PROGRESS REPORT

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Nuclear Structure at Intermediate Energies

from

RICE

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I. Overview of Project

We report here on the progress that we made for the nine months beginning October 1, 1991 (since our latest progress report) for DOE Grant No. DE-FG05-87ER40309. The report covers the third year of a three year grant. Since we are submitting an accompanying Grant Renewal Proposal, we provide in this report more background information than usual for the different projects.

The theme that unites the 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 our CEBAF experiment), or questions associated with the formation of a new state of matter predicted by QCD (the subject of AGS $\bar{p}$ -A experiment E854, AGS heavy ion experiment E810, as well as the approved STAR experiment at RHIC), – all these projects share this common goal. FNAL E683 may well open a new field of investigation in nuclear physics: that of just how colored 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. In carrying out this enterprise, we also fulfill our academic mission by training our graduate (and undergraduate) students to do physics research.

The format we follow in the Progress Report is to provide a concise, but fairly complete write-up on each project. The publications listed in Section III give much greater detail on many of the projects. The aim in this report is to focus on the physics goals, the results, and their significance.

II. Progress on Research Projects

A. AGS E854 $\bar{p}$ -Nucleus Interactions at 5 to 9 GeV/c

Introduction

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 process probes the high temperature-low density region of the nuclear matter phase diagram and complements heavy ion experiments (such as AGS E810, reported below) which access the low temperature-high density region. In the only previous experiment where $\bar{p}$ -nucleus interactions were observed 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 (factor of ten!) in the number of Λ 's, a large decrease in the number of $\bar{\Lambda}$'s and a small increase in the number of K_S 's relative to what would be expected from simple scaling from $\bar{p}$ annihilations on protons, as is shown in Table 1. They also measured the rapidity distributions of Λ and K_S as well as the charged particle multiplicity.

Table 1. The production cross sections for Λ , $\bar{\Lambda}$, and K_S expected by scaling from $\bar{p}p$ to $\bar{p}Ta$ together with the experimentally observed cross sections. The last column gives the predicted values from the intranuclear cascade calculation.

	$\sigma(\bar{p}p) \cdot A^{2/3}$	Observed (Ref. 1)	INC Prediction
$\sigma(\bar{p}Ta \rightarrow \Lambda)$	17 mb	193.0 ± 12.0 mb	189.9 ± 5.7 mb
$\sigma(\bar{p}Ta \rightarrow \bar{\Lambda})$	17 mb	3.8 ± 2.0 mb	2.5 ± 0.7 mb
$\sigma(\bar{p}Ta \rightarrow K_S)$	61 mb	82.0 ± 6.0 mb	89.2 ± 3.9 mb

Theoretical models and predictions

Strottman and Gibbs² modeled $\bar{p}$ annihilations in nuclei with both hydrodynamic and nuclear cascade models. An extension to their intranuclear cascade (INC) calculation, made at Rice³, reproduced all the features of Miyano's measurement. The INC shows that the dominant source of Λ production is via $\bar{p}$ annihilation into kaons and pions, followed by strangeness exchange during the cascade, the dominant reaction being $KN \rightarrow \pi\Lambda$. Since this initial startling success of the calculation, 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.*, although the statistical weight is such that the data do not provide a stringent test of the calculation.

The present model incorporates all of the known reaction processes and cross sections relevant to the interactions of the incident $\bar{p}$ as well as the annihilation products with the nucleons. 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

¹K. Miyano *et al.*, Phys. Rev. Lett. 53, 1725 (1984), and Phys. Rev. C 38, 2788 (1988)

²D. Strottman and W. R. Gibbs, Phys. Lett. 149B, 288 (1984)

³W. R. Gibbs and J. W. Kruk, Phys. Lett. 237, 317 (1990)

⁴J. Cugnon *et al.*, Phys Rev C 41, 1701 (1990)

⁵J. Rafelski, Phys. Lett. 207, 371 (1988)

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 and topical interest, since no other experiment has 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.

The experiment

The main data run occurred one year ago, in May – June, 1991, using the MultiParticle Spectrometer (MPS) facility at the Brookhaven National Laboratory (BNL) AGS accelerator. 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

Fig. 1a. Layout of the Multiparticle Spectrometer for the data run in 1991. Drift chamber modules (7 planes each) are labeled 1–7, and TPX is a timing proportional chamber.

Fig. 1b. Plan view of the MESB beam line as it was configured for E854. Abbreviations used in the figure. A–F: Beam Chambers; S1–7: Triggering Scintillators; tof1 and tof2: Time of flight counters to aid in $\bar{p}$ identification at 5 and 7 GeV/c; Ci: Threshold Cerenkov counters to help in $\bar{p}$ identification at 7 and 9 GeV/c; and, ToF hodoscope: a time of flight wall to provide particle identification for forward going annihilation products.

modules⁶ in the upstream and four in the downstream region of the target as sketched in Fig. 1a. The complete beamline layout is shown in Fig. 1b. Since we were interested in measuring the total charged particle multiplicity from $\bar{p}$ annihilation in nuclei, we detected particles emitted near 90° to the beam using a Large Angle Multiplicity Detector (LAMD) system designed and constructed at Rice. The system consisted of 240 ion-implanted silicon photodiodes arranged in twelve pad arrays. As sketched in Fig. 2, each array contained twenty 1 cm² silicon diodes with a thickness of 500 ± 25 microns. The complete LAMD system subtended about 65% of the solid angle from 35° to 145°. A paper⁷ discussing the system was presented at the IEEE Nuclear Science Symposium at Santa Fe in Nov. 1991.

The target was surrounded by a cylinder of twelve scintillator strips mounted just inside the LAMD system. The light from the scintillators was transported to two Hamamatsu R2490 mesh dynode phototubes through optical fibers. The signal from the scintillators provided a valuable part of the interaction trigger. The scintillator system was also designed and fabricated at Rice and is sketched in Fig. 3. The interaction trigger included a beam particle as defined by beam counters [S1 • S2 • S3 • S4 • S5 • S6 • S7 • C1 • C3 • TC • SV] in

Large Angle Multiplicity Detector

Fig. 2. Sketch of the LAMD, showing the silicon diodes tiling a cylinder 6 cm ϕ by 11 cm long.

Interaction (scintillation) counter

Fig. 3. A sketch of the Interaction Scintillation Counters mounted just inside the LAMD. The light from the scintillators was transported to two Hamamatsu R2490 mesh dynode phototubes (positioned in the 0.5 T MPS field) through optical fibers (one indicated). These counters were valuable in the Interaction Trigger.

⁶S. Eiseman, *et al.*, Nucl. Inst. and Meth. 217, 140 (1983)

⁷S. Ahmad, *et al.*, Proc. IEEE Nuclear Science Symposium, Santa Fe, 1991 Conf. Record p. 377

coincidence with a signal from one of the interaction scintillators and no signal in the downstream veto (see Figs. 1a and 1b). This insured that a $\bar{p}$ entered the MPS, and interacted in the target. We also accumulated "global" data taken with the interaction scintillator out of the coincidence.

Data analysis

The analysis has proceeded in a two step process with the LAMD data and the drift chamber data being analyzed in parallel. In the first phase, software was developed to determine the large angle charged particle multiplicity. An initial cut was applied to the diode data to get rid of a baseline shift arising from 120 Hz pickup in the electrically noisy MPS environment. This cut eliminated about 90% of the data. To separate the minimum ionizing particles (MIP) from the detector and preamp noise, the spectrum from each of the 240 diodes was separately fitted by a Gaussian distribution for the noise and a Landau distribution for the minimum ionizing particles. Individual cuts were then applied to each diode to eliminate the noise. A typical spectrum of a silicon diode with the fitted functions is shown in Fig. 4. The performance of the LAMD array is shown in Fig. 5. The gain for about 10% of the preamps was too low to allow a clear separation between MIP and noise. These diodes were eliminated from the analysis. The charged particle multiplicity was obtained after applying all the cuts and subtracting the background which was determined from normalized empty target runs. A preliminary charged particle multiplicity distribution for $\bar{p}$ annihilations in Pb for a $\bar{p}$ momentum of 9 GeV/c is shown in Fig. 6.

Fig. 4. Pulse height spectrum from a silicon diode. The curves are a Gaussian fit to the noise, and a Landau fit to the MIP's.

Fig. 5. The distribution of counts recorded in the LAMD diodes for 9 GeV/c $\bar{p}$'s incident on a Pb target. The diodes positioned along the beam are labeled (z) and those around the radius are labeled (ϕ).

In order to compare our measured multiplicity distributions with those expected from known physics, the entire experiment was simulated in the following fashion. Events calculated from the Intranuclear Cascade model were tracked through a GEANT simulation of our experimental setup. In this way, the effects of diode inefficiencies, the number of unused diodes, and multiple hits per diode could be included in the simulation.

The charged particle multiplicity distribution for Pb obtained in this manner is also plotted in Fig. 6. It is apparent that the multiplicity which we measure is larger than that determined from the INC. We are in the process of finalizing the results from the other momenta and targets in order to see if there is a systematic trend to the disagreement.

