PROGRESS REPORT
to the
DEPARTMENT OF ENERGY
on GRANT DE-FG05-87ER40309:
Nuclear Structure at Intermediate Energies
from

RICE

Principal Investigators

B. E. Bonner
G. S. Mutchler

T. W. Bonner Nuclear Laboratory
Rice University
Houston, Texas 77251-1892

September 30, 1991

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Table of Contents

I. Project Abstract and Overview.....	1
II. Progress on Research Projects.....	2
A. AGS E854 $\bar{p}$ -Nucleus Interactions.....	2
B. AGS E810 Strangeness Production in Heavy Ion Collisions.....	5
C. RHIC Experiment by the STAR Collaboration	8
D. CERN NA47 The SMC Experiment.....	10
E. FNAL E683 Nuclear Jets.....	19
F. AGS E818 Search for a J^{PC} Exotic Hybrid Meson.....	24
G. LAMPF Nucleon-Nucleon Experiments	26
E. Instrumentation Projects.....	27
1. The Silicon Barrel Multiplicity Detector for E854.....	27
2. The Lead Glass Array for the SMC Polarimeter.....	29
3. Detectors and Electronics for the SMC Polarimeter.....	30
4. A Cylindrical Drift Chamber for LAMPF E1097.....	30
5. Single Photon Detector for E683	31
III. Publications, Presentations, and Theses during 1991	33
IV. Copies of Selected Publications and Manuscripts.....	35
S. Ahmad et al., "A Silicon Multiplicity Detector System for Antiproton Nucleus Interaction Experiment at BNL," IEEE Nucl. Sci. Symposium, 1991.	
"Neutral V Production with 14.6 x A GeV/c Silicon Beams," S. E. Eiseman, et al., Physics Letters B 248 , 254 (1990).	
"Evidence for Multiple Scattering of High Energy Partons in Nuclei", M. D. Corcoran, et al., Physics Letters B259 , 209 (1991).	
"Three-spin Measurements in $pp \rightarrow pp$ at 730 MeV," M.W. McNaughton, et al., Phys Rev C41, 2809 (1990).	
"Accurate intensity measurements for proton beams with a 201 MHz structure," E. Gulmez, et al., Nucl Instrum and Meth A297, 7 (1990).	
"Absolute differential cross section measurements for p-d elastic scattering at 641.3 and 792.7 MeV," E. Gulmez, et al., Phys Rev C43, 2067 (1991).	
"Inclusive quasielastic spin observables for $\vec{p} + {}^2\text{H}$, ${}^{12}\text{C}$ at 500 MeV", M. L. Barlett, et al., Phys Lett B264, 21, (1991).	

MASTER

I. Project Abstract and Overview

We report here on the considerable progress that we made for the year beginning October 1, 1990 (the date of submission of our latest progress report) for DOE Grant No. DE-FG05-87ER40309. The theme that unites the sometimes seemingly disparate experiments undertaken by the Bonner Lab Medium Energy Group is a determination to understand in detail the many facets and manifestations of the strong interaction, that which is now referred to as nonperturbative QCD. Whether we are investigating the question of just what does carry the spin of baryons (as in the CERN SMC experiment), or the extent of the validity of the SU(6) wavefunctions for the excited hyperons (as will be measured in their radiative decays in our CEBAF experiment), or questions associated with the formation of a new state of matter predicted by QCD (the subject of our BNL experiments E810, E854, as well as our approved experiment at RHIC), – all these projects share this common goal. Our other experiments represent different approaches to the same broad undertaking. LAMPF E1097 will provide definitive answers to the question of the spin dependence of the inelastic channel of pion production in the n - p interaction. FNAL E683 may well open a new field of investigation in nuclear physics: that of just how quarks and gluons interact with nuclear matter as they traverse nuclei of different sizes.

In most all of the experiments mentioned above, the Bonner Lab Group is playing major leadership roles as well as doing a big fraction of the hard work that such experiments require. We use many of the facilities that are available to the intermediate energy physics community and we use our expertise to design and fabricate the detectors and instrumentation that are required to perform the measurements which we decide to do.

The format we follow in both the Progress Report and the Proposal is to have a brief writeup on each individual experiment or project and to include in the appendices copies of published papers or manuscripts which give much greater detail. The aim is to concentrate on the physics goals, the results, and their significance in the main body of the report.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

II. Progress on Research Projects

A. AGS E854 $\bar{p}$ -Nucleus Interactions

The purpose of this experiment is to search for experimental signatures of the predicted formation of hot hadronic matter by energetic antiproton absorption on a range of nuclei. This experiment probes the high temperature–low density region of the nuclear matter phase diagram and is complementary to the low temperature–high density region being studied in heavy ion collision experiments such as AGS E810, which is reported below. In the only previous experiment where $\bar{p}$ -nucleus interactions were studied at intermediate energies, Miyano *et al.*¹ used $\bar{p}$'s of momentum 4 GeV/c to bombard tantalum plates mounted in a bubble chamber. The inclusive production of K_S , Λ and $\bar{\Lambda}$ was measured and compared with that in the $\bar{p}$ -p reaction. They observed a large enhancement in the number of Λ 's, a large decrease in the number of $\bar{\Lambda}$'s and a sizeable decrease in the number of K_S 's relative to $\bar{p}$ annihilations on protons. The rapidity distribution of Λ and K_S as well as the charged particle multiplicity was also measured.

Strottman and Gibbs² have modelled $\bar{p}$ annihilations in nuclei with hydrodynamic and nuclear cascade models. An extension of the intranuclear cascade (INC) calculation, made at Rice³, reproduced all the features of Miyano's measurement. Since then, we have extended the model to include subsequent rescattering of the annihilation products according to the prescription in Ref. 4. The predicted cross sections for strangeness production is again found to be consistent with the results of Miyano *et al.* Insofar as we can determine, we have incorporated all of the known physical processes and cross sections into the model. If the model fails to predict the results from E854's much greater range of measurements and statistical power, then we will have found something interesting. In order to emphasize the potential for discovery, we recall that Rafelski⁵ recently claimed that Miyano's data provide evidence for the formation of a quark gluon plasma. In his calculation, the identity of individual nucleons is lost and the constituents of nucleons, the quarks and the gluons, are the only physical degrees of freedom. An indication that such a state of matter has been formed is of fundamental interest at this time, since no other experiment has yet confirmed the existence of a QGP.

In the INC, one assumes a straightforward reaction model in which $\bar{p}$'s deposit energy in the Lorentz–boosted forward cone of nuclear matter in the target nucleus. The calculation predicts that for $\bar{p}$ momenta of 5 GeV/c, between 2–5% of all interactions will result in an energy density of 2.5 GeV/fm³ or greater. For 9 GeV/c, this fraction rises to 50–90%, with the higher values for the heavier nuclei. Even greater energy densities are predicted. At 9 GeV/c, about 10–15% of the interactions will give energy densities greater than 3.5 GeV/fm³. It is generally thought that interesting effects will be observed at energy densities above 2.5 GeV/fm³, which corresponds to a temperature of about 170 MeV. Such large energy densities are expected to provide appropriate conditions for a phase transition resulting in a Quark Gluon Plasma.

We reported on our test run at the Multi-Particle Spectrometer (MPS) facility of the Brookhaven National Laboratory (BNL) in last year's progress report. Since then we have analysed that data in order to optimize the experimental design for our data run, which occurred in May – June, 1991. We used $\bar{p}$ beams of 5, 7 and 9 GeV/c on targets of C, Cu, Al, Pb and Sn. In order to track charged annihilation products, including the decay particles from Λ , $\bar{\Lambda}$ and K_S , we used three seven-plane MWDC modules in the upstream and four in the downstream region of the target as is shown in Fig. 1. This arrangement,

which differs from our test run, makes it easier to reconstruct events in the backward direction.

It was necessary to replace the venerable pattern recognition and tracking segments of the MPS analysis program for the present setup. We simulated the entire experiment in GEANT and tracked particles generated by the INC code through the detector geometry to create an output identical to our experimental raw data format. Optimization of the parameters of the pattern recognition program using these simulated data as well as experimental data are in progress. Typical reconstructed events are shown in Fig. 2.

