

Estimates of the collision symmetry planes in HADES experiment at GSI

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Abstract. Estimate of the collision symmetry planes is a crucial part of the anisotropic flow analysis in heavy-ion collisions. HADES experiment at GSI has different possibilities for symmetry plane estimation. In this letter different methods of the symmetry plane resolution calculation are compared and the differences are explained in terms of non-flow contribution.

1. Introduction

In heavy-ion collisions the asymmetry of overlap region of colliding nuclei leads to the azimuthal asymmetry in momentum distribution of produced particles. This asymmetry can be expressed by Fourier coefficients in the decomposition of azimuthal particle distribution with respect to the initial symmetry planes:

$$\frac{dN}{d(\phi - \Psi_n)} \sim 1 + 2 \sum_{n=1}^{\infty} v_n \cos(n(\phi - \Psi_n)). \quad (1)$$

These coefficients v_n , so called collective flow coefficients, are a sensitive probe for the properties of extreme QCD matter and can be measured experimentally, therefore it became a very important observable in heavy-ion collisions.

2. HADES experiment

The High Acceptance DiElectron Spectrometer (HADES) is a fixed-target experiment hosted at the GSI in Darmstadt. The spectrometer consists of six identical sectors, axially symmetric around the beam direction. The maximal acceptance in polar angle for charged particles is between 18° and 85° . The momentum reconstruction is carried out by a tracking system consisting in total of 24 multiwire drift-chambers (MDC), where in each sector two layers are placed in front and two behind a toroidal magnetic field of the superconducting magnet coils. The Forward Wall (FW) – a plastic scintillator hodoscope array – is placed at a distance of 7 m behind the target at the small forward angle between 0.33° and 7.17° to detect charged projectile spectators by time-of-flight and ΔE signals. It consists of 287 scintillator cells (with photomultipliers) of different size – from $4 \times 4 \text{ cm}^2$ for inner cells to $16 \times 16 \text{ cm}^2$ for outer cells [1]. The positions of hits are used to reconstruct the collision symmetry plane.



3. Flow measurements on HADES

Preliminary HADES results on directed v_1 and elliptic v_2 flow with respect to first order symmetry plane Ψ_1 for protons in Au+Au collisions at 1.23 AGeV [2] are shown on figure 1 in comparison to FOPI results [3]. These results are obtained using the event plane method [4]. For the symmetry plane estimation two random subevents from FW were used. The main point of this letter is to provide analysis which can be used as systematics study for these results.

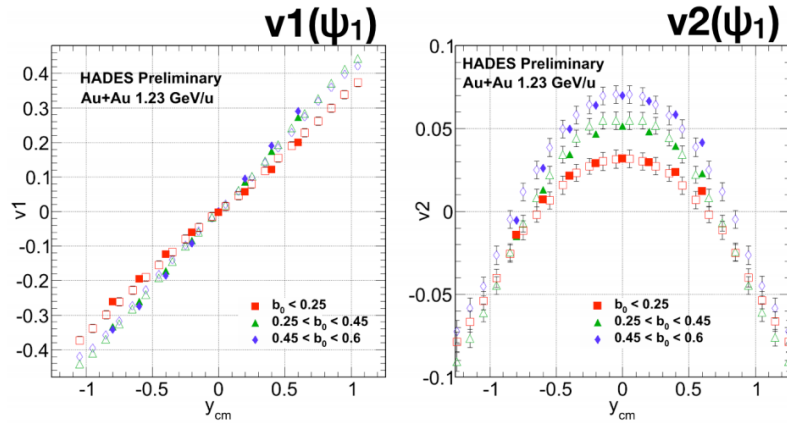


Figure 1. The preliminary HADES measurements of the v_1 and v_2 of protons in Au+Au collisions at 1.23 AGeV (solid symbols) [2] in comparison to FOPI results (open symbols) [3].

4. Symmetry plane estimates

4.1. Methods

For the analysis presented in this letter we used scalar product method which was argued to be able to resolve ambiguities in flow measurements by the event plane method caused by event-by-event fluctuations [5]. The main idea of the method is to weight azimuthal angle correlations with magnitudes of correlating Q-vectors:

$$v_n\{SP\} = \frac{\langle u_n Q_n^A \rangle}{R_n^A\{SP\}}. \quad (2)$$

We will refer to the denominator in this equation as resolution by analogy with the event plane method. It is noteworthy though that the value of resolution in the scalar product method is not equivalent to such value in the event plane method due to the correlation weighting.

