https://www.xfitter.org/xFitter

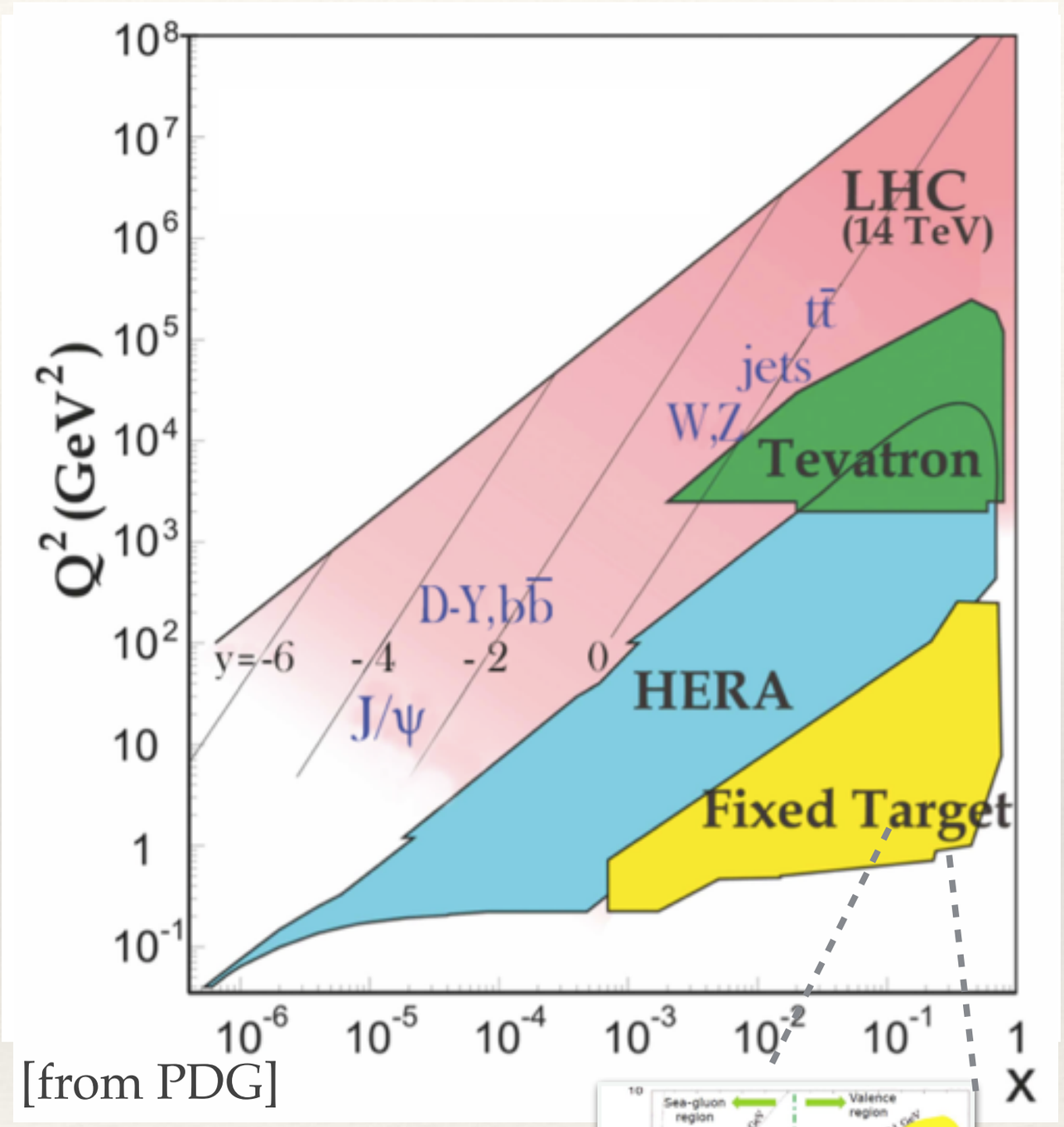
PDF4LHC CERN, March 14.03.2016

xFitter Project

Open Source QCD Fit framework

Voica Radescu
on behalf of the xFitter team

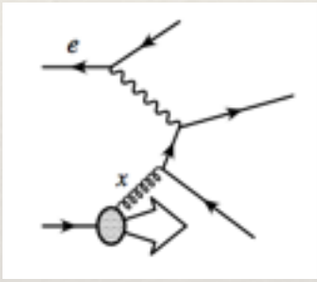
Today's data on proton structure



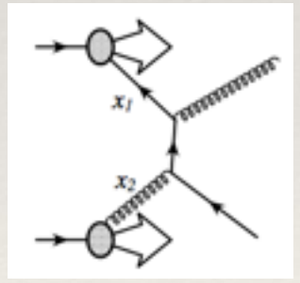
[from PDG]

Persistent experimental effort over the last 40 years both by fixed-target and collider experiments around the world supported by the intense theoretical developments

- The cleanest way to probe Proton Structure is via Deep Inelastic Scattering [DIS]:



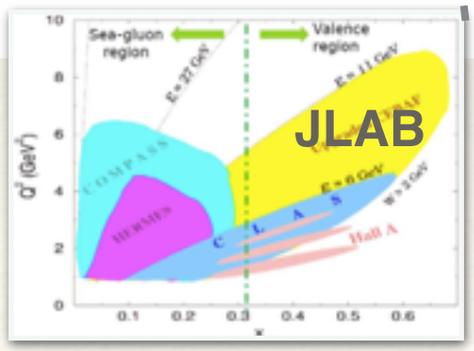
- Precision of proton structure can be complemented by the Drell Yan [DY] processes at the collider experiments



$Q^2 = -q^2 = -(k-k')^2$ Photon virtuality

$x = \frac{Q^2}{2p\cdot q}$ Bjorken variable

$y = \frac{p\cdot q}{p\cdot k}$ Inelasticity

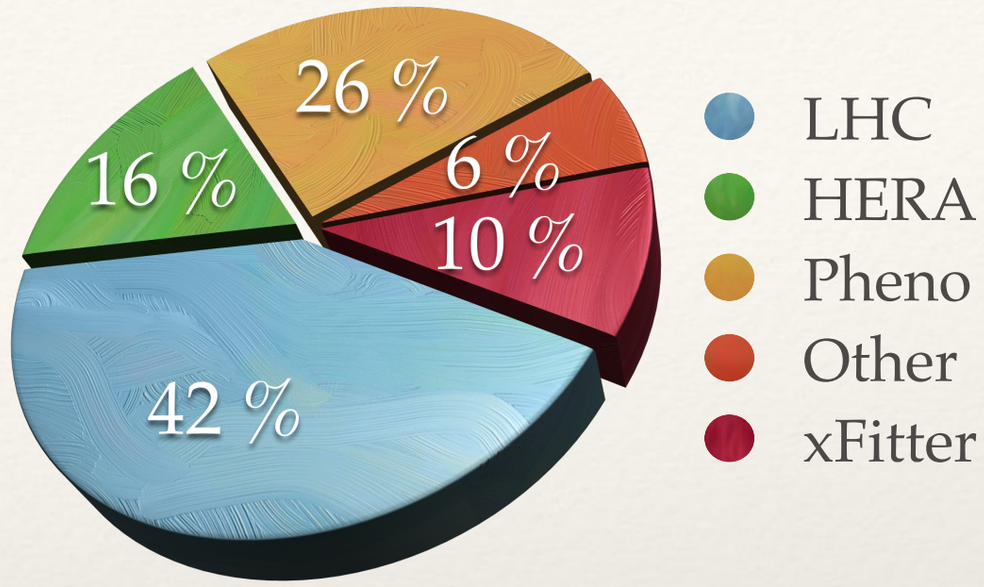


Different data constrain different parton combinations at different x, evolution with the scale is predicted by pQCD:

xFitter (former HERAFitter) www.xfitter.org

- **2011 Open Source Revolution:** EPJC (2015), 75
  - Establishing the first open source QCD Fit Platform which started the wave of sharing QCD fit codes
  - A team of ~30 developers:
    - LHC/HERA/theory/independent
    - several releases since 2011
    - 31 publications that have used the framework [in total]

