QCD phenomenology with jets at the LHC

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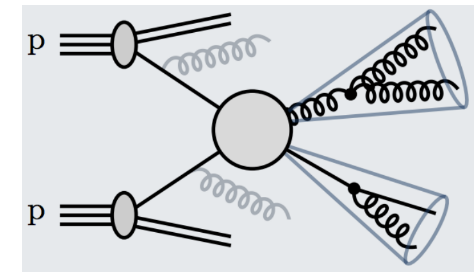
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

Introduction

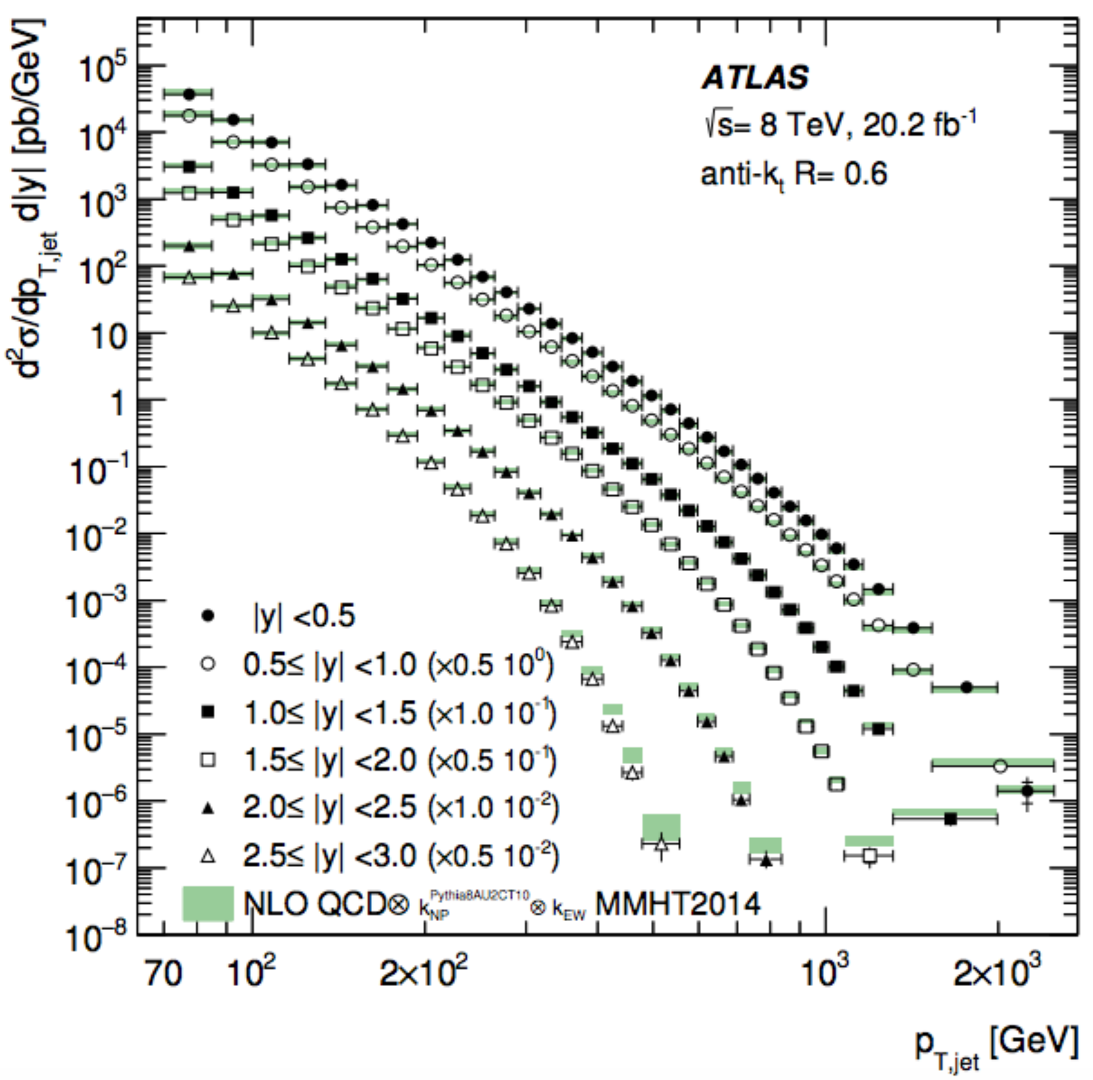
- inclusive jet cross section → dominant hard process at the LHC

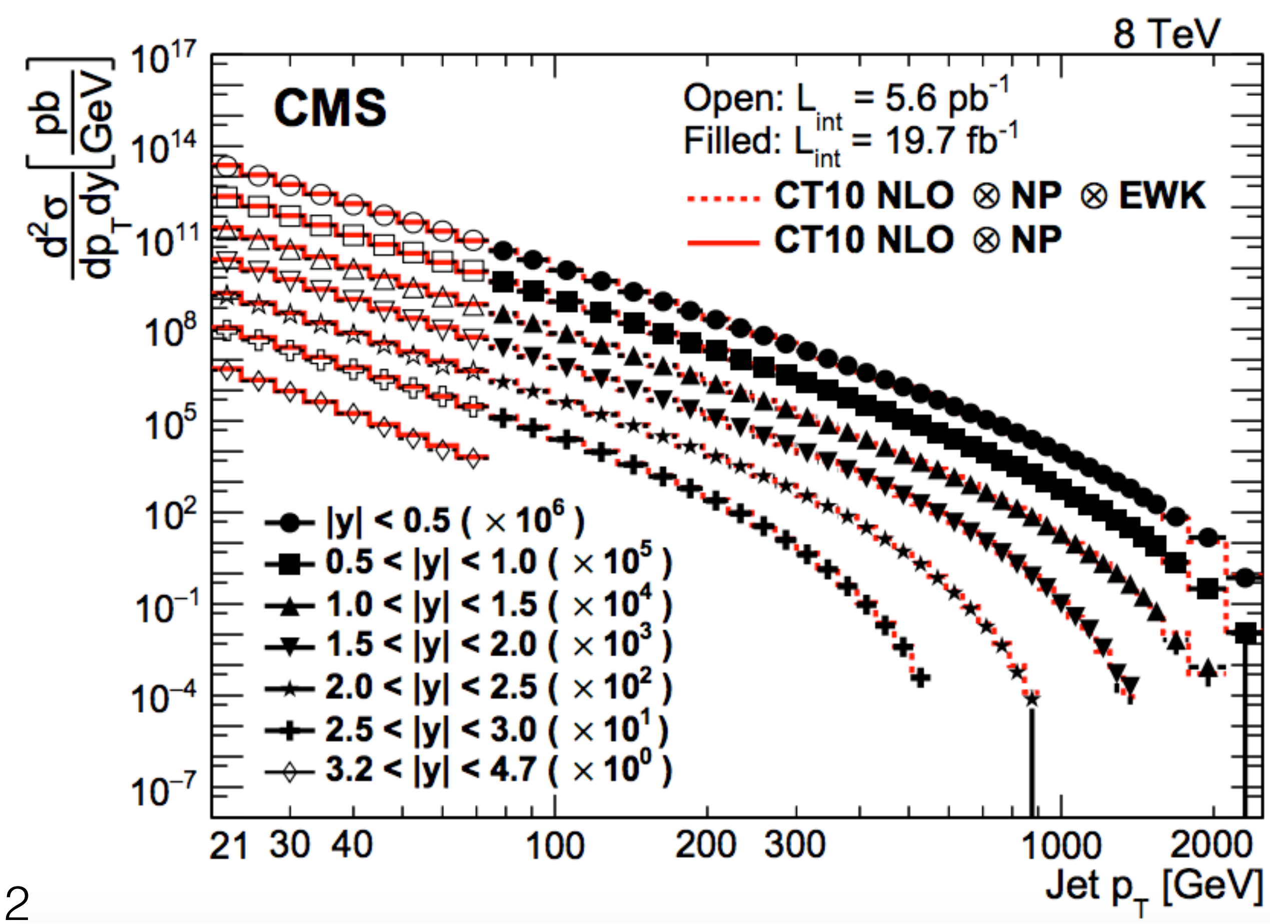


- anti-k_T jet definition: infrared and collinear safe used in experimental analysis and theory predictions

- numerous measurements by ATLAS and CMS:

$$\frac{d\sigma}{dp_T dy} = \frac{1}{\mathcal{L}} \frac{N_{jets}}{\Delta p_T \Delta y} \propto \alpha_s^2$$





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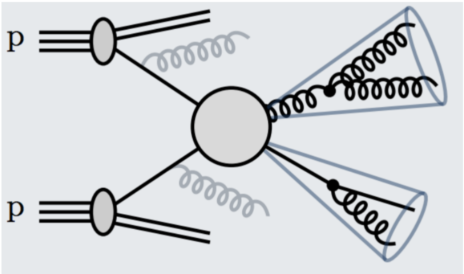
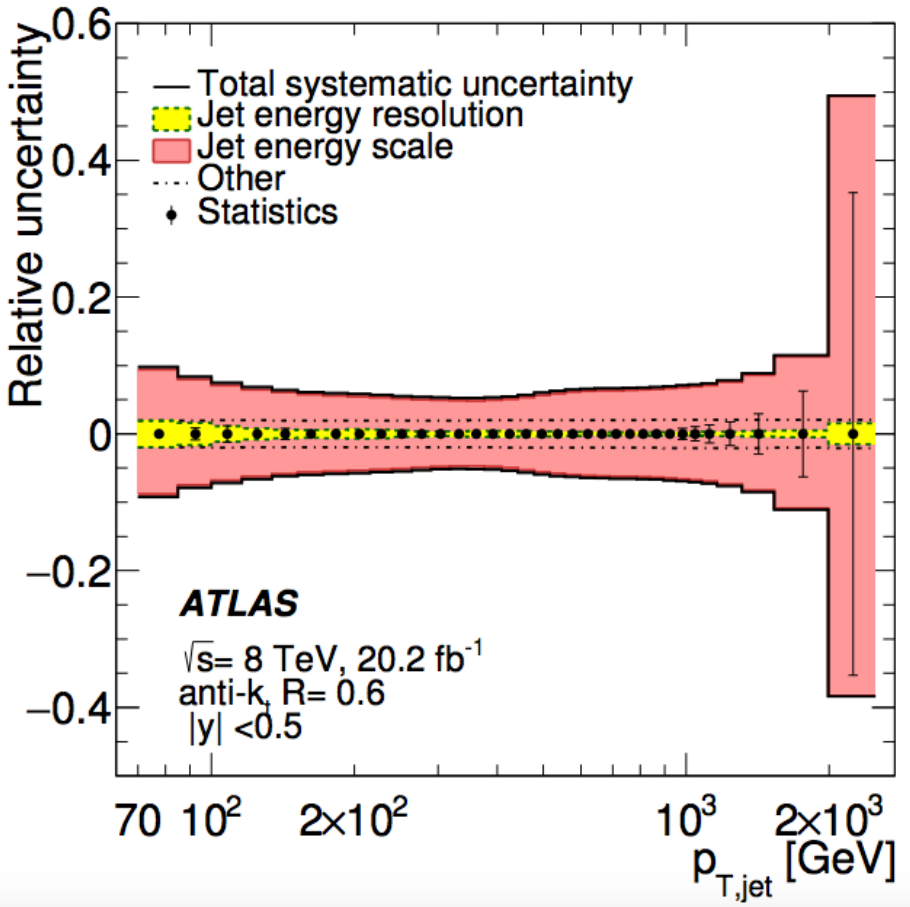
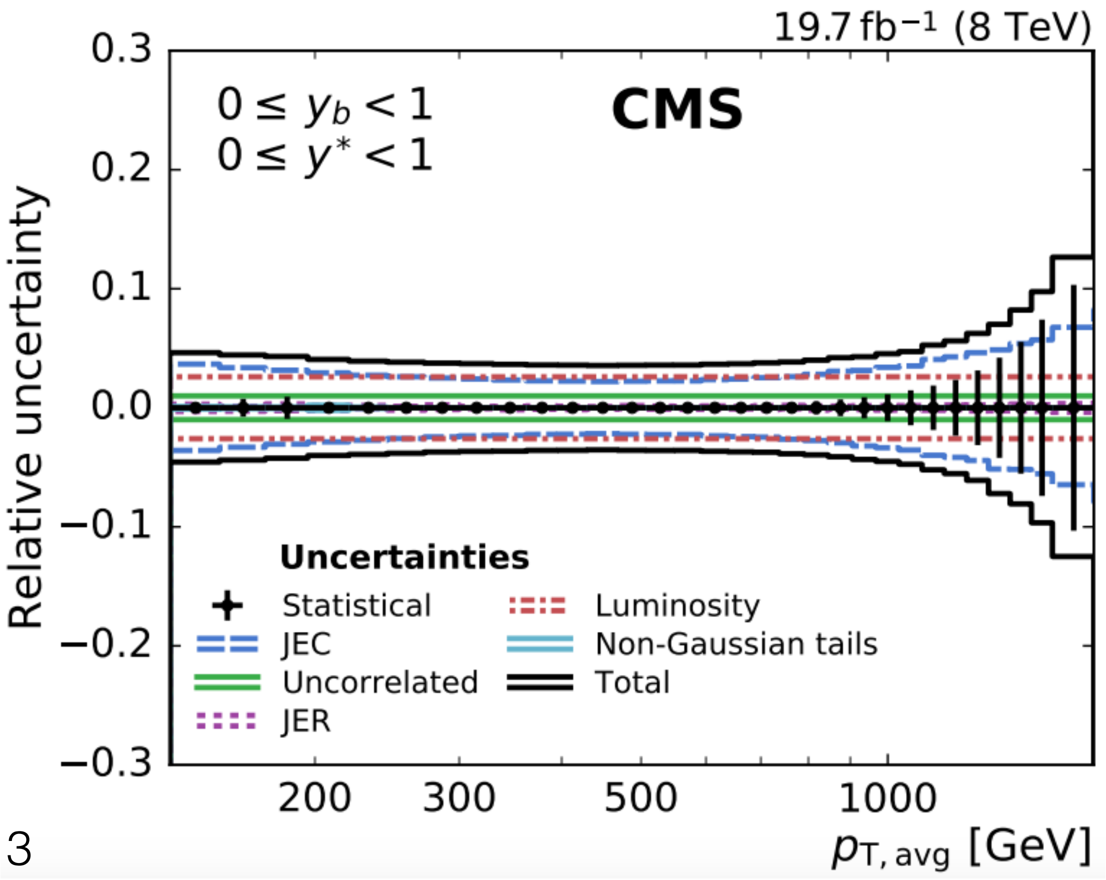


- inclusive jet cross section → dominant hard process at the LHC
- anti-k_T jet definition: infrared and collinear safe used in experimental analysis and theory predictions
- numerous measurements by ATLAS and CMS: δ_{sys}~5% in a wide range and δ_{stat}~sub-%
- *opens the path for hadron collider precision jet phenomenology*





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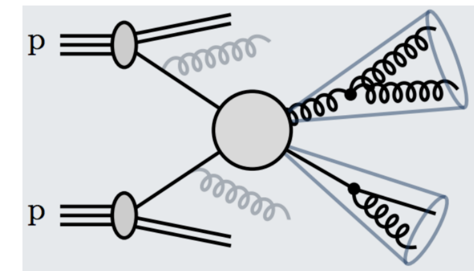

