Probing the large-x gluon PDF at NNLO with top-pair differential data

based on **JHEP** 1704 (2017) 044
with M. Czakon, A. Mitov, N.P. Hartland and J.Rojo

Heavy Flavour Production at the LHC

Emanuele R. Nocera

Rudolf Peierls Centre for Theoretical Physics - University of Oxford

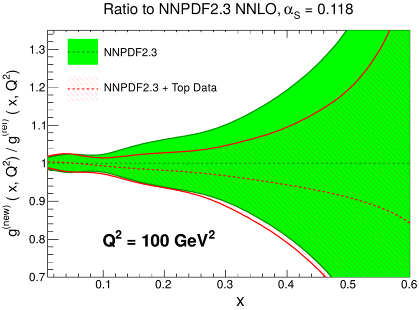
IPPP Durham – 6th September 2017

Unveiling a precision large-x gluon PDF

The gluon PDF at medium to large x plays a leading role in many BSM scenarios (gluino pair production, Kaluza-Klein graviton production, resonances in the $m_{t\bar{t}}$ spectrum, ...)

Usual constraints come from inclusive top and jet cross sections (Tevatron and LHC)

INCLUSIVE TOP

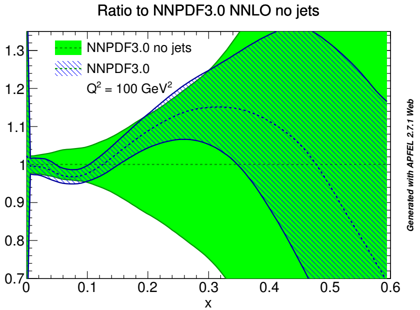


complete NNLO QCD corrections

[PRL 109 (2012) 132001] [JHEP 1301 (2013) 1380]

[PRL 110 (2013) 252004]

INCLUSIVE JETS



complete NNLO QCD corrections

[PRL 110 (2013) 162003] [JHEP 1401 (2014) 110]

[PRL 118 (2017) 072002]

Dedicated phenomenological studies [JHEP 1307 (2013) 167] [JHEP 1410 (2014) 145]

Data on inclusive top and jet production are routinely included in global PDF fits

A new ingredient: $t\bar{t}$ differential distributions (ℓ + jets)

Complete NNLO QCD corrections for stable top quarks, with scale optimization

[PRL 115 (2015) 052001; PRL 115 (2016) 082003; JHEP 05 (2016) 034; JHEP 1704 (2017) 071; PRD 94 (2016) 114033]

Precise data from ATLAS and CMS at $\sqrt{s} = 8$ TeV, with a full breakdown of systematics

[EPJ C76 (2016) 538; EPJ C75 (2015) 542]

Dataset	$N_{\rm dat}$	Kinematics	Dataset	$N_{\rm dat}$	Kinematics
ATLAS $d\sigma/dp_T^t$	8	$0 < p_T^t < 500$ GeV	CMS $d\sigma/dp_T^t$	8	$0 < p_T^t < 500$ GeV
ATLAS $d\sigma/d\lvert y_t\rvert$	5	$0 < \lvert y_t\rvert < 2.5$	CMS $d\sigma/dy_t$	10	$-2.5 < y_t < 2.5$
ATLAS $d\sigma/d\lvert y_{t\bar{t}}\rvert$	5	$0 < \lvert y_{t\bar{t}}\rvert < 2.5$	CMS $d\sigma/dy_{t\bar{t}}$	10	$-2.5 < y_{t\bar{t}} < 2.5$
ATLAS $d\sigma/dm_{t\bar{t}}$	7	$345 < m_{t\bar{t}} < 1600$ GeV	CMS $d\sigma/dm_{t\bar{t}}$	7	$345 < m_{t\bar{t}} < 1600$ GeV
ATLAS $(1/\sigma)d\sigma/dp_T^t$	8	$0 < p_T^t < 500$ GeV	CMS $(1/\sigma)d\sigma/dp_T^t$	8	$0 < p_T^t < 500$ GeV
ATLAS $(1/\sigma)d\sigma/d\lvert y_t\rvert$	5	$0 < \lvert y_t\rvert < 2.5$	CMS $(1/\sigma)d\sigma/dy_t$	10	$-2.5 < y_t < 2.5$
ATLAS $(1/\sigma)d\sigma/d\lvert y_{t\bar{t}}\rvert$	5	$0 < \lvert y_{t\bar{t}}\rvert < 2.5$	CMS $(1/\sigma)d\sigma/dy_{t\bar{t}}$	10	$-2.5 < y_{t\bar{t}} < 2.5$
ATLAS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	7	$345 < m_{t\bar{t}} < 1600$ GeV	CMS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	7	$345 < m_{t\bar{t}} < 1600$ GeV

Normalised and absolute data is provided for ATLAS

CMS provides normalised data; absolute data reconstructed from inclusive cross section

(If normalised distributions are included in a fit, the corresponding total cross section is included)

Correlations among different distributions not provided

(Only one distribution per experiment can be included in a fit, avoid multiple counting)

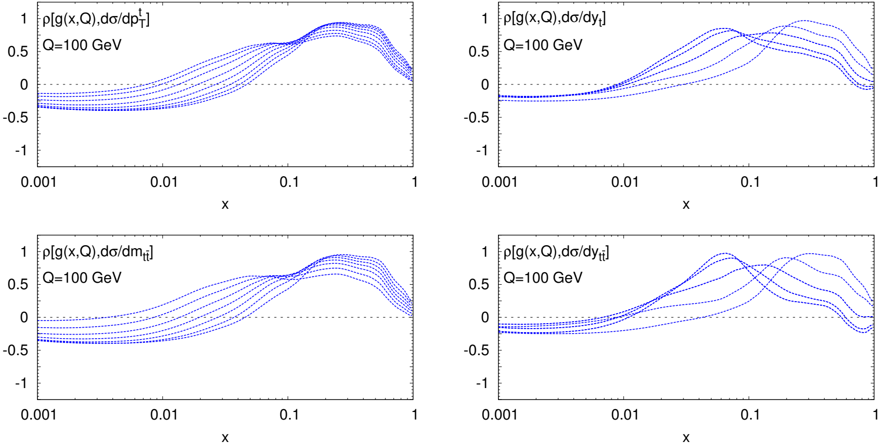
Are the various datasets compatible? What is the level of PDF constraint?

Is normalising beneficial? Which combination of distributions is the best?

