xFitter: an open-source tool for QCD analyses

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Workshop 'Ultimate precision at hadron colliders'
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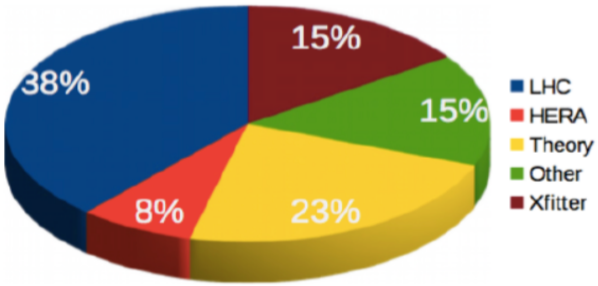
The xFitter Project

- 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**



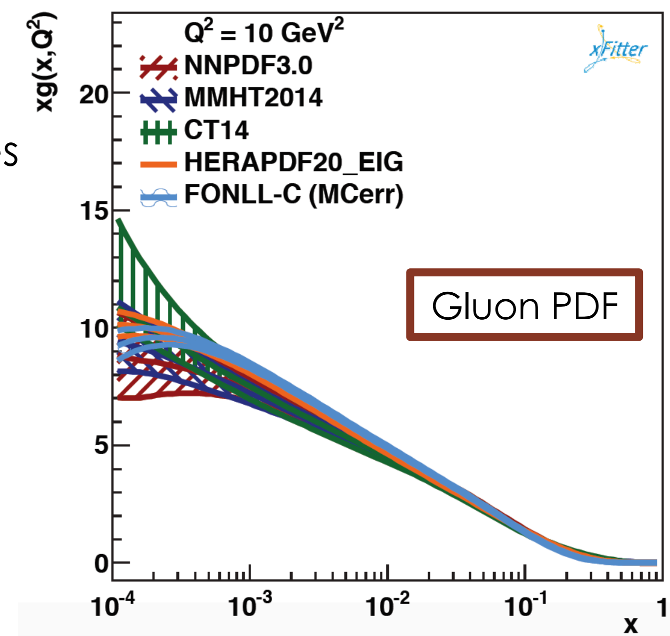
- Several active developers between experimentalists and theorists
- More than **80 publications** obtained using xFitter since the beginning of the project: https://www.xfitter.org/xFitter/xFitter/results
- List of recent analyses by the xFitter Developers' Team:

MORE IN PREPARATION!

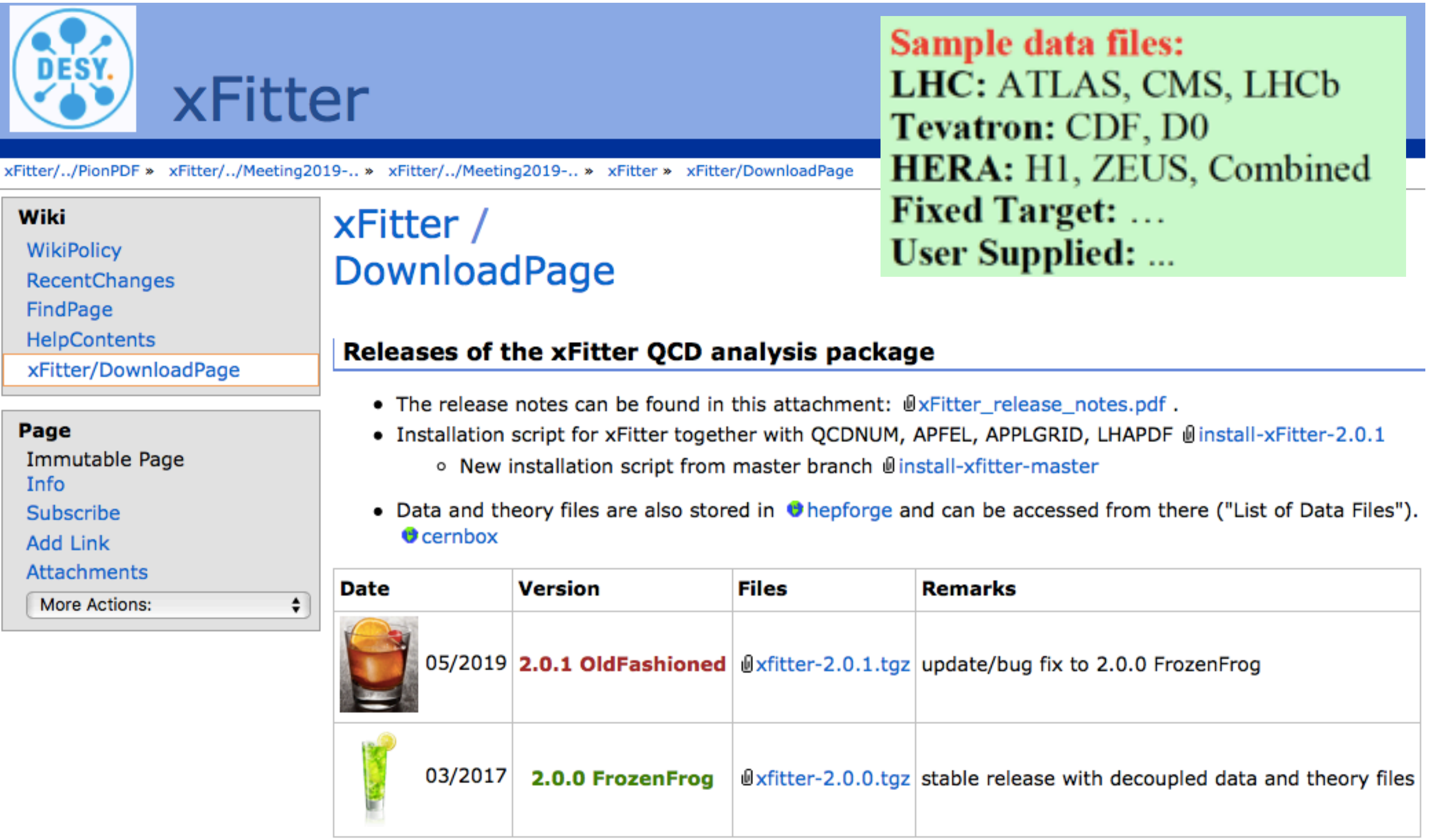
07.2019	Juri Fiaschi and xFitter Developers	arXiv:1907.07727	PDF Profiling Using the Forward-Backward Asymmetry in Neutral Current Drell-Yan Production	
07.2019	xFitter Developers	arXiv:1907.01014	Probing the strange content of the proton with charm production in charged current at LHeC	
02.2018	xFitter 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
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

xFitter in a nutshell

- **Parametrise** PDFs at the initial scale:
  - several functional forms available (more later)
  - define PDF parameters to be minimised
- **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 the data points:
  - several mass schemes available in DIS (ZM-VFNS, ACOT, FONLL, TR, 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 or by Bayesian reweighting
- **Useful drawing tools** – nice and colorful plots



xFitter release 2.0.1



xFitter

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

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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

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

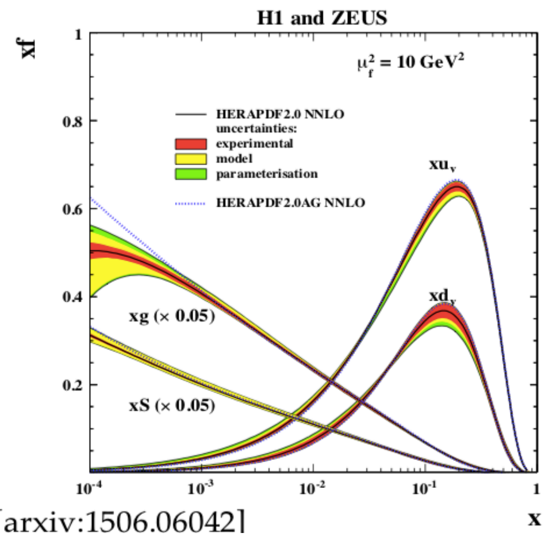
2.0.1
Old Fashioned

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

Results obtained with xFitter: Examples

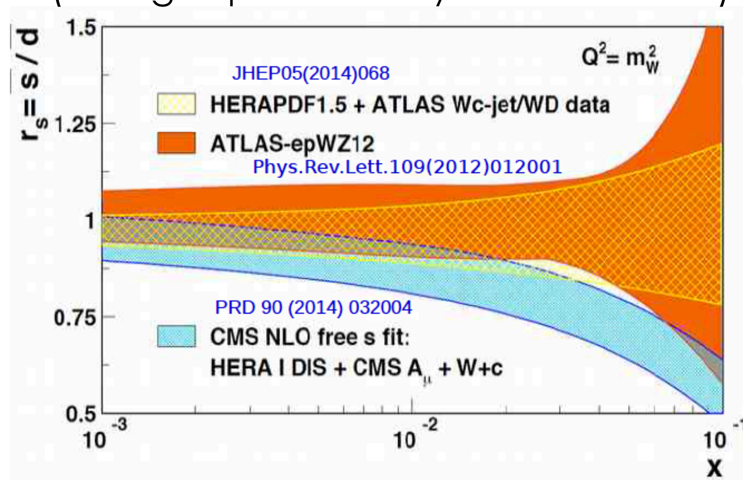
DIS inclusive processes (ep)



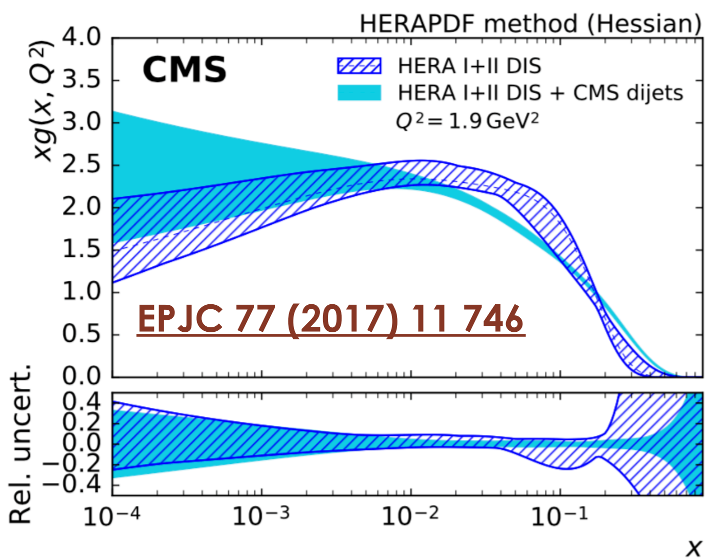
[arxiv:1506.06042]

Drell-Yan processes $(pp, p\bar{p})$

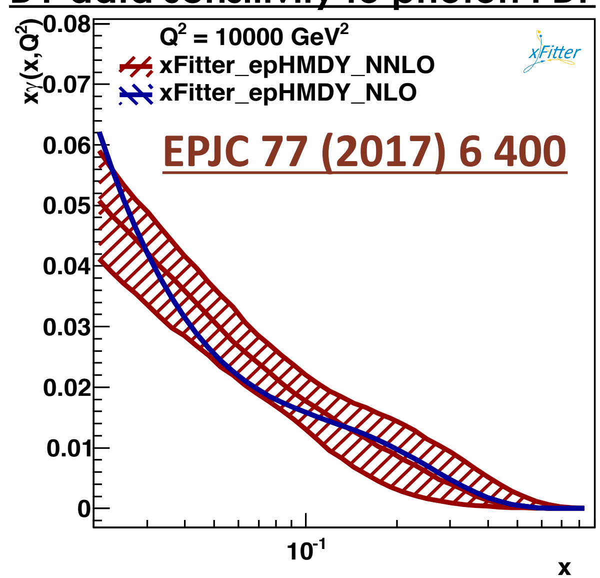
(strange quark density determination)



Jet production $(ep, pp, p\bar{p})$



DY data sensitivity to photon PDF



Code developments: APFEL++

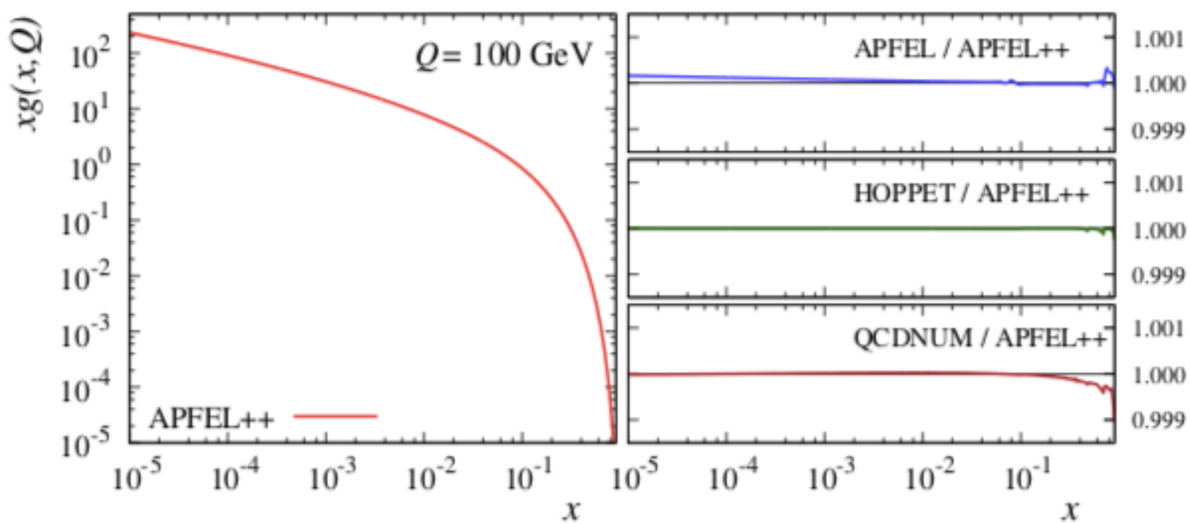
- New functionalities:
  - Semi-Inclusive DIS (SIDIS) in collinear factorisation
  - TMD phenomenology:
    - evolution and matching between collinear and TMDs regime
    - DY and SIDIS q_T distributions
  - Transversity distributions h_1

- Relevant quantities computed as convolutions between a complicated object slow to compute (perturbative hard cross section) and a fast-to-access function (non-perturbative PDF)

- Doxygen documentation

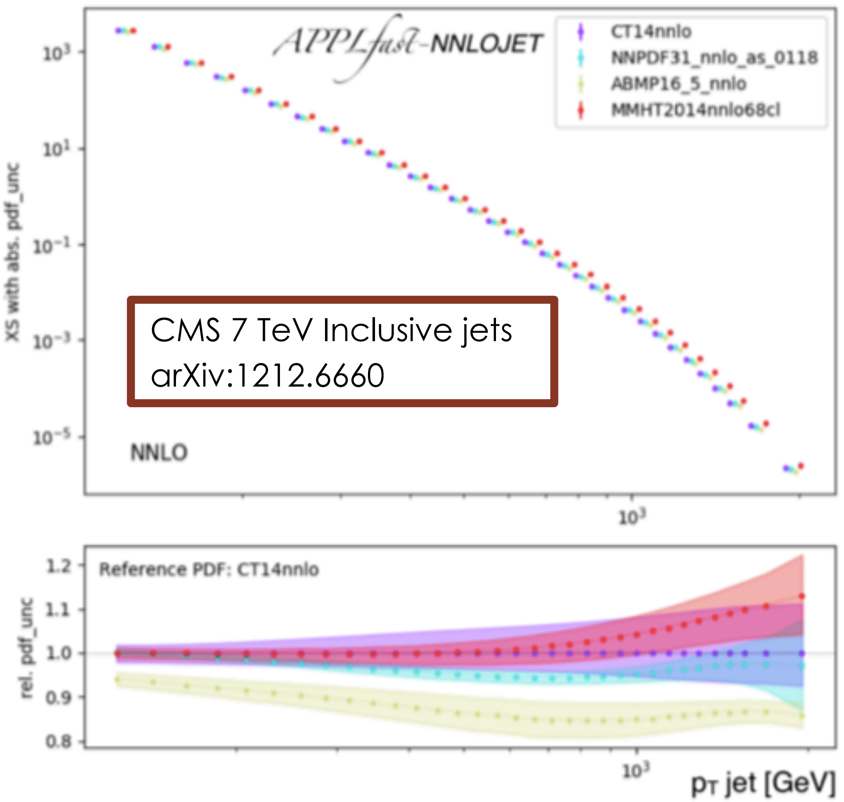
- Several NNLO applications:
  - DGLAP evolution
  - DIS structure function