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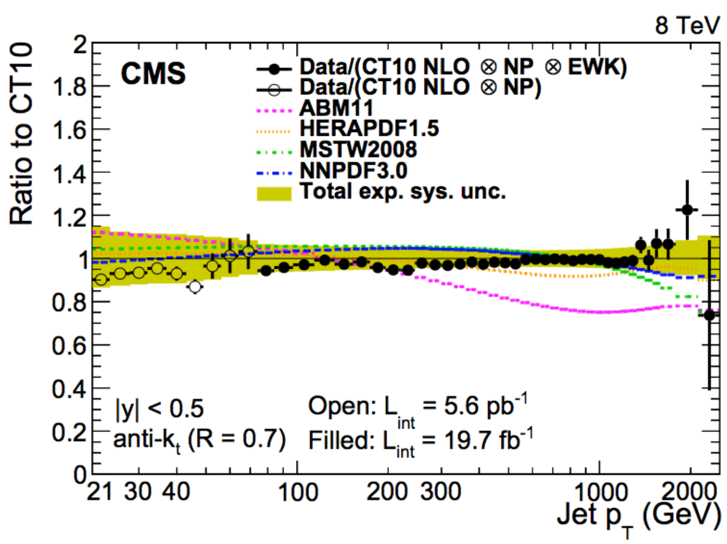
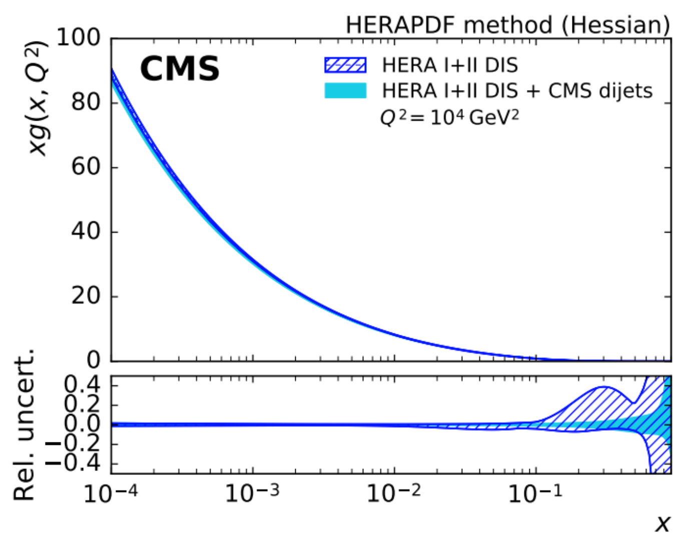
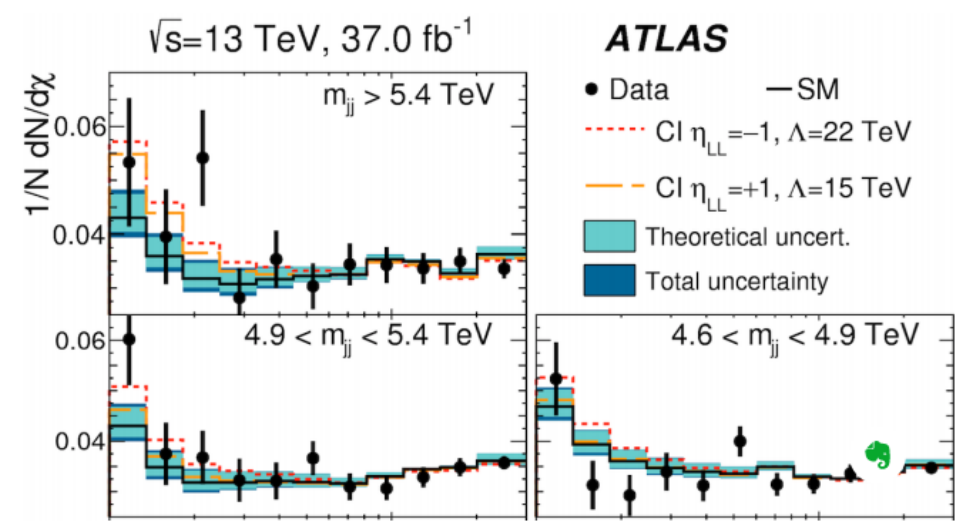


testing ground for perturbative QCD



constrain and determine PDFs



explore sensitivity to new physics

Plan

- Jet production theoretical status
- Triple differential dijet cross section at the LHC
  NNLO (QCD) + NLO (EW)
  [Gehrmann-De Ridder, Gehrmann, Glover, Huss, JP]
  [arXiv: 1905.09047] Phys. Rev. Lett. 123, 102001 (2019)
- Impact of LHC Run-I 7 & 8 TeV jet data on PDFs at NNLO
  [Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***
- Conclusions and outlook

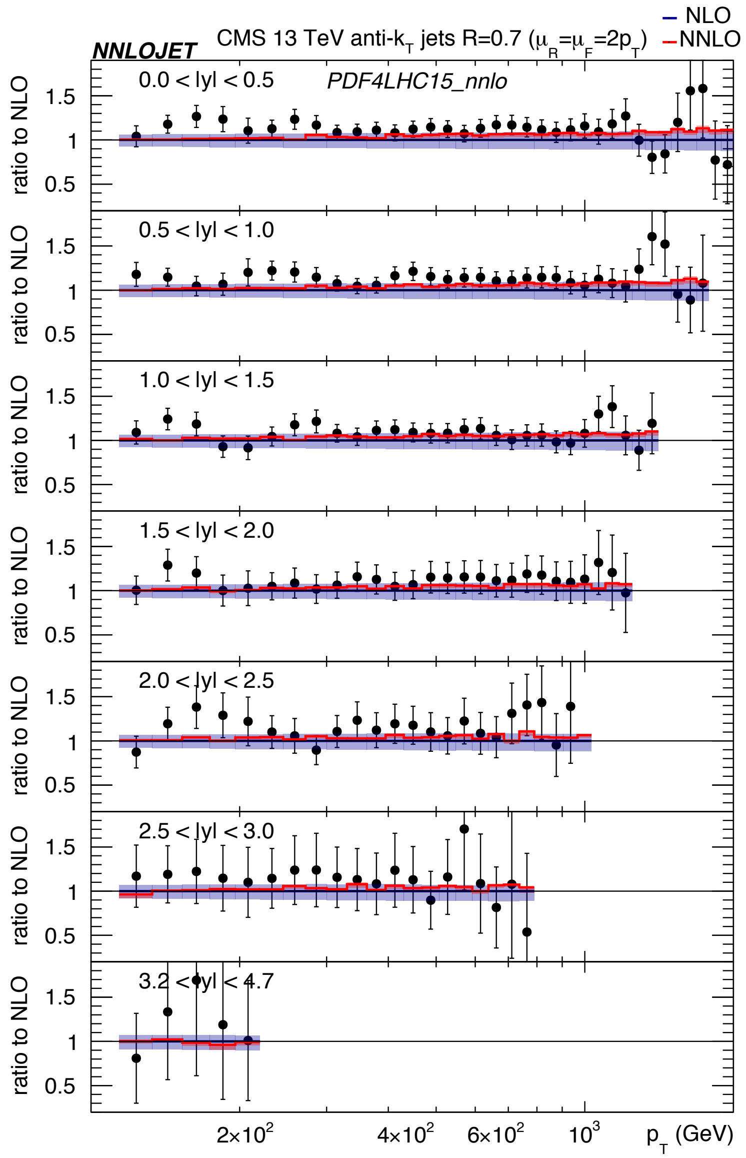
Singe jet inclusive cross section: theory status

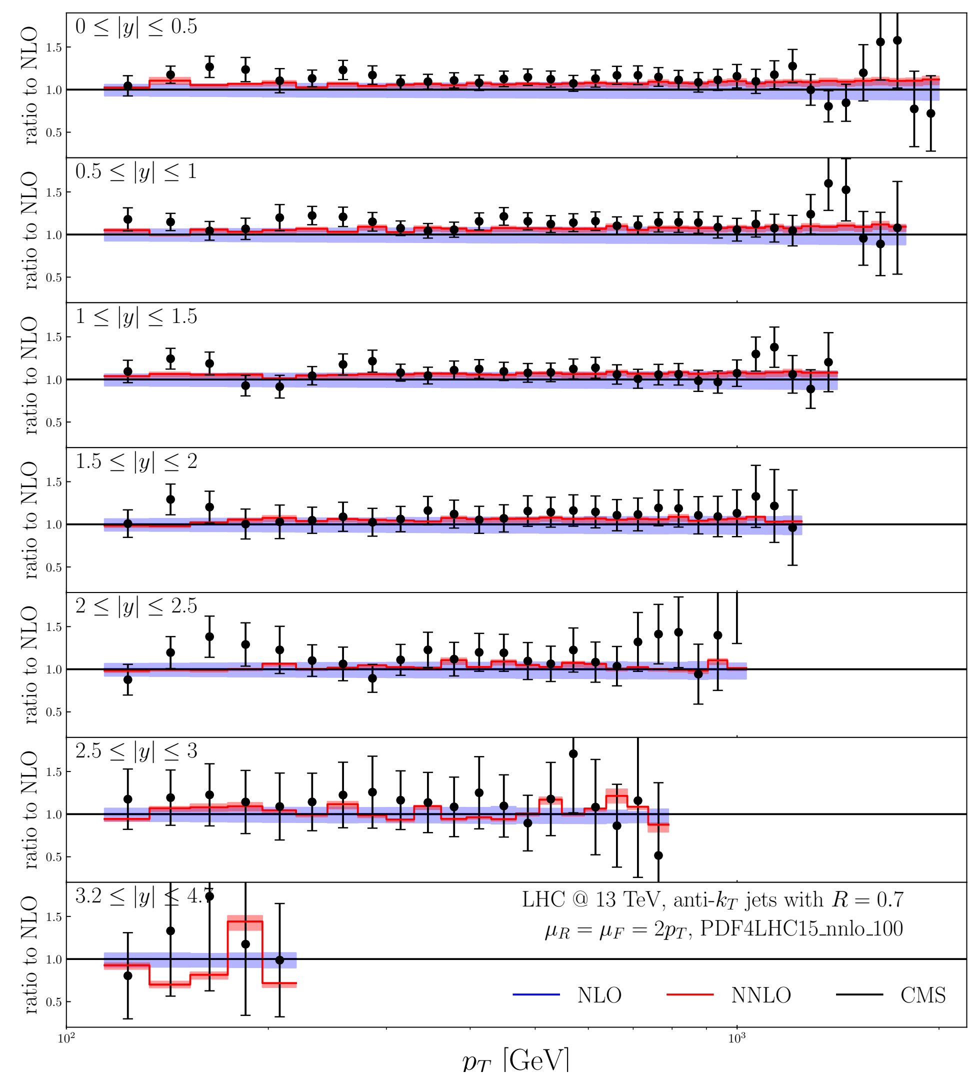
- Much progress in fixed-order calculations/resummation and parton shower predictions
  - NLO QCD [Ellis, Kunszt, Soper '92][Giele, Glover, Kosower '94] [Nagy 02]
  - NLO QCD + PS [Alioli, Hamilton, Nason, Oleari, Re '11] [Hoeche, Schonherr '12] [Herwig7 '15]
    - POWHEG, SHERPA, HERWIG
  - NLO QCD + Resummation (threshold+jet radius) [Dasgupta, Dreyer, Salam, Soyez '14] [Liu, Moch, Ringer '17]
  - NLO EW [Dittmaier, Huss, Speckner '13] [Campbell, Wackeroth, Zhou '16]
  - NLO QCD+EW [Frederix, Frixione, Hirschi, Pagani, Shao, Zaro '17
  - NNLO QCD [Gehrmann-De Ridder, Gehrmann, Glover, JP '13] [Currie, Glover, JP '16] [Currie, Gehrmann-De Ridder, Gehrmann, Glover, Huss, JP '17] [Czakon, van Hameren, Mitov, Poncelet '19]

Theoretical predictions at NNLO

- Perturbative QCD predictions for single jet inclusive production at the LHC
  - NNLO calculation with NNLOJET:
    J.Currie et al. Phys. Rev. Lett. 118 (2017) 072002
  - NNLO calculation with Sector Improved Phase Space for Real Radiation:
    M.Czakon et al. JHEP 10 (2019) 262

[arXiv:1807.03692]



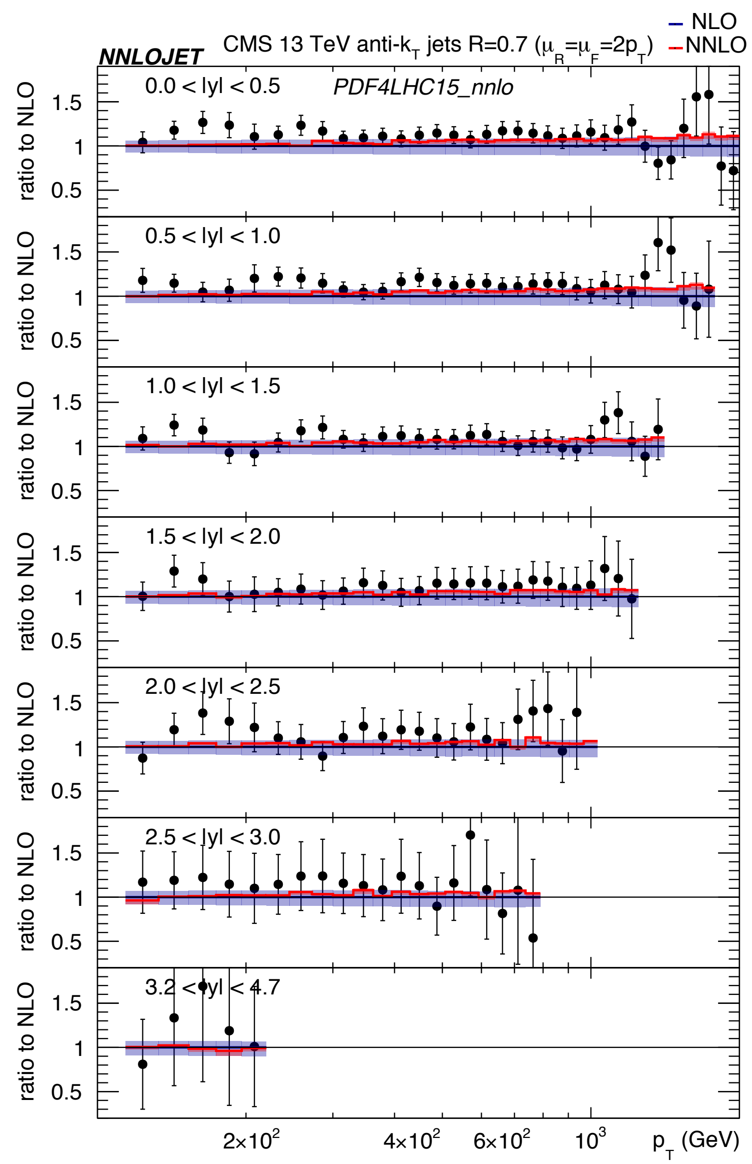


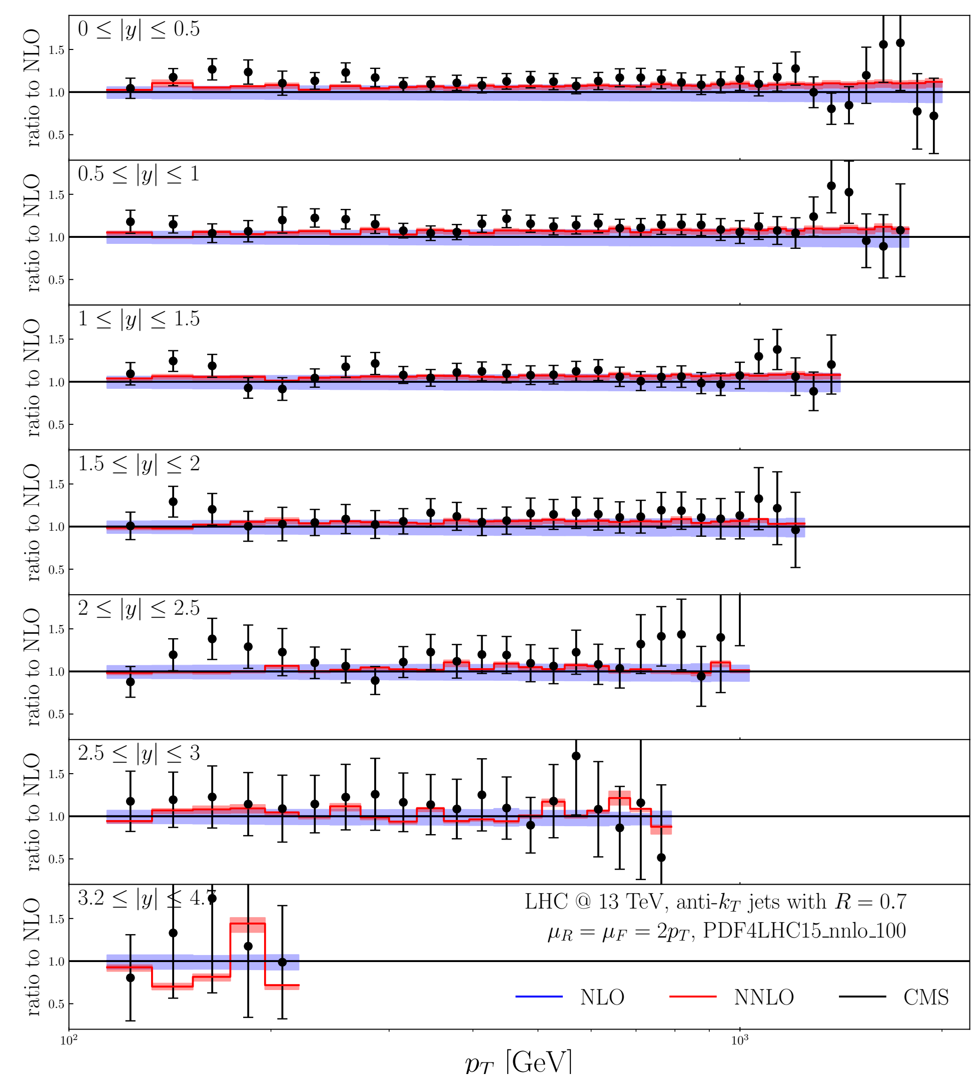
[arXiv:1907.12911]

