Impact of the LHeC data on PDFs

LHeC Workshop
Chavannes
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DESY

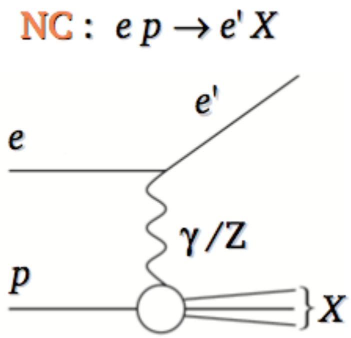
OUTLINE

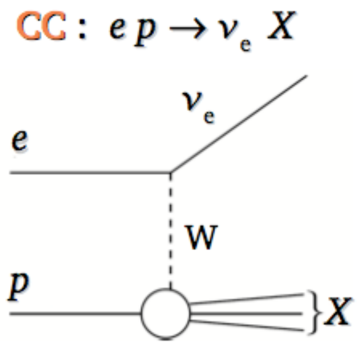
- LHeC simulated data as input
- Potential of the LHeC data on PDFs
- Summary

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:

$$\sigma_r(x, Q^2) = \frac{d^2\sigma(e^{\pm}p)}{dx dQ^2} \frac{Q^4 x}{2\pi\alpha^2 Y_+} = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2) \mp \frac{Y_-}{Y_+} x F_3(x, Q^2)$$

- 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})

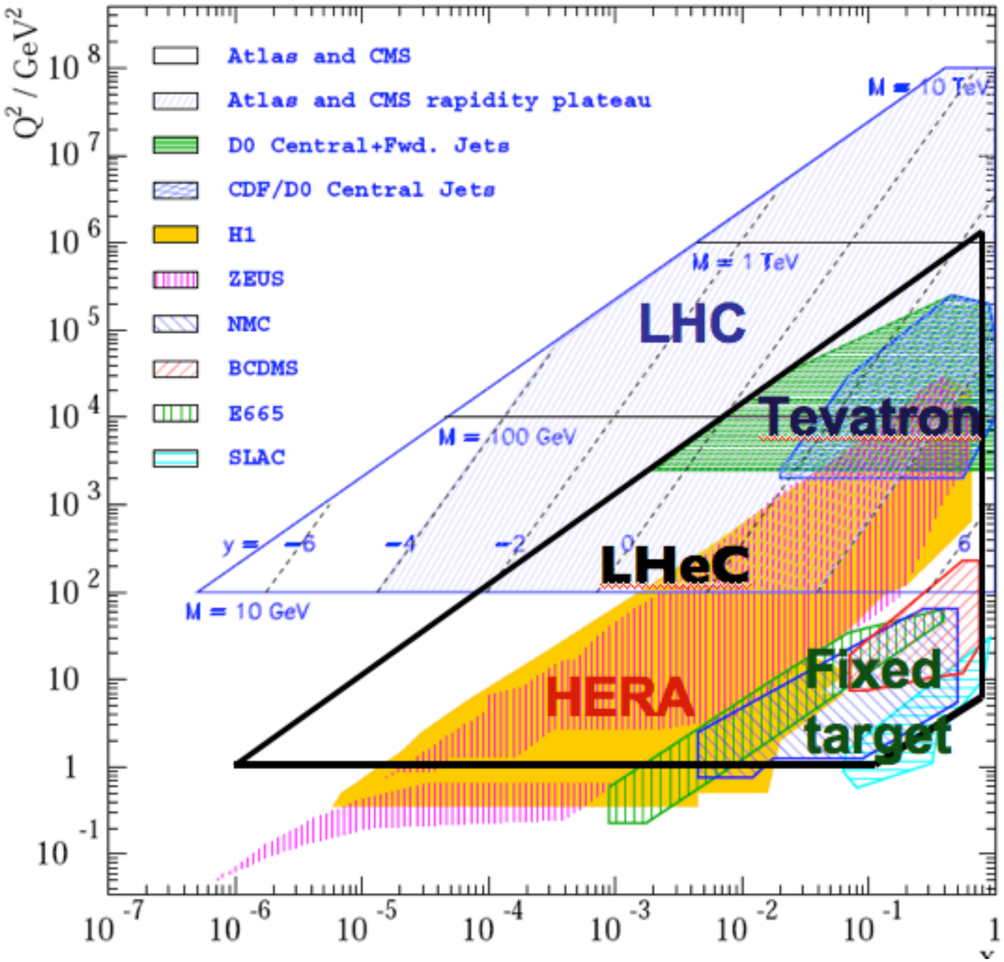
Ep=7TeV, Ee=50 GeV, Pol=±0.4

- 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

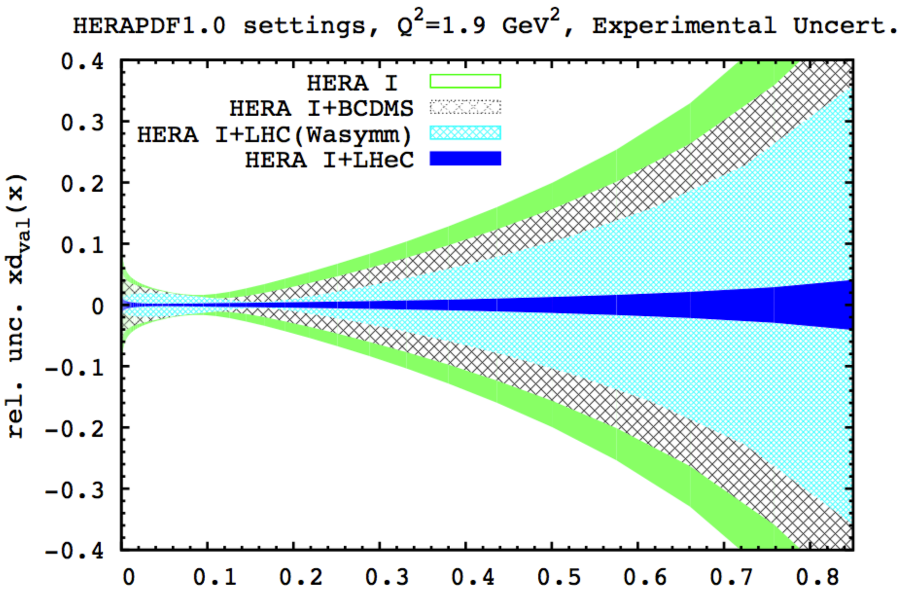
- Data:
  - Published HERA I (NC, CC $e^{\pm}p$ data, P=0)
    - Kinematics of HERA data: $0.65>x>10^{-4}$, $30\,000 > Q^2 > 3.5$ GeV^2
  - LHeC data: NC e^+p, NC, e^-p, CC e^+p, CC e^-p postive and negative polarisations P=±0.4
    - Fixed target data from BCDMS,
    - ATLAS W asymmetry (with adjusted improved uncertainties stat, unc 0.5% and total 1%)
    - New ATLAS W, Z 2010 data (with adjusted lumi uncertainty from 3.4% to 1.4%)
  - Q^2_{min}=3.5 GeV^2 (and W^2>15 GeV^2 for BCDMS data)
  - Only experimental Uncertainties

