Impact of the LHeC data on PDFs

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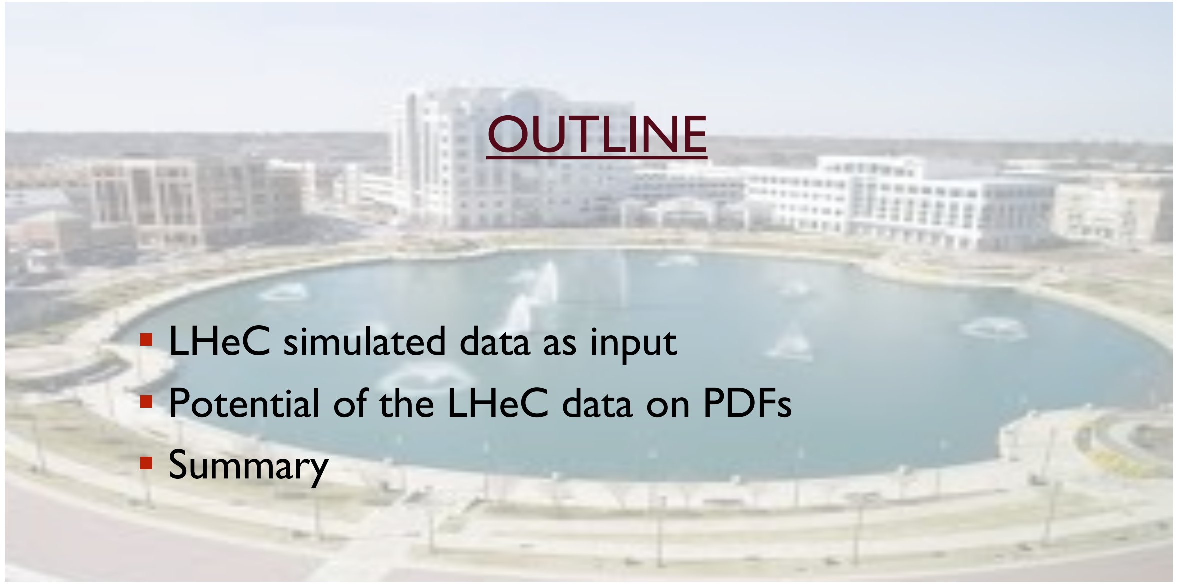
Voica Radescu

Heidelberg Physikalisches Institut



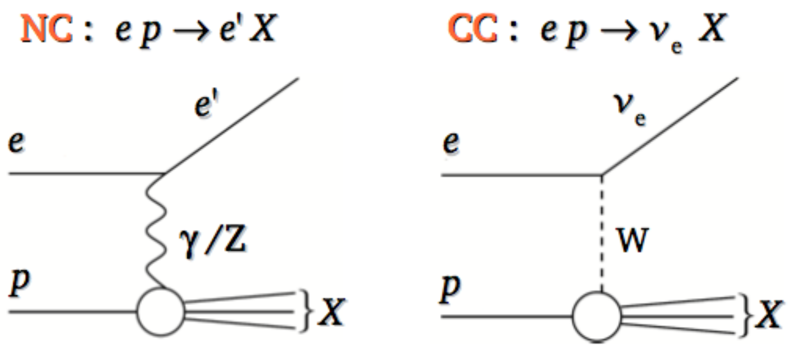
OUTLINE

- LHeC simulated data as input
- Potential of the LHeC data on PDFs
- Summary

Introduction

- PDFs are essential for precision physics at the 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 best tool to probe structure of the proton:
  - Processes:



Kinematic variables:

$Q^2 = -q^2 = -(k-k')^2$ Virtuality of the exchanged boson

$x = \frac{Q^2}{2p \cdot q}$ Bjorken scaling parameter

$y = \frac{p \cdot q}{p \cdot k}$ Inelasticity parameter

$s = (k+p)^2 = \frac{Q^2}{xy}$ Invariant c.o.m.

  - Double Differential cross sections:

$$\sigma_r(x,Q^2) = \frac{d^2\sigma(e^{\pm}p)}{dxdQ^2}\frac{Q^4x}{2\pi\alpha^2 Y_+} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) \mp \frac{Y_-}{Y_+}xF_3(x,Q^2)$$

- F_2 dominates
  - sensitive to all quarks
- xF_3
  - sensitive to valence quarks
- F_L
  - sensitive to gluons

Kinematic range of LHeC

Scenario B: (Lumi $e^{+/-}p$ = 50 fb^{-1})

Ep=7TeV, Ee=50 GeV, Pol=±0.4

- Kinematic region:
  - $2 < Q^2 < 500\,000$ GeV^2
  - $0.000002 < x < 0.8$

Scenario H: (Lumi e^-p = 1 fb^{-1})

