Scales for Jets

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Scales for Jets

http://www.aircraftscales.com/

Outline

- criteria for scale choices
- canonical scales for inclusive jets
- NNLO results for canonical scales
- novel scales for inclusive jets
- scales for dijets

Criteria for scale choice

Scale parameterization often chosen a posteriori based on:

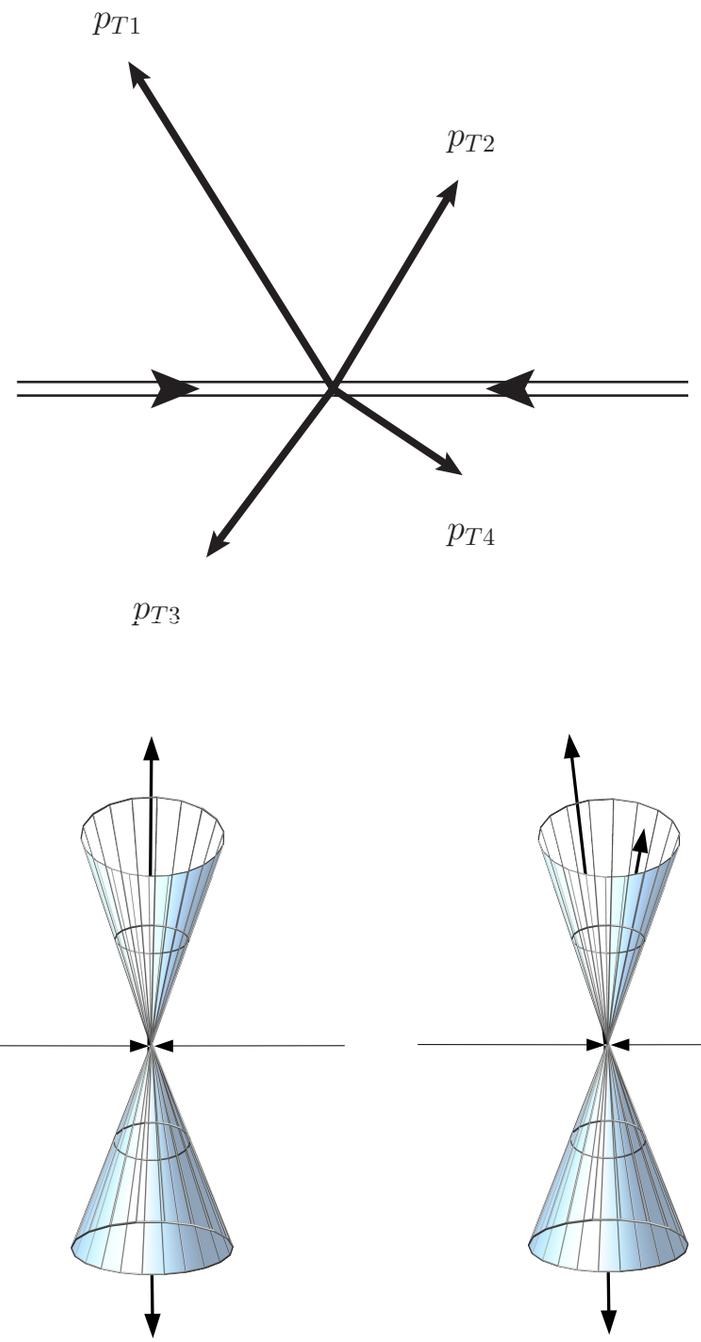
- minimal sensitivity (at what order?)
- fastest convergence
- agreement with data (if that's what you want)

or a priori based on:

- knowledge of specific large logs
- general arguments: underlying physical scales, R-V cancellations
- a formal scale fixing scheme (CORGI, PMC etc)

Canonical scale choices

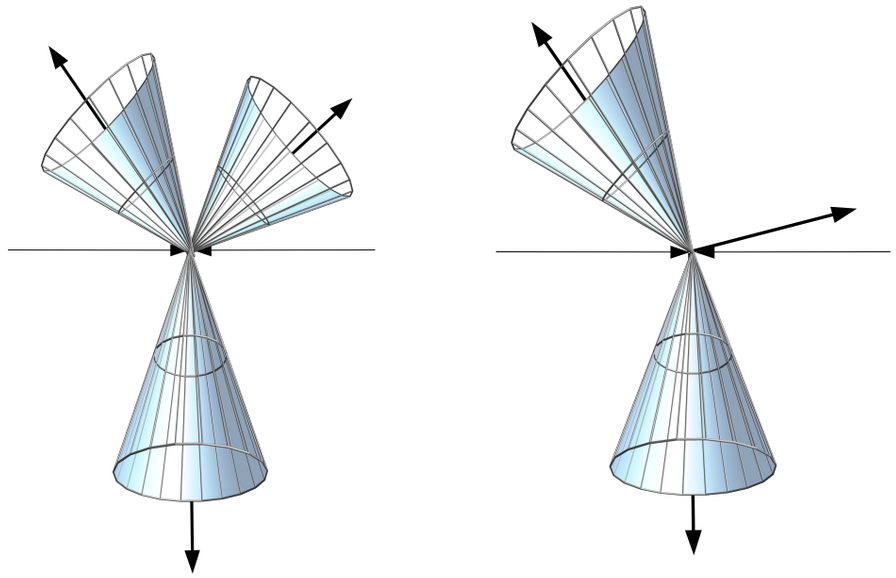
- no fixed hard scale for jet production.
- two widely used scale choices:
  - leading jet p_{T1} for all jets in an event
  - individual jet p_T
- smaller scale changes PDFs and α_s
- no difference for back-to-back jet configurations (only arises at higher orders)



