

Update on PDFs

WG1 PDF subgroup:

J. Bendavid (CMS), J. Huston (ATLAS)

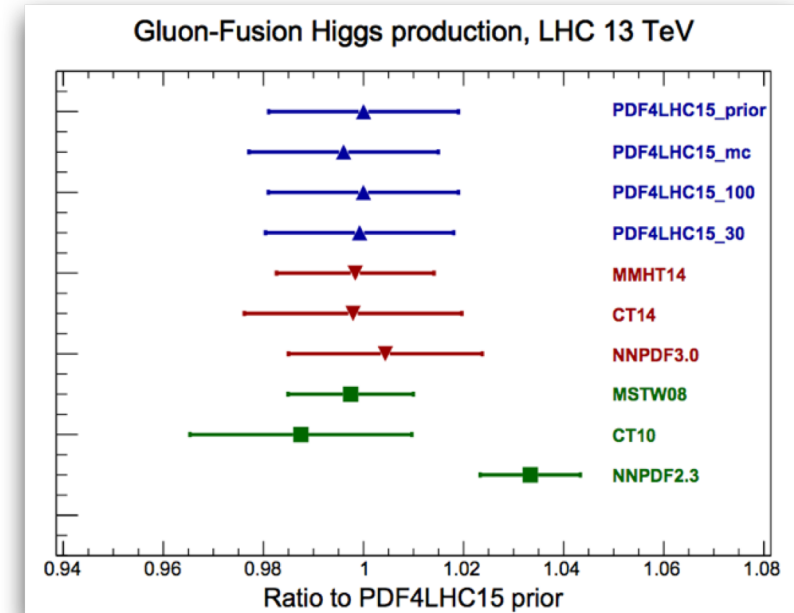
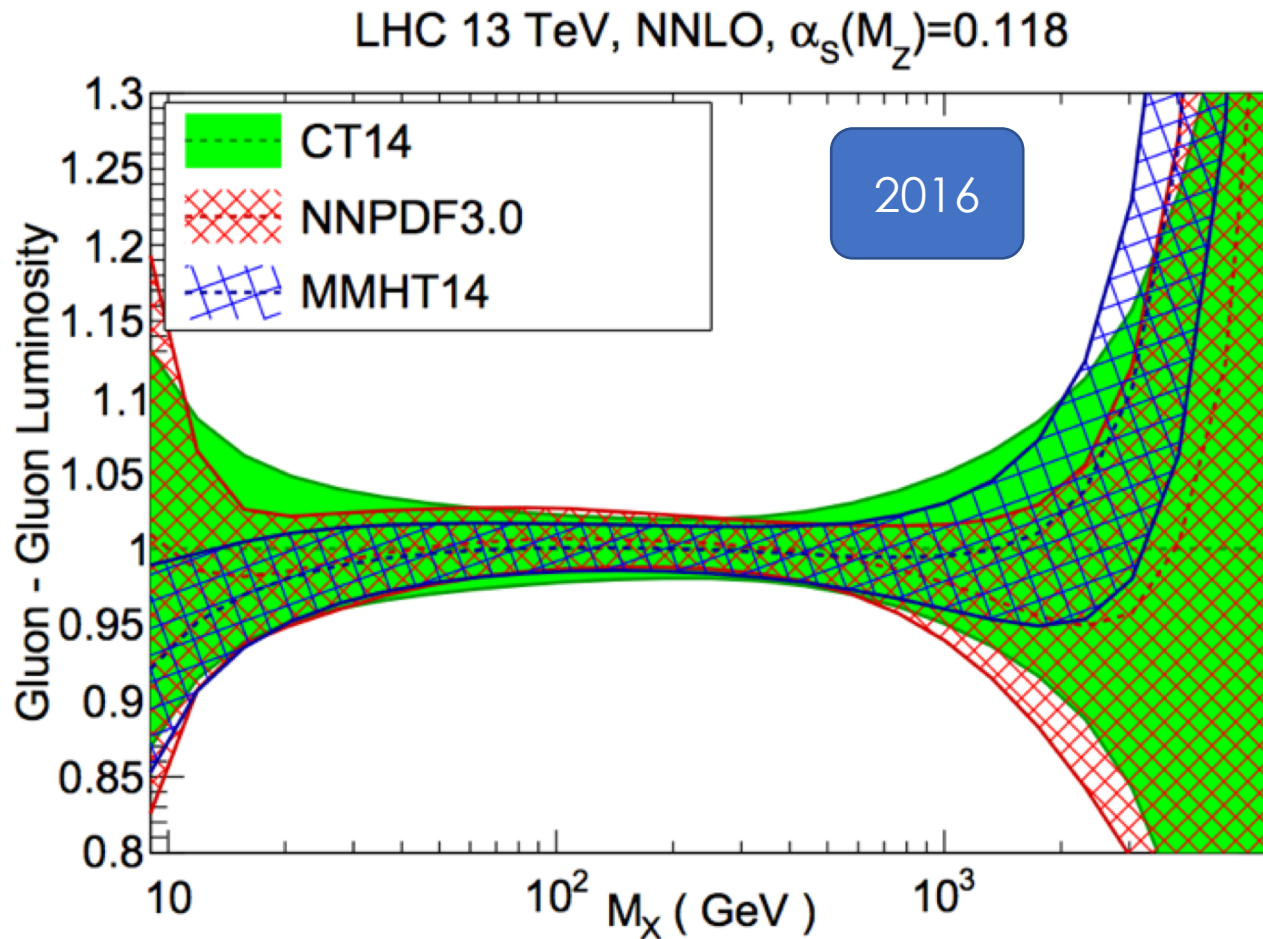
J. Huston, R. Thorne, [M. Ubiali](#) (theory)