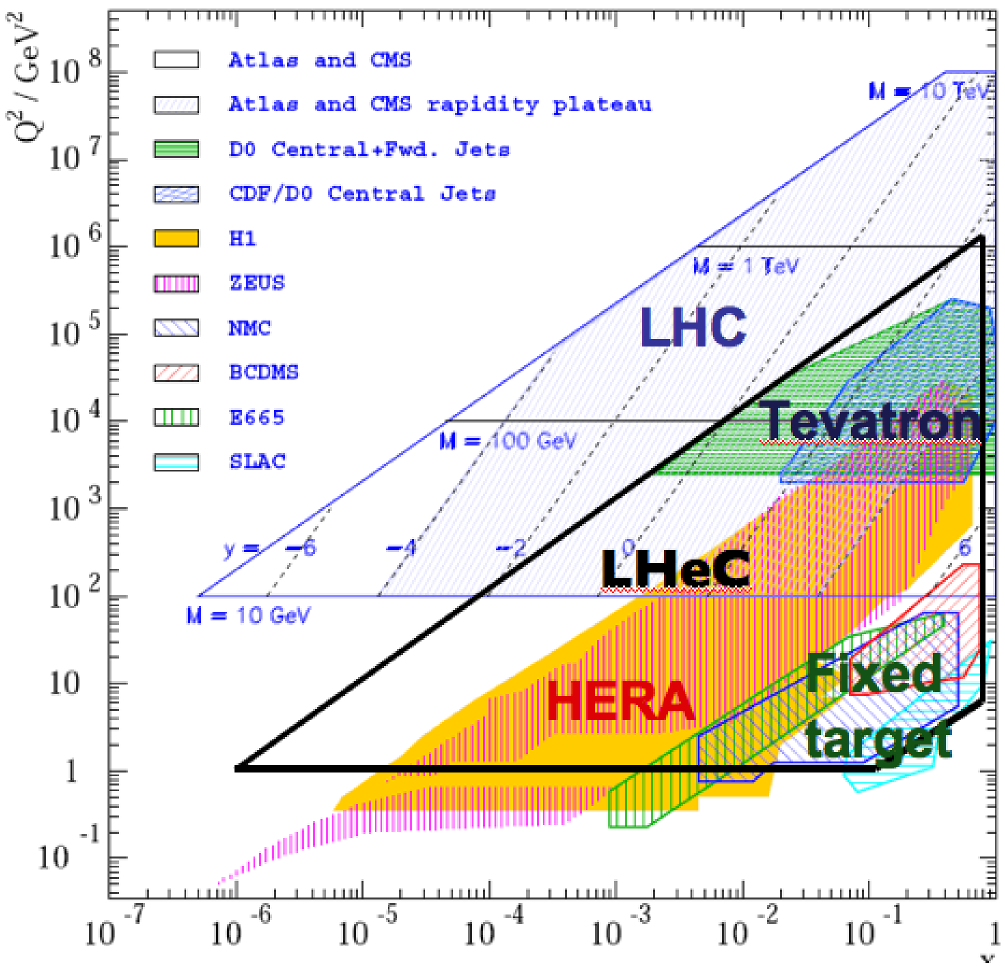
Ep=1TeV, Ee=50 GeV, Pol=0

- 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%)



Settings for the PDF determination

- Data:
  - Published HERA I (NC, CC $e^{\pm}p$ data, P=0)
    - Kinematics of HERA data: $0.65>x>10^{-4}$, $30\,000 > Q^2 > 3.5$ GeV^2
  - LHeC data: NC e^+p, NC, e^-p, CC e^+p, CC e^-p postive and negative polarisations P=±0.4
  - Fixed target data from BCDMS
  - $Q^2_{min}=3.5$ GeV^2 (and $W^2>15$ GeV^2 for BCDMS data)
  - Uncertainties are estimated using Hessian method cross checked against MC method

- Theory: Same settings as for HERAPDF1.0 has been used [JHEP 1001:109, 2010]:
  - NLO DGLAP [QCDNUM package], RT scheme
  - Fitted PDFs:

$$u_{val}, d_{val}, g, \overline{U} = \bar{u} + \bar{c}, \overline{D} = \bar{d} + \bar{s}$$

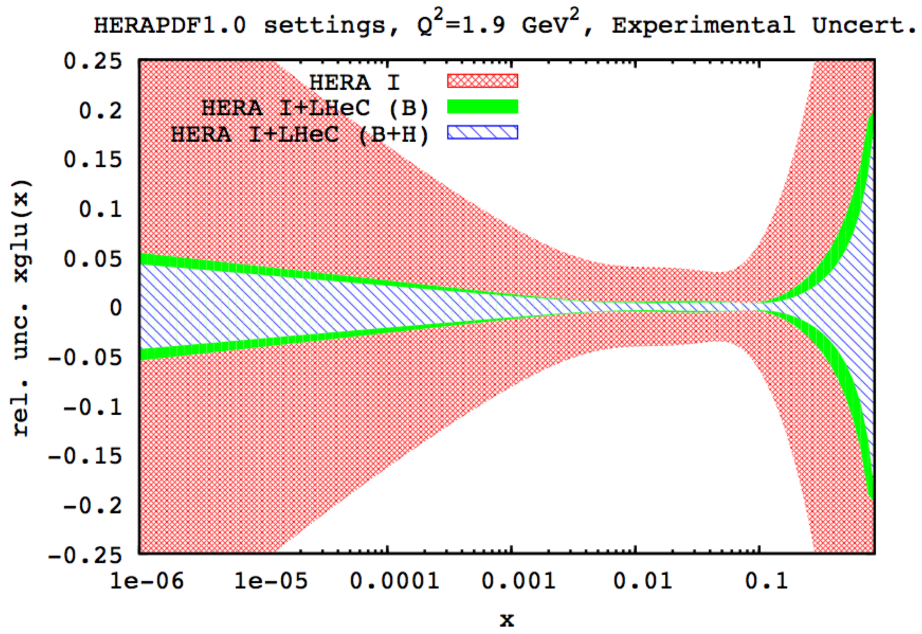
- Sea $S(x)=\overline{U}(x)+\overline{D}(x)$
- Strange $s(x)=fs\overline{D}(x)=\bar{d}(x)fs/(1-fs)$
  with constant $fs=0.31$ at $Q_0^2=1.9$ GeV^2

