PDF analysis of Z boson polarisation data from LHC and constraints to Higgs boson production cross section by xFitter

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arXiv:2012.10298 [hep-ph]

The xFitter project

The **xFitter** code is an open-source QCD fit framework which:

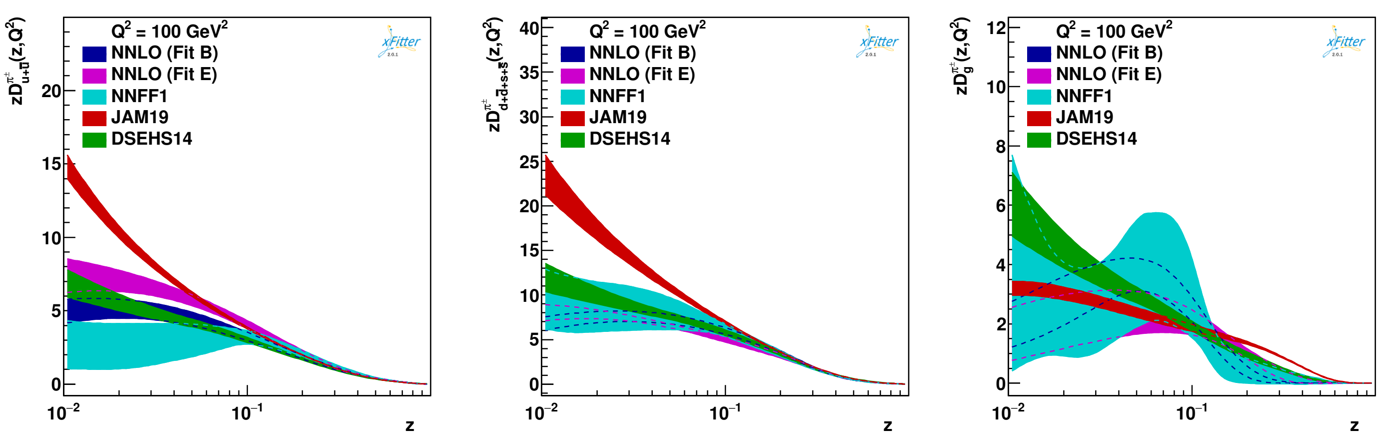
- Allows for extraction of PDFs
- Assesses the impact of new measurements on PDF through Hessian profiling or Bayesian reweighting
- Evaluate consistency of experimental data
- Test various theoretical assumptions

Over 100 publications since the beginning of the project:
https://www.xfitter.org/xFitter/xFitter/results

Recent results:

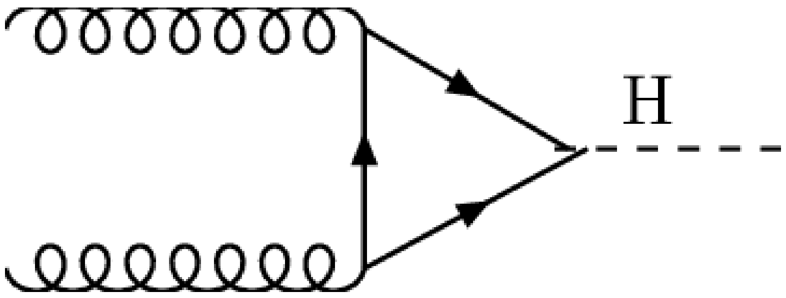
Determination of Pion PDF: Phys. Rev. D 102 (2020) 1

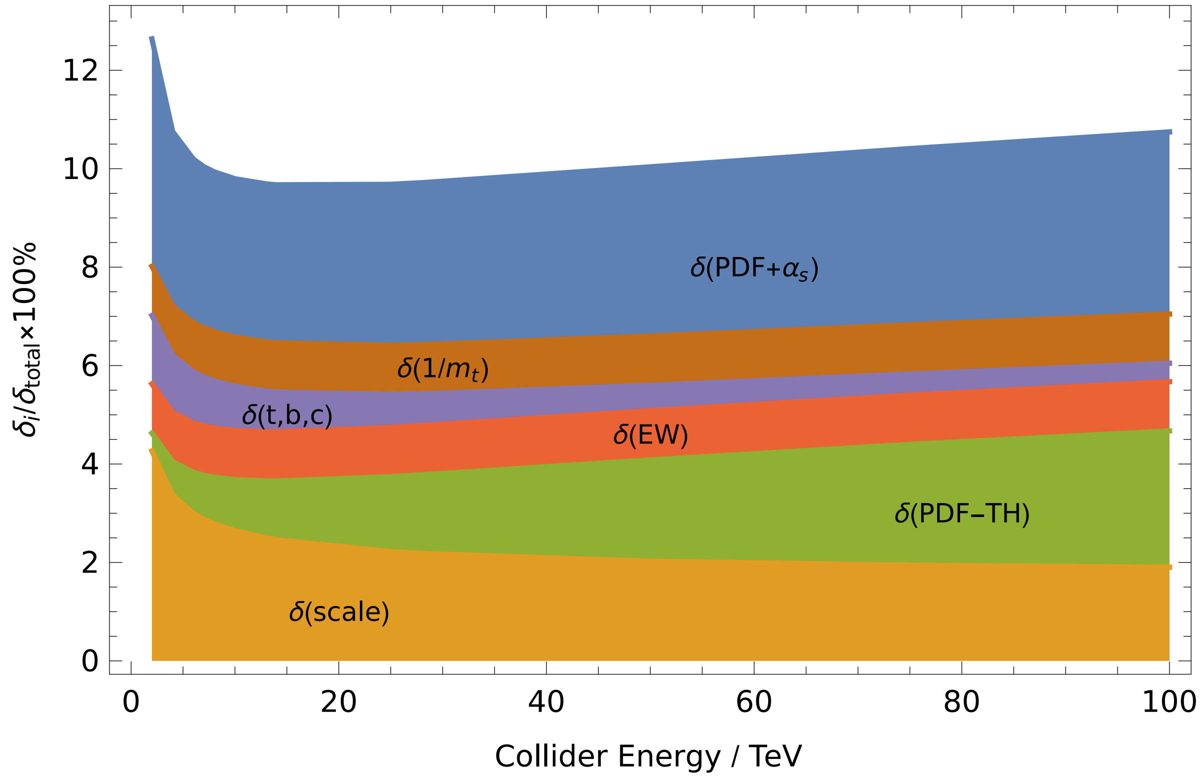
Pion fragmentation functions (FF): arXiv:2105.11306 (under review in PRD)



Motivations

- The study of the SM Higgs sector is one of the main goals of (HL-)LHC programme.





HL/HE–LHC WG2 Report
CERN-LPCC-2018-04

- PDF uncertainties are one of the dominant limiting factors.

- Gluon PDF is mostly constrained using DIS data.

- Extraction of gluon PDF from LHC jet and top data is ongoing.

