BRAHMS EXPERIMENT. FIRST EXPERIMENTAL RESULTS

ALEXANDRU JIPA

for

BRAHMS Collaboration (RHIC-BNL)


1Brookhaven National Laboratory, Upton, NY 11973, U.S.A.
2University of Bucharest, Romania
3Jagellonian University, Krakow, Poland
4Johns Hopkins University, Baltimore, MD 21218, U.S.A.
5New York University, New York, NY 10003, U.S.A.
6Niels Bohr Institute University of Copenhagen, Denmark
7Texas A&M University, College Station, TX 77843-3366, U.S.A.
8Fysisk Institutt, Universitetet i Bergen, Bergen, Norway
9University of Kansas, Lawrence, KS 66045, U.S.A.
10University of Oslo, Oslo, Norway
11Institut de Recherches Subatomiques and University Louis Pasteur, Strasbourg, France

Spokesman: Flemming Videbaek (BNL)
Deputy Spokesman: Jens Jorgen Gaardhoje (NBI)

Author address: Atomic and Nuclear Physics Department, Faculty of Physics, University of Bucharest, Romania
E-mail: jipa@brahms.fizica.unibuc.ro

(Received October 22, 2001)

Abstract. Some of the first experimental results obtained in BRAHMS Experiment at RHIC (BNL) are presented in the paper. Results on charged particle multiplicity, pseudorapidity distribution, and first results on particle identification and particle ratios for Au-Au collisions at √s_NN = 130 GeV are included. Some perspectives on future plans for the BRAHMS Experiment are also presented.

Key words: ultrarelativistic nuclear collisions, collider, multiplicity, rapidity and pseudorapidity distributions, particle ratios, hadron spectra.
INTRODUCTION

The main goal of the BRAHMS Experiment at the Relativistic Heavy Ion Collider (RHIC) from Brookhaven National Laboratory (USA), for the first running year, was the study of the general characteristics of the reactions and of the protons, pions and kaons yields in Au-Au collisions at $\sqrt{s_{NN}} = 130 \text{ GeV}$ [1].

BRAHMS experiment is designed to gather information on the interesting physical quantities characterising the various emitted particles in heavy ion reactions as functions of transverse momentum, $p_T$, and rapidity, $y$.

The yields as function of rapidity offer information on the nuclear density in the given collision, as well as on the produced entropy. The information on the collision dynamics and the degree of thermalisation can be obtained from the spectral shapes of the yields and their dependencies on rapidity. Important information on the collision dynamics is obtained from collision centrality measurements, and the information from the times in the reaction is included in the high $p_T$ parts of the spectra.

In the present paper, after a short presentation of the experimental set-up, we will present the main experimental results of the measurements during the first run in the summer of 2000 for Au-Au collisions at $\sqrt{s_{NN}} = 130 \text{ GeV}$.

BRAHMS EXPERIMENTAL SET-UP

The BRAHMS (Broad RAne Hadron Magnetic Spectrometers) Experiment is one of the five experiments at Relativistic Heavy Ion Collider (RHIC) from Brookhaven National Laboratory (BNL) [1-4].

In the BRAHMS experiment two different regimes will be studied, namely: (i) a baryon poor region with a high energy density, created at mid-rapidity; (ii) a region near the initial nuclei, at high rapidities, very rich in baryons at relatively high temperature. To reach this goal the BRAHMS experiment will measure well-identified charged hadrons – $\pi^\pm$, $K^\pm$, $p$, $\bar{p}$ – over wide ranges of rapidity and transverse momenta at all energies and beams available at RHIC. Taking into account the accelerator system structure and the size of the experimental halls, the BRAHMS spectrometers are small solid angle devices. They will provide semi-inclusive measurements in very different experimental conditions.

The experimental set-up was designed with two moveable magnetic spectrometers, namely: (a) Forward Spectrometer (FS); (b) Mid Rapidity Spectrometer (MRS) [1-5]. The Forward Spectrometer covers the angular region $2.3^\circ \leq \theta \leq 30^\circ$, and the Mid Rapidity Spectrometer covers the angular region $30^\circ \leq \theta \leq 95^\circ$. Pseudorapidity ranges covered by the two spectrometers are: $1.3 \leq \eta \leq 4.0$, $-0.1 \leq \eta \leq 1.3$, respectively. To the two magnetic spectrometers three event characterisation detector systems have been added; they will provide
global information. The three detectors systems are the following: Beam-Beam Counters (BBC), multiplicity detector (MA) and the Zero Degree Calorimeters (ZDC). Together, the three detector systems will provide centrality coverage in the mid rapidity region, namely: \(-2.2 \leq \eta \leq 2.2\), in the region \(3.2 \leq |\eta| \leq 4.3\), as well as at \(0^\circ\). A top view of the BRAHMS experimental set-up is shown in Fig.1.

