FIRST RHIC PHYSICS RESULTS FROM THE PHOBOS EXPERIMENT

Jaw-Luen Tang
for the PHOBOS Collaboration
B.B.Back[1], M.D.Baker[2], D.S.Barton[2], R.R.Betts[1,6], R.Bindel[7], A.Budzanowski[3], W.Busza[4], A.Carroll[2], M.P.Decowski[4], E.Garcia[7], N.George[1], K.Gulbrandsen[4], S.Gushue[2], C.Halliwell[6], J.Hamblen[8] G.A.Heintzelman[2], C.Henderson[4], R.Hołyński[3], D.Hofman[6], B.Holzman[6], E.Johnson[8], J.Kane[4], J.Katzy[4,6], N. Khan[8], W.Kucewicz[3], P.Kulinich[4], W.T.Lin[5], S.Manly[8], D.McLeod[6], J.Michałowski[3], A.Mignerey[7], J.Mulmenstadt[4],R.Nouicer[6], A.Olszewski[2,3], R.Pak[2], I.C.Park[8], H.Pernegger[4], C.Reed[4], L.P.Remsberg[2], M.Reuter[6], C.Roland[4], G.Roland[4], L.Rosenberg[4], P.Sarin[4], P.Sawicki[3], W.Skulski[8], S.G.Steadman[4], G.S.F.Stephans[4], P.Steinberg[2], M.Stodulski[3], A.Sukhanov[2], J.-L.Tang[5], R.Teng[8], A.Trzupek[3], C.Vale[4], G.J.van Nieuwenhuizen[4], R.Verdier[4], B.Wadsworth[4], F.L.H.Wolfs[8], B.Wosiek[3], K.Woźniak[3], A.H.Wuosmaa[1], B.Wysłouch[4],

[1] *Physics Division, Argonne National Laboratory, Argonne, IL 60439-4843*
[2] *Chemistry Department, Brookhaven National Laboratory, Upton, NY 11973-5000*
[3] *Institute of Nuclear Physics, Kraków, Poland*
[4] *Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA 02139-4307*
[5] *Department of Physics, National Central University, Chung-Li, Taiwan*
[6] *Department of Physics, University of Illinois at Chicago, Chicago, IL 60607-7059*
[7] *Department of Chemistry, University of Maryland, College Park, MD 20742*
[8] *Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627*

Abstract

In June 2000, the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) delivered the first Au+Au collisions at the highest center of mass energies achieved in the laboratory to date. This new energy regime is expected to produce unprecedented conditions of high energy density. PHOBOS is one of four experiments installed during this RHIC running phase. The ultimate goal of PHOBOS is to study systematically the collective behavior of strongly interacting matter under conditions of extreme density and temperature. The data taken from the beginning of the running period was used to obtain the first physics information about this exciting new energy regime of nuclear matter, namely a measurement of the pseudorapidity densities of primary charged particles near mid-rapidity in central Au+Au collisions at $\sqrt{s_{NN}} = 56$ and 130 GeV. The observed values are higher than previously measured in any nuclear collisions in the laboratory. In addition, our data show that the rate of increase in pseudorapidity density between the two energies is significantly steeper than that for nucleon-nucleon collisions at comparable center-of-mass energies.

In this talk we will briefly describe the PHOBOS experiment, discuss the first results of the physics measurement, and conclude with the prospects for the future.

1 Introduction

The Relativistic Heavy-Ion Collider at Brookhaven National Laboratory started providing beams in June 2000, opening a new horizon to explore highly excited nuclear matter under extreme conditions of energy density. This early running delivered the first collisions between Au nuclei at center of mass energies of $\sqrt{s_{NN}} = 56$ and 130 GeV, both of which are higher than any previously achieved under controlled laboratory experiments. Quantum chromodynamics (QCD), the fundamental theory of strong interactions, predicts that at sufficiently high temperatures or baryon density one or more phase transitions will lead to the formation of a quark-gluon plasma (QGP) [1] characterized by deconfinement, and perhaps chiral symmetry restoration. Several possible signals have been proposed for the discovery of such novel state of matter, but an unambiguous proof of its existence has not yet been achieved. The primary goals of the RHIC facility is to create and study this deconfined state.

