Parton distributions and small-x physics at the Large Hadron Electron Collider

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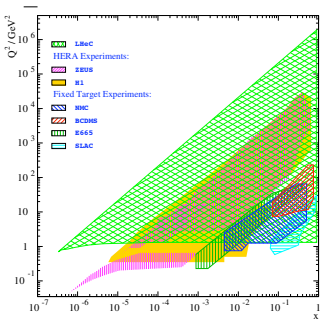
DIS 2009
Future Facilities Session
28/04/2009, Madrid



MOTIVATION

Proton PDFs and small-x effects at the LHEC

- The LHeC has the potential to constrain the proton (and nuclei) PDFs to an unprecedent level of accuracy, with important implications for LHC phenomenology
- The LHeC will also be sensitive to deviations from DGLAP evolution: small-x/BFKL resummation, non-linear QCD effects, saturation
- We report ongoing work on these issues within the NNPDF approach framework
- These studies will be part of the LHeC Conceptual Design Report

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Issues in standard PDF determinations

- Standard PDF determinations suffer of several drawbacks
  1. Fixed functional forms, $q_i(x, Q_0^2) = A_i x^{b_i}(1-x)^{c_i}(1+\ldots)$.
     Are they flexible enough?
  2. Artificially large tolerances $\Delta\chi^2 \gg 1$
     Are they really needed due to incompatible data?
  3. Gaussian linear error propagation
     Is this really enough for all observables?
- Summary $\longrightarrow$ Both the PDF input parametrization (and flavour assumptions) and the statistical treatment (value of $\Delta\chi^2$) need to be tuned to experimental data
- Situation not satisfactory, especially problematic to predict behaviour of PDFs in extrapolation regions like for the LHeC ...
- ... or when searching for non-standard DGLAP effects (saturation, small-x)
- Large tolerances $\longrightarrow$ Error blow-up by a factor $S = \sqrt{\Delta\chi^2/2.7}$
  $\longrightarrow S_{\rm cteq} \sim 6$, $S_{\rm mstw} \sim 4.5$ both in input data and in PDFs

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The NNPDF approach

- Generate $N_{\rm rep}$ Monte Carlo replicas $F_i^{({\rm art})(k)}$ of the original data $F_i^{({\rm exp})}$
  Avoid gaussian/linearized assumptions

$$F_i^{({\rm art})(k)} = \left(1 + r_N^{(k)}\sigma_N\right)\left(F_i^{({\rm exp})} + \sum_{p=1}^{N_{\rm sys}} r_p^{(k)}\sigma_{i,p} + r_i^{(k)}\sigma_{i,s}\right)$$

- Evolve each PDF parametrized with Neural Networks $\longrightarrow$ Unbiased parametrization

$$F_i^{({\rm net})({\rm k})}(x,Q^2) = C_{i\alpha}(x,\alpha(Q^2)) \otimes q_\alpha^{({\rm net})(k)}\left(x,Q^2\right)$$

- Minimization of χ^2 with Genetic Algorithms. + Dynamical Stopping:

$$\chi^{2(k)} = \frac{1}{N_{\rm dat}} \sum_{i,j=1}^{N_{\rm dat}} \left(F_i^{({\rm art})(k)} - F_i^{({\rm net})(k)}\right)\left({\rm cov}_{ij}^{-1}\right)\left(F_j^{({\rm art})(k)} - F_j^{({\rm net})(k)}\right)$$

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PDF CONSTRAINS FROM LHEC

LHeC Scenarios

Several scenarios for LHeC under investigation (M. Klein):

config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	|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 hiQ^2
C	50	7	p	1	1	0.4	1	30	1	RR lo x
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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
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PDF constraints from the LHeC - Small-x

Methodology:

- Generate predictions for $F_2(x, Q^2)$ and $F_L(x, Q^2)$ at small-x with NLO DGLAP and NNPDF1.0 as input PDF set for small-x LHeC kinematics

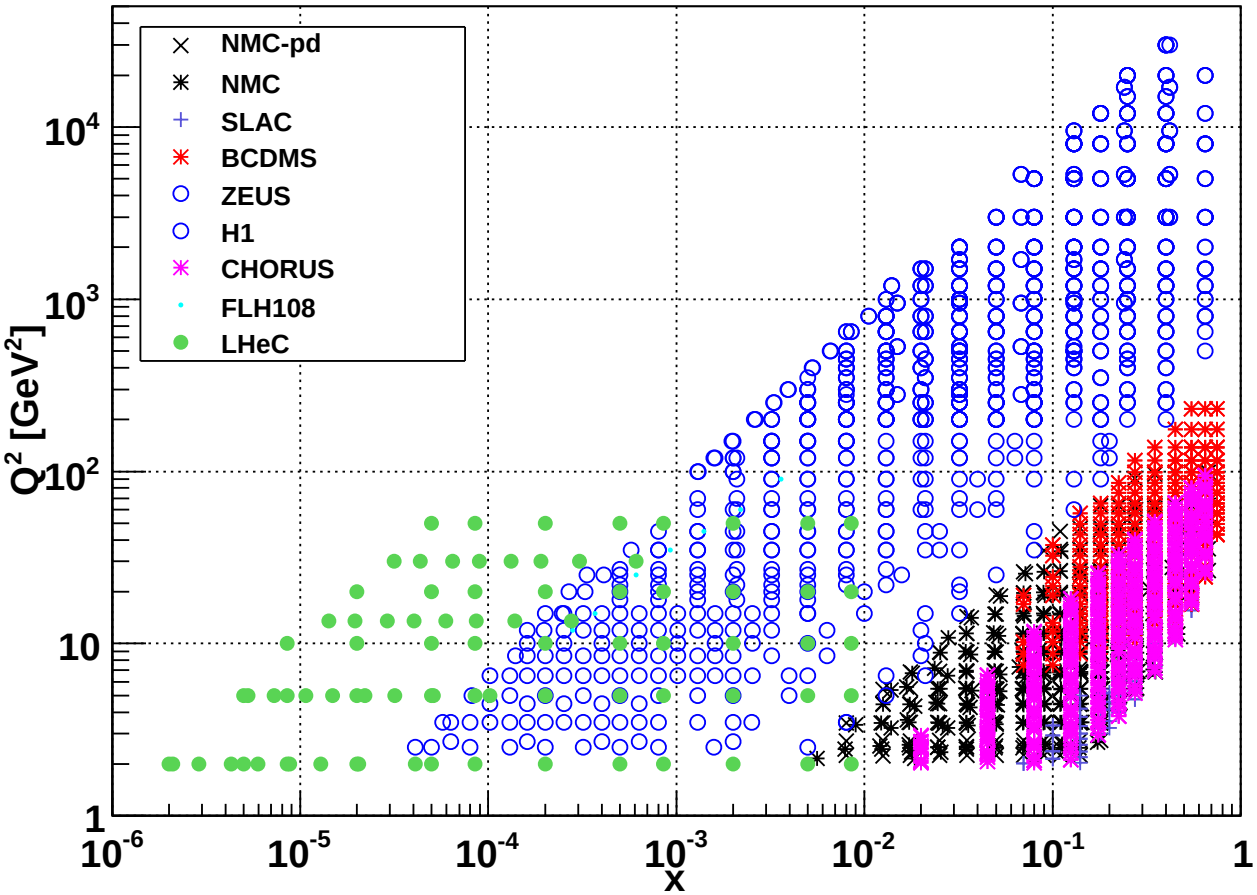
$$F_k(x, Q^2)\Big|_{\rm lhec} = F_k(x, Q^2)\Big|_{\rm nnpdf1.0} + r^{(l)}\sigma^{\rm tot}_{k,\rm lhec}$$

  accounting for statistical fluctuations

- Incorporate these pseudo-data sets into latest NNPDF release
- Investigate error reduction of PDFs at small-x
- Consider extreme DGLAP scenarios, *i.e.* generate pseudo data with NNPDF1.0 gluon $g^{\pm}(x, Q_0^2) \equiv \langle g(x, Q_0^2)\rangle \pm \sigma_g(x, Q_0^2)$.
  Can LHeC discriminate between *maximal* and *minimal* gluons?

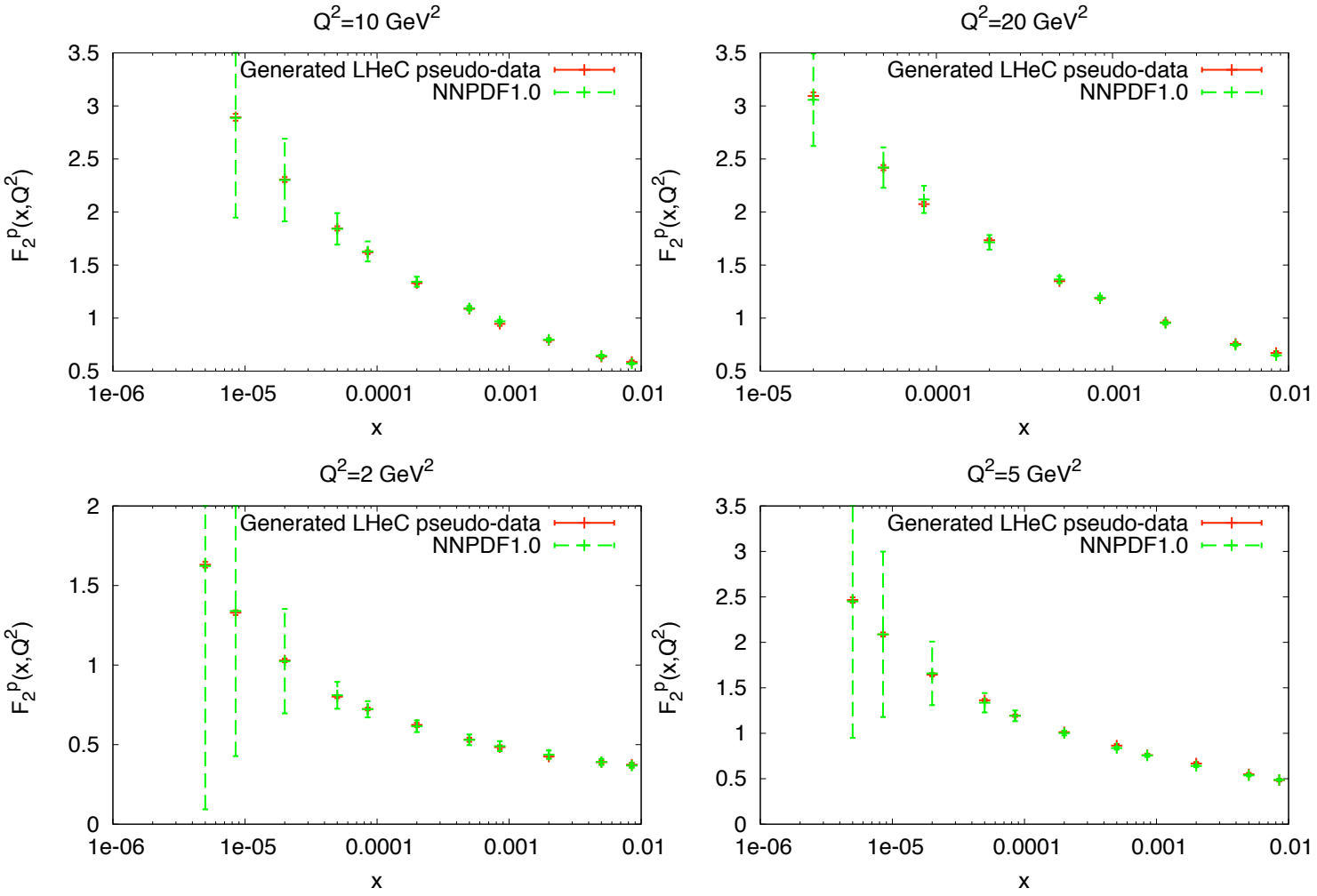
PDF constraints from the LHeC - Small-x

Consider LHeC F_2 and F_L pseudo-data at small-x (P. Newmann)
Scenario $\rightarrow$ $E_e = 70$ GeV, $\int \mathcal{L} = 1$ fb^{-1}, $\theta_e \leq 179^o$, $x \leq 0.01$, $Q^2 \leq 50$ GeV^2



