HSQCD2005, 20- 24th September St. Petersburg

# Proton Structure

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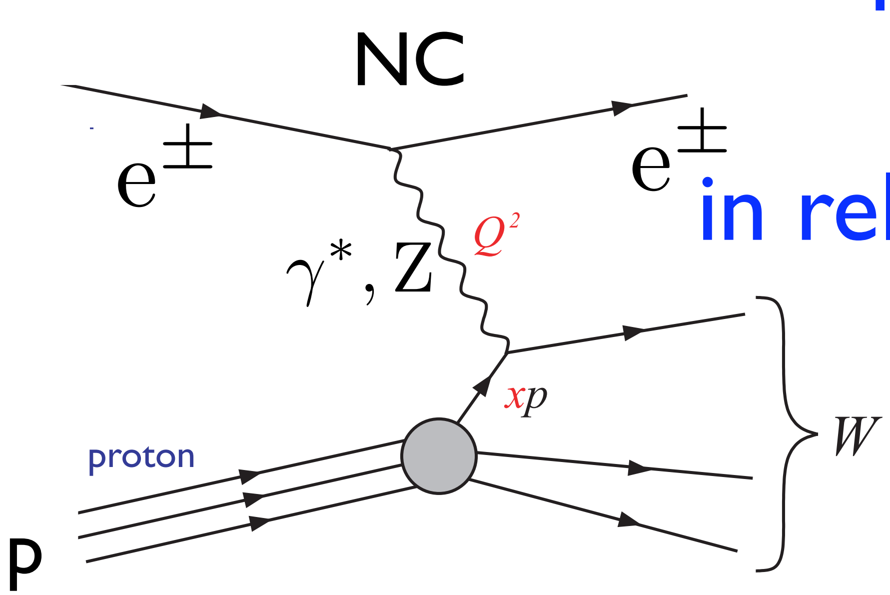
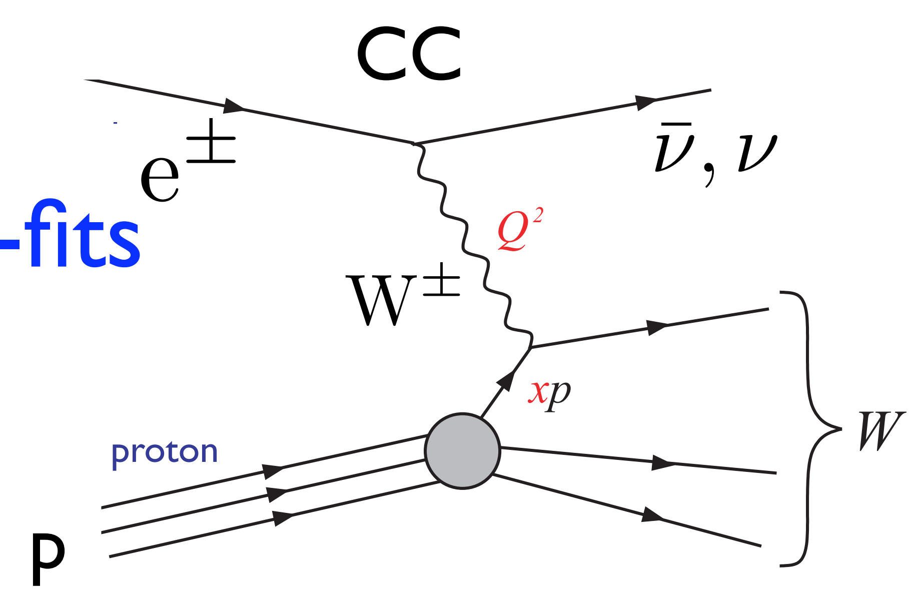
## Introduction



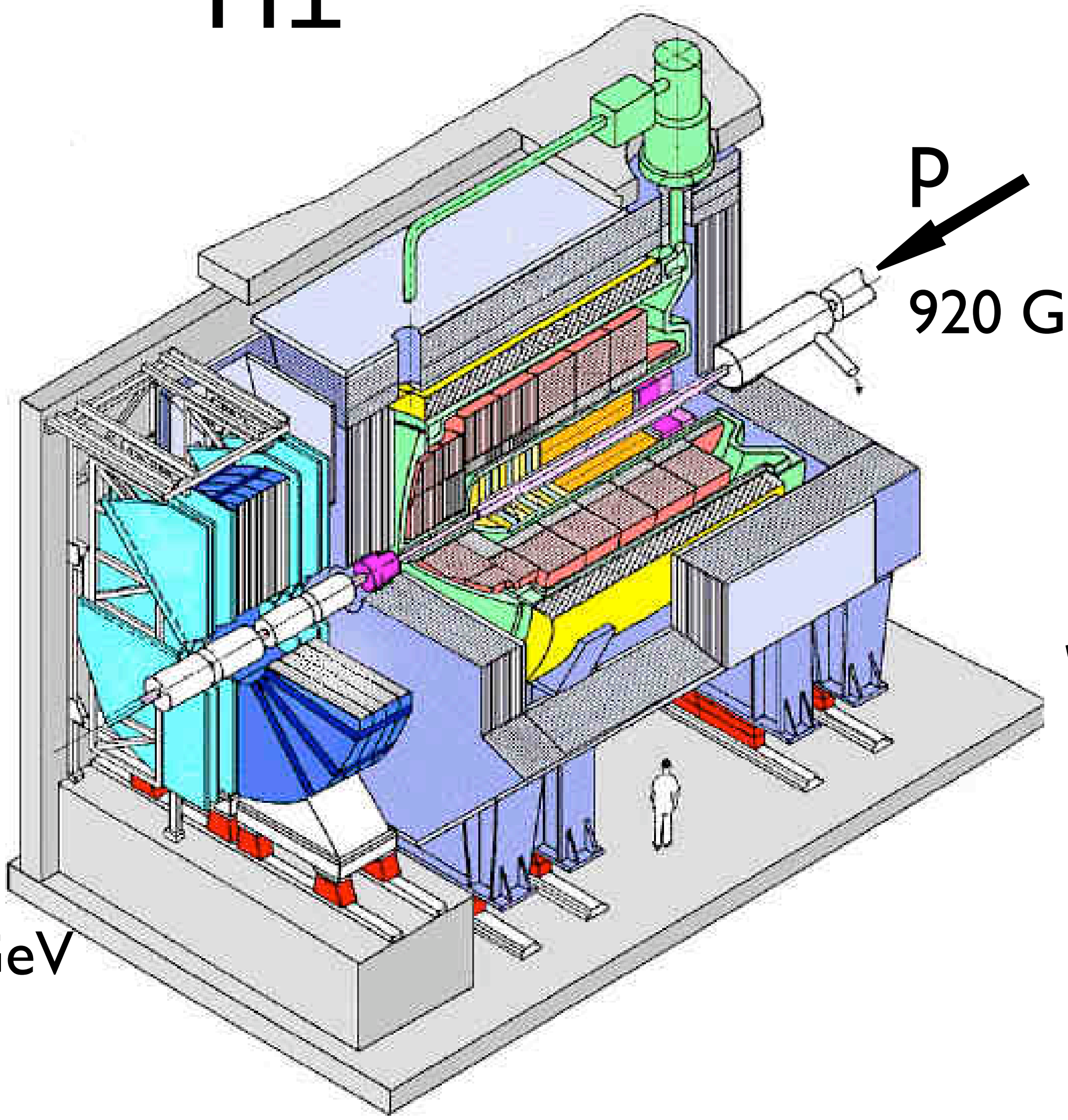

## recent inclusive data from HERA in relation to pQCD, pdf-fits



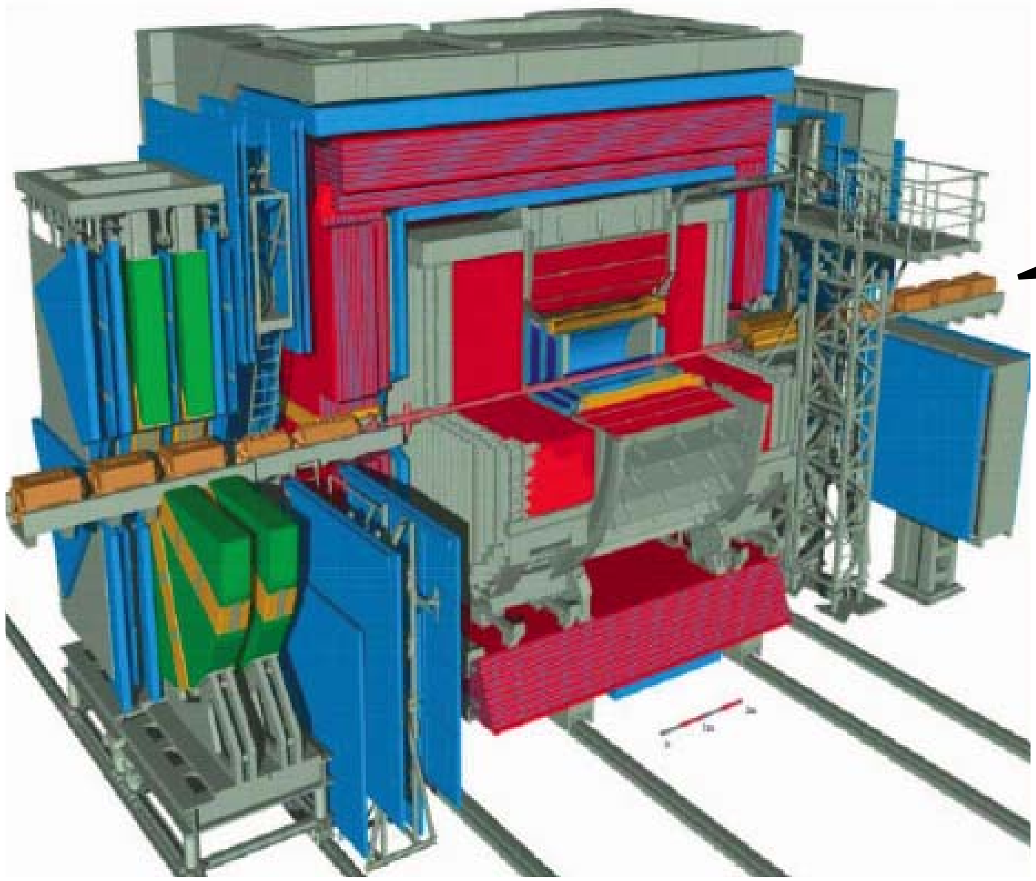

## Conclusion

emphasis is on recent results from H1 and ZEUS at HERA

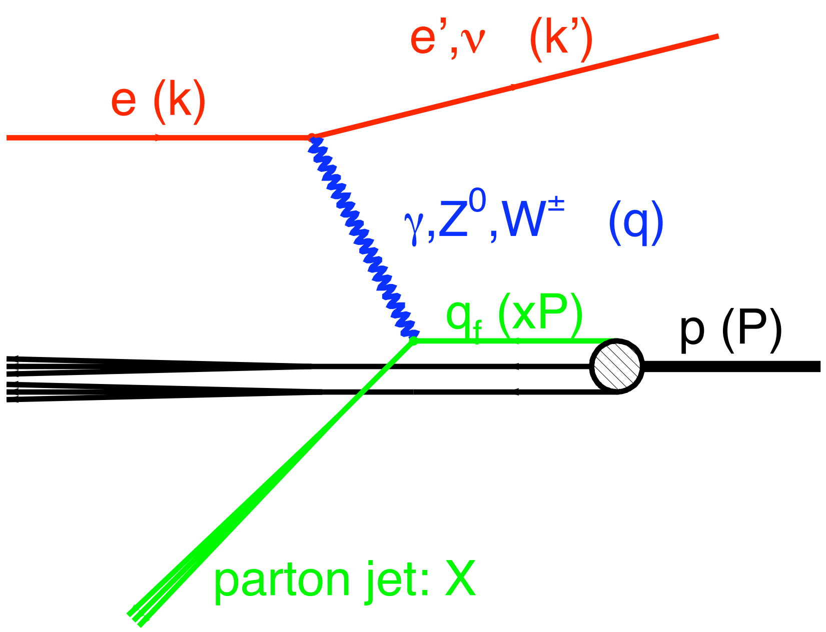
H1




ZEUS



# Inclusive DIS NC, CC




| | |
|---|---|
| $Q^2 = -q^2$ | 4-momentum transfer |
| $x = Q^2/2(P \cdot q)$ | $p$ momentum fraction of parton |
| $y = (P \cdot q)/(P \cdot k)$ | inelasticity |

$$NC \quad d^2\sigma^{\pm}_{NC}/dxdQ^2 = \frac{2\pi\alpha^2}{xQ^4}[Y_+ \cdot \tilde{F}_2 \mp Y_- \cdot x\tilde{F}_3 - y^2 \cdot \tilde{F}_L] \equiv \frac{2\pi\alpha^2}{xQ^4} Y_+ \tilde{\sigma}^{\pm}_{NC}$$

