Impact of LHeC data on PDFs

LHeC Workshop, Chavannes-de-Bogis

12 November 2010

Voica Radescu

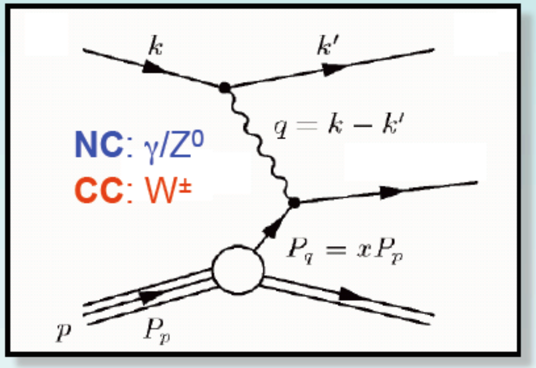
OUTLINE

- Introduction
- LHeC simulated data as input
- Impact of LHeC data on PDFs
- Summary

Introduction

- PDFs are essential for precision physics at LHC and other hadron colliders:
  - Low x: standard candle processes, W, Z production
  - High x: production of new heavy particles, study of their properties
  - → Separation of PDFs is important
- DIS is the tool to study PDFs:

processes: Neutral Current (**NC**): ep→eX; Charged Current (**CC**): ep→νX



Kinematic Variables:

- 4-momentum transfer ('resolution'): $Q^2 = -q^2 = -(k-k')^2$
- Bjorken scaling variable: $x = Q^2/2p.q$
- inelasticity: $y = p.q/p.k$

related via: $Q^2 = sxy$

[where $\sqrt{s}$ = CoM energy: $s = (k+p)^2$]

NC: "reduced" cross section:

$$\tilde{\sigma}^{\pm} = \frac{d^2\sigma^{\pm}}{dxdQ^2}\frac{Q^4 x}{2\pi\alpha^2 Y_+} = \tilde{F}_2^{\pm} \mp \frac{Y_-}{Y_+}x\tilde{F}_3^{\pm} - \frac{y^2}{Y_+}\tilde{F}_L^{\pm}$$

valence and sea quarks [gluon via scaling violations] — valence quarks — gluon

CC: similar decomposition, but **different quark combinations** accessed in e^+p or e^-p → **flavour sensitive**

Polarisation dependence

$$F_2(\pm P_e) = F_2^{\gamma} - (v_e \pm P_e a_e)\kappa_Z F_2^{\gamma Z} + \left((v_e^2 + a_e^2) \pm P_e 2v_e a_e\right)\kappa_Z^2 F_2^Z$$

$$xF_3(\pm P_e) = -(a_e \pm P_e v_e)\kappa_Z xF_3^{\gamma Z} + \left(2v_e a_e \pm P_e(v_e^2 + a_e^2)\right)\kappa_Z^2 xF_3^Z$$

[slide fromC. Gwenlan]

Studied LHeC simulated scenarios

- Studied scenarios (produced by Max Klein)

config.	E(e)	E(N)	N	∫L(e$^+$)	∫L(e$^-$)	|Pol|	L/10^{32}	P/MW	years	type
A	20	7	p	1	1	-	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	1	1	--	0.5	30	1	eD
G	50	2.7	Pb	0.1	0.1	0.4	0.1	30	1	ePb
H	50	1	p	--	1	--	25	30	1	lowEp

- Scenario B:
  - E(e$^\pm$) = 50 GeV
  - E(p) = 7 TeV
  - Pol = ±0.4
  - Lumi e$^+$p = 50 fb^{-1}
  - Lumi e$^-$p = 50 fb^{-1}
- Scenario H:
  - E(e$^-$) = 50 GeV
  - E(p) = 1 TeV
  - Pol=0
  - Lumi e$^-$p = 1 fb^{-1}

- The central values of the cross sections are based on the HERAPDF1.0 settings
- The uncertainties are taken from the simulated tables (Max Klein)

LHeC simulated data

- Scenario B: Ep=7TeV, Ee=50 GeV, Pol=±0.4
  - Kinematic region:
    - $2 < Q^2 < 500\,000$ GeV^2, $0.000002 < x < 0.8$
  - Typical uncertainties:
    - Statistical <1% (it ranges from 0.1% (low Q^2) to 45% (highest x, Q^2 CC))
    - Uncorrelated systematic: 0.7 %
    - Correlated systematic: typically 1-3 % (for CC high x up to 9%)

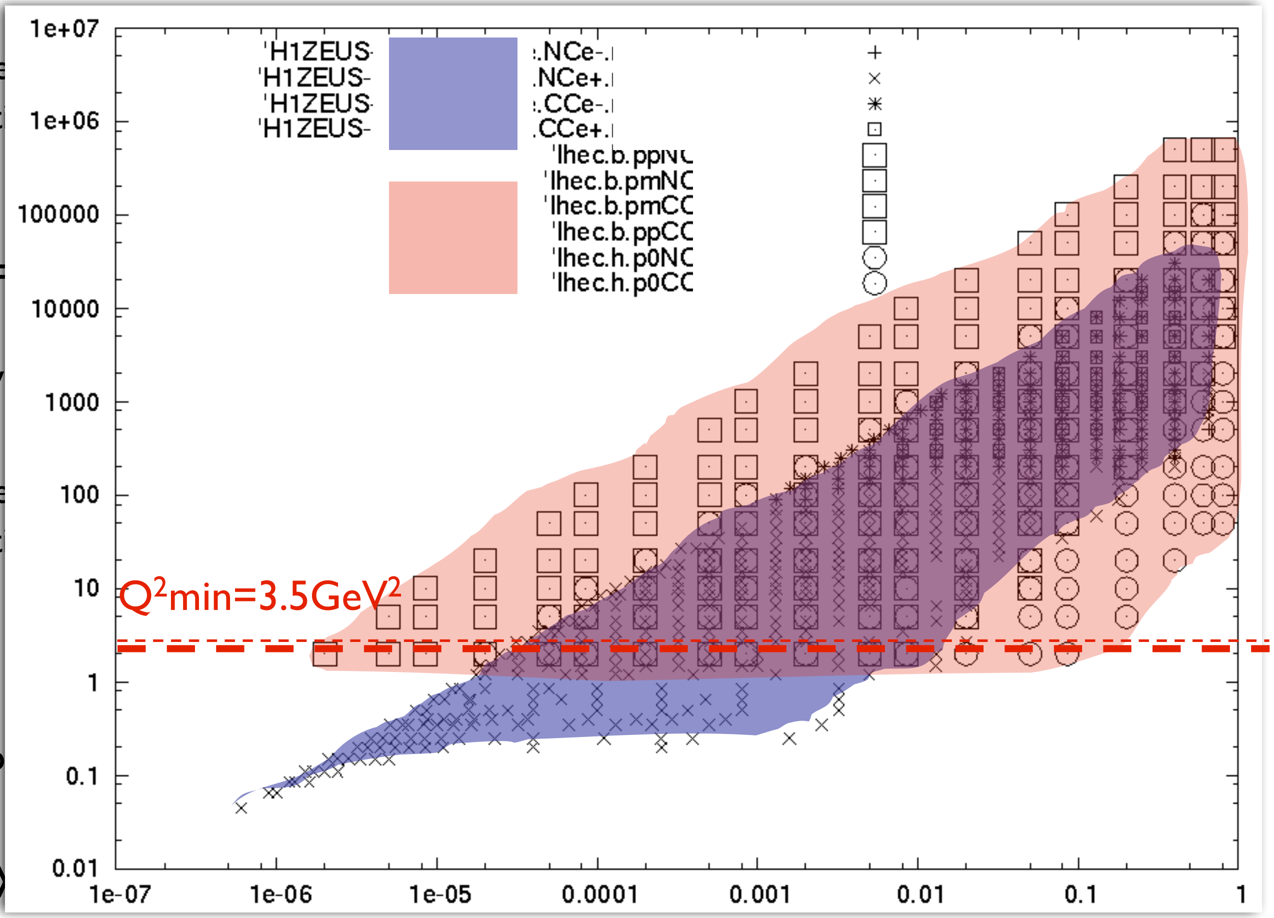
- Scenario H: Ep=1TeV, Ee=50 GeV, Pol=0
  - Kinematic region:
    - $2 < Q^2 < 100\,000$ GeV^2, $0.000002 < x < 0.8$
  - Typical uncertainties:
    - Statistical <1% (it ranges from 0.1% (low Q^2) to 45% (highest x, Q^2 CC))
    - Uncorrelated systematic: 0.7 %
    - Correlated systematic: typically 1-3 % (for CC high x up to 9%)

