Charm Production
& implications for heavy quark PDF's

Fred Olness

SMU

Collaborators:
P. Nadolsky, W. Tung, S. Kretzer, J. Owens,
S. Kuhlmann, J. Pumplin, H. Lai

DIS 2003
25 April 2003

Electroweak Mixing Angle Measurement

NuTeV Result:

$$\sin^2\theta_W^{(on-shell)} = 0.2277 \pm 0.0031\,(stat) \pm 0.0009\,(syst)$$
$$-0.00022 \times \left(\frac{M_{top}^2 - (175\ GeV)^2}{(50\ GeV)^2}\right)$$
$$+0.00032 \times \ln\left(\frac{M_{Higgs}}{150\ GeV}\right)$$

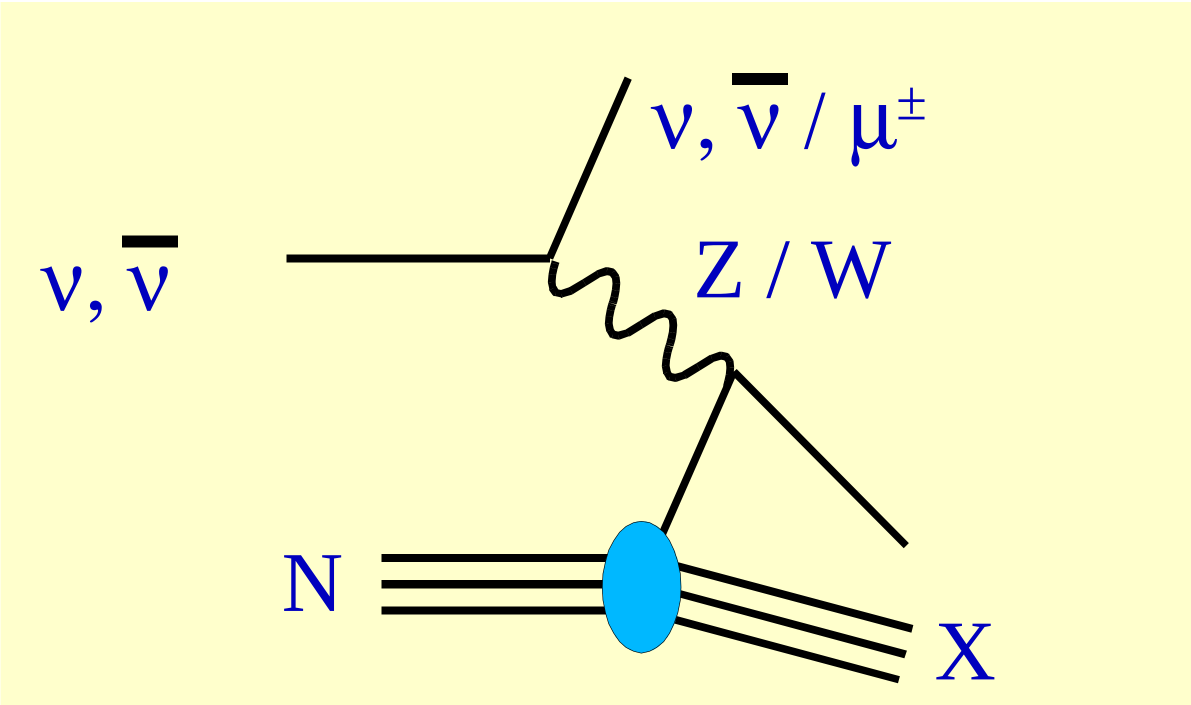
Standard Model Fit:

$$\sin^2\theta_W^{(on-shell)} = 0.2227 \pm 0.0004 \quad (LEP\ EWWG)$$

A discrepancy of 3σ

G.P. Zeller, (NuTeV) et al., PRL 88: 091802 (2002); PRD 65: 111103 (2002)

Neutrino Induced Deeply Inelastic Scattering



Paschos-Wolfenstein Relation:

$$R^- \equiv \frac{\sigma(\nu_\mu N \to \nu_\mu X) - \sigma(\overline{\nu}_\mu N \to \overline{\nu}_\mu X)}{\sigma(\nu_\mu N \to \mu^- X) - \sigma(\overline{\nu}_\mu N \to \mu^+ X)}$$

$$= \left(g_L^2 - g_R^2\right)$$

G.P. Zeller, (NuTeV) et al., PRL 88: 091802 (2002); PRD 65: 111103 (2002)

Contributions to Experimental Uncertainty

SOURCE OF UNCERTAINTY	$\delta\sin^2\theta_W$	δR^{ν}	$\delta R^{\overline{\nu}}$
Data Statistics	0.00135	0.00069	0.00159
Monte Carlo Statistics	0.00010	0.00006	0.00010
TOTAL STATISTICS	0.00135	0.00069	0.00159
$\nu_e, \overline{\nu}_e$ Flux	0.00039	0.00025	0.00044
Energy Measurement	0.00018	0.00015	0.00024
Shower Length Model	0.00027	0.00021	0.00020
Counter Efficiency, Noise, Size	0.00023	0.00014	0.00006
Interaction Vertex	0.00030	0.00022	0.00017
TOTAL EXPERIMENTAL	0.00063	0.00044	0.00057
Charm Production, Strange Sea	0.00047	0.00089	0.00184
Charm Sea	0.00010	0.00005	0.00004
$\sigma^{\overline{\nu}}/\sigma^{\nu}$	0.00022	0.00007	0.00026
Radiative Corrections	0.00011	0.00005	0.00006
Non-Isoscalar Target	0.00005	0.00004	0.00004
Higher Twist	0.00014	0.00012	0.00013
R_L	0.00032	0.00045	0.00101
TOTAL MODEL	0.00064	0.00101	0.00212
TOTAL UNCERTAINTY	0.00162	0.00130	0.00272

TABLE I. Uncertainties for both the single parameter $\sin^2\theta_W$ fit and for the comparison of R^{ν} and $R^{\overline{\nu}}$ with model predictions.

Largest model uncertainty arises from charm production and s(x)

s and s-bar difference can have large effect

... relative uncertainty is reduced for combination

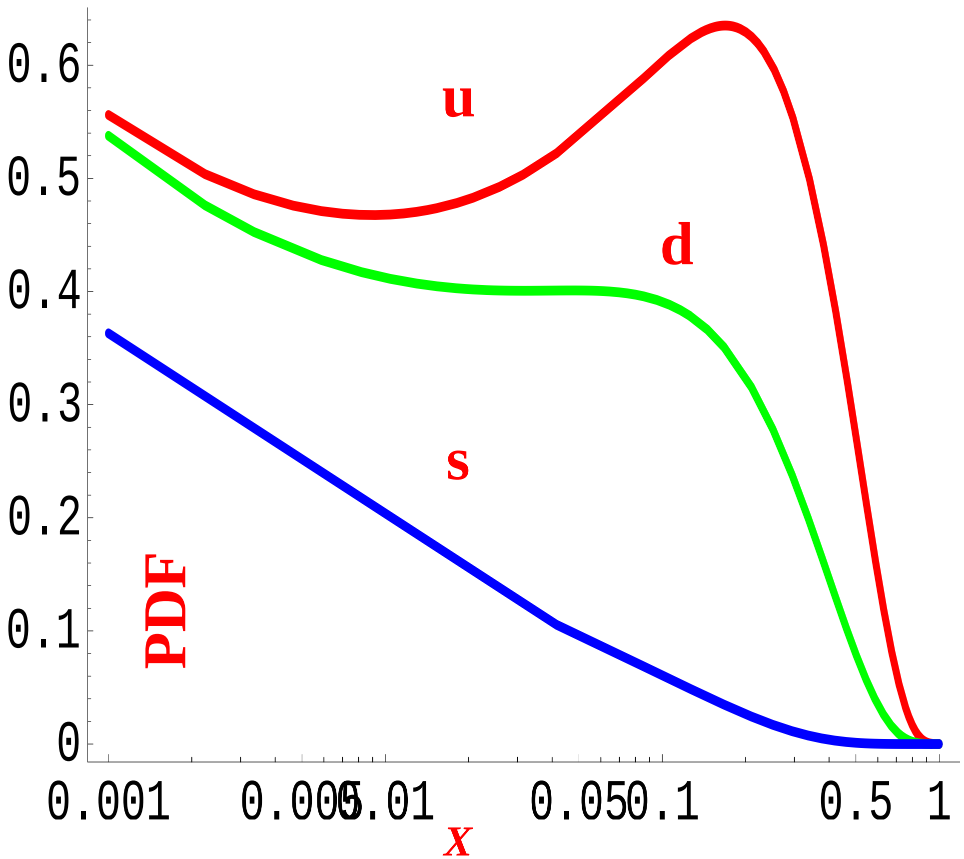
G.P. Zeller, (NuTeV) et al., PRL 88: 091802 (2002); PRD 65: 111103 (2002)

What is the mechanism for Charm production,

and

where does the $s(x)$ distribution come from?

Where does s(x) come from???



