HERAFitter
Open Source QCD Fit Platform

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for the HERAFitter team

Outline:

- Motivation
- Project overview
- Applications and results

Motivation

PDFs are essential for precision physics at the LHC:

- PDFs are one of the main uncertainties in Higgs production, Mw measurements etc.
- Affect theoretical predictions for BSM high mass production.

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

- Leads to differences in the cross section predictions

➔ **Crucial to understand theoretical differences**

➔ **Important to provide accurate data together with correlation information for better PDF discrimination**

Proton Structure

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

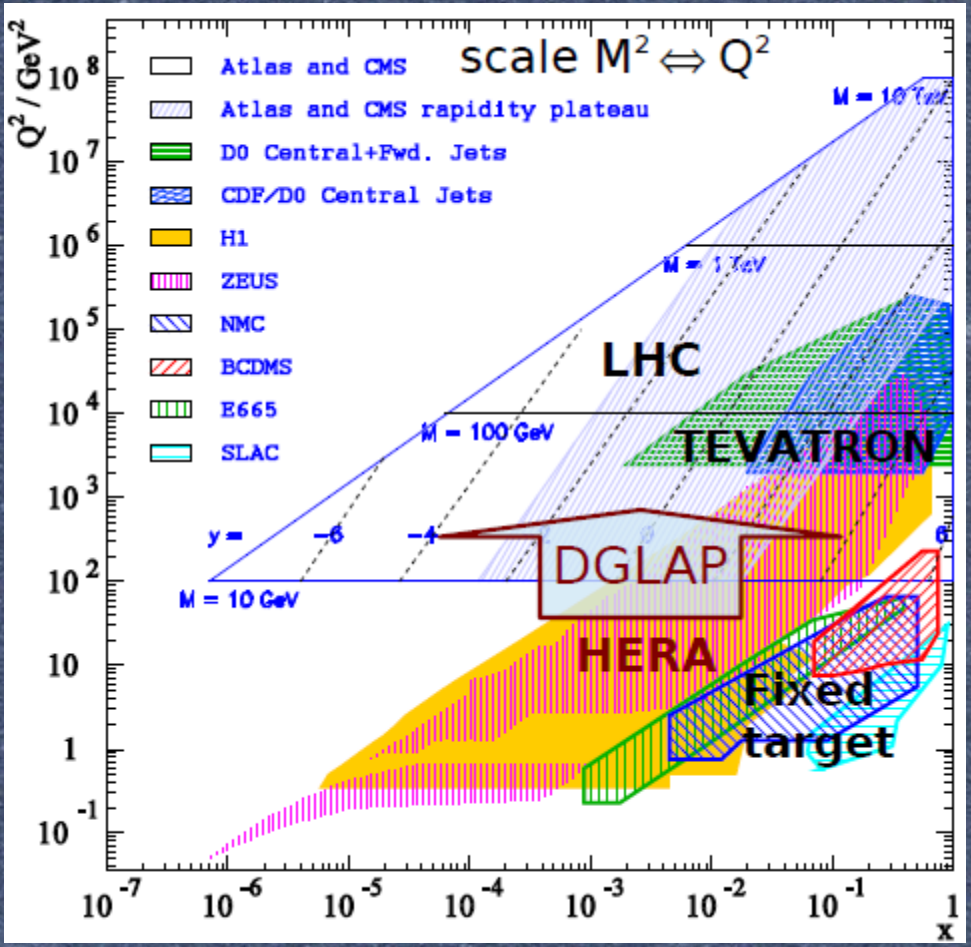
cross section: PDFs ⊗ hard scattering coefficients

Main information on PDFs comes from DIS data at HERA, which probes linear combination of quarks.

