Jets and Photons (theory)

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with A.Huss, G.Ferrera on behalf of the WG1: Standard Model QCD physics subgroup

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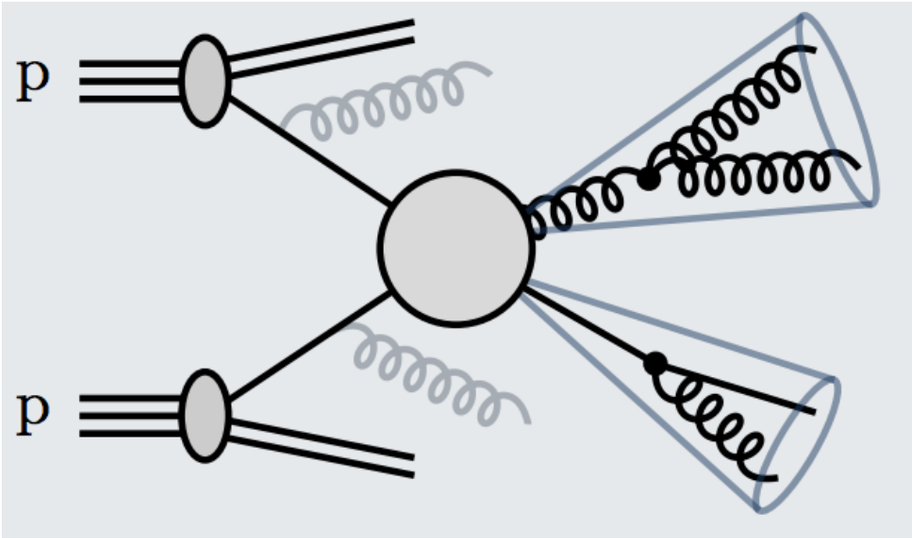
Introduction

Single inclusive and dijet inclusive production:

- *pp->jet +X ; pp->2jet +X*
- inclusive jet p_T: all reconstructed jets in the event contribute to the observable
- inclusive over all additional radiation



Single inclusive and diphoton inclusive production:

- *pp->γ +X ; pp->$\gamma\gamma$ +X*
- isolated photon pairs → clean final state. Photon energies/momenta measured with high precision.

Consider inclusive jet and photon production at 14 TeV and 27 TeV

- higher order corrections effects
- ratios of cross section and kinematical range at 14 TeV and 27 TeV

Inclusive jet production at HE/HL-LHC

Single jet inclusive production:

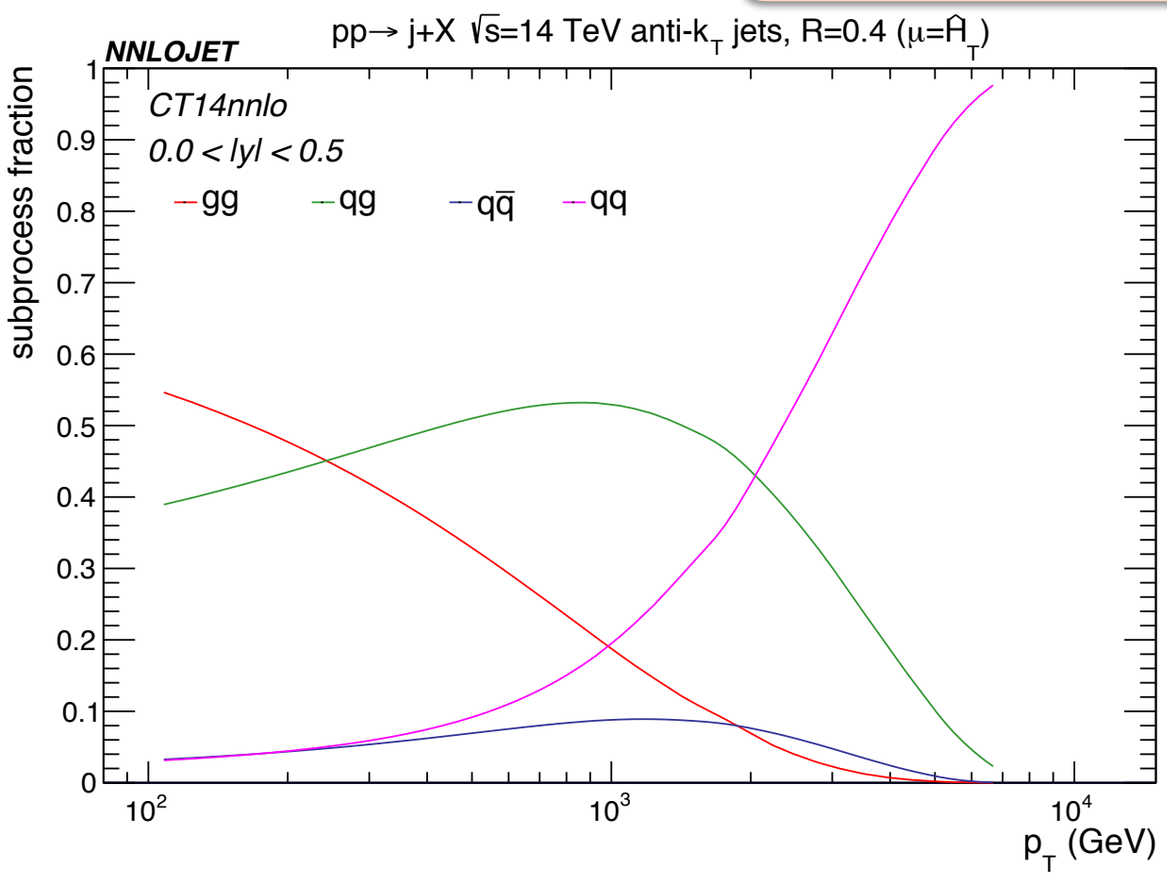
- *pp->jet +X* run with *NNLOJET** for the fixed order perturbative QCD predictions
- PDF=CT14nnlo, α_s=0.118
- $\mu_R=\mu_F=\hat{H}_T$ (scalar sum of parton transverse momenta)
- Jets: anti-k_T with *R=0.4*
- Fiducial volume defined through the cuts