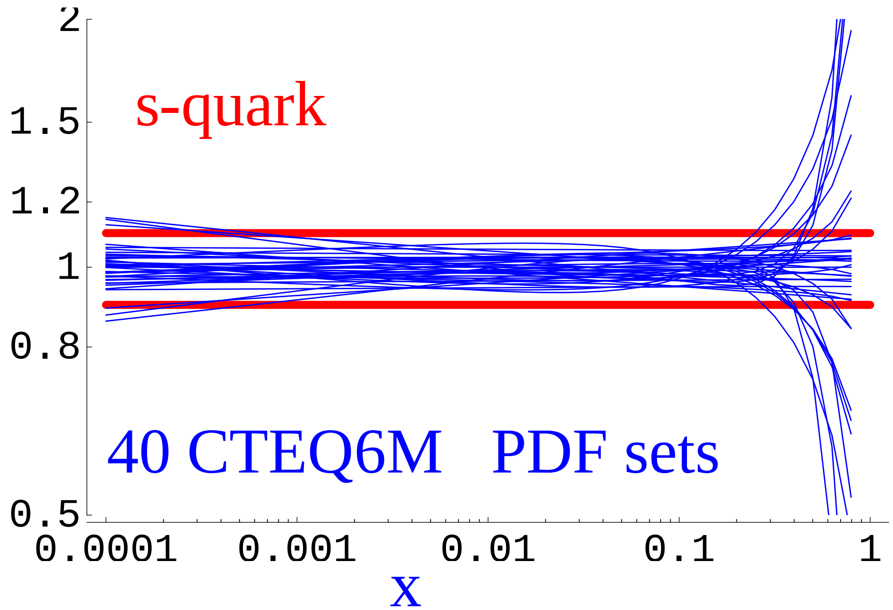
Inclusive Structure Funtions:

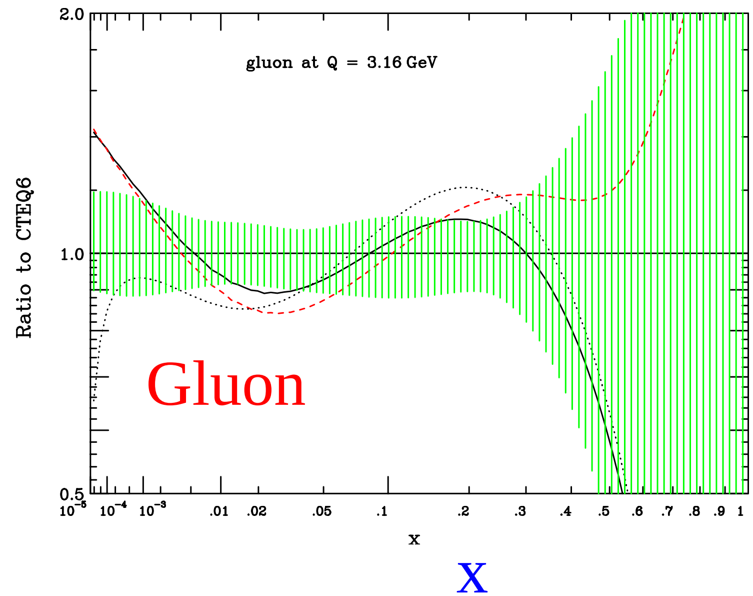
Yield s(x) in combination

Must extract s(x)
from under other PDF's

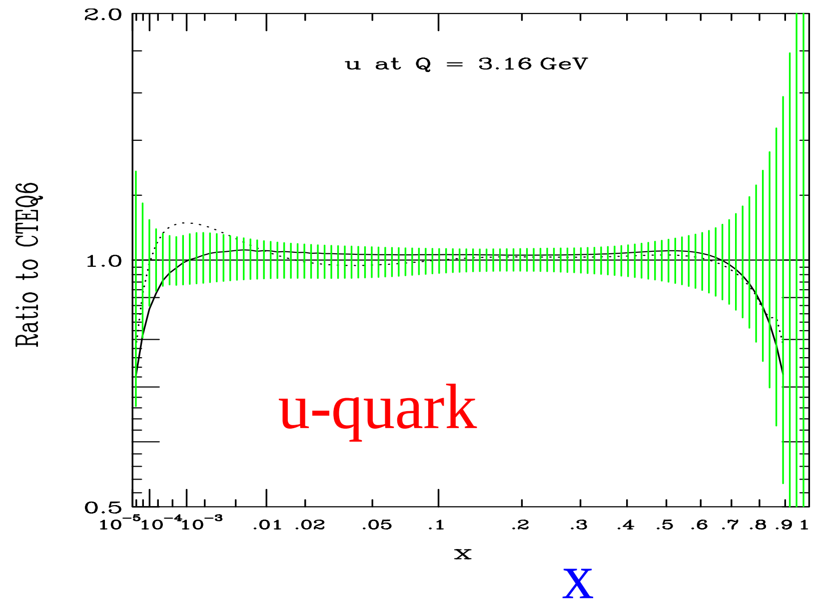
$$F_2 \cong x\,(u + \bar{u} + d + \bar{d} + s + \bar{s} + c + \bar{c} + \ldots)$$

What is relative uncertainty on s(x) ???





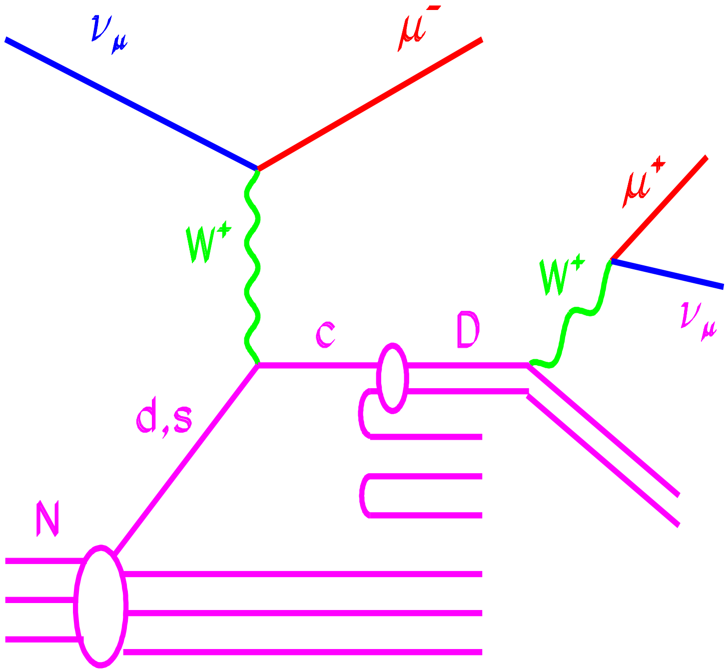
Presently, s(x) is tied to
u-bar and d-bar via kappa:



$$s(x) = \bar{s}(x) = \kappa \frac{\bar{u}(x) + \bar{d}(x)}{2}$$

We can do better!

Dimuons are ideal signal of s(x)



di-muon	NuTeV	CCFR	Combined
Neutrino	5012	5030	10042
Anti-Nu	1458	1060	2518

* High stats & high precision data
* Best constraints on strange quark

$$\frac{d\sigma^{+}_{\mu^{\pm}\mu^{\mp}}}{dx\,dy} = \int d\Gamma\, d\Omega\, \frac{d\sigma_{\mu^{\mp}c}}{dx\,dy\,d\Gamma} \otimes D_c(\Gamma) \otimes \Delta_c(\Omega)\Big|_{E_{\mu^{\pm}} > 5\ GeV}$$

Di-muon cross-section

Charm Production cross-section

Fragmentation Function

Decay Distribution

M. Goncharov et al., NuTeV Collaboration PRD 64:110226 (2001)

Parameterization of s(x) at Q_0

$$s(x, Q_0) \equiv \bar{s}(x, Q_0) = a_0 \; x^{a_1} \left(1 - x\right)^{a_2} \times f\left(a_{3,} a_{4,} a_5 ; x\right)$$

Constrained fit: $\{a_0\}$ free

Mixed fit: $\{a_0, a_2\}$ free

Free fit: $\{a_i\}$ free

Global Fit

χ^2 / DOF	CTEQ6M	Constrained	Mixed	Free
CCFR Nu	1.02	0.85	0.79	0.72
CCFR Nu-bar	0.58	0.54	0.59	0.59
NuTeV Nu	1.81	1.70	1.55	1.44
NuTeV Nu-bar	1.48	1.30	1.15	1.13
BCDMS F2p	1.11	1.11	1.11	1.11
BCDMS F2d	1.10	1.10	1.10	1.11
H1 96/97	0.94	0.95	0.94	0.94
H1 98/99	1.02	1.03	1.03	1.03
ZEUS 96/97	1.14	1.14	1.14	1.15
NMC F2p	1.52	1.50	1.51	1.49
NMC F2d/F2p	0.91	0.91	0.91	0.91
NMC F2d/F2p $\langle Q^2 \rangle$	1.05	1.07	1.06	1.03
CCFR F2	1.70	1.71	1.81	1.88
CCFR F3	0.42	0.42	0.44	0.42
E605	0.82	0.82	0.82	0.83
NA51	0.62	0.61	0.52	0.52
CDF ℓ Asym	0.82	0.83	0.82	0.82
E866	0.39	0.40	0.39	0.38
D0 Jets	0.71	0.65	0.70	0.67
CDF Jets	1.48	1.48	1.48	1.47
TOTAL	2173	2144	2142	2133

Total of 1991 data points

CTEQ6: J. Pumplin, et al., JHEP 0207:012,2002

Reasonable χ^2 values

(CTEQ6 did not fit di-muon data)

