# How do Neutrino Scattering Results Influence Parton Distribution Function Fits?

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NuFact09 - Chicago, IL

# Outline

- What do neutrinos give us that other processes do not (or at least not so directly) with respect to PDFs
- Quick review of what we have and have not learned about PDFs
  - A special look at high-x - in particular d/u as x--> 1
  - How neutrinos can help us here…
- What hinders us from using neutrino results in global PDF fits…

# What's So Special about Neutrinos with respect to PDFs?

**Recall neutrino's unique ability to taste particular flavors**
**Using Leading order expressions (for isoscalar target):**

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

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

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

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

**How neutrinos help us constrain the Strange Sea**

$$\nu N \rightarrow \mu^- c X \rightarrow \mu^- \mu^+ X$$

$$\bar{\nu} N \rightarrow \mu^+ c X \rightarrow \mu^+ \mu^- X$$

# Where are we in understanding PDFs from Global Fits

**Formalism**

LO, NLO, NNLO DGLAP
MSbar factorization
$Q_0^2$
functional form @ $Q_0^2$
sea quark (a)symmetry
etc.

$f_i(x,Q^2) \pm \delta f_i(x,Q^2)$

**Data**

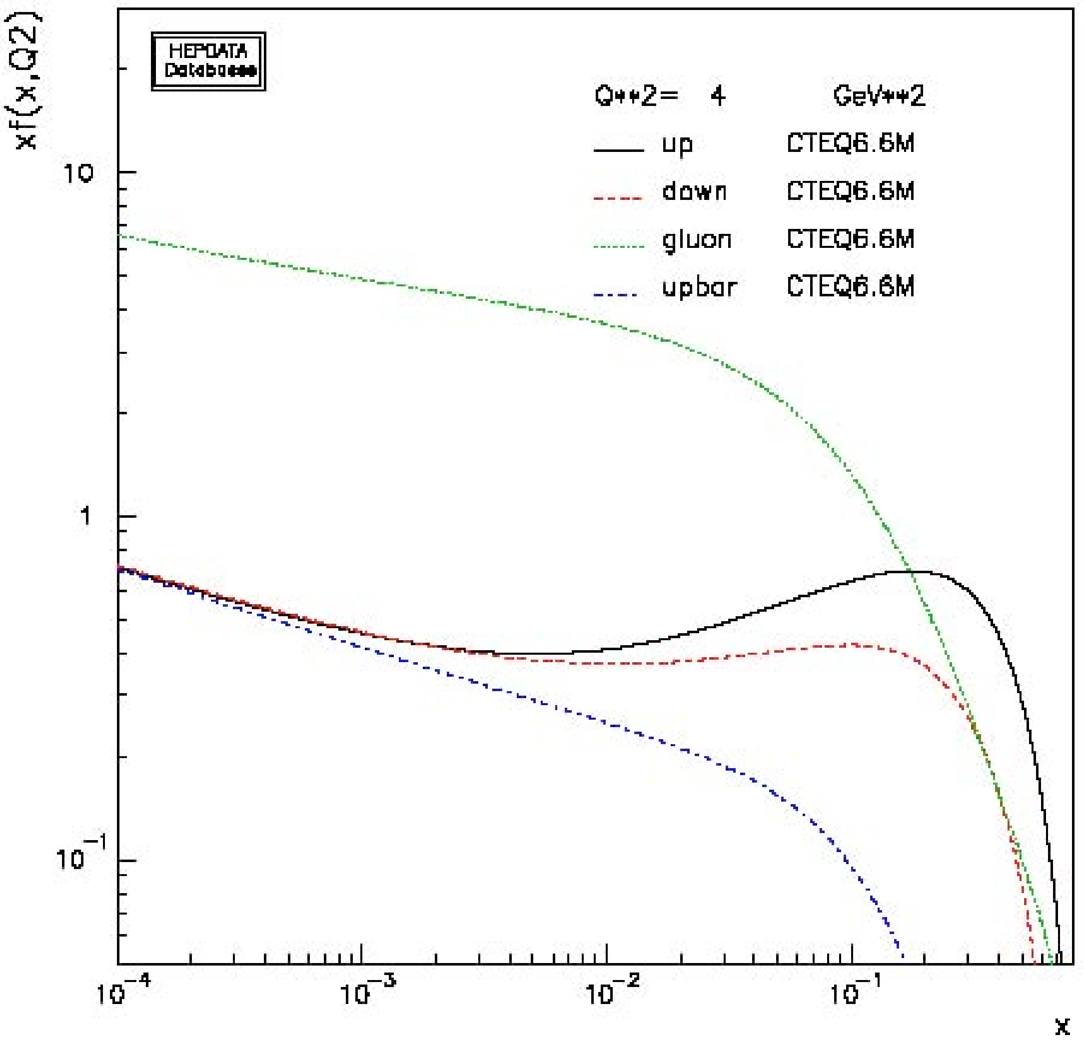
DIS (SLAC, BCDMS, NMC, E665, CCFR(?), H1, ZEUS, NuTeV(?)… )
Drell-Yan (E605, E772, E866, …)
High $E_T$ jets (CDF, D0)
W rapidity asymmetry (CDF, D0)
νN dimuon (CCFR, NuTeV)
etc.

**Who?**

Alekhin, CTEQ, MRST, Botje, H1, ZEUS, GRV, ….

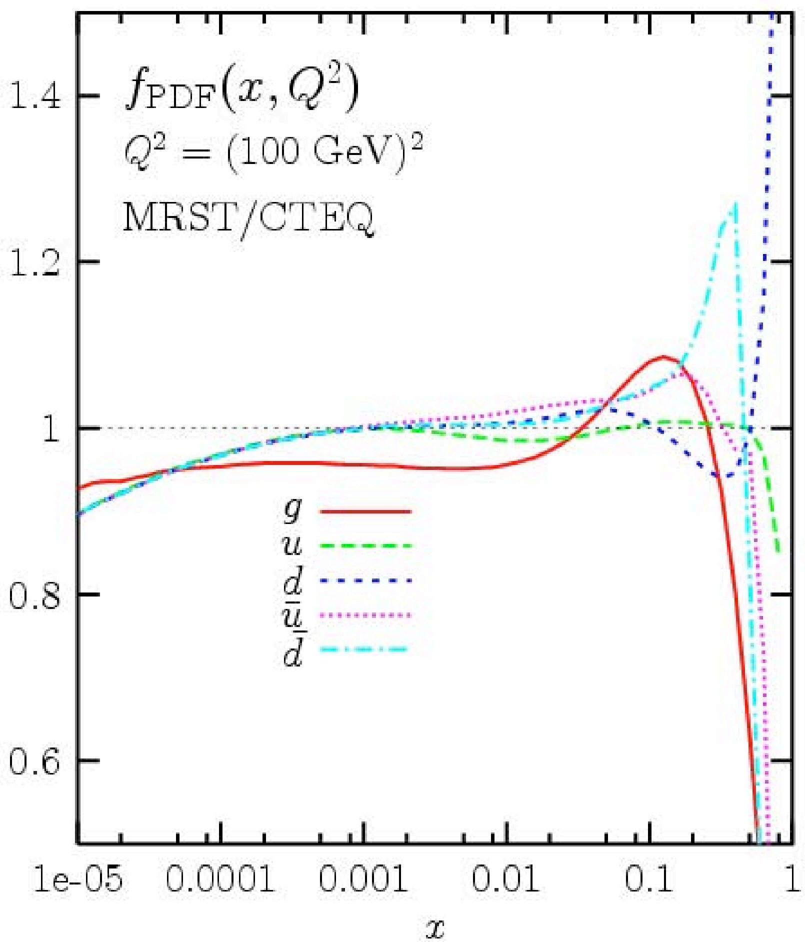
http://durpdg.dur.ac.uk/hepdata/pdf.html

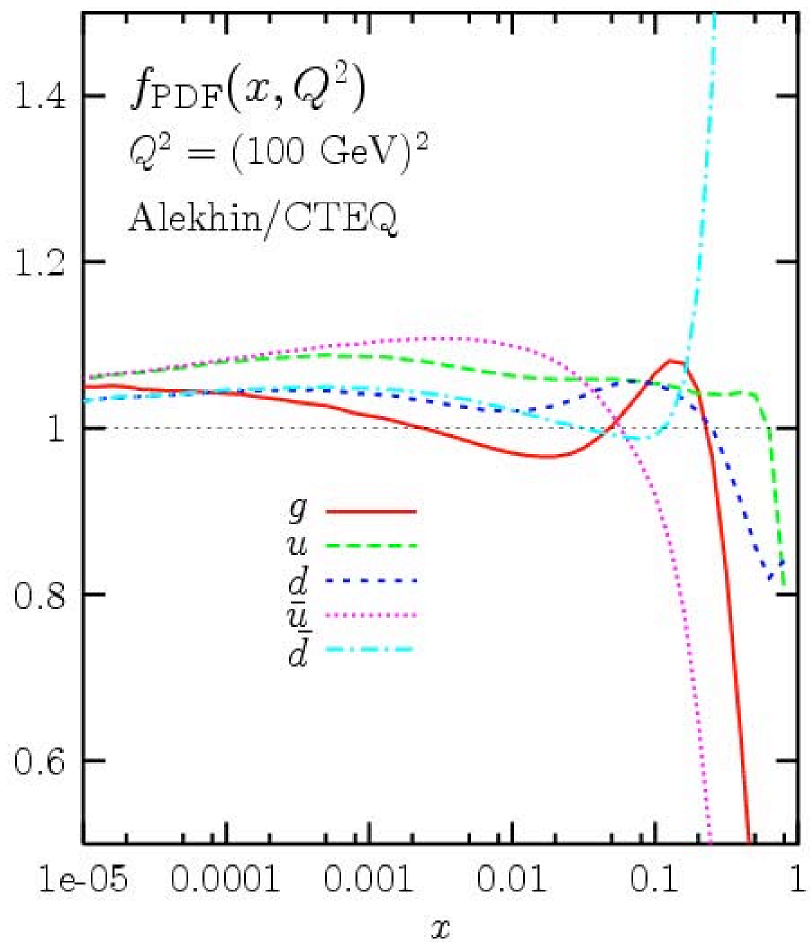
# CTEQ 6.6 Parton Distributions of the Proton



# Comparison of three recent PDF global fits

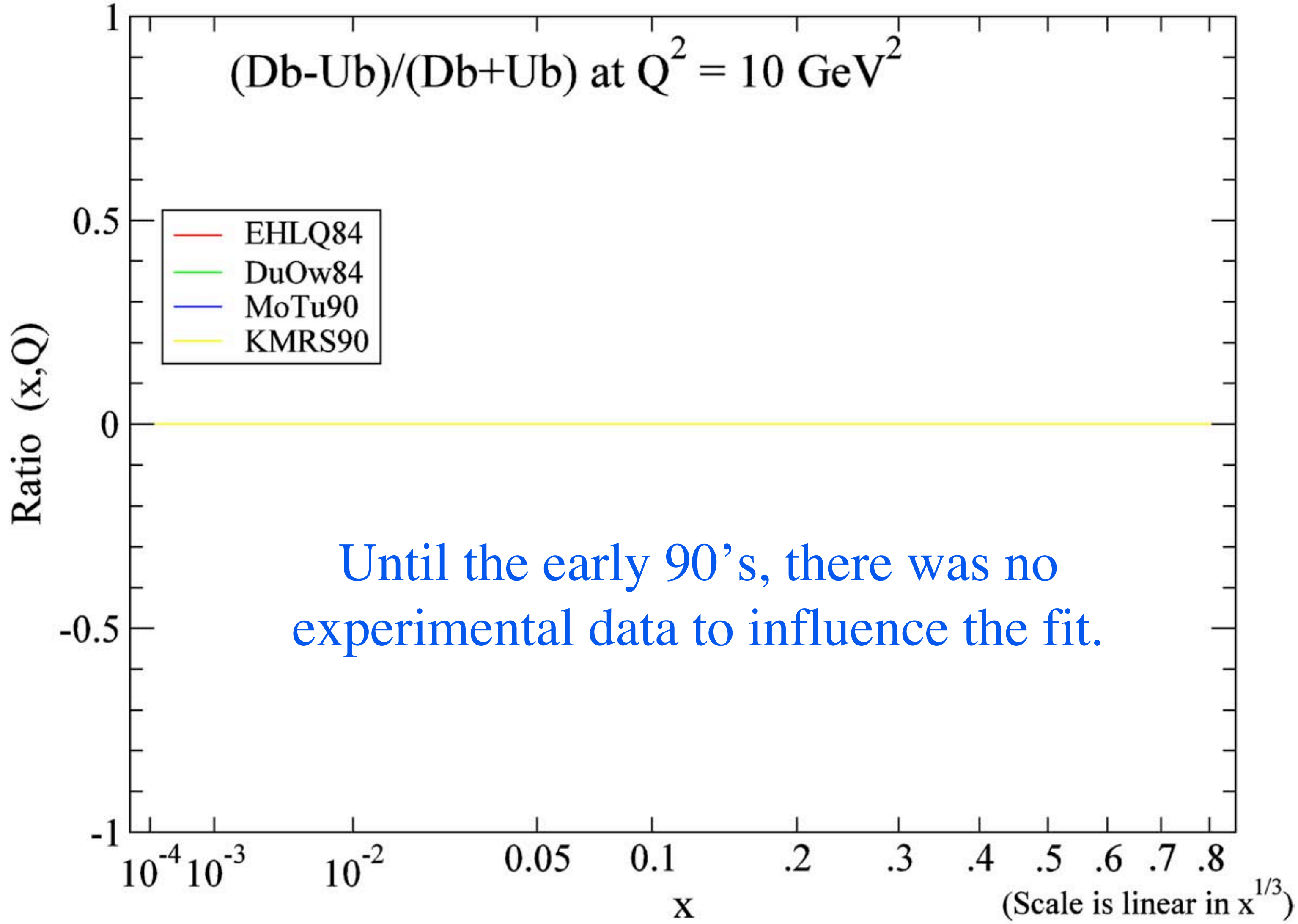
## Things start getting nasty as x increases



# How has our picture of the PDF's evolved over the years?

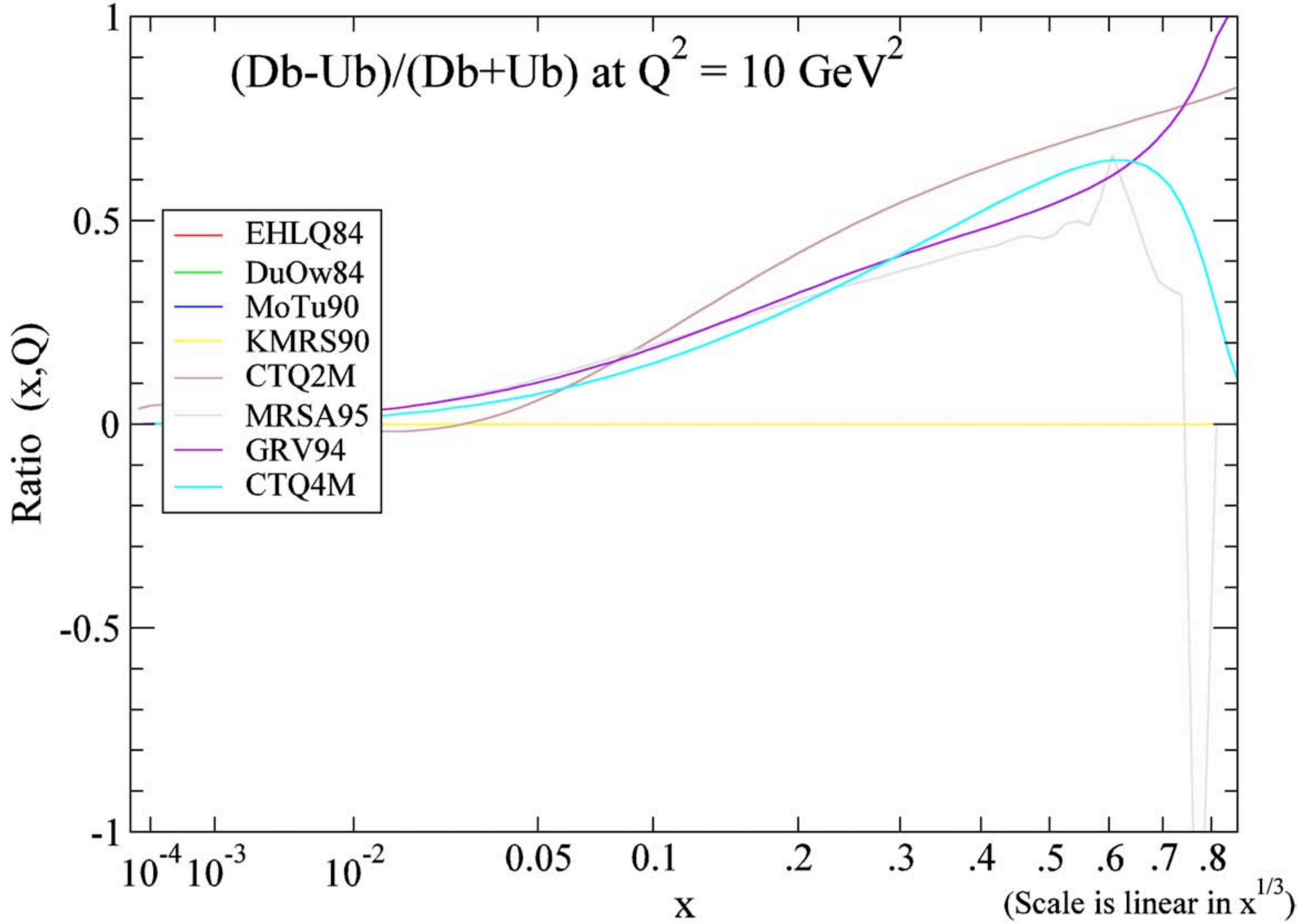
## The non-strange sea quarks: do they observe isospin symmetry?




