Elliptic Flow as a Probe for the Equation of State of High Density Nuclear Matter

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We have measured the elliptic flow of protons for semi central Au+Au collisions in the range of 2–8 AGeV. The excitation function shows a transition from a preferential out–of–plane emission at low beam energies to in–plane emission at the higher beam energies. This transition occurs at $E_{Beam} \sim 4$ AGeV. Comparisons to a set of recent calculations from a relativistic Boltzmann equation indicates a possible change of the stiffness of the nuclear equation of state.

1 Introduction

The investigation of the nuclear equation of state has been one of the major objectives in the study of heavy ion collisions [1,2]. Collective effects and in particular the elliptic flow have been predicted to be sensitive to the parameters of the EOS[3,4,5]. Furthermore theoretical calculations which involve a transition from normal nuclear matter to the quark–gluon plasma phase show a detectable softening of the EOS [6,7].

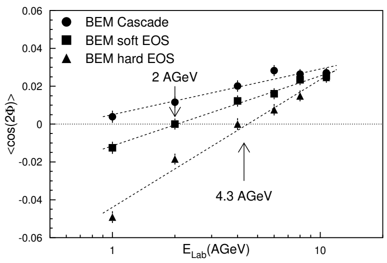

Figure 1: *The sensitivity of the elliptic flow signal and the transition energy from preferential out–of–plane to in–plane emission on the EOS within the framework of BEM.*

Elliptic flow is a measure of the anisotropy of the emission of particles with respect to the reaction plane at midrapidity. At AGS energies the sign and strength of this anisotropy is the result of a competition between an early preferential out–of–plane emission and a late in–plane emission [5]. Since the early out–of–plane emission is driven by the pressure built up during the collision the resulting elliptic flow signal has a marked sensitivity to the stiffness of the EOS. This is illustrated in fig. 1, where predictions are shown from a Boltzmann equation model (BEM) [6] for the proton elliptic flow excitation function assuming a soft and a stiff EOS is shown.

2 Experimental Setup and Event Reconstruction

The main device of the E895 experimental setup is shown in fig. 2 – the EOS TPC[8] inside the MPS magnet. Data were taken for Au beams at 2,4,6,8 AGeV incident beam energy on a Au target of 3% interaction length.

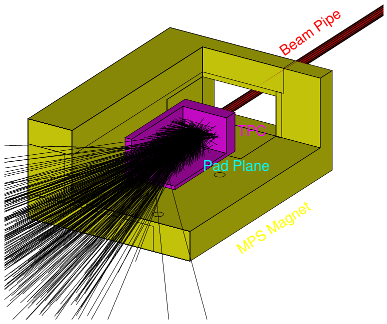

Figure 2: *A central Au+Au collision at E_{Beam} = 8 AGeV as seen by the E895 experimental setup. 300–400 charged particles are observed.*

The TPC provides 3–dimensional event reconstruction for charged particles with almost 4π phase space coverage, which makes this setup ideally suited to measure flow effects. The charged particles were identified via their energy loss in the P10 gas inside the TPC and the rigidity of their tracks in the magnetic

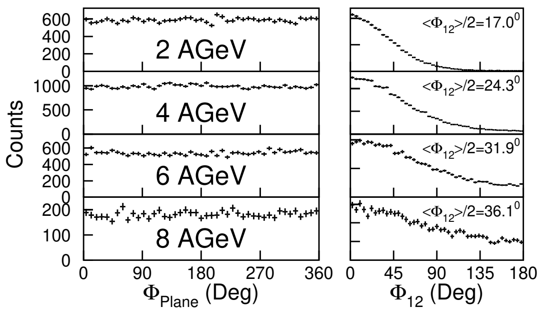

Figure 3: *The distributions of the reconstructed reaction planes and their respective dispersions for 2–8 AGeV. The essentially flat distributions of the reaction planes are achieved by applying multiplicity and rapidity dependant acceptance corrections.*

field (0.75 T at 2 AGeV, 1 T at 4,6,8 AGeV). This leads to an ambigous pid at low transverse momentum for midrapidity protons at the higher energies where they cannot be distinguished from positive pions.