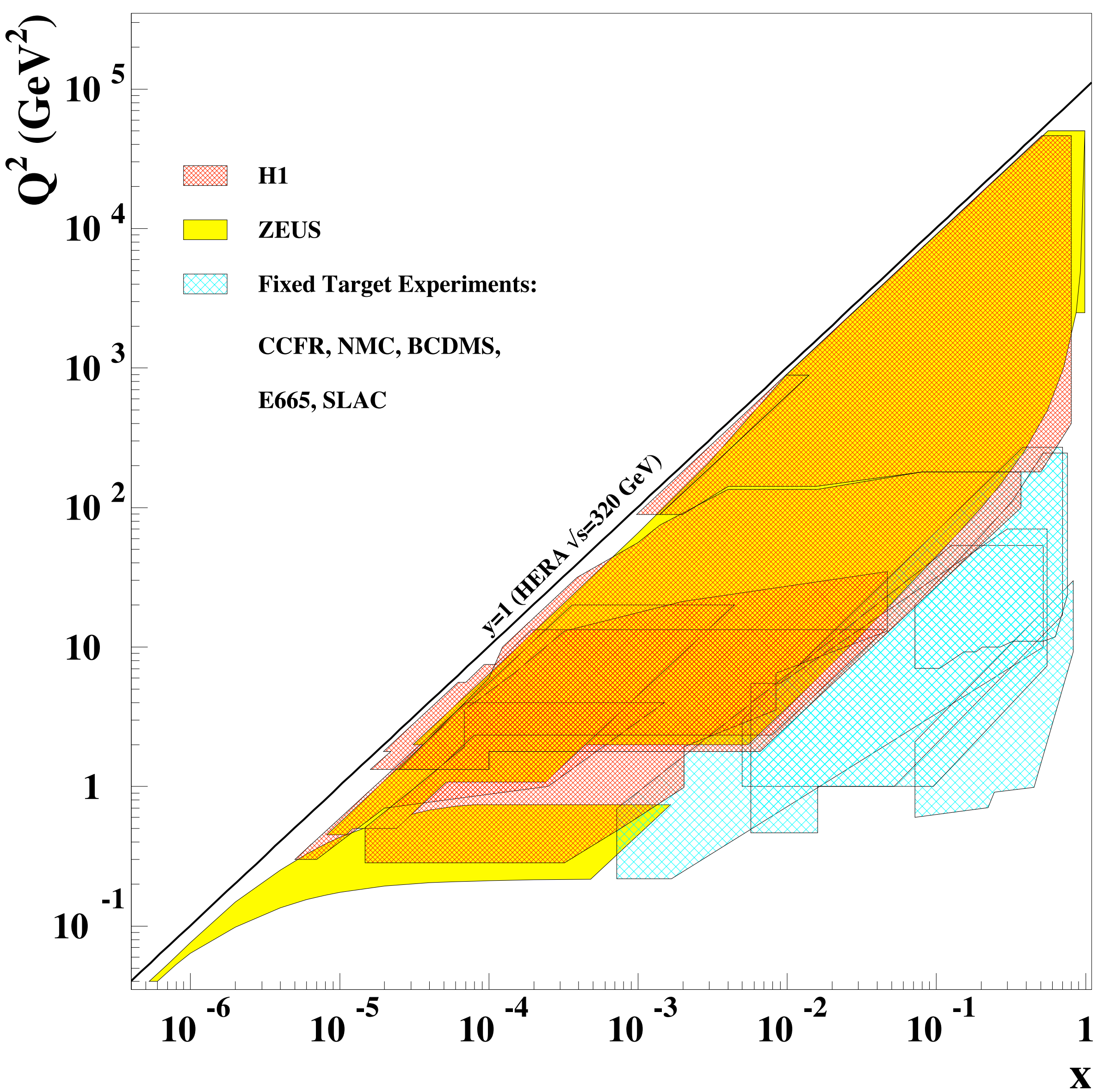
$$Y_\pm = 1 \pm (1-y)^2$$

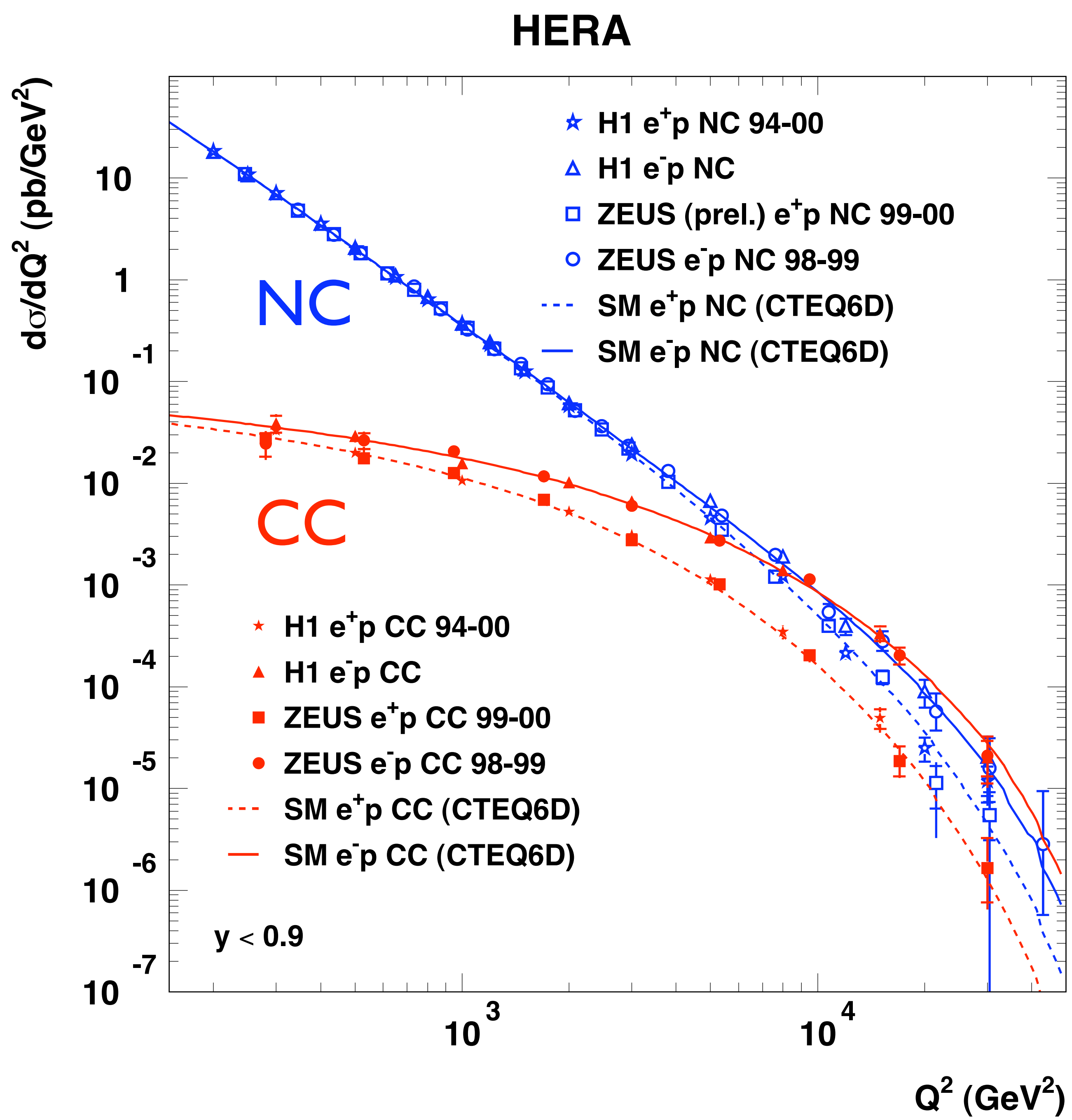
| | | | |
|---|---|---|---|
| $\tilde{F}_2$ , | **dominating contribution,** | **in leading order QCD** | $\sim x \sum_q e_q^2 (q + \bar{q})$ |
| $x\tilde{F}_3$ , | **in particular $\gamma Z$ interference,** | **significant at large $Q^2 \gtrsim M_Z^2$** | $\sim x \sum_q A_q (q - \bar{q})$ |
| $\tilde{F}_L$ , | **longitudinal contribution,** | **sensitivity at large $y$,** | **zero in LO QCD** |

$$CC \quad d^2\sigma^{\pm}_{CC}/dxdQ^2 = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{Q^2 + M_W^2}\right)^2 \cdot \tilde{\sigma}^{\pm}_{CC}$$

**LO** $\tilde{\sigma}^{+}_{CC} = x[(\bar{u} + \bar{c}) + (1-y)^2(d+s)]$ $\quad \tilde{\sigma}^{-}_{CC} = x[(u + c) + (1-y)^2(\bar{d}+\bar{s})]$

# large phase space covered by HERA $e^+p$ $e^-p$ data




illustrating electro-weak unification

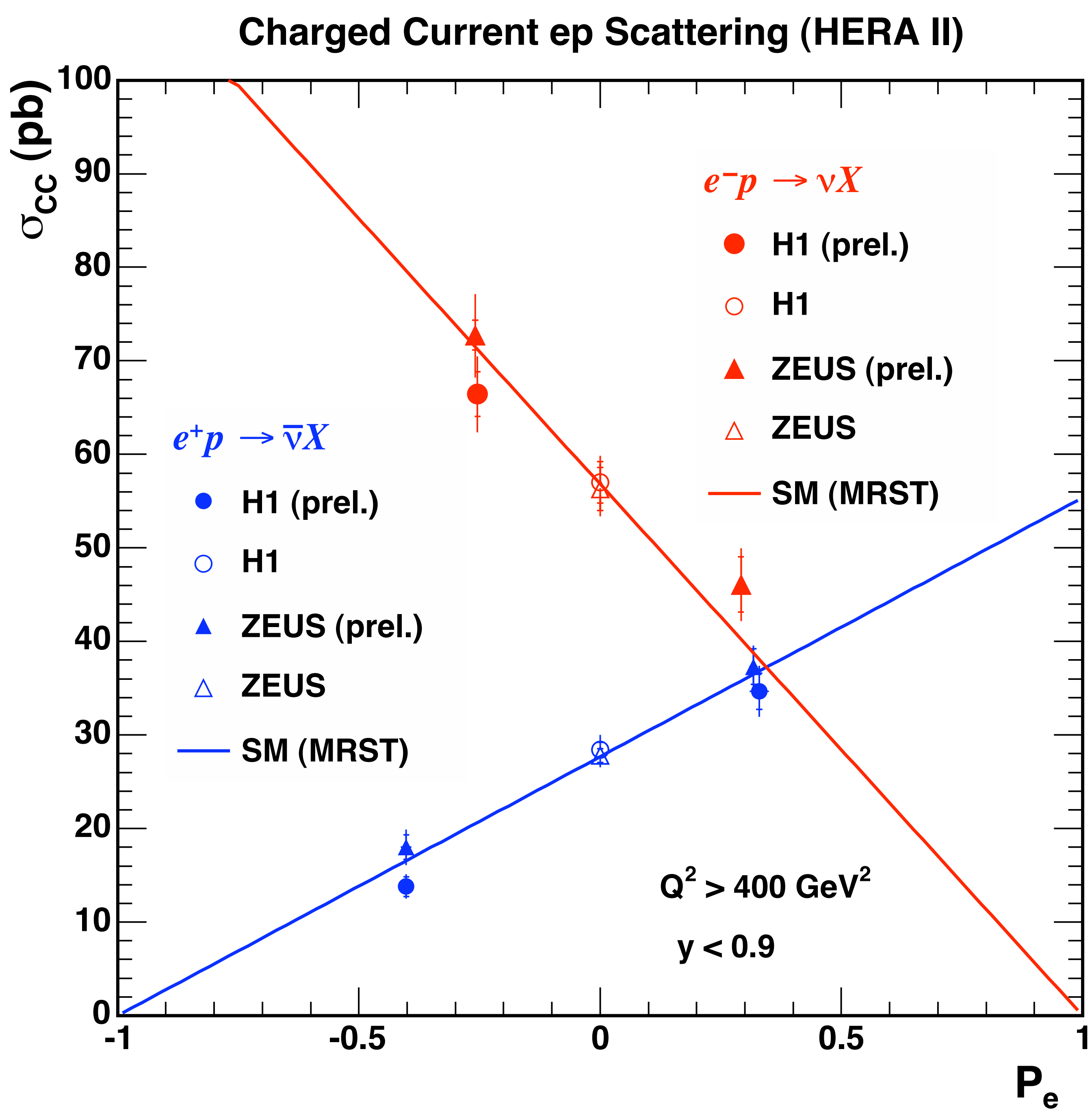
# new data from HERA II

dependence on electron polarisation in CC

linear fit
to H1 and ZEUS data

$$\sigma(e^+p) \rightarrow \bar{\nu}X \quad (\mathrm{P}_{e^+} = -1)$$
$$= 0.2 \pm 1.8 \pm 1.6 \text{ pb}$$

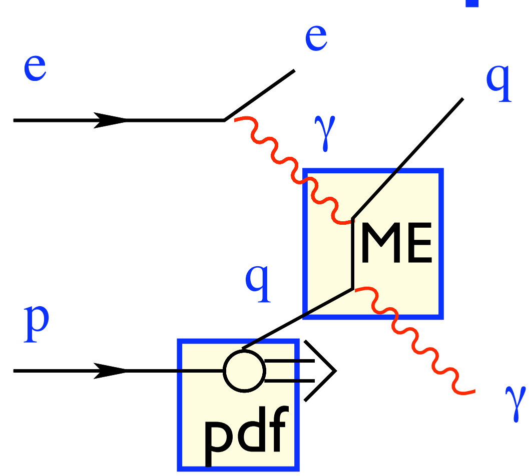
consistent with zero
(SM expectation)




no sign of right handed currents

see talk of Yongdok Ri

# Proton pdfs from NC and CC data




QCD factorisation in matrix elements and pdfs, parton density functions describing hadronic particles

Inclusive eN DIS data are the most important source for pdf determinations

fixed target ⟹ large x valence and sea distributions

HERA ⟹ low x gluon and sea distributions (gluon indirectly from scaling violations)

Tevatron $(p\bar{p})$ ⟹ gluon at medium and large x from jets (previously mostly from prompt photons)

HERA experiments aim to determine the gluon at medium x as well as u and d valence (free of nulear effects of ed scattering)

