

Leading and full colour

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Single jet inclusive

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Dijet production

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Summary

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NNLO QCD corrections at full colour for jet observables at the LHC

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DIS2022

arXiv: 2204.10173

May 3, 2022



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European Research Council
Established by the European Commission

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Single jet inclusive
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Summary
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Outline

Leading and full colour
Colour levels
NNLOJET

Single jet inclusive
Single jet inclusive

Dijet production
Doubly differential
Triply differential

Summary
Summary

Colour levels

- QCD corrections ordered in tower of colour factors N_c, n_f
- E.g. quark-gluon scattering

$$\mathcal{M}_{\text{full}} = (T^{a_1} T^{a_2})_{ij} \mathcal{M}(q, g_1, g_2, \bar{q}) + (T^{a_2} T^{a_1})_{ij} \mathcal{M}(q, g_2, g_1, \bar{q})$$

$$|\mathcal{M}_{\text{full}}|^2 = (N_c^2 - 1) N_c \left[M(q, g_1, g_2, \bar{q}) + M(q, g_2, g_1, \bar{q}) \right. \\ \left. + \frac{1}{N_c^2} \tilde{M}(q, g_1, g_2, \bar{q}) \right]$$

- Higher order, loops
 - LC: $N_c^2, n_f N_c, n_f^2$
 - SLC: $N_c^0, n_f/N_c, n_f^2/N_c^2, \dots$
 - FC = LC + SLC

Current standing

NNLO QCD corrections to jet observables at the LHC

- LC:
 - Inc. jet: [Currie, Glover, Pires '16]
 - Dijet prod.: [Currie, Gehrmann-De Ridder, Gehrmann, Glover, Huss, Pires '17] [Gehrmann-De Ridder, Gehrmann, Glover, Huss, Pires '19]
 - Three-jet: [Czakon, Mitov, Poncelet '21]
 - Gluons-only $gg \rightarrow ggg$: [Chen, Gehrmann, Glover, Huss, Marcoli '22]
- FC:
 - Gluons-only $gg \rightarrow gg$: [Currie, Gehrmann-De Ridder, Glover, Pires '13]
 - Inc. jet: [Czakon, van Hameren, Mitov, Poncelet '19]

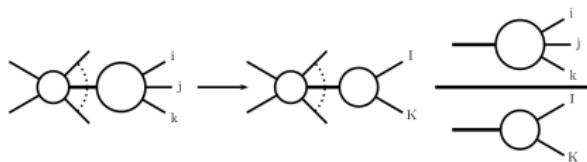
This work

This work: [Chen, Gehrmann, Glover, Huss, JM '22]

- Calculate LHC jet observables at NNLO FC
 - Single jet inclusive
 - Dijet production doubly differential
 - Dijet production triply differential
- Compare parton level predictions (+ NP + EWK) with CMS & ATLAS data
- Quantify SLC contribution and importance
- Relevant for:
 - Perturbative QCD tests over wide kinematic ranges
 - α_s determination
 - PDF constraints

NNLOJET

- Parton level event generator
- Antenna subtraction
- Based on colour ordered amplitudes representation

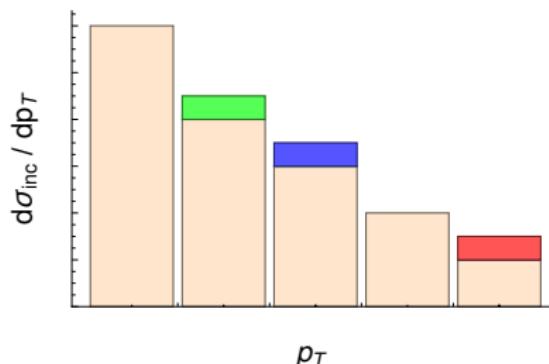
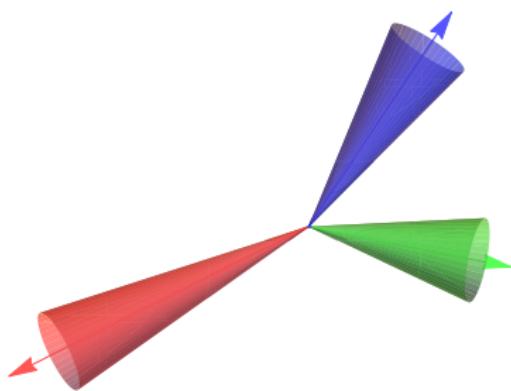


