Structure Functions at Large x

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- Introduction
- Constraints from fixed target experiments and hadron-hadron colliders
- HERA data and its impact
- Summary

Introduction

- **Importance of Precise Knowledge on Parton Density Functions (PDFs) at Large x**

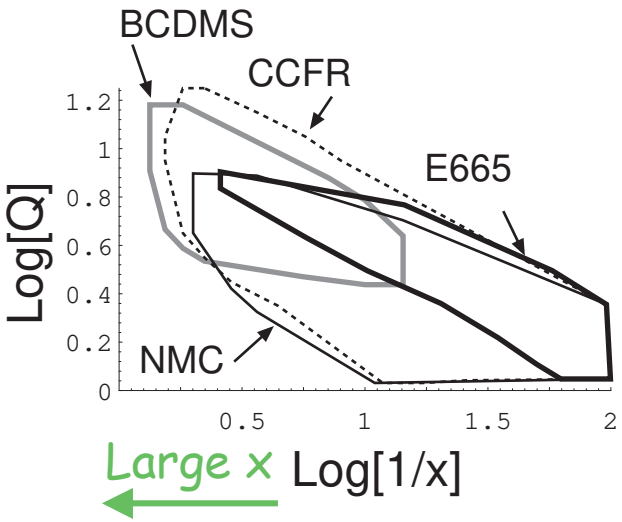
  Examples:

  1. Precision Measurements (M_W)
  2. Inclusive Jet Rate at High E_T from Tevatron
  3. Searches for New Physics
     (leptoquarks or squarks mass: $M^2=xs$)

- **Renewed Interest on d/u Behavior for $x \to 1$**

Constraints from Fixed Target DIS Experiments

The most precise data used in global QCD analyses:



Provide our best knowledge so far on PDFs in the intermediate and large x region:

F_2^P ⇨ u quark
F_2^D ⇨ d quark
F_2^D/F_2^P ⇨ d/u
$xF_3^{\nu N}$ ⇨ u+d, α_s

Potential Problems:

1. Systematic errors dominate
   ⇨ nontrivial to evaluate
2. Nuclear (binding) effects in deuterium and iron targets
3. Higher twist contributions at low Q^2 and large x values
4. Heavy target correction

Other Constraints from Fixed Target Experiments

Lepton-pair production (Drell-Yan):
(Dominant LO subproc. $q\bar{q} \rightarrow \gamma^* g$, $\gamma^* \rightarrow l\bar{l}$)

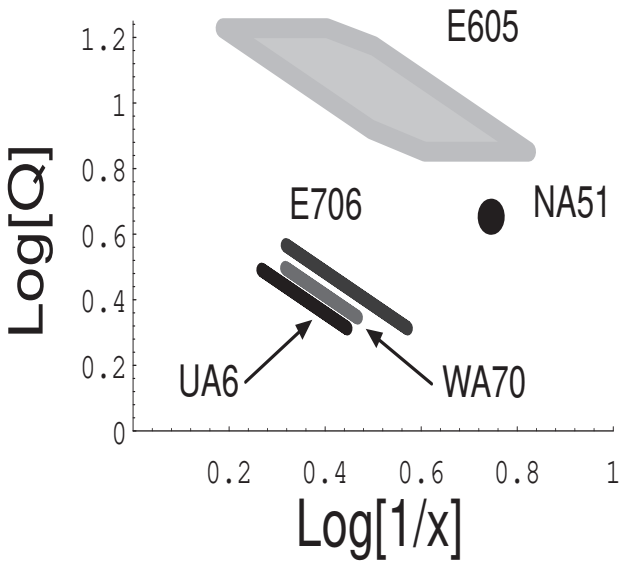
sea quarks (E605,E772:0.025<x<0.4)

Drell-Yan asymmetry:

u-d, sea (NA51,E886:0.03<x<0.35)

Direct photon production:
(Dominant LQ subproc. $qg \rightarrow \gamma x$)

gluon (xg) density



Problem in using direct photon production data:
Large discrepancy between data and prediction

Need better theoretical understanding

Constraints from Hadron-Hadron Colliders

UA2:

Direct photon process

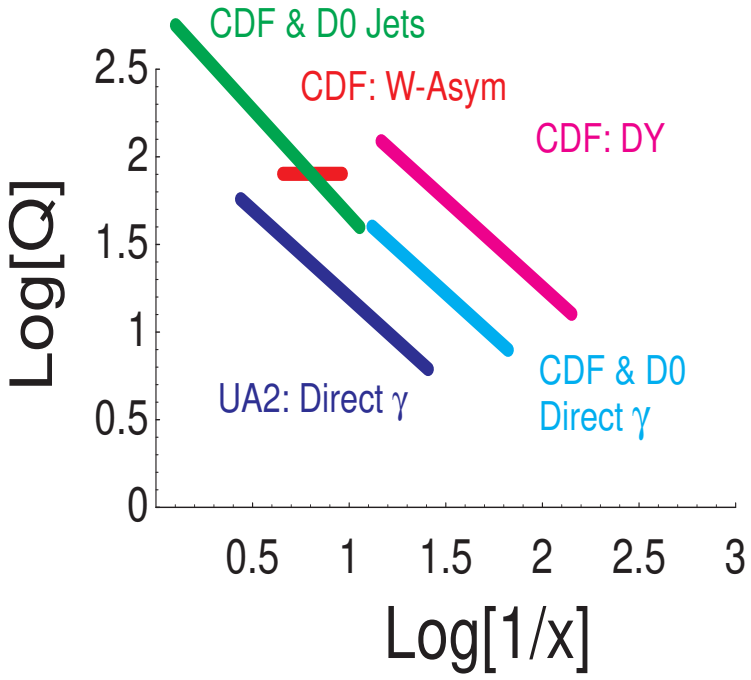
Tevatron:

Direct photon process

Drell-Yan process

Inclusive jet data
gluon density at large x

W asymmetry
d/u (x~0.1, Q~M_W)



Previous excess in CDF's inclusive jet rate at large E_T:

New Physics or Larger xg(x)?

The Behavior of the d/u Ratio at x→1

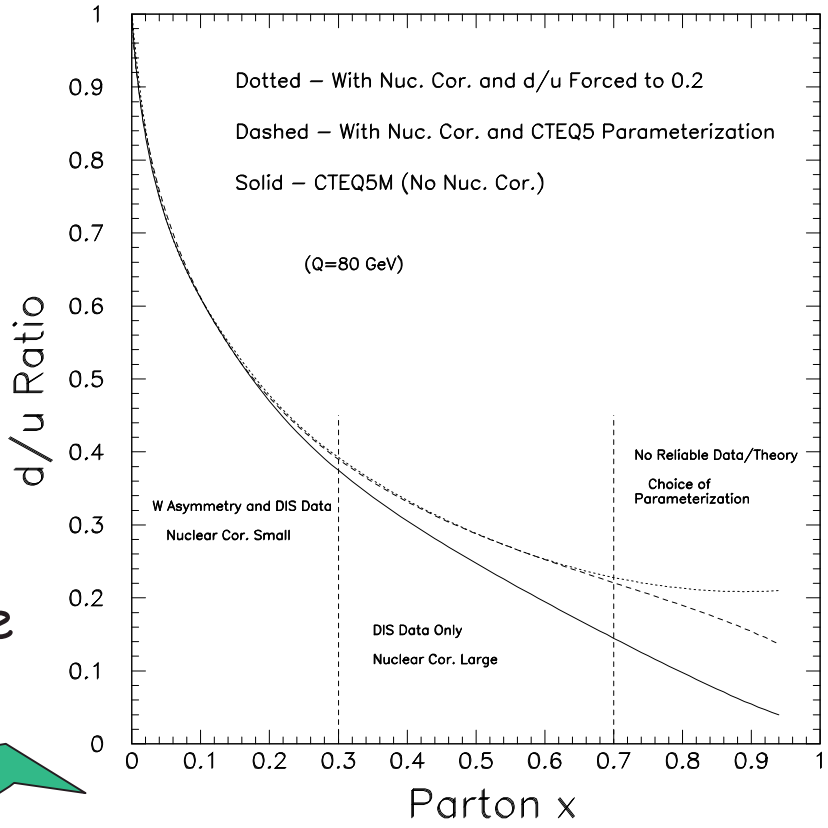
- Of theoretical interest with model predictions varying from 0 to 0.2,
- Closely related to possible nuclear binding effects in the deuteron

