PDFs at the HL-LHC and LHeC

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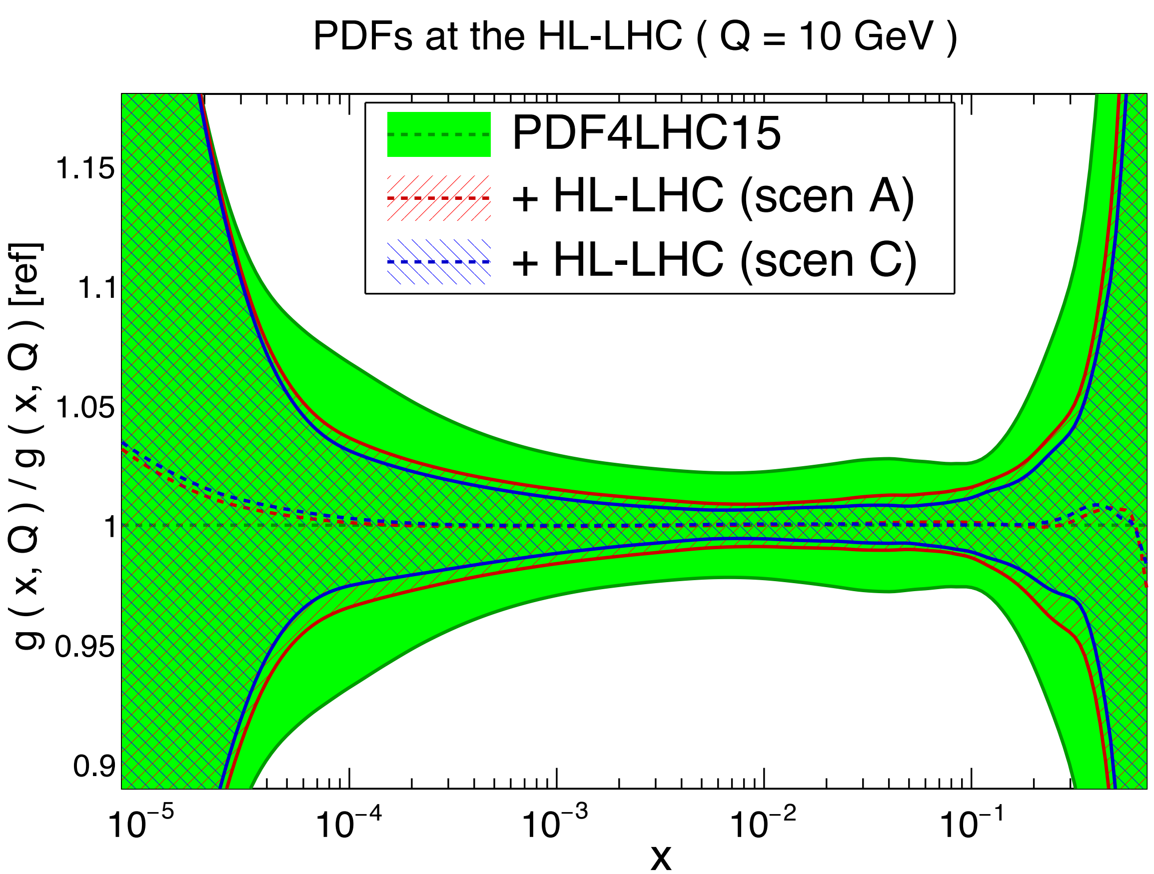
Electrons for the LHC, Chavannes de Bogis, 24 October 2019

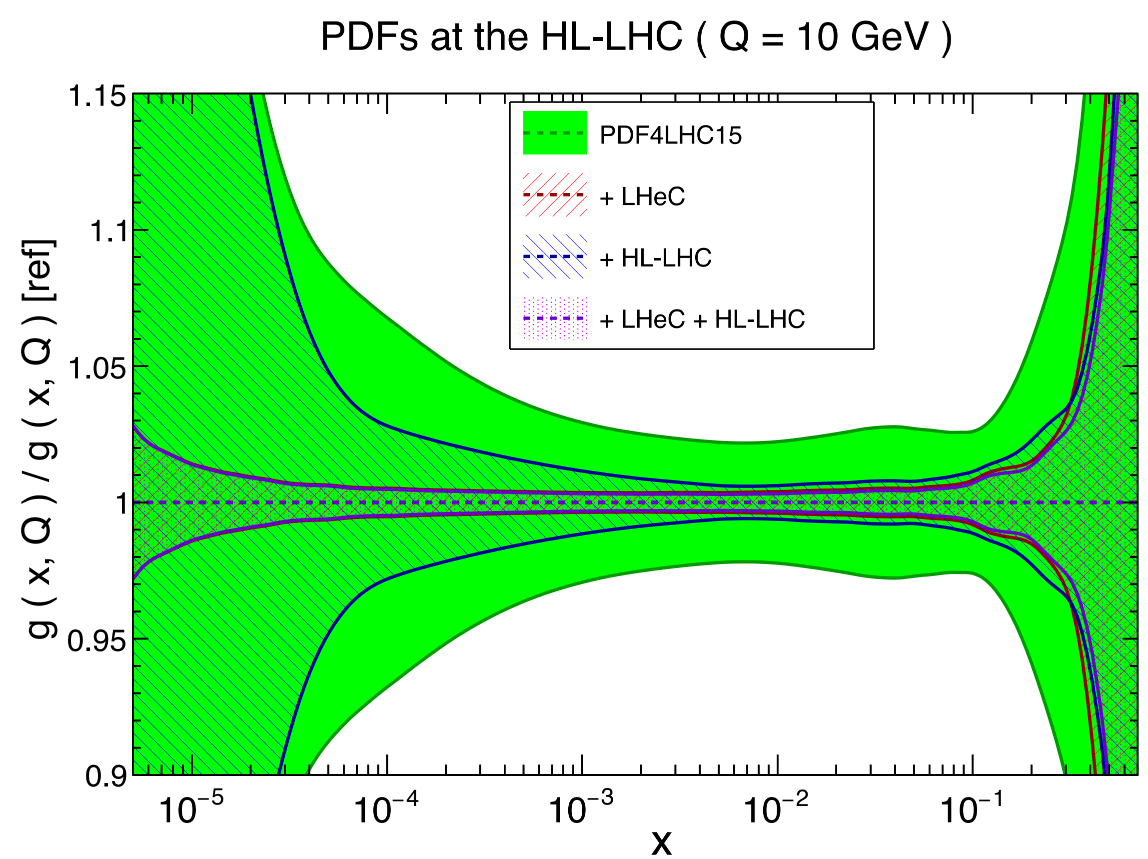
In collaboration with Rabah Abdul-Khalek, Shaun Bailey, Jun Gao and Juan Rojo

Motivation/Approach

- Earlier study: projected PDF sensitivity of final **HL-LHC** dataset.
- Based on profiling of **PDF4LHC** baseline set: 'global' PDF fit.
- This approach now extended to assess expected impact of **LHeC**



R. Abdul Khalek, S. Bailey, J. Gao, LHL, J. Rojo. Eur.Phys.J. C78 (2018) no.11, 962



R. Abdul Khalek, S. Bailey, J. Gao, LHL, J. Rojo. SciPost Phys. 7, 051 (2019)

In More Detail…

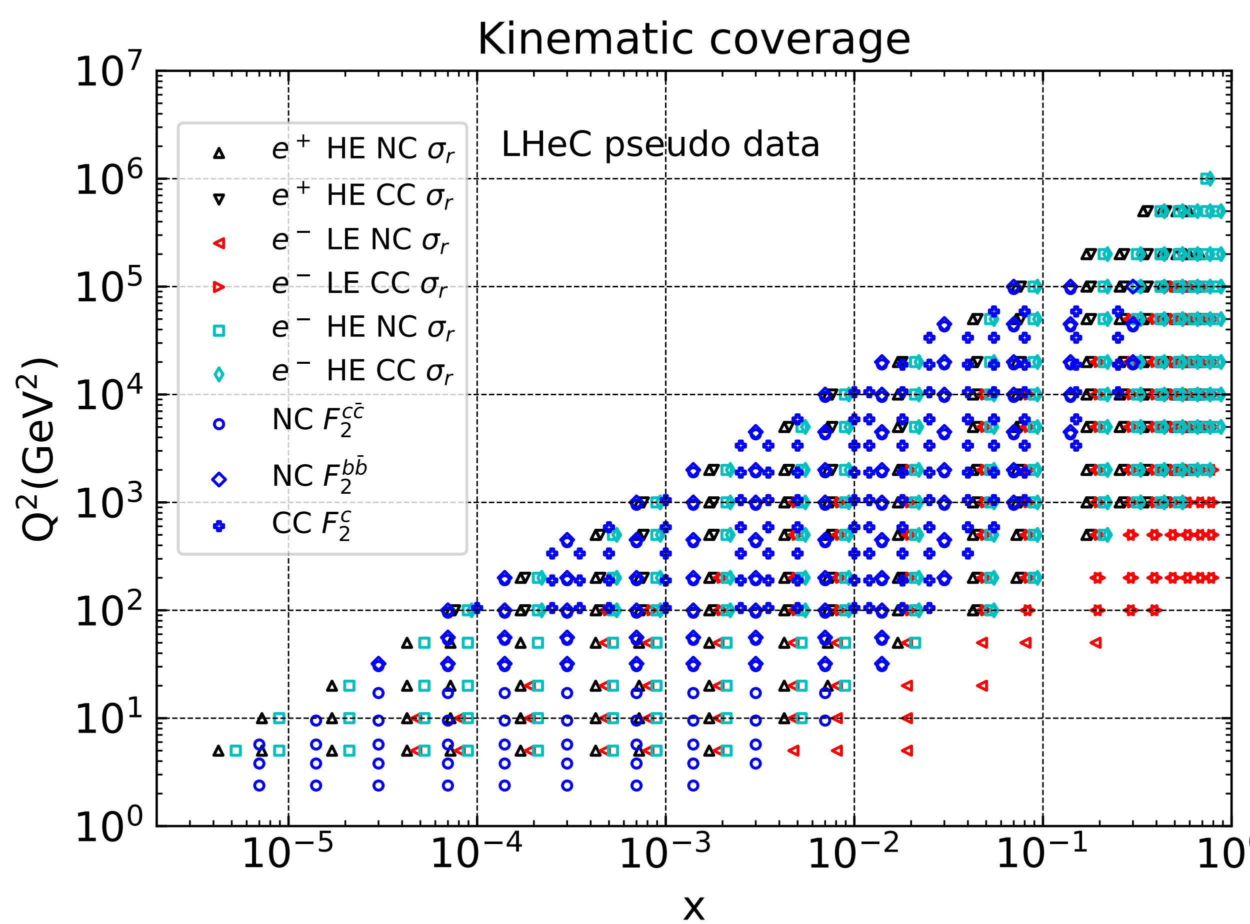
http://hep.ph.liv.ac.uk/~mklein/lhecdata/

- **LHeC dataset**: inclusive NC and CC in e^+/e^- + different energies (1,7 TeV), heavy flavour and charm quark production via CC.
- Baseline set (errors pre LHeC): PDF4LHC combination of CT14, MMHT14 and NNPDF3.0 global sets. 'Tolerance' $T \approx 3$ accounts for departure from textbook stats, tensions between datasets…
- From this, different possibilities:

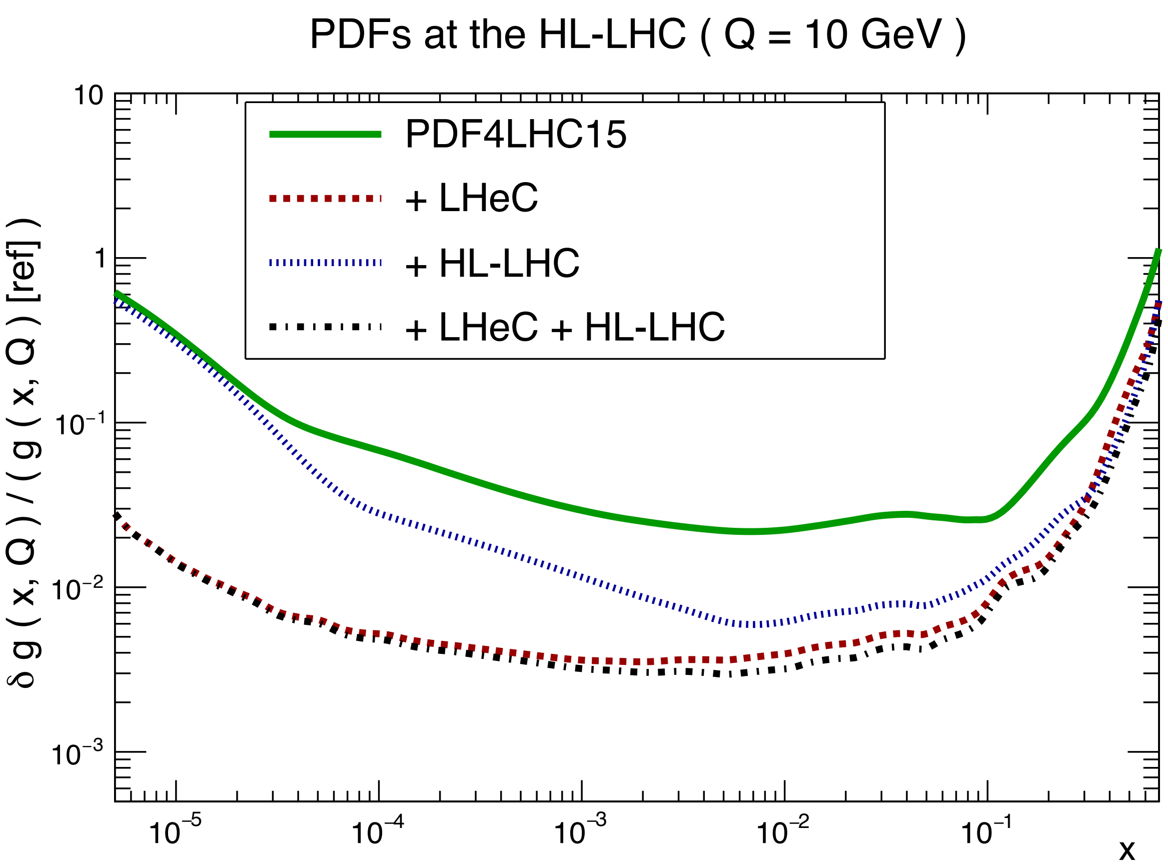
★ PDF4LHC + LHeC - **global** T=3 (T=1).

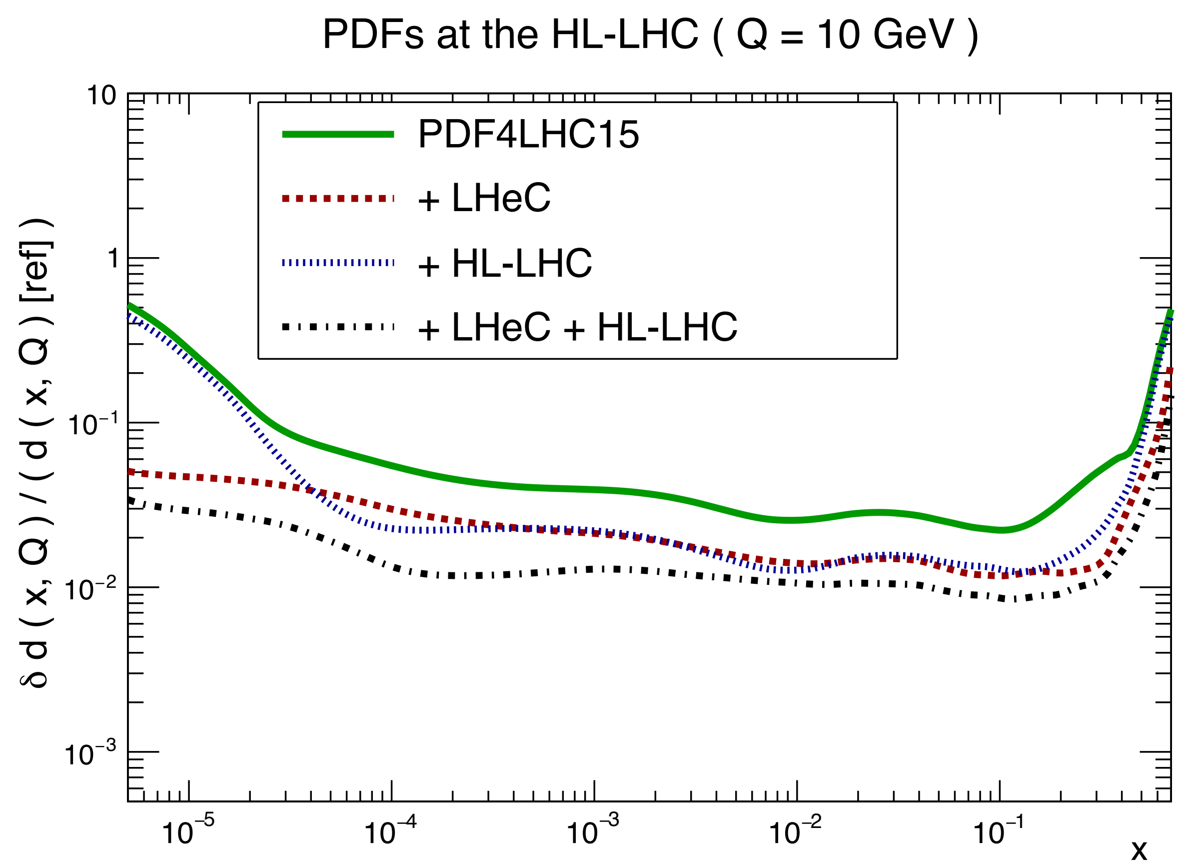
★ PDFLHC + LHeC + HL-LHC - **global** T=3.

★ PDF4LHC (no prior) + LHeC - **dedicated** T=1.