- LC coherent squares
- SLC interferences
 - More complex pole structure
 - Infrared singularities more difficult to subtract

Single jet inclusive

$$d\sigma(p + p \rightarrow j + X)$$

- Events with at least one jet
- Each jet contributes individually to histogram



Calculational setup

CMS $\sqrt{s} = 13$ TeV data

- Doubly differential in p_T and $|y|$
- Fiducial cuts

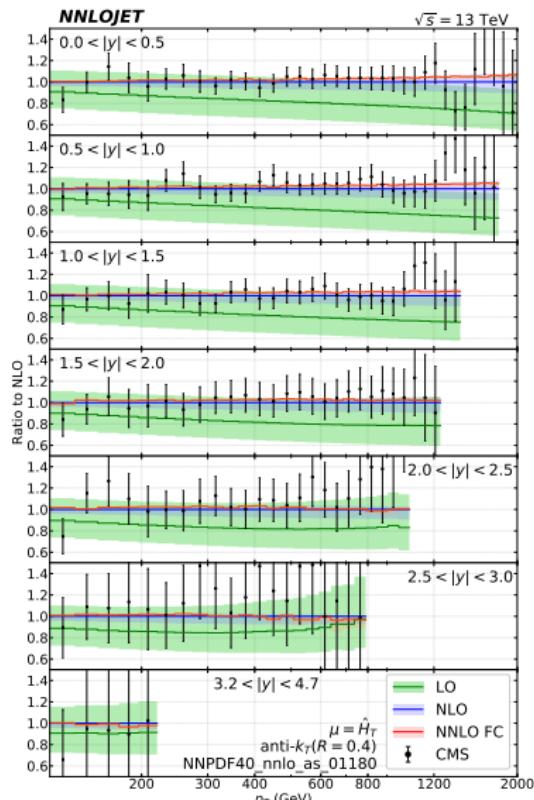
$$114 \text{ GeV} < p_T < 2000 \text{ GeV}, \quad |y| < 4.7$$

- Rapidity slices
 $|y|: [0, 0.5]; [0.5, 1]; [1, 1.5]; [1.5, 2]; [2, 2.5]; [2.5, 3]; [3.2, 4.7],$
- anti- k_T $R = 0.4$ and $R = 0.7$ jets

Predictions:

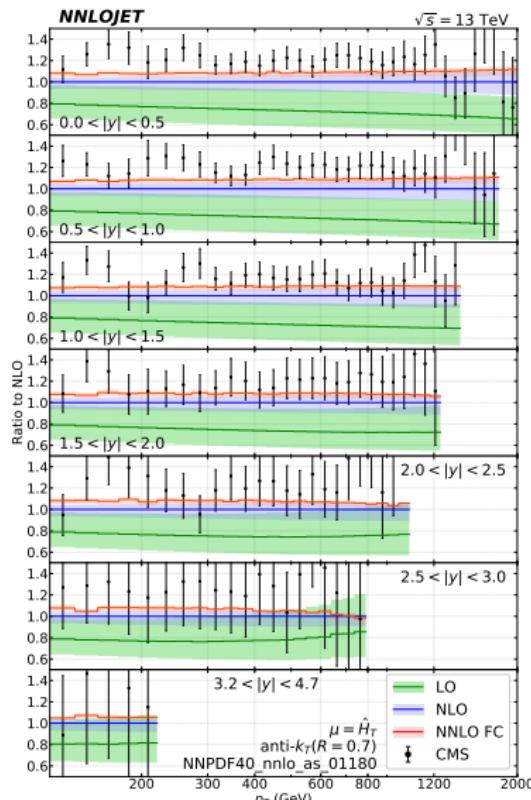
- 7-point scale variation of μ_R , μ_F around the central scale $\mu = \hat{H}_T$
- NNPDF4.0, $\alpha_s(M_Z) = 0.118$