Future plans for data analysis

The second phase of the analysis concentrates on tracking the charged annihilation products through the seven drift chamber modules in the 0.5 T dipole field of the MPS. We also search for secondary vertices of decay particles from K_S , Λ and $\bar{\Lambda}$. After lengthy and careful evaluation of the complicated MPS pattern recognition algorithms, it was found that they simply could not be adapted to our experimental setup. Instead, we developed a new pattern recognition package, 'PIROL,' specifically for the E854 setup. A reconstruction efficiency of about 90% has been achieved for downstream tracks, with comparable efficiency for upstream tracks. A typical reconstructed event demonstrating the tracking capability is shown in Fig. 7. Optimization of the parameters is proceeding. Once we accomplish this, processing of the raw data tapes to create condensed data tapes will begin. This work will form the basis for the Ph. D. thesis of Mr. A. Empl.

Fig. 6. Charged particle multiplicity distribution measured in the LAMD from 9 GeV/c $\bar{p}$ annihilations in Pb. The prediction from the Intranuclear Cascade calculation is also shown.

Fig. 7. A typical annihilation event showing the hits in the seven drift chamber modules. The y projection (non-bend plane) is shown in the upper panel and the x projection in the lower. Tracks found by the completely rewritten pattern recognition and tracking package 'PIROL' are plotted.

B. AGS E810 Strangeness Production in Heavy Ion Collisions

Introduction

The goal of E810 is to look for a possible phase transition from hadronic to quark matter, the Quark Gluon Plasma (QGP), the existence of which is predicted in non-perturbative QCD. It is estimated that the AGS energy, 14.6 GeV/c per nucleon, is near the maximum nuclear stopping that can be observed in heavy ion collisions; hence, E810 probes the high baryon density region of nuclear matter phase space. This is complementary to the region probed in E854 with antiprotons.

Fig. 8. Layout of the MPS for E810. Not shown is a high z veto scintillator 8 m downstream.

Fig. 9. The π - p effective mass, clearly showing the λ peak.

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 QGP⁸. Indeed strange antibaryon production should be an especially sensitive indicator of a QGP. An enhancement of the K^+/π^+ ratio in 14.6A GeV/c Si-Au interactions and an enhancement of Λ 's, $\bar{\Lambda}$'s and K_S^0 's in

200A GeV/c S-S interactions have been reported^{9,10}.

The 14.6A GeV/c silicon beam was incident on a target just upstream of three TPC (Time Projection Chamber) modules¹¹ in a 0.5 T magnetic field. The TPC's were used to reconstruct the angles and momentum of charged particles in the forward hemisphere in the center-of-mass (0° to 20° in the lab). The experimental arrangement is shown in Fig. 8. The incident silicon ions were identified by a plastic Cerenkov counter. Targets were $<1\%$ of a radiation length to minimize gamma ray conversions that would give incorrect multiplicities. The trigger utilized a scintillation counter, the beam veto counter, 8 meters downstream of the target to veto on high Z beam fragments as well as two counters, the interaction counters, just downstream of the target

to signal interactions in the target. This pair of counters was about 20 cm behind the target and about 2.5 cm above and below the beam line. The trigger required hits in both interaction counters and charge corresponding to $Z < 6$ in the beam veto counter. Offline,

⁸J. Rafelski and R. Hagedorn, in *Thermodynamics of Quarks and Hadrons*, Ed. H. Satz (North Holland, Amsterdam, 1981).

⁹T. Abbott *et al.*, *Phys. Rev. Lett.* **64**, 847 (1990)

¹⁰J. Bartke *et al.*, *Zeitschrift für Physik C48*, 191 (1990)

¹¹A. Etkin *et al.*, *Nucl. Instr. and Meth. in Physics Research A283*, 557 (1989)

Fig. 10. The $\pi^+-\pi^-$ effective mass with those vertices satisfying the lambda hypothesis removed.

Fig. 11. The Λ and K_s lifetime plots for the Au target data.

the beam veto counter pulse height, which correlates with the multiplicity, was required to be less than twice minimum ionization, to select "central" events.

Analysis of the June, 1989 data on the measurement of Λ and K_s^0 production in Si-Cu and Si-Au collisions has been completed and several papers and talks have been presented. We summarize the results in the following paragraphs.

Neutral vee's

The π^-p effective mass distribution for tracks forming a vertex away from the target position is shown in Fig. 9. A clear peak is seen at the Λ mass. Fig. 10 shows the

Fig. 12. The Λ yield as a function of negative track multiplicity for both Cu and Au targets with predictions from Hjet.

Fig. 13. The K_s yield as a function of negative track multiplicity. Predictions from Hjet are shown for both targets.

$\pi^+\pi^-$ effective mass distribution, with vertices removed if the Λ mass hypothesis is satisfied. The $\bar{p}\pi^+$ hypothesis yields no statistically significant Λ signal. The limit on Λ production is $N(\Lambda)/N(\Lambda) < 0.07$ (95% C.L.). The acceptance-corrected decay distributions of Λ 's and K_S^0 for our Au data are shown in Fig. 11 as a function of ct . The solid lines are not fits, but are calculated using the known lifetimes. This demonstrates that the proper particles have been selected and that the acceptance calculations are reasonable.

The Λ yield per event, corrected for the neutral branching ratio, is shown as a function of the negative particle multiplicity in Fig. 12. This multiplicity is a good measure of the energy deposited and hence, the centrality of the event. The K_S^0 yield is shown in Fig. 13. The predictions of HIJET¹², with all known meson-nucleon rescattering channels included, are included in these two figures. The formation time for secondaries is arbitrarily set equal to zero. We find that strange particle production rates increase monotonically with increasing negative multiplicity. The yield per forward negative particle is independent of multiplicity and does not differ much between Cu and Au targets. The HIJET model reproduces the Λ yield reasonably well, but not the K_S^0 yield. The absence of meson-meson rescattering in HIJET may explain the latter disagreement.

The transverse momentum distributions as a function of transverse mass, $m_\perp$ for Λ 's and K_S^0 's from both Cu and Au targets are shown in Fig. 14. The effective temperature of the fireball is found to be about 150 MeV for Λ 's and K_S^0 's from both targets.

Rapidity distributions

Rapidity distributions for different particle types provide information about the details of nucleus-nucleus scattering. The shape of the proton rapidity distribution, for instance, reflects directly the degree of stopping, and the onset of nuclear transparency expected in high energy nucleus-nucleus collisions. The measured rapidity distributions for negative particles, assuming they all have the pion mass, are given in Fig. 15 for both Cu and Au targets. Clearly, there is very little dependence on the target. In Fig. 16 we plot the rapidity distribution for positive tracks minus negative tracks, assuming the proton mass. In the limit that the positive and negative pion distributions are the same and dominate the charged particle spectrum, this approximates the proton rapidity distribution. It is distorted by the excess of K^+ over K^- observed in AGS E802, but the K^+ contamination is expected to be less than 25%. The distributions for the two targets are clearly different, with the Cu data showing more particles at high rapidity, indicating greater stopping for the larger nucleus.

Fig. 14. Transverse momentum distributions as a function of transverse mass for Λ and K_S from Au and Cu.

¹²A. Sor and A. Longacre, Phys. Lett. B218, 100 (1989)

Fig. 15. Rapidity distribution for negative particles from Cu and Au. Lack of target dependence is expected.

Chapman and Gyulassy analysis. The peak Gyulassy simply does not appear in our data.

Fig. 16. Rapidity distribution for (+) - (-) particles assuming proton mass. Clear evidence for stopping is seen in this data.

Recently, Chapman and Gyulassy¹³ published an analysis based on an extrapolation of data from the limited kinematic region seen in E802.¹⁴ They concluded that 6.4 protons out of 14 have $y > 2.4$, (beam rapidity = 3.44), indicating substantial transparency. Our data do not support this conclusion. To facilitate the comparison between the two experiments, we plot the rapidity distribution for negatives from Au using a centrality cut that approximates the E802 data, 7% of σ_{tot} , along with the E802 data, in Fig. 17. The corresponding positive rapidity distribution is shown in Fig. 18, along with the E802 data for protons plus K^+ minus K^- , which is very close to what we measure. The agreement between the two data sets is good. Also shown are the predictions using the FRITIOF and HIJET event generators, and the predicted at $y > 2.4$ by Chapman and Gyulassy. Our data show that approximately 3.4 protons out of the 14 incident protons stay in the region $2.4 < y < 3.4$, indicating substantial stopping at AGS energies.

Transverse momentum

The transverse momentum spectrum of negatively charged tracks for Si-Cu and Si-Au, plotted versus $m_{\perp} = \sqrt{m^2 + p_{\perp}^2}$ exhibit a departure from a pure exponential which does not show up well on a semi-logarithmic plot. By dividing by a reference exponential, chosen to be a reasonable fit to the data at large $p_{\perp}$, the departure is apparent as shown in Fig. 19. Both sets of data were fit to the sum of two exponentials of the form Ae^{-BT_1} where $T_1 = m_{\perp} - m_{\pi}$. The inverse slopes (temperatures) were found to be 0.165 GeV/c and 0.073 GeV/c for both sets. These fits are included in the two figures. For the copper data, 26% of the pions are in the steeper exponential

¹³S. Chapman and M. Gyulassy, Phys. Rev. Lett. 67, 1210 (1991)

¹⁴T. Abbott et al., Phys. Rev. Lett. 66, 1567 (1991)

Fig. 17. The rapidity distribution for negative particles after applying a tight centrality cut (multiplicity > 60).

