The role of top quark observables in PDFs: NNPDF

Snowmass2020 — EF03/EF06 parallel session

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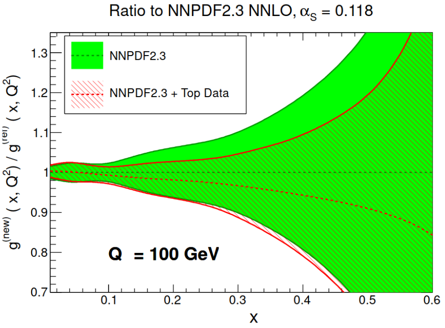
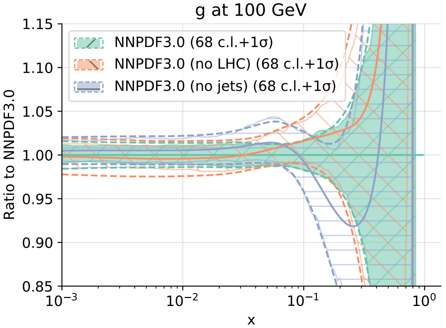
NNPDF3.0: total top-quark pair cross sections



[JHEP 07 (2013) 167]



[Nucl.Phys. B867 (2013) 244]

Considered 5 data points from Tevatron and ATLAS, CMS 7,8 TeV

Dataset	NNPDF2.3	NNPDF2.3+top
Tevatron+LHC	1.26	0.98

Considered 6 data points from ATLAS and CMS 7,8 TeV

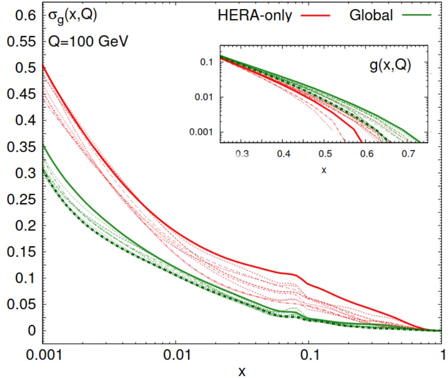
Dataset	LO	NLO	NNLO
LHC	42.1	1.43	0.66

Fixed scale used throughout: $\mu_F = \mu_R = m_t$, $m_t = 173.3$ GeV

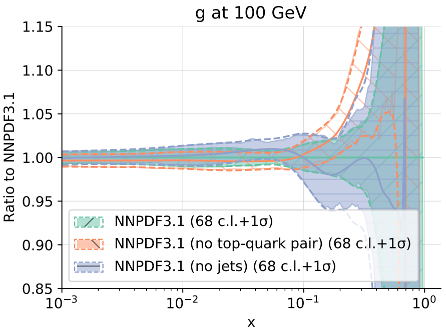
Higher-order QCD corrections essential to describe the data [Phys.Rev.Lett. 110 (2013) 252004]

Sizeable reduction of uncertainty on gluon; little suppression of central value at large x

NNPDF3.1: differential cross sections



[JHEP 04 (2017) 044]



[Eur.Phys.J. C77 (2017) 663]

ATLAS and CMS 8 TeV diff. cross sections

[Eur.Phys.J. C76 (2016), 538; Eur.Phys.J. C75 (2015) 542]

NNLO QCD corrections included

[Phys. Rev. Lett. 116 (2016) 082003]

Dataset	LO	NLO	NNLO
ATLAS $\sigma_{t\bar{t}}$ (7, 8, 13 TeV)	53.2	1.92	0.86
ATLAS $1/\sigma_{t\bar{t}} d\sigma/dy_t$	1.99	1.31	1.45
CMS $\sigma_{t\bar{t}}$ (7, 8, 13 TeV)	53.4	0.59	0.20
CMS $1/\sigma_{t\bar{t}} d\sigma/dy_t$	1.32	0.96	0.94