Constraining PDFs at the LHeC - Results

Generated pseudo-data (including statistical fluctuations) for F_2 and F_L at small-x



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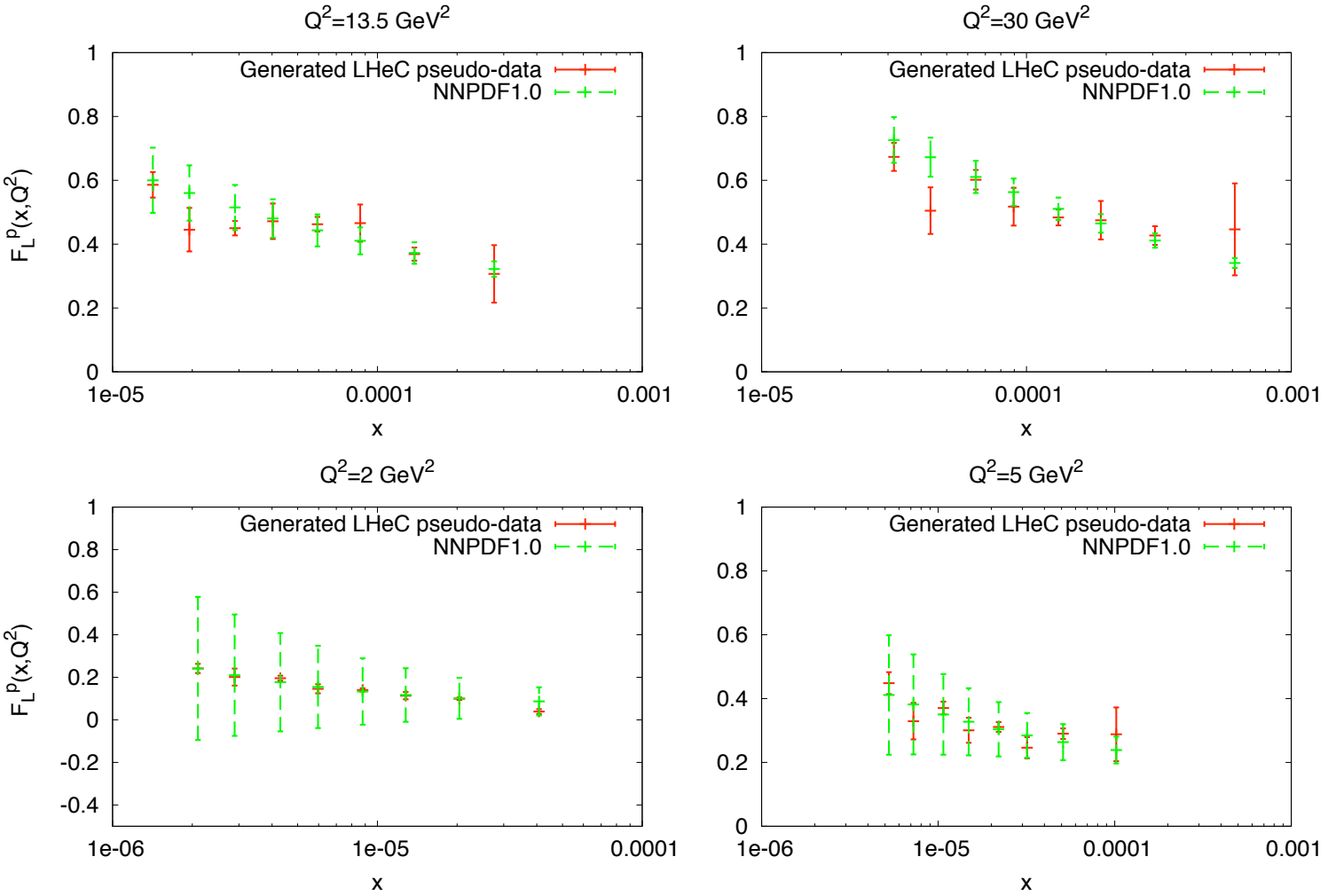
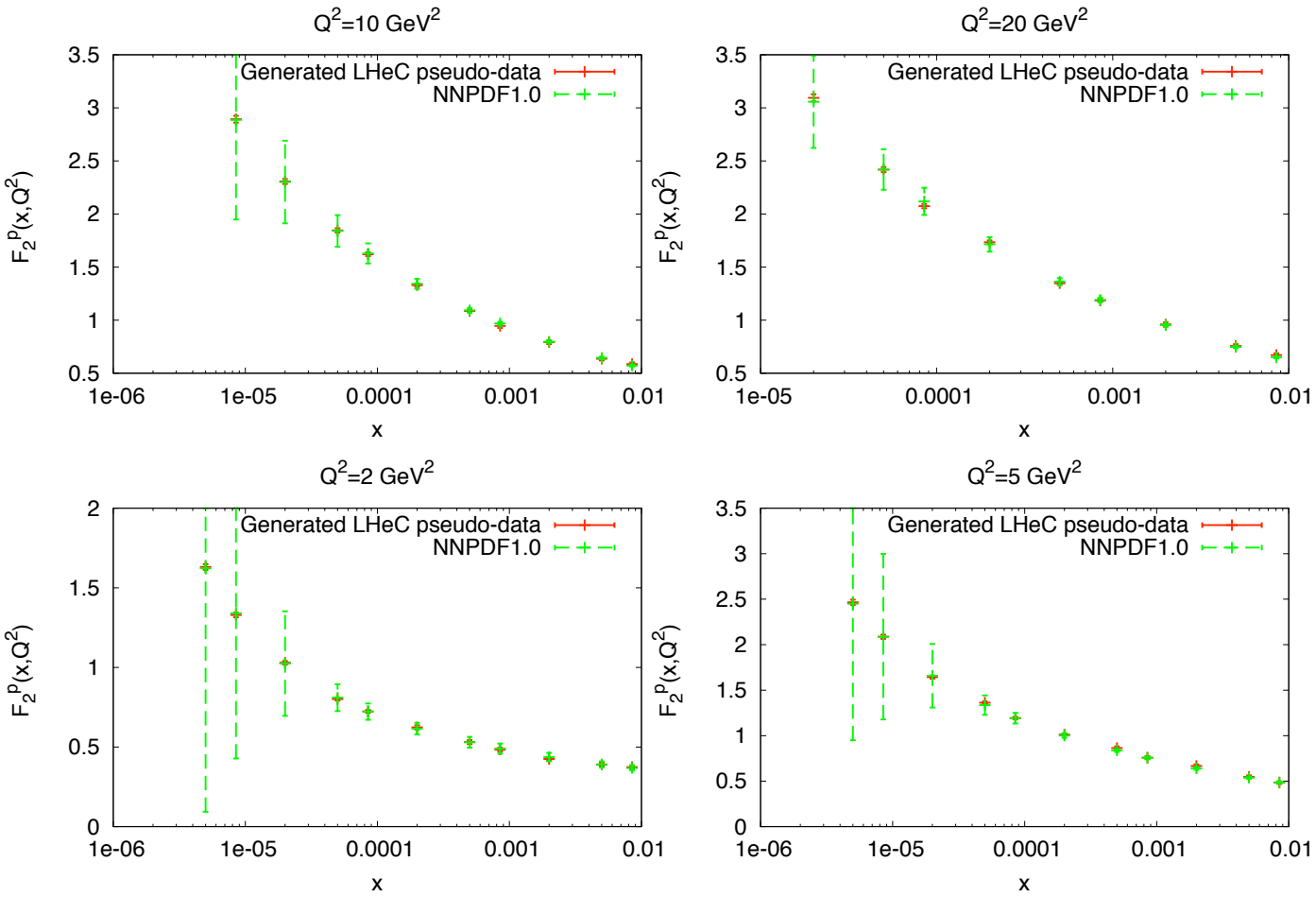


Constraining PDFs at the LHeC - Results

F_2^p and F_2^L NLO DGLAP in NNPDF analysis:

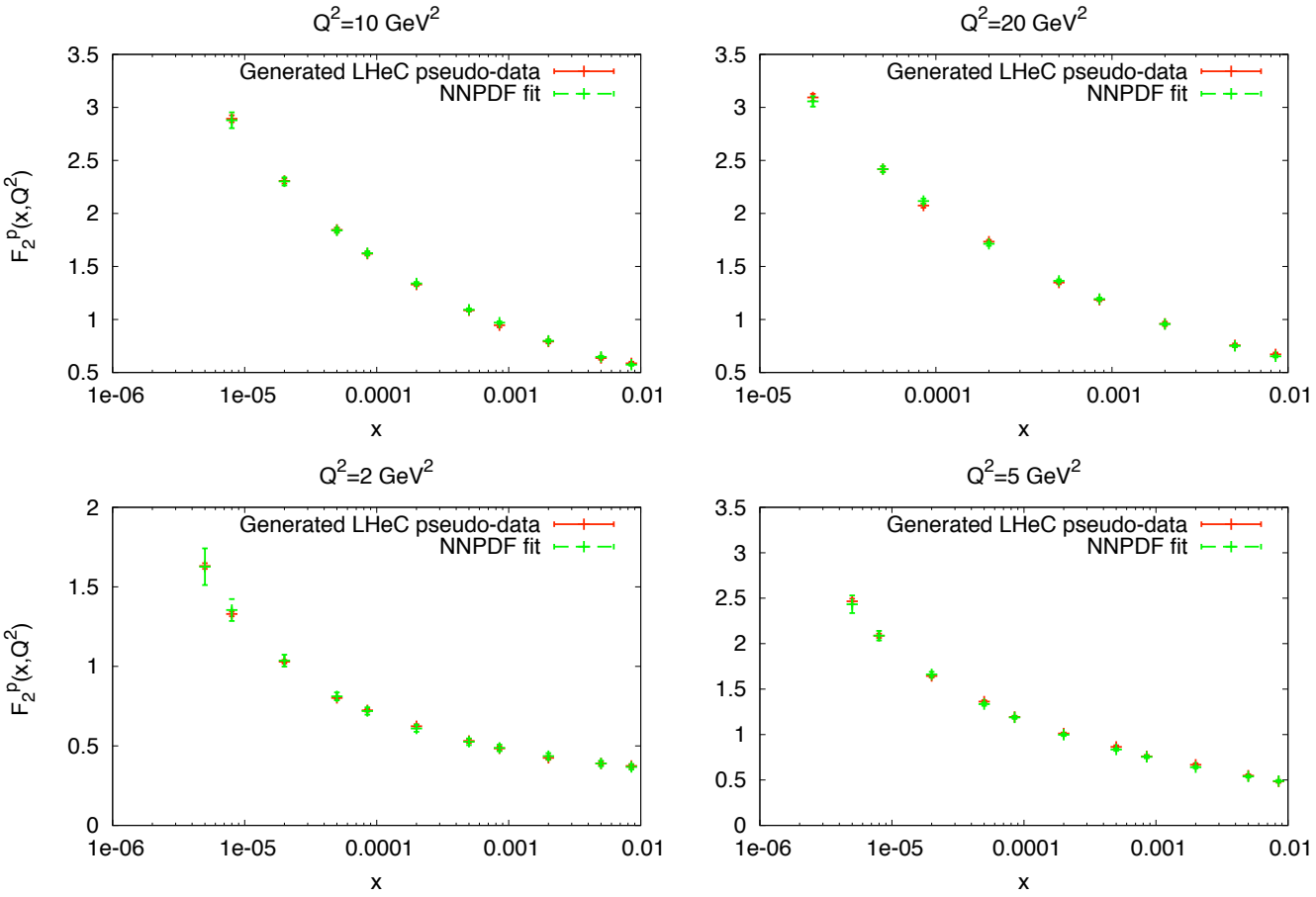
Before the fit ... (Notice small statistical errors at low$-x$)