Yang and Bodek:

d/u~0.2 + nuclear binding correction improve the description of DIS data at large x

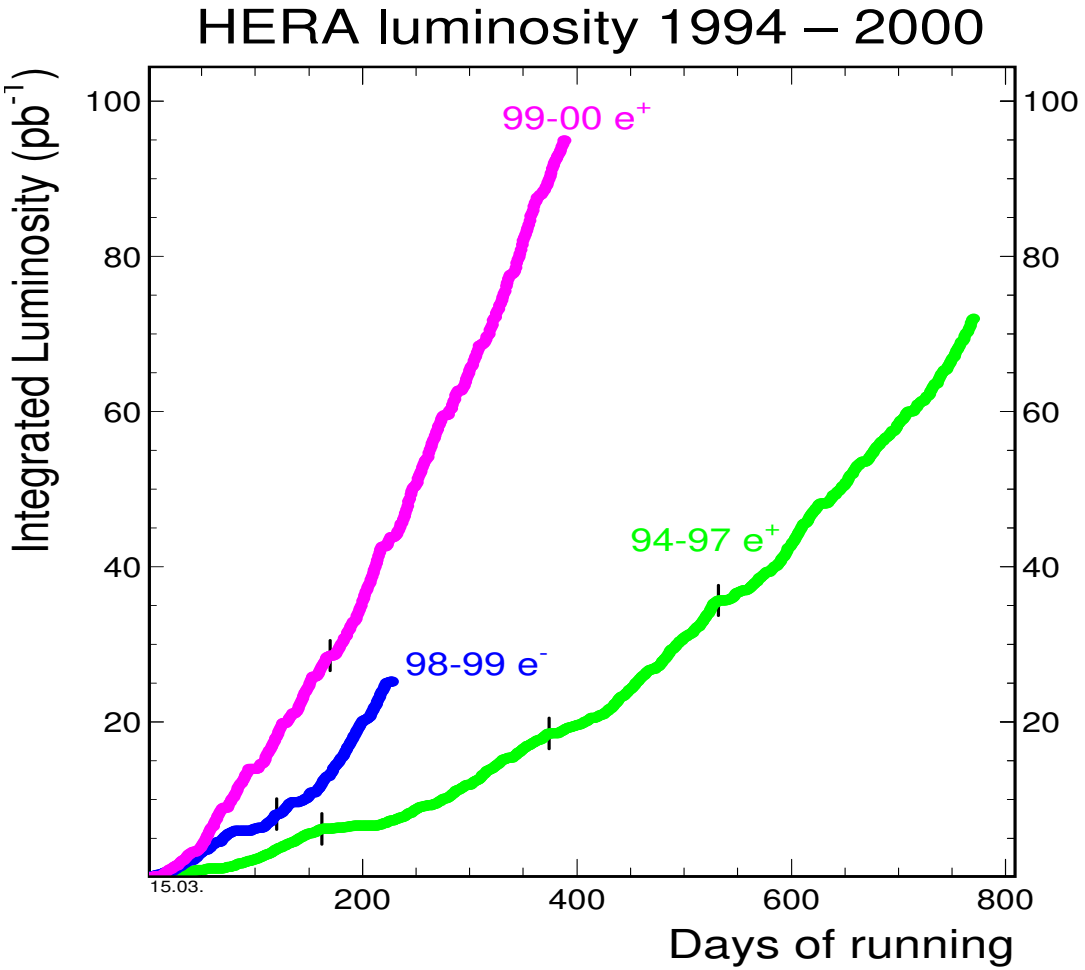
Kuhlmann et al:

If d/u~0.2, NMC data indeed need nuclear corrections
But the converse is not necessary true



HERA Data

Three most important data samples analyzed since 1994:



e^+p 1994-1997:

CM energy: 300GeV
E_e: 27.5GeV
E_p: 820GeV

e^-p 1998-1999:

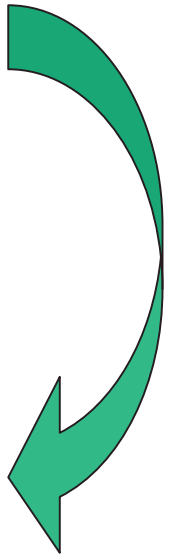
CM energy: 320GeV
E_p: 920GeV

e^+p 1999-2000:

CM energy: 320GeV
E_p: 920GeV

HERA Measurements of NC & CC Cross-Sections

1. e^+p 1994-1997:
   Final results: $d^2\sigma/dxdQ^2$, $d\sigma/dQ^2$, $d\sigma/dx$, $(d\sigma/dy)$
   (ZEUS 96-97)
2. e^-p 1998-1999:
   Final results: $d^2\sigma/dxdQ^2$, $d\sigma/dQ^2$, $d\sigma/dx$, $(d\sigma/dy)$
   (ZEUS Preliminary)
3. e^+p 1999-2000:
   Preliminary results: $d^2\sigma/dxdQ^2$, $d\sigma/dQ^2$