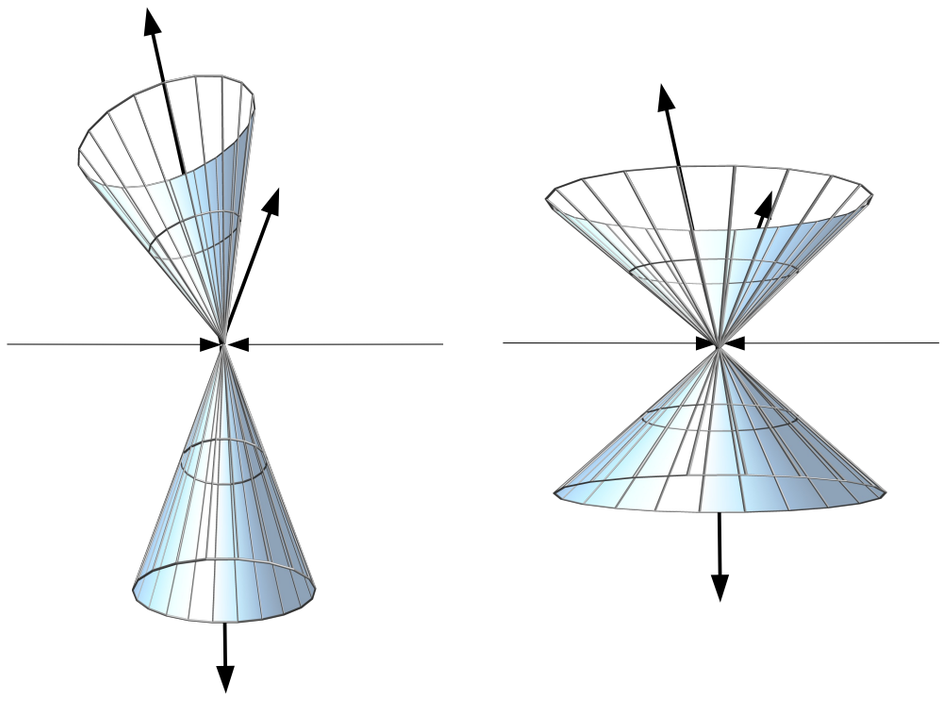
At NLO, p_T != p_{T1} for:

- 3-jet rate (small rate)
- 2-jet rate (3rd parton falls outside jet, fails cuts)

Changing *R* has an effect on the cross section, but also on the scale choice:



- introduces spurious *R*-dependence in scale choice
- p_{T1} scale has no *R*-dependence at NLO, unlike p_T
- at NNLO even p_{T1} scale choice has *R*-dependence in some four-parton configurations



Our calculation

We have recently completed the NNLO calculation [PRL 118, 072002 (2017)]:

- implemented in the NNLOJET framework: semi-automated code generation, interface to APPLGrid

- IR divergences removed using antenna subtraction: analytic pole cancellation, all ingredients known for NNLO pp scattering

- calculated at “leading colour” in each partonic subprocess: i.e. all N^2, NN_F, N_F^2 corrections to Born-level subprocesses

  e.g. RR gg: $gg \to gggg, \quad gg \to ggq\bar{q}, \quad gg \to q\bar{q}q\bar{q}$ etc