Constraining PDFs at the LHeC - Results

F_2^p and F_2^L NLO DGLAP in NNPDF analysis:

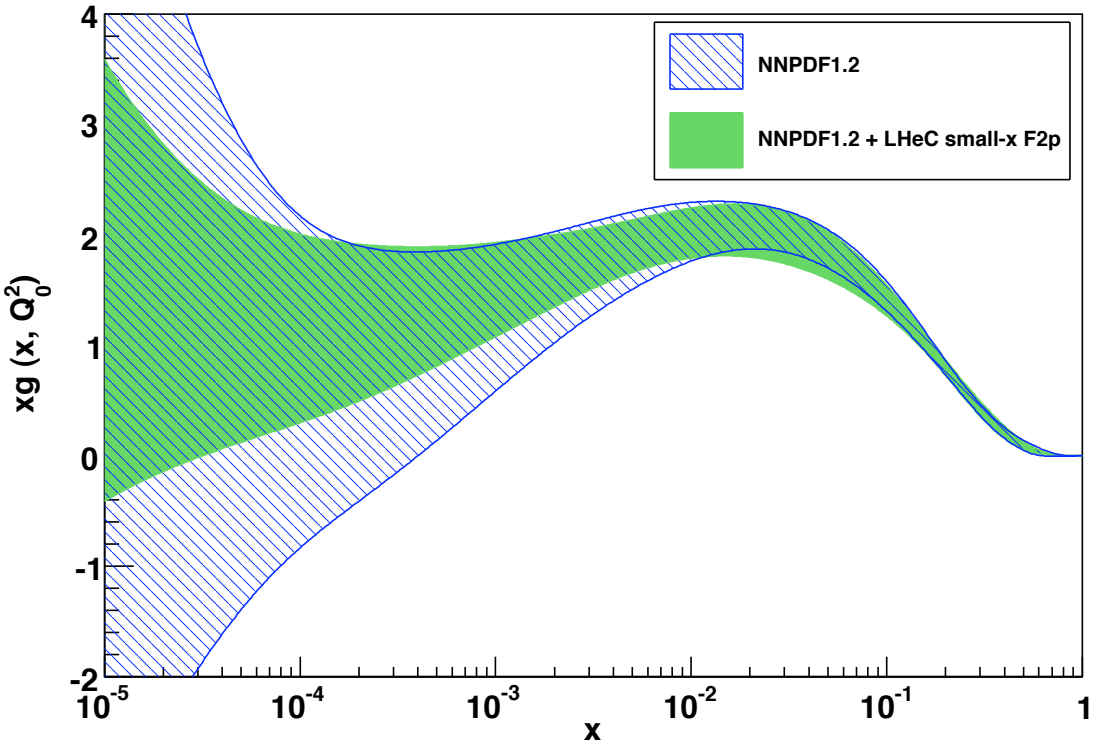
... and after the fit $\longrightarrow$ Huge error reduction in F_2^p predictions



Constraining PDFs at the LHeC - Results

F_2^p and F_2^L NLO DGLAP in NNPDF analysis:

Gluon uncertainties with F_2^p LHeC data only



Modest error reduction of gluon at small-x, need F_L for more

Constraining PDFs at the LHeC - Results

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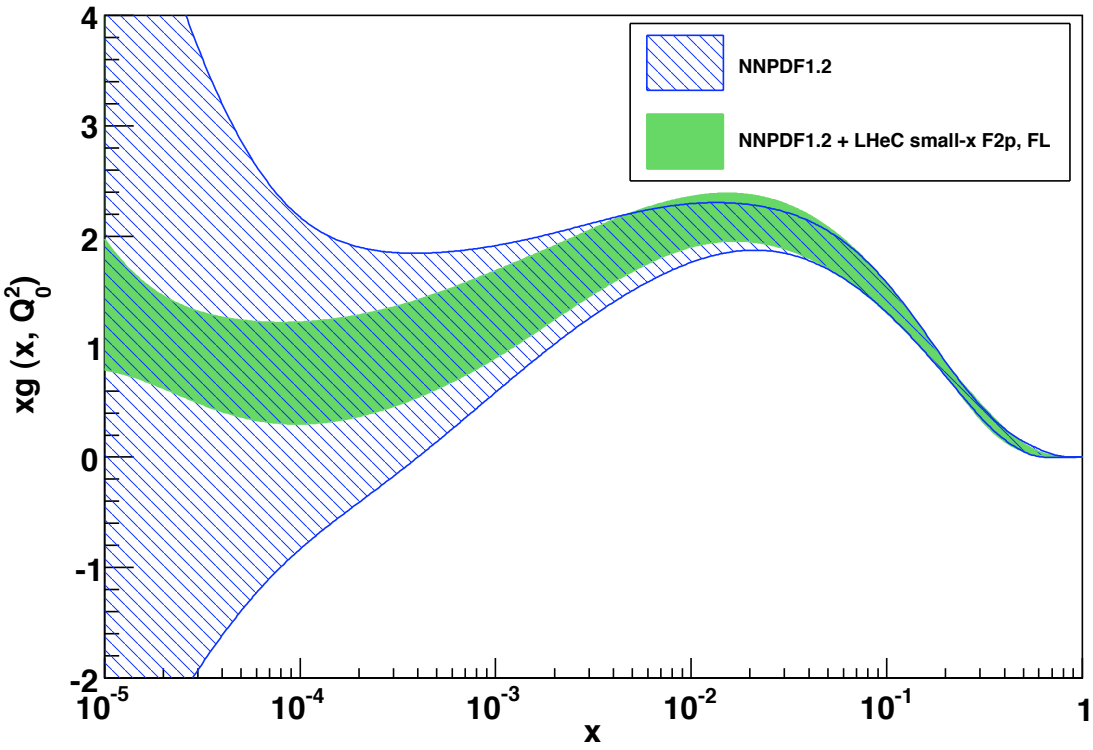
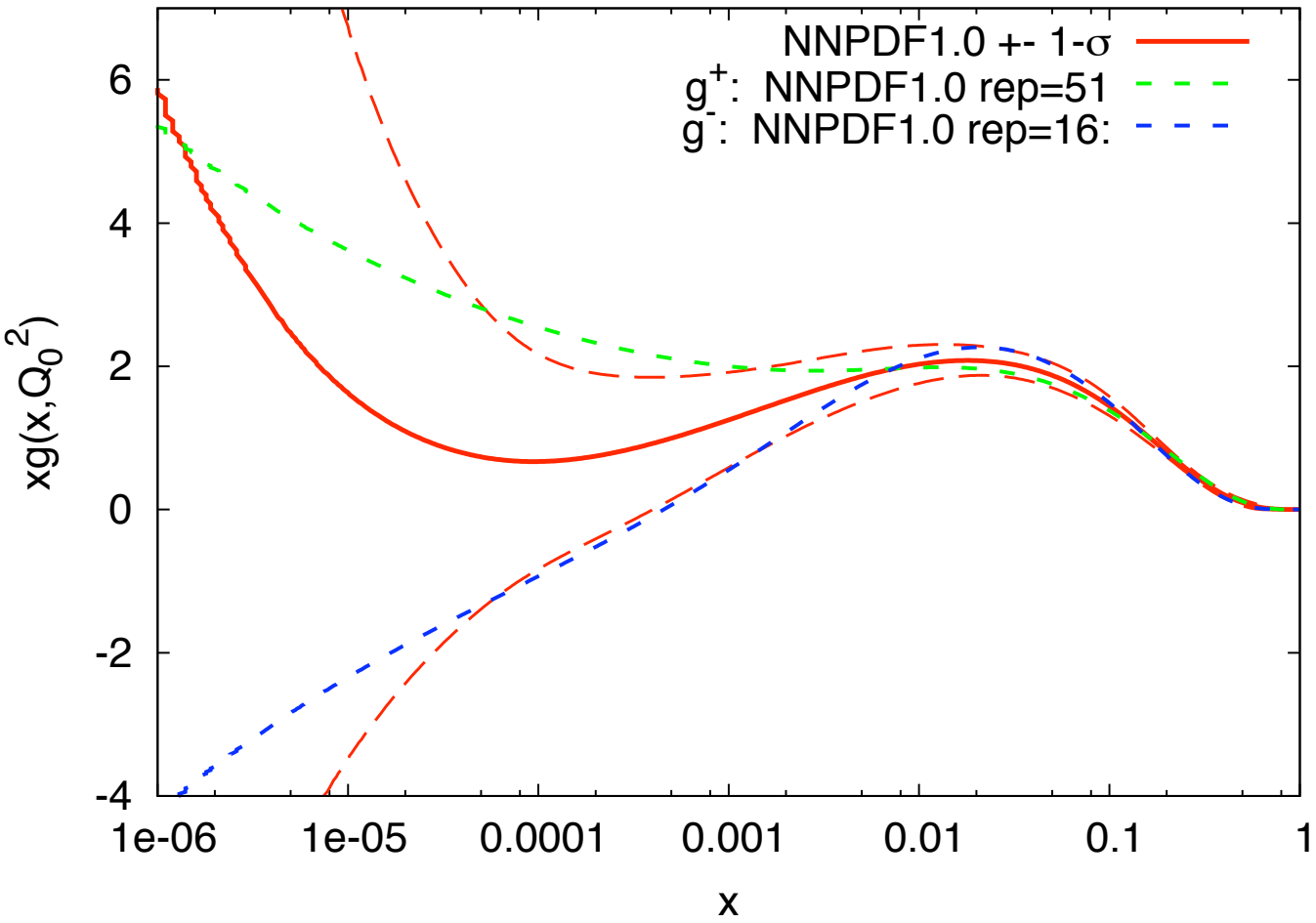
Gluon uncertainties with F_2^p and F_L^p LHeC data



$\longrightarrow$ Sizable error reduction of gluon at small-x requires LHeC F_L data

The small-x gluon at the LHeC

Can the LHeC disentangle between *extreme* DGLAP scenarios?
$\longrightarrow$ Generate LHeC pseudo-data based on two *extreme gluons* from NNPDF1.0



