Simulation study of effects induced by final granularity of detector in particle flow

A. Prozorov

Nuclear Physics Institute, Czech Academy of Sciences, 25068 Rez Czech Republic
E-mail: prozorov@ujf.cas.cz

Abstract. HADES is a large acceptance spectrometer operating at SIS18, GSI, in Darmstadt, Germany [1]. It is aimed at exploration of the QCD phase diagram at the ion beam energies of 1-2 AGeV in the region of high density baryonic matter. An unphysical behavior of particle directed flow deduced from raw experimental data obtained during experimental study of Au+Au collisions at 1.23 AGeV is observed. It is found that dependence of the directed flow on rapidity does not show the antisymmetry expected in the symmetric projectile-target system, and there is significant non-zero directed flow at midrapidity where this component has to be zero, again from the system symmetry reasons. Possible explanation of the effect is due to the final granularity of corresponding detector and hence limited resolution of close particle tracks.

1. Physics motivation

Conditions similar to the formation of the universe in the very beginning of the Big Bang can be accessed in the heavy-ion collisions with high energy. The time evolution of hadronic matter can be described by the laws of hydrodynamics [2] assuming that thermalization is achieved in the early stages of heavy-ion collisions and that the interaction between the quarks is strong enough to maintain local thermodynamic equilibrium during the subsequent expansion.

The collective flow of particles reflects the initial spatial anisotropy in the collision which is sensitive to the early stages of the system evolution. In order to characterize the distribution of particles, the expansion of the angular distribution of particle yields into a Fourier series is used [3]. The directed flow is characterized by the coefficient of the first harmonic \( v_1 \). It describes an overall shift of the distribution in the transverse plane with respect to the reaction plane defined by the beam direction and the vector of the impact parameter.

The collective motion of the final-state hadrons created in non-central heavy-ion collisions contains important information about the system dynamics [4]. The radial flow characterizes the collision system at kinetic freeze-out, i.e. when elastic collisions of the produced particles cease [5]. Anisotropic flow can result from the conversion of anisotropies in the initial density distribution into pressure gradients, and thus gives access to the equation of state.

2. Flow

Given the known reaction plane orientation, one can study physics observables relatively to the reaction plane orientation. The decomposition of the particle azimuthal distribution \( \frac{dN}{d\phi} \) relative
to the reaction plane angle $\varphi_{RP}$ in a Fourier series is convenient for such analysis [3]:

$$\frac{dN}{d\varphi} \sim 1 + 2 \sum_n v_n \cos n(\varphi - \varphi_{RP}).$$

(1)

Here $\varphi$ is the particle azimuthal angle and $v_n$ are the anisotropic transverse flow coefficients. A first few coefficients have special names, in particular the first, $v_1$, and second, $v_2$, are called the directed and elliptic flow parameters, respectively. The flow coefficients $v_n$ can be derived from Eq. 1 as

$$v_n = \langle \cos n(\varphi - \varphi_{RP}) \rangle,$$

(2)

where the brackets $\langle \ldots \rangle$ denote the average over all particles in a given event and over a large ensemble of events. The centrality of an event strongly influence on the flow. For details about the techniques used for centrality determination in HADES see [6].

3. Problem in Raw data

The directed flow deduced directly from raw data from the HADES experiment [1] exploiting Au+Au reaction at 1.23 AGeV without any efficiency corrections is shown in Fig. 1. The observed directed flow, $v_1$, is asymmetric with respect to rapidity ($y$) and does not pass through zero at $y=0$. It should be noted that:

(i) The non-symmetric uncorrected directed flow of pions is observed.
(ii) The strong uncorrected directed flow of protons is observed.
(iii) In raw data there is a limited efficiency of registration of close particles tracks.
(iv) A Monte Carlo (Geant [7]) description of HADES detector exists but unfortunately it cannot describe non-symmetric directed flow of pions - see also FOPI experiment data which had a similar problem [8].

Therefore a simplified model was developed to explain and describe the effect. Fig. 2 illustrates a three-dimensional map of the distribution of the number of particles in the azimuthal $\varphi$ and polar $\theta$ angles normalized by event and bin size. It is directly measured observable, which can be used to determine the efficiency of registration. The HADES experiment is able to detect particles for polar angles between 18 and 85 degrees.

