THE BRAHMS EXPERIMENT AT RHIC
GOALS and STATUS

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The BRAHMS experiment is designed to measure semi-inclusive spectra of charged hadron over a wide range of rapidity. It will yield information on particle production, both at central rapidity and in the baryon rich fragmentation region. Examples of measurements for soft as well as for hard physics are presented. The present status of BRAHMS is discussed, as well as the plans for measurements in the first year of running at RHIC.

1 Introduction

The main motivations for the RHIC experiments are the search for and the investigation of the quark-gluon plasma. It is thought that QGP can be created in high energy heavy ion collisions under a broad range of experimental conditions bounded in one direction by high baryon densities and in the other by zero baryon density and temperatures above the critical temperature. At RHIC with energies $\sqrt{s} = 200 GeV/c$ per nucleon pair, which is above the stopping regime presently being explored at AGS and SPS, a baryon poor region with a high energy density is expected to be created at mid-rapidity. The region near the initial nuclei i.e. at high rapidities, will be baryon rich at relatively high temperature. This gives experimental opportunities to study experimentaly both regimes at RHIC and search for the quark-gluon plasma under several different conditions.

The Broad RAnge Hadron Magnetic Spectrometers (BRAHMS) experiment is designed to gather basic information in heavy ion reactions on momentum spectra and yields for various emitted particles as function of transverse momenta, p_t, and rapidity, y. These yields as function of rapidity are important indicators of the densities reached in the collisions and of the produced entropy. The spectral shapes and their y-dependence reveal the reaction dynamics and the degree of thermalisation attained. The high p_t parts of the spectra carry information from the times in the reaction. The centrality measurements are an integral part of the experiment, and systematic studies are needed to establish an understanding of the reaction dynamics.

The BRAHMS spectrometers are small solid-angle devices so the measurements will be semi-inclusive; i.e. the average spectra for given event classes as determined by the centrality detectors will be measured. This contrasts to the

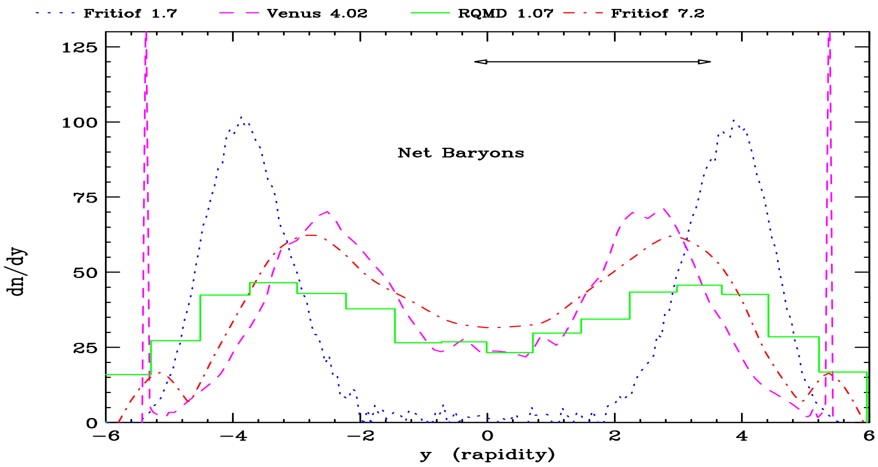

Figure 1: Predicted rapidity density distributions for central Au+Au reactions using different models as indicated by the linetype. The rapidity range to studied by BRAHMS is indicated by the arrows.

large RHIC experiments where event-by-event information can be collected. BRAHMS has a unique place in the RHIC experimental program with its wide coverage in rapidity and p_t. The coverage is essentially limited by the accelerator structures, the size of the experimental halls, and the modest budget for BRAHMS.

