Impact of future HERA measurements on the parton density functions (using the ZEUS QCD fit)

HERA-LHC workshop
21st-24th March 2005

Claire Gwenlan
(with the help of Sasha Glazov, Max Klein, Gordana Lastovicka-Medin, Tomas Lastovicka)

- Introduction (the ZEUS QCD fit)
- Investigations:
  - impact of increased HERA-II luminosity (high-Q^2 DIS, jets)
  - impact of improved (systematic) precision on low-Q^2 DIS
  - impact of a HERA measurement of F_L
- Summary

Introduction & motivation

Besides being interesting in their own right, it is essential to know the PDFs of the proton as precisely as possible in order to maximise the physics potential at the LHC
e.g. high-x gluon dominates uncertainty in several LHC processes

HERA data are now very precise and cover a wide range in (x,Q^2)

- Inclusive NC/CC provide information on valence, low-x sea and gluon
- High precision jets give direct information on the mid-to-high-x gluon through boson-gluon fusion process

With HERA-II we hope to be able to do even better …

This talk shows the results of several studies that give a first look at the potential impact of HERA-II data on the proton PDFs

The ZEUS QCD fit parameterisation

- Parameterise PDFs in x at the starting scale Q_0^2= 7 GeV^2:
  - $xf(x) = Ax^b(1-x)^c (1+dx)$
- Evolve PDFs with Q^2 using NLO DGLAP equations
- Convolute PDFs with coefficient functions in Roberts-Thorne Variable Flavour Number Scheme to get predictions for structure functions and, hence, cross sections
- Parameterise the following PDFs:
  - u-valence (u_v), d-valence (d_v), total sea (S), gluon (g), $x\Delta$=x(dbar-ubar)

(several parameters are constrained by momentum and number sum rules)

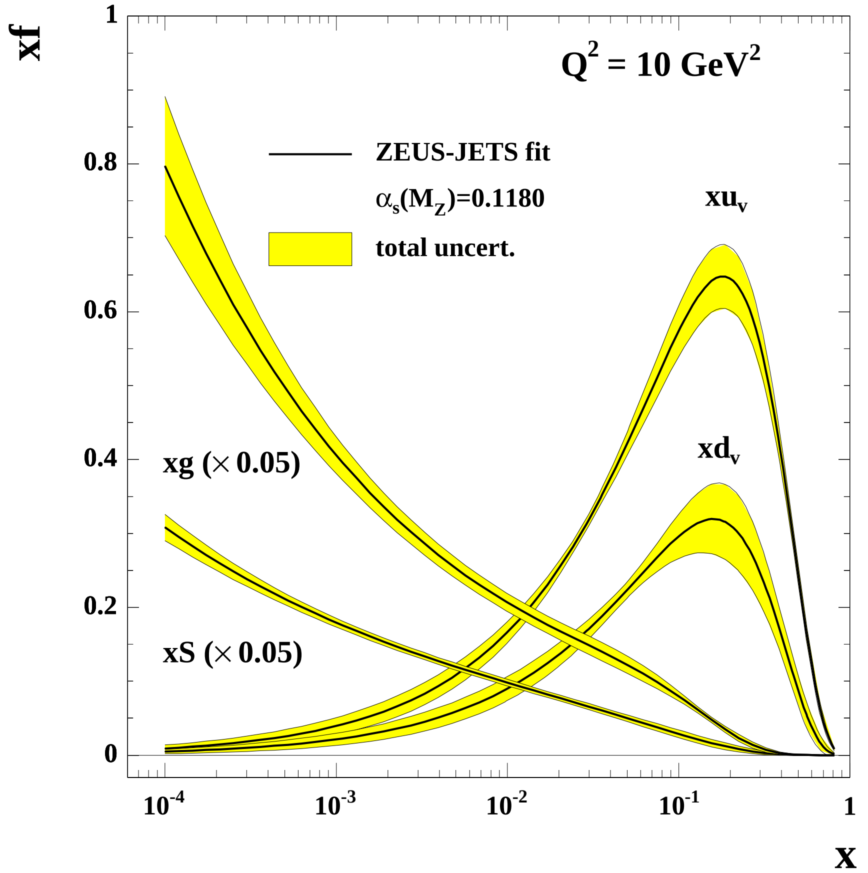
- Other assumptions:
  - $p_2u=p_2d$, $p_1\Delta$ consistent with Gottfried sum rule violation, Δ shape consistent with Drell Yan, suppression of strange sea by factor 2 (consistent with data from CCFR-NuTev)

-> 11 free parameters in total

The ZEUS-JETS QCD fit

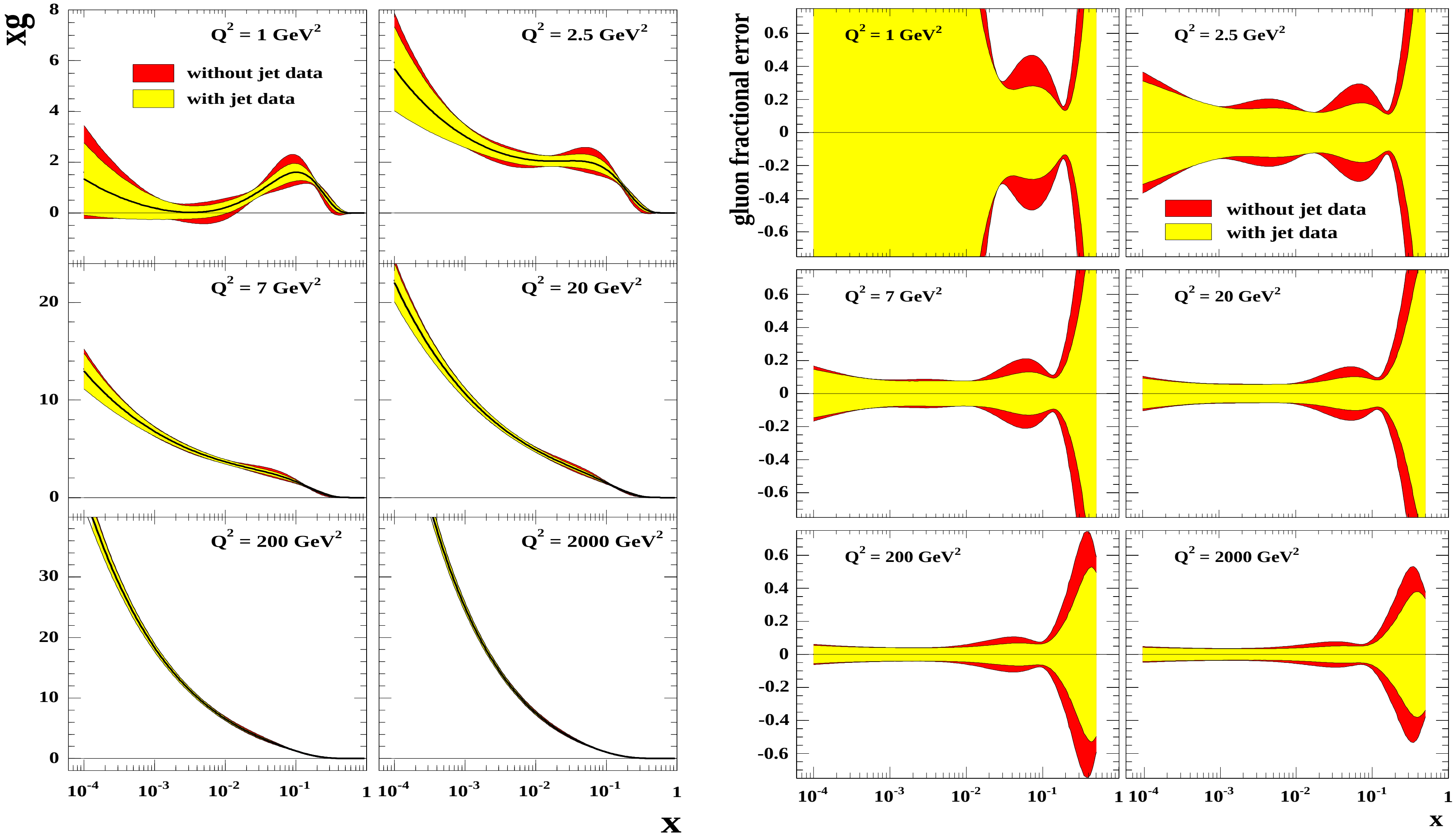
- ZEUS-JETS QCD analysis uses the full set of HERA-I inclusive DIS data and two sets of jet data
  - Cuts on inclusive data in fit:
    - $Q^2 \geq 2.5$ GeV^2, $W^2 > 20$ GeV^2

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.

