NuTeV Structure Function Results

NuFact June2003

R. Bernstein

Fermilab

- NuTeV Experiment
- Neutrino DIS
- Cross Section Measurement
- Structure Function Results, F_2, xF_3
- Conclusions and Future

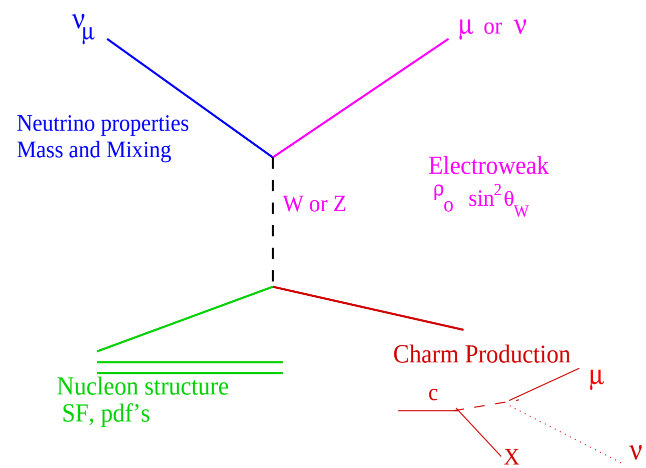
NuTeV Experiment

Neutrino DIS at Fermilab Tevatron

Data taking: 1996-1997

- multi-purpose ν experiment

WMA Sample	CC Sample
$1.3 \times 10^6 (\nu)$	$8.6 \times 10^5 (\nu)$
$0.3 \times 10^6 (\bar{\nu})$	$2.3 \times 10^5 (\bar{\nu})$



T. Adams[4], A. Alton[4], S. Avvakumov[8], L. de Barbaro[5], P. de Barbaro[8], R. H. Bernstein[3], A. Bodek[8], T. Bolton[4], S. Boyd[7], J. Brau[6], D. Buchholz[5], H. Budd[8], L. Bugel[3], J. Conrad[2], R. B. Drucker[6], B. T. Fleming[2], R. Frey[6], J.A. Formaggio[2], J. Goldman[4], M. Goncharov[4], D. A. Harris[8], R. A. Johnson[1], J. H. Kim[2], S. Koutsoliotas[2], M. J. Lamm[3], W. Marsh[3], D. Mason[6], J. McDonald[7], K. S. McFarland[8,3], C. McNulty[2], D. Naples[7], P. Nienaber[3], V. Radescu[7] A. Romosan[2], W. K. Sakumoto[8], H. Schellman[5], M. H. Shaevitz[2], P. Spentzouris[2], E. G. Stern[2], N. Suwonjandee[1], M. Tzanov[7], M. Vakili[1], A. Vaitaitis[2], U. K. Yang[8], J. Yu[3], G. P. Zeller[5], and E. D. Zimmerman[2]

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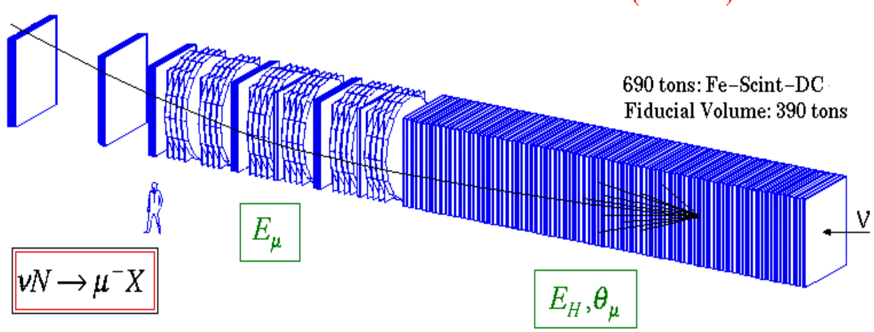
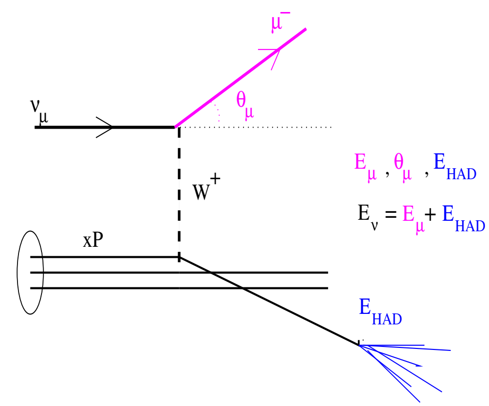
NuTeV Detector





Target Calorimeter

- Steel/Scintillator (10 cm), $\delta E/E \sim 0.86/\sqrt(E)$
- Tracking chambers (20 cm), Track μ and vertex determination.

Toroid Spectrometer

- Magnetized Iron, $B_\phi \sim 15$ kG, ($P_T = 2.4$ GeV/c)
- $\delta P/P \sim 11\%$, MCS dominated

$\Rightarrow$ Always focussing for primary muon

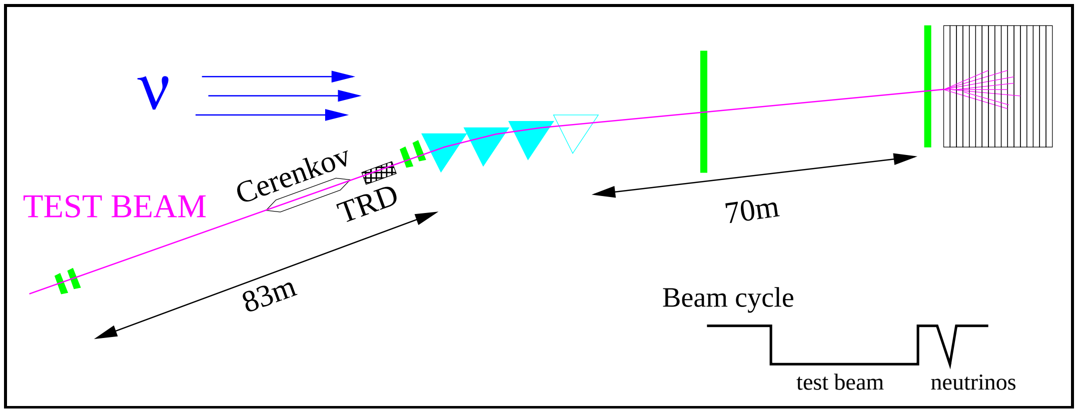
NuTeV Improvements

- *New Beam*:
  - Separate ν and anti-ν
  - Allows us to get charge of lepton from beam sign, increasing kinematic range
- *New Test Beam*
  - Taken throughout run, within beam cycle
  - Much Better Control of

    Absolute Momentum and Energy Scales

    - Limiting systematic in CCFR QCD studies

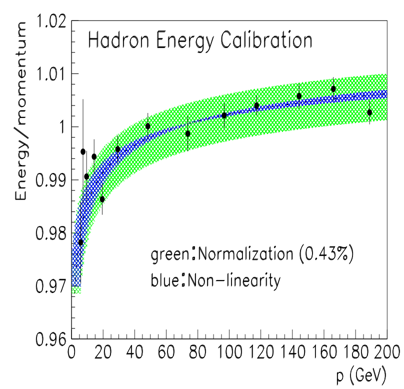
Continuous Calibration Beam

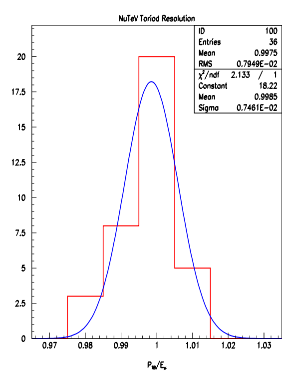


- Alternate every cycle with Neutrino beam.
- hadrons, muons, electrons (4.5–190GeV)
- Ability to map response.
- IMPROVED: Calibration of Energy Scale.

↪ Hadrons: $\frac{\Delta E_{\mathrm{HAD}}}{E_{\mathrm{HAD}}} = 0.43\%$

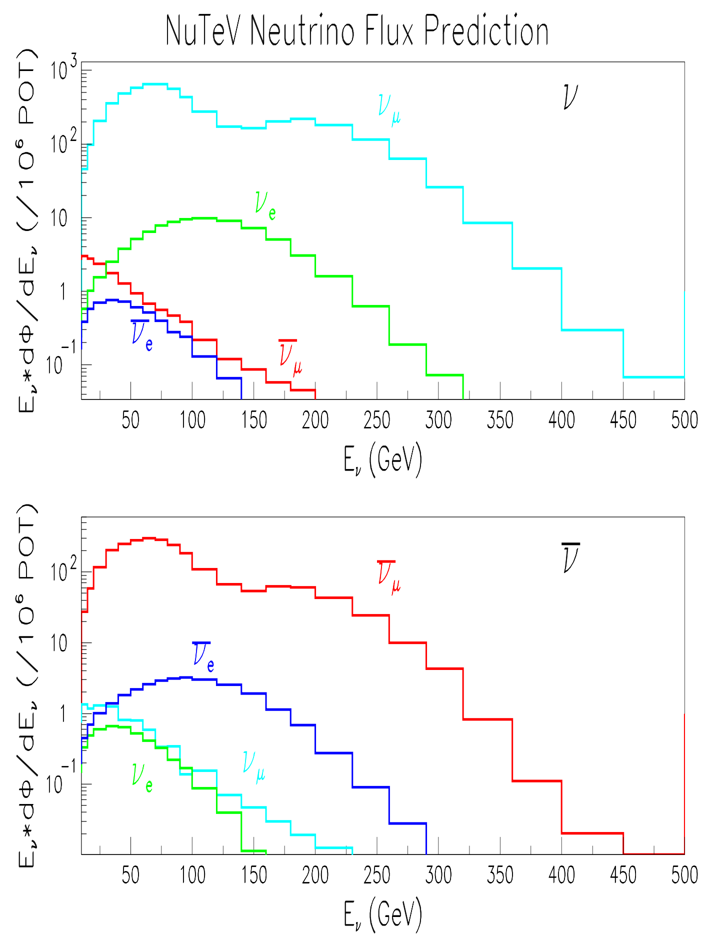
↪ Muons: $\frac{\Delta E_{\mu}}{E_{\mu}} = 0.7\%$

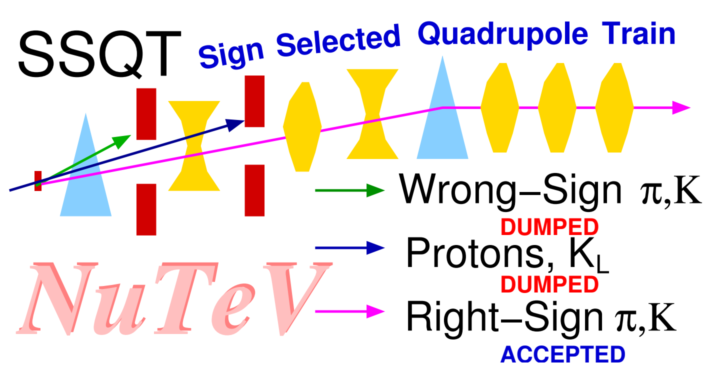




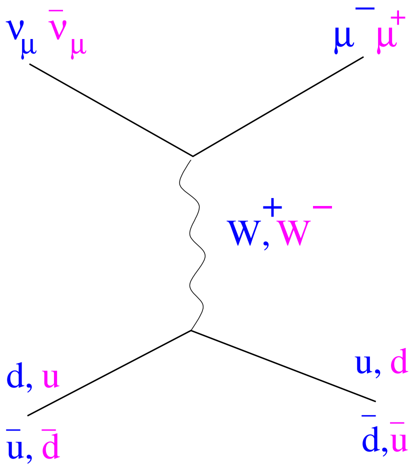
Neutrino Beam

- **Separate high-purity ν or $\bar{\nu}$ beams.**
  - $\hookrightarrow$ **ν mode 3×10^{-4} $\bar{\nu}$**
  - $\hookrightarrow$ **$\bar{\nu}$ mode 4×10^{-3} ν**
- **Lepton tag.**
  - $\hookrightarrow$ **Tags leading muon.**
  - $\hookrightarrow$ **High-y data sample.**





Neutrino Scattering



$Q^2 = 4E_\nu E_\mu \sin^2 \frac{\theta}{2}$,	Squared four momentum transfer
$x = \frac{Q^2}{2ME_{HAD}}$,	Fractional quark momentum
$y = \frac{E_{HAD}}{E_\nu}$,	Inelasticity

$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 ME_\nu}{\pi(1+Q^2/M_W^2)^2}\left[\left(1-y-\frac{Mxy}{2E}+\frac{y^2}{2}\frac{1+4M^2x^2/Q^2}{1+R(x,Q^2)}\right)F_2^{\nu(\bar{\nu})} \pm y\left(1-\frac{y}{2}\right)xF_3^{\nu(\bar{\nu})}\right]$$

Structure Functions in Neutrino Scattering

$$2xF_1^{\nu(\overline{\nu})} = \Sigma x(q+\overline{q}) = \sigma_T$$

$$F_2^{\nu(\overline{\nu})} = \Sigma x(q+\overline{q}+2k) = \sigma_T + \sigma_L \approx 2xF_1(1+R)$$

$$xF_3^{\nu(\overline{\nu})} = \Sigma x(q-\overline{q}) \pm 2x(s-c)$$

$\Rightarrow$ *Neutrino scattering*

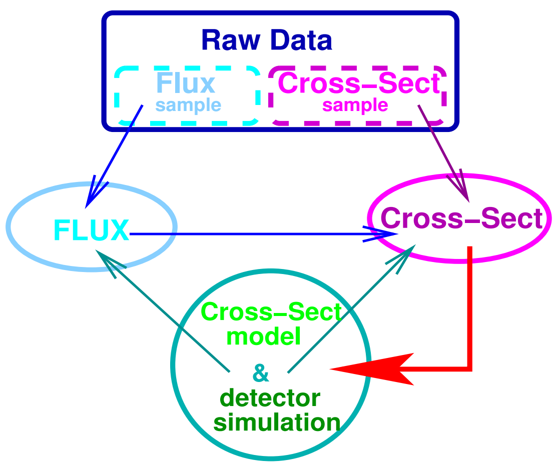
$$\Delta xF_3 = x(F_3^{\nu} - F_3^{\overline{\nu}}) = 4x(s-c)$$

$\Rightarrow$ *Sensitive to heavy flavor content*

NuTeV

Cross Section Extraction

$$\frac{d^2\sigma}{dxdy}^{\nu(\overline{\nu})} = \frac{1}{\Phi(E)} \frac{d^2N}{dxdy}^{\nu(\overline{\nu})}.$$



- Events are selected with a good muon track, containment, $E_\mu > 15$ GeV, $E_{HAD} > 10$ GeV, $E_\nu > 30$ GeV
- $Q^2 > 1$ GeV^2 required.
- Flux determined from an independent data sample at low ν ($E_{HAD} < 20$ GeV).
- Cross section and detector simulation: Used to model acceptance and detector smearing.
  - ↪ Cross section model: *parameterization fit to data.*
    - ⋆ Q^2 evolution from GRV for $Q^2 < 1.35$ GeV^2.
    - ⋆ $x > 0.45$ includes parameterization for Higher-twist from fits to SLAC, BCDMS data.
  - ↪ Detector simulation: *Measured from test beam.*
  - ↪ Process is iterated to convergence
    - ⋆ "Initial conditions" from CCFR.
    - ⋆ Converges after 2 loops. ($< 2\%$ change after 2-iterations.)

