Beam Use Proposal For RHIC Run-5

The BRAHMS Collaboration

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Abstract

The BRAHMS collaboration proposes a long run with Fe-Fe at 200 GeV as its highest priority followed by 6 weeks of polarized pp at 200 GeV for Run-5. Our preliminary requests for run-6 are: additional d–Au running to improve our forward measurements relating to the issue of CGC, additional Au-Au at 62 GeV, and more transversely polarized pp at 200 GeV.

1. Introduction

This request summarizes what BRAHMS has accomplished and what remains to be done in our initial experimental program. This proposal also discusses the implications of new physics discoveries from BRAHMS and the other RHIC experiments and how they have influenced our physics program. Based on these new physics opportunities, we propose an extension to our baseline program for light ions focusing on high-p_T and high-y physics, while retaining the survey nature of the investigations. An improved d-Au experiment is proposed for the subsequent year. The case for the measurements of transverse asymmetries in polarized proton-proton collisions with BRAHMS is also presented in detail.

BRAHMS has made a first mapping of the global features in rapidity and p_T of the Au-Au, d-Au and pp reactions. By measuring the net proton distribution we have established an energy budget for Au-Au collisions [1]. This energy measurement is complimented by systematic studies of multiplicity versus pseudo-rapidity at $\sqrt{s_{NN}}$ =130 and 200 GeV [2,3]. These data have shown the steady increase of the fragmentation region with $\sqrt{s_{NN}}$. The longitudinal dynamics has been constrained by measurements of rapidity distributions for pions, kaons and antiprotons [4]. From our p_T spectra we have measured the rapidity and centrality dependence of transverse flow. Particle ratios at $\sqrt{s_{NN}}$ =130 and 200 GeV [5,6] are consistent with the system being in chemical equilibrium over a wide rapidity range. Nuclear modification factors in Au-Au and d-Au collisions at $\sqrt{s_{NN}}$ =200 GeV have been studied via measurements of transverse spectra at y~0 [7], and at high rapidities (η ~1,2, and 3) [8]. These data are vital to understanding the rapidity dependence of jet quenching and gluon saturation and thus a tool to disentangle physical processes involved. An extensive survey of BRAHMS results to date can be found in the QM04 proceedings [9] and the soon to be released white paper.

2.4 Physics Program

The BRAHMS experiment has unique capabilities for precise momentum determination and particle identification. The Forward Spectrometer (FS) is unique within the family of RHIC experiments in that it can identify hadrons up to rapidity y ~ 4. It 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 provides comparisons between mid-rapidity and forward-rapidity spectra with the same experiment setup. Despite the small solid angles of the spectrometers, p_T spectra of identified particles can be measured up to ~ 4 GeV/c with a readily obtainable integrated luminosity. The physics topics that BRAHMS intends to address in the coming years are discussed below. The program is mainly focused on issues that can be uniquely addressed by BRAHMS by studying the hot and dense system formed in heavy ion collisions in a systematic way as function of system size, collision energy, centrality, reaction plane and rapidity.

High-p_t suppression

The detailed measurements of high-p_T suppression by all the RHIC experiments have proven a powerful tool to identify and study high density matter [10]. The suppression may result from the energy loss of quarks and gluons passing through a dense partonic system. BRAHMS is uniquely capable of studying the evolution of the high-p_T components of hadronic spectra over several units of rapidity [5]. The continued suppression out to y=2 provides information on the longitudinal extent of this dense system. 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. Systematic studies may disentangle effects related to a 'cold' versus a 'hot' medium, and to the density of the medium.

System size dependence

Light-ion collisions such as Fe-Fe will allow us to study hot nuclear systems with ~ 20 to 100 participants. This region of system sizes is not easily studied with Au-Au collisions since it is difficult to accurately determine the number of participants for peripheral events. With a lighter projectile such as Fe the matter length for suppression of high-p_T particles is about half of that in Au-Au collisions, but likely with quite similar energy densities. This 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 factor of 12 jump in energy between SPS and RHIC has opened up several new phenomena to experimental study. Now that effects such as jet quenching, or increased transparency are well established it is important to study how they "turn on" with energy. The community began this work in Run-4 by studying Au-Au collisions at 62 GeV. BRAHMS focused on measurements of baryons into the fragmentation region, and on a high p_T suppression at y~1. The one-week run fell short of our request to explore stopping and the complete shape of produced mesons spectra, as well as limiting fragmentation for identified particles. We request run time to complete these measurements so as to place additional stringent limits on the theoretical understanding of stopping, energy loss and transparency.

