Impact of future HERA data on the ZEUS PDF fit

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with the help of M. Klein (DESY),
C. Targett-Adams (UCL), R. Thorne (Cambridge), A. Tricoli (Oxford)

- **Introduction**
- **The ZEUS–JETS QCD fit: an overview**
- **Impact of future HERA data on the proton PDFS**
  - within current HERA-II running scenario
  - additional studies (F_L, sea-quark asymmetry)
- **Conclusions**

Introduction

Besides being interesting in their own right, it is essential to know the parton density functions (PDFs) of the proton as precisely as possible in order to maximise the physics potential at both current and future colliders e.g. high-x gluon is dominating uncertainty in several LHC processes

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

⏩ determination of proton PDFs now possible within one experiment

Most recently, ZEUS have performed a NLO QCD analyses on their full set of HERA-I e^+ and e^- structure function data and high precision jet data $\rightarrow$ the ZEUS–JETS PDF

With future measurements at HERA, hope to be able to do even better …

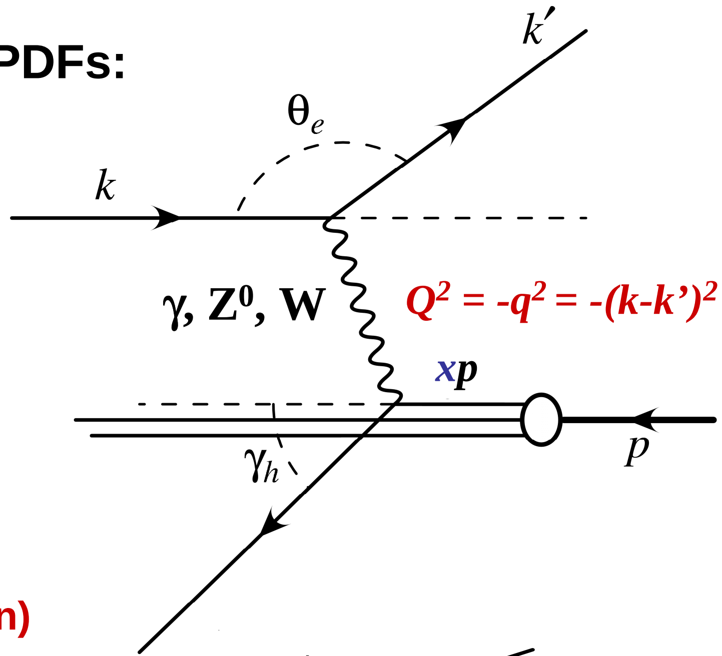
Presented here are the results of studies that give a first look at the potential impact of future HERA measurements on the proton PDFs:

1. **within current HERA-II running scenario**
   - **increased luminosity**
   - **cross sections optimised for sensitivity to PDFs**
2. **other running scenarios: low energy (F_L), eD (sea quark asymmetry)**

Determination of proton PDFs at HERA

Factorisation: observable = short range interaction ⊗ PDFs

Observables used in QCD fits to determine PDFs:



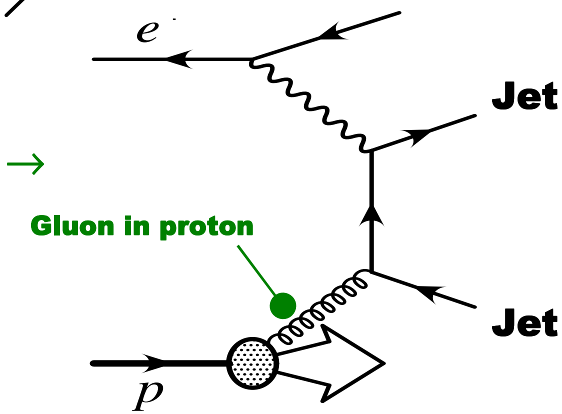
- Inclusive NC/CC DIS ep cross sections →

$$\frac{d^2\sigma(e^\pm p)}{dxdQ^2} \sim Y_+F_2 - y^2F_L \mp Y_- xF_3 \; ; \; Y_\pm = 1 \pm (1-y)^2$$

F_2	$\sim \sum x(q_i + \bar{q}_i)$	Dominates
xF_3	$\sim \sum x(q_i - \bar{q}_i)$	High Q^2
F_L	$\sim \alpha_s . xg(x,Q^2)$	High y ($\geq$NLO)

  - direct sensitivity to quarks
  - only indirect sensitivity to gluon (scaling violation)

- Jet cross sections:
  - directly sensitive to gluon through boson-gluon-fusion →



Now, after the HERA-I (94-00) phase of data-taking, the full set of inclusive NC/CC e$^+$/e$^-$ data, and high precision jet data are available for QCD analysis...

ZEUS–JETS NLO QCD fit

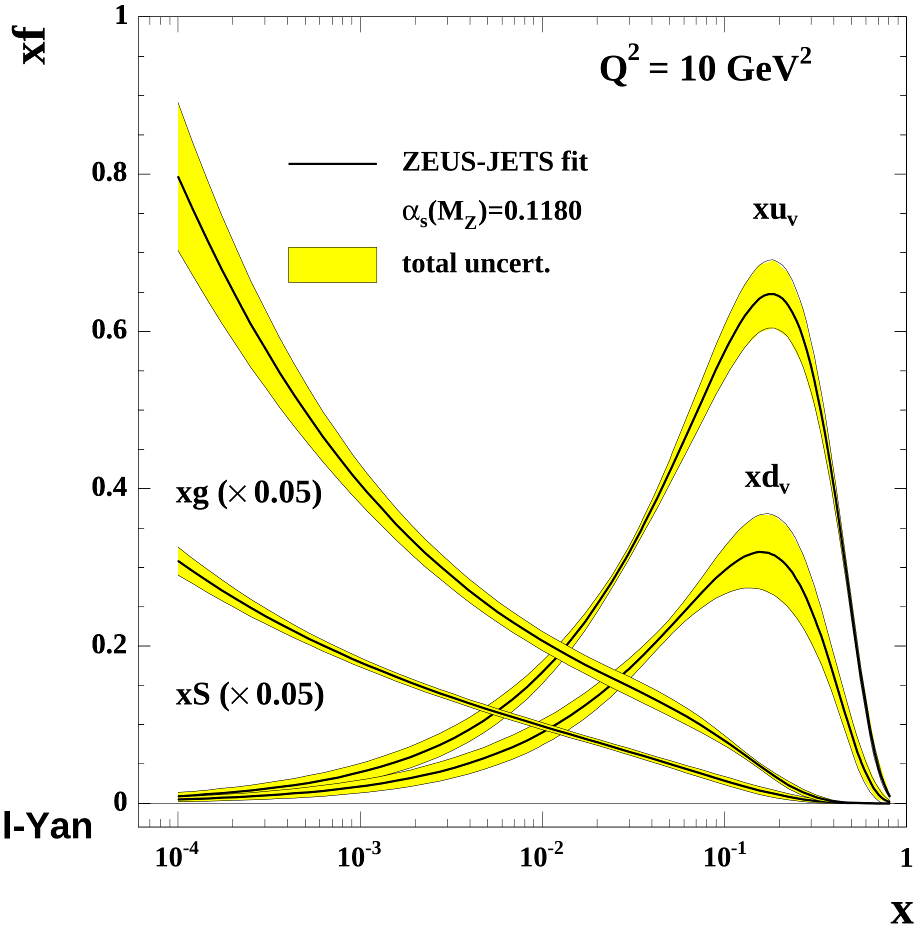
For more details on the ZEUS-JETS fit (hep-ph/05030274), and the data included, see cont. to this workshop, "Proton PDFs using Structure Functions and Jet Data from ZEUS", Juan Terron.

Data:

all HERA-I ZEUS incl. NC/CC e^+/e^- (94-00)
ZEUS inclusive jets in DIS (96-97)
ZEUS dijets in photoproduction (96-97)

Parameterisation:

PDF	Param. at $Q_0^2 = 7$ GeV^2
u-val. (xu_v)	$A_{uv} x^{buv} (1-x)^{cuv} (1+d_{uv}x)$
d-val. (xd_v)	$A_{dv} x^{bdv} (1-x)^{cdv} (1+d_{dv}x)$
total sea (xS)	$A_S x^{bs} (1-x)^{cs}$
gluon (xg)	$A_g x^{bg} (1-x)^{cg} (1+d_g x)$
dbar-ubar ($x\Delta$)	$A_\Delta x^{b\Delta} (1-x)^{c\Delta}$



- **parameter constraints:**
  - **momentum and quark number sum rules**
  - **low-x behaviour of u_v and d_v set equal**
  - **Δ set consistent with Gottfried sum and Drell-Yan**

11 free parameters in total

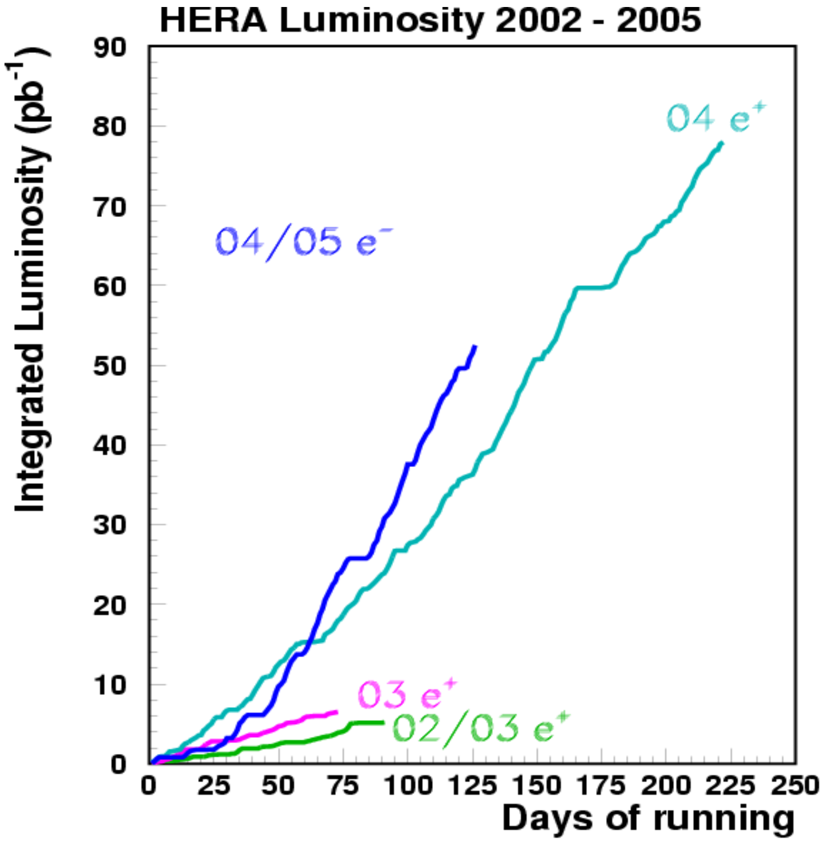
- **heavy quarks treated in variable flavour number scheme of Thorne and Roberts**
- **uncertainties evaluated using Offset Method**

PART I:

Impact of future HERA measurements on the ZEUS PDF fit: within current HERA-II running scenario

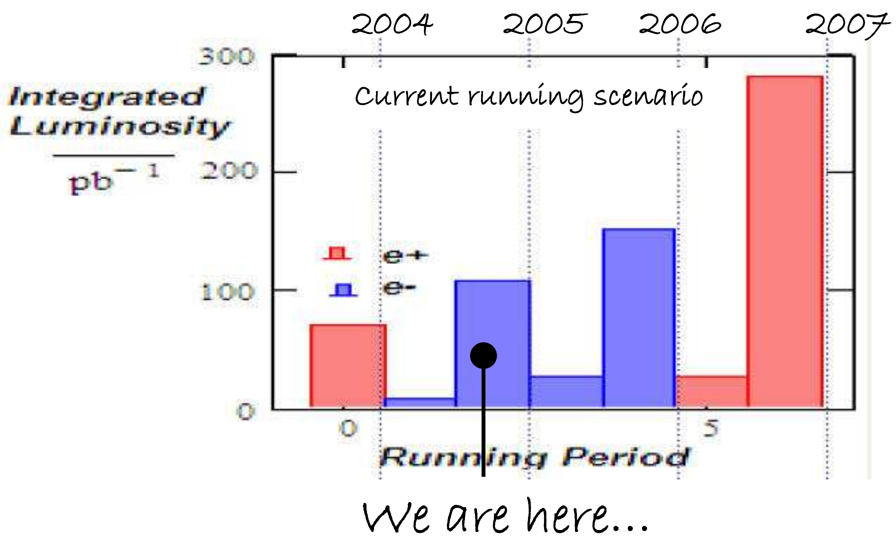
Current HERA-II running scenario

- **HERA-II is running efficiently...**



HERA delivered luminosity (pb^{-1})

	HERA-I (92-00)	HERA-II (02 →)
e$^+$	165	90
e$^-$	27	> 50



" 700pb^{-1} integrated luminosity, equally divided between e$^+$/e$^-$, expected by the end of HERA-II running in mid-2007 "

What impact will future HERA measurements have on the PDFs?

