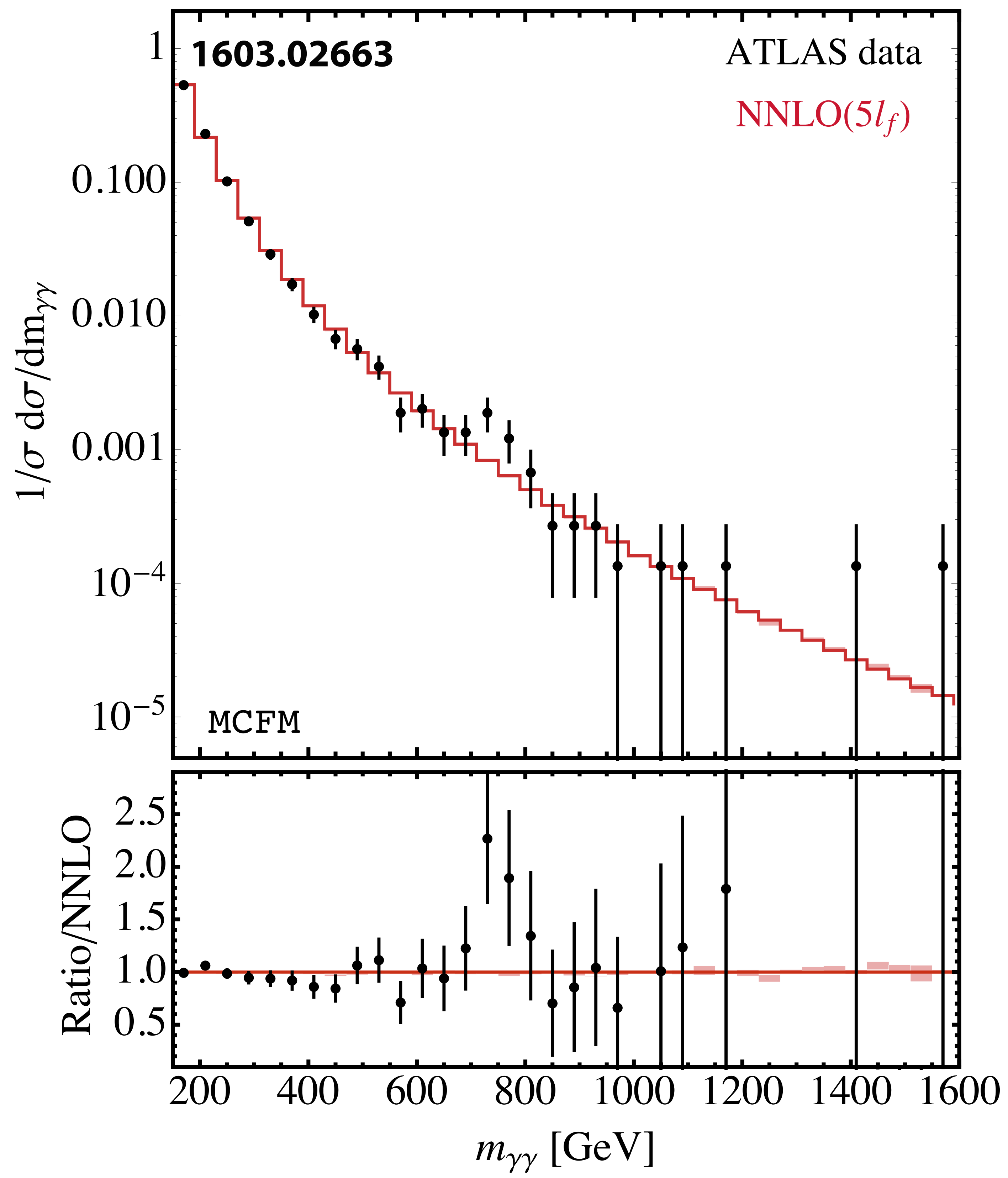
Diphoton production at small transverse momentum: resummation and challenges