Until the early 90's, there was no experimental data to influence the fit.

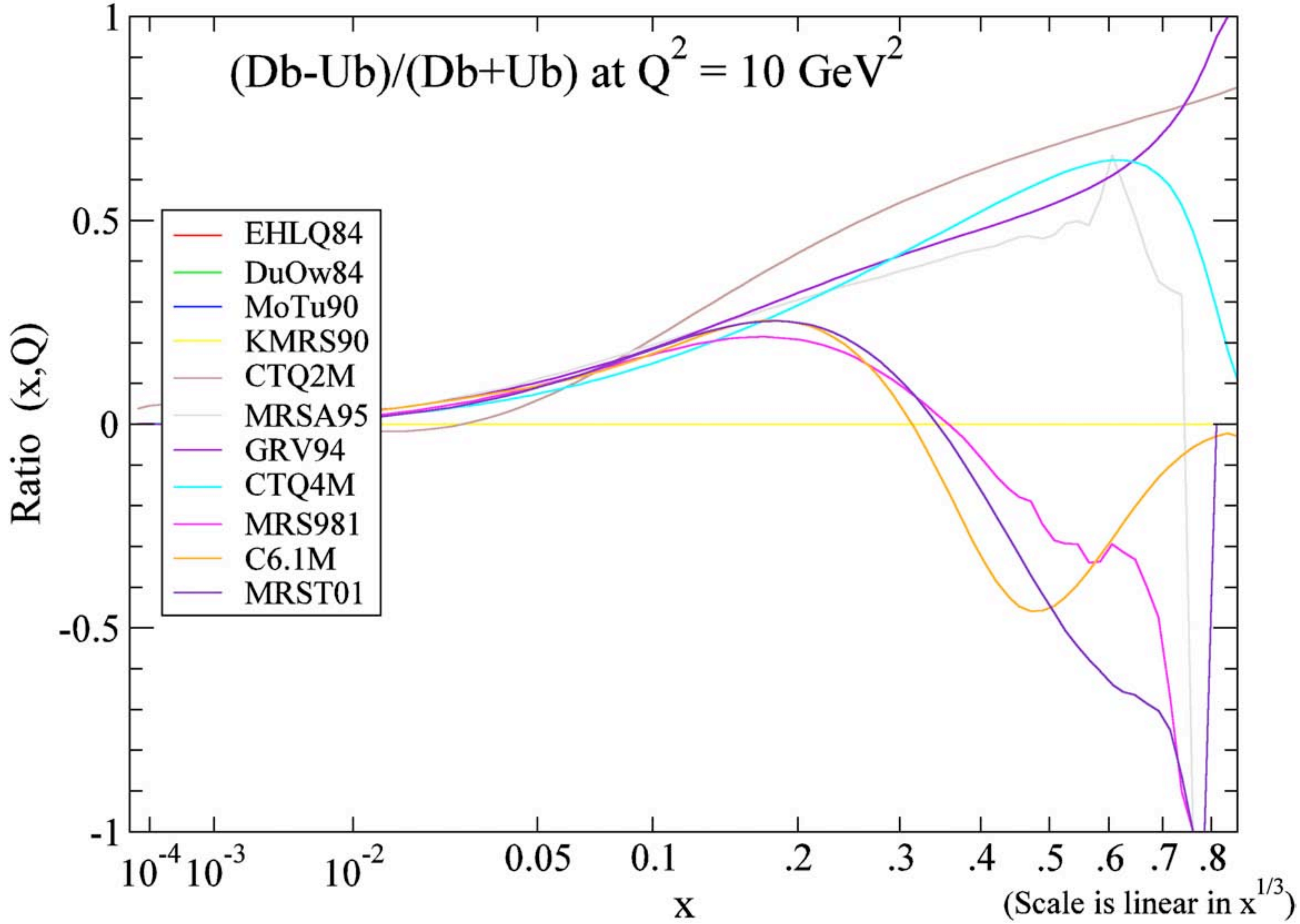
# The non-strange sea quarks

## Measurement of $F_2^n$-$F_2^p$ in DIS experiments

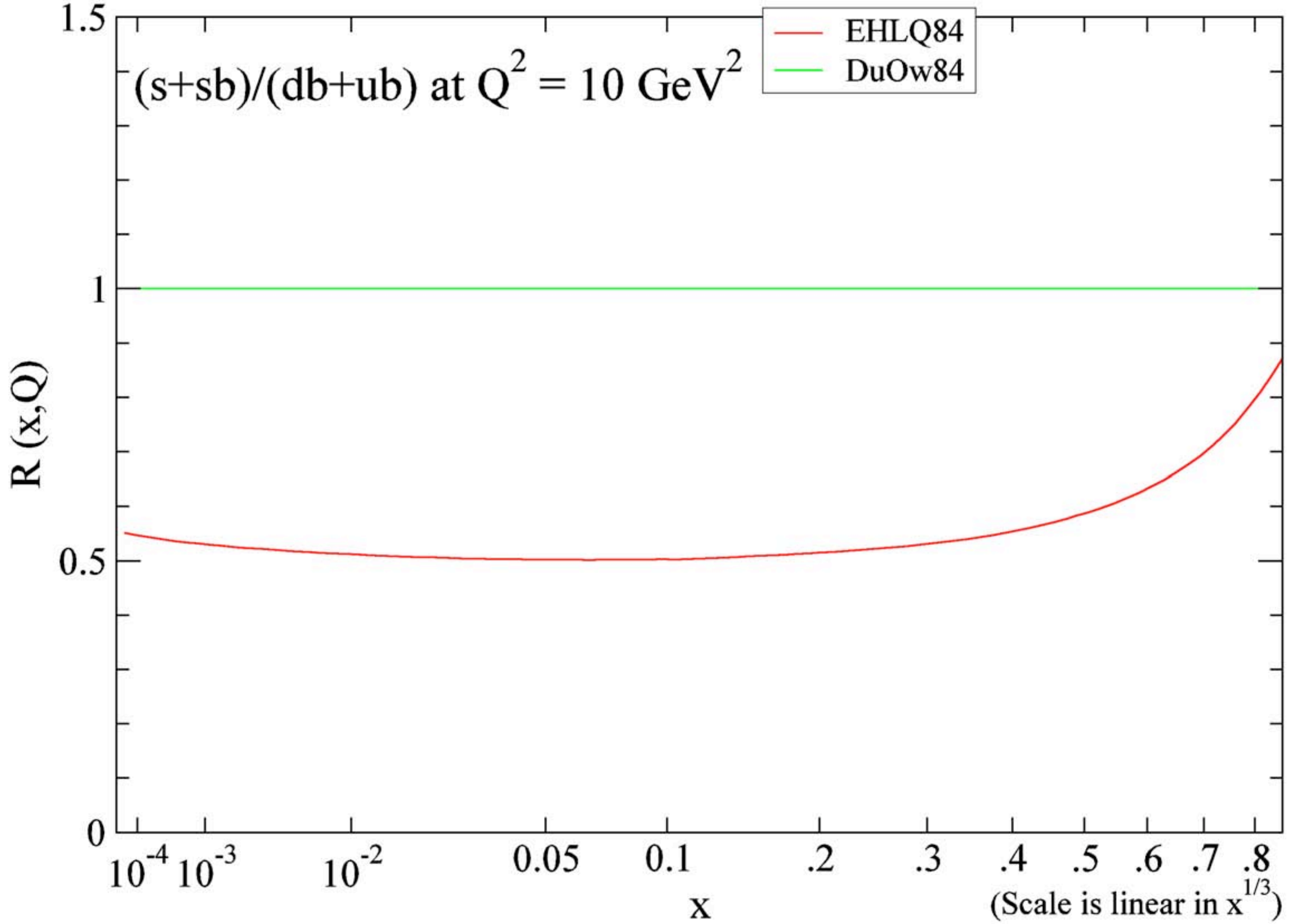


# The non-strange sea quarks

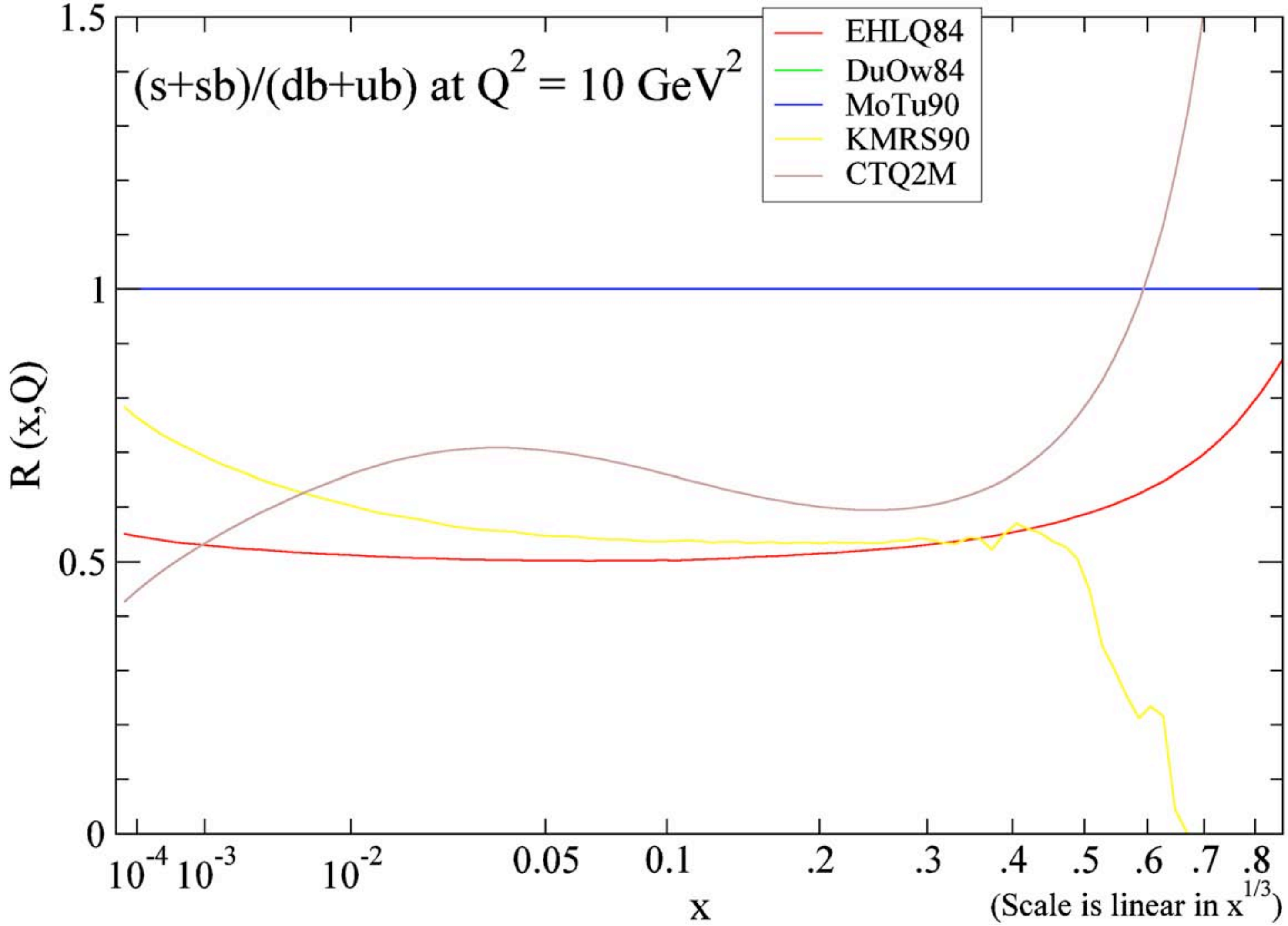
# D-Y Asymmetry exerts its Influence - NA51 and E866



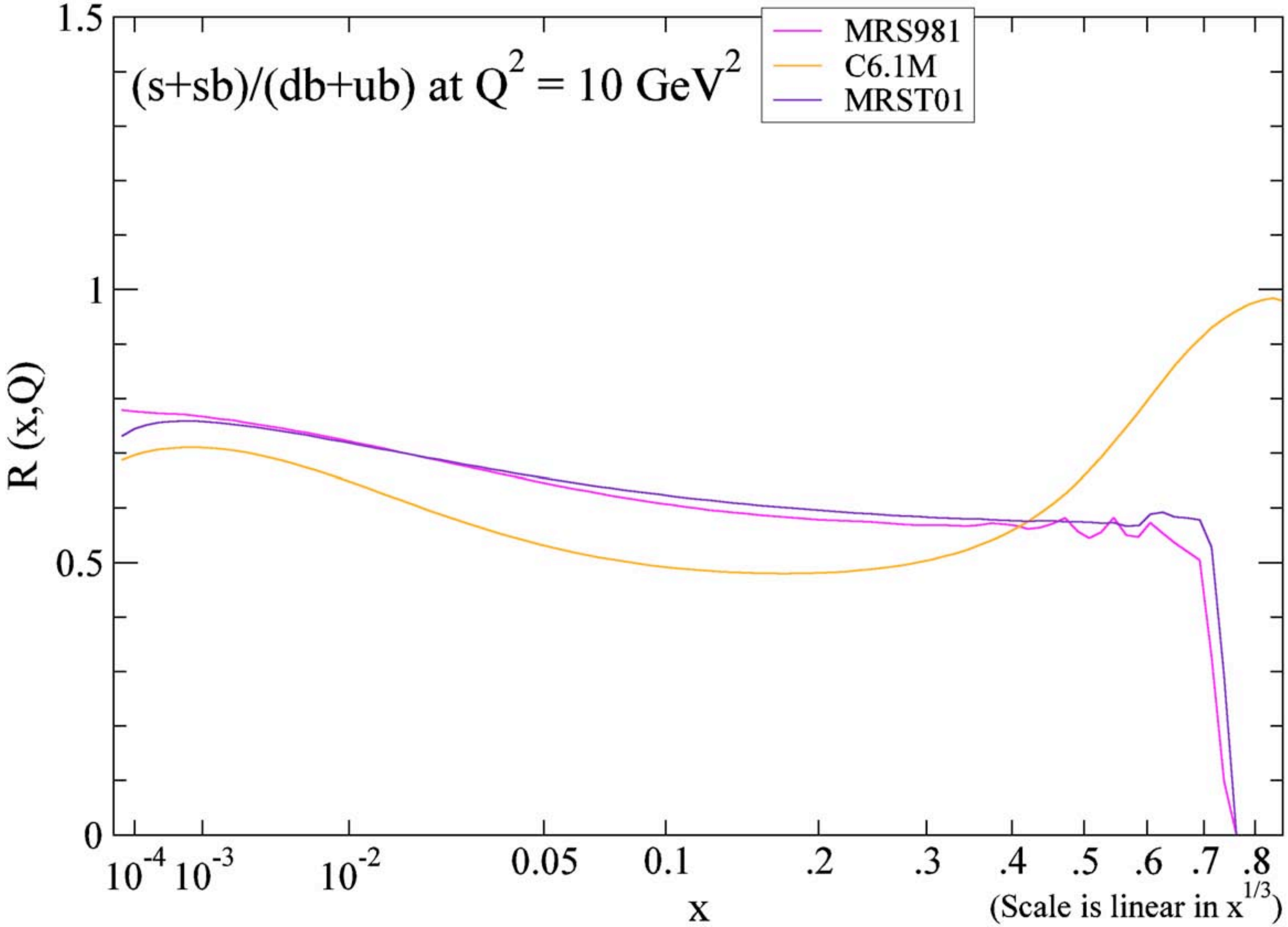
# Strange Content of the Nucleon Structure