More parameters, lower value of χ^2

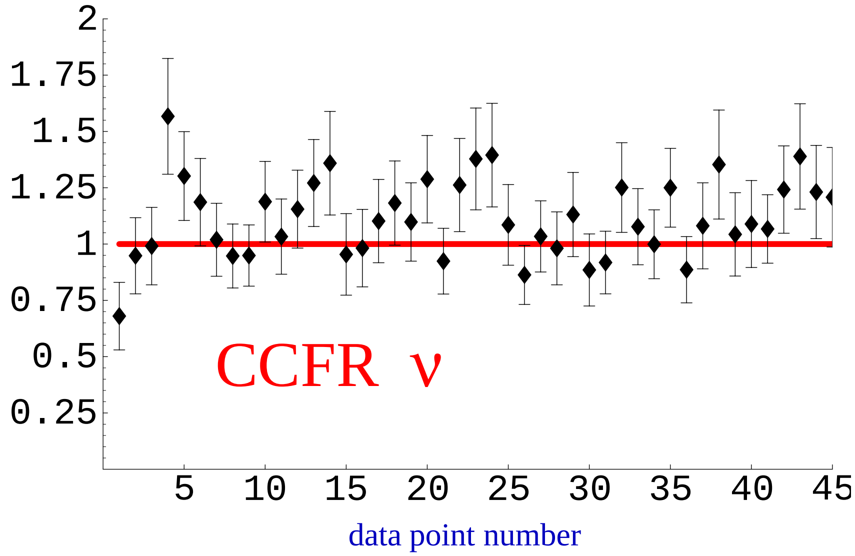
Only di-muon data is sensitive to s(x) !!!

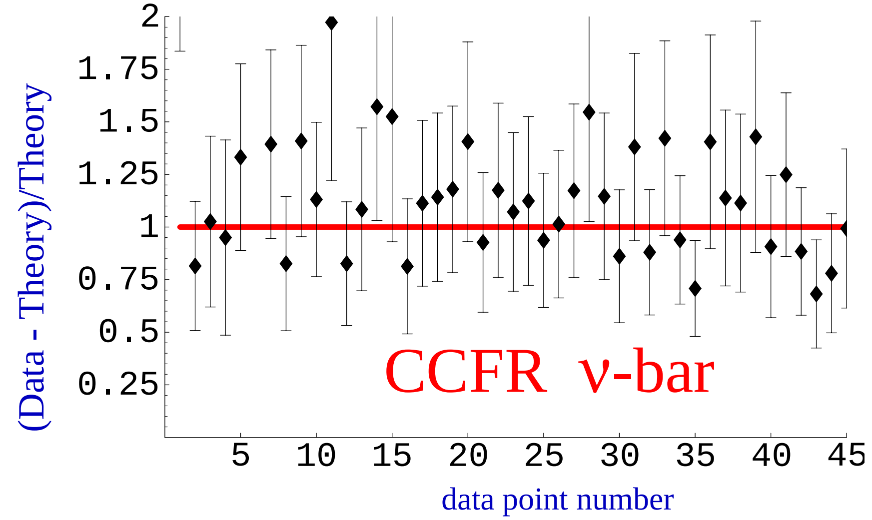
$\therefore$

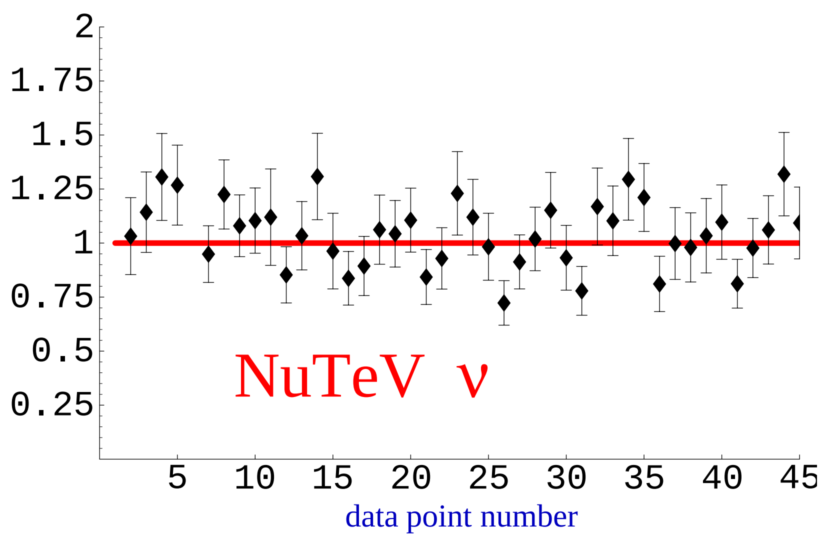
PRELIMINARY

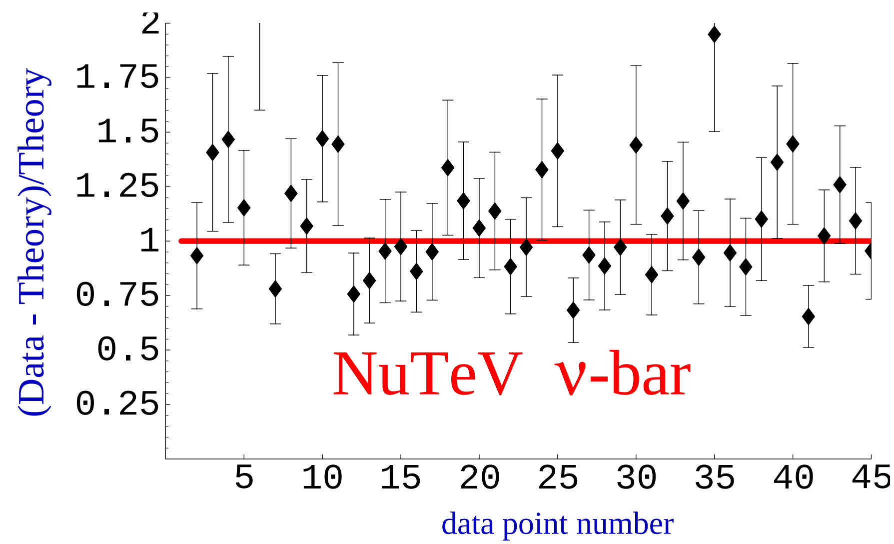
Idea: fit ν and ν-bar data separately to approximate s and s-bar distributions

How good is the fit? (Data - Theory)/Theory Plots









PRELIMINARY

Higher statistics for ν-data ⇒ stronger pull for fit

Fit ν and ν-bar data separately to approximate s and s-bar

s(x) proportional to ν $\quad\quad$ $\bar{s}$(x) proportional to $\bar{\nu}$

* Feasible since other data sets are insensitive to s(x)

* Will provide qualitative results

* Quark number sum rule not satisfied with this approximation

$$\int dx\left[s(x)-\bar{s}(x)\right]=0$$

Note, this sum rule can be violated by non-perturbative processes: eg., $p \to \Lambda K$

Global Analysis

κ	ν + anti-ν	ν	anti-ν
Constrained	0.56	0.50	0.56
Mixed	0.53	0.55	0.59
Free	0.32	0.25	0.37

PRELIMINARY

κ value at Q_0=1.3 GeV

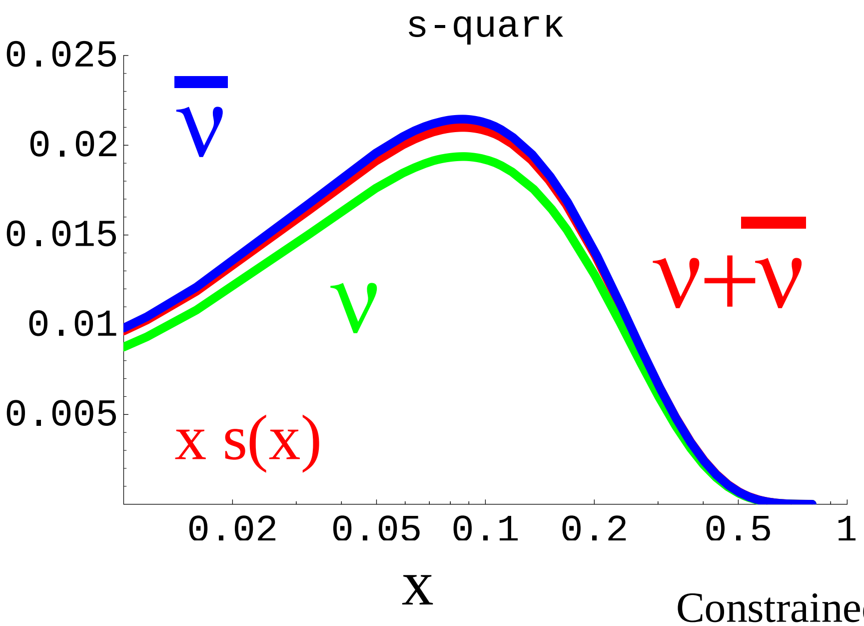
$$\kappa = \frac{s(x)+\bar{s}(x)}{\bar{u}(x)+\bar{d}(x)}$$

