
*High X 2014 - Frascati, Italy*

# HERAFitter Project

## Open Source QCD Fit framework

Voica Radescu


on behalf of the HERAFitter team

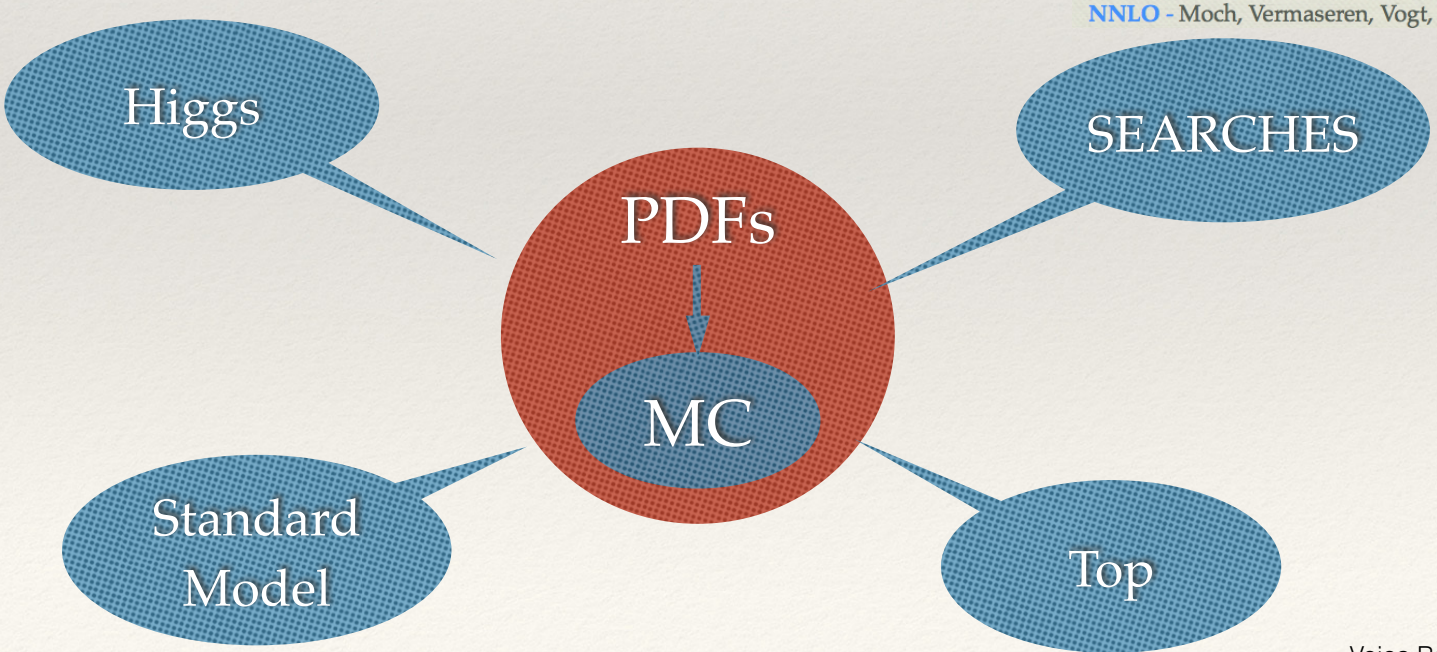
# Why do we still need to care about PDFs?

- Discovery of new exciting physics relies on precise knowledge of proton structure.
- **Factorisation theorem:**
  - Cross section can be calculated by convoluting short distance partonic reactions (calculable in pQCD) with Parton Distribution Functions (PDFs):

$$\mathrm{d}\sigma(\mathrm{h}_1\mathrm{h}_2 \to cd) = \int_0^1 \mathrm{d}x_1 \mathrm{d}x_2 \sum_{a,b} f_{a/\mathrm{h}_1}(x_1, \mu_F^2) f_{b/\mathrm{h}_2}(x_2, \mu_F^2) \mathrm{d}\hat{\sigma}^{(ab\to cd)}(Q^2, \mu_F^2)$$

  - PDFs cannot be calculated in perturbative QCD, however they are process independent (universal) and their evolution with the scale is predicted by pQCD:

LO - Dokshitzer; Gribov, Lipatov; Altarelli, Parisi, 1977
NLO - Floratos,Ross,Sachrajda; Floratos,Lacaze,Kounnas, Gonzalez-Arroyo,Lopez,Yndurain; Curci,Furmanski Petronzio, 1981
NNLO - Moch, Vermaseren, Vogt, 2004



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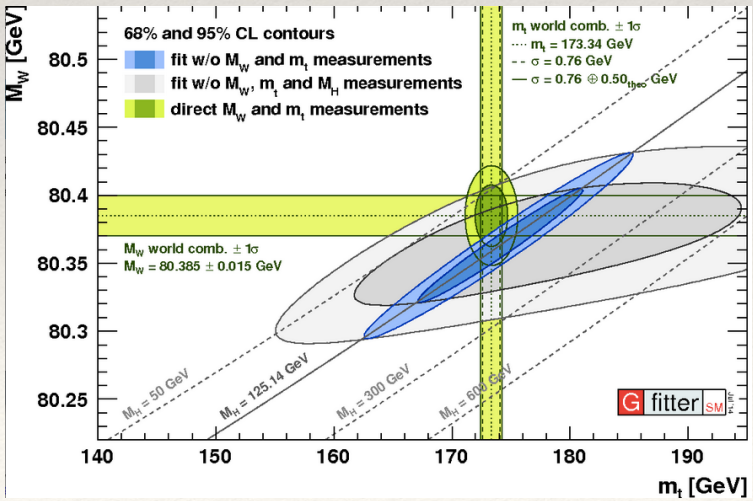
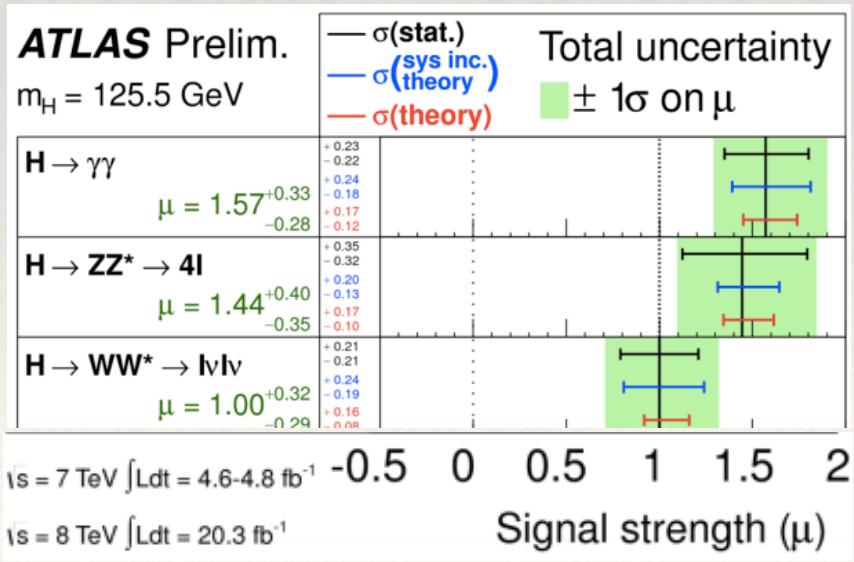
- PDFs are one of the main theory uncertainties in Mw measurement
- PDFs are one of main theory uncertainties in Higgs production.

**Theory:**
**~ 7-8 % PDF and $\alpha s$ ;**
**~ 7-8 % scale**




GFitter

ATLAS-CONF-2014-009

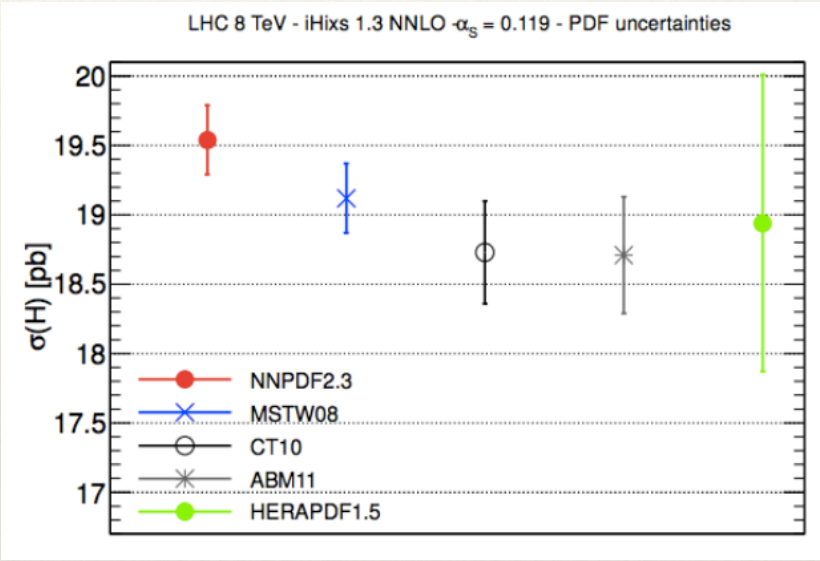


# Current PDF sets in use at LHC

- Data: targeted measurements, detailed information of sources of systematic uncertainties, addressing the importance of correlation information
- Theory: state of the art methods, advancement in computational powers that allowed fo higher order calculations to be available

Active global proton PDF groups:

| August 2014 | CT10(w) | MSTW2008 | NNPDF2.3 | ABM12 | HERAPDF15 |
|---|---|---|---|---|---|
| Fixed Target DIS | ✔ | ✔ | ✔ | ✔ | ✘ |
| HERA | ✔ | ✔ | ✔ | ✔ | ✔ |
| Fixed Target DY | ✔ | ✔ | ✔ | ✔ | ✘ |
| Tevatron W,Z | ✔ | ✔ | ✔ | ✘ | ✘ |
| Tevatron jets | ✔ | ✔ | ✔ | ✘ | ✘ |
| LHC data | ✘ | ✘ | ✔ | ✔ | ✘ |
| Stat. treatment | Hessian $\Delta\chi^2$= 100 | Hessian $\Delta\chi^2$ dynamical | Monte Carlo | Hessian $\Delta\chi^2$=1 | Hessian $\Delta\chi^2$=1 |
| Parametrization | Pol. (26 pars) | Pol. (20 pars) | NN (259 pars) | Pol. (14 pars) | Pol. (14 pars) |
| HQ scheme | ACOT-$\chi$ | TR′ | FONLL | FFN | TR′ |
| $\alpha_S$ | Varied | Fitted+varied | Varied | Fitted | Varied |

