Developments in xFitter

Open Source QCD Fit framework

https://www.xfitter.org/xFitter

Voica Radescu (CERN/Oxford)
on behalf of the xFitter developers' team

PDF4LHC meeting

7 March 2017
CERN

Outline:

- Status of xFitter releases
- Highlights of the recent results using xFitter
- Analyses by xFitter developers:
  - **determination of the photon PDF**

Status of xFitter releases

- installation scripts

- new stable release in preparations (xFitter Workshop in Oxford 19-22.03)
  http://www.physics.ox.ac.uk/confs/xFitter2017/index.asp

- svn —> git

xFitter / DownloadPage

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 getter-xfitter.sh.
- Data and theory files are also stored in hepforge and can be accessed from there ("List of Data Files").

Date	Version	Files	Remarks
TBA 03/2017	**2.0.0**	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

Documentation

- A list of datasets which can be downloaded with the help of getter script.
- Manual (under continuous improvement) can be accessed here.
- The **README** file (accessible via the package) gives an explanation for a quick start.
- The **INSTALLATION** file (accessible via the package) provides information for package installation and usage instructions.
- The package is licensed under GNU GPL, please see **LICENCE** for mode details (accessible via the package).

Web access to GIT

- The master version can be viewed and downloaded from https://gitlab.cern.ch/fitters/xfitter.git

Links to external packages

External packages that could be run with xFitter via configuration flags can be accessed for convenience HERE .

HERAverager data combination package

Information can be accessed here https://wiki-zeuthen.desy.de/HERAverager.

Subscription

We encourage users to subscribe to mailing list for news and updates related to the xFitter webpage. (average rate of e-mails is once a month), please contact xfitter-help@desy.de (or by creating a user account to this wiki we get a notification)

Status of xFitter releases

f.t.

hera

No	Collider	Reaction	arXiv
1	fixedTarget	inclusiveDis	cern-ep-89-06
2	hera	beautyProduction	0907.2643
3	hera	inclusiveDis	1012.4355
4	hera	jets	0706.3722
5	hera	jets	0707.4057
6	hera	jets	0904.3870
7	hera	jets	0911.5678
8	hera	jets	1406.4709
9	hera	charmProduction	1211.1182
10	hera	inclusiveDis	0911.0884
11	hera	inclusiveDis	1506.06042
12	hera	beautyProduction	1405.6915
13	hera	diffractiveDis	0812.2003
14	hera	jets	0208037
15	hera	jets	0608048
16	hera	jets	1010.6167
17	lhc	drellYan	1305.4192
18	lhc	drellYan	1404.1212
19	lhc	jets	1112.6297
20	lhc	jets	1304.4739
21	lhc	topProduction	1407.0371
22	lhc	topProduction	atlas-conf-2012-024
23	lhc	wzProduction	1203.4051
24	lhc	wzProduction	1612.03016
25	lhc	jets	1212.6660
26	lhc	topProduction	1208.2671
27	lhc	topProduction	1211.2220
28	lhc	topProduction	cms-pas-top-11-024
29	lhc	wzProduction	1110.4973
30	lhc	wzProduction	1206.2598
31	lhc	wzProduction	1312.6283
32	lhc	wzProduction	1603.01803
33	lhc	beautyProduction	1306.3663
34	lhc	charmProduction	1302.2864
35	tevatron	jets	0807.2204
36	tevatron	wzProduction	0901.2169
37	tevatron	wzProduction	0908.3914
38	tevatron	topProduction	1309.7570
39	tevatron	jets	0802.2400
40	tevatron	wzProduction	0702025
41	tevatron	wzProduction	1309.2591
42	tevatron	wzProduction	1312.2895
43	tevatron	wzProduction	1412.2862

lhc

tevatron

fcc/lhec

xFitter / DownloadPage

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Expect in new release:

- Fixes, Additions, Examples and Documentation

  - Technical fixes:
    - better syncronisation with lhapdf6 output
    - added extra options for plotting tools (MC replica, draw individual data sets)
    - better separation for the uncorrelated vs statistical uncertainties
    - implement flexibility to displace thresholds and switching scales

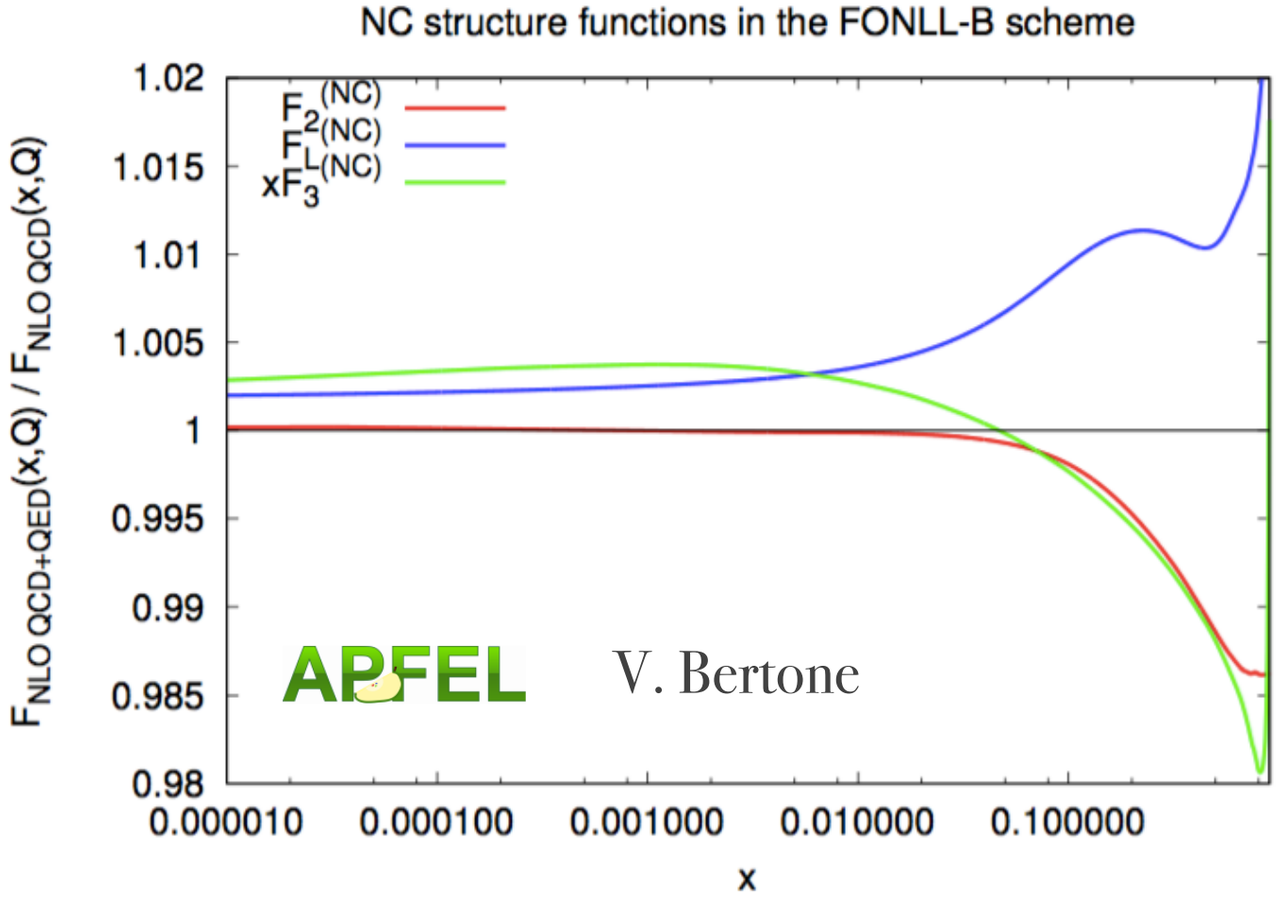
  - Include the top PDF if top mass is below kinematic limit (5 vs 6 flavour PDFs)

