First Results from the PHOBOS Experiment at RHIC

Christof Roland for the PHOBOS Collaboration

B.B.Back[1], M.D.Baker[2], D.S.Barton[2], R.R.Betts[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], G.A.Heintzelman[2], C.Henderson[4], R.Hołyński[3], D.J.Hofman[6], B.Holzman[6], E.Johnson[8], J.L.Kane[4], J.Katzy[4], N. Khan[8], W.Kucewicz[6], P.Kulinich[4], W.T.Lin[5], S.Manly[8], D.McLeod[6], J.Michałowski[3], A.C.Mignerey[7], J.Mülmenstädt[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 and C-A Departments, 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

PHOBOS is one of four experiments studying Au-Au collisions at RHIC. During the first running period RHIC provided Au+Au collisions at $\sqrt{s_{NN}}$ = 56 GeV and 130 GeV. The data collected during this period allowed us to study the energy and centrality dependence of particle production, the anisotropy of the final state azimuthal distribution and particle ratios at mid-rapidity.

1 Introduction

In June 2000, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory delivered the first collisions of gold nuclei at center of mass energies several times larger than that previously available at other accelerators. The main goal of the RHIC research program is to study the behavior of strongly interacting matter under conditions of extreme temperatures and energy densities satisfying the prerequisites predicted for the creation of the Quark Gluon Plasma (QGP).

2 Experimental setup and event selection

The PHOBOS detector employs multiple arrays of silicon pad detectors to perform track reconstruction, vertex detection and multiplicity measurements. The main components are: a single layer multiplicity detector which covers the pseudo-rapidity range $|\eta| < 5.4$ with nearly complete azimuthal coverage, a two-layer vertex detector covering $|\eta| < 1.5$ and a magnetic spectrometer

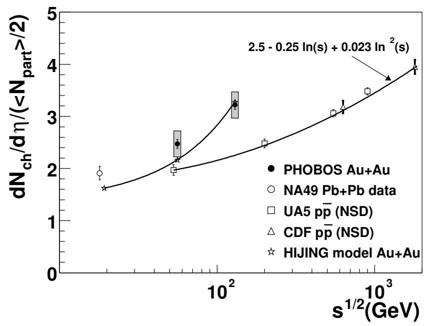

Figure 1: Measured pseudorapidity density normalized per participant pair for central Au+Au collisions. Systematic errors are shown as shaded areas. Also shown are results of Pb+Pb data (CERN SPS), HIJING[11] simulations and a parametrization of $p\overline{p}$ data.

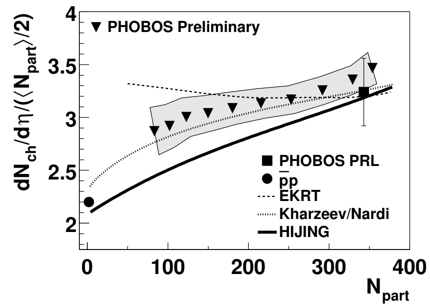

Figure 2: Normalized pseudorapidity density $dN_{ch}/d\eta|_{|\eta|<1}/(0.5 \times N_{part})$ as a function of the number of participants. The solid square is from Ref.[1]. Theoretical calculations are shown from HIJING[7] (solid line), KN[8] (dotted curve) and EKRT[9] (dashed curve).

with 16 layers providing momentum measurement and particle identification near mid-rapidity. Details of the experimental arrangement are described in [1,2].

The primary event trigger was provided by two sets of 16 scintillator paddle counters which detected charged particles in the pseudorapidity range $3 < |\eta| < 4.5$. The paddle counters were also used for offline event selection and determination of the collision centrality. Details of this procedure can be found in [3].