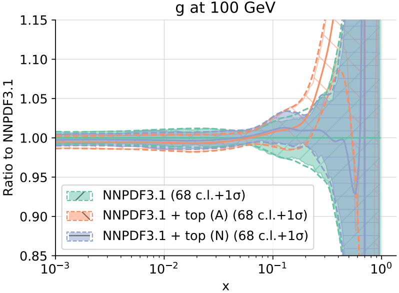
Dynamic scale used throughout: $\mu_F = \mu_R = \frac{1}{4}\left[\sqrt{m_t^2 + (p_T^t)^2} + \sqrt{m_t^2 + (p_T^{\bar{t}})^2}\right]$

Beyond NNPDF3.1: exp. correlations and pert. charm

Dataset	$N_{\rm dat}$	3.1 (FC)	3.1 (FC+N)	3.1 (FC+A)	3.1 (PC+N)	3.1 (PC+N)
ATLAS $t\bar{t}$ N (cor.)	21	[2.74]	2.28	[4.60]	2.29	[3.49]
ATLAS $t\bar{t}$ N (unc.)	21	[2.08]	[1.94]	[4.16]	[1.89]	[3.07]
ATLAS $1/\sigma d\sigma/dp_T^t$	7	[3.50]	2.94	[2.45]	2.95	[2.54]
ATLAS $1/\sigma d\sigma/dy_t$	4	1.45	1.20	[4.81]	1.10	[2.98]
ATLAS $1/\sigma d\sigma/dy_{t\bar{t}}$	4	[1.66]	1.55	[10.2]	1.40	[6.30]
ATLAS $1/\sigma d\sigma/dm_{t\bar{t}}$	6	[1.67]	1.59	[1.36]	1.61	[1.42]
ATLAS $t\bar{t}$ A (cor.)	25	[7.96]	[6.88]	5.76	[7.18]	5.23
ATLAS $t\bar{t}$ A (unc.)	25	[2.09]	[2.06]	[2.28]	[2.25]	[2.17]
ATLAS $d\sigma/dp_T^t$	8	[2.41]	[2.43]	2.50	[2.46]	2.54
ATLAS $d\sigma/dy_t$	5	[0.87]	[0.76]	1.14	[0.73]	0.87
ATLAS $d\sigma/dy_{t\bar{t}}$	5	[1.21]	[1.19]	2.36	[1.15]	1.86
ATLAS $d\sigma/dm_{t\bar{t}}$	7	[3.27]	[3.24]	2.85	[3.25]	2.94
ATLAS jets	31	0.90	1.08	1.01	1.11	1.05
CMS jets	133	0.88	0.95	1.05	0.94	0.99
ATLAS $Z\, p_T$	92	0.90	0.91	0.95	0.95	0.97
CMS $Z\, p_T$	28	1.33	1.35	1.33	1.30	1.31
ATLAS $\sigma_{t\bar{t}}$	3/2	0.86	0.74	0.68	0.72	0.83
CMS $\sigma_{t\bar{t}}$	3	0.20	0.29	0.56	0.35	0.34
CMS $1/\sigma d\sigma/dy_{t\bar{t}}$	10	0.94	0.98	1.01	0.97	1.46
Total		1.15	1.17	1.20	1.20	1.23

[Les Houches, arXiv:2003.01700]

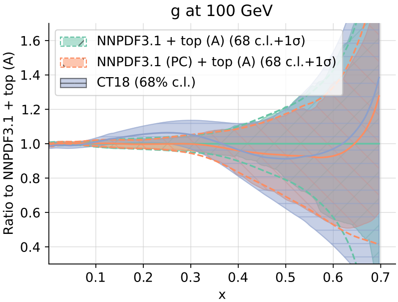
Beyond NNPDF3.1: exp. correlations and pert. charm

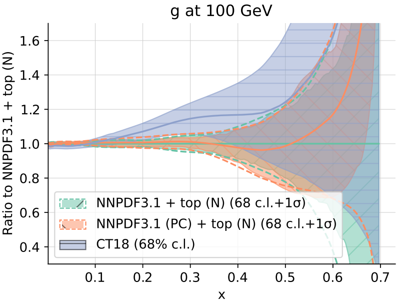


Most of the difference comes from using normalized distributions instead of absolute

Fitting (or not) charm makes little difference on central value (not on fit quality)

