Impact of low-x resummation on QCD analysis of HERA data

S. Glazov (DESY), DIS-2018, Kobe 19/04/2018

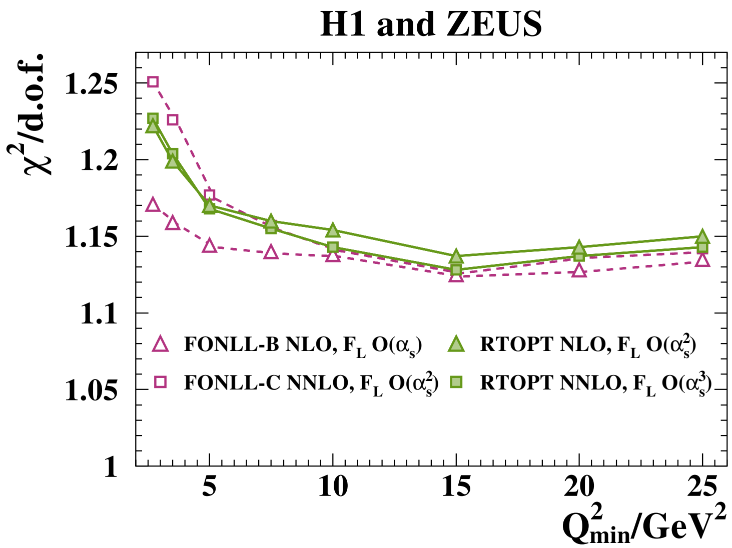
xFitter project

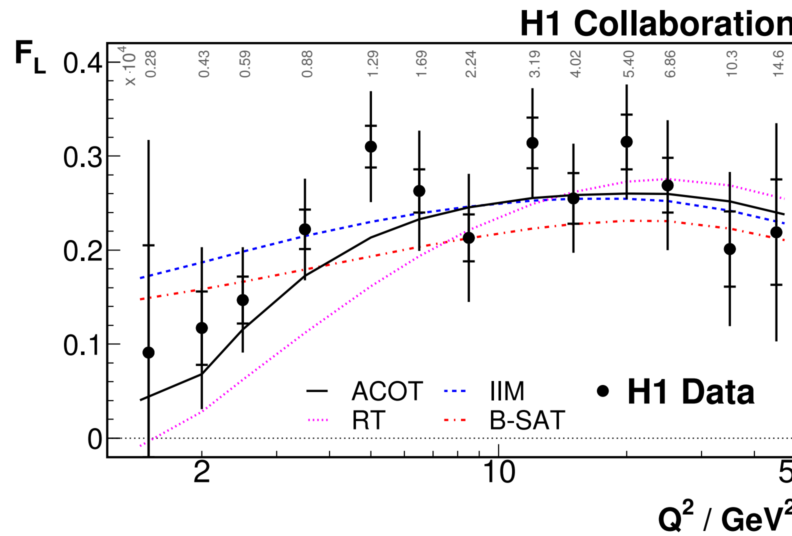
- `xFitter` is an open source QCD analysis tool.
- Last release, `2.0.0` “Frozen Frog”, used in many analyses by experimental and phenomenological groups.
- `xFitter` provides interface to many data samples, with complex correlation model, fast χ^2 computation, fast evolution using QCDNUM, build-in computation of DIS cross sections and interfaces to APPLGRID and FastNLO, and other features such as different PDF parameterisations and regularisation methods.
- `xFitter` has interfaces to a number of external packages, for this talk the most important are evolution package APFEL (CPC 185, 1647 (2014)) and $\ln 1/x$ resummation package HELL (EPJ C76(11), 597 (2016), JHEP 12, 117 (2017).) which is interfaced via APFEL.

→ see talk of Fred Olness for more details on the `xFitter` project.

This talk is focused on the studies described in 1802.00064.

