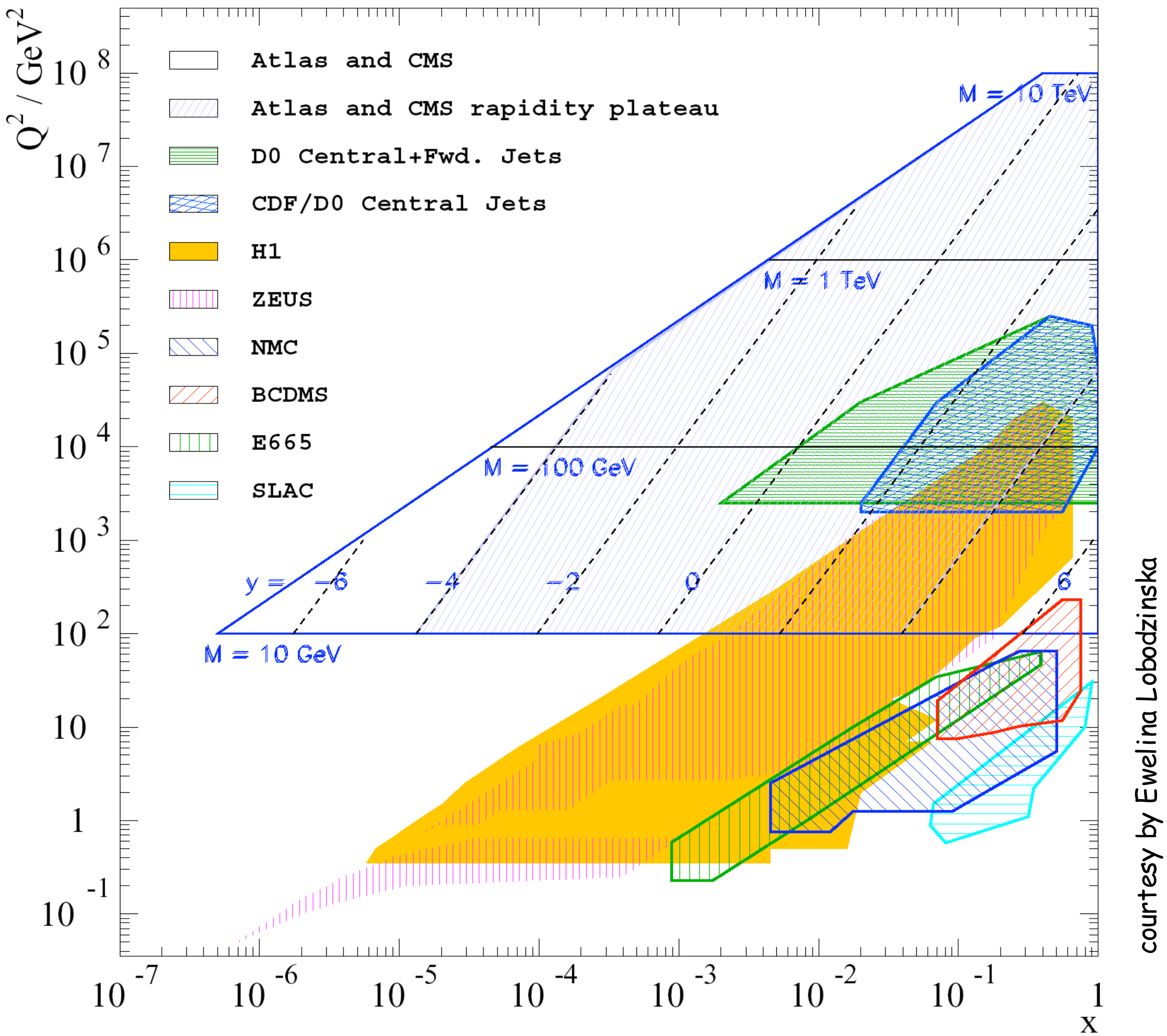
On the Determination and Measurement of the light Parton Distributions at Low x at HERA

Max Klein (DESY)

Burkard Reisert (Fermilab)

Parton evolution to the LHC

Effects of QCD fit assumptions



HERA-LHC workshop Sea Asymmetry at Low x M. Klein and B. Reisert March 21st, 2005 DESY Hamburg

$$F_2 = \frac{4}{9} x\,(U + \overline{U}) + \frac{1}{9} x\,(D + \overline{D})$$

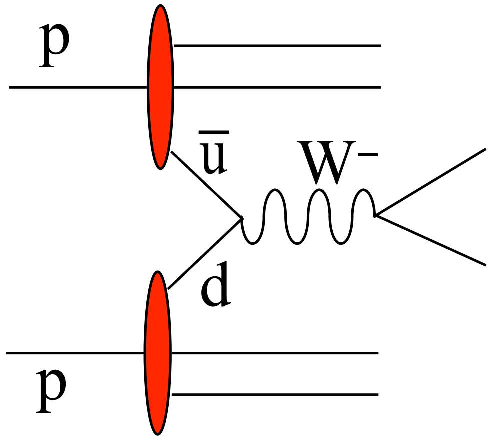
What causes rise to low x?
measured $4\bar{u}+\bar{d}$, some xg. Yet,
$\bar{u}$ and $\bar{d}$ are unknown at low x but
accessible via eD [F_L for xg].
Precision measurements required!

$\bar{u}=\bar{d}$ was natural assumption for long time, until E866, HERMES found difference at x ~ 0.1 → all global fits followed. Indications for strange-anti-strange asymmetry

Low x asymmetry expected in non-perturbative models (Sullivan, chiral soliton)

Important for nucleon structure, Tevatron and LHC, superhigh energy neutrino exp's

$$A_l(\eta) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta} \simeq \frac{\mathrm{d(x)}}{\mathrm{u(x)}}$$



Tevatron: sensitivity at x ~ 0.1
cf B.Heinemann June 04 meeting

NC

$$\frac{d^2\sigma^{\pm}_{NC}}{dx\, dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\, \phi^{\pm}_{NC}\, (1 + \Delta^{\pm,weak}_{NC}),$$

with $\phi^{\pm}_{NC} = Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L,$

$$[F_2, F_2^{\gamma Z}, F_2^Z] = x\sum_q [e_q^2, 2e_q v_q, v_q^2 + a_q^2]\{q + \overline{q}\}$$

$$[xF_3^{\gamma Z}, xF_3^Z] = 2x\sum_q [e_q a_q, v_q a_q]\{q - \overline{q}\} \overset{?}{=} 2x\sum_{q=u,d} [e_q a_q, v_q a_q] q_v$$

below bottom threshold

$$xU = x(u + c)$$
$$x\overline{U} = x(\overline{u} + \overline{c})$$
$$xD = x(d + s)$$
$$x\overline{D} = x(\overline{d} + \overline{s})$$

$$xu_v = x\,(U - \overline{U})\,, \quad xd_v = x\,(D - \overline{D})$$

Are sea and anti-quarks equal ?
Are up and down quarks equal at low x?

