ANISOTROPIC FLOW OF IDENTIFIED PARTICLES MEASURED WITH THE ALICE DETECTOR IN THE FIRST YEAR OF HEAVY ION PROGRAM*

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The anisotropic flow of identified particles is an important observable to probe the parton nature of the system created in heavy-ion collisions. We report on the measurement of elliptic and triangular flow for charged pions, kaons and protons in lead–lead collisions at 2.76 TeV per nucleon pair center of mass energy, measured with the ALICE detector at the LHC in the first year of the heavy-ion programme. In addition, we focus on the anisotropic flow of particles with strangeness (*i.e.* $K^0_{\rm s}$ and Λ) to reveal any dependence on the flavour of constituent quarks. For identified particles with intermediate transverse momenta we test the quark coalescence picture with v_2 and v_3 scaled by the number of constituent quarks as a function of scaled transverse mass $m_{\rm t}$. Comparisons with the RHIC measurements at lower energies and with predictions from models are also discussed.

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1. Introduction

The main goal of the ALICE experiment in 2010 was focused on collecting and analyzing data in Pb–Pb collisions. An interesting observable to probe the nature of the matter produced in such a collision system is the evaluation of collective phenomena and in particular of the anisotropic flow, described by the coefficients in the Fourier expansion of the azimuthal particle distribution [1, 2]. The first measurement of elliptic flow (v_2) at the

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LHC showed an increase (with respect to RHIC energies) of the integrated value by about 30% but no significant increase of the $p_{\rm t}$ differential flow [3]. This effect may be interpreted in terms of an increase of the average mean $p_{\rm t}$ due to an higher transverse radial flow at LHC with respect to RHIC.

Elliptic flow of identified hadrons, presented herein, is sensitive to the hydrodynamical radial expansion of the medium. In fact, if the flow is developed in a common velocity field, the momenta for different species should be shifted to higher values according to a mass ordering and this effect should be reflected in the flow. Such effect has been observed at RHIC [4, 5] and by ALICE at LHC.

Triangular flow (v_3) of identified particles in hydrodynamics is expected to exhibit a similar mass scaling and to be a sensitive probe for the viscosity to entropy ratio η/s of the created medium [6]. The measurement of identified particle v_3 can provide a constraint on η/s after more detailed theoretical calculations become available for LHC energies.

Therefore, we present our preliminary results for the measurement of anisotropic flow for identified particles, and compare to the RHIC results for the v_2 case, and test the quark number scaling in terms of transverse kinetic energy ($E_{\rm T}^{\rm kin}$ scaling).

2. DATA analysis

For this analysis, we use the standard ALICE minimum bias (MB) event selection with an additional requirement on the primary vertex position $|z| < 7$ cm corresponding to a sample of around 4 million events. The collision centrality was determined using the forward VZERO scintillator arrays [7]. Particle tracking was done using the Time Projection Chamber (TPC) and the silicon inner tracking system with full azimuth coverage for $|\eta| < 0.8$. The particle identification was done by the Time-of-Flight (TOF) measurement combined with the energy loss measurement in the TPC used as veto to reject wrong matching in "TPC track"–"TOF hit" assignment. The purity was estimated to be better than 95% at $p < 3$ GeV/c for kaons and at $p < 5$ GeV/c for pions and protons (Fig. 1).

To reduce the contamination from non-primary particles, the reconstructed particles were required to have a distance of closest approach to the primary vertex of less than 1 mm. Main sources of systematic uncertainty on the flow values considered in this analysis are non-flow, feed-down and centrality determination. In the next figures, uncertainty bands indicate systematic and statistical uncertainties added in quadrature. Elliptic flow is measured using the two-particle scalar product method [8] with a large η gap ($|\Delta\eta| > 1$) to reduce the contribution from short range non-flow correlations.

