Progress in PDFs

PDF Status
Evolution
Nuclear Corrections
Target Mass Corrections

Strange Quark PDF
Drell-Yan
Heavy Quark Effects

Fred Olness

SMU

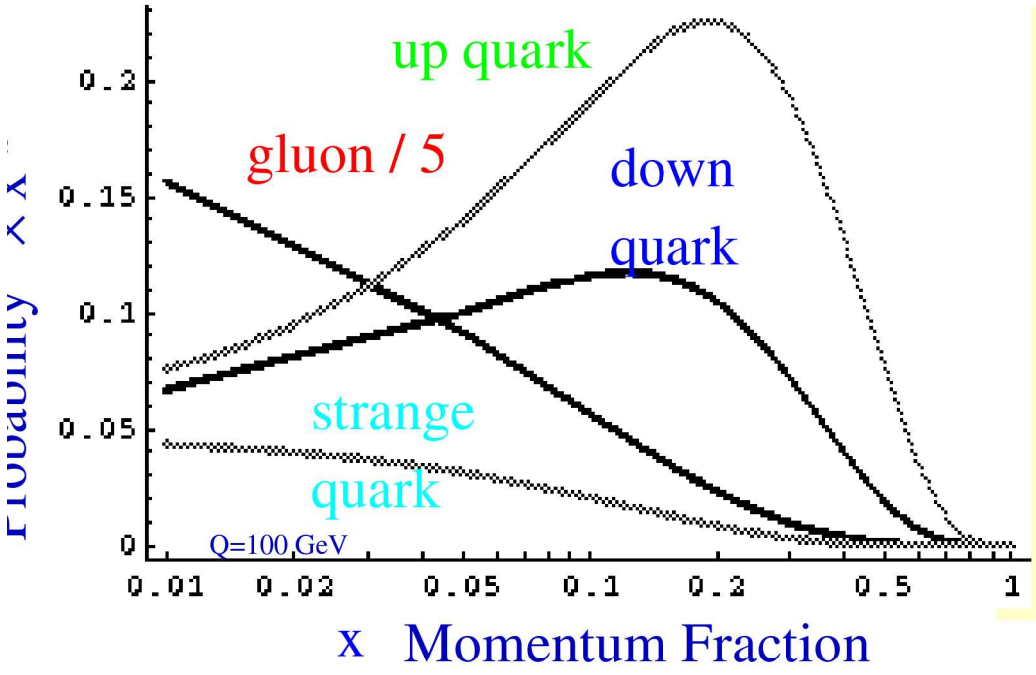
Conspirators:
P. Nadolsky, S. Berge, I Schienbein,
J.-Y. Yu, W. Tung, S. Kretzer,
J. Owens, S. Kuhlmann, J. Pumplin, H. Lai
J. Morfin, C. Keppel, V. Radescu, D. Mason

Workshop on Intersections of
Nuclear Physics with
Neutrinos and Electrons

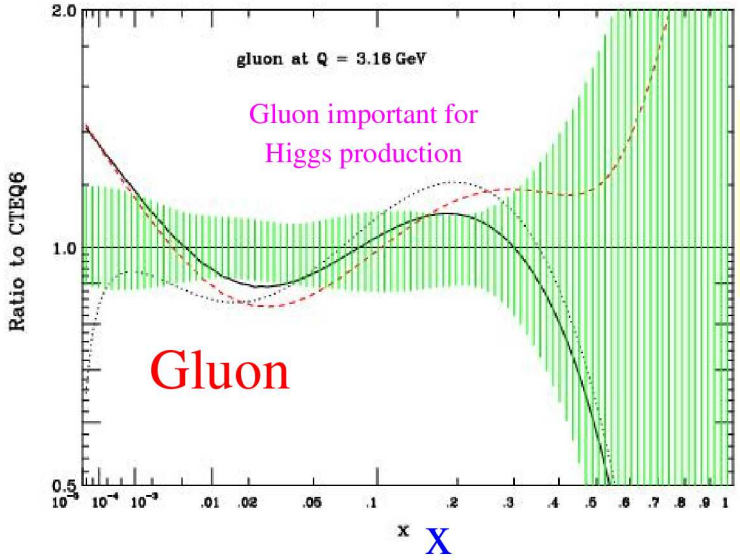
4 May 2006

Special thanks to Jeff Owens for his APS 2005 material

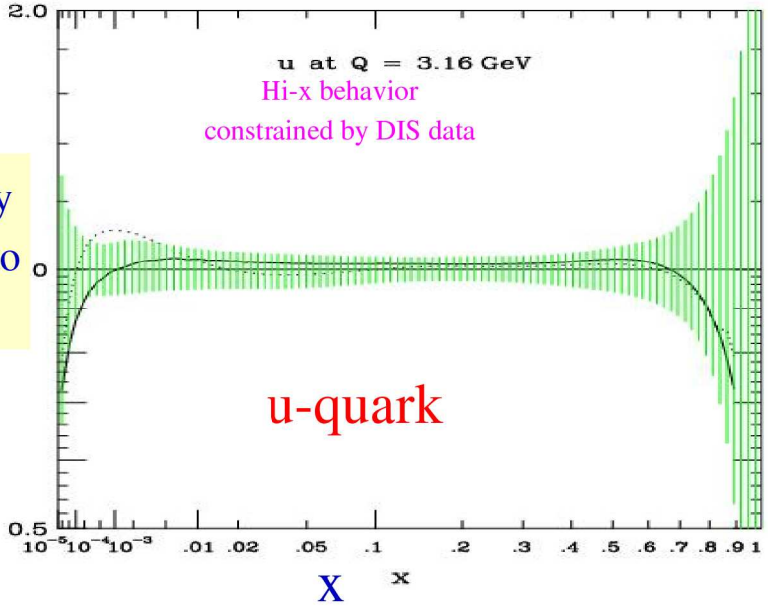
PDF STATUS



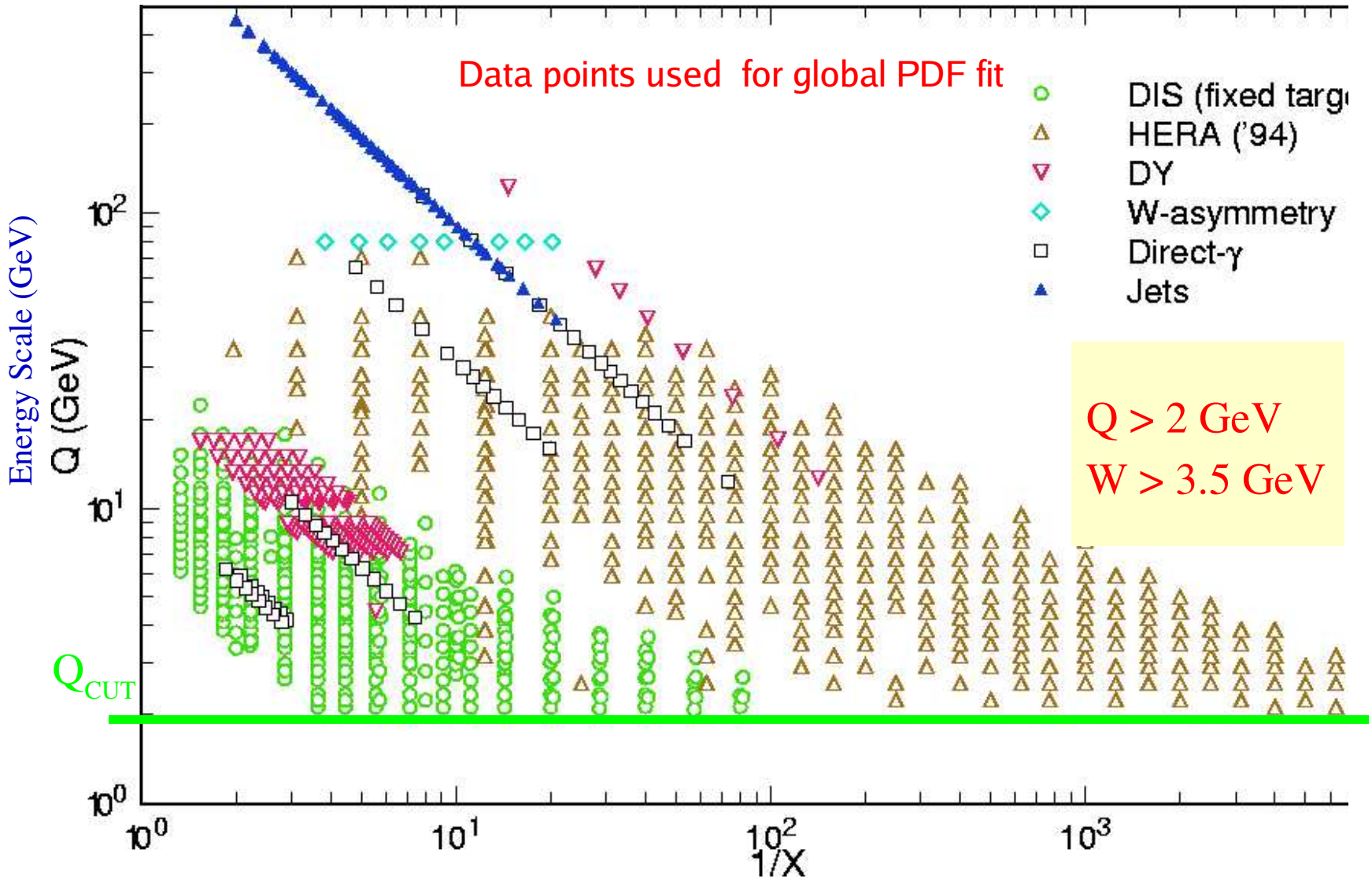
- u and d valence distributions well determined
- improved determination of flavor sea $\bar{u}, \bar{d}, \bar{s}$
- Improved Gluon
- PDF Uncertainties



