Considerations for new d + Au measurement with the BRAHMS spectrometers

Abstract. This is a draft document that outlines arguments for BRAHMS to participate in a second d+Au run that is likely to happen in 2007. The main trust of this work concentrates on data taking at 4 degrees with the FS spectrometer and its benefits to p+A physics. We also propose to study particle production at backward rapidities to characterize events while studying the already known Cronin enhancements present at those rapidities .

1. Introduction

The rapidity and centrality dependence of particle production in d+Au collisions at $\sqrt{s_{NN}} =$ 200 GeV reported by the BRAHMS Collaboration have generated much interest because of their possible connection with the onset of gluon saturation in heavy targets at RHIC energies, the modification of the so called Cronin enhancements and shadowing by medium effects, as well as possible effects due to the proximity to kinematical limits. The BRAHMS measurements were based on comparisons of differential cross sections of charged particles produced in d+Au collisions to an incoherent sum of similar distributions obtained from nucleon-nucleon collisions at the same energy, (in this case binary collision scaled p+p) [1]. Similar measurements have been done at lower energies while studying energy loss in nuclear matter with p+A systems. Those studies have produced a prominent result dubbed the "Cronin enhancement" shown in Fig. 1, where a normalized comparison between particle production from proton collisions with a heavy target and proton-proton collisions at the same energy [2]. This phenomenon has been explained as multiple elastic scatterings at the nucleon or parton level [3]: a parton from the projectile acquires additional transverse momentum in each scattering before the interaction leading to the production of the detected particle.

The Cronin enhancement found in p+A collisions appears as a good handle on the coupling between the projectile and the target, making those systems ideal testing ground for the study of hadron interactions at high energy. In addition, detection of particles close to projectile rapidity skews the kinematics of their production at the partonic level; the higher their rapidity, the smaller is the fraction of longitudinal momentum x of the target parton. The study of particle production at these high rapidities is directly connected to the very interesting and still unknown component of the hadron wave function: the small-x region where measurements from Deep Inelastic Scattering have shown that the density of partons (mainly gluons) grows as a power of x as x tends toward zero.

While nucleon degrees of freedom, together with limited phase space, appear as the proper description for the lower energy measurements, high energy p+A interactions in collider mode have opened a window into new physics at small-x where the high partonic densities may be described as a universal form of matter. The transition from a nucleonic description to a partonic one is not clearly differentiated, some of the features seen in inclusive distributions at low energy, are still present at higher energies. Measurements at high rapidity where the primary aim would