The most straightforward way to evaluate the resolution is to correlate Q-vectors from two equivalent subevents (two subevents method):

$$R_N^A\{SP\} = R_N^B\{SP\} = \sqrt{\langle Q_n^A Q_n^B \rangle}. \quad (3)$$

Since this approach requires equivalent (in terms of flow values and multiplicities) subevents, the only way to apply it in fixed target experiment is to randomly divide hits from channelized detector (or tracks from tracking detector) into two groups (two random subevents method) as it was done in HADES preliminary flow analysis using hits in FW detector. Due to the absence of rapidity separation between random subevents, this method is strongly affected by the so called non-flow effects, which are the particle correlations not related to the common symmetry plane, such as momentum conservation and nucleus fragments decay. These effects increase the magnitude of Q-vectors correlation [6]:

$$\langle Q_n^A Q_n^B \rangle \propto v_n^A v_n^B + \delta_{non-flow}^{AB} \quad (4)$$

Since it is not possible in fixed target experiment to introduce two equivalent subevents with rapidity gap between them, one can use three subevents method which does not require equivalence of subevents:

$$R_N^A\{SP\} = \sqrt{\frac{\langle Q_n^A Q_n^B \rangle \langle Q_n^A Q_n^C \rangle}{\langle Q_n^B Q_n^C \rangle}}. \quad (5)$$

In this letter we compare resolution results obtained using two random subevents and three subevents methods with different subevent selection.

4.2. Data selection

Data on Au+Au collisions at beam kinetic energy $E_{beam} = 1.23 A GeV$ collected in 2012 was used for this analysis. During the data collection one of the six sectors of HADES detector failed. Although it is believed that higher order acceptance corrections are able to recover the data, only runs with all six sectors working properly were used in the presented analysis. For the event selection we required at least one entry in each subevent (see list of the subevents in subsection 4.3). Also HADES standard event quality cuts were used. Total amount of 31 million events were selected and used to produce the results presented in this letter.

4.3. Subevent selection

For the symmetry plane reconstruction subevents from FW and MDC were used. FW was divided into 10 quadratic “rings” as shown on figure 2. The closest cells to the beam hole (Ring0) were discarded due to the high level of electronic noise. Q-vectors were calculated in each of the following subevents – combinations of “rings”: *FW (Ring1-9)*, *Ring7-9*, *Ring1-6*, *Ring1-5*, *Ring1-4*, *Ring1-3*; and also in subevents formed by random division of hits in one subevent into two groups (two random subevents method): *FWRandomA(B) (Ring1-9)*, *Ring7-9RandomA(B)*, *Ring1-6RandomA(B)*.

To suppress electronic noise following cuts were applied for hits in different “rings” of FW:

- for small cells (Ring1-4): $charge > 80$; $0.84 < \beta < 1$;
- for medium cells (Ring5-6): $charge > 85$; $0.85 < \beta < 1$;
- for large cells (Ring7-9): $charge > 86$; $0.80 < \beta < 1$;

where β is the speed which particle should have to create a hit with corresponding time.

For MDC subevents protons in different rapidity regions with the following cuts were used:

- pid code corresponds to protons;
- transverse momentum $p_T = 250 - 1700 MeV/c$;
- distance in z coordinate from main vertex to track’s point of the closest approach $|z_{ca} - z_{vertex}| < 15 mm$;
- distance of the track’s closest approach to main vertex: $|dca| < 15 mm$;
- speed (defined by time-of-flight) $\beta < 1$;
- mass $m = 600 - 1200 MeV/c^2$;
- rapidity window (in central mass system) for subevent “MDC –”: $-0.7 < Y_{CM} < -0.4$;
- rapidity window for subevent “MDC –”: $-0.7 < Y_{CM} < -0.2$;
- rapidity window for subevent “MDC +”: $0.2 < Y_{CM} < 0.7$ (see figure 3).

In FW subevents Q-vectors were calculated without weighting with amplitudes of cell responses due to its nonlinear dependence on real particles charge:

$$Q_x^{FWsub} = \frac{\sum_{i=1}^{N_{FWsub}} \cos \phi_i}{N_{FWsub}}, \quad Q_y^{FWsub} = \frac{\sum_{i=1}^{N_{FWsub}} \sin \phi_i}{N_{FWsub}}, \quad (6)$$

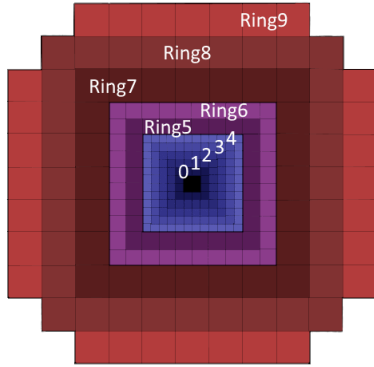


Figure 2. FW hodoscope divided into 10 “rings”.

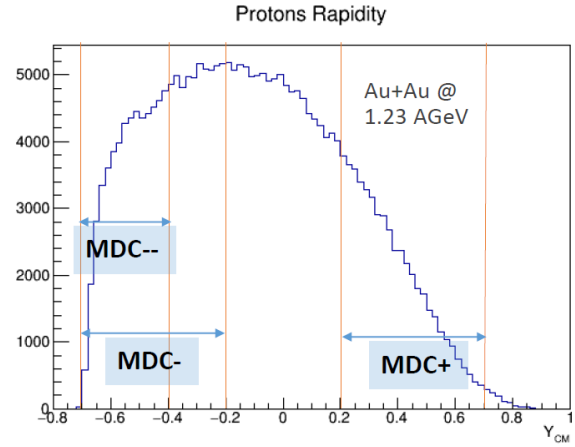


Figure 3. Subevents in MDC: distribution of protons rapidity in the central mass system.

where ϕ_i is the azimuthal angle of the center of cell containing the hit, and sum goes over hits in a current FW subevent.