# NC input

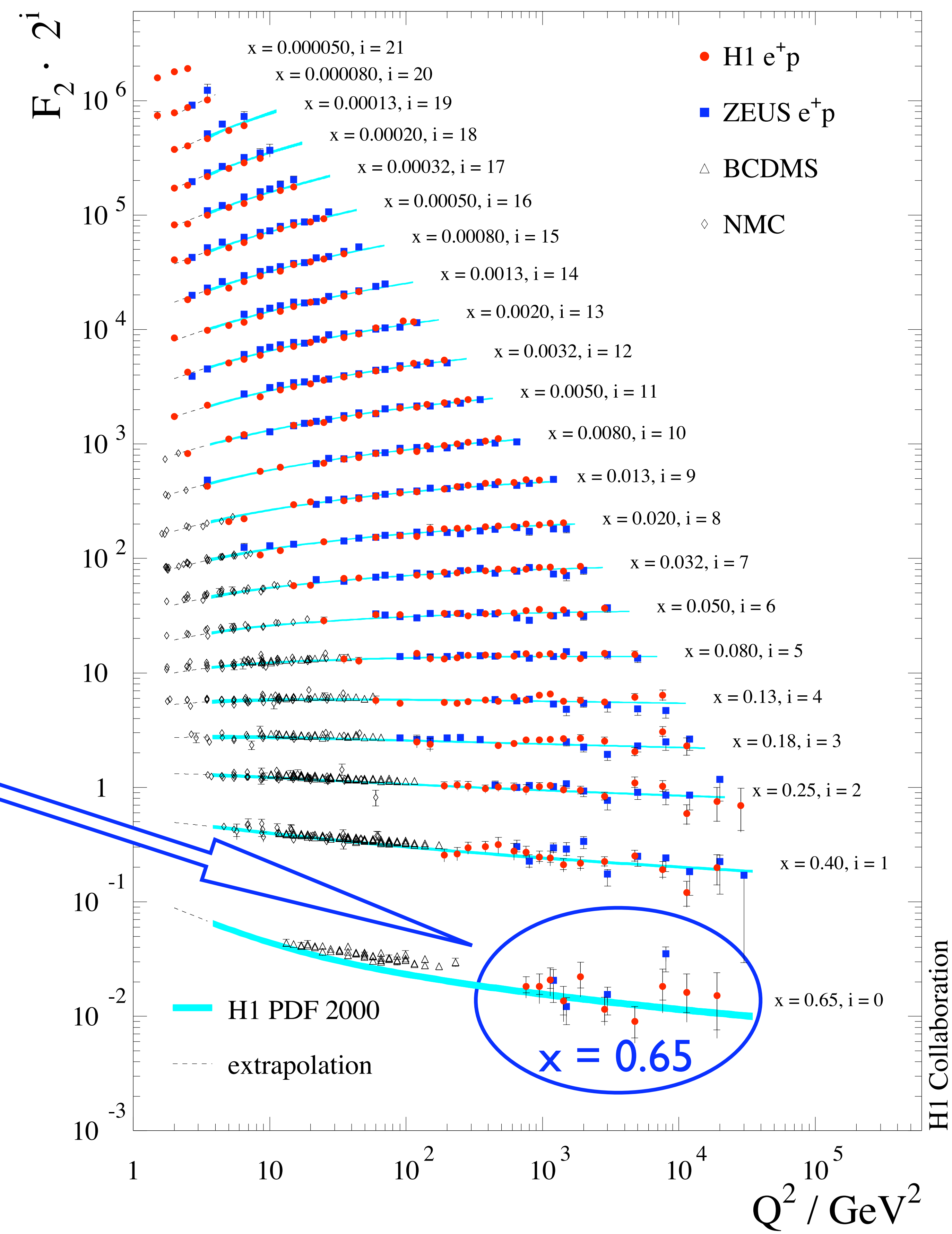
HERA provides data over

4 orders of magnitude

in x and $Q^2$

cross sections at largest x

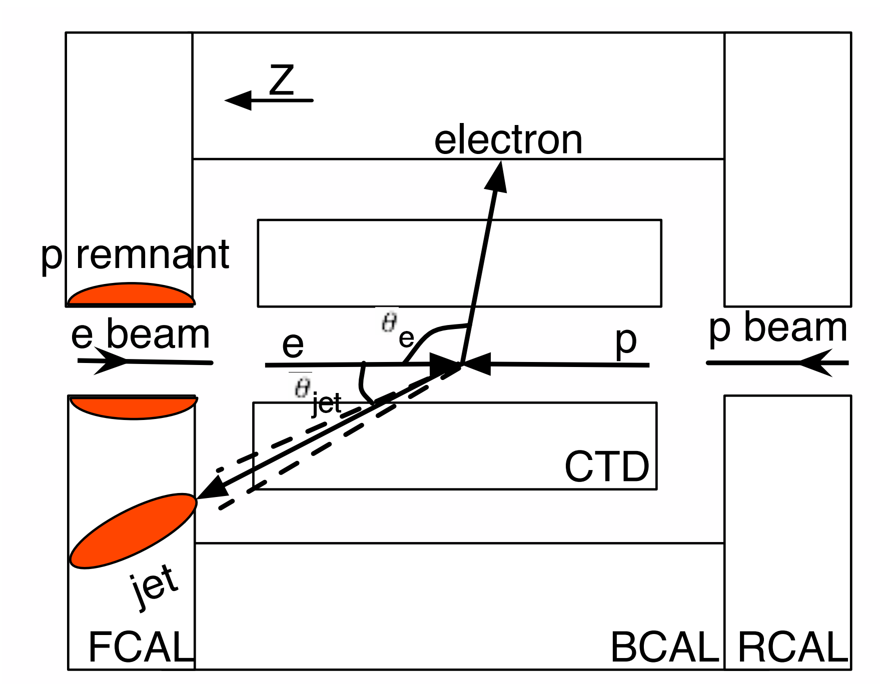
here large uncertainties



# New technique in high x region

$Q^2$ is well measured by electron, but x needs jet information

sketch of ZEUS detector



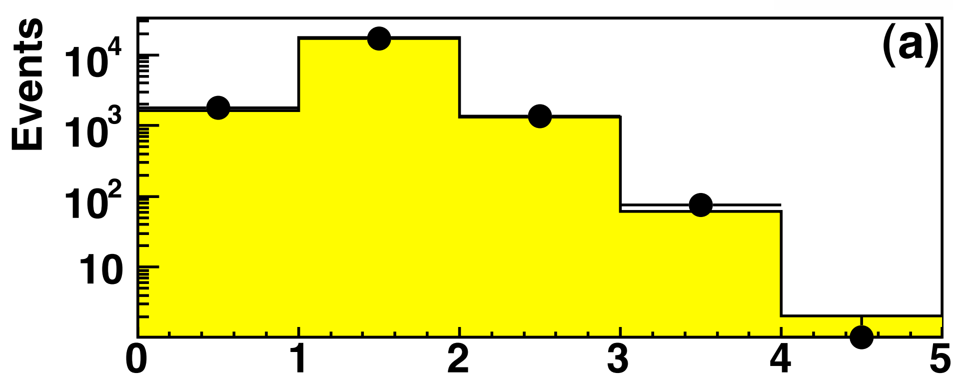

at very high x , jet moves into beam pipe

consider jets with $E_T > 10$ GeV , $\Theta > 0.12$ rad

reconstruct 1 jet $\longrightarrow$ some x − bin

reconstruct 0 jets $\longrightarrow$ $x_{edge}(Q^2) < x < 1$

discard >= 2 jets

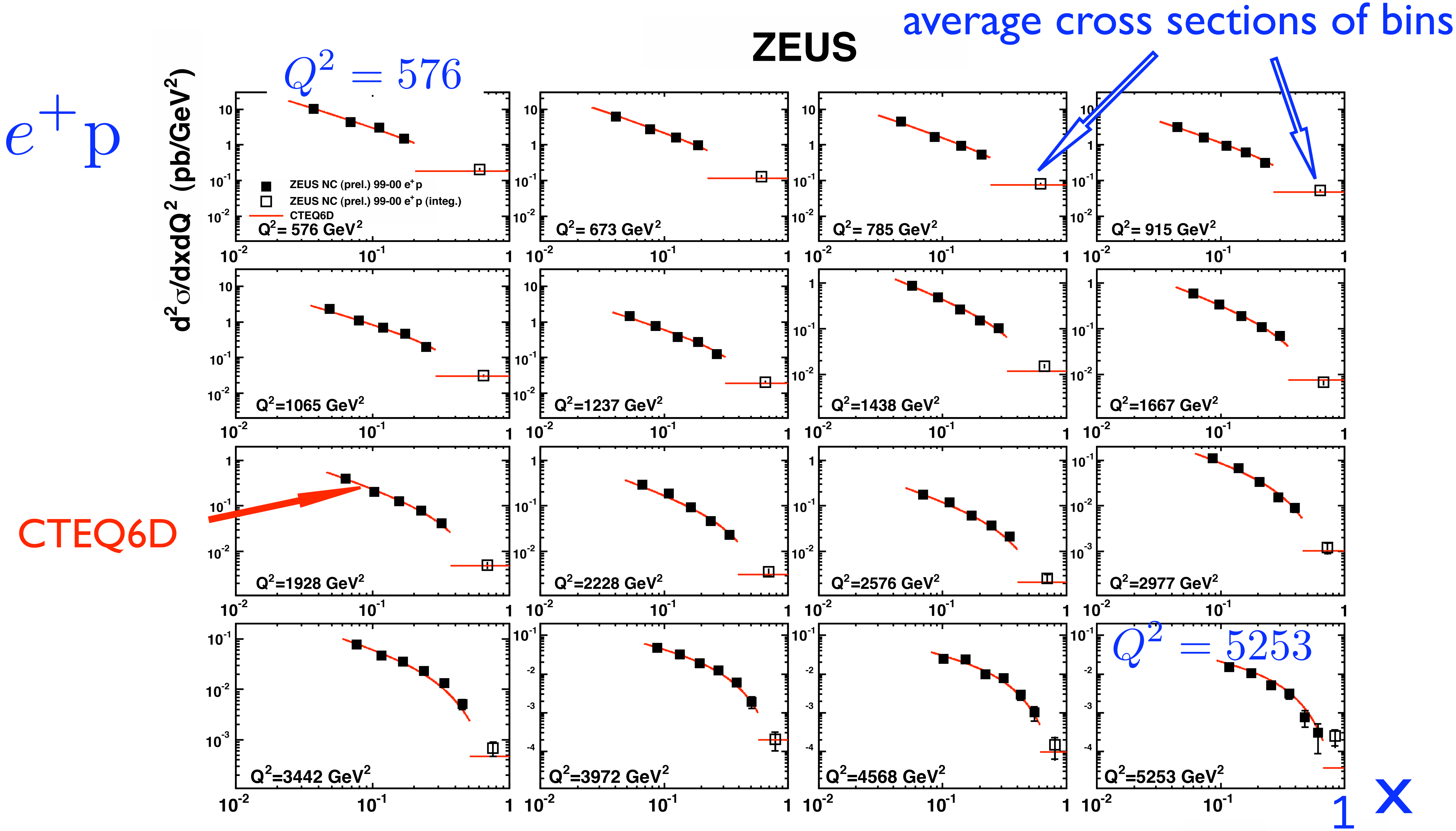



e.g. jet multiplicities well described by correcting MC (LEPTO/MEPS)

# Results

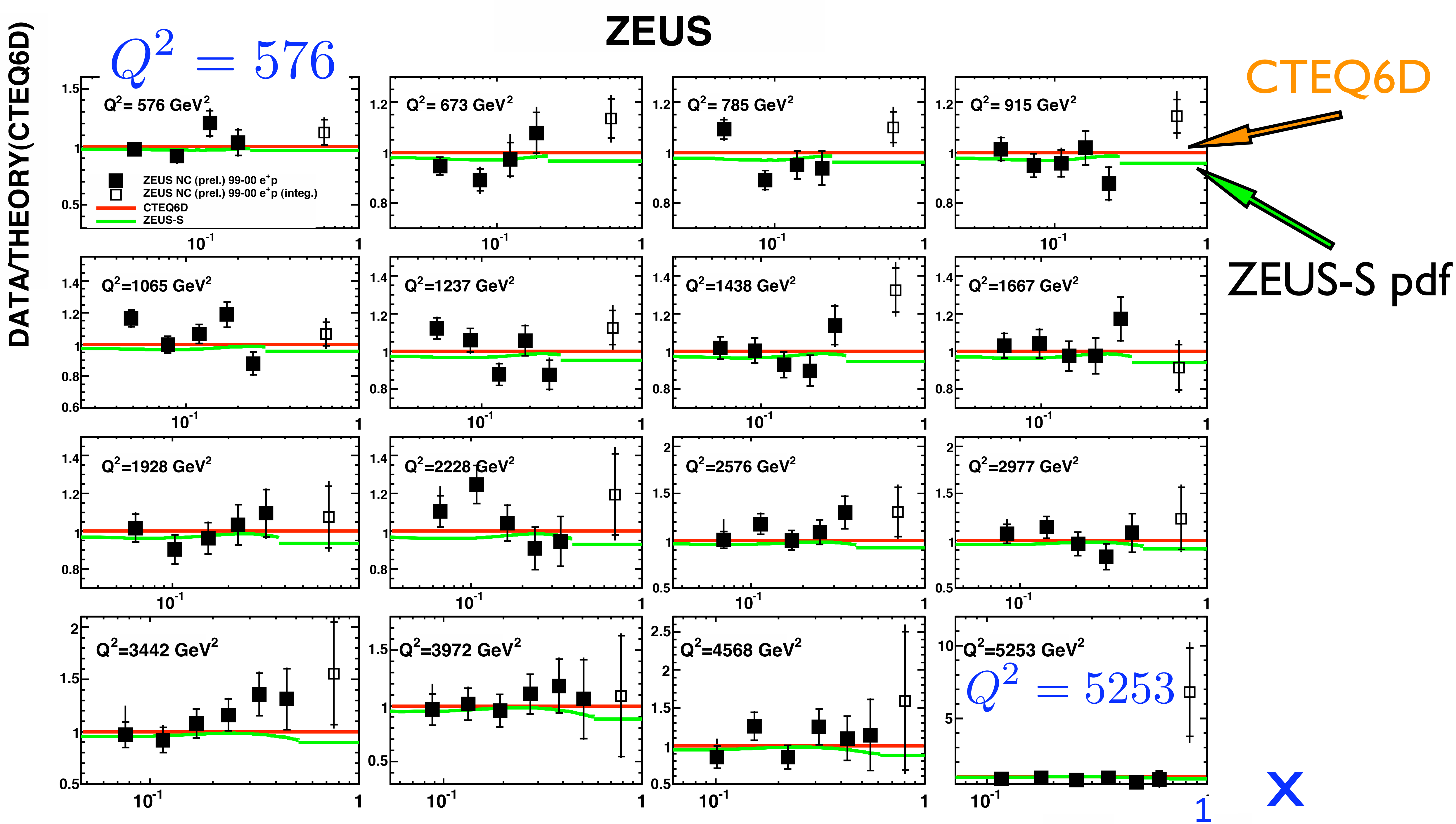
analysed $e^+$p 65 pb$^{-1}$ $e^-$p 17 pb$^{-1}$

