PHOBOS at RHIC 2000

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Abstract

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National laboratory delivered in June 2000 the first collisions between Au nuclei at the highest center-of-mass energies achieved in a in a controlled enviroment to date. PHOBOS is one of the four experiments installed during this phase of RHIC running. This paper will describe the PHOBOS experiment, and discuss the results of the first physics measurement, the pseudo rapidity densities of primary charged particles near mid rapidity in central Au + Au collisions at two different energies, $\sqrt{s_{NN}}$ = 56 and 130 GeV. The observed densities are higher than those previously observed in any collisions, and the rate of increase between the two energies is larger than that for nucleon-nucleon collisions at comparable beam energies. This talk will describe the PHOBOS experiment, discuss the first physics measurement, and conclude with the present status of the experiment, the physics analysis and the perspectives for the future.

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I. INTRODUCTION

The larger the density and the energy of the systems we observe the deeper we can look into nature. That has been the mantra of the experimental physicist. That is how the atom and the elementary particles were discovered and that is what has taken us to this point. In June 2001 RHIC will deliver collision between Au ions at $\sqrt{s_{NN}}$ = 200 GeV, the highest center of mass energies achieved in a controlled environment. The ultimate goal, to determine whether there are manifestations of the Quark Gluon Plasma (QGP).

The fundamental theory of strong interactions predicts that the QGP will be formed for systems at sufficiently high energy density [1]. The QGP was the state of matter about one micro-second after the Big Bang. In this state there are no boundaries between hadrons, and space is a conglomerate of free quarks and gluons. The challenge at RHIC is to isolate and reproduce the signatures of the formation of the QGP. Several measurements that may lead to the detection of the QGP have been proposed. Among them the systematic study of the global observables like transverse energy, and multiplicity and momentum spectra of produced particles may serve as a probe for the state of the hot hadronic matter [2]. For example, the formation of the QGP phase may lead to a change in shape of the pseudorapidity distribution of the produced charged particles.

PHOBOS is one of four experiments installed at RHIC for the first phase of running. In June 2001, RHIC delivered Au nuclei at center-of-mass energies of $\sqrt{s_{NN}} = 56$ and 130 GeV. In this talk I will present the first PHOBOS result from RHIC's early run: the measurement of charged particle multiplicity near mid rapidity in central Au-Au collisions. This measurement represents the first step toward the understanding of the heavy-ion reactions at RHIC energies and the search for signatures of the QGP.

II. THE EXPERIMENT

Since theory can provide only limited information about the heavy-ion collisions in RHIC's energy regime, PHOBOS was designed to examine these collisions in as unbiased a way as possible. To this end, PHOBOS is a detector with essentially 4π acceptance to measure the multiplicity of charged particles, a mid rapidity spectrometer and a simple, versatile and highly efficient trigger that provides a low bias selection of events. PHOBOS consists of several subsystems: the multiplicity and vertex array, with the broadest rapidity coverage at RHIC; a two-arm spectrometer, with the lowest transverse momentum acceptance at RHIC; the time-of-flight array; and the trigger detectors. Figure 1 is a drawing of the PHOBOS system.

The multiplicity and vertex array, as well and the spectrometer, are made of segmented silicon pads. Details of the setup and layout of the silicon sensors can be found in Ref. [4] for the multiplicity array and in Ref. [3] for the spectrometer. The trajectories of the particles produced in the collisions in the 2T magnetic field, are measured using the hit position in the highly segmented silicon sensors. In addition, the particle identification in the spectrometer is performed by measuring the energy deposited in the sensors (dE/dx), and their time of flight.

