Impact of jets data in PDFs determination

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“Jets and their substructure from LHC data”, CERN on-line workshop

Overview

- single-inclusive jets and dijets cross sections in PDFs fits

  R. A. Khalek, S.Forte, T.Gehrmann, A. Gehrmann-De Ridder, TG, N. Glover, A. Huss, E. R. Nocera, J. Pires, J. Rojo, G. Stagnitto [Eur.Phys.J.C 80 (2020) 8, 797]

- jets in NNPDF4.0

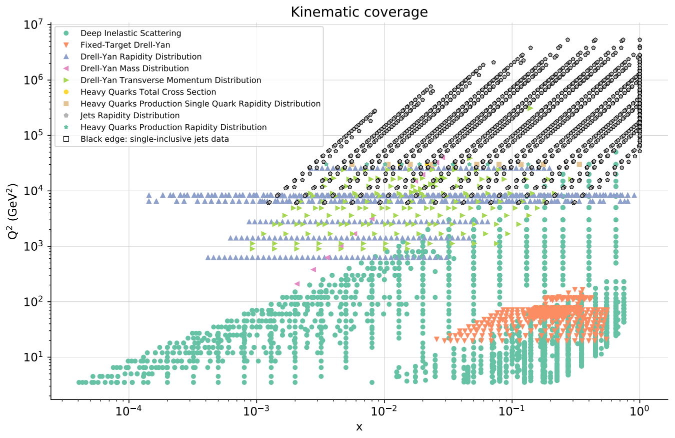
- inclusion of theory error in a PDFs fit

  [Eur.Phys.J. C (2019) 79], [Eur.Phys.J.C 79 (2019) 11]

Data and theory predictions

Single-inclusive jets data

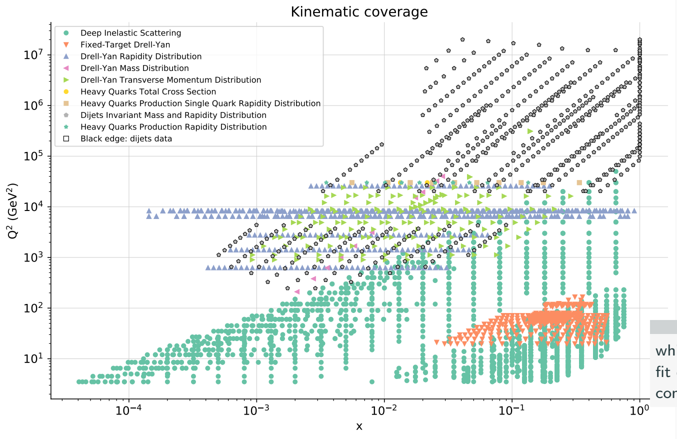
Experiment	Measurement	$\sqrt{s}$ [TeV]	$\mathcal{L}$ [fb^{-1}]	R	Distribution	$n_{\rm dat}$
ATLAS	Inclusive jets	7	4.5	0.6	$d^2\sigma/dp_T d\lvert y\rvert$	140
CMS	Inclusive jets	7	4.5	0.7	$d^2\sigma/dp_T d\lvert y\rvert$	133
ATLAS	Inclusive jets	8	20.2	0.6	$d^2\sigma/dp_T d\lvert y\rvert$	171
CMS	Inclusive jets	8	19.7	0.7	$d^2\sigma/dp_T d\lvert y\rvert$	185



- 7 and 8 TeV data from ATLAS and CMS
- some 7 TeV ATLAS data already included in previous PDFs determination (NNLO evolution + NLO partonic cross sections, central rapidity bin only)

Dijets data

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



- double and triple differential distributions from ATLAS and CMS
- similar kinematic coverage to single inclusive jets
- never included in a PDFs fit before because of strong scale dependence of NLO results

↓

NNLO QCD corrections open up the possibility for inclusion of dijets data

which observable is better in terms of fit quality, constraints on PDFs, compatibility with other data?

