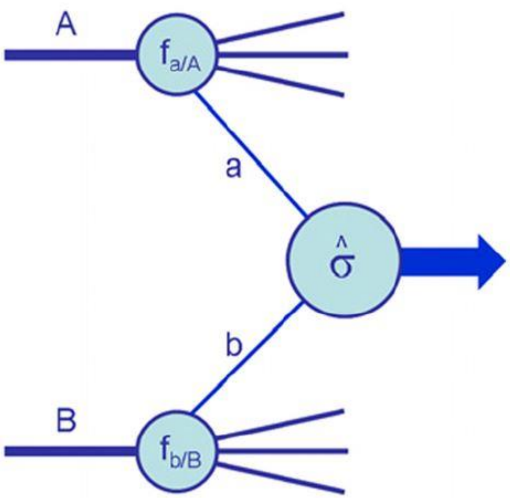
Global PDFs for LHC Run 2

- Next Generation Fits
  - data
  - theory
  - methodology
- PDF combination
- Future prospects

Richard Ball (Edinburgh and CERN)

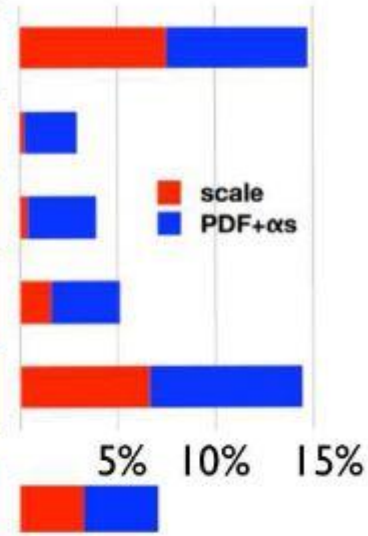
La Thuile Mar 2015

Why Global PDFs?



J. Campbell, ICHEP'12

		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
NNLO QCD +NLO EW	VBF	1.56 pb	2.9%
	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%
NNLO QCD	tt	245.8 pb	7%



- To exploit LHC data we need to compute cross-sections
- All hard LHC processes involve partons: need PDFs
- PDFs: u, ubar, d, dbar, s, sbar, c, cbar, g all fns of x, Q^2
- PDF uncertainties still significant for many LHC processes
- Use LHC data to further constrain PDFs

Next Generation Global PDFs

NNPDF2.3 (2012): becomes **NNPDF3.0** arXiv:1410.8849

MSTW08 (2008): becomes **MMHT14** arXiv:1412.3989

CT10 (2010-12): becomes **CT14** preliminary

All three combine: old FT DIS, nu and DY data
HERA DIS data
Tevatron DY, W/Z, jet data
LHC Run 1 DY, W/Z, jet data

HERAPDF1.5 (2010): becomes HERAPDF2.0 preliminary

Will include the combined HERA II data (not yet released)

ABM11/12 (2011-13): becomes ABM14?

No Tevatron data, only a little LHC data

Current Public sets: http://projects.hepforge.org/lhapdf

Next Generation Global PDFs

NNPDF3.0

NNPDF

Edinburgh 2014/15
IFUM-1034-FT
CERN-PH-TH/2013-253
OUTP-14-11p
CAVENDISH-HEP-14-11

Parton distributions for the LHC Run II

The NNPDF Collaboration:
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Abstract

We present NNPDF3.0, the first set of parton distribution functions (PDFs) determined with a methodology validated by a closure test. NNPDF3.0 uses a global dataset including HERA-II deep-inelastic inclusive cross-sections, the combined HERA charm data, jet production from ATLAS and CMS, vector boson rapidity and transverse momentum distributions from ATLAS, CMS and LHCb, $W+c$ data from CMS and top quark pair production total cross sections from ATLAS and CMS. Results are based on LO, NLO and NNLO QCD theory and also include electroweak corrections. To validate our methodology, we show that PDFs determined from pseudo-data generated from a known underlying law correctly reproduce the statistical distributions expected on the basis of the assumed experimental uncertainties. This closure test ensures that our methodological uncertainties are negligible in comparison to the generic theoretical and experimental uncertainties of PDF determination. This enables us to determine with confidence PDFs at different perturbative orders and using a variety of experimental datasets ranging from HERA-only up to a global set including the latest LHC results, all using precisely the same validated methodology. We explore some of the phenomenological implications of our results for the upcoming 13 TeV Run of the LHC, in particular for Higgs production cross-sections.

MMHT14

LCTS/2014-47
IPPP/14/97
DCPT/14/194
December 15, 2014

Parton distributions in the LHC era: MMHT 2014 PDFs

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Abstract

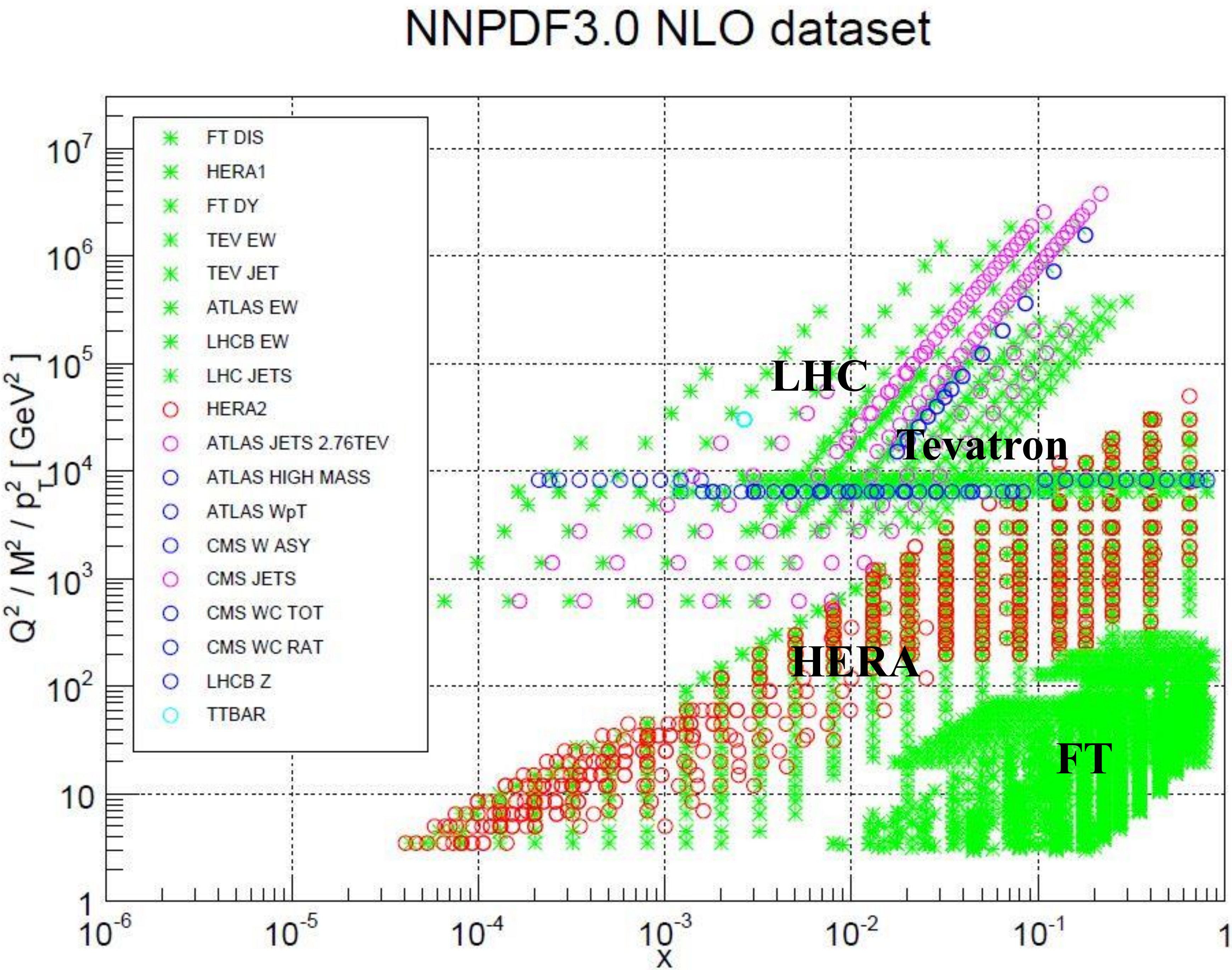
We present LO, NLO and NNLO sets of parton distribution functions (PDFs) of the proton determined from global analyses of the available hard scattering data. These MMHT2014 PDFs supersede the 'MSTW2008' parton sets, but are obtained within the same basic framework. We include a variety of new data sets, from the LHC, updated Tevatron data and the HERA combined H1 and ZEUS data on the total and charm structure functions. We also improve the theoretical framework of the previous analysis. These new PDFs are compared to the 'MSTW2008' parton sets. Almost always the PDFs, and the predictions, are within one standard deviation of those of MSTW2008. The major changes are the $u-d$ valence quark difference at small x due to an improved parameterisation and, to a lesser extent, the strange quark PDF due to the effect of some LHC data and a better treatment of the $D \to \mu$ branching ratio. We compare our MMHT PDF sets with those of other collaborations; in particular with the NNPDF3.0 sets, which are contemporary with the present analysis.

