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Studies of the initial and final states of AuAu collisions with BRAHMS

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When heavy ions collide at ultra-relativistic energy, thousands of particles are emitted and it is reasonable to use hydrodynamic descriptions, with suitable initial conditions, to describe the time evolution of the collisons. In the longitudinal direction pions seem to exhibit Landau flow. This simple model assumes that all the entropy in the collisions is created the instant the two Lorentz contracted nuclei overlap and that the system then expands adiabatically. The system also displays radial and elliptic flow. Radial flow is manifested as a broadening of the p_T distributions with respect to pp collisions. It is typically thought to result from multiple scattering of partons or hadrons before dynamic freeze-out. Elliptic flow occurs when heavy ions do not collide exactly head on. The initial geometrical asymetry is translated momentum asymetry via pressure gradiants. Since these gradients are self quenching, strong elliptic flow is thought to be linked to early thermalization and a large initial pressure. Using the concept of limiting fragmentation we attempt to sketch a link between the initial and final states of relativistic heavy ion collisions using new data from the BRAHMS collaboration on elliptic and radial flow.

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1. Introduction

The BRAHMS experiment uses two movable spectrometers to study relativistic heavy-ion collisions over a very broad range of angles and momenta. In addition a set of global detectors measure the collisions vertex as well as the centrality of the collision and the orientation of the reaction plane. One of our first goals was to make a survey of hadron yields as a function of p_T and rapidity [1]. In contrast to early expectations, we did not see a large "rapidity plateau". Rather the rapidity distributions of mesons are Gaussian. In particular pions seem to exhibit Landau flow over a wide energy range. Landau's simple model assumes that all the entropy in the collisions is created the instant the two Lorzent contracted nuclei overlap and that the system then expands adiabatically [2, 3]. We have extended this survey to study the system size and reaction plane dependence of particle yields. This allows us to map out the rapidity dependence of radial and elliptic flow.

If one observes a relativistic collision from the rest frame of one of the nuclei, called the 'target', certain quantities become independent of the energy of the 'projectile.' This phenomena is known as limiting fragmentation and implies that a certain quantity is invariant when plotted against y-y_{beam}. Feynman gave general arguments to explain this effect in pp collisions. based on the continuity of fields [4]. Limiting fragmentation was first observed at RHIC by the BRAHMS collaboration in the context of multiplicity distributions [5]. Since then, it has been seen by several groups in a variety of contexts such as particle ratios and integrated elliptic and directed flow [6, 7]. In this paper we discuss a new manifestation of this effect, namely the shape of the particle spectra in transverse mass, $m_T \equiv \sqrt{p_T^2 + m^2}$.

2. Radial flow

Particle spectra reflect the state of the collision at kinetic freeze-out. For central collisions, which are azimuthally symmetric, only radial flow is important. In the hydrodynamic blast-wave approach [8] the spectra are parametrized by a freeze-out temperature, T, and a transverse expansion velocity, β_T. Conservation of energy ensures that T and β_T are anti-correlated. Figure 1 shows simultaneous fits to $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ spectra from AuAu reactions at $\sqrt{s_{NN}} = 200$ GeV. The results are plotted versus the number of participants N_{part} and rapidity, respectively. We find that T decreases with centrality while β_T increases. This may be because larger systems have more time to convert random thermal motion into directional flow. The variations of T and β_T with rapidity suggests that the pressure gradients are weaker at forward rapidity, possibly because of the smaller particle densities.

3. Elliptic flow

One of the most exciting results obtained at RHIC is the observation of significant elliptic flow in central AuAu collisions. The large flow signal, which is consistent with the hydrodynamic evolution of a perfect fluid, indicates a strongly interacting QGP, contrary to initial expectations [7, 9, 10, 11]. The strength of elliptic flow is characterized by v_2. Recently PHOBOS has shown that the integrated v_2, (and v_1), obey a limiting fragmentation picture [7]. Figure 2 shows v_2 vs p_T and η. It is striking how similar these data are given that the integrated v_2 falls steadily with η. The drop in the integrated results is presumably related to the steady drop of mean p_T with η [1].