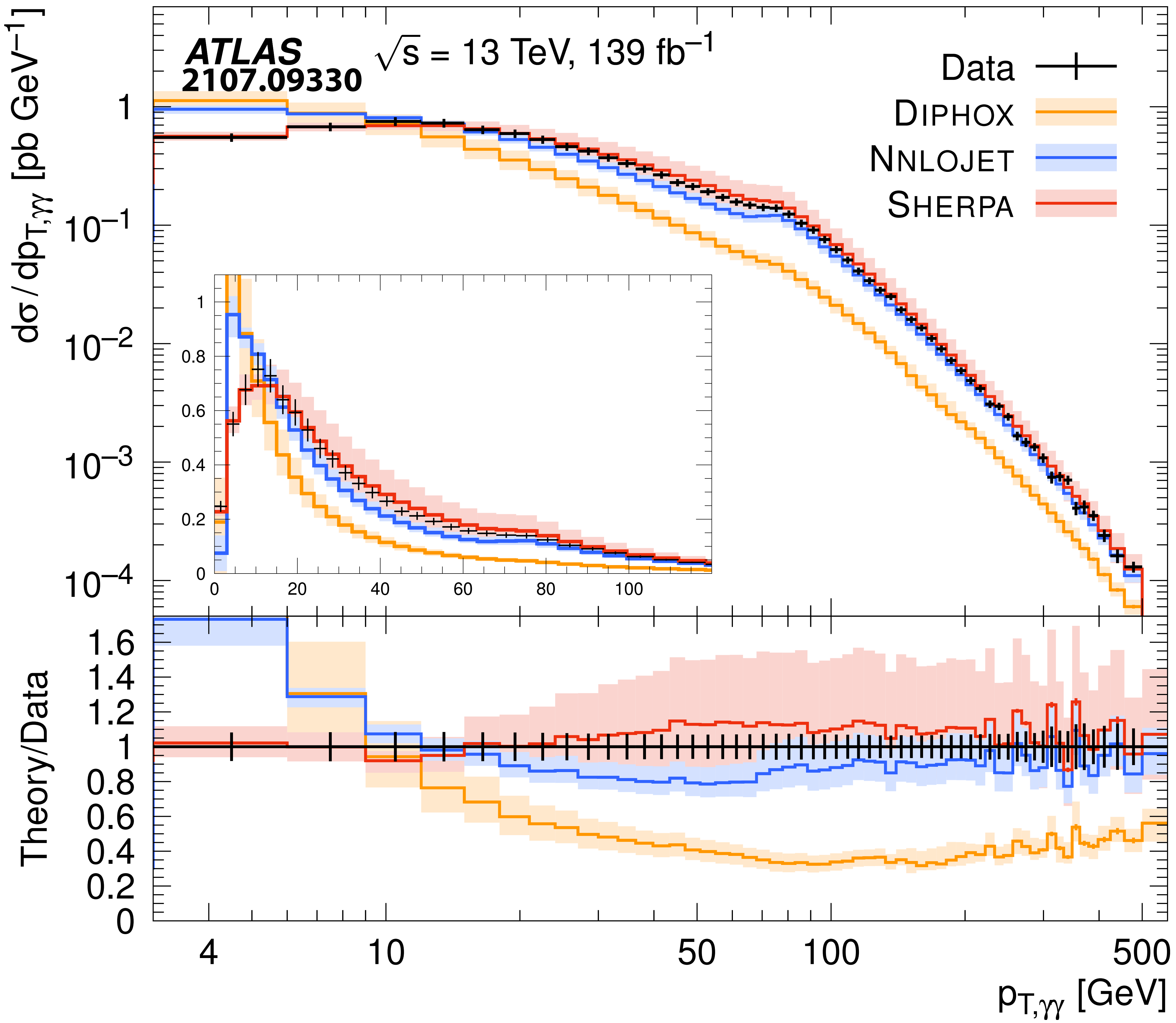
based on arXiv:2107.12478

Tobias Neumann, Brookhaven Nat'l Lab

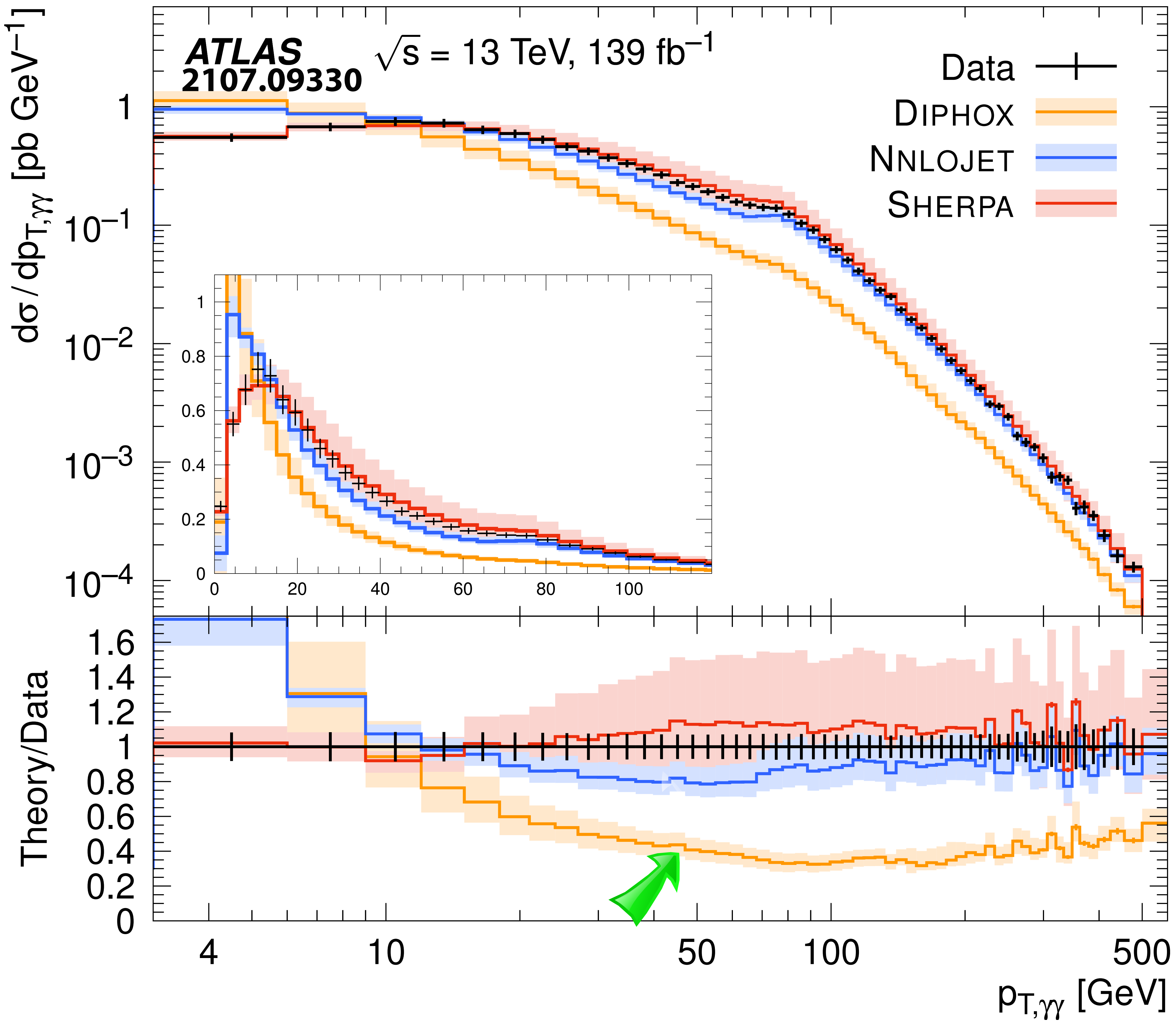
November 18th, 2021



1603.02663
ATLAS data
NNLO($5l_f$)
MCFM
1/σ dσ/dm$_{\gamma\gamma}$
Ratio/NNLO
$m_{\gamma\gamma}$ [GeV]



ATLAS
2107.09330
$\sqrt{s}$ = 13 TeV, 139 fb^{-1}
Data