synergy between experiment and theory groups



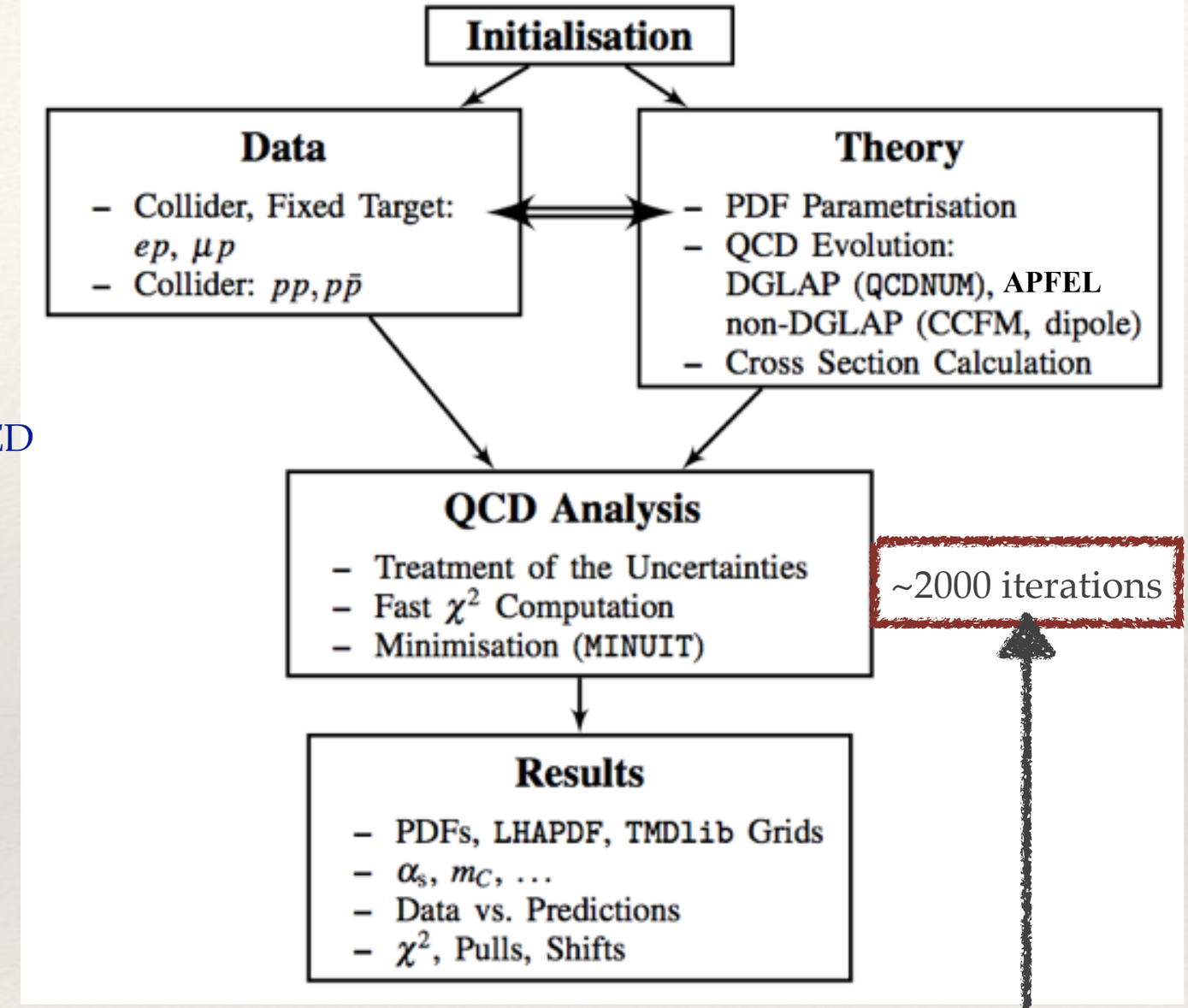
- **provides a unique QCD framework to address theoretical differences:**
  —> benchmark exercises/collaborative efforts/topical studies
- **provides means to the experimentalists to optimise the measurements:**
  —> assess impact/consistency of new data

- **Dedicated studies [xFitter developers]**
  - method in preserving correlation between PDFs extracted at different orders in pQCD EPJC (2014) 74
  - address consistency of Tevatron measurement and evaluate their collective impact on valence EPJC (2015), 75
  - determination of the running mass in MS scheme (ongoing)

xFitter Project at Glance:

Main Steps for a QCD fit:

- Parametrise PDFs at the starting scale
  - multiple options for functional forms
    - Standard Polynomial, Chebyshev, etc
- Evolve to the scale corresponding to data point
  - DGLAP evolution codes [QCDNUM, APFEL]
  - kt ordered evolution, Dipole models, DGLAP+QED
- Calculate the cross section
  - various heavy flavour schemes:
    - RT, ACOT, FONLL, FFNS(ABM)
  - fast grid techniques interfaced to DY:
    - APPLGRID, FASTNLO
- Compare with data via $\chi 2$:
  - multiple forms to account for correlations
- Minimize $\chi 2$ with respect to PDF parameters
  - MINUIT, data driven regularisation



EPJC (2015), 75:304

Importance of optimised calculations

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DESY xFitter

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xFitter

Welcome to xFitter (former HERAFitter)

Proton parton distribution functions (PDFs) are essential for precision physics at the LHC and other hadron colliders. The determination of the PDFs is a complex endeavor involving several physics process. The main process is the lepton proton deep-inelastic scattering (DIS), with data collected by the HERA ep collider covering a large kinematic phase space needed to extract PDFs. Further processes (fixed target DIS, ppbar collisions etc.) provide additional constraining powers for flavour separation. In particular, the precise measurements obtained or to come from LHC will continue to improve the knowledge of the PDF.

The xFitter project is an open source QCD fit framework ready to extract PDFs and assess the impact of new data which we would like to present here. The framework includes modules allowing for a various theoretical and methodological options, capable to fit a large number of relevant data sets from HERA, Tevatron and LHC. This framework is already used in many analyses at the LHC.

Downloads of xFitter software package

xFitter-1.2.0 release is publicly available.
All the xFitter releases can be accessed HERE.
All the former (HERAFitter) releases can be accessed HERE.
Description: http://arxiv.org/abs/1410.4412

xFitter Meetings

- Upcoming xFitter Meeting in Dubna: TBA
- User's Meetings: meetings to enhance communication between users and developers (open access)
- Developer's Meeting: technical weekly meetings to ensure communication among developers (restricted access)
- Steering Group's Meeting (restricted access)

xFitter representation

- List of results
- List of collected talks

Developers Info (restricted to developers)

- Internal Developments

Organisation

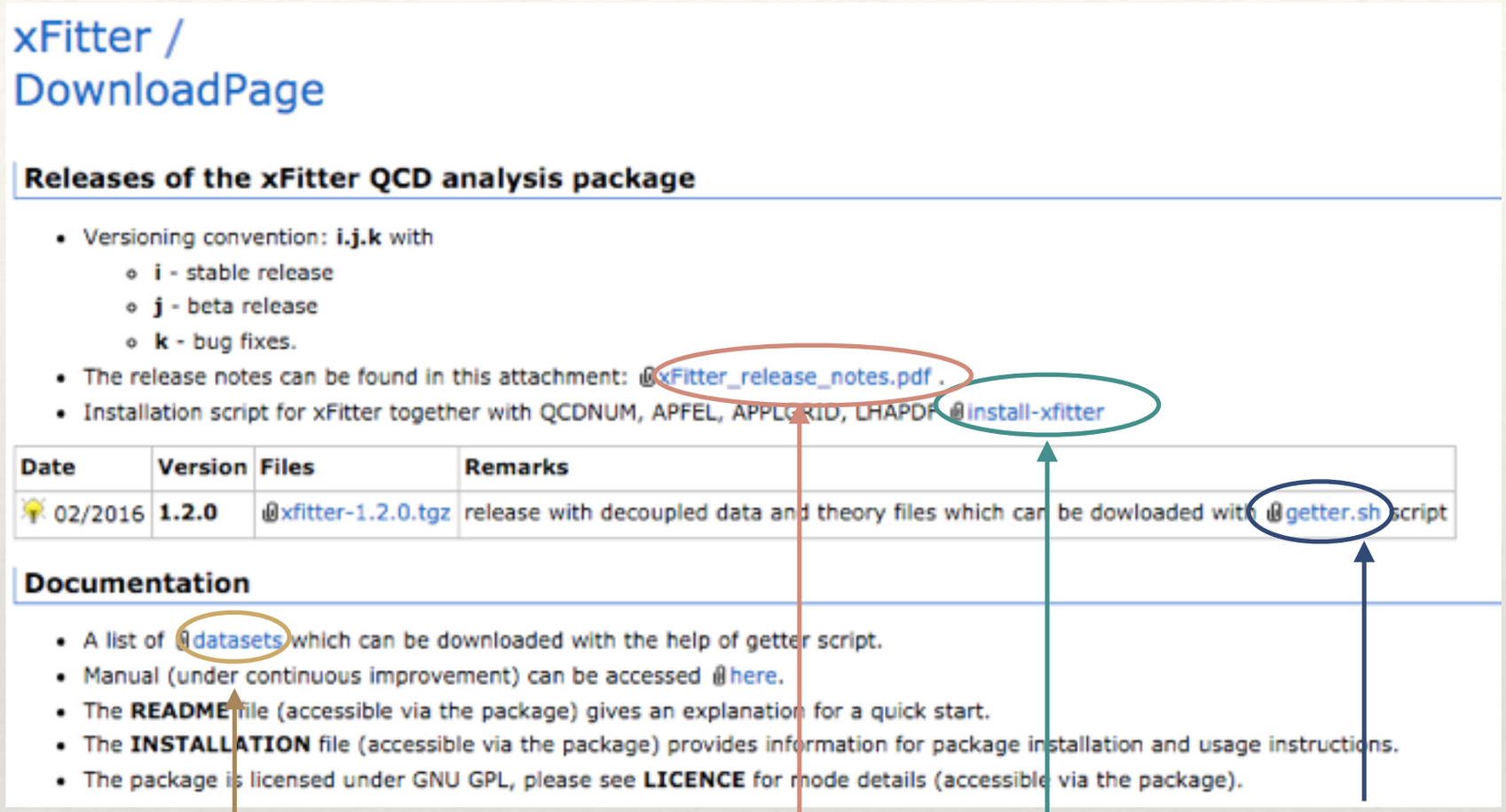
Steering Group is composed of:
- **Conveners:** Voica Radescu, Ringaile Placakyte, Amanda Cooper-Sarkar
- **Release coordinator** (revision of the release candidates): Sasha Glazov
- **Librarian** (continuous revision/development of the main code and doxygen): Hayk Pirumov, Andrey Sapronov
- **Contact Persons:** Cristi Diaconu (H1),Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS), Olaf Behnke (ZEUS), Ronan McNulty (LHCb), Gavin Salam (theory)
- **DESY IT Contact:** Yves Kemp

