

Systematic study of directed flow at RHIC energies

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Abstract Directed flow, v_1 , of charged hadrons has been measured in Au-Au collisions at RHIC for center-of-mass energies $\sqrt{s_{NN}} = 19.6, 130, 62.4, \text{ and } 200 \text{ GeV}$ using the PHOBOS detector. The large acceptance of PHOBOS for charged particles allows measurements over the full range of pseudorapidity $|\eta| < 5.4$. The results for a symmetric subevent method are shown at all four energies. Comparison is made to a mixed harmonic method for the highest energy, and compared to similar results from the STAR collaboration.

Key words relativistic heavy ions • directed flow • PHOBOS • charged hadrons

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The distribution of charged particles produced with respect to the plane of the reaction was first quantified for heavy-ion reactions at relativistic energies at the Lawrence Berkeley National Laboratory Bevalac, and later at the Brookhaven National Laboratory AGS and the CERN SPS. The so-called flow has been viewed as a sensitive measure of the equation of state of nuclear matter at those energies. With the advent of heavy-ion experiments at RHIC, these studies have been extended to ultrarelativistic energies and serve as a critical test of hydrodynamic models. Many measurements have been made of the elliptic flow or v_2 component of the distribution; only recently measurements of the deflection from the beam direction in the plane of the reaction have been made at RHIC energies. This directed flow or v_1 is much smaller than that observed at the lower energies, but is nonetheless quantifiable. This paper describes the directed flow measurements for the Au-Au system at four collision energies, $\sqrt{s_{NN}} = 19.6, 130, 62.4, \text{ and } 200 \text{ GeV}$, made using the PHOBOS detector at RHIC.

Directed flow is quantified by measuring the first harmonic, v_1 , of the Fourier decomposition of the azimuthal distribution of particle angles ϕ , where ψ_R is the true reaction plane angle defined by the impact parameter and beam axis,

$$(1) \quad \frac{dN}{d(\phi - \psi_R)} \sim 1 + \sum_n 2v_n \cos[n(\phi - \psi_R)]$$

In practice, the event plane ψ_n is used, as determined by

$$(2) \quad \psi_n = \left(\tan^{-1} \frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)} \right) / n$$

where: ψ_n = reaction plane angle derived from n -th Fourier component, $n = 1$ for v_1 ; ϕ_i = angle (in

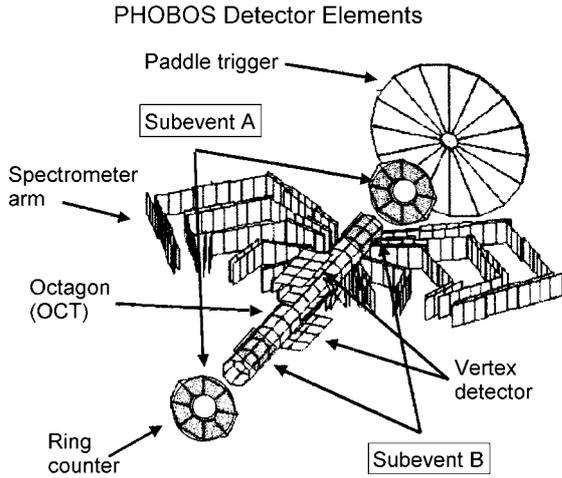


Fig. 1. A diagram of the elements of the PHOBOS detector. The regions relevant to the determination of the reaction plane are shaded.

laboratory frame) of the i -th hit; w_i = corrective weights applied to i -th hit.

A diagram of the PHOBOS detector is shown in Fig. 1. A full description of the detector can be found in [2]. The relevant segments of the detector are highlighted and labeled. This is a hit-based analysis using the silicon sensors in the Octagon (OCT) and Ring (RINGS) detectors. The paddle scintillator detectors are used to determine the event centrality. Symmetric subevents are chosen to ensure momentum conservation between the two pseudorapidity (η) hemispheres. The subevent regions used in the event plane calculations are well separated to minimize non-flow correlations and are located in the OCT ($1.5 < |\eta| < 3$) and RINGS ($3 < |\eta| < 5$) subdetectors. The reaction plane defined by the OCT subevents is used to find v_1 in the RINGS region, while that defined by the RINGS subevents is used to measure v_1 in the OCT.