# Experimental input: (low statistics) data on Dimuon (charm) production in Neutrino-Nucleus scattering.

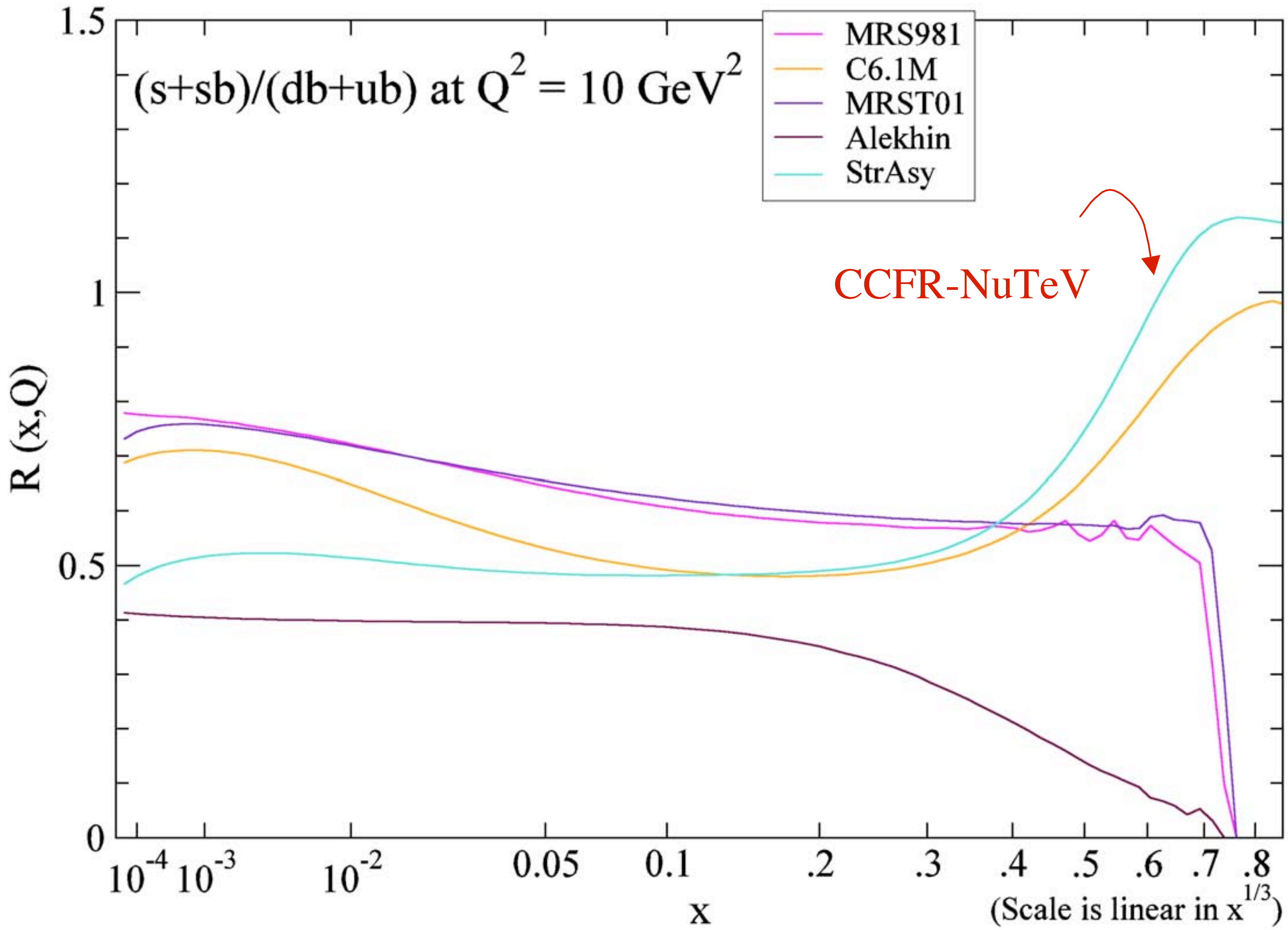


# No Qualitatively New Development



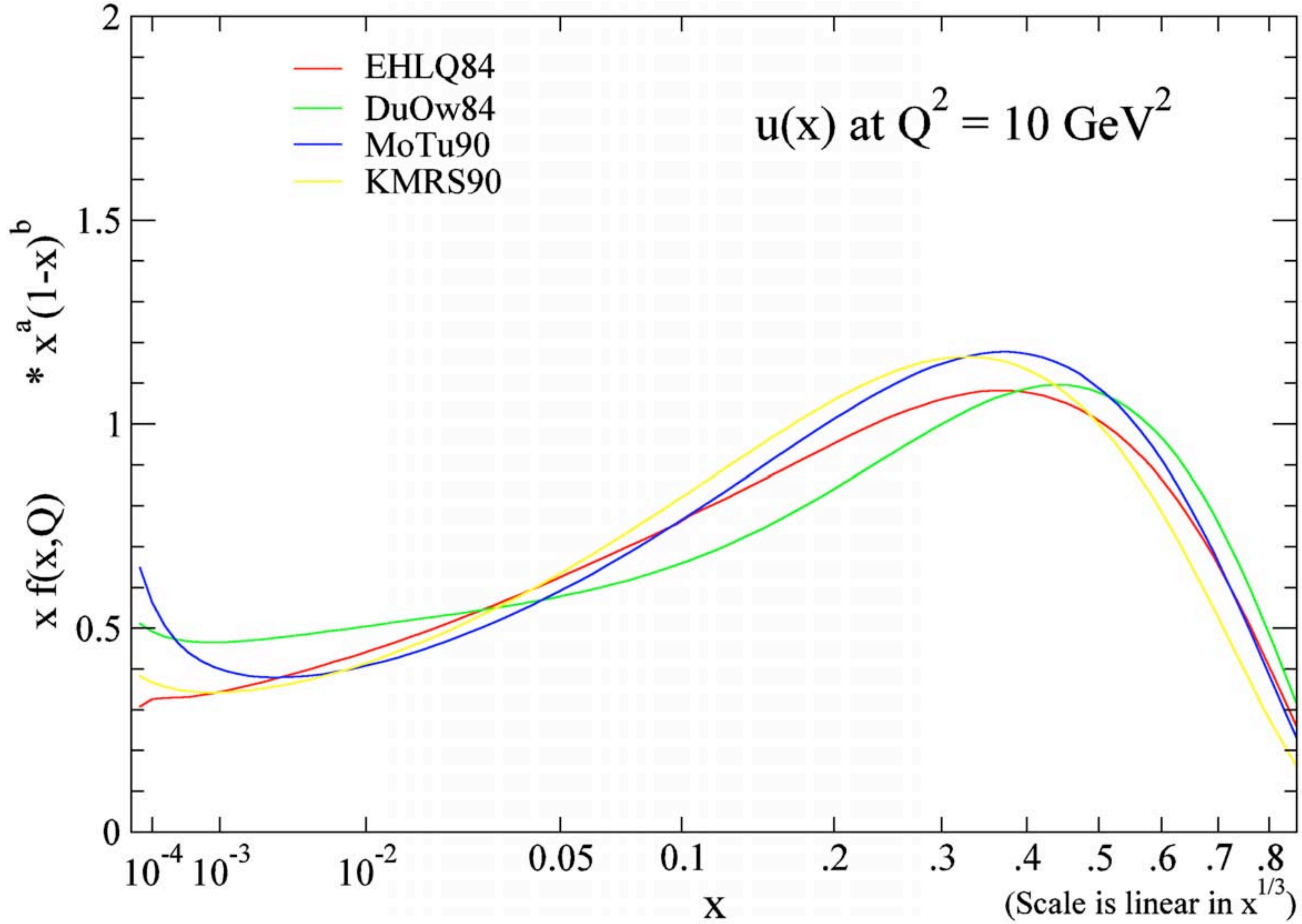
# CCFR-NuTeV (high statistics) data:

# dimuon production from $\nu N$ and anti- $\nu N$ scattering.

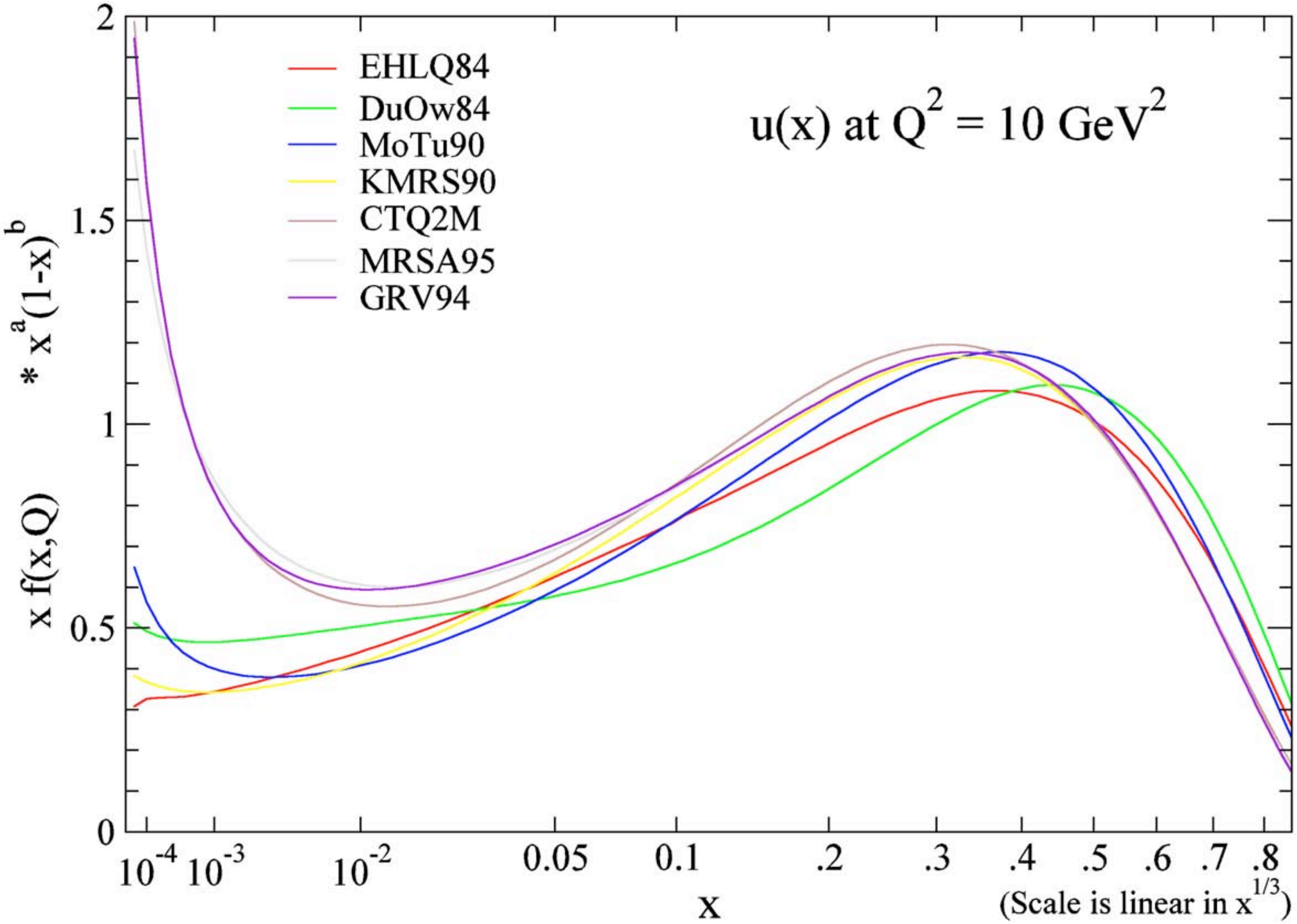


# Valence Quarks:

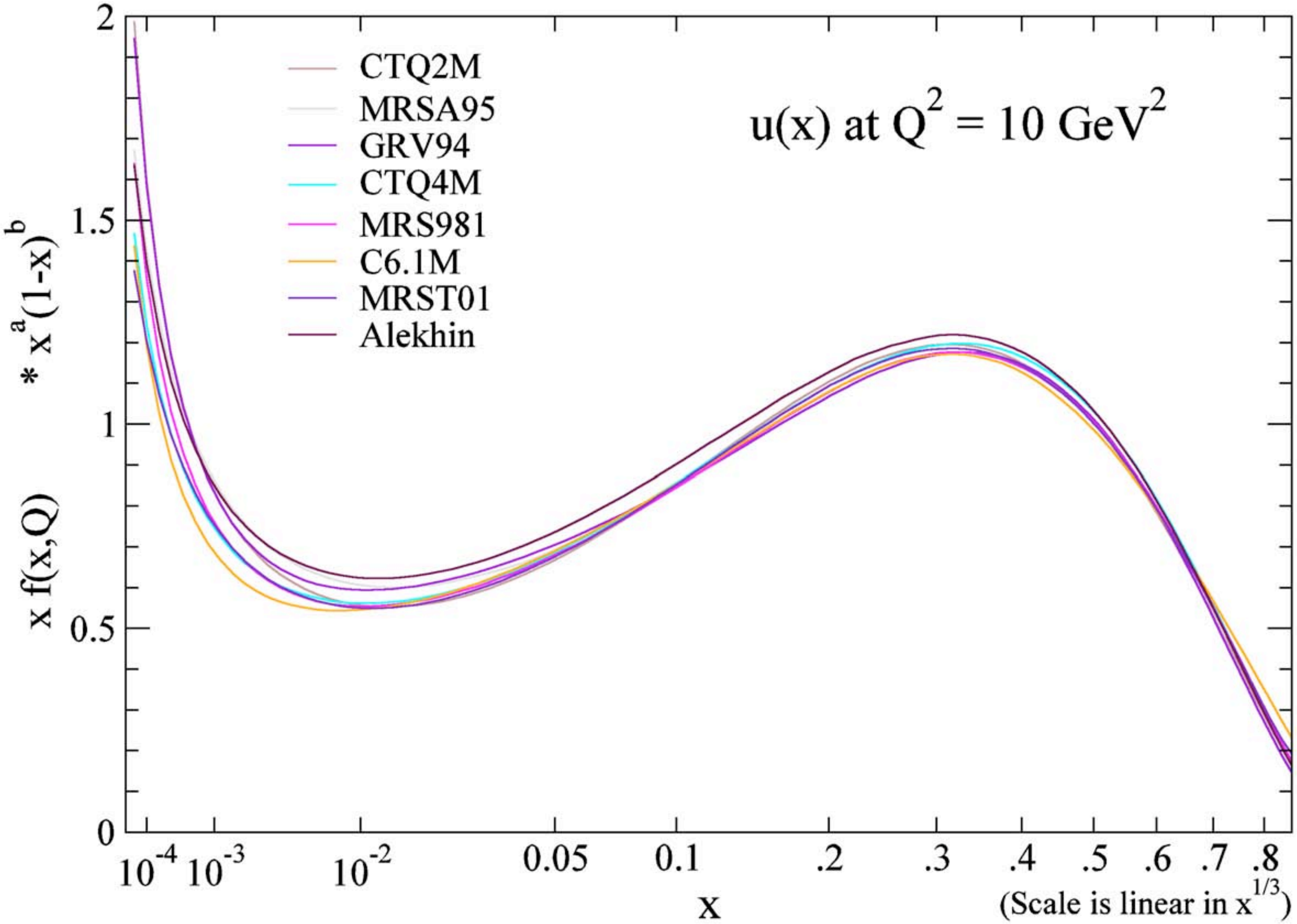
# NLO fits to fixed-target DIS data sets



