Isolated photon and photon+jet production at NNLO QCD accuracy

[1904.01044; 1905.08577]

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with X. Chen, T. Gehrmann, N. Glover, A. Huss

Introduction

Photon production at hadron colliders

- γ production at high p_T classical hadron collider observable
- sensitive to gluon distribution in proton already at LO
- recent experimental studies reach percent level accuracy (eg. [ATLAS,1701.06882,1801.00112,1901.10075] [CMS,1807.00782])

Theoretical status

- need higher order QCD corrections to improve theory uncertainty
- NNLO QCD calculated for $\gamma + X$ [J. M. Campbell et al., 1612.04333] and $\gamma + j$ [J. M. Campbell et al., 1703.10109] by MCFM group
- here: new calculation of NNLO QCD corrections, using more realistic photon isolation procedure
- Detailed comparison with MCFM in progress

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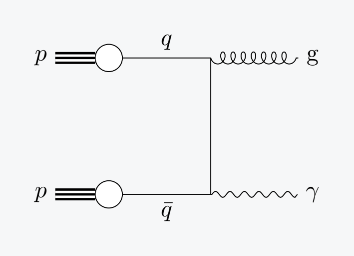

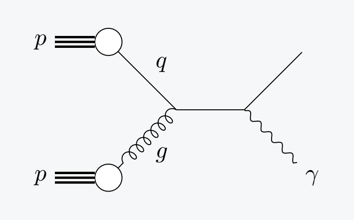

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Photon definition and isolation

- distinguish between photons from hard scattering and from hadron decay
- restrict hadronic energy around photon

$\rightarrow$ photon isolation

fixed cone

dynamical cone

hybrid

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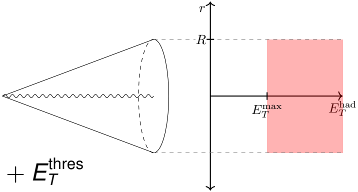

fixed cone

- within cone with fixed R:

$$E_T^{\mathrm{had}} < E_T^{\max} = \varepsilon E_T^{\gamma} + E_T^{\mathrm{thres}}$$

- experimental studies use this prescription only
- induces sensitivity on photon fragmentation → theoretically challenging

dynamical cone

hybrid

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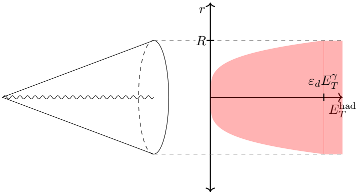

dynamical cone [S. Frixione, hep-ph/9801442]

- r_d-dependent $E_T^{\max}$:

$$E_T^{\rm had}(r_d) < \varepsilon_d E_T^\gamma \left(\frac{1-\cos r_d}{1-\cos R_d}\right)^n \qquad \xrightarrow[r_d\to 0]{} 0$$

- collinear radiation ✗ → fragmentation sensitivity ✗
- soft radiation ✓ → IR safe ✓
- can only be approximated by experiment

hybrid

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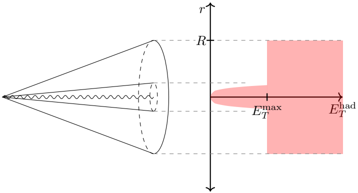

dynamical cone

hybrid [F. Siegert, 1611.07226]

- small dynamical cone to eliminate fragmentation dependence
- fixed cone with $R^2 \gg R_d^2$ mimicking experimental isolation
- correctly describes dependence on R (up to potential R-indep. shift)

The NNLOJET framework

The code

- parton-level event generator
- IR subtraction → antenna subtraction at NNLO level [A. Gehrmann-De Ridder et al., hep-ph/0505111] [A. Daleo et al., hep-ph/0612257] [J. Currie et al., 1301.4693]

The process $\gamma + jet$

The NNLOJET framework

The code

The process $\gamma + jet$

- implementation of fixed / dynamical / hybrid cone isolation procedures
- implementation of MEs up to NNLO in analytic form
- tree and 1-loop MEs numerically validated against OpenLoops [F. Cascioli et al., 1111.5206]
- NLO cross sections for $\gamma + 1j$ and $\gamma + 2j$ validated against SHERPA [F. Siegert, 1611.07226] [T. Gleisberg et al., 0811.4622] [S. Hoeche et al., 1207.5030]