We find that our pion dN/dy distributions are Gaussian with widths that are in agreement with the isentropic fluid dynamics of developed by Landau and implemented by Carruthers for massless particles[11,12]. At AGS and SPS energies the kaon rapidity widths are narrower than the Landau/Carruthers limit but at 200 GeV the kaon and pion widths are almost equal. A complete measurement at 62 GeV allows to test this.

Interpolating between our 200GeV measurements and lower energy data we expect the average baryon rapidity loss at $\sqrt{s_{NN}}$=62 GeV to be 1.8±0.2. This should put the peak of the proton distribution near y=2.5, well within our acceptance. At 200 GeV the ratios of particles measured in narrow rapidity slices can be described within the chemical framework of Becattini. The most important parameter affecting the ratios seems to be the baryo-chemical potential, which is controlled by the p-bar/p ratio. The baryo-chemical potentials in this region should be close to those observed at central rapidity by NA49. Comparing data at different $\sqrt{s_{NN}}$ but similar baryo-chemical potential would be a stringent test of thermal models.

Using the reaction plane

The ability to detect the reaction plane will open up a new dimension for BRAHMS' study of heavy-ion collisions by measuring the full three dimensional cross section, $d^3N/d\varphi dp_T dy$, and R_{AA} factors. Such studies will be essential in determining the equation of state of the hot dense, and presumably partonic state of matter produced at RHIC. For Run 4 we reconfigured our silicon detectors to give fine segmentation in the azimuthally angle φ. The analysis of these data is underway. Early results suggest that with an upgraded silicon array we will be able to measure the reaction plane for Fe-Fe collisions. The correlation between the reaction plane and spectrometer data will give information on the temporal and spatial development of pressure within the hot strongly interacting system.

Bulk properties

In Run-2 and Run-4 BRAHMS measured spectra of identified hadrons in Au-Au collisions $\sqrt{s_{NN}}$=200 GeV from which rapidity densities, $\langle p_t \rangle$, and spectral shapes were deduced. These results were used for the study of transverse flow and longitudinal dynamics for the reaction. Particle ratios as a function of rapidity were analyzed within the statistical model framework to determine the 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. In addition, global charged particle pseudorapidity densities have been measured using the BRAHMS global detectors. Together, these measurements strongly constrain models in terms of their longitudinal development. 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 BRAHMS' study of heavy-ion collisions by measuring the full three dimensional cross section, $d^3N/d\varphi dp_T dy$, and R_{AA} factors. Such studies will be essential in determining the equation of state of the hot dense, and presumably partonic state of matter produced at RHIC. The analysis of these data is underway, and is an important rationale for the choice of Fe as suitable light ion specie.

Nucleon-Nucleus (d-Au) collisions

Recent results from HERA have shown that at very small x the gluon density approaches a limiting value in a way that has received the name of "geometrical scaling" [13]. This raises the possibility that at RHIC the soft gluons from different nuclei may fuse to form a Colored Glass Condensate (CGC). Although the prediction from this model at mid-rapidity d-Au collisions had suppression at moderate p_T not consistent with the data that shows a clear enhancement, it is still possible that the CGC may exhibit a Cronin type enhancement and its presence may be detected as it evolves as function of rapidity. BRAHMS collected a sample of d-Au at higher rapidities during Run-3. The analysis of these data has shown that the RdA factor at η~3.2 is significantly below 1 at p_T~2.5 GeV/c. The same suppression was observed in the Rcp. This is consistent with the qualitative predictions of the CGC and in contrast to the prediction by Vitev [14]. Even though it is too early to rule out models without gluon saturation, the possible improvement in the data sample combined with an extended pt reach, warrant a call for additional d-Au running in the near future, in particular during Run-6. By focusing on measurements at large rapidities we expect to significantly be able to improve and extend our measurements at intermediate p_T for identified pions.