Fig. 19a. The $m_{\perp}$ spectrum for a Au target normalized to an exponential.

Fig. 18. The rapidity distribution for positive minus negative particles after applying a tight centrality cut ($M > 60$). The need for the peak, hence evidence for nuclear transparency, is not present in our data.

Fig. 19b. As for Fig. 19a except for a Cu target. In both cases, normalized to $140 \exp(-6T_{\perp})$.

and 36% for the gold target. Integrating the fits over all $m_{\perp}$, doubling to account for π^+ and dividing by 28 incident nucleons, we get the pion production in the rapidity range 2.0 to 3.0. The values are 0.67 ± 0.07 (copper) and 0.62 ± 0.06 (gold) charged pions per incident nucleon. This is remarkably close to the measurement¹⁵ of 0.633 ± 0.009 charged pions per inelastic p - p collision integrated over the corresponding rapidity range.

The data were simulated by a Monte Carlo using the HIJET generator with a formation time of 1 fm/c for secondary production. Deltas are produced in the initial N-N collisions as well as by secondaries through reactions $\pi N \rightarrow \Delta$ and $\pi N \rightarrow \pi \Delta$. These latter reactions can lead to very low $p_{\perp}$ pions. The delta decays give rise to a peak centered at about $T_{\perp} = 0.1$. The model predictions are plotted in Figs. 19a and 19b. A calculation of the effect of Coulomb interactions with the co-moving charged matter (approximately one unit of positive charge) raises the Monte Carlo calculation for the smallest $T_{\perp}$ bins to the points shown as triangles in the figures. The model represents the data reasonably well with parameters corresponding to pion slopes observed in p - p interactions with enough re-interaction to produce 0.16 Δ^- per nucleon.

Particle identification

For the June, 1990 data, the targets were 1.2 mm silicon and 0.1 mm tungsten. Using the forward angle TOF data, we extracted the rapidity and $P_{\perp}$ distributions (albeit over a limited range of phase space) for π^- , K^- , p (proton), and d (deuteron). After cuts for the veto counter S_9 and the production vertex, 70k events from the Si target and 49k events from the W target (corresponding to cross sections of 0.54 barns and 2.06 barns, resp.) were left for TOF analysis. Note that the reaction was not limited to central events.

With a time resolution of $\sigma = 120$ ps and a flight path of 13.5 m, we achieved good K to π separation up to 2.5 GeV/c, K

Fig. 20. $(1/N_{ev}) * dN^2 / dm_{\perp}^2 dy$ vs. $T_{\perp}$ for π^- , K^- , p and d from Si.

Fig. 21 $(1/N_{ev}) * dN^2 / dm_{\perp}^2 dy$ vs. $T_{\perp}$ for π^- , K^- , p and d from W.

¹⁵V. Blobel *et al.*, Nuc. Phys. B69, 454 (1974)

to p separation up to 5 GeV/c, and d to p separation up to 8.5 GeV/c. Due to the small acceptance of the hodoscope, we measured the momentum spectra of π^- , K^- , p and d over a limited range of rapidity, $1.9 < y < 2.1$. The P_T spectra, after acceptance correction, are shown in Fig. 20 for the Si target and Fig. 21 for the W target. The distributions, $(1/N_{ev}) * dN^2 / dm_T^2 dy$ are plotted as a function of the transverse kinetic energy.

The data were fit to an exponential Ae^{-T_1/T_0} , where T_0 is the effective temperature parameter. These parameters for different particles are listed in Table 2 at rapidity range $1.9 < y < 2.1$. We find that the measured effective temperature increases with increasing mass of the emitted particle,

$$T_0(\pi) < T_0(K) < T_0(p) < T_0(d)$$

which is predicted by a radially expanding flow model¹⁶.

By integrating the exponential equation, we can determine the value for dN/dy for the rapidity range $1.9 < y < 2.1$, which are given in Table 2. We also list the production ratios for the K^-/π^- and d/p there. These values should be viewed with caution because of the limited P_T range. The rapidity density dN/dy increases with A as would be expected. From the integrated results, we find a K^-/π^- ratio of $(2.7 \pm 0.3)\%$ from the Si target and $(2.4 \pm 2.0)\%$ for the W target. The deuteron production rates can be explained by a relativistic coalescence model¹⁷.

Table 2: Effective temperatures and dN/dy for π^- , K^- , p and d from Si-Si and Si-W collisions at $1.9 < y < 2.1$. All errors are statistical only

	Si		W	
Particle	$T_0(\text{MeV})$	dN/dy	$T_0(\text{MeV})$	dN/dy
π^-	88 ± 1.4	19.5 ± 0.5	87 ± 1.6	26.6 ± 0.8
K^-	103 ± 10	0.52 ± 0.08	98 ± 5.5	0.65 ± 0.05
p	137 ± 7	17.1 ± 1.2	163 ± 10	22.9 ± 1.4
d	282 ± 48	0.6 ± 0.1	325 ± 73	0.89 ± 0.2
K^-/π^-		$2.7 \pm 0.3\%$		$2.4 \pm 0.2\%$
d/p		$3.5 \pm 0.7\%$		$3.9 \pm 0.9\%$

The analysis of the 1991 data set is currently under way. Due to improvements in the TPC's this data should have significantly better quality than the 1990 data; as a result the decision was made to concentrate on the 1991 data. The current analysis will result in rapidity distributions for Λ and K_S^0 from Si-Si and Si-Pb interactions. Approximately three times as much data should be available. The Si-Si data is of special interest because in a system with symmetric beam and target nuclei the full kinematic range can be covered by reflecting the data about midrapidity.

¹⁶P. J. Siemens and J. O. Rasmussen, Phys. Rev. Lett. 42, 880 (1979)

¹⁷C. B. Dover, "Relativistic Coalescence Model for High Energy Nuclear Collisions," BNL-45865 (1991)

C. RHIC Experiment by the STAR Collaboration

Introduction

As reported last year, two collaborations had submitted RHIC Letters of Intent^{18,19} based on general purpose, large acceptance Time Projection Chamber Spectrometers for tracking of a large fraction of the enormous number of particles emitted from central collisions. The merger between the two collaborations was completed and a single Update to the Letters of Intent was presented in August, 1991. Approval of the goals of the combined group, dubbed the STAR Collaboration, was forthcoming from RHIC management. Since that time we have proceeded to define the detector that will accomplish as many of the physics goals as possible on the (approximately) \$30M that will be available from the RHIC Project. Submission of the Conceptual Design Report (CDR) for the STAR Detector is scheduled for the middle of June, 1992. Much of the present progress report on the STAR project is taken from the part of the CDR for which we were responsible.

The physics goals of the new collaboration remain 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 it is expected that the charged particle densities $dn_{ch}/d\eta \approx 1000$ to 1500 , we will be able to extract global observables such as

temperature, flavor composition, reaction dynamics, and energy or entropy density fluctuations from the information gathered from a single event. In view of the fact that no convincing prediction of an unequivocal experimental signature exists, we continue to maintain that it is necessary to have this information in order to identify possible special events which may bear special scrutiny.

Fig. 22. Elevation view of the complete STAR detector which we will build at RHIC during the next several years.

the Magnet Coil and the Magnet Yoke is the Electromagnetic Calorimeter. In addition the vertex/trigger detectors are shown. The external TPC's allow charged particle densities to be measured over the vital region between $\eta=2$ and $\eta=4$.

¹⁸RHIC Letter of Intent #3, "Search for a Quark - Gluon Plasma and Other New Phenomena with a 4 π Tracking TPC Magnetic Spectrometer at RHIC: Letter of Intent," Sep 1990, 22pp., The RLOI03 Collaboration: BNL, CCNY, Notre Dame, Rice University, B. E. Bonner, Spokesman.

¹⁹RHIC Letter of Intent #5, "An Experiment on Particle and Jet Production at Midrapidity," Sep 1990, 27pp., J. Harris, Spokesman.

Within the STAR collaboration, we have taken major responsibility for the Time of Flight (TOF) detector development. In the following sections we report the reasons for such a detector and the progress we have made in its design.

The STAR time-of-flight detector

Many of the physics goals of STAR require that particle identification be unambiguous for a large fraction of the particles emitted from central collisions. In order to accomplish these goals, a comprehensive Time of Flight (TOF) system will be an essential component of the detector. The system must measure the flight time of all charged particles in the central region of the STAR detector with a timing resolution of at least 100 picoseconds. This requires a highly segmented cylindrical counter of 2 m inner radius and 4.2 m length which is able to operate in a 5 kG magnetic field.

Fig. 23. The difference in flight times of π , K and p from $v=c$ for the middle and end of the TOF cylinder. For a time resolution of 100 ps, the 3σ bands on K's intersect the π and p lines at the PID limits quoted in the text.