Getting help

Send email to xfitter-help@desy.de

xFitter new release: 1.2.0

Realese xFitter1.2.0.tgz available at: *https://www.xfitter.org/xFitter/xFitter/DownloadPage*



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

Date	Version	Files	Remarks
02/2016	**1.2.0**	xfitter-1.2.0.tgz	release with decoupled data and theory files which can be dowloaded with getter.sh script

Documentation

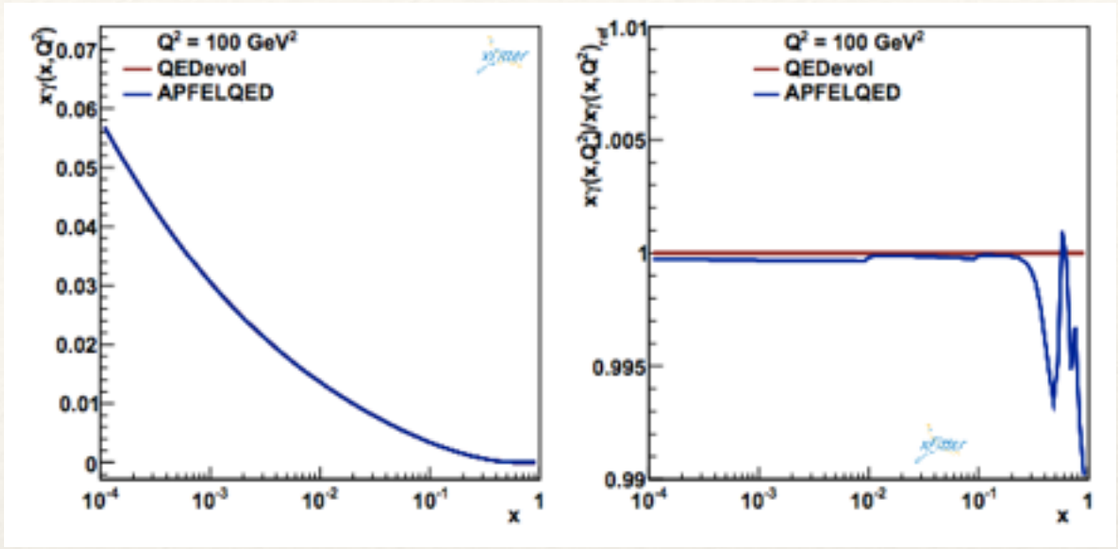
- A list of datasets which can be downloaded with the help of getter script.
- Manual (under continuous improvement) can be accessed here.
- The **README** file (accessible via the package) gives an explanation for a quick start.
- The **INSTALLATION** file (accessible via the package) provides information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

- By default only final combined HERA I+II data are distributed —> (xfitter-)getter.sh script to download data with corresponding theory files already adjusted for the xfitter format.
  - in datasets —> all available files

- A complete installation script is also provided (tested under different platforms)
- A release note to keep track of changes between releases is included
- A link to the manual

New Physics Cases in xfitter-1.2.0 (I)

- **QED PDFs up to NNLO QCD + LO 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

- **Mellin Transformation in xfitter via MELA** https://apfel.hepforge.org/mela.html
  - Mellin transformations convey convolutions in simple products —> DGLAP has a simple form
  - Motivation:
    - Mellin moments predictions work well:
      - with fixed order calculations
        - main stream in extracting PDFs
      - with all-order resummed predictions
        - needed for other fundamental parameters

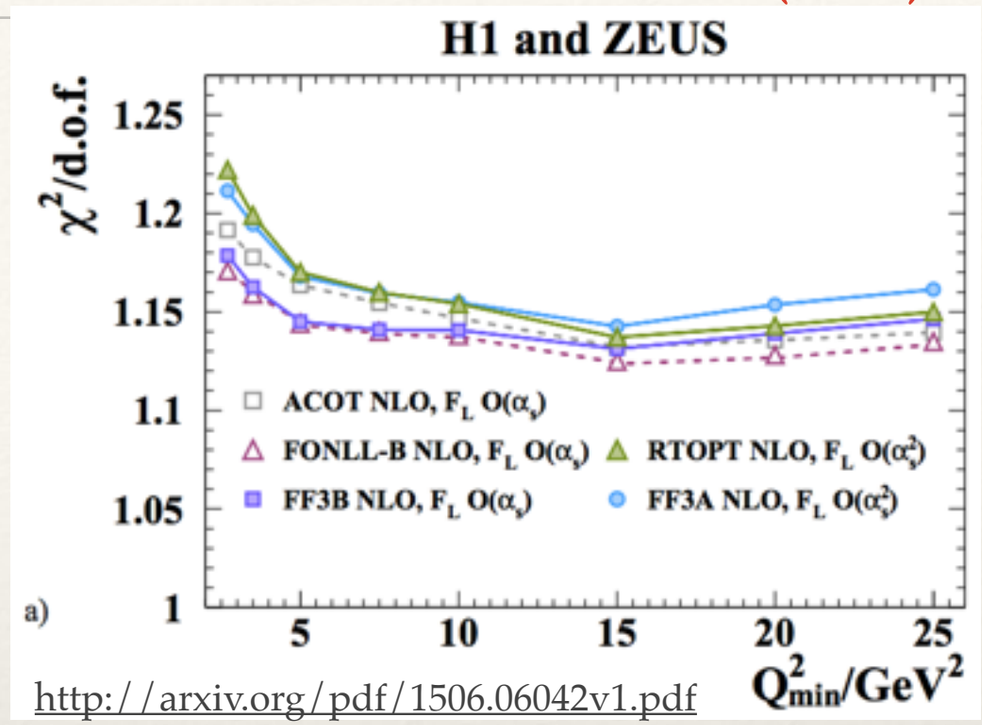
The Mellin moments implementation could allow a broader spectrum of phenomenological applications of xFitter:

- Simultaneous fits of PDFs and weak mixing in DY,
- PDFs and alphas and mt in ttbar

New Physics Cases in xfitter-1.2.0 (II)

- **Addition of new Heavy Flavour Scheme: FONLL**
  - 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 v 2.0b4

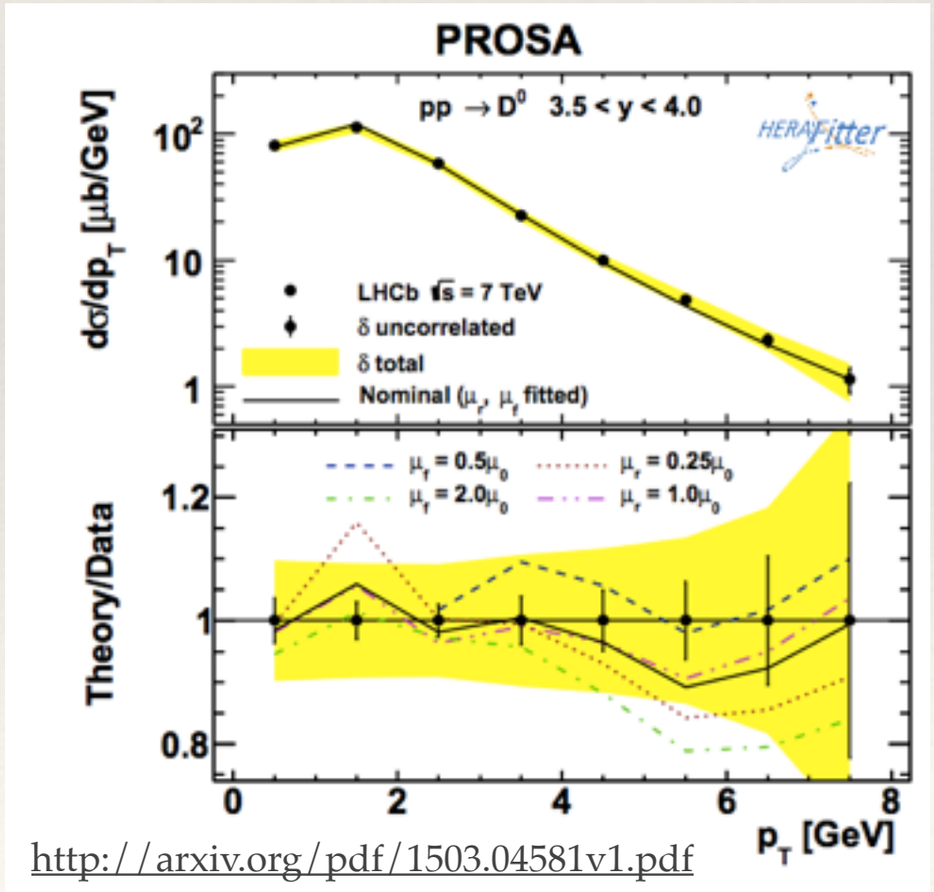
  . http://www-zeuthen.desy.de/~alekhin/OPENQCDRAD.



