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ABSTRACT

The PHOBOS research program is aimed at studying the physics of relativistic heavy-ion collisions at the RHIC accelerator. In the interactions of heavy nuclei at a center-of-mass energy of 200 A GeV extreme energy densities will be produced and a phase transition to a new state of hadronic matter may occur. The PHOBOS collaboration plans to find signals of new physics by studying selected event properties that may be strongly influenced by the formation of a quark–gluon plasma. Special attention will be paid to the particles with very low momenta, for which the manifestation of new phenomena is most likely.

1. Introduction

Interactions of relativistic nuclei have already been studied for several years. Their global characteristics are satisfactorily described by incoherent superposition of elementary nucleon–nucleon interactions. Some deviations from this description can be explained without introduction of new physics. To date, heavy ion collisions have been investigated in fixed target experiments at relatively low center-of-mass energies (about 5 GeV/nucleon at the AGS (BNL) and below 20 GeV/nucleon at the SPS (CERN)). This energy will increase 10 times in the Relativistic Heavy Ion Collider (BNL) where two beams of 100 GeV/nucleon Au ions will collide. [1] The study of the nuclear matter at very high energy densities will become possible at RHIC. PHOBOS [2] is one of four experiments that will operate at this accelerator after its completion in the beginning of 1999.

The theory of strong interactions, quantum chromodynamics (QCD), predicts that at sufficiently high energy density a transition from hadronic matter to a state of unbound quarks and gluons (quark–gluon plasma, QGP) will occur. It is expected that the transition to this new phase will affect the final state particles. Several specific phenomena have been proposed as signals of the QGP occurrence.

The phase transition may result in fluctuations of particle densities with various sizes and characteristics. [3] In the PHOBOS experiment the study of particle density fluctuations will be possible in almost full phase space since the multiplicity of the charged particles and photons will be measured as a function of emission angle in a very wide pseudorapidity interval.

Creation of dense matter in large volumes and associated collective effects will modify the spectra of particles, especially those with momenta below 200 MeV/c. [4] The measured correlations between such particles will tell us about large emission sources. [5] An increased production of low momentum particles is also expected if the QGP is formed in small droplets. All those effect will be studied in the PHOBOS multiparticle spectrometer, which is designed to measure and identify the particles with momenta as low as 50 MeV/c.

Coherent pion production from disoriented vacuum bubbles may lead to fluctuations in the local $\pi^0/\pi^\pm$ ratio; this will be detected as an unusually large number of photons from the π^0 decays. [6] The ability of PHOBOS experiment to detect photons will be used to test this signature.

The differences between a hadronic gas and a QGP may be measurable. The restoration of chiral symmetry in the QGP could lead to an increase in the number of heavier quarks which will favor the production of particles with strange and charm quarks. [7] The PHOBOS multiparticle spectrometer will be used to measure $\pi/K/p$ ratios which may show an enhancement in the production of strange particles. Interesting results may be provided by the study of vector mesons (e.g. ϕ) [8] which decay inside the dense matter. In this case a measurable change of their properties (mass, width, branching ratios) is possible. The precise measurements of ϕ mesons will be used to study their properties as a function of other event characteristics. [9]