1-7 : DRIFT CHAMBER MODULES; 8 : BEAM COUNTER; 9 : TARGET
10 : INTERACTION SCINTILLATORS; 11 : SILICON DETECTORS
12 : VETO COUNTER

Fig. 1 Plan view of the MPS and the detector system used for the data run of E854.

Fig. 2 Two typical reconstructed events showing the tracking capability in the backward direction.

The MPS system as it existed before our experiment had no provision for detecting particles emitted near 90° to the beam. Since we were very interested in measuring the total charged multiplicity from $\bar{p}$ annihilation in nuclei, we designed and constructed a large angle multiplicity detector system⁶ which consists of 240 silicon diodes arranged in twelve 20-pad strips. This system is described later in this report in the section on instrumentation. In the data run, the target was encircled first by a cylinder of twelve scintillators and then by the multiplicity detector system. Signals from the scintillators were propagated through optical fibers to Hamamatsu magnetic field insensitive phototubes, and then used as part of an interaction trigger. The mechanical support for target, interaction scintillators and the silicon multiplicity detectors was designed and constructed at Rice.

Fig. 3. Charged particle multiplicity distribution from $\bar{p}$ annihilation on Pb, Sn, Al, and C as measured by the silicon diodes.

The data is now in hand, and we are well along in the analysis. The silicon detectors will yield final results on charged multiplicities near 90° soon. Typical multiplicity distributions from $\bar{p}$ annihilation in nuclei is shown in Fig. 3. E854 will form the basis for the Ph.D. thesis of Tony Empl.

References

- ¹ K. Miyano et al., Phys. Rev. Lett. 53, 1725 (1984), and Phys. Rev. C. 38, 2788 (1988)
- ² D. Strottman and W. R. Gibbs, Phys. Lett. 149B, 288 (1984)
- ³ W. R. Gibbs and J. W. Kruk, Phys. Lett. 237, 317 (1990)
- ⁴ J. Cugnon et al., Phys Rev C. 41, 1701 (1990)
- ⁵ J. Rafelski, Phys. Lett. 207, 371 (1988)
- ⁶ S. Ahmad et al., Proc. of the IEEE Nuclear Science Symposium, (1991).

B. AGS E810 Strangeness Production in Heavy Ion Collisions

The purpose of E810 is to look for a possible phase transition from hadronic to quark matter: the Quark Gluon Plasma (QGP). The production of strangeness in heavy ion collisions is generally regarded as one of the hadronic signals that may be indicative of the formation of a QGP; indeed, strange anti-baryon production should be an especially sensitive indicator of a QGP. In the present experiment, our interest is to study the strangeness production in heavy ion collisions using beams from the AGS. The results for central Si-Cu and Si-Au collisions from previous runs have been reported extensively in several conferences, and in last year's progress report.

The final data run for E-810 was completed during the Feb-March, 1991 running cycle at the AGS. This run employed three large area drift chambers behind the usual three Time Projection Chambers (TPC) to provide accurate calibration tracks for the TPC's. In addition, a better purity gas mixture improved the track reconstruction efficiency in the TPC's. We took data using a 14.6x4 GeV/c Si beam on Si and Pb targets. Approximately a factor of four times more data was taken than in the 1989 or 1990 runs due in part to the improved operation of the chambers. Some data was taken at 1 T field (in addition to the usual .5 T) in order to improve the momentum resolution of the measured tracks. This data should give improved Hanbury-Brown Twiss results. Data was also taken with a 14.6 GeV/c proton beam on a range of nuclear targets to calibrate the model calculations and for comparison to the heavy ion data. The analysis of this large data set is just beginning.

Analysis of the June 1990 data is well along. All that remains is the track efficiency corrections and the TOF acceptance corrections. Analysis of the TOF results has been the responsibility of the Rice group. Several improvements have been made in the TOF data and analysis techniques, which have allowed us to achieve a time resolution of $\sigma = 115$ ps, as shown in Fig. 1, for Si-Si interactions. Figure 2 shows scatter plots of P versus β for negative and positive particles. Using a $\beta < 0.985$ cut to suppress the large pion flux we get good mass separation as shown in Fig. 3. For the negative particles there is a sharp kaon peak and a small $\bar{p}$ peak; for the positive particles we see a clearly defined proton and even a deuteron peak. Higher mass particles such as tritons and He^3 would have overflowed our ADC's and hence be lost.

Fig. 1. A time of flight spectrum for negative particles from Si-Si interactions..

The TOF hodoscope was offset from the beamline and accepted a $P_{\perp}$ range of $0.0 < P_{\perp} < 0.5 \text{ GeV/c}$ for negative particles and $0.5 < P_{\perp} < 1.2 \text{ GeV/c}$ for positive particles. It subtended a rapidity range of $1.8 < y < 2.5$ for Kaons, $1.6 < y < 2.2$ for protons, $1.4 < y < 2.3$ for deuterons and $2 < y < 4$ for pions. Low momentum positive pions and kaons are bent away from TOF hodoscope by the MPS magnet, and hence are strongly suppressed. We achieved good K/ π separation up to 3 GeV/c, p/K separation up to 5 GeV/c, and deuteron to proton separation up to 10 GeV/c.

Fig. 2 Plots of momentum vs beta for negative and positive particles detected in the TOF hodoscope from Si-Si interactions.

We are currently working on calculating the acceptance of the TOF hodoscope. We are using HIJET¹ to generate heavy ion central collision events and GEANT3 to simulate the TPC chambers. Once these calculations are completed we will have momentum distributions of identified $\pi^\pm$, K^- , p , and d from central Si-Si and Si-W collisions. These distributions can then be compared to those determined from the TPC data alone, in regions of similar phase space, without particle identification. Due to the small number of antiprotons detected, we were not able to unambiguously identify $\bar{\Lambda}$'s. In fact the antiprotons appeared to come from the target, i. e. direct production, rather than from neutral Vee decays. This was due in large part to the limited acceptance of the TOF detector. More detail on this topic will be available when the TOF acceptance calculations are completed.

Fig. 3. Mass spectra for the data shown in Fig. 2 with a $\beta < 0.985$ cut.

Reference

¹A. Shor and A. Longacre, Phys Lett B218 100 (1989).

C. RHIC Experiment by the STAR Collaboration

As reported last year, we submitted a Letter of Intent (RLOI#3) that detailed our desire to build and operate a general purpose TPC spectrometer at RHIC. The collaboration consisted of BNL, Notre Dame, CCNY, and Rice with B. E. Bonner as spokesman. The LOI was presented to the PAC in early November, 1990 along with eight others. The response to our particular detector design and physics motivations was generally favorable, even though some reservations were expressed about the capability of TPC's to withstand the very large multiplicities anticipated from central collisions of heavy ions at RHIC. Another collaboration submitted a similar Letter of Intent (RLOI#5), the

major difference being the magnetic field geometry. As anticipated, the PAC strongly encouraged the two groups to submit a single proposal. In January we instigated merger discussions. By the time of the presentation of updates to the LOI's in August, 1991, the two collaborations had merged into a single one with the acronym STAR, standing for Solenoidal Tracker At RHIC. The reservations regarding the capabilities of TPC's were addressed in tests that were performed at BNL and at CERN. It was conclusively demonstrated that the distortions that are introduced by track densities far in excess of that anticipated at RHIC are still manageable.

The physics goals of the new collaboration remains the detection of experimental signatures of the predicted new form of matter called the Quark Gluon Plasma (QGP). The tracking and identification of a large fraction of the charged particles emitted in a central collision will allow the very powerful technique of correlation of many observables on an *event-by-event* basis. Since no convincing prediction of an unequivocal experimental signature exists, we maintain that it is necessary to have this information in order to identify possible special events.

