xFitter project - a framework for QCD studies

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on behalf of the xFitter Developers' Team

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Outline

- Description of the xFitter project: methods, schemes and data used for PDF determination.
- The main results for: "The impact of low x resummationof QCD analysis of HERA data" xFitter Developers' Team, EPJC 78 (2018) 8, 621.

Motivation

- The recent discovery of the Higgs boson and the extensive searches for signals of new physics in LHC pp collisions demand high-precision calculations to test the validity of the Standard Model (SM) and factorisation in (QCD).
- The factorisation theorem for a hadronic cross section read:

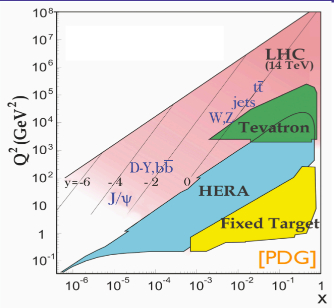
$$d\sigma_{had} = W_{ij} \otimes f_i \otimes f_j d\Phi$$

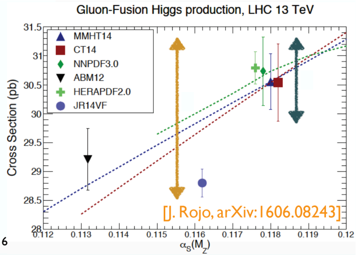
- partonic cross section:
  - Process dependent
  - High-energy dominated
  - Computable in perturbation theory
- parton distribution functions:
  - Universal (for a given hadronic species)
  - Low-energy dominated
  - Perturbation theory inapplicable

- The rapid flow of new data from the LHC has motivated the development of a tool to combine them together in a fast, efficient, open-source framework : **xFitter framework**
- How do we determine parton distribution functions (PDFs)?
- Presently, the most accurate and reliable way is through **fits to data**

Fitting PDFs: Introduction

- Data sets:
  - as large and varied as possible
  - spanning a wide kinematic range
- Estimate of the uncertainties:
  - include full experimental uncertainties
  - ensure a faithful representation
- Choice of the parametrisation:
  - avoid parametrisation biases
- Theoretical inputs:
  - higher order corrections
  - Heavy-quarks mass effect
  - ...
- Different choices may lead to different results

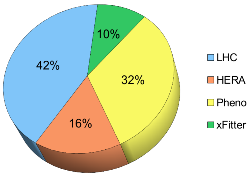




The xFitter Project

- The xFitter project (former HERAFitter) is an unique open-source QCD fit framework.
- GitLab (CERN) is now the main repository of the project: https://gitlab.cern.ch/fitters/xfitter (open access to download for everyone - read only)

- This code allows users to:
  - extract PDFs from a large variety of experimental data
  - assess the impact of new data on PDFs
  - check the consistency of experimental data
  - test different theoretical assumptions



- Around 30 active developers between experimentalists and theorists.
- LHC experiments provide the main developments and usage of the xFitter platform.

The xFitter Project - list of analysis

- More than 50 publications obtained using xFitter from the beginning of the project:https://www.xfitter.org/xFitter/xFitter/results

List of analyses by xFitter

The link to the list of analyses using former HERAFitter can be accessed here

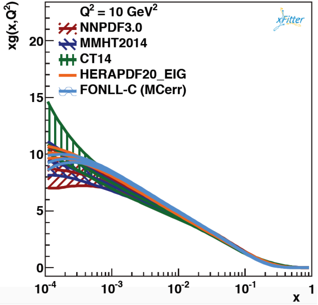
7	02.2018	xFitter Developers and Marco Bonvini	Eur.Phys.J. C78 (2018) no.8, 621, arXiv:1802.00064	Impact of low-x resummation on QCD analysis of HERA data	LHAPDF6 grid files
6	07.2017	xFitter Developers	Eur.Phys.J. C77 (2017) no.12 837, arXiv:1707.05343	Impact of the heavy quark matching scales in PDF fits	LHAPDF grids
5	01.2017	F. Giuli, xFitter Developers' team and M. Lisovyi	Eur.Phys.J. C77 (2017) no.6 400, arXiv:1701.08553	The photon PDF from high-mass Drell Yan data at the LHC	
4	03.2016	xFitter and APFEL teams and A. Geiser	JHEP 1608 (2016) 050, arXiv:1605.01946	A determination of mc(mc) from HERA data using a matched heavy flavor scheme	