3 Results

Multiplicity and charged particle density. The first observable studied was the energy dependence of the charged particle pseudo-rapidity density near mid-rapidity for central collisions, $dN_{ch}/d\eta|_{|\eta|<1}$. The measurement is described in detail in [4]. We observed a primary charged particle density of $dN_{ch}/d\eta|_{|\eta|<1} = 408 \pm 12(\text{stat}) \pm 30(\text{syst})$ at $\sqrt{s_{NN}} = 56$ GeV and $555 \pm 12(\text{stat}) \pm 35(\text{syst})$ at $\sqrt{s_{NN}} = 130$ GeV. Normalizing per participant pair, we deduce $dN_{ch}/d\eta|_{|\eta|<1}/(0.5 \times N_{part}) = 2.47 \pm 0.1(\text{stat}) \pm 0.25(\text{syst})$ and $3.24 \pm 0.1(\text{stat}) \pm 0.25(\text{syst})$, respectively. The data were corrected for backgrounds from decay feed-down, secondary interactions, stopping particles in the beampipe and detector inefficiencies using Monte Carlo simulations of our apparatus. The normalized yield per participant obtained for Au+Au collisions, proton-antiproton ($p\overline{p}$) collisions [5] and central Pb+Pb collisions [6] are presented in Fig. 1. Central Au+Au collisions show a significantly larger charged particle density per participant than non-single diffractive (NSD) $p\overline{p}$ collisions at comparable energies. The observed 31% increase of density from 56 to 130 GeV in central Au+Au collisions is significantly larger than the increase for $p\overline{p}$ data in the same energy interval [5]. Comparing our data to those obtained at the CERN SPS for Pb+Pb collisions at $\sqrt{s_{NN}} = 17.2$ GeV, we find a 70% higher charged particle density per participant near $\eta = 0$ at $\sqrt{s_{NN}} = 130$ GeV. The dependence of the charged particle density $dN_{ch}/d\eta|_{|\eta|<1}$ on event centrality together with theoretical predictions [7,8,9] are shown in Fig. 2.

Further information on the underlying physics can be obtained by studying the change in particle production over a wider range in η. We performed this measurement using the PHOBOS multiplicity detector, consisting of the Octagon barrel covering $|\eta| \leq 3.2$ and the Ring counters detecting particles with $3 \leq |\eta| \leq 5.4$. Details of the hit-counting procedure and the background correction can be found in [10]. For the most central 3% of the collisions we find an average number of charged particles of $4100 \pm 100(\text{stat}) \pm 400(\text{syst})$ within $|\eta| < 5.4$.

The measured $dN_{ch}/d\eta$ distributions scaled by $0.5 \times N_{part}$ for three selected centrality bins are shown in Fig. 3a. For comparison, the predictions of HIJING [11] appear in Fig. 3b. At

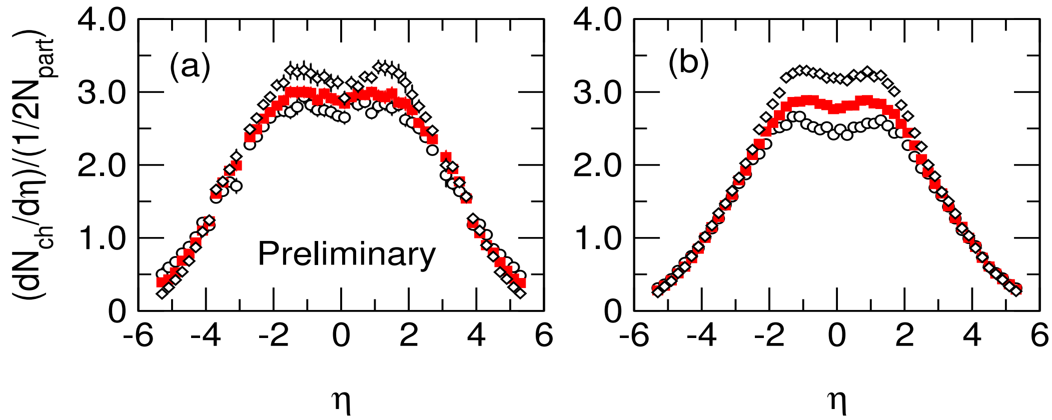

Figure 3: (a). Measured $dN_{ch}/d\eta/(\langle N_{part}\rangle/2)$ for $\langle N_{part}\rangle$=102 (circles), 216 (squares) and 354 (diamonds). We estimate a systematic uncertainty of 10% independent of η. (b). Same as (a) from HIJING.

