HERAFitter Project

Ringailė Plačakytė

on behalf of the HERAFitter team

76.PRC 24th of October

Content:

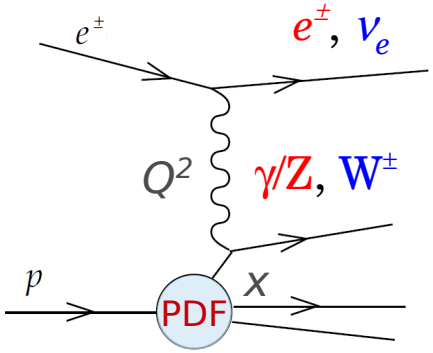
- Introduction and motivation
- HERAFitter project overview and recent developments
- Results obtained with HERAFitter
- Future developments
- Summary

Introduction

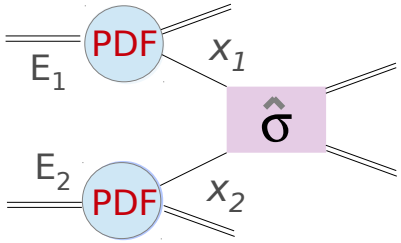
QCD factorisation: hadronic cross section is a convolution of the PDFs and perturbatively calculable hard-scattering coefficients:

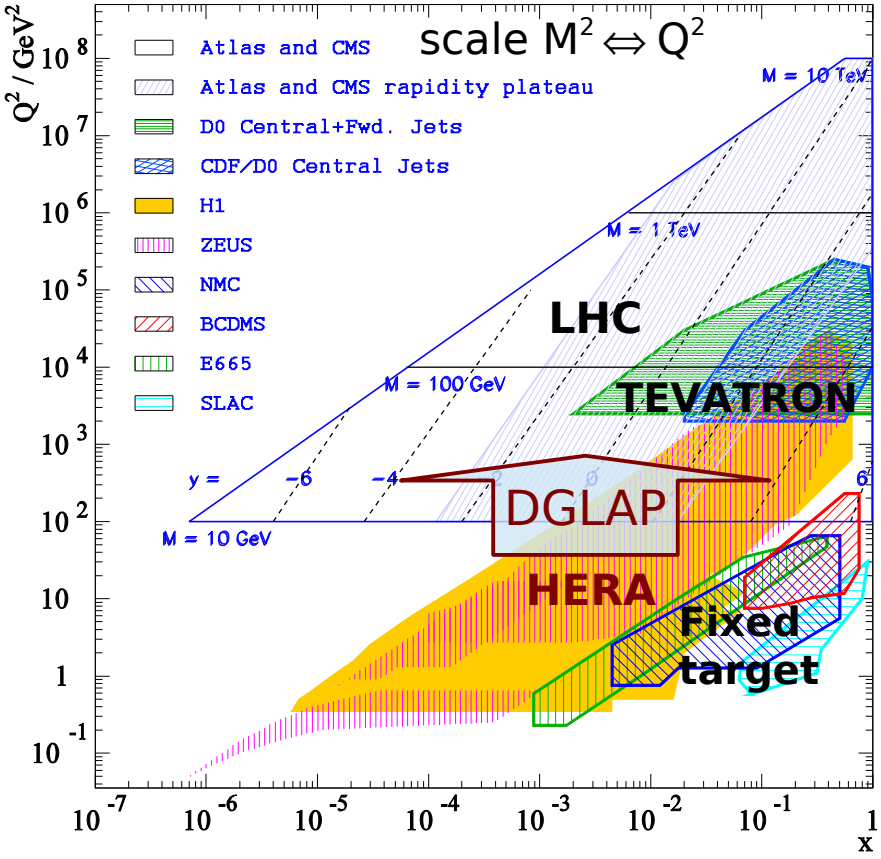
$$\sigma \approx \hat{\sigma} \otimes \text{PDF}$$

Deep Inelastic Scattering (DIS): unique opportunity to study PDFs



same PDFs can be used to predict *pp* collisions





Motivation

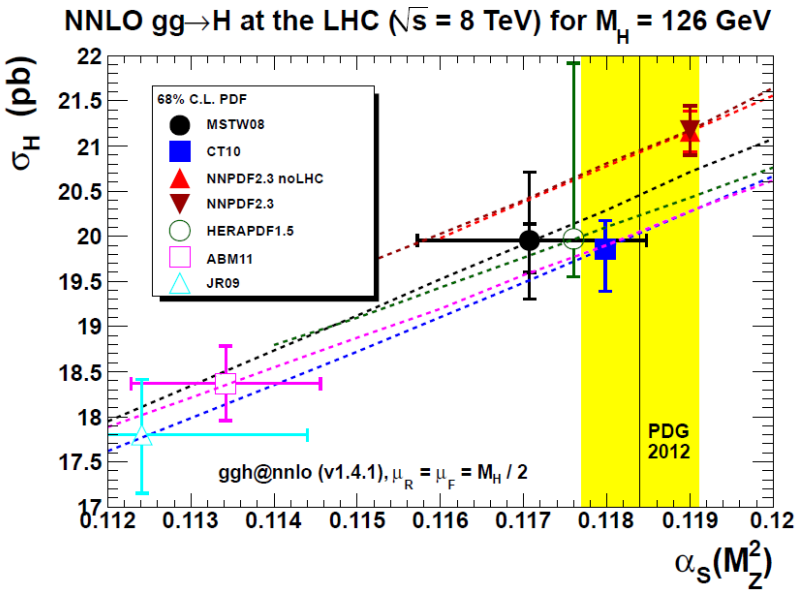
PDFs are essential for precision physics at LHC

e.g. PDFs one of main theory uncertainties in Higgs production

Different PDF fitting groups (CT, MSTW, NNPDF, HERAPDF, ABM, JR) use different data and methodology to extract PDFs

→ lead to differences in the predicted cross sections

HERAFitter is an open source QCD platform which can be used for benchmarking and understanding such differences