Theory predictions

✓ NNLO QCD predictions from NNLOJET

A. Gehrmann-De Ridder, T. Gehrmann, E. W. N. Glover, A. Huss, and J. Pires [Phys.Rev.Lett. 123 (2019)]

$$K^{\mathrm{QCD}}_{\mathrm{NNLO}}(p_T, y, \sqrt{s}) = \frac{\sum_{ij} \hat{\sigma}^{\mathrm{NNLO}}_{ij} \otimes \mathcal{L}^{\mathrm{NNLO}}_{ij}}{\sum_{ij} \hat{\sigma}^{\mathrm{NLO}}_{ij} \otimes \mathcal{L}^{\mathrm{NNLO}}_{ij}},$$

✓ NLO EW corrections from

S. Dittmaier, A. Huss, and C. Speckner [JHEP 11 (2012) 095]

$$K^{\mathrm{EW}}(p_T, y, \sqrt{s}) = \frac{\sum_{ij} \hat{\sigma}^{\mathrm{LO\ QCD+EW}}_{ij} \otimes \mathcal{L}^{\mathrm{NNLO}}_{ij}}{\sum_{ij} \hat{\sigma}^{\mathrm{LO\ QCD}}_{ij} \otimes \mathcal{L}^{\mathrm{NNLO}}_{ij}},$$

Scale choice: scalar sum of the transverse momenta of all partons in the event

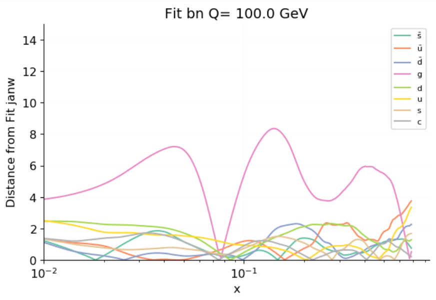
J. Currie, A. Gehrmann-De Ridder, T. Gehrmann, E.W.N. Glover, A. Huss, J. Pires [JHEP 10, 155 (2018)]

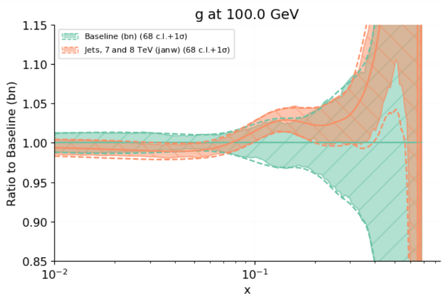
$$\hat{H}_T = \sum_{i \in \mathrm{partons}} p_{T,i}\,.$$

$$\left.\frac{d^2\sigma}{dp_T dy}\right|_{NNLO+EW} = \left.\frac{d^2\sigma}{dp_T dy}\right|_{\mathrm{NLO_{QCD}}} \times K^{\mathrm{QCD}}_{\mathrm{NNLO}} \times K^{\mathrm{EW}}\,.$$

Results

single-inclusive jets 7, 8 TeV

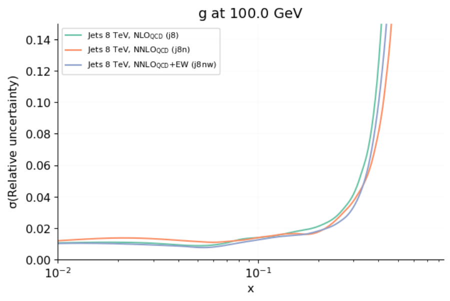


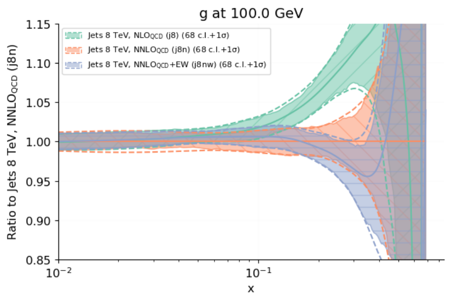


Dataset	$n_{\rm dat}$	baseline	jets 7, 8 TeV
DIS NC	2103	1.17	1.18
DIS CC	989	1.10	1.11
Drell-Yan	577	1.33	1.30
$Z\ p_T$	120	1.01	1.02
Top pair	24	1.05	1.25 ✗
Jets (all)	520	[2.60]	1.88
Jets (fitted)		—	1.88
ATLAS 7 TeV	31	[1.87]	1.59
ATLAS 8 TeV	171	[5.01]	3.22 ✗
CMS 7 TeV	133	[1.06]	1.09
CMS 8 TeV	185	[1.59]	1.25
Dijets (all)	266	[3.07]	[2.10]
Dijets (fitted)		—	—
ATLAS 7 TeV	90	[2.47]	[1.95] ✓
CMS 7 TeV	54	[2.40]	[2.08] ✓
CMS 8 TeV	122	[3.81]	[2.21] ✓
Total		1.18	1.28