List of analyses using xFitter

Number	Date	Group	Reference	Title
2018				
58	02.2018	M. Goharipour, H. Khanpour, V. Guzey.	arXiv:1802.01363	First global next-to-leading order determination of diffractive parton distribution functions and their uncertainties within the xFitter framework
2017				
57	12.2017	V. Bertone, M. Botje	arXiv:1712.08162	A C++ interface to QCDNUM
56	12.2017	A. Kusina et. al.	arXiv:1712.07024	Gluon shadowing and antishadowing in heavy-flavor production at the LHC
55	12.2017	A. Luszczak, W. Schaefer	Phys. Rev. C 97, 024903 (2018) arXiv:1712.04502	Incoherent diffractive photoproduction of J/ψJ/ψ and YY on heavy nuclei in the color dipole approach
54	11.2017	H-W. Lin et. al.	arXiv:1711.07916	Parton distributions and lattice QCD calculations: a community white paper

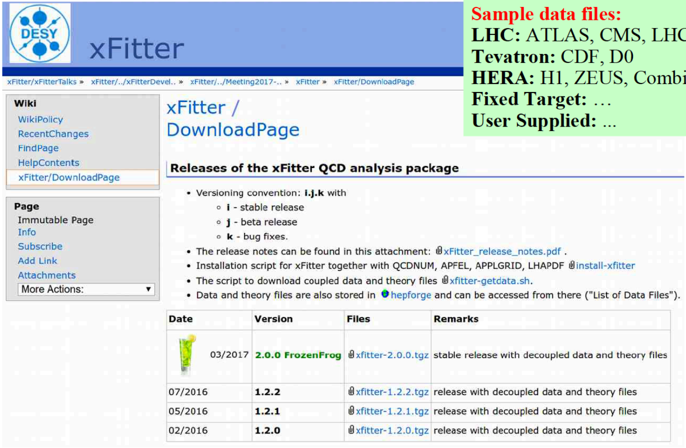
PDFs Fits in xFitter

- Parametrise PDFs at the initial scale:
  - several functional forms available ("standard", Chebyshev, etc.)
  - define parameters to be fitted
- Evolve PDFs to the scales of the fitted data points:
  - DGLAP evolution up to NNLO in QCD and NLO QED (QCDNUM, APFEL, MELA)
  - non-DGLAP evolutions (dipole, CCFM)
- Compute predictions for DIS and hadron colliders:
  - several heavy quarks treatments are avaliable in DIS (ZM-VFNS, ACOT, FONLL, RT, FFNS)
  - predictions for hadron-collider data through fast interfaces (APPLgrid, FastNLO)
- Comparison data-predictions via χ^2 :
  - multiple definitions available
  - consistent treatment of the systematic uncertainties
- Minimise the χ^2 w.r.t. the fitted parameters:
  - using MINUIT
- Useful drawing tools.



xFitter release 2.0.0

- https://www.xfitter.org/xFitter/xFitter/DownloadPage



xFitter

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Releases of the xFitter QCD analysis package

- Versioning convention: **i.j.k** with
  - **i** - stable release
  - **j** - beta release
  - **k** - bug fixes.
- The release notes can be found in this attachment: xFitter_release_notes.pdf .
- Installation script for xFitter together with QCDNUM, APFEL, APPLGRID, LHAPDF install-xfitter
- The script to download coupled data and theory files xfitter-getdata.sh.
- Data and theory files are also stored in hepforge and can be accessed from there ("List of Data Files").