  - Updates of dipole steering cards

  - Added extra PDF parameters for the photon parametrisation

New Physics Cases in xFitter

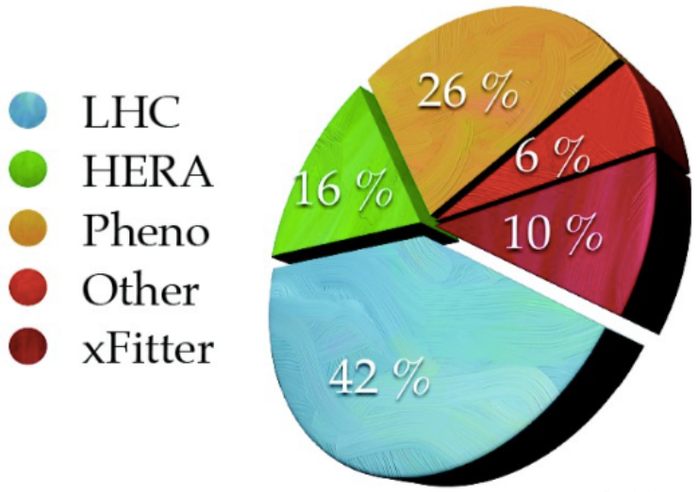
- NLO QCD+QED via APFEL in xFitter:
  - At NLO QED, access to new diagrams: **new diagrams**: $\gamma^*\gamma \to qq$ and $\gamma^* q \to q\gamma$,
  - Implementing the O($\alpha_s\alpha$) and the O(α^2) corrections to the DGLAP splitting functions on top of the O(α) ones
  - Implementing O($\alpha_s^2\alpha$) and the O(α^2), O($\alpha^2\alpha_s$) corrections to β functions
  - when including NLO QED corrections, not only the evolution is affected but also the DIS structure functions get corrected.



- Possibility to fit for photon PDF:
  - parametrisation form
  - sum rules adjusted
- Dipole Model: added a flag for the saturation option

List of Analyses using xFitter since last PDF4LHC

More than 4**0 public results** obtained using xFitter from the beginning of the project (2011)



LHC experiments provide the main developments and usage of the xFitter platform

https://www.x tter.org/xFitter/xFitter/results

List of analyses using xFitter

Number	Date	Group	Reference	Title
2016				
41	02.2017	A. Aleedaneshvara, M. Goharipour, S. Rostami	Chin Phys C 41, 2 (2017) 023101	Uncertainty of parton distribution functions due to physical observables in a global analysis
40	01.2017	Y.G. Gbedo, M. Mangin-Brinet	arXiv:1701.07678	Markov Chain Monte Carlo technics applied to PDF determination: proof of concept
39	01.2017	ABMP	arXiv:1701.05838	Parton Distribution Functions, αs and Heavy-Quark Masses for LHC Run II
38	12.2016	ATLAS	arXiv:1612.03636	Measurements of top-quark pair to Z-boson cross-section ratios at s = 13; 8; 7 TeV with the ATLAS detector
37	12.2016	ATLAS	arXiv:1612.03016	Precision measurement and interpretation of inclusive W and Z production with the ATLAS detector
36	12.2016	A. Aleedaneshvara, M. Goharipour, S. Rostami	EPJA (2016) 52: 352	The impact of intrinsic charm on the parton distribution functions
35	11.2016	A. Luszczak and H. Kowalski	arXiv:1611.10100, PRD 95 (2017)014030	Dipole model analysis of highest precision HERA data, including very low Q2's
34	11.2016	PROSA	arXiv:1611.03815	Prompt neutrino fluxes in the atmosphere with PROSA parton distribution functions

–> talk @ PDF4LHC

–> talk @ PDF4LHC

high x

–> talk @ PDF4LHC

–> talk @ PDF4LHC

low x

List of analyses by xFitter

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

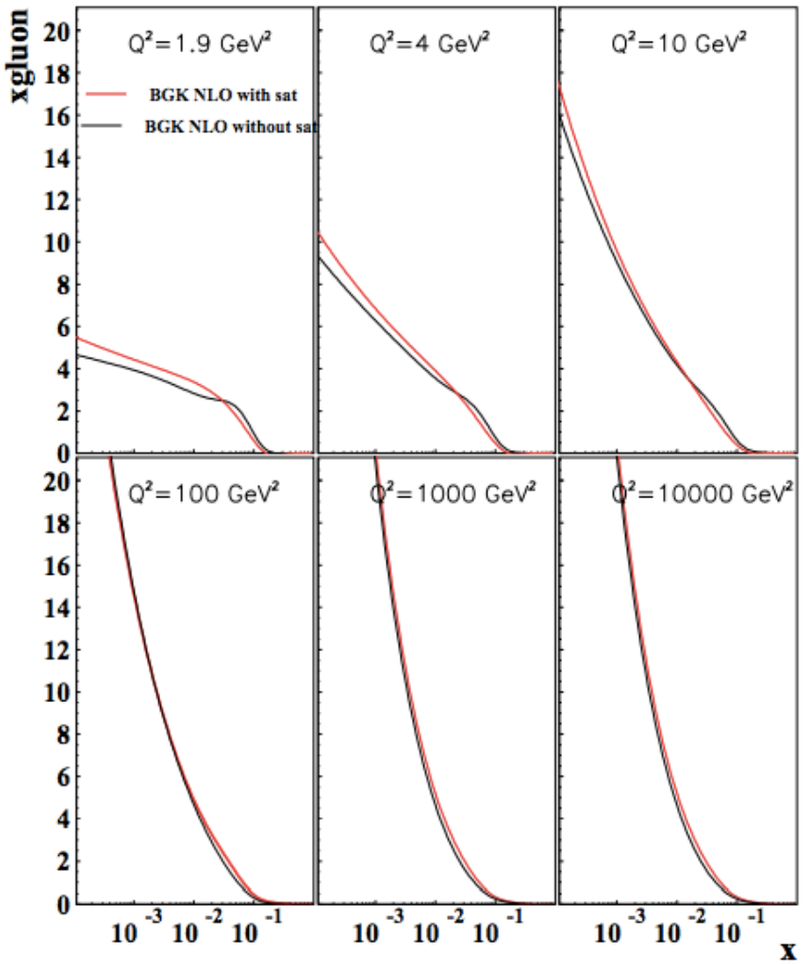
43	01.2017	F. Giuli, xFitter Developers' team and M. Lisovyi	arXiv:1701.08553	The photon PDF from high-mass Drell Yan data at the LHC

–> this talk

Highlights: importance of low x region

Saturation investigation: fits with and without saturation ansatz to final HERA data using BGK model

arXiv:1611.10100



- No significant differences between the saturated and no-saturated fits were observed.
- For fits to data including the low Q2 region (<3.5 GeV2) the saturated gluon density is preferred:
  - $\chi 2/\mathrm{dof} = 1.56$ vs 1.21

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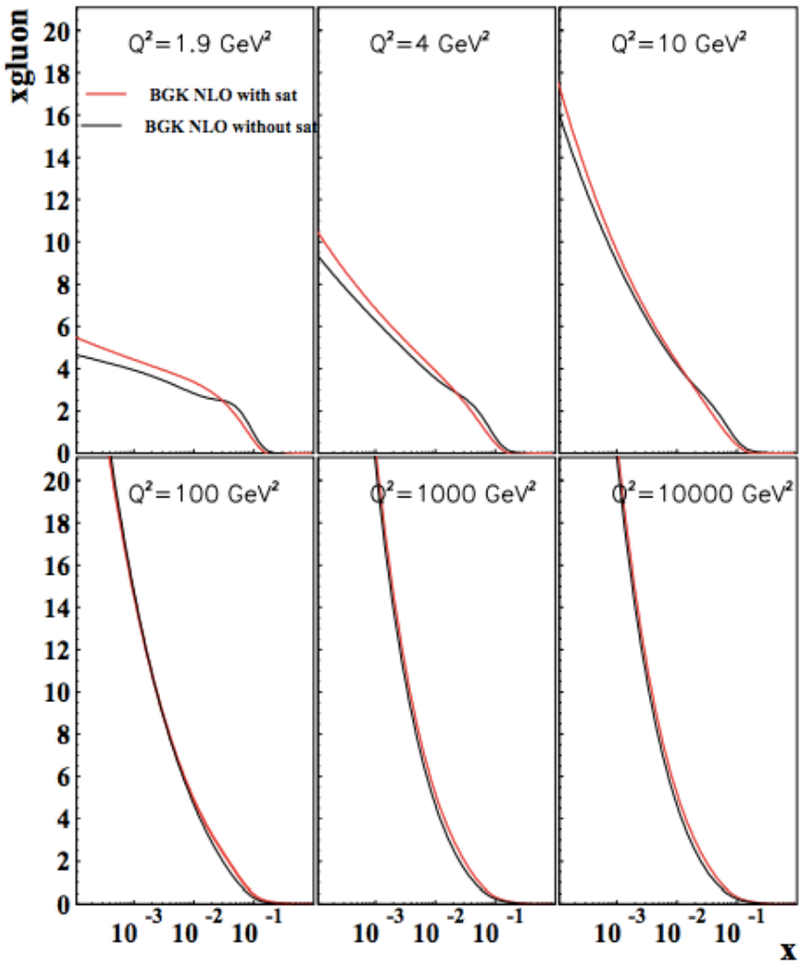