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Drell-Yan

Drell-Yan measurements are capable of providing high sensitivity to PDFs as they feature low theoretical and experimental systematics, high statistical precision and good control of correlations.

$$\frac{d\sigma}{dp_T^Z\, dy^Z\, dm^Z\, d\cos\theta\, d\phi} = \frac{3}{16\pi} \frac{d\sigma^{U+L}}{dp_T^Z\, dy^Z\, dm^Z}$$

Unpolarised cross-section

$$\Big\{(1+\cos^2\theta) + \frac{1}{2} A_0(1-3\cos^2\theta) + A_1 \sin 2\theta \cos\phi$$

Helicity cross-sections

$$+\frac{1}{2} A_2 \sin^2\theta \cos 2\phi + A_3 \sin\theta \cos\phi + A_4 \cos\theta$$

$$+A_5 \sin^2\theta \sin 2\phi + A_6 \sin 2\theta \sin\phi + A_7 \sin\theta \sin\phi\Big\}.$$

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JHEP 10 (2019) 176

A_i are the coefficients of the expansion of the (fully) differential cross section in spherical harmonics

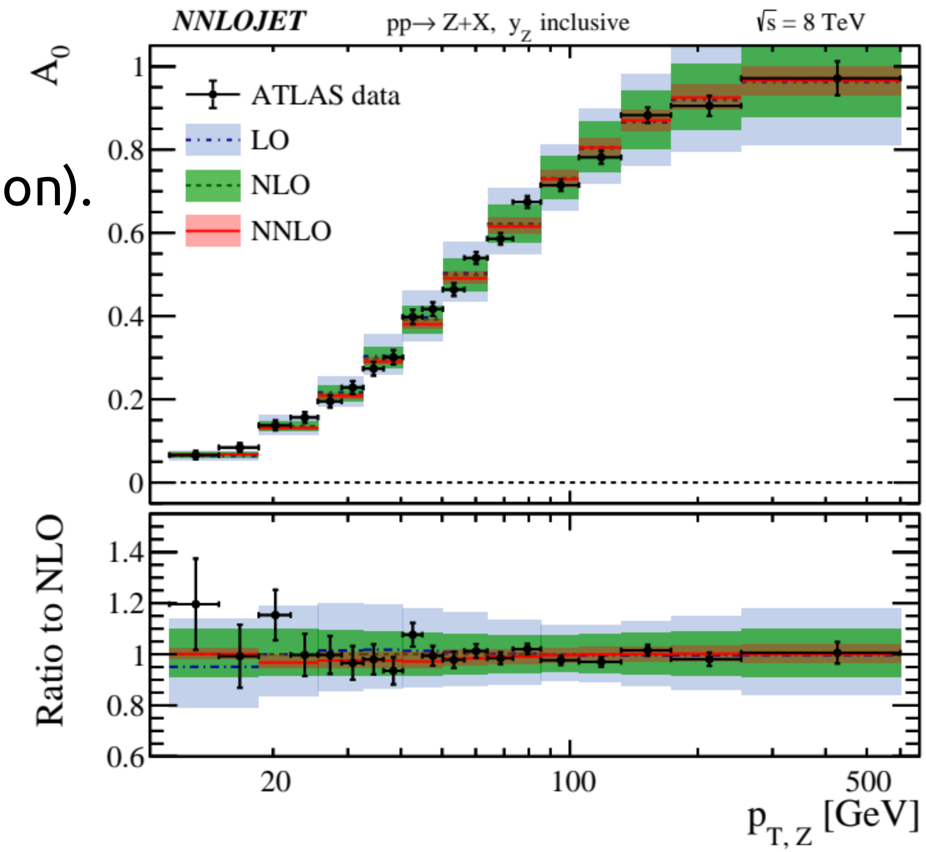
Angles measured in the Collins-Soper frame

The angular coeficient A_0

- **A_0** coefficient is parity conserving and sensitive to the flavor singlet PDFs.
- Can be contructed from longitudinal and unpolarized cross sections:

$$A_0(s, M, Y, p_T) = \frac{2d\sigma^{(L)}/dM\,dY\,dp_T}{d\sigma/dM\,dY\,dp_T}$$

- Can be measured with great accuracy from the precise measurements of di-lepton angular distributions.
- It has been calculated at NNLO QCD (good convergence of perturbative expansion). JHEP 11 (2017) 003

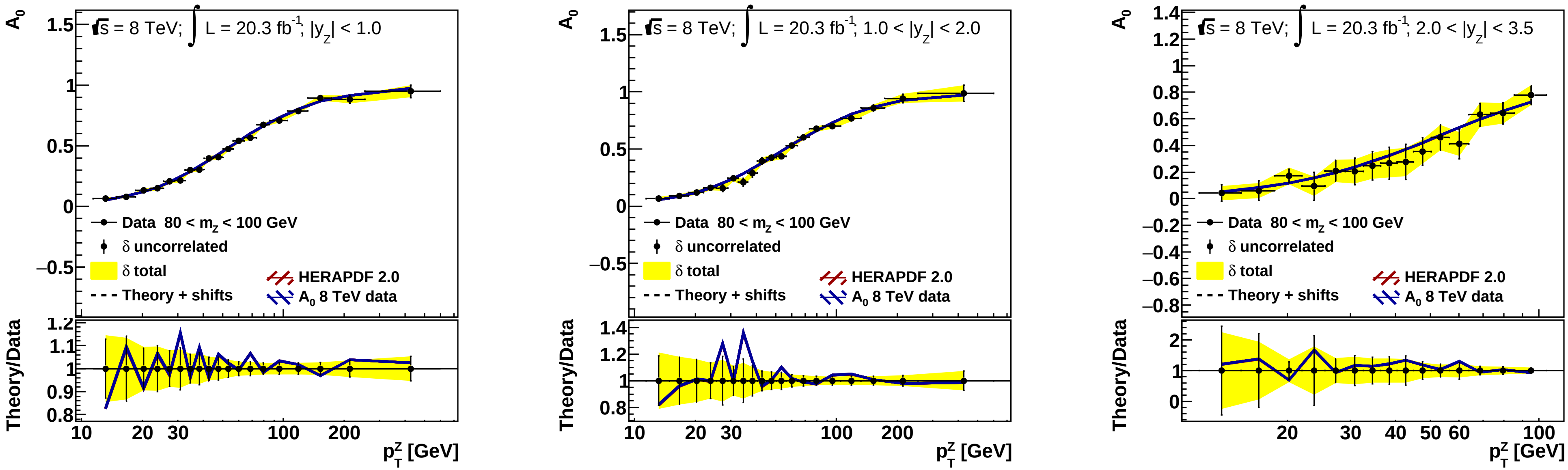


- NLO EW corrections are small at high pTZ. EPJC 80 (2020) 10

Validation

Validation of the implementation of the observable in xFitter:

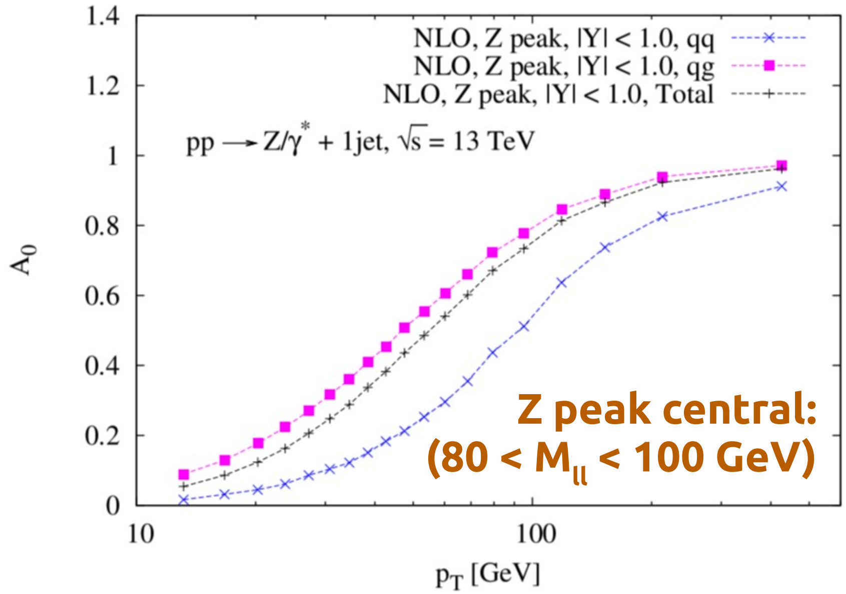
- 3 rapidity bins
- $p_T > 11.4$ GeV
- Predictions at order α_s^2 from mg5_aMC@NLO
- Covariance matrix of experimental uncertainties included