Outline

- Introduction
- Updates from PDF fitting collaborations
- Summary and conclusions

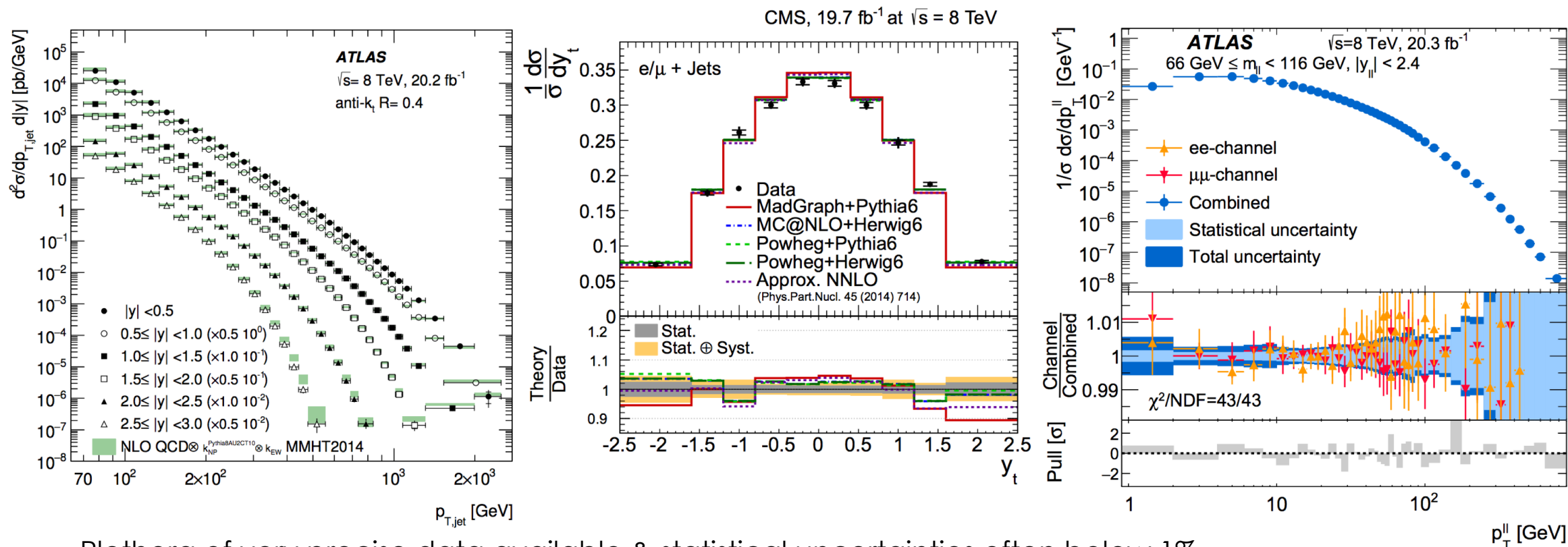
Disclaimer: not a comprehensive review, for that see e.g. [J. Gao et al, arXiv:1709.04922](#) , here focus on global PDF sets combined in Yellow Report 4

The PDF4LHC15 combination



Yellow report 4, [Deciphering the nature of the Higgs sector](#), arXiv: 1610.07922
PDF4LHC15, [J. Butterworth et al](#), J.Phys. G43 (2016) 023001

