PROCEEDINGS OF SCIENCE

Collective flow measurements with HADES in Au+Au collisions at 1.23A GeV

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HADES has a large acceptance combined with a good mass-resolution and therefore allows the study of dielectron and hadron production in heavy-ion collisions with unprecedented precision. With the statistics of seven billion Au-Au collisions at 1.23A GeV recorded in 2012, the investigation of higher-order flow harmonics is possible. At the BEVALAC and SIS18 directed and elliptic flow has been measured for pions, charged kaons, protons, neutrons and fragments, but higher-order harmonics have not yet been studied. They provide additional important information on the properties of the dense hadronic medium produced in heavy-ion collisions. We present here a high-statistics, multi-differential measurement of v_1 and v_2 for protons in Au+Au collisions at 1.23A GeV.

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1. Introduction

Collective flow phenomena are a sensitive probe for the general properties of extreme QCD matter [1], such as its shear viscosity [2]. To achieve a good understanding of these phenomena, flow observables are deduced and compared with model calculations to constrain the nuclear Equation-of-State (EoS) [3, 4]. The understanding of the EoS of dense matter is of great importance for the investigation of supernovae and compact stars [5]. In high-energy collisions 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, leading to *radial flow*, observable in the transverse-mass spectra of the produced particles. Less central collisions are characterized by an overlap region which is more anisotropically shaped. This *event-shape* characteristics is usually studied via the azimuthal anisotropy of the momentum space of identified particles w.r.t a corresponding symmetry plane and it is common to analyze this by a Fourier decomposition yielding the flow coefficients v_1, v_2, v_3 and higher. Due to their correlation to the collision geometry, the directed v_1 and elliptic v_2 are linked to the reaction plane, which itself is also observable via the spectators.

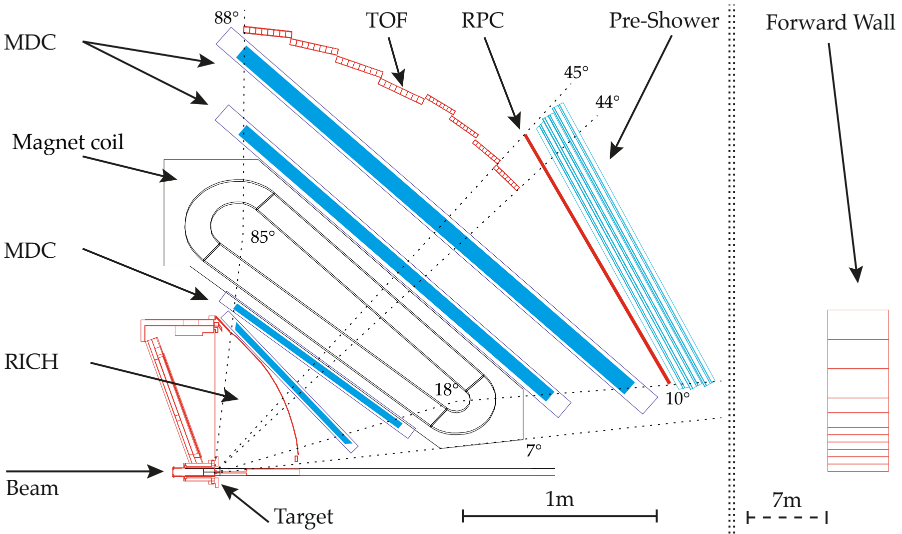

Figure 1: Cross section of one sector of the HADES spectrometer. The segmented target irradiated by the beam, the RICH detector, the magnet spectrometer consisting of four layers of drift chambers (MDC) and the magnet coils, the two *time-of-flight* detectors (TOF and RPC) and the Forward Wall (FW) are shown. The maximal acceptance in polar angle for charged particles, defined by the coverage of the magnetic field, is between 18° and 85°, which corresponds to a rapidity range for protons of $-0.6 < y - y_{cm} < 0.8$ ($y_{cm} = 0.74$).

