Beam Use Proposal For RHIC Run IV and beyond (FY 2004+)

The BRAHMS Collaboration

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1. Beam Request Overview

With the significant progress already made by the BRAHMS experiment, it should be possible to complete the program initially described in the experiment's CDR in the next few years. This proposal summarizes what has been accomplished and what yet remains from our initial experimental program. The proposal also discusses the new results from BRAHMS and the other RHIC experiments that influence the details of how we plan to proceed. Because of these new physics opportunities, we propose a modest extension to our baseline program, while retaining the essential survey nature of the investigations.

The following has been proposed – since it is still in its infancy should we really have it here. An informal letter will be written to Kirk on this same timescale.

Discussions have been initiated on a new, refocused, forward-physics experiment to be implemented after completing of the BRAHMS baseline program. Some initial areas of interest are indicated, but a formal Letter of Intent will be presented at a later time.

2. BRAHMS Experiment and Physics Goals

The BRAHMS experiment has unique capabilities for precise momentum determination and particle identification for studying relativistic heavy-ion collisions. The forward spectrometer (FS) is unique within the family of RHIC experiments in that it can identify hadrons up to rapidity $y = 4$, and covers a large momentum and transverse momentum range. The excellent Particle Identification (PID) and angular coverage of the Mid-Rapidity Spectrometer (MRS) extends and complements measurements by the other RHIC detectors, and it provides for comparisons between mid-rapidity and forward-rapidity spectra.

Despite the small solid angles of the spectrometers, p_t spectra of identified particles can be measured up to 3-5 GeV/c and at several rapidities with a readably obtainable integrated luminosity. This permits, for example, studies of high p_t-suppression in heavy ion reactions over a wide rapidity range.

Results from the BRAHMS experiment obtained in RHIC runs I-III.

The near term plans of the collaboration for RHIC runs IV to VI emerge naturally from the first results that have been obtained from the commissioning run at $\sqrt{s_{NN}}$=130 GeV (run I), the first major run at the design energy $\sqrt{s_{NN}}$ = 200 GeV for Au+Au collisions (run II), and the p+p and d+Au runs at the same energy of 200 GeV in runs II and III.

The data taking in these runs has been characterized by a first mapping of the global features of the reactions listed above exploiting the unique features of the BRAHMS experiment, namely the ability to study a large region of the (y, p_t) space with excellent particle identification for charged hadrons over a wide range in momentum and rapidity The time estimates for completion of the program made initially were based on the design estimates of the integrated luminosity at RHIC. It is clear that the integrated luminosity and diversity in species that has been delivered so far has not been sufficient to complete our baseline program. In addition, a number of very interesting new physics topics have been identified which the collaboration wish to investigate in greater depth. These topics tend either to involve low production cross section events, such as those leading to high p_t particles, or the measurement of correlations among particles. In either case, measurements with higher integrated luminosity are needed.

Below we briefly summarize our main accomplishments to date. These have led to a number of publications, with several additional papers currently being prepared.

Publications

- Rapidity density of charged hadrons at $\sqrt{s_{NN}}$ =130 and 200 GeV [1,2]. These studies establish the baseline charged-particle pseudorapidity densities in Au-Au collisions over a wide pseudorapidity range.
- Hadron to anti-hadron ratios at $\sqrt{s_{NN}}$ =130 and 200 GeV. The particle ratios constrain dynamical models, and establish that a system is formed that is consistent with being in chemical equilibrium over a wide rapidity range[3,4]
- Nuclear modification factors in Au-Au and d+Au collisions at $\sqrt{s_{NN}}$ =200 GeV. Despite the small solid angles of the BRAHMS spectrometers, their capabilities can develop unique information about high p_t suppression,. A Letter has recently been published on the Au+Au R_{AA} distributions at η = 0 and 2.2 and for the d+Au data at y=0 [5]. Further analysis will focus on identified

hadrons in particularly at higher rapidities. The d+Au data at higher rapidity has been collected and are being analyzed .

