Report of the WG1 – Parton Density Functions

Conveners: M. Dittmar, S. Forte, A. Glazov, S. Moch

Questions addressed by the group

HERA X-sections → PDFs → LHC processes

The keywords: Precision, Completeness and Self-consistency.

- What are relevant measurements/ultimate precision of HERA data ?
- What additional measurements we should/could do ?
- What is impact of these data on PDFs ?
- Do we understand experimental/fitting uncertainties ?
- Do we have a self-consistent global picture ?
- What are theoretical uncertainties, how to estimate/control them ?
- What are the LHC processes with small theoretical uncertainties, which benefit from precise pdfs in particular? Can we achieve comparable experimental precision ?

Determination of PDFs

PDF decomposition (ignoring b and t):

$$xU(x) = x(u + c) \quad xD(x) = x(d + s) \quad xG(x)$$

Well determined PDFs:

At high $x > 0.1$, $u, \bar{u}, d, \bar{d}$ are resolved using HERA NC/CC as well as fixed target data.

At low x, measure sea quark contribution: $F_2 \sim 4(U + \bar{U}) + (D + \bar{D})$ and determine gluon from $\partial F_2 / \partial \log Q^2$.

Less known PDFs:

Gluon at $x \sim 0.1$ is from jet data (Tevatron/HERA).
Gluon at low and high x is coupled through momentum sum rule.
<u>Can measure</u> gluon at low $x \sim 0.001$ from F_L.

Little known PDFs:

$s, \bar{s}$ as well $\bar{u} - \bar{d}$, $u_p - d_n$ at $x \sim 0.1$

Assumed PDFs:

Assume that non-singlet $x(q - \bar{q})$ is valence like and that $\bar{d} - \bar{u}$ difference vanishes at small x.

Part I – Hera experiments

Kinematics reconstruction

- Electron method – high y
  - scattered electron kinematics only
  - y-resolution deteriorates as 1/y

$$y_e = 1 - \frac{E'_e}{E_e}\sin^2\frac{\theta_e}{2} \qquad Q^2_e = 4E'_eE_e\cos^2\frac{\theta_e}{2} = \frac{E'^2_e\sin^2\theta_e}{1-y_e}$$

- Sigma method - low y
  - combines scattered electron and hadronic final state measurements
  - independent on the incoming electron energy → initial state radiation insensitive.

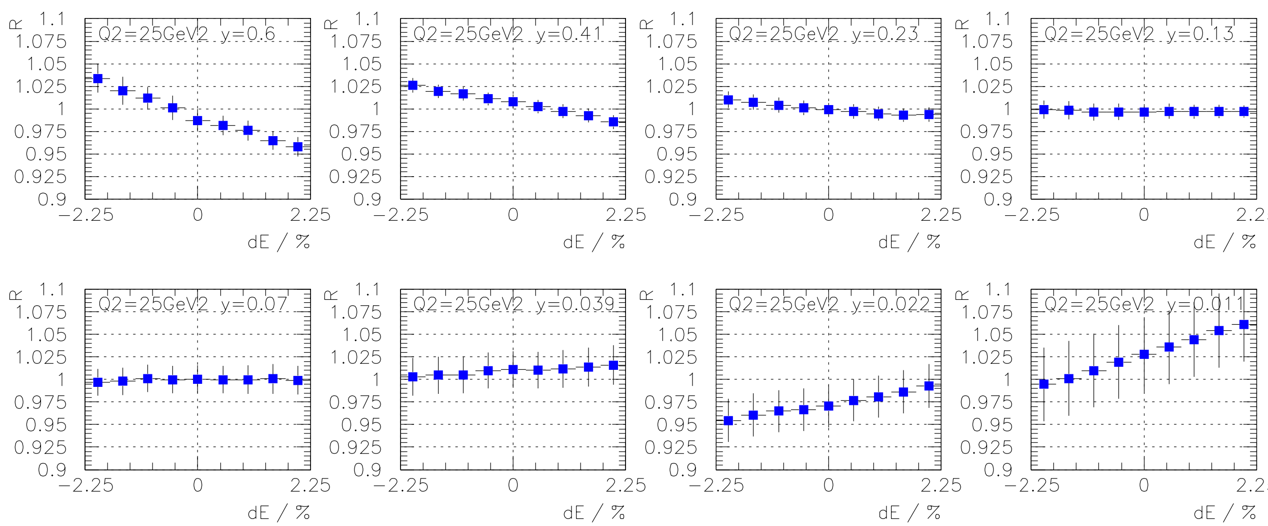
$$y_\Sigma = \frac{\Sigma}{\Sigma + E'_e(1-\cos\theta_e)} \qquad Q^2_\Sigma = \frac{E'^2_e\sin^2\theta_e}{1-y_\Sigma}$$

$$\Sigma = \sum_h E_h(1-\cos\theta_h)$$

Ultimate precision at HERA (G.Lastovicka-Medin)

Electron/Sigma method σ_r comparison

- Half of available Monte Carlo statistics [12 mil.ev.] used to simulate data.
- Number of subsamples N=12
- Example of ratio scan (hadronic final state calibration):

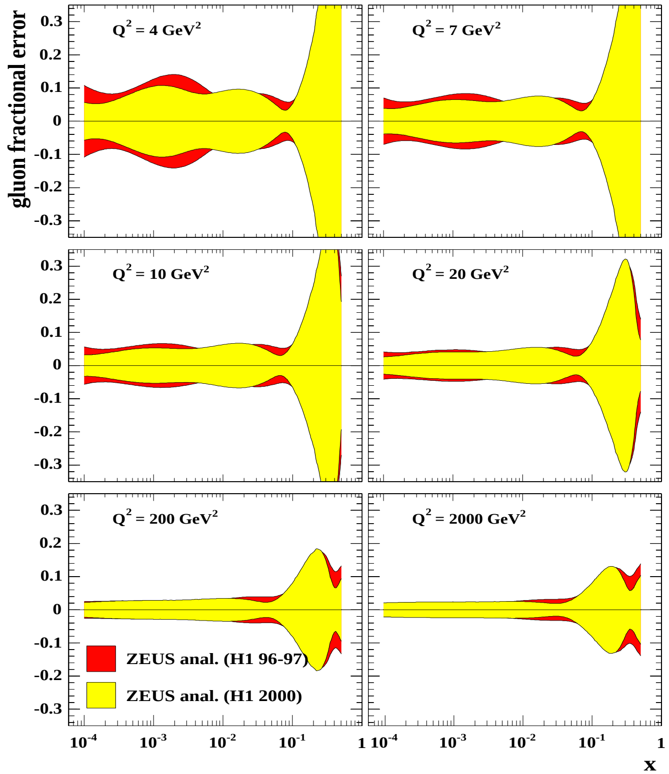


Different systematic sensitivity allows cross calibration of the methods. → precision of 1% is feasible