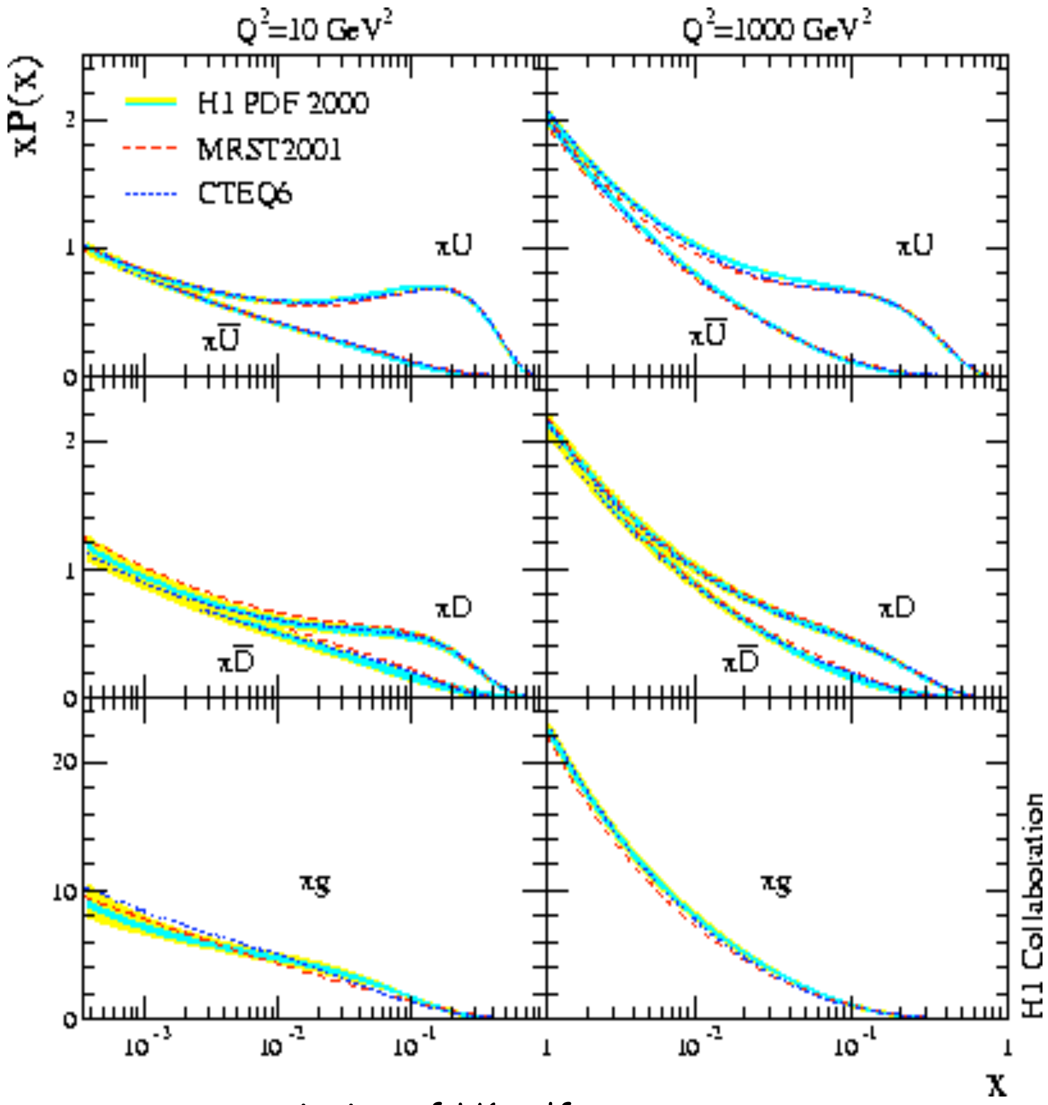
CC

$$\frac{d^2\sigma^{\pm}_{CC}}{dx\, dQ^2} = \frac{G_F^2}{2\pi x}\left[\frac{M_W^2}{Q^2 + M_W^2}\right]^2 \phi^{\pm}_{CC}\, (1 + \Delta^{\pm,weak}_{CC})$$

with $\phi^{\pm}_{CC} = \frac{1}{2}(Y_+ W_2^{\pm} \mp Y_- xW_3^{\pm} - y^2 W_L^{\pm}),$

$$W_2^+ = x(\overline{U} + D)\,, \quad xW_3^+ = x(D - \overline{U})$$
$$W_2^- = x(U + \overline{D})\,, \quad xW_3^- = x(U - \overline{D})$$

$$\phi^+_{CC} = x\overline{U} + (1-y)^2 xD, \quad \phi^-_{CC} = xU + (1-y)^2 x\overline{D}$$



exp uncertainties of H1 pdfs

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

← artificial @low x

CC and NC cross sections are sensitive only to

$$U, \bar{U}, D, \bar{D}$$

In the H1 PDF 2k fit, uv,dv,sea are replaced by these observables. Possible with H1/HERA data alone and assumption on sea symmetry

$$xP = A_P x^{B_P} (1-x)^{C_P} f_p(x)$$

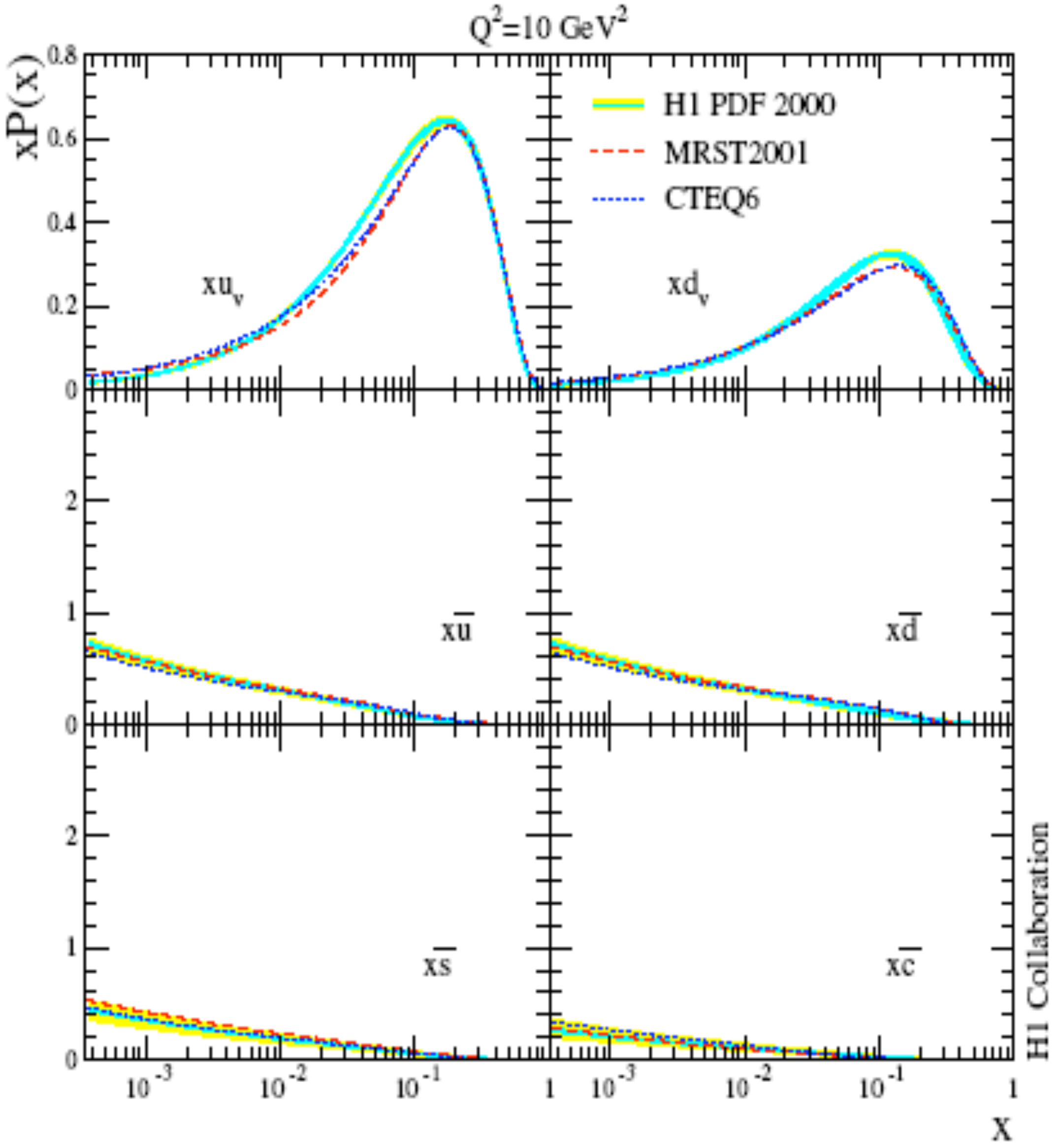
$$f_g = (1 + D_g x)$$

$$f_U = (1 + D_U x + F_U x^3)$$

$$f_D = (1 + D_D x)$$

$$f_{\bar{U}} = 1$$

$$f_{\bar{D}} = 1$$



The 2k fit uses only 3 assumptions:

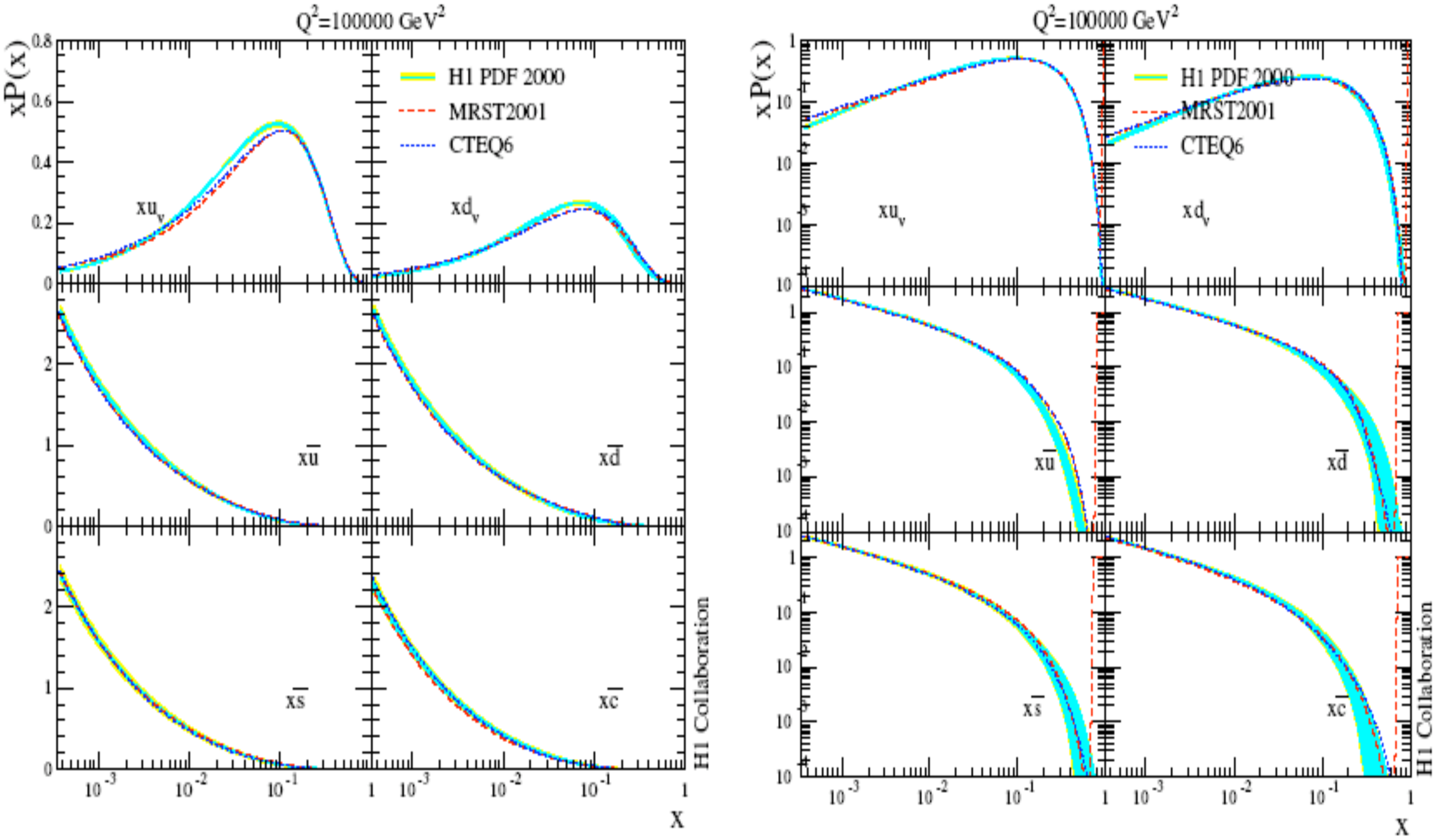
- momentum sum rule
- quark counting rule
- sea is flavour symmetric at low x

For the flavour decomposition further assumptions are made, only partially checked by the data:

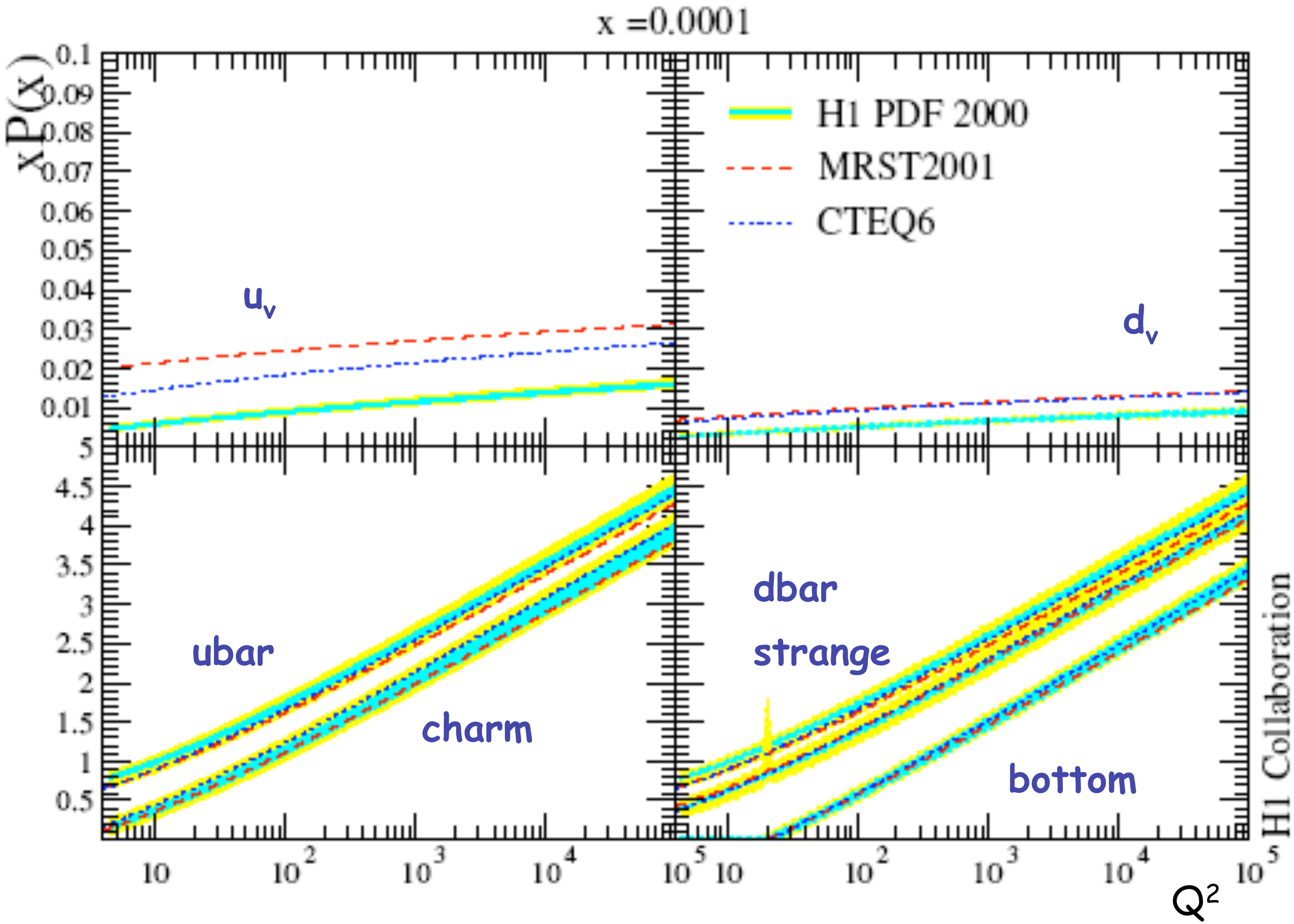
$$\bar{c} = f_c \bar{U}$$
$$\bar{s} = f_s \bar{D}$$
$$\bar{s} = s, \bar{c} = c$$