Flux for Dummies

- Don't Directly Measure Flux of Neutrinos
- Very Hard to Extract from Mesons (just ask MINOS)
- Get *Relative* *Flux from a "Trick:"*

$$\frac{d\sigma}{dy}(\nu) \quad \propto \quad q(x) + (1-y)^2\bar{q}(x)$$

$$\frac{d\sigma}{dy}(\bar{\nu}) \quad \propto \quad \bar{q}(x) + (1-y)^2 q(x)$$

and as $y \rightarrow 0$

$$\frac{d\sigma}{dy}(\nu) \quad \propto \quad q(x) + (1-0)^2 \bar{q}(x)$$

$$\frac{d\sigma}{dy}(\bar{\nu}) \quad \propto \quad \bar{q}(x) + (1-0)^2 q(x)$$

so

$$\frac{d\sigma}{dy}(\nu) \quad \propto \quad \Phi_{\nu}(E)(q+\bar{q})(x)$$

$$\frac{d\sigma}{dy}(\bar{\nu}) \quad \propto \quad \Phi_{\bar{\nu}}(E)(q+\bar{q})(x)$$

- *And as* $y \to 0$ *all the neutrino energy goes into the muon, so easily identified, well-measured track!*

- *Extract ratio of fluxes:*

$$\frac{\frac{d\sigma}{dy}(\nu)}{\frac{d\sigma}{dy}(\bar{\nu})} = \frac{\Phi_{\nu}(E)}{\Phi_{\bar{\nu}}(E)}$$

- *Absolute scale (level of cross-section) from separate experiment*

the rest is making this work in practice. . .

Relative Flux Extraction

"Fixed ν_o method": Integrate data at low ν

Write $\frac{dN}{d\nu} = \Phi(E)\frac{d\sigma}{d\nu}$ in terms of $y (= \frac{\nu}{E_\nu})$

$$\frac{dN}{d\nu} = \Phi(E) A \left(1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{A}\frac{\nu^2}{2E^2}\right)$$

$$A = \frac{GM}{\pi}\int F_2(x)dx$$
$$B = -\frac{GM}{\pi}\int (F_2(x) \mp xF_3(x))\,dx$$
$$C = B - \frac{GM}{\pi}\int F_2(x)\left(\frac{1+\frac{2Mx}{\nu}}{1+R(x)} - \frac{Mx}{\nu} - 1\right)dx$$

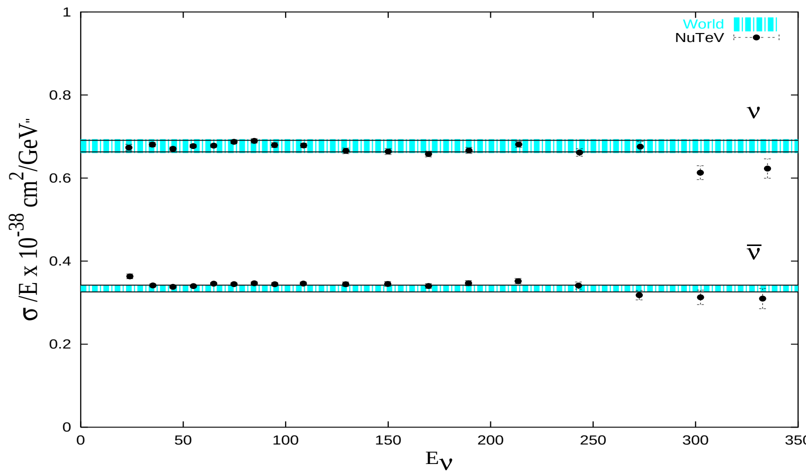
$\Rightarrow$ At low ν ($\nu < \nu_o$) and high $E_\nu \to (\frac{\nu}{E})$, and $(\frac{\nu}{E})^2$ terms are small.

- Fit to $\frac{dN}{d\nu}$ determines $\frac{B}{A}$ $(\frac{C}{A})$.
- Integrate up to a fixed $\nu = \nu_o$ and apply correction up to order $(\frac{\nu}{E})^2$.

$$\Phi(E) = \int_0^{\nu_0}\left(\frac{\frac{dN(E)}{d\nu}}{1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{A}\frac{\nu^2}{2E^2}}\right)d\nu$$

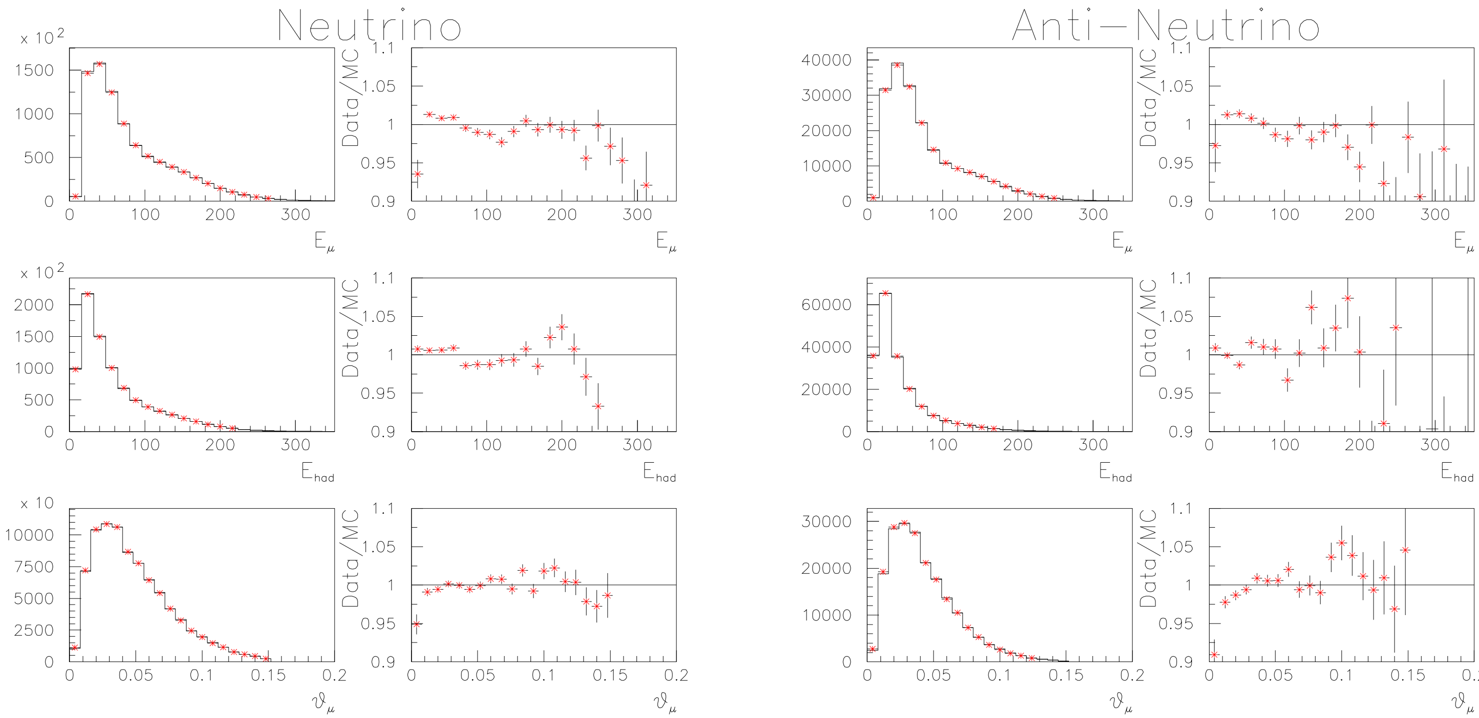
- Normalize total neutrino cross section 30-200 GeV to World average.

$$\frac{\sigma^\nu}{E} = 0.677 \pm 0.014 \;\times 10^{-38}\frac{cm^2}{GeV}$$



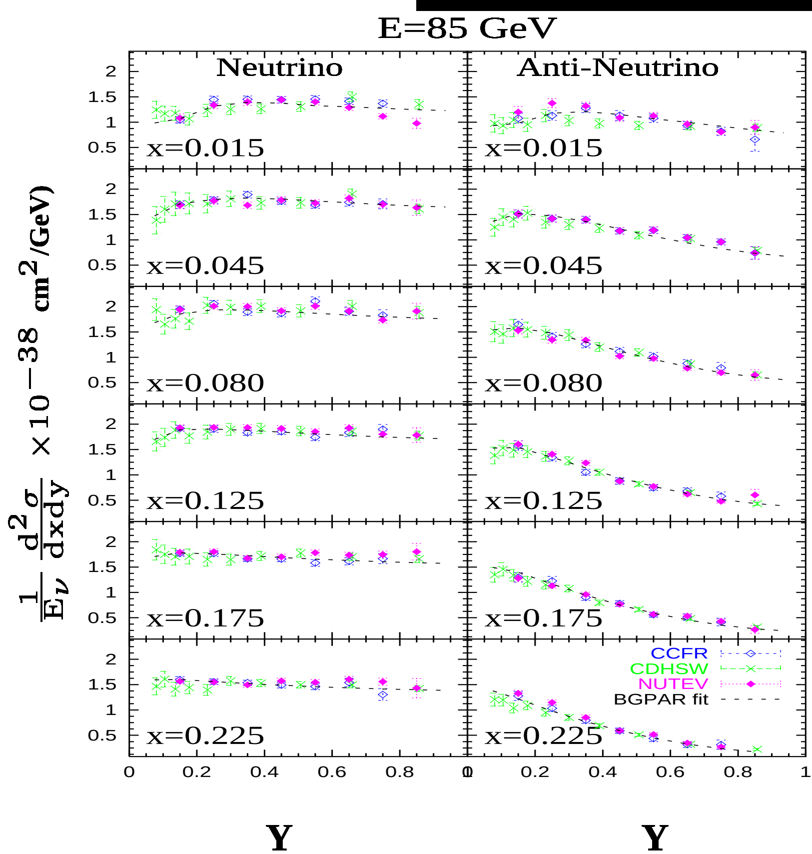
- Test of Flux Extraction.
  - ↪ Energy dependence of $\frac{\sigma}{E}$.
    - ⋆ NuTeV $\frac{\sigma}{E}$ Flat within $< \pm 2\%$
  - ↪ Relative $\overline{\nu}$ cross section $r = \frac{\sigma^{\overline{\nu}}}{\sigma^\nu}$
    - ⋆ Agrees with world average.

How Well is the Data Modeled?



- Monte Carlo Describes the data well over entire kinematic range.
  - ↪ E_μ and E_{HAD} Smearing parameterized from Test beam measurements.
  - ↪ θ_μ from Geant Detector simulation.

Preliminary NuTeV Cross Section



NuTeV Preliminary result.
CDHSW (Z. Phys C49 187, 1991.)
CCFR (U. K. Yang PhD. Thesis)

- Better control of largest systematics.
  $\hookrightarrow$ E_μ and E_{HAD} energy scales.

	E_μ Scale	E_{HAD} Scale	E_ν Range
CDHSW	2%	2.5%	20-200 GeV
CCFR	1%	1%	30-350 GeV
NuTeV	0.7%	0.43%	30-350 GeV

NuTeV

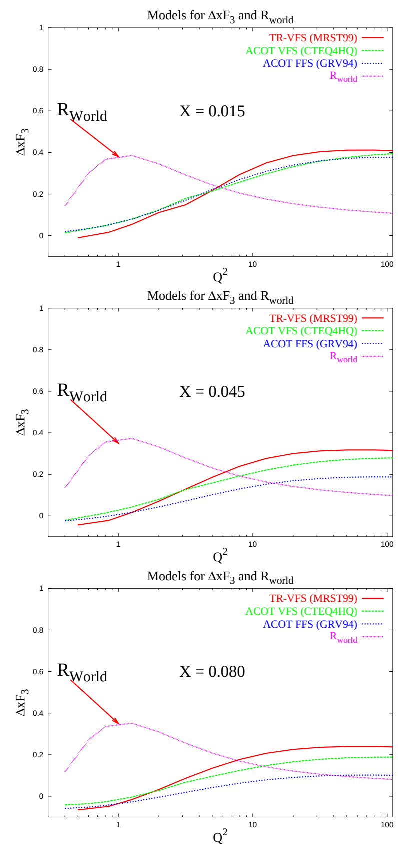
F_2 Measurement

$$\left[\frac{d^2\sigma^{\nu}}{dx\,dy} + \frac{d^2\sigma^{\overline{\nu}}}{dx\,dy}\right] = \frac{2MG^2E}{\pi}\left[1-y-\frac{Mxy}{2E}+\frac{1+(\frac{2Mx}{Q})^2}{1+R(x,Q^2)}(\frac{y^2}{2})\right] F_2(x,Q^2) + \left[y-\frac{y^2}{2}\right]\Delta xF_3(x,Q^2)$$

- $F_2(x,Q^2)$ from 1-parameter fits to cross section sum.
- Input $R_{\mathrm{world}}(x,Q^2)$ (Phys. Lett. **B250**, 193 (1990).)
- Input $\Delta xF_3(x,Q^2) = xF_3^{\nu} - xF_3^{\overline{\nu}}$
  - ↪ Small for $x > 0.1$
  - ↪ Model calculations agree.

    Thorne and Roberts, Phys Lett **B421**, 303 (1998).

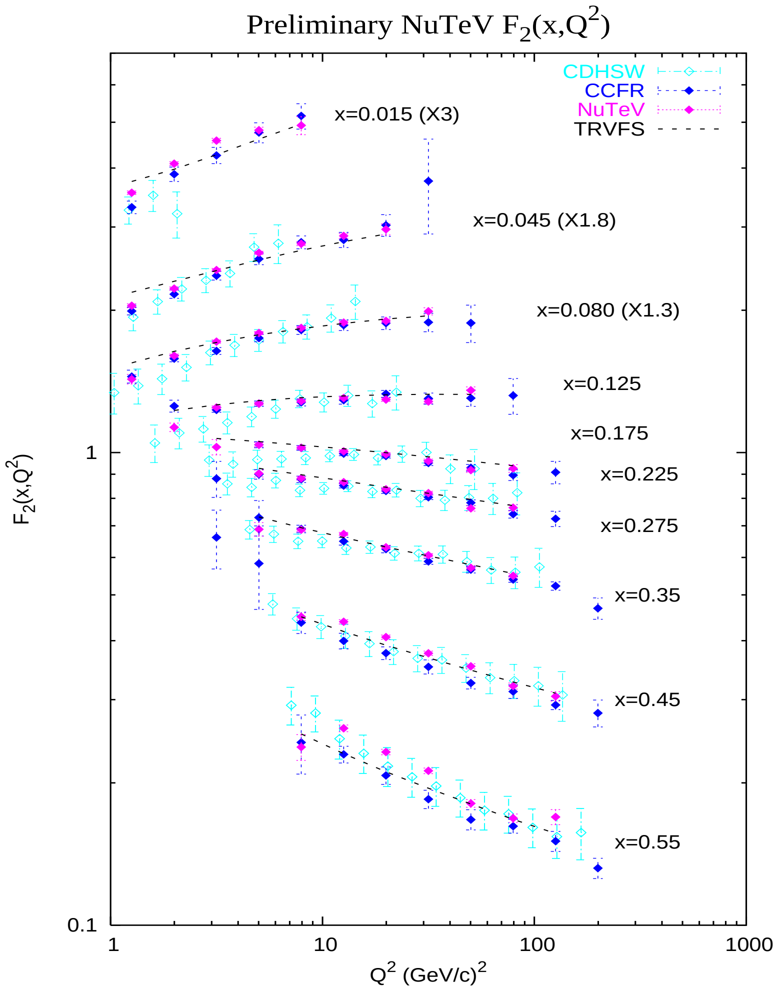
    ACOT Phys Rev **D50**, 3102 (1994).



- Corrected to Isoscalar target.
  - ↪ Iron $\frac{N-Z}{A} = 0.0567$
- Radiative corrections applied before F_2 fits performed.

