Vol. 27 (1996) ACTA PHYSICA POLONICA B No 11

THE PHOBOS EXPERIMENT AT THE RELATIVISTIC HEAVY ION COLLIDER*

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(Received October 9, 1996)

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The purpose of the PHOBOS experiment is to study the physics of heavy ion collisions at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. The PHOBOS detector is designed and optimized for detailed measurements of various experimental observables which may signal the onset of new phenomena expected in central collisions of gold nuclei at the center-of-mass energy of 200 GeV/nucleon. In particular, a comprehensive study of hadrons and photons produced in such collisions should reveal the existence and properties of a new phase of matter, the Quark-Gluon Plasma, which is predicted to be formed at high energy densities. In this paper a short overview of the PHOBOS apparatus and its measurement capabilities is presented.

PACS numbers: 25.75. -q, 12.38. Mh

* Presented at the "Meson 96" Workshop, Cracow, Poland, May 10–14, 1996.

1. Introduction

The PHOBOS experiment [1] will explore the rich physics programme for the collisions of heavy nuclei at the highest energy ever obtained in the laboratory. The new energy scale, available at the Relativistic Heavy Ion Collider (RHIC), will boost the high energy heavy ion physics to the range of energy densities where according to Quantum ChromoDynamics (QCD) a new state of matter, the Quark-Gluon Plasma(QGP) is created. Extrapolating the present results on nucleus-nucleus collisions to the RHIC energy, allows us to predict that in a single central collision of gold ions about 6000 charged particles will be produced and the energy density in the interaction region of the order of 3 GeV/fm^3 will be reached. Such energy density should provide favourable conditions, according to QCD, for the formation of a QGP.

The existence of a large volume of matter containing deconfined quarks and gluons could be detected by detailed measurements of the final state particles, produced after the phase transition of a QGP to hadronic matter. This phase transition may lead to strong non-statistical fluctuations of particle densities [2]. The collective effects, expected to be present over large time and distance scales, should affect the properties of low momentum particles [3]. Measurements of the Bose-Einstein correlations between these particles should reveal the size scales of the volume from which they are emitted. The restoration of chiral symmetry in the QGP could lead to the increase of the number of heavier quarks in the initial phase of the collision. In consequence the particle flavour composition is changed, leading to an enhanced production of strange and charm particles [4]. It is also predicted that the properties of light vector mesons, which decay inside high energy density matter, should be modified. In particular, it is expected that the mass and width of the ϕ meson should be distorted [5].

Studies of the particle production in nucleus-nucleus collisions at lower energies, pursued up to now at the AGS and SPS accelerators, have shown [6] that high energy densities are indeed reachable. Although some hints for the onset of new phenomena such as strangeness enhancement or J/ψ suppression have been observed [7], no clear evidence for a new state of matter was found. Thus, this is a challenge for the experiments planned at the RHIC accelerator (there are three other experiments, besides PHOBOS, approved for running at RHIC) where a significantly better environment for the study of strongly interacting matter will be provided.

The main goal of the PHOBOS experiment is to find manifestations of the presence of a new state of matter, by measuring a number of observables in a systematic and comprehensive way. The unique property of the PHOBOS experimental set-up is the possibility to track and identify low momentum particles produced at midrapidity where the search for a QGP should be most promising and where the PHOBOS spectrometer gives excellent momentum resolution and particle identification. Thus, with the PHOBOS spectrometer, we will be able to measure spectra of π, K, p, Λ and ϕ mesons down to very low transverse momenta as well as particle ratios which may show an enhancement in the production of strange particles. We will perform interferometry measurements of source sizes via the Bose-Einstein correlations between pairs of identical pions and kaons and also study the shift of the mass and the change in the width of ϕ mesons reconstructed from the invariant mass measurements for K^+K^- pairs. These precise measurements with the multiparticle spectrometer, of about 1% of all charged particles, will be complemented by the measurements of complete multiplicity distribution in almost a full phase space, provided by the PHOBOS multiplicity detector. These data allow for the analysis of particle density fluctuations.

2. The PHOBOS detector

The PHOBOS detector, shown in Fig. 1, consists of two main components, a multiplicity array and a two-arm multiparticle spectrometer. The construction of the both subsystems is based on the same, silicon technology, read out by a single type of electronics. The overall number of electronics channels is about 140000. The electronics and Data Acquisition System will be able to handle the expected "minimum bias" event rate of 600 Hz for collisions to be recorded at the nominal RHIC luminosity.