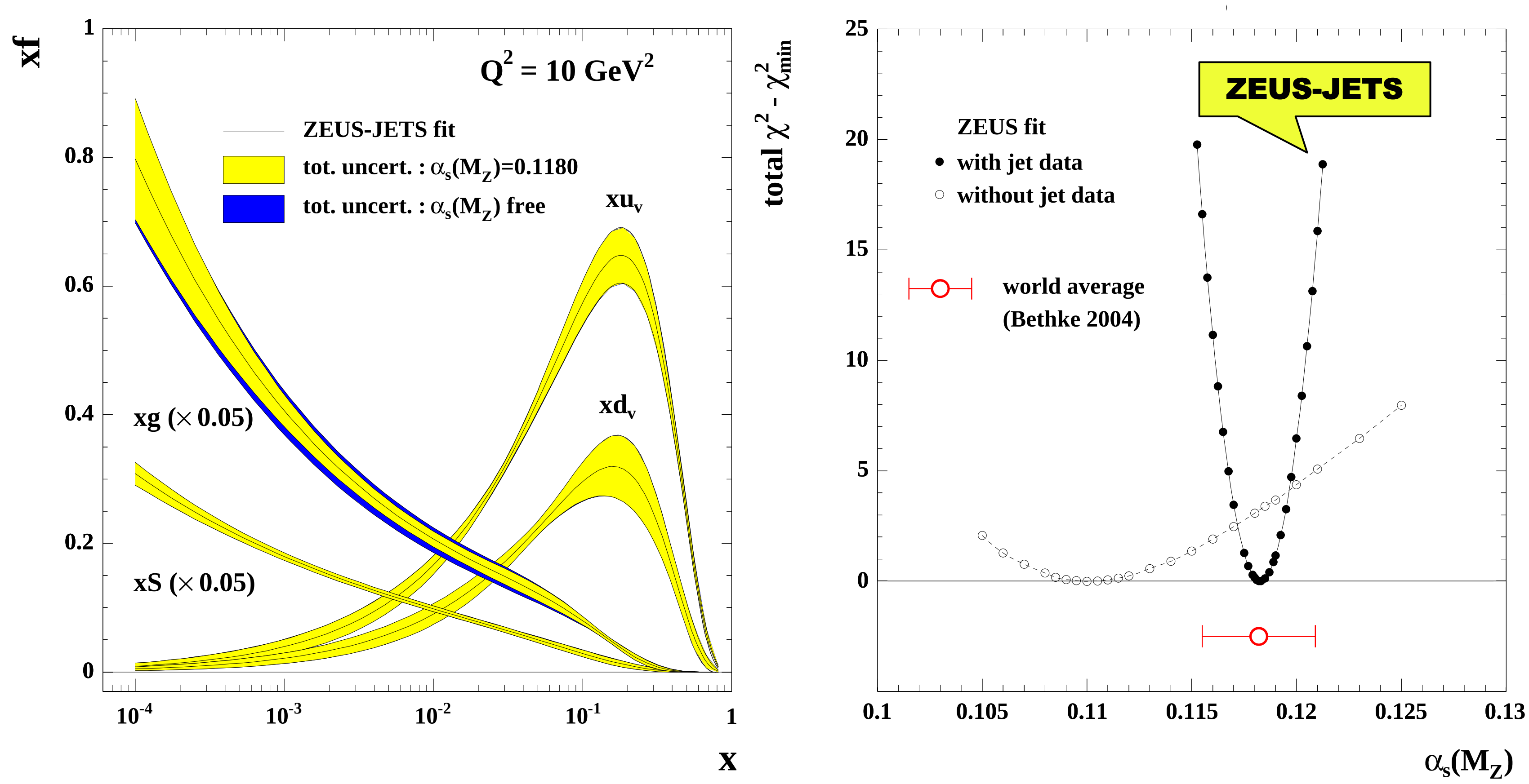
Impact of jet data on the gluon PDF



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

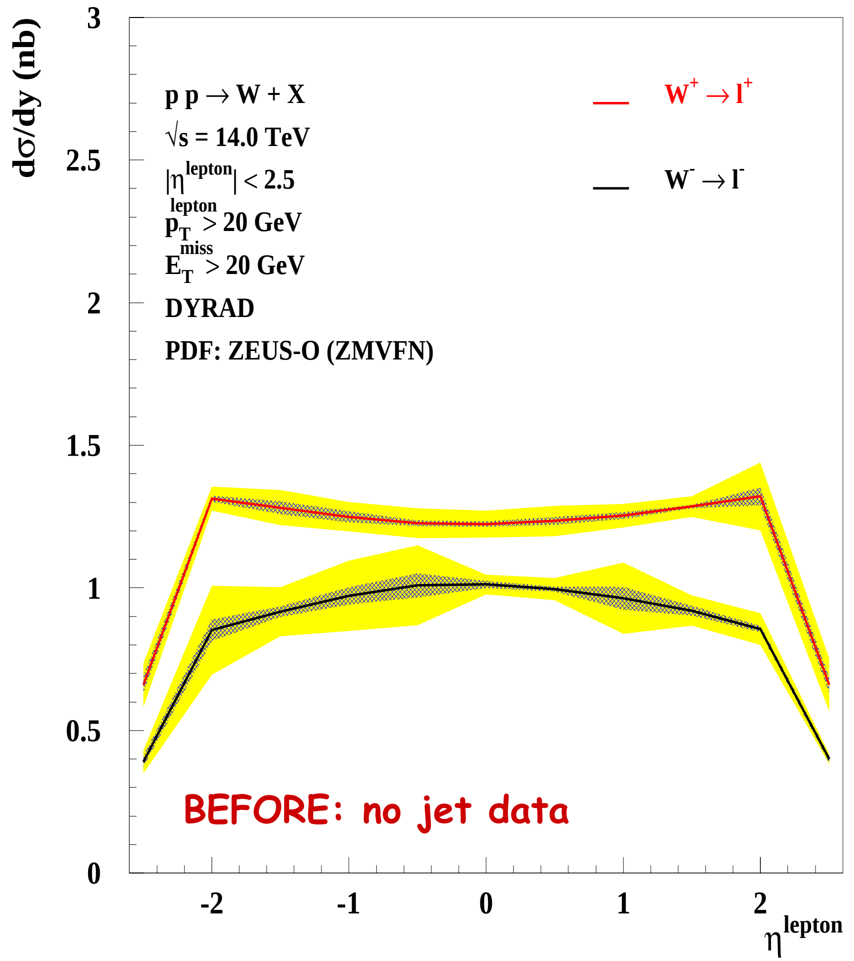
Extraction of $\alpha_s(M_Z)$

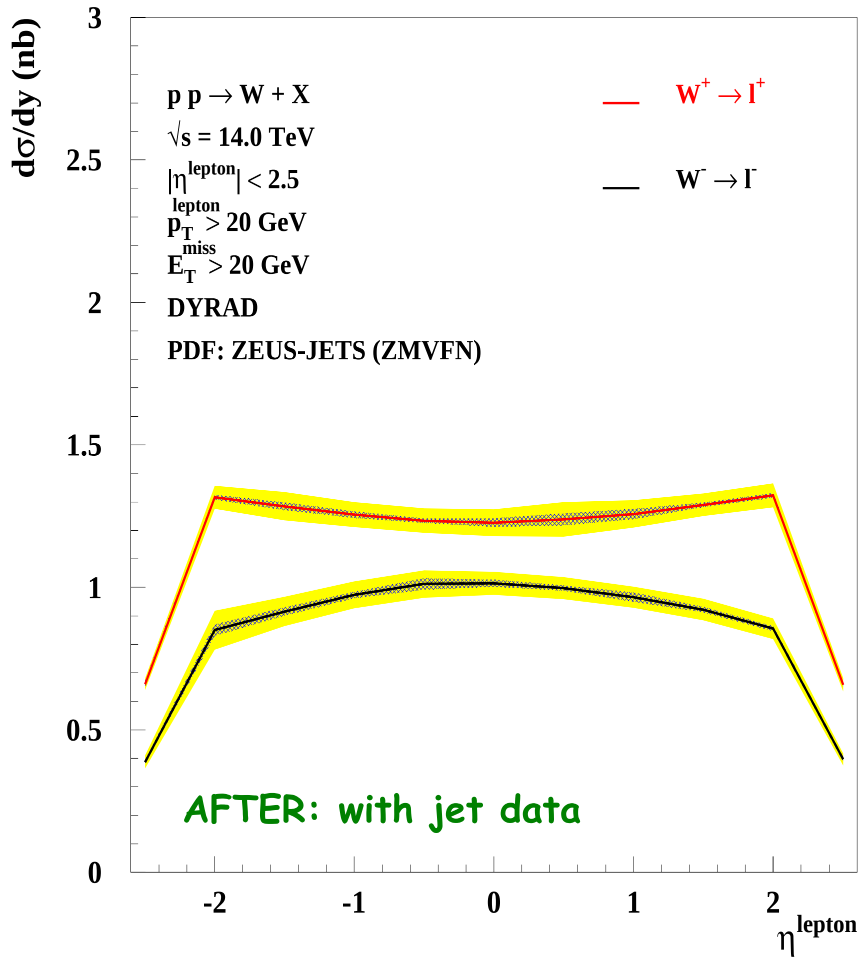
- Extra constraint on gluon provided by jet data allows accurate extraction of α_s -> treat $\alpha_s(M_Z)$ as free parameter
  - Value extracted: $\alpha_s(M_Z)=0.1183\pm0.0028(\text{exp.})\pm0.0008(\text{model})$
  - gluon uncertainties increased when α_s free (gluon and α_s correlated)



Impact on the LHC (an example)

$W^{\pm}$ production (plots from Kunihiro Nagano)

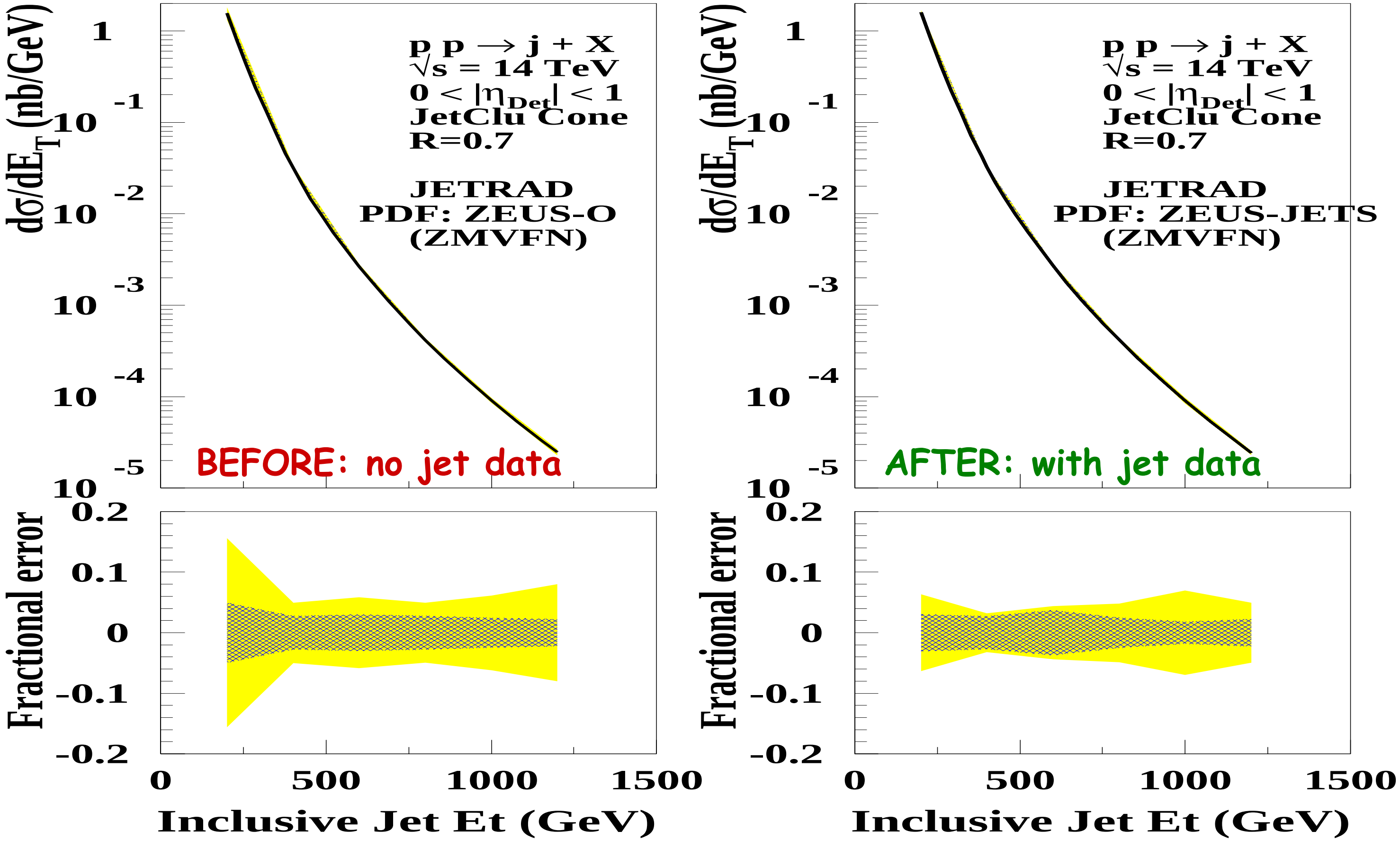




Precise knowledge of the gluon essential for many LHC processes

Impact on the LHC (an example)

Jet production (plots from Kunihiro Nagano)



Precise knowledge of the gluon essential for many LHC processes

Impact of future measurements

<u>Case studies:</u>

(I) is a recap from January '05
HERA-LHC workshop meeting, CERN

I Impact of higher luminosity delivered by HERA-II

- measurements at high-Q^2 (and/or high-E_T) are <u>statistics</u> limited at HERA-I
  - expect maximum of $1fb^{-1}$ luminosity at HERA-II

II Impact of improved systematic uncerts. on low-Q^2 HERA data

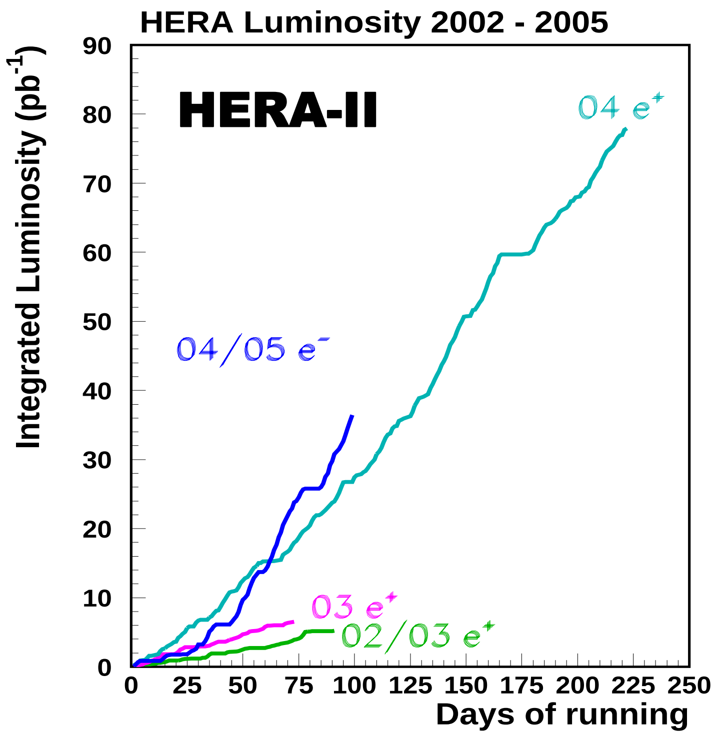
- measurements at low-Q^2 tend to be <u>systematics</u> limited at HERA-I -> systematics must be reduced if data to have increased impact in the future
  - "measurement uncertainty analysis for H1 low-Q^2 data" from Gordana Lastovicka-Medin (January '05 HERA-LHC workshop meeting) suggests 1% precision achievable

III Impact of a HERA measurement of F_L at low-x and low-Q^2

- using simulated F_L data from Max Klein

I. Impact of increased HERA-II luminosity

- HERA-II now running efficiently: hope is for 1fb^{-1} divided equally between e+/e- by end of HERA-II running



Want to estimate the impact of increased HERA-II luminosity on statistically limited data-sets

CASE STUDY: reduce statistical uncertainties on existing high-Q^2 inclusive DIS and high-E_T jet data

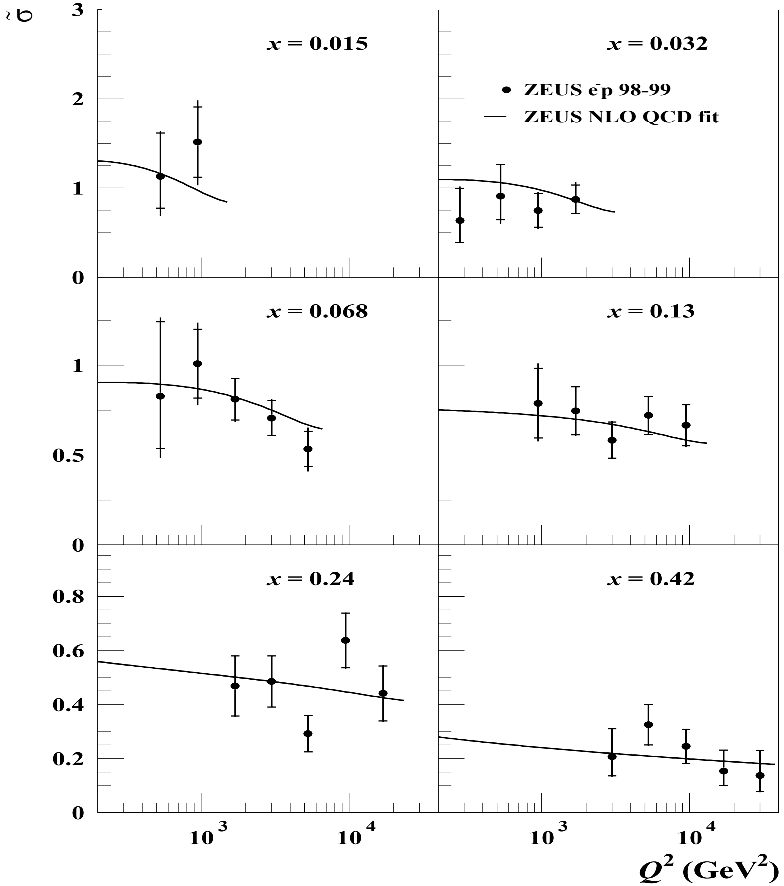
- assume maximum of 1fb^{-1}

	Sample of data	L (pb^{-1}) [ZEUS-JETS]	L (pb^{-1}) [CASE STUDY]
A	Inclusive e+/e- DIS	115/15	500/500
B	DIS/γp jet data	40	500

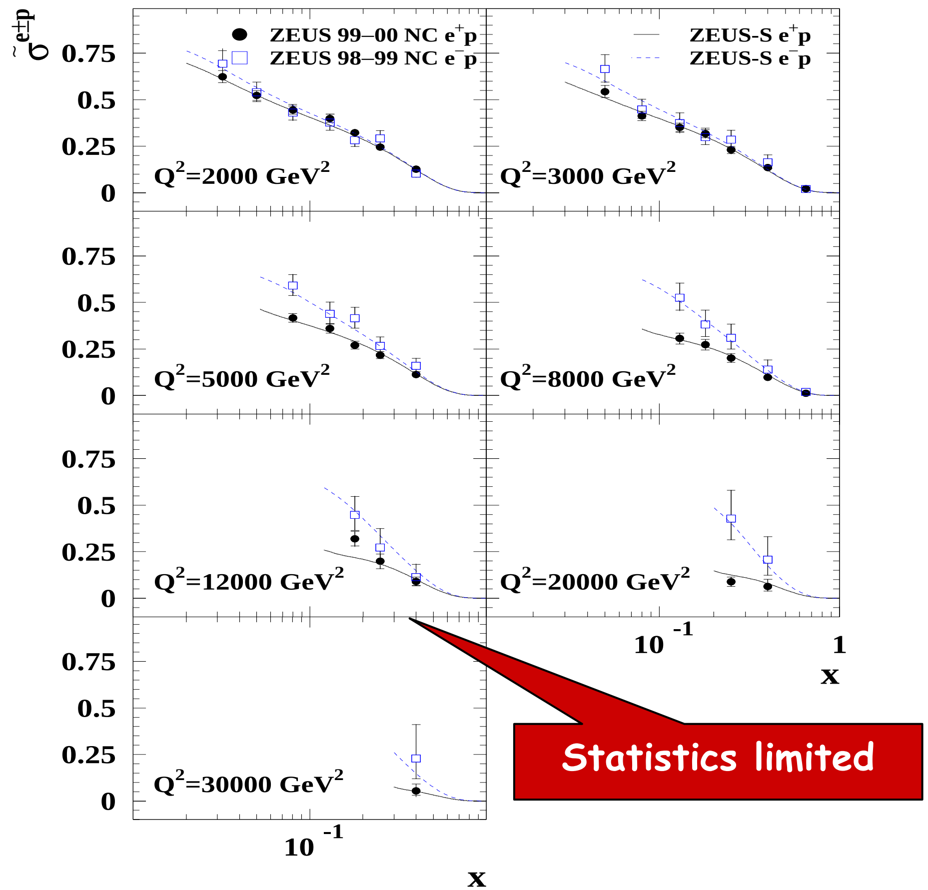
A. Increased statistics on high-Q^2 data