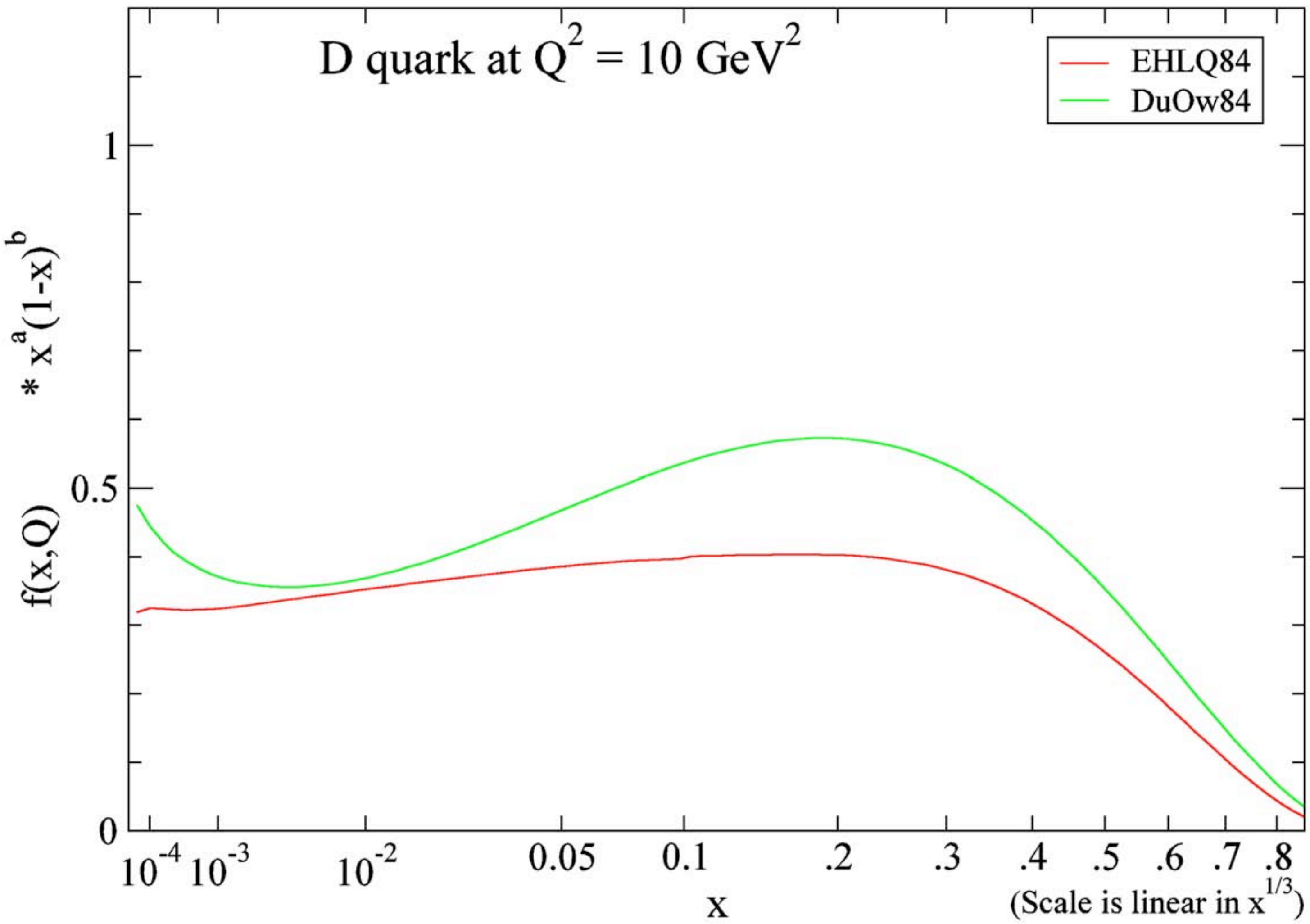
# HERA exerts its influence



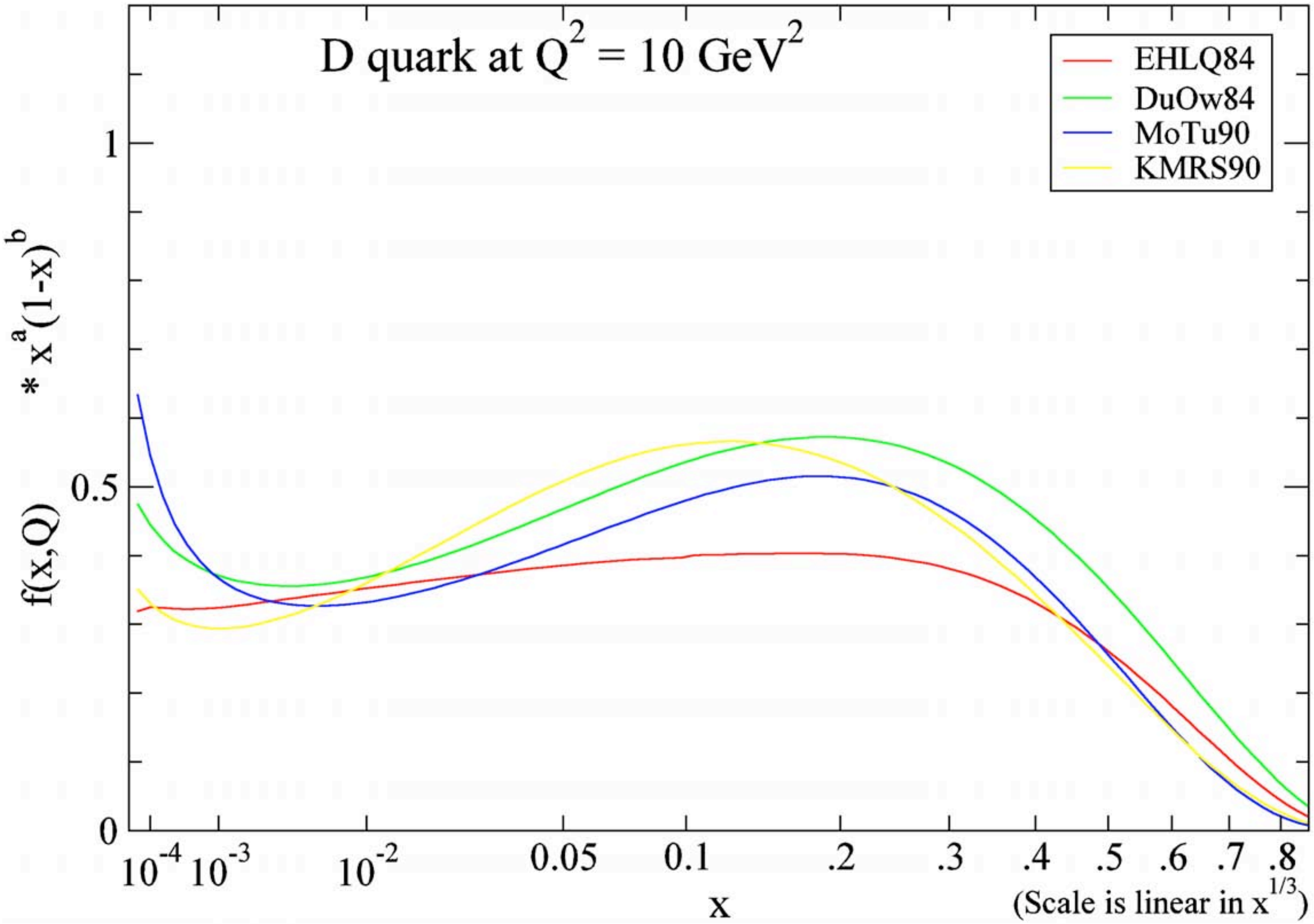
# All in the details now, at least for lower x



# Similar Story for the D quark

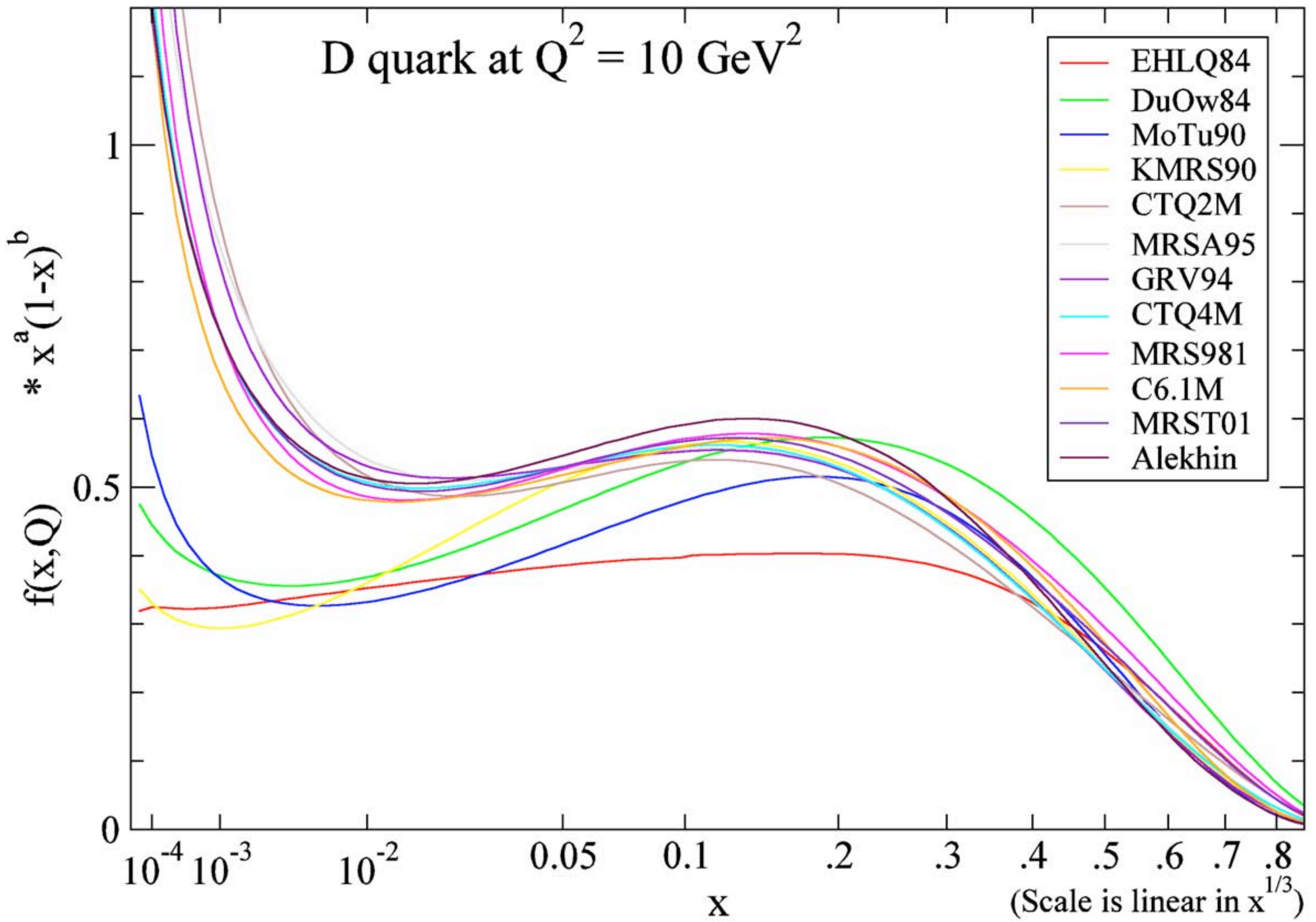


# NLO, no dramatic changes



# The impact of HERA

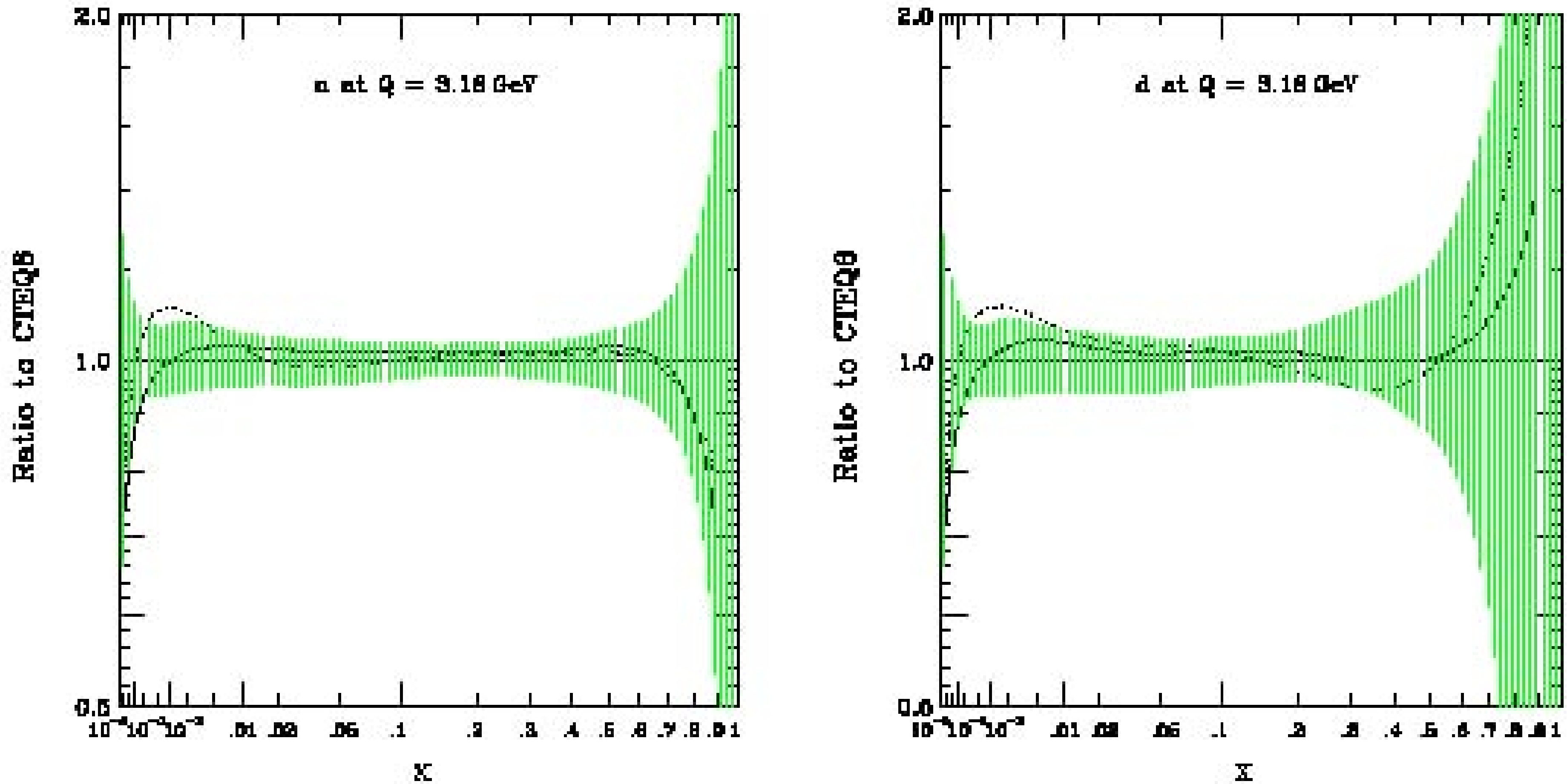
## It looks like we know the d and u quark fairly well…right?