The multiplicity array is composed of single-layer silicon detectors that provides event-by-event measurement of charged particle multiplicity for pseudorapidity $|\eta| < 5$ and complete azimuthal coverage (where $\eta = -ln(tan(\theta/2))$, θ being the polar angle from the beam axis (z)). In addition, the vertex position is measured by two layers of silicon detectors named vertex detectors. The multiplicity detector consists of a barrel section, the "octagon", detector and forward ring detectors. The two arm spectrometer covers $0.5 \leq \eta \leq 1.5$ and 1% of 4π on either side of the beam pipe. Each arm of the spectrometer has a total of 14 planes of silicon. The spectrometer is placed between the poles of a magnet which provides a field of 2 T for the momentum measurement. It is expected that the spectrometer will reconstruct the tracks of about 1% of the produced charged particles in Au + Au collision at 200 AGeV.

The time-of-flight array (TOF) was designed to enhance the particle identification of the spectrometer. It consists of two walls of 240 scintillators sitting behind the spectrometer. The system is designed to have a timing resolution of 100ps, and will double the momentum region over which particles can be identified. A π/K separation up to 0.65 GeV/c and p/K separation up to 1.2 GeV/c is expected using the spectrometer alone. Including the time of flight the separation will be extended to π/K up to 1150MeV/c and p/K up to 1900MeV/c.

The trigger signals are provided by three sets of detectors, the "Cerenkov"counters, the "paddle" counters and the zero degree calorimeters. The Cerenkov counters are two sets of 16 Cerenkov radiators arranged in a ring around the beam pipe at $\eta = \pm 4.5$ to ± 4.8. These counters detect the occurrence of an interaction and will measure a crude vertex position in time for the level one trigger (ready 1 μs after the interaction). The Cerenkov counters will also provide the start signal for the time-of-flight system.

The paddle counters are the main source of the minimum bias trigger or level zero trigger (ready 380 ns after the interaction), they are also used to select and measure event centrality. The paddle counters are at $\eta = \pm 3.0$ to ± 4.5 and are two arrays of 16 scintillators forming a disk which encircles the beam line. The signals from the paddle counters used for triggering are the combination of total signal height (proportional to the number of particles), the timing information of the hits, and the number of scintillators fired.

Finally, the zero degree calorimeters (ZDC's) are also used for centrality selection and for the level one trigger. They are sampling hadron calorimeters sitting at both sides of the nominal interaction region (± 18 m). The ZDC measures the energy of the spectator neutrons emitted at $\theta \simeq 0$ degrees along both beam directions. The ZDC coincidence of 2 beam spectator neutrons is a minimal bias selection for heavy ion collisions. This make them useful as an event trigger and a luminosity monitor. For this reason, all 4 RHIC experiments have these detectors. They provide a "common" event characterization [5].

III. FIRST PHOBOS PHYSICS

Data taken with a partial installation of the detector described in Section II was used to extract the first physics result in the early period of the 2000 run. This measurement consisted of the pseudo rapidity densities of primary charged particles near mid rapidity in central Au + Au collisions at two different energies, $\sqrt{s_{NN}} = 56$ and 130 GeV [6]. The data presented are for the 6% most central collisions and $|\eta| < 1$. The results are presented in Table I, and the details of the setup, the analysis and the implications of the measurements are discussed in the following subsections.

A. The experimental conditions

For the initial running period of RHIC only a fraction of the PHOBOS system was installed. This configuration is shown in Fig. 2. The setup consisted of the first 6 planes of the silicon spectrometer (SPEC), part of the vertex detector (VTX) and one ladder of the octagon multiplicity detector. Figure 2 (inset) shows the acceptance of the silicon subdetectors as a function of the interaction point along z (the beam axis). For triggering and event selection the setup included the paddle counters (PP and PN) and the zero degree calorimeters (ZDCP and ZDCN).

B. Triggering and the event selection

The minimum bias trigger of PHOBOS selected events is based on the coincidence of at least one hit in any of the modules of both the positive (PP) and negative paddles (PN) within a time widow of 76 ns (the PP and PN gates were 38 ns each). This trigger selected the collision events as well as various forms of background. The background rejection was then achieved in either hardware (on line) or via software (off line).

