HERAFitter: Project and Related Studies

Hayk Pirumov
on behalf of the HERAFitter's developers team

Parton Distribution Functions

Parton Distribution Functions (PDFs) are of crucial for precision physics at hadron colliders because:

- ➤ PDFs limit the accuracy of the SM predictions (including Higgs)
- ➤ reach of new physics searches depends on PDF knowledge at high Bjorken-x

Factorisation theorem

- ◆ Cross section can be calculated by convoluting short distance partonic reactions (calculable in pQCD) with PDFs:

$$\sigma(\alpha_s, \mu_R^2, \mu_F^2) = \sum_{a,b} \int_0^1 \underbrace{f_a(x_1, \mu_F^2) f_b(x_2, \mu_F^2)}_{\text{PDF}} \underbrace{\hat{\sigma}(x_1, x_2; \alpha_s, \mu_R^2, \mu_F^2)}_{\text{hard-scattering ME}} + \ldots$$

- ◆ PDFs cannot be calculated in perturbative QCD, however they are process independent (universal) and their evolution with the scale is predicted by pQCD
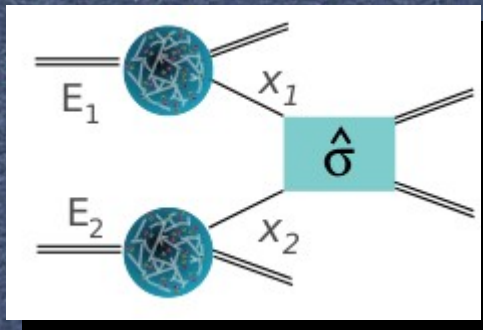
Parton Distribution Functions

Factorisation theorem: ***cross section: PDFs ⊗ hard-scattering coefficients***
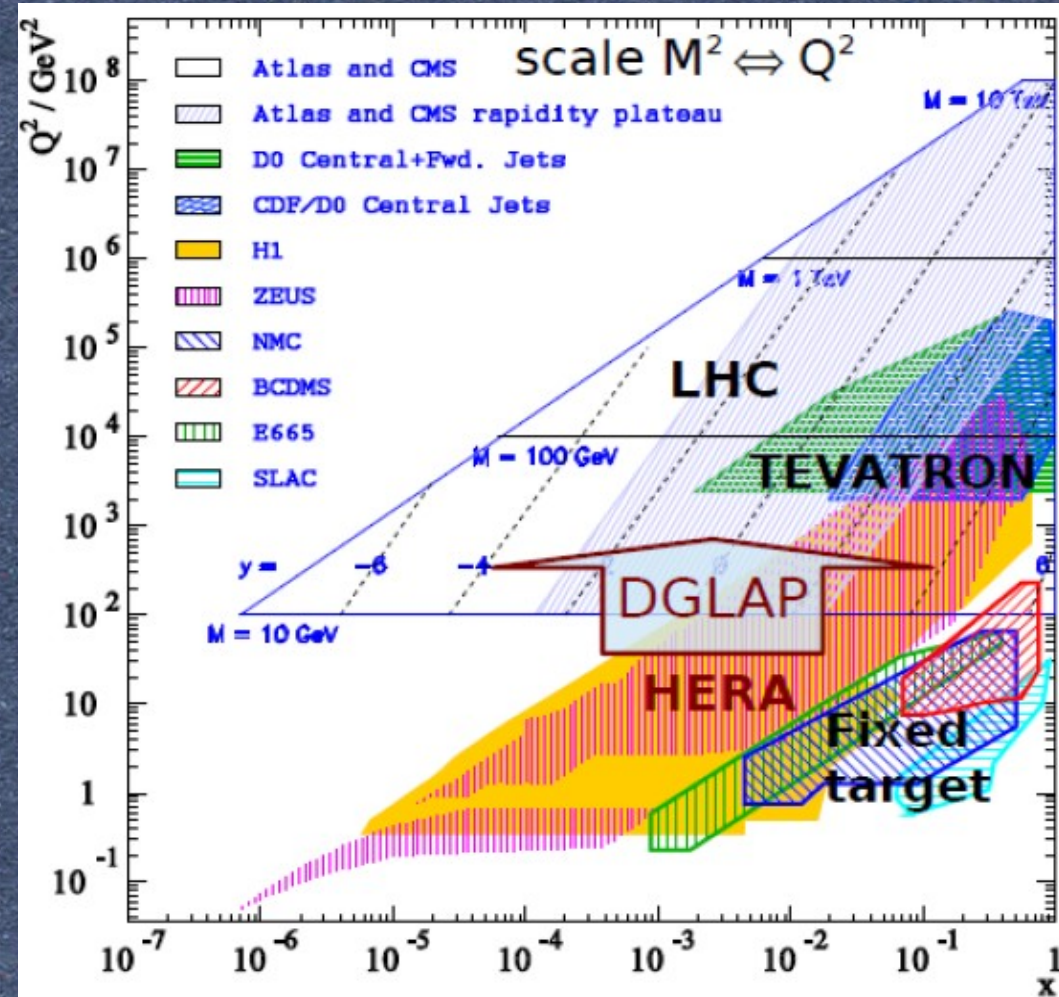
Deep Inelastic Scattering (DIS):
unique opportunity to study PDFs
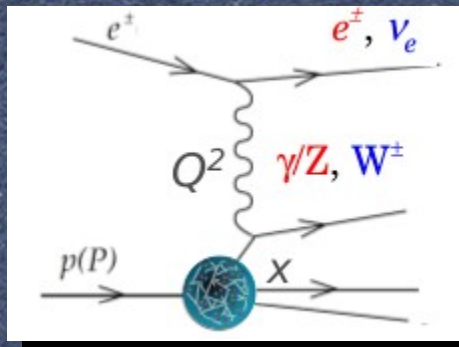
same PDFs can be used to predict
pp collisions