- Faster than LHAPDF6 in performing PDF evolution

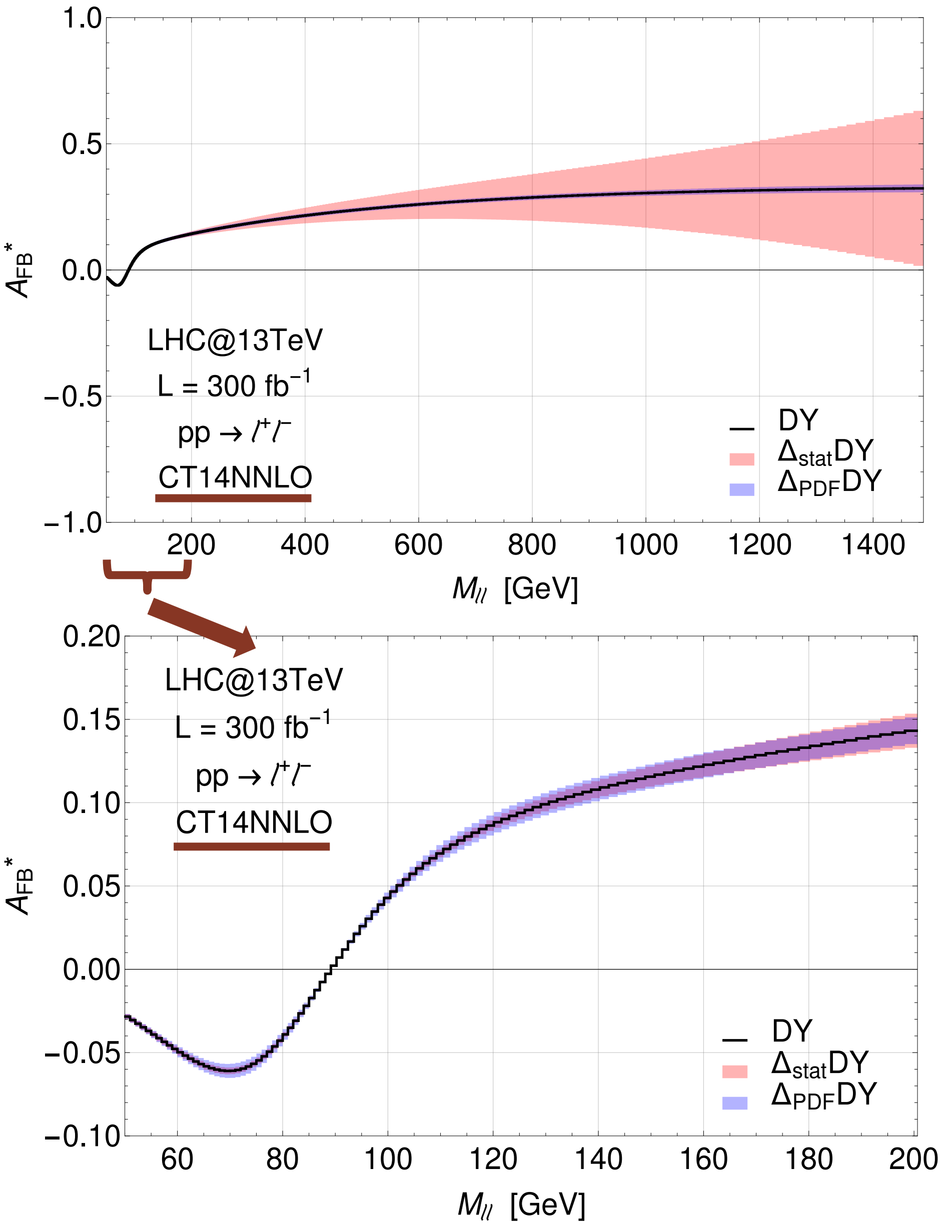


Code developments: NNLOjet

- NNLOjet grids can be used within xFitter framework
- PDF error determinations and PDF fits reasonably fast
- Scale variations vary fast for all scale-variations concepts
- NNLO grids production is ongoing:
  - **ep → jets:** Grids for all HERA inclusive jet and dijet cross sections available
  - **pp → jets:** Grids are being produced
    - First full statistics grids are currently validated
    - Low statistics grids publicly available
  - **pp → anything else (Z,Z+jets,…):**
    - Grids can be produced on request
- Ploughshare may be used for distribution of grids: http://ploughshare.web.cern.ch



Drell-Yan 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: $\cos\theta^* = \frac{p_{Z,ll}}{M_{ll}|p_{Z,ll}|}\frac{p_1^+p_2^- - p_1^-p_2^+}{\sqrt{M_{ll}^2 + p_{T,ll}^2}}$

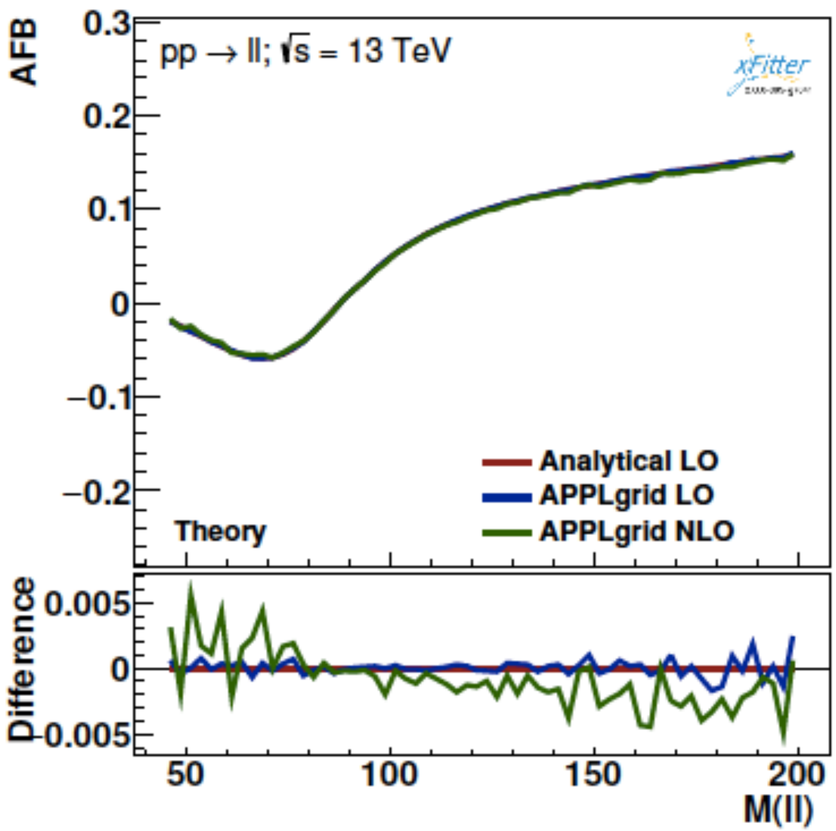
  where $p_i^\pm = E_i \pm p_{Z,i}$
- $\sigma_F = \int_0^1 \frac{d\sigma}{d\cos\theta^*} d\cos\theta^*$
- $\sigma_B = \int_{-1}^0 \frac{d\sigma}{d\cos\theta^*} d\cos\theta^*$

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

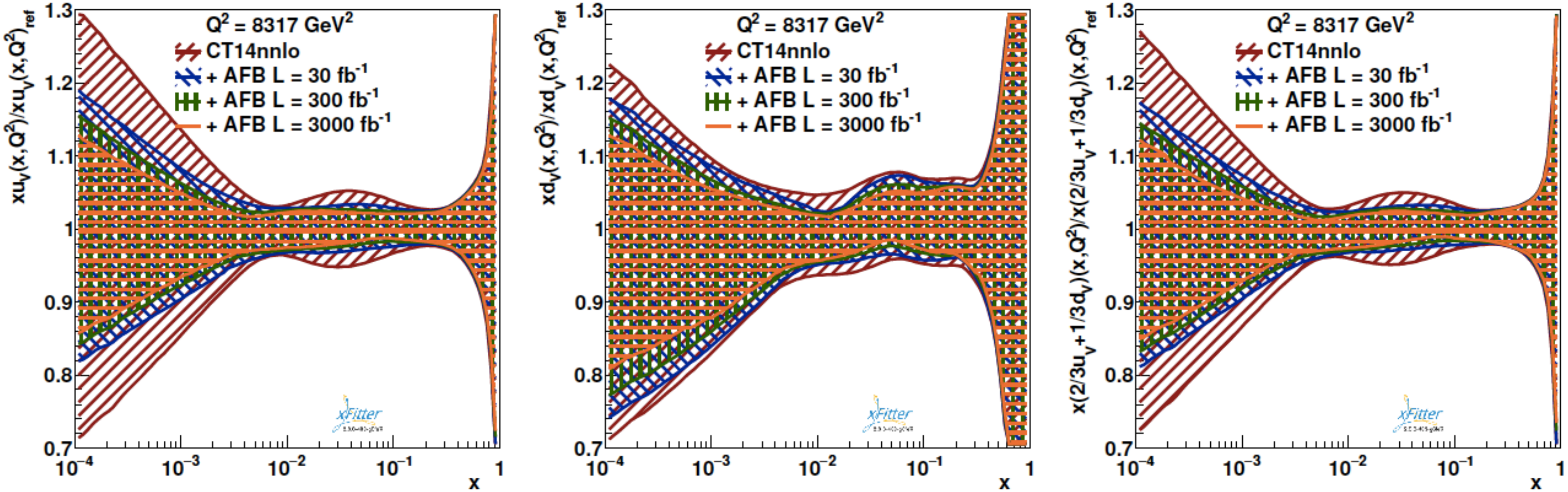
- A_{FB} has smaller systematic but larger statistical error compared to cross section measurements
- Sensitive to ($2/3u_V + 1/3d_V$) and complementary to DY Charged Current asymmetry (u_V - d_V)
- High-invariant mass region: dominated by statistical uncertainties
- $m_{l^+l^-} \simeq m_Z$: high-stats 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 for estimating the number of events in each invariant mass bin R. V. Harlander and W. B. Kilgore, Phys. Rev. Lett. 88, 201801 (2002)
- No sensible difference LO analytic and LO from APPLgrid
- 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)

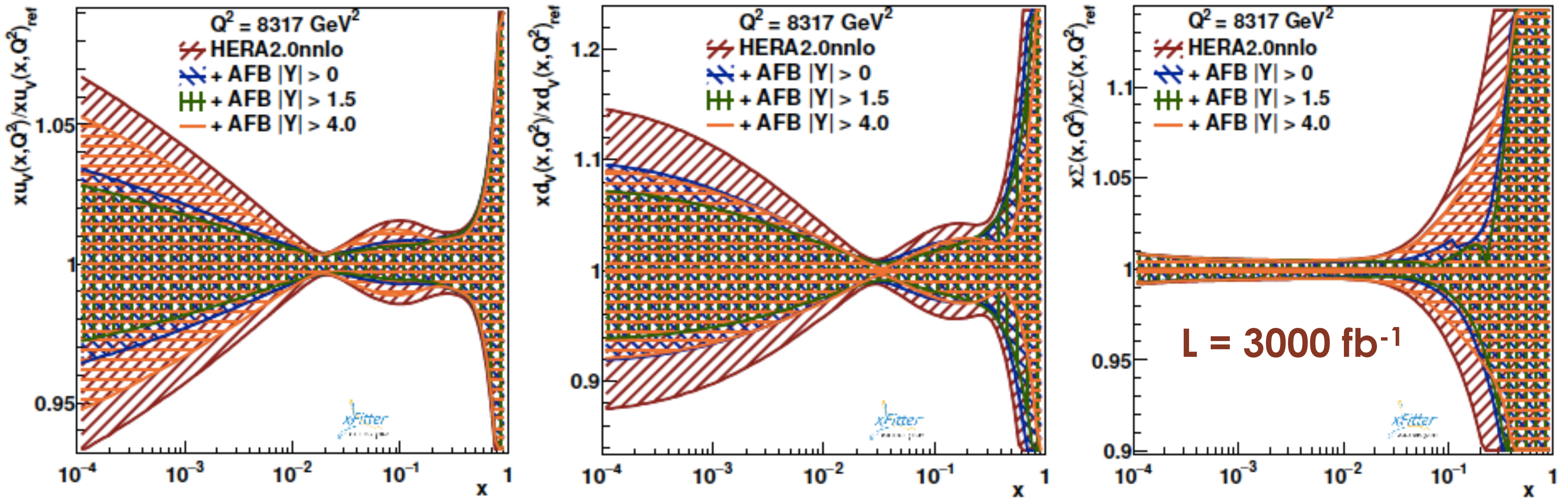


PDF profiling



- 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 (backup)
- Similar and comparable effects found using other NNLO PDF sets (backup)

PDF profiling (different rapidity cuts)



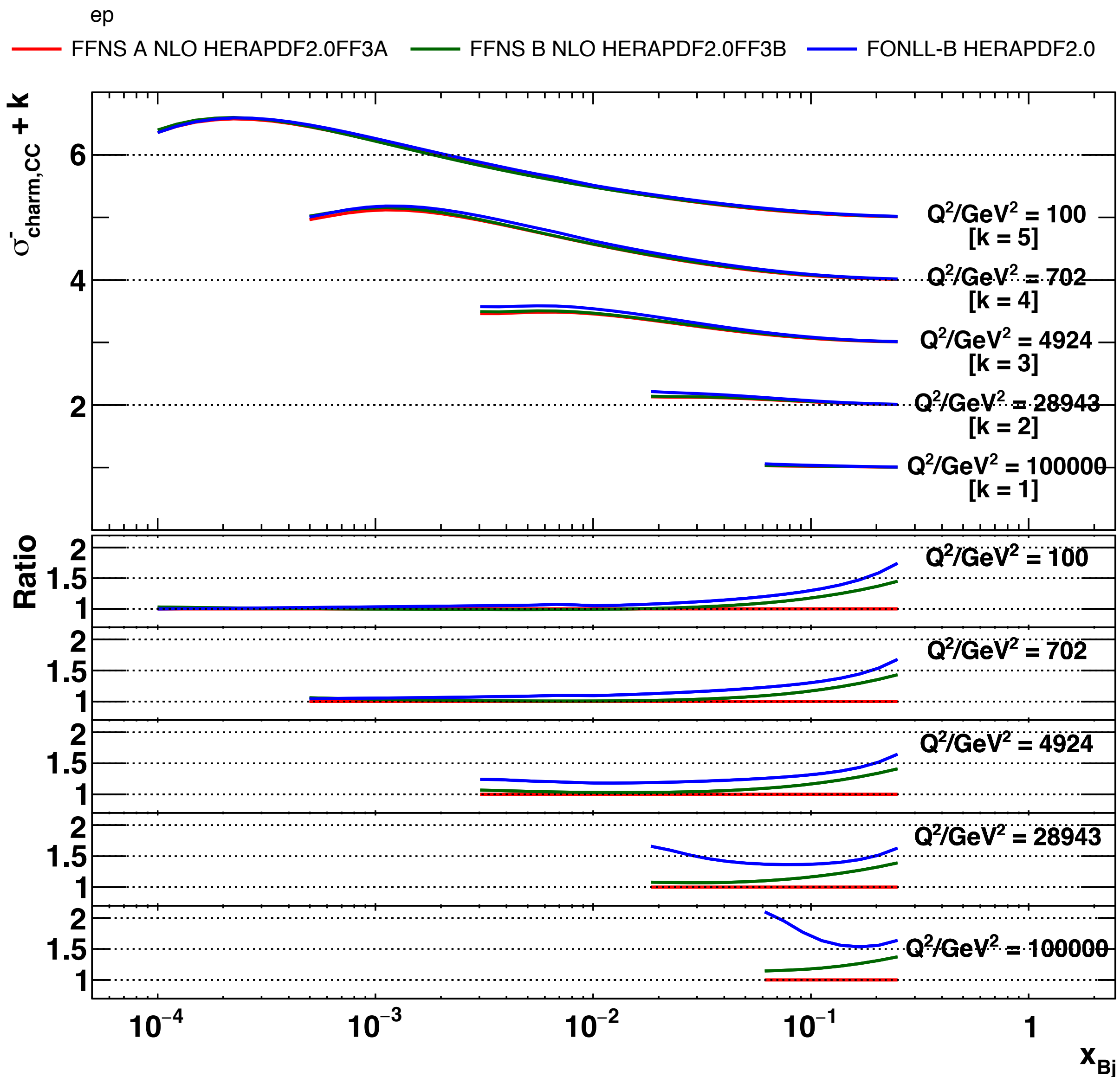
- Comparing results for |Y| > 0.0 and > 1.5, some improvement for d_V at low-x
- **|Y| > 4.0 profiling at LO**: 120 bins of 1 GeV-width from 80 to 200 GeV - detector acceptance enlarged up to $|\eta_l|$ < 5.0 (symmetrically applied to both the leptons in the final state)
- Poorer profiling due to reduced statistics in the low-x regime
- Reduction of uncertainty bands concentrated in the high-x region (not accessible before) – remarkable improvement for d_V for x > 0.6

Charm production in charged-current

- What is the difference in predictions for different heavy flavour schemes?
- How can future data on charm production in charged-current DIS at the LHeC constrain the strange-quark PDF?
- All calculations and PDFs are at NLO
- Heavy-flavour schemes:
  - **FFNS A**: 3 flavours in both PDFs and α_S evolution. Charm appears in matrix elements only
  - **FFNS B**: 3 flavours in PDFs, but variable number of active flavours in α_S evolution. Same matrix element as in FFNS A at NLO for Charged Current only
  - **FONLL-B**: Variable number of active flavours in both PDFs and α_S evolution, neglecting masses

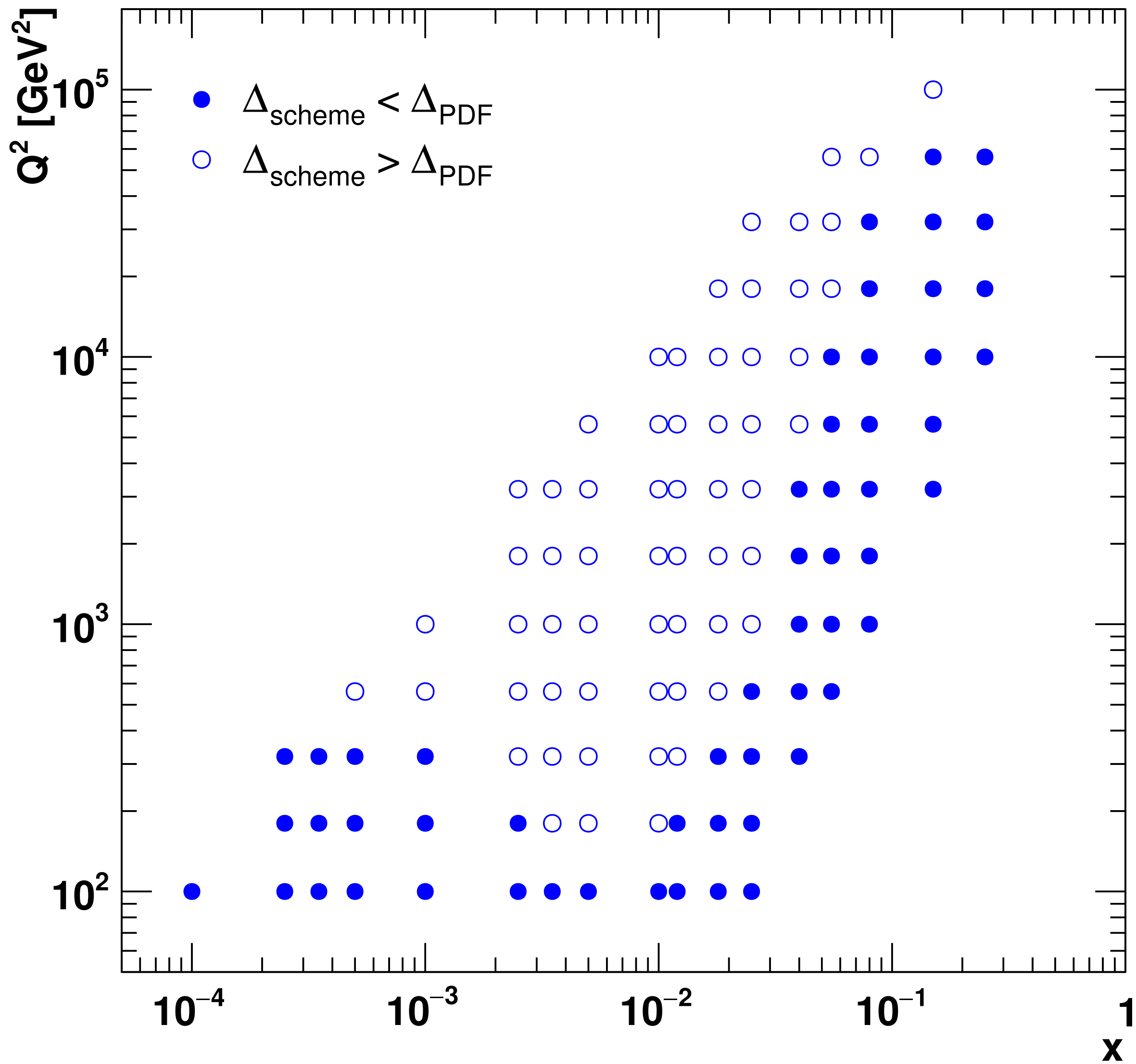
Charm production in charged-current

- Predictions are different at large Q^2 and high-x
- PDF uncertainties relatively stable across the Q^2 for a fixed x_{B_j}
- μ_R uncertainty is small, and the total uncertainty is dominated by μ_F
- Impact of NNLO corrections for $Q > m_c$ is 10% at most
- Mainly because of the different treatment of heavy quarks in the running of α_S at high x_{B_j} or low y