The Rice group has been particularly active in the areas of simulation, tracking of simulated events under realistic conditions, and particle identification by time-of-flight. Before the recent merging of the two collaborations, we had devoted considerable effort towards the development and testing of a tracking program for the Time Projection Chambers (TPC) of the dipole configuration proposed in RLOI#3, which constitute the main tracking device of the detector. The pattern recognition program was tested using Monte Carlo generated events and proved to perform extremely well, having a reconstruction efficiency of about 91%. After the merger, it was decided to propose a solenoid magnet rather than the dipole. The solenoid is to be complemented by two high- η detectors in the forward and backward regions, outside the magnetic field, each consisting of four TPC modules with 5 pad rows. They cover the $2 < |\eta| < 4$ regions and have very little overlap with the internal TPC around $\eta = 2$. Fig. 1 shows the STAR experimental configuration. The algorithms which have been developed at Rice for tracking for dipole configuration are have been adapted to perform the tracking in the solenoidal configuration. We find the reconstruction efficiency to be 96% for the primary tracks, and about 62% for the secondaries. The great majority of the secondaries which are not reconstructed are low energy particles, typically below 100 - 200 MeV/c.

Within the STAR collaboration, we expect to take major responsibility for the Time of Flight (TOF) detector development. A workshop was held at Rice on August 23-24 for the members of the STAR collaboration who have an active interest in the TOF subsystem of the STAR detector. It was very clear that the optimal design for the TOF system to be used in the STAR detector is yet to be found. The necessity for a timing resolution of at least 100 picoseconds in a highly segmented cylindrical counter of radius 2 m and length 5 m puts a severe demand on the technology that will finally be chosen. Although 100 ps resolution in short scintillator bars (approximately one meter) viewed by two phototubes can be considered standard technology, the requirement of operating inside a 0.5 T magnetic field is not. At the Rice workshop, we also identified multiple hits in a single TOF pixel as another severe problem facing the TOF subsystem. Various ideas to handle these problems were proposed. Test data are needed to evaluate these ideas. In addition, detailed simulations of the different designs will be essential if we are to succeed in accomplishing the stated requirements. At Rice we expect to continue our efforts to design and construct the detector to be used by the STAR collaboration.

STAR

Fig. 1 Schematic layout of the STAR detector that has been approved at RHIC.

D. CERN NA47 The SMC Experiment

Rice has assumed the lead role in a collaboration with Saclay and Trieste for the construction of a polarimeter to measure the muon beam polarization for the SMC experiment. This experiment will make the first measurement of the spin dependent structure function g_1^n of the neutron and will increase the accuracy of the SLAC-YALE and the EMC¹ measurements of g_1^p of the proton.

The spin-dependent structure functions of the proton and neutron contain the basic information about the spin composition of the nucleons and make possible important tests of QCD and of our models of the nucleon. These spin-dependent structure functions are independent of the exhaustively studied spin-independent structure functions. They are determined from measurements of spin-dependent asymmetries in the deep inelastic scattering of polarized electrons or muons on polarized nucleons¹.

The quantity which is measured in these experiments is

$$A_1(x) \equiv \frac{(\sigma_{1/2} - \sigma_{3/2})}{(\sigma_{1/2} + \sigma_{3/2})}$$

where $\sigma_{1/2}(\sigma_{3/2})$ is the absorption cross section for polarized virtual photons by polarized nucleons when the total component of angular momentum along the collision axis is $1/2(3/2)$. The existing data are shown in Fig. 1.

A fundamental sum rule, originally derived by Bjorken² from current algebra but now recognised to be based on QCD in the scaling limit relates the first moments of the spin-dependent structure functions of the nucleon to the weak interaction coupling constants for neutron beta decay. It reads

$$\int_0^1 dx (g_1^p(x) - g_1^n(x)) = \frac{1}{6} \left| \frac{g_A}{g_V} \right| \left(1 - \frac{\alpha_s(Q^2)}{\pi} \right) = 0.191 \pm 0.002 \quad \text{BJ}$$

$$\text{where } g_1^{p(n)}(x) = \frac{1}{2x} \frac{A_1^{p(n)}(x) F_2^{p(n)}(x)}{1 + R^{p(n)}(x)}$$

in which $F_2(x)$ and $R(x)$ have their usual meanings¹. The factor involving the strong coupling constant $\alpha_s = 0.27$ at $Q^2 = 10 \text{ GeV}^2$ is the correction to the zeroth order Bjorken sum rule due to perturbative QCD. In the naive quark-parton model

Fig. 1. Existing data on the quantity $A_1(x)$.

$$g_1^{p(n)}(x) = \frac{1}{2} \sum_i e_i^2 \left[q_i^\uparrow(x) - q_i^\downarrow(x) \right]$$

where i indicates the quark type with charge e_i and where $q_i^{\uparrow(\downarrow)}(x)$ is the probability that quark of type i with fractional momentum x of the nucleon has its spin parallel (antiparallel) to the nucleon spin. Hence, the quantity

$$\frac{1}{2} \Delta q_i(x) = \frac{1}{2} \left[q_i^\uparrow(x) - q_i^\downarrow(x) \right]$$

is the contribution of quark type i with momentum fraction x to the proton spin.

Auxiliary sum rules for the proton and neutron separately, which involve model-dependent assumptions (principally the validity of flavor SU(3) and that the strange quark sea is unpolarized) have been given by Ellis and Jaffe³ (EJ)

$$\Gamma_p = \int_0^1 dx g_1^p(x) = 0.189 \pm .005$$

EJ

$$\Gamma_n = \int_0^1 dx g_1^n(x) = -0.002 \pm 0.005$$

where the above numbers contain QCD corrections.

Thus far, experimental data are available only for the proton so that the Bjorken sum rule cannot be tested. However, the EJ sum rule can be tested for the proton. From the CERN data alone it was found that¹

$$\int_0^1 dx g_1^p(x) = 0.114 \pm .012 \text{ (stat.)} \pm 0.026 \text{ (syst.)}$$

in substantial disagreement with EJ. Combination of the CERN and SLAC data gave¹

$$\int_0^1 dx g_1^p(x) = 0.116 \pm .009 \pm 0.019$$

Fig. 2 shows the CERN and SLAC data on the first moment of g_1^p as a function of the lower limit x of the integral, from which the above result is derived. Note that the low x region ($x < 0.1$), measured for the first time by the EMC group, was decisive in showing the violation of the Ellis-Jaffe sum rule. Assuming the Bjorken sum rule and the above experimental result, we conclude that Γ_n for the neutron is much more negative ($-0.075 \pm 0.009 \text{ (stat.)} \pm 0.019 \text{ (syst.)}$) than the value predicted by the Ellis-Jaffe sum rule.

Finally using the Bjorken polarization sum rule, the experimental results, and the naive quark-parton model relation, it follows that the fraction of the proton spin carried by quarks is $(3 \pm 9 \pm 17)\%$, giving rise to the so-called "spin crisis" in QCD. This unexpectedly small value implies that the spin of the proton is carried by gluons and/or orbital angular momentum.

From this introduction, it is clear that the measurement of the spin dependent structure functions of the proton and the neutron is a crucial next step. Briefly, such a measurement will accomplish the following goals.

- It will allow a test of the fundamental Bjorken polarization sum rule. This sum rule is obtained from QCD without model-dependent assumptions; hence its experimental verification will be of fundamental importance.
- It will provide a further basis for testing model-dependent sum rules, such as those from Ellis and Jaffe for the proton and neutron.

Fig. 2. The first moment of $g_1^p(x)$ as a function of the lower limit, x , of the integral.

- It will provide important new information and constraints concerning the spin-isospin structure of the nucleon.
- Such information is essential for understanding high energy scattering processes which involve polarized nucleons. These include hadron-hadron scattering, the polarized Drell-Yan process and production of polarized W or Z vector bosons in collisions of polarized protons in a high energy storage ring.

