Deviations from NLO DGLAP in HERA data

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Motivation: search for deviations at small-x

A lot of interesting phenomena at small-x

- Perturbative resummation
- Saturation effects
- Higher twist effects ...

We need to properly understand the small-x region:

- QCD at high parton densities interesting di per se
- Important for precision physics

The LHeC is the natural place to study small-x QCD!

- x can be very small, with Q^2 still in the perturbative region

Motivation: a strategy to single out deviations

Small effects

Deviations from NLO DGLAP are small and difficult to single out, even at the LHeC

A strategy to disentangle them from NLO DGLAP is needed!

Outline

How to single out possible deviations: a proposal

- "Safe" vs "unsafe" kinematic region for DGLAP evolution
- Determine PDFs from global fit in the "safe region"
- Use "safe" PDFs to find deviations from NLO DGLAP

Our strategy @ work: small-x HERA data

- Evidence for deviations from NLO DGLAP!
- Possible explanations: not NNLO!
- Effects on LHC physics

Conclusions and outlook

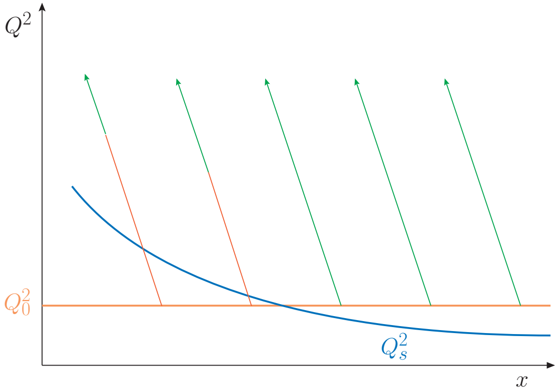
- Our strategy at the LHeC

1. Our Strategy

DGLAP evolution and safe - unsafe regions

Schematic DGLAP evolution:

$$Q^2 \frac{d}{dQ^2} G(x, Q^2) = \int_x^1 \frac{dy}{y} P\left(\alpha_s(Q^2), \frac{x}{y}\right) G(y, Q^2)$$



- Standard DGLAP: "safe region", driven by asymptotic DGLAP solution
- Interesting effects: "unsafe region"

How to single out the unsafe region?

Strategy

- Fit PDFs only in a safe region
- Back-evolve safe PDFs in the might not so safe region, and use them to compute observables
- Compare these predictions with data

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Tension between data and predictions $\rightarrow$ evidence for deviations from DGLAP!

Caveat: Possible deviations from NLO DGLAP are small

- This analysis is meaningful only on statistical grounds
- A reliable estimate of PDFs uncertainties is mandatory!

2. Our Strategy @ Work: Small-x HERA data

How can we find out the safe region?

Useful safe PDFs

- Safe region: fit only data with $Q^2 > Q^2_{min}$, $x > x_{min}$
- But if we cut too many data: huge errors on PDFs!

Our proposal

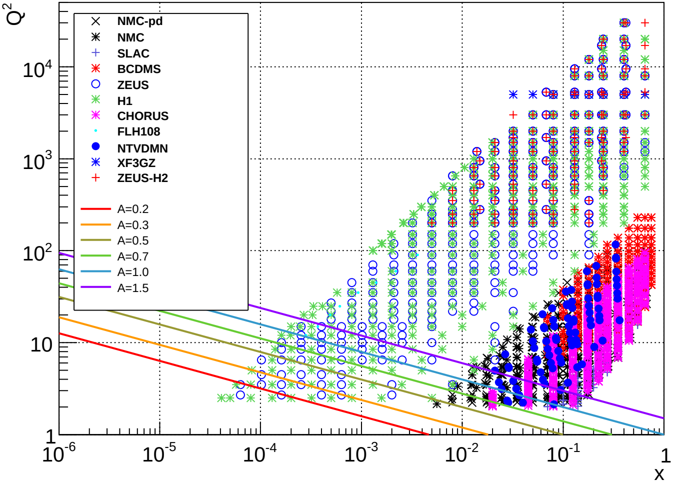
Use the saturation-inspired cut

$$Q^2 > Q_s(x)^2 \equiv A\, x^{-\lambda},$$

with $\lambda = 0.3$ and varying A.

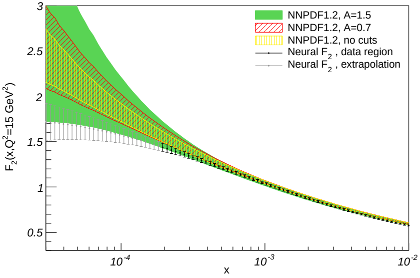
- Theoretically appealing (also with r.c.)
- Always keep large-x data to constrain PDFs

Our "safe" regions



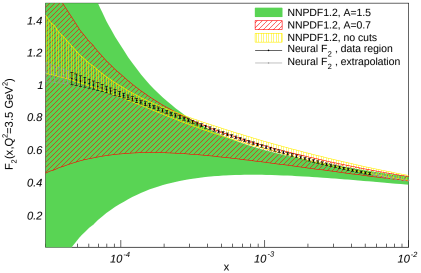
Reliable error estimates → NNPDF1.2 *(See A. Guffanti's talk)*

Qualitative results: F_2 at small x



Observables at higher scales: only larger errors

At lower scales: systematic overestimation of the evolution!