- ✗ unsatisfactory description of the ATLAS 8 TeV data
- ✗ slight deterioration in the description of the ATLAS top pair rapidity distributions
- ✓ improvement in the description of the not fitted dijet data

Impact of NNLO QCD and EW corrections: jets





	NLO	NNLO	NNLO+EW
$Z\ p_T$	1.89	1.03	1.03
ATLAS top pair	2.00	1.61	1.24
ATLAS jets 8 TeV	2.03	3.18	3.25
CMS jets 8 TeV	0.81	1.01	1.23

Similar picture for the 7 TeV jets data

- NLO gluon distorted wrt the NNLO baseline
  $\rightarrow$ significant impact of NNLO corrections
- moderate impact of EW corrections
- fit quality to $Z\ p_T$ and ATLAS top pair distributions improves upon inclusion of NNLO corrections

✗ fit quality to jet data deteriorates upon inclusion of NNLO and EW corrections

Correlation model

Issues in the covariance matrix for the ATLAS 7 TeV data
L. A. Harland-Lang, A. D. Martin, R. S. Thorne [Eur.Phys.J.C 78 (2018) 3]

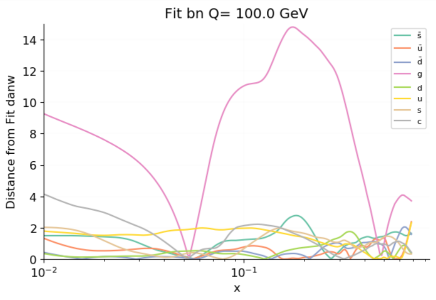
→ only central rapidity bin of ATLAS single-inclusive jets 7 TeV included in the default fit

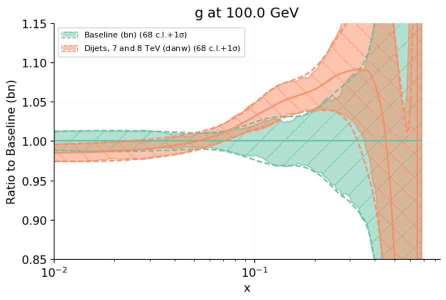
Similar issue might affect 8 TeV data.

Dataset	full corr 7, 8 TeV	partial corr 7 TeV	partial corr 8 TeV
ATLAS jets 7 TeV	2.44	1.22	1.61
ATLAS jets 8 TeV	3.16	3.20	0.98

- correlation model suggested in [Eur.Phys.J.C 78 (2018) 3] leads to a good description of 7 TeV data
- correlation model suggested in ATLAS [JHEP 09 (2017) 020] leads to a good description of 8 TeV data