Theoretical predictions at NNLO

- Perturbative QCD predictions for single jet inclusive production at the LHC
  - Full agreement between two independent calculations using different IR subtraction schemes
  - Sub-leading color effects negligible

[arXiv:1807.03692]

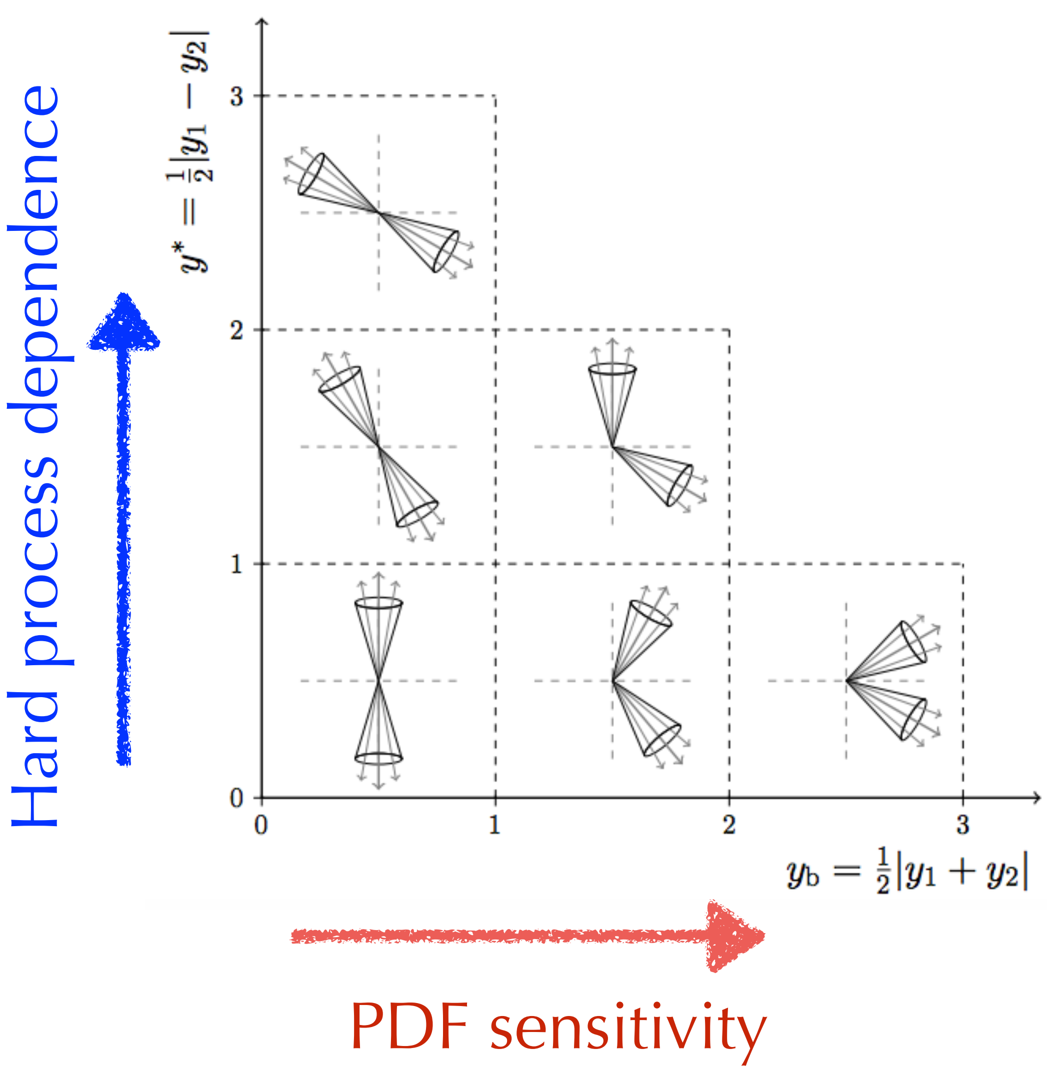




[arXiv:1907.12911]

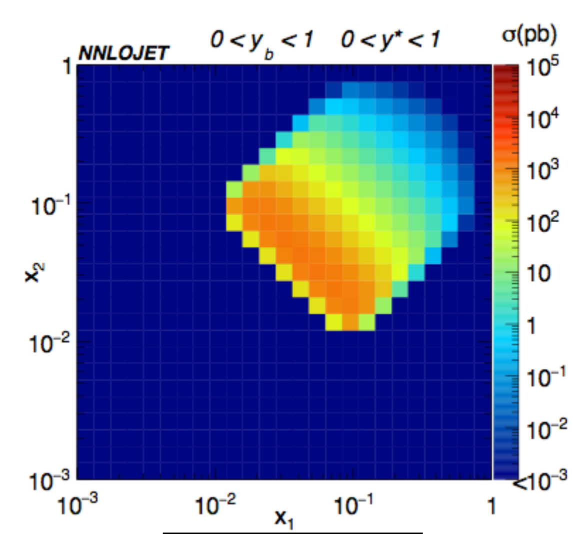
Triple differential dijet cross section

- Dijet cross section: *pp→2jets+X*
  - Measured triple differentially by CMS at 8 TeV [arXiv:1705.02628] as a function of
    - Average p_T $\quad p_{T,\mathrm{avg}} = (p_{T,1} + p_{T,2})/2$
    - Rapidity separation $\quad y^* = |y_1 - y_2|/2$
    - Boost of the dijet system $\quad y_b = |y_1 + y_2|/2$
  - y_b cut probes parton distribution functions at symmetric and asymmetric x_1, x_2 values

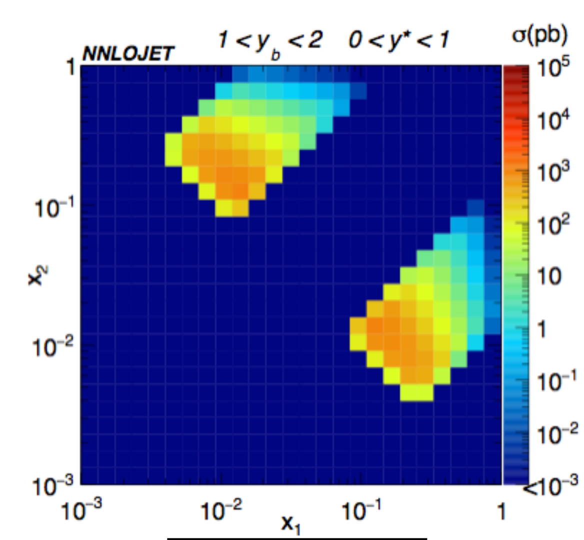


$$x_1 = \frac{p_T}{\sqrt{s}}\left(e^{y_1} + e^{y_2}\right) = \frac{2\,p_{T,\mathrm{avg}}}{\sqrt{s}}\, e^{\pm y_b} \cosh(y^*),$$

$$x_2 = \frac{p_T}{\sqrt{s}}\left(e^{-y_1} + e^{-y_2}\right) = \frac{2\,p_{T,\mathrm{avg}}}{\sqrt{s}}\, e^{\mp y_b} \cosh(y^*). \quad (1)$$