LHC data improve PDFs further

HERAFitter Project

HERAFitter is an open source QCD analysis tool

www.herafitter.org

Provides a framework for:

- ♦ addressing theoretical differences and benchmarking
- ♦ studying impact / consistency of new data on PDFs
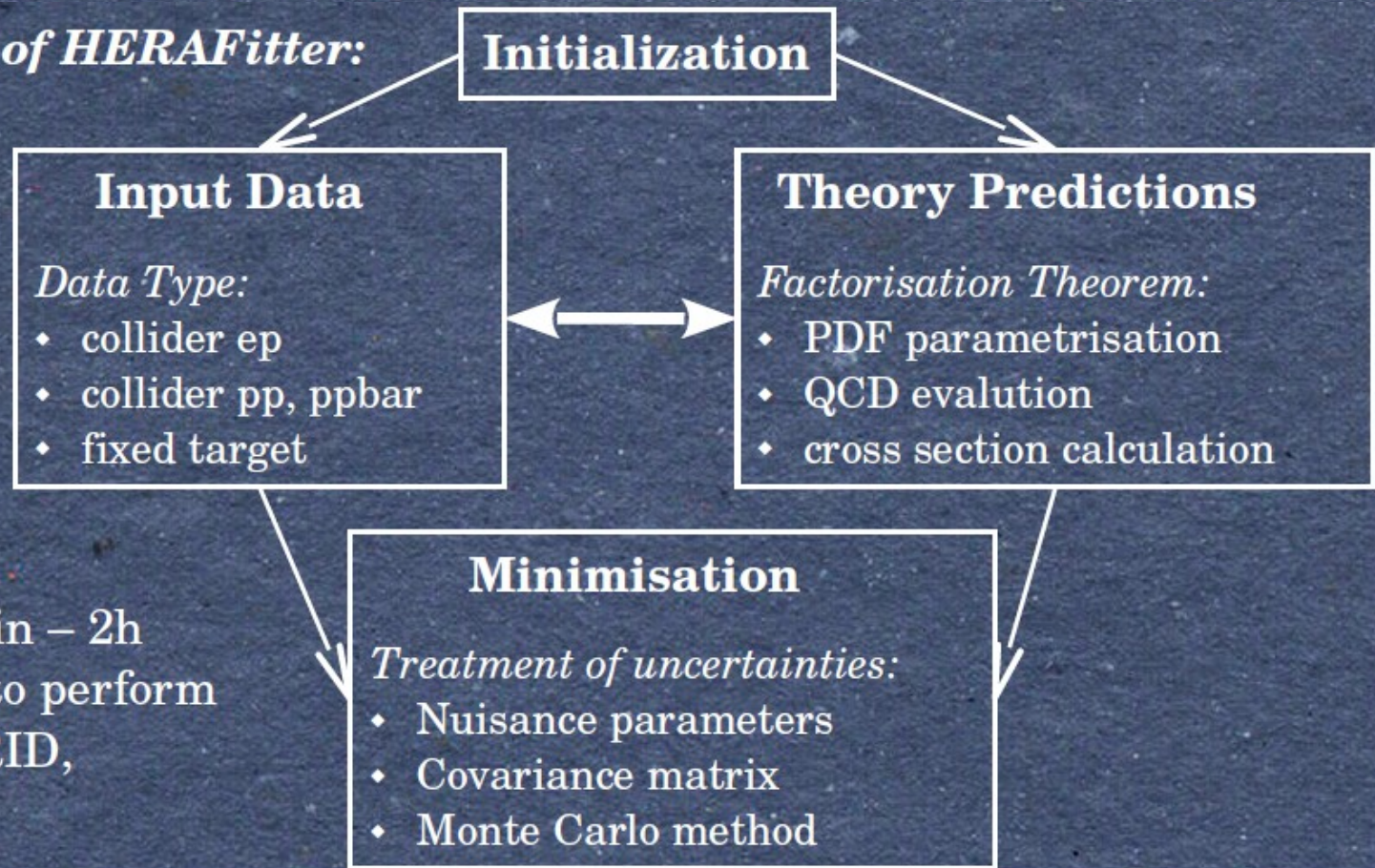
HERAFitter

Open Source QCD Fit Project

S. Alekhin[1,2] · O. Behnke[3] · P. Belov[3,4] · S. Borroni[3] · M. Botje[5] · D. Britzger[3] · S. Camarda[3] · A.M. Cooper-Sarkar[6] · K. Daum[7,8] · C. Diaconu[9] · J. Feltesse[10] · A. Gizhko[3] · A. Glazov[3] · A. Guffanti[11] · M. Guzzi[3] · F. Hautmann[12,13,14] · A. Jung[15] · H. Jung[3,16] · V. Kolesnikov[17] · H. Kowalski[3] · O. Kuprash[3] · A. Kusina[18] · S. Levonian[3] · K. Lipka[3] · B. Lobodzinski[19] · K. Lohwasser[1,3] · A. Luszczak[20] · B. Malaescu[21] · R. McNulty[22] · V. Myronenko[3] · S. Naumann-Emme[3] · K. Nowak[3,6] · F. Olness[18] · E. Perez[23] · H. Pirumov[3] · R. Plačakytė[3] · K. Rabbertz[24] · V. Radescu[3] · R. Sadykov[17] · G.P. Salam[25,26] · A. Sapronov[17] · A. Schöning[27] · T. Schörner-Sadenius[3] · S. Shushkevich[3] · W. Slominski[28] · H. Spiesberger[29] · P. Starovoitov[3] · M. Sutton[30] · J. Tomaszewska[31] · O. Turkot[3] · A. Vargas[3] · G. Watt[32] · K. Wichmann[3]

