PDF profiling using the Forward-Backward asymmetry in Neutral-Current Drell-Yan

F. Giuli (on behalf of E. Accomando, J. Fiaschi,
F. Hautmann, S. Moretti and xFitter Developers' team)

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xFitter

Drell-Yan production measurements

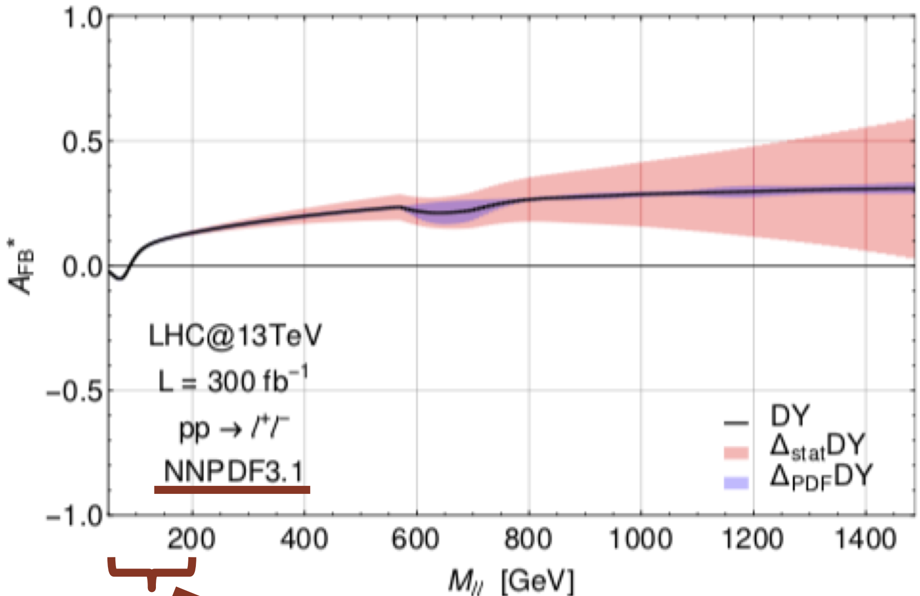
- DY cross section (differential in m_{ll}, y_{ll}) have long been used to constrain PDFs
- So is charged-current (CC) lepton charge asymmetry

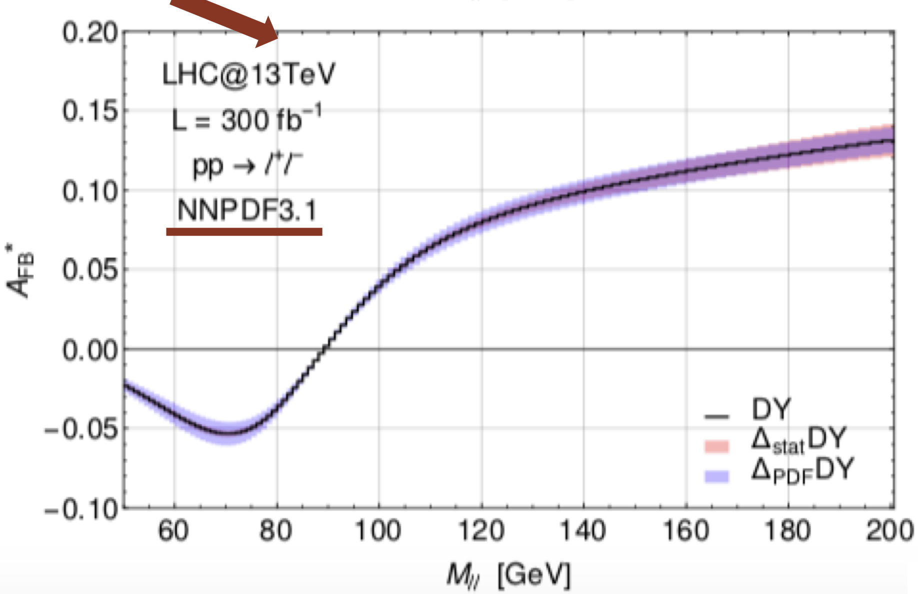
  L. Harlang-Lang et al., EPJC 75, 204 (20175)
- Neutral-current (NC) forward-backward asymmetry A_{FB}, traditionally used for weak mixing angle θ_W determination, can usefully be employed for PDF determinations as well

  ATLAS collaboration, ATLAS-CONF-2018-037
  CMS collaboration, arXiv:1808:03170
- Analysis performed both at LO and NLO within the xFitter framework
- Acceptance $*$ efficiency $\simeq$ 20% corresponding to realistic detector response

  ATLAS collaboration, JHEP 12, 059 (2017)
- **Three different scenarios for luminosities**: from Run2, 3 to HL-LHC
  - Estimate of statistical uncertainties at 30 fb^{-1}, 300 fb^{-1} and 3000 fb^{-1}
- Following results available here:
  - E. Accomando, J. Fiaschi, F. Hautmann, S. Moretti, Phys. Rev. D 98, 013003 (2018), arXiv:1712.06318
  - E. Accomando, J. Fiaschi, F. Hautmann, S. Moretti, Eur. Phys. J C (2018) 78: 663, arXiv:1805.09239
  - E. Accomando, J. Fiaschi, F. Hautmann, S. Moretti and xFitter Developers' team, arXiv:1906.11793, WORK IN PROGRESS

Asymmetry measurements





- At LO, angle defined w.r.t. the direction of the boost of the di-lepton system
- At NLO, angle defined in the Collin-Soper frame: $\cos\theta^* = \frac{p_{Z,ll}}{M_{ll}|p_{Z,ll}|}\frac{p_1^+p_2^- - p_1^-p_2^+}{\sqrt{M_{ll}^2 + p_{T,ll}^2}}$

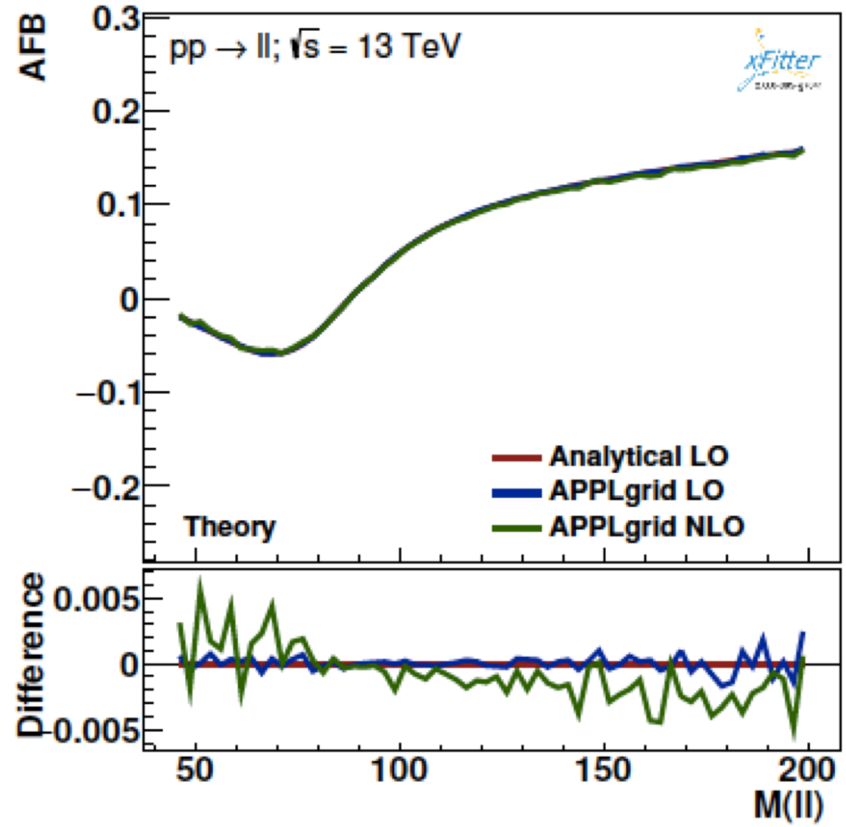
  where $p_i^\pm = E_i \pm p_{Z,i}$
- $\sigma_F = \int_0^1 \frac{d\sigma}{d\cos\theta^*} d\cos\theta^*$
- $\sigma_B = \int_{-1}^0 \frac{d\sigma}{d\cos\theta^*} d\cos\theta^*$

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

- W.r.t. cross section measurements, A_{FB} has smaller systematic but larger statistical error
- Sensitive to $u_V + d_V$ and complementary to DY Charge Current asymmetry ($u_V - d_V$)
- High-invariant mass region: dominated by statistical uncertainties…
- $m_{l^+l^-} \simeq m_Z$: high-stats to perform very precise measurements

