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Collective flow with PHOBOS

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Abstract. This paper reviews recent results on directed and elliptic flow from the PHOBOS experiment using data taken during Au+Au runs at RHIC. The systematic dependence of flow on pseudorapidity, energy, transverse momentum and centrality is discussed.

Keywords: flow, heavy ion collisions
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1. Introduction

Collective flow has proven to be one of the more fruitful probes of the dynamics of heavy ion collisions at RHIC. The elliptic flow signal (v_2) at mid-rapidity is large and consistent with expectations from hydrodynamic models at low p_T[1]. It has been interpreted as evidence for the production of a highly thermalized state, and perhaps for partonic matter [2]. At high p_T, the observed suppression of elliptic flow [3, 4] is consistent with calculations incorporating jet quenching [5] and quark coalescence [6]. Interestingly, the fall of v_2 with pseudorapidity ($|\eta|$) has been less amenable to understanding [7].

This paper provides an update on the status of flow studies by the PHOBOS collaboration using data from Au+Au collisions at RHIC. The data were recorded in the years 2000 ($\sqrt{s_{_{NN}}}$ =130 GeV) and 2001 ($\sqrt{s_{_{NN}}}$ =19.6 and 200 GeV). Given the wide range of pseudorapidity coverage and energies present in the data, it is interesting to examine the extent to which the shape of the flow distributions change with energy in the frame of reference of one of the incoming nuclei. In this paper, the term "limiting fragmentation" will be used to describe the extent to which energy independence holds in this frame of reference. This usage may extend well beyond the region of the collision normally thought of as the fragmentation region.

2. PHOBOS flow measurement techniques

The PHOBOS experiment employs silicon pad detectors to perform tracking, vertex detection and multiplicity measurements. Details of the setup and the layout of the silicon sensors can be found in reference [8].

PHOBOS flow analyses to date have made use of the subevent technique described in reference [9]. Results from three independent methods are shown in this paper. The two "hit-based" analyses make use of position information (only) for tracks traversing the octagon and ring subdetectors which cover $-5.4 < \eta < 5.4$ [10]. The "track-based" analysis includes, in addition, reconstructed track (momentum) information from the spectrometer subdetector which covers $0 < \eta < 1.5$ [11].

The two hit-based analyses differ primarily in the selection of the event collision point. In the first method, known as the offset vertex method, interactions are chosen such that they are centered in an azimuthally symmetric part of the detector. The second method, called here the full acceptance method, makes use of interactions centered near the nominal interaction point in the azimuthally asymmetric parts of the detector. These azimuthal asymmetries are symmetrized in software in the early stages of the analysis. The earlier PHOBOS flow results were obtained with the former technique [10]. However, the latter method is more compatible with the event trigger used for the bulk of our data and is the only available technique for data taken at $\sqrt{s_{_{NN}}}$ = 19.6 GeV. Good agreement has been shown between PHOBOS elliptic flow measurements using hit-based and track-based methods, even though the susceptibility of the two techniques to background effects is quite different [11].