![Figure 1: Dependence of directed flow on rapidity for $\pi^-$ for different centralities.](#)

![Figure 2: Averaged yield of particles in HADES data.](#)
4. Model
In the presented work a simple model of particle detection is constructed by division of the whole phase space into cells. One can imagine it as a detector hemisphere partitioned with equal area-cells $d\cos\theta d\phi$ situated after the target. If a cell in a given event contains more than one particle (e.g. 2 or 3 directionally close particles hit almost the same area of a detector), only one particle is selected and stored into the final data file. For the check of this effect the IQMD generator \cite{9} data is used because this event generator appears to reproduce available data from the FOPI experiment at GSI and agrees well with the HADES data. The result of the simulated $\nu_1$ for different cell sizes for $0 - 10\%$ central collisions is shown in Fig. 3. The directed flow in which all particles are registered with 100\% efficiency is shown in yellow. The directed flow is zero at midrapidity ($y=0$) and symmetric with respect to rapidity. Detection models with cell sizes equal to 2x2, 5x5, 6x6, 8x8 and 10x10 degrees are shown in blue, red, gray, purple and green lines, respectively. With the increase of the cell sizes, $\nu_1$ begins to show a significant asymmetry. Qualitatively closest to the experimental case (see Fig. 1) is 6x6 degrees $\sin\theta d\phi - d\theta$ angles. See also Fig. 3. Similarly for other centralities, see Fig. 4. In order to correct the data, an efficiency correction method has been developed. The idea is to take into account unregistered particles using the efficiency of registration that shows a ratio of registered particles to all particles in a given detector cell.

In Fig. 5a the true multiplicity distribution is shown, to be compared with one in Fig. 5b where the data is distorted due to detection loses. By dividing second histogram(Fig. 5b) of registered particles by first histogram for all particles (Fig. 5a) one can get the true efficiency of registration (Fig. 6) that shows which part of all particles was registered in a single cell. It is seen that in lowest polar angles about 60\% of particles are not recorded by model while in upper polar angles there is almost 100\% efficiency of registration. Using the efficiency of registration (Fig. 6) and particle distribution at the azimuthal and polar angles for the 6x6 degree model (Fig. 5b), a 2D histogram was estimated (Fig. 7) showing how the efficiency of all particles depends on the average number of registered particles (normalized to one event). For the same $\varphi - \theta$ cell the true particle detection efficiency and the normalized average number of registered particles in event for the 6x6 detection model were matched. It was observed that efficiency had a linear dependence on multiplicity of registered particles in low multiplicity region as it can be seen in Fig. 7 with $k$ equal to 0.42 when fitted.

Depending on known multiplicity and efficiency one can add some weight to already registered pions.
(a) Average yield of ideal detector 0-10% centrality.

(b) Average yield of 6x6 degrees detection model for 0-10% centrality

Figure 5: Multiplicity distributions

Figure 6: True efficiency of registration for 6x6 degrees detection model.

Figure 7: True efficiency vs. multiplicity of registered particles for each $\theta - \varphi$ bin, profile in X axis and a linear fit.

In order to get the parameter $k$ without knowing all data (like in experiment) $k$ is chosen in a such way that $\nu_1$ equals zero at midrapidity. In figure 8 one can also compare values of original and corrected directed flow knowing the true efficiency (Fig. 8a) and a estimated efficiency (Fig. 8b) with slope parameters equal to 0.38 and 0.42 respectively.

In Fig. 8b it is seen that the corrected directed flow (yellow) is very close to the original data directed flow (blue). Due to small statistics of the provided IQMD generator events (also pions account for 1/10 of all particles) the deviations are quite big. In order to improve results there is an option to take into account different approximation function like parabola when estimating efficiency dependence on multiplicity.

5. Conclusions
The directed flow of $\pi^-$ depends strongly on the spatial resolution of the detector. The assumption is verified on a simple model, that the strange directed flow observed in the experiment can be explained by the efficiency losses due to the high track density. Proposed method can be used to correct information about registered particles (not particle type dependent). The correction matrix can be used in order to add weight to registered particles. The next step will be to investigate the dependence on other models and compare new
Figure 8: Comparison of directed flow corrected by true efficiency (right) and estimated efficiency (left)

6. Acknowledgment
The work is supported by MEYS CZ - LM2015049 grant, FAIR-CZ-OP grant CZ.02.1.01/0.0/0.0/16 013/0001677 and LT17003 grants

7. References
[1] Agakishiev G et al. (HADES) 2009 Eur. Phys. J. A41 243–277 (Preprint 0902.3478)
[2] Jaiswal A and Roy V 2016 Adv. High Energy Phys. 2016 9623034 (Preprint 1605.08694)
[3] Poskanzer A M and Voloshin S 1998 Phys.Rev. C58 1671
[4] Leupold S, Metag V and Mosel U 2010 Int. J. Mod. Phys. E19 147–224 (Preprint 0907.2388)
[5] Magas V K, Anderlik C, Csernai L P, Grassi F, Greiner W, Hama Y, Kodama T, Lazar Z I and Stoecker H 1999 Acta Phys. Hung. A9 193–216 (Preprint nucl-th/9903045)
[6] Adamczewski-Musch J et al. (HADES) 2018 Eur. Phys. J. A54 85 (Preprint 1712.07993)
[7] Brun R, Bruyant F, Maire M, McPherson A and Zanarini P 1987
[8] Reisdorf W et al. (FOPI) 2007 Nucl. Phys. A781 459–508 (Preprint nucl-ex/0610025)
[9] Ch H and J A 96 Rapport Interne SUBATECH 08