

Energy-energy correlators in p–Pb collisions at ALICE

Anjali Nambrath^{1,*}

¹University of California, Berkeley, USA

Abstract.

Jet substructure is a powerful tool for testing QCD in elementary particle collisions. The two-point energy-energy correlator (EEC), defined as the energy-weighted cross section of particle pairs inside jets, is a novel jet-substructure observable probing the correlation of energy flow within jets. In pp collisions, the angular dependence of the EEC cross section shows a distinct separation of the perturbative and non-perturbative regimes, revealing the partonic dynamics of jet formation and the confinement of partons into hadrons. In these proceedings, we present measurements of the EECs for inclusive jets in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. By comparing our results to a measured pp baseline, we study jet modification to probe for cold nuclear-matter (CNM) effects. Understanding modifications due to CNM effects is vital to interpreting EEC results in Pb–Pb collisions and separating hot and cold nuclear-matter effects.

1 Introduction

We present measurements by the ALICE collaboration of a novel jet-substructure observable called the energy-energy correlator (EEC) [1–3]. The EEC captures the correlation function of energy flow inside jets. It is experimentally defined as an energy-weighted two-particle correlation between pairs of particles inside a jet, as a function of the angular distance (R_L) separating the pair. The energy-energy correlation function, $\Sigma_{\text{EEC}}(R_L)$, is defined as follows:

$$\Sigma_{\text{EEC}}(R_L) = \frac{1}{N_{\text{jet}} \cdot \Delta} \int_{R_L - \frac{1}{2}\Delta}^{R_L + \frac{1}{2}\Delta} \sum_{\text{jets}} \sum_{i,j} \frac{p_{T,i} p_{T,j}}{(p_T^{\text{ch jet}})^2} \delta(R'_L - R_{L,ij}) dR'_L. \quad (1)$$

Here, $p_T^{\text{ch jet}}$ refers to the total charged-particle jet p_T . The sum runs over all particle pairs (i, j) inside the jet. For each pair, an energy weight is calculated: $p_{T,i} p_{T,j} / (p_T^{\text{ch jet}})^2$. The number of weighted track pairs is counted as a function of the angular distance between both tracks, $R_{L,ij} = \sqrt{(\varphi_j - \varphi_i)^2 + (\eta_j - \eta_i)^2}$. The angular bin width is Δ , and the EEC is normalized by the total number of jets N_{jet} . Here, we present measurements of the EEC in p–Pb collisions from the ALICE collaboration.

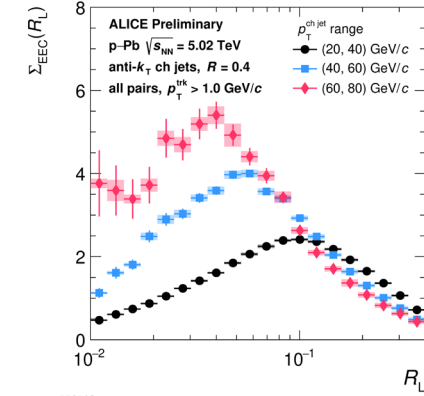
2 Inclusive measurement of EECs in p–Pb

Proton–lead collisions are different from pp events: the initial state is modified by the presence of a modification of the nuclear parton distribution function (PDF) relative to the proton PDF. There is also the possibility of final-state effects, i.e. any effects occurring after the

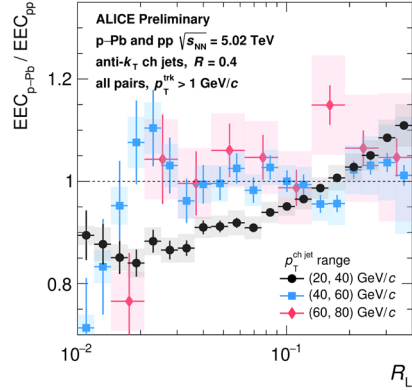
*e-mail: nambrath@berkeley.edu

initial hard scattering. Studying EECs in p–Pb gives us a window into the interactions at play in small collision systems and in cold nuclear matter.

The ALICE collaboration previously reported an inclusive measurement of p–Pb EECs in jets in three $p_T^{\text{ch jet}}$ ranges, which are shown in Figure 1 [4]. The ratios of the p–Pb EEC distributions to pp are shown in Figure 2. We see that in the lowest $p_T^{\text{ch jet}}$ range, there is a significant difference between EECs in p–Pb and pp. There is a distinct enhancement at large R_L , and a suppression at small R_L . This modification is not visible for higher- p_T jets.