The asymmetry (A) for longitudinally polarized muons scattered by longitudinally polarized nucleons is defined as

$$A = \frac{d\sigma^{\uparrow\downarrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\uparrow\downarrow} + d\sigma^{\uparrow\uparrow}}$$

where $d\sigma^{\uparrow\uparrow(\downarrow\downarrow)}$ is the cross section for parallel (antiparallel) muon and nucleon spins. It is derived from the measured asymmetry

$$A = \frac{A_{\text{meas}}}{P_{\mu} P_T f}$$

where P_{μ} and P_T are the beam muon and target polarizations and f is the dilution factor arising from unpolarized material in the polarized target. In first order QED, the asymmetry A is related to the virtual photon – nucleon asymmetries A_1 and A_2 by

$$A = D (A_1 + \eta A_2)$$

where D and η are kinematical functions. To a good approximation $A_1 = A/D$.

This experiment will measure the proton and neutron asymmetries A_1^p and A_1^n , thus determining the spin dependent structure functions in order to test the Bjorken sum rule with about 10% accuracy. The neutron asymmetry will be derived from the proton and deuteron asymmetries A_1^p and A_1^d by the relation

$$A_1^n = \frac{1 + \left(\frac{F_2^p}{F_2^n}\right)}{1 - 1.5 W_D} A_1^d - \left(\frac{F_2^p}{F_2^n}\right) A_1^p$$

where W_D represents the D-state probability of the deuteron ($\sim 5\%$). The Bjorken sum rule will then be evaluated.

The experiment uses the EMC spectrometer (Fig. 3) with a new polarized target and a muon polarimeter added. The new polarized target system will provide polarized deuterons as well as polarized protons and will have the capability of rapid spin reversal with over 40% deuteron polarization.

To reduce the systematic errors on the measured asymmetries it is essential to reverse the nucleon spins frequently and thus rapidly. In this way effects due to drift in the acceptance are largely avoided. The magnet construction will be completed at Saclay early next year. Construction of the cryostat will begin soon. In the 1991 run, the old EMC target filled with a deuterated sample is being used, currently giving about 25% deuteron polarization.

The polarimeter was designed at Rice and is shown schematically in Fig. 4. Rice has assumed responsibility for the construction of the multiwire proportional chambers (MWPCs) downstream of the bending magnet (MNP26) and for the lead glass wall. Trieste has furnished the fast 1 mm beam chambers and Saclay the data acquisition electronics, two Sun work stations for data acquisition, on-line data analysis, and the trigger scintillation hodoscopes.

Fig. 3. Plan view of the overall experiment.

Fig. 4. Schematic plan of the polarimeter for the muon beam.

Fig. 5. Dependence of the energy spectrum of the decay positrons on the muon polarization.

The muon beam polarization will be measured by two methods: (1) the shape of the energy spectrum of decay positrons in the laboratory system is sensitive to the muon polarization as is shown in Fig. 5; and (2) the muon spin will be analyzed by detecting the elastic scattering of muons from electrons in a polarized iron target.

In the decay method, the muons decay in a magnetic field free region of 30m, upstream of the MNP26 bending magnet. The shower veto counter (SV) insures that the incident particle was a muon, not a positron previously produced by muon bremsstrahlung or decay. The quadrupoles Q34 and Q35 refocus the muon beam which has blown up downstream of the polarized deuteron target. Decay positrons are deflected out of the incident beam into the downstream MWPCs and lead glass wall (LG) by the MNP26.

Fig. 6a. The difference between the tracked position of the downstream particle and the detected position of the cluster in the lead glass array. The offset is a temporary artifact.

The muon decay trigger is a pulse height greater than 10 GeV in the lead glass in coincidence with a single minimum ionizing particle in the shower veto counter (SV). Lead placed upstream of the SV initiates a shower for unwanted incident positrons, which are vetoed as multiple pulse heights by these crossed scintillation hodoscopes. Various veto counters (BV) suppress events initiated by beam halo particles. The positron momentum is then measured by the MWPC's, and compared with the clustered energy of the shower in the lead glass wall. The extrapolated track minus the lead glass cluster position has about a 2 cm width for 10 cm lead glass blocks as is shown in Fig. 6a.

Fig. 6b. Pulse height measured in the LG wall plotted as a function of particle momentum.

In Fig. 6b, the dark 45 degree stripe is due to the positrons of interest from beam muon decays upstream of the MNP26; in addition there is scattered background due to muon decays in the MNP26 and beam halo muon induced showers in the lead glass. The downstream hodoscope VLG, separated from the LG by a lead wall, detects halo muons which have initiated a shower in the LG. Cuts on the ADCs and TDCs of the SV, BV, LG and VLG, along with the requirement of energy and momentum matching on the positron track should eliminate backgrounds due to beam halo muons, decays not occurring in the decay region, and positrons produced upstream of the decay region.

The decay polarimeter is now fully operational and we expect to make a measurement of the muon beam polarization during the present data taking run. This will be the first high quality measurement of this type ever made, and should be of sufficient accuracy so that the beam polarization does not contribute to the error on the spin-dependent neutron structure function measured during this current data run.

The MWPCs, PPC4 and PPC3, were built by Rice graduate students and constitute an M.A. thesis project for Steve Eichblatt. The Rice students Eichblatt, Gaussiran, and Cranshaw, along with postdoctoral fellow Mark Lowe, have largely debugged the system and gotten it working. Mark Lowe has written, from scratch, an event reconstruction program which has allowed us to debug the polarimeter and is coordinator for the data analysis of the polarimeter. Lowe and the three Rice graduate students have been in residence at CERN without interruption for the entire run and have contributed a major fraction of the work in the setup and debugging of the polarimeter.

For 1992 and following runs, we will also implement the μ -e scattering polarimeter (Fig. 7). This requires the construction of one additional MWPC (PPC1), a special large 1 mm wire spacing chamber. We will construct this in collaboration with the Saclay shops,

Fig. 7. Schematic of the muon - electron elastic scattering polarimeter.

using a design developed at Rice. This chamber must count efficiently in the region of the muon beam, as the Trieste built beam chambers do, but must also cover the complete solid angle for μ -e scattering. The design is now final. The chamber will be constructed either at Saclay or at Rice, and the PCOS III electronics will be furnished by Rice. We also must furnish faster photomultipliers than are currently installed on the LG wall. They were donated to us by BNL along with the lead glass, but to fully implement the polarimeter we must purchase the faster phototubes. This is of modest cost (\$30K) compared to that of the total polarimeter and still represents a considerable savings over the originally projected cost of the lead glass wall. We are also utilizing three MWPCs built for FNAL experiments E704 and E683 to reduce the total cost.

Trieste will furnish four more beam chambers and Saclay (in addition to the 1mm MWPC) the polarized Fe target. The Fe target will have the capability of polarization reversal on alternate SPS pulses to reduce systematic errors. We expect using the two polarimeter techniques to reduce the error on the beam polarization measurement so that it never contributes to the final error on g_1^n of the neutron or to the check of the Bjorken sum rule.

References

- ¹G.Baum *et al.*, Phys Rev Lett 51 1135,(1983); M.J. Alguard, *et al.* Phys Rev Lett 37 1261, (1976); *ibid.*, 41,70(1978); J. Ashman, *et al.* Phys Lett 51,1135(1988)
- ²J.D. Bjorken, Phys Rev 148 1467,(1966); Phys Rev D1 1376,(1970)
- ³J. Ellis and R. Jaffe, Phys Rev D9 1444,(1974)

E. FNAL E683 Nuclear Jets

In Fermilab experiment E683 we are studying the photoproduction of jets in the Wide Band photon beam. Rice is the lead institution on this experiment. Collaborating institutions are Ball State University, Fermilab, University of Iowa, University of Maryland, University of Michigan, Vanderbilt University and University of Wisconsin. The Wide Band Beam at Fermilab provides the world's highest energy tagged photon beam, with usable photon fluxes extending to 400 GeV. The large-solid-angle coverage of our calorimeters, including full coverage in the forward direction, provides us with a unique opportunity to study the direct-coupling of the photon to partons in the target nucleons. The first-order QCD processes of interest are the QCD Compton and photon-gluon fusion diagrams. In some cases, the photon first dissociates into a quark-antiquark pair before it interacts. Events of this type, instead of just being a nuisance, will allow us to obtain new information on the photon structure function. Complete second-order calculations have been done by Jeff Owens of Florida State, who has helped us a great deal in understanding and applying his work.