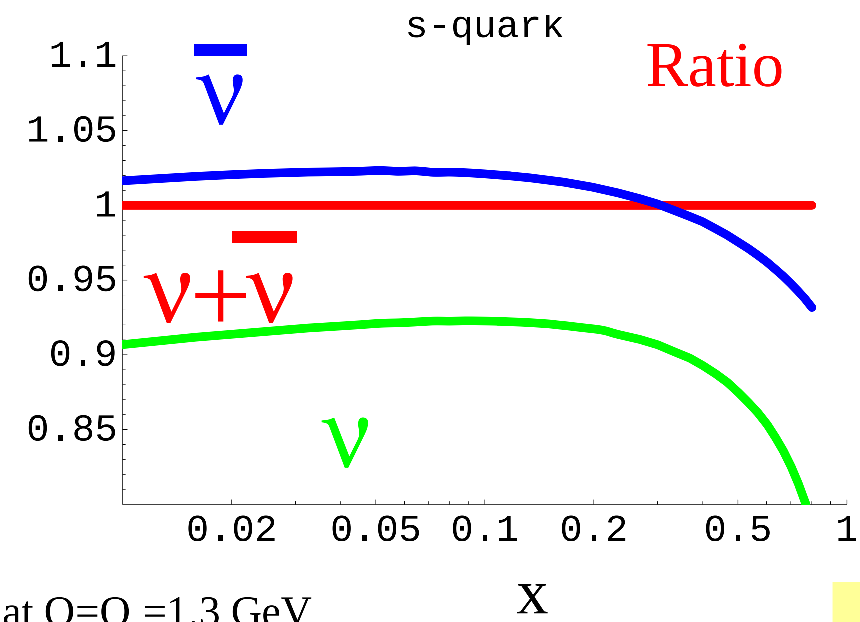
Compare with Goncharov:

$$\begin{cases} \kappa = 0.35 & for \quad \nu \\ \bar{\kappa} = 0.41 & for \quad \bar{\nu} \end{cases}$$