PDF sensitivity to $t\bar{t}$ differential distributions

Plot correlation coefficients of PDFs with absolute $t\bar{t}$ differential distributions

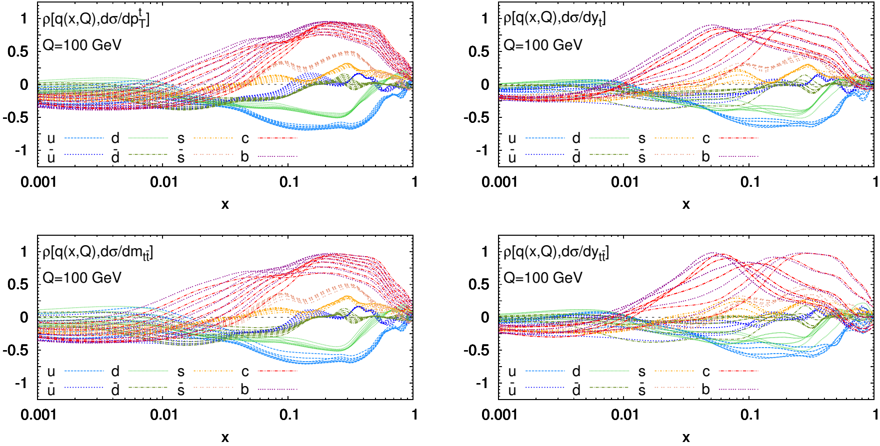
$$\rho[A,B] = \frac{\langle AB\rangle_{\rm rep} - \langle A\rangle_{\rm rep}\langle B\rangle_{\rm rep}}{\sigma_A \sigma_B}$$



PDF sensitivity to $t\bar{t}$ differential distributions

Plot correlation coefficients of PDFs with absolute $t\bar{t}$ differential distributions

$$\rho[A,B] = \frac{\langle AB\rangle_{\rm rep} - \langle A\rangle_{\rm rep}\langle B\rangle_{\rm rep}}{\sigma_A \sigma_B}$$



Theory configuration: NLO/NNLO computation

At NLO, use interpolated partonic cross section tables (APPLgrid/FK tables)

Matrix elements: (`Sherpa` $\times$ `Openloops`) via `MCgrids`

Stong coupling: set as per PDF set, *e.g.* $\alpha_s(M_Z) = 0.118$ (NNPDF), $\alpha_s(M_Z) = 0.113$ (ABM)

Top mass: set as per PDG average, $m_t = 173.3$ GeV (m_t sensitivity in [PRD 94 (2016) 114033])
variation below $6‰$ for y_t and $y_{t\bar{t}}$ distributions, up to 4% close to threshold for p_T^t and $m_{t\bar{t}}$ upon $\Delta m_t = 1$ GeV

Choice of dynamical scales: set as per [arXiv:1606.03350]

$$y_t,\, y_{t\bar{t}},\, m_{t\bar{t}}: \quad \mu_R = \mu_F = \frac{1}{4}\left(\sqrt{m_t^2 + {p_T^t}^2} + \sqrt{m_t^2 + {p_T^{\bar{t}}}^2}\right)$$

$$p_T^t: \quad \mu_R = \mu_F = \frac{1}{2}\sqrt{m_t^2 + {p_T^t}^2} \text{ as average over } t/\bar{t}$$

At NNLO, a full computation remains prohibitively expensive for inclusion in a PDF fit

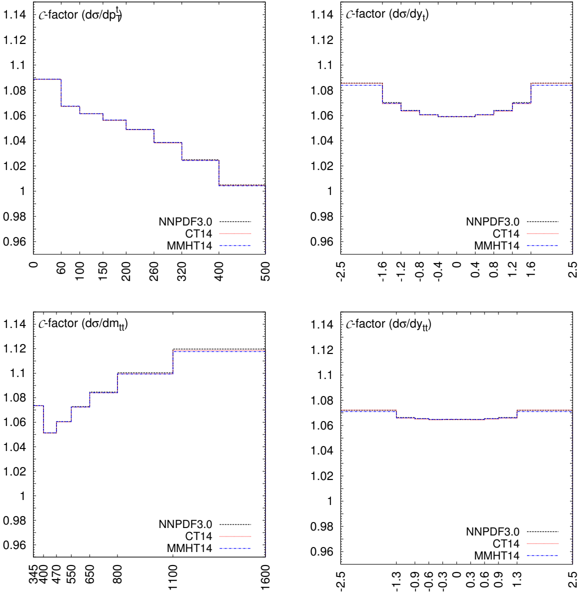
Use of bin-by-bin K-factors ($\mathcal{C}$-factors) computed with identical settings as for NLO

$$\mathcal{C} = \frac{\hat{\sigma}^{\mathrm{NNLO}} \otimes \mathcal{L}^{\mathrm{NNLO}}}{\hat{\sigma}^{\mathrm{NLO}} \otimes \mathcal{L}^{\mathrm{NNLO}}}$$

Total cross sections computed using `top++` [CPC 185 (2014) 2930] at NNLO

integration of differential distributions with dynamical scales in close agreement with NNLO+NNLL `top++` ($\sim 2\%$ higher than NNLO `top++`), but inconsequential for this study

Theory configuration: NNLO $\mathcal{C}$-factors



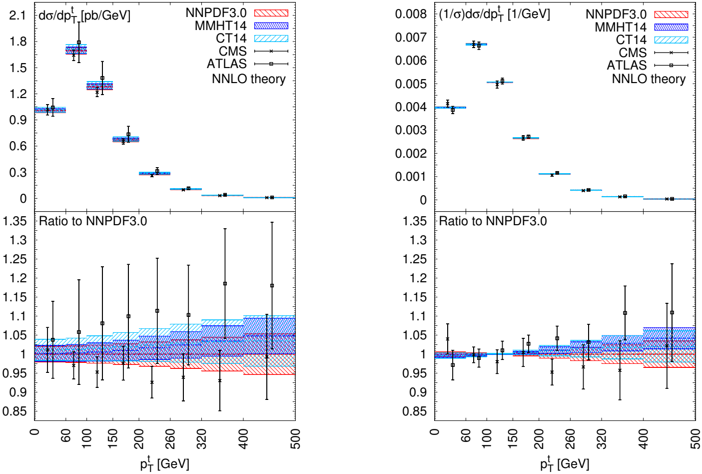
$\mathcal{C}$-factors are stable under variation of applied PDF

p_T^t distribution: from 9% (low p_T^t) to close to unity ($p_T^t \simeq 500$ GeV)

$m_{t\bar{t}}$ distribution: from 5% (low $m_{t\bar{t}}$) to 12% ($m_{t\bar{t}} \gtrsim 1$ TeV)

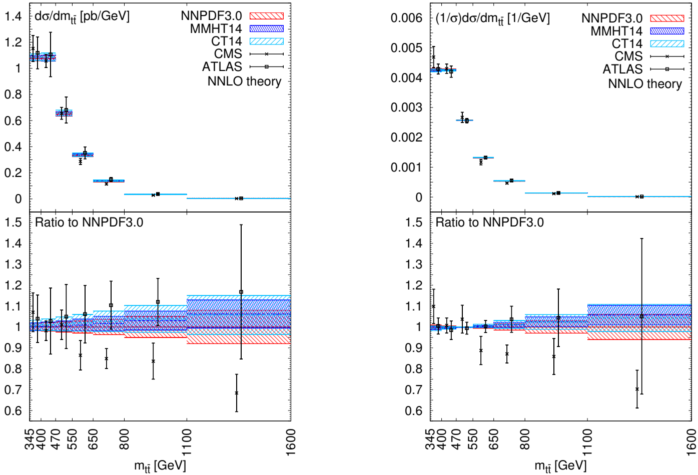
y_t and $y_{t\bar{t}}$ distributions: around 6%-9%, almost flat in the data region

