

Measurement of the jet-particle v_2 in p–Pb and Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE at the LHC

Siyu Tang on behalf of the ALICE Collaboration^{a,b,*}

^aCentral China Normal University,
Wuhan, China

^bLaboratoire de Physique de Clermont,
Clermont-Ferrand, France

E-mail: siyu.tang@cern.ch

The elliptic flow of jet particles at midrapidity ($|\eta| < 0.8$) is measured for the first time in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and extended down to lower p_T in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The jet particles are extracted with the two-particle correlation method using a two-dimensional fit, and their v_2 is calculated with the novel three-particle correlation technique. The v_2 of jet particles is found positive in high-multiplicity p–Pb collisions and exhibits no dependence on p_T within uncertainties. Comparisons with the jet-particle v_2 in Pb–Pb collisions and the inclusive charged-particle v_2 in both collision systems are also discussed, aiming to bring new insights into the understanding of the origin of the high- p_T azimuthal anisotropy observed in small collision systems.

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*Speaker

1. Introduction

The particles which originate from hard scattering of partons (quarks and gluons), commonly known as hard probes, play an important role in investigating the properties of quark–gluon plasma (QGP) formed in ultrarelativistic heavy-ion collisions. Since the hard scattering processes with a large momentum transfer ($1/Q \ll 1 \text{ fm}/c$) occur prior to the QGP formation, the hard partons and the subsequent parton shower experience the entire evolution of the system. The angular distribution of final-state particles from hard partons, including high- p_T particles or jets [1], can be expanded as Fourier series. The second harmonic coefficient, v_2 , refers to the elliptic flow. The elliptic flow is sensitive to the path-length dependent energy loss during the interactions between initial partons and the QGP medium [2], which is the so-called jet quenching [3]. However, recent measurements show also a non-zero v_2 value for high- p_T charged particles at high multiplicities in p–Pb collisions [4], but no jet quenching effect is observed in small systems [5, 6]. To understand the origin of such collectivity, the ALICE Collaboration measured the v_2 of charged particles in jets in p–Pb collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$, which allow us to further separate hard and soft components of collectivity in small collision systems. The v_2 of jet particles in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ is also measured and extended to lower p_T compared to previous measurements at the LHC [2] in order to provide a baseline for collectivity of hard probes in small systems.

The analysis is carried out with ALICE apparatus [7] using the main sub-detectors: the Time Projection Chamber (TPC), the Forward Multiplicity Detectors (FMD), the V0, and Silicon Pixel Detector (SPD). The TPC used for charged-particle tracking covers the pseudorapidity range $|\eta| < 0.8$ and has a full azimuthal acceptance. The FMD is located at $1.7 < \eta < 5.0$ (FMD1,2) and $-3.4 < \eta < -1.7$ (FMD3) with full azimuthal coverage. The FMD1,2 is employed in p–Pb collisions for the event selection and to construct long-range correlations with TPC tracks to extract the v_2 coefficient. The V0 detector, made of two scintillator arrays, is used for triggering, event selection, and event activity determination. In addition, the V0 is also used to calculate the flow vector in Pb–Pb collisions, together with the reconstructed tracklets¹ in the SPD detector.

2. Analysis Strategy

2.1 Extraction of the jet signal

A reconstruction algorithm is usually employed to identify jets, but here the jet particles are extracted via two-particle correlations. Both trigger and associated particles are chosen from TPC tracks, and only the same-sign charged particles are selected to suppress the resonances. The associated yield per trigger particle as a function of the pseudorapidity difference $\Delta\eta$ and azimuthal angle difference $\Delta\varphi$ between the trigger and associated particles is defined as

$$Y(\Delta\varphi, \Delta\eta) = \frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{assoc}}}{d\Delta\varphi d\Delta\eta} = \frac{S(\Delta\varphi, \Delta\eta)}{B(\Delta\varphi, \Delta\eta)}, \quad (1)$$

where N_{trig} is number of trigger particles, $S(\Delta\varphi, \Delta\eta) = \frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{same}}}{d\Delta\varphi d\Delta\eta}$ is the associated yield per trigger in the same event, and $B(\Delta\varphi, \Delta\eta) = \alpha \frac{d^2 N_{\text{mixed}}}{d\Delta\varphi d\Delta\eta}$ is the pair yield in different events obtained

¹The track segments formed by the clusters in the two SPD layers and the primary vertex

with the event-mixing technique [8] and normalized to unity at maximum. By dividing $S(\Delta\varphi, \Delta\eta)$ by $B(\Delta\varphi, \Delta\eta)$, the finite-acceptance effect is accounted for [9]. The corrected associated yield per trigger particle is shown in the Fig. 1, where the jet peak is clearly observed in the near-side region for both p-Pb (left) and Pb-Pb (right) collisions. The yield associated to the near-side jet peak is extracted with a two-dimensional fit method, using a double Gaussian on the near-side superimposed on the sum of harmonics up to fifth order [10]. Figure 2 shows the extracted jet-peak yield (left) and background yield² (right) in p-Pb collisions, which will be used to extract the v_2 of jet particles in the next step.