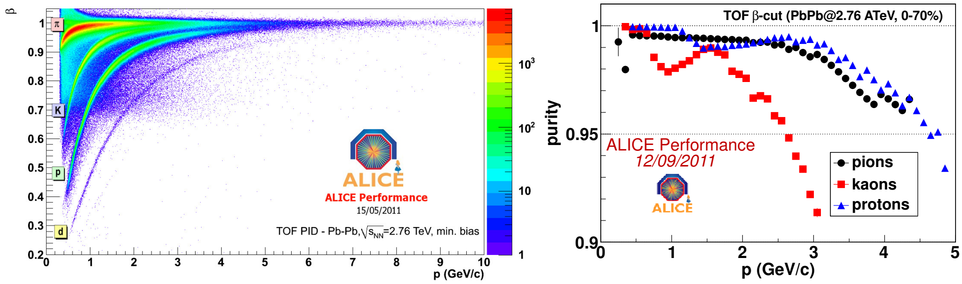

Fig. 1. TOF β *versus* p plot in Pb–Pb collisions (left panel) and estimated purity in particle identification after the TOF β cut is applied (right panel).

3. Results

In Fig. 2 v_2 results are shown for π, K and $\bar{p}$ in two different centrality classes (10%–20% and 40%–50%). The theoretical curves reported in the figures are taken from hydrodynamic predictions [9] with and without the inclusion of a final hadronic rescattering effect. Both models describe the data well at low to intermediate p_{t} except for the antiproton v_2 for the more central collisions (10%–20%). This suggests hadronic rescattering should be included in the model to reproduce the data.

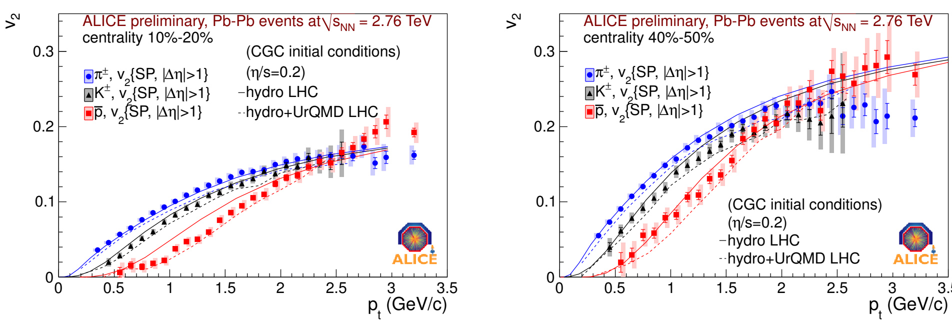

Fig. 2. Identified particle elliptic flow in two centrality bins compared to hydrodynamic predictions [9].

The same comparison is performed in Fig. 3 for neutral strange particles and the same behaviour can be observed. In particular, Λs v_2 seems similar to the antiproton's v_2 looking independently of the flavour content.

The measured v_2 is also compared to the results published by the PHENIX [4] and STAR [5] collaborations in Fig. 4. Since PHENIX reports combined result for pions and kaons we only compare the antiproton flow which shows lower values in ALICE data consistent with larger radial flow at 2.76 TeV. In the comparison with STAR data we observe a larger mass splitting in both pion and antiproton comparisons.

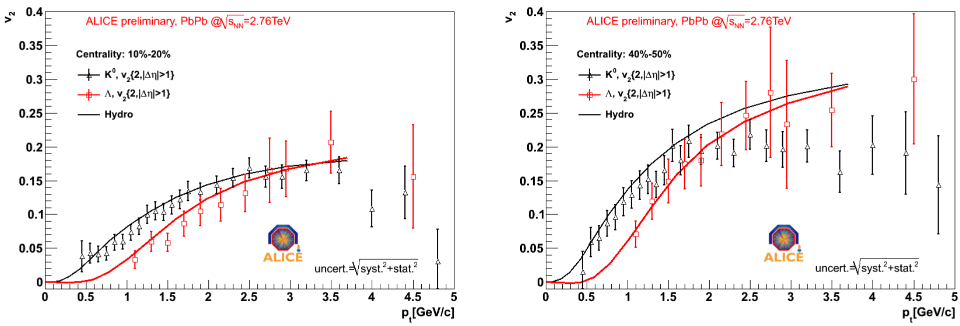

Fig. 3. Strange particle elliptic flow in two centrality bins compared to a hydrodynamic prediction including hadronic rescattering [9].