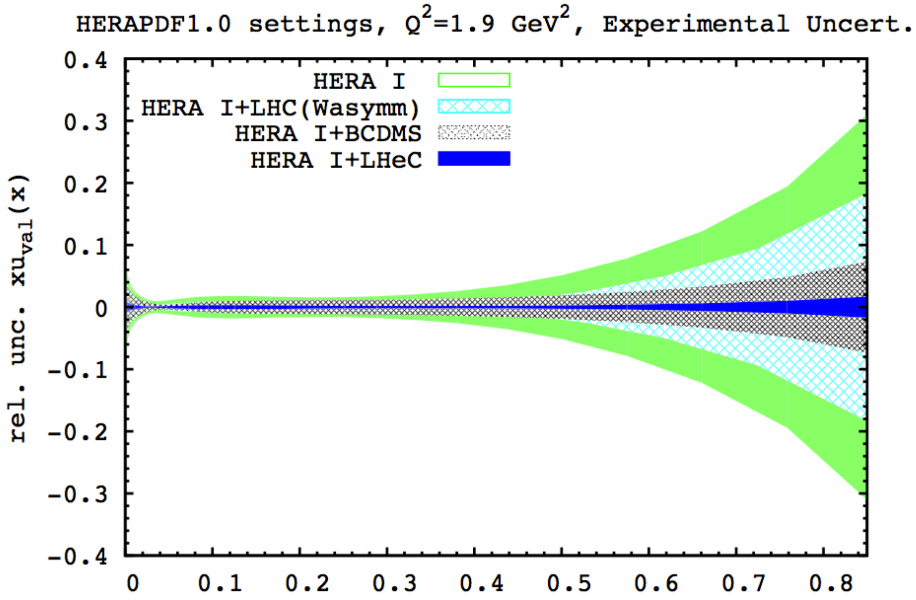
- Initial Theory settings:
  - Same settings as for HERAPDF1.0 has been used [JHEP 1001:109, 2010]:
    - NLO DGLAP [QCDNUM package], RT scheme
  - $u_{val}, d_{val}, g, \overline{U} = \bar{u} + \bar{c}, \overline{D} = \bar{d} + \bar{s}$
    - Sea $S(x)=\overline{U}(x)+\overline{D}(x)$
    - Strange $s(x)=fs\overline{D}(x)=\bar{d}(x)fs/(1-fs)$ 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

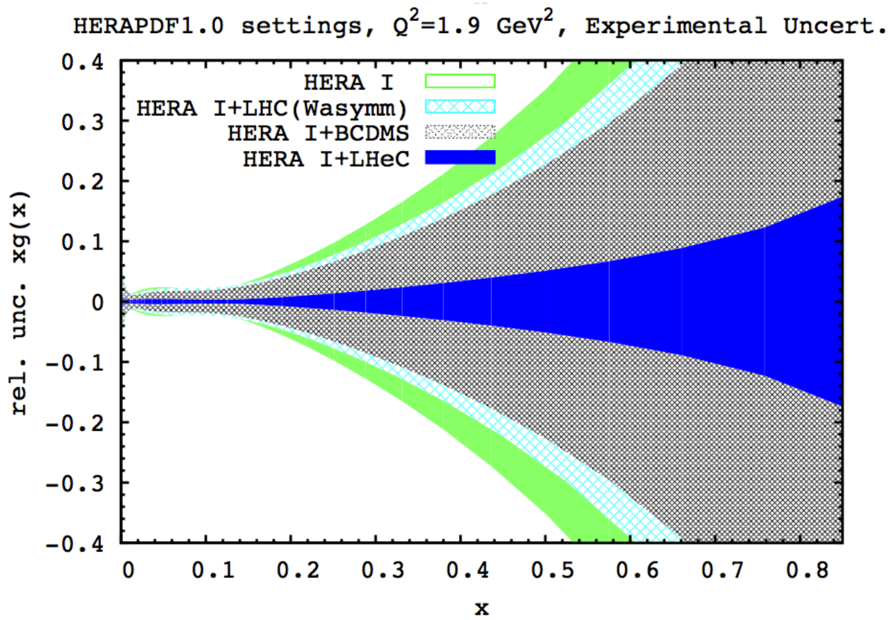
$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.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

