Towards the Understanding of Jet Shapes and Cross Sections in Heavy Ion Collisions Using Soft-Collinear Effective Theory

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Overview

Jet physics in heavy ion collisions is a complex, multi-scale problem. On one hand we have scales associated with jets, on the other we have the thermal scales underlying the medium dynamics. Effective field theory techniques are well-suited in this context and provides systematic studies of jets in the complex environment.

The studies of jets can provide precision tests of the QCD dynamics. Jet substructure observables and production cross sections give complimentary information about the jet-formation mechanism in the medium. In order to extract the medium properties accurately through the studies of jet modifications, precision calculation of jet observables is of ultimate importance. This involves the all-order resummation of large logarithms in the perturbative series.

We use soft collnear effective theory (SCET) and its extension (SCET$_G$) including Glauber gluon interactions in the medium to calculate the jet shape and the jet cross section in heavy ion collisions. The resummation of jet shapes is performed at next-to-leading logarithmic accuracy using the renormalization group techniques. The medium modification of jet shapes is calculated using the leading order medium-induced splitting functions obtained in SCET$_G$. The resummation and the medium modification are consistently performed in this framework. For the jet cross section, the splitting functions in the medium allow us to relate jet energy loss and the cross section suppression in the medium.

We compare our theoretical calculations of the jet shape and the jet cross section to the experimental data at the 2.76 TeV LHC. We examine the dependence of the nuclear modification factor R_{AA} on the jet radius, jet kinematics and collision centrality. Also, we provide for the first time the quantitative understanding of the jet shape modification measurements. We then make prediction for the anticipated jet measurements of inclusive and photon-tagged jets at the 5.10 TeV LHC.

Theory references: C. W. Bauer, S. Fleming, and M. E. Luke Phys.Rev. D63 (2000) 014006. G. Ovanesyan and I. Vitev JHEP 1106 (2011) 080 and Phys.Lett. B706 (2012) 371-378. Y.-T. Chien and I. Vitev JHEP 12 (2014) 061. Y.-T. Chien Int. J. Mod. Phys. Conf. Ser. 37 (2015) 1560047.