Date	Version	Files	Remarks
03/2017	**2.0.0 FrozenFrog**	xfitter-2.0.0.tgz	stable release with decoupled data and theory files
07/2016	**1.2.2**	xfitter-1.2.2.tgz	release with decoupled data and theory files
05/2016	**1.2.1**	xfitter-1.2.1.tgz	release with decoupled data and theory files
02/2016	**1.2.0**	xfitter-1.2.0.tgz	release with decoupled data and theory files

Sample data files:
LHC: ATLAS, CMS, LHCb
Tevatron: CDF, D0
HERA: H1, ZEUS, Combined
Fixed Target: …
User Supplied: ...

- By default, only final combined HERA I+II data are distributed.
- getter-xfitter.sh script to download data with corresponding theory files.
- In directory 'datasets' located all available files.

xFitter on Hepforge: data access

- http://xfitter.hepforge.org/

- Possibility to download data files (including theory).
- Updated automatically with new data added to svn.
- Your feedback is welcome! (via email: xfitter-help@desy.de)

- http://xfitter.hepforge.org/data.html

This page contains the list of publicly available experimental data sets (with corresponding theory grids if available) in the xFitter package.
To download data set please click on the arXiv link (and open/save tar.gz file).

No	Collider	Experiment	Reaction	arXiv	Readme
1	fixedTarget	bcdms	inclusiveDis	cern-ep-89-06	README
2	hera	h1	beautyProduction	0907.2643	
3	hera	h1	inclusiveDis	1012.4355	
4	hera	h1	jets	0706.3722	README
5	hera	h1	jets	0707.4057	README
6	hera	h1	jets	0904.3870	README
7	hera	h1	jets	0911.5678	README
8	hera	h1	jets	1406.4709	README
9	hera	h1zeusCombined	charmProduction	1211.1182	
10	hera	h1zeusCombined	inclusiveDis	0911.0884	
11	hera	h1zeusCombined	inclusiveDis	1506.06042	
12	hera	zeus	beautyProduction	1405.6915	
13	hera	zeus	diffractiveDis	0812.2003	
14	hera	zeus	jets	0208037	
15	hera	zeus	jets	0608048	
16	hera	zeus	jets	1010.6167	
17	lhc	atlas	drellYan	1305.4192	
18	lhc	atlas	drellYan	1404.1212	
19	lhc	atlas	jets	1112.6297	

xFitter Developers Meeting

- External xFitter's meeting at Cracow University of Technology, March 2018:
  - 30 participants
  - 2.5 days workshop with number of talks and many discussions

My contribution to the xFitter projects

- Implementation of dipole model of DIS in xFitter framework (2012)
  - BGK (Bartels-Golec-Kowalski) parametrization

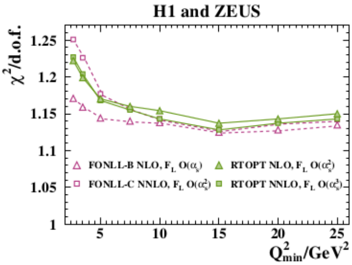
$$\hat{\sigma}(r,x) = \sigma_0 \left\{1 - \exp\left[-\pi^2 r^2 \alpha_s(\mu^2) x g(x,\mu^2)/(3\sigma_0)\right]\right\}$$

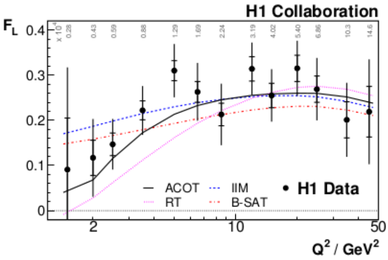
  - $\mu^2 = C/r^2 + \mu_0^2$ is the scale of the gluon density
  - μ_0^2 is a starting scale of the QCD evolution. $\mu_0^2 = Q_0^2$
  - gluon density is evolved according to the LO or NLO DGLAP eq.
  - soft gluon:

$$xg(x,\mu_0^2) = A_g\, x^{\lambda_g}\, (1-x)^{C_g}$$

- Comprehensive analysis of HERA data using xFitter and dipole models
  - "Dipole model analysis of highest precision HERA data, including very low Q^2's" A.Luszczak, H.Kowalski, Phys.Rev. D95 (2017) 014030
  - "Dipole model analysis of high precision HERA data" A.Luszczak, H.Kowalski, Phys.Rev. D89 (2014), 074051
- Collaboration with xFitter Team in several analysis: co-author of 8 papers
- Analysis with gluons obtained in xFitter (BGK gluon)
  - "Incoherent diffractive photoproduction of J/ψ and Υ on heavy nuclei in the color dipole approach" A.Luszczak, W.Schafer, Phys.Rev. C97 (2018), 024903