CT14

J. Gao (ANL), M. Guzzi (Manchester), J. Huston, J. Pumplin, D. Stump, C. Schmidt, C.-P. Yuan (MSU), P. Nadolsky, T.-J. Hou (SMU), S. Dulat (Xinjiang)

Preliminary

Experimental Data



NNPDF3.0 NLO dataset
FT DIS
HERA1
FT DY
TEV EW
TEV JET
ATLAS EW
LHCB EW
LHC JETS
HERA2
ATLAS JETS 2.76TEV
ATLAS HIGH MASS
ATLAS WpT
CMS W ASY
CMS JETS
CMS WC TOT
CMS WC RAT
LHCB Z
TTBAR
LHC
Tevatron
HERA
FT
Q^2 / M^2 / p^2_T [GeV^2]
x

DATASETS in detail

- CT14 missing CHORUS, but retains older CDHSW and CCFR data
- All now use combined HERA I data, but only NNPDF3.0 includes also HERA II data
- D0 jets dropped from NNPDF3.0 because not infrared safe
- All include significant amount of Run I LHC data: CT14 still missing double diff DY
- Total number of data pts reflects choice of cuts etc

	NNPDF3.0	MMHT14	CT14(prel)
SLAC p,d DIS	✔	✔	✗
BCDMS p,d DIS	✔	✔	✔
NMC p,d DIS	✔	✔	✔
E665 p,d DIS	✗	✔	✗
CDHSW nu-DIS	✗	✗	✔
CCFR nu-DIS	✗	✔	✔
CHORUS nu-DIS	✔	✔	✗
CCFR dimuon	✗	✔	✔
NuTeV dimuon	✔	✔	✔
HERA I NC,CC	✔	✔	✔
HERA I charm	✔	✔	✔
H1,ZEUS jets	✗	✔	✗
H1 HERA II	✔	✗	✗
ZEUS HERA II	✔	✗	✗
E605 & E866 FT DY	✔	✔	✔
CDF & D0 W asym	✗	✔	✔
CDF & D0 Z rap	✔	✔	✔
CDF Run-II jets	✔	✔	✔
D0 Run-II jets	✗	✔	✔
ATLAS high-mass DY	✔	✔	✔
CMS 2D DY	✔	✔	✗
ATLAS W,Z rap	✔	✔	✔
ATLAS W pT	✔	✔	✗
CMS W asy	✔	✔	✔
CMS W +c	✔	✗	✗
LHCb W,Z rap	✔	✔	✔
ATLAS jets	✔	✔	✔
CMS jets	✔	✔	✔
ttbar tot xsec	✔	✔	✗
TOTAL NLO	4276	2996	3248?
TOTAL NNLO	4078	2663	???

LHC data: (partial) shopping list

Light Flavour Separation

- Low Mass and High Mass Drell-Yan — NNLO
- Double Differential DY Rapidity Distributions — NNLO
- Z Rapidity Distributions — NNLO
- W,Z asymmetries — NNLO

Strangeness, Charm and Beauty

- W+charm (strangeness) — NLO
- Z+charm, gamma+charm (charm) — NLO
- Z+b (beauty) — NLO

Medium & Large x Gluon

- Top Rapidity Distributions — NNLO
- Inclusive W,Z pT Distributions — NNLO
- Inclusive Jets — Partial NNLO
- Dijets — NLO
- Prompt Photons — NLO
- W/Z + jets — NLO

To take full advantage of data, need full systematic errors, additive or multiplicative

Theory and Methodology

Theory

	NNPDF3.0	MMHT14	CT14
LO, NLO, NNLO	✔	✔	✔
Heavy quarks schemes	VFN FONLL	VFN TR	VFN ACOT
$s + \bar{s}$ fitted	✔	✔	✔
$s - \bar{s}$ fitted	✔	✔	✗

- Common value of $\alpha_s = 0.118$, other values pm 0.001
- No consensus yet on treatment of m_c and m_b
- No intrinsic charm (though recent studies by CTEQ)
- NNLO ttbar (Top++, HATHOR, Difftop)
- NNLO inclusive jets (gg, qq channels only, rest soon)

TOOLS:

- New PDF plotting tool, APFEL
- New fitting tool, HERAfitter
- Fast interface tools FastNLO, FastKernel, Applgrid, Apfelcomb,….

(need to precompute xsecs into lookup tables to include hadronic data in fits)

Methodology

	NNPDF3.0	MMHT14	CT14
No. of fitted PDFs	7	7	6
Parametrization	neural nets	$x^a(1-x)^b\times$ Chebyschev	$x^a(1-x)^b\times$Bernstein
Free parameters	259	37	30-35
Uncertainties	Replicas	Hessian	Hessian
Tolerance	None	Dynamical	Dynamical
Closure test	✔	✗	✗
Reweighting	replicas	eigenvectors	eigenvectors

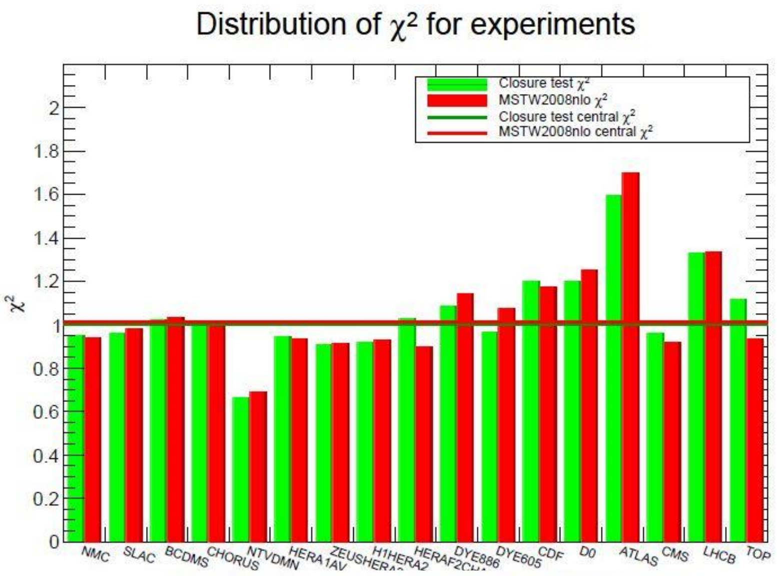
- Dynamical Tolerance: if $\Delta\chi^2=1$, Hessian PDF errors too small