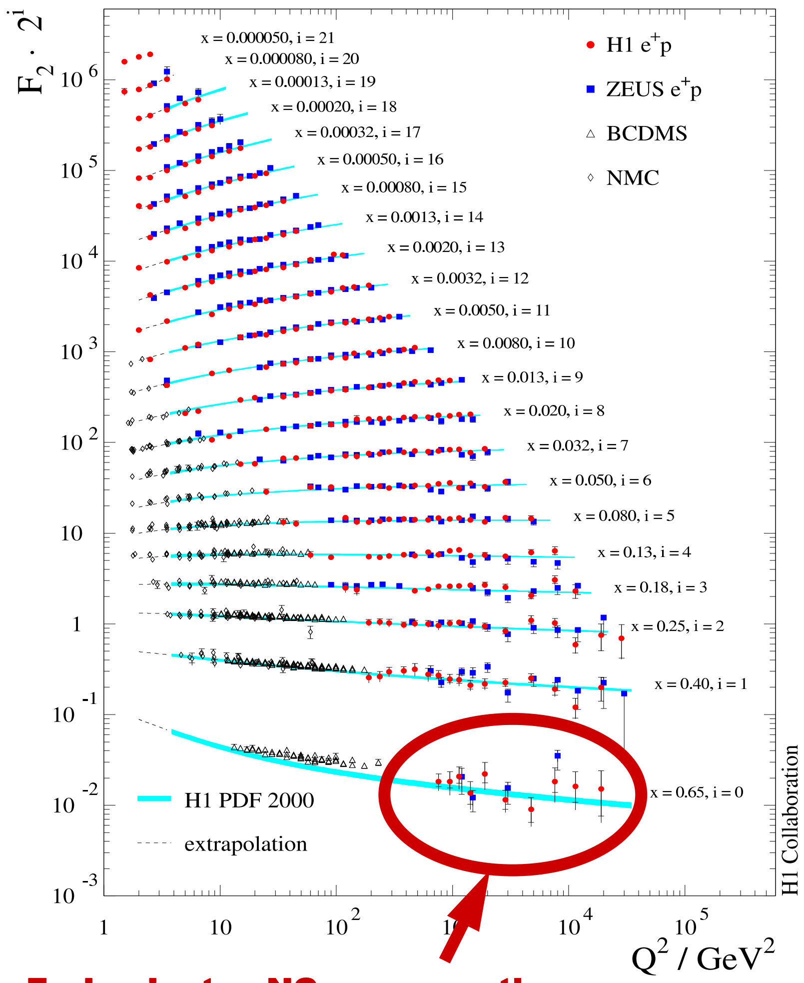
Where does the information come from in a HERA-Only fit ?

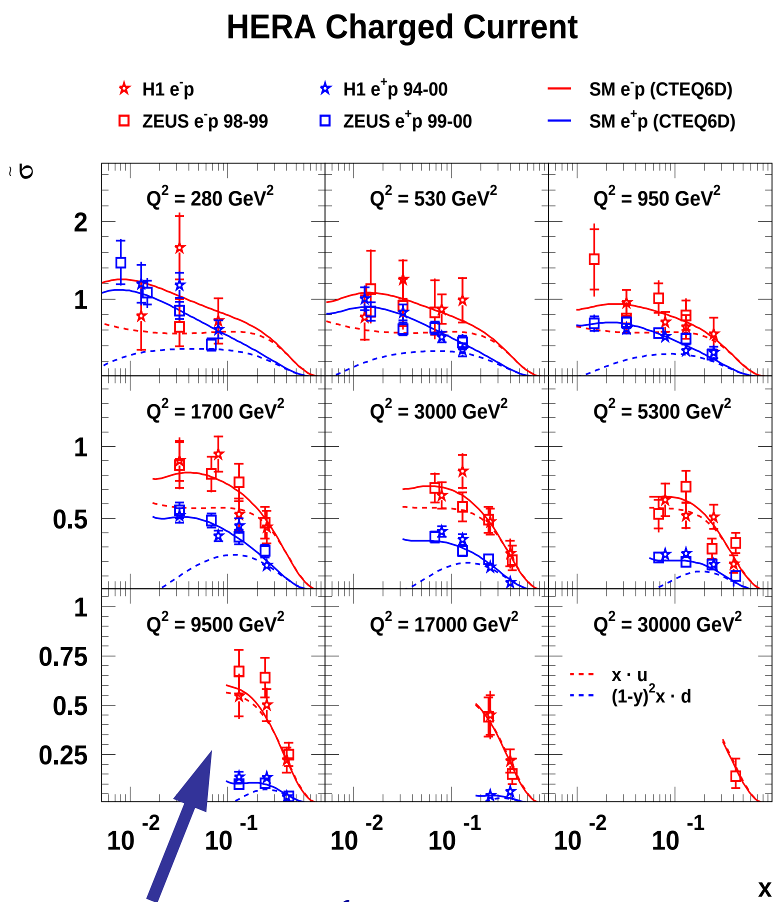
Valence	**High Q^2 inclusive NC/CC $e^{\pm}$ cross sections**
Sea	**Low-x from inclusive NC DIS** **High-x ? Flavour ? (assumptions needed)**
Gluon	**Low-x from HERA $dF_2/d\ln Q^2$** **Mid-to-high-x from HERA jet data** **High-x from momentum sum rule**

HERA-I: statistics limited

HERA-I: statistics limited at high-E_T and high-Q^2

Example: high-Q^2 NC and CC data





F_2 dominates NC cross section, HERA-I: $\delta F_2/F_2 \sim 30\%$

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

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

e+ <u>and</u> e- needed for flavour separation, but high-Q^2 CC statistically limited at HERA-I, especially e^-p data

- **HERA-II will provide greatly increased luminosity**

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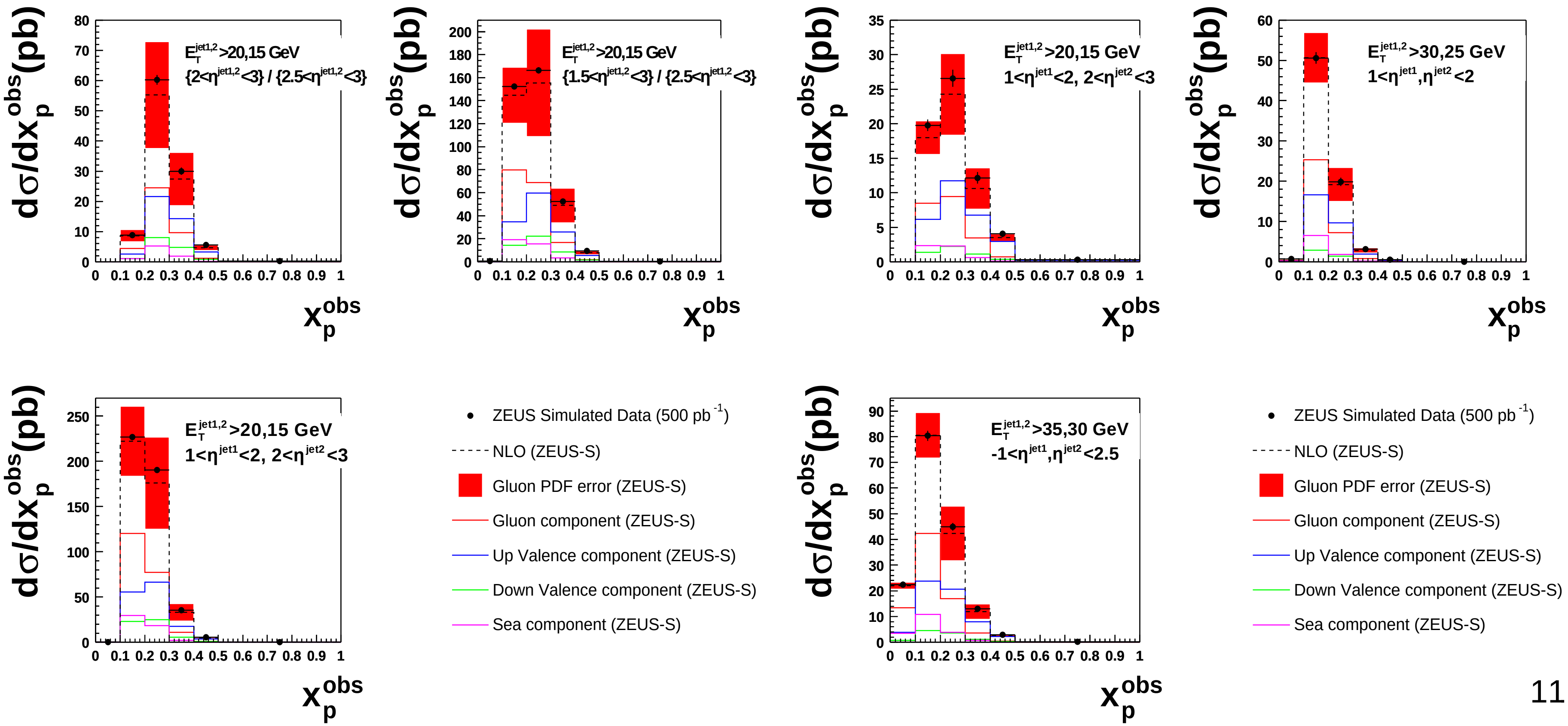
HERA-I: measurements in only certain kinematic regions – potential to optimise cuts for sensitivity to gluon

Optimised jet cross sections

Christopher Targett-Adams (UCL)

- Measure jet cross sections in kinematic regions "optimised" for sensitivity to gluon
  - ongoing ZEUS study: dijets in photoproduction ($Q^2 < 1$ GeV^2)
    - data simulated using NLO QCD (Frixione-Ridolfi) and CTEQ5M1 proton PDF (500 pb^{-1})

resolved-photon enhanced: x_γ^{OBS}<0.75 **direct-photon enhanced: x_γ^{OBS}>0.75**



Impact of HERA-II in current running scenario:- case study

Data sample	L of HERA-I measurement (pb^{-1})	assumed L of HERA-II measurement (pb^{-1})	Central values taken from...	Systematic uncertainties taken from...
High-Q^2 NC e+	63	350	existing data	existing data
High-Q^2 NC e-	16	350	existing data	existing data
High-Q^2 CC e+	61	350	existing data	existing data
High-Q^2 CC e-	16	350	existing data	existing data
Inclusive DIS jets	37	500	existing data	existing data
Dijets in γp	37	500	existing data	existing data

statistically limited data-sets

- **scale statistical uncerts. on existing data assuming max. 700 pb^{-1} (equally between e+/e-)**
- **systematic uncertainties taken from existing data**

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Inclusive DIS jets	37	500	existing data	existing data
Dijets in γp	37	500	existing data	existing data
Optimised dijets in γp	-	500	NLO QCD	NOT INCLUDED

statistically limited data-sets

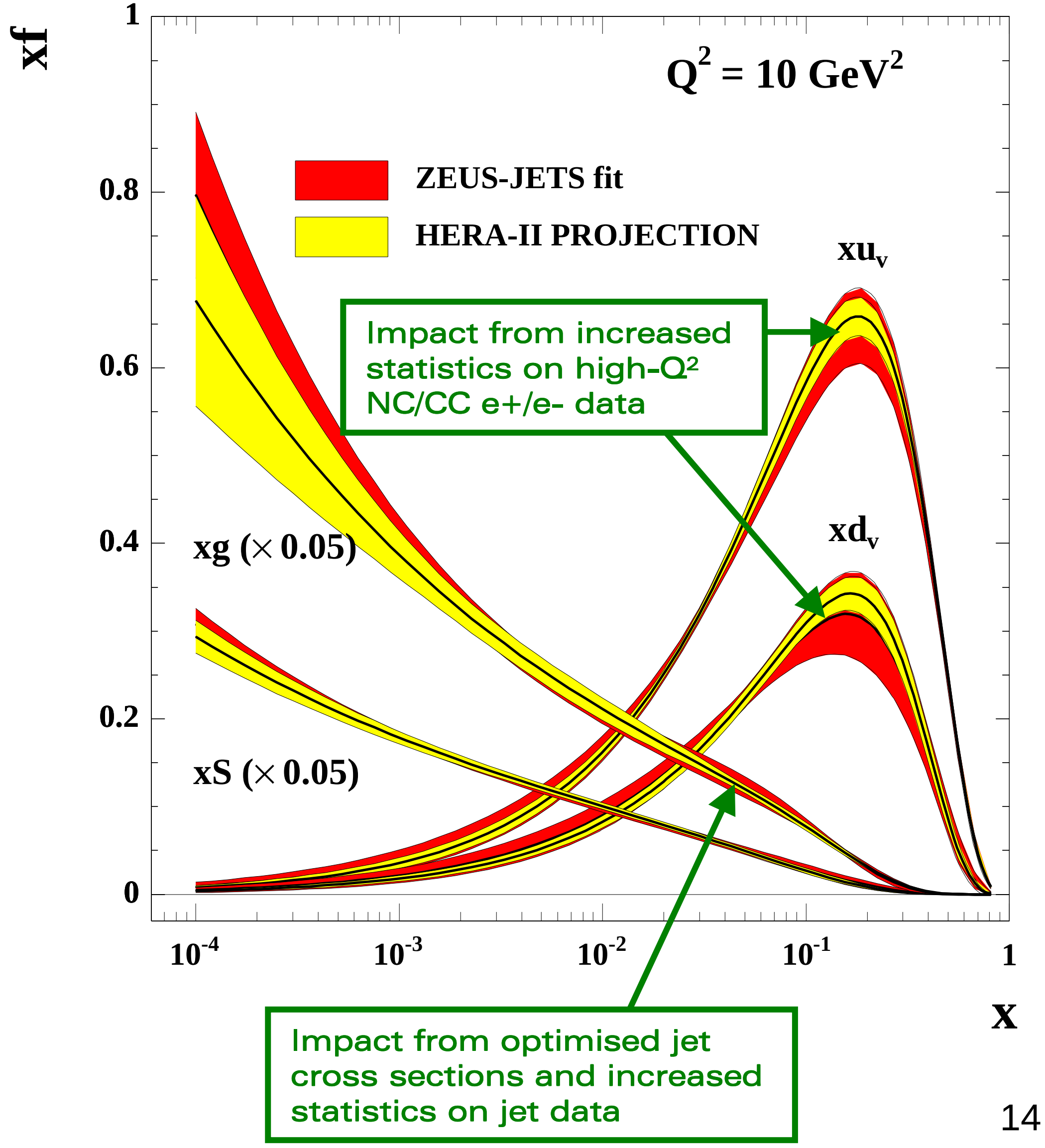
- **scale statistical uncerts. on existing data assuming max. 700 pb^{-1} (equally between e+/e-)**
- **systematic uncertainties taken from existing data**