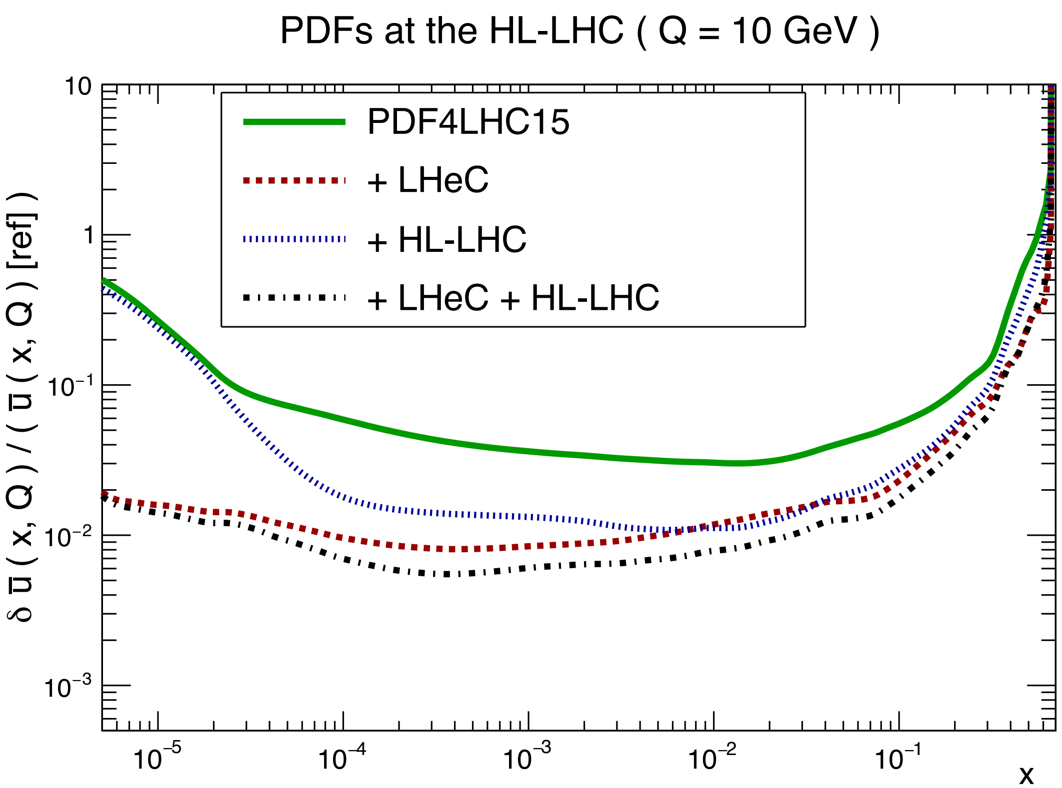
Results: Global Fits

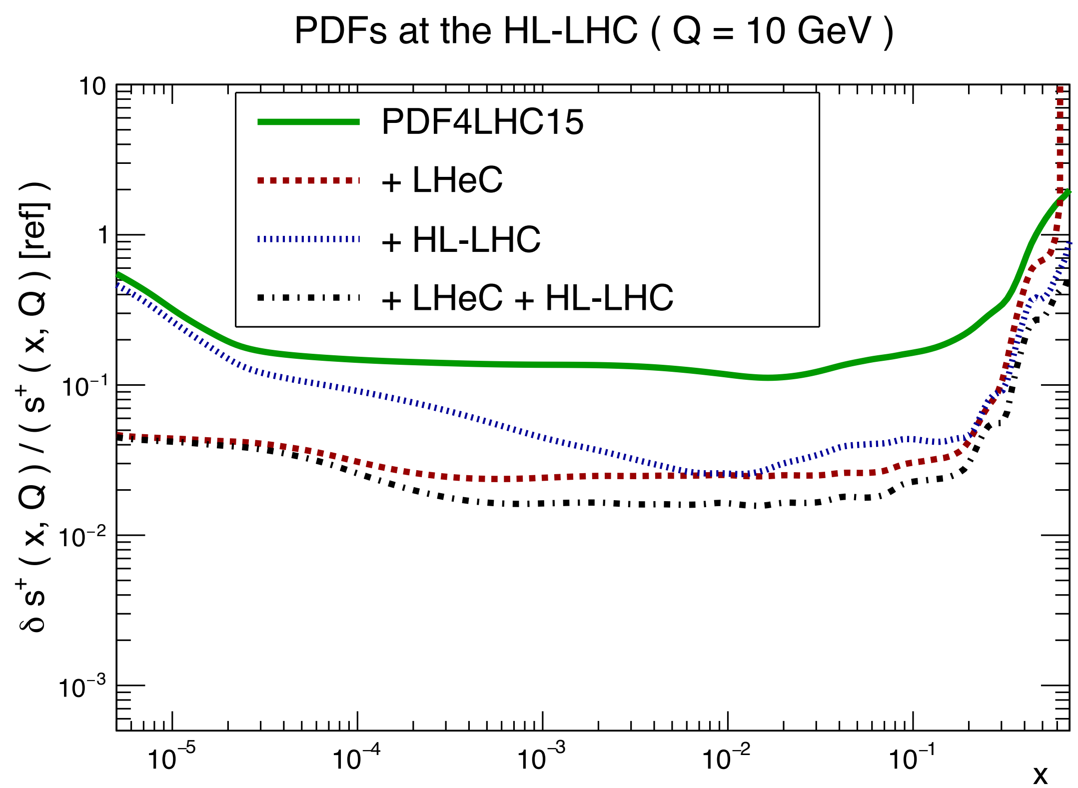




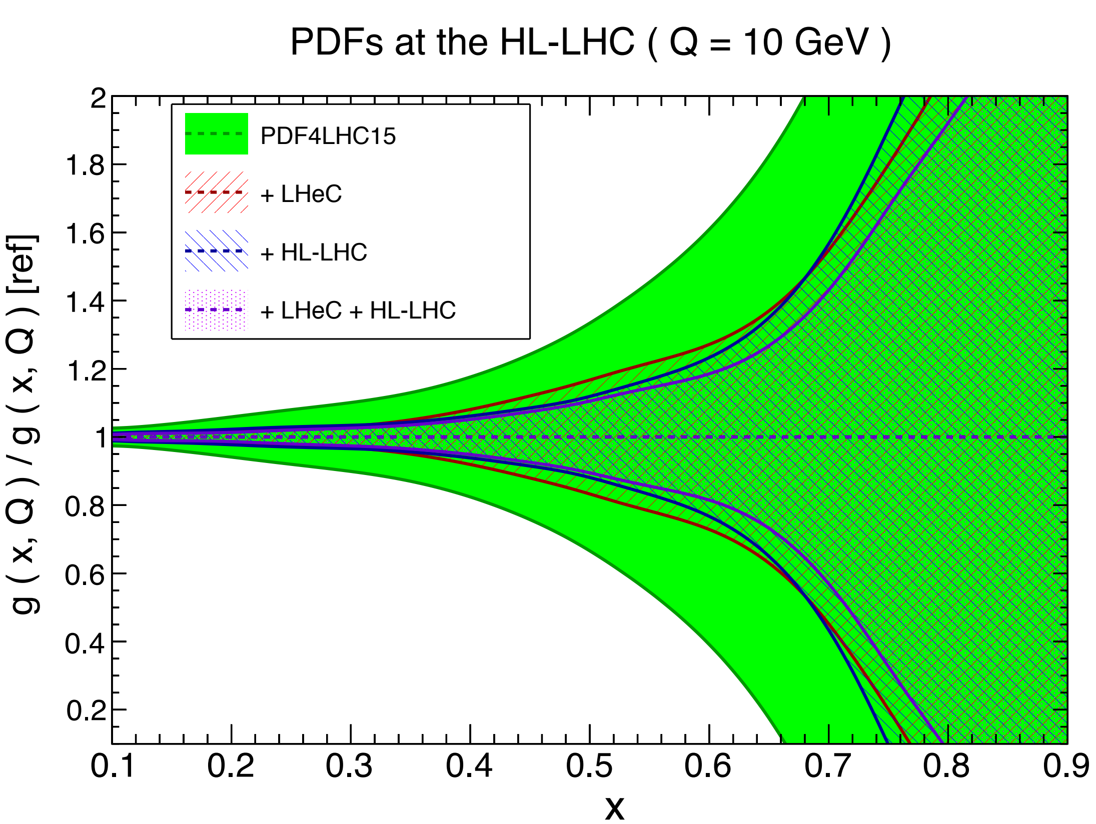
- Impact of LHeC significant, in particular at low/intermediate x .
- At higher x impact of LHeC and HL-LHC expected to be rather comparable.
- LHeC results above with T=3 but T=1 investigated: qualitatively similar.

More Results





- Similar picture as before for other partons.
- High x complementarity clear.



Dedicated LHeC Fits

- Figure of merit:

$$\chi^2\left(\beta_{\rm th}\right) = \sum_{i,j=1}^{N_{\rm dat}} \left(\sigma_i^{\rm exp} - \sigma_i^{\rm th} - \sum_k \sigma_i^{\rm th}\Gamma_{ik}^{\rm th}\,\beta_{k,{\rm th}}\right) C_{ij}^{-1} \left(\sigma_j^{\rm exp} - \sigma_j^{\rm th} - \sum_m \sigma_j^{\rm th}\Gamma_{jm}^{\rm th}\,\beta_{m,{\rm th}}\right) + T^2 \sum_k \beta_{k,{\rm th}}^2 \;. \quad (3.1)$$

Pseudodata errors

PDF shifts

- Minimising yields 'Hessian' - determines profiled PDF errors:

$$H_{kl} = \sum_{i,j} \sigma_i^{\rm th}\Gamma_{ik}^{\rm th} C_{ij}^{-1} \sigma_j^{\rm th}\Gamma_{jl}^{\rm th} + T^2\delta_{kl}\;,$$

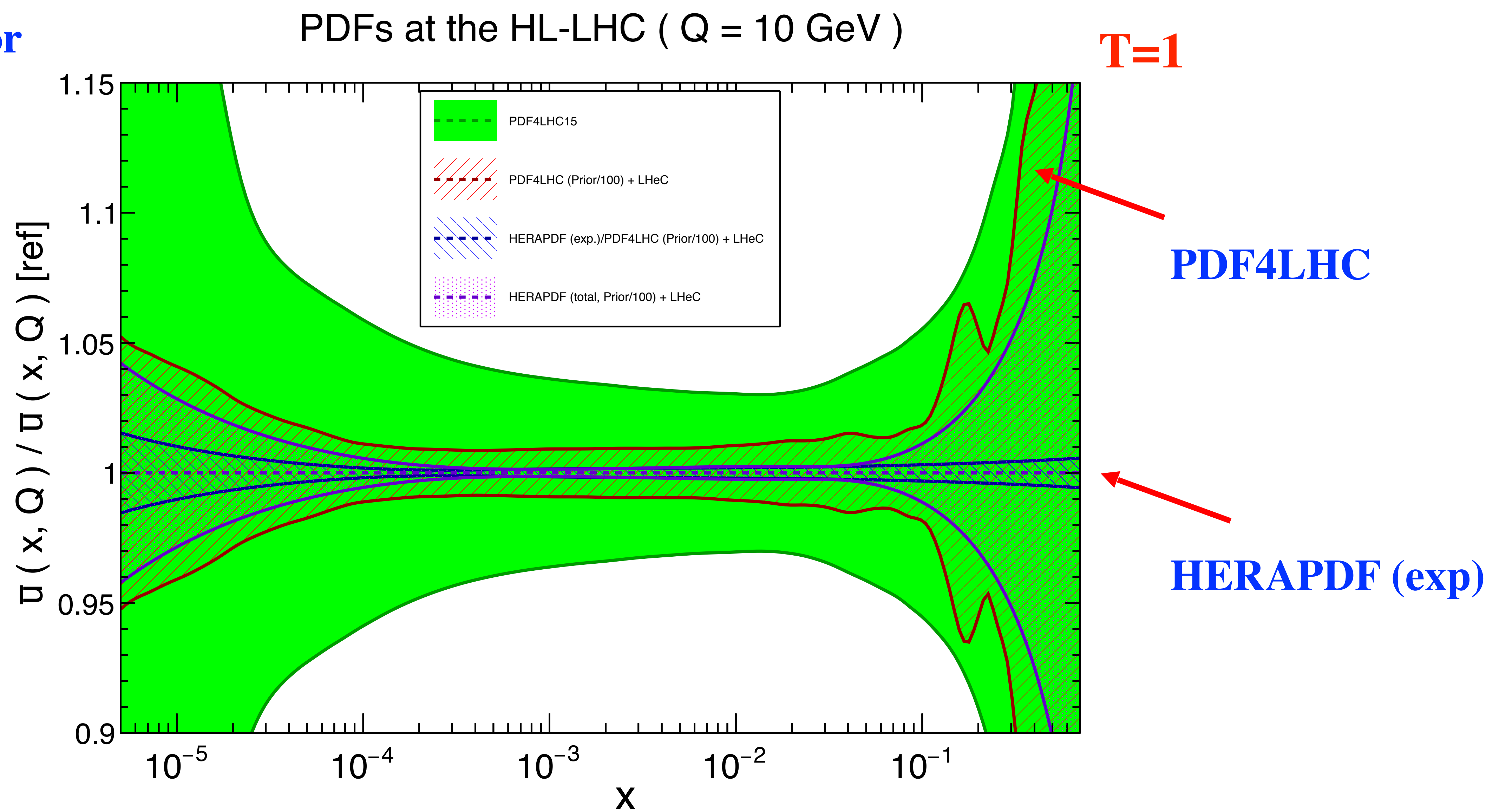
Impact of Pseudodata

Impact of data entering baseline PDF

- Dialing down second term allows:
  - ★ Assess impact of **LHeC pseudodata alone** in T = 1 fit.
  - ★ Examine impact of **parameterisation** in prior set.

Dedicated LHeC Fits: Results

(Similar results for other partons)



- Consistent T=1 **LHeC-only** results!
- Impact of LHeC always significant, but level of impact v. sensitive to parameterisation, in particular in regions where LHeC constraints smaller.
- Why? When generating pseudodata with given parameterisation, one is implicitly assuming that eventual LHeC data will be describable with this.

LHeC Projections: Summary

- ★ Impact of LHeC on future **global** PDF fits **significant**. Generally, LHeC more competitive at low/intermediate x. At higher x, LHeC/HL-LHC impacts comparable.

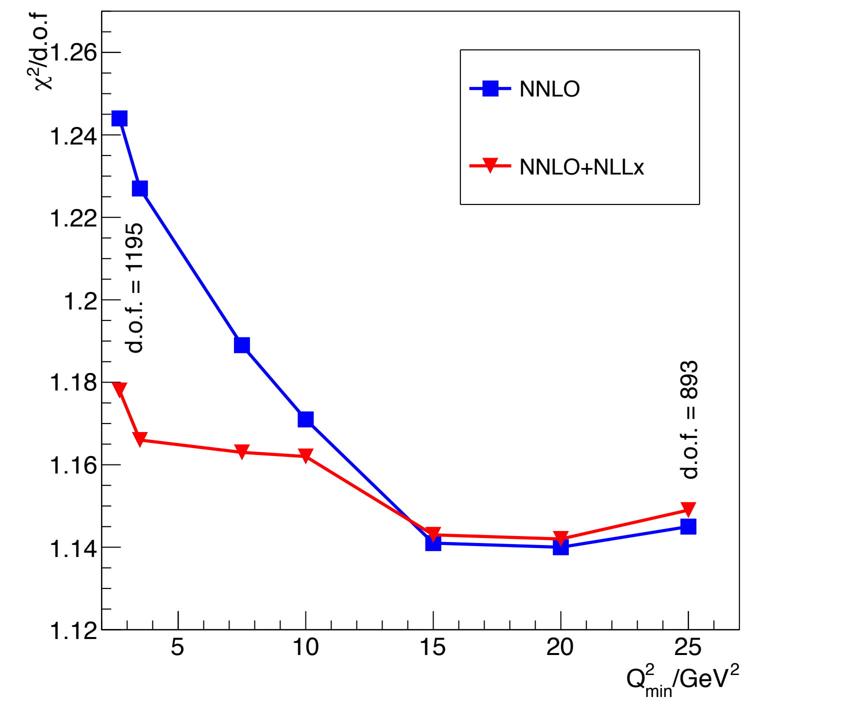
- ★ **LHeC-only** fits performed. Again sizeable impact, but significant dependence on baseline parameterisation: one is implicitly assuming that eventual LHeC data will be describable with this!

- ★ **Caveat**: have not included all possible datasets, e.g. DIS jets (will improve high x) while HL-LHC projections focussed on low x .

