

News from HERAFitter

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for HERAFitter team



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Motivation

The proton PDFs are the crucial ingredient in calculation of hadronic interactions:

- According to factorization theorem, the hadronic cross section is a convolution of PDFs and hard-scattering cross sections
- Due to their non-perturbative nature the PDFs are subject to empirical determination

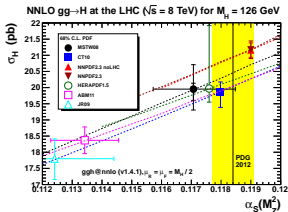
$$\sigma \approx \hat{\sigma} \otimes \text{PDF}$$

PDFs are universal:

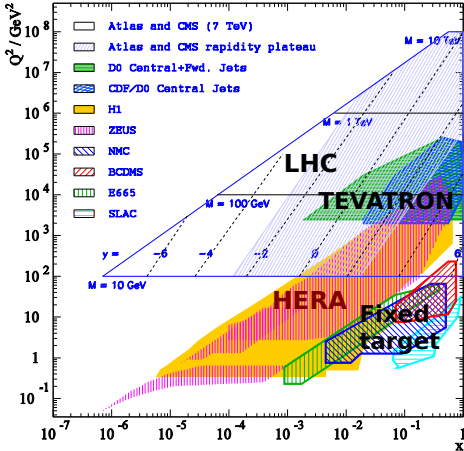
- Essential ingredients of precision theoretical predictions for the LHC
- Dominant uncertainty in the SM Higgs cross section, M_W measurements, predictions for high scale BSM production etc.

Different extraction methods and input datasets used by global PDF fitting groups (CT, MSTW, NNPDF, HERAPDF, ABM, JR) generate additional uncertainty.

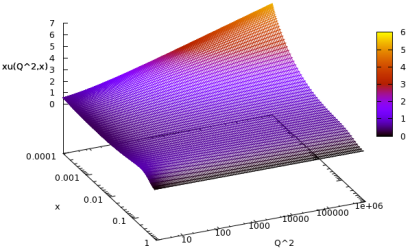
arXiv:1301.6754[hep-ph]



PDF kinematic coverage

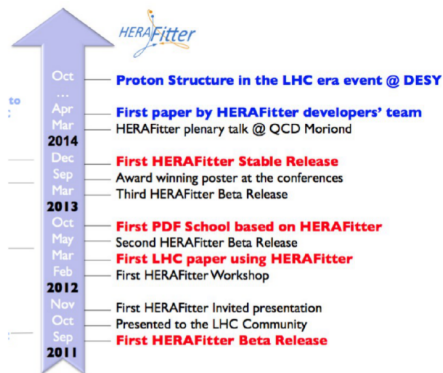


- The PDFs are measured as a function of momentum fraction x and scale Q^2
- The larger range of x is covered the better
- Higher values of Q^2 are accessed via DGLAP evolution



HERAFitter project

HERAFitter is an open source QCD fit platform allowing to:

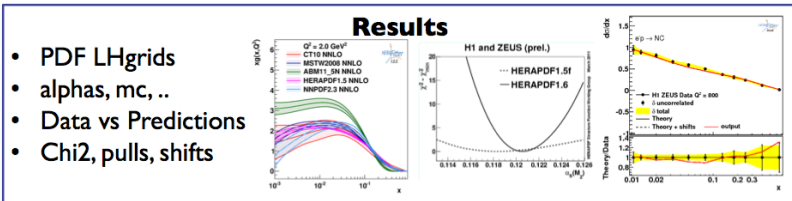
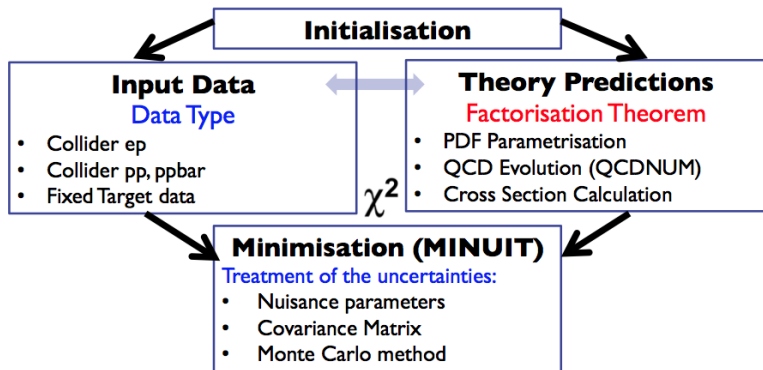


- Perform QCD analysis of proton structure using experimental data
- Extract and improve precision of the PDFs
- Assess impact of the new data on PDF determination
- Check experimental data consistency
- Test different theoretical approaches to the proton structure description