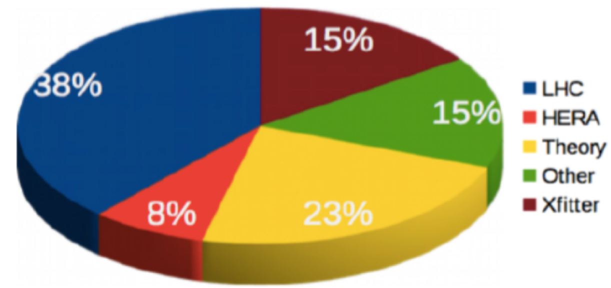
Setup of the xFitter analysis

- Datafiles with pseudo-data generated for several PDF sets within xFitter
- **NLO AFB central values:** 62 bins of 2.5 GeV-width from 45 to 200 GeV
- NNLO QCD mass dependent k-factor included
  R. V. Harlander and W. B. Kilgore, Phys. Rev. Lett. 88, 201801 (2002)
- NLO EW corrections not included (~3.5%)
- No sensible difference between A_{FB} calculated at LO or NLO
- Various lower rapidity cuts applied:
  - |Y| > 0 (no cut applied)
  - |Y| > 1.5
  - |Y| > 4.0 (only at LO)
- Profiling exercise on 5 different PDF sets:
  - ABMP16NNLO
  - CT14nnlo
  - HERAPDF2.0nnlo (EIG)
  - MMHT14nnlo
  - NNPDF3.1nnlo (Hessian set)



The xFitter Project

- The xFitter project (former HERAFitter) is a **unique open-source QCD fit framework**
- 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**



- Several active developers between experimentalists and theorists
- More than **80 publications** obtained using xFitter since the beginning of the project: https://www.xfitter.org/xFitter/xFitter/results
- List of recent analyses by the xFitter Developers' Team:

MORE IN PREPARATION!

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
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
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

xFitter release 2.0.1

DESY. xFitter

xFitter/../PionPDF » xFitter/../Meeting2019-.. » xFitter/../Meeting2019-.. » xFitter » xFitter/DownloadPage

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

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Releases of the xFitter QCD analysis package

- 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-2.0.1
  - New installation script from master branch install-xfitter-master
- Data and theory files are also stored in hepforge and can be accessed from there ("List of Data Files"). cernbox

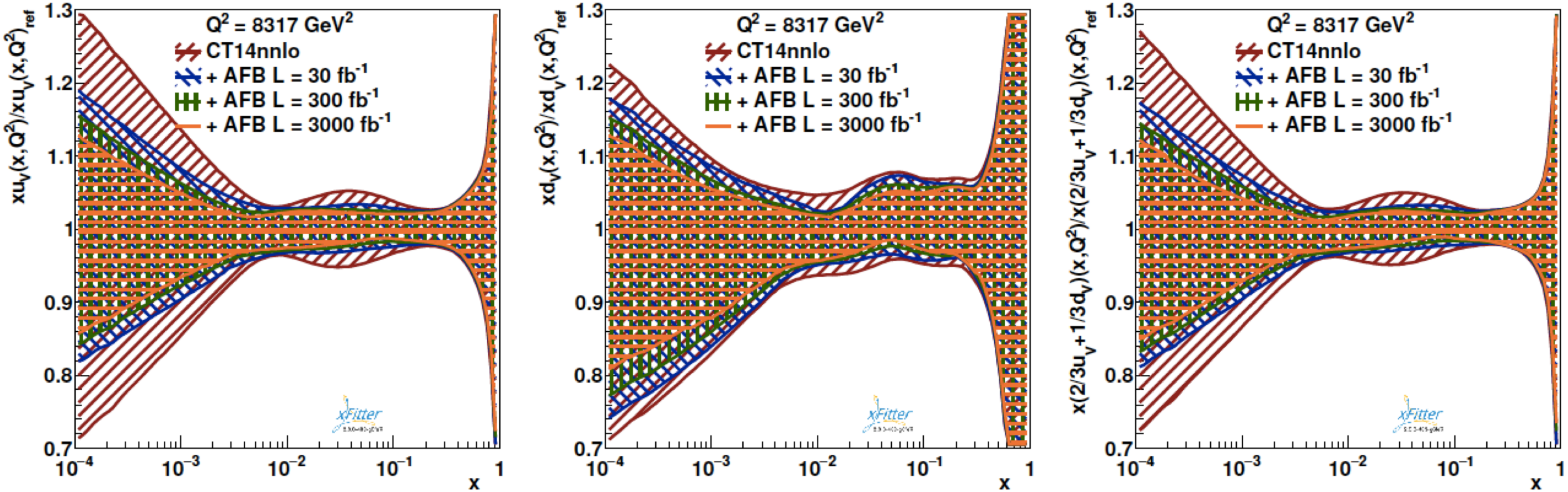
Date	Version	Files	Remarks
05/2019	2.0.1 OldFashioned	xfitter-2.0.1.tgz	update/bug fix to 2.0.0 FrozenFrog
03/2017	2.0.0 FrozenFrog	xfitter-2.0.0.tgz	stable release with decoupled data and theory files

2.0.1
Old Fashioned

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

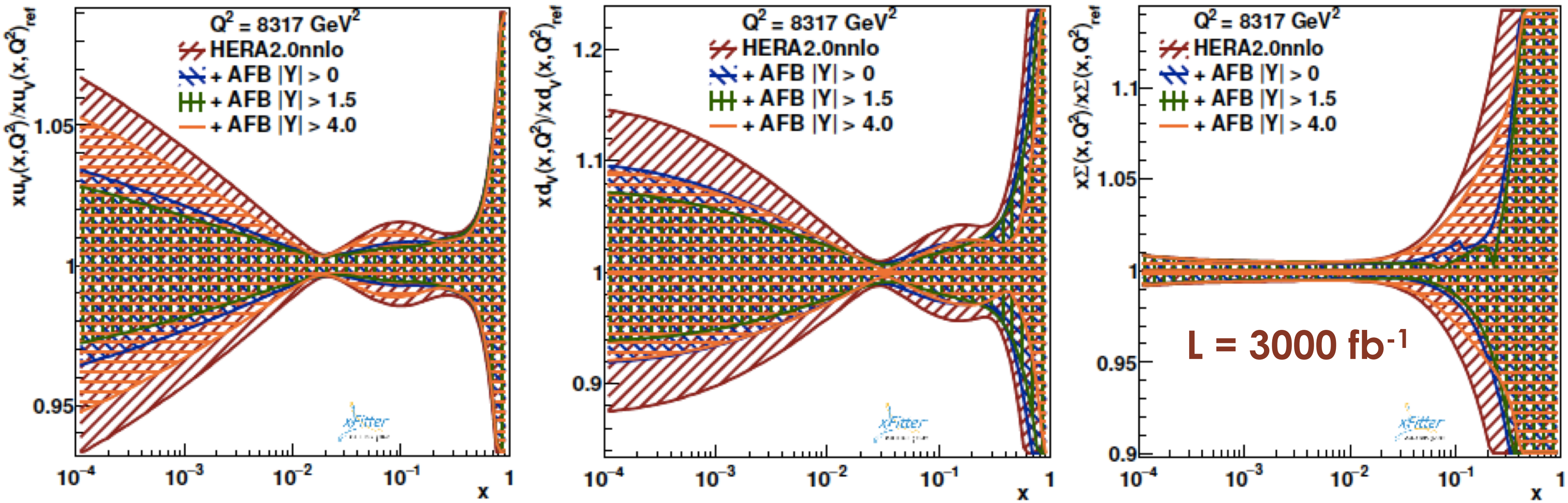
- Release 2.0.1 just released! (updates to latest software versions + bug fixes)
- Script to install xFitter and all its dependencies: **install-xFitter-2.0.1**
- New xfitter-users@googlegroups.com mailing list to provide feedback and help