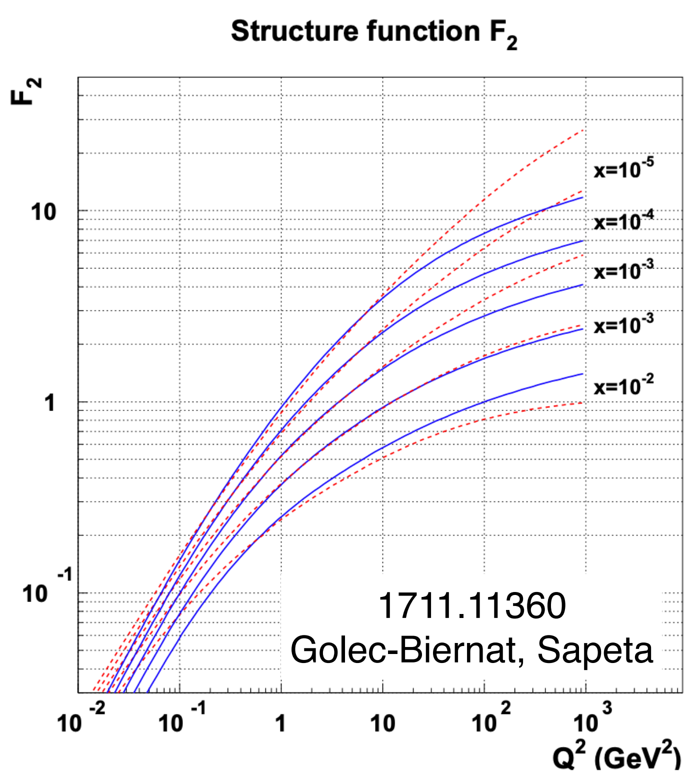
Discovering Saturation at the LHeC

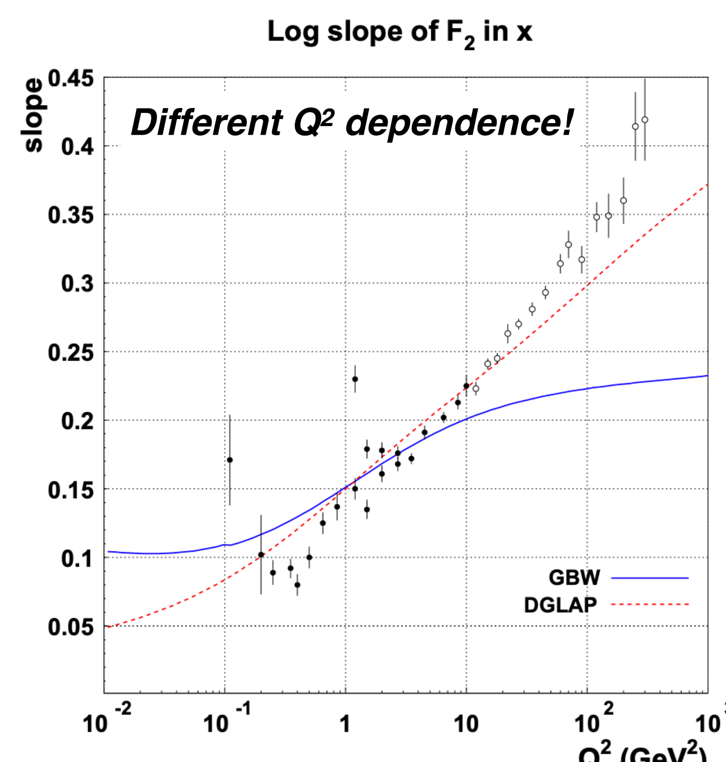
Motivation

H. Abdolmaleki et al., Eur. Phys. J. C78 (2018), no. 8 621



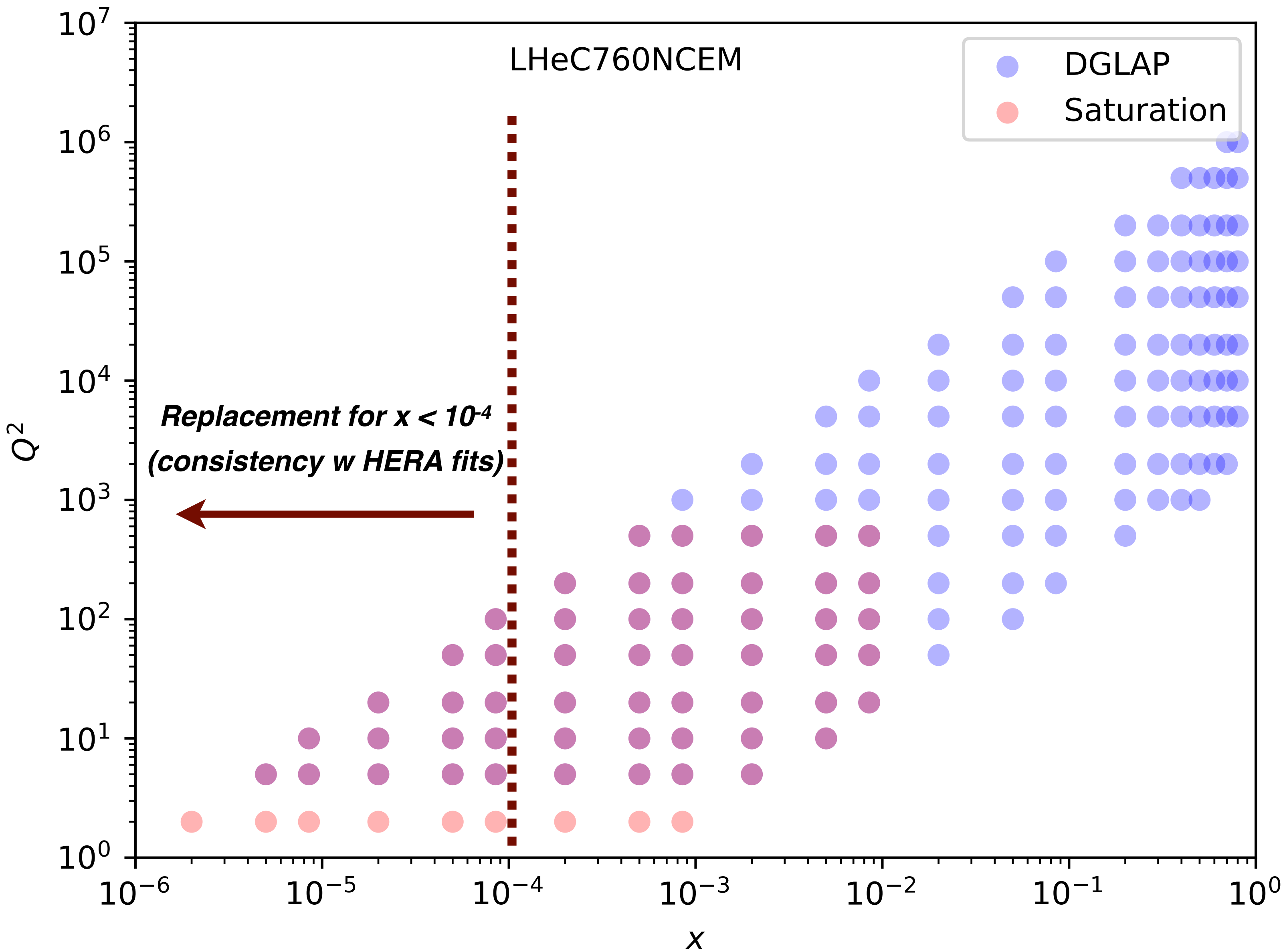
- Issues with describing low x, Q^2 HERA data with standard DGLAP.
- Improved with low x **BFKL** resummation - will be essential at LHeC. But room also for non-linear **saturation** effects?
- If these are present at the LHeC, will we be able to see them?
- To find out: fit LHeC pseudo data based on saturation model with standard DGLAP (PDF4LHC baseline). Can these be fitted away?





Pseudodata

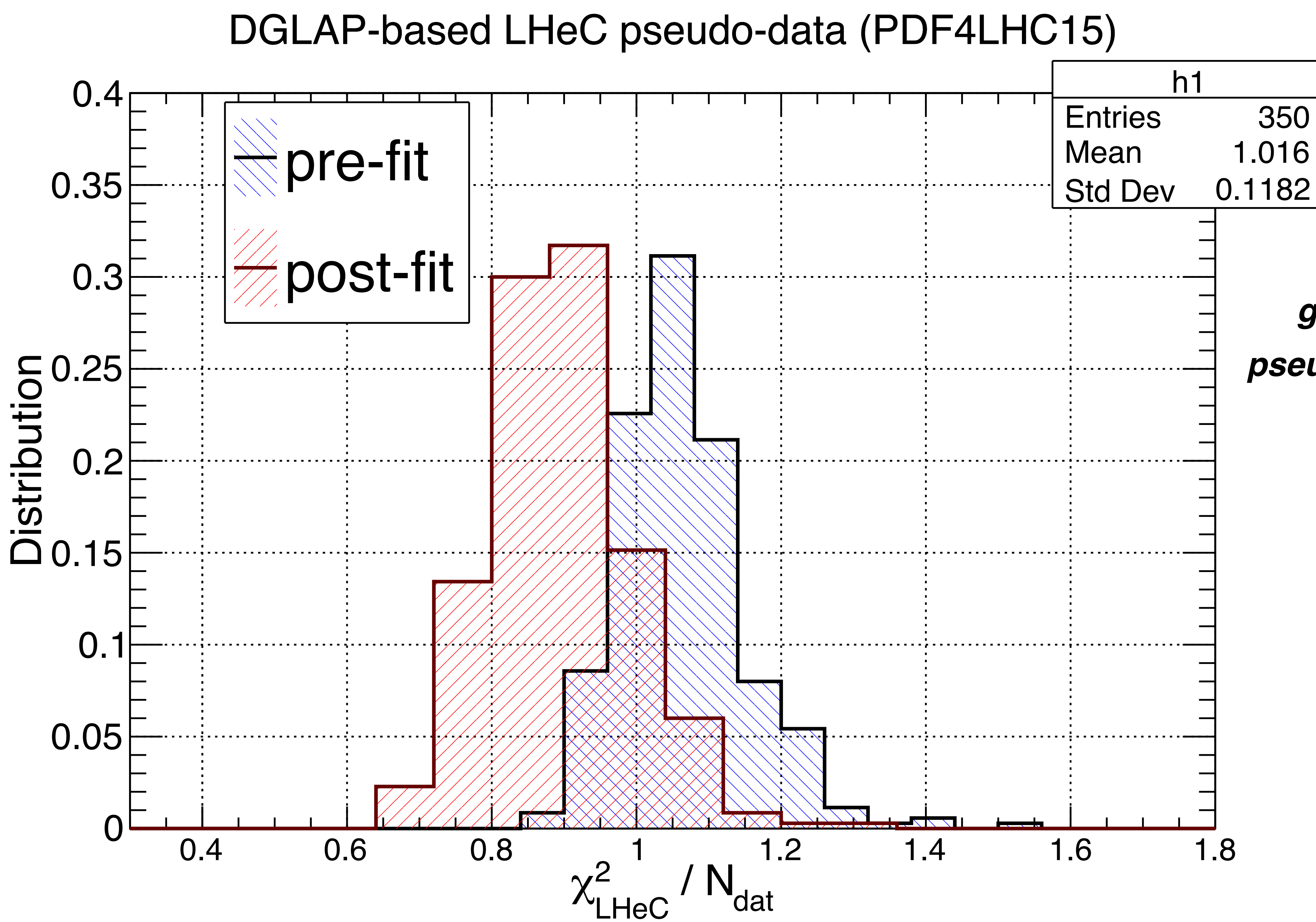
- Replace e^-p NC pseudodata (E_p -1 and 7 TeV) in $x < 10^{-4}$ region with that due to saturation model.