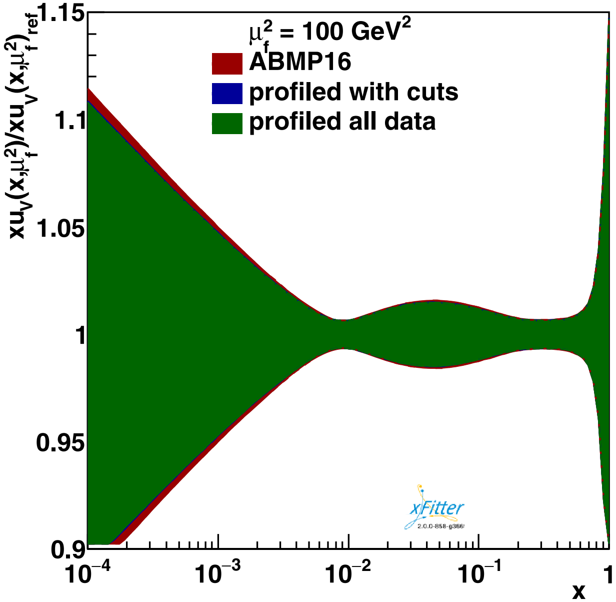


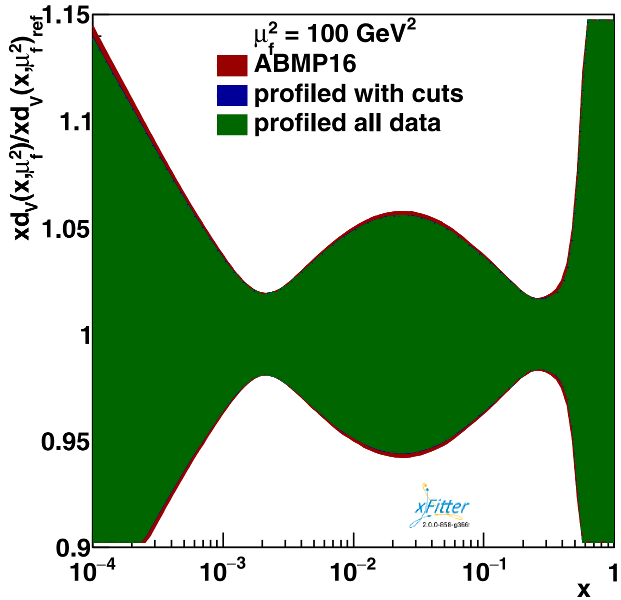
LHeC pseudo-data generation

- Pseudo-data generated for a total luminosity L = 100 fb^{-1}
- Electron polarisation P = -0.8
- Profiling study performed using two sets of LHeC data:
  - The full set
  - Restricted set with data points for which the difference between FFNS A and FONLL-B are smaller than the present PDF uncertainties



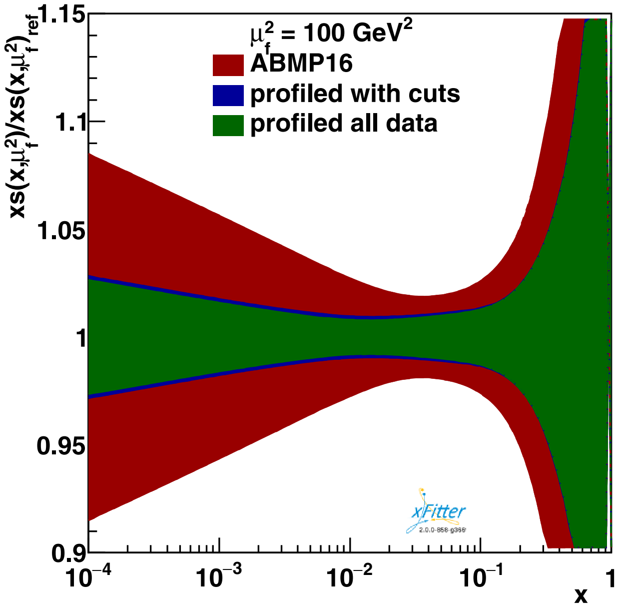
Profiling ABMP16 - Q^2 = 100 GeV^2

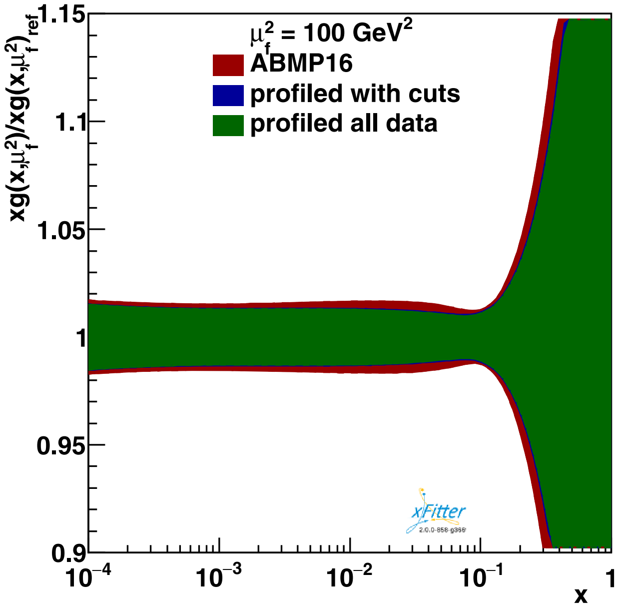


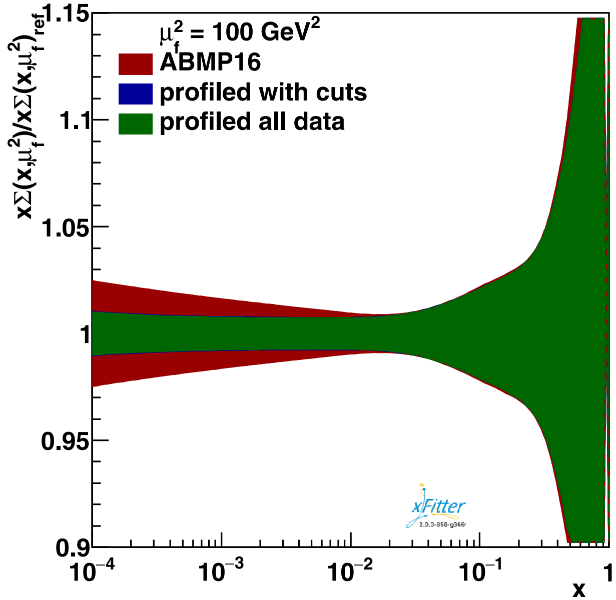


The strange PDF is the most constrained distribution

Similar results found profiling NNPDF31

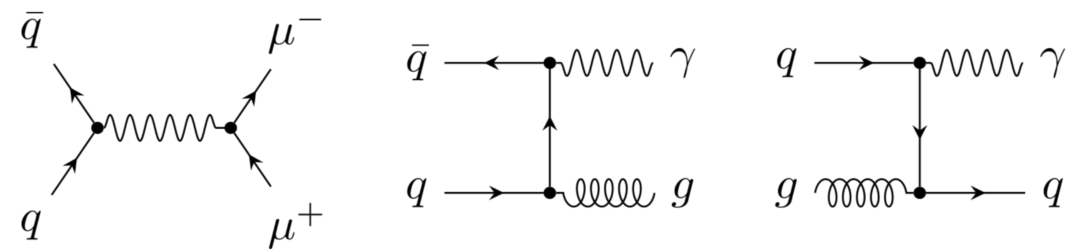






Charged Pion PDF

- Pion structure is poorly studied experimentally
- Currently available pion PDF sets in LHAPDF6 are provided without error bands
- Data from **E615**, **NA10** and **WA70** experiments (di-muon and direct photon production)



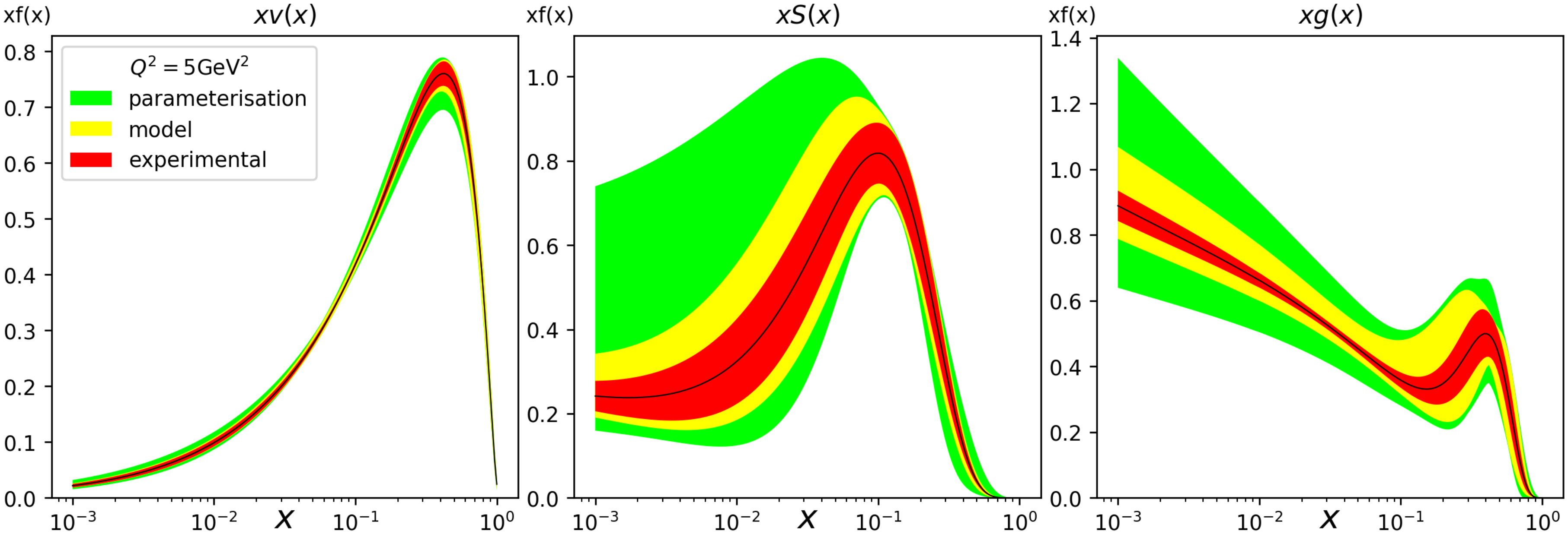
- Charge symmetry $d = \bar{u}$ and SU(3)-symmetric sea $u = \bar{d} = s = \bar{s}$ at the initial scale $Q_0^2 = 1.9$ GeV^2

$$v := (d - \bar{d}) - (u - \bar{u}), \qquad xv(x) = A_v x^{B_v}(1-x)^{C_v}(1 + D_v x^{\frac{5}{2}}),$$
$$S := 2u + 2\bar{d} + s + \bar{s} = 6u, \qquad xs(x) = A_S x^{B_S}(1-x)^{C_S},$$
$$g := g, \qquad xg(x) = A_g x^{B_g}(1-x)^{C_g}.$$

- The A_v and A_g parameters are determined by the sum rules:

$$\int_0^1 v(x)\mathrm{d}x = 2, \qquad \int_0^1 x(v(x) + S(x) + g(x))\mathrm{d}x = 1$$

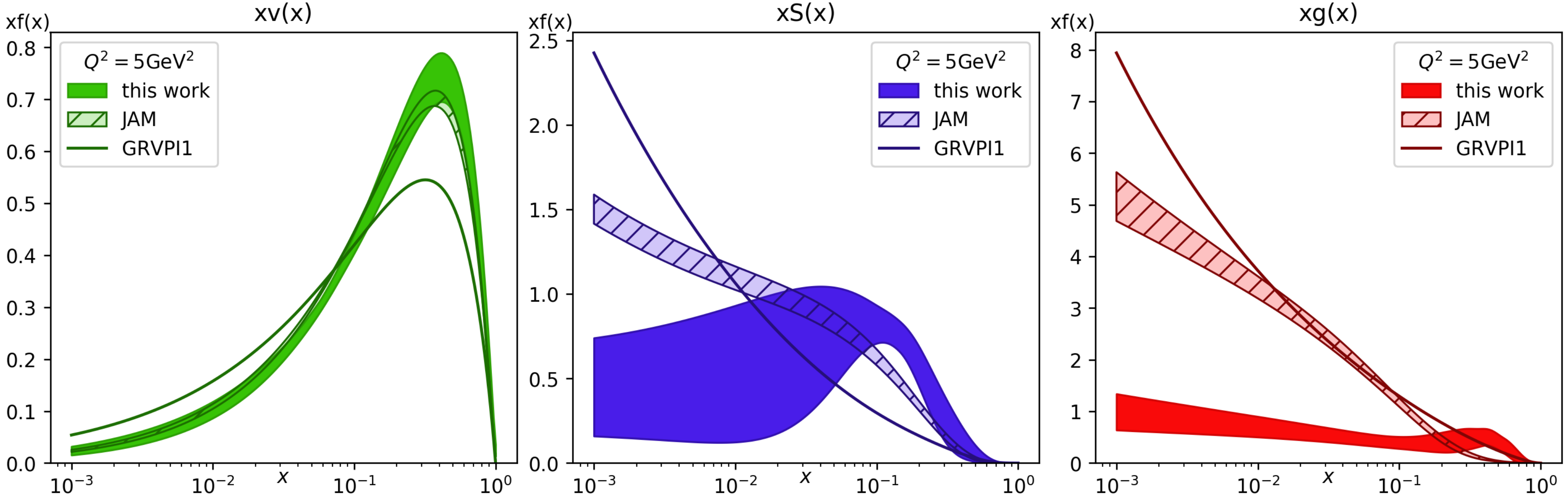
Pion PDF



- PDFs with full uncertainties (e.g. α_S, Q_0^2, μ_R variations)
- Parametrisation uncertainties considered as well (e.g. fixing C_g or C_s)
- μ_R variation has the strongest impact
- Valence distribution is well-constrained
- Hard to determine sea and gluon distributions

Experiment	χ^2/N_{points}
E615	194/140
NA10 (194 GeV)	98/67
NA10 (286 GeV)	92/73
WA70	74/99

Pion PDF



- Comparison with recent pion PDF determinations:
  - JAM collaboration
  - GRVPI1 pion PDF set
- Valence distribution in good agreement with JAM and both disagree with the early GRV analysis
- The relatively hard-to-determine sea and gluon distributions are different in all the three PDF sets

Conclusion

- The xFitter project (former HERAFitter) is a **unique open-source QCD fit framework**
- With its flexibility and modular structure, easy to use - **OldFashioned 2.0.1** out!
- Foreseen future physics (low-x phenomenology, nuclear PDF, etc…)
- Technical developments ongoing e.g. improved user interface for new PDF parametrisation, user-friendly interface for adding new reactions, QCD+EW fits
- Interfaced with APFEL/APFEL++ → TMD phenomenology and FO predictions matched to small-q_T resummed calculations
- NNLOjet grids can be used in xFitter (aiming for a consistent set of predictions)
- Three new analyses:
  - PDF Profiling Using the Forward-Backward Asymmetry in Neutral Current Drell-Yan Production - **Eur. Phys. J. C79 (2019) 864**
  - Probing the strange content of the proton with charm production in charged current at LHeC - **JHEP 10 (2019) 176**
  - Parton distribution functions of the charged pion within the xFitter framework – **out soon**

Backup Slides

xFitter on Hepforge: data access

http://xfitter.hepforge.org/

- This website contains complementary information to https://www.xfitter.org/
- Possibility to download data files (including theory)
- Updated automatically with new data added to git

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

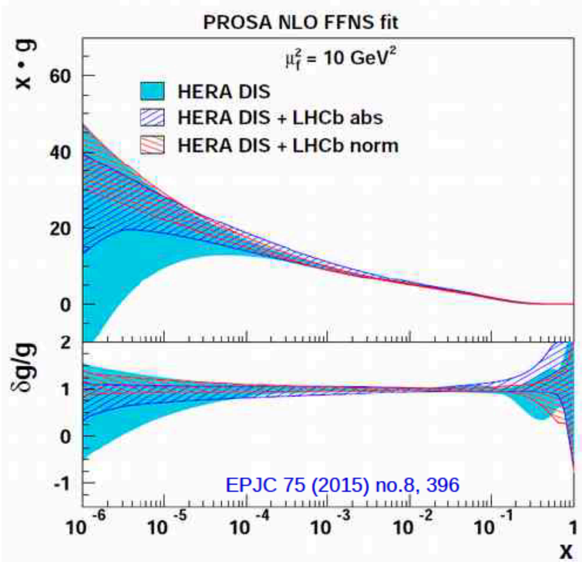
This page contains the list of publicly available experimental data sets (with corresponding theory grids if available) in the xFitter package.
To download data set please click on the arXiv link (and open/save tar.gz file).