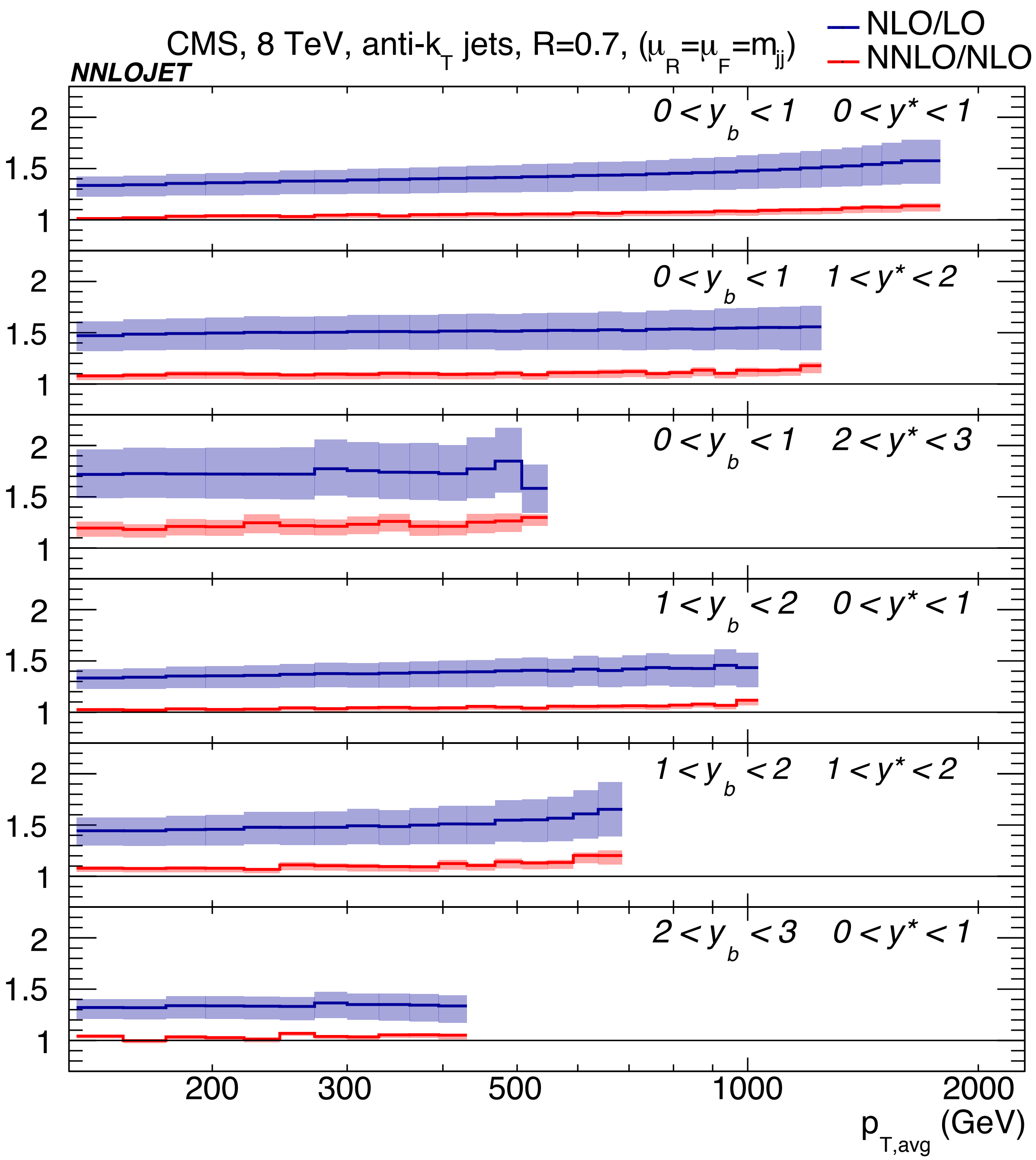


0<y*<1
0<y_b<1



0<y*<1
1<y_b<2

Triple differential dijet cross section



Gehrmann-De Ridder, Gehrmann, Glover, Huss, JP
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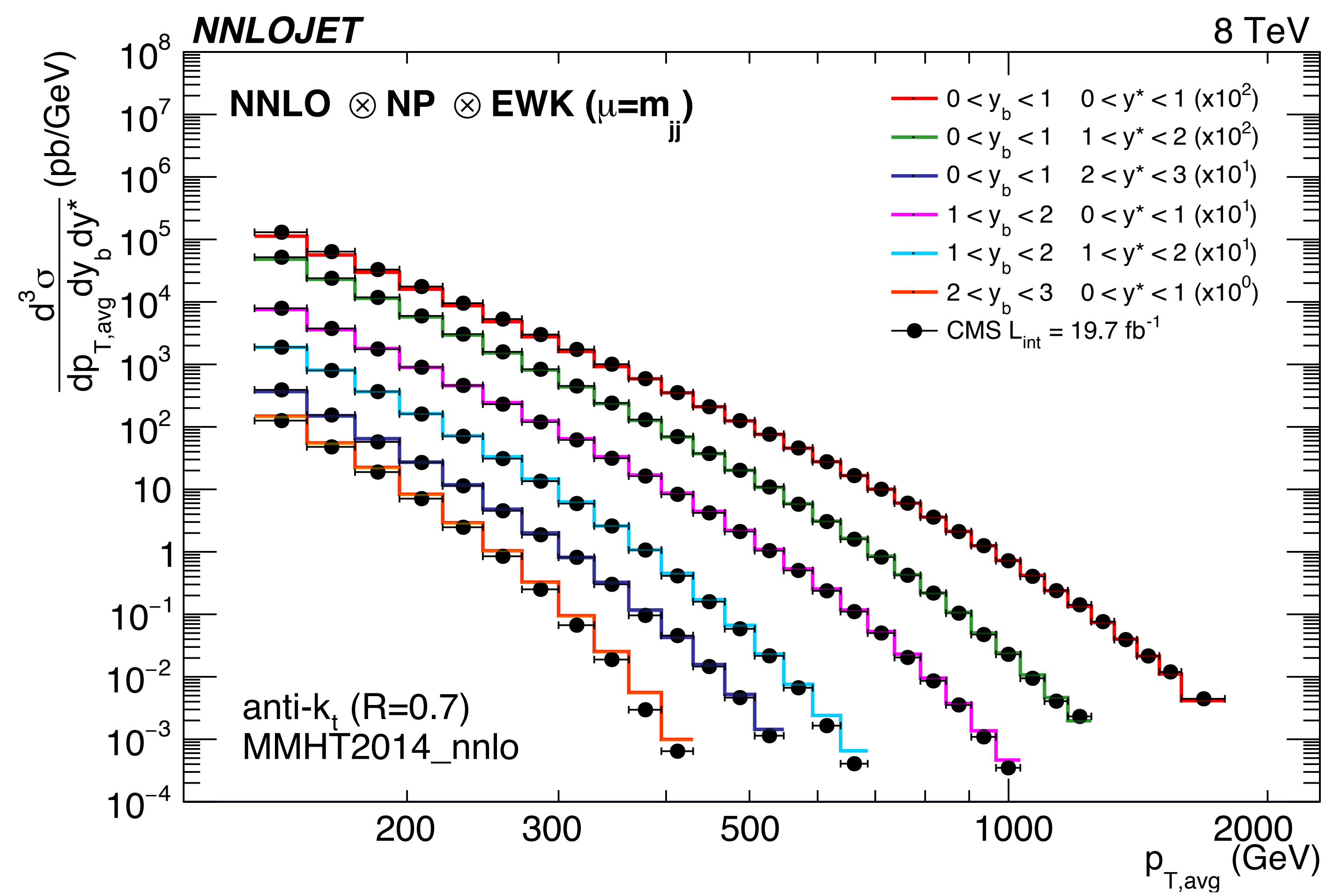
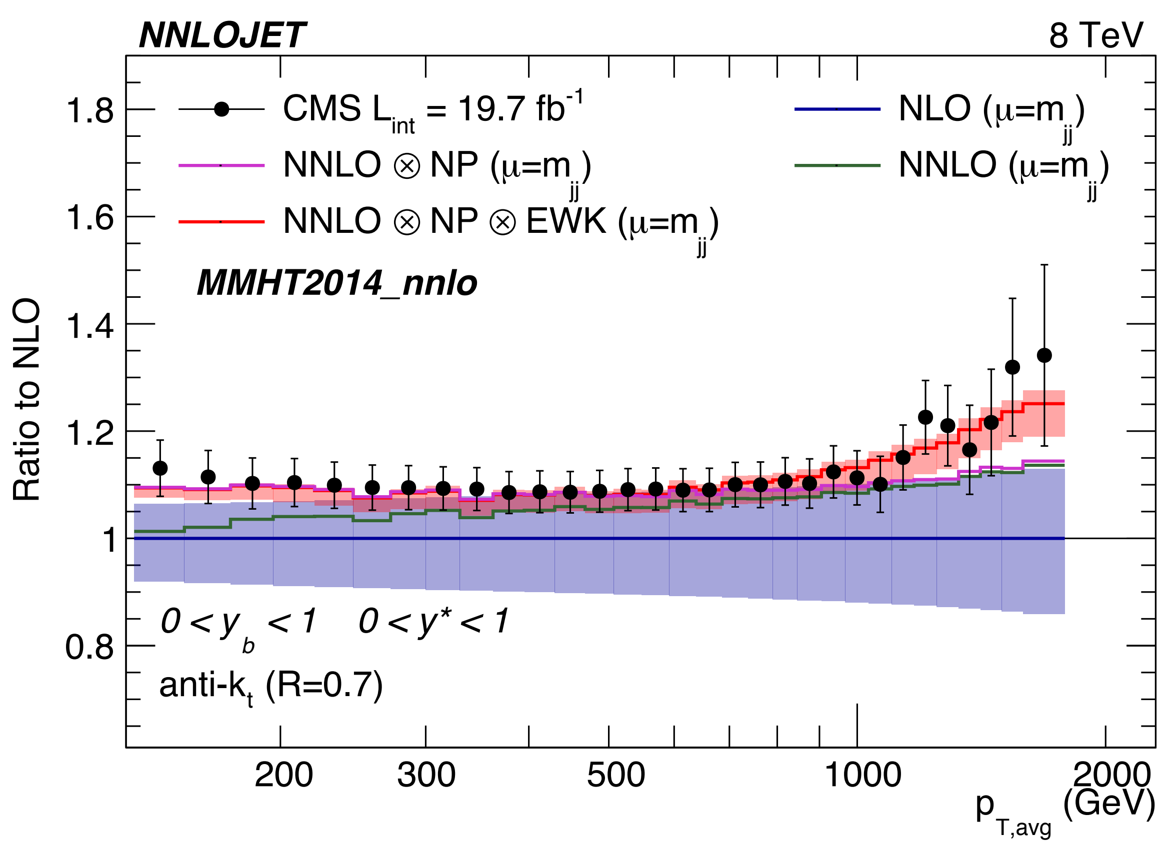
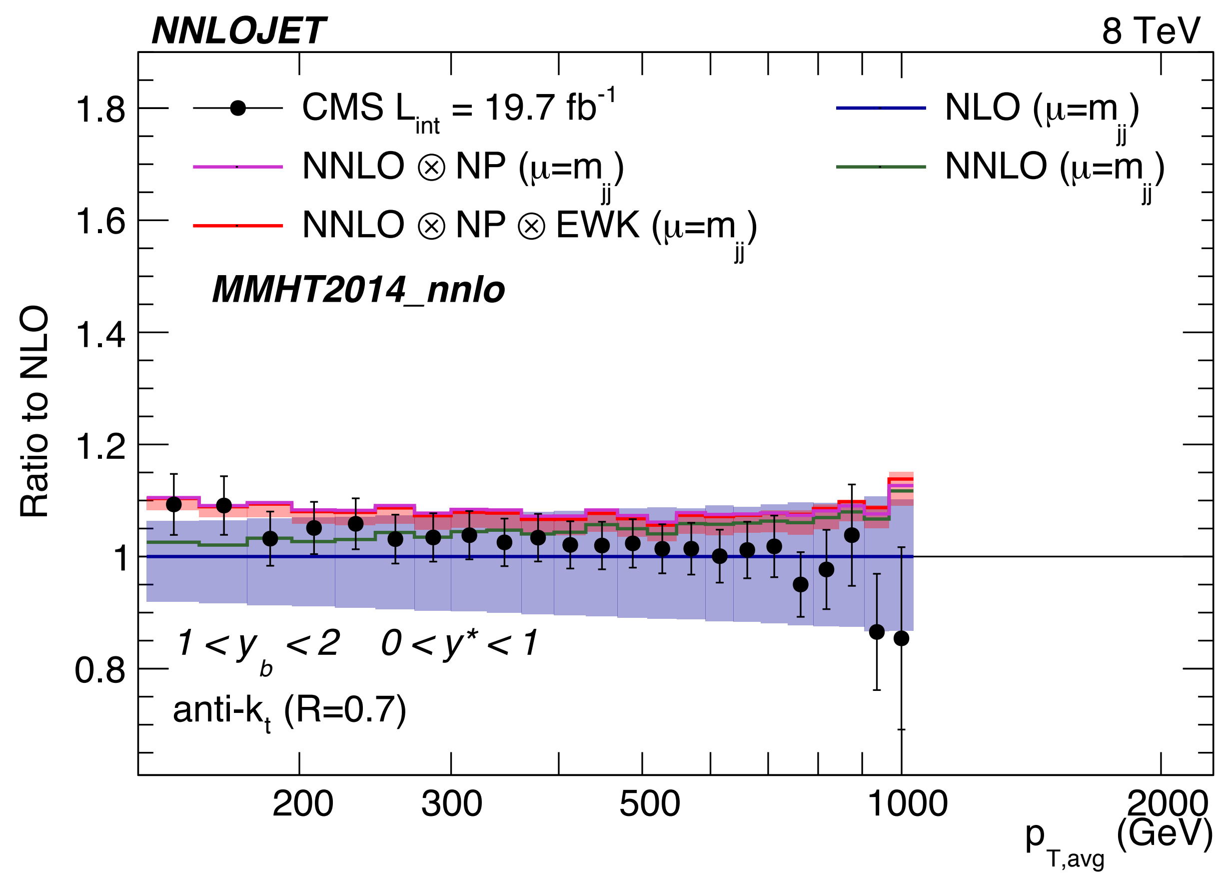


- size of the corrections varies significantly as a function of $p_{T,avg}$ and the applied cuts on y^* and y_b
- NNLO correction changes both the shape and normalisation of the NLO result
- QCD scale choice $\mu_R = \mu_F = m_{jj}$

Triple differential dijet cross section





- comparison with triple differential CMS dijet 8 TeV measurement [arXiv:1705.02628]
  - NNLO+electroweak+hadronization — *Gehrmann-De Ridder, Gehrmann, Glover, Huss, JP* ***[arXiv: 1905.09047] Phys. Rev. Lett. 123, 102001 (2019)***
  - $0 < y_b < 1$: good agreement with NNLO⊗NP⊗EWK
  - $1 < y_b < 2$: data below NNLO theory prediction
  - PDF effect since matrix element contribution invariant under y_b variation

Impact of LHC Run-I 7 & 8 TeV jet data on PDFs at NNLO

- In the context of a global PDF determination with NNPDF, study:
  - effect of adding jet cross section data to the global baseline NNPDF3.1 set
  - separately the impact of the single-inclusive jets or dijets observables on the PDFs
  - for each observable assess fit quality and compatibility with other data
  - determine optimal choice of jet observable for future global PDF fits

Experiment	Measurement	$\sqrt{s}$ [TeV]	$\mathcal{L}$ [fb^{-1}]	R	Distribution	$n_{\rm dat}$
ATLAS	Inclusive jets	7	4.5	0.6	$d^2\sigma/dp_T d\|y\|$	140
CMS	Inclusive jets	7	4.5	0.7	$d^2\sigma/dp_T d\|y\|$	133
ATLAS	Inclusive jets	8	20.2	0.6	$d^2\sigma/dp_T d\|y\|$	171
CMS	Inclusive jets	8	19.7	0.7	$d^2\sigma/dp_T d\|y\|$	185
ATLAS	Dijets	7	4.5	0.6	$d^2\sigma/dm_{jj} d\|y^*\|$	90
CMS	Dijets	7	4.5	0.7	$d^2\sigma/dm_{jj} d\|y_{\rm max}\|$	54
CMS	Dijets	8	19.7	0.7	$d^3\sigma/dp_{T,\rm avg} dy_b dy^*$	122

- Summary of full LHC Run-I jet experimental data included in the global study for proton PDF determination at NNLO

Impact of LHC Run-I 7 & 8 TeV jet data on PDFs at NNLO

- Theory calculations included in the PDF fits at NNLO in QCD and NLO in EW

$$\left.\frac{d^2\sigma}{dp_T dy}\right|_{\mathrm{NNLO}_{\mathrm{QCD}}+\mathrm{EW}} = \underbrace{\left.\frac{d^2\sigma}{dp_T dy}\right|_{\mathrm{NLO}_{\mathrm{QCD}}}}_{\text{fastNLO grid}} \times \underbrace{K^{\mathrm{QCD}}_{\mathrm{NNLO}}(p_T, y, \sqrt{s})}_{\text{NNLO k-factors}} \times \underbrace{K^{\mathrm{EW}}(p_T, y, \sqrt{s})}_{\text{EW k-factor}}$$

- fastNLO grids reweighted bin by bin for each experimental setup with
  - NNLO QCD k-factors calculated with NNLOJET *Gehrmann-De Ridder, Gehrmann, Glover, Huss, JP* ***[arXiv: 1905.09047] Phys. Rev. Lett. 123, 102001 (2019)***
  - NLO EW k-factors *Dittmaier, Huss, Speckner* ***[arXiv:1210.0438] JHEP 11 (2012) 095***
- renormalization and factorisation scale choices
  - single jet inclusive cross section $\mu = \hat{H}_T$
  - dijet inclusive cross section $\mu = m_{jj}$
- non-perturbative corrections applied to the data with fully correlated systematic uncertainty as determined by the experimental collaborations
- fit methodology follows the NNPDF3.1 global analysis

PDF fits with single-inclusive jet data at NNLO

χ^2 per data point for all fits

Dataset	$n_{\rm dat}$	b	bn	janw	j7	j7n	j7nw	j8	j8n	j8nw
DIS NC	2103	1.17	1.17	1.18	1.17	1.18	1.17	1.17	1.17	1.18
DIS CC	989	1.06	1.10	1.11	1.06	1.11	1.10	1.08	1.11	1.11
Drell-Yan	577	1.35	1.33	1.30	1.35	1.31	1.31	1.34	1.31	1.31
Z p_T	120	1.84	1.01	1.02	1.85	1.02	1.02	1.89	1.03	1.03
Top pair	24	1.10	1.05	1.25	1.09	1.06	1.02	2.00	1.61	1.24
ATLAS $\sigma_{t\bar{t}}$	3	2.02	0.90	0.70	1.68	0.74	0.72	1.70	0.79	0.78
ATLAS $t\bar{t}$ rap	9	1.12	1.22	2.01	1.25	1.38	1.31	2.93	2.78	1.96
CMS $\sigma_{t\bar{t}}$	3	0.53	0.22	0.21	0.42	0.24	0.31	0.34	0.17	0.19
CMS $t\bar{t}$ rap	9	0.98	1.17	0.98	0.96	1.09	1.04	1.65	1.12	0.99
Jets (all)	520	[1.48]	[2.60]	1.88	[1.86]	[2.45]	[2.53]	[1.20]	[1.75]	[1.89]
Jets (fitted)		—	—	1.88	0.79	1.15	1.12	1.40	2.05	2.20
ATLAS 7 TeV	31	[1.26]	[1.87]	1.59	1.12	1.73	1.15	[1.07]	[1.69]	[1.62]
ATLAS 8 TeV	171	[2.60]	[5.01]	3.22	[3.55]	[4.76]	[4.58]	2.03	3.18	3.25
CMS 7 TeV	133	[0.60]	[1.06]	1.09	0.71	1.01	1.11	[0.72]	[0.94]	[1.14]
CMS 8 TeV	185	[1.10]	[1.59]	1.25	[1.24]	[1.47]	[1.80]	0.81	1.01	1.23
Dijets (all)	266	[3.49]	[3.07]	[2.10]	[4.16]	[2.96]	[2.56]	[3.34]	[2.21]	[2.22]
Dijets (fitted)		—	—	—	—	—	—	—	—	—
ATLAS 7 TeV	90	[1.49]	[2.47]	[1.95]	[1.77]	[2.46]	[1.97]	[1.43]	[2.28]	[2.01]
CMS 7 TeV	54	[2.06]	[2.40]	[2.08]	[2.43]	[2.50]	[2.12]	[1.65]	[2.00]	[2.15]
CMS 8 TeV	122	[5.60]	[3.81]	[2.21]	[6.70]	[3.53]	[3.20]	[5.48]	[2.26]	[2.39]
Total		1.20	1.18	1.28	1.17	1.17	1.17	1.39	1.27	1.27

[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

- χ^2 values for data not included in fits enclosed in square brackets
- ***bn* fit**: baseline PDF fit at NNLO
- ***jawn* fit**: includes all 7 & 8 TeV single-inclusive jet data at NNLO QCD + NLO EW
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- individual single-inclusive jet data sets well described $\chi^2 \approx 1$, except 8 TeV ATLAS data (χ^2 =3.22)

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Dijets (fitted)		—	—	—	—	—	—	—	—	—
ATLAS 7 TeV	90	[1.49]	[2.47]	[1.95]	[1.77]	[2.46]	[1.97]	[1.43]	[2.28]	[2.01]
CMS 7 TeV	54	[2.06]	[2.40]	[2.08]	[2.43]	[2.50]	[2.12]	[1.65]	[2.00]	[2.15]
CMS 8 TeV	122	[5.60]	[3.81]	[2.21]	[6.70]	[3.53]	[3.20]	[5.48]	[2.26]	[2.39]
Total		1.20	1.18	1.28	1.17	1.17	1.17	1.39	1.27	1.27

[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

- χ^2 values for data not included in fits enclosed in square brackets
- ***bn*** **fit**: baseline PDF fit at NNLO
- ***jawn*** **fit**: includes all 7 & 8 TeV single-inclusive jet data at NNLO QCD + NLO EW
- ***j7nw & j8nw*** **fits**: same perturbative accuracy as *jawn* fit but 7 & 8 TeV single-inclusive jet data fitted separately

- individual single-inclusive jet data sets well described $\chi^2 \approx 1$, except 8 TeV ATLAS data (χ^2 =3.22)
- improved description of the dijet data not included in the fit