Signals of the formation of a QGP depends on the initial conditions of the dense matter created at the early stage of heavy-ion collisions. The charged particle density at mid-rapidity, one of the global observables for high-energy collisions, provides information on those initial conditions as it is expected to be proportional to the initial energy density of the system. Studying the dependence of charged particle densities on energy and system size provides information on the interplay between hard parton-parton scattering processes, which can be calculated using perturbative QCD, and soft processes, which are treated by phenomenological models that describe the non-perturbative sector of QCD. Surprisingly, predictions of this quantity obtained from a variety of models typically vary by up to a factor of two [2].

PHOBOS is one of the four experiments installed during the early period of the running. The aim of PHOBOS is to study systematically the collective behavior of hadronic matter under conditions of extreme energy density. Data collected with a sub-set of the full detector setup was used to obtain the first physics information in this new regime of nuclear matter. In this paper, we report on the first data on pseudorapidity density, $dN/d\eta$, of charged particles near mid-rapidity in Au+Au reactions at energies of $\sqrt{s_{NN}} = 56$ and 130 GeV as measured with the PHOBOS detector.

2 Experimental Setup

The PHOBOS detector consists of a $\sim 4\pi$ multiplicity array, vertex detectors, two multi-particle tracking spectrometers, a set of plastic scintillator time-of-flight walls , and trigger detectors. The experiment makes heavy use of silicon pad detectors for charged particle detection. With their good position resolution, low multiple scattering and good energy loss resolution, the silicon pad detectors have been employed to perform tracking, vertex finding and multiplicity measurements. Details of the setup and the layout of the silicon sensors can be found elsewhere [3, 4]. During the initial running period at RHIC only a small fraction of the full setup was installed around the interaction region. This commissioning run configuration is shown in Fig. 1. It consists of the first 6 layers of the silicon spectrometer (SPEC), part of the two-layer silicon vertex detector (VTX) and one ladder of the large acceptance Octagon multiplicity detector. The present data analysis involved only data from SPEC and VTX, whose rapidity acceptance covering $-1 < \eta < 2.5$, is shown in the insert in Fig. 1. The strong dependence on the vertex position (z_{vtx}), along the beam-line allows us to check Monte Carlo calculation of the acceptance and backgrounds by studying the stability of our results as a function of z_{vtx}.

The trigger system consists of two sets of 16 scintillator counters ("paddle counters") located at distances of -3.21 m (PN) and 3.21 m (PP) from the nominal interaction point along the beam (z) axis. These detectors served as the event trigger and were used for event selection. They subtended pseudorapidities of $3 < |\eta| < 4.5$. Two zero-degree calorimeters (ZDCP,ZDCN) at $z = \pm 18.5$ m provided additional information for event selection by measuring the energy deposited by spectator neutrons; a feature common to

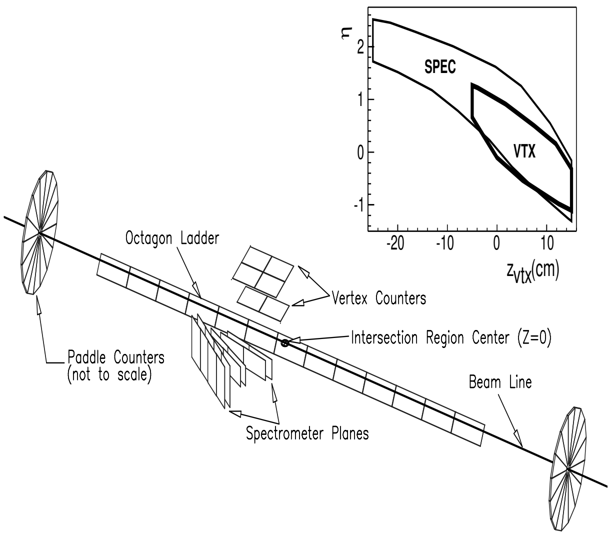

Figure 1: Detector setup for the initial running period. The insert shows the η acceptance of the SPEC and VTX subdetectors as a function of primary vertex position.

all four experiments at RHIC. These were used in some of the off-line data analysis.