The multiplicity and vertex detectors cover almost a full solid angle ($-5.3 < \eta < 5.3$). Around the beam pipe, centered on the nominal interaction point is an octagonal tube which comprises silicon strip detectors, with strips oriented perpendicular to the beam axis. It covers the pseudorapidity range $-3.2 < \eta < 3.2$. On the top of the multiplicity octagon, two parallel planes of fine-resolution silicon strip detectors are placed which allow for determination of the vertex position with a precision of about 0.1 mm. Along the beam pipe, symmetrically on both sides of the interaction region, six rings of multiplicity detectors are positioned (the four closest to the interaction region are shown in Fig. 1). Segmentation of the silicon in the ring detectors enables measurements of particle pseudorapidities with an accuracy of 0.1 η units and azimuthal angles with a precision of 0.1 radians over a total coverage of more than 10 η units.

The electronics used in the multiplicity detectors can register correctly signals from several particles that hit the same detector element. This signal, proportional to the sum of energy losses of particles, is sufficient to estimate the number of these particles. Fig. 2 illustrates the PHOBOS de-

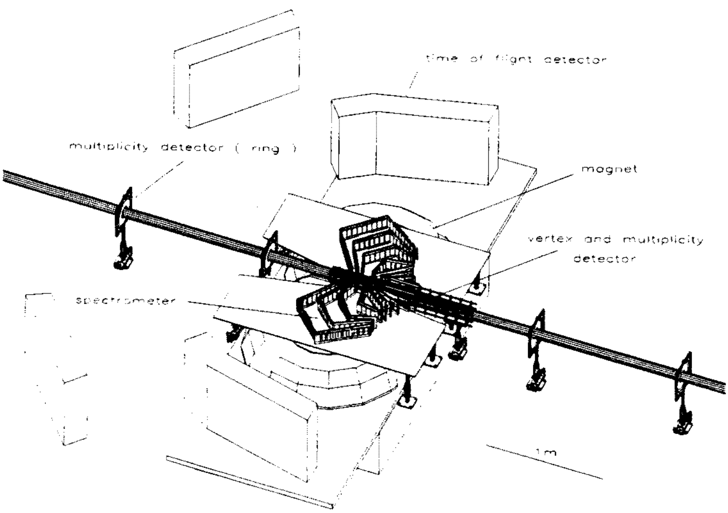
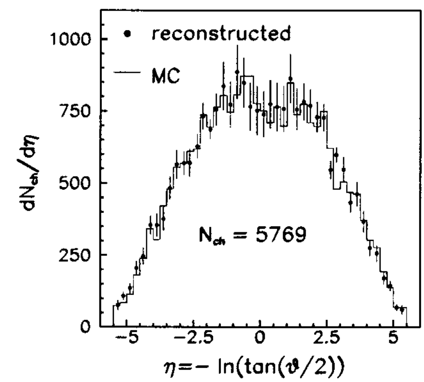


Fig. 1. Schematic view of the PHOBOS detector

tector ability to measure the total multiplicity, N_{ch}, and pseudorapidity distribution, $dN_{ch}/d\eta$, on an event-by-event basis. The solid histogram represents one central event generated by the HIJET Monte Carlo, while the data points represent the reconstructed angular distribution of this event. The reconstruction algorithm takes into account expected contributions of the hits from particles produced in secondary interactions and calculates corrected pseudorapidity distribution for particles originating from the primary vertex. The reconstructed $dN_{ch}/d\eta$ distribution agrees very well (the differences are smaller than 1% in the total multiplicity) with the true one in almost entire range of pseudorapidities. The agreement shown in Fig. 2 guarantees that the presence of any statistically significant fluctuations in real events will not be obscured by the reconstruction procedure [8].

The two arms of the PHOBOS spectrometer are located on both sides of the beam axis in a 2 Tesla magnetic field. The magnet was optimized (through shaping of the pole pieces) to provide a large uniform magnetic field for momentum measuring area and a low magnetic field near the beam pipe. In Fig. 1 the upper part of the magnet is removed to better show the spectrometer. Each arm of the spectrometer comprises 16 detector planes composed of silicon elements, with geometrical shapes optimized for a good acceptance of particles with momenta below about 1 GeV/c and with pseudorapidities $0 < \eta < 2$. The lowest transverse momenta accessible in the PHOBOS spectrometer are about 20 MeV/c for pions, 50 MeV/c for kaons and 70 MeV/c for protons [9]. The two-arm spectrometer has in total 1% coverage in the solid angle.