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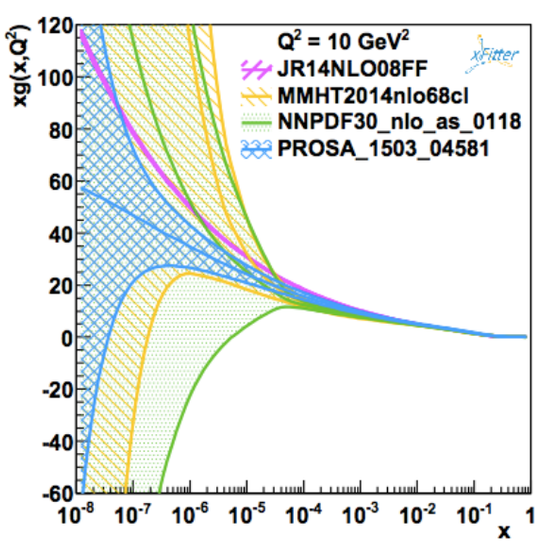
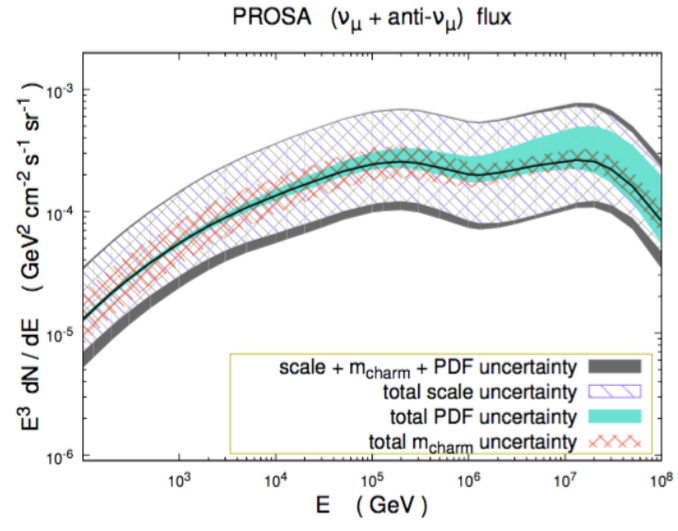
Also for low x —> TMDs (see Hannes talk)

- Accurate predictions for atmospheric lepton fluxes are of crucial importance both to refine veto experimental techniques and to get a precise estimate of the actual spectrum of astrophysical neutrinos (IceCube)
  - it requires extension of the PDF precision to low x
  - PROSA used LHCb data -> relevant for high-energy neutrino production
  - using PROSA PDFs calculated predictions for the flux of prompt neutrinos in the atmosphere.





arXiv:1611.03815

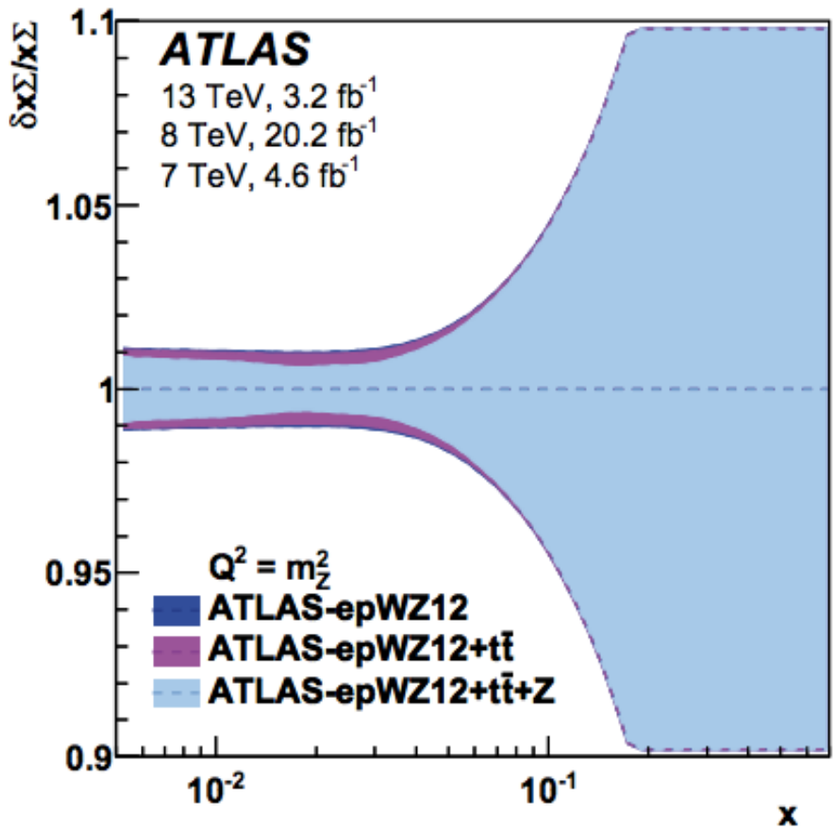
- PDF uncertainties on the prompt neutrino flux increase with increasing neutrino energies.
- PDF uncertainties are already quite well constrained and are subdominant
  - dominant: the renormalisation and factorisation scales

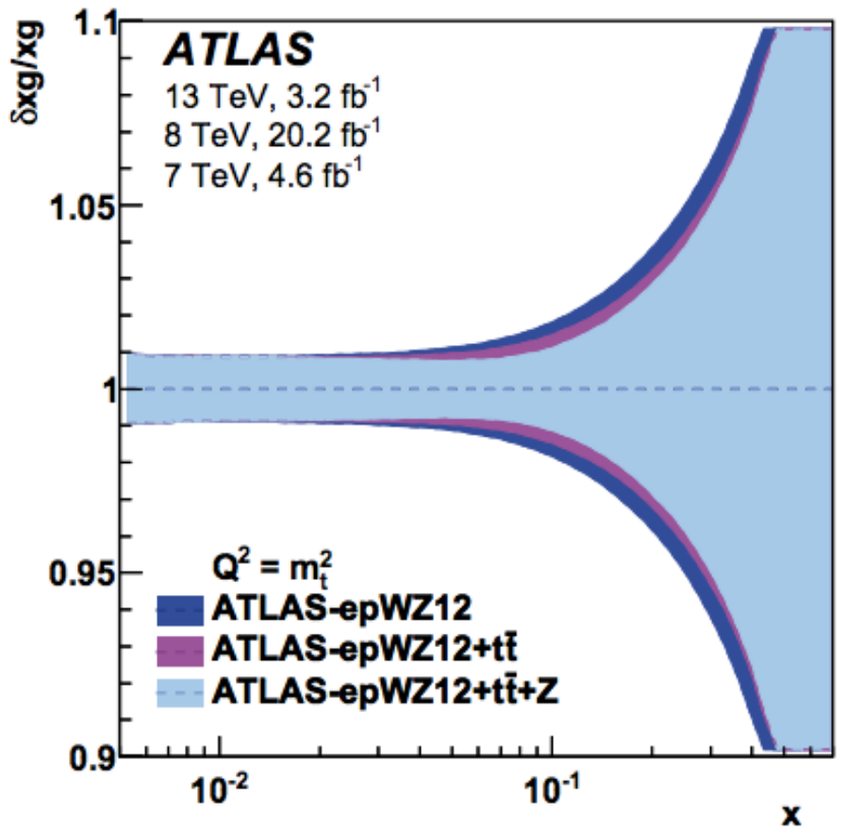
Highlights: importance of high x region

- Ratios of top-quark pair to Z-boson cross sections measured from proton-proton collisions at √s=13TeV, 8TeV, and 7TeV are presented by the ATLAS Collaboration. arXiv:1612.03636
- Quantitative comparison with the SM predictions based on different PDFs is provided:

	ATLAS-epWZ12	CT14	MMHT14	NNPDF3.0	HERAPDF2.0	ABM12
χ^2/NDF	8.3 / 6	15 / 6	13 / 6	17 / 6	10 / 6	25 / 6
p-value	0.22	0.02	0.05	0.01	0.11	< 0.001

- The impact of the ATLAS data on the PDF uncertainties is quantified using the PDF profiling method
- The bands represent the uncertainty for the ATLAS-epWZ12 PDF set and the uncertainty of the profiled ATLAS-epWZ12 PDF set using ttbar + Z data





also see S. Camarda and CMS results O. Zenaev

New Results by xFitter developers team

APFEL

High Energy Physics - Phenomenology

The photon PDF from high-mass Drell Yan data at the LHC

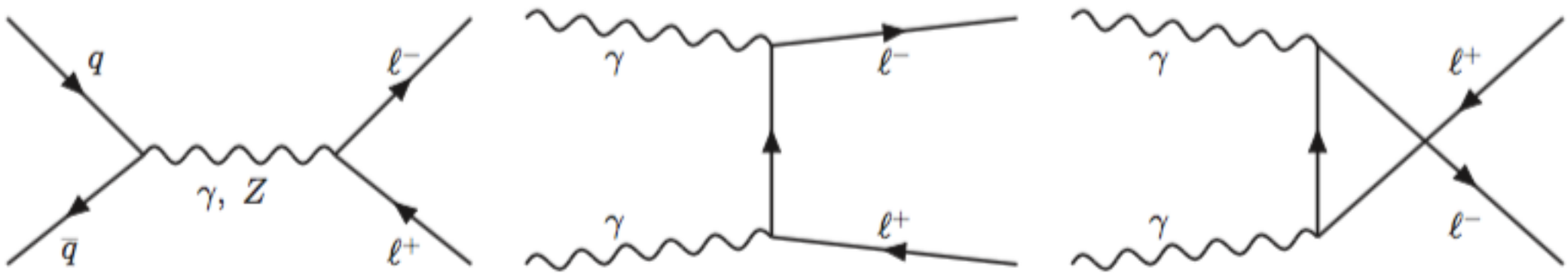
F. Giuli, xFitter Developers' team: V. Bertone, D. Britzger, S. Carrazza, A. Cooper-Sarkar, A. Glazov, K. Lohwasser, A. Luszczak, F. Olness, R. Placakyte, V. Radescu, J. Rojo, R. Sadykov, P. Shvydkin, O. Zenaiev, M. Lisovyi

(Submitted on 30 Jan 2017)

Achieving the highest precision for theoretical predictions at the LHC requires the calculation of hard-scattering cross-sections that include perturbative QCD corrections up to (N)NNLO and electroweak (EW) corrections up to NLO. Parton distribution functions (PDFs) need to be provided with matching accuracy, which in the case of QED effects involves introducing the photon parton distribution of the proton, $x\gamma(x, Q^2)$. In this work a determination of the photon PDF from fits to recent ATLAS measurements of high-mass Drell-Yan dilepton production at $\sqrt{s} = 8$ TeV is presented. This analysis is based on the xFitter framework, and has required improvements both in the APFEL program, to account for NLO QED effects, and in the aMCfast interface to account for the photon-initiated contributions in the EW calculations within MadGraph5_aMC@NLO. The results are compared with other recent QED fits and determinations of the photon PDF, consistent results are found.

Motivation

- Interpretation of the LHC data requires theoretical calculations that include not only QCD corrections, but also the EW effects for the TeV regions.
- DY data at LHC can provide direct sensitivity to photon PDFs:
  - from qqbar s-channel scattering, from $\gamma\gamma$ t- and u- channels scattering mediated by a lepton

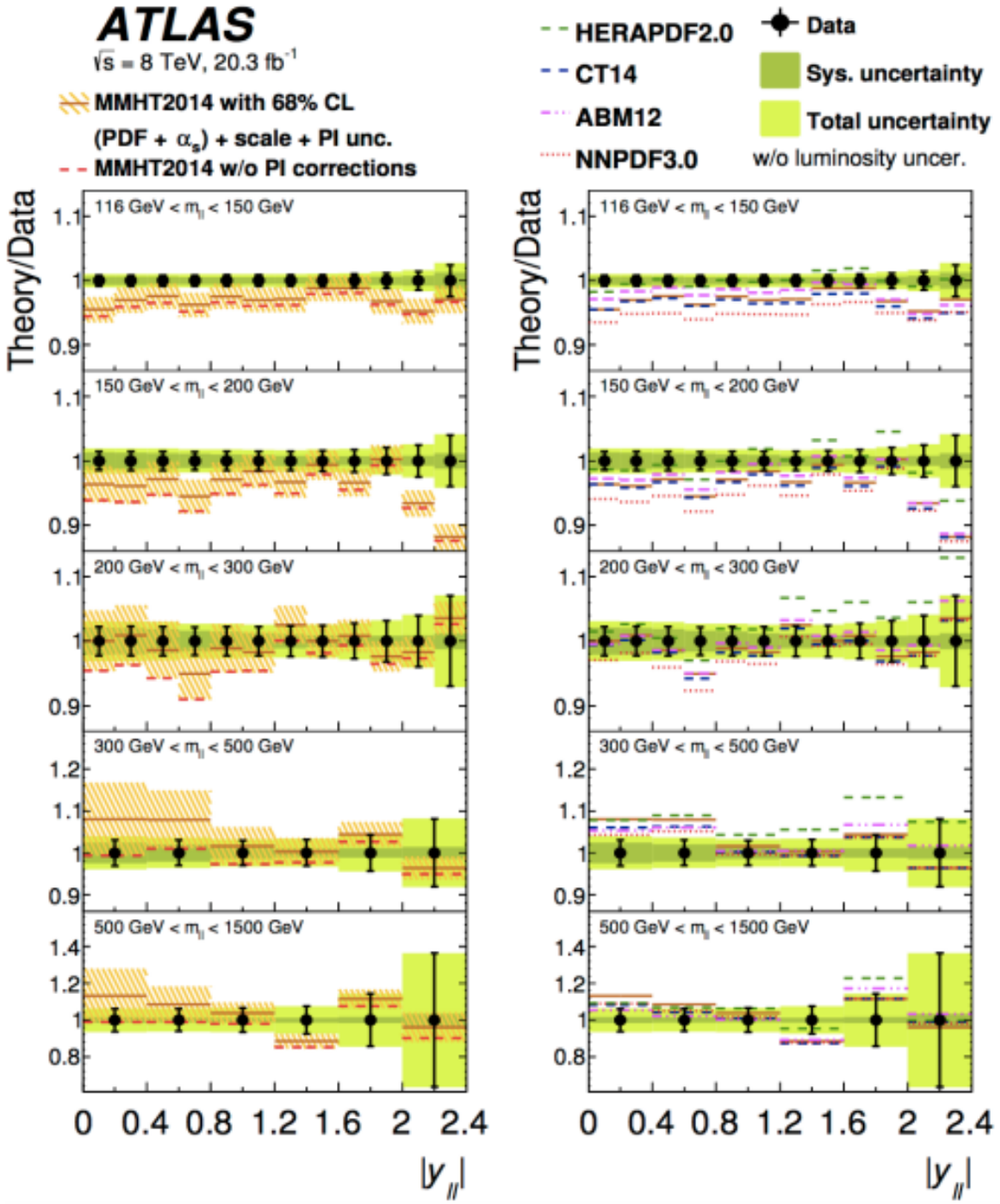


- An important ingredient of the EW corrections is the photon PDF of the proton
  - Historically, the first set was MRST2004 QED: photon taken from a model and tested on direct photon production at HERA
  - NNPDF2.3 QED provided a first model independent determination from fits to DY LHC data
  - More photon PDFs followed: CT, NNPDF.
  - A new approach was from LUXqed which was calculated from inclusive SF -> percent level precision
    - similarly HKR (no uncertainties)