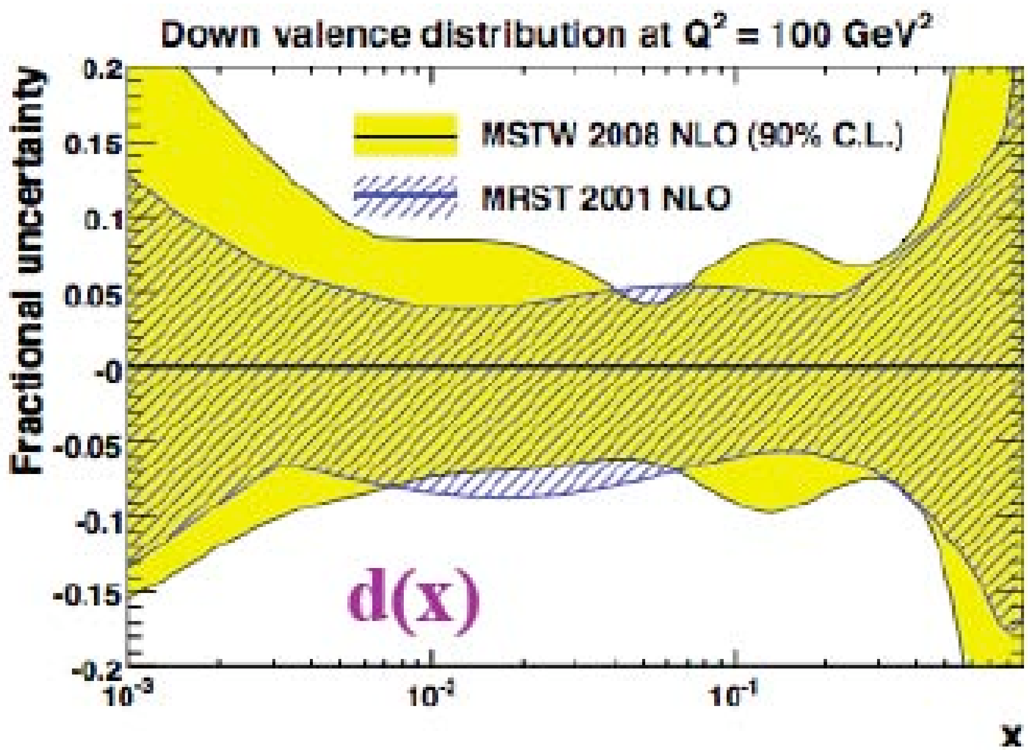
# CTEQ uncertainties in u and d quark fits

Theory uncertainties NOT included

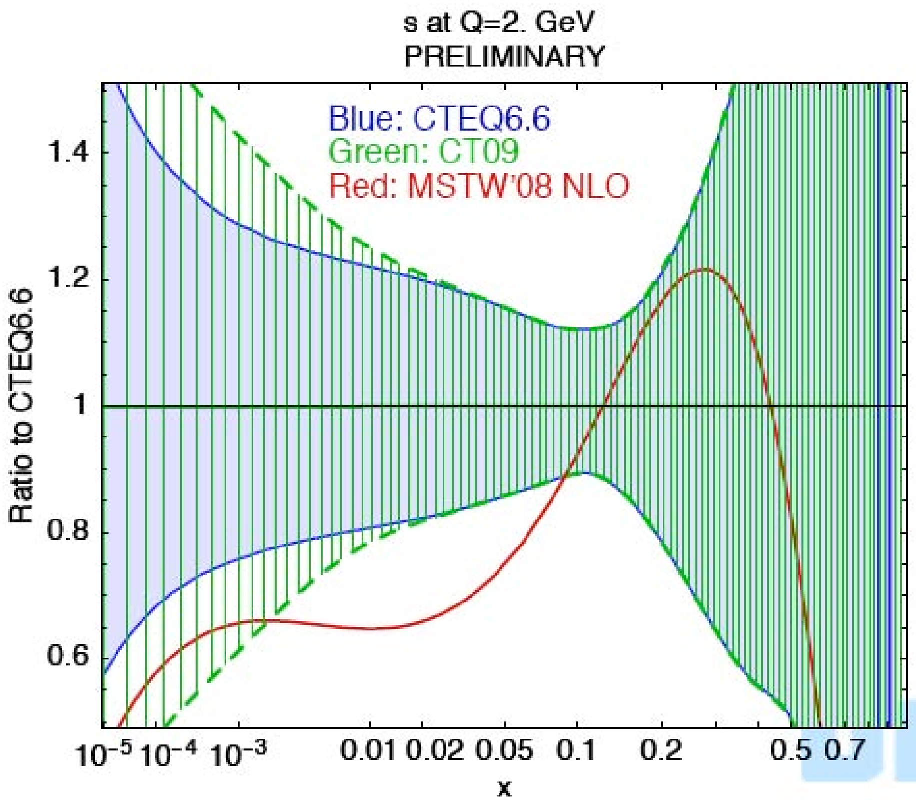
Fig. 9 : Uncertainty bands for the $u$- and $d$-quark distribution functions at $Q^2 = 10\,\mathrm{GeV}^2$. The solid line is CTEQ5M1 and the dotted line is MRST2001.

