xFitter (former HERAFitter) Project
Open Source QCD Fit framework

PDF4LHC, September 13, 2016

Ringailė Plačakytė

University of Hamburg

on behalf of the xFitter team

Introduction

xFitter

Precise knowledge of the PDFs are essential for predictions at hadron colliders

QCD factorisation:

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

Experimental Data:

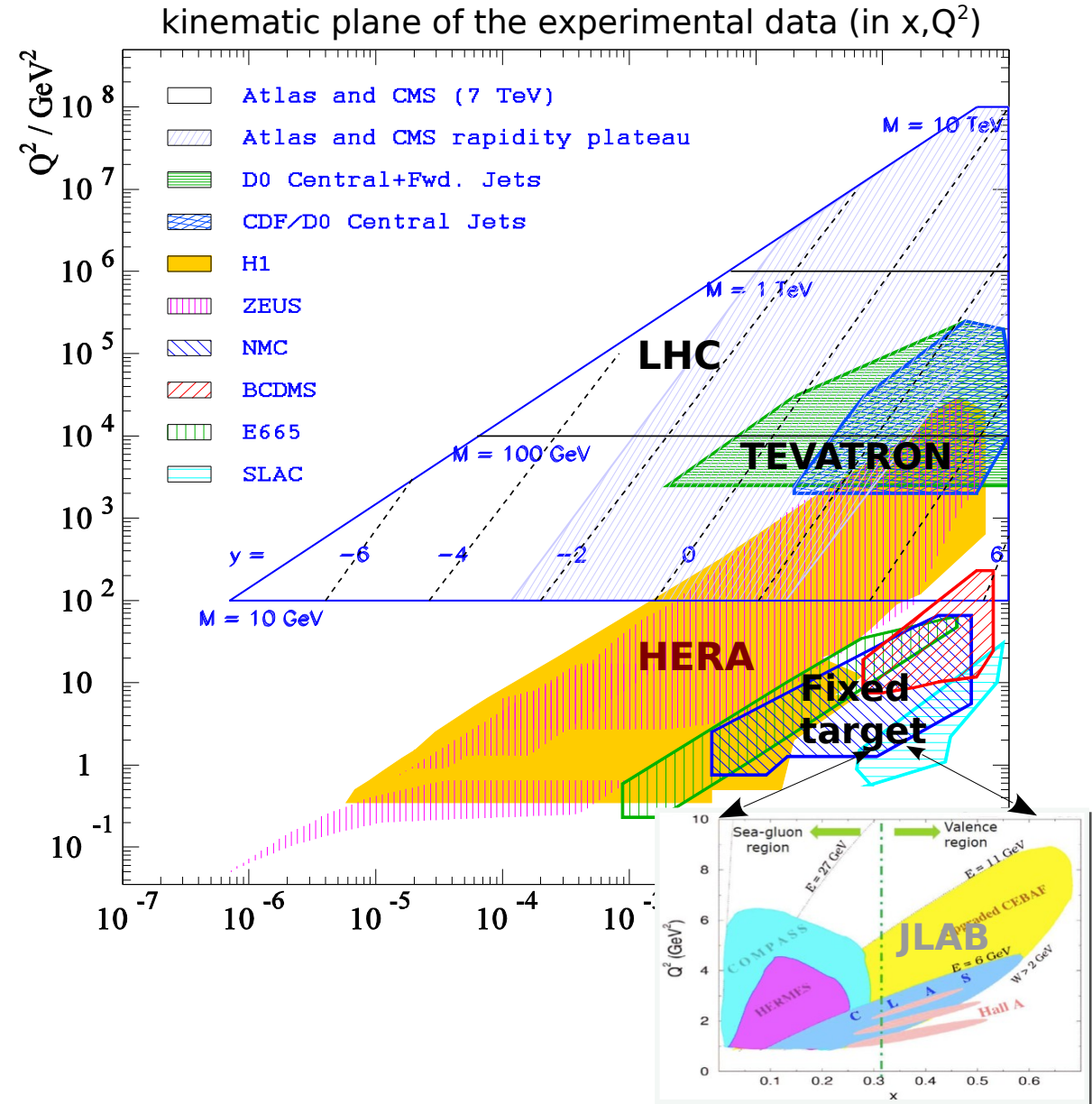→ a large variety of data from fixed-target and collider experiments

Theory:

→ intense theoretical developments

QCD Analysis:

→ available PDFs: CT/CJ, MMHT, NNPDF, ABM, HERAPDF, JR

... and **Tools**

kinematic plane of the experimental data (in x,Q^2)

Tools for PDF determination

Available (open-source) tools for the PDF determination:

xFitter (former HERAFitter): an open-source package that provides a framework for the determination of the PDFs of the proton and for many different kinds of analyses in QCD

EPJC (2015), 75: 304, xfitter.org

OPENQCDRAD (ABM collaboration: numerical computation of all hard scattering cross sections (DIS structure function calculation including heavy quark contributions, W and Z production)

PRD86 (2012) 054009, www-zeuthen.desy.de/~alekhin/OPENQCDRAD

APFEL (NNPDF collaboration): a PDF evolution library, is a computer library specialized in the solution of DGLAP evolution equations up to NNLO in QCD and to LO in QED

arXiv.1310.1394, apfel.hepforge.org

QCDNUM: Fast QCD Evolution and Convolution (numerically solves the evolution equations for parton densities and fragmentation functions in pQCD)

Comp.Phys.Com.182:490,2011

ALPOS: an object-oriented data to theory comparison and fitting tool (profit from and exchange with xFitter experience)

http://desy.de/~britzger/alpos/

→ access from a public svn repository (via request)

xFitter Project

2011 Open Source Revolution:

first open source QCD Fit Platform which started the wave of sharing QCD fit codes