http://arxiv.org/pdf/1506.06042v1.pdf

Nucl. Phys. B373 (1992) 295

- **Interface to Mangano-Nason-Ridolfi (MNR) theory code added** in xfitter and it 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 also corresponding LHCb data
- Added extra reweighing options using Giele-Keller weights



http://arxiv.org/pdf/1503.04581v1.pdf

New technicalities in xfitter-1.2.0

- **Change of name of executables:**
  - FitPDF —> xfitter
  - DrawPdfs —> xfitter-draw
  - DrawResults —> xfitter-draw
  - Postproc —> xfitter-process

- Note that in the previous releases there was a theoryfiles directory
  - —> now theoryfiles are stored with datafiles to be in sync

- **Installation:**
  - xfitter-1.2.0 is compatible with new QCDNUM version > 17.01.10
    - QCDNUM is available now also with autotools installations
    - QCDNUM provides now access to more than standard 13 PDFs, e.g. photon PDF can be added
  - Installation of the xfitter-1.2.0 can also be configured via prefix
  - Added the possibility to disable root

- Theory formats in xfitter (usage/parsing) have been unified between FASTNLO and APPLGRID
  - old format for FASTNLO is still operational

- Profiling and Reweighing codes now use same general infrastructure

- Possibility to access directly PDFs as stored in LHAPDF (surpassing QCDNUM)
  - LHAPDFNATIVE option added

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

xfitter-1.2.0 latest release

- New release provides access to new phenomenological studies to follow thanks also to intensive collaboration with theory groups such as APFEL, SANC, CUTE, ABM, CT, NCTEQ, etc…

Outlook: plenty foreseen developments

- Improve user interface for various parametrisation
- Simplification of the steering card for easier access to profiling module [no fit]
- Add resummation options
- More on low x phenomenology: higher twists
- Nuclear PDFs
- Interface to other kind of grids [APFELgrids, TMDgrids]

See Mandy's talk

xFitter Contacts

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Getting help

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extra

(not necessarily useful nor current)

Release Notes

xFitter: Releases and Updates

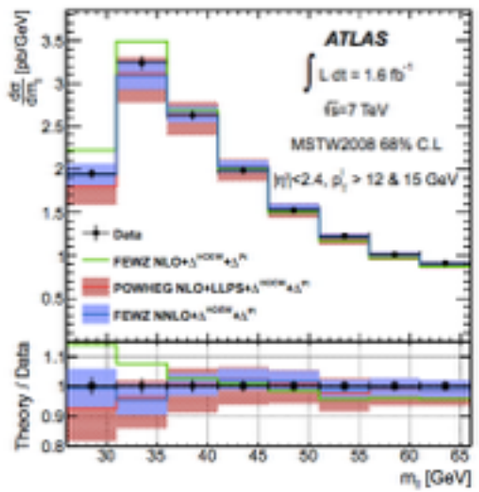
February, 2016

xFitter versions are labeled as **xfitter-i.j.k** where **i** is the stable release number, **j** is beta release number, and **k** is bug fixes.

Release	Date	Description
xfitter-1.2.0	15.02.2016	• Project renamed from herafitter to xfitter. • Added stand-alone scripts for downloading data/theory files: `getter` . No need of theory directory anylonger, the theory files are now stored under same location with data files. • Change in the executable names: – FitPDF → xfitter – DrawPdfs → xfitter-draw – postproc → xfitter-process • Updated configure.ac to work with latest QCDNUM which is now available with autotools installation (> 17.01.10). – new QCDNUM allows possibility to have more than standard PDFs. • Added QED PDFs via generalised `nxn` convolution engines of QCDNUM. • Added interface to APFEL which provides access to: – evolution code: added DGLAP_APFEL option for standard evolution, or DGLAP_APFEL_QED for QED adjusted evolution. – FONLL heavy flavour schemes with multiple options. • Added interface to n-space code MELA for Mellin Transformation and it is available via configuration flag. • Added direct access to LHAPDFs avoiding QCDNUM: LHAPDFNATIVE option • Added more data formatted for xfitter: updated Tevatron data, LHCb, HERA) • Added `--disable-root` option (root is enabled by default). • Default steering updated to HERAI+II data. • Removed DrawResults package, which was redundant, and added and updated drawing options for data files. • Added fixes to DIS electroweak part of the code. • Fixed several fortran warning messages. • Unifying theory interface for expression between FastNLO and APPLGRID usage. • Updated FastNLO to the latest version • Installation possible with `--prefix` option, added xfitter-config script. • Added MNR calculation code as used for the LHCb and HERA data analysis [Eur.Phys.J. C75 (2015) 8, 396] • Added new options for the reweighting using Giele-Keller weights. Merged common codes between profiling and reweighting. • Fixing lapack and blas tests to give configure errors and stop • Updated the ABM calculations in sync with OPENQCDRAD 2.0b4 • Added possibility to get integrated cross sections for DIS. • Tools/RunJobs and steerings for diffraction adjusted to xFitter.

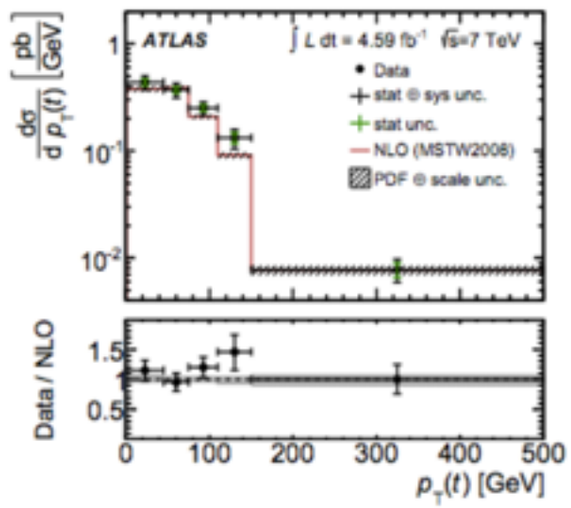
Highlighted Results using HERAFitter

- **HERAFitter platform can be used for quantitative assessment** in level of agreement between measurements and SM theoretical predictions, accounting for all uncertainties:
  - Low Mass DY (ATLAS) data [arXiv:1404.1212]



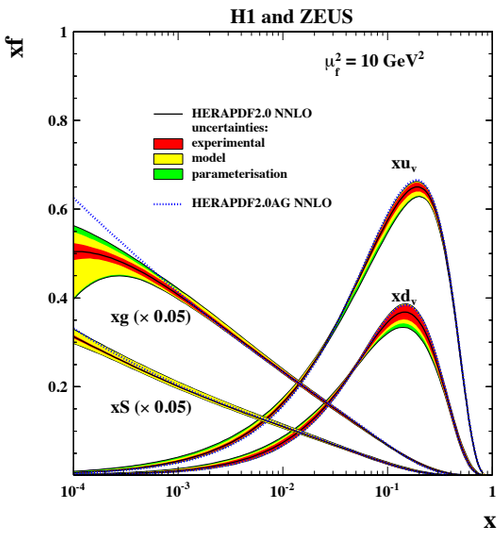
Prediction	χ^2 (8 points) Nominal
POWHEG NLO+LLPS	22.4 (19.8)
FEWZ NLO	48.7 (28.6)
FEWZ NNLO	13.9 (12.9)

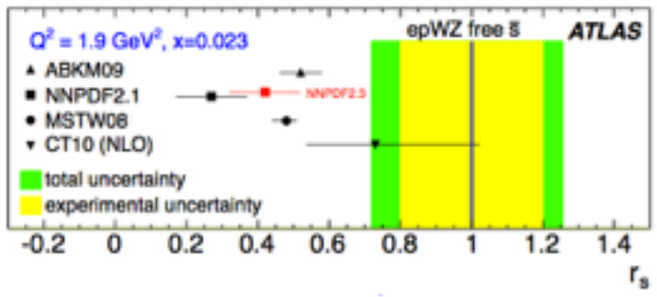
t-channel single top-quark production cross sections (ATLAS) [arXiv:1406.7844]