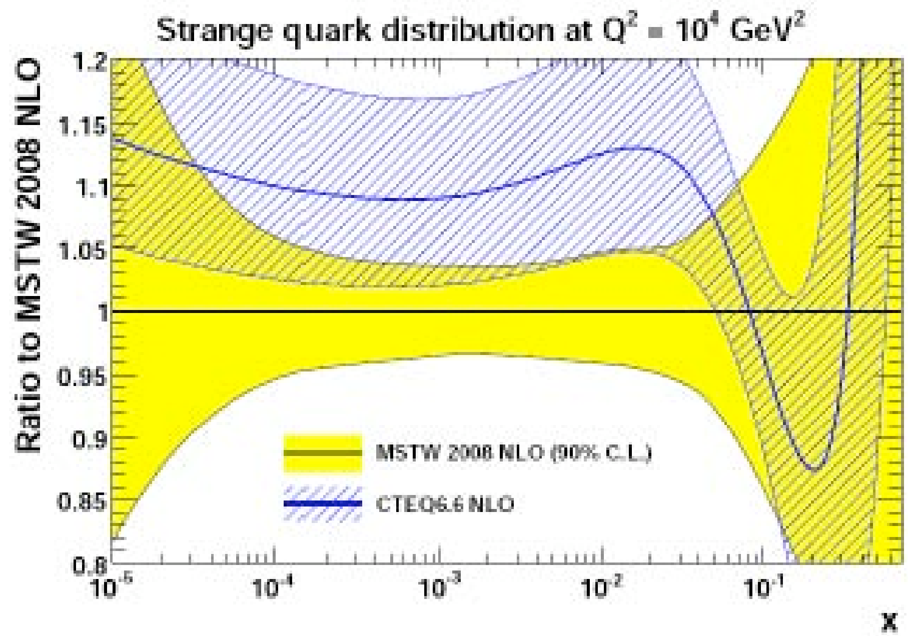


# d Uncertainty at higher Q



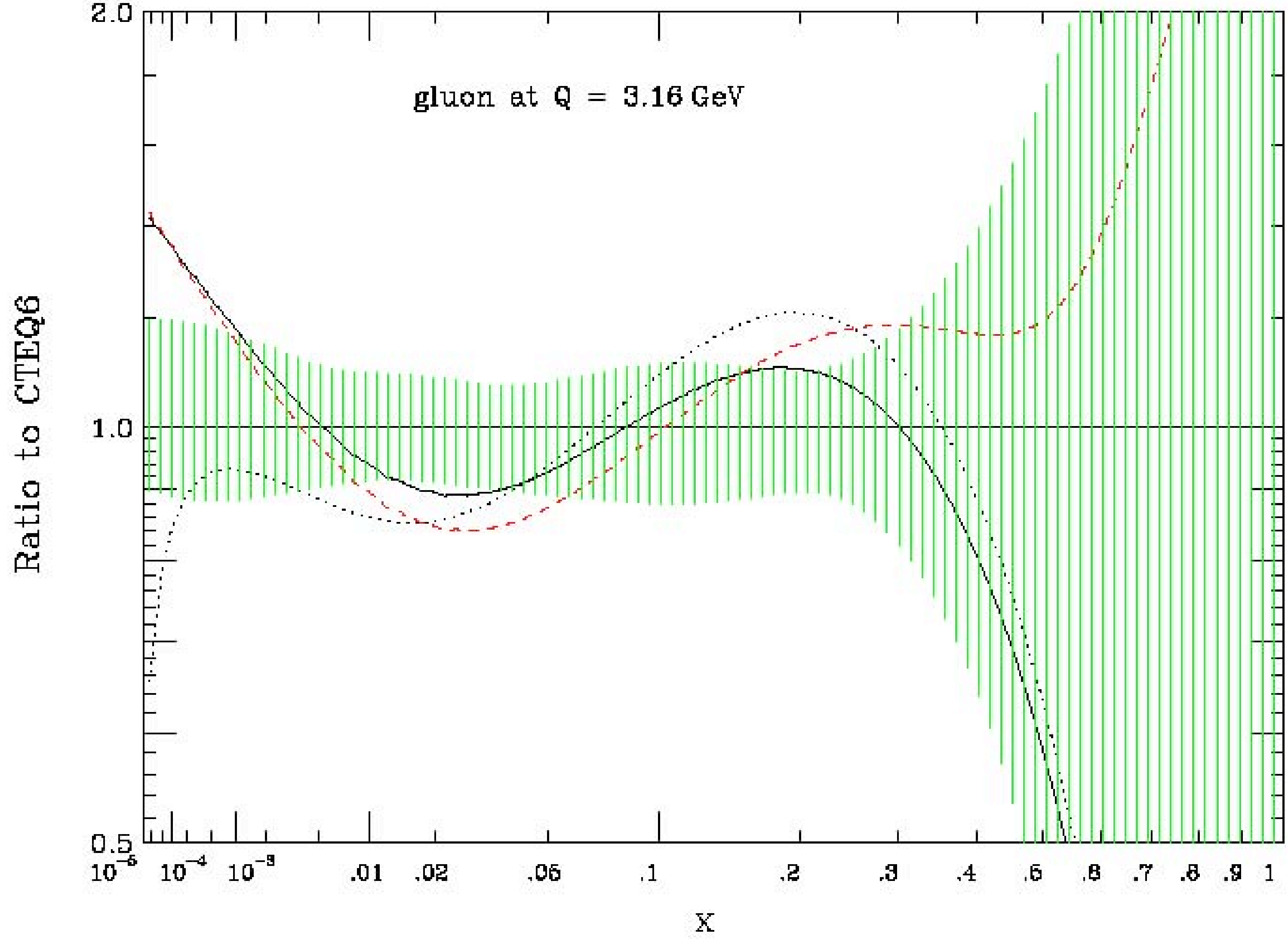
# Strange Quark Uncertainties



# Uncertainty in the Gluon Distribution

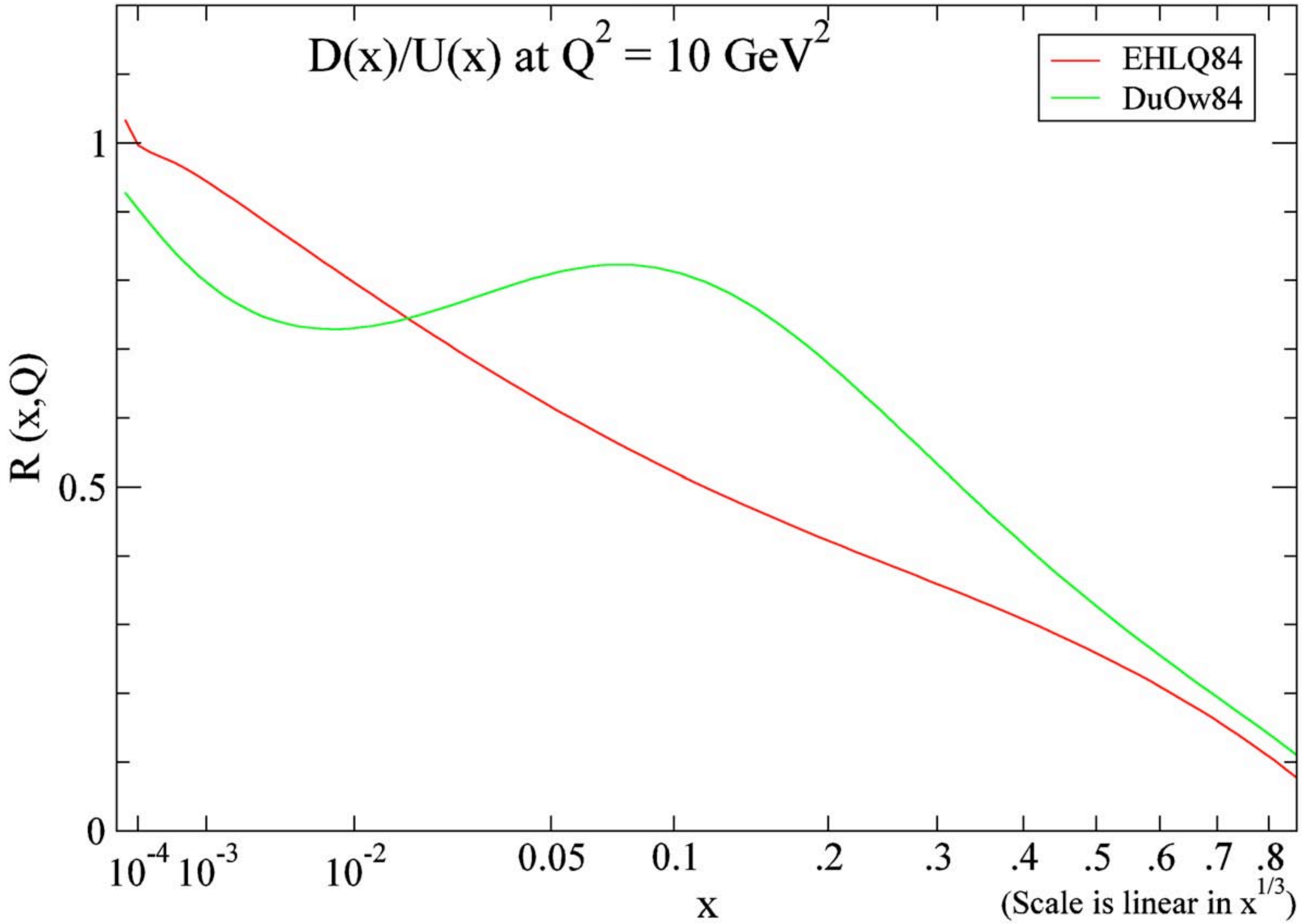
Normalized to CTEQ6.1M



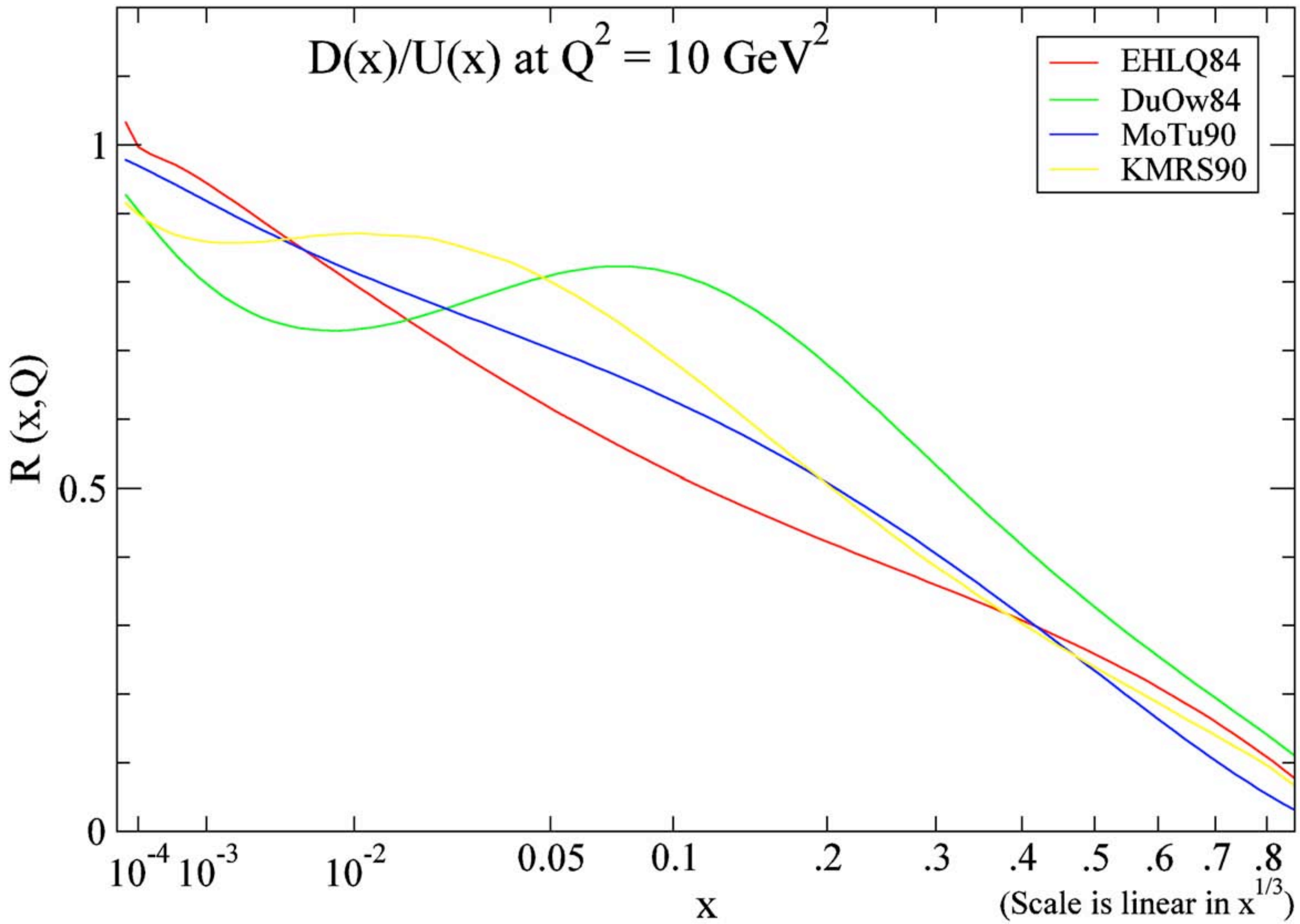

Dashed - CTEQ5HJ
Dotted - MRST01
Solid - CTEQ5M

# Relative Concentration of Valence Quarks in the Nucleon

## d/u

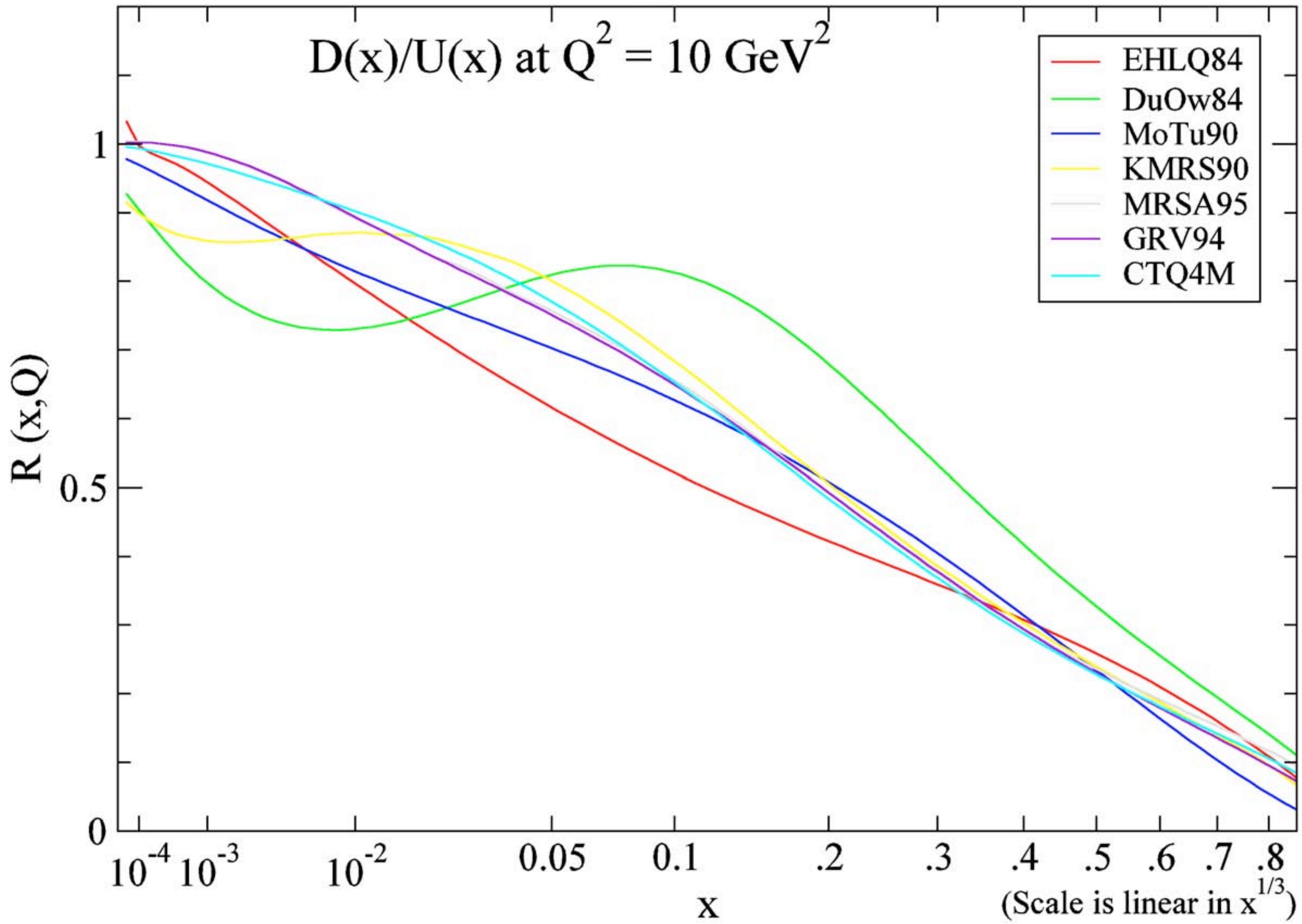


# d/u



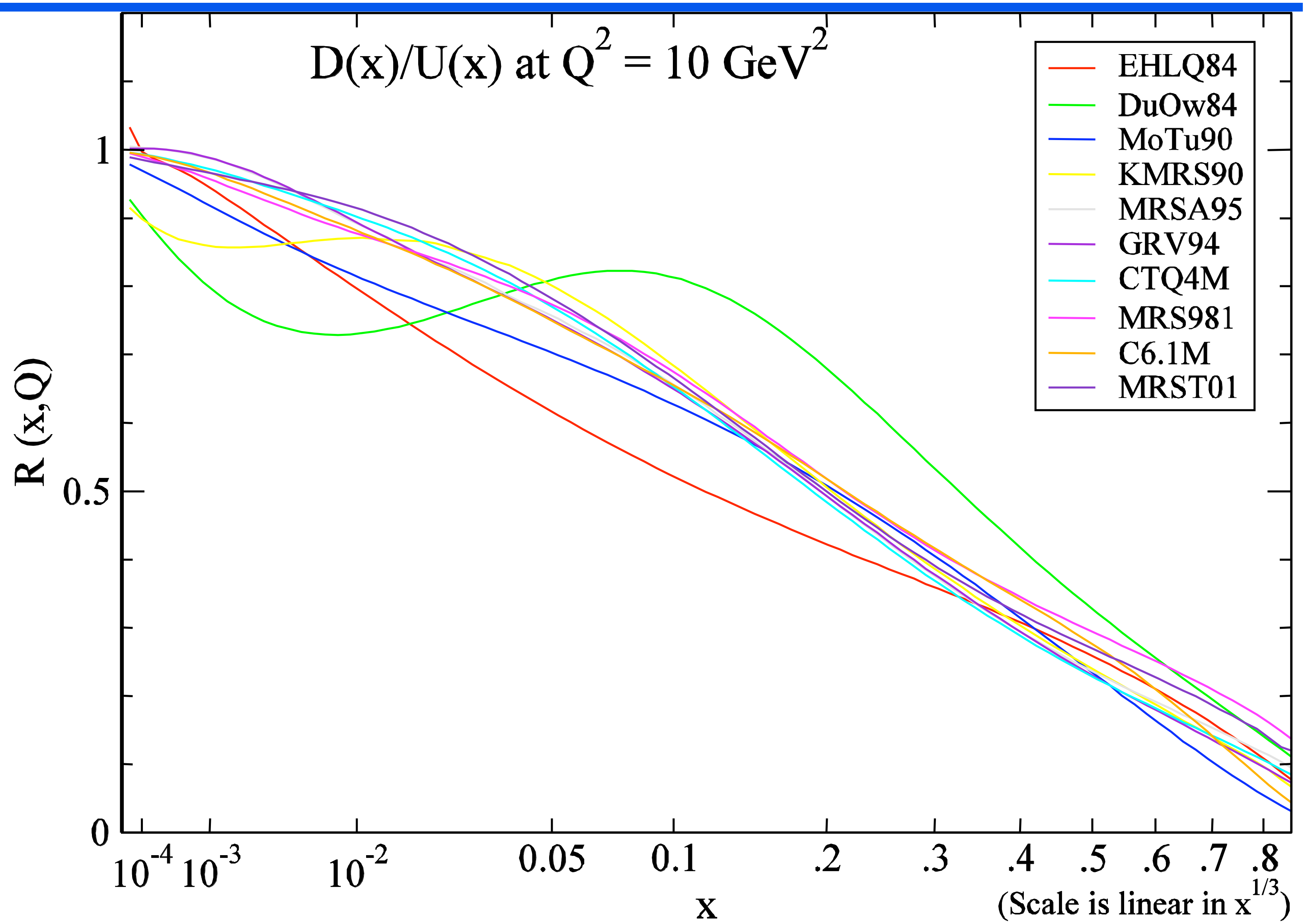
D(x)/U(x) at Q^2 = 10 GeV^2
EHLQ84
DuOw84
MoTu90
KMRS90
R (x,Q)
1
0.5
0
10^-4
10^-3
10^-2
0.05
0.1
.2
.3
.4
.5
.6
.7
.8
x
(Scale is linear in x^1/3)

# d/u



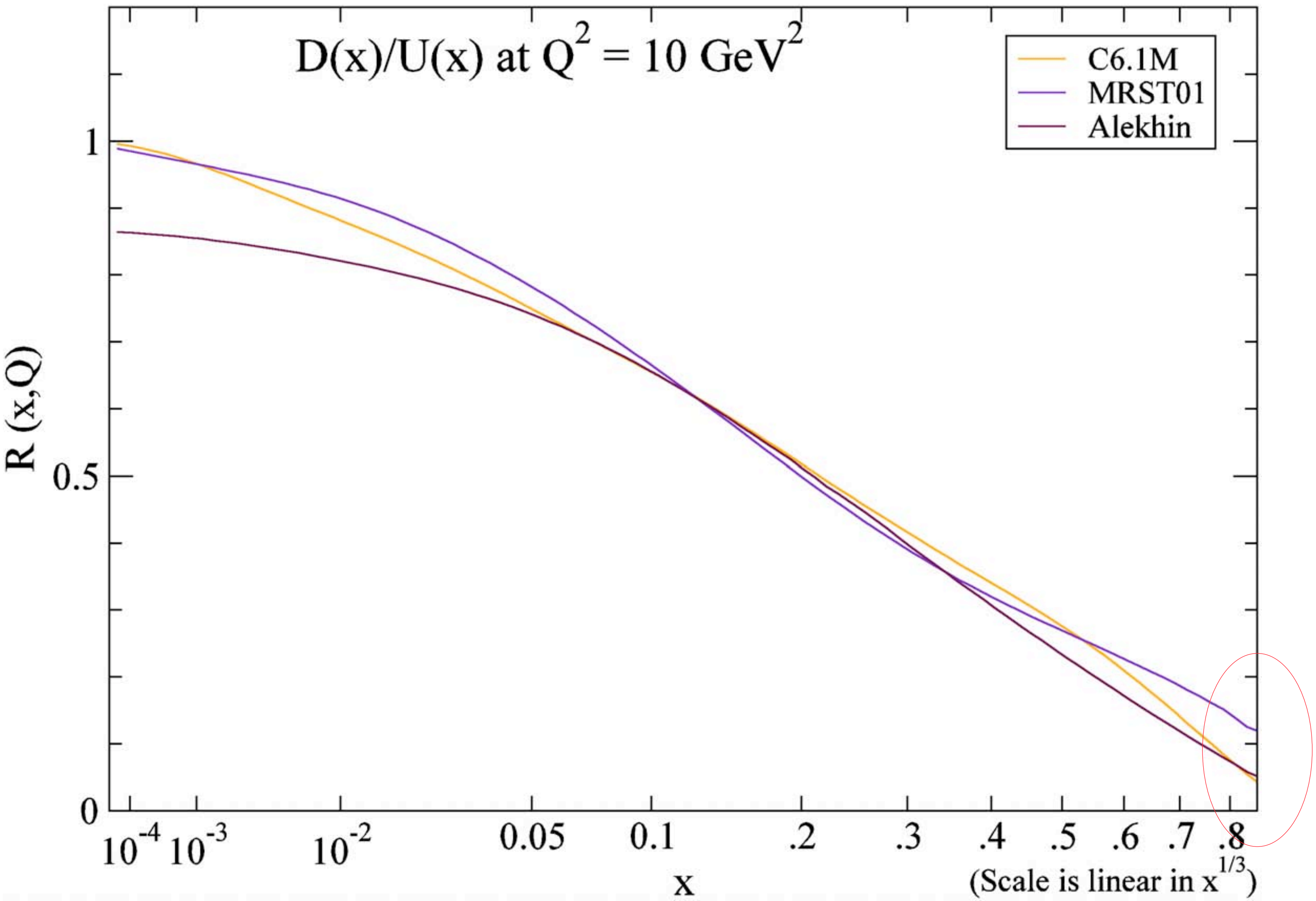
D(x)/U(x) at Q^2 = 10 GeV^2
EHLQ84
DuOw84
MoTu90
KMRS90
MRSA95
GRV94
CTQ4M
R (x,Q)
1
0.5
0
10^-4 10^-3
10^-2
0.05
0.1
.2
.3
.4
.5
.6
.7
.8
x
(Scale is linear in x^1/3)