PDF Uncertainty band compared to CTEQ6M



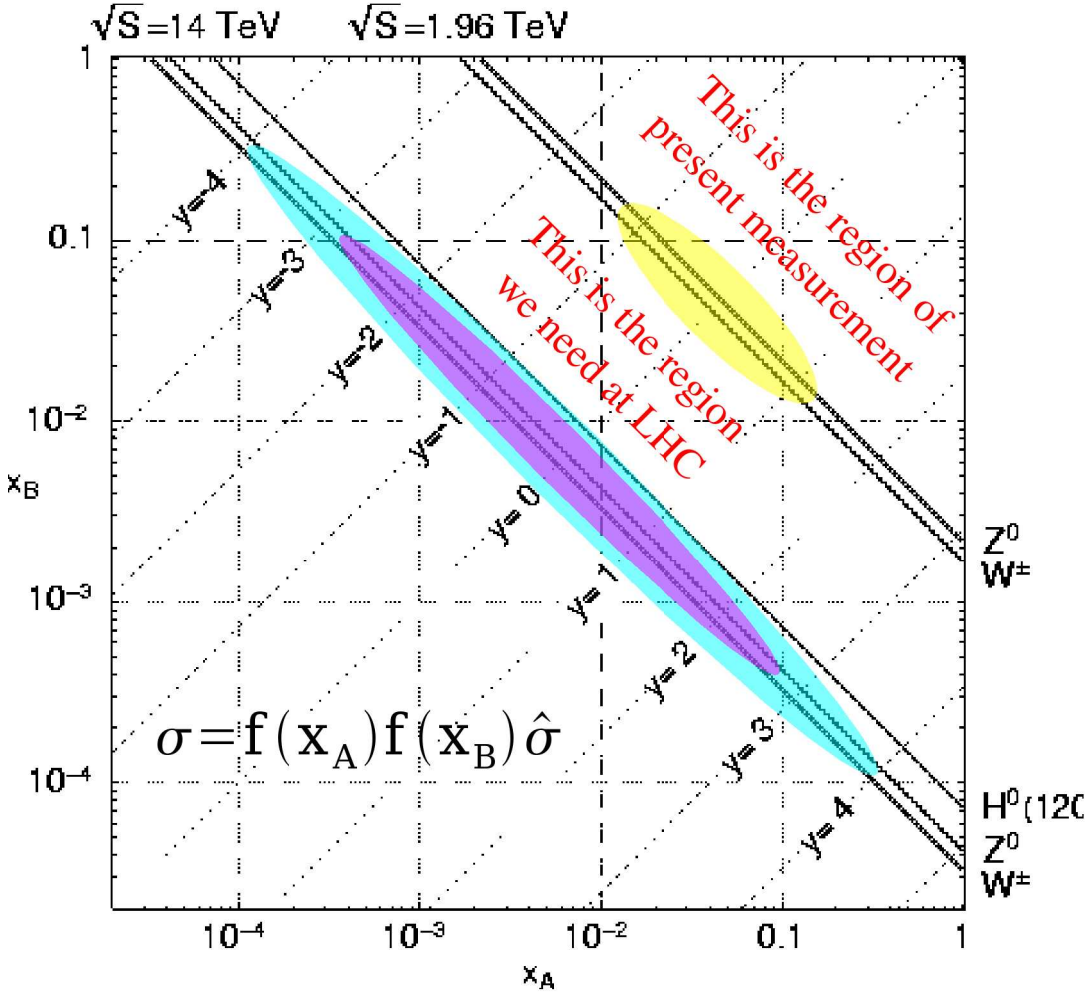
Many different experiments are required for Global Fit to proton structure



