Neutrino Physics at High-x_{Bj}

High-x Workshop
Jefferson Lab
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Fermilab

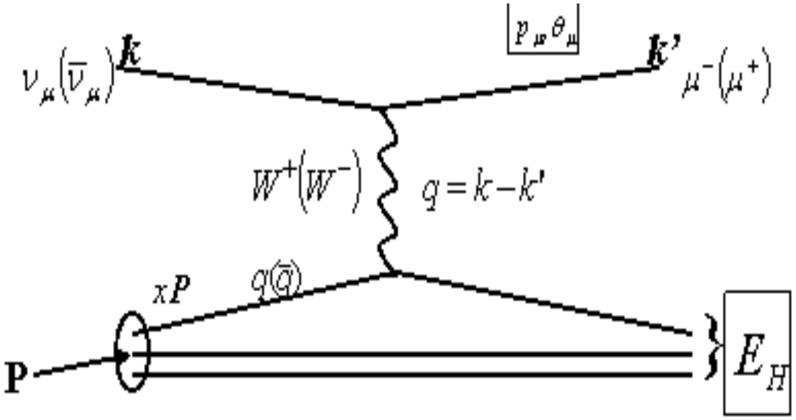
With thanks for the contributions of Trung Li (Rutgers), Martin Tzanov (LSU) and Lingyan Zhu (Hampton)

Studying high x_{Bj} with ν (DIS)

- Interacting with the weak current means a **much smaller interaction rate** than e/μ scattering
    - Need huge, higher-A detectors and/or intense neutrino beams to get reasonable statistics
- The incoming neutrino energy is not a priori known and even the neutrino energy dependent flux is difficult to predict.
- However **can select which set of quarks involved in the interaction via ν or $\overline{\nu}$**
- While F_2 is measured precisely by the charge lepton scattering, **xF_3 is accessible by neutrino DIS** and yields increased sensitivity to the **valence quark distributions.**
- Measuring charm production with **ν or $\overline{\nu}$** also gives us insight into the **s and $\overline{s}$ quark distributions**.

- Being forced to use heavy nuclear targets presents some challenges in disentangling nuclear effects from high-x phenomena. **Need to study nuclear effects with neutrinos (as compared to charged lepton scattering) or use lighter nuclear targets, like H_2, …. or do both!**

The Parameters of ν DIS



$Q^2 = 4E_\nu E_\mu \sin^2\frac{\theta}{2},$ Squared 4-momentum transferred to hadronic system

$x = \frac{Q^2}{2ME_{HAD}},$ Fraction of momentum carried by the struck quark

$y = \frac{\nu}{E_\nu} = \frac{E_{HAD}}{E_\nu},$ Inelasticity

Differential cross section in terms of structure functions:

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

Structure Functions in terms of parton distributions (for ν-scattering)

$$F_2^{\nu(\bar{\nu})N} = \sum\left[xq^{\nu(\bar{\nu})N}(x) + x\bar{q}^{\nu(\bar{\nu})N}(x) + 2xk^{\nu(\bar{\nu})N}(x)\right],$$

$$xF_3^{\nu(\bar{\nu})N} = \sum\left[xq^{\nu(\bar{\nu})N}(x) - x\bar{q}^{\nu(\bar{\nu})N}(x)\right] = x\left(d_V(x) + u_V(x)\right) \pm 2x\left(s(x) - c(x)\right),$$

$$R = \frac{\sigma_L}{\sigma_T}$$

Parton Distribution Functions:

What Can We Learn With All Six ν and $\bar{\nu}$ Structure Functions?

Recall Neutrinos have the ability to directly resolve flavor of the nucleon's constituents: ν interacts with d, s, $\bar{u}$, and $\bar{c}$ while $\bar{\nu}$ interacts with u, c, $\bar{d}$ and $\bar{s}$.

Using Leading order expressions:

$$F_2^{\bar{\nu}N}(x,Q^2) = x\left[u+\bar{u}+d+\bar{d}+2\bar{s}+2c\right]$$

$$F_2^{\nu N}(x,Q^2) = x\left[u+\bar{u}+d+\bar{d}+2s+2\bar{c}\right]$$

$$xF_3^{\bar{\nu}N}(x,Q^2) = x\left[u+d-\bar{u}-\bar{d}-2\bar{s}+2c\right]$$

$$xF_3^{\nu N}(x,Q^2) = x\left[u+d-\bar{u}-\bar{d}+2s-2\bar{c}\right]$$

Taking combinations of the Structure functions

$$F_2^{\nu} - xF_3^{\nu} = 2\left(\bar{u}+\bar{d}+2\bar{c}\right)$$

$$F_2^{\bar{\nu}} - xF_3^{\bar{\nu}} = 2\left(\bar{u}+\bar{d}+2\bar{s}\right)$$

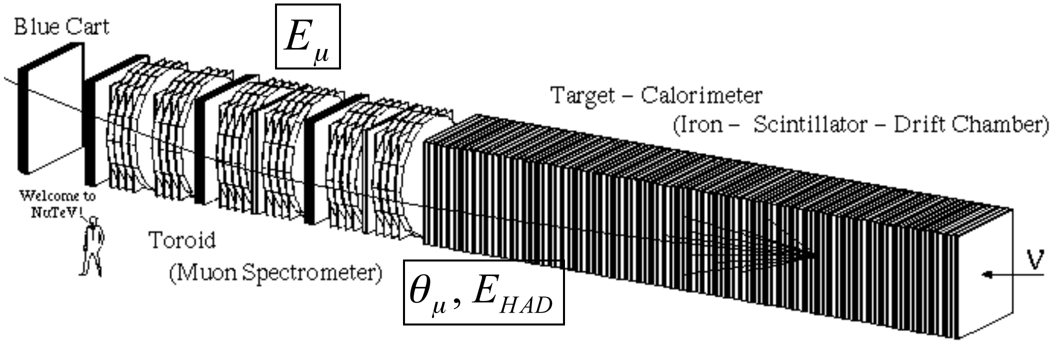
$$xF_3^{\nu} - xF_3^{\bar{\nu}} = 2\left[\left(s+\bar{s}\right)-\left(\bar{c}+c\right)\right]$$

Most “Recent” ν DIS Experiments

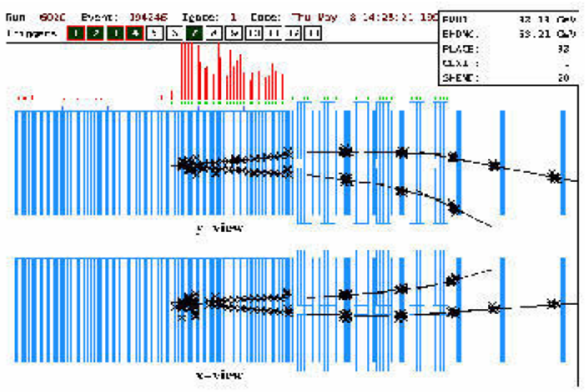
	E_ν range (< E_ν>) (GeV)	Run	Target A	E_μ scale	E_{HAD} scale	Detector
NuTeV (CCFR)	30-360(120)	96-97	Fe	0.7%	0.43%	Coarse
NOMAD	10-200(27)	95-98	Various (mainly C)	--	---	Fine-grained
CHORUS	10-200(27)	95-98	Pb	2%	5%	Fine-grained
MINOS	3-15	05-10	Fe	2.5%	5.6%	Coarse

The NuTeV Experiment: 800 GeV Protons

> 3 million neutrino/antineutrino events with $20 \leq E_\nu \leq 400\ GeV$



Refurbished CCFR detector



Target Calorimeter:

- Steel-Scintillator Sandwich (10 cm)

$$\frac{\delta E}{E} \approx \frac{0.86}{\sqrt{E}}$$ -resolution

- Tracking chambers for muon track and vertex

- Muon Spectrometer:

  Three toroidal iron magnets with five sets of drift chambers

$$\langle B_\varphi \rangle \approx 1.7T,\ p_t \approx 2.4 GeV/c$$

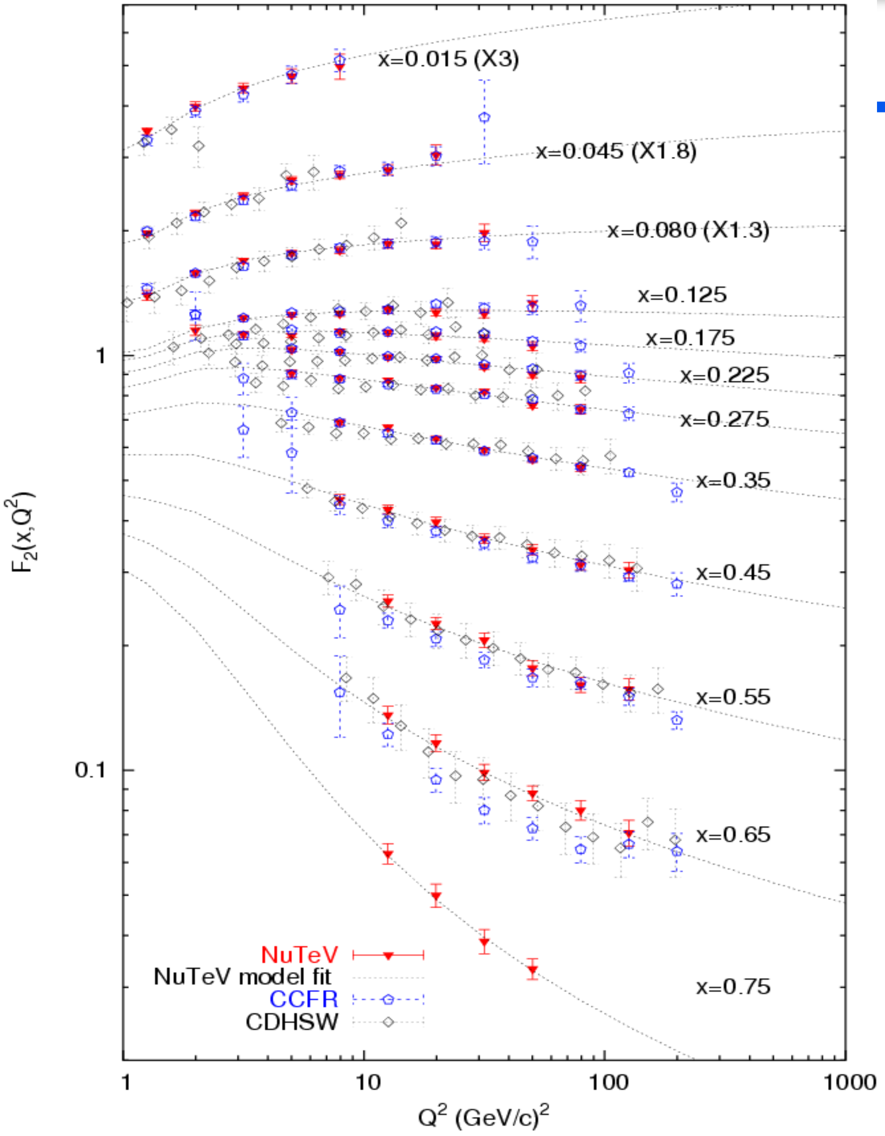
$$\delta(1/p)/(1/p) \sim 11\%$$ MCS dominated

- Always focusing for leading muon

1170 ν and 966 $\bar{\nu}$ data points with seven correlated systematic errors.

To confront leading systematic errors, there was a continuous calibration beam

F_2 Measurement

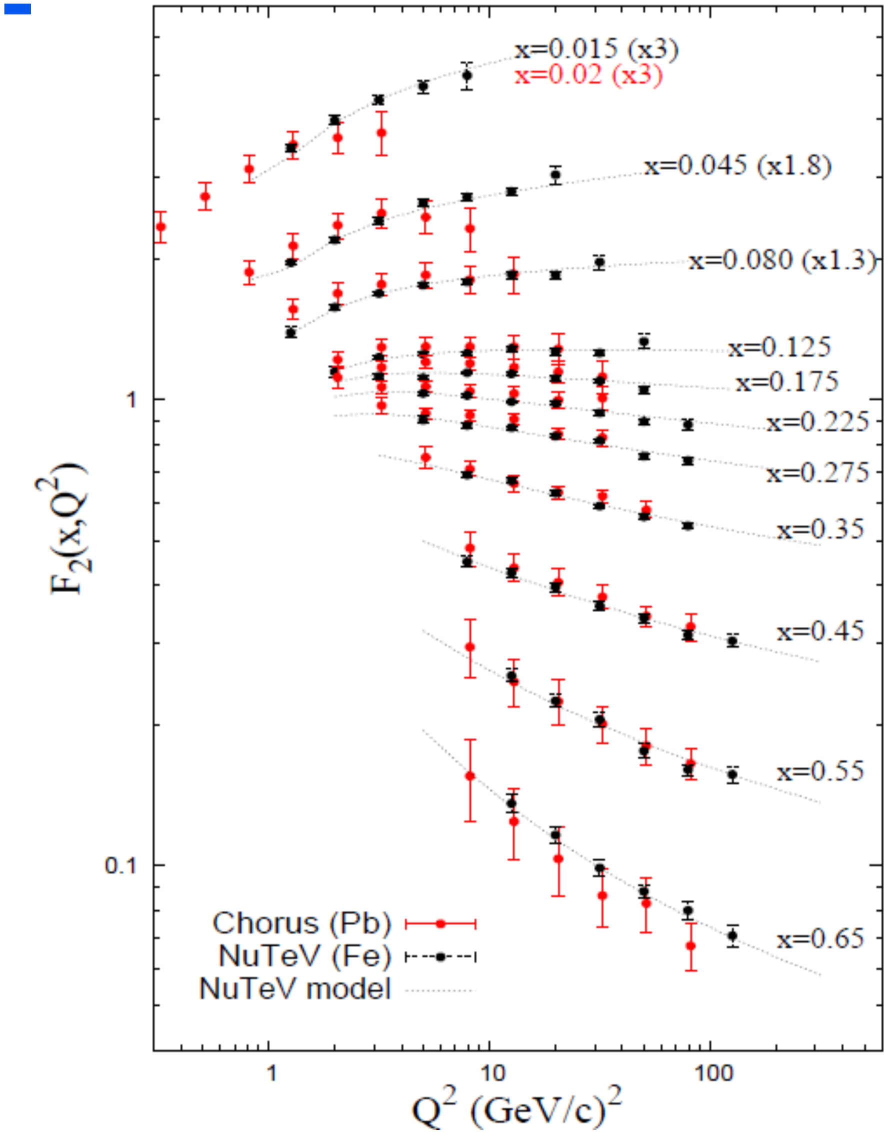


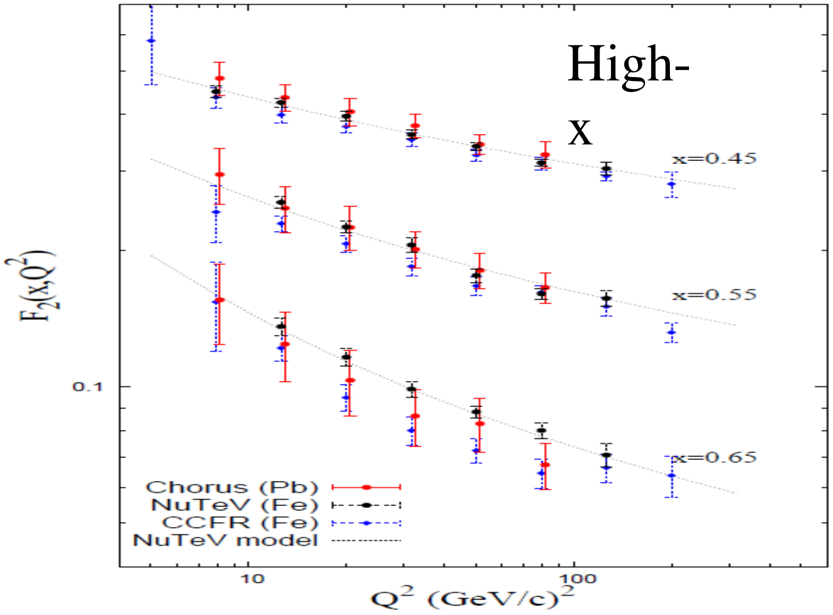
Notice the Q^2 range!