M. Goncharov et al., NuTeV Collaboration PRD 64:110226 (2001)

Fit ν and ν-bar data separately





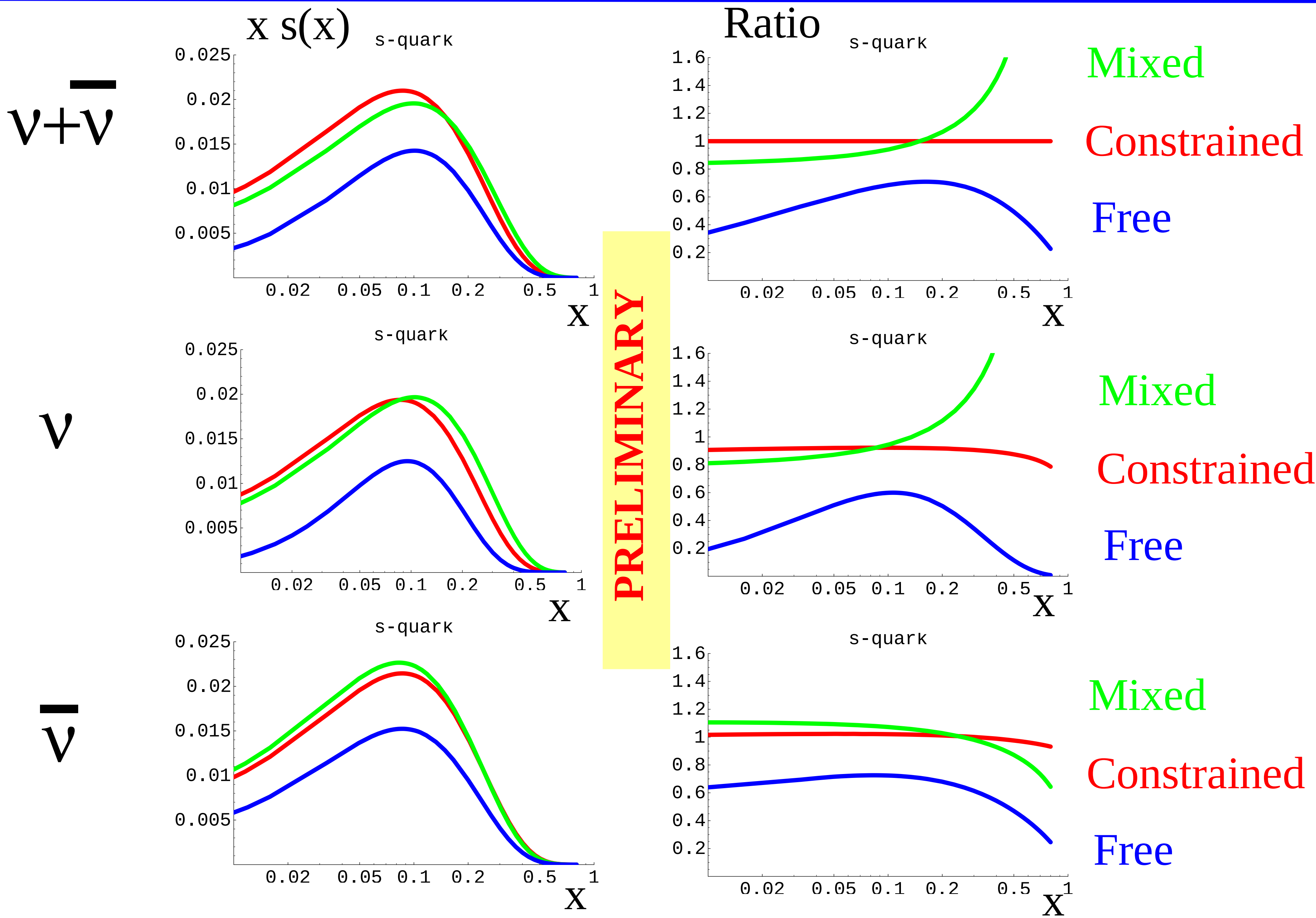
Constrained fit at $Q=Q_0=1.3$ GeV

ν data pulls s(x) down

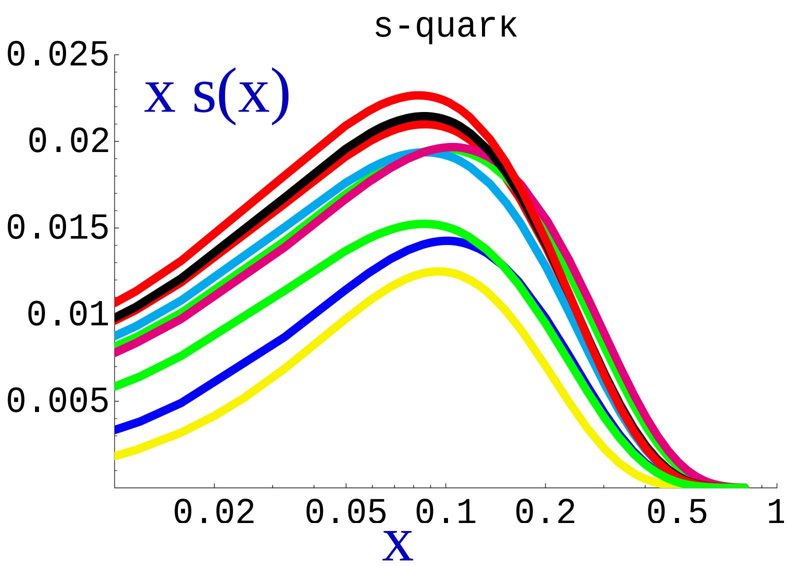
$\bar{\nu}$ data pulls $\bar{s}$(x) up

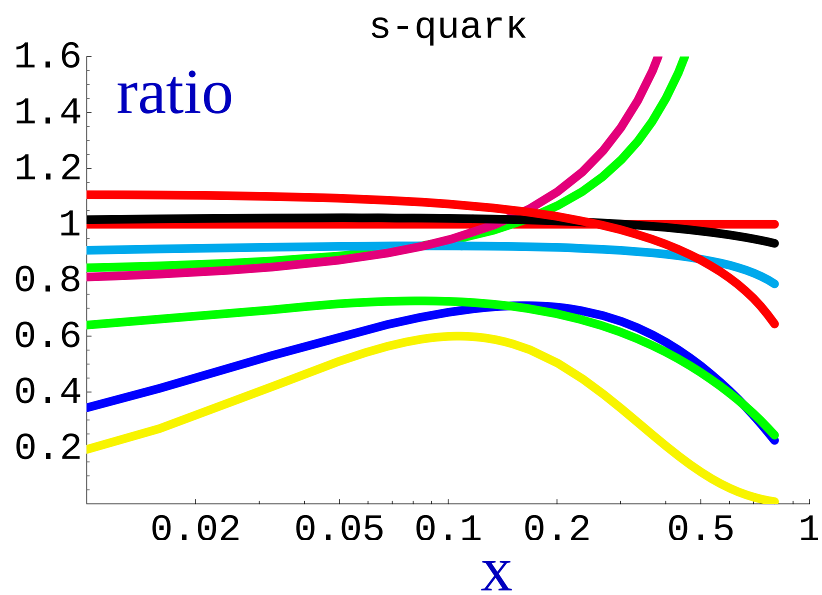
PRELIMINARY

Fit ν and ν-bar data separately

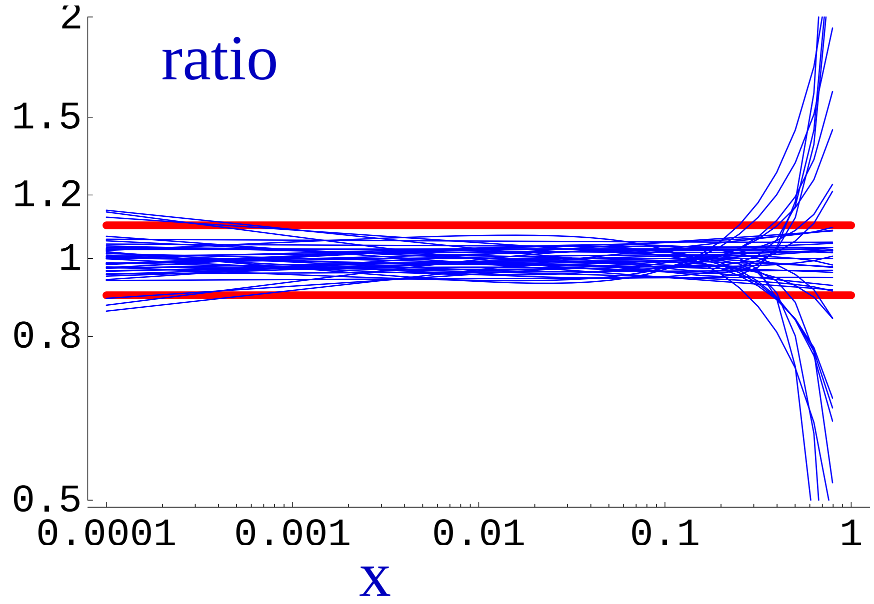


Examine variational range of s(x)

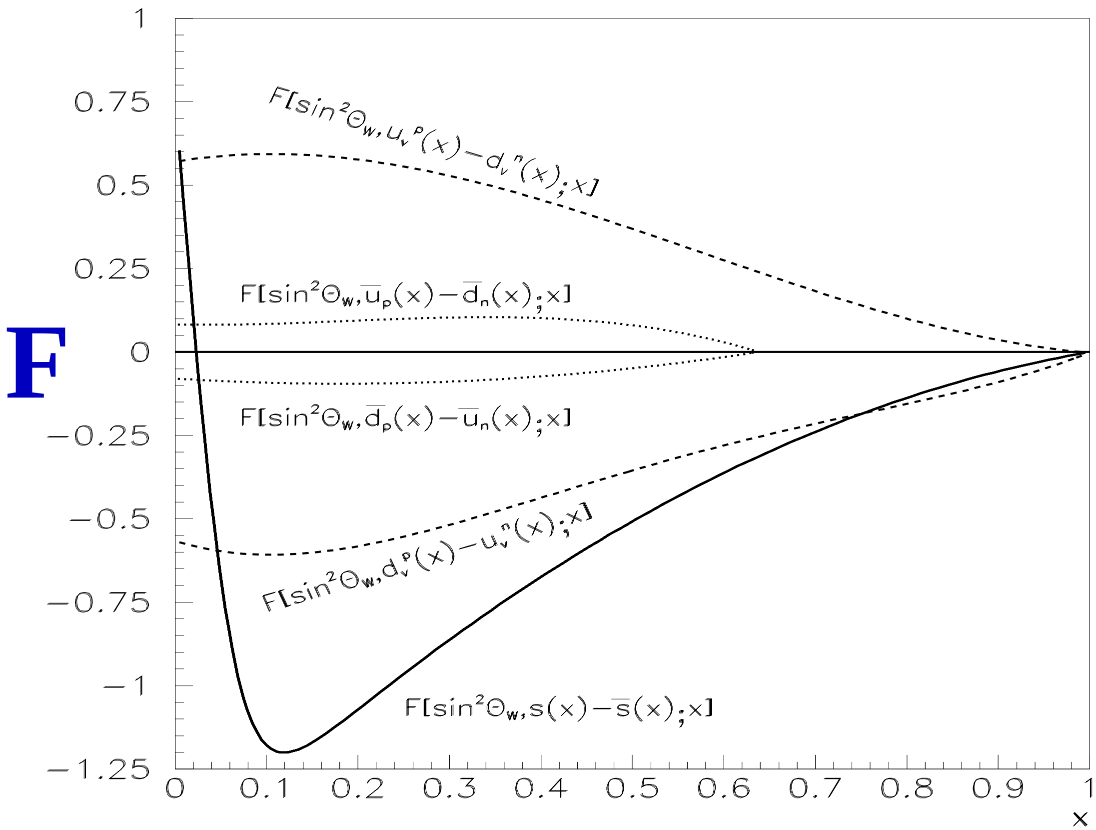




PRELIMINARY



Strange Asymmetry



$$\Delta \sin(\theta_W) = \int_0^1 F[x]\,\delta(x)\,dx$$

$$where \quad \delta(x) = s(x) - \bar{s}(x)$$

$$For \quad s(x) < \bar{s}(x)$$

$$\Delta \sin(\theta_W) > 0$$

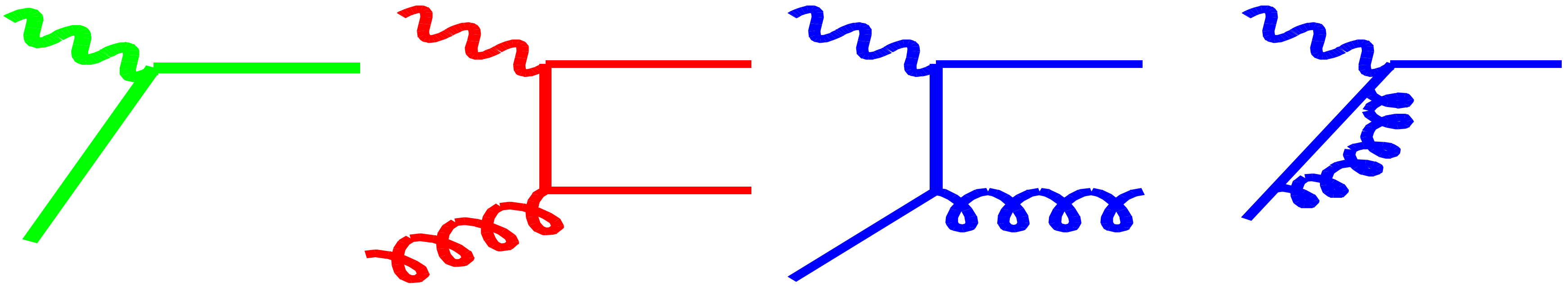
Discrepancy Increases !

* Preliminary analysis appears consistent with above

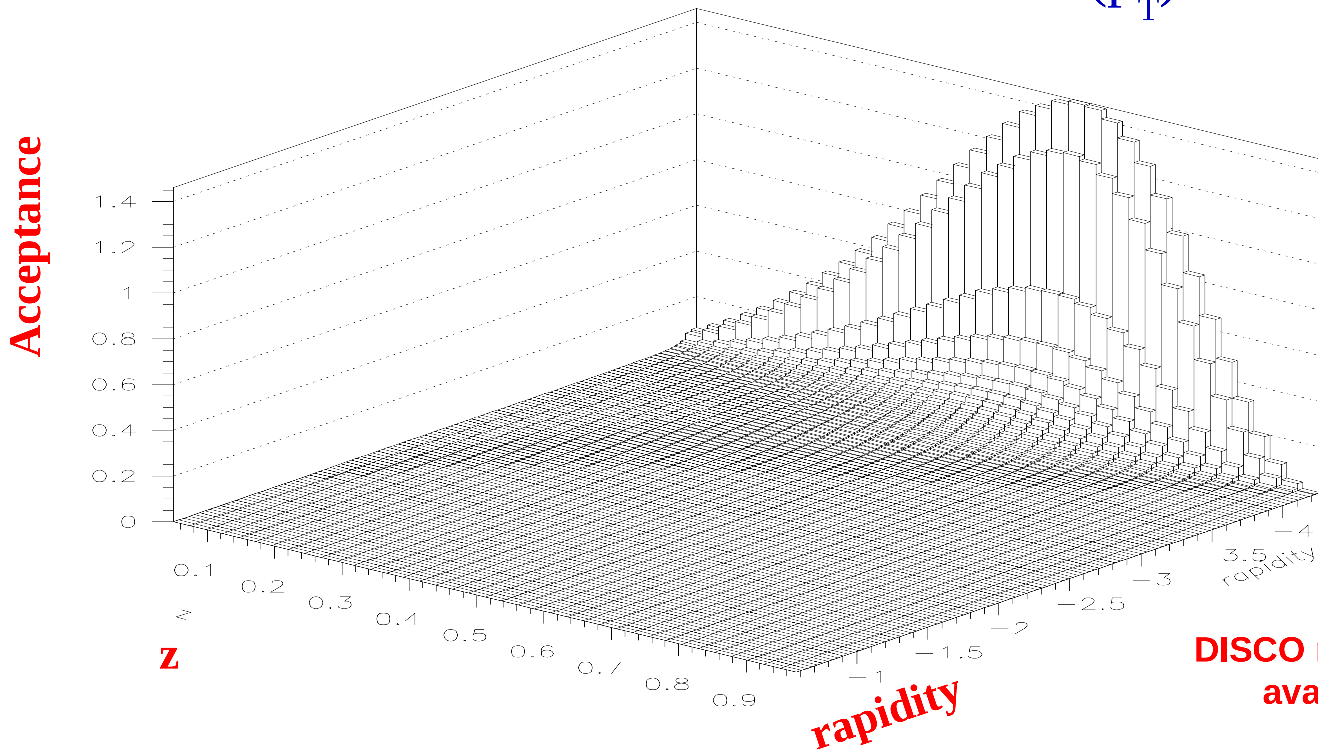
* Need to implement quark-number sum rule