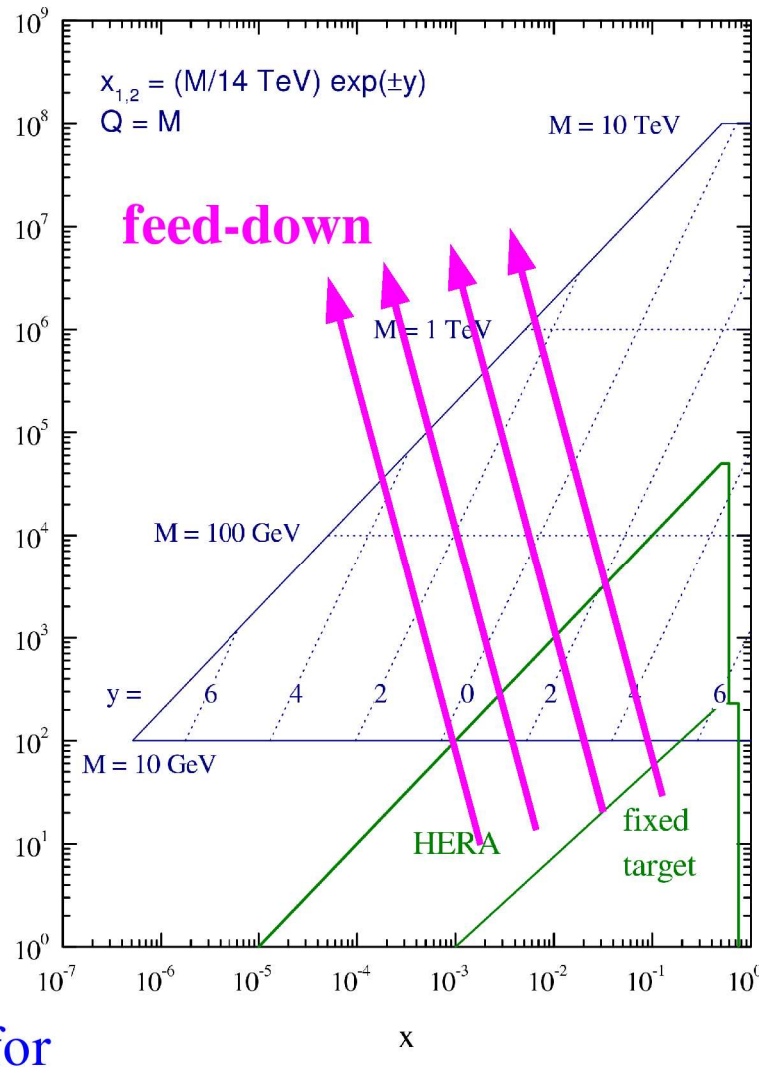
Kinematics
&
Evolution

Low Q & Hi-x: Feeds down to Hi Q & intermediate x

Kinematics of boson production



LHC parton kinematics



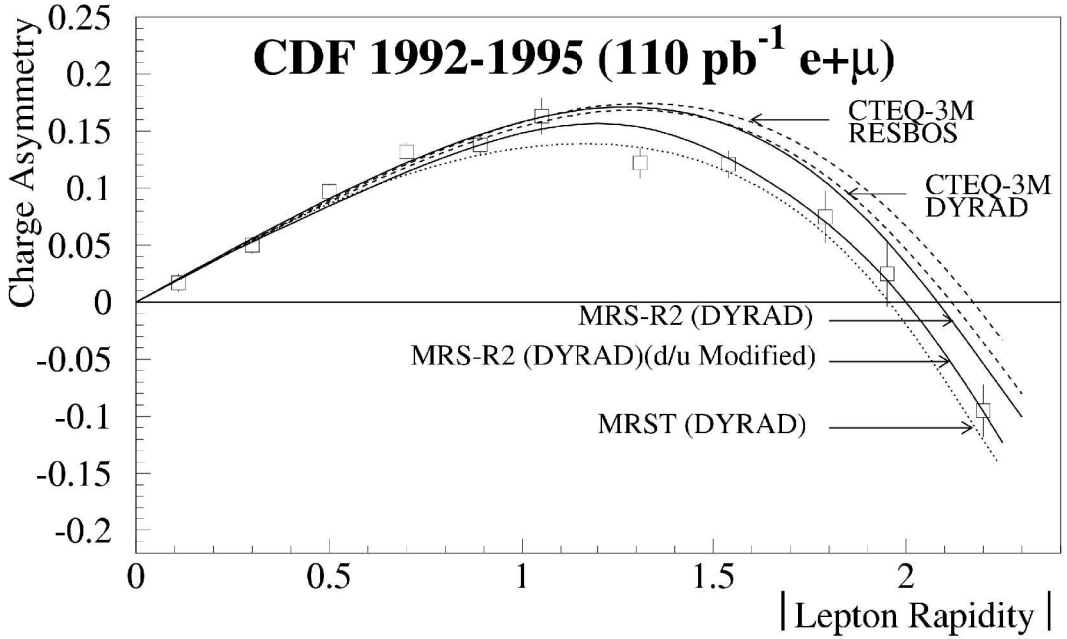
x range for Tevatron

x range for LHC

borrowed from R. Thorne, et al., hep-ph/0507015

Nuclear Corrections

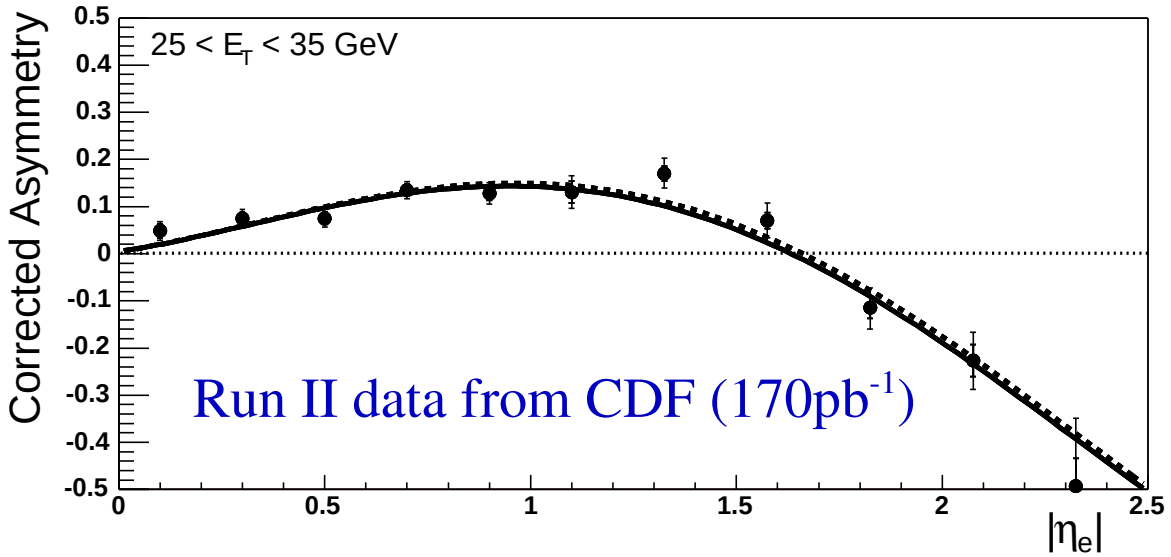
W Asymmetry from Tevatron: Constrains d/u



$$u\bar{d} \rightarrow W^+ \rightarrow \ell^+ \nu_\ell$$

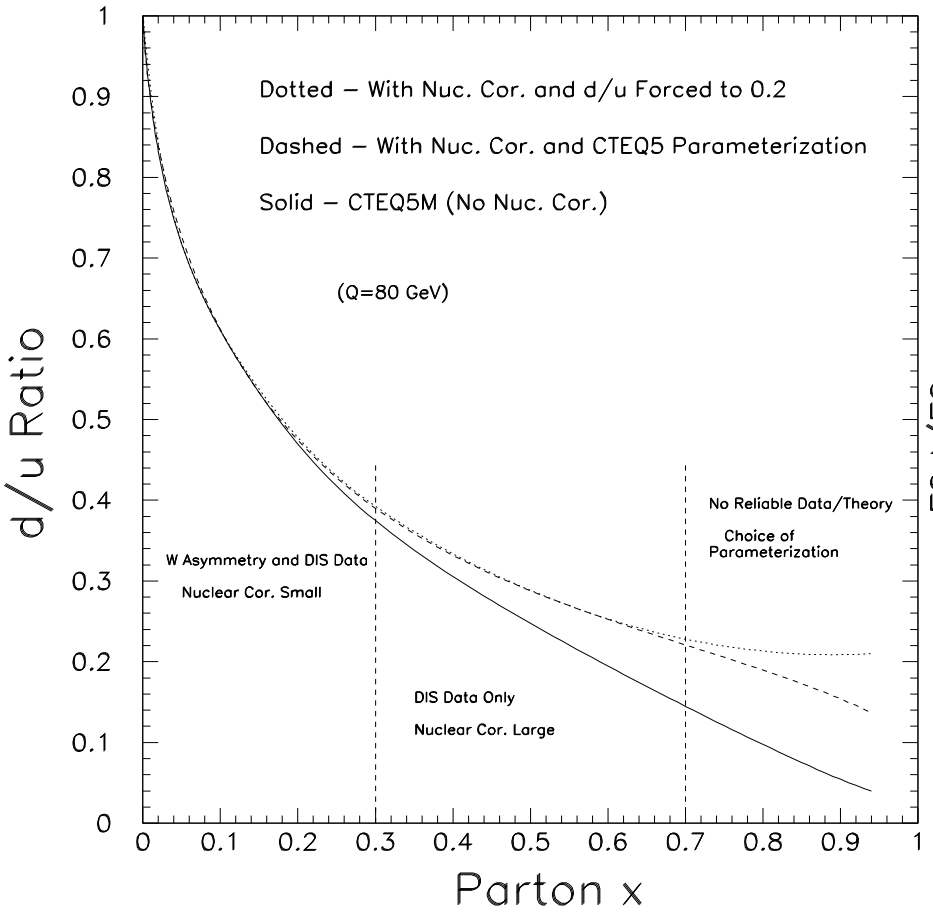
$$d\bar{u} \rightarrow W^- \rightarrow \ell^- \bar{\nu} \ell$$

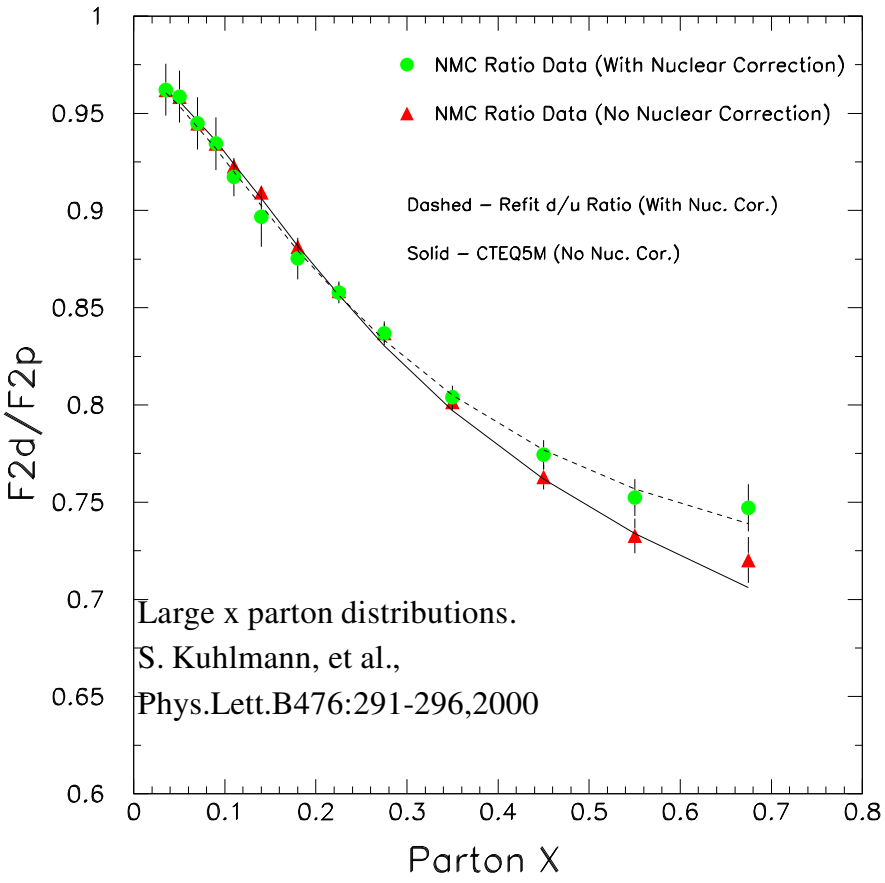
Run I data provided constraints out to x ≈0.3