Impact of LHeC on PDFs: zoom on high x

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







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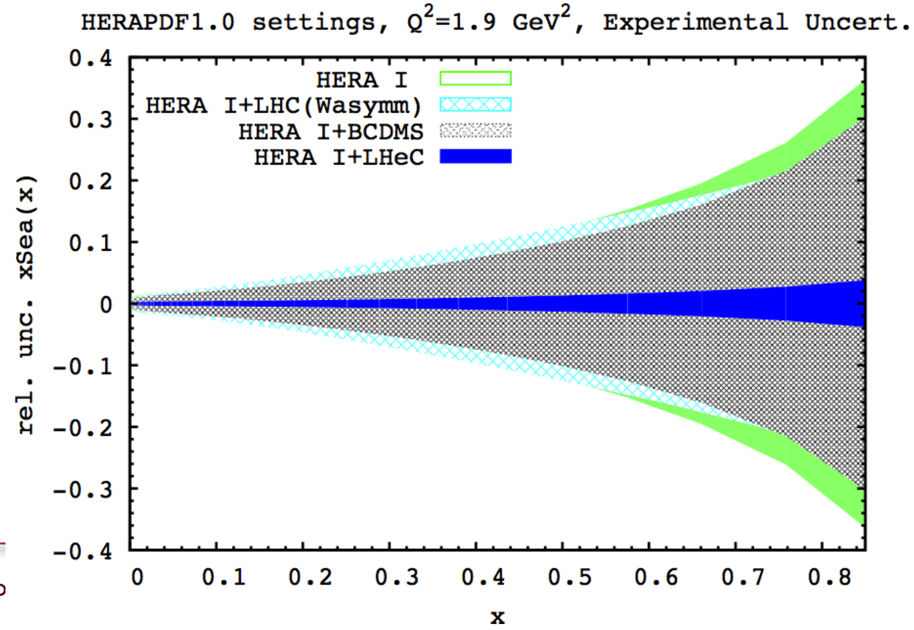
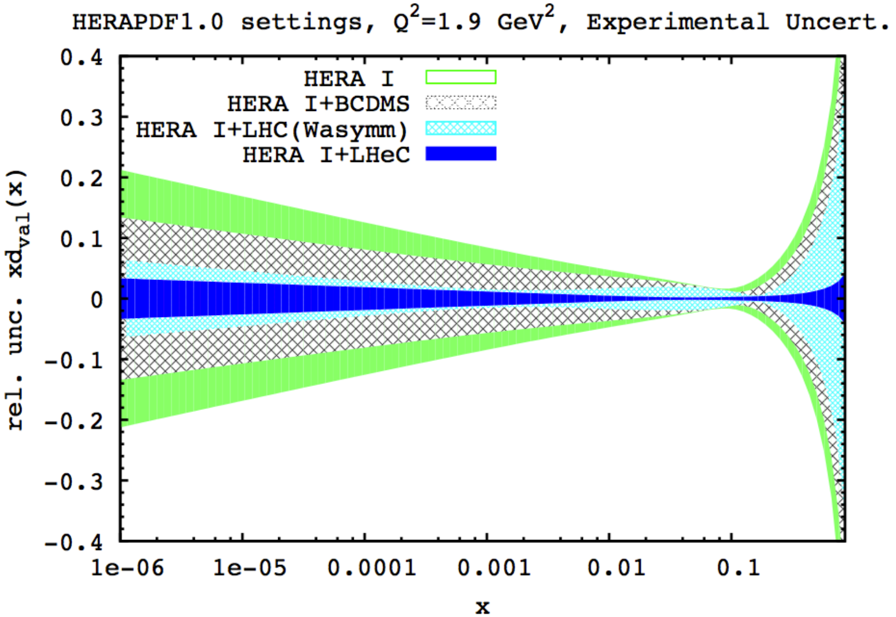
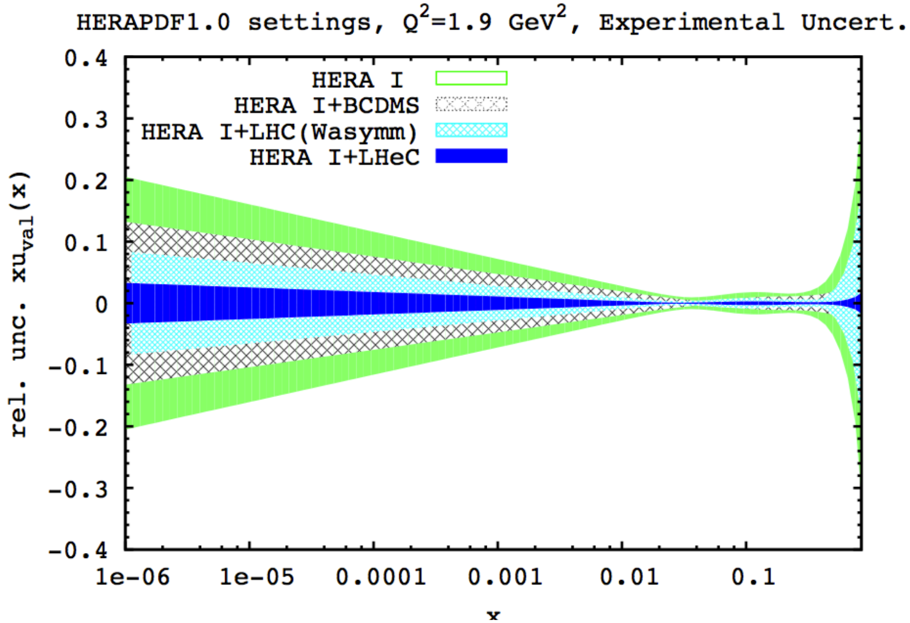
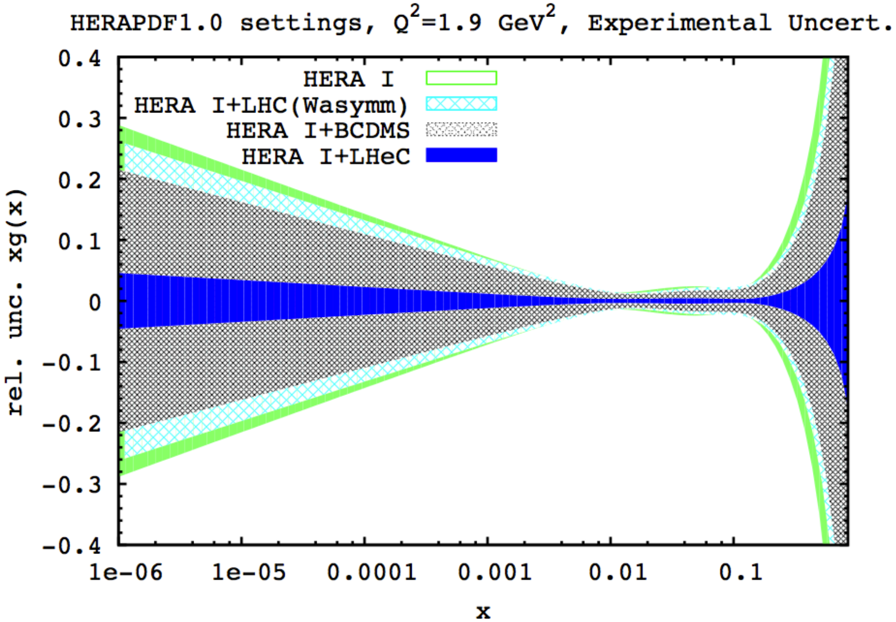


