FLOW PHENOMENA AS POSSIBLE SIGNALS OF THE QCD PHASE TRANSITION

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In recent years azimuthal anisotropies in the particle und energy distributions were observed in collisions of the heaviest nuclei at the Brookhaven AGS and the CERN SPS. Initially such effects were established in heavy ion collisions at the Bevalac and later studied in much detail in a similar energy regime at the SIS at GSI. These anisotropies are in recent analyses characterized in terms of Fourier coefficients of the azimuthal distributions in a given rapidity window following a method developed by the E877 collaboration [1, 2]. The first moment, v_1, also called directed (sideways) flow, is related to the mean transverse momentum projected in the reaction plane by normalizing to the mean transverse momentum: $v_1 = \langle p_x \rangle / \langle p_t \rangle$. The second moment, v_2, is the socalled elliptic flow and was in the past also refered to as 'squeeze-out'.

The derivative of the first moment with respect to rapidity, evaluated close to midrapidity, $\mathrm{d}\langle p_x \rangle / \mathrm{dy}$ is in hydrodynamics a scale invariant quantity which should not change unless there is a change in the equation of state. In the beam kinetic energy range between 100 and 1000 MeV per nucleon this quantity, evaluated for protons, has a value around 350 MeV/c [3]. The recent measurements at the AGS and SPS show that it is falling drastically towards high beam energies. At 10 GeV per nucleon it has a value of about 130 MeV [4, 5], at 158 GeV per nucleon it had dropped to around 10 MeV [6, 7]. This suggests that the equation of state may be softening in the systems produced at the high collision energies. In fact, vanishing sideways flow has been predicted when a socalled softest point, a minimum in the pressure per energy density, is reached due to a transition from hadronic matter to a quark-gluon plasma [8]. Therefore one might expect a minimum in the flow at a certain beam energy and experiments are exploring whether such a minimum exists. The energy range not explored yet is between 10 and 158 GeV per nucleon.

Increasingly information is becoming available not only on the integrated anisotropies but on the differential dependence on the transverse momentum. At the AGS the p_t dependence of v_1 has been mapped out in detail and a gradual increase with p_t is found [5]. It is interesting to note that the functional dependence cannot be accounted for by typical cascade codes like RQMD. The interaction between nucleons can be chosen such that the integrated flow is roughly reproduced; but systematically a rapid rise and then levelling off with increasing p_t is found at variance with the data. Modelling, in a picture inspired by hydrodynamics, a source that moves sideways (and expands) reproduces the experimentally observed shape and it's rapidity dependence very well [5, 9].

Elliptic flow has recently been established both at the AGS and SPS and, studying the beam energy dependence, a very interesting picture emerges. At beam kinetic energies of a few hundred up to 1000 MeV per nucleon the elliptic flow shows preferential emission of protons perpendicular to the reaction plane and values of v_2 in the range of -(5-10) % are measured [10, 11, 12]. At 10 GeV per nucleon kinetic energy it was shown that the elliptic flow is preferentially in the reaction plane with typical values of v_2 of +(1-2) %. The zero crossing in between was recently mapped out by measurements at 2, 4, 6, and 8 GeV [13] and was found to be at a kinetic energy of 4 GeV per nucleon. At SPS energies the elliptic flow is found to still point into direction of the reaction plane with larger values of +(5-10) % [6, 14]. It has been pointed out that elliptic flow is sensitive to the equation of state [15] and in particular to the pressure in the early phase of the collision [16]. A recent study [17] shows that the shape of the beam energy dependence and the exact location of the zero crossing are, for a given equation of state for the hadronic matter, sensitive to the occurance of a phase transition to a quark-gluon plasma.

Experimental information is available as well for the directed and elliptic flow of other particles such as pions [5, 6], kaons [18], light nuclei [19] and most recently even of antiprotons [20].

In view of this wealth of accurate experimental data acquired recently at the AGS and SPS a thorough theoretical exploration of the flow phenomena is called for in order to extract quantitative information concerning the equation of state and expected modifications due to the phase transition to the quark-gluon plasma. This is particularly tantalizing since experimental data on hadron yields indicate that hadrochemical freeze-out occurs close to or at the phase boundary [21]. Since flow integrates over the earlier time history and particular features may be sensitive specifically to the early times in the collision this is likely to provide a view into the plasma phase with hadronic observables.

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