Heavy Ion Physics at the Brookhaven Alternating Gradient Synchrotron

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Heavy Ion Physics at the Brookhaven Alternating Gradient Synchrotron

A Final Report for the Office of Scientific and Technical Information
on LDRD Project 92-DE-088

Submitted by:

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Abstract

The collision of large nuclei at relativistic energies is the only known mechanism for creating and studying the properties (equation-of-state, EOS) of extremely dense nuclear matter. At sufficiently high matter densities, one of the most exciting possibilities is the formation of a Quark Gluon Plasma (QGP). However, it is an extremely difficult task to determine the ultimate density achieved during these collisions due to the fleeting nature of the high density state (the lifetime of these states is typically a few times 10^{-24} ns). We must rely on detailed comparisons between experimental measurements and complex Monte Carlo simulations of the colliding nuclei in order to extract meaningful estimates of the nuclear matter EOS. Our approach has been to study the behavior of the spectator matter (those protons and neutrons which do not directly interact during the collision) to determine the dynamics of the high density state which must necessarily influence the spectator matter as it decays. This report summarizes some of the key results of our study.

Introduction

The experimental work summarized in this report was performed at the Brookhaven National Laboratory Alternating Gradient Synchrotron as part of the E802 Collaboration. The specific experiment numbers are E859 (for the 14.6 GeV/c/A Si+A reaction studies) and E866 (for the 11.7 GeV/c/A Au+Au reaction studies). We proposed to measure pion, proton, deuteron and triton emission in relativistic Si+A and Au+Au reactions at large laboratory angles correlated with collision impact parameter. Particle emission beyond the free scattering kinematic limit is a sensitive probe of rescattering mechanisms. Rescattering of the primary projectile nucleons and the secondary produced particles leads to the rapid increase in baryon density in the overlap region during the collision of the two nuclei. The pressure gradient across the collision zone further leads to collective phenomena such as hydrodynamical flow and shadowing. The collective response of the nuclear matter and produced particles are then a sensitive measure of the nuclear equation-of-state. Therefore, we further proposed in experiment E866 to measure the reaction plane of the colliding nuclei on an event-by-event basis to directly study the collective flow and shadowing in relativistic Au+Au collisions.

To perform these measurements, the LLNL Relativistic Heavy Ion Group constructed three detector subsystems for the basic E859 and E866 apparatus. The E859 Target Phoswich Array is described in [1]. For experiment E866, this array was completely rebuilt to increase the segmentation for the higher particle multiplicities expected with the Au beam reactions. The E866 Phoswich Array consists of 100 modules each capable of particle identification (π , p, d, t) and kinetic energy measurement. In addition, the readout electronics for the E866 Array were upgraded and simplified from the NIM-based readout scheme in E859. The solid angle coverage of both arrays was nearly identical. The data from the two different detectors shown in Figure 1 compares remarkably well for the same target-projectile system.

We also designed and fabricated a high rate, high multiplicity tracking chamber for the primary E866 spectrometer. This chamber significantly enhanced the data collection capabilities of the spectrometer by extending the

range of allowable track multiplicities thereby increasing the rapidity coverage of the spectrometer for the Au+Au reactions.

Finally, to address the questions of collective phenomena in Au+Au collisions, we designed and fabricated a Projectile Hodoscope. The hodoscope consists of two orthogonal scintillator slat arrays approximately 11 meters downstream of the target. The rather simple conceptual idea is that the Hodoscope measures the deflection of the projectile spectator matter caused by the pressure gradient in the high density participant zone (the region of overlap between the two colliding nuclei). This deflection is quite small and the hodoscope segmentation is fairly high: 39 1-cm wide by 40-cm long X slats and an equal number of identical Y slats. Each slat is readout using two photomultiplier tubes and both pulse height and time-of-flight information are recorded for the reaction plane analysis (see Figure 2). To determine the reaction plane, we search for the X and Y charge centroid weighted additionally by the transverse momentum. Since we continuously monitor the position of the beam spot on the array (see Figure 3) as a function of time within the beam spill, the reaction plane is simply the plane defined by the line joining the beam spot and the charge centroid and the line of the beam. The milestone of the final year of this proposal was to install and commission the Projectile Hodoscope. This data has not yet appeared in any publication, however preliminary data is shown in the following section.