PDF fits with single-inclusive jet data at NNLO

χ^2 *per data point for all fits*

Dataset	n_{dat}	b	bn	janw	j7	j7n	j7nw	j8	j8n	j8nw
DIS NC	2103	1.17	1.17	1.18	1.17	1.18	1.17	1.17	1.17	1.18
DIS CC	989	1.06	1.10	1.11	1.06	1.11	1.10	1.08	1.11	1.11
Drell-Yan	577	1.35	1.33	1.30	1.35	1.31	1.31	1.34	1.31	1.31
$Z\ p_T$	120	1.84	1.01	1.02	1.85	1.02	1.02	1.89	1.03	1.03
Top pair	24	1.10	1.05	1.25	1.09	1.06	1.02	2.00	1.61	1.24
ATLAS $\sigma_{t\bar{t}}$	3	2.02	0.90	0.70	1.68	0.74	0.72	1.70	0.79	0.78
ATLAS $t\bar{t}$ rap	9	1.12	1.22	2.01	1.25	1.38	1.31	2.93	2.78	1.96
CMS $\sigma_{t\bar{t}}$	3	0.53	0.22	0.21	0.42	0.24	0.31	0.34	0.17	0.19
CMS $t\bar{t}$ rap	9	0.98	1.17	0.98	0.96	1.09	1.04	1.65	1.12	0.99
Jets (all)	520	[1.48]	[2.60]	1.88	[1.86]	[2.45]	[2.53]	[1.20]	[1.75]	[1.89]
Jets (fitted)		—	—	1.88	0.79	1.15	1.12	1.40	2.05	2.20
ATLAS 7 TeV	31	[1.26]	[1.87]	1.59	1.12	1.73	1.15	[1.07]	[1.69]	[1.62]
ATLAS 8 TeV	171	[2.60]	[5.01]	3.22	[3.55]	[4.76]	[4.58]	2.03	3.18	3.25
CMS 7 TeV	133	[0.60]	[1.06]	1.09	0.71	1.01	1.11	[0.72]	[0.94]	[1.14]
CMS 8 TeV	185	[1.10]	[1.59]	1.25	[1.24]	[1.47]	[1.80]	0.81	1.01	1.23
Dijets (all)	266	[3.49]	[3.07]	[2.10]	[4.16]	[2.96]	[2.56]	[3.34]	[2.21]	[2.22]
Dijets (fitted)		—	—	—	—	—	—	—	—	—
ATLAS 7 TeV	90	[1.49]	[2.47]	[1.95]	[1.77]	[2.46]	[1.97]	[1.43]	[2.28]	[2.01]
CMS 7 TeV	54	[2.06]	[2.40]	[2.08]	[2.43]	[2.50]	[2.12]	[1.65]	[2.00]	[2.15]
CMS 8 TeV	122	[5.60]	[3.81]	[2.21]	[6.70]	[3.53]	[3.20]	[5.48]	[2.26]	[2.39]
Total		1.20	1.18	1.28	1.17	1.17	1.17	1.39	1.27	1.27

[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

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- individual single-inclusive jet data sets well described $\chi^2 \approx 1$, except 8 TeV ATLAS data (χ^2 =3.22)
- improved description of the dijet data not included in the fit

⇒ inclusion of single jet or dijet data points to a similar impact on the PDFs

PDF fits with single-inclusive jet data at NNLO

χ^2 *per data point for all fits*

Dataset	n_{dat}	b	bn	janw	j7	j7n	j7nw	j8	j8n	j8nw
DIS NC	2103	1.17	1.17	1.18	1.17	1.18	1.17	1.17	1.17	1.18
DIS CC	989	1.06	1.10	1.11	1.06	1.11	1.10	1.08	1.11	1.11
Drell-Yan	577	1.35	1.33	1.30	1.35	1.31	1.31	1.34	1.31	1.31
$Z\ p_T$	120	1.84	1.01	1.02	1.85	1.02	1.02	1.89	1.03	1.03
Top pair	24	1.10	1.05	1.25	1.09	1.06	1.02	2.00	1.61	1.24
ATLAS $\sigma_{t\bar{t}}$	3	2.02	0.90	0.70	1.68	0.74	0.72	1.70	0.79	0.78
ATLAS $t\bar{t}$ rap	9	1.12	1.22	2.01	1.25	1.38	1.31	2.93	2.78	1.96
CMS $\sigma_{t\bar{t}}$	3	0.53	0.22	0.21	0.42	0.24	0.31	0.34	0.17	0.19
CMS $t\bar{t}$ rap	9	0.98	1.17	0.98	0.96	1.09	1.04	1.65	1.12	0.99
Jets (all)	520	[1.48]	[2.60]	1.88	[1.86]	[2.45]	[2.53]	[1.20]	[1.75]	[1.89]
Jets (fitted)		—	—	1.88	0.79	1.15	1.12	1.40	2.05	2.20
ATLAS 7 TeV	31	[1.26]	[1.87]	1.59	1.12	1.73	1.15	[1.07]	[1.69]	[1.62]
ATLAS 8 TeV	171	[2.60]	[5.01]	3.22	[3.55]	[4.76]	[4.58]	2.03	3.18	3.25
CMS 7 TeV	133	[0.60]	[1.06]	1.09	0.71	1.01	1.11	[0.72]	[0.94]	[1.14]
CMS 8 TeV	185	[1.10]	[1.59]	1.25	[1.24]	[1.47]	[1.80]	0.81	1.01	1.23
Dijets (all)	266	[3.49]	[3.07]	[2.10]	[4.16]	[2.96]	[2.56]	[3.34]	[2.21]	[2.22]
Dijets (fitted)		—	—	—	—	—	—	—	—	—
ATLAS 7 TeV	90	[1.49]	[2.47]	[1.95]	[1.77]	[2.46]	[1.97]	[1.43]	[2.28]	[2.01]
CMS 7 TeV	54	[2.06]	[2.40]	[2.08]	[2.43]	[2.50]	[2.12]	[1.65]	[2.00]	[2.15]
CMS 8 TeV	122	[5.60]	[3.81]	[2.21]	[6.70]	[3.53]	[3.20]	[5.48]	[2.26]	[2.39]
Total		1.20	1.18	1.28	1.17	1.17	1.17	1.39	1.27	1.27

[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

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- ***j7nw & j8nw*** **fits**: same perturbative accuracy as *jawn* fit but 7 & 8 TeV single-inclusive jet data fitted separately

- observe slight deterioration in the description of the ATLAS top pair rapidity χ^2(bn) 1.22→2.01

PDF fits with single-inclusive jet data at NNLO

χ^2 per data point for all fits

Dataset	n_{dat}	b	bn	janw	j7	j7n	j7nw	j8	j8n	j8nw
DIS NC	2103	1.17	1.17	1.18	1.17	1.18	1.17	1.17	1.17	1.18
DIS CC	989	1.06	1.10	1.11	1.06	1.11	1.10	1.08	1.11	1.11
Drell-Yan	577	1.35	1.33	1.30	1.35	1.31	1.31	1.34	1.31	1.31
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Jets (all)	520	[1.48]	[2.60]	1.88	[1.86]	[2.45]	[2.53]	[1.20]	[1.75]	[1.89]
Jets (fitted)		—	—	1.88	0.79	1.15	1.12	1.40	2.05	2.20
ATLAS 7 TeV	31	[1.26]	[1.87]	1.59	1.12	1.73	1.15	[1.07]	[1.69]	[1.62]
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Dijets (all)	266	[3.49]	[3.07]	[2.10]	[4.16]	[2.96]	[2.56]	[3.34]	[2.21]	[2.22]
Dijets (fitted)		—	—	—	—	—	—	—	—	—
ATLAS 7 TeV	90	[1.49]	[2.47]	[1.95]	[1.77]	[2.46]	[1.97]	[1.43]	[2.28]	[2.01]
CMS 7 TeV	54	[2.06]	[2.40]	[2.08]	[2.43]	[2.50]	[2.12]	[1.65]	[2.00]	[2.15]
CMS 8 TeV	122	[5.60]	[3.81]	[2.21]	[6.70]	[3.53]	[3.20]	[5.48]	[2.26]	[2.39]
Total		1.20	1.18	1.28	1.17	1.17	1.17	1.39	1.27	1.27

[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

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- effect seems to be driven when adding the 8 TeV ATLAS jet data to the global dataset

PDF fits with single-inclusive jet data at NNLO

χ^2 per data point for all fits

Dataset	n_{dat}	b	bn	janw	j7	j7n	j7nw	j8	j8n	j8nw
DIS NC	2103	1.17	1.17	1.18	1.17	1.18	1.17	1.17	1.17	1.18
DIS CC	989	1.06	1.10	1.11	1.06	1.11	1.10	1.08	1.11	1.11
Drell-Yan	577	1.35	1.33	1.30	1.35	1.31	1.31	1.34	1.31	1.31
Z p_T	120	1.84	1.01	1.02	1.85	1.02	1.02	1.89	1.03	1.03
Top pair	24	1.10	1.05	1.25	1.09	1.06	1.02	2.00	1.61	1.24
ATLAS $\sigma_{t\bar{t}}$	3	2.02	0.90	0.70	1.68	0.74	0.72	1.70	0.79	0.78
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Jets (all)	520	[1.48]	[2.60]	1.88	[1.86]	[2.45]	[2.53]	[1.20]	[1.75]	[1.89]
Jets (fitted)		—	—	1.88	0.79	1.15	1.12	1.40	2.05	2.20
ATLAS 7 TeV	31	[1.26]	[1.87]	1.59	1.12	1.73	1.15	[1.07]	[1.69]	[1.62]
ATLAS 8 TeV	171	[2.60]	[5.01]	3.22	[3.55]	[4.76]	[4.58]	2.03	3.18	3.25
CMS 7 TeV	133	[0.60]	[1.06]	1.09	0.71	1.01	1.11	[0.72]	[0.94]	[1.14]
CMS 8 TeV	185	[1.10]	[1.59]	1.25	[1.24]	[1.47]	[1.80]	0.81	1.01	1.23
Dijets (all)	266	[3.49]	[3.07]	[2.10]	[4.16]	[2.96]	[2.56]	[3.34]	[2.21]	[2.22]
Dijets (fitted)		—	—	—	—	—	—	—	—	—
ATLAS 7 TeV	90	[1.49]	[2.47]	[1.95]	[1.77]	[2.46]	[1.97]	[1.43]	[2.28]	[2.01]
CMS 7 TeV	54	[2.06]	[2.40]	[2.08]	[2.43]	[2.50]	[2.12]	[1.65]	[2.00]	[2.15]
CMS 8 TeV	122	[5.60]	[3.81]	[2.21]	[6.70]	[3.53]	[3.20]	[5.48]	[2.26]	[2.39]
Total		1.20	1.18	1.28	1.17	1.17	1.17	1.39	1.27	1.27

[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

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- ***bn* fit**: baseline PDF fit at NNLO
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- ***j7nw* & *j8nw* fits**: same perturbative accuracy as *jawn* fit but 7 & 8 TeV single-inclusive jet data fitted separately

- observe slight deterioration in the description of the ATLAS top pair rapidity χ^2(bn) 1.22→2.01
- effect seems to be driven when adding the 8 TeV ATLAS jet data to the global dataset
- stronger incompatibility when jet predictions are taken at NLO χ^2(bn) 1.22→2.93

PDF fits with single-inclusive jet data at NNLO

χ^2 per data point for all fits

[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] **[arXiv: 2005.11327]**

Dataset	n_{dat}	b	bn	janw	j7	j7n	j7nw	j8	j8n	j8nw
DIS NC	2103	1.17	1.17	1.18	1.17	1.18	1.17	1.17	1.17	1.18
DIS CC	989	1.06	1.10	1.11	1.06	1.11	1.10	1.08	1.11	1.11
Drell-Yan	577	1.35	1.33	1.30	1.35	1.31	1.31	1.34	1.31	1.31
Z p_T	120	1.84	1.01	1.02	1.85	1.02	1.02	1.89	1.03	1.03
Top pair	24	1.10	1.05	1.25	1.09	1.06	1.02	2.00	1.61	1.24
ATLAS $\sigma_{t\bar{t}}$	3	2.02	0.90	0.70	1.68	0.74	0.72	1.70	0.79	0.78
ATLAS $t\bar{t}$ rap	9	1.12	1.22	2.01	1.25	1.38	1.31	2.93	2.78	1.96
CMS $\sigma_{t\bar{t}}$	3	0.53	0.22	0.21	0.42	0.24	0.31	0.34	0.17	0.19
CMS $t\bar{t}$ rap	9	0.98	1.17	0.98	0.96	1.09	1.04	1.65	1.12	0.99
Jets (all)	520	[1.48]	[2.60]	1.88	[1.86]	[2.45]	[2.53]	[1.20]	[1.75]	[1.89]
Jets (fitted)		—	—	1.88	0.79	1.15	1.12	1.40	2.05	2.20
ATLAS 7 TeV	31	[1.26]	[1.87]	1.59	1.12	1.73	1.15	[1.07]	[1.69]	[1.62]
ATLAS 8 TeV	171	[2.60]	[5.01]	3.22	[3.55]	[4.76]	[4.58]	2.03	3.18	3.25
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CMS 8 TeV	185	[1.10]	[1.59]	1.25	[1.24]	[1.47]	[1.80]	0.81	1.01	1.23
Dijets (all)	266	[3.49]	[3.07]	[2.10]	[4.16]	[2.96]	[2.56]	[3.34]	[2.21]	[2.22]
Dijets (fitted)		—	—	—	—	—	—	—	—	—
ATLAS 7 TeV	90	[1.49]	[2.47]	[1.95]	[1.77]	[2.46]	[1.97]	[1.43]	[2.28]	[2.01]
CMS 7 TeV	54	[2.06]	[2.40]	[2.08]	[2.43]	[2.50]	[2.12]	[1.65]	[2.00]	[2.15]
CMS 8 TeV	122	[5.60]	[3.81]	[2.21]	[6.70]	[3.53]	[3.20]	[5.48]	[2.26]	[2.39]
Total		1.20	1.18	1.28	1.17	1.17	1.17	1.39	1.27	1.27

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- ***bn* fit**: baseline PDF fit at NNLO
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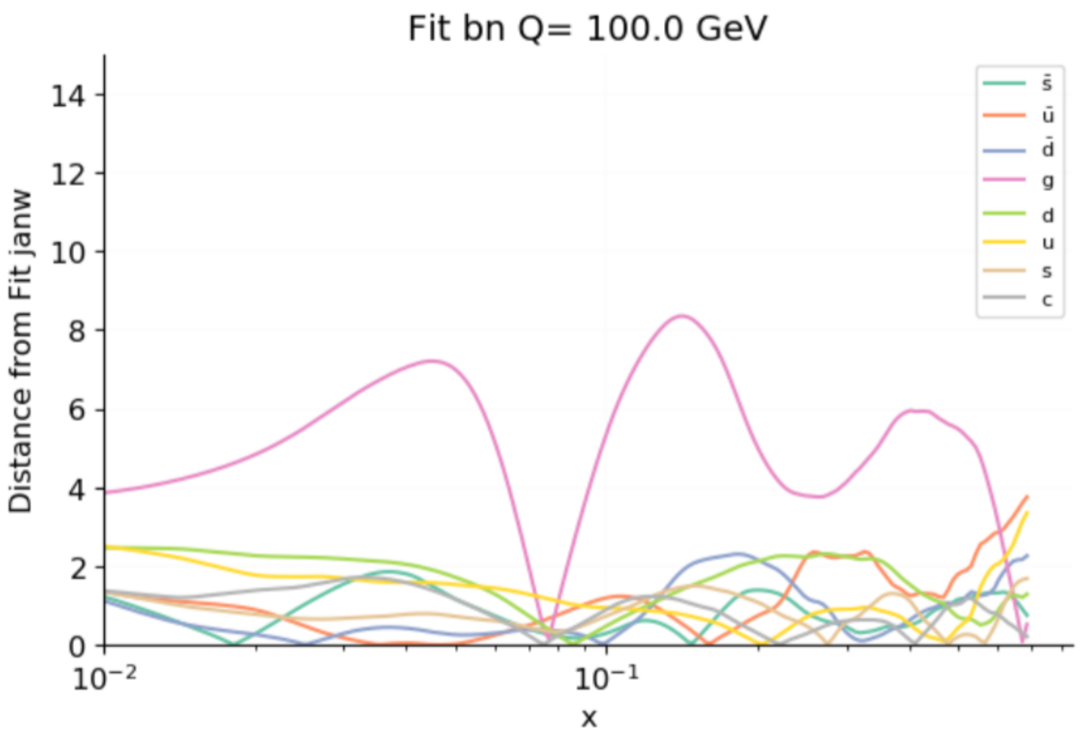
- ***j7nw & j8nw* fits**: same perturbative accuracy as *jawn* fit but 7 & 8 TeV single-inclusive jet data fitted separately