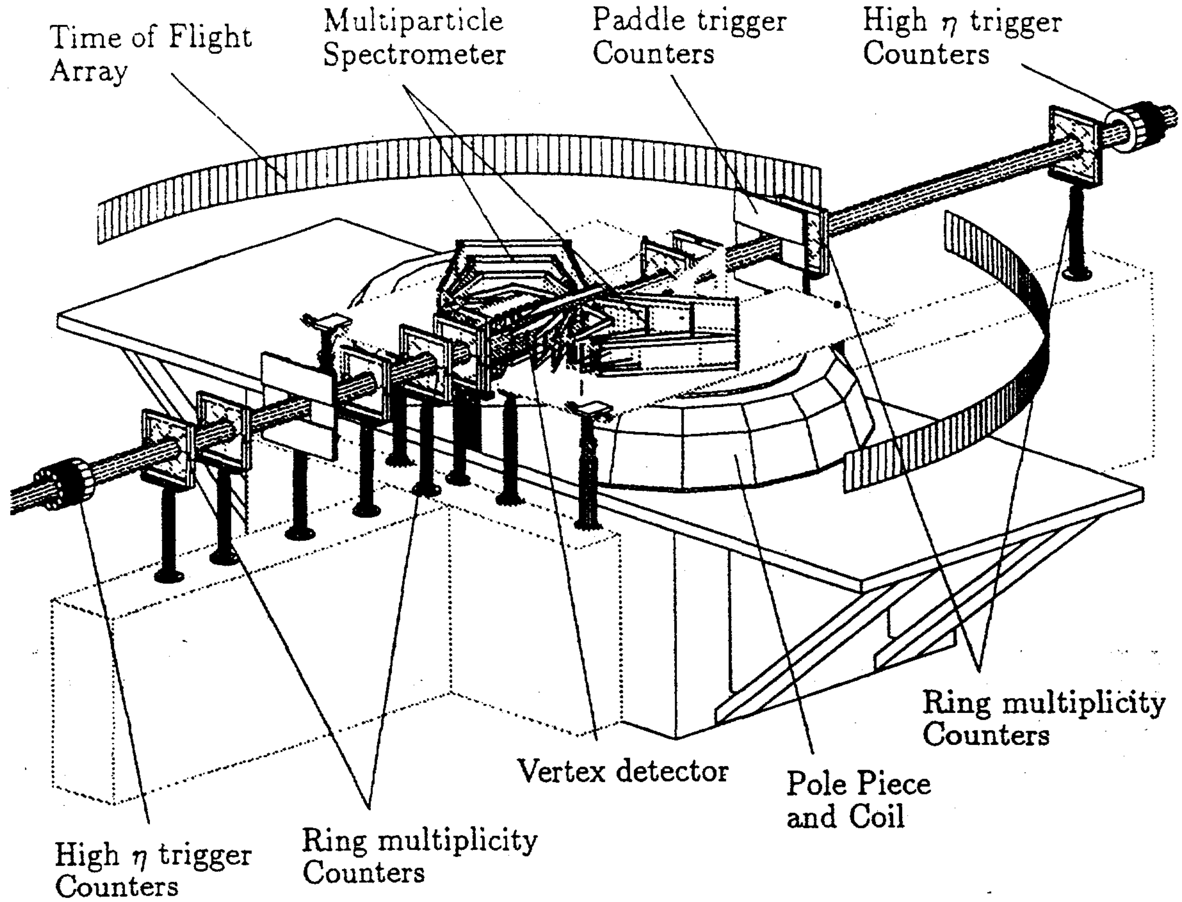

Fig. 1. The PHOBOS detector.

2. PHOBOS detector

The PHOBOS detector was designed to provide both general event characteristics in almost full phase space and precise measurements of the particles in the central rapidity region where the presence of new physics may be easiest to disclose. The first task will be performed by the multiplicity detector (including vertex detector), the second by the multiparticle spectrometer extended by time of flight array. Details of the detector layout are presented in Fig. 1. Most elements of the PHOBOS apparatus (spectrometer, multiplicity and vertex detectors) will be built using silicon strip and pad planes. The signals from them will be read-out using identical electronics.

Scintillators will be used in the time of flight array and trigger counters.

2.1. Trigger

The first level trigger includes high η trigger counters and paddle trigger counters. The signals from those detectors will be used as a first indication of an interaction and to estimate the position of the vertex. Additional information from the multiplicity detectors (a sum of signals from all channels as a measure of total multiplicity) can also be used to select more central events. Due to fast triggers the PHOBOS detector is capable of takeing data at a rate sufficient to record all central events occuring at the nominal RHIC luminosity.