2.1. Results

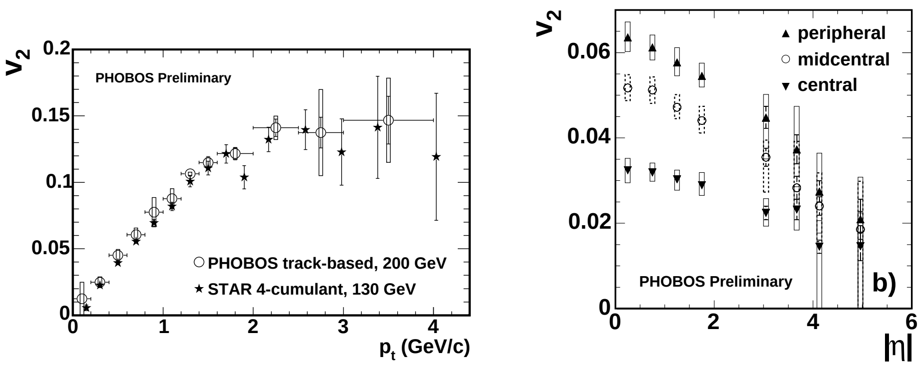

Fig. 1. a) Comparison of PHOBOS (circles) v_2 for 0-55% centrality Au+Au collisions to STAR Au+Au collisions at 5-53% centrality. STAR results using the 4-particle cumulant (stars) method are shown [12]. PHOBOS error bars are statistical, with error boxes representing systematic uncertainty at a 90% confidence level(CL). b) v_2 vs. $|\eta|$ at different centralities: peripheral (25-50%), midcentral(15-25%), and central(3-15%) for 200 GeV Au+Au collisions. Statistical error bars are smaller than the data points, and boxes show systematic errors at 90% CL.

The charged hadron v_2 as a function of p_t, measured by PHOBOS for 200 GeV Au+Au collisions is shown in Figure 1a). Also shown are STAR data for 130 GeV Au+Au collisions analyzed with the 4-particle cumulant technique. Previous measurements demonstrate that elliptic flow changes little from 130 to 200 GeV at $p_T > 1$ GeV/c [13]. The PHOBOS measurement is very similar to STAR's 4-particle cumulant results, which has been shown to be insensitive to non-flow effects [12]. This confirms our expectation that the PHOBOS track-based flow results are largely unaffected by non-flow correlations. It was also determined that the hit-based and track-based results agree extremely well, implying that the hit-based results are also free from large non-flow effects.

Figure 1b) shows the pseudorapidity dependence of the elliptic flow for 200 GeV Au+Au collisions for three broad centrality bins. In this plot, the hit-based and track-based results are combined. The peripheral data do not appear to be flat, even at midrapidity. Within the uncertainties, the shape of $v_2(|\eta|)$ is not strongly centrality dependent, appearing to differ by only a scale factor.

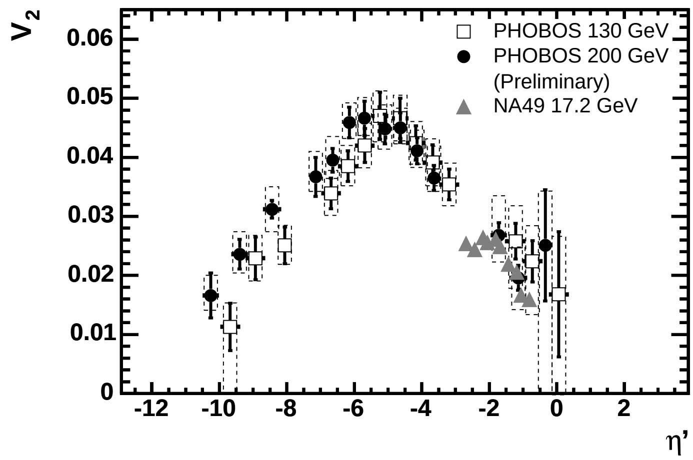

Fig. 2. Elliptic flow at three energies as a function of $\eta' = \eta - y_{beam}$. The 200 [11] and 130 [10] GeV data are previously published Au+Au results from PHOBOS. The 17.2-GeV points represent Pb-Pb data (for pions) from NA49 [14].

The elliptic flow at three energies, plotted in the frame of reference of one of the beam nuclei as a function of $\eta' = \eta - y_{beam}$, is shown in Figure 2. Note the remarkable agreement in the curves all the way from $\eta' = 0$ to the mid-rapidity region for each energy. The results are qualitatively unchanged if one factors out the $\sim$10% peaking in v_2 near mid-rapidity expected due to the fact that the results are determined in η rather than in y [15].