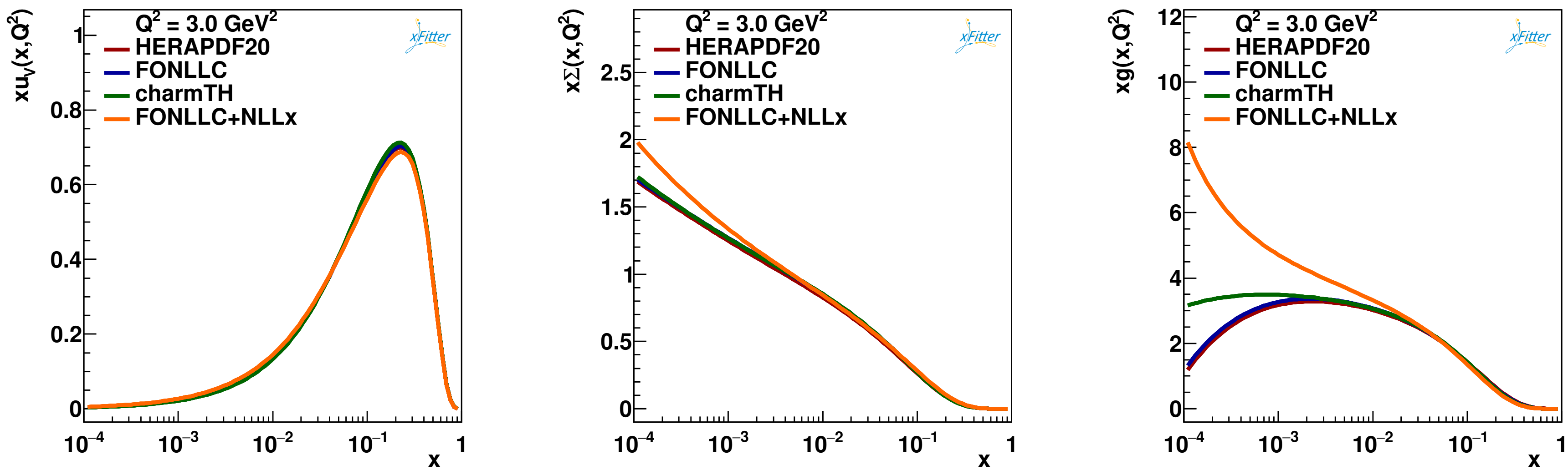
Low x analysis motivations





- Several indications that NNLO DGLAP fits have difficulty with to describe low Q^2 HERA data, NLO being better vs NNLO, depending on order of F_L (EPJC75 (2015) 12, 580).
- Alternative models, such as dipole, provide good description of the data (EPJC71(2011) 1579).
- Recent study from NNPDF collaboration, showing that $\ln 1/x$ resummation improves NNLO fits arXiv:1710.05935.

From HERAPDF-like NNLO to NNLO+NLLx



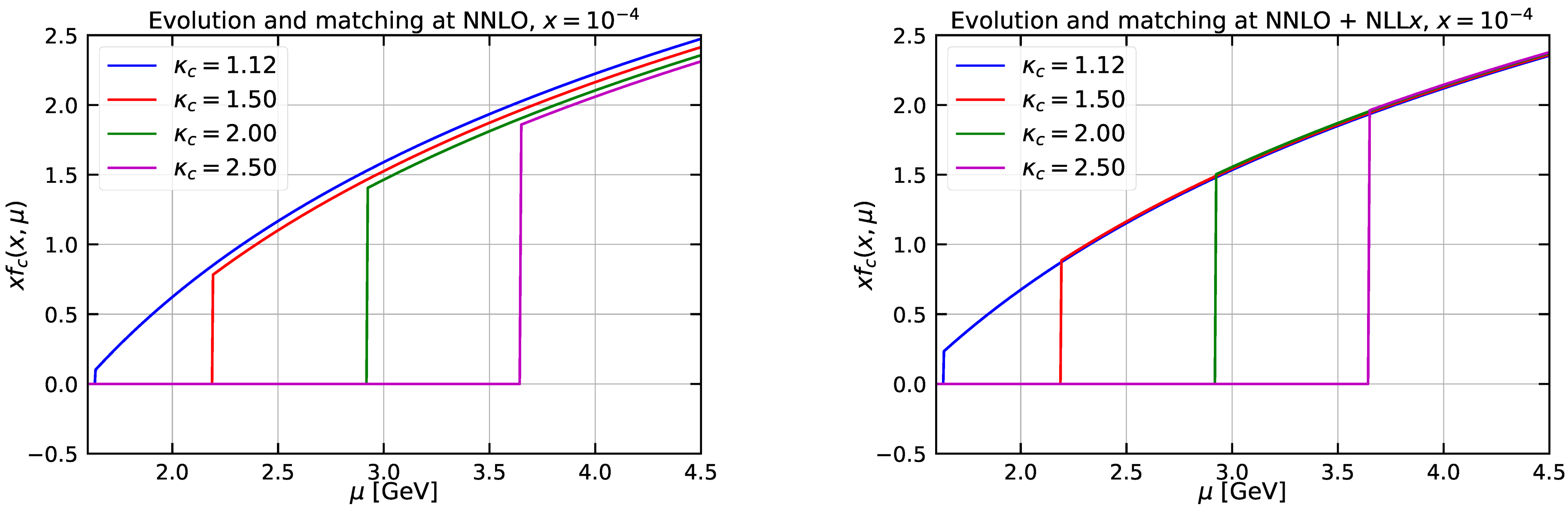
- Start with HERAPDF20-like settings, using RT scheme. Input data: HERA2.0 inclusive and combined charm.