EPJC (2015), 75: 304

- A team of ~30 developers:
  - LHC/HERA/theory/independent
  - several releases since 2011
  - 33 publications that have used the framework [in total]

synergy between experiment and theory groups

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

Dedicated studies [xFitter developers]
  method in preserving correlation between PDFs extracted at different orders in pQCD
  address consistency of Tevatron measurement and evaluate their collective impact on valence
  determination of the running mass in $\overline{\text{MS}}$ scheme

xFitter Project

→ open access, no registration required

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. 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-1.2.2 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

- 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

Schematic View of the xFitter Program

Main steps in QCD analysis:

Parametrise PDFs at the starting scale

→ multiple options for functional forms
  → Standard Polynomial, Chebyshev, etc

Evolve to the scale corresponding to data point

→ QCD(DGLAP) evolution codes [QCDNUM, APFEL]
→ kt ordered evolution, dipole models, QCD(DGLAP)+QED
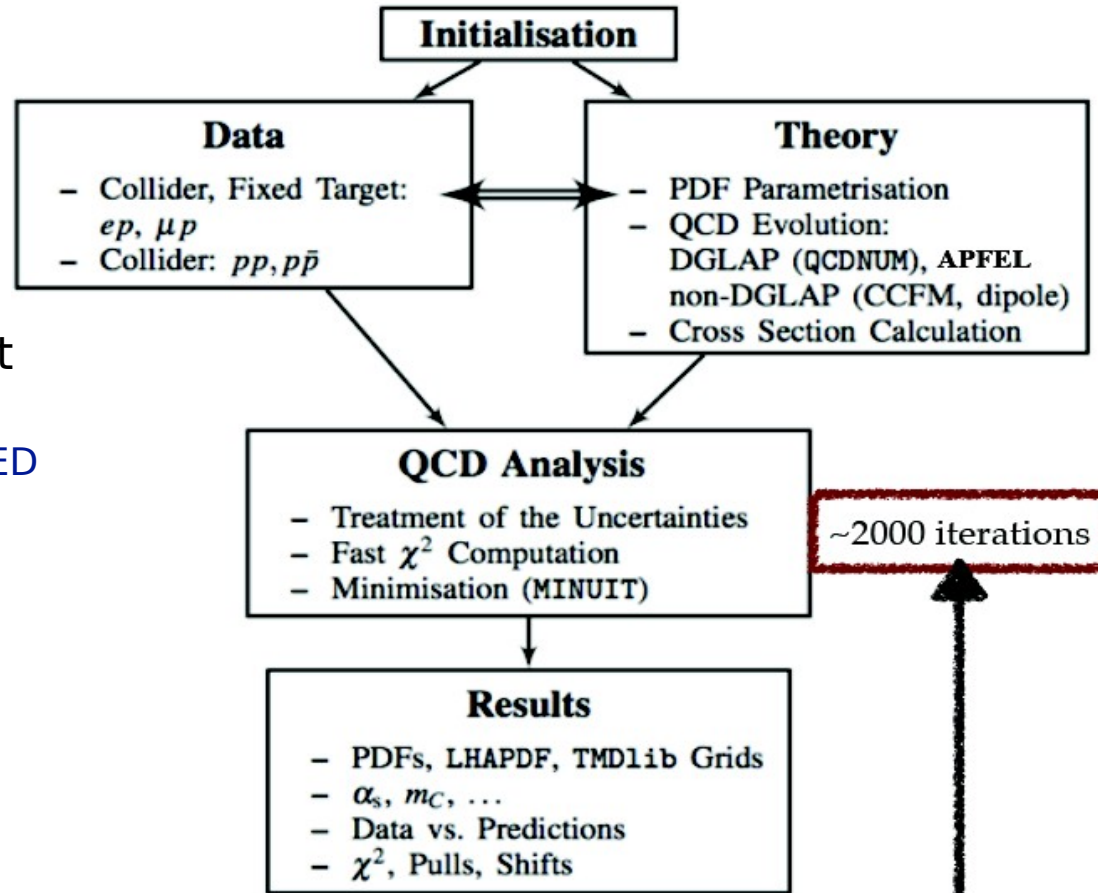
Calculate the cross section

→ various heavy flavour schemes:
  → RT, ACOT, FONLL, FFNS(ABM)
→ fast grid techniques interfaced to DY:
  → APPLGRID, FASTNLO

Compare with data via χ^2:

→ multiple forms to account for correlations

Minimize χ^2 with respect to PDF parameters

→ profiling, reweighting
→ fit: MINUIT, data driven regularisation

Initialisation

Data
- Collider, Fixed Target:
  $ep, \mu p$
- Collider: $pp, p\bar{p}$

Theory
- PDF Parametrisation
- QCD Evolution:
  DGLAP (QCDNUM), APFEL
  non-DGLAP (CCFM, dipole)
- Cross Section Calculation

QCD Analysis
- Treatment of the Uncertainties
- Fast χ^2 Computation
- Minimisation (MINUIT)

~2000 iterations

Results
- PDFs, LHAPDF, TMDlib Grids
- $\alpha_s, m_C, \ldots$
- Data vs. Predictions
- χ^2, Pulls, Shifts

EPJC (2015), 75:304

Importance of optimised calculations

xFitter release xfitter-1.2.2

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
- The script to download coupled data and theory files getter-xfitter.sh.