- Isoscalar ν-Fe F_2
- NuTeV F_2 compared with CCFR and CDHSW results
- All systematic uncertainties are included
- All data sets agree for *x<0.4*.
- At *x>0.4* NuTeV agrees with CDHSW.
- At *x>0.4* NuTeV is systematically above CCFR.

Martin Tzanov

CHORUS (using Pb targets and nuclear emulsions), NuTeV and CCFR F_2 Comparison

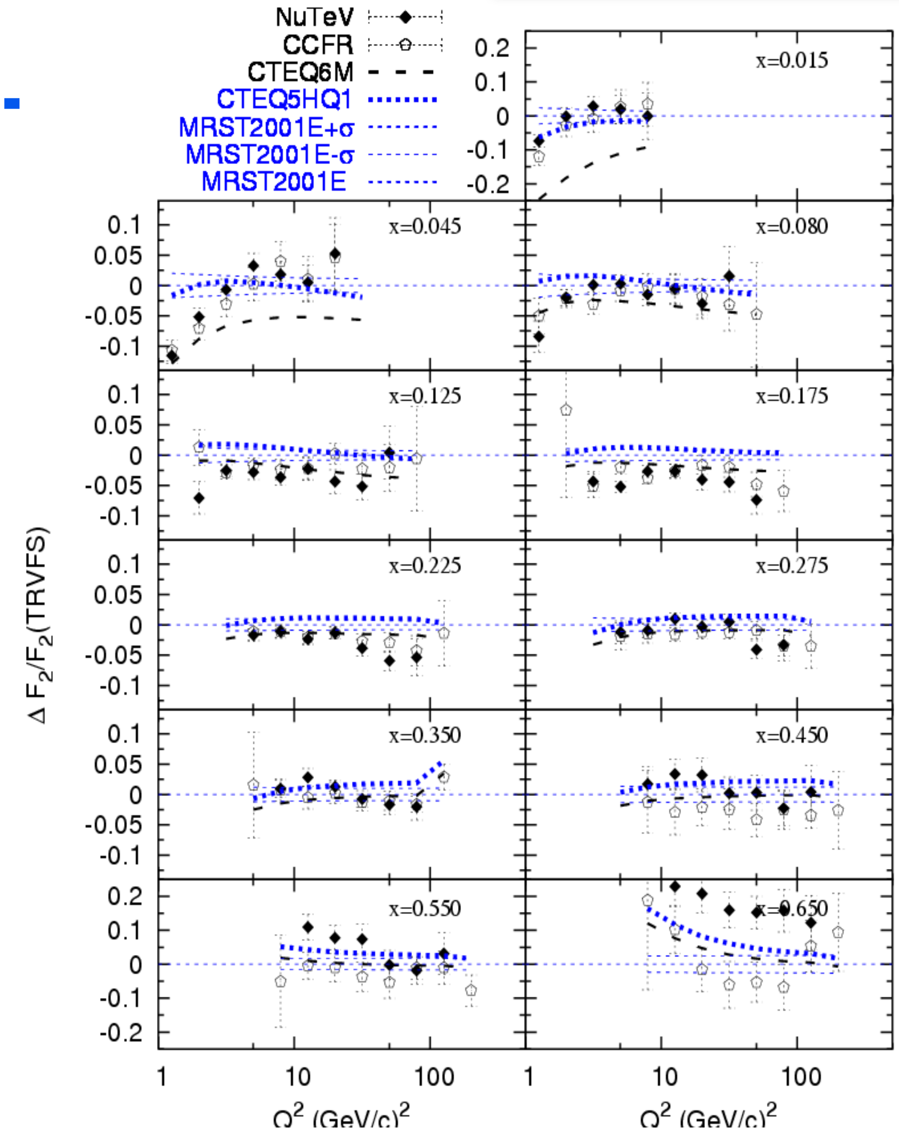




High-x

- CHORUS is not as precise,
- CHORUS agrees well with NuTeV **and** CCFR over the whole range,
- hint of a different Q^2 shape at low-x
- This comparison assumes nuclear corrections similar for Fe and Pb.

Comparison with Global Fits for F_2



- Baseline is TRVFS(MRST2001E)

- NuTeV and CCFR F_2 are compared to TRVFS(MRST2001E)

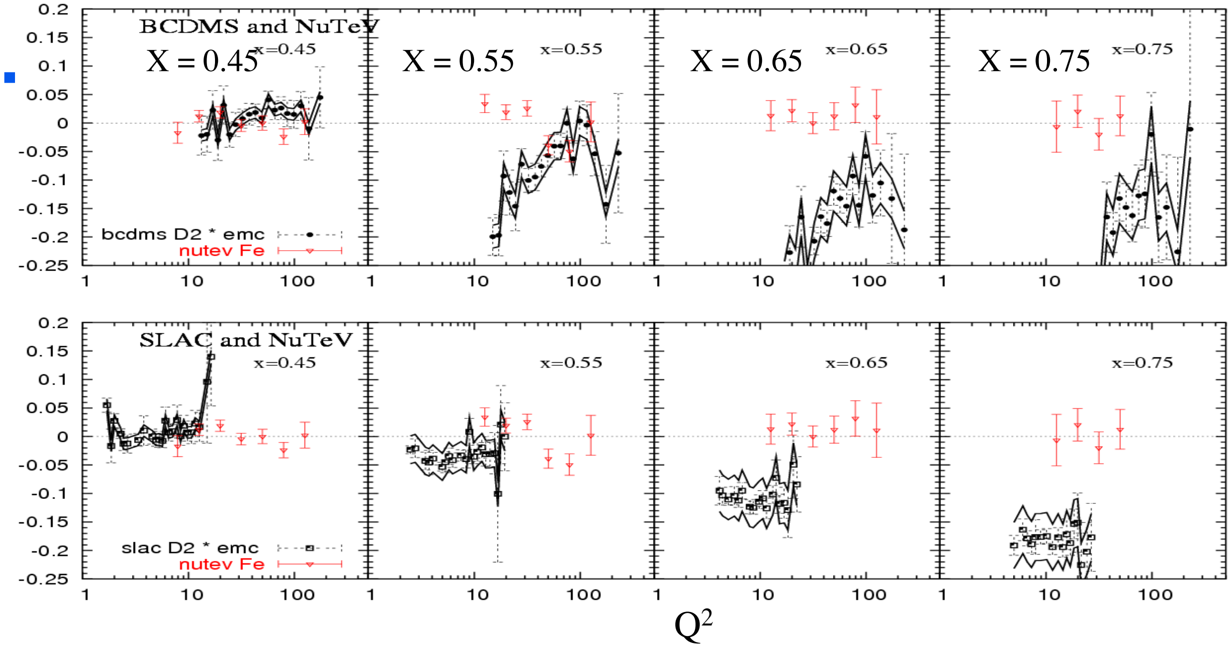
$$\frac{F_2^{NuTeV} - F_2^{TRVFS}}{F_2^{TRVFS}}$$

- Theoretical models shown are:
  - ACOT(CTEQ6M)
  - ACOT(CTEQ5HQ1)
  - TRVFS (MRST2001E)

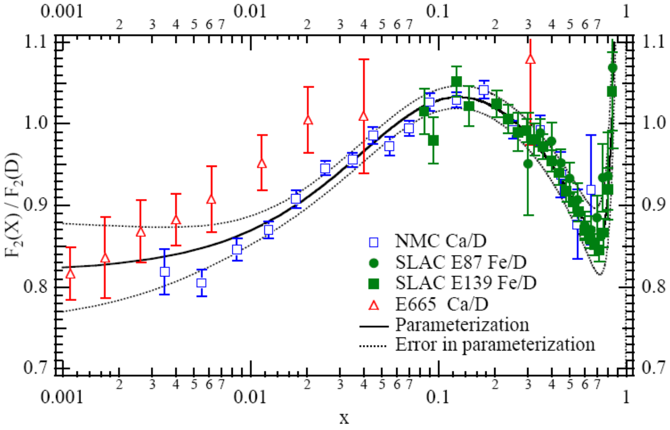
- Theory curves are corrected for:
  - target mass *(H. Georgi and H. D. Politzer, Phys. Rev. D14, 1829)*
  - nuclear effects – parameterization from charge lepton data, assumed to be the same for neutrino scattering (no Q^2 dependence added) nuclear effects parameterization is dominated by SLAC (lower Q^2 in this region) data at high-x

- NuTeV F_2 agrees with theory for medium x.
- At low x different Q^2 dependence.
- At high x (x>0.5) NuTeV is systematically higher.

Comparison with Charge Lepton Data for *x>0.4*



- Baseline is NuTeV model fit
- data points are $\frac{F_2^{DATA} - F_2^{BG}}{F_2^{BG}}$
- charge lepton data is corrected for:
  - $\frac{F_2^{\nu}}{F_2^{l}}$ using CTEQ4D
  - heavy target $\frac{F_2^{N}}{F_2^{D}}$



- NuTeV agrees with charge lepton data for x=0.45.
- NuTeV is higher than BCDMS(D_2), different Q^2 dependence
  - *7%* at *x=0.55*, *12%* at *x=0.65*, and *15%* at *x=0.75*
- NuTeV is higher than SLAC(D_2) (bottom 4 plots)
  - *4%* at *x=0.55*, *10%* at *x=0.65,* and *17%* at *x=0.75*

the nuclear correction is dominated by SLAC data, which is at lower Q^2 than NuTeV in this region

“Perhaps the nuclear correction is smaller for neutrino scattering at high x.”

Martin Tzanov

Summary ν Scattering Results – NuTeV

NuTeV accumulated over 3 million neutrino / antineutrino events with $20 \leq E_\nu \leq 400$ GeV. Most accurate results available until NOMAD.

NuTeV considered multiple correlated systematic uncertainties.

NuTeV agrees with other ν experiments and theory for medium x.

NuTeV has a different Q^2 dependence at low x .

NuTeV **is systematically higher at high x (x > 0.6).**

"The origin of this discrepancy is now understood by both groups and the NuTeV data set is believed to be "the more reliable" of the two."

How do we now incorporate these NuTeV results in the analysis of nucleon structure at high x_{Bj} ?

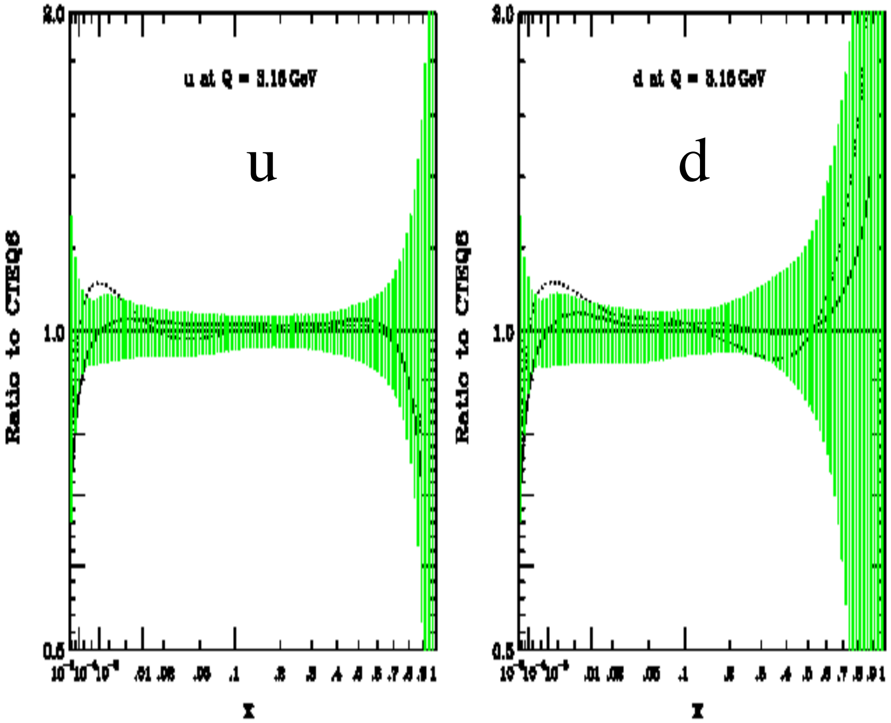
CTEQ study: The Impact of new neutrino DIS and Drell-Yan data on large-x parton distributions

Joey Huston - MSU, Cynthia Keppel - Hampton, Steve Kuhlmann - ANL,
JGM - Fermilab, Fred Olness - SMU, Jeff Owens - Florida State,
Jon Pumplin and Dan Stump - MSU

Published in **Phys.Rev.D75:054030,2007**. e-Print: **hep-ph/070215**

Basic impetus for this analysis:

- the NuTeV data expected to pull the valence distributions upward at large x,
- the E-866 data indicated the valence distributions at high x were already too high in the CTEQ6 PDFs.



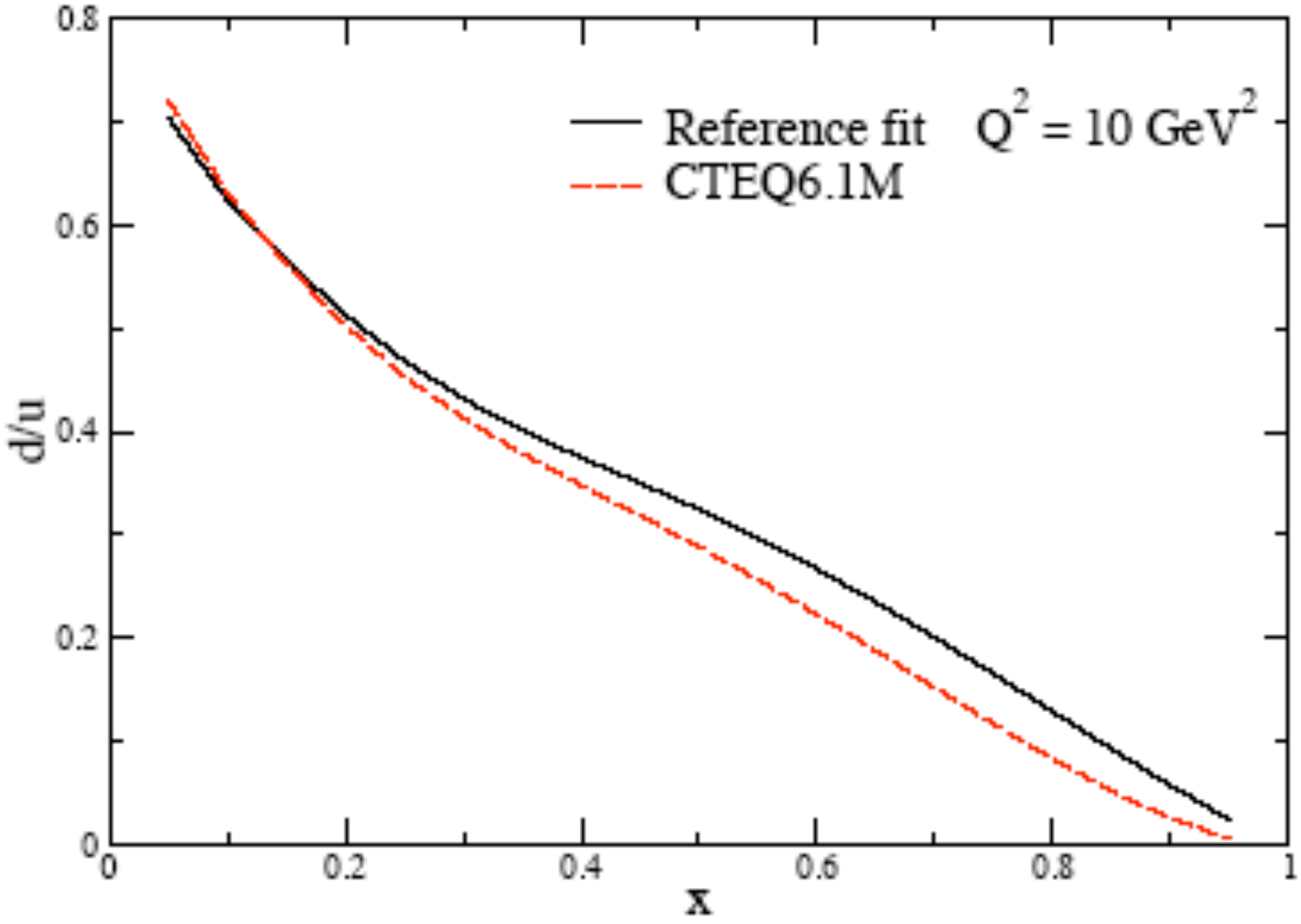
CTEQ High-x Study

Create a New Reference Fit for the Analysis

- Starting with the CTEQ6.1M PDFs, form a reference fit mainly nucleon (removing the CCFR data) scattering results:
  - BCDMS results for F_2^p and F_2^d
  - NMC results for F_2^p and F_2d/F_2^p
  - H1 and ZEUS results for F_2^p
  - CDF and DØ result for inclusive jet production
  - CDF results for the W lepton asymmetry
  - E-866 results for the ratio of lepton pair cross sections for pd and pp interactions
  - E-605 results for dimuon production in pN interactions.
- Correct for deuteron nuclear effects

