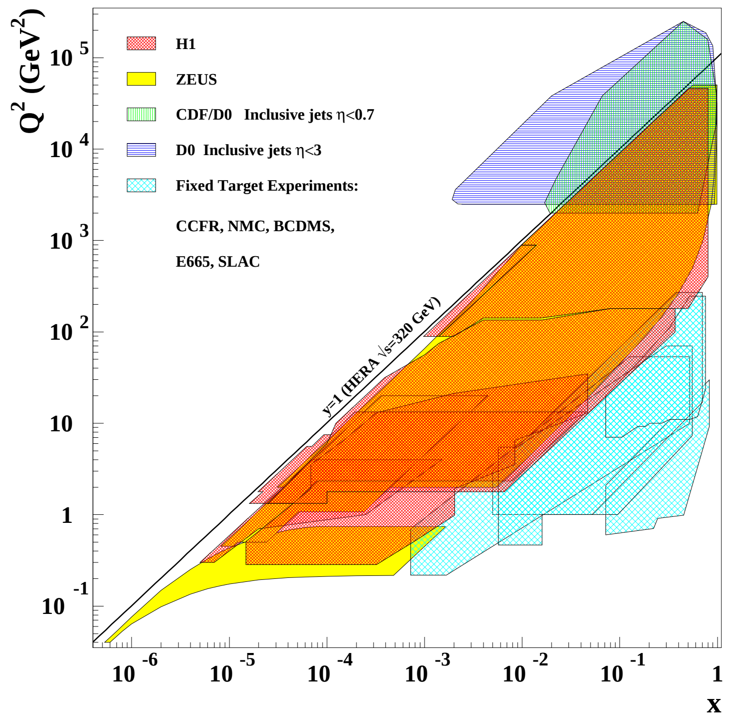
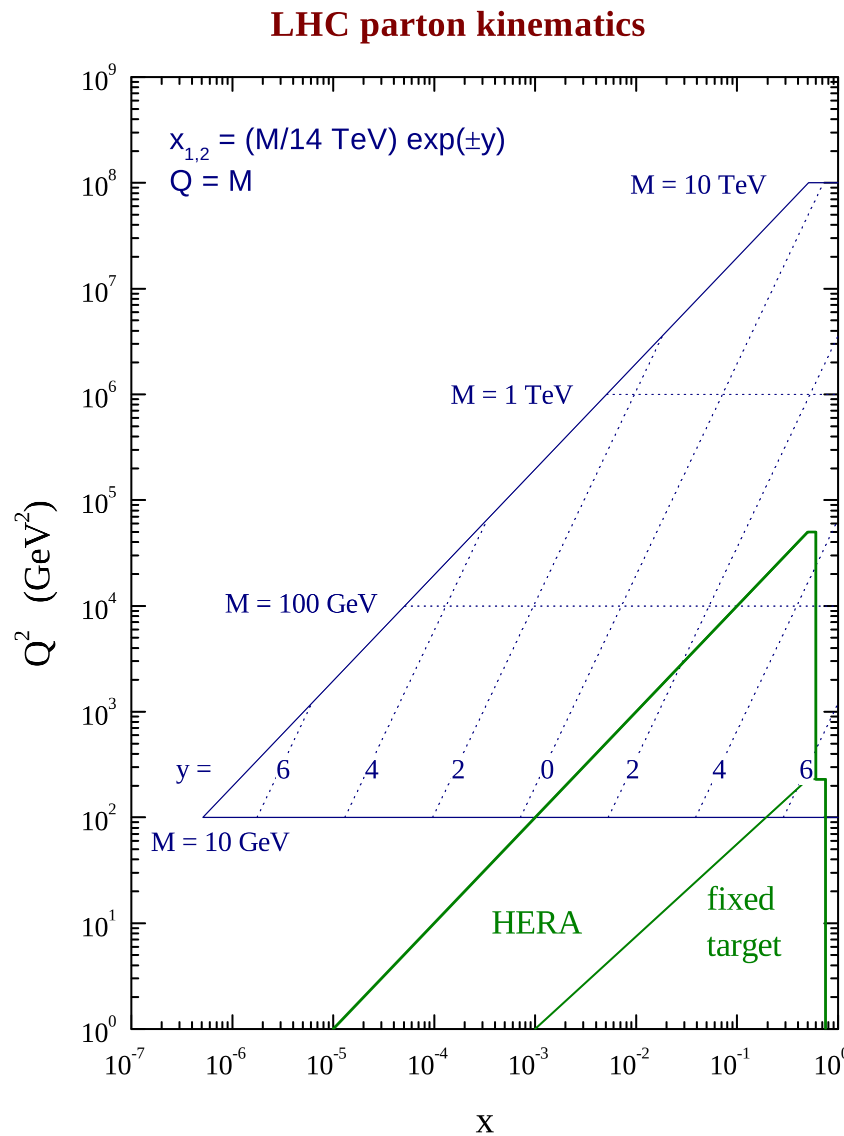
PDFs from H1 at HERA

Vladimir Chekelian (*MPI for Physics, Munich*)

Kinematic Reach at HERA and the LHC
NC and CC at HERA I and HERA II
NLO QCD fits
Gluon and strong coupling α_s
Charm & beauty & jets
F_L
PDFs, extrapolation to the LHC
Prospects for large x
If eD: $x(\bar{d}-\bar{u})$, d_v/u_v
Conclusion

Kinematic Reach at HERA and the LHC





$Q^2 \geq 1$ GeV^2 QCD *evolution*

$x \to 0$ *saturation (?)*

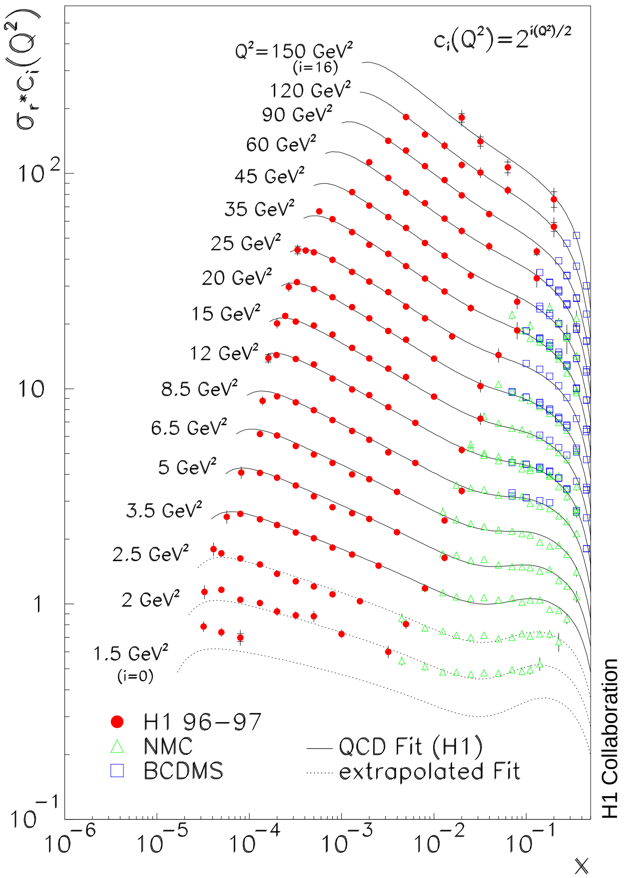
$y \to 1$ *sensitivity to* F_L

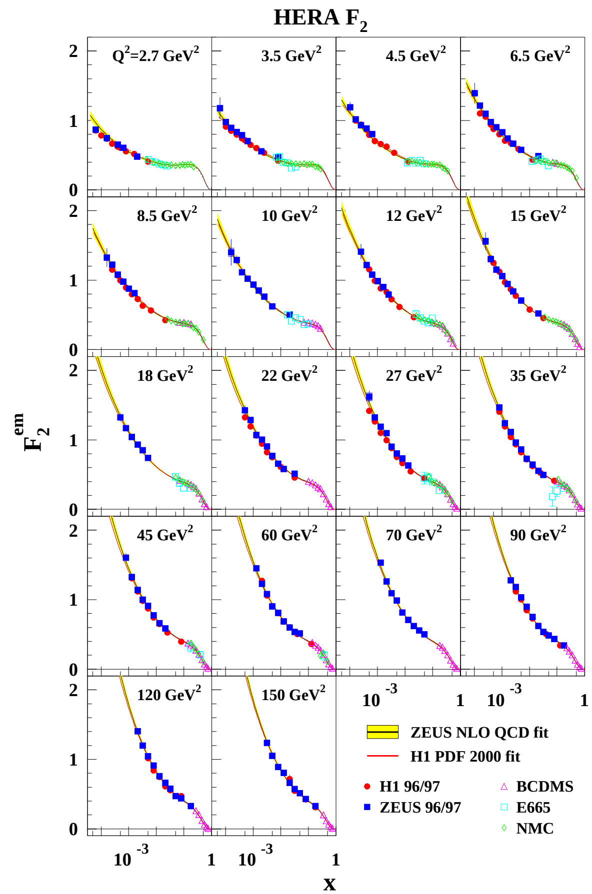
$Q^2 \to s$ *electroweak physics*

$x \to 1$ *probe valence quarks*

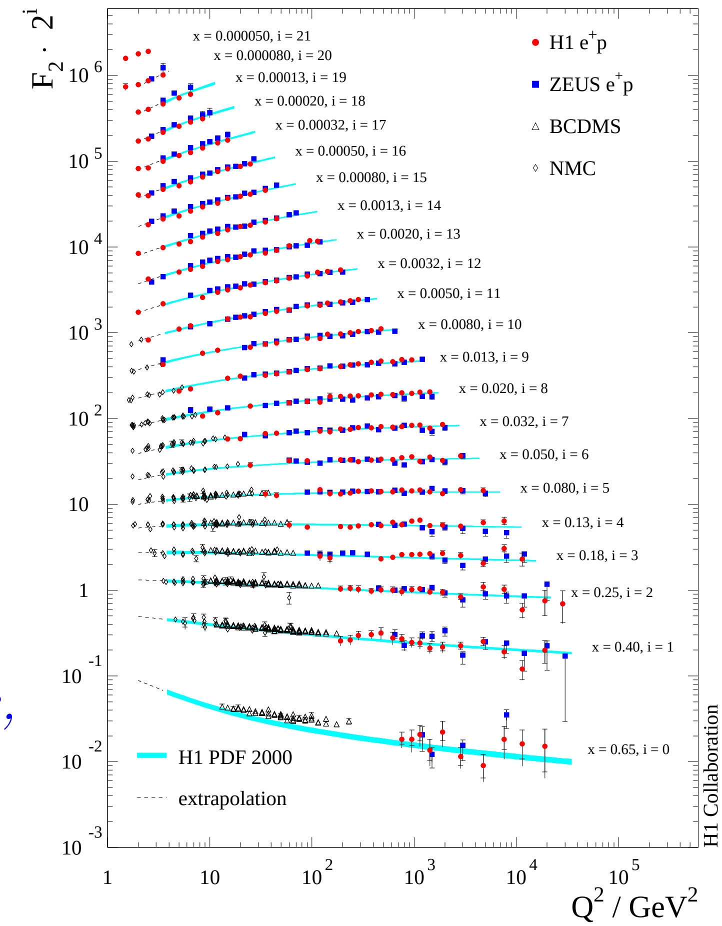
full HERA x range needed for LHC

Inclusive DIS Measurements at HERA I





precision data ±2-3%
5 decades in x
5 decades in Q^2



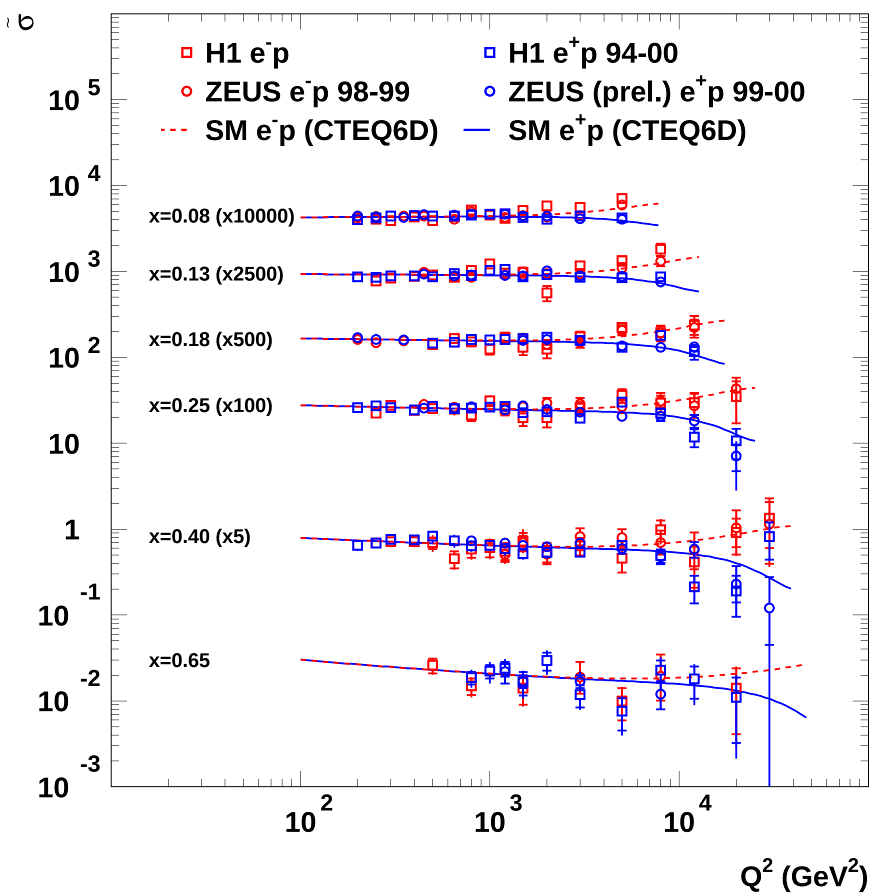
rich possibilities to test QCD, to determine pdfs,
search for saturation effects, ...