PDF profiling



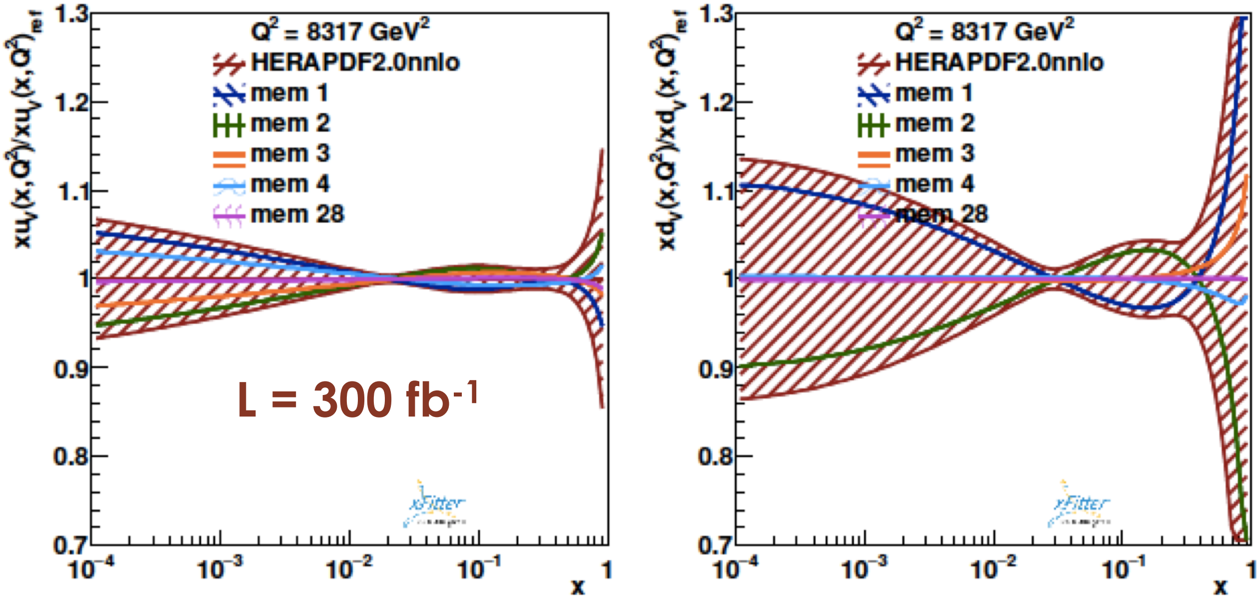
- The largest reduction of the uncertainty bands is obtained for u_V
- Visible improvement for d_V as well
- Main effects concentrated in the low- and intermediate-x region
- Mild effect on other PDFs
- Similar and comparable effects found using other NNLO PDF sets

PDF profiling (different rapidity cuts)



- Comparing results for |Y| > 0.0 and > 1.5, some improvement for d_V at low-x
- **|Y| > 4.0 profiling at LO**: 120 bins of 1 GeV-width from 80 to 200 GeV - detector acceptance enlarged up to $|\eta_l|$ < 5.0 (symmetrically applied to both the leptons in the final state)
- Poorer profiling due to reduced statistics in the low-x regime
- Conversely, reduction of uncertainty bands concentrated in the high-x region (not accessible before) – remarkable improvement for d_V

PDF eigenvectors rotation



HERA2.0nnlo	Total χ^2/dof
mem1	4.8/106
mem2	8.0/106
mem3	0.48/106
mem4	0.74/106
mem5	0.01/106

- We want to determine the PDFs (and their combinations) more sensitive to the A_{FB} data – **reparametrisation of the eigenvectors**
- New set of eigenvectors will be the result of a rotation of the original set and they will be sorted according to their impact on the predictions
- Mem1 – 28: eigenvectors which if summed give the Hessian experimental uncertainties on PDFs

J. Pumplin, Phys. Rev. D80 (2009) 034002

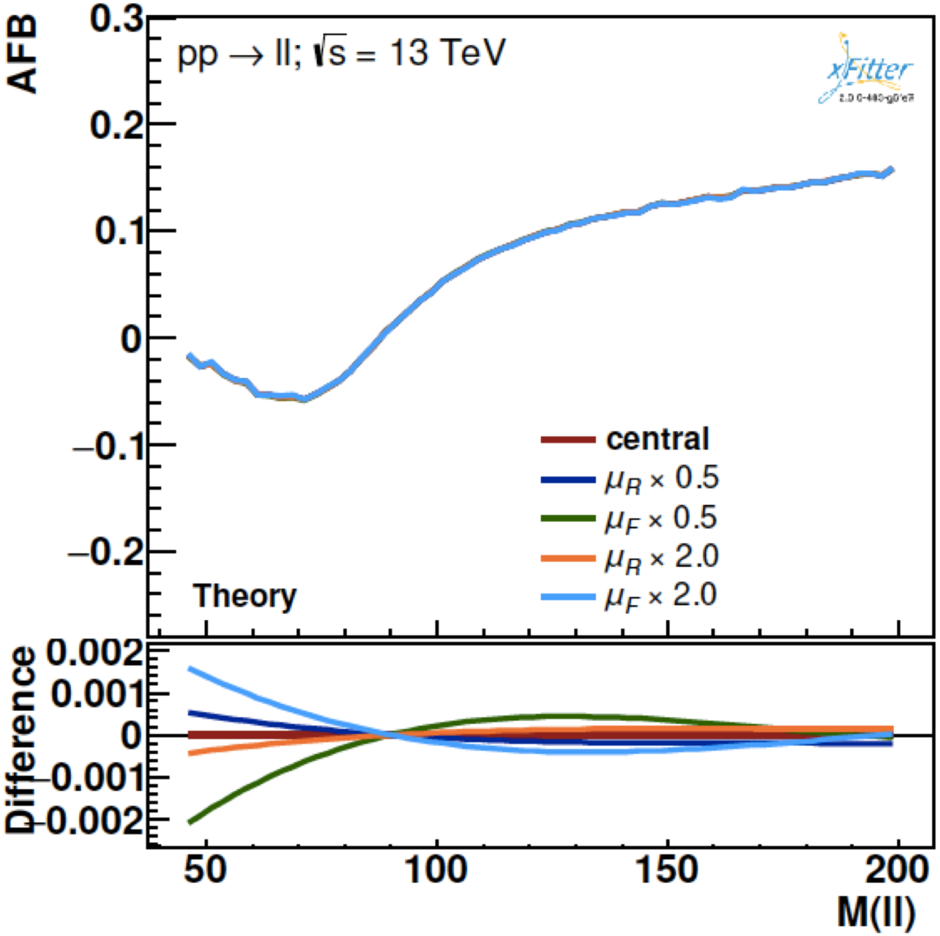
- First two eigenvectors almost completely determine the error bands

Theoretical and systematic uncertainties

- Aim: to access the dependence of A_{FB} on renormalisation (μ_R) and factorisation (μ_F) scales

- "Seven points" method employed

Point	$\mu_F/M_{\ell\ell}$	$\mu_R/M_{\ell\ell}$
1	0.5	0.5
2	1.0	0.5
3	0.5	1.0
4	1.0	1.0
5	1.0	2.0
6	2.0	1.0
7	2.0	2.0



- HERAPDF2.0nnlo (EIG) PDF set in use

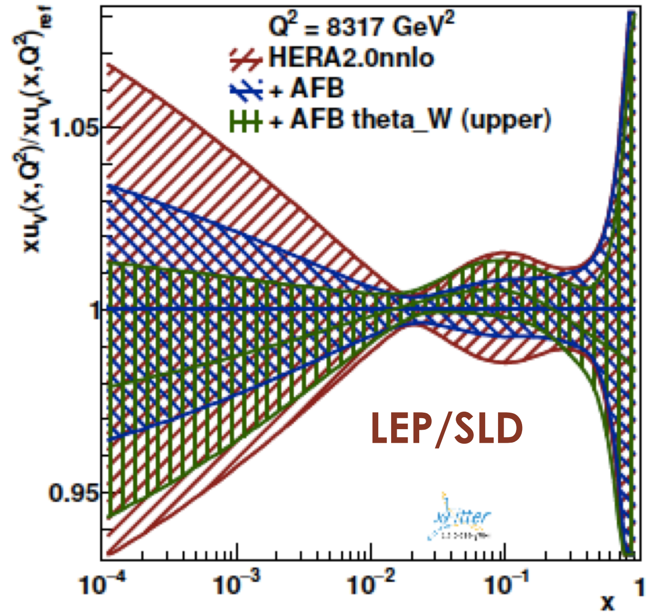
- Deviations wrt "point 4" (nominal μ_R and μ_F) presented