Run II
improved statistics

Nuclear Corrections at Large-x

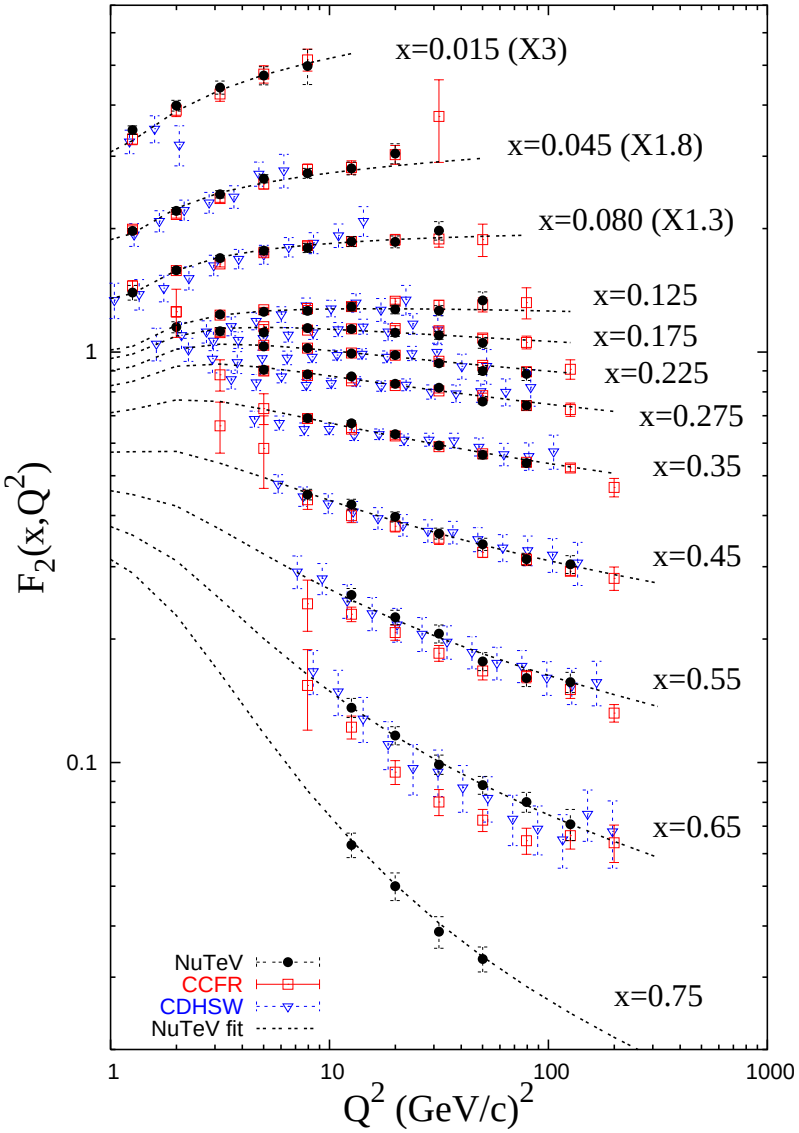




Large x parton distributions.
S. Kuhlmann, et al.,
Phys.Lett.B476:291-296,2000

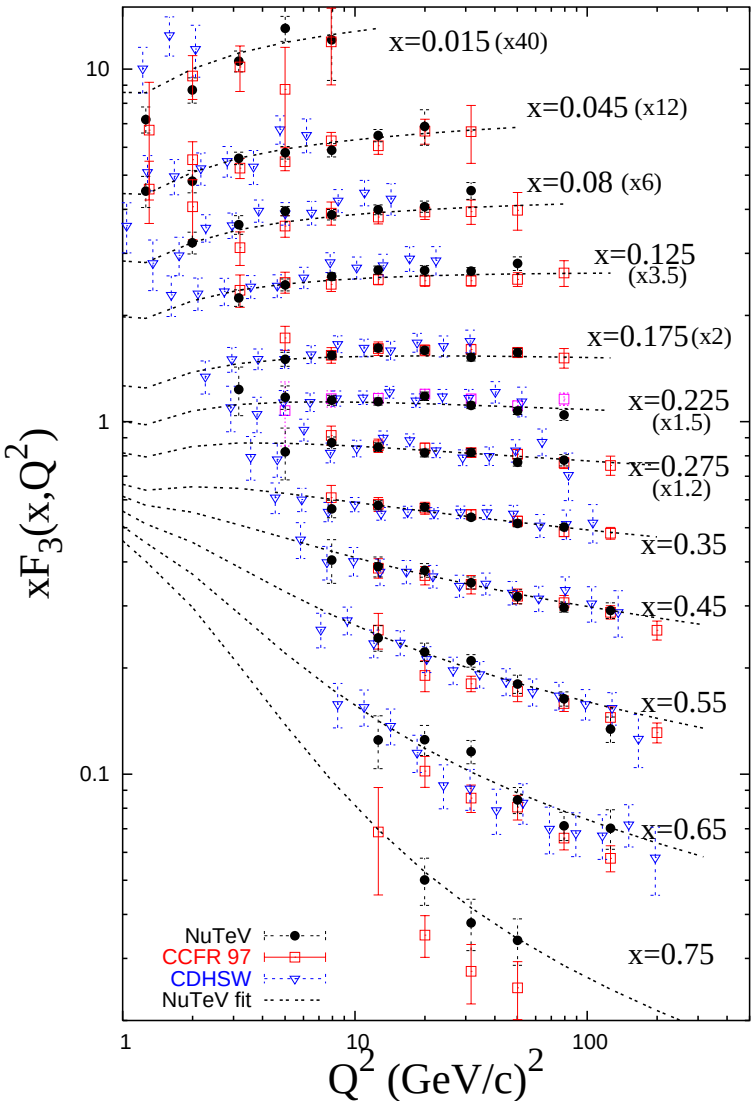
- Tevatron W-Asymmetry data constrains d/u out to x ≈0.3
- DIS data extends to higher x, but Nuclear Corrections important
- Time to revisit

NuTeV Structure Functions



NuTeV higher at large-x

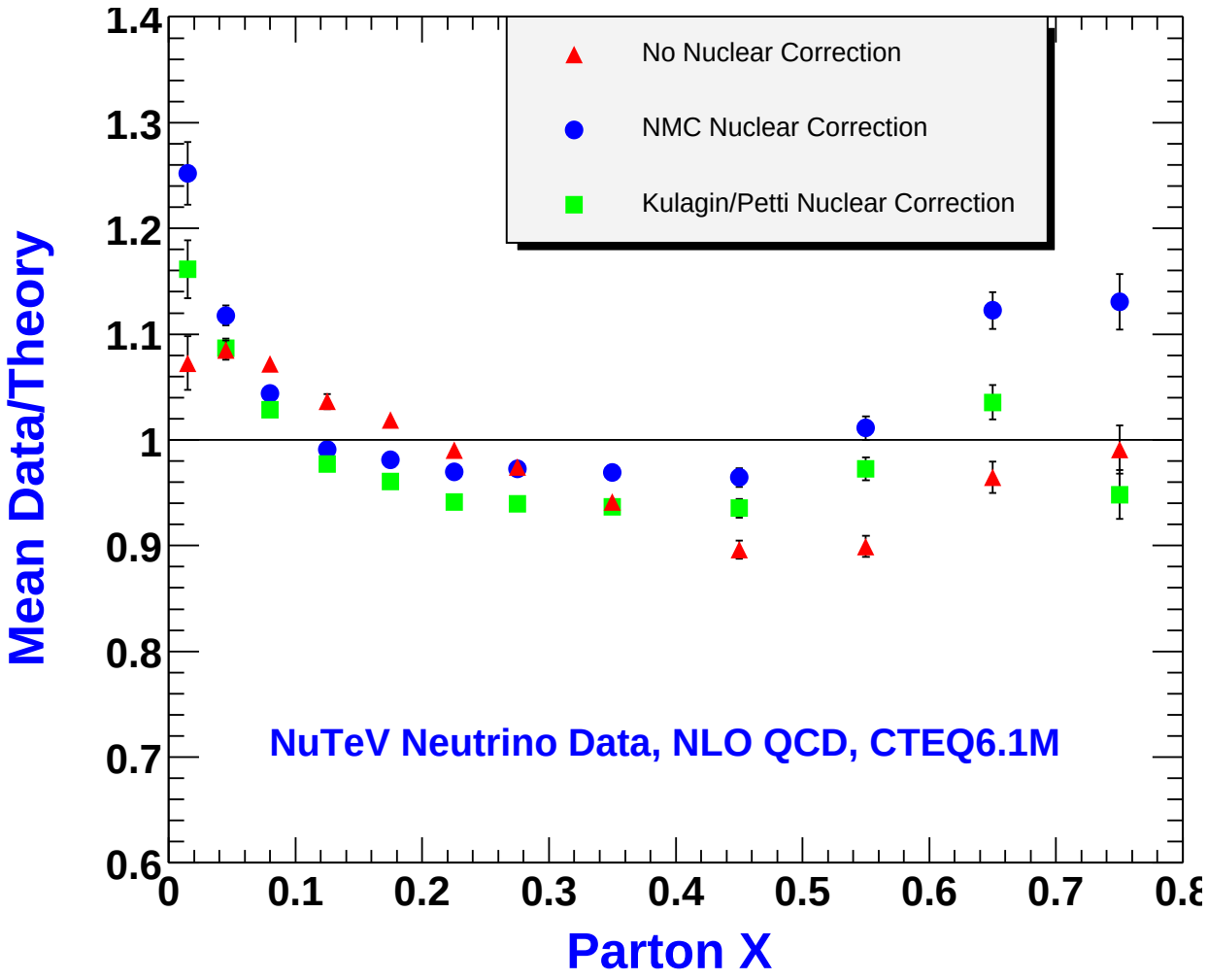
Implications for valence PDF



Nuclear Corrections

important at large-x

Nuclear Corrections for Neutrino Data



NMC too large at both small & large-x

K/P does better

Shape not ideal

Large-x not too bad

Small-x: what to do??

K/P depends on F_{123}

Should correction depend on NC/CC???