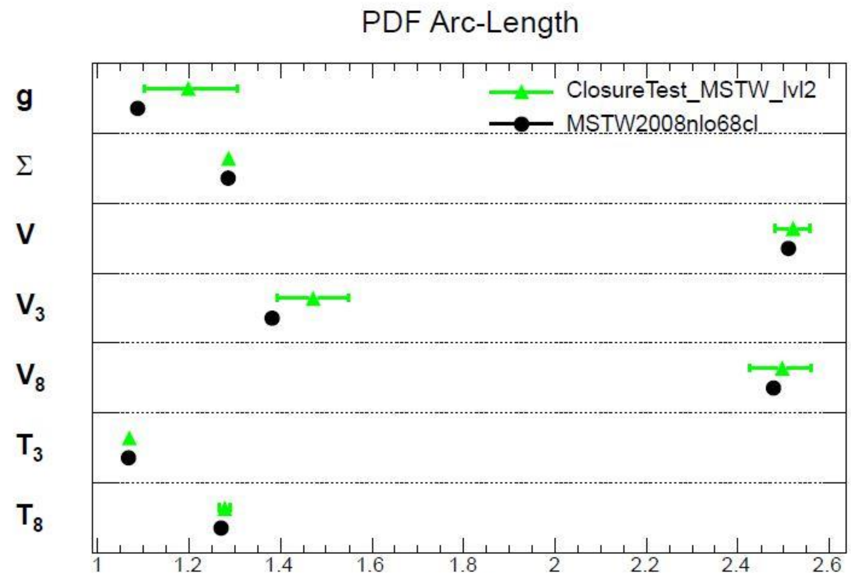
  Solution: inflate uncertainties by factor T, dynamically for each eigenvector
- Closure tests: if statistical methodology perfect

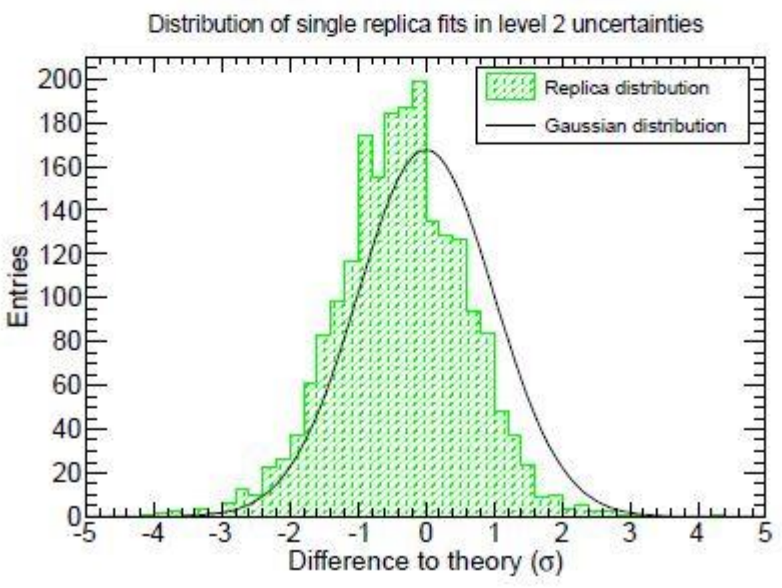
  Perfect data + Perfect theory → Perfect fit

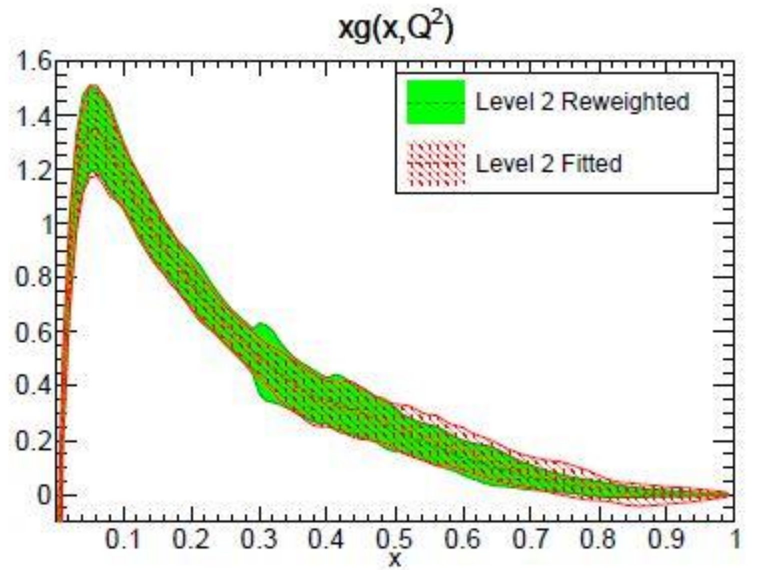
  1) Take a set of data, an assumed theory (eg NLO QCD), and some prior pdf, f_0
  2) Generate a set of perfect pseudodata from f_0 , by MC, using data errors
  3) Fit the pseudodata using your statistical methodology, giving fitted pdf, f
  4) If the methodology is perfect, should find $\chi^2=N$, $f = f_0$ within stated errors
- Reweighting: allows addition of new datasets without refitting