- No information on flavour decomposition of the sea

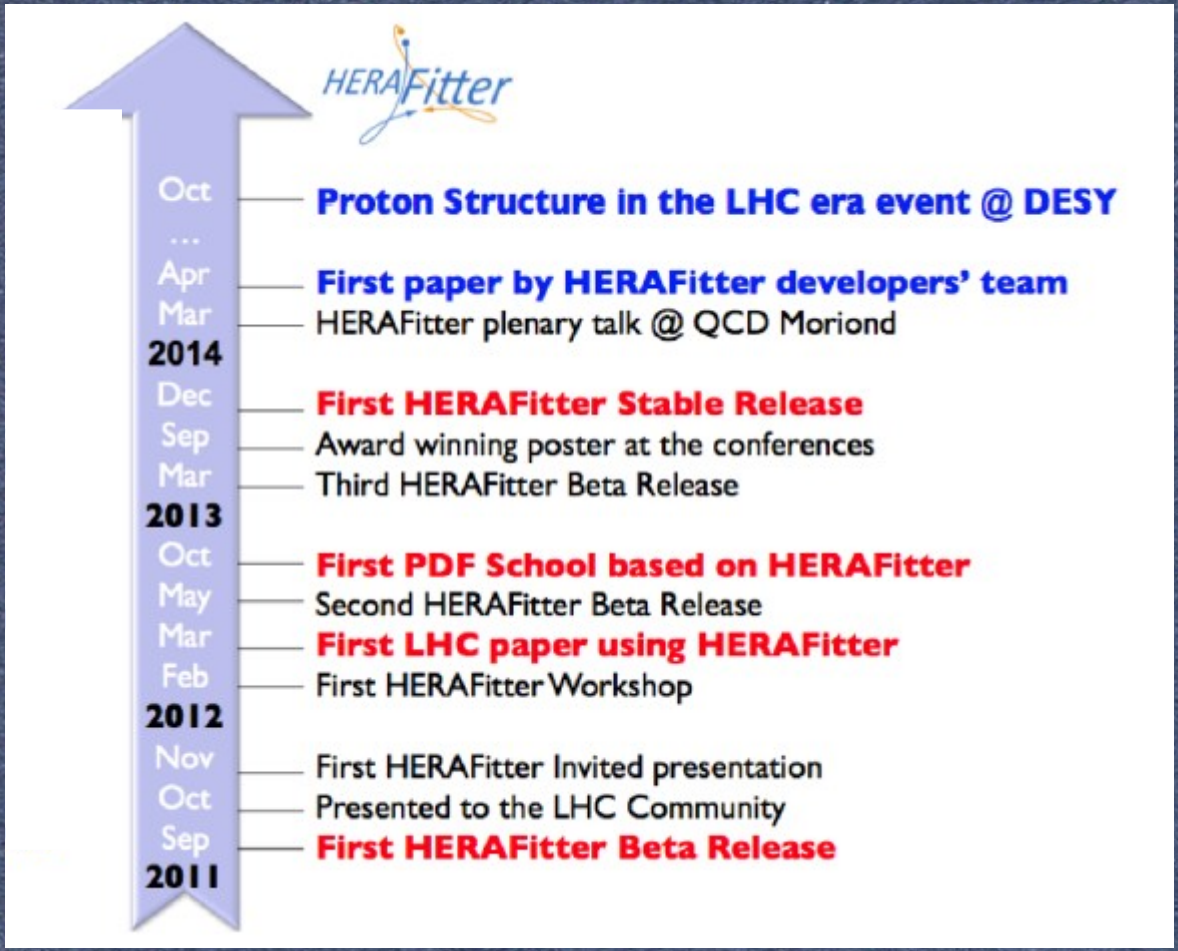
LHC data provide flavour separation and better understanding of gluon:

- Inclusive jets and dijets → gluon and alphas
- W / Z production, asymmetry → flavour separation
- W+charm → direct sensitivity to s-quark
- Isolated photons → gluon at medium and high x
- W / Z + jet production → gluon at medium x
- Top production → gluon, u and d



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 impact of new data on PDFs

PDF Extraction in HERAFitter

Modular structure of HERAFitter:

Initialization

Input Data

Data Type:
- collider ep
- collider pp, ppbar
- fixed target

Theory Predictions

Factorisation Theorem:
- PDF parametrisation
- QCD evalution
- cross section calculation