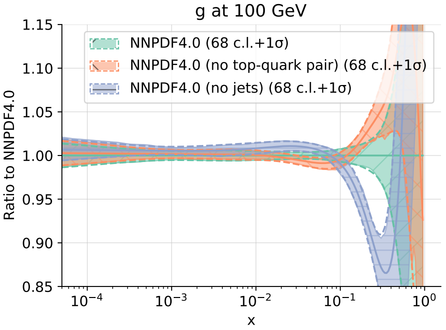
If absolute distributions are fitted with perturbative charm, the NNPDF and CT18 gluons become similar





NNPDF4.0: more LHC data

Dataset	$N_{\rm dat}$	$\chi^2_{4.0}$
CMS $\sigma_{tt}^{\rm tot}$ 5 TeV	1	0.54
ATLAS $\sigma_{tt}^{\rm tot}$ 7 TeV	1	1.59
CMS $\sigma_{tt}^{\rm tot}$ 7 TeV	1	1.06
ATLAS $\sigma_{tt}^{\rm tot}$ 8 TeV	1	0.02
CMS $\sigma_{tt}^{\rm tot}$ 8 TeV	1	0.26
ATLAS $\sigma_{tt}^{\rm tot}$ 13 TeV (139 fb^{-1})	1	0.51
CMS $\sigma_{tt}^{\rm tot}$ 13 TeV	1	0.06
ATLAS ℓ+j 8 TeV $(1/\sigma d\sigma/dy_t)$	4	3.22
ATLAS ℓ+j 8 TeV $(1/\sigma d\sigma/dy_{t\bar{t}})$	4	3.77
ATLAS 2ℓ 8 TeV $(1/\sigma d\sigma/dy_{t\bar{t}})$	5	1.61
CMS ℓ+j 8 TeV $(1/\sigma d\sigma/dy_{t\bar{t}})$	9	1.23
CMS 2ℓ 8 TeV $(1/\sigma d\sigma/dy_t dm_{t\bar{t}})$	16	1.03
CMS ℓ+j 13 TeV $(d\sigma/dy_t)$	11	0.63
CMS $t\bar{t}$ 2ℓ 13 TeV $(d\sigma/dy_t)$	10	0.52
ATLAS dijets 7 TeV, $R=0.6$	90	2.15
CMS dijets 7 TeV	54	1.81
ATLAS incl. jets 8 TeV, $R=0.6$	171	0.69
CMS incl. jets 8 TeV	185	1.19
Total	4618	1.16



Dataset significantly extended in NNPDF4.0 (top and jets)

