Low-x physics at LHeC with NNPDFs (Exploratory studies)

Juan Rojo[5]
on behalf of the **NNPDF Collaboration**: R. D. Ball[1], L. Del Debbio[1], S. Forte[2], A. Guffanti[3], J. I. Latorre[4], A. Piccione[2], J. R.[5], M. Ubiali[1]

[1]University of Edinburgh, [2] Università di Milano, [3]Albert-Ludwigs-Universität Freiburg, [4]Universitat de Barcelona, [5]LPTHE, UPMC Paris VI

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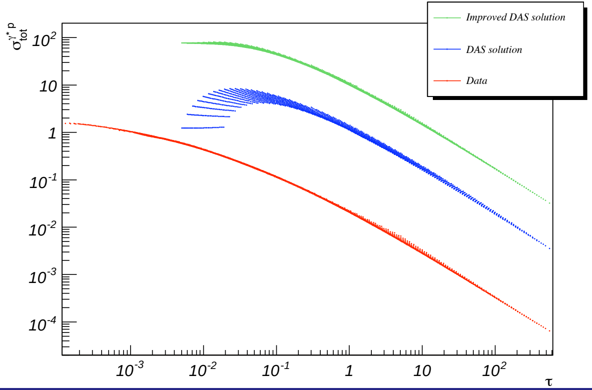
Introduction

- The study of Quantum Chromodynamics and the structure of the proton at very low-x is an important aspect of the LHeC potential (with implications for LHC precision physics)
- Standard PDF determinations neither not flexible enough nor with trustable uncertainties in LHeC (extrapolation) regions → Need statistically sound methods: the NNPDF approach (see morning talk)
- With such approach one can address questions quantitatively like whether or not LHeC can disentangle saturation/resummation/higher orders ...
- Related studies in this workshop in P. Newmann's talks (+ J. Forshaw talk at DIS08)
- Disclaimer → Very preliminary studies (no quantitative conclusions possible)

NNPDFs @ LHeC

Saturation

- Saturation has been extensively studied at HERA ...
- ... but so far no undisputed smoking gun has appeared
- Example: Geometric Scaling in $\sigma^{\gamma p}(x, Q^2)$ reproduced also within DGLAP (Caola, Forte 08)



Probing saturation

Two extreme views: saturation effects either large for all observables or can always be absorbed in DGLAP analysis. Truth probably in the middle ...
How to quantify if LHeC can disentangle saturation or related effects?

1. Generate pseudo-data in LHeC kinematics with realistic uncertainties
2. Assume different underlying physics (saturation, NLO/NNLO DGLAP with different PDFs, DGLAP + small-x resummation ...)
3. Perform a DGLAP PDF analysis and check if data can be reproduced

Need PDFs with flexible enough parametrizations and whose uncertainty statistical analysis is independent of the data set $\rightarrow$ the NNPDF approach

Simulated LHeC data

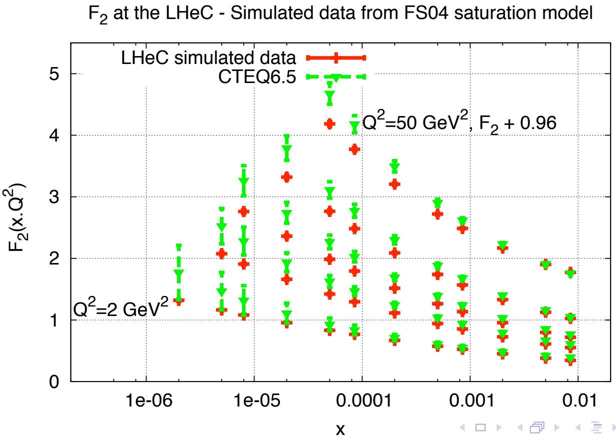
First exercise → Take simulated LHeC data from FS04 saturation model for $F_2(x, Q^2)$ and $F_L(x, Q^2)$ (Forshaw and Shaw 2004)

Set	$N_{\rm dat}$	$x_{\rm min}$	$x_{\rm max}$	$Q^2_{\rm min}$	$Q^2_{\rm max}$	$\sigma_{\rm tot}$
LHeCF2	50	$2 \cdot 10^{-6}$	$8.5 \cdot 10^{-3}$	2	50	2%
LHeCFL	32	$2 \cdot 10^{-6}$	$6.1 \cdot 10^{-4}$	2	30	14%

Expectations for F_L uncertainties a factor of 7 of F_2 uncertainties (Caveat →Pseudo-data taken from LHeC webpage. Would be very useful to have all pseudo-data shown by M. Klein publicly available!)