Input Data for Photon Determination

- xFitter analysis is based on the fits o the recent ATLAS high mass DY data at 8 TeV:
  - which is added on top of the HERA I+II inclusive data for full PDF coverage
- The ATLAS high mass DY data:
  - single differential
  - double differential distributions: mass and rapidity or mass and pseudo-rapidity
    - 48 data points in 5 mass ranges:
      - [116-150], [150-200], [200-300], [300-500], [500-1500] GeV
    - $p_T l > 40$ (30) GeV, $\eta < 2.5$
- It was observed that Photon-induced (PI) contribution increases with mass ranges.
- Good agreement with SM predictions

ATL-COM-PHYS-2014-376

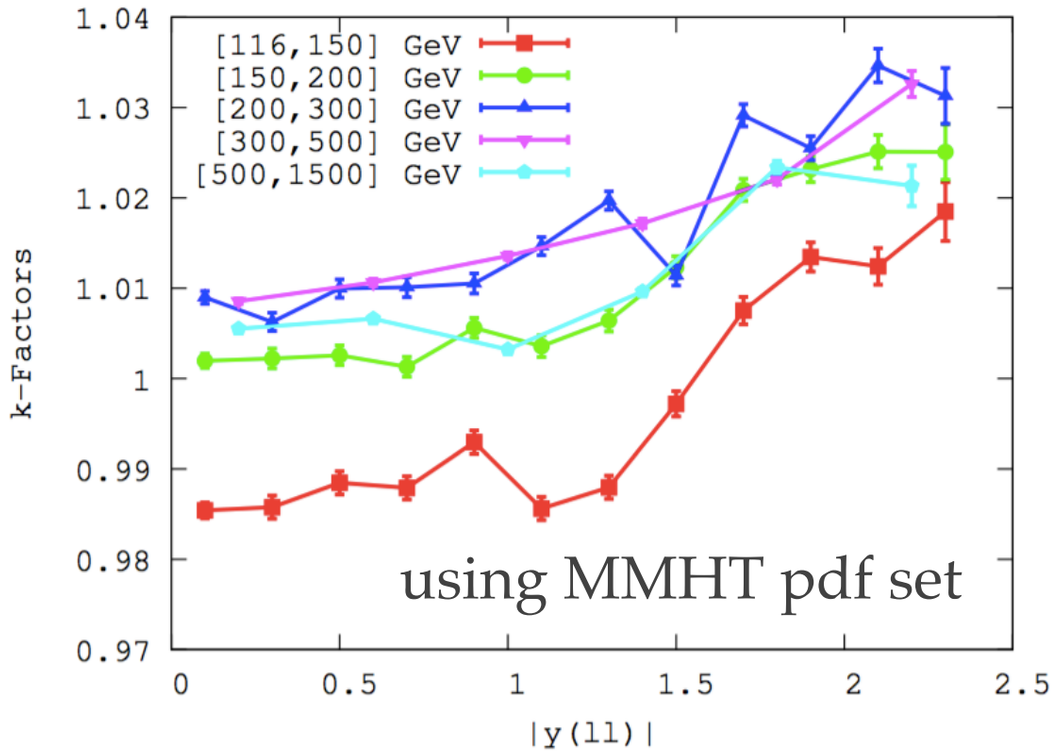


	m_{ee}	$\lvert y_{ee}\rvert$	$\lvert\Delta\eta_{ee}\rvert$
MMHT2014	18.2/12	59.3/48	62.8/47
CT14	16.0/12	51.0/48	61.3/47
NNPDF3.0	20.0/12	57.6/48	62.1/47
HERAPDF2.0	15.1/12	55.5/48	60.8/47
ABM12	14.1/12	57.9/48	53.5/47

Theory inputs for QCD+QED Fits

Fit Settings:

- PDF evolution computed with APFEL program:
  - accurate up to NNLO in QCD, NLO in QED, it includes the relevant mixed QCD+QED corrections
- HERA cross sections: using FONLL C HF scheme (NNLO)
- LHC high mass DY cross sections: calculated via MadGraph5_aMC@NLO which includes the photon-initiated diagrams
  - interfaced to Applgrids via aMCfast
  - a tailored version of Applgrid used to account for photon contributions.
- NNLO QCD+NLO QED predictions obtained using FEWZ:
  - dynamical scales are used (set to m_{ll})



$$K(m_{ll}, |y_{ll}|) \equiv \frac{\text{NNLO QCD} + \text{NLO EW}}{\text{NLO QCD} + \text{LO EW}}$$

PDF Parametrisation [optimised through chi2 scan]:

$$xu_v(x) = A_{u_v} x^{B_{uv}} (1-x)^{C_{uv}} (1 + E_{u_v} x^2),$$
$$xd_v(x) = A_{d_v} x^{B_{dv}} (1-x)^{C_{dv}},$$
$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}},$$
$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}},$$
$$xg(x) = A_g x^{B_g} (1-x)^{C_g} (1 + E_g x^2),$$

while for the photon PDF it is used:

$$x\gamma(x) = A_\gamma x^{B_\gamma} (1-x)^{C_\gamma} (1 + D_\gamma x + E_\gamma x^2).$$