Hybrid isolation vs. dynamical isolation (NLO)

Example: p_T^γ-spectrum in $(pp \to \gamma + X)$ @ 8TeV

Setup:

- $\mu_R = \mu_F = p_T^\gamma$
- scale uncertainty by means of 7-point scale variation
- NNPDF3.1 [NNPDF coll., 1706.00428]

dyn. iso. $R_d = 0.4\,, \qquad \varepsilon_d = 0.1\,, \qquad n = 2$

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hyb. iso. $R_d = 0.1\,, \qquad \varepsilon_d = 0.1\,, \qquad n = 2$

$R = 0.4\,, \qquad E_T^{\text{max}} = 0.0042 E_T^\gamma + 4.8\text{GeV}$ [ATLAS,1605.03495]

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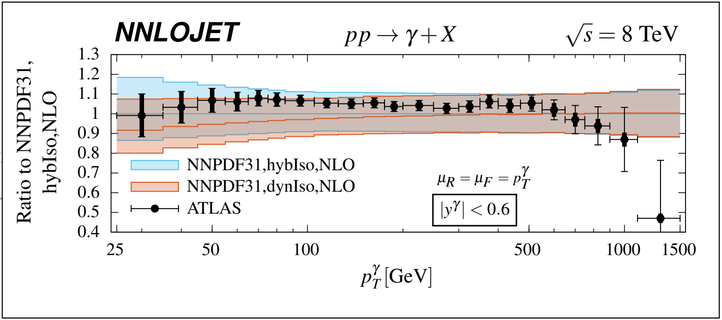

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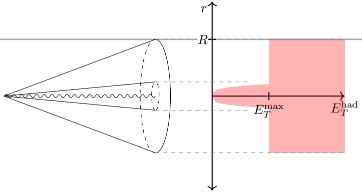
Dependence on conesize R



Idea - when using hybrid cone isolation:

- inner dynamical cone ensures IR safety and eliminates fragmentation contribution
- correctly accounts for radiation between R_d and R
  $\Rightarrow$ correct parametric dependence on outer cone R for $R^2 \gg R_d^2$
- dependence can be studied by experiments

Example: $(pp \to \gamma + X)$ @ 13TeV

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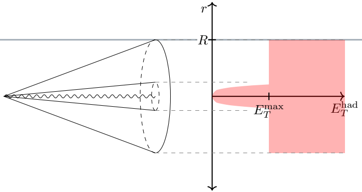

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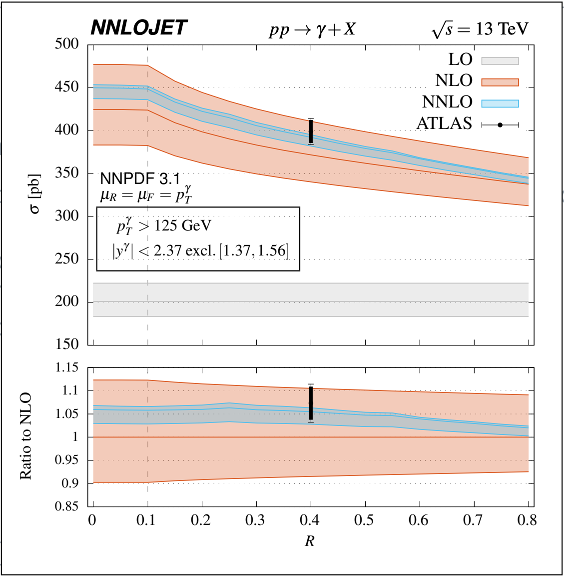

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Results at 13TeV

Available measurements at 13TeV

– ATLAS:	$pp \to \gamma + X$,	3.2fb^{-1}	[1701.06882]
– ATLAS:	$pp \to \gamma + j$,	3.2fb^{-1}	[1801.00112]
– CMS:	$pp \to \gamma + X \,/\, \gamma + j$,	2.26fb^{-1}	[1807.00782]
– ATLAS:	$R^{\gamma}_{13/8}$		[1901.10075]

predictions and comparison to data

- produce differential distributions an compare to data
- Example: ATLAS $pp \to \gamma + j$ & $R^{\gamma}_{13/8}$