NNPDF3.0 Closure test Results





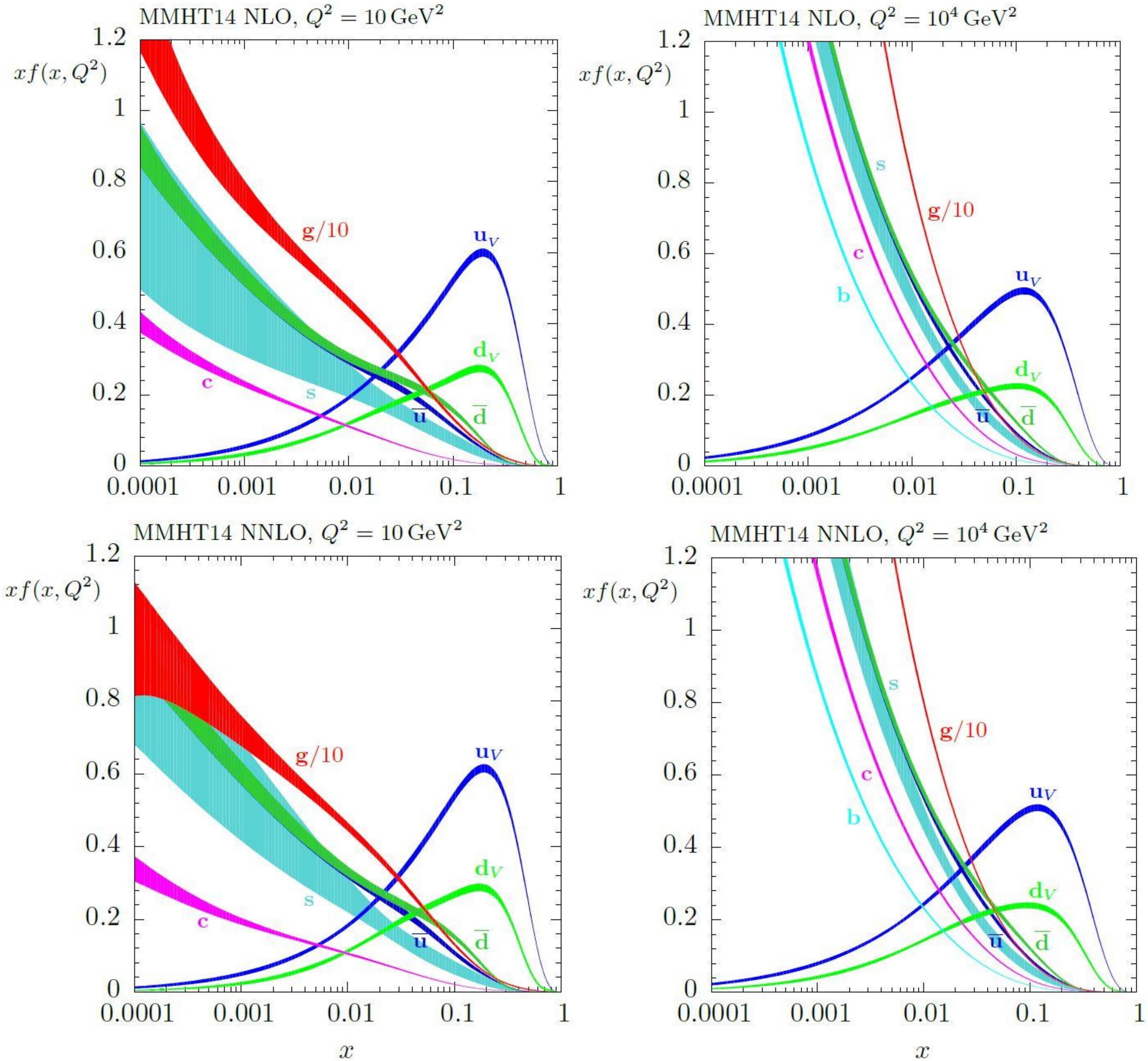


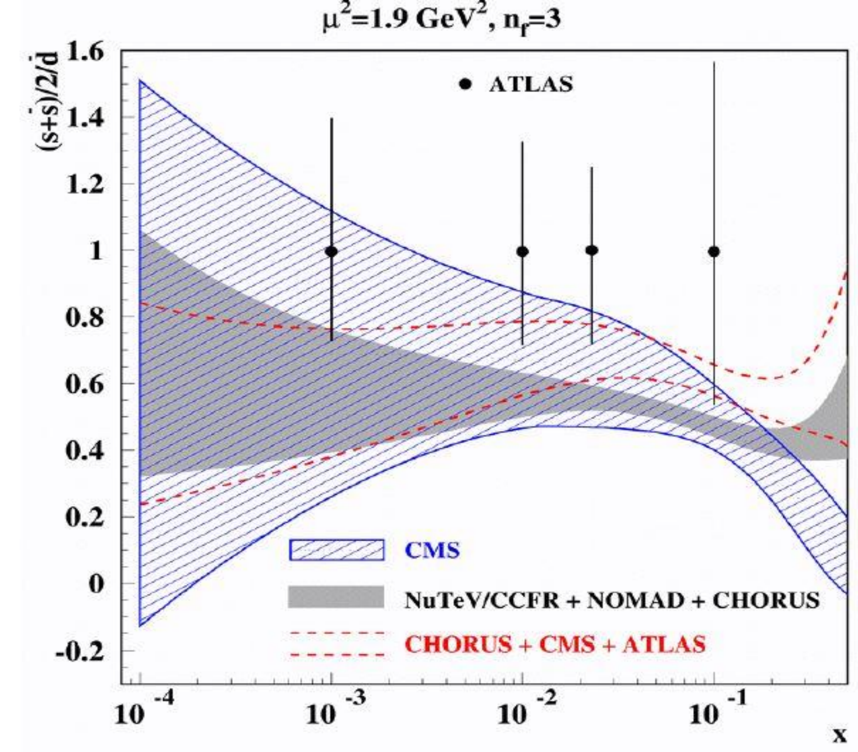


Conclusion: PDF uncertainties really are genuine uncertainties!

Results

MMHT14 PDFs


MMHT14 NLO, $Q^2 = 10\,\mathrm{GeV}^2$
MMHT14 NLO, $Q^2 = 10^4\,\mathrm{GeV}^2$
MMHT14 NNLO, $Q^2 = 10\,\mathrm{GeV}^2$
MMHT14 NNLO, $Q^2 = 10^4\,\mathrm{GeV}^2$
$xf(x, Q^2)$
x
g/10
u_V
d_V
$\bar{u}$
$\bar{d}$
s
c
b
0
0.2
0.4
0.6
0.8
1
1.2
0.0001
0.001
0.01
0.1
1

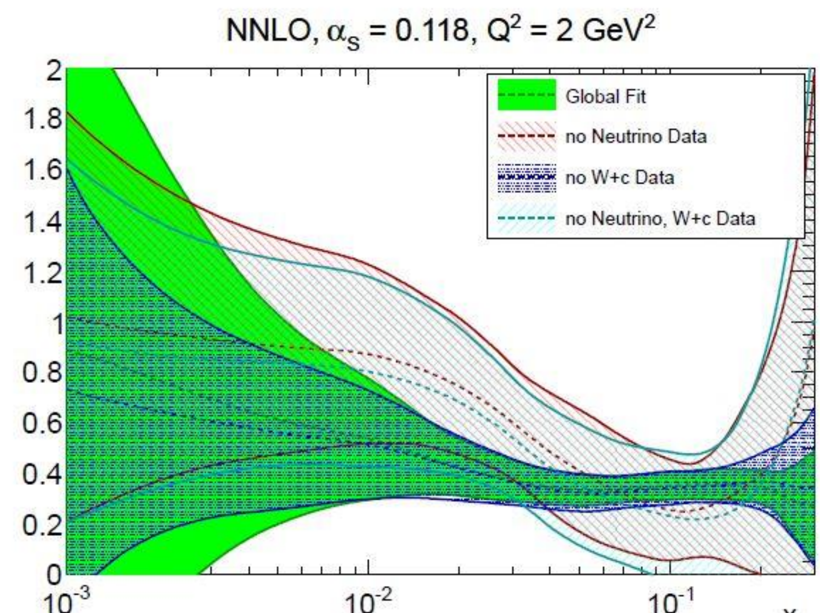


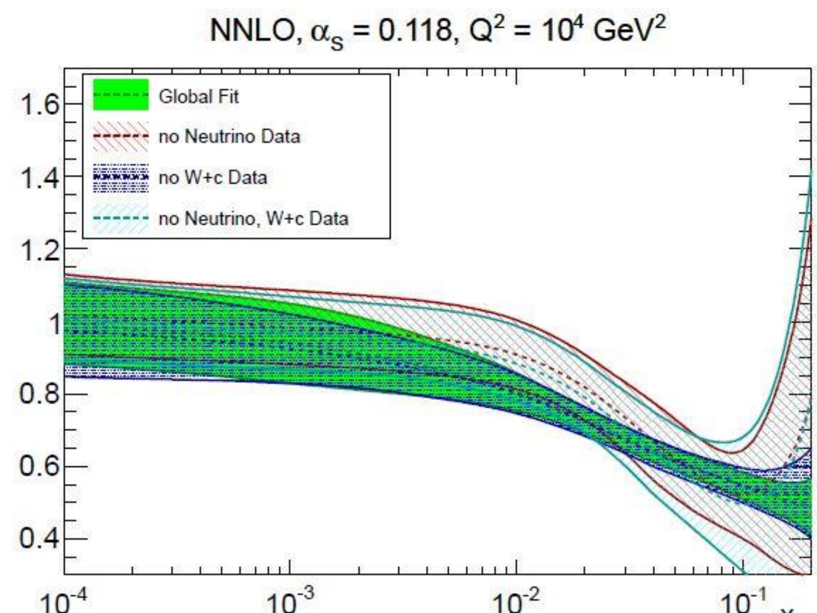
Strangeness

$$r_s(x, Q^2) = \frac{s(x, Q^2) + \bar{s}(x, Q^2)}{\bar{d}(x, Q^2) + \bar{u}(x, Q^2)}$$