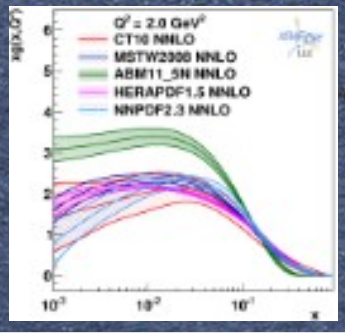
Minimisation

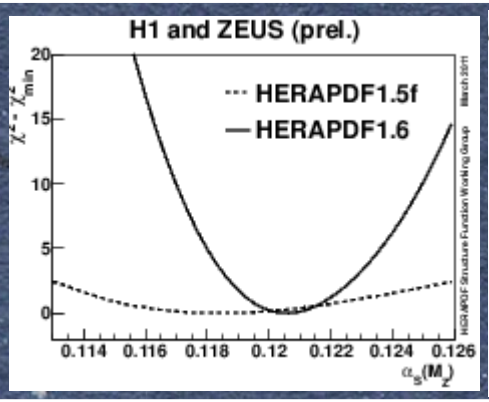
Treatment of uncertainties:
- Nuisance parameters
- Covariance matrix
- Monte Carlo method

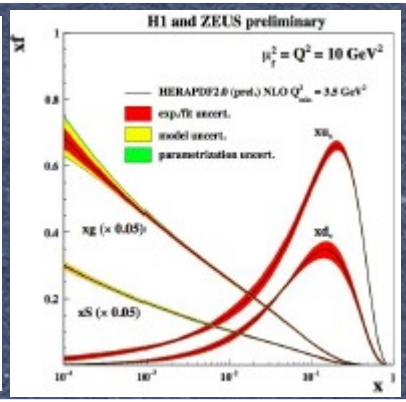
- Performance: 15min – 2h
- Fast tools needed to perform PDF fits: APPLGRID, FASTNLO

Results

- LHAPDF grids
- alphas, mc, …
- data to theory comparison
- χ^2, shifts, pulls







χ^2 Definitions and Experimental Uncertainties

HERAFitter package allows for various types of data uncertainty treatment

- χ^2 representation using:
  - nuisance parameters

$$\chi^2(m,b) = \sum_i \frac{\left[\mu_i - m_i\left(1-\sum_j \gamma_j^i b_j\right)\right]^2}{\delta_{i,\mathrm{unc}}^2 m_i^2 + \delta_{i,\mathrm{stat}}^2 \mu_i m_i \left(1-\sum_j \gamma_j^i b_j\right)} + \sum_j b_j^2$$

  - covariance matrix

$$\chi^2(m) = \sum_{i,j}(m_i-\mu_i)C_{ij}^{-1}(m_j-\mu_j). \quad C_{ij} = C_{ij}^{stat} + C_{ij}^{uncor} + C_{ij}^{sys}.$$

  - mixed (covariance and nuisance)

- Various types of uncertainty treatment:
  - Hessian - error inflation by nuisance parameters to accommodate inconsistencies between data sets
  - Monte Carlo - MC replicas by shifting data points randomly within their uncertainties.
  - Offset - correlated sources accommodated in uncertainties