In addition to studying jet photoproduction with a hydrogen target, the A -dependence of jet photoproduction will be studied in detail. We will take data with a liquid deuterium target and six solid nuclear targets ranging from Be to Pb. We know from our previous experiment E609 that large A -dependent effects are seen in jet production in p - A interactions. Some new results on A -dependent effects have recently been published¹ from E609. The presence of the nucleus greatly decreases the energy flow in the forward direction; the energy loss is consistent with an $A^{1/3}$ dependence. In addition, we see strong evidence for a significant amount of multiple-scattering of the partons as they exit the nucleus, producing an additional p_t unbalance or k_t of 1 GeV for p -Pb interactions. Our data are consistent with the hadronization process occurring outside the nucleus.

The origin of such large A -dependent effects is not well understood. Multiple-scattering models qualitatively produce the type of effects that we observe, but in general the effects they predict are too small. Most multiple-scattering models would also predict substantial A -dependent effects in Drell-Yan production, since one would expect the incoming hadron to also undergo multiple scattering. But the Drell-Yan data indicate that any A -dependent effects are small. Sivvers has suggested that our results may be due to a final-state interaction between the outgoing partons, whereas Sterman has suggested that there may be interference effects between multiple scattering in the initial and final states.

Data from E683 as well as other currently-running Fermilab experiments should shed light on the question. E706 will study the A -dependence of direct photon production in a hadron beam; the final state in this case is one parton and one photon. And E665 will study the A -dependence of deep inelastic muon scattering, in which the final state is one parton and one muon. Information from all these experiments together gives us a real opportunity to learn about the passage of colored objects through nuclear matter.

After a short test run in August of 1990, E683 was ready for data. We took advantage of a scheduled three-month shutdown to make some necessary repairs and to add a detector upstream of the lead radiator to monitor beam pile-up. The three-month shutdown grew to 4.5 months, and we were ready for startup in January. However, in mid-December, shielding problems were discovered in several of the external beam lines and in the accelerator itself, and startup was delayed until late June. The first useful beam for data was in early July. For the first month the accelerator ran at low intensity and was plagued

with normal start-up problems. Nevertheless, there have been periods of stable beam in the last month, and we have eagerly put them to use.

Beam Tagging

A crucial part of the beamline is the tagging of the electron beam using the Si microstrip detectors provided by the Milano group from E687. With a momentum spread of $\pm 15\%$ in the electron beam, it is necessary to measure the momentum of each electron, which is accomplished to an accuracy of 2% with the Si tagging system. For calibration, when the beam was collimated so that the Si tagging detectors have full coverage, the tagging efficiency often exceeded 90%. For regular data-taking, with collimators completely open, the efficiency at low intensities approached the maximum possible 85% due to the acceptance of the microstrips. At higher intensities the efficiency drops somewhat due to multiple occupancy of buckets, but even at our normal running intensity we achieve tagging efficiencies of about 65-70%. Fig. 1 shows the energy spectrum of the incident electron beam as measured by the Si microstrip detectors. After the lead radiator, a

Fig. 1. The energy spectrum of the Wide Band electron beam as measured by the silicon microstrip detectors.

series of shower counters measures the energy of the recoil electron, allowing us to deduce the energy of the bremsstrahlung photon to an accuracy of 2-3%.

Calorimeter Calibration

A plan view of the experimental apparatus is shown in figure 2a. The most important part of our apparatus is a highly-segmented, sampling calorimeter. The

Fig. 2. a) Plan view of the apparatus. b) Segmentation of the sampling calorimeter.

segmentation of this detector is shown in figure 2b. Each tower consists of one layer of lead-scintillator sandwich, followed by three layers of iron-scintillator sandwich. Both the EM and hadronic energy resolutions are important in the data analysis and must be measured with care. This necessitates a careful calibration of the entire detector. We calibrated each of the 132 towers with 90 GeV electrons, and twelve towers were calibrated with electrons of 30 GeV, 60 GeV, and 150 GeV as well. Twelve regions of the calorimeter were calibrated with pions of energies 30, 60, 100, and 150 GeV. From a preliminary analysis of the calibration data, we show typical results in Figs. 3a and 3b. The energy resolution for both EM and hadronic particles is well within expected values. The constant factors quoted include the resolution of the beam tagging, so they will be somewhat smaller when that contribution is removed.

Fig. 3. Energy resolution measured in the main calorimeter for:
 a) Electromagnetic showers, and b) Hadronic particles.

One of the distinctive aspects of photoproduction is the expected absence of forward energy for high p_t events. The beam calorimeter, which measures forward energy flow, is therefore crucial and must be calibrated with care. This was completed early in the

Fig 4. Measured energy resolution for the beam calorimeter for: a) EM, and b) hadronic particles.

run, and preliminary results for both the EM and hadronic response are shown in Figs. 4a and 4b. Due to the coarser sampling in the beam calorimeter, the energy resolution is not quite as good as for the main calorimeter, but still well within acceptable values.

Preliminary Results

Fig 5. A typical spectrum of photon energy measured in the main calorimeter for events which pass a high- E_t trigger.

The calibration data were interspersed with preliminary photon data, so that all trigger logic and timing could be checked. All trigger hardware was found to be functioning, and we began data-taking within two weeks of accelerator turn-on. As of this writing (September 22, 1991) we have completed all preliminary checkouts and calibrations of our apparatus and have entered into production data-taking. So far we have about 3.1 million triggers from hydrogen, 1.8 million triggers from the solid targets, and 0.5 million triggers from the deuterium target.

Figure 5 shows a typical spectrum of photon energy for events which pass one of our high- E_t triggers. Even a modest E_t requirement in the main calorimeter is sufficient to discriminate against all EM background. The minimum photon energy we are sensitive to is about 100 GeV.

Fig. 6. a) The ratio of energy measured in the main calorimeter to that of the incident photon. b) The ratio of the total energy measured in both calorimeters to the energy of the beam photon.

Figure 6a shows the ratio of energy observed in the main calorimeter to the energy of the incident photon. Figure 6b shows the ratio of the total energy observed in both calorimeters to the photon energy. Although the absolute energy scale of our calorimeters has not yet been determined to better than 10%, it is clear that we see nearly all of the incident energy. The high-energy tail is due to pileup in the beam calorimeter from electrons in nearby RF buckets. Information from our pileup monitor, located upstream near the Si tagging stations, will allow us to eliminate or make corrections for events with pileup.

Figure 7 shows a typical E_t distribution in the main calorimeter for events satisfying a "global" trigger, which is a threshold requirement on the total E_t in the calorimeter. Above threshold the distribution is seen to be exponential. Figure 8 shows two "lego" plots of jet-like events.

One potential problem in the analysis is the presence of soft photons accompanying the high-energy photon which interacted. The soft photons will typically enter the beam calorimeter; the problem is to discriminate them from energy in the beam calorimeter from the hadronic interaction of the energetic photon. To study this problem, we have taken some fraction of the data with a thinner lead radiator (10% vs 20%) and we have taken some data with a pion beam. We see a clear difference in the EM fraction of energy in the beam calorimeter for a pion beam compared to a photon beam. The difference can be attributed to soft photons, and we are currently studying ways to correct for the effect.

Fig. 7. A typical E_t distribution in the main calorimeter for events satisfying a "global" trigger.

Fig. 8. "Lego" plots of two jet-like events.

We are expecting to continue data-taking through the end of November or December 1991. We are pleased with the quick startup of the experiment and the quality of the data taken so far. There are six Ph.D. students on E683 (three from Rice and three from other institutions), and two Masters students from Rice. Data analysis tasks will be divided up among the various institutions.

Reference

¹M. D. Corcoran *et al.*, Phys. Lett. B259, 209 (1991); R. C. Moore *et al.*, Phys. Lett. B244, 347 (1991).

