

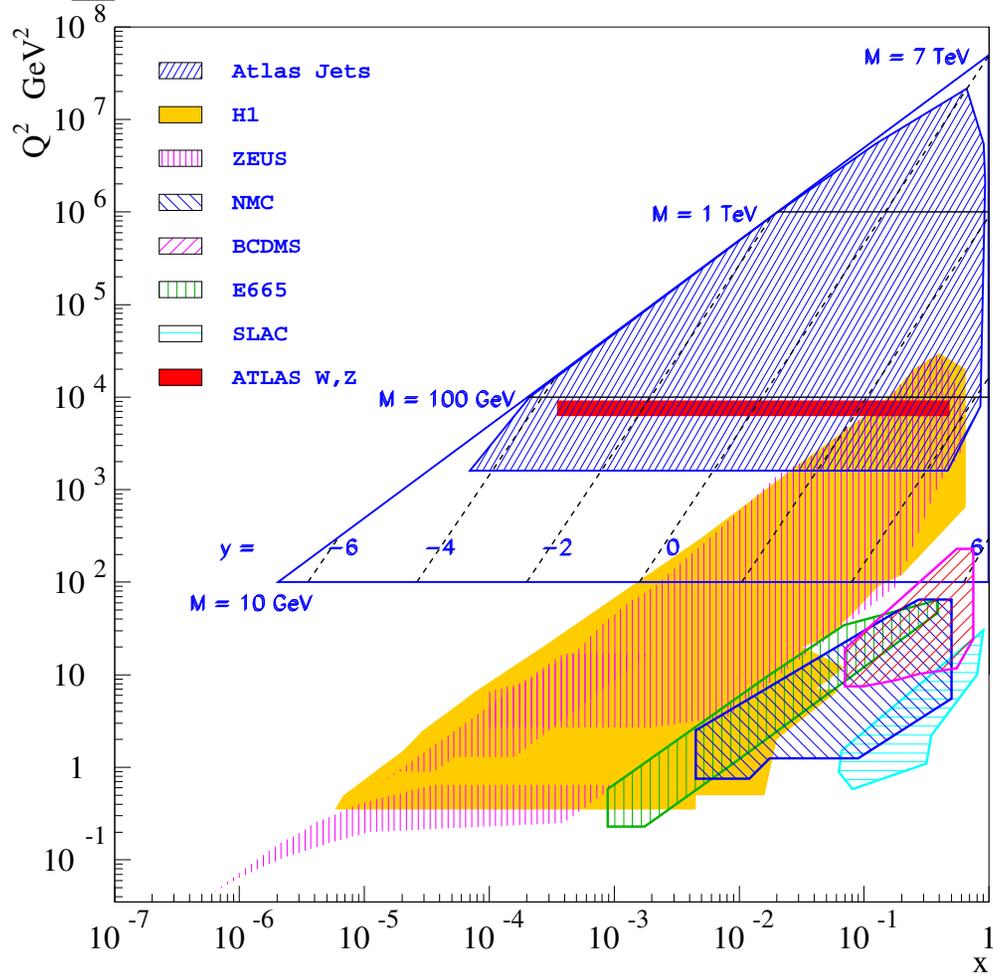


The HERAFitter project

S. Glazov (DESY), for the HERAFitter developers' team

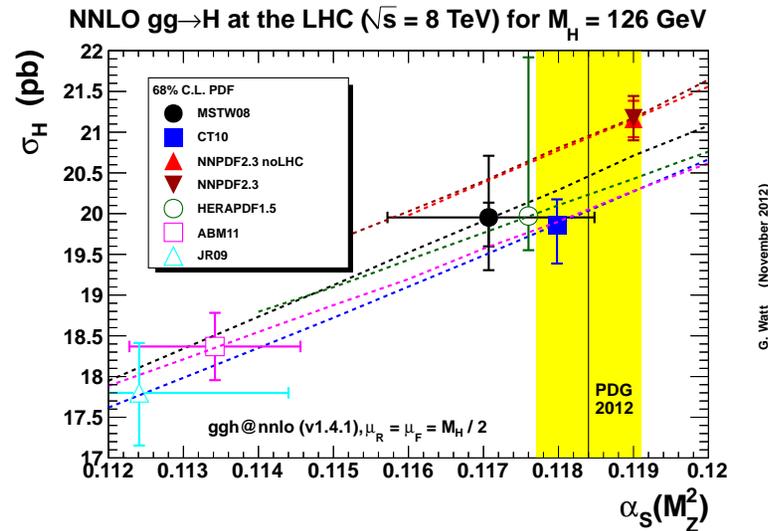
Pheno 2014, Pittsburgh.