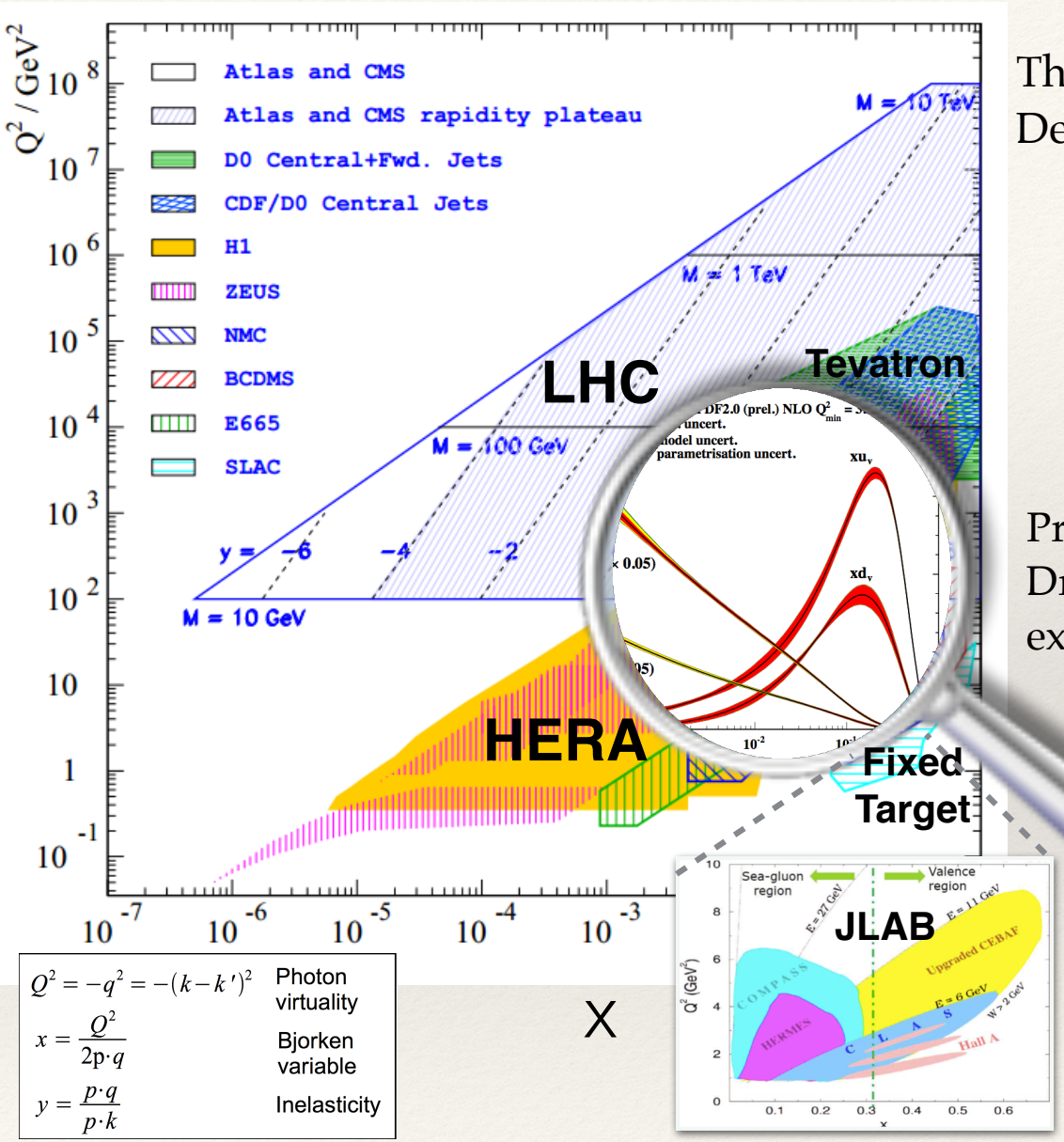



Dedicated studies to address this difference, PDF4LHC, http://arxiv.org/pdf/1405.1067.pdf

The analyses differ in many areas:

- different treatment of heavy quarks
- inclusion of various data sets and account for possible tensions
- different alphas assumption

# Proton Structure Measurements



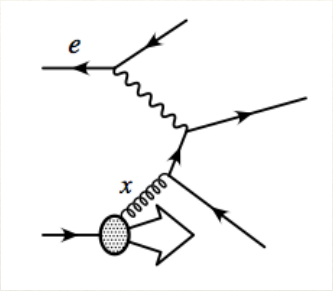

$Q^2 = -q^2 = -(k-k')^2$ Photon virtuality

$x = \frac{Q^2}{2p\cdot q}$ Bjorken variable

$y = \frac{p\cdot q}{p\cdot k}$ Inelasticity

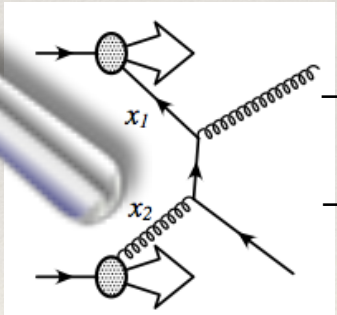
The cleanest way to probe Proton Structure is via Deep Inelastic Scattering [DIS]:

- Neutrinos, muons, electrons




—> probes linear combination of quarks

Precision of PDFs can be complemented by the Drell Yan [DY] processes at the collider experiments - [Tevatron and LHC]




—> can provide flavour separation and more insight into gluons

—> probes bilinear combination of quarks

**Different data constrain different parton combinations at different x, evolution with the scale is predicted by pQCD:**

# HERAFitter Project: www.herafitter.org

- HERAFitter Project was initiated in 2011 as a necessity to transfer the legacy and expertise on proton structure from HERA to LHC:
  - a unique open source QCD Fit Platform:

arXiv.org > hep-ph > arXiv:1410.4412

Search or

High Energy Physics – Phenomenology

**HERAFitter, Open Source QCD Fit Project**

S. Alekhin, O. Behnke, P. Belov, S. Borroni, M. Botje, D. Britzger, S. Camarda, A.M. Cooper-Sarkar, K. Daum, C. Diaconu, J. Feltesse, A. Gizhko, A. Glazov, A. Guffanti, M. Guzzi, F. Hautmann, A. Jung, H. Jung, V. Kolesnikov, H. Kowalski, O. Kuprash, A. Kusina, S. Levonian, K. Lipka, B. Lobodzinski, K. Lohwasser, A. Luszczak, B. Malaescu, R. McNulty, V. Myronenko, S. Naumann-Emme, K. Nowak, F. Olness, E. Perez, H. Pirumov, R. Placakyte, K. Rabbertz, V. Radescu, R. Sadykov, G.P. Salam, A. Sapronov, A. Schoening, T. Schoerner-Sadenius, S. Shushkevich, W. Slominski, H. Spiesberger, P. Starovoitov, M. Sutton, J. Tomaszewska, O. Turkot, A. Vargas, G. Watt, K. Wichmann

*(Submitted on 16 Oct 2014)*

HERAFitter is an open-source package that provides a framework for the determination of the parton distribution functions (PDFs) of the proton and for many different kinds of analyses in Quantum Chromodynamics (QCD). It encodes results from a wide range of experimental measurements in lepton-proton deep inelastic scattering and proton-proton (proton-antiproton) collisions at hadron colliders. These are complemented with a variety of theoretical options for calculating PDF-dependent cross section predictions corresponding to the measurements. The framework covers a large number of the existing methods and schemes used for PDF determination. The data and theoretical predictions are brought together through numerous methodological options for carrying out PDF fits and plotting tools to help visualise the results. While primarily based on the approach of collinear factorisation, HERAFitter also provides facilities for fits of dipole models and transverse-momentum dependent PDFs. The package can be used to study the impact of new precise measurements from hadron colliders. This paper describes the general structure of HERAFitter and its wide choice of options.

Comments: 18 pages, 8 figures
Subjects: **High Energy Physics – Phenomenology (hep-ph)**
Report number: DESY Report 14-188
Cite as: arXiv:1410.4412 **[hep-ph]**
(or arXiv:1410.4412v1 **[hep-ph]** for this version)

- **HERAFitter:**
  - provides a unique QCD framework to address theoretical differences
  - provides means to the experimentalists to optimise the measurement and assess impact/consistency of new data

# HERAFitter Releases:

- https://www.herafitter.org/HERAFitter/HERAFitter/DownloadPage

## List of releases:

| Date | Version | Files |
|---|---|---|
| 09/2014 | **1.1.0** | herafitter-1.1.0.tgz |
| 12/2013 | 1.0.0 | herafitter-1.0.0.tgz |
| 06/2013 | 0.3.1 | herafitter-0.3.1.tgz |
| 03/2013 | 0.3.0 | herafitter-0.3.0.tgz |
| 07/2012 | 0.2.1 | herafitter-0.2.1.tgz |
| 05/2012 | 0.2.0 | herafitter-0.2.0.tgz |
| 09/2011 | 0.1.0 | herafitter-0.1.0.tgz |

- Versioning convention: **i.j.k** with
  - **i** - stable release
  - **j** - beta release
  - **k** - bug fixes.