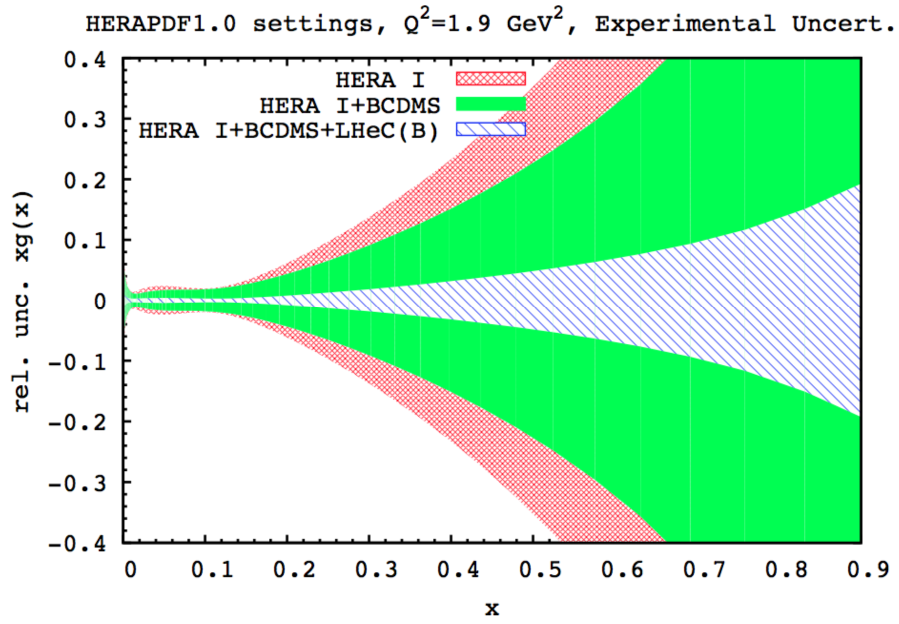
- Impose the fermion and momentum sum rules
- One B parameter for sea and one for valence

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

Impact of LHeC on PDFs: gluon

* Experimental uncertainties are shown at the starting scale $Q^2=1.9\ GeV^2$

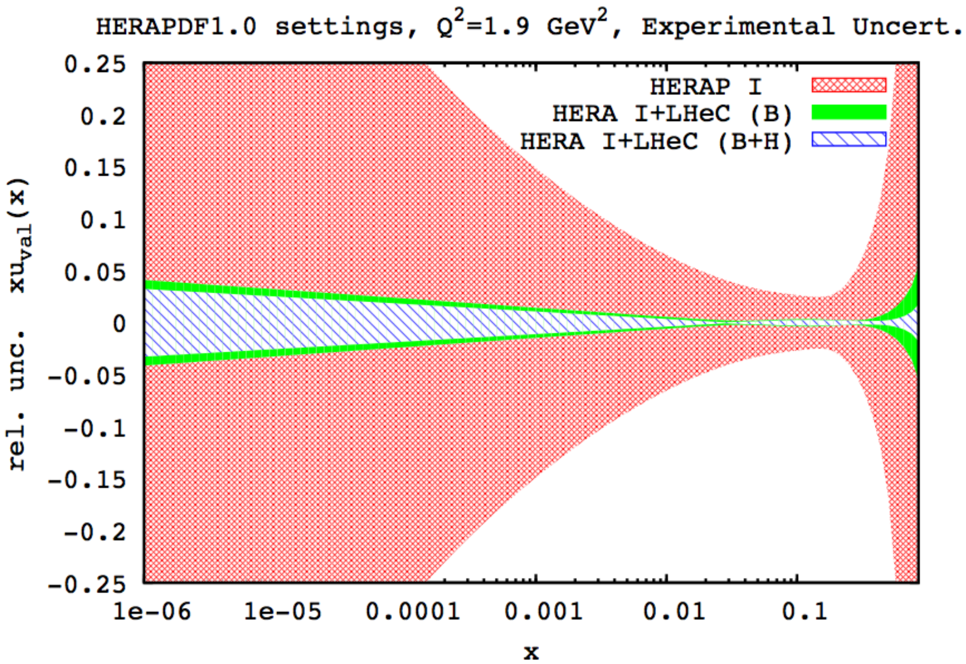


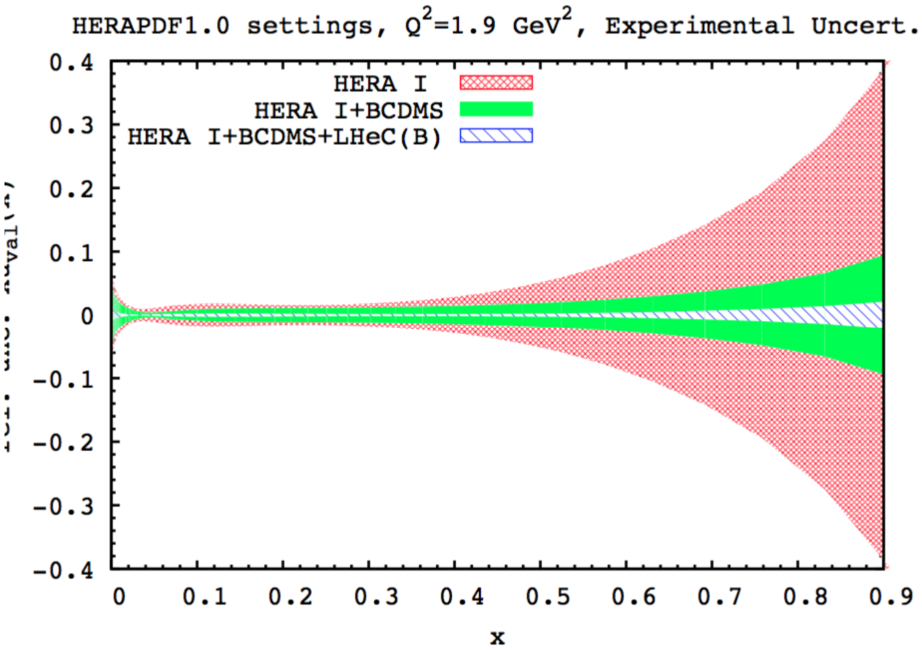


- Based on simulated data, impressive capability for LHeC to constrain gluon:
  - At low and high x