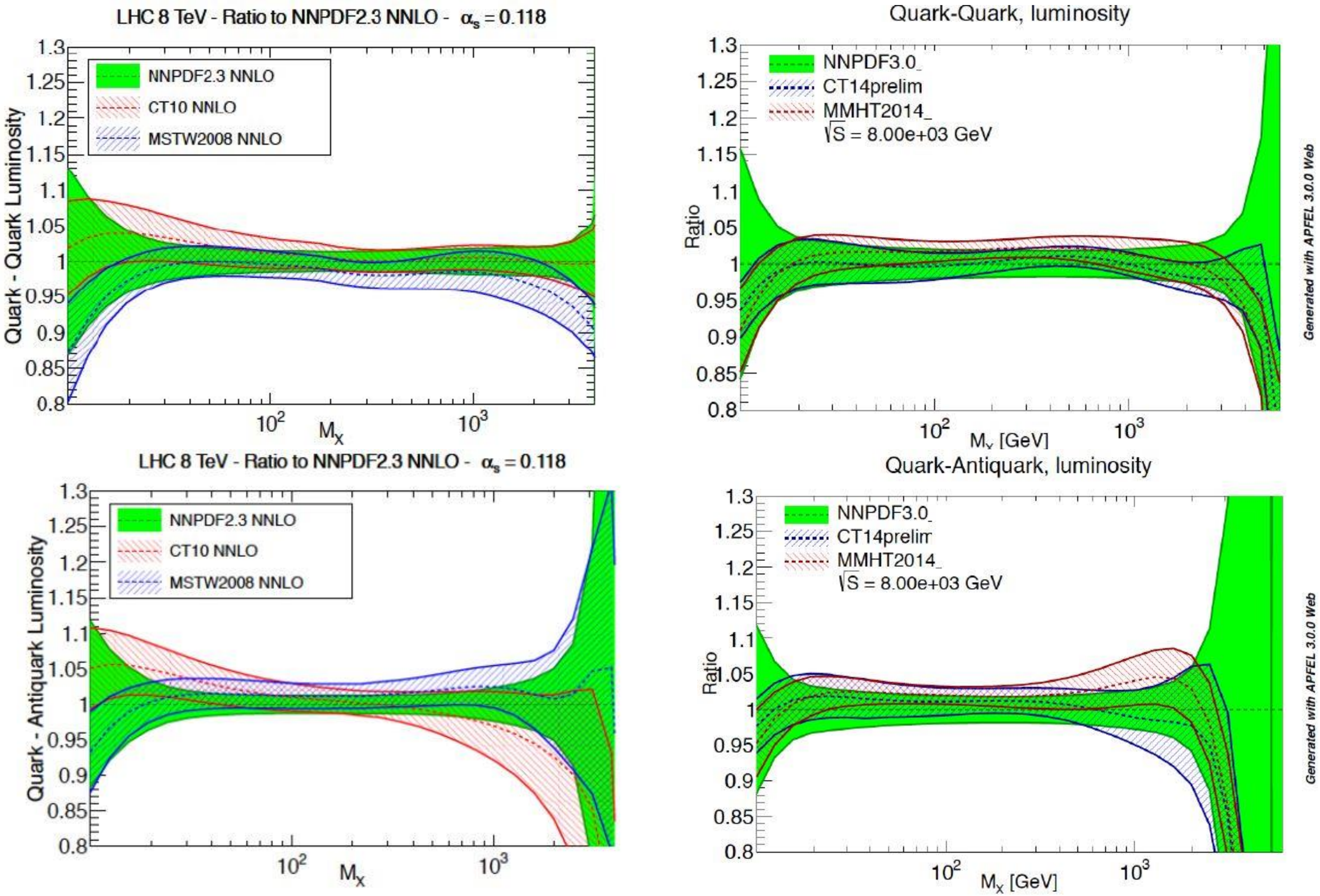
New fits compatible with usual expectations, eg dimuon data, NOMAD Alekhin

NNPDF3.0: MMHT14 also compatible

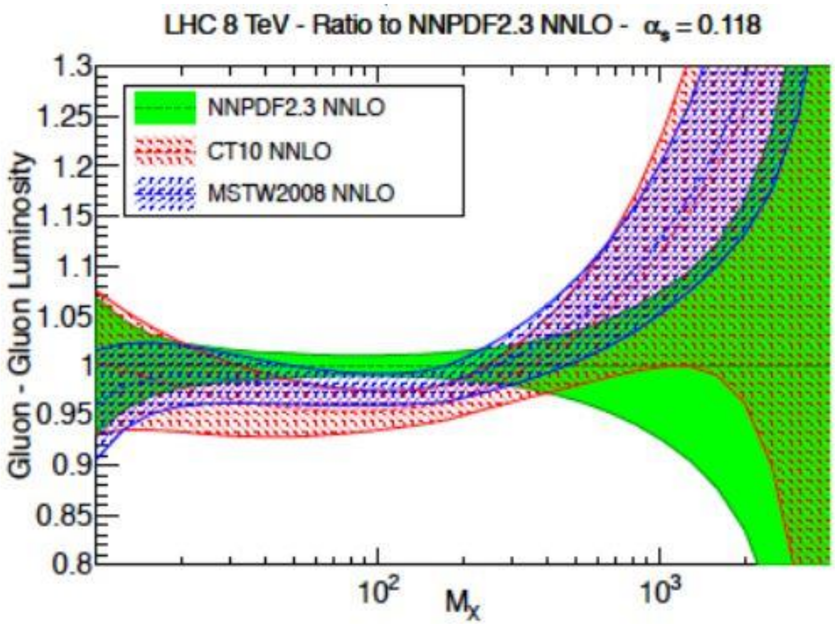


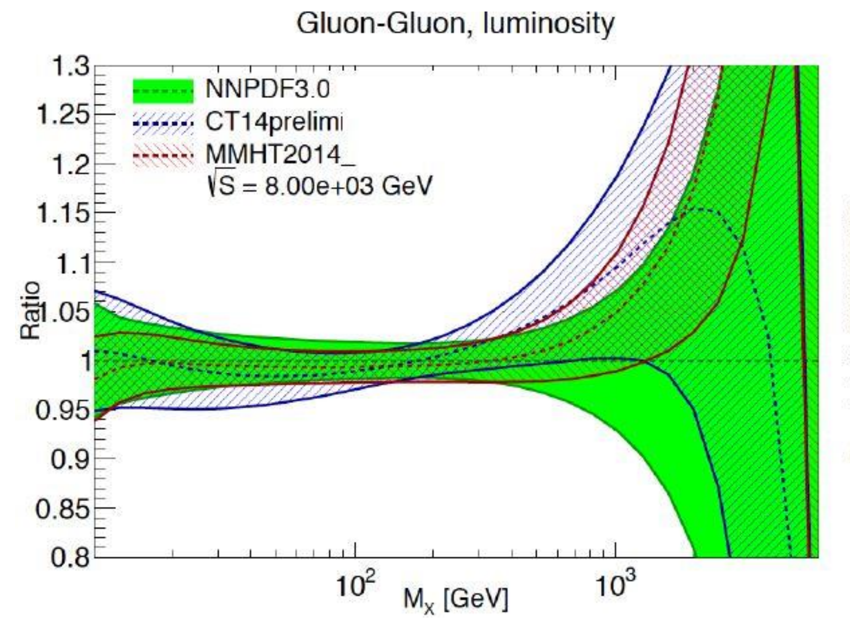


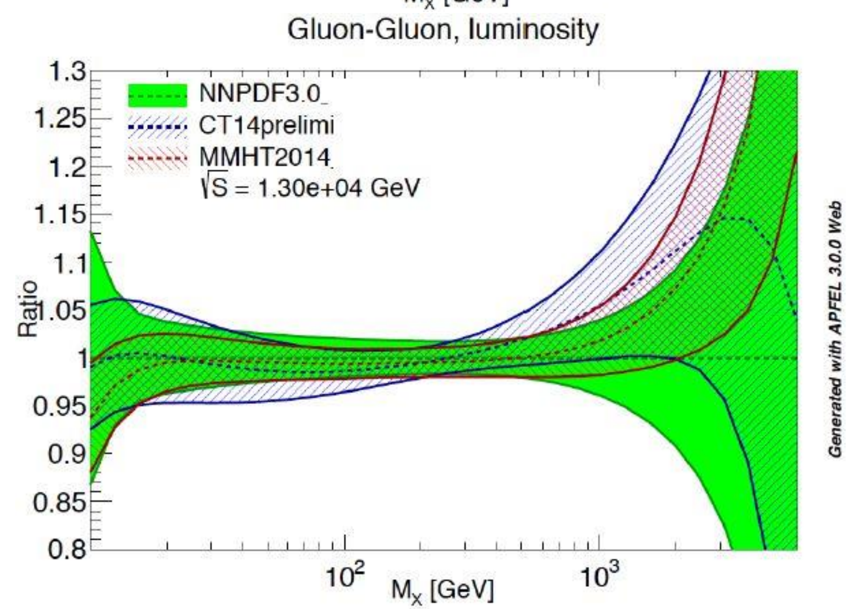
Luminosities: NNPDF3.0 vs MMHT14 vs CT14