**HERAFitter: Releases and Updates**

September, 2014

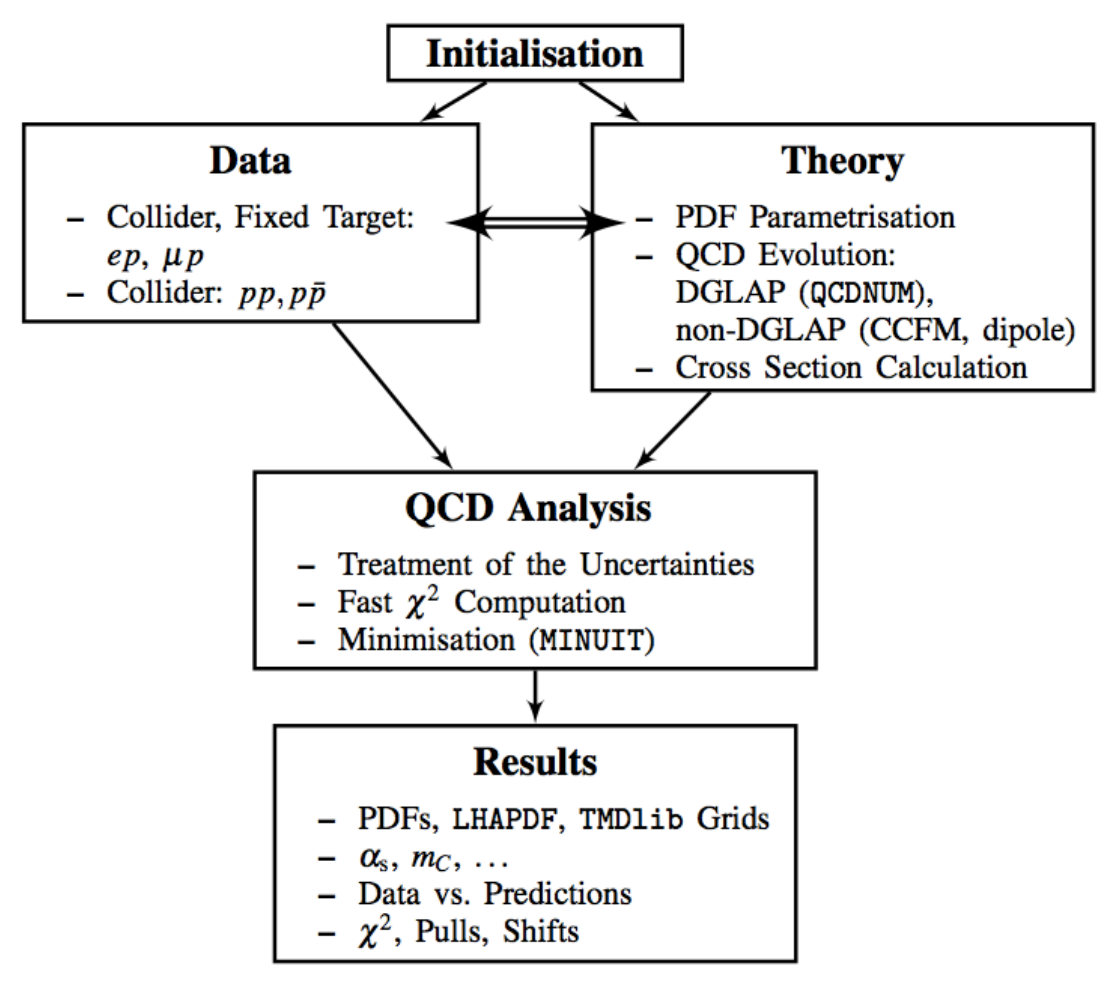
**HERAFitter** versions are labeled as **herafitter-i.j.k** where **i** is the stable release number, **j** is beta release number, and **k** is bug fixes.

| Release | Date | Description |
|---|---|---|
| herafitter-1.1.0 | 29.09.2014 | • Removed dependence on CERNLIB and related libraries.<br>• Added interface to LHAPDFv6.<br>• Added more and improved drawing options for visualisation of results.<br>• Added possibility to deal with multi-dimensional data (virtual grids).<br>• Additional options in parametrisation styles: added mixed forms between HERA style for gluon and sea and CTEQ style for valence.<br>• Added new data from Tevatron, ATLAS and CMS.<br>• Added improvements and more flexibility in the $\chi^2$ and covariance matrix code: possibility to transform into nuisance representation for data with uncertainties given in the covariance form.<br>• Included a new fastNLO version, which was generalised in order to accommodate DiffTop grids.<br>• Added DiffTop grids via fastNLO. |

# HERAFitter Program at glance

- HERAFitter code is a combination of C++ and Fortran 77 libraries with minimal dependencies and modular structure with interface to external packages:
  - QCDNUM, APPLGRID, FASTNLO, ACOT, TR', OPENQCDRAD, TMD, HATHOR

| Experimental Data | Process | Reaction | Theory schemes calculations |
|---|---|---|---|
| HERA, Fixed Target | DIS NC | $ep \to eX$<br>$\mu p \to \mu X$ | TR′, ACOT, ZM (QCDNUM), FFN (OPENQCDRAD, QCDNUM), TMD (uPDFevolv) |
| HERA | DIS CC | $ep \to \nu_e X$ | ACOT, ZM (QCDNUM), FFN (OPENQCDRAD) |
| | DIS jets | $ep \to e$ jets$X$ | NLOJet++ (fastNLO) |
| | DIS heavy quarks | $ep \to ec\bar{c}X$,<br>$ep \to eb\bar{b}X$ | TR′, ACOT, ZM (QCDNUM), FFN (OPENQCDRAD, QCDNUM) |
| Tevatron, LHC | Drell-Yan | $pp(\bar{p}) \to l\bar{l}X$,<br>$pp(\bar{p}) \to l\nu X$ | MCFM (APPLGRID) |
| | top pair | $pp(\bar{p}) \to t\bar{t}X$ | MCFM (APPLGRID), HATHOR, DiffTop |
| | single top | $pp(\bar{p}) \to tl\nu X$,<br>$pp(\bar{p}) \to tX$,<br>$pp(\bar{p}) \to tWX$ | MCFM (APPLGRID) |
| | jets | $pp(\bar{p}) \to$ jets$X$ | NLOJet++ (APPLGRID), NLOJet++ (fastNLO) |
| LHC | DY heavy quarks | $pp \to VhX$ | MCFM (APPLGRID) |



# Latest Results from HERAFitter

- Research activities of HERAFitter are steered by demands of the users

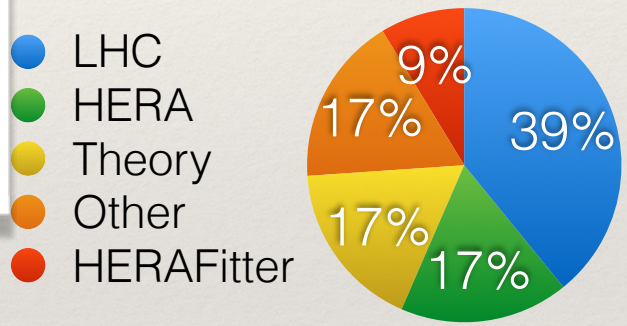
**List of analyses by HERAFitter**

| | | | | |
|---|---|---|---|---|
| NEW 10.2014 | **HERAFitter team** | arXiv:1410.4412 | HERAFitter Open Source QCD Fit Project | |
| NEW 04.2014 | **HERAFitter team** | EPJC (2014) 74: 3039, arXiv:1404.4234 | Parton distribution functions at LO, NLO and NNLO with correlated uncertainties between orders | Material |

**List of analyses using HERAFitter**

| Date | Group | Reference | Title |
|---|---|---|---|
| NEW 10.2014 | LHC/ATLAS | ATL-PHYS-PUB-2014-015 | Studies of theoretical uncertainties on the measurement of the mass of the W boson at the LHC |
| NEW 10.2014 | LHC/CMS | arXiv:1410.6765 (CMS-SMP-12-028) | Constraints on parton distribution functions and extraction of the strong coupling constant from the inclusive jet cross section in pp collisions at sqrt(s) = 7 TeV |
| NEW 09.2014 | LHC/ATLAS | arxiv:1406.7844 | Comprehensive measurements of t-channel single top-quark production cross sections at s√=7 TeV with the ATLAS detector |
| NEW 09.2014 | M.Guzzi, K.Lipka, S-O.Moch | arxiv:1406.0386 | Top-quark pair production at hadron colliders: differential cross section and phenomenological applications with DiffTop |
| NEW 08.2014 | PROSA | preliminary | Impact of the LHCb measurements of forward charm and beauty production on PDFs |
| NEW 08.2014 | LHC/CMS | PRD 90 (2014) 032004 / arXiv:1312.6283 | Measurement of the muon charge asymmetry in pp W production at 7 TeV |

Overall distribution:
(of all publications)