- $F_2^{c,b}$
- Ws→c?
- ?

pdfs extrapolated to LHC



at very high Q^2 strange and charm quarks are of size comparable to light sea quarks



Differences between the quark distributions are maintained at higher Q^2

The low x limit of the parton distributions determined in H1 fits

$$\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g} \cdot [1 + D_g x] \\
xU(x) &= A_U x^{B_U}(1-x)^{C_U} \cdot [1 + D_U x + F_U x^3] \\
xD(x) &= A_D x^{B_D}(1-x)^{C_D} \cdot [1 + D_D x] \\
x\overline{U}(x) &= A_{\overline{U}} x^{B_{\overline{U}}}(1-x)^{C_{\overline{U}}} \\
x\overline{D}(x) &= A_{\overline{D}} x^{B_{\overline{D}}}(1-x)^{C_{\overline{D}}},
\end{aligned}$$

B_g not well constrained
-0.05 … -.8
D related to B

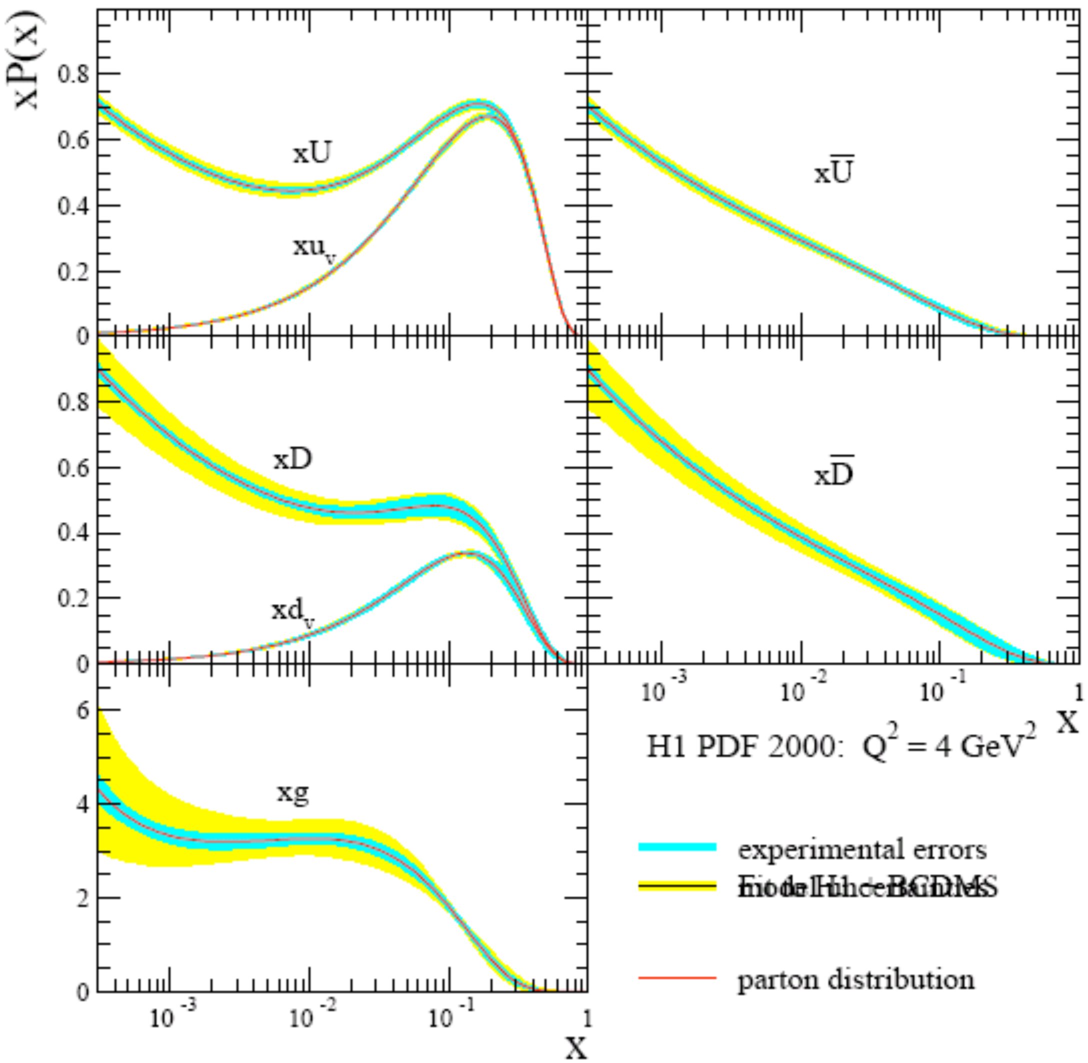
At low x have only one measurement: $F_2 = \frac{4}{9} x \left(U + \overline{U}\right) + \frac{1}{9} x \left(D + \overline{D}\right)$