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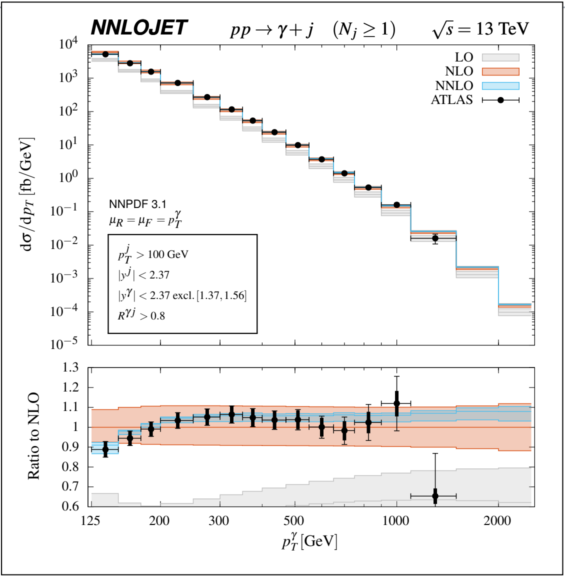

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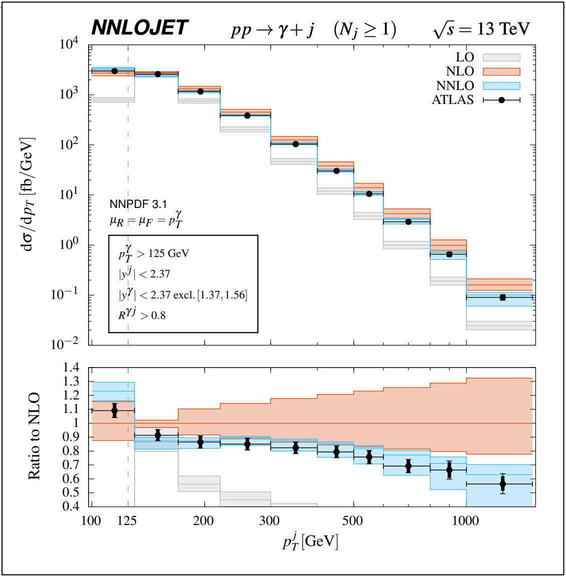

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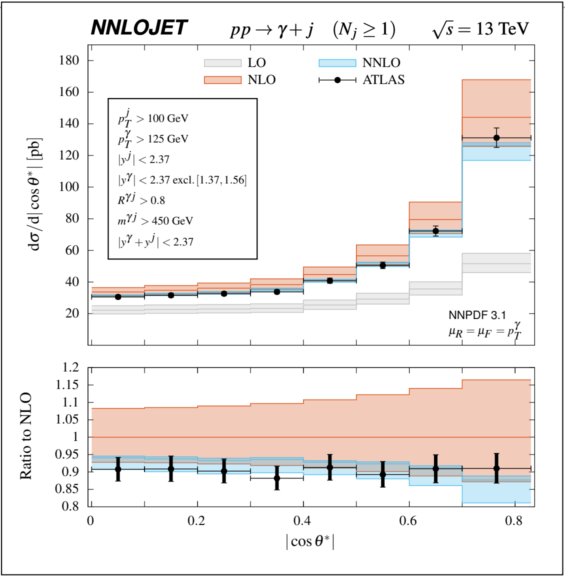
$$\left(\cos\theta^* = \tanh\frac{\Delta y^{\gamma j}}{2}\right)$$