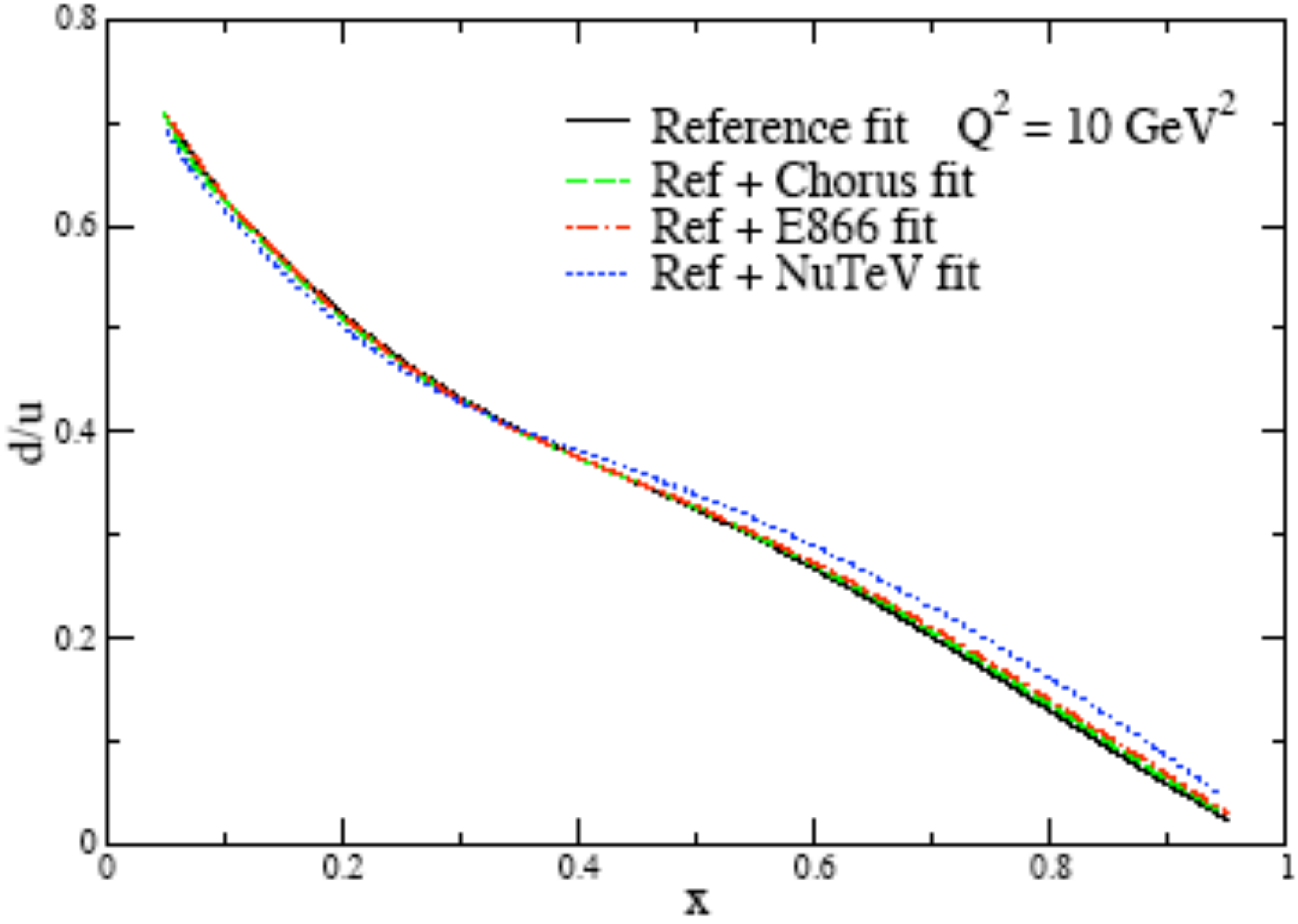
High x → valence quark dominance: d/u ratio

Reference Fit compared to the CTEQ6.1M PDFs

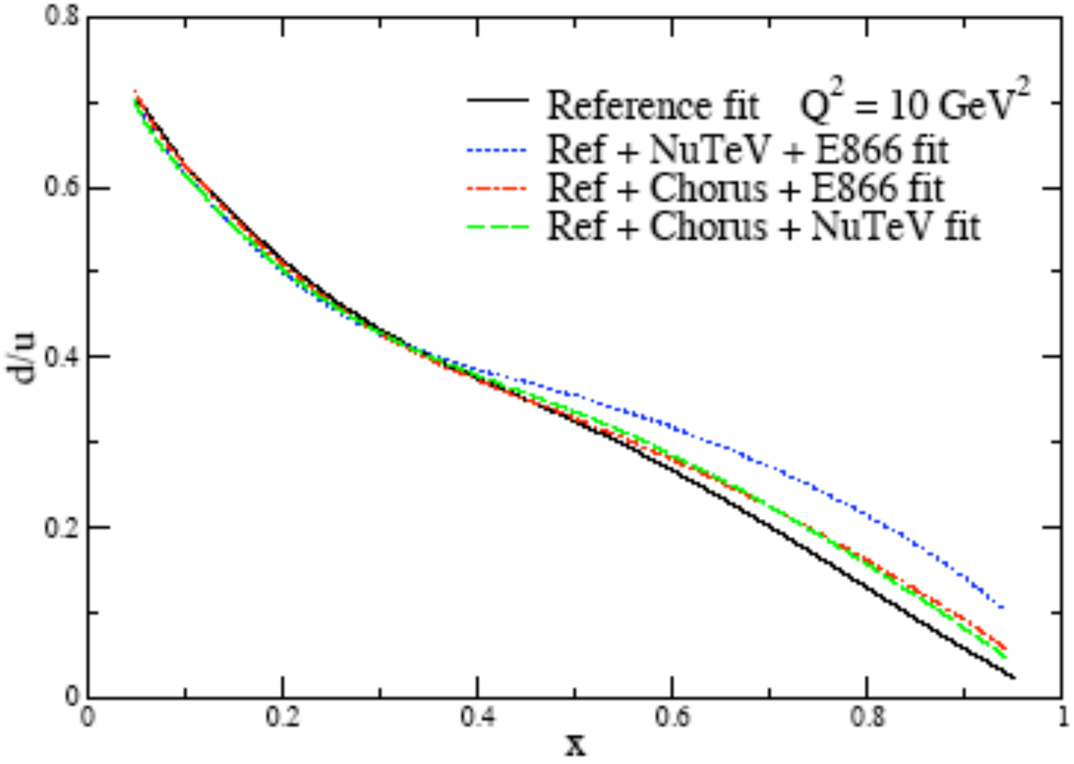


Adding New Data Sets to Ref: one-at-a-time

using Kulagin-Petti nuclear corrections



Adding New Data Sets to Reference Fits

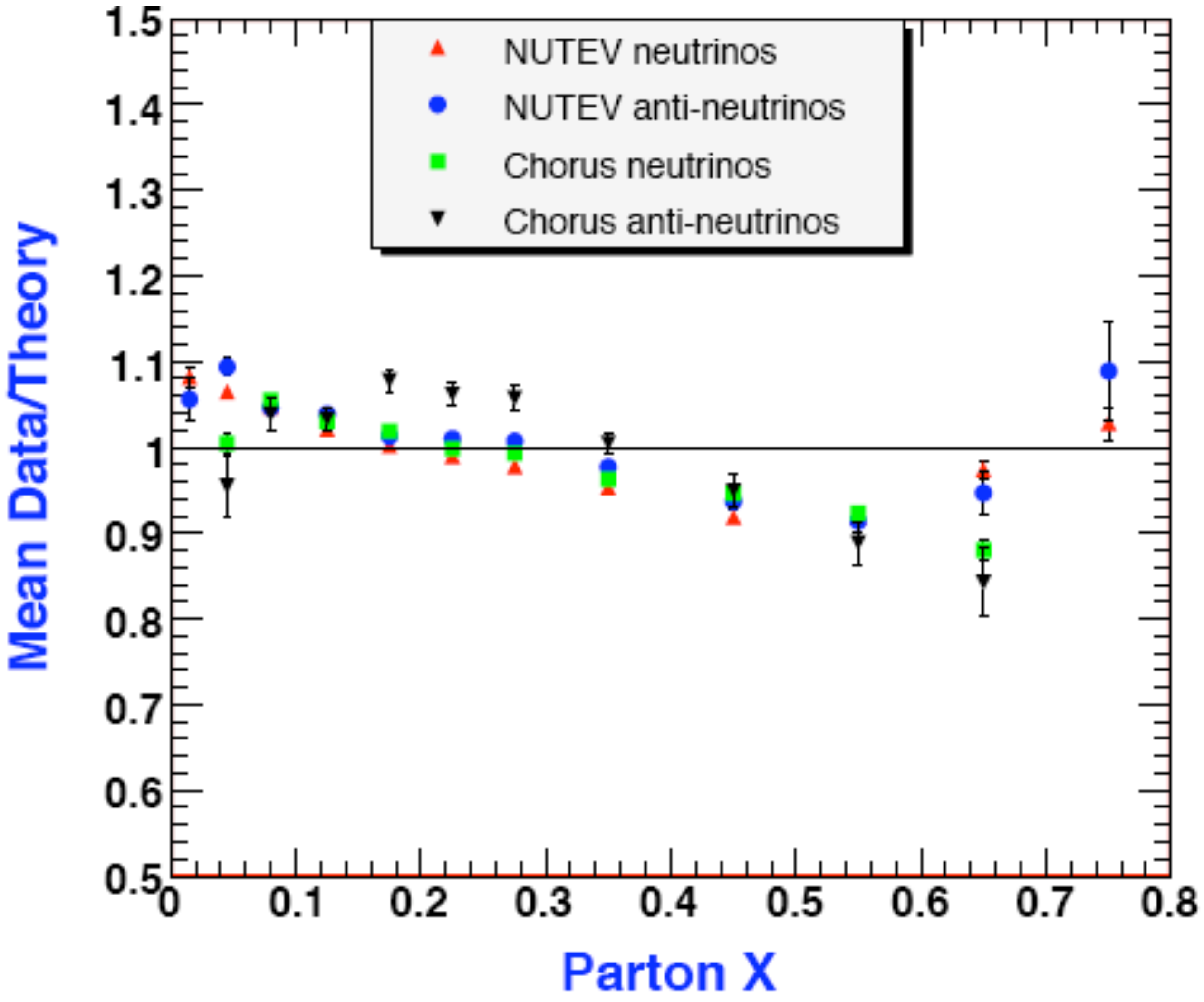


This solution appears as a compromise — increasing the d quark and slightly decreasing the u quark allows an increase in u + d along with a decrease in 4u + d.

There are elevated chi square values for the E-866 data, the NMC ratio data, and for other charged lepton DIS data sets. This again shows that the NuTeV and E-866 data sets are pulling against each other

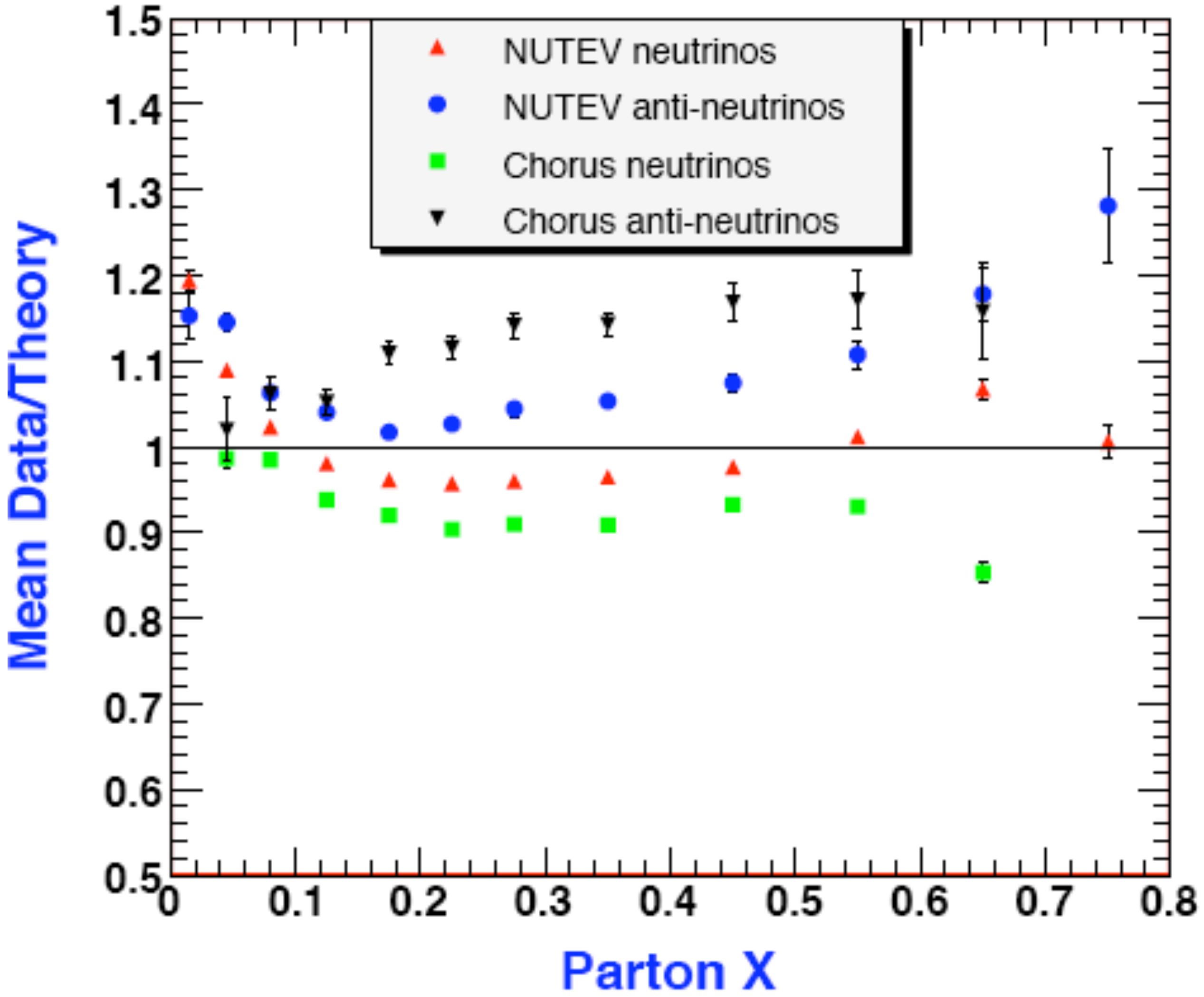
NuTeV(Fe) and CHORUS (Pb) ν scattering (unshifted) results compared to reference fit

no nuclear corrections



NuTeV σ(Fe) & CHORUS σ(Pb) ν scattering (un-shifted) results compared to reference fit