→ Move to FONLL-C: no change in PDFs.

→ Raise the charm matching point from $\mu_C = m_C = 1.43$ GeV to $\mu_C = 1.12 m_C = 1.6$ GeV (needed for HELL). Notable change in the gluon distribution.

→ Include $\ln 1/x$ resummation: large change in the gluon, χ^2 drops by 73 units (for 1131 degrees of freedom).

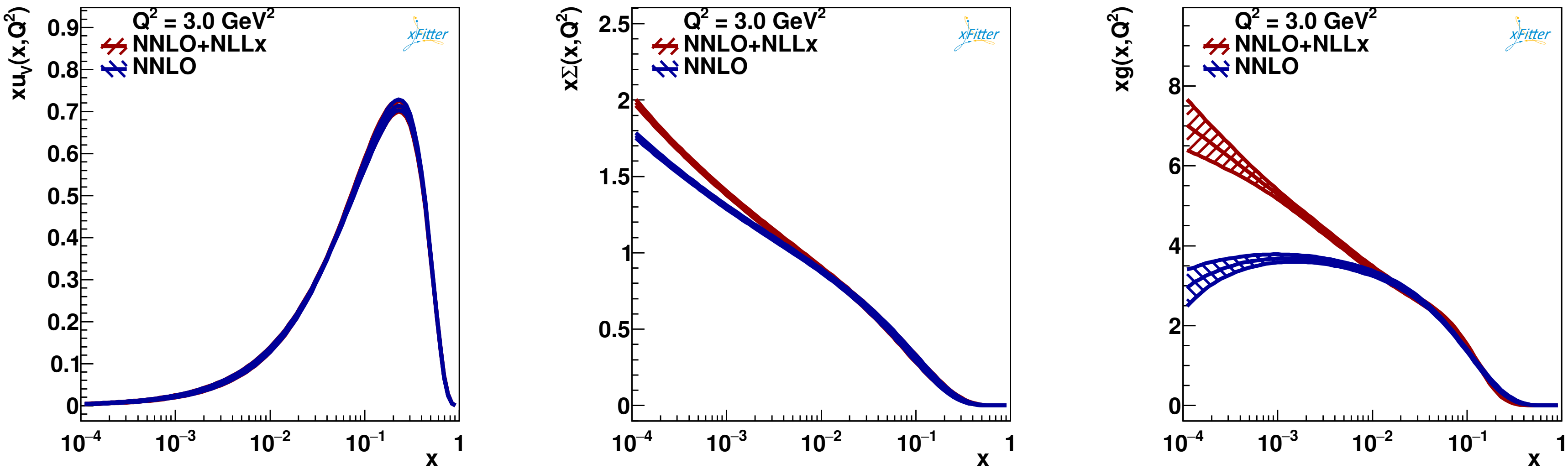
Matching at NNLO vs NNLO+NLLx



- Vary charm matching point μ_c between $1.12 m_c$ and $2.5 m_c$, study low $x = 10^{-4}$.
- For NNLO, steps observed at the matching point; to compensate for smaller charm PDF the gluon distribution is increased.
- Much smoother behavior when $\ln 1/x$ resummation is included.