optimised jet cross sections

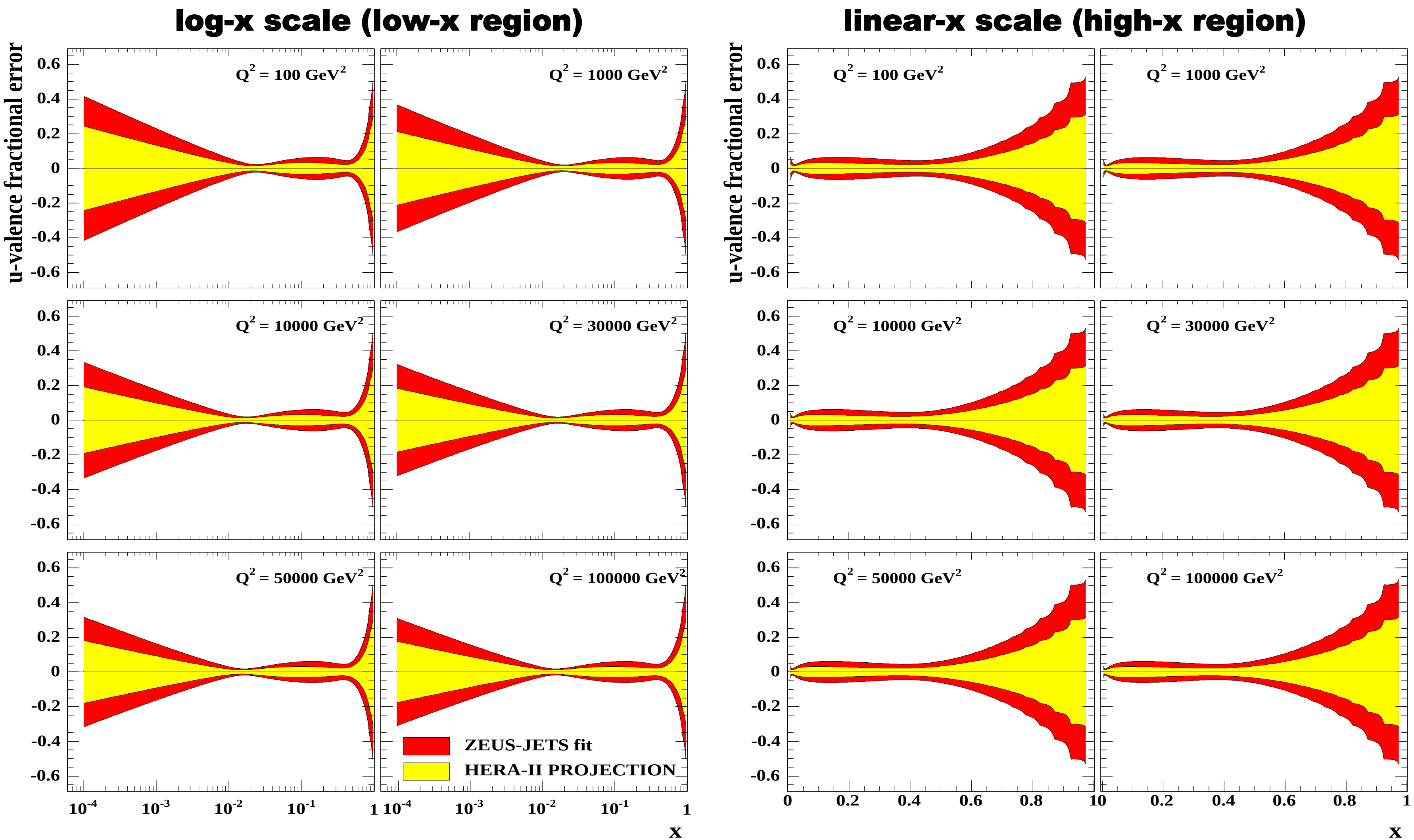
- **include simulated data-points from NLO QCD, statistical uncertainties assume 500 pb^{-1}**
- **no systematics included**

HERA-II projected fit

- Impact of the projected HERA-II measurements has been studied in context of the ZEUS-JETS fit

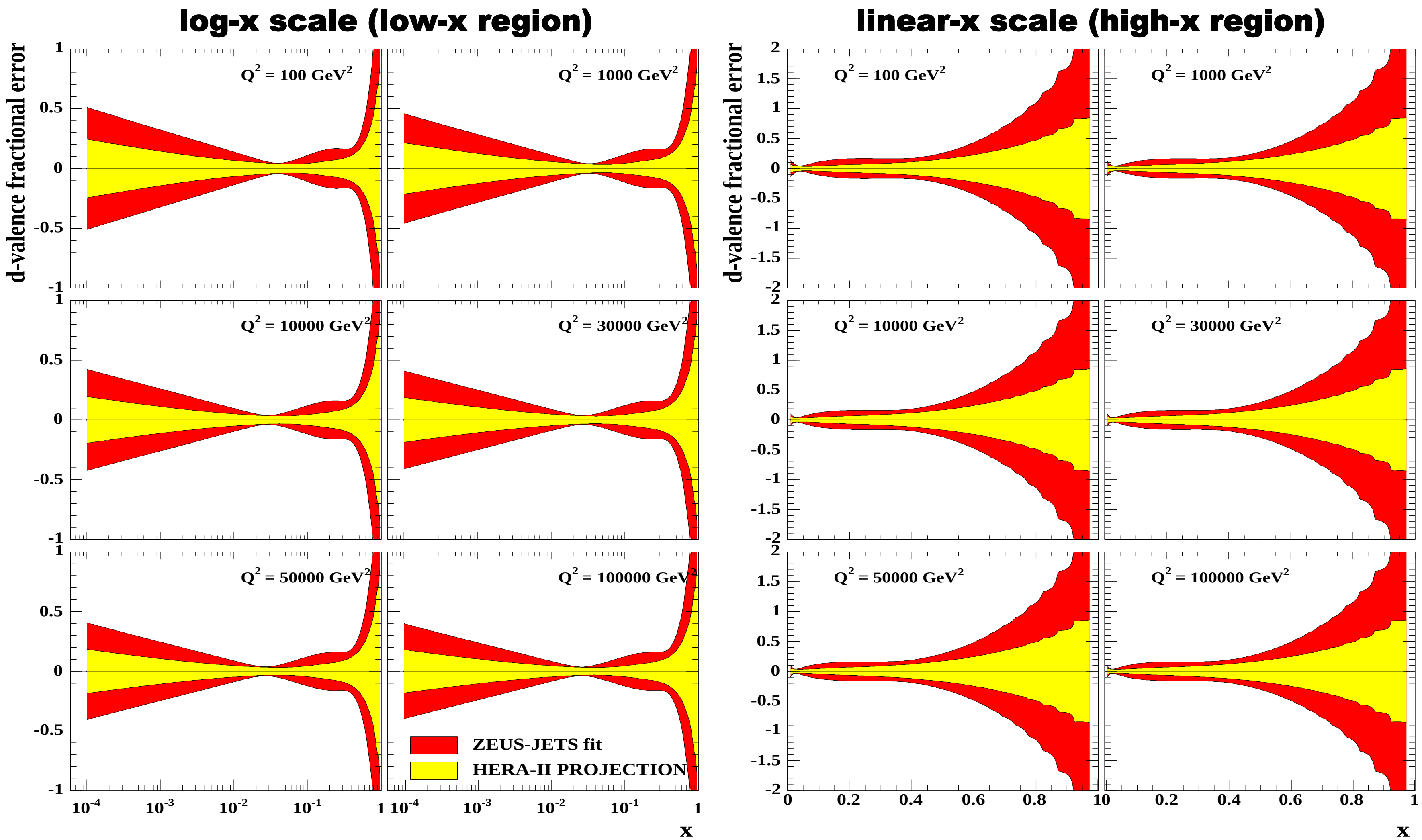


u-valence uncertainties



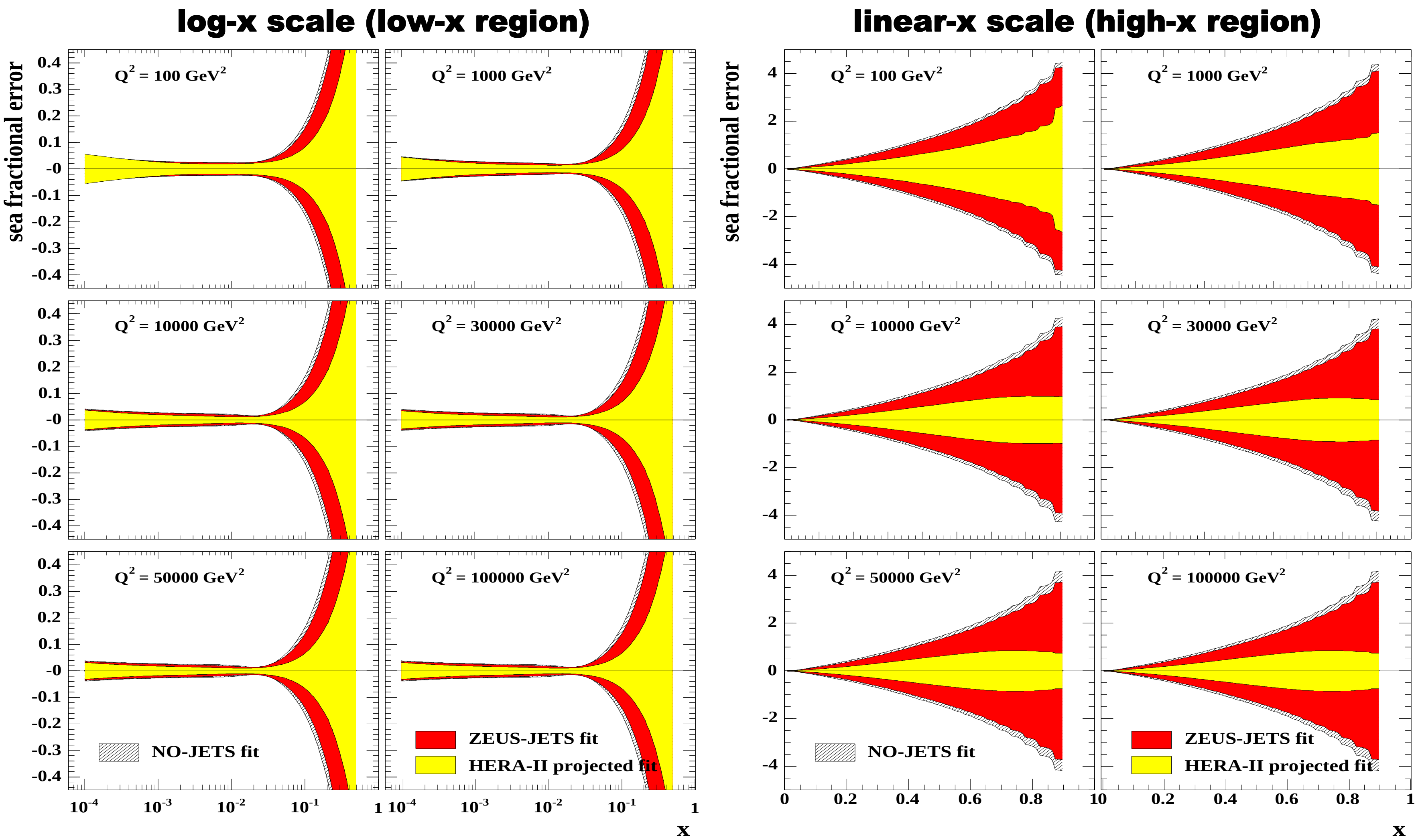
- uncertainties on u-valence distribution significantly reduced over visible x range

d-valence uncertainties



- uncertainties on d-valence distribution significantly reduced over visible x range