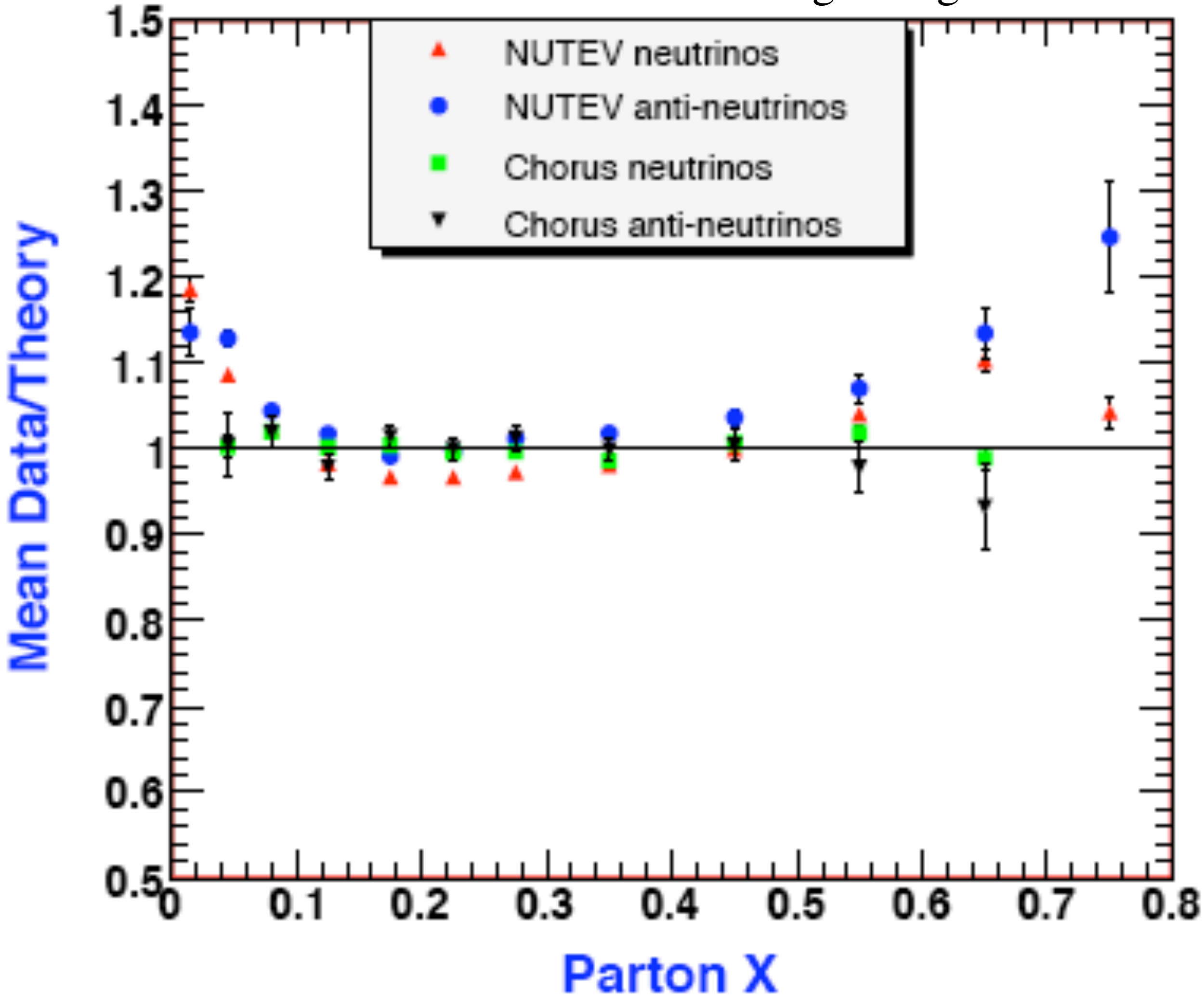
Kulagin-Petti nuclear corrections



Comparison of the Reference Fit and NuTeV and CHORUS Cross section Data

Data already optimally shifted within correlated systematic errors

Corrected for nuclear effects using Kulagin-Petti



Here we are….

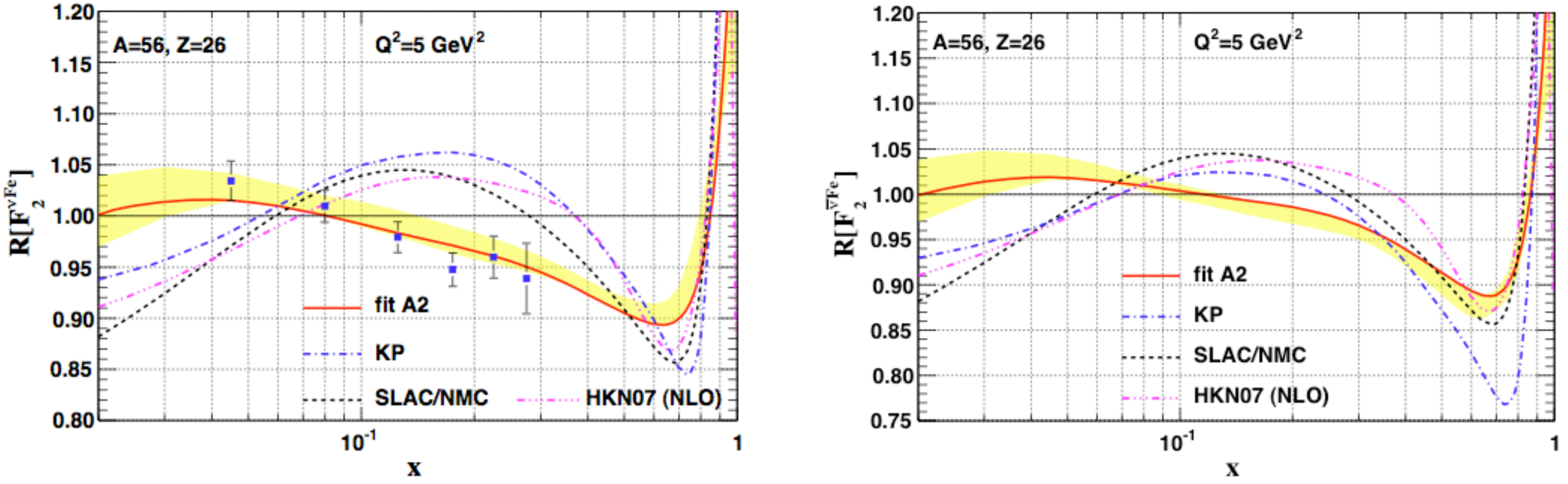
- All of the NuTeV Results are for $\nu/\bar{\nu}$ – Fe interactions while the CHORUS results are for $\nu/\bar{\nu}$ – Pb
- We have used the nuclear corrections for neutrino interactions from Kulagin-Petti model of ν−nucleus interactions
- Whereas CHORUS results, with their larger systematics, are consistent with the reference fit, NuTeV results at both high- and low-x are <u>not</u>!
- **Are neutrinos trying to tell us something new about high-x? Are the nuclear corrections for $\nu/\underline{\nu}$ interactions different than predicted by Kulagin-Petti?**
- **We decided to look at neutrino nuclear corrections!**

Nuclear PDFs from neutrino deep inelastic scattering

Fred Olness Presentation Tomorrow AM

I. Schienbein (SMU & LPSC-Grenoble, J-Y. Yu (SMU)
C. Keppel (Hampton & JeffersonLab) J.G.M. (Fermilab),
F. Olness (SMU), J.F. Olness (Florida State U)

F_2 Structure Function Ratios: ν-Iron and $\overline{\nu}$-Iron



Next Conclusions

- All high-statistics neutrino data is off nuclear targets. Need nuclear correction factors to include data off nuclei in fits with nucleon data.
- Nuclear correction factors (R) seems to be different for neutrino-Fe scattering compared to charged lepton-Fe.
  - Results from one experiment on one nuclear target… careful.
- **We need a neutrino experiment to measure these nuclear correction factors!**
- **For the cleanest study of high-x nucleon structure, a $\underline{\nu/\bar{\nu}}$-hydrogen experiment is excellent!**

High-*x* Structure Functions & PDFs

ν - p Scattering

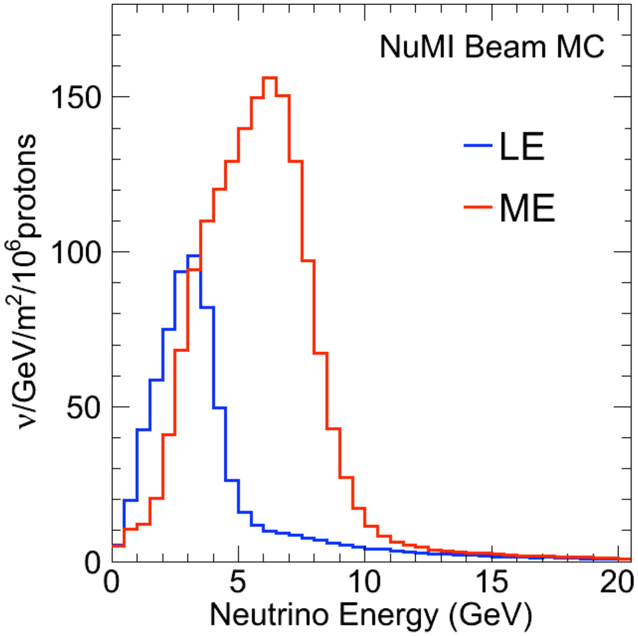
$$\left.\begin{array}{l} F_2^{\nu p} = 2x\,(d + \bar{u} + s) \\[1em] F_2^{\bar{\nu} p} = 2x\,(\bar{d} + u + \bar{s}) \end{array}\right\} \xrightarrow{\text{At high x}} \boxed{\frac{F_2^{\nu p}}{F_2^{\bar{\nu} p}} \approx \frac{d}{u}}$$

Add in…

$$\left.\begin{array}{l} xF_3^{\nu p} = 2x\,(d - \bar{u} + s) \\[1em] xF_3^{\bar{\nu} p} = 2x\,(-\bar{d} + u - \bar{s}) \end{array}\right\} \longrightarrow \begin{array}{l} F_2^{\nu p} - xF_3^{\nu p} = 4x\bar{u} \\[1em] F_2^{\bar{\nu} p} + xF_3^{\bar{\nu} p} = 4xu \end{array}$$

By chance, such an experiment already exists!

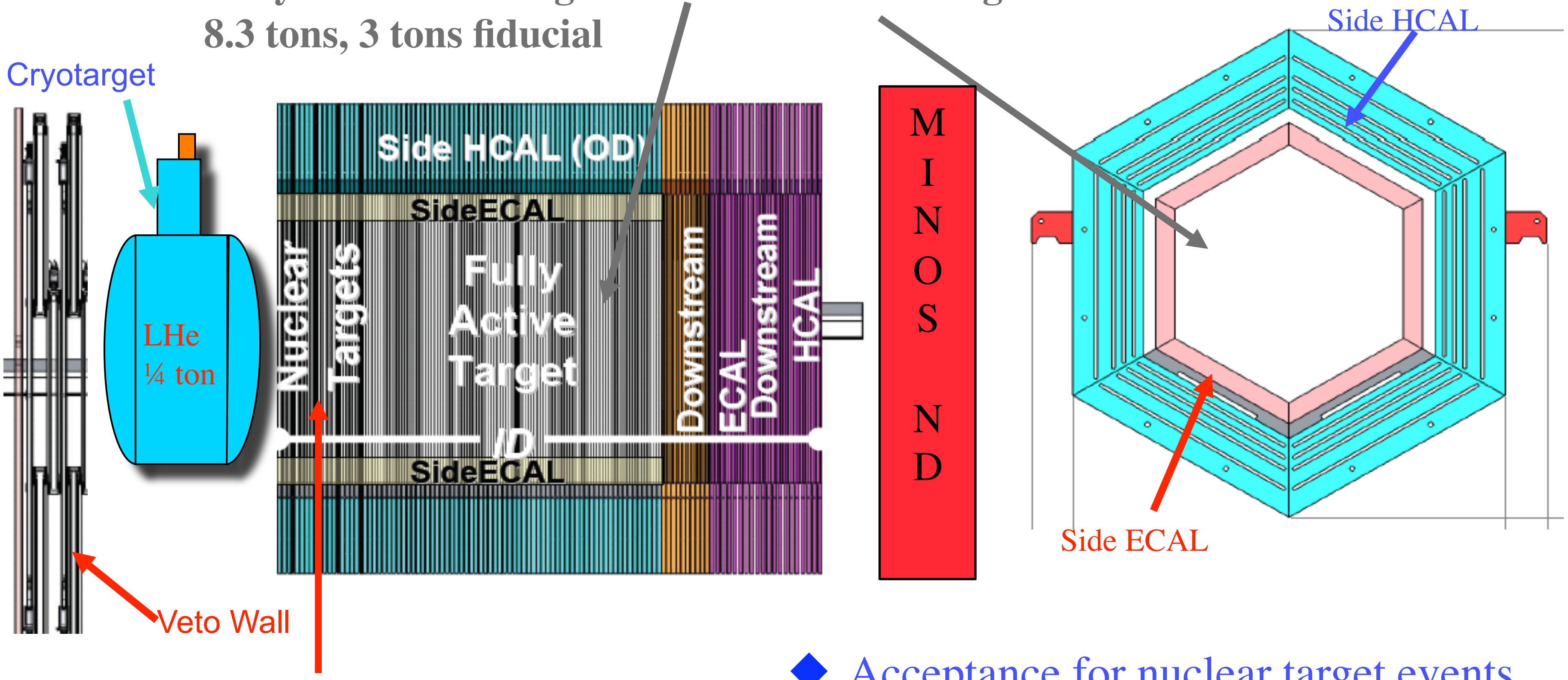
The MINERνA Experiment at Fermilab



The MINERνA Detector

MINOS Near Detector is our μ Spectrometer

Fully Active Fine Segmented Scintillator Target
8.3 tons, 3 tons fiducial



Nuclear Targets with Pb, Fe, C, H_2O,CH
Simultaneous in the same neutrino beam
reduces systematic errors between nuclei

- Acceptance for nuclear target events in the MINOS near detector is …. Complicated.

Estimated MINERνA Produced Event Rates

Using the NUGEN Neutrino Event Generator

Assume 4.0x10^{20} **POT in LE and** 12.0x10^{20} **POT in the ME NuMI beam configurations**

Fiducial Volume = 3 tons CH, 0.2t He, 0.15t C, .35t H_2O, 0.7t Fe and 0.85t Pb
Expected CC event samples:
9.0 M ν events in CH
0.6 M ν events in He
0.4 M ν events in C
0.9 M events in H_2O
2.0 M ν events in Fe
2.5 M ν events in Pb

Main CC Physics Topics (Statistics in CH)

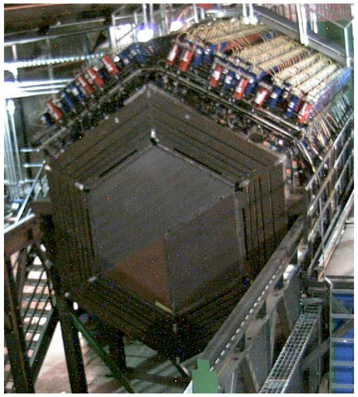
◆ **Quasi-elastic**	**0.8 M events**
◆ **Resonance Production**	**1.7 M total**
◆ **Transition: Resonance to DIS**	**2.1 M events**
◆ **DIS, Structure Funcs. and high-x PDFs**	**4.3 M DIS events**
◆ **Coherent Pion Production**	**89 K CC / 44 K NC**
◆ **Strange and Charm Particle Production**	**> 240 K fully reconstructed events**
◆ **Generalized Parton Distributions**	**order 10 K events**
◆ **Nuclear Effects**	**nuclear target event rates as above**

Broad Range of Nuclear Targets

Acceptance for μ’s in MINOS from the nuclear targets…complicated!