$$|y^j| < 4.0, \qquad p_T^j > 100 \text{ GeV}$$

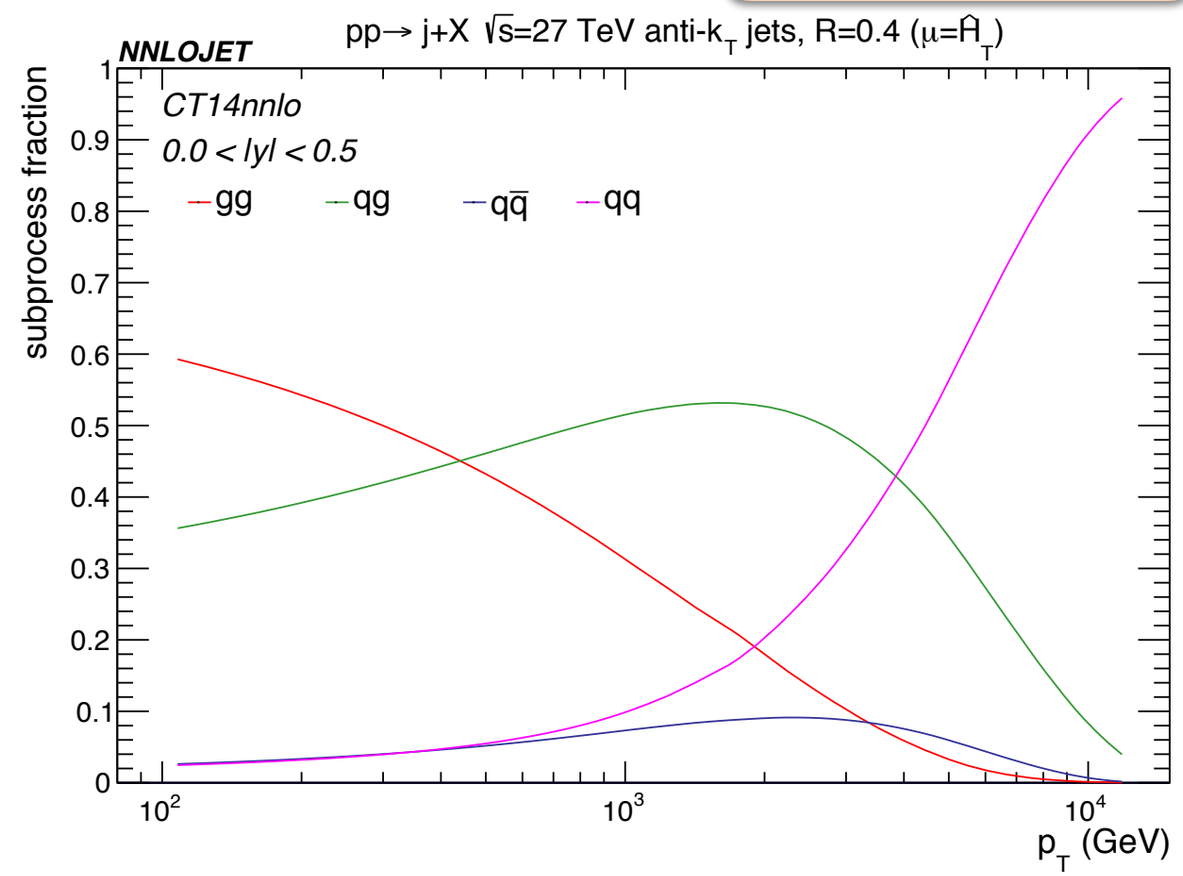
X.Chen,J.Cruz-Martinez, J.Currie, R.Gauld, T.Gehrmann, A.Gehrmann-De Ridder,E.W.N.Glover, M.Höfer, A.Huss, T.Morgan, I.Majer, J.Niehues, D.Walker, JP* *[arXiv: 1801.06415]*** *and references therein*