$e^+$p




consistent with expectation over wide range of $Q^2$

# NC e+p, ratio to NLO expectation




data close to expectation, but tend to be above at highest x

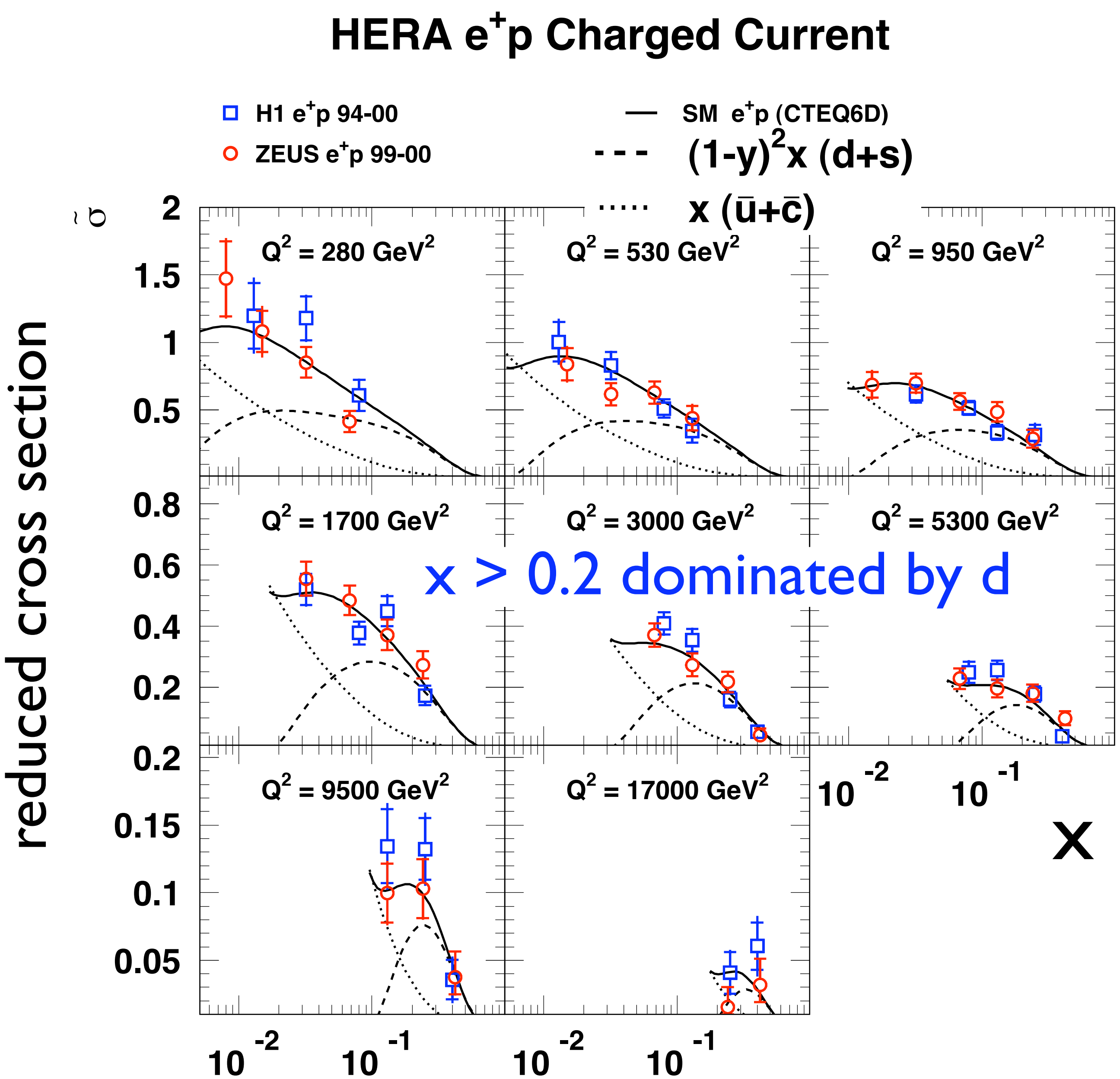
→ to include in pdf fits

# u - d separation at high x

CC

$$\sigma(e^- p) \sim x(\mathrm{u} + \mathrm{c}) + (1-y)^2 x\,(\bar{\mathrm{d}} + \bar{\mathrm{s}})$$
$$\sigma(e^+ p) \sim x(\bar{\mathrm{u}} + \bar{\mathrm{c}}) + (1-y)^2 x\,(\mathrm{d} + \mathrm{s})$$

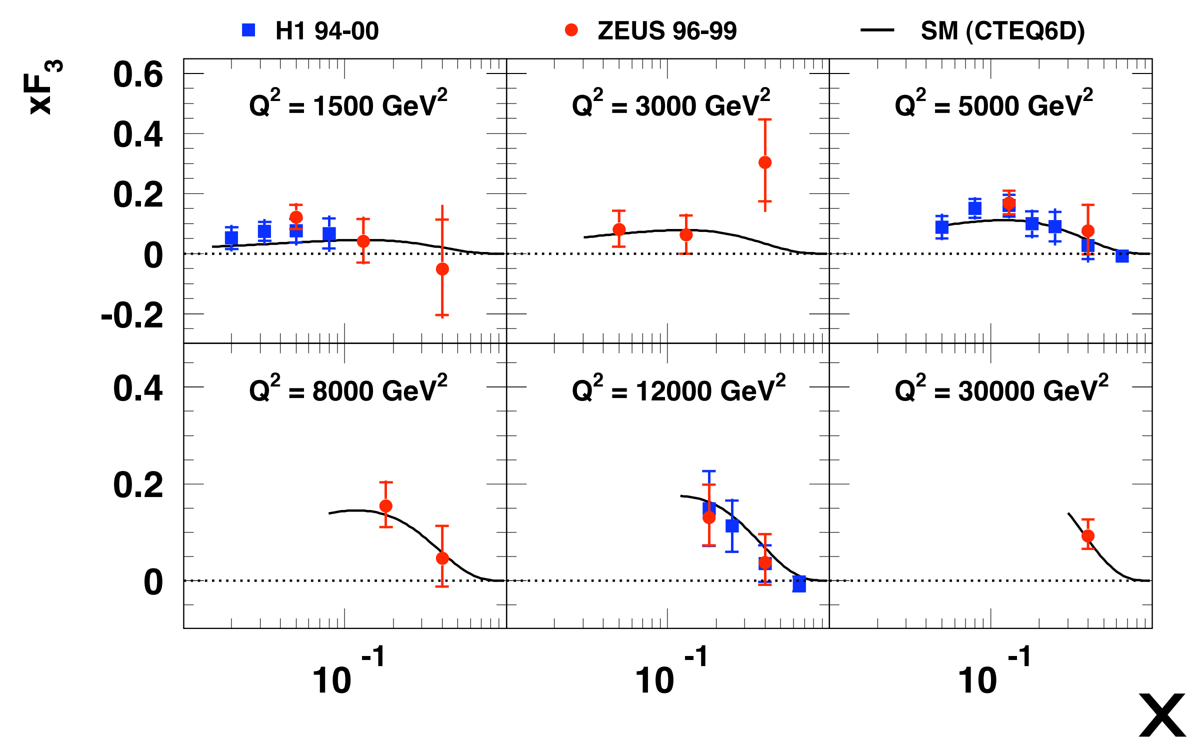
using CC (and NC)
HERA disentangles flavours
free of nuclear effects




when enough data,
consistency check also with

$$xF_3 \sim 2\mathrm{u}_v + \mathrm{d}_v$$

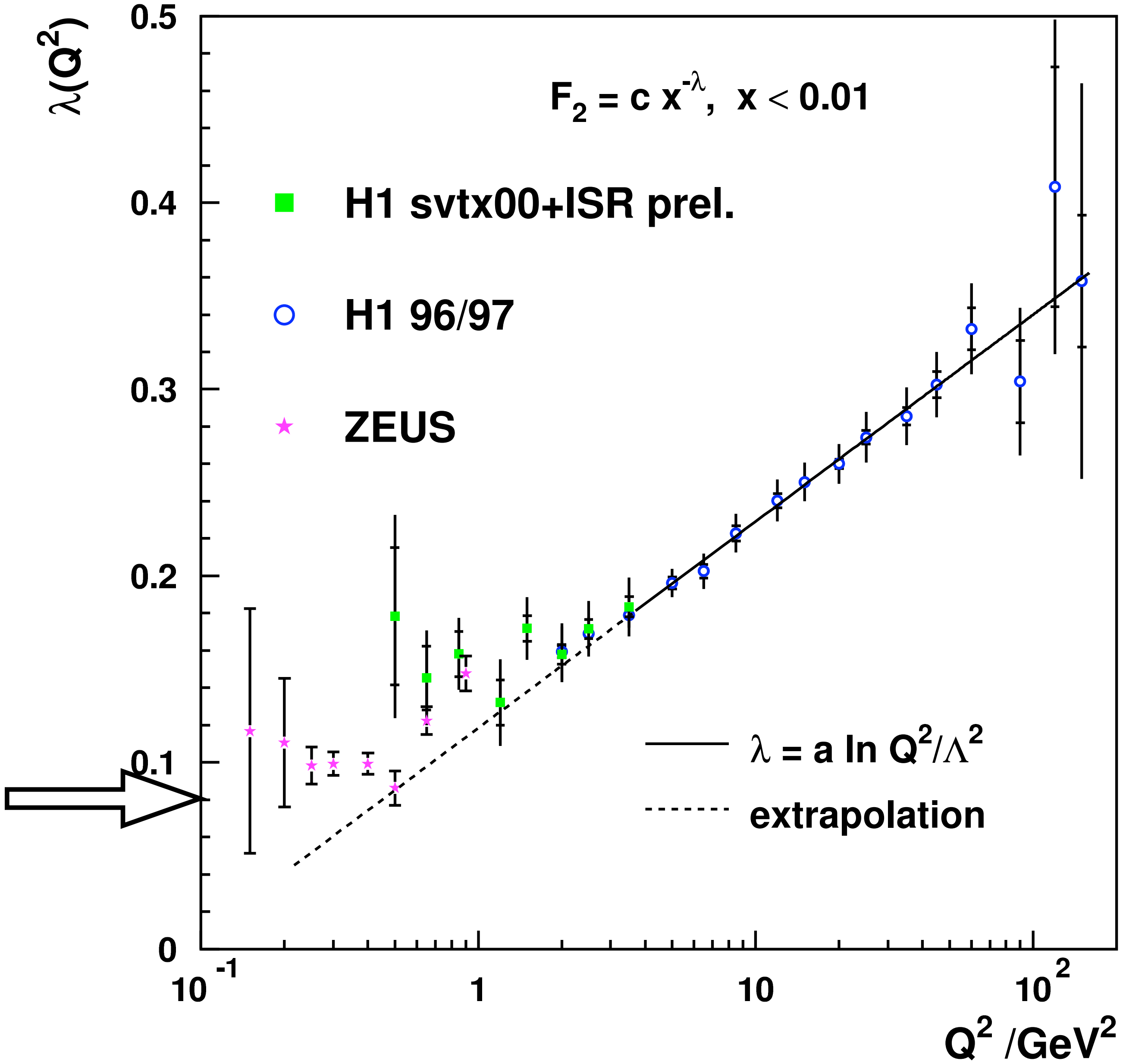
(mainly $\gamma Z^0$ interference)



# input from HERA at low $x, Q^2$

main behaviour for x < 0.01

rise of $\mathrm{F}_2$




$$\mathrm{F}_2 = \mathrm{c}(Q^2) \cdot \mathrm{x}^{-\lambda(Q^2)}$$

$Q^2 > 3\ \mathrm{GeV}^2$

$\lambda \sim \ln(Q^2/\Lambda^2)$ $\quad$ $\mathrm{c} \approx \mathrm{const}$

$Q^2 \approx 1\ \mathrm{GeV}^2$

$\lambda$ deviates from log dependence

expect $\lambda \to 0.08$ for $Q^2 \to 0$

from soft hadronic interactions

rise of the parton densities vs low x increasing with $Q^2$

# Impact of $F_L$

sensitive to gluon density

$$F_L \sim \alpha_s(Q^2)\,g(x,Q^2)$$

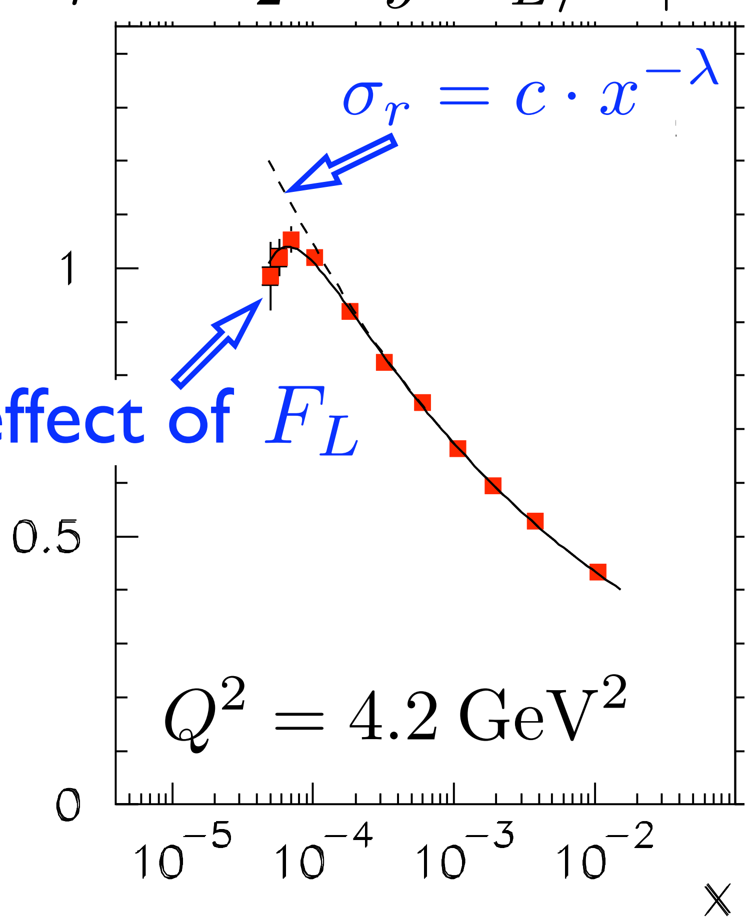
$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4 x} Y_+ \left(F_2(x,Q^2) - y^2 F_L(x,Q^2)\right)$$