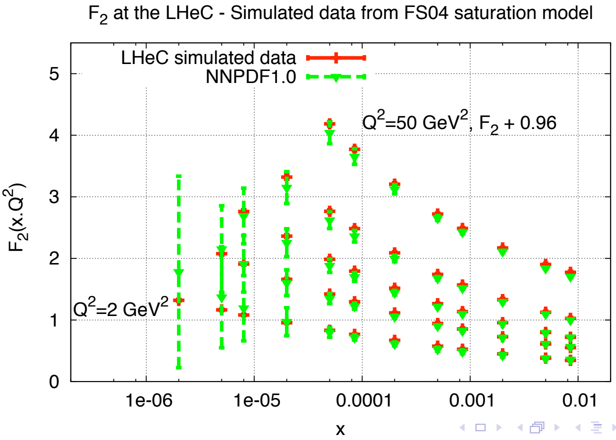
Extrapolations from global PDF analysis

Compare LHeC pseudo data (FS04sat) with DGLAP extrapolations
CTEQ6.5 $\rightarrow F_2^{\rm sat}|_{\rm LHeC}$ inconsistent with DGLAP extrapolations ....



Extrapolations from global PDF analysis

Compare LHeC pseudo data (`FS04sat`) with DGLAP extrapolations
NNPDF1.0 $\to$ $F_2^{\rm sat}|_{\rm LHeC}$ not that far from DGLAP extrapolations



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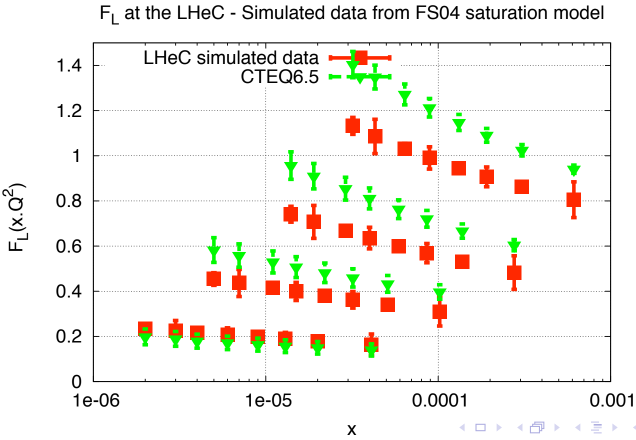

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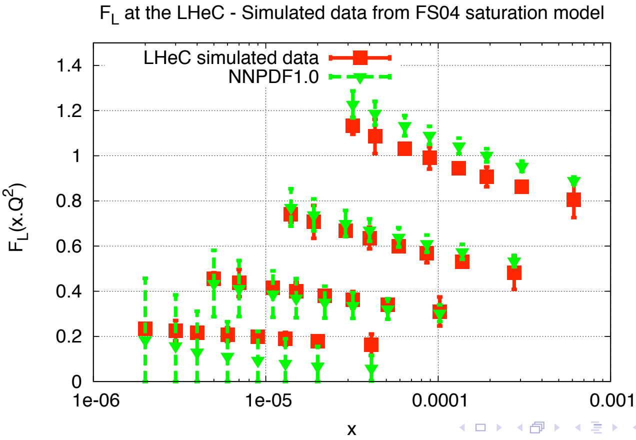

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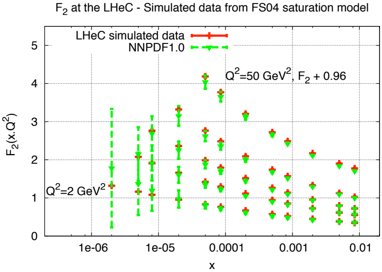
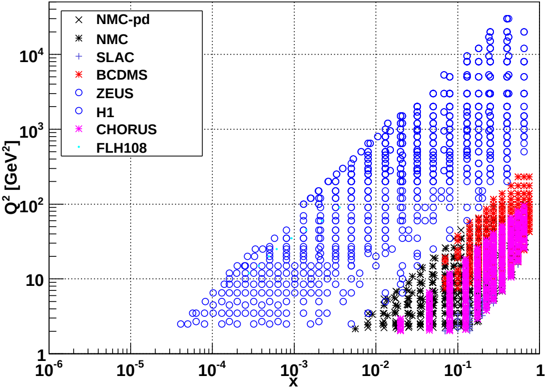


Lesson I → Need PDFs with trustable error in low-x region to assess how much small-x models differ from DGLAP extrapolations

Include LHeCsat data in NNPDF1.0

Can saturation effects be absorbed in a DGLAP PDF analysis?