  Bardin, D. Y. and Dokuchaeva, JINR-E2-86-260 (1986).

NuTeV Preliminary $F_2(x, Q^2)$



- NuTeV Preliminary Result
- Agreement with Previous ν-Fe (CDHSW, CCFR).
- Agreement with NLO QCD curve, $x < 0.55$. (TR-VFS with MRST99).

  Thorne and Roberts, Phys Lett **B421**, 303 (1998).

Cross Section Systematics

Systematic	Value
E_μ scale	0.7%
E_{HAD} scale	$\pm$0.43%
Flux normalization: World ν cross section	$\pm$ 2.1%
ν Flux B/A correction	-0.45 ± 0.035
$\overline{\nu}$ Flux B/A correction	-1.73 ± 0.027
Model Systematic (13-parameter fit)	$\pm\ 1\sigma$
Higher-Twist (3-parameter fit)	$\pm\ 1\sigma$
Slow Rescaling Parameters m_c, κ, α	$\pm\ 1\sigma$

Note: Systematics will in general be point to point correlated,
A correlation matrix for the largest systematic will be determined.

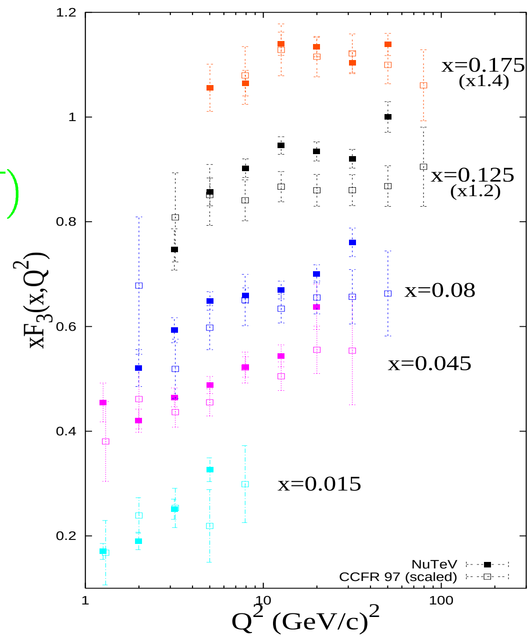
F_2 Systematics

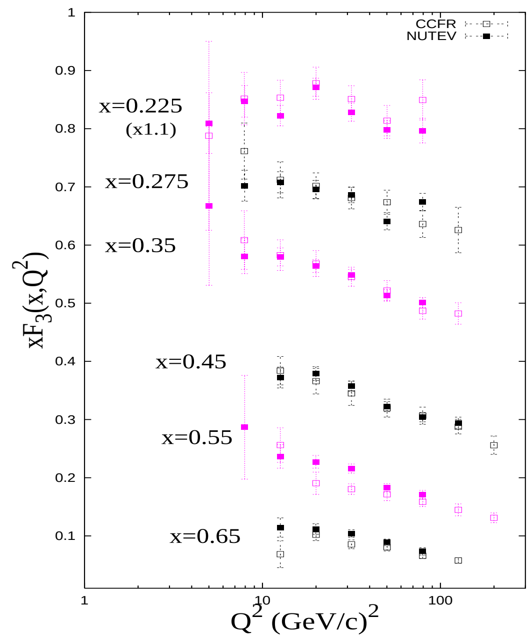
Systematic	Value
E_μ scale	0.7%
E_{HAD} scale	$\pm$0.43%
Flux normalization: World ν cross section	$\pm$ 2.1%
ν Flux B/A correction	-0.45 ± 0.035
$\overline{\nu}$ Flux B/A correction	-1.73 ± 0.027
Model Systematic (13-parameter fit)	$\pm$ 1σ
Higher-Twist (3-parameter fit)	$\pm$ 1σ
Slow Rescaling Parameters m_c, κ, α	$\pm$ 1σ
ΔxF_3 Alternative Models	
$R(x, Q^2)$ Model	$\pm 15\%$

NuTeV Preliminary xF_3

$$\left[\frac{d^2\sigma^{\nu}}{dx\,dy} - \frac{d^2\sigma^{\overline{\nu}}}{dx\,dy}\right] = \frac{2MEG^2}{\pi}\left(y - \frac{y^2}{2}\right) xF_3^{AVG}(x,Q^2)$$

- $xF_3^{AVG}(x,Q^2) = \frac{1}{2}(xF_3^{\nu} + xF_3^{\overline{\nu}})$ from 1-parameter fit.
- Small $\Delta F_2(x,Q^2) = \left(F_2^{\nu} - F_2^{\overline{\nu}}\right)$ term neglected.
- Preliminary NuTeV $xF_3(x,Q^2)$
  - $\hookrightarrow$ Systematics included: E_μ, E_{HAD} scales
- Good agreement with CCFR.
  CCFR, PRL 79, 1213 (1997).
  (CCFR low-x bins rescaled).





Simultaneous Fit $F_2(x, Q^2)$ and $R(x, Q^2)$

- **"Physics Model Independent method"** **CCFR: Yang, *et al.*, PRL 87 251802 (2001), PRL 86, 2742, (2001).**

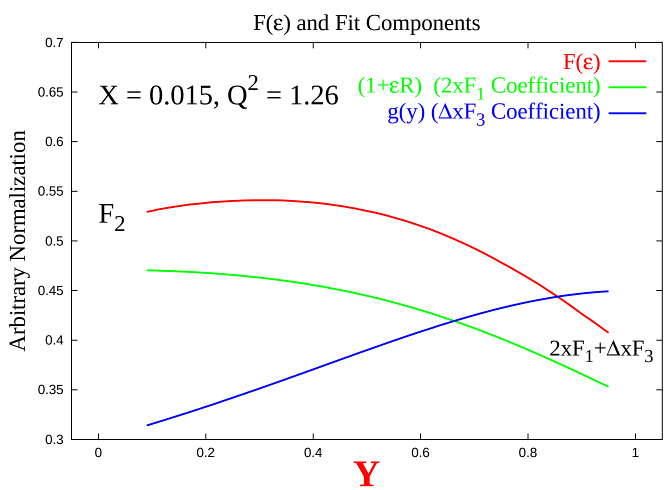
$$\left(\frac{d^2\sigma^{\nu}}{dxdy} + \frac{d^2\sigma^{\overline{\nu}}}{dxdy}\right) = \mathbf{F}(\epsilon) = \frac{\mathbf{y^2 G^2 ME}}{\pi(\mathbf{1}-\epsilon)}\left(\mathbf{2xF_1}(\mathbf{1}+\epsilon\mathbf{R}) + \mathbf{g(y)}\Delta\mathbf{xF_3}\right)$$

$$\epsilon = \frac{2(1-y) - M_p x y/E}{1+(1-y)^2 + M_p x y/E}; \quad g(y) = \frac{y(1-y/2)}{1+(1-y)^2}$$

[polarization of the virtual W boson]

$\hookrightarrow$ **Extract F_2 and R from two-parameter fits to y dependence.**

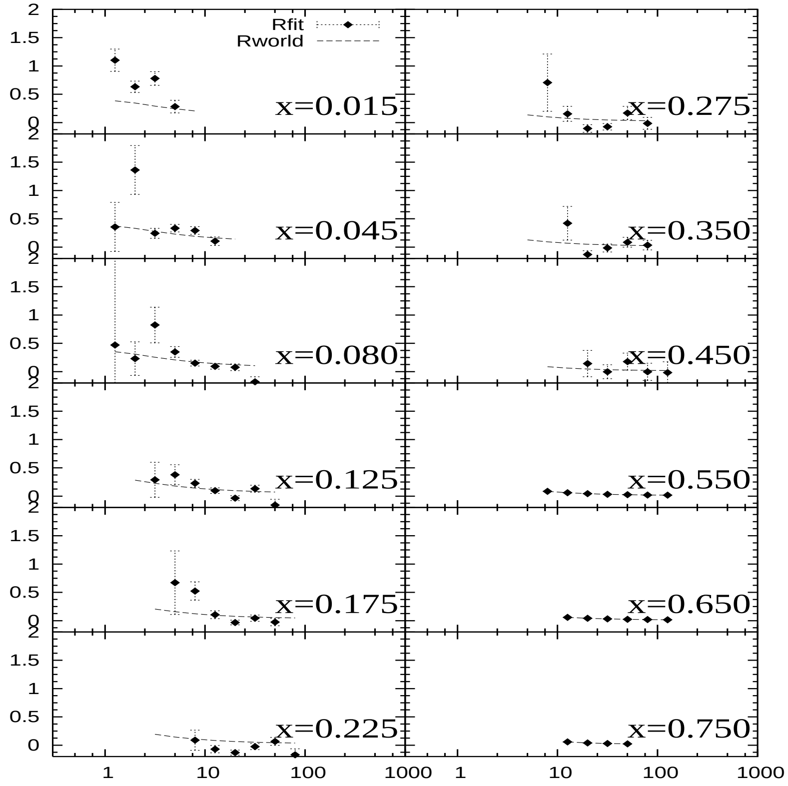
$\star$ **ΔxF_3 and R strongly correlated $\rightarrow$ input QCD model for ΔxF_3**



- **when $y \rightarrow 0$ then $\epsilon \rightarrow 1$:**
  - $\star$ **Sensitive to F_2** **[ΔxF_3 term vanishes]**
- **when $y \rightarrow 1$ then $\epsilon \rightarrow M_p/E_\nu \approx 0$:**
  - $\star$ **Sensitive to $2xF_1$, ΔxF_3** **[R term vanishes]**
- **Measure $F(\epsilon)$ over wide range in ϵ (y)**
  - $\star$ **Sensitive to R**

- **NuTeV improves sensitivity to R by extending the y range**

Preliminary $R(x, Q^2)$ Fits



- **Statistical Errors only.**
- **Does not use “High-y” data sample.**

NuTeV High-y Data

⋆ Sign Selected beam allows pure ν, $\bar{\nu}$ samples

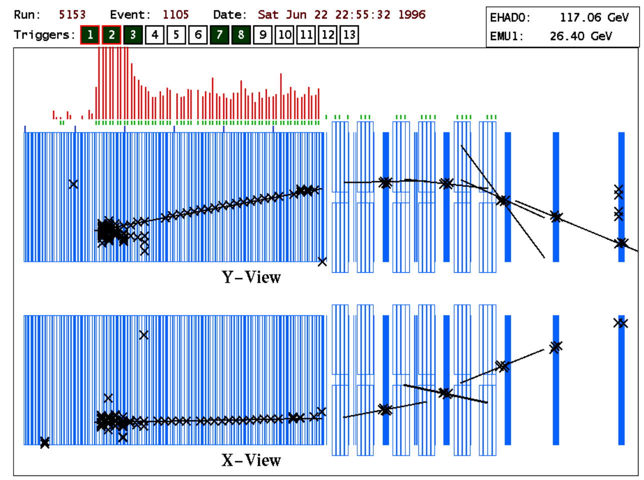
⋆ Use low E_μ data: High $y = \frac{E_{\rm HAD}}{E_\mu + E_{\rm HAD}}$

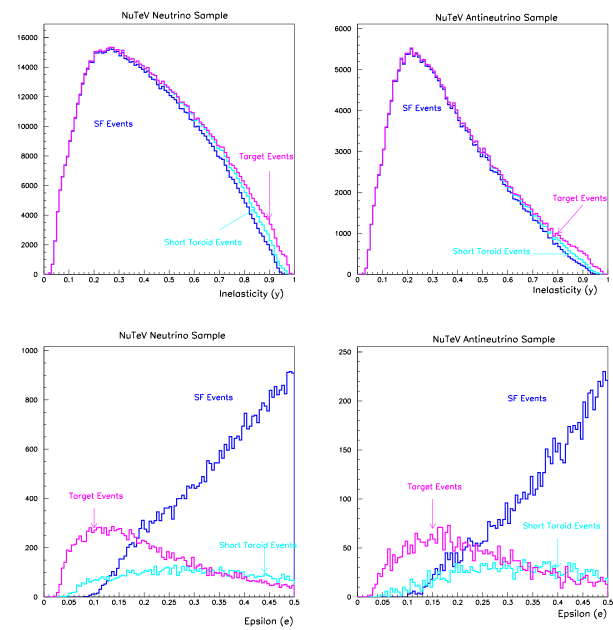
- New data samples:
  - ⋆ Target μ: stopped in the target
  - ⋆ Short Toroid μ: stopped after 1 gap

The reach in ϵ variable for the new samples:

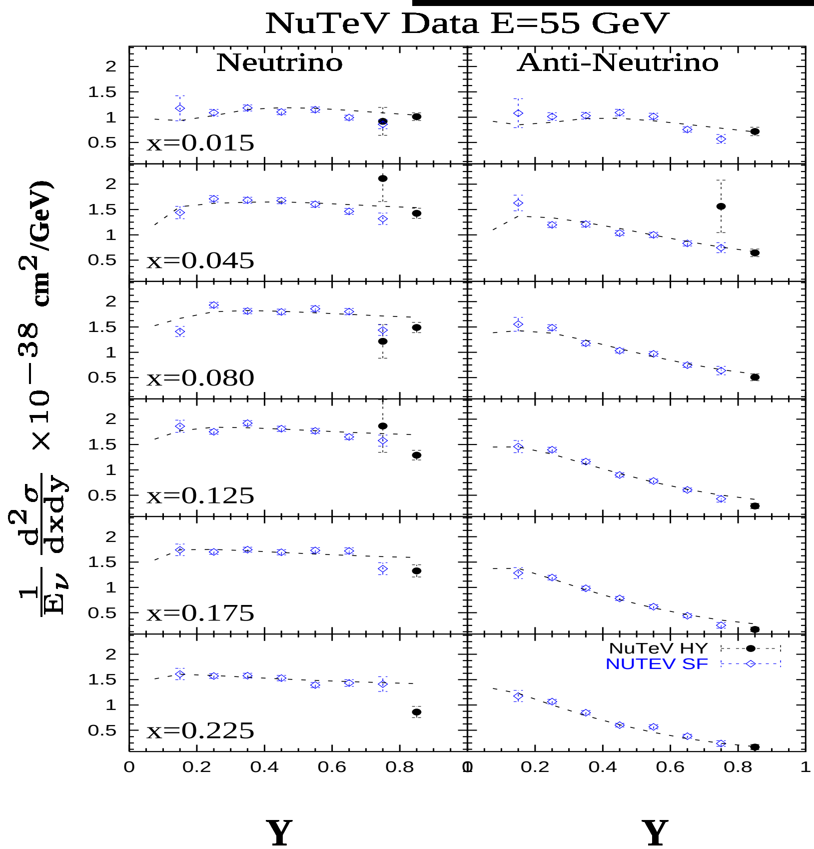
$$\epsilon \approx \frac{2(1-y)}{1+(1-y)^2} \xrightarrow{y \to 1} 0$$

- Data to very low $\epsilon \approx 0.03$
- 10% more data below $\epsilon = 0.5$
- Lever arm in ϵ will better constrain R and $2xF_1$ in 2-parameter fits. As $\epsilon \to 0$, $F(\epsilon) \to 2xF_1$.