Data/Theory comparison: p_T^t



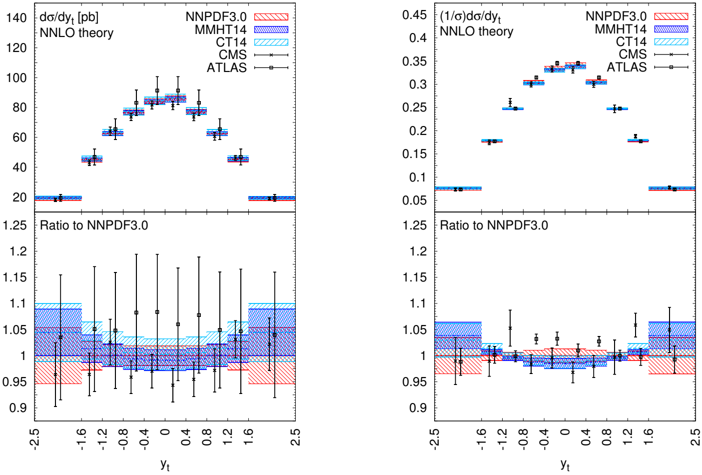
PDF set	ATLAS $d\sigma/dp_T^t$	CMS $d\sigma/dp_T^t$	ATLAS $(1/\sigma)d\sigma/dp_T^t$	CMS $(1/\sigma)d\sigma/dp_T^t$
NNPDF3.0	0.84 (0.66)	1.24 (0.91)	3.13 (0.94)	2.03 (0.51)
MMHT14	0.63 (0.44)	1.54 (1.47)	2.23 (0.54)	3.15 (0.77)
CT14	0.76 (0.42)	1.67 (1.77)	2.33 (0.62)	2.88 (0.70)

Data/Theory comparison: $m_{t\bar{t}}$



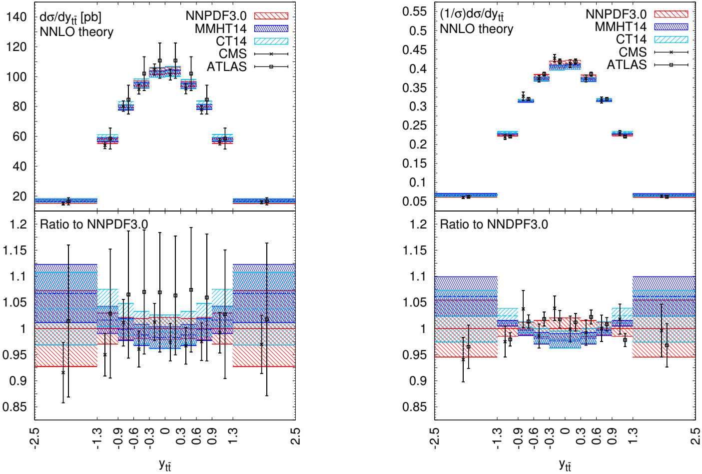
PDF set	ATLAS $d\sigma/dm_{t\bar{t}}$	CMS $d\sigma/dm_{t\bar{t}}$	ATLAS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	CMS $(1/\sigma)d\sigma/dm_{t\bar{t}}$
NNPDF3.0	0.77 (0.38)	5.73 (4.36)	1.57 (0.10)	10.6 (3.87)
MMHT14	0.58 (0.24)	7.32 (5.74)	1.01 (0.05)	13.5 (4.93)
CT14	0.61 (0.19)	7.28 (6.06)	1.09 (0.05)	13.5 (4.82)

Data/Theory comparison: y_t



PDF set	ATLAS $d\sigma/dy_t$	CMS $d\sigma/dy_t$	ATLAS $(1/\sigma)d\sigma/dy_t$	CMS $(1/\sigma)d\sigma/dy_t$
NNPDF3.0	0.73 (0.28)	3.04 (1.05)	4.06 (2.85)	3.29 (1.49)
MMHT14	1.36 (0.29)	2.12 (0.98)	12.1 (6.82)	2.40 (1.09)
CT14	1.28 (0.20)	2.23 (1.47)	10.3 (5.71)	2.33 (0.96)

Data/Theory comparison: $y_{t\bar{t}}$



PDF set	ATLAS $d\sigma/dy_{t\bar{t}}$	CMS $d\sigma/dy_{t\bar{t}}$	ATLAS $(1/\sigma)d\sigma/dy_{t\bar{t}}$	CMS $(1/\sigma)d\sigma/dy_{t\bar{t}}$
NNPDF3.0	0.84 (0.21)	0.99 (0.74)	3.59 (1.48)	1.17 (0.75)
MMHT14	2.36 (0.29)	2.27 (1.52)	15.6 (5.49)	3.33 (2.10)
CT14	2.69 (0.19)	1.88 (1.67)	12.7 (5.26)	2.53 (1.51)

Including $t\bar{t}$ distributions in a fit: fit settings

Qualitative tension between CMS and ATLAS data, use fits to investigate quantitatively

Fits are performed in the NNPDF3 framework, with perturbative charm

Dataset	Fit ID									
	1	2	3	4	5	6	7	8	9	10
Baseline +	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
ATLAS $d\sigma/dp_T^t$			☑							
ATLAS $d\sigma/dy_t$				☑						
ATLAS $d\sigma/dy_{t\bar{t}}$					☑					
ATLAS $d\sigma/dm_{t\bar{t}}$						☑				
ATLAS $(1/\sigma)d\sigma/dp_T^t$							☑			
ATLAS $(1/\sigma)d\sigma/dy_t$								☑		
ATLAS $(1/\sigma)d\sigma/dy_{t\bar{t}}$									☑	
ATLAS $(1/\sigma)d\sigma/dm_{t\bar{t}}$										☑
ATLAS $\sigma_{\mathrm{t\bar{t}}}$		☑					☑	☑	☑	☑
CMS $d\sigma/dp_T^t$			☑							
CMS $d\sigma/dy_t$				☑						
CMS $d\sigma/dy_{t\bar{t}}$					☑					
CMS $d\sigma/dm_{t\bar{t}}$						☑				
CMS $(1/\sigma)d\sigma/dp_T^t$							☑			
CMS $(1/\sigma)d\sigma/dy_t$								☑		
CMS $(1/\sigma)d\sigma/dy_{t\bar{t}}$									☑	
CMS $(1/\sigma)d\sigma/dm_{t\bar{t}}$										☑
CMS $\sigma_{\mathrm{t\bar{t}}}$		☑					☑	☑	☑	☑