Impact of LHeC on PDFs: u valence

* Experimental uncertainties are shown at the starting scale $Q^2=1.9\ GeV^2$

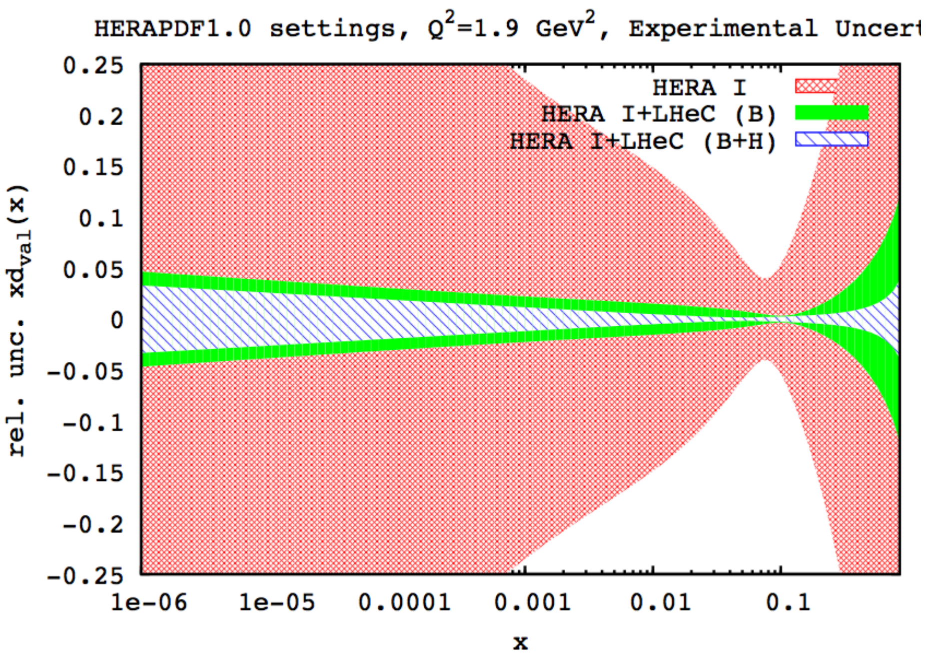


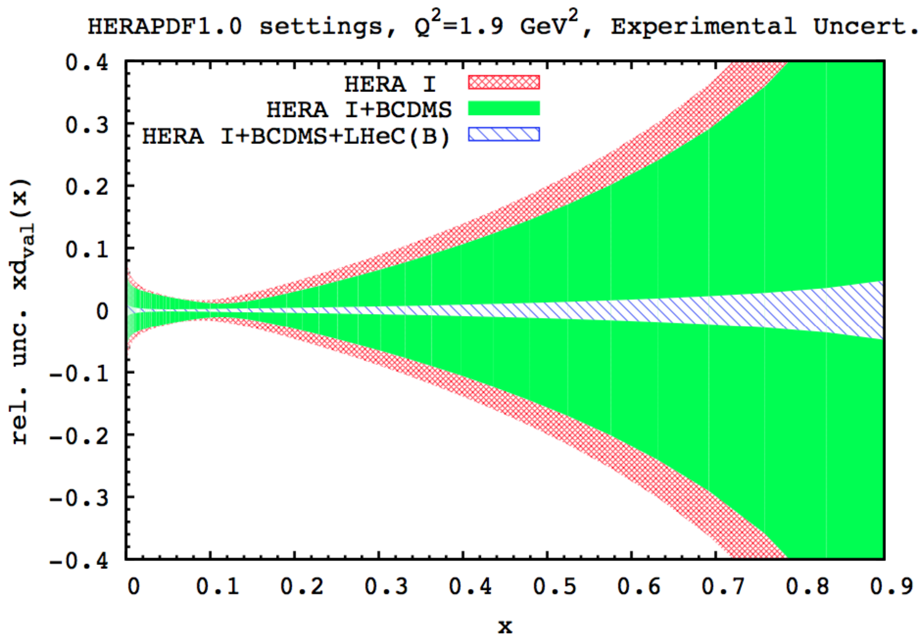


- Similar improvement also for u valence (linear and log plots are shown)

Impact of LHeC on PDFs: d valence

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

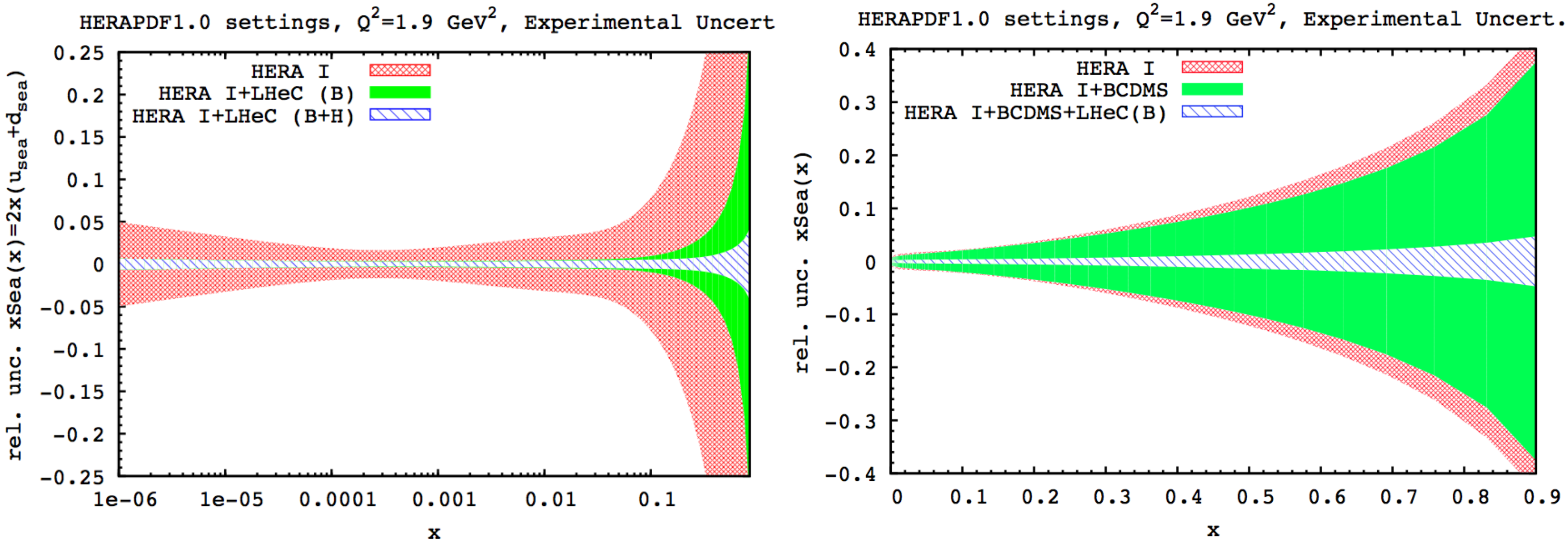




- Similar improvement also for u valence (linear and log plots are shown)