It is anticipated that the TPC will provide particle identification by multiple dE/dx measurements along the particle trajectory. Such detectors at Aleph, PEP4, and others have demonstrated good particle identification. Based on this, we expect to achieve particle separation over the following momentum ranges, although there are regions of ambiguity arising from overlap with electrons.

$$\pi / K \leq 0.7 \text{ GeV}/c$$

$$K / p \leq 1.2 \text{ GeV}/c$$

It is generally agreed that at least 1 m of track is required in order to obtain particle identification over the ranges listed above. It should be noted, however, that the unprecedented charged particle densities anticipated at RHIC in the region within 0.5 m of the inner field cage will lead to pixel occupancies of up to 28%. It has never been demonstrated, either in the lab or in realistic simulation, that particle identification for closely spaced tracks can be achieved by dE/dx under such conditions.

For such reasons it appears to be more than just prudent to include a TOF system to ensure that particle identification is achieved as demanded by the physics. The baseline TOF design, which covers the cylinder with a total of 7776 shingle detectors, will allow particle identification over more

than double the momentum range given by the TPC, and it does so without the ambiguity

introduced by electrons. As is clearly shown in Fig. 23, for a realistically achievable time resolution of 100 ps, particle identification at the 3σ level is possible over the following momentum ranges.

$$\pi / K \leq 1.5 \text{ GeV}/c$$

$$K / p \leq 2.6 \text{ GeV}/c$$

Because of budget constraints, we are proposing a de-scoped version for the initial turn-on of the detector. This will consist of filling only 8 of the 216 trays with shingle

counters, covering two sections of 6.6 degrees in azimuth. The rest of the cylinder will be covered with much larger detectors, namely, 416 double ended TOF slats. These will be used both to measure the multiplicity and as a valuable trigger device for midrapidity. As the simulations and experimental measurements reported in the Instrumentation Section demonstrate, the slats also give lower resolution, albeit still useful, TOF data. In particular the Monte Carlo studies show that a time resolution of 250 ps can be obtained for a substantial fraction of the particles reaching the slats. From Fig. 24 we see that PID at the 3σ level would then be possible over the following momentum range.

$$\pi / K \leq 1.0 \text{ GeV}/c$$

$$K / p \leq 1.5 \text{ GeV}/c$$

For this slat configuration, particles can be identified by TOF independently of the dE/dx measurement. The de-scoped TOF thus provides PID as good or better than the TPC while also yielding an excellent central rapidity trigger. The slats are designed to fit in the same trays as the baseline shingle detectors.

Fig. 24. As the preceding figure but for a time resolution of 250 ps.

The modular nature of the design allows expansion to the original design in a very straightforward manner as funds become available and the physics dictates.

D. CEBAF PR-89-024 Radiative Decays of Hyperons

The object of this experiment is to probe the quark wavefunctions of the hyperons by measuring the electromagnetic decays of low lying states of the Λ and Σ hyperons – the uds quark systems. The experiment was approved to be run at CEBAF, which will produce continuous electron beams up to 4 GeV. Specifically, we will measure the branching ratios of the electromagnetic decays of the low lying excited hyperons, $\Lambda(1405)$, $\Lambda(1520)$, and the $\Sigma^0(1385)$, using the CEBAF Large Angle Spectrometer (LAS) which will be in Experimental Hall B. We will produce the excited hyperons using a tagged photon beam with $\Delta E_\gamma / E_\gamma = 0.25\%$ FWHM, via the reaction $\gamma p \rightarrow K^+ Y^* \rightarrow K^+ \Lambda \gamma \rightarrow K^+ p \pi^- \gamma$. The kaon, proton and π^- will be detected in the LAS with both large solid angle and good momentum resolution. The four momentum of the excited hyperon can be reconstructed from the beam photon energy and the kaon momentum; that of the Λ (from the $Y^* \rightarrow \Lambda \gamma$ decays) can be reconstructed from the proton and π^- momentum. Extensive computer modeling of the system indicates that the hyperon mass will be determined to better than 5 MeV FWHM and the Λ mass to better than 2 MeV FWHM. This mass resolution is adequate to suppress the backgrounds due to π^0 decays that threaten to mask the photons from the $Y^* \rightarrow \Lambda \gamma$ decays. The $Y^* \rightarrow \Sigma^0 \gamma$ decays require the detection of two photons with large solid angle. The current design of the LAS will not have sufficient coverage to accomplish this so that part of the proposal was deferred.

The level diagram for the low lying hyperon system is shown in Fig. 25. A typical set of theoretical branching ratios for the various photon transitions²⁰ are given along with the existing experimental values^{21,22,23}, which can be identified by the error bars. The portion of our proposal that has been approved is to measure the following transitions:

$$\begin{aligned}\Lambda(1520) &\rightarrow \gamma \Lambda, \\ \Lambda(1405) &\rightarrow \gamma \Lambda, \text{ and} \\ \Sigma(1385) &\rightarrow \gamma \Lambda.\end{aligned}$$

Some idea of the experimental situation is conveyed by the fact that the existing data for the $\Lambda(1520)$ level disagree by a factor of 5. In addition, the results for the $\Lambda(1405)$ level are model dependent, and are nonexistent for the $\Sigma(1385)$ level. Values for the branching ratios vary even more between various models. As a result of this uncertainty, this proposal has been strongly supported by many theorists.

As construction proceeds, system parameters for the LAS are being finalized. For example, the photon tagger has been descoped to provide $\Delta E_\gamma / E_\gamma = 0.3\%$. Monte Carlo studies show that this change will not affect our hyperon mass resolution, which was dominated by the momentum resolution of the Kaon and proton.

Our experiment was approved for 30 days running during the first 3 years of CEBAF operations. It will run concurrently with PR-89-004 "Electromagnetic Production of Hyperons," R. Schumacher spokesman, and PR-91-009 "Photoproduction of η and η' Mesons," B. Ritchie, spokesman. LAS installation is scheduled to be

²⁰J. W. Darewych, M. Horbatsch and R. Koniuk, Phys Rev D28, 1125 (1983)

²¹T. S. Mast *et al.* Phys Rev Lett 21, 1715 (1968)

²²R. Bertini *et al.* Nucl Phys B279, 49(1987)

²³D. A. Whitehouse *et al.* Phys Lett 63, 1352 (1989)

Fig. 25. Level diagram for the low lying hyperon system. A typical set of theoretical branching ratios is given in the boxes. For those transitions that have been measured, the experimental value is given with quoted errors.

completed by the fall of 1995. Commissioning and calibration runs are scheduled to take place in 95-96. Thus, we do not expect to take data before late 96.

Rice University has signed a Memorandum of Understanding with CEBAF to design and build the TOF Start Counters for the LAS detector. These six counters are primarily intended to identify which tagged photon a given LAS event corresponds to. To properly associate a tagged photon from a given accelerator beam bucket (one bucket each 2 ns) and a LAS event requires a time resolution of $\sigma = 500$ ps or better. This will identify the *rf* bucket to a C.L. of better than 99%. There are several factors that enter into the final time spread of the start counter. The variance is the sum of

$$\sigma_{tot}^2 = \sigma_{rf}^2 + \sigma_{tof}^2 + \sigma_{pos}^2 + \sigma_{scint}^2$$

where σ_{rf}^2 is the variance associated with the *rf* timing, σ_{tof}^2 is associated with the time spread due to different path lengths from the target to the start counter, σ_{pos}^2 is associated with the transit time spread of the light in the start counter, and σ_{scint}^2 is associated with the photon statistics and response of the scintillator-phototube combination. σ_{tof}^2 can be estimated from Monte Carlo studies. The current effort is to determine σ_{pos}^2 and σ_{scint}^2 from Monte Carlo studies in addition to measurements on a prototype. This work is described in Section I.6. In the final LAS detector, σ_{pos}^2 will be reduced offline from extrapolating reconstructed tracks. However, it would be useful to try to eliminate this effect in the hardware, as a consistency check. (for tracks that did not register in the Drift Chamber system, for example). Designs to achieve this are under consideration.

E. CERN NA47 The SMC Experiment

Introduction and background to the "spin crisis"

Rice initially 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 (Spin Muon Collaboration) experiment. This experiment is making 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 EMC²⁴ measurements of g_1^p of the proton.

Fig. 26. Existing data on the quantity $A_1(x)$.

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 nucleons.

The quantity actually measured 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. 26.

A fundamental sum rule, originally derived by Bjorken²⁵ from current algebra but now recognized 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

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

BJ

where

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

²⁴G. Baum *et al.*, Phys Rev Lett 51, 1135 (1983); M.J. Algard, *et al.*, Phys Rev Lett 37, 1261 (1976); *ibid.*, 41, 70 (1978); J. Ashman, *et al.*, Phys Lett 51, 1135 (1988)

²⁵J.D. Bjorken, Phys Rev 148, 1467 (1966); Phys Rev D1, 1376 (1970)

in which $F_2(x)$ and $R(x)$ have their usual meanings. The factor involving the strong coupling constant α_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

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

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

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

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 Jaffe²⁶

$$\Gamma_p = \int_0^1 g_1^p(x) dx = 0.189 \pm 0.005$$

EJ

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

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, EJ for the proton can be tested. From the CERN data alone it was found that

$$\int_0^1 g_1^p(x) dx = 0.114 \pm 0.012 (\text{stat}) \pm 0.026 (\text{syst.})$$

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

$$\int_0^1 g_1^p(x) dx = 0.116 \pm 0.009 (\text{stat}) \pm 0.019 (\text{syst.})$$

Fig. 27 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

²⁶J. Ellis and R. Jaffe, Phys Rev D9, 1444 (1974)

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.