- fully differential results in p_T and y

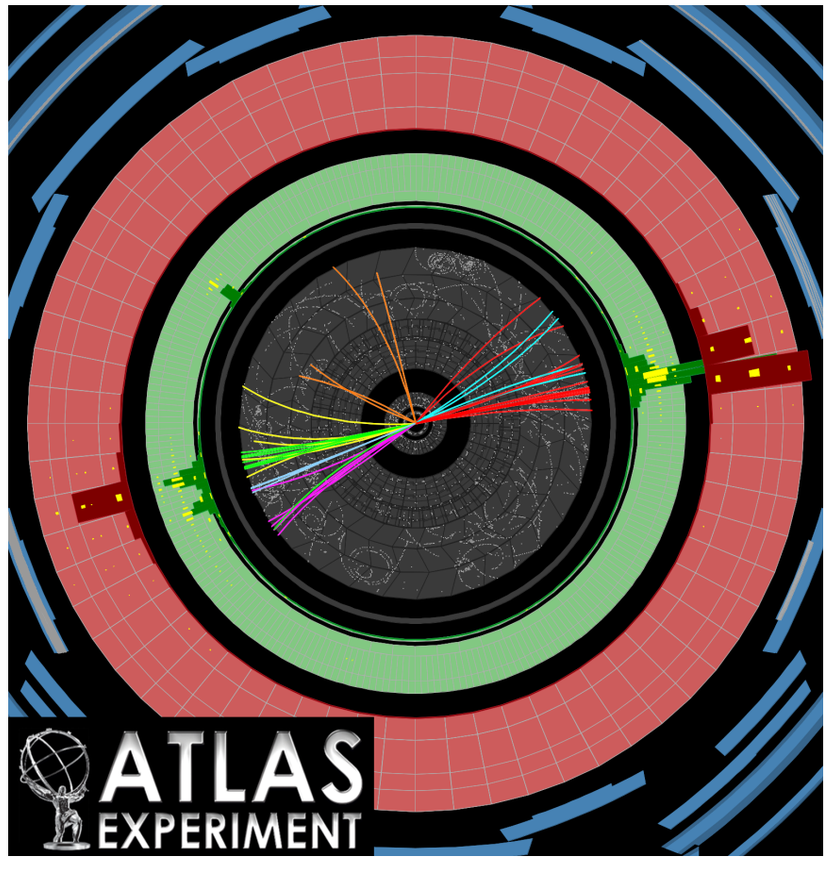
Setup

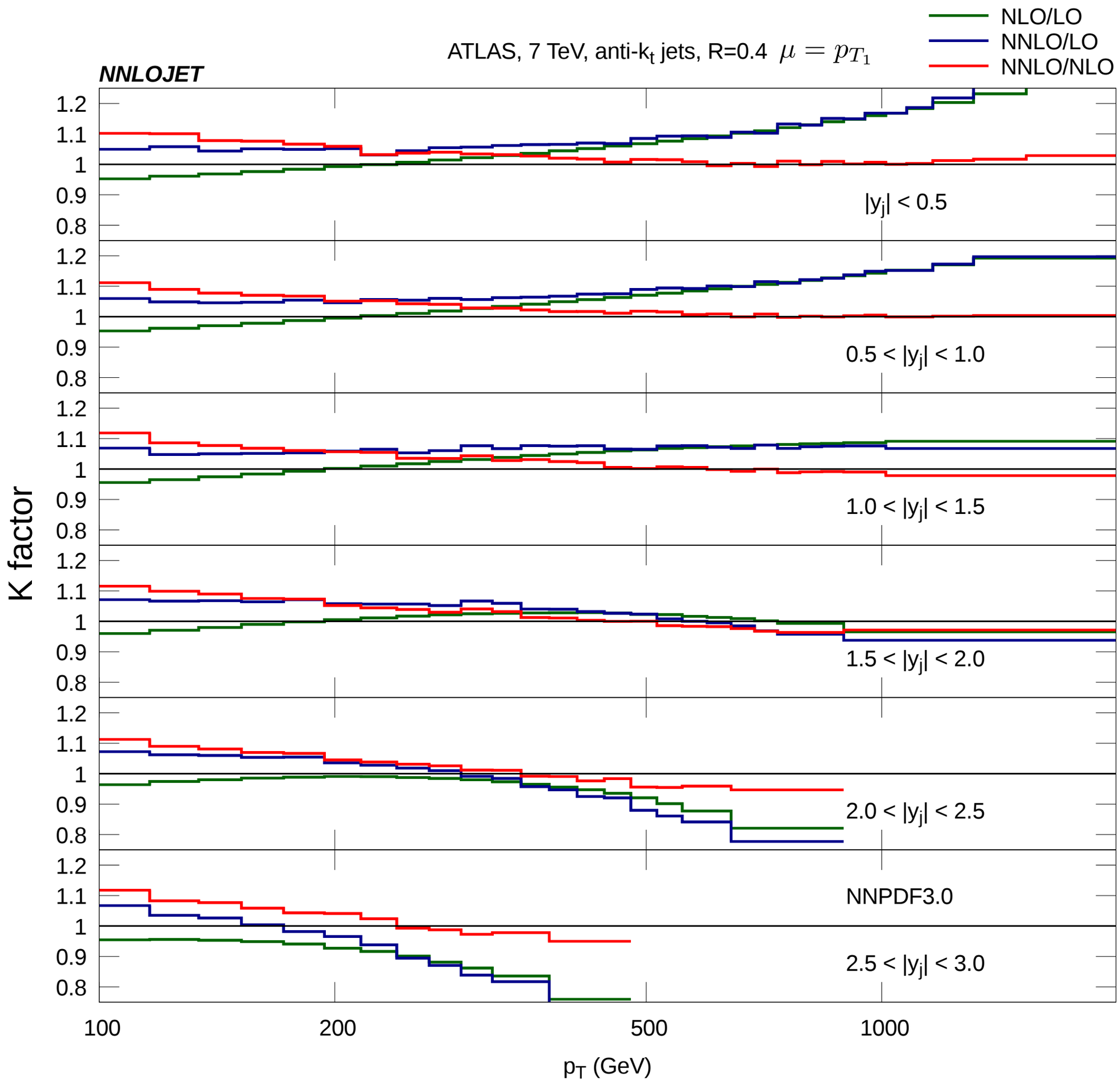
Theory setup:

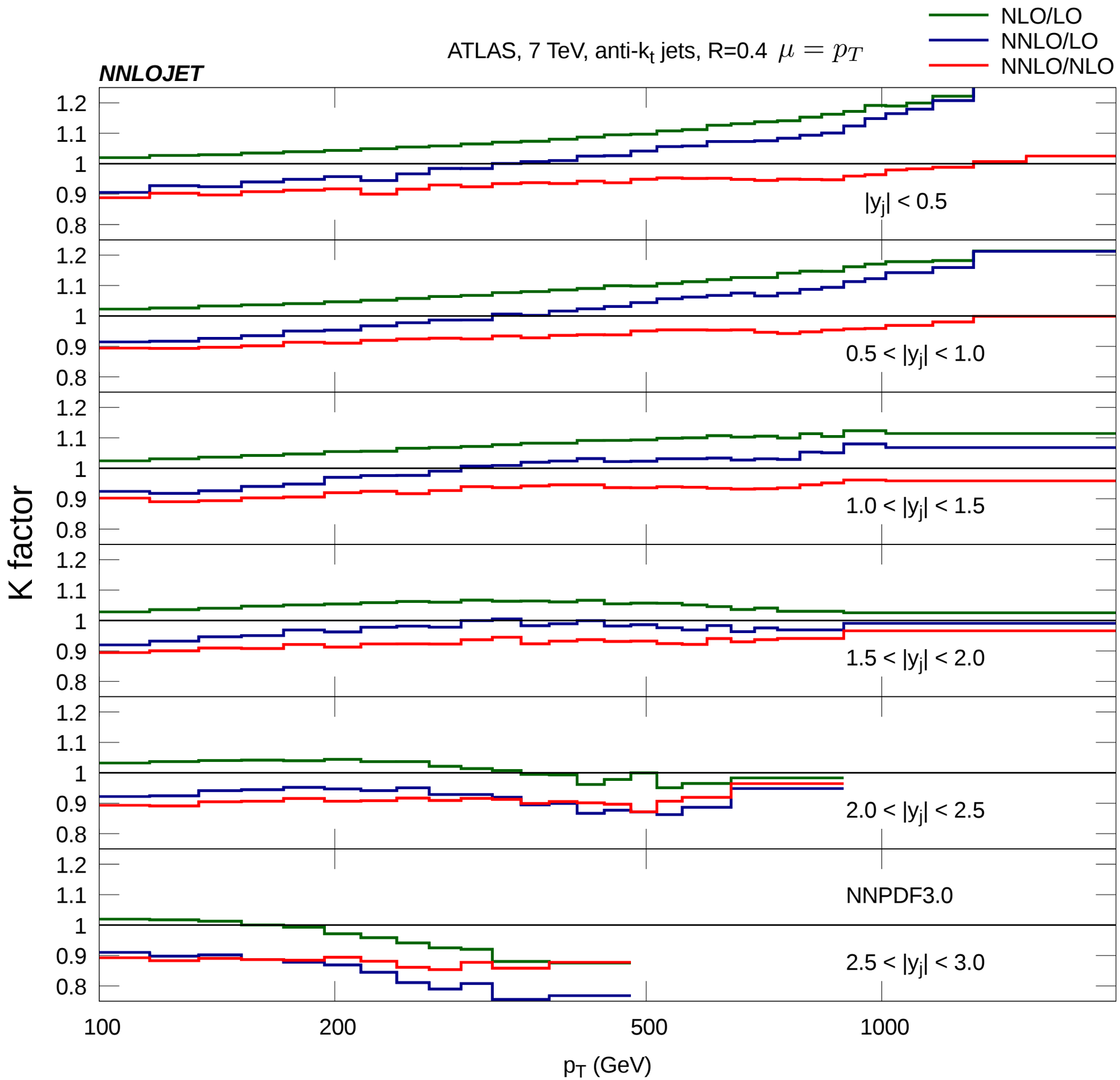
- NNPDF3.0_NNLO
- anti-k_T jet algorithm, 4-vector recombination
- scale choices $\mu_R = \mu_F = \{p_{T_1}, p_T\}$
- vary up and down by factors of 2

Comparison to data:

- ATLAS 7 TeV 4.5 fb^{-1}
- p_T > 100 GeV, |y| < 3.0
- R=0.4




NLO/LO
NNLO/LO
NNLO/NLO
ATLAS, 7 TeV, anti-k$_t$ jets, R=0.4 $\mu = p_{T_1}$
NNLOJET
|y$_j$| < 0.5
0.5 < |y$_j$| < 1.0
1.0 < |y$_j$| < 1.5
1.5 < |y$_j$| < 2.0
2.0 < |y$_j$| < 2.5
2.5 < |y$_j$| < 3.0
NNPDF3.0
K factor
p$_T$ (GeV)
100
200
500
1000
0.8
0.9
1
1.1
1.2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100
200
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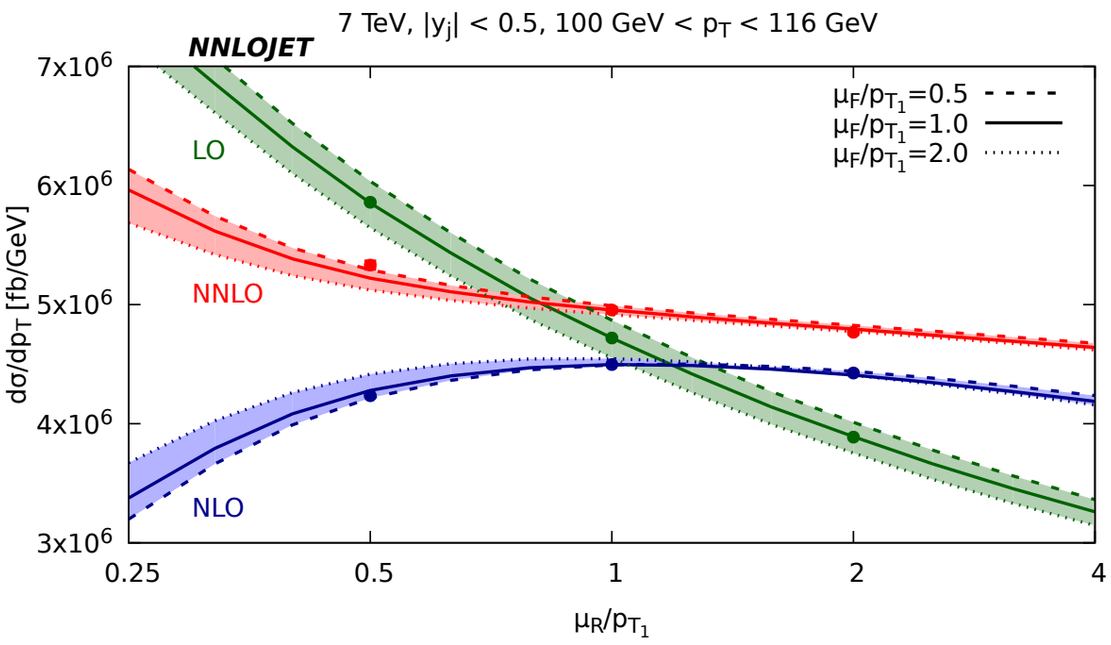
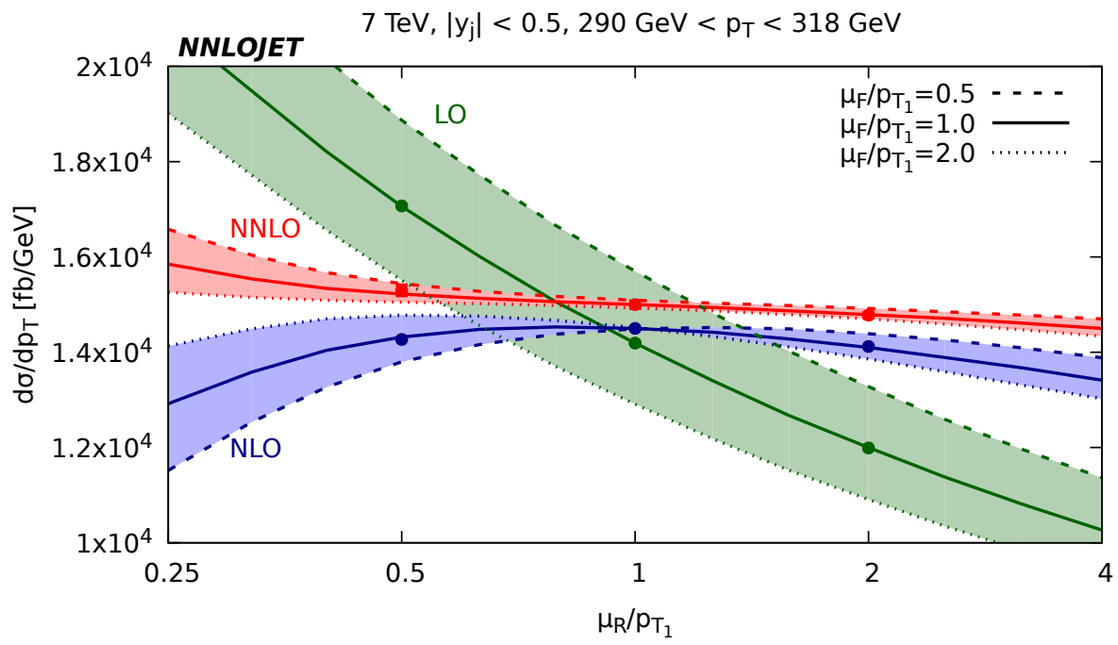
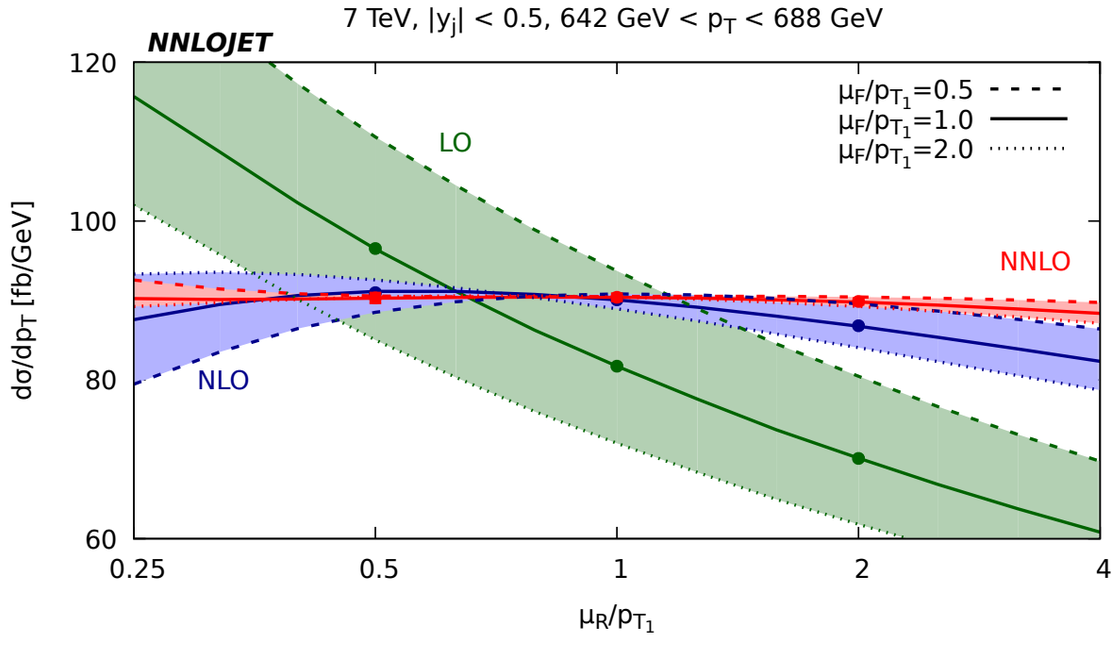
p_T (GeV)