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	

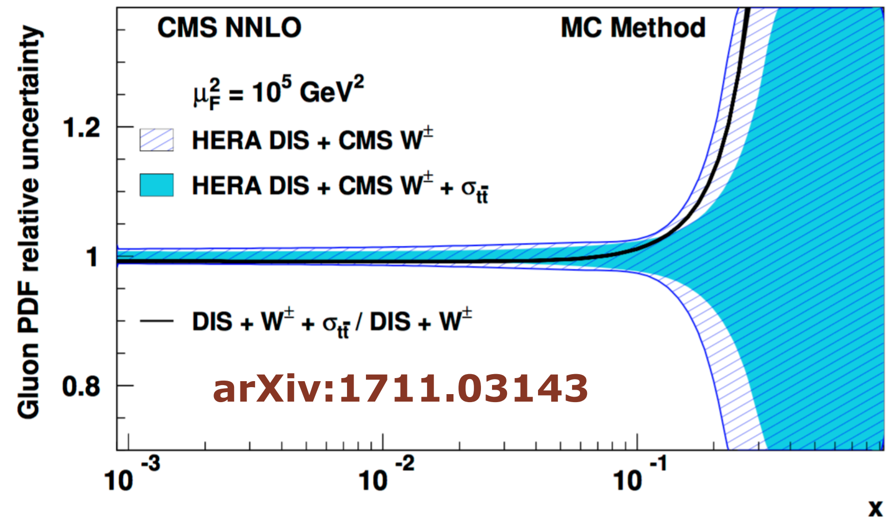
(more datasets available on the website)

Results obtained with xFitter: Examples (2)

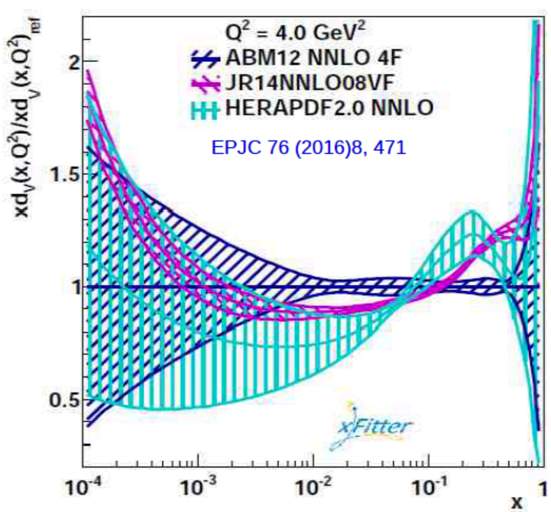
Heavy quark production$(ep, pp, p\bar{p})$



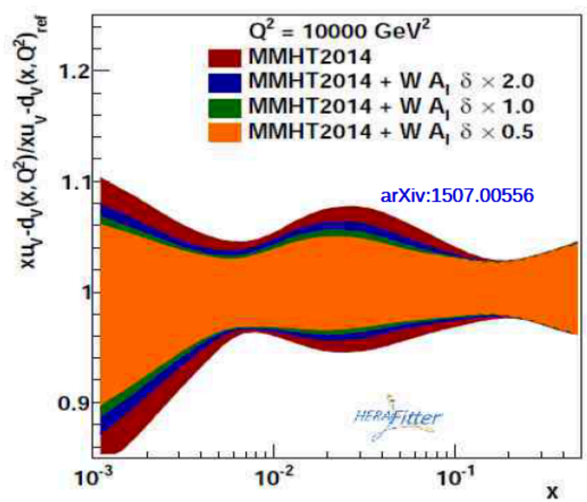
Top-quark production $(pp, p\bar{p})$



Evolution of moder PDFs (benchmarking)

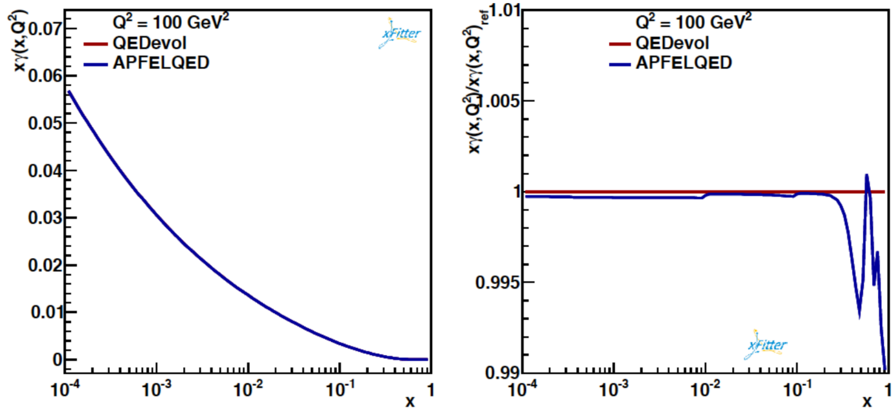


PDF4LHC report (benchmarking)



Physics cases in xFitter

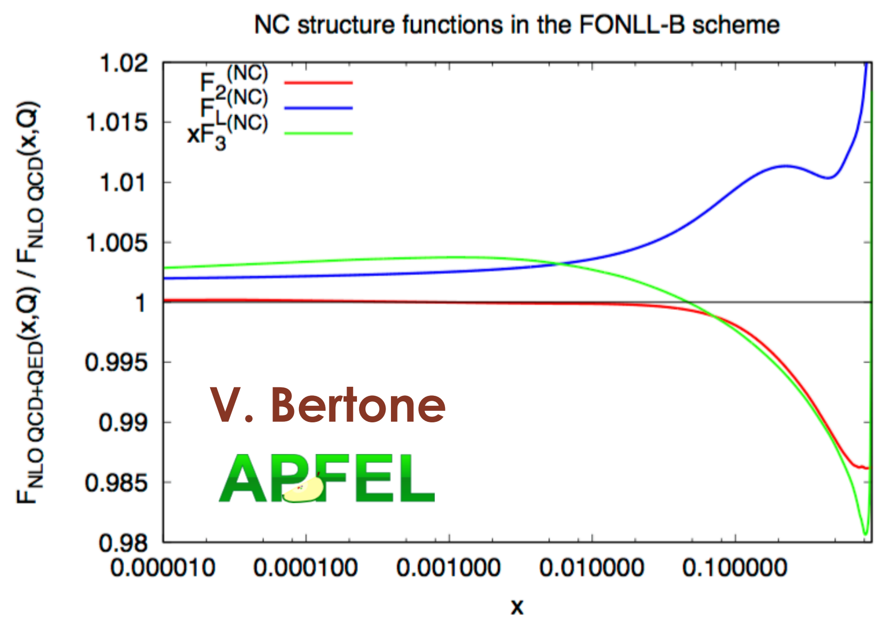
- **New QED PDFs up to NNLO QCD + NLO QED** in FFNS and VFNS are now available via evolutions in:
  - QCDNUM adjusted for DGLAP+QED [R. Sadykov] http://www.nikhef.nl/~h24/qcdnum
  - APFEL DGLAP+QED as used by NNPDF2.3 [V. Bertone et al.] https://apfel.hepforge.org/
  - plan to add NLO QED, interface APPLGRID to SANC https://apfel.hepforge.org/mela.html



[Plots produced by R. Sadykov and V. Bertone]

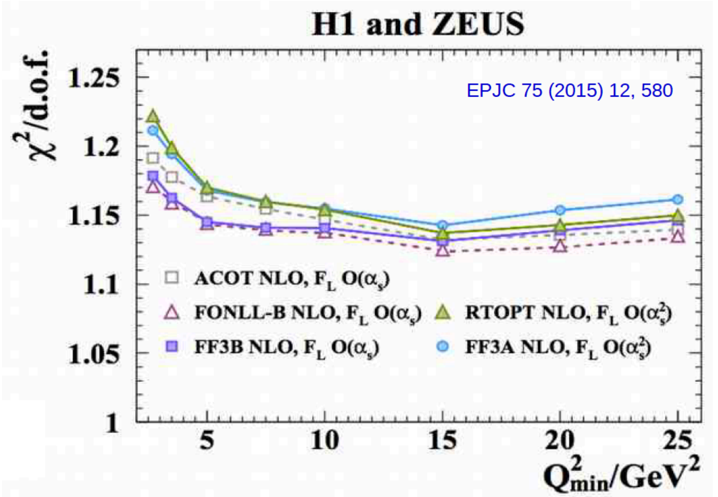
Perfect agreement between QEDEVOL and APFEL

- **NLO QCD + QED via APFEL in xFitter:**
  - implementing the $O(\alpha\alpha_S)$ and the $O(\alpha^2)$ corrections to the DGLAP splitting functions on top of the $O(\alpha)$ ones
  - implementing $O(\alpha\alpha_S^2)$ and the $O(\alpha^2)$, $O(\alpha^2\alpha_S)$ corrections to β functions
  - when including NLO QED corrections, not only the evolution is affected but also the DIS structure functions

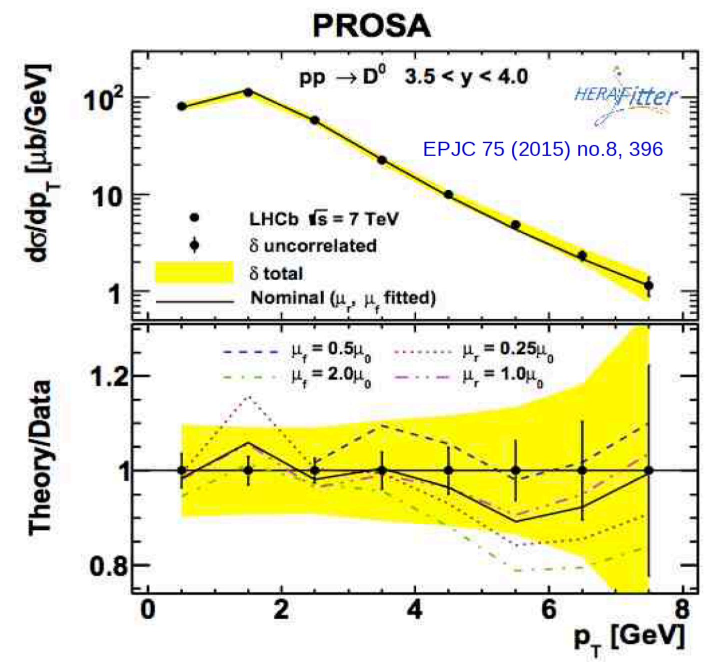


Physics cases in xFitter (2)

- Addition of new Heavy Flavour Scheme: **FONLL VFNS**
  - it is available thanks to collaboration with APFEL
  - various FONLL options available via interface to APFEL https://apfel.hepforge.org/
  - ABM scheme was up-to-dated to OPENQCDRAD v2.0b4 http://www-zeuthen.desy.de/~alekhin/OPENQCDRAD



- **Interface to Mangano-Nason-Ridolfi** (MNR, NPB 373 (1992) 295) theory code added in xFitter:
  - was used for analysing the heavy-flavour production at
  - LHCb and at HERA (via OPENQCDRAD)
  - use of FFNS for accounting of heavy quark masses at NLO
  - added corresponding LHCb data



- **Added extra reweighing option** using Giele-Keller weights

Code developments: APFEL++

- New functionalities:
  - Semi-Inclusive DIS (SIDIS) in collinear factorisation
  - TMD phenomenology:
    - evolution and matching
    - DY and SIDIS q_T distributions
  - Transversity distributions (PDFs and FFs)
- In SIDIS, what enters the computations of the cross section is:

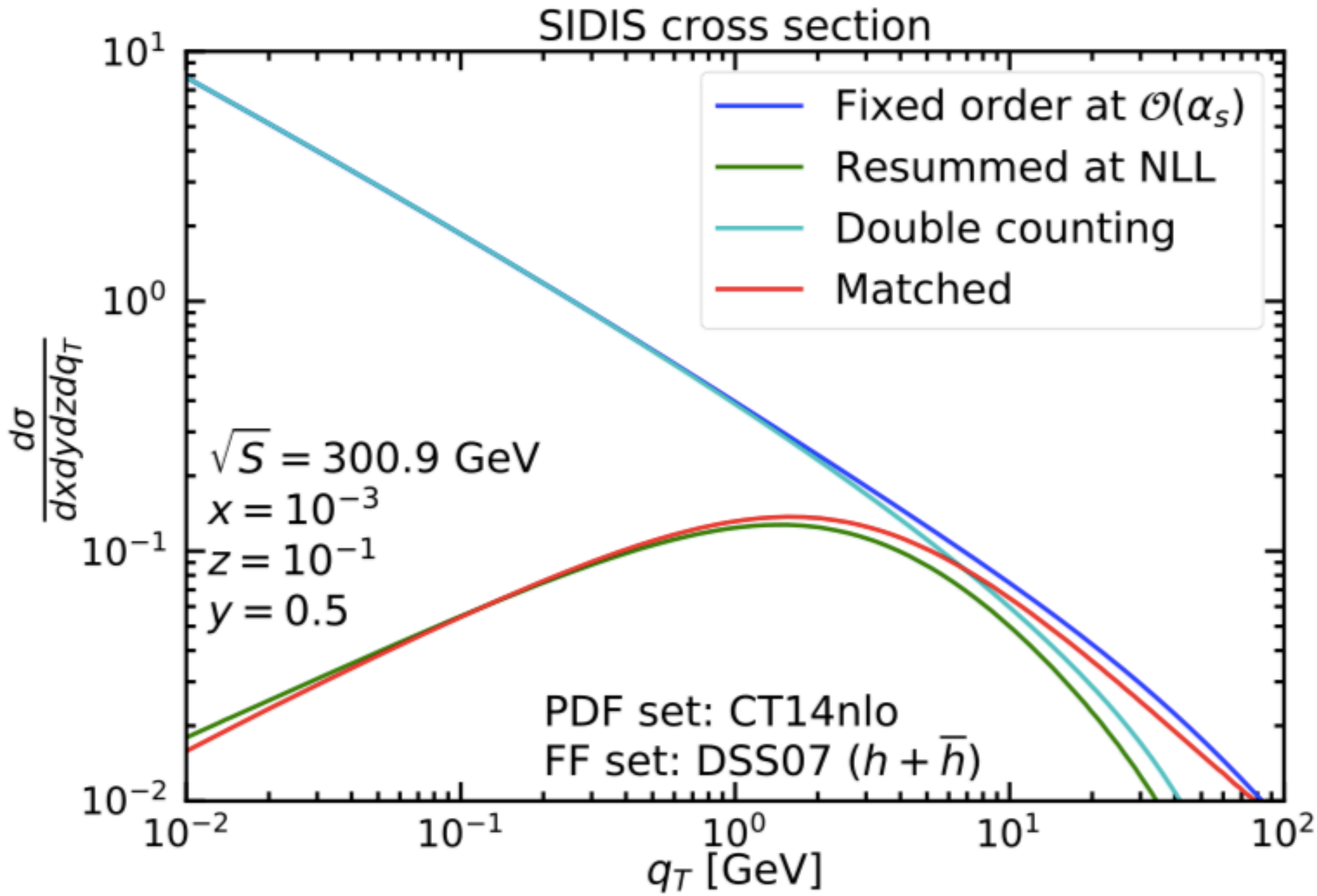
$$\mathcal{L}_{\mathrm{SIDIS}} = \int \frac{d^2\mathbf{b}_T}{(2\pi)^2} e^{-i\mathbf{q}_T\cdot\mathbf{b}_T} F_{f/P}(x,\mathbf{b}_T;\mu,\zeta_F) D_{H/f}(x,\mathbf{b}_T;\mu,\zeta_D)$$

Fourier transform PDFs FFs

- APFEL provides the ideal environment for this computation:
  - fast and accurate interpolation techniques
  - precomputation of the time consuming bits

Code developments: APFEL++

- Matching collinear and TMDs regime:



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

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.