(see also talk by Fred Olness on the heavy flavor matching point studies)

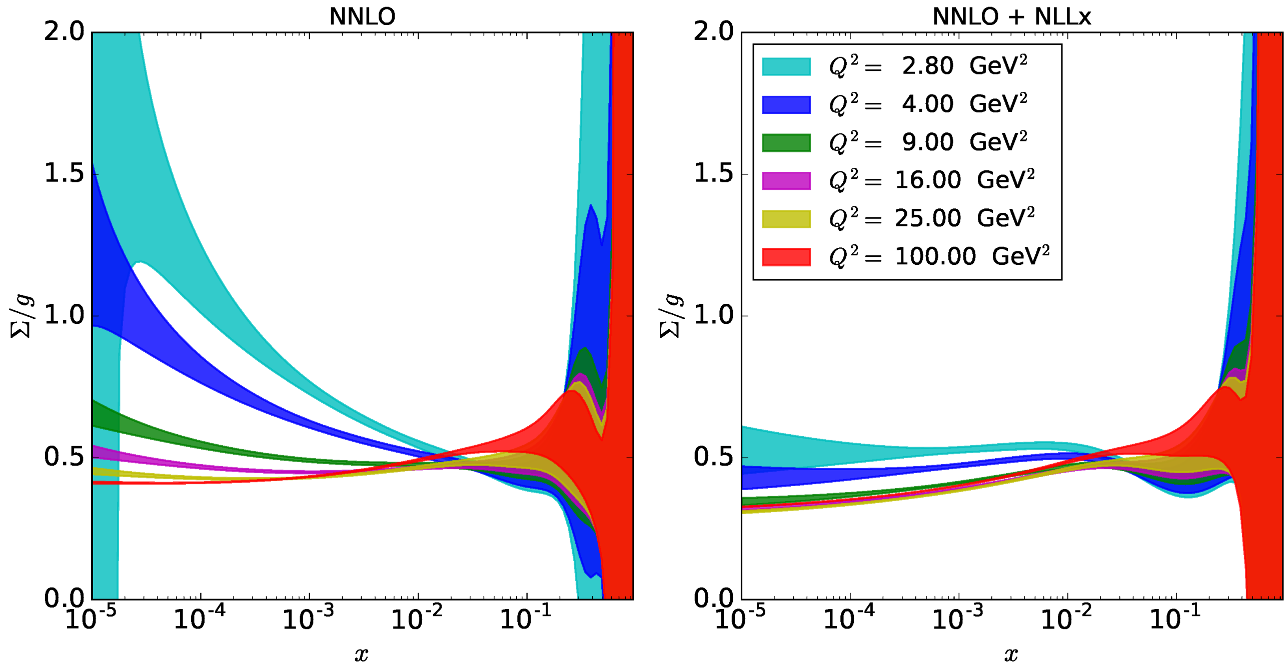
PDFs at NNLO and NNLO+NLLx



- Optimize settings for the NNLO and NNLO+NLLx fits: charm/bottom-quark mass scan, parametersiation scan.
- Evaluate experimental uncertainties.
- Valence shape is unchanged by including $\ln 1/x$ resummation, singlet is affected slightly while gluon is affected the most.

→ The rise of the gluon and the singlet towards low x seems to have the same power after resummation is included.

