Results from the PHOBOS Experiment at RHIC

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PHOBOS is one of the four experiments at the Relativistic Heavy Ion Collider measuring $p+p$, $d+Au$, and $Au+Au$ collisions over a broad range of energies. PHOBOS is a silicon-pad based detector with a 4π multiplicity detector and a high resolution mid-rapidity spectrometer, along with other detectors (time-of-flight walls, proton and zero degree calorimeters). PHOBOS is able to measure particles at low transverse momentum, spectra, flow, particle ratios, and multiplicity over a large region of phase space. A comparison of results for $Au+Au$ and $d+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV will be discussed.

1. Introduction

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory provides the ability to test theories of particle physics at a number of collision energies. It has been proposed that the collisions of relativistic nuclei with high parton density may create conditions like those in the early universe, a state in which quarks and gluons are no longer confined within hadrons.

The collision dynamics can be expressed as reflecting "hard" or "soft" particle production. Events characterized by mostly "soft" processes scale with N_{part}, the number of participating nucleons. The bulk of produced charged particles produced in a colli-

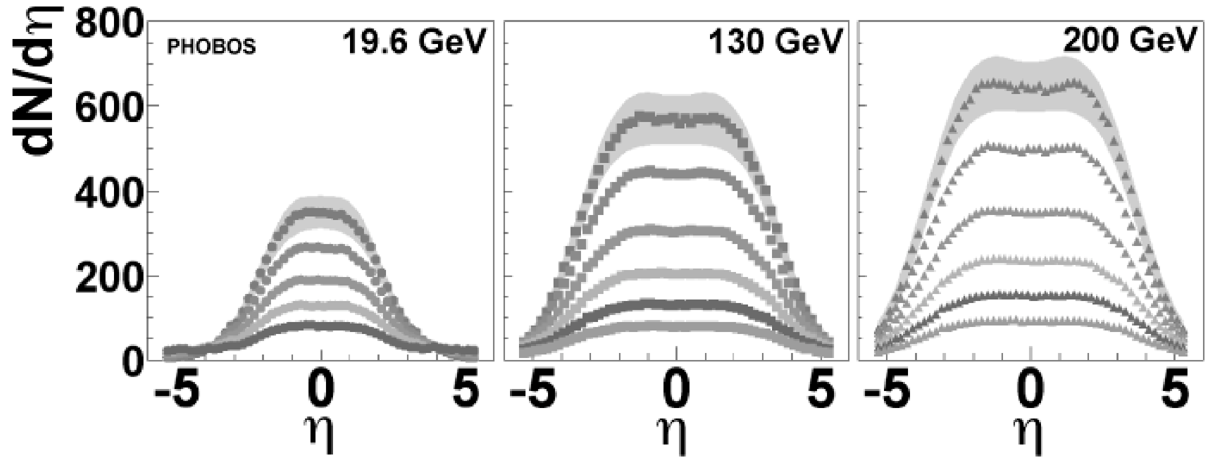


Figure 1. Density of charged particles per unit pseudorapidity (η), measured in $Au + Au$ collision energies of 19.6, 130, and 200 GeV from left to right. Centrality decreases from top to bottom, with bins of 0-6%, 6-15%, 15-25%, 25-35%, 35-45%, and 45-55%. The grey band shows the size of the systematic error.

sion are from "soft" processes. "Hard" processes from interactions of individual partons should scale by N_{coll}, the number of binary nucleon-nucleon collisions, usually seen at high transverse momentum p_t.

2. Detector

The PHOBOS experiment at RHIC consists largely of silicon multiplicity detectors, as well as a spectrometer[1]. It has nearly 4π coverage for multiplicity within pseudorapidity of $-5.4 < \eta < 5.4$ ($\eta \equiv -\ln\tan(\theta/2)$). PHOBOS has a 12m long Beryllium beampipe which reduces background, allowing precise measurements of hadrons close to the interaction region. Triggering is provided by scintillator paddle and Cerenkov counters. Further event selection cuts can be made by forward zero-degree calorimeters, measuring spectator neutrons. For the 130 and 200 GeV $Au+Au$ datasets, event centrality was found with measurements in the plastic scintillator ("paddle") counters. For the $Au+Au$ data taken at 19.6 GeV, the energy deposited in the octagon silicon detector was used. For $d + Au$ 200 GeV collisions, silicon ring detectors were used to characterize event centrality.