G.P. Zeller, NuTeV Collaboration, hep-ex/0203004, PRD

NLO Analysis



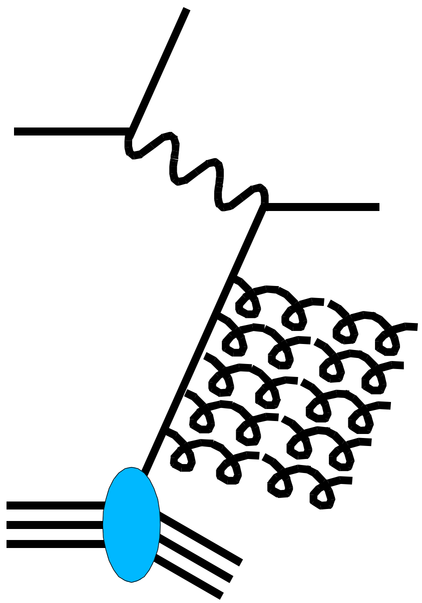
* Higher order diagrams
* More differential distributions
* Encounter distribution functions: $\delta(p_T)$ and $1/(1-x)_+$



Kretzer, Mason, Olness
PRD 65:074010 (2002)

DISCO numerical Fortran program
available for data analysis

Resummation of soft gluons for massive processes



* Uses CSS Formalism to resum Log(q_T/Q)
* Uses ACOT Formalism to resum Log(M/Q)

Satisfies appropriate limits:

$q_T \to Q$, obtain usual perturbative result

$M \to 0$, obtain usual massless result

$M, q_T \to 0$, obtain usual Sudakov form

Theoretical basis for NLO Monte Carlo program

... provides full kinematic description

Nadolsky, Kidonakis, Olness, Yuan, hep-ph/0210082, PRD

Thanks to ...

Tim Bolton

Max Goncharov

Dave Mason

Un-Ki Yang

Janet Conrad

Mike Shaevitz

Andrew Barzarko

Conclusions

* Di-Muon data incorporated in Global fit:

provides important information on s(x)

search for "New Physics" signals

* Need to consider s ≠ s-bar

This is real progress!!! We now can discriminate!

Poor Man's fit indicates s < s-bar in data region.

Need complete analysis including s-quark Σum rule

... for the future ...

* NLO Experimental Dimuon analysis:

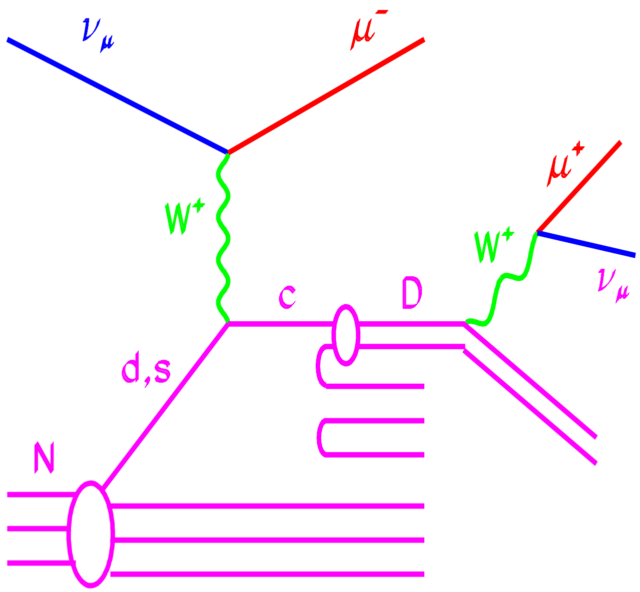
NLO Experimental analysis in progress (D. Mason)

NLO code (DISCO) is available (S. Kretzer)

* Resummation of large logarithms:

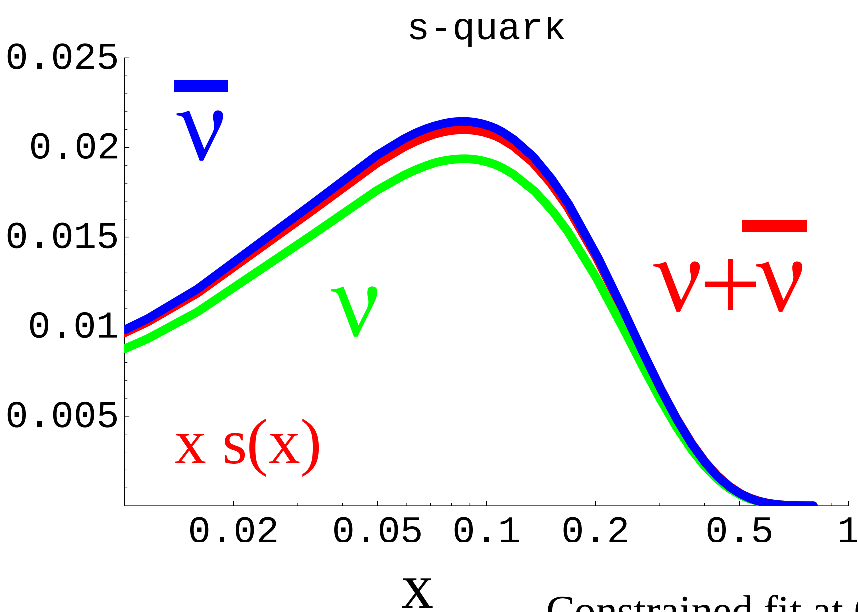
Resummation of Log(q_T/Q) and Log(M/Q) (P. Nadolsky ...)

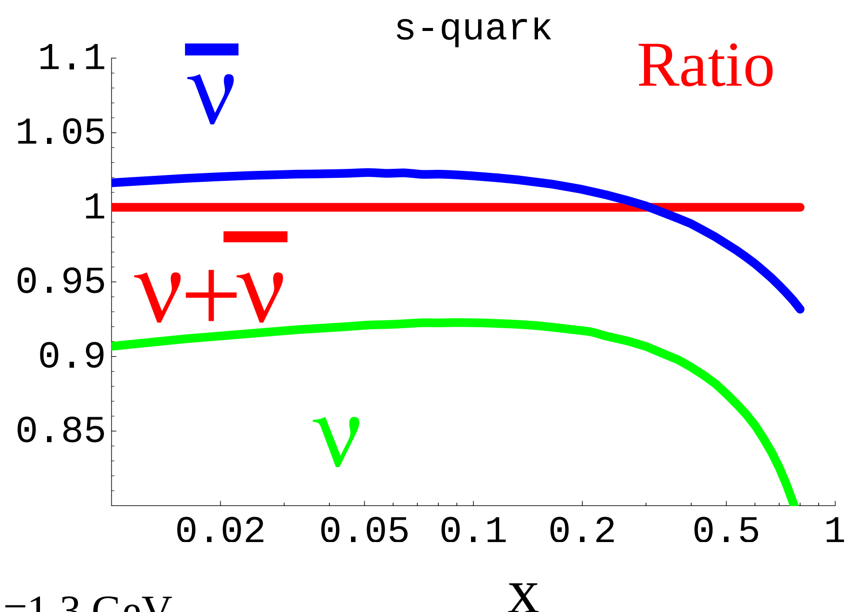
Include neutrino-induced dimuon data into global analysis fit



- * Di-muon data included in global fit
- *** Provides strong constraint on s(x)**
- * Extend analysis for s ≠ s-bar
- * Preliminary analysis: s < s-bar †