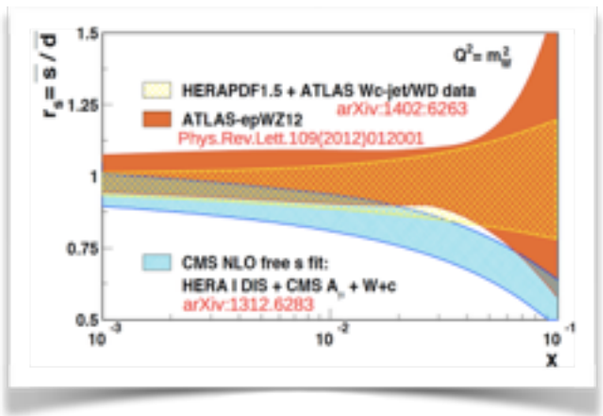


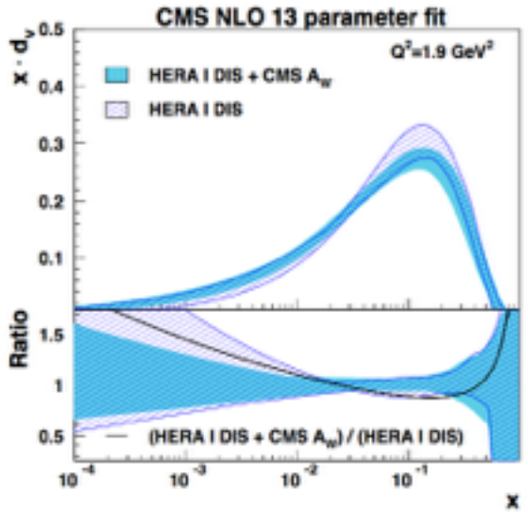
	$\frac{d\sigma}{dp_T(t)}$
χ^2/NDF	7.55/5

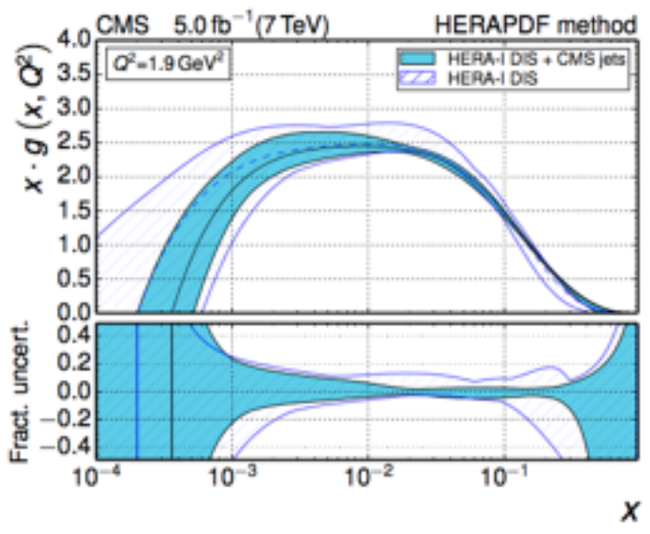
- **HERAFitter platform can be used for QCD fits to extract PDFs or to study the impact of new data on PDFs**
  - HERAPDF2.0 (H1 and ZEUS), ATLASepWZ2012, CMS PDF fits using W+c, W asymmetry, CMS PDF+alphas from jets











Potential impact of 13TeV data on PDFs

PDF4LHC studies accepted by JPG, arXiv:1507.00556

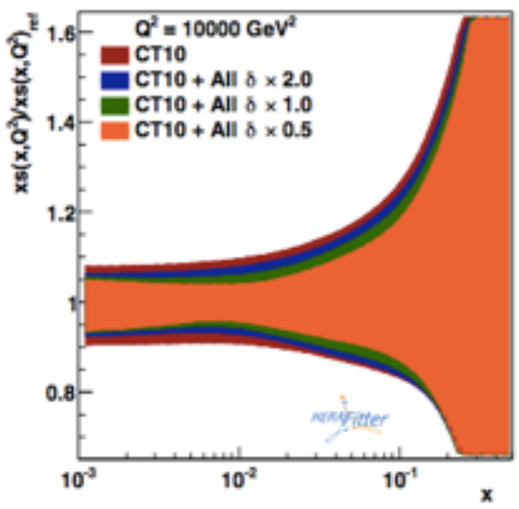
- HERAFitter provides possibility to study the potential impact of Run II data on the current precision of PDFs using profiling method:
  - Profiling method uses the minimisation of the $\chi 2$ function that includes both data and PDF uncertainties

$$\chi^2(\beta_{\mathbf{exp}}, \beta_{\mathbf{th}}) = \sum_{i=1}^{N_{\text{data}}} \frac{\left(\sigma_i^{\text{exp}} + \sum_j \Gamma_{ij}^{\text{exp}} \beta_{j,\text{exp}} - \sigma_i^{\text{th}} - \sum_k \Gamma_{ik}^{\text{th}} \beta_{k,\text{th}}\right)^2}{\Delta_i^2} + \sum_j \beta_{j,\text{exp}}^2 + \sum_k \beta_{k,\text{th}}^2$$

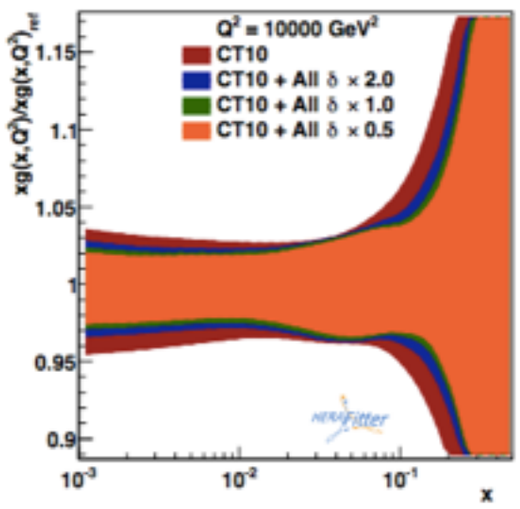
β - nuisance parameters
Γ - influence on data / theory

  - Using global PDFs: CT10, MMHT, NNPDF3.0 and benchmark measurements: **inclusive W, Z and $t\bar{t}$ production**
    - generated pseudo data: uncertainties are based on Run 1 results as published by ATLAS and CMS:
      - baseline scenario: data uncertainties are taken to be similar to those of the Run I measurements
      - conservative scenario: data uncertainties are scaled up by factor of two
      - aggressive scenario: data uncertainties are reduced by factor of two.

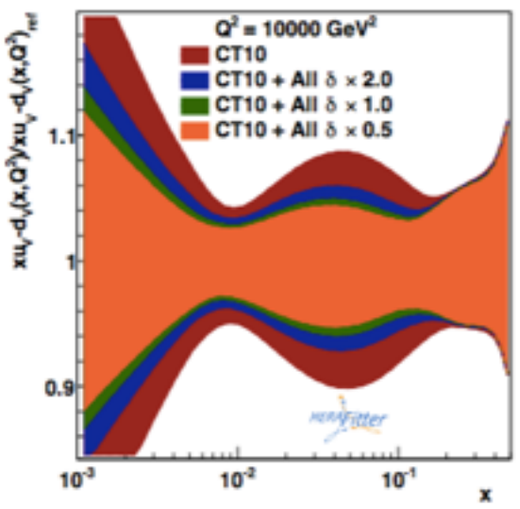
	$R_{W/Z}$	$R_{t\bar{t}/Z}$	A_ℓ	y_Z
Kinematic range			$p_{t,\ell} > 25\,\text{GeV}, \lvert\eta_\ell\rvert < 2.5$	
Number of bins	1	1	10	12
Baseline accuracy per bin	1%	2%	≈ 1.5%	≈ 1.5%



σ_W/σ_Z, y_Z~xs(x)



σ_{ttbar}/σ_Z ~xg(x)



W lepton asymmetry~(uv-dv)

—> early 13TeV data can be very interesting already

Correlations of PDF uncertainties at LO, NLO, NNLO

Eur. Phys. J. C (2014) 74:3039

- Ratios of cross sections are used to reduce common uncertainties, however the theoretical calculations sometimes are not available at the same order of accuracy in pQCD:
  - how to minimize theory error on predictions of cross-section ratio?

$\frac{\hat{\sigma}_X^{NLO} \otimes PDF_{NLO}}{\hat{\sigma}_Y^{NLO} \otimes PDF_{NLO}}$ PDF uncertainties cancel
large scale uncertainty

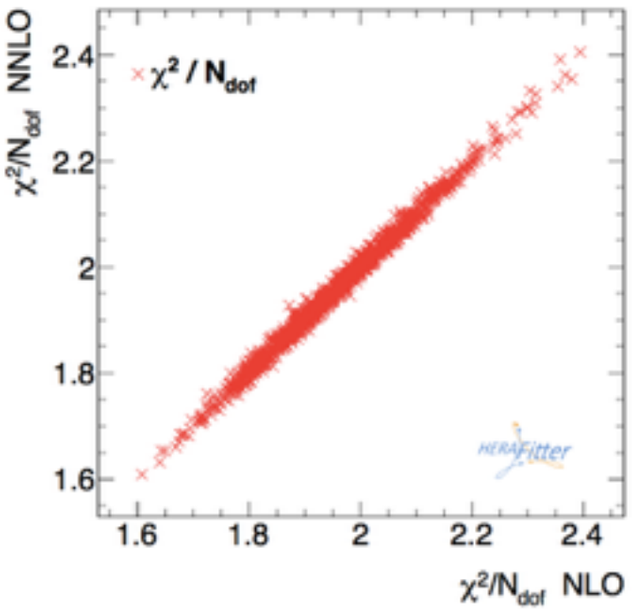
$\frac{\hat{\sigma}_X^{NLO} \otimes PDF_{NNLO}}{\hat{\sigma}_Y^{NNLO} \otimes PDF_{NNLO}}$ PDF uncertainties cancel
improved scale uncertainty
not clear definition in pQCD