2.2. Multiplicity detectors

The measurements of charged particles multiplicity and their angular distribution will be performed by two subsystems of silicon detectors. The first of them consists of several silicon strip planes that surround the interaction point forming an octagon. In this part of the multiplicity detector the particles with emission angles, θ, greater than about 7° will be registered. The upper and lower planes of the octagon are followed by additional planes that form a vertex detector used to determine precisely the position of the actual interaction point. Particles with emission angles less than 7° (down to 0.5°) will be measured in the ring multiplicity detectors. The rings are placed at distances adjusted to measure those particles down to the smallest accessible angles, which are limited only by the distance between the accelerator magnets and the radius of the beam pipe. The pseudorapidity (η) interval covered by the ring detectors extends to ± 5.4 pseudorapidity units. Segmentation of the multiplicity detector enables to measure the pseudorapidity distribution in the bins of 0.1 η unit or narrower as a function of the azimuthal angle.

In addition to the charged particles, the measurements of photons are also foreseen (in special runs). This will be done using thin radiators placed before the silicon planes in the ring detectors, where the photons will convert into detectable e^+e^- pairs.

The PHOBOS multiplicity detector is capable to measure events with multiplicity several times exceeding present theoretical estimations. The electronics can register correctly signal (total energy loss) from many particles that hit the same element. Such information is sufficient to estimate the most probable number of those particles. The reconstruction algorithm takes also into account expected contributions of the hits from particles produced in secondary interactions and finally calculates corrected pseudorapidity distribution for particles originating from the primary vertex. The analysis of the Monte Carlo data has shown that systematic errors are of the order of statistical ones or even smaller. Any statistically significant fluctuations will be thus

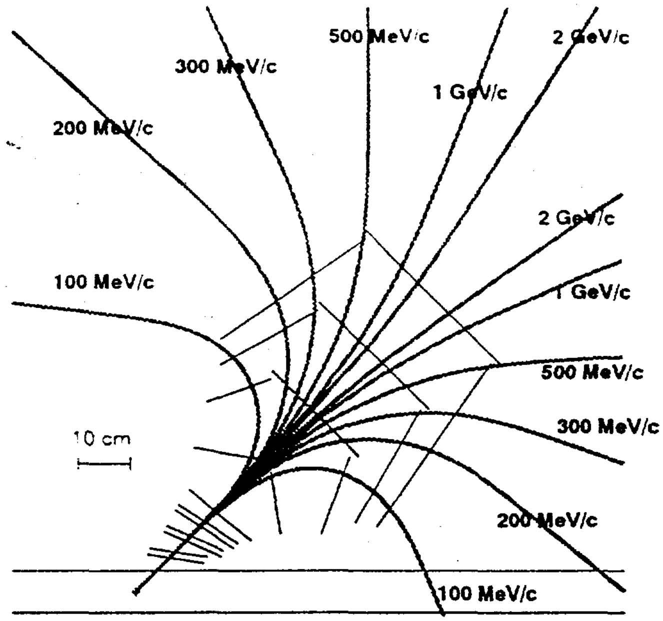

Fig. 2. Examples of the trajectories of particles (pions) with different momenta and charge.

visible in the reconstructed data.

2.3. Multiparticle spectrometer

The general event characteristics from the multiplicity detectors will be complemented by detailed measurements of about 1% of particles in the PHOBOS spectrometer. In the two spectrometer arms particles emitted at large angles (central rapidity region) will be measured.

The spectrometer arms are placed at both sides of the beam pipe in the field of a conventional magnet. The diameter of the magnet poles is about 1 m and the spacing between them is 15 cm. In the volume inside the magnet an approximately constant field of 2 Tesla is created. The first 6 planes of the spectrometer are however placed outside the magnet, in a very weak field. Charged particles will thus first follow straight lines, and then bend in the increasing magnetic field (Fig. 2). This design was intended to simplify the pattern recognition.