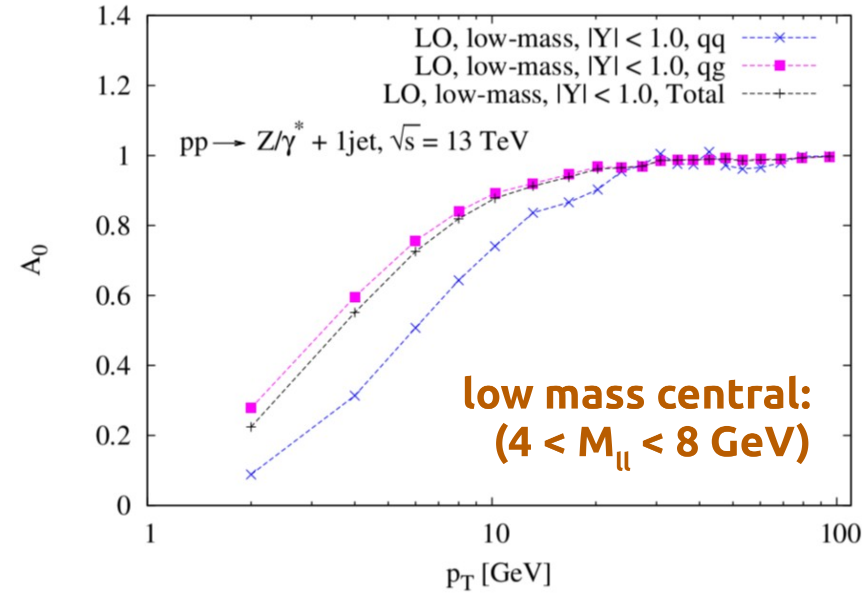


Good description of the data from modern PDFs

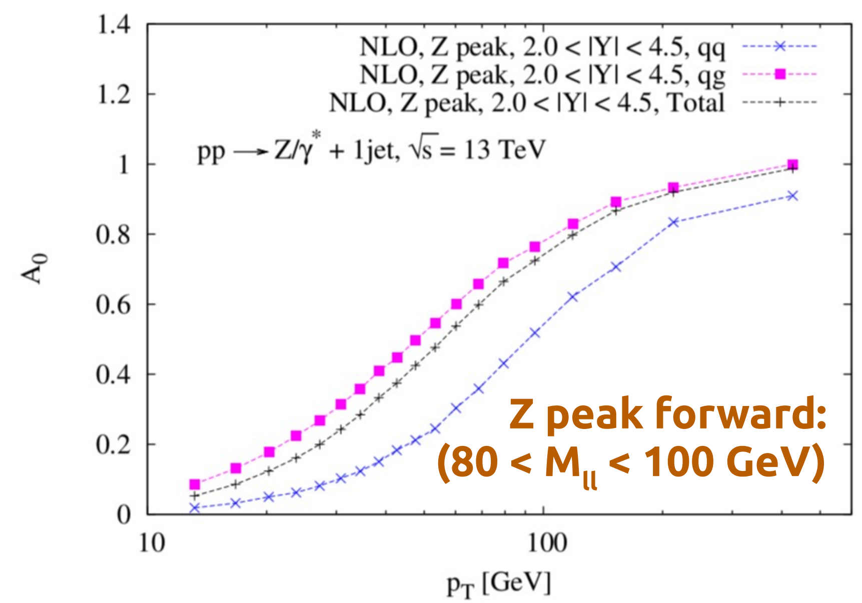
PDF set	Total χ^2/d.o.f.
CT18NNLO	59/53
CT18Annlo	44/53
NNPDF31_nnlo_as_0118_hessian	60/53
ABMP16_5_nnlo	62/53
MSHT20nnlo_as118	59/53
HERAPDF20_NNLO_EIG	60/53

Analysis setup



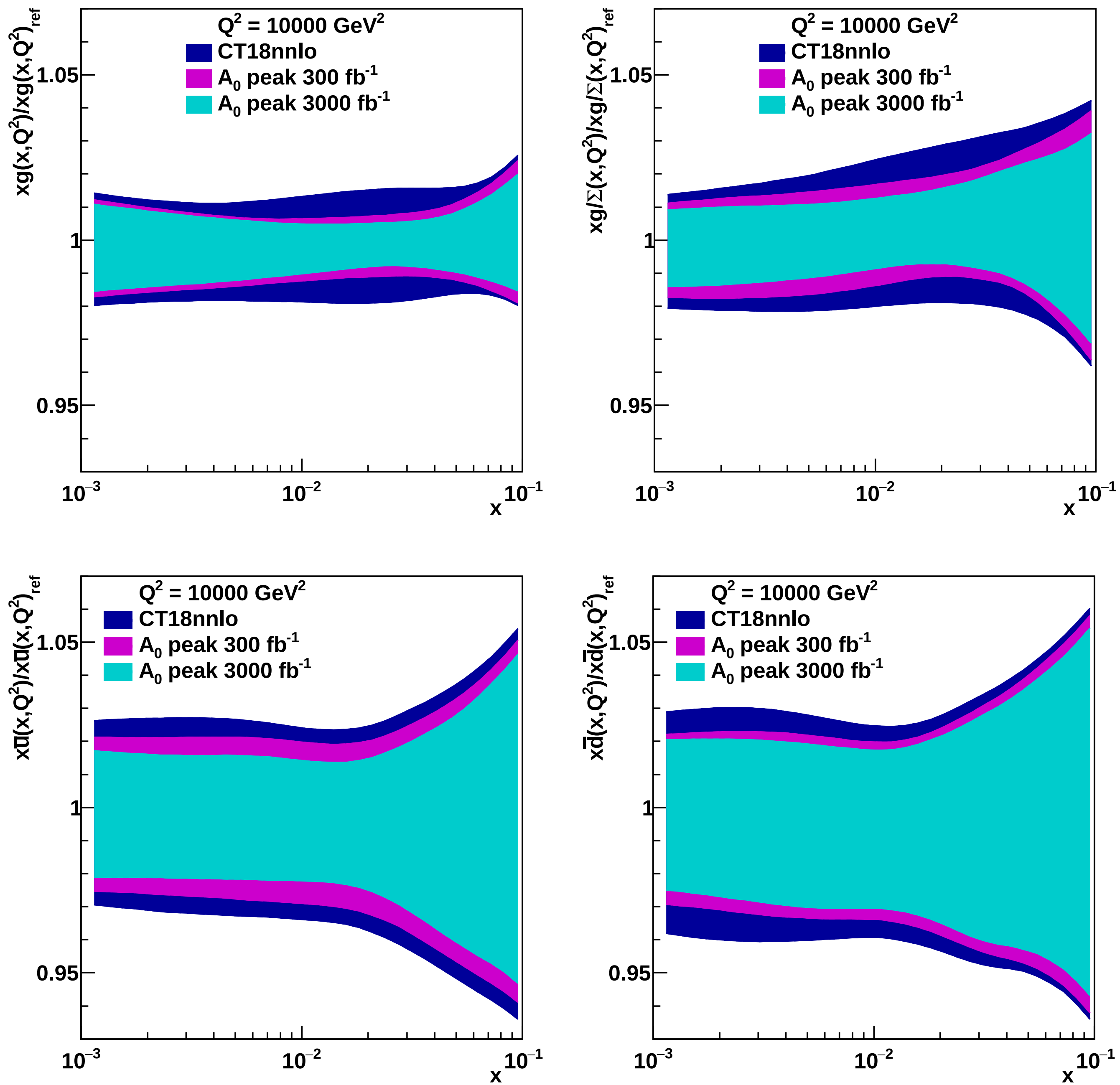


- A_0 pseudodata evaluated in different invariant mass regions and rapidity ranges.
- Contributions from both $q\bar{q}$ and qg channels.
- Largest sensitivity on PDFs in the region at the saddle point ($\partial^2 A_0/\partial p_T^2=0$).
- Pseudodata generated for 13 TeV c.o.m. energy and projected statistical uncertainties for **300** and **3000 fb^{-1}** luminosity.
- 0.1% systematic uncertainty on leptons momentum scale.