Measurements planned by the SMC

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

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

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

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

Fig. 27. The first moment of g_1^p as a function of the lower limit, x , of the integral.

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

This experiment measures the proton and deuteron asymmetries A_1^p and A_1^d . The neutron asymmetry A_1^n can be extracted from the proton and deuteron asymmetries A_1^p and A_1^d by the relation

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

where W_D represents the D-state probability of the deuteron ($\sim 5\%$). The Bjorken sum rule can then be evaluated with about 10% accuracy.

Fig. 28. Plan view of the overall experiment.

The experiment uses the EMC spectrometer (Fig. 28) 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 up to 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 has been completed at Saclay. Construction of the cryostat is underway. In the 1992 run the old EMC target filled with a deuterated sample is being used, currently giving about 27% deuteron polarization.

Fig. 29a. Plan view of the muon decay polarimeter.

Fig. 29b. μ -e scattering polarimeter

The muon beam polarimeter

The polarimeter was designed at Rice and is shown schematically in Fig. 29a in the decay configuration and Fig 29b for the μ -e scattering setup. Rice has assumed responsibility for the construction of the multiwire proportional chambers (MWPC's) 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 workstations for data acquisition and analysis, and the trigger scintillation hodoscopes.

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; this dependence is shown in Fig. 30; and
- (2) the muon spin will be analyzed by detecting the elastic scattering of muons from electrons in a polarized iron target.

A measurement of the beam polarization using muon decays was performed during the initial run in 1991 at 100 GeV/c. 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

Fig. 30. Dependence of the energy spectrum of the decay positrons on the muon polarization.

bremsstrahlung or decay. The quadrupoles Q34 and Q35 refocus the muon beam which has blown up after its upstream focus on the polarized deuteron target. Decay positrons are deflected out of the incident beam into the downstream MWPC's and lead glass wall (LG) by the MNP26.

A simple muon decay trigger was used: a pulse height greater than about 10 GeV in the lead glass in coincidence with a single minimum ionizing particle (MIP) signal in the shower veto (SV). An incident positron tends to produce a shower giving multiple particles in SV. Events with only single MIP pulse height in the summed SV were used in the trigger. This effectively eliminated upstream shower events,

as can be seen in SV ADC spectra. However, this hard-wired requirement was probably overly restrictive and resulted in the loss of some good decay events.

Offline, simple ADC and TDC cuts require the lead glass and shower veto hits to be in proper time correlation and the summed amplitude in each shower veto plane to be less than 1.6 MIP. We require a single fitted track in both upstream and downstream chamber telescopes with three of four coordinates in each beam chamber and two of three in each downstream chamber. With these event reconstruction requirements, the positron momentum is then determined using the mapped magnetic field of the MNP26, and compared with the clustered energy of the shower in the lead glass wall. The resolution of the lead glass cluster centroid is about 2 cm for 10 cm blocks. The clustered energy

92/06/29 17.25

Fig. 31a Pulse height measured in the LG wall vs. particle momentum.

92/06/29 17.30

Fig. 31b. As in Fig. 31a for events satisfying track matching in MNP26

from the lead glass is plotted versus the momentum determined from the magnetic spectrometer in Fig. 31a. The dark 45 degree stripe is due to the positrons of interest from beam muon decays upstream of the MNP26. As anticipated, there is a small background due to muon decays in the MNP26, which fall below the 45 degree stripe. In addition, beam halo muons induce showers in the lead glass and cause another small background

A powerful constraint is provided by requiring that the upstream and downstream tracks intersect in the MNP26. Fig. 31b illustrates how this requirement essentially eliminates these backgrounds. This also allows very loose ADC cuts on the lead glass pulse height to be used. Background due to positrons not from μ^+ decays was studied by reversing the MNP26 magnetic field, and by comparing spectra with an incident μ^- beam. A comparison of $\mu^+ \rightarrow e^+$ with $\mu^- \rightarrow e^+$ gives a non-decay background of 1.6% in the positron spectrum. Use of the beam halo veto and muon induced shower veto counters to eliminate background was found to be unnecessary.

There are several effects, both experimental and theoretical, that modify the pristine Michel spectrum of positrons arising from μ^+ decay. These include the following.

- geometric acceptance
- internal radiative corrections
- bremsstrahlung in the upstream chambers, vacuum windows, and air.

Fig. 32. The corrected Michel spectrum measured from μ^- decays in one shift of data taking.

These were calculated by Monte Carlo simulation of the entire setup. The effects are insensitive to the muon polarization, hence they are applied to the observed positron spectrum, and the muon polarization is extracted from a fit to the corrected spectrum. The data plotted in Fig. 32 was attained in about one shift of data taking, and the value of the muon beam polarization which we extract is -0.865 ± 0.053 . The polarization estimated from the beam design is -0.83 , in good agreement with our observed value. The sources of systematic error are the following: the measurement of E_e/E_μ ; the background of non-decay positrons; real bremsstrahlung and internal radiative corrections; and acceptance. Each of these contributes about 1-2% error to the measurement of the beam polarization. We thus expect about a five percent overall

systematic error in the final polarization measurement using the decay method. We can make such a measurement about twice a day during the data taking.

The MWPC's, PPC4 and PPC3, were built by Rice graduate students and constituted an M.A. thesis project for Steve Eichblatt. The Rice students Gaussiran and Cranshaw expect to obtain Ph.D. theses on the decay and μ -e scattering polarimeters, respectively. These students, along with postdoctoral fellow Mark Lowe, have been in residence at CERN for almost the entire experiment, and have been major contributors to the installation, debugging, operation, and data analysis for the muon polarimeter. Mark Lowe has led the analysis of the polarimeter data which is now in constant production. Eichblatt expects to obtain his Ph.D. thesis from the 1993 data run.

We are now in the process of implementing the μ -e scattering polarimeter. This requires some additional MWPCs. PPC1, a special large 1mm wire spacing chamber has been constructed in the Saclay shops. The design was a collaborative Rice-Saclay effort, with the PCOS III electronics furnished by Rice. (See instrumentation section) We have also refurbished three MWPCs, PPC2, PPC5, and PPC6, originally built for FNAL experiments E704 and E683, along with existing Rice MWPC electronics. The lead glass, reconfigured from a wall donated to us by BNL, has been implemented with fast Hamamatsu phototubes and is in operation in the polarimeter.

Trieste has furnished four more beam chambers (PBC4-7) and Saclay the polarized Fe target. The Fe target will have the capability of polarization reversal on alternate SPS pulses to reduce systematic errors. We will begin debugging this polarimeter later in the summer. We expect that, with a crosscheck of the two methods, the error on the beam polarization measurement can be reduced so that it does not contribute to the final error on the check of the Bjorken sum rule.

F. FNAL E683 Nuclear Jets

Introduction

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 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 is of particular interest. We took 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 interactions²⁷. 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 imbalance 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 were observed in E609, 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. Sivars has suggested that our results may be due to a final-state interaction between the two outgoing partons and nuclear matter.

Data from E683 as well as other recently-completed Fermilab experiments should shed light on the question. E706 has data on 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 has data on the A -dependence of deep inelastic muon scattering, in which the final state is one parton and one muon. Taken together, these experiments will teach us a lot about the passage of colored objects through nuclear matter.

The experimental run and the apparatus

Radiation shielding problems in both the external beam lines and in the accelerator itself delayed the start of the fixed-target run until late June of 1991. After

²⁷M. D. Corcoran, *et al.*, Phys. Lett. B259, 209 (1991); R. C. Moore *et al.*, Phys. Lett. B244, 347 (1991); M. D. Corcoran, "Hard Scattering in Nuclei," Proceedings of the Fourth Conference on the Intersections Between Nuclear and Particle Physics, Willem T. H. Van Oers, ed., Tucson, AZ, 1991, p. 838; T. H. Fields, "Anomalous Nuclear Enhancements in Hard pA Collisions at Fermilab Energies," invited talk presented at Quark Matter 91, to be published in Nuclear Physics A

the start-up period, the accelerator ran fairly reliably, with the run lasting about six months. The fixed-target run ended January 8, 1992. Below is a summary of the raw triggers and estimated dijet samples for each of the targets which we used. The nuclear target data is split roughly evenly between the six targets, which were Be, C, Al, Cu, Sn and Pb.

Target	Raw Triggers	Dijets, $p_t > 3$
LH2	3.6M	54K
LD2	3.0M	45K
Nuclear	3.5M	45K

Electron Beam Energy

Fig. 33. The electron beam spectrum as measured by the silicon tagging system.

The photon beam is generated from bremsstrahlung in a Pb target by a high energy electron beam. Crucial elements of the beamline are the Si microstrip detectors provided by the Milano group from E687. Since the momentum spread in the electron beam is 15%, it is necessary to measure the momentum of each electron before and after it has radiated a photon. The initial energy is measured to an accuracy of 2% with the Si tagging system; the spectrum is shown in Fig. 33. Under normal running conditions the Si tagging efficiency was about 70%, due both to acceptance of the microstrip detectors and to double occupancy of beam buckets. After the lead radiator, shower counters measure the electron energy, thus determining the energy of the photon to 2–3%.