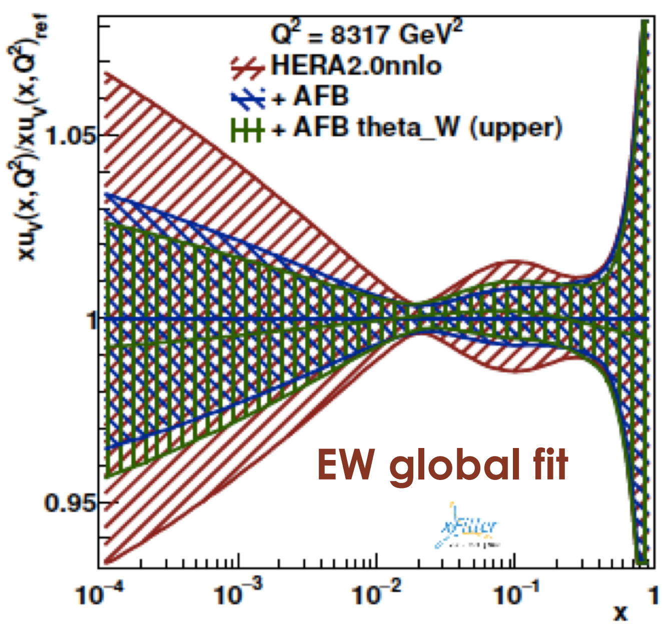
- Small variations observed (per-mille level)

- De-correlated scale variations checked as well (per-mille level)

Theoretical and systematic uncertainties

- Another source of uncertainty lies in the employed value of $\sin^2\theta_W$
- Most accurate measurement from LEP and SLD data: $\Delta\sin^2\theta_W = 16 \cdot 10^{-5}$
  S. Schael et al., Phys. Rept. 427, 257 (2006)
- Most accurate prediction from EW global fit: $\Delta\sin^2\theta_W = 6 \cdot 10^{-5}$
  J. Haller et al., Eur. Phys. J. C78, 675 (2018)
- Pseudo-data corresponds to L = 3 ab^{-1}
- HERA2.0nnlo (EIG) PDF set in use
- When adopting values for $\sin^2\theta_W$ at the extremes of these intervals, some differences in the profiled curves obtained
- Deviations are clearly more visible in the first case with LEP and SLD accuracy while we observe smaller differences when employing EW global fit estimate

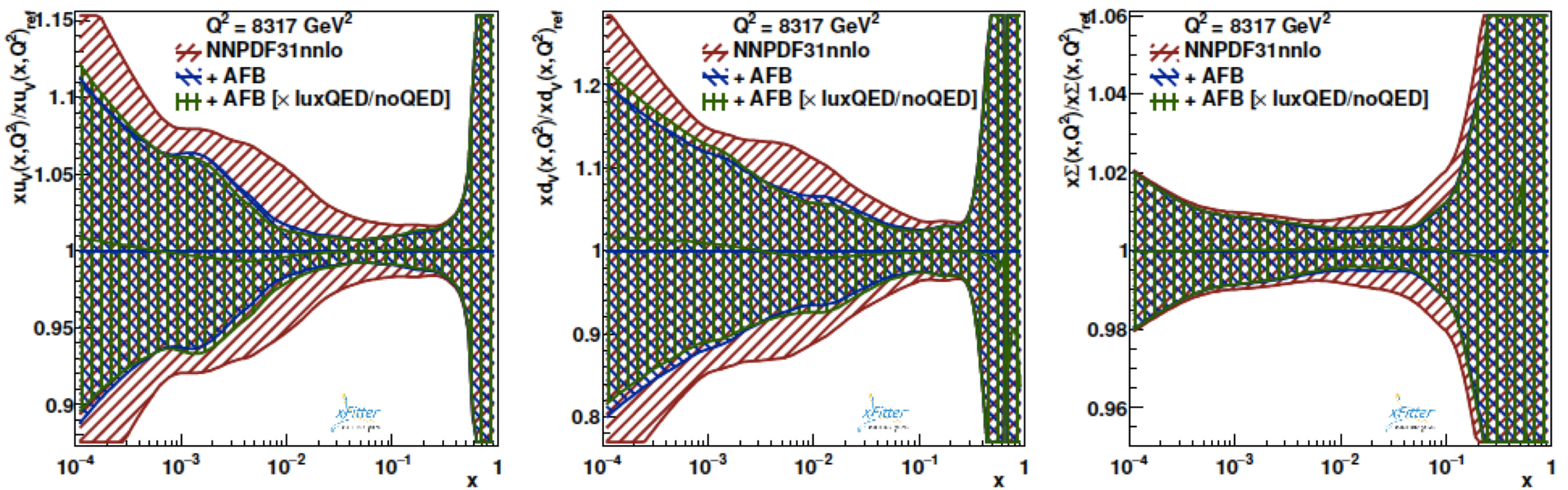




Higher-order EW corrections

- We have neglected any EW radiative corrections so far BUT higher order EW effects have been shown to be relevant
- Check whether in these sets we would obtain substantial differences when importing A_{FB} data in the profiling
- NNPDF31_nnlo_as_0118_luxqed PDF is use
- Differences in the A_{FB} predictions obtained between the QED and non-QED sets are small e.g. $|\Delta A_{FB}| < 2 \cdot 10^{-4}$
- Impact on profiled PDFs is also small

L = 3000 pb^{-1}



Conclusion and outlook

- We have implemented the AFB observable at LO and NLO into **xFitter**
- The potential of AFB pseudo-data in the LHC run-II setup in the profiling of selected PDF sets has been analysed
- Different luminosities considered and various rapidity cuts applied to study their effects in the reduction of PDF uncertainty bands
- Visible reduction of the uncertainties, especially for the valence up and down quarks
- Smaller effects are visible in the sea quark distributions
- This conclusion is also confirmed from the analysis of equivalent PDF sets whose eigenvectors have been rotated and sorted accordingly to their sensitivity to the pseudo-data
- A_{FB} measurements can be used to distinguish between different PDFs parametrizations → High rapidity cuts enhance the differences between PDF sets primarily at high-x (backup)

Backup Slides

Asymmetry measurements at LO

3D xsec:

$$\frac{d^3\sigma}{dM_{\ell\ell}dy_{\ell\ell}d\cos\theta^*} = \frac{\pi\alpha^2}{3M_{\ell\ell}s}\sum_q P_q\left[f_q(x_1,Q^2)f_{\bar{q}}(x_2,Q^2) + f_{\bar{q}}(x_1,Q^2)f_q(x_2,Q^2)\right]$$

$$\begin{aligned} P_q &= e_\ell^2 e_q^2(1+\cos\theta^*) \\ &+ \frac{2M_{\ell\ell}^2(M_{\ell\ell}^2 - M_Z^2)}{\sin^2\theta_W\cos^2\theta_W\left[(M_{\ell\ell}^2-M_Z^2)^2+\Gamma_Z^2M_Z^2\right]}(e_\ell e_q)\left[v_\ell v_q(1+\cos^2\theta^*) + 2a_\ell a_q\cos\theta^*\right] \\ &+ \frac{M_{\ell\ell}^4}{\sin^4\theta_W\cos^4\theta_W\left[(M_{\ell\ell}^2-M_Z^2)^2+\Gamma_Z^2M_Z^2\right]}[(a_\ell^2+v_\ell^2)(a_q^2+v_q^2)(1+\cos^2\theta^*) \\ &+ 8a_\ell v_\ell a_q v_q\cos\theta^*] \end{aligned}$$

where M_Z and Γ_Z are the mass and the width of the Z boson, e_ℓ and e_q are the lepton and quark electric charges, $v_\ell = -\frac{1}{4} + \sin^2\theta_W$, $a_\ell = -\frac{1}{4}$, $v_q = -\frac{1}{2}I_q^3 - e_q\sin^2\theta_W$, $a_q = \frac{1}{2}I_q^3$ are the vector and axial couplings of leptons and quarks respectively with I_q^3 the third component of the weak isospin; the angle θ^* is the lepton decay angle.