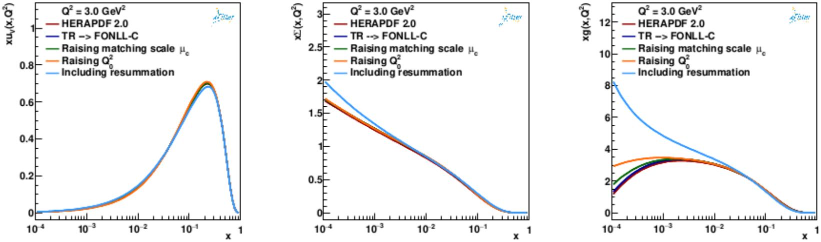
Low x analysis motivations





- 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 EPJC78 (2018) 4, 321.

From HERAPDF-like NNLO to NNLO +NLLx



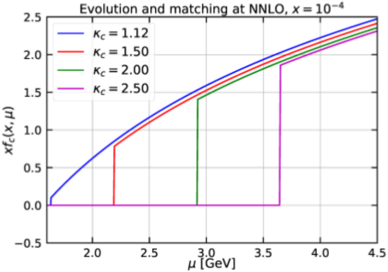
- Start with HERAPDF20-like settings, using RT scheme. Input data: HERA2.0 inclusive, combined charm, and bottom data.

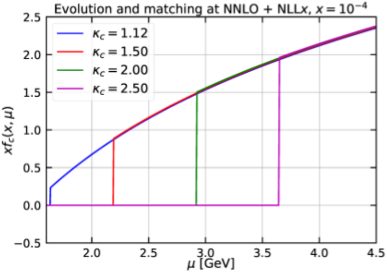
→ Move to FONLL-C: no change in PDFs.

→ Raise the evolution starting scale as well as 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).

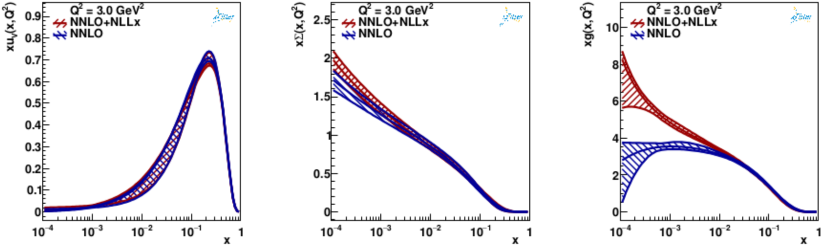
Matching at NNLO vs NNLO+NLLx





- Vary charm matching point μ_c between $1.12m_c$ and $2.5m_c$, 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.

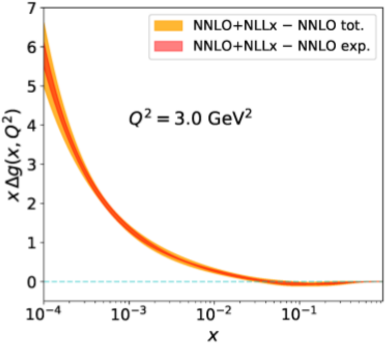
PDFs at NNLO and NNLO+NLLx



- Optimize settings for the NNLO and NNLO+NLLx fits: charm/bottom-quark mass scan, parametersiation scan.
- Evaluate experimental, model and parameterisation 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.

$\Delta x f(x)$ for NNLO vs NNLO+NLLx evolution



- Significance in the gluon shape change can estimated using toy MC method.
- Synchronized toy MC replica of the data are fitted at NNLO and NNLO+NLLx.
- Model and parameterisation uncertainties also propagated in a coherent way.