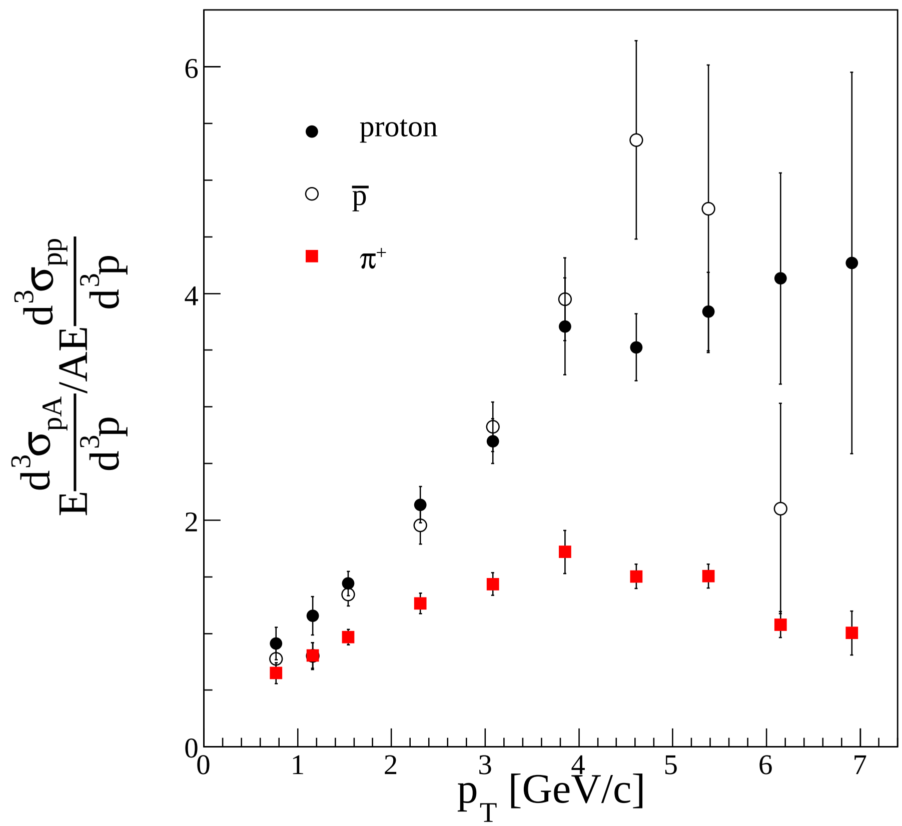

Figure 1. Left panel: Nuclear modification factor for pions, protons and anti-protons at mid-rapidity in p+W at $\sqrt{s_{NN}} = 27.4GeV$ at Fermilab [2]. These data were collected with the spectrometer at a fixed angle, protons and anti-protons at low p_T have rapidities smaller but still close to mid-rapidity. Right panel: Ratios of baryon to mesons for heavy (W) and light (Be) targets measured around mid-rapidity in the same experiment.

be the identification of phenomena clearly related to the partonic description would bring much needed new input to p+A physics.

2. Existing d+Au BRAHMS measurements

The d+Au collisions at RHIC, with their high energy and large rapidity access have, for the first time, provided data samples that extend to transverse momenta that reach to values close or even higher than the expected scale of the phenomena we are trying to understand. An extrapolation of the previously measured "Cronin enhancement" to RHIC energies would have yielded enhancements at mid-rapidity that were expected to grow even stronger at higher rapidities, because as mentioned earlier, the projectile partons would interact with higher number of target partons. In contrast, the BRAHMS results depicted in Fig 2 show a gradual disappearance of a small Cronin type enhancement visible at mid-rapidity till the nuclear modification factor is consistently smaller than 1, for all measured values of p_T, at the highest pseudo-rapidity ($\eta \sim 3$).

Figure 3 shows a similar nuclear modification factor. This time the ratio labeled R_{cp} is a comparison between d+Au data samples with different centrality; the most peripheral sample (60% to 80%) is used as the reference (close to nucleon-nucleon collisions) to study the rapidity

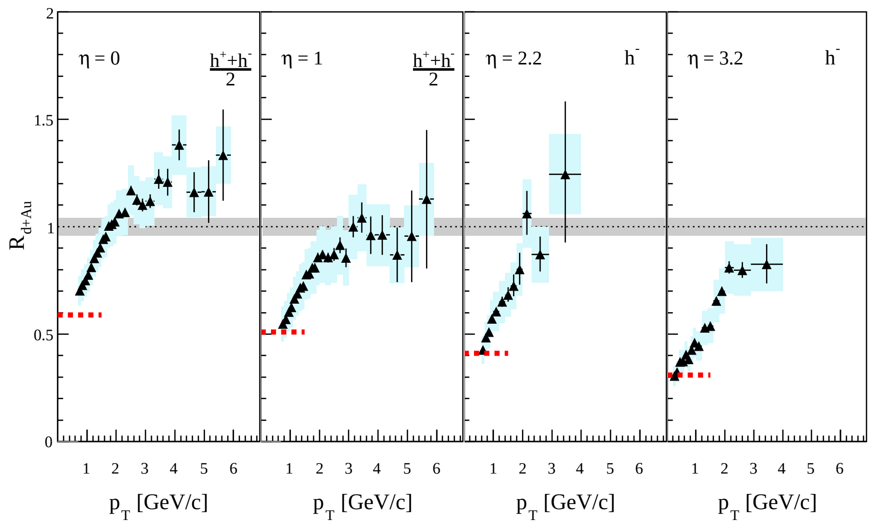

Figure 2. Nuclear modification factor for charged hadrons at pseudorapidities $\eta = 0, 1.0, 2.2, 3.2$. Statistical errors are shown with error bars. Systematic errors are shown with shaded boxes with widths set by the bin sizes. The shaded band around unity indicates the estimated error on the normalization to $\langle N_{coll} \rangle$. Dashed lines at $p_T < 1$ GeV/c show the normalized charged particle density ratio $\frac{1}{\langle N_{coll} \rangle}\frac{dN/d\eta(d+Au)}{dN/d\eta(pp)}$.