F. AGS E818 Search for a J^{PC} Exotic Hybrid Meson

The object of BNL E818 is to search for non- $q\bar{q}$ states in the light quark meson sector. One possibility of a non- $q\bar{q}$ state is one which includes gluonic degrees of freedom. These degrees of freedom are expected in QCD to give rise to two new spectroscopies, Hybrid¹ and Glueball². Several models predict such spectra with the lowest lying states in the 700 to 3000 MeV mass range.

The search for gluonic degrees of freedom in hadron spectroscopy has so far been confined to that of glueballs. However, the endeavor has been less than conclusive because the isoscalar meson sector is relatively poorly known and in addition, the glueballs can mix with them. It is therefore advantageous to search for the gluonic excitations in mesons called hybrids (or meiktons or hermaphrodites) which can be thought of as the meson states with a $q\bar{q}$ in a color octet combined with a "valence" gluon to form color-singlet physical states.¹ Sum rule and flux tube models³ predict that the lowest lying states are J^{PC} exotic and slightly higher in mass than the lowest lying glueballs. The cross section for hybrid production is expected to be about the same as that of ordinary mesons, but decay to a pair of $L = 0$ mesons is suppressed. In E818, we are investigating the production of $I = 1$, $J^{PC} = 1 \rightarrow$ hybrid X(1900), which is predicted to decay to $\pi^- b_1$ and $\pi^- f_1$ final states. We are interested in one of these decays which was seen through the decay chain:

$$X(1900) \rightarrow \pi^- f_1(1285)$$

$$f_1(1285) \rightarrow \pi^- a(980)$$

$$a(980) \rightarrow K^+ \bar{K}^0$$

$$\bar{K}^0 \rightarrow \pi^- \pi^+$$

In addition, we are also looking at the $KK\pi$ system produced in the reaction:

$$\pi^- p \rightarrow K^+ \bar{K}^0 \pi^- n$$

$$\bar{K}^0 \rightarrow \pi^- \pi^+$$

in order to investigate the E/t region^{3,4} (i.e., 1.3 to 1.6 GeV). The $E/f_1(1420)$ has recently been tentatively identified as a $J = 1^{++}$ state, but there is still some confusion about this. Although this is a non-exotic state, it would be difficult to place it in the scheme of SU(3) nonet families, indicating a non- $q\bar{q}$ state⁴. It has been suggested that the $E/f_1(1420)$ is either a 1^{++} bound state of KK at threshold⁵, or a P-wave π orbiting an S-wave KK at the center⁶.

Fig. 1. Experimental arrangement used for E818 at the AGS.

The E818 measurement was performed at the MPS facility in 1990 using an 18 GeV pion beam incident on a 60 cm liquid hydrogen target. The experimental arrangement is shown in Fig. 1. The trigger included a RAM trigger system for the identification of a fast forward Kaon. The RAM trigger looked for coincidences between appropriate clusters in the proportional chamber P3, the scintillator hodoscopes H1 and Time-of-Flight, T1, and no signal from the corresponding section of the segmented Cerenkov counter C1. A multiplicity increase of two between P1 and P2 was also included in the trigger, and would signal the decay of a K^0 . A cylindrical drift chamber (PC) was used in the X(1900) trigger to demand a recoil proton coming out of the target, which reduced the background due to diffractive dissociation of the beam. For the $E/f_1(1420)$ trigger, it was required that no signal be present in PC. Drift chambers DC(1-7) were used for tracking in the magnetic field, and hodoscope H2 was used to provide additional information in the event reconstruction.

Initial processing of the data from over 800 hours of running has been done. The resulting data set, while showing interesting structure, does not have quite enough events for a full partial wave analysis. Modifications which we made to the reconstruction software provided by the MPS facility has yielded approximately a 30% increase in the number of events in the final event sample, and reprocessing is now beginning. In addition, the $E/f_1(1420)$ trigger will allow us to look for the H-particle, a strangeness -2 dibaryon resonance predicted by Jaffe⁷ to lie about 70 MeV below the $\Lambda\Lambda$ threshold. Calculations done subsequently using a variety of models, which added corrections to the bag model, expanded the range of expected masses for the H-particle. Most of these, however, remain in the bound region. Portions of the analysis discussed above will comprise the Ph.D. thesis of Rice graduate student J. Cummings. Due to our heavy involvement in other projects, this is the extent of our commitment to E-818 at this time.

References:

- ¹M.Chanowitz and S. Sharpe, Nucl. Phys. B222, 211 (1983); J. M. Cornwall and A. Soni, Phys. Lett. B210, 431 (1983); K. Ishikawa et al. Z. Phys. C21, 167 (1983).
- ²F. E. Barnes, F. E. Close and S. Monaghan, Nucl. Phys. B198, 380 (1982); M. Chanowitz and S. Sharpe, Nucl. Phys. B222, 211 (1983); E. Golowich, E. Haqq and G. Karl, Phys. Rev. D28, 160 (1983).
- ³N. Isgur and J. Paton, Phys. Lett. 124B, 247 (1983); N. Isgur, R. Kokoski and J. Paton, Phys Rev Letts. 54, 869 (1985).
- ⁴S. U. Chung, BNL Report-43263, Sept. 1989, Invited talk given at the International Meeting on Physics at Kaon Factory for TRIUMF, Vancouver, Canada, held at Bad Honnef, W. Germany, June, 1989.
- ⁵D. Caldwell, Workshop on Glueballs, Hybrids and Exotic Hadrons, Brookhaven, 1988, AIP Conf. Proc. No. 185, ed. S. U. Chung, page 465.
- ⁶R. Longacre, BNL preprint, to be published in Phys. Rev. and as quoted in reference 4.
- ⁷R. L. Jaffe, Phys. Rev. Lett. 38, 195 (1977)

G. LAMPF Nucleon-Nucleon Experiments

The Bonner Lab remains active in the area of nucleon-nucleon physics. Our major interest continues to be LAMPF experiment 1097 in which we plan to measure cross section and spin observables for the reaction $np \rightarrow pp\pi^-$. Data will be taken with an unpolarized target in the first phase and with a spin-frozen L-type target in the second. The heart of this experiment is a cylindrical drift chamber which was assembled at Rice during the past year. This effort is described in the section on instrumentation. The chamber was moved to Los Alamos last spring and some data was taken parasitically with E876. The

objective of this test run was to optimize the operation of the chamber and associated electronics. We were able to convince ourselves that the chamber and the present on-chamber electronics do provide adequate signals in the counting house. We had planned to instrument eight 16-wire modules in the chamber but high voltage and data acquisition problems finally allowed us to run with only three. We also discovered a problem with the counting house electronics which is discussed in the section on instrumentation. We hope to resolve all of these problems in the upcoming year and carry out more extensive tests of the chamber next summer.

Last summer, we participated in the second run of LAMPF E876 which is measuring a wide range of spin observables in np elastic scattering. The LAMPF polarized neutron beam interacts in a 15 liter LH₂ target and the spin of the recoil protons is measured using the Janus polarimeter. The data from last summer's 800 MeV run have already been analyzed and a paper has been submitted¹. The measurements differed significantly from the previous phase shift solutions and, with their inclusion, the nucleon-nucleon phase shifts are now well determined at this energy. The Janus polarimeter was moved to zero degrees and the LH₂ target replaced with LD₂ to perform E1234 which provides a direct measure of the zero-degree spin transfer coefficient K_{LL}. This is needed to extract the neutron beam polarization from the measured proton beam polarization.

Significant progress was made in the analysis of a number of nucleon-nucleon experiments to which we had made earlier contributions. Results from LAMPF E1035 which measured two- and three-spin observables in pp elastic scattering were published at the end of last year². E818, which measured the same observables for pd elastic scattering, has been analyzed and the submitted paper is currently under revision. Experiments 1119 and 1072 made precision measurements of the pd and pp elastic cross sections, respectively. Results from the former were published last year³ while the latter are still being analyzed. Both these experiments required us to count the incoming beam protons and this procedure is described in a NIM article⁴. Finally, the data-taking for TRIUMF E372 was completed and the analysis has begun. This experiment measures cross section and analyzing powers for the same reaction as LAMPF E1097 but does not have the complete angular coverage or make use of a polarized target. It is hoped that the analyses of all these experiments will be completed during the next year.