Abstract HERAFitter is an open-source package that provides a framework for the determination of the parton distribution functions (PDFs) of the proton and for many different kinds of analyses in Quantum Chromodynamics (QCD). It encodes results from a wide range of experimental measurements in lepton-proton deep inelastic scattering and proton-proton (proton-antiproton) collisions at hadron colliders. These are complemented with a variety of theoretical options for calculating PDF-dependent cross section predictions corresponding to the measurements. The framework covers a large number of the existing methods and schemes used for PDF determination. The data and theoretical predictions are brought together through numerous methodological options for carrying out PDF fits and plotting tools to help visualise the results. While primarily based on the approach of collinear factorisation, HERAFitter also provides facilities for fits of dipole models and transverse-momentum

**EPJC (2015), 75:304,   arXiv:1410.4412**

HERAFitter Structure

Modular structure of HERAFitter:

Initialization

Input Data

Data Type:
- collider ep
- collider pp, ppbar
- fixed target

$\longleftrightarrow$

Theory Predictions

Factorisation Theorem:
- PDF parametrisation
- QCD evaluation
- cross section calculation

Minimisation

Treatment of uncertainties:
- Nuisance parameters
- Covariance matrix
- Monte Carlo method

- Performance: 15min – 2h
- Fast tools needed to perform PDF fits: APPLGRID, FASTNLO

Results

- LHAPDF grids
- alphas, mc, ...
- data to theory comparison
- χ^2, shifts, pulls
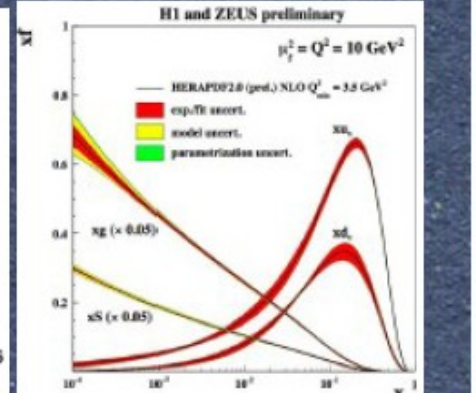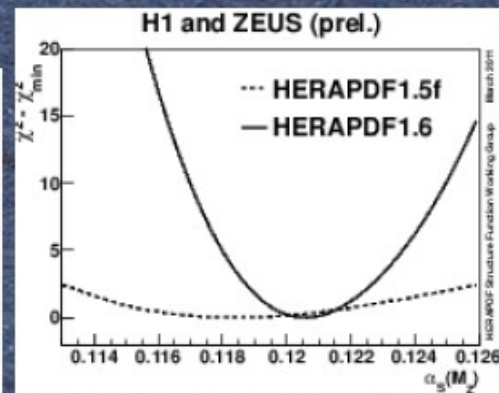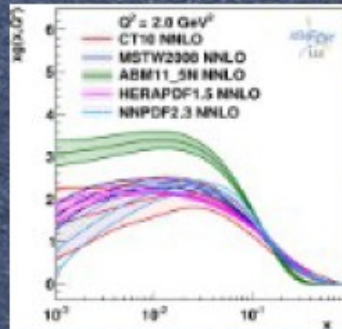
Results using HERAFitter

- 30 public results obtained using HERAFitter from the beginning of the project

- LHC experiments provide the main developments and usage of HERAFitter platform

- 3 HERAFitter publications carried out by HERAFitter developers (~30)
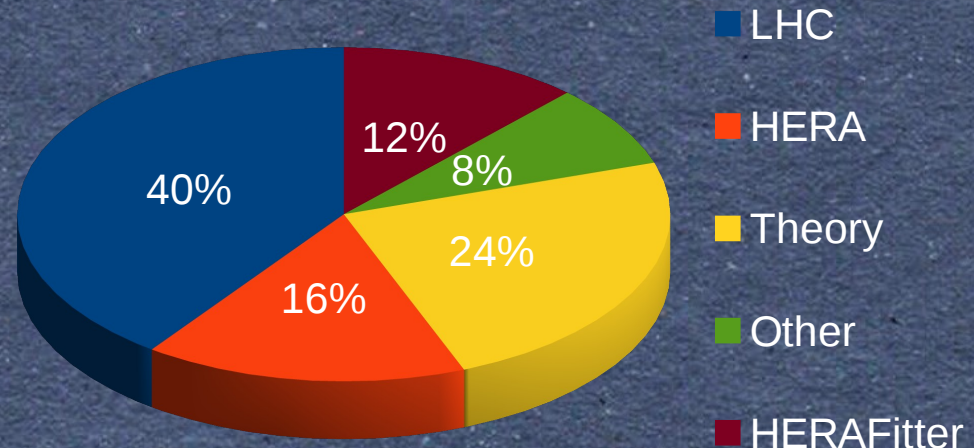
Full list of the results using HERAFitter:

https://www.herafitter.org/HERAFitter/HERAFitter/results

Highlighted Results using HERAFitter

♦ HERAFitter provides a quantitative assessment of level of agreement between data and theory by taking into account theoretical and experimental uncertainties:
  ➢ Low mass Drell-Yan, *t*-channel single top