2. HADES

The High Acceptance DiElectron Spectrometer (HADES) is a fixed-target experiment located at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany [6]. The data analyzed in this work are from the Au+Au run done in 2012 [7]. The spectrometer is subdivided into six identical sectors, axially symmetric around the beam direction (see Fig.1). The momentum

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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 a toroidal magnetic field of the superconducting magnet coils. 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 a scintillator *Time-Of-Flight wall* (TOF), and in the forward region between 18° and 45° it is instrumented with *Resistive Plate Chambers* (RPC) with a subsequent Pre-Shower detector. The *Forward Wall* (FW), a plastic scintillator hodoscope array, is placed at a distance of 7 m downstream of the target covering forward angles between 0.3° and 7.3° to identify charged projectile spectators by the time-of-flight and their ΔE signal. The FW hits are used to reconstruct the event plane.

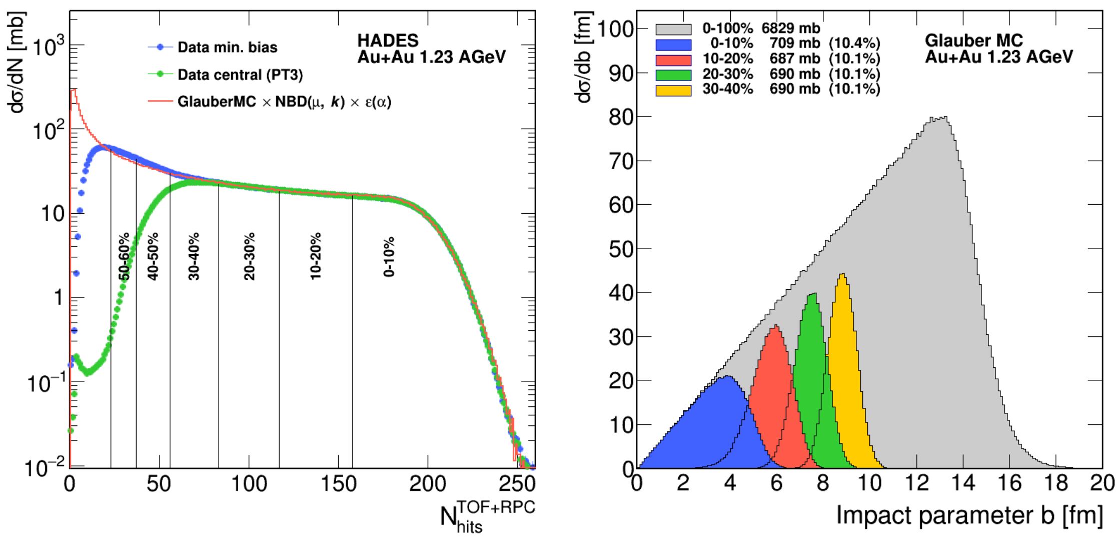

Figure 2: Left panel: The $N_{\text{hits}}^{\text{TOF+RPC}}$ distributions for the sum of TOF and RPC hits. The minimum bias (blue symbols) and central (PT3 trigger, green symbols) data is shown in comparison with the Glauber MC model (red histogram). Right panel: The distributions of the impact parameter b calculated with the Glauber MC model. The colored distributions represent the four 10% most central centrality classes selected by the number of hits in the TOF and RPC detectors $N_{\text{hits}}^{\text{TOF+RPC}}$.

3. Data sample

Within the 5 weeks of the Au+Au run the SIS18 synchrotron delivered 684 hours of Au^{69+} ion beam to the HADES cave [8] 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 was 140 Tbyte, including calibration and cosmic runs. A fraction of around 80% of the total recorded events was triggered by selecting mostly 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. In this analysis 4.32×10^7 events were used after event selection. According to detailed comparison of the charged track and hit multiplicity distribution with a Glauber Model simulation, this central trigger selects about 43% of the total hadronic cross section of 6.83 ± 0.43 barn, corresponding to a maximum impact parameter of $b_{max} = 10$ fm [9] (see Fig. 2).

