PROCEEDINGS OF SCIENCE

HERAFitter - an open source QCD Fit platform

Hayk Pirumov[*†]
DESY (Deutsches Elektronen-Synchrotron)
E-mail: hayk.pirumov@desy.de

The first stable release of the HERAFitter package is presented. HERAFitter is an open source project which provides a framework for QCD analyses in the context of multi-process and multi-experiment settings, bridging the state-of-the-art theory developments with an appropriate treatment of the precise experimental measurements. The HERAFitter program allows determination of the PDFs from the various measurements of the cross sections at ep, pp or $p\bar{p}$ colliders. It includes various options for theoretical models and different choices to account for the experimental uncertainties. Therefore, this project represents not only an ideal environment for benchmarking studies, but also a support for the QCD interpretation of data analyses within the LHC experiments, as already demonstrated by several publicly available LHC results using the HERAFitter framework.

XXII. International Workshop on Deep-Inelastic Scattering and Related Subjects,
28 April - 2 May 2014
Warsaw, Poland

[*] Speaker.
[†] On behalf of HERAFitter developers' team.

PoS(DIS2014)045

1. Introduction

Increasing accuracy of the experimental measurements at the LHC makes the uncertainties of proton's parton distribution functions (PDFs) play dominant role for the precision tests of the Standard Model (SM), such as measurements of the electroweak mixing angle and the W boson mass. PDF uncertainties are one of the dominating uncertainties in Higgs production and they substantially affect the theory predictions for beyond SM high mass production. This platform also provides the basis for comparisons of different theoretical approaches and can be used for direct tests of the impact of new experimental data in the QCD analysis.

`HERAFitter` is an open source project [1] which provides a framework for QCD analysis of hadron-induced processes and determination of PDFs as well as extraction of fundamental QCD parameters such as the heavy quark masses or strong coupling constant.

2. HERAFitter project

2.1 Structure

In `HERAFitter` the extraction of the PDFs is based on factorisation theorem, according to which, the hard-scattering cross section is a convolution product of the PDFs and the putatively cacalculable hard scattering coefficients. The PDFs are usually extracted from the QCD fits by measure of agreement between data from various processes and theory models. The functionality

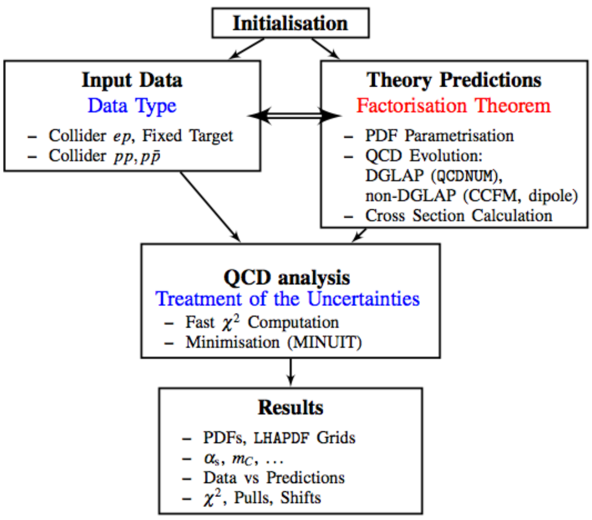

Figure 1: Schematic structure of the `HERAFitter` program.

of `HERAFitter` is schematically illustrated in Fig. 1.

Input data: Different available measurements from the various processes are implemented in the `HERAFitter` package with the full information on their uncorrelated and correlated uncertainties.

Theory predictions: The PDFs are parametrised at a starting input scale Q_0^2 by a chosen functional form with a set of free parameters, which are then evolved [2] to the scale of the measurement Q^2. The prediction of a particular process cross section is calculated at a certain order in QCD using relevant theory program.

QCD analysis: The PDFs are determined by minimising the χ^2 function with respect to free PDF parameters using the MINUIT [3] program. The experimental uncertainties are taken into account, either using a nuisance parameter method for the correlated systematic uncertainties, or a covariance matrix method.

Results: The resulting PDFs are provided in format of `LHAPDF` [4]. `HERAFitter` drawing tools can be used to display the PDFs with their uncertainties at a chosen scale. The comparison of data used in the fit to the theory predictions are also produced.

2.2 Functionality

All main experimental data sets relevant for PDFs can be fitted within the `HERAFitter` framework. In case of inclusive cross sections from HERA DIS and fixed target experiments the structure functions can be calculated in different heavy flavour schemes, i.e. fixed-flavour (FFN) or variable flavour number (VFN) schemes. The VFN schemes available in `HERAFitter` framework are Thorne Roberts (TR) scheme at LO, NLO and NNLO as provided by the MSTW group, the ACOT scheme at LO and NLO as provided by the CTEQ group. Drell Yan *pp* processes are accessed in `HERAFitter` either using calculations at LO and NLO based on *k*-factor technique or grid technique (i.e. APPLGRID or FastNLO). Applgrid and FastNLO can also be used as fast input to NLO jet cross sections.