Results

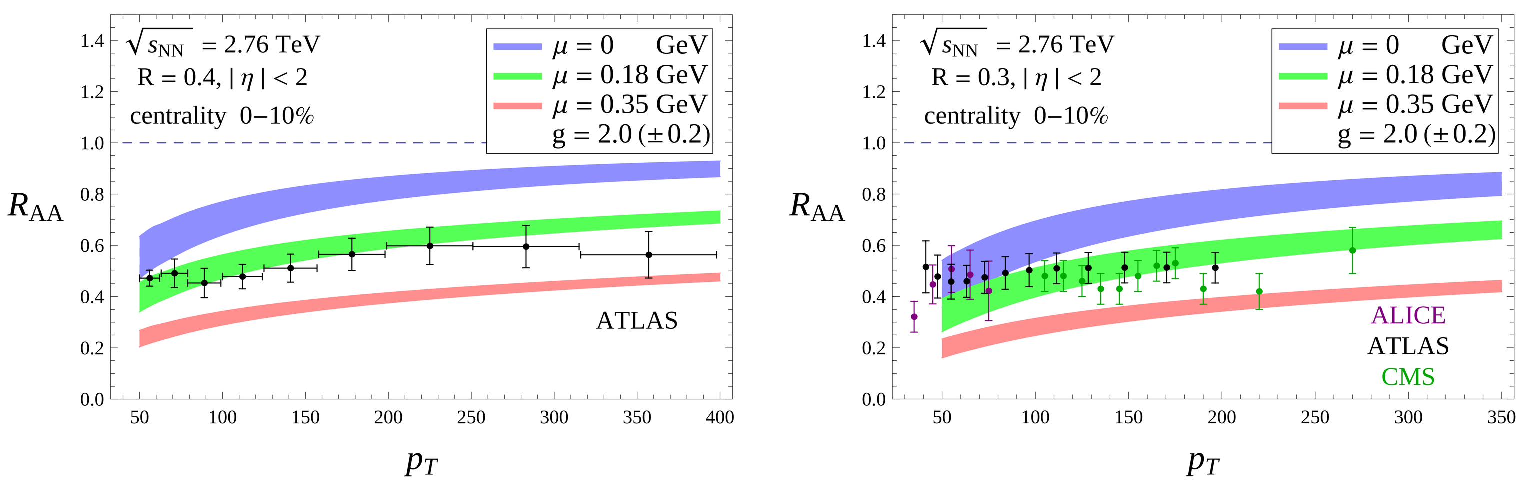

Figure 1: Comparison of theoretical calculations for the jet R_{AA} of inclusive jets to experimental data in central Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV at the LHC. Bands correspond to the theoretical uncertainty estimated by varying the coupling between the jet and the medium ($g = 2.0 \pm 0.2$). The blue band corresponds to the calculations with no CNM effects ($\mu = 0$ GeV), the green band corresponds to the calculations with small CNM effects ($\mu = 0.18$ GeV) and the red band corresponds to the calculations with moderate CNM effects ($\mu = 0.35$ GeV). Left panel: comparison to the ATLAS R_{AA} measurement [1] with $R = 0.4$. Right panel: comparison to the ALICE charged jets R_{CP} [2], ATLAS calorimeter jet R_{CP} [3] and CMS jet R_{AA} [4] results with $R = 0.3$.

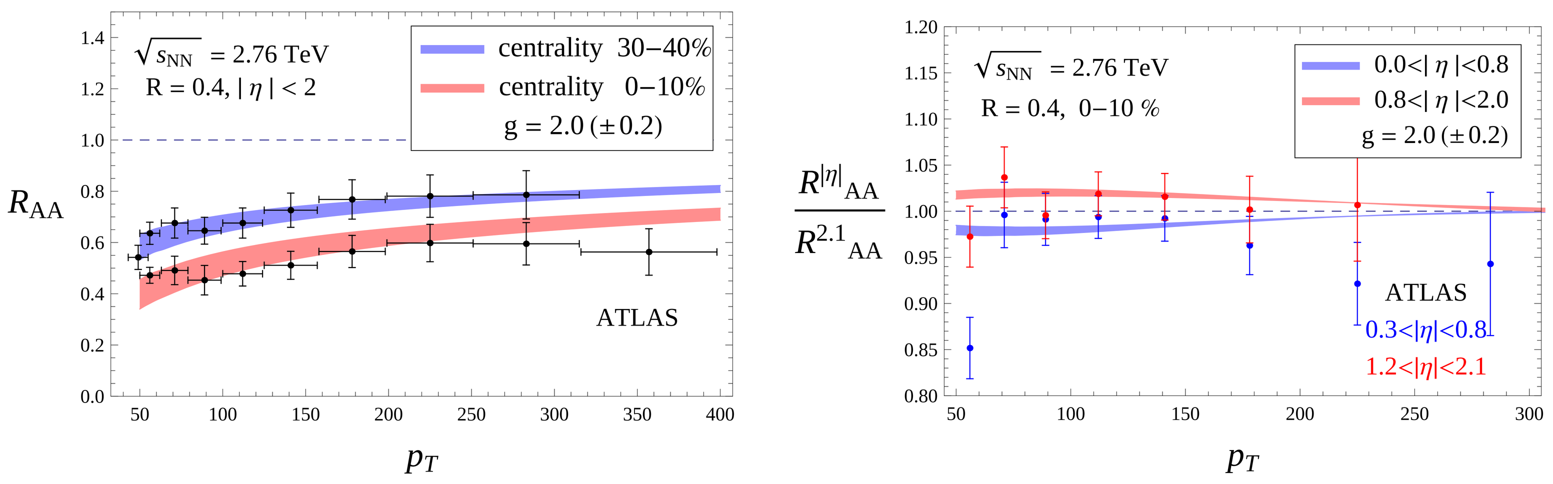

Figure 2: Left panel: comparison of theoretical calculations for the jet R_{AA} of inclusive jets to experimental data in $\sqrt{s_{\rm NN}} = 2.76$ TeV Pb+Pb collisions at the LHC, with different collision centralities. Two centrality classes, 0 - 10% and 30 - 40%, are considered. The data is from ATLAS [1] with $R = 0.4$. Right panel: comparison of theoretical calculations for the ratios of jet R_{AA}'s within different pseudo-rapidity bins as a function of the jet transverse momentum to the ATLAS experimental data [1] in central Pb+Pb collisions. The blue band corresponds to the ratio $R_{AA}(0.0 < |\eta| < 0.8)/R_{AA}(0.0 < |\eta| < 2.0)$, and the red band corresponds to the ratio $R_{AA}(0.8 < |\eta| < 2.0)/R_{AA}(0.0 < |\eta| < 2.0)$. The derived data corresponds to $R_{AA}(0.3 < |\eta| < 0.8)/R_{AA}(0.0 < |\eta| < 2.1)$ and $R_{AA}(1.2 < |\eta| < 2.1)/R_{AA}(0.0 < |\eta| < 2.1)$.

