Conclusion of Small Systems Task Force

Constantin Loizides, Oak Ridge National Laboratory
Jean-Yves Ollitrault, Institute of theoretical Physics, Saclay, France
Sergei Voloshin, Wayne State University

The PHENIX [1] and STAR [2] collaboration have reported conflicting results on anisotropic flow in p+Au, d+Au, ^{3}He+Au collisions at energy 200 GeV per nucleon-nucleon collisions. Both collaborations analyze elliptic flow, v_2, and triangular flow, v_3, in the central rapidity region. STAR finds a value of v_3 significantly larger than PHENIX in d+Au and p+Au collisions.

Anisotropic flow is defined as the azimuthal anisotropy of the single-particle distribution, which cannot be directly measured. The conflicting results from STAR and PHENIX are both inferred from analyses of two-particle correlations.

In order to extract anisotropic flow from two-particle correlations, one must first eliminate nonflow effects, which are not due to anisotropic flow. There is no robust way of eliminating nonflow, and the two analyses differ in how they treat them. It is known that nonflow effects are much suppressed if the two particles are separated by a pseudorapidity gap. The PHENIX analysis has made use of the broad pseudorapidity coverage of the detector (see table below) in order to implement large gaps, and estimated residual nonflow effects as systematic uncertainties. The STAR analysis uses a detector which spans a much smaller range in pseudorapidity, and smaller gaps can be implemented. In order to evaluate the residual nonflow effects, they use data on proton-proton collisions, which are thought to be dominated by nonflow. A subtraction method is then implemented, based on the assumption that the dipole component of the correlation is solely due to nonflow. This is however questionable, since a dipolar flow is seen in nucleus-nucleus collisions [3].

Nonflow effects are larger for smaller collision systems, and are likely to be a sizable source of uncertainty on the final results, which must be carefully evaluated. We recommend that STAR continues to explore the robustness of their results with respect to the subtraction method. We also suggest that they explore the dependence of flow and non-flow on p_T to 3 GeV or beyond to possibly see the transition from a regime dominated by flow to a regime dominated by non-flow. We also recommend that PHENIX carry out additional estimates of the magnitude of the residual nonflow correlation, in addition to the systematic uncertainty estimated in earlier publications.

The two collaborations also differ in how they model the rapidity dependence of anisotropic flow. STAR neglects it. PHENIX uses a more conservative assumption that the rapidity dependence of anisotropic flow is the same in all events. Analyses of proton-nucleus collisions at the LHC have shown that this assumption does not strictly hold due to longitudinal fluctuations [4]. There is no known robust method for correcting for this effect, but its magnitude should be carefully evaluated. When anisotropic flow is analyzed by correlating particles from two rapidity windows, as in the case of STAR (note that the windows are not fixed), longitudinal fluctuations lead to a v_n which is underestimated. When anisotropic flow is analyzed by correlating particles from three different rapidity windows, as in the case of PHENIX, rapidity-dependent fluctuations lead to a v_n which is overestimated in the inner window, and underestimated in the two outer windows. The effect of these longitudinal fluctuations is likely to be larger for PHENIX, which spans a broader range in pseudorapidity. They would imply that v_n in the central rapidity region is underestimated.

We recommend that both collaborations explore in further detail the rapidity structure of the two-particle correlation. This could be done for STAR already within the acceptance of the TPC, even though the range is limited. The forthcoming publication by PHENIX with the detailed rapidity dependence of the correlations will be a very useful input. We furthermore recommend that more data will be taken in the future, with the upgraded STAR and the new sPHENIX detectors which significantly extend the rapidity coverage.

The comparison between the two collaborations should be carried out within similar centrality ranges. PHENIX uses the 0-5% centrality measured on the Au-going side for all three systems, while STAR uses 0-10% for d+Au, ^{3}He+Au, and 0-2% for p+Au determined at mid-rapidity. The definition of the centrality, which does have a nontrivial effect for small systems, should not be overlooked.

In summary, there is no sign that any of the two analyses is technically wrong. We believe that all the observed differences could be ascribed to the different treatment of nonflow effects and of the flow (and non-flow) rapidity dependence. The differences lie mostly in the values of v_3, which is smaller than v_2 and typically more difficult to analyze. The differences are also larger in the smallest systems (p+Au and d+Au) where nonflow effects are a larger relative contribution. More specifically, the subtraction of nonflow carried out by STAR increases v_3, while longitudinal fluctuations neglected by PHENIX decrease v_3, and it is at this stage plausible that a combination of these two effects could explain the conflicting results. More detailed studies of the rapidity dependence might even reveal that at negative rapidities (Au going direction, where PHENIX evaluates the event-plane), anisotropic flow is determined by the positions of participant nucleons, while at midrapidity probed by STAR, it is mostly due to fluctuations at the sub-nucleonic scale. In this case, not only the analyses, but also the interpretation of the results by the collaborations would both be correct.

In conclusion, this controversy brings up useful physics questions. Resolving them will require more data, taken with upgraded STAR and the sPHENIX detectors, and probably improved methods of analysis. It is likely that the whole field of nucleus-nucleus collisions will benefit from these ongoing and future efforts to analyze the flow in small systems.