The PHOBOS experiment at RHIC - Physics and Capabilities

A. H. Wuosmaa
Physics Division, Argonne National Laboratory
Argonne, IL 60439, USA
E-mail: wuosmaa@anl.gov
for the PHOBOS Collaboration

B. B. Back[a], M. D. Baker[b], D. Barton[c], R. R. Betts[a,d], A. Bialas[e], W. Bogucki[f], C. L. Britton[g], D. A. Brosnan[b], A. Budzanowski[f], W. Busza[b](spokesman), A. Carroll[c], Y-H. Chang[h], A. E. Chen[h], W. Czyz[e], P. Decowski[b], K. Galuszka[f], R. Ganz[d], E. Garcia-Solis[i], J. Godlewski[f], K. Gulbandsen[b], S. Gushue[b], C. Halliwell[d], J. Halik[f], P. Haridas[b], A. Hayes[j], R. Holynski[f], B. Holzman[d], E. Johnson[j], J. Katzy[d], J. Kotula[f], W. Kucewicz[d], P. Kulinich[b], M. Lemler[f], W. T. Lin[h], S. Manly[j,k], D. McLeod[d], J. Michalowski[f], A. Mignerey[i], J. Mülmenstädt[b], M. Neal[b], G. van Nieuwenhuizen[b], R. Nouicer[d], A. Olszewski[f], L. Osborne[b], R. Pak[j], H. Pernegger[b], M. Plesko[b], L. Remsberg[c], M. Reuter[d], G. Roland[b], L. Rosenberg[b], P. Sarin[b], P. Sawicki[f], P. J. Stanskas[i], S. G. Steadman[b], G. S. F. Stephans[b], M. Stodulski[f], C. Taylor[l], A. Trzupek[f], C. M. Vale[b], R. Verdier[b], B. Wadsworth[b], F. L. H. Wolfs[j], D. Woodruff[b], B. Wosiek[f], K. Wozniak[f], A. H. Wuosmaa[a], B. Wyslouch[b], K. Zalewski[e], P. Zychowski[f].

[a]*Argonne National Laboratory,* [b]*Massachusetts Institute of Technology,* [c]*Brookhaven National Laboratory,* [d]*University of Illinois at Chicago,* [e]*Jagiellonian University, Krakow* [f]*Institute of Nuclear Physics, Krakow* [g]*Oak Ridge National Laboratory,* [h]*National Central University, Taiwan*
[i]*University of Maryland,* [j]*University of Rochester,* [k]*Yale University,* [l]*Case-Western Reserve University*

The PHOBOS experiment at RHIC is designed to study multiplicity distributions and fluctuations over all of 4π, as well as particle spectra and correlations at mid rapidity, with a particular emphasis on physics at low p_T. The experiment is relatively small and relies almost entirely on silicon pad detector technology. The flexibility of the design, the conservative nature of the technologies used, and the ability to take data at high rates place the experiment in a good position to search for exotic physics from heavy-ion collisions at the early stages of RHIC operations.

1 Introduction

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory will, when operations begin, produce conditions which have not been present since the early stages of the evolution of the universe. Two beams of Au ions with energies of 100 GeV/nucleon will collide, producing energy densities of a few GeV/fm^3, over a large volume. In this regime, Quantum

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Chromodynamics (QCD) predicts that the nature of the QCD vacuum will change, resulting in a deconfined, chirally symmetric phase where the partons are no longer bound within color-singlet mesons or hadrons [1]. Many possible signatures for such transitions have been suggested, such as the suppression (or enhancement) of the production of strange or charmed mesons, fluctuations in the numbers of emitted charged particles, or the modification of the free-space properties of various mesons propagating through the highly excited region produced in the Au-Au collisions.