2 Physics Goals

2.1 Soft Hadron Measurements

The dominant part of the particle spectra is the soft part with transverse momenta $p_t \leq 1GeV/c$. Particle spectra have been studied in elementary pp (p$\overline{p}$) over a wide range of energies covering the RHIC energy regime. Even with this knowledge in hand it is not trivial to extrapolate to nucleus-nucleus collisions. It has been learned from heavy ion reactions at AGS and SPS that heavy ion collisions cannot be considered a super-position of elementary nucleon-nucleon collisions, but that multiple collisions and collective effects are important to a proper description of the experimental data. At the much higher energies considered here it is likely that additional many-body effects, even for a pure hadronic description, have to be taken into account. Understanding of the reaction mechanism will clearly come from systematic studies of pp to p-nucleus and nucleus-nucleus reactions.

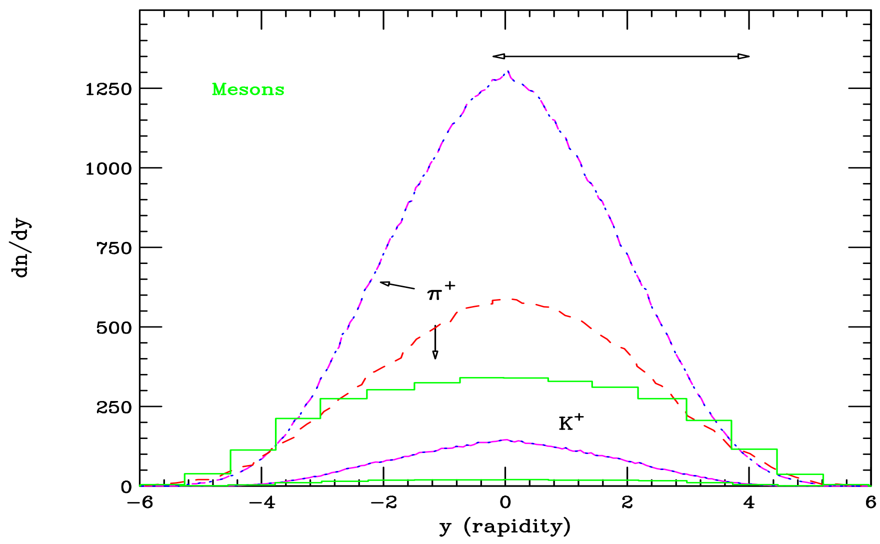

Figure 2: Predicted rapidity density distributions for π^+ and K^+. The curves are labelled as in fig1

One basic question is the amount of stopping, i.e. the mean rapidity shift of projectile nucleons, see e.g. ref. [1], and how high the net baryon density is in the central region of Au+Au collisions. In fig.1 is shown the prediction for the net baryon density $\frac{dn}{dy}$ for 4 different models successfully used to describe pp and nucleus-nucleus reactions at lower energies. These are Fritiof 1.7 [2], Fritiof 7.2 [3], Venus [4], and RQMD [5]. The predicted mean rapidity losses are in the range of 1.7-3.1. The coverage of BRAHMS is shown by the arrow. Even though the fragmentation region as observed in pp (i.e. y $\approx$ 4-5) is outside the range, the measurements do cover the region $y \leq 3.8$ sufficiently to map and study the stopping in nucleus-nucleus collisions at RHIC.

The predictions for meson production are given in figure 2. The experiment will essentially cover the complete distribution for π and K, and can address details of the shape and particle yields. The predictions vary almost a factor of 4 at mid-rapidity, so with this in mind the spectrometers were designed to handle the highest expected values.

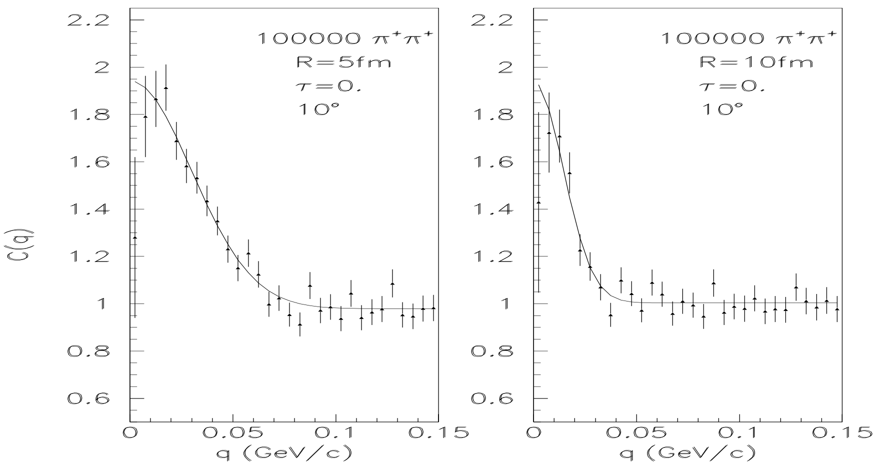

Figure 3: Predicted quality of two-particle correlation measurements at 10 deg. See text for details