Papers in preparation

- Run II yielded sufficient data to map the net proton rapidity distributions at $\sqrt{s_{NN}}$ =200GeV for Au+Au collisions, demonstrating that at RHIC the rapidity scaling for AA energy loss [Ref. ?] is broken.
- Yield of charged hadrons vs. rapidity at $\sqrt{s_{NN}}$ =200. One remarkable result is the demonstration of nearly Gaussian rapidity density distributions, in contrast to the naïve expectation of nearly flat Bjorken boost invariant distributions.
- Centrality dependence of identified hadron yields at mid-rapidity.
- Rapidity dependence of deuteron and anti-deuteron coalescence factors at $\sqrt{s_{NN}}$ =200GeV.
- The pp experiments in run II and run III have so far been analyzed for ratios of charged hadrons vs. rapidity in $\sqrt{s_{NN}}$ =200 GeV p+p collisions, and will be contrasted with the AA ratios.
- Yield of charged hadrons and p_t dependence vs. rapidity in p+p collisions at $\sqrt{s_{NN}}$ =200GeV.
- Pseudorapidity density distributions vs. centrality for d+Au collisions over a wide pseudorapidity range.

2.2 Present Detector configuration

The BRAHMS detector consists of 3 major spectrometers:

- The Front Forward Spectrometer (FFS), consisting of 2 magnets, tracking and time-of-flight detectors, and a threshold Cherenkov detector, is moveable from 2.3° to 30° ($1.3 < \eta < 3.9$)
- The Back Forward Spectrometer (BFS), consisting of 2 magnets, tracking and time-of-flight detectors, and a ring-imaging Cherenkov detector, is used in combination with the FFS to measure in the angular range from 2.3° to 15°. ($2.0 < \eta < 3.9$)
- The Mid-Rapidity Spectrometer (MRS), consisting of a single magnet, tracking and time-of-flight detectors, is moveable from 30° to 95° ($0< \eta < 1.3$). The particle identification was enhanced during run III with the installation of a threshold Cherenkov counter that allows us to identify charged pions in the momentum range of 3.5 to 6 GeV/c. Too a second time of flight wall (TFW2) that extends PID for protons/kaons was added.

BRAHMS has a set of global detectors that are used for event characterization, triggering and timing:

- The Centrality detector consists of an inner layer of Si-detectors and an outer layer of large scintillator tiles covering the range of about $-2.2 < \eta < 2.2$.

- The Beam-Beam counter array provides accurate start timing information to the experiment, rough vertex determination, and multiplicity measurements at high $|\eta| \sim 3\text{-}4$.
- The Zero Degree Calorimeters (ZDC), a device common to all RHIC experiments, provide luminosity information and online vertex trigger and neutron multiplicity at 0^o and 180^o.
- Inelastic counters observe ~85% of the non-single-diffractive pp cross section that provide trigger and vertex information in pp collisions.

2.3 Detector upgrades for RUN-4

In anticipation of higher luminosity Au beams, spectrometer trigger detectors for both the MRS and FS are being constructed and will be installed to provide efficient triggering for peripheral collisions. VME electronics has been developed for the trigger setup. A portion of the Si-detector system will be reconfigured to allow for event-plane determination in Au-Au collisions. A new flow detector is being prototyped, and will be added to the experiment, hopefully for an extended part of the RUN-4.

2.4 Physics Program

High-pt suppression

A tool for understanding the initial partonic state is to study identified high p_T hadrons over a range of rapidities. BRAHMS is uniquely capable of studying the evolution of the high p_t components of hadronic spectra over several units of rapidity. Recently all RHIC experiments have reported suppression of high p_T spectra compared to expectations from pp collisions [6] near midrapidity. BRAHMS, with its extended pseudorapidity coverage, also observes this suppression at y~2. The suppression may result from the energy loss of quarks and gluons passing through a dense partonic system. The continued suppression out to y=2 provides information on the longitudinal extent of this dense system. In the next set of measurements we will explore the suppression signature at even larger rapidity.