The first condition for background rejection was requiring the paddle time difference to be less than 78 ns, eliminating the background that was not synchronized (within that time window) with the beams crossing. Another background cut was achieved by requiring that more than one module of each paddle counter was hit in coincidence, that is by requiring a coincidence between PP(n) and PN(n), where n is the numbers of modules that have fired in a given paddle counter. Finally, the sum of the currents from the pulses of each of the 16 modules can be discriminated at a certain level to produce the logic signals PP_{sum} and PN_{sum}, which in coincidence give a centrality trigger.

The paddles proved to be good tool to calculate the event centrality for physics analysis. The assumption underlying this statement is that the number of particles hitting the paddle counters in a collision increases monotonically with the increasing number of participants, which is a measure of the reaction centrality. As explained in detail in ref. [6], in order to select the 6% most central events the mean of the normalized ADC values of the individual modules of each of the paddles were used. In average, one mip from the collision will deposit about 1.7 MeV in the scintillators. Fluctuations in this energy may occur due to slow secondary particles that transverse the counters at large angles. To reduce this effect, instead of the average of the 16 modules, only the average pulse height of the 12 lowest signals from the 16 scintillators of each paddle were used to calculate the signal sums (PN_{12} and PP_{12}). Then the paddle mean sum $\frac{1}{2}(PN_{12}+PP_{12})$ was used as an observable proportional to the number of particles detected by the paddles, with the largest six percent of events in this sum representing the six percent most central events of the collision. Figure 3 shows the derived sum of the paddle signal distribution for events at $\sqrt{s} = 130$ A GeV. The centrality cut at 6 % of events with the largest paddle mean sum is shown as the shaded region.

Another event selection was performed by requiring the location of the interaction vertex to be in the region for which the VTX and SPEC detectors had a good acceptance. The distribution of the vertex positions was calculated with straight-line tracks found in at least 4 layers of the SPEC detector. The distribution of the collision vertices, which were determined by the beam orbit, was found to be very stable within each data set. The events were then confined to a distribution of vertex positions within 3 mm of the beam orbit in the transverse direction, and within -22 $< z_{vtx} <$ 15 cm longitudinally. Within the fiducial volume there were 103 central events for the low energy and 151 central events for the high energy data set.

C. Track counting and extraction of charged-particle density

For the final set of events, the counting of charged particles was performed using the SPEC and VTX subdetectors independently. Tracklets were defined as two hit (pads with a signal 5σ above threshold) combinations in consecutive layers of the SPEC or VTX subdetectors consistent with a track originating at the primary vertex. In addition, the tracklets had to satisfy a cut of $\sqrt{\delta\eta^2 + \delta\phi^2} < 0.015$ for the SPEC modules and $|\eta| < 1$ for the VTX detector. In order to study the inefficiencies in the sensors, the multiplicity of single hits in VTX and SPEC were compared to the number of tracklets and to the the number of tracks in the SPEC. No evidence of inefficiencies beyond 2% were found. This was consistent with the number of non-functioning readout channels (< 2% out of 20 k channels).

Monte Carlo studies show that the number of tracklets is proportional to the number of primary charged particles per event, where primary particles are defined as all charged hadrons produced in the collision, including the products of strong and electromagnetic decays, but excluding the products from weak decays and particles produced in secondary interactions (in material between collisions and sensors). HIJING [7] events were propagated through a the GEANT simulation of the experiment. The events from the simulation were then processed through the complete data chain, including the event selection based on the paddles. From the simulations $\alpha(z_{vtx})$ was calculated, where $\alpha(z_{vtx}) = dN/d\eta(\text{tracklets}) \, / \, dN/d\eta|_{|\eta|<1}$. For VTX it was found $\alpha(z_{vtx}) \approx 0.1$ and for SPEC $\alpha(z_{vtx}) \approx 0.06$. The dominant contribution to the value of α comes from the geometrical acceptance of the subdetectors, with the remaining corrections contributing only 10% of the value of alpha. Changing the event generator to VENUS [8], and varying the beam energy the gave a variation in α of less than $\pm 2.5\%$.