$$Y_+ = 1 + (1-y)^2$$

$\sigma$ sensitive to $F_L$ at high y

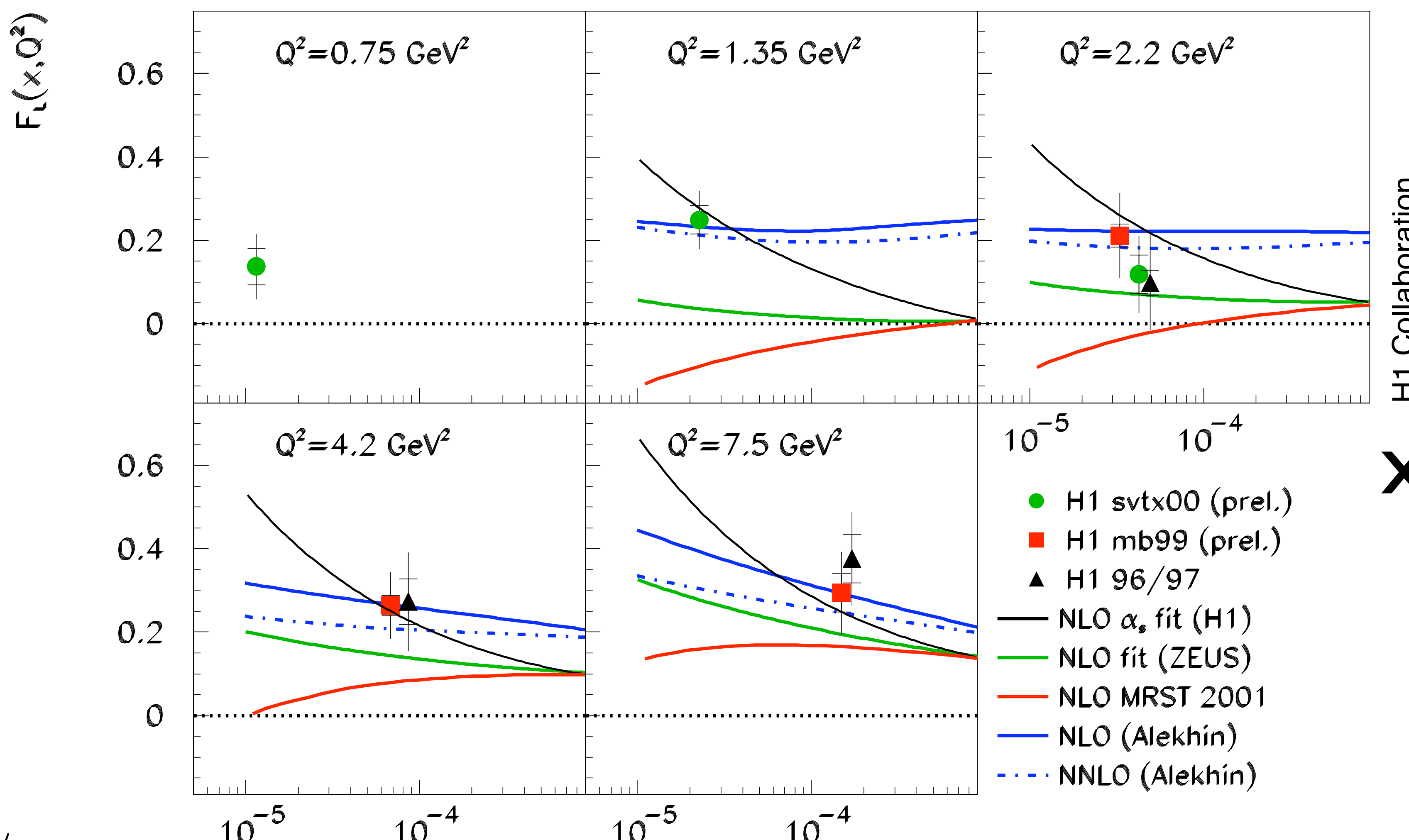
measure reduced $\sigma$

$$\sigma_r = F_2 - y^2 F_L / Y_+$$




effect of $F_L$

$= Q^2/ys$



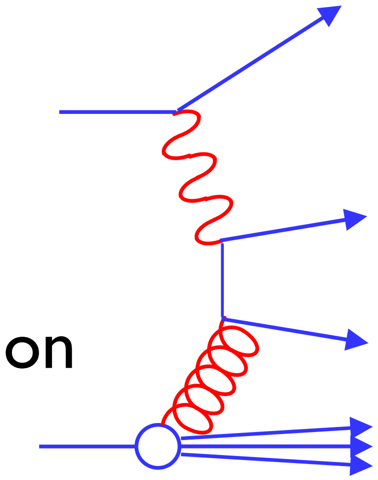

large spread of predictions

⇒ assumption free masurement needed

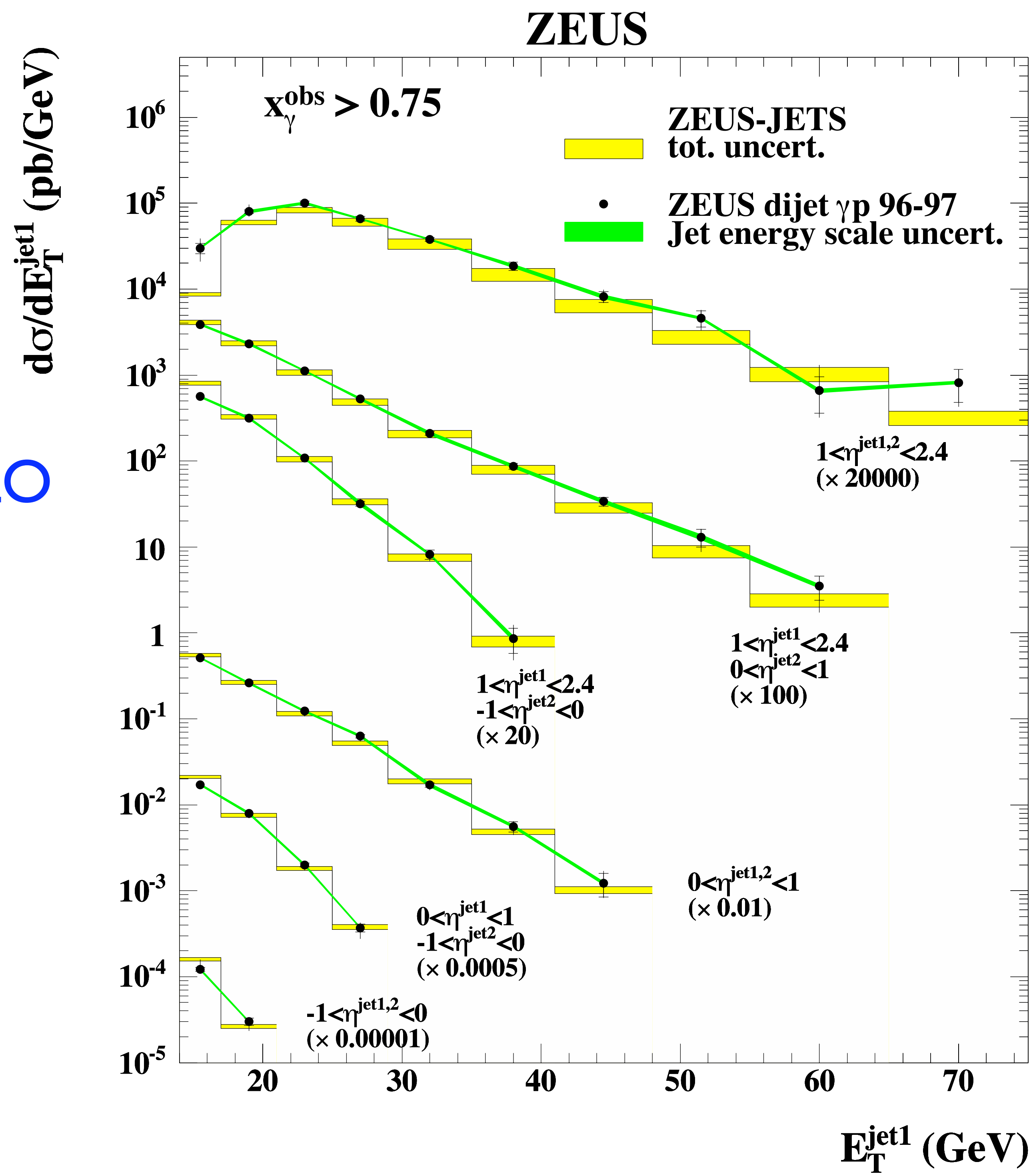
# increased sensitivity to gluons using inclusive ep and jets in QCD analysis

BGF

Boson Gluon Fusion

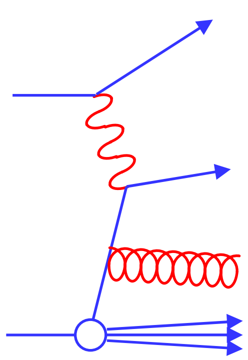


di-jets in photoproduction

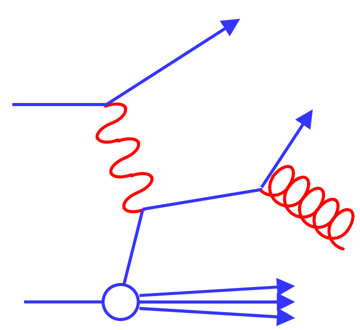



jets sensitive to gluon distribution in LO

in BGF full correlation with $\alpha_s$ ,
different in QCD-Compton graphs



QCDC



# Recent fits by H1 and ZEUS

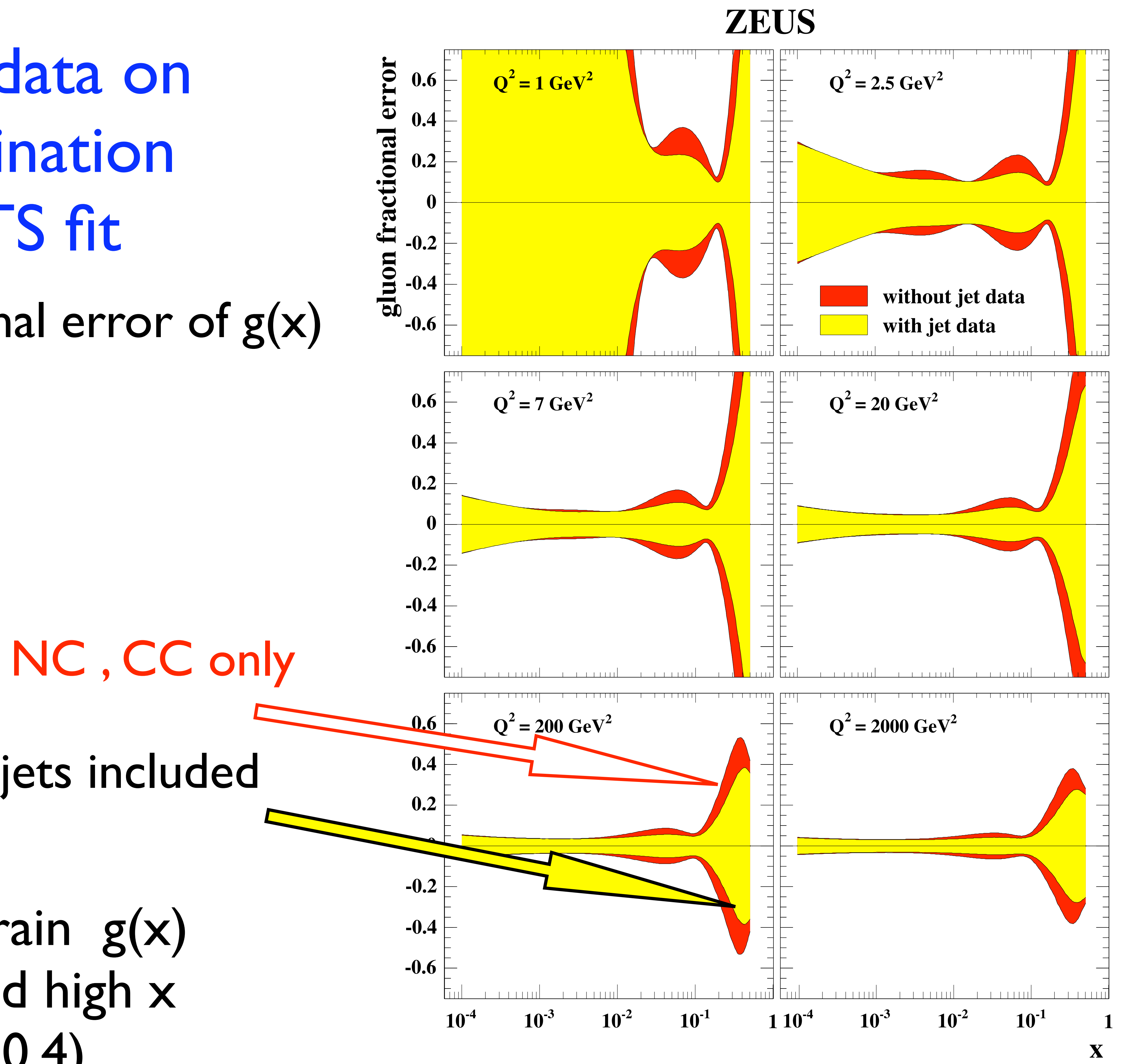
procedure :
- parametrisation of pdfs at starting scale $Q_0^2$
- $Q^2$ dependence by DGLAP pQCD evolution in NLO
- pdf parameters at $Q_0^2$ determined by fits to $\sigma_{red}$ at $Q^2 > Q^2_{min}$

main differences in :
- used data
- parametrisations at $Q_0^2$
- treatment of heavy quarks
- treatment of systematics

| | H1 PDF 1997 Eur.Phys. J C21 (2001) | H1 PDF 2000 Eur.Phys. J C30 (2003) | ZEUS-S Phys.Rev.D67 (2003) | ZEUS-JET Eur.Phys. J C42 (2005) |
|---|---|---|---|---|
| other experiments used | BCDMS $(\mu p)$ | $(\mu p, \mu d)$ | BCDMS, NMC, E665, CCFR $(\mu p,\ \mu d)$ $(\nu Fe)$ | – (but jets) |
| fittted distributions | ep valence and sea terms | $u+c,\ \bar{u}+\bar{c}$ $d+s,\ \bar{d}+\bar{s},\ g$ | $u_v,\ d_v$ $S,\ \bar{d}-\bar{u},\ g$ | $u_v,\ d_v$ $S,\ \bar{d}-\bar{u},\ g$ |
| $Q_0^2$ $Q^2_{min}$ | 4 3.5 | 4 3.5 | 7 2.5 | 7 2.5 |
| main aim | $\alpha_s$ $g(x)$ | pdfs | pdfs $\alpha_s$ | pdfs $\alpha_s$ |

# Impact of jet data on gluon determination in ZEUS-JETS fit

fractional error of g(x)




jet data constrain g(x) at medium and high x (0.01 to 0.4)