- M_c = 1.41 GeV
- M_b = 4.5 GeV
- Q_0^2 = 7.5 GeV^2

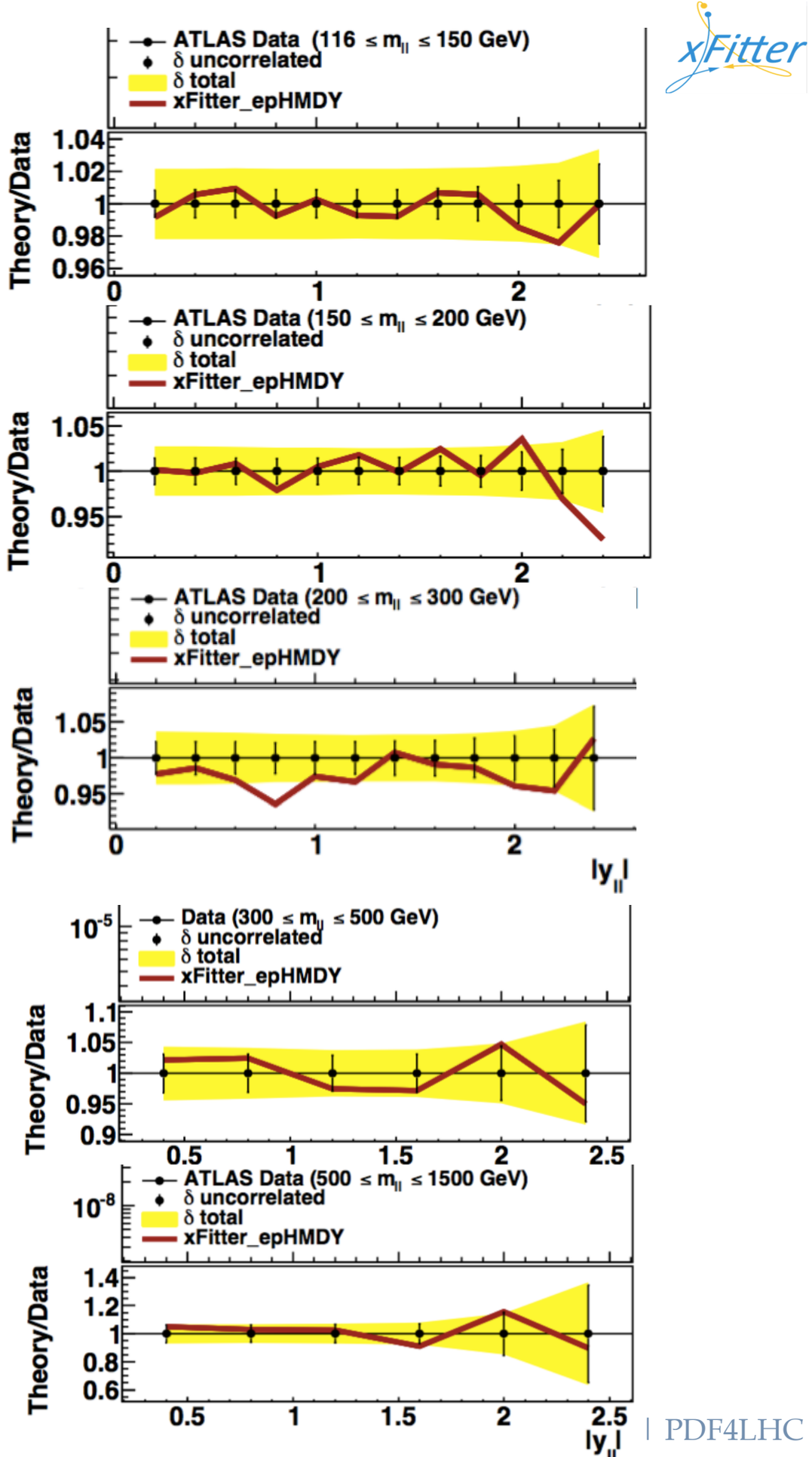
Fit Results

Chi2 from the fit to data:

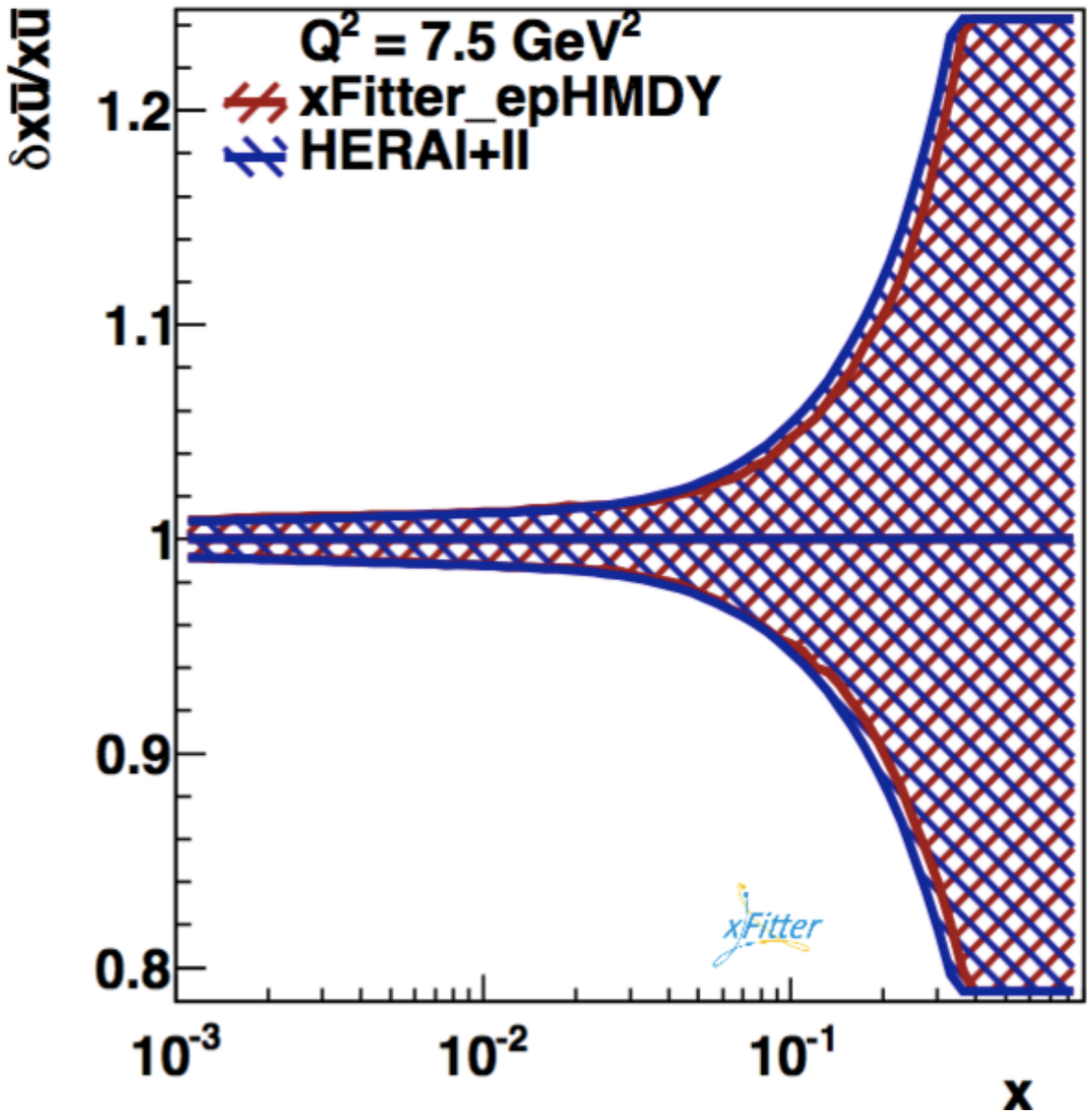
Dataset	χ^2 /$N_{\rm dat}$
HERA I+II	1236/1056
high-mass DY 116 GeV $\leq m_{ll} \leq$ 150 GeV	9/12
high-mass DY 150 GeV $\leq m_{ll} \leq$ 200 GeV	15/12
high-mass DY 200 GeV $\leq m_{ll} \leq$ 300 GeV	14/12
high-mass DY 300 GeV $\leq m_{ll} \leq$ 500 GeV	5/6
high-mass DY 500 GeV $\leq m_{ll} \leq$ 1500 GeV	4/6
Correlated (high-mass DY) χ^2	1.17
Log penalty (high-mass DY) χ^2	-0.12
Total (high-mass DY) $\chi^2/N_{\rm dat}$	48/48
Combined HERA I+II and high-mass DY $\chi^2/N_{\rm dof}$	1284/1083