assume that quark and anti-quark distributions are equal at low x, and u=d

$$B_U = B_D = B_{\overline{U}} = B_{\overline{D}} \equiv B_q$$

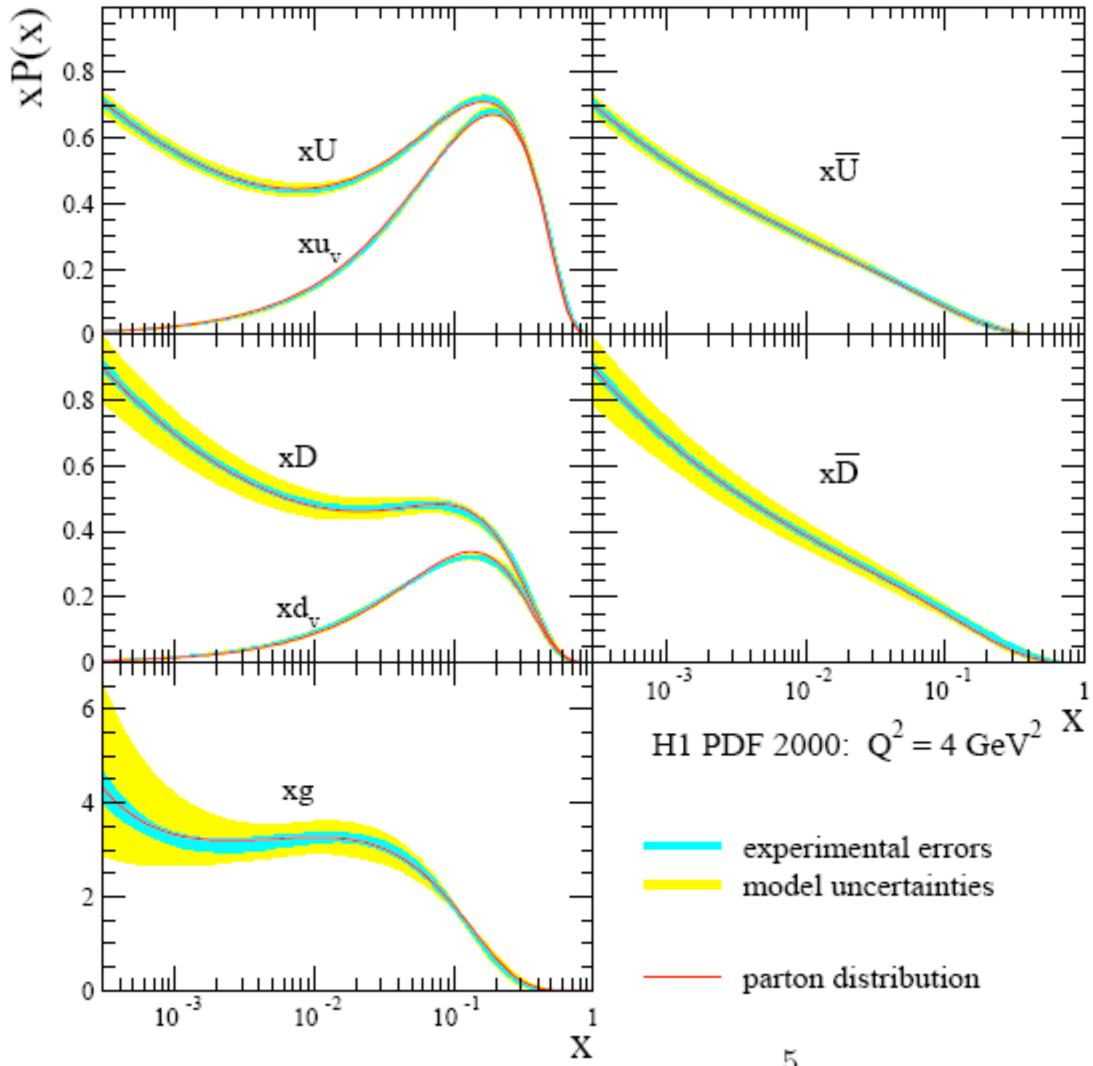
$A_{\overline{U}} = A_{\overline{D}} \cdot (1 - f_s)/(1 - f_c)$, which imposes that $\bar{d}/\bar{u} \to 1$ as $x \to 0$.

default assumptions - H1 data only



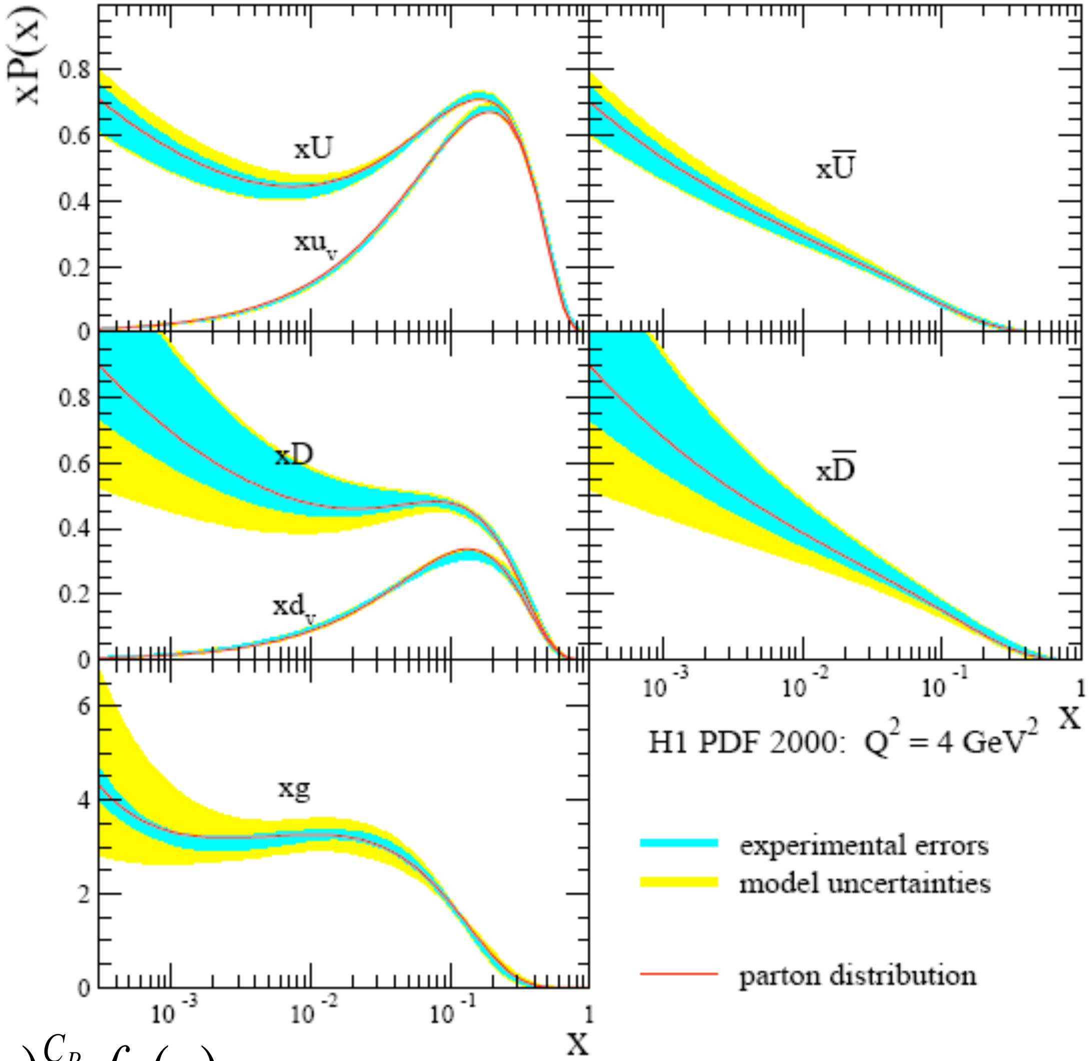
Fit published in:
hep-ex/0304003
EPJ C30(2003)1

Default assumptions - H1 + BCDMS (p,d) data



$$F_2^N = \frac{5}{18}\,x\left(U + \overline{U} + D + \overline{D}\right) + \frac{1}{6}\,x\left(c + \overline{c} - s - \overline{s}\right)$$

