Structure Function Results from the CCFR Neutrino Experiment at the Fermilab Tevatron

1. ν Deep Inelastic Scattering Structure Functions
2. Experimental Procedure
3. CCFR Results
   - xF_3, F_2
   - Q^2 evolution
   - Extraction of $\alpha_s(M_Z^2)$

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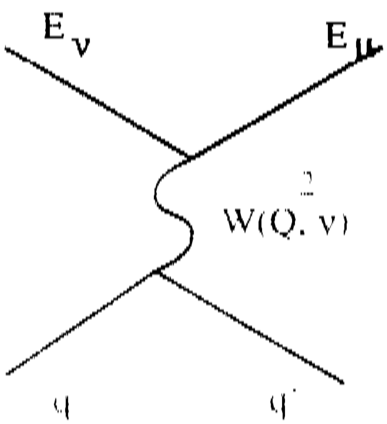
ν Deep Inelastic Scattering Structure Functions

$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dxdy} = \frac{G_F^2 ME}{\pi} \times$$
$$\left\{F_2(x, Q^2)\left[1 - y + \frac{y^2}{2(1+R)}\right] \pm xF_3(x, Q^2)\left[y - \frac{y}{}\right.\right.$$

And in leading order pQCD:

$$\begin{aligned} F_2^{\nu,\overline{\nu}} &= xq + x\overline{q} \\ xF_3^{\nu,\overline{\nu}} &= xq - x\overline{q} \pm 2(s - c) \end{aligned}$$



y= ν/ E_ν

Q = 4-momentum transfered

x = fractional momentum of struck quark

Advantages of ν DIS:

- Weak Q^2 dependence of the xsection, less sensitive to experimental resolution
- xF_3 purely non-singlet → determination of α_s independent of the gluon
- Completely inclusive, independent of hadronization and jet definition uncertainties

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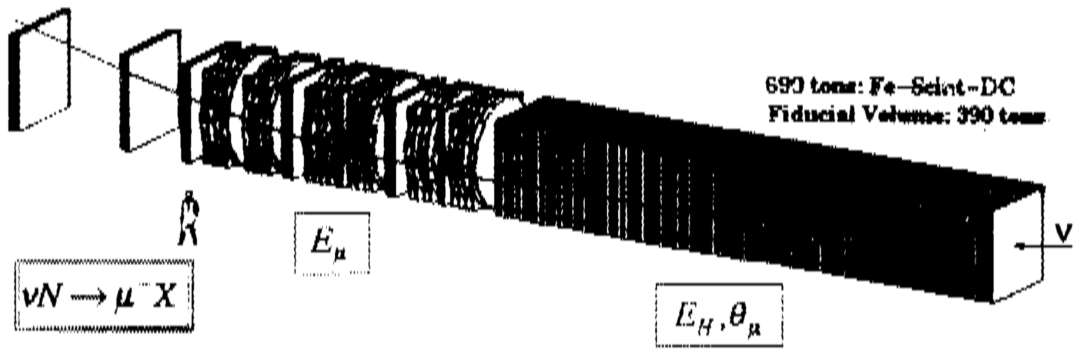
Measuring Structure Functions with ν's (CCFR)

LAB–E Detector – Fermilab E815 (NuTeV)



CCFR $\nu \& \overline{\nu}$ beam:

- Wide Band Beam, Simultaneous $\nu \& \nu$
- Energy Range: $30\,GeV$ to $500\,GeV$

CCFR Data Sample (Charged Current) :	ν	$\overline{\nu}$
Events	1.0×10^6	1.8×10^5

Target Calorimeter:

- 84 Scint. Counters (spacing 0.6λ Fe)
- 42 Drift Chambers (spacing 1.2λ Fe)
- $3\,m \times 3\,m \times 18\,m$
- $\frac{\Delta E_H}{E_H} = \frac{0.89}{\sqrt{E_H(GeV)}}$, $\Delta\theta \cong .3 + \frac{60\,mr}{E_\mu(GeV)}$

Toroid Spectrometer:

- $15\,kG$ Field ($P_T = 2.4\,GeV/c$)
- $\frac{\Delta p_\mu}{p_\mu} = 0.11$

Calibrated using test beam

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Experimental Procedure

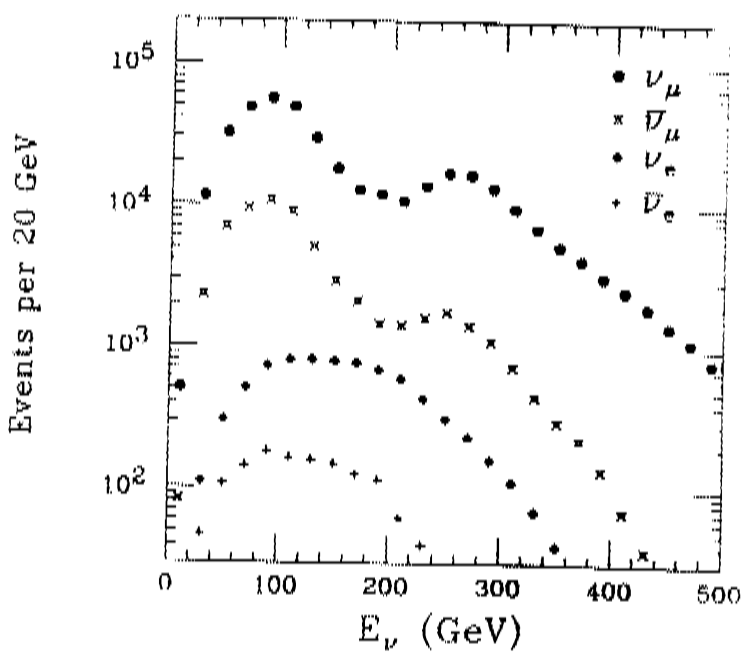
1. Measure relative flux ($\Phi(E_\nu)$), from low ν events ($\sigma^{\nu,\bar{\nu}}/E_\nu = C^{\nu,\bar{\nu}}$)
2. Normalize using world σ^ν and $\sigma^{\bar{\nu}}/\sigma^\nu \rightarrow$ Extract cross sections
3. Extract Structure Functions; Iterate $\rightarrow$ 1

{ SF Cuts: $p_\mu > 15GeV$, $\theta_\mu < .150$, $\nu > 10GeV$, $Q^2 > 1GeV^2$, $E_\nu > 30GeV$ }

MC corrections for:

- Acceptance, Resolution and Smearing
- Electroweak radiative corrections (Bardin)
- target non-isoscalarity
- charm production