Transverse Asymmetries for charged hadrons in pp collisions.

In addition to these heavy-ion 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. A first set of data was taken during the 10 shift physics running in run-4.

The E704 experiment at Fermilab observed large (~30%) single-spin transverse asymmetries in pion production at forward angles from p-p collisions for $\sqrt{s}$ =19.4 GeV [15,16]. Because pQCD predicts only small effects, these observations spurred significant theoretical progress. Presently, it is recognized that, with the inclusion of intrinsic transverse momentum, k_T, pQCD calculations can predict such large asymmetries arising from, for example, the Sivers effect [17] (spin dependence of the k_T distribution of the proton), the Collins effect [18] (final state interactions of a transversely polarized quark fragmenting into a pion), twist-three contributions beyond the leading power picture [19], or a combination of these three. With precise measurements of these asymmetries at the higher $\sqrt{s}$ of RHIC (200 GeV), it may be possible to discern between these explanations because the predictions of each one exhibit different dependence on the energy. During Run-2 and Run-3, the STAR experiment measured this asymmetry for forward neutral pions [20] and found that it was as large as (if not slightly larger than) those observed by the E704 experiment. Given the excellent PID and momentum resolution achievable with the BRAHMS forward spectrometer, we propose to measure these asymmetries for positive and negative pions over the x_F region up to ~0.45 (y ~ 4) during Run-5 in order to provide a complete measurement of these quantities. In addition, we intend to measure the charged kaon asymmetries. These measurement would test the expectations based on the partonic content of the initial and final particles, namely that: the positive kaon and pion asymmetries would be roughly equal because the production process for both mesons is expected to be dominated by the valence u-quark and (2) the negative kaon asymmetry would be zero since the negative kaon is an all-sea object and the sea is basically unpolarized. If merited, we will also explore the p_t dependence of the asymmetry at fixed x_F in run-6.

3. Planning for coming run period.

The overall request for BRAHMS baseline program, i.e., for the coming few years, is based on the physics outlined above. This is done under the assumptions that as in Run-4 β^* =3 at BRAHMS , and with the recent guidelines from CA-D for expected luminosities. Under these conditions this program can be carried out in the next 2 years depending on the amount of running weeks available to RHIC.

The primary request and justification is for the upcoming Run-5. The collaboration will be discussing requests for Run-6 as analyses of the remaining d-Au data from Run-3 and the large dataset of Au-Au at both 200 and 62 GeV from Run-5 is progressing. A final outcome depends on this. The request presented for Run-6 thus constitutes what is at this point is viewed of high physics interest and what is lacking in the base-line program.

RUN-5

Fe-Fe at full energy

Probably the most interesting results from RHIC so far are high-p_T suppression, strong elliptic flow and saturation effects in the forward region. A full energy Fe-Fe run can illuminate all of these effects. If heavy ion collisions really create a perfect fluid the elliptic flow, v_2, should depend only upon the eccentricity of the collisions, and not on the mass of the colliding nuclei.

Preliminary BRAHMS' results from Au+Au suggests that the suppression of high-p_T particles observed at y=0 is still present at y=3. However our d-Au data also show some suppression at large rapidity, so the interplay between initial and final states effects is not clear. Studying Fe-Fe collisions in the forward region will help disentangle the effects of jet quenching; where the energy loss $\propto$ multiplicity, or A, and gluon saturation, where the saturation scale Q_S varies as $A^{1/6}$. The reaction plane will be another helpful tool in this analysis since jet quenching is larger in the reaction plane than out, [20] whereas gluon saturation should depend only upon rapidity and p_T. Our program will have two parts:

- **High p_T:** Our focus will be on measuring identified particles in the high p_t region of at y~1 and y~2.5. The request is for 4 nb^{-1}.
- **Rapidity distributions:** We will also make a survey of the soft physics by measuring the complete rapidity distribution and p_T spectra for pions, kaons and (anti) protons vs centrality. This should require 2 nb^{-1}.