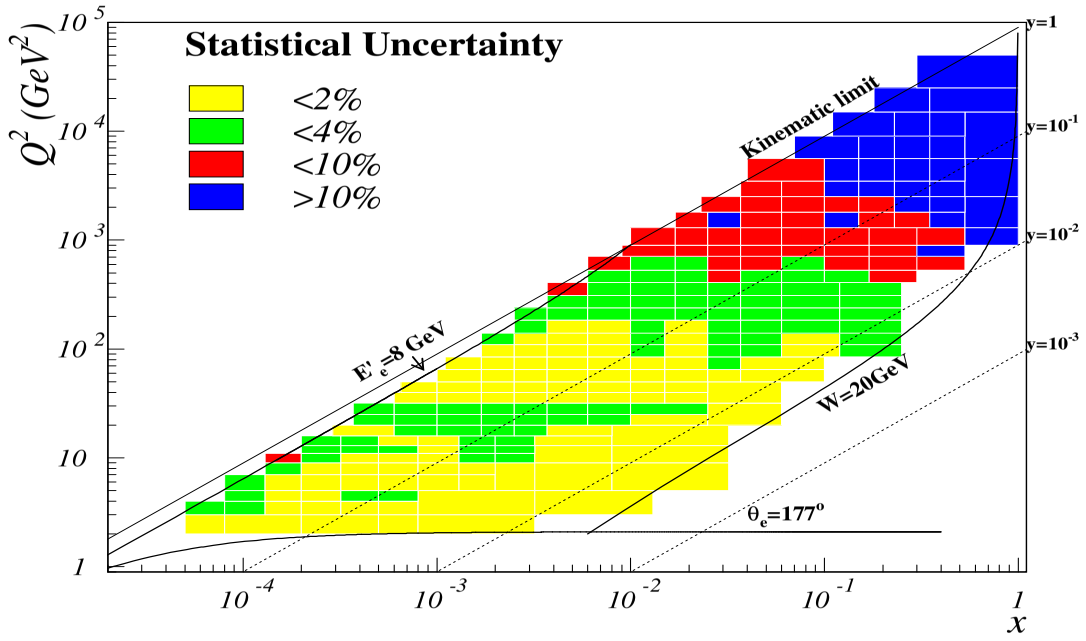


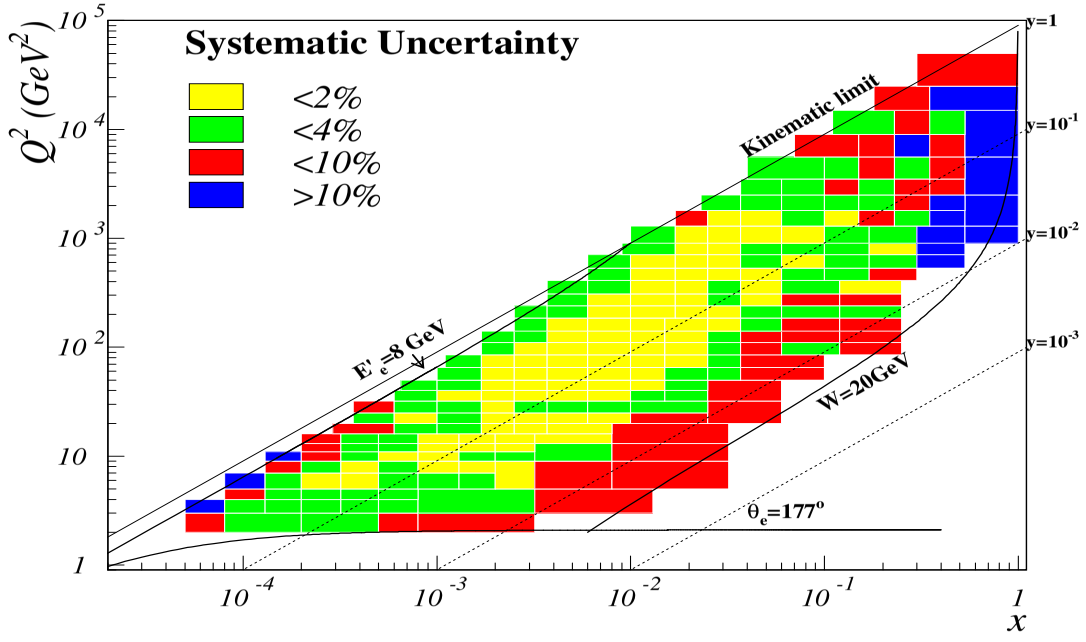
1+2 NC ⇨ γ+Z Interference (xF_3)
1+2 CC ⇨ Sensitivity to u_v, d_v
HERA(+F_2)+Fixed Target exp's ⇨ Global Fits
1+2+3 NC+CC ⇨ Impact of HERA Data