The following corrections have been made to the raw hit distributions and the resulting flow signal:

- A weighting matrix is applied to correct for phase space differences between detector pads and to account for detector occupancy.
- The reaction plane resolution correction is found by comparing the symmetric $\eta < 0$ with $\eta > 0$ regions [5].
- A suppression correction based on a reconstructed known Monte Carlo flow signal is applied. This accounts for a reduction in the measured flow due to background particles that carry no flow information.

The resulting directed flow v_1 is shown in Fig. 2 for the four Au-Au energies. Note that the magnitude is much larger for the two lower energies and the v_1 axes for these and the two higher energies are different. There is a directed flow observed at all energies, with a turn around or inversion seen at the highest $|\eta|$ in all cases. This is most pronounced for the lowest energies, where the flow changes sign at high $|\eta|$. A direct comparison of the four energies can be made by reflecting about $\eta = 0$ and transforming to reference frame $\eta' = |\eta| - y_{\text{beam}}$. This gives the results in a reference frame approximately equal to the rest frame of one of the beams. Figure 3 (top) shows the data for each energy from Fig. 2

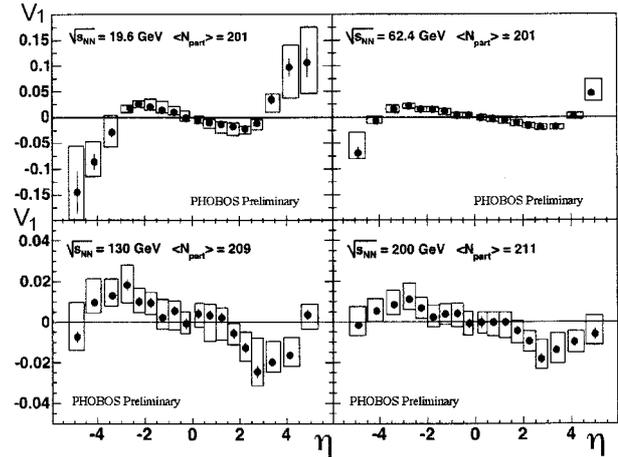


Fig. 2. Directed flow in Au-Au collisions at $\sqrt{s_{NN}} = 19.6, 62.4, 130,$ and 200 GeV, as a function of pseudorapidity, for the centrality range of 0–40%. The lines represent one-sigma statistical errors and the boxes are 90% C.L. systematic errors.

reflected and averaged. For clarity, only the statistical error bars are included. It is now apparent that the inversion of sign takes place around the beam rapidity and is probably due to spectator protons. There is a remarkable universal scaling in terms of η' , reminiscent of that which is observed in the elliptic flow, shown in Fig. 3 (bottom) (taken from [3]). This extended longitudinal scaling seen in directed flow and elliptic flow