Add $F_L^{\rm sat}|_{\rm LHeC}$ and $F_L^{\rm sat}|_{\rm LHeC}$ pseudo-data into NNPDF1.0 analysis



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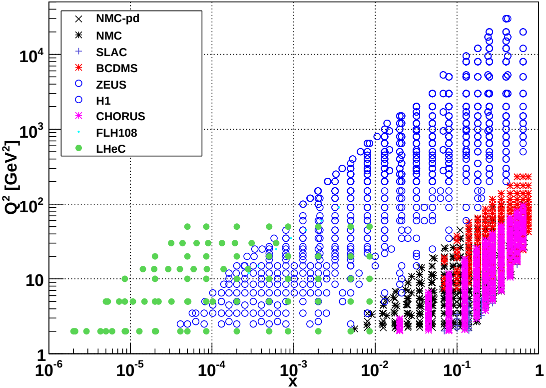

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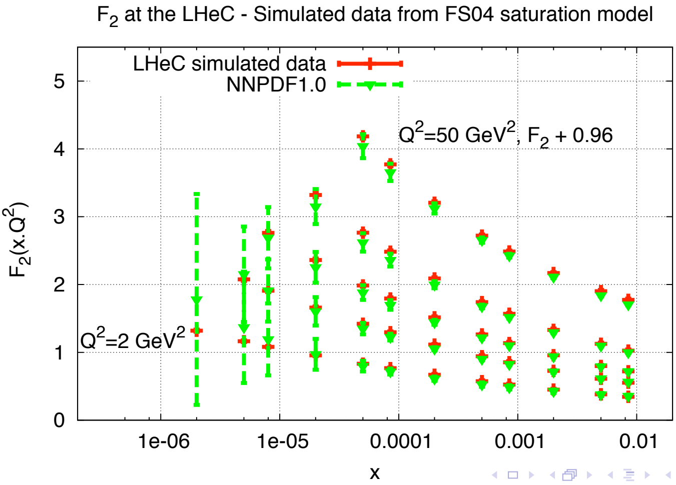
Compare saturation with DGLAP extrapolations (NNPDF1.0) for $F_2(x, Q^2)$:



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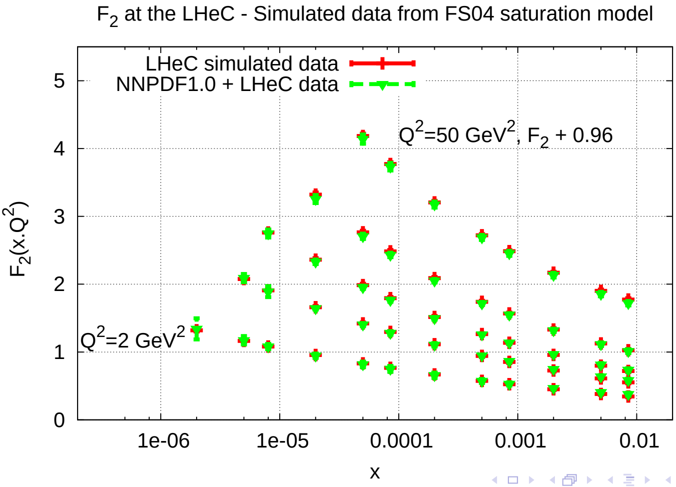
… after LHeCsat pseudo data included in fit