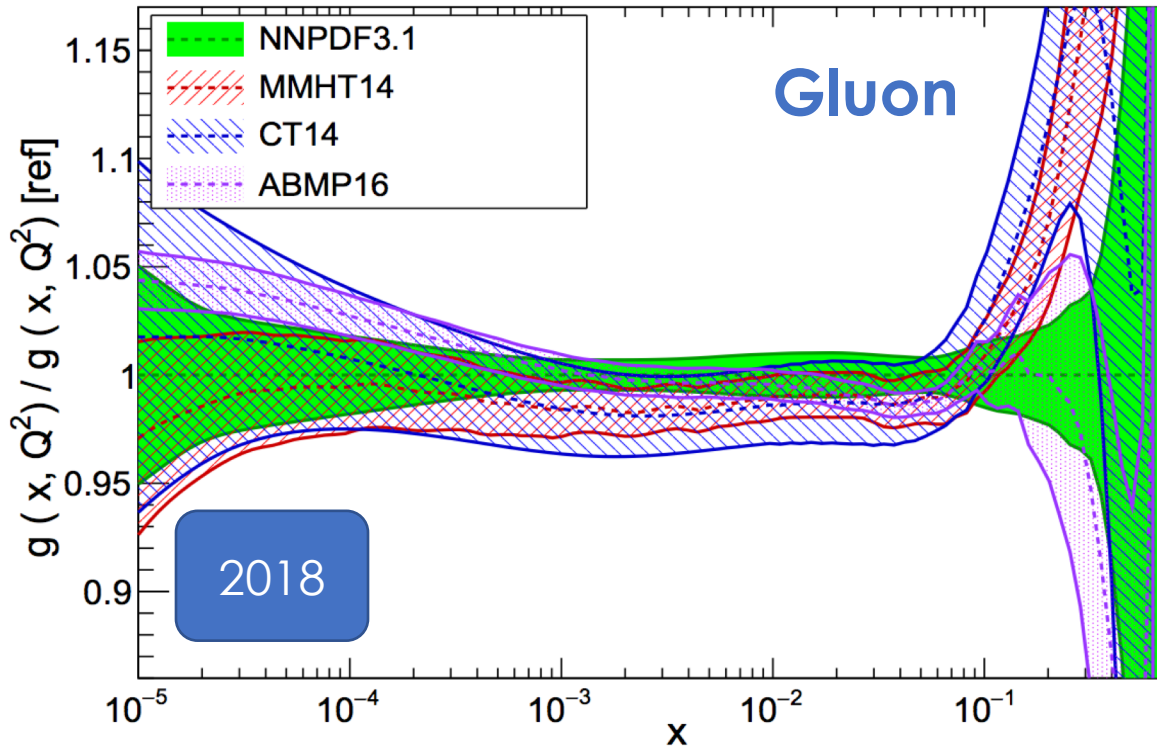
A new precision era



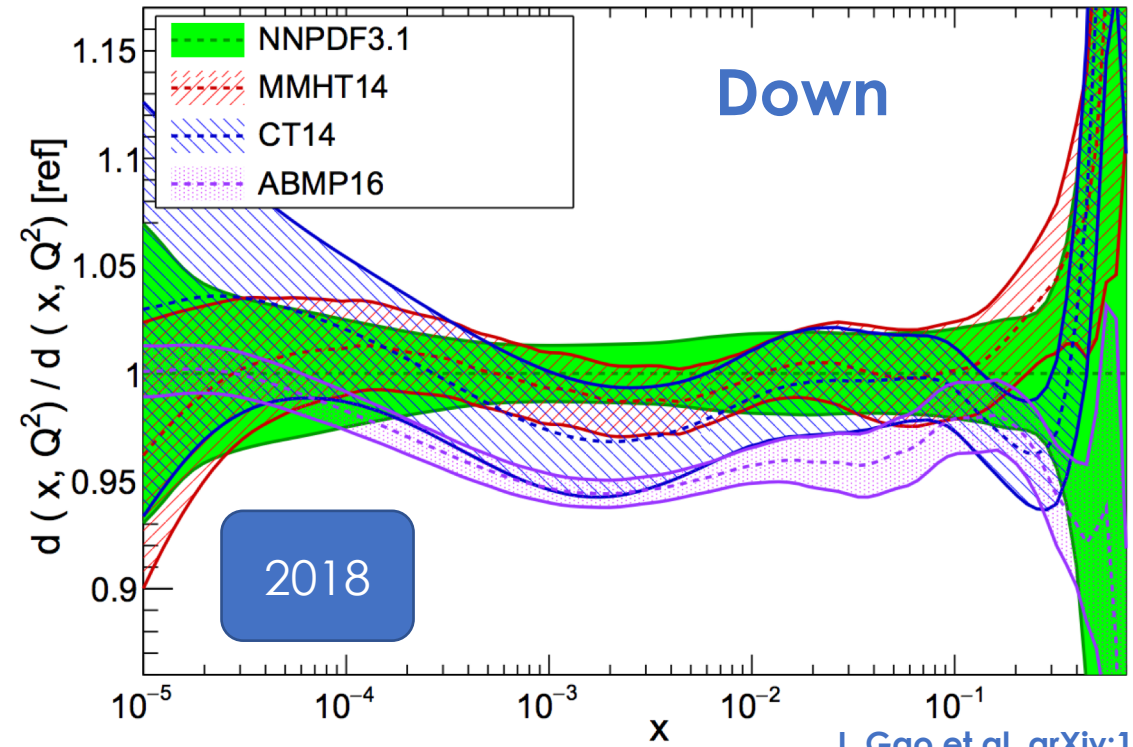
- Plethora of very precise data available & statistical uncertainties often below 1%
E.g. Gluon: top pair, jets and Z transverse momentum distributions all constrain gluon at large x
- NNLO calculations available
[Czakon et al \[PRL 110\(2013\)\]](#), [Czakon et al \[JPCP \(2014\)\]](#), [Czakon et al \[JHEP 1301\(2015\)\]](#)
[Gehrmann-De Ridder et al \[JHEP 07 \(2016\)\]](#), [Gehrmann-De Ridder et al \[JHEP 11 \(2016\)\]](#), [Boughezal et al \[PRL 16 \(2016\)\]](#), [Boughezal et al \[PRD 14 \(2016\)\]](#)
[Currie et al \[PRL 118 \(2017\)\]](#) [Currie et al \[PRL 119 \(2017\)\]](#) [Gehrmann-De Ridder et al \[PRL 110 \(2016\)\]](#)
- Fast interface available now also at NNLO ([M. Sutton et al APPLfast-NNLO](#))