The project is developed and maintained by ~ 30 developers from HERA and LHC experiments and theorists.

www.herafitter.org

Structure of the HERAFitter package



Input data and available processes

Experimental Data	Process	Reaction
HERA Fixed Target	DIS NC	$ep \rightarrow eX$
HERA	DIS CC	$ep \rightarrow \nu_e X$
	DIS jets	$ep \rightarrow e \text{ jets} X$
	DIS heavy quarks	$ep \rightarrow ec\bar{c}X$ $ep \rightarrow eb\bar{b}X$
Tevatron LHC	Drell-Yan	$pp(\bar{p}) \rightarrow l\bar{l}X$ $pp(\bar{p}) \rightarrow l\nu X$
	top pair	$pp(\bar{p}) \rightarrow t\bar{t}X$
	single top	$pp(\bar{p}) \rightarrow t\nu X$ $pp(\bar{p}) \rightarrow tX$ $pp(\bar{p}) \rightarrow tWX$
	jets	$pp(\bar{p}) \rightarrow \text{jets} X$
LHC	DY+heavy quarks	$pp \rightarrow VhX$

A number of datasets from ep , pp and $p\bar{p}$ colliders can be used in the HERAFitter to constrain proton PDFs in various kinematic domains

HERAFitter functionality: PDFs parametrisation

Different forms of parametrisation are realized in HERAFitter:

- Standard Polynomial Forms (HERAPDF, MSTW, ABM)

$$xf_j(x) = A_j x^{B_j} (1-x)^{C_j} P_i(x)$$

- Bi-Log-Normal

$$xf_j(x) = a_j x^{p_j - b_j \log(x)} (1-x)^{q_j - d_j \log(1-x)}$$

- Chebyshev Polynomials

$$xg(x) = A_g (1-x) \sum_{i=0}^{N_g-1} A_{g_i} T_i \left(-\frac{2 \log x - \log x_{\min}}{\log x_{\min}} \right),$$

$$xS(x) = (1-x) \sum_{i=0}^{N_S-1} A_{S_i} T_i \left(-\frac{2 \log x - \log x_{\min}}{\log x_{\min}} \right)$$

- Hybrid Forms

HERAFitter functionality: PDFs evolution

QCD evolution:

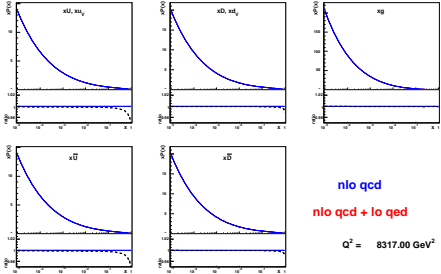
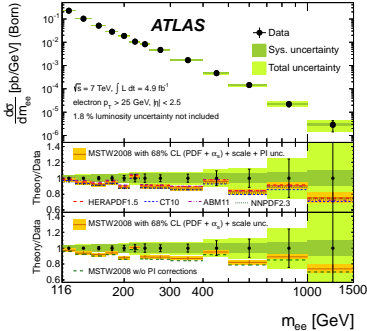
- **DGLAP formalism** (performed with QCDNUM with different schemes of heavy quark treatment):
 - VFNS: RT(MSTW), ACOT(CTEQ)
 - FFNS (pole and running mass)
- **non-DGLAP formalism:**
 - Dipole models (GBW, IIM, BGK) — an alternative approach to the low- x region
 - Unintegrated PDFs (CCFM evolution)

QCD+QED evolution ([under development](#)):

- **QED-modified DGLAP** (performed with new beta version of QCDNUM)

QED-modified PDFs

- Recent studies on high mass Drell-Yan production in ATLAS [arXiv:1305.4192] has shown that the size of the photon-induced contribution ($\gamma\gamma \rightarrow e^+e^-$) is as large as the uncertainties arising from the different choice of PDF set



- The possibility of QED fits in HERAFitter will be realized with new version of QCDNUM programm and APPLGRID interface to SANC MC generator for $\gamma\gamma \rightarrow e^+e^-$ process

HERAFitter functionality: χ^2 , uncertainty

Several types of χ^2 definitions can be used (D - data, T -theory):

- nuisance parameters:

$$\chi^2 = \sum_i \frac{(D_i - T_i^*)^2}{(\delta_{unc}^2)}, \quad T_i^* = T_i + \sum_j \xi_j \delta_i^{cor,j}$$