The PHOBOS results on directed flow (v_1) are measured with the full acceptance hit-based method [16]. The flow is calculated for hits measured in the octagon with an event plane determined from widely separated subevents (constructed to be symmetric in η). Subevents in the octagon are used for flow measured in the rings. Figure 3a) shows v_1 vs. η for charged hadrons measured in Au+Au collisions for three different energies. The v_1 values are averaged over a centrality range of 6-55%. In the mid-rapidity region a significant change in slope can be seen from low to high energy Au+Au collisions. In both 130- and 200-GeV measurements, it is seen that, within uncertainties, v_1 is flat at mid-η, in contrast to the 19.6-GeV results. At all three energies, v_1 is non-zero at high $|\eta|$. Similar directed flow results have been observed at low energy in NA49 [14] and at high energy from STAR [17].

A comparison of v_1 measured at different energies in the reference frame of one of the beam nuclei is show in Figure 3b). The directed flow for the three energies

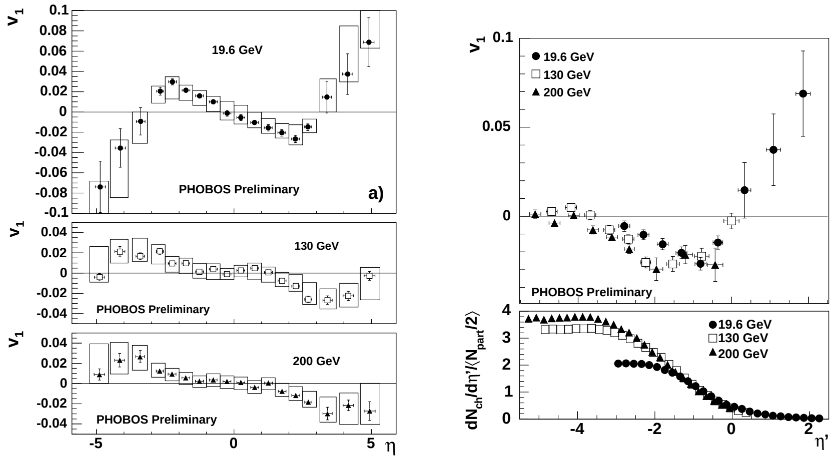

Fig. 3. (a) The directed flow measured as a function of η for $\sqrt{s_{NN}} = 19.6$ (top), 130(middle), and 200 GeV(bottom) Au+Au collisions. Error bars are statistical, the height of boxes represents the systematic error, and the width of the boxes marks the size of the η bin. (b) Directed flow, as shown in (a), but translated to $\eta' = \eta - y_{beam}$. Systematic error boxes are omitted for clarity. (c) Scaled pseudorapidity distributions for 0-6% central 19.6, 130, and 200 GeV Au+Au collisions as a function of η' [18]. Systematic errors not shown.

is similar at $\eta' \gtrsim -1.5$. It should be noted that the $v_1(\eta')$ measurements at the low and high energies originate from different parts of the detector and have differing systematic error susceptibilities and sensitivities to the reaction plane.

For comparison with Figures 2 and 3b), Figure 3c) shows previously published results on the particle multiplicity, scaled by $< Npart/2 >$, as a function of η' for the same three energies [18].

3. Conclusions

Charged hadron elliptic flow has been measured as a function of transverse momentum and pseudorapidity for 200 GeV Au+Au collisions. The centrality dependence of v_2 is shown over a large range in pseudorapidity. For peripheral collisions, v_2 as a function of $|\eta|$ is not flat, even at midrapidity.

PHOBOS measurements of charged hadron directed flow for 19.6, 130 and 200 GeV Au+Au collisions are shown as a function of pseudorapidity for $|\eta| < 5.4$. Looking in the rest frame of the nucleus, both the elliptic and directed flow show energy independent behavior which extends to mid-rapidity. It should be noted that close to mid-rapidity one expects to see changes in the curves determined as a function of pseudorapidity as opposed to rapidity. For the elliptic flow, these changes are relatively small (10% at $\eta = 0$) [15]. Thus, the degree to which the energy independence of the results extends to mid-rapidity for the elliptic flow is intriguing. It is difficult to reconcile this fact with the common assumption that the particle production at mid-rapidity differs from that in the fragmentation region, particularly at the higher energies.

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