Model: K Golec-Biernat, S. Sapeta, JHEP 03 (2018) 102. Pseudodata due to Nestor Armesto

Pure DGLAP fits

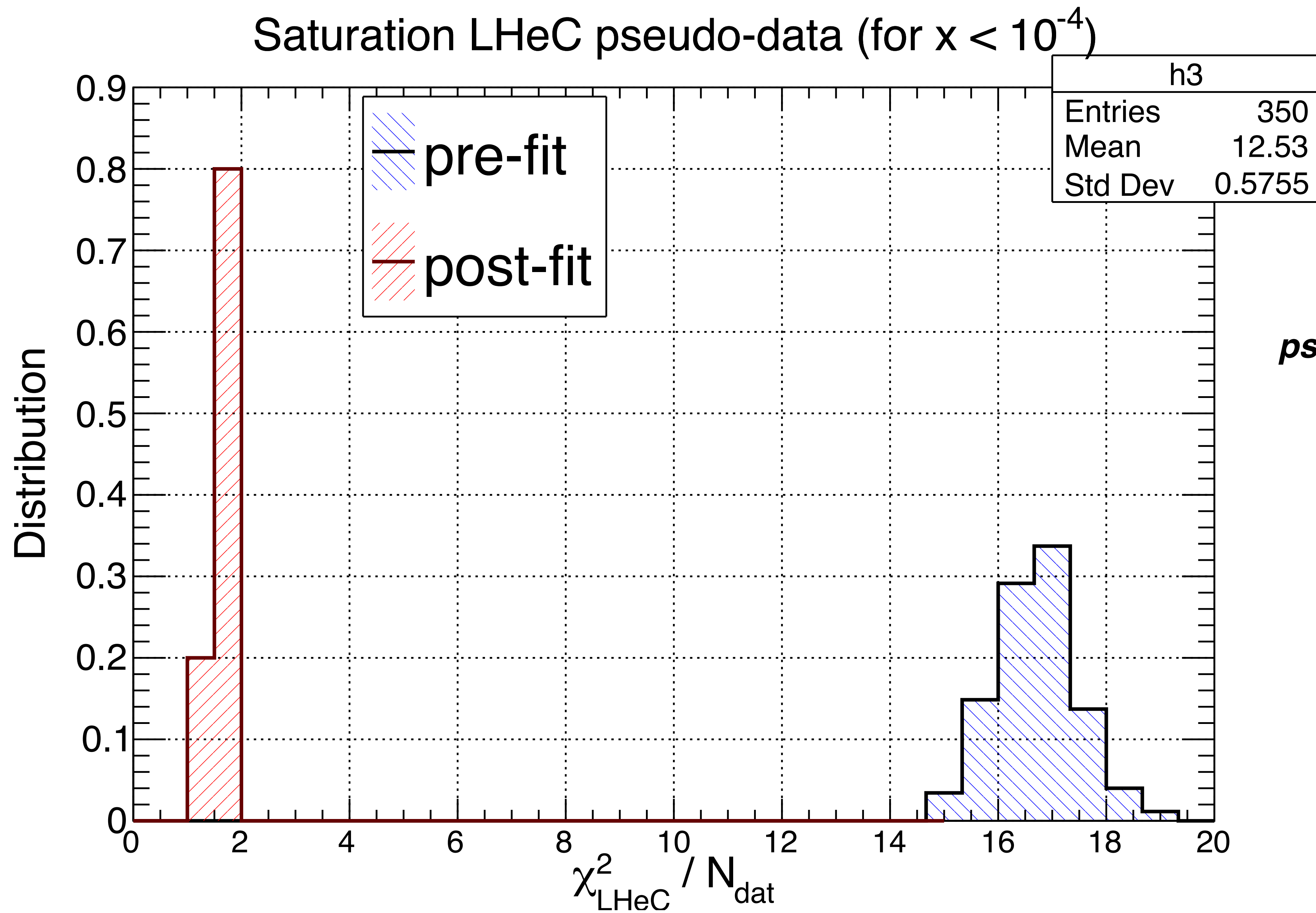
- Before doing this: look at result of pure DGLAP pseudodata.
- Compare fit quality before and after profiling. By construction have agreement with little improvement after refitting.



generated 500 pseudo-experiments

Adding Saturation

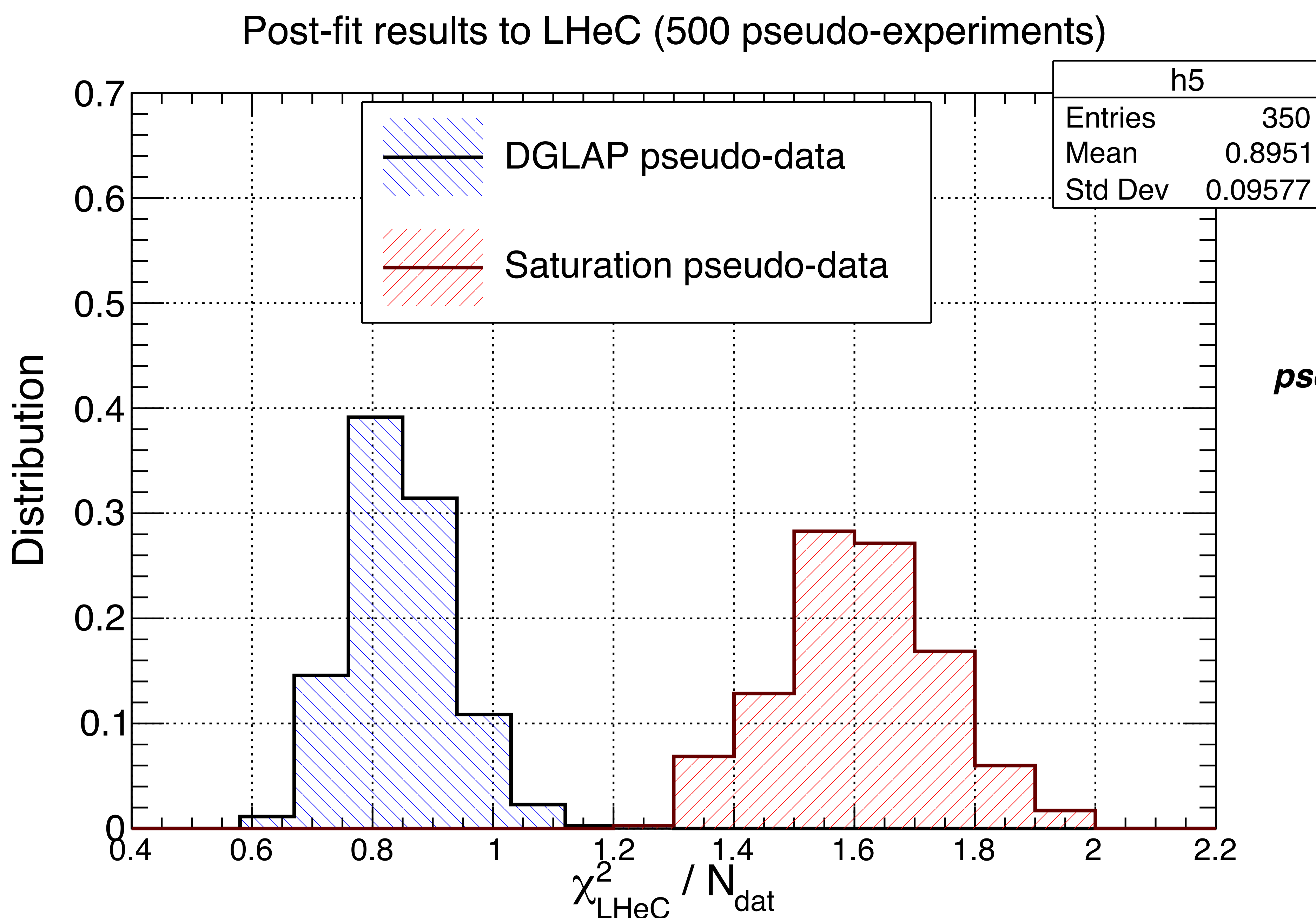
- Before fitting: huge $\chi^2/N_{\rm pts}$: saturation pseudodata strongly disagrees with pure DGLAP theory. But a lot of this can be fitted away.
- But **not all**! In more detail…



generated 500 pseudo-experiments

Adding Saturation

- Even after refitting, clear **tension** ($\chi^2/N_{\rm pts} > 1$) when using DGLAP theory. Can disentangle saturation from DGLAP at LHeC!
- Will be even clearer if we isolate x, Q^2region where saturation largest.