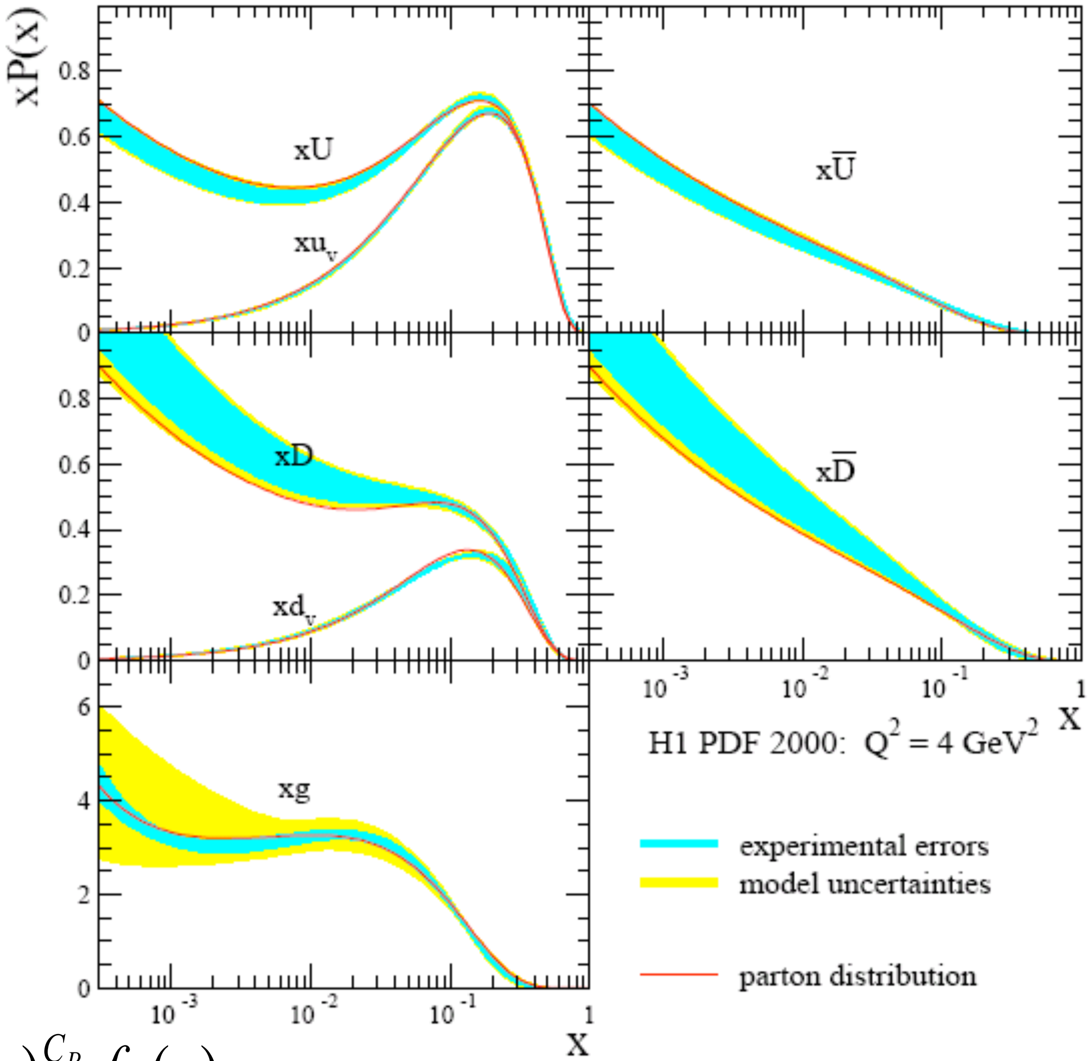
release $B_d = B_u$ constraint → D,U get uncertain at low x



H1 + BCDMS

$$xP = A_P x^{B_P} (1-x)^{C_P} f_p(x)$$

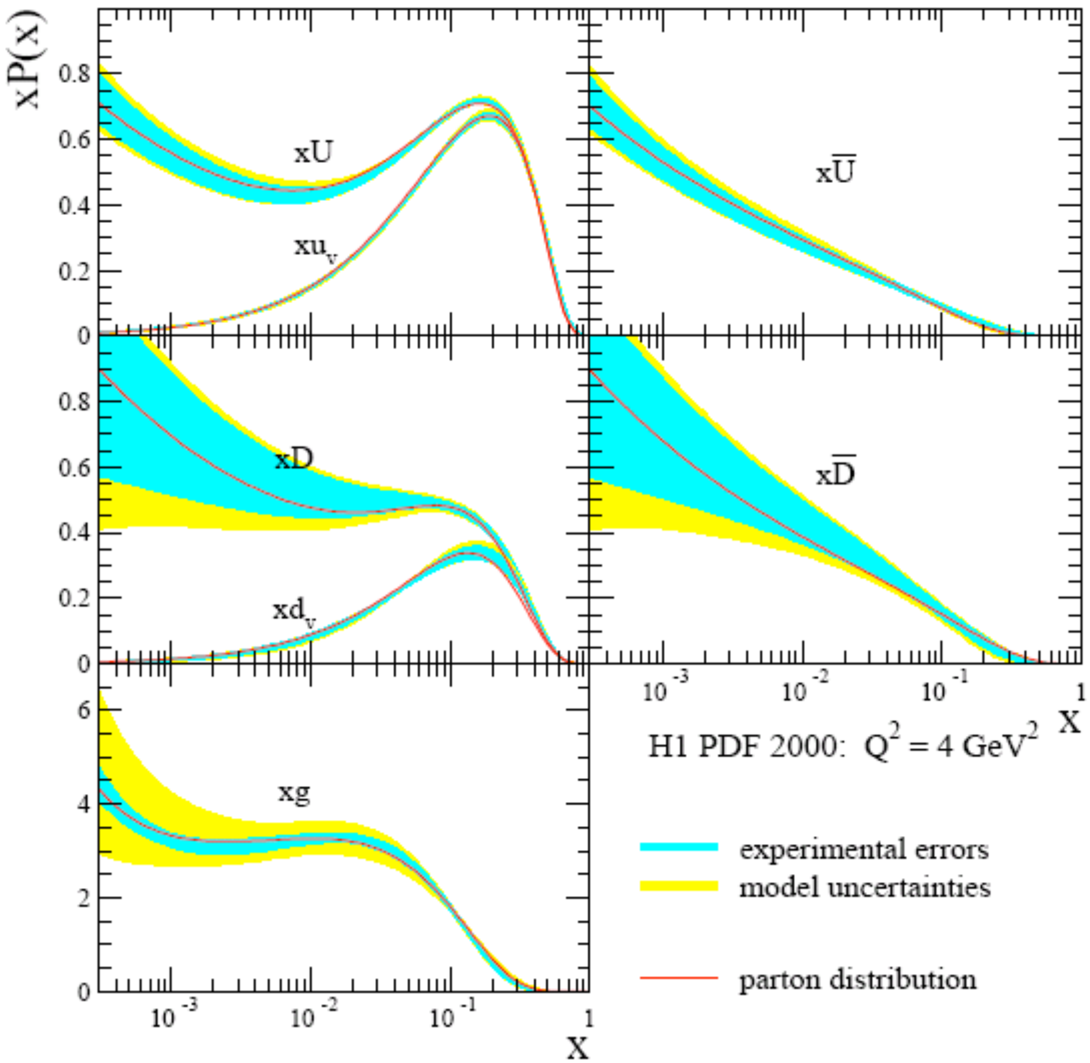
release A_d=A_u constraint → D,U get uncertain at low x