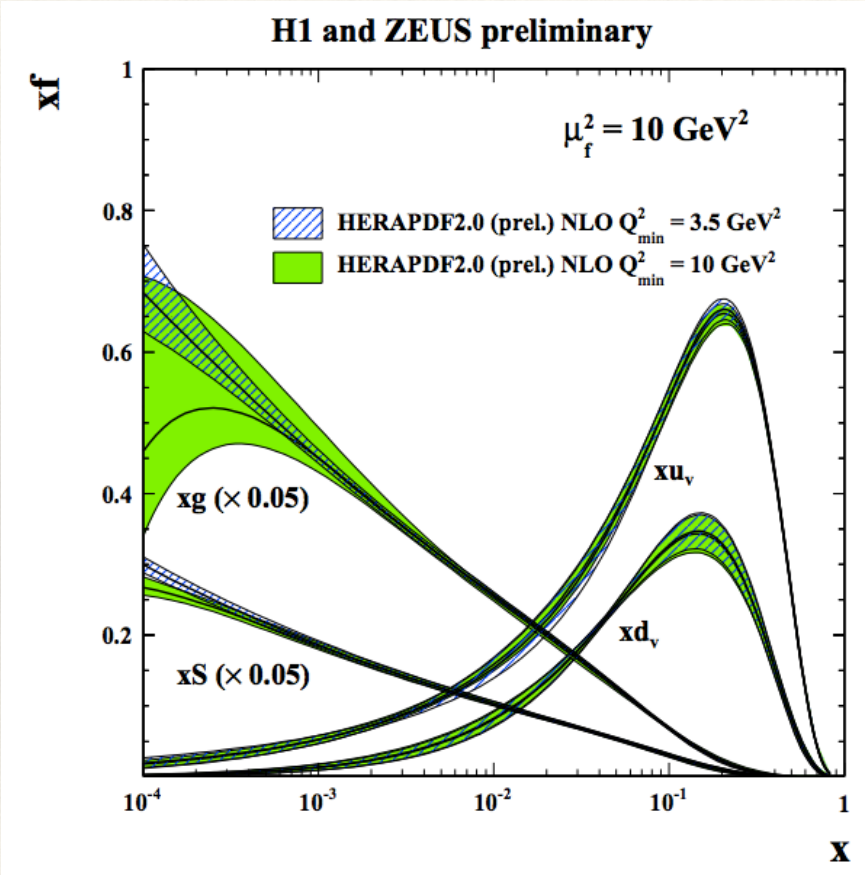


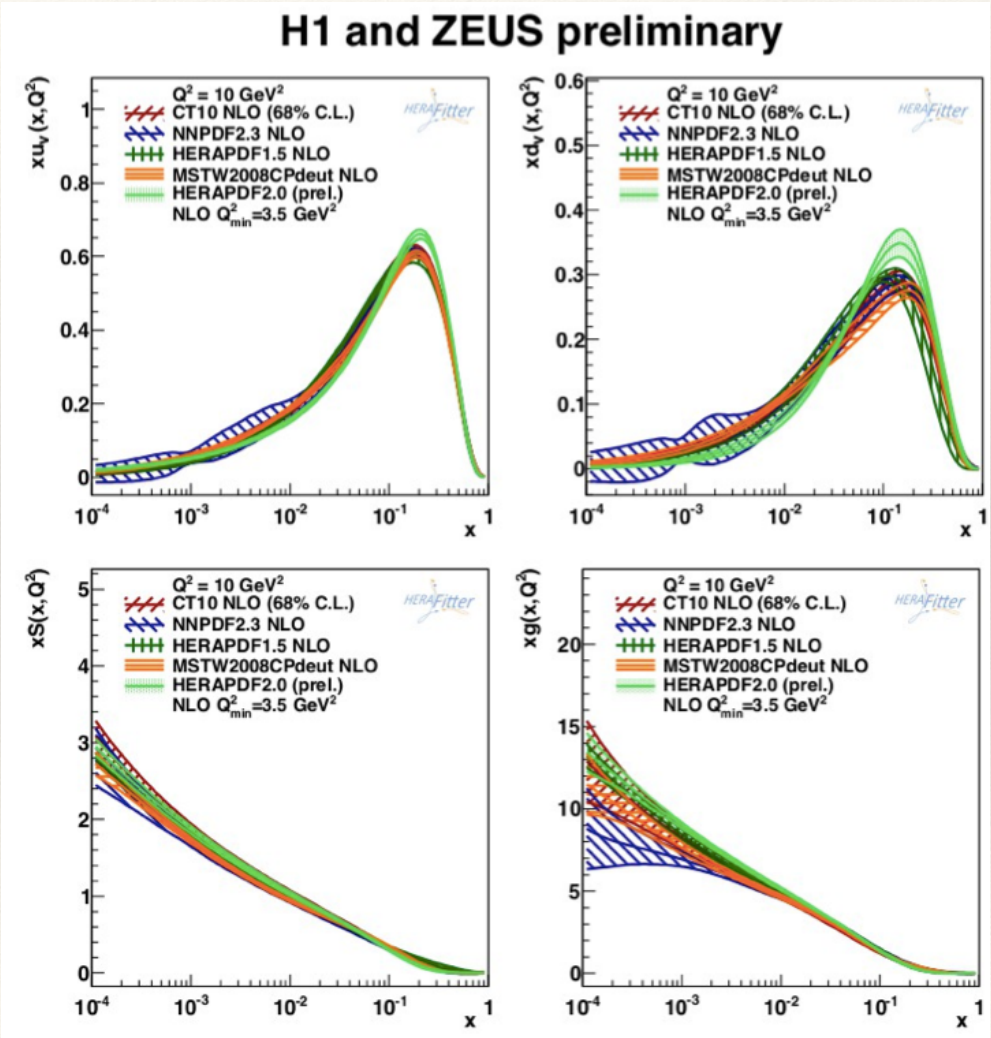

https://www.herafitter.org/HERAFitter/HERAFitter/results

# HERAPDF2.0prel with HERAFitter

HERA has finalised its separate measurements relevant to PDFs and there are ongoing efforts on combining final measurements to reach their ultimate precision:

- HERAFitter is used to extract PDFs, mc, mb, alphas …



# HERAFitter in the ggH benchmark studies

- Efforts in reducing the PDF uncertainties arising from discrepancy between PDF groups:
  - Benchmark comparisons of NNLO neutral current DIS cross sections (Exercise on HERA-I only data)

arxiv:1405.1067

**Les Houches 2013: Physics at TeV Colliders**
**Standard Model Working Group Report**

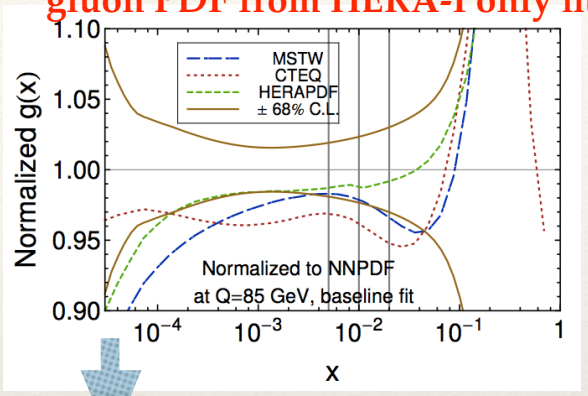
**Conveners**

*Higgs physics: SM issues*
D. De Florian (Theory), M. Kado (ATLAS), A. Korytov (CMS),
S. Dittmaier (Electroweak Contact)

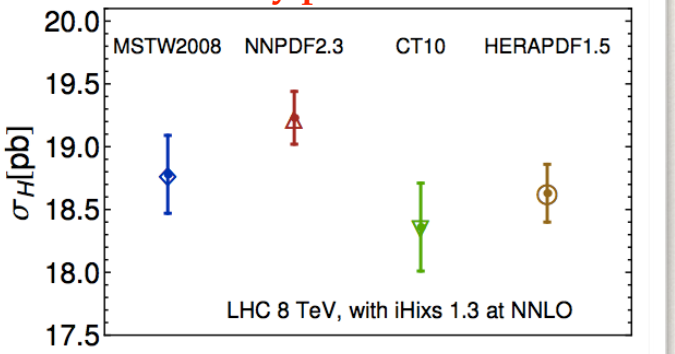
*SM: Loops and Multilegs*
N. Glover (Theory), J. Huston (ATLAS), G. Dissertori (CMS),
S. Dittmaier (Electroweak Contact)

*Tools and Monte Carlos*
F. Krauss (Theory), J. Butterworth (ATLAS), K. Hamilton (MC-NLO Contact),
G. Soyez (Jets Contact)

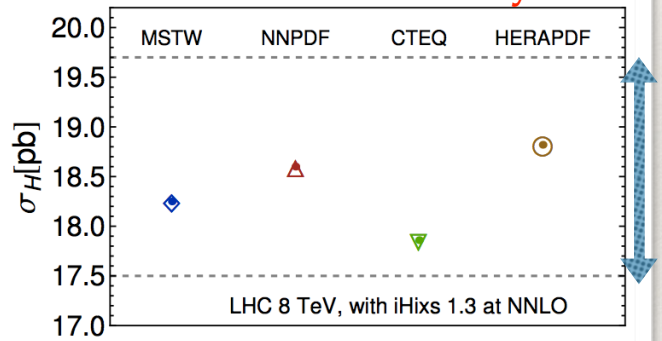
**gluon PDF from HERA-I only fits**




**based on recently published NNLO PDFs.**




**based on HERA-I only fits**




PDF uncert

  - predictions from MSTW, CT, NNPDF and HERAPDF all consistent within PDF uncertainties
  - however the tendency among NNPDF, MSTW and CT is maintained
- **Next step:**
  - continue this exercise by adding additional experimental data sets into the PDF fits sequentially:
  - benchmarking the theoretical predictions used by each group for the different observables -
  - **==> HERAFitter will continue to participate in these studies.**

# Transverse Momentum Distributions

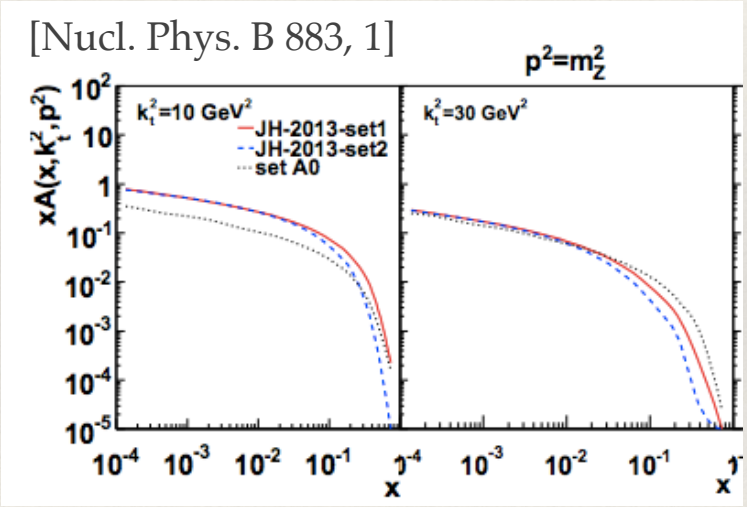
- QCD applications to multiple-scale scattering problems and complex final-state observables require in general formulations of factorisation which involve transverse-momentum dependent (TMD) - or known also as unintegrated PDFs.