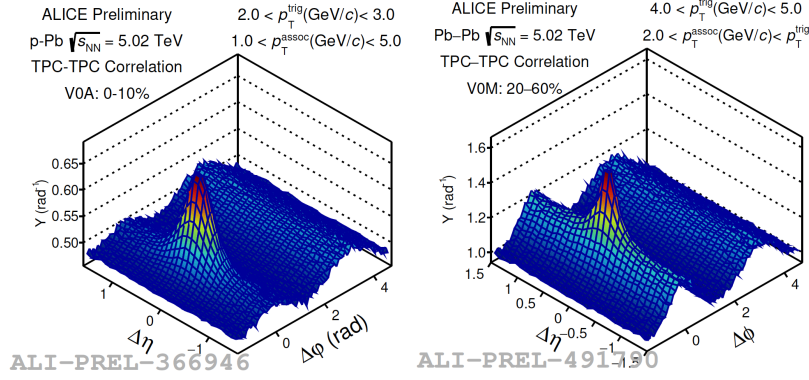


Figure 1: The associated yield per trigger particle in TPC-TPC correlation for p-Pb (left) and Pb-Pb (right) collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

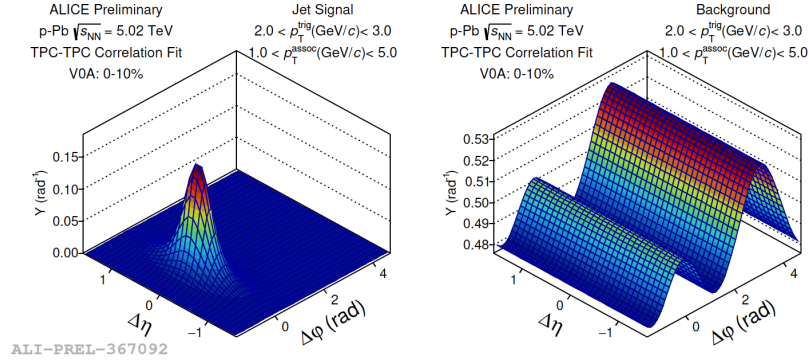


Figure 2: The extracted near-side jet (left) and background (right) yields after the fit of TPC-TPC correlation distribution in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

2.2 Calculation of jet-particle v_2

The calculation of the jet-particle v_2 is based on the so called "three-particle correlation" technique. In the three-particle correlations, two of them are chosen from the particle pair obtained in TPC-TPC correlations, as shown in Fig. 1, and the third particle is selected in the forward rapidity region. The long-range correlations between the trigger particle of the TPC-TPC particle pairs and the forward particles are constructed. In p-Pb collisions, the forward particles are chosen from

²The background corresponds to the particles which are not from the near-side jet peak.

the "FMD1,2" and the flow coefficient is extracted from the Fourier expansion of the long-range correlation after the subtraction of the scaled low-multiplicity class ((0-10%)-(60-100%)) to remove the non-flow contribution [9]. In Pb-Pb collisions, the forward particles are measured in V0A, and the v_2 is calculated directly by means of the scalar product method with the three sub-event technique [11]. Figure 3 (left) shows the v_2 distribution as a function of $\Delta\varphi$ and $\Delta\eta$ of TPC-TPC pairs. The concavity is observed in ($\Delta\varphi \sim 0, \Delta\eta \sim 0$) where the jet peak is located. This indicates that the jet-particle v_2 is different from the v_2 of the background particles. Considering that $v_2(\Delta\varphi, \Delta\eta)$ is the weighted sum of the v_2 from jet particles ($v_{2,\text{jet}}$) and background ($v_{2,\text{bkg}}$), where the weight is the ratio of the yield of jet-peak (Y_{jet}) to the background (Y_{bkg}) obtained when fitting the TPC-TPC correlation, it can be written as