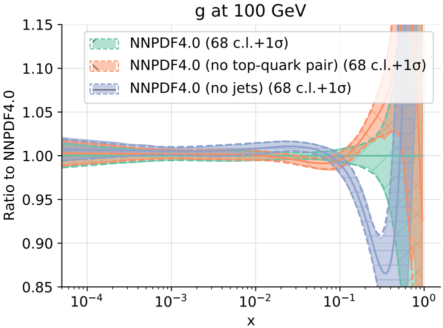
top: 40 data points more than NNPDF3.1

jet: 336 data points more than NNPDF3.1

Competing pulls of top and jets

NNPDF4.0: more LHC data

Dataset	$N_{\rm dat}$	$\chi^2_{n/j}$
CMS $\sigma_{tt}^{\rm tot}$ 5 TeV	1	1.03
ATLAS $\sigma_{tt}^{\rm tot}$ 7 TeV	1	2.36
CMS $\sigma_{tt}^{\rm tot}$ 7 TeV	1	2.89
ATLAS $\sigma_{tt}^{\rm tot}$ 8 TeV	1	0.40
CMS $\sigma_{tt}^{\rm tot}$ 8 TeV	1	1.12
ATLAS $\sigma_{tt}^{\rm tot}$ 13 TeV (139 fb^{-1})	1	0.77
CMS $\sigma_{tt}^{\rm tot}$ 13 TeV	1	0.01
ATLAS ℓ+j 8 TeV $(1/\sigma d\sigma/dy_t)$	4	1.89
ATLAS ℓ+j 8 TeV $(1/\sigma d\sigma/dy_{t\bar{t}})$	4	2.13
ATLAS 2ℓ 8 TeV $(1/\sigma d\sigma/dy_{t\bar{t}})$	5	1.22
CMS ℓ+j 8 TeV $(1/\sigma d\sigma/dy_{t\bar{t}})$	9	1.28
CMS 2ℓ 8 TeV $(1/\sigma d\sigma/dy_t dm_{t\bar{t}})$	16	1.85
CMS ℓ+j 13 TeV $(d\sigma/dy_t)$	11	0.26
CMS $t\bar{t}$ 2ℓ 13 TeV $(d\sigma/dy_t)$	10	0.49
ATLAS dijets 7 TeV, $R=0.6$	90	[2.61]
CMS dijets 7 TeV	54	[2.65]
ATLAS incl. jets 8 TeV, $R=0.6$	171	[1.30]
CMS incl. jets 8 TeV	185	[1.35]
Total	4118	1.14



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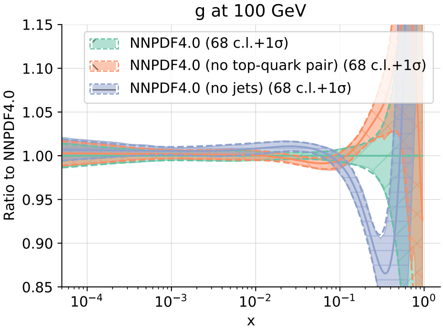
jet: 336 data points more than NNPDF3.1

Competing pulls of top and jets

NNPDF4.0: more LHC data

Dataset	$N_{\rm dat}$	$\chi^2_{n/t}$
CMS $\sigma_{tt}^{\rm tot}$ 5 TeV	1	[0.43]
ATLAS $\sigma_{tt}^{\rm tot}$ 7 TeV	1	[1.09]
CMS $\sigma_{tt}^{\rm tot}$ 7 TeV	1	[0.79]
ATLAS $\sigma_{tt}^{\rm tot}$ 8 TeV	1	[0.01]
CMS $\sigma_{tt}^{\rm tot}$ 8 TeV	1	[0.17]
ATLAS $\sigma_{tt}^{\rm tot}$ 13 TeV (139 fb^{-1})	1	[0.49]
CMS $\sigma_{tt}^{\rm tot}$ 13 TeV	1	[0.06]
ATLAS ℓ+j 8 TeV $(1/\sigma d\sigma/dy_t)$	4	[6.38]
ATLAS ℓ+j 8 TeV $(1/\sigma d\sigma/dy_{t\bar{t}})$	4	[8.10]
ATLAS 2ℓ 8 TeV $(1/\sigma d\sigma/dy_{t\bar{t}})$	5	[1.83]
CMS ℓ+j 8 TeV $(1/\sigma d\sigma/dy_{t\bar{t}})$	9	[2.16]
CMS 2ℓ 8 TeV $(1/\sigma d\sigma/dy_t dm_{t\bar{t}})$	16	[0.82]
CMS ℓ+j 13 TeV $(d\sigma/dy_t)$	11	[1.08]
CMS $t\bar{t}$ 2ℓ 13 TeV $(d\sigma/dy_t)$	10	[0.67]
ATLAS dijets 7 TeV, $R=0.6$	90	2.18
CMS dijets 7 TeV	54	1.78
ATLAS incl. jets 8 TeV, $R=0.6$	171	0.69
CMS incl. jets 8 TeV	185	1.14
Total	4552	1.16