PARTICLE SPECTRA

Particle momenta were determined by projecting the straight-line tracks as reconstructed in the two TPCs to the magnet and calculating the bending angle at matched tracks using an effective edge approximation. Preliminary invariant inclusive spectra of negative hadrons and positive hadrons, respectively, at \(\eta = 0.0\), for central collisions, are shown in Fig.2. For obtaining these spectra the vertex
dependent acceptance maps were used. Vertex position is in the range from -15 cm to +15 cm and transverse momentum is in the range from 0.3 GeV/c to 3.0 GeV/c. The average values of the transverse momentum are, for negative and positive hadrons, the following: $<p_T>_{-} = 0.480$ GeV, $<p_T>_{+} = 0.450$ GeV/c, respectively. These values are higher than those obtained by extrapolation at other energies [1]; for example, at ISR and UA1 energies, average transverse momentum is $<p_T>_{\alpha} = 0.365$ GeV/c.

![Graph of invariant spectra of negative hadrons](image1)

![Graph of invariant spectra of positive hadrons](image2)

Fig. 2 – Invariant spectra of negative hadrons and positive hadrons for $\eta \approx 0.0$ recorded with an inclusive trigger (logarithmic scale; solid lines are linear fits in this scale).
The momentum resolution obtained at BRAHMS experimental set-up in the first run was 0.07 % [2,3]. Thus, in FS the momentum resolution is around 0.02%, and in MRS is around 0.07 (at 90°) or around 0.05 (at 40°), respectively. This resolution is sufficient for tracking considerations, particle identification and spectra measurements.

**PARTICLE IDENTIFICATION**

Particle identification is done combining different detectors. First of all, the detectors from the two spectrometers can be used to combine the time-of-flight measurements in the two hodoscopes (H1 and H2 in Fig.1) with measurements in the threshold Cherenkov counter (C1) and the Ring Imaging Cherenkov Counter (RICH). The 48 scintillator slats in the first hodoscope and the 32 scintillator slats in the second hodoscope – instrumented with photomultiplier tubes (PMT) at each end – allow the particle identification in the momentum range 1-20 GeV/c, in Forward Spectrometer. The time-of-flight array in Forward Spectrometer is place at 8.6 m from the nominal vertex position. Mid Rapidity Spectrometer uses for particle identification two time projection chambers (TPC1 and TPC2), a dipole magnet (D5) and a time-of-flight wall (TOFW) with 83 scintillator slats, placed at 4.3 m from the nominal vertex position. In the two arms of the experimental set-up the overall time resolution is around 120 ps. Therefore, in Forward Spectrometer the separation of kaons and protons is possible in the momentum range $p < 4.5 \text{ GeV/c}$, and in Mid Rapidity Spectrometer in the momentum range $p < 2.2 \text{ GeV/c}$. The time-of-flight performances for Mid Rapidity Spectrometer are presented in Fig. 3.

![Fig.3 – Time-of-flight performance for Mid Rapidity Spectrometer at 90° (pions, kaons and protons).](image)

Another way is related to the momentum spectra and effective mass. In the MRS, pions and kaons could be well separated up to 1.5 GeV/c. For two fixed
rapidities ($y=0.0$ and $y=2.0$, respectively) the $m^2$ spectra for positive and negative particles were obtained. The following relation was used:

$$m^2 = p^2 \left( \frac{t^2}{L^2} - 1 \right),$$

where $p$ is the particle momentum, $t$ is the time-of-flight and $L$ is the flight distance.

For the experimental results included in Fig.4 the transverse momenta are in the following ranges: $0.15 \text{ GeV}/c < p_T < 0.55 \text{ GeV}/c$ (in FS), $0.4 < p_T < 2.2 \text{ GeV}/c$ (in MRS), respectively. Separation in $m^2$ is better at lower momenta.

![Fig.4 – $m^2$ distributions for charge particles detected by BRAHMS experimental set-up (MRS at 90°).](image)

It is important to stress here that the acceptances for the two spectrometers, at a given field, for positive charged particles, are equal to the acceptances for negative charged particles at the opposite polarity of the given field. By combining runs with opposite fields most systematic errors cancel out.