New insights on PDFs

NNLO, $\alpha_s=0.118$, $Q = 100$ GeV



NNLO, $\alpha_s=0.118$, $Q = 100$ GeV



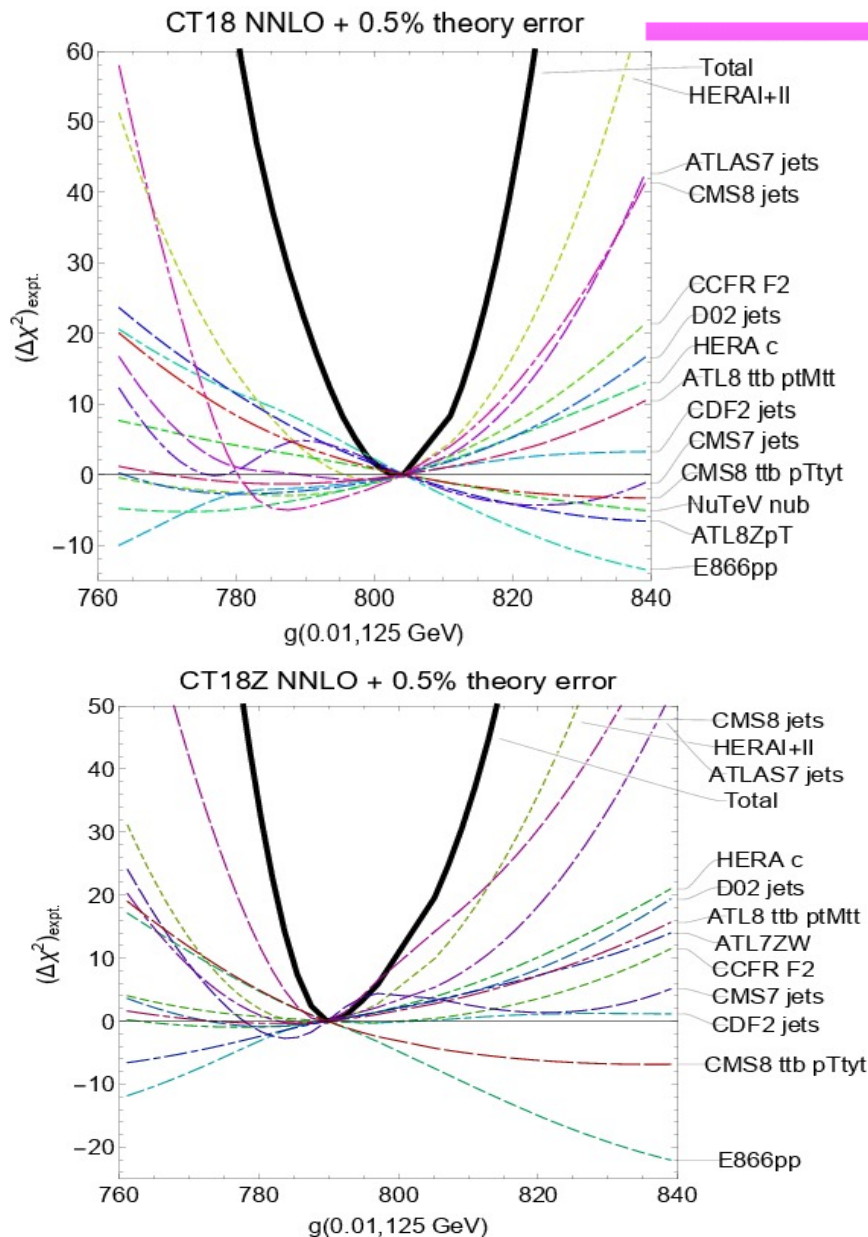
J. Gao et al, arXiv:1709.04922

- A number of LHC Run I data included in PDF fits and impact of several data analyzed. Sizeable impact.
- Breakthrough in theory constraints on photon [Manohar et al Phys.Rev.Lett. 117 \(2016\)](#)
- Progress in QCD+EW PDF evolution and corrections in hard processes
- Developments in fitted/intrinsic charm

CT updates → CT18 and CT18Z

- CT18 PDFs to be released in near future
 - ◆ >10 new LHC data sets at 7 and 8 TeV from ATLAS, CMS and LHCb included
 - ◆ ATLAS/CMS inclusive jets are most constraining LHC data sets; include all ATLAS 7 single-inclusive jet data using decorrelation models provided by the experiment
 - ◆ Drell-Yan (including W,Z, Z p_T)
 - $t\bar{t}$ double differential distributions from ATLAS and CMS with statistical correlations
 - ◆ CT14 data set, including some early LHC data and fixed-target DIS, continues to impose dominant
- PDFsense (arXiv:1803.02777) allows a preliminary determination of the impact (correlation+sensitivity) of each new data set
- ePump (arXiv:1806.07950) allows new data sets to be added into an existing PDF (such as CT14)
- Global PDF fit is carried out at NNLO (using applgrid, fastNNLO) with a faster, parallelized version of the fitting code
 - when justified, a small Monte-Carlo error added for NNLO/NLO K-factors
- Further detailed studies are carried out using Lagrange Multiplier Technique, not dependent on the Hessian approximation (next slide)
- A complementary **CT18Z** fit with alternative choices of data sets, charm mass and factorization scale in DIS

Lagrange Multiplier scan: $g(0.01, 125 \text{ GeV})$



•Upper figure: CT18

- HERA1+II data set provides the dominant constraint, followed by ATLAS, CDF2, CMS, D02 jet production, HERA c
- tT double differential cross sections provide weaker constraints