Baseline 1: HERA-only (legacy combinations of inclusive and charm measurements)

Baseline 2: Global (same dataset as NNPDF3.0 without jet data)

NNLO HERA-only fit quality: $\chi^2/N_{\rm dat}$

Dataset	Fit ID 1	2	3	4	5	6	7	8	9	10	one distribution at a time
ATLAS $d\sigma/dp_T^t$	2.30	2.48	**0.73**	3.16	3.46	2.04	1.34	3.28	4.88	2.89	**0.44**
ATLAS $d\sigma/dy_t$	0.82	1.14	1.21	**1.06**	0.75	1.04	1.31	0.59	0.75	0.74	**0.47**
ATLAS $d\sigma/dy_{t\bar{t}}$	1.12	1.90	2.40	2.83	**0.45**	4.43	1.96	1.88	0.40	1.49	**0.43**
ATLAS $d\sigma/dm_{t\bar{t}}$	4.27	2.93	2.41	2.81	4.33	**1.53**	2.70	2.88	4.37	5.09	**0.39**
ATLAS $(1/\sigma)d\sigma/dp_T^t$	3.47	2.60	3.80	2.92	3.15	3.91	**1.46**	3.31	3.98	4.01	**0.60**
ATLAS $(1/\sigma)d\sigma/dy_t$	1.21	6.07	3.32	5.95	1.34	2.24	4.27	**1.48**	1.58	1.61	**0.75**
ATLAS $(1/\sigma)d\sigma/dy_{t\bar{t}}$	3.11	12.8	5.09	8.34	0.72	7.04	4.95	3.60	**0.53**	2.60	**0.45**
ATLAS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	8.14	3.07	6.53	4.94	5.42	20.5	6.44	5.61	4.40	**3.03**	**0.55**
ATLAS $\sigma_{t\bar{t}}$	3.88	**0.35**	3.38	0.63	1.58	1.29	**0.87**	**0.37**	**0.42**	**0.66**	
CMS $d\sigma/dp_T^t$	2.04	2.29	**0.82**	3.29	2.99	1.52	1.44	2.81	4.16	2.32	**0.82**
CMS $d\sigma/dy_t$	3.38	2.48	2.91	**1.75**	3.51	3.47	2.32	3.03	3.48	4.81	**1.30**
CMS $d\sigma/dy_{t\bar{t}}$	1.00	1.58	2.29	1.68	**1.08**	3.05	1.51	1.34	1.07	1.85	**0.74**
CMS $d\sigma/dm_{t\bar{t}}$	3.96	5.85	4.81	4.70	4.23	**1.73**	4.46	4.23	4.71	3.74	**1.28**
CMS $(1/\sigma)d\sigma/dp_T^t$	2.78	4.86	1.78	5.23	4.05	2.84	**1.57**	4.69	5.29	3.40	**0.85**
CMS $(1/\sigma)d\sigma/dy_t$	5.73	3.15	4.10	2.35	5.04	4.88	3.13	**1.94**	4.60	6.71	**1.70**
CMS $(1/\sigma)d\sigma/dy_{t\bar{t}}$	1.68	2.27	2.62	2.11	1.40	3.42	1.78	1.49	**1.20**	1.98	**0.75**
CMS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	5.30	10.3	7.83	8.24	7.06	2.71	7.45	7.41	8.06	**6.26**	**0.92**
CMS $\sigma_{t\bar{t}}$	6.95	**1.04**	6.17	1.59	3.24	2.75	**1.02**	**1.09**	**1.17**	**1.64**	
TOTAL	1.18	1.18	1.17	1.19	1.18	1.19	1.18	1.20	1.18	1.22	

Overall satisfactory description of most of the fitted differential distributions
worst fit in the case of top rapidity and top-pair mass distributions

Disagreement from a tension between ATLAS and CMS data rather than from theory inconsistency resolved by examining fits in which ATLAS and CMS data are included separately

The overall quality of the fit does not deteriorate upon the inclusion of $t\bar{t}$ data

NNLO global fit quality: $\chi^2/N_{\rm dat}$

Dataset	Fit ID 1	2	3	4	5	6	7	8	9	10	one distribution at a time	no fixed-target DIS
ATLAS $d\sigma/dp_T^t$	2.37	2.30	**1.99**	2.36	2.24	2.23	2.09	2.18	2.34	2.24		
ATLAS $d\sigma/dy_t$	0.93	0.80	0.74	**1.09**	0.76	0.76	0.86	0.69	0.76	0.66		
ATLAS $d\sigma/dy_{t\bar{t}}$	2.44	2.03	1.96	2.59	**1.32**	2.32	2.11	1.74	1.26	1.80		
ATLAS $d\sigma/dm_{t\bar{t}}$	4.27	4.47	4.68	4.14	4.92	**4.02**	4.34	4.79	4.98	4.99		
ATLAS $(1/\sigma)d\sigma/dp_T^t$	2.93	3.97	3.29	4.36	5.22	4.35	**2.96**	4.26	4.92	5.68	**2.38**	**0.79**
ATLAS $(1/\sigma)d\sigma/dy_t$	5.00	3.17	2.47	6.36	1.55	2.93	3.94	**1.68**	1.45	1.10	**1.11**	
ATLAS $(1/\sigma)d\sigma/dy_{t\bar{t}}$	9.69	5.59	5.89	8.95	2.68	5.73	6.73	3.57	**2.17**	3.73	**1.12**	
ATLAS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	2.30	2.80	3.31	2.67	3.96	4.21	3.09	3.68	3.77	**2.98**	**1.88**	**0.61**
ATLAS $\sigma_{t\bar{t}}$	0.12	**0.10**	0.21	0.10	0.10	0.12	**0.36**	**0.29**	**0.26**	**0.10**		
CMS $d\sigma/dp_T^t$	3.50	3.46	**2.60**	3.50	3.03	3.00	2.85	3.11	3.24	2.92		
CMS $d\sigma/dy_t$	3.48	3.71	4.05	**2.66**	4.18	3.49	3.38	4.23	4.43	4.99		
CMS $d\sigma/dy_{t\bar{t}}$	1.36	1.13	1.00	1.32	**0.89**	0.86	1.00	1.01	1.04	1.24		
CMS $d\sigma/dm_{t\bar{t}}$	7.07	6.27	5.79	6.33	5.09	**5.11**	6.00	5.37	5.21	4.31		
CMS $(1/\sigma)d\sigma/dp_T^t$	4.31	4.00	3.39	4.28	3.65	3.59	**3.56**	3.57	3.73	3.48	**3.03**	**0.90**
CMS $(1/\sigma)d\sigma/dy_t$	3.66	4.10	4.45	3.10	4.98	4.06	3.65	**4.76**	5.13	6.09	**1.66**	
CMS $(1/\sigma)d\sigma/dy_{t\bar{t}}$	1.59	1.20	1.06	1.73	0.94	1.01	1.20	0.99	**1.05**	1.32	**0.93**	
CMS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	12.0	10.8	9.81	11.1	8.72	8.72	10.3	9.15	8.97	**7.27**	**4.12**	**1.01**
CMS $\sigma_{t\bar{t}}$	0.10	**0.05**	0.26	0.19	0.32	0.21	**0.11**	**0.10**	**0.15**	**0.35**		
TOTAL	1.20	1.19	1.20	1.20	1.19	1.21	1.20	1.21	1.20	1.21		