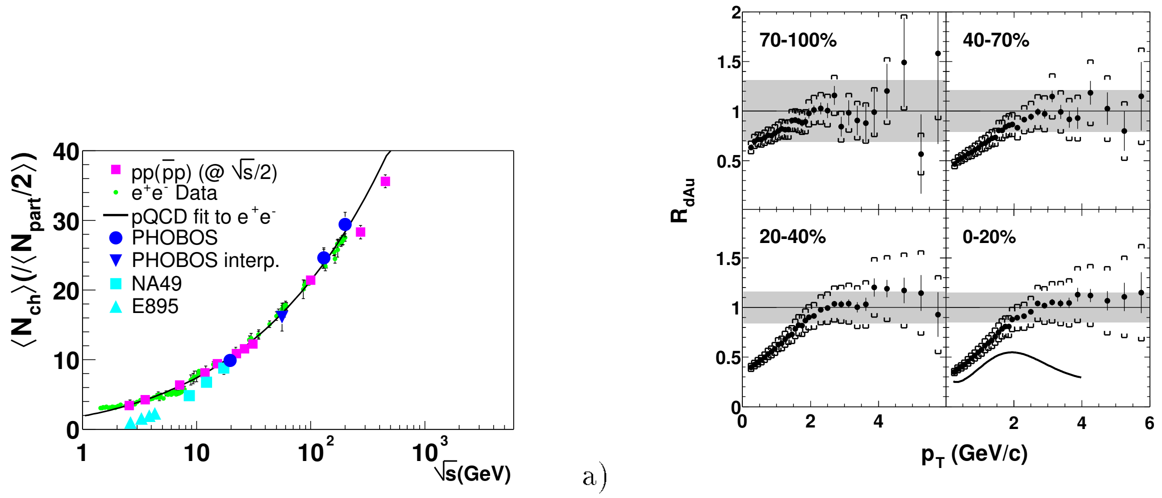
3. Multiplicity

The pseudorapidity density of charged particles ($dN_{ch}/d\eta$), can be related to the entropy density of a system at freezeout. This pseudorapidity distribution, given in Figure 1, is shown over the large range of η which PHOBOS measures, as well as a variety of system energies and centralities[2]. The light grey bands show the systematic error at a 90%

confidence level. Centrality of the collision system increases from the lowest to the highest curve for each energy. These densities can be integrated to obtain the average charged particle multiplicity ($\langle N_{ch} \rangle$) for each centrality and collision energy. When comparing $\langle N_{ch} \rangle$ to N_{part}, a linear scaling is found for each collision energy measured.

4. Comparison With Other Collision Systems

It was found that the $\langle N_{ch} \rangle$ for e^+e^- collisions is similar to that of $p+p$ collisions where the leading particle energy is removed from $\sqrt{s_{pp}}$ [4]. This was seen as a universal mechanism of particle production. $Au+Au$ collisions can be compared to $p+p$ and e^+e^-, considering that $\langle N_{part} \rangle/2$ is one for both of the lighter systems. Figure 2a) shows this comparison. The $p+p$ data is shown in dark squares, e^+e^- in dots. PHOBOS $Au+Au$ data are dark circles, with an interpolated point (dark inverted triangle) at 56 GeV. Lower energy $Pb+Pb$ events from NA49 (SPS) are light squares, and $Au+Au$ collisions measured at E895 (AGS) are light triangles. The dotted line shows a fit to the e^+e^- data. What can be seen is that the heavy ion data does not follow the same multiplicity scaling that $p+p$ does at lower energies. Above CERN SPS energies, the multiplicity per participant pair of heavy ion collisions scales in the same way as e^+e^- collisions. This suggests a universal mechanism of particle production in strongly-interacting systems which is controlled by the amount of energy available.



a) b)

Figure 2. a)$\langle N_{ch} \rangle/(\langle N_{part} \rangle/2)$ in PHOBOS $Au+Au$ (dark circles), and interpolated PHOBOS (inverted triangle) as a function of energy. e^+e^- data is shown as light dots and $p+p(p+\bar{p})$ are the dark squares. b)R_{dAu} for 200 GeV collisions measured at 4 centralities. The line at $R_{dAu}=1$ indicates collision scaling. The grey band is the error in the estimation of N_{coll}. In the 0-20% centrality bin, a solid line indicates the nuclear modification factor for 200 GeV $Au+Au$ central events.

5. $d + Au$ Data

The "soft", or low p_t, part of the particle spectrum contains the bulk of the produced particles. The "hard" part of the produced particle spectrum covers $p_t \geq 2$ GeV/c. High p_t hadron production in $Au + Au$ collisions at $\sqrt{s_{NN}} = 130$ and 200 GeV was expected to scale with the number of binary nucleon-nucleon collisions, however, measurements show a violation of N_{coll} scaling[5]. This effect can be understood as a result of energy loss of high p_t partons in the hot, dense medium formed in the $Au + Au$ collisions. However, it is possible that this violation of collision scaling is a result of initial state effects in the Au nuclei. This initial state effect can be studied with a comparison to measurement of $d + Au$ collisions at the same energy.

The yield of particles produced in the collision $((2\pi p_t)^{-1} d^2N/d\eta dp_t)$ can be measured for events of different centralities as a function of p_t, giving particle spectra[3]. A Glauber model calculation including full detector simulation gives estimates for $\langle N_{part}\rangle$ and $\langle N_{coll}\rangle$ for the measured centralities. The nuclear modification factor, R_{dAu}, is calculated:

$$R_{dAu} = \frac{\sigma^{inel}_{p\overline{p}}}{\langle N_{coll}\rangle} \frac{d^2N_{dAu}/dp_T d\eta}{d^2\sigma(\mathrm{UA1})_{p\overline{p}}/dp_T d\eta}. \tag{1}$$

Figure 2b) shows R_{dAu} measured for four centralities in $d + Au$ collisions in PHOBOS. The solid line in the most central bin shows the shape for $Au + Au$ collisions relative to $p + \bar{p}$ collisions, the violation of N_{coll} scaling for $Au + Au$ at high p_t can be seen. The $d + Au$ nuclear modification factor, however, does not show suppression relative to N_{coll} scaling. This was also measured in the other RHIC experiments[6]. The measurements indicate that the suppression of high p_t hadrons in $Au + Au$ collisions is not due to initial state effects that would have been present in $d + Au$ collisions.

6. Conclusion

The PHOBOS experiment has measured particles produced in relativistic heavy ion collisions. Multiplicity measurements of the produced particles were made over a large range of pseudorapidites, $\langle N_{part}\rangle$, and collision energy. Comparison of PHOBOS $Au + Au$ data to e^+e^-, and $p + p$ with the leading particle effect removed shows what may be a universality in the scaling behavior of particle production. Comparing the nuclear modification factor in $Au + Au$ collisions to $d + Au$ collisions shows that $d + Au$ does not have suppression with respect to collision scaling at high p_t, indicating that the violation of scaling seen in $Au + Au$ is probably not due to initial state effects.

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