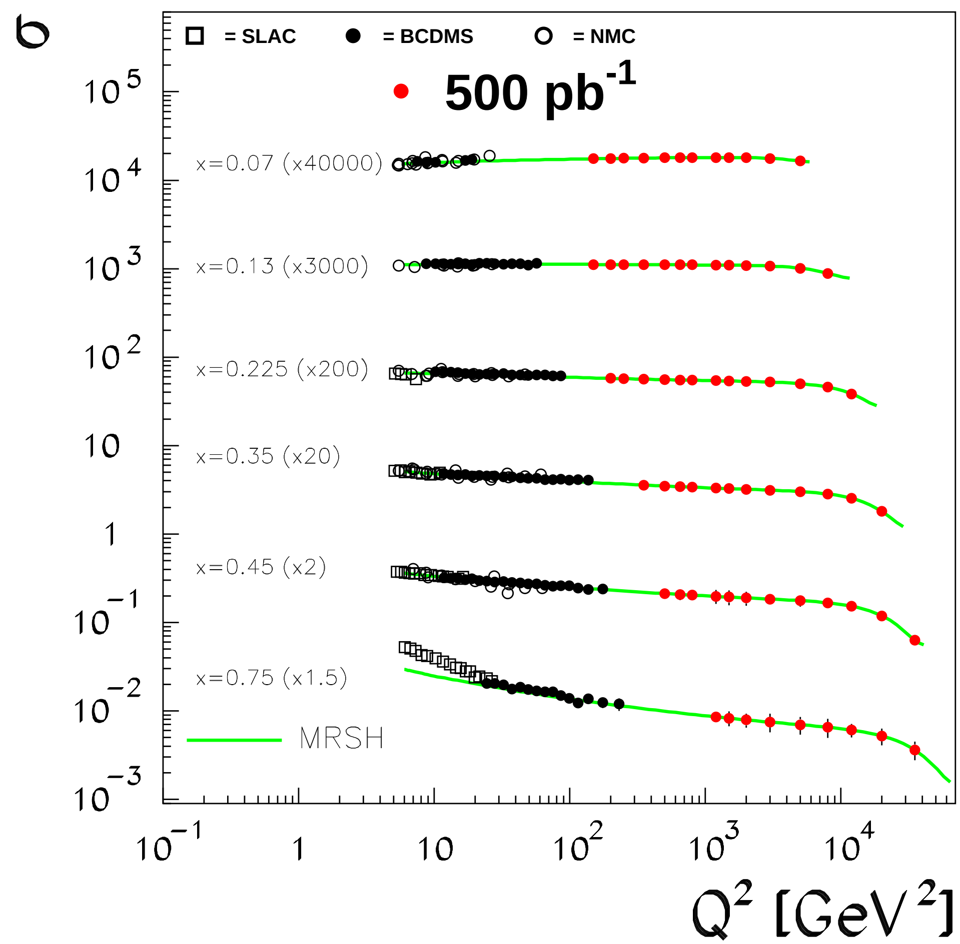
still to come: bulk,svx,mb 1999/2000 ($Q^2 < 150$ GeV^2)

Neutral Currents at Hera I and HERA II

$$\tilde{\sigma}_{NC}^{e^{\pm}p}(x,Q^2) \equiv \frac{1}{Y_+}\,\frac{Q^4\ x}{2\pi\alpha^2}\,\frac{\mathrm{d}^2\sigma_{NC}^{e^{\pm}p}}{\mathrm{d}x\mathrm{d}Q^2} = \tilde{F}_2(x,Q^2) \mp \frac{Y_-}{Y_+} x\tilde{F}_3(x,Q^2) - \frac{y^2}{Y_+}\tilde{F}_L(x,Q^2)$$

HERA Neutral Current at high x

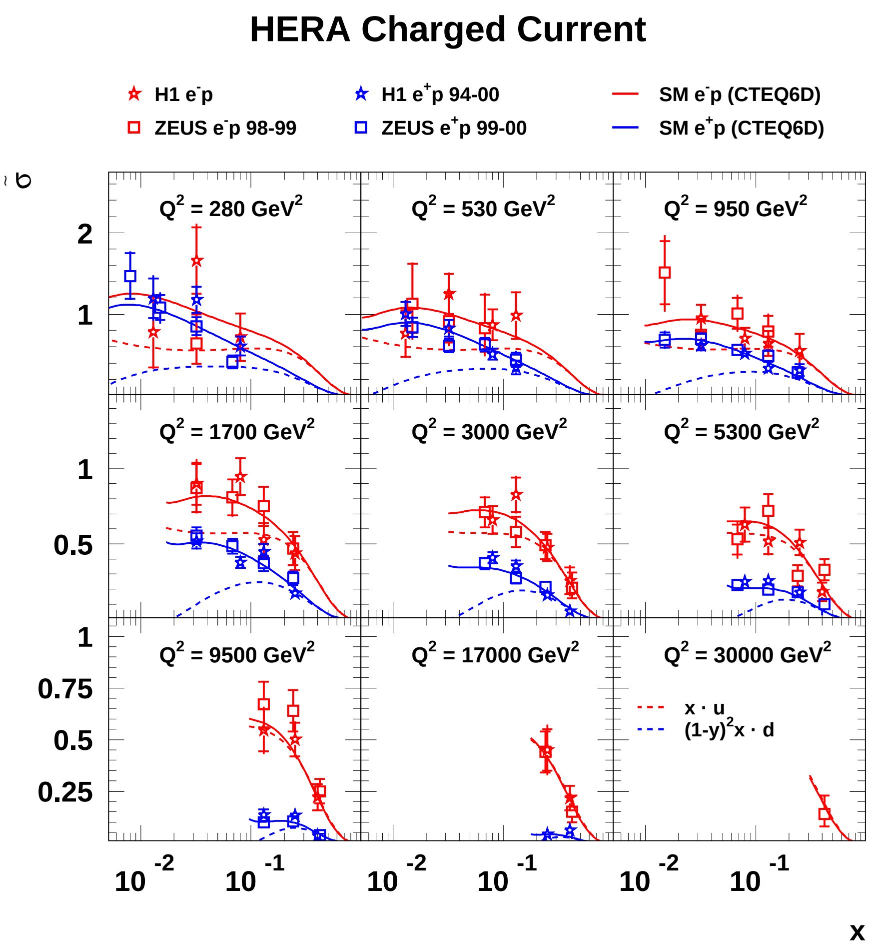


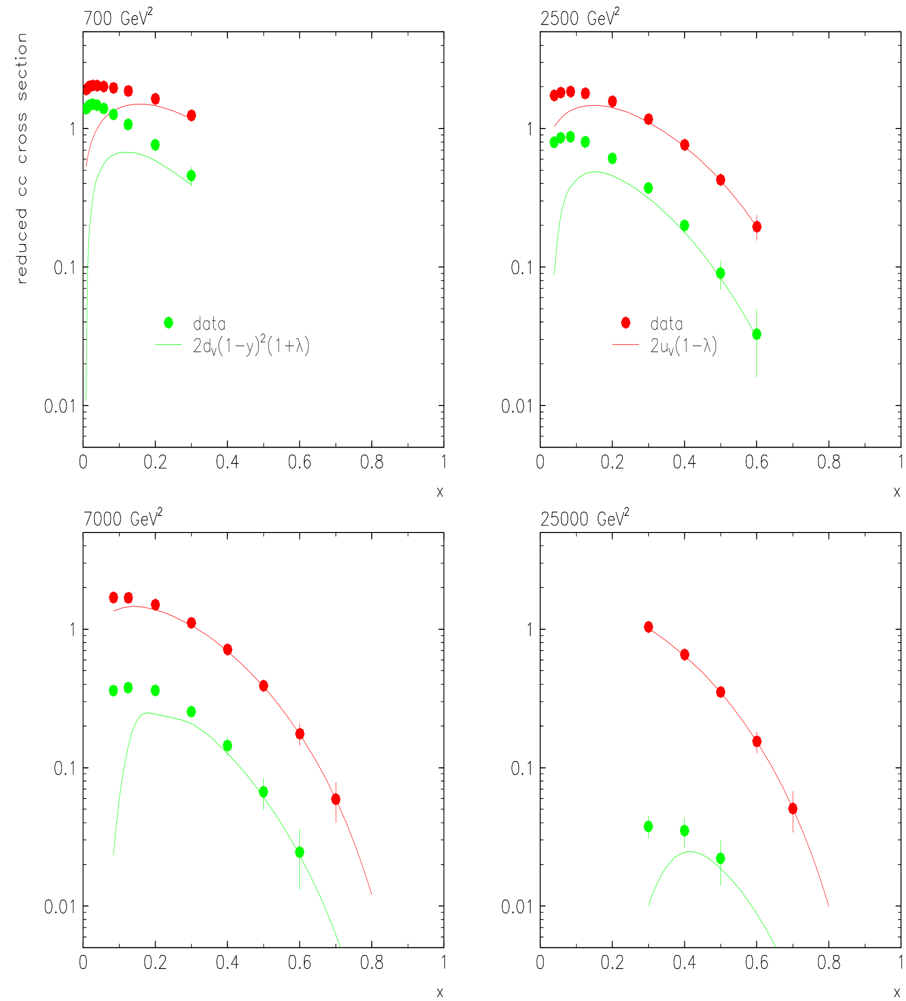


Charged Currents at Hera I and HERA II

in leading order (LO): $\tilde{\sigma}_{CC}(e^+p) = x\left[(\bar{u}+\bar{c}) + (1-y)^2(d+s)\right] \simeq (1-y)^2 x d_v$ **for** $x \to 1$

$$\tilde{\sigma}_{CC}(e^-p) = x\left[(u+c) + (1-y)^2(\bar{d}+\bar{s})\right] \simeq x u_v$$





e^+ **250pb^{-1}**, $\lambda =\ 0.2$ e^- **250pb^{-1}**, $\lambda = -0.5$

The HERA NLO DGLAP QCD Fits

$xg\&\alpha_s$ Fit of H1

$\overline{\mathrm{MS}}$,massive,$F_2 = F_2^{n_f=3} + F_2^{c\bar{c}}$(NLO BGF)

only ep H1 and μp BCDMS ($y_\mu > 0.3$)

$xg, V \approx \frac{9}{4}u_v - \frac{3}{2}d_v, A \approx \bar{u} - \frac{1}{4}(u_v - 2d_v)$

$xP = a_p x^{b_p}(1-x)^{c_p}[1 + d_p\sqrt{x} + e_p x]$

$Q_o^2 = 4$ GeV^2, $3.5 \le Q^2 \le 3000$ GeV^2

momentum sum rule, $\int_0^1 V dx \approx 3$

ZEUS Global Fit

$\overline{\mathrm{MS}}$, VFNS (Thorne, Roberts)

ZEUS, NMC, E665, BCDMS, CCFR

$xg, xu_v, xd_v, xS, x\Delta(norm)$

$xP = a_p x^{b_p}(1-x)^{c_p}[1 + e_p x]$

$Q_o^2 = 7$ GeV^2, $2.5 \le Q^2 \le 30000$ GeV^2

mom. sum rule, $\int_0^1 (u_v + d_v)dx = 3$

shape of $x\Delta = x(\bar{d} - \bar{u})$ from MRST

$b_{u_v} = b_{d_v} = 0.5$

H1 PDF 2000

$\overline{\mathrm{MS}}$, massless, H1 data only (NC/CC), $xu_v = x(U - \bar{U}), xd_v = x(D - \bar{D})$

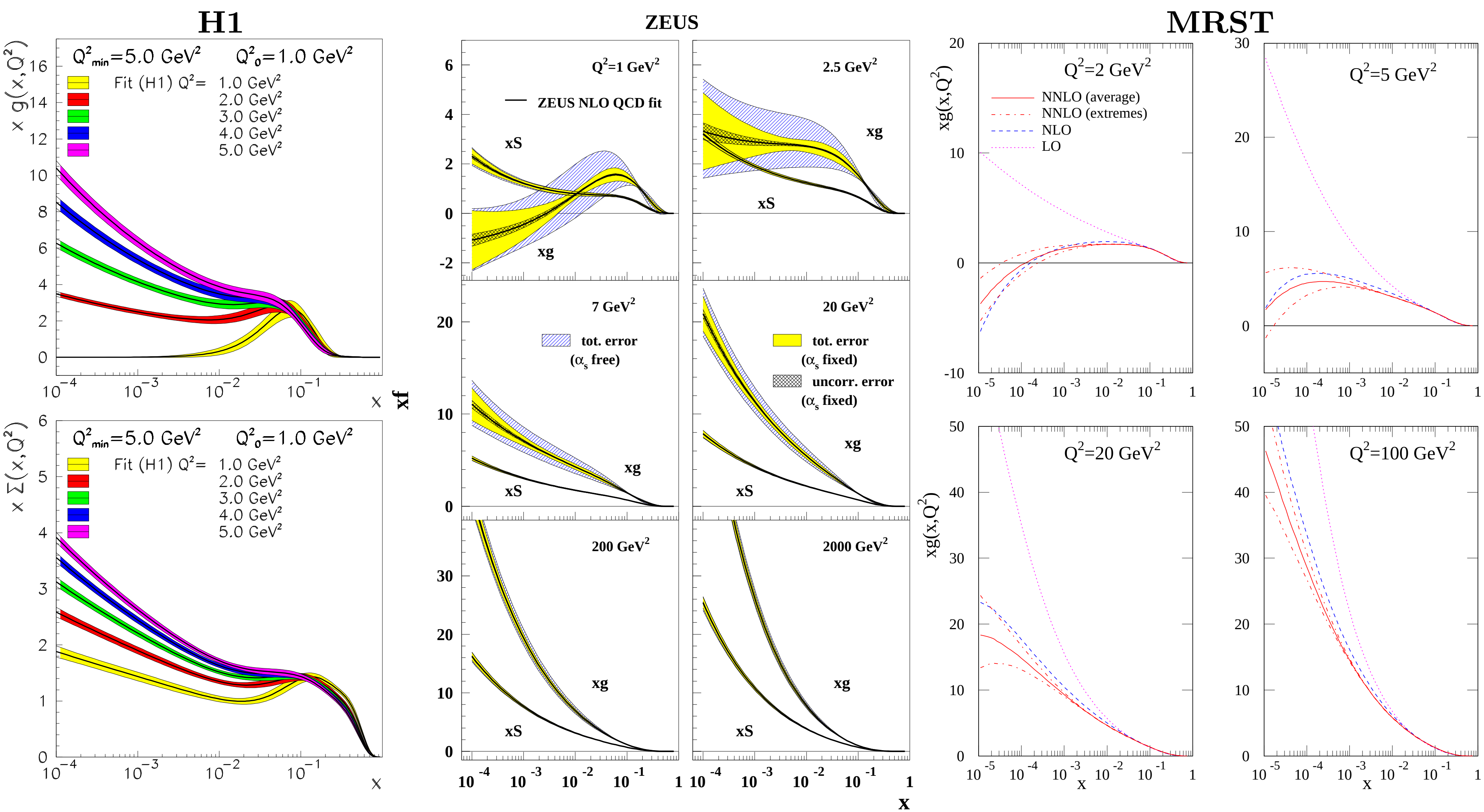
$xg(x) = A_g x^{B_b}(1-x)^{C_g}[1 + D_g x]$, $x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}$, $x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}$