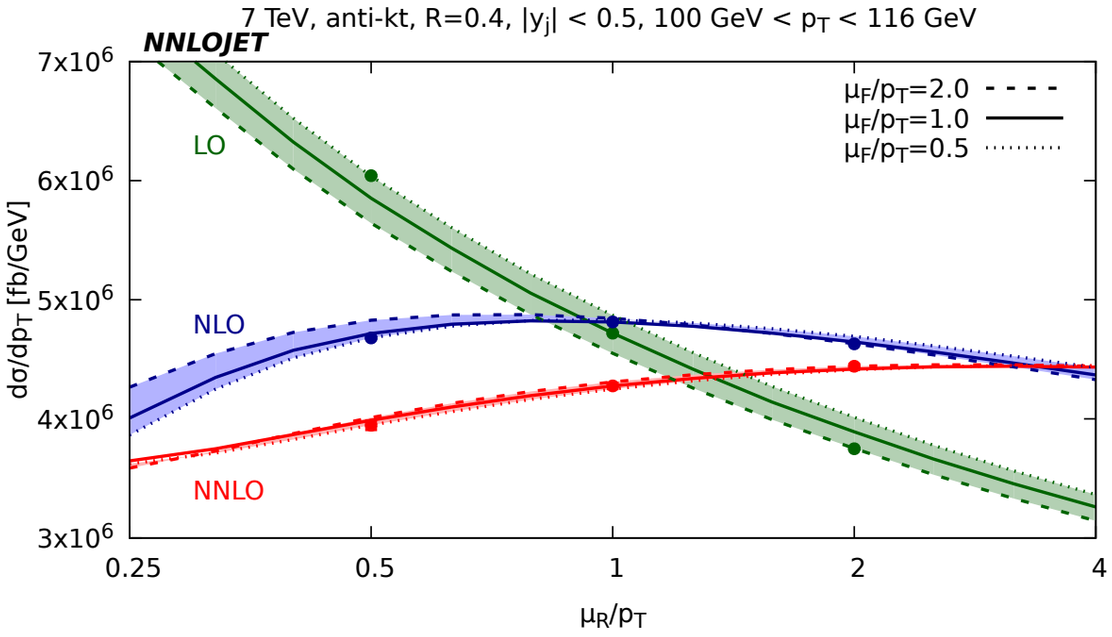
Scale variation p_{T1}

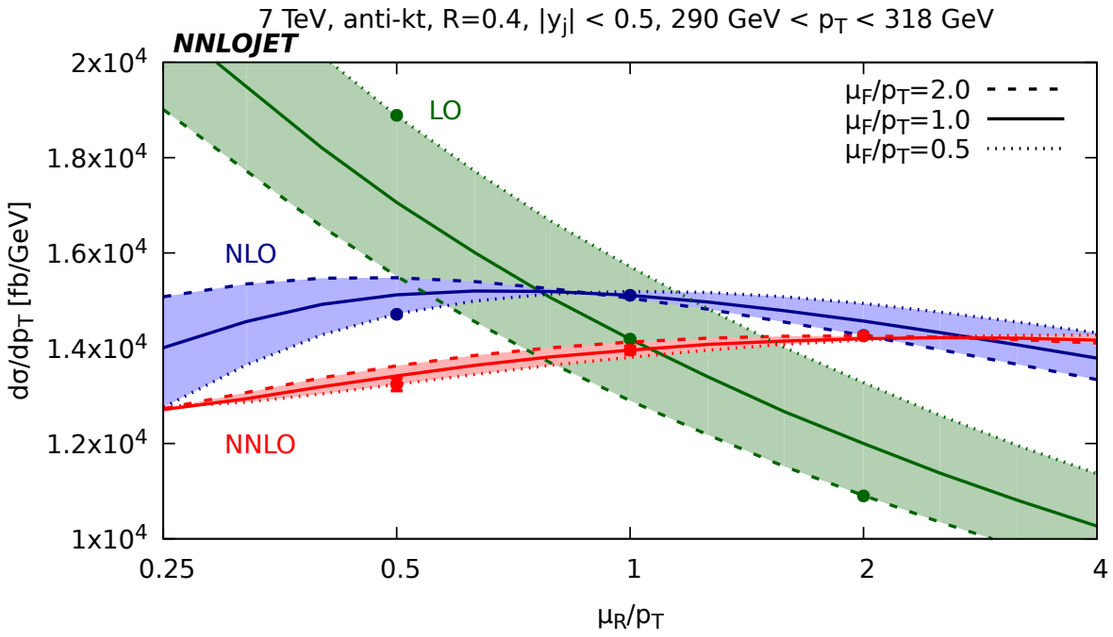


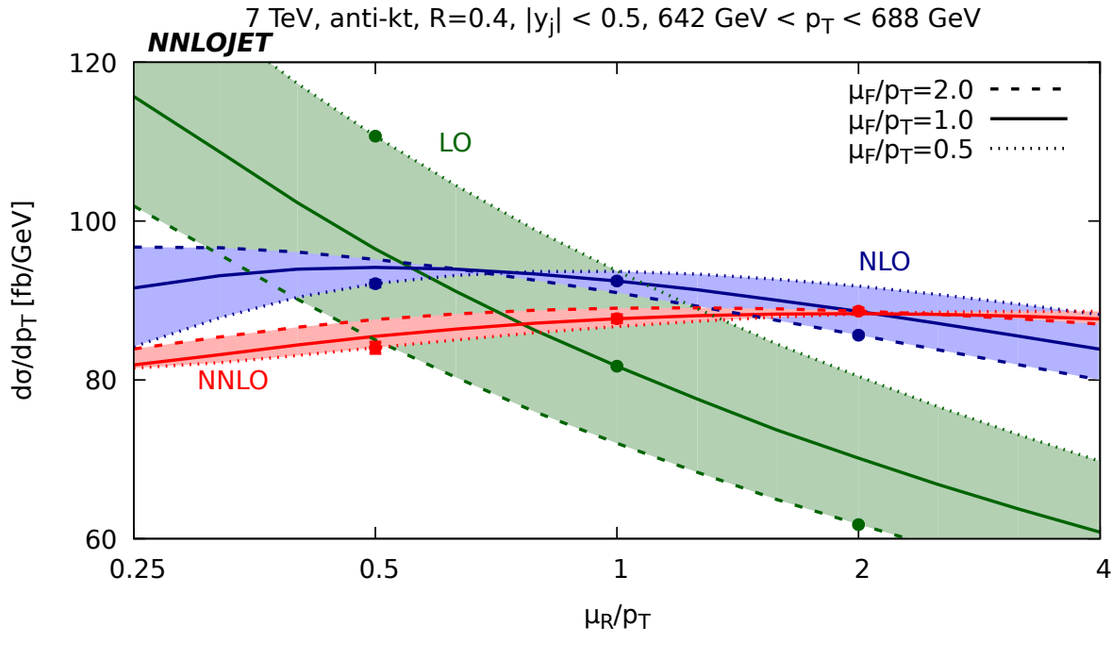




Scale variation p_T







NLO
NNLO
NNLOxEW

ATLAS, 7 TeV, anti-k_t jets, R=0.4 $\mu = p_{T_1}$

NNLOJET

Ratio to NLO

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NNPDF3.0

p_T (GeV)

