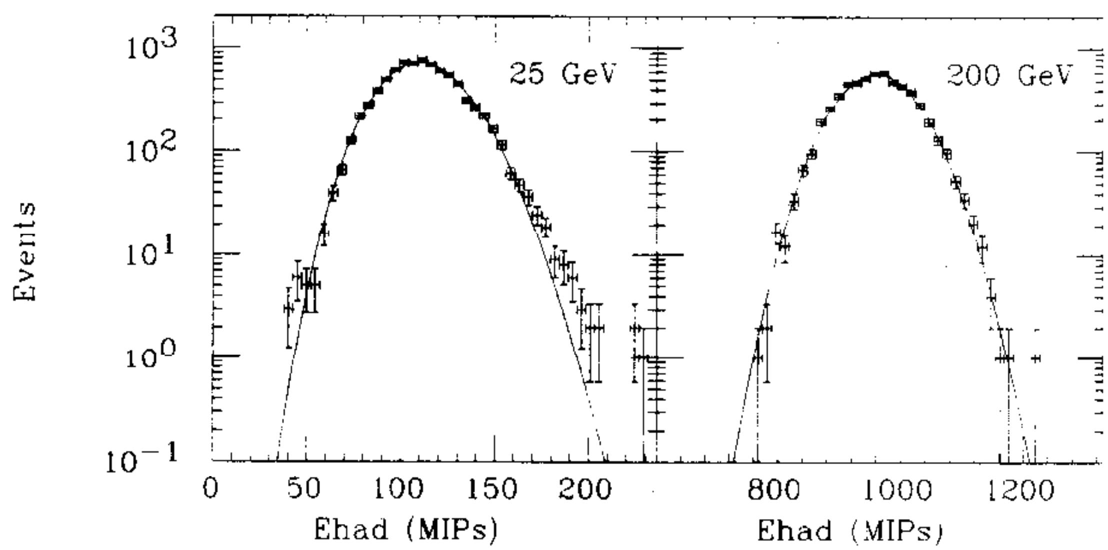
Future Prospects

- NuTeV in Data-Taking Now
- Same Statistical Power as This Data
- Improved Calibration $\times 3$ Reduction in Systematic Error from Muon Calibration
- Better $\alpha_S, \Lambda_{\overline{\rm MS}}$