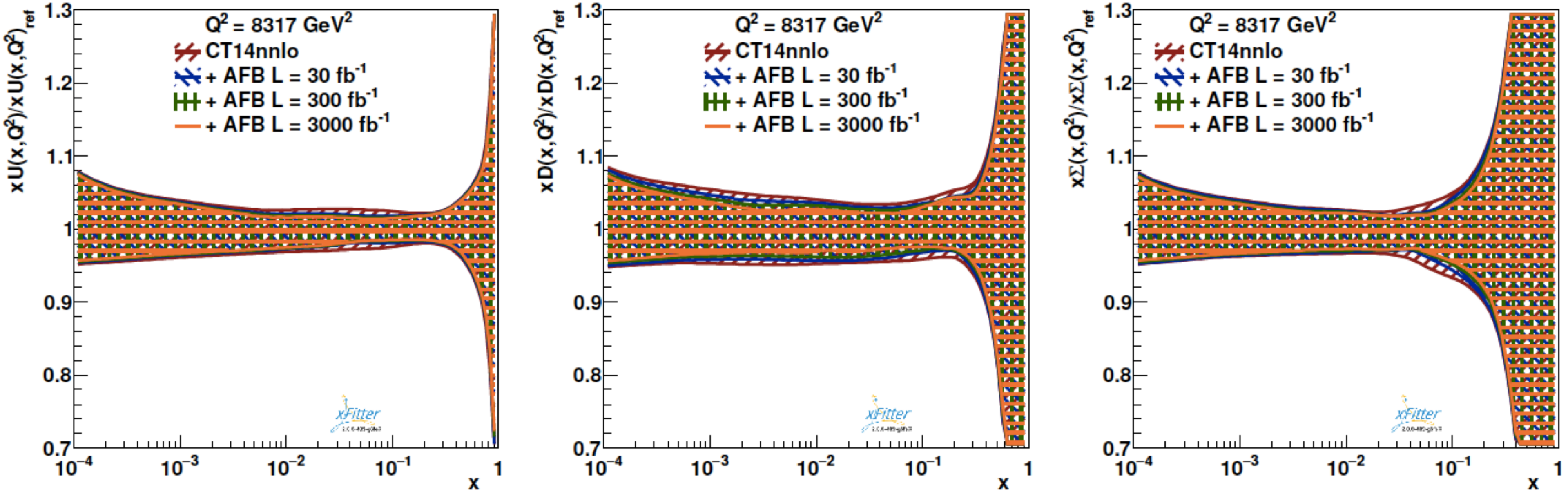
Asymmetry defined as:

$$A_{\rm FB}^* = \frac{d\sigma/dM(\ell^+\ell^-)[\cos\theta^*>0] - d\sigma/dM(\ell^+\ell^-)[\cos\theta^*<0]}{d\sigma/dM(\ell^+\ell^-)[\cos\theta^*>0] + d\sigma/dM(\ell^+\ell^-)[\cos\theta^*<0]}$$

Expected to be sensitive to:

$$e_\ell a_\ell[e_u a_u u_V(x,Q^2) + e_d a_d d_V(x,Q^2)] \propto \frac{2}{3}u_V(x,Q^2) + \frac{1}{3}d_V(x,Q^2)$$

PDF profiling



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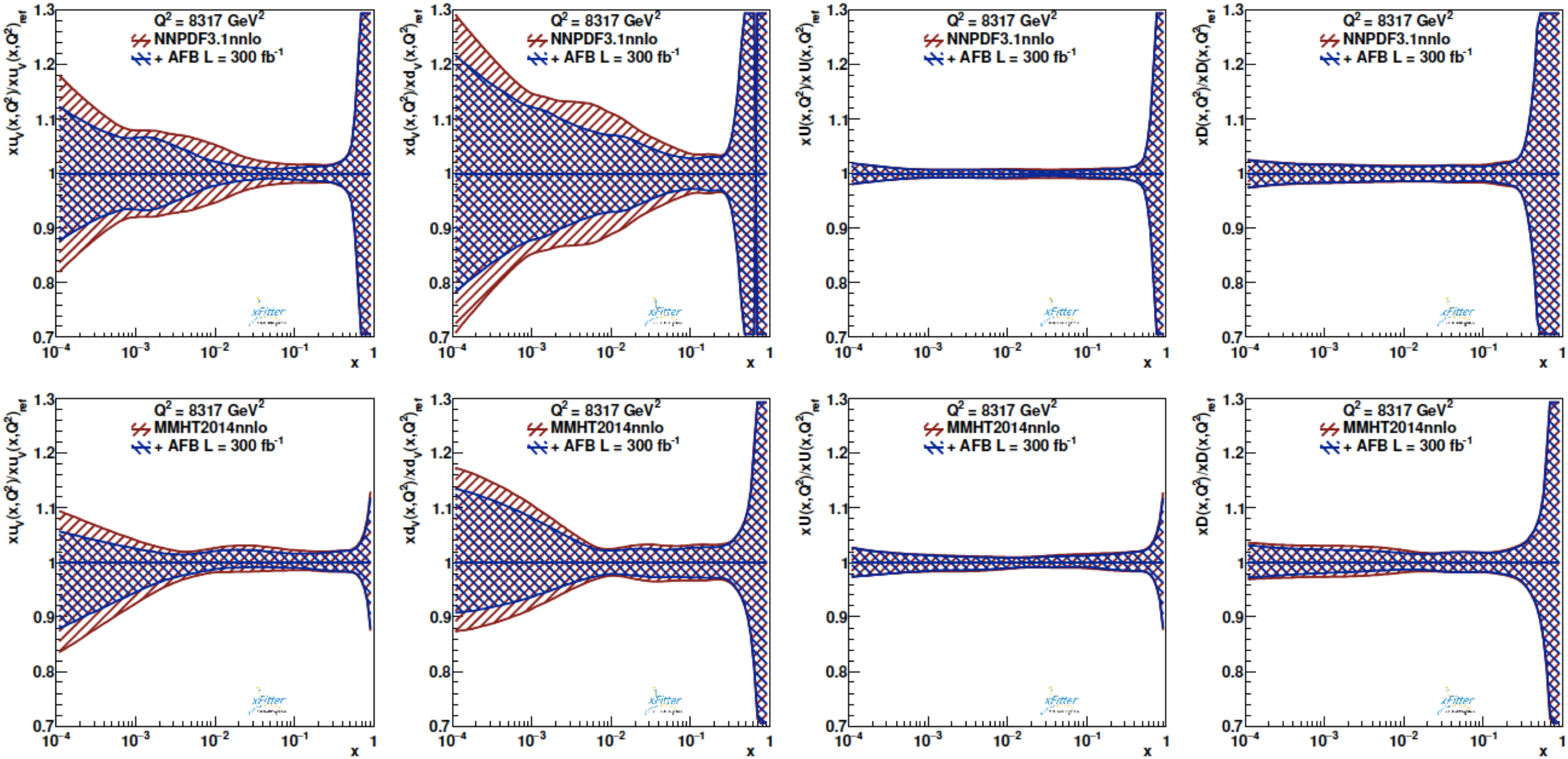
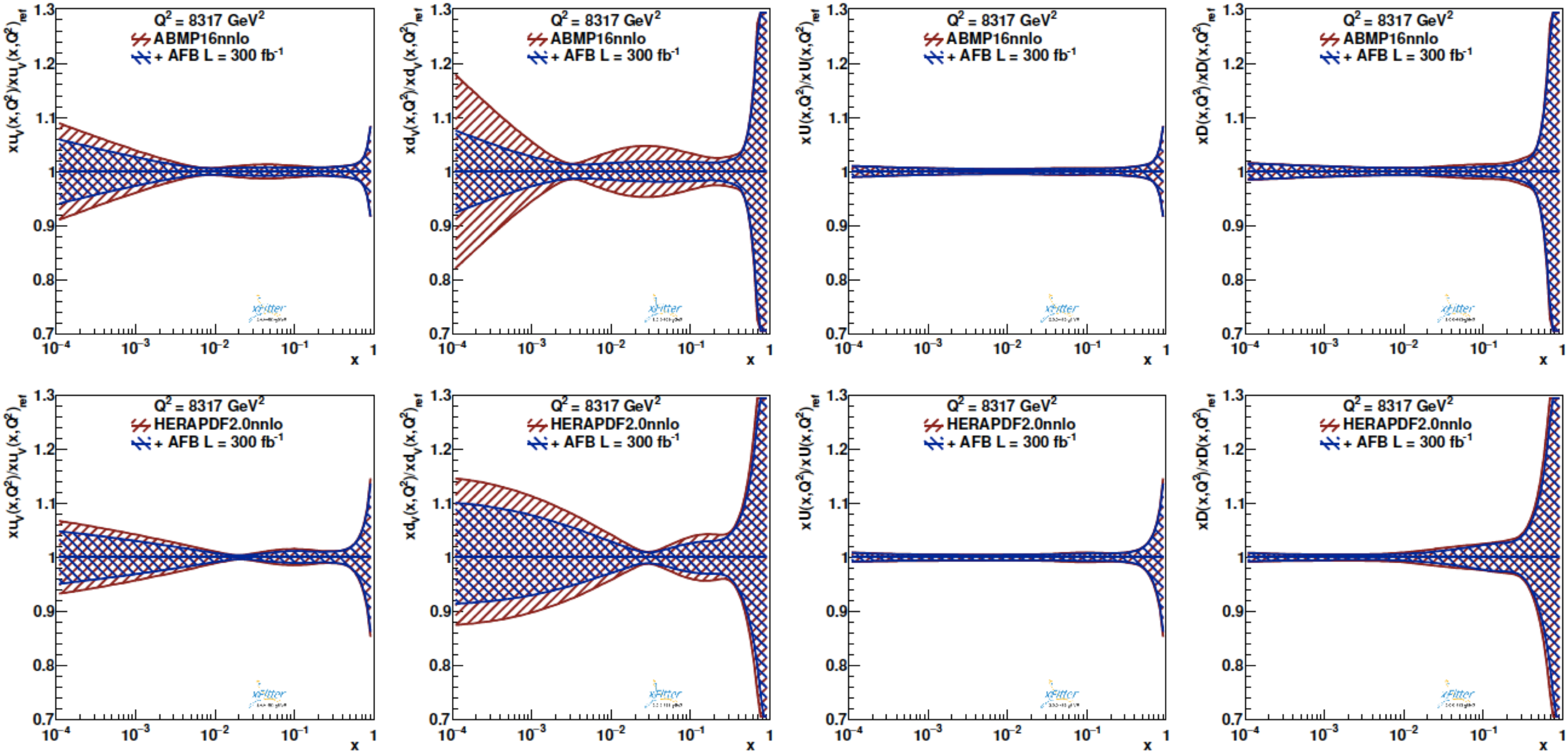