EXAMPLES: HERA-I inclusive NC/CC high-Q^2 measurements

HERA-I: ZEUS CC e- data

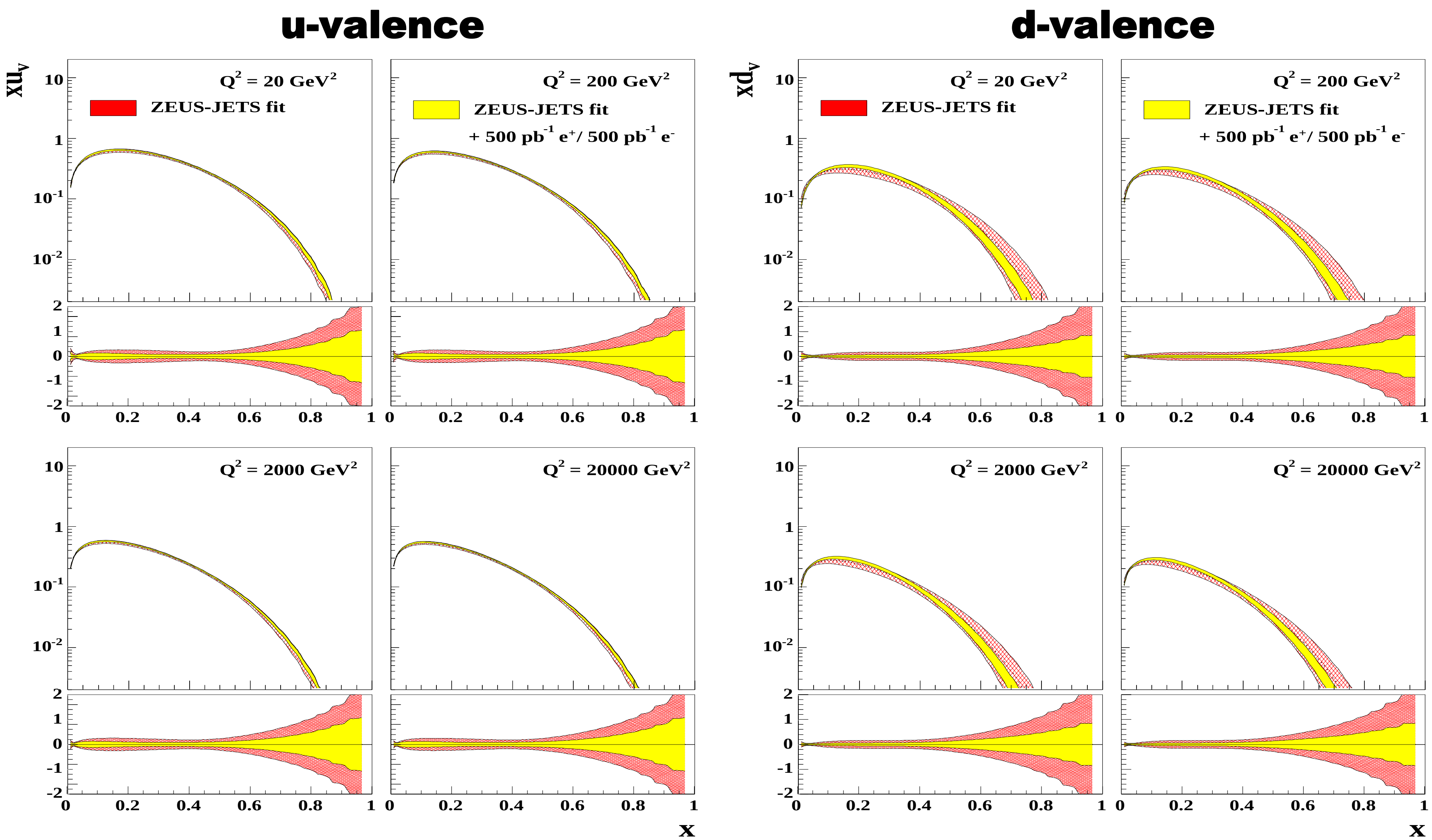


HERA-I: ZEUS NC e+/e- data



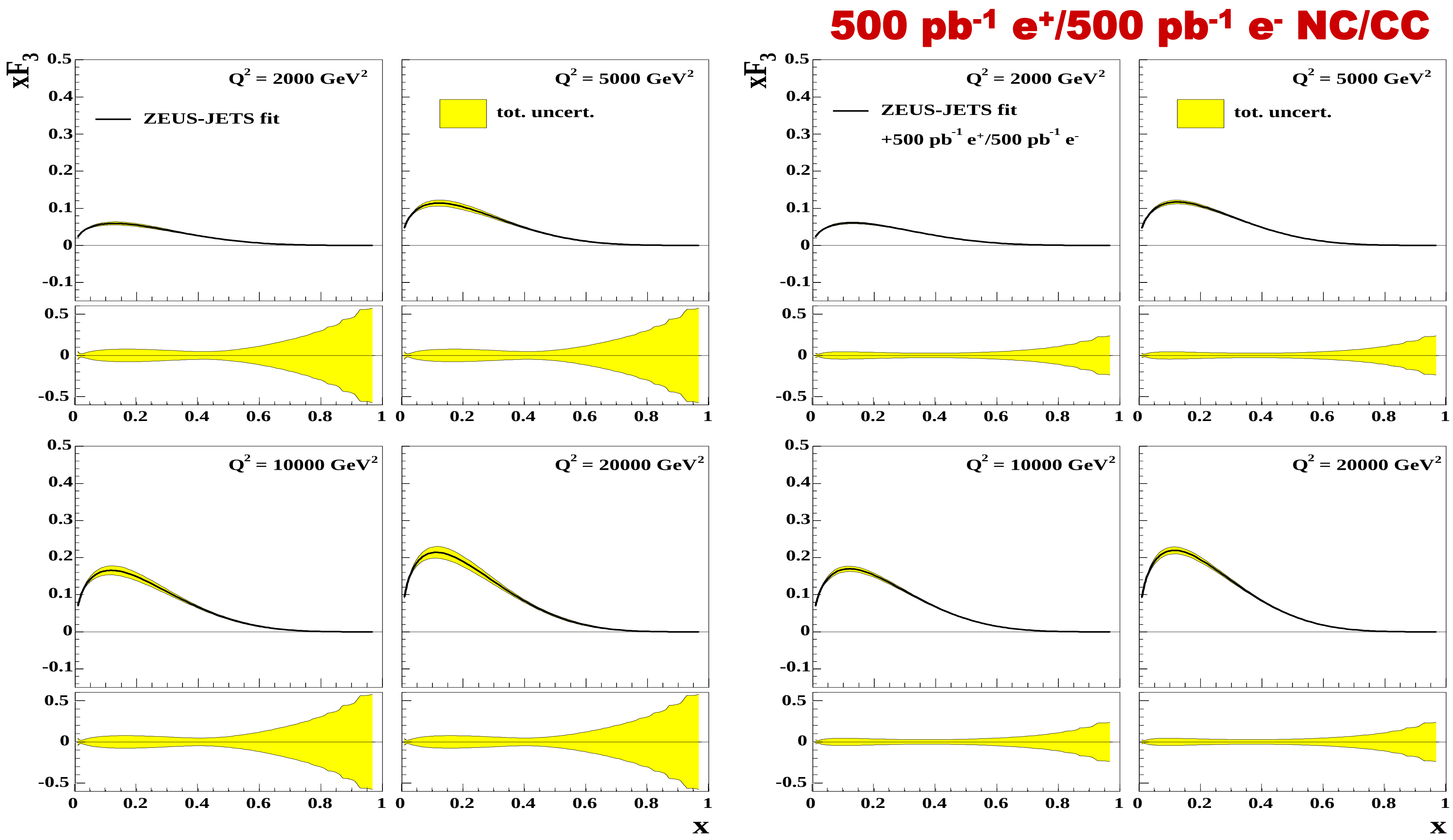
- Reduce statistical uncertainties to correspond to $500pb^{-1}$ e+/ $500pb^{-1}$ e-
  - expect impact on valence distributions

Impact on valence distributions



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

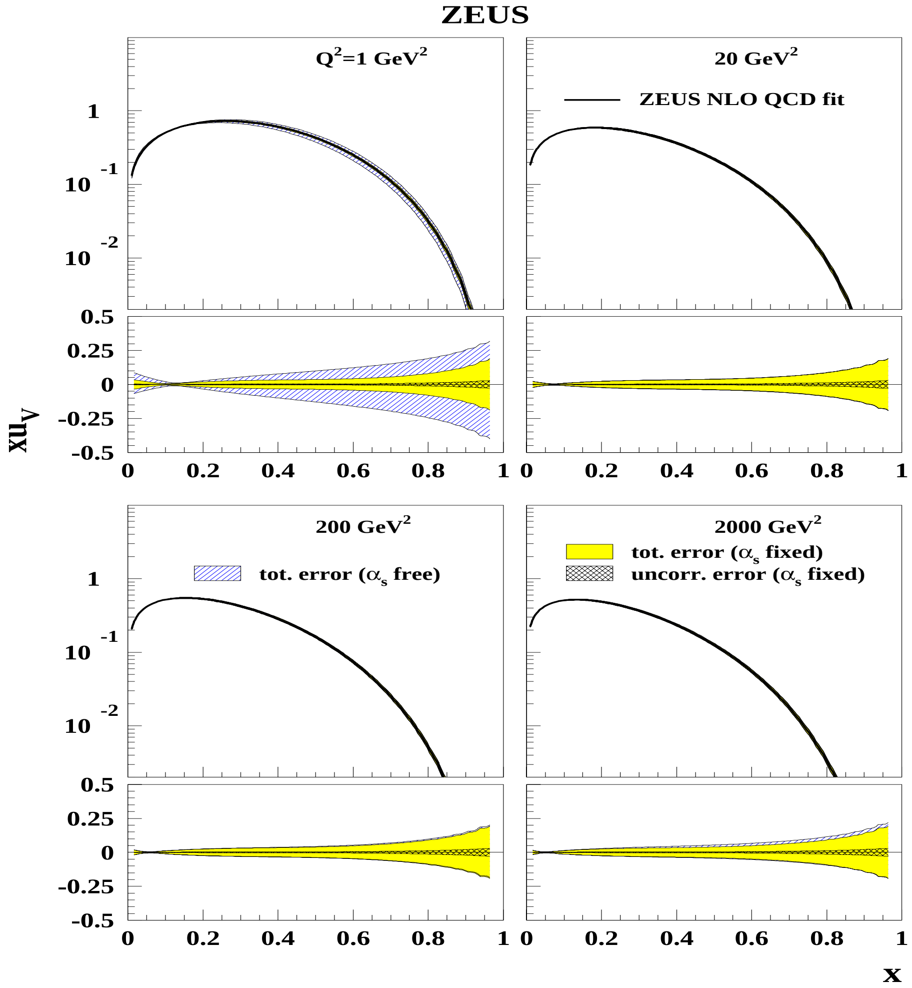
Impact on $xF_3 \sim \Sigma x(q-\bar{q})$

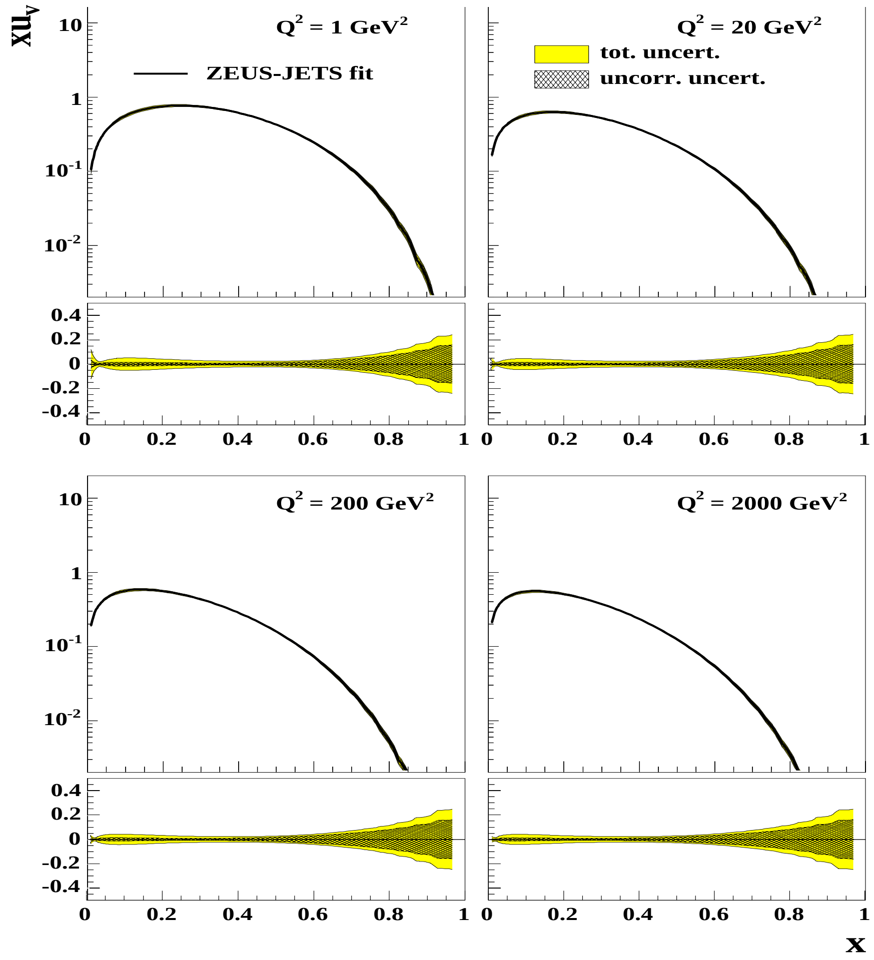


- Significant improvement in xF_3 uncertainties (up to a factor of three)

Comparison with global fit (u-valence)

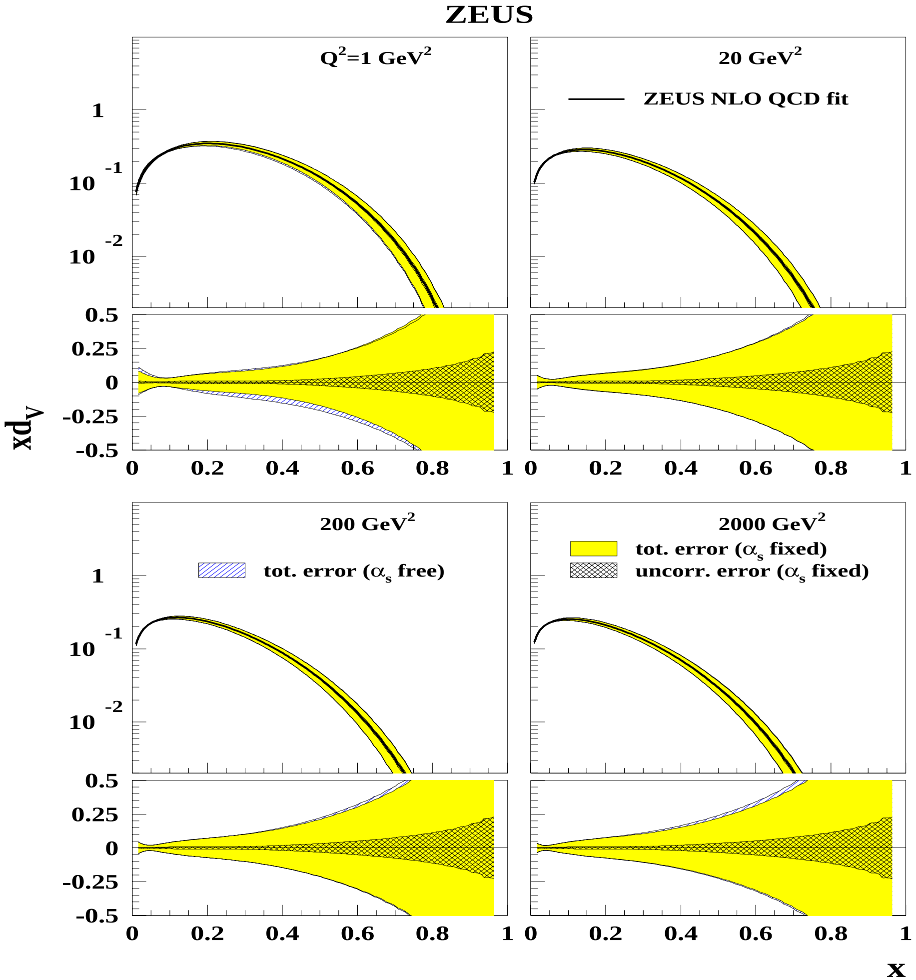
500 pb^{-1} e^{+}/500 pb^{-1} e^{-} NC/CC