dijets 7, 8 TeV

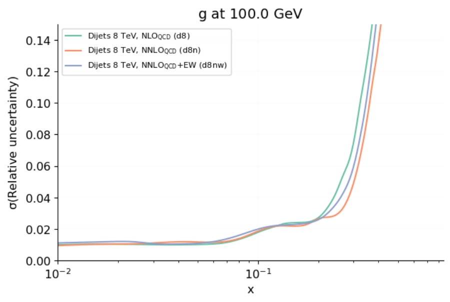


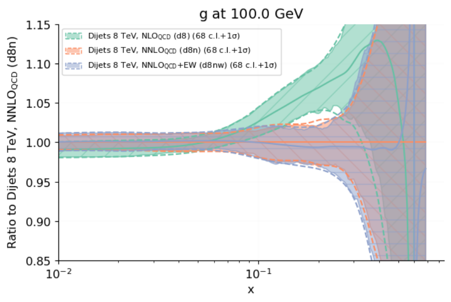


Dataset	n_{dat}	baseline	dijets 7, 8 TeV
DIS NC	2103	1.17	1.18
DIS CC	989	1.10	1.12
Drell-Yan	577	1.33	1.29
$Z\ p_T$	120	1.01	1.07
Top pair	24	1.05	1.14
Jets (all)	520	[2.60]	[2.06]
Jets (fitted)		—	—
ATLAS 7 TeV	31	[1.87]	[1.63]
ATLAS 8 TeV	171	[5.01]	[3.36]
CMS 7 TeV	133	[1.06]	[1.06]
CMS 8 TeV	185	[1.59]	[1.64]
Dijets (all)	266	[3.07]	1.65
Dijets (fitted)		—	1.65
ATLAS 7 TeV	90	[2.47]	1.76
CMS 7 TeV	54	[2.40]	1.60
CMS 8 TeV	122	[3.81]	1.58
Total		1.18	1.22

- ✓ effect on gluon PDF qualitatively similar to those observed for jets
- ✓ individual dijets datasets well described
- ✓ improvement in the description of the not-fitted jets data

Impact of NNLO QCD and EW corrections: dijets

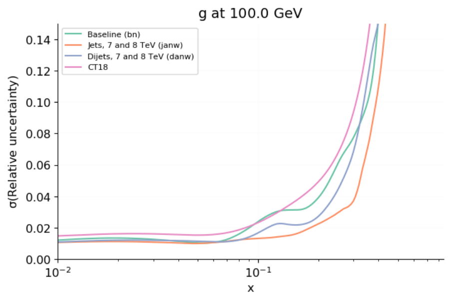


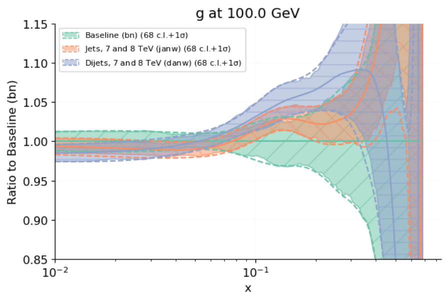


	NLO	NNLO	NNLO+EW
$Z\ p_T$	1.89	1.03	1.03
ATLAS top pair	1.57	1.34	1.26
CMS 8 TeV dijets	3.69	1.59	1.68

- NLO gluon distorted wrt the NNLO baseline
  $\rightarrow$ significant impact of NNLO corrections
- moderate impact of EW corrections
- ✓ improvement of fit quality of both dijets data and gluon sensitive distributions

Jets vs. dijets





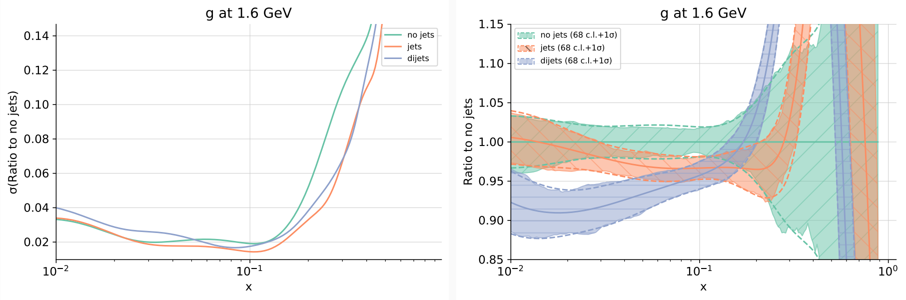
- effect on PDFs from the inclusion of jets and dijets data is qualitatively very similar
- consistency between single-inclusive and dijet data
- consistency with baseline dataset, only exception is ATLAS top rapidity
- reduction in the gluon uncertainty
- better perturbative behaviour, stronger pull on the gluon and slightly better fit quality for dijets observables

NNPDF4.0

Jets data in NNPDF4.0

- CMS dijets data at 7, 8 TeV
- ATLAS dijets at 7 TeV, ATLAS single-inclusive jets 8 TeV (with decorrelation model)

Similar relative effects of single-inclusive vs dijets data, but enhanced within the reduced NNPDF4.0 uncertainties.



