

# Event shape engineering with ALICE

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## Abstract

The strong fluctuations in the initial energy density of heavy-ion collisions allow an efficient selection of events corresponding to a specific initial geometry. For such “shape engineered events”, the elliptic flow coefficient,  $v_2$ , of unidentified charged particles, pions and (anti-)protons in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV is measured by the ALICE collaboration.  $v_2$  obtained with the event plane method at mid-rapidity,  $|\eta| < 0.8$ , is reported for different collision centralities as a function of transverse momentum,  $p_T$ , out to  $p_T = 20$  GeV/c. The measured  $v_2$  for the shape engineered events is significantly larger or smaller than the average which demonstrates the ability to experimentally select events with the desired shape of the initial spatial asymmetry.

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## 1. Introduction

An important observable used for the characterization of the properties and the evolution of the system created in a nucleus-nucleus collision is the anisotropic flow [1]. Anisotropic flow arises due to the asymmetry in the initial geometry of the collision and is characterized by the Fourier coefficients [2, 3]:

$$v_n(p_T, \eta) = \langle \cos[n(\phi - \Psi_n)] \rangle, \quad (1)$$

where  $p_T$ ,  $\eta$ , and  $\phi$  are the particle’s transverse momentum, pseudo-rapidity, and the azimuthal angle, respectively, and  $\Psi_n$  is the  $n$ -th harmonic symmetry plane angle. The second Fourier coefficient  $v_2$  is called elliptic flow. Recently, experimental measurements [4] confirmed the existence of non-zero odd harmonic coefficients due to fluctuations in the initial energy density distribution.

Two approaches are currently utilized to study the effect of the initial geometry on final observables: variation of the collision centrality and collisions between nuclei of different size and shape. A new method to select events corresponding to different initial system shapes based on the fluctuations in the initial geometry was proposed in [5]. In this paper, following [5], we select events with elliptic flow values significantly larger or smaller than the average. For those events, we present the measurement of unidentified charged particle  $v_2$  out to  $p_T = 20$  GeV/c, and for protons and charged pions <sup>2</sup> out to  $p_T = 16$  GeV/c.

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<sup>1</sup>A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

<sup>2</sup>In this analysis we do not differentiate between particle and antiparticle.

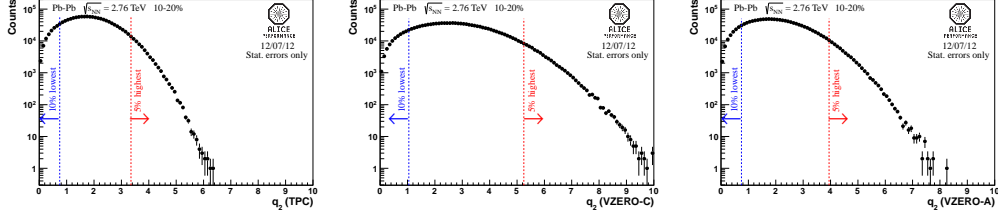


Figure 1: (color online) Distribution of  $q_2$  from the TPC (left), VZERO-C (middle), and VZERO-A (right) for the 10-20% centrality class. The dashed lines indicate the  $q_2$  value used to select events with 10% lowest (blue) and 5% highest (red)  $q_2$ , respectively. Only statistical errors are shown.

## 2. Analysis details

The data sample recorded by ALICE during the 2010 heavy-ion run at the Large Hadron Collider is used for this analysis. The Time Projection Chamber (TPC) was used to reconstruct charged particle tracks and measure their momenta with full azimuthal coverage in the pseudo-rapidity range  $|\eta| < 0.8$ , and particle identification via the specific ionization energy loss,  $dE/dx$ , in the transverse momentum region  $p_T > 3$  GeV/c [6]. Two scintillator arrays (VZERO) which cover the pseudo-rapidity ranges  $-3.7 < \eta < -1.7$  (VZERO-C) and  $2.8 < \eta < 5.1$  (VZERO-A) were used for triggering, centrality [7] and symmetry plane determination. The trigger conditions and the event selection criteria are identical to those described in [4, 7]. Approximately  $1.1 \times 10^7$  minimum-bias Pb-Pb events with a reconstructed primary vertex within  $\pm 10$  cm from the nominal interaction point in the beam direction are used for this analysis. Charged particles reconstructed in the TPC in  $|\eta| < 0.8$  and  $0.2 < p_T < 20$  GeV/c which pass the quality cuts described in [8] were selected.