Impact of 1% F_2 on PDFs (C.Gwenlan)

Precision HERA data and low-x gluon

- Comparison of gluon PDFs
  - reduced systematic uncertainties give improved knowledge of gluon at low-x for relatively low-Q^2
  - Some reduction in uncertainties also seen at mid-to-high-x, continuing to high scales (momentum sum?)



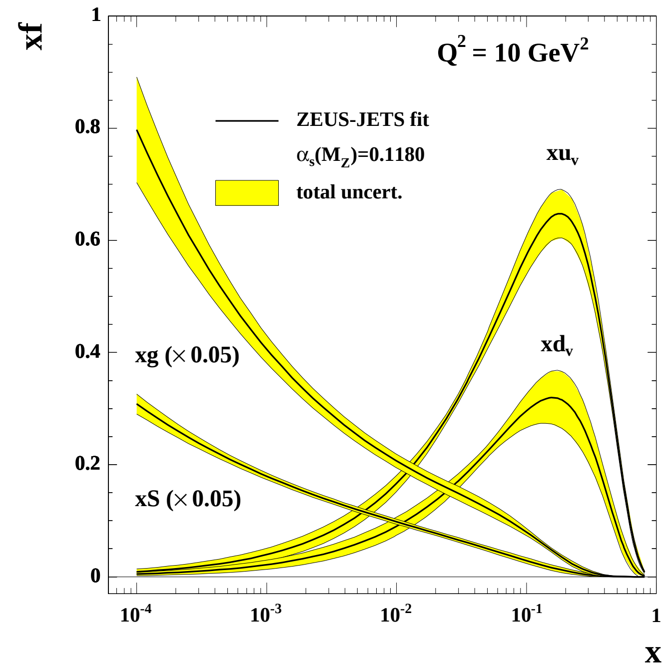
$\longrightarrow$ Moderate impact on xG

HERA jets (C.Gwenlan)

The ZEUS-JETS QCD fit

- ZEUS-JETS QCD analysis uses the full set of HERA-I inclusive DIS data and two sets of jet data
  - Cuts on inclusive data in fit:
    - $Q^2 \geq 2.5\ GeV^2$, $W^2 > 20\ GeV^2$

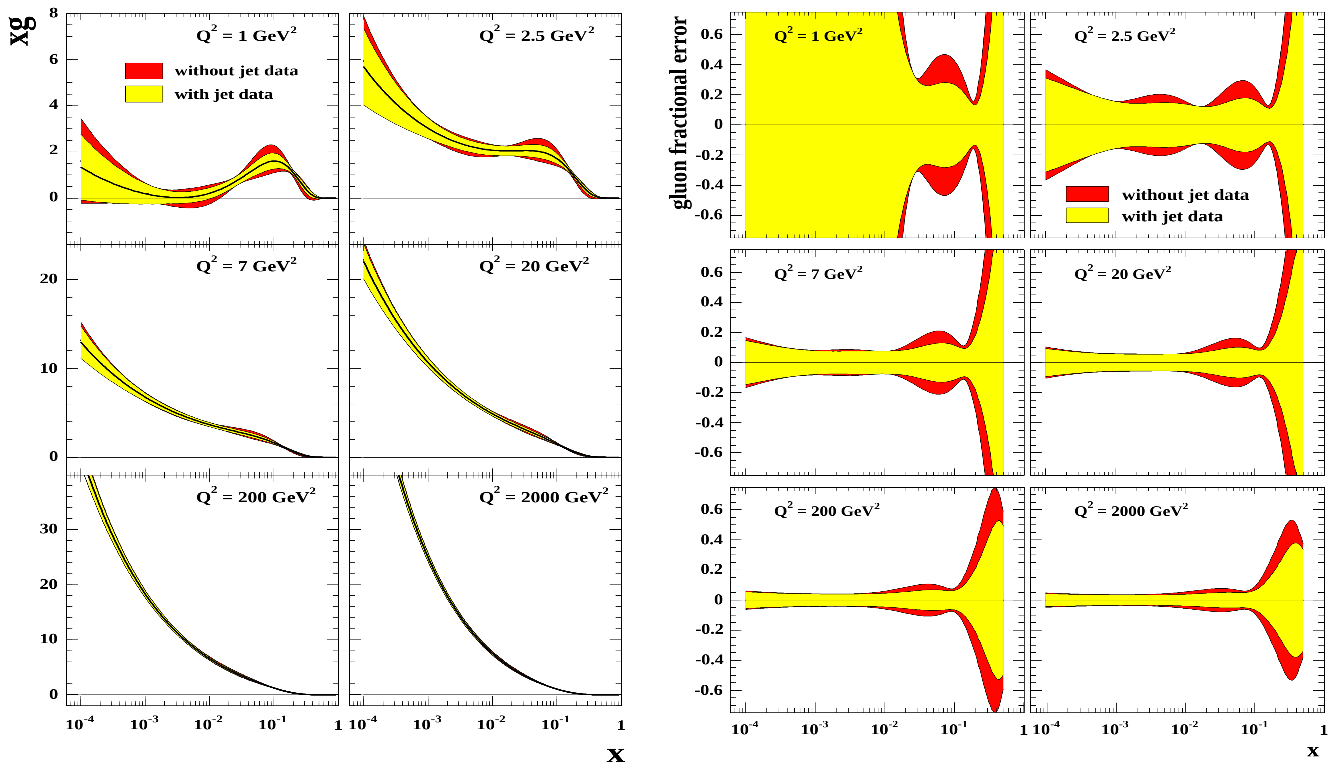
ZEUS Data Set	N_{data}
NC e+p 96-97	242
CC e+p 94-97	29
NC e-p 98-99	92
CC e-p 98-99	26
NC e+p 99-00	90
CC e+p 99-00	30
DIS jets e+p 96-97	30
γp two-jets e+p 96-97	38
χ^2/data-points	470/577



NOTE: Full details of the ZEUS-JETS fit have been presented previously, see HERA-LHC PDF subgroup meeting, "Addition of jet data to the ZEUS QCD Fit", Claire Gwenlan, June 2004. Also see DESY-05-050.