$xU(x) = A_U x^{B_U}(1-x)^{C_U}[1 + D_U x + F_U x^3]$, $xD(x) = A_D x^{B_D}(1-x)^{C_D}[1 + D_D x]$

$B_U = B_D = B_{\bar{U}} = B_{\bar{D}}$, $A_{\bar{U}} = A_{\bar{D}}(1 - f_s)/(1 - f_c)$ i.e. $\bar{d}/\bar{u} \to 1$ as $x \to 0$

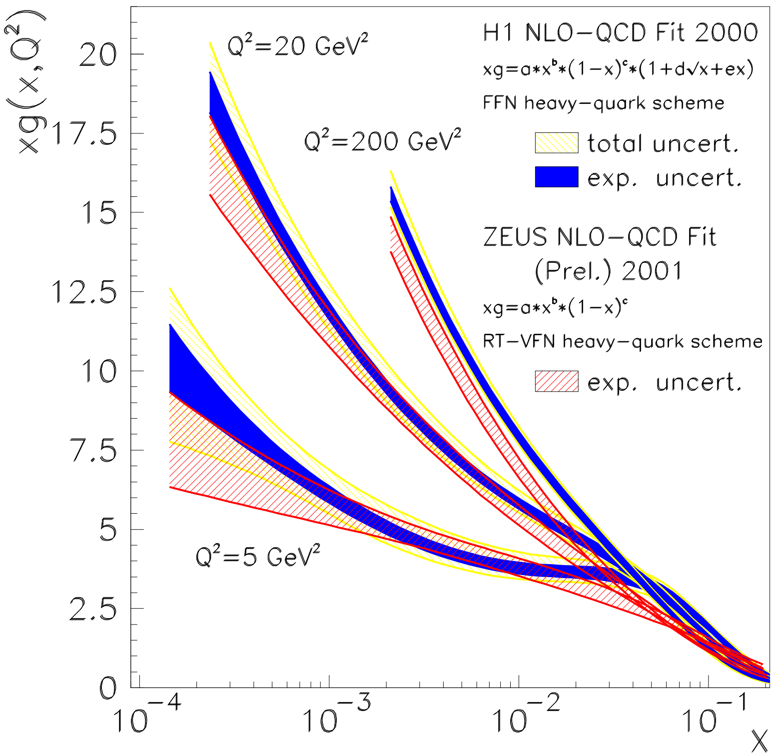
$Q_o^2 = 4$ GeV^2, $Q^2 \ge 3.5$ GeV^2, mom. sum rule, $\int_0^1 (u_v + d_v)dx = 3$

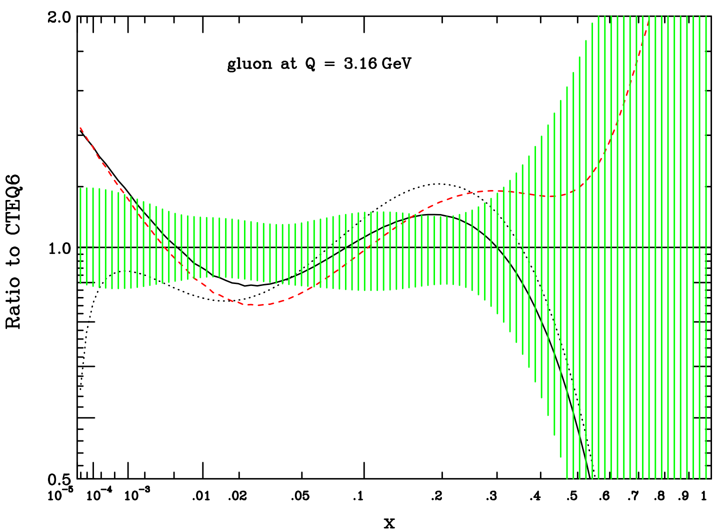
Gluon and Sea

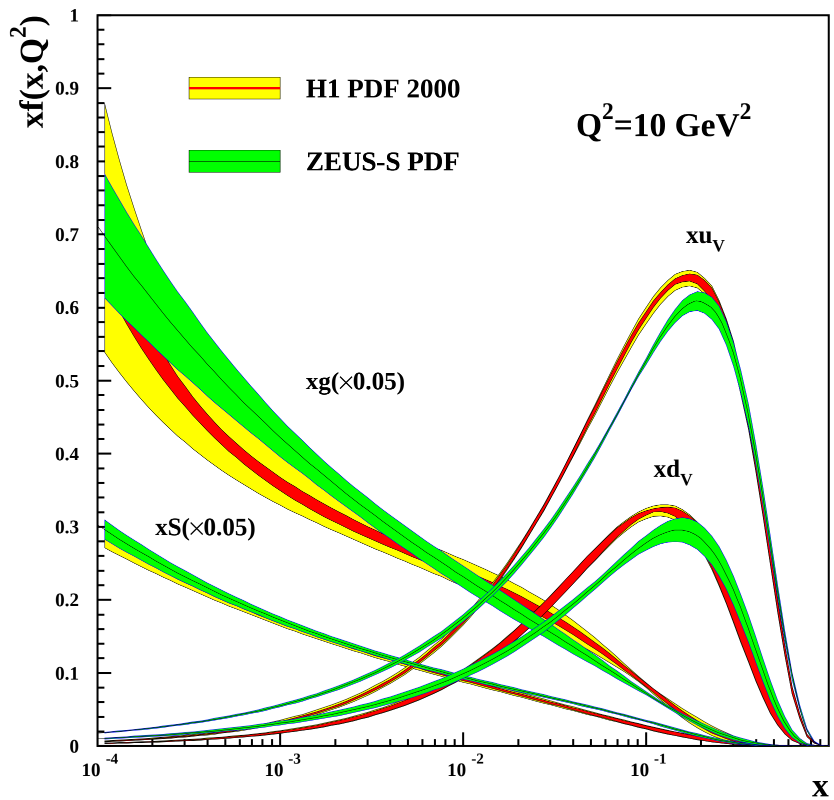


- *rise of the sea (driven by gluon) towards low x*
- *rise of gluon towards low x for $Q^2 > 2 - 3$ GeV^2* - *similar to F_2, $(\partial F_2/\partial \ln Q^2)_x$*
- *flat or even negative gluon at smallest Q^2*

Gluon



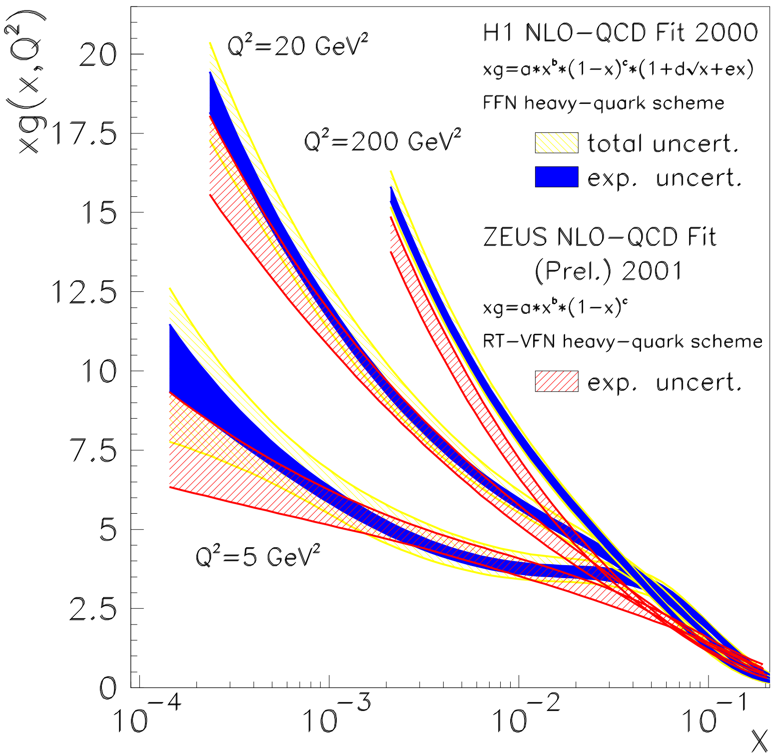


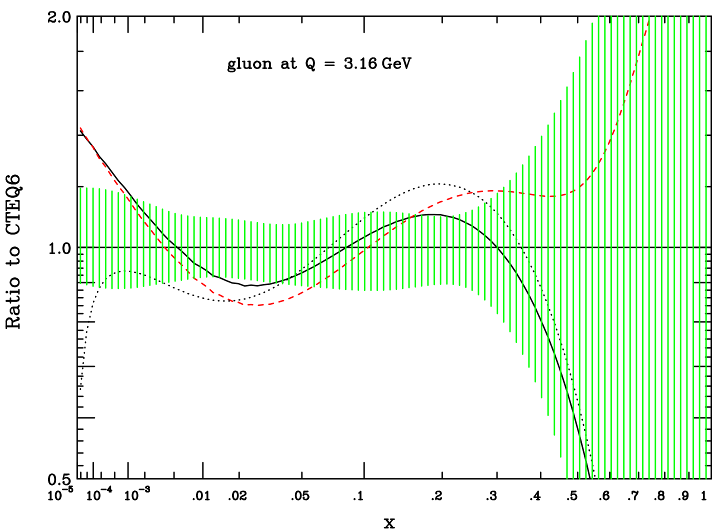


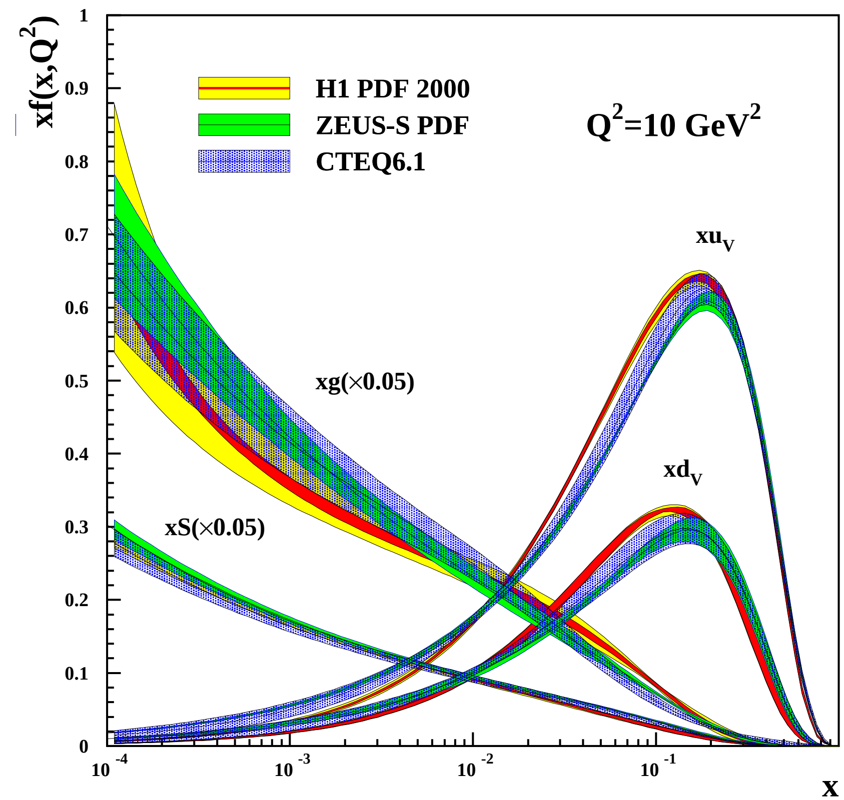
Remaining uncertainties of PDFs:

- *different assumptions*
- *parametric forms of PDFs*
- *missing pieces in theory*
- *consistency of data sets*

Gluon







Remaining uncertainties of PDFs:

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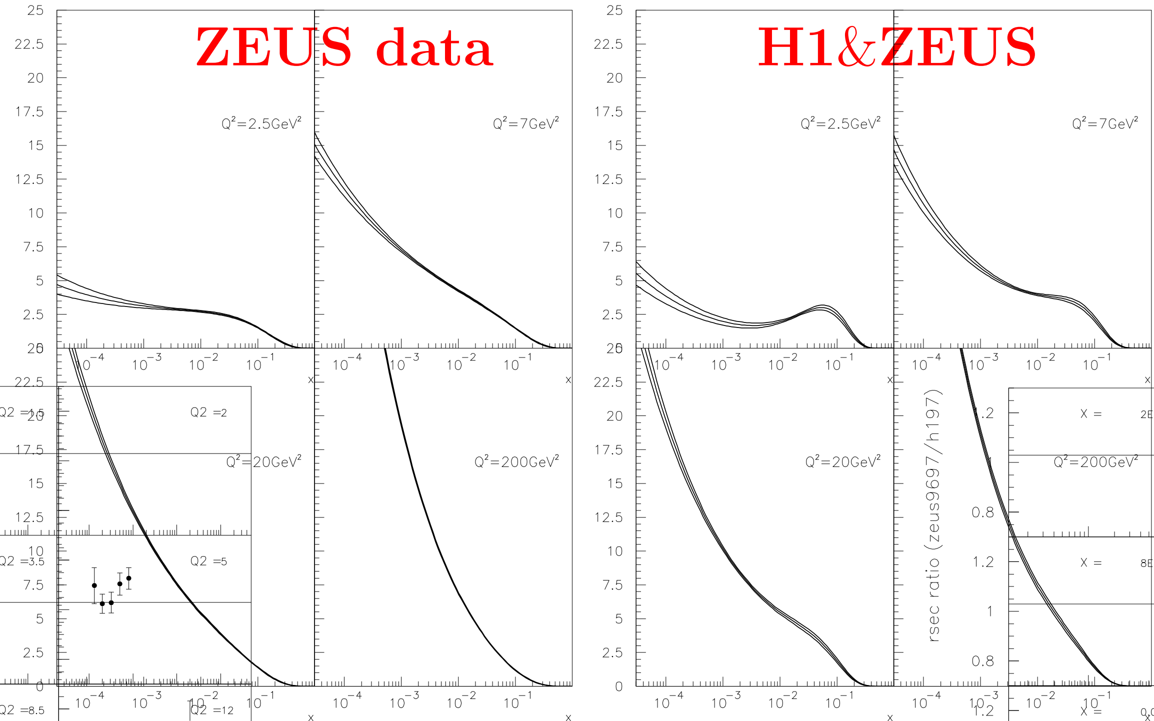
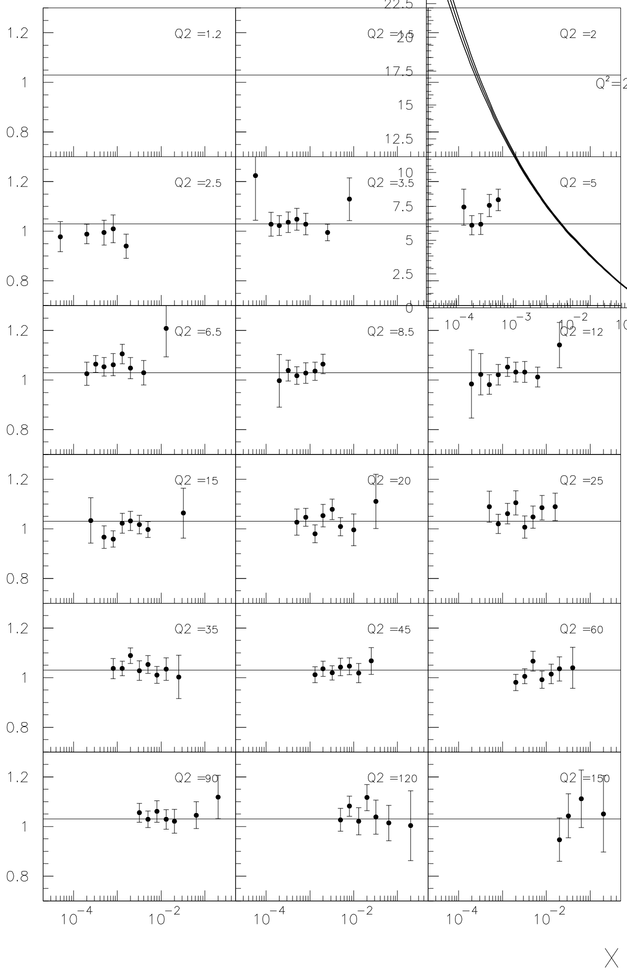
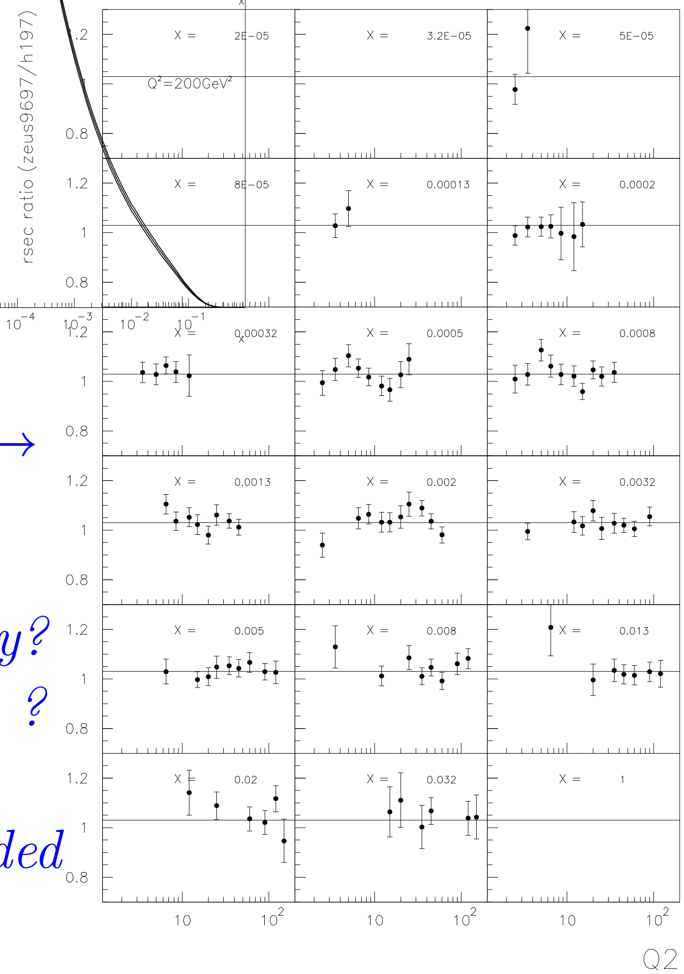
More about H1&ZEUS Data and Gluon

$xg(x) \rightarrow$



the same QCD fit procedure applied to H1, ZEUS data (A.Cooper-Sarkar)

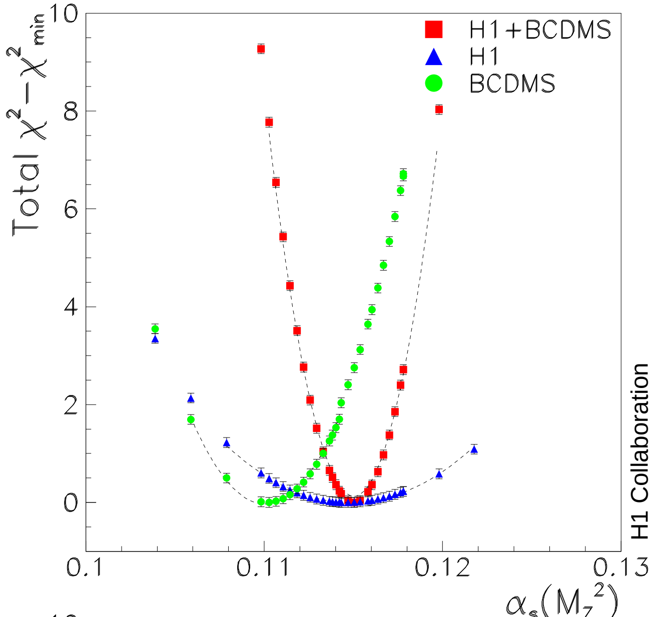


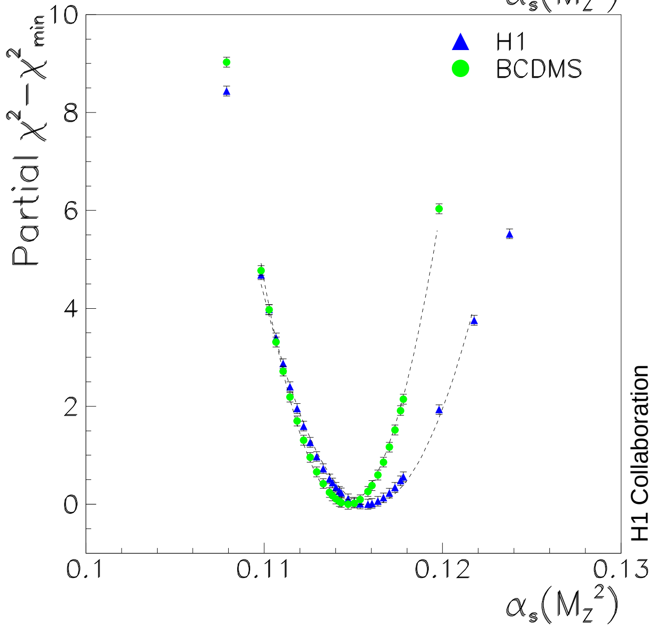


$\leftarrow$ F_2**(ZEUS/H1)** $\rightarrow$

- *data look very consistent*
- *gluon shows difference,why?*
- *sensitive to small features ?*
- *even more precision ?*
- *further investigations needed*

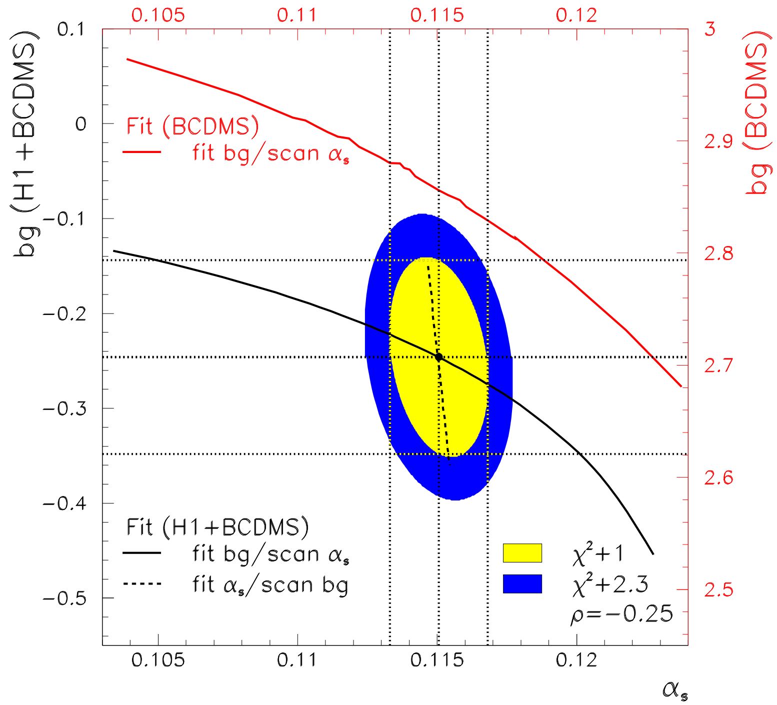
Two Remarks about $xg\&\alpha_s$ Fit of H1





H1, BCDMS, H1+BCDMS fits

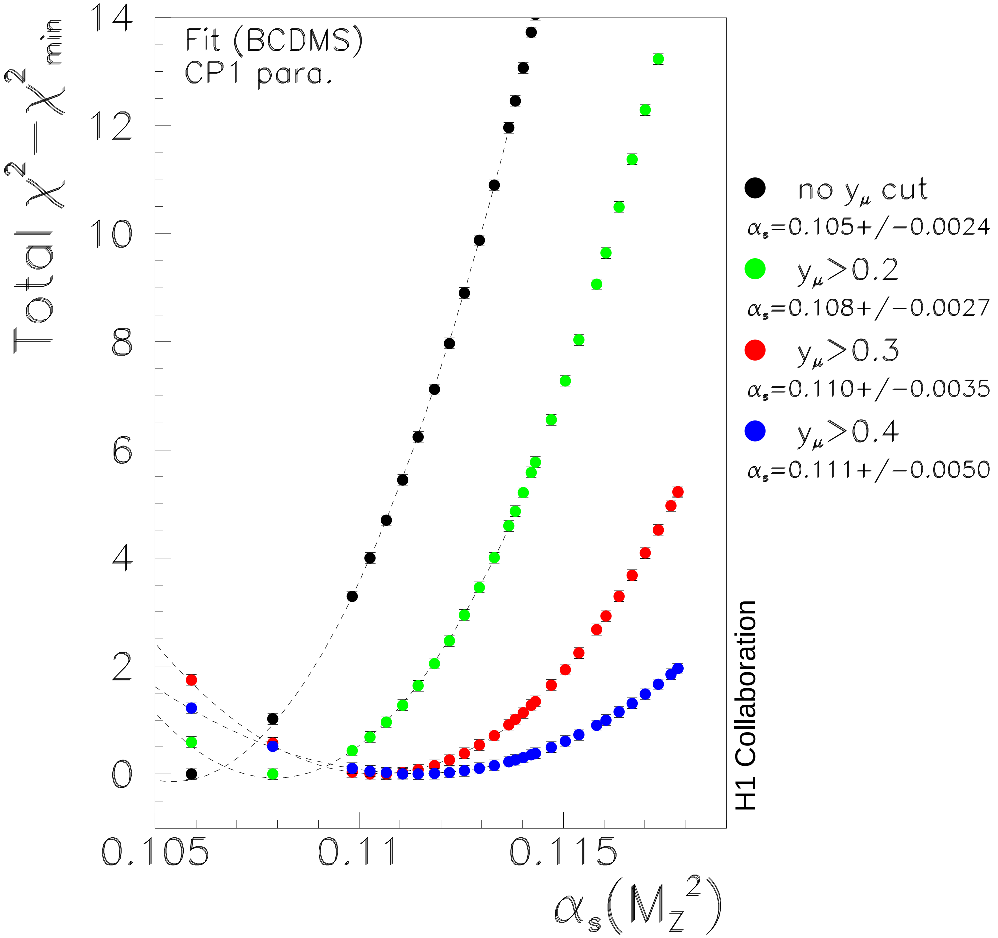
- *H1 pins down gluon at low x*, $xg(x) \propto x^{b_g}$ *and shifts* α_s*(BCDMS)* $= 0.110 \rightarrow 0.115$