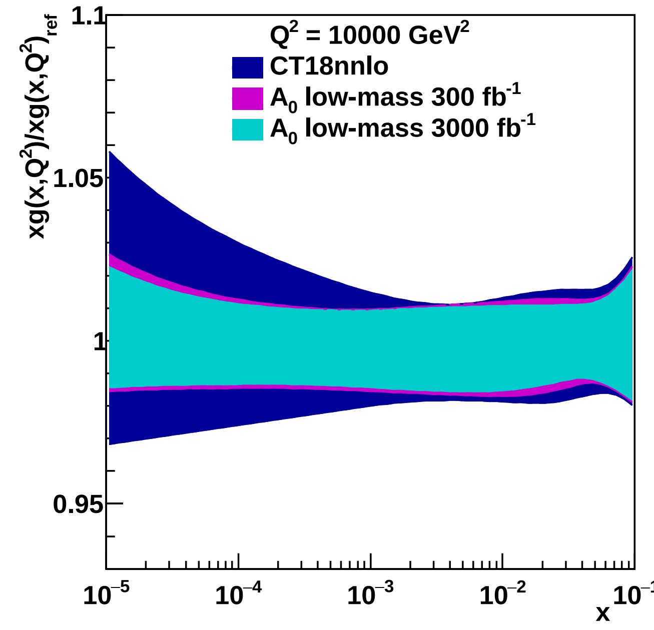
Z peak results

- Profiling of xg, xg/Σ, $x\bar{u}$, $x\bar{d}$
- Largest constrains in the region $10^{-3} < x < 10^{-1}$
- Largest impact from 300 fb^{-1} data, but 3000 fb^{-1} data can further constrains $x\bar{u}$, $x\bar{d}$
- Results are stable against variations of ren/fact scales

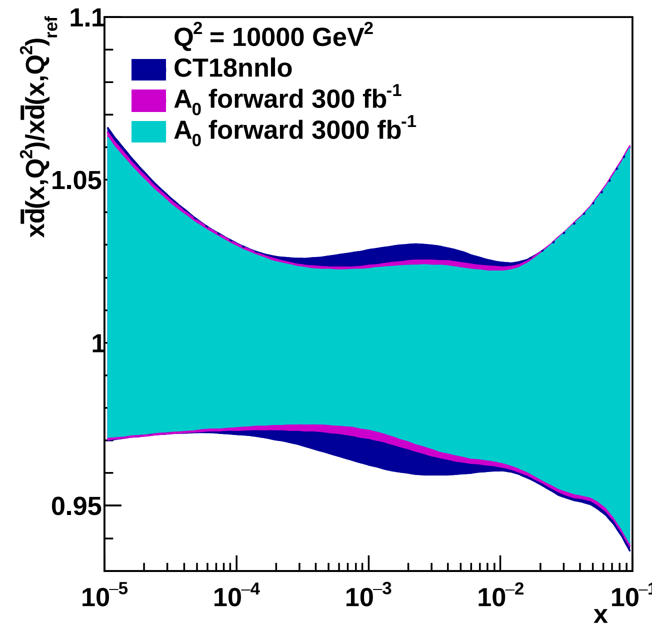


Low invariant mass and high rapidity

- Profiling using low invariant mass data
  ($4 < M_{ll} < 8$ GeV)
  - Sensitive to gluon PDF at low-*x*, $x < 10^{-3}$
  - Possibly useful for TMD PDFs determination

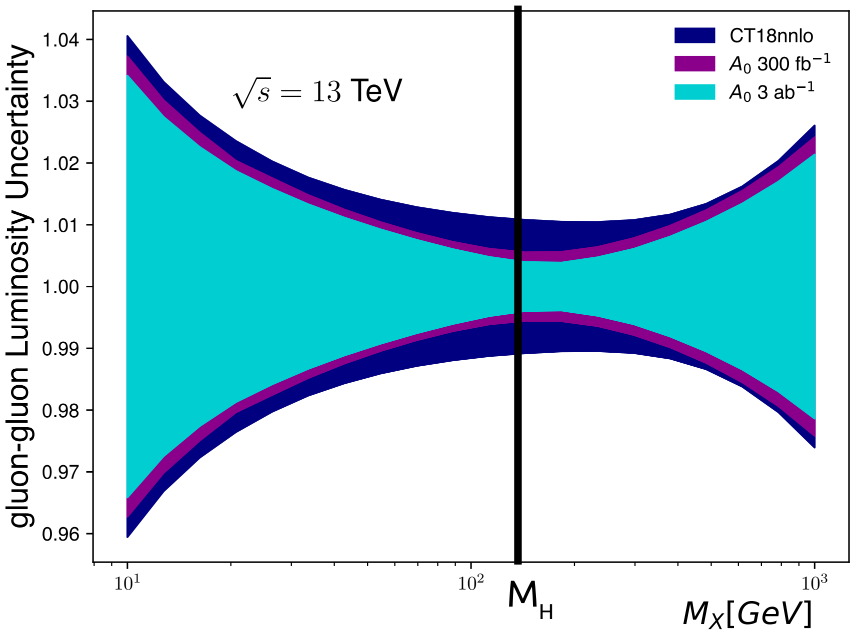


- Profiling using forward rapidity region (LHCb reach):
  ($2.0 < y_{ll} < 4.5$)
  - Improvements in sea quark PDFs at intermediate *x*, $x \sim 10^{-3}$



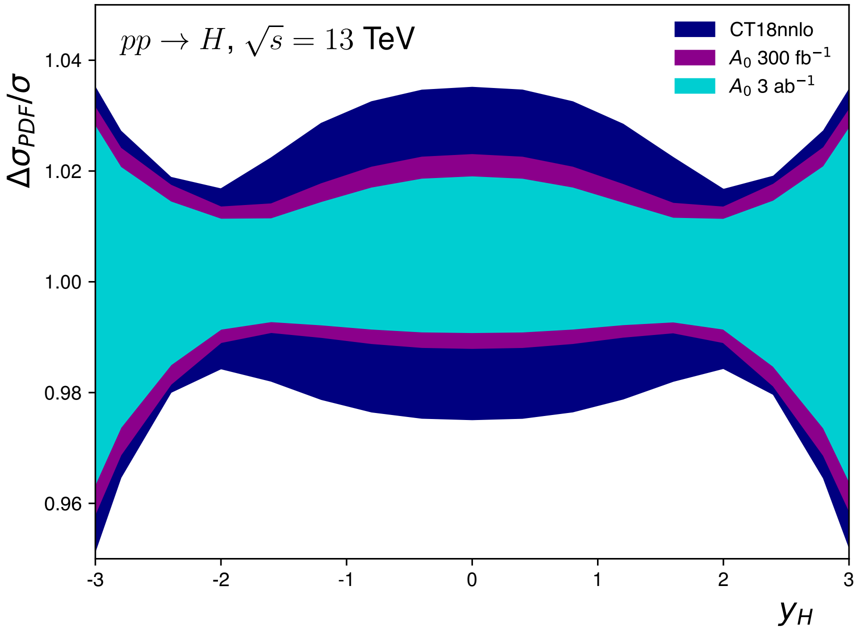
The Higgs cross section

- Gluon-gluon luminosity as function of M_X computed at NLO QCD with MCFM.

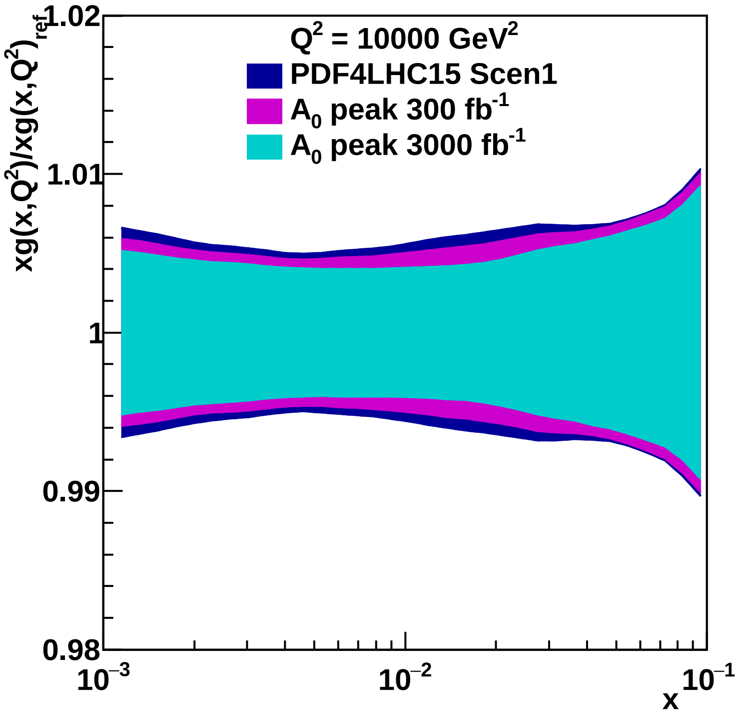


- PDF uncertainties are reduced by 30%-40% in the Run-III scenario and about 50% in the HL-LHC scenario in the region **100 < M_X < 200 GeV** .