Fit	ATLAS 2j	CMS 2j	ATLAS 1j 7 TeV	ATLAS 1j 8 TeV	CMS 1j	total
NNPDF4.0	1.93	1.56	[1.28] [3.42]*	0.61 [2.82]*	[1.31]	1.17
single-jets instead of dijets	[2.41]	[2.68]	1.23 [3.36]*	0.85 [3.10]*	1.07	1.14

*No decorrelation model

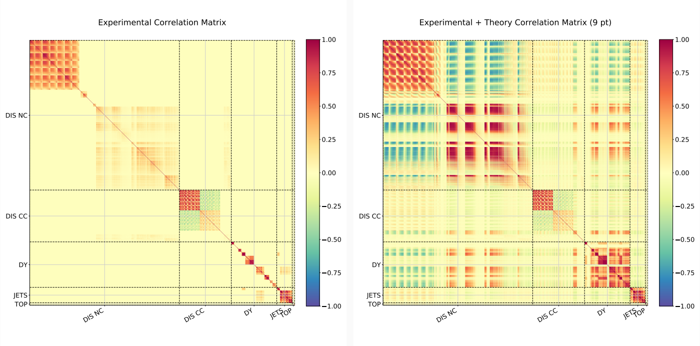
Missing Higher Order Uncertainties in a PDFs fit

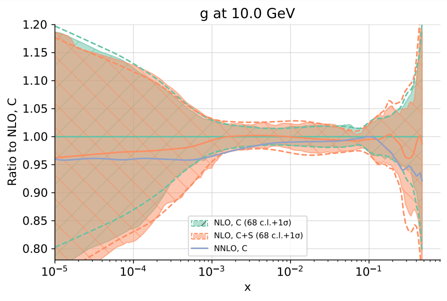
- standard global PDFs fits are base on Fixed-Order computation → how do we include Missing Higher Order Uncertainties in a fit?

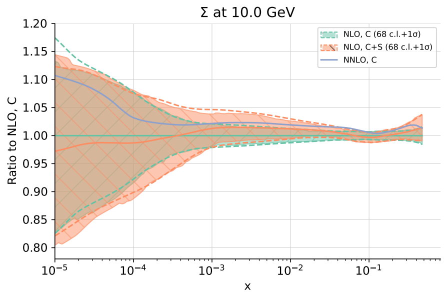
- assuming gaussian theory error, MHOU can be included in a global PDFs fit by means of an additional contribution to the covariance matrix

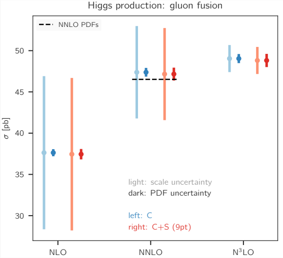
$$\chi^2(\theta) = \sum_{i,j} [D_i - T_i(\theta)] \left(\text{cov}_{\text{exp}} + \text{cov}_{\text{th}}\right)^{-1}_{ij} [D_j - T_j(\theta)]$$

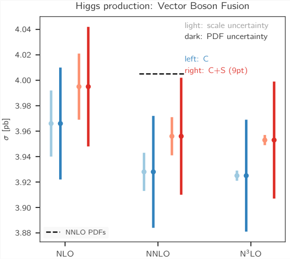
- cov_{th} determined at NLO through scales variation and validated against the known NNLO results [Eur.Phys.J. C (2019) 79], [Eur.Phys.J.C 79 (2019) 11]











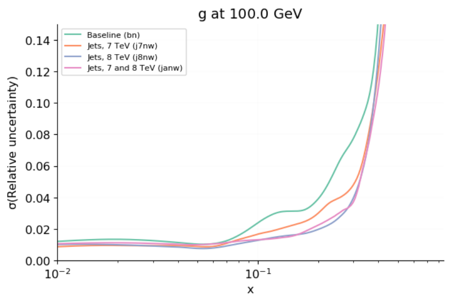
- PDFs error increases only marginally
- shift of the NLO PDF central value towards the NNLO result