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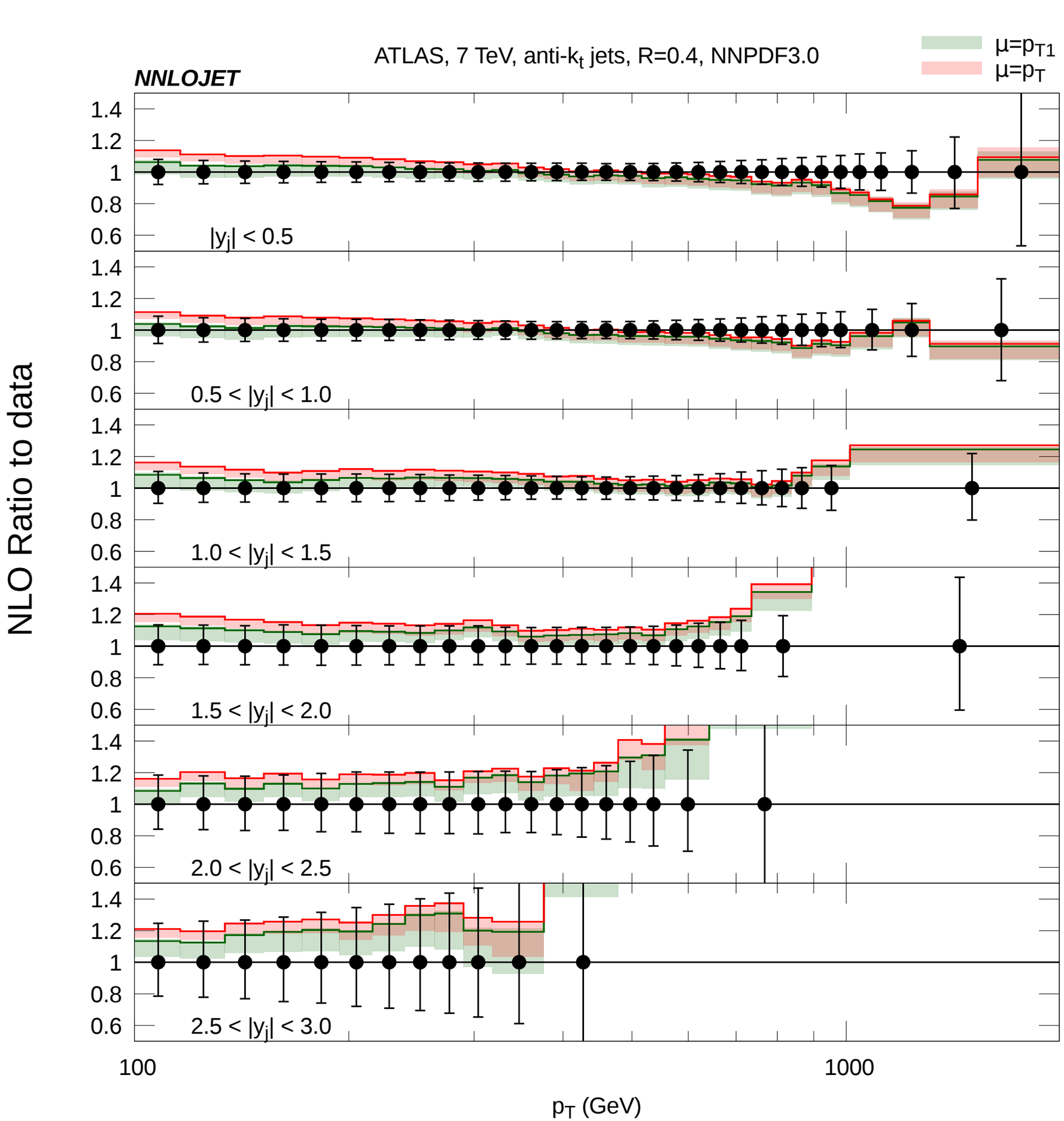
NNPDF3.0

p_T (GeV)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μ=p$_T$
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$\mu=p_{T1}$

$\mu=p_T$

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1.2
1
0.8
0.6

100

1000

p_T (GeV)

Novel scales

Neither p_{T1} nor p_T are wholly satisfactory; can consider other scale choices:

$$\frac{1}{2}H_T = \frac{1}{2}\sum p_{T,i}$$

$$\bar{p}_{T,12} = \frac{1}{2}(p_{T_1} + p_{T_2})$$

$$\hat{p}_{T,12} = \sqrt{p_{T_1} p_{T_2}}$$

- all reduce to p_T, p_{T1} for balanced jets (LO, V, VV, ~ high p_T)
- Hotness of partons harder than p_{T1} whenever real radiation
- average p_T scales smaller than p_T scale for 1-jet, larger for 2,3,4-jet sample
- geometric average smaller than arithmetic average
- can also define scales with different R [Dasgupta, Dreyer, Salam, Soyez]

Dijet scales @ NLO

For dijets some obvious scale choices

$$\mu \sim \ m_{jj},\ p_{T_1},\ \bar{p}_{T_{12}}$$

Ellis, Kunszt, Soper ['92] suggested a form that interpolates between m_{jj} and p_{T1}

$$\mu = \frac{a\ m_{jj}}{2\cosh\left(b\ y^*\right)}$$

At LO $m_{jj} = 2p_T \cosh\left(y^*\right)$

EKS found that a=0.5, b=0.7 minimizes NLO corrections across a range of y*

Experiments have commonly used $\mu = p_{T_1} e^{0.3y^*}$ i.e. approx a=1, b=0.7

- p_{T1} and p_{T12} scales give large negative NLO corrections (even negative x-sec) for large y*
- $m_{jj}/2$ scale is natural and gives reasonable NLO corrections for all y*

Summary

- we have recently completed the NNLO calculation of jet production using antenna subtraction in NNLOJET framework

- two canonical scale choices for inclusive jets: p_{T1}, p_T identical at LO, differences emerge at NLO, get larger for NNLO (…and beyond?)

- for medium to high p_T: series highly convergent, small scale variation, small parametric uncertainty

- for low p_T: significant NNLO K-factors, scale variation and non-overlapping bands for different scale choices

- other scales available, NNLO investigation ongoing, also dijets

- unless a scale choice can be settled on, can't justify using low p_T data for phenomenology