Overall data description significantly worse than in HERA-only fits

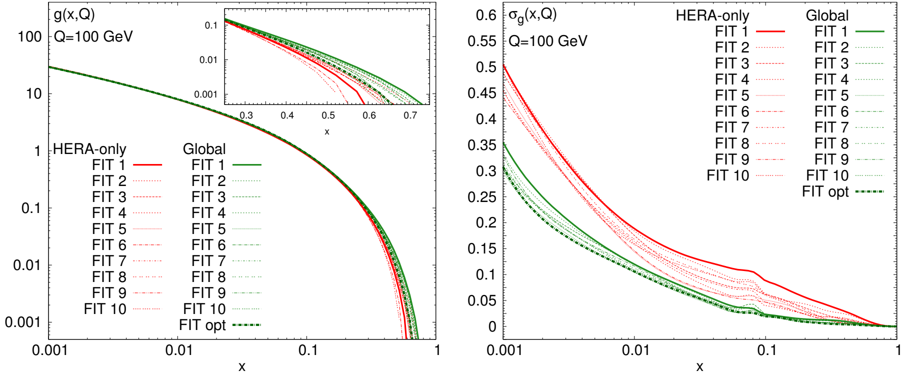
Clear tensions between ATLAS and CMS data and the rest of the dataset

inconsistency resolved in fits to individual ATLAS/CMS distributions, no fixed-target DIS data

The overall quality of the fit does not deteriorate upon the inclusion of $t\bar{t}$ data

$t\bar{t}$ data has not enough weight to result in a deterioration in fit quality to the data in tension

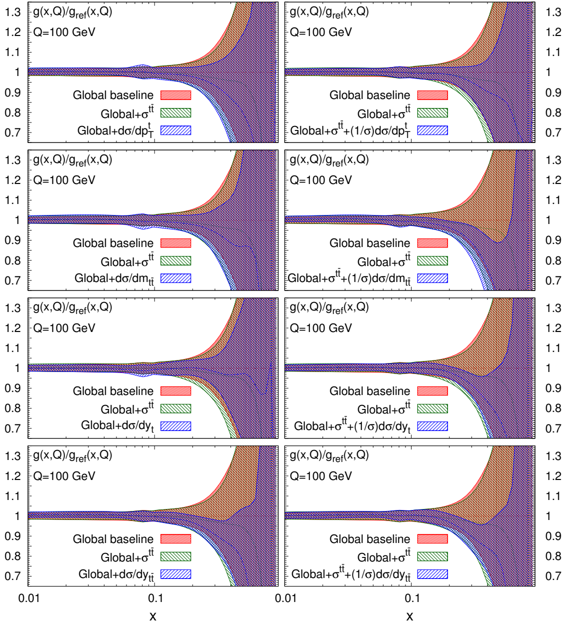
Impact of $t\bar{t}$ distributions on the gluon PDF at large x



Fair degree of consistency in the impact of various distributions on the gluon PDF
HERA-only fit (red): $t\bar{t}$ data prefers a harder gluon w.r.t. to the baseline (solid red)
Global fit (green): $t\bar{t}$ data prefers a softer gluon w.r.t. to the baseline (solid green)
Nice convergence/consistency check

Largest constraining power on the gluon PDF uncertainty in the global fit
There exists an optimal combination of $t\bar{t}$ data that maximises this effect (bold dashed green)

Impact of $t\bar{t}$ distributions on the gluon PDF at large x



Significant reduction in the gluon uncertainty at large x

Affected kinematic region as expected from the correlation coefficients $(0.1 \lesssim x \lesssim 0.7)$

Gluon remarkably consistent in the fit across the choice of distributions

Normalised distributions appear to lead to a greater reduction of uncertainties

Almost negligible impact of total inclusive cross sections (in green)

Procedural suggestion

OBSERVATIONAL FACTS

Impact of data on PDF central values appears relatively insensitive of distribution choice
all distributions are equal in the pool on the gluon PDF central value

While some distributions exhibit tensions, some appear perfectly compatible
select distributions whose inclusion in the global fit leads to $\chi^2/N_{\rm dat} \sim 1$

Normalised distributions + total cross sections exhibit the largest constraining power
they lead to the largest reduction of the gluon PDF uncertainties

Different distributions have their largest impact on a slightly different region of x
choose different distributions from ATLAS and CMS in order to maximise the kinematic coverage

Rapidity distributions have the weakest dependence on the value of m_t
and on potential BSM contaminations (kinematic suppression of heavy resonances)

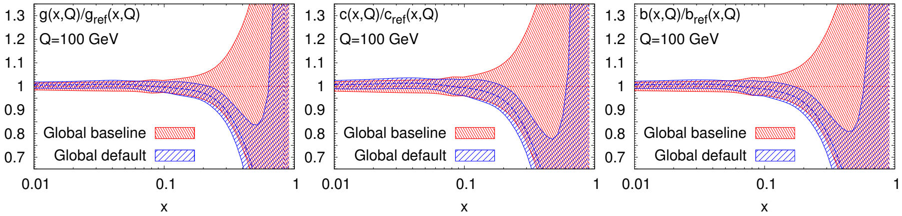
OUR RECOMMENDATION FOR INCLUDING 8 TeV ℓ+JETS $t\bar{t}$ DISTRIBUTIONS IN A FIT

the normalized top rapidity distribution $(1/\sigma)d\sigma/dy_t$ from ATLAS
the normalized top-pair rapidity distribution $(1/\sigma)d\sigma/dy_{t\bar{t}}$ from CMS
the corresponding total cross section $\sigma_{t\bar{t}}$ from ATLAS and CMS

Selection minimises
tension between ATLAS/CMS
tension with existing data
sensitivity to m_t/BSM contaminations

Balanced against
optimal fit quality
PDF constraining power
varied kinematic coverage