Date	Version	Files	Remarks
07/2016	**1.2.2**	xfitter-1.2.2.tgz	release with decoupled data and theory files
05/2016	**1.2.1**	xfitter-1.2.1.tgz	release with decoupled data and theory files
02/2016	**1.2.0**	xfitter-1.2.0.tgz	release with decoupled data and theory files

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

→ getter-xfitter.sh script to download data with corresponding theory files

→ in directory 'datasets' located all available files

xfitter-1.2.2 vs xfitter-1.2.1

Several fixes were applied:

Release	Date	Description
xfitter-1.2.2	8.07.2016	• Fix in profiling due to multiple sign flips, affects also reweighting. • Fix in the output of PDFs, strange is symetrised to $(s + \bar{s})/2$. • Fix in calculation of theory error bands for parametrisation uncertainties for the `--therr` option. • Fix for `has_photon` LHAPDF variable and protection against LHAPDFQ0 with photon PDFs. • Fixes to dipole steering file in input steering file, updated now to current settings. • Added the H1 beauty data to the list of data files • Fix in the default theoretical parameters for HVQMNR to be used not in Fit mode. • Fix on warning message from Fastnlo. • Added examples in the example directory together with the tutorial slides from CTEQ 2016 school. • Fix in configuratuon for `--disable-root` option. • Fix in α_s interpolation and protection in overriding the output directories. • Fix in photon PDF sum rules.

https://indico.desy.de/contributionDisplay.py?contribId=11&confId=13506

xfitter-1.2.2 examples (CTEQ school)

xFitter

https://indico.desy.de/contributionDisplay.py?contribId=11&confId=13506

A list of educational examples are provided in the package - prepared for the CTEQ summer school 2016:

Exercise 1: PDF fit
→ learn the basic settings of a QCD analysis, based on HERA data only

Exercise 2: Simultaneous PDF fit and αs
→ learn the basic of an αs extraction using H1 jet data

Exercise 3: LHAPDF analysis
→ how to estimate impact of a new data without fitting:
→ profiling and reweighting techniques

Exercise 4: Plotting LHAPDF files
→ direct visualisation of PDFs from LHAPDF6 using simple python scripts

Exercise 5: Equivalence of χ^2 representations
→ understand different χ^2 representations

New Physics Cases in xFitter

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
https://apfel.hepforge.org/mela.html
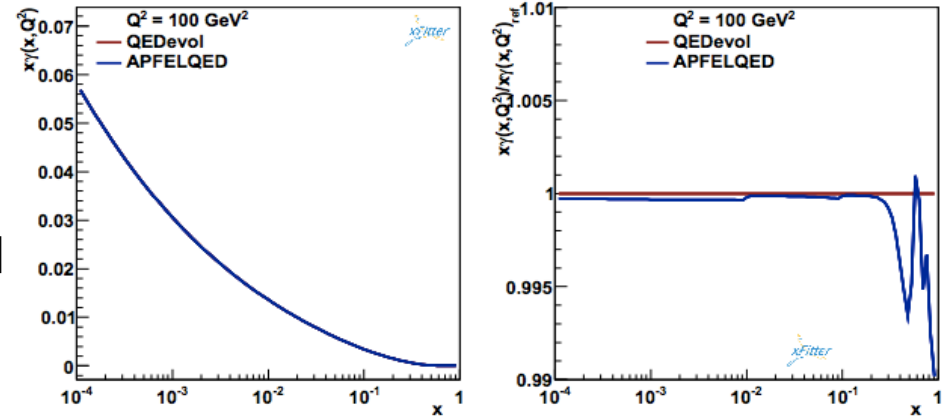
V. Bertone, R. Sadykov

New: NLO QCD + QED via APFEL in xFitter:

→ at LO QED, no corrections to the SFs are needed

→ at NLO QED, access to new diagrams: $\gamma^*\gamma \to qq$ and $\gamma^*q \to q\gamma$

→ implementing the $O(\alpha_s\alpha)$ and the $O(\alpha^2)$ corrections to the DGLAP splitting functions on top of the $O(\alpha)$ ones

→ implementing $O(\alpha_s^2\alpha)$ and the $O(\alpha^2)$, $O(\alpha^2\alpha_s)$ corrections to β functions

→ when including NLO QED corrections, not only the evolution is affected but also the DIS structure functions get corrected

ONLY ON GIT
very new!
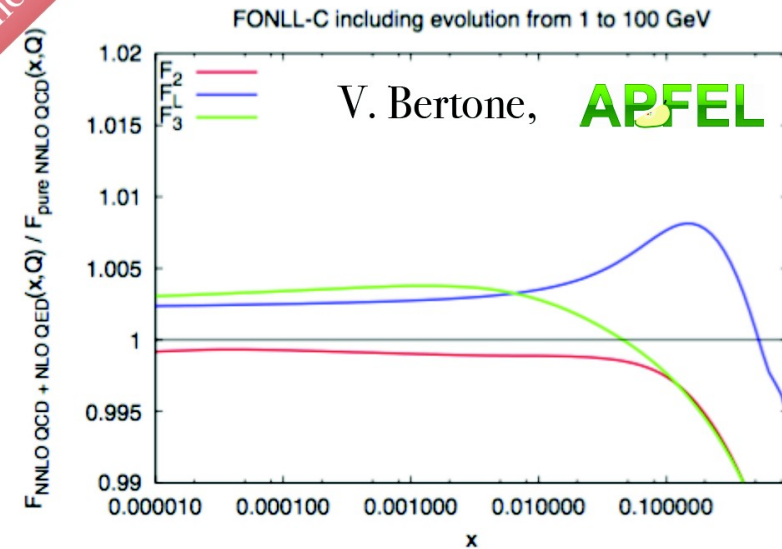
V. Bertone, APFEL

New Physics Cases in xFitter

Addition of new Heavy Flavour Scheme: **FONLL VFNS**

→ 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

Interface to Mangano-Nason-Ridolfi (MNR, NPB 373 (1992) 295) theory code added in xFitter

