DOE/ER/40281--6

DE92 003036

1 Introduction

The present document describes our second-year application for a continuation grant on relativistic heavy-ion research at Nevis Laboratories, Columbia University, over the two-year period starting from November 15, 1990. The progress during the current budget year is presented in Section 2 and our plans for the coming year are described in Section 3.

This year, construction of RHIC officially began. As a result, the entire Nevis nuclear physics group has made a coherent effort to create a new proposal for an Open Axially Symmetric Ion Spectrometer (OASIS) proposal. Future perspectives and our plans for this proposal are described in Section 4.

2 Progress in FY91

2.1 Overview

At BNL, participation in the E802 experiment, which was the first major heavy-ion experiment at the BNL-AGS, has been the main focus of the group during the past five years. Data-taking for this experiment is now completed, and extensive data analysis is in progress. During the current budget year, the primary E802 activity will be publication of the remaining data. The Nevis group is actively involved in writing papers on the baryon distribution in Si-induced reactions, on $\pi\pi$ boson interferometry, and on the comparison of O-induced reactions with Si-induced reactions. These papers will appear within the next few months, in addition to other E802 related papers. In addition, one graduate student (K. Kurita) is writing a thesis based on the E802 data (^{16}O vs. ^{28}Si), including his analysis on the segmented gas Cerenkov counter which was fabricated at Nevis by Mr. Kurita and another student (Y. Wu).

The first results from E802 have demonstrated the need for further measurements beyond the sensitivity of the original E802 spectrometer. The group, therefore, proposed a significant upgrade of the E802 apparatus. This new experiment, E859, utilizes a sophisticated Level II trigger scheme to perform on-line particle identification. This permits triggering on physics-specific events: for example, a one kaon of either sign, or $2K^+$'s for Hanbury-Brown/Twiss correlations. In addition, new Phoswich detectors to cover angles larger than 55° were installed to measure particle spectra in the target rapidity region. W. Zajc is co-spokesman (with L. Remsberg of BNL) for this experiment.

The Columbia group has also participated in a small-scale experiment, E858, including one graduate student, P. Stankus. The data analysis is now completed and the first publication of the data is in progress. Mr. Stankus is presently writing a thesis based on the E858 data.

At CERN, the ongoing program in heavy ion physics is the experiment NA44. This experiment first took data with proton beams on nuclear targets in 1990 and also again in Spring and Summer of 1991. In Fall 1991 data with sulphur beams will be taken. The goal of this experiment is to measure two-particle correlations with high statistics

and high momentum resolution for pairs of positive and negative K-mesons, as well as pions. The experiment was designed to provide optimum results with the heavy nuclear beams, up to lead, which are expected to be available at the SPS in 1994. It utilizes large aperture superconducting quadrupoles to achieve relatively large angular coverage in the center-of-mass system. The momentum resolution of 0.25%, as well as the good angular resolution provided by quadrupole focusing, is essential in order to measure the large radii expected in Pb + Pb collisions. At the same time, the selective nature of the focusing spectrometer makes it easy to work in a very high multiplicity environment.

In our near-future activities, we will continue to concentrate on the relativistic heavy-ion experiments at both the BNL-AGS and the CERN-SPS. At BNL the major emphasis will be on continued participation in E859. In addition, we plan to participate actively in E866, an extension of the E802-type experiment to Au beams. We plan to upgrade the existing spectrometer, and perhaps to build a segmented Cerenkov counter for the new arm. Also, a new proposal to detect strangeness -2 states is under investigation with H. Crawford. At CERN the participation in NA44 will continue for at least the next three years.

In the last year we have participated extensively in the preparation of a Letter of Intent for the OASIS experiment at RHIC. Most recently, the Nevis group, in collaboration with 21 other institutions, submitted a revised version of the OASIS Letter of Intent, with S. Nagamiya as spokesman. Immediately after the August PAC, we plan to produce a full OASIS proposal. For this proposal the entire nuclear physics group at Nevis will make a joint effort.

2.2 AGS Experiment E859

The initial investigations of particle production in heavy-ion collisions at the BNL AGS by E802 determined that the K^+/π^+ ratio is enhanced by roughly a factor of 4-5 over that observed for p-p collisions at these energies[1]. Although subsequent observations have shown that this enhancement is a monotonically increasing function of the masses of the colliding species[3], the fundamental processes responsible for the change in the K^+/π^+ ratio remain ill-understood. To further study the nature of strangeness enhancement in heavy ion collisions, the E859 collaboration[2] has upgraded the E802 apparatus to provide very high statistics single-particle spectra for charged kaons produced in these reactions. Additionally, E859 has chosen to examine the space-time structure of the meson source(s) by measuring $2\pi^{\pm}$ and $2K^+$ correlations, as well as making more precise measurements of anti-proton production.