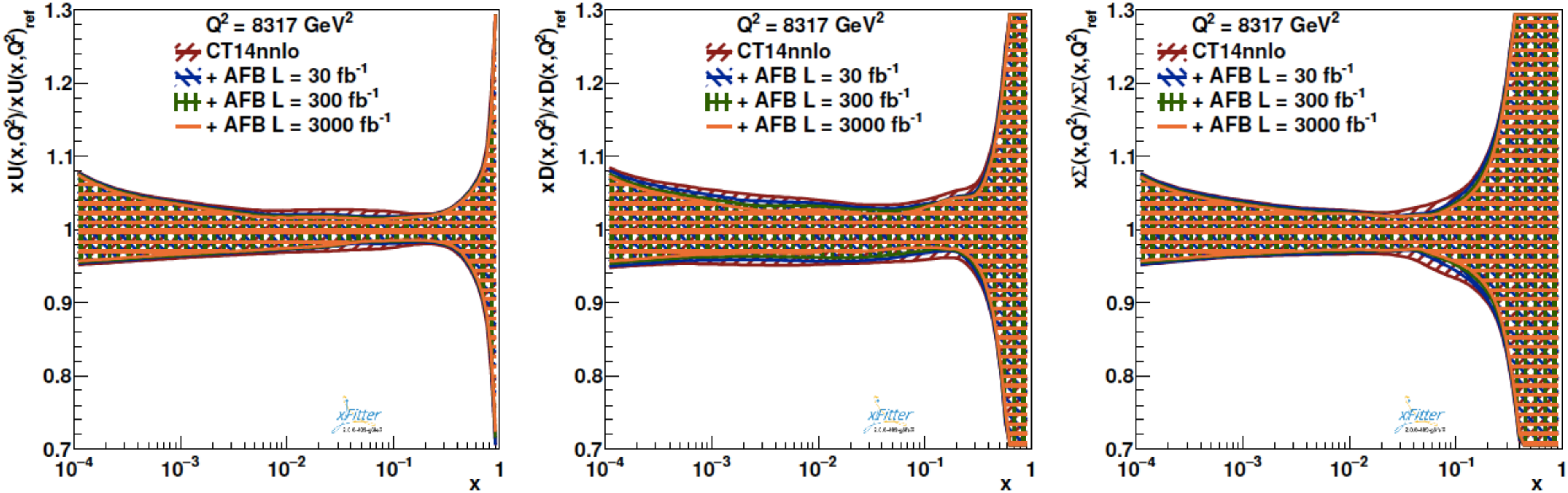
Asymmetry defined as:

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

Expected to be sensitive to:

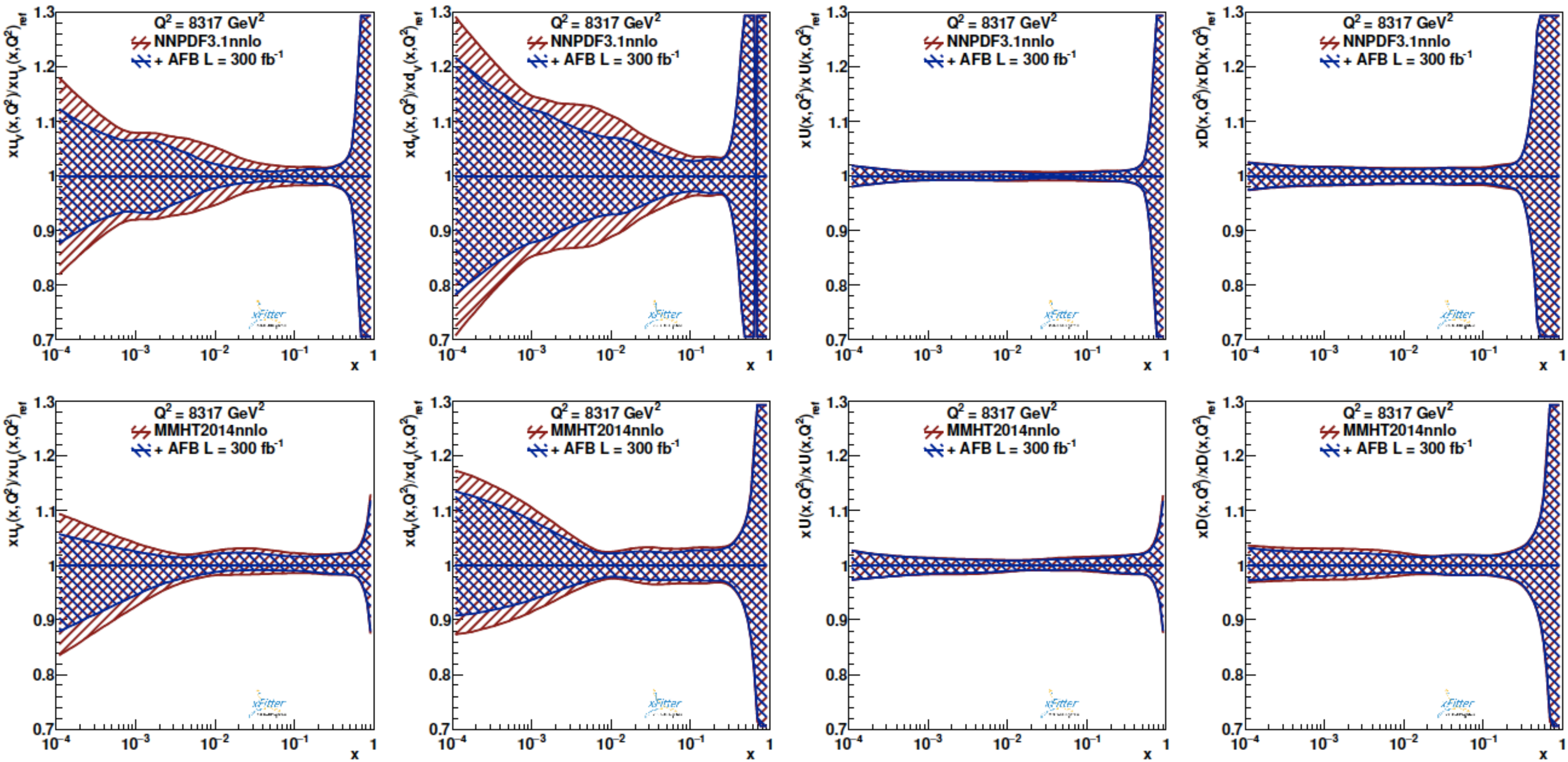
$$e_\ell a_\ell[e_u a_u u_V(x,Q^2) + e_d a_d d_V(x,Q^2)] \propto \frac{2}{3}u_V(x,Q^2) + \frac{1}{3}d_V(x,Q^2)$$

PDF profiling



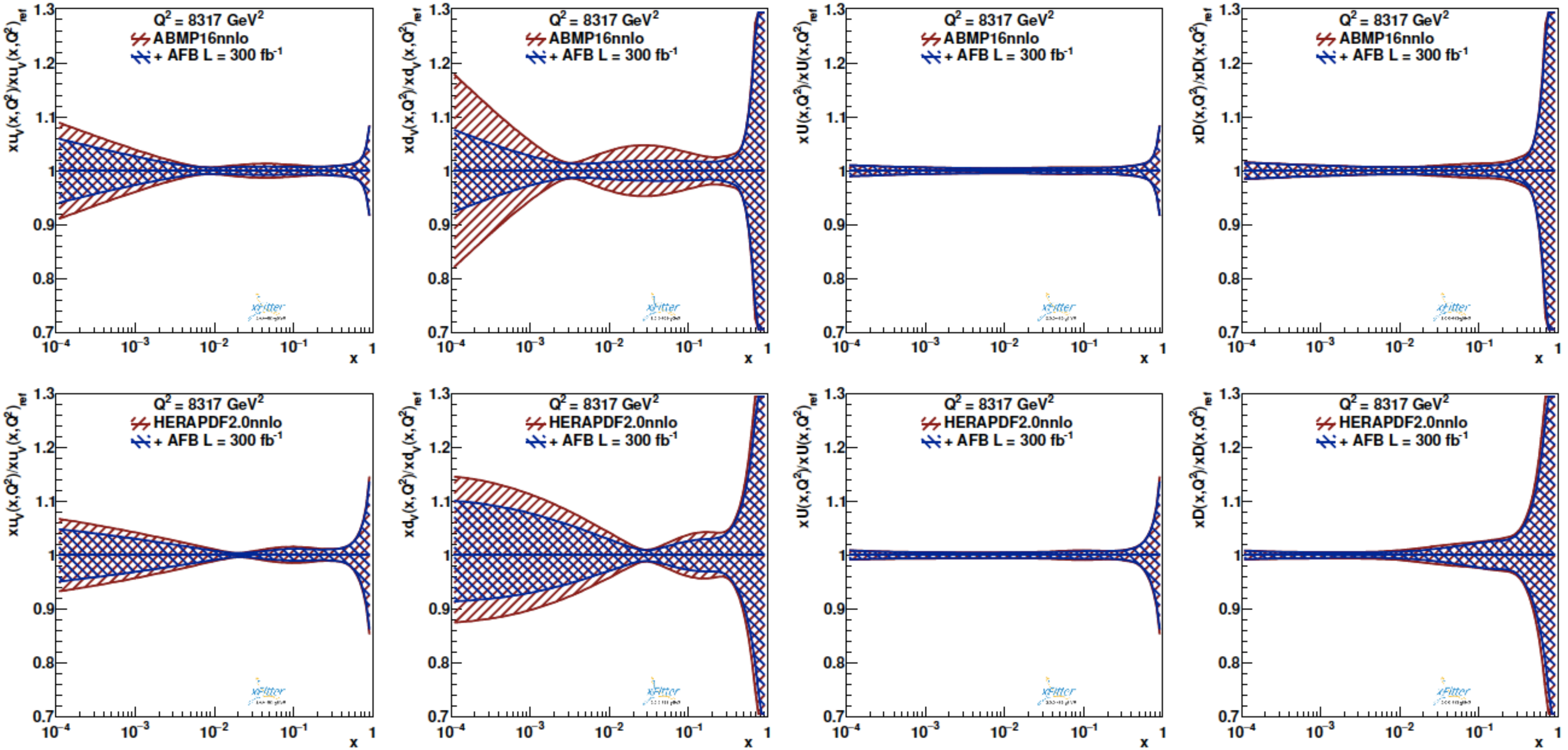
- The largest reduction of the uncertainty bands is obtained for u_V
- Visible improvement for d_V as well
- Main effects concentrated in the low- and intermediate-x region
- Mild effect on other PDFs
- Similar and comparable effects found using other NNLO PDF sets

PDF profiling



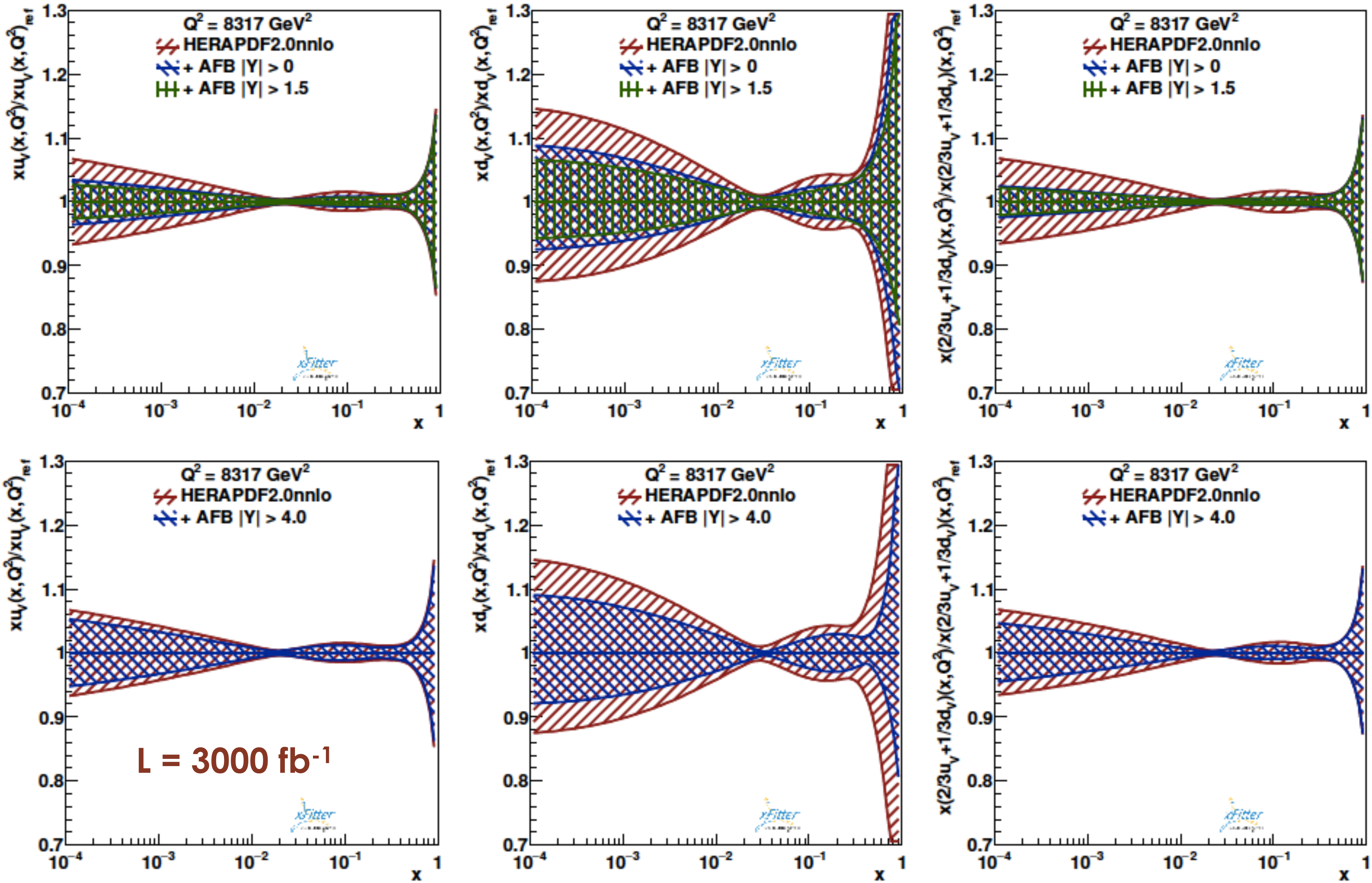
- Study performed with pseudo-data at L = 300 fb^{-1}
- NNPDF3.1nnlo (top) and MMHT2014nnlo (bottom)

PDF profiling

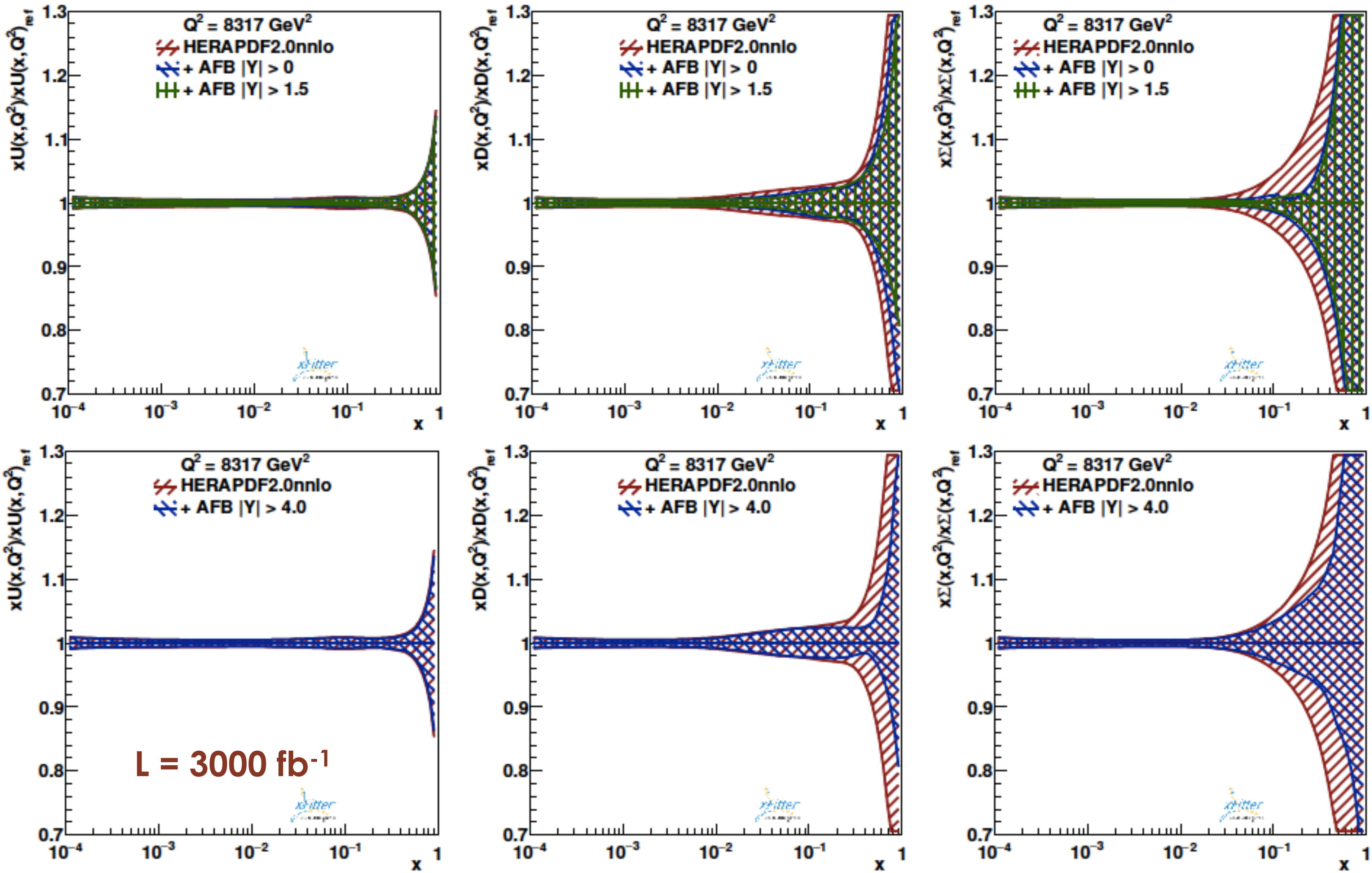


- Study performed with pseudo-data at L = 300 fb^{-1}
- ABMP16nnlo (top) and HERAPDF2.0nnlo (bottom)

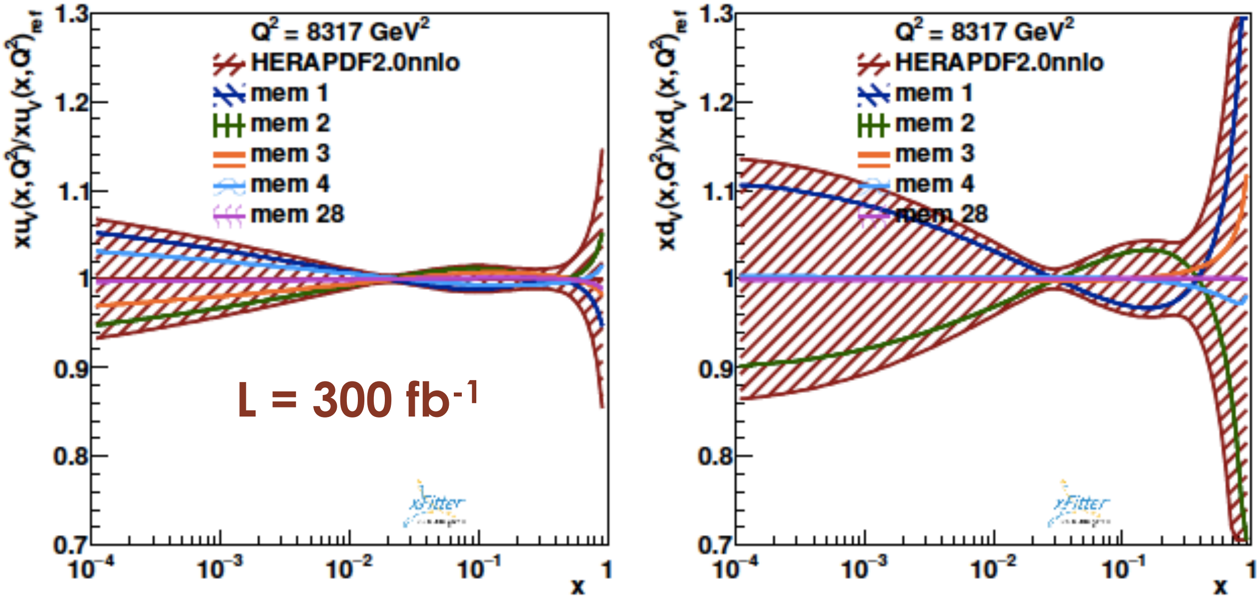
PDF profiling (different rapidity cuts)