→ 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 corresponding LHCb data

Added extra reweighing option using Giele-Keller weights
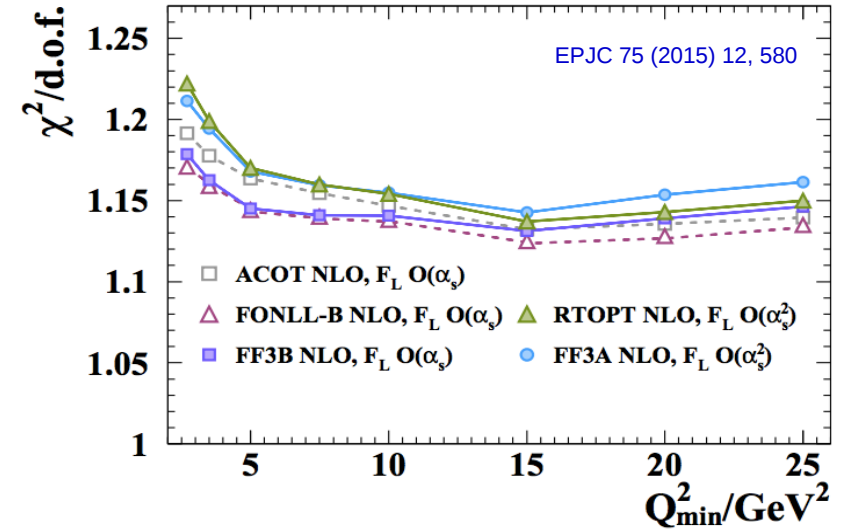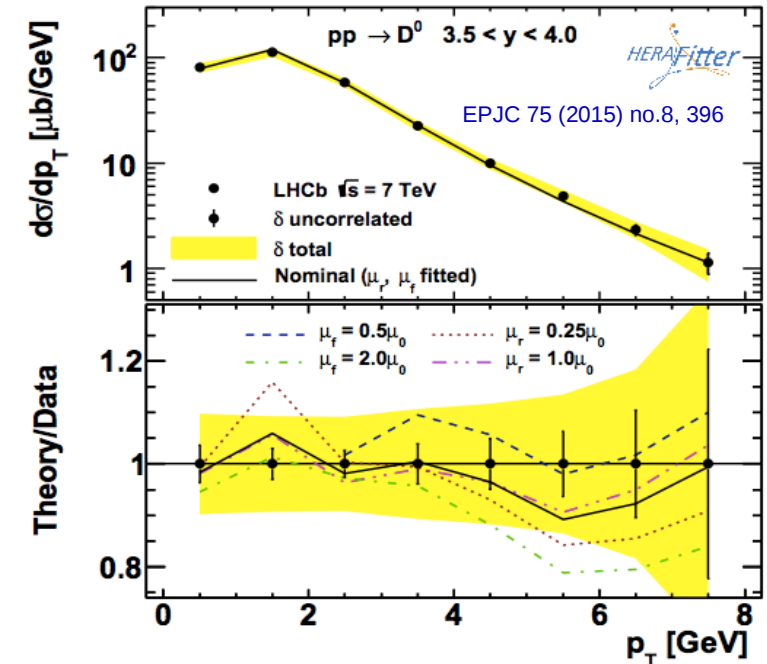
xFitter on GitLab
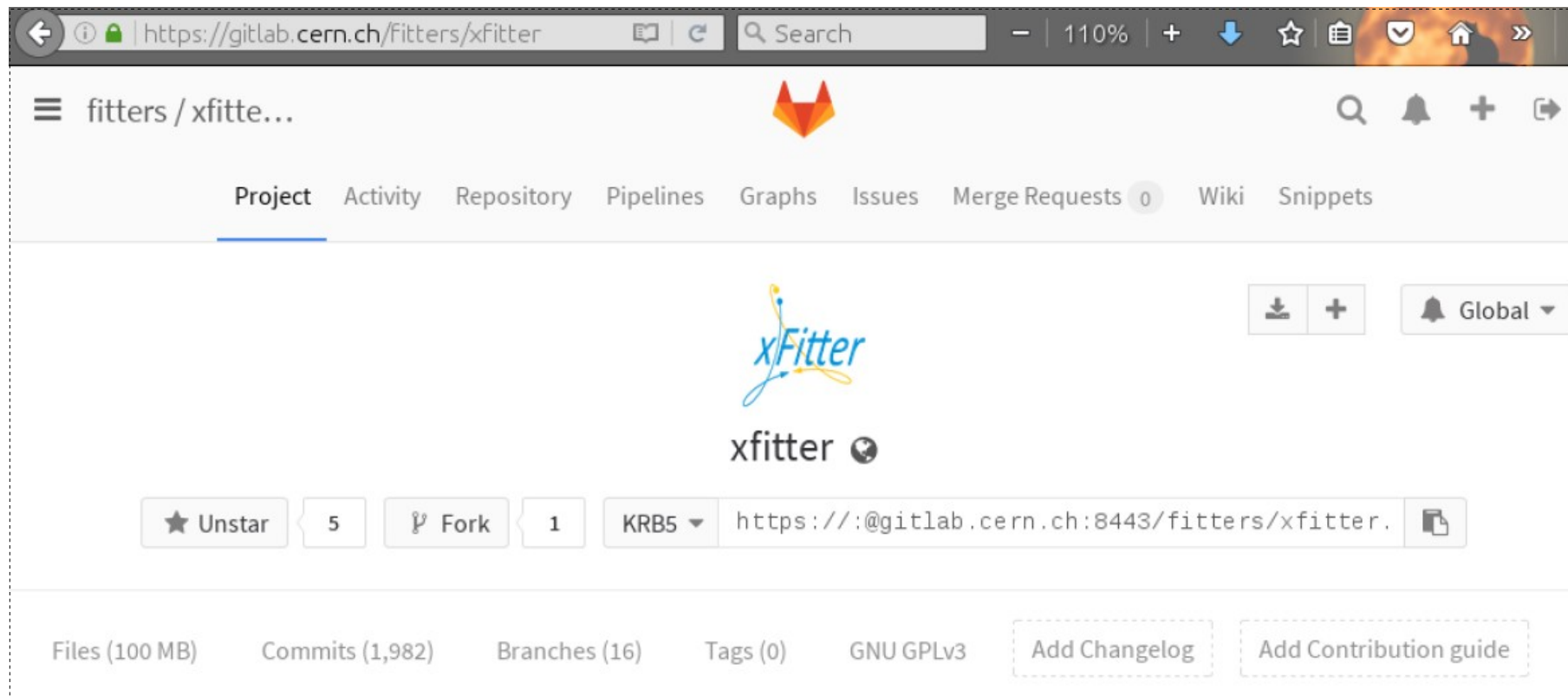
GitLab (CERN) is now the main repository of the project

→ open access to download for everyone (read only)

https://gitlab.cern.ch/fitters/xfitter

- **1951** commits during **1917** days
- Average **1.0** commits per day

Commits from developers which have no CERN account handled via mirror-GIT public page

xFitter on Hepforge: data access

http://xfitter.hepforge.org/

- Home
- Source Code
- List of Data Files
- xFitter Wiki
- xFitter Releases
- Contact

An Open Source QCD Fit Project

Welcome! This site is under development.
(use: xFITTER site .)