midrapidity, the non-central data are higher than the predictions. Both data and HIJING show that the bulk of additional particle production in central collisions, as compared to peripheral ones, occurs near mid-rapidity. The central plateau observed in the data is significantly wider than the HIJING prediction.

Event Anisotropy. The momentum space anisotropy, which is a reflection of the initial-state space anisotropy for non-central collisions, is commonly quantified by the first and second Fourier coefficients of the azimuthal particle distribution relative to the event-by-event reaction plane, $dN/d(\phi - \Psi_R) = N_0(1 + \sum_i 2v_i \cos[i(\phi - \Psi_R)])$, where Ψ_R is the reaction plane angle. Usually, the first Fourier component (v_1) is referred to as directed flow and the second one (v_2) as elliptic flow.

In PHOBOS, the elliptic flow was calculated from the azimuthal distribution of hits in the Octagon detector. For every event the event plane was determined by a fit to the azimuthal hit distribution. The observed raw value of v_2 was corrected for the effects of detector granularity, the resolution of the event-by-event determination of the event plane relative to the true reaction plane and the contribution of background hits. Details of the analysis can be found in [12].

We determined v_2 for events in seven classes of centrality based on the normalized paddle signal. We observed a strong centrality dependence of v_2 ranging from 0.03 for the most central events up to 0.07 for peripheral events (Fig. 4). We have also studied the pseudorapidity dependence of v_2 over a large range in centrality (Fig. 5). Outside of the central pseudorapidity region, i.e. $|\eta| > 1$, v_2 drops very quickly, approximately following the shape of the charged particle distribution (see Fig. 3).

Particle ratios. The ratio of antibaryons to baryons plays a key role in understanding the properties of the hot and dense system formed in heavy-ion collisions at high energies. Using the mid-rapidity spectrometer, we have studied the ratios of multiplicities of particles and antiparticles for primary charged pions, kaons and protons at $\sqrt{s_{NN}} = 130$ GeV.

The particle ratios were measured for the 12% most central events, for which we estimate $\langle N_{part}\rangle = 312 \pm 10$(syst). As the geometrical layout of the PHOBOS detector leads to an asymmetry in the acceptance and detection efficiency for positively and negatively charged particles in the same events, we used data taken with both polarities of the PHOBOS magnet. The most important systematic effects such as geometrical acceptance and tracking efficiency cancel in the ratio. The raw particle ratios are corrected for particle decays, secondary interactions and the contribution from feed-down of strange hadrons. Further details can be found in [13]. Within our acceptance we find the following ratios:

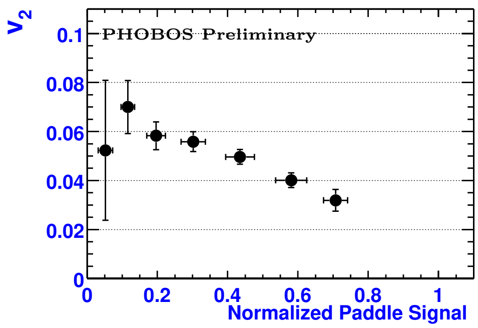

Figure 4: Elliptic Flow v_2, in the region -1.0< η <1.0 as a function of normalized paddle signal. The error bars are statistical only. The estimated systematic error is $\Delta v_2 = 0.007$.

