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Universal Behavior of Charged Particle Production in Heavy Ion Collisions at RHIC Energies

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The PHOBOS experiment at RHIC has measured the multiplicity of primary charged particles as a function of centrality and pseudorapidity in Au+Au collisions at $\sqrt{s_{NN}} = 19.6$, 130 and 200 GeV. Two observations indicate universal behavior of charged particle production in heavy ion collisions. The first is that forward particle production, over a range of energies, follows a universal limiting curve with a non-trivial centrality dependence. The second arises from comparisons with $pp/\bar{p}p$ and e^+e^- data. $\langle N_{ch}\rangle/\langle N_{part}/2\rangle$ in nuclear collisions at high energy scales with $\sqrt{s}$ in a similar way as N_{ch} in e^+e^- collisions and has a very weak centrality dependence. These features may be related to a reduction in the leading particle effect due to the multiple collisions suffered per participant in heavy ion collisions.

1. Introduction

The PHOBOS experiment has measured $dN_{ch}/d\eta$ and the average multiplicity of charged particles $\langle N_{ch}\rangle$ produced in heavy ion collisions for center of mass energies in the nucleon-nucleon center of mass system, $\sqrt{s_{NN}}$, of 19.6, 130 and 200 GeV. The data is also binned as a function of event centrality (impact parameter) characterized by the number of participating nucleons, N_{part}, allowing comparisons to elementary systems, like $pp/\bar{p}p$ and $e^+e^- \rightarrow$ hadrons.

The PHOBOS multiplicity detector consists of two arrays of silicon detectors which cover nearly the full solid angle for collision events. The event centrality is characterized by two sets of 16 paddle counters which measure charged particles in the region $3 < |\eta| < 4.5$. The methods used for measuring the multiplicity of charged particles as well as for extracting N_{part} has been described in more detail in Ref. [1].

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2. Limiting Behavior in Pseudorapidity Distributions

Fig. 1 shows $dN_{ch}/d\eta'/\langle N_{part}/2\rangle$ ($\eta' = \eta - y_{\rm beam}$) measured at three different RHIC energies for peripheral ($N_{part} \sim 100$) and central events ($N_{part} \sim 355$), in the left and right panels, respectively. These show a clear "limiting behavior" in the fragmentation region. That is, the distributions are independent of beam energy in a substantial range in η'. As the beam energy increases, $dN/d\eta'$ follows the universal trend until it reaches 85-90% of it's maximum value at midrapidity, at which point it stops following the trend. Similar behavior has been observed in el-

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ementary collisions as well, both in $\overline{p}p$ collisions [2] and in e^+e^- collisions over a large range of energies ($\sqrt{s} = 14 - 183$ GeV [4]).

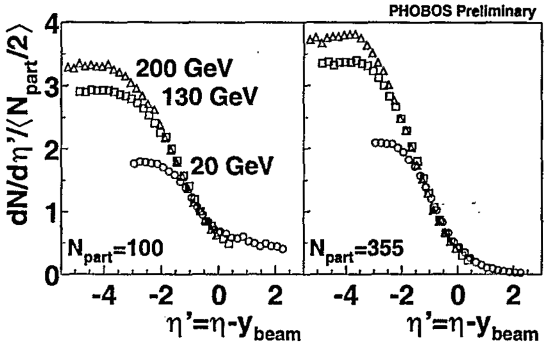

Figure 1. $dN/d\eta'/\langle N_{part}/2\rangle$ for peripheral and central events at three RHIC energies.

While the limiting curve constrains the energy dependence of the charged particle multiplicity, it varies with centrality in such a way that the increases seen at low η' (which is midrapidity in η) as N_{part} increases, are accompanied by decreases near $\eta' \sim 0$ (forward rapidities), as seen in Fig. 1. It is not clear why this behavior occurs, e.g. whether it is from energy conservation or a true long-range correlation.

3. Comparison with Elementary Systems

The angular distributions of charged particles for different strongly-interacting systems are shown in Fig. 2, where central Au+Au (divided by $\langle N_{part}/2\rangle$), $\overline{p}p$ [2] and e^+e^- [3] data are compared, all at $\sqrt{s} = 200$ GeV. In this figure, the Au+Au and $\overline{p}p$ data are shown as $dN_{ch}/d\eta$, while the e^+e^- data (with cuts applied to reject events with large initial-state photon radiation) is shown as dN/dy_T, the rapidity distribution along the event thrust axis, assuming the pion mass. The shapes of Au+Au and e^+e^- are similar (within 10%) in shape and magnitude, especially within $|\eta| < 4$. In the lower panel, we also observe that the shapes of Au+Au and $\overline{p}p$ are also very similar