Complementary information about the project (to xfitter.org)

→ possibility to download **data** files (including theory)

→ updated automatically with new data added to svn

will include script to download all data at once

Your feedback is welcome
(via email xfitter-help@desy.de)

This page contains the list of publicly available experimental data sets (with corresponding theory grids if available) in the xFitter package.
To download data set please click on the arXiv link (and open/save tar.gz file).

No	Collider	Experiment	Reaction	arXiv	Readme
1	fixedTarget	bcdms	inclusiveDis	cern-ep-89-06	README
2	hera	h1	beautyProduction	0907.2643	
3	hera	h1	inclusiveDis	1012.4355	
4	hera	h1	jets	0706.3722	README
5	hera	h1	jets	0707.4057	README
6	hera	h1	jets	0904.3870	README
7	hera	h1	jets	0911.5678	README
8	hera	h1	jets	1406.4709	README
9	hera	h1zeusCombined	charmProduction	1211.1182	
10	hera	h1zeusCombined	inclusiveDis	0911.0884	
11	hera	h1zeusCombined	inclusiveDis	1506.06042	
12	hera	zeus	beautyProduction	1405.6915	
13	hera	zeus	diffractiveDis	0812.2003	
14	hera	zeus	jets	0208037	
15	hera	zeus	jets	0608048	
16	hera	zeus	jets	1010.6167	
17	lhc	atlas	drellYan	1305.4192	
18	lhc	atlas	drellYan	1404.1212	
19	lhc	atlas	jets	1112.6297	

Results Obtained with xFitter

xFitter

More than **30 public results** obtained using xFitter from the beginning of the project
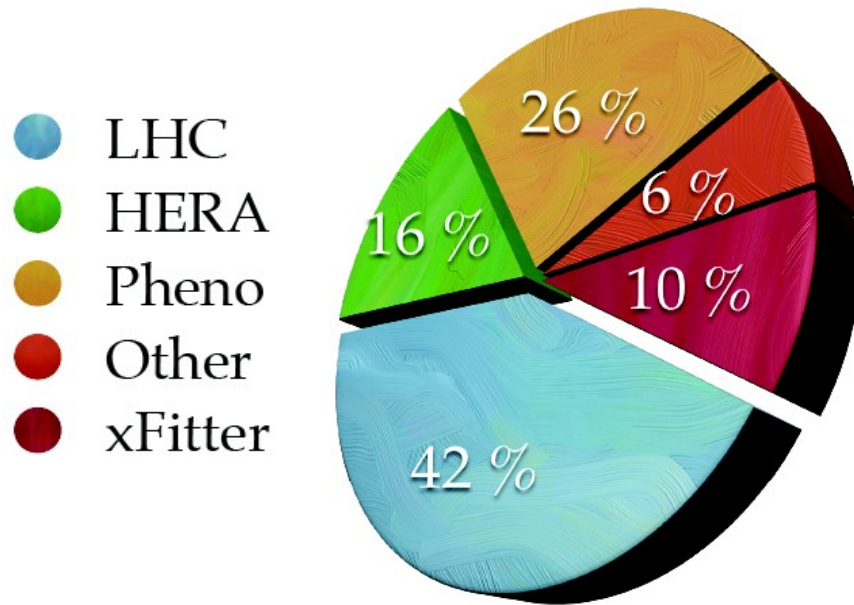
LHC experiments provide the main developments and usage of the xFitter platform

Legend:
- LHC
- HERA
- Pheno
- Other
- xFitter

Pie chart values:
- 26 %
- 6 %
- 16 %
- 10 %
- 42 %

xFitter publications:

| List of analyses using HERAFitter			
03.2016	xFitter and APFEL teams and A. Geiser	JHEP 1608 (2016) 050, arXiv:1605.01946	A determination of mc(mc) from HERA data using a matched heavy flavor scheme
03.2015	**HERAFitter team**	EPJC 75 (2015) 9, 458, arXiv:1503.05221	QCD analysis of W- and Z-boson production at Tevatron
10.2014	**HERAFitter team**	EPJC (2015), 75: 304, arXiv:1410.4412	HERAFitter Open Source QCD Fit Project
04.2014	**HERAFitter team**	EPJC (2014) 74: 3039, arXiv:1404.4234	Parton distribution functions at LO, NLO and NNLO with correlated uncertainties between orders