In progress: NuTeV Cross section data analysis

Target Mass Corrections

Sources of Target Mass Corrections

1) Nachtmann variable ξ

$$\xi = \frac{2x}{1+\sqrt{1+4M^2\frac{x^2}{Q^2}}}$$

2) $p^- \neq \xi P^-$ results in mixing partonic & hadronic F's (diagonal in helicity basis)

3) Transverse momentum (k_T) effects

4) Threshold effects as $x \to 1$

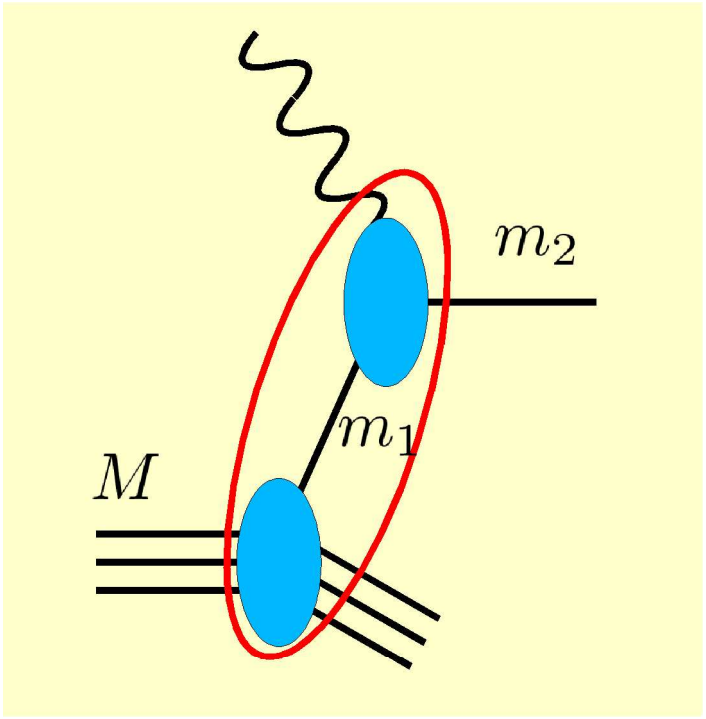
F.M. Steffens, W. Melnitchouk, nucl-th/0603014

Target Mass Corrections:

$$F_j^{TMC}(x,Q^2) = \sum_{i=1,5} A_i^j F_j^{(0)}(\eta,Q^2) + B_i^j h_j^{(0)}(\eta,Q^2) + C_i^j g_j^{(0)}(\eta,Q^2)$$

Kretzer, Reno PRD69, 034002 (2004)

$$F_j^{(0)}(\eta,Q^2) \equiv \left\{ \lim_{M\to 0} F_j(x,Q^2) \right\}\Big|_{x\to\eta}$$



$$\bar{\eta} = x R_M R_{ij}$$

$$\eta = x R_M$$

$$R_M = \frac{2}{1+\sqrt{1+4x^2M^2/Q^2}}$$

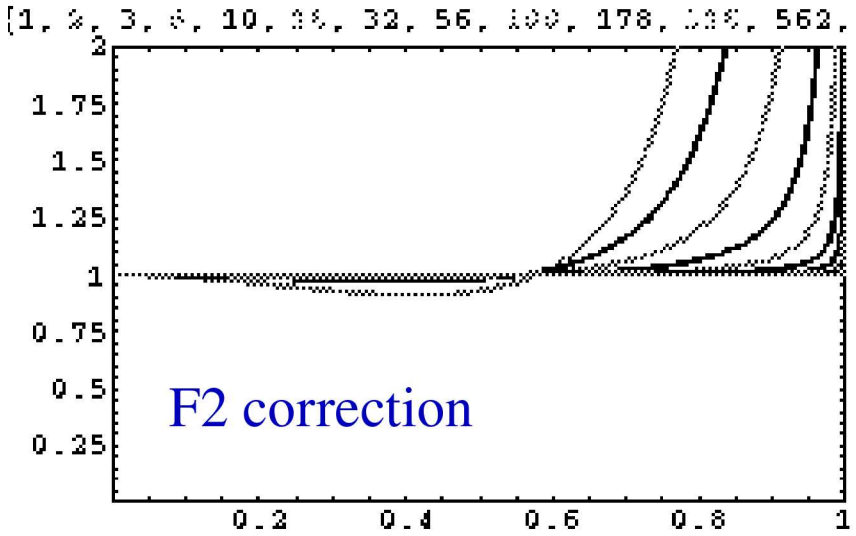
$$R_{ij} = \frac{(Q^2 - m_1^2 + m_2^2) + \Delta}{2Q^2}$$

$$\Delta = \Delta[-Q^2, m_1^2, m_2^2]$$

$$\Delta[a,b,c]^2 = a^2 + b^2 + c^2 - 2(ab+bc+ca)$$

Size of TMC vs. Q and X

$$F_j^{TMC}(x,Q^2) = \sum_{i=1,5} A_i^j F_j^{(0)}(\eta,Q^2) + B_i^j h_j^{(0)}(\eta,Q^2) + C_i^j g_j^{(0)}(\eta,Q^2)$$



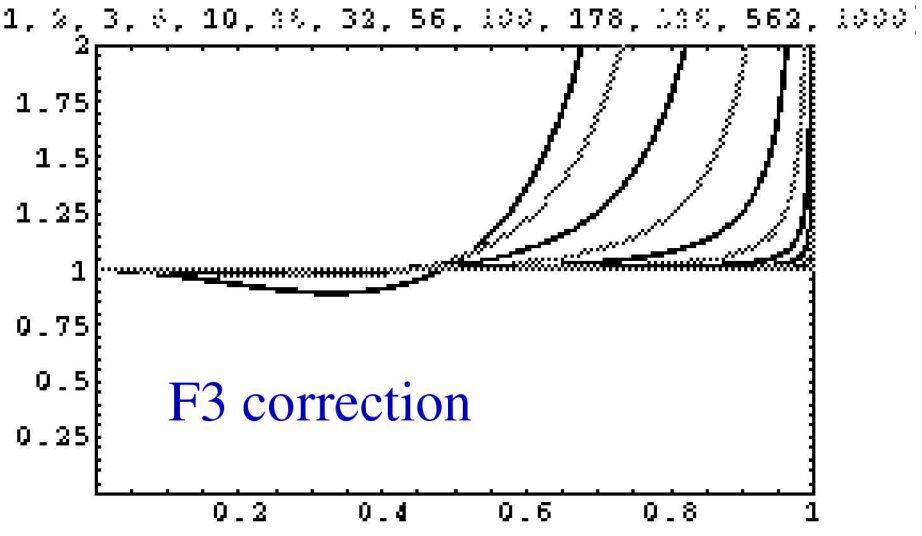


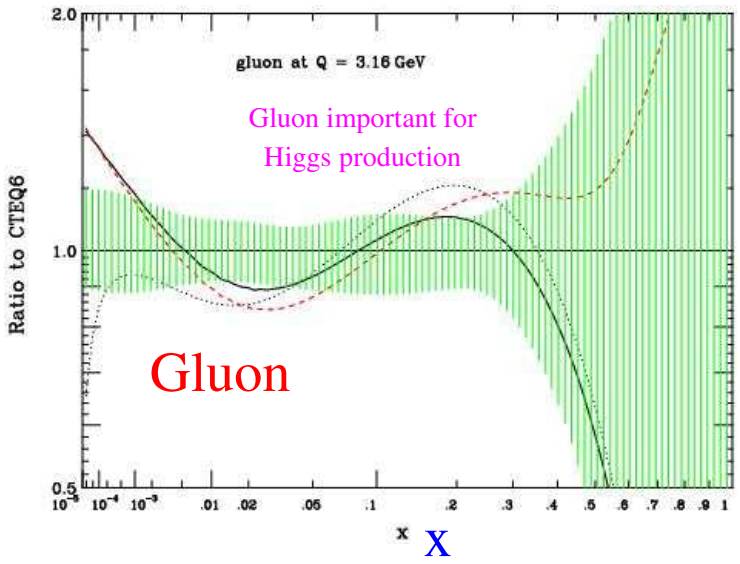
TABLE 1. Coefficients A_j^i in Eq. (3.17).

A_j^i	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$
$j=1$	$\frac{x}{\xi\rho}$	0	0	0	0
$j=2$	0	$\frac{x^2}{\rho^3\xi^2}$	0	0	0
$j=3$	0	0	$\frac{x}{\rho^2\xi}$	0	0
$j=4$	0	$\frac{\mu^2x^3}{\rho^3}$	0	$\frac{1}{(1+\mu\xi^2)}$	$-\frac{2\mu x^2}{\rho^2}$
$j=5$	0	$-\frac{\mu x^2}{\rho^3\xi}$	0	0	$\frac{x}{\rho^2\xi}$