- 5 nuclear targets + water target
- He target upstream of detector
- Near million-event samples
  (4×10^{20} POT LE beam + 12×10^{20} POT in ME beam

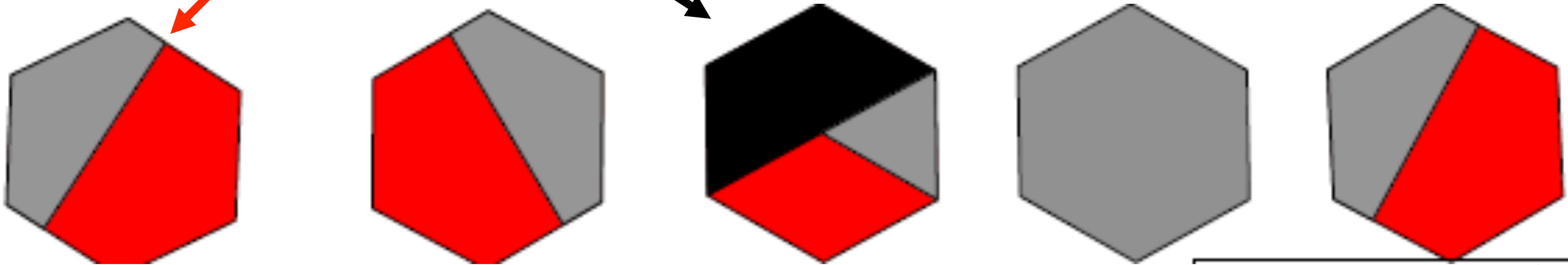
Target	**Mass in tons**	**CC Produced Events (Million)**
Scintillator	3	9
He	0.2	0.6
C (graphite)	0.15	0.4
Fe	0.7	2.0
Pb	0.85	2.5
Water	0.3	0.9



Water target

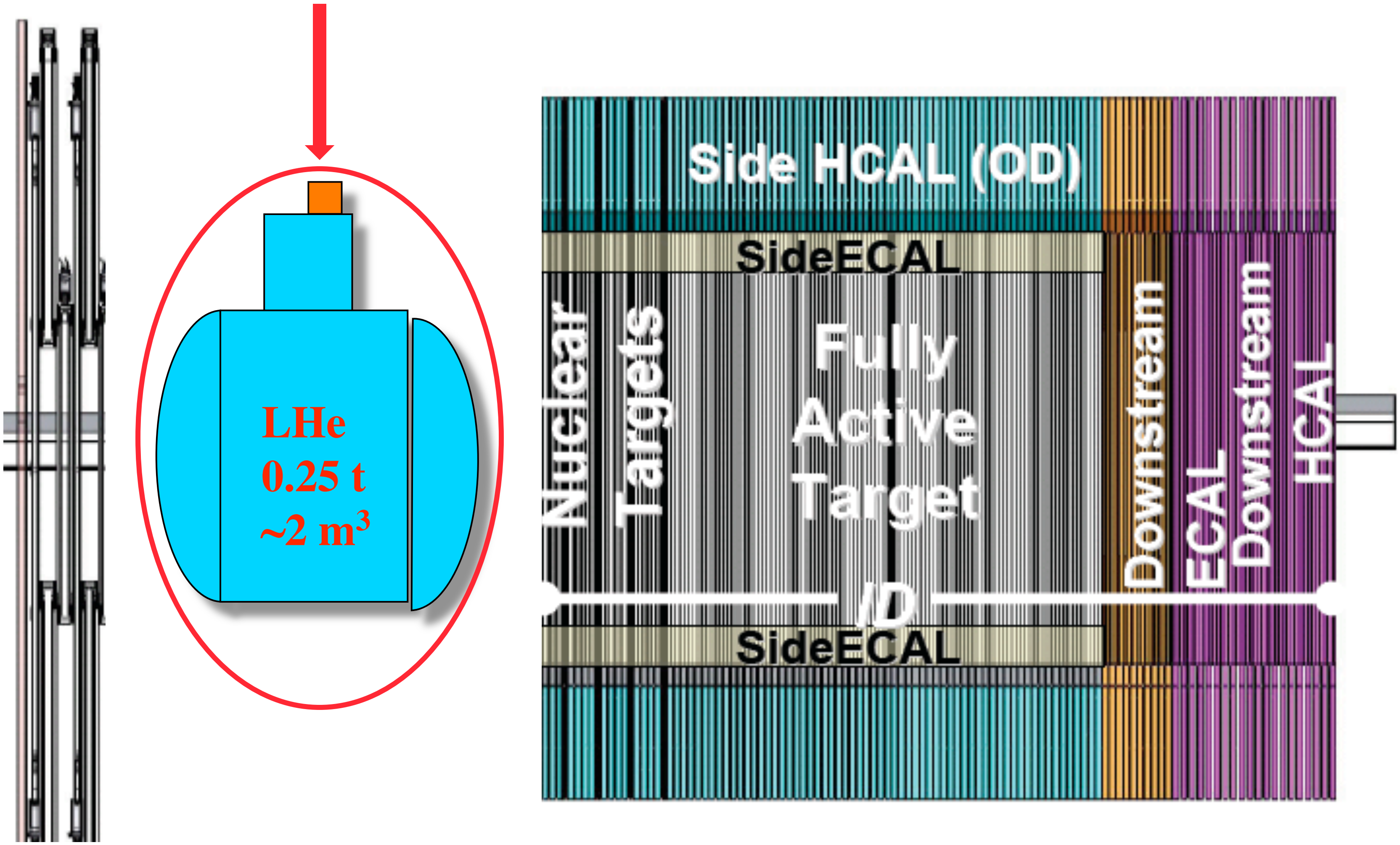
5 Nuclear Targets

Fe Pb C



The MINERνA Cryo Target

Submit Proposal to fill with Hydrogen/Deuterium? - Hampton



A MINERνA Proposal for H/D Cryo-fill - Hampton

Pre-proposal Cryo-Target Event estimates from Lingyan Zhu – Hampton

- With the Cryo target filled with liquid hydrogen and an exposure of $5x10^{20}$ POT in the ME ν beam we expect:
  - Total of ≈ 90 k CC ν_μ events produced.
  - Of these, ≈ 15% have $x_{bj} > 0.5$ and
  - ≈ 10% have $x_{bj} > 0.5$ and $Q^2 > 1$ GeV^2
  - Acceptance will further reduce the $x > 0.5$ statistics by a factor of 3 – 15
- With the Cryo target filled with deuterium and an exposure of $5x10^{20}$ POT in the ME ν beam we expect:
  - Total of ≈ 340 k CC ν_μ events produced.
  - Of these, ≈ 25% have $x_{bj} > 0.5$ and
  - ≈ 15% have $x_{bj} > 0.5$ and $Q^2 > 1$ GeV^2
  - Acceptance will further reduce the $x > 0.5$ statistics by a factor of 3 – 10
- NOνA Me run with $3x10^{21}$ POT on each ν and $\bar{\nu}$

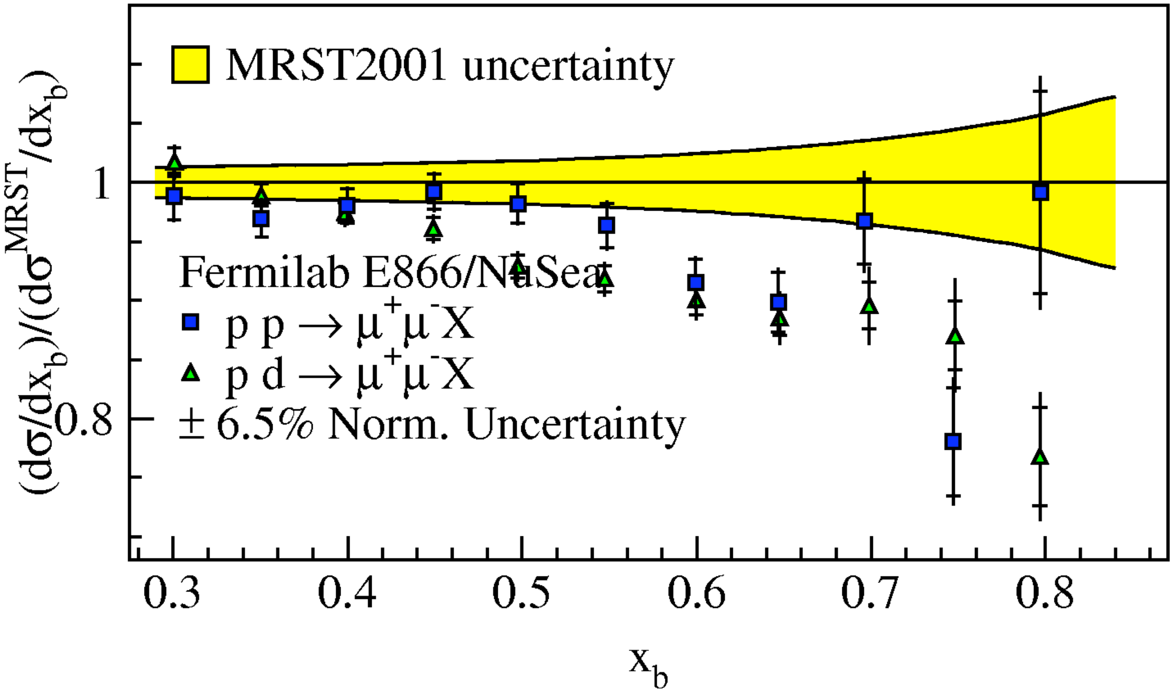
Summary and Conclusions

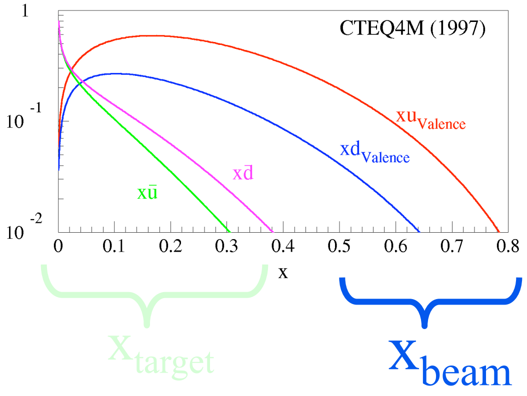
- Neutrino scattering can provide an important look at the nucleon at high x from a different (and complimentary) direction than electro-production.
  - The ability of neutrinos and anti-neutrinos to taste particular flavors of quarks can help isolate PDFs
- To acquire the needed statistics, neutrino experiments use heavy nuclear targets. **Need to understand ν-induced nuclear effects!**
  - **Use the difference between ν and $\bar{\nu}$ to measure** δ^{CP}**. Are and nuclear effects the same?**
- There are indications from **one** experiment using **one** nucleus that **ν-induced nuclear effects are different** than ℓ±-nuclear effects.
  - You'll hear from Fred Olness tomorrow that there is no good compromise fit to the ℓ±A + DY and νA data.
- Need a systematic **experimental** study of **ν-induced nuclear effects.**
  - **Need collaborative NP input to fully and correctly analyze crucial high-accuracy neutrino experiments!**
- **The best way for neutrinos to contribute to our undestanding of the nucleon at high-x is to look at ν/ν – hydrogen scattering with MINERνA**

Additional Details

Further indications that the valence quarks not quite right at high-x??

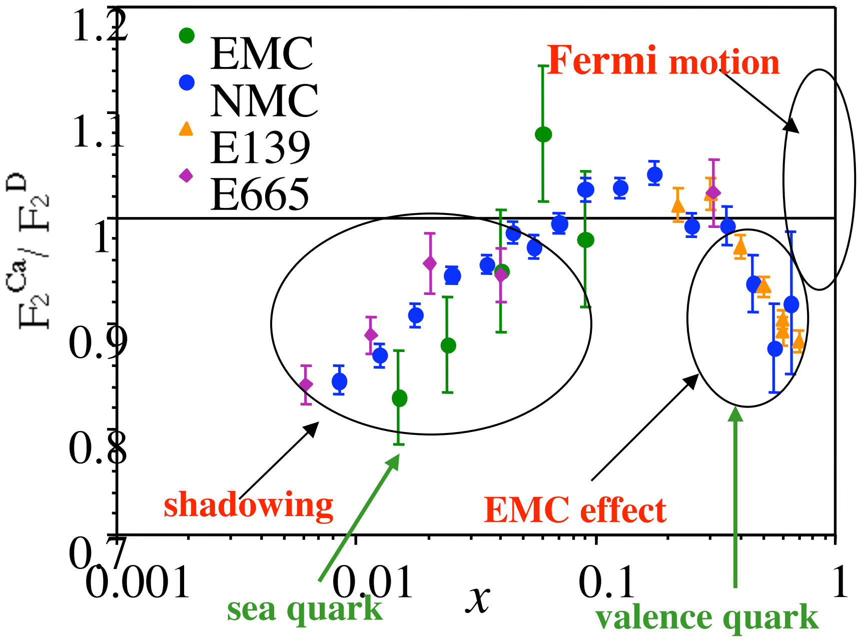
E866 -Drell-Yan Preliminary Results (R. Towell - Hix2004)

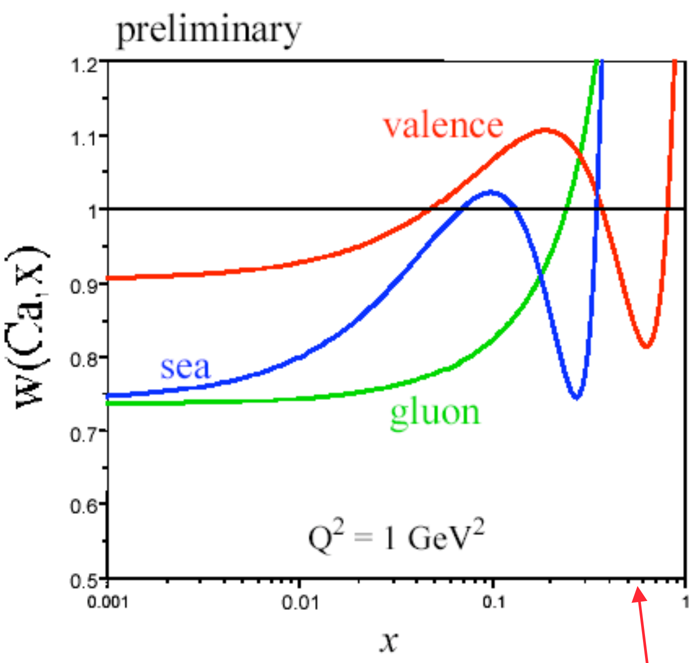




- **x_{beam} distribution measures *4u + d* as *x--> 1*.**
- **Both MRST and CTEQ <u>*overestimate*</u> valence distributions as *x --> 1* by 15-20%.**
- **Possibly related to *d/u* ratio as *x --> 1*, but requires full PDF-style fit.**
- *Radiative corrections have recently been calculated. (Not yet fully applied)*

Knowledge of Nuclear Effects with Neutrinos: essentially NON-EXISTENT





- F_2 / nucleon changes as a function of A. Measured in μ/e - A **not in ν − A**
- **Good reason to consider nuclear effects are DIFFERENT in ν - A.**
    - **Presence of axial-vector current.**
    - **SPECULATION: Much stronger shadowing for ν -A but somewhat weaker "EMC" effect.**
    - **Different nuclear effects for valance and sea --> different shadowing for xF_3 compared to F_2.**
    - **Different nuclear effects for d and u quarks.**

Formalism

- PDF Parameterized at Q_0 = 1.3 GeV as

$$xf_i(x,Q_0) = \begin{cases} A_0 x^{A_1}(1-x)^{A_2} e^{A_3 x}(1+e^{A_4}x)^{A_5} & : i = u_v, d_v, g, \bar{u}+\bar{d}, s, \bar{s}\,, \\ A_0 x^{A_1}(1-x)^{A_2} + (1+A_3 x)(1-x)^{A_4} & : i = \bar{d}/\bar{u}\,, \end{cases}$$

- PDFs for a nucleus are constructed as:

$$f_i^A(x,Q) = \frac{Z}{A}\, f_i^{p/A}(x,Q) + \frac{(A-Z)}{A}\, f_i^{n/A}(x,Q)$$

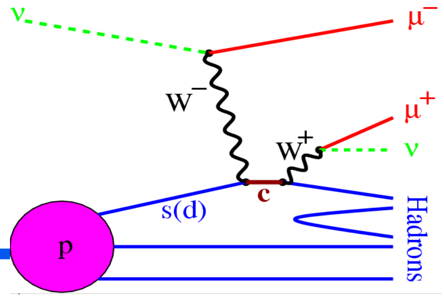
- Resulting in nuclear structure functions:

$$F_i^A(x,Q) = \frac{Z}{A}\, F_i^{p/A}(x,Q) + \frac{(A-Z)}{A}\, F_i^{n/A}(x,Q)$$

- The differential cross sections for CC scattering off a nucleus::

$$\frac{d^2\sigma}{dx\,dy}^{\overset{(-)}{\nu}A} = \frac{G^2 M E}{\pi}\left[(1 - y - \frac{Mxy}{2E})F_2^{\overset{(-)}{\nu}A} + \frac{y^2}{2} 2xF_1^{\overset{(-)}{\nu}A} \pm y(1-\frac{y}{2})xF_3^{\overset{(-)}{\nu}A}\right]$$

Charm Production by Neutrinos
a direct look at strange sea.