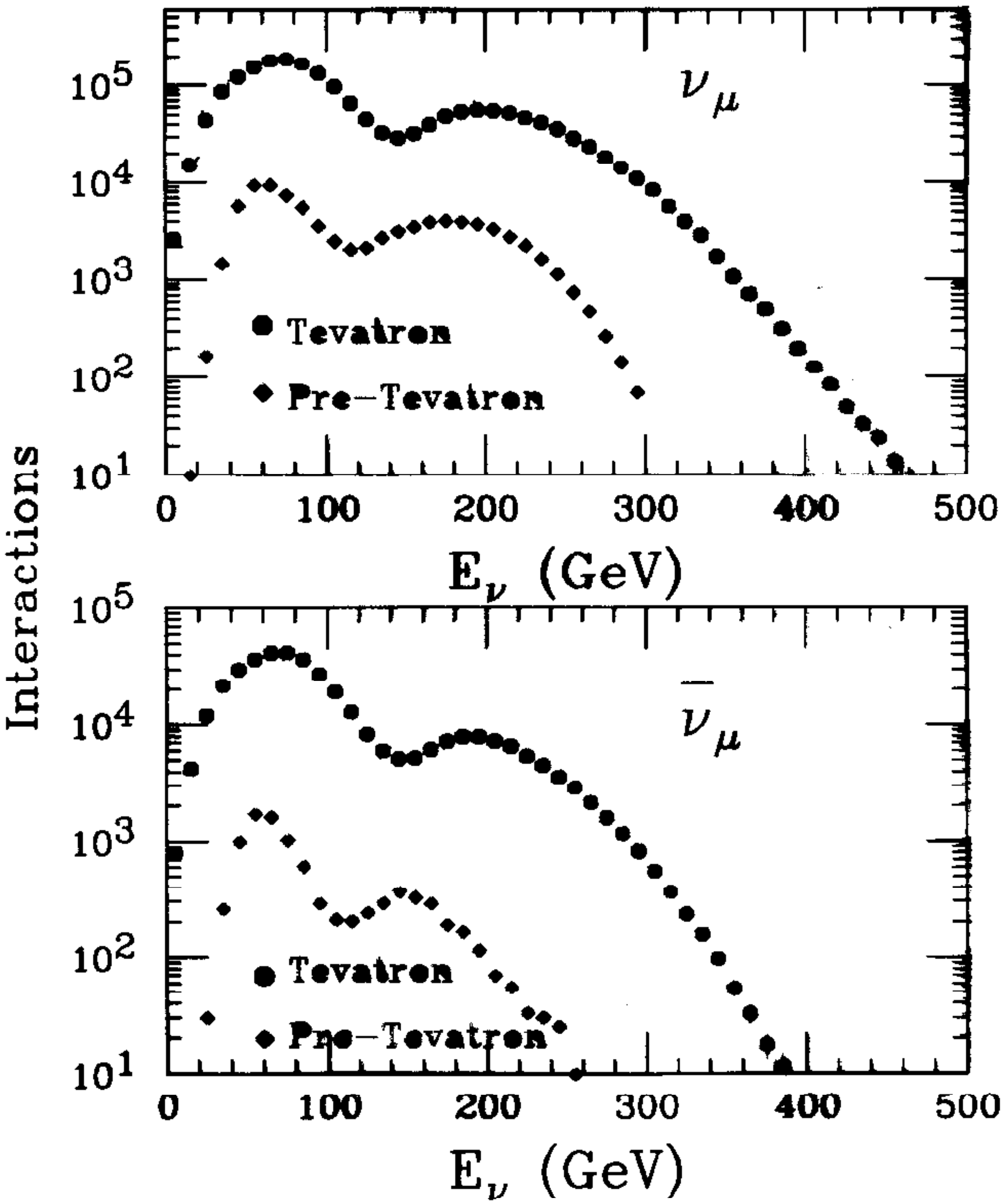
Muon Momentum Resolution



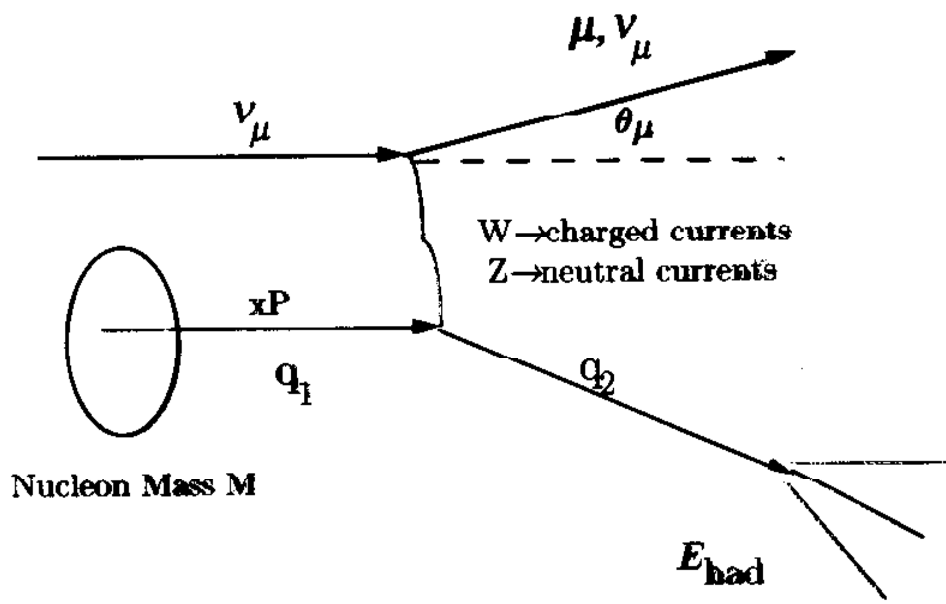
Hadron Energy Resolution



Neutrino Energy Spectrum: Tevatron vs. Pre-TeV



What Does A Neutrino Interaction Look Like to a Theorist?



Kinematic Variables:

$$
\begin{aligned}
y &= E_{\text{had}}/E_\nu \\
&= \text{inelasticity} \\
Q^2 &= 4E_\nu E_\mu \sin^2\frac{\theta}{2} \\
&= (4-\text{momentum transfer})^2 \\
x &= \frac{Q^2}{2ME_{\text{had}}} \\
&= \text{fractional momentum of struck quark}
\end{aligned}
$$