The reaction plane was reconstructed from the emission angles of baryons with z≤2 similar to the standard transverse momentum analysis [9]. The experimentally determined $<p_x>/<p_t>$ as a function of rapidity was used as a weight in a second pass for further improvement of the resolution.

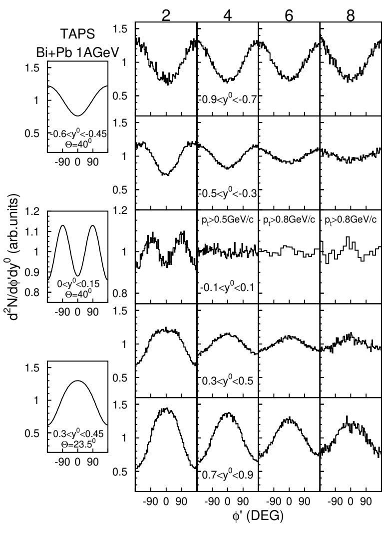

Figure 4: *The distributions of protons with respect to the reaction plane as function of the normalized rapidity ($y^0 = (y/y_{c.m.}) - 1$). The clear out–of–plane enhancement at 1–2 AGeV changes to an in–plane enhancement at 6–8 AGeV.*

The distribution of the reconstructed reaction plane and its dispersion is shown in fig. 3. The latter distribtion is used to correct for reaction plane dispersion effects [10].

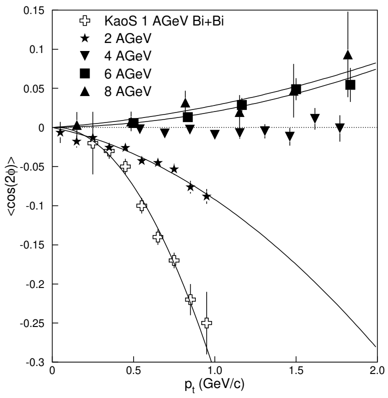

Figure 5: *The differential elliptic flow shows a quadratic dependancy on the transverse momentum.*

3 Results

Fig. 4 shows the azimuthal distributions of protons as a function of the c.m. rapidity with respect to the reaction plane. The clear out–of–plane enhancement at midrapidity for 1 AGeV [11] and 2 AGeV changes to in–plane at 6–8 AGeV, with the transition occuring at about 4 AGeV. Further evidence is shown in fig. 5 where the transverse momentum dependance of the elliptic flow [14,12] is displayed. The lines indicate a quadratic fit assuming the predicted parabolic dependancy [4,13]. This quadratic dependancy is used for the higher beam energies to extrapolate the elliptic flow signal into low transverse momentum regions where the proton sample is contaminated by positive pions due to the ambigous pid. The flat distribution for the 4 AGeV data shows again that the transition occurs very close to 4 AGeV.

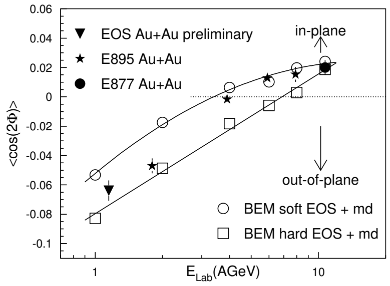

Figure 6: *The elliptic flow excitation function seems to indicate a softenening of the EOS between 2 AGeV and 6 AGeV when compared to recent BEM calculations.*

Fig. 6 shows a comparison of the proton elliptic flow excitation function with calculations of the BEM model which includes momentum dependent interactions. This comparison indicates an apparent change in the stiffness of the EOS from a hard EOS (K=380MeV) to a softer form (K=210MeV) at higher beam energies i.e. $E_{Beam} \geq 4$ AGeV. But compared to calculations made by the ART model [13] without momentum dependant interactions the elliptic flow data are consistent with a hard EOS.

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