HERA jets impact on PDFs (C.Gwenlan)

Impact of jet data on the gluon PDF



- Inclusion of jet data improves knowledge of gluon at mid-to-high-x
  -> improvement persists up to high scales

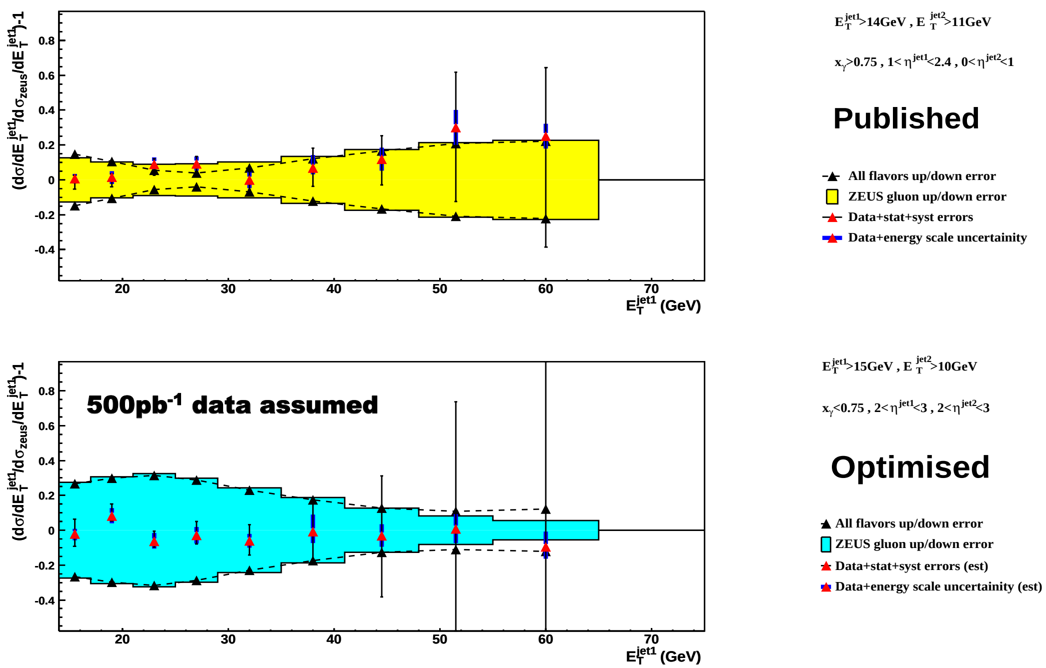
5

$\longrightarrow$ Improvement of xG at $x \sim 0.01 - 0.1$

HERA jets prospects (C.Gwenlan)

Optimised jet cross sections

by Christopher Targett-Adams

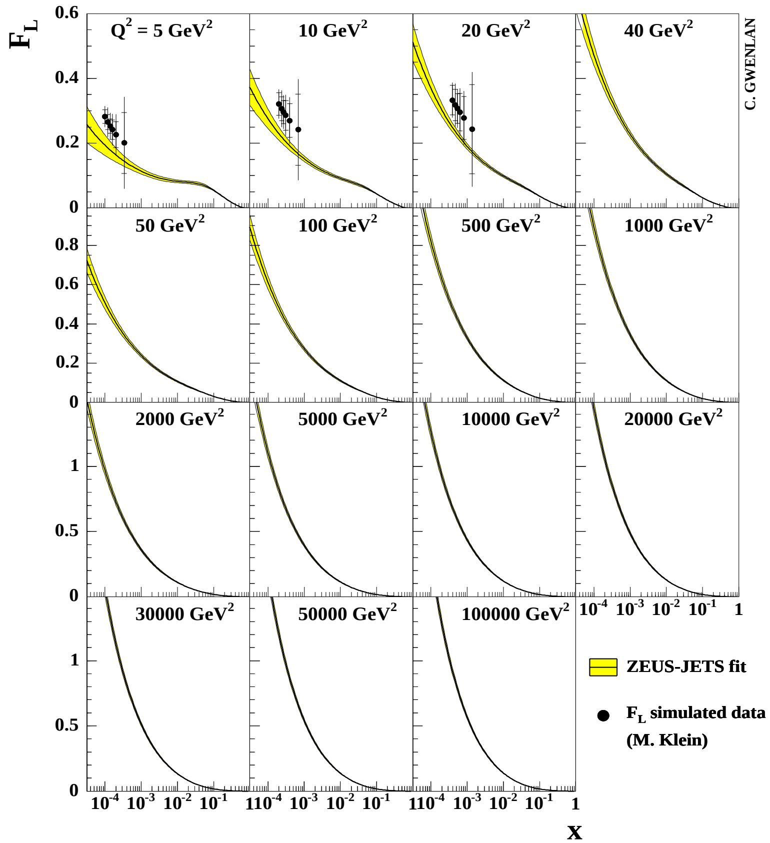


With HERA-II data, potential to measure cross sections designed to maximise sensitivity to gluon

HERA jets is a new method, optimization/improvements in systematic can be significant

HERA F_L measurement (C.Gwenlan)