ALI-PREL-579718

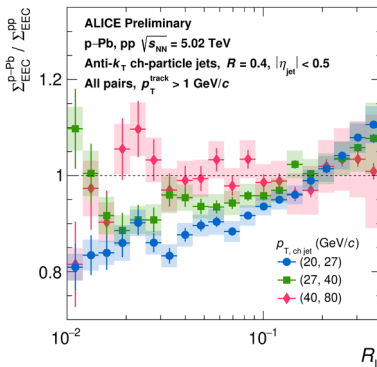


ALI-PREL-581947

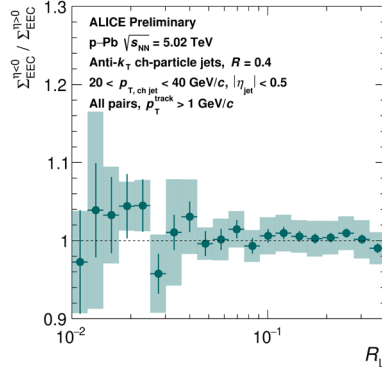
Figure 1. Σ_{EEC} in p–Pb jets in three $p_T^{\text{ch jet}}$ ranges. **Figure 2.** Ratio of Σ_{EEC} distributions in p–Pb/pp.

It was previously found that nPDF models in PYTHIA do not reproduce this data [4]. Various theoretical models have emerged since then [5–7], suggesting explanations for the measured enhancement in 20–40 GeV/c jets. To better discriminate between these models, we can perform more differential studies in the data and investigate the dependence of the p–Pb modification on $p_T^{\text{ch jet}}$, jet pseudorapidity, event activity, and track charge.

3 Differential studies



ALI-PREL-604392



ALI-PREL-604364

Figure 3. Ratio of Σ_{EEC} in p–Pb to pp, in 20–27, 27–40, and 40–80 GeV/c jets.

Figure 4. Backward ($\eta_{\text{jet}} < 0$) to forward ($\eta_{\text{jet}} > 0$) Σ_{EEC} ratio in 20–40 GeV/c p–Pb jets.

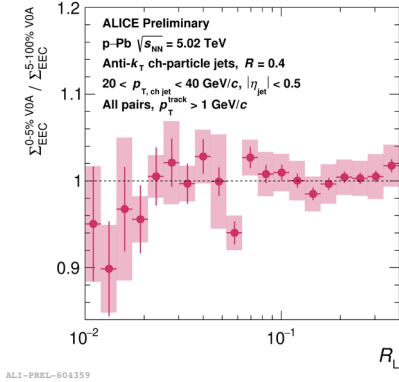


Figure 5. Σ_{EEC} ratio in 20–40 GeV/c p–Pb jets, in high- and low-multiplicity events (determined by VOA multiplicity).

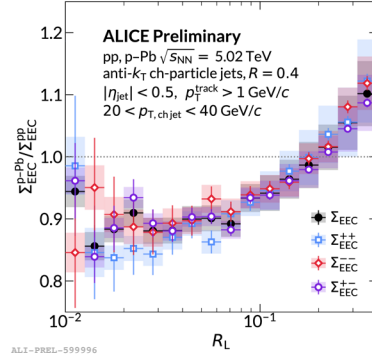


Figure 6. Ratio of charged EEC in p–Pb to pp in 20–40 GeV/c jets, for like-sign and unlike-sign pairs.

3.1 Modification in 20–40 GeV/c jets

To better understand the modification in 20–40 GeV/c jets, we measured the EEC for jets in narrow $p_T^{\text{ch jet}}$ selections: 20–27 and 27–40 GeV/c. The results are shown in Figure 3. We see that the p–Pb EEC differs from the pp in both intervals, but the modification is much stronger in 20–27 GeV/c jets than in 27–40 GeV/c jets. Additionally, Figure 3 also shows the EEC in pp and p–Pb for a combined 40–80 GeV/c $p_T^{\text{ch jet}}$ interval. We see that in this combined range, there is no evidence for a modification of the EEC.

3.2 Dependence on jet rapidity

We can study how the EEC depends on jet rapidity. We construct the EEC for forward jets ($0 < \eta_{\text{jet}} < 0.5$, Pb-going direction) and backward jets ($-0.5 < \eta_{\text{jet}} < 0$, p-going direction). The ratio $\Sigma_{EEC}^{\eta < 0} / \Sigma_{EEC}^{\eta > 0}$ is shown in Figure 4. Backward and forward EECs agree within 5%, showing no rapidity dependence. The $dN/d\eta$ distribution in p–Pb is asymmetric due to the asymmetric collision system [8], but it appears this does not affect the EEC.

3.3 Dependence on event activity

Next we consider forward multiplicity. The forward multiplicity is determined by the ALICE VOA scintillator counter [9], which covers the full azimuth over $2.8 < \eta < 5.1$ on the Pb-going side. The amplitude in the VOA hodoscopes is a measure of event activity in p–Pb collisions. We define two classes, high-multiplicity (HM) and low-multiplicity (LM), as percentiles of the VOA amplitude. LM events are defined as all those below the 95% percentile, and HM events as those above the 95% percentile. The EEC is separately constructed for jets in each event class, and the ratio $\Sigma_{EEC}^{0-5\% VOA} / \Sigma_{EEC}^{5-100\% VOA}$ is shown in Figure 5. The EECs agree within 5% for most of the reported R_L range, indicating no event activity dependence.