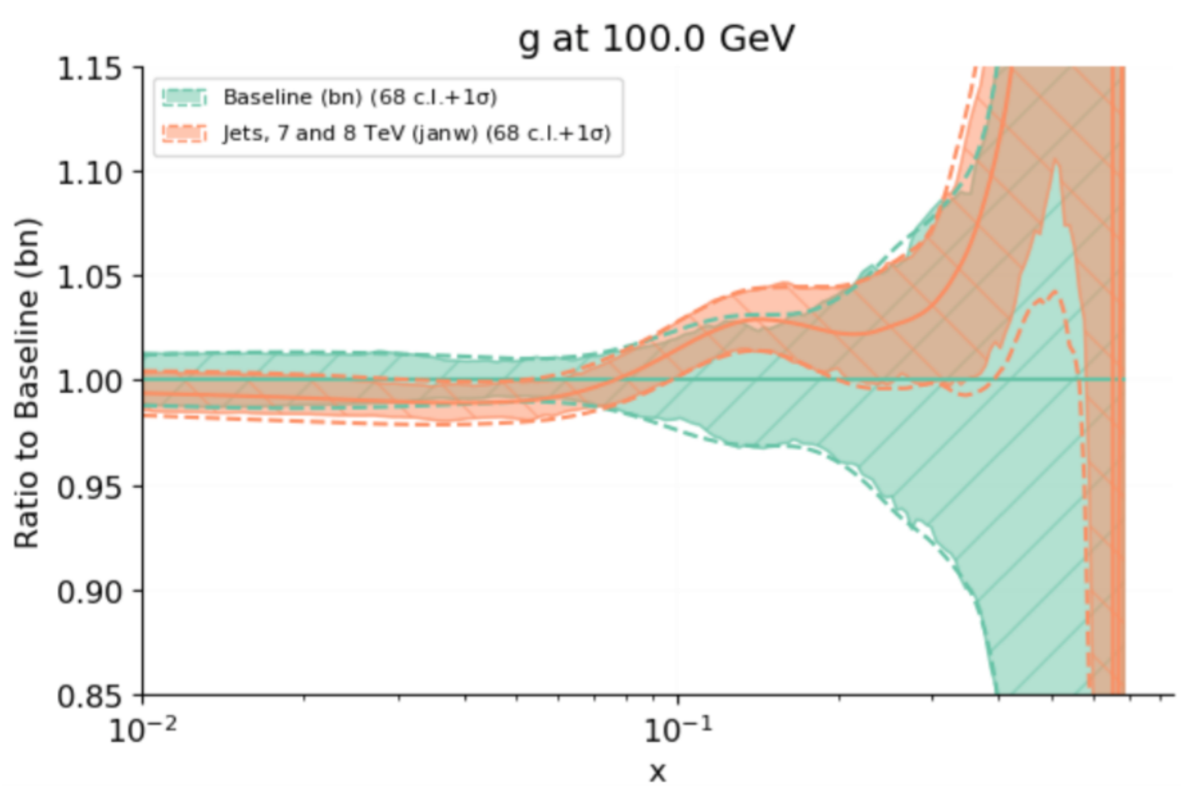
- observe slight deterioration in the description of the ATLAS top pair rapidity χ^2(bn) 1.22→2.01
- effect seems to be driven when adding the 8 TeV ATLAS jet data to the global dataset
- stronger incompatibility when jet predictions are taken at NLO χ^2(bn) 1.22→2.93

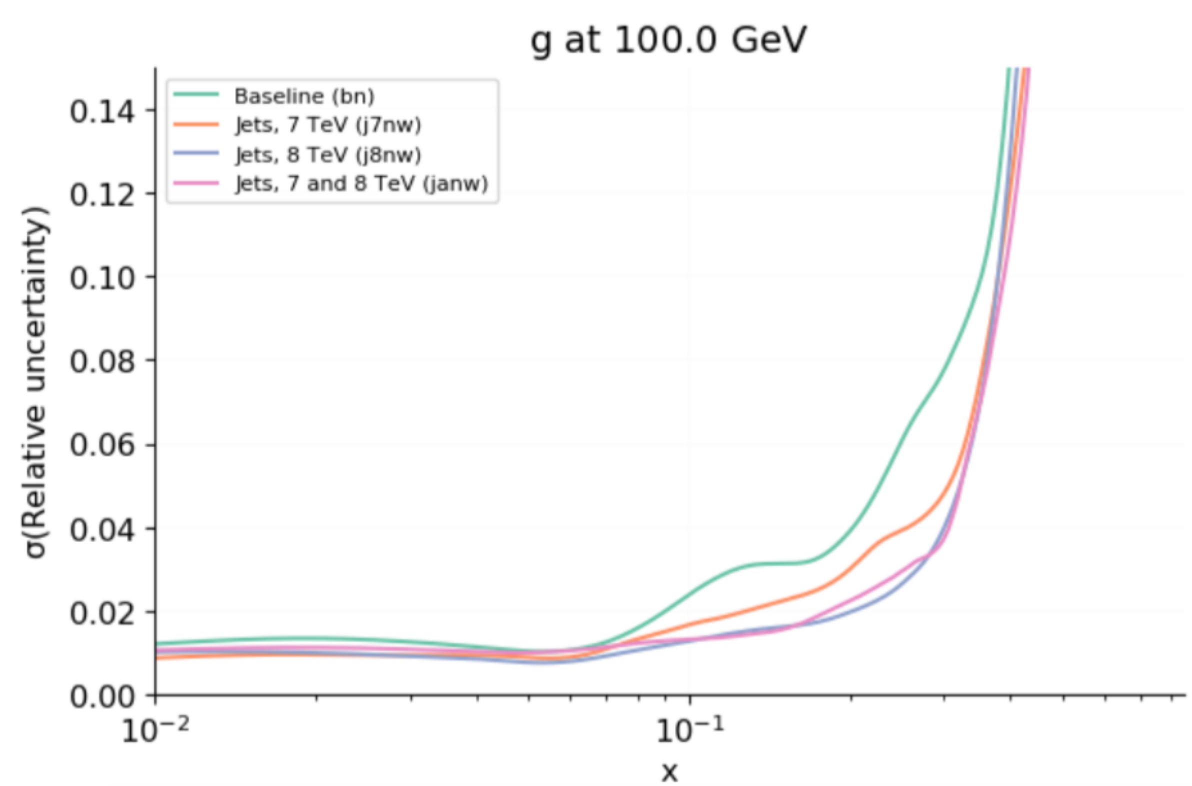
⇒ points to a slight tension between ATLAS 8 TeV jet data and the rest of the global dataset ⇒ worse if top and jet data are not fitted with the same perturbative accuracy

PDF fits with single-inclusive jet data at NNLO



- single-inclusive jet data only have an impact on the gluon
- gluon suppressed by 2% in the small *x*-region and enhanced by 4% in the large *x*-regions, within the uncertainty of the baseline PDF
- reduction of gluon uncertainty at *x*≃0.2 from 4% to 1.5% ; driven by the inclusion of the 8 TeV data





[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

PDF fits with dijet data at NNLO

χ^2 *per data point for all fits*

Dataset	n_{dat}	b	bn	danw	d7	d7n	d7nw	d8	d8n	d8nw
DIS NC	2103	1.17	1.17	1.18	1.17	1.17	1.17	1.21	1.18	1.18
DIS CC	989	1.06	1.10	1.12	1.07	1.09	1.09	1.11	1.11	1.12
Drell-Yan	577	1.35	1.33	1.29	1.36	1.33	1.32	1.32	1.28	1.28
Z p_T	120	1.84	1.01	1.07	1.85	1.03	1.03	2.06	1.07	1.08
Top pair	24	1.10	1.05	1.14	1.16	1.06	1.04	1.57	1.34	1.26
ATLAS $\sigma_{t\bar{t}}$	3	2.02	0.90	0.66	1.79	0.74	0.73	0.80	0.68	0.69
ATLAS $t\bar{t}$ rap	9	1.12	1.22	1.57	1.26	1.34	1.32	2.41	2.02	1.82
CMS $\sigma_{t\bar{t}}$	3	0.53	0.22	0.53	0.48	0.29	0.28	0.01	0.74	0.67
CMS $t\bar{t}$ rap	9	0.98	1.17	1.04	1.07	1.09	1.07	1.42	1.04	1.04
Jets (all)	520	[1.48]	[2.60]	[2.06]	[1.62]	[2.75]	[2.70]	[1.42]	[1.94]	[2.14]
Jets (fitted)		—	—	—	—	—	—	—	—	—
ATLAS 7 TeV	31	[1.26]	[1.87]	[1.63]	[1.26]	[1.86]	[1.74]	[1.00]	[1.70]	[1.61]
ATLAS 8 TeV	171	[2.60]	[5.01]	[3.36]	[2.62]	[4.80]	[4.65]	[2.18]	[3.30]	[3.55]
CMS 7 TeV	133	[0.60]	[1.06]	[1.06]	[0.71]	[1.13]	[1.14]	[0.77]	[0.97]	[1.07]
CMS 8 TeV	185	[1.10]	[1.59]	[1.64]	[1.42]	[2.16]	[2.17]	[1.27]	[1.41]	[1.68]
Dijets (all)	266	[3.49]	[3.07]	1.65	[3.03]	[2.21]	[2.16]	[2.38]	[1.74]	[1.71]
Dijets (fitted)		—	—	1.65	1.33	1.79	1.72	3.69	1.59	1.68
ATLAS 7 TeV	90	[1.49]	[2.47]	1.76	1.20	1.94	1.78	[1.04]	[1.96]	[1.78]
CMS 7 TeV	54	[2.06]	[2.40]	1.60	1.54	1.55	1.63	[1.67]	[1.70]	[1.66]
CMS 8 TeV	122	[5.60]	[3.81]	1.58	[5.03]	[2.70]	[2.67]	3.69	1.59	1.68
Total		1.20	1.18	1.22	1.33	1.20	1.19	1.33	1.20	1.20

[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

- χ^2 values for data not included in fits enclosed in square brackets
- ***bn* fit:** baseline PDF fit at NNLO
- ***dawn* fit:** includes all 7 & 8 TeV dijet data at NNLO QCD + NLO EW
- ***d7nw & d8nw* fits:** same perturbative accuracy as *dawn* fit but 7 & 8 TeV dijet data fitted separately

PDF fits with dijet data at NNLO

χ^2 per data point for all fits

Dataset	n_{dat}	b	bn	danw	d7	d7n	d7nw	d8	d8n	d8nw
DIS NC	2103	1.17	1.17	1.18	1.17	1.17	1.17	1.21	1.18	1.18
DIS CC	989	1.06	1.10	1.12	1.07	1.09	1.09	1.11	1.11	1.12
Drell-Yan	577	1.35	1.33	1.29	1.36	1.33	1.32	1.32	1.28	1.28
Z p_T	120	1.84	1.01	1.07	1.85	1.03	1.03	2.06	1.07	1.08
Top pair	24	1.10	1.05	1.14	1.16	1.06	1.04	1.57	1.34	1.26
ATLAS $\sigma_{t\bar{t}}$	3	2.02	0.90	0.66	1.79	0.74	0.73	0.80	0.68	0.69
ATLAS $t\bar{t}$ rap	9	1.12	1.22	1.57	1.26	1.34	1.32	2.41	2.02	1.82
CMS $\sigma_{t\bar{t}}$	3	0.53	0.22	0.53	0.48	0.29	0.28	0.01	0.74	0.67
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[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] **[arXiv: 2005.11327]**

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PDF fits with dijet data at NNLO

χ^2 *per data point for all fits*

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[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

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- improved description of the single-inclusive jet data not included in the fit