PDF profiling (different rapidity cuts)



PDF eigenvectors rotation



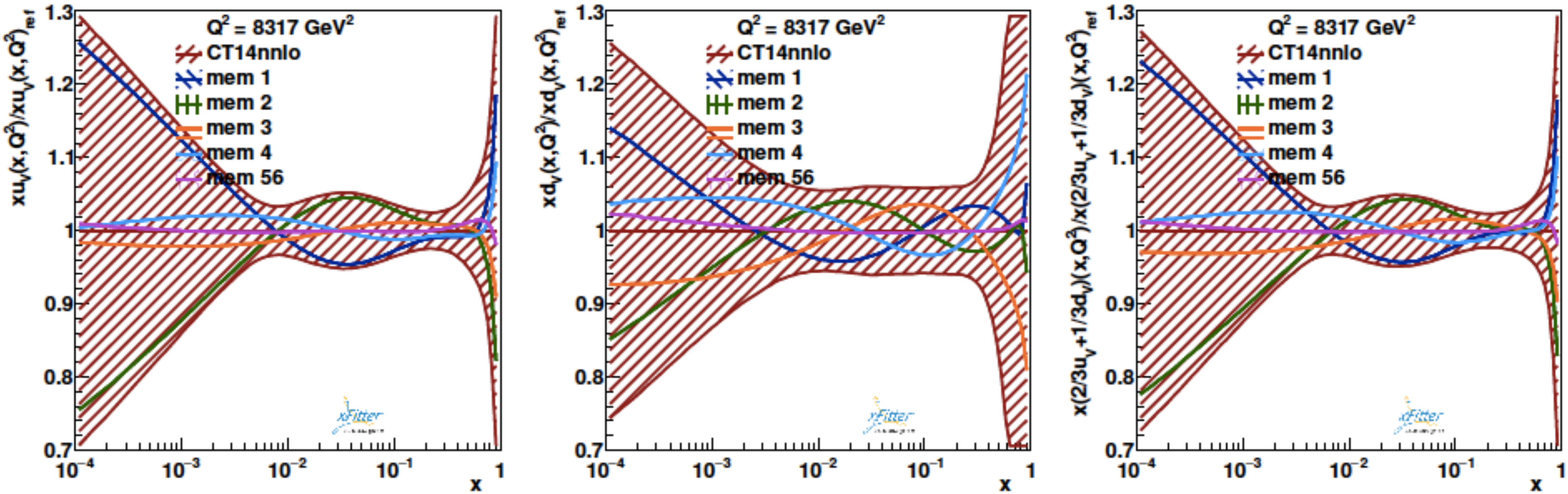
HERA2.0nnlo	Total χ^2/dof
mem1	4.8/106
mem2	8.0/106
mem3	0.48/106
mem4	0.74/106
mem5	0.01/106

- 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

PDF eigenvectors rotation



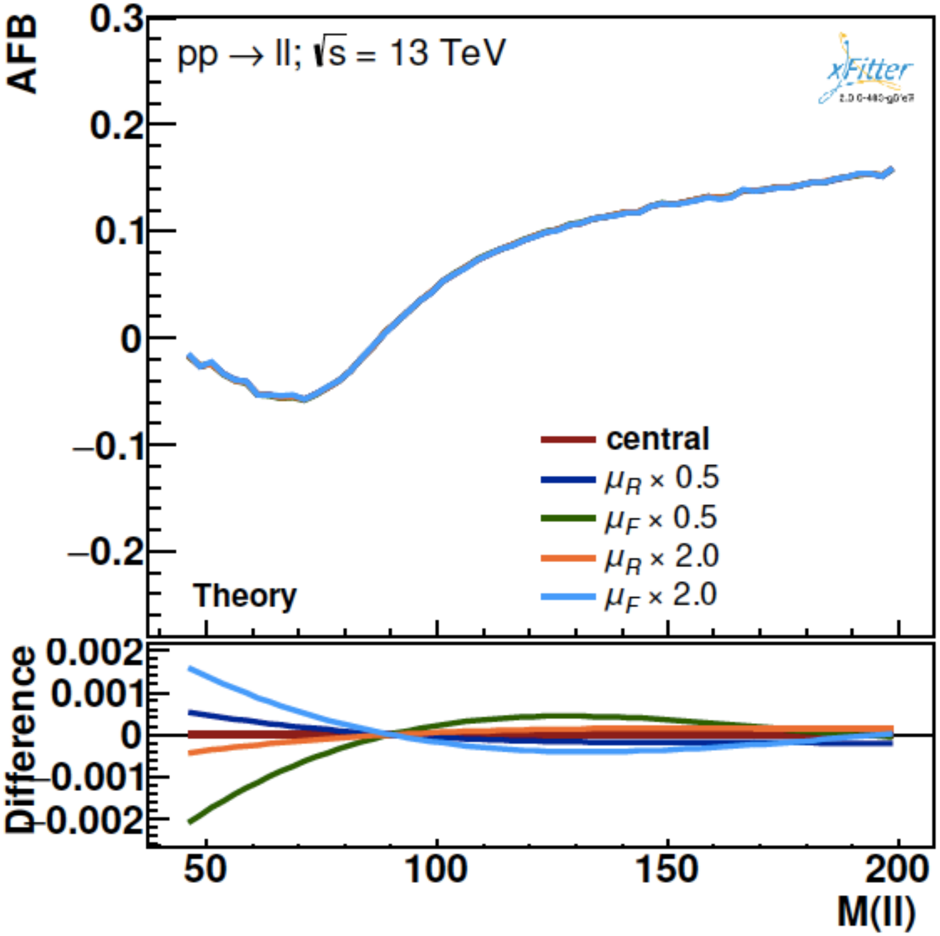
- Study performed at **L = 300 fb^{-1}**
- We want to determine the PDFs (and their combinations) more sensitive to the A_{FB} data (sorted according to their sensitivity to the new data)
- First two eigenvectors almost completely determine the error bands

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
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)

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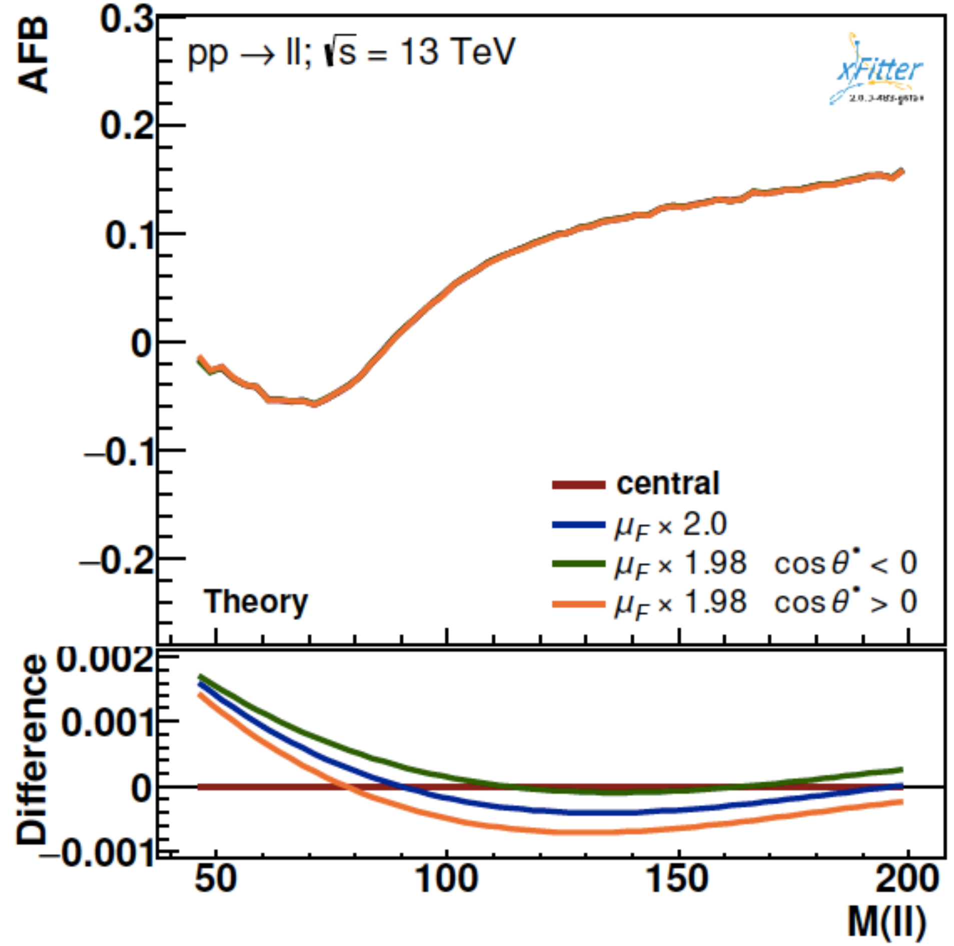
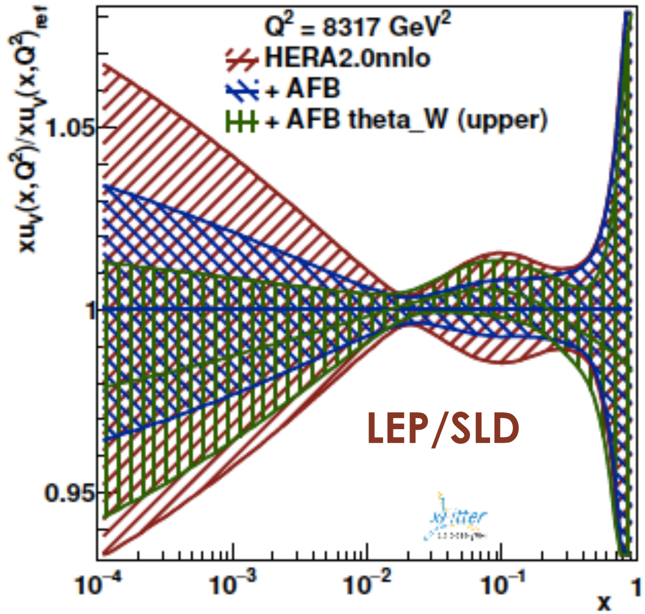
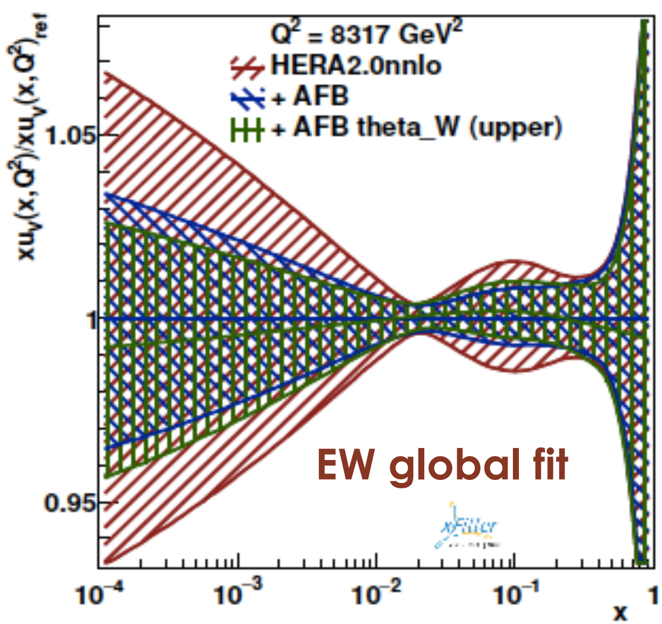


- HERAPDF2.0nnlo (EIG) PDF set in use
- Deviations wrt "point 4" (nominal μ_R and μ_F) presented
- Small variations observed (per-mille level)
- De-correlated scale variations checked as well (per-mille level)