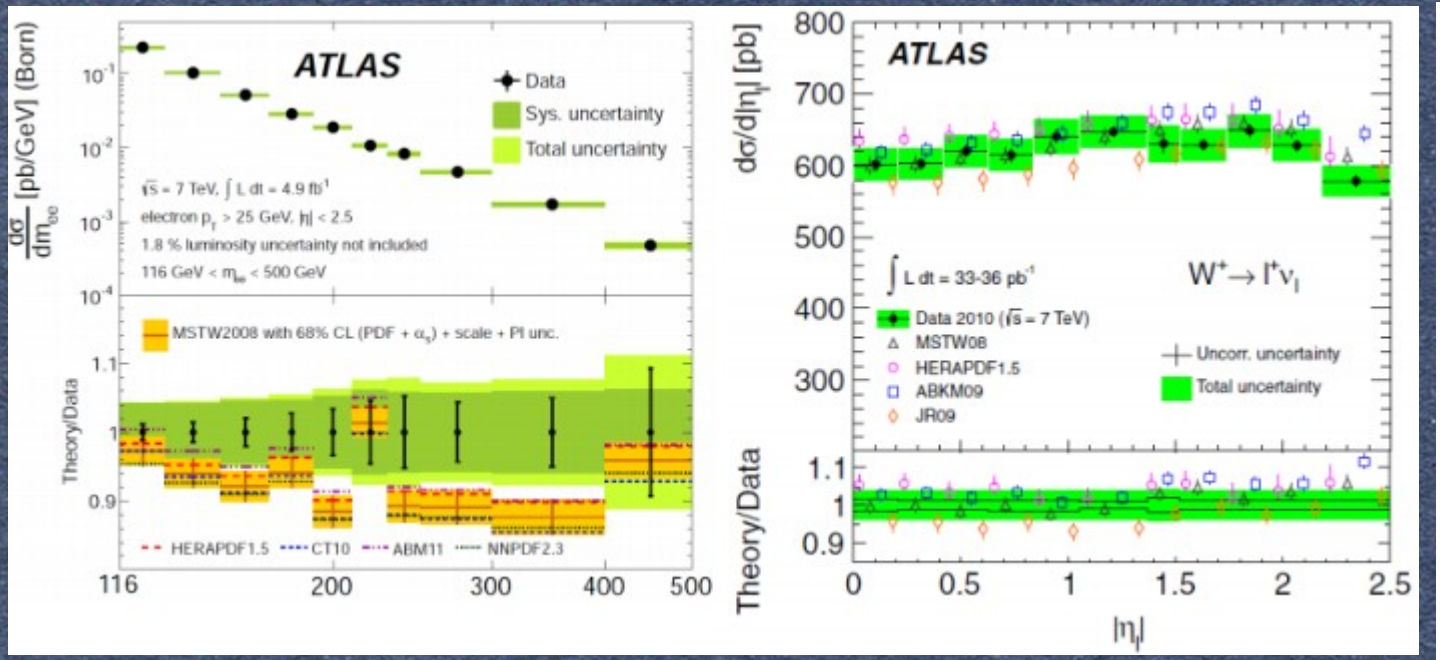
➔ **The platform is used in various benchmark exercises.**

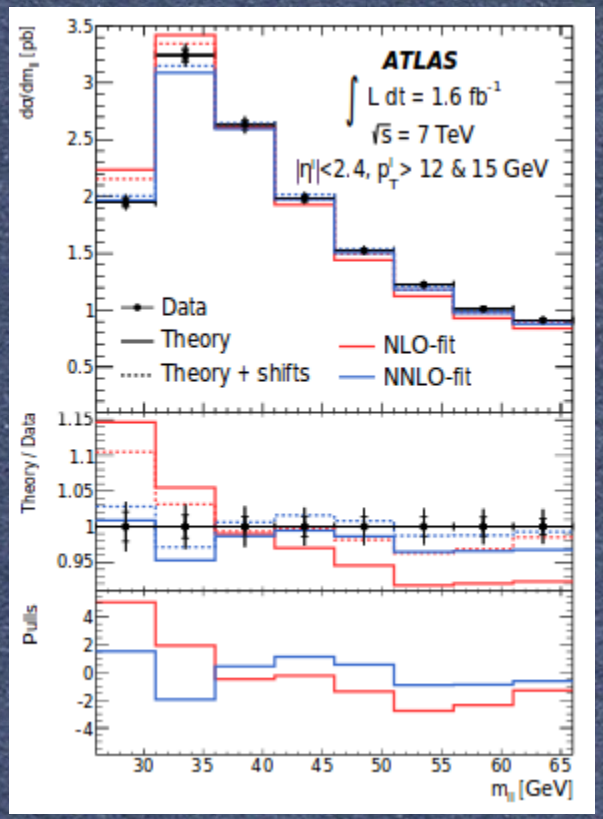
Quantitative Comparison between Data and Theory

HERAFitter provides a quantitative assessment of level of agreement between data and theory by taking into account theoretical and experimental uncertainties.