DIPHOX
NNLOJET
SHERPA
dσ / dp$_{T,\gamma\gamma}$ [pb GeV^{-1}]
Theory/Data
p$_{T,\gamma\gamma}$ [GeV]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2107.09330
√s = 13 TeV, 139 fb−1
Data
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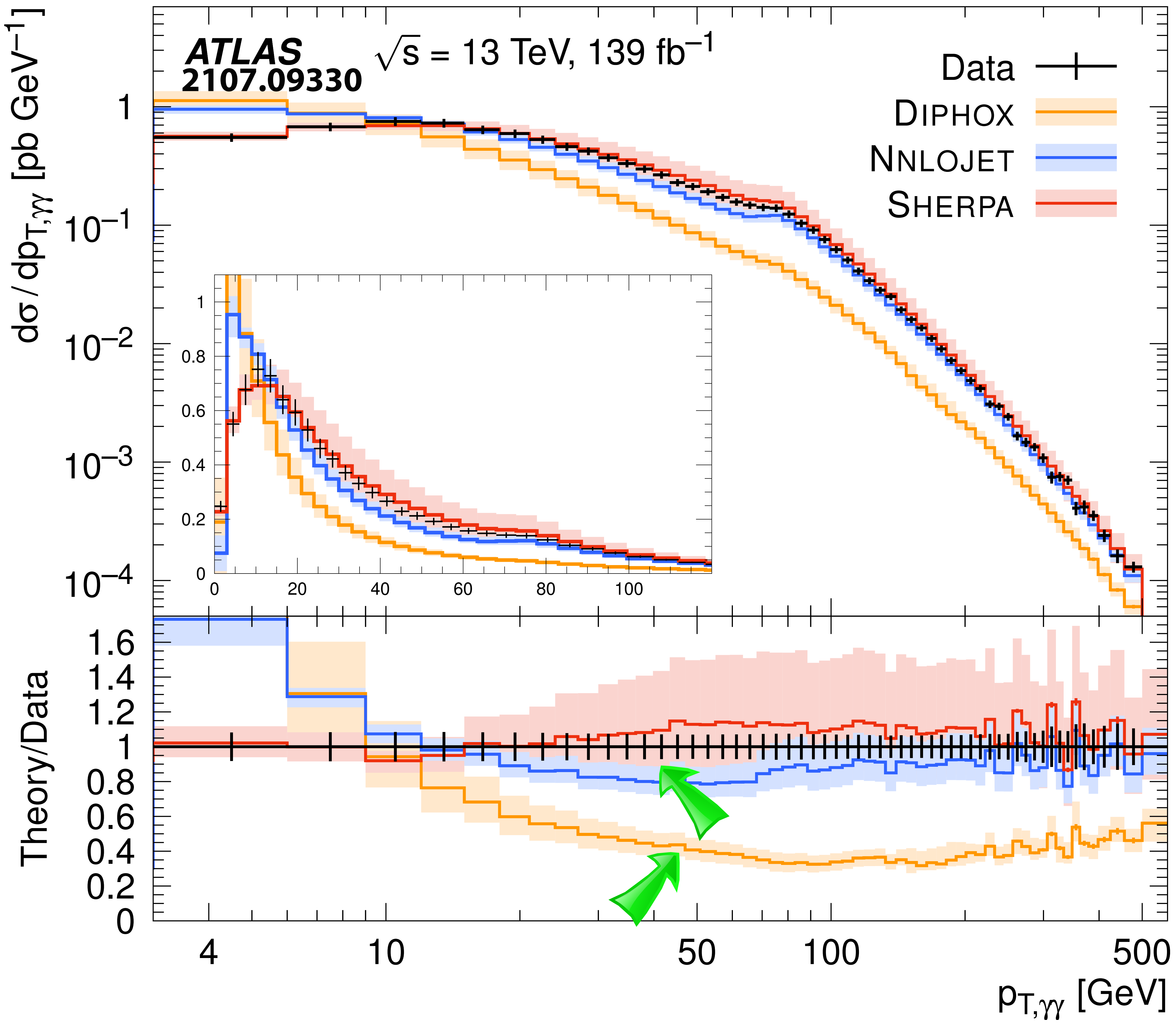
dσ / dpT,γγ [pb GeV−1]
Theory/Data
pT,γγ [GeV]