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

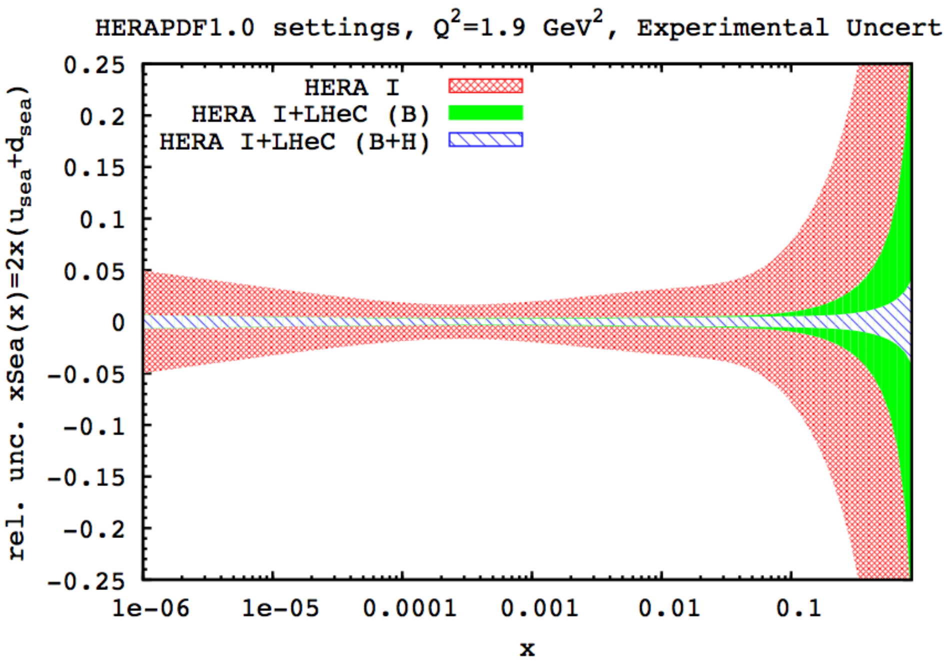
- Beautiful reduction of the uncertainties given the precision and kinematic span of the LHeC simulation.

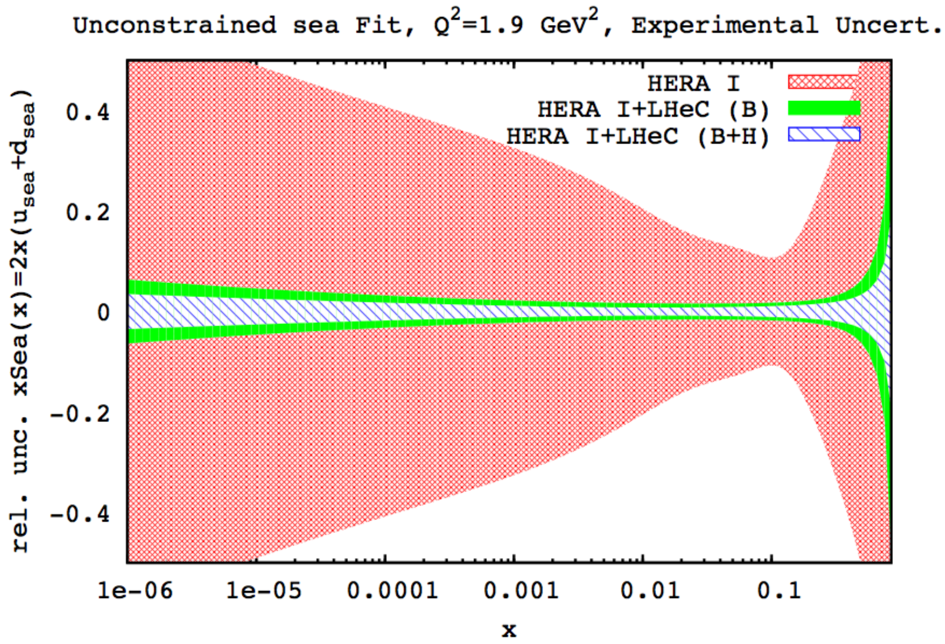


Accurate high x sea is important to study production of heavy particles at the LHC, e.g. Z'

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:

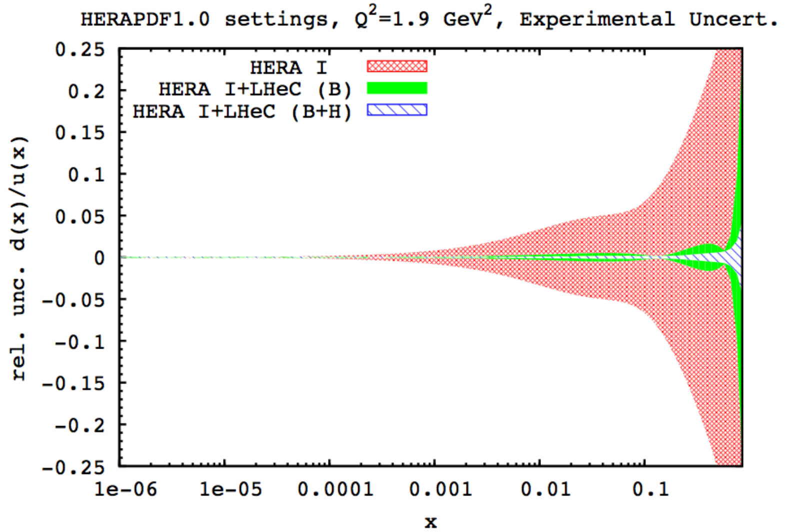


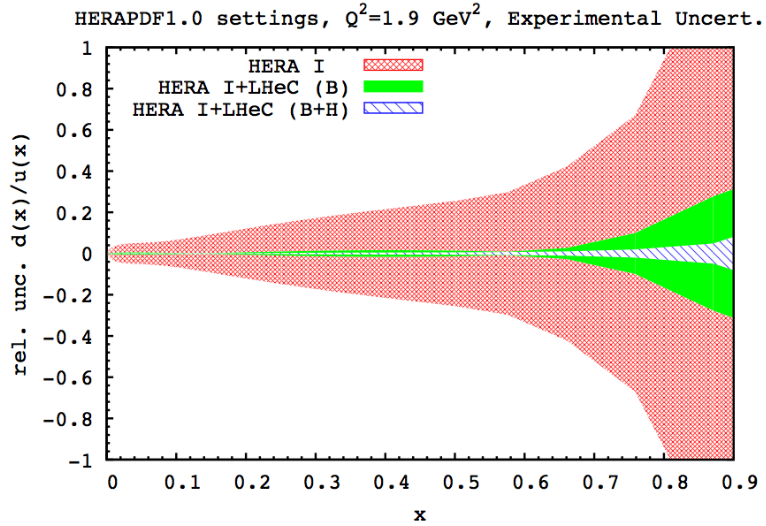


- One can see that for HERA data, if we relax the low x constraint on u and d, the errors are increased tremendously!
- However, when adding the LHeC simulated data, we observe that uncertainties are visibly improved even without this assumption.

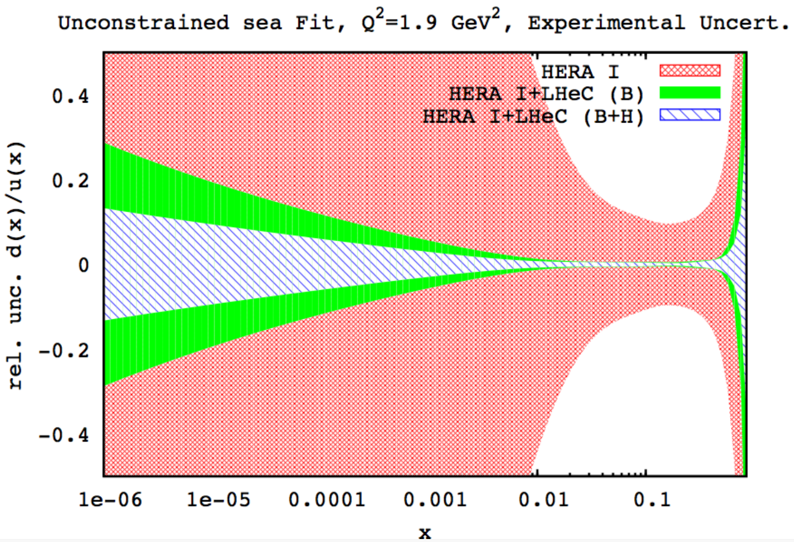
Impact on d/u ratios

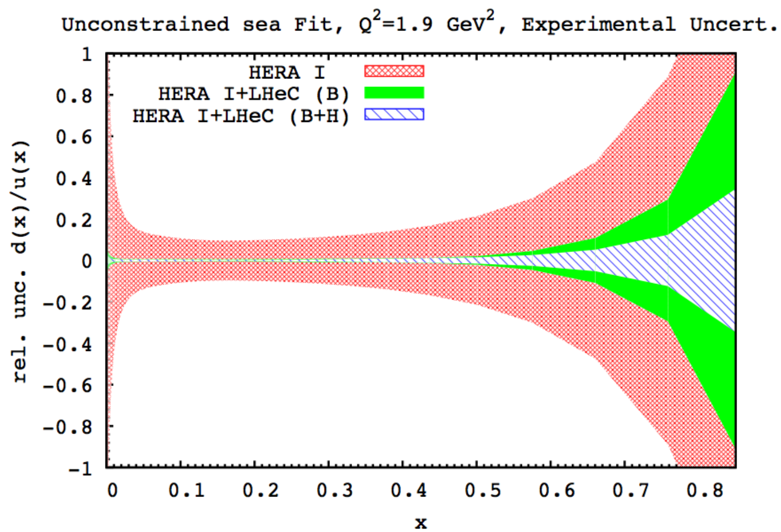
- Standard decomposition:





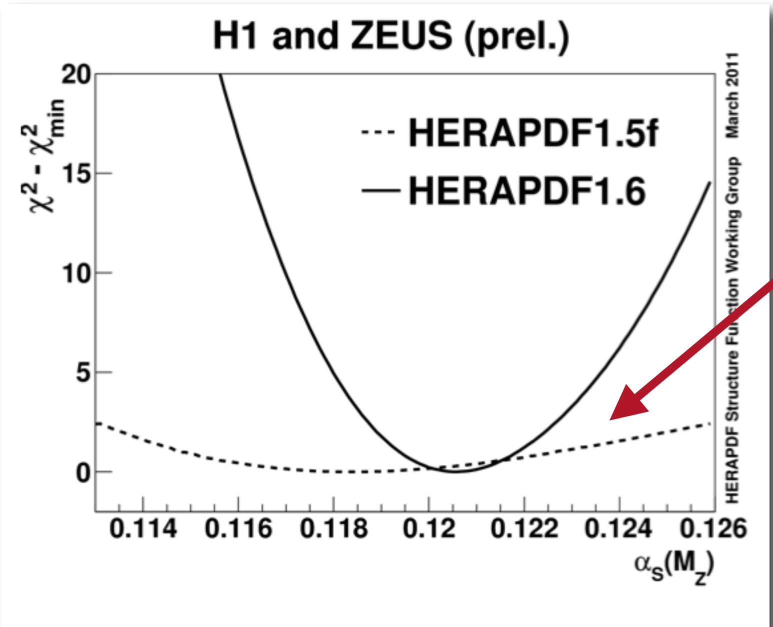
- Unconstrained sea decomposition:

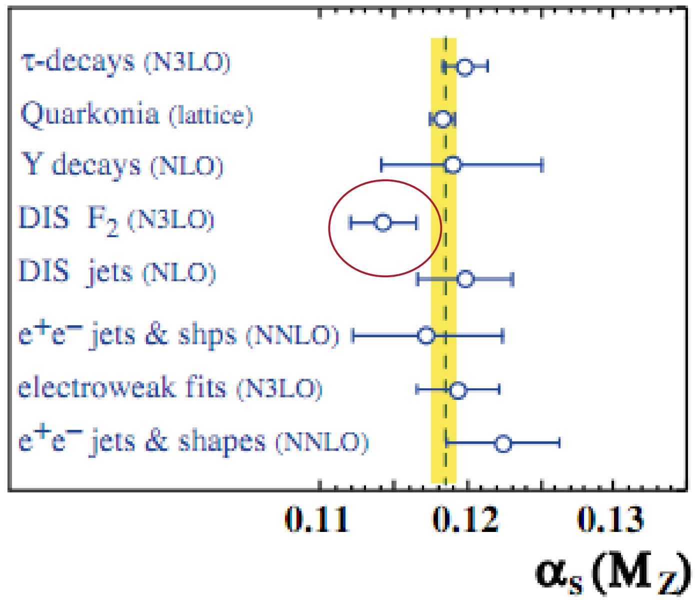




Precise Alphas from DIS at the LHeC

- Strong coupling from DIS processes still seem to prefer smaller values
  - Recent results from HERA show that even with precise HERA data one has to rely on jet measurements in order to constrain gluon PDFs





- Therefore, the determination of the strong coupling at the LHeC could solve this ambiguity.

Summary

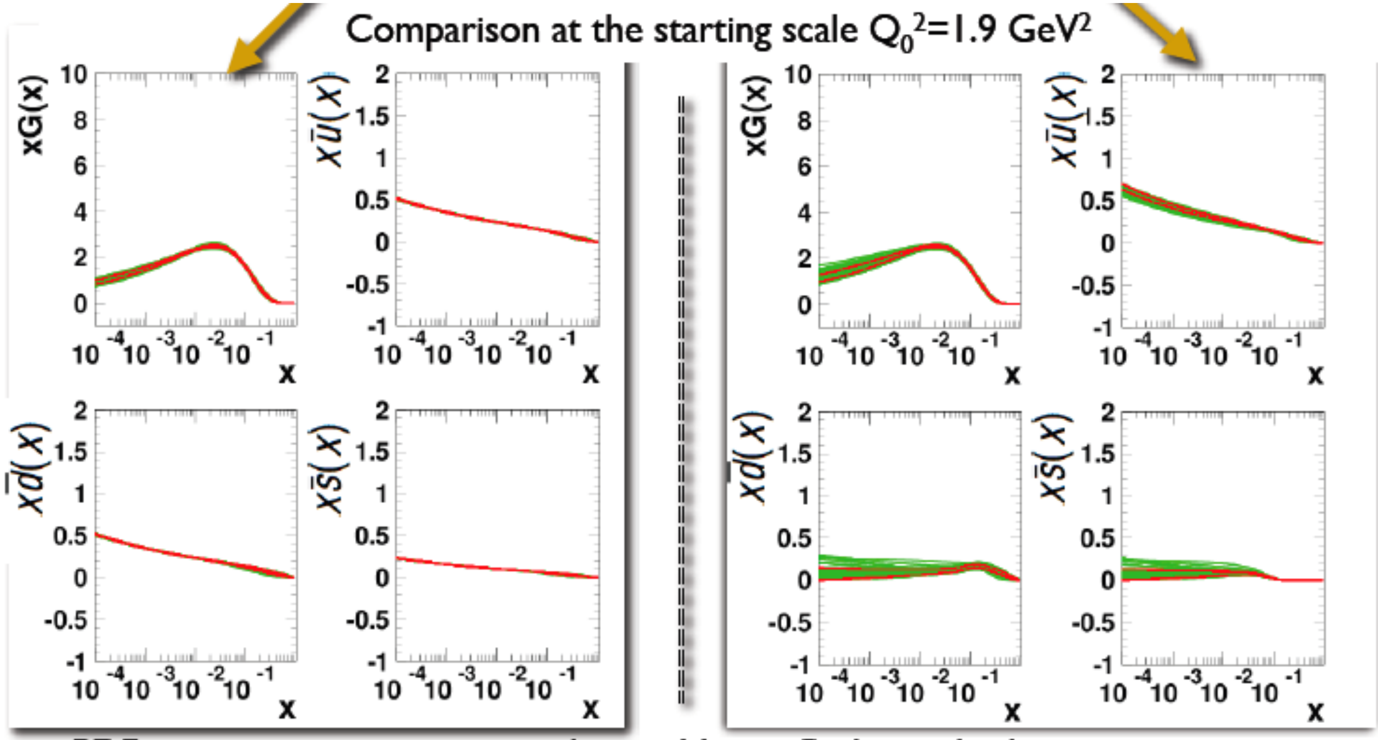
- Presented an impact study of the LHeC on PDF based on settings used for HERAPDF fits.

- LHeC could provide stringent constraints on PDF both at high and low x:
  - mix of high/low energy improves precision by better coverage at high x, hence better flavour decomposition.

- LHeC could also address the question of the strong coupling from DIS inclusive data.