$R = 0.4$



- Excellent perturbative convergence
- Large reduction of scale uncertainties
- Improved agreement with data
- Modest positive $d\delta\sigma_{NLO}$ 10-30%
- Very small $d\delta\sigma_{NNLO}$ 1-3%
- Net effect of SLC contributions on cross section tiny

$$R = 0.7$$

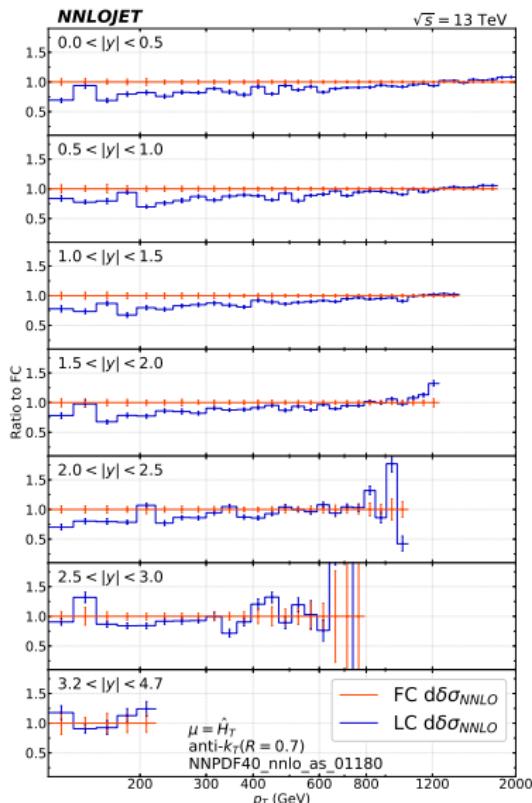


- Larger $d\delta\sigma_{NLO}$ 25-40%
- Larger positive throughout $d\delta\sigma_{NNLO}$ 8-10%
- Small overlap of scale bands
- Improved agreement with data

LC vs FC

 $R = 0.7$

- Positive NNLO SLC contributions
- SLC largest at low p_T : $\sim 20\%$ of FC $d\delta\sigma_{NNLO}$
- Diminishes to 0 at high p_T for all rapidity bins
- Small SLC effect ($< 2\%$) on NNLO, within scale uncertainty
- SLC fulfills $\frac{1}{N_c^2}$ expectation



Leading and full colour
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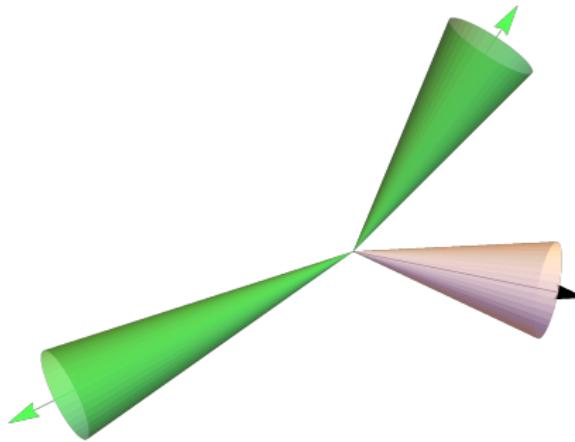
Single jet inclusive
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Dijet production
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Summary
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Dijet production

- Reconstruction based on the 2 leading jets
- Each event contributes once to the cross section



Calculational setup

ATLAS 7 TeV 4.5 fb⁻¹ data

- Cross section as function of m_{jj} , spanning from 260 GeV to 5 TeV
- Rapidity difference slices y^* from 0.0 to 3.0 with width 0.5
- Fiducial cuts:

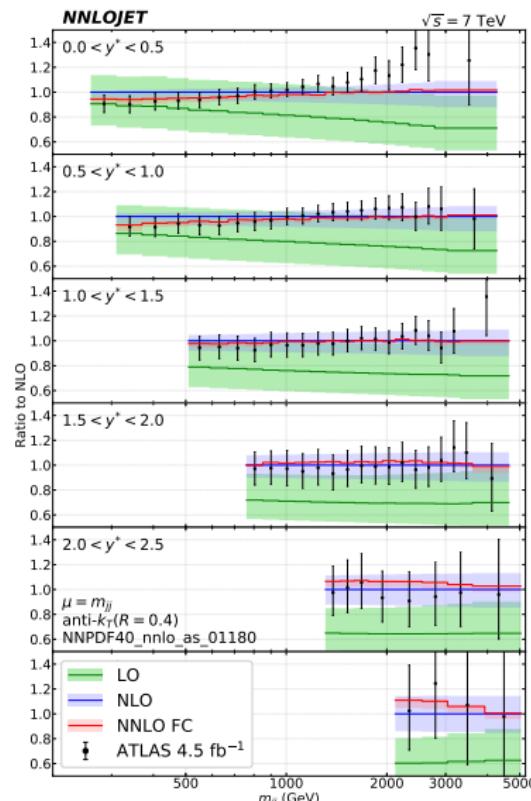
$$p_{T_1} > 100 \text{ GeV}, \quad p_{T_2} > 50 \text{ GeV}, \quad |y| < 3.0$$

- anti- k_T $R = 0.4$ jets

Predictions:

- 7-point scale variation of μ_R , μ_F around the central scale $\mu = m_{jj}$
- NNPDF4.0, $\alpha_s(M_Z) = 0.118$

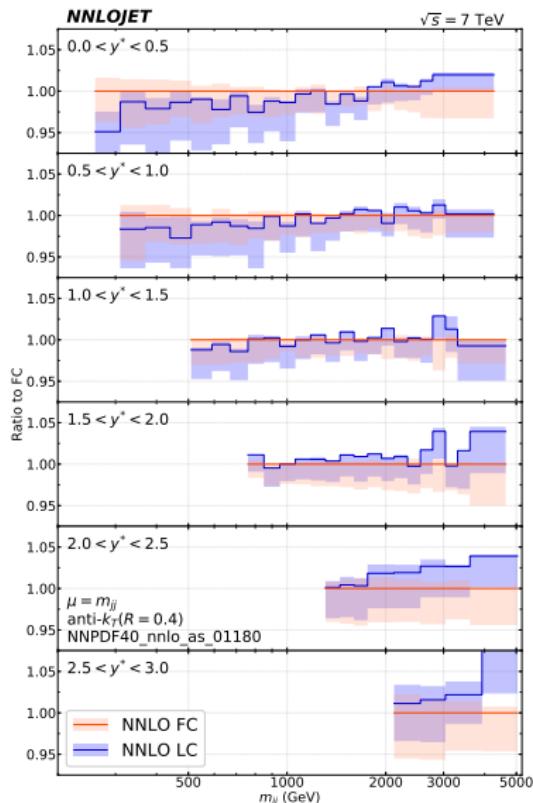
Comparison with data



- Low y^* :
 - Modest $d\delta\sigma_{NLO}, d\delta\sigma_{NNLO}$
 - $d\delta\sigma_{NNLO}$ negative at low m_{jj} , negligible at higher m_{jj}
- Higher y^*
 - Larger $d\delta\sigma_{NLO}$
 - $d\delta\sigma_{NNLO}$ positive throughout m_{jj}
- Substantial decrease of scale variation
- Data well described by NNLO QCD

LC vs FC

- Small SLC effect
- At low y^* and small m_{jj} FC larger than LC
- Reverse at higher y^*
- FC $d\delta\sigma_{NNLO}$ tiny and changing sign



Triply differential

CMS 8 TeV 19.7 fb⁻¹

- Differential in $p_{T,\text{avg}}$
- Six bins in (y_b, y^*) space:

$$y_b \times y^* : \quad [0, 1] \times [0, 1]; \quad [0, 1] \times [1, 2]; \quad [0, 1] \times [2, 3]; \\ [1, 2] \times [0, 1]; \quad [1, 2] \times [1, 2]; \quad [2, 3] \times [0, 1],$$

- Fiducial cuts:

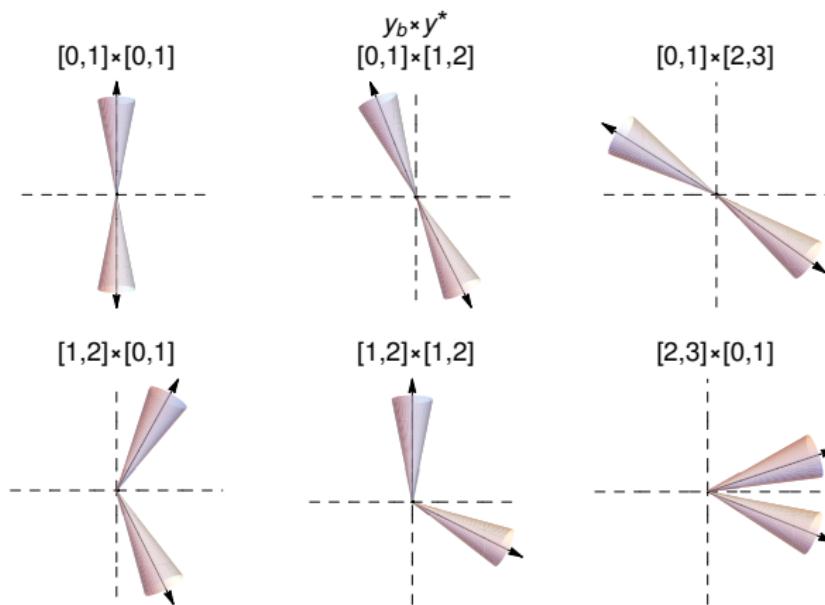
$$|y| \leq 5.0, \quad p_{T_{1,2}} \geq 50 \text{ GeV}, \quad |y_{1,2}| \leq 3.0$$

- anti- k_T $R = 0.7$ jets

Predictions:

- 7-point scale variation of μ_R , μ_F around the central scale $\mu = m_{jj}$
- NNPDF4.0, $\alpha_s(M_Z) = 0.118$
- Parton level predictions supplemented with NP and EWK