References:

¹M. W. McNaughton et al., submitted to Phys. Rev. C (1991)

²M. W. McNaughton et al., Phys. Rev. C41, 2809 (1990)

³E. Gulmez et al., Phys. Rev. C43, 2067 (1991)

⁴E. Gulmez et al., NIM A297, 7 (1990)

E. Instrumentation Projects

1. The Silicon Barrel Multiplicity Detector for E854

We have developed a Large Angle Cylindrical Multiplicity Detector (LAMCD) system for BNL experiment E854 to measure the charged particle multiplicity distributions from $\bar{p}$ annihilations in nuclei from 48° to 158° with respect to the beam. As sketched in Fig. 1, the detector consists of 240 ion-implanted silicon photodiodes arranged in 12 pad arrays. Each array contains twenty 1 cm x 1 cm silicon diodes with a thickness of 500 ± 25 microns. These low-noise, fast-response diodes together with low noise front end quad preamplifiers (CERN MSP-1) were purchased from Micron Semiconductor Limited,

England. The quad preamplifier output is differential and is intended to drive balanced lines.

Fig. 1. A sketch of the Large Angle Multiplicity Detector developed for E854.

Because of the low signal levels from the silicon detectors, a further stage of amplification was required. We designed and constructed shaping amplifiers, which were mounted on the same printed circuit support card as the preamplifier. The inputs are AC coupled to a Motorola MC1733 amplifier chip, the outputs of which are connected via an integrating network to complementary emitter followers. The gain of the shaper amplifier is variable from 10 to 30. The output of the shaper amplifier drives 50 meters of twisted pair ribbon cables, which is then terminated in a transformer isolation matching card. The matching card terminates 16 twisted pair lines with 100 ohm impedance and provides 16 lines to match the 50 ohm impedance of the LeCroy FERA CAMAC ADC's.

Extensive tests were performed with one silicon pad array at Rice. We studied the characteristics of the diodes using the complete electronic set up, triggering on minimum ionising particles from a ^{106}Ru source. The complete system performed admirably with the $\bar{p}$ beams of 5, 7 and 9 GeV/c. We accumulated sufficient data to extract the charged particle multiplicity distributions arising from $\bar{p}$ annihilations in five different nuclei. A paper on our LAMMD detector system will be presented at the IEEE Nuclear Science Symposium¹. Hits in the diodes from a typical run is shown in Fig. 2. Some diodes are more sensitive than the others which will be taken care at the offline analysis.

Fig. 2. Hits recorded in the 240 diodes during a typical run.

Reference

- ¹S. Ahmad et al., "A Large Angle Multiplicity Detector (LAMD) for Antiproton Nucleus Interaction Experiment at BNL," IEEE Nuclear Science Symposium, 1991.

2. The Lead Glass Array for the SMC Polarimeter

The lead glass wall which we used for BNL E817 was dismantled and reconfigured to build a lead glass calorimeter for the SMC polarimeter. Our design called for an area of 30 cm x 100 cm of SF5 lead glass. Since we possessed 60 blocks with a length of 21.4 cm, and a square face of edge 10.14 cm, we decided to improvise. The length of each block is 14.7 radiation lengths, which is insufficient for the present application; therefore we glued pairs of blocks together to make the total thickness a more than adequate 29.4 radiation lengths. The counters were stacked in three rows with 10 blocks per row. Thirty PMT's (RCA 4900) were attached to the back of the lead glass blocks. A light tight container and transporter for this lead glass wall was designed and constructed at Rice.

The entire system was assembled and tested at Rice before being sent to CERN in March. During beam tests in June, we found that the transit time of the RCA tubes is simply too slow to allow building a fast first level trigger for the very inflexible RMH

electronics used for the Trieste beam wire chambers. We must therefore replace the slow RCA tubes by a faster tube, possibly the Hamamatsu R2238, which will allow the complete lead glass system to be used for the 1992 data taking period.

3. MWPC Detectors and Electronics for the SMC Polarimeter

Two large planar MWPCs (PPC3 and PPC4) were constructed by Rice graduate students and instrumented at Rice for the SMC experiment at CERN. These chambers are now being used as tracking chambers in the SMC polarimeter. The Rice students S. Eichblatt, T. Gaussiran and J. Cranshaw along with post doctoral fellow M. Lowe have largely debugged the PCOS III electronics and read out system. An event reconstruction program for the polarimeter has been written by the Rice group and we are taking a major role in the polarimeter data analysis.

For 1992 and subsequent runs, we will implement the μ -e elastic scattering polarimeter which requires the construction of one additional MWPC (PPC1), a large 1 mm spacing wire chamber. The design of this special chamber has been developed at Rice and the construction of this chamber will be done at the Saclay shop and/or at Rice in collaboration with the Saclay group. This chamber must count efficiently in the muon beam, as do the Trieste-built beam chambers, but in contrast it covers the complete solid angle for muon electron scattering – about a factor of four larger than the beam chambers. The front end and the readout electronics (PCOS III) from LeCroy will be furnished by Rice for this chamber.

4. A Cylindrical Drift Chamber for LAMPF E1097

The major detector for LAMPF experiment 1097 is a cylindrical drift chamber 30 cm in radius and 110 cm in height. There are four detection rings each including three rings of high voltage wires and two rings of alternating sense and high voltage wires. All wires are parallel to the cylinder axis. The drift time will be used to calculate the r-phi coordinate for each plane and charge division is used to determine the z-position. The sense wires are at ground and are read out at both ends in modules of 16 wires. They are connected by a short wire to a preamplifier board mounted on the chamber. Signals from the preamplifier boards on either end of each module are carried on ribbon cables to a receiver board in the counting house. On this board, each of the signals is split, part going directly to an ADC while the remainder is summed with that from the the other side and then discriminated. The output of the discriminator is fed to a TDC (actually a TAC and then an ADC). There are a total of 28 modules in the chamber including a total of 448 sense wires and 1792 high voltage wires.

Most of the assembly of the chamber was carried out during the last year. Carbon fiber inner and outer walls were constructed at the University of Houston and then these were glued to the aluminum end plates that had been previously constructed at the University of Texas. This procedure and the painstaking process of inserting the wires into the chamber was carried out at Rice, requiring six months to place all the high voltage wires and eight modules of sense wires. Only eight modules were strung because our plan for last summer called for testing only this number. The design of the receiver boards was completed and eight boards along with eight pairs of preamplifier boards were constructed.

Tests at LAMPF this summer showed that the chamber and electronics are capable of producing signals of the desired size at the ADC's. However there were some problems in producing the discriminated signal for the TDC's and this part of the receiver board will be redesigned. The passive addition used in the original design will be replaced with an

active device. We hope that this change can be made with minor modification to the existing circuit, adding a small daughter board if required. There were also problems holding high voltage in some sections of the chamber. We suspect this problem is due to pieces of broken wires which were not completely removed. These wires were broken during shipping to LAMPF, causing us to plan to do all future work on the chamber at LAMPF.

Our plans for the immediate future include "cleaning" the chamber to fix the latter problem and building a new set of receiver boards. We also need to replace a number of high voltage and sense wires. We plan to take additional test data during the next LAMPF run period which we expect to take place in summer 1992. If the ADC's and TDC's are available and time permits, we would also like to add more sense wires to increase the usable volume of the chamber for these tests. At some point we must also verify operation in the field of the magnet that will be used to maintain the target polarization for phase 2 of the experiment.

5. Single Photon Detector for E683

In order to study the very interesting QED Compton process in E683, we augmented the existing main calorimeter with a detector having adequate spatial resolution to distinguish single from double photons. This additional detector, the Single Photon Detector (SPD), will allow separation of the QED process from the vastly more abundant QCD processes. It consists of a lead-scintillator calorimeter with two embedded proportional wire chambers (PWC's) and has an active area of 42" by 32". The calorimeter consists of a total of 10 layers of 5/8" scintillator and 9 layers of 1/8" lead sheets. Two half-inch steel plates from the support stand act as absorber as well. The detector has about 5 radiation lengths of lead and 1.5 radiation lengths of iron. Sampling occurs following the first layer iron plate (.7 radiation lengths), and after each layer of lead (.56 radiation lengths), for each of the nine layers of Pb. The first of the two chambers is placed after the fourth layer of Pb, and the second after the last layer of Pb. No sampling is done in the SPD after the last steel plate. Sampling then resumes in the E683 main calorimeter. Fig 1 shows a schematic of the detector.