In the spectrometer silicon pad planes are used. Electronics used will register the amplitude of the signal that is proportional to the energy lost by the particle while traversing the silicon. This information is crucial for identification of particles with lower momenta. Particles with higher momenta, after traversing the spectrometer, can also hit the time of flight array. Their identification will be based on the measured

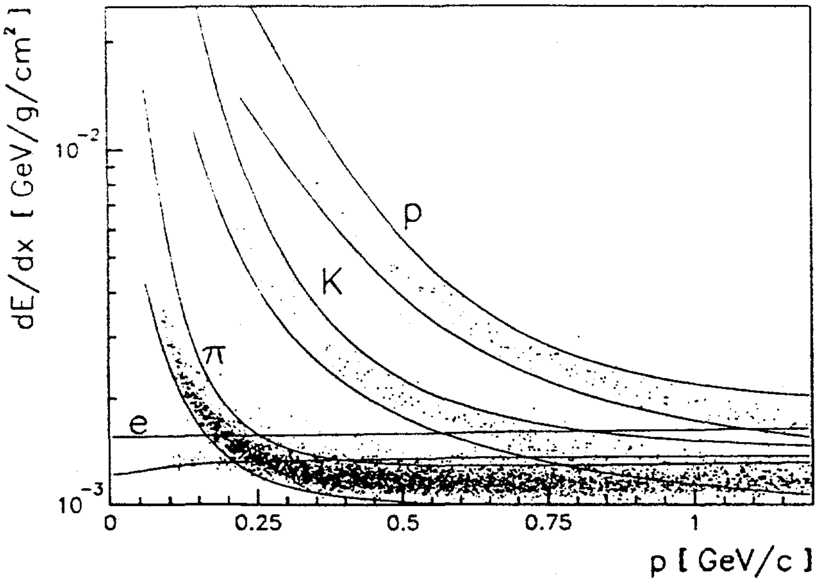

Fig. 3. Energy loss as a function of momentum for different particles. The bands contain 95% of the particles of a given type at the fixed momentum.

momentum and velocity. More details are given in the next section.

3. Particle identification

One of the main goals of the PHOBOS experiment is to study particles spectra in a wide momentum range. This task will be performed by the PHOBOS spectrometer where momenta of particles will be measured and the particles will be identified using three different methods, depending on the momentum of the particle.

Particles with lowest momenta lose a large fraction of their energy while traversing the beam pipe or a silicon plane and thus they stop in the first part of the spectrometer. In the very weak field they move along approximately straight lines and can be easily recognized by unusually large energy deposits in the silicon planes. Those particles can be reconstructed and identified only if they reach at least third plane and thus its total momentum has to be greater than about 40 MeV/c for pions, 110 MeV/c for kaons and 160 MeV/c for protons. The sum of the energy losses in the silicon planes gives the kinetic energy of the particle and the distribution of the energy losses is used for particle identification.

Particles with larger momenta traverse the spectrometer planes placed in the magnetic field and their momenta can be calculated from the curvature of the trajectory (Fig. 2). For their identification the measured energy loss in the silicon (which depends on both the momentum and the mass of the particle) will be used (Fig. 3). By this method we can identify electrons below 200 MeV/c, distinguish kaons from pions up to 600 MeV/c and separate protons from kaons and pions up to 1.2 GeV/c. The number of electrons with momenta above 200 MeV/c, that go through all required planes, is negligible as compared to the other particles.

Particles with higher momenta can reach the time of flight array. They will be identified from the velocity dependence on the particle mass and momentum. The accuracy of the time measurements allows us to separate pions and kaons with momenta below 1.2 GeV/c and protons up to 2 GeV/c.

4. Measurements in the central rapidity region

The central rapidity region is the most promising one for the search of a QGP signals in heavy ion interactions, as it is the most suitable for measurements of particles with lowest momenta that carry information on large sources or on changes in the particle production mechanism.

The PHOBOS multiparticle spectrometer was designed to measure particles emitted at relatively large angles and identify them in a wide momentum range. We can recognize correctly trajectories of particles in the spectrometer only if they enter it through the first plane and then traverse the successive planes (see Fig 2). Angular acceptance is thus determined by the geometry of the first planes of the spectrometer. The polar emission angle, θ, can vary between $20°$ and $90°$ (pseudorapidity 0 to 2), and the exact limits depend on the position of the interaction point which may vary ± 10 cm along the beam. The azimuthal angle interval covered by each spectrometer arm is $10°$ to $18°$ wide.