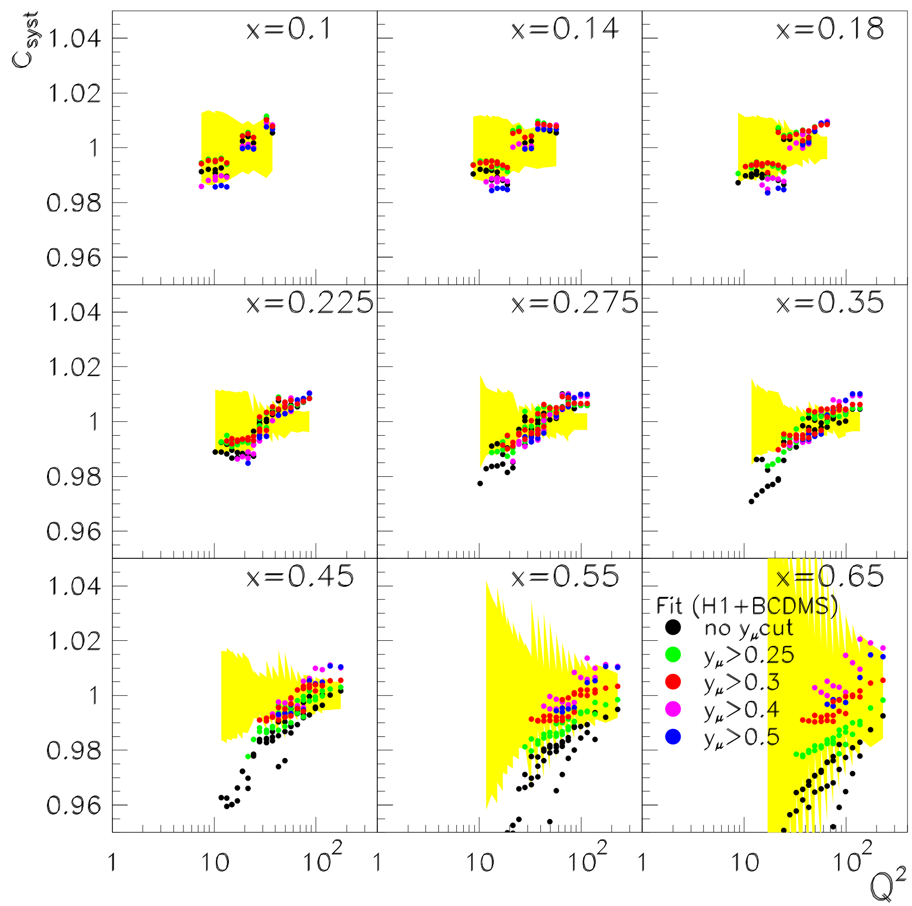
- *H1 and BCDMS data are fully consistent after cut* $y_{BCDMS} > 0.3$ *(see next slide →)*

Treatment of the BCDMS Data

α_s^{BCDMS} and cuts on y



Shifts imposed by QCD fits



- α_s^{BCDMS} *strongly* y *dependent*
- *large systematics at low* y *(large* x*)*
- *shifts are larger than systematics at lowest* y $\quad \rightarrow$ *apply cut* $y > 0.3$

$\alpha_s(M_Z^2)$ in the HERA NLO QCD Fits

$xg\&\alpha_s$ fit of H1

$\alpha_s(M_Z^2) = 0.1150 \pm 0.0017(exp)^{+0.0009}_{-0.0005}(model)$

$\pm 0.005(theory)$

	$m_r^2 = 0.25$	$m_r^2 = 1$	$m_r^2 = 4$
$m_f^2 = 0.25$	-0.0038	-0.0001	$+0.0043$
$m_f^2 = 1$	-0.0055	$--$	$+0.0047$
$m_f^2 = 4$	$--$	$+0.0005$	$+0.0063$

ZEUS fit

$\alpha_s(M_Z^2) = 0.1166 \pm 0.0008(uncor) \pm 0.0032(cor)$
$\pm 0.0036(norm) \pm 0.0018(model)$

$\pm 0.004(theory)$

variation of m_r^2, m_f^2 by factor of 2

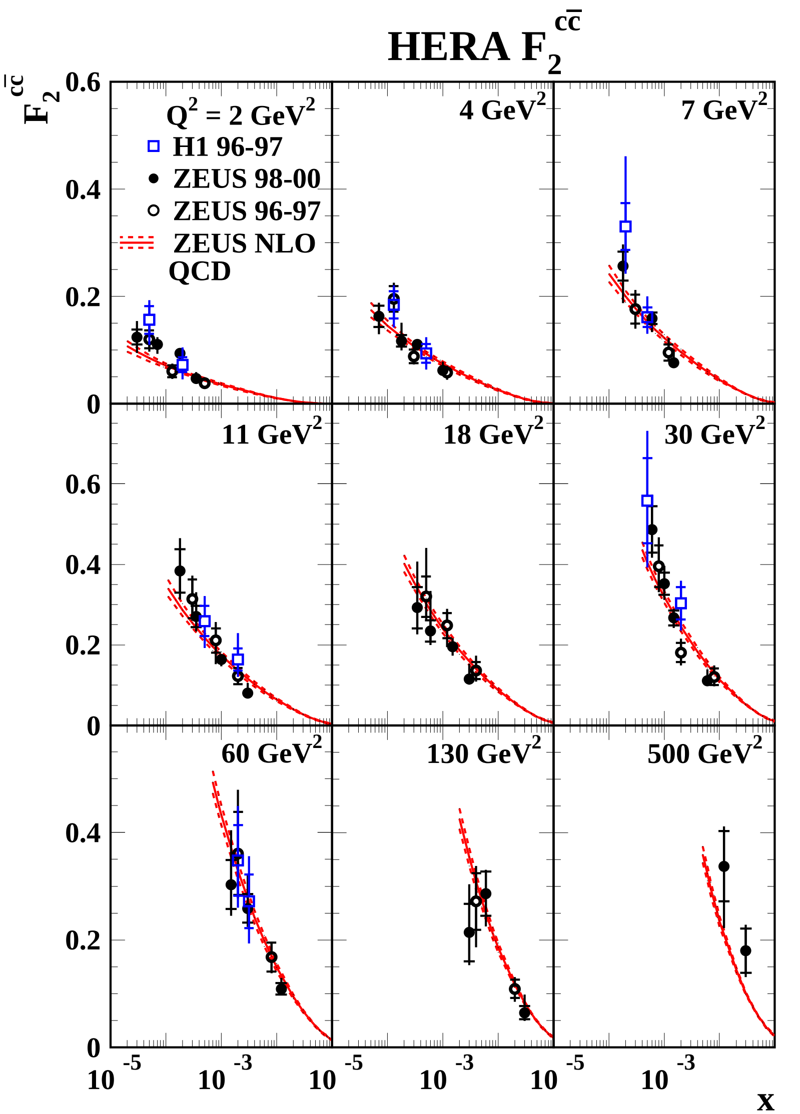
- *Experimental error (H1) is excellent (about 2%)*
- *Theory error (NLO) is by far dominating*

  Variation factors (4 or 2) are arbitrary
  Large χ^2 variations if ren. scale is varied (+20 units)

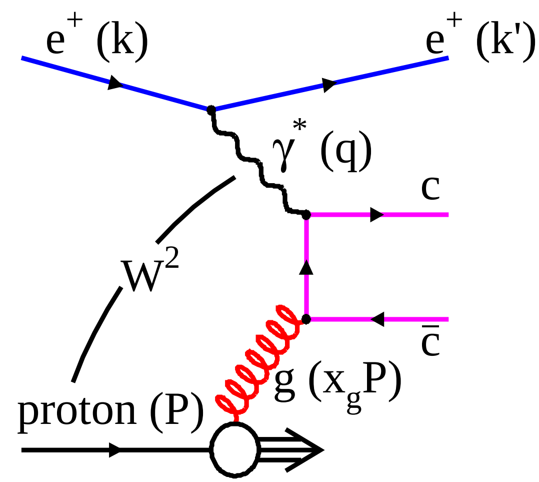
$\rightarrow$ *reduction of the theory error in NNLO by a factor of* ≈ 3 **:**

Alekhin	**NLO**	$\alpha_s(M_Z^2) =$	$0.1171 \pm 0.0015(exp) \pm 0.0033(theory)$
Alekhin	**NNLO**	$\alpha_s(M_Z^2) =$	$0.1143 \pm 0.0014(exp) \pm 0.0013(theory)$

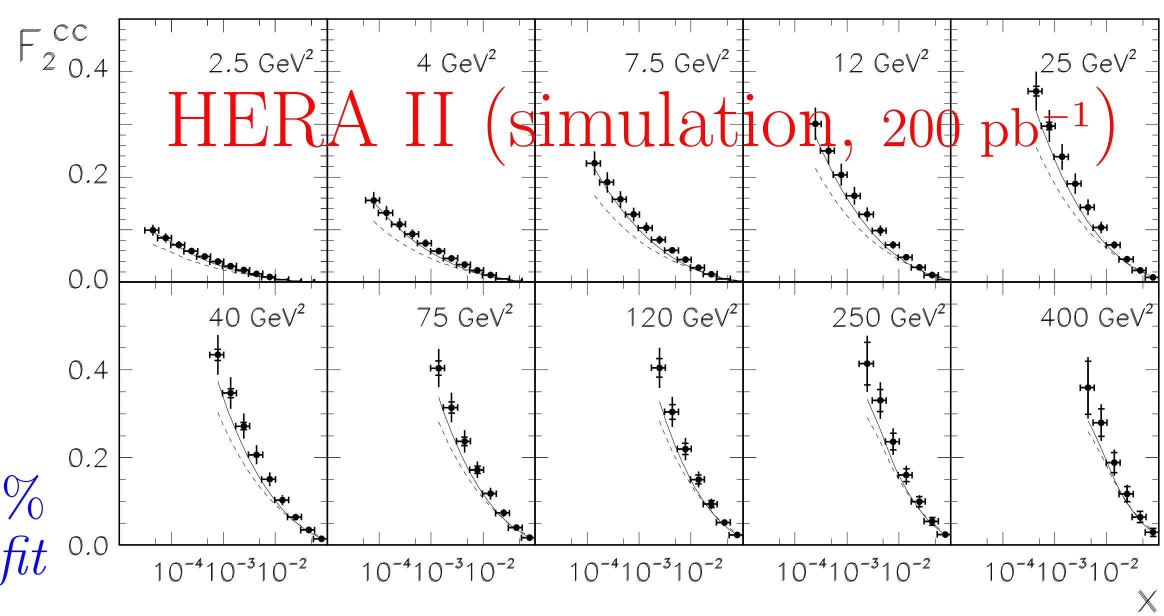
Gluon and Open Charm Production



Boson Gluon Fusion (BGF)

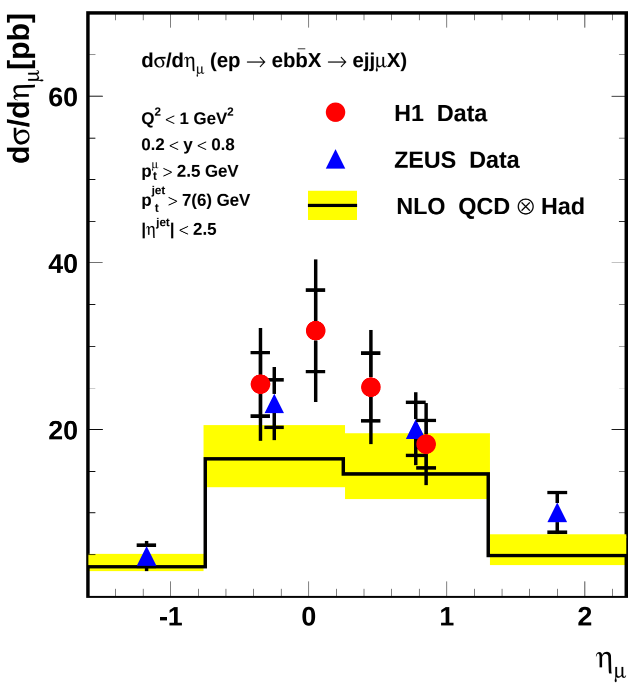


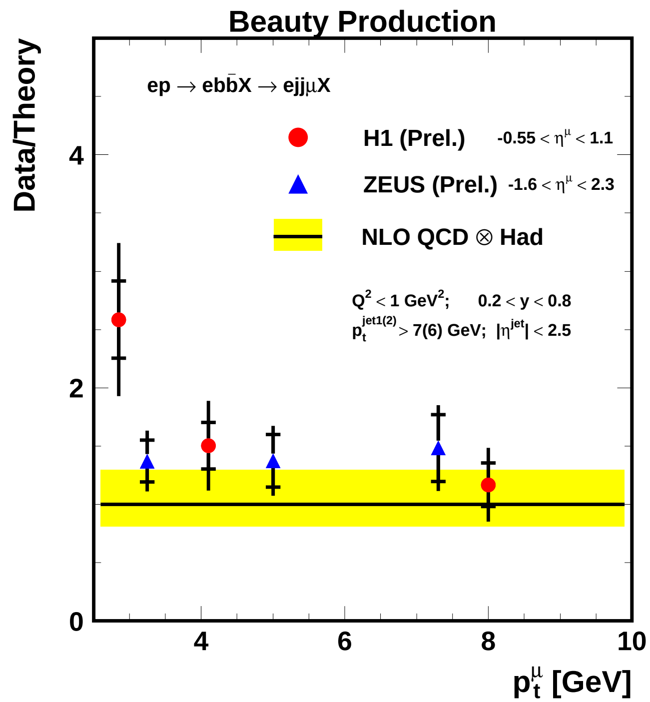
$$D^* \rightarrow D^0 \pi_{slow} \rightarrow K \pi \pi_{slow}$$