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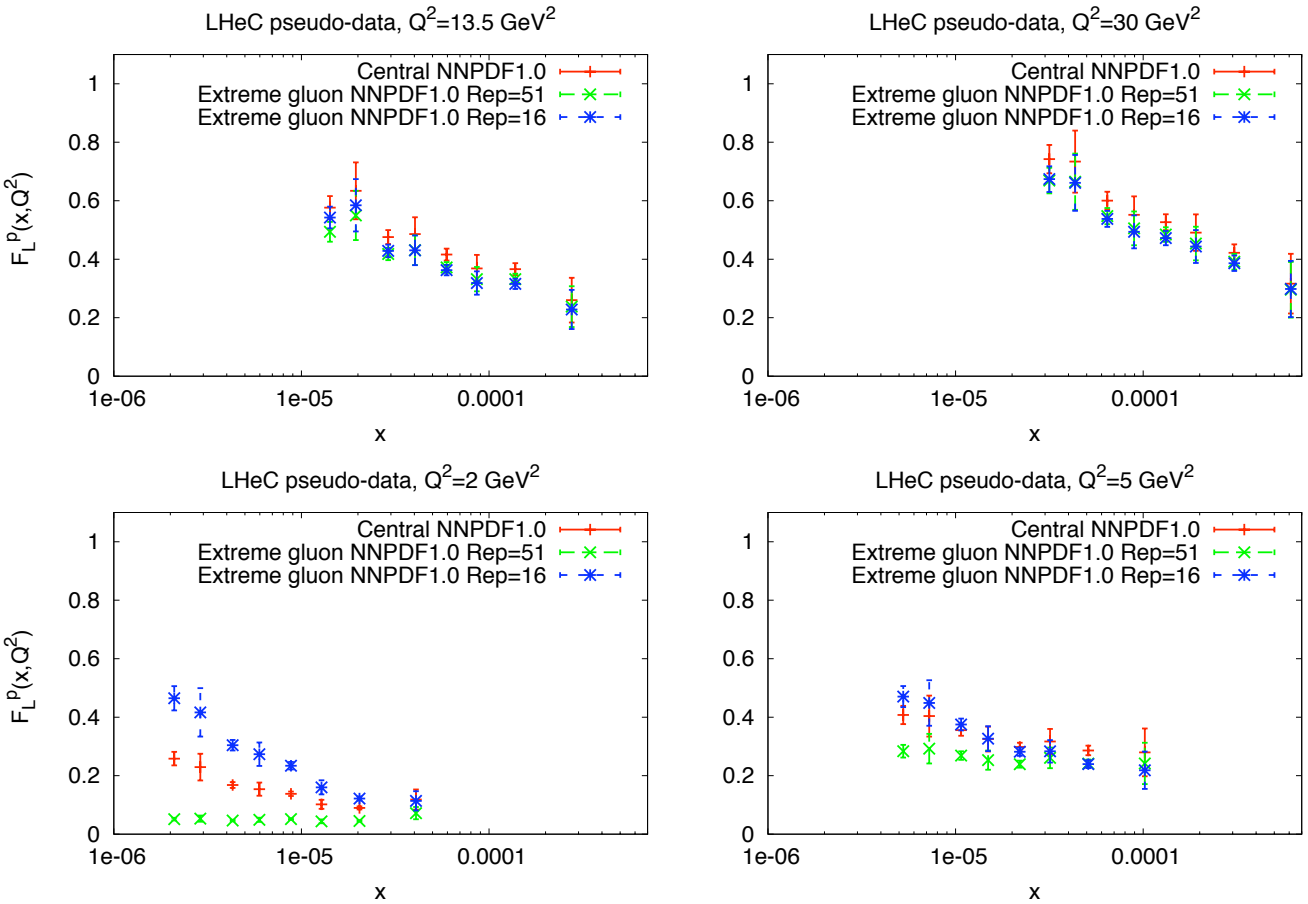
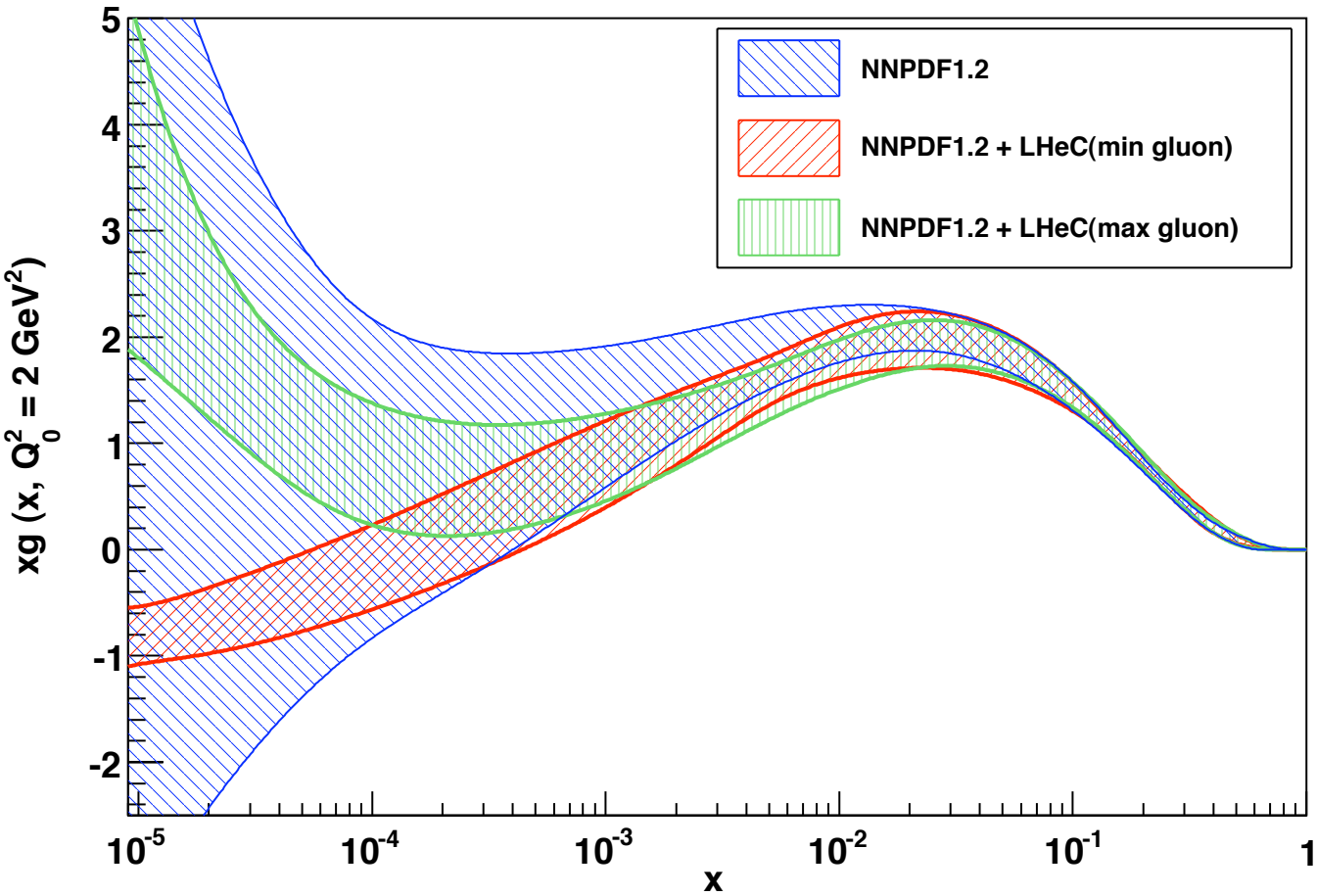
Extreme gluons affect mostly F_L at small-x



The small-x gluon at the LHeC

Small-x data can unambigously determine the low-x gluon behaviour with very precision
Next step $\longrightarrow$ Implications for LHC phenomenology



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LHeC Scenarios

Assume **scenario E:** Linac-Ring option $E_e = 150 GeV$

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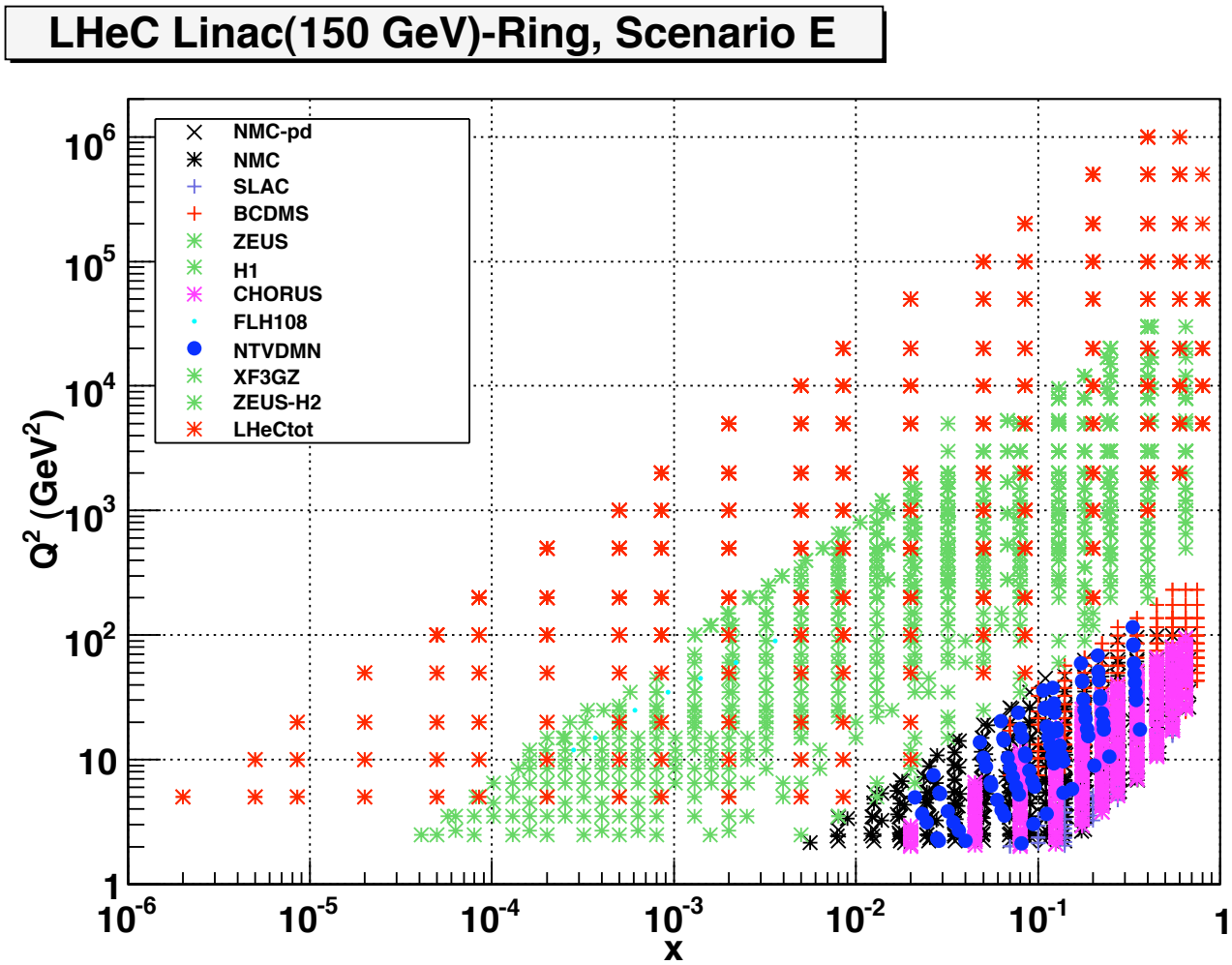
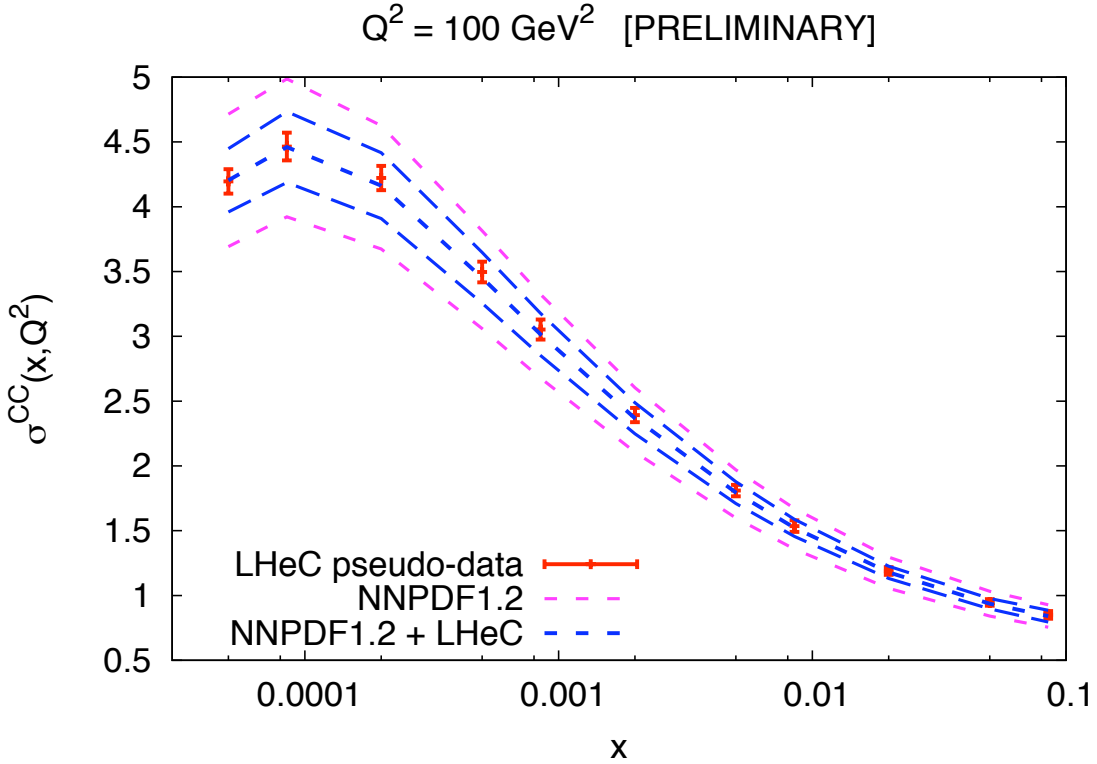
Constraining PDFs at the LHeC - Full kinematics