- Also Included in the fit:
  - 1% luminosity, 0.5% theoretical lumi

- At HERA: total uncertainty: up to 1% at low Q^2, x and 10-20% at high Q^2, x

LHeC simulated data

- Scenario B: Ep=7TeV, Ee=50 GeV, Pol=±0.4
  - Kinematic region:
    - $2 < Q^2 < 500\,000$ GeV^2, $0.000002 < x < 0.8$
  - Typical uncertainties:
    - Statistical <1% (it range
    - Uncorrelated systemat
    - Correlated systematic:
- Scenario H: Ep=1TeV, Ee=
  - Kinematic region:
    - $2 < Q^2 < 100\,000$ GeV
  - Typical uncertainties:
    - Statistical <1% (it range
    - Uncorrelated systemat
    - Correlated systematic:
- Also Included in the fit:
  - 1% luminosity, 0.5% theo
- At HERA: total uncertainty



Settings for the PDF determination

- Same settings as for HERAPDF1.0 has been used [JHEP 1001:109, 2010]:
  - Data:
    - To assess the impact of LHeC, published HERA I data has been used (NC, CC e±p data, P=0)
      - Kinematics of HERA data: $0.65>x>10^{-4}$, $30\,000 > Q^2 > 3.5$ GeV^2
      - Kinematics of LHeC simulated data: $0.8 > x > 10^{-6}$, $500\,000 > Q^2 > 3.5$ GeV^2
    - LHeC data: NC e^+p, NC, e^-p, CC e^+p, CC e^-p postive and negative polarisations P=±0.4
    - $Q^2_{min}=3.5$ GeV^2
    - Uncertainties are estimated using Hessian method
      - 113 for HERA data, 0.5% on correlated lumi between all data sets
      - 1% lumi for LHeC data, 1 total systematic uncertainty for each LHeC data (correlated)
  - Theory:
    - NLO DGLAP [QCDNUM package], RT scheme
    - $u_{val}, d_{val}, g, \bar{U} = \bar{u} + \bar{c}, \bar{D} = \bar{d} + \bar{s}$
      - Sea $S(x)=\bar{U}(x)+\bar{D}(x)$
      - Strange $s(x)=fs\bar{D}(x)=\bar{d}(x)fs/(1-fs)$ with constant fs=0.31 at $Q_0^2=1.9$ GeV^2
    - In the limit $x \to 0$ and $Q^2 >> m_s^2$ we have $s \sim \bar{u} = \bar{d}$, therefore:
      → Assume at the starting scale Q_0^2 symmetry $\bar{u}=\bar{d}$ for low x
    - Impose the fermion and momentum sum rules
    - One B parameter for sea and one for valence

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}
$$

Uncertainty treatment in the fit

- The impact of the LHeC data is studied at the level of the experimental uncertainty
- Monte Carlo techniques has been used to evaluate the experimental uncertainties:
  - Method consists in preparing replicas of data sets allowing the central values of the cross sections to fluctuate within their systematic and statistical uncertainties taking into account all point to point correlations [A.Glazov and VR, HERA-LHC proceedings, arXiV:0901.2504, page 41-42]
    - Shift central values randomly within the uncorrelated errors assuming Gauss distribution of the errors:

$$\sigma_i = \sigma_i(1 + \delta_i^{uncorr} RAND_i)$$

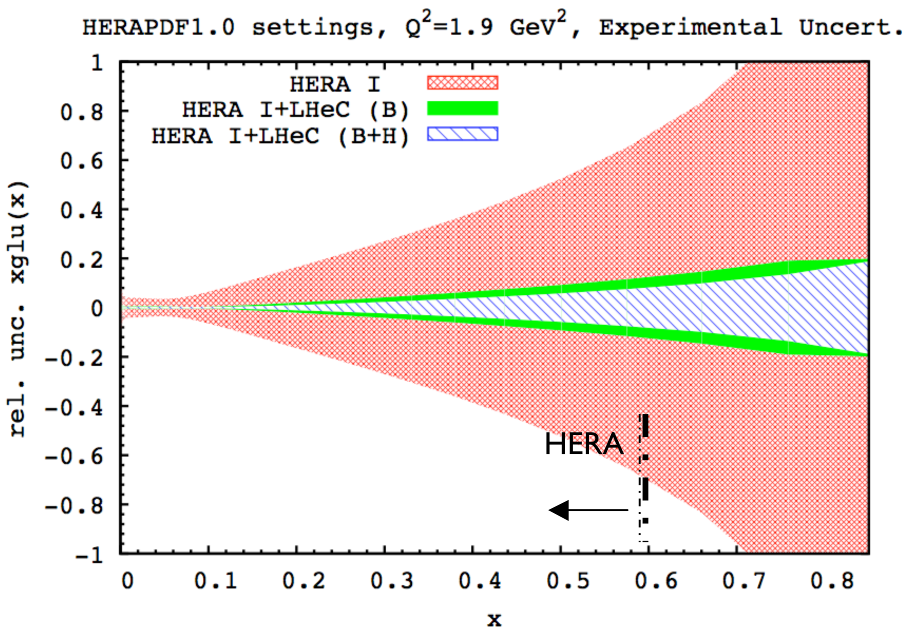
    - Shift central values with the same probability of the corresponding correlated systematic shift assuming Gauss distribution of the errors:

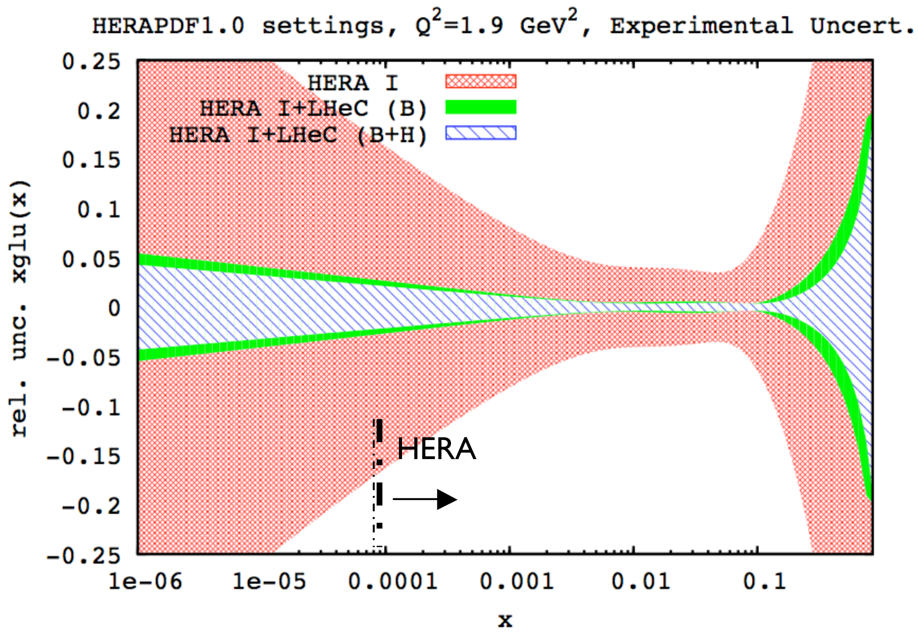
$$\sigma_i = \sigma_i(1 + \delta_i^{uncorr} RAND_i + \sum_j^{N_{sys}} \delta_{ij}^{corr} RAND_j)$$

  - Preparation of the data is repeated for N times (N>100)
    - For each MC replica, NLO QCD fit is performed to extract the N PDF sets
  - Errors on the PDFs are estimated from the RMS of the spread of the N curves corresponding to the N individual extracted PDFs

Impact of LHeC on PDFs: gluon

- Impressive impact of the LHeC simulated data on PDFs:
  - At high x (see linear plot) and at very low x (see log x plot)!

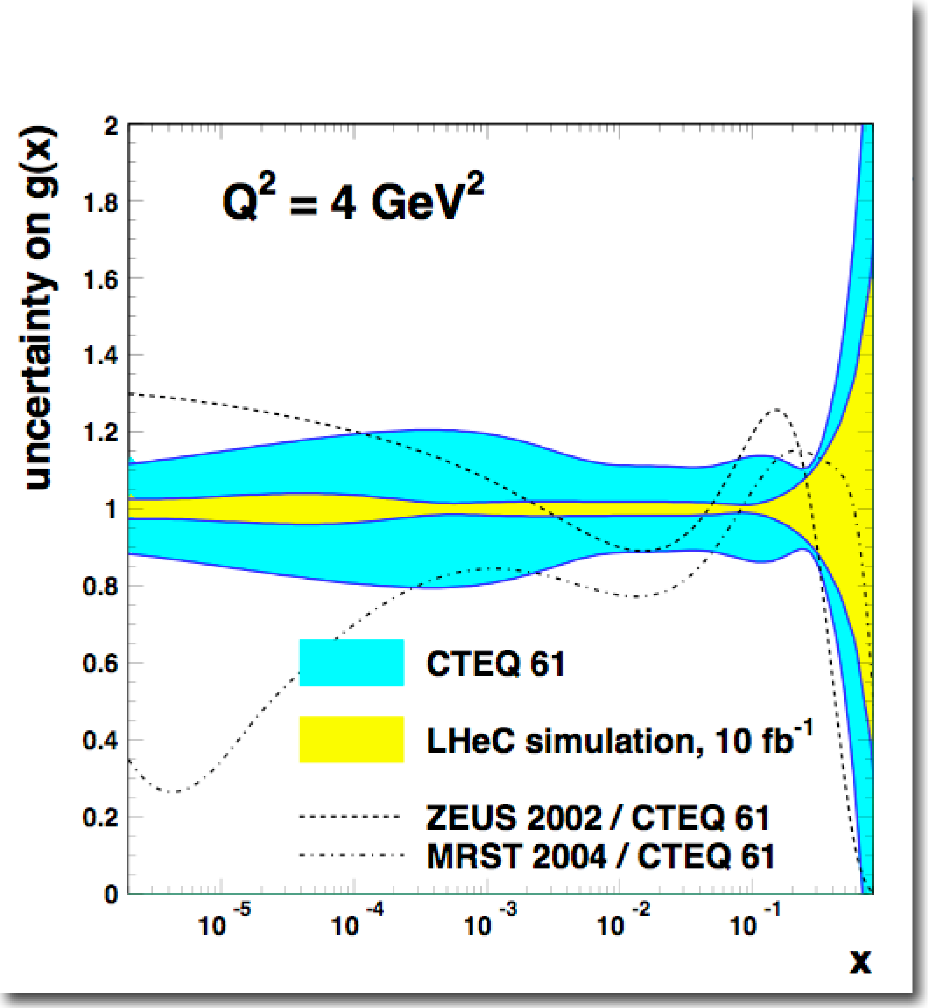


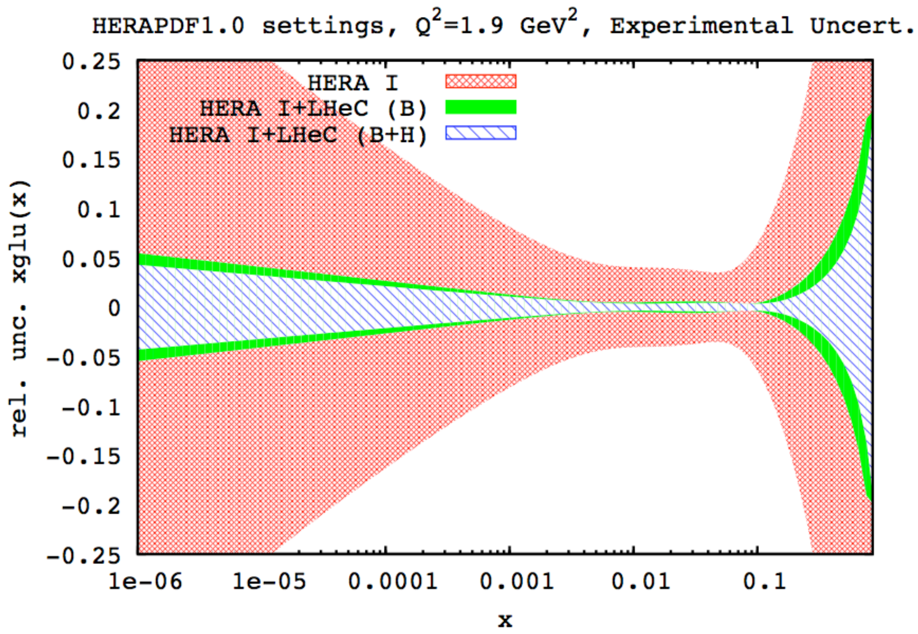


* All uncertainties are shown at the starting scale Q^2=1.9 GeV^2

Impact of LHeC on PDFs: gluon

- Impressive impact of the LHeC simulated data on PDFs:
  - At very low x (see log x plot) and at high x (see linear plot) too!