Luminosities: NNPDF3.0 vs MMHT14 vs CT14







New Generation PDFs more consistent in data region: better determination of ggH…

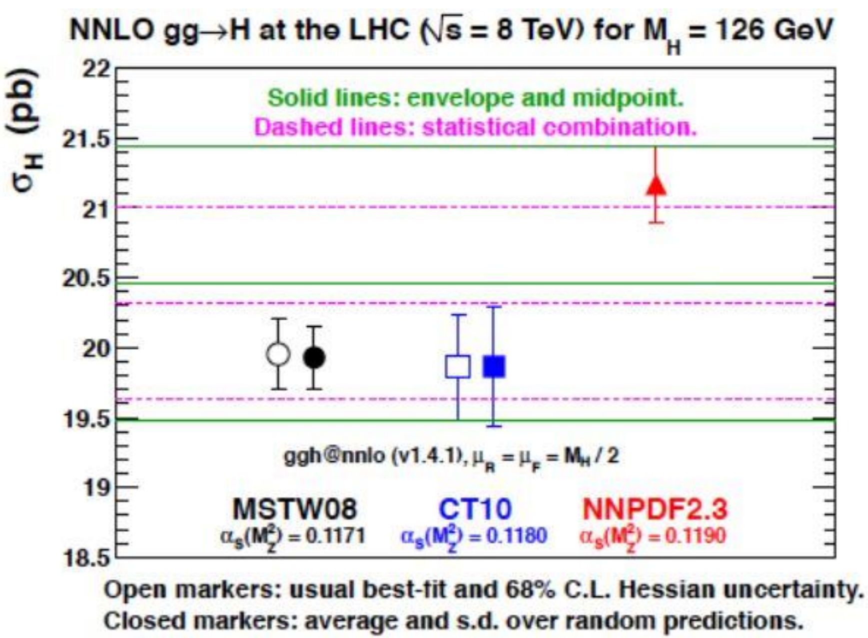
Combining Global PDFs

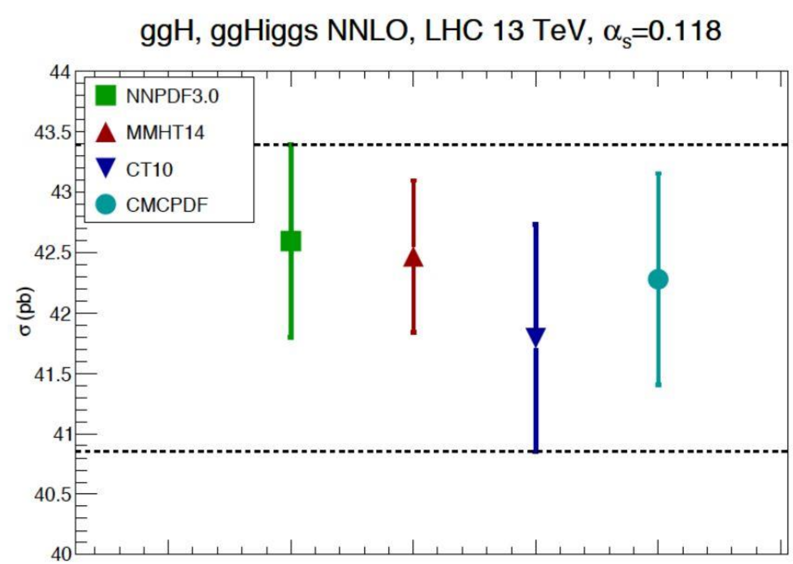
Envelope method: PDF4LHC 2010-11, update 2013-14

- Compute xsec with each of MSTW08, CTEQ6.6, NNPDF2.0, diff α_s
  [later MSTW08, CT10, NNPDF2.3, $\alpha_s = 0.118$]
- Take envelope of resulting predictions. Conservative but time-consuming

Replica combination method: Thorne-Watt: PDF4LHC 2014-15

- Generate 100 PDF replicas for NNPDF3.0, MMHT14, CT14 at $\alpha_s = 0.118$
- Combine in fixed proportions to give combined set of 300 replicas
- Add α_s uncertainty in quadrature to combined PDF uncertainty



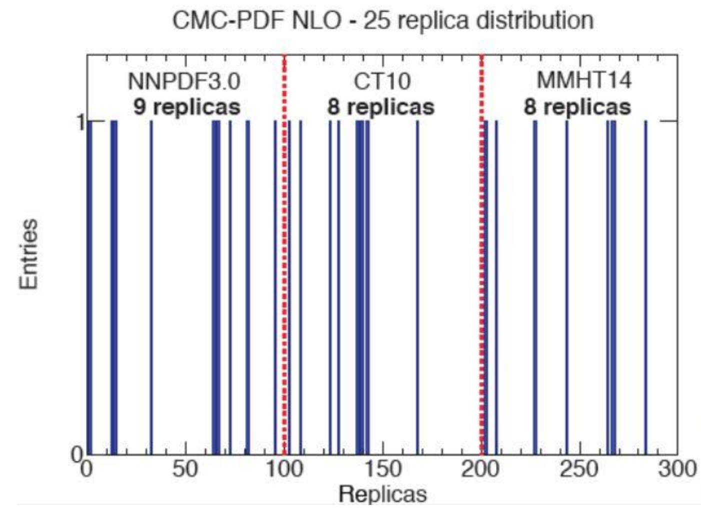


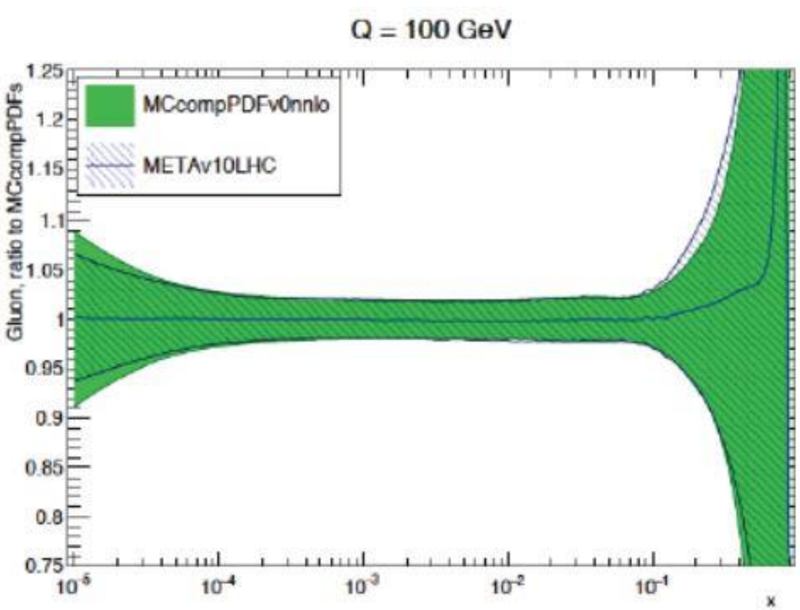
Delivery of (Combined) Global PDFs

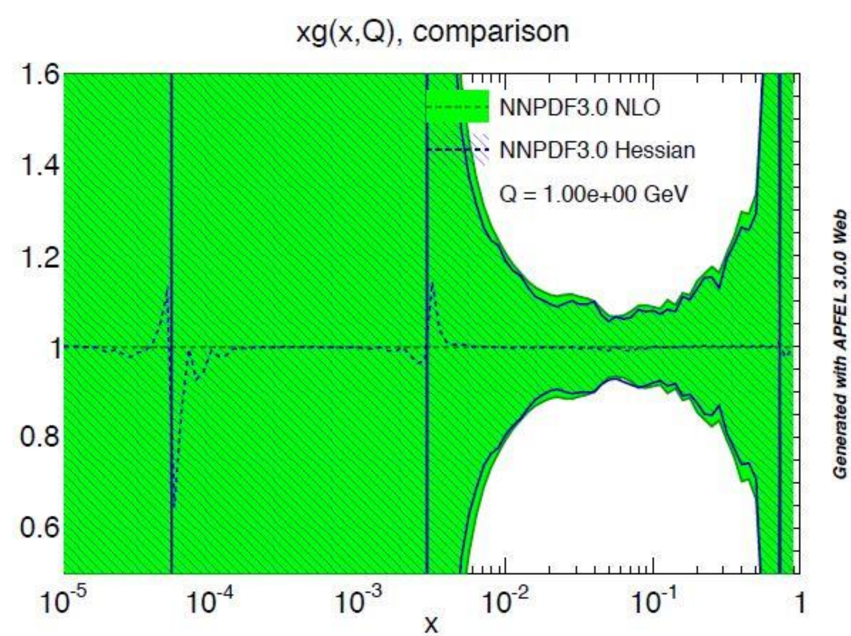
Replicas more precise (non-Gaussian), but Hessian preferred for eg nuisance parameters