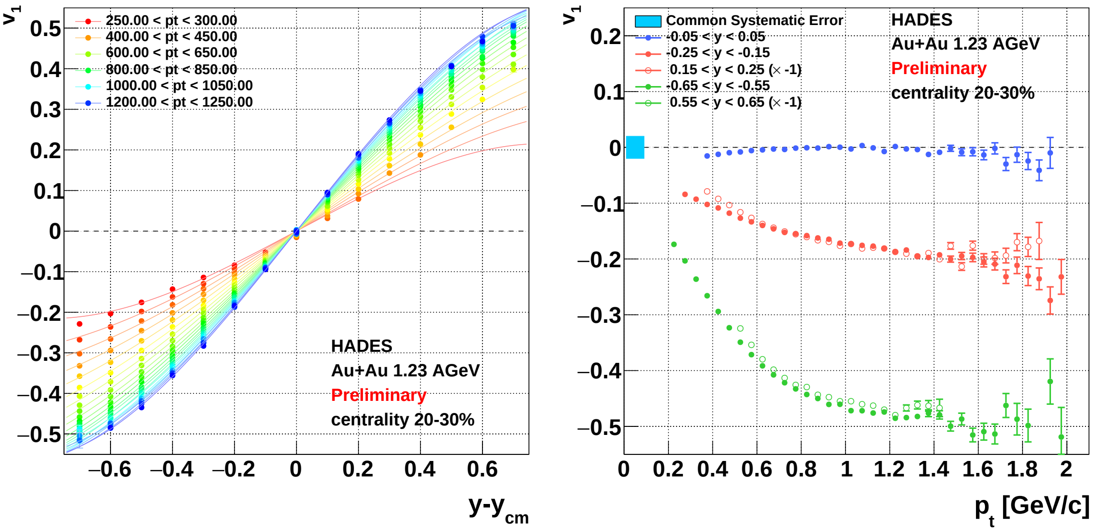

Figure 3: Preliminary data on directed flow (v_1) of protons measured with HADES in semi-central (20 – 30%) Au+Au collisions at 1.23A GeV. The left panel shows v_1 as a function of the center-of-mass rapidity in transverse momentum intervals of 50 MeV$/c$ (lines are to guide the eye). In the right panel, a comparison of the p_t dependence of v_1 in five rapidity intervals, symmetric around mid-rapidity, is presented.

4. Directed and elliptic flow

The directed and elliptic flow (v_1 and v_2) of protons has been extracted over a large region of phase space using the standard event plane method. The data have been corrected for the event plane resolution [10, 11]. In addition, a correction for efficiency losses due to the differential detector load has been applied track-by-track, as a function of the polar angle, the relative angle to the event plane and the track multiplicity in a given sector. Figure 3 shows the results on v_1. A good forward-backward symmetry with respect to mid-rapidity is seen, as expected due to the symmetry of the collision system. Remaining discrepancies are well within the systematic error, which has been estimated by embedding simulated protons into real and UrQMD background events. A similar symmetry is seen for v_2, see Fig. 4. A sizeable negative v_2 is measured around mid-rapidity. Its value clearly depends on the centrality of the collision, as illustrated in Fig. 5. The preliminary results indicate a good consistency of the first two flow coefficients of protons with FOPI data [4, 12, 13] and are in the process of being finalized.

5. Outlook

Due to the large collected events statistics and high-quality data in Au+Au collisions at 1.23A GeV measured by HADES, will also be able to address the measurement of higher-order flow harmonics in the low energy regime. This will allow the extension of the existing data into so far

