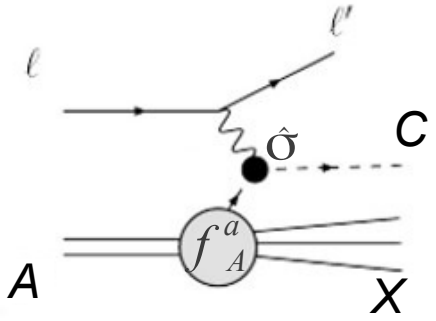
HERAFitter — open source QCD Fit framework and its related studies

V. Myronenko (DESY)
on behalf of HERAFitter developers

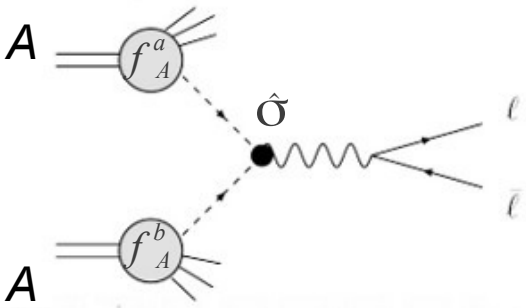
PANIC conference
Hamburg, Germany 28.08.2014

Motivation



According to the **factorisation theorem,** the hadronic cross section is a convolution of **PDFs** and **hard-scattering cross section**

$$l + A \to l' + C + X: \quad \sigma^{i}_{A\to C}(q, p) = \sum_{a} \int_{x}^{1} d\xi\, f^{a}_{A}(\xi, \mu)\, \hat{\sigma}^{i}_{a\to C}(q, \xi p, \mu, \alpha_s)$$



PDFs are **universal** => essential ingredients for precision measurements at LHC.

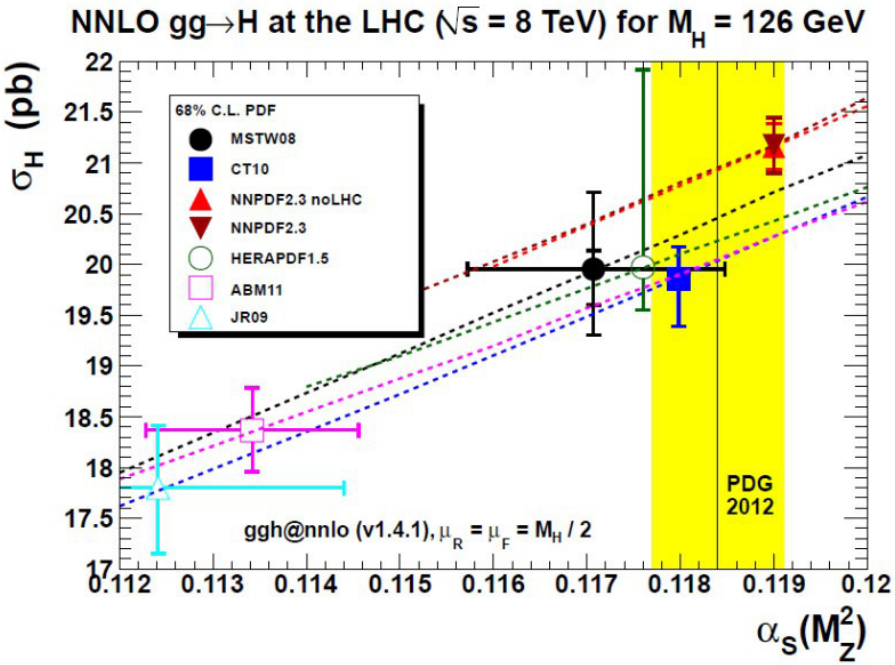
PDFs uncertainties are one of dominant in **SM Higgs** cross sections, $\mathbf{M_W}$ measurements, predictions for **high scale BSM** production etc.

Differences among global PDF sets:

- use of various data sets;
- use of different extraction methods.

