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PROPOSAL FOR CAPITAL EQUIPMENT FUNDS FOR EXPERIMENT E-864,
AN EXPERIMENT TO MEASURE RARE COMPOSITE OBJECTS
AND TO CARRY OUT HIGH SENSITIVITY SEARCHES
FOR NOVEL FORMS OF MATTER
PRODUCED IN HIGH ENERGY HEAVY ION COLLISIONS

Final Report

for Period June 1, 1993 - November 14, 1996

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Final Report for DOE Capital grant for E-864 (DE-FG02-93ER40787)

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1 Overview

The capital grant for the construction of E-864, the high energy heavy ion experiment at the AGS searching for strangelets and measuring the production of rare composite objects, expired on November 14, 1996. The grant, originally for three years, had been extended twice, each time for six months, to allow a prudent use of the funds.

In summary, all of the equipment proposed was constructed on schedule and precisely within the budget. As will be detailed in the following, the equipment performed at the expected level or in a superior fashion. This equipment, together with other devices supported by funds provided by the Brookhaven National Laboratory (BNL) allowed the construction of the E-864 spectrometer and its use in experiment 864. An article is under preparation for Nuclear Instruments and Methods [1] which describes the spectrometer.

The experiment first operated in the fall of 1994 with a partial complement of the equipment. The 94 run was primarily an engineering run but went well and a substantial physics output resulted. Two Ph.D. theses were based on data taken in the 94 run [2, 3] and one other (study of coalescence yields of nuclear states) is nearing completion. The major incomplete component in the 94 run was the scintillating fiber calorimeter which was about 20% complete for the 94 run and the second level trigger system (so-called "late energy trigger" (LET)). This was according to our plan as the completion of the calorimeter required the third year of funding (which was 1994) and we wanted a test run with a prototype of the LET to verify its performance before committing the funds to its production.

The strangelet limits, the antiproton data, and the coalescence data from the 94 run were presented in an invited paper at the international conference, Quark Matter 96 [4]. A paper reporting our results on antiproton production has been prepared and submitted to Physical Review letters.

The next run of the experiment was in the late fall of 1995. For this run all of the detector was in place with the exception of the straw tube chamber, S1, which was to be built by our Bari, Italy collaborators and was not part of the capital grant equipment. The calorimeter was commissioned and the Late Energy Trigger system was integrated into the D/A and performed well. Several problems were encountered, such as a rate dependence in the functioning of the digitizers, but there was sufficient additional calibration equipment in place so that the data was still analyzable. Another problem was radiation damage to the quartz beam counter which occurred at the high beam rates made possible by the late energy trigger system, and thus not observed in the 1994 run. This required several changes of the counter and somewhat degraded the timing resolution, although again the data was analyzable with little loss. The major effect of the radiation damage was the efficiency of the double beam rejection on line. This could be checked off line so the final effect was that the experiment did not take data as fast as it ultimately could. Nevertheless, the data collected was about 100 times greater in 95 than in 94.

One thesis has been completed based on the 95 data [5] and one is nearing completion (on improved limits for positive strangelets and coalescence yields of ${}^6\text{He}$). A Physical Review Letter summarizing our positive and negative strangelet limits from 94 and 95 is nearly complete and will be submitted in April (1997).

The most recent run of the experiment (at the time of writing) occurred in December 1996 and January 1997. In this run the radiation damage problem was eliminated by operating the quartz beam counters in a vacuum environment and the rate dependences were removed by suitable modifications to the low voltage power supplies which "fed" the Cockcroft-Walton high voltage supplies in the phototube bases. The run was very successful and the data should allow an improvement over the 95 results by about a factor of seven.

At the time of writing it is not clear whether or not there will be a run in the 1997-98 period. If it does occur, it would be the last major run of E-864 as the heavy ion program at BNL would shift to RHIC after that date.

We do hope to have short runs with the 864 apparatus after the RHIC operation begins coincident with test beam runs for the RHIC detectors. There are numerous (non-strangelet) physics topics that can be studied with the powerful apparatus of 864, and these would be the target of the "short runs".

2 Beam Counter System

The design of the E-864 experiment calls for the measurement of individual beam particles. The beam counter must operate in a flux of 10^7 particles per second and measure the time of arrival to about 100ps. The amplitude measurement should also be sufficiently precise so that double beam particles (i.e. two beam particles arriving within about 15 ns) can be rejected because they produce too large an amplitude.

The beam counter design chosen was a quartz Cerenkov counter which was 150 μ m thick in the 1994 and 1995 runs. At low rates this counter worked well but showed radiation damage at higher rates. In the 1996 run the counter was rebuilt with 300 μ m thick quartz and it was operated in a vacuum environment. In addition, a second beam counter was built which differed only in the phototube used (the newer counter used Hamamatsu R5600 whereas the older counter used Hamamatsu R2059). The older counter (dubbed MITCH) achieved 41.8ps (rms) and the newer one (dubbed MIC) achieved 30.2ps (rms).

