BULK OBSERVABLES IN pp, dA AND AA COLLISIONS at RHIC

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Results on charged particle production in p+p, d+Au and Au+Au collisions at RHIC energies ($\sqrt{s_{NN}} = 19.6$ to 200 GeV) are presented. The data exhibit remarkable, and simple, scaling behaviors, the most prominent of which are discussed.

1 Introduction

In this paper, we report on the bulk features of particle production, focusing on results from the PHOBOS experiment at the Relativistic Heavy-Ion Collider (RHIC). A primary strength of PHOBOS is the ability to measure the total charged multiplicity, with practically no extrapolations necessary, due to the $\sim 4\pi$ acceptance of the detector. The specific detectors that allow
the measurement of charged particle multiplicity \(dN_{ch}/d\eta\) over the broad pseudorapidity range \(|\eta| < 5.4\) are the midrapidity Vertex detector \(|\eta| < 1\), the centrally located Octagon barrel \(|\eta| < 3.2\), and a series of six Ring counters \(3.1 < |\eta| < 5.4\), all of which closely surround a thin Be beam-pipe. These detectors are silicon pad sensors, see Ref. 1 for details.

2 Bulk Charged Particle Production

A surprising discovery at RHIC is the existence of simple scaling behaviors observed in bulk charged particle production (i.e. integrated over p\(_T\) and particle species). Some of these features are similar to those seen at lower energies, as well as in simpler systems, including p(p) + p and e\(^+\)+e\(^-\) collisions. These scaling properties are found to exist both as a function of the collision geometry as well as in the rest-frame of one of the colliding nuclei. In the following discussion, it is important to note that the measured bulk charged particle multiplicities are completely dominated by the emission of low p\(_T\) \((\leq 1.5\text{ GeV}/c)\) particles.

Determining the centrality (or impact parameter \(b\)) of a heavy-ion collision is extremely important to provide a geometrical scale for use in the studies of underlying collision dynamics. The event centrality is characterized by charged particle multiplicities measured in various regions of phase-space. Comprehensive Monte Carlo (MC) simulations of these signals, that include Glauber model calculations of the collision geometry, allow the estimation of \(N_{part}\), the number of participating nucleons in the collision, 2,3 for a selected class of events. The most central \((b \sim 0)\) collisions will have the largest number of participants with the obvious upper limit of 394 for a “perfectly central” Au+Au collision where all the nucleons interact. For a particular collision geometry, the MC simulation also allows calculation of the number of binary collisions, \(N_{coll}\), which provides an expected baseline scaling for large-momentum transfer processes.

One of the first measurements at RHIC was the multiplicity of charged particles, \(dN_{ch}/d\eta\) (pseudorapidity density), produced in head-on collisions of Au+Au nuclei and emitted at midrapidity, defined here as \(|\eta| < 1\). This and subsequent results 2,3 are shown in Fig. 1 where the midrapidity \(dN_{ch}/d\eta\) is divided by the average number of participating nucleon pairs, \((\frac{1}{2}N_{part})\),
in order to compare directly to results from p(\(\overline{p}\)) + p collisions. What is most notable in the heavy-ion data of Fig. 1 is the apparent linear logarithmic growth of the midrapidity particle production per participant pair with collision energy (\(\sqrt{s_{NN}}\)). This multiplicity in central Au+Au collisions is larger, however, than seen in inelastic p(\(\overline{p}\)) + p collisions at similar energy, indicated by the open diamonds 5 in Fig. 1.

The centrality dependence of midrapidity multiplicity per participant pair in Au+Au collisions at \(\sqrt{s_{NN}} = 200\) and 19.6 GeV is shown in Fig. 2, where the heavy-ion data has been normalized by the corresponding multiplicity in inelastic p(\(\overline{p}\)) + p collisions. The most dramatic feature of the Au+Au centrality dependence is the similarity of the collision geometry scaling at both energies, a scaling which follows a strong \(N_{\text{part}}\)-like dependence. Despite a factor of 10 increase in collision energy from \(\sqrt{s_{NN}} = 19.6\) to 200 GeV, both data sets are consistent with only a small (\(\approx 13\%\)) fraction of binary collision (\(N_{\text{coll}}\)) scaling 3.

Although there is a slight increase in midrapidity multiplicity per participant pair in Au+Au collisions as a function of centrality (see Fig. 2), we find this increase exhibits a simple scaling at RHIC. This scaling is shown in Fig. 3 where the ratio of 200/130 and 200/19.6 GeV midrapidity \(dN_{\text{ch}}/d\eta/(\frac{1}{2}\langle N_{\text{part}} \rangle)\) is given as function of centrality. Within errors, the ratio is independent of centrality for the most central 40\% of the cross section and yields a simple scale factor \(R_{200/130}=1.14 \pm 0.01\) (stat)\(\pm 0.05\) (syst) 2 and \(R_{200/19.6}=2.03 \pm 0.02\) (stat)\(\pm 0.05\) (syst) 3.

Expanding to the full phase space, we find the midrapidity increase in \(dN_{\text{ch}}/d\eta/(\frac{1}{2}\langle N_{\text{part}} \rangle)\) with centrality is remarkably compensated by a corresponding decrease in yield at high \(\eta\) such that the total charged particle production per participant pair is independent of centrality. This can be seen in Fig. 4 for both Au+Au collisions as well as for d+Au collisions. We also observe that the Au+Au and d+Au data give different values of \(N_{\text{ch}}/(\frac{1}{2}\langle N_{\text{part}} \rangle)\), but they are different in a very interesting way. For the same collision energy, the Au+Au data matches that seen in e\(^+\)+e\(^-\) collisions and the d+Au data matches that seen in p(\(\overline{p}\)) + p collisions.

The last scaling feature we examine is evident when particle production is viewed in the rest frame of one of the colliding nuclei. This is approximately achieved by effectively transforming measured \(dN_{\text{ch}}/d\eta\) multiplicities to the rest frame of the beam with rapidity \(y_{\text{beam}}\), using \(dN/df'\) where \(f' = |\eta| - y_{\text{beam}}\). In the late 1960’s it was hypothesized that in hadronic collisions, at high enough collision energy, the charged particle yield (\(d^2N/dy'dp_T\)) reaches a limiting value and becomes independent of energy when viewed near beam rapidity 6. This “limiting
fragmentation” hypothesis works in many elementary systems including p(\overline{p}) + p as shown in the \(dN_{ch}/d\eta\) multiplicities in Fig. 5. We find the same features in the Au+Au heavy-ion data at RHIC (see Fig. 6). The same “limiting fragmentation” features are also seen in \(dN_{ch}/d\eta\) data from d+Au collisions. Most recently, PHOBOS has additionally observed the same type of scaling in the magnitude of elliptic flow, \(v_2(\eta')\), for heavy-ion collisions.

3 Conclusions

We report here a few of the bulk properties of charged particle production seen in relativistic heavy-ion collisions at RHIC energies. We find that much of the data can be described in terms of simple scaling behaviors. These observations are not yet understood, but could suggest the existence of strong global constraints or some form of universality in the bulk hadron production mechanism. These behaviors must be understood before a complete picture of the properties of the high energy-density matter created at RHIC can be definitively determined.

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