Subprocess fractions

$\sqrt{s} = 14$ TeV



$\sqrt{s} = 27$ TeV



- enhanced *gluon*-luminosity at 27 TeV over 14 TeV → large-x PDF turn into medium-x PDFs
- increased sensitivity to *qg/gg* initiated channels → dominate between 100 GeV-4000 GeV
- *qq* contribution dominant at high-p_T > 4 TeV
- $q\bar{q}$ contribution small across the entire p_T range

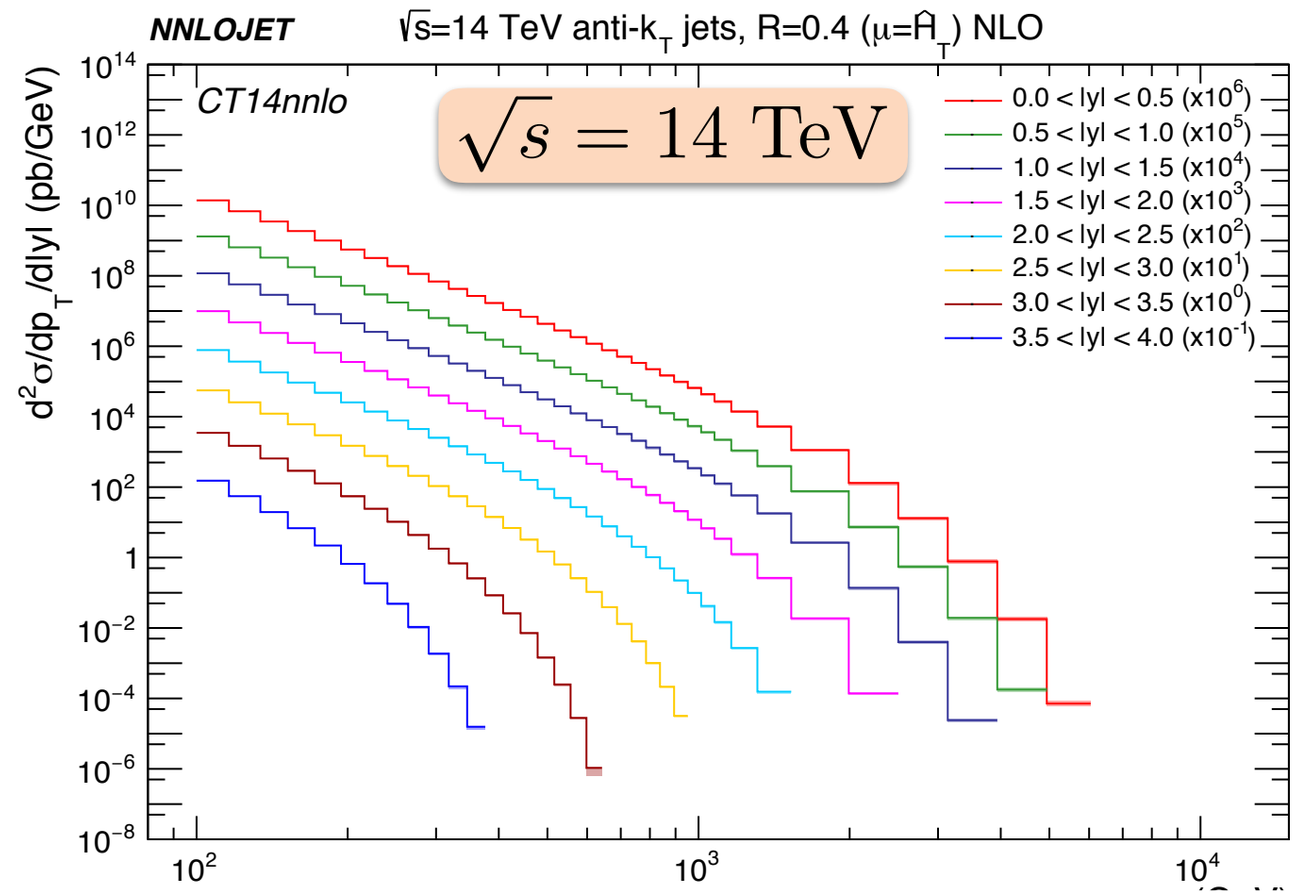
Jet p_T and rapidity at 14 and 27 TeV

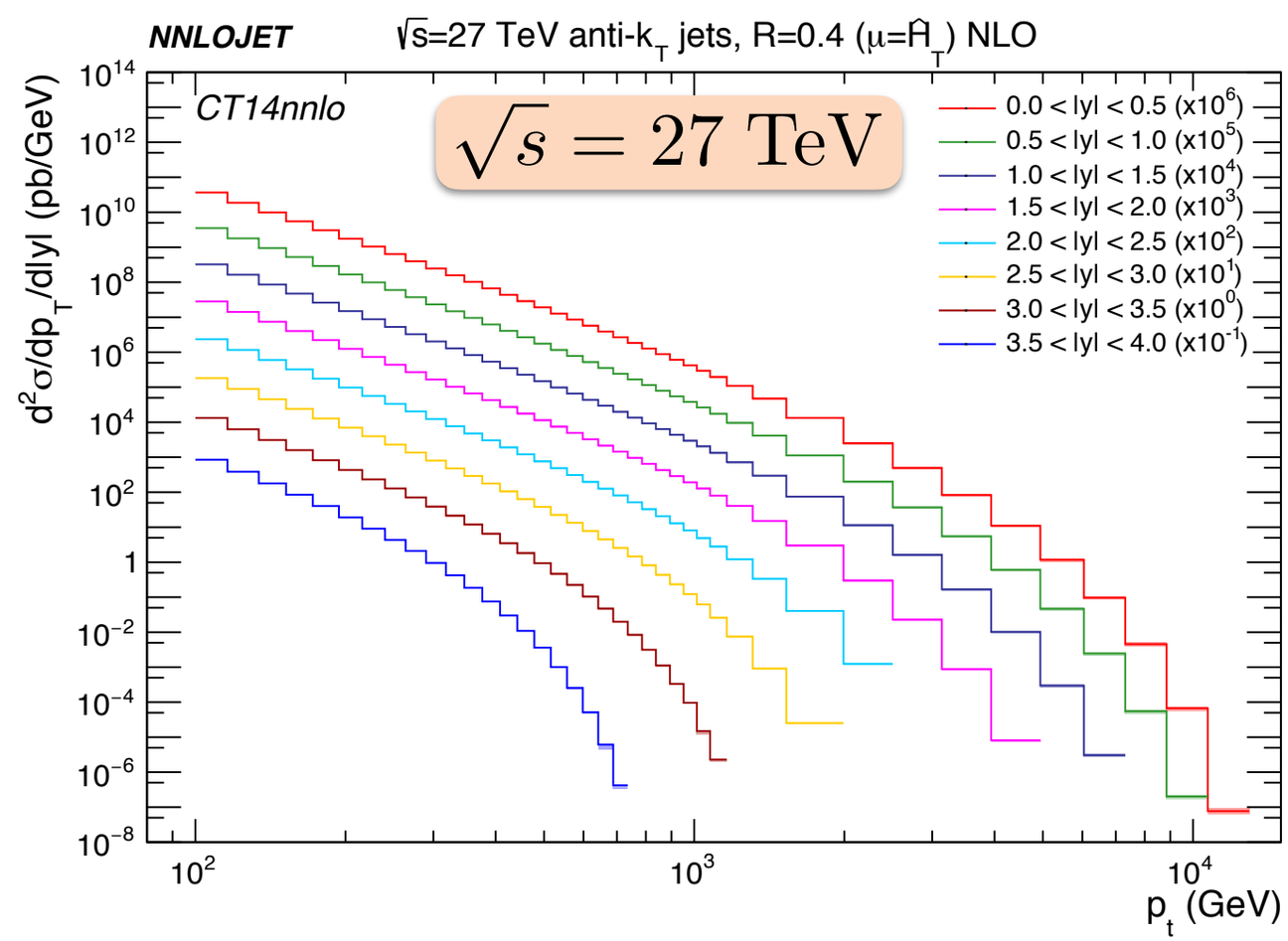
- NLO prediction shown
- Increased range of the observable into the TeV region at 27 TeV
- Large rates allow multi-differential measurements

