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Excitation function of elliptic flow in Au + Au collisions and the nuclear matter equation of state

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Abstract

We present measurements of the excitation function of elliptic flow at midrapidity in Au + Au collisions at beam energies from 0.09 to 1.49 GeV per nucleon. For the integral flow, we discuss the interplay between collective expansion and spectator shadowing for three centrality classes. A complete excitation function of transverse momentum dependence of elliptic flow is presented for the first time in this energy range, revealing a rapid change with incident energy below 0.4 A GeV, followed by an almost perfect scaling at the higher energies. The equation of state of compressed nuclear matter is addressed through comparisons to microscopic transport model calculations.

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Keywords: Elliptic flow; Compressed nuclear matter; Equation of state

The study of collective flow in nucleus–nucleus collisions has been an intense field of research for the past twenty years [1,2]. At beam energies below several GeV per nucleon, the main motivation for studying flow is the extraction of the equation of state (EoS) of nuclear matter. This can only be accomplished via comparisons to theoretical transport models which treat the collision at a microscopic level [3,4]. It is essentially due to the competing effects of two-body collisions and mean field dependences that no firm conclusion on EoS is established for the moment [4].

Elliptic flow at midrapidity (called "squeeze-out" in the early days) is a prominent collective flow observable that has received great attention in the past. After the pioneering measurements at Saturne [5] and Bevalac [6], a wealth of experimental results have been obtained at Bevalac and SIS [7–14] as well as at AGS [15,16], SPS [17,18], and RHIC [19]. Elliptic flow is consequently established as a powerful observable in the study of relativistic nucleus–nucleus collisions [20,21]. In what concerns the range of beam energies of 0.1–10 A GeV, recent microscopic transport model calculations [4,22–25] have emphasized the importance of elliptic flow for imposing constraints on the models, towards the extraction of EoS. In this energy range, the densities, extracted from transport model calculations [4], are up to several times normal nuclear matter density. Probing EoS at such densities has implications to astrophysical questions [4]. At beam energies below 2 A GeV, no existing set of experimental data can be compared on equal footing to the measurements at higher energies. Moreover, recent experimental results have demonstrated that directed flow is correlated with transparency [26]. To complete the picture, it is important to correlate also elliptic flow with these observations.

In this Letter we present new elliptic flow data at midrapidity for Au + Au collisions for the energy range 0.09–1.49 A GeV. The data have been measured with an almost complete phase-space coverage using the FOPI detector [27] at SIS, GSI. The reaction products are identified according to their charge (Z) in the forward Plastic Wall (PW) at $1.2° < \theta_{lab} < 30°$ using time-of-flight (ToF) and specific energy loss. In the Central Drift Chamber (CDC), covering $34° < \theta_{lab} < 145°$, the particle identification is on mass (A), obtained using magnetic rigidity and specific energy loss. For the beam energies above 0.4 A GeV, measured in a separate run, the forward drift chamber Helitron, covering the interval $7° < \theta_{lab} < 29°$ is employed for particle identification on A. We use normalized center-of-mass (c.m.) transverse momentum (per nucleon) and rapidity $p_t^{(0)} = (p_t/A)/(p_P^{\text{c.m.}}/A_P)$, $y^{(0)} = (y/y_P)^{\text{c.m.}}$, where the subscript P denotes the projectile. Our midrapidity selection is $|y^{(0)}| < 0.1$. Most of our results are for $Z = 1$ particles. For the beam energies above 0.4 A GeV we also present integral elliptic flow for protons. Identified by CDC and Helitron, pions are excluded from the $Z = 1$ sample. For the acceptance of CDC ($p_t^{(0)} > 0.8$, at midrapidity) ^{3}He is included in the $Z = 1$ sample. For the centrality selection we use the charged particle multiplicities, classified into five bins, M1 to M5. We present results for the centrality bins M2, M3, and M4, which correspond, at each energy, to constant fractions of the maximum multiplicity [6]. Based on the measured total inelastic cross section, these classes correspond on