Comparison to prediction of ZEUS-JETS fit



With central values from GRV94, F_L data lies above predictions of ZEUS-JETS

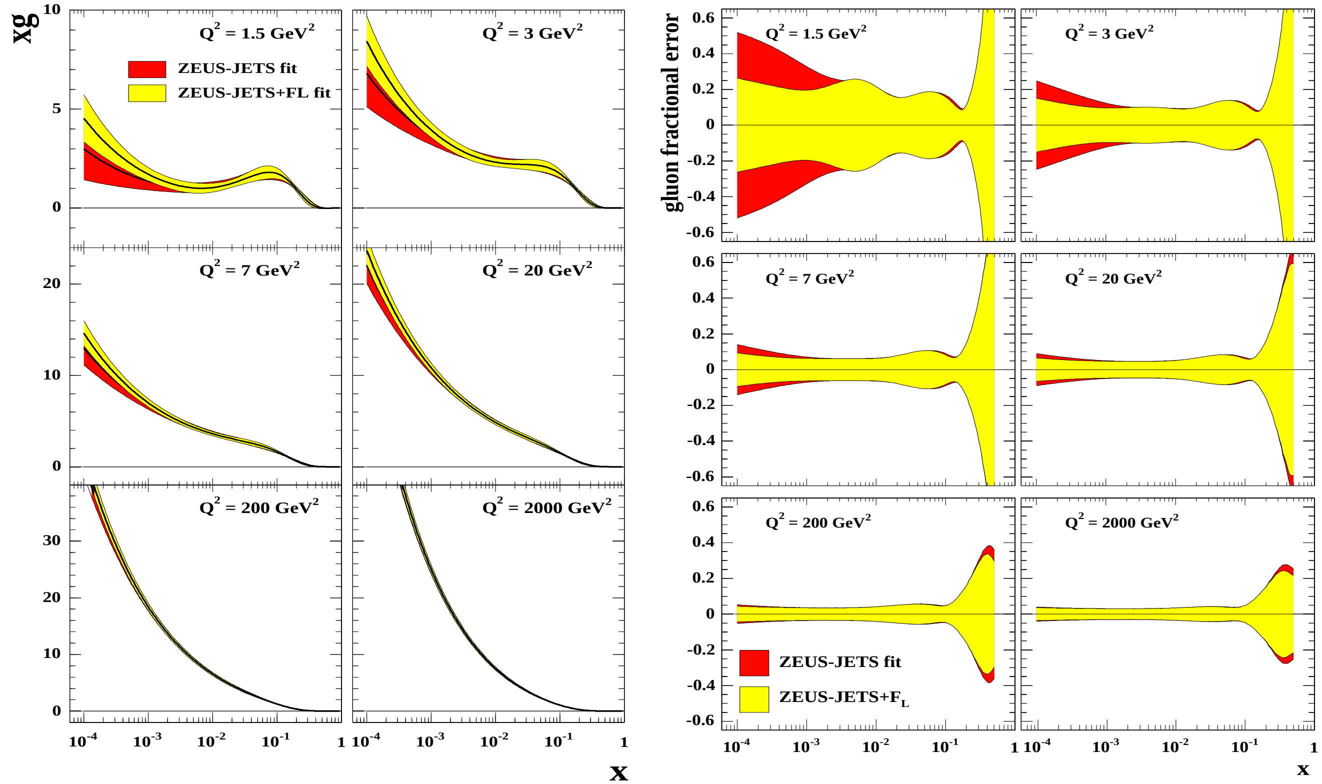
How much impact would an F_L measurement of this precision have on PDF fits?

← No FL "data" included in fit

Study based on F_L "measured" at $E_p = 575, 465, 400$ GeV (M. Klein)

HERA F_L impact on PDFs (C.Gwenlan)

The gluon distribution

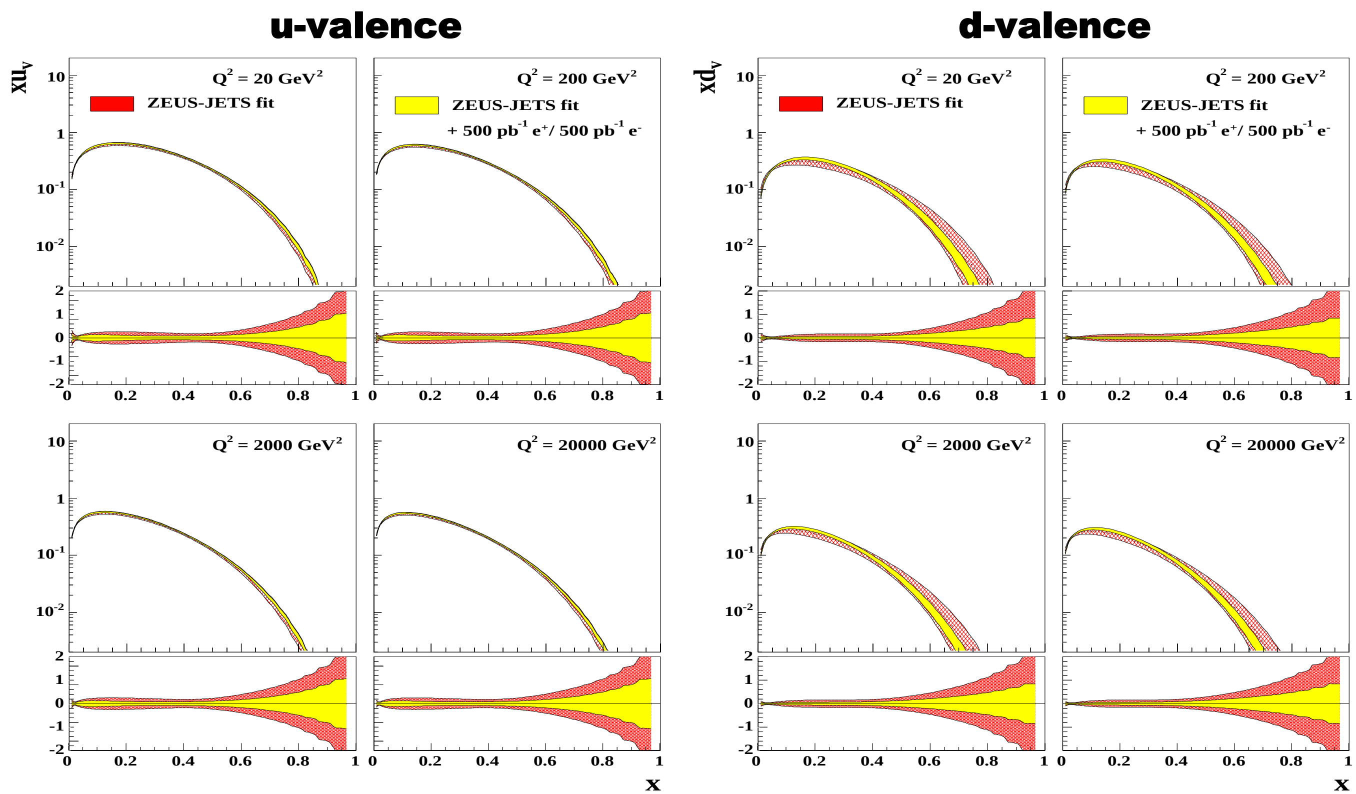


- Gluon is pulled higher at low-x (most significant at low-Q^2)
- Gluon uncertainties reduced at low-x and low-Q^2 (up to Q^2 of F_L "data")

Significant localized improvement on $xG(x)$ at low x, around the region where F_L would be measured.