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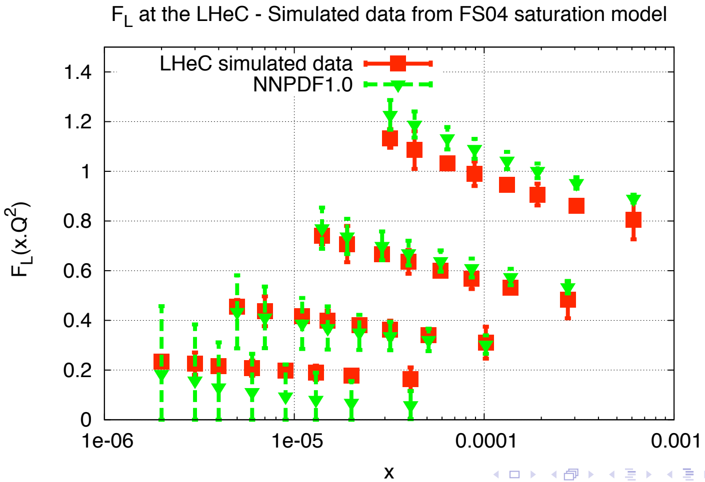

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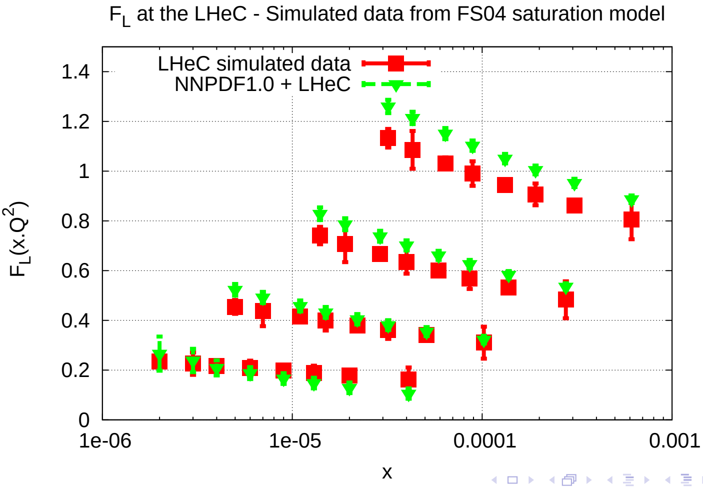

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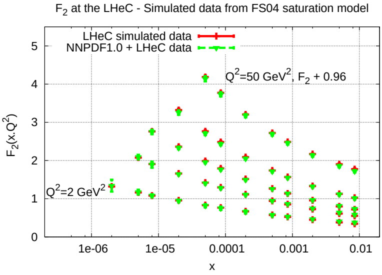
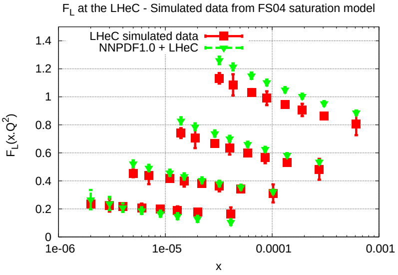




NLO DGLAP + NNPDFs seem to be able to reproduce $F_2^{\mathrm{sat}}(x, Q^2)$, but more difficulties for $F_L^{\mathrm{sat}}(x, Q^2)$

Lesson II :

1. $F_L(x, Q^2)$ crucial observable to understand low-x QCD at LHeC (But require precise measurements)
2. Not all observables equivalent to disentangle saturation

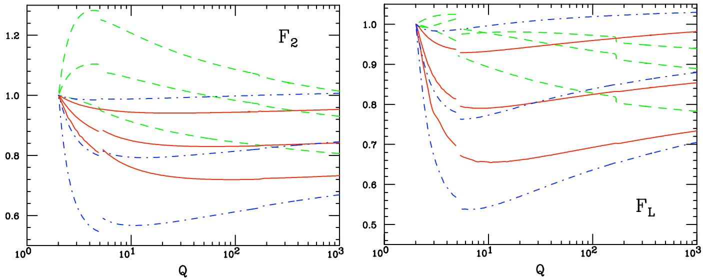
SMALL-X RESUMMATION

Small-x resummation

- Perturbation theory unstable at small-x (G. Altarelli's plenary talk)
- Small-x resummations (ABF, CCSS, WT) cures this stability $\longrightarrow$ Sizable differences with respect NNLO in $x-$region relevant for LHeC physics
- Is low-x resummation required/relevant for LHeC phenomenology? $\longrightarrow$The need or not for small-x resummed evolution can be studied in the same way as we studied previously saturation