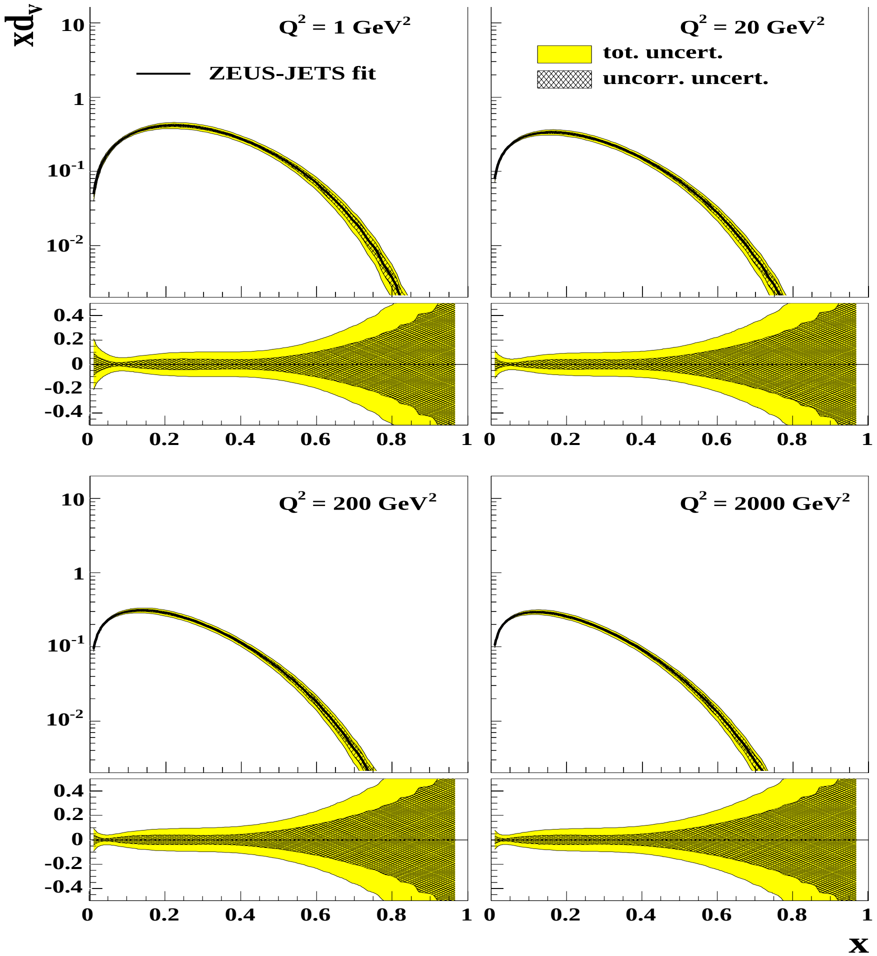


- Uncertainties with full HERA-II incl. data set comparable with global fits

Comparison with global fit (d-valence)



500 pb^{-1} e$^+$/500 pb^{-1} e$^-$ NC/CC

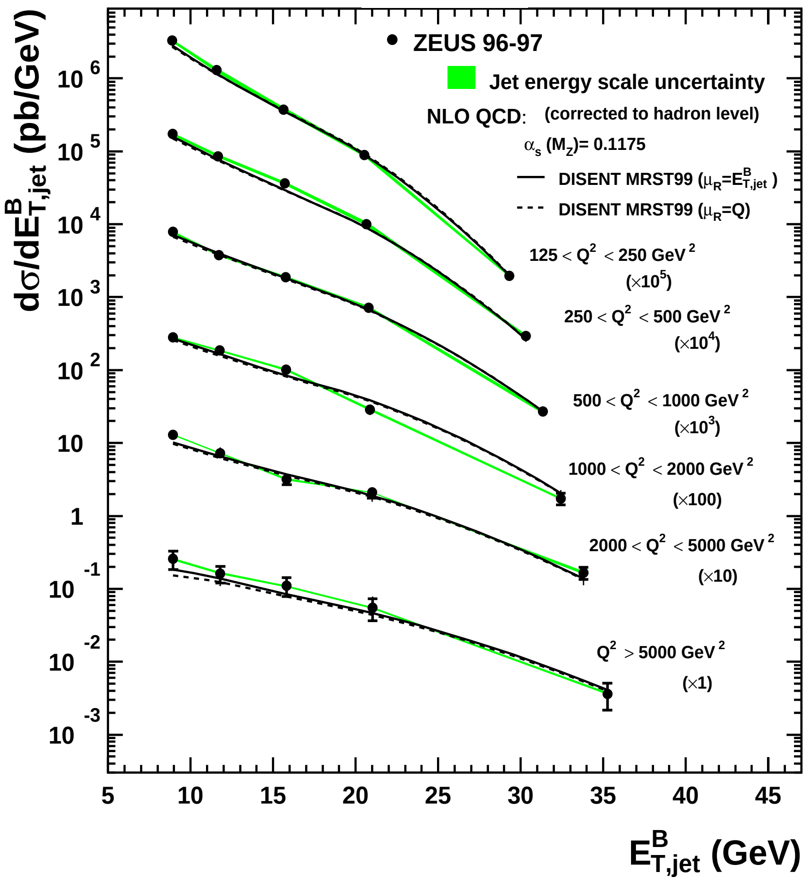


- Uncertainties comparable to or better than current global fits

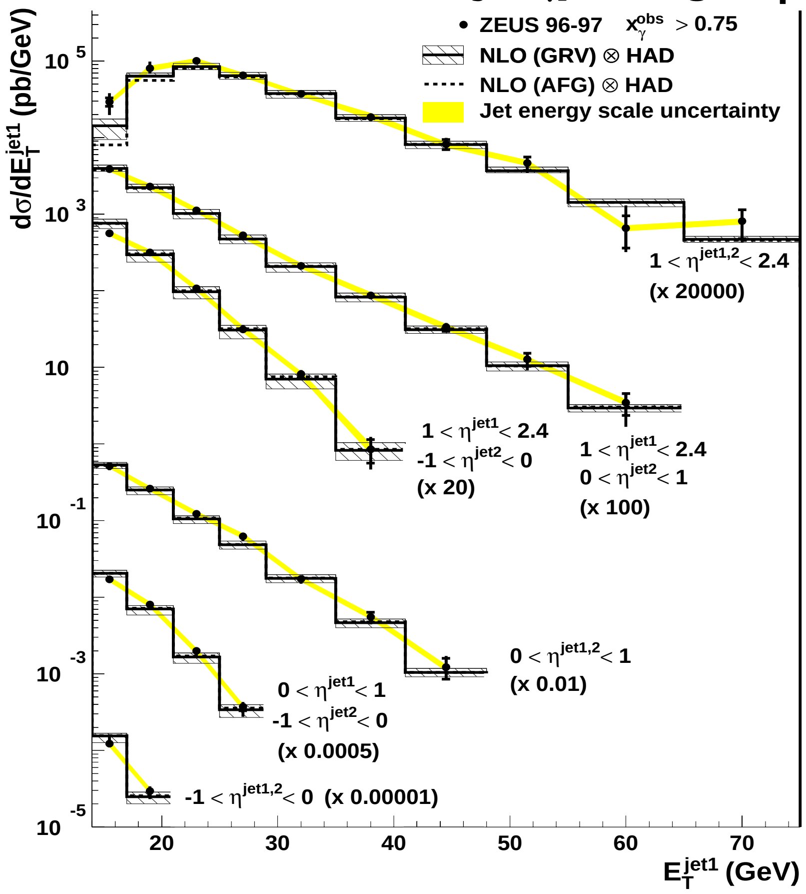
B. Increased statistics on jet data

EXAMPLES: HERA-I high-E_T jet measurements in DIS and γp

HERA-I: ZEUS inclusive jets in DIS

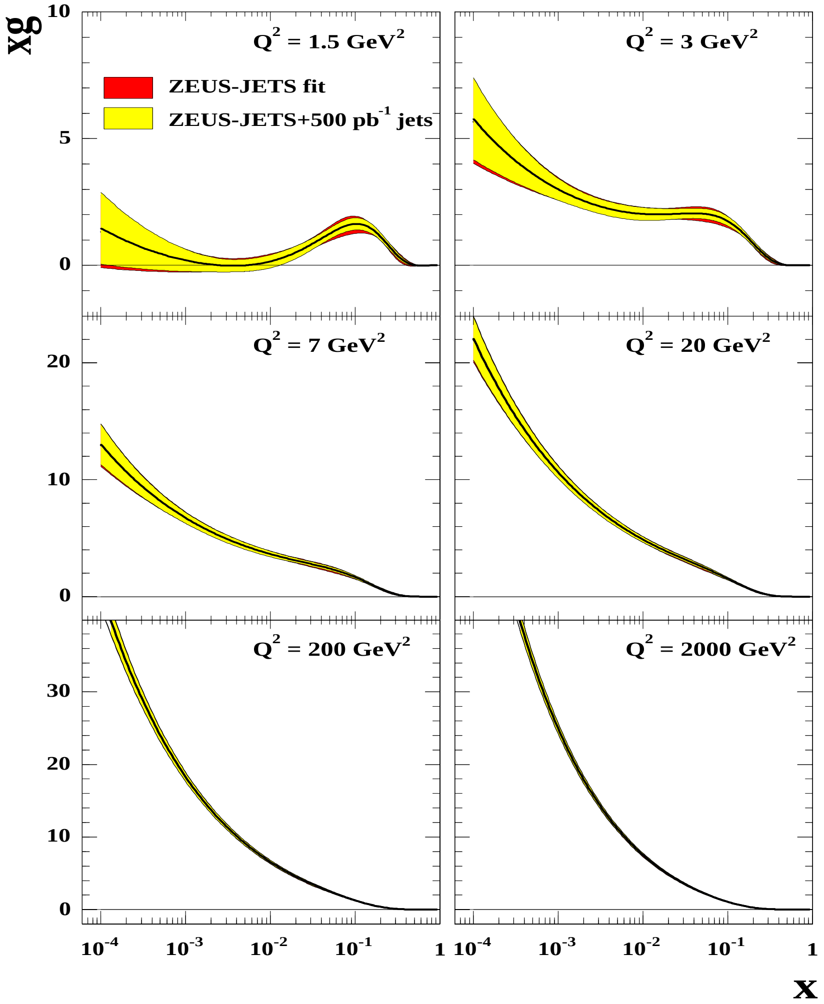


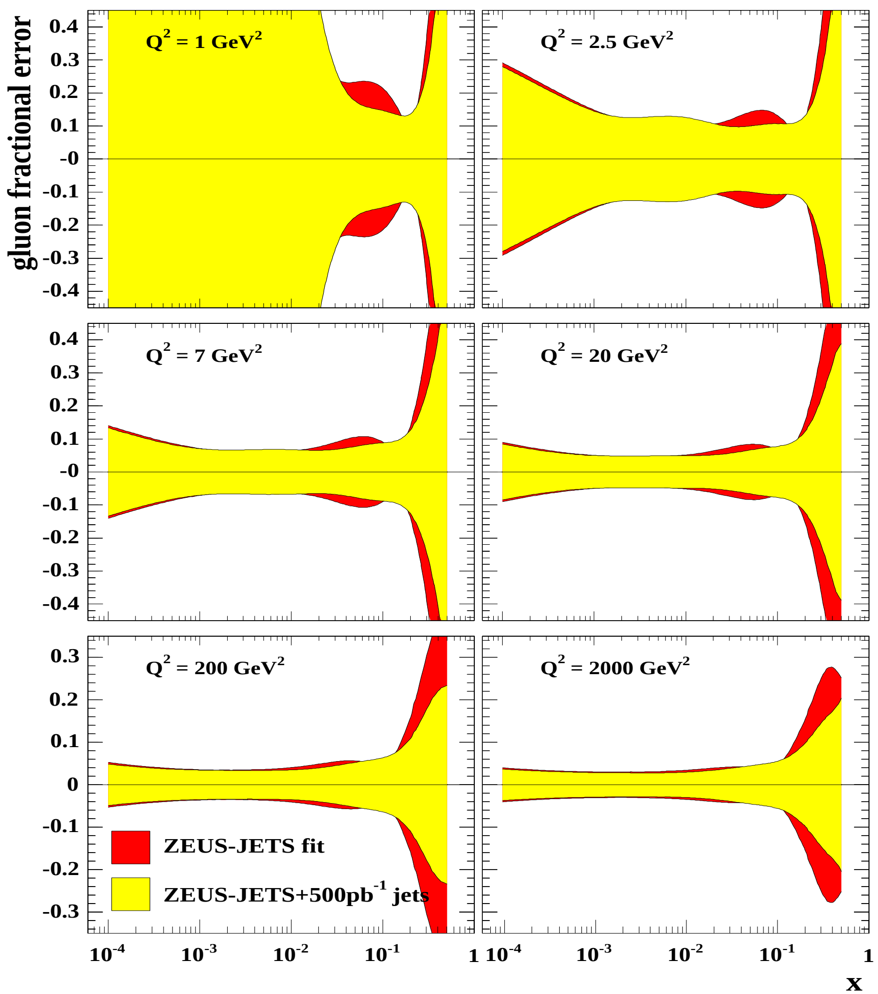
HERA-I: ZEUS two-jet γp at high-E_T



- Reduce statistical uncertainties to correspond to 500pb^{-1} jet data
  - expect impact on gluon distribution