dependence of the two most central samples: central 0-20% (red filled symbols in Fig. 3) and semi-central 30-50% (open symbols). At mid-rapidity both central and semi-central R_{cp} show the Cronin type enhancement with the central events having a systematicaly higher enhancement, one unit of pseudo-rapidity is enough to make the enhancement disappear, and at $\eta = 2.2$ and 3.2 the suppression of the nuclear modification factor is evident at all values of p_T for both centrality samples, but the effect on the central events is much more pronounced.

One description of these results has the mid-rapidity d + Au yields produced by the interaction of the Au "target" described as a Color Glass Condensate [4] and a dilute deuteron "projectile". When compared to collisions of protons at the same energy, the nuclear modification factor exibits a Cronin enhancement. The observed change of R_{dAu} and R_{CP} as function of rapidity is then associated to the effect of the so called "quantum evolution" of the Au target wave function. Quantum evolution is a non linear process that includes the effects of gluon emission and fusion as partons from the target propagate from target rapidity toward the rapidity of the detected particle. The net effect of this evolution changes the shape as well as the magnitude of the nuclear modification factors making then smaller than 1 at all values of p_T [5].

Other descriptions of the data have been offered and all reproduce the data within some degree of accuracy [6, 7, 8]. We propose an extension of the study of d+Au collisions in order to increase the transverse momentum reach and to study particle production at a fixed rapidity close to the target fragmentation region. The study of these collisions is intimately related to the coupling between projectile and target, the results that we already have cannot be fully explained by calculations that utilize standard parametrizations of parton fragmentation. We believe that the study of fully identified particles at forward rapidity is an integral part of these studies: the high yield of protons with large transverse momenta at $y \sim 3$ can be seen as a probe on the way objects like di-quarks or baryon junctions couple with the target, in contrast to single partons that are detected as pions. Similar diferences can be explored between kaons and pions.

The p+A collisions studied in rapidity space at RHIC are in fact QCD laboratories; the skewed kinematics at rapidities far from y=0 opens a window to the not yet completely understood nucleon-nucleon interaction. At rapidities close to the projectile, the results should be strongly affected by the small-x components of the target wave function. The size of the target (directly related to the atomic number A) can be used to investigate the effects of multiple interactions: are the results scaled by the number of binary collisions? or is there some coherence in the target that scales measurements by quantities that are mostly dependent on the target?

3. Plans for a next d+Au run at RHIC

3.1. Forward spectrometer

We believe that an extension in the p_T reach of fully identified charged hadrons would discriminate between some of the models that describe the data so far. We would like to reach a value of p_T at the highest pseudo-rapidity studied by BRAHMS, where particle production in d+Au collisions is equal to the one from p+p interaction at the same energy scaled by the number of collisions. Both systems would then be considered as dilute and should be described by pQCD. The same projected data sample would add more information about the physics of p+A collisions, and it may even allow us to quantify the presence and effects of quantum evolution. We plan to compare the nuclear modification factors at the two rapidities we selected (-1.5 and 3) for events that belong to the same centrality bin. We want to explore further the already measured but unexpexted different behavior between baryon and mesosns (baryons exhibit Cronin enhancement at all rapidities while mesons show suppression close to beam rapidities). The reason for such different behavior is not yet understood, but under the assumption that the detected baryons are connected to partonic entities with higher cross sections (di-quarks or baryon junctions) and their Cronin enhancement can be related to the number of multiple scatterings. We would then use the baryons to estimate the number of collisions.