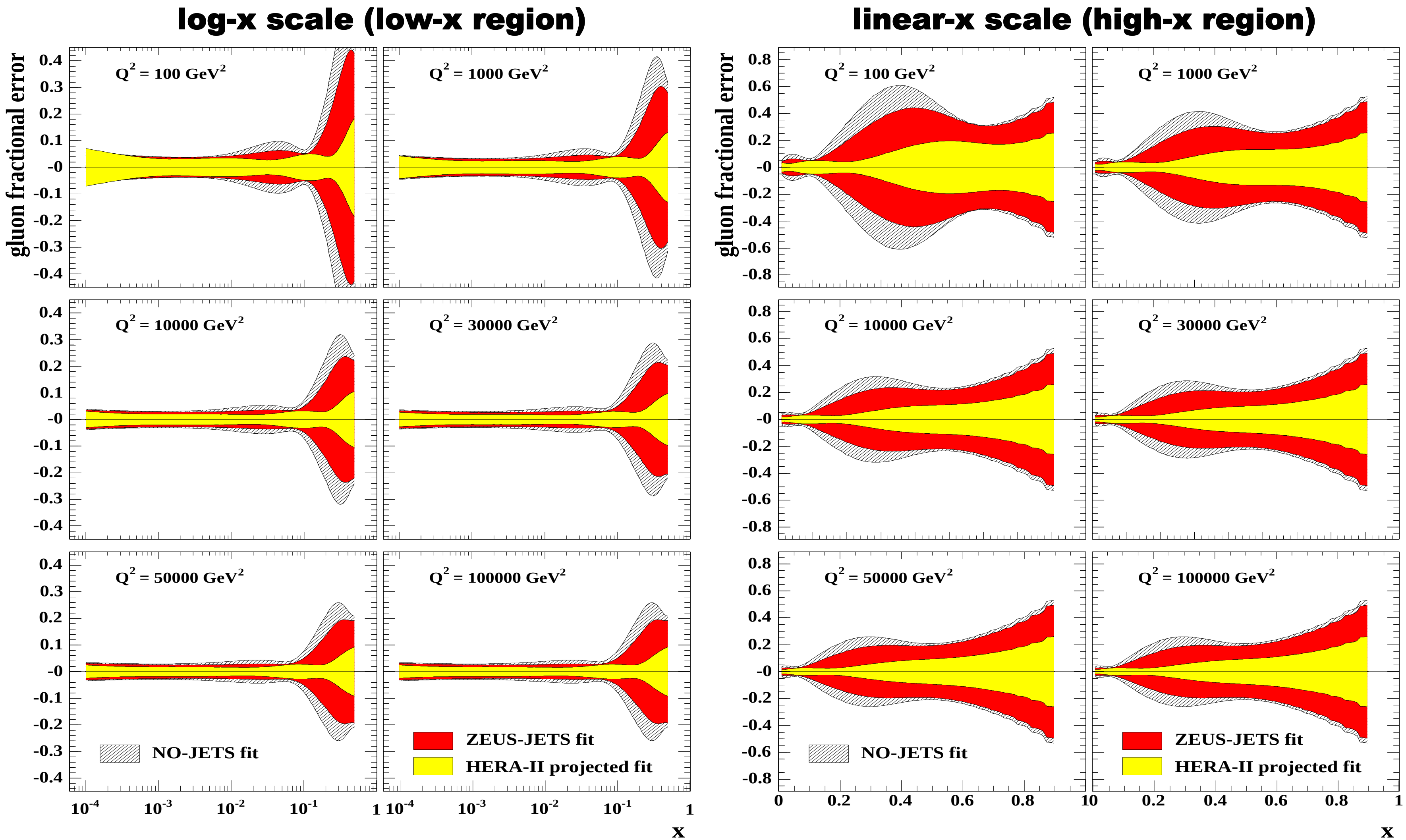
Sea-quark uncertainties



- uncertainties on sea-quark distribution significantly reduced at high-x

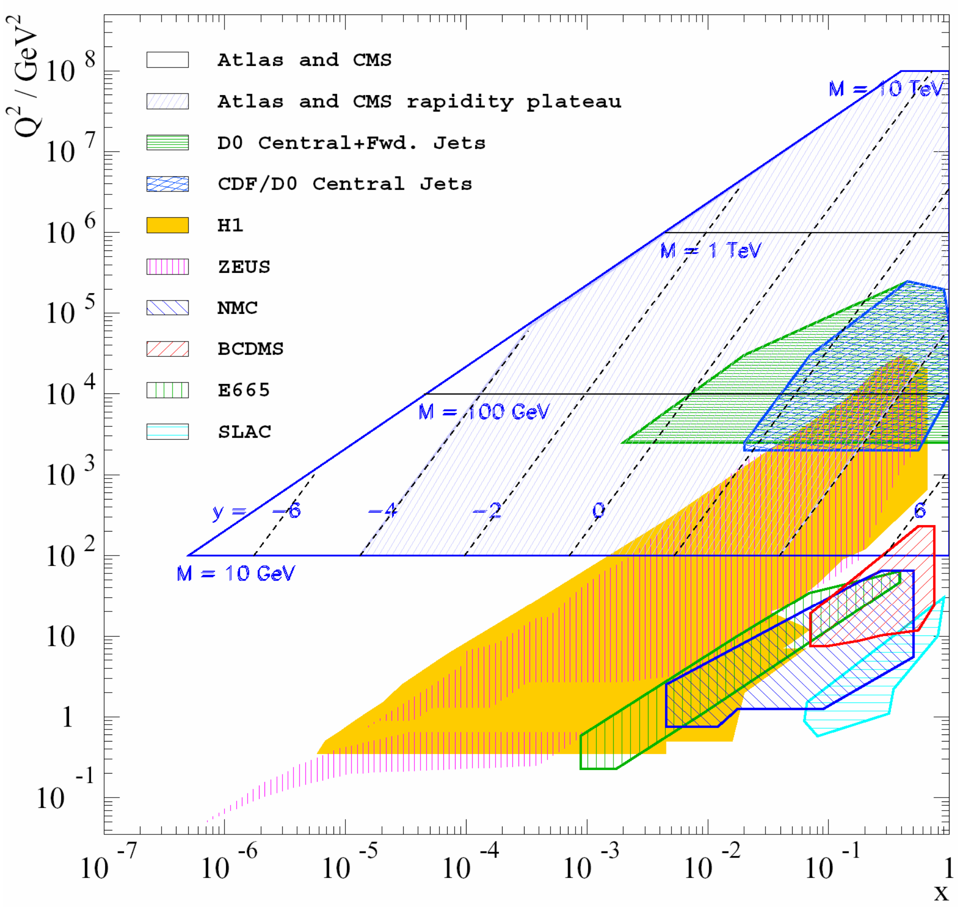
  → most significant improvement from increased statistics at HERA-II

gluon uncertainties



- uncertainties on mid-to-high-x gluon significantly reduced
  → most significant improvement comes from optimised cross section

HERA Kinematic (x,Q^2) Range



HERA data covers large region in (x,Q^2)
→ also relevant x-region for LHC

High-p_T jets, new particle searches etc at LHC all depend strongly on high-x partons → improvement to LHC cross section uncertainties after HERA-II

Impact of HERA-II projected PDF on LHC cross sections under study

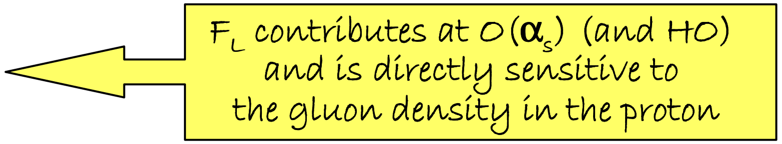
PART II:

Alternative HERA running scenarios:

low energy running and a precision measurement of F_L

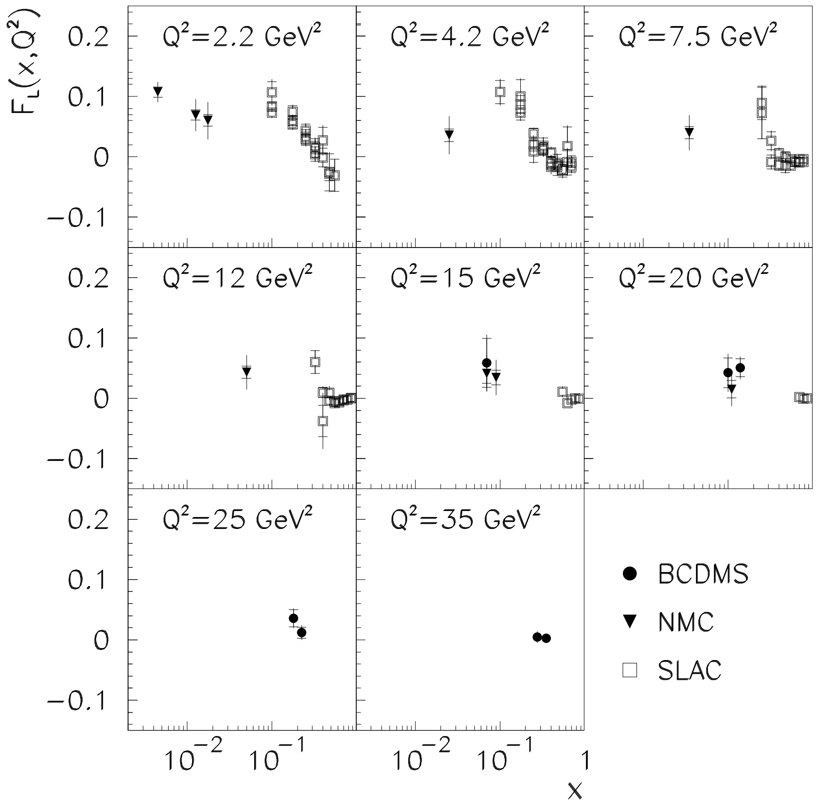
Impact of a HERA measurement of F_L

$$\frac{d^2\sigma_{NC}(e^{\pm}p)}{dxdQ^2} \sim Y_+F_2 - y^2F_L \;\; \text{where} \;\; F_L = \alpha_s . g(x, Q^2)$$



- measured at fixed target exps. ($x > 10^{-3}$)

- precision F_L measurement at HERA requires low-E_p running → vary y at fixed (x,Q^2)



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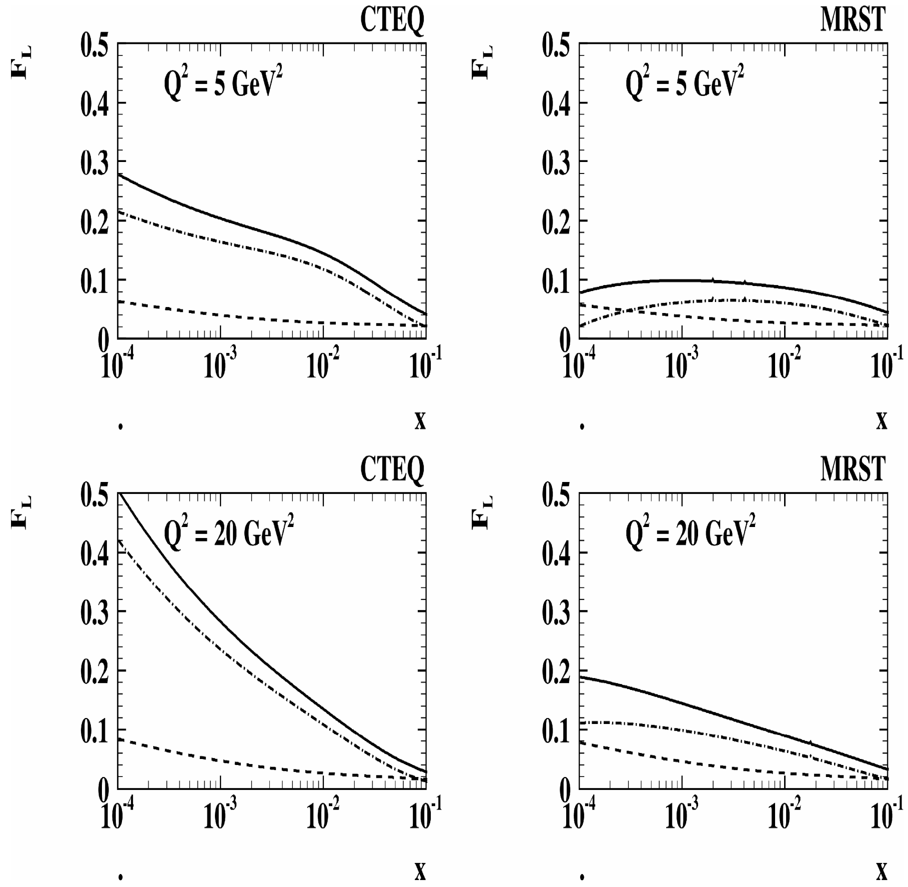
F_L contributes at $O(\alpha_s)$ (and HO) and is directly sensitive to the gluon density in the proton

- precision measurement of F_L at HERA-II:
  - pin down gluon density at low-x
  - reduce uncertainties on gluon PDF



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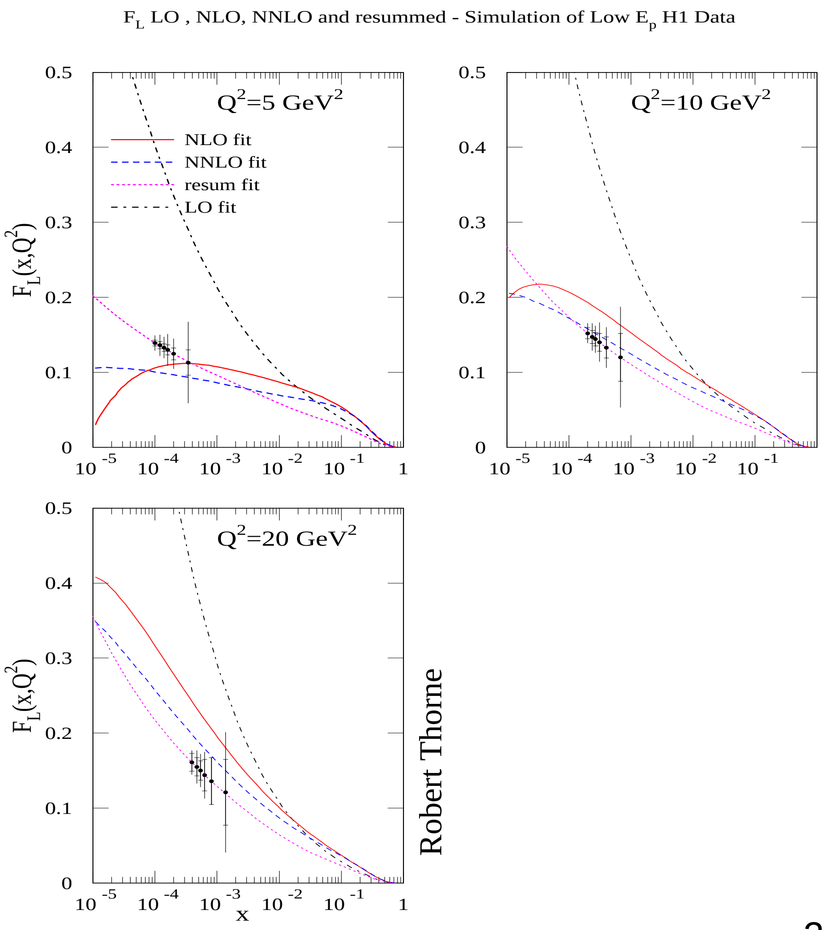
  - provide tests of higher order QCD
  - test the need for extensions to DGLAP at low-x



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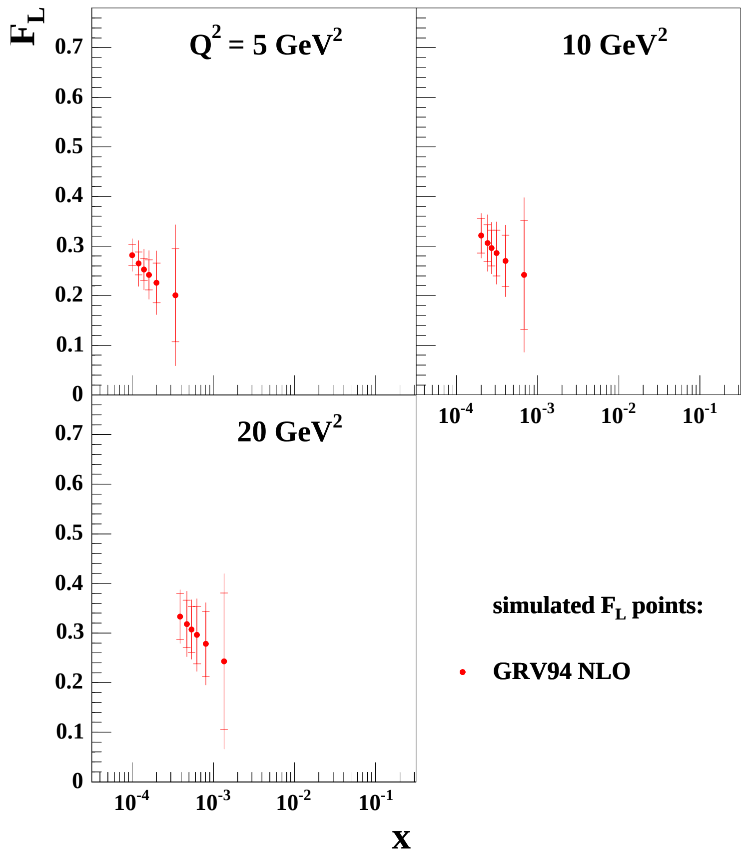

Simulation of HERA-II F_L: *Max Klein (DESY)*

- F_L simulated using GRV94 NLO PDF
- statistical uncertainties correspond to:

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

- systematic uncertainties from current H1 analysis of 99-00 data (few %)

For further details, see "On the future measurement of F_L at low-x at HERA", Max Klein, in proceedings, DIS04.