Impact on the gluon density



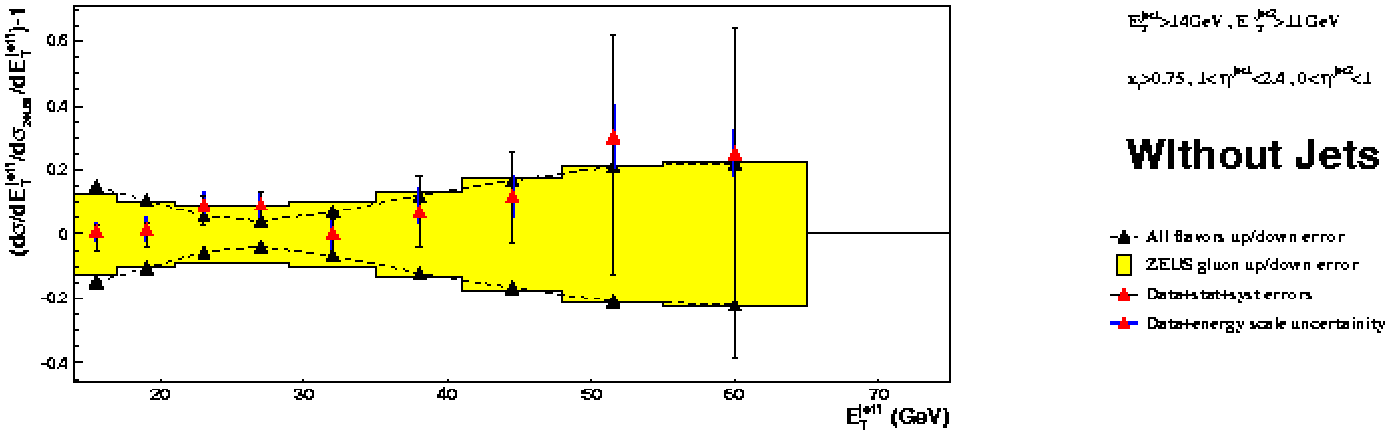


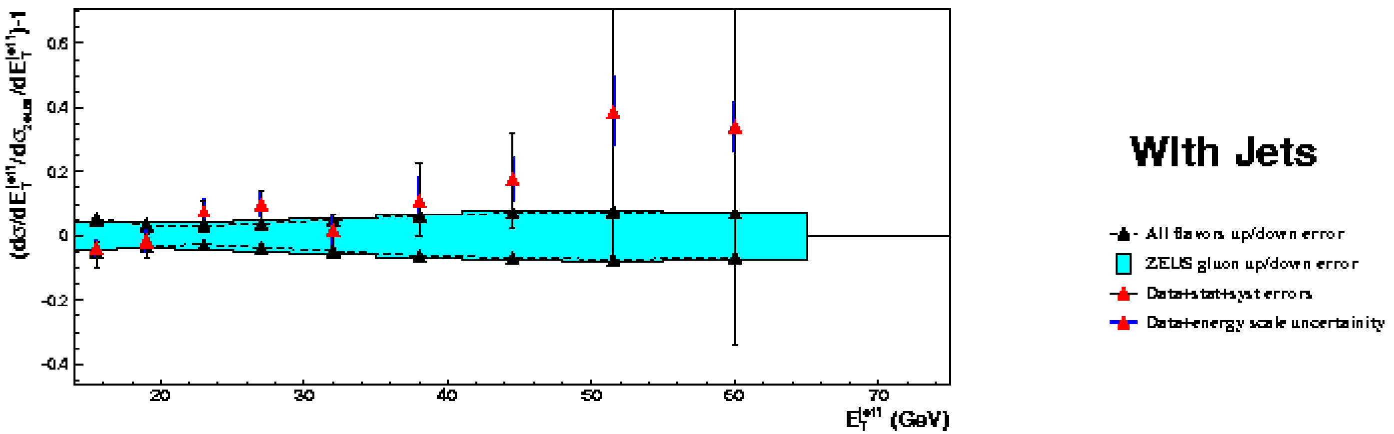
- Impact at mid-to-high-x -> gluon uncertainties are reduced

Optimised jet cross sections

by Christopher Targett-Adams

Example: $1 < \eta^{jet1} < 2.4,\ 0 < \eta^{jet2} < 1,\ x_\gamma > 0.75$



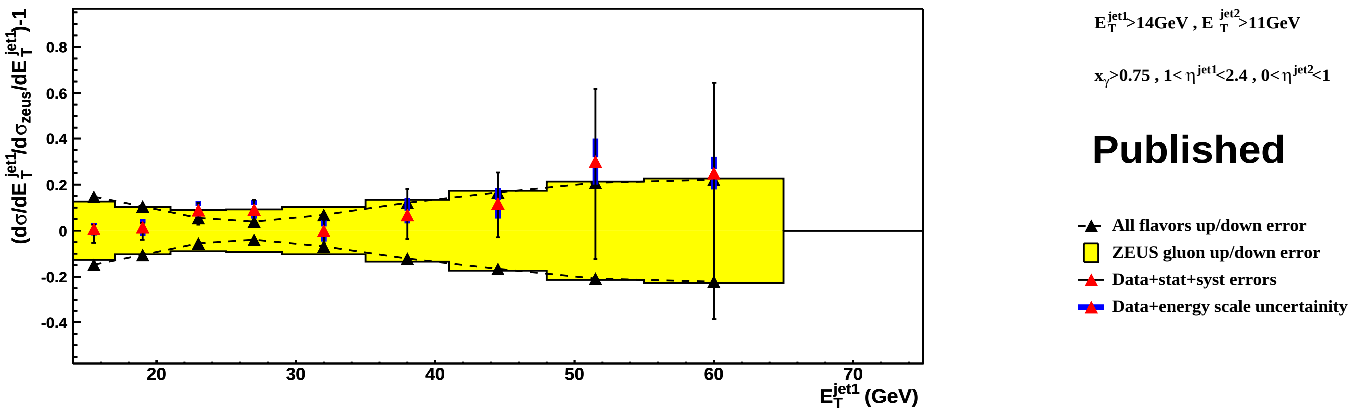


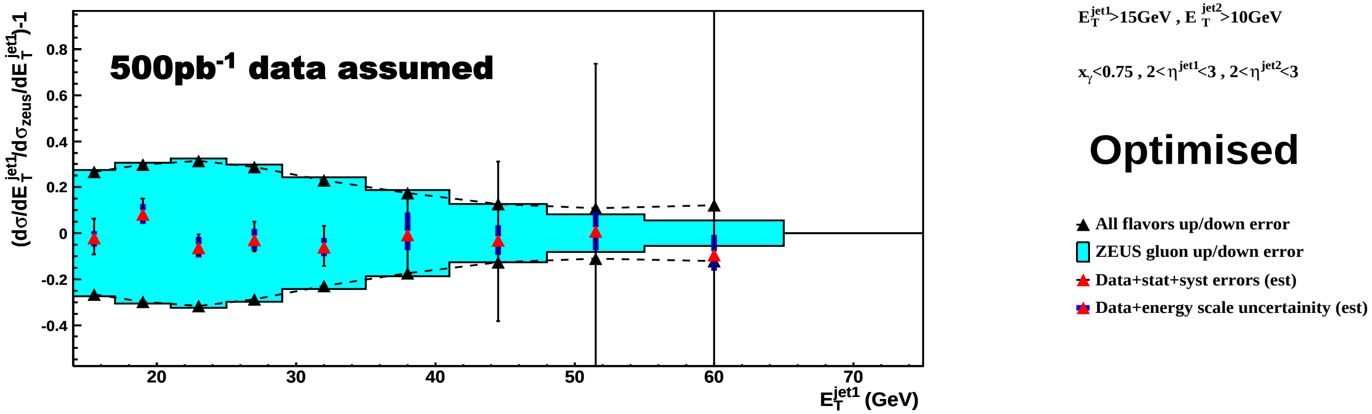
Predictions for a typical high-E_T photoproduction jet cross section

- uncertainties shown for fits with and without jets

Optimised jet cross sections

by Christopher Targett-Adams





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

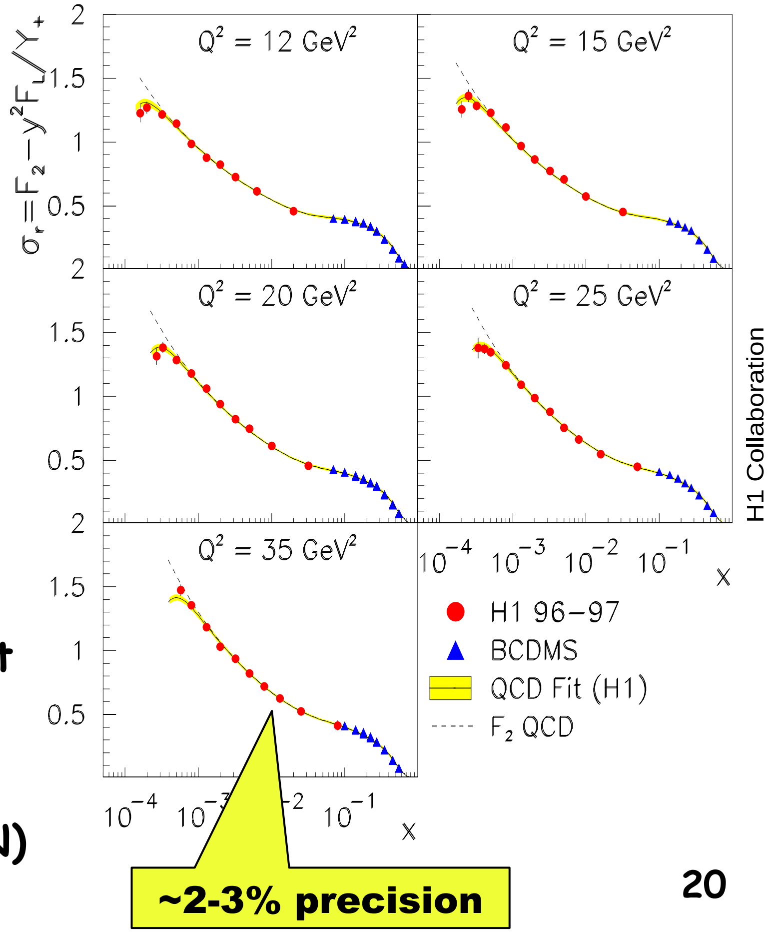
II. Precision low-Q^2 HERA data

- HERA low-Q^2 inclusive DIS data is systematics limited
  - simple increase in luminosity from HERA-II will not help much!

<u>CASE STUDY: H1 2000 low-Q^2 data</u>

- aim to replace published 96-97 NC low-Q^2 H1 data -> analysis started
- GOAL: high precision (~1% level)
  - study by Gordana Lastovicka-Medin:
    - 1% uncertainties realistically achievable
    - full error tables have been calculated
      - as close as possible to final values
      - including uncorrelated uncertainties

(for more details see, "Uncertainty measurement analysis for H1 low-Q^2 data", presented by Sasha Glazov (on behalf of Gordana), at January '05 HERA-LHC workshop meeting, CERN)



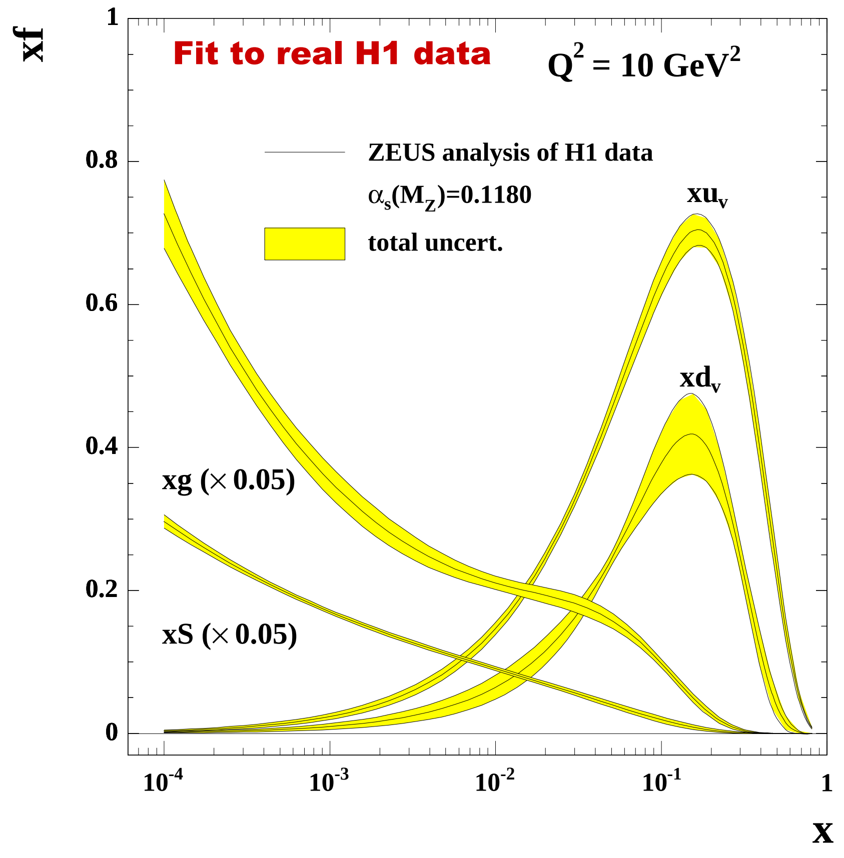
ZEUS fit to H1 data

AIM: assess impact on the PDFs of improved uncertainties for future H1 low-Q^2 NC DIS analysis of 2000 data
-> concentrating particularly on low-x gluon
(full error tables provided by Gordana Lastovicka-Medin)

- For this study, ZEUS QCD analysis performed on H1 data only

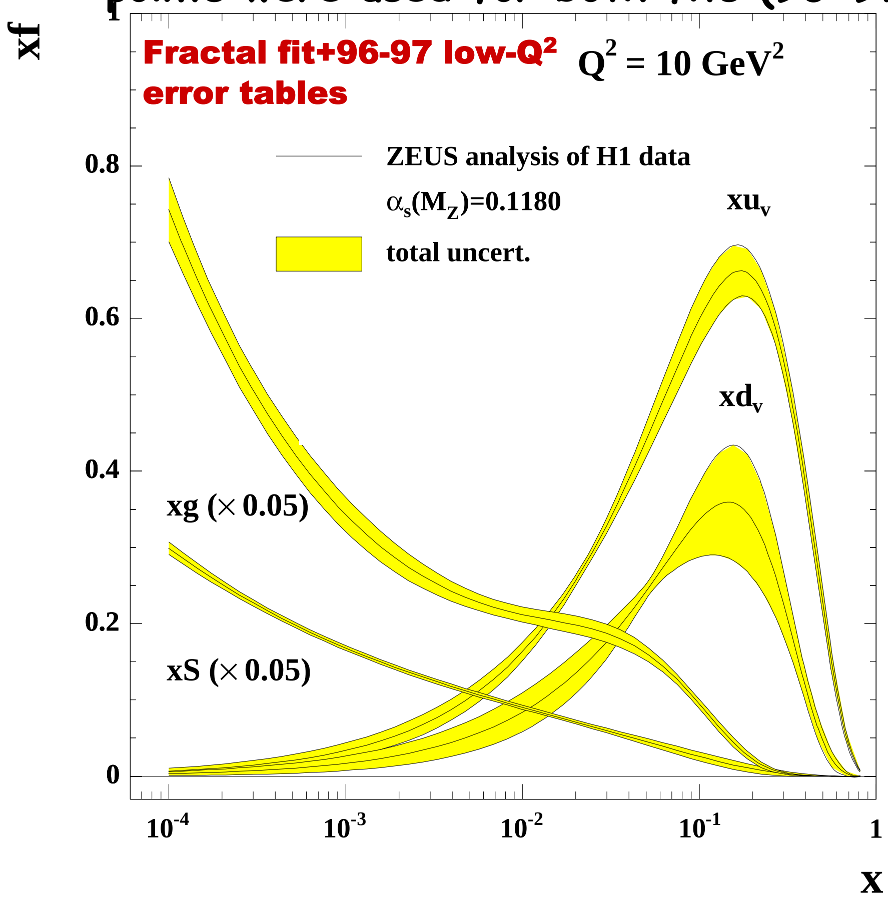
Nominal H1 Data Set	N_{data}
NC minimum bias e^+p 96-97	55
NC low Q^2 e^+p 96-97	80
NC high Q^2 e^+p 94-97	130
CC high Q^2 e^+p 94-97	25
NC high Q^2 e^-p 98-99	126
CC high Q^2 e^-p 98-99	28
NC high Q^2 e^+p 99-00	147
CC high Q^2 e^+p 99-00	28