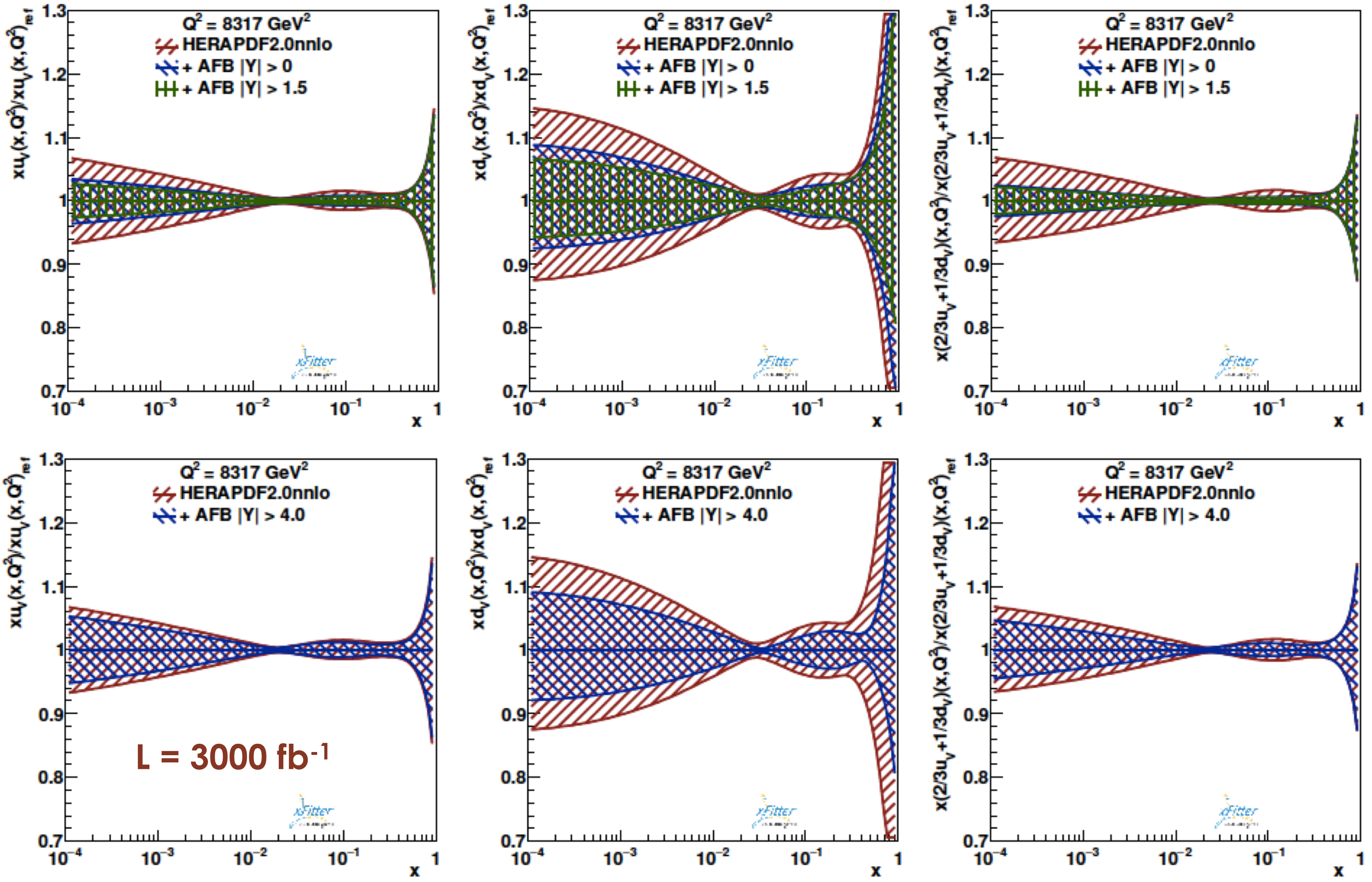
- Study performed with pseudo-data at L = 300 fb^{-1}
- NNPDF3.1nnlo (top) and MMHT2014nnlo (bottom)

PDF profiling

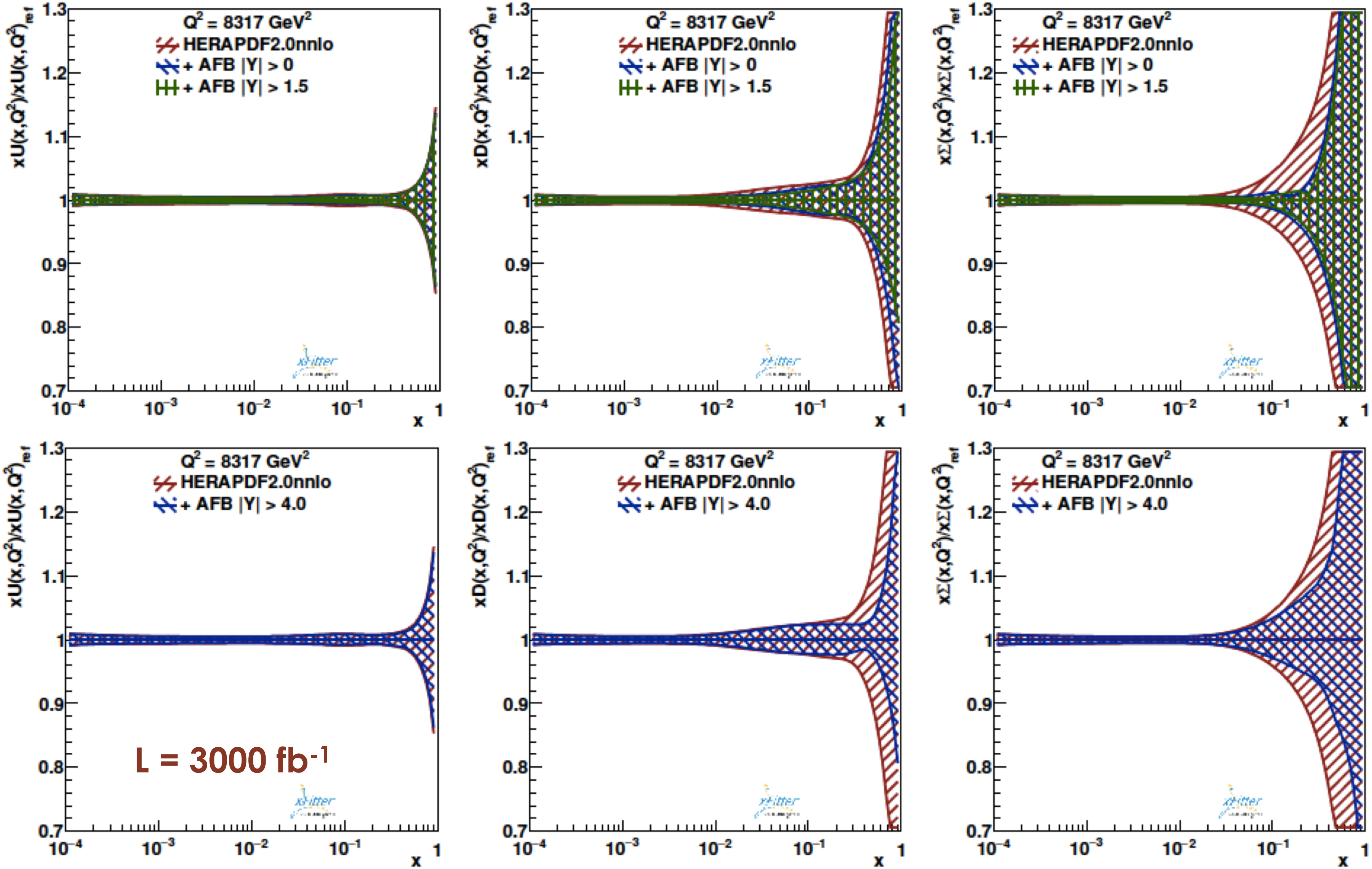


- Study performed with pseudo-data at $L = 300\ fb^{-1}$
- ABMP16nnlo (top) and HERAPDF2.0nnlo (bottom)

