STUDIES OF RELATIVISTIC HEAVY ION COLLISIONS

Annual Progress Report

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ANNUAL PROGRESS REPORT AND RENEWAL PROPOSAL FOR THE PERIOD
JANUARY 1, 1994 THROUGH DECEMBER 31, 1996:

ABSTRACT

With the completion of the experimental runs with the DLS, which included both heavy ion and nucleon projectiles and targets, we are completing the analysis of these high statistics experiments. The Hopkins group has a major responsibility in comparing the experimental results with recently developed simulation codes for a theoretical comparison. The second major activity involves the STAR experiment at RHIC where we expect to continue involvement with simulations and developing prototypes of detector systems. Our program for studying optical properties of mirrors and gas scintillations related to Cerenkov ring imaging will continue.

INTRODUCTION

After having established the existence of lepton pairs in heavy ion collisions at energies in the few GeV range, we have devoted the past three years to obtaining unprecedented statistical results with the DLS spectrometer to determine with much greater certainty the origin of the pairs. This program consists of experiments with pp and pd collisions to establish the baseline source of pairs from bremsstrahlung and Dalitz pairs from well-known hadronic radiative sources. A second experimental program on heavy ions, utilizing collisions of Nb-Nb, Ca-Ca, C-C, has been recently completed. Additionally, pair production has been examined in d-Ca and α -Ca in the winter/spring of 1993. A fuller description of this work and a proposal for the completion of the analysis will be given in Section I.

During this period we also established our connection with what is now the STAR collaboration. Our physics interests and responsibility for the future, described in Section II, are related to physics at the RHIC collider.

We have also participated in a number of experiments which involved the study of strange particle production and other physics associated with heavy ion collisions at the energy available at the AGS. This work with a TPC, in collaboration with the Brookhaven 810 group, is described in Section III. In this connection, our interest in the polarization of hyperons produced in heavy ion collisions as well as those created with incident polarized proton beams was also done in collaboration with the Rice group and the 810 group. These results and possible future experiments that fit in with a new proposal are described in Section III as well.

Our work on detectors, especially those related to the ring-imaging Cerenkov detectors, and those related to the STAR detectors for which we have taken a responsibility, is given in Section IV.

Finally, we make a comment on the nature of the budget for the three-year period. This comment will be given in Section V.

SECTION I - The Dilepton Program

The final experimental phase of the Dilepton program was completed this last winter (1993). The purpose of this last phase was to obtain high statistics for both pp and pd, and heavy ion pairs such as C-C, Ca-Ca and Nb-Nb. The former group provided the level of elementary cross-sections such as bremsstrahlung in pp and pn reactions, Dalitz decays from radiative decays of hadrons, and other possible sources. The latter group of experiments on heavy ions was designed to study additional sources which could appear due to the new regime of high density hadronic matter. This included pi-pi annihilation and effects due to the dispersive nature of the medium in which secondary hadrons are produced. To investigate the onset of the additional sources the experimental program was extended to include pairs from d-Ca and α -Ca collisions. The analysis is now in progress, and Hopkins has taken a major responsibility in providing a uniform reduction of data in order to make the comparisons described above. We expect to complete this work sometime in the calendar year 1994, when a full review of these experiments and their interpretation will be prepared. It is interesting to note that a lepton pair program is being developed at the GSI with a detector entitled "HADES". The extension of our work will be pursued with a detector utilizing a much higher aperture to include a wide range of kinematic variables that were difficult to obtain with the DLS spectrometer.

The Appendix to this Annual Report and Proposal contains some relevant publications. Publications Ia and Ib include the analysis path that we are taking and some of the preliminary results. Finally, we will look for comparisons of theory with the data using Monte Carlo cascade programs, whose input will include some of our own data. Our work, especially on the pp and pd pair production has led to a number of theoretical publications reevaluating bremsstrahlung and other processes.¹

Publications Ia and Ib give a fuller discussion of the heavy ion work. Ic and Id are publications related to the pp and pd work. Publication Ie is a paper accepted for publication, showing results for niobium collisions. Publications If through Ih were early work that laid the foundation for this program. Papers Ii through Ij review the early work on the DLS spectrometer.

We propose, therefore, to complete the analysis of the high statistics experimental work and help prepare the final publication of this work.

SECTION II - Activities with the STAR Collaboration

A major collaboration was recently formed to develop a detector for RHIC. This detector is based on a TPC for particle tracking and, due to projections of the initial cost, other components are to be included as upgrades. The Hopkins group has been very active in the preparation of the design of the system that has recently been approved.