H1 + BCDMS

$$xP = A_P x^{B_P} (1-x)^{C_P} f_p(x)$$

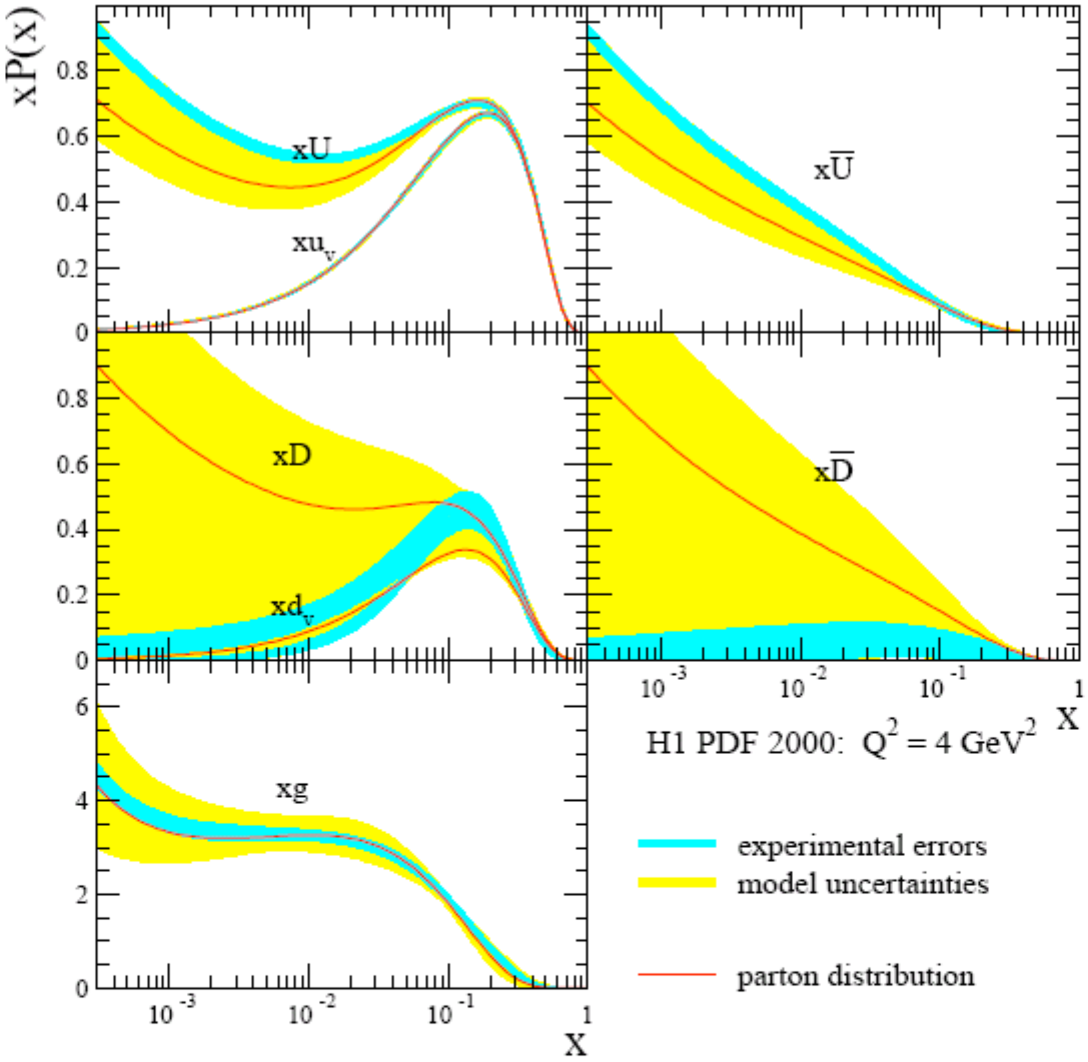
no constraint on A, B → the genuine uncertainties at low x [+)]



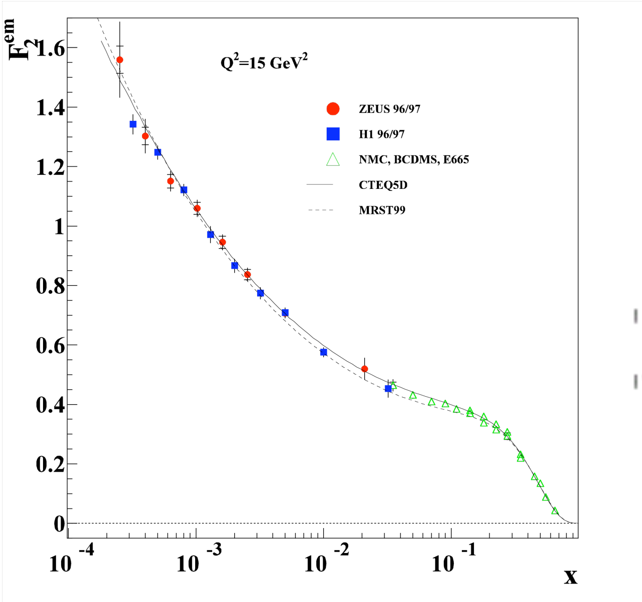
H1 + BCDMS

[+)] MCS/CG analysis in progress using ZEUS global fit framework and data

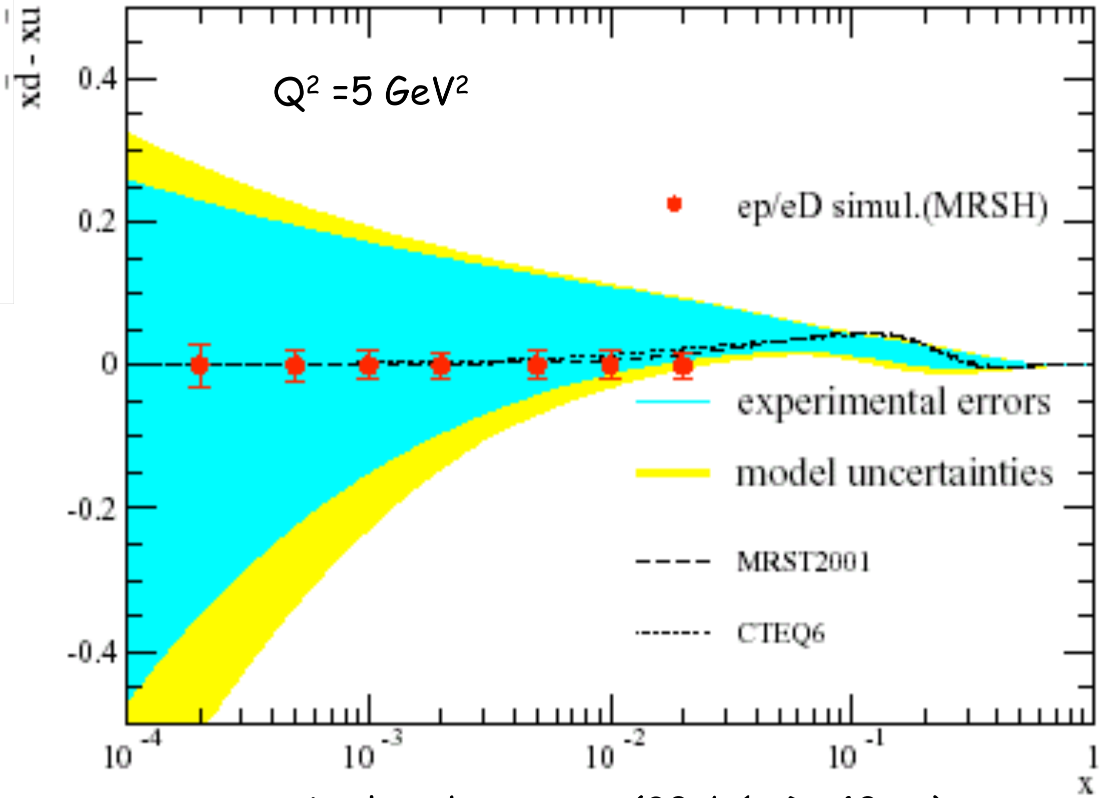
HERA data alone do not constrain u, d at low x – deuteron data are necessary