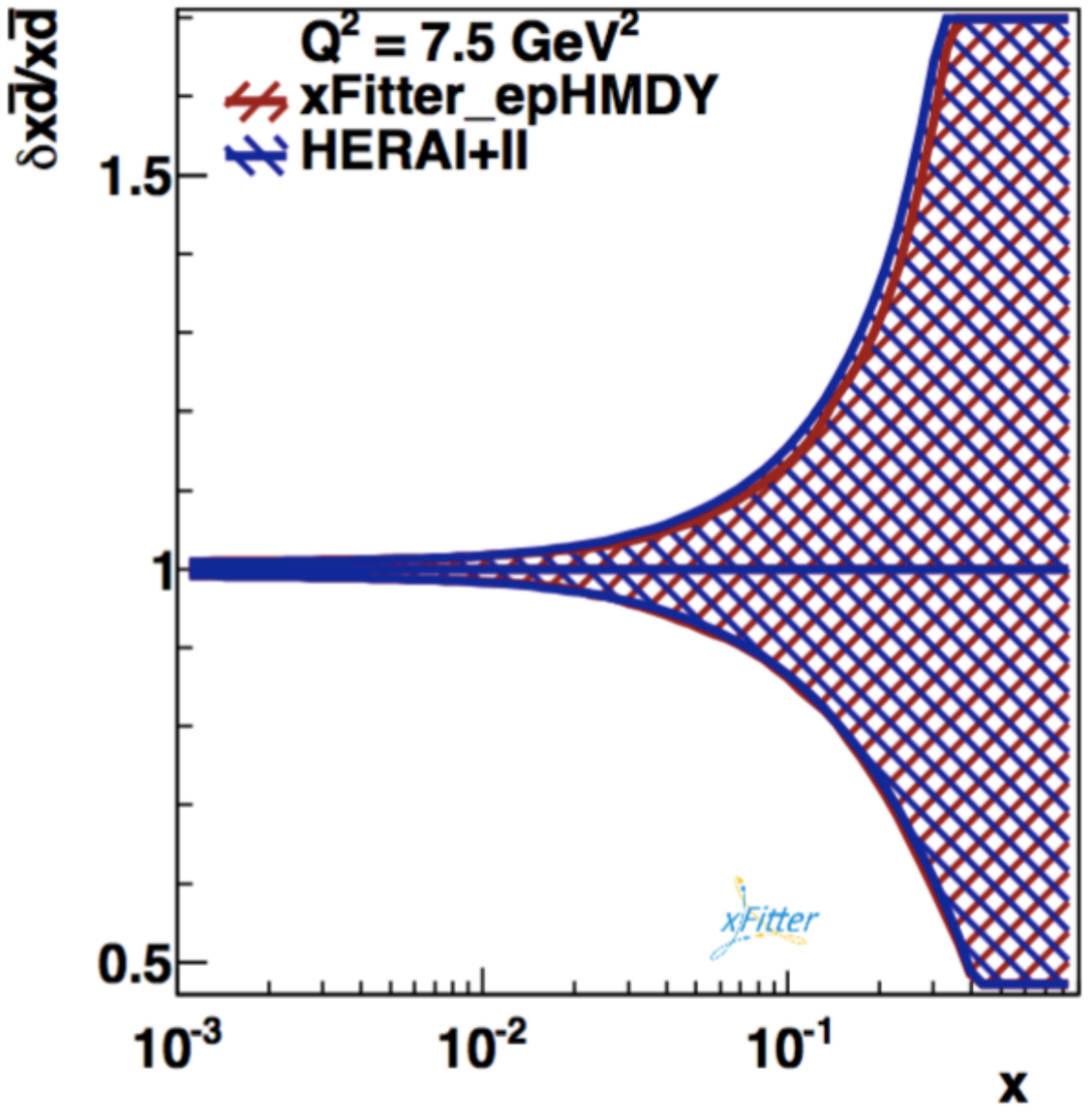
Table 1 The $\chi^2/N_{\rm dat}$ in the NNLO fits for the HERA inclusive structure functions and for the various invariant mass m_{ll} bins of the ATLAS high-mass DY data. In the latter case, the contribution to the χ^2 arising from the correlated and log-penalty terms are indicated, as well as the overall $\chi^2/N_{\rm dof}$ is provided, where $N_{\rm dof}$ is the number of degree of freedom in the fit.

—> a good agreement between ATLAS data and the NNLO theory predictions obtained from the xFitter_epHMDY fit.



Impact on light quarks

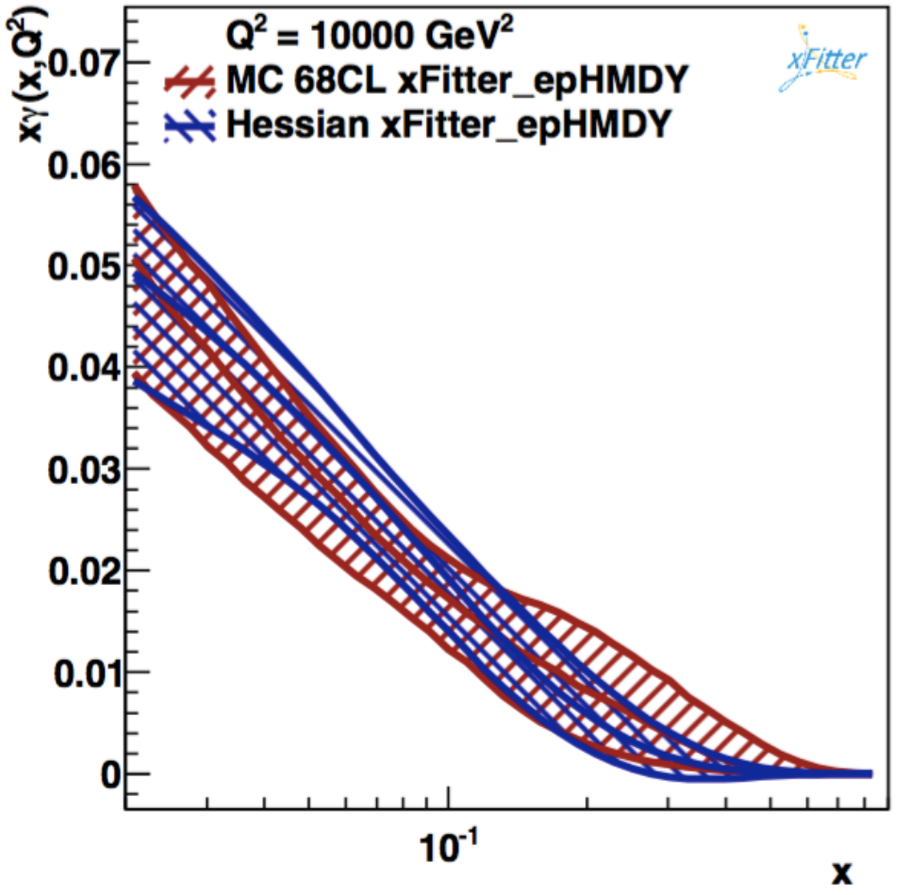


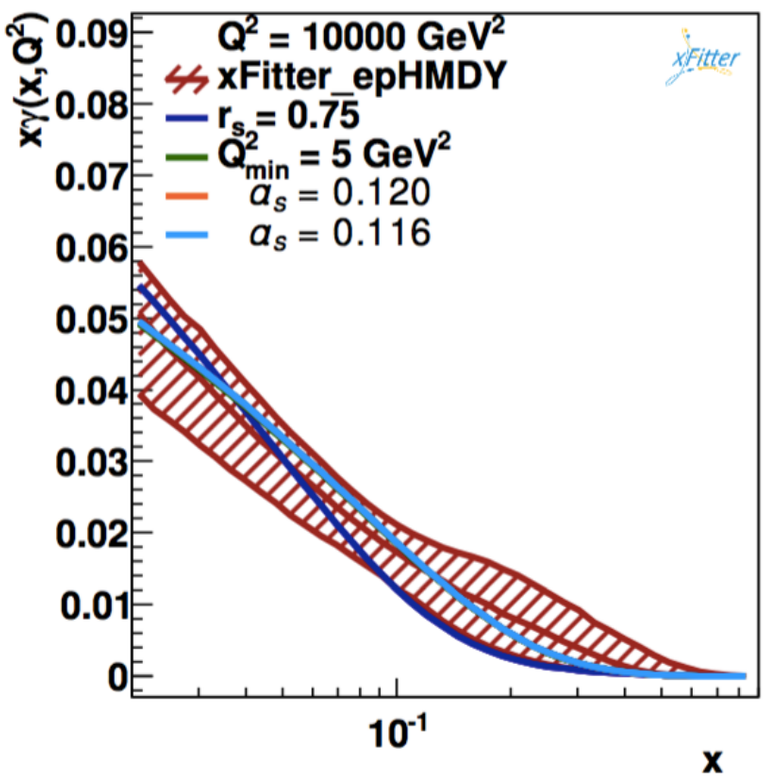


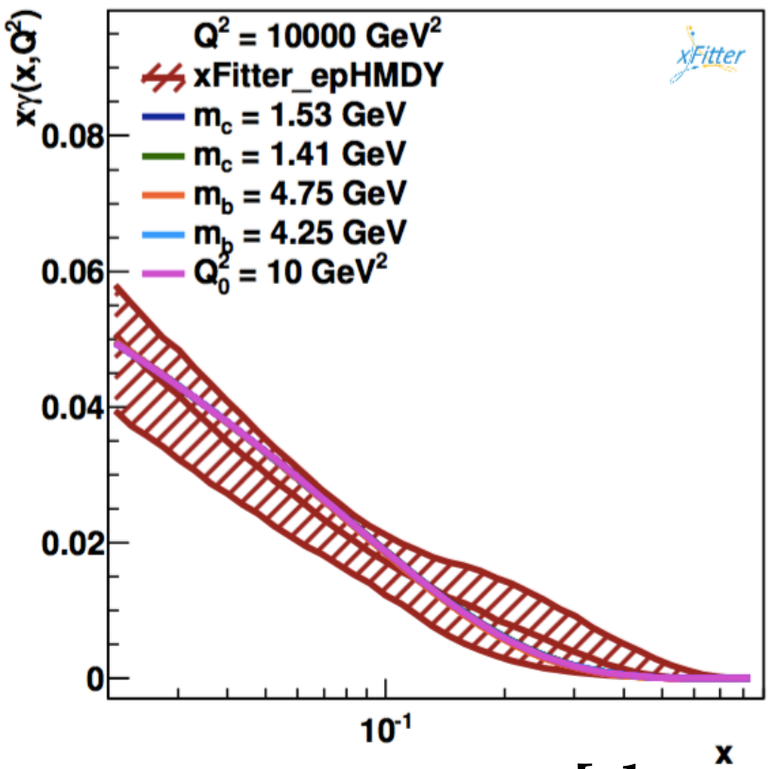
The impact in the medium and large-x antiquark distributions from the high mass DY data are rather moderate.