Figure 4 shows the comparison of the SPEC and VTX tracklet distributions for data and Monte Carlo events. The shapes of the two distributions agree quite well, confirming the good understanding of the detector geometry and tracklet inefficiencies. From the comparison between the numbers of tracklets found from the SPEC and VTX analysis, it is estimated that the overall systematic uncertainty is less than 8%. The main contribution to this number comes from the correction for combinatorial noise in the SPEC subdetector.

D. Results

The results of the analysis are showed in Table I and Fig. 5. In 5 are also plotted the normalized yield per participant, for proton-proton collisions [9], the central Pb+Pb collisions from the CERN SPS [10] and a HIJING simulation. The $dN/d\eta$ value for the Pb+Pb system was obtained by numerical integration of the momentum distributions of Ref. [10].

Several important features become manifest from the results. The central Au + Au collisions at RHIC have a significantly larger charged-particle multiplicity per participant than non-single diffractive $p\overline{p}$ collisions. This behavior rules out superposition models such as the wounded nucleon model [11], and is more compatible with predictions that include particle production via hard-scattering processes, like HIJING. The other feature that emerges from the data is that the normalized yields for nucleus-nucleus collisions rise significantly faster with beam energy than the increase shown by $p\overline{p}$ collisions. Finally comparing the data to those obtained at CERN SPS for Pb+Pb at $\sqrt{s_{NN}} = 17.8$ GeV, we find a 70% higher particle density per participant near $\eta = 0$ at $\sqrt{s_{NN}} = 130$ GeV. General arguments (Bjorken's estimate [12]) suggest that this increase should correspond to a similar increase in the maximal energy density achieved in the collision.

IV. PERSPECTIVES

For the second part of the run 2000, a full single arm configuration of PHOBOS was installed. Data were taken for the remainder of the run which lasted until the first week of September, and the physics results from this data will be ready for presentation in early 2001.

There are several physics topics that can be studied with PHOBOS. The multiplicity detector will allow to search for events with unusual particle distributions and to study event-by-event and global fluctuations. The spectrometer will enable the collaboration to study particle spectra, rations and correlations. Furthermore, we will be able look at all these physics topics as a function of global variables like the centrality or the reaction plane.

If the QGP is formed in RHIC collisions, PHOBOS is well siuted to find the signatures of this state of matter and provide a comprehensive study of heavy ions collision in this new physics field.

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TABLES

TABLE I. PHOBOS first physics results

Energy	$\sqrt{s_{NN}} = 56$ GeV	$\sqrt{s_{NN}} = 130$ GeV
$dN/d\eta$	408±12(stat)±30(syst)	555±12(stat) ±35(syst)
$dN/d\eta\|_{\|\eta\|<1}$ (per participant pair)	2.47±0.1(stat)±0.25(syst)	3.24±0.1(stat) ±0.21(syst)
Ratio (density per participant)		1.31±0.04(stat)±0.05 (syst)