JHEP 06 (2014) 112
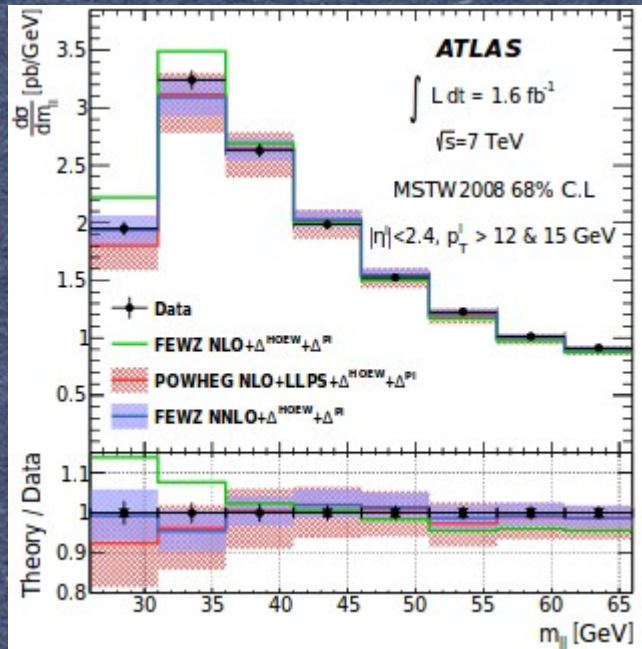
arXiv:1406.7844

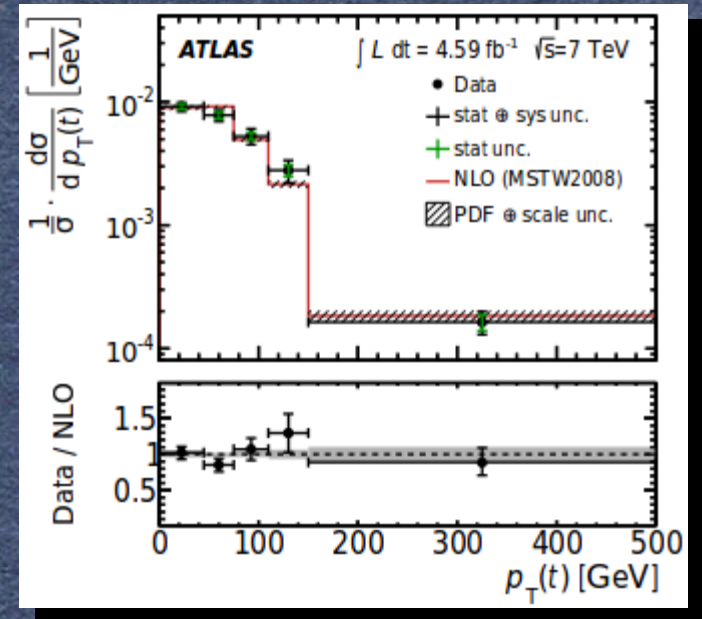| Prediction	χ^2 (8 points) Nominal
POWHEG NLO+LLPS	22.4 (19.8)
FEWZ NLO	48.7 (28.6)
FEWZ NNLO	13.9 (12.9)

TABLE VIII. Comparison between the measured differential cross sections and the predictions from the NLO calculation using the MSTW2008 PDF set. For each variable and prediction a χ^2 value is calculated with HERAfitter using the covariance matrix of each measured spectrum. The theory uncertainties of the predictions are treated as uncorrelated. The number of degrees of freedom (NDF) is equal to the number of bins in the measured spectrum.

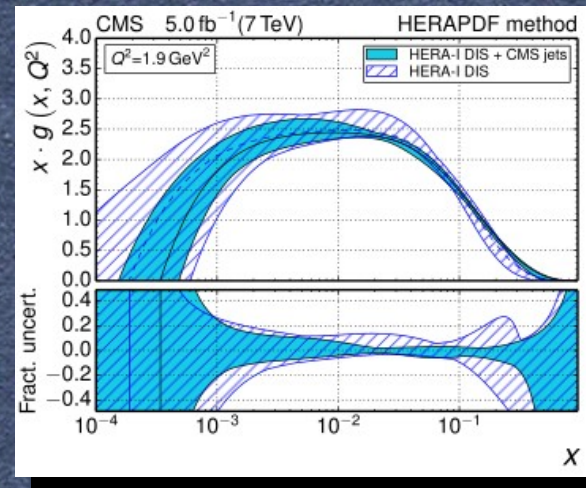|	$\frac{d\sigma}{dp_T(t)}$	$\frac{d\sigma}{dp_T(\bar{t})}$	$\frac{d\sigma}{d|y(t)|}$	$\frac{d\sigma}{d|y(\bar{t})|}$
χ^2/NDF	7.55/5	4.68/5	6.30/4	0.32/4