Cross sections at LHC and PDFs



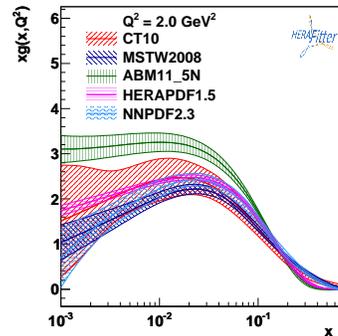
The cross sections are given by a convolution of the **parton distribution** and coefficient **functions**, $\sim x_1 f_1(x_1, \mu) x_2 f_2(x_2, \mu) \hat{\sigma}(x_1, x_2, \mu)$. PDFs are essential for predictions at the LHC.

PDFs from different groups



- Many groups, [ABM](#), [MSTW](#), [CTEQ](#), [HERAPDF](#), [NNPDF](#), [JR](#), provide PDFs based on QCD analysis of DIS and pp data.
 - In some cases, results of these groups do not agree with each other within quoted uncertainties.
- [HERAFitter](#) is an open source platform to include coefficient function codes from different groups, common ground for benchmarking.
- [HERAFitter](#) is a tool to optimize experimental measurements to maximize their PDF sensitivity.

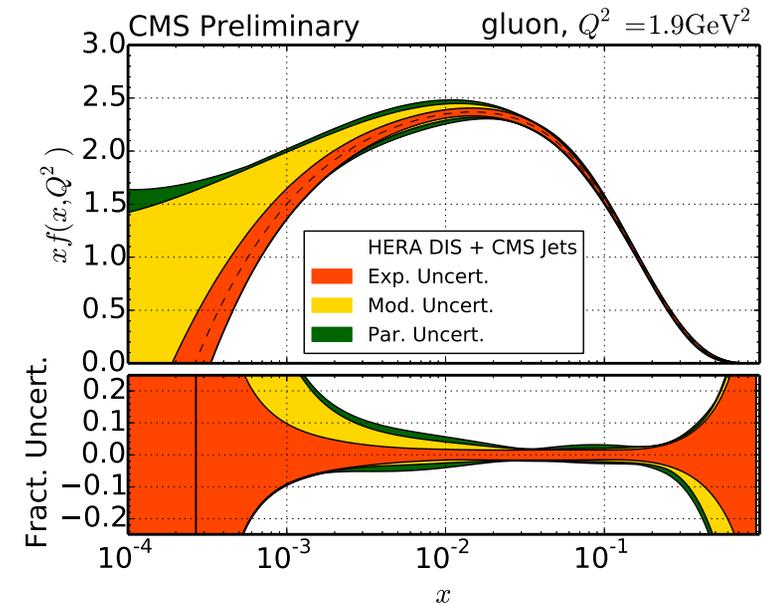
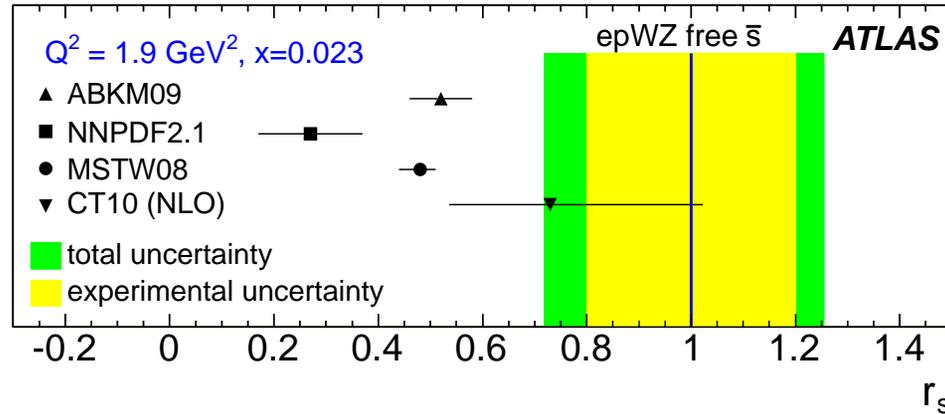
HERAFitter in a nutshell