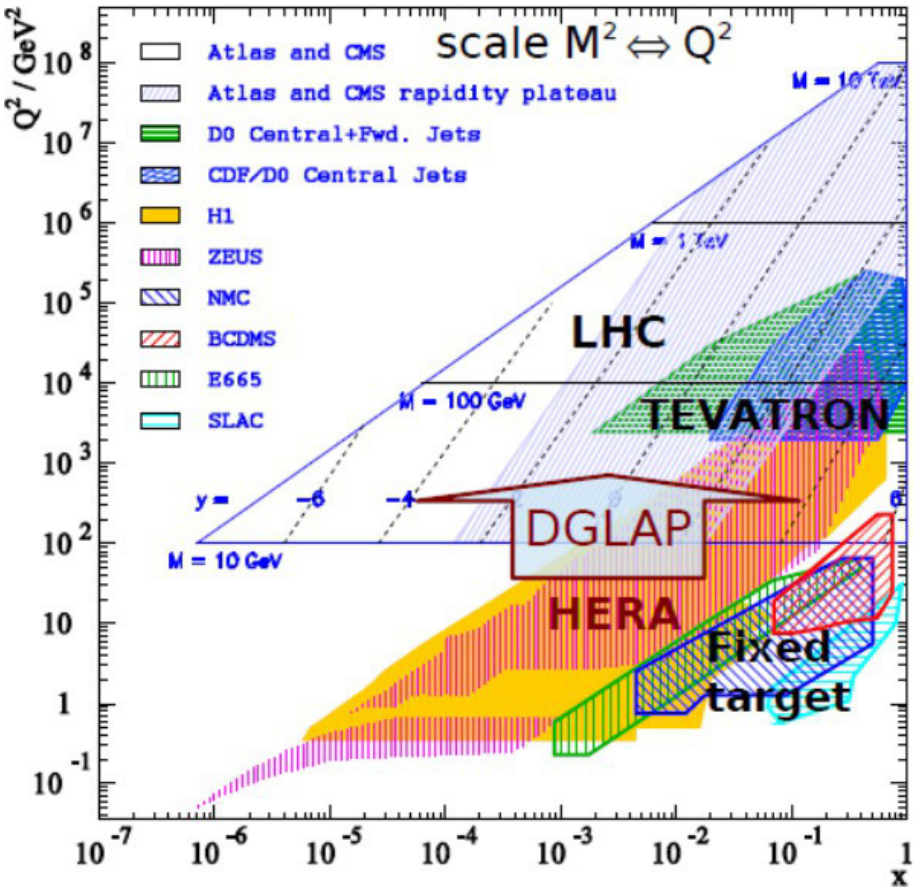
Differences in predictions that need to be understood

G. Watt (November 2012)



Motivation

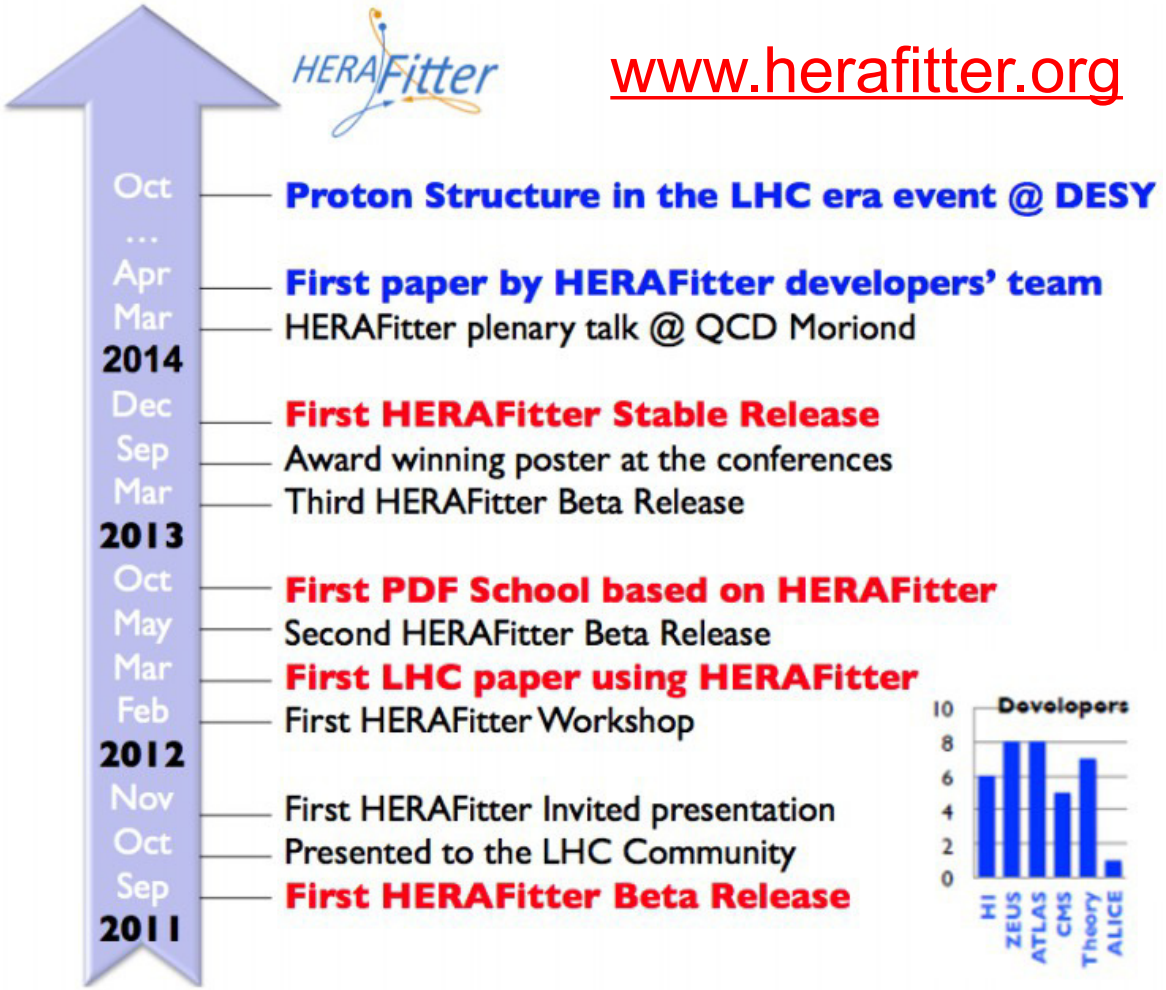
- Current knowledge on PDFs is dominated by the HERA data.
  - Probes linear combination of quarks.
  - No information on flavor decomposition of the sea
- More information from LHC and TEVATRON.
  - Inclusive jets and dijets → gluon and α_s.
  - W/Z production → flavor separation.
  - W+charm → direct sensitivity to strange.
  - Prompt γ → gluon at medium and high x.
  - W/Z + jet production → gluon at medium x.
  - Top production → gluon, u- ans d-quarks.