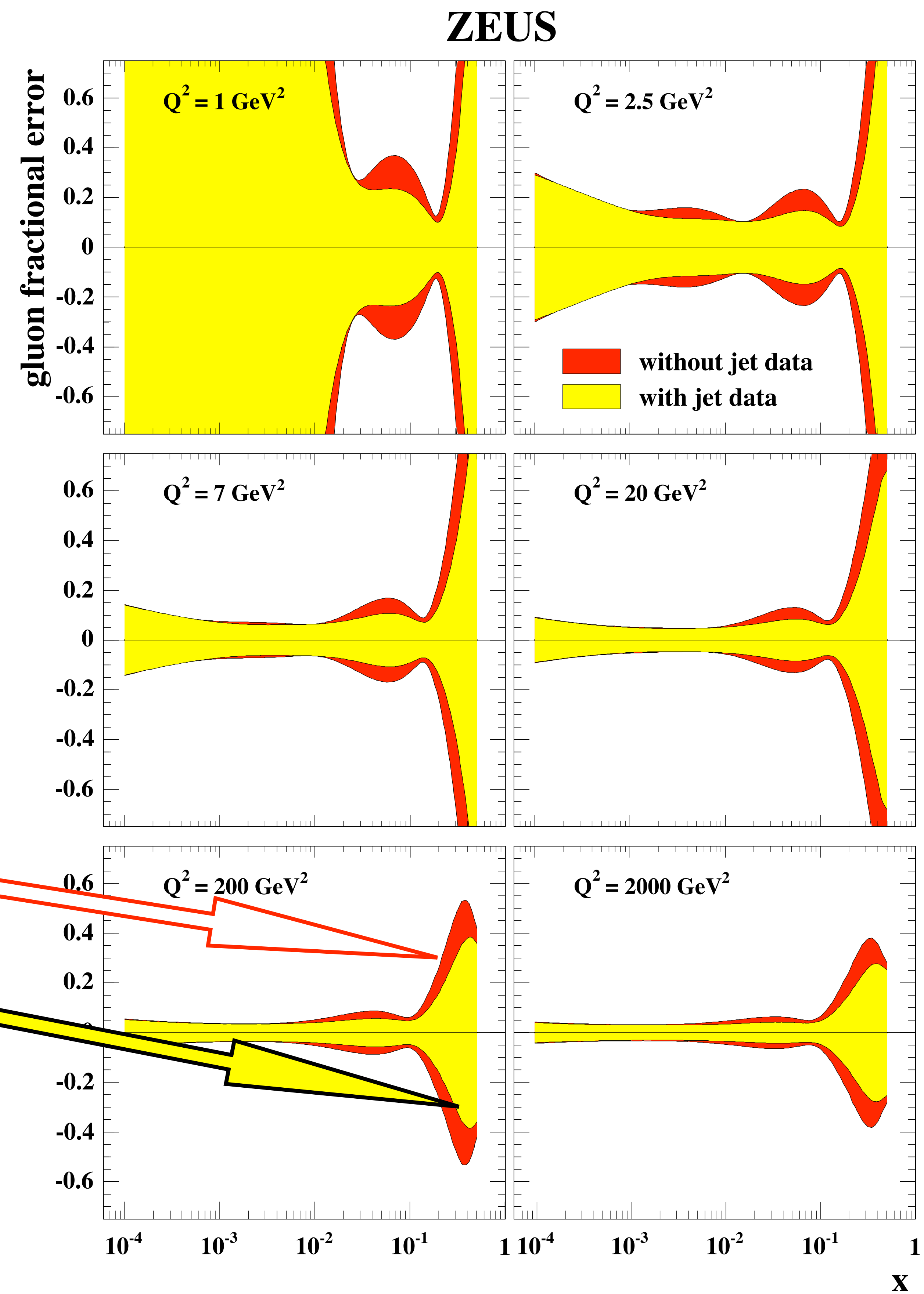
# Impact of jet data on gluon determination in ZEUS-JETS fit

fractional error of g(x)

lively progress

NC , CC only

jets included




jet data constrain g(x) at medium and high x (0.01 to 0.4)