HERA-II high Q^2 data (C.Gwenlan)

Impact on valence distributions



- Increased statistics on NC/CC e+/e- data has a significant impact on the valence
  → uncertainties reduced by up to a factor of two

Study based on 500pb^{-}1 of each e^+p and e^-p data

Small x behaviour of $U, \bar{U}, D, \bar{D}$ (M.Klein)

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

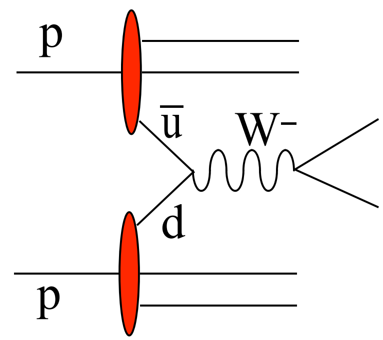
What causes rise to low x?
measured 4ū+đ, some xg. Yet,
ū and đ are unknown at low x but
accessible via eD [F_L for xg].
Precision measurements required!

ū=đ 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

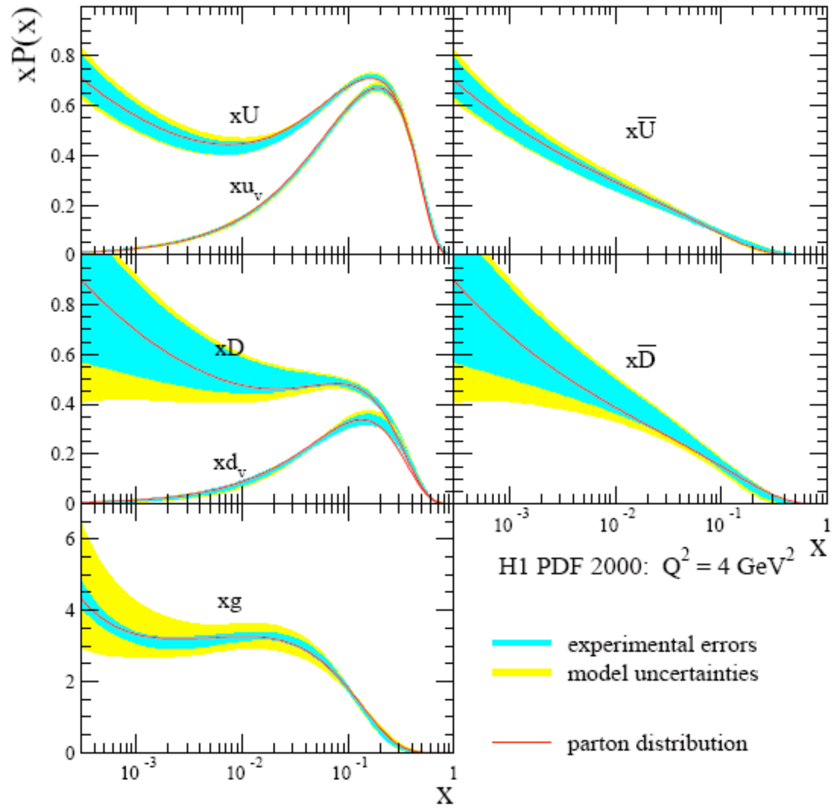
$$A_l(\eta) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta} \simeq \frac{d(x)}{u(x)}$$



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

Fit with "free" $U, D, \bar{U}, \bar{D}$ at low x (M.Klein)

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

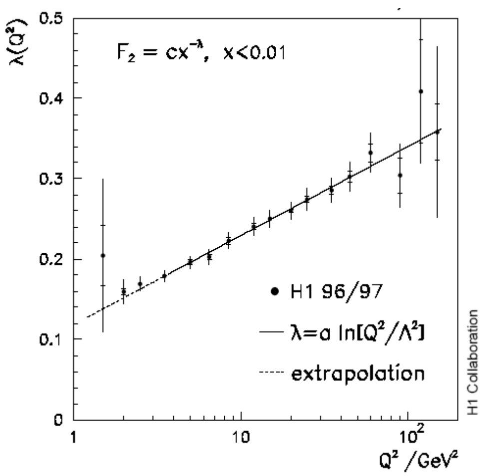


H1 + BCDMS

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

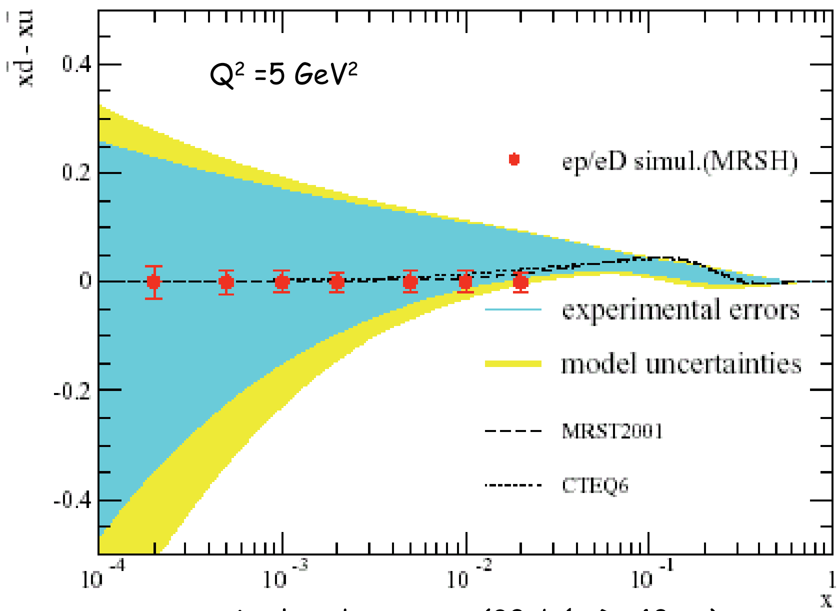
Difference between $x\bar{d} - x\bar{u}$ stays constant vs Q^2

$\bar{d} - \bar{u}$ measured with deuteron data (M.Klein)



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.