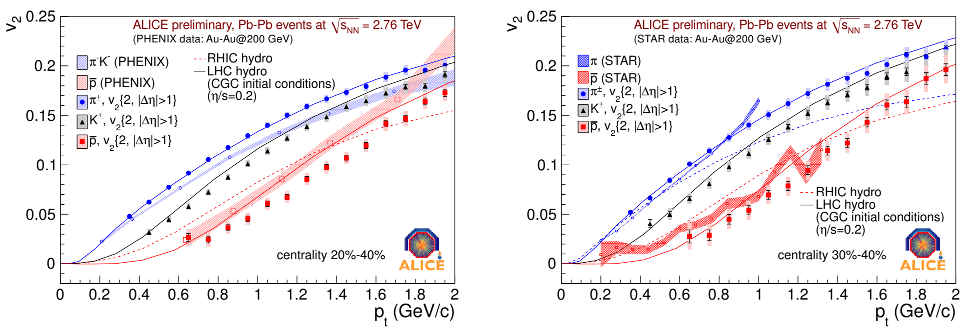

Fig. 4. Elliptic flow measured by ALICE compared to RHIC results (left panel: PHENIX [4], right panel: STAR [5]).

The test of $E_{\mathrm{T}}^{\mathrm{kin}}$ scaling at the LHC energies is reported in Fig. 5. It can be seen that, within the errors, the pion and kaon v_2 follow the scaling while the antiproton one deviates notably for the more central events.

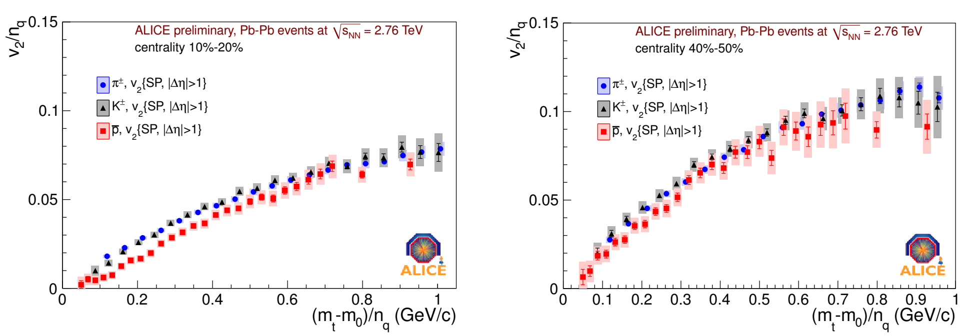

Fig. 5. Elliptic flow per constituent quark *versus* transverse kinetic energy per quark (the $E_{\mathrm{T}}^{\mathrm{kin}}$ scaling) for 10–20% (left) and 40–50% (right) central Pb–Pb collisions.

The ALICE elliptic flow measurement at very high momenta (identification based on the TPC dE/dx in the relativistic rise region) is reported for charged particles, pions and protons in Fig. 6 and is compared to the PHENIX measurement for neutral pions. The statistics used by ALICE to reach $p_{\mathrm{t}} > 10$ GeV$/c$ corresponds to about 13 M MB events. ALICE and PHENIX results are consistent, within the errors, while the ALICE $\bar{p}$s flow seems to meet the πs one well before 10 GeV$/c$.

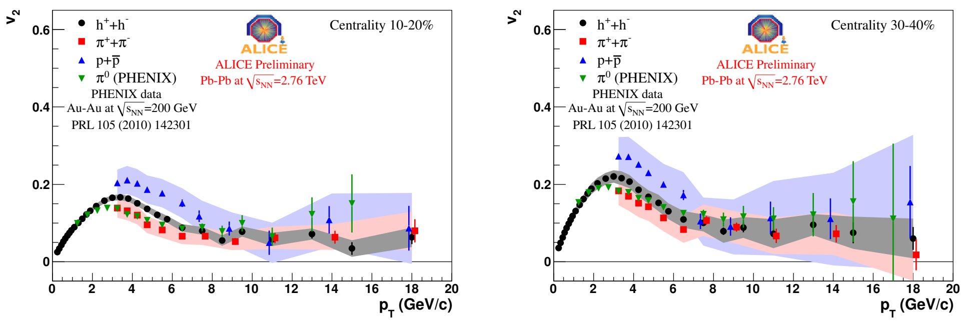

Fig. 6. Pion and proton elliptic flow by ALICE compared to RHIC results at very high momenta, in two centrality bins.