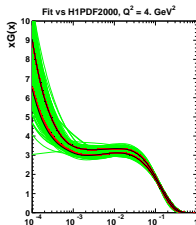
- covariance matrix:

$$\chi^2 = \sum_{i,j} (D_j - T_j) Cov_{i,j}^{-1} (D_i - T_i)$$

- their mixture

Various types of uncertainty treatment for experimental data:

- Hessian: nuisance parameters are fitted, χ^2 tolerance > 1 can also be used to account for marginally compatible input data sets
- Offset method: nuisance parameters are applied as 1σ shifts
- Monte Carlo: data points are shifted randomly within 1σ limits to form MC replicas

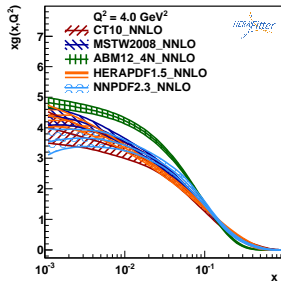
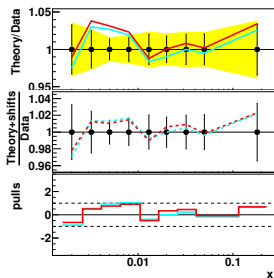
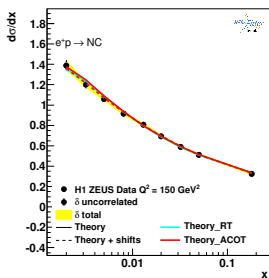


HERAFitter functionality: output

The resulting PDFs are provided in a format ready to be used by the LHAPDF library (both V5 and V6)

HERAFitter drawing tools can be used to display the PDFs with their uncertainties at a chosen scale:

- Plot and compare PDFs (via LHAPDF)
- Compare different PDF sets to data
- Estimate agreement using χ^2 criteria



Results with HERAFitter

List of analyses by HERAFitter

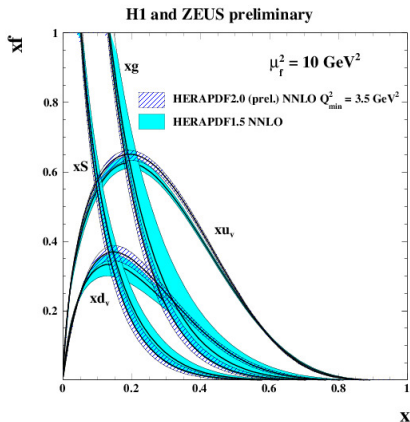
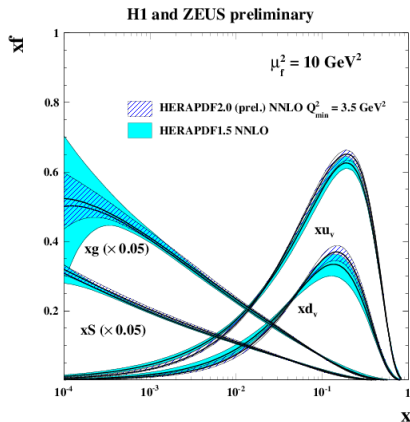
new 04.2014 **HERAFitter team** arXiv:1404.4234 [Parton distribution functions at LO, NLO and NNLO with correlated uncertainties between orders](#) [Material](#)