Used in ATLAS publications:

Phys. Lett. B 725 (2013) 223 *Phys. Rev. D 85 (2012) 072004* *arXiv:1404.1212*





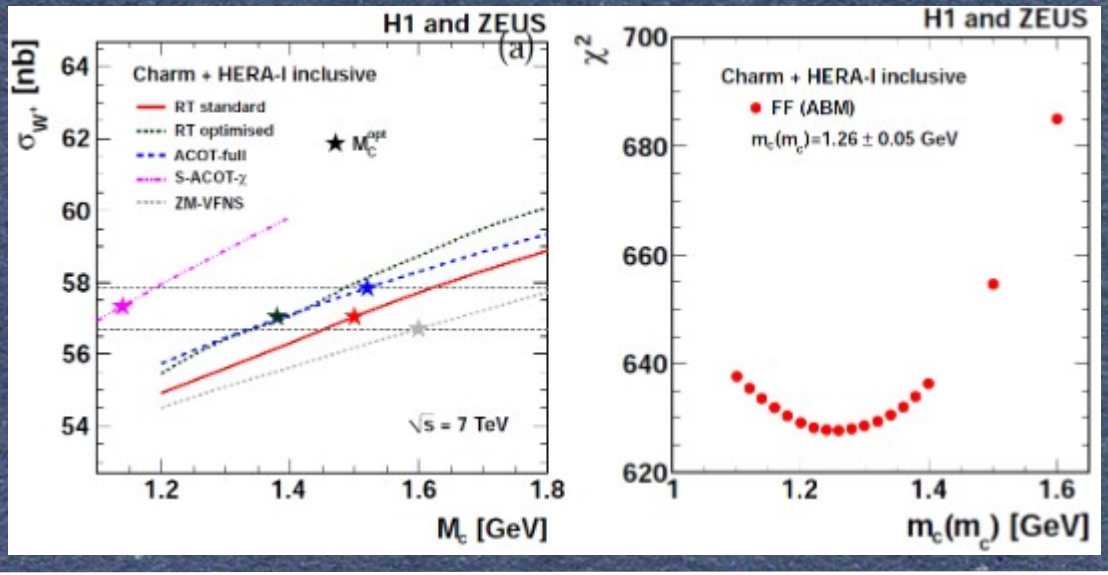
Heavy Flavour Schemes

Several schemes for heavy quark treatment in DIS processes:

- Variable Flavour Number Schemes *(VFNS)*
  - RT-VFNS schemes (Standard, Optimal) as used by MSTW group
  - Zero Mass VFNS
  - Various ACOT (Full, Chi, ZM) schemes, based on k-factors as used by CT group.

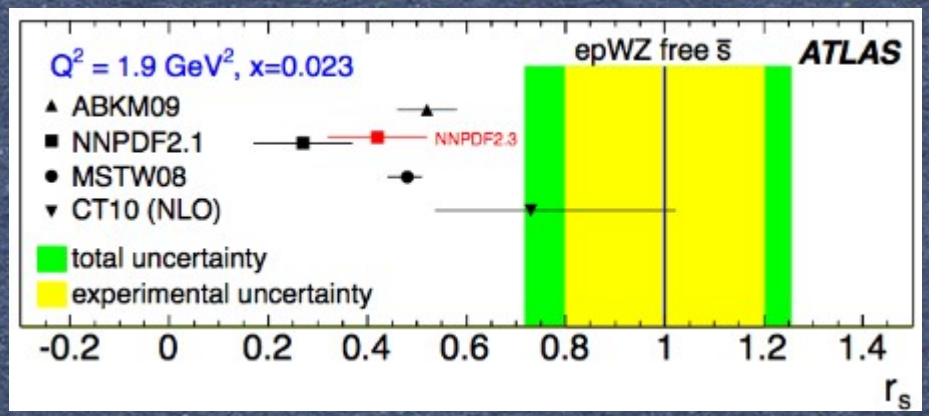
- Fixed Flavour Number Scheme *(FFNS)*
  - via QCDNUM
  - via QCDRAD (ABM)