H1 only



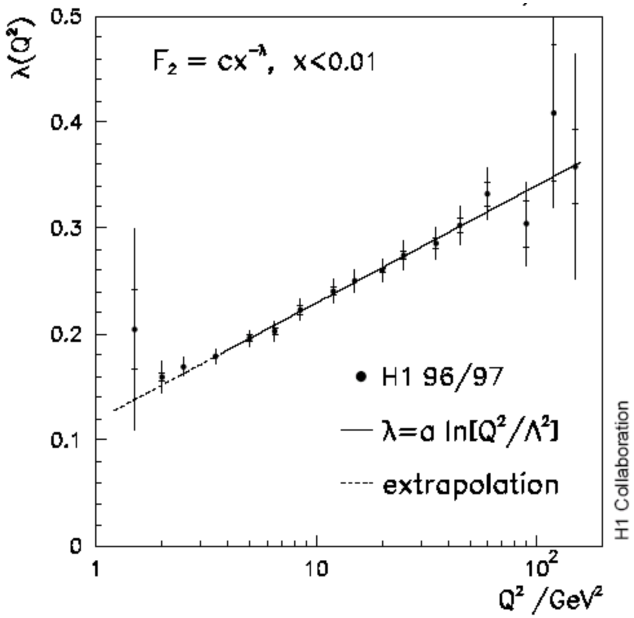
The light sea quark asymmetry is expected and has been assumed to vanish at low x. However, F_2 rises strongly towards low x which deserves to be studied.



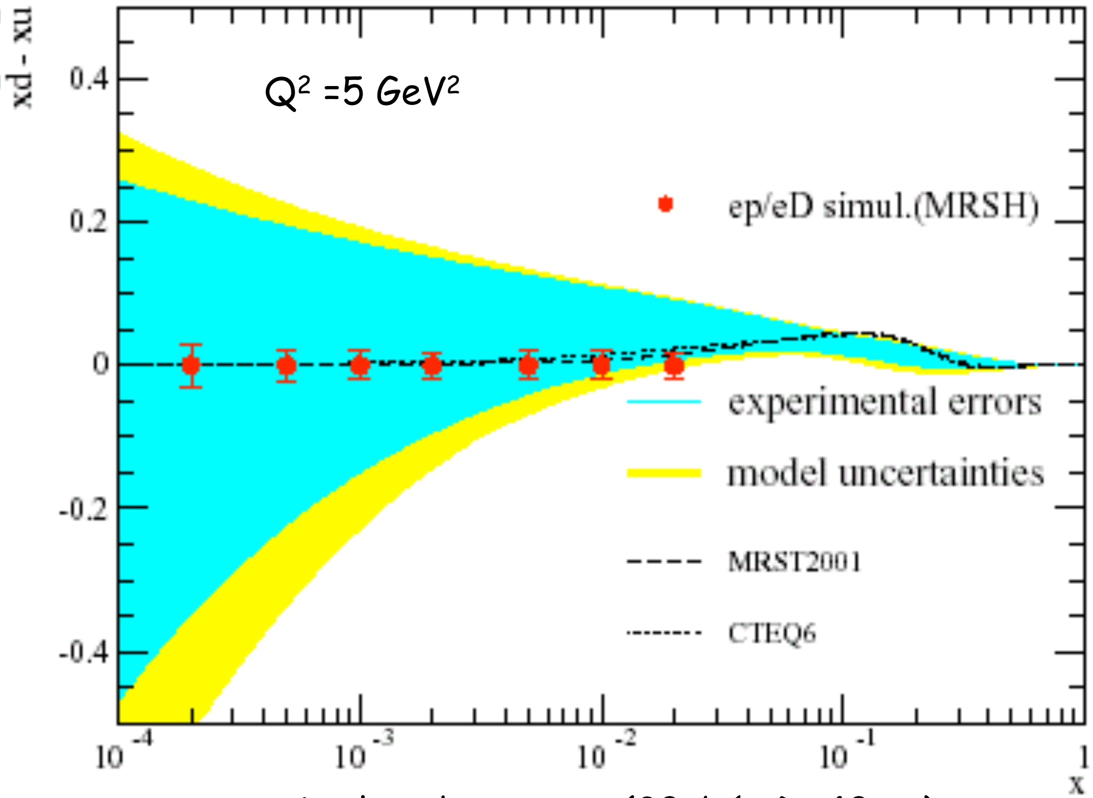
simulated accuracy (20pb^{-1} eD, 40 ep)

$$\tfrac{1}{2}\left(F_2^{\,p} + F_2^{\,n}\right) - F_2^{\,p}$$
$$= x\left(\tfrac{1}{6}d_v - \tfrac{1}{6}u_v + \tfrac{1}{3}\bar{d} - \tfrac{1}{3}\bar{u}\right)$$
$$\approx \tfrac{1}{3}x\left(\bar{d} - \bar{u}\right) \text{ at low } x.$$

H1 + BCDMS



The light sea quark asymmetry is expected and has been assumed to vanish at low x. However, F_2 rises strongly towards low x which deserves to be studied.



$$\tfrac{1}{2}\left(F_2^{\,p}+F_2^{\,n}\right)-F_2^{\,p}$$
$$=x\left(\tfrac{1}{6}d_v-\tfrac{1}{6}u_v+\tfrac{1}{3}\bar{d}-\tfrac{1}{3}\bar{u}\right)$$
$$\approx\tfrac{1}{3}x\left(\bar{d}-\bar{u}\right)\text{ at low } x.$$

simulated accuracy (20pb^{-1} eD, 40 ep)

H1 + BCDMS

Electron-deuteron scattering at HERA[+)]

New source, standard apparatus with FPS added for ½ beam energy

Tag spectator proton to reconstruct en scattering kinematics 'free' of nuclear corrections

Shadowing controlled at per cent level with diffraction

Luminosity requirement for low x physics modest ~ 20pb^{-1} (one year)

Need higher luminosity for CC and high x programme (two-three years)

[+)] proposed to PRC 5/03 - not rejected but said to be in contradiction with (I)LC, PETRAIII
two proposals: eD with H1': DESY 03-194 and low x with new detector: MPI-PhE/2003-06

Summary

The parton distributions determined at HERA when evolved to the LHC region change their relative importance (heavy flavours rise relatively to light quarks) and maintain their differences in absolute: they ought to be determined precisely.

So far HERA has not resolved the light sea quarks at low x. Thus the QCD fits employ the ("reasonable") assumption that $\bar{u}=\bar{d}$ and that $u=\bar{u}$ and $d=\bar{d}$ at low x.

[This reasonable assumption was proven to be wrong at larger x ~ 0.1.]

Without these requirements the fits become unstable, existing lD data (BCDMS as used here) help but can't solve the problem as they are at higher x, as DY data.

The question of a sea asymmetry is important for npQCD (chiral soliton model for example), for superhiE neutrino scattering (on nuclei) and for precise predictions for the LHC extending to the rapidity plateau ($\eta \leq 0$). A precision measurement of $\bar{u}$, $\bar{d}$ in the low x range can be done within 1 year of (further) operation of HERA. This measurement has further basic implications on the understanding of parton dynamics (diffraction – shadowing, improvement by a factor ~2 of the α_s measurement by disentangling nonsinglet-singlet evolution).

In the light of the LHC operating HERA in eD mode should be reconsidered.