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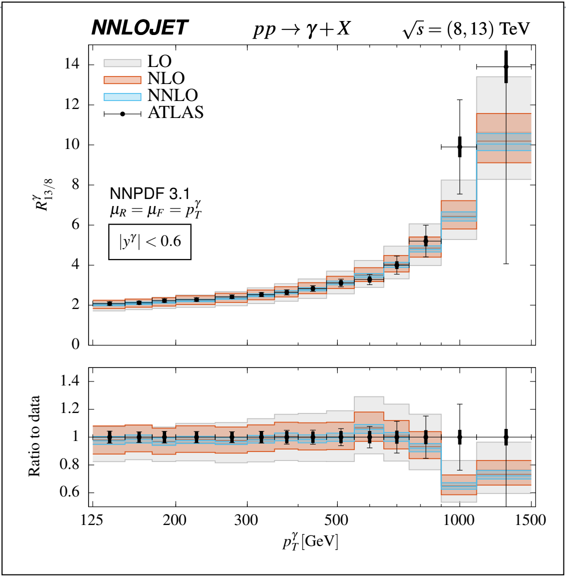

Low p_T^γ

Motivation & difficulties

- constrain gluon PDF at (very) low $x \lesssim 10^{-3}$
- exp. difficulties: e.g. low photon purity at low p_T
- theo. difficulties: not all subtraction methods suited

Example: $(pp \to \gamma + X)$ @ 7TeV

- based on [ALICE,1906.01371] ($L = 473\text{nb}^{-1}$)
- $10\text{GeV} \leq p_T^\gamma \leq 60\text{GeV}$

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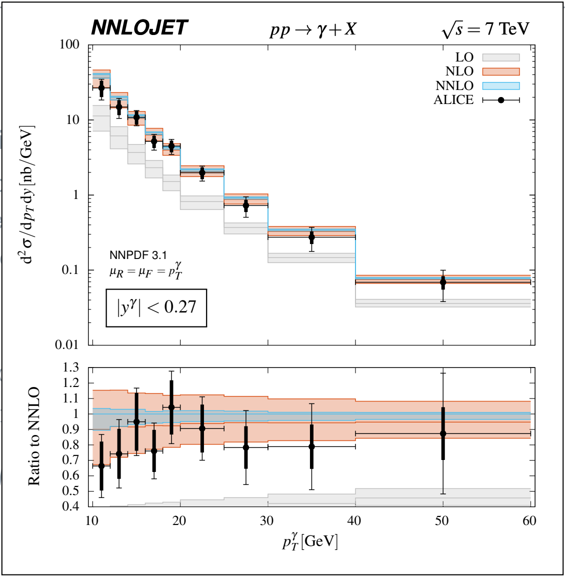

Conclusion

- new calculation of NNLO QCD corrections to isolated photon and photon+jet production
- NNLOJET framework, using antenna subtraction
- hybrid isolation procedure → realistic description of photon isolation used in experiment
- impact of NNLO corrections: reduced theory uncertainty, better description of the data

Outlook

- in-depth study of isolation parameter dependence, both in experiment and theory
- inclusion of NNLO photon fragmentation functions
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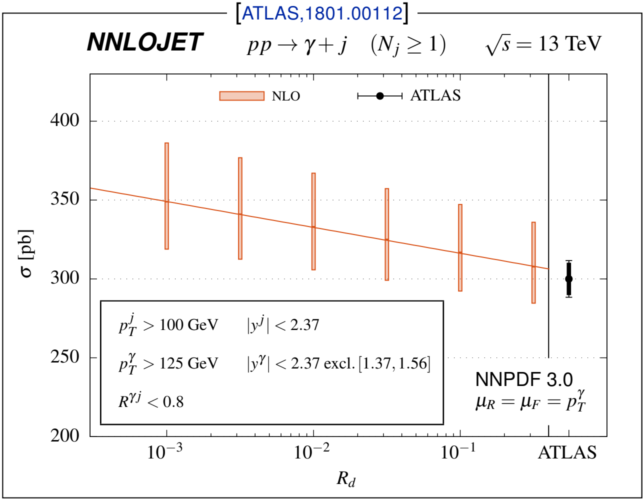
Backup slides

[ATLAS,1801.00112]