2.2 Two Particle Correlations

The correlation of like-bosons as a function of the relative momenta can provide a measure of the space-time extent of the emission source [6,7]. Pair correlation coupled with single-particle measurements is thought to help in providing a good understanding of the dynamics which control the evolution from the initial hot dense phase to the system at freeze-out. A detailed description of the HBT capabilities can be found in ref. [16], in particular regarding the measurements and sensitivity in the mid-rapidity spectrometer. Here is shown an example of the kind of measurement which can be done at the higher rapidities utilizing the forward spectrometer arm. The pion correlations are simulated using a simple gaussian correlation function $C(q) = 1 + \lambda e^{-(q^2R^2+q_0^2\tau^2)}$, where q is the magnitude of the relative 3-momentum, R the source radius, q_0 the relative energy, and τ the lifetime parameter. Here τ is explicitly set to 0. Pairs of pions are accepted through the spectrometer at 10^o with an momentum acceptance of $1 \leq p \leq 3$ GeV/c. The extracted correlation function for 100,000 π^+ pairs is shown for two representative samples with R=5 and 10 fm. Additional studies using the Bertsch-Pratt parametrization [9,8] has shown that in this same rapidity range BRAHMS has sensitivity to and capabilities to perform multi-dimensional analysis in terms of R_{long},R_{side} and R$_{out}$. The simulation illustrates that for a limited range of rapidity and momenta the forward spectrometer has sufficient resolution and two-particle separation to

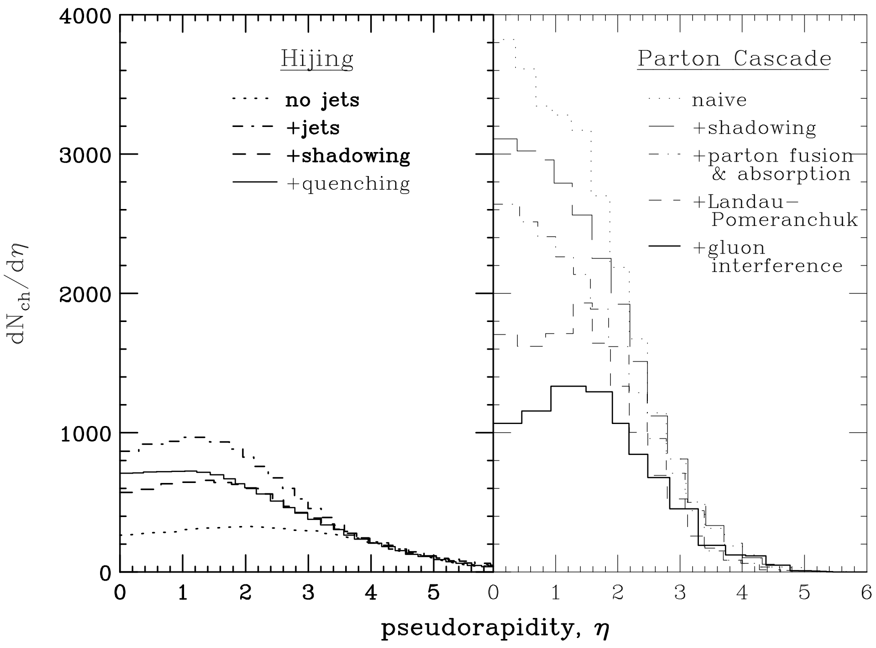

Figure 4: Prediction for dn/dη for charged particle distributions

make modest measurements of pion-correlation functions.