The Precision of the HERA Data

Example: σ_{NC}

ZEUS 96-97 e^+p, 30pb^{-1}

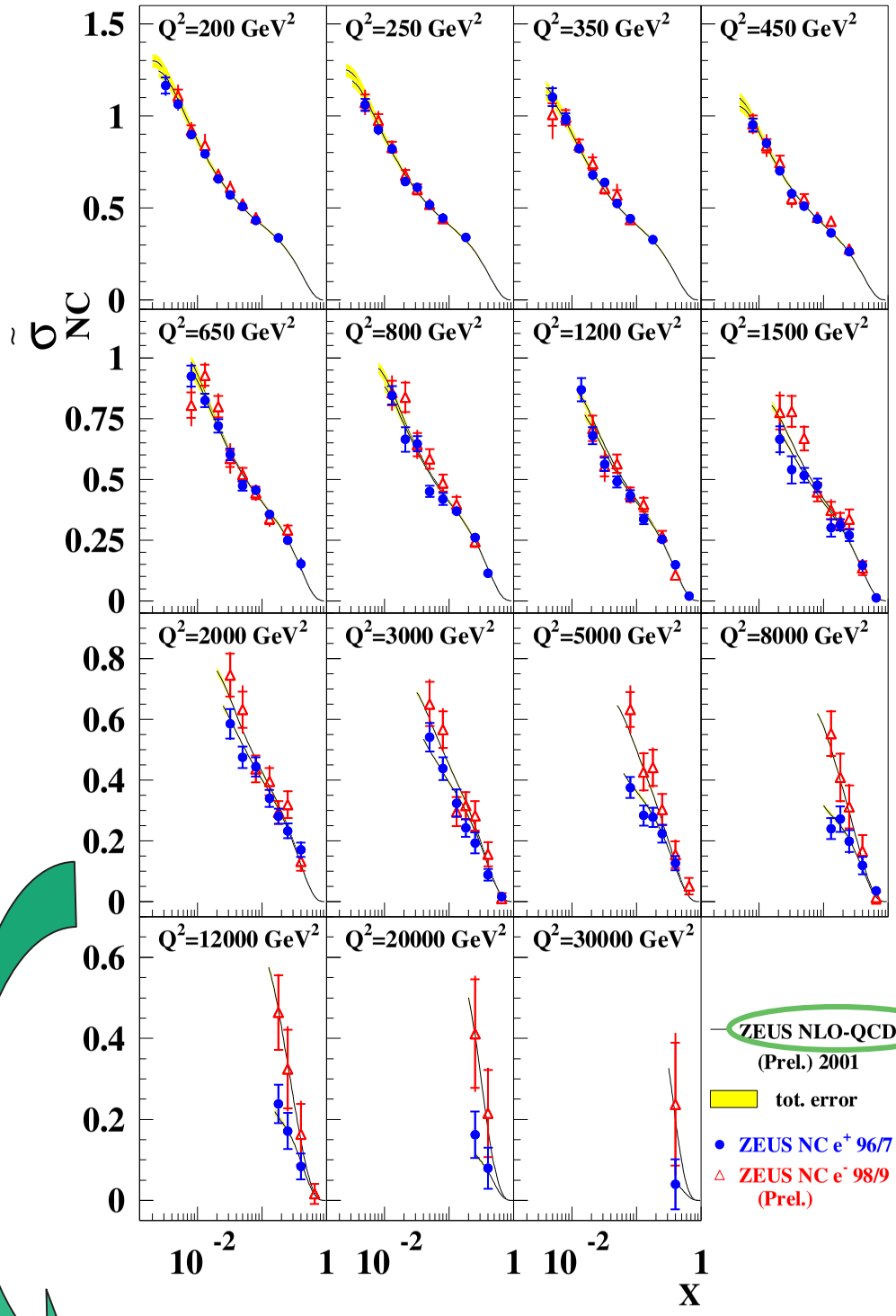




The bulk HERA data are precise within ~3%

At high Q^2, data are statistics limited

NC Cross-Sections e^+p vs. e^-p

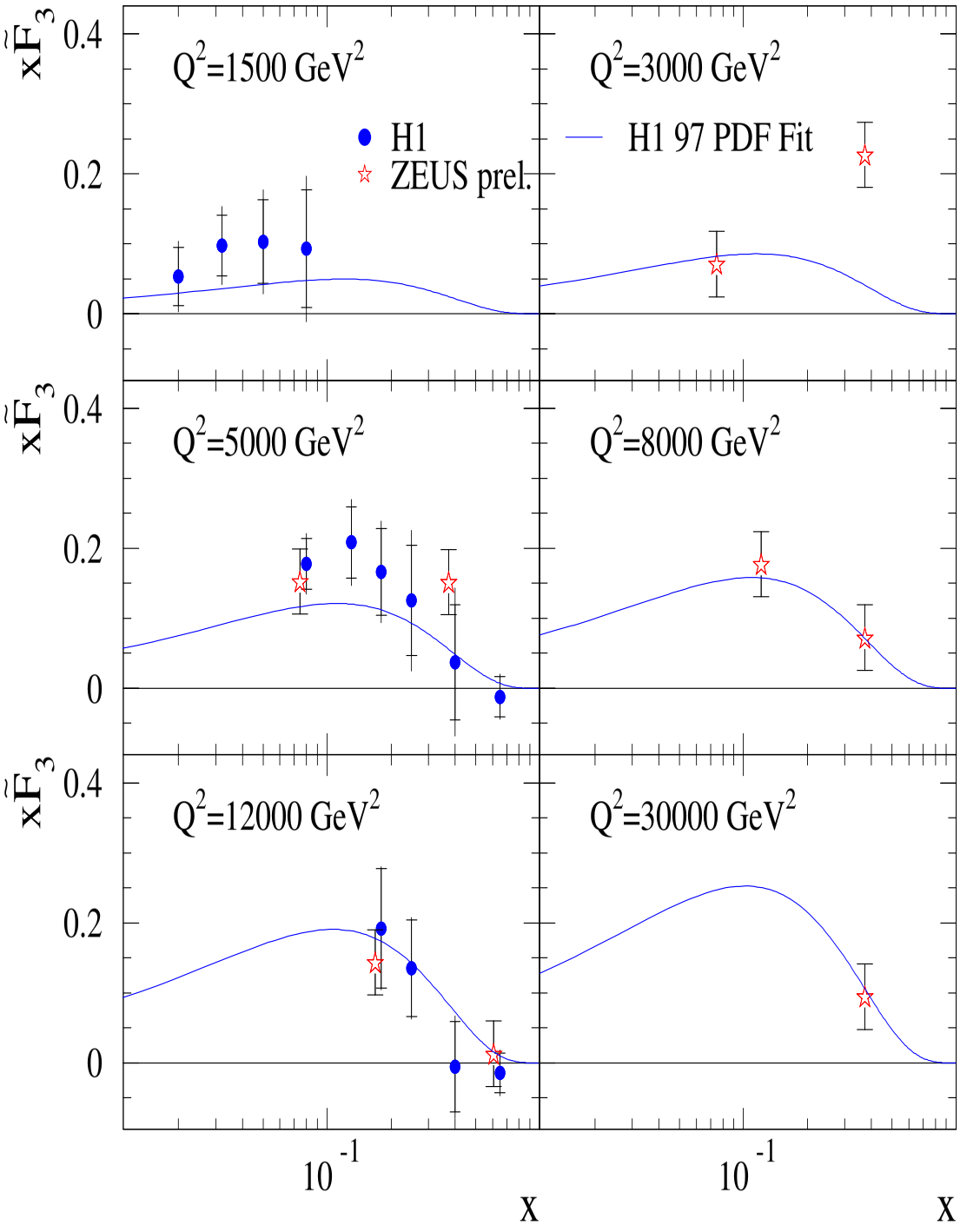


Dominance at low Q^2 by γ exchange

e^-p not used in the fit

e^+, e^- asymmetry due to γ+Z Interference → xF_3

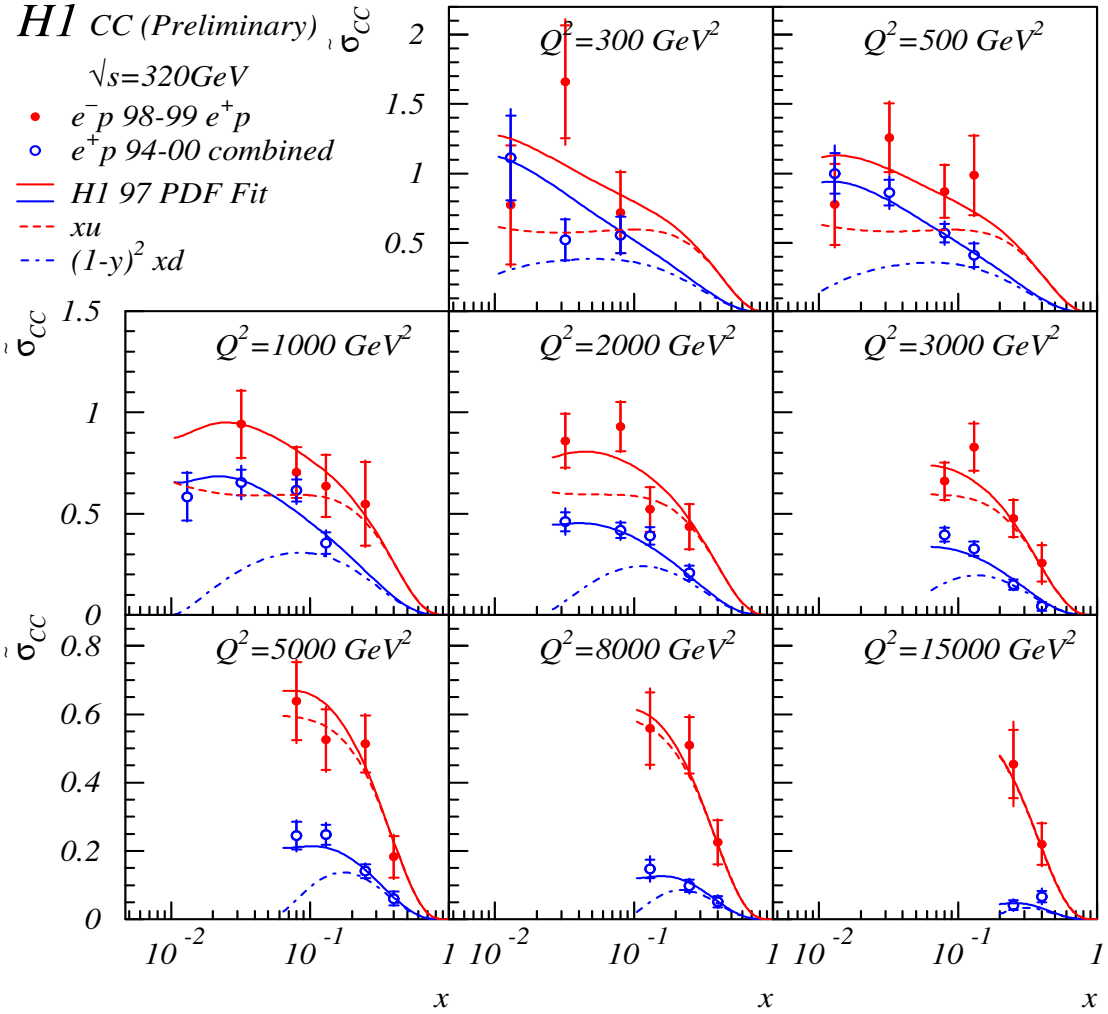
First xF_3 Measurement at HERA



$xF_3 \sim 2 \Sigma e_i a_i x(q_i - q_{ibar}) = (2xu_v + xd_v)/3$

Sensitive to valence quark densities

CC Cross-Sections e^+p vs. e^-p



$\sigma(e^-p) \sim (u+c)$

$\sigma(e^+p) \sim (1-y)^2(d+s)$

At large x:

CC e^- probes u_v

CC e^+ probes d_v

ZEUS' Global NLO QCD Analysis

1. Analysis Method

a. NLO evolution of Altarelli-Parisi equations in MS_{bar} (QCDNUM)

b. Heavy quark: RT-VFN scheme

2. PDF Parameterizations (Q^2_0=7GeV^2)

$$xu_v = A_u\, x^{0.5}\, (1-x)^{Cu}\, (1+a_u x)$$

$$xd_v = A_d\, x^{0.5}\, (1-x)^{Cd}\, (1+a_d x)$$

$$xg = A_g\, x^{Bg}\, (1-x)^{Cg}$$

$$xS = A_1\, x^{0.5}\, (1-x)^{C1}\, (1+a_1 x)$$

$$x(d_{bar}-u_{bar}) = A_2\, x^{B2}\, (1-x)^{C1+2}$$

3. Error Treatment

Point-to-point systematic errors properly taken into account

4. Simultaneous α_s extraction

Data Sets and Goodness of the Fit

Data Sets	χ^2/N_{data} stat	(total)	N_{data}
CC Not Used			
ZEUS 96/7 NC	1.75	(0.85)	242
NMC P	1.74	(1.21)	218
NMC D	1.52	(0.92)	218
NMC D/P	0.98	(0.94)	129
BCDMS	1.29	(0.94)	305
E665 P	1.33	(1.16)	47
E665 D	1.14	(0.94)	47
CCFR xF_3	1.79	(0.40)	57
Total	1.48	(0.95)	1263

Cuts Applied:

$W^2 > 20 GeV^2$

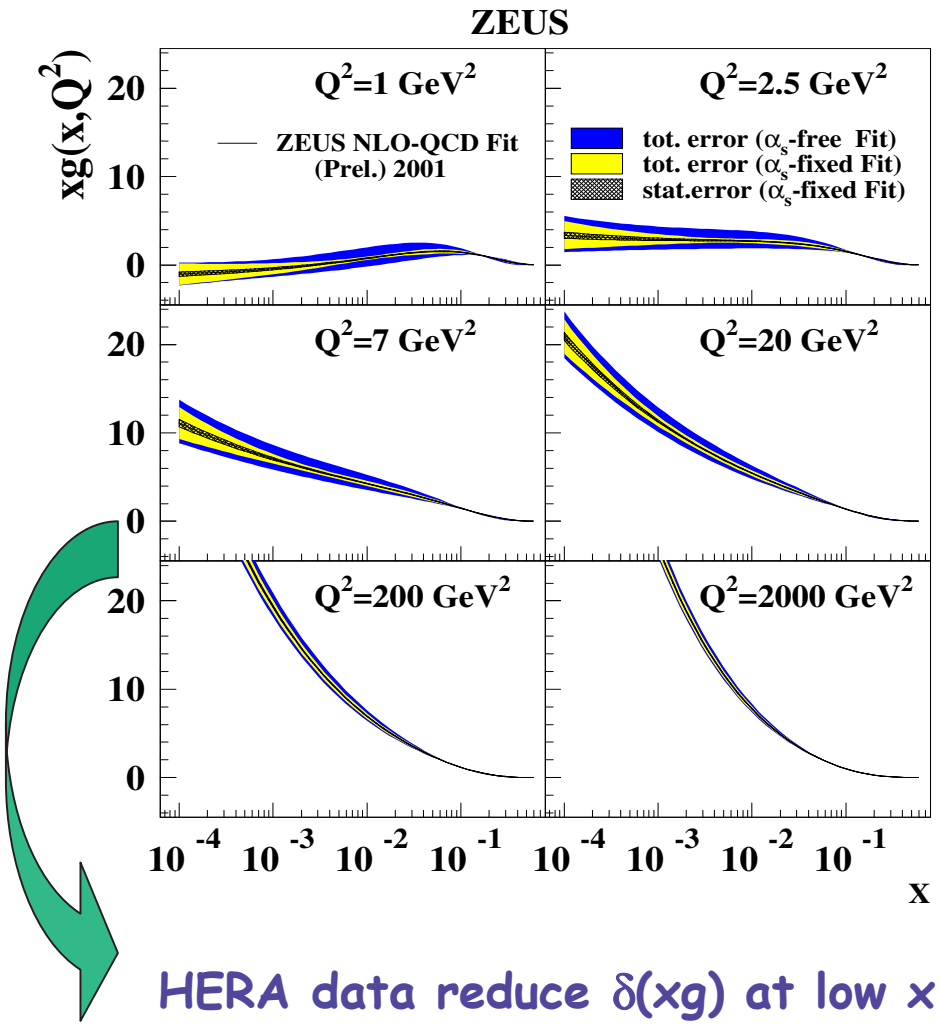
$Q^2 > 2.5 GeV^2$

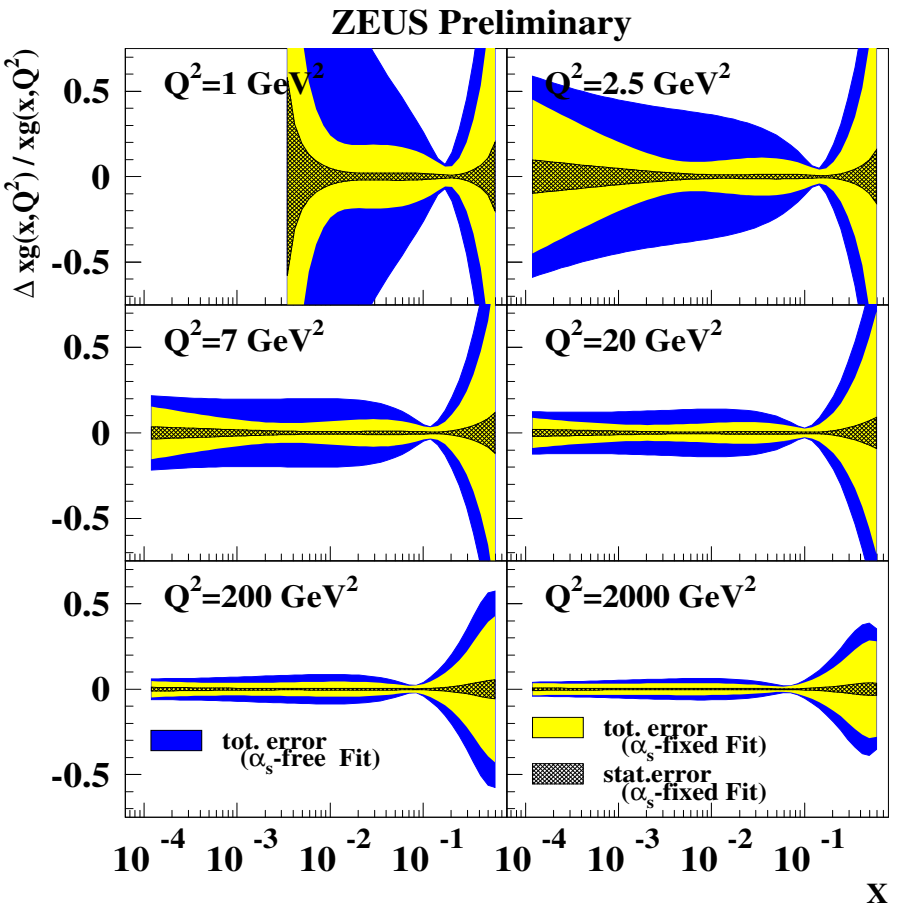
$0.1 < x < 0.75$ (CCFR)