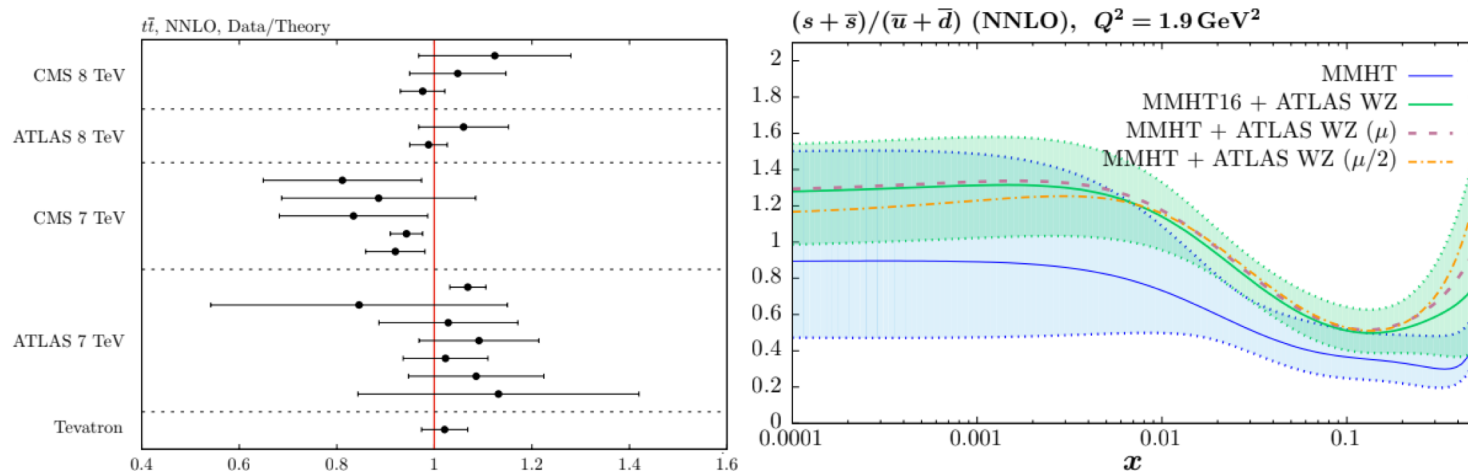
•Lower figure: CT18Z

- CT18Z: a lower NNLO gluon in the Higgs production region than for CT14/CT18 as a result of
 - higher charm mass, $m_{c\text{pole}}=1.4 \text{ GeV}$
 - including ATLAS7 W/Z production
 - a special factorization scale in DIS that mildly improves χ^2 and approximates effect of small x resummation

MMHT preliminary set - fit to new hadron collider (mainly **LHC**) data. Predictions good. Fit gives slight improvement and PDF uncertainty reduction.

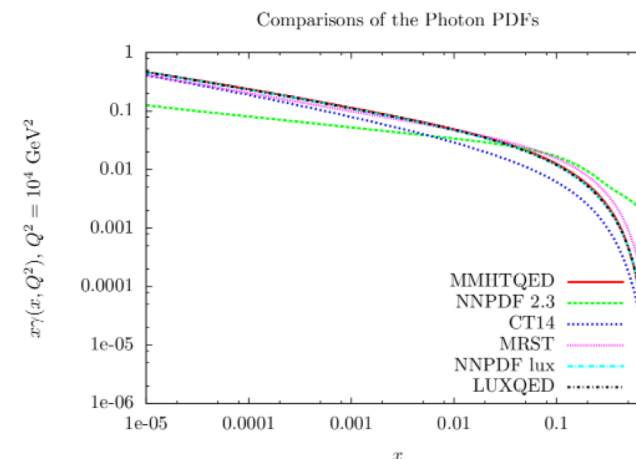
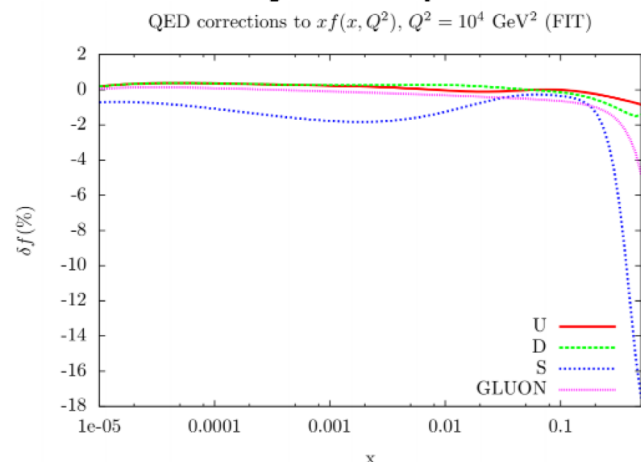
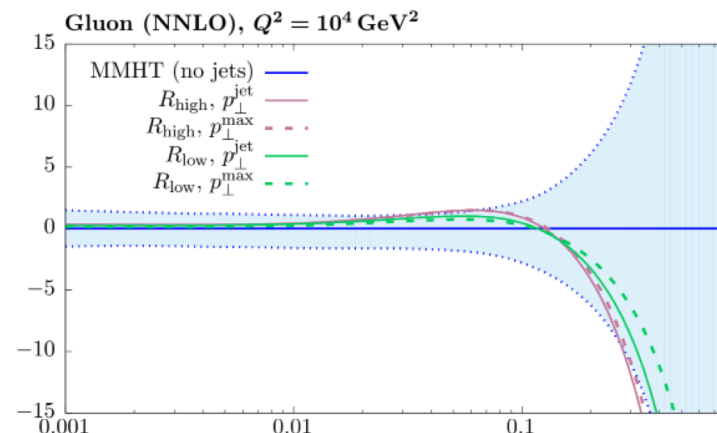
	no. points	NLO χ^2_{pred}	NLO χ^2_{new}	NNLO χ^2_{pred}	NNLO χ^2_{new}
$\sigma_{t\bar{t}}$ Tevatron +CMS+ATLAS	18	19.6	20.5	14.7	15.5
LHCb 7 TeV $W + Z$	33	50.1	45.4	46.5	42.9
LHCb 8 TeV $W + Z$	34	77.0	58.9	62.6	59.0
LHCb 8 TeV e	17	37.4	33.4	30.3	28.9
CMS 8 TeV W	22	32.6	18.6	34.9	20.5
CMS 7 TeV $W + c$	10	8.5	10.0	8.7	8.0
D0 e asymmetry	13	22.2	21.5	27.3	25.8
total	3738/3405	4375.9	4336.1	3741.5	3723.7