Small-x resummation

- Resummed splitting functions and DIS coefficient functions public and available from the ABF group



- Work in progress → Implementation in the public $x-$space evolution code `HOPPET` (G. Salam and J.R, arxiv:0804.3755)

  `http://projects.hepforge.org/hoppet/`

  Useful tool for LHeC studies

OUTLOOK

Outlook

- The NNPDF approach provides a useful technique to quantify if LHeC can disentangle saturation/resummation from standard PDF evolution
- Work in progress: similar exercises with LHeC pseudo-data generated with NLO DGLAP (with CTEQ6.6 and NNPDF1.0) and with low-x resummation
- In other (safer) kinematical regions:
  - Simulate LHeC data for other structure functions in different kinematical regions
  - Include in (NN)PDF analysis (M. Klein talk)
  - Study reduction in PDF uncertainties and implications for precision LHC physics

Thanks for your attention!

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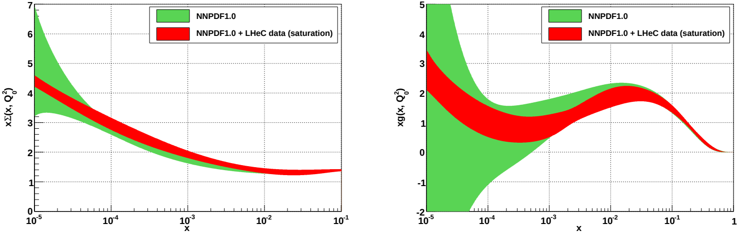
EXTRA MATERIAL

Preliminary results

Errors at low-x do indeed shrink.



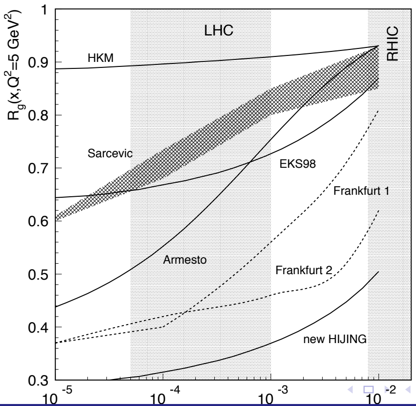
Should be compared with PDFs with LHeC pseudo data simulated with NLO DGLAP extrapolation → Further error reduction in this case is expected

NUCLEAR PDFS AT THE LHeC

Nuclear PDFs at the LHeC

- Nuclear PDFs much less constrained that proton PDFs → No *eA* runs in HERA

From N. Armesto, ... *to* Predictions for $R_g(x, Q^2, A) = g^{(A)}/g^{(p)}$



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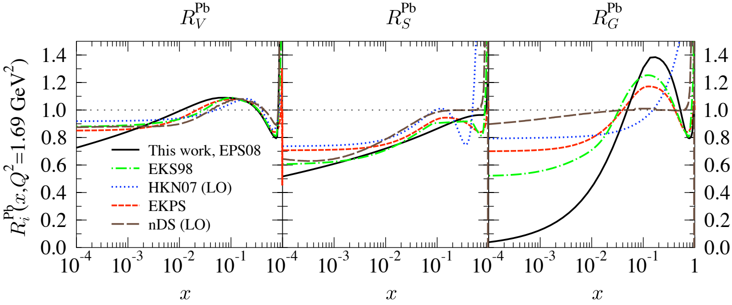
From EPS08 global nPDF analysis (K. Eskola et al., arxiv:0802.)



Nuclear PDFs at the LHeC

- Nuclear PDFs much less constrained that proton PDFs → No *eA* runs in HERA
- Precise measurent of initial state nuclear effects in *pA* (LHC) and *eA* (LHeC) → Baseline to discriminate QGP effects in HIC
- Nuclear PDFs parameterized like proton PDFs, but with extra dependence on *A* and more uncertain *x*−dependence → Potential functional form bias?
  EPS08 analysis (K. Eskola et al., arxiv:0802.)