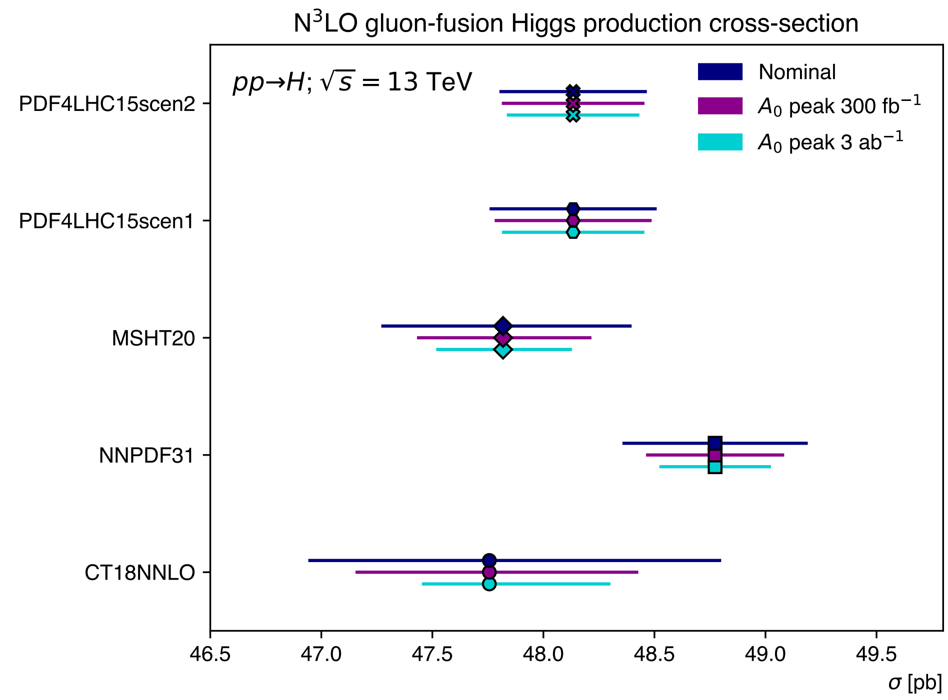
- Reduction of uncertainties concentrated in the central rapidity region **$|y_H|$ < 2.0** .



The Higgs cross section

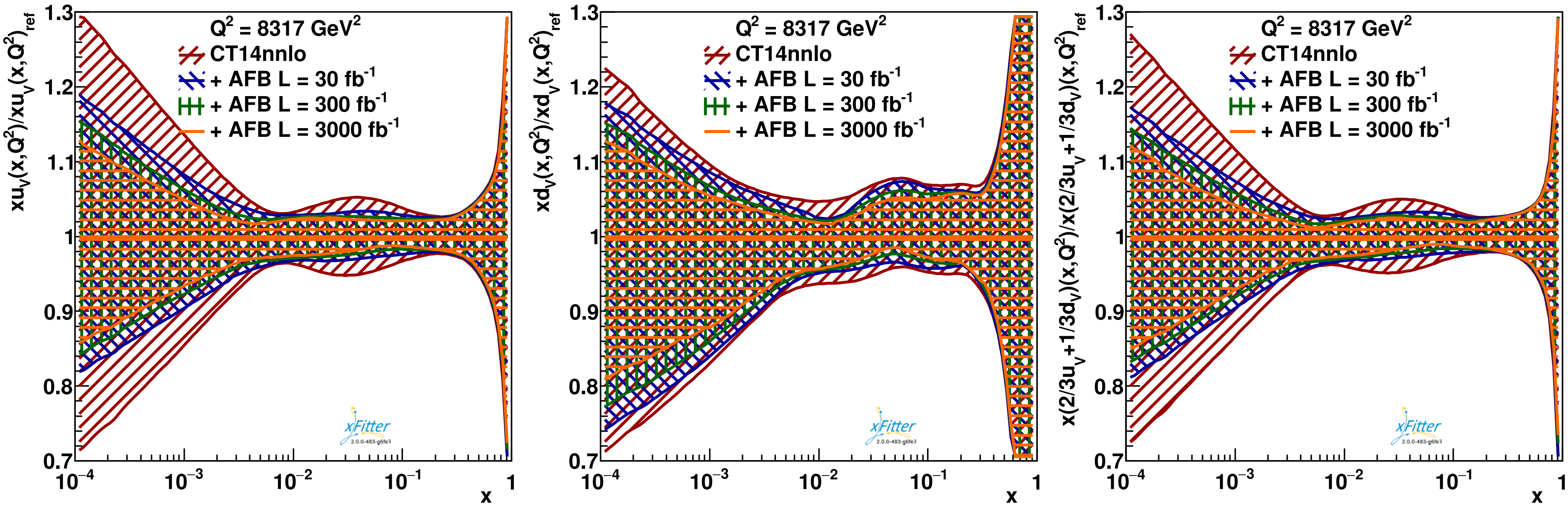


- Profiling projected PDFs based on complete HL-LHC data sample (include jet and top measurements). EPJC 78 (2018) 11
- Further reduction of uncertainty can be obtained.



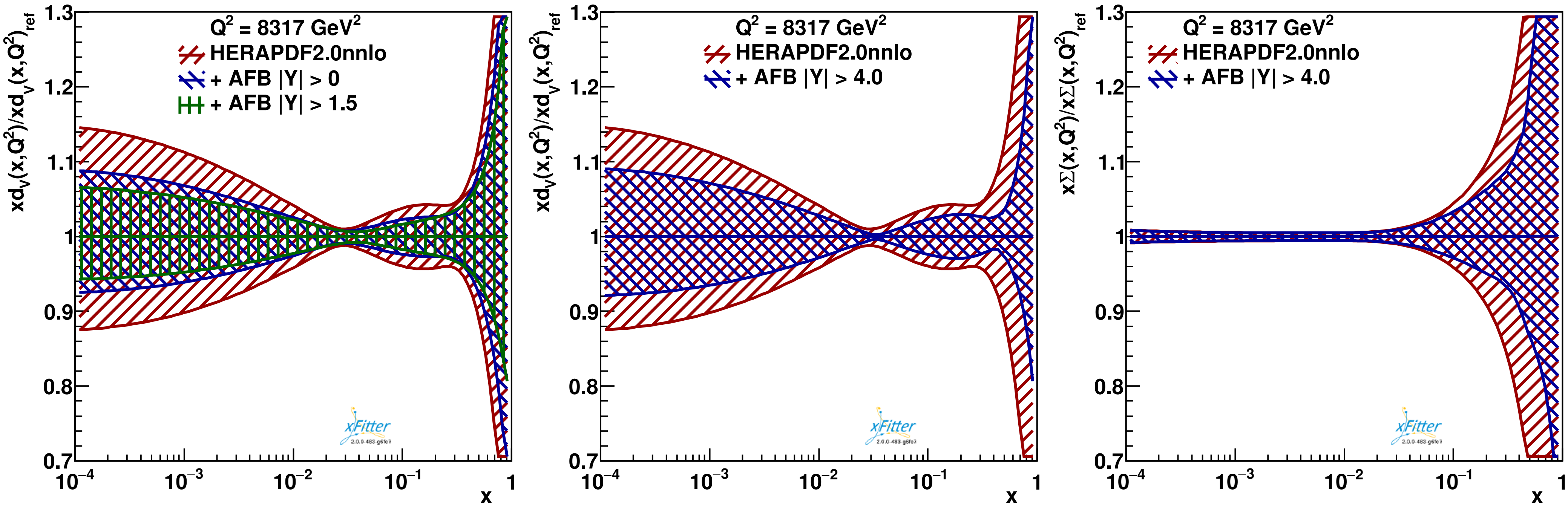
- In ggF computed at N^3LO, the reduction of uncertainty is visible in all modern and projected PDF sets.

