Conference on the Intersections of Particle and Nuclear Physics 2003: Relativistic Heavy Ion Parallel Session Summary

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Abstract. The Relativistic Heavy Ion Collider (RHIC) came online in 2000, and the last three years have provided a wealth of new experimental data and theoretical work in this new energy frontier for nuclear physics. The transition from quarks and gluons bound into hadrons to a deconfined quark-gluon plasma is expected to occur at these energies, and the effort to understand the time evolution of these complex systems has been significantly advanced. The heavy ion parallel session talks from the Conference on the Intersections of Particle and Nuclear Physics (CIPANP) 2003 are posted at: "http://www.phenix.bnl.gov/WWW/publish/nagle/CIPANP/". We provide a brief summary of these sessions here.

INTRODUCTION

Many speakers separated the topics of heavy ion reactions into two broad categories. (1) The bulk system created which includes of order 5000 hadrons - with transverse momentum below 1.0 GeV/c. These hadrons result from the interaction of approximately 10,000 virtual gluons liberated from the nuclear wavefunction upon impact. These particles contain information about equilibration and thus the equation of state. (2) The probes of the bulk system, that are defined as colored systems such as hard scattered quarks and gluons that traverse the bulk media and tell us about its properties. Although these high $p_T$ partons or heavy quark states are relatively rare, and thus do not impact the equation of state (they are very non-equilibrium), because they are accessible via pQCD or QCD phenomenology, they represent a key calibration of the system properties. M. Gyulassy referred to the importance of these pQCD probes as analogous to the "tail that wags the QGP dog."

BULK EFFECTS

P. Steinberg reviewed the contrasting pictures of bulk thermalization and initial state scaling behavior. The former implies a collective system whose properties are dictated by the dynamics after the first collision impact, while the latter are remnants of the initial parton distributions or first reaction mechanisms. P. Kolb pointed out that it appears for the first time in nuclear reactions, that hydrodynamics with no additional
viscosity or multi-fluid expressions appears to describe the bulk momentum distribution of hadrons at low $p_T$, including the azimuthal anisotropy. However, the calculations appear to yield too long a lifetime for the system relative to two particle correlation measurements (HBT) or $R_{out}$. The calculations indicate enormous initial pressure, with a system decoupling rather quickly, of the time scale of 10 fm/c. P. Kolb gave a status report on the success of these calculations, and that some require a phase transition to extend the lifetime thus giving additional boost to the heavier particles.

M. Lisa gave a detailed presentation of the nearly complete experimental information at central rapidity on the phase space distribution - both momentum and position - for hadrons at the freeze-out (point of final interaction). Good progress has been made toward tracing back in time to the initial conditions and the equation of state. D.Magestro showed the outstanding agreement between statistical models and hadron ratios, including strange and multi-strange baryons. However, the suggestion that the fast time scale for thermalization implies that the system is “born into” into equilibrium was not a clear physical picture. Z. Xu and A. Tang presented data on flow and more exotic hadron production that help to complete the hadronic freeze-out picture. Results from STAR indicate modifications to the low mass vector mesons as observed via hadronic decay channels. Comparing these with reconstruction in the leptonic channels will be an interesting future measurement from PHENIX. R. Debbe showed that the BRAHMS hadron yields at forward rapidity appear as part of a “different source” than particles in the mid-rapidity region with a different net baryon density.

Y. Kovchegov and K. Tuchin presented global and azimuthal anisotropy observables that were generated with only initial state effects included - using a parton saturation picture as the calculation tool. If correct, this implies that the measured $v_2$ has no relation to a physical reaction plane. M. Lisa pointed out that the HBT results into and out of the reaction plane seem to disprove this assertion.

**PROBES**

An excellent probe of the medium is a hard scattered parton (quark or gluon) that transverses the medium. One can use QCD factorization to calculate the expected rate of these partons and their resulting fragmentation hadron products. It has already been observed by all four RHIC experiments in Au-Au reactions, that high $p_T$ hadrons are suppressed relative to this particular expectation. Since a parton scattering through a dense gluonic medium loses additional energy via gluon bremsstrahlung, it can be used as a “gluonometer” - a calibratable probe of the color charge density of the medium. Another explanation for the lack of high $p_T$ hadrons is that the high virtual parton density in the incoming nuclei saturates, and thus distinct partons are replaced by a gluon wavefunction that inherently break factorization. This saturation effect that might be probed in protons at $x \approx 10^{-4}$ (for example in HERA DIS), moves to $x \approx 10^{-2}$ in heavy nuclei due to the additional thickness. Many attempts to use this framework - sometimes referred to as the Color Glass Condensate (CGC) - to describe the bulk global observables have shown some success. More recently, D. Kharzeev and collaborators tried to extend the saturation regime via DGLAP evolution to higher $Q^2$, referred to as
the Color Quantum Liquid (CQL) regime. This CQL region suppressed hard scattering for hadrons even up to $p_T \approx 8$ GeV/c - thus also providing a possible explanation of suppressed high $p_T$ hadrons observed in Au-Au reactions.