3 Data Analysis and Results

The data analysis consists of three steps; triggering and event selection, tracklet analysis and charged particle density reconstruction. Only the 6% most central events were studied in this analysis. These were selected on the basis of the energy signal in the paddle counters. In addition, it was required that the event vertex fell in the region $-25\ cm < z_{vtx} < 15\ cm$, see Fig. 1. Particle "tracklets" were constructed by selecting hit combinations in two Si detector layers, which pointed back to the vertex position. Results of the Monte Carlo (MC) simulations are used to extract the primary charged particle density from the tracklet analysis. Monte Carlo simulations of detector performance were carried out using the HIJING [5] model and propagating the event through GEANT 3.21 package, folding in signal response for scintillator counters and silicon sensors with the measured electronic noise.

3.1 Triggering and Event Selection

The PHOBOS readout system uses minimum bias trigger which selects events based on the coincidence of at least one hit in both paddle counters (PP and PN) within a maximum time window of 38 ns. Simulations indicate that this condition selected most collision events (90%) as well as various backgrounds.

The background rejection was achieved in either hardware (on-line) or software (off-line) levels. The first condition of background rejection required the paddle time difference to be less than 8 ns, corresponding to a maximum displacement of roughly ±120 cm relative to $z = 0$. Additional background reduction can be achieved by selecting the ZDC time difference to be less than 20 ns. Since the ZDCs detect only spectator neutrons, they are slightly inefficient for the most central events. To avoid losses due to this effect, we accepted events with good ZDC timing or high multiplicity in the paddles or both. Backgrounds

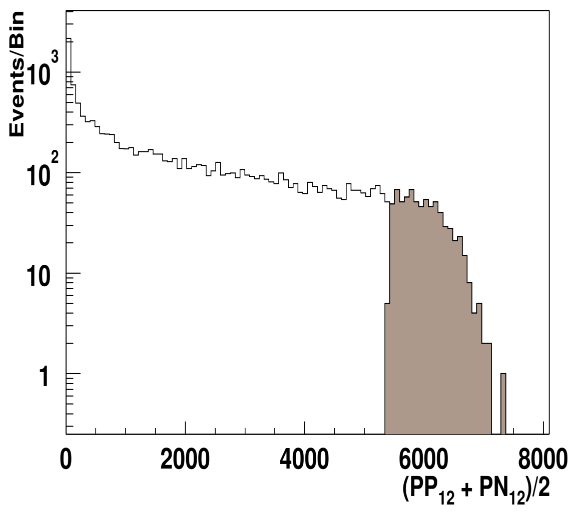

Figure 2: Paddle signal distribution for data events at $\sqrt{s_{NN}} = 130$ GeV.

from double-beam, beam-gas, beam-halo or other effects were studied using data where the beams did not collide. The overall background component was extremely low (less than 1% of all events) and none of these events had sufficiently large signals in both paddle counters to be mis-identified as central events.

The final step in the event selection was to restrict the location of the collision vertex to be in the region where the VTX and SPEC detectors had good acceptance (see Fig. 1). The distribution of the interaction vertices was found to be very stable within each run. The events used in this analysis were restricted to a distribution of vertex positions within 3 mm of the beam orbit in the transverse direction, and within $-25 < z_{vtx} < 15$ cm longitudinally. For central events in this region, Monte Carlo simulations show that the efficiency of the vertex finding algorithm is $> 99\%$. For a sample of 382 and 724 events satisfying the 6 % cut, we found a total of 103 central events for the low energy and 151 central events for the high energy data set.

3.2 Tracklet Analysis

For each of the selected events, the reconstruction of charged multiplicity was carried out using hits in either the VTX or SPEC subdetectors independently. The analysis was done by counting tracklets, which are two hit combinations in consecutive layers of detectors consistent with a track originating at the common vertex. For any two hits to be accepted as tracklets the difference of two hit locations in η and ϕ relative to the vertex was required to satisfy $\sqrt{\delta\eta^2 + \delta\phi^2} < 0.015$ in the SPEC subdetector and $|\delta\eta| < 0.1$ in the VTX subdetector, where ϕ is the azimuthal angle in radians.