In addition to the beam counters (MITCH and MIC) we also installed a quartz Cerenkov hole veto counter which defined the cross section of beam accepted by the experiment. The centrality was measured by a four counter array (dubbed MULT) which detected particles produced in the target at space angles between 16.6° and 45.0°. The MULT counter was placed behind 15 radiation lengths of heavymet (90% tungsten alloy) in order to shield it from the intense yield of delta rays produced by the passage of the gold ions through the target. The centrality was estimated from the summed pulse height in the four MULT counters. This system worked well and pulse height spectra showed the shape expected. They also agreed well with Monte carlo studies based on HiJet and RQMD.

Finally a scintillation hole veto counter was placed between the MITCH counter and the target. The purpose of this counter was to veto any upstream interactions which would fire MULT. This counter had a 5.5 cm hole and was shielded from direct exposure to the gold ions of the beam. This counter also served to veto interactions which occurred in the MITCH counter. The rates observed (a few %) were consistent with expectations from simulations.

3 Hodoscope

The details of the hodoscope construction are given in [1]. There are three hodoscope planes, H1, H2, and H3, 206 slats each, and varying in length from 63.6 cm (H1) to

Table 1: Hodoscope Resolutions

Detector	Time Resolution	y Resolution
H1	$140 \pm 10ps$	$1.6cm$
H2	$140 \pm 10ps$	$1.9cm$
H3	$160 \pm 10ps$	$2.2cm$

106.4 cm (H3). The widths varied from 1.1 cm (H1) to 2.3 cm (H3). These were assumed to have a time resolution of 200 ps in the experimental proposal. We list in Table 1 the performance obtained.

As can be seen, the performance exceeded the specifications in the proposal. The y (vertical) measurement is obtained from top - bottom tube timing and the resolution in y simply reflects the time resolution in the difference between the top and bottom tube times.

4 Straw Tube System

The straw tube system involved two straw tube stations called S2 and S3 respectively. There was a first station S1, which was located inside the vacuum chamber between the two analyzing magnets. This was constructed by our Bari (Italy) colleagues and is not part of the equipment covered by the DOE capital grant.

S2 and S3 were constructed of three planes each. The tube diameter in both was 4 mm. The planes of S2 contained 960 straws each 48.55 cm long and each plane of S3 contained 1920 straws each 90.2 cm long. Thus the total number of straws was 8640. Each plane actually consisted of two , staggered, close packed planes. This was done so that the "doublet" plane would have a good efficiency for detecting particles. The chambers achieved 95%-98% efficiency. The resolution was exactly as would be predicted from a 4 mm diameter tube.

5 Calorimeter

A distinctive feature of the E-864 apparatus was the lead-scintillating fiber calorimeter (so called "spaghetti" design). The calorimeter consisted of 58 (horizontal) $\times$ 13

(vertical) towers. Each tower was $10\text{ cm} \times 10\text{ cm} \times 1.17\text{ m}$ in dimension. The total weight of the calorimeter is close to 100 tons. The design was the result of detailed study, both of earlier CERN tests and Monte Carlo. It was checked in a test run of 12 towers in 1993 prior to commitment of funds for the construction. Early prototype work which was crucial to the success of the design was made possible by an R&D grant from the high energy physics division of the DOE (\$75,000).

The calorimeter performed very well. One major advantage for the spaghetti design (and a major reason for its choice) is its ability to measure both the time of arrival and the energy of particles striking the calorimeter. This worked well and the time resolution for hadrons is better than 400ps and for electromagnetic signals (electrons and photons) is about 200ps . The energy resolution for hadrons is $(3.5 \pm 0.5)\% + \frac{34.4 \pm 0.8\%}{\sqrt{E(\text{GeV})}}$. The calorimeter was designed to be compensating to obtain the best hadronic energy resolution, and as noted, an excellent hadronic resolution was obtained. The compensation achieved was nearly complete with $e/\pi = 1.1$.

6 Data Acquisition Sysytem

The D/A system was designed to be a highly parallel system with a high data rate. A complete account of the D/A system is given in [3] and [6]. The D/A was designed to record 4000 events per AGS spill (with one beam spill every four seconds). In the 1995 running the system operated at approximately 1300 events per spill. The difference from the design was largely due to two sources. One was the fluctuation in beam intensity from spill to spill which led to a degradation from 1800 events per spill to the actual 1300. The second and more significant source was the performance of the VME event builder modules purchased from General Micro Systems, which did not perform at the advertised level.

It should be noted however, that the experimental design assumed that the LET would give a conservative rejection factor of 50 while, in fact, it gave a factor of nearly 100. The burden on the D/A was thus reduced by about a factor of two. For this reason we did not choose to carry out the (expensive) replacement with faster event builders which would have restored the design performance.

References

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