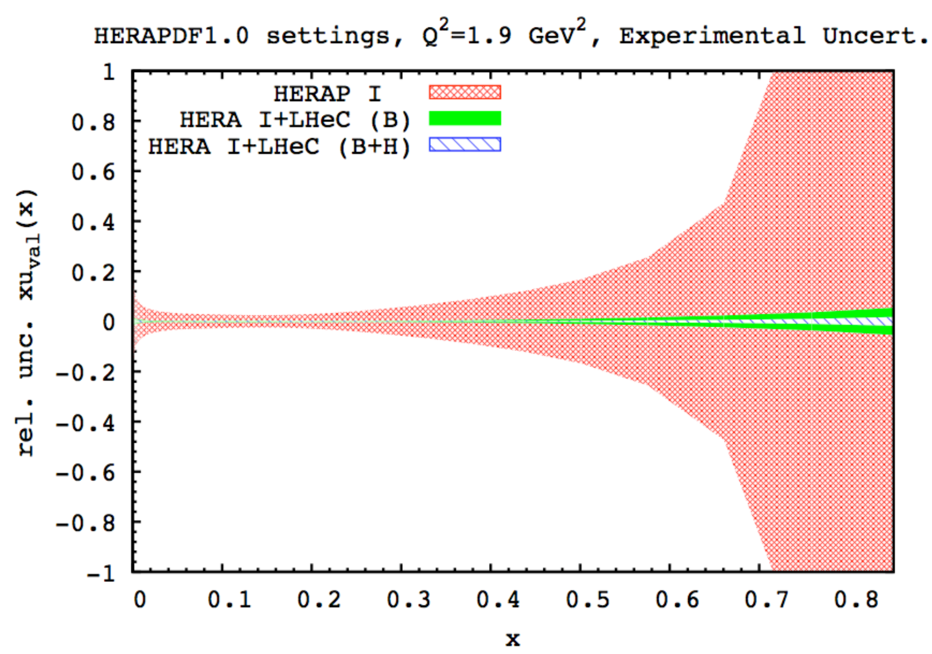


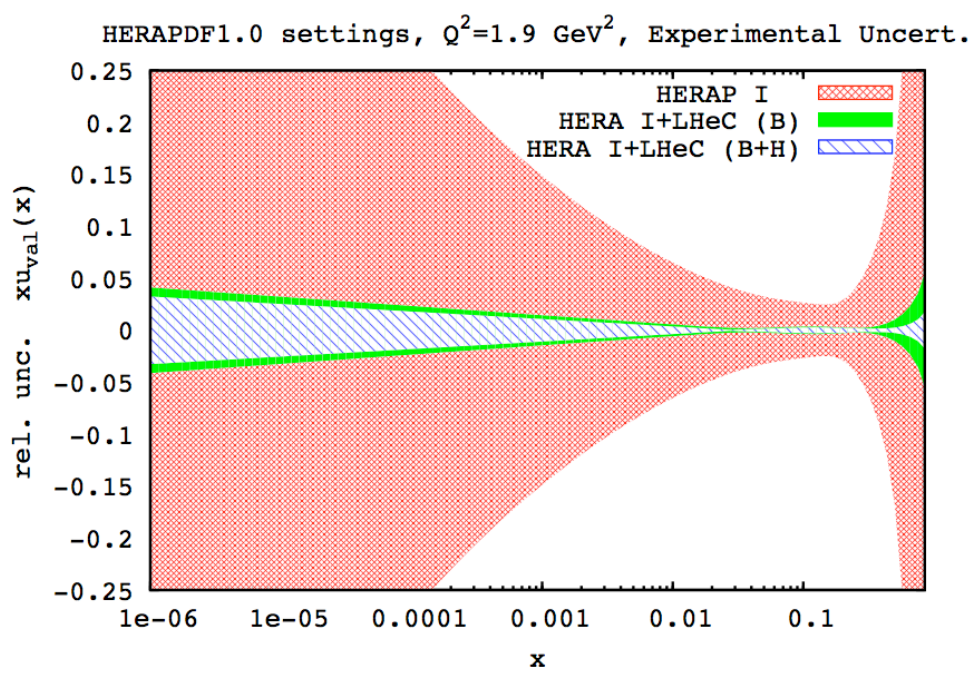


[Consistent with E.Perez]

Impact of LHeC on PDFs: u valence

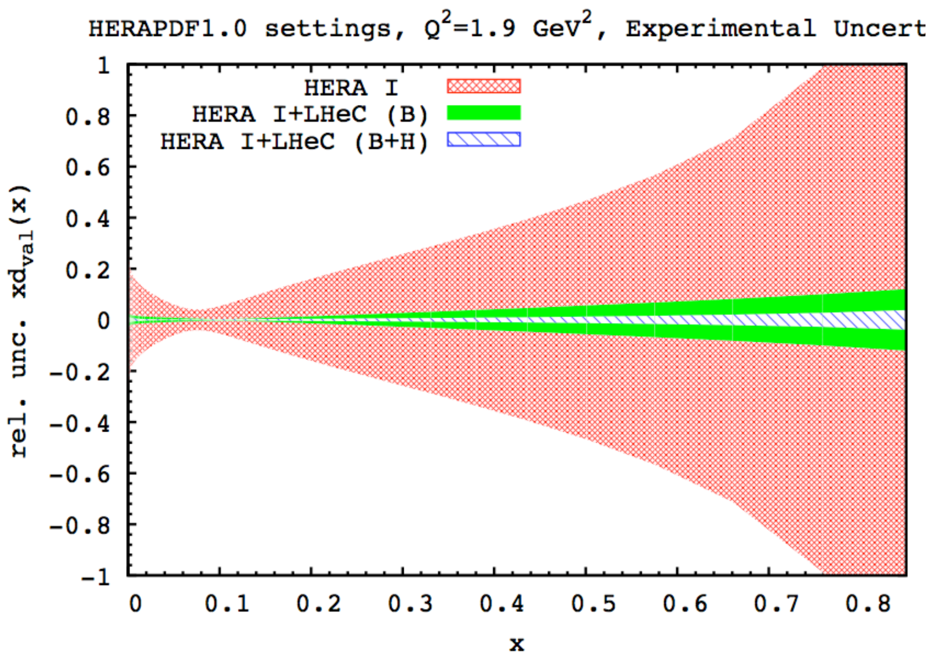
- Similarly for u valence (linear and log plots are shown)