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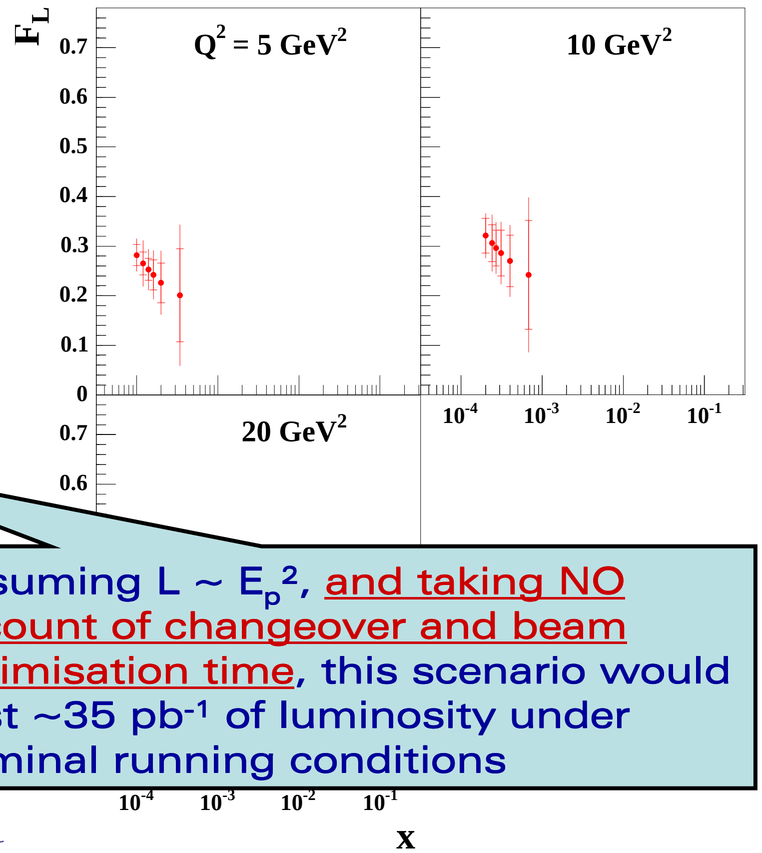

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- statistical uncertainties correspond to:

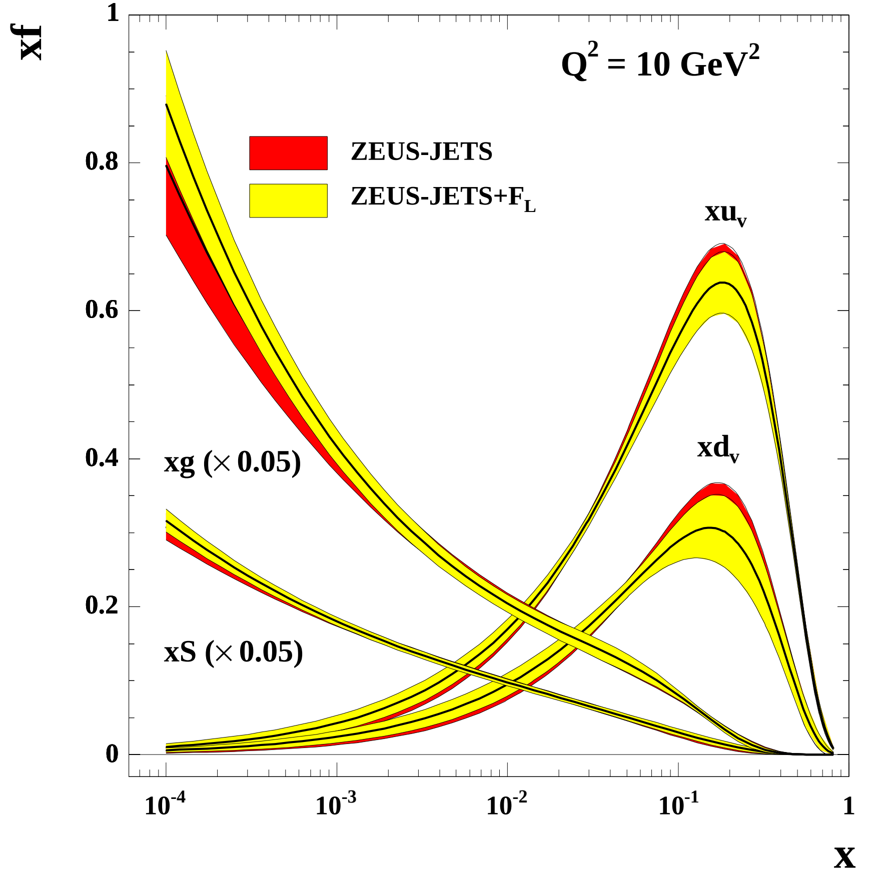
E_p (GeV)	920	575	465	400
L (pb^{-1})	10	5	3	2

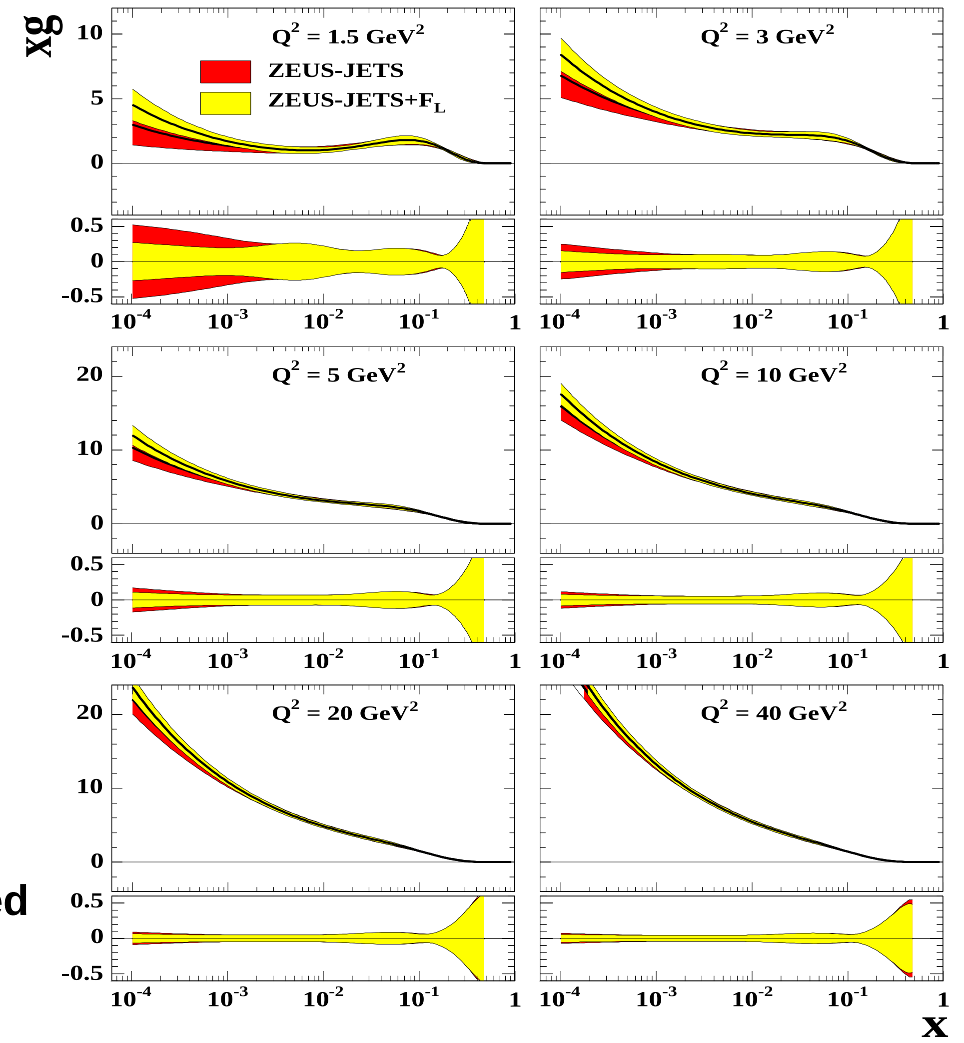
Assuming $L \sim E_p^2$, and taking NO account of changeover and beam optimisation time, this scenario would cost ~35 pb^{-1} of luminosity under nominal running conditions

- systematic uncertainties from current H1 analysis of 99-00 data (few %)

For further details, see "On the future measurement of F_L at low-x at HERA", Max Klein, in proceedings, DIS04.

Impact on gluon distribution





- Fit including simulated F_L data compared to the ZEUS-JETS PDF ↑
- Gluon uncertainties reduced at low-x and <u>low-Q^2</u> (not relevant for LHC)

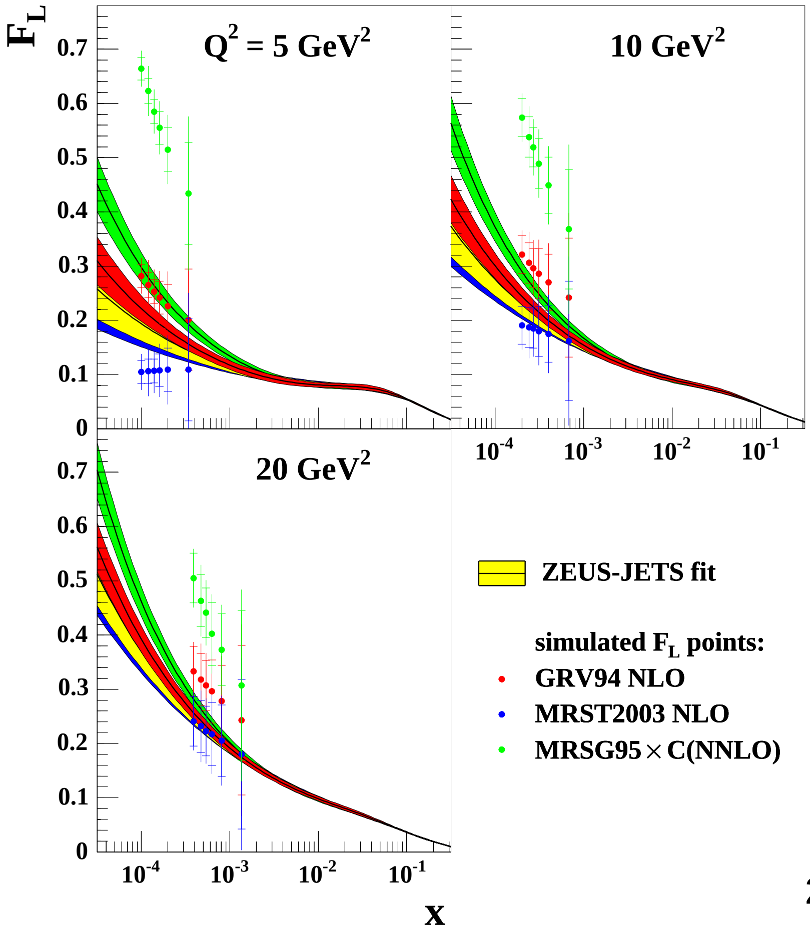
Sensitivity of the NLO QCD fit

- F_L predictions very sensitive to underlying theory
  → choice of PDF, order of QCD calculation …
- how sensitive is the NLO QCD fit to <u>inclusion</u> of "extreme" sets of simulated F_L data?

<u>Simulated F_L data</u>

extremes provided by Robert Thorne (Cambridge)

	PDF	QCD theory
Max. F_L	MRSG95	NNLO*
Mid. F_L	GRV94	NLO
Min. F_L	MRST2003	NLO



- ZEUS fit relatively stable to inclusion of extreme F_L data-sets
- an F_L measurement of this precision should have power to discriminate between theoretical models

Bonus Extra:

Alternative HERA running scenarios:

deuteron running and the sea quark asymmetry

sea quark asymmetry
a study by Max Klein and Burkard Reisert
(in the context of the H1 fit)

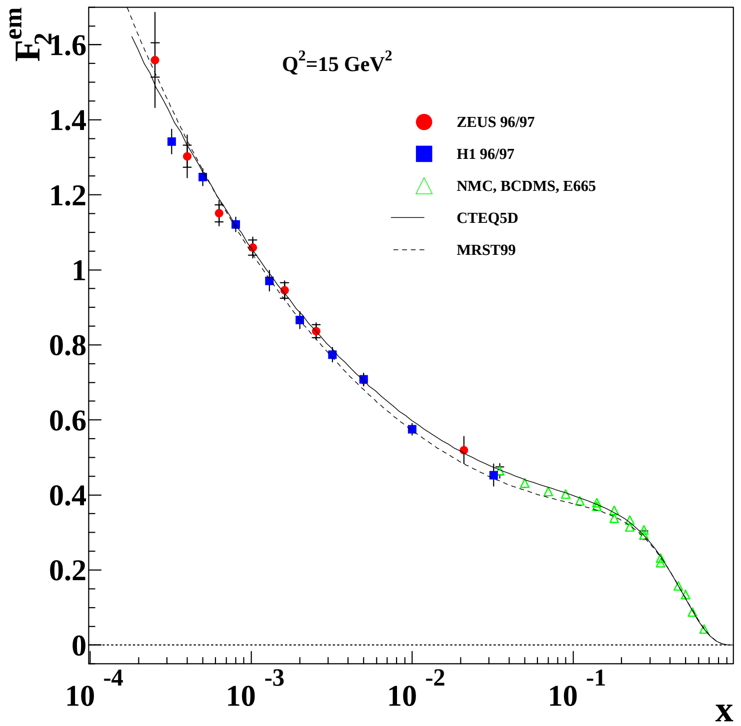
What causes the rise of F_2 at low-x?