All of these highly desirable physics topics are characterized by their low production cross sections. This is exacerbated by the broad-band acceptance of the E802 spectrometer[4], which, while essential for good pair acceptance, makes development of physics-sensitive Level I hardware triggers extremely difficult. Therefore, E859 decided to develop a Level II trigger that would determine the mass of all charged particles in the spectrometer aperture. Such a trigger must:

- Track and identify all charged particles in a "typical" event (up to roughly 5 tracks/event).
- Cover a dynamic range in momentum from $\sim 0.3 < p <\sim 2.0$ GeV/c.
- Make a trigger decision in $\sim 40\mu$s.
- Be sufficiently flexible to provide user-selectable "physics" triggers at run time.

The E859 Level II trigger is implemented using LeCroy ECLine modules to perform various read-out, table look-up, calculation and control functions[5]. The trigger was designed to be constructed in a two-stage process. The first stage, implemented for the June-90 heavy ion run, used the E802 TOF wall in conjunction with two new MWPC's to find and momentum-analyze tracks. This provided a "two-like-sign" trigger, which was used to significantly extend the E802 two-pion data, and also to obtain a large sample of two-proton events. The last day of the June-90 running period was also used to demonstrate a proof-of-principle of the second stage in the implementation of the Level II trigger, which involves using the TOF wall to provide high quality on-line particle identification. This capability was further developed and exploited in the February-91 run, where we demonstrated the ability to calibrate and maintain the TOF wall to within $\sim$ 100ps for the entire data-taking period.

By using the full Level II trigger in the February-91 run, E859 improved the E802 statistics on single-particle K^+ and K^- spectra by roughly an order-of-magnitude. Two-pion pairs were measured as a function of the event multiplicity, which should test the connection between source radii measured via interferometry and those inferred from geometric models of particle production. Significant running time was devoted to running two parallel triggers, which accepted either one anti-proton or two kaons (in any sign combination). Again, the anti-proton measurement should increase the E802 statistics by a factor of 10, while the two-kaon data should provide a first look at AGS energies in this very interesting channel. Preliminary results from the two-pion measurements have been reported at the July-91 Gordon conference, while the two-kaon data will be presented in November at the Quark Matter 91 Conference.

2.3 AGS Experiment E858

The BNL-PAC approved 100 hours of running time for this experiment to search for rare negative secondaries — anti-protons, anti-nuclei and possibly strangelets — produced in heavy-ion collisions. H. Crawford (UCSSL-Berkeley) is spokesman for this experiment. From Columbia, P. Stankus and S. Nagamiya joined the experiment.

The experiment was the first to use full-intensity beams of ^{28}Si at the AGS; no stable negative particles heavier than the $\bar{d}$, and none with $|Z| > 1$ were seen. The observed cross sections for π^-, K^-, $\bar{p}$, and $\bar{d}$ produced at 0^o were measured. Preliminary results show that the $\bar{d}$ yield is one order of magnitude smaller than the prediction of a coalescence model, while it is two orders of magnitude larger than what a direct $d\bar{d}$ creation calculation

would predict. A feature observed in the $\bar{p}$ data is that the target-mass dependence shows the $\bar{p}$ yield to be proportional to $(A_t^{1/3} + A_p^{1/3})^{2\cdot\alpha}$ with $\alpha = 1.3 \pm 0.1$, suggesting that reabsorption of $\bar{p}$'s is not a strong effect.

E858 will be followed by E878 in the AGS 1992 running period. E878 is an upgraded rare-particle search, and will provide a factor of 20 greater sensitivity through a combination of increased intensity, acceptance and running time (300 hours). P. Stankus has been involved in the proposal, design and preliminary setup/tests of E878.

2.4 CERN Experiment NA44

The data from the 1990 test run were largely analyzed before the start of the 1991 run and the results presented at two status reports to the SPSC, including results on the low p_T "enhancement" in p-Be and p-Pb interactions, and the two pion correlations in p-Pb collisions. The SPSC recommended approval of NA44 for running with lead beams in 1993 or 1994. This was the first experiment to be recommended for approval. The Research Board has not yet acted on this recommendation pending clarification of issues concerning the large new experiments proposed, none of which appear to impact on our experiment.

Our long data taking run with proton beams took place May to July 1991. We feel that we may have obtained sufficient data for π, K and p spectra and correlations at low p_T in proton collisions. To answer this question and to provide insight into the results useful for our upcoming ion run, we have carried out a six week "analysis workshop" following the run. Our six week run with Sulfur beams will begin October 1.

