Flow harmonics of Au+Au collisions at 1.23 AGeV with HADES

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Abstract. Collective flow phenomena are a sensitive probe for the properties of extreme QCD matter. However, their interpretation relies on the understanding of the initial conditions e.g. the eccentricity of the nuclear overlap region. HADES [1] provides a large acceptance combined with a high mass-resolution and therefore allows to study di-electron and hadron production in heavy-ion collisions with unprecedented precision. In this contribution, the capability of HADES to study flow harmonics by utilizing multi-particle azimuthal correlation techniques is discussed. Due to the high statistics of seven billion Au+Au collisions at 1.23 AGeV collected in 2012, a systematic study of higher-order flow harmonics, the differentiation between collective and non-flow effects, and as well the multi-differential (p_t, rapidity, centrality) analysis is possible.

1. Introduction

Collective flow phenomena are a sensitive probe for the properties of extreme QCD matter. However, their interpretation relies on the understanding of the initial conditions, e.g. the eccentricity of the nuclear overlap region. To achieve a good understanding of this phenomena, event-by-event flow observables and their fluctuations are deduced and compared with model calculations and other measured data.

2. HADES

The High Acceptance DiElectron Spectrometer (HADES) is a fixed-target experiment hosted at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt [1]. The data analyzed in this work are from the Au+Au campaign measured in 2012 [2]. This is the largest reaction system, which was measured with HADES, and requires high granularity detectors to cope with the high particle multiplicities. Due its large acceptance, which covers almost full azimuth angle, combined with its high mass-resolution and good particle-identification capability, it is well equipped to study the azimuthal flow pattern not only for protons and charged pions, but also for kaons, ϕ-mesons and electrons/positrons, as well as d, t, and light nuclear fragments.

The spectrometer is subdivided into six identical sectors, axially symmetric around the beam direction. The maximal acceptance in polar angle for charged particles, as shown in Fig.1, defined by the coverage of the magnetic field, is between $18°$ and $85°$, which corresponds to a rapidity range for protons of $-0.6 < y - y_{cm} < 0.8$ around mid-rapidity ($y_{cm} = 0.74$). The momentum reconstruction is carried out by a tracking system consisting in total of 24 multi-wire drift-chambers (MDC), where in each sector two layers are placed in front and two behind
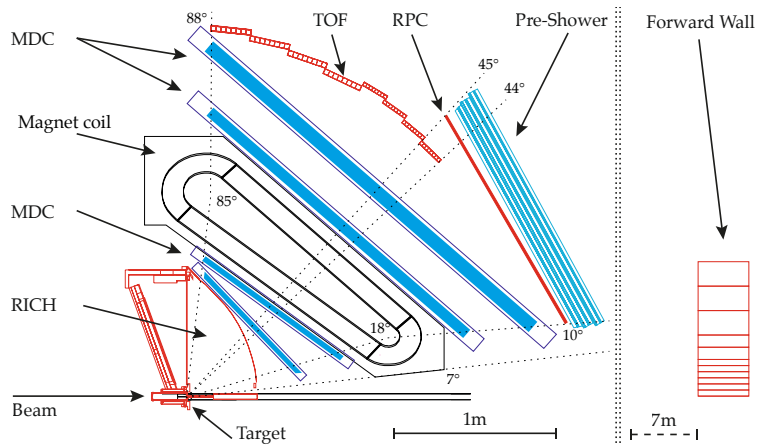
Figure 1. Cross section of one HADES sector. The segmented target irradiated by the beam, the RICH detector, the magnet spectrometer consisting of four layers of drift chambers (MDC) and the magnet coils, the two *time-of-flight* detectors (TOF and RPC) and the Forward Wall (FW) are here shown.