Backup

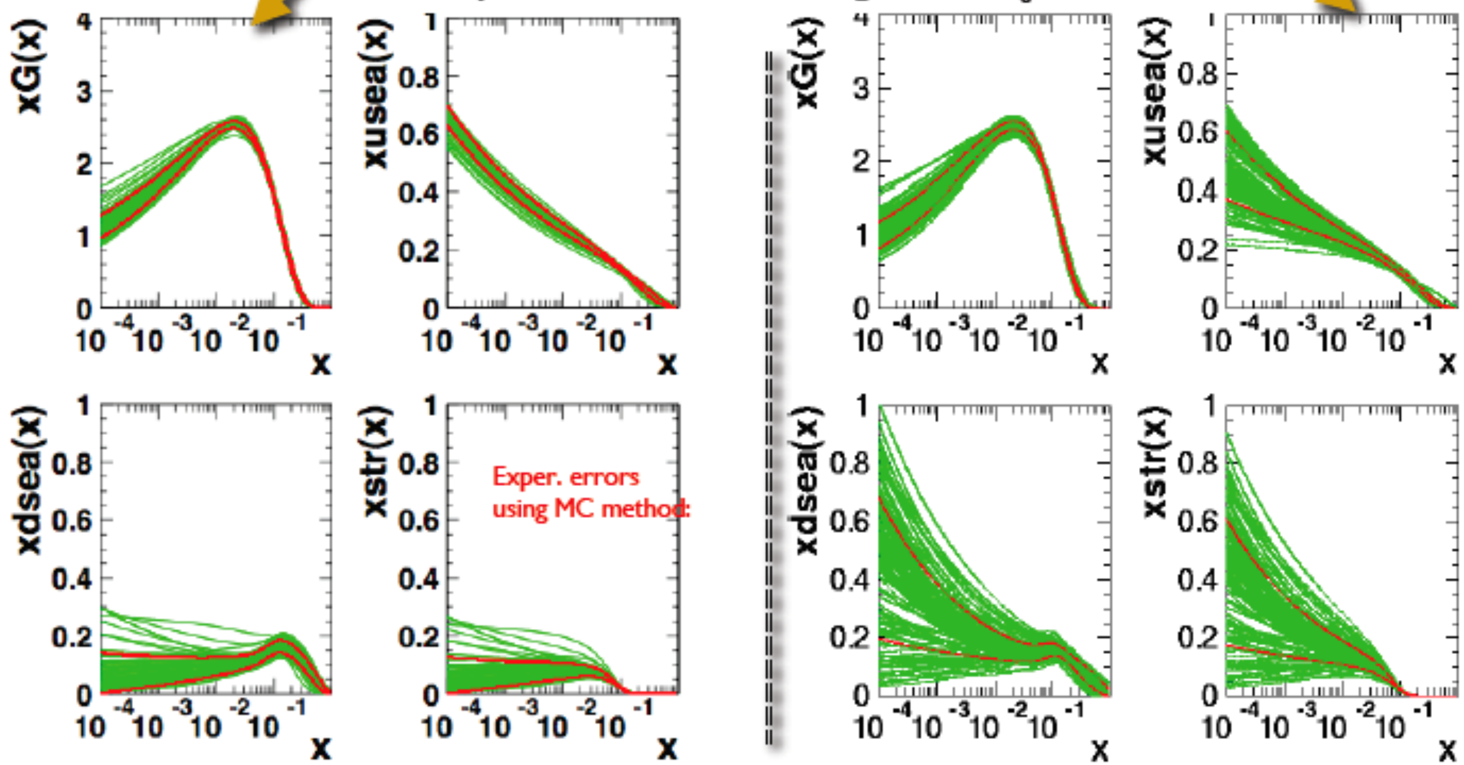
- Standard vs Unconstrained settings (HERA I)



- 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)

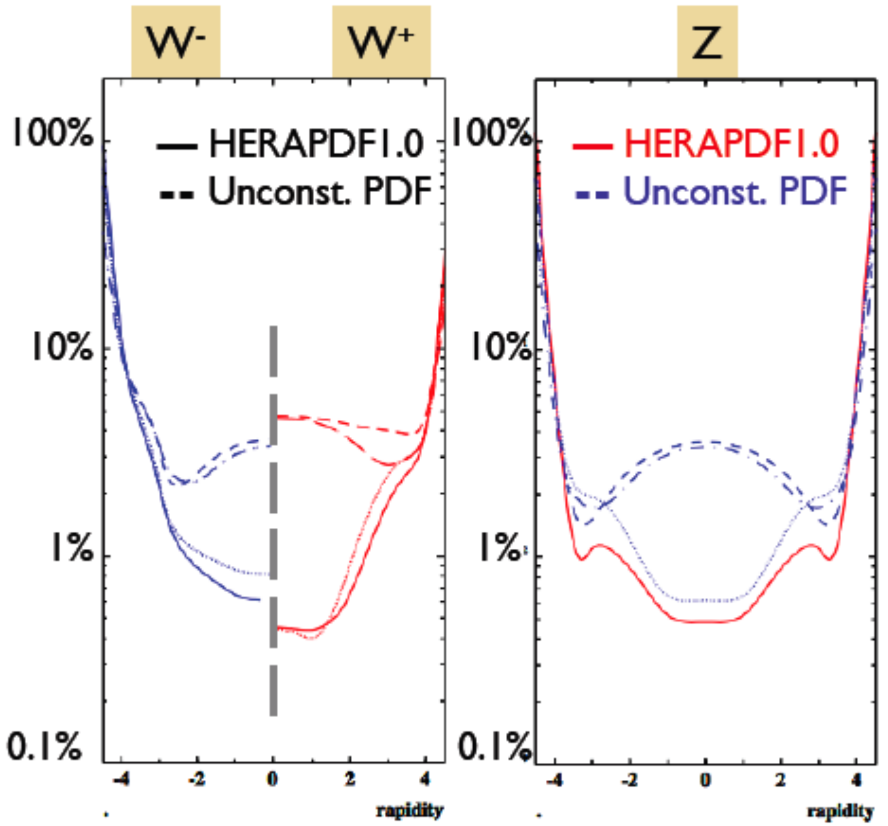
Comparison at the starting scale Q_0^2=1.9 GeV^2



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.



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