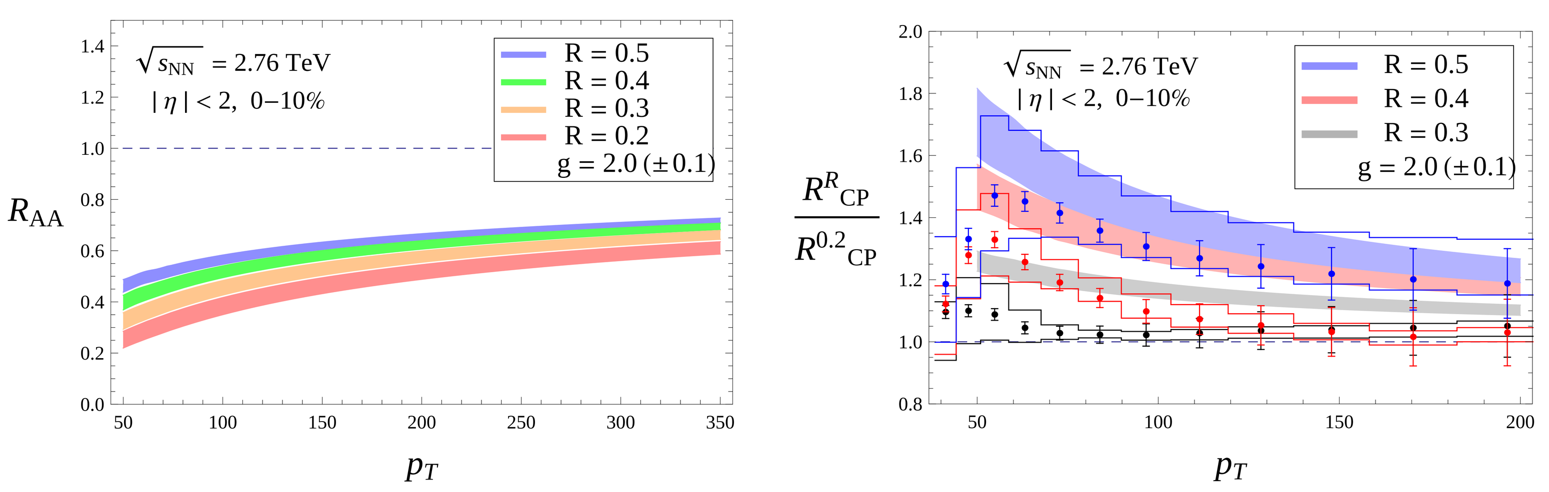

Figure 3: Left panel: theoretical calculations for the jet R_{AA} of inclusive jets with $R = 0.2$, 0.3, 0.4 and 0.5 in central Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV at the LHC. Right panel: comparison of theoretical calculations for the central-to-peripheral R_{CP} ratios for inclusive jets with different jet radii to data in central Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV at the LHC. The bands and the data correspond to $R_{CP}(R = 0.3,\ 0.4,\ 0.5)/R_{CP}(R = 0.2)$. The data is from ATLAS [3].