R parameterization from L.W. Whitlow *et al.*, Phys.Lett.B282:1992 475



CCFR Neutrino Events

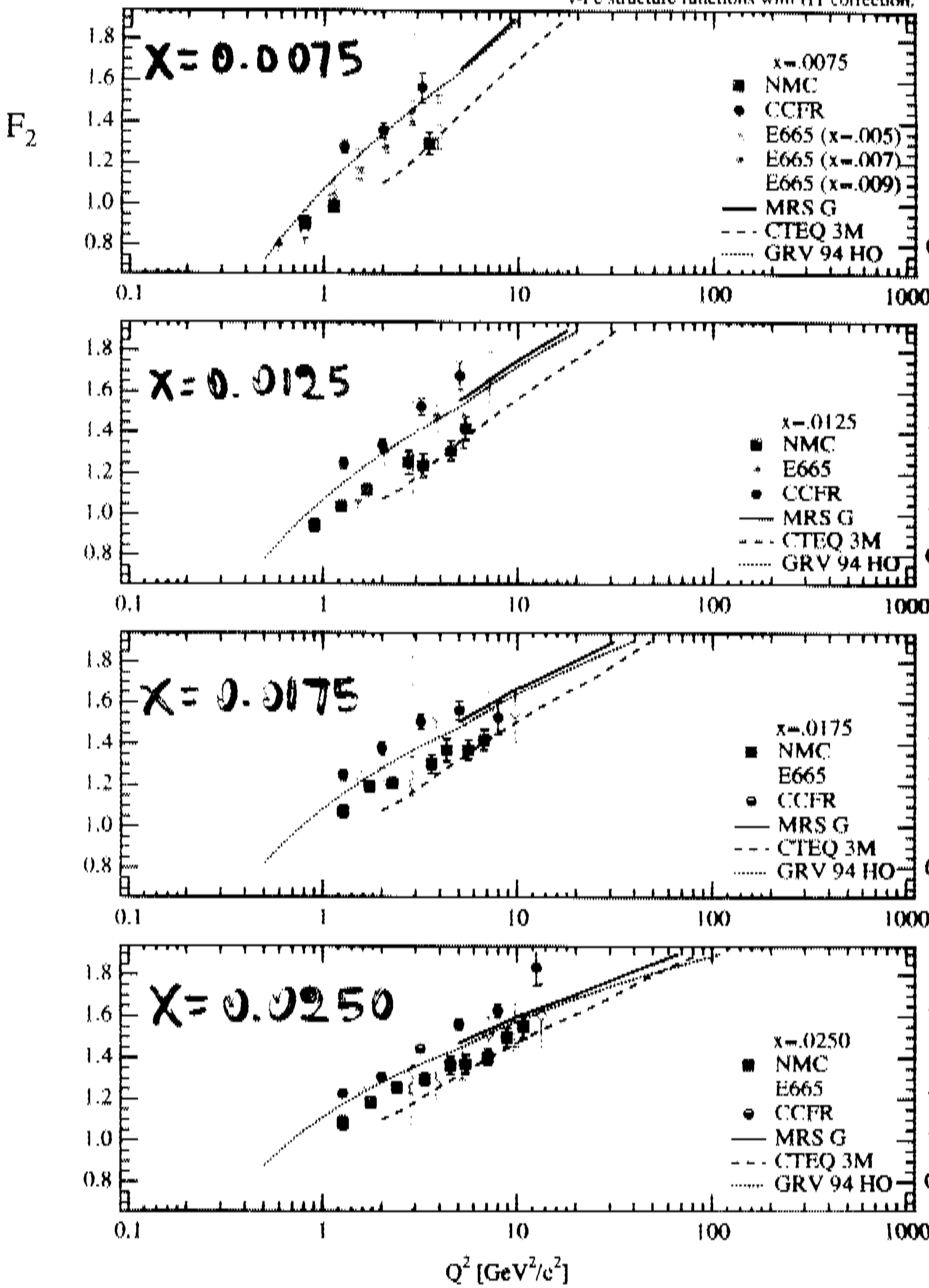
→ Measurement of $\sigma^{\bar{\nu}}/\sigma^\nu = 0.509 \pm 0.010$

The SF normalizations are: $\sigma^{\nu N}/E_\nu = 0.674 \pm 0.014$

$\sigma^{\bar{\nu}}/\sigma^\nu = 0.500 \pm 0.007$ (including CCFR)   AΦ5290, 5/14

All data have been corrected to ν-Fe and to the x-bin center. All fits have been computed for ν-Fe structure functions with HT correction.