Highlighted Results using HERAFitter

- 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
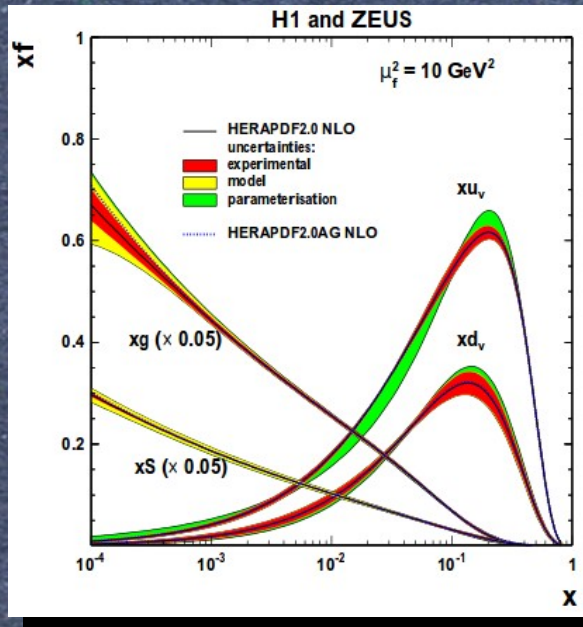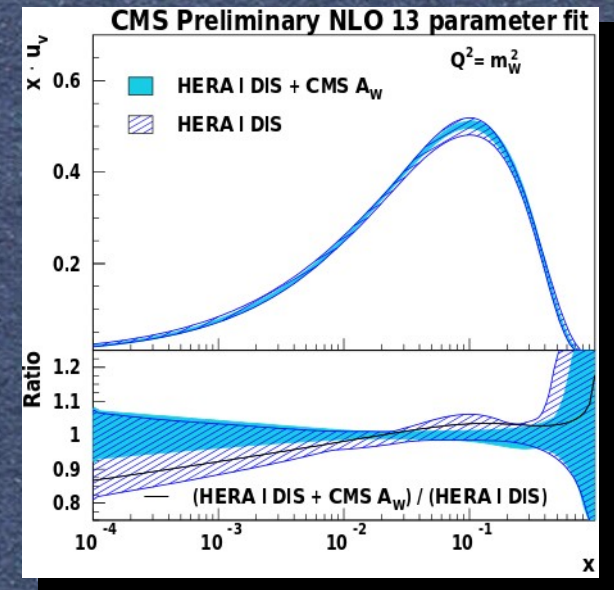
CMS PAS SMP-14-022

arXiv:1506.0604

arXiv:1410.6765

arXiv:1402.6263
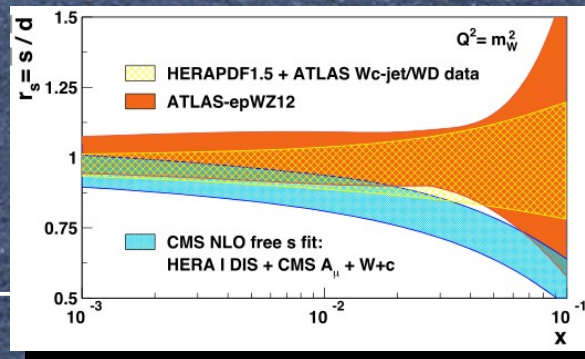
PRL 109 (2012) 012001
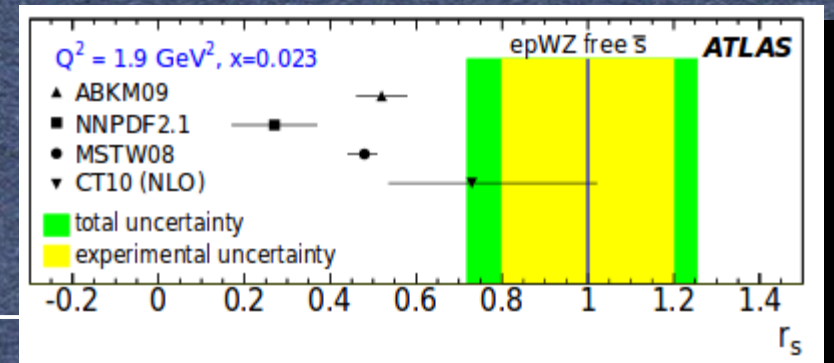
Potential impact of 13TeV data on PDFs

HERAFitter provides possibility to study the potential impact of Run II data on the current precision of PDFs using profiling method:

- Effect of data on PDF set is estimated by making a comparison of data to theoretical prediction using a χ^2 function, which treats PDF uncertainties in terms of nuisance parameters

Possible effect of inclusive W, Z and $t\bar{t}$ production measurements on global PDFs: CT10, MMHT, NNPDF3.0 is studied:

- Pseudo data is generated using uncertainties
  - similar to those of the Run I measurements (baseline scenario)
  - scaled up by factor of two (conservative scenario)
  - reduced by factor of two (aggressive scenario)
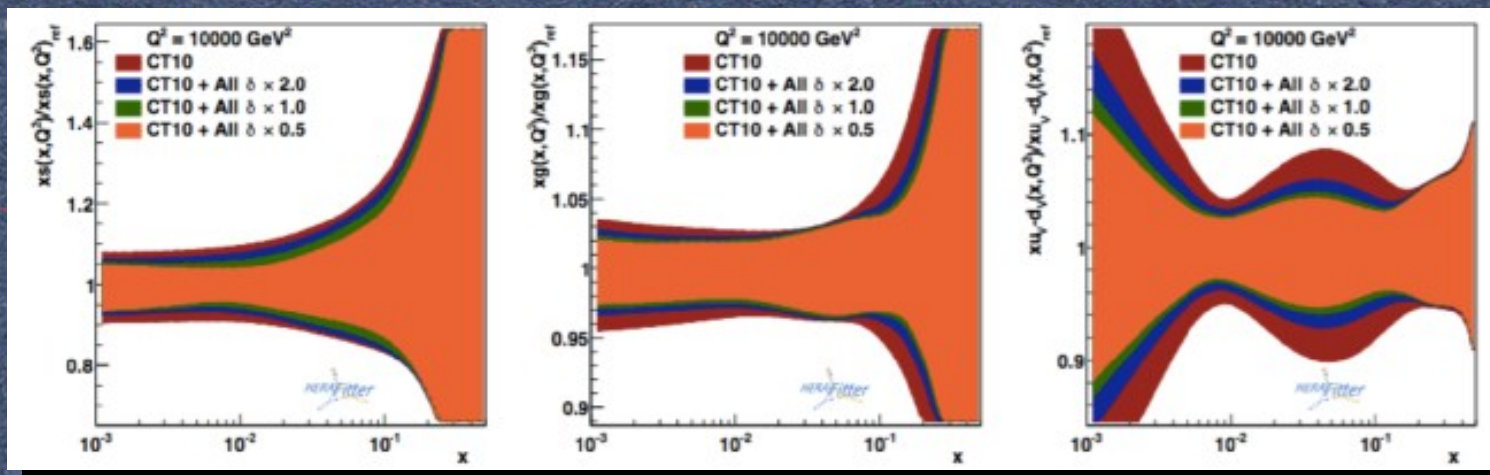
σ_W / σ_Z $\sigma_{ttbar} / \sigma_Z$ W lepton asymmetry