Results Obtained with xFitter: Examples

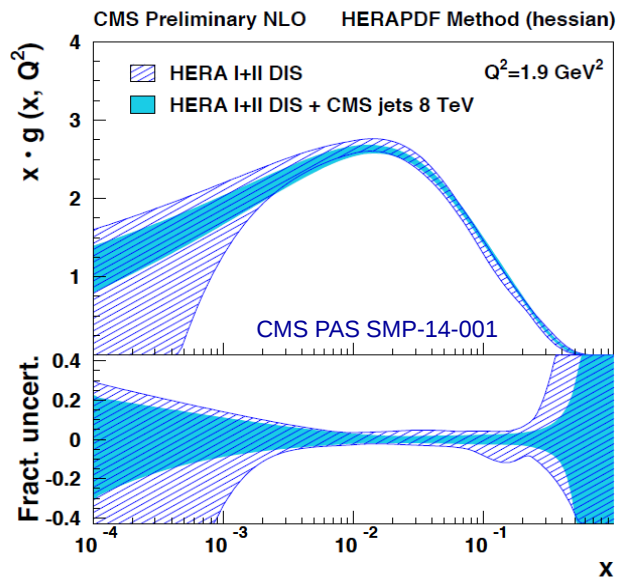**DIS inclusive processes in *ep* (fixed target)**
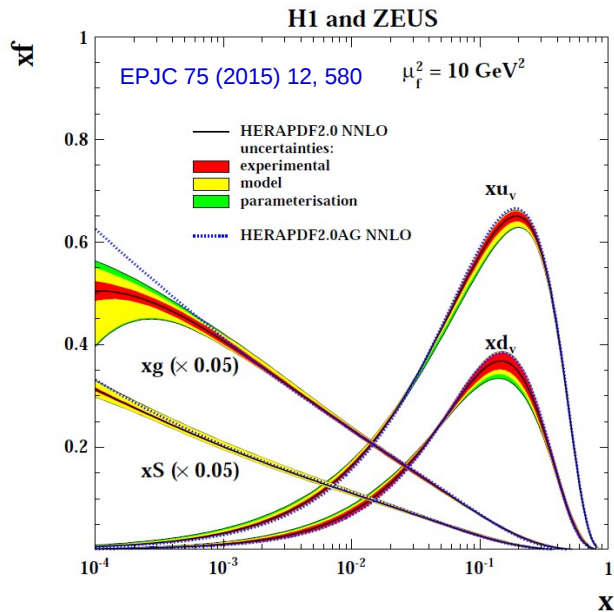
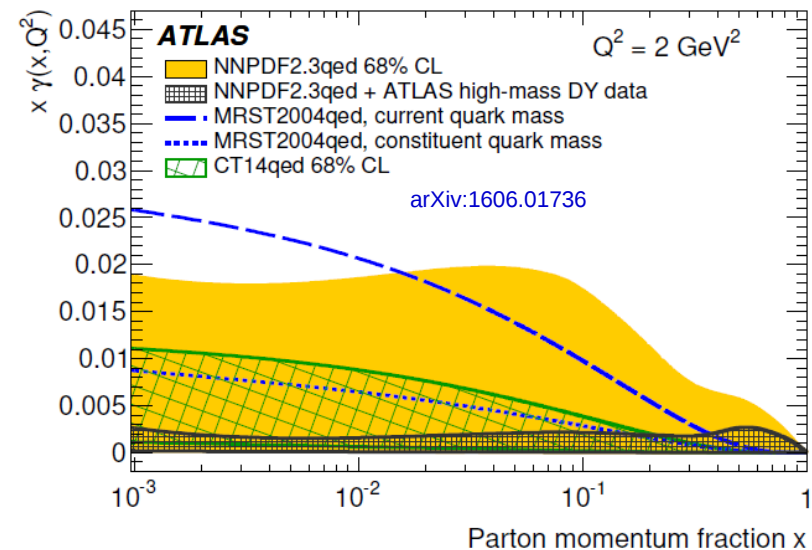**Drell-Yan processes** (*pp, ppbar*)

→ strange quark density determination
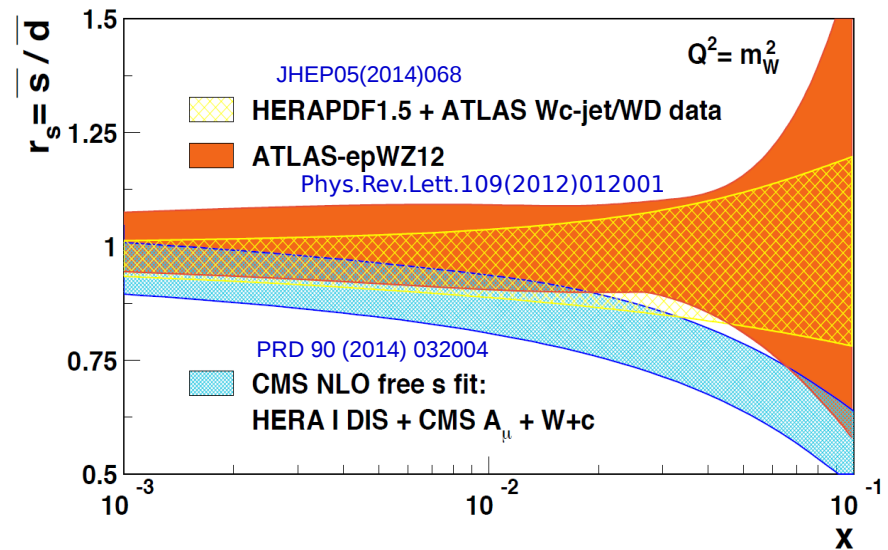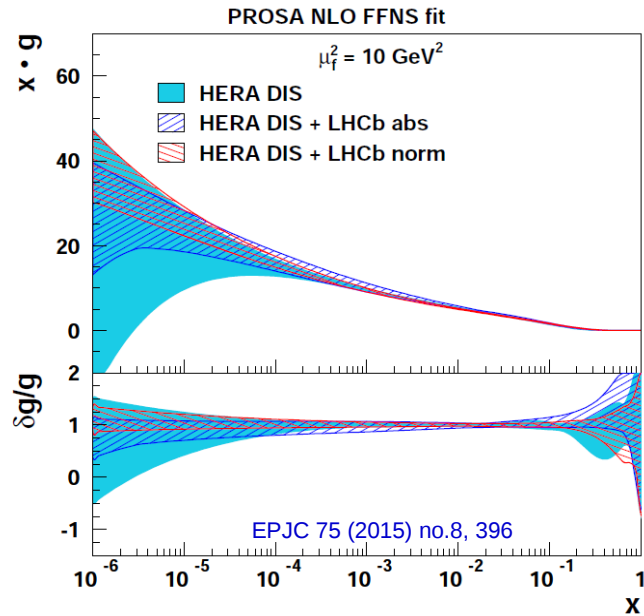

Jet production (*ep, pp, ppbar*)