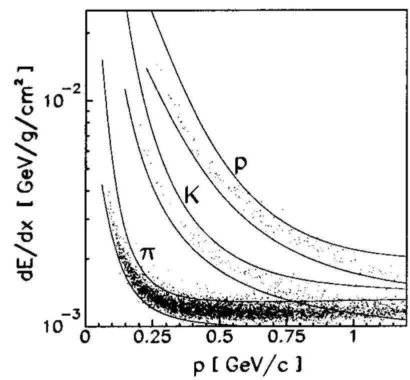


Fig. 2

Fig. 3

Fig.2. Multiplicity measurement in the PHOBOS detector. The solid line shows the angular distribution of a single Monte Carlo central event. The points show the ability of the PHOBOS detector to measure this distribution.

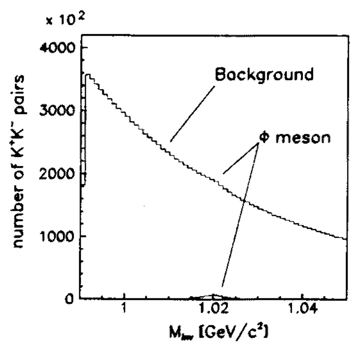
Fig.3. Ionization energy loss in spectrometer silicons as a function of momentum for different particles. The bands contain 95% of the Monte Carlo simulated particles (100 central HIJET events).

The pad structure of the silicon elements of the spectrometer will yield a precise three dimensional information on particle trajectories in the high track density environment expected in central gold-gold collisions. In a typical central event (with total number of charged particles of 6000) the spectrometer will reconstruct about 50 charged particle tracks with an efficiency of 90% [10]. From the curvature of reconstructed particle trajectories in the magnetic field, particle momenta will be determined with a very good resolution - about 10 MeV/c for 1 GeV/c pion. The ionization energy loss measured in silicon pads along particle trajectories will be used to identify particles. The detector will be able to identify $\pi^{\pm}$, $K^{\pm}$, p, $\overline{p}$ as well as decays of ϕ, Λ, $\overline{\Lambda}$, ... The capability to identify charged particles is shown in Fig. 3 where energy deposit in the spectrometer planes, dE/dx, is plotted as a function of momentum. Kaons and pions are separated up to 0.55 GeV/c and protons and kaons up to 1.2 GeV/c.

The time-of-flight (TOF) system, shown in Fig. 1, is planned as an upgrade to the spectrometer extending the physics capabilities of the PHOBOS detector [11]. It will provide additional coverage and particle identification for high momentum particles. In particular, time measurements allow for separation of pions and kaons up to 1.2 GeV/c and kaons and protons up to 2 GeV/c.

3. Physics capabilities

The capabilities of the PHOBOS detector are subject to extensive simulation studies based on the CERN GEANT package and the reconstruction program. A detailed description of the relative positions and sizes of sensitive elements of the detector together with all support structures, magnet and materials near the accelerator beam was created. The magnetic field was calculated using the TOSCA program and implemented in the simulation. This detector description is based on the technical documentation of the PHOBOS project ensuring that calculated estimates from the simulations will apply to the real response of the detector. The simulation data allowed for optimization of the detector and for estimation of its capabilities. In this Section we show the results of the simulations concerning the detector ability to measure the parameters of ϕ mesons and analyze two-particle Bose–Einstein correlations.



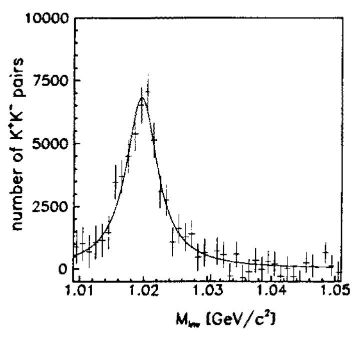


Fig. 4

Fig. 5

Fig.4. The distribution of invariant masses with background, $M_{\rm inv}$, for kaon pairs reconstructed in the spectrometer.

Fig.5. The background subtracted distribution of $M_{\rm inv}$. The solid line is the Breit-Wigner function fit to the data.