The angular coefficient A_4 (aka A_{FB})



- **A_4** coefficient (related to the Forward-Backward Asymmetry A_{FB}=3/8 A_4) is parity violating and sensitive to $\sin^2\theta_W$ and to the flavor non-singlet PDFs.
- The profiling of PDFs using A_{FB} pseudodata leads to large reductions of uncertanty on *u* and *d* valence quarks PDFs, and mostly on the linear combination $2/3u_V + 1/3d_V$.
- Improvement is concentrated in low and intermediate Bjorken *x* regions.

The angular coefficient A_4 (aka A_{FB})



$L = 3000\ fb^{-1}$

- Applying specific rapidity cuts, high-*x* regions can be accessed.
- Remarkable improvement in valence and sea quark distributions for $x > 0.3$.
- The reduced statistic due to the strong rapidity cuts require a high integrated luminosity.

Conclusions

- We assessed the impact of future precise determination of the Drell-Yan angular coefficient $\mathbf{A_0}$ on PDFs, assuming the integrated luminosity of end of Run-III and HL-LHC.
- We find a significant reduction of PDF uncertainties, with complementary constrains with respect to what was found using other angular coefficients, i.e. $\mathbf{A_4}$.
- In particular, the improvement on gluon PDF determination remains visible even when considering projected PDF sets based on future LHC data samples.
- The consequent reduction of uncertainty in the gluon-gluon luminosity leads to important improvements in the determination of Higgs production cross section through gluon-gluon fusion.
- These results open a new area of phenomenological studies on connections between the gauge and Higgs sectors of the SM.
- Future developments will involve a more comprehensive study of the constrains on PDF from the full set of $\mathbf{A_i}$ angular coefficients.

Thank you!

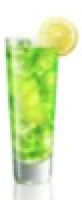
Backup slides

The xFitter project

xFitter / DownloadPage

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 can be downloaded from gitlab gitlab data repository

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

The xFitter project: other results

Determination of Pion PDF:

Consistent with previous determination from the JAM collaboration.
Reasonable agreement between data and theory obtained with the fitted PDFs.

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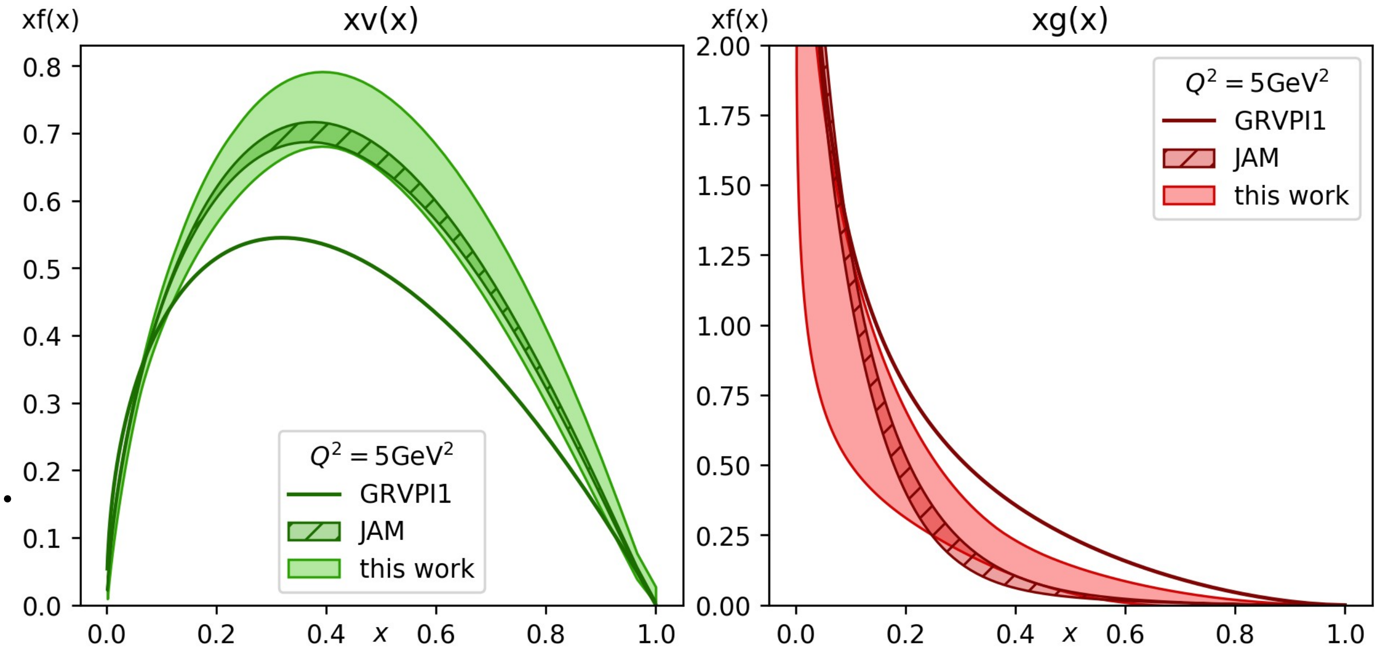
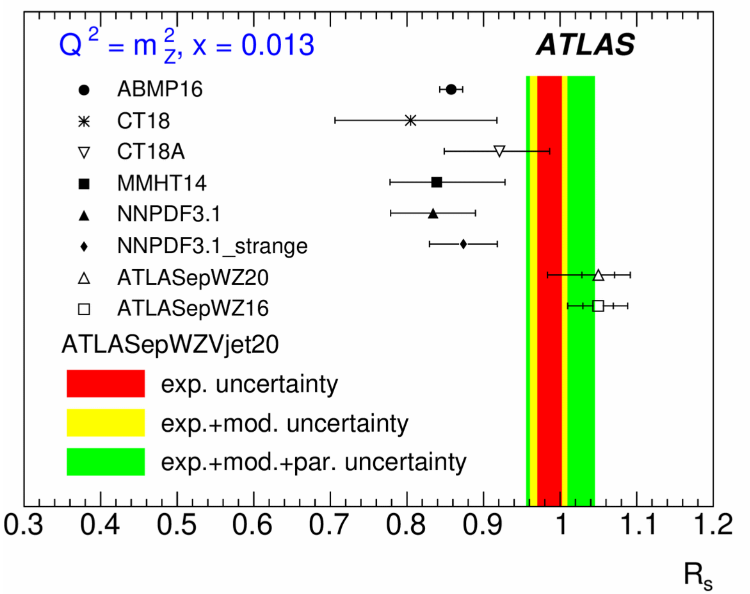
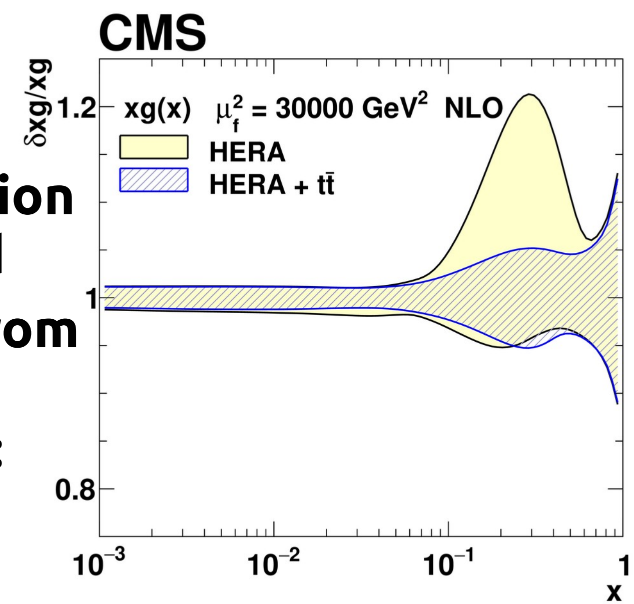


