Identified charged hadron production in Pb-Pb collisions with event shape engineering

Marco Antonio Tangaro for the ALICE collaboration
Dipartimento Interateneo di Fisica "M. Merlin" and Sezione INFN, Via Orabona 4, 70126
Bari, Italy
E-mail: marco-antonio.tangaro@cern.ch

Abstract. The Event Shape Engineering technique allows the selection of different event shapes for a definite centrality and colliding system. The event selection is based on the azimuthal distribution of produced particles, using the so-called flow vector. For such shape selected events, the elliptic flow coefficient ($v_2$) is significantly different with respect to the unbiased events. Moreover, recent Monte-Carlo studies show a strong correlation between the (final state) event shape selection and the (initial state) eccentricity of the collision. This opens the opportunity to characterize events according to the initial geometry. An approach to select the eccentricity of the event with the Event Shape Engineering is presented. Then the effect of this selection on identified particle spectra, mean transverse momentum and $v_2$ of charged particles in heavy-ion collisions at $\sqrt{s_{NN}} = 2.76$ TeV center-of-mass energy is discussed.

1. Introduction

At present, the overlap geometry in nucleus-nucleus collisions is usually studied by fixing the collision centrality or by using colliding nuclei of different size and shape. The Event Shape Engineering (ESE) technique, recently proposed in [1], allows to bias the event sample by selecting events characterized by a well defined initial geometry, by means of the flow vector evaluated from the azimuthal distribution of produced particles. Monte Carlo (MC) simulations [1] show that anisotropic flow coefficients and flow vector are strongly correlated. Moreover a strong positive correlation between the flow vector and the eccentricity of the collision has been observed [2]. These results suggest that the shape of the initial geometry can be constrained using the flow vector in the final state.

2. Event Shape Engineering

In this analysis data from Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV collected by ALICE [3, 4] in 2010, are used.

The main tracking detectors used are the Inner Tracking System (ITS) [5] and the Time Projection Chamber (TPC) [6]. The ALICE detector is capable of performing Particle IDentification (PID) over a broad range of transverse momentum using different PID techniques. In this analysis a combined selection of the TPC-TOF (Time Of Flight [7]) signal has been used to cleanly identify pions, kaons and protons over a wide momentum range, without loss of efficiency. The centrality of the Pb–Pb collisions has been evaluated using the information of the event multiplicity measured in the V0 detectors [8], which consist of two rings of plastic scintillators named V0A ($2.8 < \eta < 5.1$) and V0C ($-3.7 < \eta < -1.7$).
The event selection is based on the magnitude of the reduced flow-vector \( q_2 \) [9, 10], defined as:

\[
q_2 = \frac{|Q_2|}{\sqrt{M}}
\]

(1)

where

\[
Q_2 = Q_{2,x} + iQ_{2,y}
\]

(2)

and

\[
Q_{2,x} = \sum_i w_i \cos(n\phi_i), \quad Q_{2,y} = \sum_i w_i \sin(n\phi_i)
\]

(3)

Here the sum goes over all V0 detector channels, \( \phi_i \) and \( w_i \) are the azimuthal angle and the multiplicity of the channel i, respectively, and M is the event multiplicity.

**Figure 1.** \( q_2 \) distribution from V0A in 10-20% centrality class.

In Fig. 1 the \( q_2 \) distribution from the V0A is reported. From the flow vector distribution events with 5% highest and 10% lowest \( q_2 \) can be selected, called, in the following, large-\( q_2 \) and small-\( q_2 \) respectively.

To avoid trivial bias from non-flow processes (e.g. resonance decay, jet fragmentation and Bose-Einstein correlations) two sub-events, with large \( \eta \)-gap, are considered. The flow vector is evaluated from V0A (-2.8 < \( \eta \) < 5.1), while the experimental observables are measured in the TPC. This ensures a large \( |\Delta \eta| \) separation between the detectors involved in the analysis, leading to non-flow suppression.

**3. Results**

The \( v_2 \) and hadron spectra are reported for primary particles, defined as particles produced directly in the collision or in the decay of short-lived resonances and not particles from the weak decays of strange hadrons or from interactions with material.

In the analysis of \( v_2 \) only tracks reconstructed in the TPC with 0.2 < \( p_T \) < 20 GeV/c are used, since the detector provides the smallest azimuthal non-uniformities. The \( v_2 \) is evaluated with the event plane method [9], correlating tracks in the TPC (-0.8 < \( \eta \) < 0.8) with the event plane from V0C (-3.7 < \( \eta \) < -1.7).

The effect of the event-shape selection on the distribution of \( v_2(p_T) \) of unidentified charged hadron is shown in Fig. 2 (left) for the 30-40% centrality class. The ratio between large(small)-\( q_2 \) and unbiased sample is reported on the right. The event shape selection results in a change in the value of the \( v_2 \) of 20% for large-\( q_2 \) and 10% for the small-\( q_2 \). Ratios are constant up to
$p_T = 6$ GeV/$c$, while for $p_T > 6$ GeV/$c$ the ratios seem to approach unity, even though large statistical uncertainties do not allow a strong conclusion.

![Figure 2](image1.png)

**Figure 2.** (left) $v_2(p_T)$ distribution for the unbiased (black), 5% large-$q_2$ (red) and 10% small-$q_2$ (blue) sample, in 30-40% centrality class. (right) Ratio between large(small)-$q_2$ and unbiased sample in red(blue).

We characterize the selected sample with a measurement of transverse momentum distributions. This allows to study the correlation between anisotropic and radial flow, by measuring $p_T$ distributions of primary particles in strongly or weakly anisotropic environments, at fixed impact parameter.

Figure 3 shows the ratio between $p_T$-spectra in 10% large(small)-$q_2$ and the unbiased sample, in 30-40% centrality class. In the ratio the spectra corrections cancels out, allowing a precise measurement of the effect of the event shape selection on $p_T$ spectra.

![Figure 3](image2.png)

**Figure 3.** Ratio between the transverse momentum spectra in the sample with 10% highest (lowest) $q_2$ and the unbiased sample.

A modification of the $p_T$-spectrum is observed for $1 \leq p_T \leq 5$ GeV/$c$: in the large-$q_2$ sample
the \( p_T \) distribution is harder than the unbiased, while the opposite happens in small-\( q_2 \) sample, where softer \( p_T \) spectra are observed. The modification seems to vanish at high \( p_T \), at the limit of applicability of the hydrodynamical picture. The selection does not introduce any trivial bias related to the multiplicity shift or jet contribution, which would have influenced the \( p_T \) spectra shape even at high \( p_T \).

The trend is the same for pions, kaons and protons. A hint of mass ordering is observable in the transverse momentum range \( p_T \leq 3 \text{ GeV}/c \) suggesting a stronger(weaker) radial flow in the large(small)-\( q_2 \) event sample.

4. Summary
The effect of the event shape engineering technique on \( v_2 \) and spectra has been reported. The event shape selection allows to select events with larger or smaller elliptic flow. The \( v_2(p_T) \) is independent on \( p_T \). This suggests that the \( q_2 \) selection allows to select event based on the initial geometry of the collision.

Particle spectra in event shape selected events has been also presented: large-\( q_2 \) values lead to harder spectra, while softer spectra have been found in small-\( q_2 \) events. The effect vanishes at high \( p_T \), showing a behaviour similar to that observed for the elliptic flow in shape engineered events. This, with the mass ordering observed at low \( p_T \), suggests that the origin of the effect is related with the hydrodynamic response of the system to the initial geometry rather than with hard processes.

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