ATLAS
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√s = 13 TeV, 139 fb⁻¹
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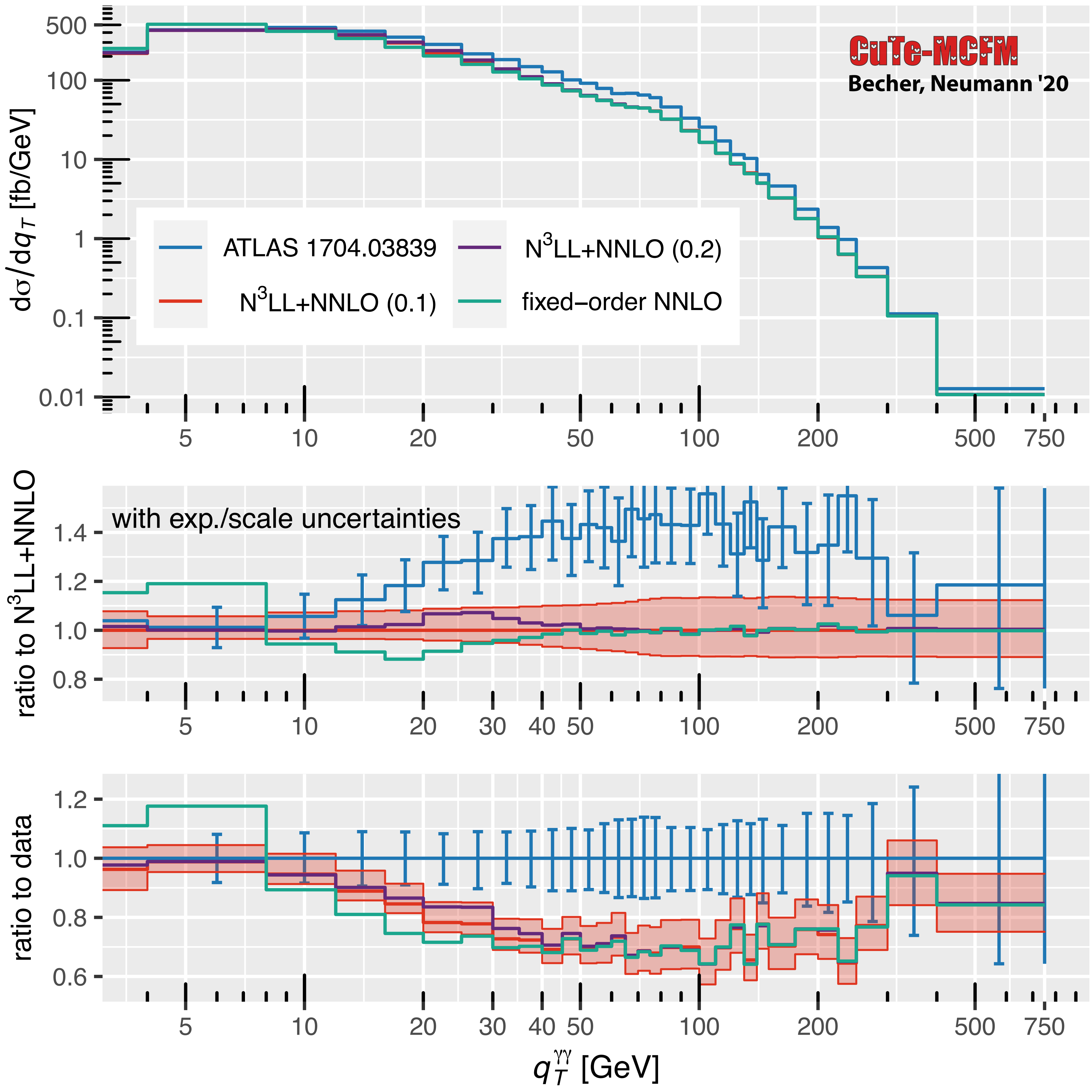
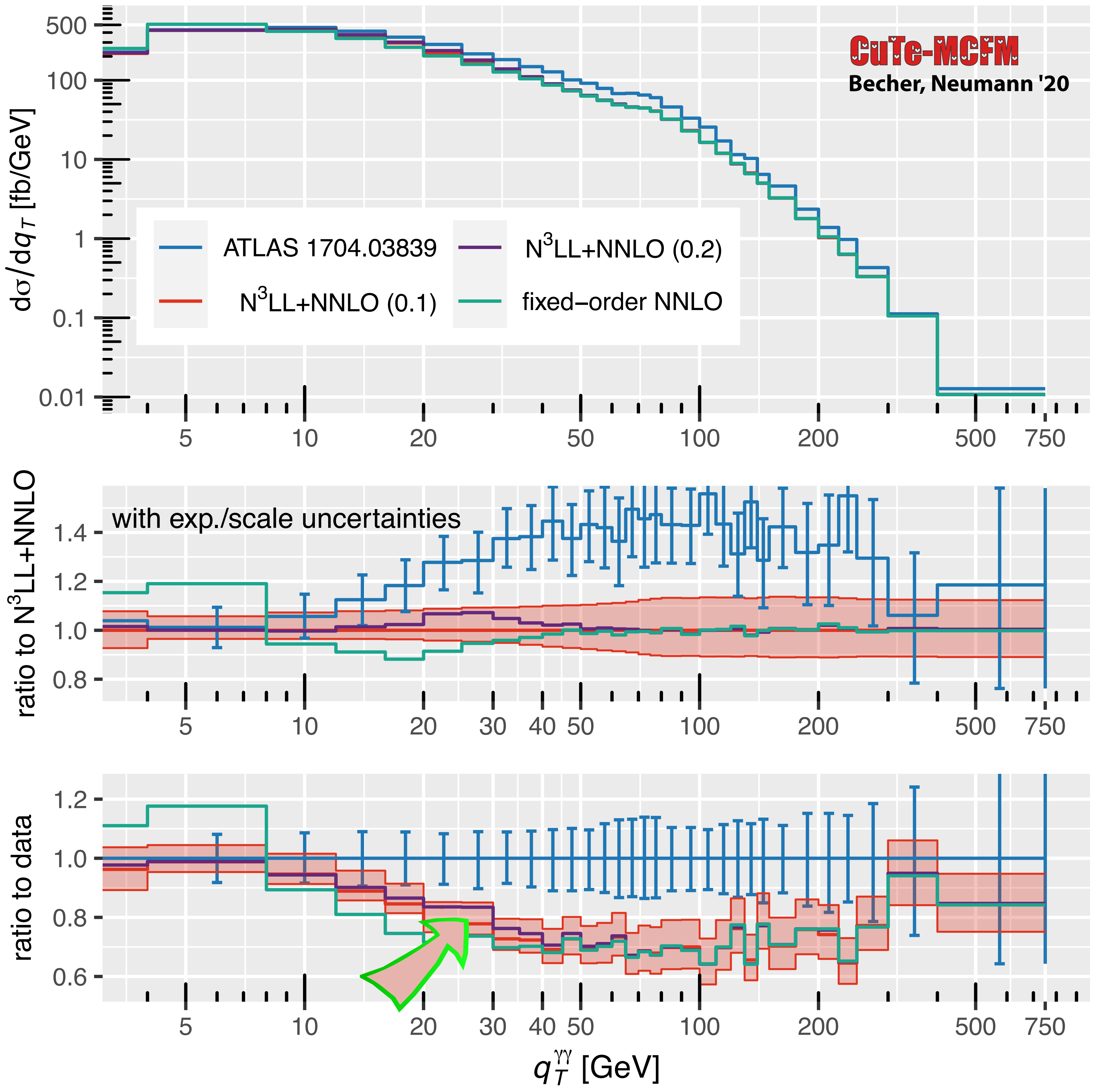
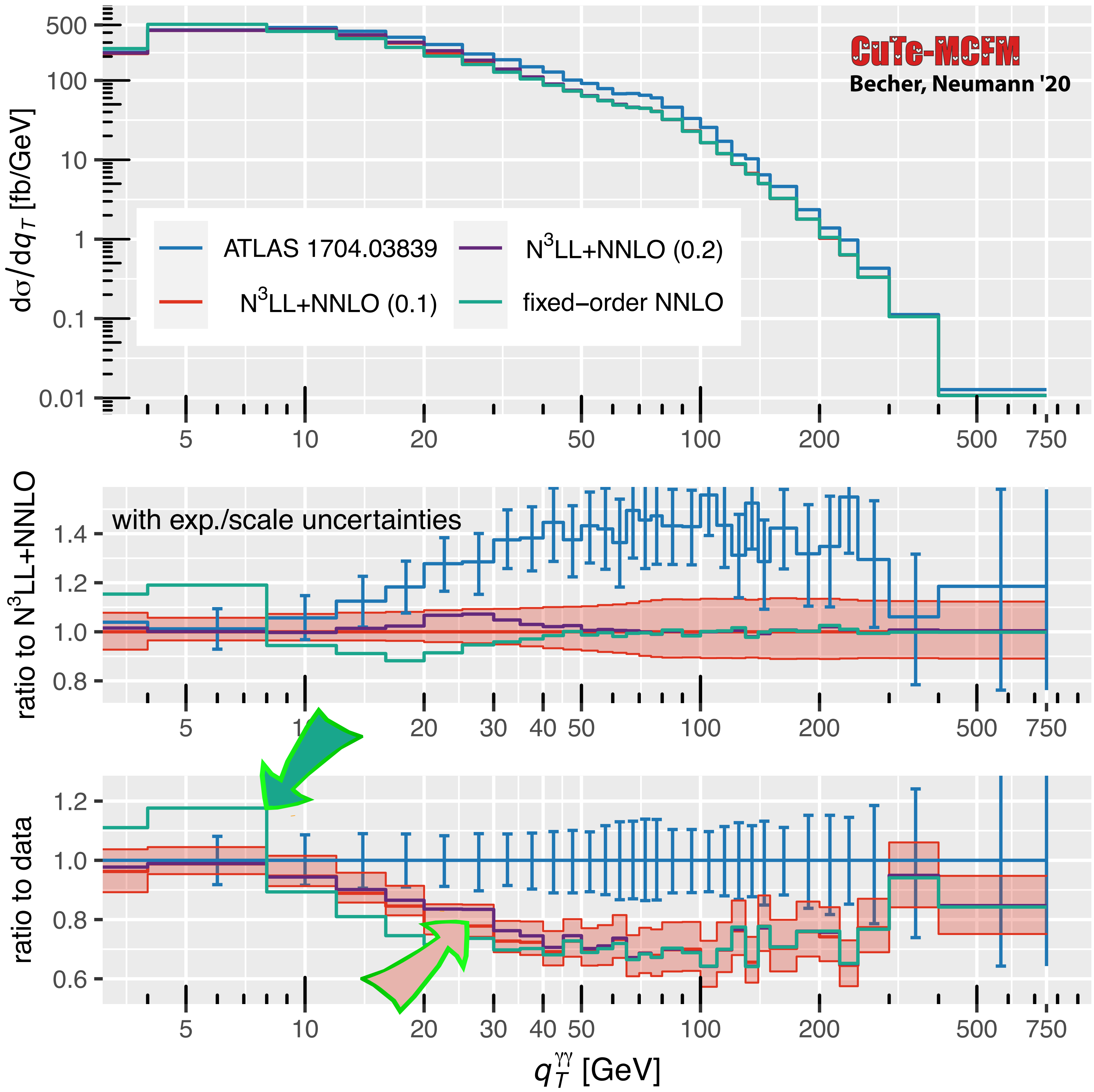
p_T,γγ [GeV]