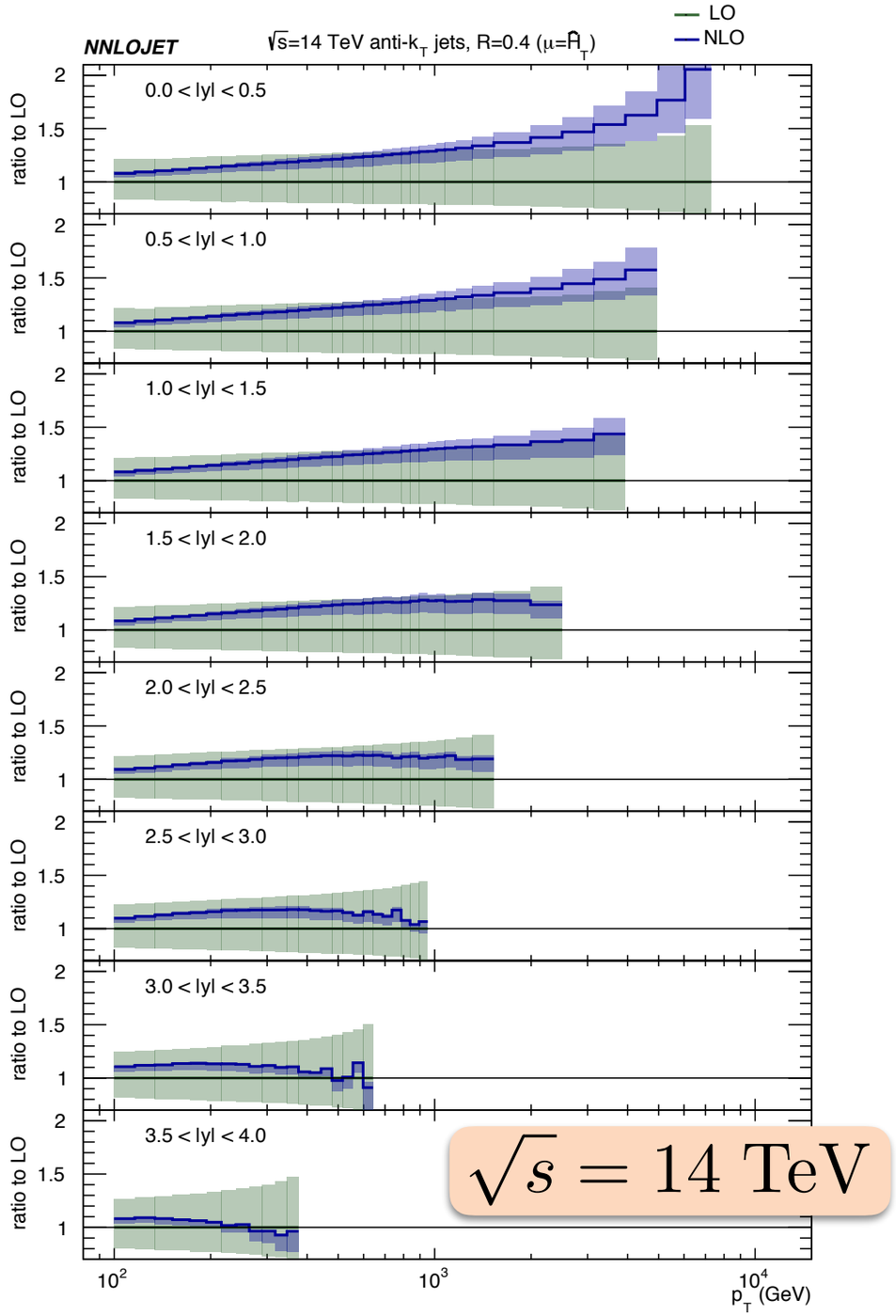
$$x_1 = \frac{p_T}{\sqrt{s}}(e^{y_{j1}} + e^{y_{j2}})$$

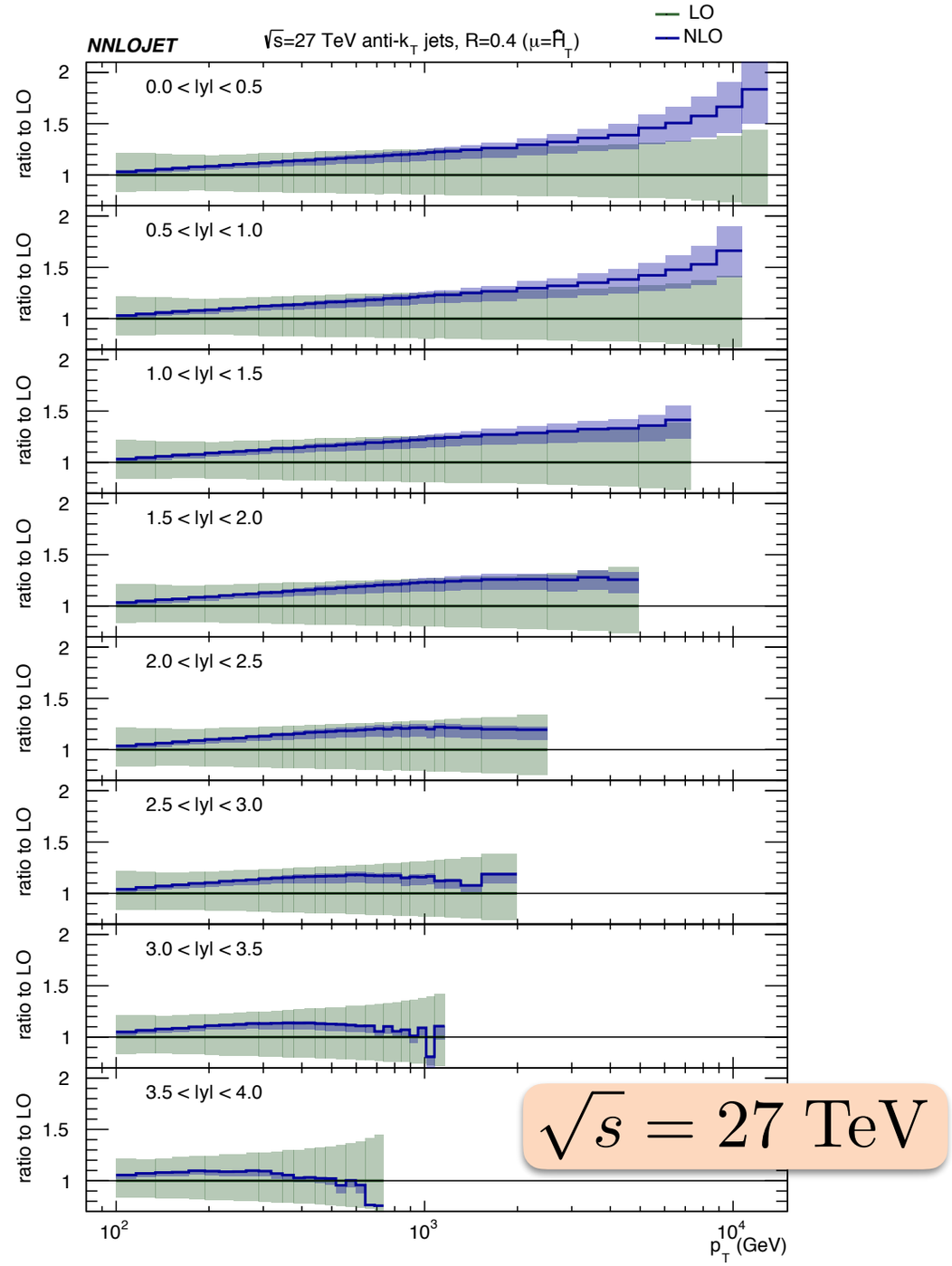
$$x_2 = \frac{p_T}{\sqrt{s}}(e^{-y_{j1}} + e^{-y_{j2}})$$