PDF fits with dijet data at NNLO

χ^2 *per data point for all fits*

[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] **[arXiv: 2005.11327]**

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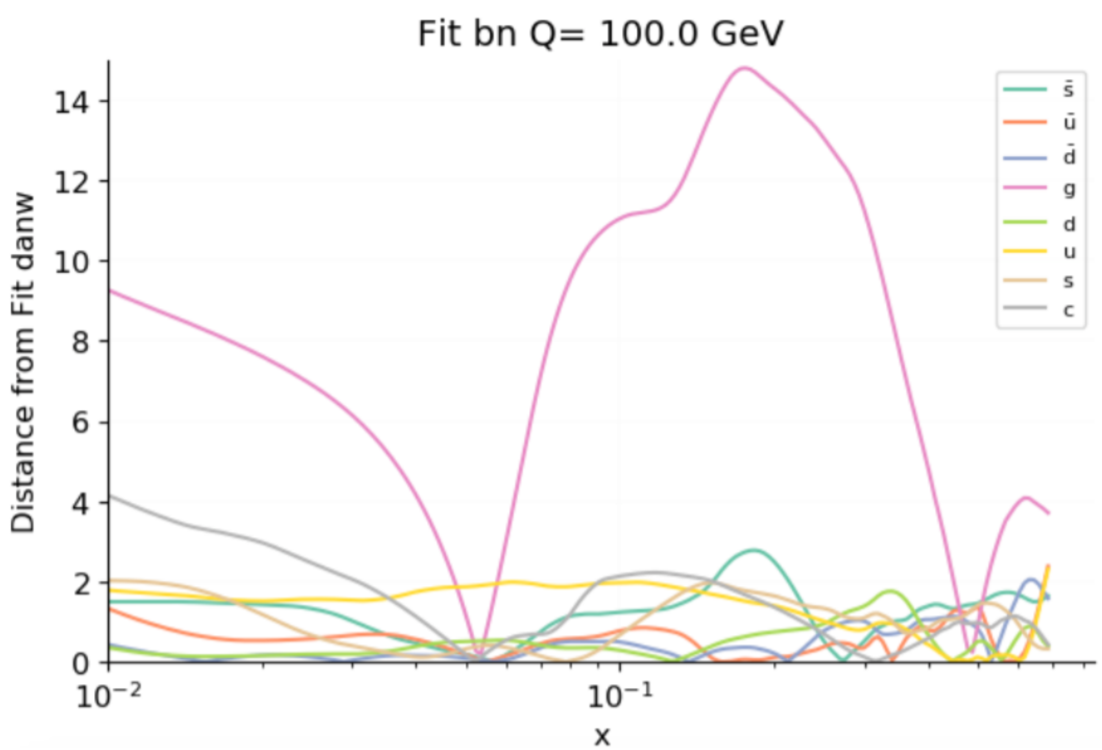
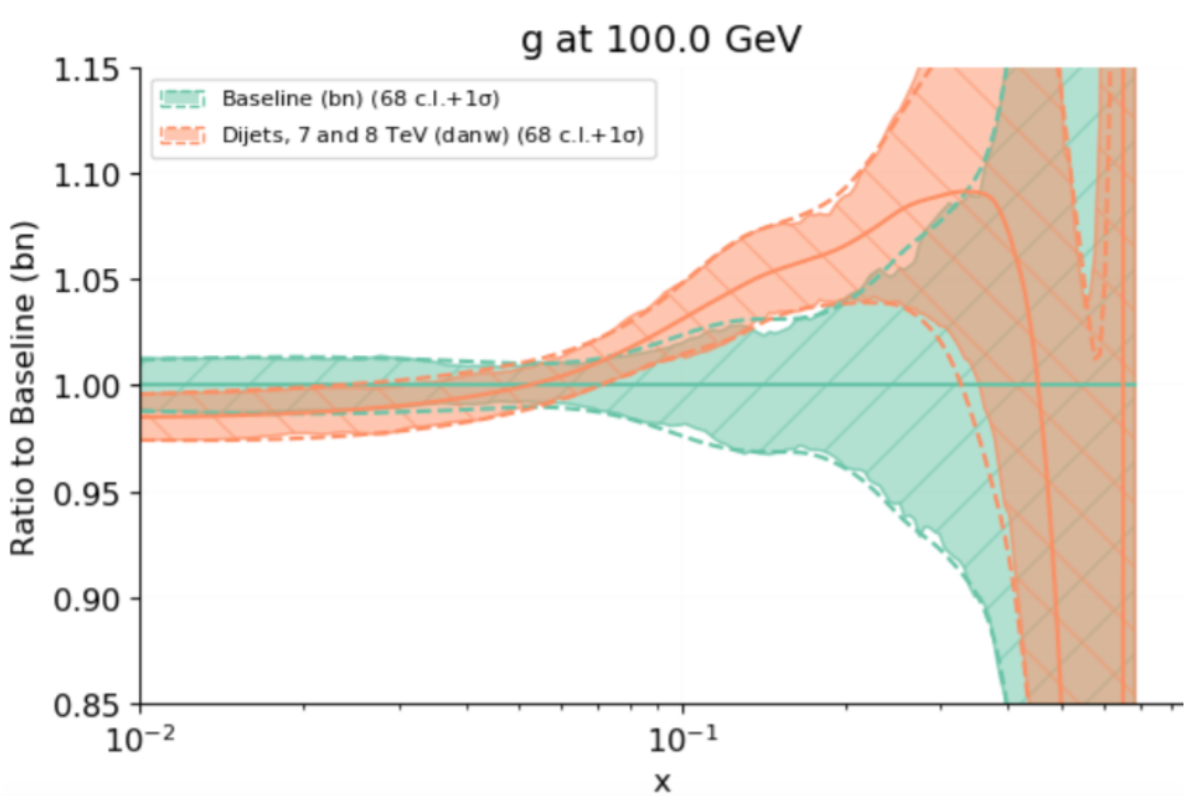
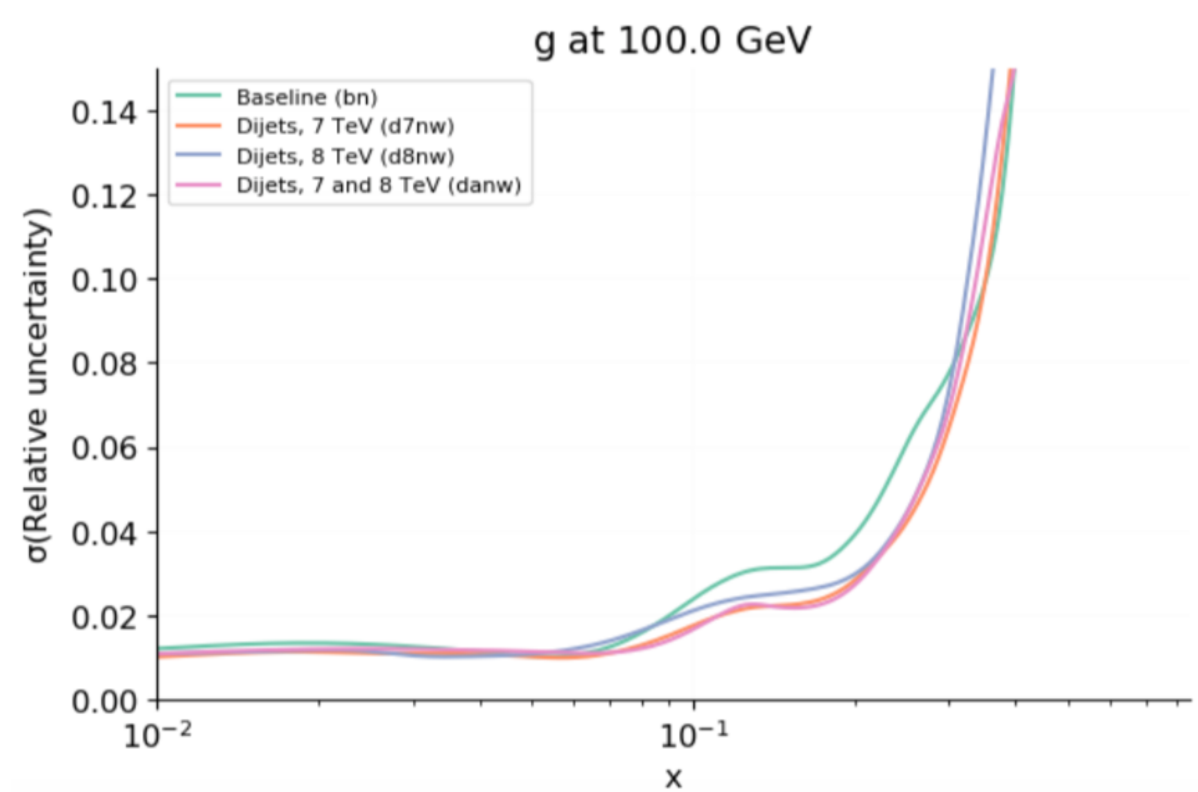
- individual dijet data sets well described $\chi^2 \approx 1$ for each of them
- improved description of the single-inclusive jet data not included in the fit
- no tension observed between dijet data and the rest of the global dataset, e.g., top rapidity distributions

PDF fits with dijet data at NNLO



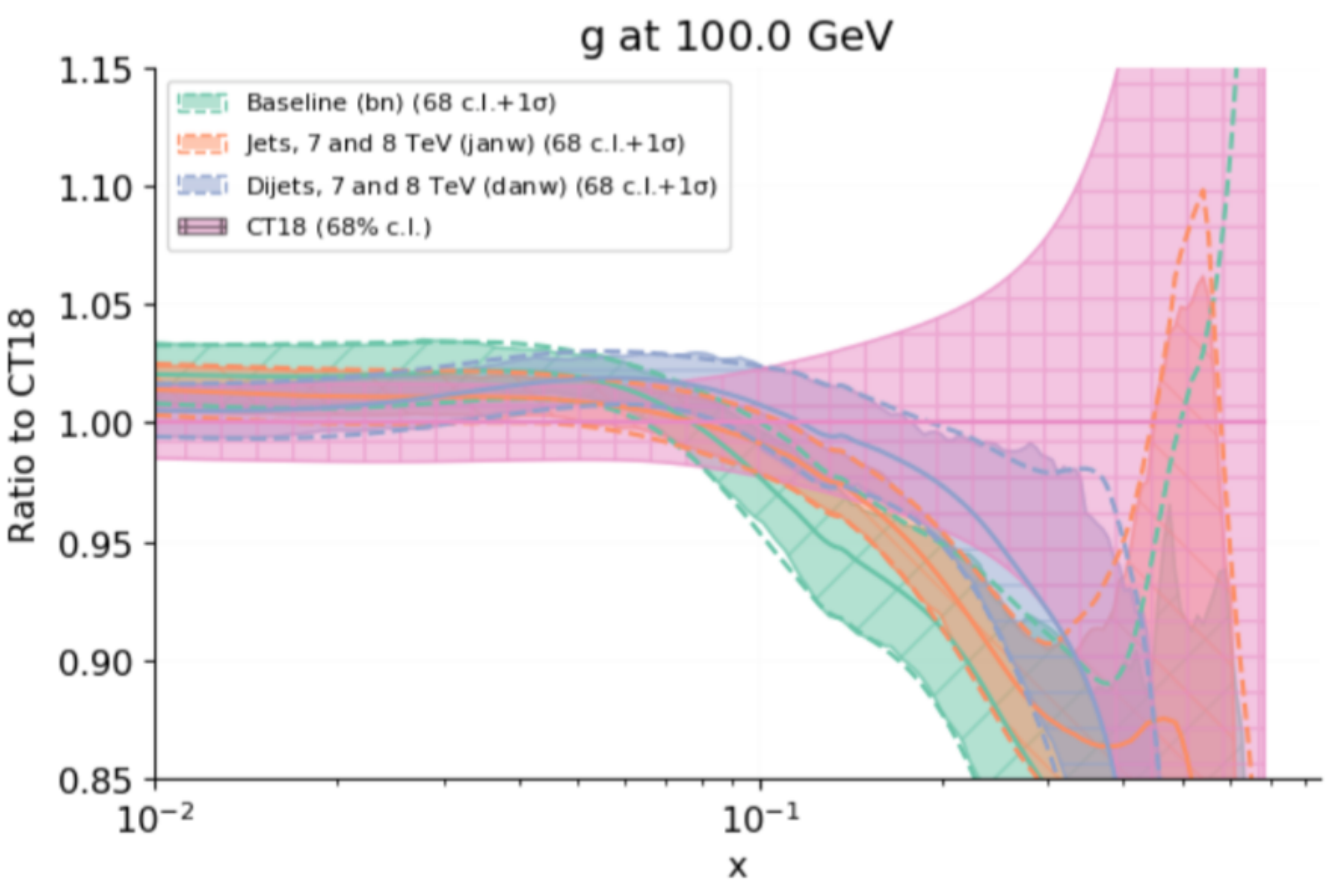
- only gluon PDF is affected by the dijet data
- gluon suppressed by 2% in the small x-region and enhanced by 10% at x~0.3 (1.5σ shift)
- qualitatively similar shifts observed with single-jet inclusive data but more pronounced and in a wider kinematic region → 8 TeV 3d CMS dijet measurement
- reduction of gluon uncertainty at x≃0.2 to 3%
- smaller reduction in gluon uncertainty w.r.t to single inclusive fits; at 8 TeV only CMS dijet data is available





[Khalek, Forte, Gehrmann, Gehrmann-De Ridder, Giani, Glover, Huss, Nocera, JP, Rojo, Stagnitto] ***[arXiv: 2005.11327]***

Consistency with CT18 and top data



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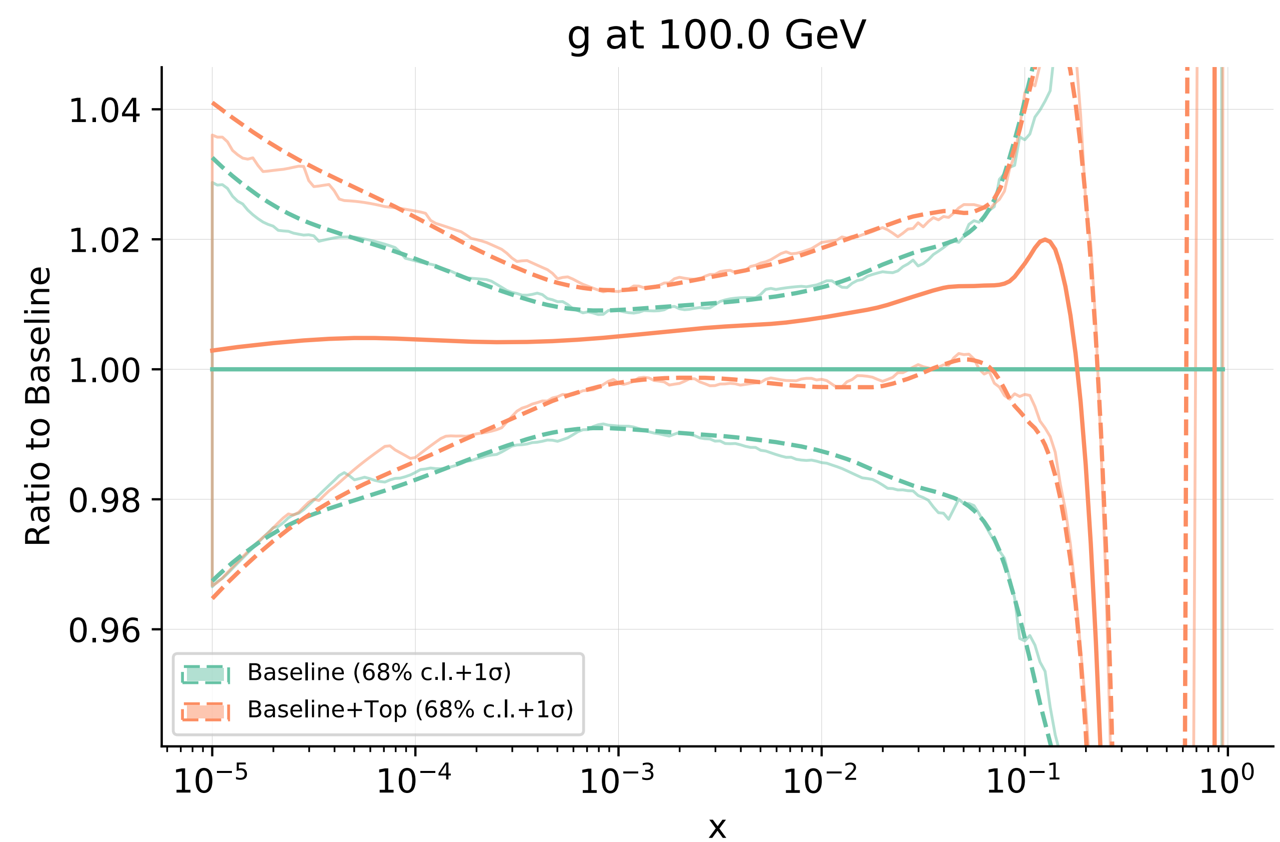


[Nocera, Ubiali] ***[arXiv: 1709.09690]***

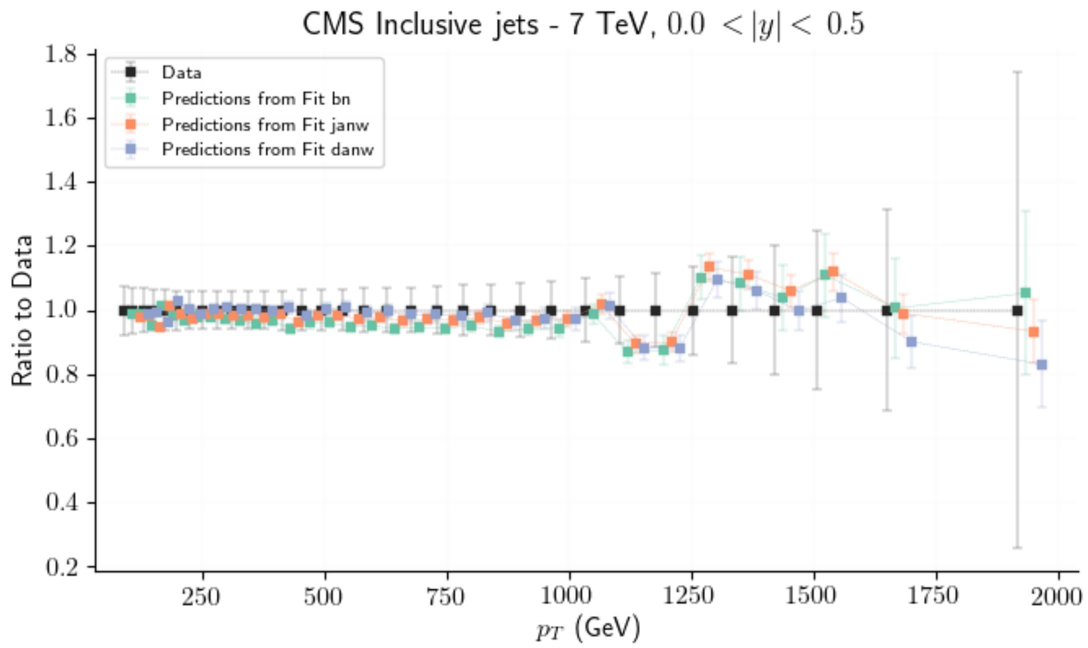
- findings in line with CT18 analysis which includes 8 TeV CMS single-inclusive jet data and presents an enhanced gluon → gluon PDF consistency