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

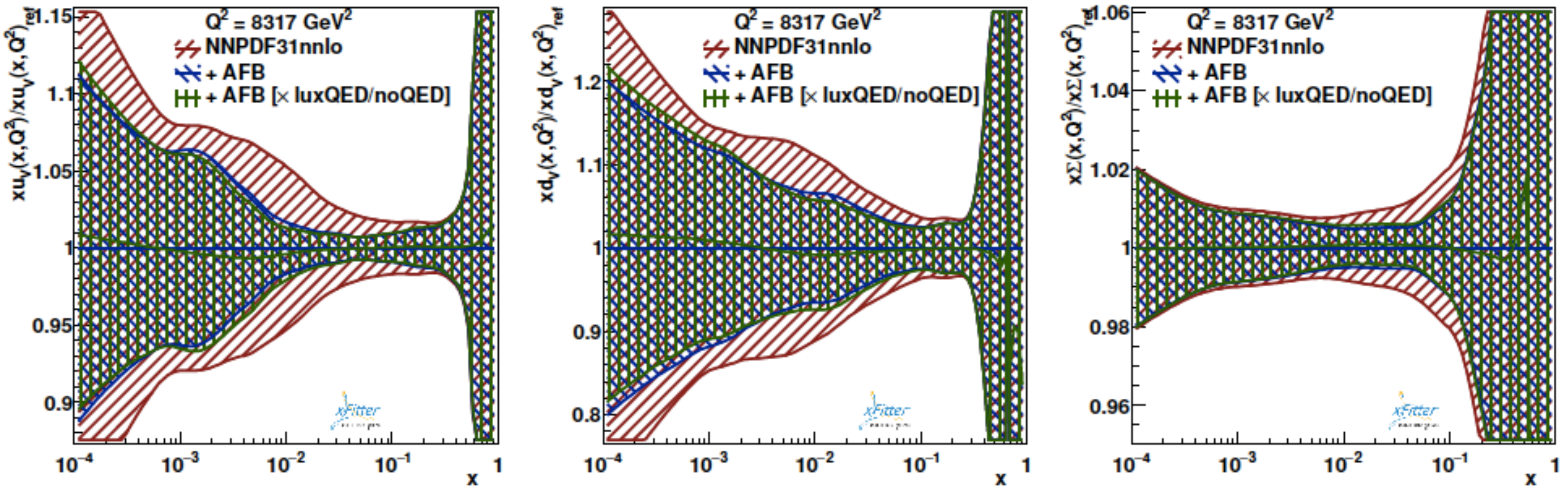




Higher-order EW corrections

- 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

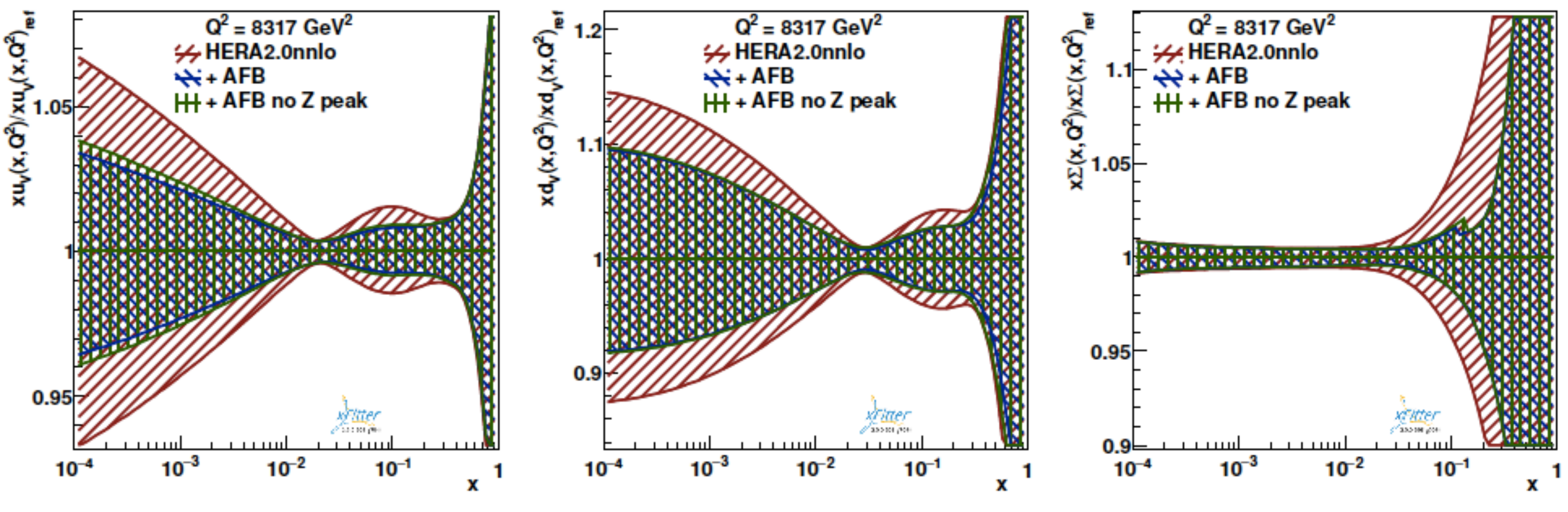
L = 3000 pb^{-1}



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

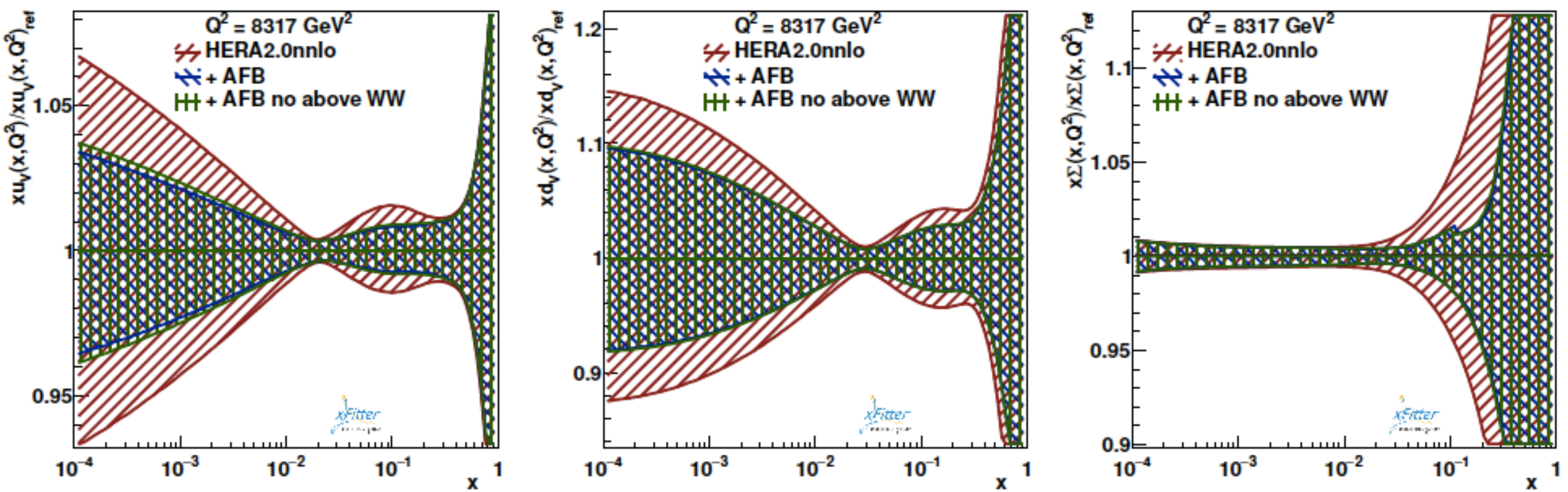
L = 3000 pb^{-1}



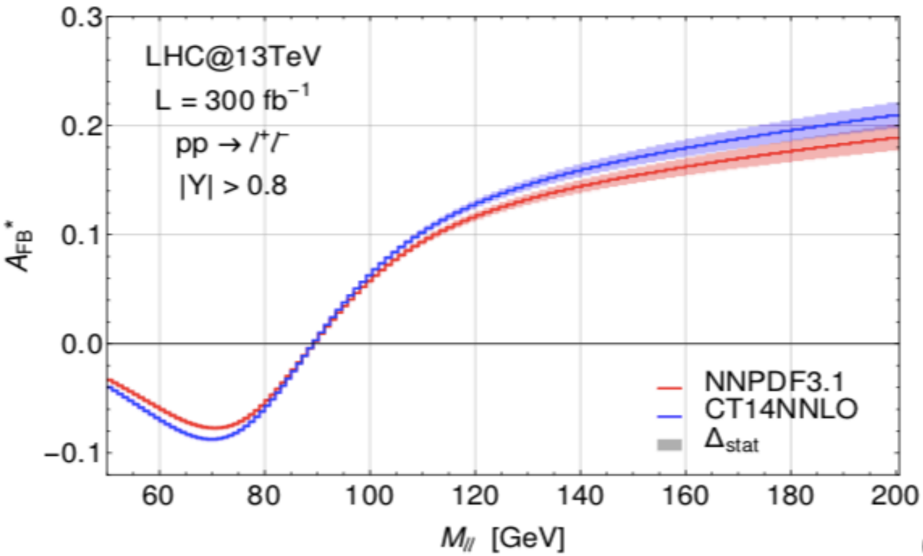
Higher-order EW corrections

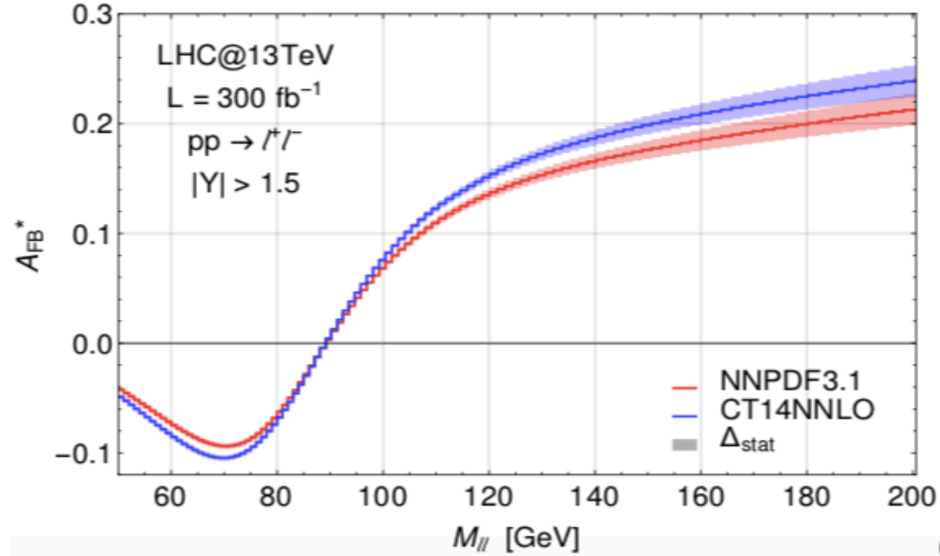
- EW corrections could also have an impact for WW production
- We employ again the HERA2.0nnlo PDF set
- Profiled curves removing the data above the WW production threshold, $m_{l^+l^-}$ > 161 GeV
- Error band of the u_V quark distribution shows a small increment (smaller statistical precision → smaller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