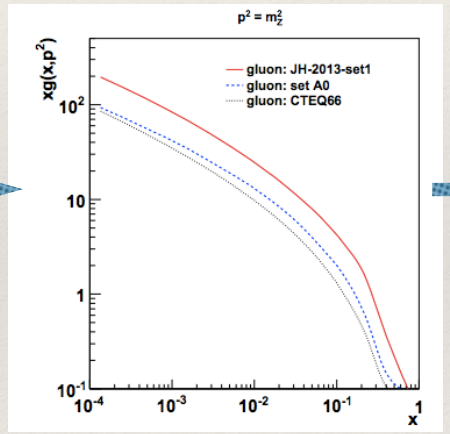
$$\sigma_j(x,Q^2) = \int_x^1 dz \int d^2k_t\ \hat{\sigma}_j(x,Q^2,z,k_t)\ \mathcal{A}(z,k_t,\mu)$$

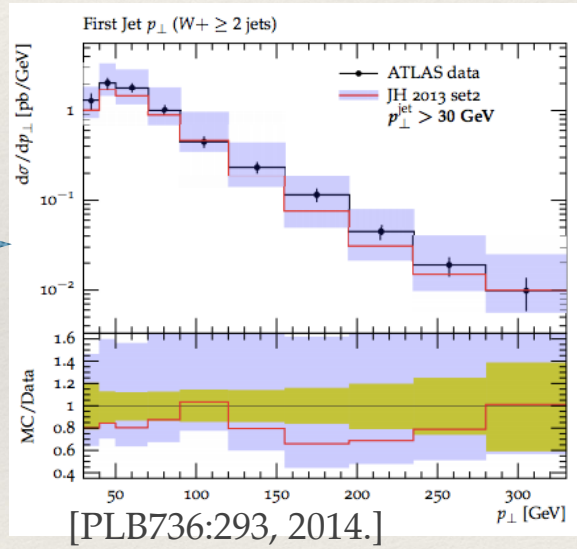
→ a convolution in both longitudinal and transverse momenta of TMD with off-shell partonic matrix elements

- Fits to combined measurements of proton's structure functions from HERA using transverse momentum dependent QCD factorisation and CCFM evolution is performed using HERAFitter platform

[Nucl. Phys. B 883, 1]




[PLB736:293, 2014.]

- The extracted gluon TMD with experimental and theory uncertainty [JH-2013-set1] is then used as prediction to vector boson+jet production process at the LHC [Phys. Rev. D 85 (2012) 092002.]

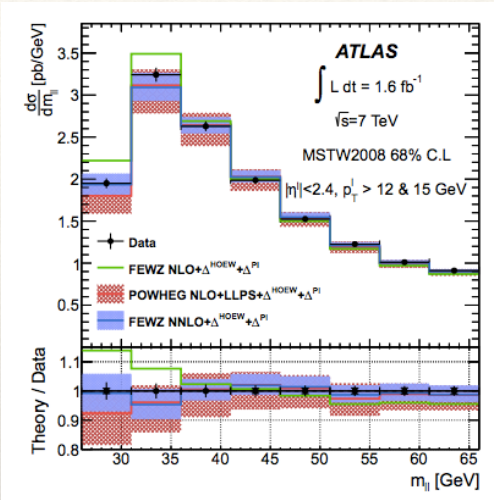
- Currently, fits to COMPAS data using HERAFitter [T. Rogers, P. Nadolski, B. Wang]

# Quantitative Assessment

- HERAFitter program can be used with external predictions (i.e. not built-in) to quantify the level of agreement when confronting theory with measurements, taking into account all sources of provided uncertainties (either exp. or th. like PDFs, scale)
- **Applied recent examples:**
  - Low Mass DY (ATLAS) data [arXiv:1404.1212]

| Prediction | $\chi^2$ (8 points) Nominal |
|---|---|
| POWHEG NLO+LLPS | 22.4 (19.8) |
| FEWZ NLO | 48.7 (28.6) |
| FEWZ NNLO | 13.9 (12.9) |

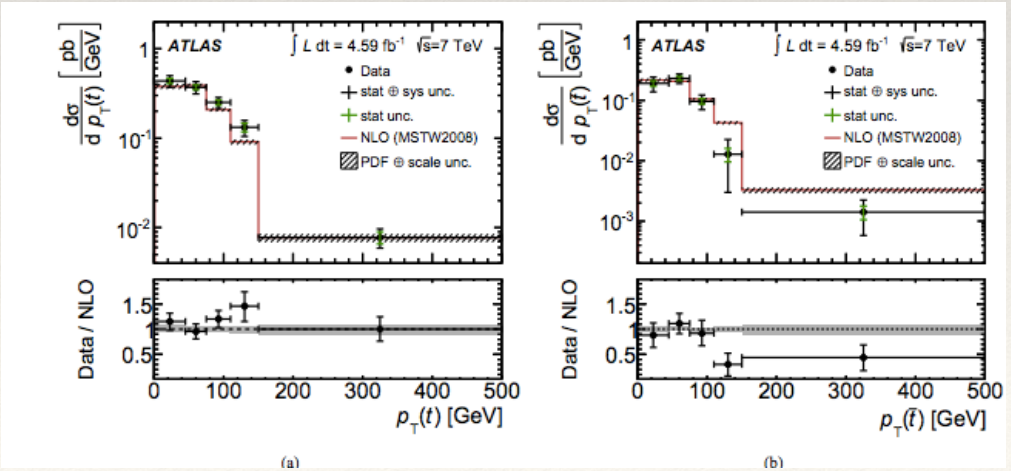
—> conclusion NNLO is needed to describe data




- t-channel single top-quark production cross sections (ATLAS) [arXiv:1406.7844]

TABLE VIII. Comparison between the measured differential cross sections and the predictions from the NLO calculation using the MSTW2008 PDF set. For each variable and prediction a $\chi^2$ value is calculated with HERAfitter using the covariance matrix of each measured spectrum. The theory uncertainties of the predictions are treated as uncorrelated. The number of degrees of freedom (NDF) is equal to the number of bins in the measured spectrum.

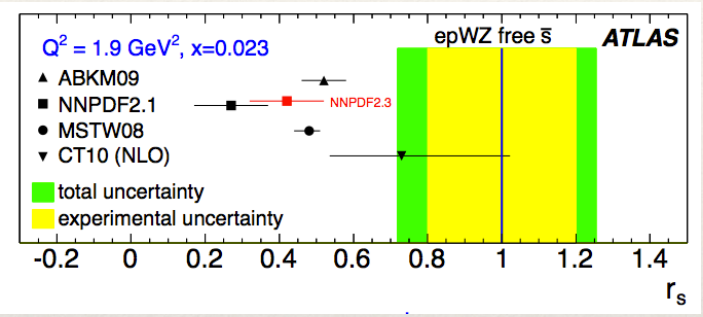
| | $\frac{d\sigma}{dp_T(t)}$ | $\frac{d\sigma}{dp_T(\bar{t})}$ | $\frac{d\sigma}{d\lvert y(t)\rvert}$ | $\frac{d\sigma}{d\lvert y(\bar{t})\rvert}$ |
|---|---|---|---|---|
| $\chi^2$/NDF | 7.55/5 | 4.68/5 | 6.30/4 | 0.32/4 |



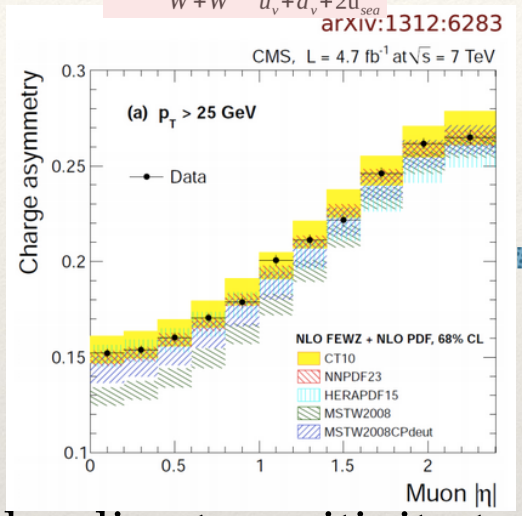
# QCD interpretation of W production at LHC

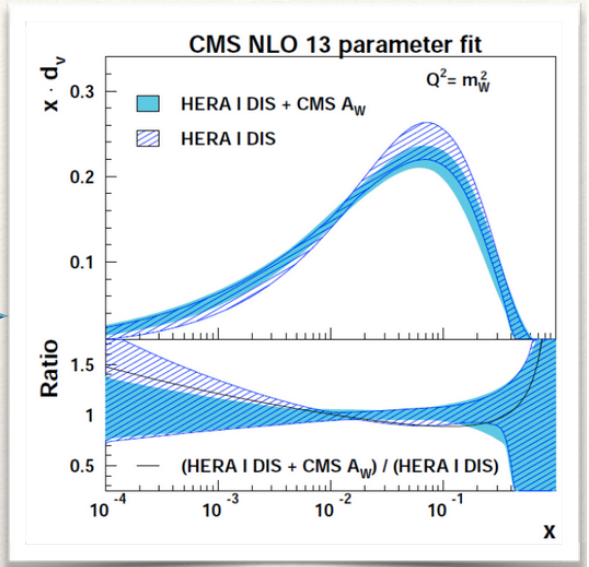
- Impact on PDFs from W+, W-, Z production at ATLAS and CMS is investigated within the HERAFitter framework through a QCD fit analysis

$$r_s(x) = 0.5(s(x) + \bar{s}(x))/\bar{d}(x)$$

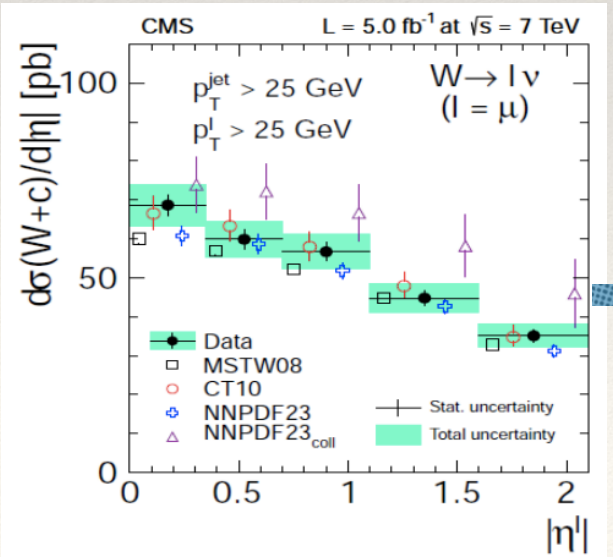


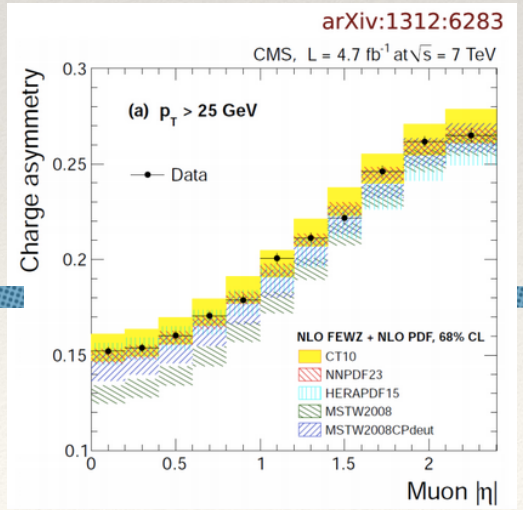

$$A_W = \frac{W^+ - W^-}{W^+ + W^-} \approx \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$