Our *optimal* fit: features



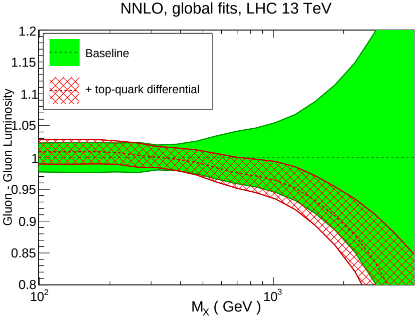
	ATLAS $d\sigma/dp_T^t$	ATLAS $d\sigma/dy_t$	ATLAS $d\sigma/dy_{t\bar{t}}$	ATLAS $d\sigma/dm_{t\bar{t}}$	ATLAS $(1/\sigma)d\sigma/dp_T^t$	ATLAS $(1/\sigma)d\sigma/dy_t$	ATLAS $(1/\sigma)d\sigma/dy_{t\bar{t}}$	ATLAS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	ATLAS $\sigma_{t\bar{t}}$	CMS $d\sigma/dp_T^t$	CMS $d\sigma/dy_t$	CMS $d\sigma/dy_{t\bar{t}}$	CMS $d\sigma/dm_{t\bar{t}}$	CMS $(1/\sigma)d\sigma/dp_T^t$	CMS $(1/\sigma)d\sigma/dy_t$	CMS $(1/\sigma)d\sigma/dy_{t\bar{t}}$	CMS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	CMS $\sigma_{t\bar{t}}$
Fit opt	2.19	0.64	1.84	5.01	2.49	**1.16**	3.81	4.55	**0.78**	2.91	4.98	1.07	4.77	3.33	5.78	**1.05**	8.05	**0.50**

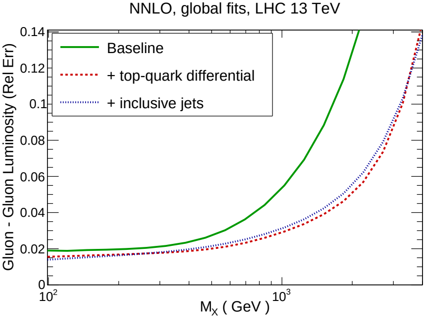
Overall good description of the $t\bar{t}$ differential distributions included in the fit
no evident signs of tension between ATLAS/CMS and with the rest of the dataset

Distributions not included in the fit not well described, except companion absolute distr.

Charm and bottom quark PDFs (generated radiatively) affected similarly as the gluon

Our *optimal* fit: phenomenological implications





Significant reduction of gg luminosity uncertainties at $M_X \geq \mathcal{O}(1)$ TeV
e.g., at $M_X \sim 2$ TeV, uncertainties decrease from 13% to 5%

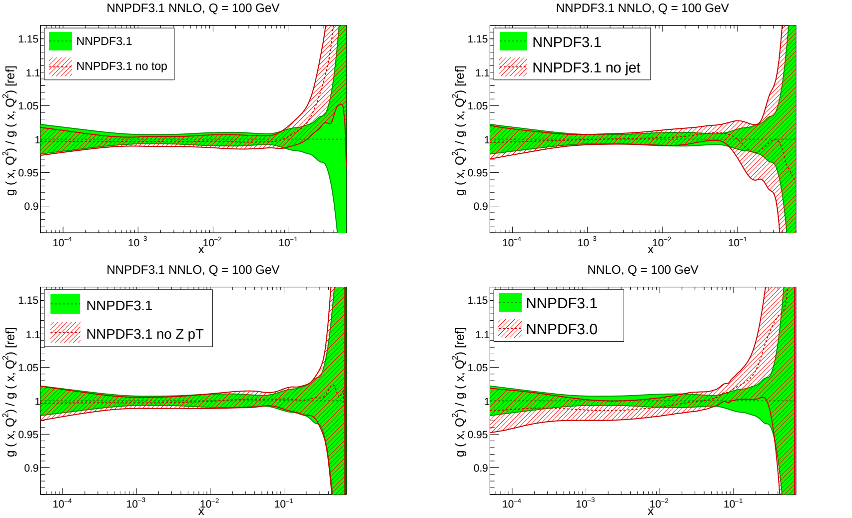
Impact of $t\bar{t}$ differential data similar to that of jet data
though jet data analysed neglecting NNLO QCD corrections in the matrix element

A precision determination of the gluon PDF at large x is now possible at NNLO
the situation should only improve thanks to the recent NNLO jet calculation

$t\bar{t}$ differential distributions are included in the new NNPDF3.1 PDF set

[arXiv:1706.00428, accepted for publication in EPJC]

The gluon PDF in NNPDF3.1

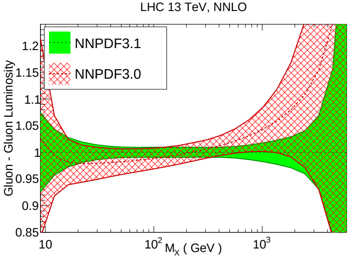


Nice consistency of the three data sets in driving the gluon PDF

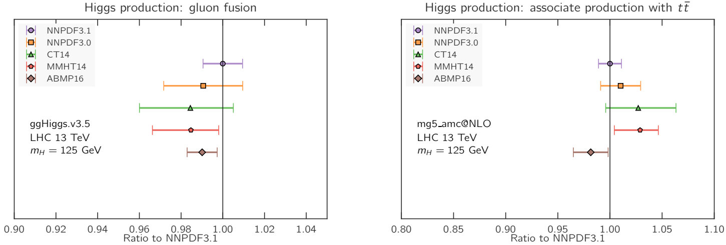
The central value changes by a significant amount, compatible with reduced uncertainties

NNPDF3.1 is more accurate than NNPDF3.0

Luminosities and Higgs production

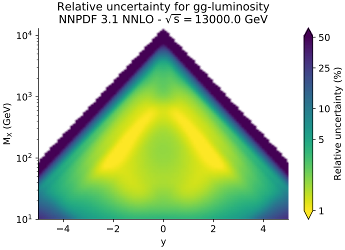


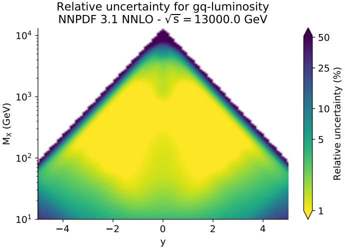
enhancement at small M_X, suppression at large M_X; shift below one-sigma uncertainties of $1-2\%$ in a wide range $|y| \lesssim 2$ and 100 GeV$\lesssim M_X \lesssim$ 1 TeV



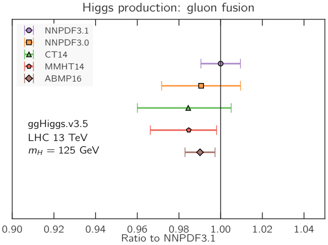
reduced uncertainties for Higgs production in gg fusion and $t\bar{t}h$

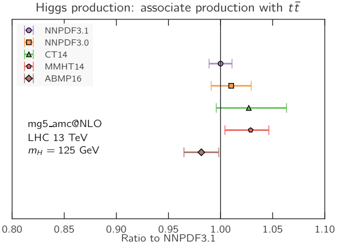
Luminosities and Higgs production





enhancement at small M_X, suppression at large M_X; shift below one-sigma uncertainties of $1-2\%$ in a wide range $|y| \lesssim 2$ and 100 GeV$\lesssim M_X \lesssim$ 1 TeV





reduced uncertainties for Higgs production in gg fusion and $t\bar{t}h$

Summary and final remarks

A new landscape

A combination of theoretical and experimental advances are shedding light on the gluon
Precise constraints on the large-x gluon PDF are now available at NNLO
from LHC top-pair differential data and inclusive jet data