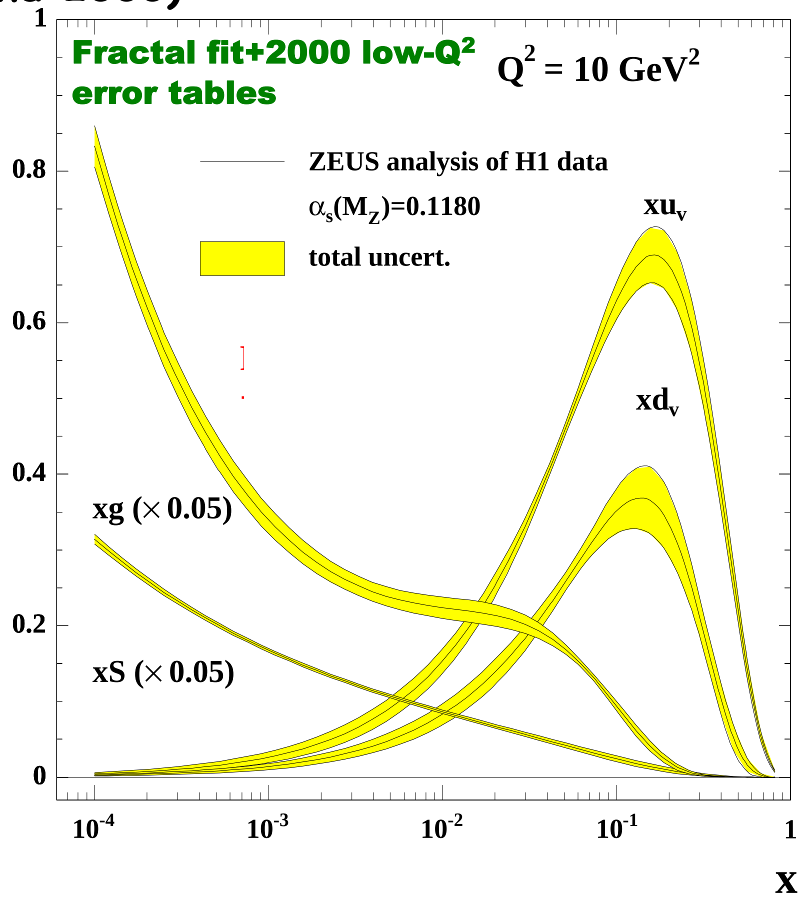
Data-set under study



PDF summaries

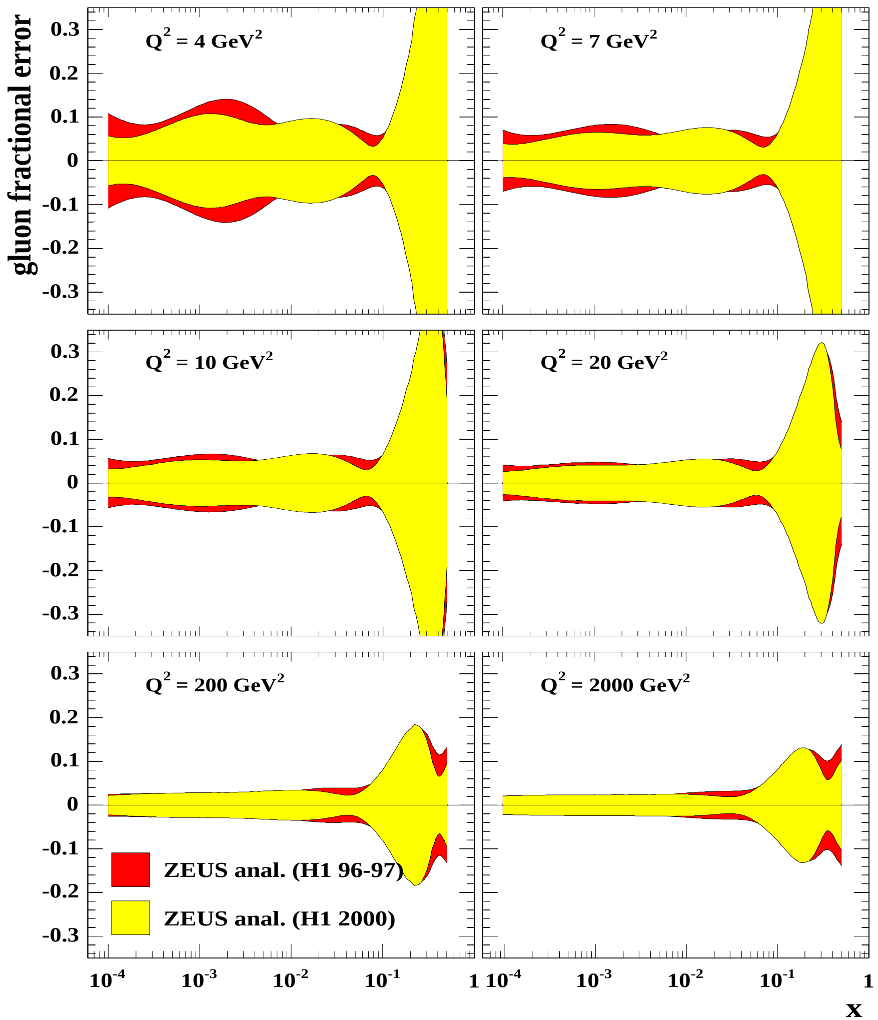
- Published points available for 96-97 but not for 2000
- Central points simulated by Fractal Fit (hep-ph/0203260)–Tomas Lastovicka
  - since we are interested only in impact of improved uncertainties, simulated points were used for both fits (96-97 and 2000)





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?)



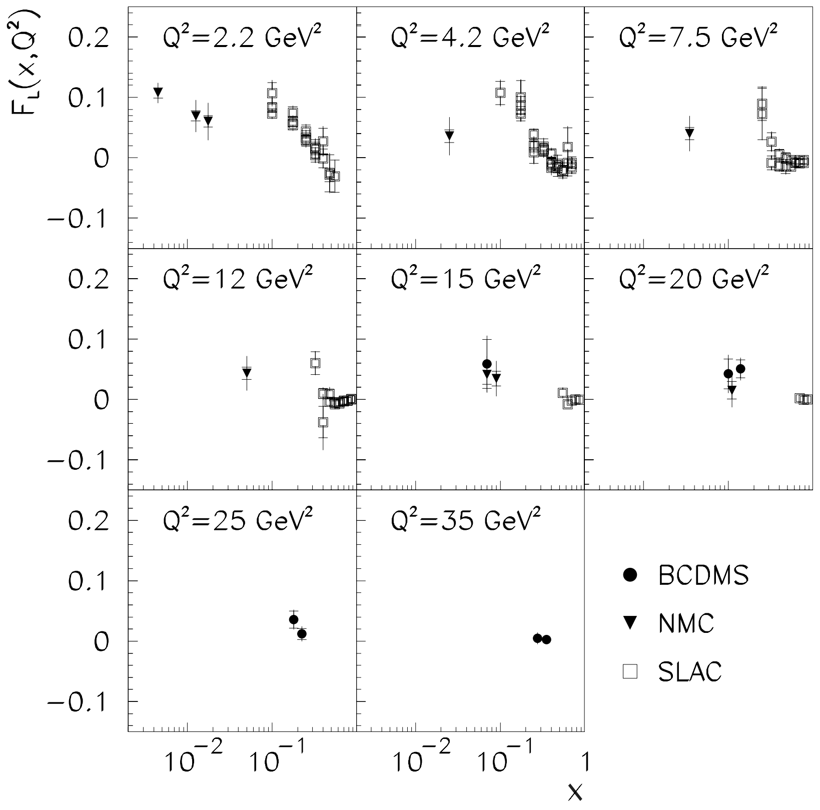
III. Impact of a HERA measurement of F_L

- Inclusive DIS reduced cross section written in terms of structure functions F_2 and F_L

$$\tilde{\sigma} = F_2(x,Q^2) - f(y).F_L(x,Q^2)$$

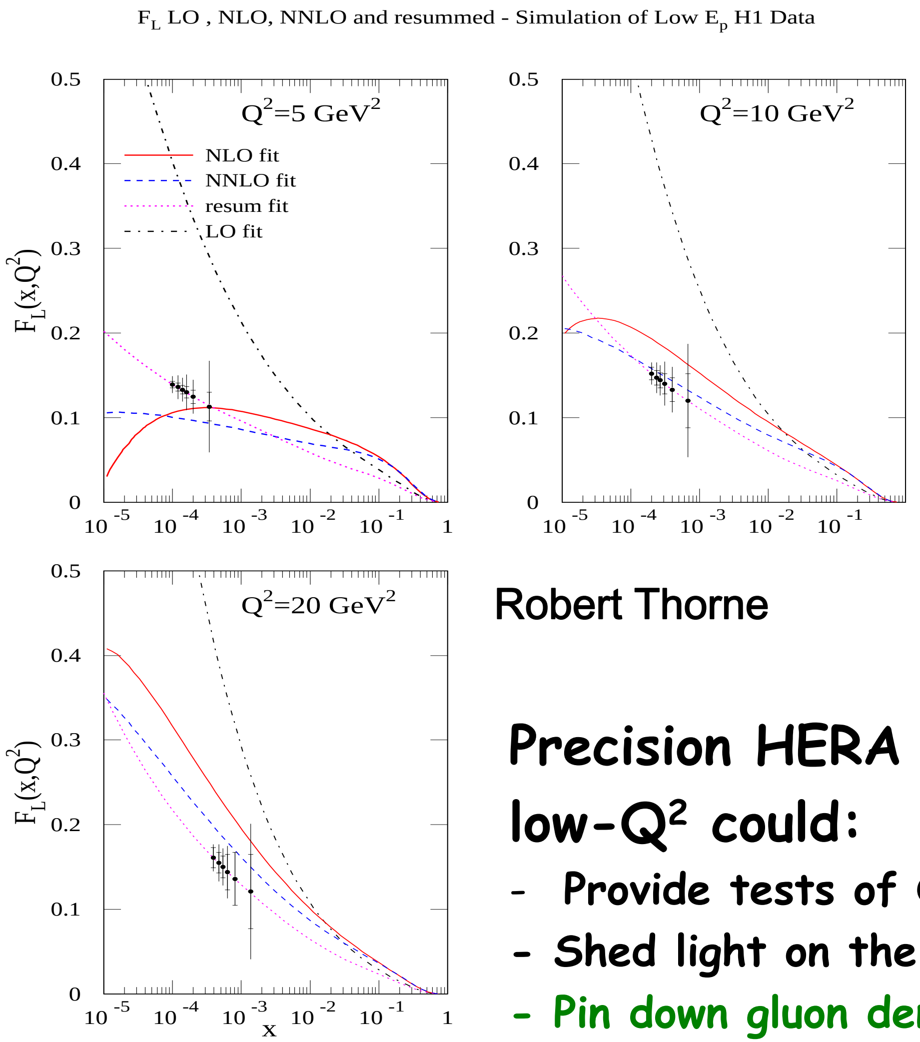
  - where $y=Q^2/sx$, $Y_+=1+(1-y)^2$
  - $f(y)=y^2/Y_+$

STRUCTURE FUNCTIONS:	
$F_2 \sim \sum x(q_i+\bar{q}_i)$	Dominates
$F_L \sim \alpha_s.xg(x,Q^2)$	High y

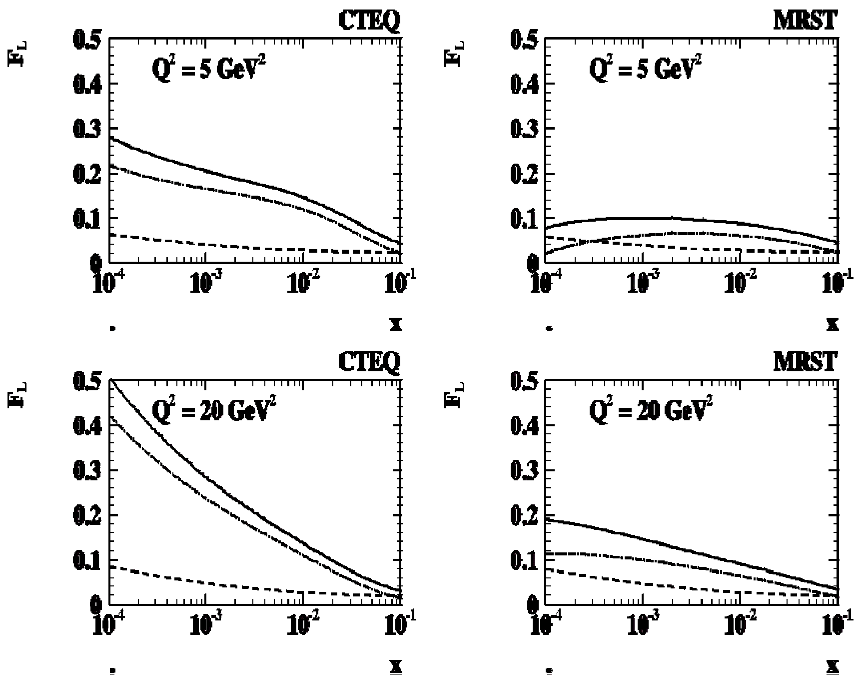


- To disentangle F_2 and F_L, need accurate measurement of cross section at high-y and a variation of y at fixed x,Q^2
  - previously done by fixed target experiments (BCDMS, NMC, SLAC) BUT not yet at HERA -> possibility at HERA-II !?

Why a HERA measurement of F_L?



Robert Thorne



Precision HERA measurement of F_L at low-x, low-Q^2 could:

- Provide tests of QCD at higher orders
- Shed light on the need for extensions to standard DGLAP
- Pin down gluon density
- Improve low-x gluon uncertainties

Simulation of HERA F_L (M. Klein)

CASE STUDY: Study the impact of a future HERA F_L measurement on QCD fits (concentrating particularly on the gluon PDF (and F_L))

The F_L "data" used for this study were simulated by Max Klein. (for full details, see contribution, "On the future measurement of F_L at low-x at HERA", M.Klein, in proceedings of DIS04).