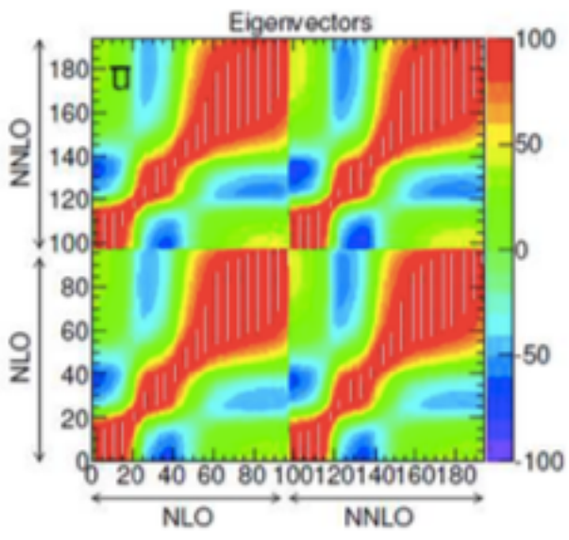
$\frac{\hat{\sigma}_X^{NLO} \otimes PDF_{NLO}}{\hat{\sigma}_Y^{NNLO} \otimes PDF_{NNLO}}$ improved scale uncertainty
No cancellation of PDF uncertainty

$\frac{\hat{\sigma}_X^{NLO} \otimes PDF^{corr}_{NLO}}{\hat{\sigma}_Y^{NNLO} \otimes PDF^{corr}_{NNLO}}$ PDF uncertainties cancel
improved scale uncertainty

- HERAFitter provides a possibility to account for correlations between PDFs at different orders which can lead to reduction of overall theoretical uncertainties:

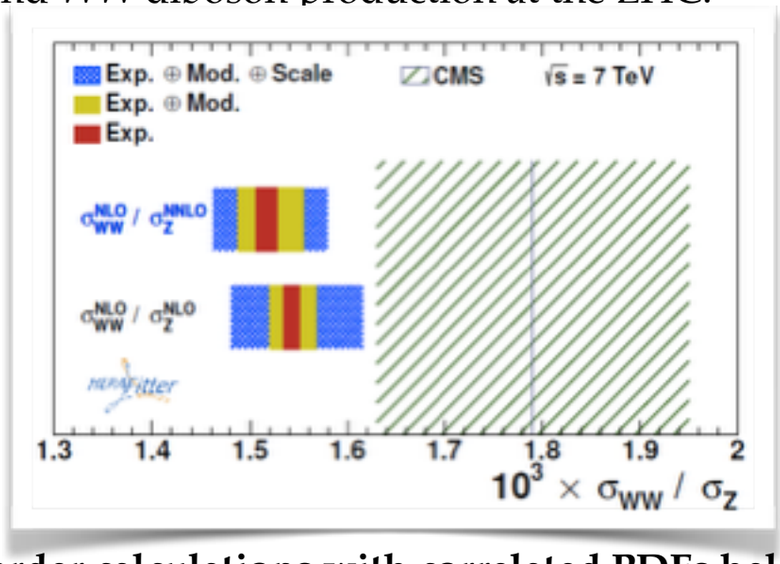
—> PDFs extracted using HERA I data with syncronised uncertainties at NLO and NNLO using MC method with synchronised seeds





High correlations for PDFs at similar x values [binned 1-100(NLO), 101-200(NNLO)].

Propagated to use case scenario of Z boson and WW diboson production at the LHC.



- **mixed-order calculations with correlated PDFs help to reduce PDF and scale uncertainties**
- **total theoretical uncertainty is reduced by 30-40%**

QCD Analysis of W and Z production at Tevatron

submitted to Eur. Phys. J. C, arXiv:1503.05221

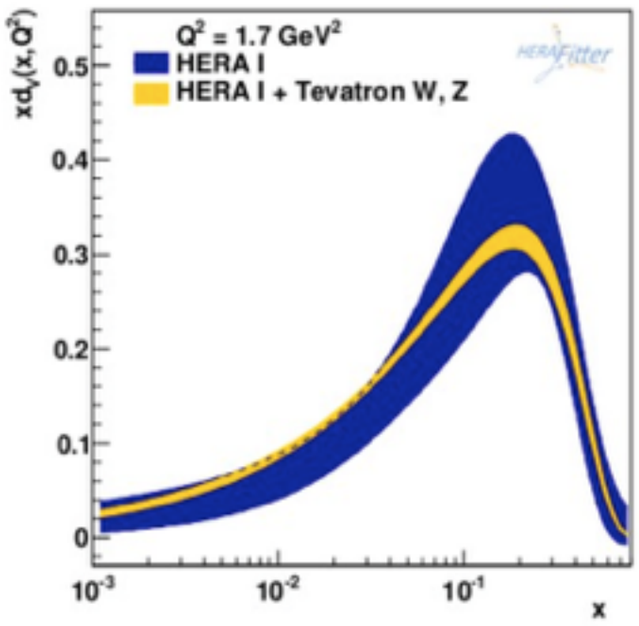
- In proton-antiproton collisions at Tevatron, DY processes of W and Z production are valence-quark dominated
  - —> they can be used to improve quark valence PDFs - especially the d-quark type
  - However, long history of tensions between CDF and D0 W asymmetry
- HERAFitter team examines the compatibility of the Tevatron data with QCD for:
  - Z rapidity distributions [CDF and D0]
  - Lepton charge asymmetry in W—> l,ν [D0]
  - W charge asymmetry [CDF and D0]

  Ref: arXiv:0702025, arXiv:0908.3914, arXiv:1309.2591, arXiv:0901.2169, arXiv:1312.2895, arXiv:1412.2862
- A QCD Fit analysis is performed at NLO, using HERA I data as a reference and adding Tevatron data on top:
  - a revised correlation model is used by treating the uncertainties of data-driven corrections as bin-to-bin uncorrelated: lepton ID, trigger, and charge efficiencies
  - it required a more flexible parametrisation wrt to fits to HERA I data:

$$f(x) = \overbrace{Ax^B(1-x)^C}^{} \times \overbrace{e^{Fx}}^{}\overbrace{(1+Dx+Ex^2)}^{}$$

Data set	Experiment	χ^2/points
DIS	H1 - ZEUS	516/550
Z dσ/dy	D0	23/28
Z dσ/dy	CDF	32/28
W μ-asymmetry	D0	12/10
W asymmetry	CDF	14/13
W asymmetry	D0	8/14
Total χ^2/dof		606/628

Good χ2 (partial and overall) for the QCD analysis



Large impact on d-valence PDF

QCD Analysis of W and Z production at Tevatron

submitted to Eur. Phys. J. C, arXiv:1503.05221

- In proton-antiproton collisions at Tevatron, DY processes of W and Z production are valence-quark dominated
  - —> they can be used to improve quark valence PDFs - especially the d-quark type
  - However, long history of tensions between CDF and D0 W asymmetry
- HERAFitter team examines the compatibility of the Tevatron data with QCD for:
  - Z rapidity distributions [CDF and D0]
  - Lepton charge asymmetry in W—> l,ν [D0]
  - W charge asymmetry [CDF and D0]