Deuterium Corrections (a la SLAC)

Heavy Target Corrections (a la MRST)

Gluon Density and Its Uncertainty

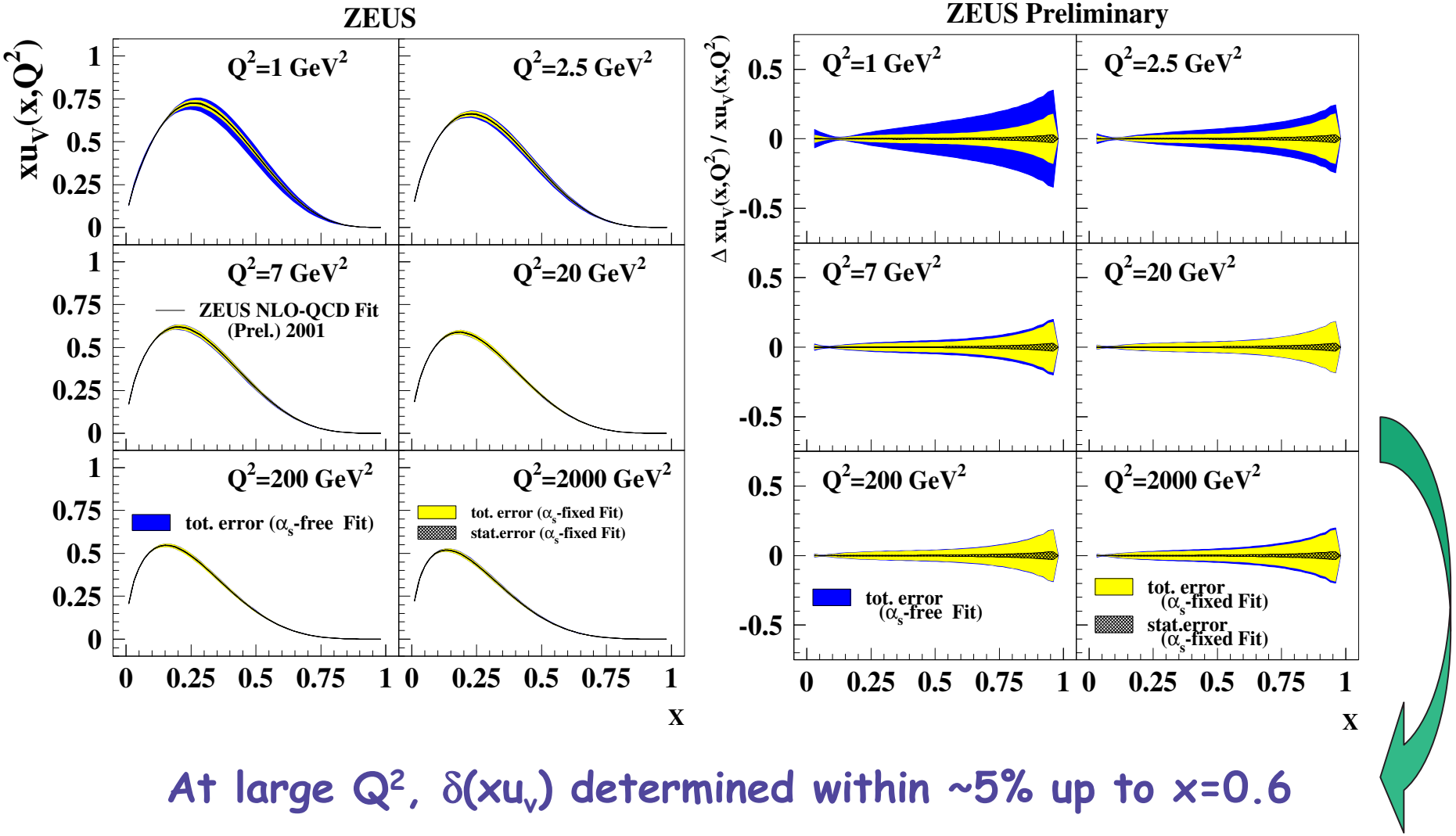




HERA data reduce δ(xg) at low x.