a toroidal magnetic field of the superconducting magnet coils (ILSE). The *Multiplicity and Trigger Array* (META) detector together with the beam detector (diamond counter) provides the time-of-flight measurements and the trigger information. For polar angles between 44° and 88° it consists of the scintillating *time-of-flight wall* (TOF), at the forward region between 18° and 45° it is instrumented with *Resistive Plate Chambers* (RPC) with a subsequent PreShower detector. 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 0.3° and 7.3° to detect charged projectile spectators by the time-of-flight and by the ΔE signal in the scintillator modules. The hit-position is used to reconstruct the event plane.
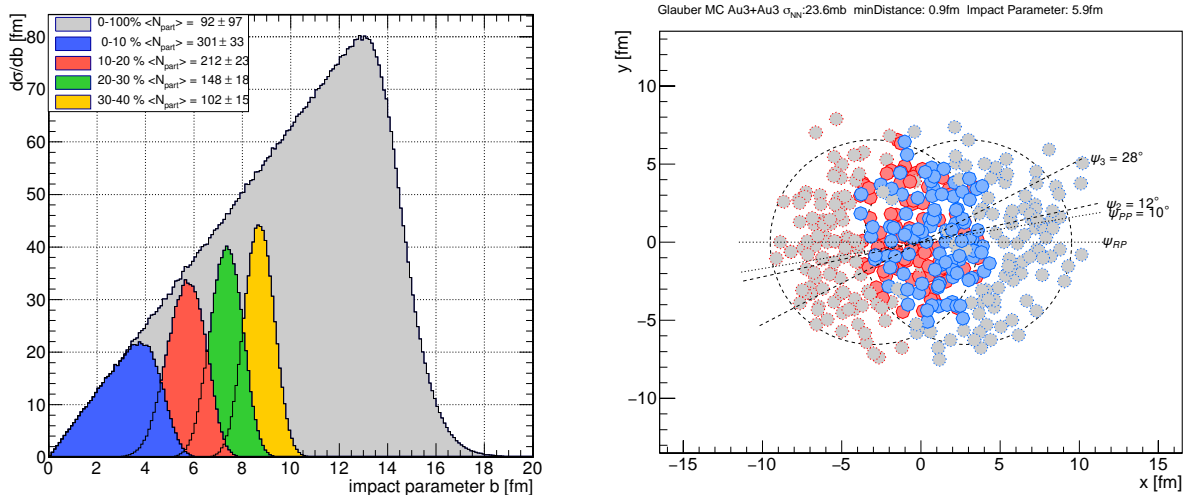

Figure 2. left: The impact parameter distribution of the total hadronic cross section of the Au+Au reaction and the estimates of the four most central centrality classes of 10% width are shown. The measured charged track and hit multiplicities are modeled by a Glauber MC simulation.

right: Glauber MC event with an impact parameter $b = 5.9$ fm showing the participating nucleons (full colored dots) and the spectators (light colored dots). The reaction plane ψ_{RP}, the participant plane ψ_{PP} and its harmonic decompositions into higher-order phase angles ψ_n are shown.
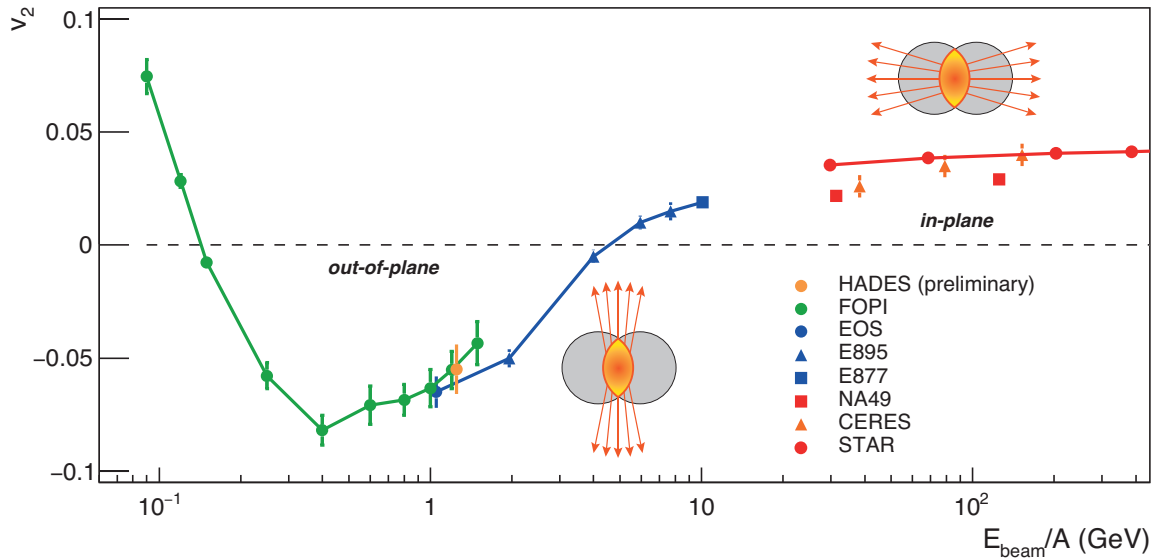
Figure 3. The excitation function of elliptic flow v_2 at mid-rapidity as a function of the beam energy. The preliminary HADES point at 1.23 AGeV, FOPI (15-29% centrality) [5], EOS and E895 [6], E877 [7], CERES [8], NA49 [9] and the STAR (10-20% centrality) [10] data points are here shown.