†Need to consider quark-number sum rule

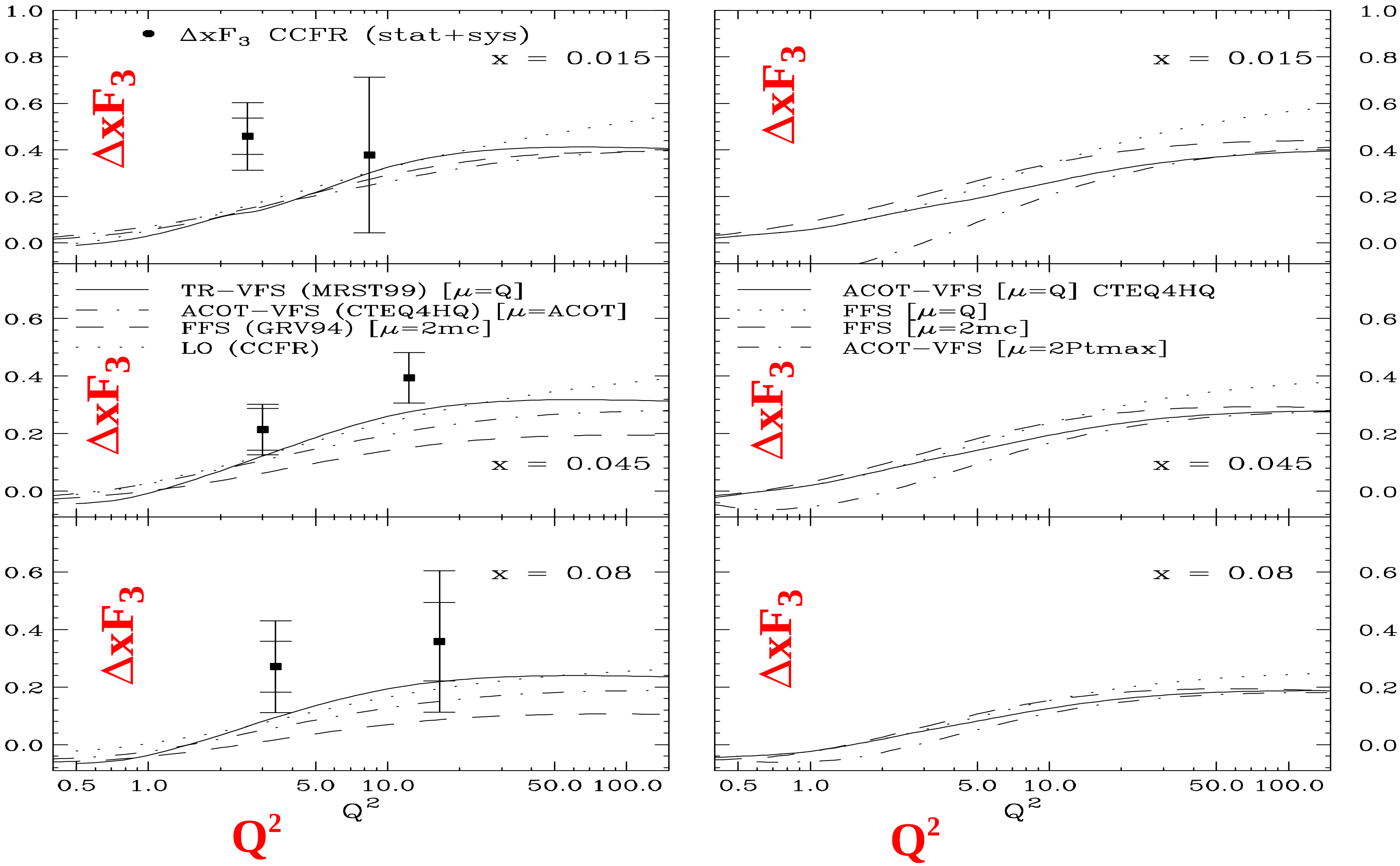




PRELIMINARY

Constrained fit at $Q=Q_0=1.3$ GeV

ΔxF_3 Structure Function

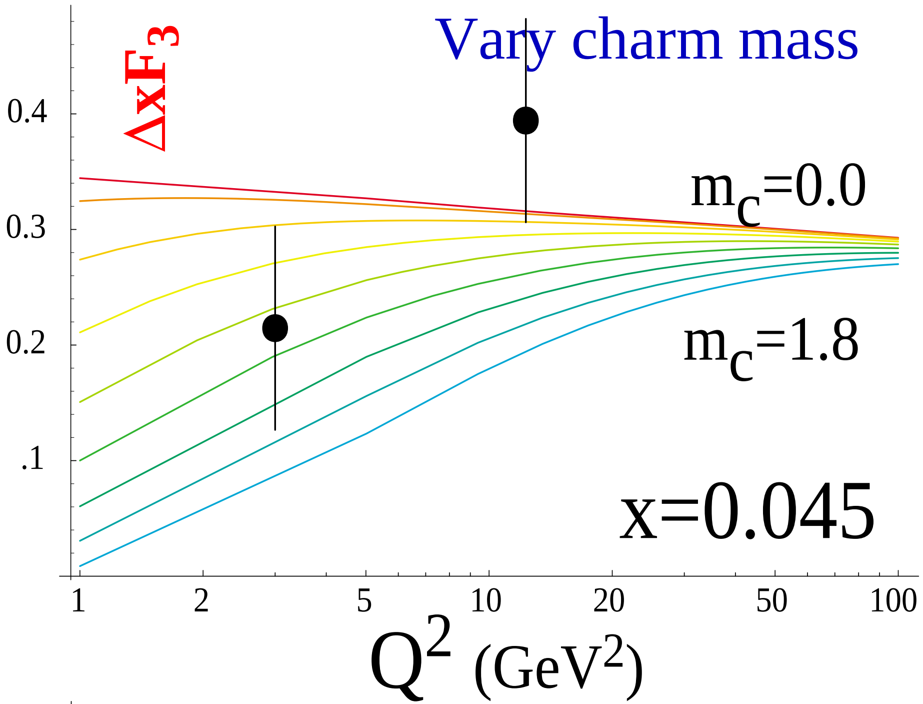


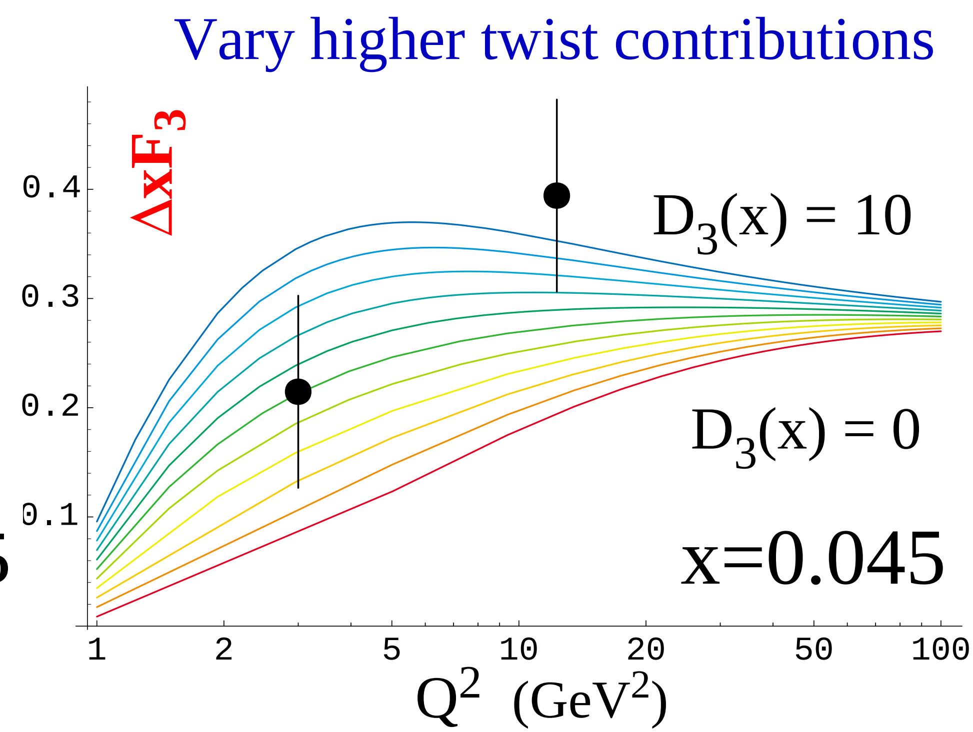
$$\Delta xF_3 \sim 4\, x\, (\, s - c\,)$$

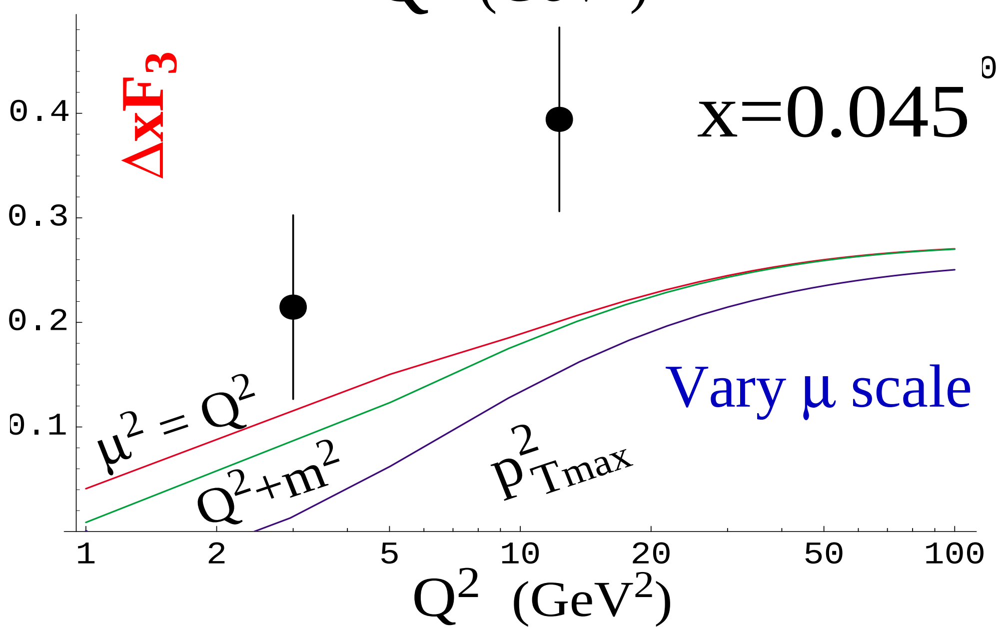
Un-Ki Yang
NuTeV Collaboration

PRL 86:2742 (2001)

Can we make the problem go away?