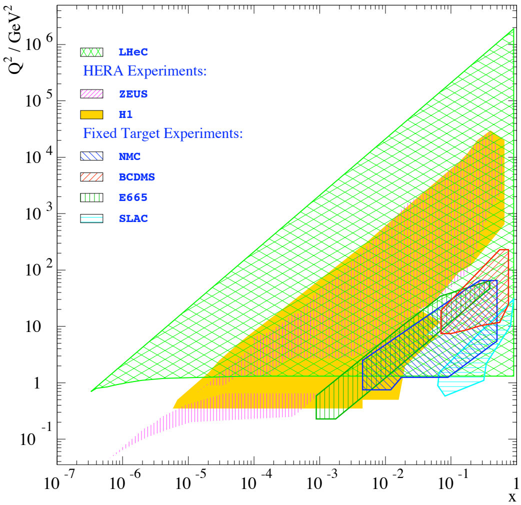
$$
\begin{aligned}
R_1^A(x) &= c_0^A + (c_1^A + c_2^A x^{\alpha^A})[\exp(-x/x_s^A) - \exp(-x_a^A/x_s^A)], & x \le x_a^A \\
R_2^A(x) &= a_0^A + a_1^A x + a_2^A x^2 + a_3^A x^3, & x_a^A \le x \le x_e^A \\
R_3^A(x) &= \frac{b_0^A - b_1^A x}{(1-x)^{\beta^A}} + b_2^A\,(x - x_e)^2\,, & x_e^A \le x \le 1.
\end{aligned}
$$

PRECISION QCD AT THE LHeC

References:

J. Dainton et al., *Deep Inelastic Electron-Nucleon Scattering at the LHC*, JINST 1 10001

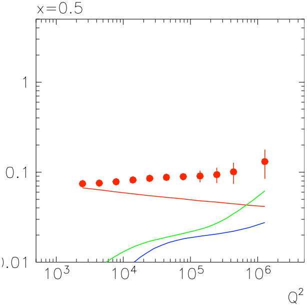
Precision QCD at the LHeC

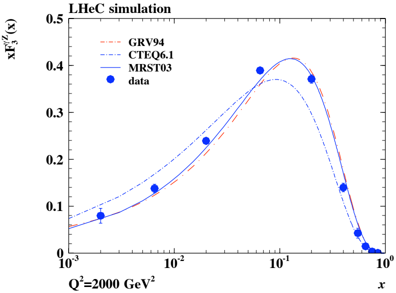


Constraining proton structure at LHeC

LHeC (+ final HERA data), → unprecedent improvement on proton structure determination

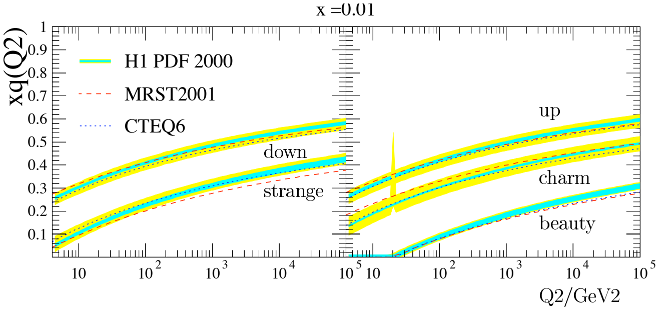
- Precision measurements of NC/CC with large electroweak contributions
- $F_2^{\gamma Z}$ → Antiquark sea asymmetry $(= 2x\left[a_u e_u(U - barU) + a_d e_d(D - \bar{D}\right]$
- u/d ratio at large-x
- Gluon and quark sea down to $x = 10^{-6}$





Constraining proton structure at LHeC

- Measurement of heavy flavor SFs, $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ → Important constraints on PDF analysis → Sizable impact on LHC phenomenology (σ_W up by 7% from CTEQ6.1 to CTEQ6.5)
- LHeC potential for very precision heavy flavour measurements



LHeC/LHC interplay

- Accurate determination of PDFs at LHeC could improve the new physics measurements and precision studies at the LHC
- Example I: more accurate $g(x,Q^2)$ at small x at LHeC *to* more accurate $g(x,Q^2)$ at large x (momentum sum rule) $\rightarrow$ More accurate $d\sigma_{\rm jet}/dE_T$ at LHC (window to new physics) + better jet energy scale calibration
- Example II: more accurate $F_2^{c\bar{c}}$ at LHeC $\rightarrow$ More accurate $\sigma_{W^\pm}, \sigma_Z$ at LHC $\rightarrow$ Luminosity monitors at 1%?