Three possibilities under discussion:

- Replica Compression: optimise the replicas 300 $\rightarrow$ 25, deliver as compressed replica set
- META-PDFS: refit the combined replicas using a meta-parametrization (66 parameters), deliver Hessian evecs
- MC2Hess: derive Hessian evecs directly by using replicas as basis functions (so no bias)



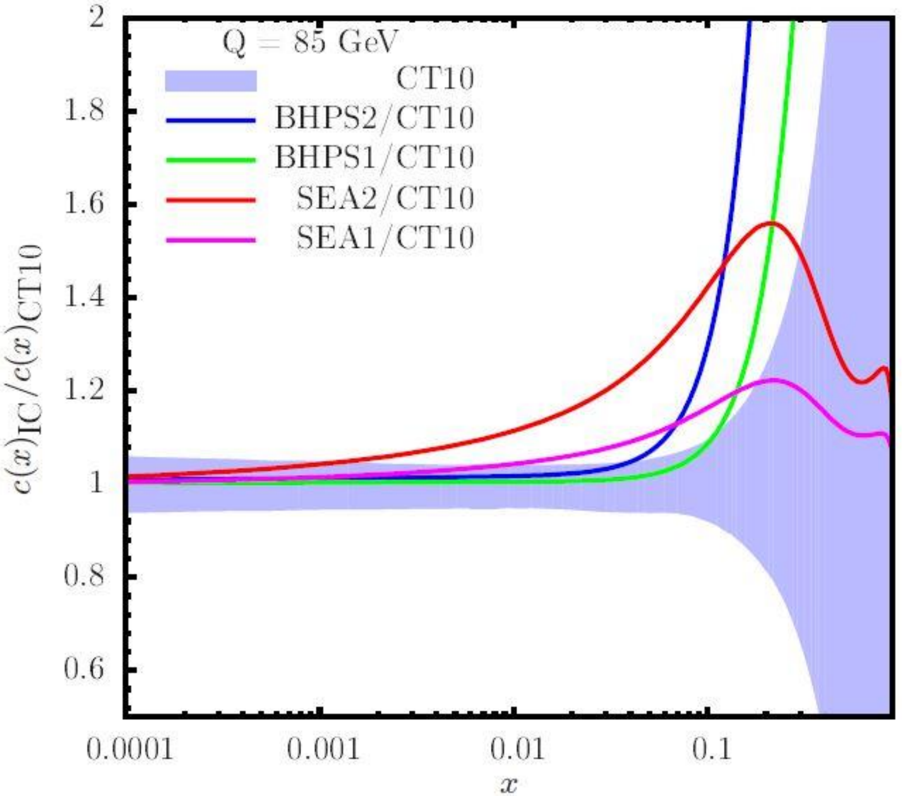


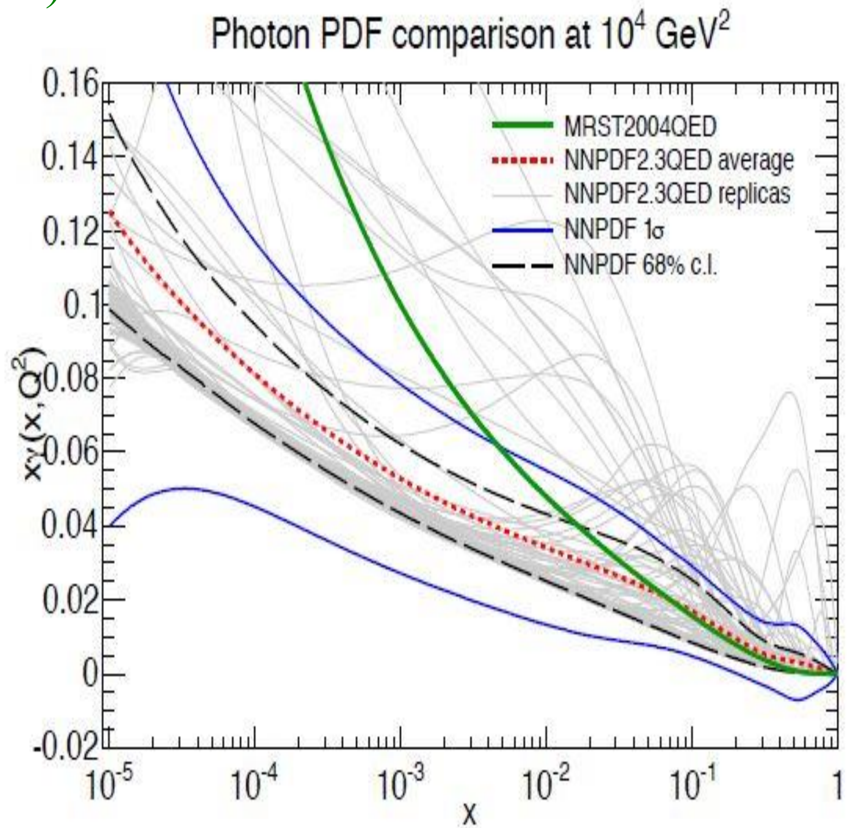


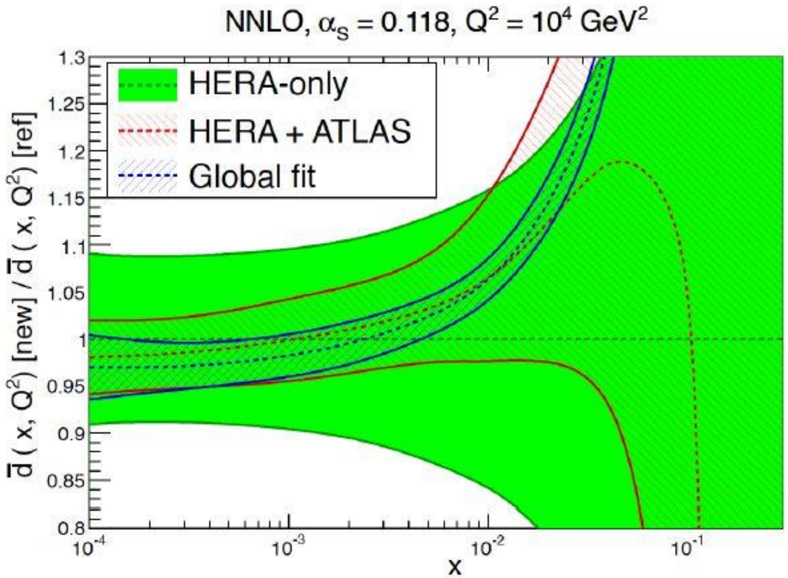
Future Prospects

Variations on a Theme

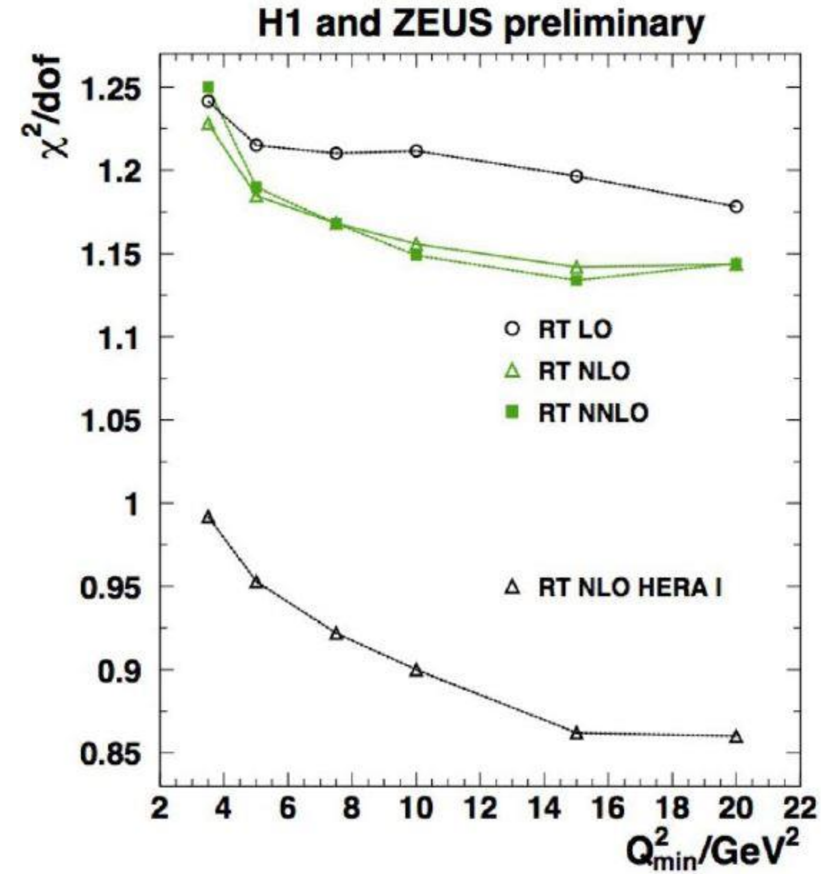
- PDF Fits with Intrinsic Charm (CTEQ studies with IC: arXiv: 1309.0025)
- PDFs with QED corrections: photon PDF (NNPDF2.3QED: arXiv:1308.0598)
- Collider only fits (eg HERAPDF: arXiv:1404.4234)
- PDFs with resummation (both large x and small x)
- NuclearPDFs (eg nCTEQ: arXiv:1307.3454)