LHC and HERA experiments published a number of publications with results obtained using HERAFitter

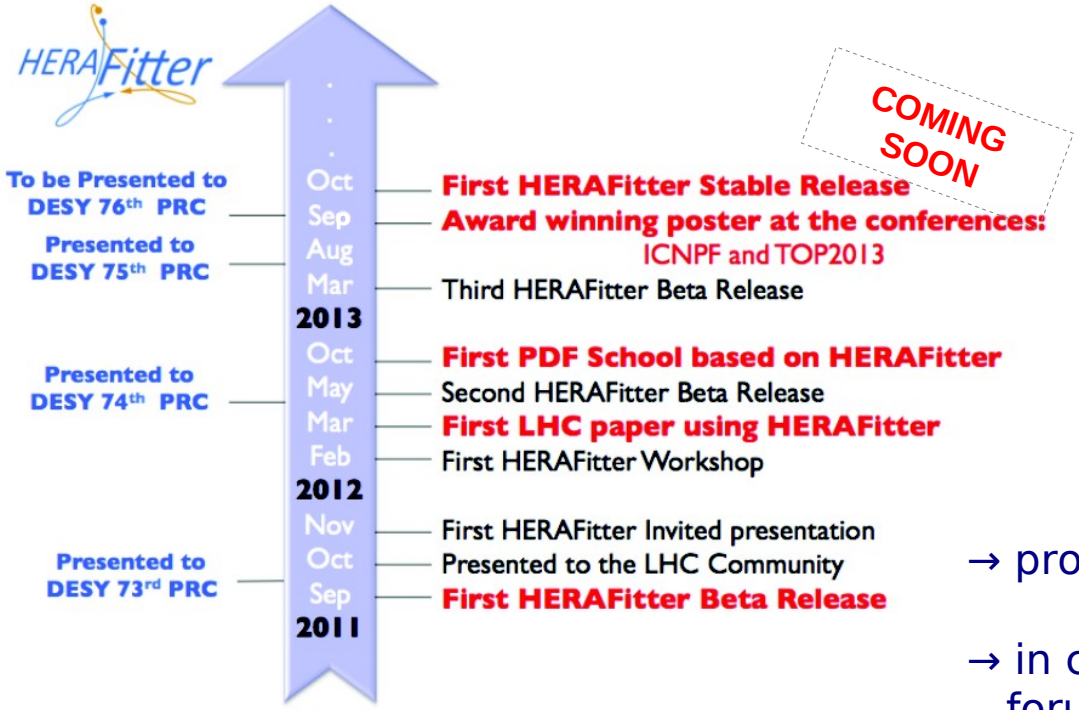
HERAFitter provides tools to assess impact of new data on PDFs

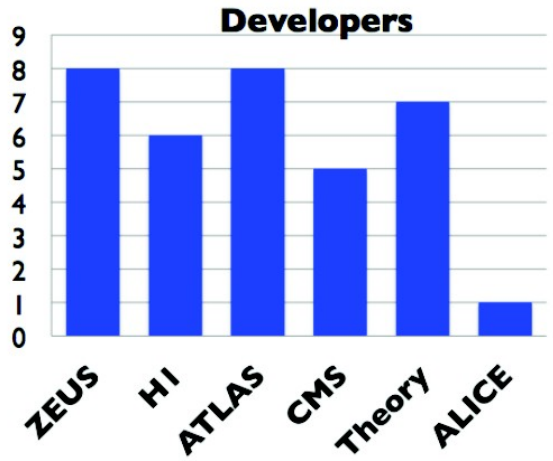
HERAFitter Project

HERAFitter project is a QCD fit framework ready to extract PDFs and assess the impact of new data