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



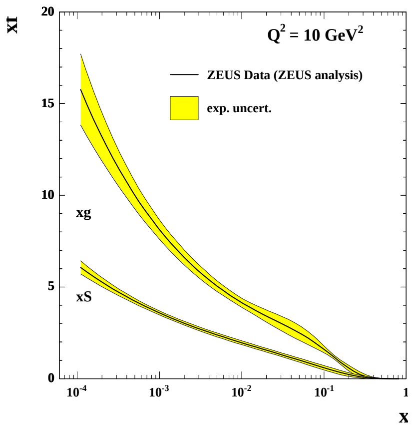
simulated accuracy (20pb⁻¹ eD, 40 ep)

H1 + BCDMS

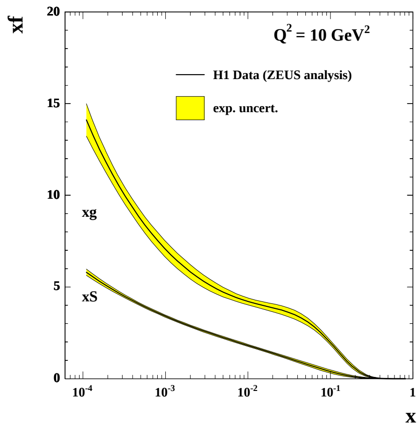
HERA-LHC workshop Sea Asymmetry at Low x M. Klein and B. Reisert March 21st, 2005 DESY Hamburg

LHC W^+/W^- data is also sensitive to $\bar{d} - \bar{u}$.
Predictability vs a posteriori tuning ?

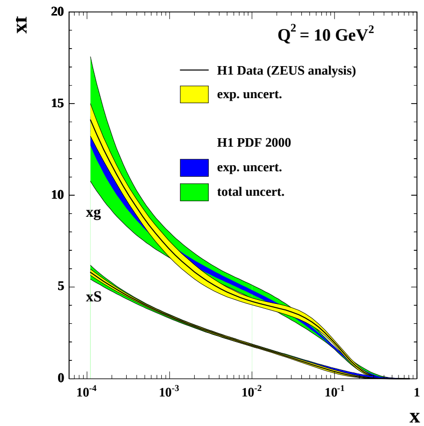
Comparison of H1 and Zeus (M. Cooper-Sarkar)



ZEUS analysis/ZEUS data



ZEUS analysis/H1 data



ZEUS analysis/H1 data compared to

H1 analysis/H1 data

Here we see the effect of differences in the data, recall that the gluon is not directly measured (no jets)

The data differences are most notable in the large 96/97 NC samples at low-Q2 The data are NOT incompatible, but seem to 'pull against each other'

IF a fit is done to ZEUS and H1 together the χ2 for both these data sets rise compared to when they are fitted separately………..

Here we see the effect of differences of analysis choice - form of parametrization at Q2_0 etc

"Hessian" vs "Offset" fitting (M. Cooper-Sarkar)

Hessian and Offset uncertainty estimation in PDF fitting……

Experimental systematic errors are correlated between data points, so the correct form of the **χ2** is

$$\chi^2 = \sum_i \sum_j [F_i^{QCD}(p) - F_i^{MEAS}] V_{ij}^{-1} [F_j^{QCD}(p) - F_j^{MEAS}]$$

$$V_{ij} = \delta_{ij}(\sigma_i^{STAT})^2 + \sum_\lambda \Delta_{i\lambda}^{SYS} \Delta_{j\lambda}^{SYS}$$

Where $\Delta_{i\lambda}^{SYS}$ is the correlated error on point **i** due to systematic error source **λ**

It can be established that this is equivalent to

$$\chi^2 = \sum_i \frac{[F_i^{QCD}(p) - \sum_\lambda s_\lambda \Delta_{i\lambda}^{SYS} - F_i^{MEAS}]^2}{(\sigma_i^{STAT})^2} + \sum s_\lambda^2$$

Where s_λ are systematic uncertainty fit parameters of zero mean and unit variance

This form modifies the fit prediction by each source of systematic uncertainty

Average of the DIS X-section data (S.Glazov)

Standard F_2 representation:

$$\chi^2(\{F_2^{true}\},\{\alpha\}) = \sum_i \frac{\left[F_2^{i,true} - \left(F_2^i + \sum_j \frac{\partial F_2^i}{\partial \alpha_j}\alpha_j\right)\right]^2}{\sigma^2_{F_2}} + \sum_j \frac{\alpha_j^2}{\sigma^2_{\alpha_j}}. \quad (1)$$

Here α_j — are correlated systematic uncertainty sources.

For several experiments, $\chi^2_{tot} = \sum_{exp} \chi^2_{exp}$. This χ^2 is normally used in QCD fits where $F_2^{true} = F_2^{theory}(glue, quarks)$.