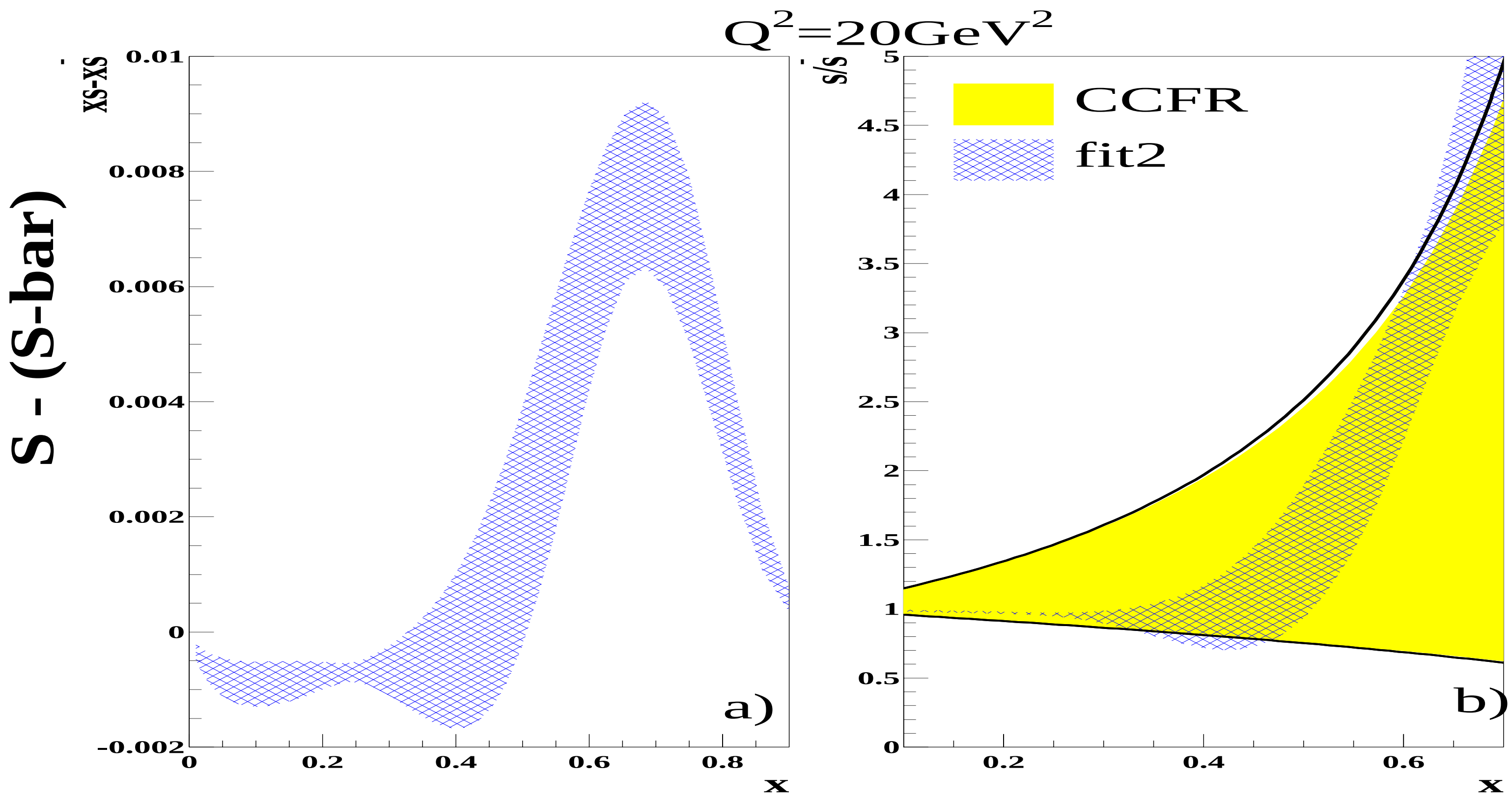
Kretzer, Olness, Scalise, Thorne, Yang
PRD64: 033003, 2001

Strange Asymmetry

Global analysis: Barone, Pascaud, Zommer

DIS: BEBC, CDHS, CDHSW, BCDMS, H1, NMC

Drell-Yan: E605, NA51, E866

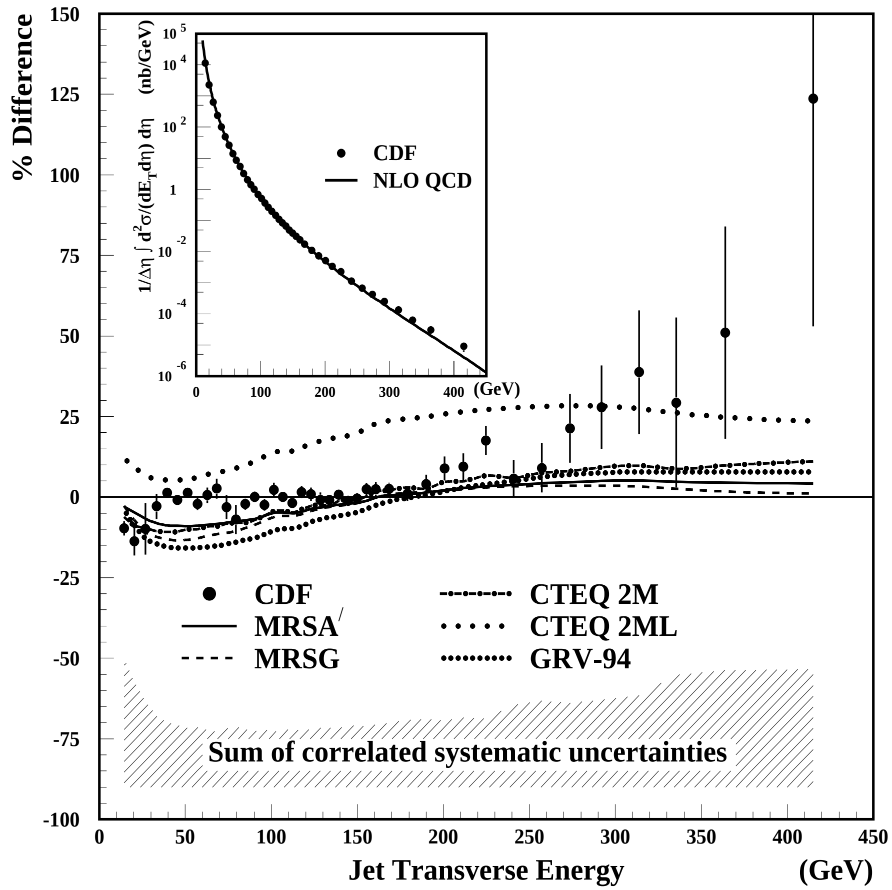


Barone, Pascaud, Zommer, Eur. Phys. J. C12: 243, 2000

The Search For New Physics

1996: Excess High E_T Jets at Tevatron

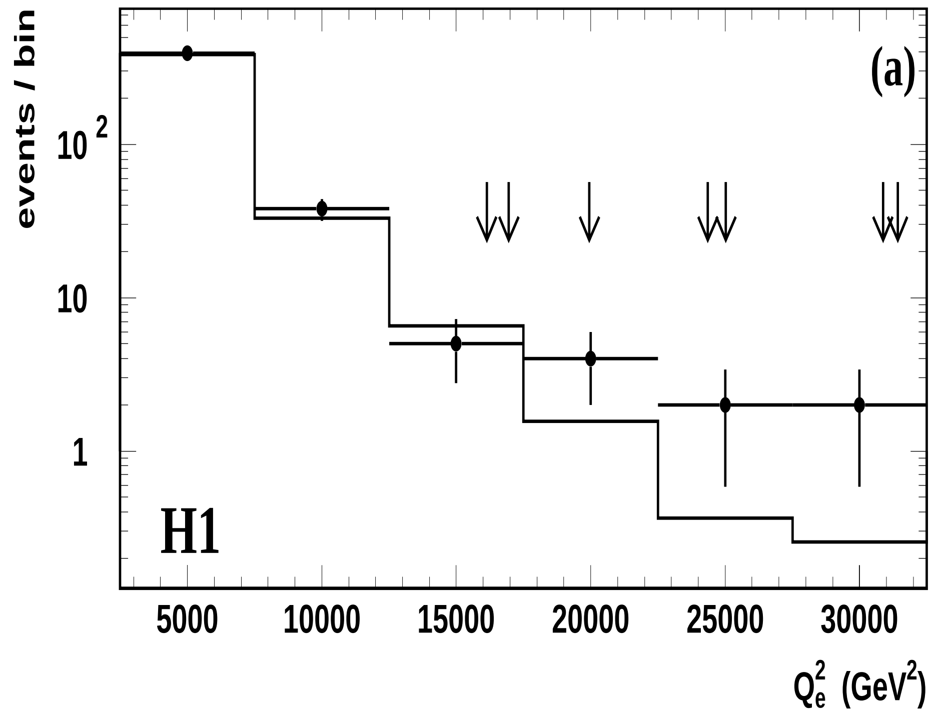
Is this a sign of compositeness?



CDF Collaboration
PRL 77, 438 (1996)

1997: Excess DIS events at large $\{x,Q^2\}$

Is this a sign of lepto-quarks?



H1 Collaboration, ZPC74, 191 (1997)
ZEUS Collaboration, ZPC74, 207 (1997)

Precision PDF's are essential