ATLAS PDFs from W/Z + 1jet data:



CERN-EP-2020-237

CMS determination of $\alpha_s(m_Z)$, mt and the gluon PDF from top quark pair production data:



EPJC 80 (2020) 658

Drell-Yan angular coefficients

$$< 1 + \cos^2\theta >$$

Normalization of the unpolarised cross-section

$$< \frac{1}{2}(1 - 3\cos^2\theta) > = \frac{3}{20}(A_0 - \frac{2}{3})$$

Longitudinal polarisation

$$< \sin 2\theta \ \cos\phi > = \frac{1}{5} A_1$$

Interference term: longitudinal/transverse

$$< \sin^2\theta \ \cos 2\phi > = \frac{1}{10} A_2$$

Transverse polarisation

$$< \sin\theta \ \cos\phi > = \frac{1}{4} A_3$$

Product of V-A couplings, sensitive to the Weinberg angle

$$< \cos\theta > = \frac{1}{4} A_4$$

8/3*A_{FB}, non-zero at LO

$$< \sin^2\theta \ \sin 2\phi > = \frac{1}{5} A_5$$

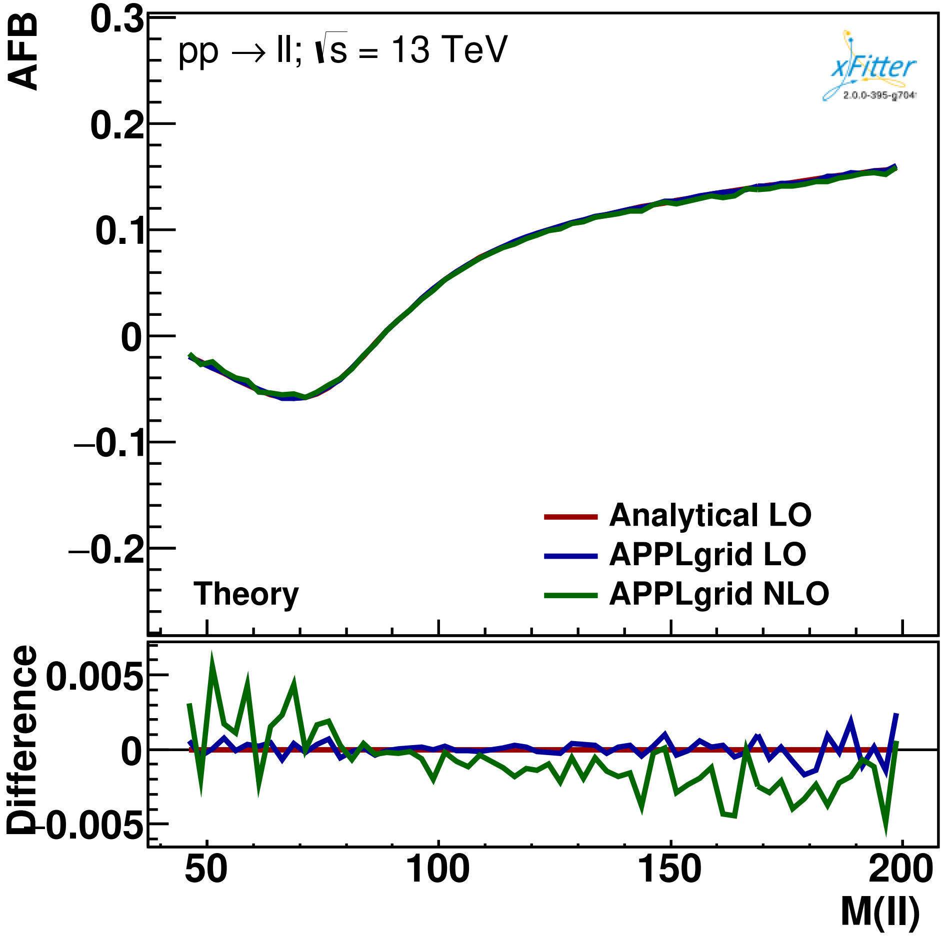
$$< \sin 2\theta \ \sin\phi > = \frac{1}{5} A_6$$

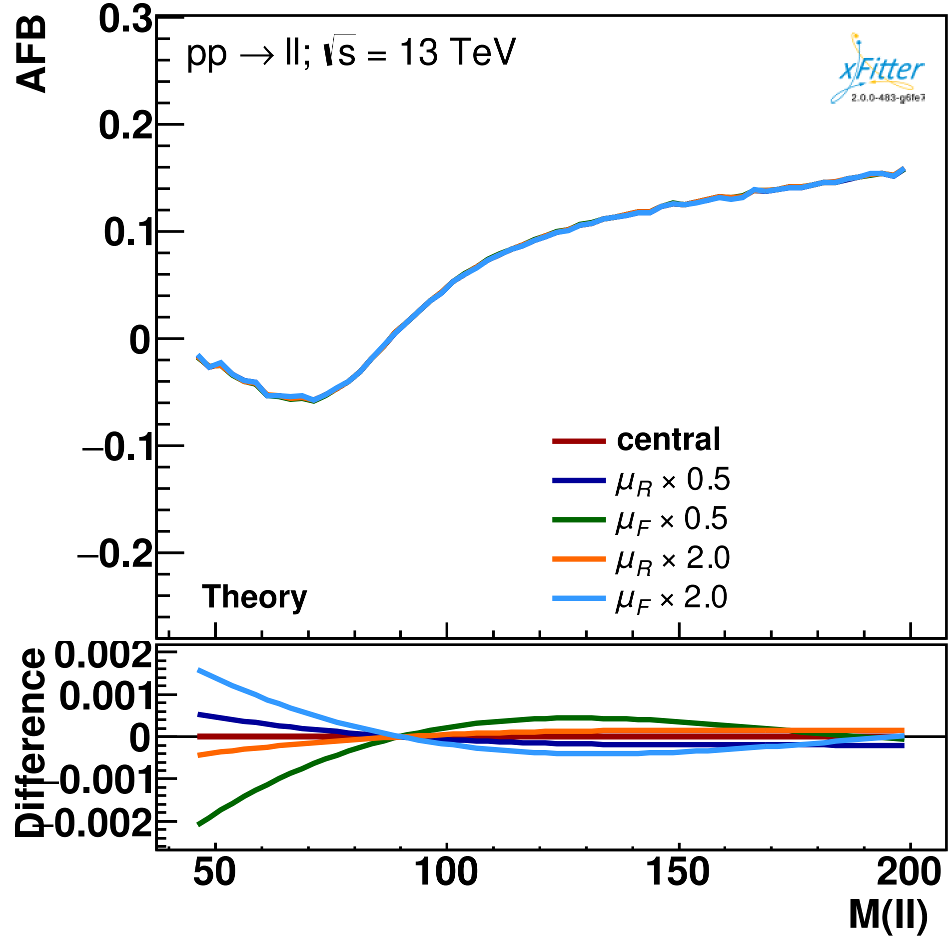
$$< \sin\theta \ \sin\phi > = \frac{1}{4} A_7$$

Zero at NLO, first contributions at NNLO

$$\left\langle P\left(\cos\theta, \phi\right)\right\rangle = \frac{\int P(\cos\theta, \phi)\, d\sigma(\cos\theta, \phi)\, d\cos\theta\, d\phi}{\int d\sigma(\cos\theta, \phi)\, d\cos\theta\, d\phi}$$

A_{FB}





Radiative corrections are small.

Theory uncertainty from scale variation under control.