- PDFs are evolved up in scale using the DGLAP equations to make predictions for LHC cross sections

HERAFitter project

- HERAFitter is an open source QCD fit platform with a continuing rapid development.



- HERAFitter provides a framework for:
  - Addressing theoretical differences and benchmarking.
  - Studying an impact of new data to PDFs.
- HERAFitter is developed by collaboration of experimentalists from HERA (H1 and ZEUS), LHC (ALICE, ATLAS, CMS), theorists. (~30 developers)

PDF extraction in HERAFitter

Input Data

Data type:

- Collider ep, fixed target
- Collider pp, ppbar

Theory predictions

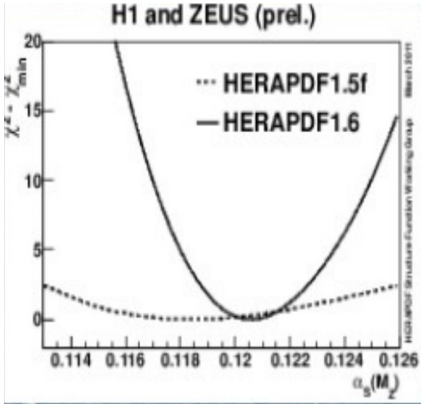
Factorization theorem:

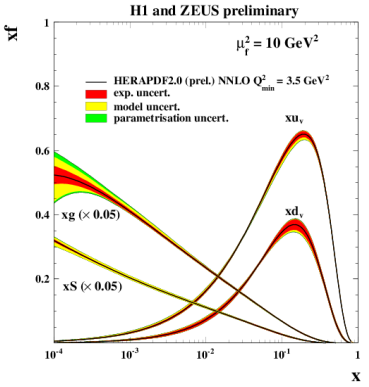
- PDF parametrisation
- QCD evolution (QCDNUM)
- Cross section calculation

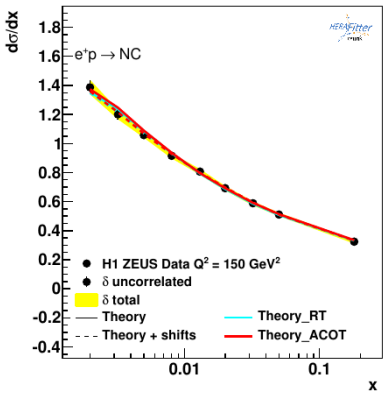
- Important to provide correlation information.
- Important to have fast tools to perform PDF fits (APPLGRID, FASTNLO)
- Performance: 15min - 3h.

QCD Analysis

- Fast χ^2 computation
- Minimisation (MINUIT)
- Uncertainty treatment







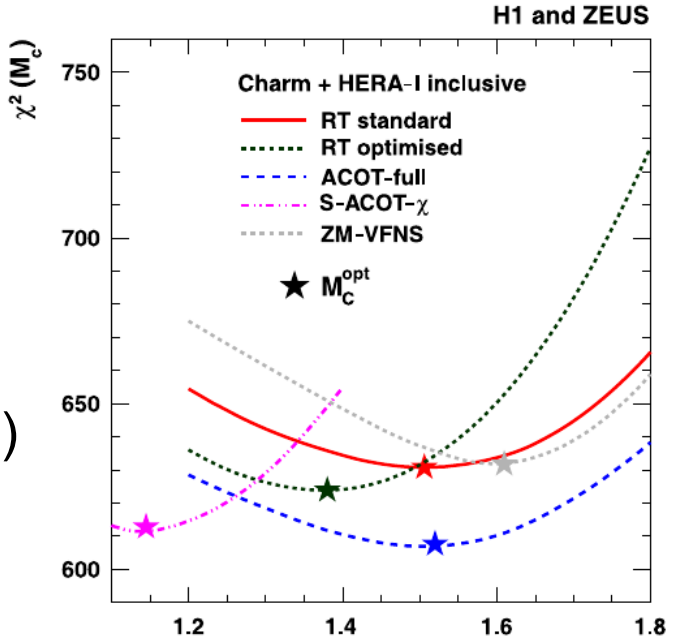
Results

- LHAPDF grids.
- α_S, m_c, m_b, ...
- Data vs theory comparison.
- χ^2, shifts, pulls.