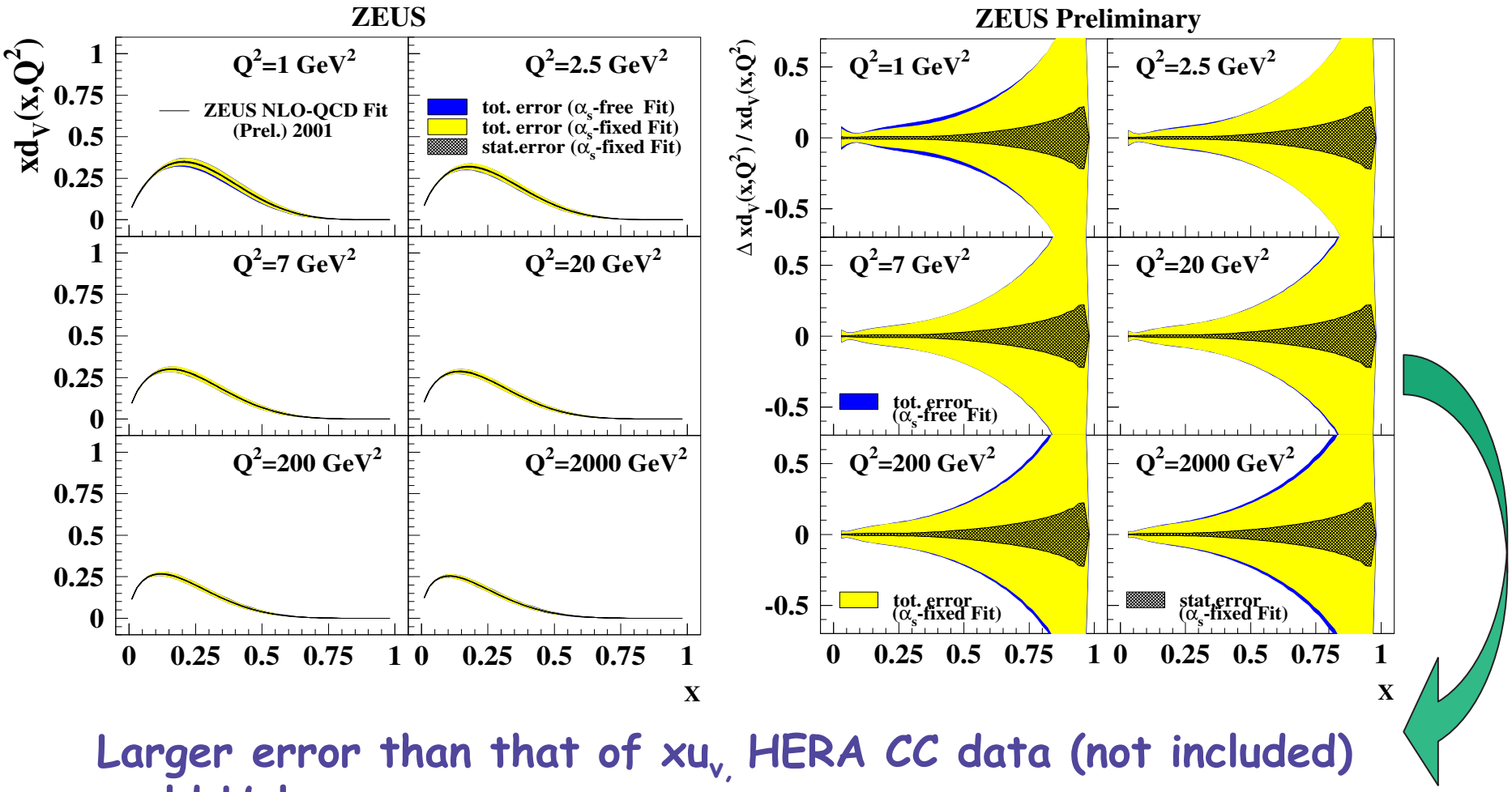
Need new constraints at large x

U Valence Quark Density and Its Uncertainty



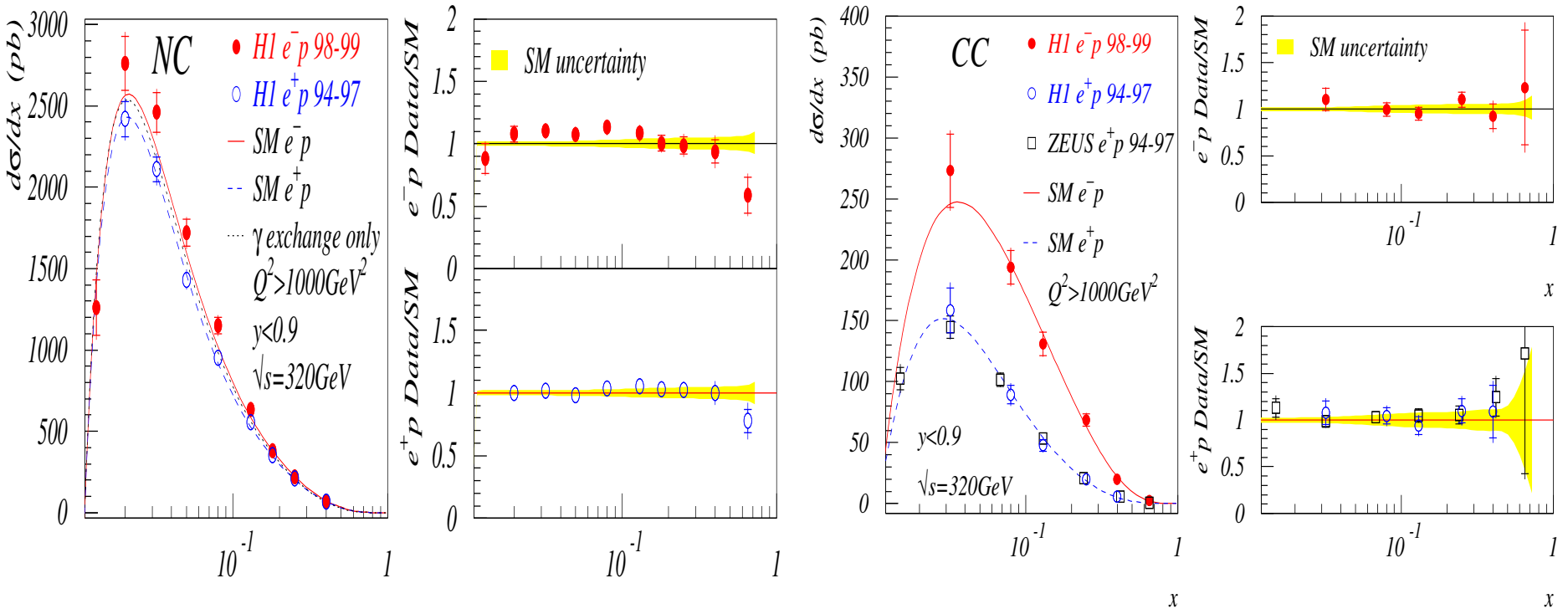
At large Q^2, $\delta(xu_v)$ determined within ~5% up to x=0.6

D Valence Quark Density and Its Uncertainty



Larger error than that of xu_v, HERA CC data (not included) could Help

Measurements of NC/CC Cross-Sections dσ/dx



HERA Data seem to prefer a smaller u quark density

and a higher d quark density at large x

Analyze HERA data alone to see its impact

Constraining Valence Quark Densities With H1 Data Alone

H1 Data: F_2(96-97), All High Q^2 NC+CC Data Since 1994

1. NLO QCD Fit:

PDF Parameterizations (Q^2_0=15GeV^2)