Systematic deviations from NLO DGLAP?

Still compatible within errors...

Quantitative analysis: statistical estimators

Interesting deviations from NLO DGLAP:
These deviations should not be due only to statistical fluctuations

How to single out systematic deviations

- Local indicators:
  Find a quantity to measure deviations in a statistical meaningful way
- Global informations:
  Use global fit details (χ^2) as a cross check

Local indicators: statistical distance

How to measure deviations

Introduce the statistical distance

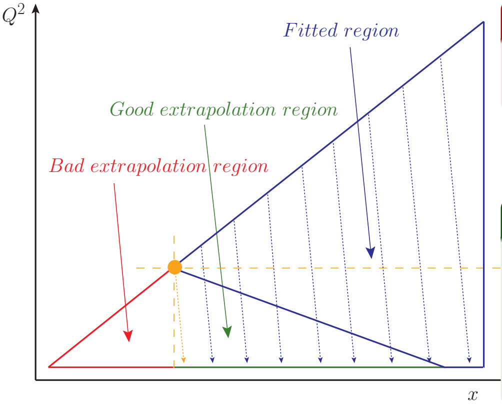
$$d\left(x, Q^2\right) \equiv \sqrt{\frac{\left(F_{fit} - F_{data}\right)^2}{\sigma_{fit}^2 + \sigma_{data}^2}} \cdot \mathrm{sgn}\left[F_{data} - F_{fit}\right],$$

Expectations:

- Statistical fluctuations:
  $|d| \sim 1$ or less; $\langle d \rangle \sim 0$
- Systematic deviations:
  $|d| >> 1$; $\langle d \rangle \neq 0$

The DGLAP causal region: where to compute distances

Recall the convolution-structure of DGLAP evolution:



Bad extrapolation region

DGLAP prediction meaningless
(although continuity...)

Good extrapolation region

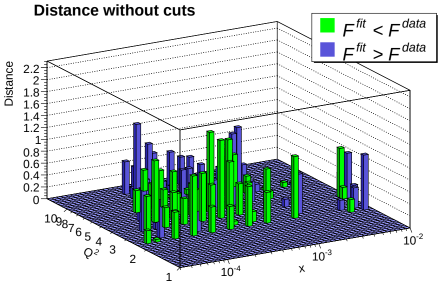
- Study DGLAP trajectories*
- Trust DGLAP from the *smallest-x trajectory* on

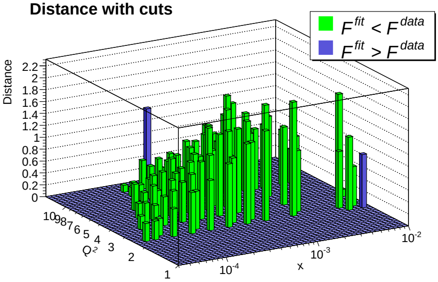
* In our case: almost vertical trajectories

Distances, results: systematic effect!

Fit without cuts:

- Distances sgn uncorrelated
- $|d| \sim 1$ as expected
- $\langle d \rangle_{causal} \approx -0.05$





Fit with A=1.5 cut

- Strong correlation
- $|d| \sim 1.5 - 2$
- $\langle d \rangle_{causal} \approx -0.8$

Cross check: a global analysis I - the fitted region

Fitting the unsafe region

In the unsafe region, NLO DGLAP is not the right theory

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The fit quality should be poor

$\chi^2/d.o.f.$ for different cuts

A	# of fitted points	χ^2_{fit}	$\chi^2_{fit}/d.o.f.$
0	3382	4430	1.31
0.5	3341	4301	1.29
1.0	3236	4077	1.26
1.5	3092	3896	1.26

With cuts, the fit quality improves!

Cross check: a global analysis II - the excluded region

Use χ^2 to estimate tension between data and NLO DGLAP

1. Compute χ^2 in the excluded causal region for different fits
2. Compare $\chi^2_{\text{without cuts}}$ with χ^2_{cuts}

see Eur.Phys.J.C35:325-348,2004 and JHEP 0506:080,2005 for MRST/CTEQ studies

χ^2 in the excluded HERA causal region

A	$\chi^2_{\text{without cuts}}/d.o.f.$	$\chi^2_{\text{cut}}/d.o.f$
0.5	$19.68/25 = 0.79$	$106.22/25 = 4.25$
1.0	$54.41/44 = 1.24$	$138.24/44 = 3.14$
1.5	$62.31/59 = 1.06$	$860.65/59 = 14.6$

The effect is confirmed!