Results

Much of our work and the results are summarized in the publications listed at the end of this report [1-11]. Indeed, the final results of both the Si beam experiment, E859, and the initial experimental run of the Au beam experiment, E866, including the detailed comparisons with the microscopic models RQMD and ARC, are presented in [11]. Detailed descriptions of these models can be found in the references of [11].

The final year of this project was devoted to the commissioning of the Projectile Hodoscope. Figures 2 through 4 show some of the preliminary Hodoscope data as well as our preliminary correlations with the protons measured in the Target Phoswich Array. The data in Figure 4 show the mean

proton transverse momenta measured in the Phoswich Array projected into the reaction plane measured by the Hodoscope. The net negative momentum is the first indication for hydrodynamical flow in relativistic heavy ion collisions. These are important new data which will have a profound influence on our understanding of the reaction dynamics and nuclear equation-of-state. In addition, the observation of this signal indicates the utility of the reaction plane measured on an event-by-event basis. We expect that additional reaction plane correlations involving the produced particles will give us invaluable information on in-medium scattering cross sections, identical particle Hanbury-Brown-Twiss correlations and spectator shadowing.

Summary

We have made measurements which are crucial for our understanding of the nuclear equation-of-state. Working with microscopic collision models to make detailed comparisons with our data, we have demonstrated that it is possible to extract information related to the nuclear matter equation-of-state. The detector subsystems now in operation in experiment E866 at the Brookhaven Alternating Gradient Synchrotron will continue to provide unique information during future experiments. The Projectile Hodoscope, in particular, has proven to be an invaluable tool whose potential for new physics is only just now being realized.

References

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10. "Experimental Status of the AGS Relativistic Heavy Ion Program", T. C. Sangster, Proceedings of the 27th International Conference on High Energy Physics, Glasgow, Scotland, July 20-27, 1994; UCRL-JC-118789.
11. "Baryon Emission at Target Rapidities", Y. Akiba *etal.*, to be published in Phys. Rev. C; UCRL-JC-119319.

Figure Captions

Figure 1: A comparison of the proton yields as a function of pseudorapidity for the 11.7A GeV/c Au+Au reaction taken with the E859 Target Phoswich Array and the new E866 Array. The two Arrays were designed to make measurements over the same kinematic region. The agreement demonstrates the consistency of our measurements between the two experiments, E859 and E866.

Figure 2: (Top) The geometric mean of the two photomultiplier tube (PMT) pulse heights for X slat 14 showing the remarkable charge resolution of a single slat. (Bottom) The time-of-flight sum and difference spectra for the two PMTs. The width of the time sum distribution indicates a time resolution of approximately 225-ps. The width of the time difference spectrum corresponds directly to the length of the hodoscope slat: $48 \text{ ch} \times 25\text{-ps/ch} = 1.2 \text{ ns}$ times 30-cm/ns (speed of light) equals 37-cm (the length of the slat is 40-cm).

Figure 3: In all six panels, we show the slat position of the beam (vertical axis) versus the spill time, an arbitrary measure of the time during the beam spill. Note that the location of the beam spot depends on the time during the spill. We must know the location of the beam very accurately to get the correct magnitude for the collective flow.

Figure 4: The preliminary mean transverse momentum of the protons measured in the Target Phoswich Array and projected into the Hodoscope reaction plane as a function of pseudorapidity (or laboratory angle). The net negative transverse momentum is the signal for collective flow, a directed momentum transfer which can only be understood in terms of the nuclear equation-of-state. These two plots show the magnitude of the flow for two different trigger conditions.

Preliminary E866 Au+Au Proton Results

Figure 1

Hodo Slat 14, Run 14766

Geo Mean, X14

Geo Mean, X14

Time sum for X14

Time dif for X14

Figure 2

Beam Location in Hodoscope During Spill

10
X beam vs Spill time

10
Y beam vs Spill time

X beam vs Spill time

Y beam vs Spill time

X beam vs Spill time

Y beam vs Spill time

Figure 3

Preliminary E866 Au+Au

Figure 4