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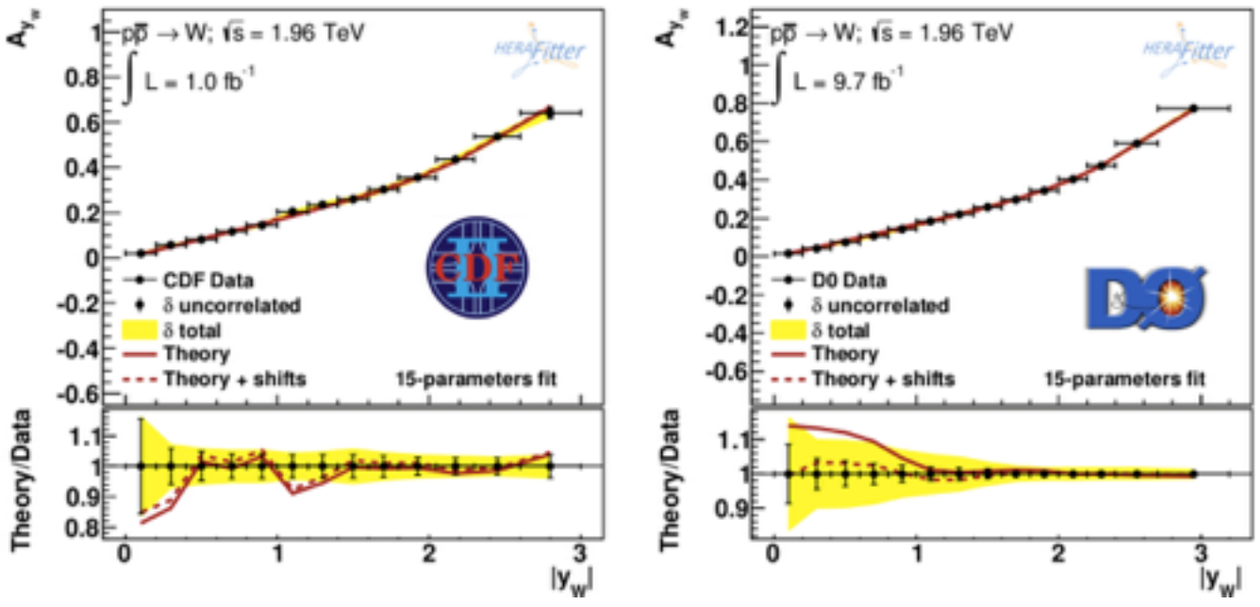
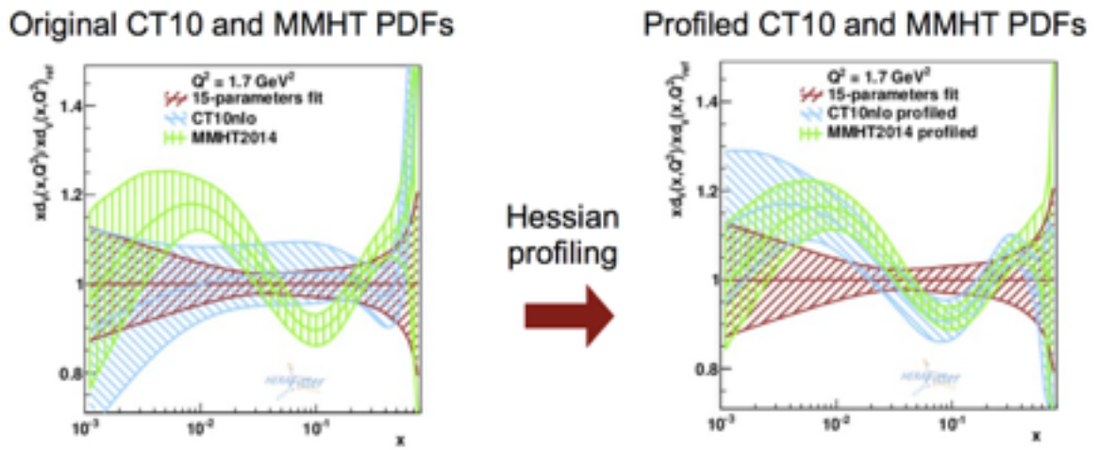


Good agreement between latest CDF and D0 W asymmetry data!



The inclusion of the the Tevatron W asymmetry data improves the agreement between CT10 and MMHT

Transverse Momentum Distributions

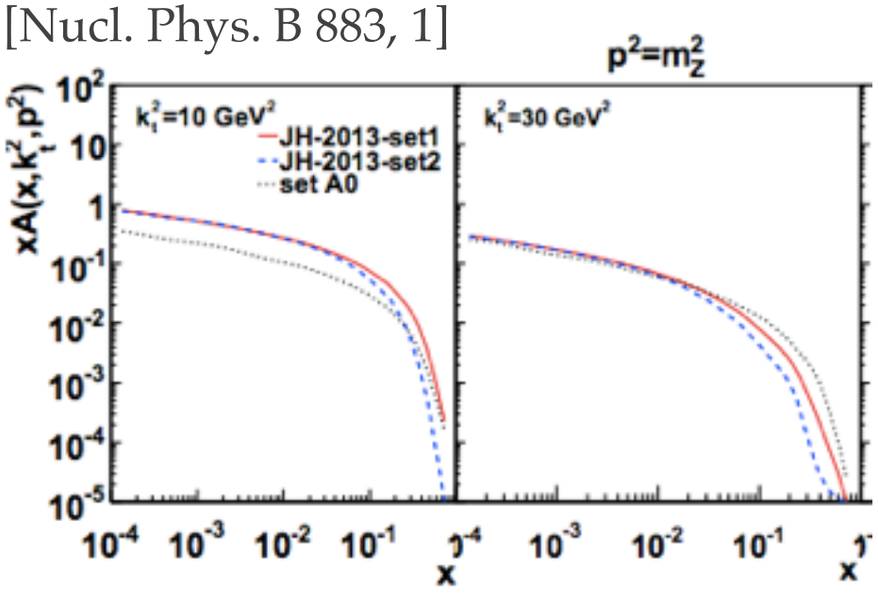
- QCD applications to multiple-scale scattering problems and complex final-state observables require in general formulations of factorisation which involve transverse-momentum dependent (TMD) - or known also as unintegrated PDFs.

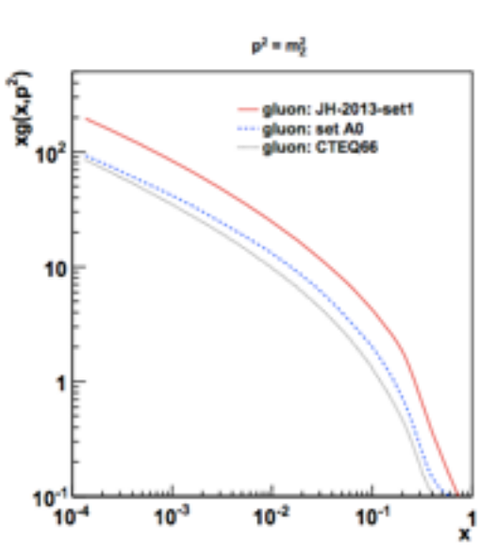
$$\sigma_j(x,Q^2) = \int_x^1 dz \int d^2k_t\ \hat{\sigma}_j(x,Q^2,z,k_t)\ \mathcal{A}(z,k_t,\mu)$$

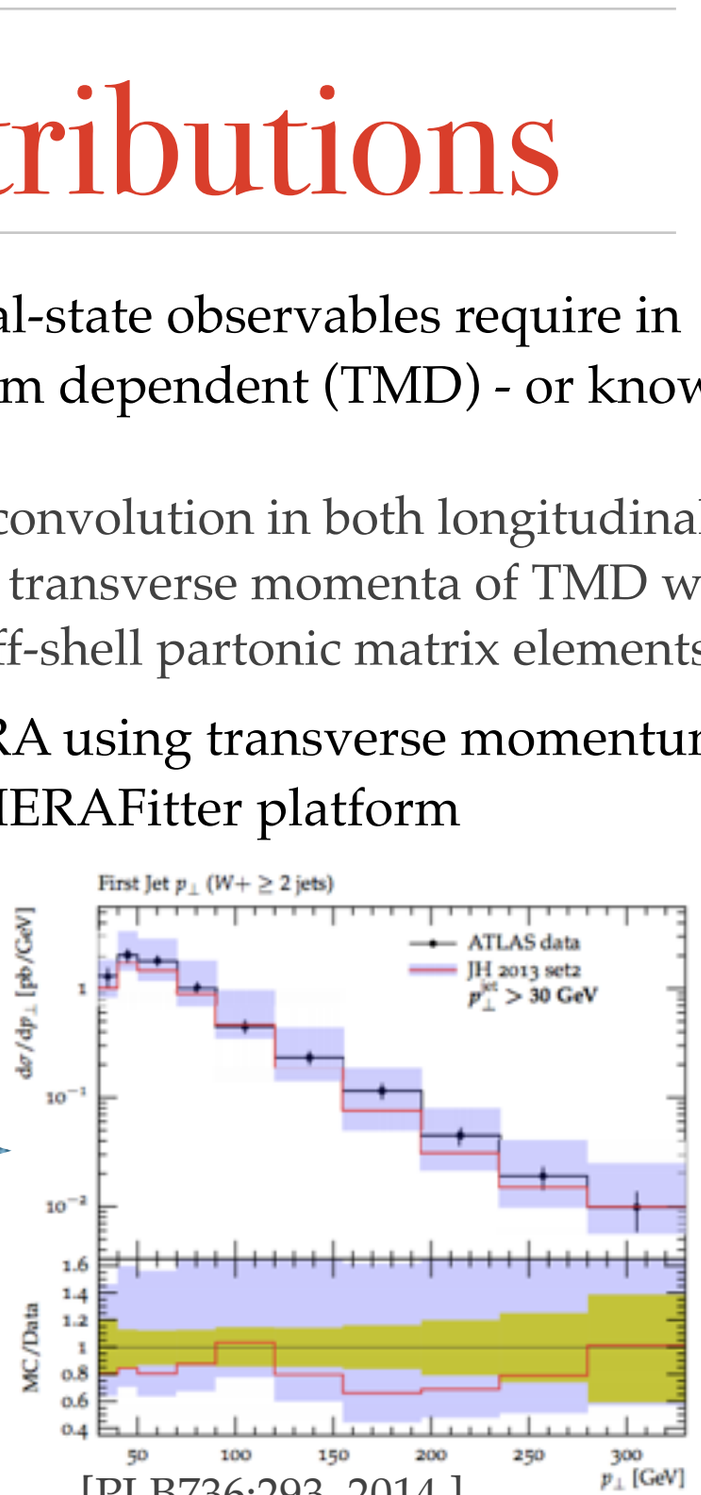
→ a convolution in both longitudinal and transverse momenta of TMD with off-shell partonic matrix elements