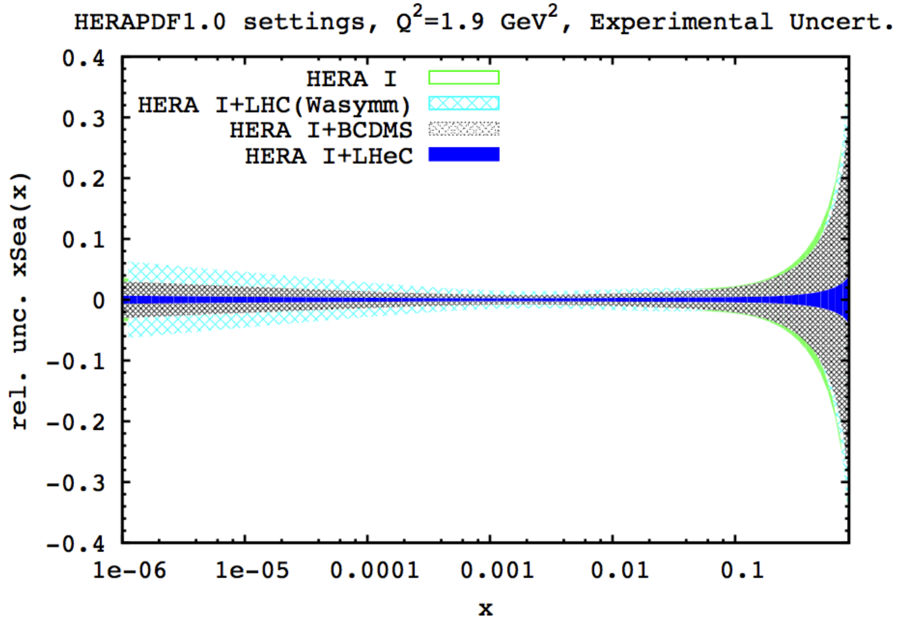
Impact of LHeC on PDFs: zoom on low x

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



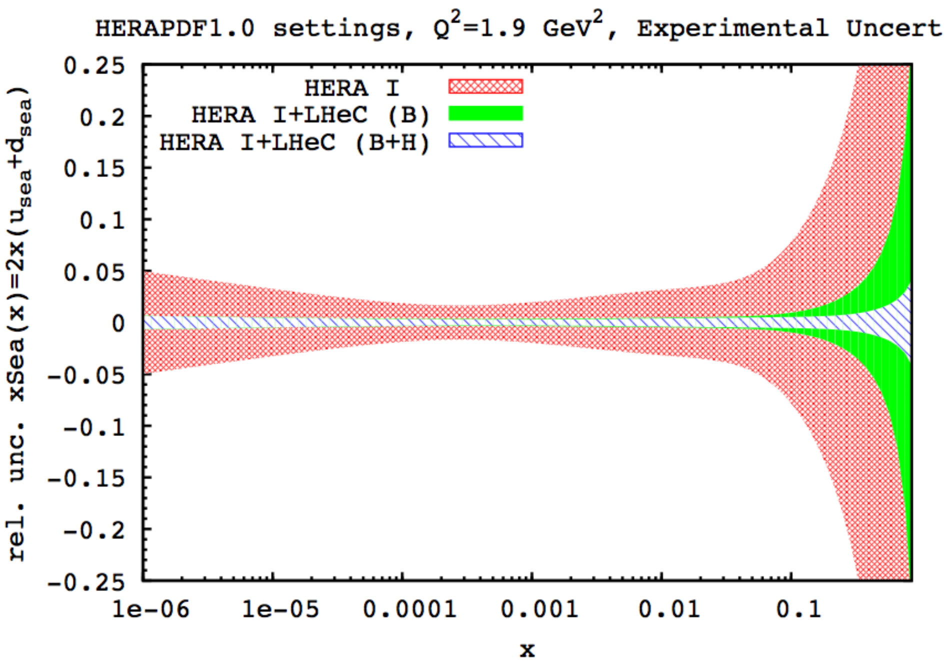


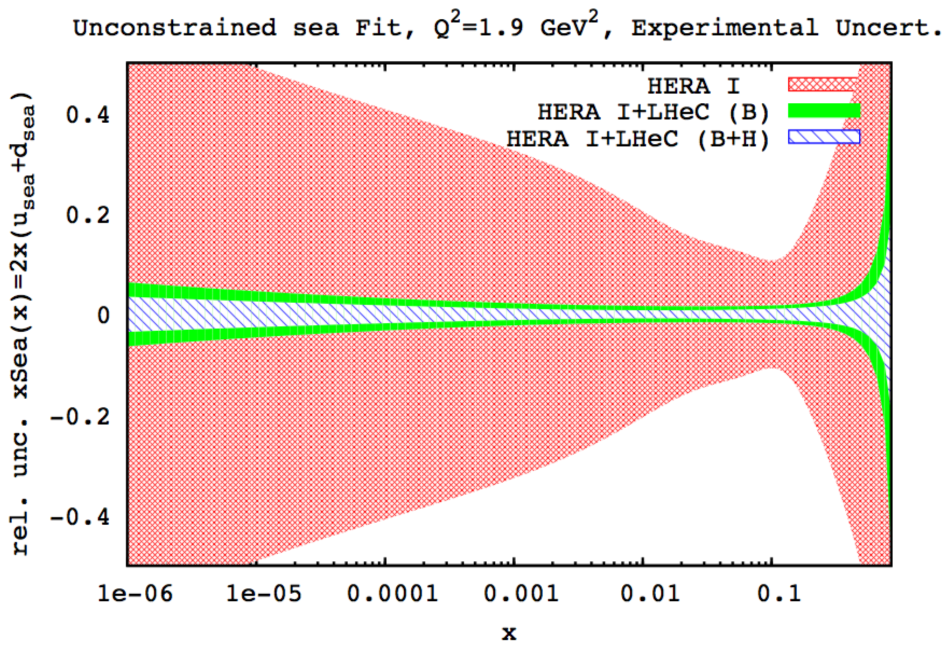




Unconstrained setting at low x

- Usual assumptions for light quark decomposition at low x may not necessary hold.