- Higher Q^2 coverage → sensitivity to higher order effects QCD-EW/ BSM signals
- Increased coverage in lower-*x* → sensitivity to role of resummation effects





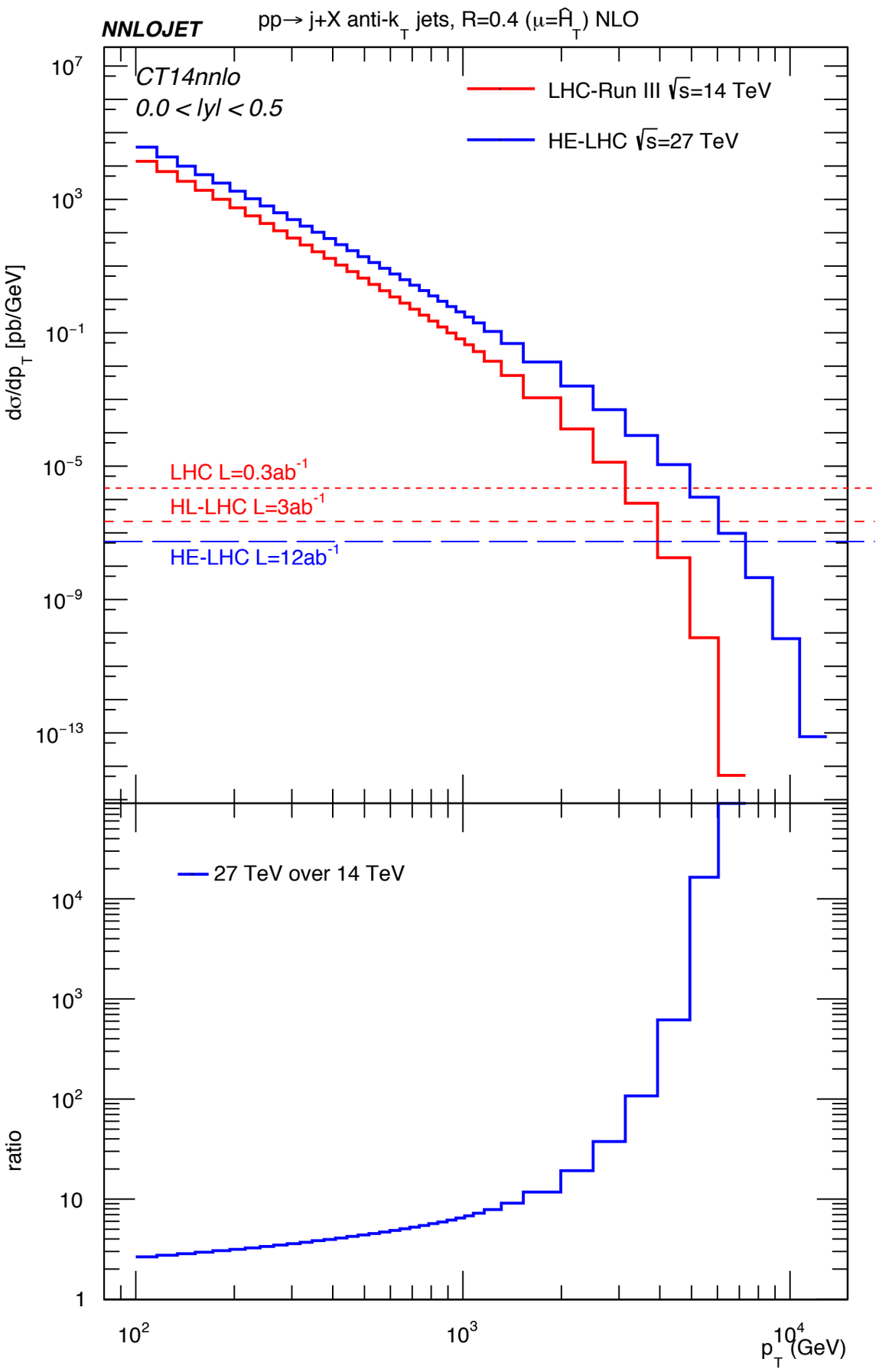




Double differential k-factors at 14 TeV and 27 TeV

- large NLO QCD effects at high-pT and central rapidity ~ 90% (14 TeV) ~ 50% (27 TeV) with large NLO scale uncertainties $\mathcal{O}$(50%) ⇒ **NNLO numbers needed for the final report**

- NLO k-factor rapidity dependent probing different PDF x-ranges



Jet p_T and rapidity at 14 and 27 TeV

- Fiducial single jet inclusive cross section ratio 27 TeV/14 TeV
- Enhancement of the cross section by a factor between 2-100 growing with the jet p_T in the LHC-range and larger at the HE-LHC
- with HL-LHC more events in tails with higher statistics → increased resolution at high-*x* where BSM effects and PDFs are less constrained