2 PHOBOS Philosophy

Although several signatures for the Quark-Gluon Plasma (QGP) phase transition have been suggested, it remains unclear which, if any of these alone would provide the strongest experimental evidence for new physics from relativistic heavy ion collisions. It is likely that a preponderance of circumstantial evidence, with the concurrent anomalous behavior of several observables, will point to the experimental verification of the existence of these new states of matter. To study this behavior, the PHOBOS experiment is designed to combine measurements of global properties, such as the charged-particle multiplicity N, with detailed studies aimed at characterizing the microscopic aspects of the collisions. Furthermore, the experiment will concentrate on performing measurements at low p_T, where the physics will be dominated by elementary interactions rather than hard, parton-parton scattering events. It is in this regime that particles produced from long range, long time-scale collective phenomena are expected. Since the events which signify new physics are likely to be quite rare, PHOBOS is designed to obtain minimum-bias data at the full luminosity and event rate. The aim is to obtain a data sample which is initially as unbiased as possible, so that trends in many observables may be followed.

3 RHIC Environment and PHOBOS

RHIC will provide a very challenging environment for any experiment. Although it is not known exactly what this environment will be like, all models of relativistic heavy-ion collisions suggest that it will be inhospitable. The RHIC design luminosity of 2×10^{26} cm^{-2}sec^{-1} is expected to yield approximately 600 minimum-bias collisions per second. Current models predict between 5000 and 10000 charged particles to be produced for each central collision, with this number decreasing as the collisions become more peripheral. For minimum bias events, the event rate coupled with the number of produced particles very roughly suggests a charged particle flux on the order of 3×10^6 particles per

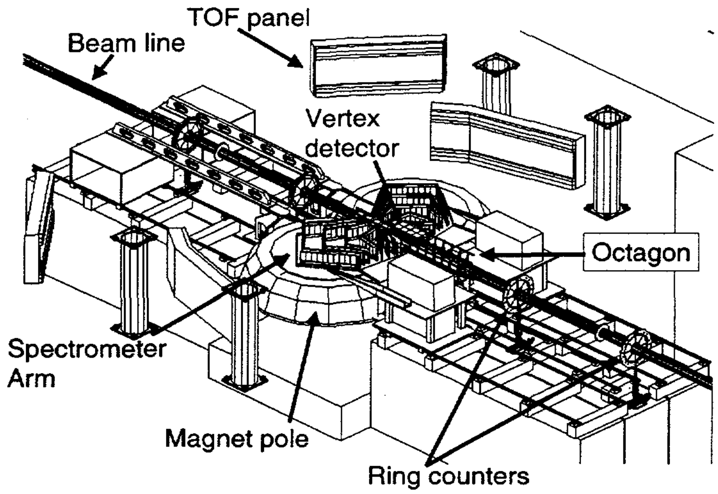

Figure 1: Schematic drawing of PHOBOS showing the major components. For reasons of clarity, top half of the magnet has been removed.

second incident on the experiment. Depending on the complexity of the experiment, and the detail with which each particle is characterized, expected data rates will range from a few to several tens or even hundreds of MB per second. PHOBOS approaches this challenge by making simple measurements on every particle in every collision, as well as a detailed study of approximately 1% of the particles for each event in the most interesting central rapidity region. The global measurement includes a determination of the total multiplicity, and the multiplicity distribution, for each event, over all of 4π. The detailed measurement includes a high-resolution determination of the momentum of particles at mid rapidity, which are identified by differential energy loss, and time of flight measurements.

4 Technical Implementation

4.1 Overview

The PHOBOS experiment [2,3,4,5] consists of five general detector subsystems. These include a large solid-angle multiplicity array, vertex finding detectors, two multiparticle tracking spectrometers, a set of plastic scintillator time-of-flight (TOF) walls, and trigger detectors. The multiplicity arrays are divided into an octagonal barrel of silicon pad detectors surrounding the beam pipe in the central rapidity region, and several rings of silicon pad detectors which count particles at large η. Together, these arrays cover $|\eta| \leq 5.3$. The vertex arrays consist of two sets of silicon pad detectors above and below the beam line around the interaction region. The spectrometers are positioned on either side of the beam, partially within a 2T magnetic field produced by a conventional magnet with two pole gaps with opposite polarity. The TOF walls provide particle identification for high-energy particles exiting the spectrometers. Finally, trigger counters consisting of plastic-scintillator paddles and Čerenkov rings are placed at large rapidity (small angles) around the beam pipe. A schematic diagram of the experiment, showing most of these elements, appears in Fig. 1.