Methodology → Same as for the small-x data, but now full NC and CC datasets included



Constraining PDFs at the LHeC - Full kinematics

LHeC will provide accurate CC data up to low-x
Precise quark flavour separation possible within a single experiment



Work in progress with pseudo-data in other scenarios

SMALL-X QCD AT THE LHEC

Small-x QCD at the LHeC

- Proceed as for the DGLAP case, but now take central predictions for $F_2(x, Q^2)$ and $F_L(x, Q^2)$ at small-x from dipole/saturation models
  1. FS04 - Dipole model (Forshaw and Shaw, JHEP 0412:052,2004)
  2. AAMS09 - Model based on BK equation with running coupling effects (Albacete et al., arXiv:0902.1112)
- Added these pseudo-data sets into current NNPDF analysis
- Investigate if a DGLAP analysis finds evidence from deviations from standard evolution $\rightarrow$ Value of χ^2, data inconsistency ... $\rightarrow$ Disentangling non-standard effects in inclusive data requires special techniques
- DGLAP with small-x BFKL resummed results for DIS structure funtions recently available (ABF, Altarelli at al., NPB799:199-240,2008) $\rightarrow$ Determine their impact for LHeC physics (see my talk this afternoon in the PDF session)

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Small-x QCD at the LHeC

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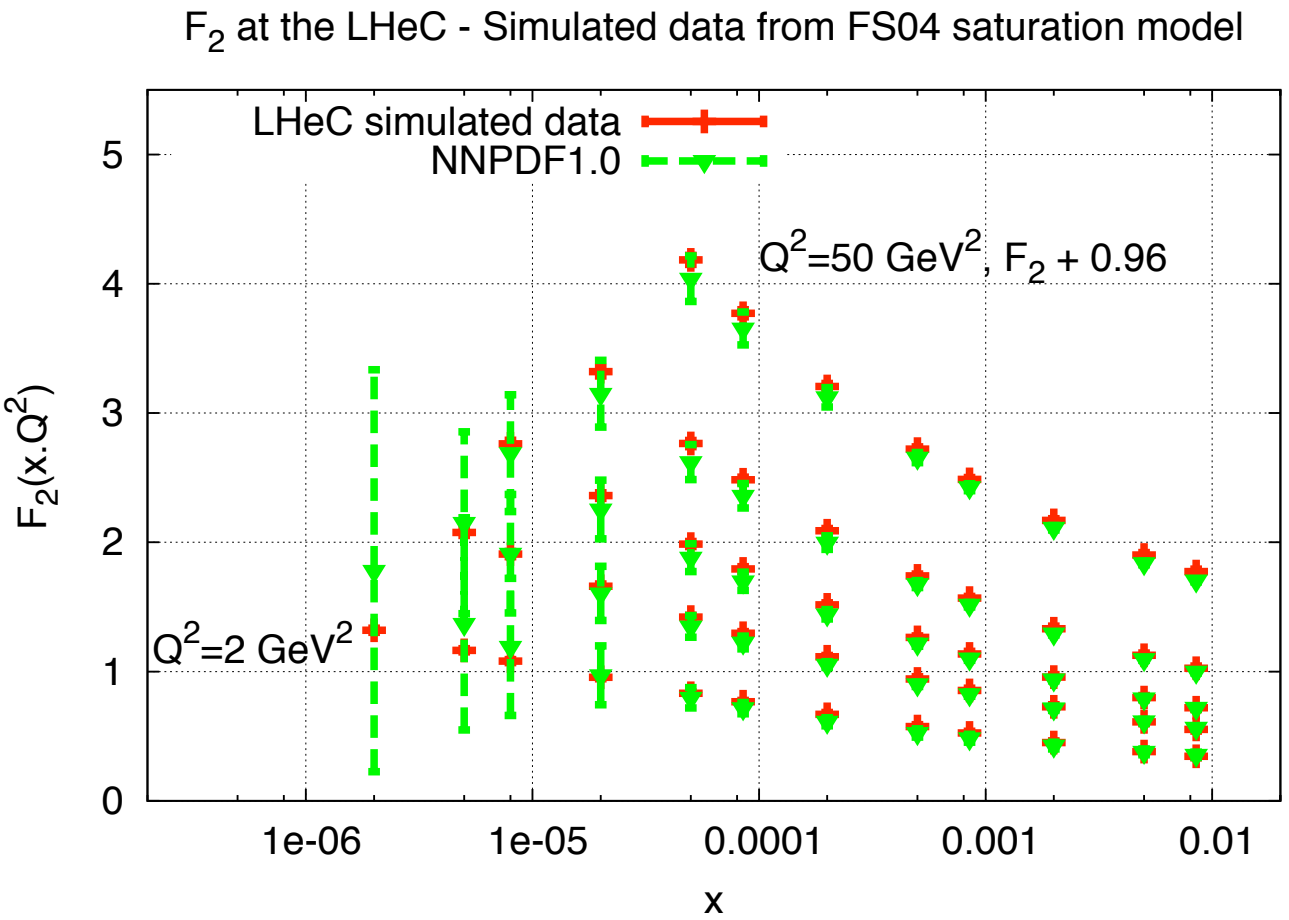
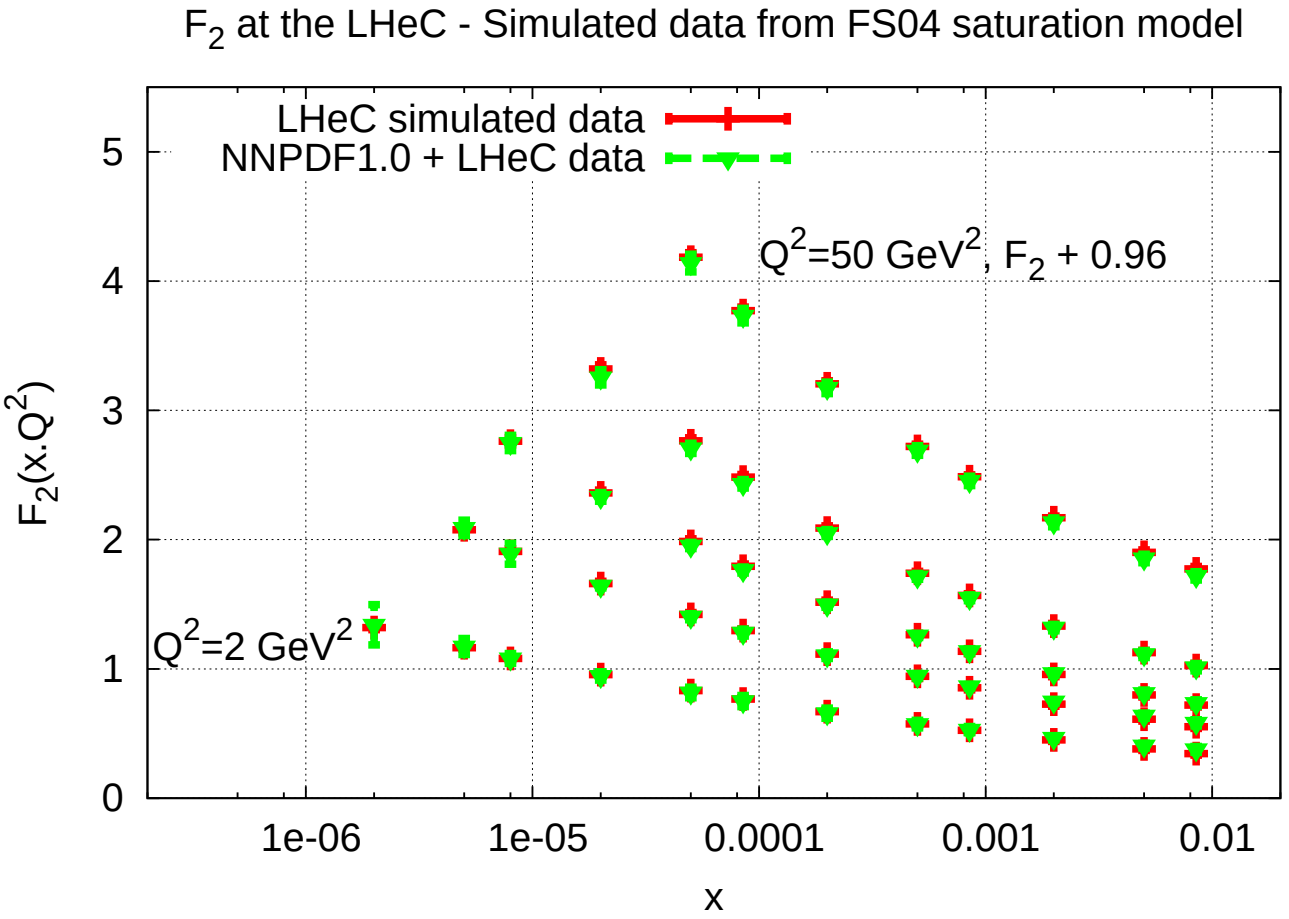
Small-x models at the LHeC

Comparison between NNPDF1.0 and FS04 pseudo-data for $F_2(x, Q^2)$ before the fit ....