The study of particle spectra in the p_t range of 1-4 GeV/c will help in the understanding of initial scattering (Cronin) effects, gluon shadowing effects and jet quenching. The relative importance of these processes depends on energy, rapidity and the mass of the collision system. Initial results from 130 and 200 GeV Au+Au collisions demonstrate that the nuclear medium modifies the spectra. Systematic studies may disentangle effects related to a ‘cold’ versus a ‘hot’ medium, and to the density of the medium. At higher rapidities (~3-4) the shape of the pion spectra may allow the study of the Color Glass Condensate (gluon saturation) in the initial state [3] in p(d)A reactions.

Bulk properties

In Run II BRAHMS investigated the multiplicity density, transverse flow as deduced by $<p_t>$ and spectral shape. These data were interpreted with the statistical model framework as baryon and strangeness chemical potentials, and the chemical and thermal freeze-out temperatures as a function of rapidity. From the proton and antiproton rapidity densities we can deduce the net energy loss of the beam and projectile. Together these measurements strongly constrain models in terms of their longitudinal development. We wish to extend these measurements to the highest rapidities allowed by the detector and beam line geometry (2.3^o), which will allow us to better determine the net-proton distribution and relate our measurements to current models and measurements at at lower energy.

Collective flow

The analysis of radial and elliptic flow gives access to information on the temporal and spatial development of pressure within the hot strongly interacting system. The ability to detect the reaction plane will open up a new dimension for the BRAHMS' study of heavy ion collisions. Besides measuring the full three dimensional cross section, $d^3N/d\varphi dp_t dy$, and R_{AA} factors, we can also study the φ and p_t dependence of coalescence at different rapidities. Such studies will be essential in determining the equation of state of the hot dense, and presumably partonic state of matter produced at RHIC.

Particle correlations

Interferometry and nucleon and anti-nucleon coalescence allow us to measure the final state of the system as it breaks up. The “HBT puzzle” at RHIC is the striking similarity of the outward and sideward correlation functions and the lack of any dependence of the radii on $\sqrt{s_{NN}}$. NA44 at SPS has combined π, k and p interferometry and coalescence measurements to determine the transverse flow of the system [4]. However, at high expansion velocities one would expect hydrodynamics to break down and, indeed, some evidence for this effect in high pion interferometry may be seen. We will study coalescence at both high rapidity and at higher p_t values to address these issues, and will collect data for HBT analysis in conjunction with other data taking. Combining interferometry and coalescence volume information with single particle momentum spectra will allow us to measure the density of particles in phase space [5]. Integrating this density can reveal the entropy of the system. Finally comparing the formation of nuclear clusters and anti-clusters will help us understand the time interval between hadronization and thermal freeze-out.

System size dependence

Light ion collisions such as Fe+Fe will allow us to study hot nuclear systems with ~ 10 to 100 participants. This region of system sizes is not accessible with Au+Au collisions since it is very difficult to accurately determine the number of participants for peripheral events. The collision geometry for central collisions in a light system is similar to Au-Au the main differences being the radial extension. With a light projectile like Si or Fe the matter length for suppression of high pt particles is about half of that in AuAu, but likely with quite similar energy densities. This increased lever arm will be very useful for studying models of particle production but perhaps more importantly will allow us to study high p_t suppression as a function of system size. BRAHMS can study this effect at $\sqrt{s_{NN}}$ = 200 GeV. Finally it would be interesting to see if the coalescence radius decreases significantly when we reduce the number of participants by a large factor.