Preliminary High-Y Cross Section



- New points from target μ data.
- Statistical errors only, No iteration

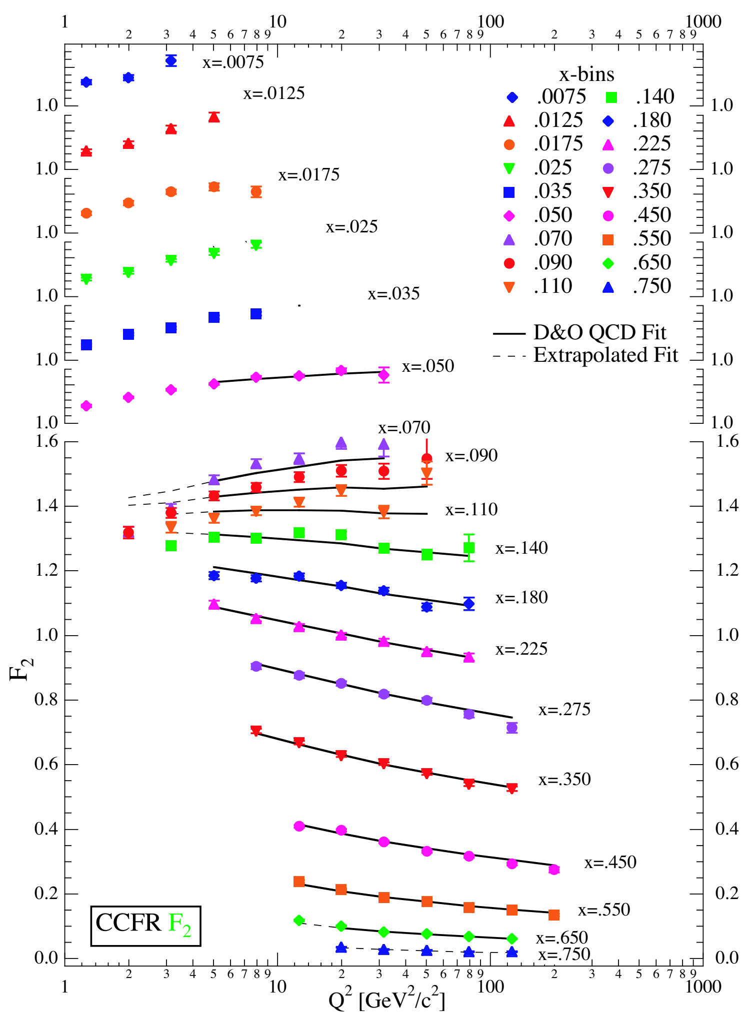
	SF Sample	Target μ Sample
ν	1802	196
$\overline{\nu}$	1344	79

Conclusions

- New measurement of ν and $\overline{\nu}$ differential cross sections.
  - $\hookrightarrow$ Better control of largest systematics.
    - $\star$ E_μ and E_{HAD} energy scales.
- Preliminary Structure Functions cross section fits.
  - $\hookrightarrow$ $F_2(x, Q^2)$
    - $\star$ Good agreement with Previous ν-Fe Measurements.
    - $\star$ NLO QCD calculation TR-VFS.
  - $\hookrightarrow$ $xF_3(x, Q^2)$
    - $\star$ Good agreement with Previous ν-Fe Measurements.
- Future
  - $\hookrightarrow$ QCD fits: F_2, xF_3
  - $\hookrightarrow$ 2-Parameter fits F_2 and R
    - $\star$ Nutev high-y data samples.

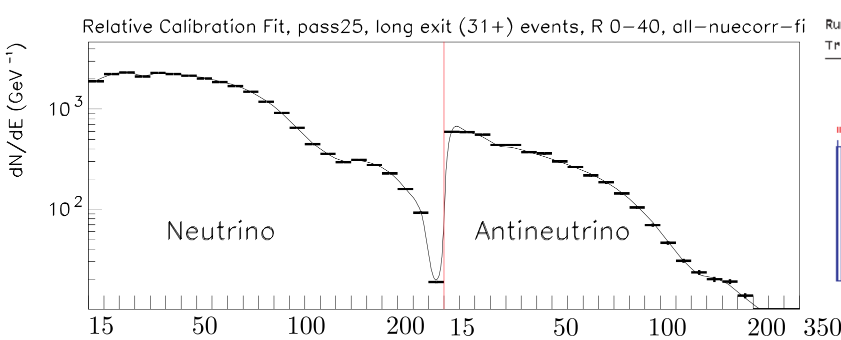
Determine Structure Functions from this Data

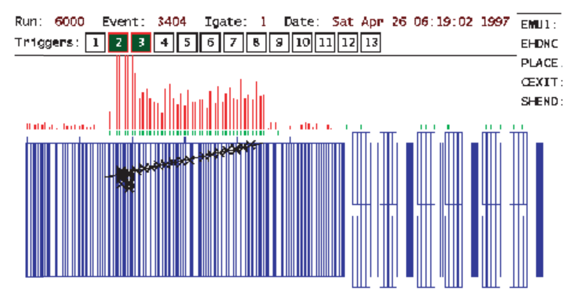
- Measure Structure Functions⇒ PDFs
  (Among Best PDF Inputs)
- Measured Internally With *Same Data Set*
  - Be Careful Applying External Corrections
  - Can't Just Take Your Favorite PDFs and Apply
  - We Try to produce Model-Independent Results

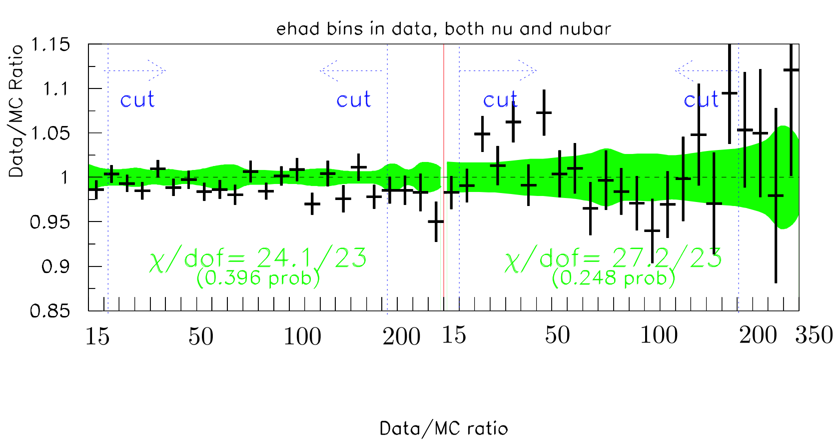


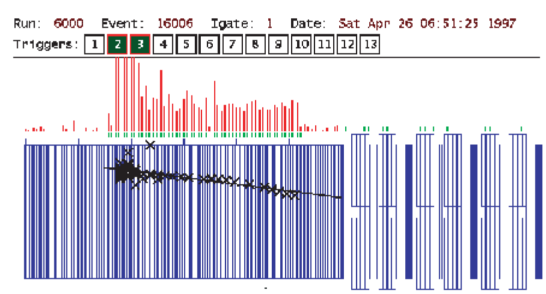
Charged-Current Control Sample

- High y charged-current is background to NC sample
  - CC subtraction is 20%/10% in $\nu/\overline{\nu} \Rightarrow$ want $\sim 1\%$ accuracy
- Check by looking at "long exit" CC events which start in the detector center and stop before toroid
- Kinematically Similar to Short Events, but no ν_e









- Agreement in this "short" charged-current sample is good within systematic uncertainties

Standard Model Explanations

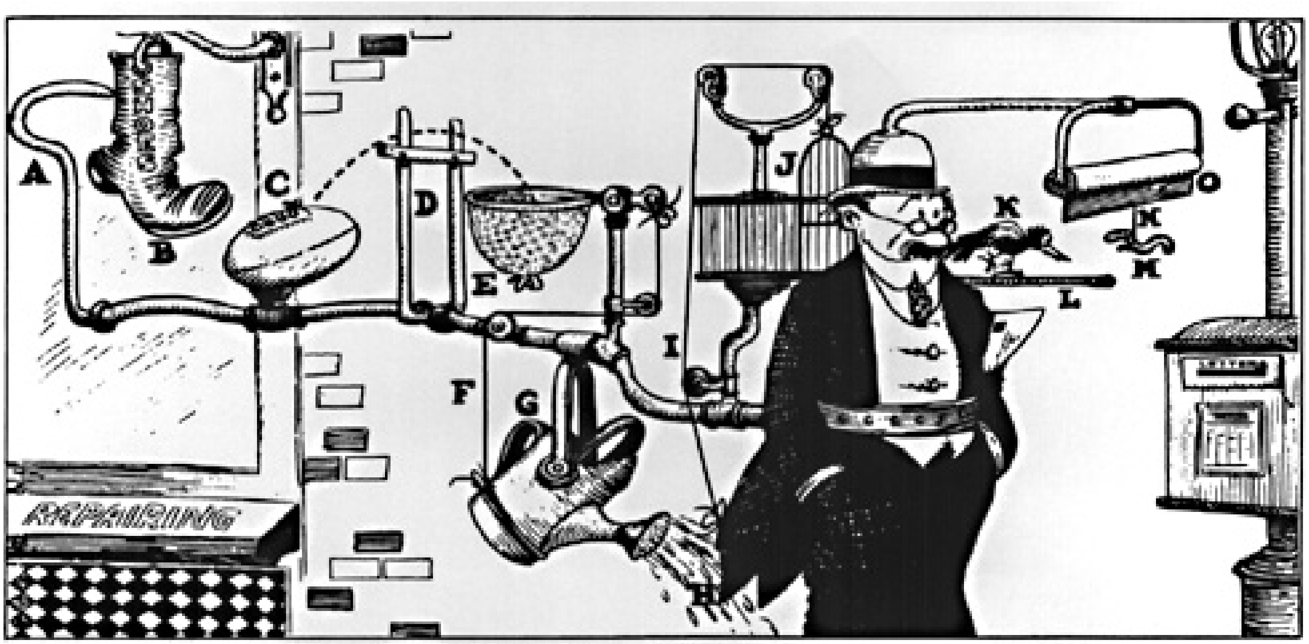
§1. Isospin Violation (1⋆) (reasonable, but no clear model)

§2. Strange Sea Asymmetry (0⋆)

- Davidson et al., hep-ph/0112302 v4
- Reasonable *a priori* , but ruled out within our data
- See Next Talk

§3. Neutrino Oscillations (−2⋆)

- $\nu_e \to \nu_S$ (Giunti et al., hep-ph/0202152)
- Ruled Out By Direct Measurement of ν_e Flux (which is in our talks and paper...)



Keep You From Forgetting To Mail Your Wife's Letter RUBE GOLDBERG (tm) RGI 049

Unnamed Theorist Mailing Preprint to xxx.lanl.gov

Isospin Violating PDFs

- Isospin symmetry may not be good for PDFs ($u^p \neq d^n$).
  - PDF fits performed under this assumption ... but $m_n \neq m_p$
  - NuTeV is sensitive since make this assumption to assign u,d types to scatterers
  - Has been calculated in several classes of non-perturbative model

Bag model

Thomas *et al.*, Phys. Lett˙**A9**, 1799

– $\delta \sin^2 \theta_W^{(\text{on-shell})} = -0.0001$

– ~ 0.0004 shifts at high, low x cancel

Meson Cloud model

Cao & Signal, Phys. Rev. **C62**, 015203.

– $\delta \sin^2 \theta_W^{(\text{on-shell})} = +0.0002$

- NC/CC Shadowing Differences:

  Talking with Miller and Thomas but disagreement about applicability of shadowing model in hep-ex/0204007:

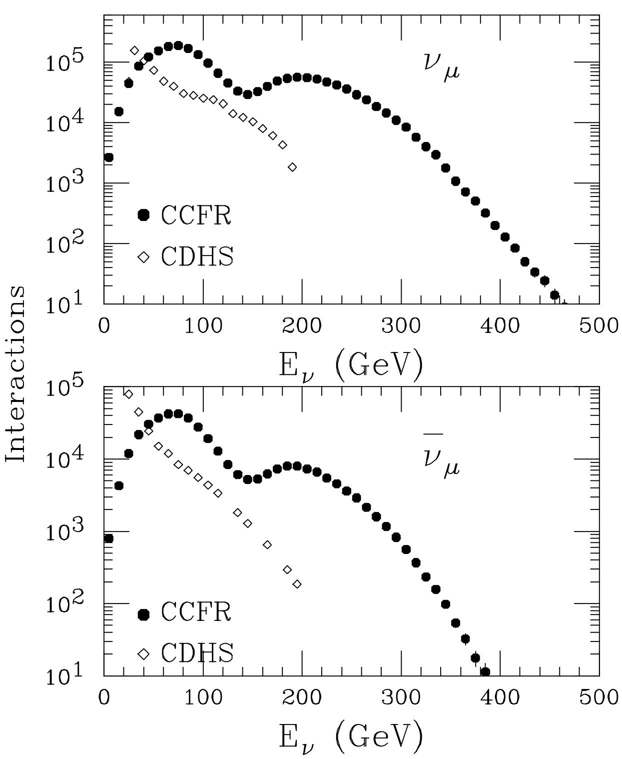
  Comment on "A Precise Determination of Electroweak Parameters in Neutrino-Nucleon Scattering"

  - Experimentally x, Q^2 distribution needs to be included – they use same value of correction for entire range, not convoluted over actual data
  - No Comment about theoretical validity
  - Looking forward to working together to nail this down
  - Miller now agrees effect would increase anomaly . . . (APS Conf., Priv. Comm.) ⇒ New Paper?

Strange Sea Asymmetry

Is $xs(x) = x\bar{s}(x)$*?*

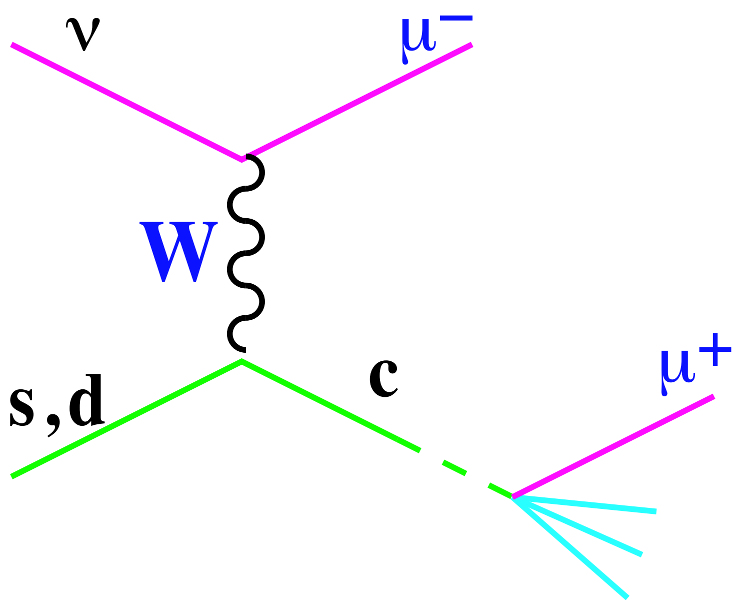
- Davidson *et al.* suggest
  - Asymmetry in strange sea could explain 0.0026 (1/2) of result. . ., "eliminating anomaly"
  - Quote Re-Analysis of CDHS Data, hep/ph-0004268 (Barone, Pascaud, Zomer)
  - Effect is -1.75σ, $s > \bar{s}$



	ν_μ	$\bar{\nu}_\mu$
CCFR	951000	170000
CDHS	638605	551390
$E_H > 25$	187688	13625
CCFR/CDHS	$\times 5.1$	$\times 12.5$

P.Berge *et al.*, Z.Phys C49,187(1991)

- We use our own NuTeV/CCFR Dimuon Data



Goncharov *et al.*,
Phys.Rev.D64
(2001) 112006

- Effect is $\approx +2.0\sigma$, $\bar{s} > s$ at high-x:
  Opposite Sign, *Increasing Anomaly*