$$xu_v = A_u\, x^{Bu}\, (1-x)^{Cu}\, (1+a_u x^{1/2})$$

$$xd_v = A_d\, x^{Bd}\, (1-x)^{Cd}\, (1+a_d x^{1/2})$$

$$x_g = A_g\, x^{Bg}\, (1-x)^{Cg}$$

$$x(u_{bar}+c_{bar}) = A_1\, x^{B1}\, (1-x)^{C1}\, (1+a_1 x)$$

$$x(d_{bar}+s_{bar}+b_{bar}) = A_2\, x^{B2}\, (1-x)^{C2}\, (1+a_2 x)$$

Data selected with Q^2>20GeV^2

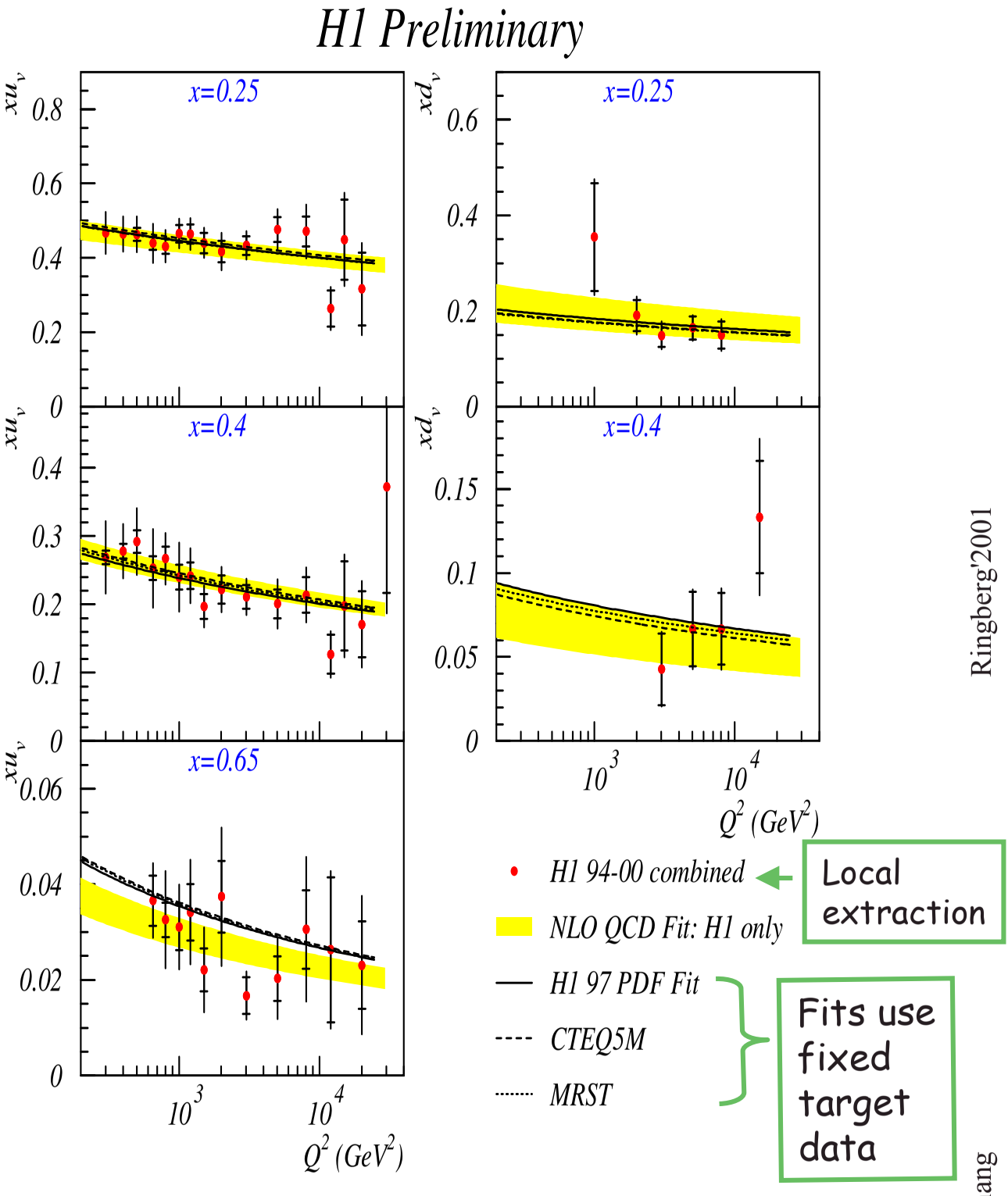
Data	e^+p NC	e^+p CC	e^-p NC	e^-p CC	F_2
N_{Data}	134	29	115	26	62
χ^2	81.9	19.9	95.6	36.4	55.3

2. Local Extraction Method:

$$xq_v(x,Q^2) = \sigma_{H1}(x,Q^2)\, (xq_v(x,Q^2)/\sigma(x,Q^2))_{th}$$

Only applied if xq_v dominates (>70%) in σ

Valence Quark Densities from H1

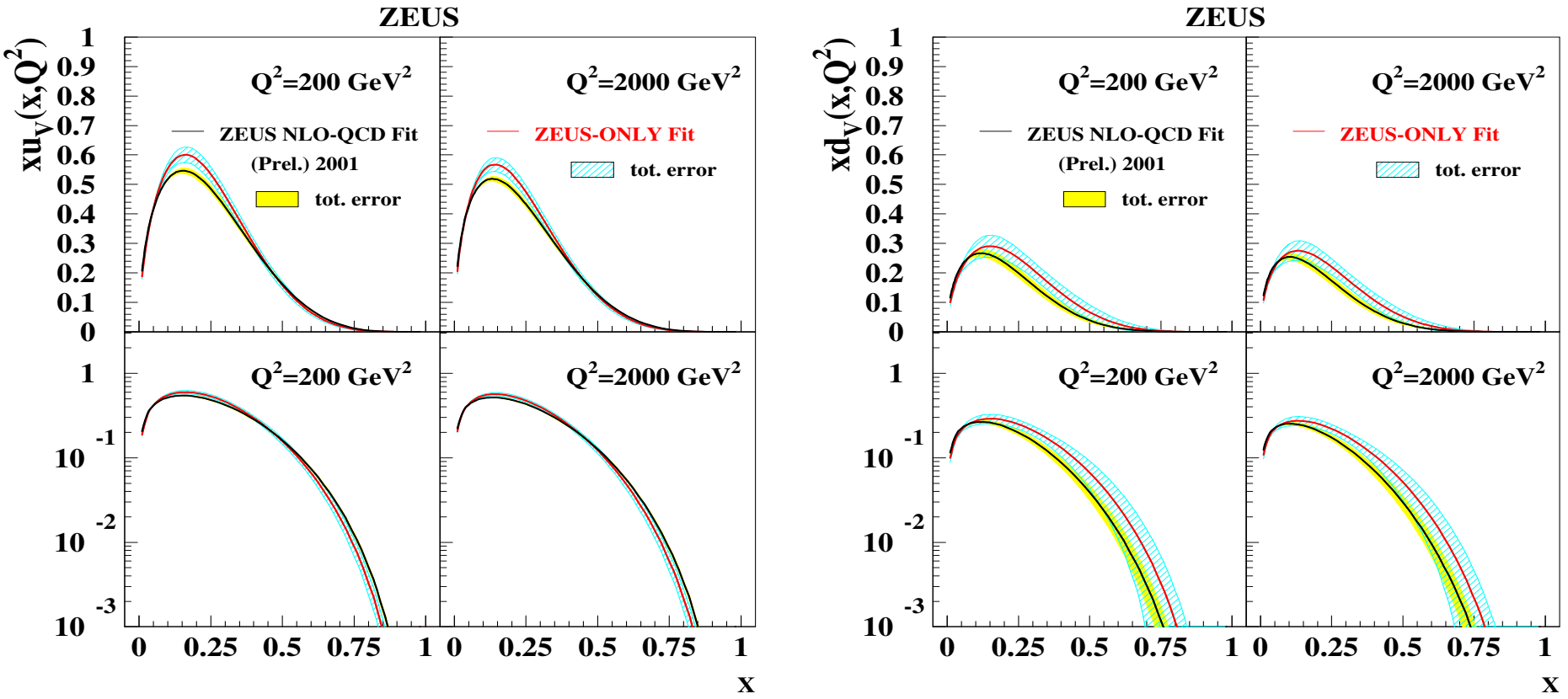


H1 data alone determine xu_v with 6%-10%, xd_v with 20%

At x=0.65 xu_v is lower by ~17% (<2σ) than the other fits

Constraining xu_v, xd_v With ZEUS Data Only

ZEUS Data: F_2(96-97), High Q^2 NC+CC e^+p(96-97) & e^-p(98-99)



ZEUS Data prefer a larger xu_v at x~0.2 and a shift in xd_v to higher x
a smaller xu_v at larger x

Future Prospects for Improving PDFs Knowledge at Large x

Valence quarks:

HERA high Q^2 Data with
the upgraded machine and detectors and
the polarized longitudinal lepton beams (u and d)

Measurements of π^-/π^+ production in DIS (d/u) $N_p^{\pi^-} \sim 4u(x)D_{bar}(z)+d(x)D(z)$, $N_p^{\pi^+} \sim 4u(x)D(z)+d(x)D_{bar}(z)$

Gluon:

Direct photon data (once the discrepancy data/th. is resolved)

Tevatron jet data

Drell-Yan process ($qg \to \gamma^* q$, $\gamma^* \to \mu^+\mu^-$ dominates when $E_{T,\mu} > m_{\mu\mu}/2$)

NNLO QCD analyses

Summary

Fixed target and hadron-hadron collider data:

constrain PDFs at intermediate and large x

Including HERA data:

provide best knowledge on the xg(x) and sea quarks at small x

HERA data alone:

are able to constrain u_v, d_v at large x

free from certain uncertainties inherent in low Q^2 data

Future HERA data:

will improve significantly our knowledge at large x

Precise knowledge of PDFs:

essential for the physics programme at the LHC