Included some more up-to-date results on $\sigma_{t\bar{t}}$. Helps drive slight increase in $\alpha_S(M_Z^2)$. Updated fits also with high precision **ATLAS W, Z** data - increase strange quark.



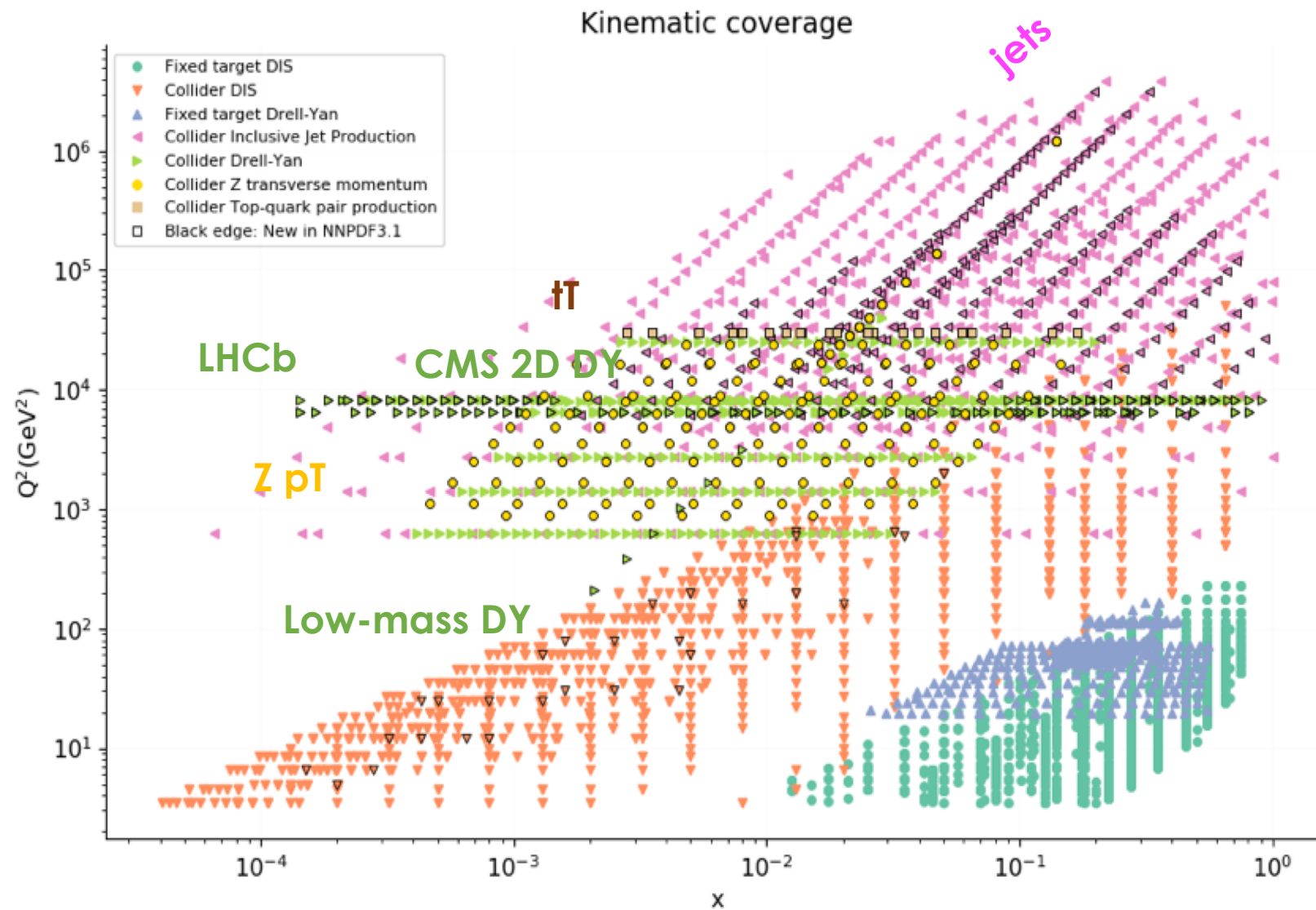
Fit to high luminosity **ATLAS** and **CMS 7 TeV** inclusive jet data – **MMHT** at **NLO** and **NNLO**. For **ATLAS** improve χ^2 by decorrelating two uncertainty sources. Central values and uncertainties insensitive to decorrelation, and scales and jet radii.

MMHT PDFs with **QED** corrections - base photon input for PDFs on **LUX**. Evolution fully incorporated with quarks and gluon.