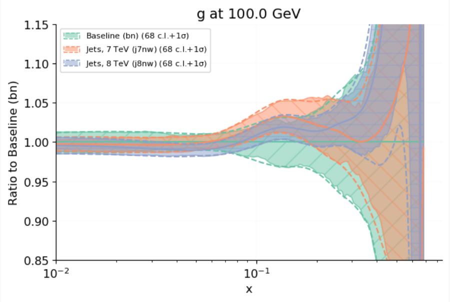
Summary

- considering NNLO QCD + NLO EW theory predictions, the impact of single-inclusive jets and dijets data is qualitatively similar
- better perturbative behaviour and internal consistency of dijets data
- NNPDF4.0 will contain dijets from CMS and ATLAS at 7 and 8 TeV + single-inclusive jets from ATLAS at 8 TeV
- encouraging results for a NLO PDFs set with MHOU. Work in progress for NNLO

Additional slides

7 TeV vs. 8 TeV single-inclusive jets data

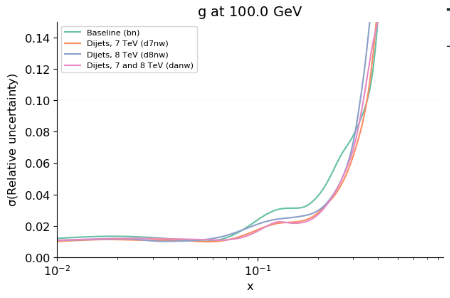


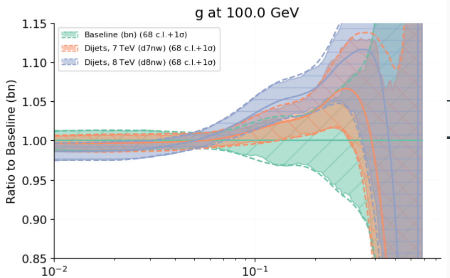


Dataset	baseline	jets 7 TeV	jets 8 TeV
DIS NC	1.17	1.17	1.18
DIS CC	1.10	1.10	1.11
Drell-Yan	1.33	1.31	1.31
$Z\ p_T$	1.01	1.02	1.03
Top pair	1.05	1.02	1.24 ✗
Jets (all)	[2.60]	[2.53]	[1.89]
Jets (fitted)	—	1.12	2.20
ATLAS 7 TeV	[1.87]	1.15	[1.62]
ATLAS 8 TeV	[5.01]	[4.58]	3.25 ✗
CMS 7 TeV	[1.06]	1.11	[1.14]
CMS 8 TeV	[1.59]	[1.80]	1.23
Dijets (all)	[3.07]	[2.56]	[2.22]
Dijets (fitted)	—	—	—
ATLAS 7 TeV	[2.47]	[1.97]	[2.01]
CMS 7 TeV	[2.40]	[2.12]	[2.15]
CMS 8 TeV	[3.81]	[3.20]	[2.39]
Total	1.18	1.17	1.27

- unsatisfactory description of the ATLAS 8 TeV data persist
- deterioration in the description of the ATLAS top pair due to 8 TeV data rapidity distributions
- 8 TeV data appear to be fully consistent with the 7 TeV data
- decrease in gluon uncertainty more marked upon inclusion of the 8 TeV data

7 TeV vs. 8 TeV dijets data





Dataset	baseline	dijets 7 TeV	dijets 8 TeV
DIS NC	1.17	1.17	1.18
DIS CC	1.10	1.09	1.12
Drell-Yan	1.33	1.32	1.28
Z p_T	1.01	1.03	1.08
Top pair	1.05	1.04	1.26
Jets (all)	[2.60]	[2.70]	[2.14]
Jets (fitted)	—	—	—
ATLAS 7 TeV	[1.87]	[1.74]	[1.61]
ATLAS 8 TeV	[5.01]	[4.65]	[3.55]
CMS 7 TeV	[1.06]	[1.14]	[1.07]
CMS 8 TeV	[1.59]	[2.17]	[1.68]
Dijets (all)	[3.07]	[2.16]	[1.71]
Dijets (fitted)	—	1.72	1.68
ATLAS 7 TeV	[2.47]	1.78	[1.78]
CMS 7 TeV	[2.40]	1.63	[1.66]
CMS 8 TeV	[3.81]	[2.67]	1.68
Total	1.18	1.19	1.20

- fit quality is equally good for 7 TeV or 8 TeV data
- 8 TeV data have a dominant impact on the gluon central value