FIGURES

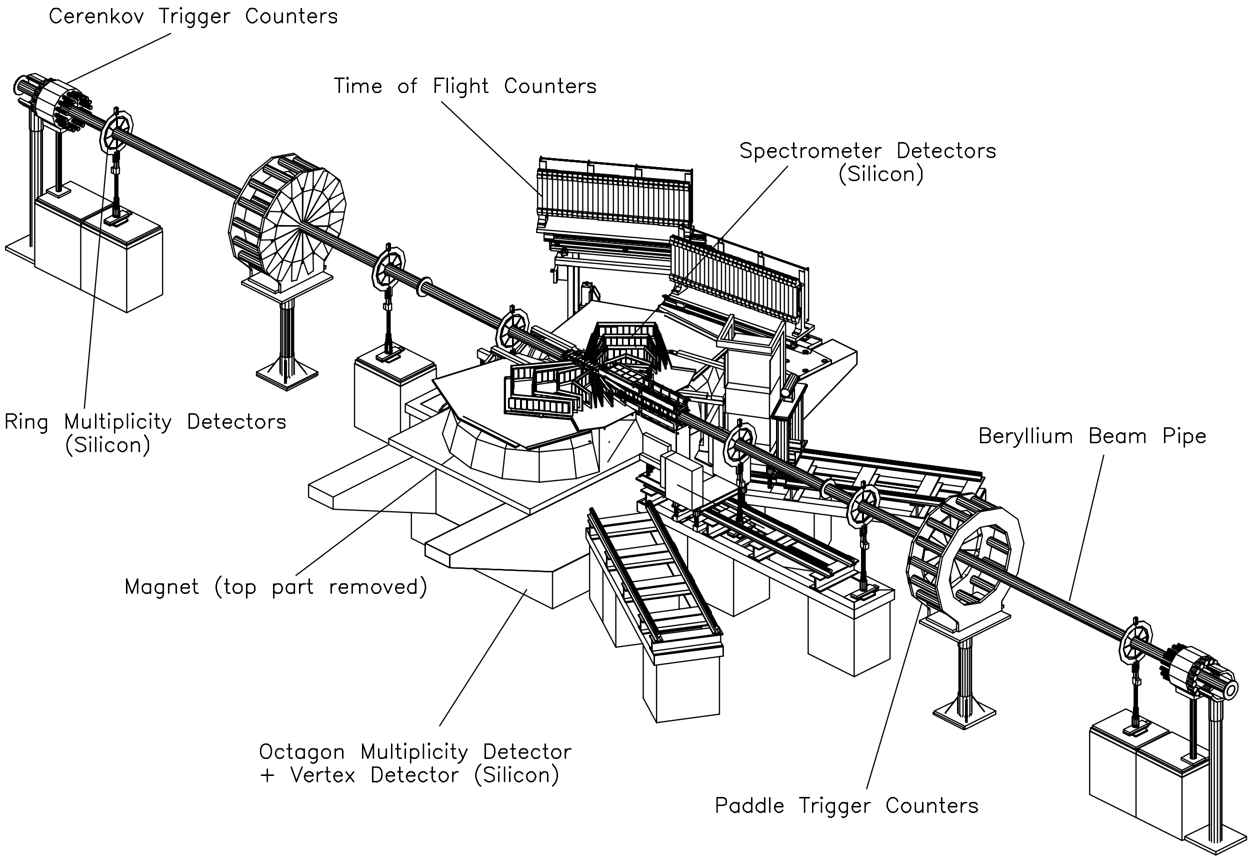

FIG. 1. The PHOBOS experiment. The multiplicity and vertex detectors, the spectrometer, time of flight and trigger counters. Only the lower half of the magnet is shown. As a reference for the scale the height of the paddle counters is about 1.7 m.