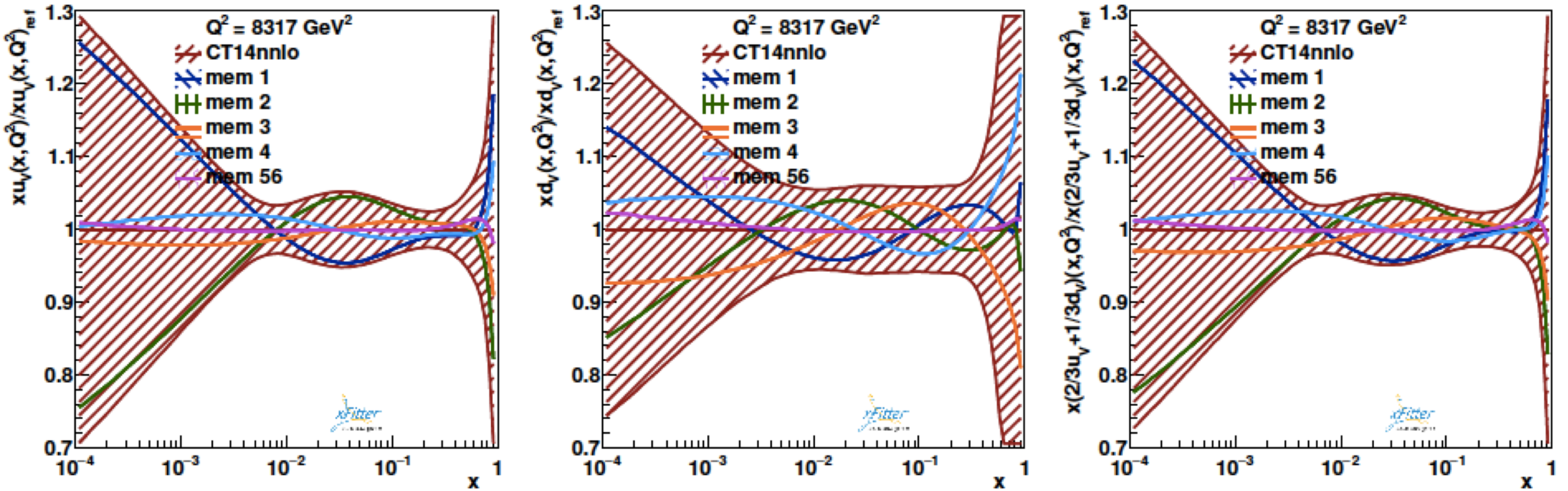
PDF profiling (different rapidity cuts)



PDF profiling (different rapidity cuts)



PDF eigenvectors rotation



- Study performed at **L = 300 fb^{-1}**
- We want to determine the PDFs (and their combinations) more sensitive to the A_{FB} data (sorted according to their sensitivity to the new data)
- First two eigenvectors almost completely determine the error bands

CT14nnlo	mem1	mem2	mem3	mem4	mem56
Total χ^2/dof	164/106	169/106	10/106	14/106	0.98/106

Theoretical and systematic uncertainties

- Aim: to access the dependence of A_{FB} on renormalisation (μ_R) and factorisation (μ_F) scales
- "Seven points" method employed

Point	$\mu_F/M_{\ell\ell}$	$\mu_R/M_{\ell\ell}$
1	0.5	0.5
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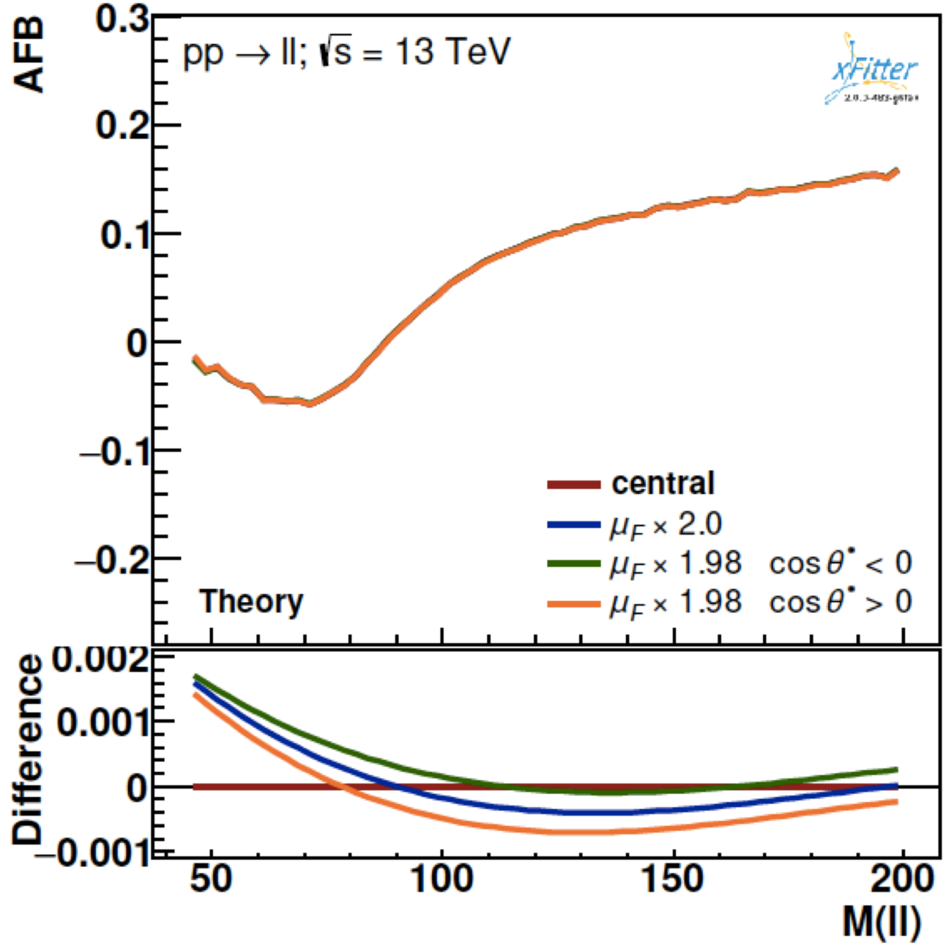
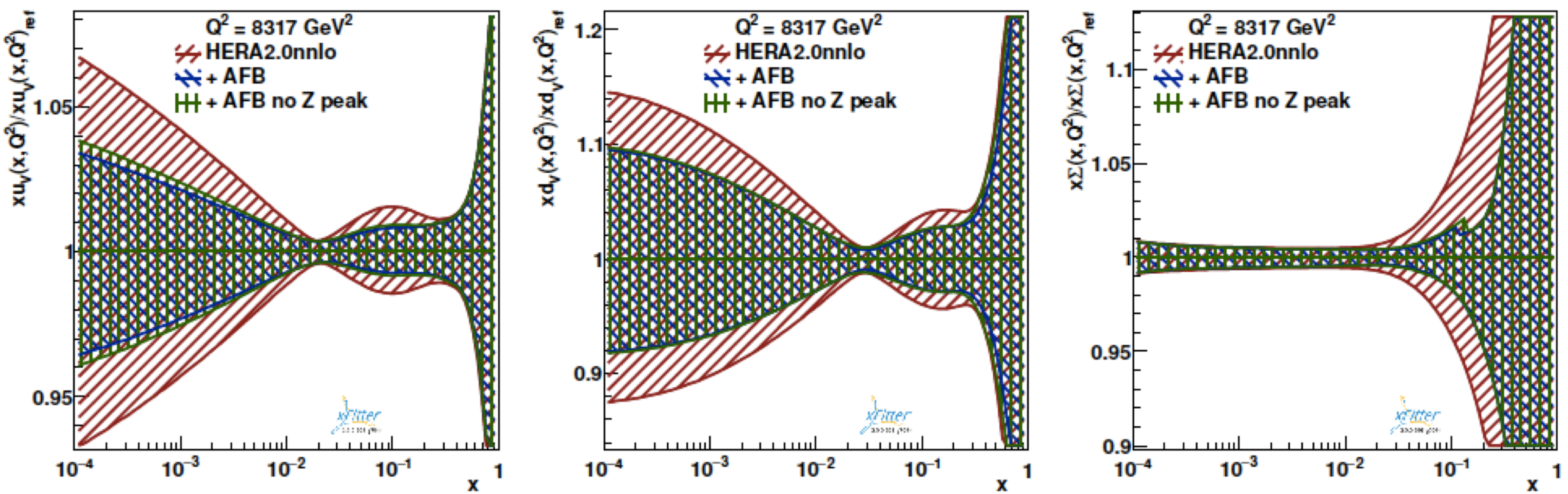