# Comparison

## ZEUS-JET fit
## H1 pdf 2000

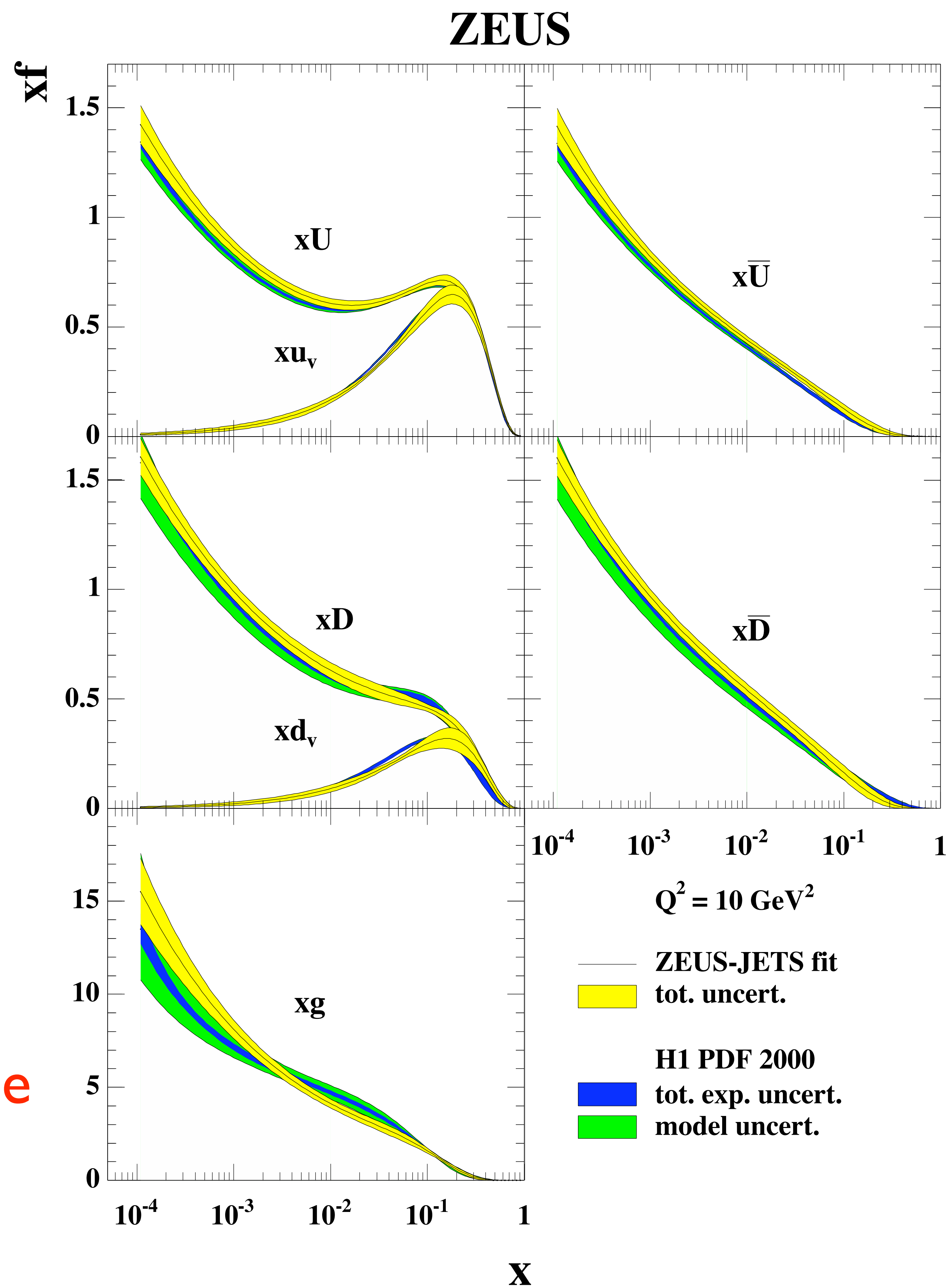
$$U = u + c$$

$$\bar{U} = \bar{u} + \bar{c}$$

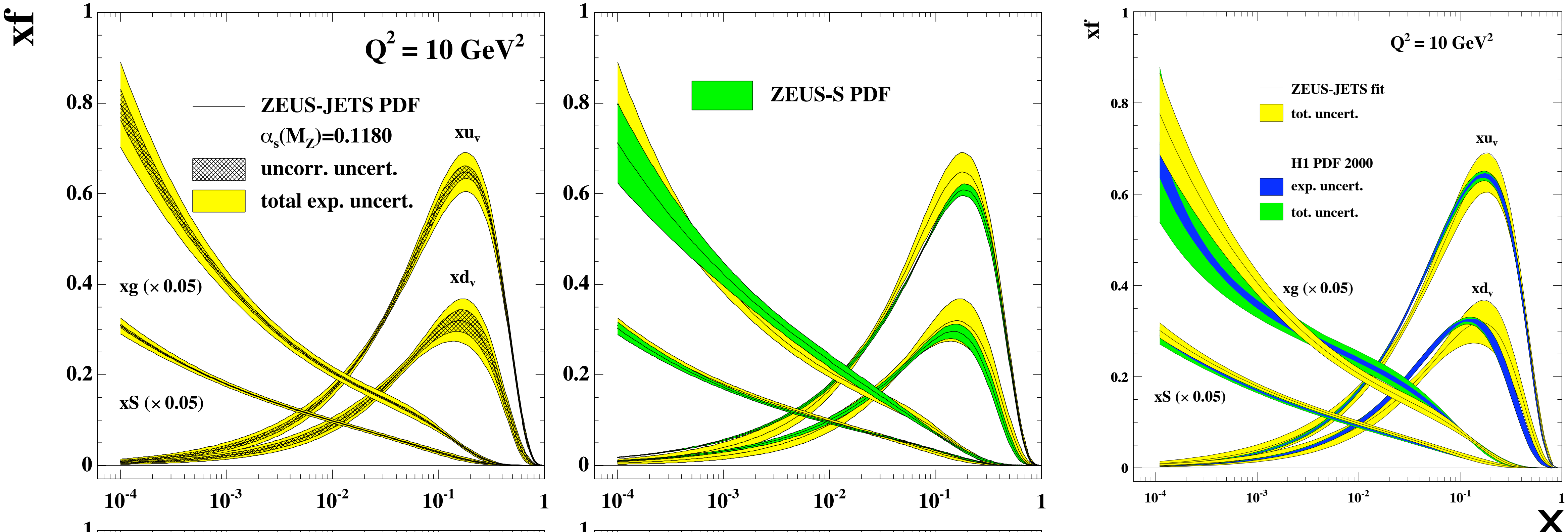
$$D = d + s$$

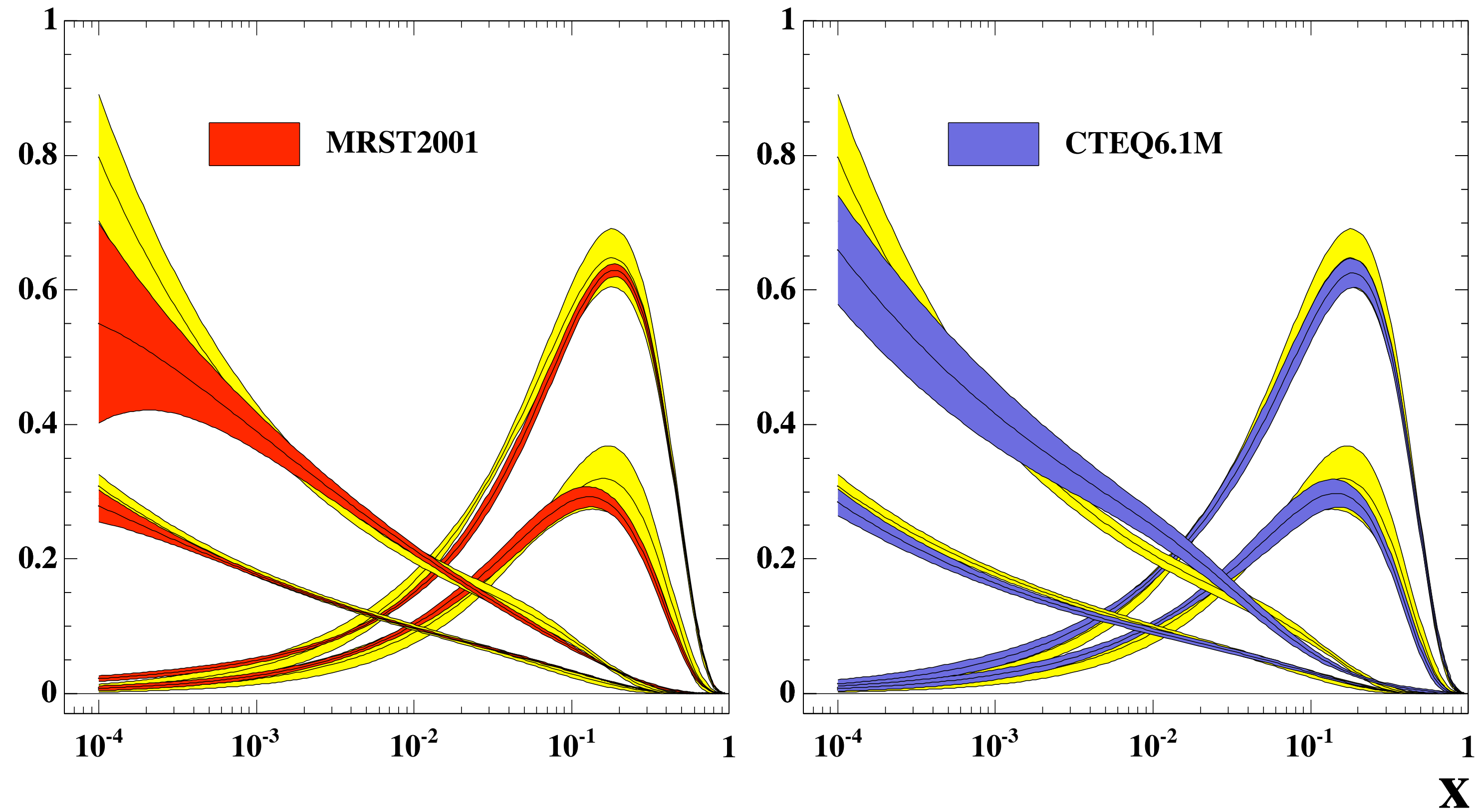
$$\bar{D} = \bar{d} + \bar{s}$$

- results consistent
- differences in gluon visible



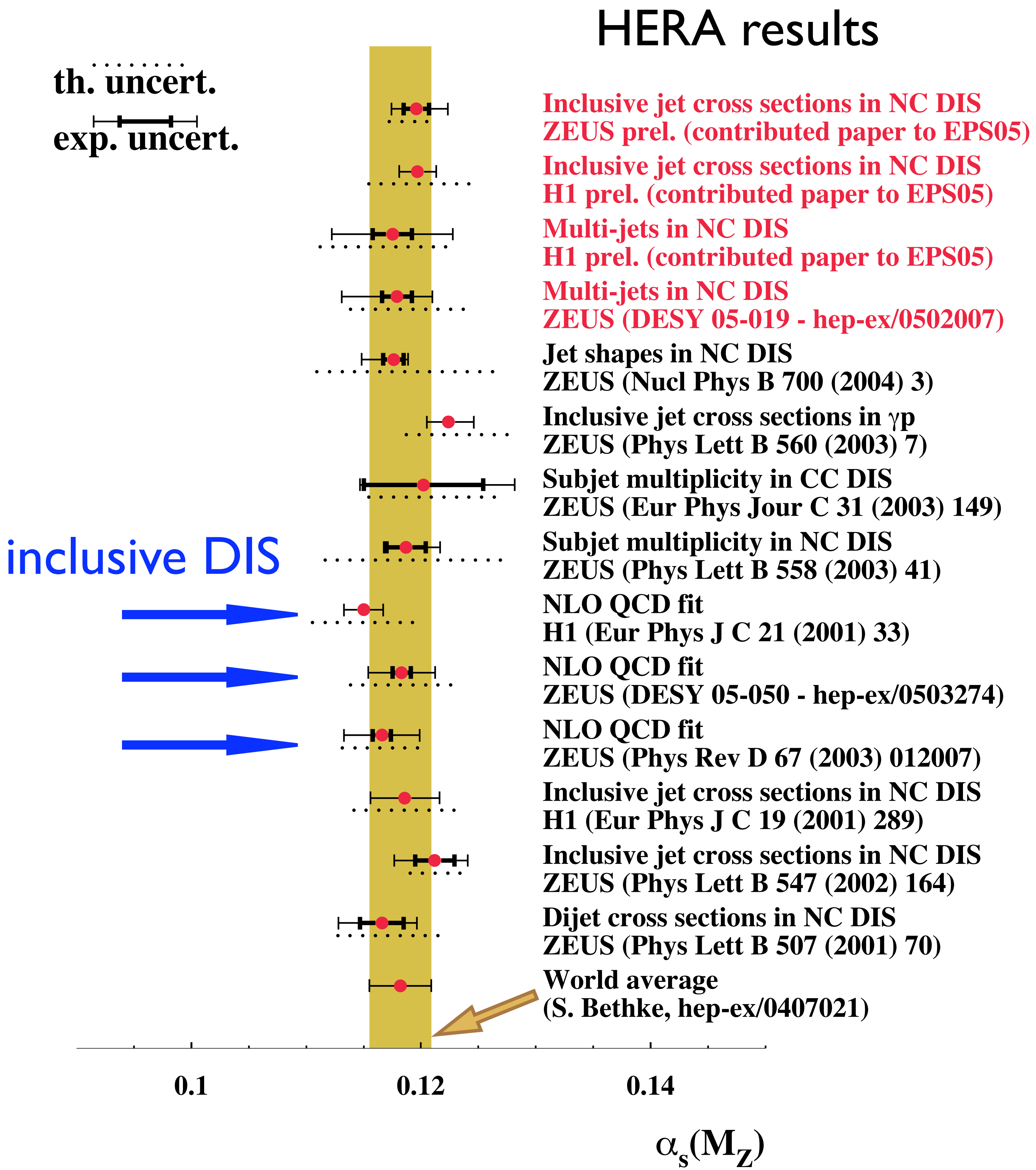
# Comparison of ZEUS-JETS with H1 pdf 2000 and global fitters




- results consistent within uncertainties
- g(x) at x ≈ 0.01 lower in ZEUS-JETS
- valence u,d higher

# $\alpha_s$




results of
inclusive DIS pdf fits
(with $\alpha_s(M_Z)$ as free parameter)
consistent with
final state analyses
and world average

- exp. precision calls for NNLO analysis
- calculations exist
  (Moch, Vermaseren, Vogt)

# treatment of charm and beauty

substantial measured

charm and beauty fractions

(see talk of Mark Bell)

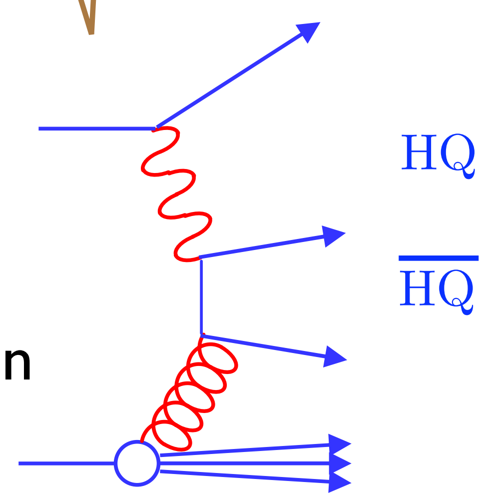
| H1 PDF 1997 | H1 PDF 2000 | ZEUS-S, -JET |
|---|---|---|
| massive | massless | VFNS |
| weight on low Q2 | on high Q2 $Q^2 >> M^2_{HQ}$ | variable flavour number scheme |

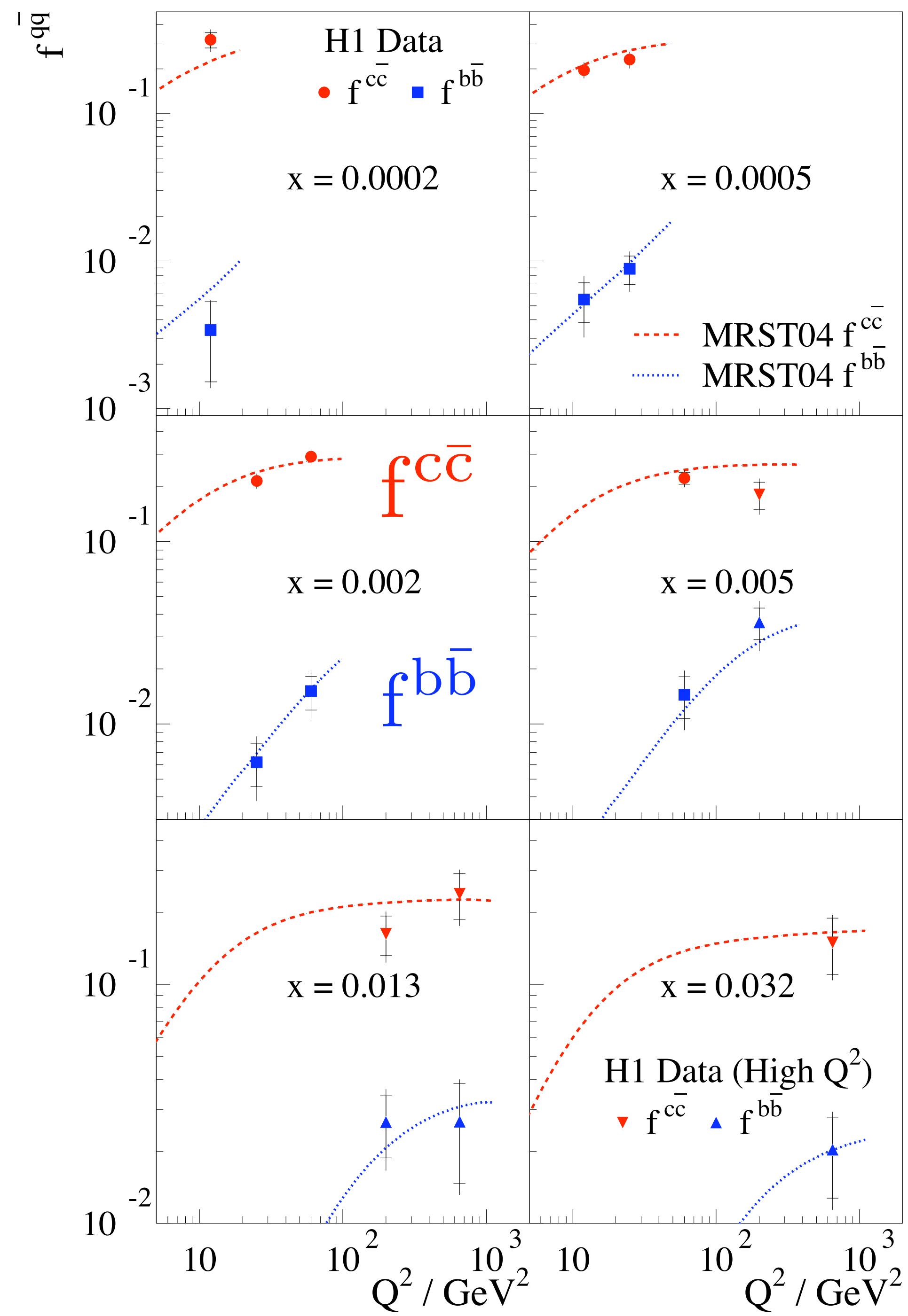
LO

NLO

BGF

Boson Gluon Fusion




$f^{c\bar{c}}$ ~ 20% to 30%

$f^{b\bar{b}}$ ~ 0.3% to 3%

constrain pdfs directly ?

# beyond collinear pdfs

collinear pdfs contain no information on
parton transverse momenta, parton correlations, proton spin...

GPDs (generalised parton densities, non-integrated pdfs)
are deduced from final state data (and the collinear pdfs)

many final states discussed with non-integrated pdfs

see talks of

jets, in particular forward jets — Didar Dobur, Mark Sutton
prompt photons (most recently by Lipatov, Zotov)

vector mesons $\rho ... J/\psi ....Y$ DVCS — Niklaus Berger

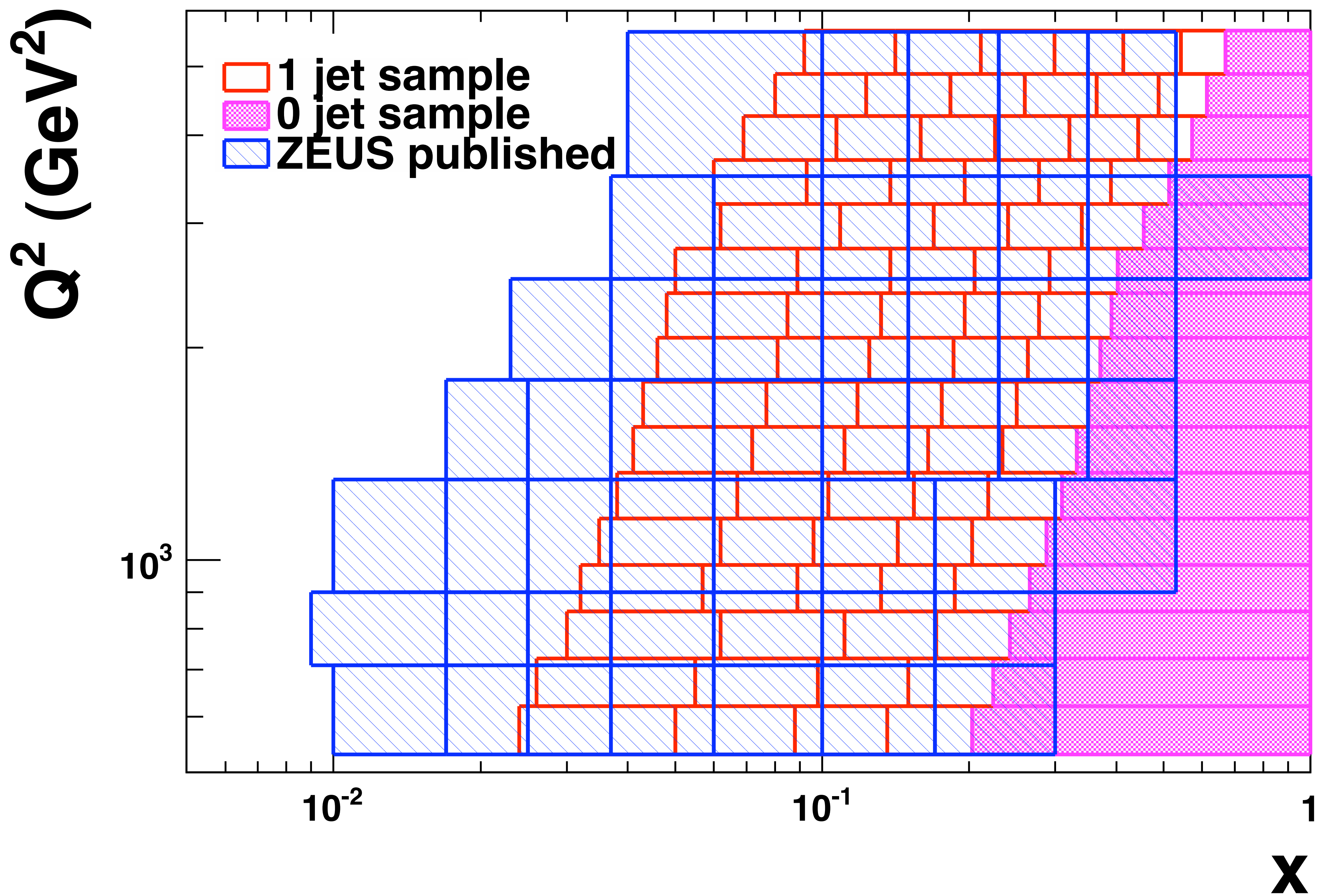
open charm, beauty — Mark Bell

Diffractive processes ⟹ "diffractive pdfs" — Vitaly Dodonov

# Conclusion and Outlook

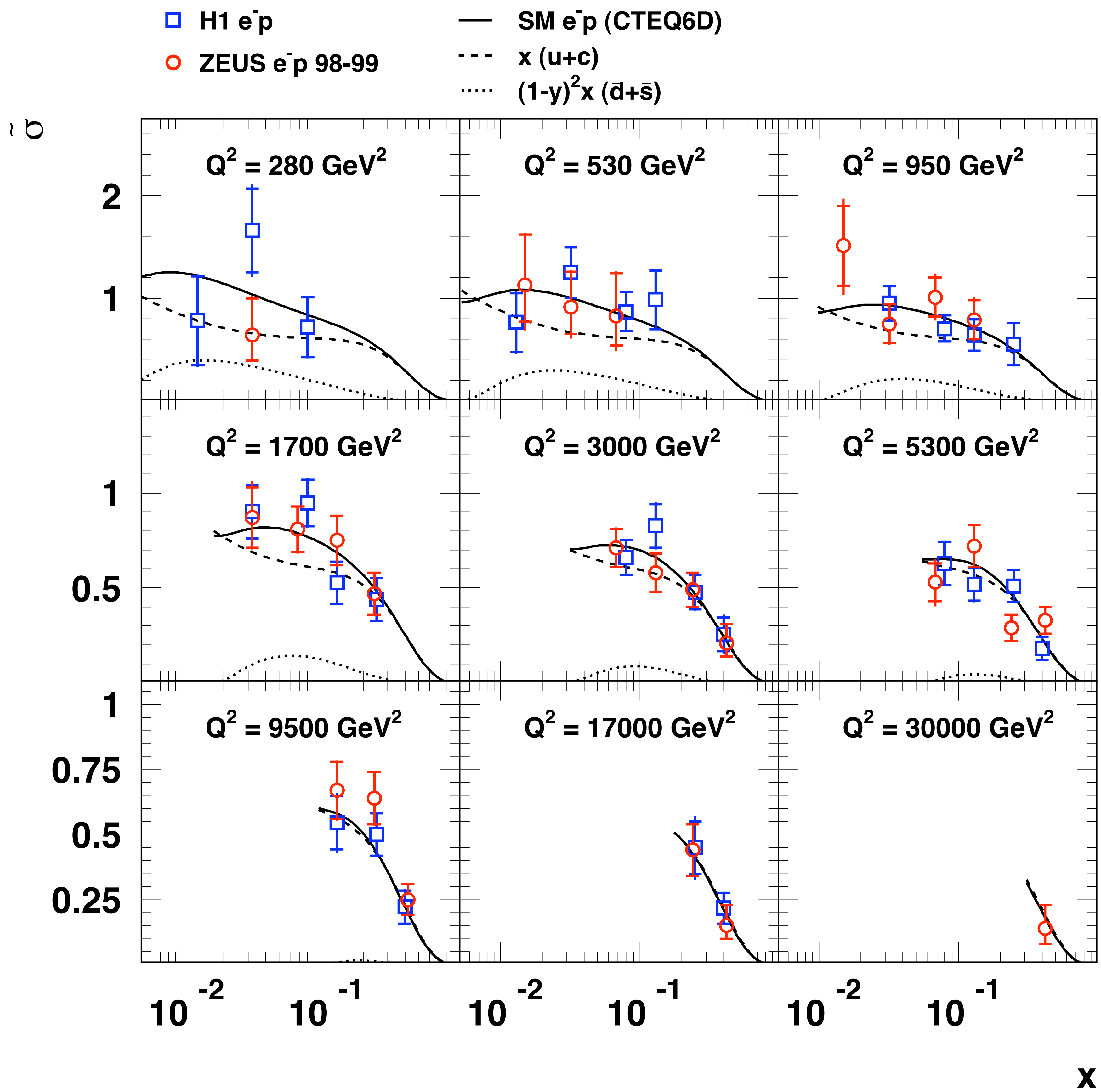
- Beautiful inclusive HERA I data available over 4 orders of magitude in x and $Q^2$
- pdf determinations are improving
  - + controlled systematics
  - + inclusion of ep jet data improves gluon determination
  - + still more HERA I NC data will be finalised
- $\alpha_s$ and pdf precision will improve with NNLO analyses
- HERA II will strongly improve precision at high $Q^2$ and provides polarised cross sections