The event shape analysis is performed with the three subevents technique. The first subevent “a” is used for the event selection based on the magnitude of the so-called reduced flow vector,  $q_2$  [1, 3]:

$$Q_{2,x} = \sum_i^M \cos(2\phi_i), \quad Q_{2,y} = \sum_i^M \sin(2\phi_i), \quad (2)$$

$$q_2 = Q_2 / \sqrt{M}, \quad (3)$$

where  $M$  is the multiplicity and  $\phi_i$  is the azimuthal angle of particle  $i$ .  $v_2$  is measured with the event plane method ( $v_2\{\text{EP}\}$  [1]) based on particles reconstructed in the second subevent “b” with the symmetry plane  $\Psi_2$  determined from particles of the third subevent “c”. Two different sets of subevents were considered: one configuration with “a” and “b” subevents determined by two  $\eta$ -subevents of TPC tracks and “c” from the VZERO detector, and another configuration with “a” and “c” subevents from the two VZERO scintillators and “b” from TPC tracks. In the latter case, the large gap in pseudo-rapidity between the charged particles in the TPC and those in the VZERO detectors greatly suppresses correlations unrelated to the azimuthal asymmetry in the initial geometry (“non-flow”). Note that the contribution from flow fluctuations was shown to be positive for  $v_2\{\text{EP}\}$  [1].

The  $q_2$  distribution is determined in one  $\eta$  window of the TPC ( $-0.8 < \eta < 0$  or  $0 < \eta < 0.8$ ) as well as in each of the two VZERO detectors, see Fig. 1. To demonstrate the ability of the event shape selection, we compared  $v_2$  measured for two classes of events: one selected based on

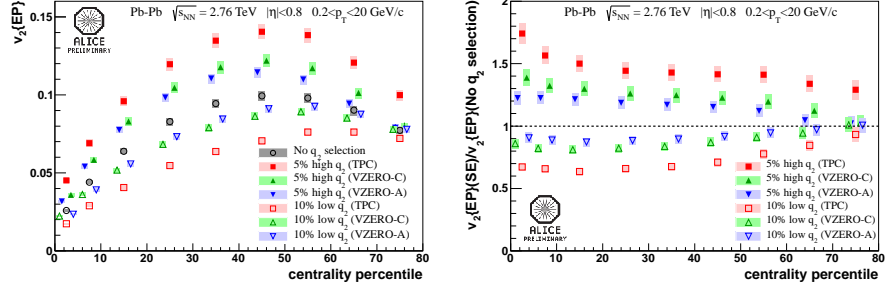


Figure 2: (color online) Unidentified charged particle  $v_2$  for event shape selected and unbiased events (left) and their ratios (right) as a function of collision centrality. Central (peripheral) collisions correspond to small (large) values of the centrality percentile. The event selection is based on  $q_2$  determined in TPC, VZERO-C, and VZERO-A. For clarity, the markers for shape engineered results (selection based on  $q_2$  determined in VZERO-C and VZERO-A) are slightly shifted along the horizontal axis. Error bars (shaded boxes) represent the statistical (systematic) uncertainties. The unbiased results are taken from [6].

events with 10% lowest and another with 5% highest values of  $q_2$  defined for subevent “a”. There are two main effects which define the performance and systematics of the event shape selection: kinematic (e.g. pseudo-rapidity) coverage of a given detector, and non-flow correlations between subevents involved in event selection and  $v_2$  calculations for selected class of events. The non-flow contributions can be controlled (suppressed) by choosing detectors (subevents) which have large rapidity separation between each other.