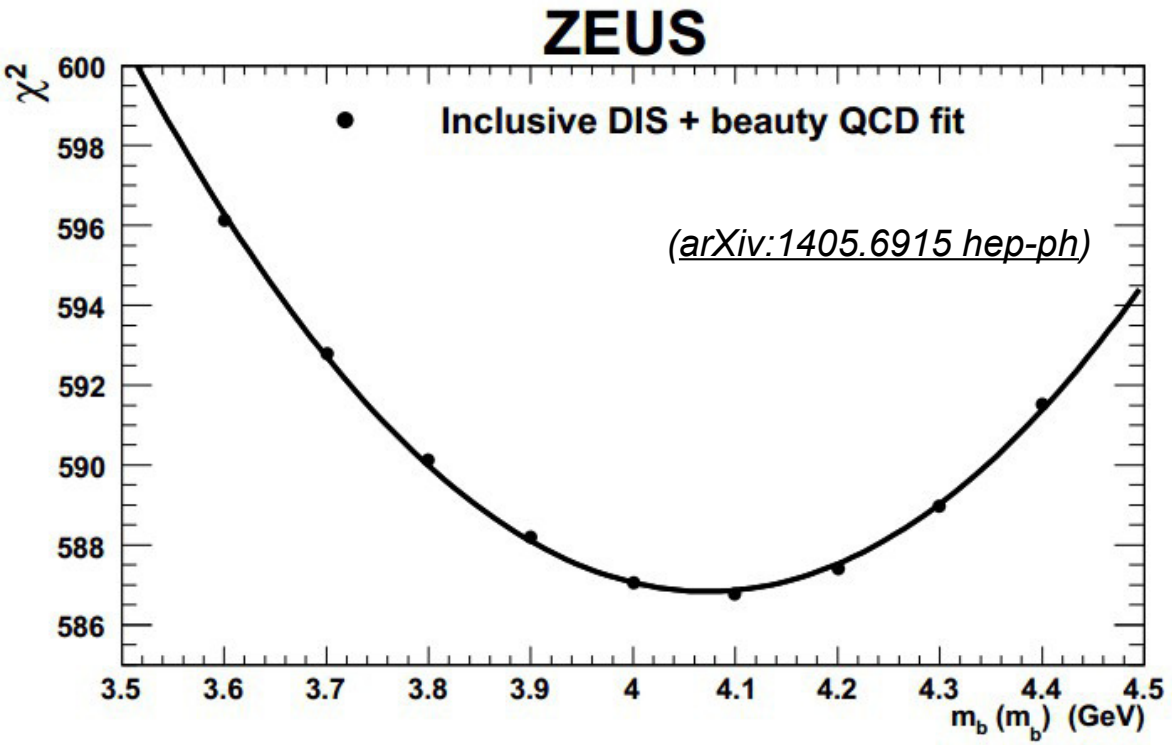
HERAFitter functionality (HF schemes)

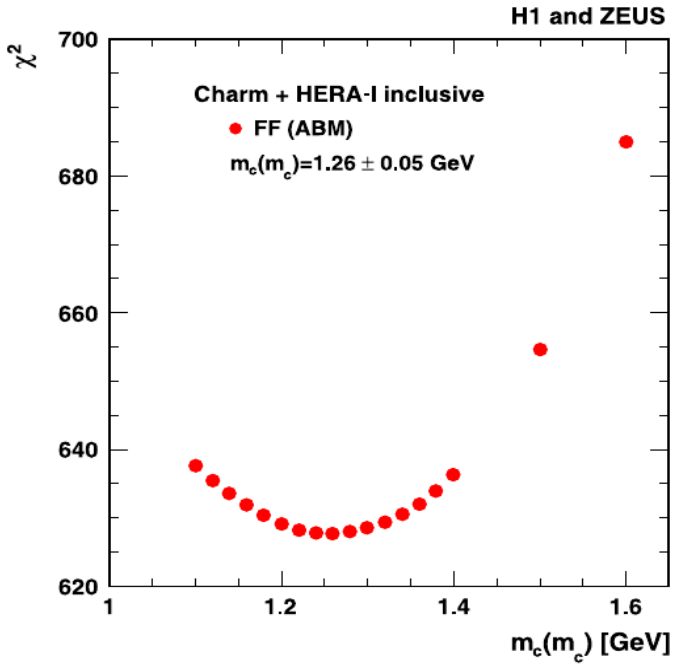
Various heavy flavour schems are available for usage:

- VFNS (variable flavour number scheme)
  - RT-VFNS: used by MSTW group
  - ACOT (ACOT Full, ACOT Chi, ACOT ZM): used by CT
  - ZM VFNS (zero mass variable flavour number scheme)
- FFNS (fixed flavour number scheme): used by ABM



(Eur. Phys. J. C73 (2013) 2311)





HERAFitter functionality (χ^2 definition and error estimation)

Various types of χ^2 definitions can be used:

- Nuisance parameter representation;

$$\chi^2 = \sum_i \frac{\left[m_i - \sum_j \gamma^i_j b_j - \mu_i\right]^2}{\delta^2_{i,uncor} m_i^2 + \delta^2_{i,stat} \mu_i m_i \left(1 - \sum_j \gamma^i_j b_j\right)} + \sum_j b_j^2 + \sum_i \ln \frac{\delta^2_{i,uncor} m_i^2 + \delta^2_{i,stat} \mu_i m_i}{\delta^2_{i,uncor} \mu_i^2 + \delta^2_{i,stat} \mu_i^2}$$

- Covariance matrix representation;

$$\chi^2 = \sum_{ij} (m_i - \mu_i) C^{-1}_{ij} (m_j - \mu_j)$$

- Mixed form (covariance form & nuisance parameters);

$$\chi^2 = \sum_{ij} \left(m_i - \sum_k \Gamma^i_k(m_i) b_k - \mu_i\right) C^{-1}_{ij}(m_i, m_j) \left(m_j - \sum_k \Gamma^j_k(m_j) b_k - \mu_j\right) + \sum_k b_k^2$$

Various types of uncertainty estimation are available:

- **Hessian** – nuisance parameters are fitted, χ^2 tolerance T > 1 can also be used to account for marginally compatible input data sets.