Energy systematic of heavy ion collisions

The study of bulk properties vs. available energy has been a key signature of nuclear physics, and has in general led to a better understanding of the reaction mechanism and the dense system formed. At present the highest SPS energy is at ~18 GeV, and the lowest RHIC data that are well studied is at 130 GeV. There is a significant change in stopping between SPS and RHIC with the former significantly stopped, and rather transparent at RHIC . An intermediate energy such as 63GeV for which some, albeit lower statistics and less systematic data exists for pp collision (ISR), would add well into the overall systematic understanding. At this energy Brahms can measure essentially into the fragmentation region, and explores both stopping and the complete shape of produced mesons, as well as limiting fragmentation for identified particles. This will place additional stringent limits on the theoretical understanding of stopping, energy loss and transparency. The rapid disappearance of high pt jet-like particles unfortunately makes a study of high pt suppression at lower energy statistically very difficult with Brahms, but we can make a measurement up to ~ 4GeV/c at y~1.

Nucleon-Nucleus (d-Au) collisions

At RHIC energies, where partonic degrees of freedom are relevant, the dA (or pA) system was early identified as one with identical partonic interactions as A-A systems but without the colored and highly opaque region that the latest measurements indicate has been formed in the A-A collisions.

Meanwhile, results from Deep Inelastic Scattering started to show hints of possible new physics as these experiments probe smaller values of x in e-p collisions. At high energy, the structure of the proton can be resolved as being populated by many gluons with a density that must reach a limit as x tends to zero. If the target of DIS is replaced by a nuclei, the density of gluons or the relevant momentum scale of the system grows as A^1/3 making it easier to identify the condensate (Color Glass Condensate) in e-A or p-A reactions. These arguments brought forward the possibility of finding saturation at RHIC. The original work on the possible studies of CGC at RHIC focused on a formalism based in a 2 to 1 partonic reaction that offered an acces to the small x components of the wave function of the nuclei whenever the single parton product of the fusion had high rapidity. This is the kind of physics that BRAHMS is well suited to pursue.

Proponents of the CGC state went as far as to say that the coherence hinted by the particle production in A-A would also

be present (reduced by sqrt(2)) in dA, but the measurements have shown different results; a reduced Cronin effect visible in charged hadrons, and a marked difference in the behavior of neutral pions. These results do not exclude the formation of the condensate. They corroborate earlier statements where the x value of the interactions at mid-rapidity was set to be around 0.01; too high to be sensitive to high gluon densities. The formation of the CGC is still possible at forward rapidities and if this new description of nuclei at high energy is true, a detailed program to study its properties should be considered not only because it is a novel state of matter but because it also provides a well defined initial state for the Quark Gluon plasma that is the main focus of RHIC.
BRAHMS has collected a sample of dA data at mid-rapidity and at 4 degrees. Without the benefit of our particle identification systems we can study charged hadron spectra that extend up to 5 GeV/c at mid-rapidity and have published those results together with the other three RHIC experiments. At 4 degrees our sample is smaller and extends only out to ~4 GeV/c
The collaboration would like to be able to complement our sample of dA data in order to be able to make the now considered standard "nuclear modification factors" for each particles species and also to make systematic studies as function of the "centrality" of the collision. We would also like to study rapidity distributions for samples of events with different transverse momenta.

Proton-proton

Transverse Asymmetries for charged pions.

(Physics section from Brendan)

In addition to these topics the collaboration is developing the tools for measuring and analyzing the charged pion asymmetry at higher x_F values in polarized p+p reactions. Towards this end we have established a collaboration with the RIKEN spin group . During the run-3 pp run it was established that the systematic errors on the asymmetry can be kept below .5%.
PS: I have seen and commented on a very good raft of this content, that is ready by late today Thursday or early Friday. The arguments for An is put forward for an early measurement as well as follow-up on more luminosity insensitive measurements (pi- an Kaons).