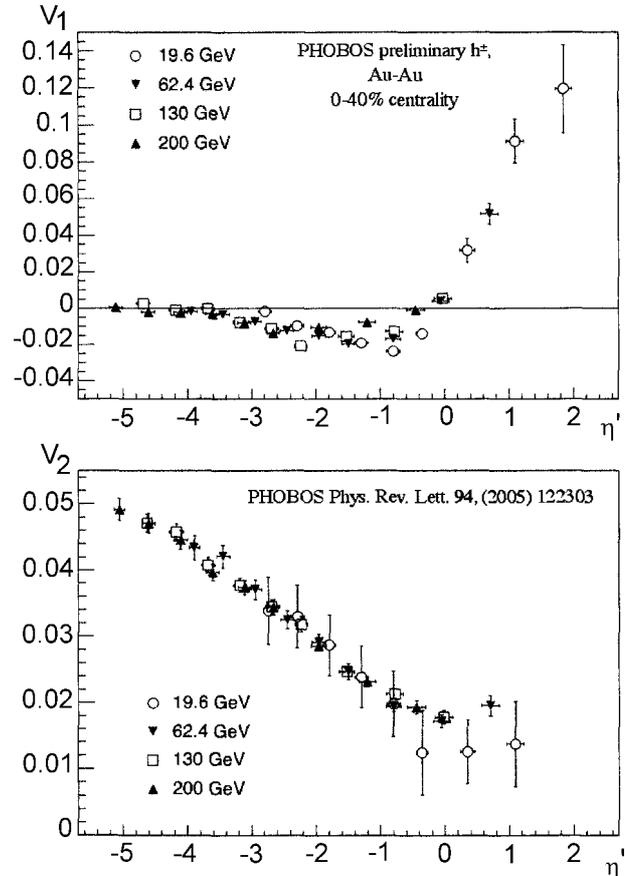


Fig. 3. Directed flow (top) and elliptic flow (bottom) as a function of $\eta' = |\eta| - y_{\text{beam}}$, averaged over the centrality range of 0–40%, for Au-Au collisions at $\sqrt{s_{NN}} = 19.6, 62.4, 130,$ and 200 GeV. Only the one-sigma statistical errors are shown.

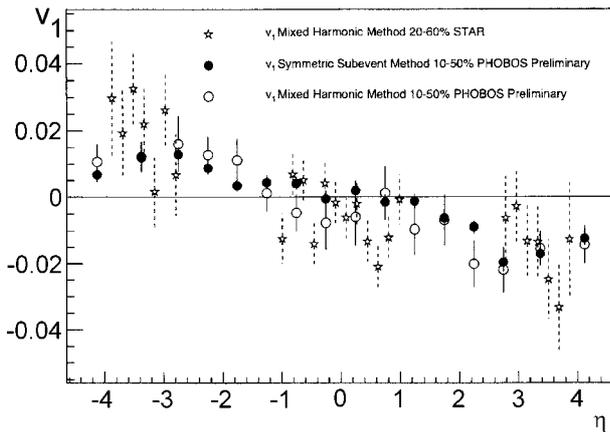


Fig. 4. The directed flow v_1 as a function of pseudorapidity, for the Au-Au system measured at $\sqrt{s_{NN}} = 200$ GeV. The data from STAR is from [1], and the centrality ranges are as noted.

was previously observed in the pseudorapidity distribution of charged particles [4].

The data were also analyzed using a mixed harmonic technique [1], which accounts for possible non-flow effects by comparing the directed flow signal obtained with respect to two different event planes, as defined by Eq. (2). The event plane, ψ_2 , is determined using the elliptic flow information. The directed flow signal perpendicular to ψ_2 is subtracted from that which is in the plane of ψ_2 . Since a directed flow signal should lie in the reaction plane, any out-of-plane signal is interpreted as due to non-flow effects.

The mixed harmonic results for all four energies are in agreement with that obtained using the subevent technique. Figure 4 shows a comparison between the two techniques for the 200-GeV data, which agree within the statistical errors. Also shown are results from STAR using the mixed harmonic method [1]. Both PHOBOS and STAR show that the flow is consistent with zero in the range of $|\eta| < 1$. There is a slight discrepancy for the larger $|\eta|$ values; PHOBOS indicates a flattening or turn over, although the centrality regions for the PHOBOS and STAR data are slightly different

and the error bars are too large to reach a definitive conclusion. The PHOBOS detector also has a lower energy cut-off in the detected particles at large $|\eta|$ due to the length of the beryllium beam pipe.

PHOBOS has measured the directed flow of charged hadrons over the pseudorapidity range $|\eta| < 5.4$ for $\sqrt{s_{NN}} = 19.6, 62.4, 130,$ and 200 GeV. When transformed into a rest frame approximately equal to that of one of the beams, the data for the four energies follow a universal curve, as seen for the elliptic flow. In this representation, it is evident that the change in the sign of the flow signal as a function of pseudorapidity occurs near the beam rapidity and is probably due to the detection of spectator protons.

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