- Fits to combined measurements of proton's structure functions from HERA using transverse momentum dependent QCD factorisation and CCFM evolution is performed using HERAFitter platform

[Nucl. Phys. B 883, 1]





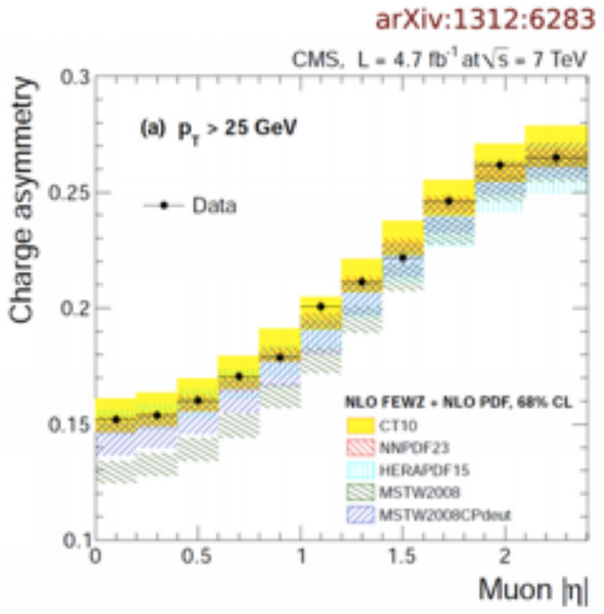


[PLB736:293, 2014.]

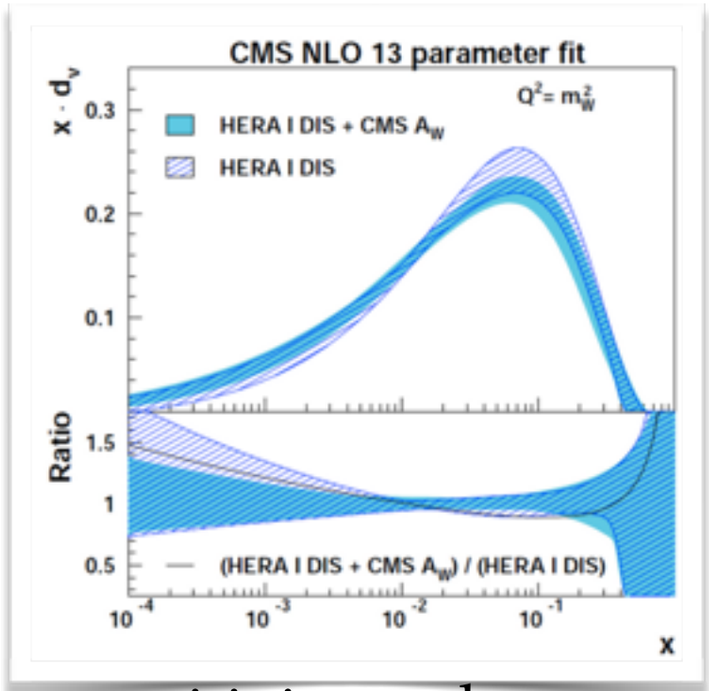
- The extracted gluon TMD with experimental and theory uncertainty [JH-2013-set1] is then used as prediction to vector boson+jet production process at the LHC [Phys. Rev. D 85 (2012) 092002.]
  - This process is important both for SM physics and for new physics searches at the LHC
  - Results compare well with the measurements of jet multiplicities and transverse momentum spectra within the pdf uncertainties

QCD interpretation of W production at CMS

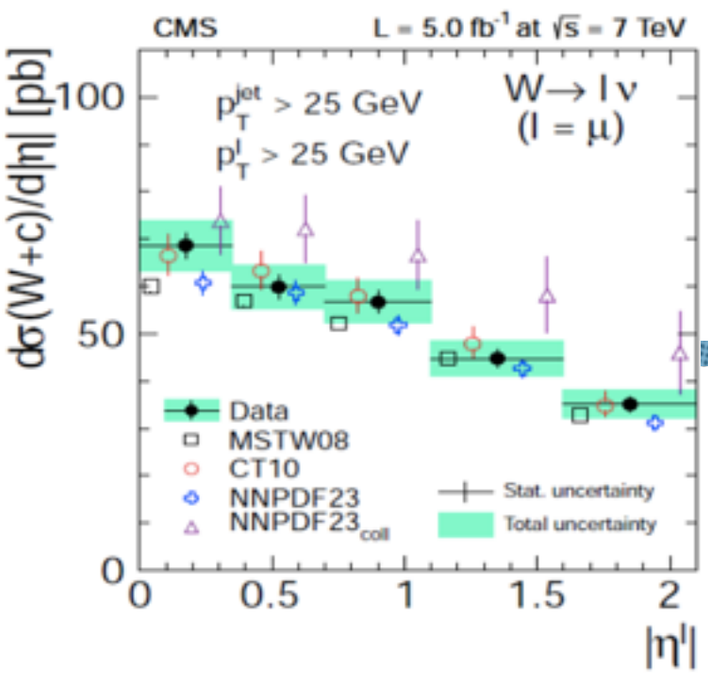
- Impact on valence PDFs from W asymmetry is investigated within the HERAFitter framework through a QCD fit analysis

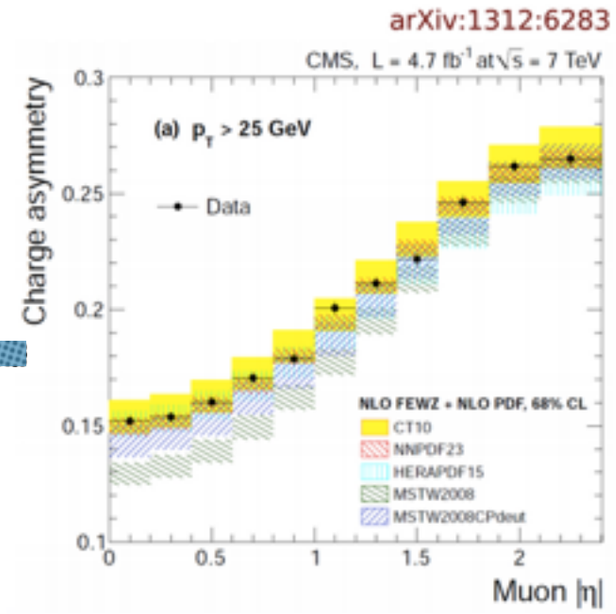


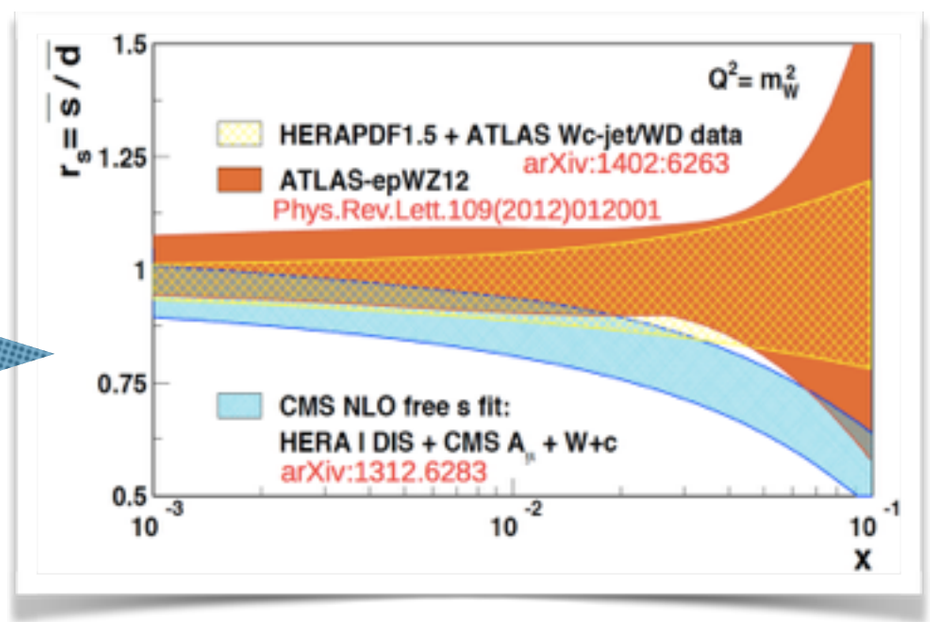
$$A_W = \frac{W^+ - W^-}{W^+ + W^-} \approx \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$



- In addition, W+charm data provides direct sensitivity to the strange quark







Studies of theoretical uncertainties of Mw mass at the LHC

ATL-PHYS-PUB-2014-015

- The measurement of the mass of the W boson provides a stringent test of the SM
- At the LHC, the best experimental precision on Mw might be achieved from the pT distribution of the charged electron/muon from leptonic decay of W:
- A quantitative study of the theoretical uncertainties due to the incomplete knowledge of the quark PDF, and to the uncertainties on the modelling of the low-pT region of W/Z bosons, was performed using HERAFitter platform.
  - Theoretical predictions is based on MCFM and CuTe (interfaced to APPLGRID)
  - A PDF set is generated using simply HERA I data to study the model variations (mc, strange) and propagated via chi2 profiling method to study the effect of PDF uncertainties