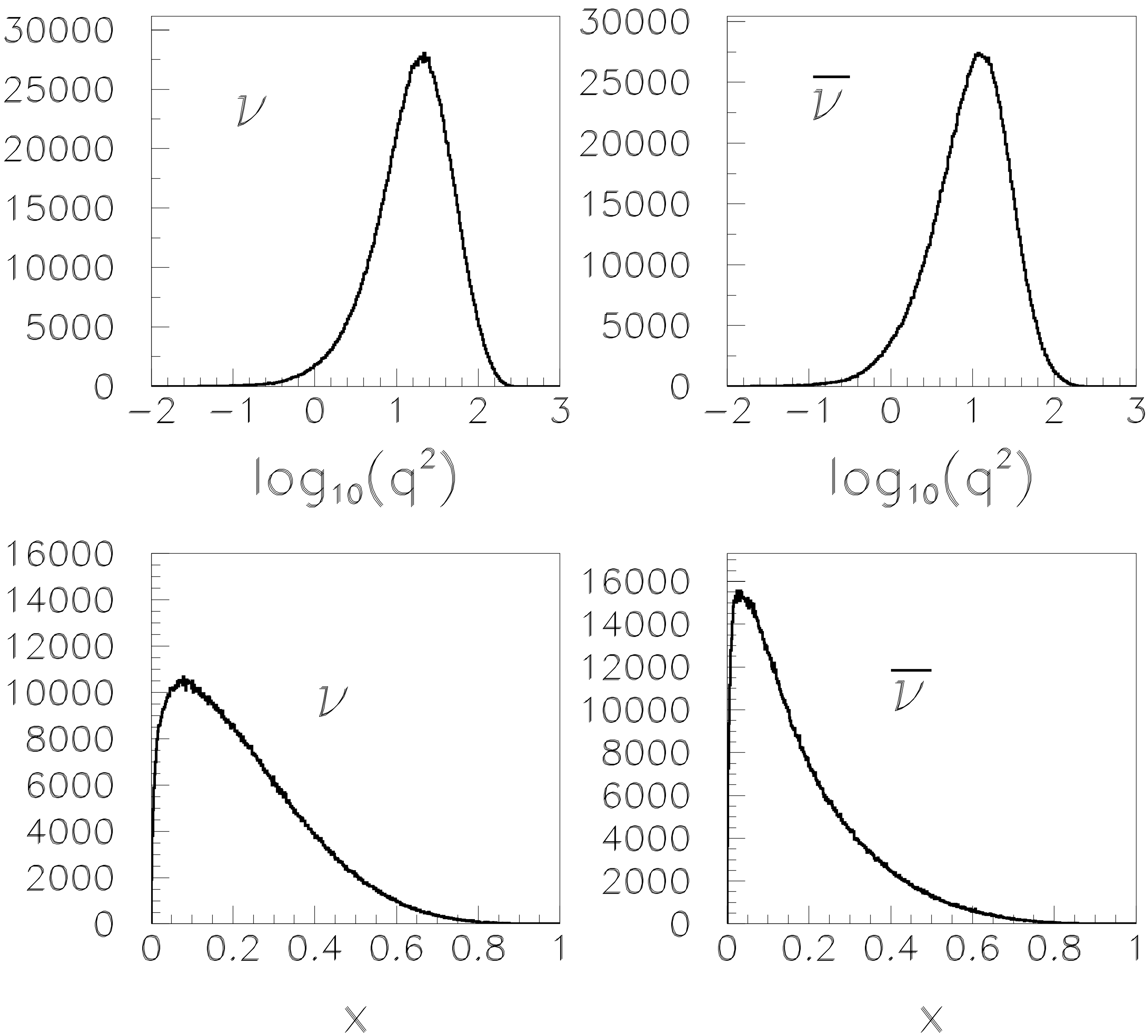
- We claim consistent with zero,
  but -1.7σ of BPZ strongly disfavored

see hep-ex/0203004, Phys.Rev.D65: (2002) 111103

- We are not fitting models,
  we are fitting our *data*

- We are open to suggestions for strange sea
  models which explain effect
  without contradicting data

Event Kinematics



ν: mean $Q^2 \sim 25$ GeV^2

$\overline{\nu}$: mean $Q^2 \sim 15$ GeV^2

- Recall most of ocean at low x and requires high E_{had} to make charm

§1. Poor Statistics at high E_{had}

§2. What About low x?

  – Quote 1 from BPZ:

    "The small-x ($x < 0.1$) ν Fe and $\bar{\nu}$ Fe are excluded in our analysis."

  – Quote 2 from BPZ:

    Finally, we reject the CDHSW data with $x < 0.1$. The reason for this cut is threefold: i) the systematic errors in the low-x region are large [44]; ii) the nuclear corrections at small x are not completely under control, as discussed in section 3.2; iii) at low-x the CDHSW results disagree with the CCFR findings for the cross sections [76] and for the structure functions [3].

- We couldn't have said it better ourselves . . .

- CCFR Energy Much Higher
  —Above Charm Threshold
- Since Determine $s, \bar{s}$ from $s \rightarrow c$
  enormous advantage in statistics

§1. Less Sensitive to Slow-Rescaling Form
In Determining Shape, Level of $s, \bar{s}$

§2. Data Analyzed Consistently Within
Same Structure as WMA

§3. LO, NLO *etc.* Not Relevant if
Parameterization Fits Data and
used in same kinematic range

- Other Objections:

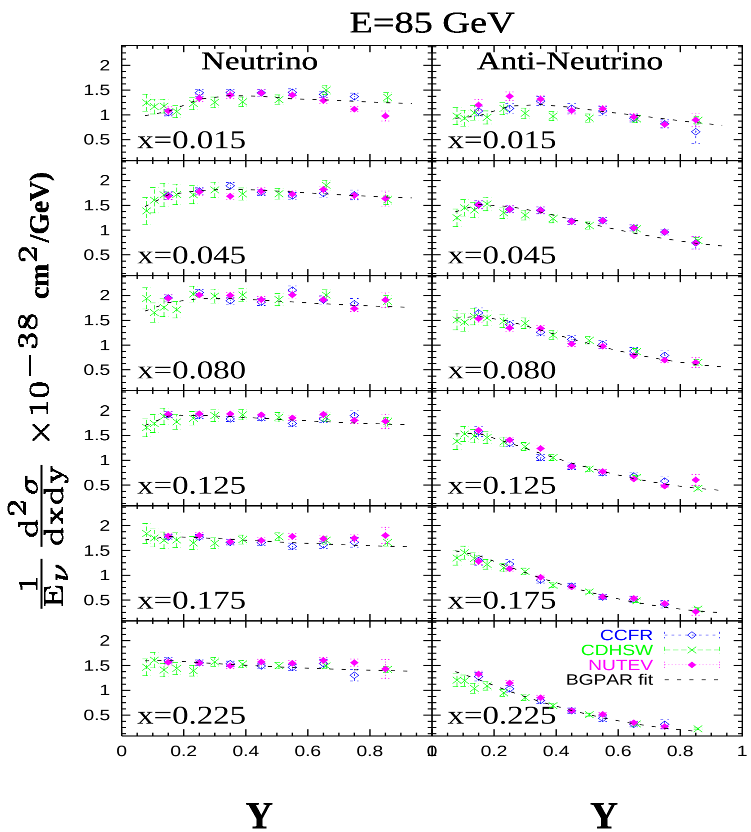
  §1. Fits don't force net strangeness zero:

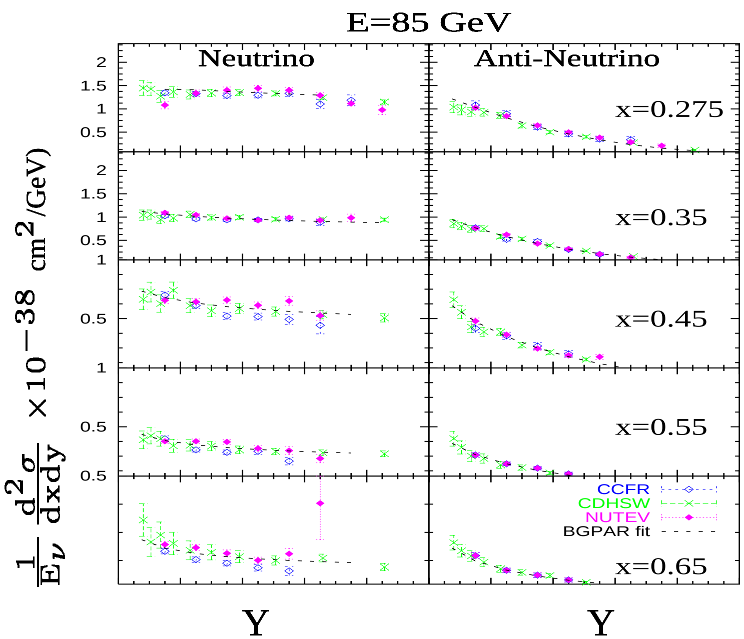
  We regard this as fitting a function where we know the intercept must be zero but letting it float. The fact that the net strangeness comes out to zero within errors is support, not weakness. We aren't fitting for $xs - x\bar{s}$, we're fitting our data for the strange sea within our kinematic range.

  §2. Functional form is not NLO.

  True, and we are working on a NLO fit. On the other hand we are fitting data, not a model and there is no concrete reason to think that changing the parameterization would change the conclusions. We are open to specific models.

Preliminary NuTeV Cross Section

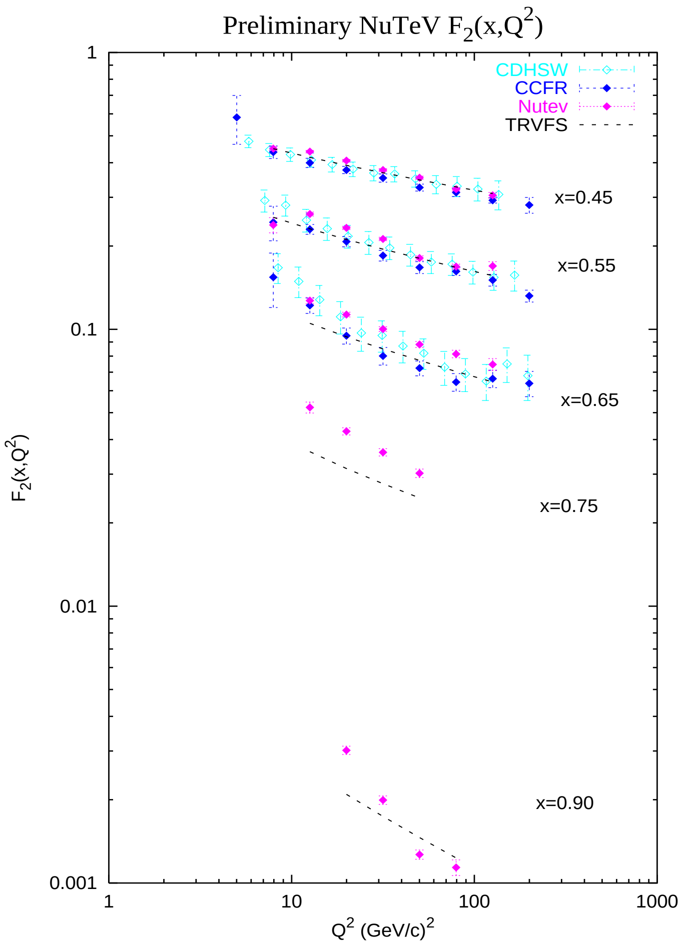




$$\frac{d^2\sigma^{\nu}}{dx\,dy} \propto [q(x)+\bar{q}(x)(1-y)^2]$$

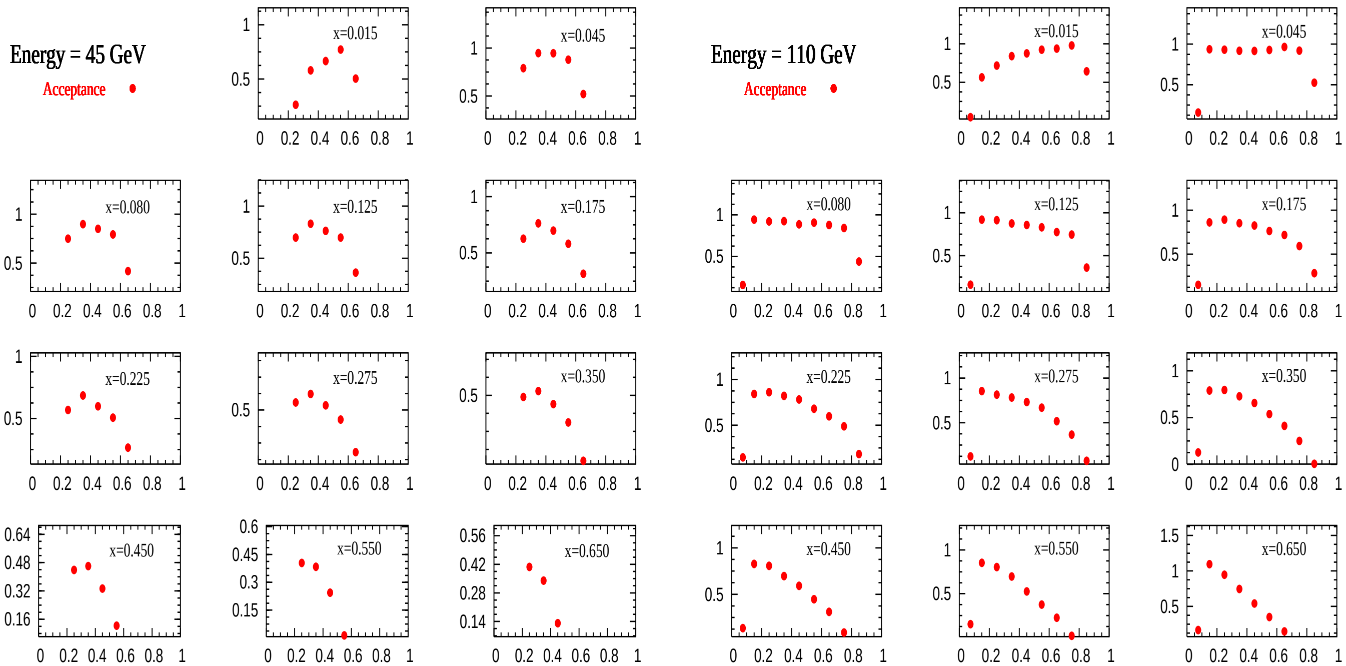
$$\frac{d^2\sigma^{\bar{\nu}}}{dx\,dy} \propto [\bar{q}(x)+q(x)(1-y)^2]$$

F_2 Measurement (High x)

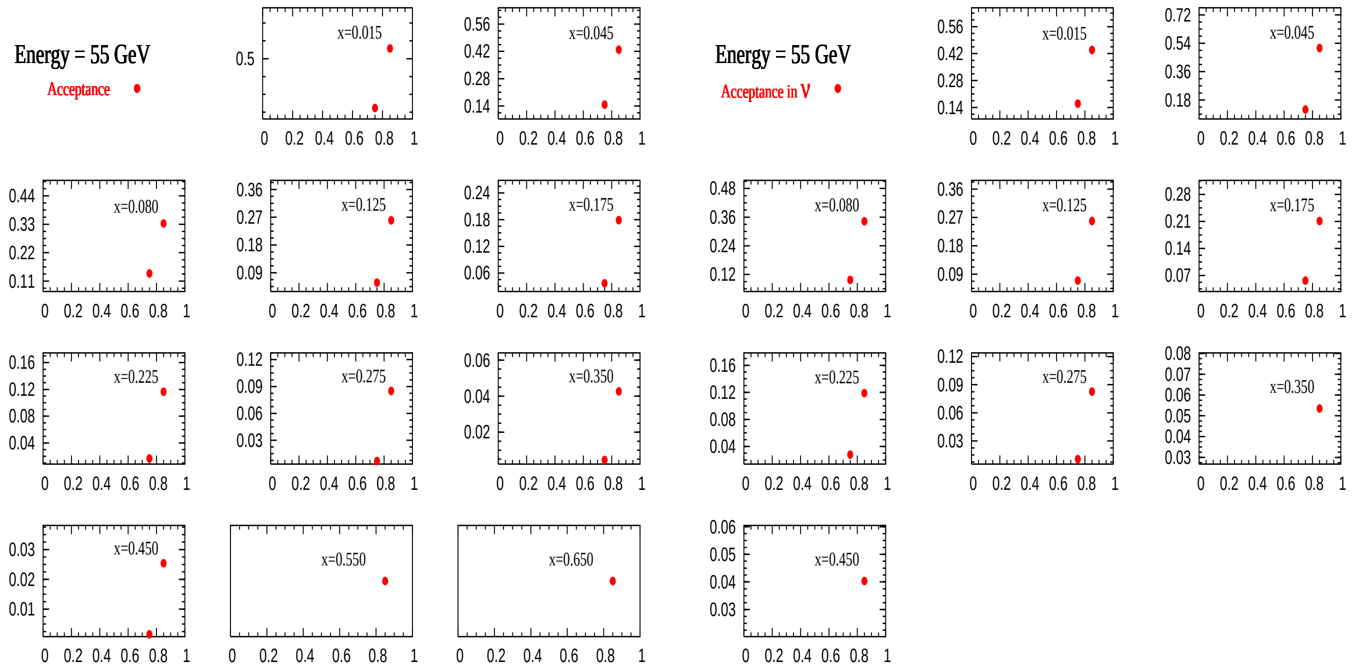


- Statisical errors only
- High x
  - ↪ Target mass effects
  - ↪ Higher-twist low Q^2.