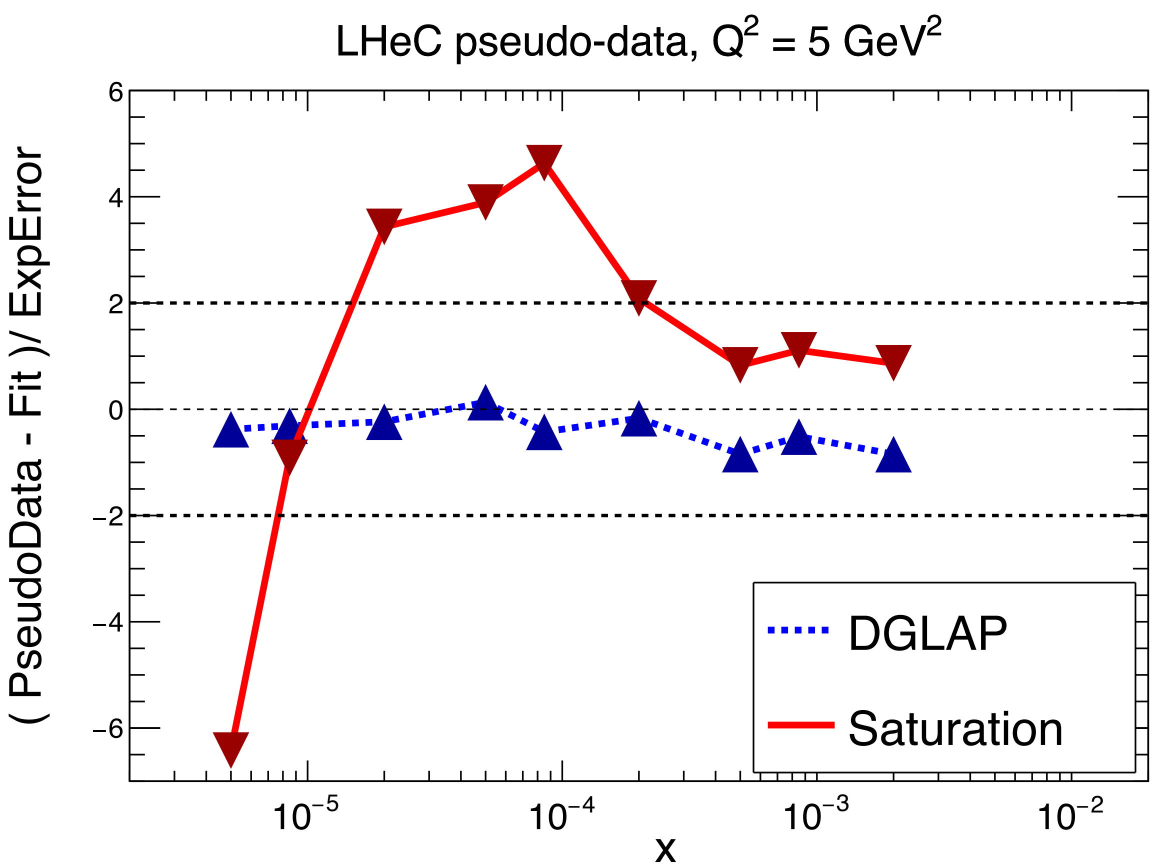


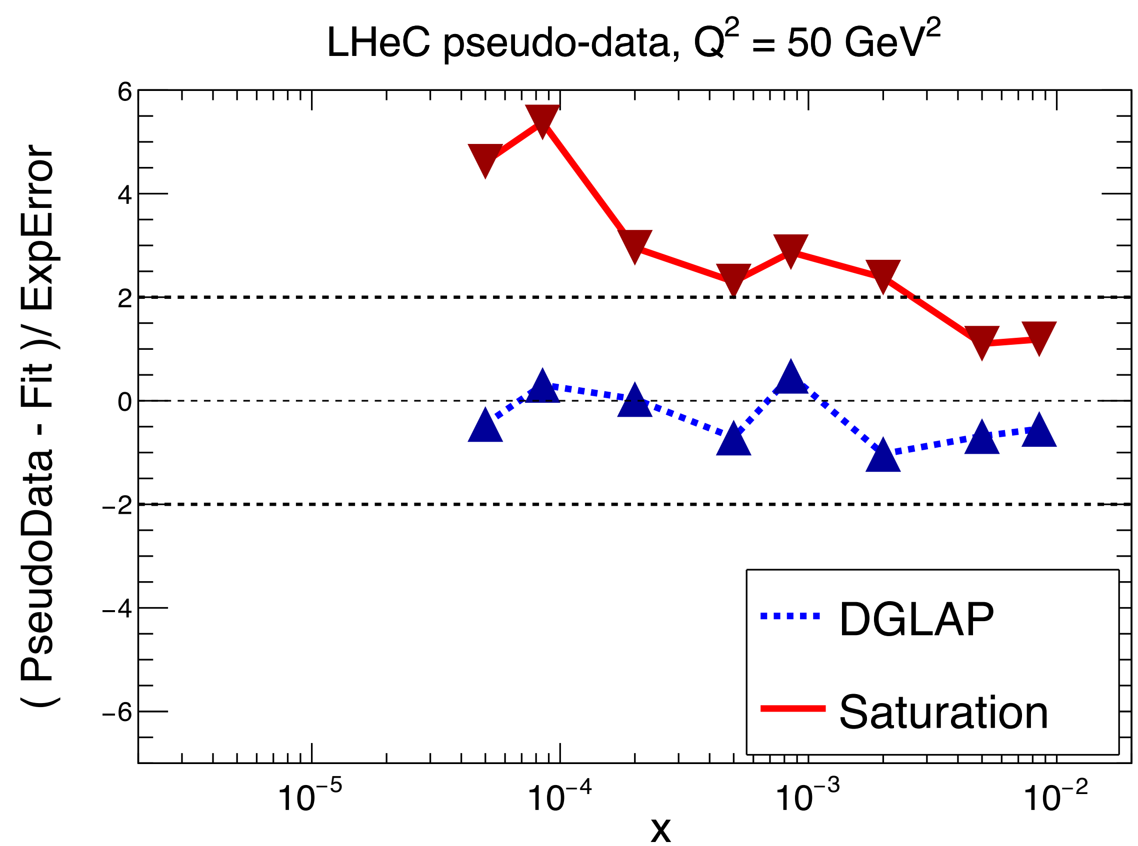
generated 500 pseudo-experiments

Pulls

- Illustrative to look at pulls: discrepancy between fit and pseudodata.

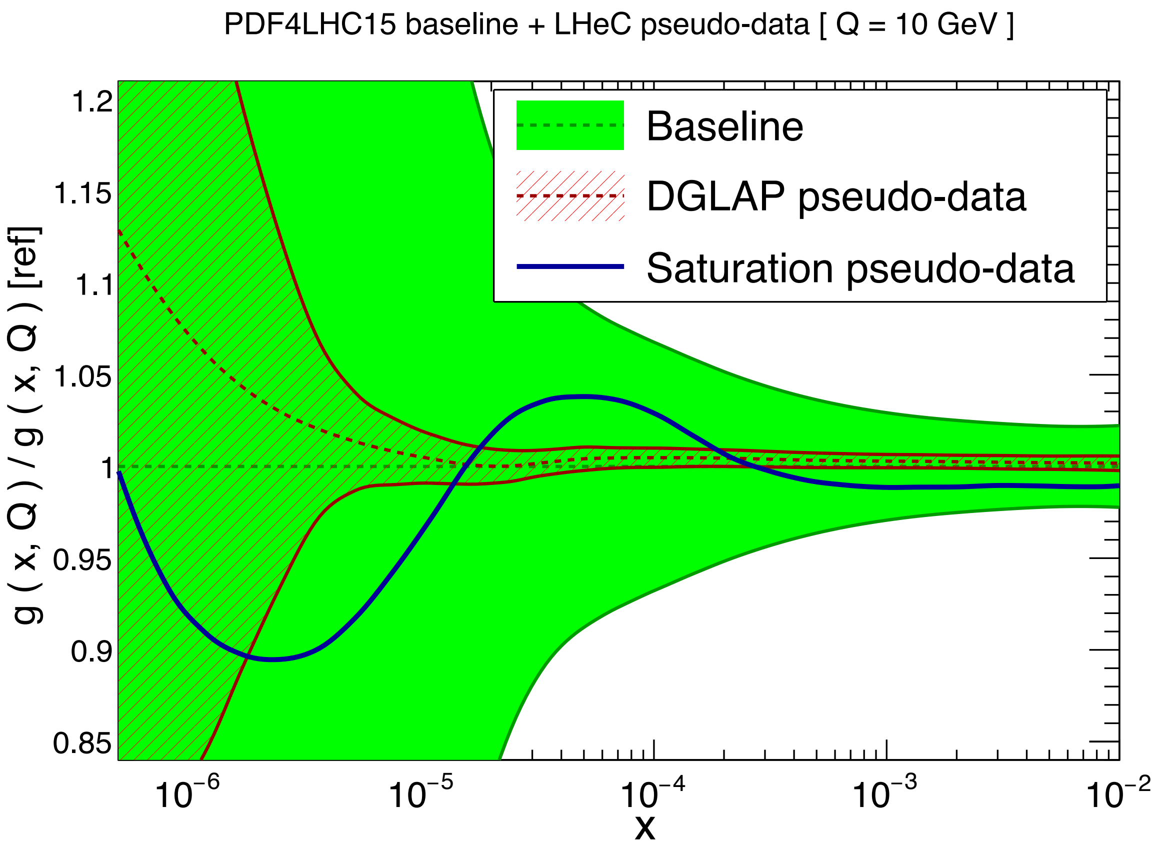
$$P(x,Q^2) = \frac{\mathcal{F}_{\rm fit}(x,Q^2) - \mathcal{F}_{\rm dat}(x,Q^2)}{\delta_{\rm exp}\mathcal{F}(x,Q^2)}$$

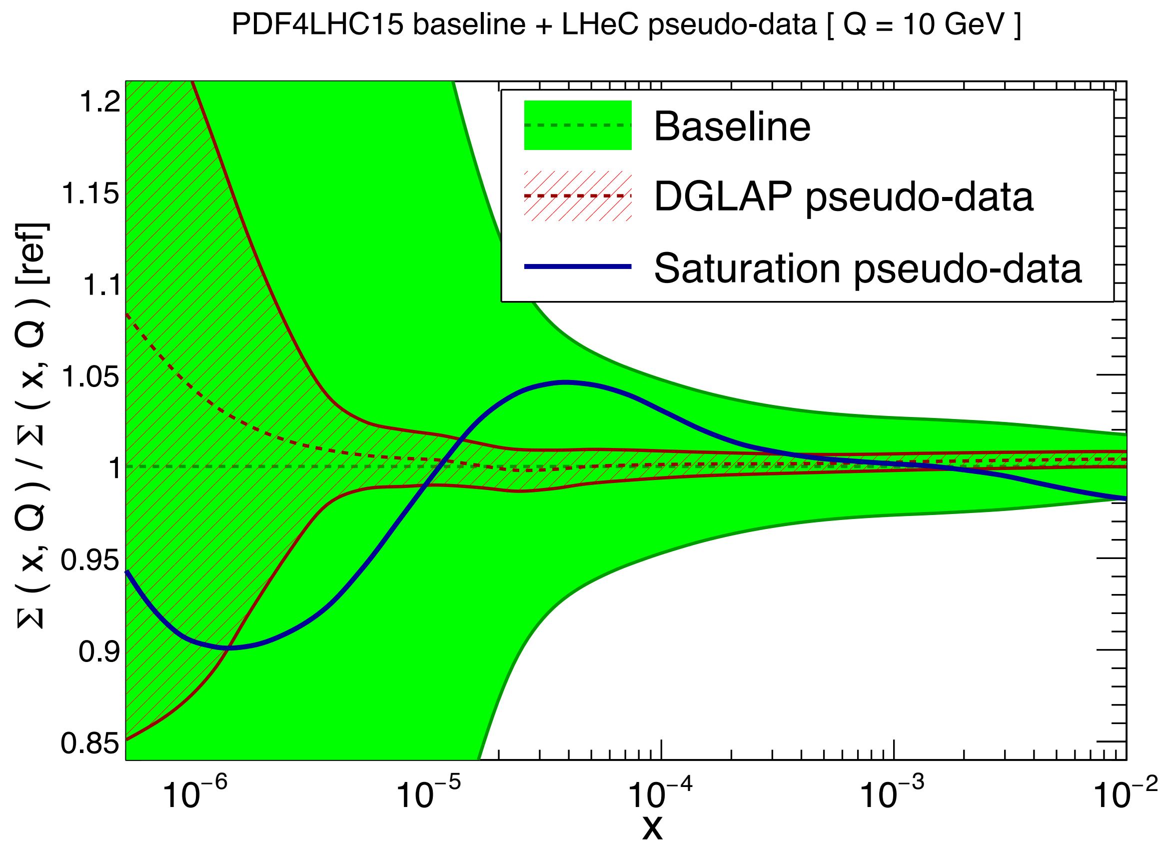




- Tendency for DGLAP to undershoot/overshoot saturation pseudodata in different x regions.
- But crucially: different Q^2 trends seen. Cannot absorb this in PDFs.
- As much lever arm as possible in Q^2 at low x crucial for these studies. Provided uniquely by LHeC.