One of our interests has been to design an electromagnetic calorimeter to study the behavior of secondary π^0 's and gamma rays resulting from the formation of quark-gluon plasma. The sources of these reactions would be jets whose progenitors (quarks and gluons) traverse the plasma and, hence, act as probes of the medium via their characteristic energy loss. The π^0 emission at lower energies is characteristic of the transverse energy that results from the collision and is, therefore, not only a characteristic signature of the collision but is a measure of fluctuation that could represent new physics.² Our group has completed Monte Carlos which help to optimize the mechanical design. An example of a study is given in IIa. In

preparing these studies our group has been called on to prepare simulations for other aspects of the physics, related to the trigger and strange particle studies, for example.

Our most immediate work for RHIC, however, will involve a major responsibility for establishing luminosity monitoring for our experiment. This is done in collaboration with the RHIC machine group. We expect this to include not only future integration of our electromagnetic calorimeter and detectors, but also methods of heavy ion beam studies by non-destructive means if it appears feasible.

We propose to have as our main responsibilities the preparation for (a) luminosity monitors, (b) setting up test beams at Brookhaven for RHIC detectors, (c) continuing to act as a source for Monte Carlos evaluations and maintain our role in the study and determination of future installations of electromagnetic calorimetry.

SECTION III - Studies of Strangeness Production

Our group has been an active participant in several programs related to the nature of strangeness production in both hadronic and nuclear collisions. In the former case, the origin of lambda polarization was studied using polarized proton beams to determine the accuracy of the theory that assumed polarization to be purely due to polarization of the strange quark from the sea. This was, in fact, verified by our experiments in collaboration with the Rice University group.³ [See IIIa in the Appendix for the most recent paper.] This work also led to the determination of other particle asymmetries resulting from polarized proton projectiles.

The latter work⁴ on lambda polarization from heavy ion collisions (see IIIb in the Appendix) hinted at some deviation from the normal polarization produced by protons incident on heavy nuclei. Our related results, together with those of experiment NA35 referred to in the Appendix mentioned above, hint at a different behavior of the strange quark sea in the presence of high density hadronic matter.

There is very general interest, therefore, in the production of strange particles from many points of view; first, to continue the polarization studies with very high statistics and, second, to search for exotic objects like a short-lived H^0 di-baryon. In this connection a proposal is being prepared [H. Crawford (LBL)⁰ spokesman] to build an apparatus which would be optimal for both these projects. The experimental setup will include a sweeping magnet to remove charged secondaries immediately downstream of the target, following by a tracking detector located in an analyzing magnet immediately downstream of the sweeping magnet. The main feature of the proposed experiment is the ability to detect and trigger on secondary vertices corresponding to decay lifetimes from that of the Λ^0 to approximately an order of magnitude longer. This will be accomplished using a distributed drift chamber in which an unambiguous decay signature can be measured in combination with a modern trigger system capable of recognizing V^0 's and kinks in the tracker fast enough to trigger on events of interest. The trigger system we propose to develop and test in this experiment is of the kind proposed for the Solenoid Tracker at RHIC.

Our group has been active in this newly-formed collaboration by doing extensive simulations to find the optimum design. We believe that an approval for this experiment at the AGS in Brookhaven later this year will allow us to participate

in this project without affecting our major responsibilities in the STAR collaboration for RHIC.

It is worthwhile mentioning that our long-term collaboration with the Brookhaven 810 group, using a TPC to study strange particle production with heavy ions, has been extremely useful for our activities in the early preparation of the RHIC proposal for STAR. Our group helped set up the beam identification and data-taking during the runs in the past few years. The results on strange particle production, which seem to indicate clear deviations from simple cascade pictures, is of interest (see publications IIIc through IIIh in the Appendix).

Our responsibilities with the Rice group in the experiment involving the nuclear stopping of antiprotons was completed several years ago (see paper IIIi on a portion of the detector). The final analysis is being completed at Rice University and should be available in the near future. Here again, the production of strange particles may give insight into the behavior of hot hadronic matter even when extremely localized in the interior of the nucleus.

Finally, our participation in the zero-degree spectrometer, E878, at Brookhaven continues. Our responsibilities included data acquisition management and Monte Carlo simulations. We are currently preparing for a 300 hour run to start in September 1993. We will be extending our understanding of π , K and $\bar{p}$ production in Au-Au collisions as well as our search for $\bar{d}$ production. First results have been published, see paper IIIj in the Appendix.