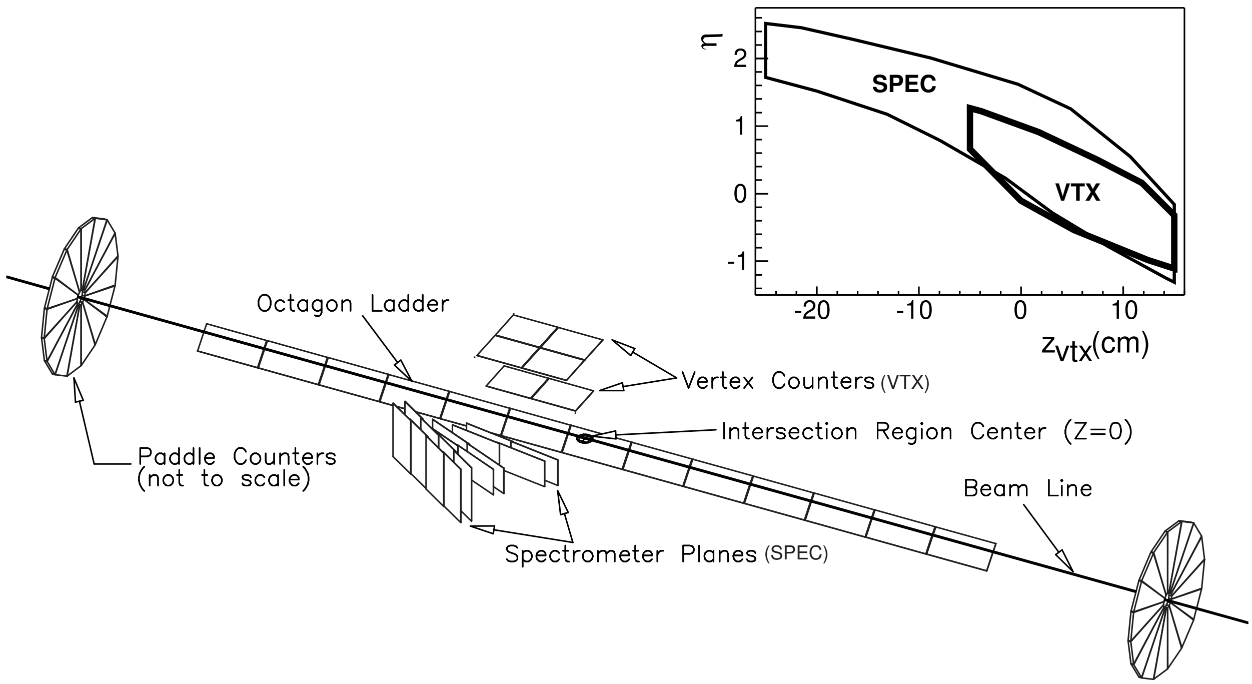

FIG. 2. Detector setup for the initial running period. The inset shows the η acceptance of the SPEC and VTX subdetectors as a function of the primary vertex position.

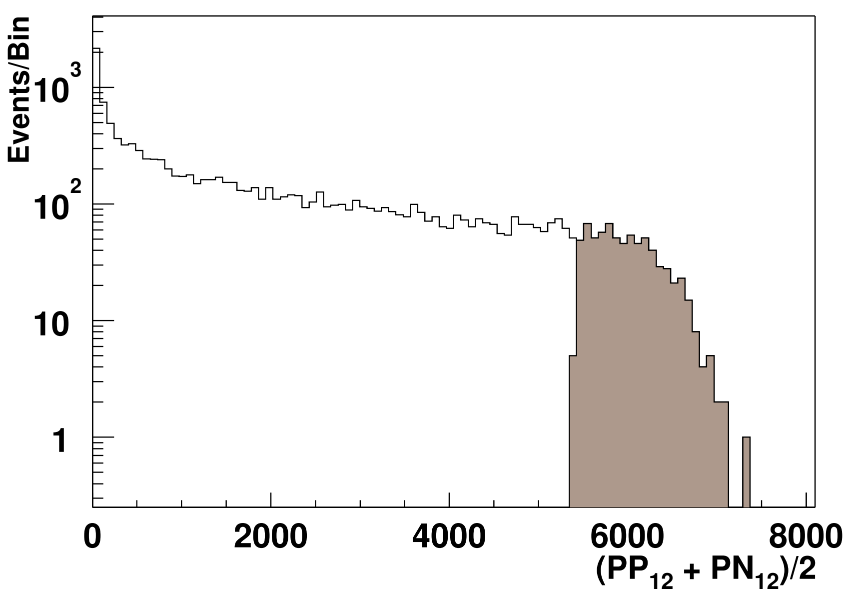

FIG. 3. Paddle signal distribution for events at $\sqrt{s} = 130$ AGeV. The shaded region corresponds to the spectra with the centrality cut at 6 % of events with the largest paddle mean sum.