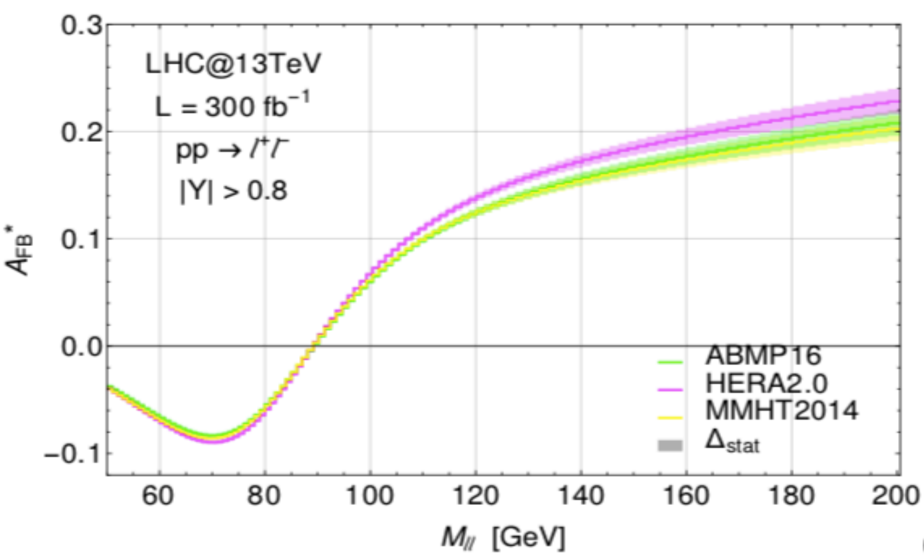
L = 3000 pb^{-1}

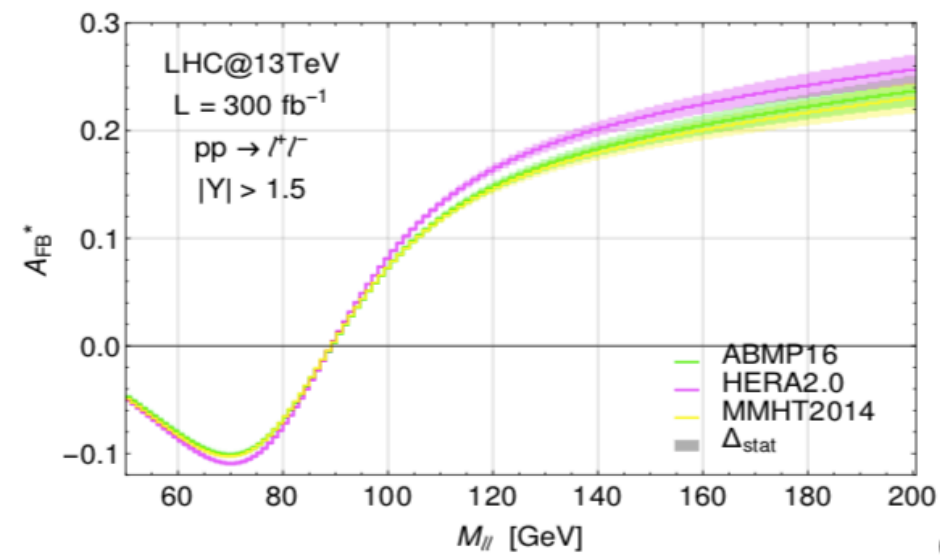


A_{FB} at high rapidities



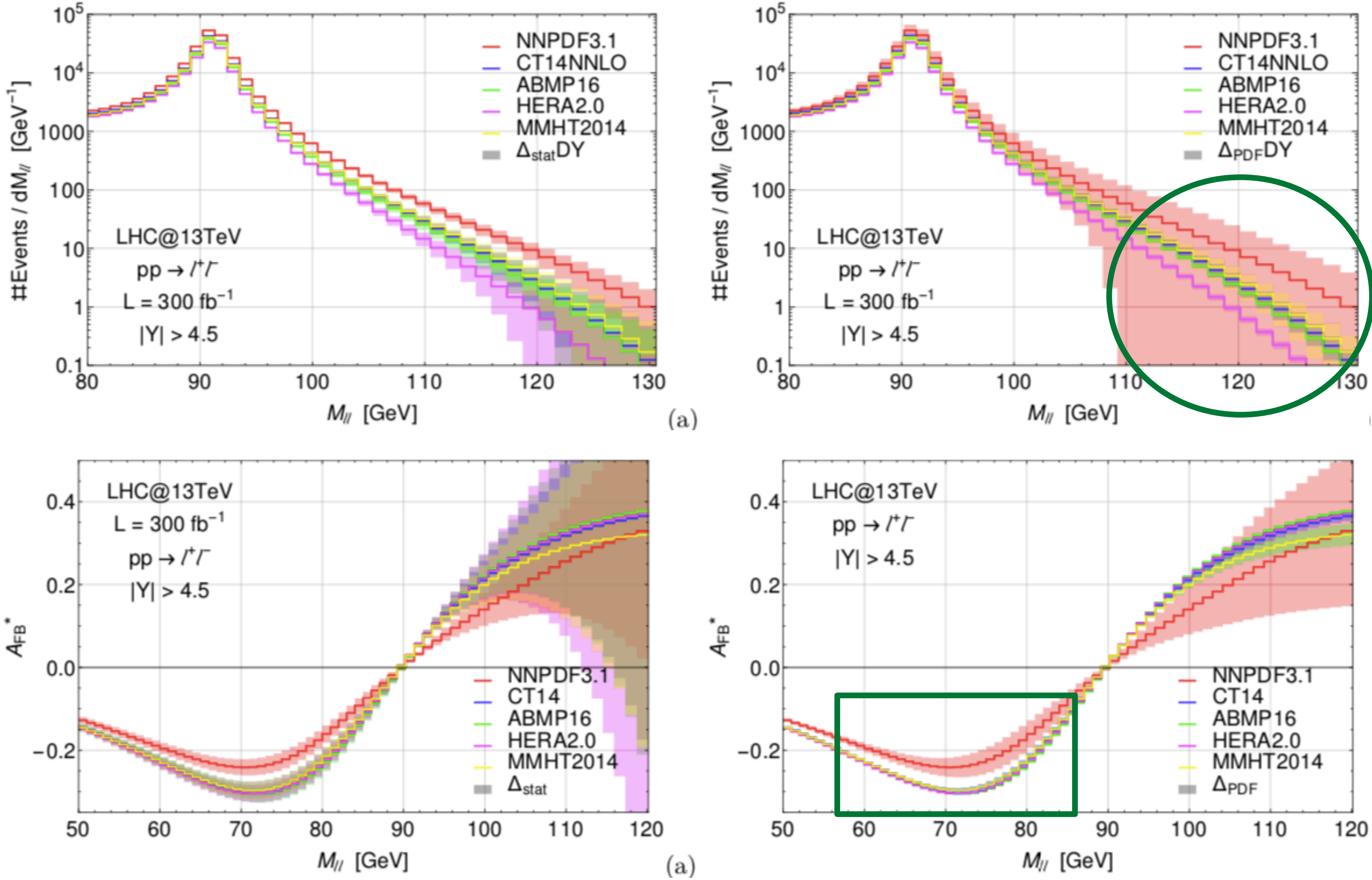




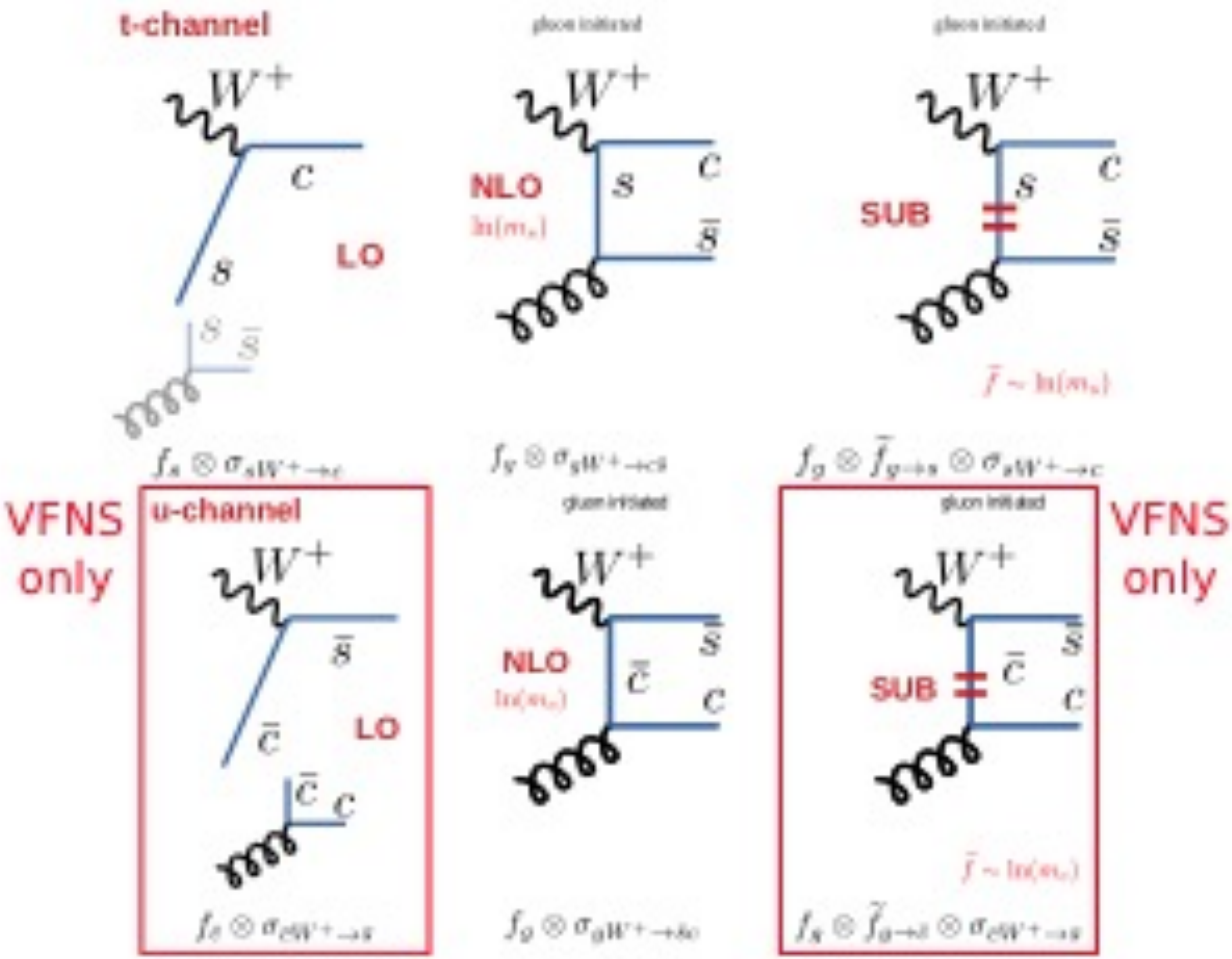


High rapidity cuts enhance the differences between PDF sets

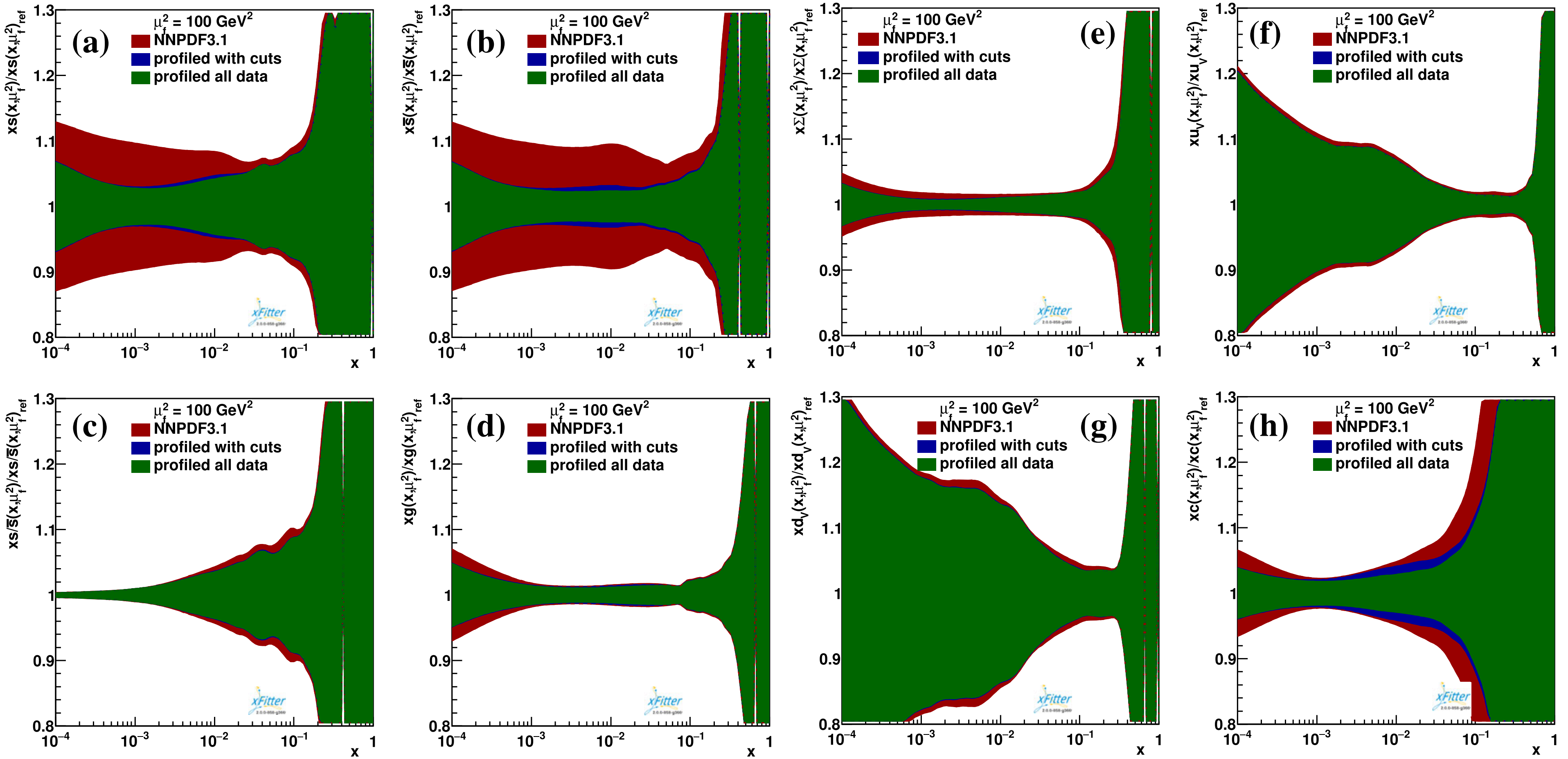
Push to the limit



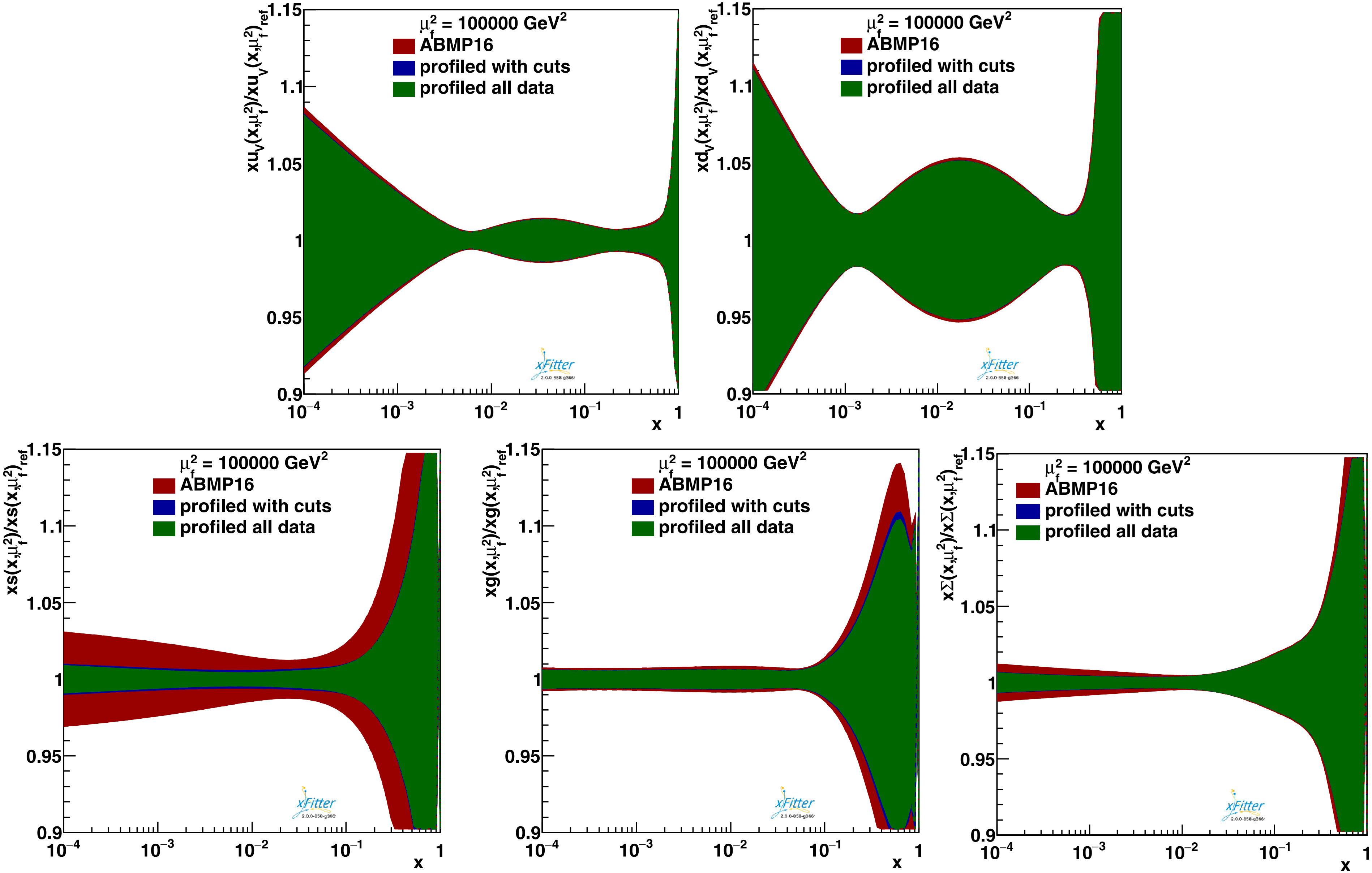
Feynman diagrams in VFNS and in FFNS



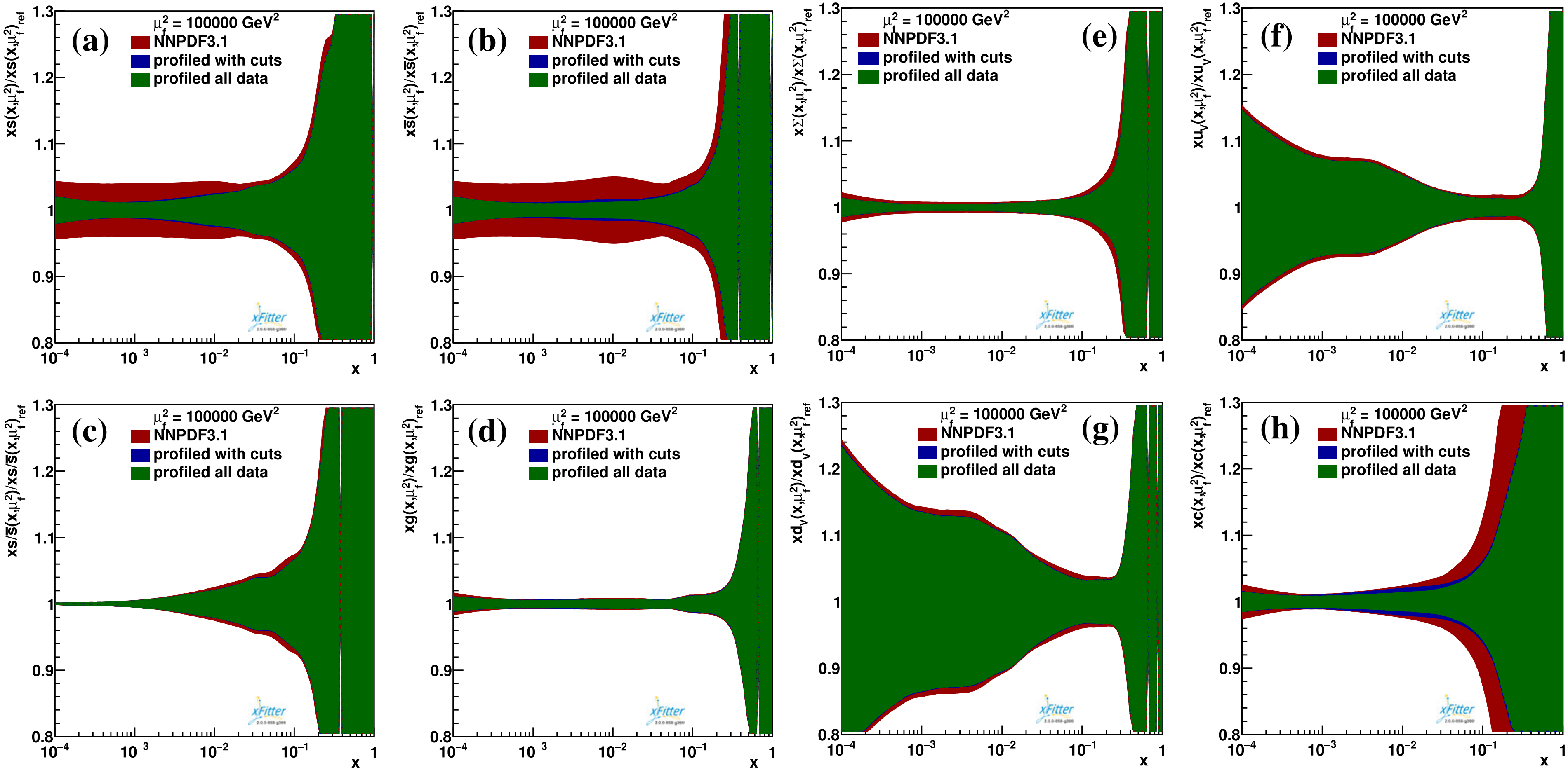
Profiling NNPDF31 - Q^2 = 100 GeV^2



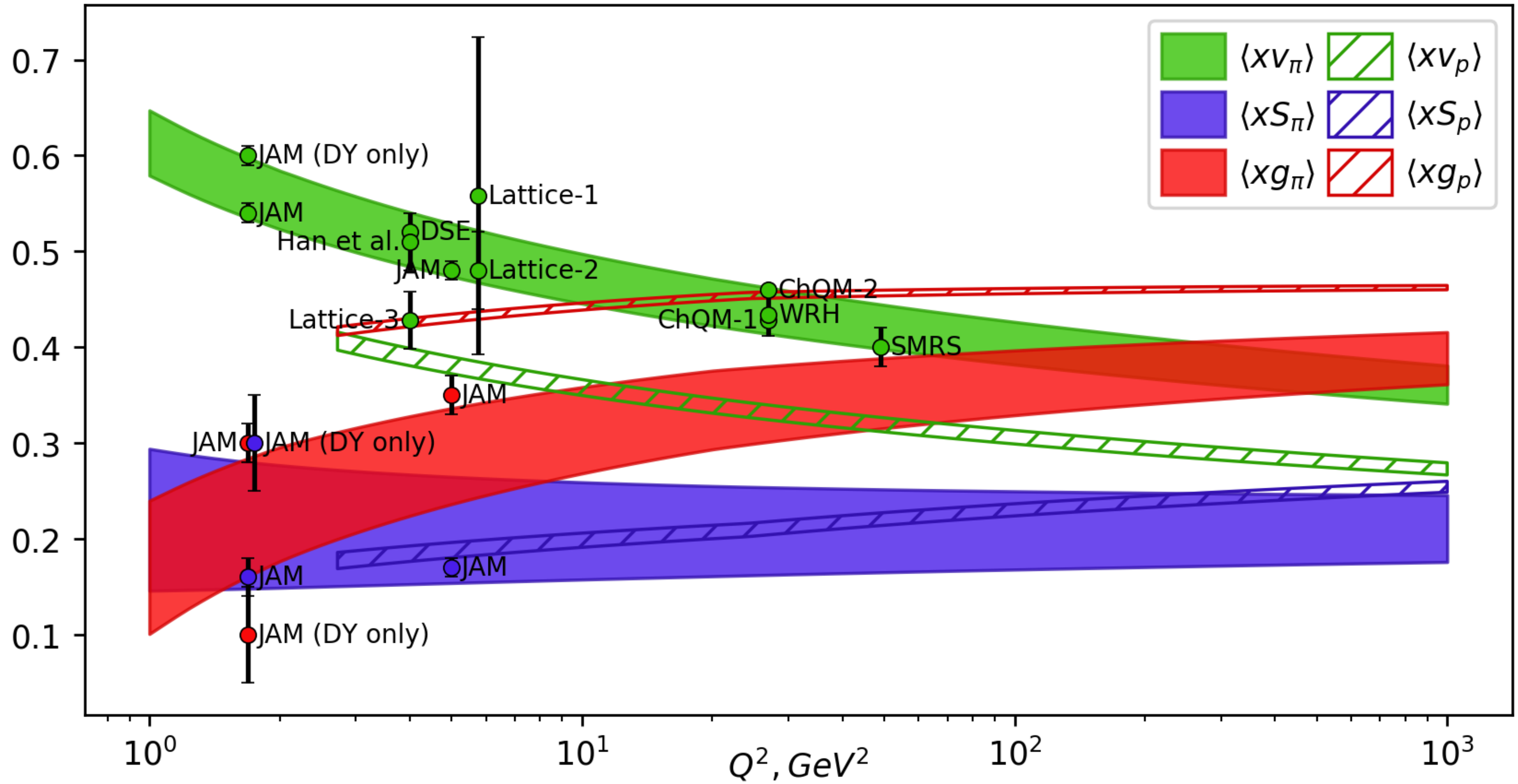
Profiling ABMP16 - $Q^2 = 10^5$ GeV^2



Profiling NNPDF31 - $Q^2 = 10^5$ GeV^2

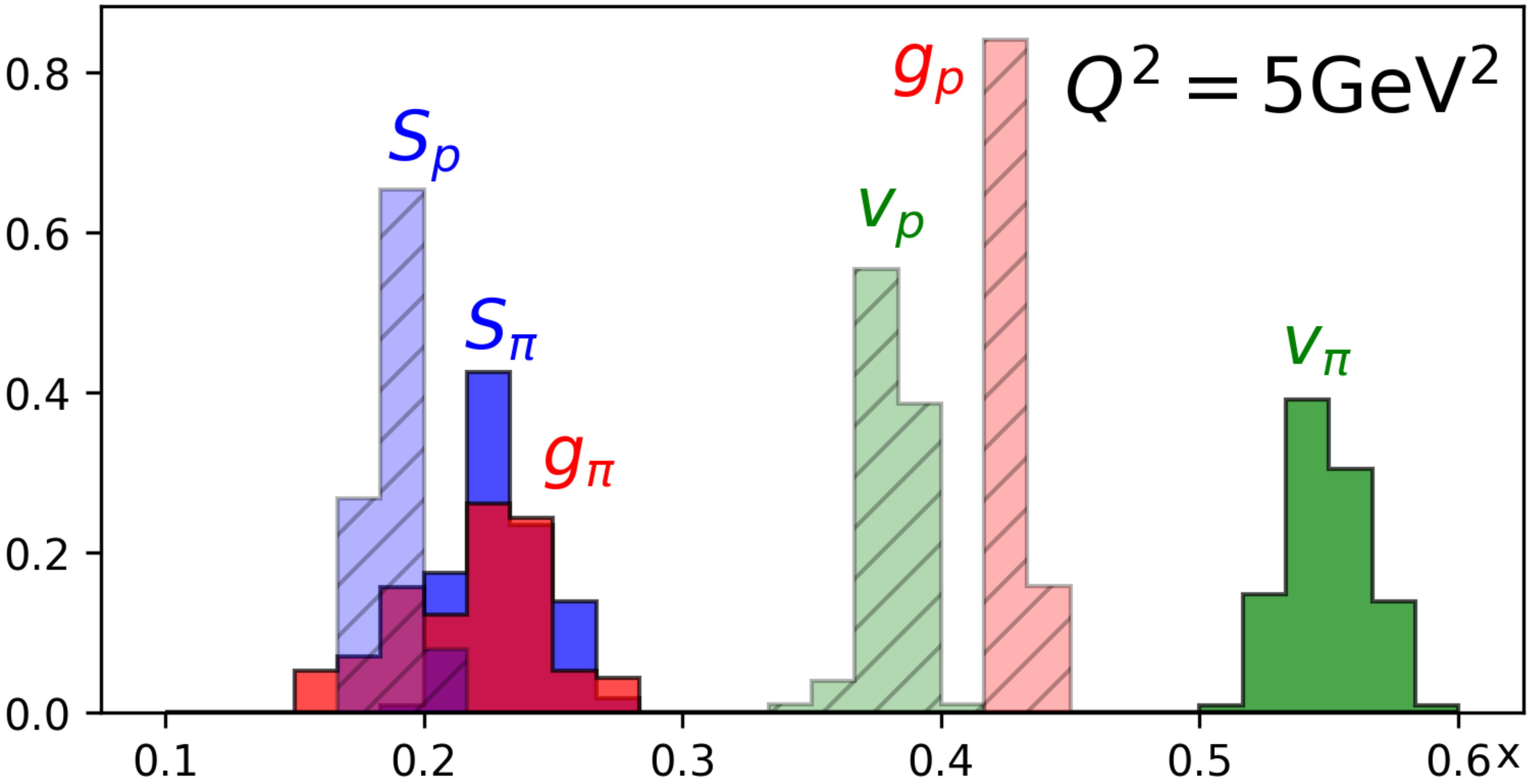


Momentum fractions as a function of Q^2



- Valence distribution in good agreement with JAM and other calculations
- Gluon and sea distribution in agreement with JAM but larger uncertainties

Momentum fractions as a function of x



- Momentum fractions of the pion in comparison to the proton PDF set NNPDF31_nlo_as_0118

Tutorial – ATLAS SM workshop 2019

- **Tutorial 1:** PDF fit
  - learn the basic settings of a QCD analysis, based on HERA data only
- **Tutorial 2:** Simultaneous PDF fit and α_S extraction
  - learn the basic of an α_S extraction using H1 jet data
- **Tutorial 6:** Fit to final combined HERAI+II data and ATLAS W,Z data at 7 TeV
  - Strange-quark density: fixed vs free r_s
  - Unsuppressed strange at low-x

$$r_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

Other useful/interesting exercise you might want to have a look at in backup:

- **Tutorial 3:** LHAPDF analysis
  - how to estimate impact of a new data without fitting
  - profiling and reweighting techniques
- **Tutorial 4 and 7:** Plotting LHAPDF files
  - direct visualisation of PDFs from LHAPDF6 using simple python scripts
- **Tutorial 5:** Equivalence of χ^2 representations
  - understand different χ^2 representations (nuisance parameters and covariance matrix χ^2 formulas)

All current and past xFitter developers had contributed to this tutorial