- Relaxing the assumption at low x that u=d , we observe that uncertainties escalate:

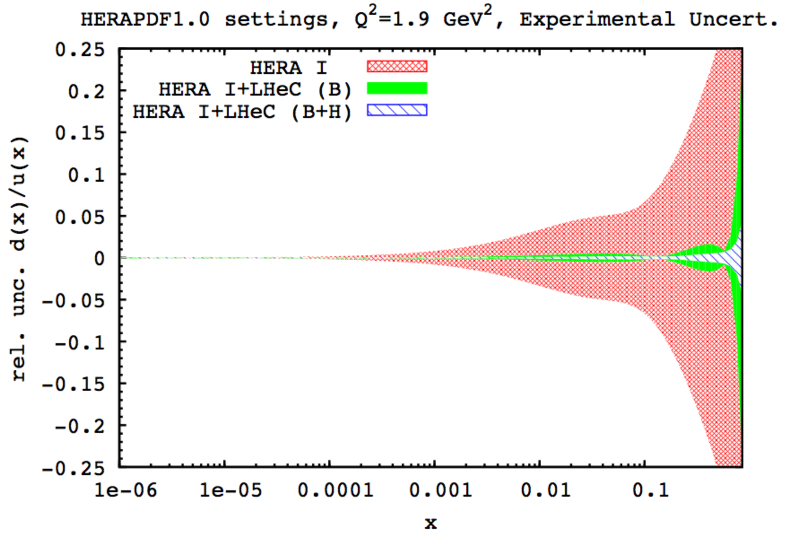


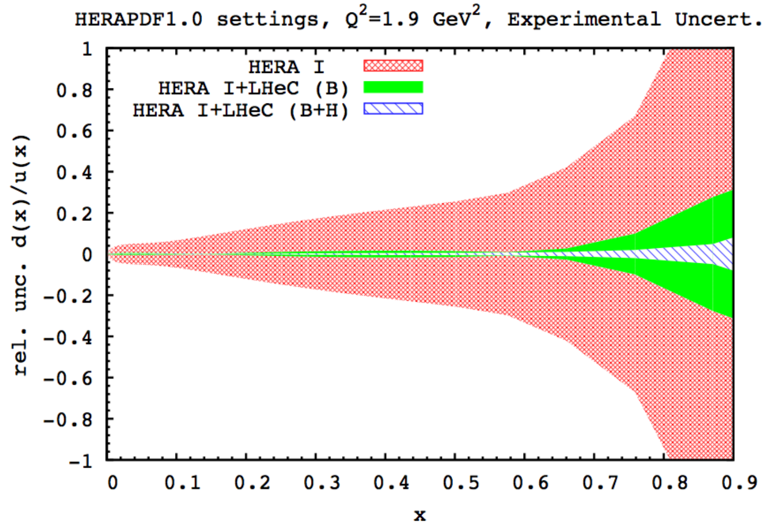


- One can see that for HERA data, if we relax the low x constraint on u and d, the errors are increased tremendously!
- However, when adding the LHeC simulated data, we observe that uncertainties are visibly improved even without this assumption.