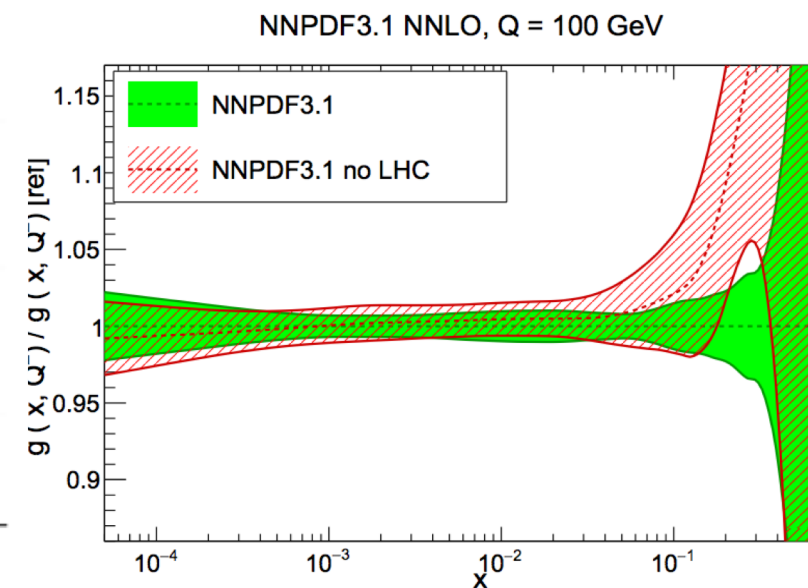
Continue including types of data shown, when released, including those sensitive to photon (e.g high-mass **Drell Yan** – already started) along with new types, e.g Z_{pT} , single top, differential $t\bar{t}$, all up to **NNLO** where feasible. Also look at theory uncertainties, building on existing study.

Updates from NNPDF



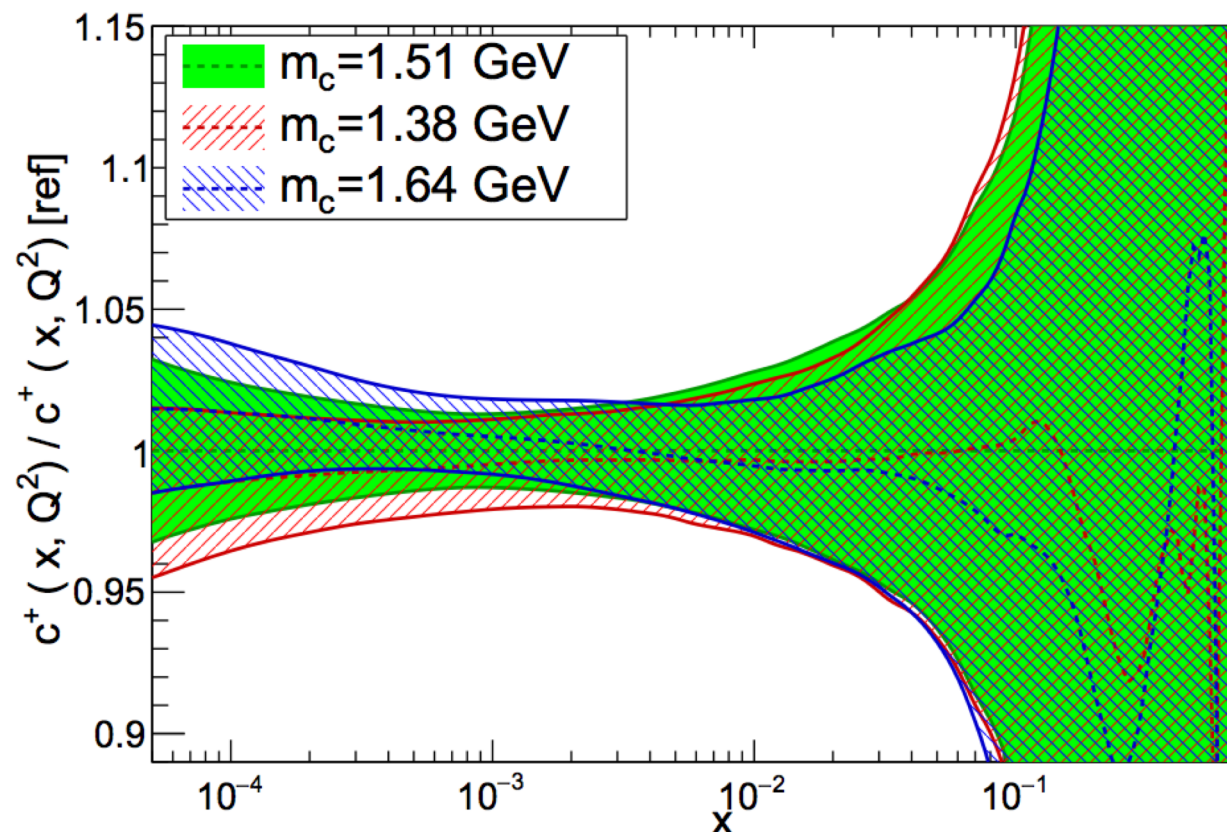
NNPDF3.1 - Eur.Phys.J. C77 (2017)

- Precise **LHC Run I** data included in NNPDF3.1: sizeable impact on PDFs
- Consistent constraints on the gluon from ZpT, jets and top data ([Nocera, MU 1709.09690](#))