Various functional forms to parametrise the PDFs at the starting scale are implemented in the `HERAFitter` package. Currently available are simple polynomials, bi-log normal function and chebyshev polynomials. The `HERAFitter` package provides access to external PDFs via `LHAPDF` library. asic plotting tools for visualising fit results are also included in the `HERAFitter`.

3. Results obtained using HERAFitter

The HERAFitter framework is actively used by HERA and LHC experiments. At the LHC, QCD analysis based on the `HERAFitter` platform involve inclusive low and high mass Drell-Yan production [5, 6], measurements of *W* and *Z* production cross sections [7], *W* production in association with the charm quark [8, 9], inclusive photon [10] and jet [11, 12] production. In addition, a study of the impact of the QED radiative corrections on the PDFs was reported in [13].

At HERA, new results of QCD analysis using `HERAFitter` include the recent preliminary HERAPDF2.0 set by t he H1 and ZEUS Collaborations based on the preliminary HERA data combination [14], the preliminary QCD analysis on the combined full HERA inclusive set, and a study on the determination of charm mass running from a combined analysis of HERA charm data. Other dedicated analysis using `HERAFitter` based on the HERA measurements were obtained, such as determination of the transverse momentum dependent gluon density and an analysis using a new dipole model [15, 16].

PoS(DIS2014)045

4. Summary

`HERAFitter` contains all necessary ingredients to study the proton PDFs, it incorporates variety of different data processes and theory calculations, contains many useful tools and is an optimal platform for various benchmarking studies. `HERAFitter` is the first open source package to perform PDF fits and is actively used by experimental and theoretical high energy physics communities.

References

[1] https://www.herafitter.org

[2] M. Botje (2010), http://www.nikef.nl/h24/qcdnum/index.html, [arXiv:1005.1481].

[3] F. James and M. Roos, Comput. Phys. Commun. 10, 343 (1975).

[4] M. R. Whalley, D. Bourilkov, and R. Group (2005), http://lhapdf.hepforge.org, [hep-ph/0508110].

[5] G. Aad *et al.* [ATLAS Collaboration], "Measurement of the low-mass Drell-Yan differential cross section at $\sqrt{s}$=7 TeV using the ATLAS detector," CERN-PH-EP-2014-020, [arXiv:1404.1212 [hep-ex]].

[6] G. Aad *et al.* [ATLAS Collaboration], "Measurement of the high-mass Drell–Yan differential cross-section in pp collisions at $\sqrt{s}$=7 TeV with the ATLAS detector," Phys. Lett. B **725** (2013) 223 [arXiv:1305.4192 [hep-ex]].

[7] G. Aad *et al.* [ATLAS Collaboration], "Determination of the strange quark density of the proton from ATLAS measurements of the $W \to l\nu$ and $Z \to ll$ cross sections," Phys. Rev. Lett. **109** (2012) 012001 [arXiv:1203.4051 [hep-ex]].

[8] S. Chatrchyan *et al.* [CMS Collaboration], "Measurement of the muon charge asymmetry in inclusive $pp \to W + X$ production at $\sqrt{s} = 7$ TeV and an improved determination of light parton distribution functions", submitted to Phys. Rev. D, 2014, [arXiv:1312.6283 [hep-ex]].

[9] H. Abramowicz *et al.* [H1 and ZEUS Collaborations], "Combination and QCD Analysis of Charm Production Cross Section Measurements in Deep-Inelastic ep Scattering at HERA," [arXiv:1211.1182 [hep-ex]].

[10] G. Aad *et al.* [ATLAS Collaboration], "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", ATL-PHYS-PUB-2013-018, 2013.

[11] S. Chatrchyan *et al.* [CMS Collaboration], "PDF constraints and extraction of the strong coupling constant from the inclusive jet cross section at $\sqrt{s} = 7$ TeV", CMS PAS SMP-12-028, 2014.

[12] G. Aad *et al.* [ATLAS Collaboration], "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", EPJC (2013) 73 2509, [arXiv:1304.4739[hep-ex]].

[13] R. Sadykov, "Impact of QED radiative corrections on Parton Distribution Functions", (2014) [arXiv:1401.1133 [hep-ph]].

[14] H. Abramowicz *et al.* [H1 and ZEUS Collaborations], H1prelim-14-041, ZEUS-prel-14-005.

[15] F. Hautmann and H. Jung, "Transverse momentum dependent gluon density from DIS precision data", (2013) [arXiv:1312.7875 [hep-ph]].

[16] A. Luszczak, and H. Kowalski, "Dipole model analysis of high precision HERA data", (2013) [arXiv:1312.4060 [hep-ph]].

[17] [HERAFitter Developers Team and M. Lisovyi], “Parton distribution functions at LO, NLO and NNLO with correlated uncertainties between orders”, DESY-2014-0524 [arXiv:1404.4234 [hep-ph]].