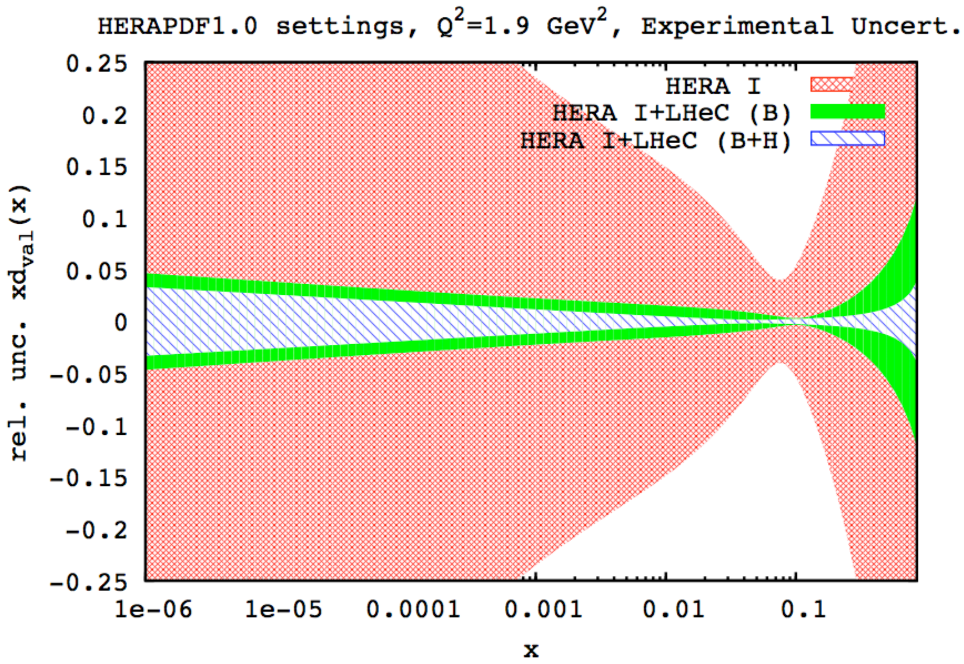




Impact of LHeC on PDFs: d valence

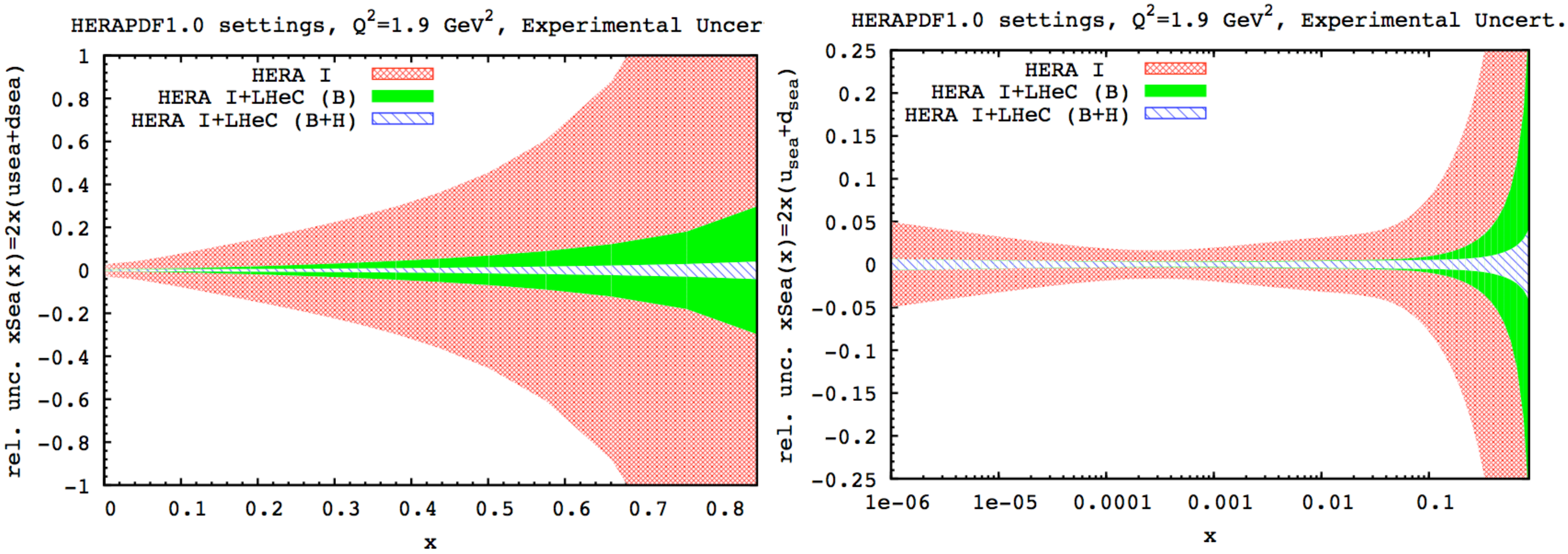
- It is harder to measure, but LHeC gives very good precision, nonetheless
  - Scenario H (low energy runs for LHeC) has impact especially at high x





Impact of LHeC on PDFs: sea = 2(usea+dsea)

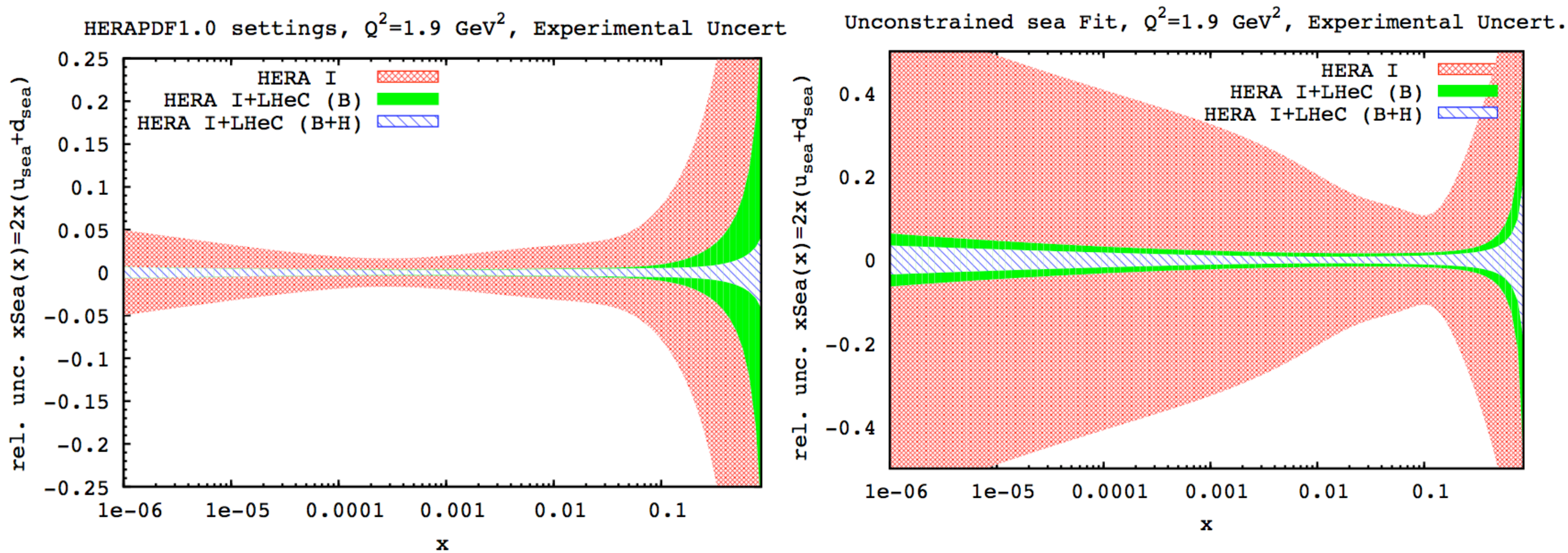
- Beautiful reduction of the uncertainties given the precision and kinematic span of the LHeC simulation.