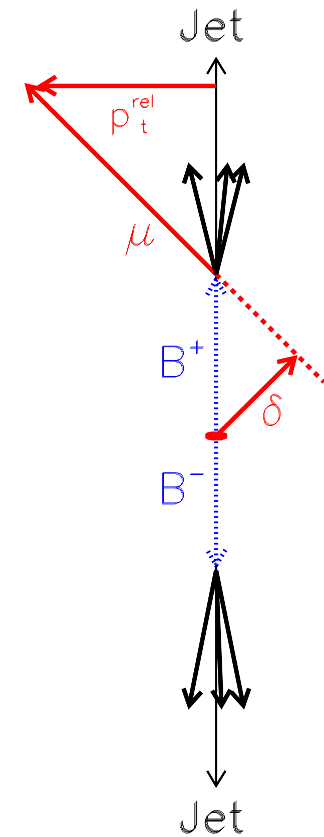


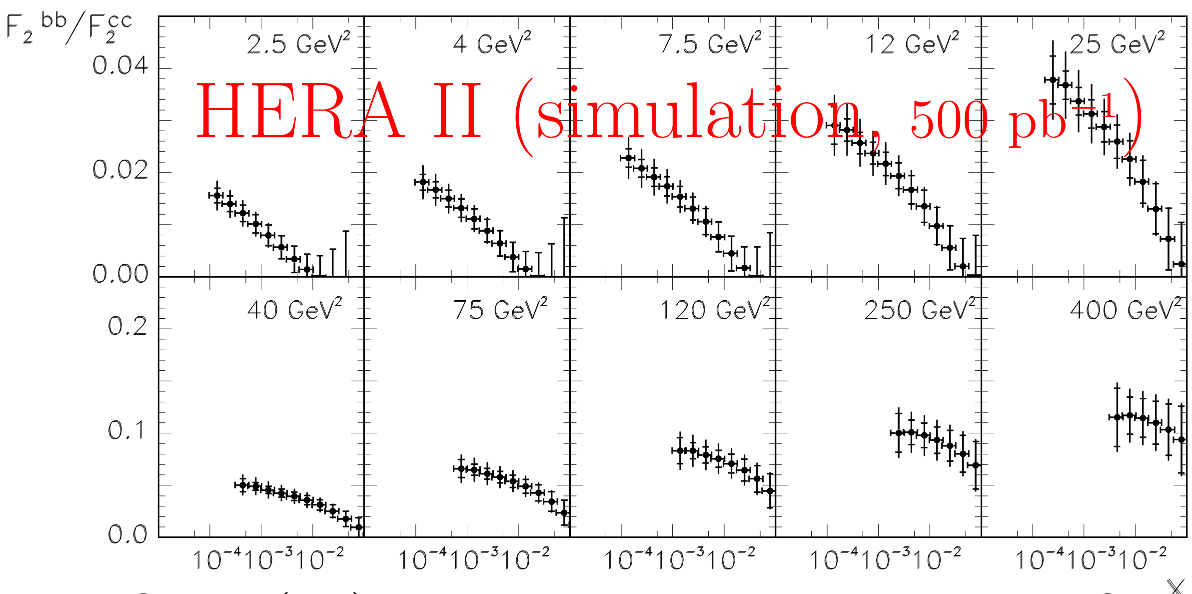
- *charm contribution up to $25-30\%$*
- *consistent with gluon from QCD fit*

Gluon and Beauty production



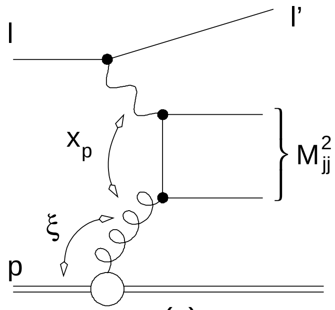






- *life time tags*
- *high statistics*
- *include into QCD fit ?*

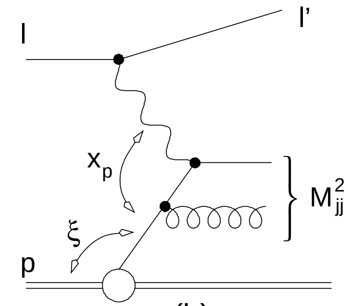
$xg \& \alpha_s$ and Jets



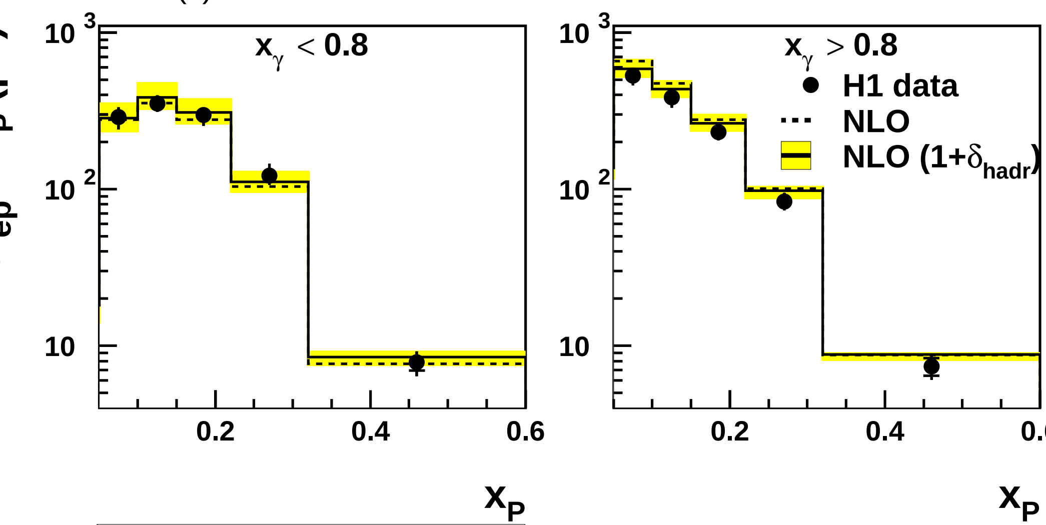
(c)

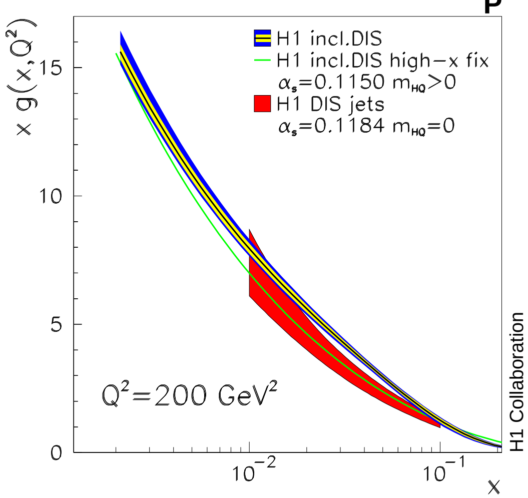
BGF: similar to $c\bar{c}$

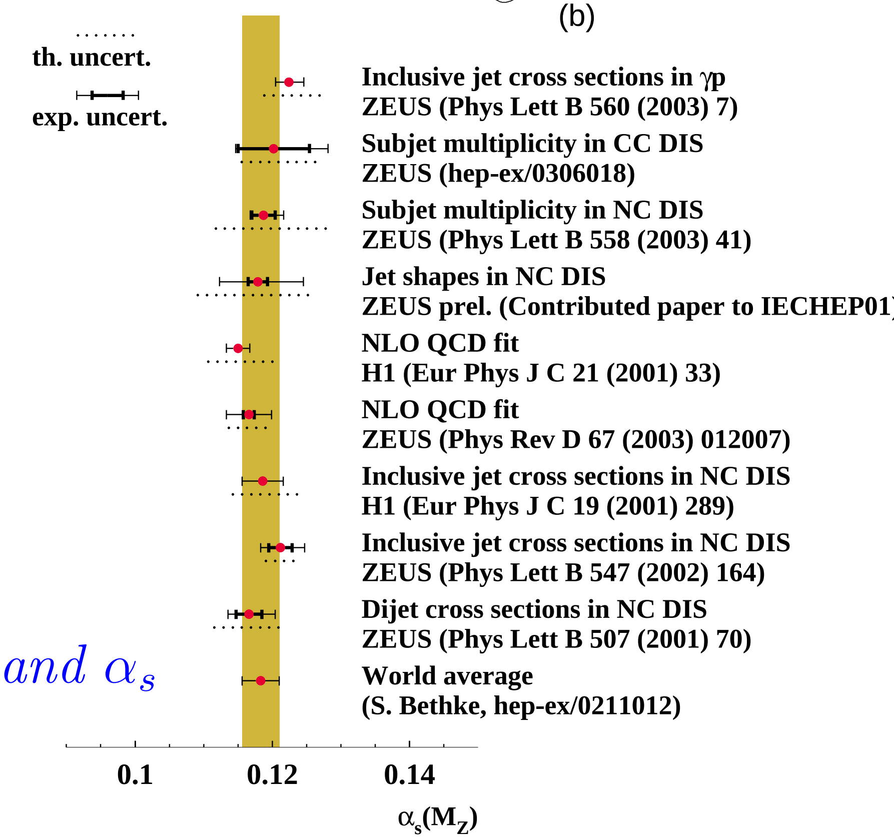
with $M_{jj} \gg M_{c\bar{c}}$



(b)

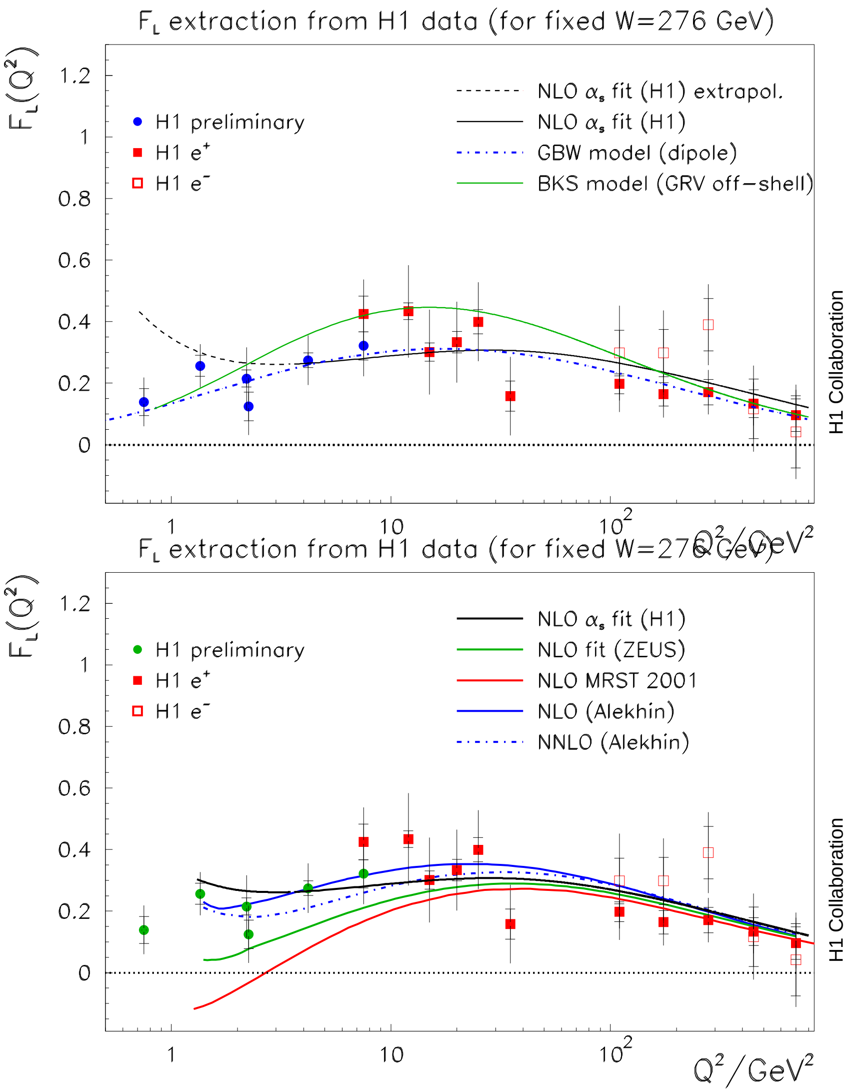






- *directly related to gluon and α_s*
- *sensitivity to larger x*
- *include c, b, jets into common QCD fit with F_2*