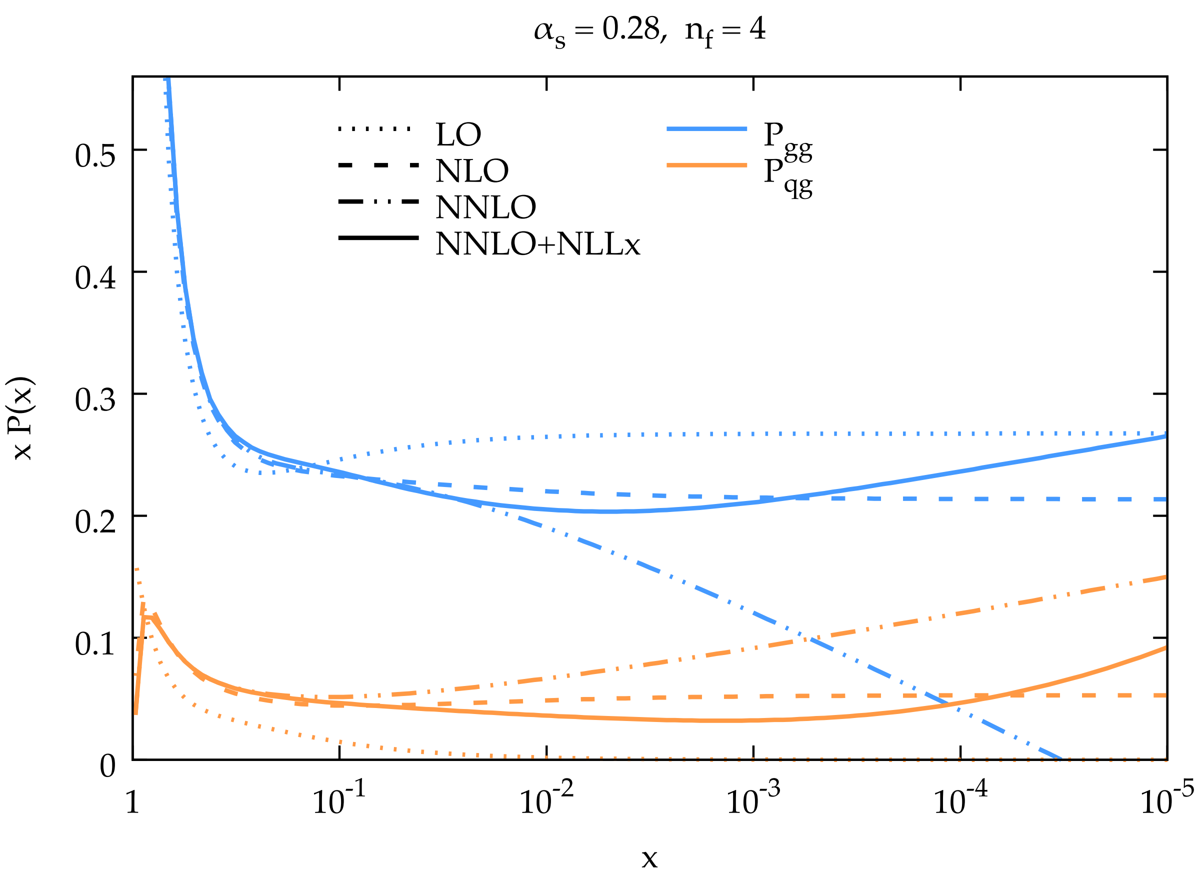
Ratio Σ/g



- Quantify the power of the rise of xg and $x\Sigma$ by examining evolution of their ratio.
- Large evolution at NNLO, with the ratio exceeding unity at low scales.
- Ratio is ≤ 0.5 when $\ln 1/x$ resummation is included.

$\rightarrow$ more inline with "dynamic" picture of PDFs in which the sea is generated from the gluon perturbativaly like in GRV fits.

Splitting functions P_{qg} and P_{gg}



Spitting functions P_{gg} and P_{qg} show un-physical behavior at NNLO: $P_{qg} > P_{gg}$ at $x \sim 10^{-3}$ for $Q \sim 2$ GeV. This leads to the fast rise of the singlet vs gluon at low scales. Resummed splitting functions show behavior inline with the expectations.