GLOBAL INFORMATION
PSEUDORAPIDITY DISTRIBUTION AND MULTIPLICITY

To obtain global information the Beam-Beam Counters (BBC), multiplicity detector and Zero Degree Calorimeters (ZDC) were used. The Beam-Beam Counters provide the initial trigger and vertex information. They assure the start
time for the time-of-flight measurements, too. Each of the elements of the BBCs has 3 cm and 4 cm UVT Cherenkov radiator read out by PMTs. The right-side of the BBCs consists of 36 elements and the left-side consists of 44 elements; they are positioned at ±2.2 m from the nominal vertex interaction. The multiplicity detector provides information on the collision centrality. 24 segmented Si-detectors with 168 channels (SiMA = Si Multiplicity Array) and 40 scintillator squared tiles with 12 cm length (TMA = Tiles Multiplicity Array) are included in this hybrid detector. The pseudorapidity range covered by the multiplicity detector is −2.0 ≤ η ≤ 2.0. Common devices for all experiments at RHIC are the Zero Degree Calorimeters [6]. At BRAHMS they are placed at ±18 m from the nominal vertex interaction, being situated behind the two DX beam-line magnets. For Au-Au collisions the two ZDCs offer information on the collision centrality measuring the forward going spectator neutrons. The coverage provided by the global detectors is in the region −2.2 ≤ η ≤ 2.2, in the region 3.2 ≤ |η| ≤ 4.3, as well as at 0°. They were used in the run from 2000 to measure the overall charged particle production and to determine collision centrality. SiMA and TMA can be hit by many different particles, including background particles. Therefore, to obtain the multiplicity information it is necessary to convert the deposited energy into a number of hits. The energy loss signal is transformed into charged particle multiplicity dividing total deposited energy to the expected deposited average energy by one particle in a tile. Conversion factors are evaluated from GEANT simulations. The background contributions are considered. They are between 10 % for SiMA elements and 30% for TMA elements. All detector elements were calibrated in energy using pulser, cosmic rays and sources measurements.

The pseudorapidity distribution, \( \frac{dN}{d\eta} \), was obtained using solid angle evaluations (Fig.5). Selecting appropriate ranges in the multiplicity spectrum (Fig.6) different cuts in collision centrality were performed. Usually, the cuts in collision centrality can be expressed in terms of the fraction of the nuclear reaction cross section by normalization to the integral of the TMA spectrum obtained, with a near minimum bias trigger. This trigger requires energy deposition in each of the two ZDCs above 25 GeV. An additional condition is that at least one tile have a hit. Almost 97% of the nuclear interaction cross section can be selected by this requirement.

For η = 0.0 the value obtained from pseudorapidity distributions is \( \frac{dN}{d\eta} = 530 \pm 5 \pm 50 \). First errors are statistical errors, and the second are systematic errors. This value is in good agreement with HIJING code predictions [7,8]. It is important to stress that similar values are obtained in the pseudorapidity range −2.0 < η < +2.0, including the range ends. This fact indicates the existence of a large
plateau for particle production in very central collisions (6%). Also, this value for $\eta = 0.0$ is in good agreement with the value reported by PHOBOS Collaboration, in similar conditions [9].

Fig. 5 – Pseudorapidity distribution, $\frac{dN}{d\eta}$, of the charged particles (determination by SiMA and TMA detectors systems for the most central 6% of all collisions).

Fig. 6 – Multiplicity spectrum for Au-Au collisions at $\sqrt{s_{NN}} = 130$ GeV.
PARTICLE RATIOS

One of the first goals for BRAHMS Collaboration was the evaluation of charged particle, anti-particle ratios. They could reflect the dynamics collision, as well as the possibility to evidence the quark-gluon plasma formation. These opportunities are related to the charged hadrons detected by BRAHMS experimental set-up.

The \( \frac{N(\pi^-)}{N(\pi^+)} \) ratio can reflect the isospin asymmetry and the Coulomb repulsion [10]. Using the selection particle method presented in paper [11] the experimental results are presented in Fig. 7 (a) (18% central events). An important observation is related to the lack of dependence on the collision centrality. The average value obtained is: \( \frac{N(\pi^-)}{N(\pi^+)} = 0.95 \pm 0.03 \pm 0.05 \); this result consistent with 1.0 is obtained for \( \eta \approx 0.0 \). This value of the ratio reflects the degree of isospin equilibration obtained in Au-Au collisions at \( \sqrt{s_{NN}} = 130 \text{ GeV} \). The very small influence of the Coulomb repulsion is reflected, too. The preliminary experimental results suggest, also, a lack of transverse momentum dependence.