CuTe-MCFM
Becher, Neumann '20
ATLAS 1704.03839
N^{3}LL+NNLO (0.2)
N^{3}LL+NNLO (0.1)
fixed−order NNLO
$d\sigma/dq_T$ [fb/GeV]
with exp./scale uncertainties
ratio to N^{3}LL+NNLO
ratio to data
$q_T^{\gamma\gamma}$ [GeV]



CuTe-MCFM
Becher, Neumann '20
ATLAS 1704.03839
N3LL+NNLO (0.1)
N3LL+NNLO (0.2)
fixed−order NNLO
dσ/dq_T [fb/GeV]
with exp./scale uncertainties
ratio to N3LL+NNLO
ratio to data
q_T^γγ [GeV]


CuTe-MCFM
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dσ/dq_T [fb/GeV]
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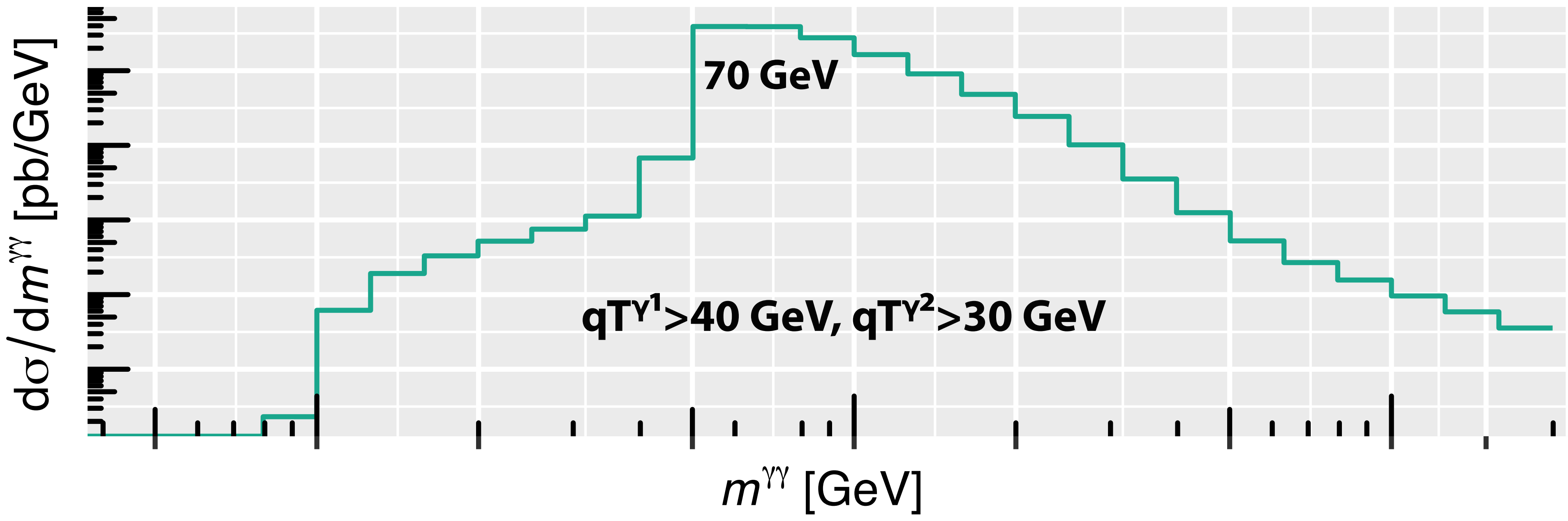
ratio to N3LL+NNLO
ratio to data
q_T^γγ [GeV]

1.



2.

resummation is not very "effective"

q_T factorization from SCET

$$\mathrm{d}\sigma_{ij}(p_1, p_2, \{\underline{q}\}) = \int_0^1 \mathrm{d}\xi_1 \int_0^1 \mathrm{d}\xi_2 \, \mathrm{d}\sigma^0_{ij}(\xi_1 p_1, \xi_2 p_2, \{\underline{q}\}) \, \mathcal{H}_{ij}(\xi_1 p_1, \xi_2 p_2, \{\underline{q}\}, \mu) \cdot$$

$$\frac{1}{4\pi} \int \mathrm{d}^2 x_\perp \, e^{-iq_\perp x_\perp} \left(\frac{x_T^2 Q^2}{b_0^2} \right)^{-F_{ij}(x_\perp, \mu)} B_i(\xi_1, x_\perp, \mu) \cdot B_j(\xi_2, x_\perp, \mu)$$

(Becher, Neubert '10; Becher, Neubert, Wilhelm '11 '12)

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(Becher, Neubert '10; Becher, Neubert, Wilhelm '11 '12)

$$+\mathcal{O}(q_T^2/Q^2)$$

Ebert, Michel, Stewart, Tackmann '20

$$E_T^{\mathrm{had}} \leq E_T^{\mathrm{iso}} \chi^{\mathrm{smooth}}(r, R_s)\,, \quad \forall r \leq R_s,$$
$$\chi^{\mathrm{smooth}}(r, R_s) = \left(\frac{1 - \cos(r)}{1 - \cos(R_s)} \right)^n$$

Large (linear) power corrections *Becher, Neumann '20; (see also Ebert, Tackmann '19)*

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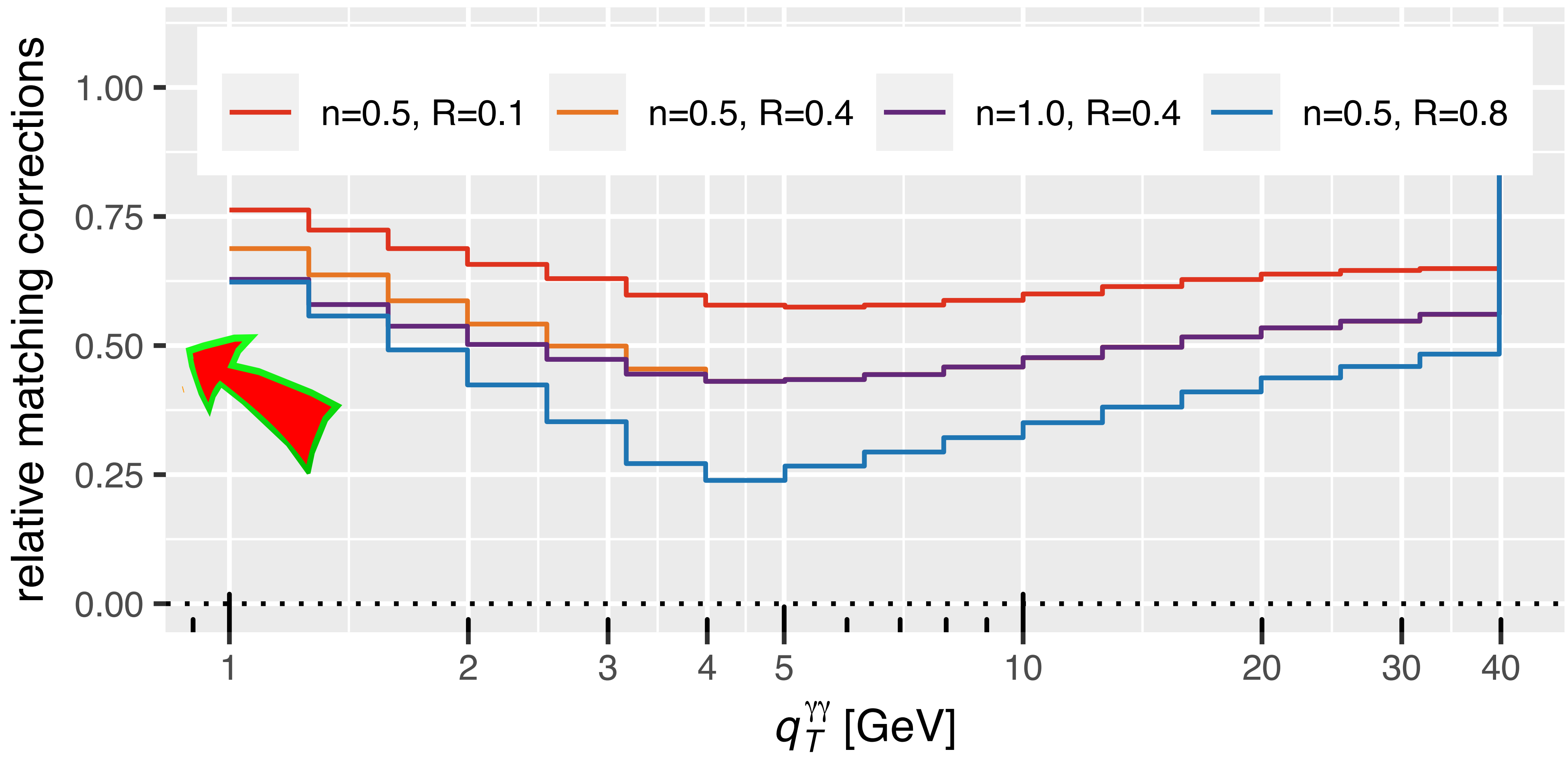