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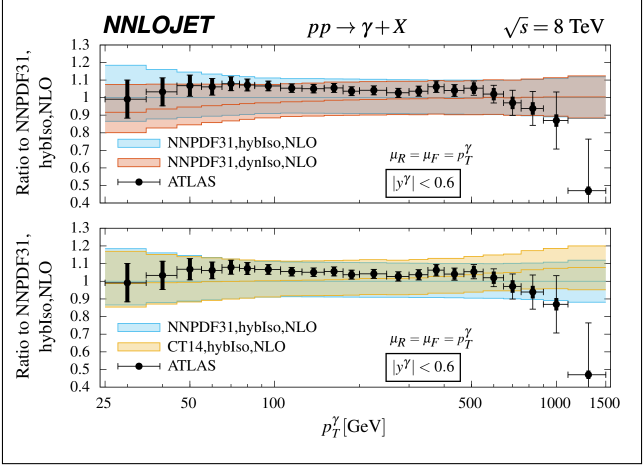

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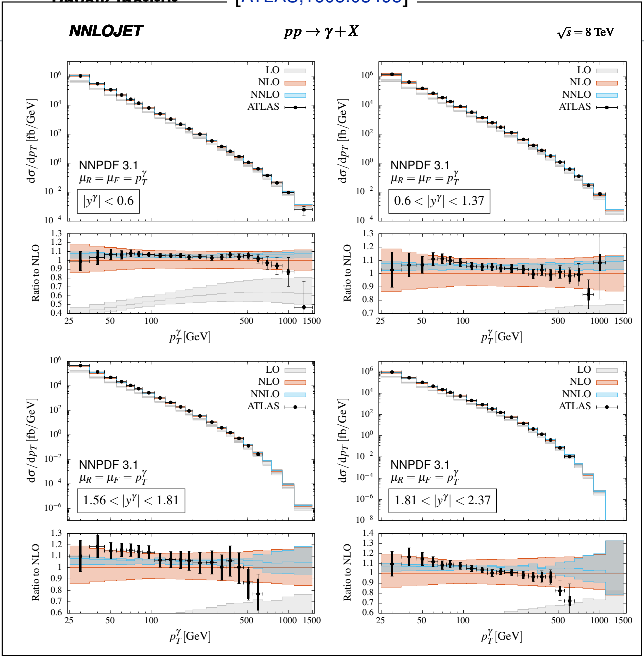
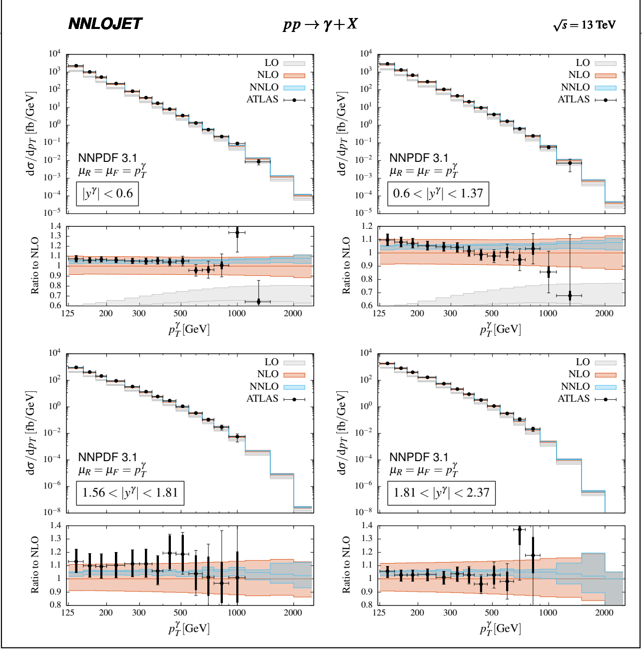


[ATLAS,1701.06882]