The width of the rapidity acceptance intervals depend on the type of particles and extends from 0 to 1.8 for pions and to about 1.3 for kaons and protons. Acceptance regions in rapidity and transverse momentum are shown in Fig. 4 and 5.

The lowest transverse momenta accessible in the PHOBOS experiment are about 20 MeV/c for pions, 50 MeV/c for kaons and 70 MeV/c for protons and antiprotons. Particles with such small momenta should be very rare and any increase in their yield (expected in the occurrence of a QGP) will be easily detected. The transverse momentum spectra provide information on the characteristic temperature of the particle creation process.

The study of correlations between particles measured in the PHOBOS spectrometer will provide the information about the size of particle source. An example of such analysis is shown in fig. 6. Two sets of Monte Carlo data were generated for this purpose: one that represents a straightforward extrapolation of the results from present heavy ion experiments to the RHIC energy and the second for which a strong first order phase transition (leading to a long living source with large final dimensions) was assumed. The results, that include the simulated response of the spectrometer, are compared to the predictions for an "ideal" detector. Good agreement between them ensures that using the PHOBOS spectrometer very large sources can be studied. [5]

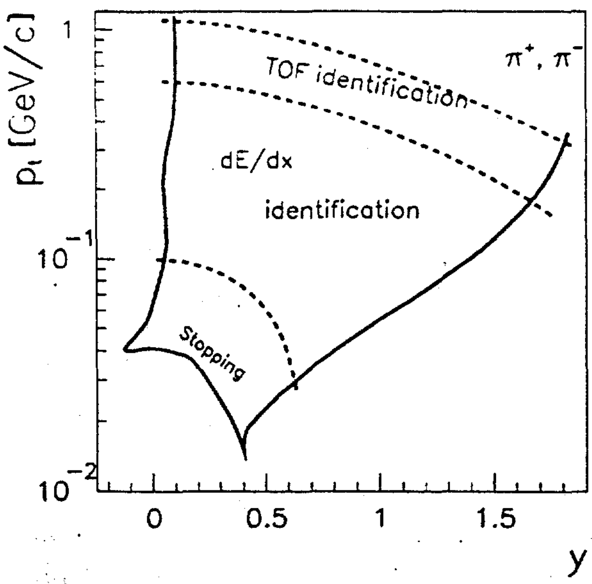

Fig. 4. Acceptance for pions.

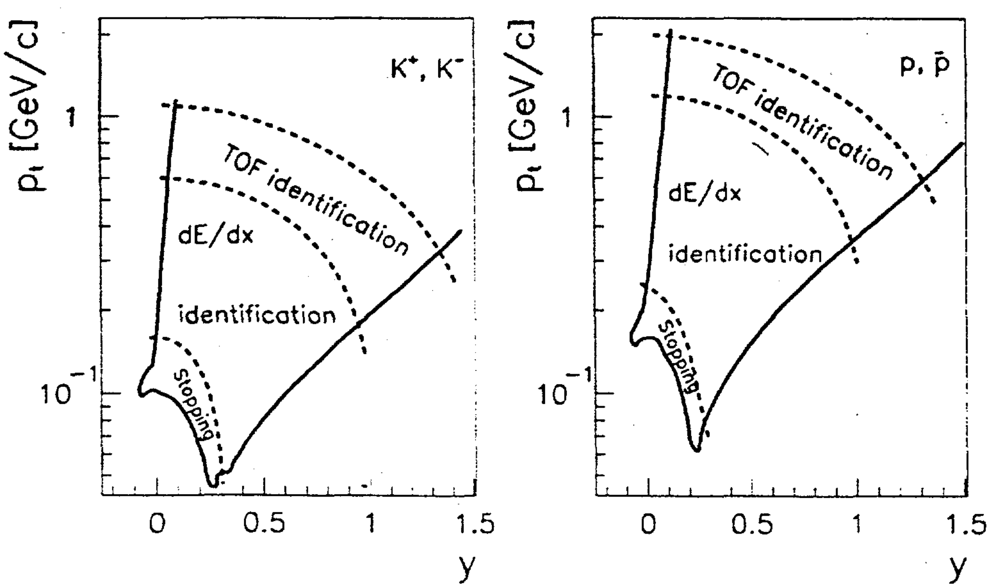

Fig. 5. Acceptance for kaons and protons.