Need for α_s^3 in fixed-order and RG-improved perturbation theory

Fixed-order:

- NNLO (α_s^3) $q\bar{q} \to \gamma\gamma$+jet *Chawdhry, Czakon, Mitov, Poncelet '21*
- NLO (α_s^4) $gg \to \gamma\gamma$+jet *Badger, Gehrmann, Marcoli, Moodie '21; Badger, Brønnum-Hansen, Chicherin, Gehrmann, Hartanto '21*

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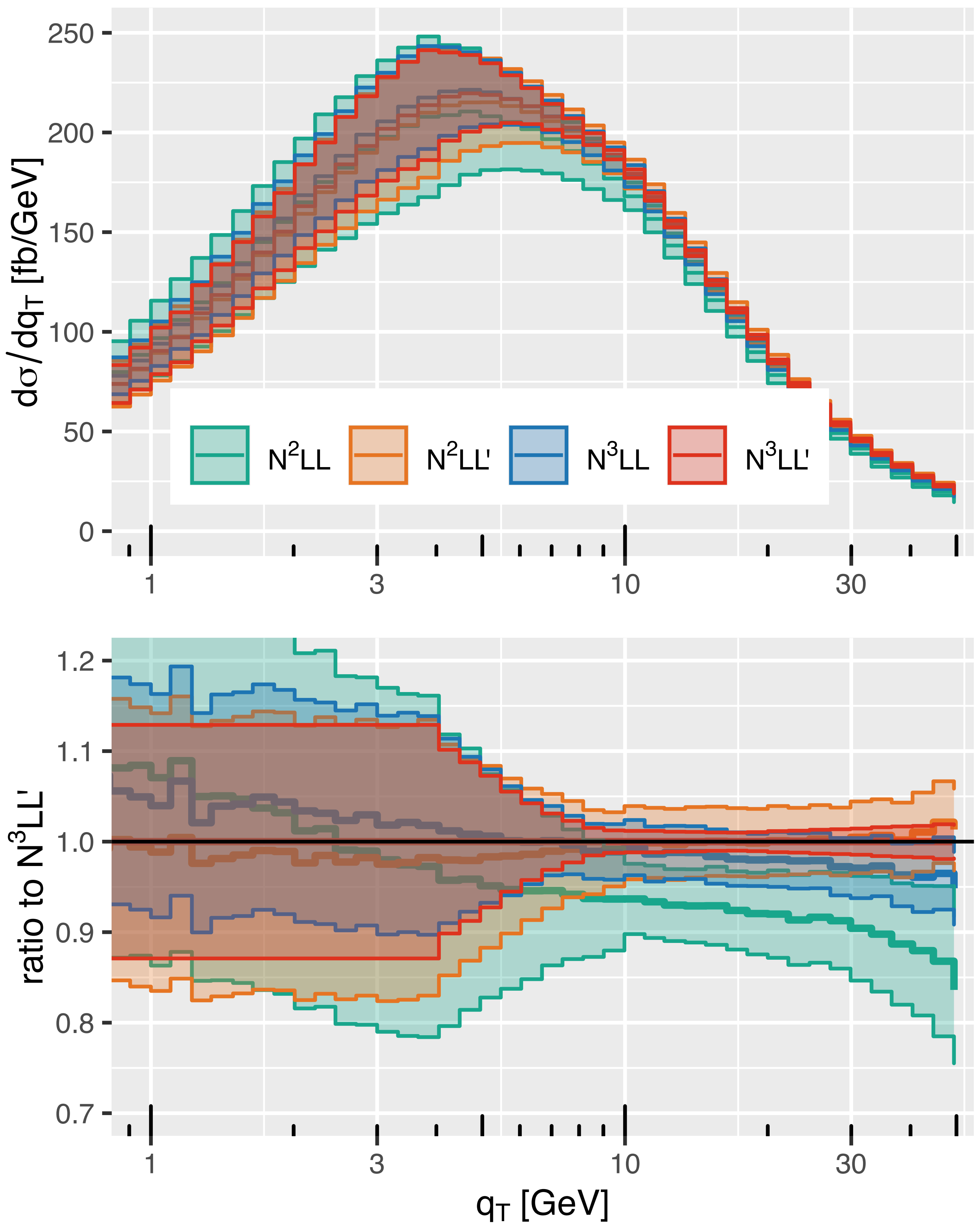
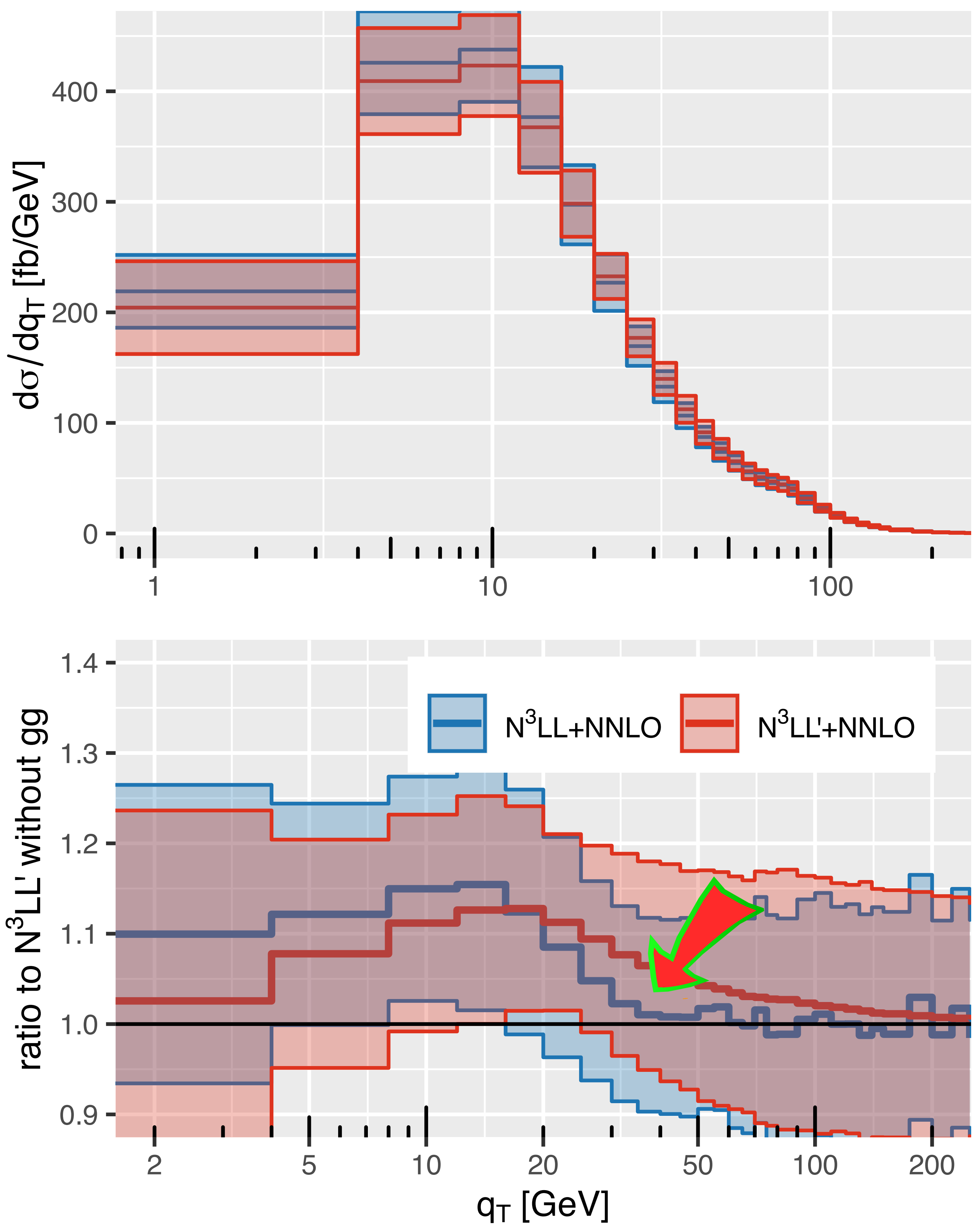
Resummation: Upgrade to N^3LL'+NNLO