Including LHC 8 TeV top-pair differential distributions in a fit

tension between ATLAS and CMS data, especially for the $m_{t\bar{t}}$ distributions
tension between ATLAS/CMS data and fixed-target inclusive DIS data
however, the data shows an excellent consistency in the pull upon gluon PDF
reduction in uncertainties is comparable to the constraining power of inclusive jets
inclusion of rapidity distributions minimises dependence on m_t and BSM resonances
$t\bar{t}$ data provides PDFs for precise predictions of (B)SM processes at large M_X
$t\bar{t}$ data are an essential ingredient in a next generation of global PDF sets

Outlook

estimate of the correlations among different distributions and between ATLAS and CMS
availability of measurements at 13 TeV (increased statistics and kinematic range)
computation of NNLO corrections for top quark differential distributions with top decays

Summary and final remarks

A new landscape

A combination of theoretical and experimental advances are shedding light on the gluon
Precise constraints on the large-x gluon PDF are now available at NNLO
from LHC top-pair differential data and inclusive jet data

Including LHC 8 TeV top-pair differential distributions in a fit

tension between ATLAS and CMS data, especially for the $m_{t\bar{t}}$ distributions
tension between ATLAS/CMS data and fixed-target inclusive DIS data
however, the data shows an excellent consistency in the pull upon gluon PDF
reduction in uncertainties is comparable to the constraining power of inclusive jets
inclusion of rapidity distributions minimises dependence on m_t and BSM resonances
$t\bar{t}$ data provides PDFs for precise predictions of (B)SM processes at large M_X
$t\bar{t}$ data are an essential ingredient in a next generation of global PDF sets

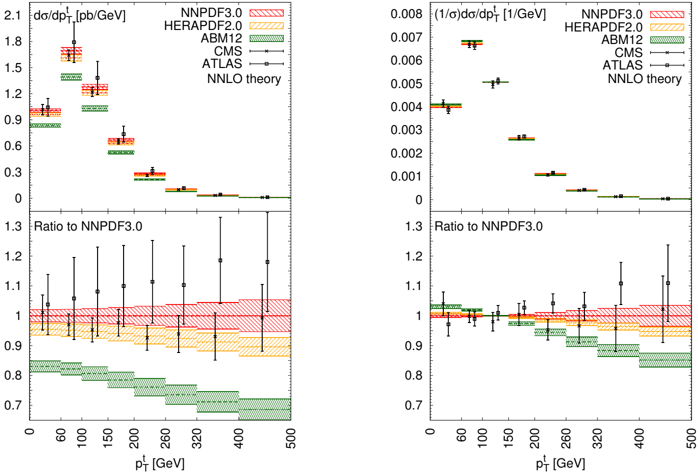
Outlook

estimate of the correlations among different distributions and between ATLAS and CMS
availability of measurements at 13 TeV (increased statistics and kinematic range)
computation of NNLO corrections for top quark differential distributions with top decays

Thank you

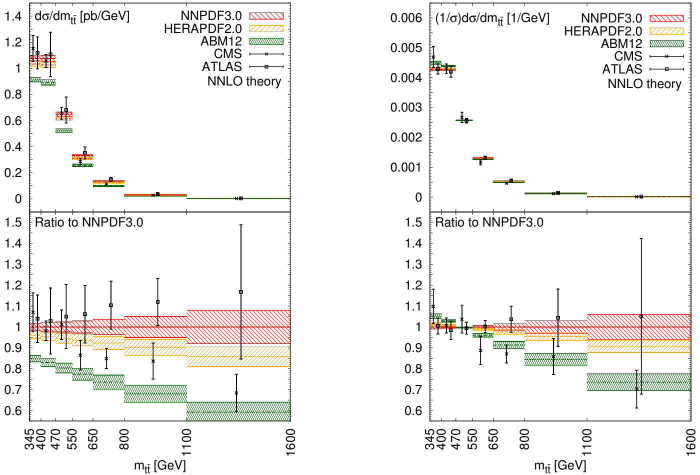
Extra material

Data/Theory comparison: p_T^t



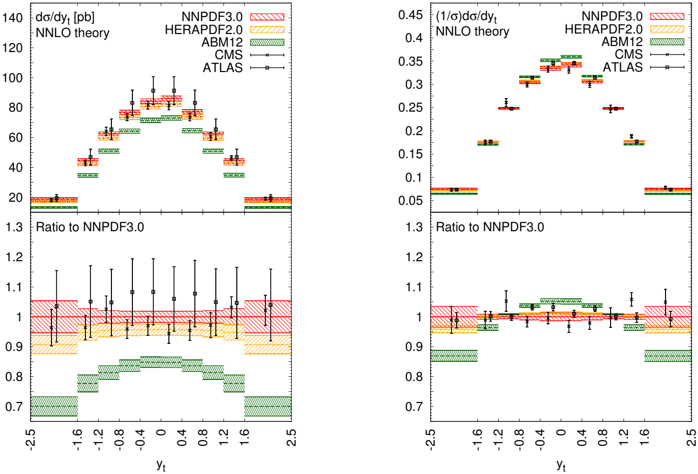
PDF set	ATLAS $d\sigma/dp_T^t$	CMS $d\sigma/dp_T^t$	ATLAS $(1/\sigma)d\sigma/dp_T^t$	CMS $(1/\sigma)d\sigma/dp_T^t$
NNPDF3.0	0.84 (0.66)	1.24 (0.91)	3.13 (0.94)	2.03 (0.51)
HERA2.0	1.13 (1.69)	0.69 (0.84)	5.19 (1.73)	1.12 (0.33)
ABM12	6.23 (1.94)	12.5 (3.00)	14.0 (4.90)	2.80 (0.80)

Data/Theory comparison: $m_{t\bar{t}}$



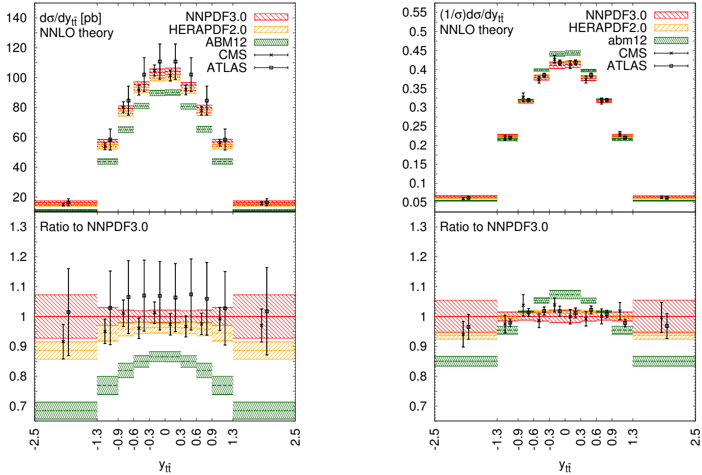
PDF set	ATLAS $d\sigma/dm_{t\bar{t}}$	CMS $d\sigma/dm_{t\bar{t}}$	ATLAS $(1/\sigma)d\sigma/dm_{t\bar{t}}$	CMS $(1/\sigma)d\sigma/dm_{t\bar{t}}$
NNPDF3.0	0.77 (0.38)	5.73 (4.36)	1.57 (0.10)	10.6 (3.87)
HERA2.0	1.40 (1.30)	3.32 (1.49)	4.36 (0.30)	5.96 (2.28)
ABM12	5.72 (3.81)	5.23 (3.22)	21.1 (1.61)	1.24 (0.47)