Event topologies

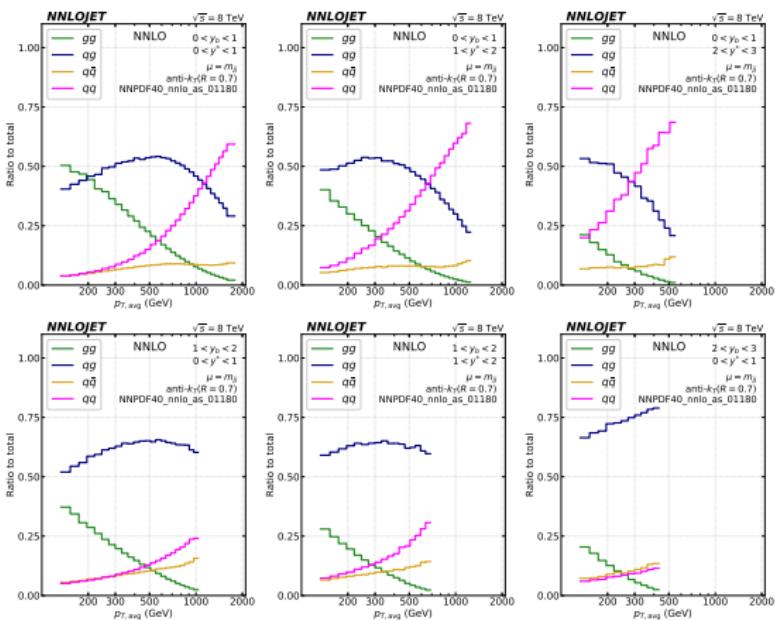


- Ideal for PDF studies and constraints

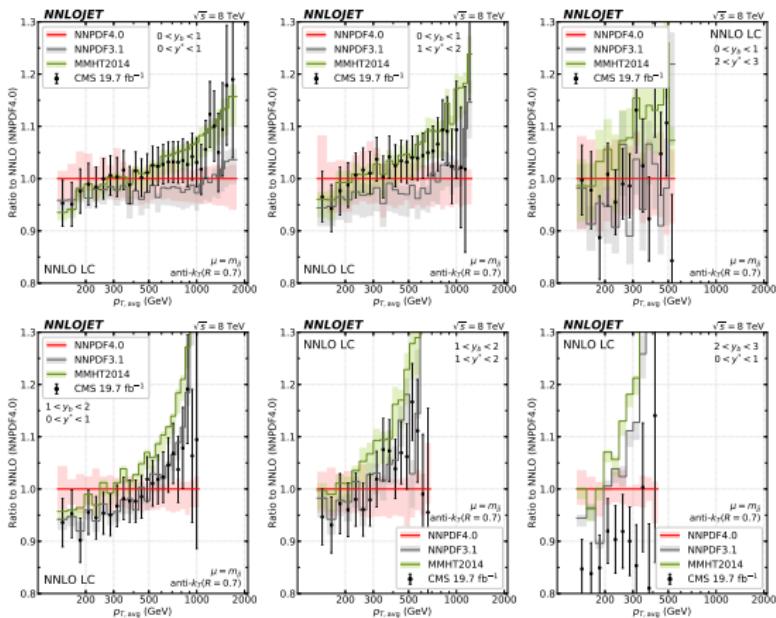
Channel breakdown

Decompose according to different partonic initial states:

- ***gg***: central y_b and low p_T
- ***qg***: dominant at high y_b , falls off at high p_T
- ***q̄q***: subdominant throughout (< 0.1)
- ***qq***: central y_b and high p_T

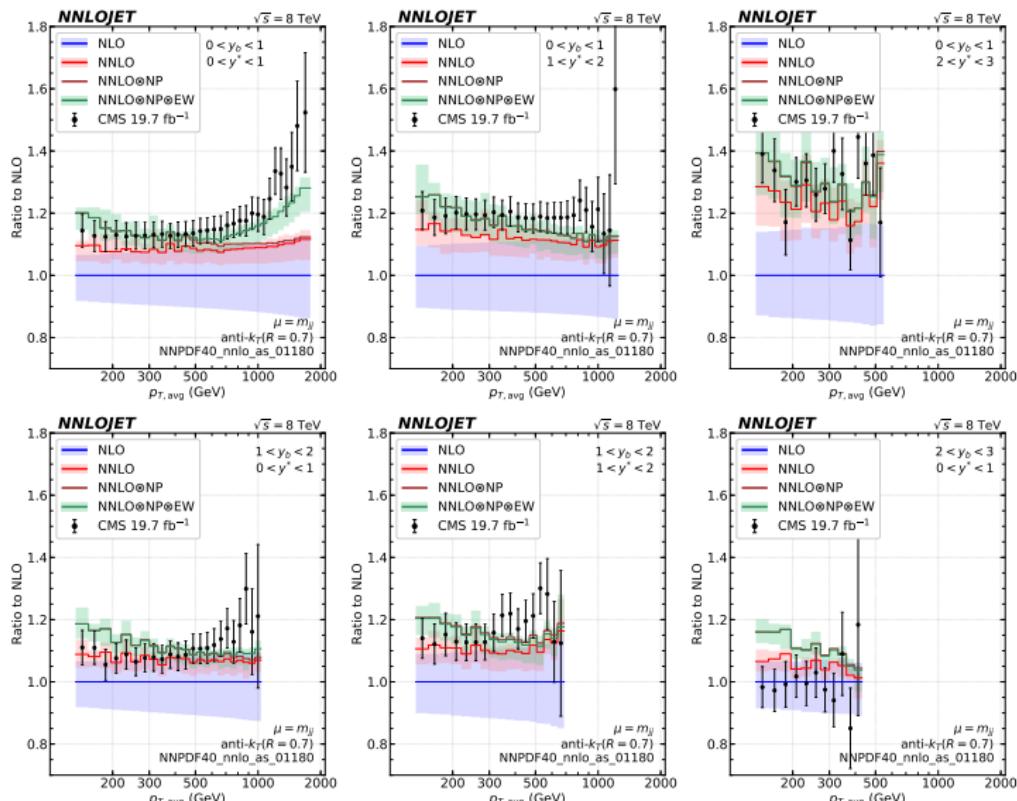


PDF comparison



- Central y_b bins described well with MMHT2014
- MMHT2014 overshoots data at higher y_b
- NNPDF3.1 good agreement in low y^* bin
- NNPDF4.0 differs significantly, especially in tail region