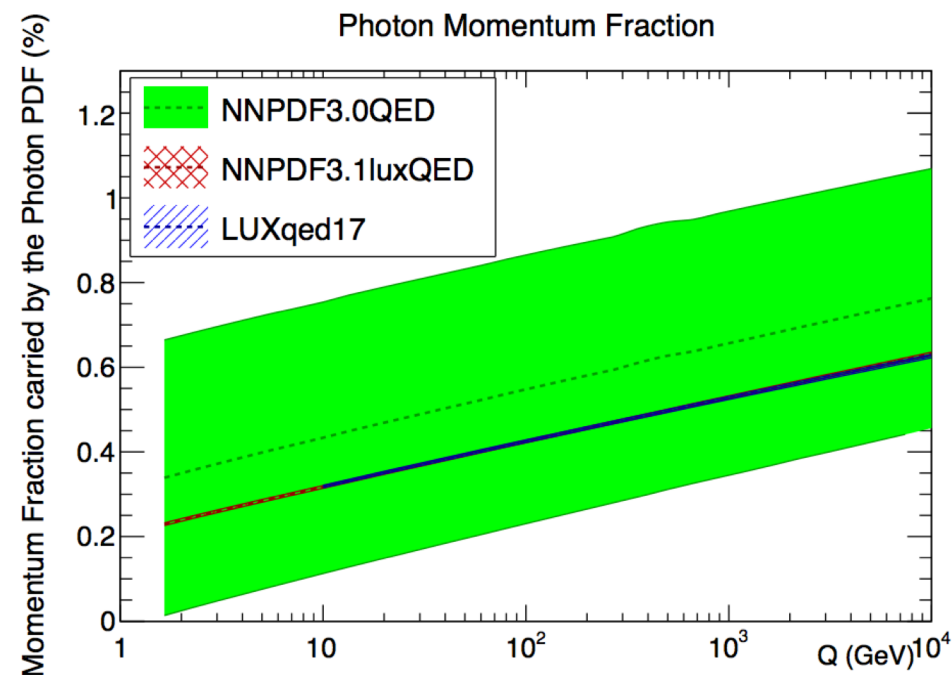


Updates from NNPDF

NNPDF3.1 NNLO fitted charm, $Q = 100$ GeV



- Charm content of the proton fitted and stability with respect to m_c
- Consistent combination of LUXqed and NNPDF formalism to include photon PDF



NNPDF4.0 – in progress

- Inclusion of many Run II data
- New process included: single top, $V+j$, isolated photon, DIS jets
- Inclusion of missing higher order uncertainties in the fit

Summary and conclusions

data

- Lots of new data in the pipeline for inclusion in new PDF sets
- **Benchmarking** exercise to assess impact of inclusion of Run I data on different PDF sets
- Assessing implications of **Run I** and **Run II** precision data will prepare us for challenges associated with **HL-LHC**

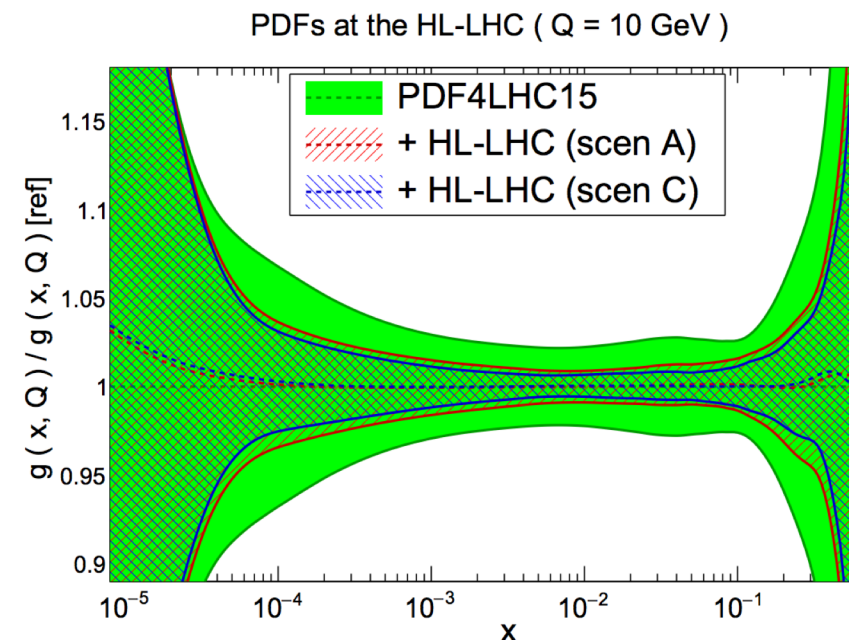
theory

- Ignoring **theory uncertainties** (missing higher orders being dominant ones) will no longer be an option
- Inclusion of EW corrections and photon-induced contributions also necessary

stats

- Closure test and statistical estimators for robust **methodology**

Time to work towards a new combination based on Run I data (PDF4LHC19 ?)



Kahlek et al, arXiv:1810.03639

PDF4LHC meeting

Thursday 13 Dec 2018, 09:00 → 19:00 Europe/Zurich

40-S2-A01 - Salle Anderson (CERN)

Albert De Roeck (CERN)

<https://indico.cern.ch/event/761343/timetable/>



PROF. JAMES STIRLING

James Stirling's legacy on PDFs
(and much more)