- **Offset method** – nuisance parameters are applied as 1σ shifts.

- **MC method** – data points are shifted randomly within 1σ limits to form MC replicas.

Results obtained using 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

www.herafitter.org

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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
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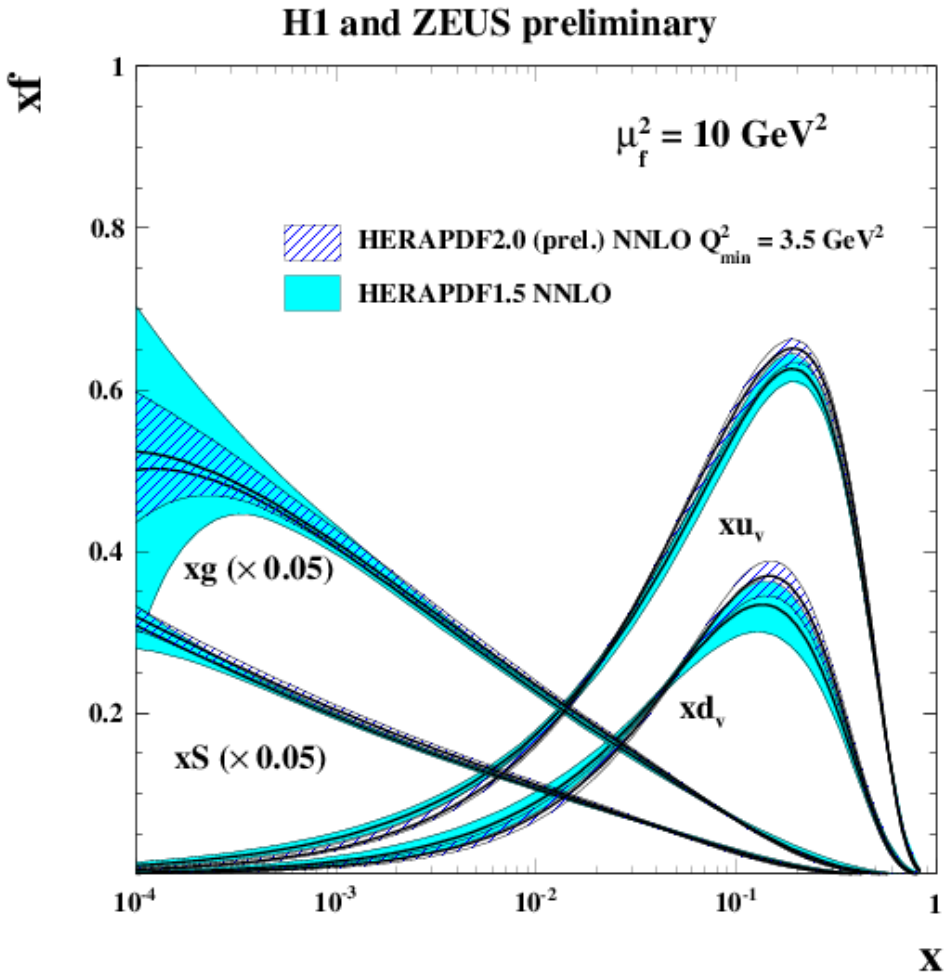
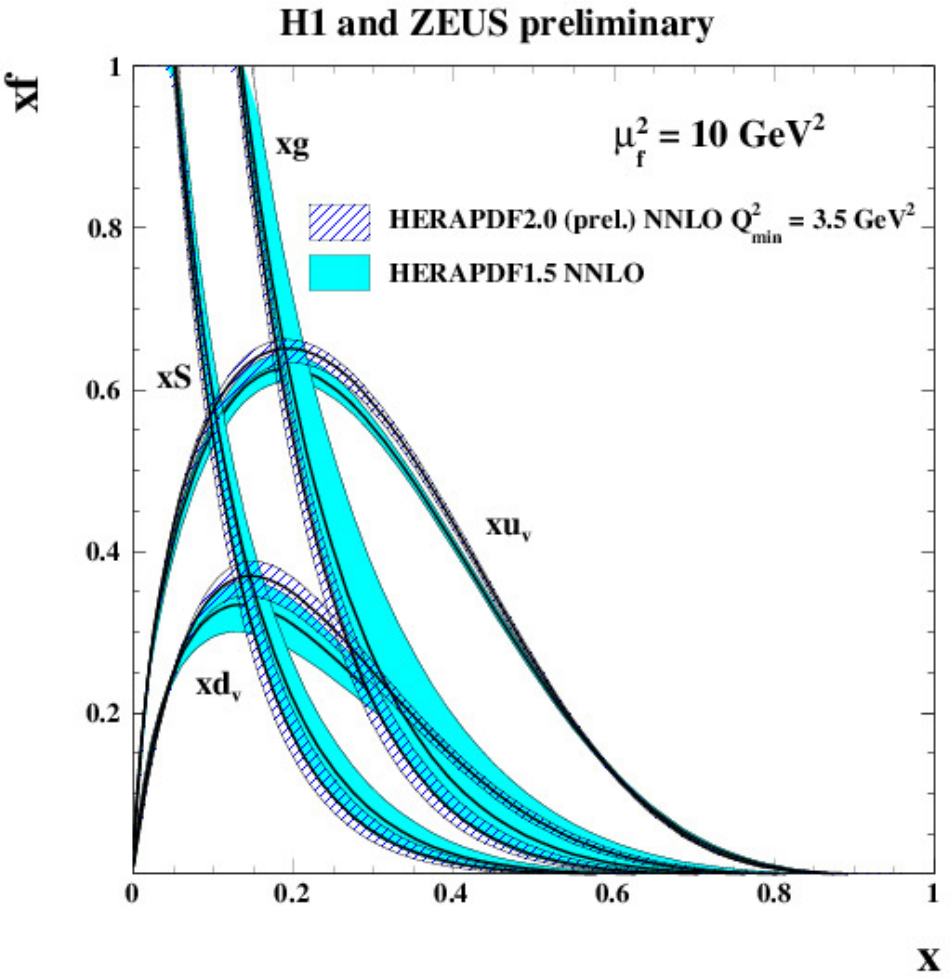
2013	LHC/ATLAS	EPJC (2013) 73 2509	Measurement of the inclusive jet cross section in pp collisions at sqrt(s) = 2.76 TeV and comparison to the inclusive jet cross section at sqrt(s) = 7 TeV using the ATLAS detector
2013	LHC/ATLAS	Phys.Rev.Lett. 109 (2012) 012001	Determination of the strange quark density of the proton from ATLAS measurements of the W -> l nu and Z -> 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 Q2 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 production