The first results from the recent run were presented at the end of July at the Lepton-Photon Conference. There was particular interest in the comparison on spectra of low central rapidity pions in p-Be and p-Pb collisions. In HELIOS, it had been determined, as described in a paper now submitted to Z. Phys., that the low p_T enhancement found in S-Pb collisions was also present in p-Pb collisions. If we accept all of these results, we can conclude that it must be a target effect. It will be very interesting to see the result in S-Pb collisions in the same apparatus this Fall. We will also be looking at the proton data as a function of event multiplicity in the next few weeks. There were statistically weak hints that the low p_T enhancement might appear even in central p-p events at very high multiplicity. Our spectrometer has proven to be very suitable for such studies.

In the analysis workshop we have been looking at the HBT effect measured in the different projections with respect to the beam, including the results with the spectrometer running in two different configurations, "horizontal focus" and "vertical focus", to emphasize different planes. These results look promising, as judged by the first examination of a large sample of p-Pb interactions.

If we conclude that we have sufficient data at small p_T, we will move the spectrometer to a larger angle for next year's Sulfur run in April-May, and the further proton running which follows. This is expected to be the end of heavy ion running until the lead beams are started.

2.5 RHIC Related Activities

In October 1990, the Nevis group together with 11 other institutions submitted a Letter of Intent (LOI) for an experiment at RHIC. The proposed detector combines an open-geometry axial magnetic field, tracking chambers, calorimeters and various particle-identification and event characterization devices to provide high-rate capability, good particle identification, and high momentum resolution. The experiment, named OASIS, concentrates on detecting hadrons, electron pairs, photons, and jets in the mid-rapidity region, with an emphasis on simultaneously measuring as many potential signatures of the quark-gluon plasma as possible.

The ambitious physics goals of OASIS raise several technical issues: The experiment will require several thousand channels of time-of-flight with sub-100 ps time resolution. The experiment achieves further e/π rejection via a novel combined transition-radiation detector (TRD) and tracking system. The rare signals sought by OASIS require a pipelined data acquisition system coupled to a multi-level trigger scheme. Therefore, immediately following submission of the LOI the Nevis group began R&D in these critical areas. Each is discussed in the following sub-sections:

2.5.1 TOF Tests

Development work on time-of-flight systems for OASIS was conducted by T. Nayak, Y. D. Wu and S. Nagamiya. A beam test was conducted at the KEK-PS for TOF counters in collaboration with the University of Tsukuba group. The goal of the test was two fold : a) to try to achieve a good time resolution ($\sigma < 100$ ps) by a fiber scintillator hodoscope, and b) to test the performance of a newly designed Cerenkov free phototube where Cerenkov light from the phototube window was shielded by separating the photocathode from the window. Prototype construction and preliminary testing were done at Nevis. Four different types of scintillating fiber bundles of 300cm long were constructed out of round fibers of 2.5mm and 5mm diameter and square fibers of 2.5mm and 5mm each side. The dependence of time resolution on different sizes and shapes of scintillating fibers, and on the hit position on the test counters was studied. The Cerenkov-free tube was placed directly on the beam with and without scintillators placed in front of the tube. The data analysis is currently in progress at Nevis. The preliminary results of our analysis show very promising results and will be reported soon.

2.5.2 TRD Tests

A TRD prototype detector, (rebuilt at Nevis from one used in experiment NA34), was tested by V. Cheniatin, C. Y. Chi, Y. F. Wang, W. Willis and two summer students at the AGS during June-91 proton run. Studies were made both on the efficiencies of various radiators and on the possibility of using dE/dx to enhance the e/pi separation around 1 GeV/c. Signals from the chamber were read out through a pre-amp and a shaper, then recorded in a 40MHz 6 bit fast sampling ADC system. This signal recording method was

chosen because it is closely related to the TRD readout method proposed in the OASIS LOI. The electrons and pions in the test beam are tagged by two Cerenkov counters before and a lead glass detector after the TRD chamber. The TRD data were taken with seven different foam and one type of foil radiator at beam momentum 1.5, 2, 2.5, 3 and 4 Gev/c. The dE/dx data were taken at beam momentum of .7, 1.0, 1.5, 2.0 and 4.0 GeV/c with the detector placed at 0, 20, and 35 degrees with respect to the beam angle. Data are currently being analyzed at Nevis, BNL and Yale University. The Nevis group took major responsibility for the readout system and online software during the run, and is presently analyzing the dE/dx data.

2.5.3 Readout system design

Nevis has taken the responsibility to design one of the OASIS front-end signal recording devices, the analog pipeline chip. This chip (based on a switched-capacitor array) will be used in both the liquid argon detector and time of flight system. This effort is headed by W. Sippach (Nevis electronics engineer), who has been closely involved with the ZEUS analog pipeline design, with the support of C.Y. Chi. We are currently designing test chips to study different procedures for constructing switches, capacitor cells and op-amps. These designs will be submitted to a silicon foundry (either MOSIS or Orbit) in September-91. Test chips should be available two months later. Real chip layout will then be started, guided by the test results from these prototypes.

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12/20/91