$$v_2(\Delta\varphi, \Delta\eta) = Y_{\text{jet}}/(Y_{\text{jet}} + Y_{\text{bkg}}) \times v_{2,\text{jet}} + Y_{\text{bkg}}/(Y_{\text{jet}} + Y_{\text{bkg}}) \times v_{2,\text{bkg}}(\Delta\varphi, \Delta\eta), \quad (2)$$

where $v_{2,\text{jet}}$ is a constant, and $v_{2,\text{bkg}}$ is a Fourier series up to the fifth order and has a dependence on $\Delta\varphi$ and $\Delta\eta$. The fit of $v_2(\Delta\varphi, \Delta\eta)$ distribution is obtained with Eq. 2 in each p_T interval of trigger and associated particles, and it is shown in the middle panel of Fig. 3. The small difference between the fit and the data shown in the right panel of Fig. 3 demonstrates that the fit strategy is suited to extract $v_{2,\text{jet}}$.

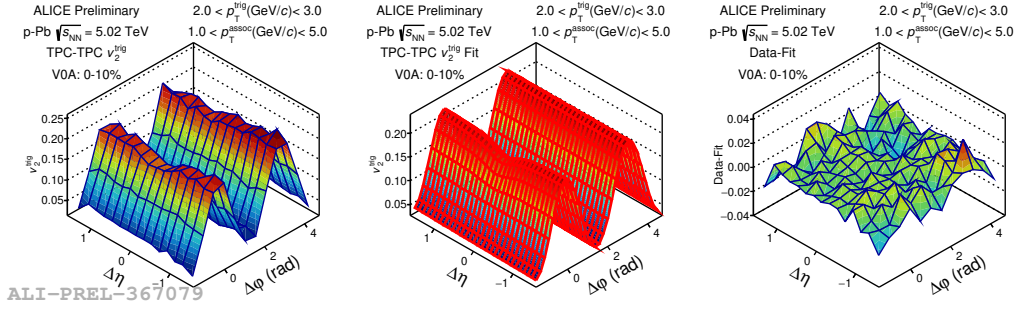


Figure 3: Left: v_2 distribution of trigger particles in TPC-TPC pairs in p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV. Middle: A fit of Eq. 2 to v_2 distribution. Right: difference between data and fit.

3. Results

A positive jet-particle v_2 is measured for the first time in high-multiplicity p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV. The magnitude is lower than the v_2 of inclusive charged particles, as shown in Fig. 4 (left). A consistent v_2 is measured with different trigger- and associated-particle p_T selections. In Pb-Pb collisions, the jet-particle v_2 is measured for the first time down to 2 GeV/c in 20–60% Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV, and does not show any dependence on the associated- p_T selections, as shown in Fig. 4 (right). Furthermore, the jet-particle v_2 converges towards the v_2 of inclusive charged particles in Pb-Pb collisions for $p_T > 7$ GeV/c, where the parton energy loss is dominant [5]. Figure 5 shows the final comparison among the jet-particle v_2 , inclusive charged-particle v_2 , and reconstructed-jet v_2 [2] in p-Pb and Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV. The jet-particle v_2 in Pb-Pb collisions is consistent with the reconstructed-jet v_2 at high p_T , which are both interpreted by the path-length dependent energy loss effect. On the other hand, in

order to compare the results obtained in p-Pb and Pb-Pb collisions directly, the v_2 of inclusive charged particles in p-Pb is multiplied by a factor 1.7, which is mainly influenced by the initial-state eccentricity [4], to match the v_2 of inclusive charged particles in Pb-Pb collisions. The same factor is also applied to the jet-particle v_2 in p-Pb collisions. After the scaling, the v_2 of jet particles in p-Pb has a magnitude comparable to the jet-particle v_2 and inclusive charged-particle v_2 in Pb-Pb collisions at high p_T . This hints to a similar collective behaviour of hard probes in large and small collision systems, even there is no jet quenching effect observed in p-Pb collisions.