- Variety of scheme options was studied in F2 charm HERA combined paper (*Eur. Phys. J. C73 (2013) 2311).*

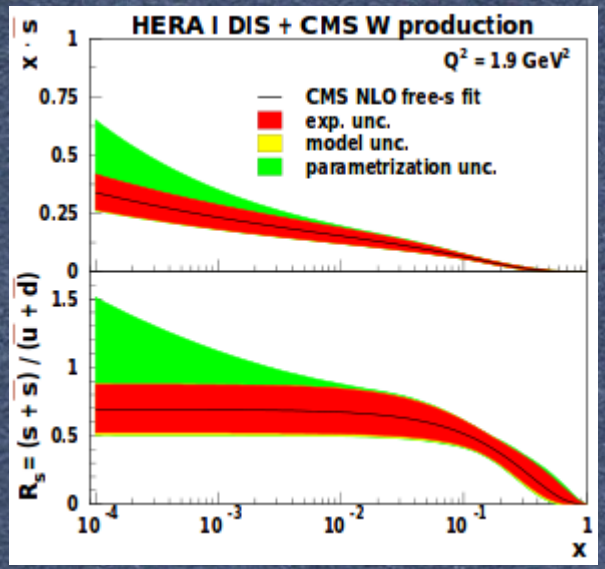


Strange Quark at LHC

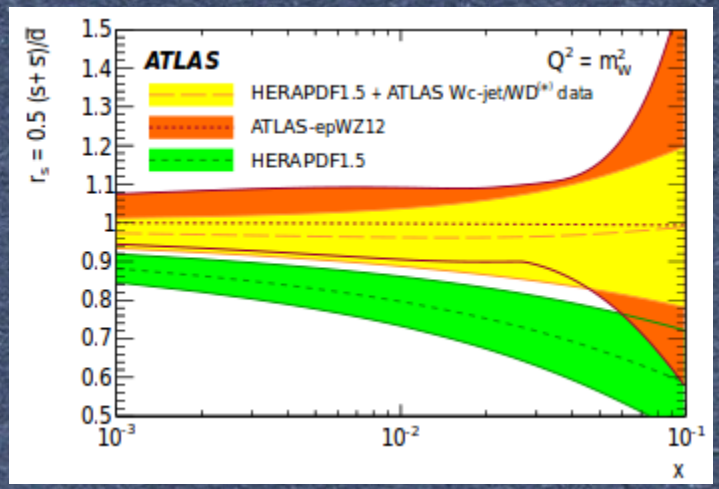
- W± and Z inclusive cross section was used by ATLAS to determine strange quark fraction in the sea *(Phys. Rev. Lett. 109 (2012) 012001)*.



- W+charm data including W asymmetry was used to probe strange quark distribution *(CMS-SMP-12-021).*
- *Details in a dedicated talk by Ringaile Placakyte at tomorrow's WG1 morning session.*