All in all, our activities in this general area, in both developing experimental apparatus and data analysis, have been extremely helpful to determine our future activities. While maintaining our present responsibilities for the DLS analysis and STAR, we believe that the RHIC staging will allow us to participate in an interim program of strangeness production.

We, therefore, propose to be participants in the preparation of simulations for the H_c search and lambda polarization studies with heavy ion collisions. Should this project be approved, we expect to play a serious role in the analysis of data and ultimate physics interpretation.

SECTION IV

During the past three years, we have been active in experimental studies of detector components that are relevant for heavy ion collisions. These are especially applicable to Cerenkov ring imaging. We have completed the construction of a system to study the behavior of special mirrors whose reflection in the ultra-violet is applicable to ring-imaging detectors. The electronics and associated computer-controlled components of the mirror holders will be completed this year, and we expect a full program at Hopkins would be completed in 1994. These projects are especially useful for undergraduate training in physics and will be an important part of our activities at home. A short report is given in paper IVa in the Appendix.

A pressing problem which we discovered in understanding our own work on the Cerenkov detector in the DLS spectrometer was the background photons from excited molecules produced by passing charged particles. Clearly, high multiplicities of

charged particles could make a serious problem for detecting Cerenkov rings. We have built a simple detector to study the gross effects of these scintillations, with photocathodes which are normally used. We have made some simple tests of this system and will use it in future test beams at Brookhaven as an auxiliary experiment to the standard tests of prototype detectors for our RHIC experiment. A short report is given in paper IVb in the Appendix.

Finally, we have recently taken the responsibility of acting as a liaison with the RHIC machine group to develop luminosity monitoring appropriate for the STAR detector. We are looking into various schemes to measure luminosity in addition to the standard Van Der Meer method, by some suitable secondary monitoring scheme. We will look into the construction of such a detector if it is necessary.

Our group has been extremely active in studying the suitability of doing jet physics at RHIC. We have been early advocates of this technique, since it really represents the studying of energy loss of energetic quarks and gluons in the medium formed by the heavy ion collisions at RHIC. Our interest has been to implement the STAR detector with an electromagnetic calorimeter. Our simulations indicate special experiments of this kind will not only be important to physics interests but also will play a key role in acting as a signature of the centrality of the collision by allowing a measure of transverse energy and/or sharp local energy deposition. This is to say, the EM calorimeter can act both as a trigger and as a device for studying the physics of the medium. We have been very active in preparing simulations of various detector geometries and, in addition, will take a responsibility in Fall, 1993 to help construct a test beam to study prototypes of calorimeters.

Therefore, we propose to continue our local studies of Cerenkov gas properties and UV mirrors with our optical system. We will maintain our collaborative effort in the future to construct the test beam at BNL for STAR detectors. We expect to act as a resource group to respond to requests from the STAR collaboration for simulations on the STAR detector related to special physics interests.

SECTION V - Comments on the Budget

Our budget request represents the costs for the completion of the DLS analysis, for which Hopkins has taken a major role, and for our activities in the STAR collaboration. Drs. R. Welsh and W. Christie have become very important participants in both these activities and are expected to maintain their connection in the coming years. The budget represents their compensation, together with travel to Brookhaven and LBL, where the core of the activities will be concentrated. We expect to have one of the postdoctoral fellows resident at Brookhaven sometime in the calendar year 1994, when a STAR collaboration presence has been established. In this way, we expect our contributions to the yearly integration of the project will be most efficient. The activities in the calendar year 1995 should be focussed on the STAR project, and in the third year we expect to introduce a student at Brookhaven and take some responsibility for detector construction. Our budget shows the introduction of technical help (shop-time) and a student for this purpose.

We would like to note that Dr. T. Hallman, who was a member of our group, is now at UCLA and has been appointed Deputy Spokesman for the STAR project.

A small fraction of the budget will be used to prepare some prototypes of detectors which may be needed for luminosity monitoring, and for specialized parts for the electromagnetic calorimeter.

The STAR detector will be an extremely suitable device for studying spin physics when the RHIC collider has introduced polarized protons. The Hopkins group has shown interest in this direction since it is a natural extension of our past activities in spin physics. There are members of the present physics faculty at Hopkins who would join in this activity should the introduction of polarized protons at RHIC become a reality.

In the past year, invited talks on the DLS project and materials related to heavy ion physics were given by Welsh and Christie (see publication list in the Appendix).

Professor Leon Madansky, Principal Investigator, has devoted fifty percent of his time and effort to the projects outlined above and expects to continue at this level of effort. We have prepared an Appendix to this Annual Progress Report and Proposal (DOE/ER/40413-6) that gives the results of our work in more detail.

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