This ambiguity led the RHIC experiments to propose a simple plan to resolve the question of whether the suppression is an initial state or final state effect. RHIC ran deuteron-Au reactions at the start of Run-3, since for the CQL picture, the suppression should still be present in the Au nucleus. In contrast, as pointed out by I. Vitev and others, the final state energy loss explanation would not be applicable with no dense medium created in deuteron-Au collisions.

Data from PHENIX, PHOBOS, and STAR as presented by L. Aphecetche, G. Roland, and P. Jacobs show an enhancement of high $p_T$ hadrons (both unidentified and $\pi^0$) relative to factorization and nuclear thickness scaling in deuteron-Au reactions - as sometimes referred to as the Cronin effect. There is no observed suppression as predicted in the saturation model extension. Angular correlations also revealed very similar near-side and away-side jet structure as observed in proton-proton reactions. M. Miller and J. Rak emphasized that the disappearance of away side correlations in Au-Au reactions, is not seen in deuteron-Au reactions. Though there was much discussion - including talks by J. Jalilian Marion and L. McLerran - there was general agreement that the data rule out the saturation model extension - referred to as the Color Quantum Liquid regime, for $x \approx 10^{-1}$. This of course does not rule out saturation at lower $x$ having an effect on the bulk dynamics as pointed out by L. McLerran and others.

Many speakers stated that with the extension to the saturation picture ruled our, parton energy loss in the dense gluonic medium is the only answer. L. McLerran stated that “if a 10 GeV quark loses 2-3 GeV of energy in medium, it seems clear that the bulk partonic matter is thermalized.” However, challenging questions still remain that must be fully explored. T. Chujo and J. Klay pointed out that although light hadrons are suppressed, at least at intermediate $p_T$, the baryons - both protons and $\Lambda$ are not. S. Bass and B. Muller both argued that while very high $p_T$ hadrons may be dominated by partons that lose energy in medium and that fragment into hadrons in vacuum, intermediate $p_T$ hadrons may come from parton recombination. This picture shows great promise in particular in the explanation of the $v_2$ scaling of different hadrons. However, the model is simple - not including gluon contributions - and further tests including $\phi$ mesons - large mass but $q\bar{q}$ state - are needed.

HERMES electron-nucleus deep inelastic scattering (DIS) data indicate modified fragmentation functions as shown by E. Kinney. These have been interpreted in the framework of fast hadronization or color dipole formation followed by re-interaction in the nucleus, and also in terms of multiple scattering from color charges in the nucleons of the nucleus inducing gluon bremsstrahlung. In Au-Au reactions, modification of QCD vacuum may also effect zeroth order gluon radiation, as described by M. Djordvic with regards to heavy quarks, and thus may also play a role for light partons. X.N. Wang argued that only the partonic energy loss explanation survives, but there was much debate and a well developed model including fast color dipole formation or hadronization is still lacking - that then needs to be confronted with all data. There is a wealth of new data that needs to be looked at in detail, and new ideas considered for a full description.
HEAVY FLAVOR PROBES

H. Woehre gave an overview of charm measurements at lower energies and detailed the constraints those place on heavy flavor production at higher energies. J. Heuser presented the detector performance of NA60, and it is clear that they have the ability to resolve the low mass vector meson states - down to low $p_T$ - and the $\chi_c$ contribution to the $J/\psi$. Many expressed that it should be a high priority for the field that they get adequate running time. First charm result via “prompt” single electrons from PHENIX were shown by S. Batsouli and indicate a surprising feature. The spectra agree both with a unmodified charm quark fragmentation in vacuum and with a completely thermalized charm plus a hydrodynamic boost.

D. Silvermyr showed the first $J/\psi$ results from at RHIC from PHENIX in proton-proton and Au-Au reactions. Despite low statistics, the Au-Au results appear to disfavor models of large $J/\psi$ enhancement relative to binary scaling. However, future high statistics measurements are critical to utilize these quarkonia probes. The $J/\psi$ measurement in proton-proton collisions of the total cross section and mean $p_T$ are the first at collider energies and should help address color-singlet versus color-octet production mechanisms.

SUMMARY OF THE SUMMARY

The heavy ion sessions included the presentation of a wealth of new data on high $p_T$ probes, including the first deuteron-Au results. It is now clear that the suppression of high $p_T$ hadrons is the result of a final state effect or some complete break-down of factorization - but not in the initial wavefunction. There was lively discussion of whether this is definitely partonic multiple scattering in the colored medium, or if contributions from fast hadronization, recombination, or zeroth order radiation modification may still play a role. New results on intermediate $p_T$ baryons, low mass vector mesons, charm mesons, and quarkonia were shown and more data from these states will help to fill in the picture. For the bulk medium an overwhelming amount of data already exists and must be reconciled in terms of hydrodynamic pictures and observations of simple scalings.

We would like to thank all the speakers for their excellent presentations and all participants for spirited discussions.

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