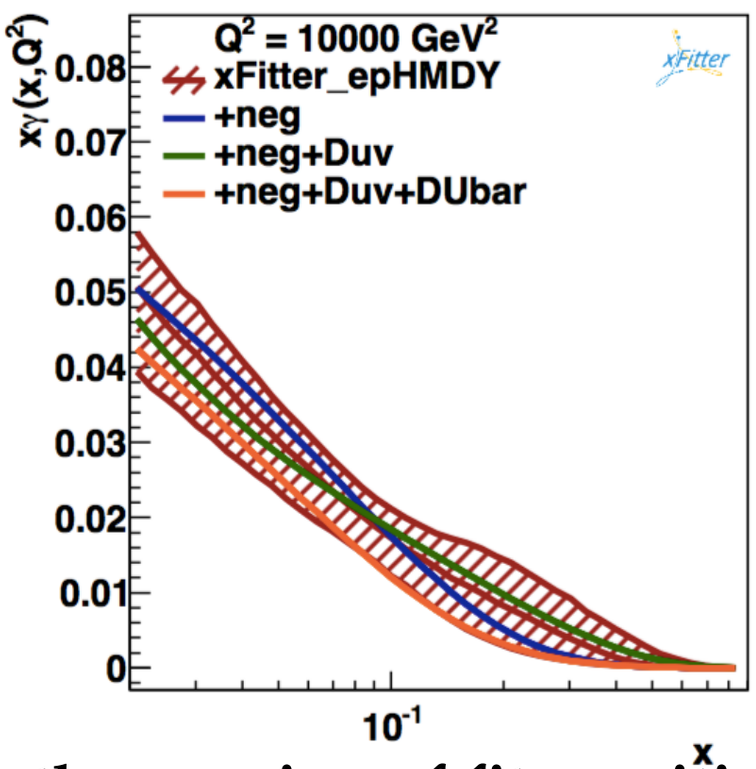
Photon PDF from Fits

- Experimental uncertainty can be determined via MC replica method (assuming here Gauss distribution of the experimental uncertainties) or via Hessian Method
  - as nominal fit the MC method is chosen
  - experimental uncertainty of the level 30% for 0.02< x<0.1
- The robustness of the fit results was also studied under various fits conditions:
  - strange fraction content assumption
  - input model variations , e.g. mc, mb, Q0
  - extra free parameters



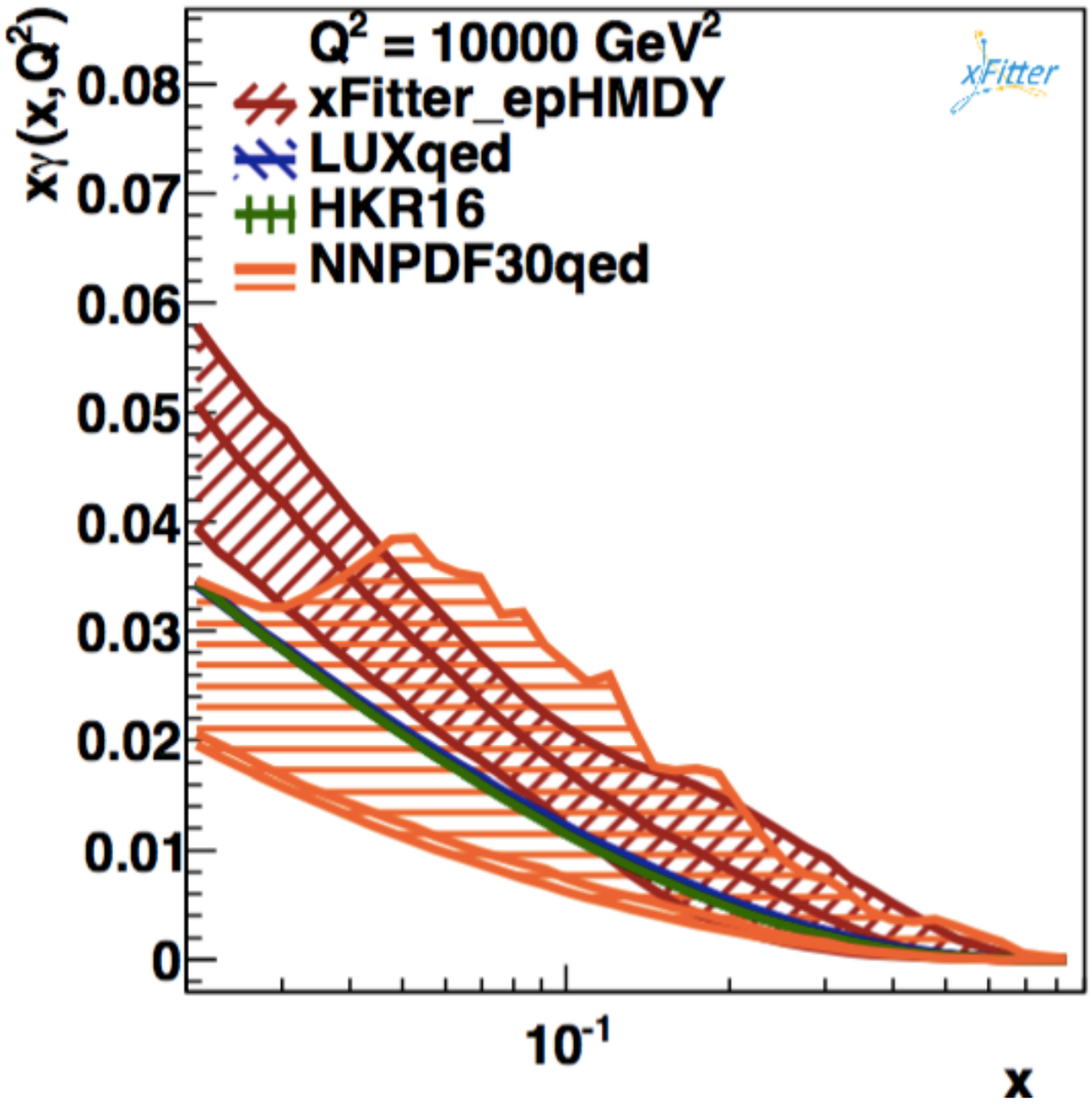






[shown in the x region of fit sensitivity]

Comparison of Photon PDF from xFitter_epHMDY



- For $x \geq 0.1$ the four determinations of the photon PDF are consistent within PDF uncertainties.
- For smaller values of x, the photon PDF from LUXqed and HKR16 is softer than xFitter_epHMDY, but still in agreement at the 2-σ level.

The results benefited from technical new developments:

- Full NLO QED corrections to the DGLAP evolution and DIS structure functions were implemented
- Possibility to fit more than standard 12 PDFs
- Extension of the APPLGRID to aMCfast for the presence of the photon-initiated channels
- Available in LHAPDFv6 format upon request.

Summary

- xFitter (former HERAFitter) project is based on a multi-functional open source QCD software package that provides a framework for scrupulous interpretations of the QCD analyses with its main application at the LHC program
  - www.xfitter.org
  - new release is imminent - first from git repository

- More results are in pipeline related to threshold displacement application, FL structure Functions, iTMD developments, PDF+PS, resummed calculations, etc..

19-22 March Workshop in Oxford (30 participants)

http://www.physics.ox.ac.uk/confs/xFitter2017/index.asp