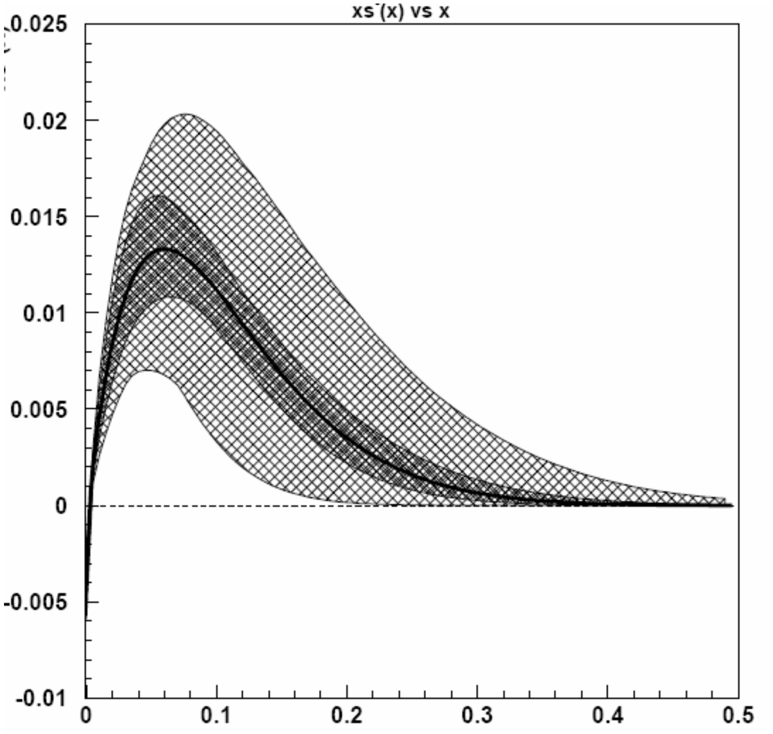
- Charm quark is produced from CC neutrino interaction with s(d) quark in the nucleon. d-quark interaction is CKM suppressed
- Detect charm via the semi-leptonic decay which yields a very clear signature – two opposite sign muons
- It is sensitive to m_c through E_ν dependence.
- With high-purity ν and $\bar{\nu}$ beams, NuTeV made high statistics separate s and $\bar{s}$ measurements: 5163 ν and 1380 $\bar{\nu}$
- Could then make a measurement of $s - \bar{s}$.

Strange Sea Asymmetry

$$s^{-} = (s - \bar{s})$$

$$S^{-} = \int_0^1 xs^{-}(x)dx = 0.00196 \pm \underset{\text{(stat)}}{0.00046} \pm \underset{\text{(syst)}}{0.00045} \pm \underset{\text{(external)}}{0.00128}$$

- CTEQ inspired NLO model,
- in the fit net strangeness of the nucleon is forced to 0.



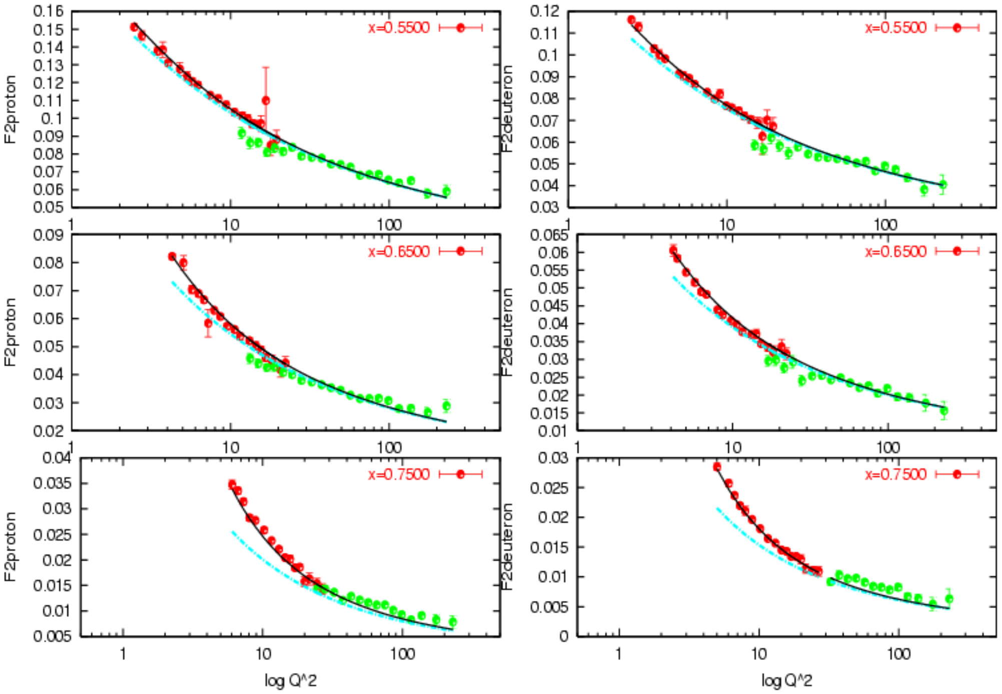
m_c = 1.41±0.10(stat)±0.008(syst)±0.12(ext) GeV/c^2

This is an anlysis of strange quarks in an Fe nucleus!

Are ν nuclear effects known? Are they the same for ν and $\bar{\nu}$?

Higher Twist

- fit to ep, ed data (SLAC, NMC,BCDMS) to account for Target Mass and Higher-Twist effects in parton level cross section model
- important at high x and low Q^2

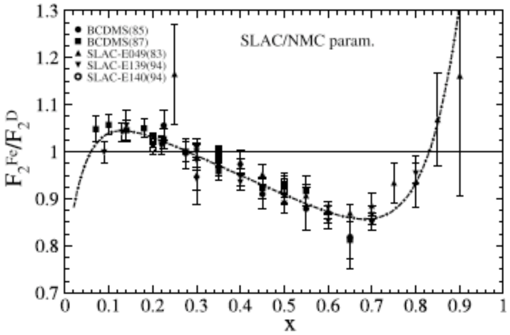


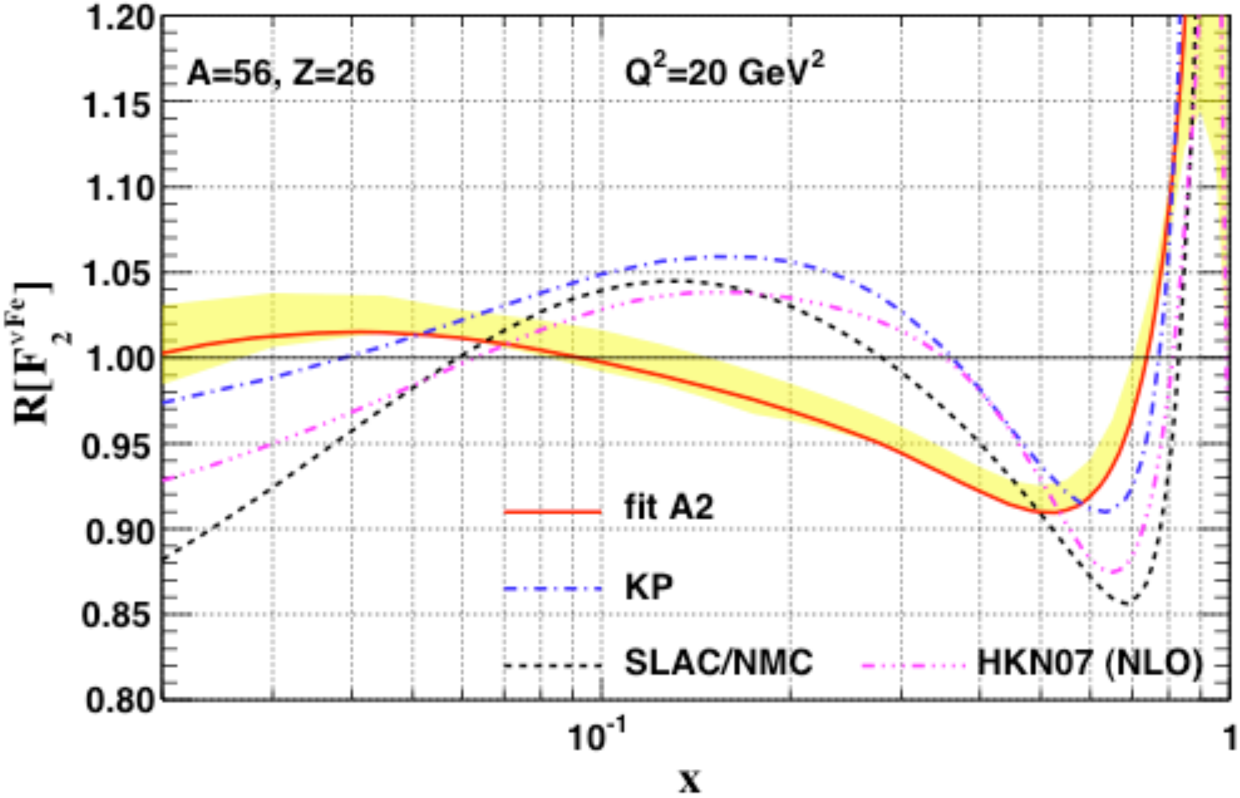
$$x' = x\frac{Q^2+B}{Q^2+Ax}$$

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

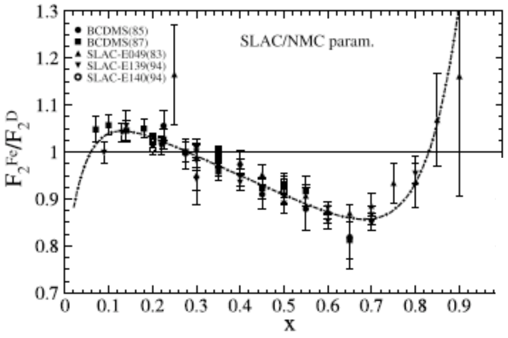
A	**0.57**
B	**0.22**
C	**0.06**
χ^2/dof	**792/312**

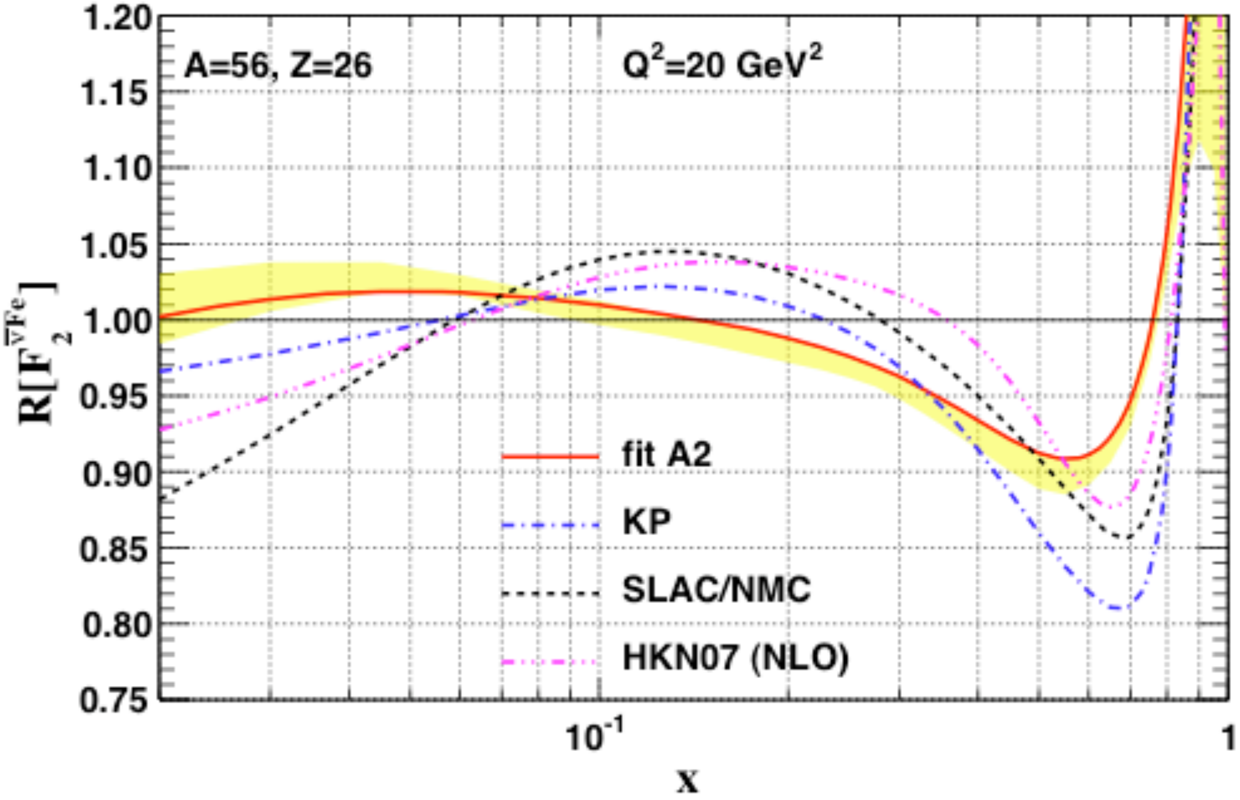
F_2 Structure Function Ratios: ν-Iron





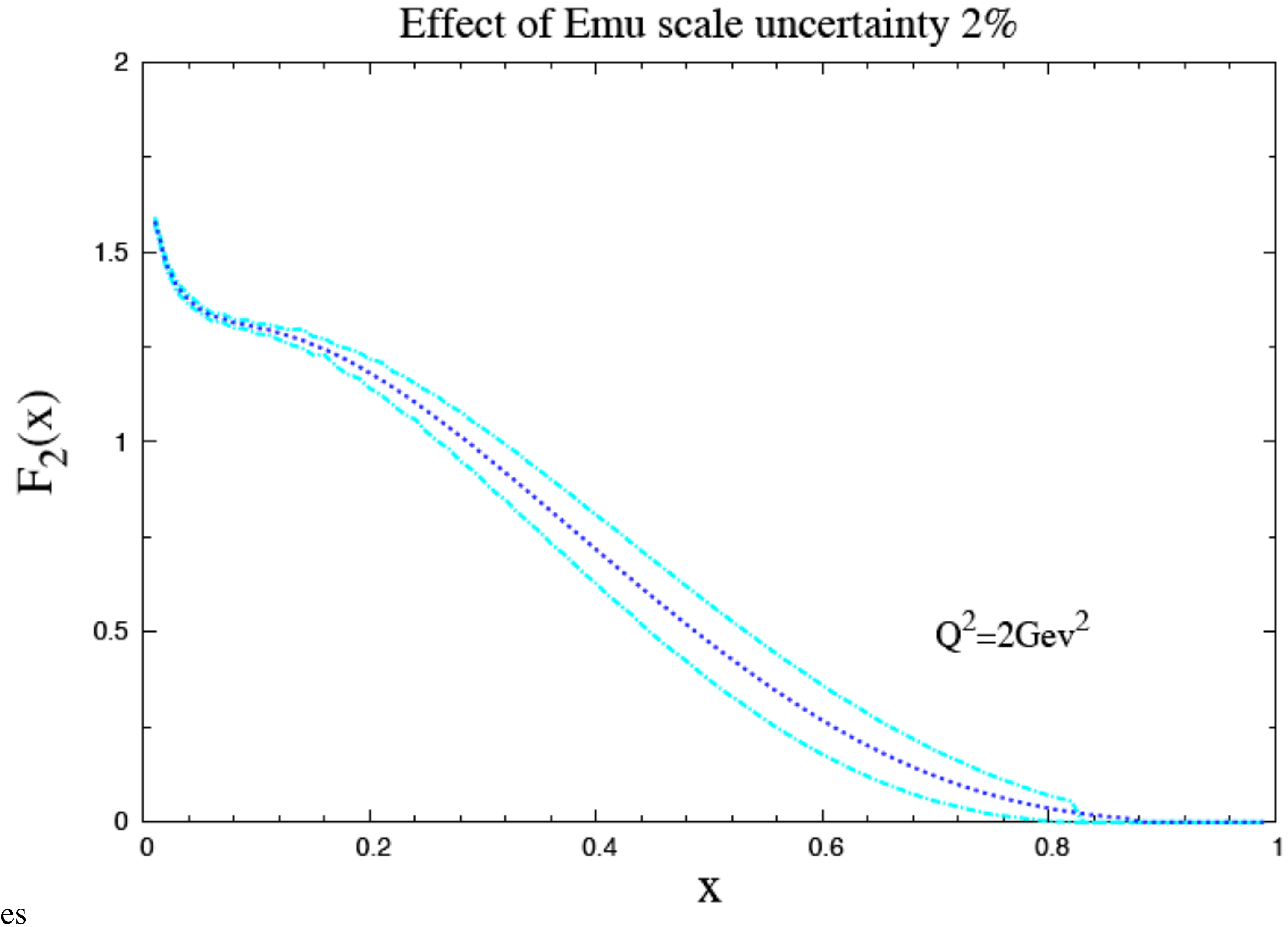
F_2 Structure Function Ratios: $\bar{\nu}$-Iron