METHOD: $\tilde{\sigma} = F_2(x,Q^2) - f(y).F_L(x,Q^2)$

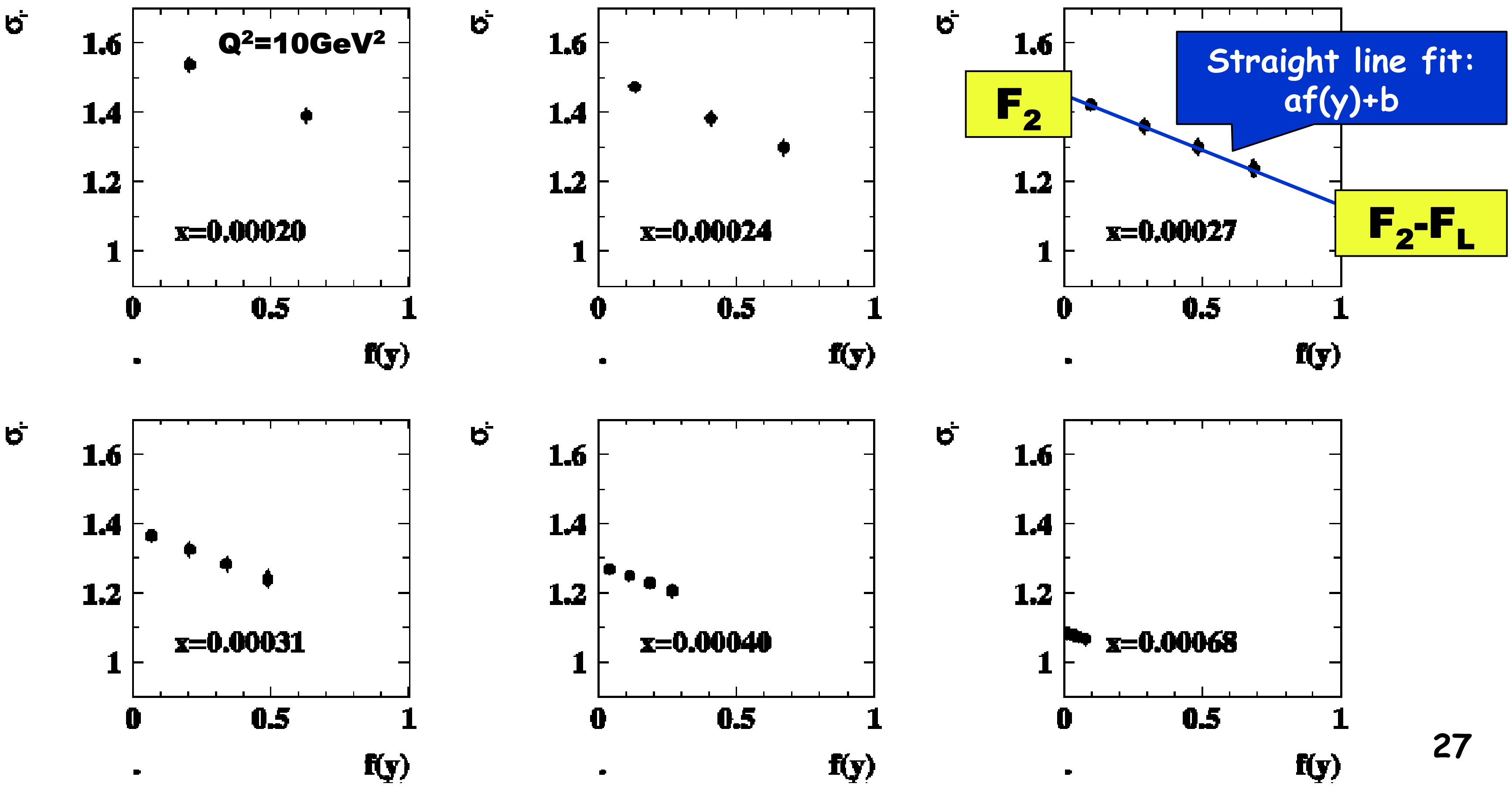
- Simulate cross section at fixed x,Q^2, varying y by changing E_p -> plot σ versus f(y); perform straight line fit to extract F_2 and F_L
- Choose set of E_p such that f(y) is binned equidistantly
- E_p and luminosity values for this study:

E_p (GeV)	920	575	465	400
L (pb^{-1})	10	5	3	2

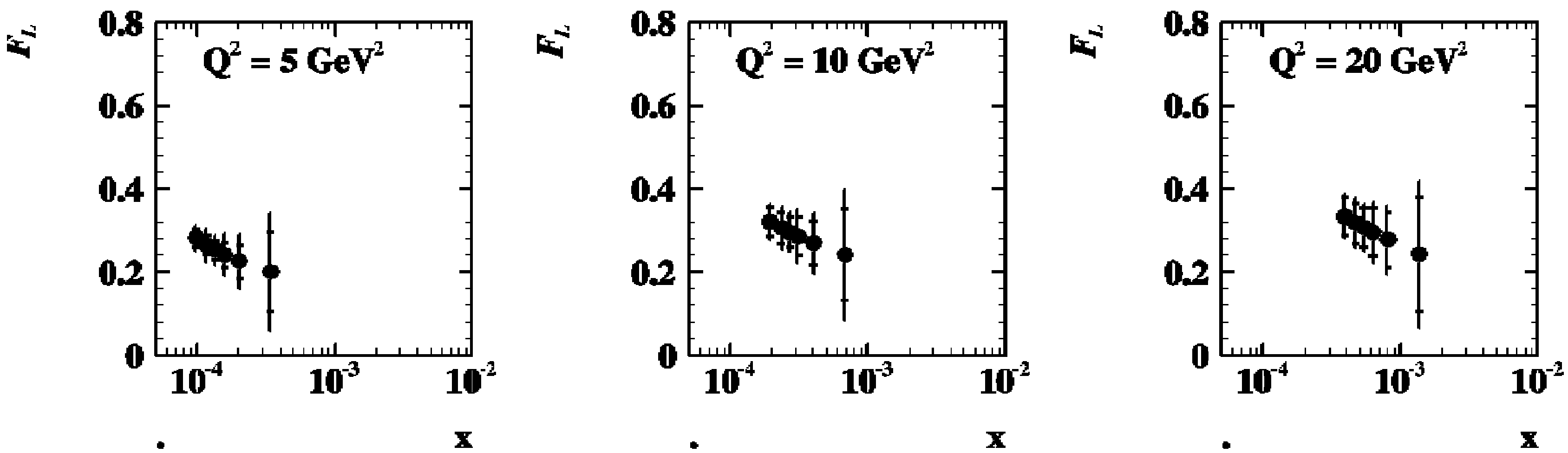
Extraction of simulated HERA F_L (M. Klein)

- reduced cross section: $\tilde{\sigma} = F_2(x,Q^2) - f(y).F_L(x,Q^2)$
  - simulated using GRV94 proton PDF

Simulation of the NC reduced cross section plotted as a function of f(y), at Q^2=10 GeV^2



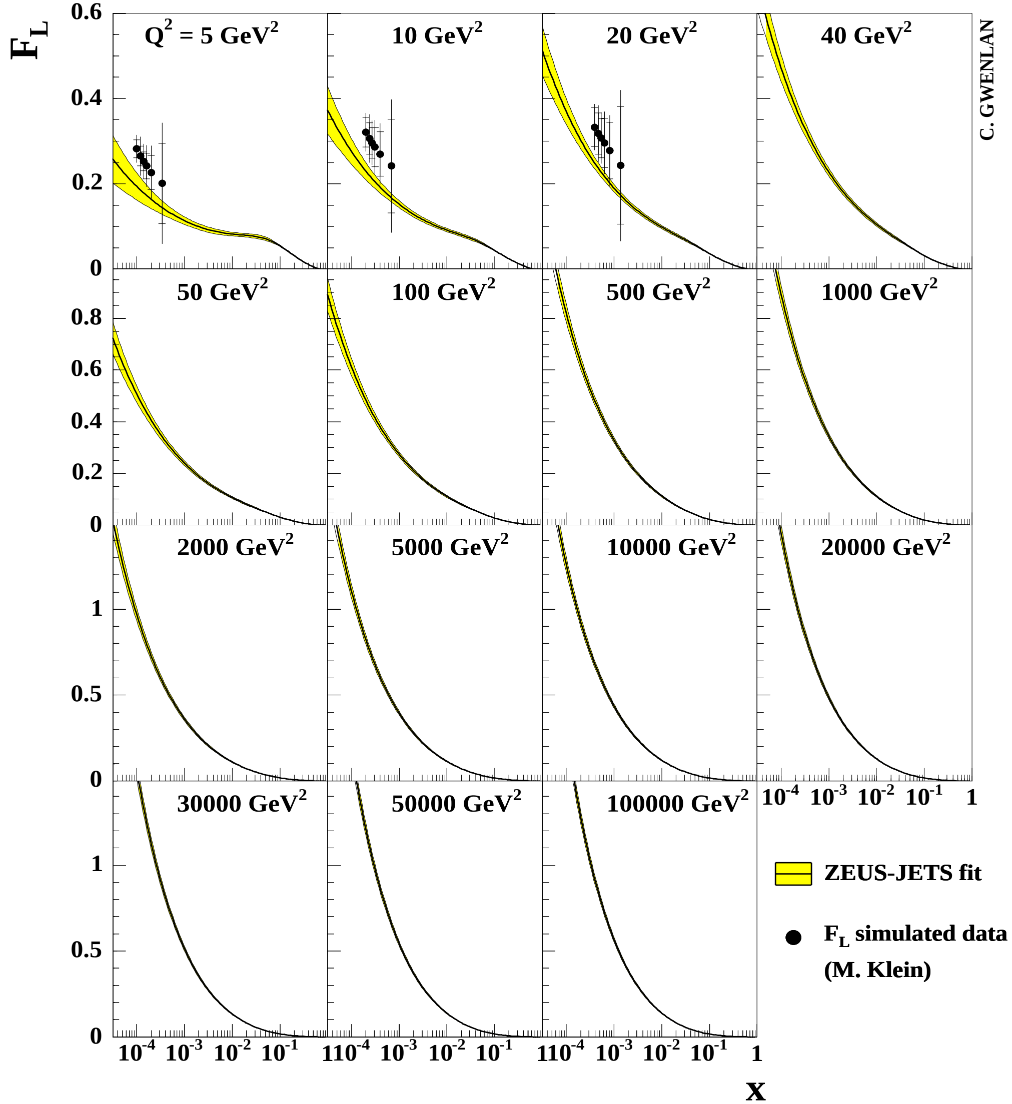
Simulated HERA F_L data (M. Klein)



- Simulated F_L data-points at Q^2=5,10,20 GeV^2
  - Central values from GRV94
  - Inner error bar: statistical
  - Full error bar: statistical & systematic

N.B. systematic uncertainties estimated from current H1 analysis of 99-00 data, leading to a few % cross section accuracy (see, for example, paper submitted to ICHEP04, H1 Coll., abstract 5-0161)