# d/u



D(x)/U(x) at $Q^2$ = 10 GeV$^2$
EHLQ84
DuOw84
MoTu90
KMRS90
MRSA95
GRV94
CTQ4M
MRS981
C6.1M
MRST01
R (x,Q)
1
0.5
0
$10^{-4}$ $10^{-3}$ $10^{-2}$ 0.05 0.1 .2 .3 .4 .5 .6 .7 .8
x
(Scale is linear in $x^{1/3}$)

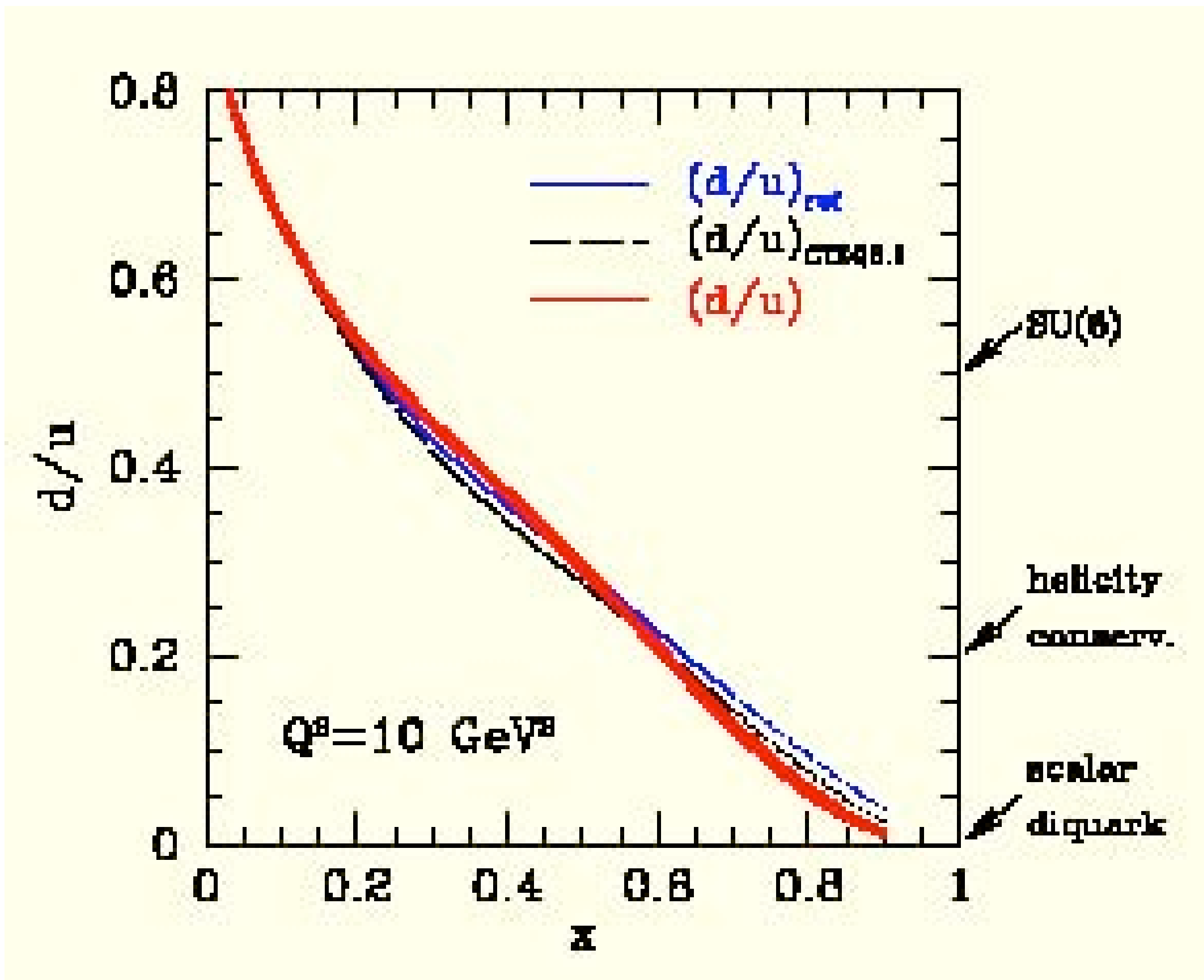
# Recent Global Fit look at d/u…
# What's going on at high-x?



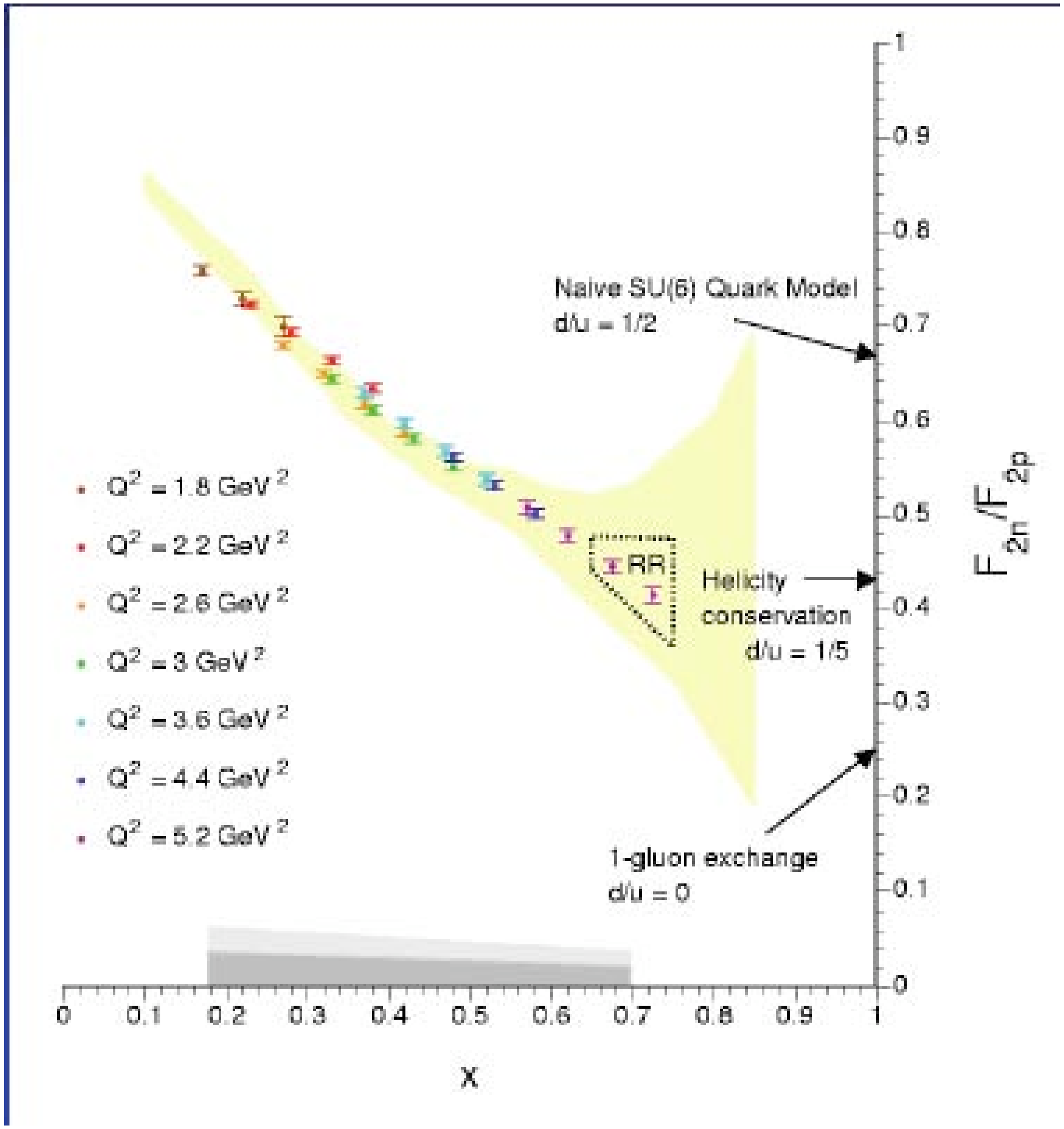
# Latest look at d/u

Alberto Accardi, Eric Christy, Cynthia Keppel, Wally Melnitchouk, Peter Monaghan, J.G.M., Jeff Owens and Lingyan Zhu

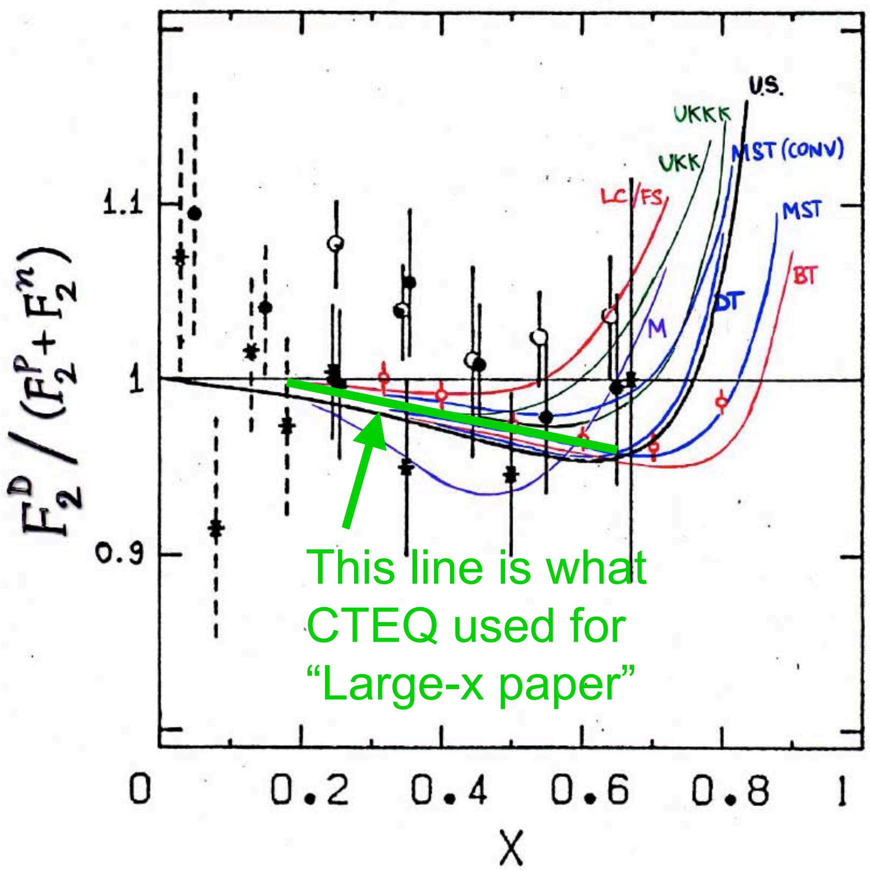
**It all comes down to the correction for nuclear effects in deuterium!**



# Extraction of d/u using deuterium targets involves **nuclear $D_2$ corrections**



# Range of Deuteron Corrections in the Literature
(a few somewhat dated)




ϕ NUCLEAR DENSITY EXTRAPOLATION
(FRANKFURT & STRIKMAN ; J. GOMEZ ET AL PRD49 (1994) 4348)

DATA FROM BODEK & SIMON ZPC29 (1985) 231

Wally Melnitchouk:

# How do we Resolve the High-x Quark Dilemma?

The cleanest, most straightforward way to study high x quarks, including the d/u ratio is with $\nu$ / $\bar{\nu}$ - proton scattering

# Neutrino - Proton Scattering

**No messy nuclear corrections!**

$$F_2^{\nu p} = 2x\,(d + \bar{u} + s)$$

$$F_2^{\bar{\nu} p} = 2x\,(u + \bar{d} + \bar{s})$$

$$xF_3^{\nu p} = 2x\,(d - \bar{u} + s)$$

$$xF_3^{\bar{\nu} p} = 2x\,(u - \bar{d} - \bar{s})$$

At high x

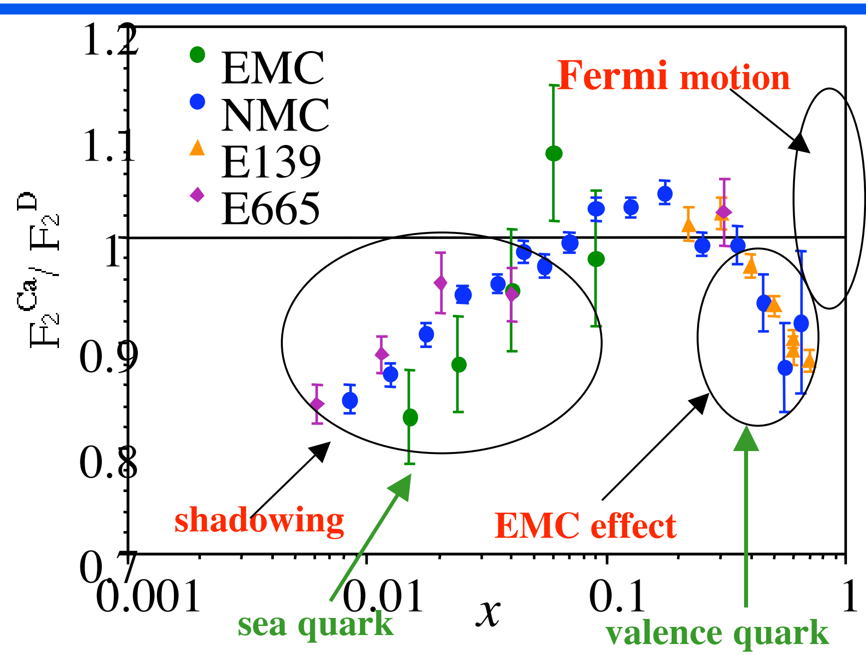
$$\frac{F_2^{\nu p}}{F_2^{\bar{\nu} p}} = \frac{d}{u}$$

$$F_2^{\nu p} - xF_3^{\nu p} = 4x\bar{u}$$

$$F_2^{\bar{\nu} p} - xF_3^{\bar{\nu} p} = 4x\bar{d}$$

# Why does CTEQ NOT Use Neutrino Data in Global Fits and Why Global Fitters Who do Use Neutrino Data are wrong..

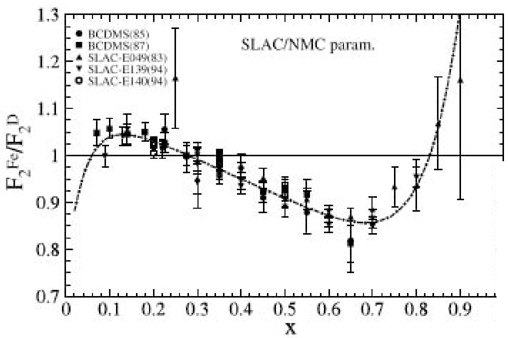
Experimental Studies of Nuclear Effects with Neutrinos: NON-EXISTENT