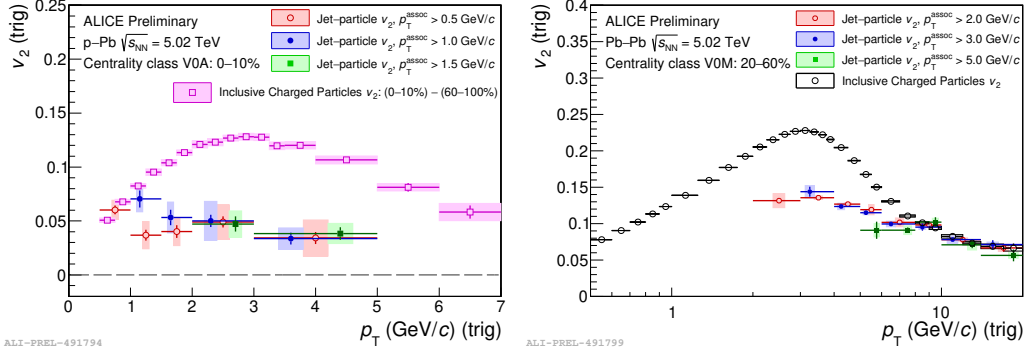


Figure 4: The jet-particle v_2 as a function of the trigger-particle p_T with different associated-particle p_T selections, compared to the inclusive charged-particle v_2 , in p-Pb (left) and Pb-Pb (right) collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

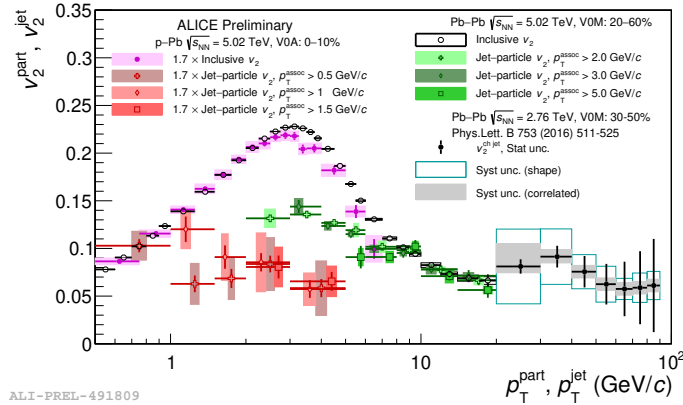


Figure 5: Comparison of jet-particle v_2 and inclusive charged-particle v_2 in p-Pb and Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, and reconstructed-jet v_2 in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

4. Summary

The v_2 of particles in jets is measured, for the first time, in p-Pb collisions and extended to low p_T in Pb-Pb collisions. A non-zero and p_T -independent jet-particle v_2 is found in p-Pb collisions which gives insight into the origin of collectivity in small collision systems. In Pb-Pb collisions, thanks to the low- p_T region reached for the first time for the jet-particle v_2 measurement, a clear picture of the p_T -dependent v_2 of the jet particles can be established and more differential information to constrain the hard parton in-medium interacting mechanisms is provided.

5. Acknowledgement

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References

- [1] G.P. Salam, *Towards Jetography*, *Eur. Phys. J. C* **67** (2010) 637 [0906.1833].
- [2] ALICE collaboration, *Azimuthal anisotropy of charged jet production in $\sqrt{s_{NN}} = 2.76$ TeV Pb-Pb collisions*, *Phys. Lett. B* **753** (2016) 511 [1509.07334].
- [3] J.D. Bjorken, *Energy Loss of Energetic Partons in Quark - Gluon Plasma: Possible Extinction of High $p(t)$ Jets in Hadron - Hadron Collisions*, .
- [4] ATLAS collaboration, *Transverse momentum and process dependent azimuthal anisotropies in $\sqrt{s_{NN}} = 8.16$ TeV p +Pb collisions with the ATLAS detector*, *Eur. Phys. J. C* **80** (2020) 73 [1910.13978].
- [5] ALICE collaboration, *Transverse momentum spectra and nuclear modification factors of charged particles in pp , p -Pb and Pb-Pb collisions at the LHC*, *JHEP* **11** (2018) 013 [1802.09145].
- [6] ALICE collaboration, *Constraints on jet quenching in p -Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV measured by the event-activity dependence of semi-inclusive hadron-jet distributions*, *Phys. Lett. B* **783** (2018) 95 [1712.05603].
- [7] ALICE collaboration, *Performance of the ALICE Experiment at the CERN LHC*, *Int. J. Mod. Phys. A* **29** (2014) 1430044 [1402.4476].
- [8] ALICE collaboration, *Long-range angular correlations on the near and away side in p -Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV*, *Phys. Lett. B* **719** (2013) 29 [1212.2001].
- [9] ALICE collaboration, *Forward-central two-particle correlations in p -Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV*, *Phys. Lett. B* **753** (2016) 126 [1506.08032].
- [10] ALICE collaboration, *Multiplicity dependence of jet-like two-particle correlation structures in p -Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV*, *Phys. Lett. B* **741** (2015) 38 [1406.5463].
- [11] ALICE collaboration, *Energy dependence and fluctuations of anisotropic flow in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ and 2.76 TeV*, *JHEP* **07** (2018) 103 [1804.02944].