4.2 Silicon sensors and readout

Much of the PHOBOS experiment utilizes a common technology of silicon pad detectors. These detectors are used in the tracking spectrometers as well as the multiplicity and vertex finding arrays. The silicon pad detectors vary in segmentation depending on their function and location in the experiment. Some of these sensors contain as many as 1500 pads, and readout of these devices presents a challenge.

The silicon sensors are produced with the usual fabrication technology. The pad junctions are made with a p^+ type implant, with a bias resistor formed from an amorphous silicon structure produced on the sensor. On top of the silicon, a layer of dielectric is deposited, followed by metal contact pads which are capacitively coupled to the junction. Also, there is a bus carrying the return leakage current. Metal readout traces laid on top of a second dielectric layer carry the pad signals to the readout electronics. A total of nine different sensor types are used in PHOBOS; some of these are shown in Fig. 2.

The sensors are read out using integrated circuit front-end electronics. In particular, these are 128 and 64 channel versions of the high-dynamic-range Viking/VA chip manufactured by IDEAS [6]. The VA outputs are digitized on nearby front-end controller boards, pedestal suppressed and corrected for common-mode noise. Finally, the data are built into events for storage and on-line analysis. The system is designed so that it can function will little or no dead time at an event rate of up to 600 Hz.

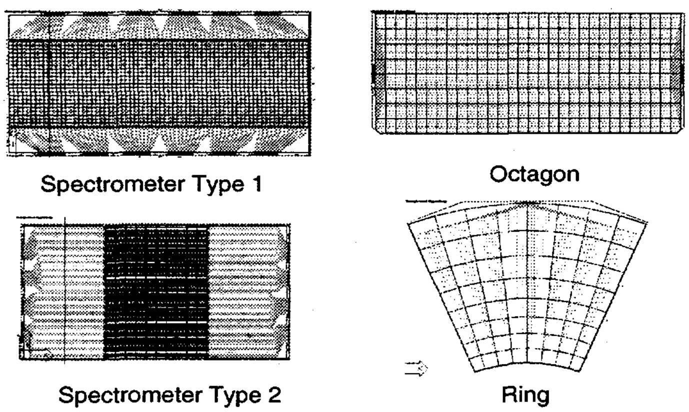

Figure 2: Schematic layout of some of the silicon sensors used in PHOBOS

4.3 Multiplicity Array

Should a transition to a deconfined QGP phase occur, it is likely that the change in entropy which accompanies this transition would result in large fluctuations in the number and distribution of produced charged particles. PHOBOS employs two silicon pad detector arrays to study these distributions on an event-by-event basis, which, in combination, subtend 2π in azimuth and the entire pseudorapidity range of $|\eta| \leq 5.3$. One of of these arrays, called the "octagon," is an eight-sided barrel which surrounds the beam pipe in the interaction region around mid-rapidity, extending to $|\eta| \leq 3.1$. The octagon contains 92 silicon sensors each with 120 pads. This segmentation corresponds to $\Delta\eta \approx 0.01$ units at mid-rapidity, and an azimuthal segmentation of $\pi/16$. Sensors are removed from the octagon at four places in the mid-rapidity section, including above and below the beam pipe, to permit particles to pass unimpeded to the vertex counters, and on either side of the beam pipe where the octagon is open to the spectrometer arms.

The remainder of the solid angle for the multiplicity measurement is covered by six ring counters, which surround the beam pipe, at distances of approximately $Z = \pm 1$, 2 and 4 meters away from the nominal center of the interaction volume. Each ring counters consists of 8 trapezoidal silicon sen-

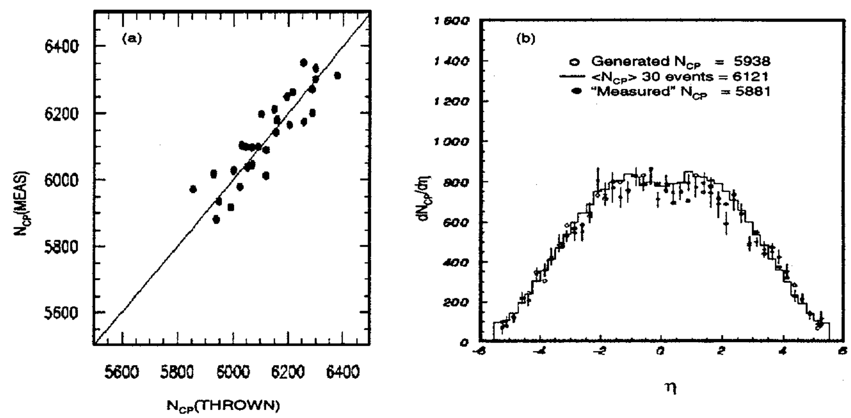

Figure 3: Reconstruction of (a) the charged particle multiplicity and. (b) the multiplicity distribution in PHOBOS.