A plan view of the experimental apparatus is shown in Figure 34a. The most important part of our apparatus is a sampling calorimeter, the segmentation of which is shown in Fig. 34b. Each tower consists of one layer of lead-scintillator sandwich, followed by three layers of iron-scintillator sandwich. Both the EM and hadronic energy

Fig. 34a. Plan view of the experiment, showing the positions of beam and main calorimeter.

Fig. 34b. Beam's eye view of the main calorimeter, showing segmentation.

resolutions are important and were carefully calibrated with electrons and pions of various energies. Analysis of the calibration data is well under way.

The energy resolution of the calorimeter is parameterized in the usual way: $(\sigma(E)/E)^2 = (N/\sqrt{E})^2 + K^2$, where K is a constant term in the resolution, and N characterizes the energy dependence. For electromagnetic particles, $N \approx 35\%$ and $K \approx 3\%$. For hadrons, $N \approx 90\%$ and $K \approx 4\%$. The hadronic energy resolution will improve as the phototubes are balanced using the calibration data.

A distinctive aspect of photoproduction is the anticipated absence of forward energy for high p_t events. The calibration of the beam calorimeter, which measures forward energy flow, is therefore crucial. It was calibrated early in the run and checked often. We discovered about two months into the run that the response of the beam calorimeter was deteriorating. Radiation damage was suspected, since this calorimeter acted as a beam stop. However, it seemed that in addition to radiation damage, there was an overall drop in pulse height. We took frequent calibration points and therefore have an excellent time history of the response, which has already been incorporated into our analysis package. The energy resolution of the beam calorimeter was $N \approx 45\%$ and $K \approx 2\%$ for electromagnetic particles. For hadrons, $N \approx 75\%$ and $K \approx 5\%$.

Photon Energy

Fig. 35. Photon energy spectrum for events passing a high p_t trigger.

Main Calorimeter E_t

Fig. 36. E_t in the main calorimeter for events above an E_t threshold.

Preliminary results: general features and A -dependence

A typical spectrum of photon energies for events which pass one of our high- p_t triggers is shown in Fig. 35. A modest E_t requirement in the main calorimeter is sufficient to discriminate against all electromagnetic background. The minimum photon energy that our trigger is sensitive to is about 100 GeV. Figure 36 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.

Fig. 37 The A dependence of the cross section for two of the high- p_t triggers.

Fig. 38 The dependence on the photon energy of the exponent α at fixed x_t .

Fig. 39. The dependence on x_t of the exponent α at fixed photon energy.

The relationship between the γA cross section and the γp cross section is parameterized as: $\sigma(\gamma A) = \sigma(\gamma p) A^\alpha$. Typical plots of $\sigma(\gamma A) / \sigma(\gamma p)$ versus A are shown in Figure 37. If the A^α parameterization were exact, the points would lie on a straight line. The slight curvature is a general feature of the data and occurs for other energy and E_t bins.

We have found that α increases with photon energy at fixed x_t , as shown in Fig. 38. Here we define x_t to be the total E_t observed in the main calorimeter divided by the total CM energy. Fig. 39 shows that α also increases with x_t at fixed photon energy. Scaling this α - x_t dependence to the x_t range covered by E609 reveals a reasonable extrapolation.

We use a variable called *planarity*, P , to characterize the "jettiness" of the events. For perfect jet-like events, $P=1$, and for totally spherically symmetric events, $P=0$. Average planarity as a function of x_t is plotted in Fig. 40 for several different ranges of photon energy. For all photon energies, the average planarity falls with x_t , reaching a minimum at about $x_t = 0.35$. Then the planarity rises with x_t and continues to rise, reaching a value of about 0.75 at the highest x_t values reached. We interpret the increase in planarity as being due to the dominance of hard scattering at large x_t .

Figure 41 shows the average planarity in one x_t bin as a function of atomic mass

Fig. 41 Average planarity as a function of the atomic mass.

Fig. 40. Average planarity as a function of x_t for several bins of photon energy.

A. Average planarity is completely flat as a function of A ; this behavior is true for all x_t bins studied. We conclude that the presence of the nucleus has very little effect on the overall event topology.

Preliminary results: dijet events

If one applies a standard jet finder to the γp data, about 3% of the raw triggers are dijet events with average p_t of 3 GeV or more. The azimuthal angle ($\Delta\phi$) between the jet pairs is plotted in Fig. 42a; perfect jet events have $\Delta\phi=180^\circ$. Fig. 42b shows the " E_t flow" for dijet events with $p_t > 4$ GeV. E_t flow is calculated as follows: the azimuthal angle of the higher- p_t jet is used to define $\phi=0$. Then each calorimeter tower is entered into the plot at the appropriate $\Delta\phi$, weighted by its E_t . The dijet structure is apparent in both figures.

$\Delta\phi$ Between Jets

Fig. 42a. Azimuthal angle between the jets for dijet events in γp interactions.

E_t Flow

Fig. 42b. " E_t flow" vs $\Delta\phi$ for dijet events with $p_t > 4$ GeV/c in γp interactions.

Fig. 43. Average planarity as a function of x_t for γp and πp events.

$\Delta\phi$ Between Jets

Fig. 44. Comparison of $\Delta\phi$ between jets for pion and photon beams. Distributions are normalized to the same area.

Fig. 45 Comparison of the A-dependence of $\Delta\phi$ for pion and photon beams.

Fig. 46 Ratio of beam calorimeter energy to photon energy for planarities <0.7 , upper, and >0.7 , lower.

In addition to measurements with a photon beam, we took a small amount of data with a pion beam. A comparison between pion and photon data is interesting. Fig. 43 shows the average planarity as a function of x_t for γp and πp events; γp interactions show the onset of hard scattering at considerably lower x_t . Fig. 44 shows $\Delta\phi$ between the jets for both pion and photon data. In this plot, cuts have been made on the photon energy so that it is in the same range as the pion energy, which was $250 \text{ GeV} \pm 15\%$. It is clear that there is a significant difference between pions and photons, with the pions being less coplanar. Figure 45 shows the A-dependence of $\Delta\phi$ for both pions and photons. Two things are apparent from this plot. First there is a definite A-dependent effect, with the jets becoming less coplanar with increasing A. This is the same trend seen in E609. In addition, the difference between pions and photons is approximately constant as a function of A.

At the present time we can only speculate as to the meaning of the observed effects. The difference in $\Delta\phi$ for pions and photons might be indicative of a difference in the amount of initial-state radiation for the two incident particles. Such a difference might be expected due to the pointlike nature of the photon, at least for some fraction of interactions.

Preliminary results: forward energy flow

One signature of the photon direct coupling process is the lack of forward energy. We have examined events with little or no energy in the beam calorimeter. Figure 46 shows evidence for the emergence of the pointlike coupling signal. The ratio of beam calorimeter energy to total beam energy is plotted for photon energies from 250 to 400 GeV and for two bins of planarity. For events with planarity > 0.7 , there is a clear excess of events at very low beam calorimeter energy; this excess is not apparent for events with $P < 0.7$. Direct coupling events are expected to be very jetlike and therefore very planar. No correction has been made for the soft photon contamination from multiple bremsstrahlung; when this correction is made the direct coupling signal will be even more pronounced.

G. AGS E818 Search for a JPC 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, hybrid²⁸ and glueball²⁹. 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 focused on glueballs. 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 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. Sum rule and flux tube models³⁰ predict that the lowest lying states are JPC 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 the $I = 1$, $J^{PC} = 1^{-+}$ 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:

$$\begin{aligned} X(1900) &\rightarrow \pi^- f_1(1285) \\ f_1(1285) &\rightarrow \pi^- a(980) \\ a(980) &\rightarrow K^+ \bar{K}^0 \\ \bar{K}^0 &\rightarrow \pi^- \pi^+ \end{aligned}$$

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

$$\begin{aligned} \pi^- p &\rightarrow K^+ \bar{K}^0 \pi^- n \\ \bar{K}^0 &\rightarrow \pi^- \pi^+ \end{aligned}$$

in order to investigate the E/π region³¹ (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- $q\bar{q}$ state. It has been suggested that the $E/f_1(1420)$ is either a 1^{++} bound state of KK at threshold³², or a P-wave π orbiting an S-wave KK at the center³³.

²⁸M. 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).

²⁹F. 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).

³⁰N. Isgur and J. Paton, Phys. Lett. 124B, 247 (1983); N. Isgur, R. Kokoski and J. Paton, Phys Rev Letts. 54, 869 (1985)

³¹S. 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.

³²D. Caldwell, Workshop on Glueballs, Hybrids and Exotic Hadrons, Brookhaven, 1988, AIP Conf. Proc. No. 185, ed. S. U. Chung, page 465

³³R. Longacre, Phys. Rev. D42, 874 (1990)

Fig. 47. Experimental arrangement used for E818 at the MPS facility 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. 47. 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 made to the reconstruction software provided by the MPS facility has yielded approximately a 50% increase in the number of events in the final event sample, and reprocessing is now underway. Event reconstruction and initial event selection is complete, with further event selection to be done in the coming weeks. The partial wave amplitude analysis should be ready to begin by September and will be finished by the beginning of next summer.