Accurate high x sea is important to study production of heavy particles at the LHC, e.g. Z'

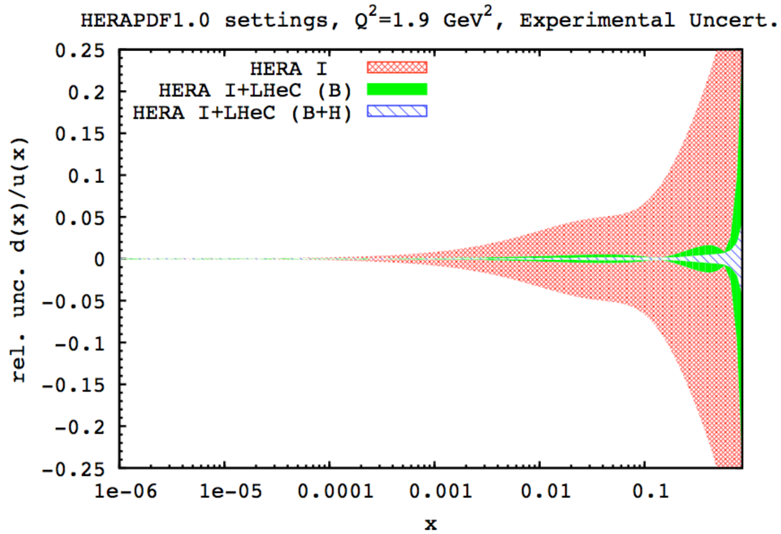
Unconstrained setting

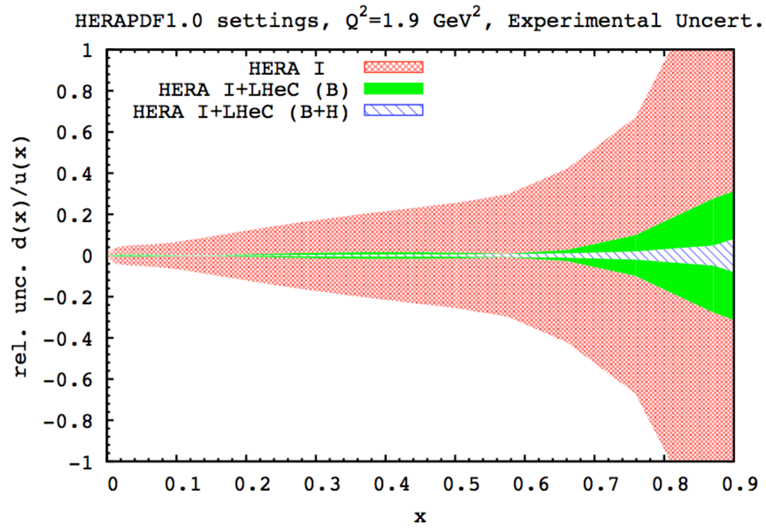
- Usual assumptions for light quark decomposition at low x may not necessary hold.
- Relaxing the assumption at low x u=d , we observe that uncertainties escalate, this has been shown that would impact considerably the size of uncertainties which could propagate further to Ws at the LHC up to 5% in the plateau region!
  - One can see that for HERA data, if we relax the low x constraint on u and d, the errors are increased tremendously!
  - However, when adding the LHeC simulated data, we observe that uncertainties are visbly improved even without this assumption.



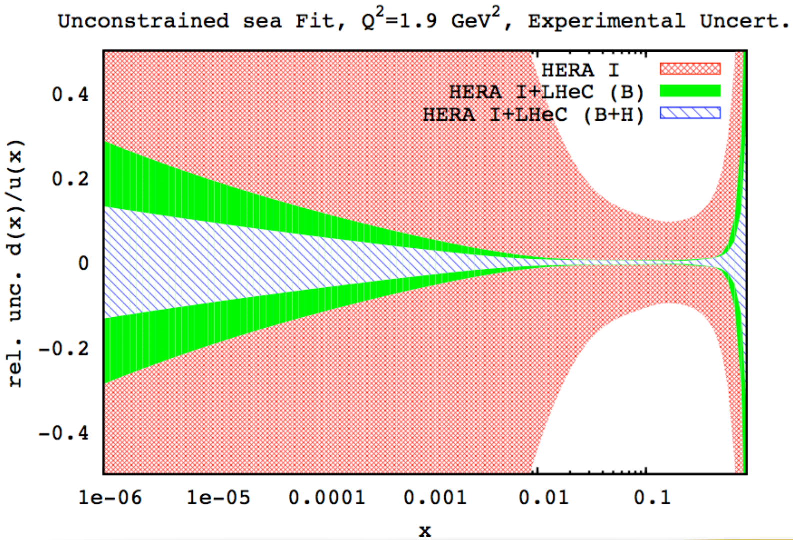
Impact on d/u ratios

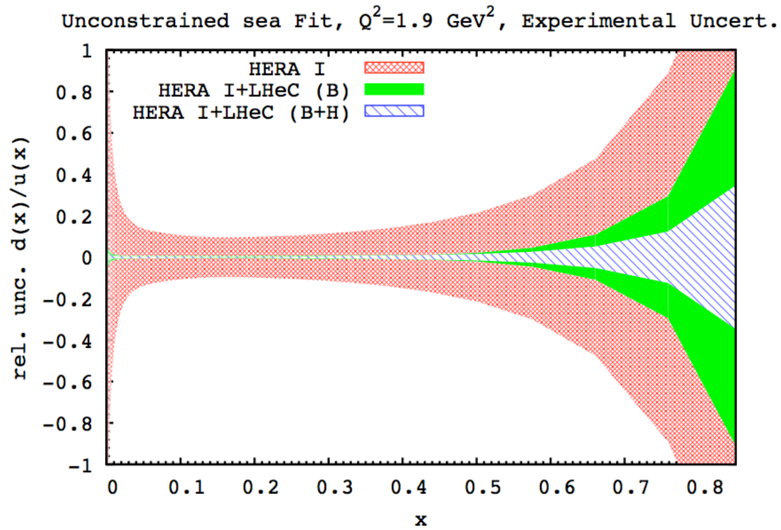
- Standard decomposition:





- Unconstrained sea decomposition:



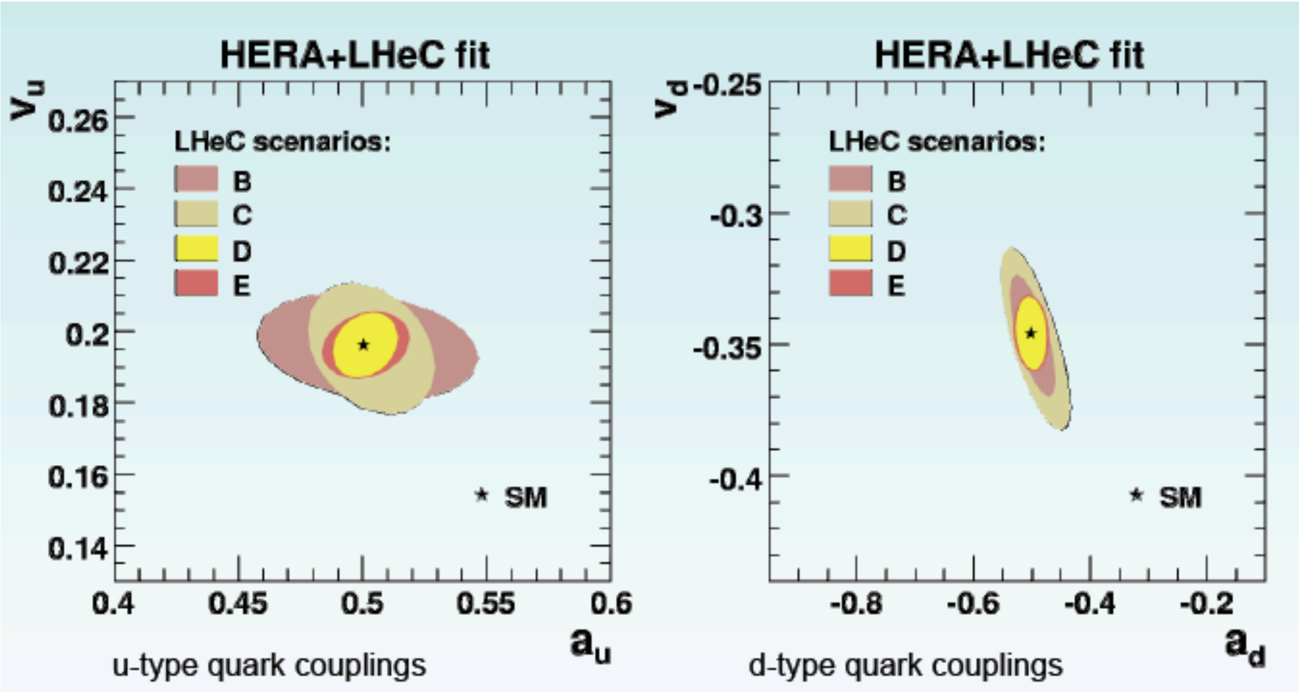


LHeC impact on the PDF+EW fits

- Simultaneous PDF and EW fit, using LHeC data alone (scenario B has been used):
  - Determine neutral current axial and vector couplings (au, vu, ad, vd)

cvu	0.20064	0.43069E-02	0.196
cau	0.48670	0.63037E-02	0.5
cvd	-0.32705	0.12187E-01	-0.346
cad	-0.53523	0.18575E-01	-0.5

Claire's results:



Summary

- Studied the impact of 2 LHeC scenarios (high and lower energies) on PDFs:
  - Based on the HERAPDF settings
  - mix of high/low energy improves precision by better coverage at high x, hence better flavour decomposition.
    - (study performed using only proton scenario, but there is also deuteron scenario)

- Observe a significant improvement in the precision of the PDFs with the LHeC simulated data;

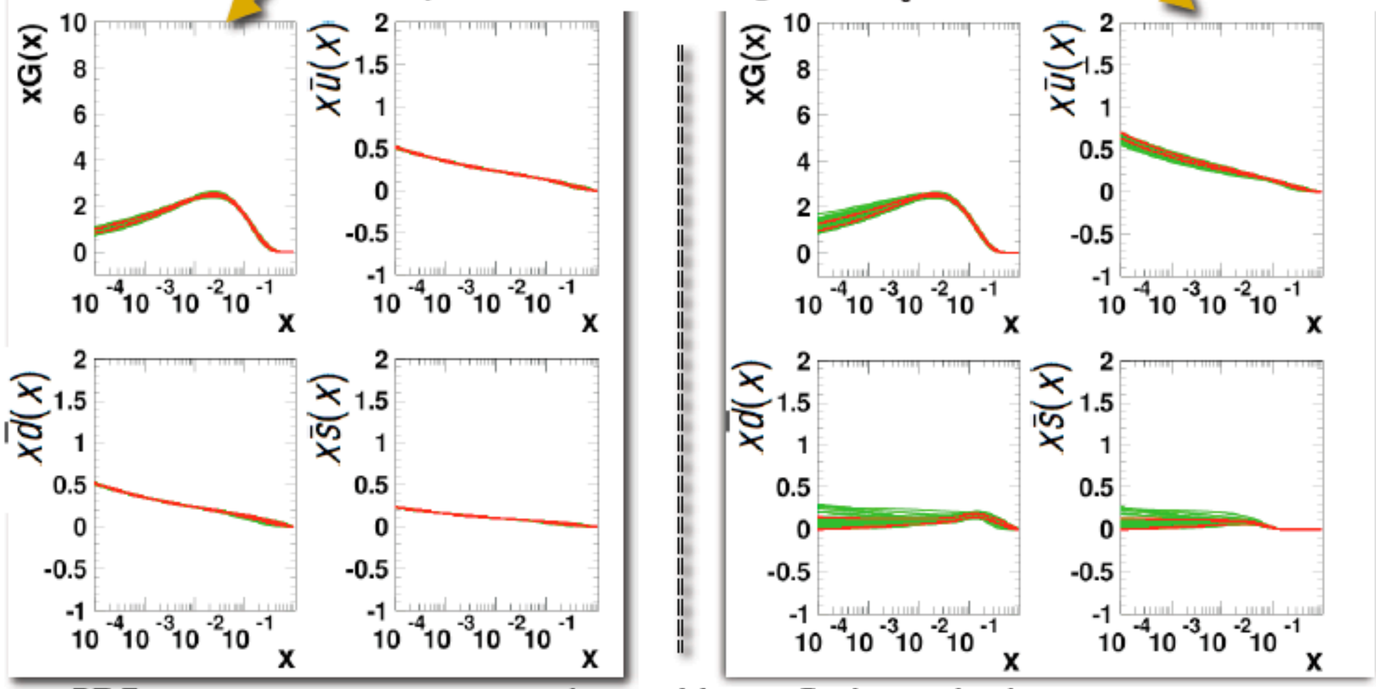
- All parton distributions can be pinned down