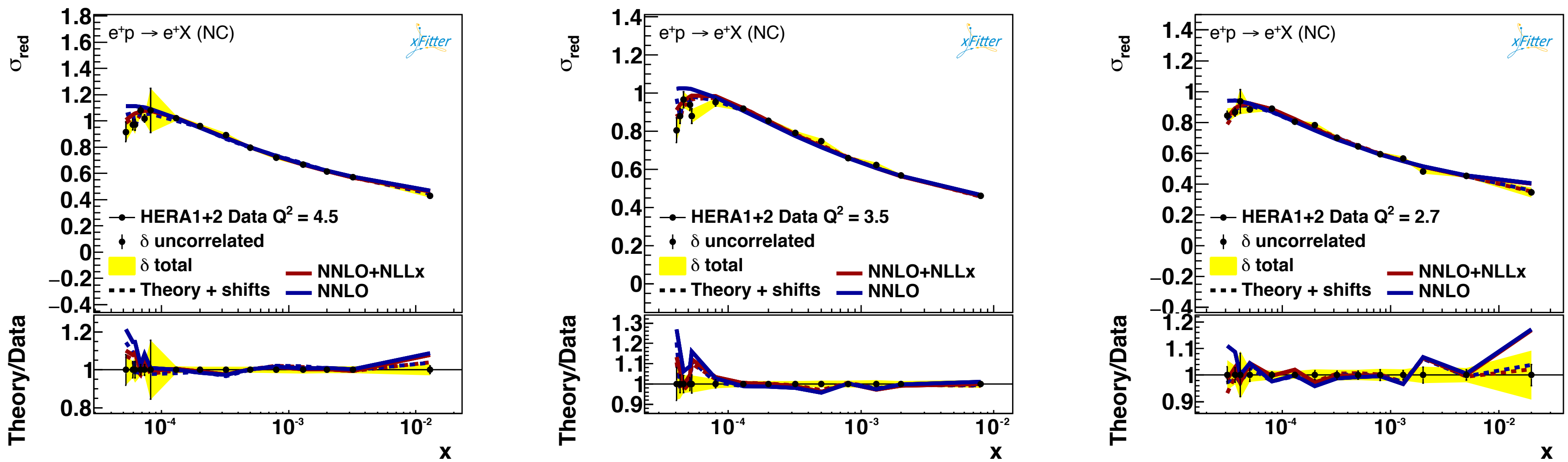
Data vs theory

	NNLO fit	NNLO+NLLx fit
Total χ^2/d.o.f	1446/1178	1373/1178
subset NC 920 $\tilde{\chi}^2$/n.d.p	446/377	413/377
subset NC 820 $\tilde{\chi}^2$/n.d.p	70/70	65/70
subset charm $\tilde{\chi}^2$/n.d.p	48/47	49/47
correlated shifts inclusive	102	77
correlated shifts charm	15	11
log term inclusive	20	-3
log term charm	-2	-1

$$\chi^2 = \sum_i \frac{\left[D_i - T_i\left(1 - \sum_j \gamma^i_j b_j\right)\right]^2}{\delta^2_{i,\mathrm{unc}} T_i^2 + \delta^2_{i,\mathrm{stat}} D_i T_i} + \sum_j b_j^2 + \sum_i \ln \frac{\delta^2_{i,\mathrm{unc}} T_i^2 + \delta^2_{i,\mathrm{stat}} D_i T_i}{\delta^2_{i,\mathrm{unc}} D_i^2 + \delta^2_{i,\mathrm{stat}} D_i^2},$$

$\rightarrow$ largest improvements in the χ^2 are observed for the precise $E_p = 920$ GeV set as well as for correlated systematic uncertainties and log-penalty term.

Data vs Theory



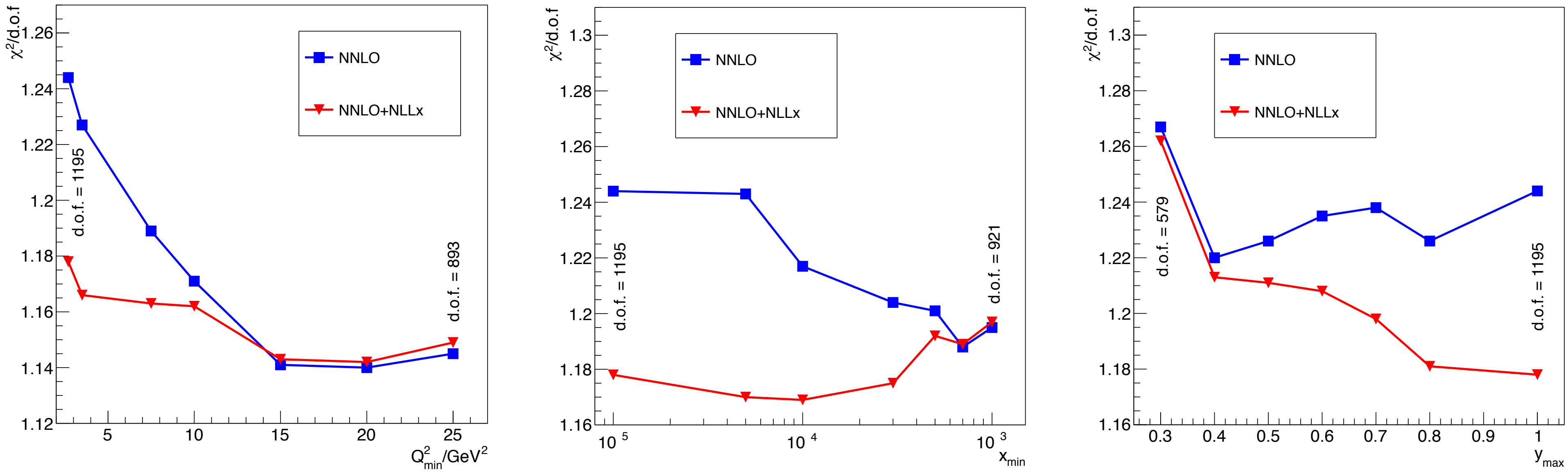
At low Q^2,

$$\sigma_{\rm red} = F_2 - \frac{y^2}{1+(1-y)^2} F_L \, .$$

where inelasticity $y = \frac{Q^2}{S\,x}$.