List of analyses using HERAFitter

Date	Group	Reference	Title
new 05.2014	HERA/ZEUS	arxiv:1405.6915	• Measurement of beauty and charm production in deep inelastic scattering at HERA and measurement of the beauty-quark mass
new 05.2014	ggH benchmark HERAPDF, CT, NNPDF, MSTW	arxiv:1405.1067	• Les Houches 2013: Physics at TeV Colliders: Standard Model Working Group Report
new 04.2014	LHC/ATLAS	arXiv:1404.1212	• Measurement of the low-mass Drell-Yan differential cross section at $\sqrt{s}=7$ TeV using the ATLAS detector
02.2014	LHC/ATLAS	arXiv:1402.6263	• Measurement of the production of a W boson in association with a charm quark in pp collisions at $\sqrt{s}=7$ TeV with the ATLAS detector
01.2014	R. Sadykov	arXiv:1401.1133	• Impact of QED radiative corrections on Parton Distribution Functions
01.2014	F. Hautmann and H. Jung	arXiv:1312.7875	• Transverse momentum dependent gluon density from DIS precision data
12.2013	M. Klein, V. Radescu (LHeC studies)	arXiv:1310.5189	• Report of the Snowmass 2013 energy frontier QCD working group
12.2013	A. Luszczak and H. Kowalski	arXiv:1312.4060	• Dipole model analysis of high precision HERA data
12.2013	LHC/ATLAS	ATL-PHYS-PUB-2013-018	• A study of the sensitivity to the proton parton distributions of the inclusive photon production cross section in pp collisions at 7 TeV measured by the ATLAS experiment at the LHC
12.2013	LHC/CMS	PRD 90 (2014) 032004 / arXiv:1312.6283	• Measurement of the muon charge asymmetry in pp W production at 7 TeV
12.2013	LHC/CMS	CMS-SMP-12-028	• PDF constraints and extraction of the strong coupling constant from the inclusive jet cross section at 7 TeV
2013	LHC/ATLAS	Phys. Lett. B 725 (2013) pp. 223	• Measurement of the high-mass Drell-Yan differential cross-section in pp collisions at $\sqrt{s}=7$ TeV
2013	LHC/ATLAS	EPJC (2013) 73 2509	• Measurement of the inclusive jet cross section in pp collisions at $\sqrt{s} = 2.76$ TeV and comparison to the inclusive jet cross section at $\sqrt{s} = 7$ TeV using the ATLAS detector
2013	LHC/ATLAS	Phys.Rev.Lett. 109 (2012) 012001	• Determination of the strange quark density of the proton from ATLAS measurements of the $W \rightarrow l \nu$ and $Z \rightarrow ll$ cross sections
2013	HERA/H1 and ZEUS	Eur. Phys. J. C73 (2013) 2311	• Combination and QCD Analysis of Charm Production Cross Section Measurements in Deep-Inelastic ep Scattering at HERA
2012	HERA/H1	JHEP 09 (2012) 061	• Inclusive Deep Inelastic Scattering at High Q^2 with Longitudinally Polarised Lepton Beams at HERA
2012	LHeC	J.Phys. G39 (2012) 075001	• A Large Hadron Electron Collider at CERN: Report on the Physics and Design Concepts for Machine and Detector

HERAPDF set

Combined HERA I+II data is used for PDF extraction



Data combination was performed using HERAverager

wiki-zeuthen.desy.de/HERAverager

Strange quark at the LHC

- W^\pm and Z^0 inclusive cross sections were used by ATLAS to determine the strange quark fraction in the sea

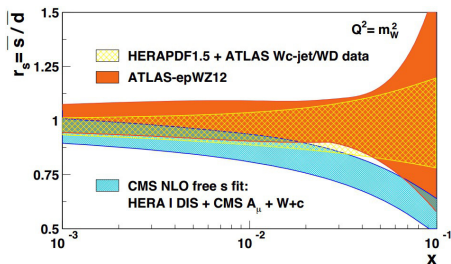
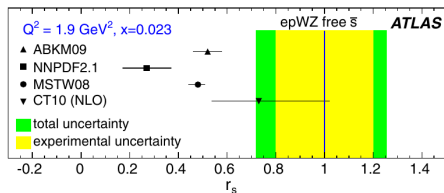
Phys. Rev. Lett. 109 (2012) 012001

- W + charm data including W asymmetry were used to measure the strange quark distribution

PRD 90 (2014) 03200

- W + charm data were used by ATLAS to determine the ratio of the strange-to-down sea quark distribution

arXiv:1402.6263



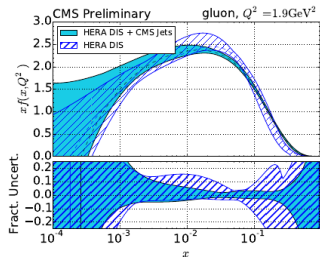
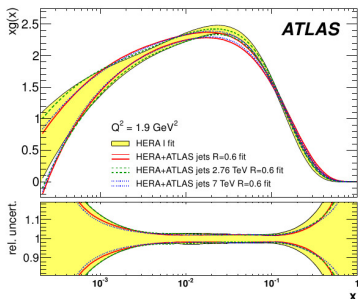
Gluon density measurements at the LHC

- Inclusive jet cross sections measured at different CMEs were exploited to study the sensitivity to gluon density both at high and low x

Eur. Phys. J. C73 (2013) 2509

- CMS Jet data were used to probe the gluon distribution and extract the α_s

CMS-PAS-SMP-12-028



PDFs at LO, NLO, NNLO and correlated errors

- Predictions for various processes at LHC are available at different orders in pQCD
- Theoretical uncertainties on predicted cross sections arise from PDFs and from missing higher orders (estimated by varying factorisation and renormalisation scales)
- To reduce uncertainties, ratios of two processes cross sections can be used. Assume that for the first process both NLO and NNLO calculations exist, while for the second process only NLO. Theoretical predictions can be constructed in several ways:

$$\frac{\sigma_1^{NLO}(PDF^{NLO})}{\sigma_2^{NLO}(PDF^{NLO})}$$

✓ cancellation of PDF unc.