An extrapolation of the existing p_T distribution from a sample of negative charged particles at 4 degrees (one polarity of a full magnetic field setting) was made with the conservative assumption that the luminosity for the next d+Au run will increase by a factor 3, and only one third of the running time will have the FS spectrometer at 4 degrees and its magnets set at full field in one polarity. The result of such an extrapolation is shown in the left panel of Fig. 4 and it extends to values of p_T close to 6 GeV/c (30-50 particles in a 200 MeV/c bin at $p_T \sim 5GeV/c$). The right panel of the same figure shows the improvement of the statistical errors in the nuclear modification factor R_{dAu} if one were to use the extrapolated spectra. The last 7 bins that have been merged into two bins of 400 MeV/c and 1 GeV/c respectively. We discussed ways to extend that coverage. The kinematical limit is 7 GeV/c, can we play with spectrometers alignment or bin size and extend the measurement to get same number of counts at 6 GeV/c?

3.2. Backward rapidities

We want to modify the MRS spectrometer to extract p_T distributions in the Au fragmentation region. (Low momentum emphasis?) We can place a fixed spectrometer at $\eta \sim -1.5$ or have a movable spectrometer scanning angles at backward rapidities. The physics of this measurement will focus on the particle composition as well as the location of the Cronin enhancement in p_T and its magnitude as function of the centrality of the collision. Ideally this measurement should extend in p_T till N_{coll} is the proper scaling, lower energy measurements show that happening around 6 GeV/c. STAR measurements at $\eta \sim -1$ show values of R_{cp} that exceed 20% [9]. We can also consider the connection between the magnitude of backward rapidity nuclear

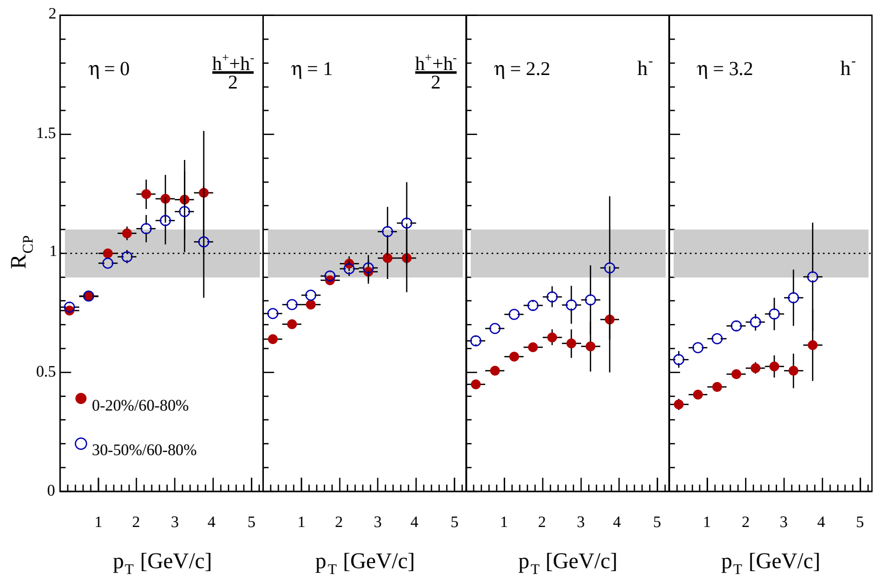

Figure 3. Central (full points) and semi-central (open points) R_{cp} ratios (see text for details) at pseudorapidities $\eta = 0, 1.0, 2.2, 3.2$. Systematic errors ($\sim 5\%$) are smaller than the symbols. The ratios at the highest pseudorapidities ($\eta = 2.2$ and 3.2) are calculated for negative hadrons. The uncertainty on the normalization of the ratios is displayed as a shaded band around unity. Its value has been set equal to the error in the calculation of N_{coll} in the most peripheral collisions (12%).

modification factor at its maximum value ($\sim 2.5 GeV/c$ in the STAR measurement) and the impact parameters of the collisions. If by any reason we cannot attain that moderate p_T we should be able to do the same measurement at a fixed lower value. The hope here is that this correlation between a measured quantity and the impact parameter b of the collision is better than the one between centrality and impact parameter (It would be great to find some way to simulate that correlation). We need to identify protons and pions, the momentum of these particles is high, particle identification is difficult for high momentum particles. hopefully a combination of TOF and C4 can do the job. Caveat: do we have $\eta = 1.5$ from p+p collisions? It may be that we will have to work at $\eta = -1$ because we only have p+p spectra at 1 not 1.5. If we do our studies with R_{cp} this problem does not exist. I have a personal preference for R_{dAu} even though one has to deal with more systematic errors and needs more statistics.