In the QGP environment the mass and width of ϕ meson are expected to change [5]. An increase of the width by a factor of 2–3 is predicted. This interesting effect, not seen yet experimentally, will be studied in the hadronic channel, $\phi \to K^+K^-$ for ϕ mesons produced in midrapidity region, where the high quality data are provided by the PHOBOS spectrometer. Fig. 4 shows the invariant mass distribution of all K^+K^- pairs measured in the spectrometer during about 4 days of RHIC running at the nominal beam luminosity. This distribution contains kaon pairs from ϕ decays as well as continuum, combinatorial background from all other pairs of kaons. The background subtracted distribution of the invariant mass is shown in Fig. 5. The solid line in this figure represents the fit by the Breit-Wigner function. The values of fitted parameters are: $m_\phi = 1019 \pm 0.2$ MeV/c^2 and $\Gamma_\phi = 4.5 \pm 0.5$ MeV/c^2 (corrected for the detector resolution) [8]. Thus, in 4 days of beam time we can measure the ϕ width with an uncertainty of 0.5 MeV, which is small enough to observe a predicted increase of the width.

The study of relative momentum correlations between identical particles (*i.e.* HBT correlations) will be performed in order to determine the space-time properties of the particle emitting source. Our experiment is particularly well suited for analysis of the correlations at very small momentum differences *i.e.* in the region most sensitive to large sources. In order to determine our detector ability to measure large sources we have performed simulation studies for two scenarios [10]. One assumes a standard size of hadronic source, with the HBT radii extrapolated from the SPS measurements to the RHIC energy. In the second scenario a strong first order phase transition is assumed leading to a long-lived source with large final dimensions, about a factor of two larger than in the first scenario. The procedure applied to reconstruct the HBT radii included the simulated response and measurement errors of the PHOBOS spectrometer. In Fig. 6a the comparison of the input radii (solid lines) with those reconstructed (data points) is shown as a function of the transverse mass ($m_T = \sqrt{m_\pi^2 + p_{T\pi}^2}$, where $p_{T\pi}$ is the average transverse momentum of the two pions) for the assumed standard source. The same comparison in the case of large source is shown in Fig. 6b. The simulations shown in Figs.6a and b correspond to 1 day of RHIC running. A good agreement between input and reconstructed radii is observed. From Fig. 6b one can see that with the PHOBOS apparatus we can reliably measure sources with radii as large as 20 fm.

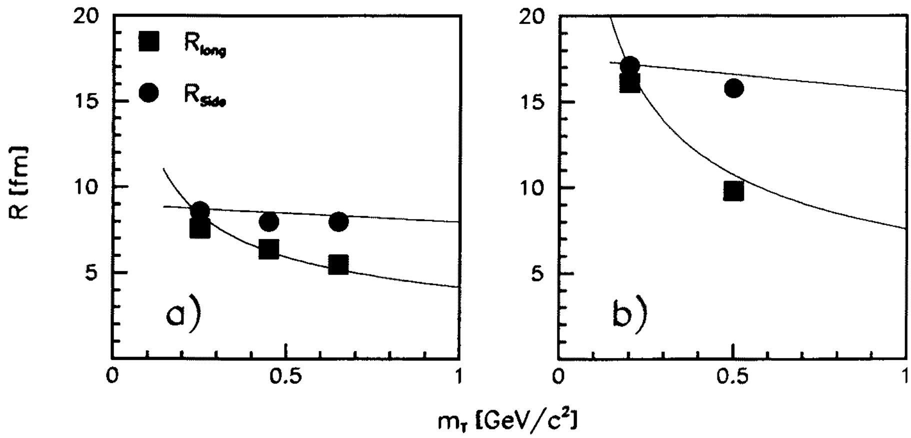


Fig.6. HBT measurements in PHOBOS for "standard" pion source (a) and large source (b). Solid lines represent input radii and points are reconstructed radii.

4. Summary

Finding clear evidence for a Quark Gluon Plasma creation at the RHIC energy, as predicted by QCD theory, strongly depends on the robustness of the detectors approved for construction. PHOBOS is a compact, high-rate detector that will be constructed from uniform, well-known technology and it has been optimized for measurements of the QGP signatures. The multiplicity array will precisely measure the total number of charged particles and their angular distributions in almost 4π solid angle. These global characteristics of events will be combined with the data from the two arm spectrometer. The spectrometer will identify charged particles and measure their momenta with a resolution sufficient to measure HBT radii up to 20 fm. The PHOBOS detector will have a good capability to measure $\phi \to K^+K^-$ decays with an accuracy of determined ϕ parameters sufficient to find any distortion in the mass and width due to the presence of a QGP. PHOBOS construction is well advanced and the detector will be ready on the turn-on day of RHIC in 1999.

This work was supported in part by Maria Skłodowska-Curie Fund II (PAA/NSF 95-229).

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