# more stuff

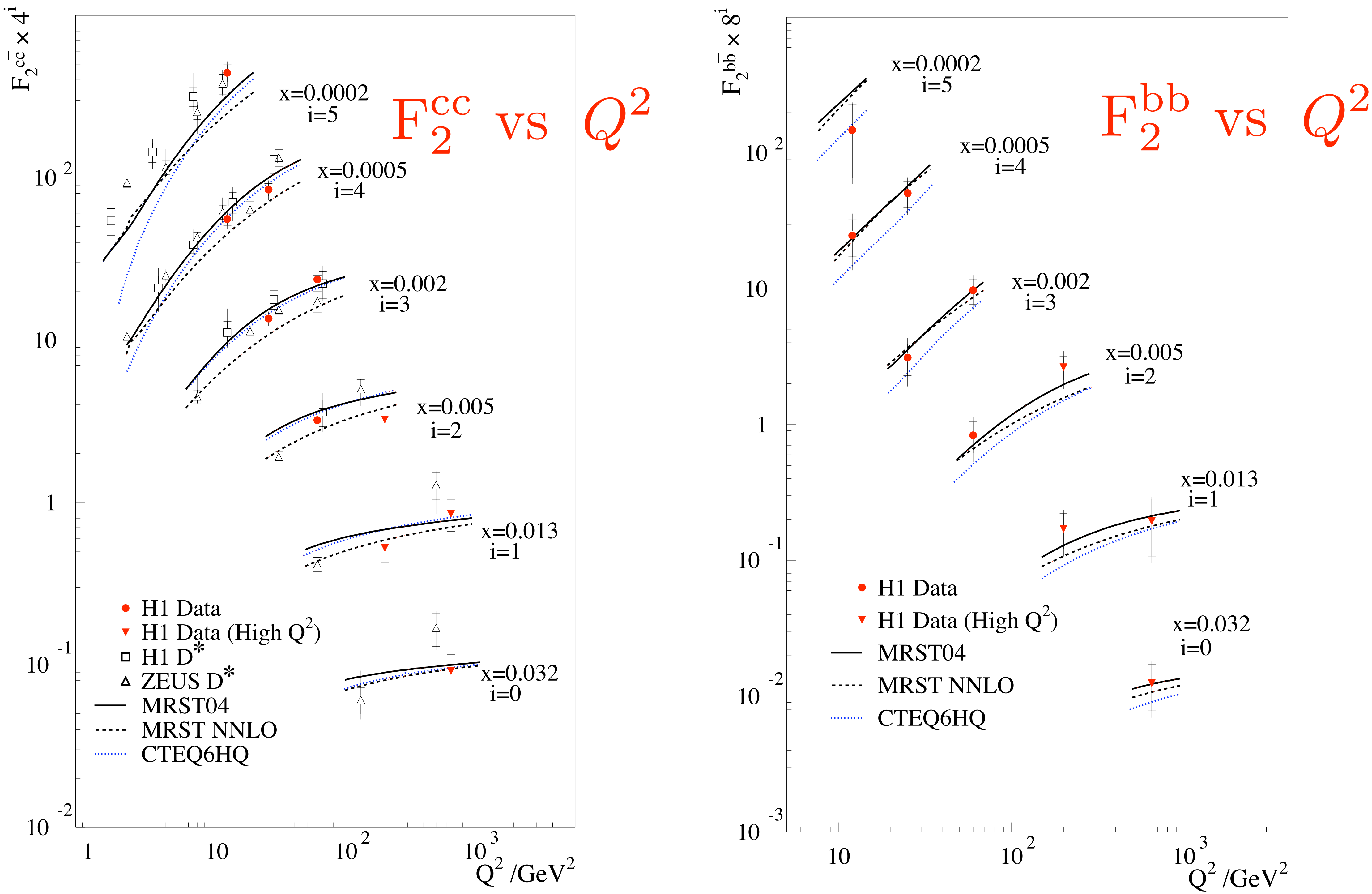


1 jet sample
0 jet sample
ZEUS published
Q² (GeV²)
10³
10⁻²
10⁻¹
1
x

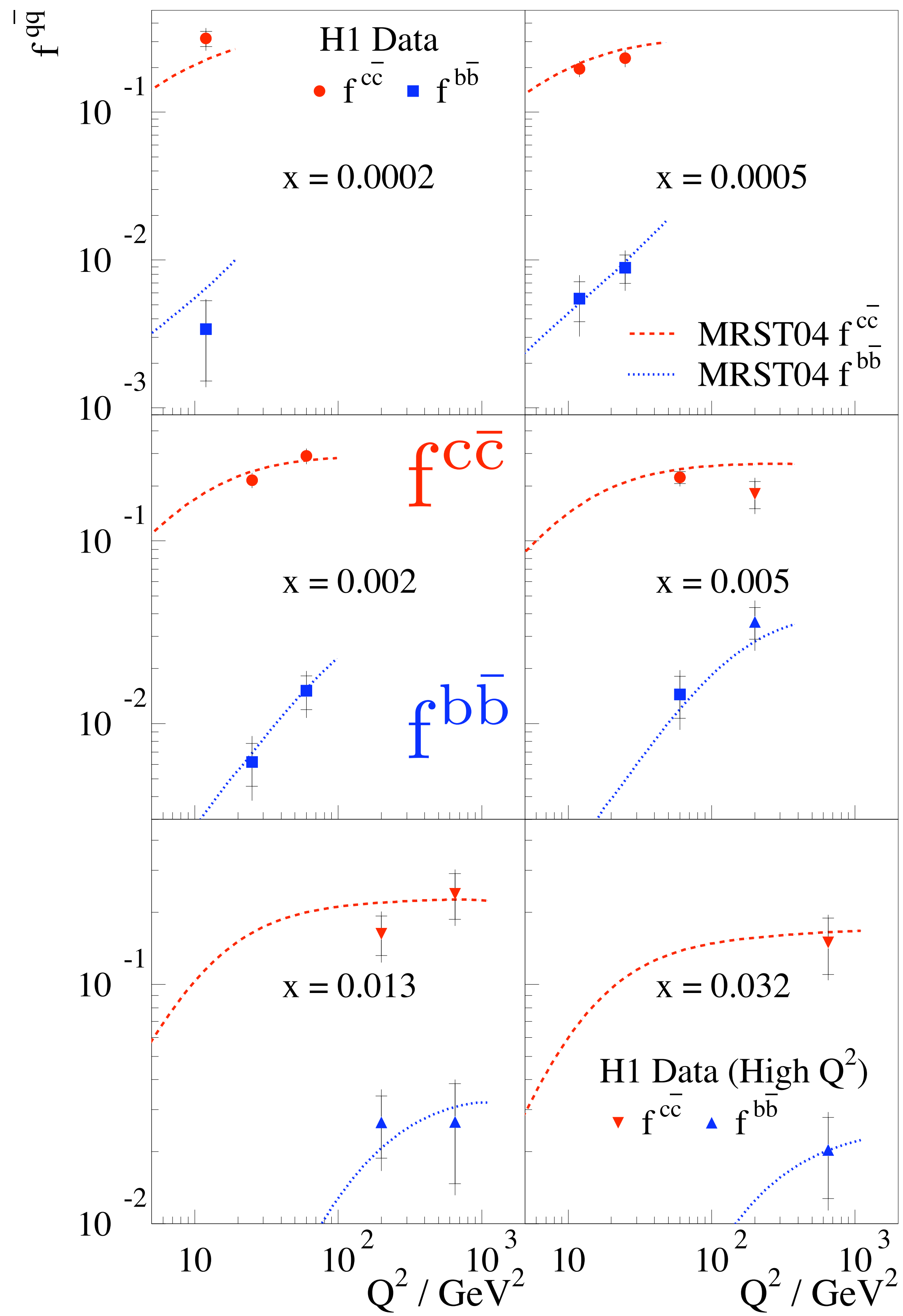
# HERA $e^-p$ Charged Current



# heavy quark piece in $F_2$




- strong scaling violations (charm and beauty)
- substantial spread of theoretical predictions



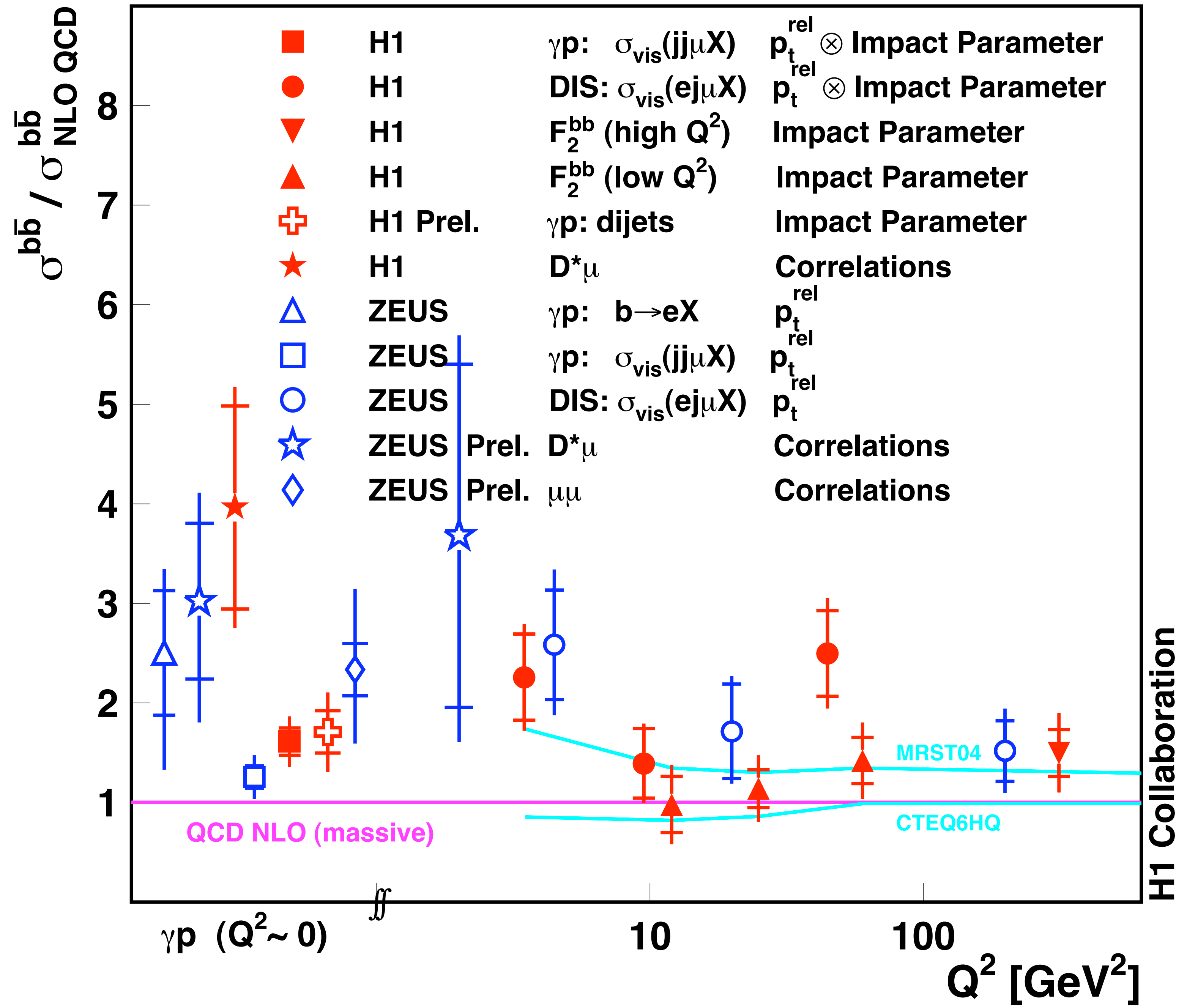

# charm and beauty fractions of cross section

$f^{c\bar{c}}$ ~ 20% to 30%

$f^{b\bar{b}}$ ~ 0.3% to 3%

in covered range

fractions well described by MRST04



H1 γp: σvis(jjμX) ptrel ⊗ Impact Parameter
H1 DIS: σvis(ejμX) ptrel ⊗ Impact Parameter
H1 F2bb (high Q2) Impact Parameter
H1 F2bb (low Q2) Impact Parameter
H1 Prel. γp: dijets Impact Parameter
H1 D*μ Correlations
ZEUS γp: b→eX ptrel
ZEUS γp: σvis(jjμX) ptrel
ZEUS DIS: σvis(ejμX) ptrel
ZEUS Prel. D*μ Correlations
ZEUS Prel. μμ Correlations
MRST04
CTEQ6HQ
QCD NLO (massive)
H1 Collaboration
γp (Q2~ 0)
10
100
Q2 [GeV2]
1
2
3
4
5
6
7
8