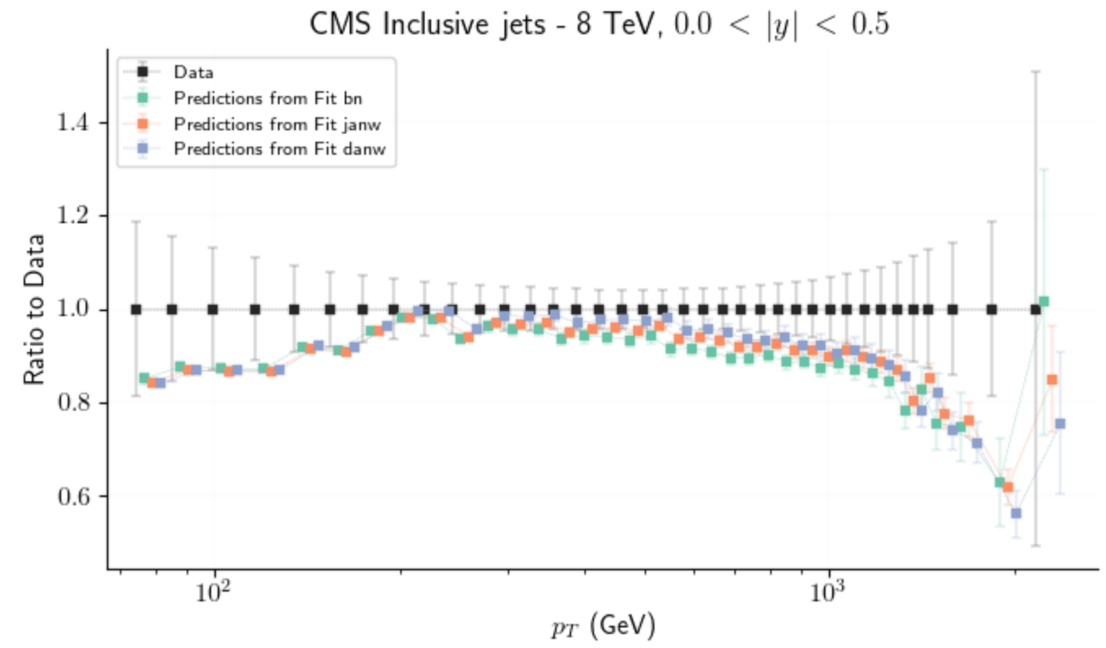
- impact of the jet data on the gluon consistent with impact of top data which also leads to an enhancement of the gluon in the $x \gtrsim 0.1$ region

Conclusions & Outlook

- significant theoretical progress in the description of inclusive jet and dijet production at the LHC
- theoretical developments driven by the increase in precision of the experimental measurements
- new calculation of triple differential dijet production at NNLO in QCD
- new study on the impact of LHC Run-I CMS and ATLAS jet data on PDFs based on NNPDF analysis
- inclusion of single-jet inclusive or dijet data has a similar qualitative impact on the PDFs
- gluon PDF enhanced at the large x-region after the inclusion of either single-jet inclusive or dijet data to the baseline fit but stronger pull observed with dijet data
- consistent with CT18 analysis which includes 8 TeV CMS single-jet inclusive data
- consistent with fitting top data which also lead to an enhancement of the gluon in the $x \gtrsim 0.1$ region
- significant reduction of the gluon PDF uncertainty with jet data included in the global fit
- expect a more clear and consistent theoretical picture with even more precise available LHC Run-II 13 TeV data, and future LHC Run-III and HL-LHC

BACKUP


CMS Inclusive jets - 7 TeV, $0.0 < |y| < 0.5$
Data
Predictions from Fit bn
Predictions from Fit janw
Predictions from Fit danw
Ratio to Data
p_T (GeV)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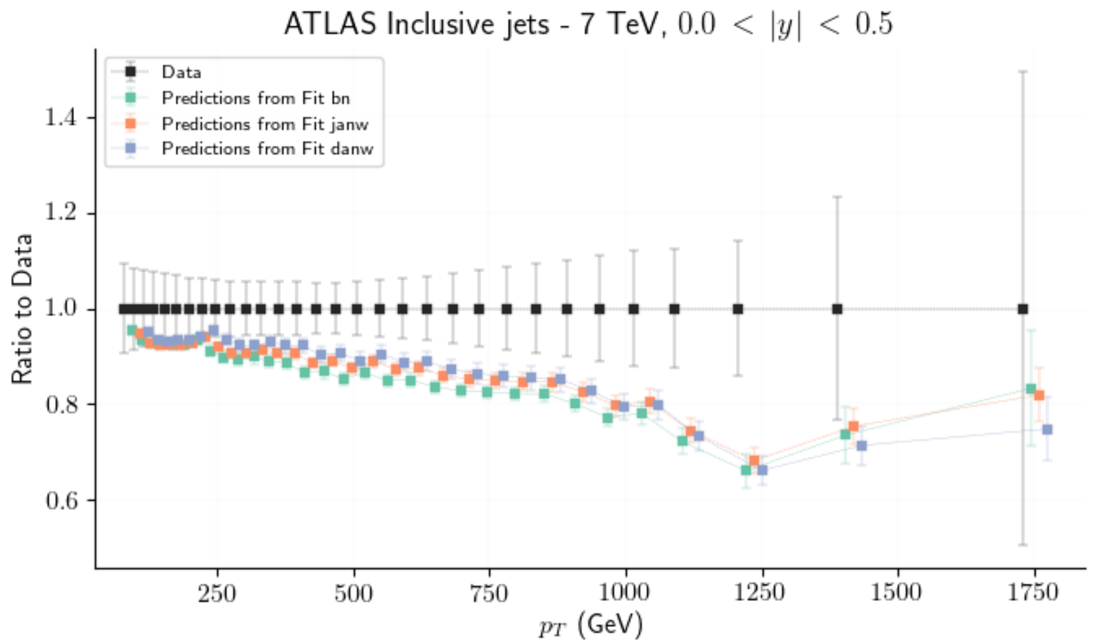
ATLAS Inclusive jets - 7 TeV, $0.0 < |y| < 0.5$
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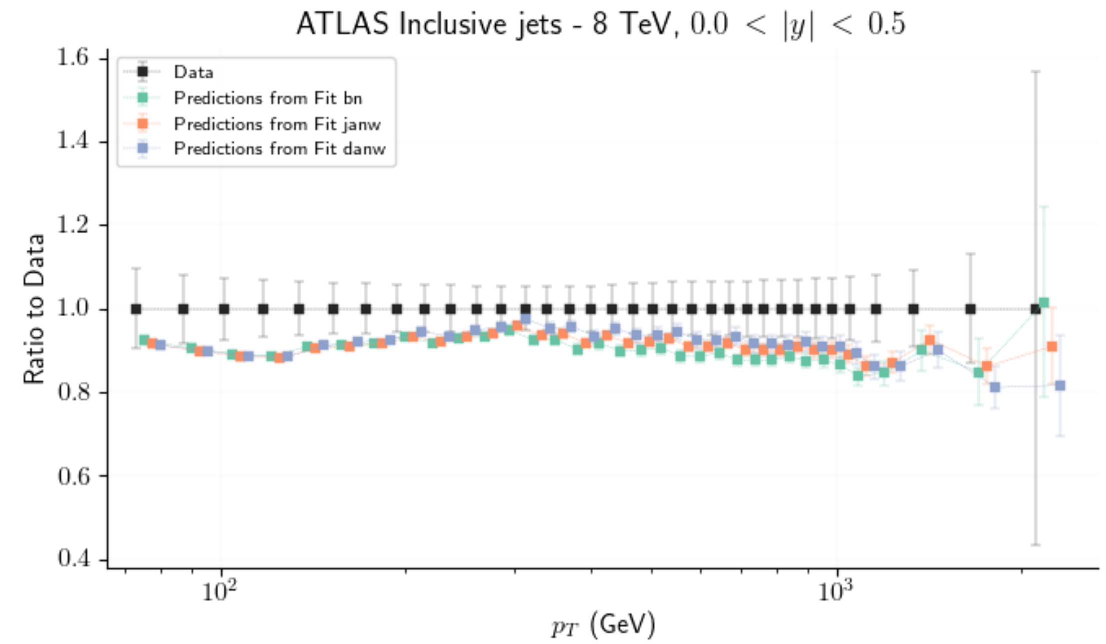
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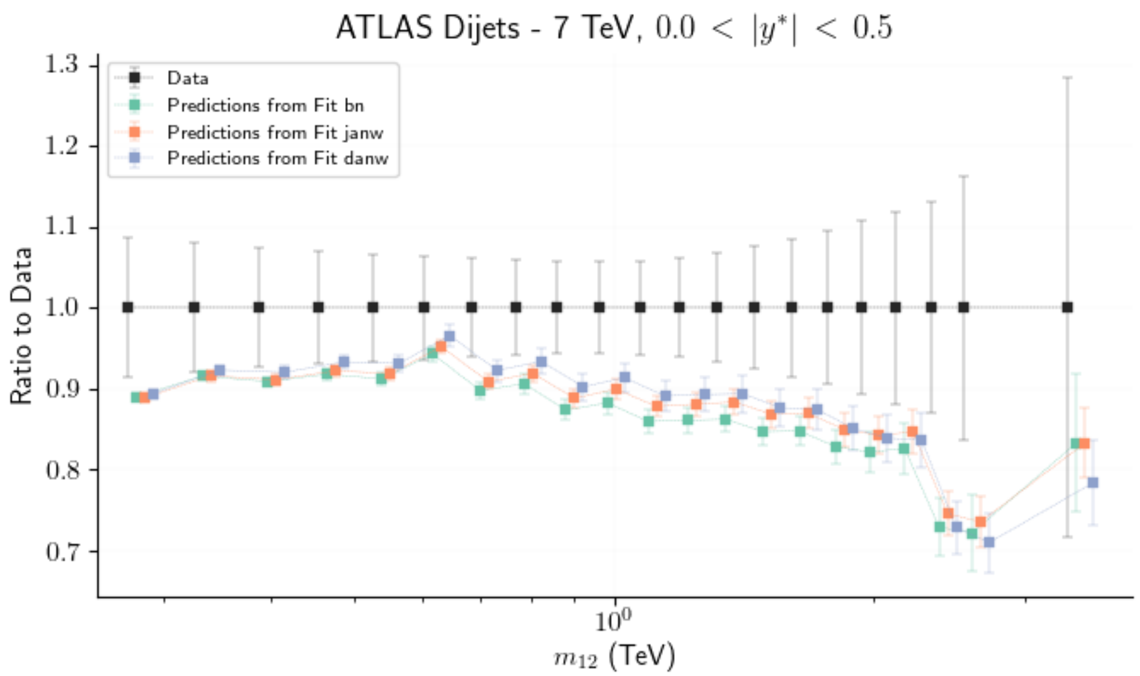
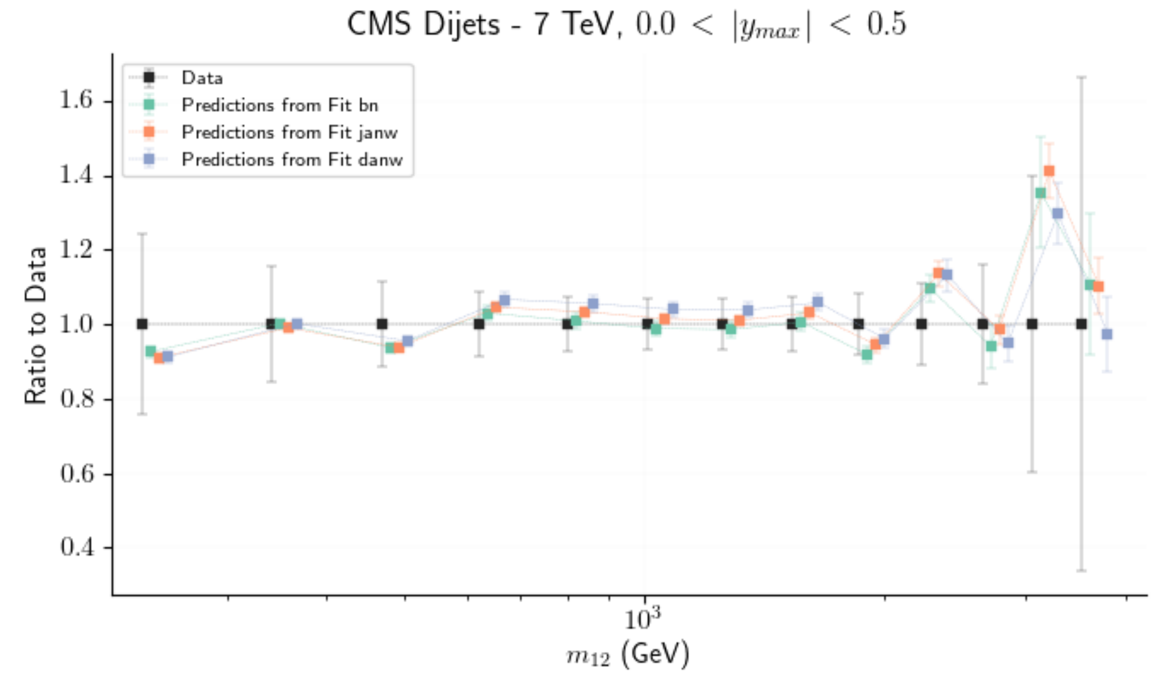
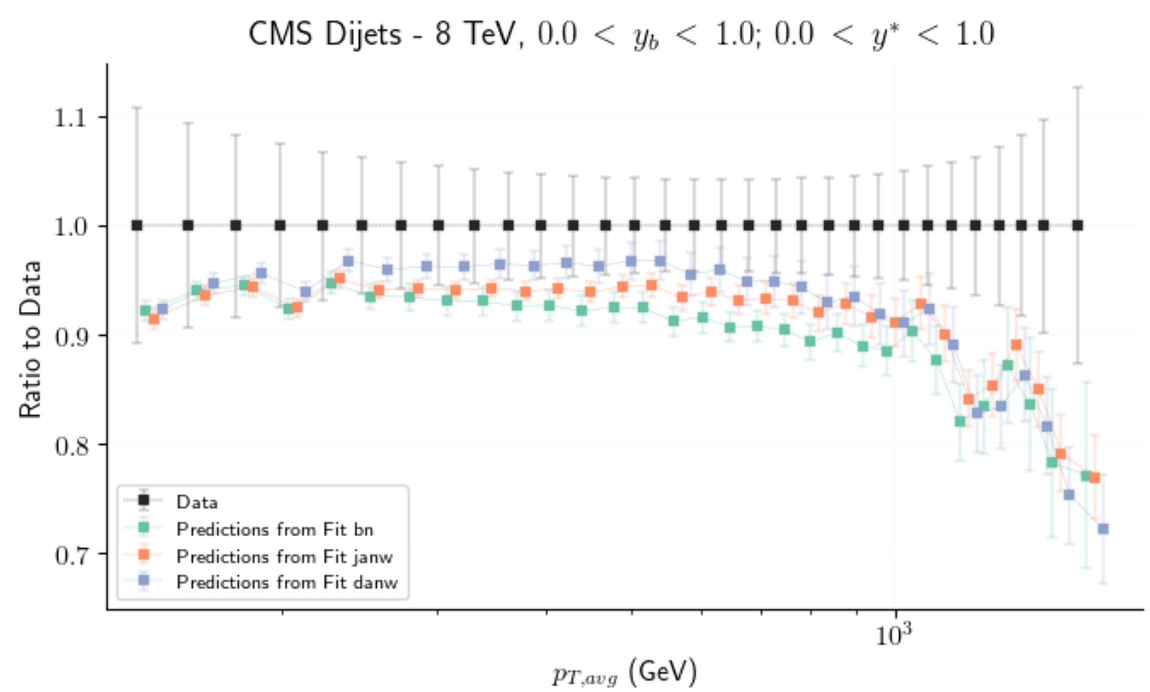


ATLAS Dijets - 7 TeV, $0.0 < |y^*| < 0.5$
Data
Predictions from Fit bn
Predictions from Fit janw
Predictions from Fit danw
Ratio to Data
m_{12} (TeV)



CMS Dijets - 7 TeV, $0.0 < |y_{max}| < 0.5$
Data
Predictions from Fit bn
Predictions from Fit janw
Predictions from Fit danw
Ratio to Data
m_{12} (GeV)



CMS Dijets - 8 TeV, $0.0 < y_b < 1.0$; $0.0 < y^* < 1.0$
Data
Predictions from Fit bn
Predictions from Fit janw
Predictions from Fit danw
Ratio to Data
$p_{T,avg}$ (GeV)