It is our understanding that Fe is a beam quite readable available from the injectors into RHIC with good expected luminosities. The choice of Fe as ion specie is not unique; any of the proposed ions around mass 60 is a suitable substitute.

Polarized protons at 200 GeV

In Run-3, the BRAHMS experiment commissioned the necessary hardware for doing a spin measurement, namely a bunch-sorted spin scalers From the data collected while this module was operational, it was demonstrated that the systematic error for the relative luminosity measurement was below 0.3% prior to any corrections for the difference in the vertex distributions of each bunch. In Run-4, during the 10 shifts of physics running we took data for π^+ and π^-t eta~4. From the measurement still being analyzed we estimate that in order of a factor 10 is needed to extend the measurements to X_f 0.4. The request is for a minimum of ~2 pb^{-1} delivered to IR2. At the run-IV luminosities this corresponds to ~6 weeks of running.

- Transverse asymmetry measurements for pi+ and pi – at X_f ~ 0.2 to 0.4. The request is for 2 pb^{-1}.

RUN-6

The data from the d-Au have been revisited, and it has been realized that even with the present spectrometer modest upgrades and more effecient running can make a significant Improevemnt to the Run-3 data. Likewise we note that albeit the Run-4 low energy run with Au-Au was succsful, it fell short of our original request. Finally it is envisioned that some additional polarized pp running migh be of value. The program outline below is thus consituttes the possibilities from the BRAHMS point of view.

Au-Au at $\sqrt{s_{NN}}$=63 GeV:

The study of high p_T suppression at 200 GeV suggests interplay between final state and initial state effects in the forward region. The $\sqrt{s_{NN}}$ dependence of these effects is probably different and so a lower energy measurement should help us to understand the transition from hot (possibly partonic) matter near y=0 to a colder state, (possible dominated by saturation effects) in the forward region.

One surprising result of our measurements at 200 GeV was the finding that the longitudinal flow of pions is consistent with Landau's isentropic relativistic hydrodynamics [11]. The completion of our survey measurements at $\sqrt{s_{NN}}$=62 GeV will allow us to test how this longitudinal hydrodynamics turns on for heavy particles.

Completion of our survey of Au+Au collisions would allow us to evaluate the hypothesis of extended limiting fragmentation of identified mesons in Au+Au collisions and help us understand the relative importance of initial conditions and final state effects on the forward spectra.

- Completion of survey of net-proton, kaon and π distributions utilizing the FS. (8 μb^{-1})

d-Au at 200 GeV: Quantifying Saturation

In 2003 BRAHMS made measurement of d-Au collisions both as a reference for the high-pt suppression observed in Au-Au collisions and for a survey a large rapidities.. Our published results from this analysis have generated a great deal of interest within the community and calls for additional data at large rapidities. For Run-6 we wish to make a qualitative improvement on these results by improving the amount and quality of data recorded. Primarily this will be achieved by longer running times at desired settings, secondarily by making improvement to the present setup. This may include addition of tracking stations in the forward spectrometer, improvements in trigger efficiency, and enhancing of the centrality detector system. We believe that in a 6-10 weeks run an order of magnitude improvement can be made.

- High-pt measurement at y~3 and 1.5 for (π+ and π-) up to p_T~4 (~10nb^{-1}).

4.Summary

The request from the previous section is summarized in the table below. The request for Run-5 is firm, while the request for Run-6 is for a program that will complete the Brahms baseline program as well a adding a significant improved measurements of the high-rapidity, high-$_{pT}$ suppression at large rapidities.

Beam Species	Energy	Luminosity	Approximate no wks.
RUN-5			
Fe-Fe	200	6 nb^{-1}	8 –10
pp	200	2 pb^{-1}	2-6
RUN-6 (preliminary)			
Au-Au	62	8 μb^{-1}	~2
d-Au	200	10 nb^{-1}	6
pp	200	2 pb^{-1}	2-6 (contingent on outcome of run-5)

Table 1. Summary of requested species and luminosities.

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