QCD Analysis of Tevatron W and Z data

W-charge asymmetry and Z-boson inclusive production data are studied:

| Observable	Experi-ment	Integrated luminosity	Kinematic requirements	Used in the nominal fit	Ref.
$d\sigma(Z)/dy$	D0	0.4 fb^{-1}	$71 < m_{ee} < 111$ GeV	yes	Phys Rev D 76 (2007) 012003
$d\sigma(Z)/dy$	CDF	2.1 fb^{-1}	$66 < m_{ee} < 116$ GeV	yes	Phys Lett B 692 (2010) 232
A_μ $W \to \mu\nu$	D0	7.3 fb^{-1}	$p_T^\mu > 25$ GeV, $p_T^\nu > 25$ GeV	yes	Phys Rev D 88 (2013) 091102
A_e $W \to e\nu$	D0	9.7 fb^{-1}	$E_T^e > 25$ GeV, $p_T^\nu > 25$ GeV	no	Phys Rev D 91 N3 (2015) 032007
A_W $W \to e\nu$	CDF	1.0 fb^{-1}	none	yes	Phys Rev Lett 102 (2009) 181801
A_W $W \to e\nu$	D0	9.7 fb^{-1}	$E_T^e > 25$ GeV, $p_T^\nu > 25$ GeV	yes	Phys Rev Lett 112 N15(2014)151803

A QCD Fit analysis is performed at NLO, using HERA I inclusive DIS data in simultaneous fit with Tevatron W, Z data :

- revised correlation model is used by treating the uncertainties of data-driven corrections as bin-to-bin uncorrelated: lepton ID, trigger, and charge efficiencies

Theory predictions are based on fast fixed order calculations: MCFM+APPLGRID
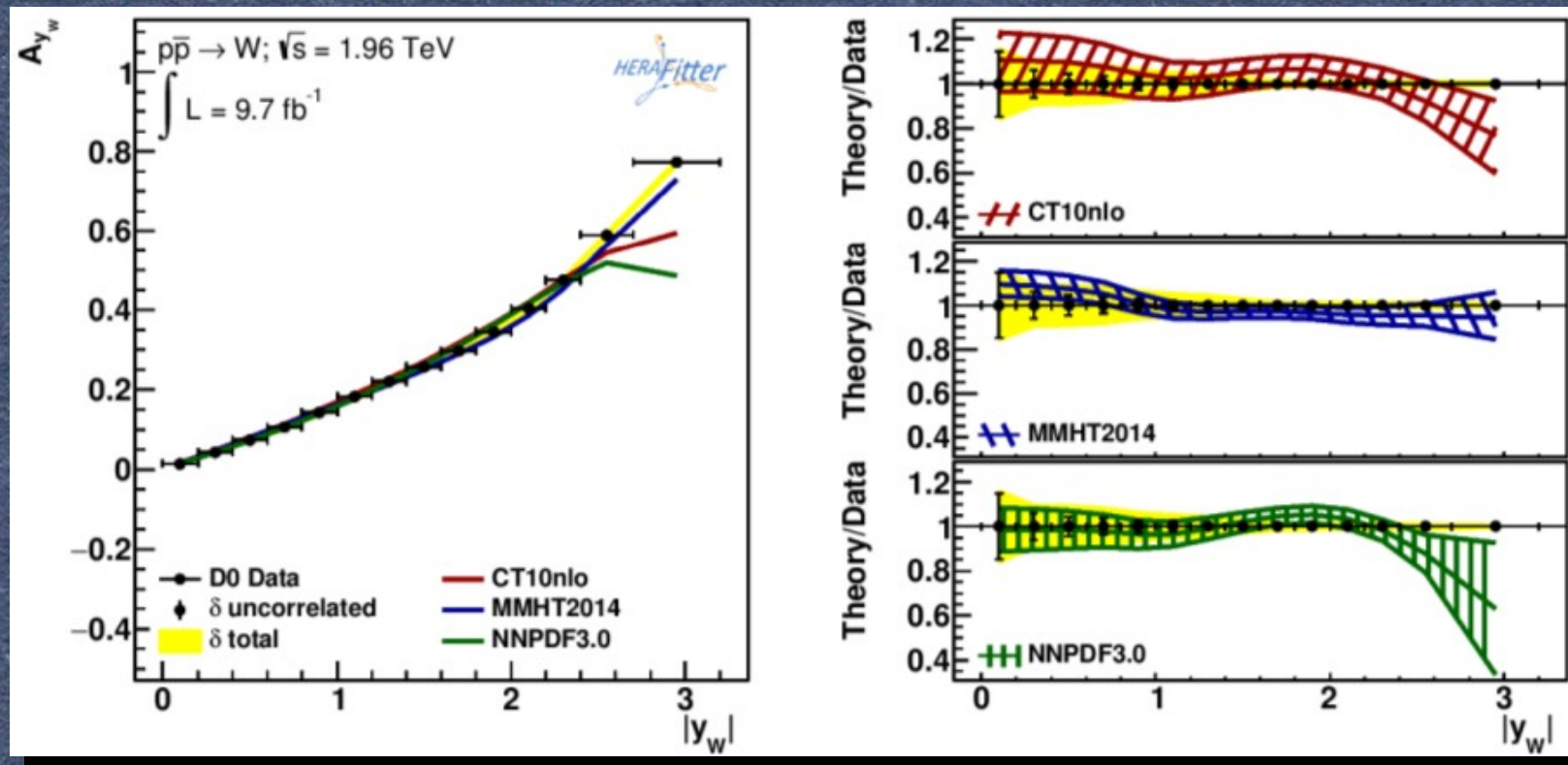
Impact on valence quarks