A_{FB}

$$\sigma_F = \int_0^1 \frac{d\sigma}{d\cos\theta} d\cos\theta \quad , \quad \sigma_B = \int_{-1}^0 \frac{d\sigma}{d\cos\theta} d\cos\theta$$

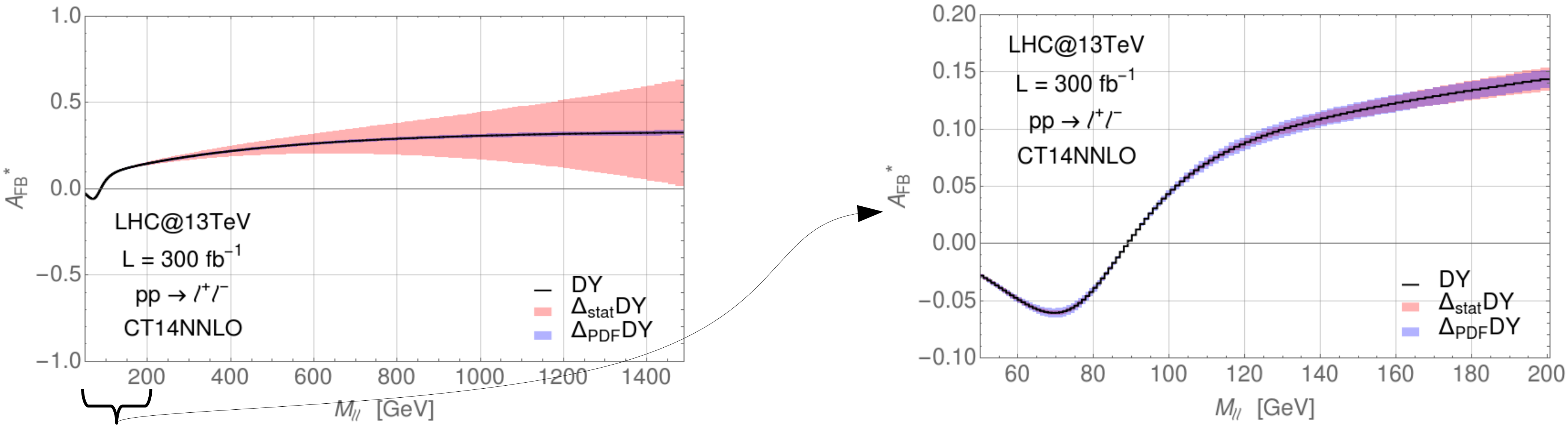
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

The angle $\boldsymbol{\theta}$ is defined as the direction between the incoming quark and the lepton in the final state.
In pp collisions, the c.o.m. frame is unobservable.

At the LHC we can observe the reconstructed AFB*

At LO the direction of the incoming quark is defined by the boost of the di-lepton system.

At NLO the angle is defined in the Collins-Soper frame.

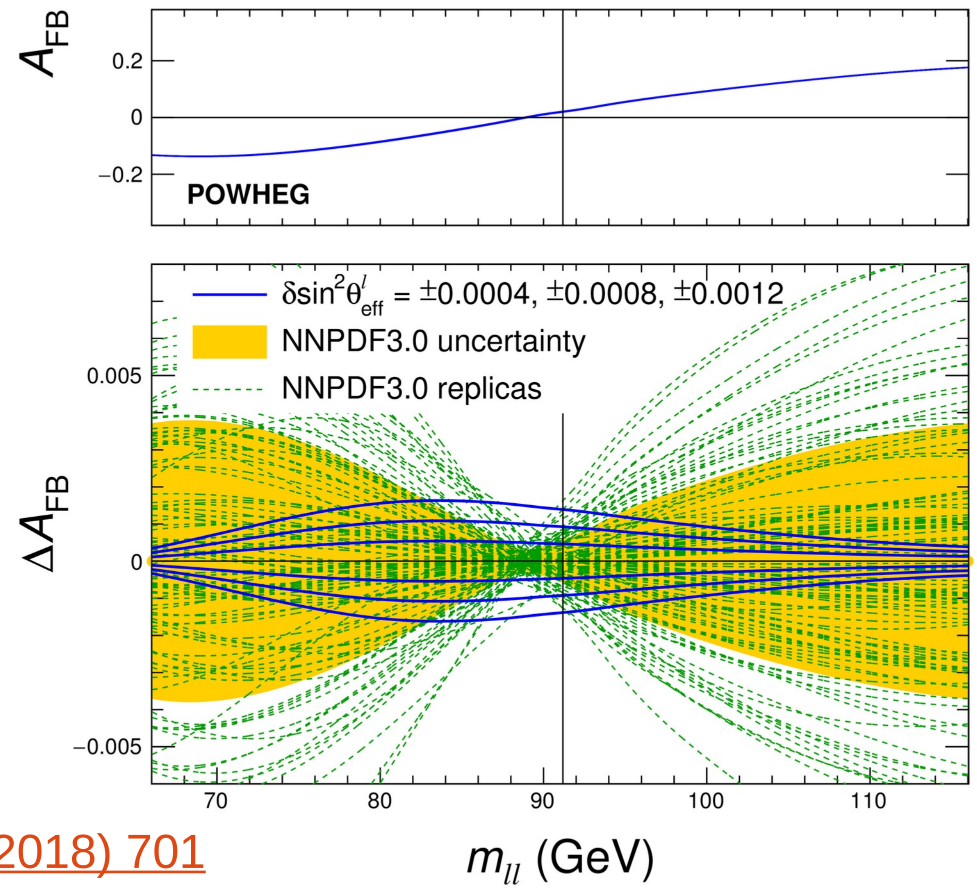


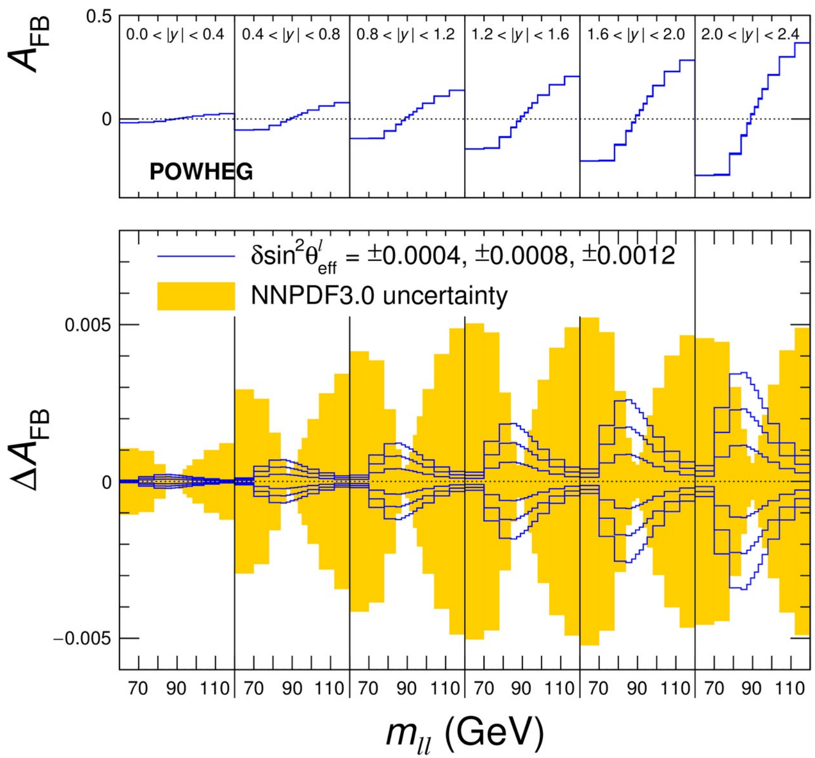
AFB has smaller systematic but larger statistical error compared to cross section measurements.

- High-invariant mass region: dominated by statistical uncertainties.
- Z peak region: high-stats to perform very precise measurements.

PDFs and $\sin^2\theta_W$

- Extraction of $\sin^2\theta_{eff}$ is performed through A_{FB} measurements.
- PDFs are the main source of uncertainty.
- Ongoing studies by LHC-EW-WG to provide different global fits and correlations between PDF sets.





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	CT10	CT14	MMHT14	NNPDF31
$\sin^2$ ‘ e	0.23118	0.23141	0.23140	0.23146
	Uncertainties in measurements			
Total	39	37	36	38
Stat.	21	21	21	21
Syst.	32	31	29	31

ATLAS-CONF-2018-037