Fit vs F_2, α values $\rightarrow$ *average* F_2

Averaging procedure is a compromise between Hessian and Offset methods. Data is pulled together following systematics (Hessian-like), no fitting to theory (Offset-like)

Average of all HERA data (S. Glazov)

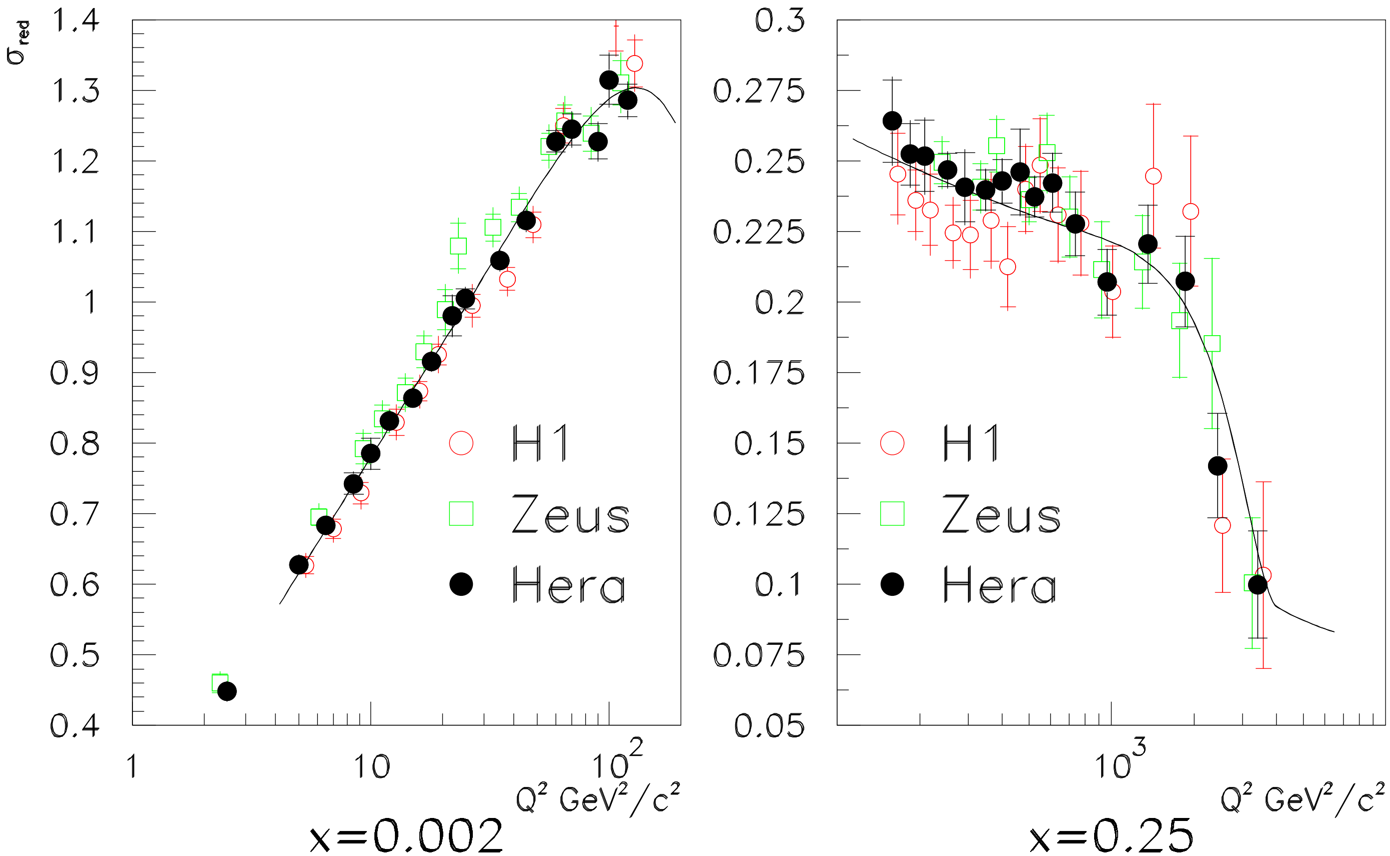
Changes in systematic uncertainties:

Fitted systematics:

		shift	uncertainty
1	zlumi1_zncepl	-1.2841	0.5836
2	h2_Ee_Spacal	0.6440	0.3281
3	h3_Ee_Lar_00	-0.8265	0.4435
4	h4_ThetaE_spacal	-0.2569	0.6566
5	h5_ThetaE_94-97	-0.1756	0.7802
6	h6_ThetaE_00	-0.3027	0.5288
7	h7_H_Scale_Spacal	0.3750	0.4813
8	h8_H_Scale_Lar	-0.8554	0.5353
9	h9_Noise_Hcal	-0.6404	0.3591
10	h10_GP_BG_Spacal	-0.1805	0.8260
11	h11_GP_BG_LAr	1.0769	0.8560
12	h12_BG_CC_94-97	0.2680	0.7883
13	h13_BG_CC_98-00	-1.0295	0.8589
14	h14_ChargeAsym	0.0246	0.9993
15	h1lumi1_SPACAL_bulk	-0.0696	0.5612
16	h1lumi2_SPACAL_MB	1.0815	0.6271
17	h1lumi3_LAr_94-97_e+p	-2.7111	0.6103
18	h1lumi4_LAr_e-p	-0.6585	0.7737
19	h1lumi5_LAr_2000	-2.5156	0.5885

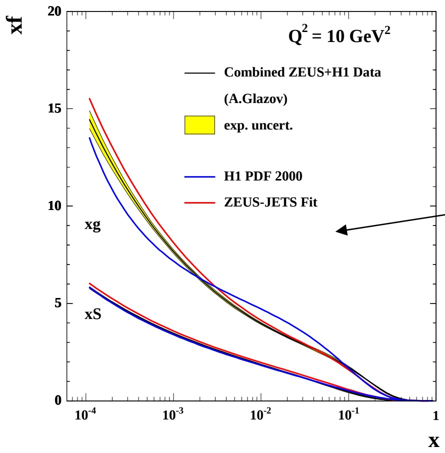
- Good global $\chi^2/ndf = 533.9/601$
- Most of the changes are within 1σ
- Several systematic sources are reduced by factor 2 and more

Average of HERA data (S.Glazov)



Factor of ~ 2 improvement in errors. For low $Q^2 \sim 10$ GeV^2/c^2 data reaches $< 2.0\%$ precision. Bins at $Q^2 \sim 1000$ GeV^2/c^2 have 4% precision (plus 0.5% overall luminosity uncertainty).