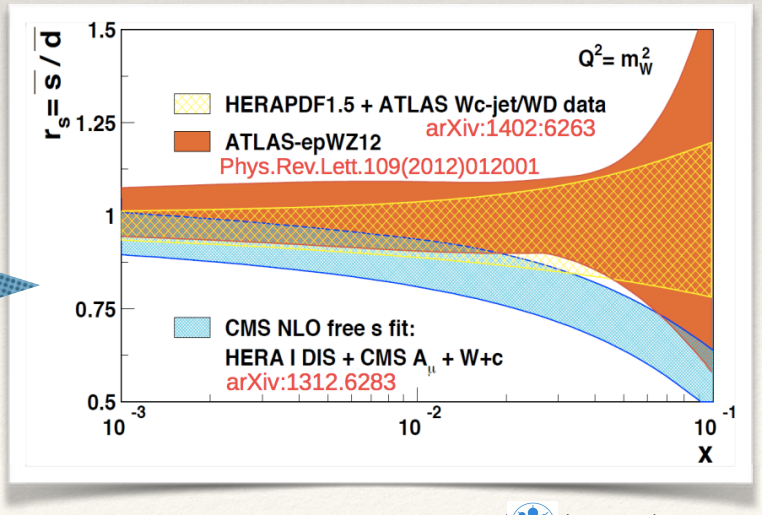



- In addition, W+charm data provides direct sensitivity to the strange quark



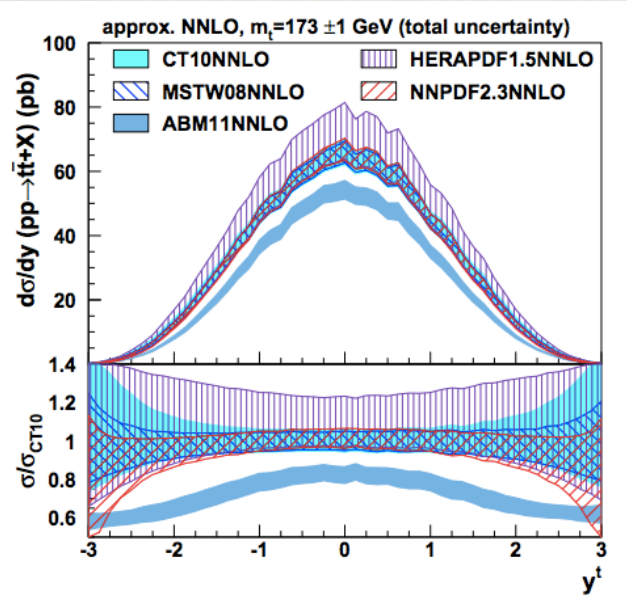



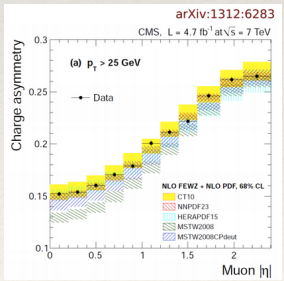



# DiffTop in HERAFitter [arXiv:1406.0386]

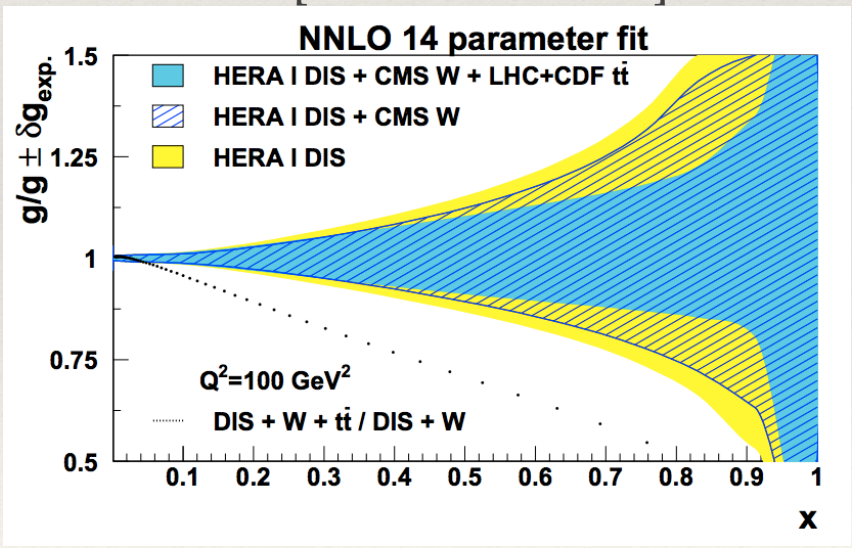
- Top-quark pair production at the LHC probes high-x gluon (x ≈ 0.1):
  —> there is a strong correlation between g(x), $\alpha$s and the top-quark mass mt
- Precise measurements of the total and differential (normalised and absolute) cross section of ttbar pair production can constrain and de-correlate $\alpha$s, gluon, mt
- DiffTop and its interface to FastNLO have been implemented into HERAFitter.

- First exploratory PDF fits at NNLO have been performed by using differential cross sections of top-quark pair production together with other data sets [HERA I, W asymm.] to study the impact on the gluon at large x.




[arXiv:1406.0386]

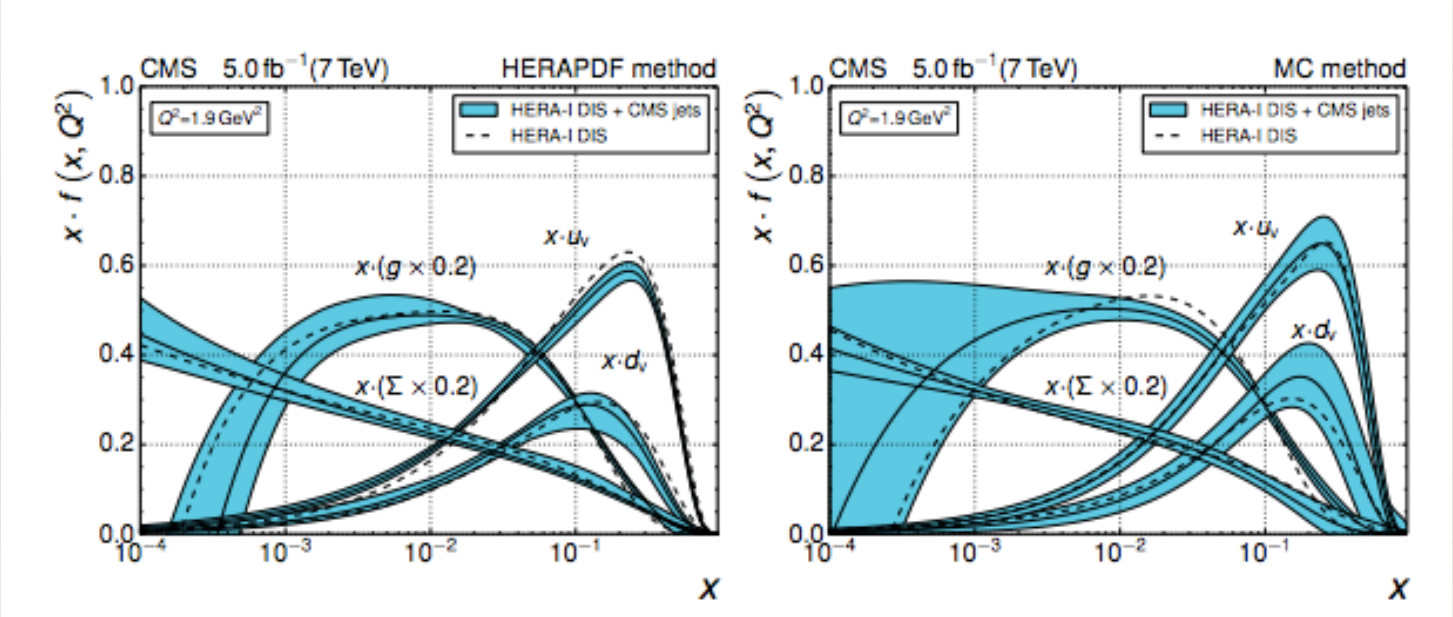



—> More data is needed: absolute differential cross section data will bring more information.

# Impact of the inclusive jet CMS measurement on the PDFs

arXiv:1410.6765

- The inclusive jet cross section measured by CMS at 7TeV provide important input for the gluon density at high x and for the strong coupling constant at large energy scales.
- The impact of the CMS inclusive jet data on proton PDFs is investigated by including the jet cross section measurement in a combined fit with the HERA-I inclusive DIS cross sections.
  - Two prescriptions were used:
    - a la HERAPDF style: HERAPDF method
    - a la NNPDF style: MC method (data driven regularisation)




- Combined fit of PDFs and the strong coupling constant:
- HERAPDF method: $\alpha_S(M_Z) = 0.1192\,^{+0.0023}_{-0.0019}$ (all except scale). vs $\alpha_S(M_Z) = 0.1185 \pm 0.0034$ (all except scale).
- MC method: $\alpha_S(M_Z) = 0.1188 \pm 0.0041$ (all except scale).