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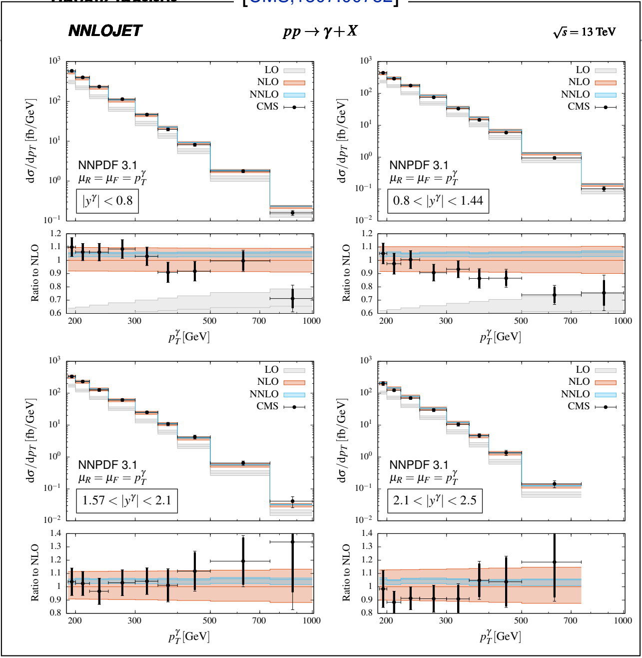

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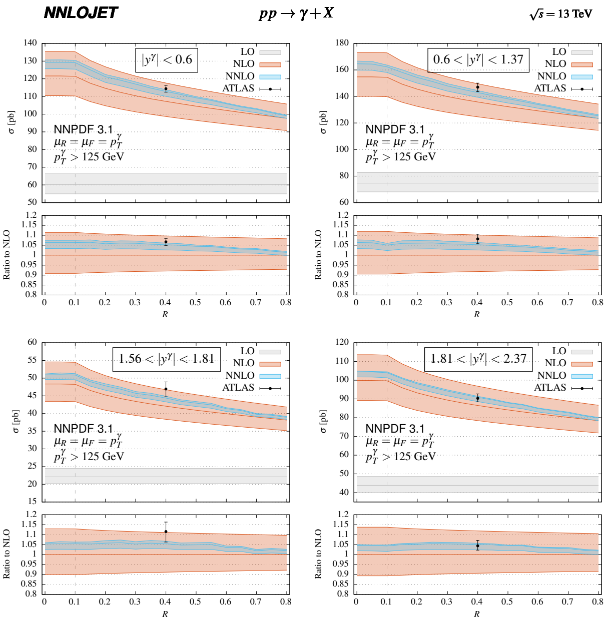

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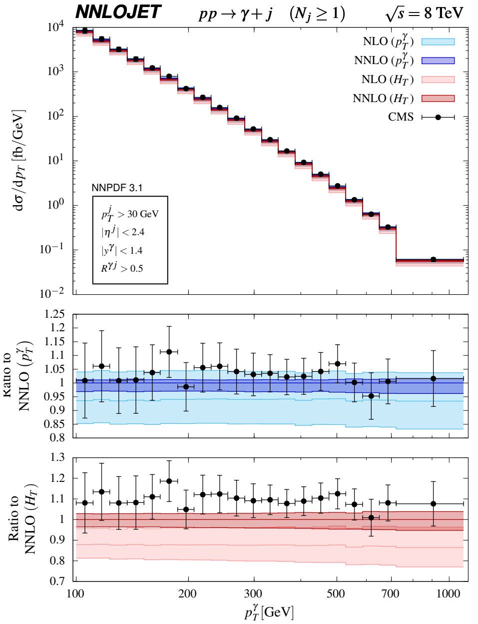

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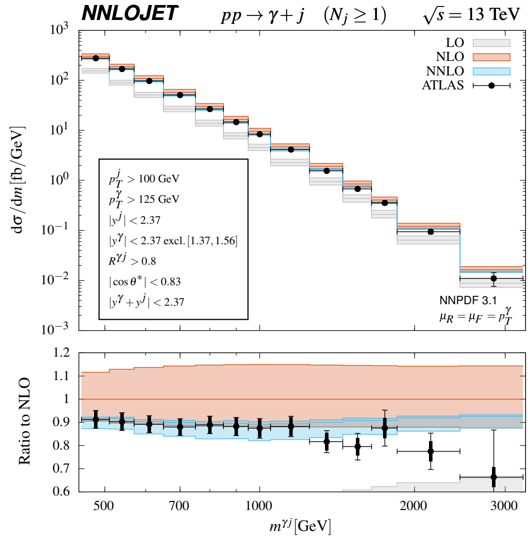