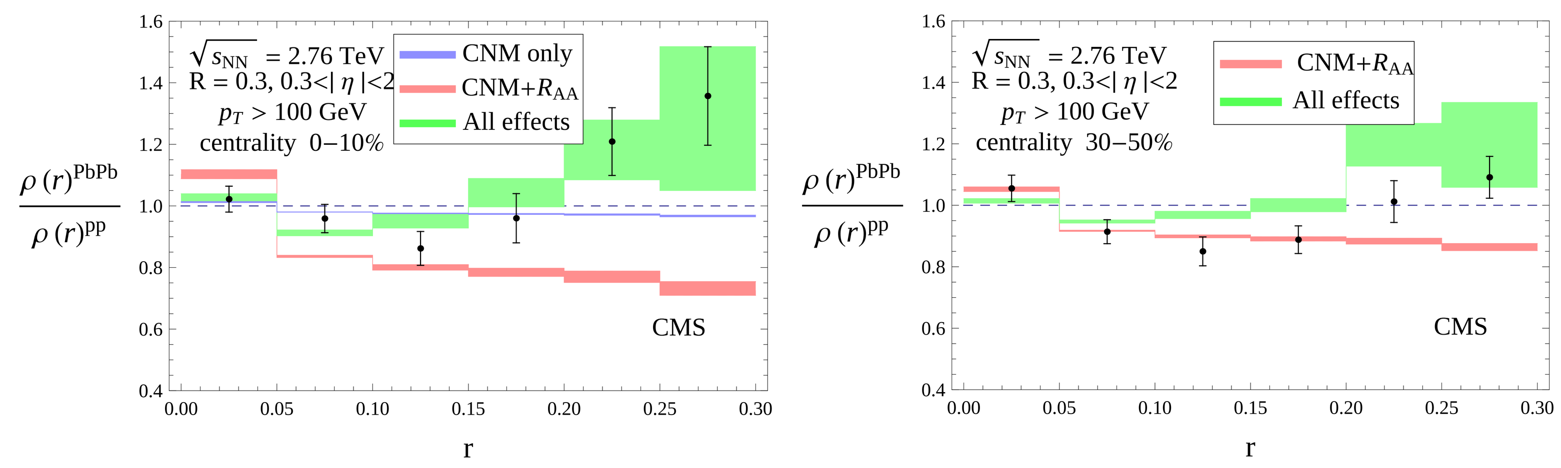

Figure 4: Comparison of theoretical calculations for the modification of jet shapes of inclusive jets in Pb+Pb central (left panel) and peripheral (right panel) collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV at the LHC. The blue band corresponds to the calculations including only the CNM effects, the red band adds the jet-medium interaction but with the jet-by-jet shape modification turned off, and the green band correspond to the full calculation. The theoretical uncertainty is estimated by varying the jet energy scales $\frac{1}{2}\mu_{j_R} < \mu < 2\mu_{j_R}$ in the calculations. The data is from CMS [5] with $R = 0.3$.