At the same value of the pseudorapidity – \( \eta \approx 0.0 \) – the \( \frac{N(K^-)}{N(K^+)} \) ratio was determined. The average value is \( \frac{N(K^-)}{N(K^+)} = 0.89 \pm 0.07 \pm 0.05 \). The value is the highest obtained up to now in relativistic and ultrarelativistic nuclear collisions [12]. It is an important indication on the equilibration degree reached in Au-Au collisions at \( \sqrt{s_{NN}} = 130 \text{ GeV} \). Experimental results are shown in Fig. 7 (b) (18% central events). Also, this ratio does not indicate dependencies on the collision centrality and transverse momentum.

Very important for the goals of the BRAHMS Experiment is the \( \frac{N(p)}{N(\bar{p})} \) ratio. In Fig. 7 (c) the rapidity dependence of the \( \frac{N(p)}{N(\bar{p})} \) ratio is shown. The experimental results are for 18% central events. The value of the \( \frac{N(p)}{N(\bar{p})} \) ratio for \( y \approx 0.0 \), namely: \( 0.62 \pm 0.05 \pm 0.06 \), is significantly higher than the values of this ratio obtained at BNL-AGS and CERN-SPS energies [13-15]. For example, in Pb-Pb collisions at BNL-AGS energy of \( \sqrt{s_{NN}} = 5 \text{ GeV} \), the value of the \( \frac{N(p)}{N(\bar{p})} \) ratio is
Fig. 7 – Behaviour of the experimental particle ratios in Au-Au collisions at $\sqrt{s_{NN}} = 130 \; \text{GeV}$: (a) $\frac{N(\pi^-)}{N(\pi^+)}$; (b) $\frac{N(K^-)}{N(K^+)}$; (c) $\frac{N(p)}{N(p)}$. 

(a) 

(b) 

(c)
around 0.00025 [13], and – for the same collisions – at CERN-SPS energy of $\sqrt{s_{NN}} = 17 \text{ GeV}$ the value of the $\frac{N(p)}{N(\bar{p})}$ ratio is between 0.07 and 0.15 [14,15]. It is important to stress here that the obtained value in Au-Au collisions at $\sqrt{s_{NN}} = 130 \text{ GeV}$ is similar to those obtained in p-p collisions at CERN-ISR energy of $\sqrt{s_{NN}} = 63 \text{ GeV}$, for $p_T \approx 0.3 \text{ GeV}/c$, namely $0.61 \pm 0.10$ [16].

From the analysis of the experimental dependence of the $\frac{N(p)}{N(\bar{p})}$ ratio on the rapidity (Fig. 8) the following conclusion is obtained: the antiproton to proton ratio is under unity at midrapidity and decreases towards forward rapidity. This behaviour suggests there is a significant contribution from participant baryons over the entire rapidity range. Such a behaviour is not observed for $\frac{N(\pi^-)}{N(\pi^+)}$ (Fig. 8, top).

![Fig. 8 – Dependence of the $\frac{N(\pi^-)}{N(\pi^+)}$ and $\frac{N(p)}{N(\bar{p})}$ ratios on rapidity. Some comparisons with simulation codes predictions are included.](image)

**FINAL REMARKS**

Some preliminary experimental results on charged particle multiplicity, pseudorapidity distribution, particle identification and particle ratios obtained in Au-Au collisions at $\sqrt{s_{NN}} = 130 \text{ GeV}$ using BRAHMS experimental set-up, in experiments performed at the new collider RHIC-BNL, are presented in this work.
Comparisons with different simulation codes were done [1, 5,17]. The used codes – FRITIOF, HIJING, VENUS and UrQMD – describe different interesting physical quantities. None of the used codes offer a consistent description of the observed features.

The new 2001 runs will complete the experimental results and will offer the possibility to investigate deeply the particle production mechanisms and the behaviour of the nuclear matter in extreme conditions of temperature and density.

Acknowledgements. The BRAHMS Collaboration wishes to thank the C-AD department of BNL for successful commissioning of RHIC and the contributions to the construction of the experiment. This work was supported by the Division of Nuclear Physics of the Office of Science of the U.S. Department of Energy under contract with BNL (No.DE-AC02-98-CH10886), Texas A&M University (DE-FG03-93ER40773), University of Kansas (DE-FG03-96ER40981), New York University (DE-FG02-99ER41121), the Danish Natural Science Research Council, the Korea Research Foundation Grant, the Norwegian Natural Science Research Council, the Jagellonian University Grant, the Romanian Ministry of Education and Research grants and “Horia Hulubei” Foundation grant.

REFERENCES