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

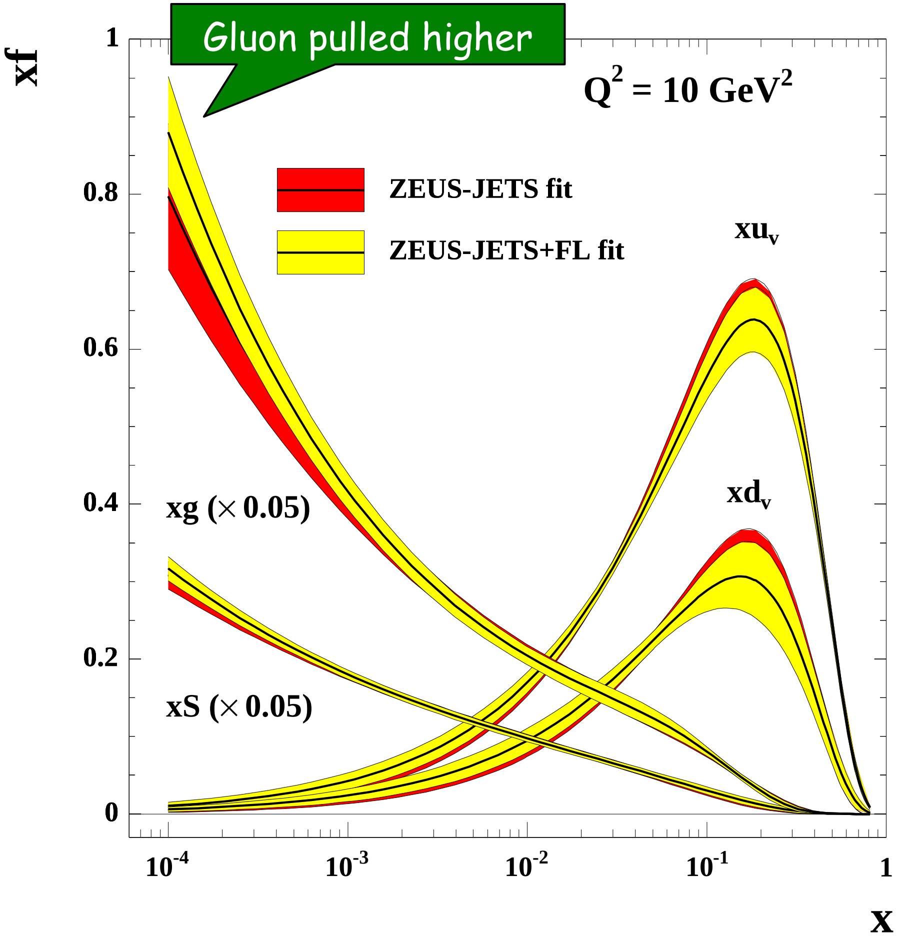
Inclusion of F_L in the ZEUS-JETS fit

Simulated F_L points included in a ZEUS-JETS style fit

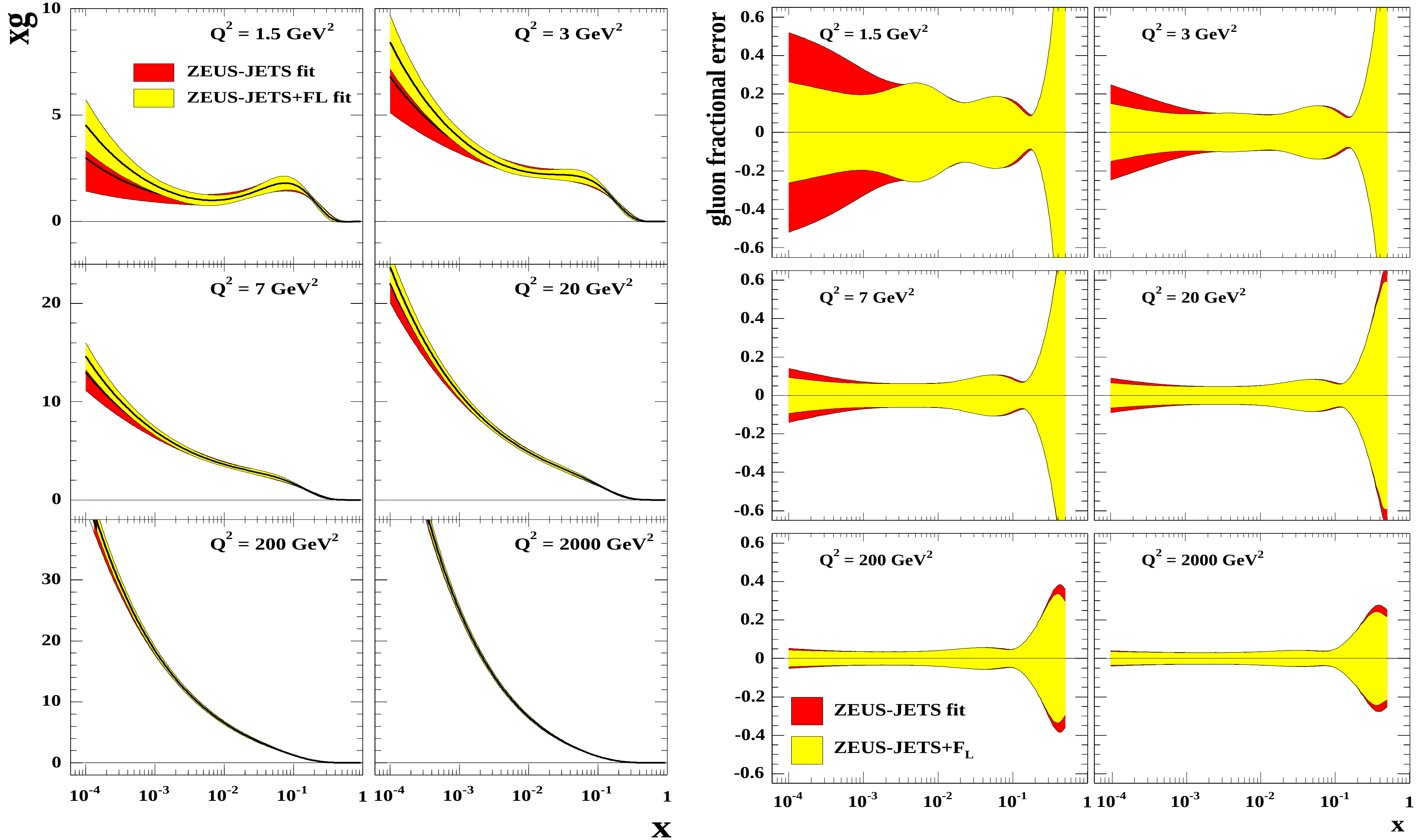
- Systematic uncertainties treated as uncorrelated

FUTURE: possible to separate systematics into uncorr./corr. sources
-> perhaps for the proceedings!?

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
Simulated F_L	18

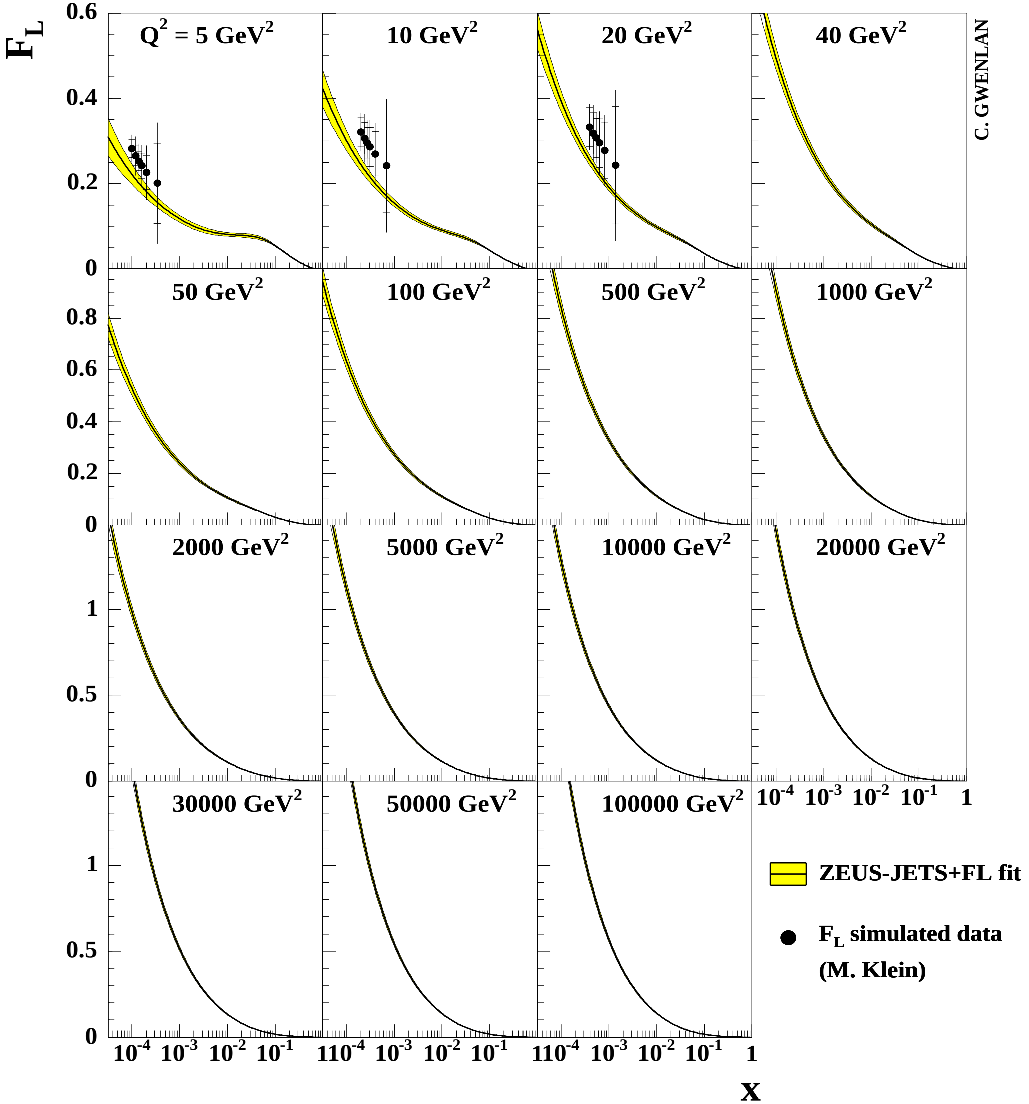


The gluon distribution



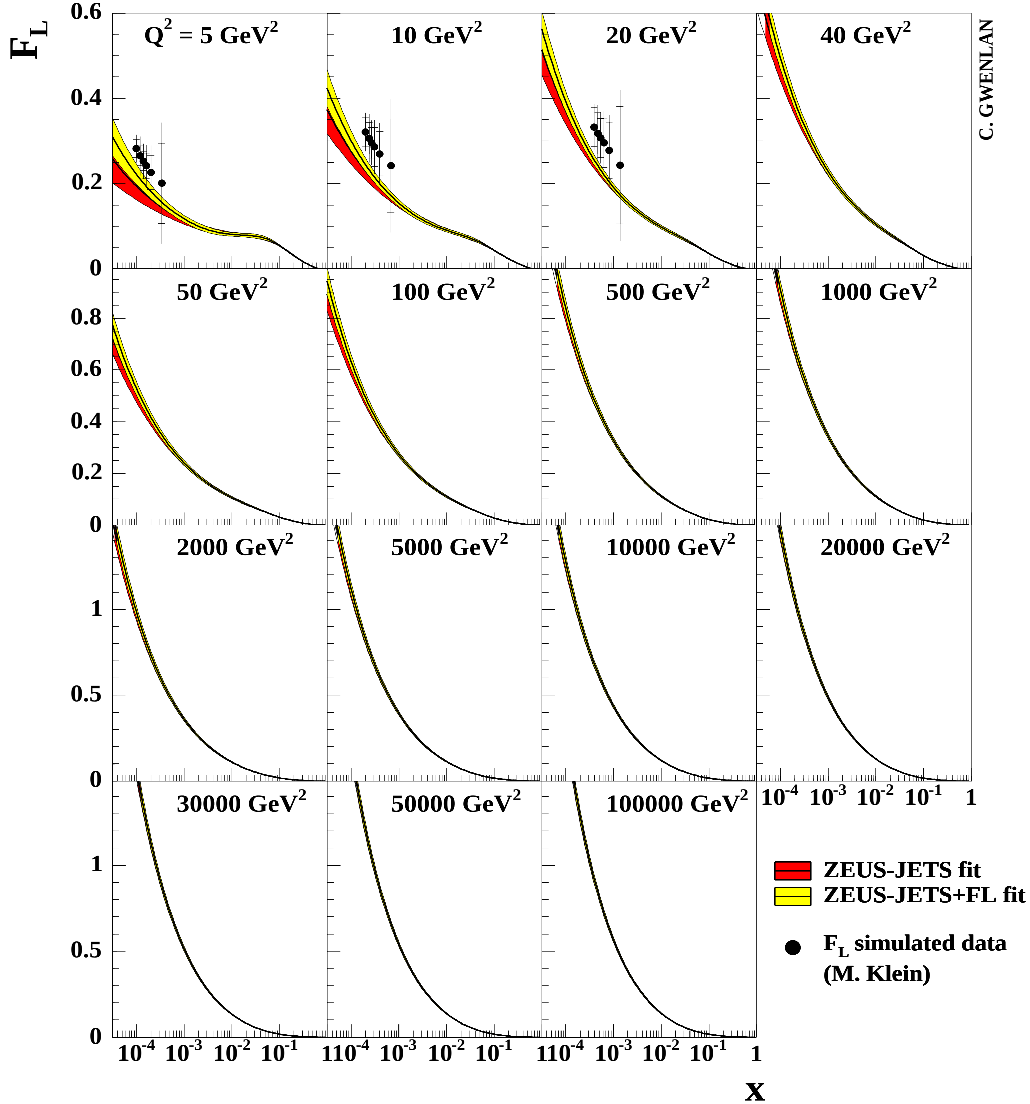
- Gluon is pulled higher at low-x (most significant at low-Q^2)
- Gluon uncertainties reduced at low-x and low-Q^2 (up to Q^2 of F_L "data")

Comparison to prediction of ZEUS-JETS+F_L



← F_L “data” included in fit

Simulated HERA F_L compared to QCD



F_L simulated data does constrain F_L (gluon) from QCD fit at low-x and low-Q^2

Would be desirable to look at the impact in other PDF analyses to see if low-x, low-Q^2 F_L (gluon) distributions move closer together!!!

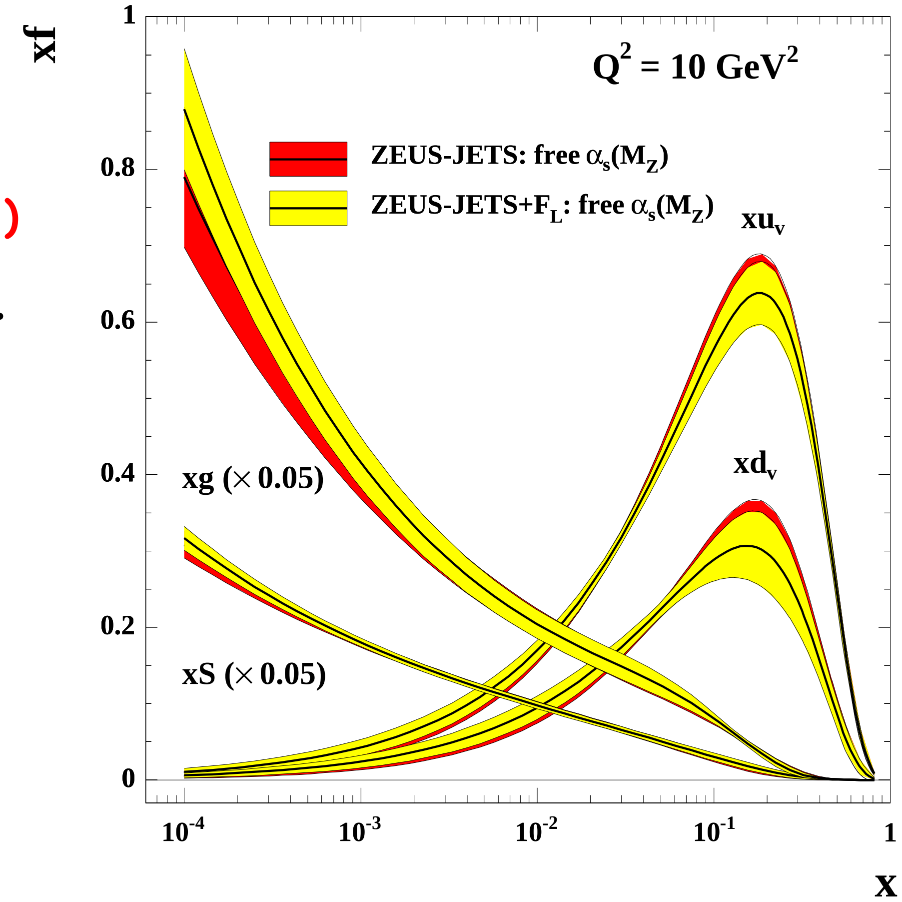
Extraction of $\alpha_s(M_Z)$ from ZEUS-JETS+F_L

- Additional fit performed with $\alpha_s(M_Z)$ treated as free parameter
  -> extraction of α_s from fit

  $\alpha_s(M_Z)$=0.1180±0.0007(uncorr.)±0.0026(corr.)

  (c.f. ZEUS-JETS value:
  $\alpha_s(M_Z)$=0.1183±0.0007(uncorr.)±0.0027(corr.))

- Lower value of $\alpha_s(M_Z)$ from fit with F_L arises from larger low-x gluon c.f. ZEUS-JETS
- Fit with F_L gives a <u>small</u> reduction in α_s uncertainty
  - but small effect compared to constraint already imposed by high precision jet data



Summary & Conclusions

- Three case studies have been presented to investigate the impact of future HERA measurements on PDFs

I Impact of increased HERA-II luminosity

A. full HERA-II high-Q^2 DIS data-set likely to have significant impact on quark distributions

- estimated HERA-II uncertainties comparable to current global fits but include no complication from heavy target corrections or potential incompatibilities between data-sets

B. improved statistics on existing HERA jet data improves gluon uncertainties at mid-to-high-x but may expect more significant improvement from optimised jet cross sections (latter still to be studied)

Summary & Conclusions

II Impact of improved systematics on low-Q^2 HERA data

- studies of systematic uncertainties on a future (in progress) H1 analysis of 2000 data suggest 1% precision achievable (Gordana Lastovicka-Medin)
- (estimated) error tables for this measurement have been included in a ZEUS PDF analysis of H1 data
  - some impact on gluon uncertainties at low-x and low-Q^2

III Impact of a HERA measurement of F_L

- simulated F_L data added to the ZEUS-JETS PDF fit (points provided by Max Klein)
  - GRV94 proton PDF used for central values
- F_L "data" have some impact on pinning down gluon (and F_L)
  - would be nice to see impact in other fits -> do gluon PDFs converge?
- also reduced gluon uncertainties at low-x and low-Q^2

Extras…

Gluon distribution at high scales

- Improvement of gluon uncertainties at high-x persists to high scales
  - -> up to factor of two improvement for x > 0.1
  - -> consequence of momentum sum rule?