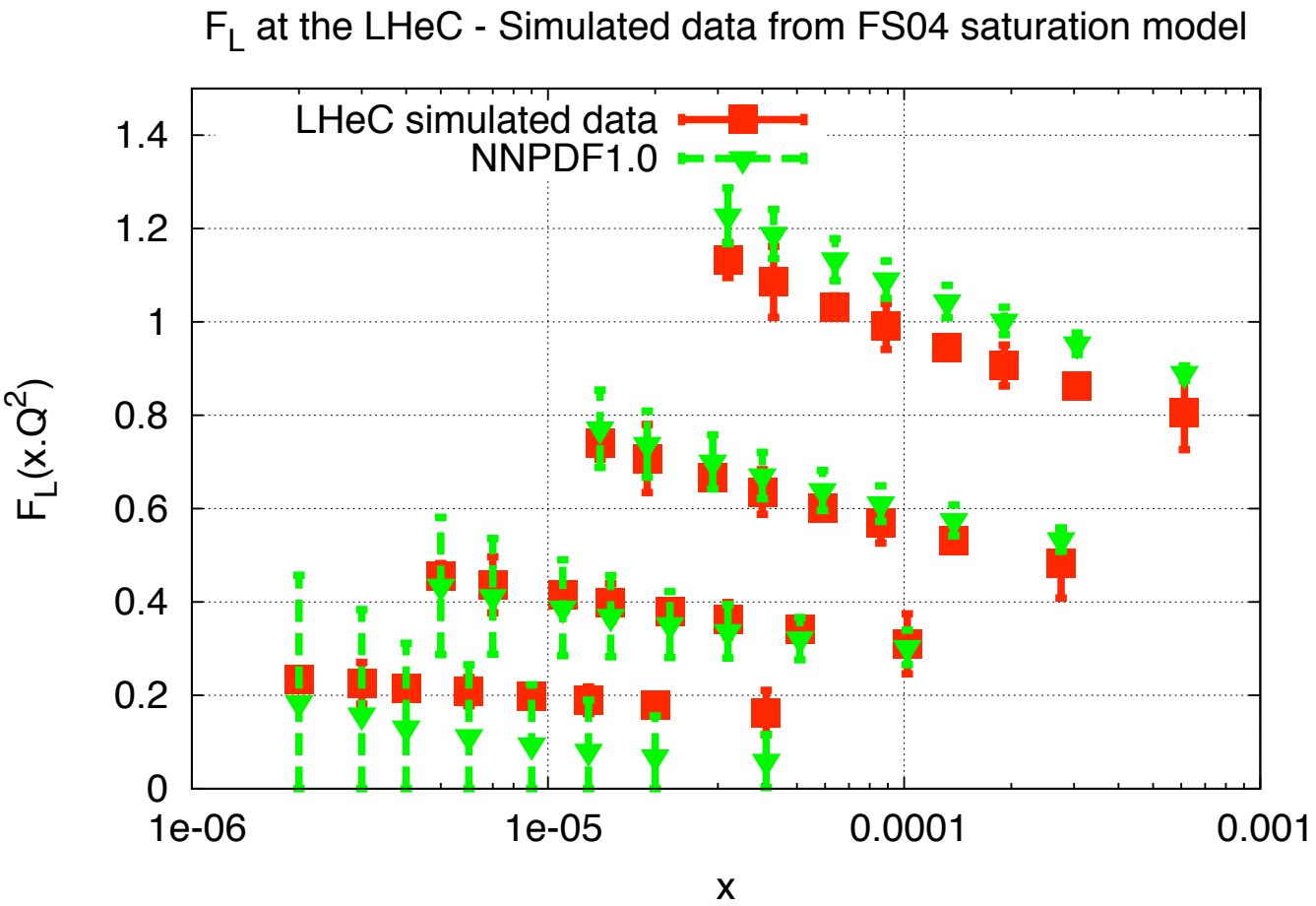
Small-x models at the LHeC

.... and after the fit



Small-x models at the LHeC

Comparison between NNPDF1.0 and FS04 pseudo-data for $F_L(x, Q^2)$ before the fit ....



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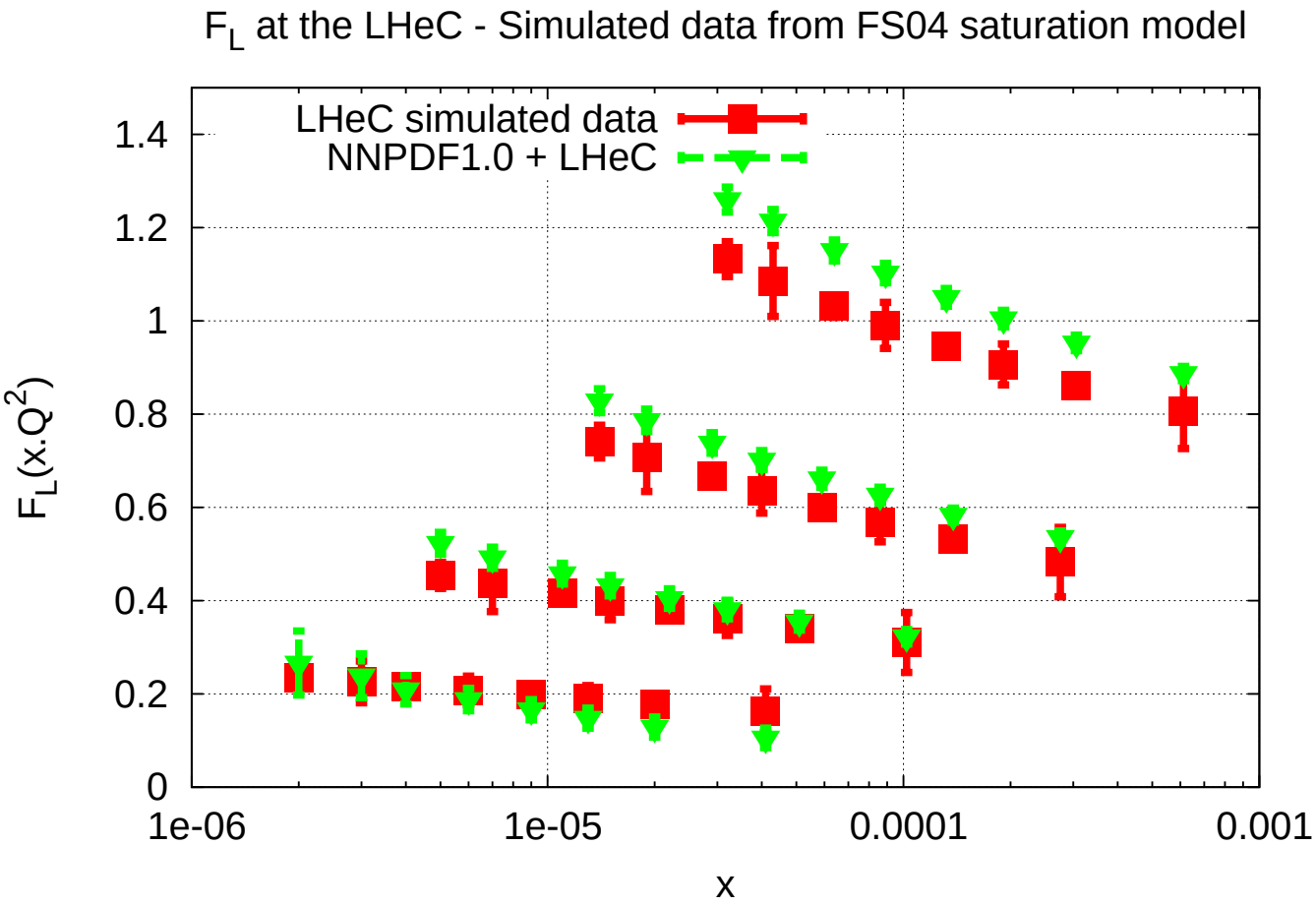

