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Laboratory Directed Research and Development
at
Lawrence Livermore National Laboratory

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One of the last frontiers in Nuclear Physics is the discovery of the high baryon density, high temperature transition from normal hadronic matter to the unbound quark-gluon plasma or QGP. We believe that it is possible to create the QGP in the laboratory by colliding large nuclei (typically beams of gold nuclei) at relativistic energies. Such experiments are underway at the Brookhaven National Laboratory Alternating Gradient Synchrotron (AGS). This proposal was submitted to take advantage of an unprecedented opportunity to study the evolution of the nuclear matter equation-of-state (EOS) as we approach the QGP transition in Au+Au collisions at relativistic energies. In conjunction with experiment E866 at the AGS (over 60 scientists from 10 institutions), we proposed to use an innovative device designed and fabricated by LLNL scientists to study collective phenomena as a function of the Au beam energy between 2 and 11 GeV/A. If the QGP is formed at these energies, it is quite possible that a measure of collective hydrodynamic flow would be a truly unambiguous signature of QGP formation.

The probability of forming the QGP in central Au+Au collisions should increase with increasing beam energy. The QGP transition is expected to trigger a number of subtle changes in the decay properties of the hot, dense system formed during the collision. However, one possible and not so subtle change would be a dramatic increase in the compressibility of the nuclear matter (with a corresponding decrease in the central density) as the collision progresses. The idea is that if the QGP forms early in the collision process, incoming nucleons simply "melt" into the plasma rather than contributing to an increasing baryon density core. Since collective flow is a response to increased baryon density in the overlap zone, the disappearance of collective flow would be a completely unambiguous signature of QGP formation.

The goal of this proposal was to measure the collective flow as a function of the incident projectile (gold beam) energy between 2 and 11 GeV/A and search for anomalies in the flow excitation function which might indicate QGP formation. This was a three-year program tied directly to the anticipated running schedule of the AGS. During the initial stage of this project, the LLNL Projectile Hodoscope was used in AGS experiment E866 to complete the measurement of collective flow in Au+Au collisions at 11 GeV/A. The Hodoscope was used to measure the reaction plane in Au+Au collisions by tagging the deflection of the projectile spectator matter (the nucleons which do not directly interact) by the central high density collision core. By studying the spatial and momentum distribution of decay products (protons, pions and kaons) relative to the reaction plane, it was possible to determine the hydrodynamic flow as a function of centrality at 11 GeV/A. These decay products were measured using standard magnetic spectrometers and an array of fast-slow plastic scintillator phoswich modules. The proton flow signature was observed as a directed momentum in the reaction plane of approximately 110 MeV/c (units of momentum) for central collisions (impact parameters less than, say, 6 fm). An important cross-check of our reaction plane reconstruction algorithm was performed by analyzing the proton momentum components normal to the reaction plane. In this case, the observed absence of any directed momentum suggested that we are indeed seeing a real flow signal.

Quite surprisingly, the in-plane proton flow appears to be considerably smaller than predicted by the Relativistic Quantum Molecular Dynamics (RQMD) model (a full collision Monte Carlo and de facto theoretical standard). Since RQMD makes accurate predictions for the single particle inclusive spectra as well as the hydrodynamic flow at much lower energies (1 GeV/A), this result suggests that either the model is failing at the higher energy (despite the agreement with the inclusive data) or that there is a fundamental change in the physics that drives the flow signal (such as a softening of the equation-of-state).

The next stage in the experimental program would have been to make identical flow measurements at beam energies of 2, 4, 6 and 8 GeV/A. Two separate running periods were scheduled in early FY96 for beams of 2 and 4 GeV/A. These measurements would have completed a full flow excitation function between the current measurement at 11 GeV/A and lower energy data (1 GeV/A) where we know the flow is considerably larger (300 MeV/c at a beam energy of 1 GeV/A). With the termination of this project after the first year, the opportunity to make these measurements has been lost.

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