2.3 High p_t Measurements

In contrast to the heavy ion experiment carried out so far at AGS and SPS, initial hard scattering processes are important for the reaction dynamics at RHIC. The importance is known from the mini-jet production at ISR energies and as evident in the inclusive hadron spectra measured from $\sqrt{s} = 50 - 1800$ GeV in p+p reactions. A hard component is observed for $p_t \geq 1.0$ GeV/c. This hard component has two aspects of consequence in heavy ion reactions. The initial fast parton scattering contribute significantly to the formation and equilibration of a hot dense system [10] and to the particle production. Nuclear effects such as jet quenching and gluon shadowing are expected [11] and can be studied in inclusive mini-jet distributions [12]. The prediction from the HIJING model and the Parton Cascade model [13] of the total charged particle rapidity distributions on this is shown in fig.4. The various physical processes are turned on successively. The parton shadowing is determined mainly from the gluon structure function, and the quenching is dominated by the gluon brehmsstralung energy loss in the nuclear medium. It is observed that depending on the rapidity region the different processes contribute with different weights. Likewise, p_t dependencies are present. Measurements at different rapidities, and in a p_t in a range as large as possible, up to 5-6 GeV/c, will be a mean to experimentally determine constrains on the various mechanisms. Comparison between different collision systems will also be important for this task.

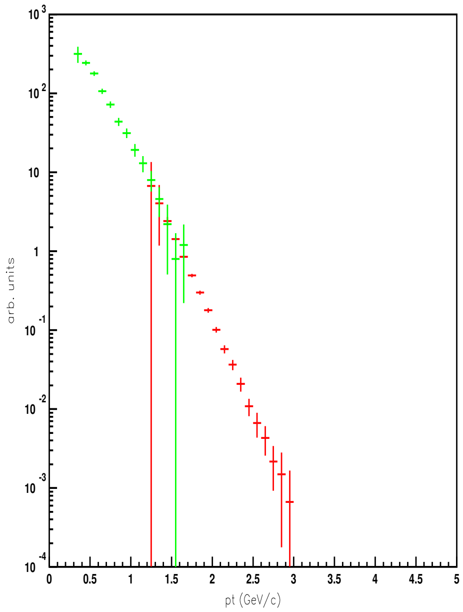

Figure 5: Predicted p_t spectrum for π at y=2.0 as measured in about 1 week of running for Au+Au central collisions.

As an example of the feasibility of this kind of studies, a simulation was performed for a measurement of π^+ at rapidity 2 in central Au+Au collisions. A sample of pions from a distribution with inverse slope parameter of 170 MeV (in m_t) and a $\frac{dn}{dy}$ of 200 was fed through the GEANT simulation of the forward spectrometer and the p_t spectrum reconstructed in two settings of the magnetic field. The resulting p_t spectrum which can be obtained in about 1 week of running is displayed in fig.5. In about another week the measurements can be extended to about 6 GeV/c with similar statistics using larger bins in

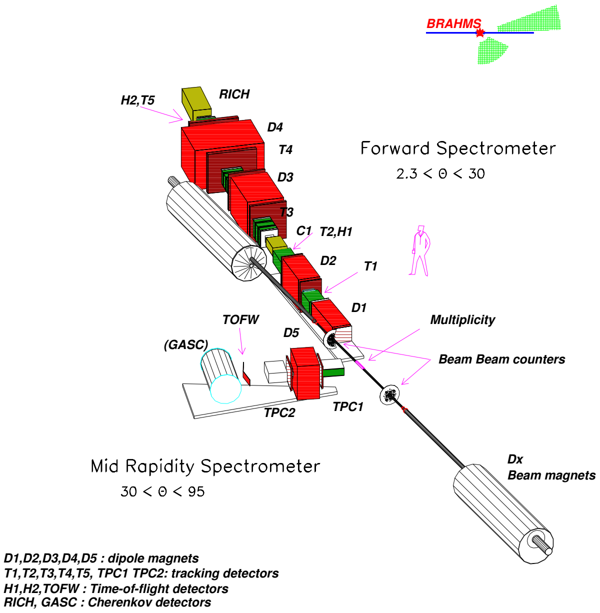

Figure 6: Top view of spectrometers. The labelled detector elements are described in the text.