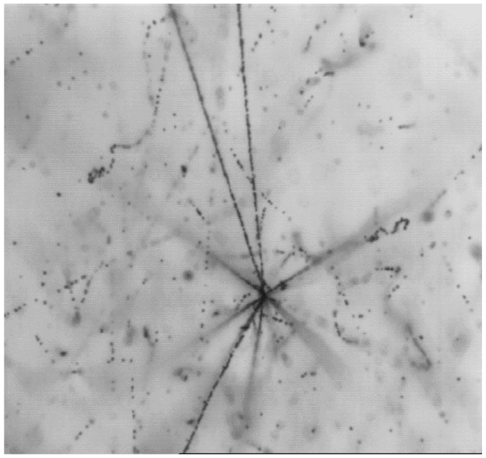
Estimated systematic error: E_μ scale

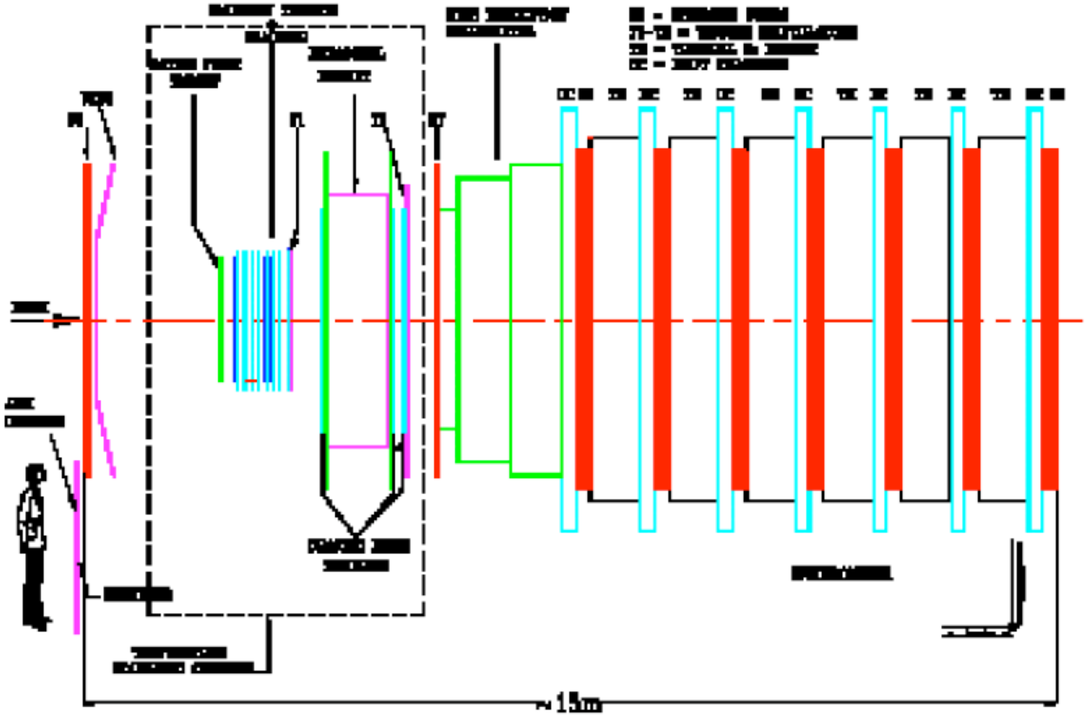
NuTev achieved 0.7%



CHORUS Experiment – nuclear emulsions

- 450 GeV protons -→ 10 – 200 GeV ν, 6% wrong-sign background
- Nuclear Emulsion Target (Pb, Fe, Ca and C)
- Scintillating Fiber tracker



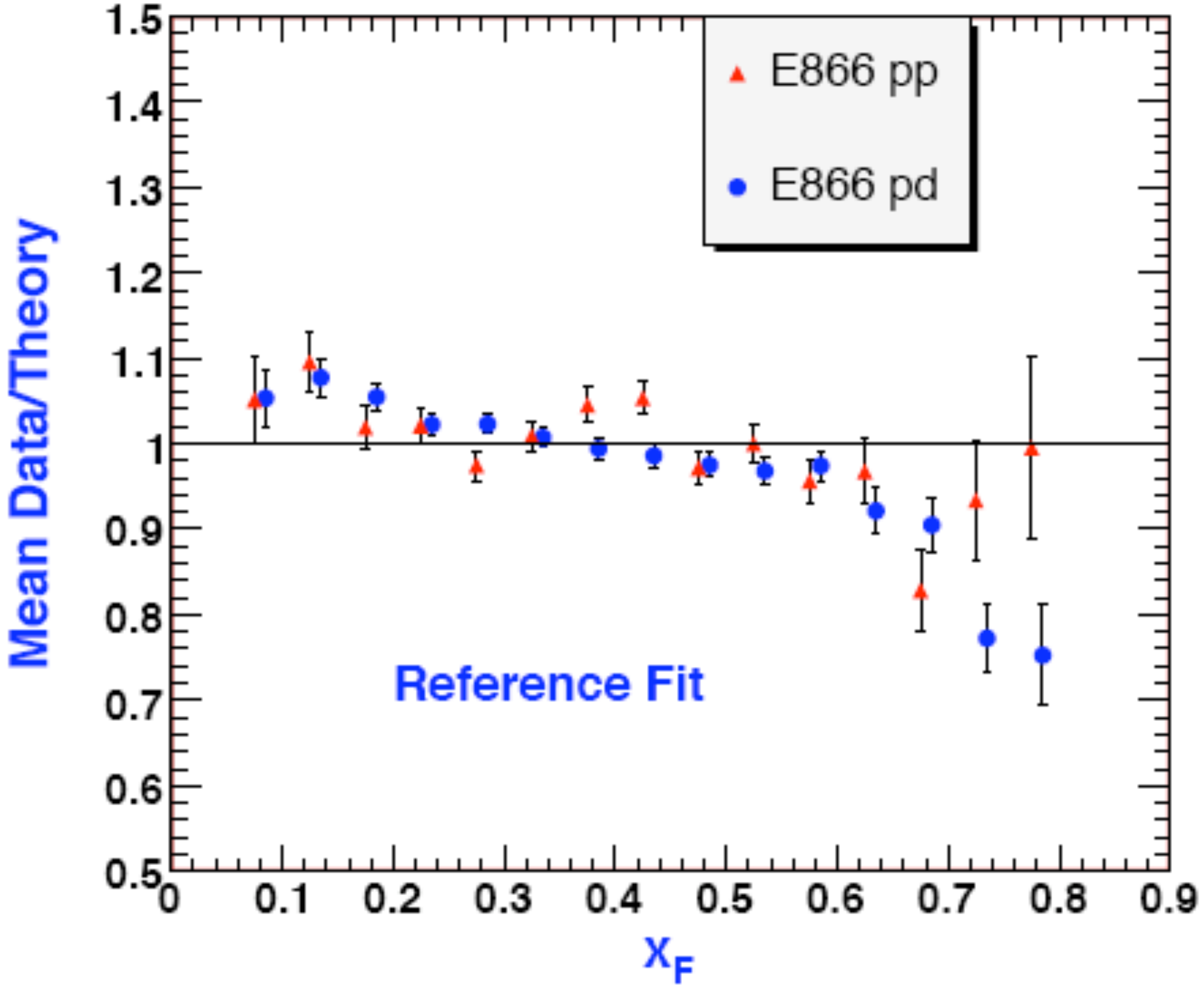


Muon energy scale – 2.5%

Hadron Energy Scale - 5%

(test beam exposure)

Comparison of the Reference Fit and D-Y Data



F_2 and xF_3 Measurement

F_2

$$\left[\frac{d^2\sigma}{dx\,dy}^{\nu}+\frac{d^2\sigma}{dx\,dy}^{\bar\nu}\right]\frac{\pi}{G_F^2 ME}=$$
$$=2\,\overline{F}_2\left(1-y-\frac{Mxy}{2E}+\frac{y^2}{2}\frac{1+4M^2x^2/Q^2}{1+R}\right)+y\left(1-\frac{y}{2}\right)\quad\Delta xF_3$$

- ◆ Perform 1-parameter fit for F_2
- ◆ $\Delta\mathrm{xF}_3$ model
- ◆ R_L model

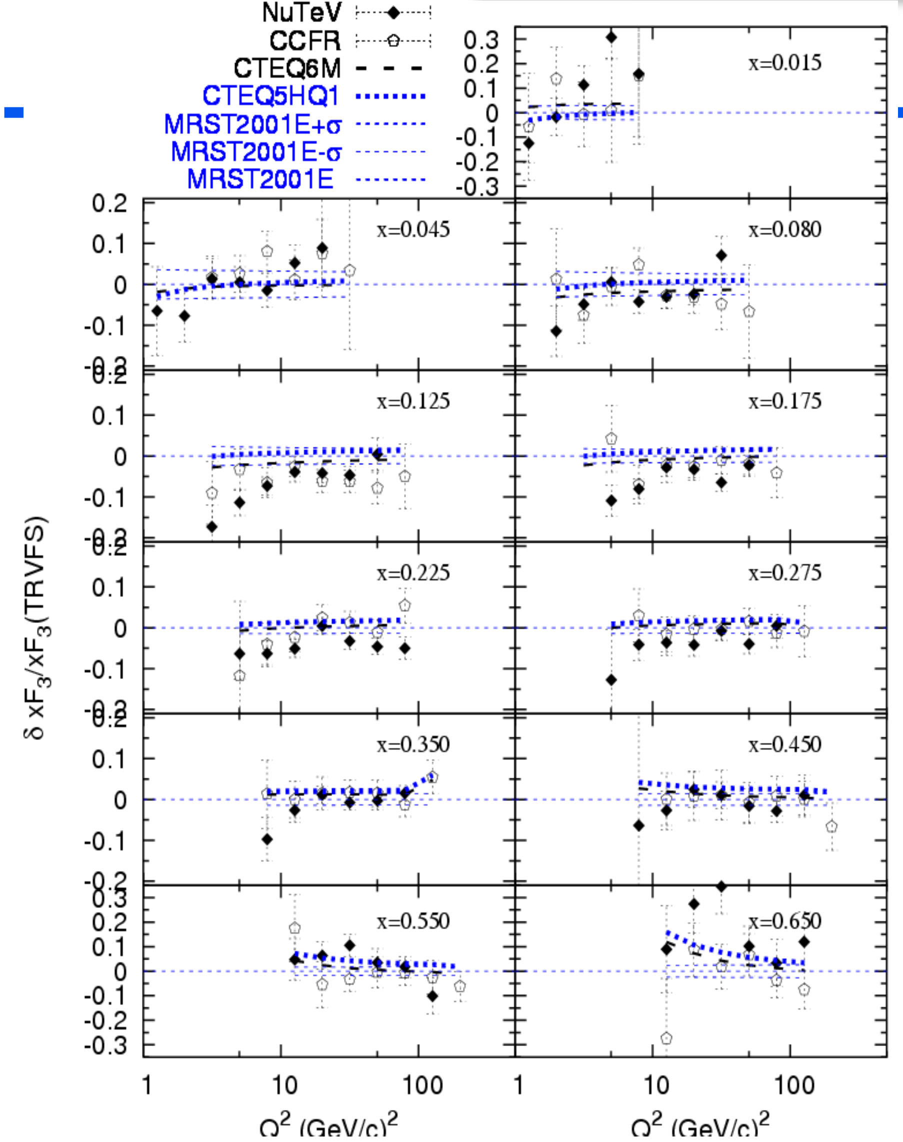
xF_3

$$\left[\frac{d^2\sigma}{dx\,dy}^{\nu}-\frac{d^2\sigma}{dx\,dy}^{\bar\nu}\right]\frac{\pi}{G_F^2 ME}=$$
$$=\Delta F_2\left(1-y-\frac{Mxy}{2E}+\frac{y^2}{2}\frac{1+4M^2x^2/Q^2}{1+R}\right)+2\,y\left(1-\frac{y}{2}\right)\quad x\overline{F}_3$$

- ◆ Perform 1-parameter fit for xF_3
- ◆ $\Delta\mathrm{F}_2$ is very small and is neglected

- ◆ Radiative corrections applied
- ◆ Isoscalar correction applied

Comparison with Global Fits for xF_3



- Baseline is TRVFS(MRST2001E).