✗ large scale unc.

$$\frac{\sigma_1^{NNLO}(PDF^{NNLO})}{\sigma_2^{NLO}(PDF^{NLO})}$$

✗ PDF unc. do not cancel

✓ scale unc. reduced

$$\frac{\sigma_1^{NNLO}(PDF^{NNLO})}{\sigma_2^{NLO}(PDF^{NNLO})}$$

✓ PDF unc. cancel

✓ improved scale unc.

✗ unclear definition in pQCD

$$\frac{\sigma_1^{NNLO}(PDF_{corr}^{NNLO})}{\sigma_2^{NLO}(PDF_{corr}^{NLO})}$$

✓ PDF unc. cancel

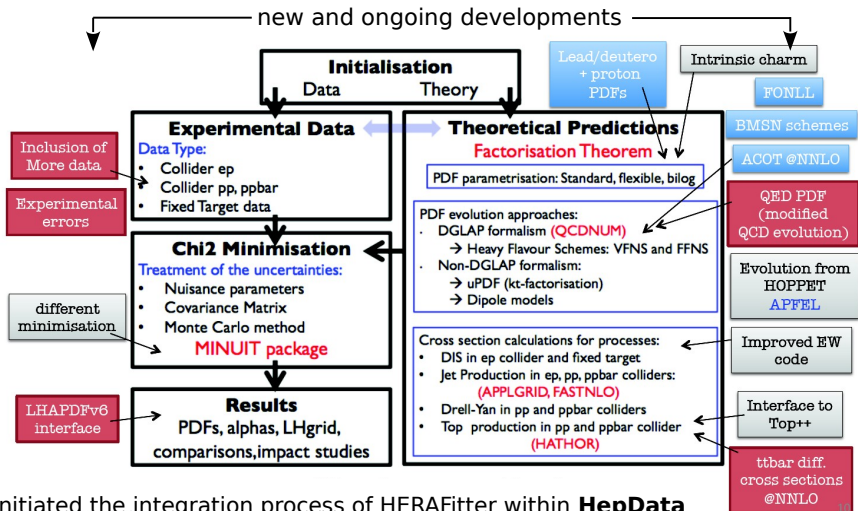
✓ scale unc. reduced

- Monte Carlo replica method is used to determine experimental uncertainties of PDFs and to preserve correlation between LO, NLO, and NNLO

[arXiv:1404.4234](https://arxiv.org/abs/1404.4234)[hep-ph]

Future developments

The **new release** is expected this autumn. Some of the following developments will be implemented:



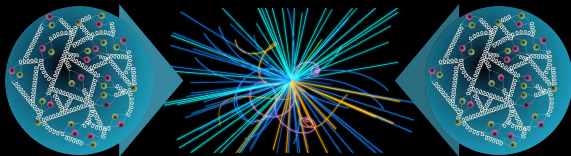
Initiated the integration process of HERAFitter within **HepData**

Proton structure in the LHC era

29 September - 02 October 2014

DESY Hamburg

Proton Structure in the LHC Era



School on phenomenology of proton-proton interactions

Lectures

Enhancing discovery potential: QCD precision measurements at the LHC	A. Cooper-Sarkar
The tricky part of the factorization: Parton Distribution Functions	D. Soper
Determination of strong coupling constant and PDFs	G. Dissertori
The precise part of the factorization: theory calculations at NLO and NNLO	M. Schulze
Jets in hadron collider at highest order	N. Glover
The number of flavors and the quark masses	S.-O. Moch

Tutorials in HERAFitter, fastNLO, Applgrid, Difftop, NNPDF reweighting:

D. Britzger, S. Camarda, A. Glazov, A. Guffanti, M. Guzzi, K. Lohwasser,
H. Pirumov, R. Plačakytė, K. Rabbertz, V. Radescu, P. Starovoitov

Workshop 01-02 October 2014

on theory and experimental issues in determination of PDFs and QCD parameters

Summary

- The HERAFitter project provides tools for QCD analysis of experimental data obtained at colliders
- The first stable release **HERAFitter-1.0.0** became available in December 2013 and can be downloaded from www.herafitter.org
- The package uses advanced uncertainty correlation treatment and contemporary higher order calculation approaches. A versatile plotting tool makes results inspection easy
- A number of results have been obtained using the HERAFitter package, including proton strange and charm density determination based on HERA and LHC data
- A new release version **HERAFitter-1.0.1** is under preparation and will be made available by the end of September
- You are welcome to attend Proton structure in the LHC era school and workshop on 29.09 – 02.10 at DESY Hamburg (www.terascale.de/pdf2014)