- HERAPDF2.0nnlo (EIG) PDF set in use
- Deviations wrt "point 4" (nominal μ_R and μ_F) presented
- Small variations observed (per-mille level)
- De-correlated scale variations checked as well (per-mille level)

Higher-order EW corrections

- EW corrections could also have an impact in the region around the Z peak
- We employ again the HERA2.0nnlo PDF set
- Profiled curves removing the data in the interval 84 < $m_{l^+l^-}$< 98 GeV
- Enlargement of the error bands in the u_V and d_V quark distributions, showing a sensible impact of the Z peak data, expected because of the large statistic in this invariant mass interval

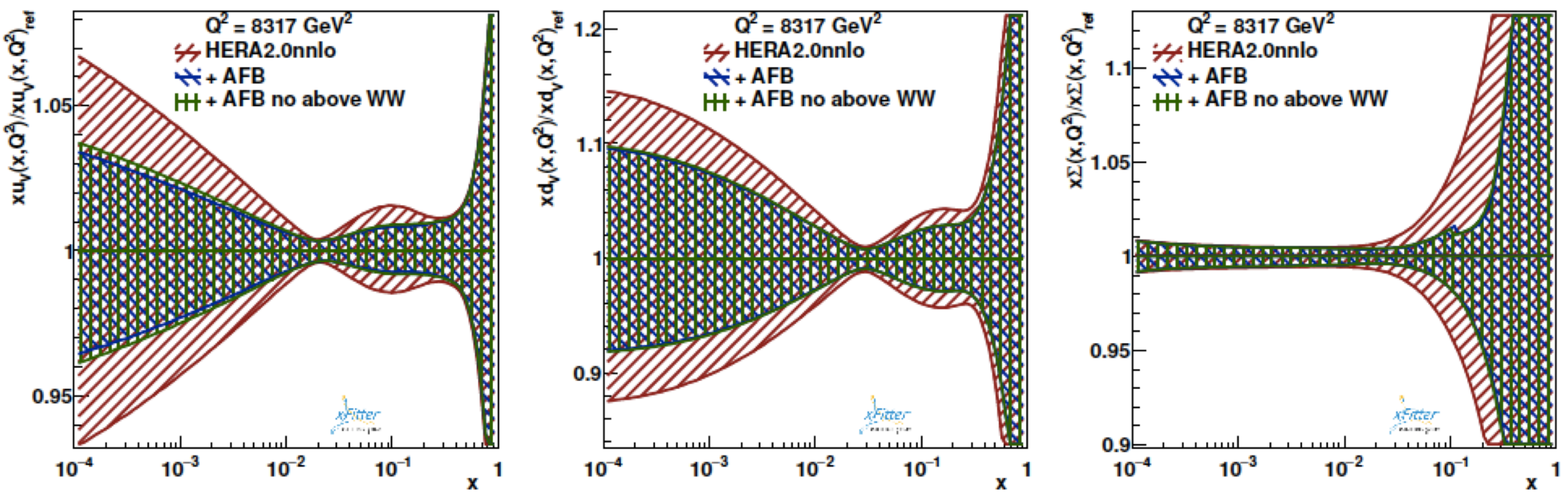
L = 3000 pb^{-1}



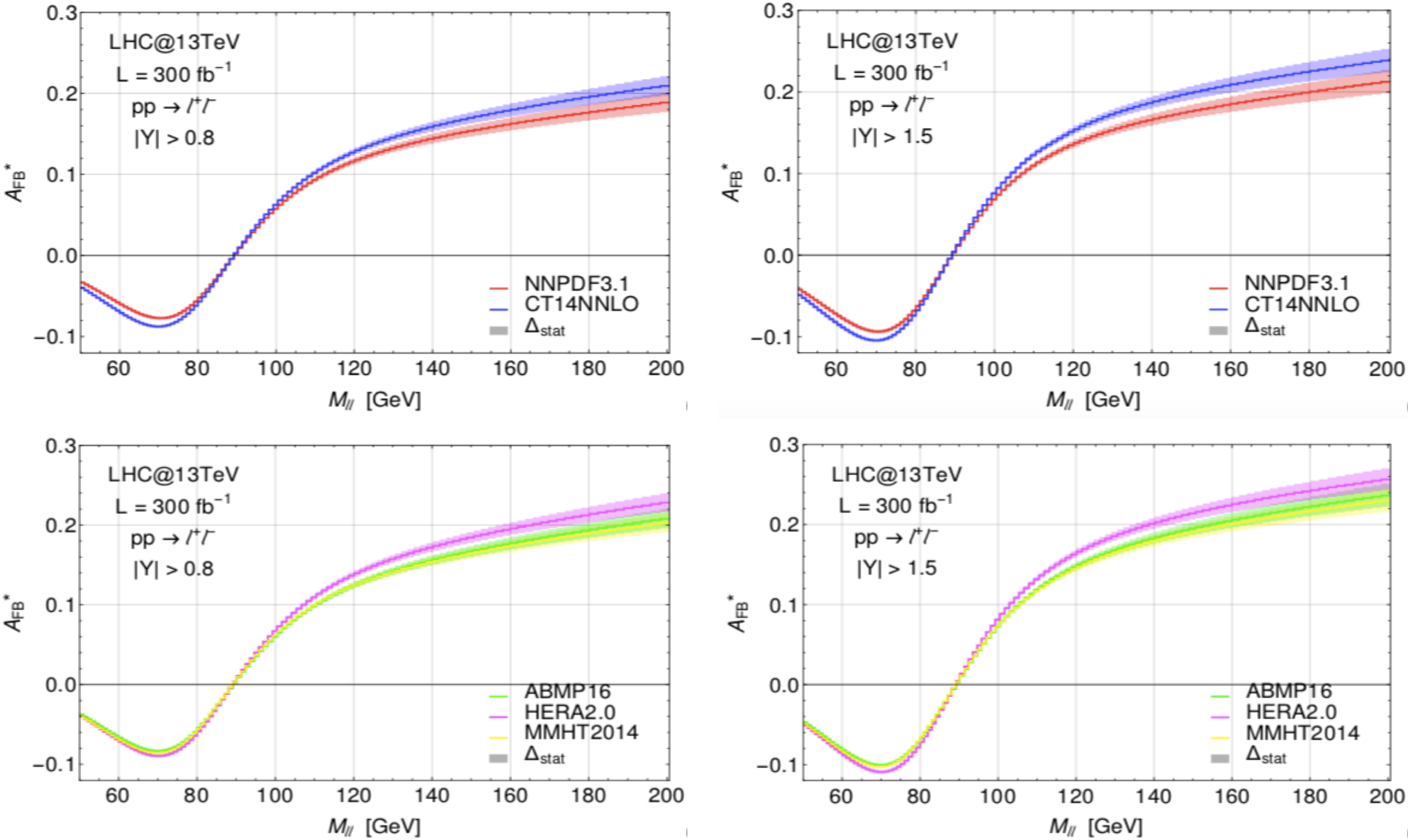
Higher-order EW corrections

- EW corrections could also have an impact for WW production
- We employ again the HERA2.0nnlo PDF set
- Profiled curves removing the data above the WW production threshold, $m_{l^+l^-}$ > 161 GeV
- Error band of the u_V quark distribution shows a small increment (smaller statistical precision → smaller impact on the profiling)

L = 3000 pb^{-1}



A_{FB} at high rapidities



High rapidity cuts enhance the differences between PDF sets

Push to the limit