www.herafitter.org

→ everyone is welcome to download it and use it



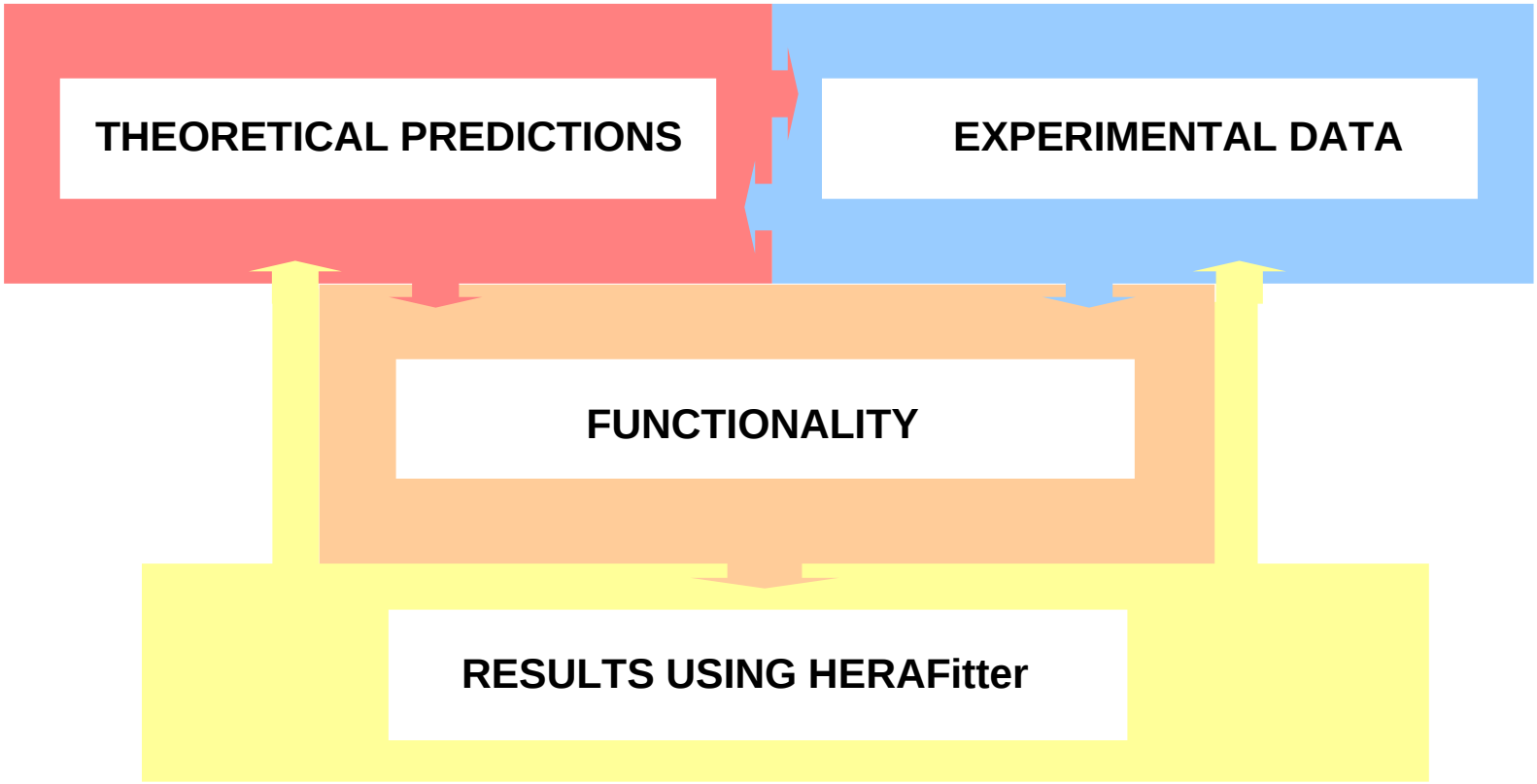


→ project is steered by DESY physicists

→ in close relation to dedicated PDF forums in Atlas and CMS collaborations

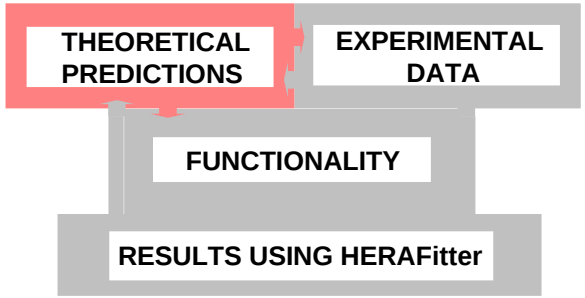
HERAFitter Overview

HERAFitter project modular structure:



→ many improvements and additions in the stable release HERAFitter-1.0.0
(in next slides marked with NEW, IMPROVED, or UPDATED)

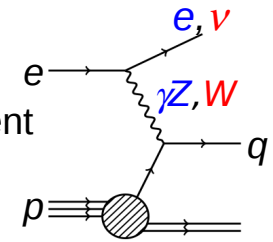
Theoretical Predictions



DIS inclusive processes in *ep* and fixed target

DGLAP formalism:

different schemes of heavy quark treatment
- VFNS: RT (MSTW), ACOT (CTEQ)
- FFNS (pole and running mass)



Electroweak corrections for *ep* scattering

Diffractive PDFs

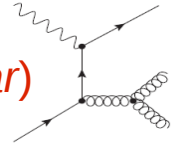
non-DGLAP formalism:

Dipole Models (GBW, IIM, BGK)
– an alternative approach for the low x region

Unintegrated PDFs
– based on CCFM evolution

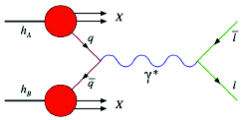
UPDATED

Jet production (*ep, pp, ppbar*)



FastNLO and APPLGRID techniques
- decoupled hard scattering coefficients from PDFs stored on grids

Drell-Yan processes (*pp, ppbar*)

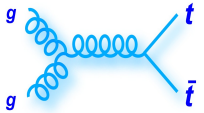


LO calculation x NLO k-factors

APPLGRID technique

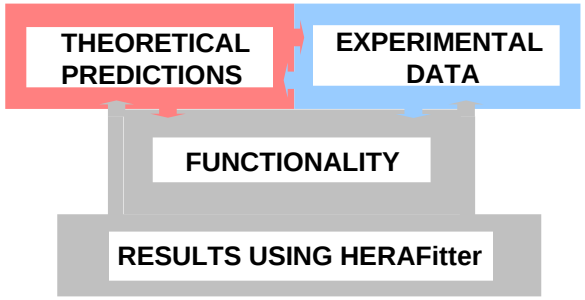
IMPROVED

Top pair production



total ttbar cross sections (differential coming soon)

Experimental Data



DIS inclusive processes in *ep* and fixed target

DGLAP formalism:

different schemes of heavy quark treatment
VFNS: RT (MSTW), ACOT (CTEQ)
FFNS (pole and running mass)

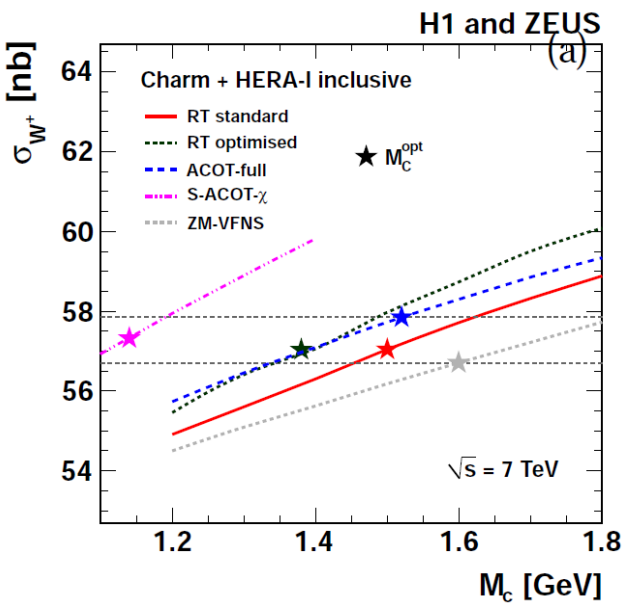
Combination and QCD Analysis of Charm Production in DIS at HERA