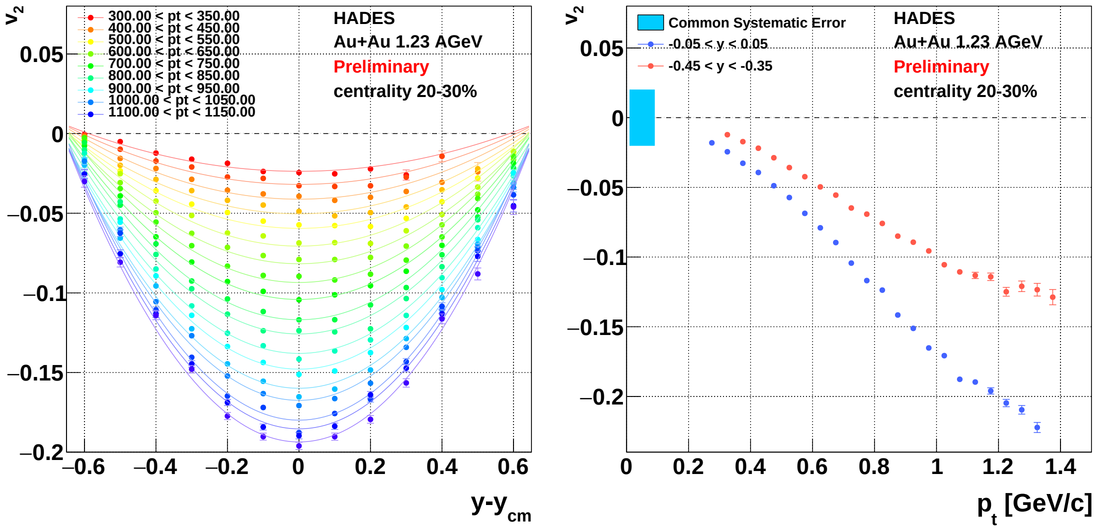

Figure 4: Preliminary data on elliptic flow (v_2) of protons measured with HADES in semi-central (20 – 30%) Au+Au collisions at 1.23A GeV. The left panel shows v_2 as a function of the center-of-mass rapidity in transverse momentum intervals of 50 MeV$/c$ (lines are to guide the eye). The right panel displays the p_t dependence of v_2 in two different rapidity intervals.

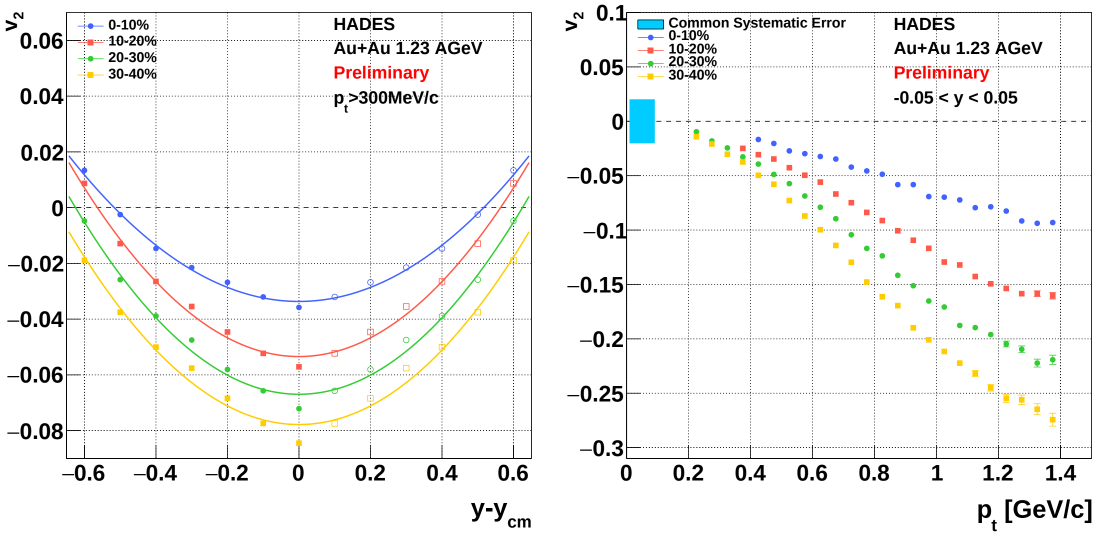

Figure 5: Preliminary data on elliptic flow (v_2) of protons measured with HADES in different centrality intervals of Au+Au collisions at 1.23A GeV. The left panel shows the p_t integrated v_2 as a function of the centre-of-mass rapidity, while in the right panel v_2 at mid-rapidity is presented as a function of p_t.

unexplored regions and will provide new insights into the properties of strongly interacting matter at extreme densities, as e.g. its viscosity.

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