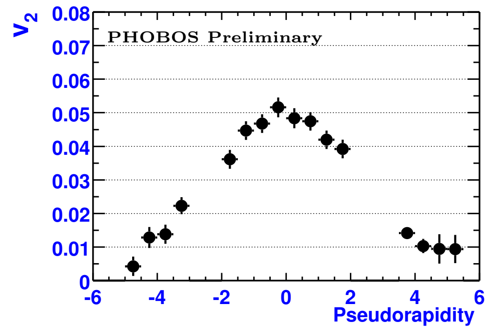

Figure 5: Elliptic Flow v_2, averaged over centrality, as a function of pseudorapidity η. The error bars are statistical only. The estimated systematic error is $\Delta v_2 = 0.007$.

$$
\begin{aligned}
\langle \pi^- \rangle / \langle \pi^+ \rangle &= 1.00 \pm 0.01(\text{stat}) \pm 0.02(\text{syst}) \\
\langle K^- \rangle / \langle K^+ \rangle &= 0.91 \pm 0.07(\text{stat}) \pm 0.06(\text{syst}) \\
\langle \overline{p} \rangle / \langle p \rangle &= 0.60 \pm 0.04(\text{stat}) \pm 0.06(\text{syst})
\end{aligned}
$$

We estimated a baryo-chemical potential μ_B from the $\langle K^- \rangle / \langle K^+ \rangle$ and $\langle \overline{p} \rangle / \langle p \rangle$ ratios, using a statistical model calculation [14]. For a realistic range of freeze-out temperatures of 160 to 170 MeV, both ratios are consistent with $\mu_B = 45 \pm 5$ MeV. This value is much lower than $\mu_B = 240 - 270$ MeV obtained in thermal fits to Pb+Pb data from the CERN SPS [15,16], showing a closer but not yet complete approach to a baryon-free regime at RHIC.

Acknowledgments

This work was partially supported by: (US) DoE grants DE-AC02-98CH10886, DE-FG02-93ER40802, DE-FC02-94ER40818, DE-FG02-94ER40865, DE-FG02-99ER41099 and W-31-109-ENG-38, NSF grants 9603486, 9722606 and 0072204, (Poland) KBN grant 2 P03B 04916, (Taiwan) NSC contract NSC 89-2112-M-008-024.

References

1. B. B. Back et al., Nucl. Phys. **A661** (1999) 690.
2. R. Pak, PHOBOS Collaboration, proceedings of Quark Matter '01 Conference (in press).
3. J. Katzy, PHOBOS Collaboration, proceedings of Quark Matter '01 Conference (in press).
4. B.B. Back, et al., Phys. Rev. Lett. **85**, 3100 (2000).
5. F. Abe et al., Phys. Rev. **D41** (1990) 2330.
6. J. Bächler et al., Nucl. Phys. **A661** (1999) 45.
7. X. Wang and M. Gyulassy, Phys. Rev. Lett. **86**, 3496 (2001).
8. D. Kharzeev and M. Nardi, http://xxx.lanl.gov/abs/nucl-th/0012025.
9. K. J. Eskola, K. Kajantie and K. Tuominen, Phys. Lett. B **497**, 39 (2001). K. J. Eskola, K. Kajantie, P. V. Ruuskanen and K. Tuominen, Nucl. Phys. B **570**, 379 (2000).
10. A. Wuosmaa, PHOBOS Coll., proceedings of Quark Matter '01 Conference (in press).
11. M. Gyulassy and X. Wang, Phys. Rev. **D44** 3501 (1991). We used HIJING V1.35 (April 1998) with standard parameter settings.
12. I. C. Park, PHOBOS Collaboration, proceedings of Quark Matter '01 Conference (in press).
13. B. B. Back, et al. hep-ex/0104032. Submitted to Phys. Rev. Lett.
14. K. Redlich, proceedings of Quark Matter '01 Conference (in press).
15. F. Becattini, Z. Phys. **C69** (1996) 485.
16. P. Braun-Munzinger, I. Heppe, J. Stachel, Phys. Lett. **B465** (1999) 15.