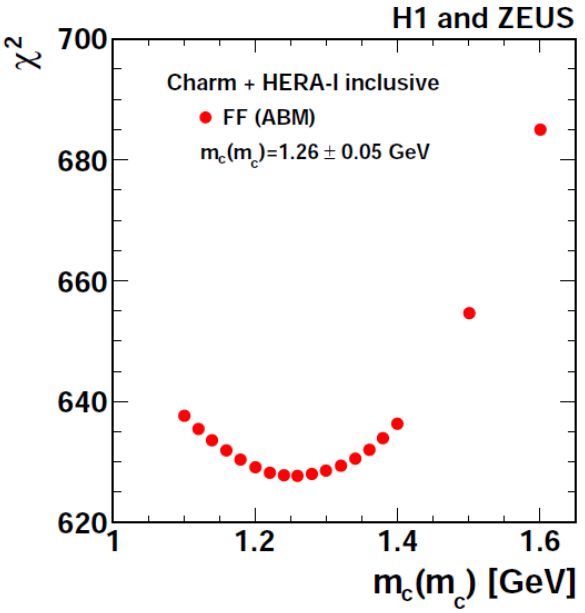
- various heavy flavour schemes and an impact on DY cross sections at LHC studied

  → possible only with HERAFitter

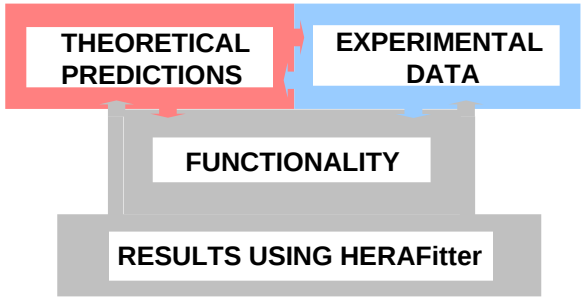
- running mass of charm quark determined

Eur. Phys. J. C73 (2013) 2311





Experimental Data



Jet production (*ep, pp, ppbar*)

FastNLO and APPLGRID techniques

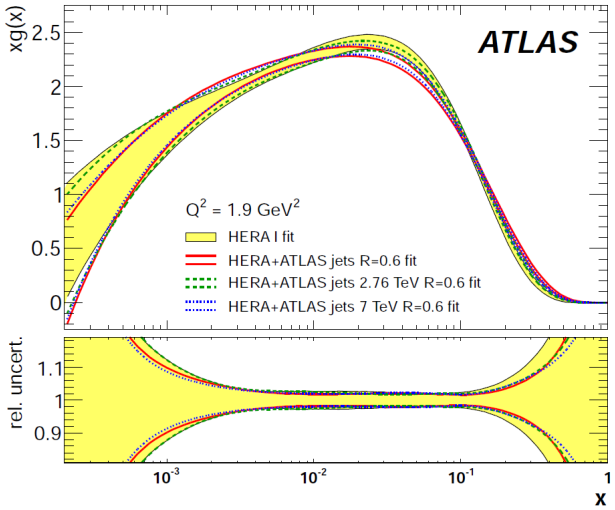
- decoupled hard scattering coefficients from PDFs stored on grids

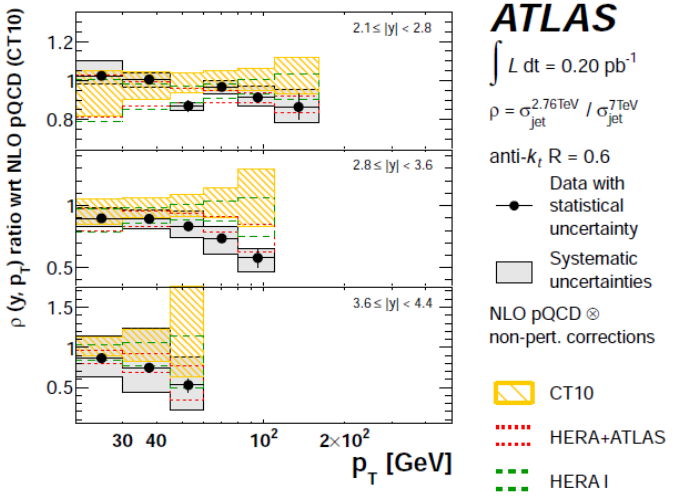
Measurement of the inclusive jet cross section at √s = 2.76 TeV and comparison to the inclusive jet cross section at √s = 7 TeV

- an NLO QCD analysis using inclusive jet data

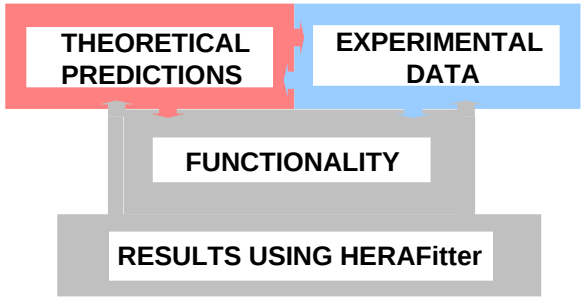
→ impact on gluon and sea distributions

EPJC (2013) 73 2509





Experimental Data



Drell-Yan processes (*pp, ppbar*)