Δp_t of .5 GeV/c. This demonstrates that high quality spectra can be collected up to rather high values of p_t. It should be stressed that these measuremnsts are for identified hadrons, and thus can also be done for kaons, protons, and anti-protons, studying the flavor dependence.

3 The Spectrometers

This section gives only a brief description of the BRAHMS detectors. For more detailed information the reader is referred to in references [14,15,16]. A perspective view of the two moveable spectrometers is shown in figure 6.

The BRAHMS experiment is designed to measure well identifiedly charged hadrons ($\pi^{\pm}, K^{\pm}, p^{\pm}$) over a wide range of rapidity and transverse momenta at all energies and beams available at RHIC. The very different experimental conditions, momenta, and particle densities at mid-rapidity and forward angles has lead to the design with two moveable magnetic spectrometers. The Mid-Rapidity Spectrometer (MRS) covers the angular region $30^o \leq \Theta \leq 95^o$ $(-.1 \leq \eta \leq 1.3)$ and the forward spectrometer (FS) the region $2.3^o \leq \Theta \leq 30^o$

($1.3 \leq \eta \leq 4.0$). FS consists of 4 dipole magnets (D1-D4), two time projection chambers (T1,T2) and three drift chamber packages (T3-T6). The particle identification is done by combining time-of-flight measurements in the hodoscopes H1 and H2 with measurements in the threshold Cherenkov counter C1 and the Ring Imaging Cherenkov Counter (RICH). The H1 and H2 consists of 48 and 32 scintillator slats instrumented with PMT at each end. This allows for particle identification in the momentum range 1-20 GeV/c in the forward spectrometer. The mid-rapidity spectrometer has two TPCs (TPC1 and TPC2), a dipole magnet (D5) for momentum measurements, a time-of-flight wall (TOFW). The experiment Conceptual dseign report included a segmented gas Cherenkov detector (GASC) for particle identification in the momentum range $p \leq 5$ GeV/c. It was deferred due to reduction in the funding of the experiment. The TPC all have driftlengths of about 20cm and the gas is a Ar-CO_2 mixture with small longitudinal and transverse diffusions coefficients. Each TPC will have up to 1152 pads read out with the STAR Front End Electronics into a BRAHMS optics-fiber receiver board. The momentum resolution is typically $\delta p/p \leq 0.01p$, which is sufficient for tracking considerations and the spectral measurements.

Three event characterization detector systems will provide global information, namely the Beam-Beam counters, a multiplicity detector and a Zero-Degree calorimeter (ZDC). A set of Beam-Beam counters provide the initial trigger and vertex information as well as the start time for the time-of-flight measurements. Each of the elements of the Beam-Beam counters consists of 3.5cm UVT Cherenkov radiator read out by PMTs. There is a total of 35 and 42 elements in the left and right counter, respectively. A multiplicity detector will be characterize the centrality of the collisions in the mir-rapidity region. It is a hybrid detector consisting of 24 segmented Si-detectors for a total of 168 channels , and 40 scintilator tiles (12*12cm) covering the pseudo rapidity range of $-2.2 \leq \eta \leq 2.2$. The Si detectors will provide a detailled response, while the main purpose of the tiles is to provide a fast trigger for centrality selection. Zero-Degree Calorimeters [17], that will be a common devices for all RHIC experiments, are situated behind the two DX beam magnets. They will partly be used to measure the luminosity in Au Au collisions, and partly to measure geometric collision conditions by measuring forward going neutrons. Together the three systems will provide centrality coverage in the mid-rapidity region $-2.2 \leq \eta \leq 2.2$, in the region $3.2 \leq |\eta| \leq 4.3$ and at zero degree.

4 Status and Plans for first year Running

Even though the BRAHMS experiment was first considered part of the RHIC program by approval of the Letter of Intent in 92, only since August 97 has it been an approved RHIC DOE construction project. Full funding was received in October. A small amount of pre construction funds were available to support engineering efforts and the ordering of a few long lead items for the magnets.