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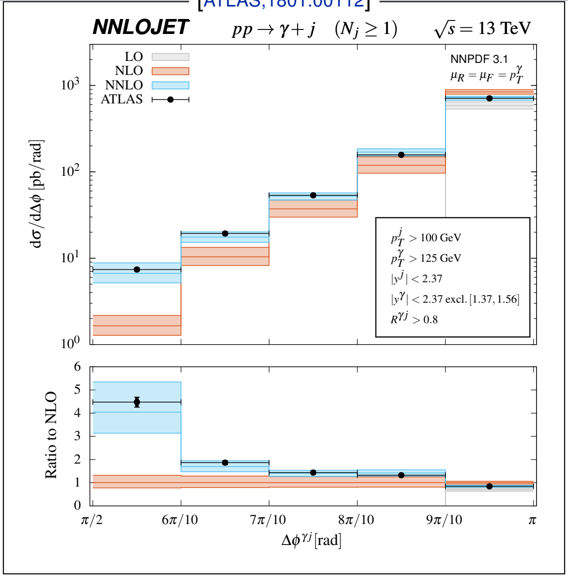

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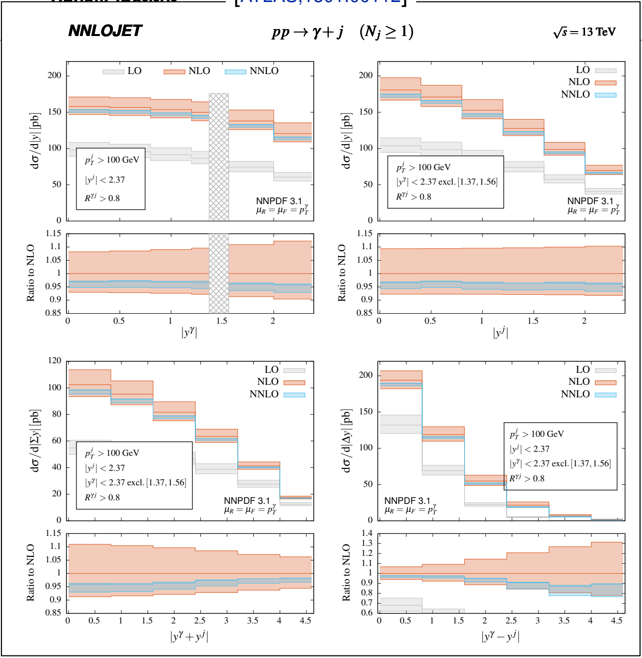

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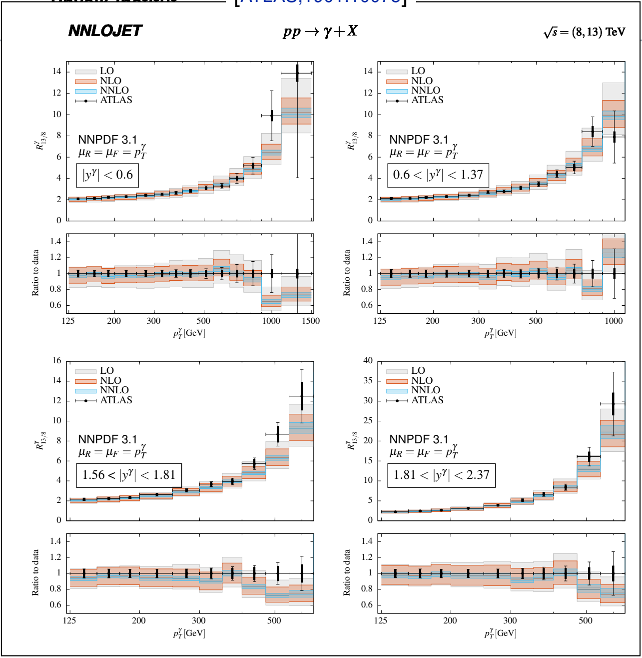

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