The Tevatron W and Z data exhibit significant impact on valence quarks relative to HERA-I data alone, especially on d-quark:
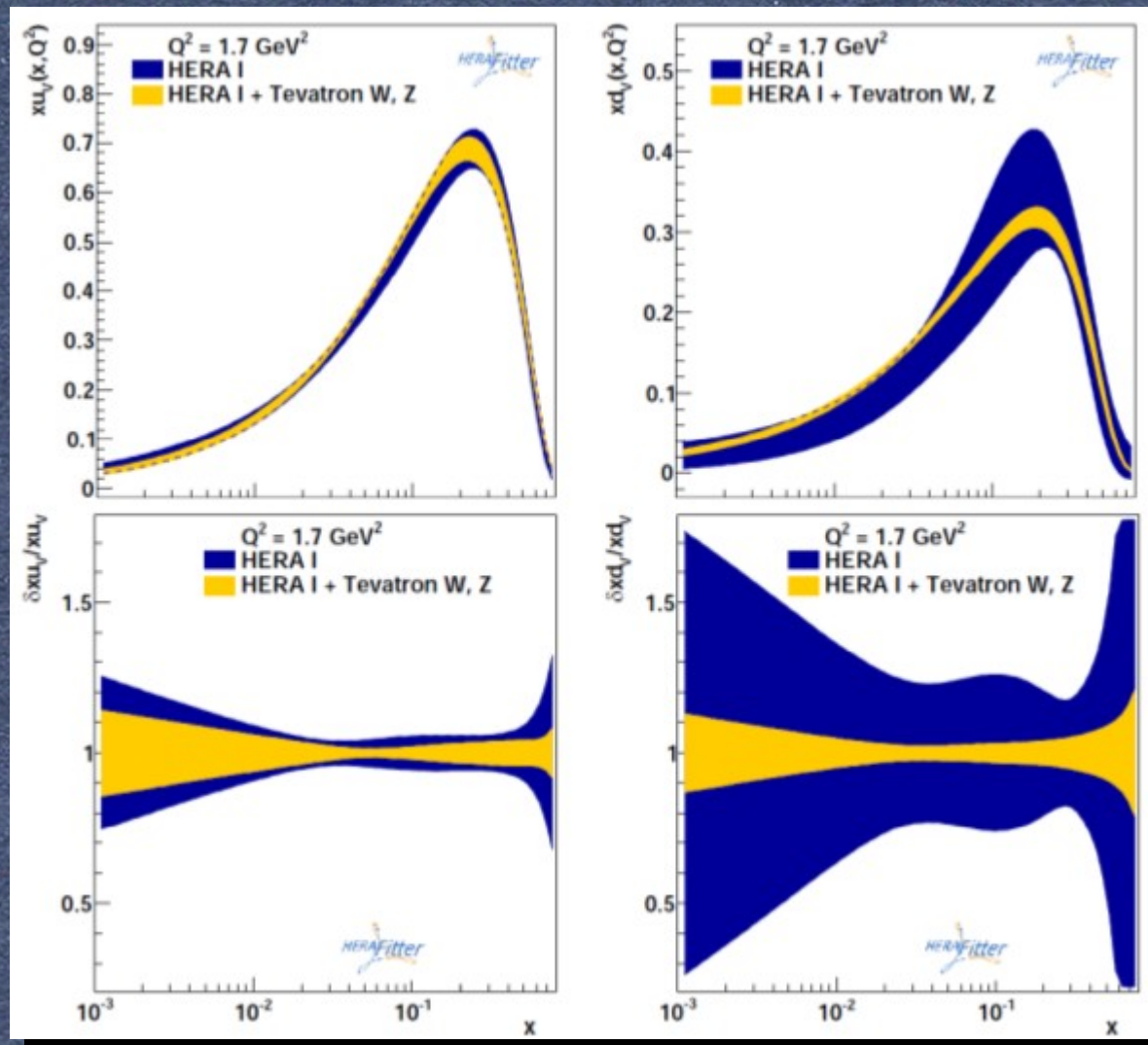
Tevatron Data vs Modern PDFs

- Test the compatibility of the Tevatron data with other global PDF sets
- Consider only the data sets which are not yet included in the PDF fits