As of today (August 98) the construction is well underway. The magnets D1, D2 and D5 are complete; D3 and D4 are expected to be assembled later this year. The infrastructure of the experiment, i.e. intersection region modifications, water systems, electric systems, and counting house are either complete or in procurement. The TPCs have been completed, ready to be instrumented and chekced out with beam. Time-of-Flight systems of fairly conventional design are in detailed design phase and construction is about to start. The C1 and RICH construction has started. Prototypes of these Cherenkov detectors have been tested [18]. The design of the global detectors is in its final phase.

Despite the compressed construction schedule, significant parts of the detector will be ready for the RHIC commisioning run in June 99. The mid-rapidity spectrometer, and the front part of the forward spectrometer will be in place, together with ZDC and beam beam counters for this short running period. It is expected that the back end of the forward spectrometer with its detectors will be ready for the first year of RHIC running with an expected start of November 99.

During the first year of RHIC running, significant time will be spent on machine studies. Only later during the year is it expected that significant integrated luminosity can be obtained. The inital instantaneous luminosity will be about 1% rising toward 10% of the design luminosity at the end of the year. The early activities of the experiment will clearly be in commisioning the detector, understanding spectrometer settings, trigger conditions, and backgrounds.

Some of the first physics results will come from the global detectors, yielding multiplicity distributions. From the spectrometers is planned a survey of p_t distributions for selected rapidities y=0, 0.5, 1, 1.5,2 and 3) up to p_t of $\approx$ 1GeV/c restricted by magnetic field, PID, and luminosity capabilities in the first year of running. This should yield high quality spectra of $\pi^{\pm}$,$K^{\pm}$ and $p^{\pm}$ as function of centrality.

Summary and Acknowledgments

This paper has presented some of the physics goals, the design, and the expected data from the first year of RHIC running with the BRAHMS spec-

trometer. It is supported by a collaboration consisting of about 50 physicist from BNL, CRN-Strasbourg, The Niels Bohr Institute, Texas A&M, New York University, Harbin Technical University, U.C. Berkeley Space Sciences Laboratory, the University of Kansas, and the Jagelloian University-Krakow, the University of Oslo, the University of Bergen, and the University of Lund. This work was supported by the US Department of Energy under contract with BNL (DE-AC02-98CH10886).

References

1. F.Videbæk and Ole Hansen, *Phys. Rev.* C **52**, 2684 (1995)
2. B.Andersson, G.Gustafson and B.Nielsson-Almquist, *Nucl. Phys.* B **281**, 289 (1987)
3. H.Pi, Comp. Phys. Comm **71**, 173 (1992)
4. K.Werner Z. Phys.C **42**, 85 (1989)
5. Th.Schönfeld,H.Stöcker,W.Greiner and H.Sorge, Mod.Phys.Lett **A8**, 2631 (1993)
6. G.Goldhaber *et al. Phys. Rev.* **120**, 300 (1960)
7. F.B.Yano and S.E.Koonin, *Phys. Lett.* **78B**, 556 (1978)
8. S. Pratt, *Phys. Rev.* D **33**, 1314 (1986).
9. G.Bertsch. *Nucl. Phys.* A **498**, 173c (1989)
10. E.Shuryak. *Phys. Rev. Lett.* **68**, 3270 (1992) 3270.
11. A.Mueller *Nucl. Phys.* A **610**, 459c (1996)
12. X.N.Wang and M.Gyulassy, *Phys. Rev.* D **44**, 3501 (1991)
13. K.Geiger *Phys. Rev.* D **47**, 133 (1993)
14. BRAHMS conceptual Design Report, October 1994, BNL-62018; WWW URL http://www.rhic.bnl.gov/export1/brahms/WWW/brahms.html
15. F.Videbæk, NPA **566**, 299c (1994) Workshop QM95.
16. D. Beavis, "Physics with the collider detectors at RHIC and the LHC",11(1995). Report UCRL-ID-121571
17. See e.g. WWW URL http://www.rhic.bnl.gov/ for more detailed information.
18. R.Debbe et.al. *Nucl. Instrum. Methods* A **371**, 327 (1996).