- Open-source program for development of QCD analyses herafitter.org
- Fast LO,NLO and NNLO evolution code using the QCDNUM program.
- Coefficient functions for deep inelastic scattering processes using the fast convolution engine of QCDNUM and codes from ACOT, RT, ABM. Coefficient functions for pp and $p\bar{p}$ processes using APPLGRID and FastNLO programs.
- Alternative evolution: dipole model and TMD gluons.
- Flexible interface to include new data with correlated uncertainties.
- Fast analytic minimization vs nuisance parameters, MINUIT for PDFs.

Time to calculate NNLO predictions and χ^2 for 592 HERA data points with 114 nuisance parameters is 0.06 seconds using i7-3687U CPU at 2.6 GHz.

Usage by LHC experiments



HERAFitter is used for a number of LHC publications and theory papers, e.g.

- Determination of the strange-sea distribution function suppression using ATLAS W, Z boson measurements ([PRL 109\(2012\) 012001](#)).
- PDF constraints and α_s from the inclusive jet measurement by CMS ([CMS-SMP-12-028](#)).

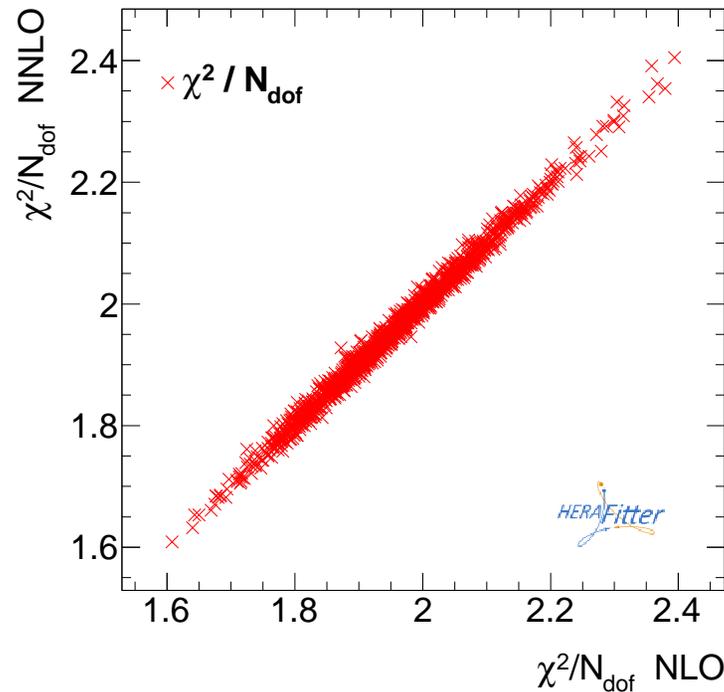
LO, NLO, NNLO PDFs with correlated uncertainties

Consider two processes, for process 1 there are NLO and NNLO calculations, for process 2 only NLO calculations exist. How to minimize theory errors for the prediction of the cross-section ratio ?

- $\frac{\sigma_1^{\text{NLO}}(PDF^{\text{NLO}})}{\sigma_2^{\text{NLO}}(PDF^{\text{NLO}})}$ — use NLO coefficient functions and PDFs for both processes. Good if scale dependence is identical (e.g. W charge asymmetry). Large scale uncertainties otherwise.
- $\frac{\sigma_1^{\text{NNLO}}(PDF^{\text{NNLO}})}{\sigma_2^{\text{NLO}}(PDF^{\text{NLO}})}$ — use NNLO (NLO) coefficient functions and different PDFs for the first (second) process. Reduces scale uncertainties, however PDF uncertainties are not treated correctly (correlation information lost).
- $\frac{\sigma_1^{\text{NNLO}}(PDF^{\text{NNLO}})}{\sigma_2^{\text{NLO}}(PDF^{\text{NNLO}})}$ — use NNLO (NLO) coefficient functions for the first (second) process and common NNLO PDF. Reduces scale uncertainties, however PDFs are treated inconsistently for process 2 calculation.