F_2 of the proton measures 4ū+đ but ū and đ are unknown at low x → **would be accessible via deuteron (eD) running at HERA-II**

ū=đ was a natural assumption for long time, until E866, HERMES found a difference at x ~ 0.1

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

$F_2 = 4/9\ x(U+\bar{U}) + 1/9\ x(D+\bar{D})$



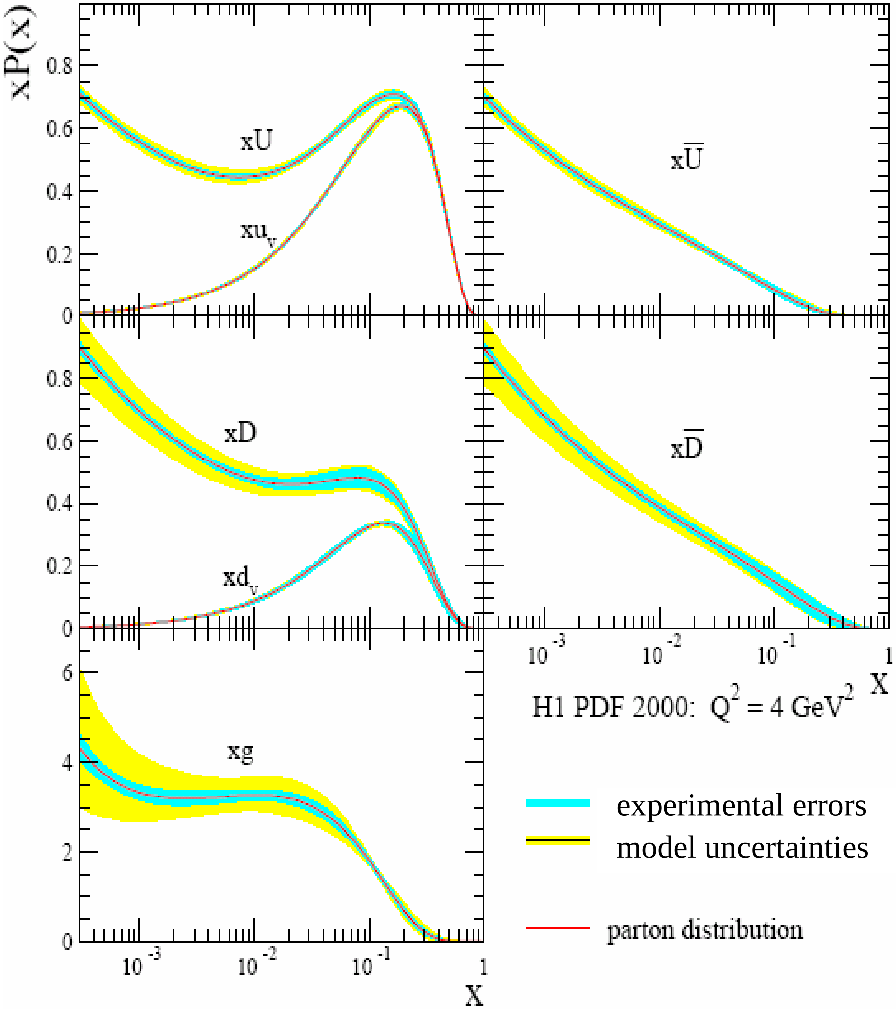
The H1 NLO QCD fit

HERA-I H1 incl. NC/CC e^+/e^- (94-00):	H1-Only
+ BCDMS (p,D data):	H1+BCDMS

PDF	Param. at Q_0^2 =4 GeV^2
xU=x(u+c)	$A_U\, x^{bU}\, (1-x)^{cU}\, (1+d_U x+e_U x^3)$
xUbar	$A_{Ubar}\, x^{bUbar}\, (1-x)^{cUbar}$
xD=x(d+s)	$A_D\, x^{bD}\, (1-x)^{cD}\, (1+d_D x)$
xDbar	$A_{Dbar}\, x^{bDbar}\, (1-x)^{cDbar}$
xg	$A_g\, x^{bg}\, (1-x)^{cg}\, (1+d_g x)$

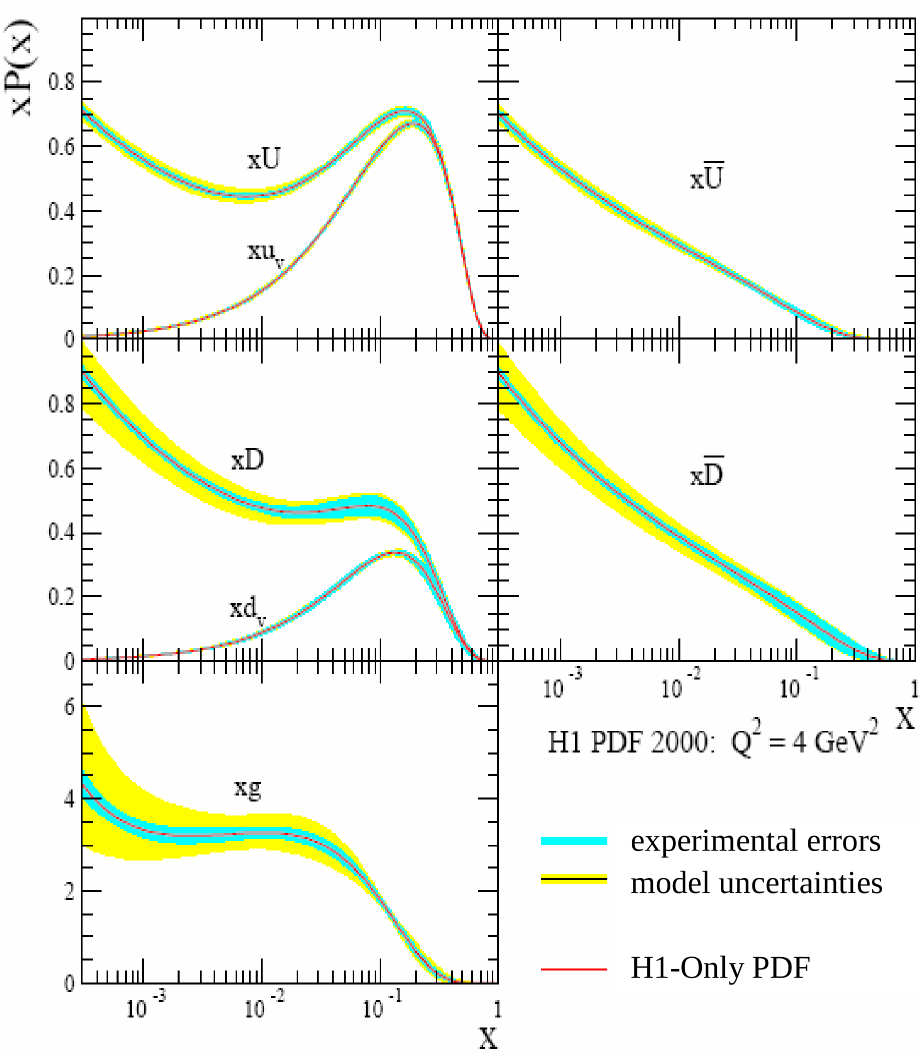
- **No information on sea flavour composition**
  - **only one measurement at low-x:**
    $F_2 = 4/9\, x(U+\bar{U}) + 1/9\, x(D+\bar{D})$
- **Assume quark and anti-quark distributions are equal at low-x and u=d**
  - $b_U = b_D = b_{\bar{U}} = b_{\bar{D}} \equiv b_q$
  - $A_{\bar{U}} = A_{\bar{D}}.(1-f_s)/(1-f_c)$, **which means that** $\bar{d}/\bar{u} \to 1$ **as** $x \to 0$

H1-Only fit

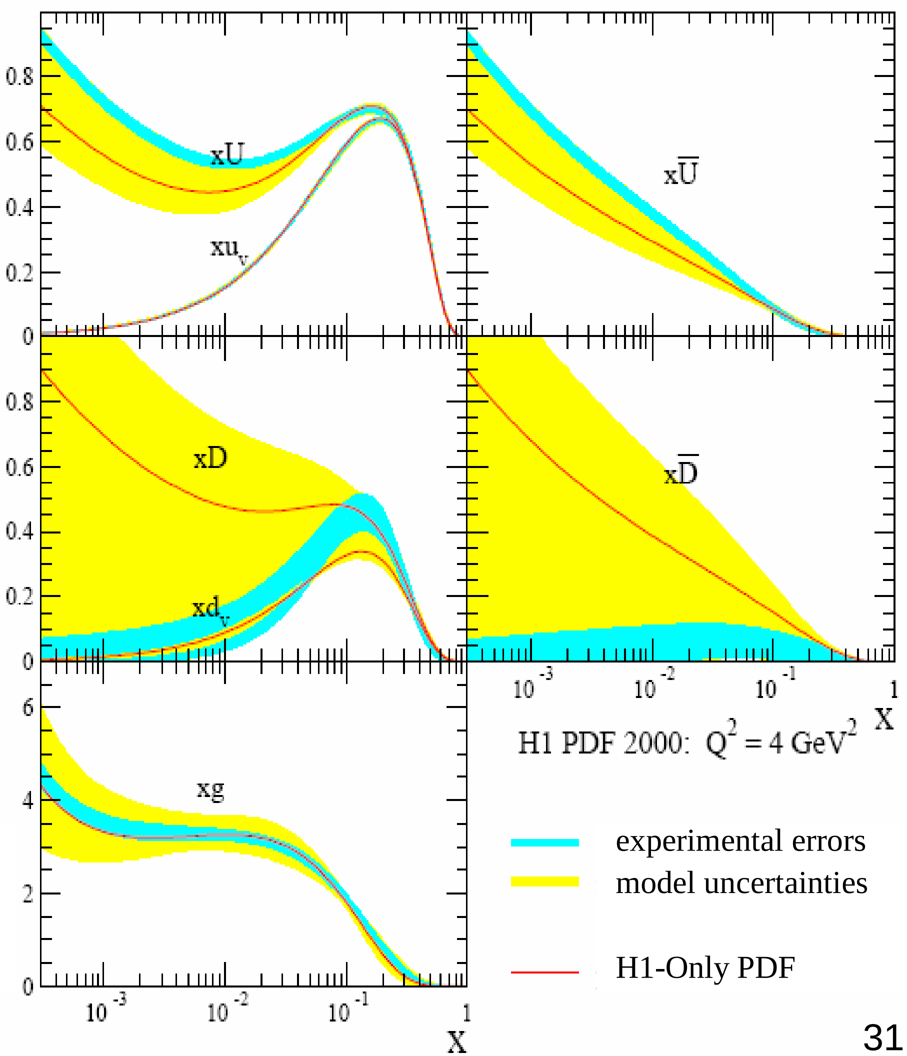


Releasing the dbar-ubar constraint

H1-Only fit (default assumptions)

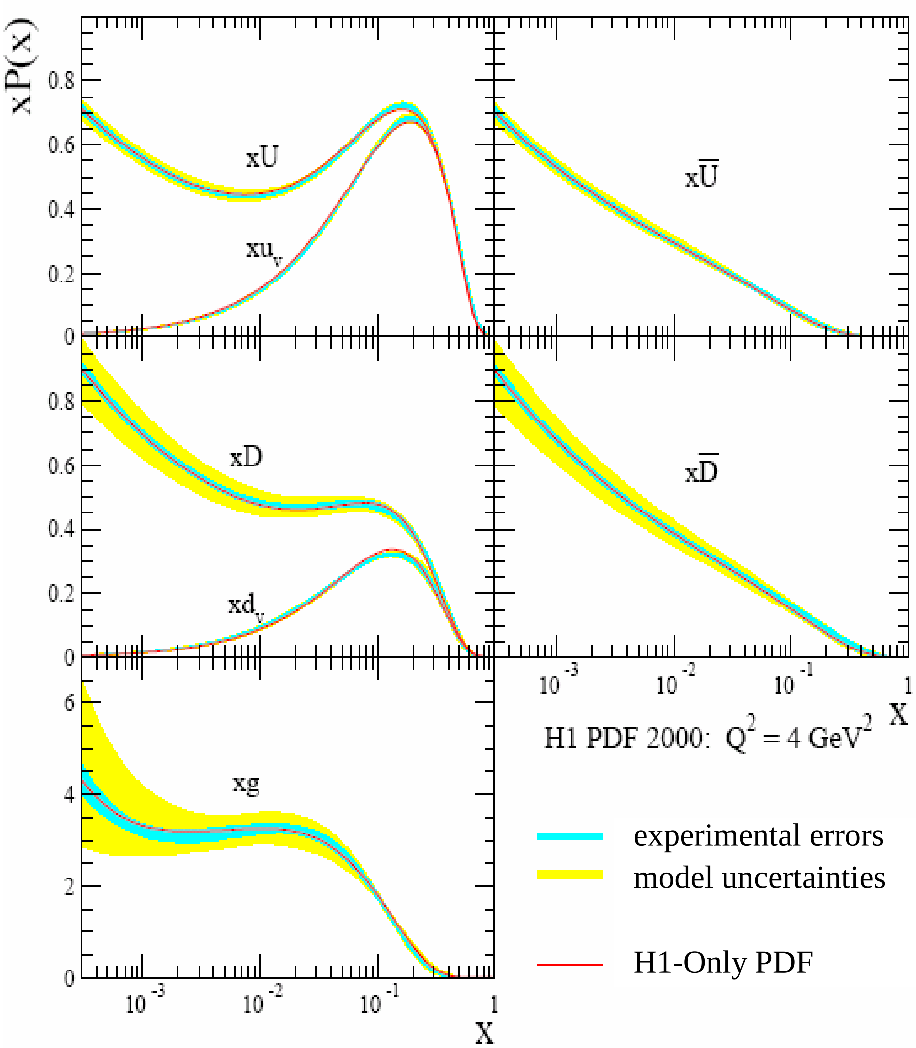


H1 - Only fit (no constraint on A, b)