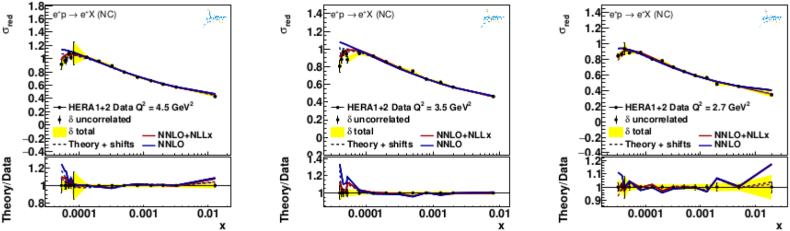
Data vs theory

	NNLO fit	NNLO+NLLx fit
Total χ^2/d.o.f	1468/1207	1394/1207
subset NC 920 $\tilde{\chi}^2$/n.d.p	447/377	413/377
subset NC 820 $\tilde{\chi}^2$/n.d.p	67/70	65/70
subset charm $\tilde{\chi}^2$/n.d.p	48/47	49/47
correlated shifts inclusive	103	78
correlated shifts charm	12	11
log term inclusive	21	−4
log term charm	−1	−1

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

→ 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



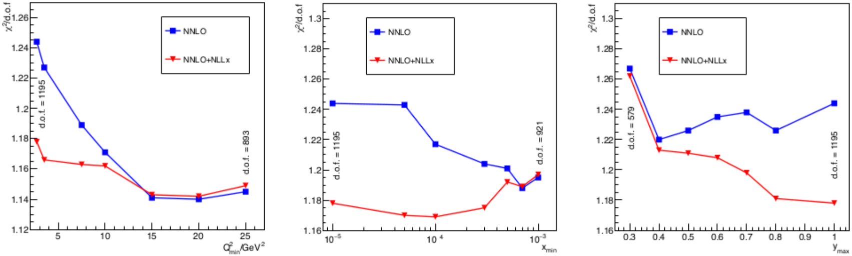
At low Q^2,

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

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

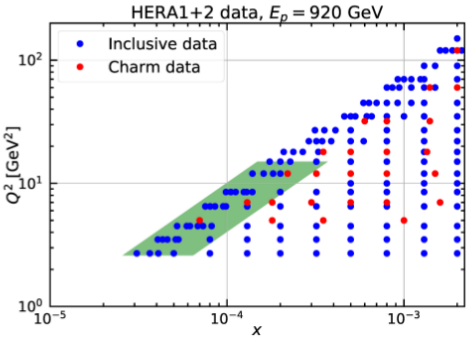
- Turn-over of the cross section at low x corresponds to large y and increased influence of F_L.
- The turn-over is better described when $\ln 1/x$ resummation is included.
- Even $Q^2 = 2.7\ \text{GeV}^2$ bin looks acceptable, however χ^2 for this bin remains poor for both fits.

Isolating the impact of NLLx



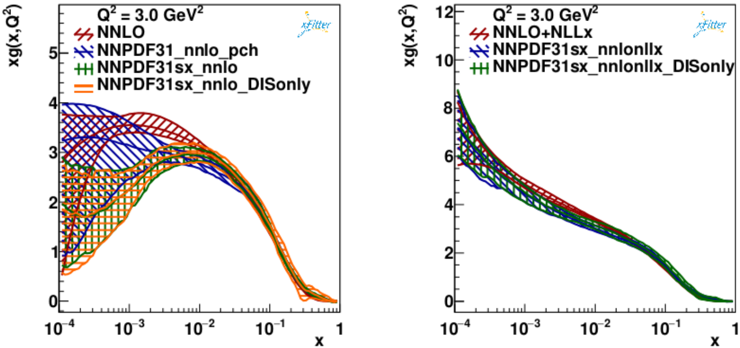
- Repeat fits with various kinematic cuts on the data.
- Include $Q^2 = 2.7\ \text{GeV}^2$ bin in this study.
- Scan in Q^2_{min}, x_{min} and additionally in y_{max}.
- Improvements when $\ln 1/x$ resummation is included for low Q^2, low x and high y.
- Quality of the description by both NNLO and NNLO+NLLx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