→ need for PDF sets with correlated uncertainties between different orders.

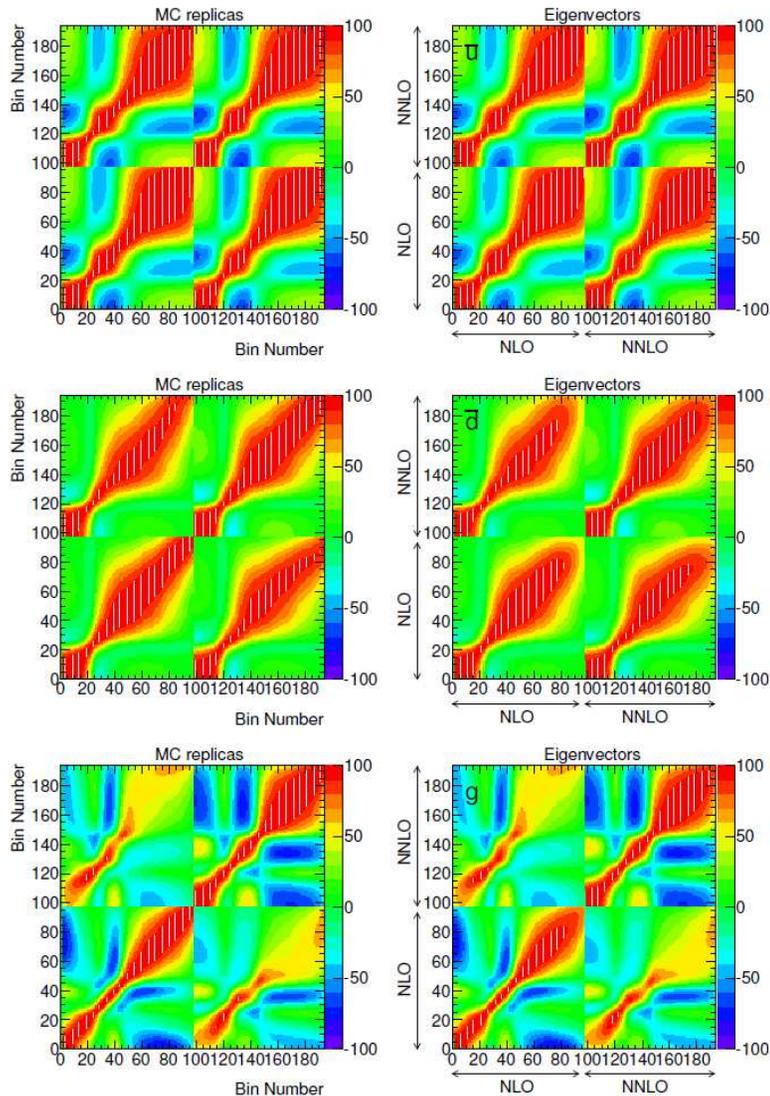
Correlated analysis methodology



- Fit using HERA data only, similar to HERAPDF1.0.
- Synchronize QCD fit settings for fits at different orders (parameterisation, starting scale, data cuts)
- Use MC method for uncertainties, synchronize seeds for fits at different orders.