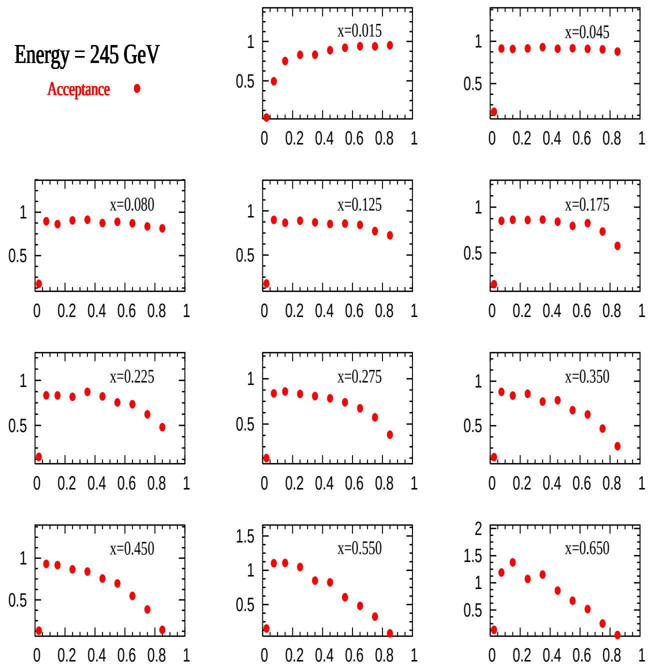
Acceptance


Energy = 45 GeV
Acceptance
x=0.015
x=0.045
x=0.080
x=0.125
x=0.175
x=0.225
x=0.275
x=0.350
x=0.450
x=0.550
x=0.650
Energy = 110 GeV
Acceptance
x=0.015
x=0.045
x=0.080
x=0.125
x=0.175
x=0.225
x=0.275
x=0.350
x=0.450
x=0.550
x=0.650

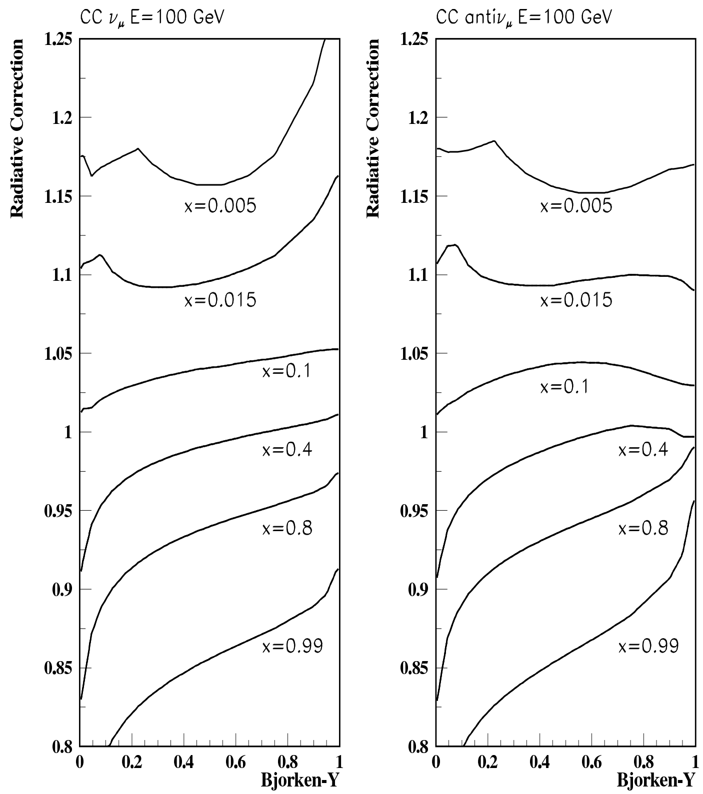
High-Y Acceptance



Acceptance (Cont'd)



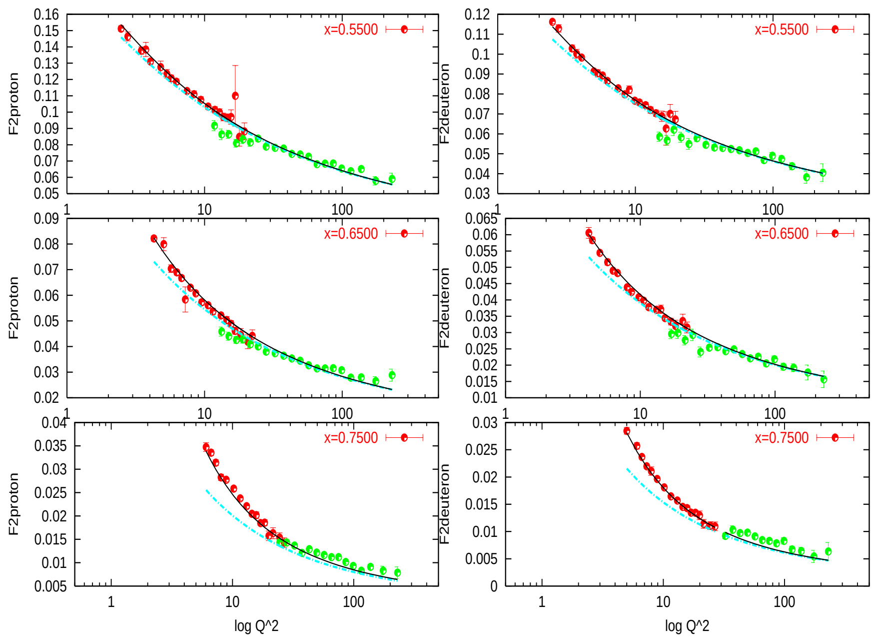
Radiative Corrections



Bardin, D. Y. and Dokuchaeva, JINR-E2-86-260 (1986).

Higher Twist Effects

- **Fit to ep, ed data (SLAC,BCDMS) to parameterize Target Mass and Higher Twist effects in parton-level cross section model important at high x and low Q^2.**
  [hep-ex/0203009 May 2002 A.Bodek and U.K.Yang]
  - $\hookrightarrow$ **At high x and low Q^2 have to take into account the nucleon mass $\rightarrow$ redefine x including these corrections which come as $1/Q^2$ term (Target Mass effect)**
  - $\hookrightarrow$ **At low Q^2 the lepton-nucleon scattering involves a double parton scattering. The contributions from HT diagrams are supressed by powers of $1/Q^2$ as compared to the leading twist diagrams.**



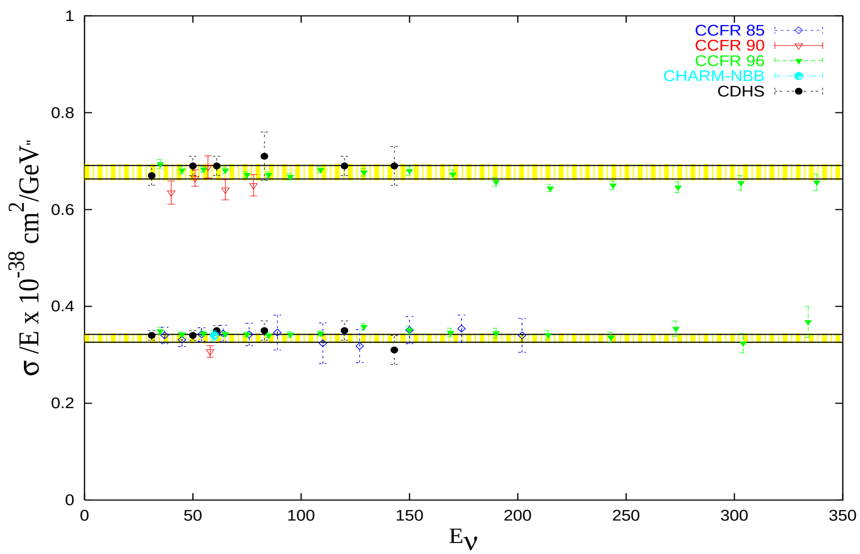
$$x' = x\frac{Q^2+B}{Q^2+Ax}$$

$$F_2 \rightarrow \left(\frac{Q^2}{Q^2+C}\right)F_2(x', Q^2)$$

A	0.57
B	0.22
C	0.06
χ^2/dof	792/312

World Average Neutrino Cross Section

Expt.	Target	E (GeV)	$\frac{\sigma^{\nu}}{E} \times 10^{-38}$ cm^2/GeV	$\frac{\sigma^{\overline{\nu}}}{E} \times 10^{-38}$ cm^2/GeV
CCFR(84)	Iron	30-230	0.669±0.024 (3.5%)	0.340±0.02 (5.9%)
CDHSW(87)	Iron	10-160	0.686±0.019 (2.8%)	0.339±0.01 (2.8%)
CHARM(88)	$CaCO_3$	10-160	0.686±0.02 (2.9%)	0.335±0.01 (3%)
CCFR(90)	Iron	30-75	0.659±0.039 (5.9%)	0.307±0.02 (6.5%)
Average		30-200	0.677±0.014 (2%)	0.334 ± 0.008 (2.4%)

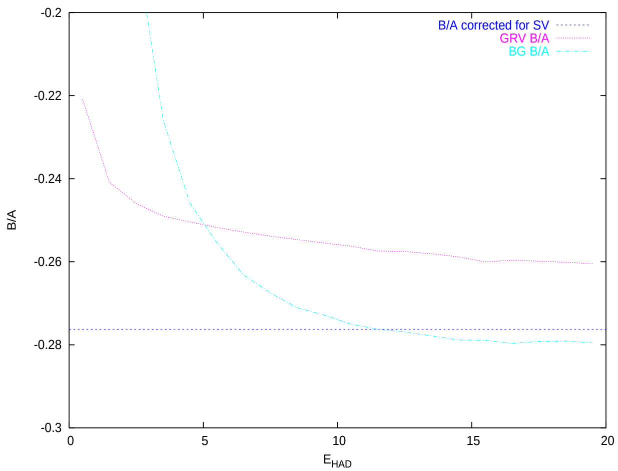


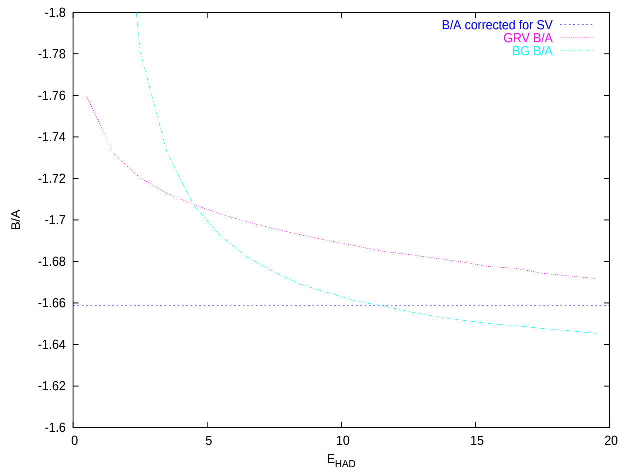
Scaling Violations in the Flux Sample

- This ignores implicit (small) ν dependence in F_2,xF_3 from scaling violations, $Q^2 = 2M\nu x$ in $F_2(x, Q^2), xF_3(x, Q^2)$.

$$\frac{B}{A} = -\frac{\int \left(F_2(x, Q^2) \mp xF_3(x, Q^2) \right) dx}{\int F_2(x, Q^2) dx}$$

- Scaling violations correction applied to correct for Q^2 dependence of data.

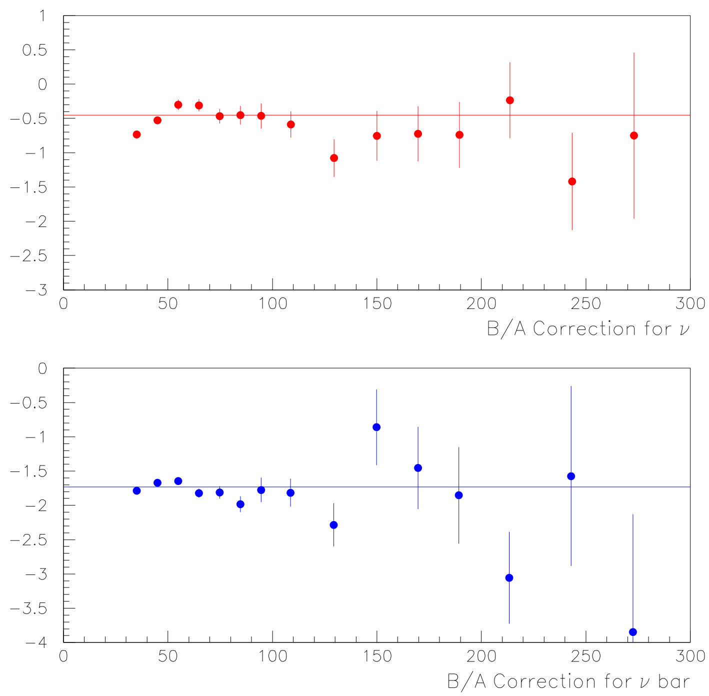




B/A values from Fits

- B/A determined from fits to DATA.
- Constant with Energy: Average value used:

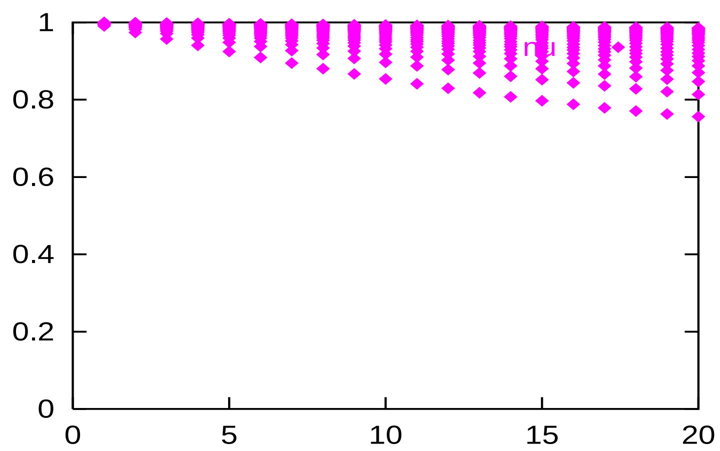
ν	-0.45 ± 0.035
$\overline{\nu}$	-1.73 ± 0.027