The effect of the changes in track reconstruction algorithm can be seen in histograms of the z-position of the production vertex. Fig. 48 shows the z-position of the production vertex of a previous experiment, E771, which used the unmodified

Fig. 48a. Z vertex resolution achieved in a previous experiment using the present apparatus, E771.

Fig. 48b. Improvement in track reconstruction in E818.

code with the same trigger. Below that we see the same plot for E818, using the modified code. The peaks at $z = 74$ cm (E771) and $z = 65$ cm (E818) represent interactions in the downstream endcap of the cylinder encasing the liquid hydrogen target. It can be seen that the z resolution of the track is improved in spite of the higher energy beam, 18 as compared to 8 GeV/c.

Fig. 49. Mass spectra from E818 for the $KK\pi$ system without and with a neutron.

In Fig. 49 we plot the mass spectra first of the $KK\pi$ system without a (neutron) missing mass cut, and then including this cut. Only about one-third of our data have been included in making these plots. We clearly see resonances at the $f_1(1420)/\eta(1430)$ and $\eta(1280)/f_1(1285)$ regions. Further investigation into the higher mass region (from 1.6 to 2 GeV) with various other kinematic constraints will be made before starting the partial wave analysis.

H. LAMPF Nucleon-Nucleon Experiments

The Bonner Lab has an interest in two active nucleon-nucleon experiments at LAMPF. E876 has been measuring spin observables in elastic np scattering. The measurements to date are described in Ref.³⁴. For the first time, it is possible to determine both the $I=1$ and $I=0$ NN amplitudes at 800 MeV. Data should be complete next summer. E1097 will measure cross section and spin observables for the reaction $np \rightarrow pp\pi^-$. We will use a liquid hydrogen target in phase one and an L-type spin-frozen hydrogen target in the second phase. This experiment will use the same beam line and counting house as E876 and is presently running parasitically with that experiment. The major goal of the parasitic test running is to demonstrate the performance of the cylindrical drift chamber which is the heart of the experiment. The current status of the drift chamber is described in the section on instrumentation. LAMPF E818 was completed in January with the publication of Ref.³⁵.

³⁴M. W. McNaughton, *et al.*, Phys. Rev. C44, 2267 (1991)

³⁵E. Gulmez *et al.*, Phys. Rev. C45, 22 (1992)

I. Instrumentation Projects

1. Time of Flight R&D for STAR at RHIC

As described in Section II.C, the STAR detector will have a time of flight mantle surrounding the central TPC to provide both particle ID and a versatile trigger for the central region. At Rice we have been active in designing and testing various concepts for the TOF subsystem. The current design for the TOF system is the "shingle" design, which consists of tiling the cylindrical Outer Field Cage of the TPC with 7776 single ended scintillators arranged in 216 trays (108 in +z ; 108 in -z direction). Fig. 50 shows a cross section of 108 trays arranged outside the TPC at a radius of 205 cm. Each tray positions and supports 36 counters and covers $\sim 3.3^\circ$ in ϕ as shown in Fig. 51. A tray is 11.8 cm wide and 2.25 meters long, each clamped by the rails mounted on the outside of the TPC.

Fig. 50 Drawing of the 108 trays that hold the TOF counters.

Fig 51. Cross section of the TOF shingle counters and trays.

Due to budget constraints a de-scoped version has been proposed for the initial configuration. The primary cost saving comes from reducing the total number of photomultiplier tubes. It was considered essential to maintain full coverage, however, in order to have flexible trigger capability for the midrapidity region. The chosen design consists of filling only 8 trays with shingle counters, covering a total of 13° in ϕ . The remainder of the cylinder will be covered with 416 double ended TOF slats. In

addition to serving as an element in the midrapidity trigger, they also provide lower resolution, but still useful, TOF data.

Design of Shingle and Slat Counters

Each shingle counter consists of a 1 inch diameter 15 stage R3432-01 Hamamatsu proximity mesh dynode phototube optically coupled to a scintillator with a Plexiglas light guide. The scintillator is Bicron BC404 with dimensions 1.5 cm x 2.6 cm x 23.5 cm.

Calibration fibers are glued to the scintillators. The 36 shingle counters are mounted four abreast in a tray. Each slat counter consists of two R3432-01 phototubes optically coupled to a BC408 1.5 cm x 5.2 cm x 200 cm scintillator with a Plexiglas light guide. The slat counters are mounted two abreast in the module tray. The module tray parts are fabricated out of extruded plastic. Each group of four shingle counters or two slat counters is supported inside the tray by a molded foam wedge or block and secured by two extruded plastic restraint struts. The preliminary engineering drawing for a shingle

Fig. 52. Drawing of a shingle counter assembly.

counter assembly is shown in Fig. 52.

The mechanical support system will consist of 108 aluminum rails bolted to the TPC outer frame. Each module tray, containing either 36 shingle counters or two slat counters, is inserted into the slots formed by the support rails from either end of the STAR detector.

Results from Simulations

Intensive Monte Carlo simulations were performed to study the performance of the de-scooped TOF system. The particular version of the de-scooped system that was used in the simulations differs slightly from the version described in the previous sections. The simulated version consisted of filling $16+16=32$ trays with shingle counters (instead of 8), which covers approximately 53 degrees in phi (rather than 13 degrees). The remainder of the cylinder is covered with 368 (instead of 416) double ended TOF slats.

We used ten Fritiof 200 GeV/c/A Au+Au events as input to Geant 3.14. The program tallies the primary tracks that make it to the TOF; this provides a direct measure of the effective coverage. It turns out that although the geometrical coverage is only 84% (caused by the gaps in phi between adjacent trays as well as the dead region of 20 cm at $\eta=0$ caused by light guides and phototubes), the effective loss in primaries is only 9% (averaged over the 10 events examined). This is due mainly to the curvature of the tracks at the TOF barrel.

Fig 53. Time resolution from simulation for (a) shingle counters, and (b) slat counters.

Table 3. Average hit and track multiplicities in the shingle and slat regions.

	Shingles	Slats
Total hits delivered	414	1950
Total tracks	326	1699
Secondary tracks	201	1007
Primary tracks	125	692
Primary pion tracks	110	618
Primary kaon tracks	8	39
Primary proton tracks	7	35

The known properties of the scintillators were used in simulating the response of the shingles (Bicron BC404) and scintillator slats (BC408). The response was parameterized in terms of the particle's beta and path length in the scintillator. The resultant light was transported to the phototube assuming a delay time of 75 ps/cm. The light attenuation for a given scintillator was calculated from the bulk attenuation length and the path length divided by the cosine of the critical angle. A 20% photocathode efficiency was used. A threshold of 100 photoelectrons was required for a light pulse to produce a signal in the PMT. The time spread of the hit was modeled by throwing a Gaussian distribution with a sigma given by $\sigma(ps) = a\sqrt{L(cm)}$ where L is the distance from the hit to the PMT and a is an empirically determined constant equal to 20 for the BC404 shingles and 30 for the BC408 short slats. These values and the value for the delay time were determined experimentally. Typical time resolutions in both the shingles and the slats are shown in Figs. 53a and 53b. For shingles the average time resolution is 64 ps; for slats, 245 ps.

Fig. 54 Experimental setup used to test the various configurations of shingle and slat counters in a 300 MeV/c π^- beam.

Table 4. Scintillators Tested

Type	Dimensions	# Tubes
BC408	1.5 x 1.5 x 42 cm	2
BC408	1.5 x 3.0 x 125 cm	1
BC420	1.5 x 1.5 x 42 cm	2
BC420	1.5 x 3.0 x 63 cm	1

The distribution of the number of tracks and hits in both the shingle and slat regions averaged over 10 events is shown in Table 3 for both primary and secondary tracks. Note that the number of hits is typically larger than the number of tracks, since a track can go through more than one scintillator.

Tests of Phototubes and Scintillators

It is now a technical reality to place the phototubes directly in the 5 kG field and achieve timing resolutions that are required for the TOF system. This was made possible by the advent of a new phototube design, the mesh dynode tube^{36,37}. Further advances in this tube design, the proximity mesh dynode structure with the dynodes positioned close to the photocathode to reduce the transit time spread (TTS), has resulted in a magnetic field insensitive tube with a single electron TTS of

100 to 150 ps. Four such tubes, Hamamatsu R3432-01, were evaluated. These are 15 stage, one inch diameter tubes, with an active area of 2 cm². Tube bases with a standard linear dynode resistor string, supplied by Hamamatsu, were used. No attempt was made to optimize the performance of the bases. At 2000 V the one MIP signal was ~900 mV.