- Three-loop hard function $q\bar{q} \to \gamma\gamma$ *Caola, von Manteuffel, Tancredi '21*
- Three-loop TMD beam functions *Luo, Yang, H.X. Zhu, Y.J. Zhu '20, '21; Ebert, Mistlberger, Vita '20*

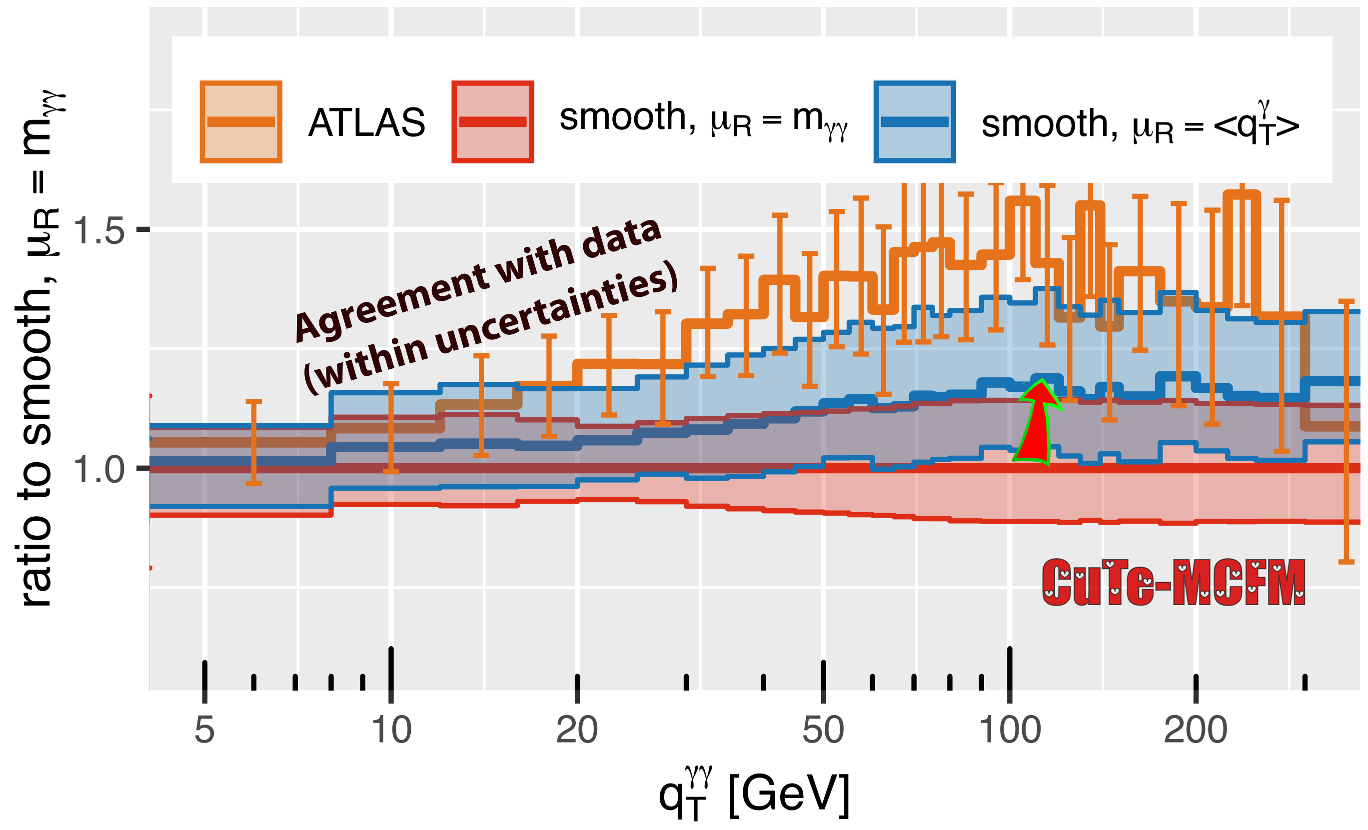
Purely resummed $q\bar{q}$ channel



Including *gg* channel, fully matched



Check proposal of different scale and isolation: *Gehrmann, Glover, Huss, Whitehead '20*



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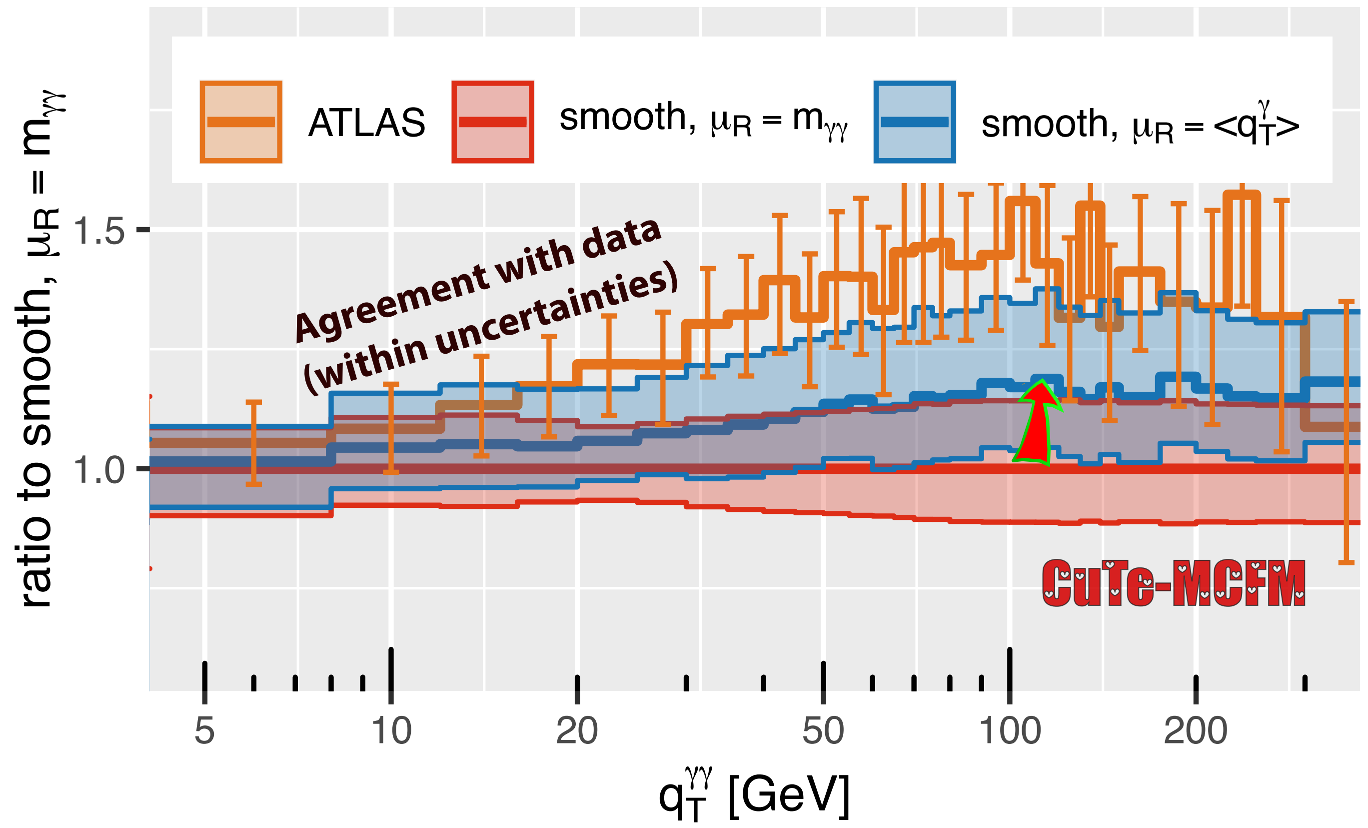