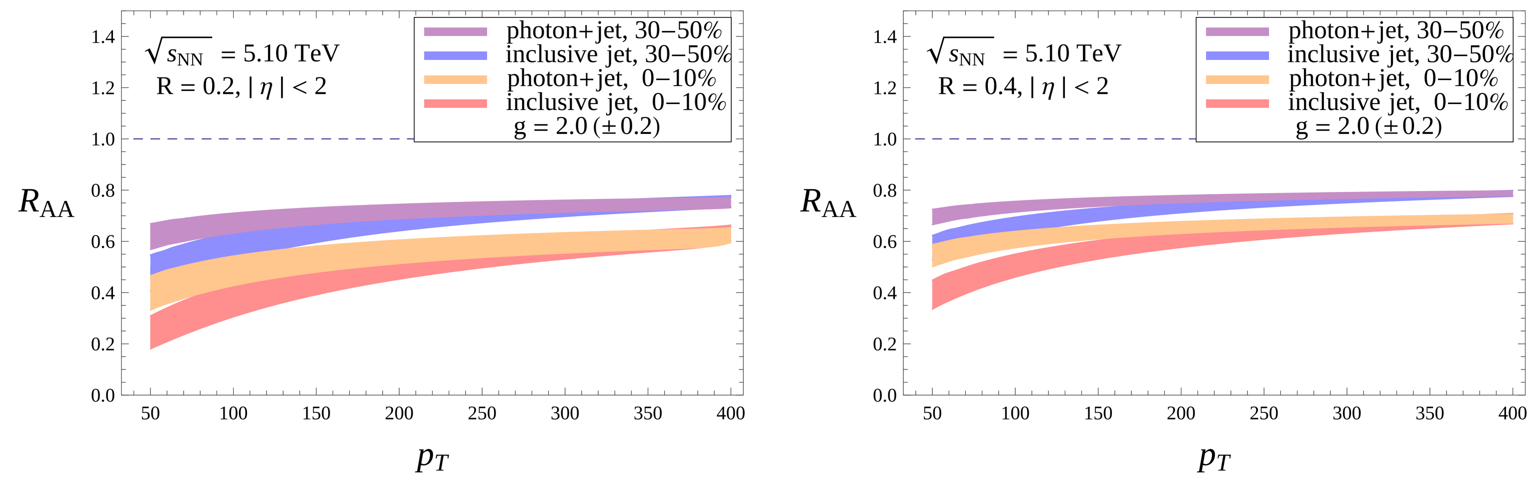

Figure 5: Comparison of the theoretical predictions of the jet R_{AA} as a function of jet transverse momentum p_T for inclusive jets and photon-tagged jets, with $R = 0.2$ (left panel) and $R = 0.4$ (right panel) in central and mid-peripheral Pb+Pb collisions at $\sqrt{s_{\rm NN}} \approx 5.10$ TeV at the LHC. The bands correspond to: inclusive jets, 0 - 10% (red), inclusive jets, 30 - 50% (blue), photon + jet, 0 - 10% (orange), photon + jet, 30 - 50% (purple).

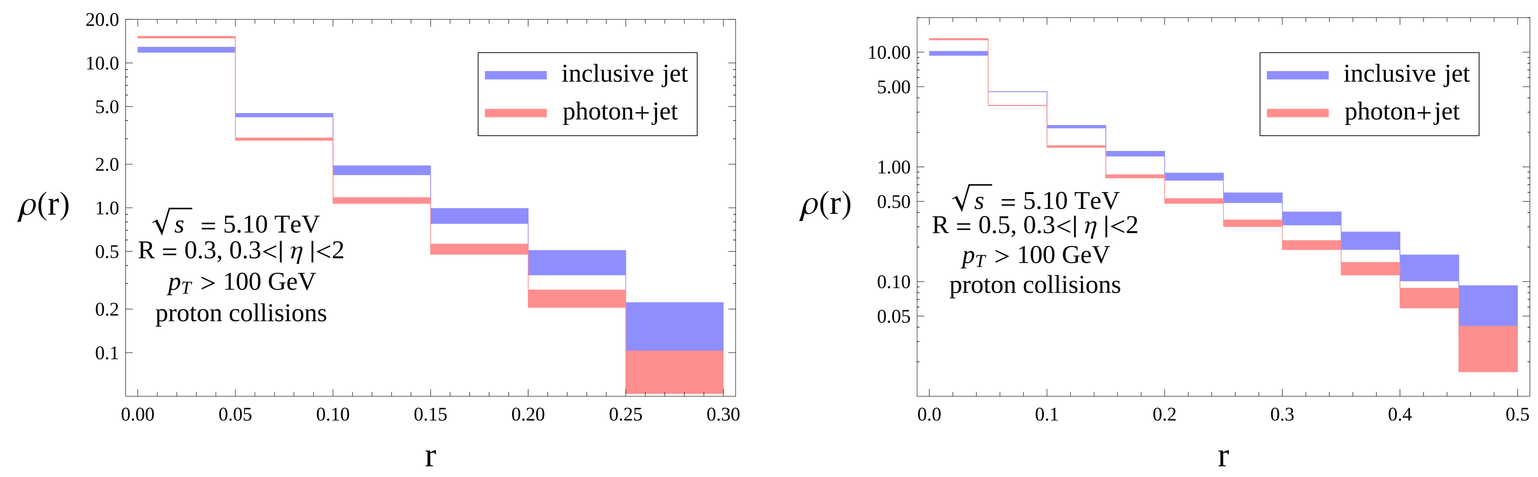

Figure 6: Comparison of the theoretical predictions of the differential jet shapes for inclusive jets (blue bands) and photon-tagged jets (red bands), with $R = 0.3$ (left panel) and $R = 0.5$ (right panel) in $\sqrt{s} \approx 5.10$ TeV p+p collisions, with next-to-leading logarithmic accuracy. Note the narrower energy profile of photon-tagged jets which are mostly quark-initiated.