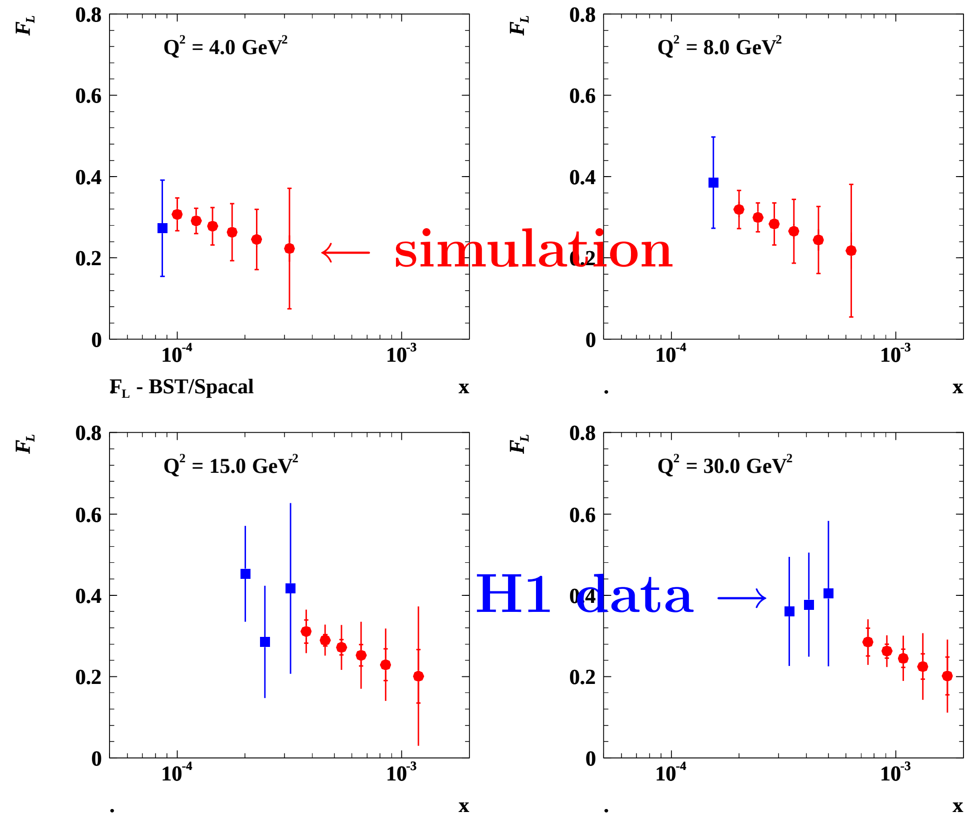
Summary for $F_L(x, Q^2)$ from H1



$\rightarrow$ *F_L "determinations" start to discriminate QCD predictions*

F_L expected at HERA II from low proton energy running

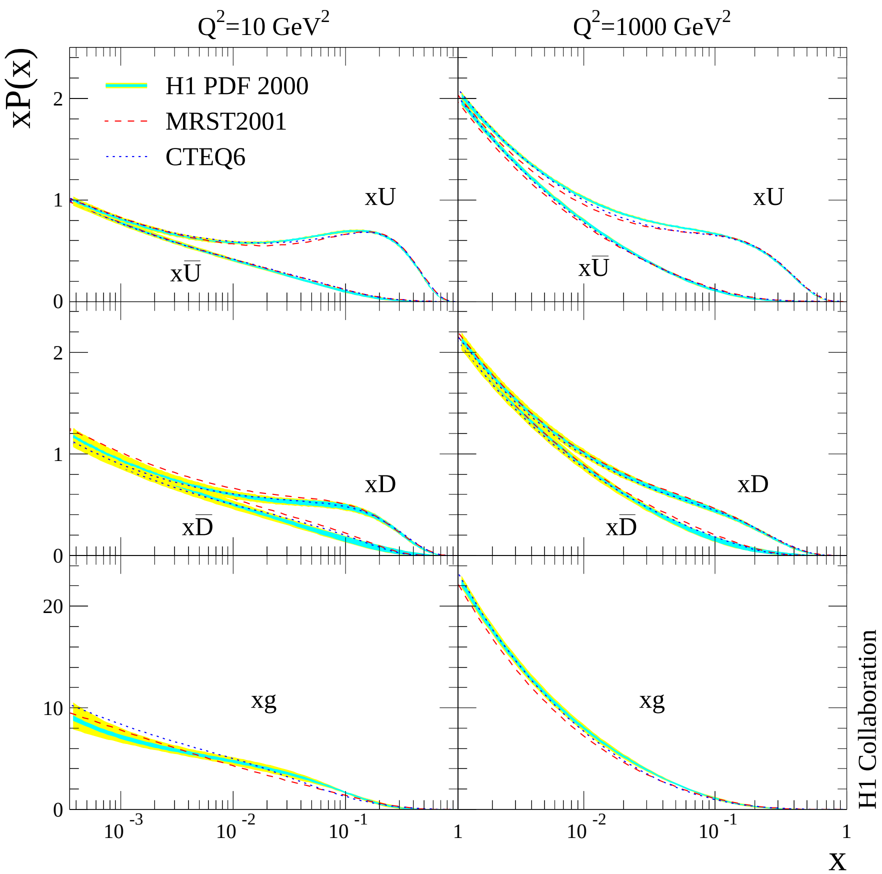
$$E_p = 460, \quad 575, \quad 920 \textbf{ GeV}$$
$$(20, \quad 10, \quad 200 \text{ pb}^{-1})$$

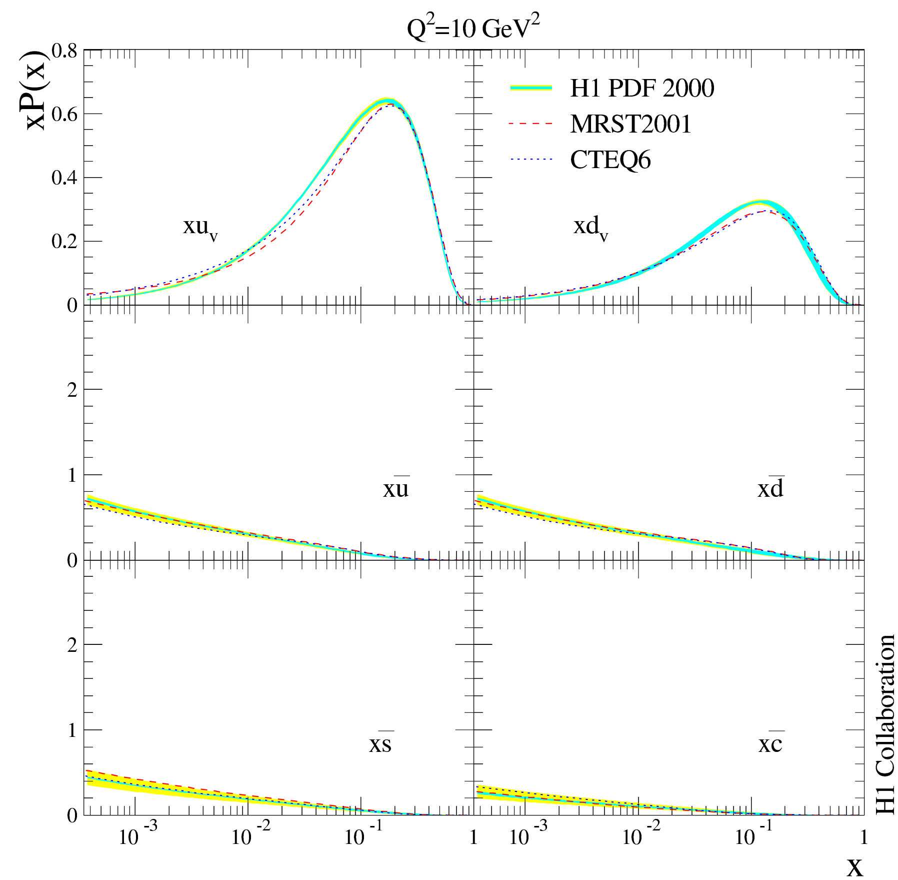


$\leftarrow$ simulation

H1 data $\rightarrow$

PDFs





Exp. unc. of PDFs

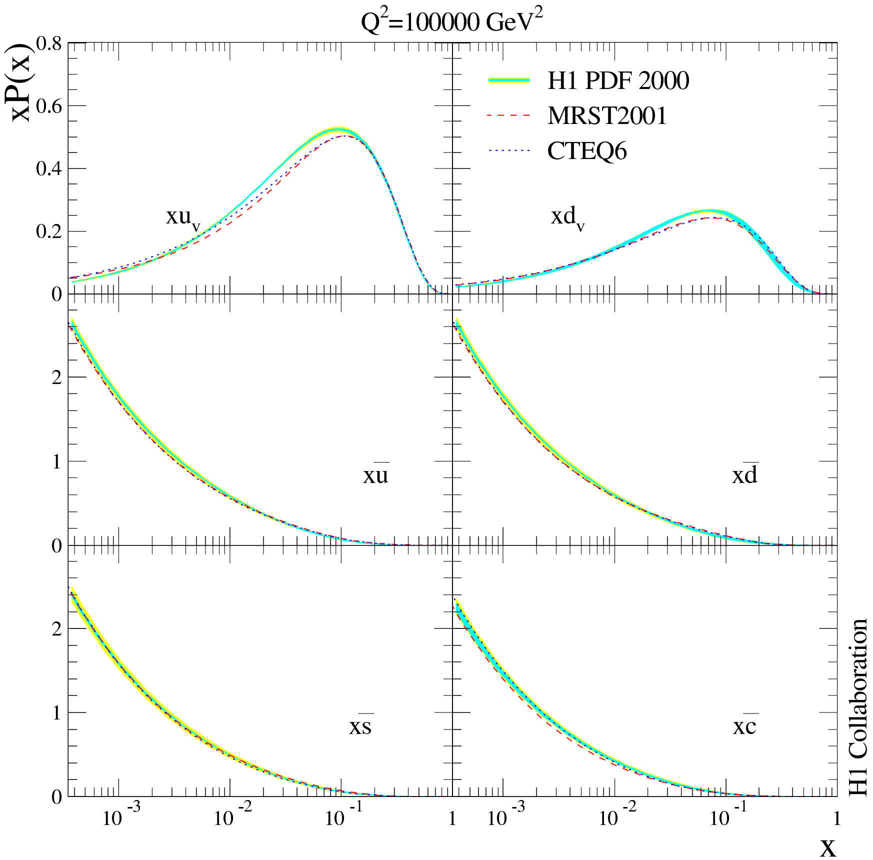
x	**0.01**	**0.4**	**0.65**
xU	**1%**	**3%**	**7%**
xD	**2%**	**10%**	**30%**

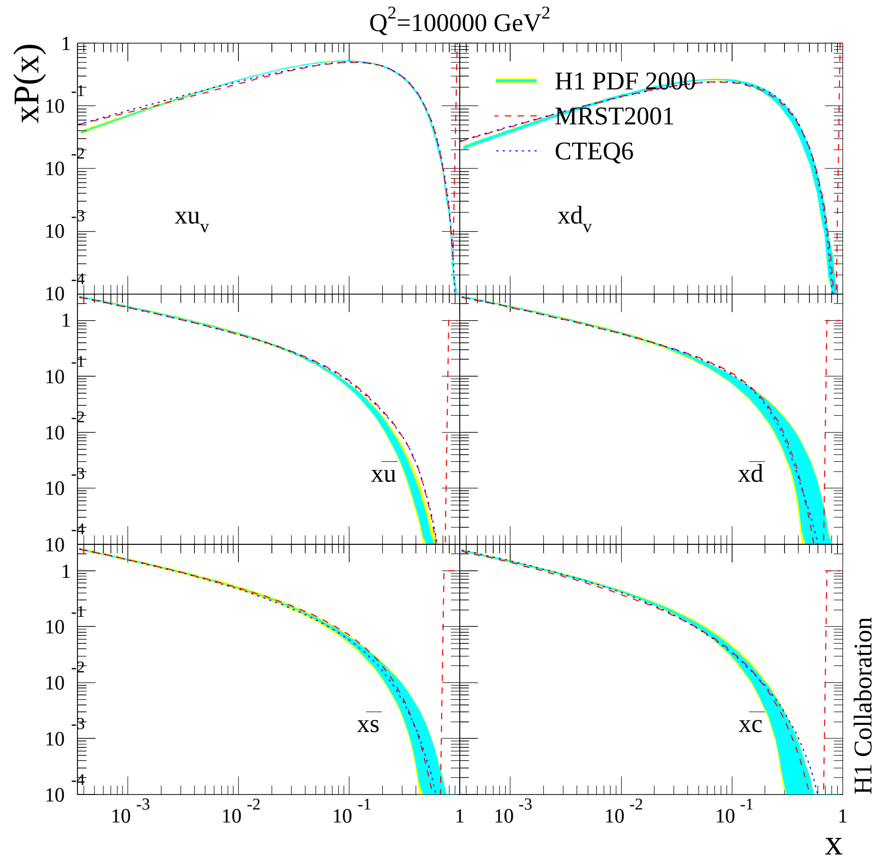
Assumptions:

$\bar{c} = f_c \bar{U}$	(F_2^c)
$\bar{s} = f_s \bar{D}$	$(s \to c$ **in CC**$)$
$\bar{s} = s, \bar{c} = c$	**(?)**
$(\bar{d} - \bar{u})\ x \to 0$	(eD)
b	(F_2^b)