Comparison to CCFR



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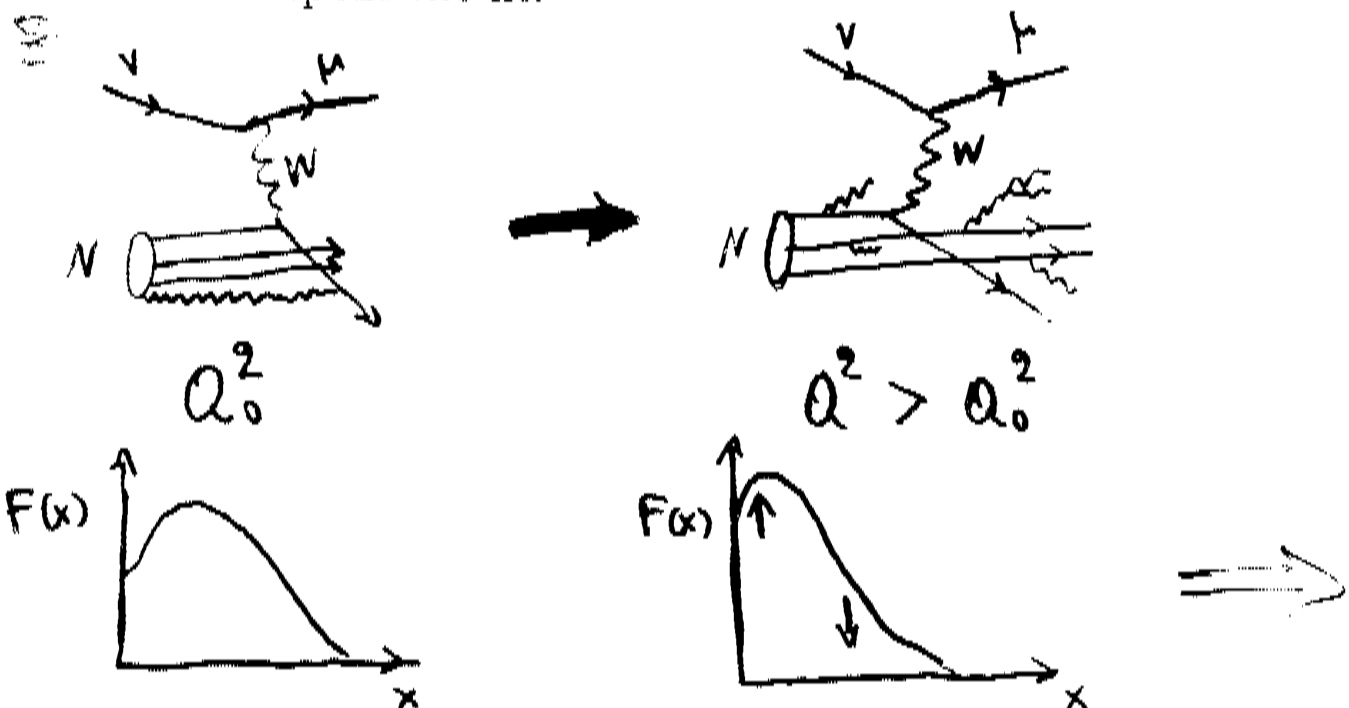
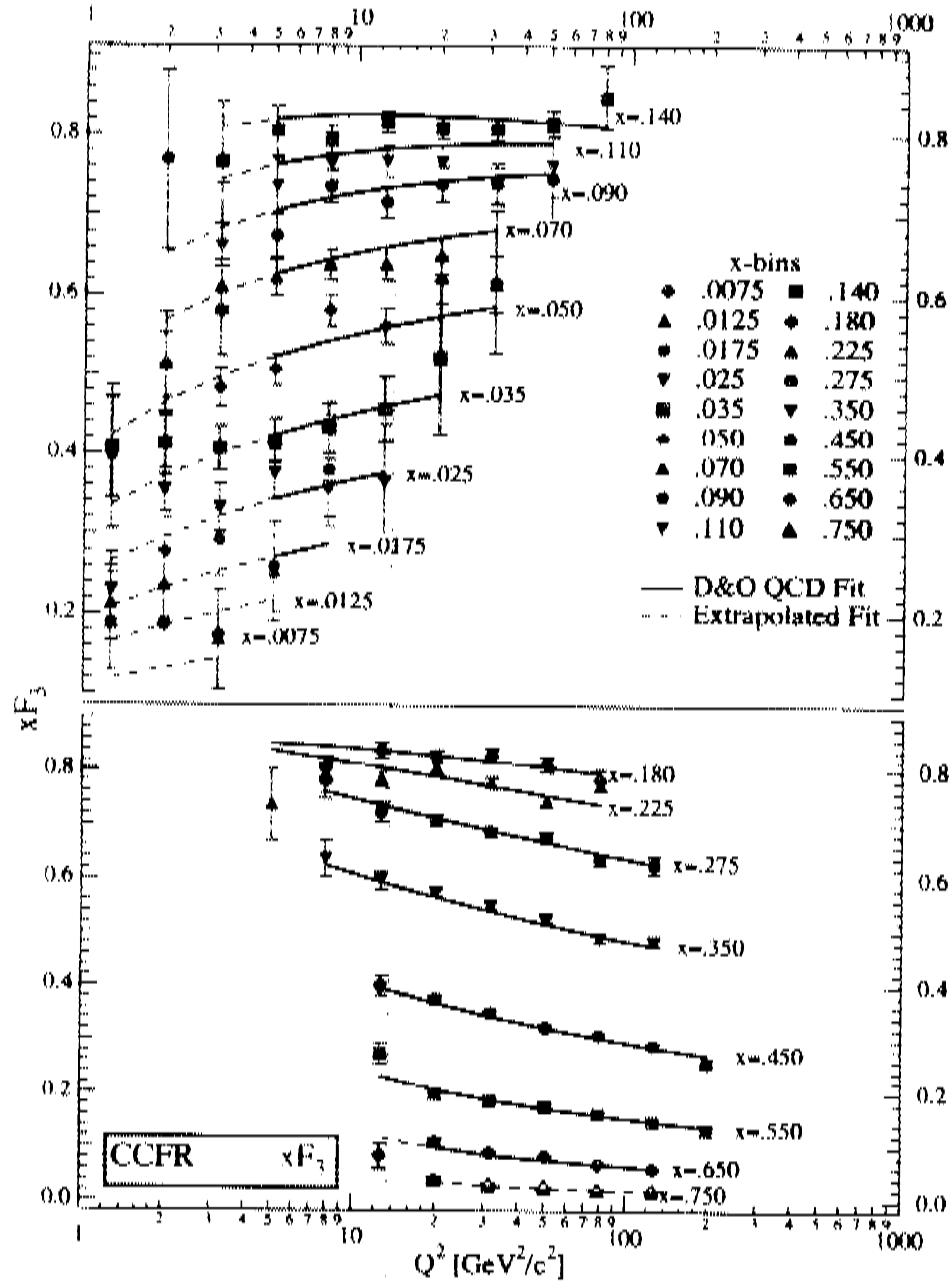
pQCD analysis