Combined HERAI+II data is used for PDF extraction. (See talk by A. Cooper-Sarkar)





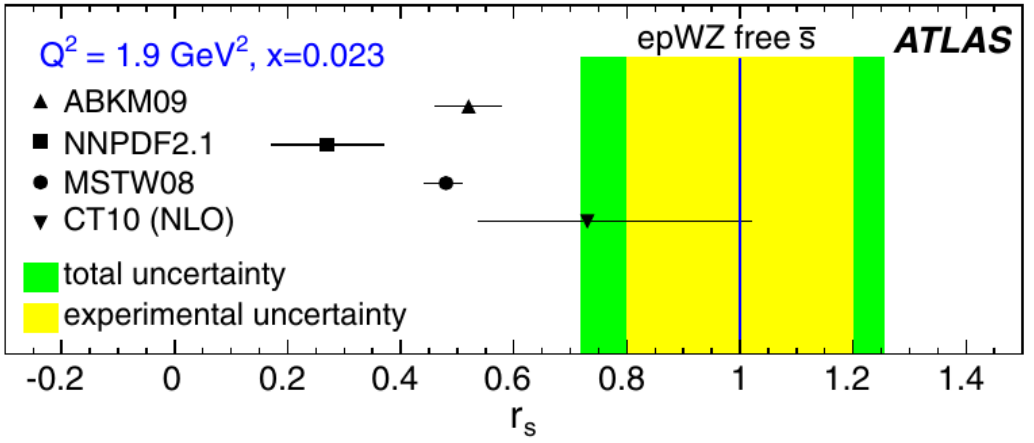
Data combination was performed using HERAverager

wiki-zeuthen.desy.de/HERAverager

Strange quark at 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)