- NuTeV and CCFR xF_3 are compared to TRVFS(MRST2001E)

$$\frac{xF_3^{NuTeV} - xF_3^{TRVFS}}{xF_3^{TRVFS}}$$

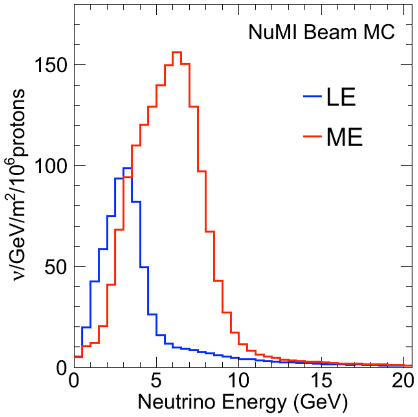
- Theoretical models shown are:
  - ACOT(CTEQ6M)
  - ACOT(CTEQ5HQ1)
  - TRVFS (MRST2001E)

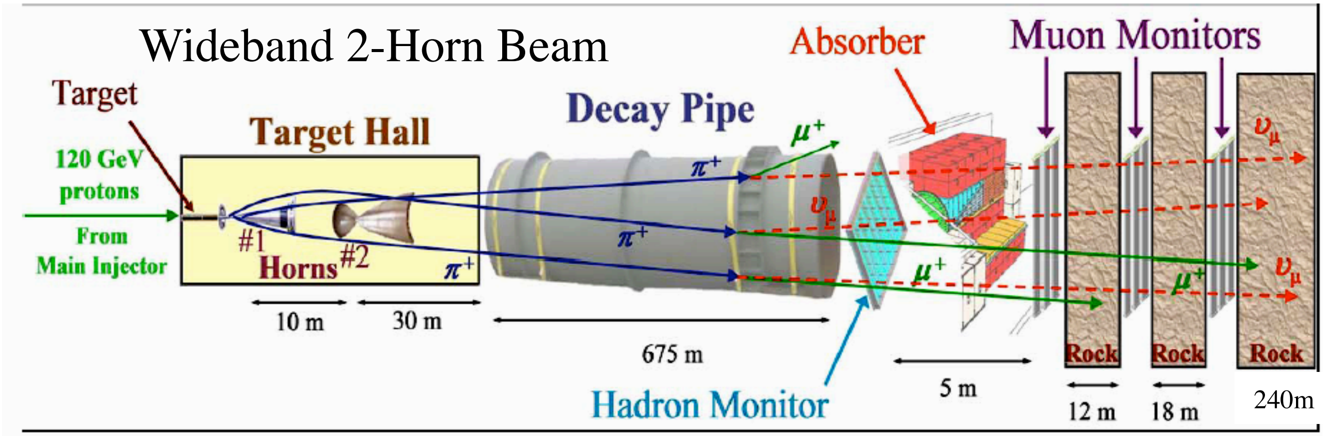
- theory curves are corrected for:
  - target mass *(H. Georgi and H. D. Politzer, Phys. Rev. D14, 1829)*
  - nuclear effects – parameterization from charge lepton data, assumed to be the same for neutrino scattering (no Q^2 dependence added) nuclear effects parameterization is dominated by SLAC (lower Q^2 in this region) data at high-x

- NuTeV xF_3 agrees with theory for medium x.
- At low x different Q^2 dependence.
- At high x (x>0.6) NuTeV is systematically higher.

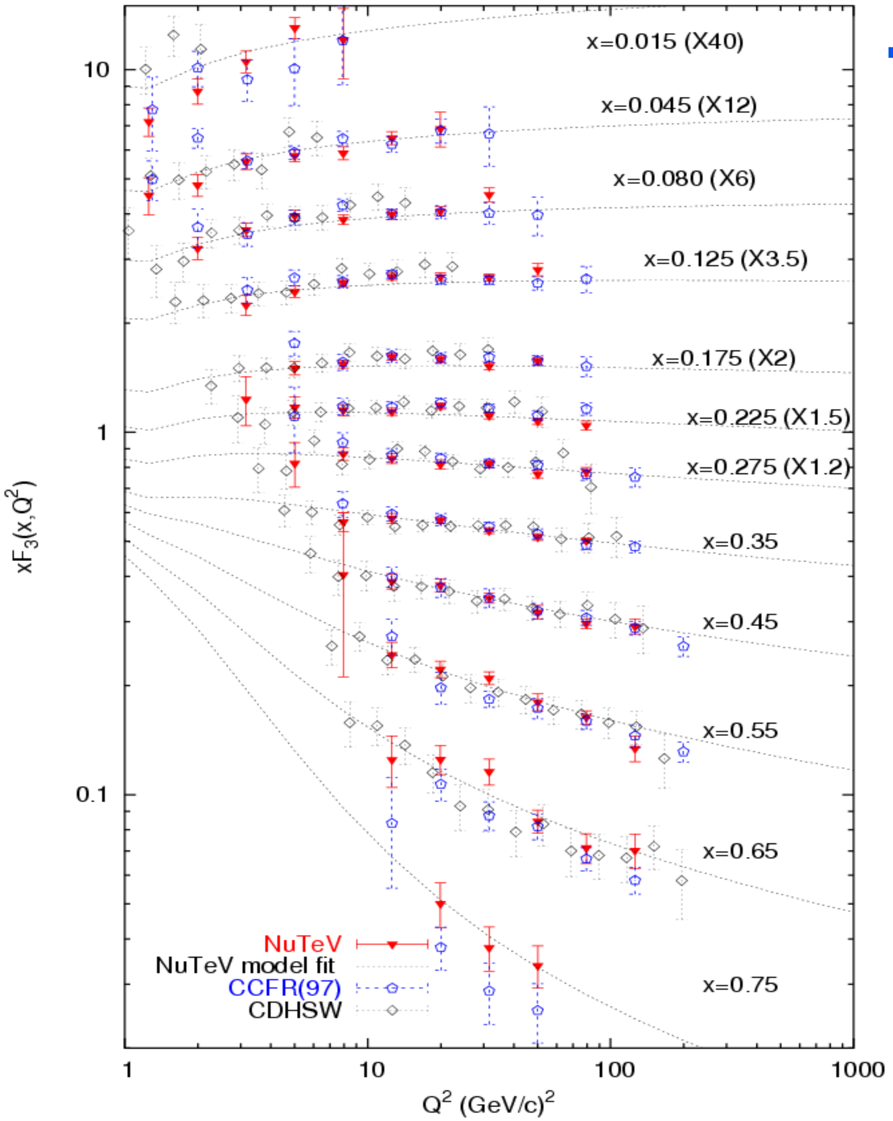
Neutrino Beamlines

- Intense proton beam on a target and collect π and K and focus into a decay space.
- Absorb hadrons and muons leaving only neutrinos.
- Do not know individual E_ν a priori and absolute flux known to 5-10%.





xF_3 Measurement

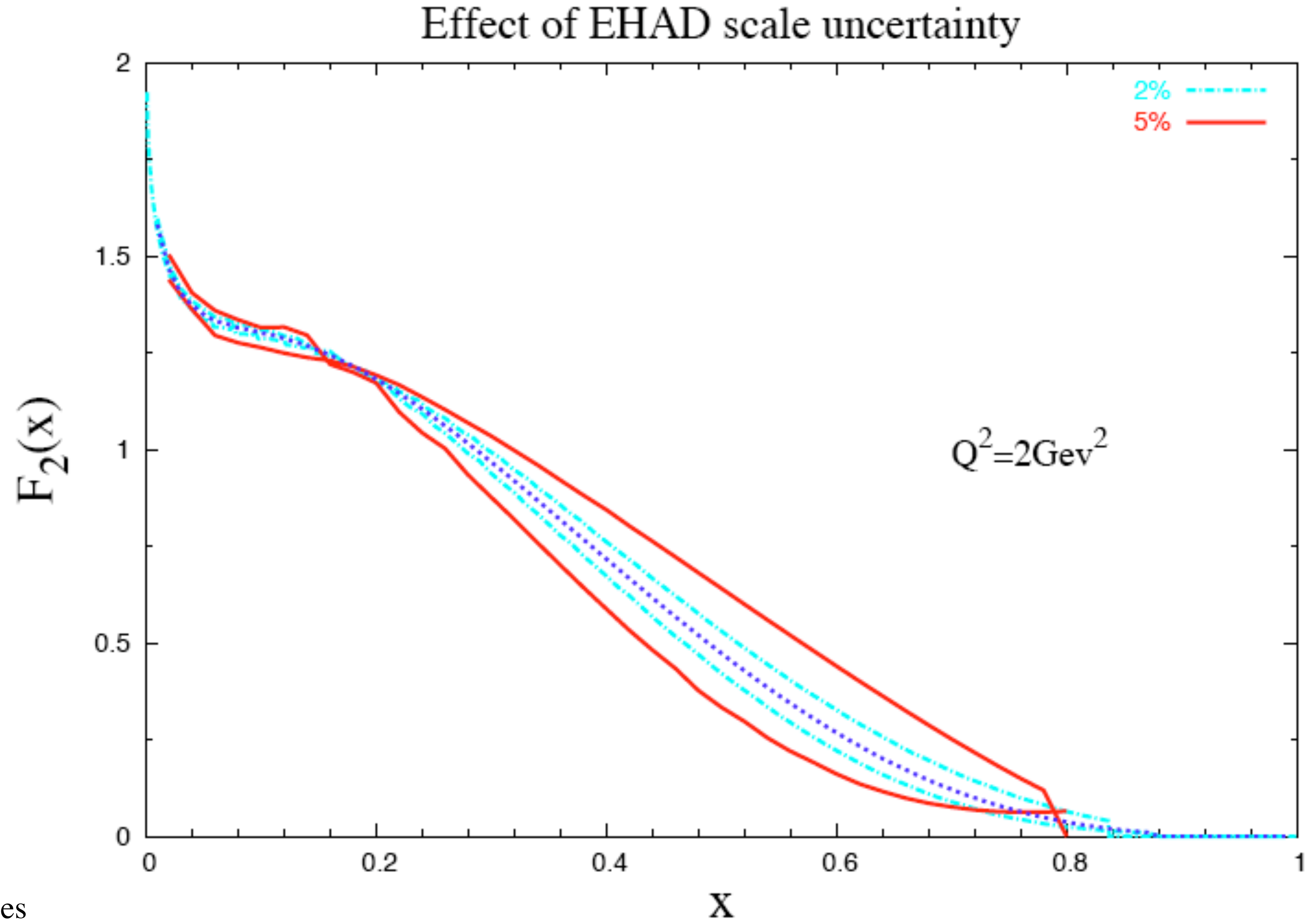


- NuTeV xF_3 compared to CCFR and CDHSW
- All systematic uncertainties are included
- All data sets agree for $x<0.4$.

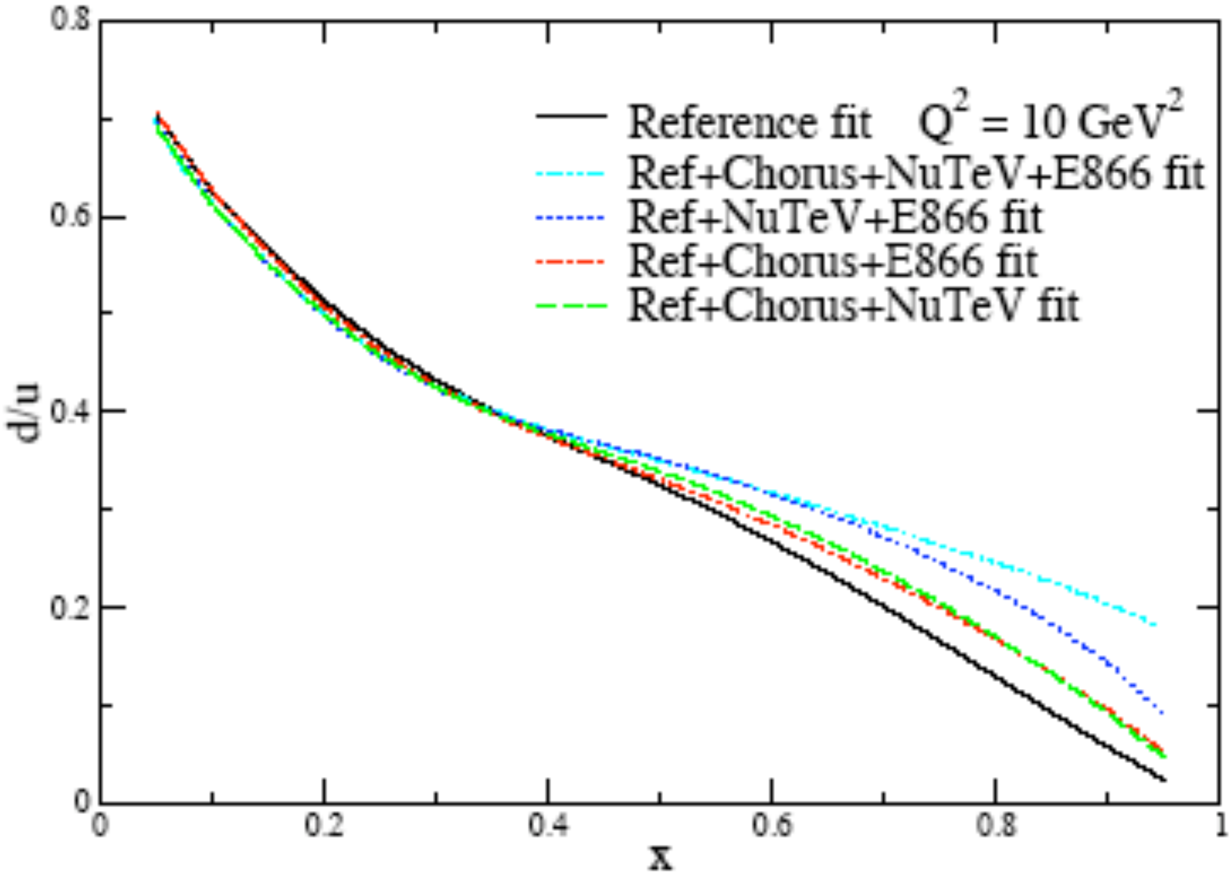
- At $x>0.4$ NuTeV agrees with CDHSW
- At $x>0.4$ NuTeV is systematically above CCFR

A leading systematic error: E_{had} scale

NuTev achieved 0.43%



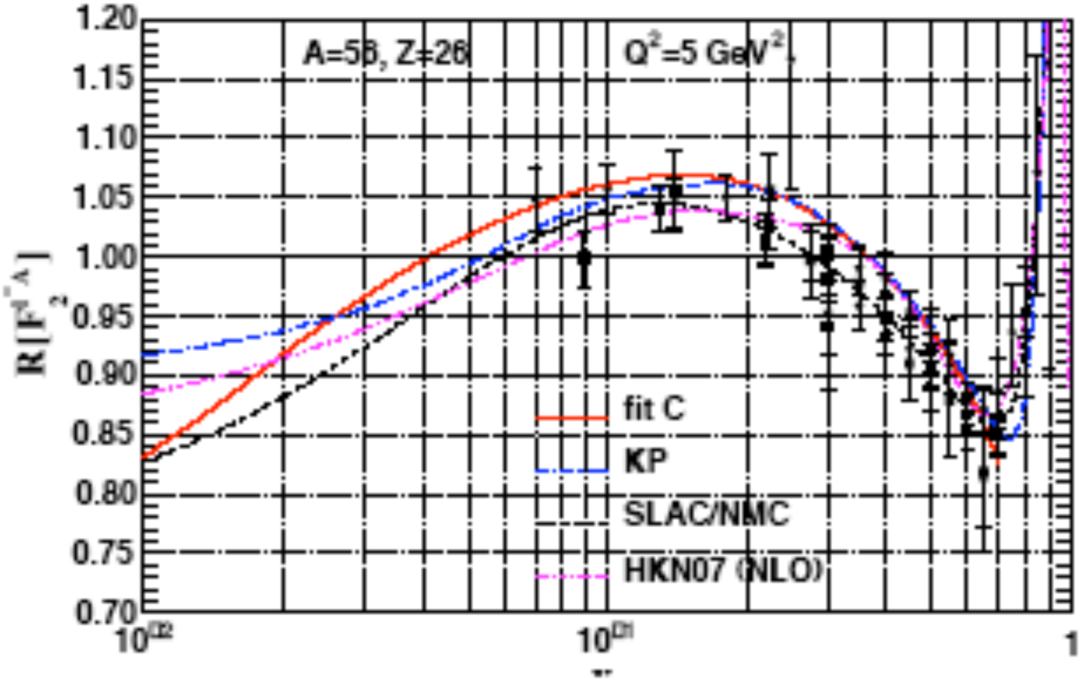
Adding New Data Sets to Ref: all three new sets



There are elevated chi square values for the E-866 data, the NMC ratio data, and for other charged lepton DIS data sets. This again shows that the NuTeV and E-866 data sets are pulling against each other.

Nuclear Structure Function Corrections
ℓ$^\pm$ (Fe/D_2)

See tomorrow's talk by Fred Olness!



- F_2 / nucleon changes as a function of A. Measured in μ/e - A, **not in ν − A**
- **Good reason to consider nuclear effects are DIFFERENT in ν - A.**
  - ▼ **Presence of axial-vector current.**
  - ▼ **Different nuclear effects for valance and sea --> different shadowing for xF_3 compared to F_2.**

NuTeV (ν-Fe) Compared to CCFR (in PDF fits).

(CHORUS (ν-Pb) in between CCFR and NuTeV at high x)