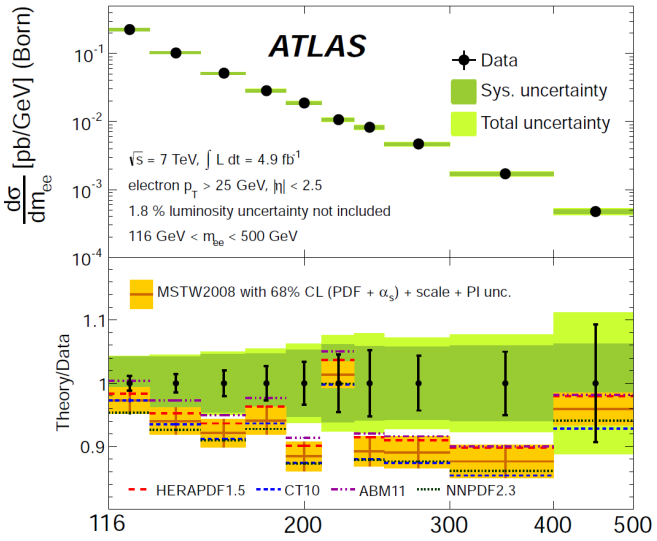
LO calculation x NLO k-factors

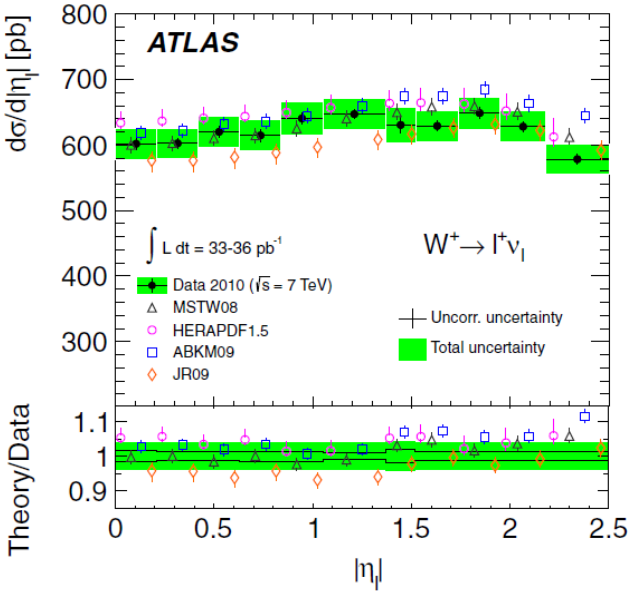
APPLGRID technique

Measurement of the inclusive W and Z/γ cross-section in pp collisions at √s = 7 TeV*

Measurement of the high-mass Drell-Yan differential cross-section in pp collisions at √s = 7 TeV

- comparison with various PDFs
- determination of strange quark density from DY data

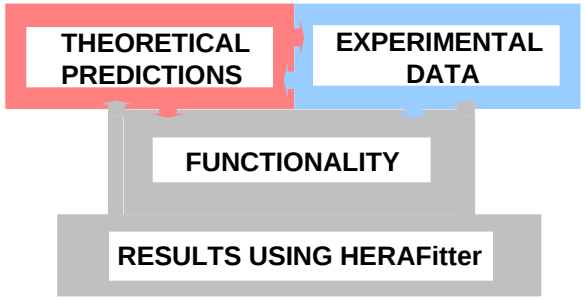




Phys. Lett. B 725 (2013) 223

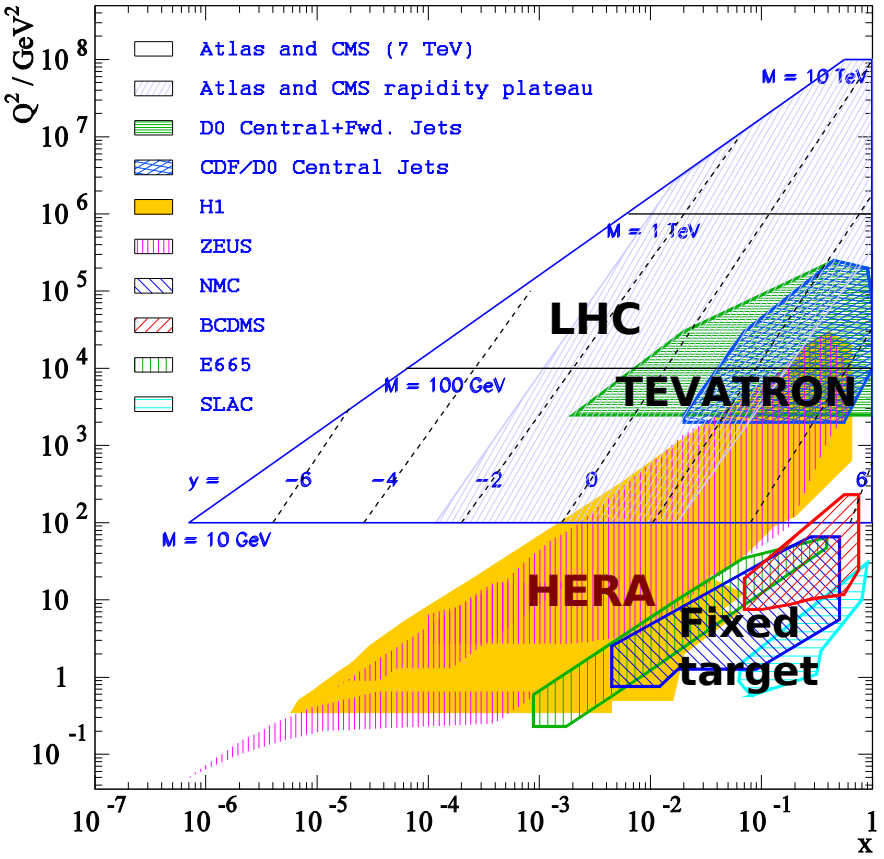
Phys. Rev. D 85 (2012) 072004

Experimental Data

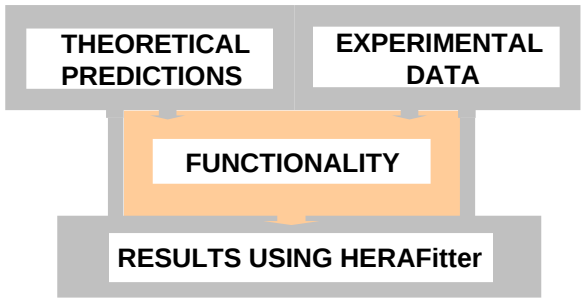


Different experimental data can be used in HERAFitter:

- **LHC**
  - → Drell-Yan
  - → jet production
  - → top quark pair production
- **TEVATRON**
  - → Drell-Yan
  - → jet production
  - → top quark pair production
- **HERA**
  - → inclusive DIS
  - → jet production
  - → diffraction
  - → low-x data
- **Fixed target**



HERAFitter Functionality



Various forms of parametrisation ansatz

→ HERAPDF, CTEQ style, Chebyshev, bi-log normal

Bayesian Reweighting technique

→ a method to study data sensitivity on PDFs without fitting the data

Regularisation methods

→ constrain PDFs in a flexible parametrisation style

χ^2 function

IMPROVED

→ nuisance parameters
→ covariance matrix
→ mixed

Various types of uncertainty treatment for experimental data:

Hessian - error inflation by a tolerance parameter (nuisance) to accommodate inconsistencies between data sets

Monte Carlo - MC replica method shifting data cross section points randomly within their uncertainties

Offset – correlated sources accommodated in uncertainties

Tools

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→ PDFs in LHAPDF format, tools for pulls and uncertainties

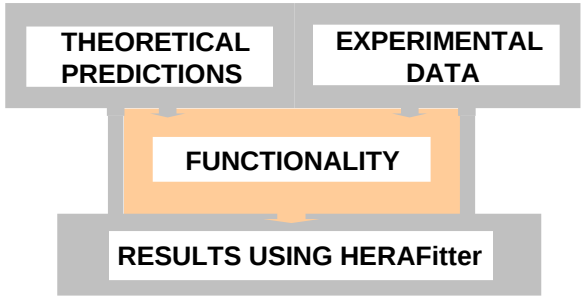
Generic minima finding solution tool

NEW

Lead PDFs

NEW

HERAFitter Functionality



χ^2 function

D - Data
T - Theory

→ nuisance parameters

$$\chi^2 = \sum_i \frac{\left(D_i - T_i^*\right)^2}{\left(\delta_i^{unc}\right)^2}$$

$$T_i^* = T_i + \sum_j \xi_j \delta_i^{cor,j}$$

Correlated error

Nuisance parameter

→ covariance matrix

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

IMPROVED

→ mixed

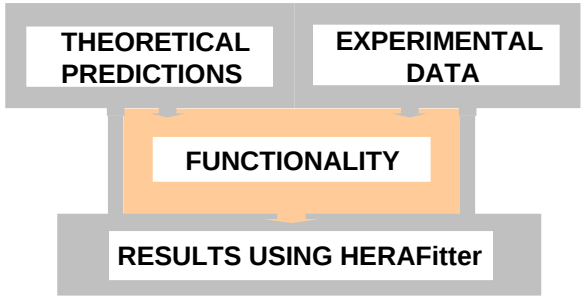
→ uncertainties can be treated as multiplicative or additive

→ various models for bias corrections

→ tool to transform covariance matrix to nuisance parameter representation NEW

→ each correlated systematic source can be modified individually

HERAFitter Functionality



Tools

→ PDFs in LHAPDF format tools for pulls and uncertainties

→ PDFs sets available in LHAPDF5.9.1: HERAPDF1.0, HERAPDF1.5, ATLAS-epWZ12, LHECNLO

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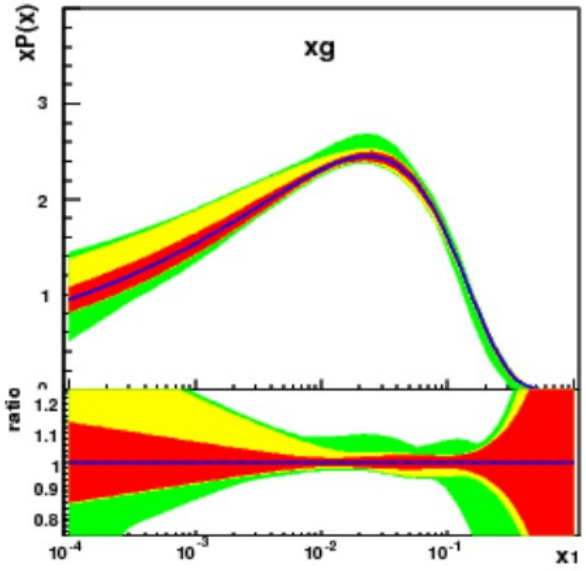
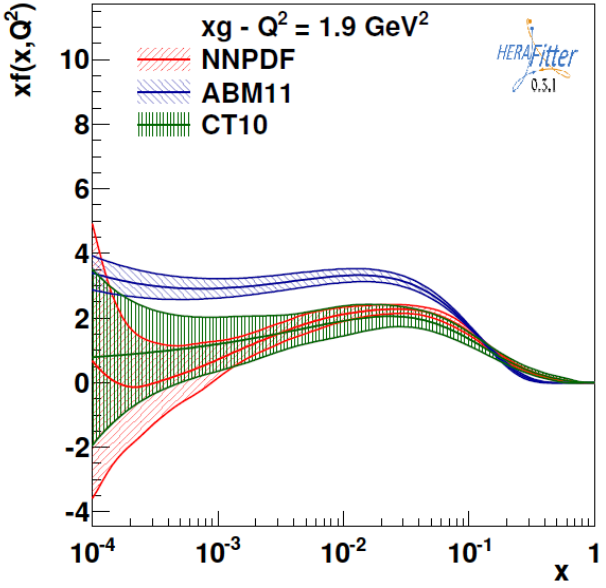
Drawing of different uncertainties (experimental, model, parametrisation)