3.3. Impact parameters determination

We will characterize centrality with the multiplicity of charged particles in the Au fragmentation region. (We have to avoid auto-correlations). We can define more than three centrality cuts if we work with a correlation of multiplicity and ZDC left sum. If we decide to use that many cuts we would forgo the extraction of N_{part} or N_{coll}. We would be able to study how the nuclear modification factor changes with centrality, but it would then be hard to connect to some particular theory or model. The definition of centrality is becoming a very important component for the physics we plan to go after. We are still looking at additional measurements that would give us a better handle on centrality. The information from the ZDC LEFT detector may be complemented with the measurement of energy deposited in a hadronic calorimeter

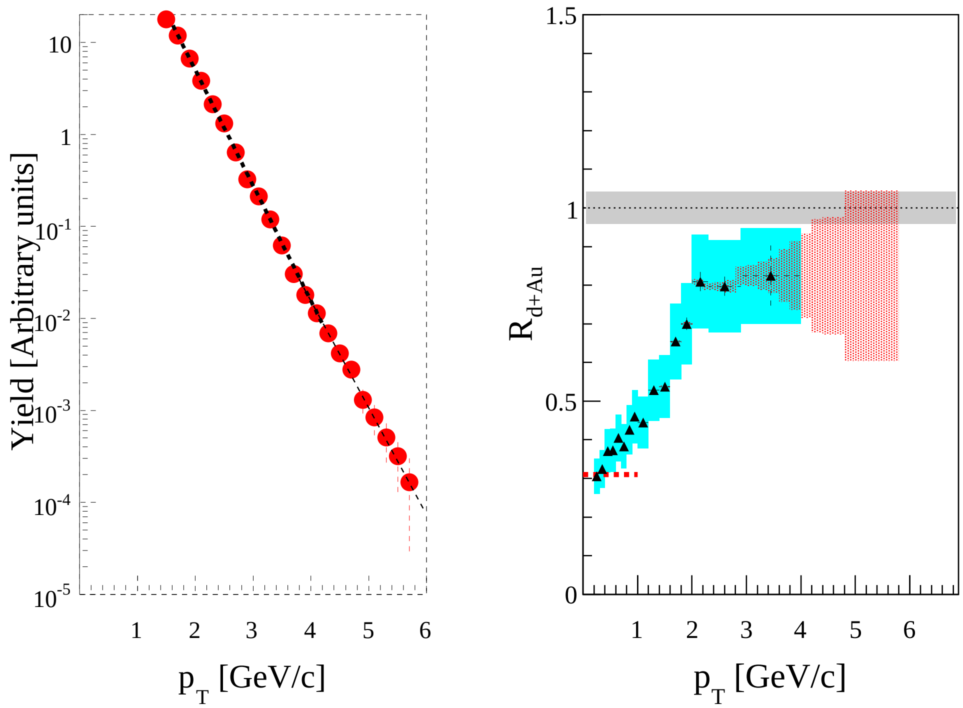

Figure 4. Left panel: expected raw yield at 4 degrees obtained from an extrapolation of data collected during the 2003 run. Right panel: Improved statistical errors shown with shaded red bands over the published R_{dAu} points. It is assumed that both d+Au and the p+p reference data samples have similar statistics.

(use AGS-E864 calorimeters?) placed at the highest possible pseudo-rapidities before the Dx magnet. We have also discussed the use of the shower max detector on both sides of the collision to improve our definition of the collision geometry.

3.4. di-Jet correlations

We think that we can make an argument about a limited measurements of the connection between leading particles detected with the FS spectrometer and azimuthal multiplicity correlations in the TMA detector. These studies may allow us to detect the presence of back-to-back jet correlations or their expected dissapearence if the Au nuclei behave as a Color Glass Condensate at RHIC energies.

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