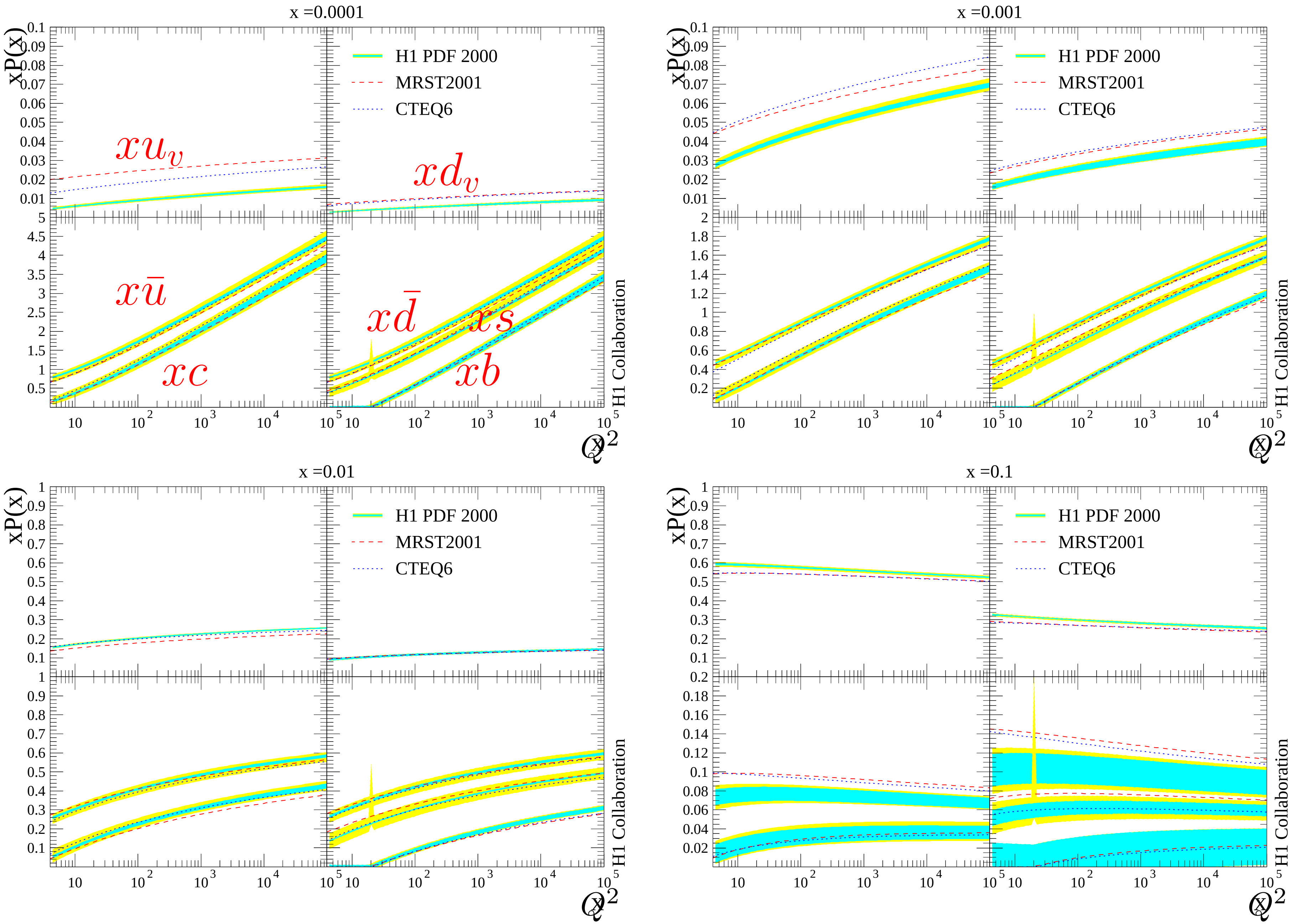
PDFs extrapolated to the LHC

at $Q^2 = 100000\ GeV^2$

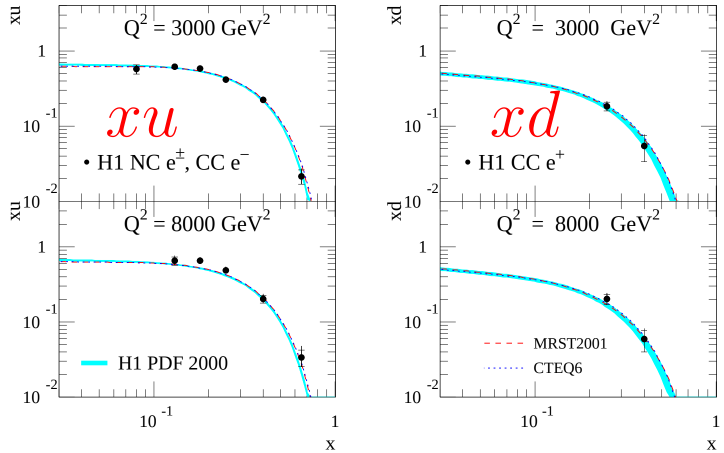


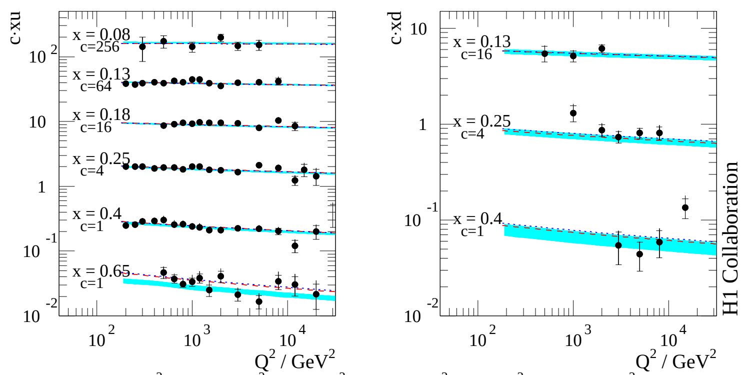


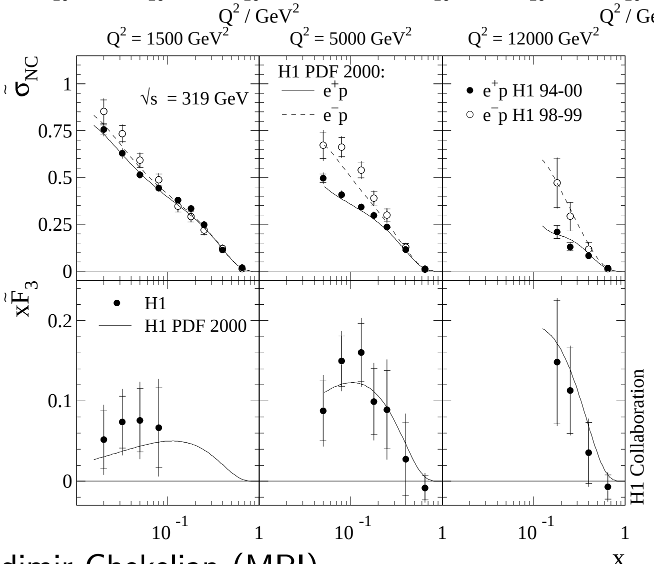
PDFs vs. Q^2 at $x = 0.0001, 0.001, 0.01, 0.1$



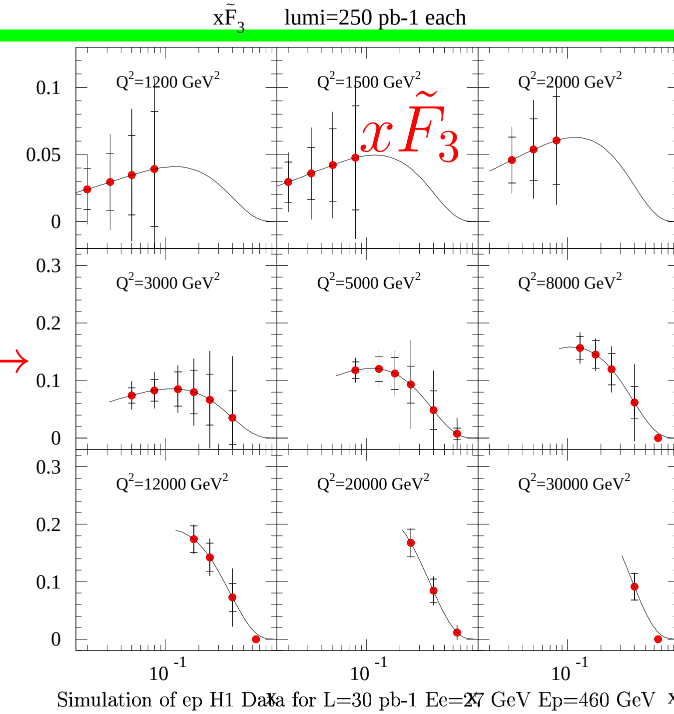
Prospects for large x



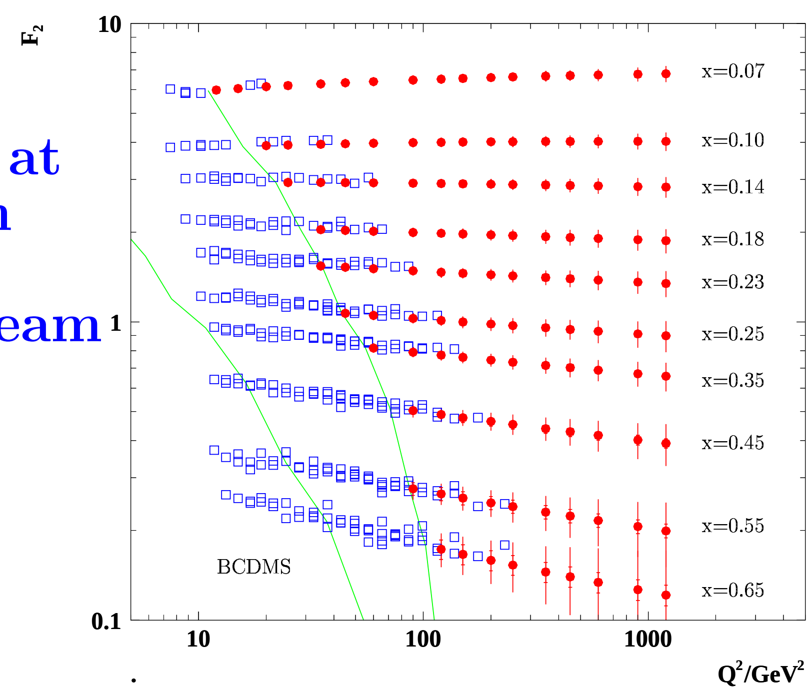




HERA II $\longrightarrow$

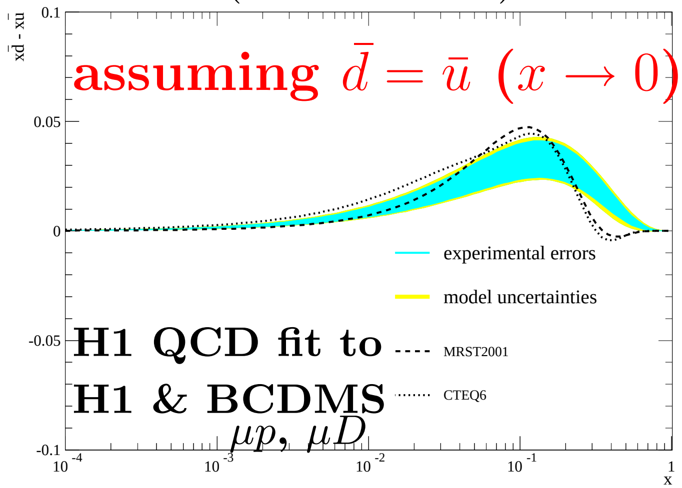


Running at minimum possible proton beam energy

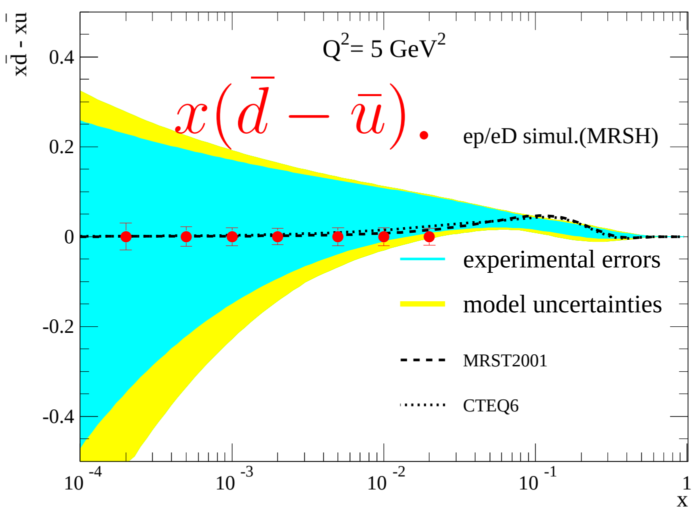


If deuteron data: $(\bar{d}-\bar{u})$, d_v/u_v

see DESY 03-194 (LoI HERA 3)

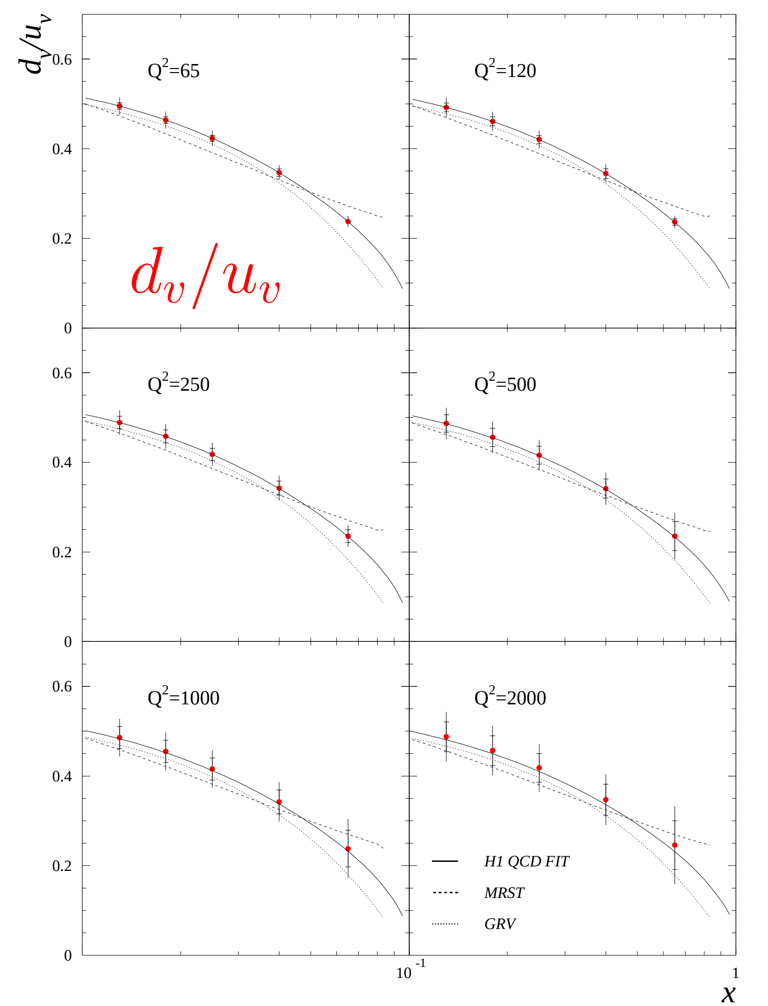


$$\frac{1}{2}(F_2^p + F_2^n) - F_2^p \approx \frac{x}{3}(\bar{d}-\bar{u})$$



eD: correct for shadowing
(20 pb^{-1} eD, 40 pb^{-1} ep)

eD: tagging of spectator proton
$(\delta p/p \approx 1\%)$ **(50 pb^{-1})**
ep: $E_p = 0.5 E_D$ **(50 pb^{-1})**



free from nuclear binding effects

Conclusion

- **HERA I: comprehensive analysis of the data from different directions:**
  - **tests of perturbative QCD in NLO**
    $\rightarrow$ *consistent picture / driven by gluon /* F_2, F_L, *charm, jets, ...*
  - **determination of PDFs, gluon density and** α_s **(input to LHC)**
    $\rightarrow$ *potentially very high precision of* α_s *in NNLO*
  - **still to come**
    $\rightarrow$ *bulk,svx,mb 1999/2000* $(Q^2 < 150\ GeV^2)$
- **HERA II: new detectors, new lumi, new possibilities**
  $\rightarrow$ **including low** E_p **running for direct** F_L **measurements**
- **Aiming for common (NLO/NNLO) QCD fit to**
  $\rightarrow$ **SF, jets, charm, beauty**

subtitle of the workshop:

"A workshop on the implications of HERA for LHC physics"

$\rightarrow$ **formulate request for HERA program in view of LHC**