- with HE-LHC factor of $10^3 \sim 10^4$ increase in the cross section extend the p_T range of the measurement by a factor of 2 up to 10 TeV

Inclusive direct photon production at HE/HL-LHC

Numerical setup:

- $pp \to \gamma + X$ at $\sqrt{s} = 14$ and $27\ TeV$
- $E_T^\gamma > 40\ GeV$.
- $|\eta_\gamma| < 2.5$.
- $R < 0.4$, $E_{T\,max} < 4.8\ GeV + 4.2 \times 10^{-3}\ E_T^\gamma$.

Differential distributions:

- $E_{T\gamma}$ at NLO and NNLO QCD + EW
- Ratios of $\sqrt{s} = 27$ over $14\ TeV$ predictions
- Theory uncertainties: standard (7-points) scale variation bands and differences between NNLO and NLO predictions.

Diphoton production at HE/HL-LHC

(thanks to L.Cieri)

Numerical setup:

- $pp \to \gamma\gamma + X$ at $\sqrt{s} = 14$ and $27\ TeV$
- $E_T^{\gamma,1} > 40\ GeV$, $E_T^{\gamma,2} > 30\ GeV$.
- $|\eta_\gamma| < 2.5$.
- $R < 0.4$, $E_{T\,max} < 5\ GeV$.

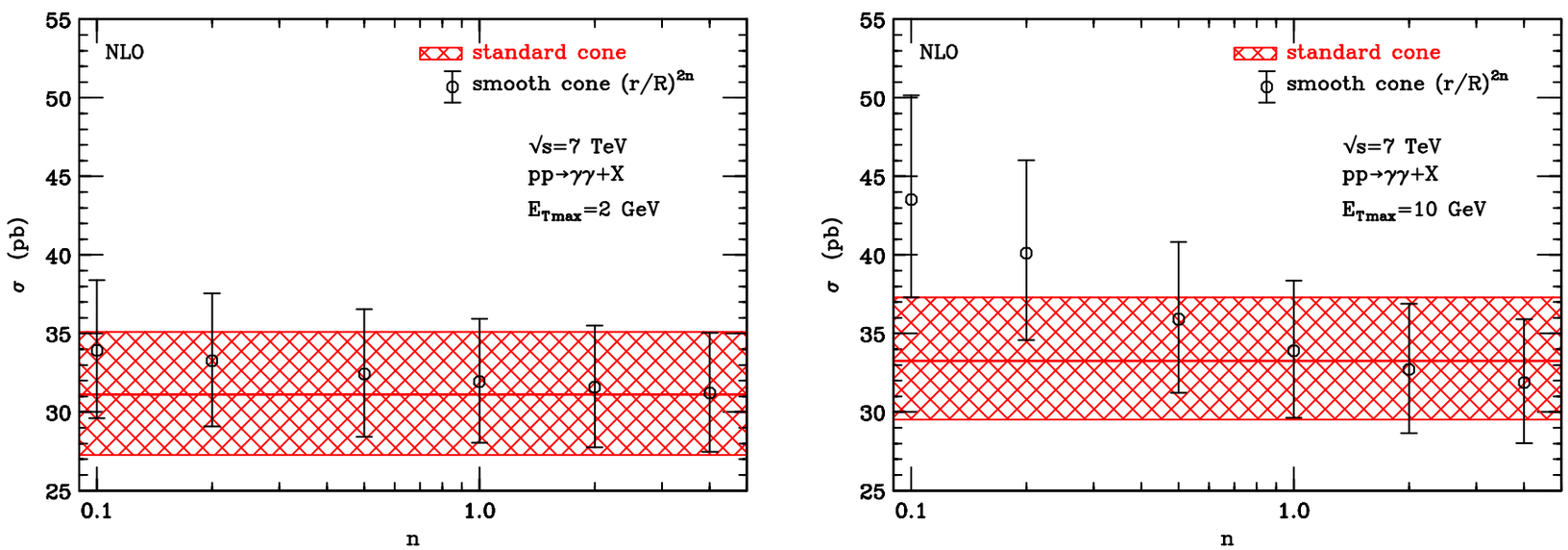
Differential distributions:

- $p_{T\,\gamma\gamma}$ at NLO and NNLO QCD + EW
- $M_{\gamma\gamma}$ at NLO and NNLO QCD + EW
- Ratios of $\sqrt{s} = 27$ over $14\ TeV$ predictions
- Theory uncertainties: standard (7-points) scale variation bands and differences between NNLO and NLO predictions.

Diphoton planned contributions

Photon isolation comparison at HL/HE-LHC

Study of differences between standard cone (used in exp. measurements) and smooth cone (used in NNLO QCD th. predictions) isolation prescriptions. Comparison between standard and smooth cone at $\sqrt{s} = 14$ and $27\ TeV$ (similar to analogous studies performed at $\sqrt{s} = 7\ TeV$ in S.Catani et al. [arXiv:1802.02095]).



	$E_{T_{max}} = 2$ GeV		$E_{T_{max}} = 10$ GeV	
	$\sigma^{\rm LO}$ (pb)	$\sigma^{\rm NLO}$ (pb)	$\sigma^{\rm LO}$ (pb)	$\sigma^{\rm NLO}$ (pb)
Standard	$12.15\ ^{+14.5\,\%}_{-14.3\,\%}$	$31.1\ ^{+12.8\,\%}_{-12.3\,\%}$	$19.51\ ^{+25.0\,\%}_{-20.8\,\%}$	$33.3\ ^{+12.3\,\%}_{-11.3\,\%}$
[direct]	$10.56\ ^{+10.7\,\%}_{-12.0\,\%}$	$27.30\ ^{+7.8\,\%}_{-9.2\,\%}$	$10.56\ ^{+10.7\,\%}_{-12.0\,\%}$	$18.45\ ^{-10.3\,\%}_{+3.8\,\%}$
Smooth	$10.56\ ^{+10.7\,\%}_{-12.0\,\%}$	$31.92\ ^{+12.6\,\%}_{-12.1\,\%}$	$10.56\ ^{+10.7\,\%}_{-12.0\,\%}$	$33.91\ ^{+13.0\,\%}_{-12.6\,\%}$

$pp \to \gamma\gamma + X$ at $\sqrt{s} = 7\ TeV$.

Jets and Photons planned contributions

Studies for 14 and 27 TeV:

- NLO QCD numbers available for single jet inclusive production
- Ongoing runs for dijet and photon observables defined with the fiducial cuts
  - Opportunity to test ideas for new measurements and observables that can maximize the:
    - increased reach with increased luminosity → more events in tails
    - extended kinematical range in p_T and rapidity y at $\sqrt{s}$=27 TeV
    - increased sensitivity to BSM making use of the beneficial 27 TeV over 14 TeV cross section ratios

Planned contributions:

- NNLO QCD numbers needed to properly assess accuracy of the theory on:
  - scale uncertainties when confronting precision data at HL-LHC
  - uncertainty due to missing higher order corrections, i.e, perturbative convergence
- NLO EW effects needed:
  - large effects at high-p_T from EW Sudakov logarithms needed for a good description of data

Inclusive dijet production at HE/HL LHC

- *pp->2jet +X* run with *NNLOJET* for the fixed order perturbative QCD predictions
- PDF=CT14nnlo, α_s=0.118
- μ_R=μ_F=M_{JJ} (dijet mass)
- Jets: anti-k_T with *R=0.4*
- Fiducial volume defined through the cuts

$$p_{T1} > 100 \text{ GeV} \qquad |y_j| < 4.0$$
$$p_{T2} > 75 \text{ GeV}$$

<u>*Differential distributions:*</u>

- M_{JJ} at NLO and NNLO QCD+EW

$$M_{JJ} \in [310, 26250] \text{ GeV}$$
$$y^\star = \frac{1}{2}|y_{j1} - y_{j2}| = \{0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0\}$$

- …