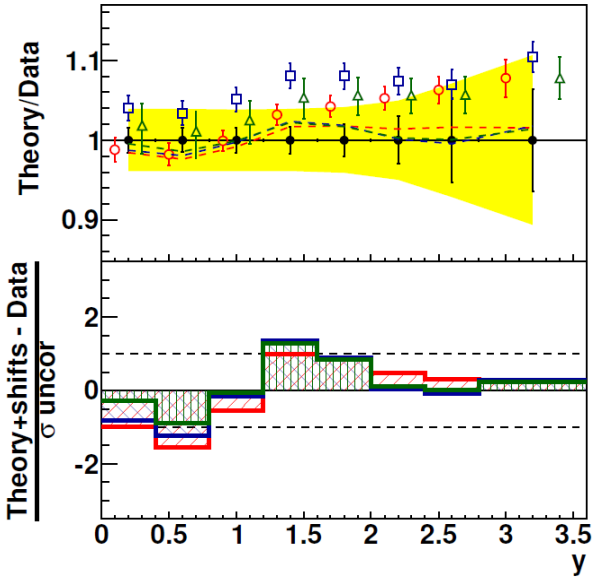


Calculation of theory uncertainties (symmetric and asymmetric, access PDFs via LHAPDF interface)

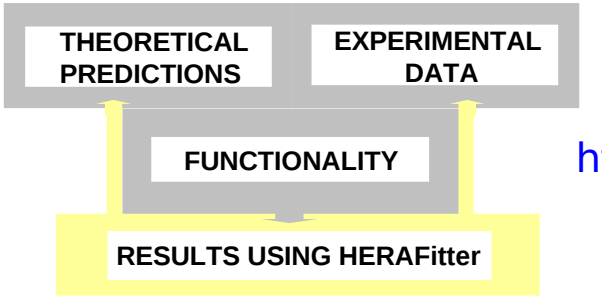


NEW

Data - theory comparison (with uncertainty band and pulls)



HERAFitter Usage



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

"Determination of the strange quark density of the proton from ATLAS measurements of the W→lν and Z→ll cross sections" Phys.Rev.Lett. 109 (2012) 012001

"Measurement of the inclusive jet cross section in pp collisions at √s = 2.76 TeV and comparison to the inclusive jet cross section at √s = 7 TeV using the ATLAS detector" EPJC (2013) 73 2509

"Measurement of the high-mass Drell-Yan differential cross-section in pp collisions at √s = 7 TeV with the ATLAS detector" Phys. Lett. B 725 (2013) 223

In CMS several analyses are using HERAFitter for PDF constraints
→ jets, DY, W+charm data

"Combination and QCD Analysis of Charm Production Cross Section Measurements in Deep Inelastic ep Scattering at HERA" Eur. Phys. J. C73 (2013) 2311

"Inclusive Deep Inelastic Scattering at High Q2 with Longitudinally Polarised Lepton Beams at HERA" JHEP 1209 (2012) 061

LHeC impact studies J.Phys.G39 (2012)

Theory: A.Glazov, A.Moch,V.Radescu "Parton Distribution Uncertainties using Smoothness Prior" Phys.Lett. B 695 (2011) 238

updates of ACOT scheme module (with CTEQ group)

inclusion of photon PDF in QCDNUM (publication is planned)

HERAFitter: Future Developments

Longer term developments planed in HERAFitter:

- **Theory side:**

→ QED+QCD PDFs (generalised evolution in QCDNUM)

→ possibility to interface APFEL (A PDF Evolution with QED corrections)

Top sector:

→ ttbar differential cross sections

→ inclusion of Top++ (total top pair production)

Heavy flavour sector:

→ ACOT scheme at NNLO

→ ACOT scheme inclusion in QCDNUM

→ intrinsic charm

- **Interfaces and code:**

→ APPLGRID interfaces to DYNNLO

→ LHAPDF6 (C++) interface

→ OpenMP (currently exist for RT scheme, planned to extend to ACOT)

- **Others:**

→ fitting photon PDFs

→ different evolution codes, ...

Summary

HERAFitter project

has grown into a multi-functional QCD framework well integrated into the high energy community (both, experimental and theory)

→ first **stable release** with many improvements and additions
→ more flexible data-theory quantitative comparison, various tools added, lead PDFs, etc.

→ long term plans include the implementation of coupled QED+QCD PDFs, new evolution codes, the possibility to fit photon PDFs, etc.

→ DESY physicists play a leading role in the project

herafitter-help@desy.de

Weekly meetings: https://herafitter.org/HERAFitter/HERAFitter/HERAFitterInternal/FitForumMeetings
Monthly meetings: https://herafitter.org/HERAFitter/HERAFitter/HERAFitterMeetings