Q^2 evolution of SFs described by NLO DGLAP Equations (*)
Use modified NLO Duke & Owens program to fit for $\Lambda_{\overline{MS}}$.

- Fit data for $Q^2 > 5\,GeV^2$, $x < 0.7$, fiducial cuts
- Include target mass corrections (Georgi-Politzer)
- Include higher twist (twist-4) corrections from the SLAC+B(analysis
- To determine the systematic uncertainty in $\Lambda_{\overline{MS}}$, re-extract SFs by varying each systematic error by $1\sigma_{syst}$, and repeat the fit.



$$\Longrightarrow \alpha_s \sim \frac{d \ln F(x,Q^2)}{d \ln Q^2}$$



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
x=.140
x=.110
x=.090
x=.070
x=.050
x=.035
x=.025
x=.0175
x=.0125
x=.0075
x=.180
x=.225
x=.275
x=.350
x=.450
x=.550
x=.650
x=.750
CCFR xF_3
xF_3
Q^2 [GeV^2/c^2]

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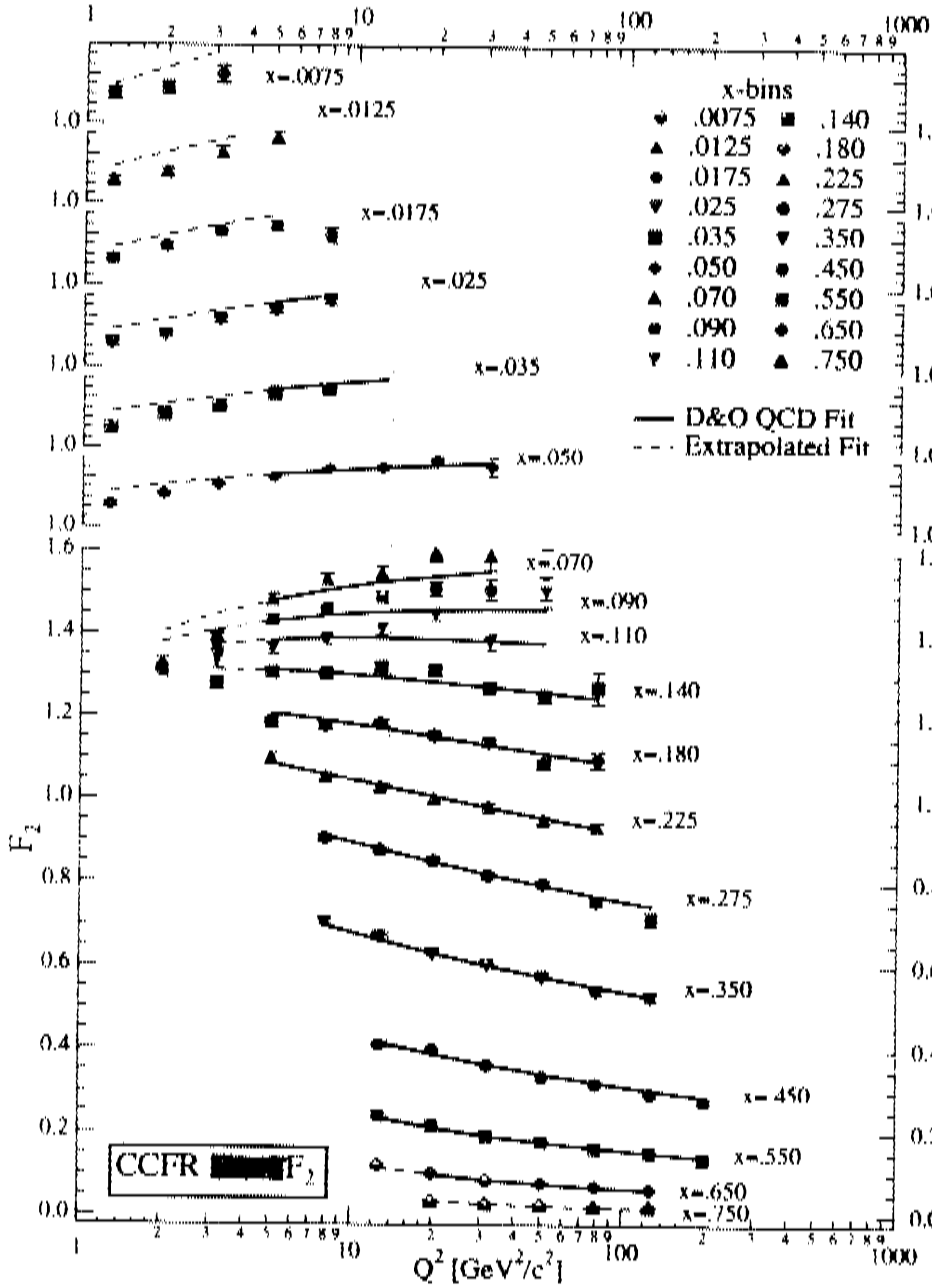
x=.0075
x=.0125
x=.0175
x=.025
x=.035
x=.050
x=.070
x=.090
x=.110
x=.140
x=.180
x=.225
x=.275
x=.350
x=.450
x=.550
x=.650
x=.750
x-bins
.0075 .140
.0125 .180
.0175 .225
.025 .275
.035 .350
.050 .450
.070 .550
.090 .650
.110 .750
D&O QCD Fit
Extrapolated Fit
F_2
Q^2 [GeV^2/c^2]
CCFR [redacted] F_2

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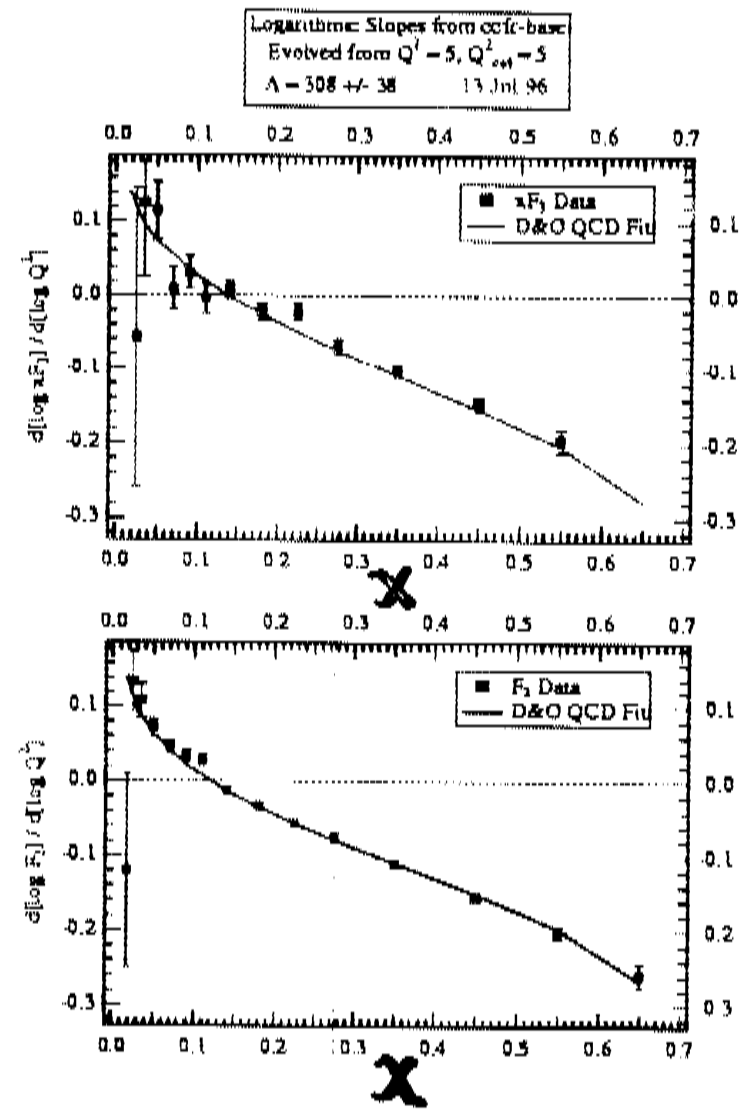