Average data in QCD fit (M. Cooper-Sarkar)

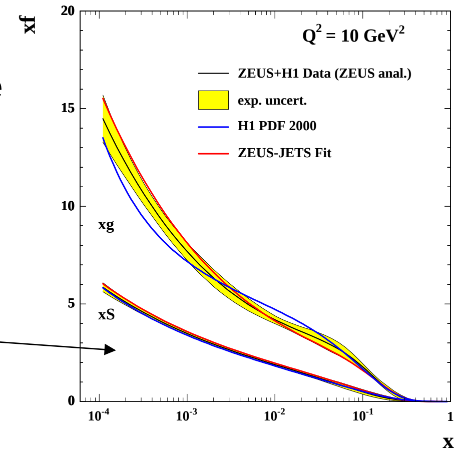


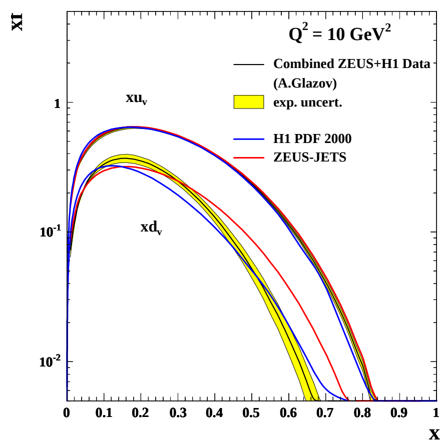
Compare this PDF fit to the H1 and ZEUS averaged inclusive xsecn data

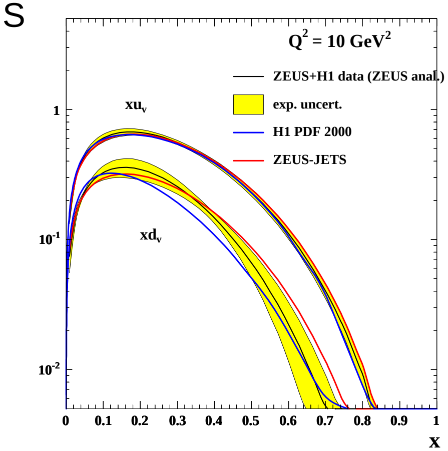
To the PDF fit to H1 and ZEUS inclusive xsecn data NOT averaged –where we get more of a compromise between ZEUS and H1 published PDF shapes

The PDF fit to H1 and ZEUS not averaged was done by the OFFSET method ..

We could consider doing it by the HESSIAN method- allowing the systematic errors parameters to be detemined by the fit







Consensus: model independent analysis of the data is desirable.
Joint H1-Zeus working group.

Param. bias free data representation (A.Piccione)

General strategy: I

- Monte Carlo sampling of data (Generation of replicas of experimental data) $\longrightarrow$ Faithful representation of uncertainties
- Neural network training over Monte Carlo replicas $\longrightarrow$ Unbiased parametrization

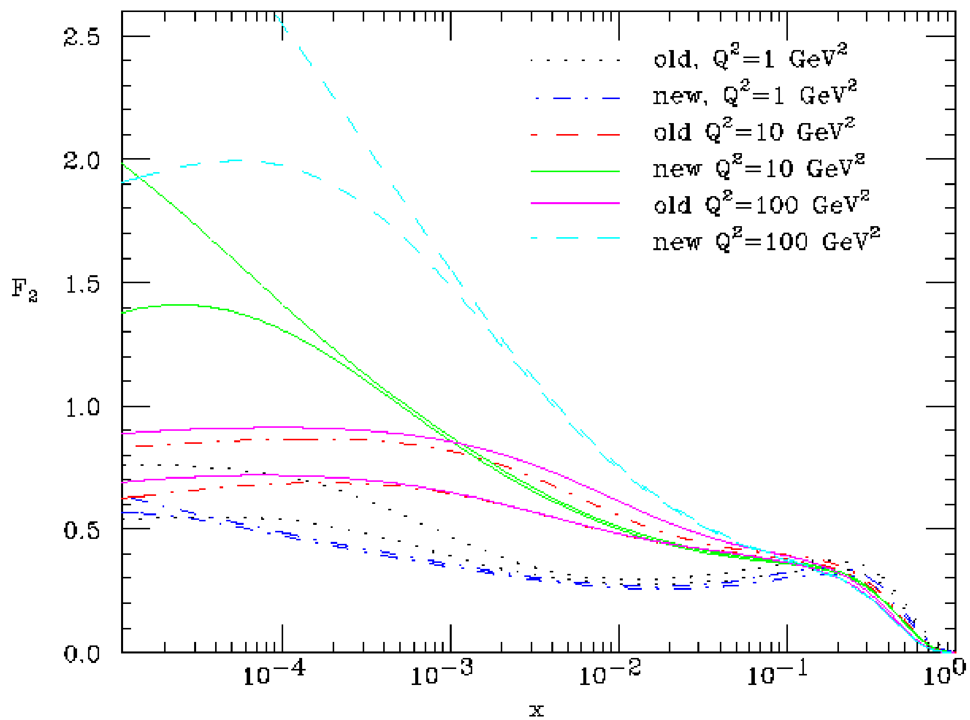
Expectation values $\longrightarrow$ Sum over the Nets

$$\left\langle \mathcal{F}\left[F(x,Q^2)\right]\right\rangle = \frac{1}{N_{rep}} \sum_{k=1}^{N_{rep}} \mathcal{F}\left(F^{(net)(k)}(x,Q^2)\right)$$

$\mathcal{P}\left[F(x)\right]$ validated through statistical estimators

Results for F_2 (A.Piccione)

Fit of $F_2^p(x, Q^2)$



Fit to F_2 excluding ("old") and including ("new") HERA data

HERA-experimental part Mini-conclusions

- HERA data has vital impact on PDFs needed for LHC predictions. More data/improved analysis techniques should lead to significant reduction of uncertainties in quark PDFs at high x, of the gluon PDF at medium and high x and to moderate improve of the gluon PDF at low x
- H1/Zeus measurements of NC/CC cross sections are in good agreement. Averaging procedure, developed during the workshop, allows to combine the data into HERA average $\leftarrow$ H1/Zeus averaging group.
- Measurement of F_L allows to reduce gluon uncertainties at low x and also provides an important check of the theory self-consistency.
- Measurement of F_2^n using eD data (HERA-III) would allow to pin down uncertainties light sea quark asymmetry at low x.