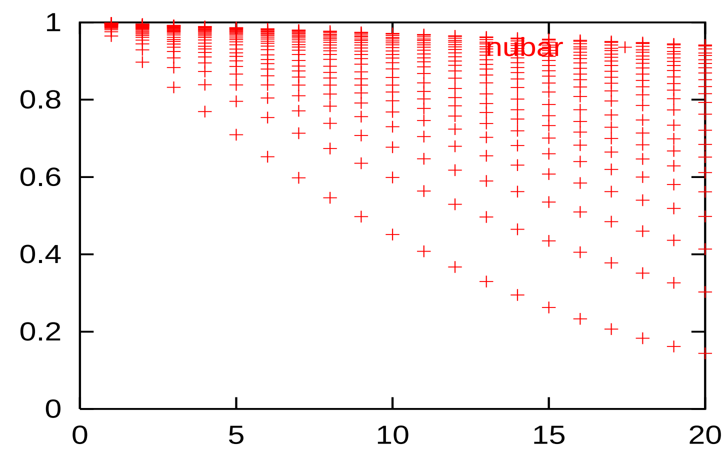
NuTeV

Flux Corrections (B/A)

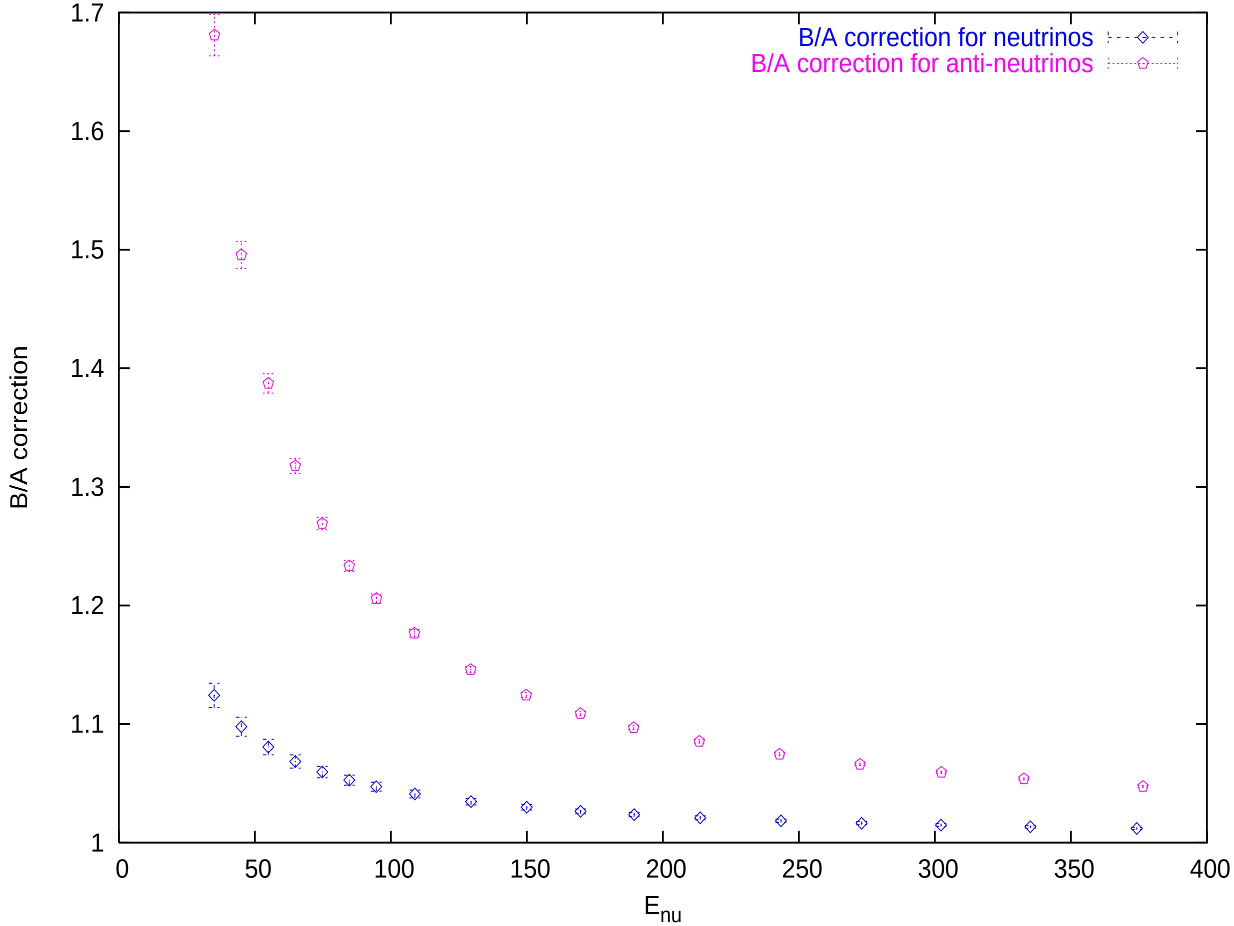
neutrino



antineutrino

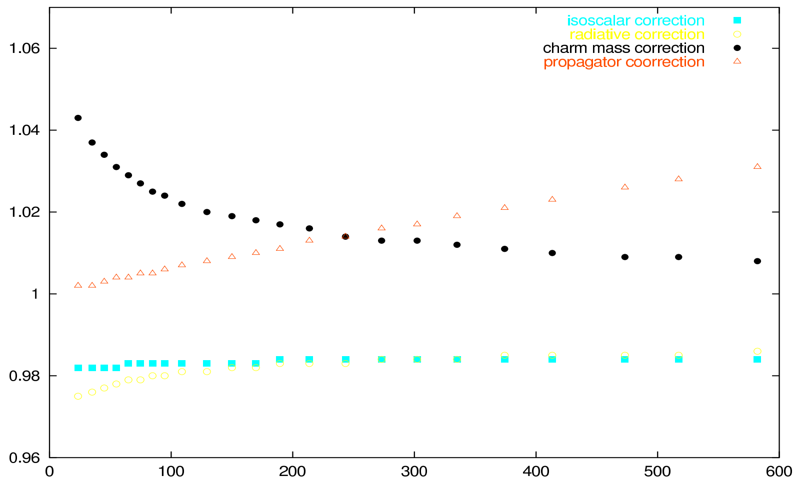


Flux Corrections (B/A)