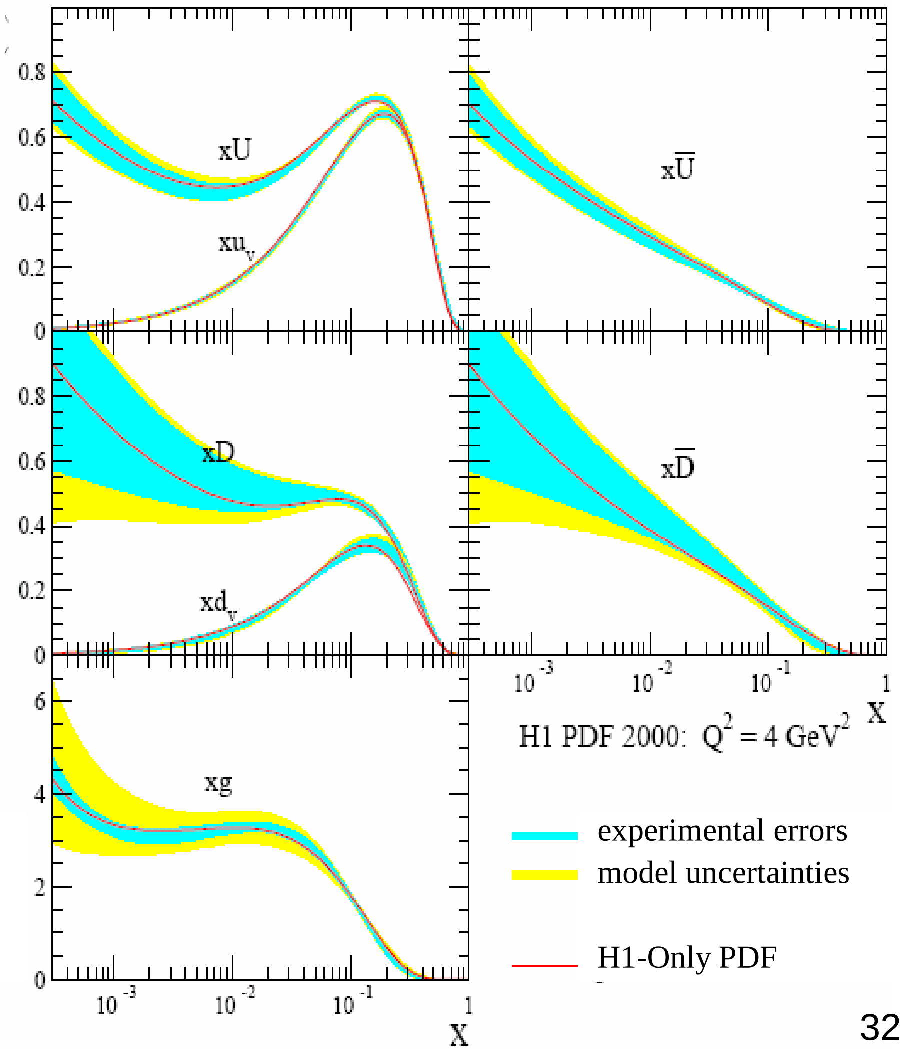


Releasing the dbar-ubar constraint

H1+BCDMS fit



H1+BCDMS fit (no constraint on A, b)



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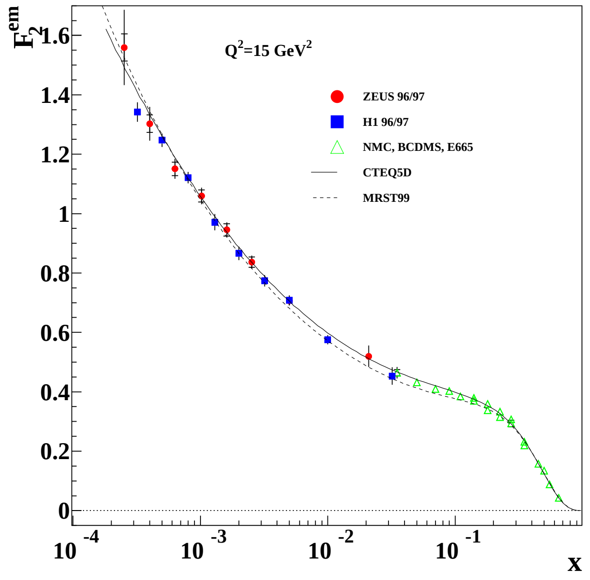
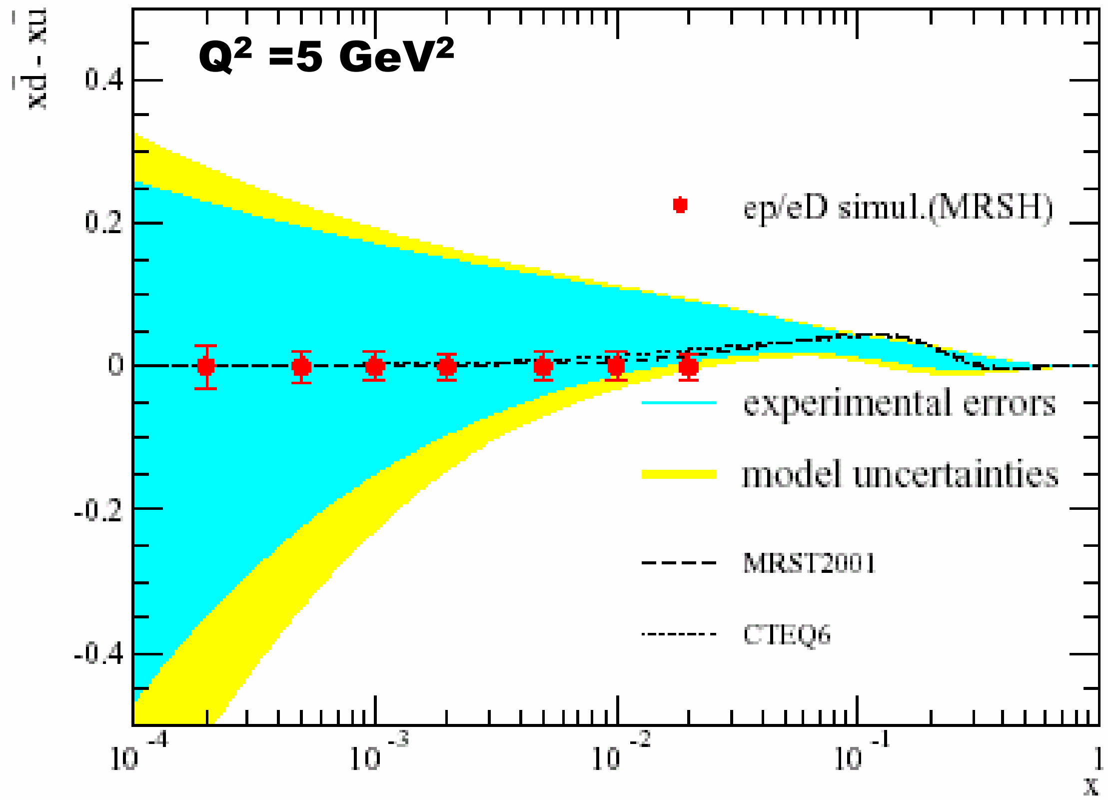


$$\frac{1}{2}(F_2^p + F_2^n) - F_2^p$$
$$= x(\frac{1}{6}d_v - \frac{1}{6}u_v + \frac{1}{3}\overline{d} - \frac{1}{3}\overline{u})$$
$$\approx \frac{1}{3}x(\overline{d} - \overline{u}) \text{ at low} - x$$

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.

H1+BCDMS fit



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

Summary

Potential impact of future HERA data on proton PDFs has been investigated:

1. <u>Impact on PDFs of current HERA-II running scenario:</u>

- **increased luminosity of HERA-II will provide**
  - → **significantly improved precision on statistically limited data-sets**
    - **high-Q^2 NC/CC data → significant improvement to <u>valence distributions</u>**
    - **high-Q^2 and high-E_T jet data → improvement to <u>high-x sea and gluon</u>**
- **measurements of jet cross sections <u>optimised</u> for sensitivity to gluon**
  - **significant improvement to <u>high-x gluon</u>**

⏩ impact of projected HERA-II PDFs on LHC cross sections under study

2. <u>Low energy running scenario:</u>

- **precise measurement of F_L at low-x possible with low-E_p running**
- **inclusion of simulated F_L data in NLO QCD fit indicates:**
  - **improvement in gluon uncertainties at low-x and low-Q^2**
  - **ability of precision HERA F_L to discriminate between theoretical models**

Summary (cont.)

3. <u>Deuteron running and the sea-quark asymmetry:</u>

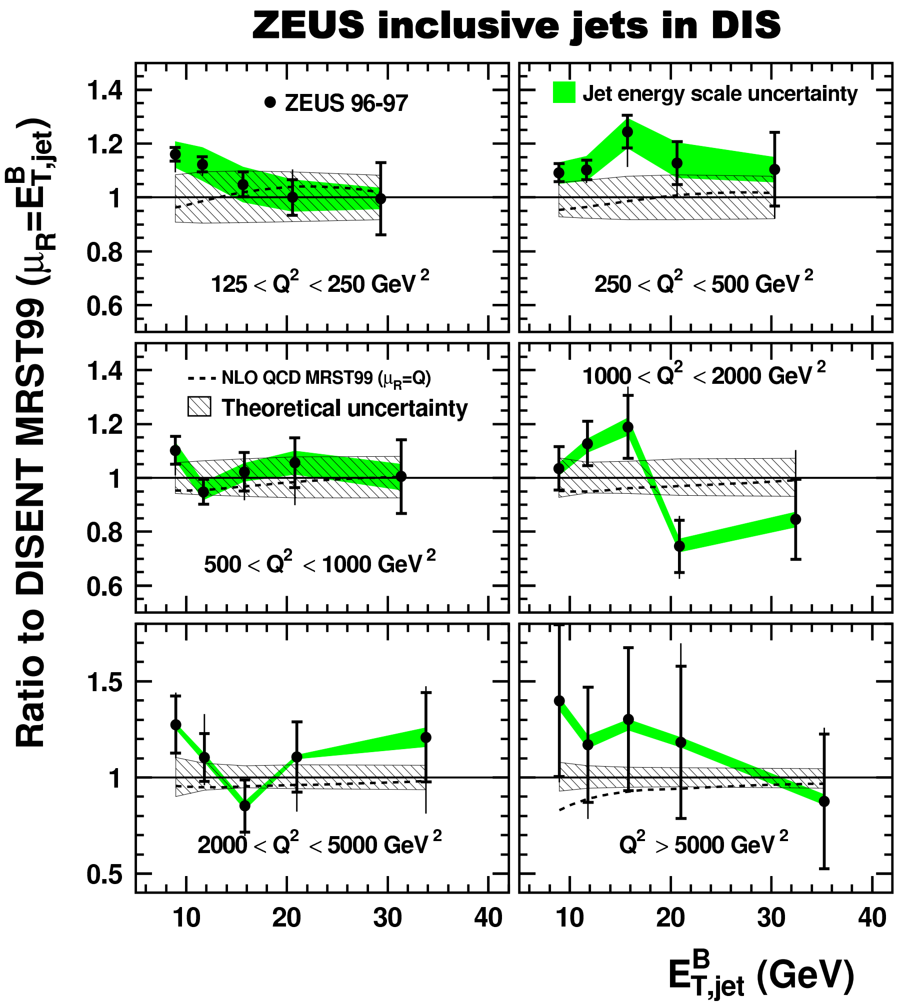
(Max Klein, Burkard Reisert):

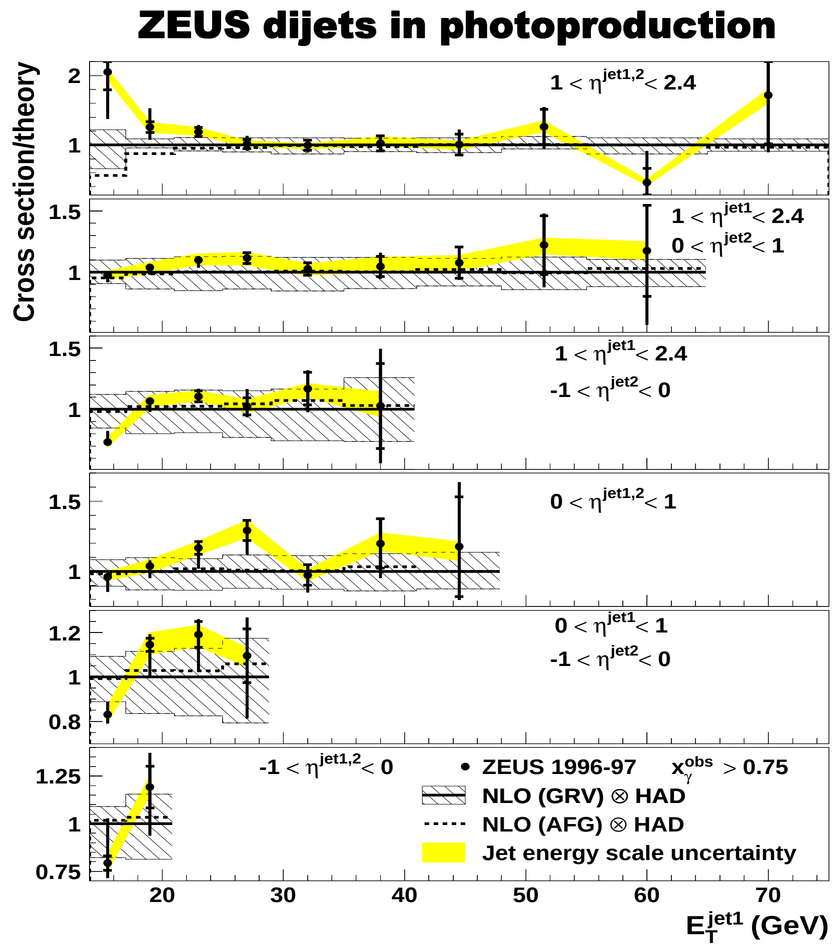
- **So far HERA has not resolved the light sea quarks at low x**
  - **relaxing assumption that $\bar{u}=\bar{d}$, $u=\bar{u}$ and $d=\bar{d}$ at low-x leads to large uncertainties**
  - **deuteron data from fixed target experiments (e.g. BCDMS) help but cannot solve the problem since the data lie at higher-x**

⏩ **would need deuteron running at HERA to resolve this issue**

Extras ...