Completion of Survey program

The Run-II and Run-III pp program yielded some results for general survey of elementary collisions at $\sqrt{s_{NN}}$ =200 GeV to be contrasted with Au Au at the same energy. The statistics obtained at relative high pt (3-4) and at large rapidity (2,3) were marginal and only obtained for one charge state (negative.) The Pythia model predicts quite significant differences between $\pi+$ and $\pi-$ Since these are not necessarily well predicted due to lack of experimental data for identified particle at larger rapidities, and these are of importance for the high pt suppression interpretation in Heavy Ion collisions, we wish to supplement these measurements.

3. Beam Request

The following beam request is divided into two sections , the first by identifying the specific measurements that BRAHMS wants to do in order to complete the baseline physics program, and the second section mapped onto specific budget scenarios of 27 and 37 cryo weeks, respectively. These sections outline a program that is both true to the goals of the original proposals and CDR, and to a follow-up of the more recent discoveries at RHIC manifested in the high pt suppression and the hydrodynamic nature of the collisions via the elliptic and transverse flow. We believe the program outlined is essential for the present discovery and survey phase of the RHIC heavy ion program.

Au-Au collisions at 200 GeV

BRAHMS has carried out a first mapping of hadronic production as a function of rapidity. Because the delivered luminosity has been considerably lower than design, the data from runs II and III were at only a few selected angles and with momentum settings that maximized the counting rates. The high-pt measurements at y~2 demonstrated this effect persists at high rapidity, and we wish to carry out a high quality measurement near y~2.5 where the dn/dy in central collisions is about ½ of the central value. The high-pt measurements are in addition also the most demanding in terms of statistics needed. The quality of the Brahms PID at forward rapidities will also allow us to study the suppression of identified hadrons thus illuminating the interesting issue of proton to pion enhancement in the pt-range of 1.5-3 GeV/c.

In summary, the Au+Au program for 200 GeV, which we would like to see done in run IV, is tabulated below. The measurements at y~1 and y~0 can be preformed in parallel with those of the forward spectrometer(high rapidity) which in fact sets the size of the request.

1. Collect high statistics for high p_t spectra at y~2.5 and y~3.5 for both charge states (100 +40 μb^{-1}).
2. Flow (v2-measurements up to about p_t~2 vs. centrality) p_t~3 overall. (40 µb-1)
3. Supplement existing lower p_t data where needed. (40 μb^{-1})

4. Perform simultaneous coalescence measurements at y~2.5. Part of this will be done under 1, but requires additional settings (20 μb-1)

The simultaneous measurements in the MRS will concentrate of higher field running at y~1 collecting higher p_t data at y~0 and y~1 utilizing the new Cherenkov for pion identification. (100 μb^{-1})

Thus to complete this set of measurements we will need to have ~ 240 μb^{-1} μb-1 delivered to IP2.
The estimates given above are made assuming that ~50% of collisions falls within within +/-20cm of the nominal collision point, and that the Brahms combined up and DAQ live time is ~70%, which has been achieved so far.

Fe-Fe at full energy

The focus will be on measuring the higher pt region of identified particle at y~1 and y~2.5. This will help in disentangling the importance of medium size vs. energy density experimentally, leading to a greater understanding of the phenomena observed with Au-Au at 200 and 130 GeV.

- Identified charged hadrons at y~1 and 2.5 (xxx nb-1)
- Complete rapidity distribution for net-protons (baryons) (xxx nb-1)
- Particle composition, and strangeness production vs rapidity (xxx nb-1)

It is our understanding that Fe is a beam quite readable available from the injectors into RHIC with expected high luminosities.

Au-Au at lower energy.

Running at reduced energy (e.g., at $\sqrt{s_{NN}}$=63 GeV) for Au+Au collisions will be of paramount importance for understanding the interesting signals that have emerged from the RHIC runs at maximum energy, notably studies of high p_t suppression and also the systematics of charged hadron spectra (e.g., kaon slopes) which may reveal features characteristic of a phase transition. In addition, BRAHMS has the unique ability to measure essentially the full net baryon distribution vs. rapidity at a lower energy. This will place additional stringent limits on the theoretical understanding of stopping, energy loss and transparency.

