Update on neural network parton distributions

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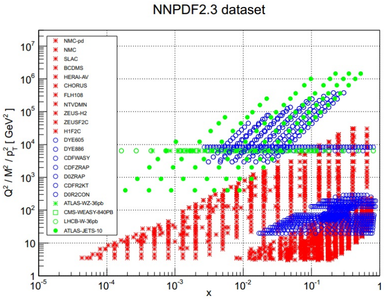
NNPDF2.3

NNPDF2.3: Only publicly available PDF set which includes LHC data in the fit. [arXiv:1207.1303]

Global fit, includes all relevant LHC data which was available with full covariance matrix:

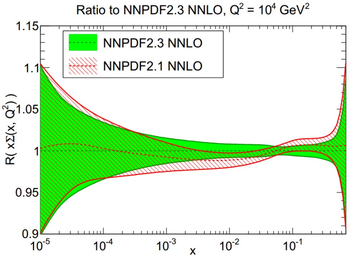
- ATLAS Inclusive Jets, 36pb^{-1}
- ATLAS W/Z lepton rapidity distributions, 36pb^{-1}
- CMS W lepton asymmetry, 840pb^{-1}
- LHCb W rapidity distributions, 36pb^{-1}

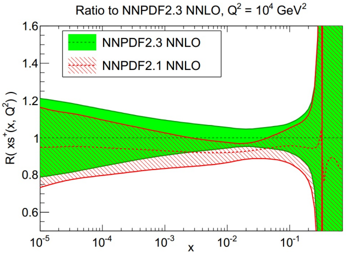


NNPDF2.3 PDFs

Impact of LHC data:

- Moderate effect from LHC data, generally less than half a sigma in central values.
- Largest impact is for Singlet and strange distributions.
- Expect more substantial improvements with 2011 and 2012 data.

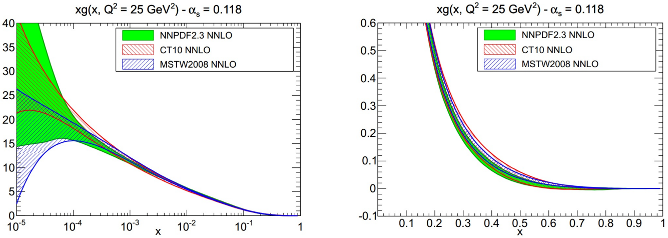




PDF Benchmarking

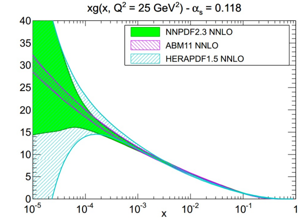
Comprehensive PDF benchmarking analysis in arXiv:1211.5142

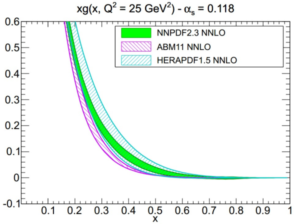
- Compares PDFs, parton luminosities and observables for available NNLO sets at common α_S.



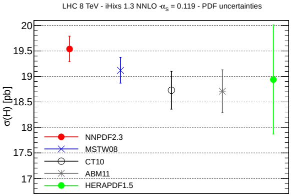
- Good consistency between the three global PDF sets.
- Most recent NNPDF, MSTW and CT NNLO sets agree at least as well as for NLO, in some places better

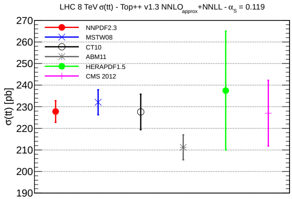
PDF Benchmarking





- HERAPDF1.5 NNLO consistent with global sets, although with larger uncertainties due to reduced dataset.
- Significant disagreement with ABM11 for some PDFs and cross sections, even at common α_S.

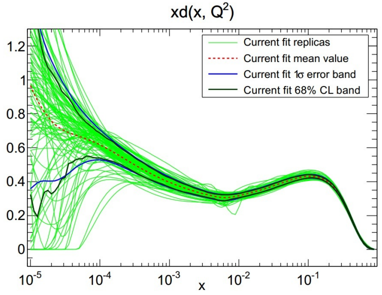




NNPDF2.3 set for MC event generators

- NLO event generators often require positive definite NLO PDFs.
- In NLO and NNLO NNPDF fits we impose positivity on observables, not on PDFs directly
- In practice, PDFs go negative in regions with few experimental constraints, and this has little effect on observables

- NNPDF2.3 MC set with exact PDF positivity, available through latest version of LHAPDF (v5.8.9, NNPDF2.3_as_0119_mc.LHgrid etc.)
- Also investigating extending range of observables for which we impose positivity.