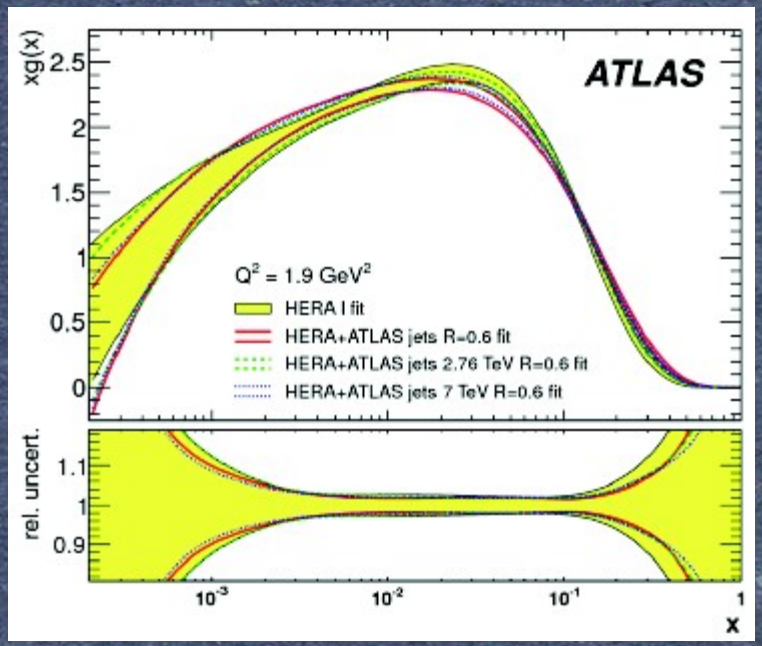


- W+charm data was used by ATLAS to determine the ratio of the strange-to-down sea-quark distributions *(arXiv:1402.6263).*

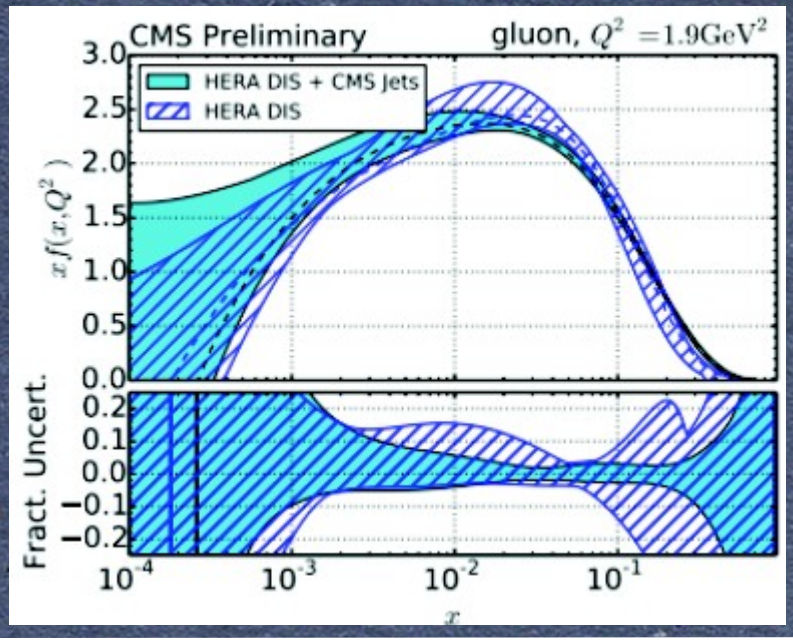


Sensitivity to Gluon and Strong Coupling

- Inclusive jet cross sections at different center-of-mass energies was used to study sensitivity of gluon density at low and high x regions. *(Eur. Phys. J. C 73 (2013) 2509).*



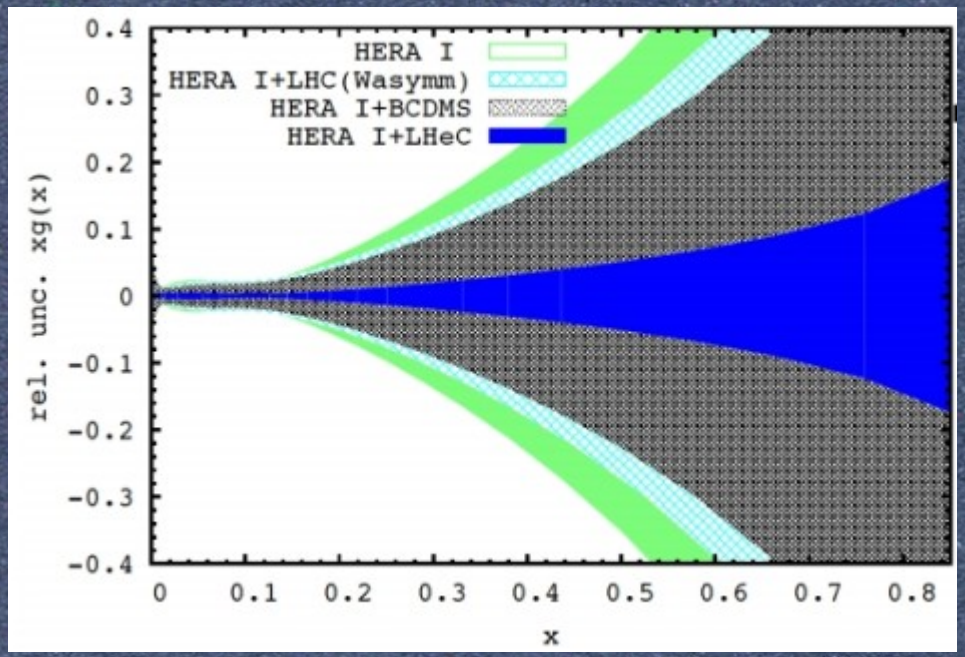
- PDF are extracted and compared to fits using HERA I data only and fits using HERA I + CMS jet data.
- The same inclusive jet cross section is also used to extract the strong coupling constant *(CMS-PAS-SMP-12-028).*
- *Details in a dedicated talk by Georg Sieber in WG1 tomorrow morning.*