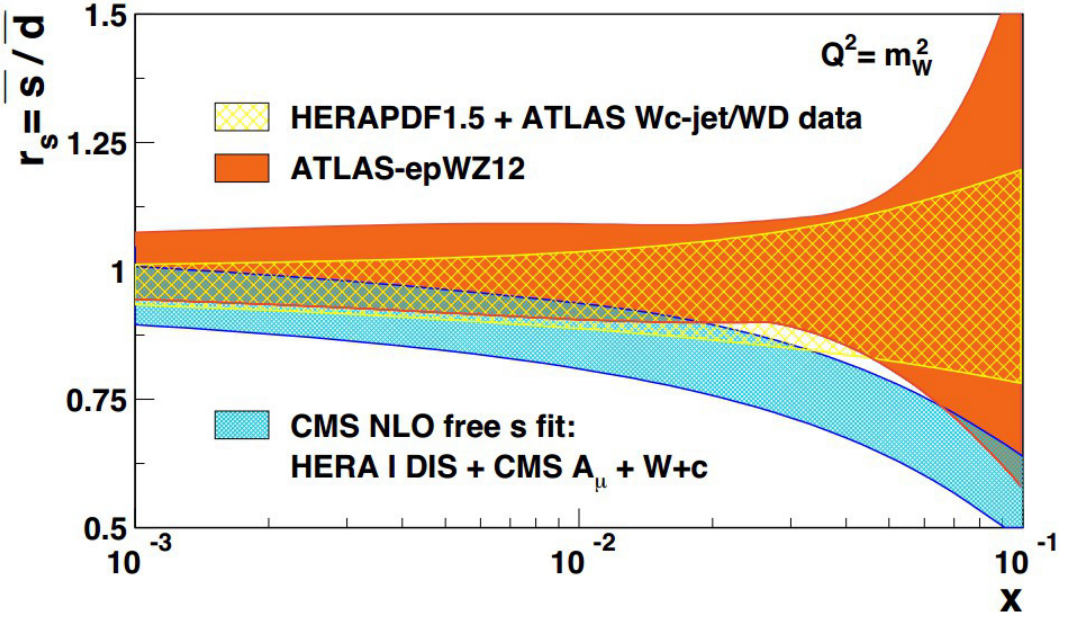


- W + charm data including W asymmetry were used to measure the strange quark distribution.

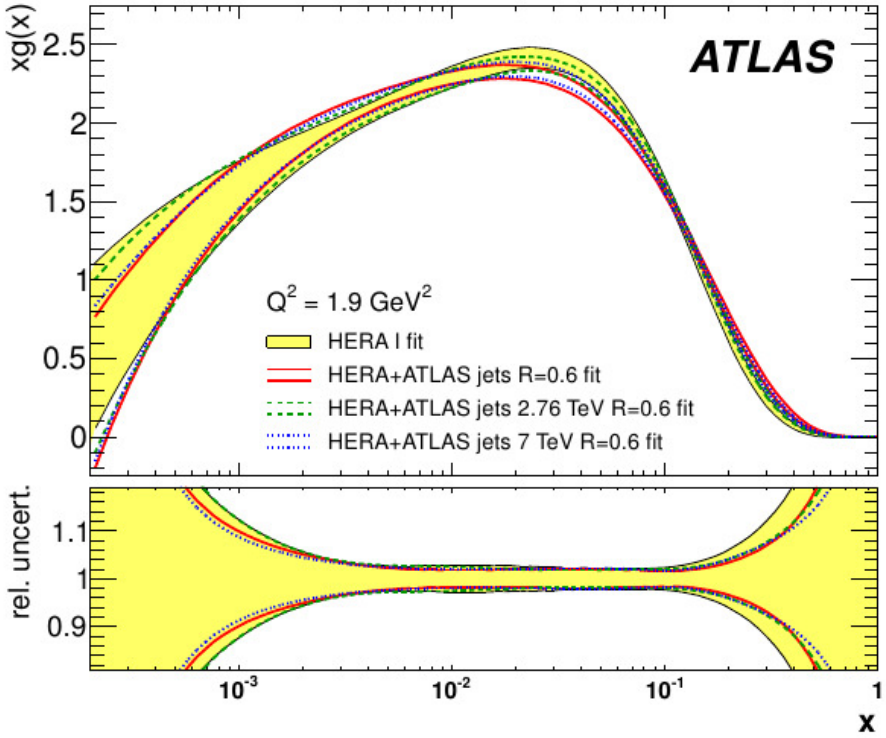
(PRD 90 (2014) 032004)

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

(arXiv: 1402.6263)

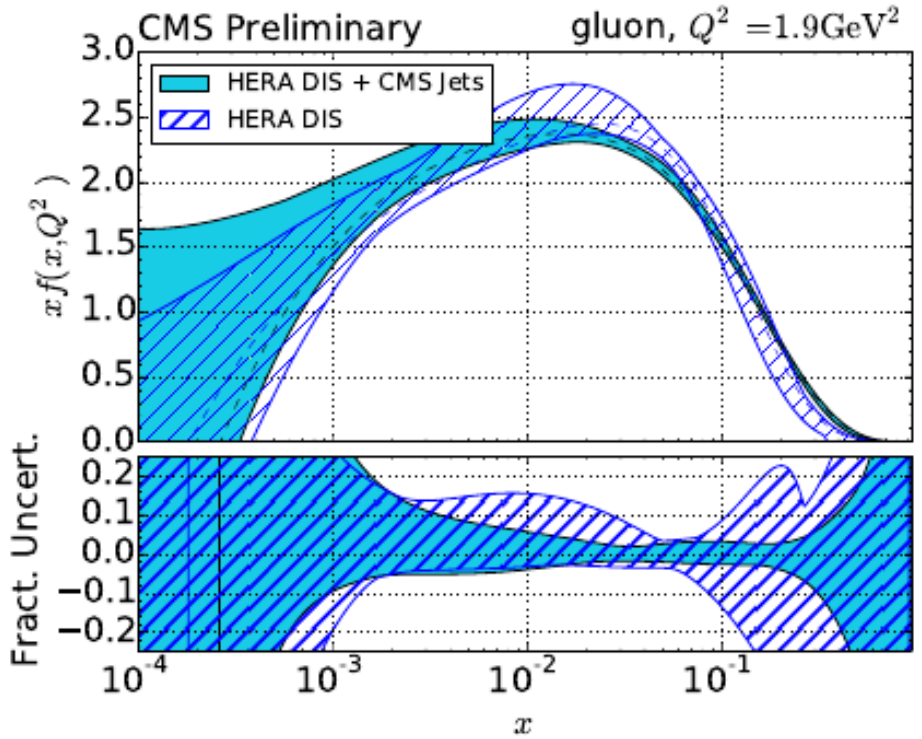


Sensitivity to gluon at LHC



- 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)

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PDFs at LO, NLO, NNLO with correlated errors between orders

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.