The effect of inefficiencies in the detectors were studied by comparing the numbers of single hits in VTX and SPEC, two-hit tracklets in SPEC and VTX and tracks in SPEC. No evidence of inefficiencies beyond 2% were found. The results are consistent with the number of dead channels ($< 2\%$) found in our standard calibration procedure. The use of tracklets, rather than individual hits significantly reduced fluctuations and systematic uncertainties due to various background and secondaries.

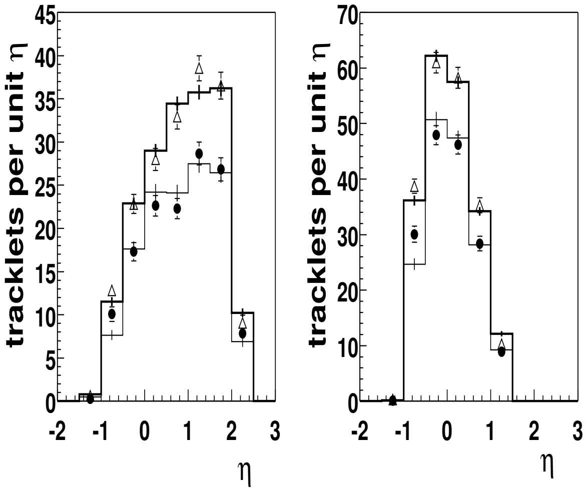

Figure 3: Distribution of tracklets per event within the detector acceptance for data at $\sqrt{s_{NN}} = 56$ (circles) and 130 GeV (triangles) for SPEC (left) and VTX (right), in comparison to scaled HIJING simulations (solid lines).

3.3 Charged Particle Density Reconstruction

Monte Carlo studies indicate that the number of tracklets per event near $\eta = 0$ is approximately proportional to the number of primary charged particles produced per event. Therefore, the final step in this analysis was to determine the vertex dependent proportionality factor $\alpha(z_{vtx})$, which is defined as the ratio of the number of observed tracklets to the number of emitted charged particles in a Monte Carlo simulation, namely $\langle N_{tracklets}/N_{primaries}\rangle$. Primary particles are all charged hadrons produced in the collisions, including the products of strong and electromagnetic decays, but excluding feed-down products from weak decays and hadrons produced in secondary interactions.

The well known geometrical acceptance of the sub-detectors is the main factor determining the value of $\alpha(z_{vtx})$. Further corrections for inefficiencies and combinatorial background are less than 10%. Monte Carlo studies showed that less than 5% of the particles emitted into the angular acceptance of the SPEC and VTX detectors stop in the material of the beam pipe or the first detector layer. The contribution from the contamination of the tracklet distribution by feed-down products from weak decays of strange particles was found to be small ($< 4\%$). All of these corrections were studied and accounted for using the GEANT simulation of the detector and processing Monte Carlo events through the identical analysis chain in the real data, including the event selection based on the energy deposition in the paddle detectors. Using these simulation results, we could extract the correction factors $\alpha(z_{vtx})$ as a function of z_{vtx}. For VTX we found $\alpha(z_{vtx}) \approx 0.1$ and for SPEC $\alpha(z_{vtx}) \approx 0.06$.

As a further cross-check we repeated the correction procedure using the VENUS [6] event generator and by using $\alpha(z_{vtx})$ obtained from running the event generators at different energies. By comparing the different Monte Carlo simulations we found that the value of α agreed to within $\pm 2.5\%$, demonstrating that the tracklet counting procedure provides a robust measure of the primary charged particle pseudorapidity density.

Fig. 3 shows a direct comparison of the SPEC (left) and VTX (right) tracklet distributions for data (symbols) and Monte Carlo events (solid lines), normalized per event. The

Monte Carlo curves have been scaled by factors of 1.15 for $\sqrt{s_{NN}} = 56$ GeV and 0.98 for $\sqrt{s_{NN}} = 130$ GeV, respectively, in order to match the integrals to the data. The scaling factor was found to be consistent for SPEC and VTX. The shape of the distribution agrees well between simulation and data, confirming our understanding of detector geometry and tracklet efficiency. Based on Monte Carlo simulations, we estimate the overall systematic uncertainty to be less than 8%. The largest source of systematic uncertainty comes from the combinatorial noise in the SPEC subdetector.