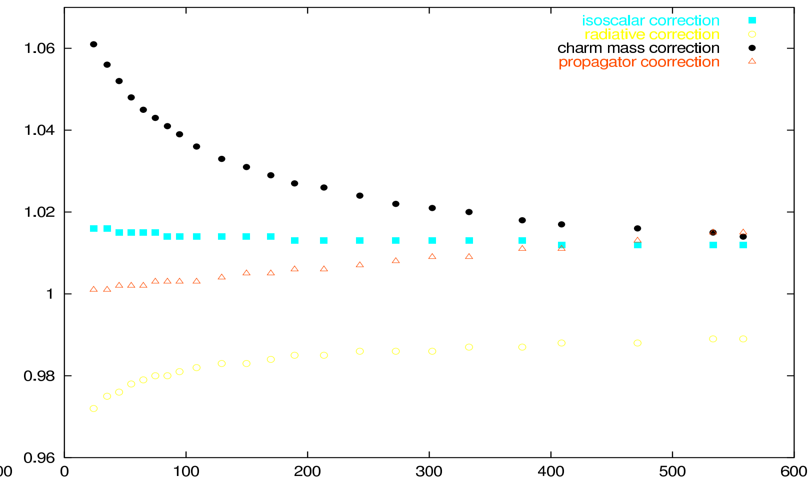


Total cross section physics Corrections

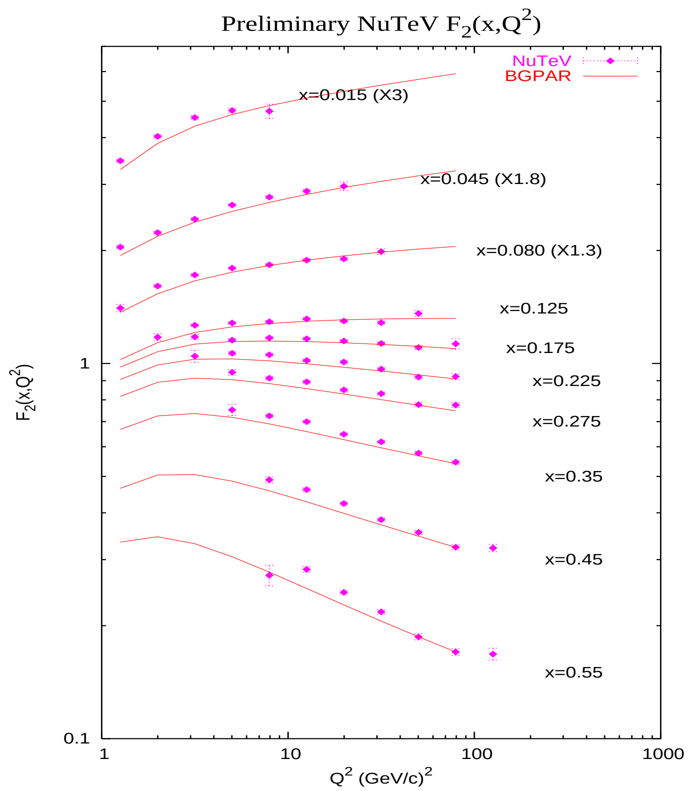
neutrino

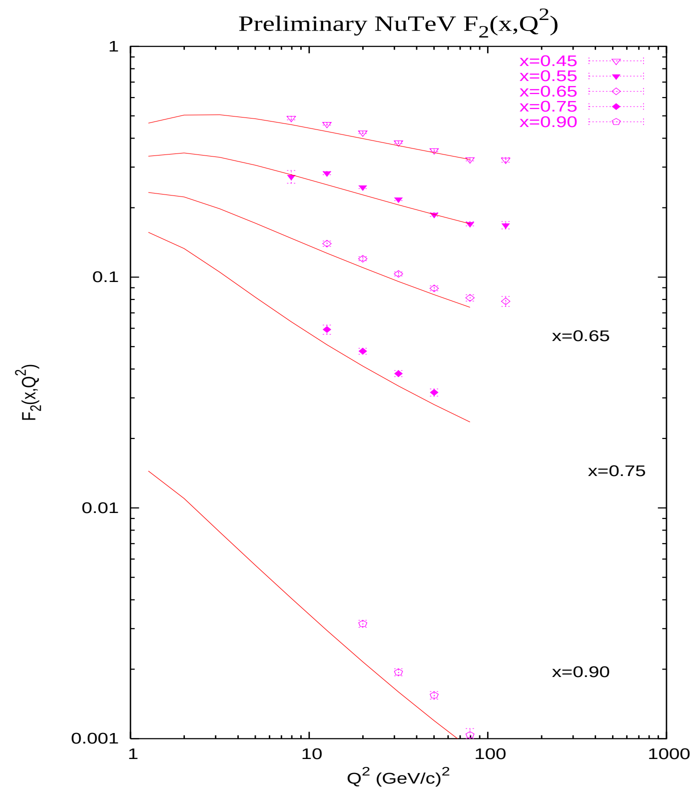


antineutrino

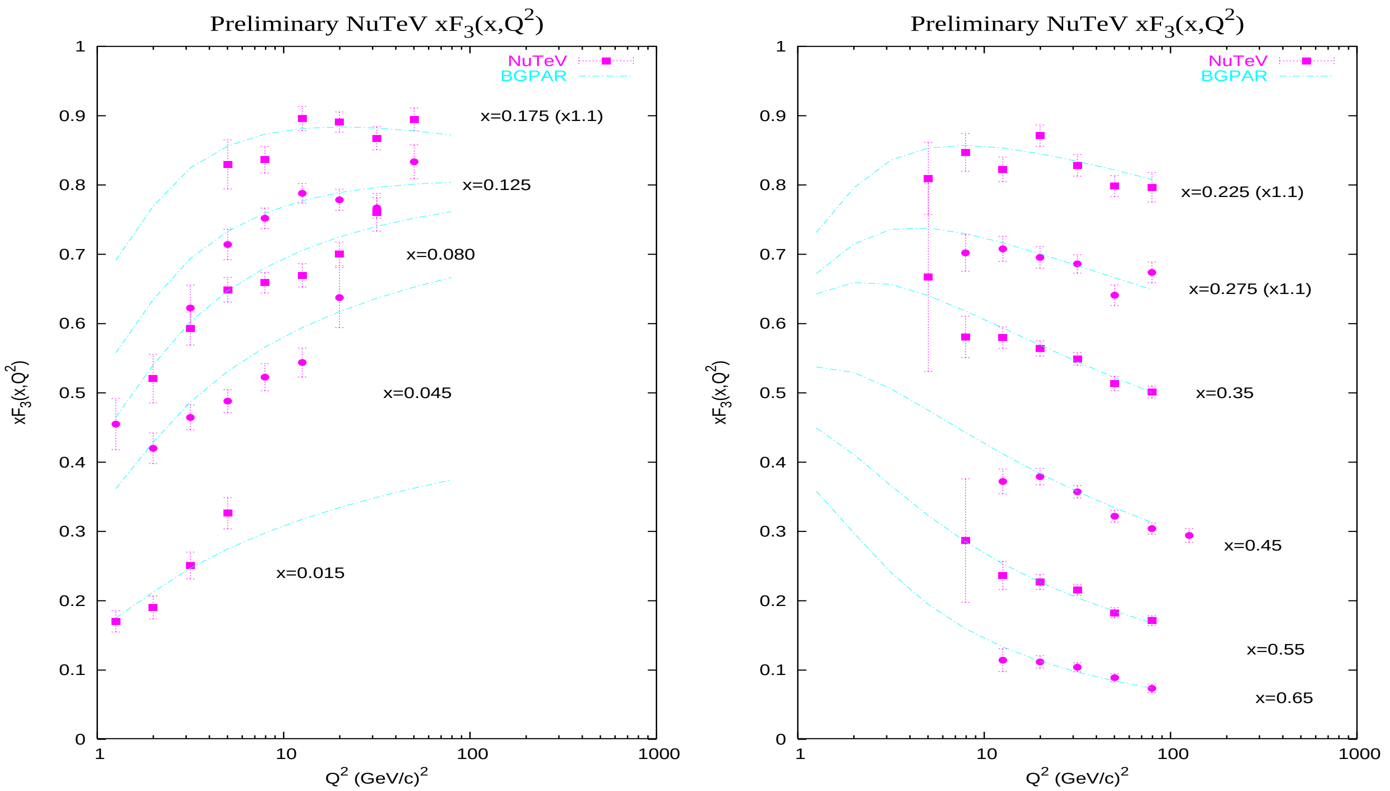


$F_2(x, Q^2)$ Comparison with Fit

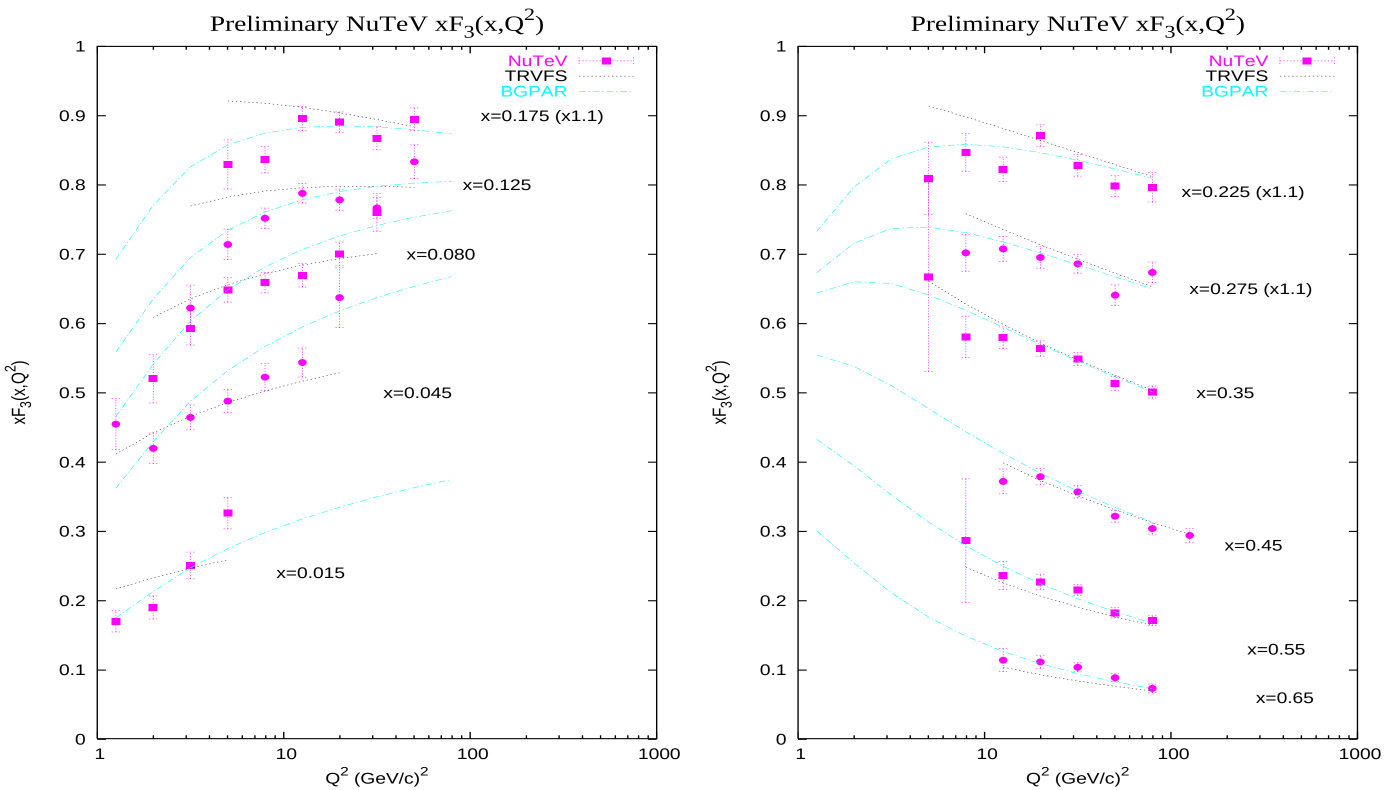




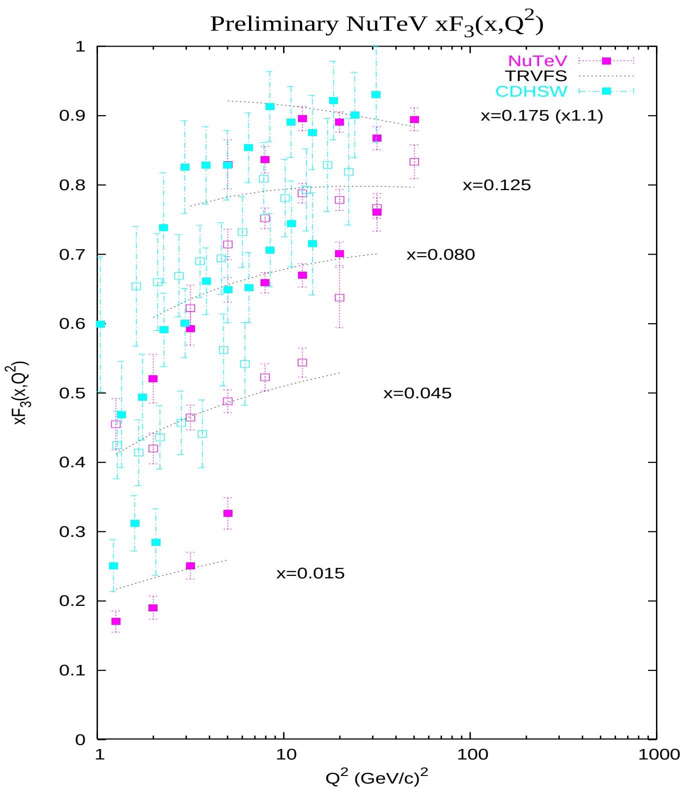
$xF_3(x, Q^2)$ Comparison with Fit

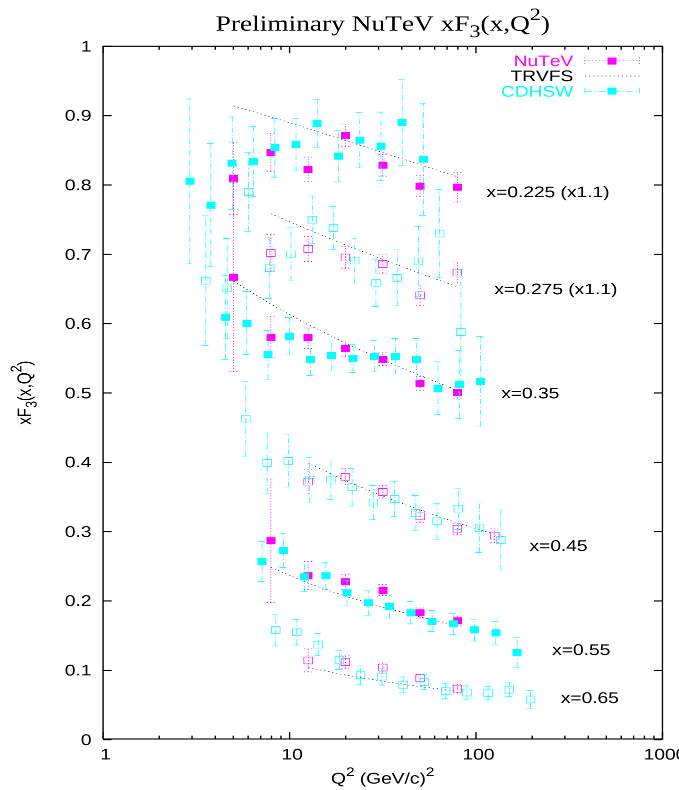


$xF_3(x, Q^2)$ Comparison with Models

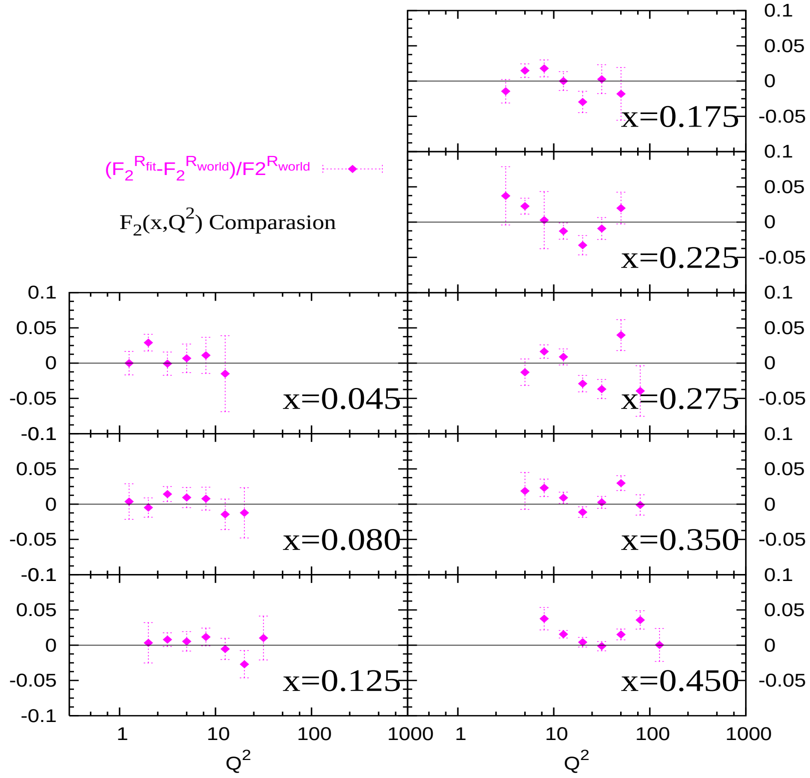


xF3 Comparison with CDHSW



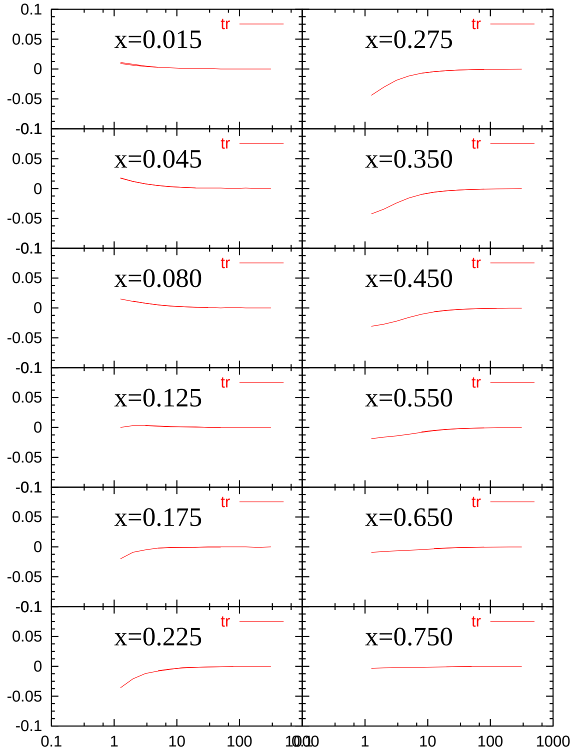


2-Parameter $F_2(x, Q^2)$

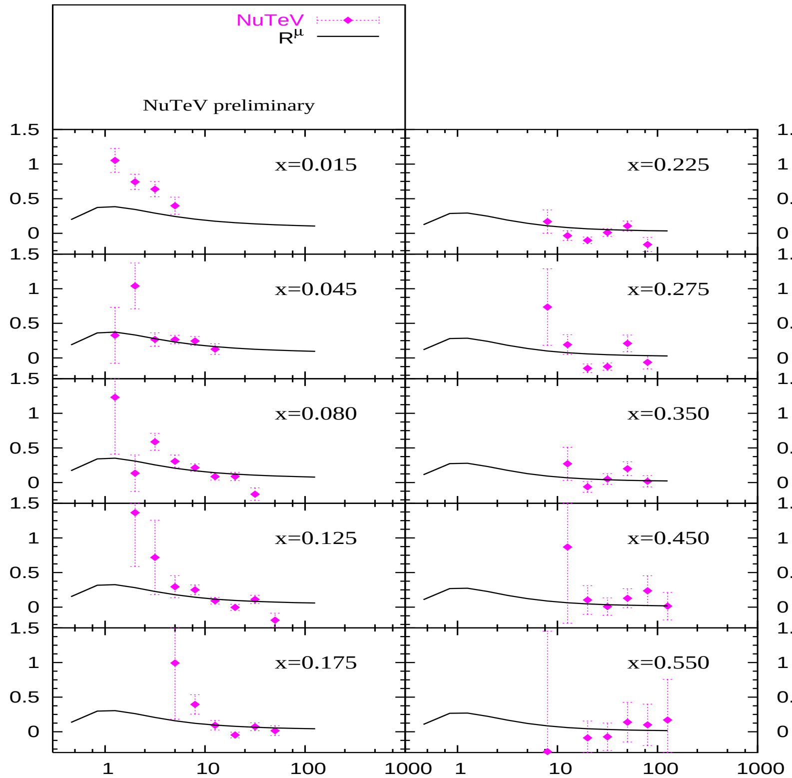


TRVFS ΔF_2

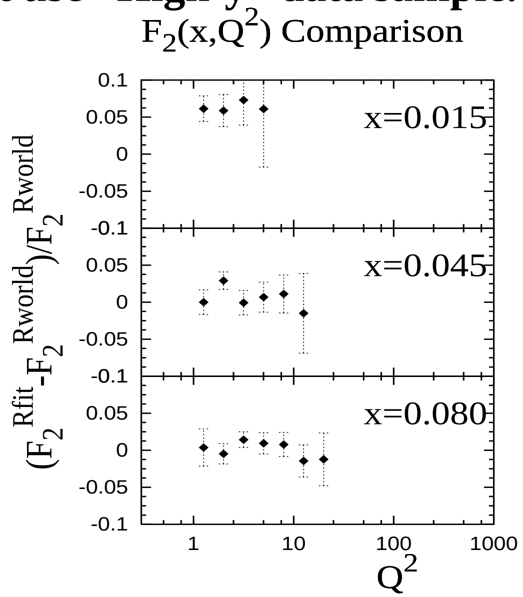
$$\Delta F_2 = \left(F_2^{\nu}(x,Q^2) - F_2^{\overline{\nu}}(x,Q^2)\right) = \left(\frac{1+R(x,Q^2)}{1+(4Mx^2/Q^2)}\right) V_{cd}^2 \left[\frac{(u_v+d_v)}{2}\right]$$

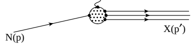


Preliminary $R(x, Q^2)$ Fits



- **Statistical Errors only.**
- **Does not use "High-y" data sample.**





Buras-Gaemers Parameterization

valence	sea
A0,A1,A2,AV2,AV3	S2,S3,G3
E10,E11,E20,E21,E30,(E31)	AS20,AS21
E40,(E41),E50,(E51),E60,(E61)	ES20, ES21

- **Valence:** $$xu_v(x,Q^2) = u_v^{tot}\, x^{E_1}(1-x)^{E_2} + AV2x^{E_3}(1-x)^{E_4} + AV3x^{E_5}(1-x)^{E_6}$$
$$xd_v(x,Q^2) = d_v^{tot}\, xu_v(x,Q^2)\cdot(1-x)$$
$$E_1 = E_{10} + E_{11}\ln\frac{\ln Q^2/A_0^2}{\ln Q_0^2/A_0^2}$$
$$E_2 = E_{20} + E_{21}\ln\frac{\ln Q^2/A_0^2}{\ln Q_0^2/A_0^2}$$
$$E_3 = E_{30} + E_{11}\ln\frac{\ln Q^2/A_0^2}{\ln Q_0^2/A_0^2}$$
$$E_4 = E_{40} + E_{21}\ln\frac{\ln Q^2/A_0^2}{\ln Q_0^2/A_0^2}$$
$$E_5 = E_{50} + E_{11}\ln\frac{\ln Q^2/A_0^2}{\ln Q_0^2/A_0^2}$$
$$E_6 = E_{60} + E_{21}\ln\frac{\ln Q^2/A_0^2}{\ln Q_0^2/A_0^2}$$
- **Sea:** $$x\bar{u}(x,Q^2) = x\bar{d}(x,Q^2) = \frac{1}{2(\kappa+2)}(AS(1-x)^{ES} + AS2(1-x)^{ES2})$$
$$xs(x,Q^2) = x\bar{s}(x,Q^2) = \frac{k}{2(\kappa+2)}\frac{AS}{ES+1}(ES+\alpha+1)(1-x)^{ES+\alpha}$$
$$AS = (ES+1)\left(\frac{SQ_2 - AS_2/(ES_2+1)}{SQ_3 - AS_2/(ES_2+1)(ES_2+2)}\right) - 2$$
$$AS = (ES+1)\left(\frac{SQ_2 - AS_2}{ES_2+1}\right)$$
$$AS_2 = AS_{20} + AS_{21}\ln(Q^2)$$
$$ES_2 = ES_{20} + ES_{21}\ln(Q^2)$$