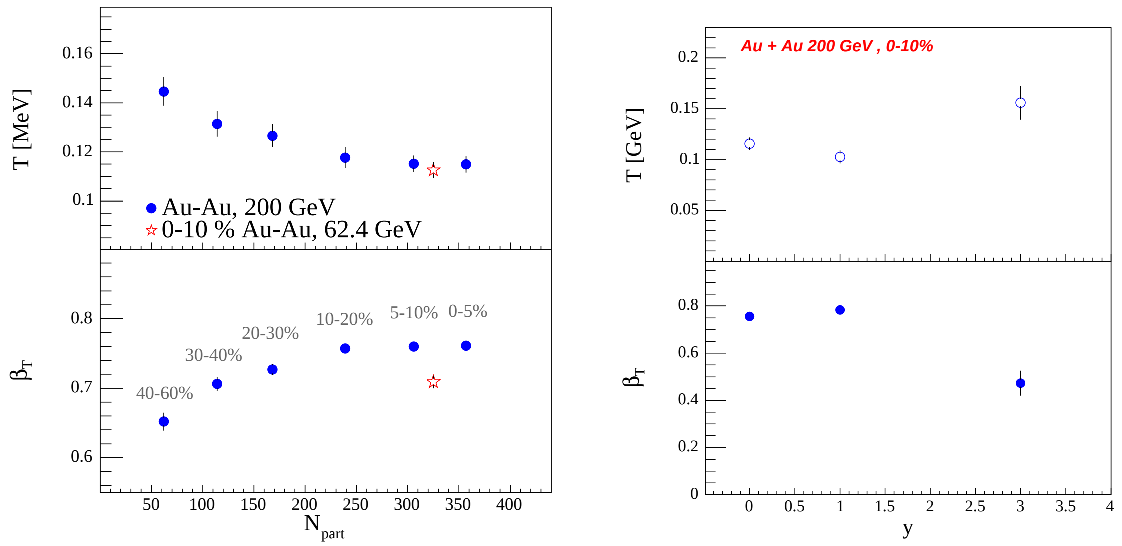

Figure 1: Kinetic freeze-out temperature and surface transverse flow velocity for AuAu collisions at $\sqrt{s_{NN}} = 200$ GeV. Left: Centrality dependence at y=0; Right rapidity dependence for central collisions.

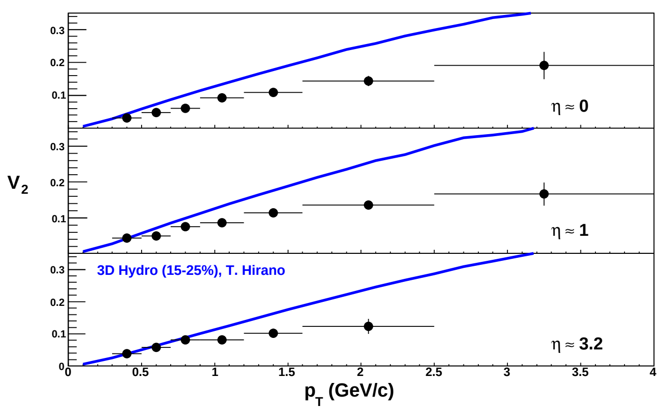

Figure 2: Elliptic flow strength v_2 versus p_T and pseudo-rapidity η for mid-central, 10-30%, AuAu collisions at $\sqrt{s_{NN}} = 200$ GeV. The curves show predictions of a hydro-dynamic model [12].

4. Limiting Fragmentation of Spectra

In order to compare the shapes of particle spectra at different rapidities and $\sqrt{s_{NN}}$ it is convenient to have a single number that characterizes theseshape. This is possible for kaons since they have spectra that are exponential over a very wide energy range. This allows us to characterize kaon spectra by the inverse slope, T_K. Figure 3 shows inverse slopes for charged kaons versus y-y_{beam}. The slopes obey limiting fragmentation over a wide energy range. It is noticable that the limiting fragmentation region extends all the way to central rapidity. This is also true for directed and elliptic flow but not for multiplicity distributions.

5. Discussion

The underlying particle distributions are three dimensional distributions in rapidity, p_T and the angle ϕ with respect to the reaction plane. The integrated v_2 represents an average over p_T of

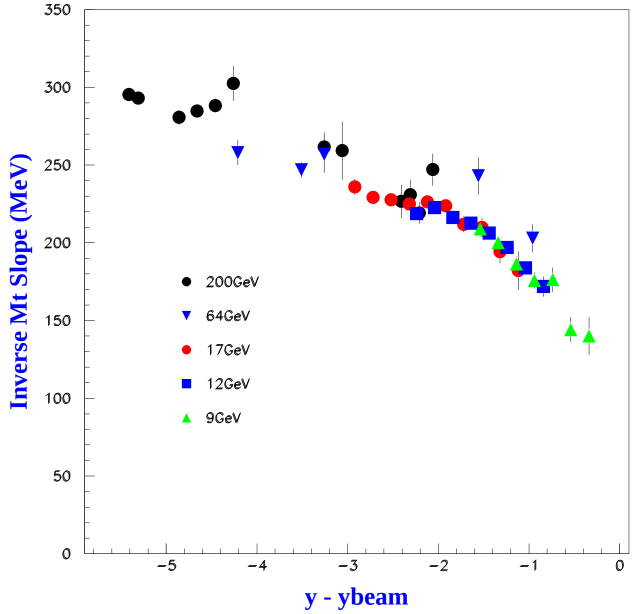

Figure 3: Inverse m_T slopes for k^- spectra from central AuAu and PbPb collisions versus y-y$_{beam}$ for various energies. The data at $\sqrt{s_{NN}} = 9, 12, 17$ GeV are from NA49 [13] while the BRAHMS results are from 64 (preliminary) and 200GeV.

the variation of the yield around the reaction plane, while the particle spectra contain the p_T dependence of the underlying distributions averaged of over ϕ. Normally we think of these two quantities as encoding information from the initial and final states of the collisions respectively. However the fact that they both obey limiting fragmentation in such a way as to keep $v_2(p_T)$ independent of rapidity implies a particular constraint on the rapidity and energy evolution of these quantities. Work supported in part by the Office of Nuclear Physics of US DOE under contract DE-FG03-96ER40981 and DOE EPSCoR DE-FG02-04ER46113.

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