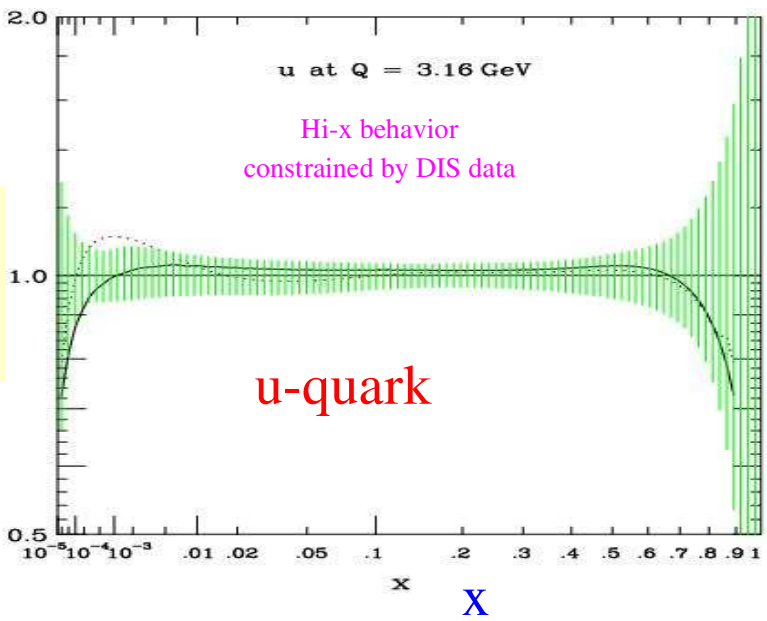
Strange

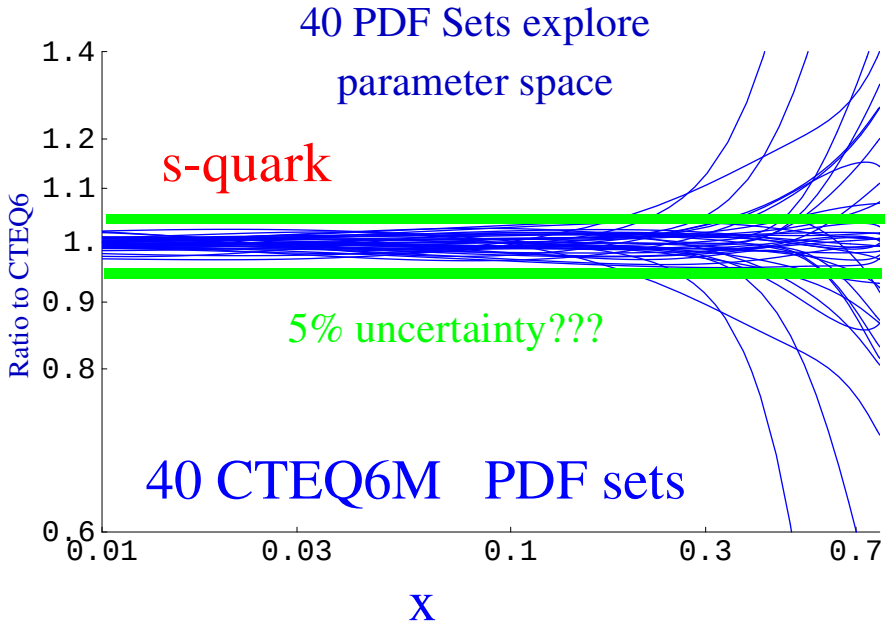
Quark PDF

What is relative uncertainty on PDFs' ???



PDF Uncertainty band compared to CTEQ6M





Previously, s(x) was tied to u-bar and d-bar via kappa:

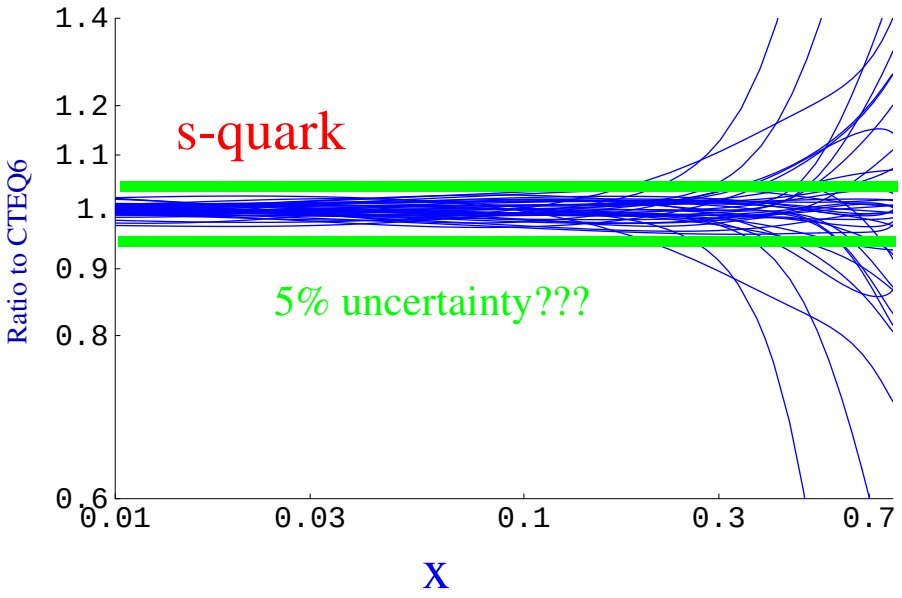
$$s(x) = \bar{s}(x) = \kappa \frac{\bar{u}(x) + \bar{d}(x)}{2}$$

Question: Do we really know the s-quark PDF to 5%???

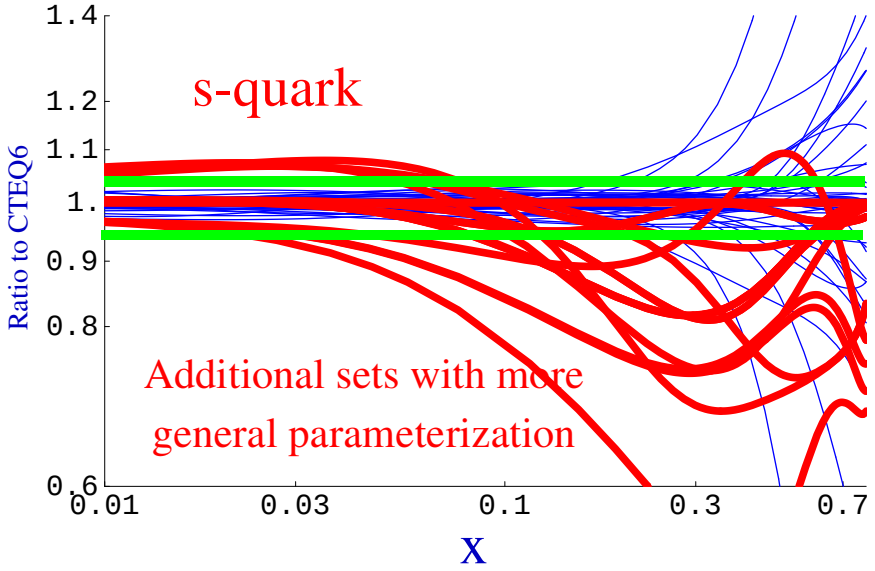
CTEQ6: Pumplin, Stump, Huston, Lai, Nadolsky, Tung, JHEP 0207, 012 (2002)

What is true uncertainty on s-quark PDF???

40 CTEQ6M PDF sets



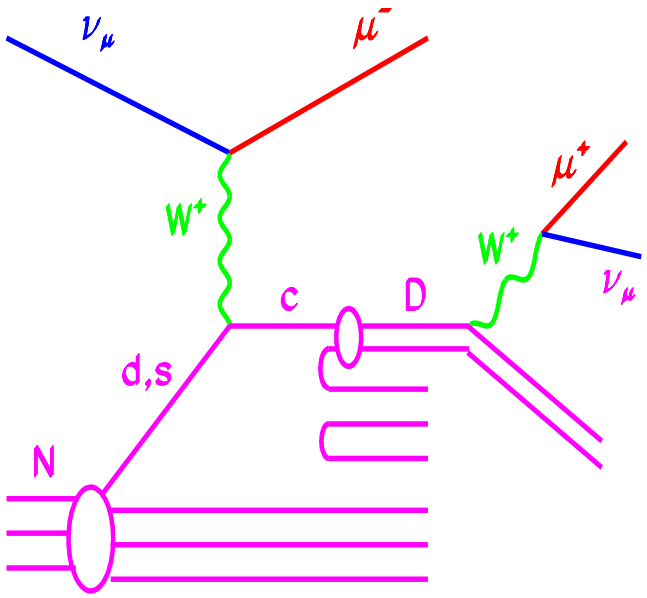
Closer to the true error



Curves shown are examples; this is not an exhaustive set

Warning: The Director General has determined the band of PDF's can greatly underestimate the true uncertainty

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)

NuTeV Collaboration (D. Mason for the collaboration). Moriond 2004, hep-ex/0405037

Global Fit: vary s(x) distribution

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 $<Q^2>$	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

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) !!!

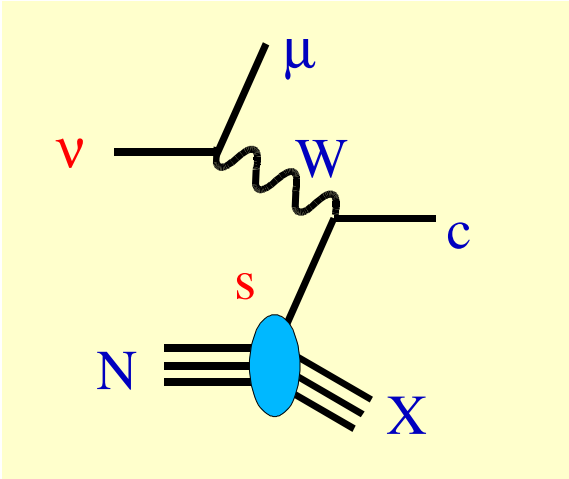
$\therefore$

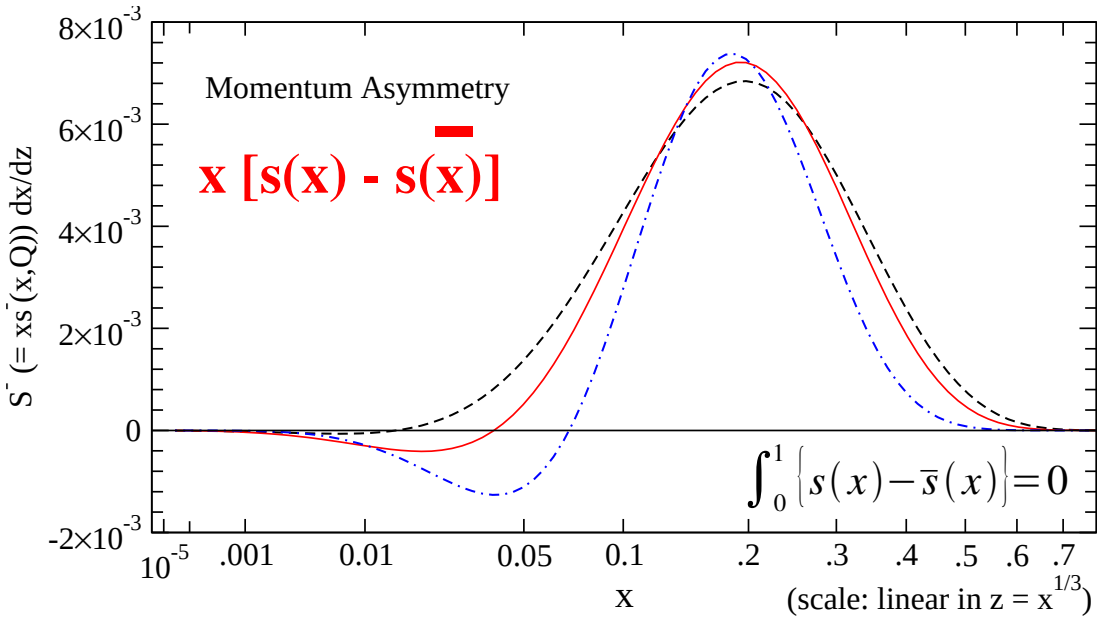
Idea: ν and ν-bar data separately determine s and s-bar distributions