3.4 Results

Applying the proportionality factor to the measured tracklet distributions we obtain a primary charged particle density of $dN/d\eta|_{|\eta|<1} = 408 \pm 12(\mathrm{stat}) \pm 30(\mathrm{syst})$ for $\sqrt{s_{NN}} = 56$ GeV and $555 \pm 12(\mathrm{stat}) \pm 35(\mathrm{syst})$ at $\sqrt{s_{NN}} = 130$ GeV. From Monte Carlo simulation of the paddle counter selection we deduce that the mean number of participating nucleons is $\langle N_{part}\rangle = 330 \pm 4(\mathrm{stat})^{+10}_{-15}(\mathrm{syst})$ for $\sqrt{s_{NN}} = 56$ GeV and $343 \pm 4(\mathrm{stat})^{+7}_{-14}(\mathrm{syst})$ for $\sqrt{s_{NN}} = 130$ GeV.

Normalizing to participant pair, we obtain $dN/d\eta|_{|\eta|<1}/0.5\langle N_{part}\rangle = 2.47 \pm 0.1(\mathrm{stat}) \pm 0.25(\mathrm{syst})$ and $3.24 \pm 0.1(\mathrm{stat}) \pm 0.25(\mathrm{syst})$, respectively. Finally, taking the strong correlation between the systematic errors at the two energies into account, we obtain an increase in the charged particle density per participant pair by a factor of $1.31 \pm 0.04(\mathrm{stat}) \pm 0.05(\mathrm{syst})$ from 56 to 130 GeV.

In Fig. 4 the normalized yield per participant pair obtained in the present analysis of Au+Au collisions is compared to proton-antiproton ($p\overline{p}$) collisions [7] from CERN and Fermilab and central Pb+Pb collisions at the CERN SPS [8]. The $dN/d\eta$ value for the Pb+Pb data was obtained by numerically integrating the momentum distributions shown in [8].

Several important features of the results emerge: First, the central Au+Au collisions yield a significantly larger charged multiplicity per participant nucleon than non-single diffractive (NSD) $p\overline{p}$ collisions at comparable energies. This rules out simple superposition models such as the wounded nucleon model [9] and is compatible with predictions of models like HIJING that include particle production via hard-scattering processes. Secondly, the normalized yield rise significantly faster with beam energy, (an increase by 31% from 56 to 130 GeV) in nucleus-nucleus than in nucleon-nucleon reactions. Finally, comparing our data to those obtained at the CERN SPS for Pb+Pb collisions at $\sqrt{s} = 17.8$ AGeV, we found a 70% higher particle density per participant pair near $\eta = 0$ at $\sqrt{s_{NN}} = 130$ GeV. General arguments (c.f. Bjorken's estimate [10]) suggest that this increase should correspond to a similar increase in the maximal energy density achieved in the collision.

4 Future Prospects

During the shutdown in July 2000, the Year-1 PHOBOS physics setup was installed and used for the remainder of the run, which ended at the first week of September 2000. This consists of the full multiplicity array, vertex detectors, two Time-of-Fight walls, one full instrumented spectrometer arm and one partially populated arm. The remainder of the second arm will be installed in the spring of 2001, which will complete the fully proposed PHOBOS configuration.

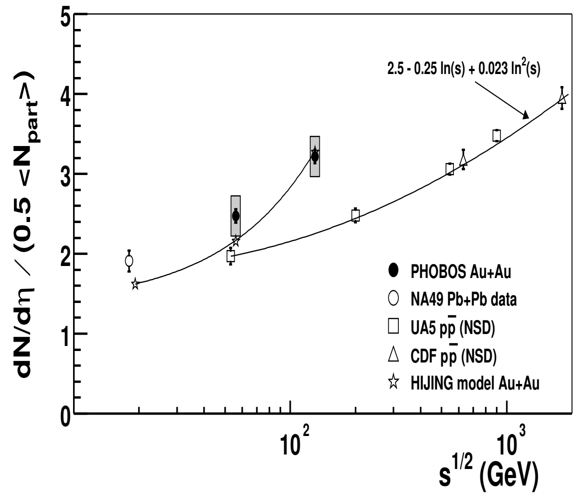

Figure 4: Measured pseudorapidity density normalized per participant pair for central Au+Au collisions. Systematic errors are shown as shaded area. Data are compared with $p\overline{p}$ data and Pb+Pb data from the CERN SPS. Also shown are results of a HIJING simulation (with a line to guide the eye) and a parametrization of the $p\overline{p}$ data [7].