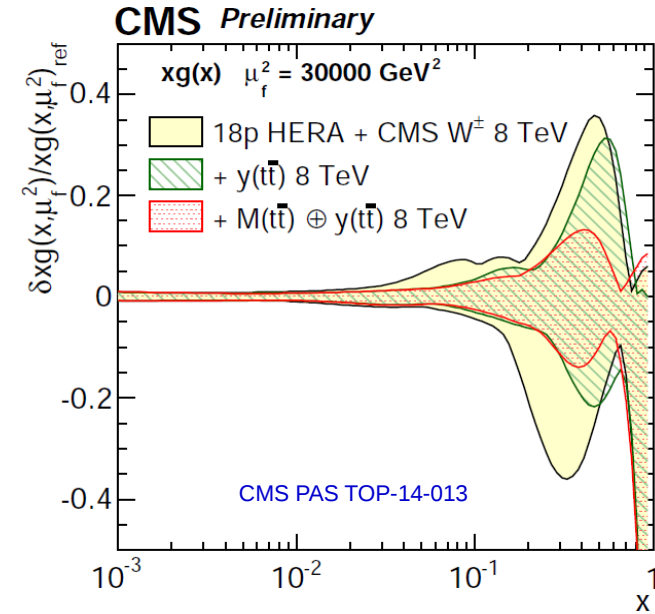**DY data sensitivity to photon PDF**
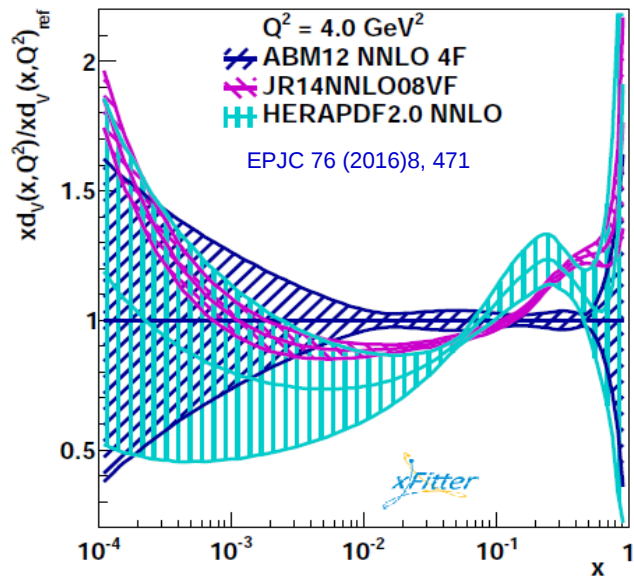
Results Obtained with xFitter: Examples

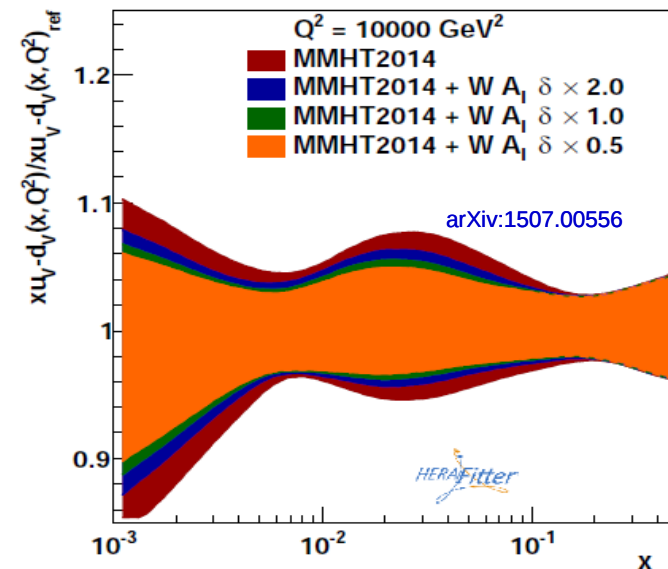**Heavy Quark production** (*ep, pp, ppbar*)

Top-quark production (*pp, ppbar*)

Evaluation of modern PDFs (benchmarking)

PDF4LHC report (benchmarking)

Latest xFitter Developers Team Publication

arXiv.org > hep-ph > arXiv:1605.01946

High Energy Physics – Phenomenology

A determination of mc(mc) from HERA data using a matched heavy-flavor scheme

xFitter Developers' team: Valerio Bertone, Stefano Camarda, Amanda Cooper-Sarkar, Alexandre Glazov, Agnieszka Luszczak, Hayk Pirumov, Ringaile Placakyte, Klaus Rabbertz, Voica Radescu, Juan Rojo, Andrey Sapranov, Oleksandr Zenaiev, Achim Geiser

(Submitted on 6 May 2016)

The charm quark mass is one of the fundamental parameters of the Standard Model Lagrangian. In this work we present a determination of the MSbar charm mass from a fit to the inclusive and charm HERA deep-inelastic structure function data. The analysis is performed within the xFitter framework, with structure functions computed in the FONLL general-mass scheme as implemented in APFEL. In the case of the FONLL-C scheme, we obtain mc(mc) = 1.335 +- 0.043(exp) +0.019 −0.000(param) +0.011 −0.008(mod) +0.033 −0.008(th) GeV. We also perform an analogous determination in the fixed-flavor-number scheme at next-to-leading order, finding mc(mc) = 1.318 +- 0.054(exp) +0.011 −0.010(param) +0.015 −0.019(mod) +0.045 −0.004(th) GeV, compatible with the FONLL-C value. Our results are consistent with previous determinations from DIS data as well as with the PDG world average.
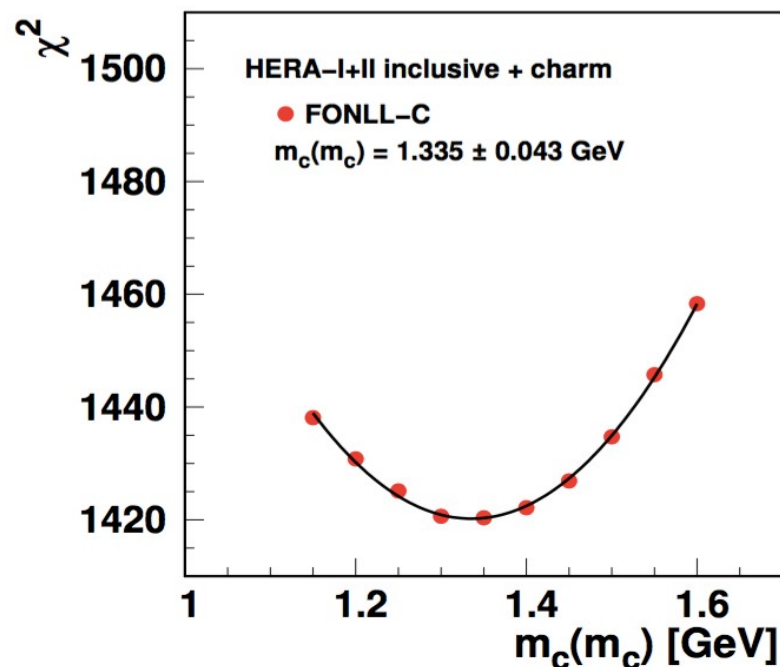
The extraction of $m_c(m_c)$ was performed using FONLL scheme in terms of the $\overline{\text{MS}}$ masses → improves perturbative convergence