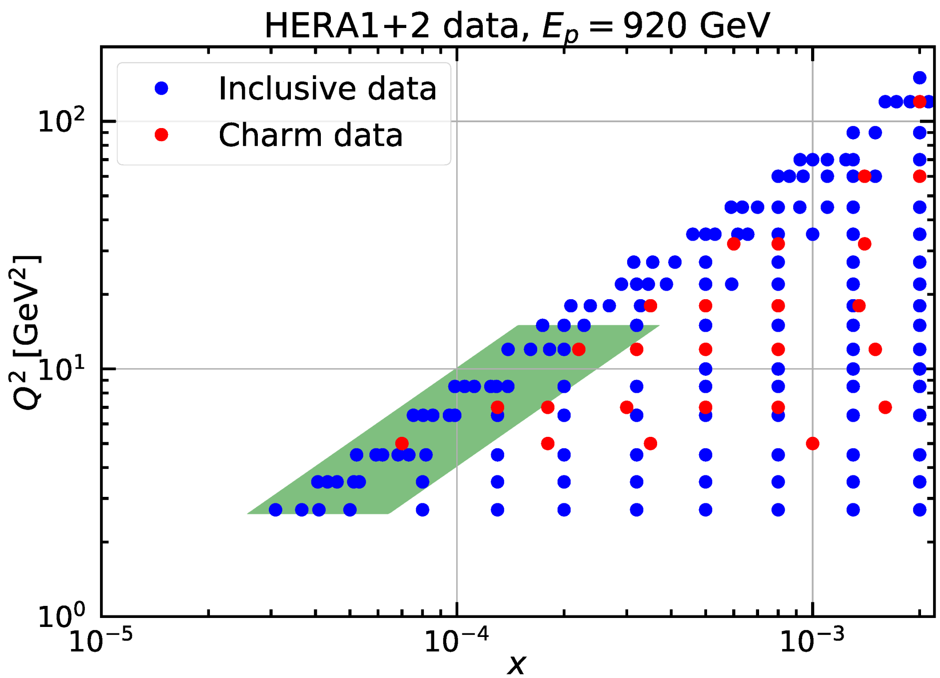
- Turn-over of the cross section at low x corresponds to large y and increased influence of F_L.
- The turn-over is better described when $\ln 1/x$ resummation is included.
- Even $Q^2 = 2.7$ GeV^2 bin looks acceptable, however χ^2 for this bin remains poor for both fits.

Isolating the impact of NLLx



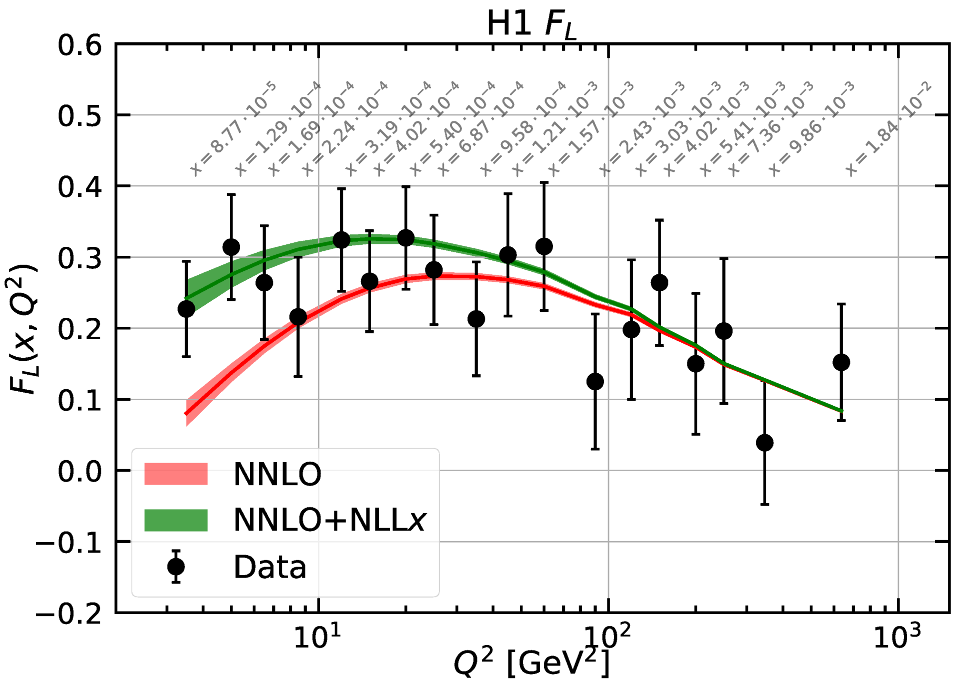
- Repeat fits with various kinematic cuts on the data.
- Include $Q^2 = 2.7\ \mathrm{GeV}^2$ bin in this study.
- Scan in Q^2_{min}, x_{min} and additionally in y_{max}.
- Improvements when $\ln 1/x$ resummation is included for low Q^2, low x and high y.
- Quality of the description by both NNLO and NNLO+NLLx fits becomes similar when these regions are excluded.