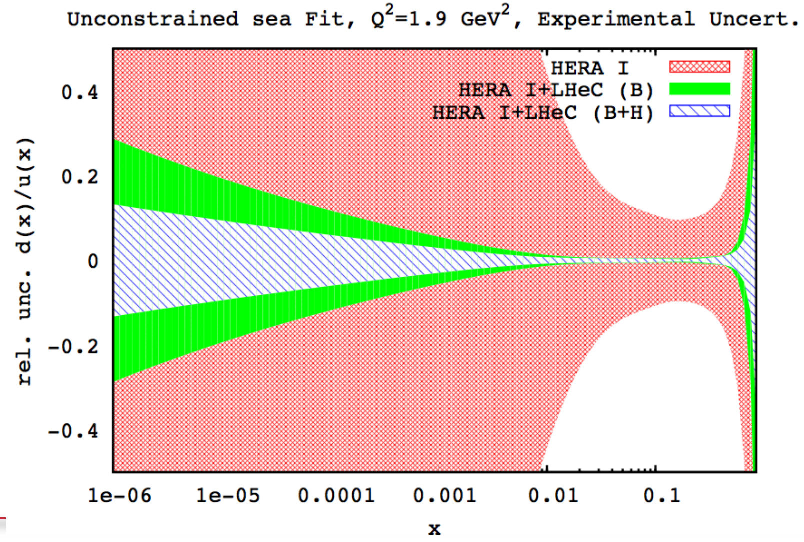
Impact on d/u ratios

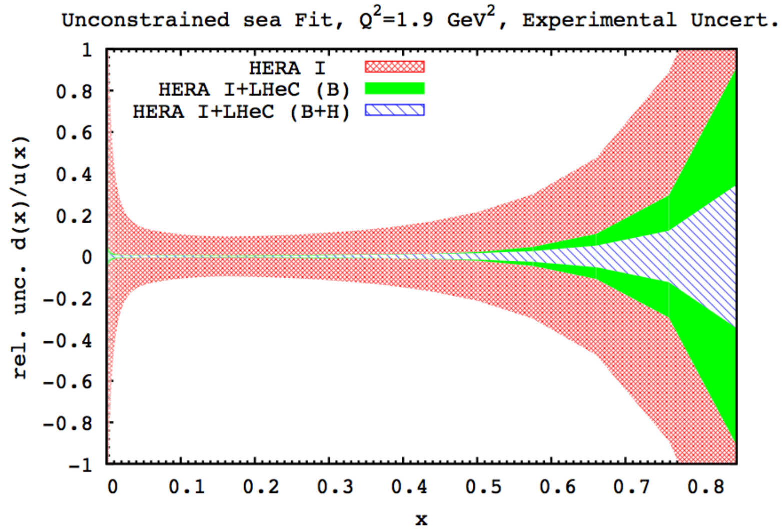
- Constrained decomposition:





- Unconstrained sea decomposition:





Releasing further PDF constraints

- Releasing further the assumptions:

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

→

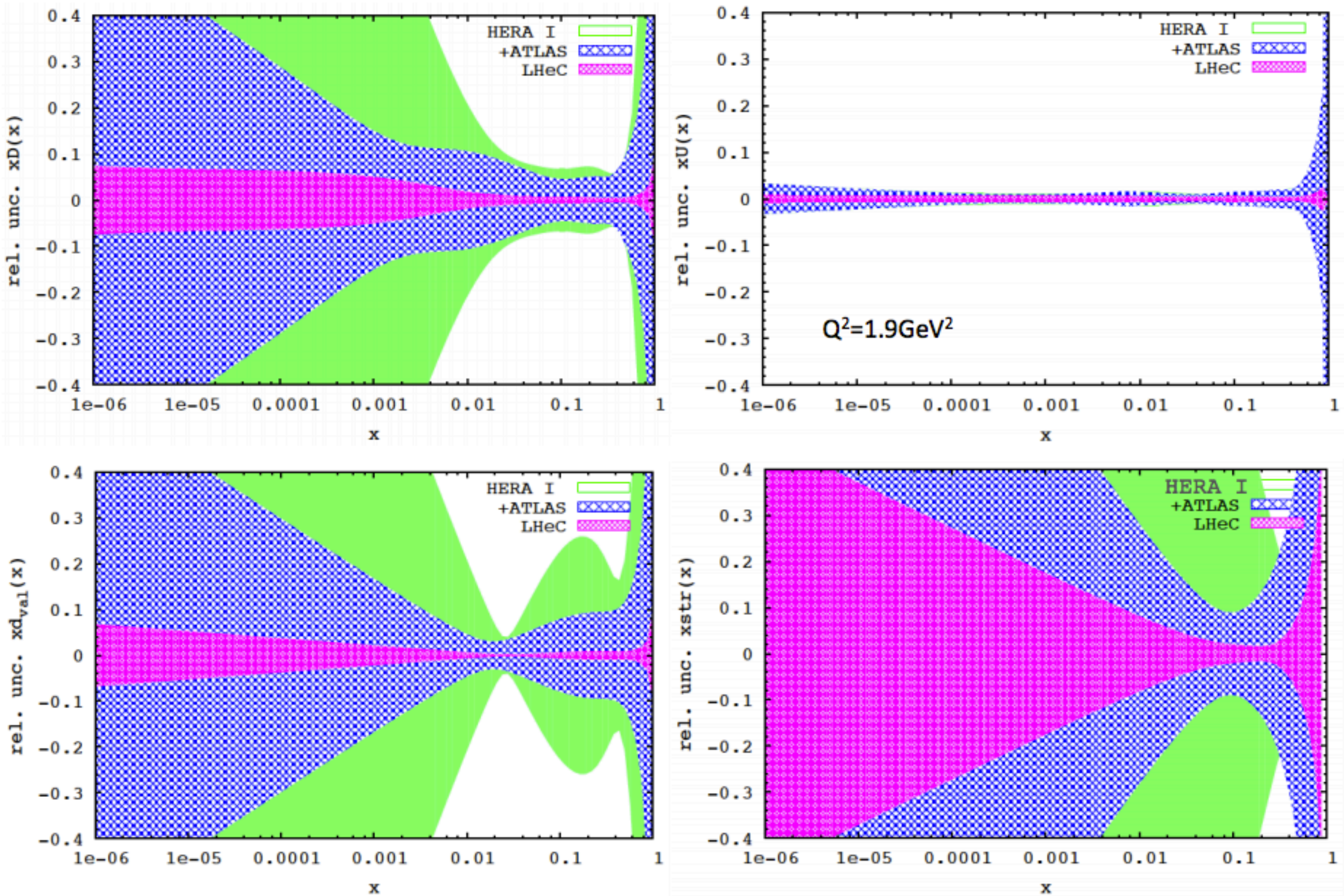
$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}\,(1+D_g x)\ ,\\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\,(1+E_{u_v}x^2)\ ,\\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}\ ,\\
x\bar{u}(x) &= A_{\bar{u}} x^{B_{\bar{u}}}(1-x)^{C_{\bar{u}}}\,,\\
x\bar{d}(x) &= A_{\bar{d}} x^{B_{\bar{d}}}(1-x)^{C_{\bar{d}}}\,,\\
xs(x) &= r_s A_s x^{B_s}(1-x)^{C_s}
\end{aligned}
$$

$$
\begin{aligned}
&B_{u_v} \neq B_{d_v},\\
&A_{\bar{u}} \neq A_{\bar{d}},\ B_{\bar{u}} \neq B_{\bar{d}},
\end{aligned}
$$

- Added additional flexibility to gluon
- Removing the correlation that ubar=dbar at low x
- Added more flexibility to uval and dval at low x
- Free parameters for the strange quark are introduced

- This study was driven by the recent ATLAS results on strange determination, hence we have repeated the impact of LHeC study under the new conditions.