Summing all our results up, we can safely state that there is evidence for deviations from NLO DGLAP in small-x HERA data

Possible explanations for deviations from DGLAP: HQ

Can we understand the origin of such deviation?

A first trivial explanation: HQ effects

- In our present analysis, HQ effects are not properly included
- HQ effects point in the right direction!

However:

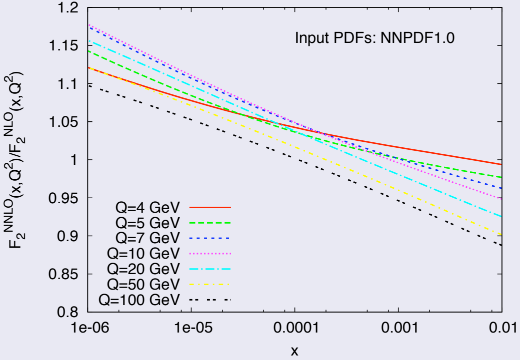
- From a preliminary analysis HQ effects seem not to be large enough to explain our deviations

HQ alone are not enough

HQ effects are likely to mild our observed deviation, but not to completely wash it out!

Possible explanations for deviations from DGLAP: NNLO

Compare NNLO $K-$factors with our observation

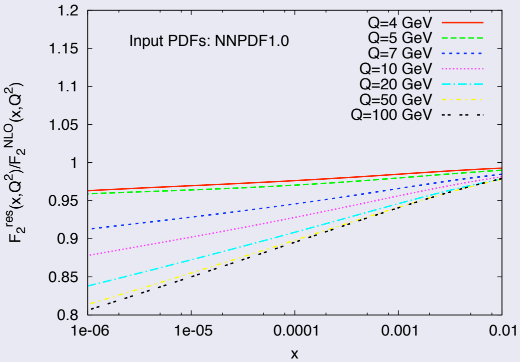


Wrong sign! NNLO ruled out!

At small-x: $F_2^{NNLO} - F_2^{NLO} > 0$, while $F_2^{data} - F_2^{NLO} < 0$

Possible explanations: resummation

Consider now perturbative resummation:

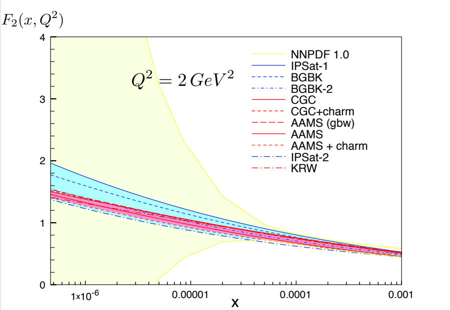


Correct sign!

Possible explanations: saturation

Another possibility: parton saturation

Consider saturation predictions for F_2 [courtesy J. Albacete]



Again correct sign!

Possible explanations: summary

Sources for deviations

Different possible sources for deviations from NLO DGLAP:

- NNLO $\rightarrow$ ruled out
- HQ: it is likely to reduce our observed deviation, but not to completely explain it
- Resummation / saturation: both qualitatively compatible with our observation

Can we quantitatively understand the deviation?

Too few data to disentangle resummation/saturation effects

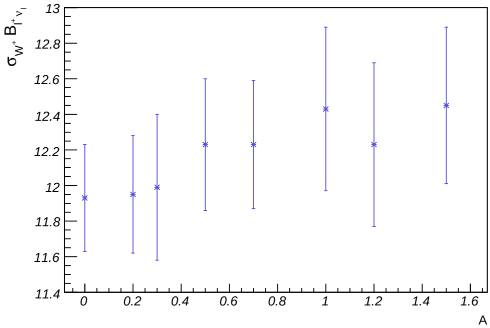
$\Downarrow$

LHeC?

Effects on precision physics

Consider "standard candles", i.e. very precise observables

- General trends for central values, but still too large errors



After LHC/LHeC → smaller PDFs errors

If the trend is confirmed, issue for SM precision physics!

Conclusions

Summarizing...

- A strategy for finding deviations from NLO DGLAP has been proposed
- This strategy has been successfully applied to small-x HERA data

Results from HERA data

At HERA there is evidence for deviations from NLO DGLAP!

More precisely:

- at low enough $Q^2 \lesssim 10$ GeV^2: deviations from NLO DGLAP
- deviations compatible with resummation / saturation, not with NNLO

Outlook

Refine the HERA analysis

- Consider HQ effects properly
- Perform a resummed fit

Once the machinery has been successfully tested with HERA data:

Perform a LHeC analysis!

Study deviations with LHeC pseudo-data:

- Is it possible to quantitatively understand such deviations? Disentangle saturation from resummation...
- Sizeable effects on precision physics?

The LHeC could (hopefully) answer these questions!