arXiv:1404.4234

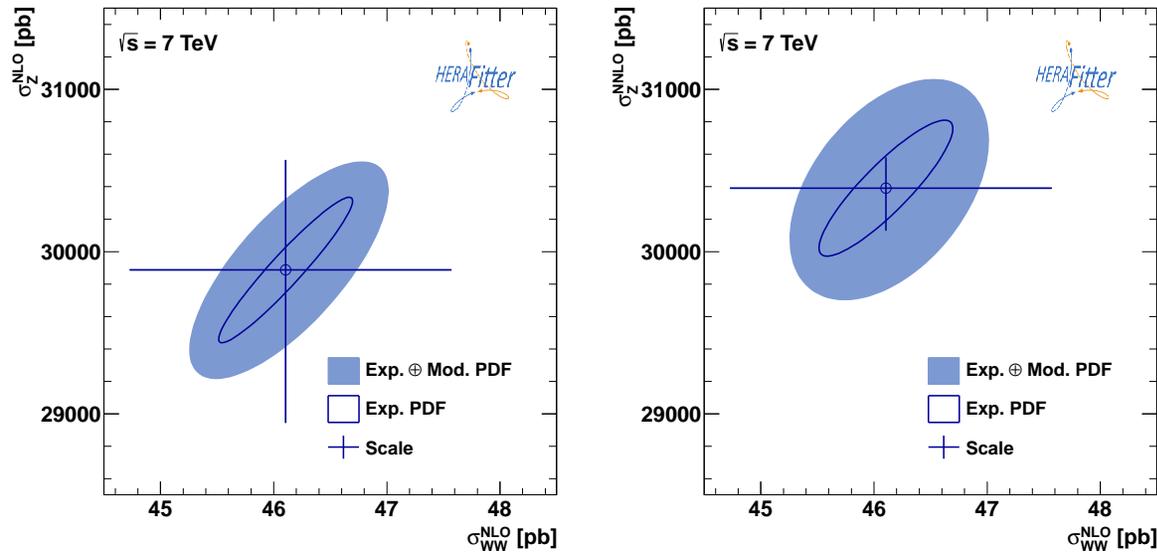
Correlated PDFs



(Bin number: $\sim x$)

- PDF uncertainties determined by MC method are also transformed to eigenvector representation. This is achieved by diagonalization NLO-NNLO covariance matrix of PDF values at the QCDNUM x -grid points at the evolution starting scale $Q^2 = 1.7 \text{ GeV}^2$ (fragments of the correlation matrix are shown here).
- High correlations for PDFs at similar x values. Very good description of the correlations using eigenvector representation. All PDFs except gluon at high x show high correlations between NLO and NNLO.

Z and WW production at LHC



- Use case: Z boson and WW diboson production at the LHC.
- Z boson cross section calculated using FEWZ at NLO and NNLO; WW diboson cross section calculated using MCFM at NLO.
- Similar PDF dependence leads to high correlation of PDF uncertainties. The correlation is reduced when using NNLO calculation for σ_Z .
- Scale uncertainty is reduced when using σ_Z^{NNLO} .