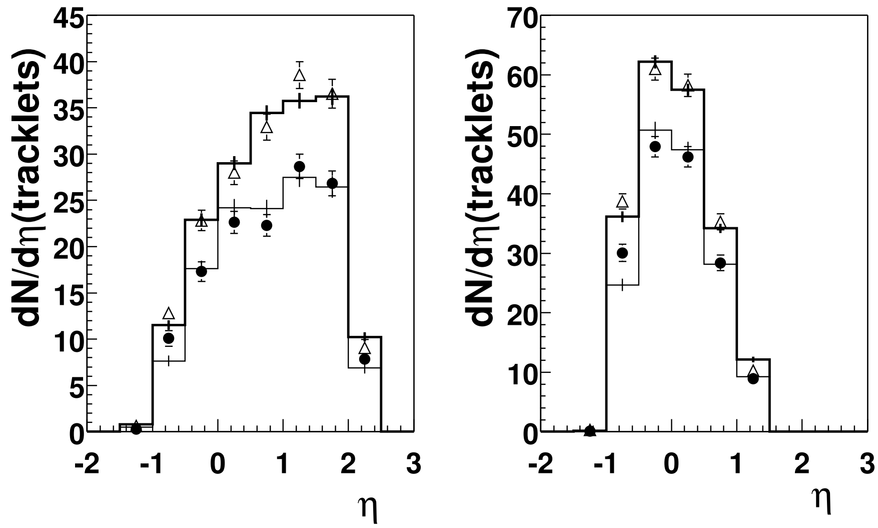

FIG. 4. Tracklet pseudorapidity density per event for data at $sqrts_NN = 56$ (circles) and 130 GeV (triangles). The tracklets for the SPEC are in the left panel, and for the VTX in the right panel. The solid lines are scaled to HIJING simulations (solid lines).

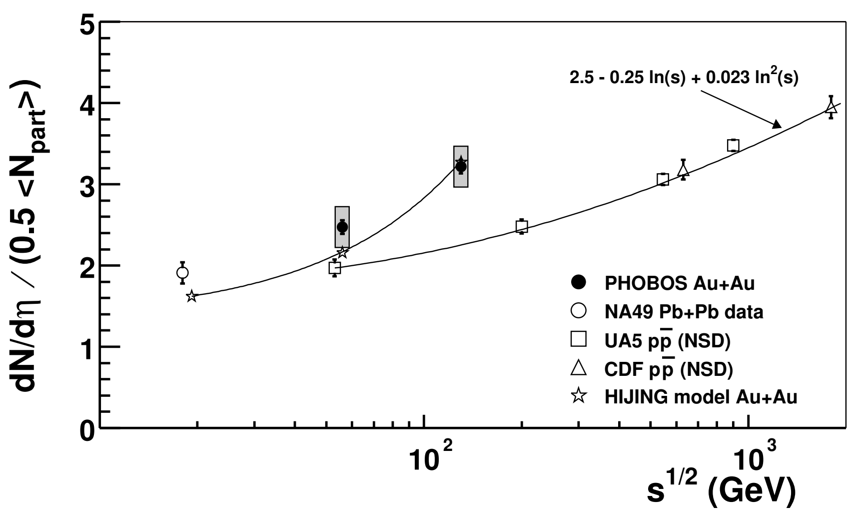

FIG. 5. Measured pseudorapidity density normalized per participant pair for central Au + Au collisions. Systematic errors are shown as shaded area. Data are compared with $p\overline{p}$ data in Pb + Pb data from the CERN SPS. Also shown are the results of a HIJING simulation (with a line to guide the eye) and the parameterization for the $p\overline{p}$ data.