### 3. Results

Figure 2 shows the unidentified charged particle  $v_2$  averaged over  $0.2 < p_T < 20$  GeV/c as a function of collision centrality for event shape selected and unbiased samples.  $v_2$  for events with the 5% highest (10% lowest)  $q_2$  values is larger (smaller) than that for events without  $q_2$  selection. Results are consistent for event selection based on  $q_2$  determined in VZERO-C and VZERO-A, while results with  $q_2$  from TPC differ significantly mainly due to large non-flow

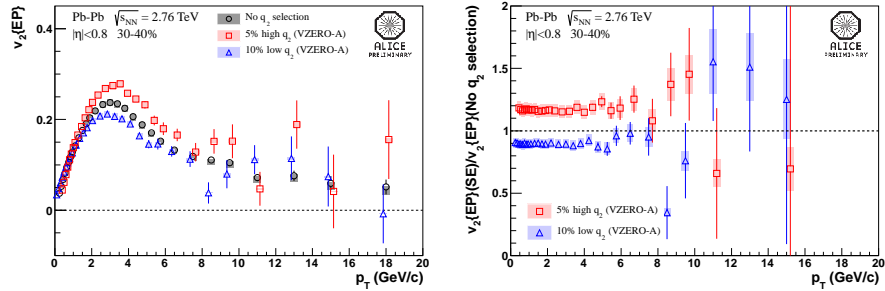


Figure 3: (color online)  $v_2(p_T)$  of unidentified charged particles for event shape selected and unbiased events (left) and their ratios (right) for 30-40% centrality class. The event selection is based on  $q_2$  determined in VZERO-A. For clarity, the markers for shape engineered results are slightly shifted along the horizontal axis. Error bars (shaded boxes) represent the statistical (systematic) uncertainties. The unbiased results are taken from [6].

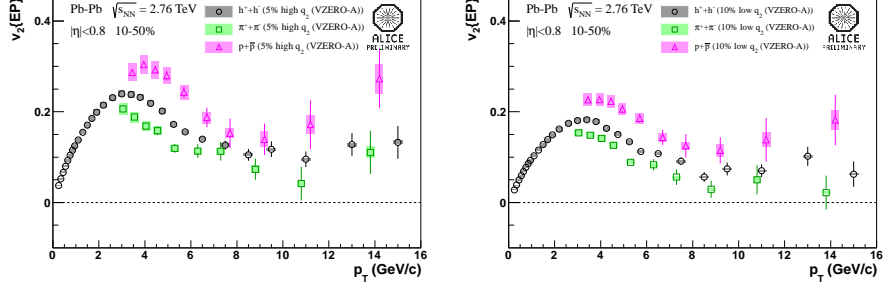


Figure 4: (color online)  $v_2(p_T)$  of charged pion and proton for event shape selected events compared to unidentified charged particle results for 10-50% centrality range. The event selection is based on  $q_2$  determined in VZERO-A. For clarity, the markers for pion and proton  $v_2$  are slightly shifted along the horizontal axis. Error bars (shaded boxes) represent the statistical (systematic) uncertainties.

contributions. Sensitivity of the event shape selection deteriorates for peripheral collisions due to small multiplicity and reduced magnitude of flow. Only results obtained with the event selection using VZERO-A detector which yields the strongest reduction of non-flow are reported next.

Figure 3 (left) demonstrates that the unidentified charged particle  $p_T$ -differential elliptic flow,  $v_2(p_T)$ , differs for event shape selected and unbiased events. The flatness of the ratio between  $v_2(p_T)$  for event shape selected and unbiased events indicates that flow fluctuations are similar at least up to  $p_T = 6$  GeV/c independent of the magnitude of the initial anisotropy of the event. For  $p_T > 6$  GeV/c, the effect of flow fluctuations may become small though currently large experimental uncertainties does not allow to make a firm conclusion.

We also studied the effect of the event shape selection on charged pion and proton  $v_2$  in comparison to unidentified charged particle  $v_2$ . Figure 4 shows this comparison as a function of transverse momentum in the 10-50% centrality range for event shape selected events. The proton  $v_2$  is higher than that of pions out to  $p_T = 8$  GeV/c where the uncertainties become large, which is similar to the result for the unbiased sample [6].

#### 4. Summary

We demonstrated that event shape selection based on the azimuthal asymmetry of the event can be used to select event samples with elliptic flow significantly larger or smaller than the average. This opens many new possibilities to study the properties of the system created in high energy nucleus-nucleus collisions.

#### References

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