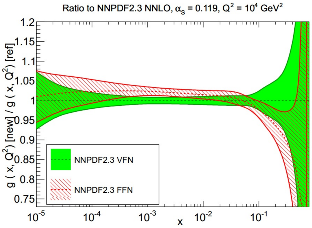


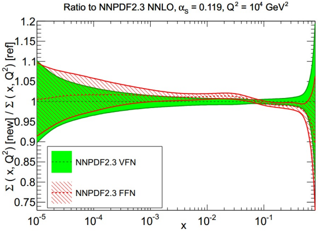
Other NNPDF developments

Study of theoretical uncertainties

Recent paper [arXiv:1303.1189] looks at the effects of three sources of theoretical uncertainties in the framework of NNPDF2.3.

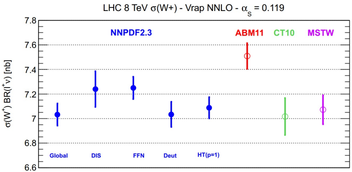
- Fixed Flavor Number (FFN) scheme for heavy quark masses
  - NNPDF fit performed using FFN scheme and compared to default (GM-VFN)
  - Significant differences found for PDFs
    - Large change in gluon due to differences in scaling violations
    - Effect increase with evolution to LHC scales
  - These differences translate to observables, results in worse quality of fit and affects LHC cross sections

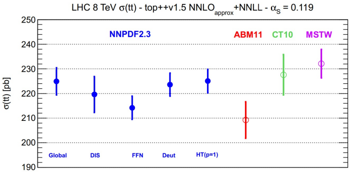




Study of theoretical uncertainties

- Higher twist effects – using same corrections as ABM
  - Negligible impact on PDFs or observables
  - Doubling size of corrections results in change less than half sigma in all PDFs
- Deuterium nuclear corrections
  - Moderate impact, confined to up-down separation for large x.
  - Theoretical knowledge of effects still poor.





- These results suggest that difference between ABM11 and the three global PDF sets is largely due to use of FFN scheme and an almost DIS-only dataset.

C++ development

We are currently in the process of developing a C++ version of our fitting code.

Having a new more modular object-oriented code has several benefits:

- It has been possible to cleanly separate the theory, data and fitting element of the code.
- Easier to maintain and to add new improvements.
- Easier to add new LHC data, and to add cross-correlations between datasets.
- New code was developed with minimal reference to old code, so provides a cross-check for bugs.
- Have also gained a large speedup through structural changes.

Development should be complete in time for next major NNPDF release.

Outlook

Many things planned for NNPDF in the future

- NNPDF2.3QED: PDF set with QED corrections
  - see Stefano's talk up next.

- New strangeness analysis using recently released $W+$charm data

- Further in the future, NNPDF3.0:
  - Based on C++ code
  - Including many new LHC processes
    - top pair production
    - double differential Drell-Yan
    - Z p_T distributions
    - CMS jet data
    - prompt photon
    - $+$ others...
  - Improved NNPDF methodology

Summary

- NNPDF2.3: Only PDF fit which includes LHC data, shows that available LHC data already has a small but significant impact on PDF determination.
- New NNPDF2.3 NLO set specifically for use in NLO event generators.
- Looking ahead, lots of new LHC data coming out over the next months and years and we'll have a refined NNPDF methodology to fit it with.

NNPDF website: `nnpdf.hepforge.org`

Our PDFs are also available through the LHAPDF interface (`lhapdf.hepforge.org`)

[Backup Slides]

NNPDF approach - key features

- Global Fit
  - Use data from wide variety of processes (e.g DIS, W/Z cross sections from colliders, fixed target Drell-Yan, jet data)
- Fit PDFs at initial scale using neural networks
  - Provides a flexible and unbiased fitting basis
- Perform χ^2 minimization to experimental data using genetic algorithm
  - Suitable for efficiently searching for minima in a large parameter space
- Monte Carlo approach to PDF uncertainties
  - Direct sample of probability distributions of PDFs without assumptions of Gaussianity

Neural network PDFs

- We model 7 independent PDF combinations:

Gluon	$g(x)$	Sea asymmetry	$\Delta_s(x) = \bar{d}(x) - \bar{u}(x)$
Singlet	$\Sigma(x) = \sum_i [f_i(x) + \bar{f}_i(x)]$	Total strangeness	$s^+(x) = s(x) + \bar{s}(x)$
Valence	$V(x) = \sum_i [f_i(x) - \bar{f}_i(x)]$	Strange valence	$s^-(x) = s(x) - \bar{s}(x)$
Triplet	$T(x) = [u(x) + \bar{u}(x)] - [d(x) + \bar{d}(x)]$		

- Each PDF is parametrized by a neural network defined by 37 parameters per PDF, so 259 for the fit in total.
- Large number of parameters increases risk of overfitting – fitting statistical noise in data as well as underlying pattern.
- We prevent this using Cross-Validation:
  - Data is split into *training* and *validation* sets.
  - The networks are trained on only the training set and the fit is stopped when quality of fit to validation set increases.