- Good agreement between W asymmetry and NLO predictions from global PDFs

Impact of Tevatron data on PDF determination

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

- Studies performed using profiling techniques

- Note that only the measurements that are not included in the each of PDF sets are considered for the profiling
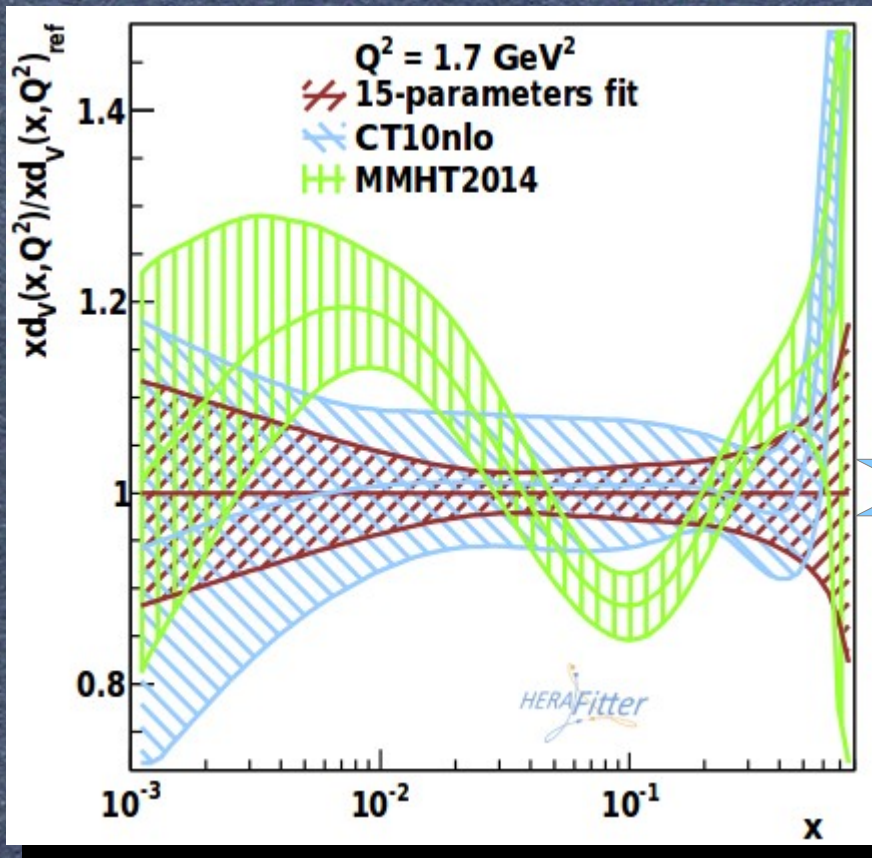
PROFILING
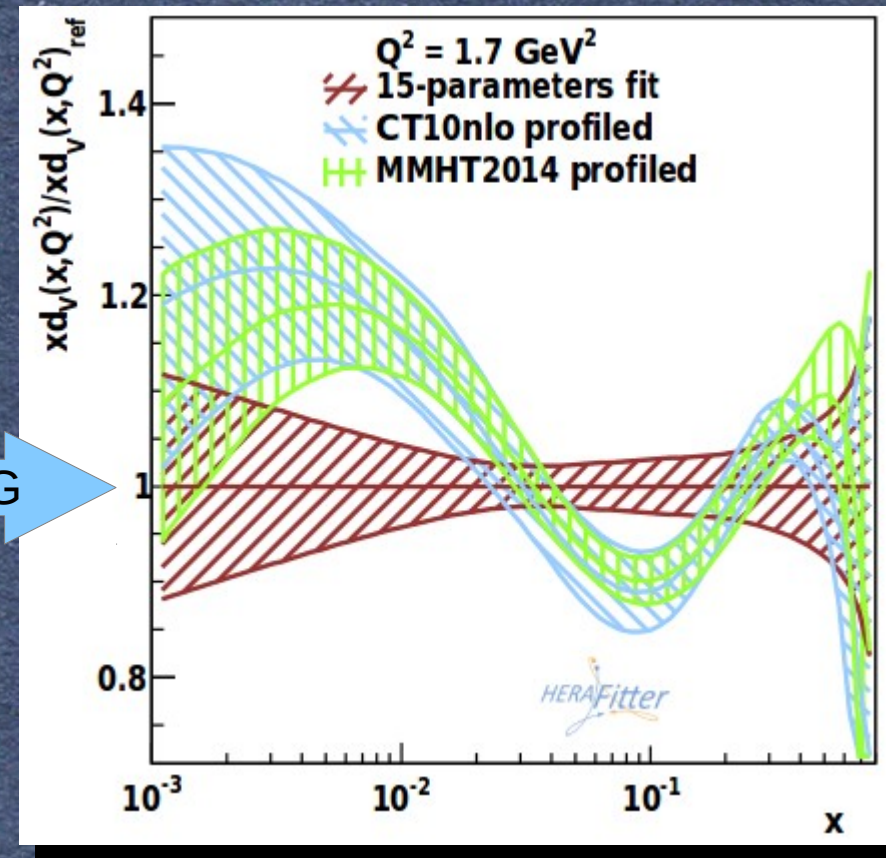
Summary

- HERAFitter project - a multi-functional QCD framework well integrated into the high energy experimental and theory communities

- HERAFitter is developing rapidly, more functionality is added frequently

- Data sets that are of a particular interest for PDFs are added to HERAFitter as soon as publicly available, together with all the available information on correlations

- General HERAFitter description paper published in **EPJC (2015), 75:304**

- **Latest release:**
  - herafitter-1.1.1, can be found at *www.herafitter.org*

- **Latest studies by HERAFitter developers:**
  - Fits and profiling studies of the recent Tevatron W, Z data show importance of them to constrain d-valence, which is essential for the W-boson mass measurement at the LHC