sors, divided into 8 radial columns, and 8 cylindrical rows. Together, these rings subtend from $|\eta| \leq 3.1$ to 5.3.

The expected performance of the multiplicity array has been studied using Monte Carlo simulations of the apparatus, taking as input physics events generated by the code HIJET. The modeling of the response of the PHOBOS apparatus was carried out using the GEANT simulation package. Figure 3(a) shows the relationship between the number of charged particles produced in 30 HIJET central collisions, and the charged particle multiplicity reconstructed from the Monte Carlo treated data [5]. Effects such as secondary production and energy loss in the silicon detectors have been included in this simulation. There is a good correlation between the "thrown" and reconstructed charged-particle multiplicity. The scatter around the diagonal in Fig. 3(a) represents an estimate of the systematic, instrumental contribution to the uncertainty in the absolute multiplicity measurement. This scatter corresponds to approximately 2/3 the uncertainty arising from simple counting statistics for charged particle multiplicities on the order of N≈6000 [5].

The ability of the multiplicity array to measure the differential charged-particle multiplicity distribution $dN/d\eta$ on an event-by-event basis is illustrated in Fig. 3(b). This figure shows the average $dN/d\eta$ for the 30 events in Fig. 3(a) (histogram), the "thrown" $dN/d\eta$ for one such collision (open symbols) and the reconstructed $dN/d\eta$ (filled symbols with error bars). The agreement between the reconstructed and original distributions is quite good, within statistical errors.

4.4 Vertex Detector

To track particles accurately in the multiparticle spectrometers, to determine the zero point for the pseudorapidity distribution, and to perform the needed corrections for secondary particle production in the multiplicity measurement, the interaction vertex must be located precisely. In PHOBOS this task is accomplished with two, two-layer arrays of silicon pad detectors positioned above and below the beam, centered about the nominal intersection region. The inner layer of four pad detectors each have 512 pads, while the outer layer consists of two rows of four sensors, each with 256 pads. The two vertex arrays subtend an azimuthal angle of 45°, and are traversed by approximately 200 to 300 charged particles in each central event.

Vertices are located by a brute-force method, where all possible combinations of hits in the inner and outer vertex layers are projected onto the beam axis. In the case where the correct tracks are chosen, these projections lead to a common point on the beam axis. Figure 4 shows a histogram of all possible vertex projections for a single HIJET event at Z=0. The broad continuum represents incorrect vertex projections, but when the hits in the inner and outer layers of the vertex array are all correctly associated, they point to the location indicated by the spike in the vertex distribution histogram, in this case, at Z=0. With the pad size of the vertex counters, interaction vertices may be reconstructed with a resolution of approximately 500μm.

4.5 Multiparticle Tracking Spectrometers

The high-resolution detectors in PHOBOS are the multi-particle tracking spectrometers. The tracking spectrometers consists of two arms each with multiple layers of silicon pad detectors. The particles are momentum analyzed in a 2T magnetic field produced with a conventional magnet. The two arms of the PHOBOS spectrometer are made up of 14 layers of silicon pad detectors, with varying degrees of segmentation. The first 5 planes of silicon pad detectors are positioned in a region outside the magnetic field to define straight tracks, and provide some initial particle identification information from the energy loss recorded for each pad (See Fig. 5 [4].)