3. Data sample

Within the 5 weeks of Au+Au beamtime the Schwerionen-Synchrotron (SIS18) at GSI delivered 684 hours of Au^{69+} ions beam to the HADES cave [3] with an intensity of $1.2 - 2.2 \times 10^6$ ions per sec. A 15-fold segmented gold target with an interaction probability of 1.51% was used. The overall total data volume recorded on disc is 140 Tbyte, including calibration and cosmic runs. A fraction of around 80% of the total recorded events are triggered by selecting most central events with a charged hit multiplicity in the TOF detector $N_{ch} > 20$, corresponding to 5.85×10^9 events before off-line event selection. According to detailed comparison of the charged track and hit multiplicity distribution with a Glauber Model simulation, this central trigger selects about 47% of the total hadronic cross section of 6.83 ± 0.43 barn, corresponding to a maximal impact parameter of $b_{max} < 10$ fm [4], see left panel of Fig. 2.

4. Collective Flow

In a high-energy collision of nuclei a highly excited nuclear medium is created and its collective expansion produces a correlated emission of particles. In perfectly central collisions the expansion should be isotropic in the transverse plane, known as *radial flow*, which is observed in the transverse mass spectra of produces particles. Going to more non-central collisions, the overlap region is getting more anisotropically shaped. This *event-shape* characteristic is usually studied via the azimuthal anisotropy of the momentum space of identified particle w.r.t a corresponding symmetry plane and it is common to analyze this by a Fourier decomposition with the coefficients v_1, v_2, v_3 and v_4. Due to their origin induced by the collision geometry, the directed v_1 and elliptic v_2 are linked to the reaction plane which is also spanned by the spectators.

Figure 3 shows the elliptic flow of charged particles as function of beam energy (from SIS18, AGS, SPS to RHIC energies). From a minimal negative value at around 400 MeV it increases with rising energy to positive values at high energies. At low energies this *out-of-plane* emission
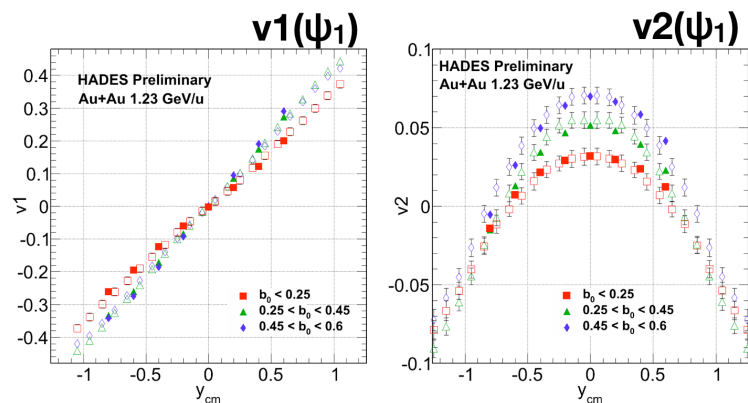
Figure 4. The preliminary HADES measurements of the directed v_1 and elliptic v_2 flow of protons for Au+Au collisions at 1.23 AGeV (full) in comparison to FOPI data [12] (open symbols) are here shown. The same procedure outlined in [12] was used to select the centrality classes $b_0 = b/b_{max}$ and the phase space region with a lower transverse momentum cut.