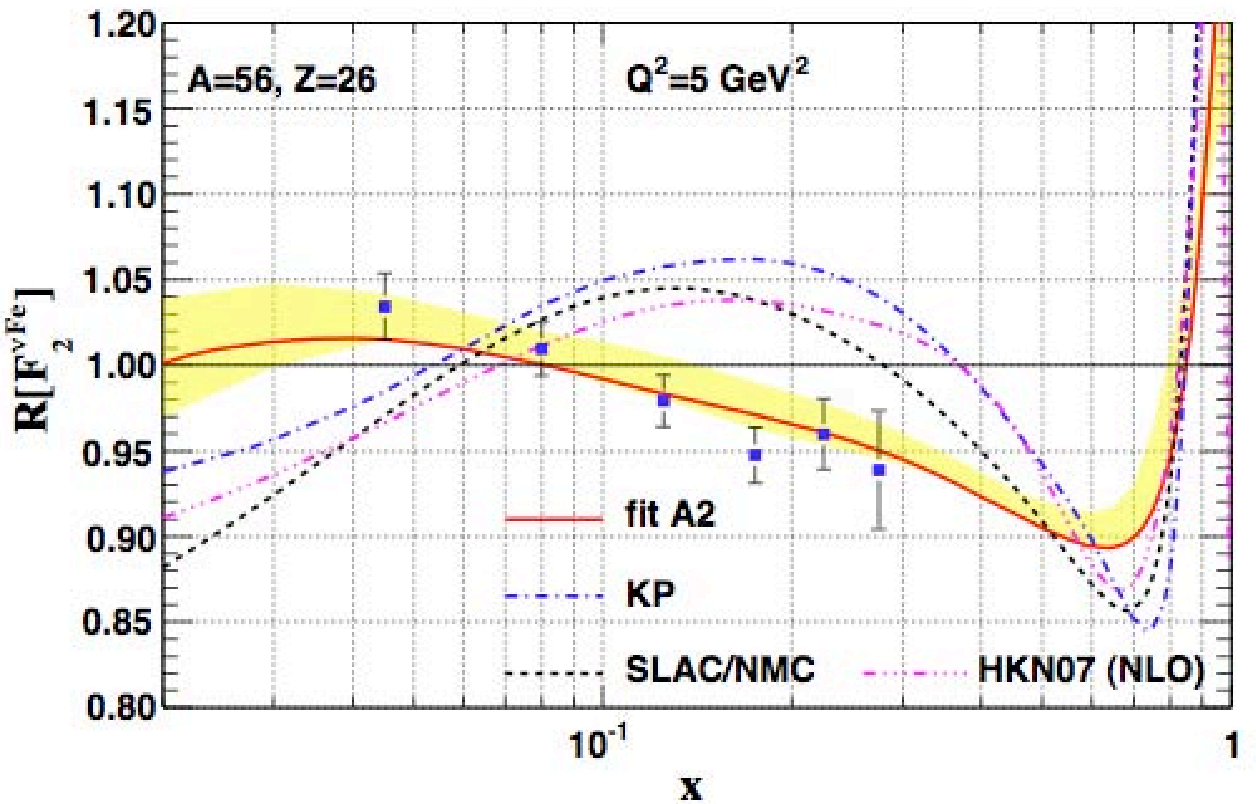

- $F_2$ / nucleon changes as a function of A. Measured in μ/e - A, **<u>not in ν – A</u>**
- **<u>Good reason to consider nuclear effects are DIFFERENT in ν - A</u>**.
  - **Presence of axial-vector current.**
  - **Different nuclear effects for valance and sea --> different shadowing for $xF_3$ compared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

# $F_2$ Structure Function Ratios: NuTeV ν-Iron

See NuFact08 Proceedings for Details




**I. Schienbein, J-Y. Yu, C. Keppel, J.G.M., F. Olness, J.F.Owens**



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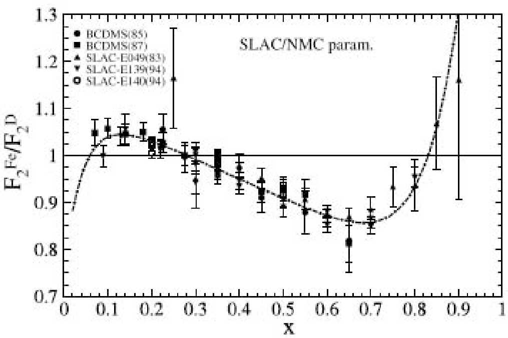
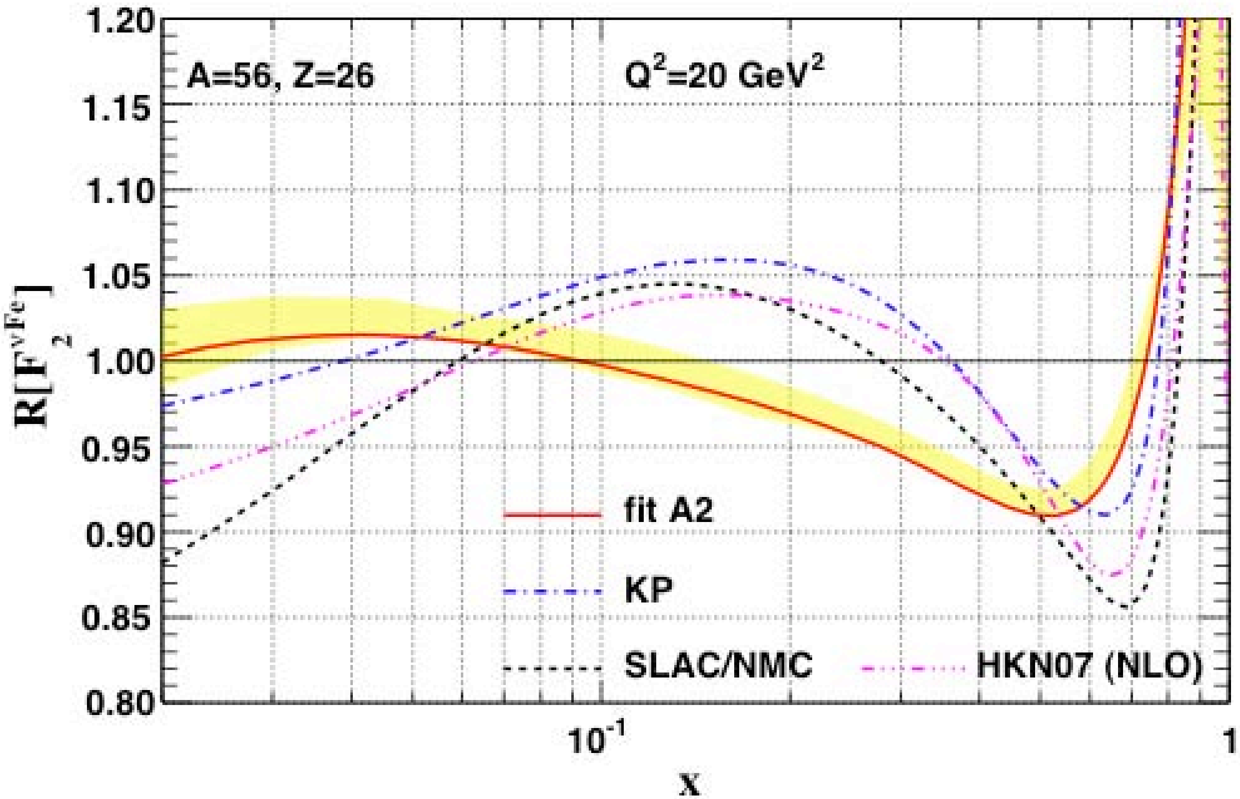
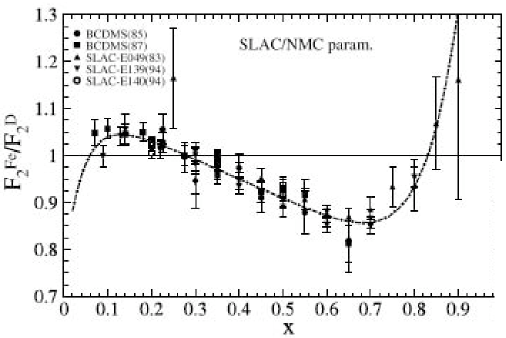
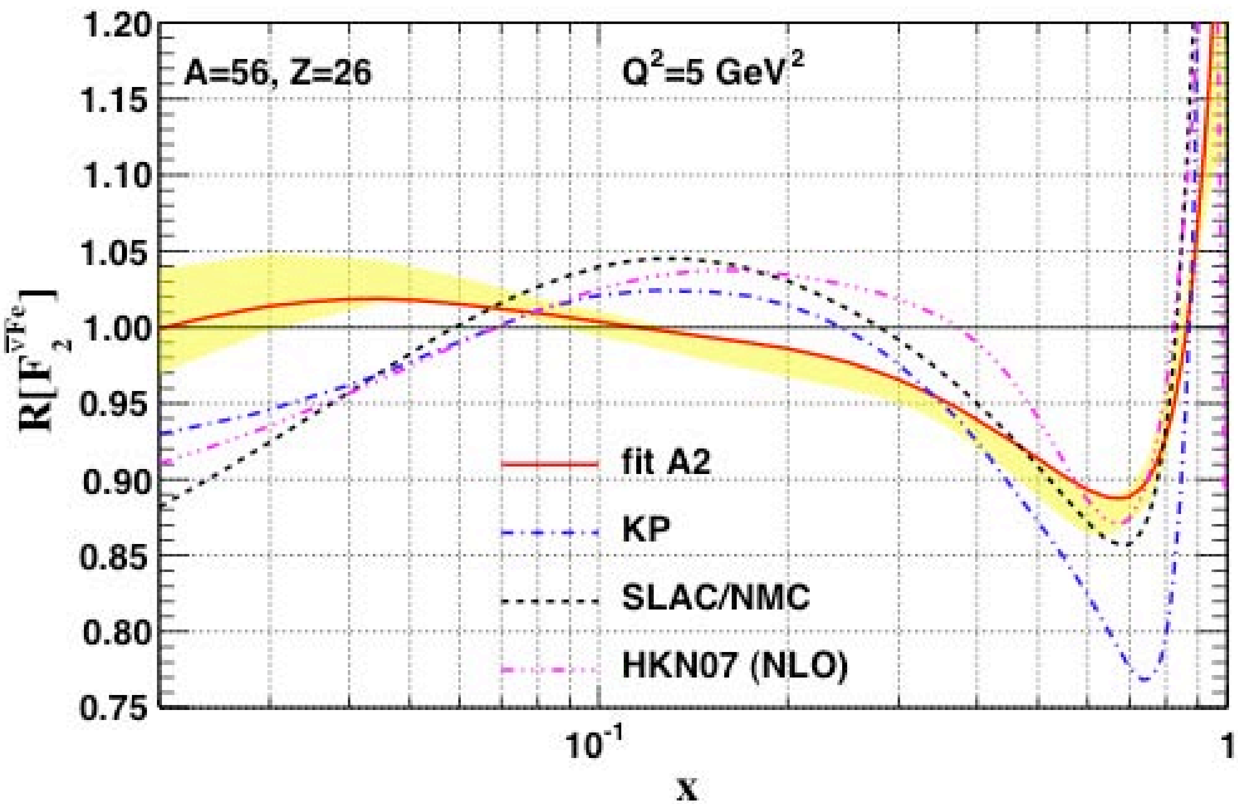


# $F_2$ Structure Function Ratios: $\overline{\nu}$-Iron



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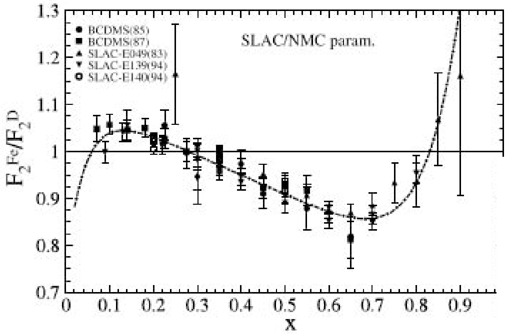


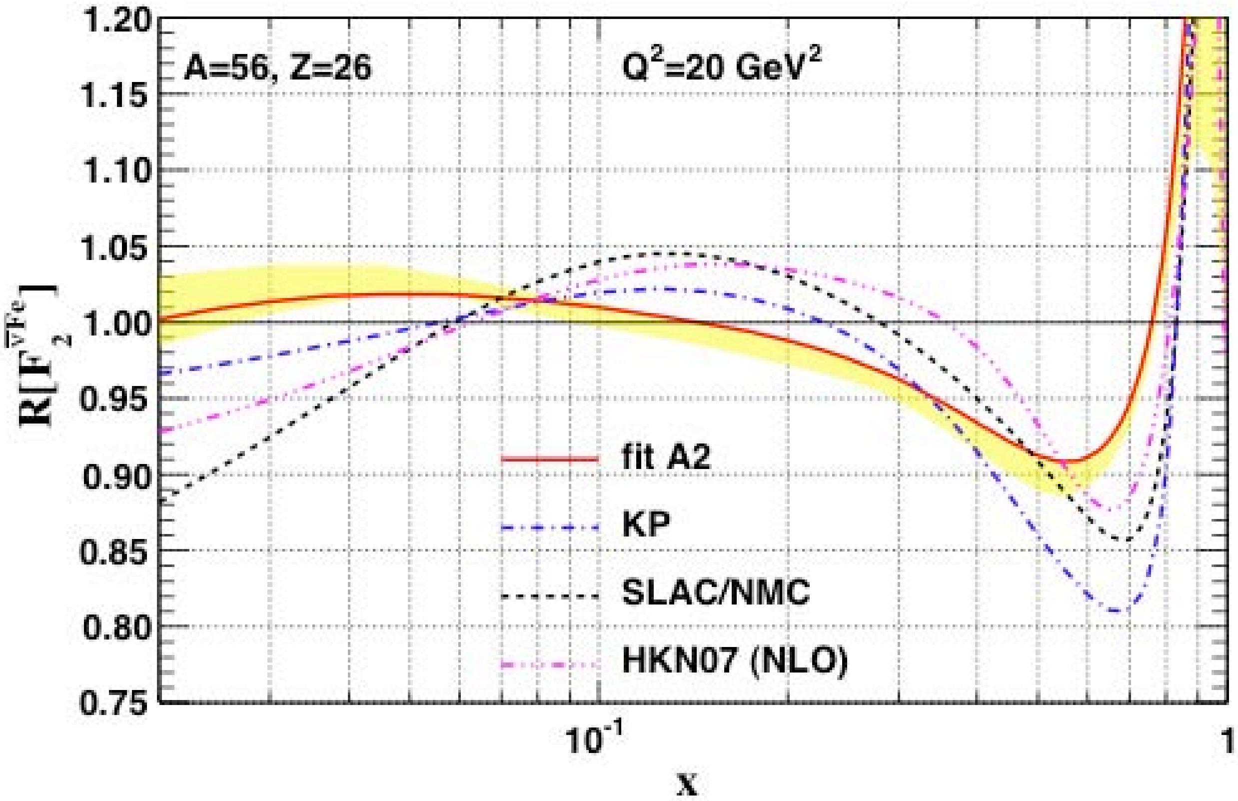

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$$xF_3^{\bar{\nu}N}(x,Q^2) = x\left[u+d-\bar{u}-\bar{d}-2\bar{s}+2c\right]$$

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

**How neutrinos help us constrain the Strange Sea**

$$\nu N \rightarrow \mu^- c X \rightarrow \mu^- \mu^+ X$$

$$\bar{\nu} N \rightarrow \mu^+ c X \rightarrow \mu^+ \mu^- X$$

# Summary

- **Neutrino scattering could be a powerful tool to determine PDFs particularly the strange and high-x valence quarks**
- $(\bar{d} - \bar{u}) / (\bar{d}+\bar{u})$ reasonably constrained out to $x \approx 0.4$.
- $\kappa = (s + \bar{s}) / (\bar{u} + \bar{d})$ seems to be increasing with x.
- $(s - \bar{s}) / (s + \bar{s})$ and heavy quarks need further clarification.
- The valence u-quark is reasonable out to $x = 0.5$, while the d-quark uncertainty blows up around $x = 0.3$.
- d/u at high-x still uncertain due to spread in deuteron correction.
- There is a serious need for new input to global QCD fits at HIGH X
- **The Cleanest Way To Measure d/u: $\nu$ + p Scattering**
- **UNKNOWN nuclear corrections in neutrino scattering are keeping the special abilities of neutrinos out of global fits for PDFs**