Comparison with data

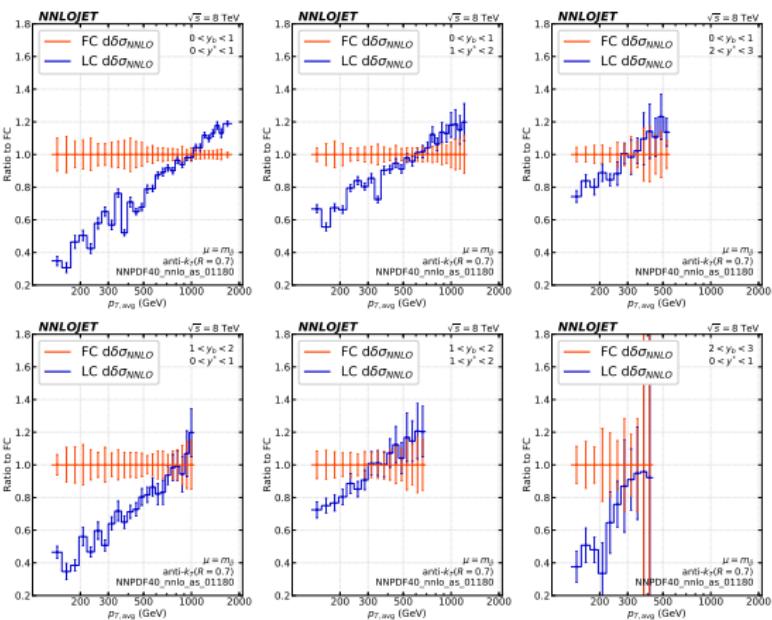


LC vs FC

- Large SLC contributions

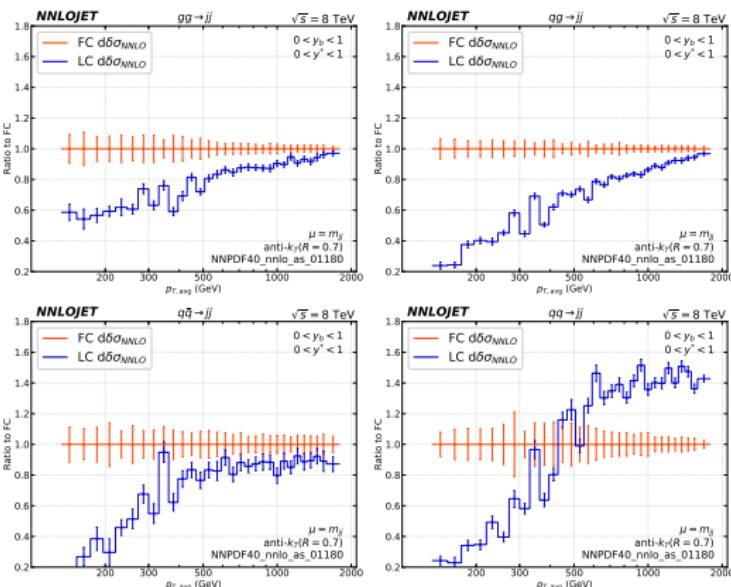
- Low $p_{T,\text{avg}}$: 30% to 60%
- Medium $p_{T,\text{avg}}$: decreasing magnitude
- High $p_{T,\text{avg}}$: -20% SLC

- Enhance LC NNLO with 5% at low $p_{T,\text{avg}}$



Central rapidity region

- Low p_T : SLC in all channels positive and comparable magnitude as LC
- $gg, qg, q\bar{q}$: magnitude SLC decreases to $\sim 10\%$ as p_T increases
- qq : SLC becomes negative (-30%)
- Cancellations among different partonic channels



Summary

- FC NNLO QCD corrections have been calculated for single jet inclusive and dijet production cross sections at the LHC
 - Good agreement with data
- SLC contributions have been quantified
 - Nonuniform, with variation between different channels
 - Small impact on NNLO predictions for single inclusive jet cross sections
 - Larger effect in dijet cross sections
 - Still small effect for double differential $R = 0.4$ histograms
 - Substantial in the triple differential $R = 0.7$ distributions
 - Potential impact on PDF constraints from jet data