3.4 Dependence on track charge

We can look at the dependence on track charge as well by building a charged EEC separately from like-sign (Σ_{EEC}^{++} and Σ_{EEC}^{--}) and unlike-sign (Σ_{EEC}^{+-}) pairs. Charged EECs are sensitive to the parton shower and hadronization mechanisms [10]. The charged EEC p–Pb/pp ratios are shown in Figure 6, where we see no difference between like- and unlike-sign EECs, suggesting no charge dependence either.

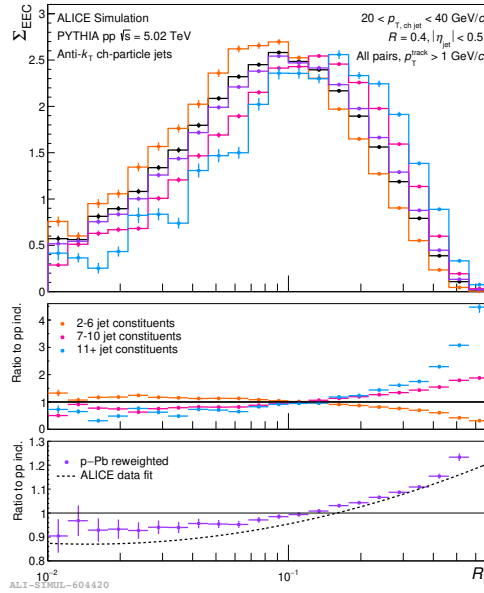


Figure 7. Upper panel: Σ_{EEC} in pp events simulated with PYTHIA, in jets with 2–6 tracks (orange), 7–10 tracks (pink), and 11 or more tracks (blue). The inclusive EEC is in black. Middle: ratio of Σ_{EEC} in jet multiplicity classes to the inclusive pp EEC. Bottom: Σ_{EEC} ratio obtained by shifting the jet multiplicity distribution to mimic p–Pb data, compared to a fit to the measured p–Pb/pp EEC ratio [4].

3.5 Dependence on jet constituent multiplicity

Finally, we show an instructive study using PYTHIA pp events. We separately construct EECs based on the number of jet constituents, shown in Figure 7. We separate jets with 2–6 tracks, 7–10 tracks, and 11 or more tracks. In the upper panel, we see a dramatic shift in simulated pp EECs due to the jet constituent multiplicity. This shift manifests as a suppression at small R_L and a large enhancement at large R_L , seen in the middle panel. If we shift the jet multiplicity distribution, redistributing 12% of jets to higher multiplicities, we can largely reproduce the measured p–Pb EEC modification, as seen in the bottom panel. This suggests a per-jet modification is not the only mechanism that might cause the measured modification in inclusive p–Pb jets. A shift in the overall jet population can have a similar effect.

4 Summary

In this talk, we showed that the EEC for 20–40 GeV/c jets in p–Pb events shows a modification relative to pp. This does not depend on jet rapidity, forward multiplicity, or track charge. We present a simulation study suggesting that the p–Pb modification could come from a relative increase in jets with larger constituent multiplicity. This differential exploration of EECs in p–Pb expands on the previously measured modification and constrains theory explanations.

References

- [1] H. Chen et al., Rethinking jets with energy correlators: Tracks, resummation, and analytic continuation, *Phys. Rev. D* **102**, 054012 (2020). [10.1103/physrevd.102.054012](https://doi.org/10.1103/physrevd.102.054012)
- [2] K. Lee et al., Conformal collider physics meets LHC data, *Phys. Rev. D* **111**, L011502 (2025). [10.1103/physrevd.111.L011502](https://doi.org/10.1103/physrevd.111.L011502)

- [3] P.T. Komiske et al., Analyzing N -Point Energy Correlators inside Jets with CMS Open Data, *Phys. Rev. Lett.* **130**, 051901 (2023). [10.1103/PhysRevLett.130.051901](https://doi.org/10.1103/PhysRevLett.130.051901)
- [4] A. Nambrath (2024), 12th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions, <https://indico.cern.ch/event/1339555/contributions/6040810/>
- [5] Y. Fu, B. Müller, C. Sirimanna, Modification of the jet energy-energy correlator in cold nuclear matter (2024), 2411.04866 [nucl-th], <https://arxiv.org/abs/2411.04866>
- [6] J. Barata et al., Energy-Energy Correlator for jet production in pp and pA collisions (2024), 2411.11782 [hep-ph], <https://arxiv.org/abs/2411.11782>
- [7] C. Andres et al., Simple scaling laws for energy correlators in nuclear matter (2024), 2411.15298 [hep-ph], <https://arxiv.org/abs/2411.15298>
- [8] ALICE Collaboration, Pseudorapidity density of charged particles in p+pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, *Phys. Rev. Lett.* **110**, 032301 (2013). [10.1103/physrevlett.110.032301](https://doi.org/10.1103/physrevlett.110.032301)
- [9] The ALICE collaboration, Performance of the ALICE VZERO system, *JINST* **8**, P10016 (2013). [10.1088/1748-0221/8/10/P10016](https://doi.org/10.1088/1748-0221/8/10/P10016)
- [10] K. Lee, I. Moulton, Energy correlators taking charge (2023), 2308.00746 [hep-ph], <https://arxiv.org/abs/2308.00746>