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

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

What does the Δs(x) strange PDF look like?





General range of the asymmetry

$$[S^-] \equiv \int_0^1 x\{s(x)-\bar{s}(x)\}$$

$$+0.0040 \geq [S^-] \geq -0.0010$$

Δs(x): large uncertainty affected by:

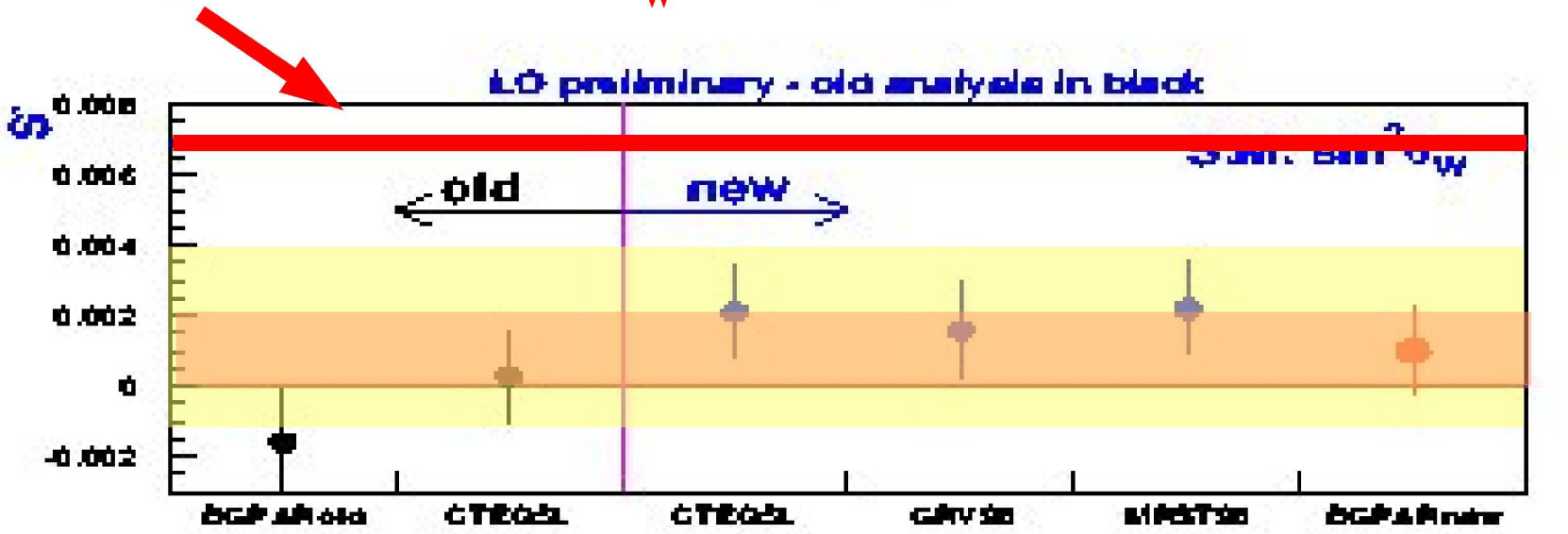
- charm fragmentation
- charm mass
- PDF set

Olness, Pumplin, Stump, Huston, Nadolsky, Lai, Kretzer, Owens, Tung, Eur.Phys.J.C40:145-156,2005

Kretzer, Olness, Pumplin, Stump, Tung, Reno, PRL 93,041802 (2004)

Does this solve the $\sin\theta_W$ problem???

Required to resolve $\sin\theta_W$ discrepancy



- Tremendous new information on BOTH $s+\bar{s}$ and $s-\bar{s}$
- Work is ongoing: extend to higher orders
- Include this information in next generation PDF sets

Three-loop kernel generates asymmetry

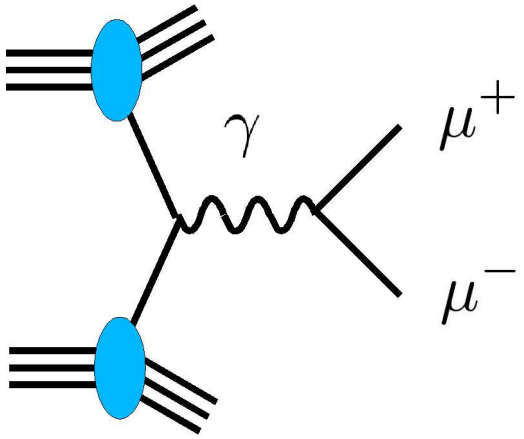
$\langle x(s-\bar{s})\rangle \approx -5\times10^{-4}$ @ Q^2 20GeV^2

S. Catani, D. de Florian, G. Rodrigo,
W. Vogelsang; Phys.Rev.Lett. 93 (2004) 152003

D. Mason for the NuTeV Collaboration; AIP Conf.Proc.792:851-854,2005

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

Fixed Target Drell-Yan



Fixed Target Drell-Yan

FNAL-E866/NuSea Collaboration (J.C. Webb et al.)

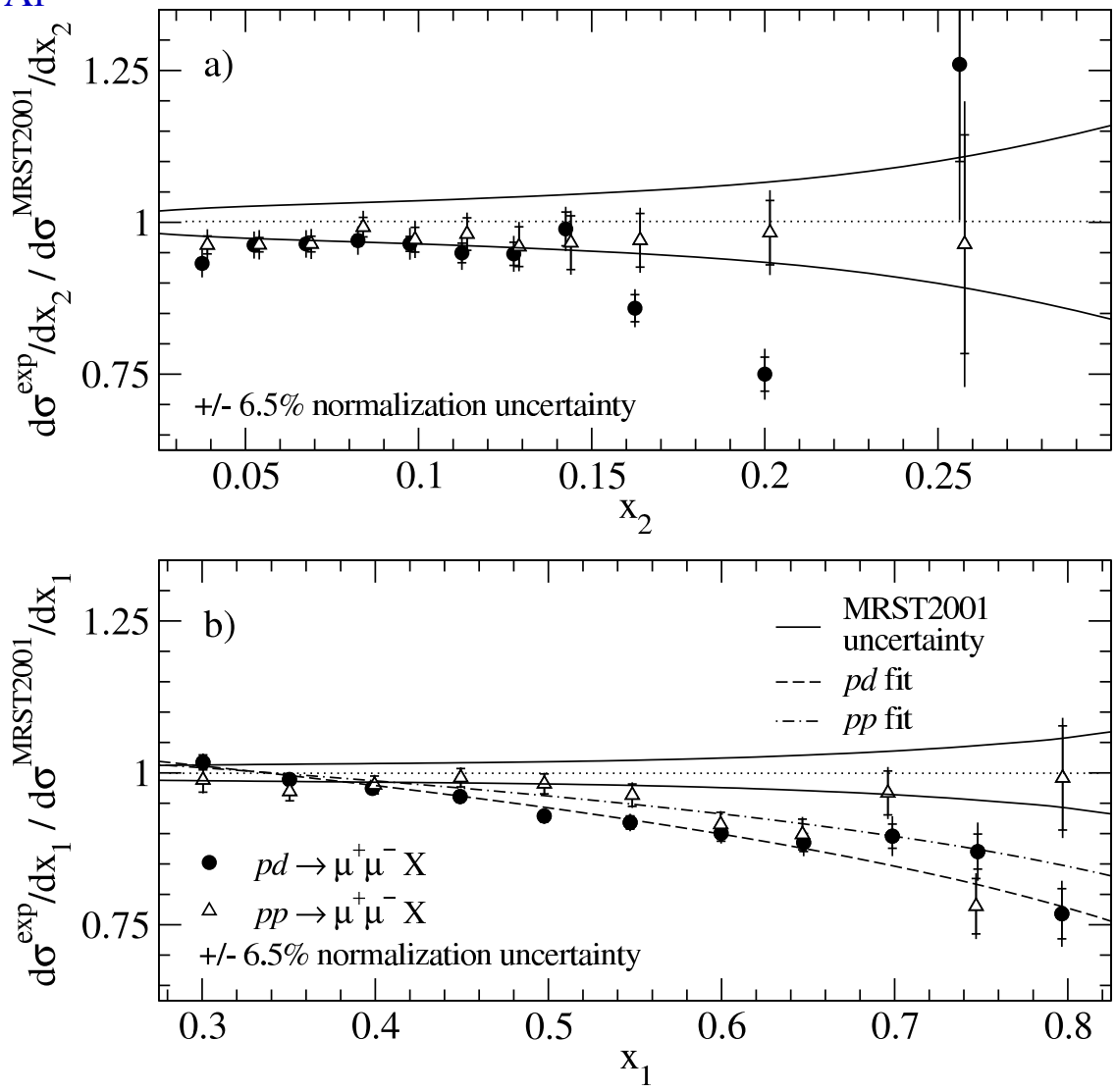
Constrains $\bar{d}/\bar{u}$

AIP Conf.Proc.549:532-535,2002 Al

Theory is uncomfortably high at large-x

Implications for valence...