# HERAFitter Paper

Eur. Phys. J. C (2014) 74:3039

- Ratios of cross sections are used to reduce common uncertainties, however the theoretical calculations sometimes are not available at the same order of accuracy in pQCD

$$\frac{\hat{\sigma}_X^{NLO} \otimes PDF_{NLO}}{\hat{\sigma}_Y^{NLO} \otimes PDF_{NLO}}$$ PDF uncertainties cancel, large scale uncertainty

$$\frac{\hat{\sigma}_X^{NLO} \otimes PDF_{NLO}}{\hat{\sigma}_Y^{NNLO} \otimes PDF_{NNLO}}$$ improved scale uncertainty, No cancellation of PDF uncertainty

$$\frac{\hat{\sigma}_X^{NLO} \otimes PDF_{NNLO}}{\hat{\sigma}_Y^{NNLO} \otimes PDF_{NNLO}}$$ PDF uncertainties cancel, improved scale uncertainty, not clear definition in pQCD

$$\frac{\hat{\sigma}_X^{NLO} \otimes PDF^{corr}_{NLO}}{\hat{\sigma}_Y^{NNLO} \otimes PDF^{corr}_{NNLO}}$$ PDF uncertainties cancel, improved scale uncertainty

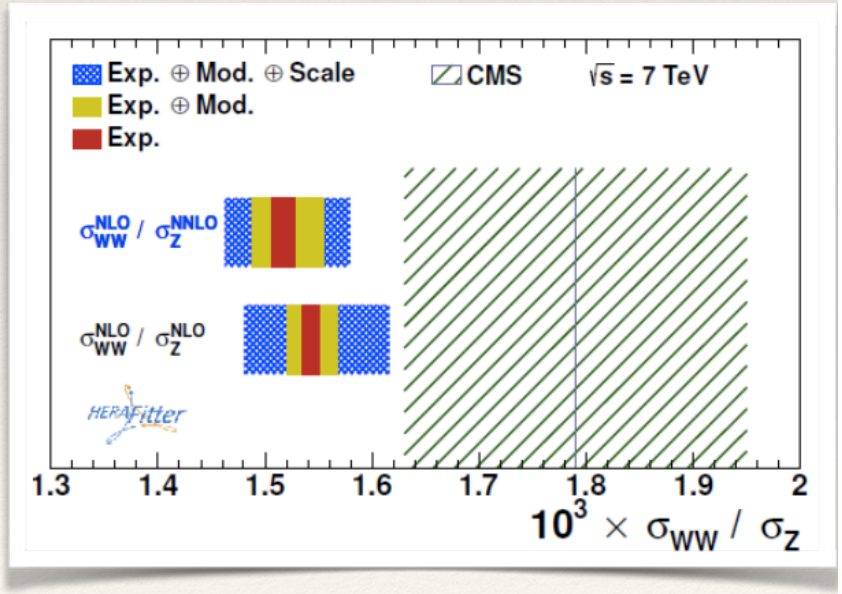
- HERAFitter provides possibility to account for correlations between PDFs at different orders which can lead to reduction of overall theoretical uncertainties:

**Parton distribution functions at LO, NLO and NNLO with correlated uncertainties between orders**

HERAFitter developers' team Collaboration (P. Belov , D. Britzger, S. Camarda (DESY) , A.M. Cooper-Sarkar (Oxford U.) , C. Diaconu (Marseille, CPPM) , J. Feltesse (IRFU, Saclay) , A. Gizhko, A. Glazov (DESY) , V. Kolesnikov (Dubna, JINR) , K. Lohwasser (DESY, Zeuthen) , A. Luszczak (AGH-UST, Cracow) , V. Myronenko, H. Pirumov, R. Placakyte (DESY) , K. Rabbertz (Karlsruhe U., EKP) , V. Radescu (DESY) , A. Sapronov (Dubna, JINR) , A. Schönig (Heidelberg U.) , S. Shushkevich (DESY) , W. Slominski (Jagiellonian U.) , P. Starovoitov (DESY) , M. Sutton (Sussex U.) , J. Tomaszewska (Warsaw U. of Tech.) , O. Turkot (DESY) , G. Watt (Durham U., IPPP) , K. Wichmann, M. Lisovyi (DESY) ) *Hide*

Apr 16, 2014 - 10 pages

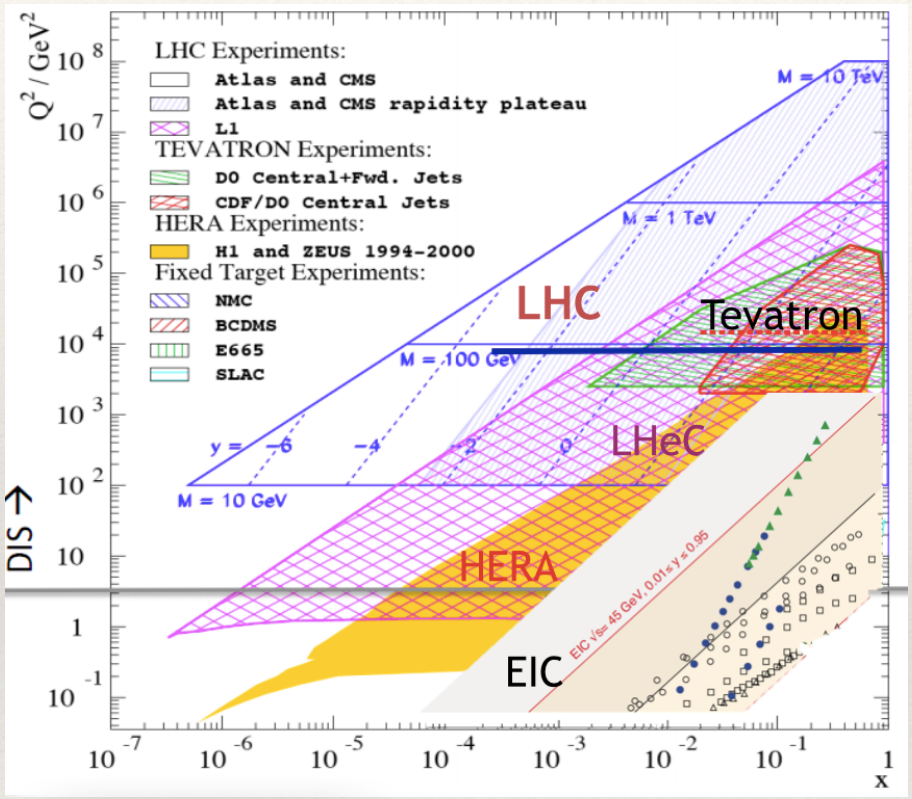
**Eur.Phys.J. C74 (2014) 3039**
(2014-09-30)
DOI: 10.1140/epjc/s10052-014-3039-4
DESY-2014-054, DESY-14-054
e-Print: arXiv:1404.4234 [hep-ph] | PDF



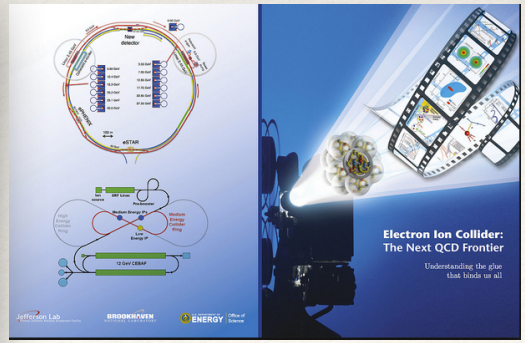

- mixed-order calculations with correlated PDFs help to reduce PDF and scale uncertainties
  - total theoretical uncertainty is reduced by 30-40%

# Sensitivity and impact studies

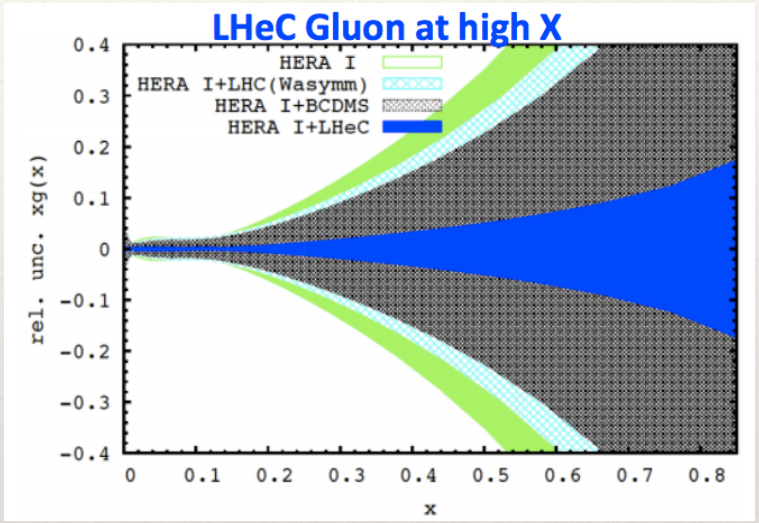
- LHeC (also part of Future Circular Collider project: ee, eh, hh (100 TeV proton))
- EIC (Brookhaven, JLAB)








LHeC could provide a complete PDF set with precise gluon, valence at high x, as well as strong coupling at per mile precision.




| case | cut [$Q^2$ in GeV$^2$] | relative precision in % |
|---|---|---|
| HERA only (14p) | $Q^2 > 3.5$ | 1.94 |
| HERA+jets (14p) | $Q^2 > 3.5$ | 0.82 |
| LHeC only (14p) | $Q^2 > 3.5$ | 0.15 |
| LHeC only (10p) | $Q^2 > 3.5$ | 0.17 |
| LHeC only (14p) | $Q^2 > 20.$ | 0.25 |
| LHeC+HERA (10p) | $Q^2 > 3.5$ | 0.11 |
| LHeC+HERA (10p) | $Q^2 > 7.0$ | 0.20 |
| LHeC+HERA (10p) | $Q^2 > 10.$ | 0.26 |