The very much reduced expected luminosities (~3-9 times less than at full energy) implies that only a few focused measurements will be performed for the high-pt measurements due to the solid angles of brahms spectrometers. Complete rapidity distributions for soft physics particle production will be obtaine.

1. High-pt measurement at y~1 (20 μb-1) (MRS)
2. Survey of net-proton distributions utilizing the FS (10 μb-1)

p-p at 200 GeV

Yield section from Brendan.

We wish to complete the reference data set at $\sqrt{s_{NN}}$ of 200 GeV that was taken during RUN II. One emphasis is to record reference spectra at intermediate to high p_t (2-5 GeV/c) in order to compare to pA and AA reactions. The other objective is to complete measurements of reference rapidity distributions and particle yields for ion-ion collisions; the request is for ~ 2 pb^{-1}

FIXME: Be more specific for the pp reference. (+/- for y~2.2 and 3 I think) and recheck the luminosity numbers requirements

<u>Preferred Distribution on Running periods</u>

The overall request for BRAHMS baseline program, i.e., for the coming few years, is based on the physics outlined above and translates to the following requested delivered luminosities to BRAHMS. This is done under the assumptions that in Run-4 the IP-2 is at beta* of 3, and with a very modest upgrade of power supply distribution in the triplet with beta* of 2 in subsequent years. Further for conversion to weeks it is assumed that the luminosity development is in the middle of the estimates by Roser in the August 20 document.

Beam Species	Energy	Luminosity	Approximate no wks.[1]
AuAu	200	240 μb-1	24
FeFe	200	**FIXME (2nb-1?)**	8
AuAu	63	20 μb-1	6
pp	200	2 pb-1	6
Au-d,-Au	200		

[1] The required luminosity is translated into weeks assuming β* =3 for Brahms, and selecting a scenario for luminosity development above the minimum given by T.Roser, at roughly ½ the maximum expected range. Recall that his tables are for β*=1, i.e. Phenix and Star. The second number is the time needed for Brahms to set up before physics running (i.e. part of the 2+3 week setup + ramp up period). It is our experience that only a very small amount of this time is useful for the experiment, and data collected during this period has not been useful in the past (short runs, unstable beam conditions, much better runs later in run period).

Thus under optimal conditions this program can be carried out in the next 2-3 years depending on the amount of running weeks available to RHIC.

27 cryo weeks scenario

Run-4	Au-Au 200 GeV	19
Run-5	FeFe 200 GeV	8
	pp 200 GeV survey pp 200 GeV transverse An	2 2
Run-6	Au-Au 63 GeV AuAu 200 GeV	6 5

37 cryo weeks scenario

Run-4	Au-Au 200 GeV	19
	Au-Au 63 GeV	6
	pp 200 GeV	4
Run-5	FeFe 200 GeV	8
	Pp 200 GeV	8
Run-6	Au-Au 200 GeV	2

The BRAHMS collaboration has a strong preference, in part because of the commitments that the Danish and Norwegian groups have to ALICE (which is expected to start taking physics data in 2008, but with construction completed before then), and in part because the physics program is part of the RHIC heavy ion survey and discovery phase, that the heavy ion program be given priority for the next few years, with the polarized pp program during this time emphasizing development and measurements requiring only short run periods.

We want to comment too on the Brahms Heavy Ion program in relation to the overall Spin program that is being developed at RHIC, primarily a Phenix and Star effort. We understand that machine development time I needed to make this endeavor successful. Should it be determined that a pp beam commissioning will take place at the end of run-4 as requested by T.Roser, we will like to make clear that this offers an opportunity for a short run for Brahms to perform the first measurement of Ann for π+ at xF ~.25 as outlined in the request for ~ ½-1 week.

<u>Summary of Request.</u>

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FIXME: Update publication/ref list to relevance. With the writing.

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