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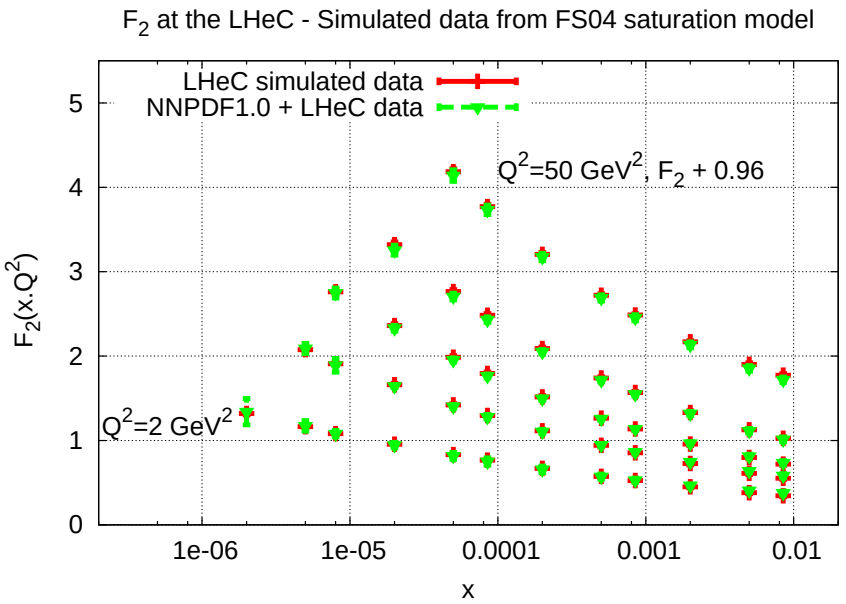
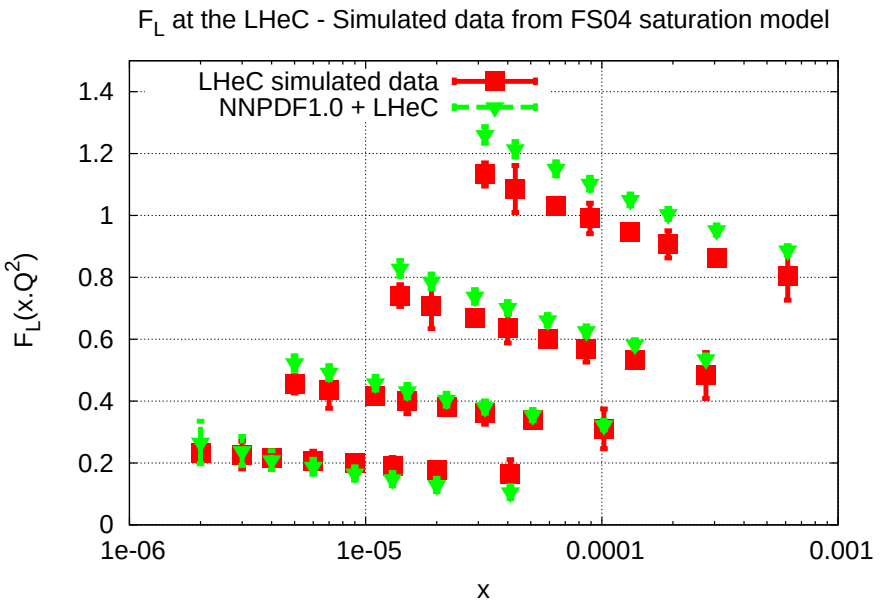
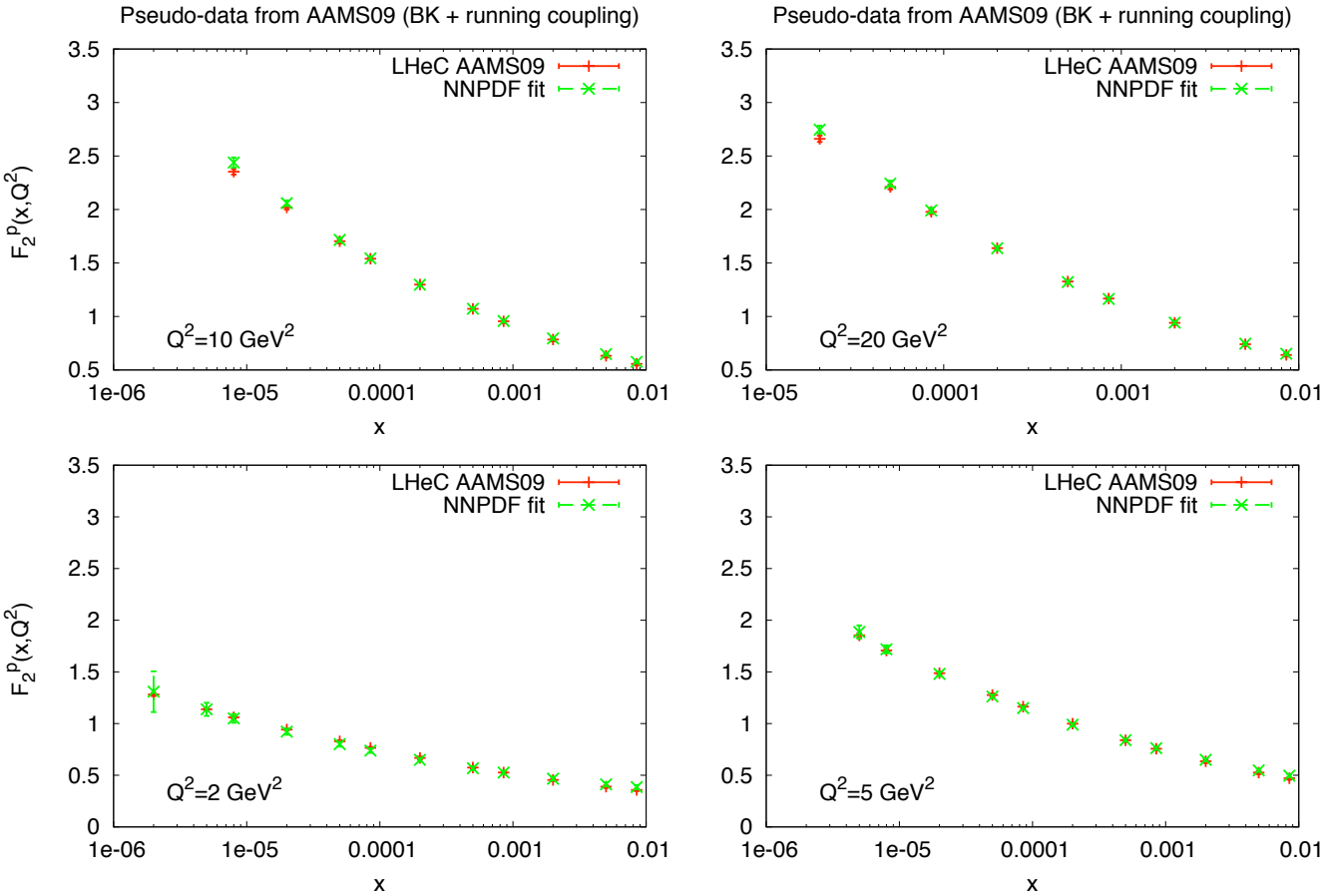




- F_2 alone not enough discrimination power (at least with the *Hypothesis Testing Criterion*)
- F_L measurements vital to disentangle between scenarios $\rightarrow$ But precise data with large lever arm in Q^2 required

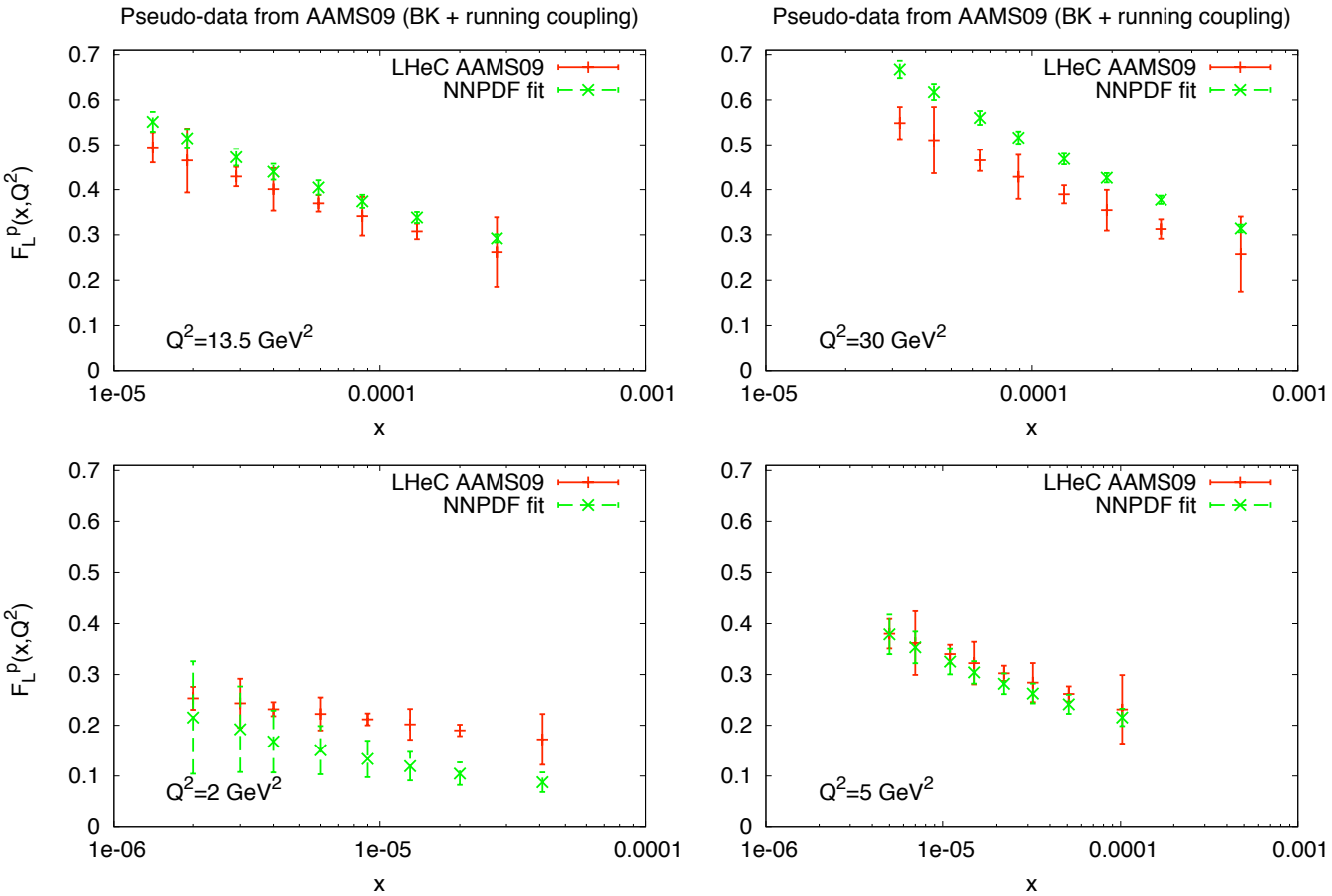
Small-x models at the LHeC

Same for AAMS09 (BK equation with running coupling) $\longrightarrow$ For F_2 alone:



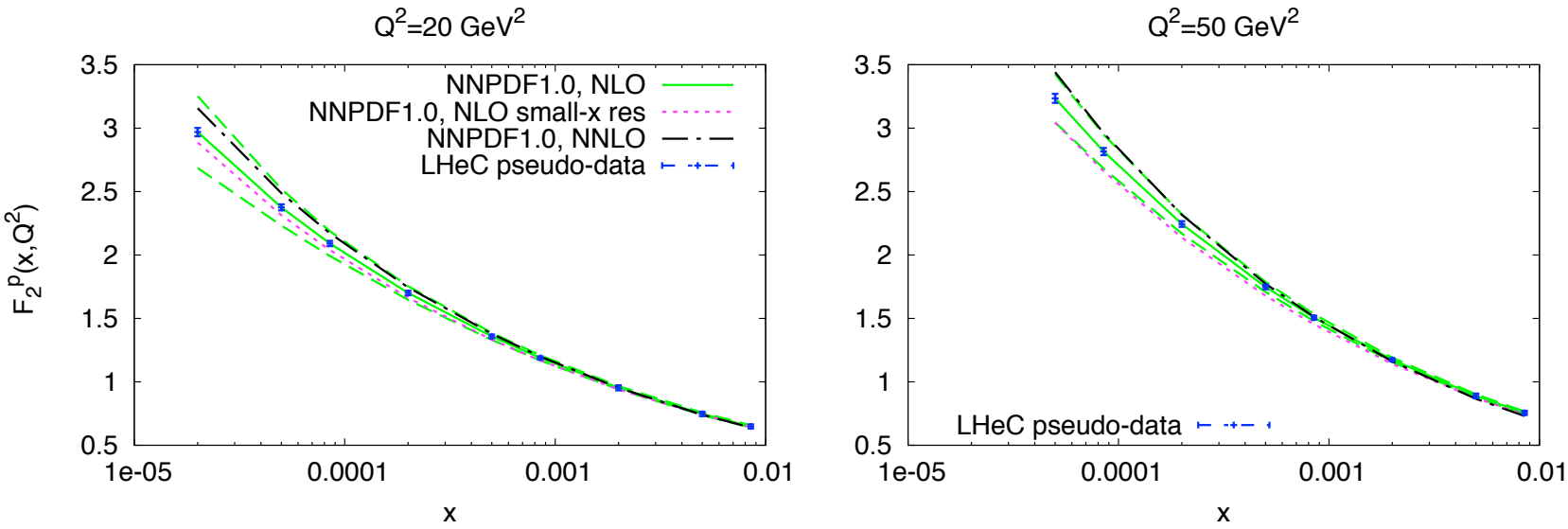
Small-x models at the LHeC

Same for AAMS09 (BK equation with running coupling) $\longrightarrow$ For joint $F_2 + F_L$ fit:



Small-x resummation

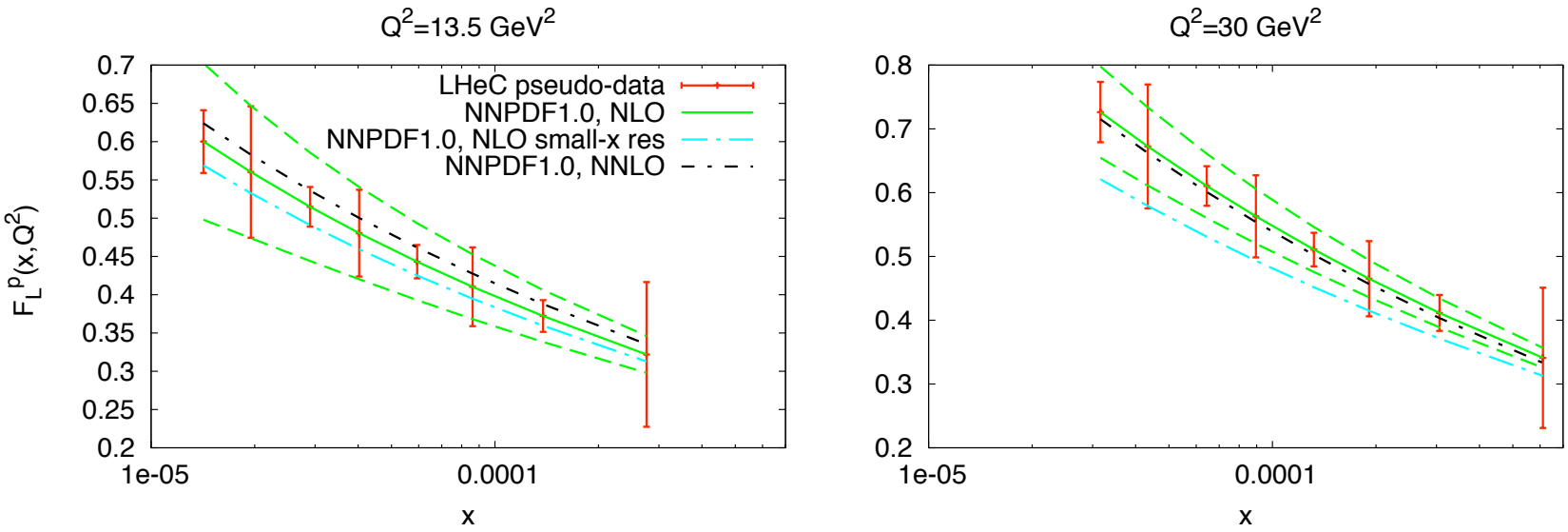
Compare predictions at LHeC from NLO, NNLO and NLO+small-x resummation (ABF) in NNPDF1.0 for $F_2(x, Q^2)$



Experimental LHeC uncertainties smaller than spread between small-x QCD scenarios (NNLO vs. NLOres)

Small-x resummation

Compare predictions at LHeC from NLO, NNLO and NLO+small-x resummation (ABF) in NNPDF1.0 for $F_L(x, Q^2)$



The LHeC has the potential to disentangle between different scenarios for small-x pQCD
$\rightarrow$ But this requires a fully small-x resummed global PDF analysis!

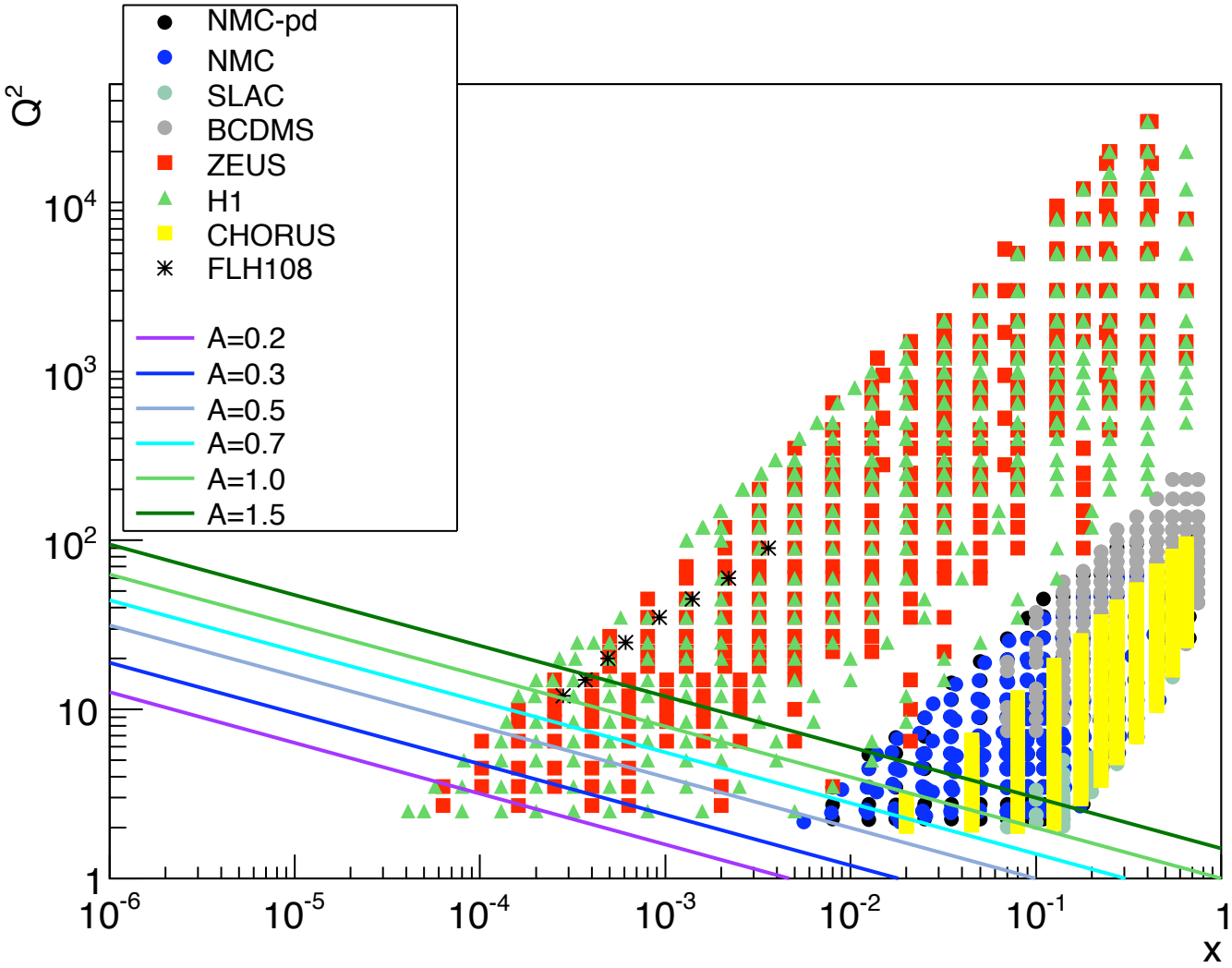
Deviations from DGLAP in inclusive observables

- BFKL/non-linear effects are difficult to identify in inclusive observables since they can be absorved in the initial condition for flexible enough parametrizations
- This might be the case at HERA, also at the LHeC for F_2^p
- New statistical approaches required
  A possible approach is the following: (Caola, Forte, Rojo, in progress)
  1. Repeat PDF analysis removing subsets of data (Reference analysis NNPDF1.2)
  2. Determine if NLO DGLAP extrapolation predicts excluded subsets
  3. Assess fit quality in fitted data region $\rightarrow$ Should improve if there is *tension* between DGLAP and other scenarios

  Note that a PDF analysis with no parametrization bias and faithful uncertainty estimation is mandatory in such analysis

Deviations from DGLAP in inclusive observables

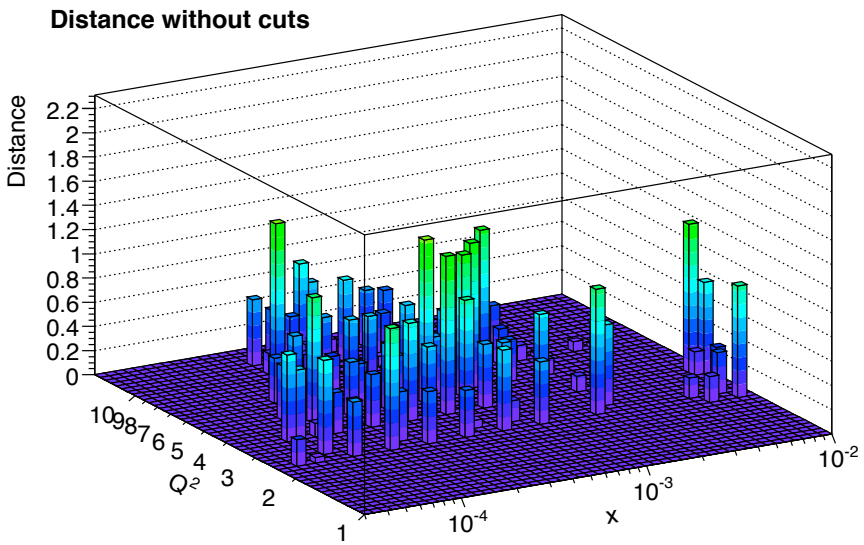
Kinematical cuts for $Q^2 \geq Q_S^2(x) \equiv A \cdot x^{-0.3}$ GeV^2 (saturation-inspired)

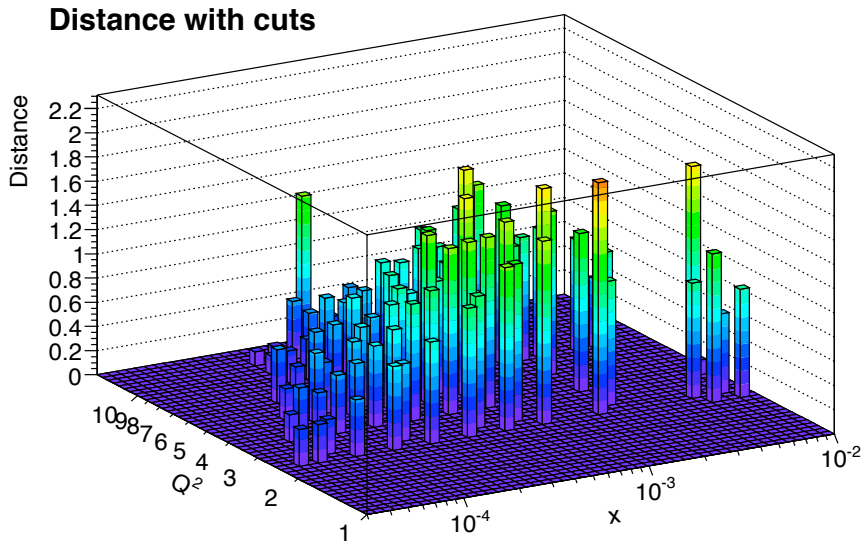


Deviations from DGLAP in inclusive observables

Compare distances for points excluded in DGLAP analysis $Q^2 \geq 1.5 \cdot x^{-0.3}$ GeV^2

$$d(x,Q^2) \equiv \sqrt{\frac{\left(F^{\rm net}(x,Q^2) - F^{\rm dat}(x,Q^2)\right)^2}{\sigma^{\rm net,2} + \sigma^{\rm dat,2}_{tot}}}$$





Distances worsen in region of *larger* Q^2, x

$\longrightarrow$ Hints of BFKL resummation/non-linear effects present in HERA data?

OUTLOOK

PDFs and low-x at LHeC: Outlook

- The LHeC will probe the structure of the proton and QCD dynamics at the smallest-x even considered
- Low-x inclusive measurents severely constrain the low-x gluon, while precision NC and CC data allows quark flavour separation within a single experiment
- F_L measurents mandatory both to pin down the gluon PDF at small-x and to disentangle small-x QCD scenarios
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- ToDo: Comparison between various LHeC scenarios, implications for LHC phenomenology, resummed small-x PDF analysis ....

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