# Summary and Outlook

**PDFs are very important as they still limit our knowledge of cross sections whether SM or BSM.**

- HERAFitter is an open source QCD software package which encodes results from a wide range of experimental data in ep, pp, ppbar complemented with a variety of theoretical options for calculating PDF-dependent cross section predictions and extracting QCD parameters from data.

  www.herafitter.org

  latest release: herafitter-1.1.0

- The further progress of HERAFitter is driven by the latest QCD advances in theoretical calculations and in the precision of experimental data:
  - QED +QCD via QEDEvol (R. Sadykov)
  - Interface to APFEL (J.Rojo, V. Bertone, S. Carrazza) -> access to FONLL
  - ACOT @ NNLO (P. Nadolsky)
  - Nuclear PDFs (F. Olness)
  - TMDs (T. Rogers, P. Nadolski, B. Wang)

# HERAFitter Program at glance

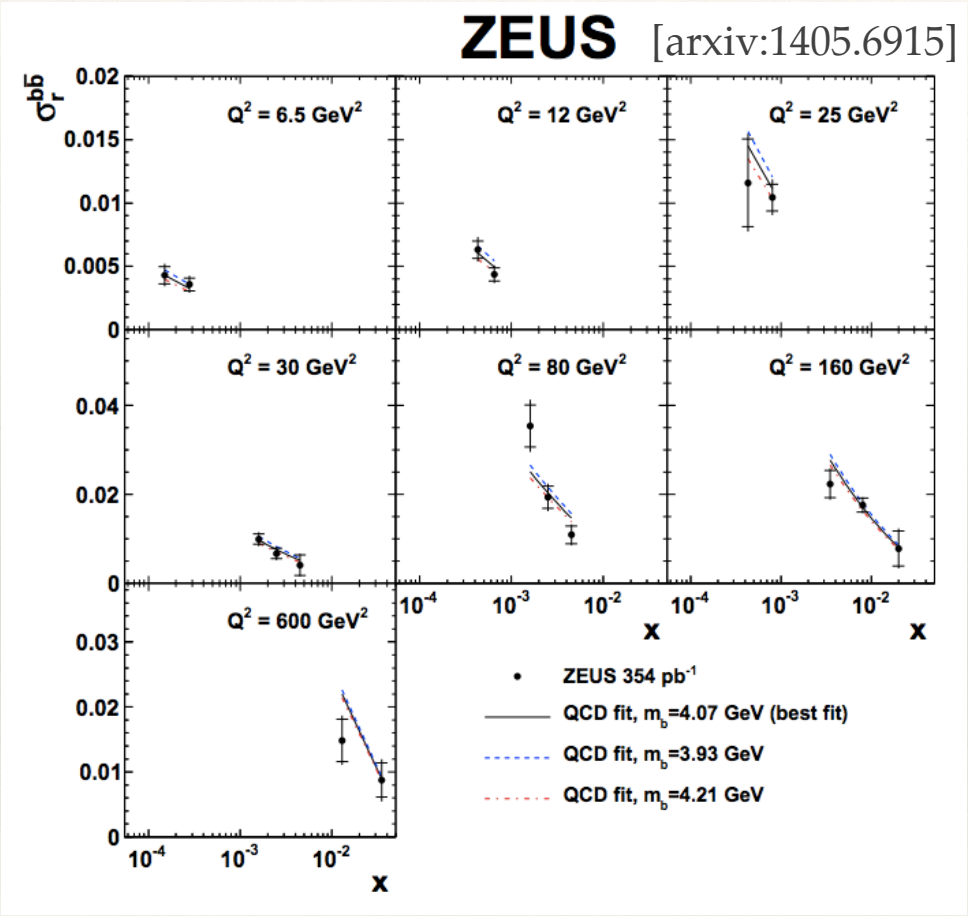
- HERAFitter code is a combination of C++ and Fortran 77 libraries with minimal dependencies and modular structure with interface to external packages:
  - QCDNUM for evolution of PDFs
- DIS inclusive processes in ep and fixed target
  - Different schemes of heavy quark treatment
    - VFNS, FFNS:
      - OPENQCDRAD (ABM)
      - TR' (MSTW)
      - ACOT (CT)
  - Diffractive PDFs
  - Dipole Models
  - Unintegrated PDFs (TMDs)
- Jet production (ep, pp, ppbar)
  - FastNLO and APPLGRID techniques
- Drell-Yan processes (pp, ppbar)
  - LO calculation x NLO k-factors
  - APPLGRID technique
- Top pair production
  - total inclusive ttbar cross sections (HATHOR)
  - differential (DiffTop approx NNLO via fastNLO grids)

```
--enable-openmp          enable openmp support
--enable-trapFPE         Stop of floating point errors (default=no)
--enable-checkBounds     add -fbounds-check flag for compilation (default=no)
--enable-nnpdfWeight     use NNPDF weighting (default=no)
--enable-lhapdf          use lhapdf (default=no)
--enable-applgrid        use applgrid for fast pdf convolutions (default=no)
--enable-genetic         use genetic for general minimia search (defaults=no)
--enable-hathor          use hathor for ttbar cross section predictions
                         (default=no)
--enable-updf            use uPDF evolution (default=no)
--enable-doc             Build documentation (default=no)
```

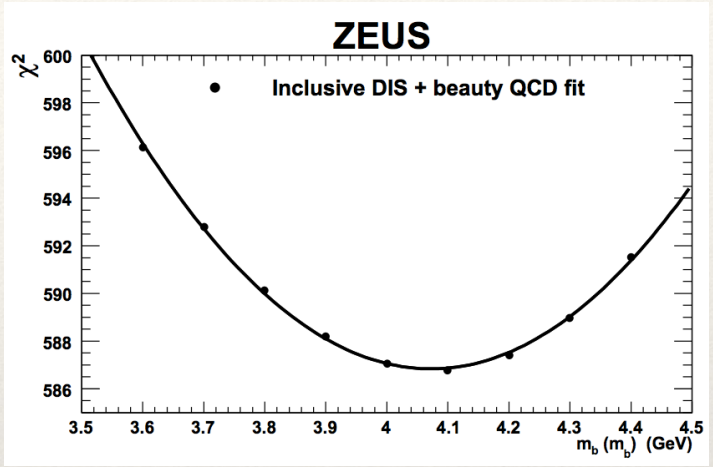
| Experimental Data | Process | Reaction | Theory schemes calculations |
|---|---|---|---|
| HERA, Fixed Target | DIS NC | $ep \to eX$<br>$\mu p \to \mu X$ | TR′, ACOT, ZM (QCDNUM), FFN (OPENQCDRAD, QCDNUM), TMD (uPDFevolv) |
| HERA | DIS CC | $ep \to \nu_e X$ | ACOT, ZM (QCDNUM), FFN (OPENQCDRAD) |
| | DIS jets | $ep \to e$ jets$X$ | NLOJet++ (fastNLO) |
| | DIS heavy quarks | $ep \to ec\bar{c}X$,<br>$ep \to eb\bar{b}X$ | TR′, ACOT, ZM (QCDNUM), FFN (OPENQCDRAD, QCDNUM) |
| Tevatron, LHC | Drell-Yan | $pp(\bar{p}) \to l\bar{l}X$,<br>$pp(\bar{p}) \to l\nu X$ | MCFM (APPLGRID) |
| | top pair | $pp(\bar{p}) \to t\bar{t}X$ | MCFM (APPLGRID), HATHOR, DiffTop |
| | single top | $pp(\bar{p}) \to tl\nu X$,<br>$pp(\bar{p}) \to tX$,<br>$pp(\bar{p}) \to tWX$ | MCFM (APPLGRID) |
| | jets | $pp(\bar{p}) \to$ jets$X$ | NLOJet++ (APPLGRID), NLOJet++ (fastNLO) |
| LHC | DY heavy quarks | $pp \to VhX$ | MCFM (APPLGRID) |

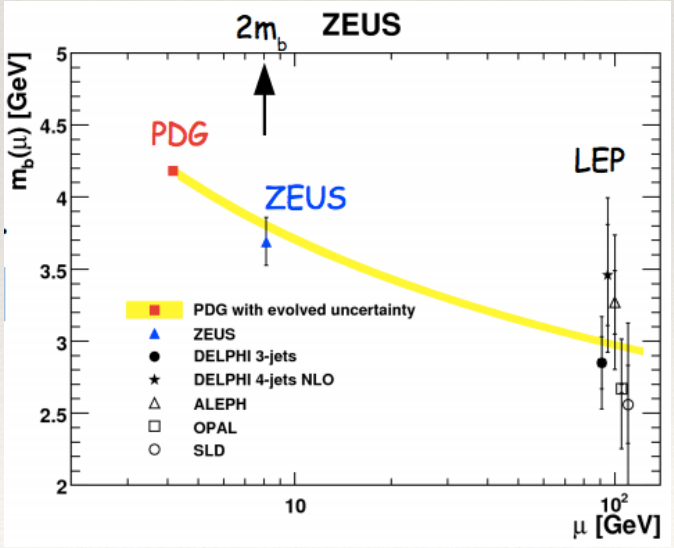
# Running beauty mass from F2b

- The value of the running beauty mass is obtained using HERAFitter (via OPENQCDRAD):
  - chi2 scan method from QCD fits in FFN scheme to the combined HERA I inclusive data + beauty measurements, beauty-quark mass is defined in the $\overline{\text{MS}}$ scheme.




QCD Fits
HERA I+beauty




The extracted $\overline{\text{MS}}$ beauty-quark mass is in agreement with PDG average and LEP results.

# Studies of theoretical uncertainties of Mw mass at the LHC

ATL-PHYS-PUB-2014-015

- The measurement of the mass of the W boson provides a stringent test of the SM
- At the LHC, the best experimental precision on Mw might be achieved from the pT distribution of the charged electron/muon from leptonic decay of W:
- A quantitative study of the theoretical uncertainties due to the incomplete knowledge of the quark PDF, and to the uncertainties on the modelling of the low-pT region of W/Z bosons, was performed using HERAFitter platform.
  - Theoretical predictions is based on MCFM and CuTe (interfaced to APPLGRID)
  - A PDF set is generated using simply HERA I data to study the model variations (mc, strange) and propagated via chi2 profiling method to study the effect of PDF uncertainties