Monte Carlo replicas

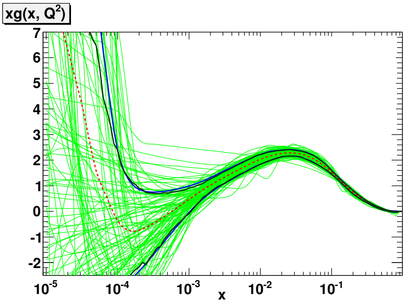
We use a Monte Carlo approach to calculating PDF uncertainties:

- Generate a large number of replica datasets according to multigaussian probability distributions suggested by the experimental uncertainties.
- Perform a separate fit using each data replica.

Expectation values for any quantity dependent on PDFs can be determined directly using

$$\langle \mathcal{F} \rangle = \frac{1}{N_{rep}} \sum_{k=1}^{N_{rep}} \mathcal{F}\left(S_k\right)$$

and uncertainties, confidence intervals, correlations using similar formula.

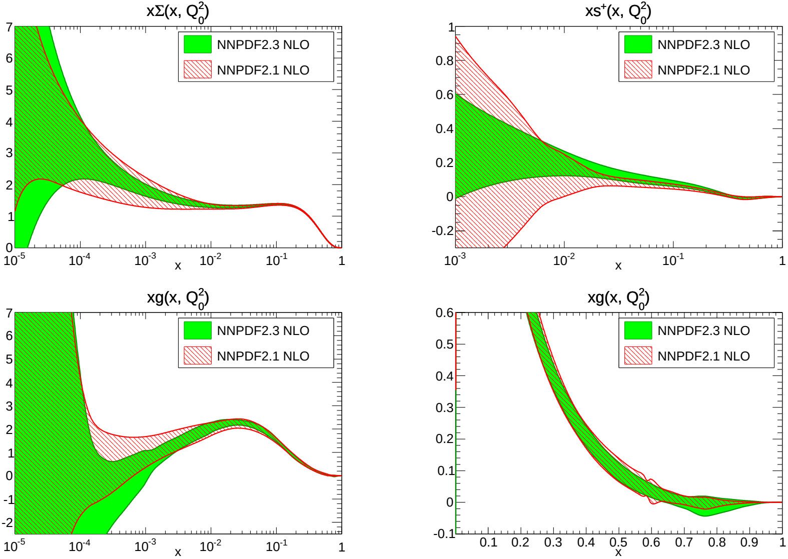


Results: Fit Quality

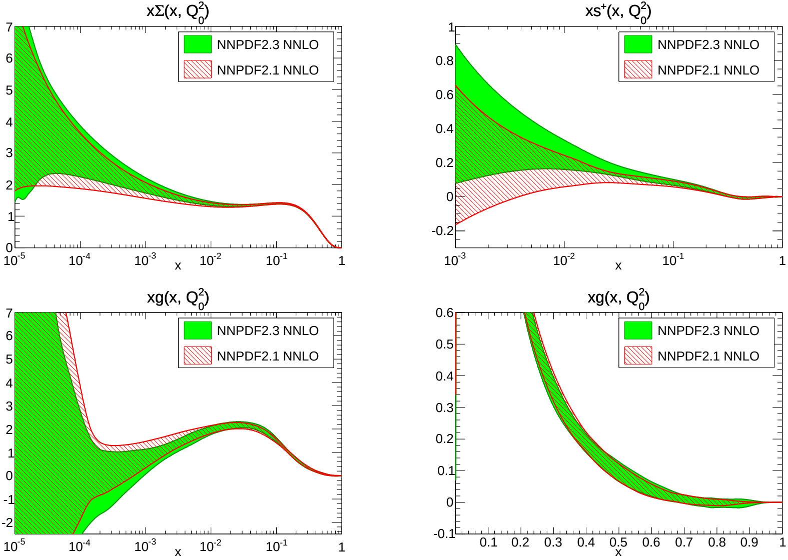
- Comparison of χ^2 to data for NNPDF2.1 and 2.3 sets.
- Improvement for NLO fit in most datasets due to methodological improvements.
- Inclusion of LHC data improves quality of their descriptions with little impact on other experiments – no sign of tension.
- Fit quality comparable between NLO and NNLO, with NLO slightly better.