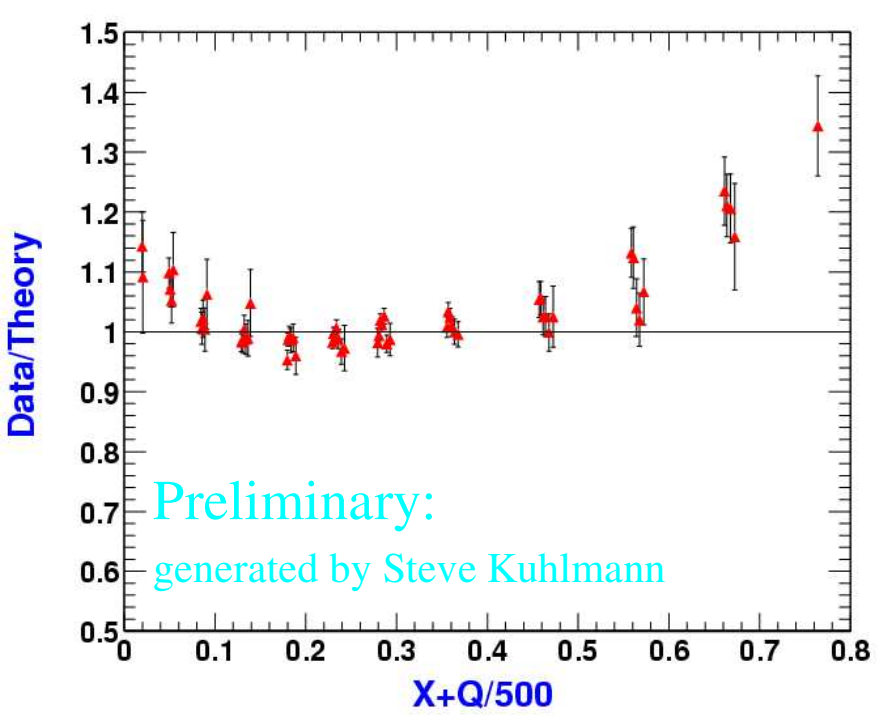
Radiative Corrections in progress

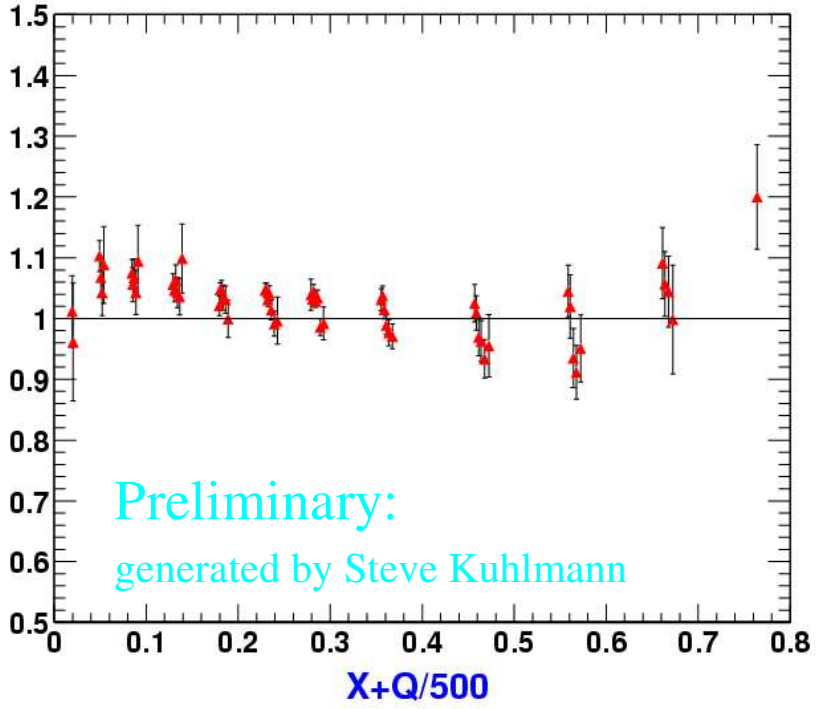


The radiative corrections change both the normalization of the data w/respect to the theory, and the slope vs x1. The pp data are consistent with MRST w/in errors. The pd aren't.

Heavy Quark Effects

Effect of Fully Massive Calculation

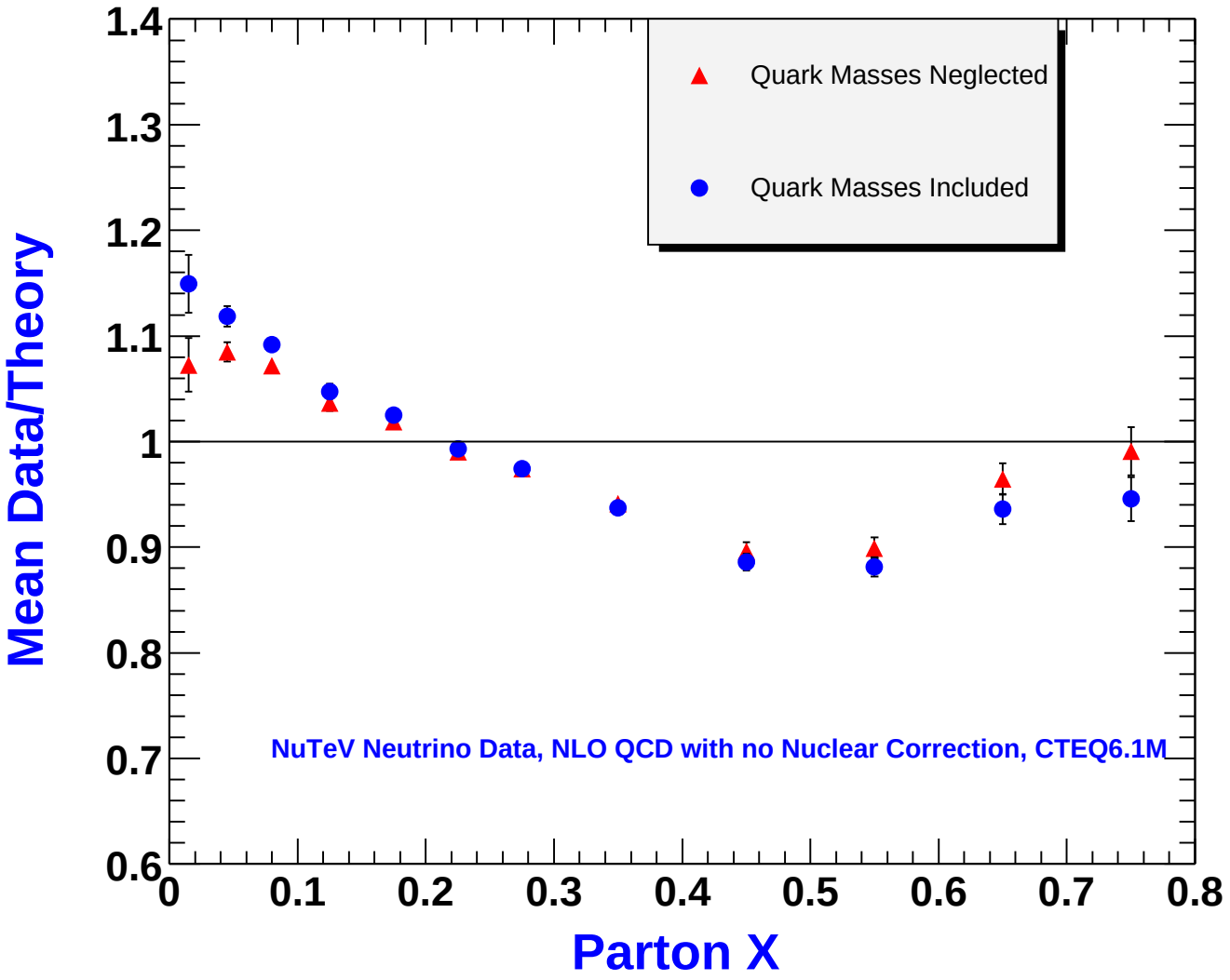




NuTeV F2, evaluated with zero mass NLO QCD, CTEQ6.1M PDFs, and EMC nuclear correction

NuTeV F2, evaluated with S-ACOT heavy quark scheme, CTEQ6.1M PDFs, and EMC nuclear correction

Effect of Fully Massive Calculation



Minimal effect for this kinematic range with inclusive quantity

Does make a difference for specific observables

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