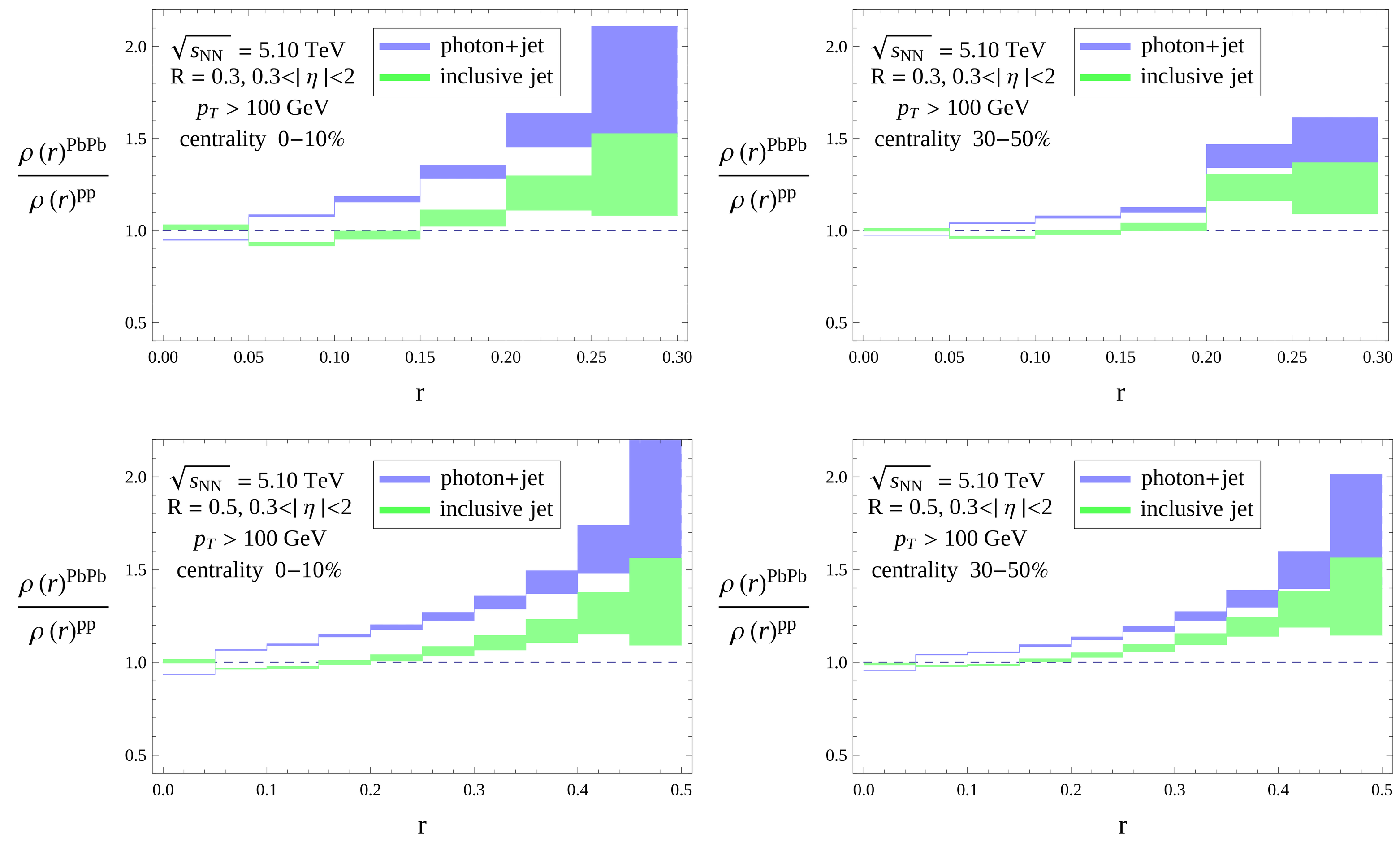

Figure 7: Theoretical predictions of the modification of differential jet shapes for inclusive jets (green band) and photon-tagged jets (blue band), with $R = 0.3$ (upper panels) and $R = 0.5$ (lower panels) in central (left panels) and mid-peripheral (right panels) Pb+Pb collisions at $\sqrt{s_{\rm NN}} \approx 5.10$ TeV at the LHC.

Conclusions

Effective field theory techniques prove to be powerful in the studies of jet physics in heavy ion collisions, allowing us to understand jet shapes and cross sections with the higher level accuracy. Promising applications to the studies of other jet substructure observables are in working progress.

References

[1] **ATLAS** Collaboration, G. Aad *et al. Phys. Rev. Lett.* **114** (2015), no. 7 072302.

[2] **ALICE** Collaboration, B. Abelev *et al. JHEP* **03** (2014) 013.

[3] **ATLAS** Collaboration, G. Aad *et al. Phys.Lett.* **B719** (2013) 220–241.

[4] **CMS** Collaboration, S. Chatrchyan *et al.* CMS-HIN-12-004.

[5] **CMS Collaboration** Collaboration, S. Chatrchyan *et al. Phys.Lett.* **B730** (2014) 243–263.