PDFs



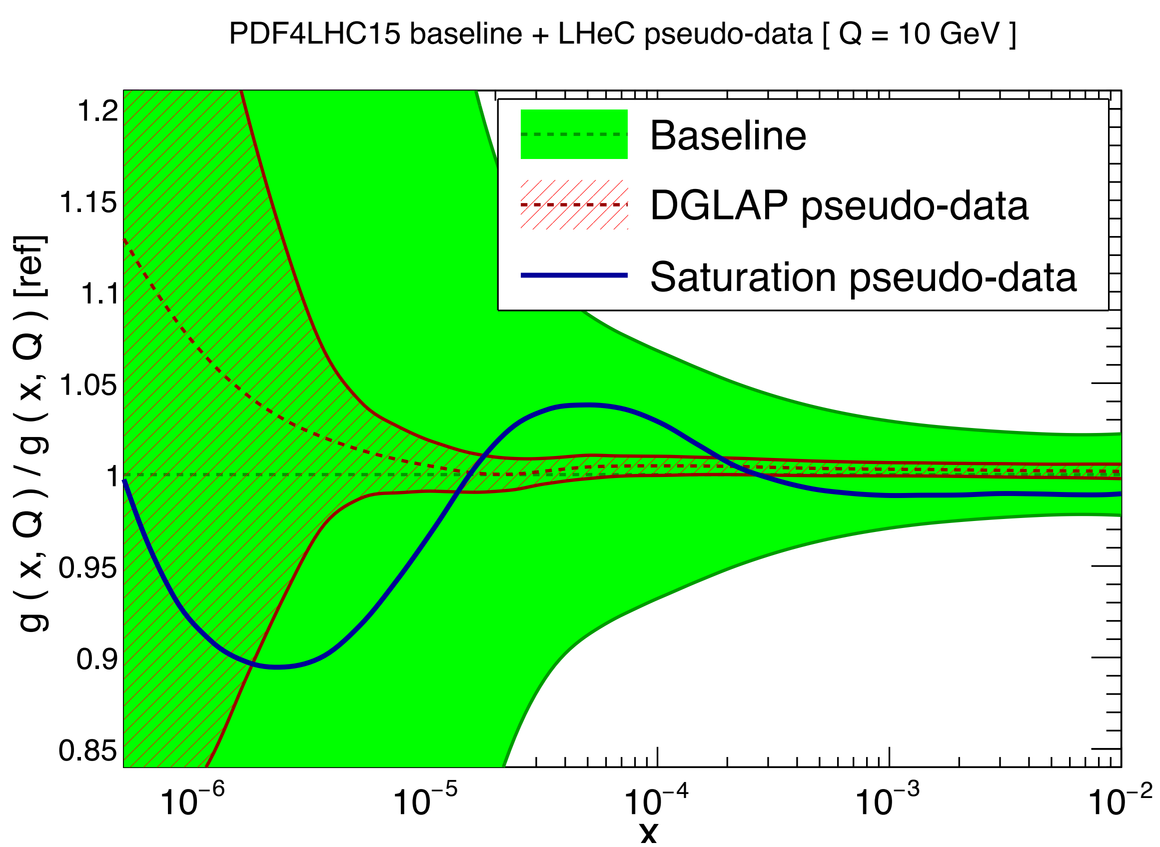


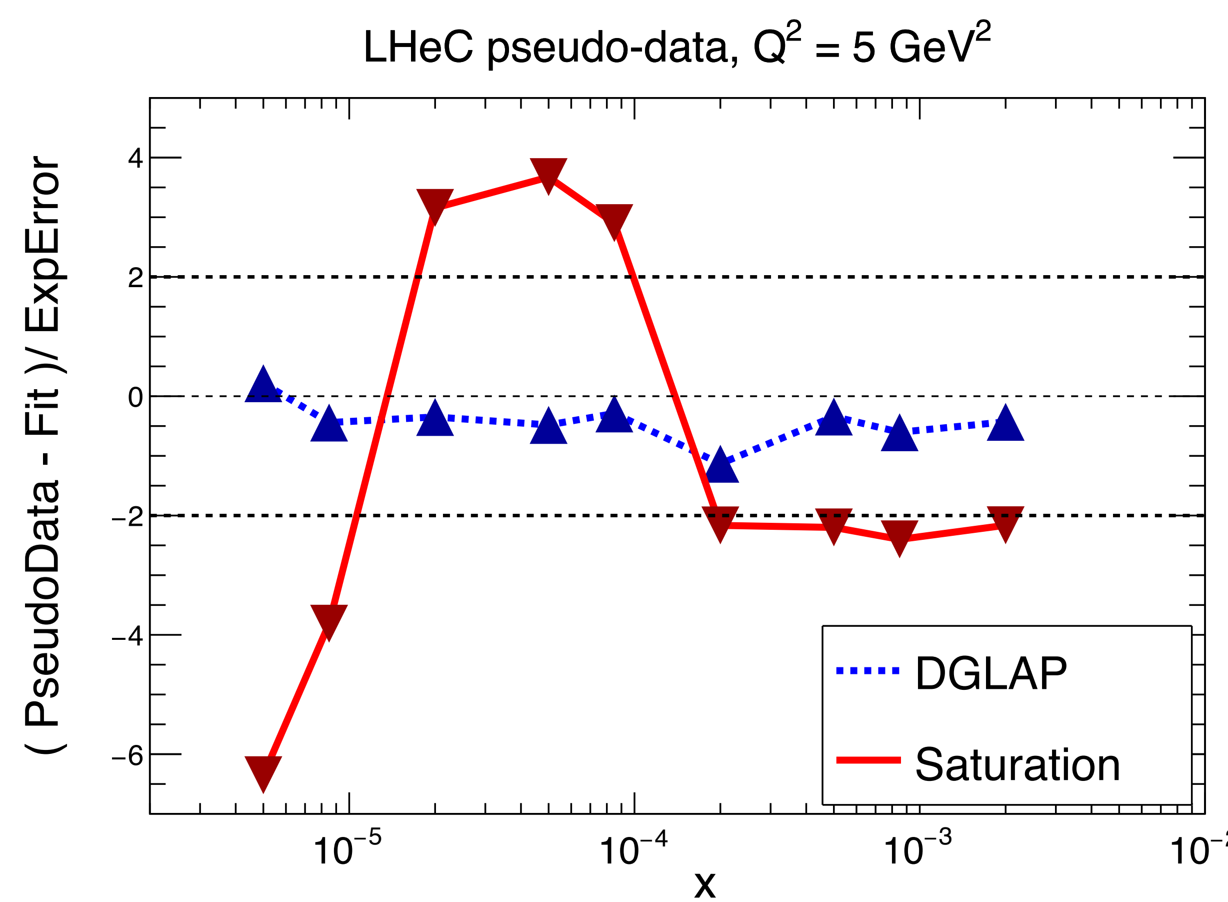
- Distortion in fit PDFs caused by mismatch between saturation pseudodata and DGLAP theory larger than PDF errors.
- Highlights that these effects are observable (~ lie outside PDF uncertainty) at the LHeC.

Summary/Outlook

★ If saturation (non-linear) dynamics are well described by current theory models they should be detectable at LHeC. An important milestone in the LHeC programme and in QCD physics.

★ In principle should combine with BFKL resummation to see how these can be disentangled. Different Q^2 scaling implies should be possible.

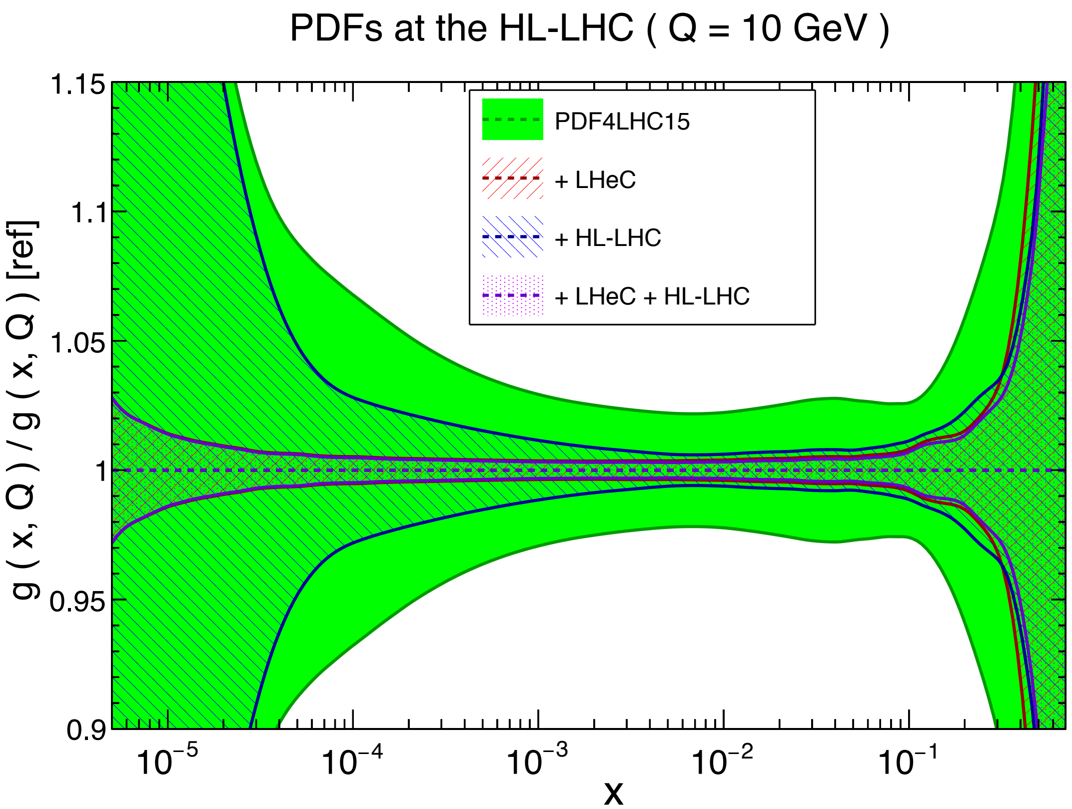




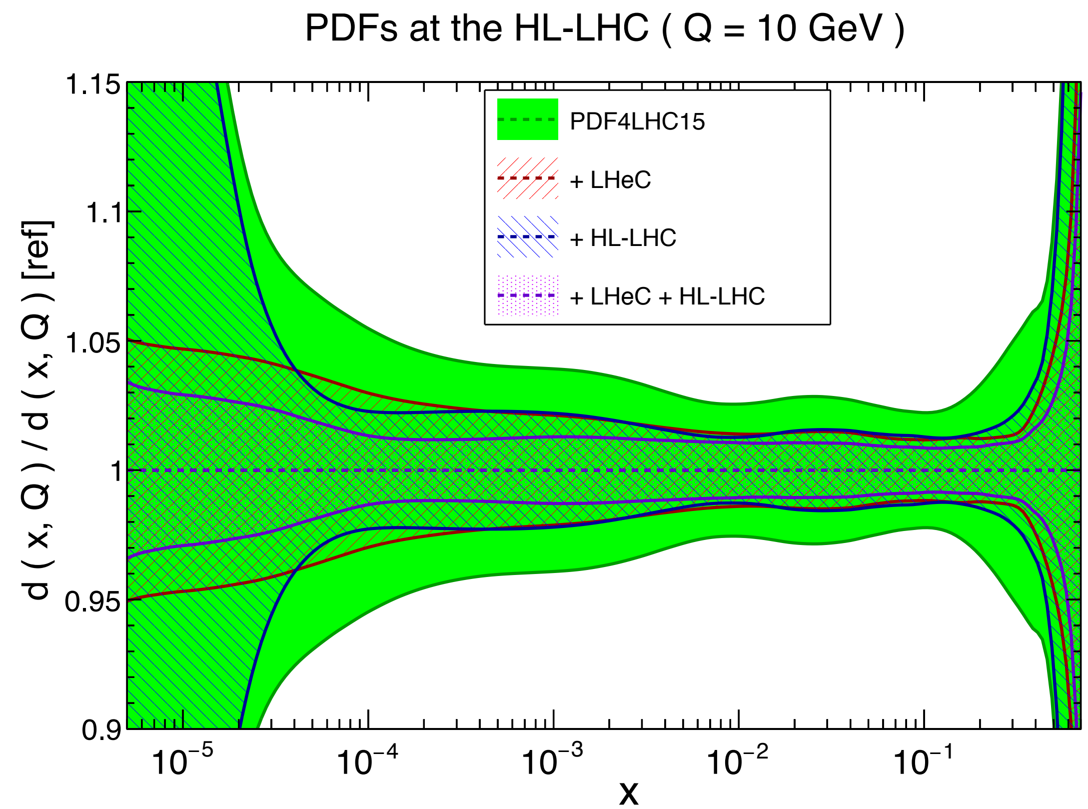
Thank you for listening!

Backup

HL-LHC + LHeC



PDFs at the HL-LHC (Q = 10 GeV)
PDF4LHC15
+ LHeC
+ HL-LHC
+ LHeC + HL-LHC
g (x, Q) / g (x, Q) [ref]
1.15
1.1
1.05
1
0.95
0.9
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
x