is caused by the long passing time of the colliding nuclei in comparison to the time of the expansion of the excited nuclear medium. The effect that the relatively slow spectators are shadowing the particle emission in the direction of the reaction plane is also called *squeeze-out*. At higher energies elliptic flow is observed in *in-plane*, made possible by a much shorter passing time of the spectators than the expansion time of the medium. A higher pressure gradient in-plane is building up due to the anisotropic shape of the overlap region. In comparison to directed and elliptic flow, originating from the dynamics of the reaction, the observation of higher-order collective flow is described by the anisotropic and fluctuating shape of the overlap region [11]. It can be shown in Glauber Monte Carlo calculations [4] that higher-order eccentricities, originating from the fluctuations of the initial configuration, are independent from the reaction plane and that each harmonic (ϵ_3, ϵ_4, ϵ_5) is aligned to its specific symmetry plane (Ψ_3, Ψ_4, Ψ_5), see right panel of Fig. 2. The approach to map *flow observables*, like elliptic v_2 or triangular flow v_3, to their corresponding *pseudo-observable*, like eccentricity ϵ_2 and ϵ_3, calculated from Glauber Monte Carlo, can reveal the response of the nuclear medium to the initial anisotropies. This enables the study of the bulk properties of the excited and extreme nuclear matter and provides access to its properties, like its viscosity.

At low energies v_1 and v_2 have been measured for pions, charged kaons, protons, neutrons and fragments, but so far higher-order harmonics have not been studied in the SIS18 energy regime. Preliminary analyses, as shown in Fig. 4, indicate a good consistency of the first two harmonic components of proton flow with FOPI data [2, 12, 13] and the unprecedented statistics not only allows the multi-differential flow analysis (p_t, rapidity, centrality) of charged particles, measurable by HADES, but also makes higher-order flow analysis possible.

5. Multi-Particle Flow-Analysis

The advantage of multi-particle azimuthal correlation techniques is that a separate determination of the event plane is not needed. This exploit the fact that if the particle flow pattern is aligned to a symmetry plane, the particles by themself are correlated to each other. Without any further knowledge of the symmetry plane the flow coefficients can be deduced by correlation functions or cumulants. Multi-particle correlation methods allow to differentiate between collective (flow) and genuine few particle correlations, also called non-flow effects, like those due to interactions (Coulomb and resonance decays) or quantum statistics effects. A general flow analysis framework based on different approaches like the event-plane or the multi-particle azimuthal correlation techniques [14] is in preparation. This will allow to implement different methods such as Cumulants, Lee-Yang Zeroes and more in future analyses.

6. Conclusions

Due to its large collected events statistics and its large acceptance HADES is able to address the measurement of higher-order flow harmonics in the low energy regime. This will allow to extend the existing measurements, as shown in Fig. 5, into so far unexplored regions and will provide new insights into the properties of strongly interacting matter at extreme densities, as e.g. its viscosity. The employment of multi-particle methods will thereby enable the disentanglement of the contributions of collective and non-flow processes.
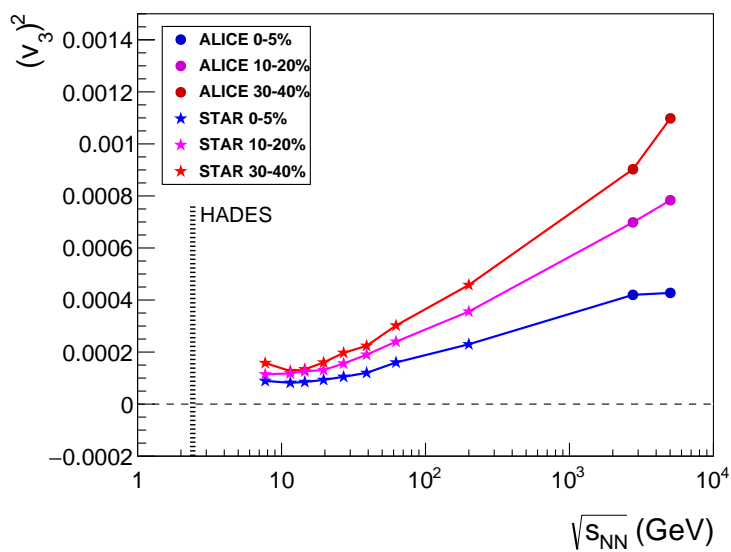
Figure 5. The energy dependence of v_3 as measured for different centralities by STAR [15] and ALICE [16, 17] are here shown. The dashed line indicates the position of the data set measured by HADES at 1.23 AGeV.

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