Triangular flow, shown in Fig. 7, qualitatively exhibits the same features as elliptic flow, *i.e.* mass splitting and mass ordering as expected from hydrodynamic models as well as a crossing point between pion and proton flow at intermediate p_{t} as expected from the quark coalescence picture. However, the magnitude of triangular flow looks very different from the case of v_2, in particular, with respect to the centrality dependence. This difference is probably connected with the different origin of the two effects: eccentricity for v_2 and fluctuations for v_3. Similarly to elliptic flow, triangular flow shows deviations from $E_{\mathrm{T}}^{\mathrm{kin}}$ scaling (see Fig. 8) [10].

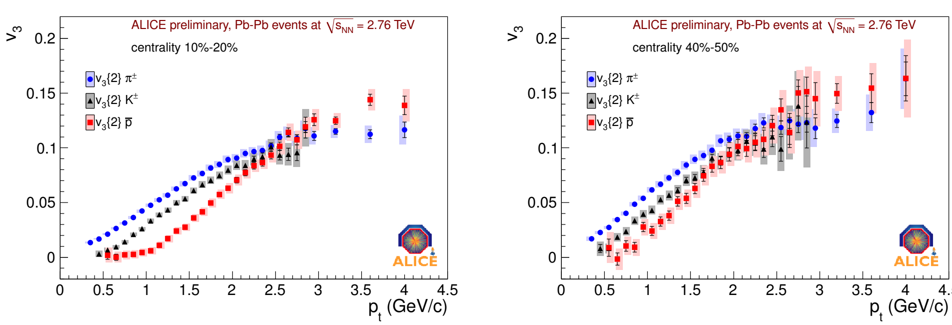

Fig. 7. Triangular flow for 10–20% (left) and 40–50% (right) central Pb–Pb collisions.

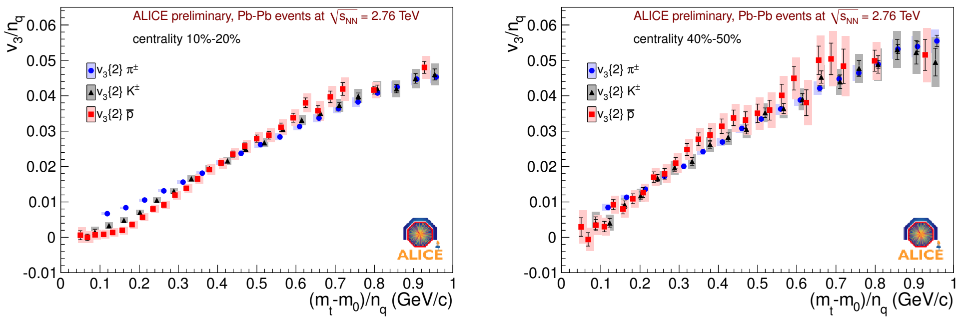

Fig. 8. $E_{\mathrm{T}}^{\mathrm{kin}}$ scaling of triangular flow for 10–20% (left) and 40–50% (right) central events.

4. Summary

We presented the p_{t} differential elliptic flow of identified particles for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV measured by ALICE. The comparison with RHIC results and with hydrodynamic models was also shown. The pure hydrodynamic model correctly describes elliptic flow of pions and kaons, but over-predicts the flow of protons for more central collisions. However, the inclusion in the model of a final hadron rescattering effect allows one to reproduce the data quite well. Compared to the RHIC data we observed a larger mass splitting, mostly apparent in the proton flow. We also showed deviations of elliptic flow from $E_{\mathrm{T}}^{\mathrm{kin}}$ scaling. Additionally, we presented the measurement of p_{t} differential triangular flow of identified particles at the LHC. We observed that v_3 has features similar to v_2, although with a very small dependence on the centrality. Pion and proton elliptic flows were also measured up to 18 GeV/c and they meet well before 10 GeV/c.

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