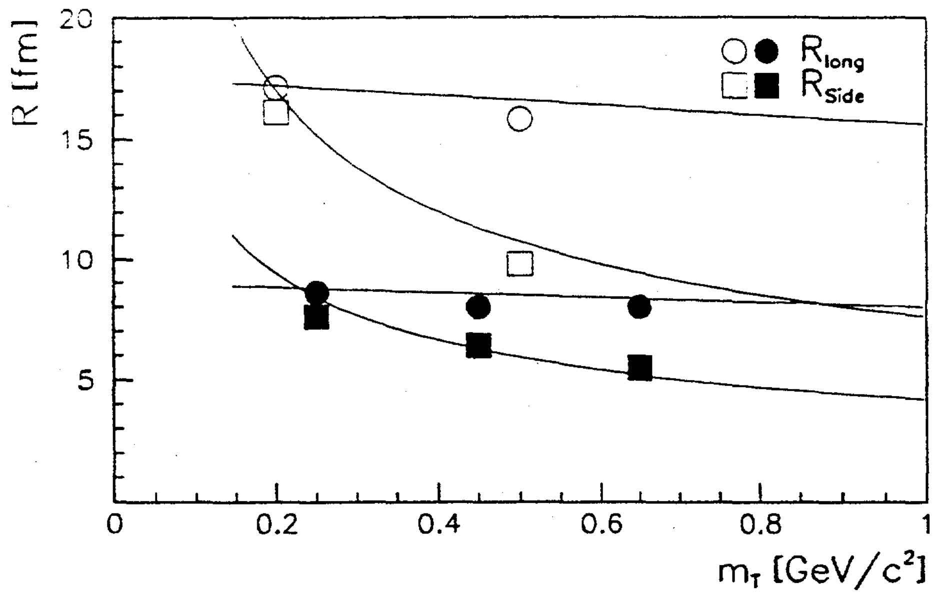

Fig. 6. HBT resolution. Lines represent an "ideal" detector response. Full circles and squares were obtained for "standard" data; open circles and squares were obtained for long living, large source data.

Identification of particles in a wide momentum interval is important for calculating particle yields that may be affected in the presence of a new particle production mechanism. It is also essential for detecting particles that decay into kaons (e.q. ϕ, Λ), because the acceptance is larger at higher total momentum. Monte Carlo simulations of ϕ meson detection in the PHOBOS spectrometer were performed in order to estimate the accuracy of the mass and width measurements [9] and were subsequently refined. The current estimate is that the data from about three days of running will be sufficient to measure the mass and width of ϕ meson with errors of 0.2 MeV/c^2 and 0.5 MeV/c^2 respectively.

5. Conclusions

The study of relativistic heavy nuclei collisions at RHIC opens a new area of physics — the physics of hadronic matter at very high energy densities. The conditions necessary to create a new state of matter, never before seen in the laboratory, may be reached. It gives a chance to study the quantum chromodynamics predictions of the phase transition from hadronic matter to a quark–gluon plasma.

The PHOBOS experiment will investigate almost all predicted signals of the QGP formation. General event properties (angular distribution of charged particles, total multiplicity) will be combined with detailed information on particles emitted in the central rapidity region (particle ratios $\pi/K/p$, p_t spectra, correlations, ϕ meson properties).

Similar studies will be done also in the other three experiments at RHIC, but there are many important observables for which PHOBOS will provide an unique information. The multiplicity detector covers almost a full phase space, recording all charged particles with pseudorapidities $|\eta| \leq 5.4$. In the PHOBOS spectrometer particles emitted in the central rapidity region will be measured and identified starting from lowest transverse momenta (20 MeV/c for pions). The high rate unbiased trigger gives a chance to see unpredicted phenomena and enables the study of very rare processes that require large statistics. The measurements of the converting photons planned for some runs will be used to study the $\pi^0/(\pi^+ + \pi^-)$ ratio in selected phase space intervals.

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