	NNPDF2.1		NNPDF2.3	
	NLO	NNLO	NLO	NNLO
Total	1.145	1.167	1.121	1.153
NMC-pd	0.97	0.93	0.93	0.94
NMC	1.68	1.58	1.61	1.57
SLAC	1.34	1.04	1.26	1.02
BCDMS	1.21	1.29	1.19	1.29
CHORUS	1.10	1.08	1.10	1.06
NTVDMN	0.70	0.50	0.45	0.55
HERAI-AV	1.04	1.04	1.00	1.01
FLH108	1.34	1.23	1.28	1.20
ZEUS-H2	1.21	1.21	1.20	1.22
ZEUS F_2^c	0.75	0.81	0.82	0.90
H1 F_2^c	1.50	1.44	1.58	1.52
DYE605	0.94	1.09	0.88	1.02
DYE886	1.42	1.76	1.28	1.62
CDF W asy	1.87	1.63	1.54	1.70
CDF Z rap	1.77	2.42	1.79	2.12
D0 Z rap	0.57	0.68	0.57	0.63
ATLAS W,Z	[1.58]	[2.22]	1.27	1.46
CMS W e asy	[2.26]	[1.45]	1.04	0.96
LHCb W,Z	[1.34]	[1.42]	1.21	1.22
CDF RII k_T	0.68	0.65	0.61	0.67
D0 RII cone	0.90	0.98	0.84	0.93
ATLAS jets	[1.65]	[1.48]	1.55	1.42

NNPDF2.3 PDFs: NLO



NNPDF2.3 PDFs: NNLO



FFN fit quality

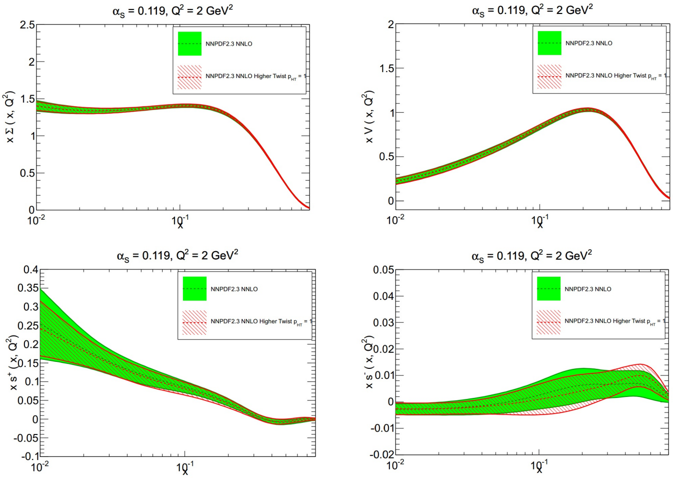
$x_{\rm min}$	$x_{\rm max}$	$Q^2_{\rm min}$ (GeV)	$Q^2_{\rm max}$ (GeV)	$\Delta\chi^2$ (DIS)	$N_{\rm dat}^{\rm DIS}$	$\Delta\chi^2$ (HERA-I)	$N_{\rm dat}^{\rm hera-I}$
$4 \cdot 10^{-5}$	1	3	10^6	72.2	2936	77.1	592
$4 \cdot 10^{-5}$	0.1	3	10^6	87.1	1055	67.8	405
$4 \cdot 10^{-5}$	0.01	3	10^6	40.9	422	17.8	202
$4 \cdot 10^{-5}$	1	10	10^6	53.6	2109	76.4	537
$4 \cdot 10^{-5}$	1	100	10^6	91.4	620	97.7	412
$4 \cdot 10^{-5}$	0.1	10	10^6	84.9	583	67.4	350
$4 \cdot 10^{-5}$	0.1	100	10^6	87.7	321	87.1	227

$\Delta\chi^2 \equiv \chi^2_{\rm FFN} - \chi^2_{\rm VFN}$ of the deep-inelastic data in different kinematic regions. The contribution from combined HERA-I data is also shown in the last column.

The difference is always positive, indicating that the FFN fit is always worse.

See arXiv:1211.5142 for more details.

PDFs with Higher Twist corrections [arXiv:1211.5142]



Collider-only NNPDF2.3

- NNPDF fit only using HERA, Tevatron and LHC data
- Gluon is fairly well constrained.
- Large uncertainties in other PDFs e.g. T3
- Situation will change with more LHC data