Data/Theory comparison: y_t



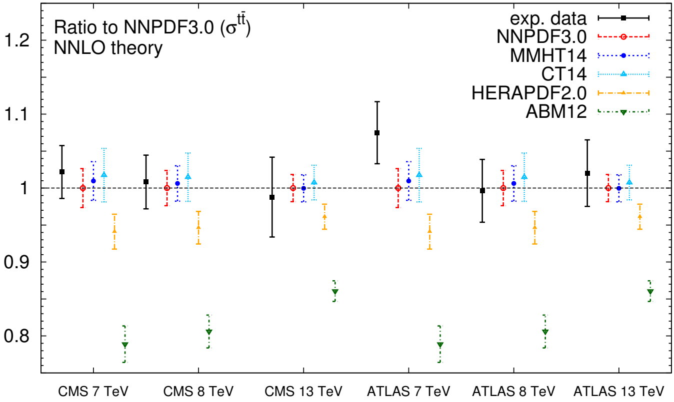
PDF set	ATLAS $d\sigma/dy_t$	CMS $d\sigma/dy_t$	ATLAS $(1/\sigma)d\sigma/dy_t$	CMS $(1/\sigma)d\sigma/dy_t$
NNPDF3.0	0.73 (0.28)	3.04 (1.05)	4.06 (2.85)	3.29 (1.49)
HERA2.0	0.72 (0.99)	3.65 (1.49)	1.76 (1.62)	4.99 (2.29)
ABM12	5.32 (1.45)	22.1 (9.78)	7.09 (15.5)	17.7 (8.72)

Data/Theory comparison: $y_{t\bar{t}}$



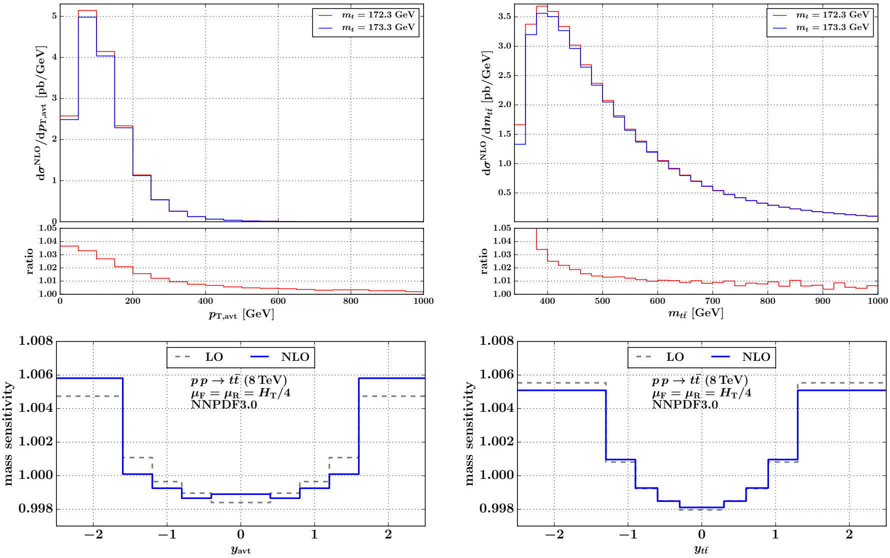
PDF set	ATLAS $d\sigma/dy_{t\bar{t}}$	CMS $d\sigma/dy_{t\bar{t}}$	ATLAS $(1/\sigma)d\sigma/dy_{t\bar{t}}$	CMS $(1/\sigma)d\sigma/dy_{t\bar{t}}$
NNPDF3.0	0.84 (0.21)	0.99 (0.74)	3.59 (1.48)	1.17 (0.75)
HERA2.0	0.53 (0.74)	1.02 (0.78)	1.20 (0.60)	1.23 (0.73)
ABM12	4.04 (1.05)	18.0 (5.48)	20.2 (6.06)	8.26 (4.52)

Data/Theory comparison: $\sigma^{t\bar{t}}$

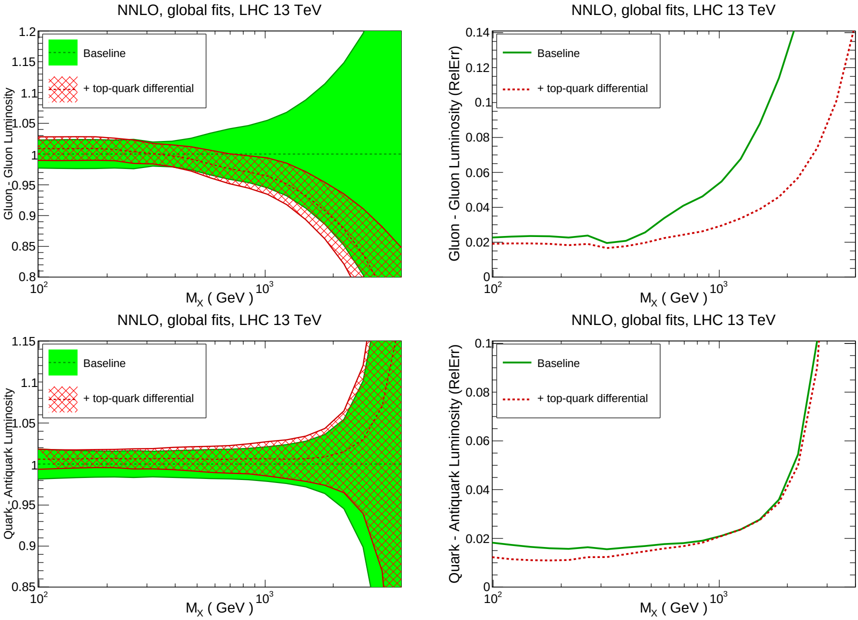


PDF set	ATLAS $\sigma^{t\bar{t}}$	CMS $\sigma^{t\bar{t}}$
NNPDF3.0	2.21	1.36
MMHT14	2.51	1.32
CT14	2.19	1.72
HERA2.0	0.74	0.21
ABM12	12.6	16.7

Sensitivity of $t\bar{t}$ absolute distributions to m_t (NLO)



Phenomenological implications



Phenomenological implications