Region of maximal impact



- 1D scans define the regions where $\ln 1/x$ resummation has largest impact: $Q^2 < 15$ GeV, $x < 5 \cdot 10^{-4}$, and $y > 0.4$ (assuming $E_p = 920$ GeV).
- This defines the "green region" in x, Q^2 kinematic plane.
- When this region is excluded, the difference in χ^2 between NNLO and NNLO+NLLx fits is only 15 units compared to 73 units when it is included.

The structure function F_L

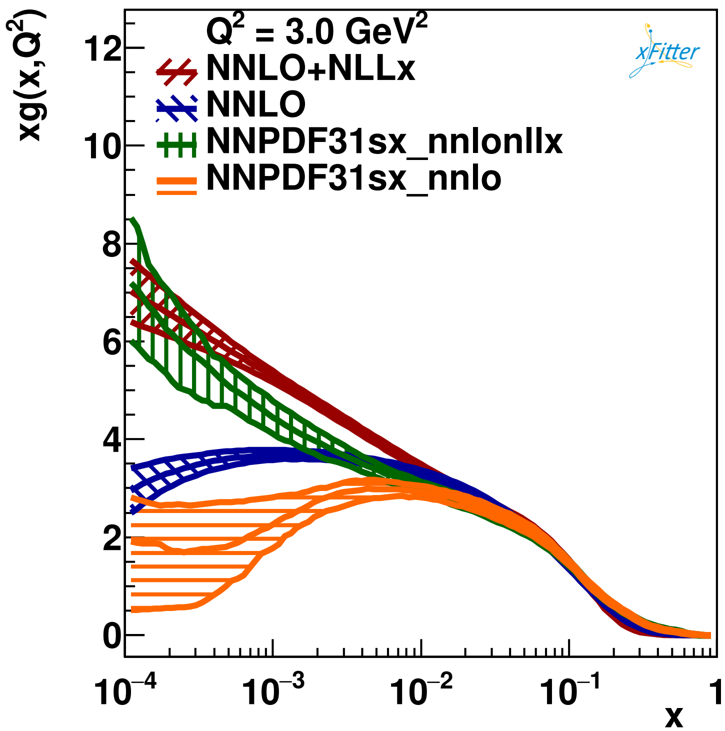


- The fit with $\ln 1/x$ resummation included gives better description of the SF F_L measured by H1 (EPJ C74, (2014) 2814).
- However, given uncertainties, more important is the accurate measurement at high y using large $E_p = 920$ GeV sample ("indirect F_L").

Summary

- NNLO fits with and without $\ln 1/x$ resummation are performed to the HERA data.
- Significant improvement in the χ^2 is observed when $\ln 1/x$ resummation is included, concentrated in the region at low x, low Q^2 and high y where the contribution of the structure function F_L is sizable.
- NNLO+NLLx fits have increased gluon distribution at low x and low Q^2. The rise of the singlet and gluon distribution towards low x becomes similar, in contrast to suppressed gluon for pure NNLO fits, suggesting more simple relation between them.

Comparison to NNPDF3.1sx PDF sets



- Similar trend that NNLO+NLLx gluon is larger at low *x* vs NNLO.
- Many differences in the fits to compare them directly: fitted vs perturbative charm, charm threshold, methods for uncertainty estimate.