- EW+PDf fits show tight constraints on neutral current vector and axial quark couplings

Backup

- Standard vs Unconstrained settings (HERA I)

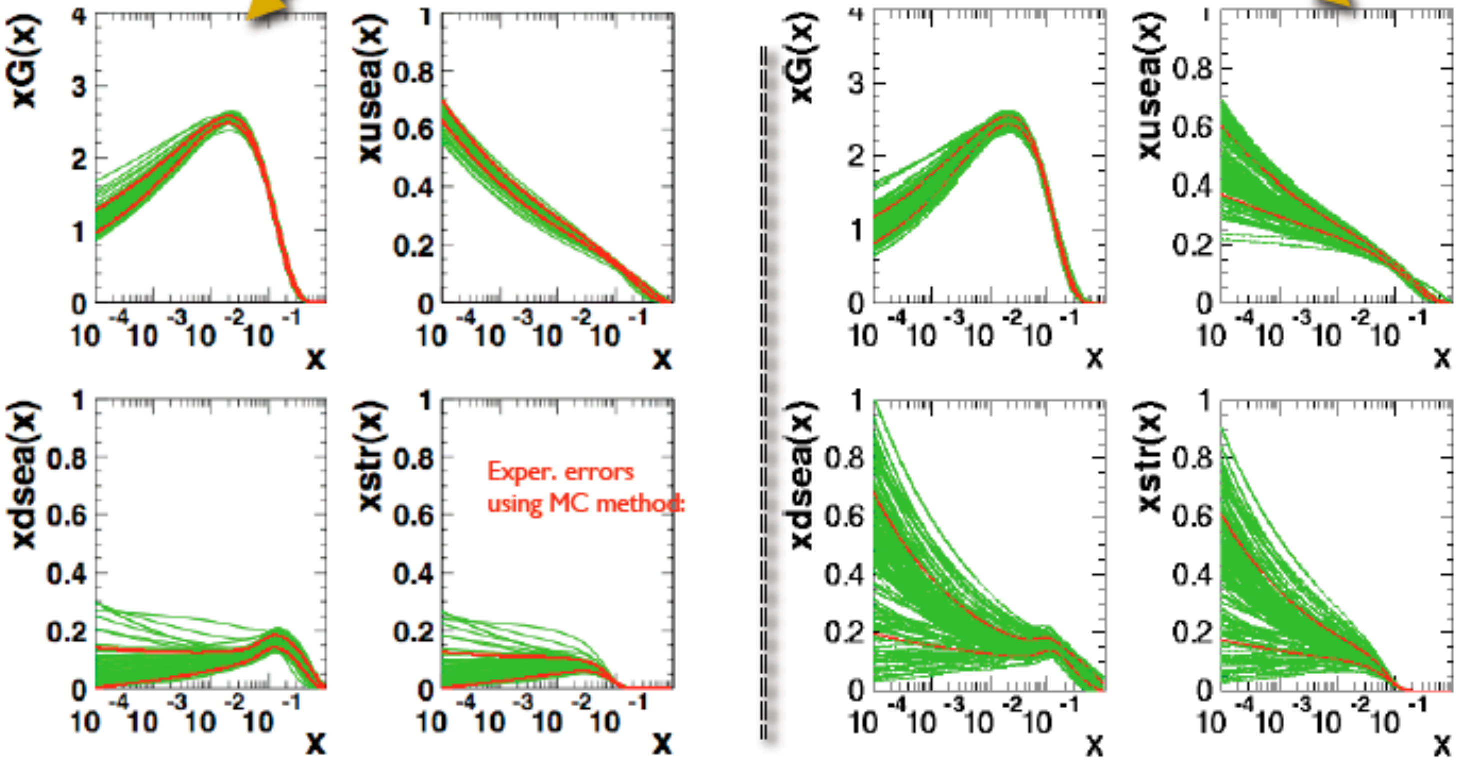
Comparison at the starting scale Q_0^2=1.9 GeV^2



- PDF uncertainties are estimated using Monte Carlo method [arXiV:0901.2504, p 41-42]
  - RMS of ~100 MC replicas of the data represents the PDF uncertainty
- Uncertainties increase considerable for the unconstrained low x sea PDF case!

HERA I vs HERA I+II data (DISS PDFs)

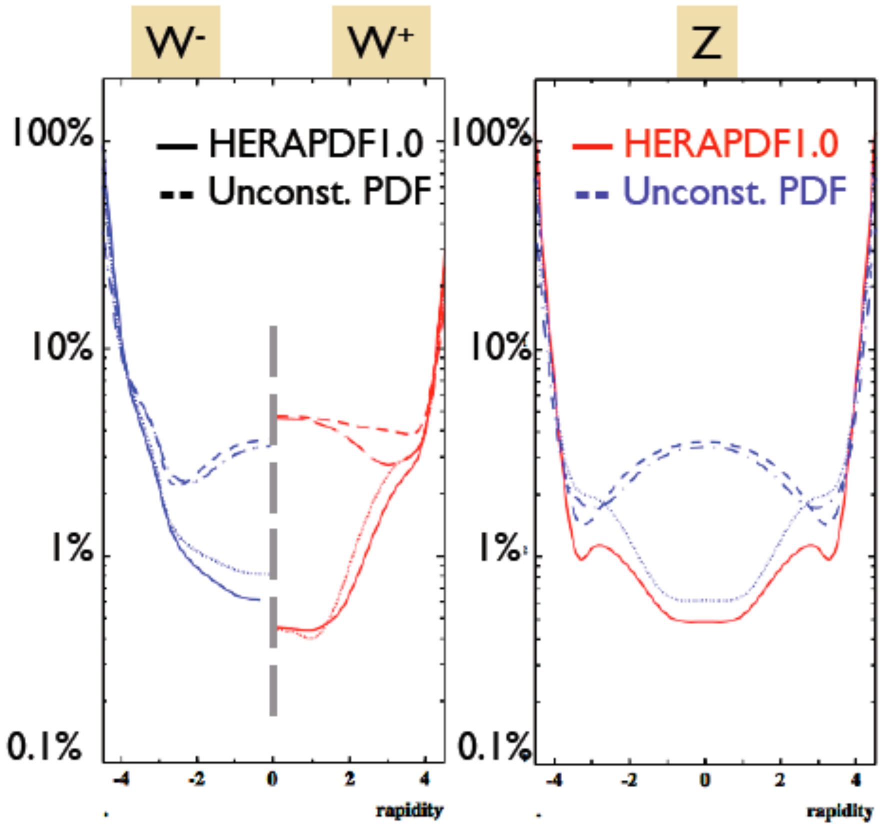
Comparison at the starting scale Q_0^2=1.9 GeV^2



Effect of the unconstrained fit (using HERA data)

Propagate experimental uncertainties of PDFs to W,Z cross sections via MC technique:

- Observe rise in the experimental uncertainty in the platform region up to 5% for the unconstrained PDF set
- Measurements of W, Z may constrain better $\bar{u}/\bar{d}$ at low x.



Standard vs Unconstrained for gluon