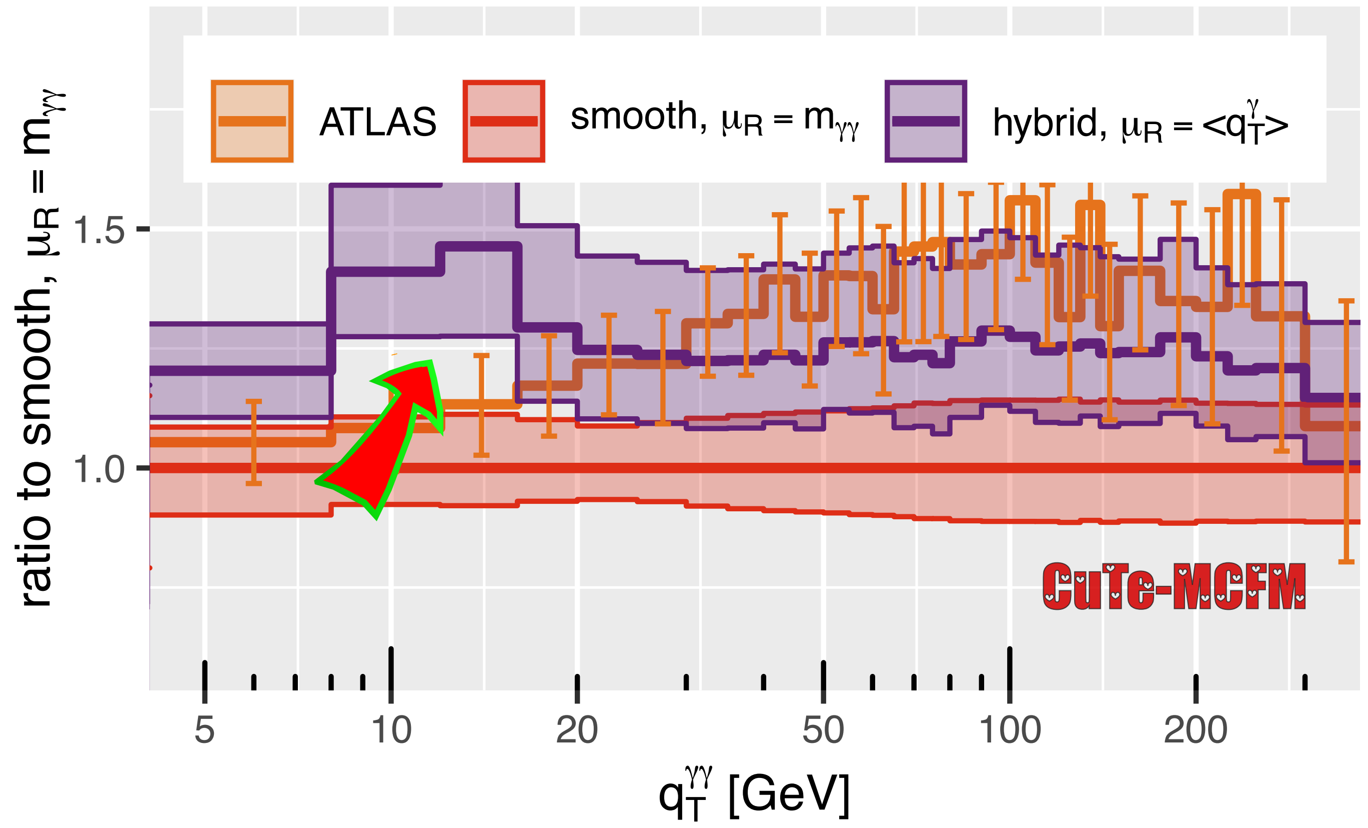

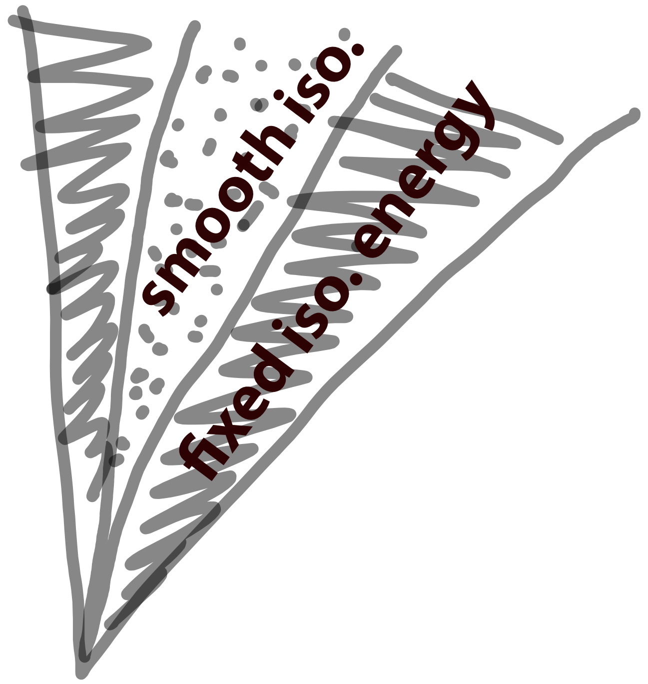

Conclusions: $\gamma\gamma$ is a challenge

We have implemented N^{3}LL'+NNLO (using three-loop hard and beam functions)

- photon isolation induces large linear power corrections
- i.e. ~50% of cross-section from fixed-order
- future needs: matching with α_s^3 at large q_T
- future needs: inclusion of gg channel at at least α_s^4

For now: N^{3}LL'+NNLO does sufficient job with $\mu = \langle q_T^\gamma \rangle$

- hybrid-cone isolation is a bad band aid
- but isolation uncertainties underestimated
- revive fragmentation function program at NNLO?

Code public in CuTe-MCFM/MCFM 10.1, mcfm.fnal.gov