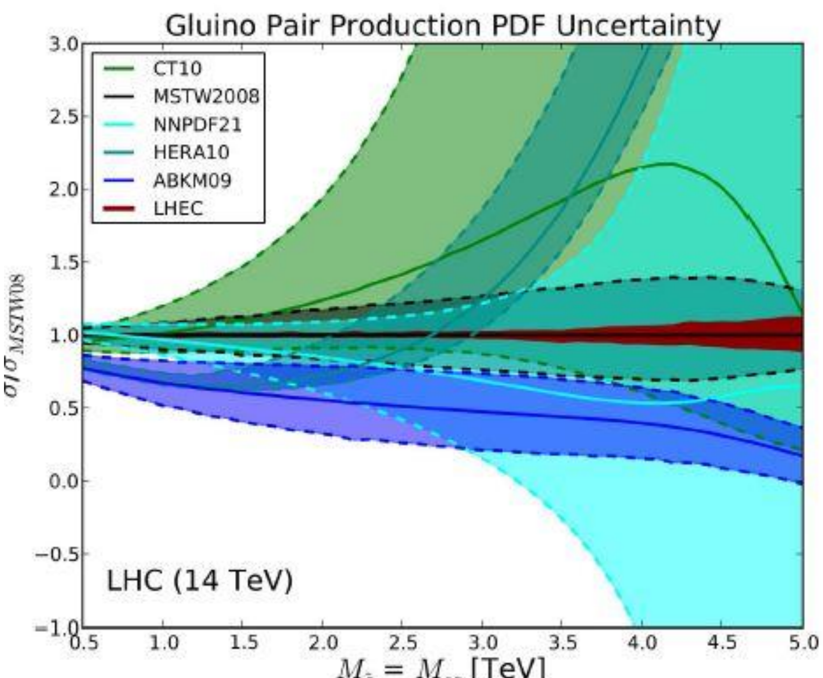




Collider only fits still a long way off!



Small x: evidence for resummation?



High x: need to do better – limits potential of LHC for discovery

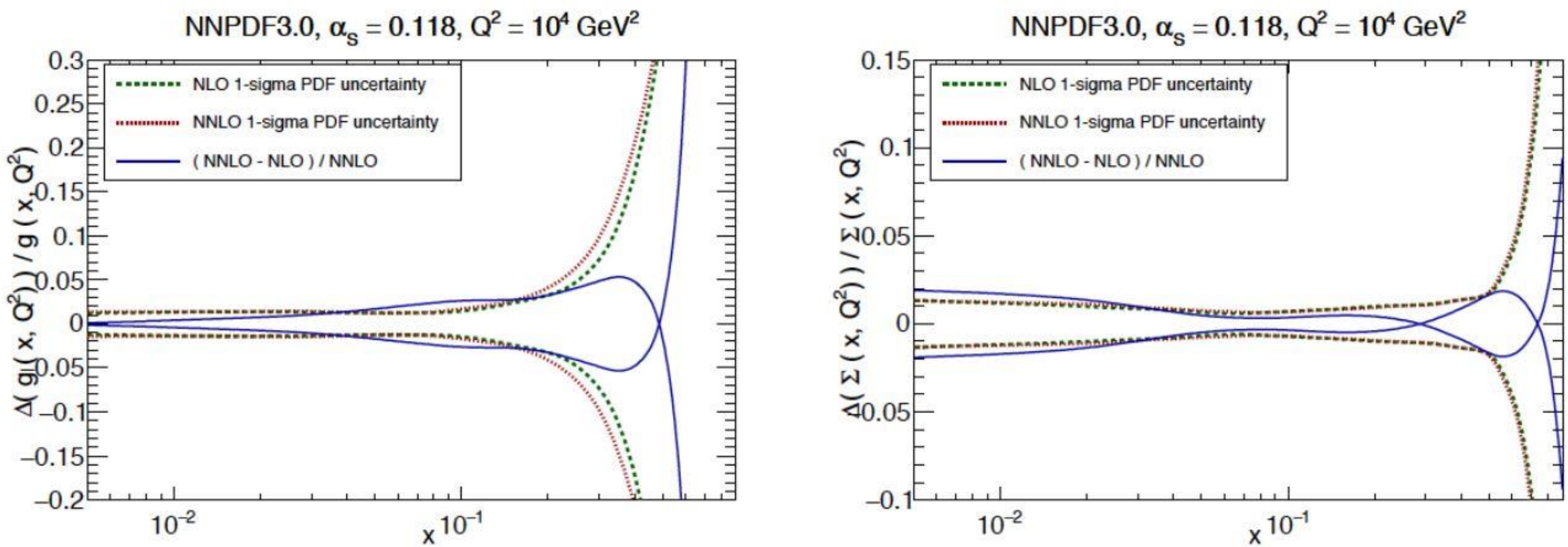
Experimental and Methodological Uncertainties under control: what about Theoretical Uncertainties???

Two categories:

- Parametric uncertainties: eg $\alpha_s, m_c, m_b, m_t, CKM, \theta_W$, ...

  determine externally (PDG) *or* as parameters in the fit
- Higher order QCD corrections: estimate by

  - scale variation (usual problems…)
  - Bayesian methods (Cacciari-Houdeau)
  - comparing orders (need approx N3LO….)



Summary & Outlook

- Global Fits with LHC Run I Data
  NNPDF3.0, MMHT14, CT14
- New Methodologies: Closure Testing
- Better PDF Combination and Delivery
- Theory Uncertainties: the new frontier