Back-up

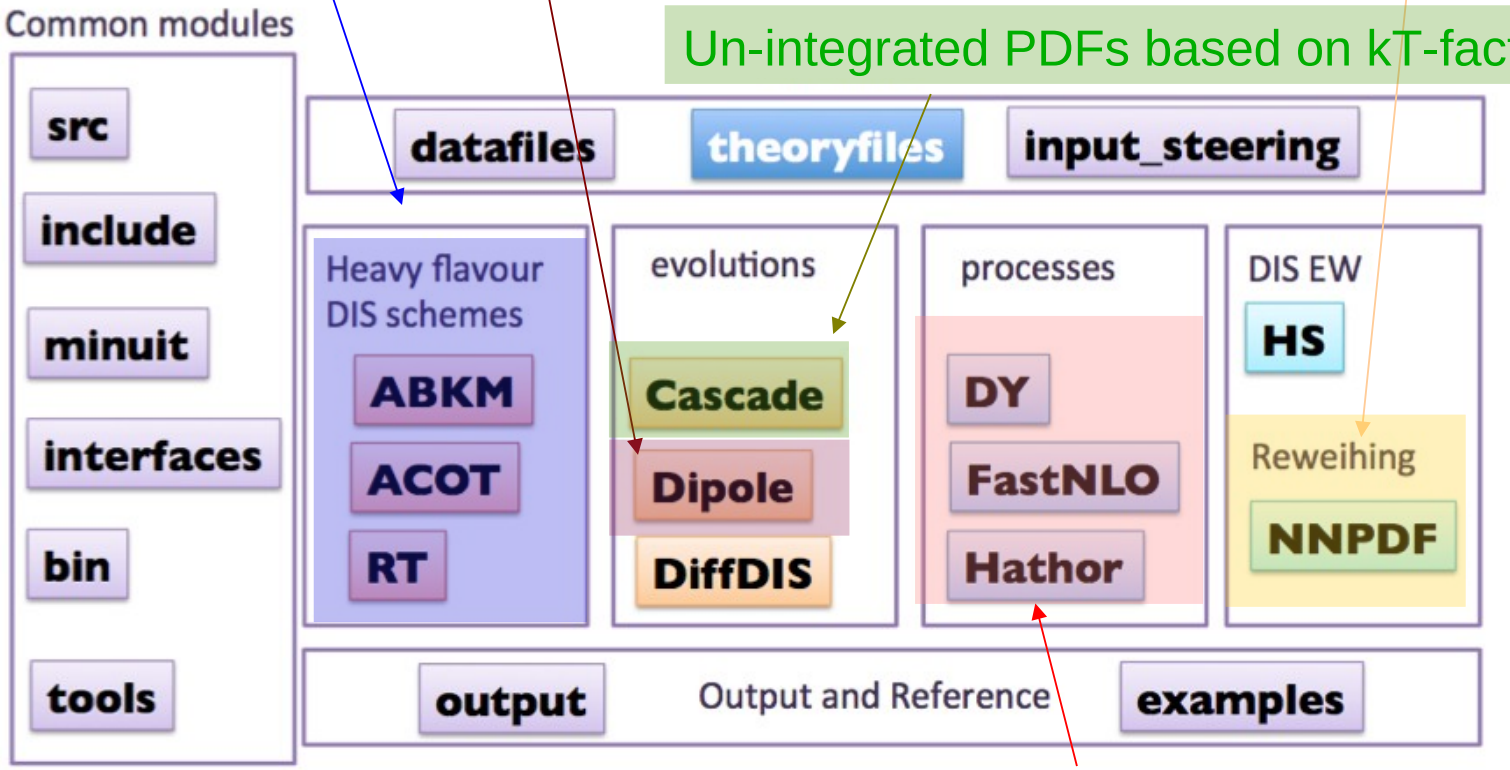
HERAFitter functionality

DIS: VFNS (ACOT, RT, ZM) and FFNS

Different dipole models

Regularisation techniques (data driven or external)

Un-integrated PDFs based on kT-factorisation



Various χ^2 representations,
Hessian and MC replica methods,
various data uncertainty treatments,
etc...

Interfaces to:
APPLGRID
FastNLO
HATHOR

Download

HERAFitter / DownloadPage

Releases of the HERAFitter 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: HERAFitter_release_notes.pdf.

Date	Version	Files	Remarks
06/2013	0.3.1	herafitter-0.3.1.tgz	fix release includes manual-0.3.1.pdf and decoupled theoryfiles.tgz
03/2013	0.3.0	herafitter-0.3.0.tgz	release includes manual-0.3.1.pdf and decoupled theoryfiles.tgz
07/2012	0.2.1	herafitter-0.2.1.tgz	fix release for 0.2.0
05/2012	0.2.0	herafitter-0.2.0.tgz	added functionality for LHC users
09/2011	0.1.0	herafitter-0.1.0.tgz	first release

Documentation

- From 0.3.0 on a manual is provided together with an example directory.
- The **README** file (accessible via the package) gives an explanation for a quick start.

Web access to SVN

- For users with a valid DESY account, the SVN repository is accessible on the web at https://svnsrv.desy.de/k5viewvc/h1fitter .
- For users without DESY account, the SVN repository is accessible on the web at https://svnsrv.desy.de/basviewvc/h1fitter/ with herafitter-user@desy.de account and PDFfits password.

Doxygen Documentation

- The doxygen documentation is located here

Links to external packages

External packages that could be run with HERAFitter via configuration flags can be accessed for convenience HERE .

HERAverager data combination package

Information can be accessed here https://wiki-zeuthen.desy.de/HERAverager.

Subscription

We encourage users to subscribe to mailing list for news and updates related to the HERAFitter webpage. (average rate of e-mails is once a month), please contact herafitter-help@desy.de (or by creating a user account to this wiki we get a notification)

Releases (publicly accessible)

Documentation: manual, release notes, README, DOXYGEN

External packages

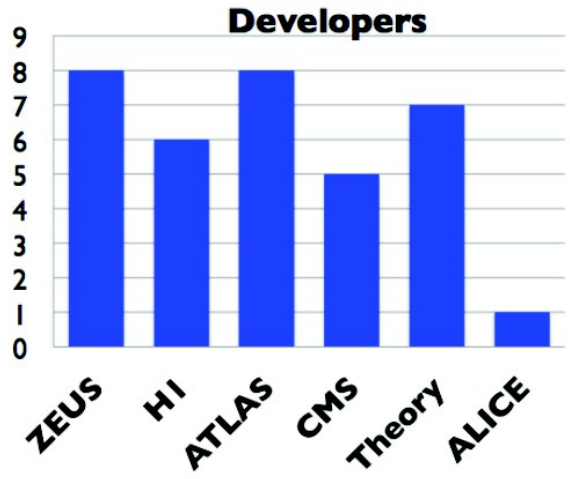
HERAFitter Project Structure

Organisation:

- **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
- **Contact Persons:** Cristi Diaconu (H1),Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS), Olaf Behnke (ZEUS), Ronan McNulty (LHCb), Gavin Salam (theory)
- **Steering Group:** Voica Radescu, Ringaile Placakyte, Sasha Glazov, Amanda Cooper-Sarkar, Gavin Salam (theory), Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS), Ronan McNulty (LHCb), Olaf Behnke (ZEUS), Cristi Diaconu (H1, chair)

Users: LHC experiments, theory groups, independent users

Developers: H1 and ZEUS, ATLAS, CMS, LHCb, active support by theory group



→ project is steered by DESY physicists

→ in close relation to dedicated PDF forums in Atlas and CMS collaborations