PROCEEDINGS OF SCIENCE

Jet measurements in small systems relevant for in-medium modifications

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Ultrarelativistic heavy-ion collisions provide insights into the early stages of the expanding universe. The quark-gluon plasma (QGP) is a unique state of matter formed in such high-energy interactions. The existence of this hot and dense strongly interacting medium is associated with several signatures, such as jet suppression and the collective behaviour of the final state particles. The ALICE, ATLAS and CMS Collaborations are actively investigating these properties in various configurations. Proton-nucleus and high-multiplicity proton-proton collisions are considered as small systems and are used as benchmarks for the interpretation of heavy-ion collisions. The aim of this paper is to summarise recent measurements of the jet-related QGP signatures observed in small systems.

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1. Introduction

Proton-nucleus and high-multiplicity proton-proton collisions have been extensively studied to determine the limits of QGP formation. Although the ALICE [1], ATLAS [2] and CMS [3] Collaborations have found evidence of collectivity in small systems, jet quenching has not been observed in such events.

2. Constraints on jet quenching

The spectrum of the jets is expected to be modified by the energy loss of the outgoing particles in the medium. This quenching effect is observed in heavy-ion collisions, but has been strongly disfavoured in previous analyses of small systems [4].

The ATLAS Collaboration measured the per-jet charged particle yields in events where at least one jet is reconstructed with high transverse momentum [5]. Ratios between the proton-lead and proton-proton yields ($I_{\rm pPb} = Y_{\rm Pb}/Y_{\rm pp}$) are calculated for the near-side and away-side side particles, where they may loose transverse momentum due to the interaction with the dense medium. The distribution on the near-side distribution shows a modest enhancement described by the Angantyr shown in Figure 1. The away-side ratios remain consistent with unity across all transverse momentum ranges, indicating that no quenching occurred after the hard scattering.

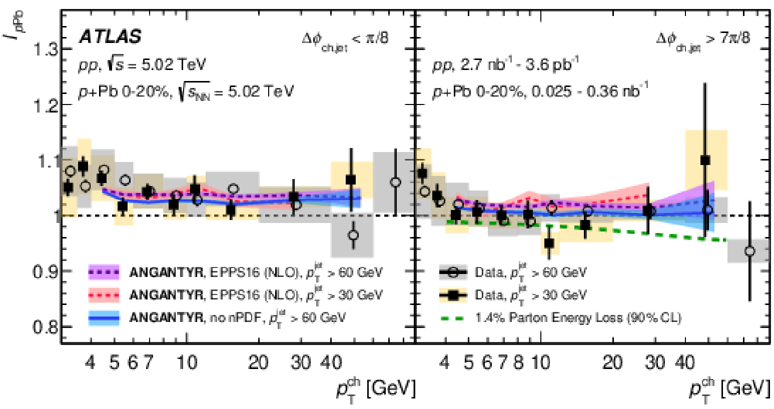

Figure 1: $I_{\rm pPb}$ on the near-side (left) and the away-side (right) for central collisions. The particles are correlated with the jet above transverse momentum limits of 30 GeV or 60 GeV. The results are compared with the predictions of the Angantyr [5] .

3. Elliptic flow of jet particles

In non-central collisions, the initial spatial distortions in the overlapping regions can cause anisotropy in the momentum space. The final state anisotropies are quantified by the coefficients of the Fourier expansion [6]:

$$Y(\phi) = G\left[1 + 2\sum_{n=1}^{\infty} v_n \cos\left(n\left(\phi - \psi_n\right)\right)\right], \quad (1)$$

where G is a normalization factor, v_n are the coefficients and ψ_n is the orientation of the anisotropy. v_2 corresponds to the elliptic flow in this particular case.

The ALICE Collaboration has measured the angular correlations for different trigger particle selections in pPb collisions [7]. The resulting jet particle v_2 is compared with the predictions of the AMPT model. The AMPT model includes a string melting step where all minijets and strings are converted into quarks and anti-quarks. In AMPT, the correlations arise exclusively from initial state anisotropies, as the partons are more likely to escape along the shorter axis of the medium. The enhancement of the jet particle v_2 is attributed to the absence of string fragmentation.

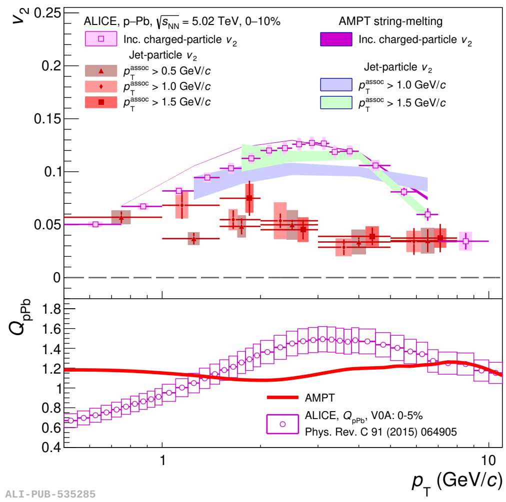

Figure 2: Top figure displays the jet particle v_2 as a function of the trigger particle p_T for various associated particle transverse momentum intervals in central collisions. The measurements are compared with the AMPT predictions. The bottom figure shows the nuclear modification factor from previous studies plotted alongside the AMPT calculations [7] .

4. Dijet properties

Differential dijet yields can provide insight into final states of small systems [8] [9] [10]. CMS discovered non-trivial angular correlations in dijet systems resulting from photonuclear collisions, as shown in Figure 3. The RAPGAP model fails to accurately describe the angular difference dependence of the reconstructed systems, and a bias in the second Fourier coefficient is also observed.

5. Summary

Hard probes are effectively used to investigate the characteristics of small systems. Recent measurements from various detectors have shown that even in high multiplicity proton-proton collisions, long-range correlations are present. Angular correlation measurements indicate a positive elliptic flow coefficient. However, there is no evidence of jet quenching in the pp or pPb colliding systems. The AMPT model shows a positive v_2 without hydrodynamical flow effects. Differential dijet per event yields in various systems show correlations that are not fully explained by the models. The

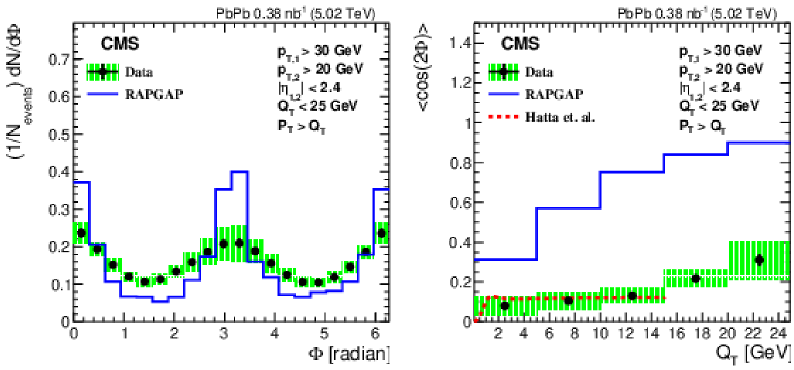

Figure 3: The differential dijet yield in photonuclear collisions is compared to the calculations fromt the RAPGAP model (left). On the right, the second moment of the azimuthal angle anisotropy is shown with respect to the vector sum of the two jets' transverse momenta relative to the beam axis [10] .

Run 3 data-taking period of the LHC provides an increased number of proton-lead collisions, and the recently proposed oxygen-oxygen collisions [11] will offer a unique opportunity to enhance our understanding of small systems.

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