In the magnetic field region, the tracks are followed in several additional silicon planes. The redundancy of the arrangement of the planes in the spec-

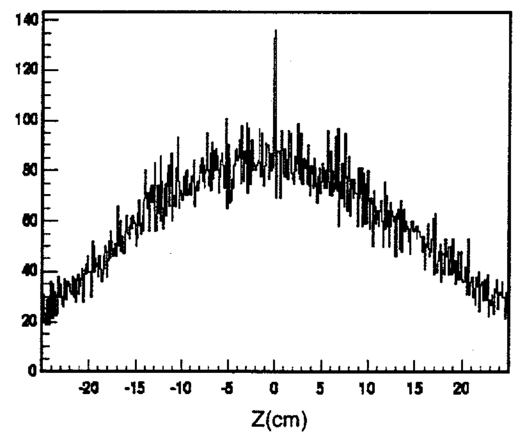

Figure 4: Vertex reconstruction in PHOBOS.

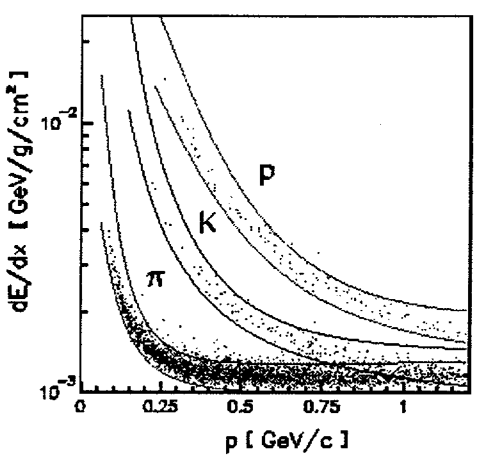

Figure 5: Particle identification by energy loss in PHOBOS.

trometer arms ensures that even if there are small numbers of dead pads in one or another layer, there will be enough hits for each track to enable it to be identified. The segmentation of the tracking planes in the spectrometer arms is such that, when multiple scattering and energy loss are taken into account, the momentum resolution for the tracking spectrometer will be approximately 5-10 MeV/c for particles with momenta of 50-1000 MeV/c. The momentum acceptance of the spectrometer is determined both by geometry and by which particles stop in the front spectrometer planes. For example, the low-momentum threshold for pions is 55 MeV/c, and for kaons is approximately 135 MeV/c. As an example of the capabilities of the spectrometer, Fig. 6 [4] shows a spectrum of reconstructed invariant mass for $K^+ - K^-$ pairs in the region of the ϕ meson, expected to be obtained after one week of data taking at full luminosity. After subtraction of the combinatorial background, the ϕ signal is cleanly observed, with a centroid and width which agree with the free space values used in the Monte Carlo simulation. Any deviation from these free space values, in particular for classes of events which display unusual fluctuations in N or $dN/d\eta$, could represent new physics. In addition, Hanbury-Brown-Twiss correlations for like pions will yield information on the volume of the region emitting charged particles. Unusually large source volumes, accompanied by multiplicity fluctuations or unexpected behavior of reconstructed mesons could also signal the existence of new QCD phases.

5 Summary

The PHOBOS experiment at RHIC is well positioned to obtain crucial information about relativistic heavy ion collisions at RHIC in the early stages of running. The philosophy of coupling global and highly focussed measurements results in a highly flexible experiment sensitive to many different possible signatures of the expected QCD phase transitions. Also, the ability to run at a high data rate with minimum bias triggering makes it likely that rare physics events will not be missed by the apparatus. Currently, preparations are underway for data taking in an upcoming RHIC engineering run to take place in the summer of 1999, with the full experiment in place and fully functional in October, 1999.

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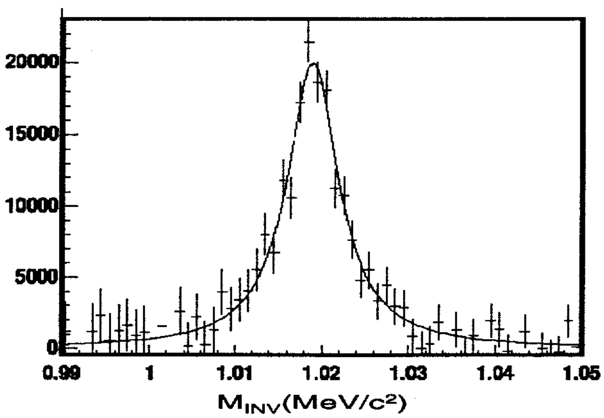

Figure 6: Phi-meson reconstruction in PHOBOS.

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