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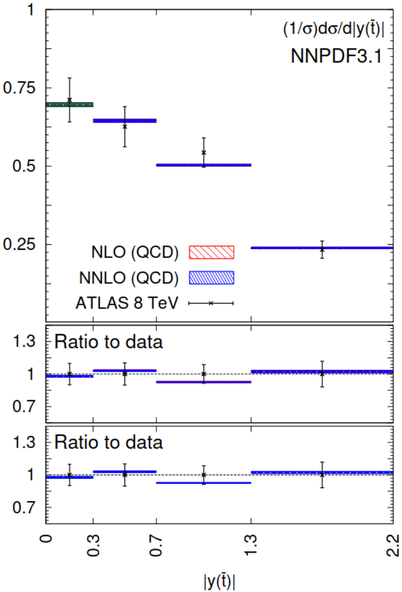
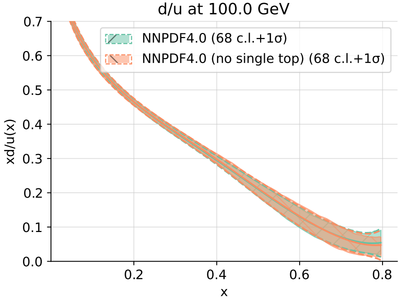
Competing pulls of top and jets

NNPDF4.0: single top



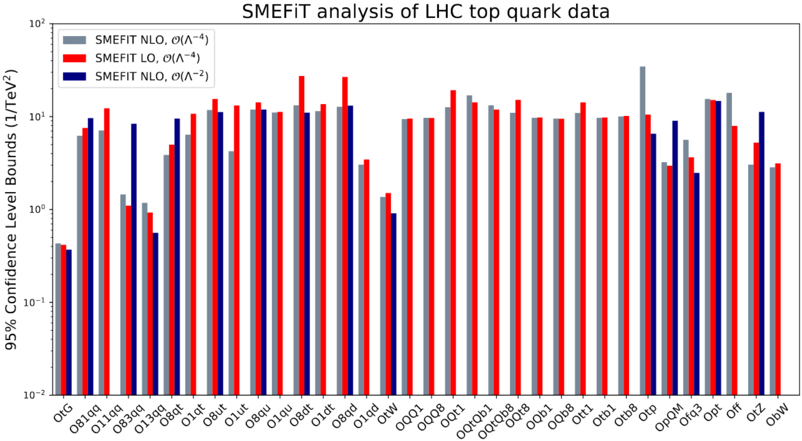
Dataset	$N_{\rm dat}$	χ^2
ATLAS single t R_t 7 TeV	1	0.50
CMS single t $\sigma_t + \sigma_{\bar{t}}$ 7 TeV	1	0.73
CMS single t R_t 8 TeV	1	0.17
ATLAS single t R_t 13 TeV	1	0.06
CMS single t R_t 13 TeV	1	0.36
ATLAS sing. t 7 TeV $(1/\sigma d\sigma/dy_t)$	3	0.96
ATLAS sing. t 7 TeV $(1/\sigma d\sigma/dy_{\bar{t}})$	3	0.06
ATLAS sing. t 8 TeV $(1/\sigma d\sigma/dy_t)$	3	0.25
ATLAS sing. t 8 TeV $(1/\sigma d\sigma/dy_{\bar{t}})$	3	0.19



[JHEP 05 (2020) 067]

Beyond PDF fits: SMEFiT

$$\sigma^{pp\to ab} = \sigma_{\rm SM} + \sum_{i=1}^{N_6} \frac{c_i}{\Lambda^2}\sigma_i^{(\rm eft)} + \sum_{i,j=1}^{N_6} \frac{c_i c_j}{\Lambda^4}\tilde{\sigma}_{ij}^{(\rm eft)} \quad \mathcal{L} = \mathcal{L}_{\rm SM} + \sum_{d=5}^{\infty}\sum_{i=1}^{N_d} \frac{c_i^{(d)}}{\Lambda^{d-4}}\mathcal{O}_i^{(d)}$$



[JHEP 04 (2019) 100]

Summary

Top-quark measurements are particularly relevant in PDF fits.

Top-quark pair measurements have a significant effect on the gluon PDF.

Correlations across different differential distributions may hinder their analysis.

Input from experimentalists is of utmost importance.

A different pull w.r.t. jet measurements is observed in NNPDF fits.

Single top-quark (t-channel) production is not yet sufficiently precise to constrain PDFs.

Top data (beyond top-pair and single-top production) also relevant for BSM searches.

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Thank you