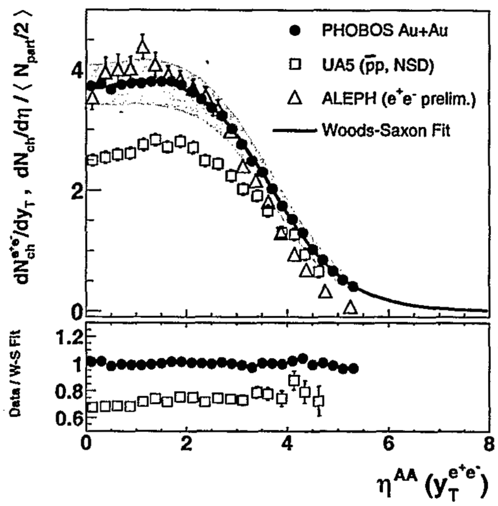

Figure 2. Top: $dN_{ch}/d\eta/\langle N_{part}/2\rangle$ for central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV compared with $\overline{p}p$ and e^+e^-. Bottom: Au+Au and $\overline{p}p$ data divided by a fit to the Au+Au data.

over a large range in η, but the integral differs by $\sim 40\%$.

In Fig. 3, we compare $\langle N_{ch}\rangle/\langle N_{part}/2\rangle$ in heavy ion collisions to e^+e^- and $pp/\overline{p}p$ data over a large range in $\sqrt{s}$. It is observed that $\langle N_{ch}\rangle/\langle N_{part}/2\rangle$ lies below pp at low energies, passes through the pp data around $\sqrt{s} \sim 10$ GeV, and then gradually joins with the e^+e^- trend above CERN SPS energies. These comparisons can be seen more clearly by dividing all of the data by a fit to the e^+e^- data [7].

The $pp/\overline{p}p$ data follows the same trend as e^+e^-, but it can be shown that it matches very well if the "effective energy" $\sqrt{s}_{\rm eff} = \sqrt{s}/2$ is used, which accounts for the leading particle effect seen in pp collisions [8]. Ref. [8] finds that bulk particle production in pp and e^+e^- data does not depend in detail on the collision system but rather the energy available for particle production. In this scenario, the Au+Au data suggests a substantially reduced leading particle effect in central collisions of heavy nuclei at high energy.

The alleviation of the leading particle effect

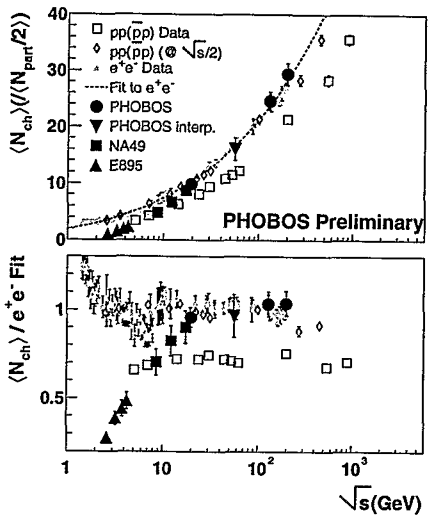

Figure 3. Comparison of $\langle N_{ch}\rangle/\langle N_{part}/2\rangle$ for A+A, $pp/\overline{p}p$, and e^+e^- data compared with a fit to the e^+e^- data.

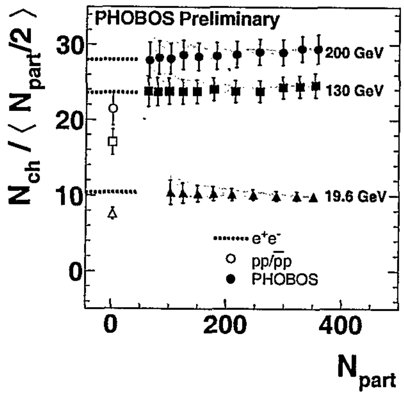

Figure 4. $\langle N_{ch}\rangle/\langle N_{part}/2\rangle$ vs. N_{part} for $\sqrt{s_{NN}} =$ 19.6, 130, and 200 GeV.

might not be so surprising in nuclear collisions. Each participating nucleon is typically struck $\overline{\nu} > 3$ times on average as it passes through the oncoming gold nucleus for $N_{part} > 65$. One could speculate that the multiple collisions transfer much more of the initial longitudinal energy into particle production. This naturally leads to the scaling of total particle production in heavy ion collisions with N_{part}, as seen in Fig. 4, reminiscent of the "wounded nucleon model" [9] but with the scaling factor determined by e^+e^- rather than *pp*.

In conclusion, PHOBOS has observed two types of universal behavior. The first is an energy-independent, but centrality-dependent, universal limiting distribution of charged particle production in the forward direction. The second is that the total particle production is consistent with an effective energy per participant pair of approximately $\sqrt{s}$ (rather than $\sqrt{s}/2$ seen in $\overline{p}p$) that fragments into a similar number of particles as e^+e^- annihilations. These features may offer a new perspective on particle production in heavy ion collisions.

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