→ combined HERA I + II charm production and DIS cross sections

→ FONLL-C scheme used – NLO accuracy in the massive sector

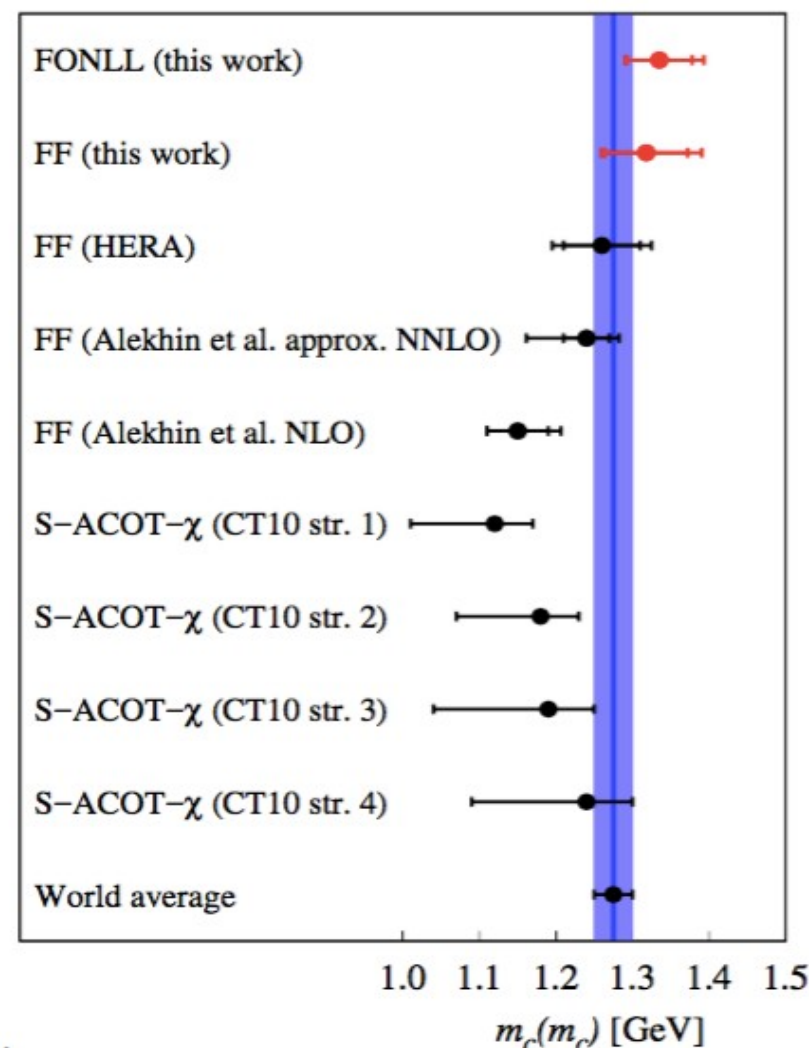→ also tested in FFNS (fixed flavour number scheme) at NLO

→ $m_c(m_c)$ value is determined from a parabolic minimum of the global χ^2 scan vs $m_c(m_c)$ with 1σ uncertainty determined from $\Delta\chi^2$ variation

→ $m_c(m_c)$ measurement is comparable to previous determinations from DIS as well as PDG world average:

HERA–I+II inclusive + charm

● FONLL–C
$m_c(m_c) = 1.335 \pm 0.043$ GeV

FONLL-C:

$$m_c(m_c) = 1.335 \pm 0.043(\text{exp})^{+0.019}_{-0.000}(\text{param})^{+0.011}_{-0.008}(\text{mod})^{+0.033}_{-0.008}(\text{th}) \text{ GeV}$$

FONLL (this work)
FF (this work)
FF (HERA)
FF (Alekhin et al. approx. NNLO)
FF (Alekhin et al. NLO)
S−ACOT−χ (CT10 str. 1)
S−ACOT−χ (CT10 str. 2)
S−ACOT−χ (CT10 str. 3)
S−ACOT−χ (CT10 str. 4)
World average

$m_c(m_c)$ [GeV]

Summary

> **xFitter** project - a multi-functional QCD framework well integrated into the high energy community (both, experimental and theory) EPJC (2015) 75: 304

→ many active developments thanks to the close collaboration with experiments and theory groups

  → technical updates include usage of GitLab and HEPFORGE

→ **xfitter-1.2.2** is latest (recommended) release

→ over 30 public results obtained using xFitter (main applications are from LHC)

→ several published dedicated physics studies (developers team publications), more studies are ongoing

→ foreseen future physic (low-x phenomenology, nuclear PDF, etc...) and technical developments (improved user interface for PDF parametrisation form, data cards, python interface, etc...)

we welcome new ideas and developers :)

www.xfitter.org

Back-up Slides

Technical Changes (since 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   16

Release Notes