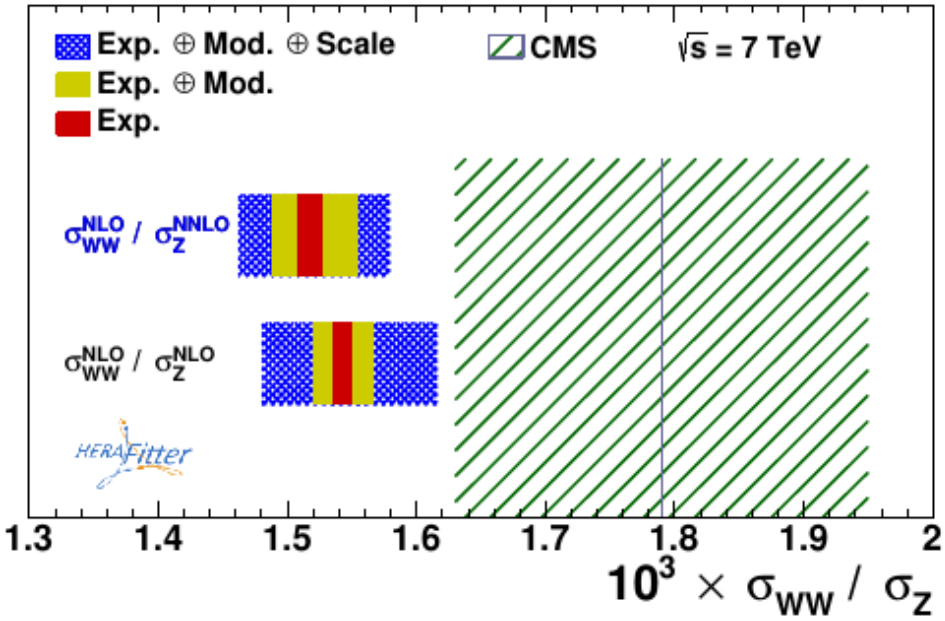
(arXiv:1404.4234 hep-ph)

PDFs at LO, NLO, NNLO with correlated errors between orders

- Predictions of the ratio WW to Z production cross sections are compared to the CMS measurement *(Eur. Phys. J. C73 (2013) 2610)*

Ratio	Value $\times 10^{-3}$	Exp. PDF $\times 10^{-3}$	Mod. PDF $\times 10^{-3}$	Scale $\times 10^{-3}$
$\frac{\sigma_{WW}^{NLO}}{\sigma_{Z}^{NLO}}$	1.543	± 0.008	$^{+0.023}_{-0.021}$	$^{+0.069}_{-0.058}$
$\frac{\sigma_{WW}^{NLO}}{\sigma_{Z}^{NNLO}}$	1.517	± 0.010	$^{+0.036}_{-0.027}$	$^{+0.050}_{-0.046}$

(arXiv:1404.4234 hep-ph)



- Usage of the mixed-order NLO – NNLO predictions allows reduction (by ~ 30-40%) of the total uncertainty due to the reduction of the scale uncertainty for Z production predictions.

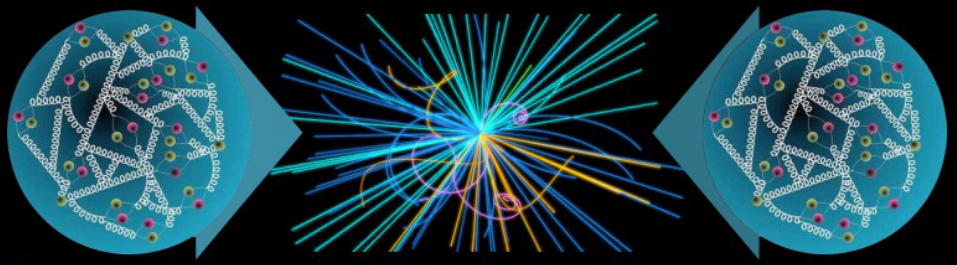
- PDFs are planned to be released in LHAPDF6: HF14cor*.

Helmholtz Alliance "Physics at the Terascale" and the CTEQ collaboration

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

Registration deadline: 15th September 2014
Registration fee: 40 €
Contact: anacen@desy.de

HERAFitter

CTEQ

PHYSICS AT THE TERA SCALE Helmholtz Alliance

DESY

www.terascale.de/pdf2014

Summary

- HERAFitter project - a multi-functional QCD framework well integrated into the high energy community (both, experimental and theory)
  - open to everyone and everyone can contribute
  - first **stable release** HERAFitter-1.0.0 (Dec 2013)
- Stable release: herafitter-1.0.0, can be found at www.herafitter.org.
- Sets of LO, NLO and NNLO PDFs with correlated uncertainties at different orders were extracted using HERAFitter *(arXiv:1404.4234 hep-ph)*
- Proton structure in the LHC era: school & workshop (29.09 – 2.10)
  www.terascale.de/pdf2014