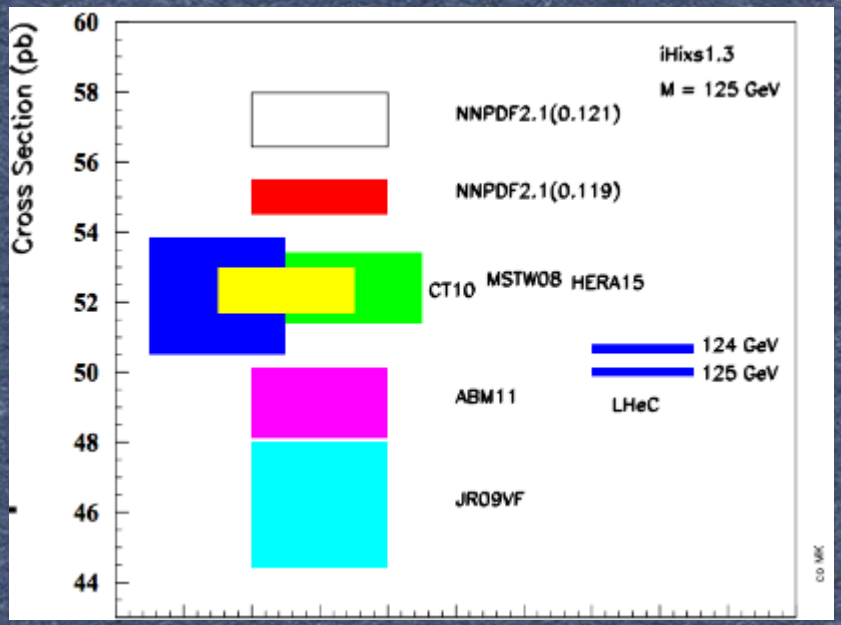
Sensitivity Studies

Platform can be used for sensitivities studies of the potential of future colliders:

- LHeC ep simulated data was used for to study sensitivity to PDFs:



- The output in LHAPDF format can be used for Higgs predictions:



(Journal of Phys. G 39 (2012))

- *See also talk in WG7 by Voica Radescu*

Results Using HERAFitter

Date	Group	Reference	Title
NEW 04.2014	**HERAFitter team**	arXiv:1404.4234	Parton distribution functions at LO, NLO and NNLO with correlated uncertainties between orders
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
NEW 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	CMS-SMP-12-021 / 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 -> 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

- **New development of the HERAFitter is dedicated studies made by developers and interested users.**

Results Using HERAFitter

The first HERAFitter Developers Team publication
Do not miss the talk by Misha Lisovyi !

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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

Summary

- HERAFitter is an open source QCD framework and it has proved to be a successful platform that is well integrated in the high energy physics community.
- HERAFitter infrastructure has increased the scientific output of the HERA and LHC data, provides a flexible environment for theory benchmarking.
- Stable release: herafitter-1.0.0, can be found at *www.herafitter.org.*