From xF_3 +

$\Lambda^4_{\overline{MS}} = 324 \pm$

$\pm$

α_s Results

xF_3 Only:

$$\alpha_s(M_Z^2) = 0.118 \pm 0.0025(\text{stat}) \pm 0.0055(\text{syst}) \pm 0.004(\text{scale})$$

$$\chi^2/DOF = 85/81$$

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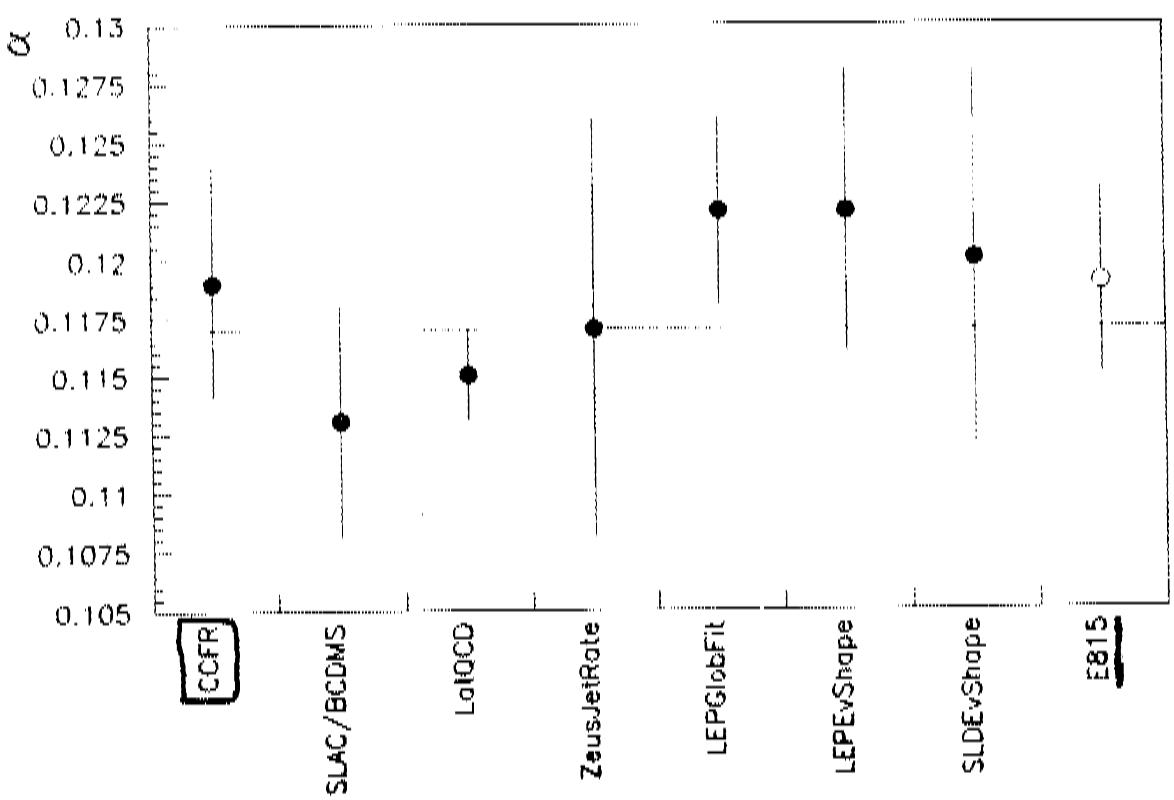
xF_3 and F_2:

$$\alpha_s(M_Z^2) = 0.119 \pm 0.0015(\text{stat}) \pm 0.0035(\text{syst}) \pm 0.004(\text{scale})$$

$$\chi^2/DOF = 200/169$$

Summary of α_s Measurements:

→ CCFR F_2, xF_3 evolution	0.119 ± 0.005	
SLAC/BCDMS F2 evolution	0.113 ± 0.005	PLB274:1992
GLS Sum Rule	??? $\pm .008$?	
Lattice QCD:	0.115 ± 0.002	Davies, 1994
Zeus Jet Rates	$0.117 \pm ^{+.009}_{-.008}$	PLB363(1995)
LEP Global EW Fit	0.122 ± 0.004	Busnietz, EPS95
LEP Event Shapes	0.122 ± 0.006	Bethke, CTEQ95
SLD Event Shapes	0.120 ± 0.008	PRD, V.51,1995
World Average:	0.117 ± 0.005	



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Uncertainty	xF_3 Only		xF_3&F_2	
($\delta(\Lambda_{\overline{MS}})$ in MeV)	$\Lambda_{\overline{MS}}^{(4)}$	$\alpha_s(M_Z^2)$	$\Lambda_{\overline{MS}}^{(4)}$	$\alpha_s(M_Z^2)$
Statistical Only	38	0.0025	20	0.0015
CCFR Experimental Uncertainties				
Energy Calibration	74	0.005	54	0.003
Flux Measurement	24	0.002	14	0.001
External Input Uncertainties				
σ^{ν},$\sigma^{\bar{\nu}}/\sigma^{\nu}$,$R$	18	0.001	1	< 0.001
Heavy Quark Effects	23	0.002	10	0.001
Total Systematic	83	0.0055	56	0.0035
QCD Theoretical Uncertainties				
Scale (Virchaux, Martin)		0.004		0.004
TOTAL	91	.007	60	.005

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Previous CCFR Result:

xF_3 and F_2:
$\alpha_s(M_Z^2) = .111 \pm 0.003(\text{exp}) \pm 0.004(\text{scale})$
$\chi^2/DOF = 61.6/56$, Ref: Quintas *et al* PRL71:1993

The improvements are:

1. Better understanding of the energy calibration (use of Test Beam data)
2. Better Modeling of muon energy loss in detector
3. Remove and correct for events with two muons
4. Other changes with smaller effects include:
   - Bardin Electroweak Radiative Corrections
   - More accurate Strange Sea from CCFR 2-muon data
   - Improved flux extraction technique

In the near future: (from CCFR)

- Combined Systematic Error Fit to improve $\Lambda_{\overline{MS}}$ errors significantly

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Conclusions

- F_2 and xF_3 measured with improved energy calibration.
- The discrepancy between F_2 from CCFR and NMC at low-x is still present ($\sim 20\%$ at $x \sim 0.1 - 0.2$). The agreement with the charged lepton DIS data is good above $x \sim 0.2$.
- The new SFs were used to extract α_s. The results are in good agreement with results obtained at higher energy scales:

Fit xF_3 Only:
$\alpha_s(M_Z^2) = 0.118 \pm 0.0025(\text{stat}) \pm 0.0055(\text{syst}) \pm 0.004(\text{scale})$

Fit xF_3 and F_2:
$\alpha_s(M_Z^2) = 0.119 \pm 0.0015(\text{stat}) \pm 0.0035(\text{syst}) \pm 0.004(\text{scale})$

The Future . . .

The FNAL E815 (NuTeV) is now taking data

The goal is to decrease the systematic errors in the extraction of α_s by a factor of 2, with:

- 2 (4) times the $\nu(\overline{\nu})$ CCFR Statistics
- Continuous Calibration Beam: Goal: 0.3% with π, μ, e's
- Sign Selected ν Beam -No $\nu(\overline{\nu})$ ambiguity

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