Impact of LHeC after releasing assumptions

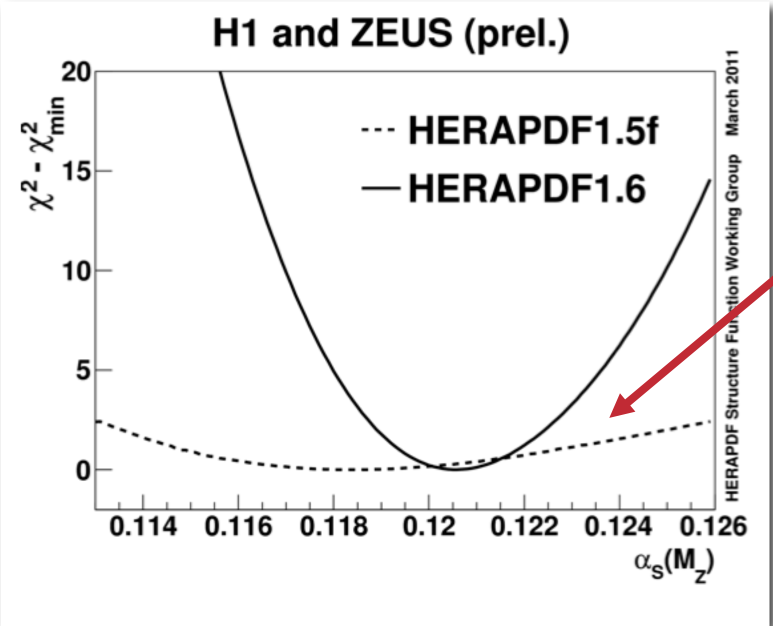


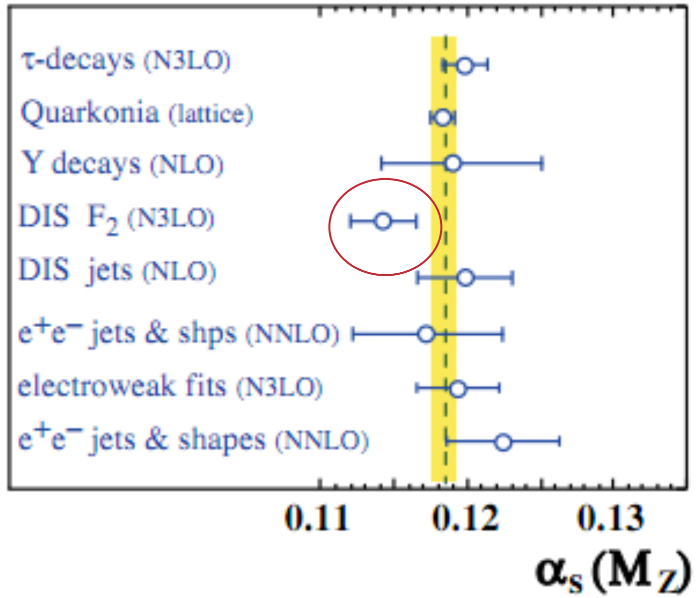
Remarks

- Relaxation of the up and down parameters leads for HERA I data to no constraining power of the down quark for $x<0.01$, however the total U quark remains constrained as it dominates F2 at low x for HERA.
- There is marginal sensitivity of the inclusive HERA data to the strange quark.
- ATLAS has recently released W and Z data that bring constraints to the strange density for $0.01<x<0.2$, and favour symmetric sea decomposition.
- Inclusive LHeC data leads to very precise determination of all PDFs even after removing large bulk of assumptions:
  - LHeC ep data constrain better U than D distributions, however it is planned to have also deuteron data which would symmetrise our understanding.
  - Determination of the strange is accurate to few % and can complement the strange determination from the charm data

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.

Expected precision on alphas(Mz) from DIS

- A dedicated study to determine the accuracy of alphas from the LHeC was performed using for the central values the SM prediction smeared within its uncertainties assuming Gauss distribution and taking into account correlations.

case	cut [Q^2 in GeV^2]	α_S	$\pm$uncertainty	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	0.11529	0.002238	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.12203	0.000995	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.11680	0.000180	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.11796	0.000199	0.17
LHeC only (14p)	$Q^2 > 20.$	0.11602	0.000292	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11769	0.000132	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.11831	0.000238	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.11839	0.000304	0.26

Table 4.4: Results of NLO QCD fits to HERA data (top, without and with jets) to the simulated LHeC data alone and to their combination. Here 10p or 14p denotes two different sets of parametrisations, one, with 10 parameters, the mimimum parameter set used in [38] and the other one with four extra parameters added as has been done for the HERAPDF1.5 fit. The central values of the LHeC based results are obviously of no interest. The result quoted as relative accuracy includes all the statistical and the systematic error sources taking correlations as from the energy scale uncertainties into account.

Summary

- Presented an impact study of the LHeC on PDF based on settings used for HERAPDF fits and updated to more flexible parametrisation and releasing assumptions in order to explore the full potential of the LHeC.

- 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.