Region of maximal impact



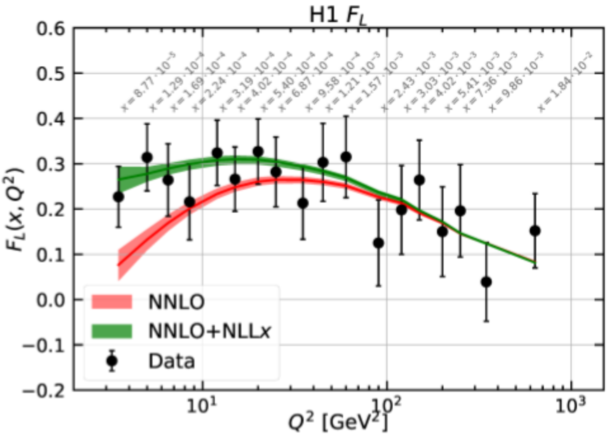
- 1D scans define the regions where $\ln 1/x$ resummation has largest impact: $Q^2 < 15$ GeV, $x < 5 \cdot 10^{-4}$, and $y > 0.4$ (assuming $E_p = 920$ GeV).
- This defines the "green region" in x, Q^2 kinematic plane.
- When this region is excluded, the difference in χ^2 between NNLO and NNLO+NLLx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

Region of maximal impact



- For comparison at NNLO, include NNPDF sets with fitted and perturbative charm. Gluon for xFitter analysis is closer to the gluon with perturbative charm treatment.
- For NNLO+NLLx gluon shapes agree much better, despite difference in the charm treatment.

The structure function F_L



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

Summary

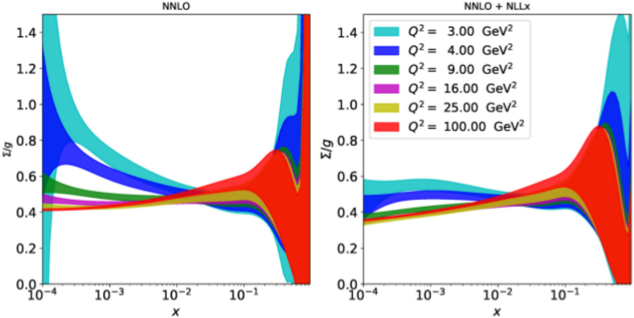
- xFitter is an open source QCD analysis tool.
- xFitter provides interface to many data samples, with complex correlation model, fast χ^2 computation, fast evolution using QCDNUM, build-in computation of DIS cross sections and interfaces to APPLGRID and FastNLO, and other features such as different PDF parameterisations and regularisation methods
- 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.

We welcome new ideas and developers :)

special thanks to: S. Glazov (DESY), S. Zenaiev (DESY)

Ratio Σ/g: backup

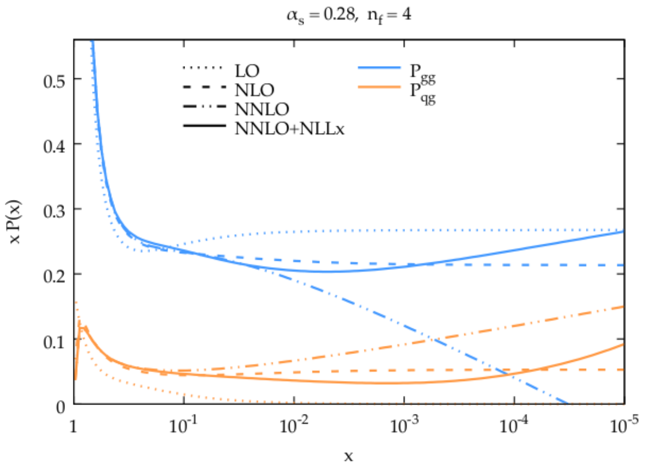
Ratio Σ/g



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

→ more inline with "dynamic" picture of PDFs in which the sea is generated

Splitting functions P_{gg} and P_{qg}: backup



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.