PDF uncertainties for Z and WW production

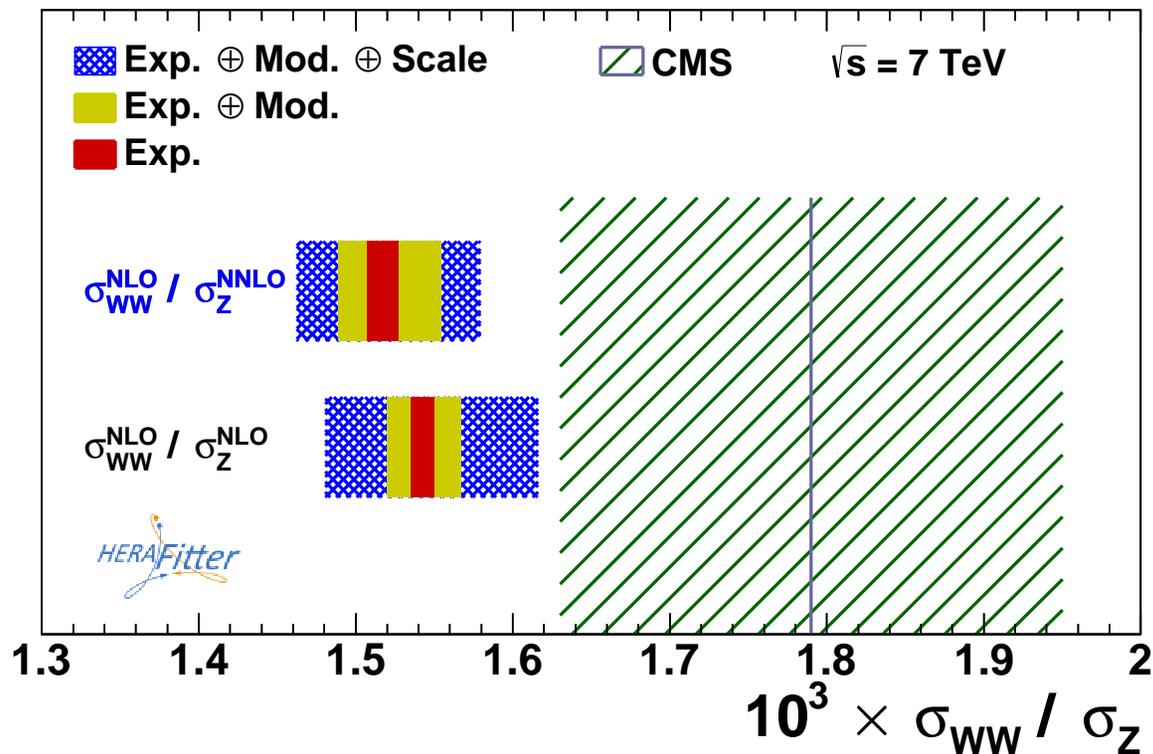
Variation	σ_{WW}^{NLO} %	σ_Z^{NLO} %	σ_Z^{NNLO} %
$r_s(-0.3)$	1.00	-0.29	-0.33
$r_s(+0.3)$	-0.81	0.39	0.42
$M_c(-0.06 \text{ GeV})$	-0.81	-0.89	-0.76
$M_c(+0.06 \text{ GeV})$	0.55	0.66	0.61
$M_b(-0.45 \text{ GeV})$	0.13	0.11	-0.02
$M_b(+0.25 \text{ GeV})$	-0.07	-0.07	0.00
$\alpha_S(M_Z)(-0.002)$	-0.54	-1.27	-1.17
$\alpha_S(M_Z)(+0.002)$	0.52	1.23	1.17
$Q_{\min}^2(-2.5 \text{ GeV}^2)$	-0.25	-0.35	0.23
$Q_{\min}^2(+2.5 \text{ GeV}^2)$	0.75	0.73	-1.06
$Q_0^2(-0.2 \text{ GeV}^2)$	-0.21	-0.19	-0.14
$+D_{u_v}$	-0.03	-0.32	0.97
$+D_{\bar{v}}$	-0.04	-0.02	-0.01
$+E_{\bar{v}}$	0.01	0.00	0.00

Table 2 Shifts of the WW di-boson and Z boson production cross sections due to the model and parameterisation variations in the PDF fit.

While experimental PDF uncertainties are all very highly correlated, uncertainties related to model and parameterisation assumptions show anticorrelation for some sources:

- Charm- (M_C), bottom- (M_B) quark mass parameters, strong coupling ($\alpha_S(M_Z)$) and evolution starting scale (Q_0^2) variations cause correlated variations of the cross sections.
- $r_s = \bar{s}/\bar{d}$ variation is anticorrelated between Z and WW .
- Requirement on input data scale (Q_{\min}^2) is anticorrelated between NLO and NNLO.

WW/Z cross-section ratio



- Compare the ratio of WW to Z production cross sections to the measurement by the CMS collaboration ([EPJC73 \(2013\) 2610](#))
- While PDF uncertainty increases when using mixed NNLO-NLO predictions, the total uncertainty is reduced due to reduction of the scale uncertainty for the σ_Z prediction.

Summary

- HERAFitter is an open-source platform for QCD analyses.
- HERAFitter provides state-of-the-art calculations for LO,NLO,NNLO predictions and fast minimization tools.
- HERAFitter is actively used by the LHC experiments and theory community.
- An analysis performed by the HERAFitter developers' team yields PDF sets which provide correlated uncertainties between different orders. Usage of these sets can reduce total theoretical uncertainty for the WW to Z cross-section ratio.