- Gluon

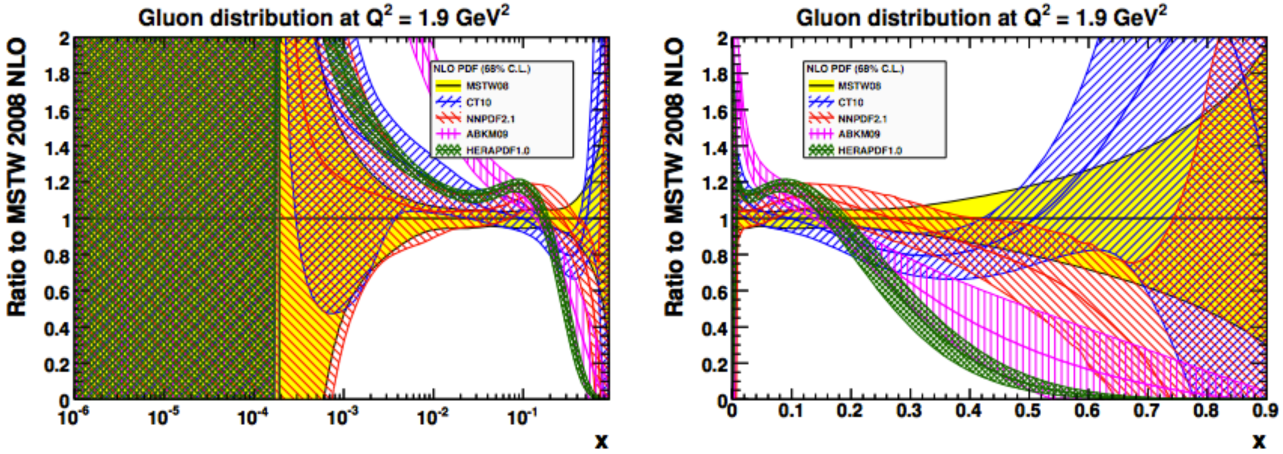


Figure 4.17: Ratios to MSTW08 of gluon distribution and uncertainty bands, at $Q^2 = 1.9\,\mathrm{GeV}^2$, for most of the available recent PDF determinations. Left: logarithmic x, right: linear x.

- Strange

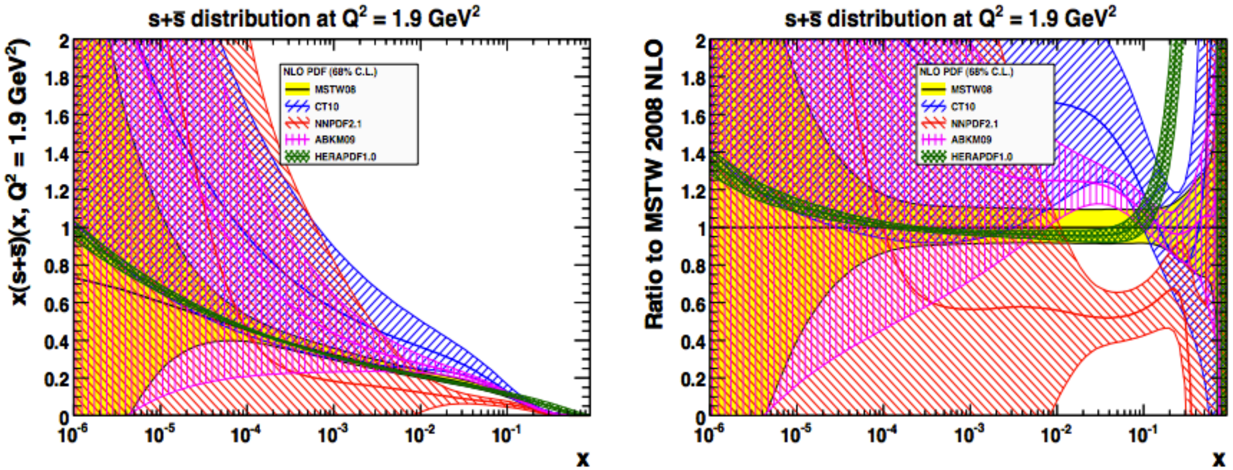


Figure 4.12: Sum of the strange and anti-strange quark distribution as embedded in the NLO QCD fit sets as noted in the legend. Left: $s + \bar{s}$ versus Bjorken x at $Q^2 = 1.9\,\mathrm{GeV}^2$; right: ratio of $s + \bar{s}$ of various PDF determinations to MSTW08. In the HERAPDF1.0 analysis (green) the strange quark distribution is assumed to be a fixed fraction of the down quark distribution which is conventionally assumed to have the same low x behaviour as the up quark distribution, which results in a small uncertainty of $s + \bar{s}$.

ATLAS recent result on strange:

- (Accepted by PRL)

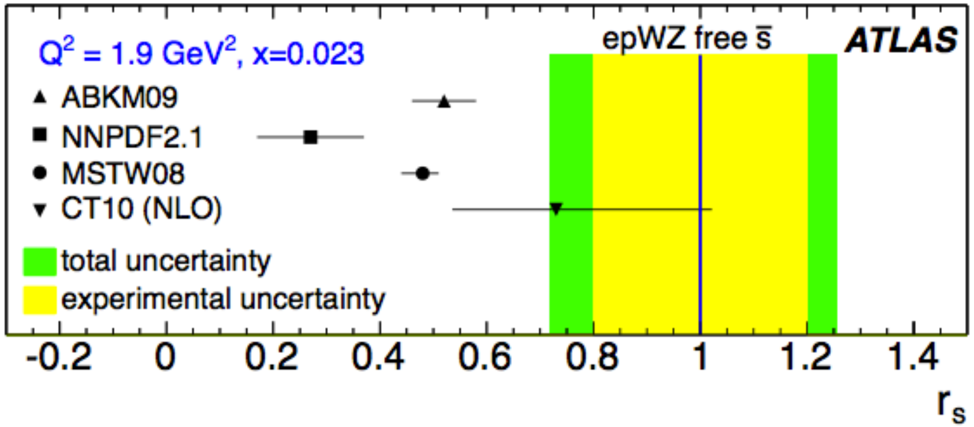


FIG. 2. Predictions for the ratio $r_s = 0.5(s + \bar{s})/\bar{d}$, at $Q^2 = 1.9\,\mathrm{GeV}^2$, $x = 0.023$. Points: global fit results using the PDF uncertainties as quoted; bands: this analysis; inner band, experimental uncertainty; outer band, total uncertainty.

The result on r_s, Eq. 2, evolves to

$$r_s = 1.00 \pm 0.07_{\mathrm{exp}} \pm 0.03_{\mathrm{mod}}{}^{+0.04}_{-0.06}{}_{\mathrm{par}} \pm 0.02_{\alpha_S} \pm 0.03_{\mathrm{th}} \quad (3)$$

ATLAS Recent Results

- s/d