Q-vectors in MDC subevents were calculated as followed:

$$Q_x^{MDCsub} = \frac{\sum_{i=1}^{N_{MDCsub}} w_i \cos \phi_i}{N_{MDCsub}}, \quad Q_y^{MDCsub} = \frac{\sum_{i=1}^{N_{MDCsub}} w_i \sin \phi_i}{N_{MDCsub}}, \quad (7)$$

where ϕ_i is the track azimuthal angle, $w_i = \text{sign}(Y_i^{CM})$, and sum goes over selected particles in a current MDC subevent.

To correct Q-vectors on the effect of detector non-uniformity, recentering procedure were applied to Q-vectors in all subevents:

$$Q_{x(y)}^{rec} = Q_{x(y)} - \langle Q_{x(y)} \rangle_{multbin}, \quad (8)$$

where brackets denote average over events in a subevent in a chosen multiplicity bin.

4.4. Results

Figure 4 shows comparison of FW resolutions obtained using two random subevents (black circles) and three subevents methods, where MDC – and MDC + were used as reference subevents (B and C in the equation 5) for red points, and MDC – – with MDC + for green points.

The form of resolution dependence on track multiplicity in MDC reflects the form of such a dependence of flow coefficients itself, as expected from the way of resolution construction. Resolution obtained using two random subevents method is 5-10% higher then from three subevents method in midcentral collisions and up to 30% higher in central collisions (with the highest track multiplicity). These differences are caused by non-flow effects (see equation 4). In three subevents method rapidity gaps between subevents allow to suppress non-flow effects. The difference between red and green points on figure 4 is caused by the difference of rapidity gaps in MDC – : MDC + and MDC – – : MDC + combinations.

The non-flow affects resolution more significantly in two random subevents method with cells of smaller size. This is due to the increasing probability of two short-range correlated particles to end up in different subevents, which will increase the correlation between Q-vectors of such subevents. Figure 5 shows the comparison of resolutions of inner FW cells (rings from 1 to 6)

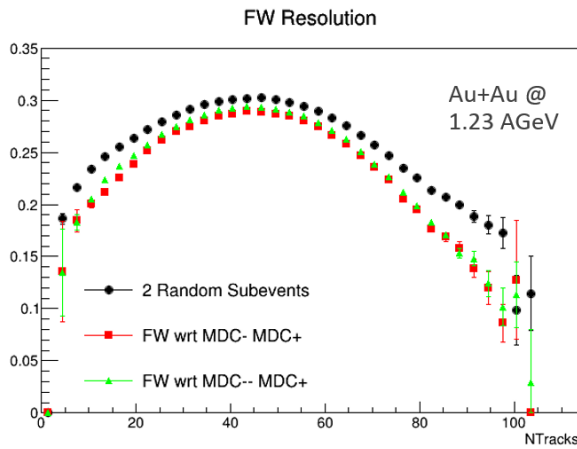


Figure 4. FW resolution dependence on track multiplicity in MDC obtained with different methods: two random subevents FWRandomA : FWRandomB (black points); three subevents FW : MDC – : MDC + (red points); three subevents FW : MDC – – : MDC + (green points).

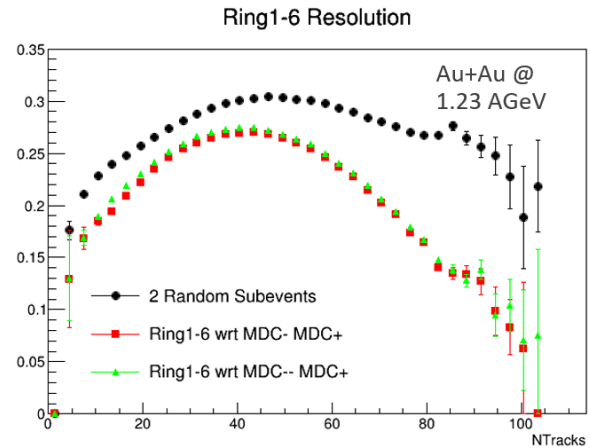


Figure 5. Dependence of inner FW cells resolutions (rings from 1 to 6) on track multiplicity in MDC obtained with different methods: two random subevents Ring1-6RandomA : Ring1-6RandomB (black points); three subevents Ring1-6 : MDC – : MDC + (red points); three subevents Ring1-6 : MDC – – : MDC + (green points).

obtained using different methods. In these smaller FW cells two random subevents method is affected by non-flow effects so strongly that it does not provide the resolution dependence of proper form anymore: the difference with three subevents method is about 15% in midcentral collisions and up to 100% in the most central collisions.

5. Summary

In this letter different methods of calculation of symmetry plane resolutions are discussed and compared using HADES data on Au+Au collisions at 1.23 AGeV beam energy. The differences between obtained results are caused by non-flow contribution which becomes larger in smaller cells of channelized detector (FW).

Acknowledgments

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