Example: high-Q^2/high-E_T jet data

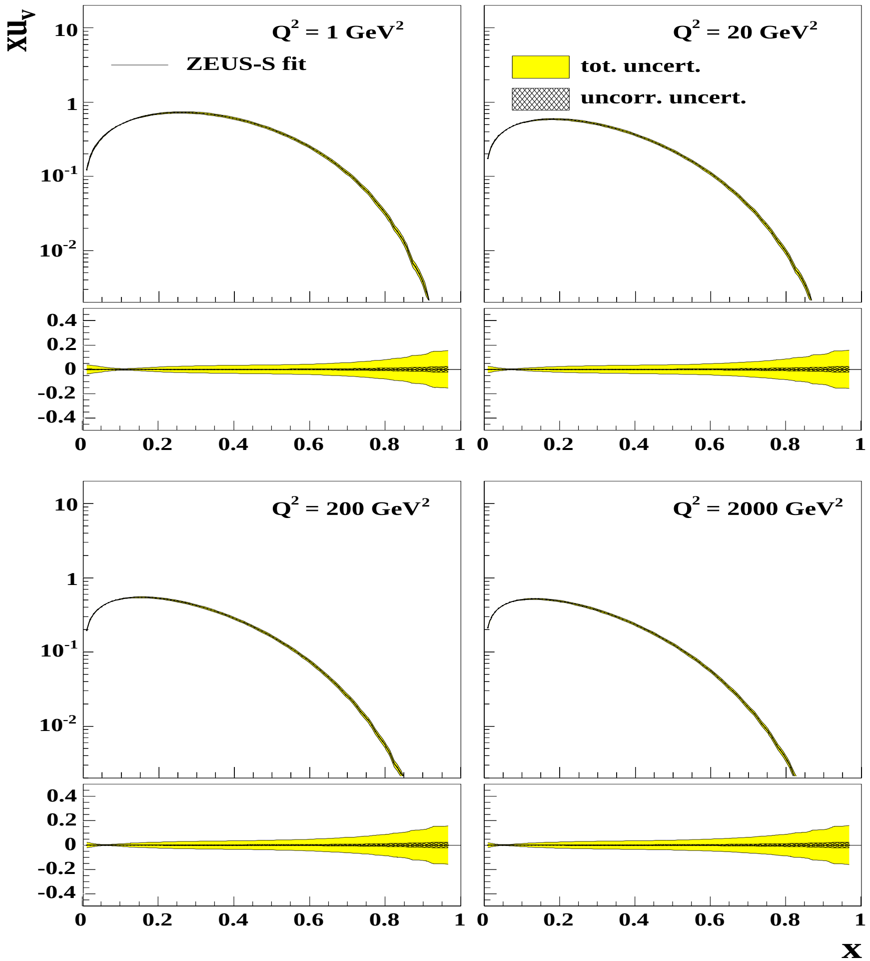




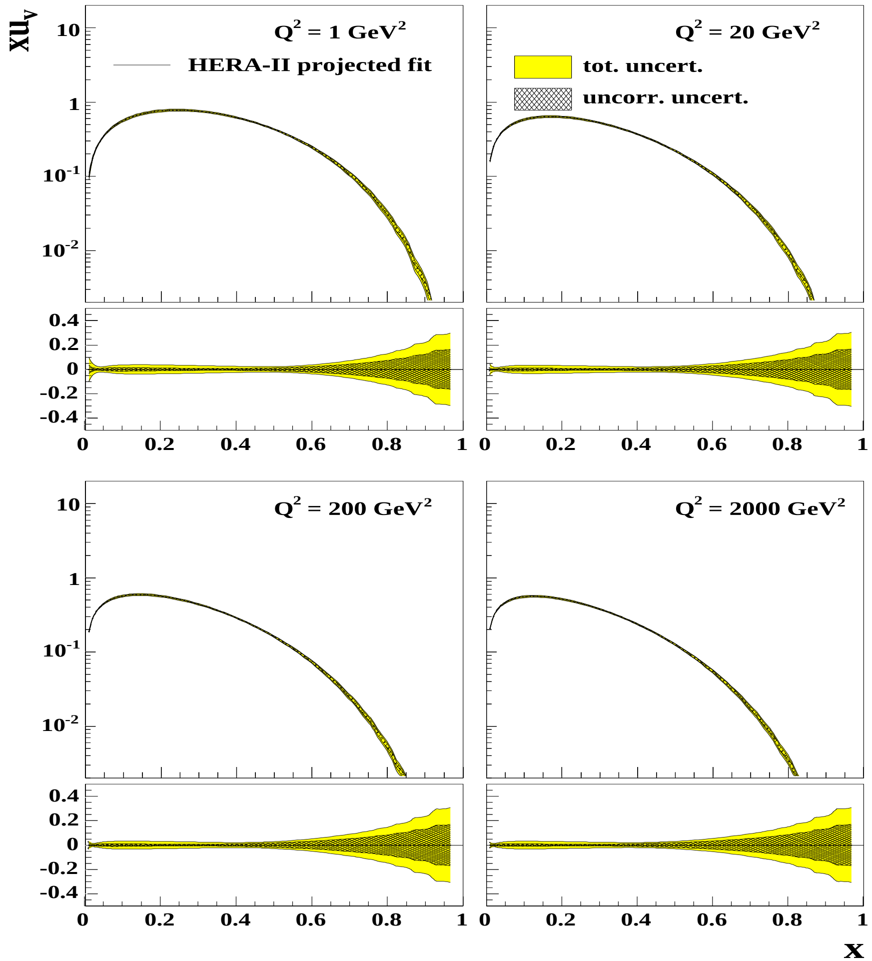
- HERA-II will provide greatly increased luminosity

Comparison with global fit (u-val.)

ZEUS-S global PDF



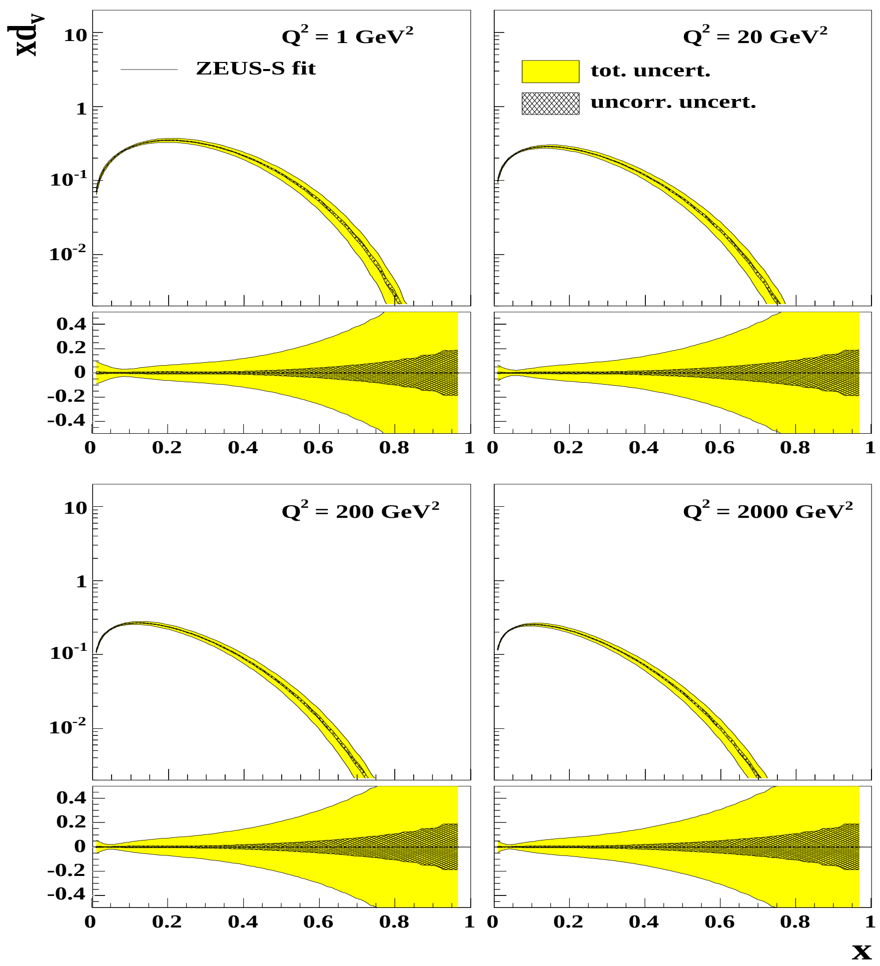
HERA-II Projected PDF



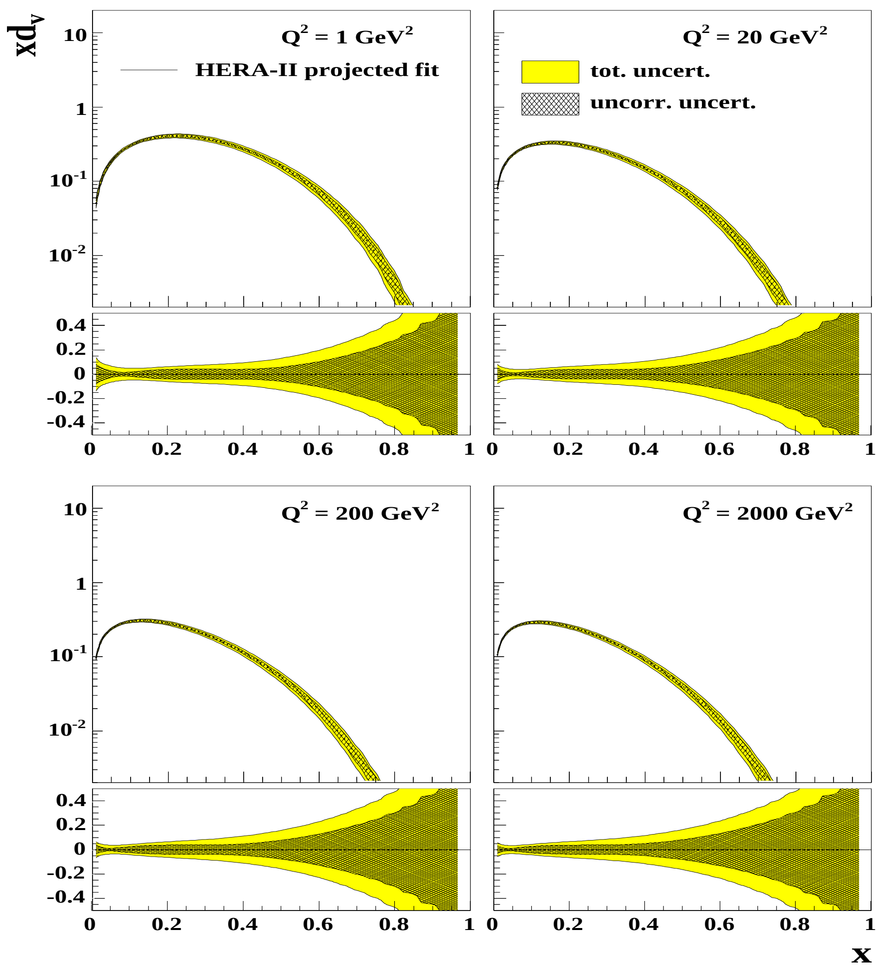
- **Uncertainties with full HERA-II inclusive data-set comparable to global fits**

Comparison with global fit (d-val.)

ZEUS-S global PDF

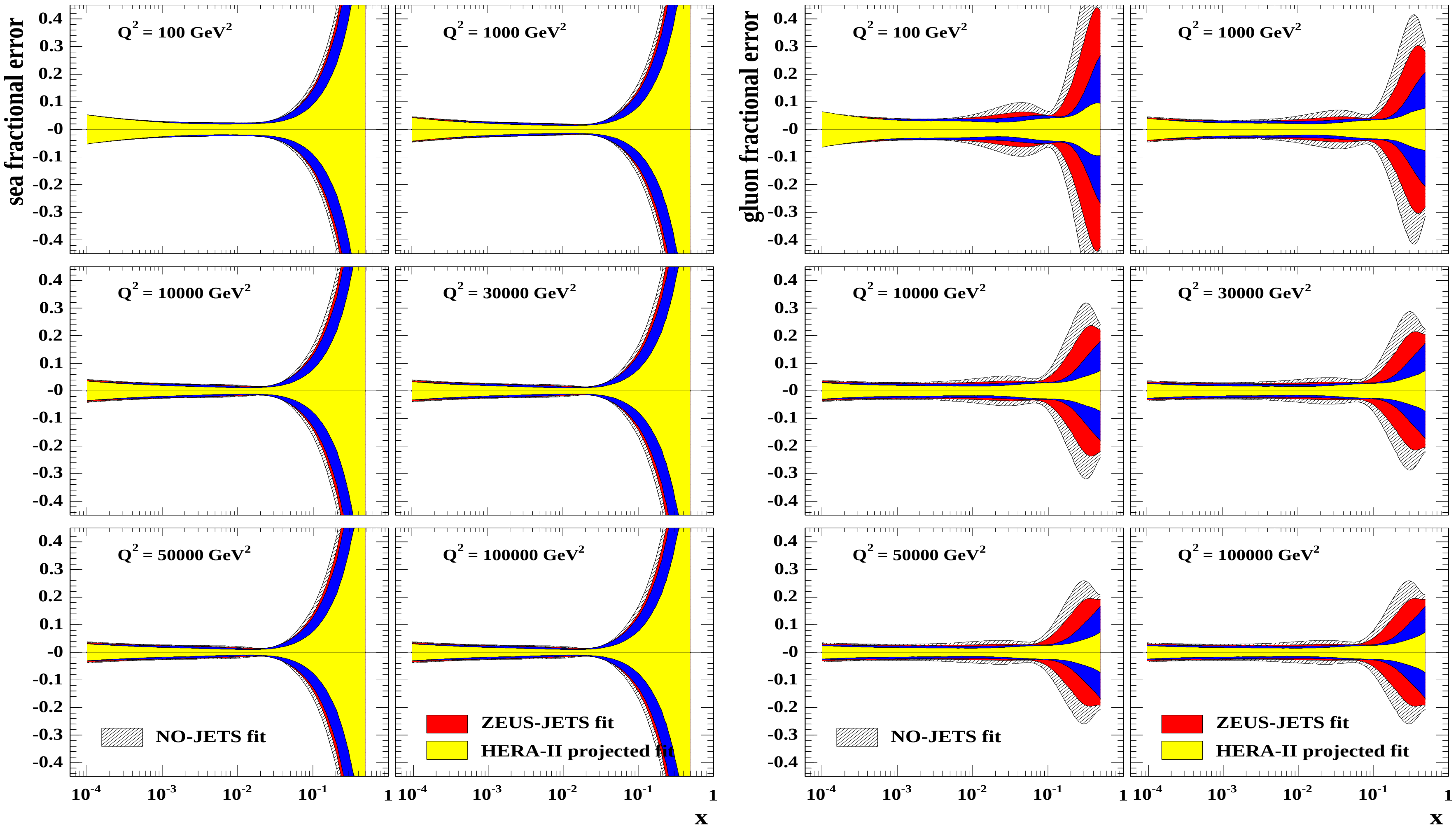


HERA-II Projected PDF



- Uncertainties comparable to or better than current global fit

Impact on sea/gluon uncertainties



- blue band: ZEUS-JETS fit + 120 pb^{-1} (HERA-I) optimised jet cross sections only
  - already at HERA-I, optimised jet cross sections would have significant impact on high-x gluon