The analysis of data taken from the first run is still ongoing. Several interesting aspects of relativistic heavy ion collisions can be studied using various PHOBOS detectors and the results will be available in early 2001. The multiplicity detectors, covering a wide range of rapidity and azimuthal angle, will search for events with unusual charged particle distribution, including both global and local event-by-event fluctuations. In particular, the centrality dependence of the charged particle density allows one to discriminate among various models of particle production and to verify the possible gluon saturation at RHIC energies. The data taken with the two-arm magnetic spectrometer will study charged particle spectra, ratios and correlations. The design of the spectrometer has been optimized to allow the tracking of particles emitted near mid-rapidity with very low transverse momentum. These particles should be sensitive to changes in physics over large volumes. One very interesting measurement is the ratio of baryon to antibaryon which plays a key role in understanding the properties of the hot and dense nuclear matter formed at high energies. Such an analysis will provide first means to test various baryon transport mechanisms at RHIC energies.

5 Conclusion

In conclusion, we have presented the first data of charged multiplicity at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}} = 56$ and 130 GeV. For the most central collisions, the energy dependence of measured charged multiplicity per participant pair was shown to be enhanced relative to pp collisions. Our results provide the first means to constraint various models of multiparticle production in heavy-ion collisions at RHIC energies and thus represent an initial step in the proper prediction or description of other observables.

Using the various detectors, PHOBOS will be able to study the characteristics of global observables at RHIC such as the charged particle multiplicity produced in the collisions over a wide range of conditions. Other quantities such as the temperature, size and density of the fireball produced in the collisions could also be measured. PHOBOS will also study the ratios of the various particles produced. With the unique configuration of the PHOBOS detector and the capability of RHIC to collide a variety of projectiles over a broad energy range, PHOBOS is well equipped to yield a comprehensive study of matter in this new energy frontier and to study a phase transition that might occur between QGP and ordinary nuclear matter.

Acknowledgements

We acknowledge the generous support of the entire RHIC project personnel, C-A and Chemistry Departments at BNL. We thank Fermilab and CERN for help in silicon detector assembly. We thank the MIT School of Science and LNS for financial support. This work was partially supported by US DoE grants DE-AC02-98CH10886, DE-FG02-93ER40802, DE-FC02-94ER40818, DE-FG02-94ER40865, DE-FG02-99ER41099, W-31-109-ENG-38. NSF grants 9603486, 9722606 and 0072204. The Polish groups were partially supported by KBN grant 2 P03B 04916. The NCU group was partially supported by NSC of Taiwan under contract NSC 89-2112-M-008-024.

References

[1] J.P.Blaizot, Nucl. Phys. **A661** (1999) 3.

[2] Proceedings of the 14th Quark Matter conference, Nucl. Phys. **A661** (1999)

[3] B.Back et al., Nucl. Phys. **A661** (1999) 690.

[4] H.Pernegger et al. Nucl. Instrum. Methods. **A419** (1998) 549.

[5] M.Gyulassy and X.N.Wang, Phys. Rev. **D44** (1991) 3501. We used HIJING V1.35 (April 1998) with standard parameter settings.

[6] K.Werner, Phys. Rep. **232** (1993) 87.

[7] F.Abe et al., Phys. Rev. **D41** (1990) 2330.

[8] J.Bächler et al., Nucl. Phys. **A661** (1999) 45.

[9] A.Białas, B.Bleszyński and W.Czyż, Nucl. Phys. **B111** (1976) 461.

[10] J.D.Bjorken, Phys. Rev. **D27** (1983) 140.