Fig. 1. Schematic of the Single Photon Detector for FNAL E683.

The estimated uniformity across the instrument, from measurements of wavelength shifter (WLS) and scintillator performance, is 4% center to left or right edge, and 5% center to top or bottom. This uniformity is a consequence of the long attenuation length (70") in the acrylic scintillator, as well as the effective attenuation length (40") in the WLS. The light is collected in WLS of dimensions 9" x 36" x 1/8" (two sheets per side). The light then goes into 4 adiabatic light guides (one at each corner) which transports the light through a 90 degree bend into four Hamamatsu R-2154 phototubes. The WLS is Y-7 (30 ppm) produced by Kyowa Gas of Japan. The acrylic scintillator was salvaged from a previous experiment. Foil placed behind the WLS will boost the collected light by approximately 20%. This backing will be applied to the central portion of the calorimeter to help achieve better uniformity if necessary. The R-2154 tube is the 2" version of the ten-stage Hamamatsu R-580. The spectral response is well matched to light from the Y-7. Thirteen tubes have been tested and are ready for use. Bases were designed specifically to give linear response from the R-2154 and have the added feature of a potentiometer to allow gain matching at a given voltage. The two chambers have spatial resolutions of 1 cm for the sense wires and approximately 2 cm for the cathode strips.

Monte Carlo studies indicate that this detector will do a good job of distinguishing QED Compton events from QCD processes. The program LUCIFER was used to generate both QED and QCD processes. The following cuts were made on the simulated data:

1. No hadron with energy greater than 8 GeV near the photon.
2. P_t in electromagnetic particles in the SPD greater than 4 GeV.
3. No second photon with $E > 3$ GeV and within 2 cm in x of the primary photon.
4. No second photon with $E > 3$ GeV and within 7 cm in y of the primary photon.

All of these cuts are well within the capability of the main calorimeter and the SPD. After applying these cuts to 700K LUCIFER events, we find that the ratio of true to false single photons is about 50% at $P_t = 4$ GeV/c. This ratio improves rapidly with P_t , and is also likely to improve when the cuts are studied in more detail.

III. Publications, Presentations, and Theses during 1991

Publications

- "Neutral V Production with 14.6 x A GeV/c Silicon Beams," S. E. Eiseman, *et al.*, Physics Letters B 248 , 254 (1990).
- "Evidence for Multiple Scattering of High Energy Partons in Nuclei", M. D. Corcoran, *et al.*, Physics Letters B259 , 209 (1991).
- "Study of the Reaction $\bar{p}p \rightarrow \Lambda\Lambda$ at 1.546 GeV/c and 1.695 GeV/c, P.D. Barnes, *et al.*, Nuclear Physics A526, 575 (1991).
- "Three-spin Measurements in $pp \rightarrow pp$ at 730 MeV," M.W. McNaughton, S. Pentilla, K.H. McNaughton, P. J. Riley, D. L. Adams, J. Bystricky, E. Gulmez and A.G. Ling, Phys Rev C41, 2809 (1990).
- "Accurate intensity measurements for proton beams with a 201 MHz structure," E. Gulmez, A.G. Ling, C. A. Whitten Jr., J. F. Amann, M. W. McNaughton, T. Noro, D. L. Adams, V. R. Cupps, R.D. Ransome, G. Glass, A.J. Simon, K. H. McNaughton, and P.J. Riley, Nucl Instrum and Meth A297, 7 (1990).
- "Absolute differential cross section measurements for proton-deuteron elastic scattering at 641.3 and 792.7 MeV," E. Gulmez, S. Beedoe, T. Jaroszewicz, A. G. Ling, C.A. Whitten Jr, M.W. McNaughton, J. R. Santana, D.L. Adams, V. R. Cupps, A.J. Simon, M.L. Bartlett, K. H. McNaughton, and P.J. Riley, Phys Rev C43, 2067 (1991).
- "Inclusive quasielastic spin observables for $\vec{p} + {}^2\text{H}$, ${}^{12}\text{C}$ at 500 MeV", M. L. Barlett, R. W. Fergerson, G. W. Hoffmann, J. A. Marshall, L. Ray, J. F. Amann, B. E. Bonner, and J. B. McClelland, Physics Letters B264, 21, (1991).
- "Differential cross section for n-p scattering in the angular region $50^\circ < \theta^* < 180^\circ$ at 459 MeV", L. C. Northcliffe, M. L. Evans, G. Glass, J. C. Hiebert, Mahavir Jain, R. A. Kenefick, B. E. Bonner, J. E. Simmons, C. W. Bjork, and P. J. Riley, Submitted to Physical Review C.
- "Radiative muon capture on Carbon, Oxygen, and Calcium," D. S. Armstrong, S. Ahmad, *et al.*, Phys. Rev. C43, 1425 (1991).

Presentations

- "Hard Scattering in Nuclei," M. D. Corcoran, 9th Conf on the Intersections between Nuclear and Particle Physics, Tucson, May 1991.
- LOI: Studies of Au Interactions at the AGS using Time Projection Chambers. S.E. Eiseman *et al.*, August, 1991.
- "Search for a Quark - Gluon Plasma and Other New Phenomena with A 4 π Tracking TPC Magnetic Spectrometer at RHIC: Letter of Intent," BNL-RLOI-3, Sep 1990. 22pp. B. E. Bonner, Spokesman, with G. Danby, S.E. Eiseman, A. Etkin, K.J. Foley, R.W. Hackenburg, M. LeVine, R.S. Longacre, W.A. Love, T.W. Morris, E.D. Platner, A.C. Saulys, J.H. Van Dijk (Brookhaven), S.J. Lindenbaum (Brookhaven & City

Coll., N.Y.), C.S. Chan, M.A. Kramer, K. Zhao, Y. Zhu (City Coll., N.Y.), A. Aprahamian, N. Biswas, U. Garg, P. Kenney, J. Piekarz (Notre Dame U.), D.L. Adams, S. Ahmad, B.E. Bonner, J.A. Buchanan, C.N. Chiou, J.M. Clement, M.D. Corcoran, T. Empl, H.E. Miettinen, G.S. Mutchler, J.B. Roberts, J. Skeens (Rice U.)

"Studies of Neutral Vee Production by Si Ions at 14.5xA GeV/c in Au and Cu", by E-810 Collaboration (B.E. Bonner, et al.), BNL-45691-mc (microfiche), Nov 1990. 2pp. Contributed to Int. Conf. on High Energy Physics, Singapore, Aug 2-8, 1990.

"An Experiment to Observe Strange Particle Production in Ion Collisions at the AGS," E. Platner (to be pub in Proc International Symposium on High Energy Nuclear Collisions and Quark Gluon Plasma, Kyoto Japan June 6-8, 1991)

"Results on Search for a QGP with a TPC Magnetic Spectrometer at AGS and Plans for an $\sim 4\pi$ TPC Magnetic Spectrometer at RHIC," S. Lindenbaum, *et al*, Proc of the Seventh Winter Workshop on Nuclear Dynamics, Key West, Florida, Jan 26 - Feb 2 1991 (to be pub).

"Silicon-Ion Interactions Measured in the E-810 TPC at the AGS," W. Love, *et al*, Proc of QUARK MATTER 90, Menton, France, 7-11 May 1990, ed J.P Blaizot, C. Gerschel, B. Pire, and A. Romana, Nuclear Physics A525, 601c (1991).

Thesis

"Charge Division in a Cylindrical Drift Chamber for E1097," Thomas Gaussiran, M. A., May, 1991.

END

**DATE
FILMED**

12/10/91