PDFs at the HL-LHC (Q = 10 GeV)
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+ LHeC
+ HL-LHC
+ LHeC + HL-LHC
d (x, Q) / d (x, Q) [ref]
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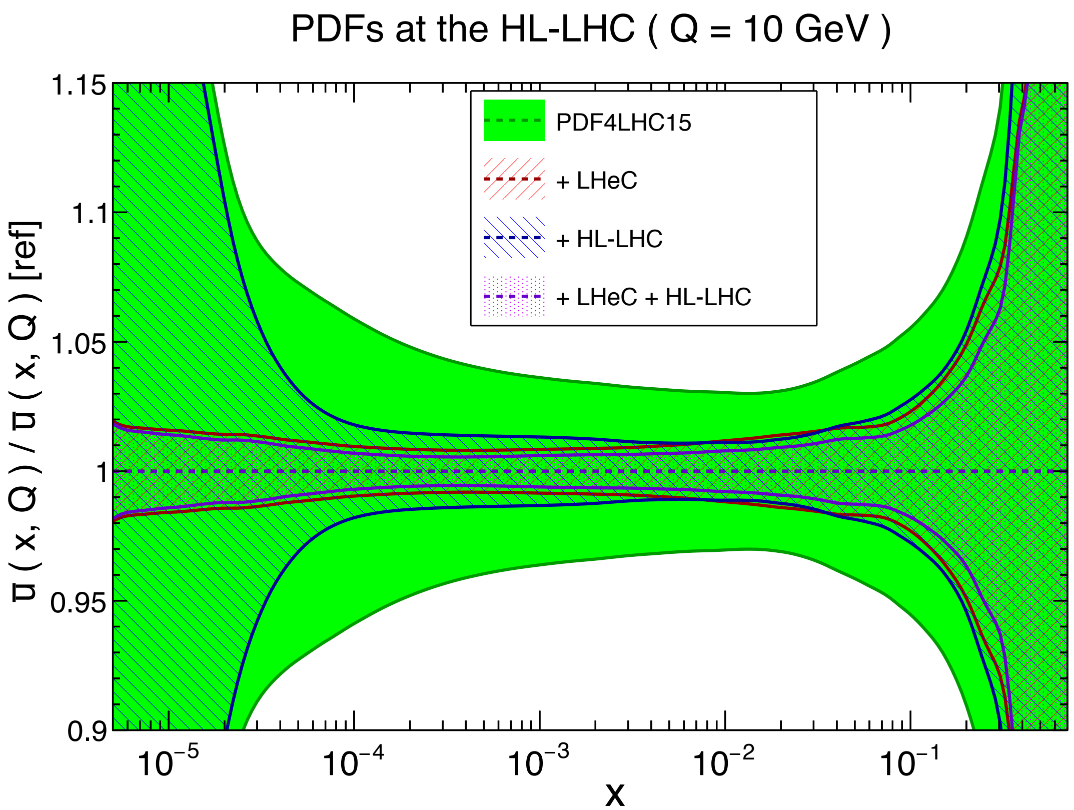
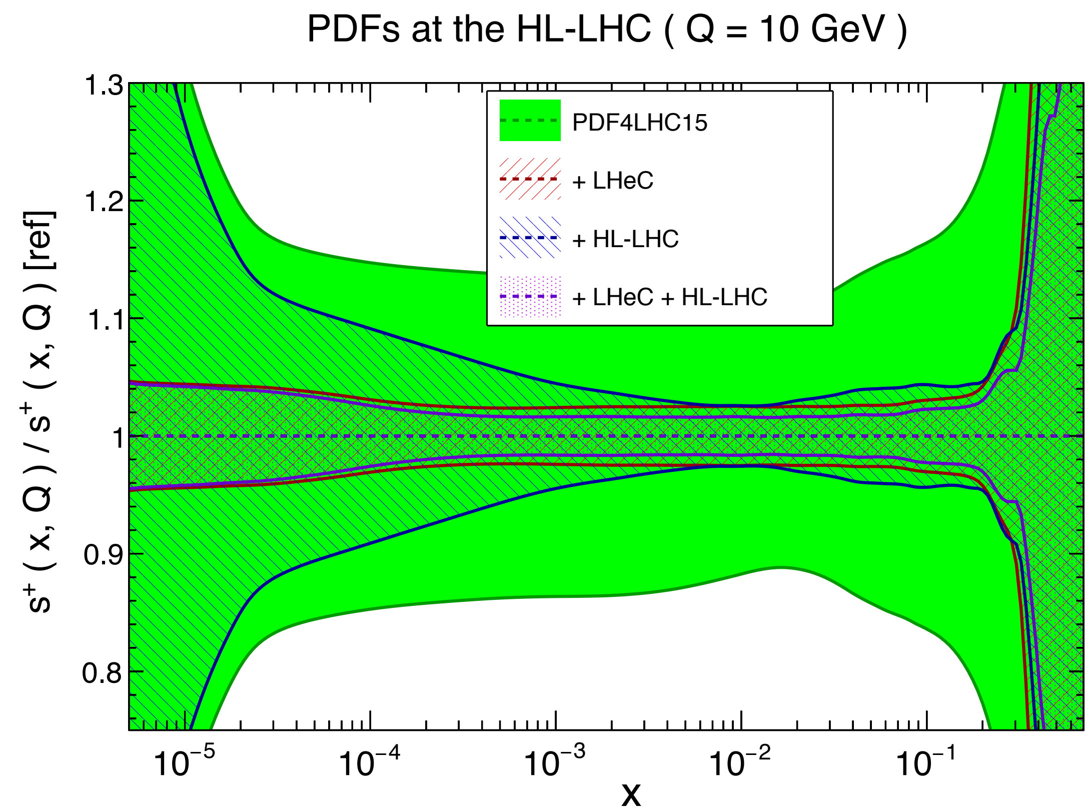
0.9
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
x



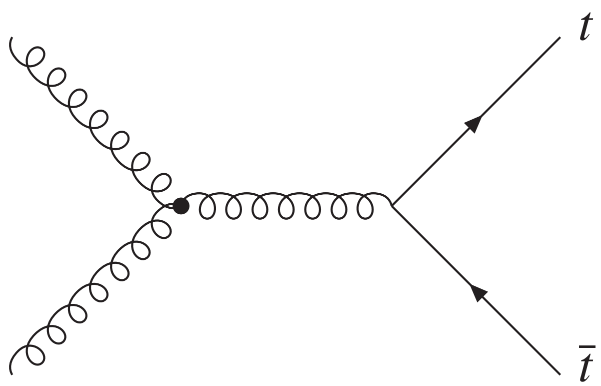
PDFs at the HL-LHC (Q = 10 GeV)
PDF4LHC15
+ LHeC
+ HL-LHC
+ LHeC + HL-LHC
$\bar{u}$ (x, Q) / $\bar{u}$ (x, Q) [ref]
1.15
1.1
1.05
1
0.95
0.9
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
x



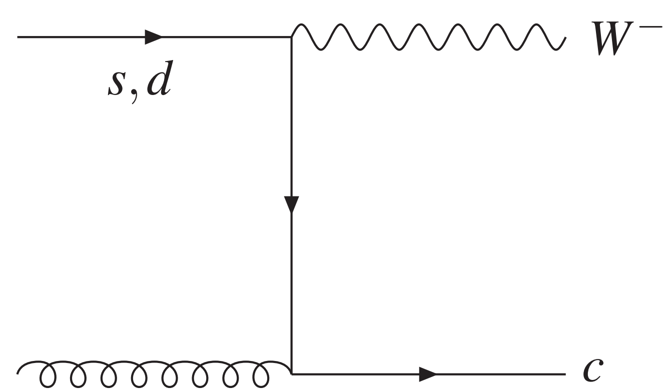
PDFs at the HL-LHC (Q = 10 GeV)
PDF4LHC15
+ LHeC
+ HL-LHC
+ LHeC + HL-LHC
s^+ (x, Q) / s^+ (x, Q) [ref]
1.3
1.2
1.1
1
0.9
0.8
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
x

HL-LHC: Processes

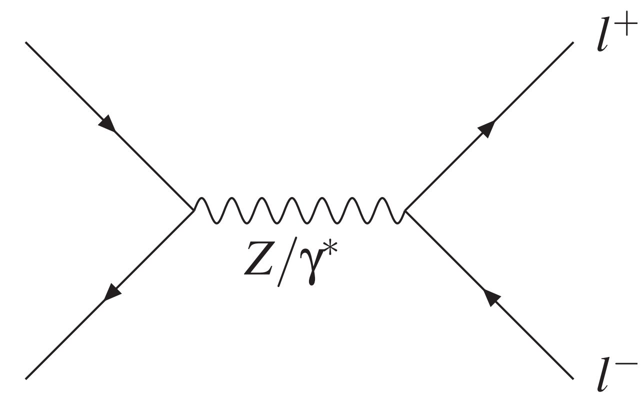
Top quark pair production



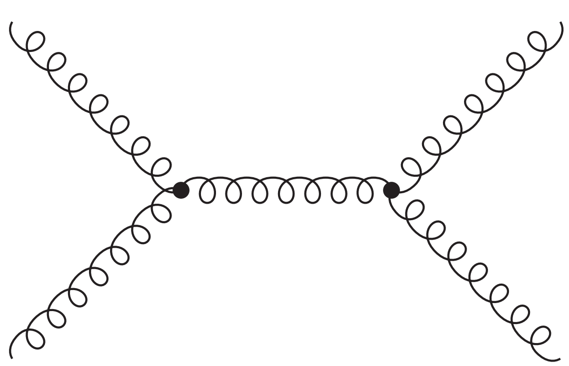
$W + c$ production



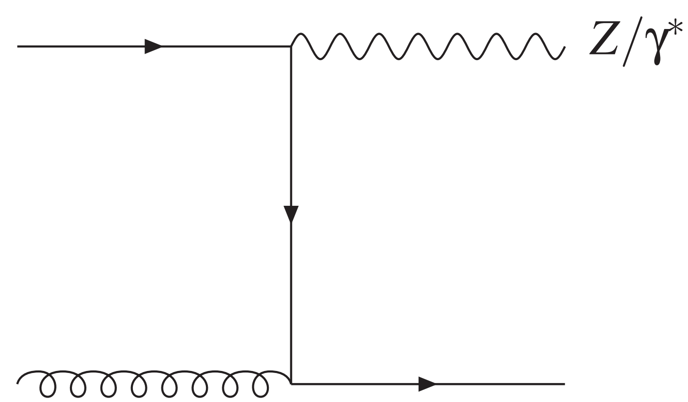
Drell–Yan production



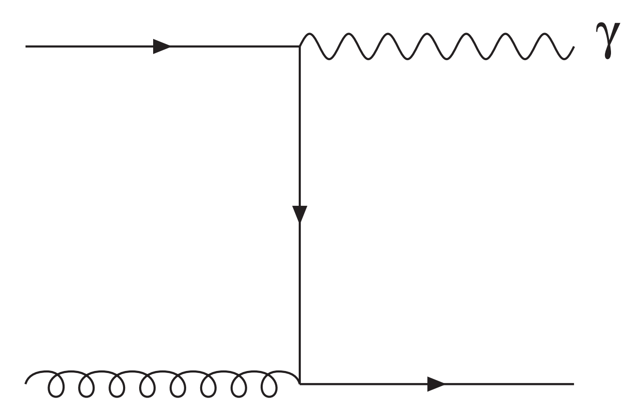
Jet production



$Z\ p_T$



Direct photon production



HL-LHC: Datasets

Process	Kinematics	$N_{\rm dat}$	$f_{\rm corr}$	$f_{\rm red}$	Baseline
$Z\ p_T$	$20\,\text{GeV} \le p_T^{ll} \le 3.5$ TeV $12\,\text{GeV} \le m_{ll} \le 150$ GeV $\lvert y_{ll}\rvert \le 2.4$	338	0.5	$(0.4, 1)$	[52] (8 TeV)
high-mass Drell-Yan	$p_T^{l1(2)} \ge 40(30)\,\text{GeV}$ $\lvert\eta^l\rvert \le 2.5,\ m_{ll} \ge 116\,\text{GeV}$	32	0.5	$(0.4, 1)$	[47] (8 TeV)
top quark pair	$m_{t\bar{t}} \simeq 5$ TeV, $\lvert y_t\rvert \le 2.5$	110	0.5	$(0.4, 1)$	[50] (8 TeV)
W+charm (central)	$p_T^{\mu} \ge 26\,\text{GeV},\ p_T^{c} \ge 5\,\text{GeV}$ $\lvert\eta^{\mu}\rvert \le 2.4$	12	0.5	$(0.2, 0.5)$	[24] (13 TeV)
W+charm (forward)	$p_T^{\mu} \ge 20\,\text{GeV},\ p_T^{c} \ge 20\,\text{GeV}$ $p_T^{\mu+c} \ge 20\,\text{GeV}$ $2 \le \eta^{\mu} \le 4.5,\ 2.2 \le \eta^{c} \le 4.2$	10	0.5	$(0.4, 1)$	LHCb projection
Direct photon	$E_T^{\gamma} \lesssim 3$ TeV, $\lvert\eta_{\gamma}\rvert \le 2.5$	118	0.5	$(0.2, 0.5)$	[55] (13 TeV)
Forward W, Z	$p_T^{l} \ge 20\,\text{GeV},\ 2.0 \le \eta^{l} \le 4.5$ $60\,\text{GeV} \le m_{ll} \le 120\,\text{GeV}$	90	0.5	$(0.4, 1)$	[49] (8 TeV)
Inclusive jets	$\lvert y\rvert \le 3,\ R = 0.4$	58	0.5	$(0.2, 0.5)$	[61] (13 TeV)
Total		768			