Tests of the shingle geometry using the R3432 phototube at zero field were done in the M-11 beam line at TRIUMF. A minimum ionizing beam of 300 MeV/c π^- was used. The setup is shown in Fig. 54. Scintillators S1 and S2 were 1 cm x 1 cm x 0.6 cm thick paddles and defined the beam size. The scintillator bar, TS, determined the start time. It consisted of a 2 cm x 2 cm x 10 cm bar of BC418 viewed at both ends by two Hamamatsu R2083 fast phototubes, TS1 and TS2. The "shingle" scintillator to be tested, viewed by one or two R3432's T1 and T2, was placed between S1 and S2. The various scintillator combinations tested are listed in Table 4. The discriminators were Phillips 708 octal 300 MHz leading edge discriminators, and the TDC was a Phillips 7186 with 25 ps/channel resolution. A Phillips 715 CFD was also used in some tests. The signal from S1 was used for the common start of the TDC. An event required a coincidence between S1, S2, S3, TS1 and TS2. When this was satisfied all pulse heights and TDC's were read into a computer via CAMAC and stored on magnetic tape for later analysis.

³⁶S. Suzuki, *et. al.*, IEEE Trans. on Nucl. Sci. 33, No. 1, 377 (1986)

³⁷G. Finset, *et. al.*, NIM A290, 450 (1990)

Offline the data were corrected for leading edge pulse height walk, using the formula:

$$T = T_{meas} + A(1/\sqrt{Q_0} + 1/\sqrt{Q})$$

where Q is the ADC pulse height, Q_0 is a reference pulse height, and A is an empirically determined constant, depending on the time constants of the tube and scintillators. The walk corrected times, T_1 and T_2 , were then corrected for the S1 time jitter using the TS counter according to the following prescription.

$$\begin{aligned} T &= (T_1 + T_2) / 2 - (TS_1 + TS_2) / 2 && \text{double ended} \\ T &= T_1 - (TS_1 + TS_2) / 2 && \text{single ended} \end{aligned}$$

The measured widths of these time distributions correspond to

$$\begin{aligned} \sigma_m^2 &= \sigma_T^2 / 2 + \sigma_{TS}^2 / 2 \\ \bar{\sigma}^2 &= \sigma_m^2 - \sigma_{TS}^2 / 2 && \text{double ended, and} \\ &= \sigma_T^2 / 2 && \text{single ended} \end{aligned}$$

$$\begin{aligned} \sigma_m^2 &= \sigma_{T1}^2 + \sigma_{TS}^2 / 2 + \sigma_x^2 \\ \sigma_{T1}^2 &= \sigma_m^2 - \sigma_{TS}^2 / 2 - \sigma_x^2 \end{aligned}$$

where σ_m^2 is the measured variance, σ_T^2 is the variance of one R3432, σ_{TS}^2 is the variance of one R2083, and σ_x^2 is the variance due to the one cm^2 beam spot size. Tubes of the same type are assumed to have equal variances. $\bar{\sigma}^2$ is the variance that would be measured using a double ended TOF element. The value for the TS variance was obtained from the equations

$$\begin{aligned} T_{diff} &= T_{S1} - T_{S2} + 2nx / c \\ \sigma_{diff}^2 &= \sigma_{TS}^2 + \sigma_{TS}^2 + 4\sigma_x^2 \\ \sigma_{TS}^2 &= \sigma_{diff}^2 / 2 - 2\sigma_x^2 \end{aligned}$$

where n is the index of refraction for the scintillator (~ 1.58) and x is the position of the beam. Since $\sigma_x \approx 20 ps$, we take σ_x^2 to be zero. The results are listed in Table 5. For the TS counter, we achieved a bar resolution of 35 ps! The performance of the shingle counters surpassed requirements. The R3432 covered only 86% and 44% of the bar areas, respectively. Thus one would expect $\sqrt{2}$ worse performance from the larger area bar. Also we expect the same performance from the larger area bar with the beam incident on its 3.0 cm length. The data in Table 5 support this conclusion.

Empirically, long scintillator bars have a time resolution given by

$$\sigma = a\sqrt{L / N_e}$$

where L is the bar length in cm and N_e is the average number of photoelectrons collected. (usually taken as a MIP at the center of the bar). The constant a depends on the statistics of the arrival of the leading edge of the light pulse. This in turn depends on the inverse of the square root of the photoelectron density per unit time of the leading edge. Since the time spread is given by

$$\Delta t = nL(1 / \cos\theta - 1) / c$$

the photoelectron density is then proportional to

$$N_e = N_0 \pi r^2 / tw$$

where t is the thickness of the scintillator, N_0 is the number of photons generated per unit length, w is the width of the scintillator and r is the radius of the photocathode. The term $\pi r^2 / tw$ accounts for the fraction of the light collected by the photocathode. (We have assumed that t and w are greater than or equal to $2r$). Collecting all the constants,

$$\sigma \cong a \sqrt{Lw / \pi r^2}.$$

Table 5 Timing results.

The beam traversed the thickness listed first in the cross section column. X is the length of scintillator the light traversed. σ gives the results for the single tube analysis. LE=(Phillips 708, leading edge) with pulse height corrections. CFD=(Phillips 715, constant fraction). The Bar column gives the results for the double ended analysis. The column labeled % gives the fraction of light collected.

Type	Cross Section (cm)		X(cm)	σ (ps)	DISC	Bar(ps)	%
BC408	1.5 x	1.5	10	61	LE	50	86
	1.5 x	1.5	21	69	"	46	"
	1.5 x	1.5	32	94	"	50	"
	1.5 x	3.0	5	85	"		44
	1.5 x	3.0	25	113	"		"
	1.5 x	3.0	63	193	"		"
	3.0 x	1.5	5	51	"		44
	3.0 x	1.5	25	74	"		"
	1.5 x	1.5	10	45	LE	41	86
	1.5 x	1.5	15	50	"	37	"
	1.5 x	1.5	21	56	"	35	"
	1.5 x	1.5	27	72	"	37	"
BC420	1.5 x	1.5	32	83	"	41	"
	1.5 x	1.5	21	98	CFD	69	"
	1.5 x	3.0	5	55	LE		44
	1.5 x	3.0	10	75	"		"
	1.5 x	3.0	25	100	"		"
	1.5 x	3.0	25	123	CFD		"
	3.0 x	1.5	5	38	LE		44
	3.0 x	1.5	10	41	"		"
	3.0 x	1.5	25	68	"		"
	2 x	2	5	53	LE	38	100

Fig. 55. Time resolution as a function of position for the BC408 and R3432 mesh dynode phototube.

Fig. 56 Time resolution as a function of position for the BC420 and R3432 combination.

The measured time resolutions from Table 5 are plotted and fitted in Fig. 55 for BC408 and Fig. 56 for BC420. From these figures we can estimate the behavior of the proposed 2.6 cm x 1.5 cm x 23 cm shingle counters. The worst resolution expected, namely at $L = 23$ cm, would be 87 ps for BC420 and 103 ps for BC408. Near the phototube, $\sigma \leq 50$ ps.

To conclude this section, we have evaluated the scintillator performance for BC408 and BC420 using the R3432 proximity mesh dynode photomultiplier at zero field. A system resolution of better than 100 ps seems eminently feasible.

2. The 1 mm MWPC for the μ^+e^- Elastic Scattering Polarimeter

At the SMC (NA47) experiment at CERN, the muon beam polarization is being measured by two methods: 1) by determining the shape of the energy spectrum of the decay positrons, and 2) by measuring the elastic scattering of muons from electrons in a polarized iron target. For the muon electron scattering polarimeter, a special large 1 mm wire spacing chamber is required. It must count efficiently in the region of the muon beam and must also cover the complete solid angle for muon electron scattering which overlaps the beam region. The design of this special chamber was developed at Rice.

The chamber has four wire planes (two Y, one U and one V). The anode wires are 10 micron diameter gold-plated tungsten and the cathodes are made of graphite layer on mylar foil. The anode-cathode gap is 5 mm and the anode wire spacing is 1 mm. There are 1280 anode wires in each of the Y planes; 960 wires in U and 960 in V planes.

3. The Cylindrical Drift Chamber for LAMPF E1097

One very important problem was electronic noise, to which we are sensitive since charge division is used to determine the position along the wire. The introduction of shielded cables between the preamplifiers and shaping amplifiers helped a great deal. We are replacing much of our electronics with some that were designed and built for the MEGA experiment which has opted not to use charge division. We have integrated these new electronics and will instrument more than half the chamber for the 1992 summer test run. The goal of this run is to demonstrate the performance of a large fraction of the chamber. Performance indicators include the efficiency and resolution in both r - ϕ (drift) and z (charge division). We will also study the possibility of multiplexing some of the electronics to reduce costs.

4. Timing Detectors for the LAS at CEBAF

required since an accelerator bucket arrives every 2 ns. This will identify the rf bucket to a C.L. of better than 99%. In addition, the detector must cover the angular range from 7° to 150° in the six sectors of the LAS. Finally, it should not introduce excessive multiple scattering; this requirement limits the thickness to $< 1\%$ L_{rad} . A sketch of what such a detector might look like is shown in Fig. 57.

Fig. 57. Sketch of a possible design for the LAS timing counter to associate events with the proper tagged photon.

Fig. 58 Time spectrum from the RCA 583009E positioned on the narrow end of the scintillator. $\tau_{\text{rise}}=0.8$, $\tau_{\text{fall}}=2.25$, and $\tau_{\text{RMS}}=1.3$ ns.

Fig. 59 Time response of the RCA 8578; $\tau_{\text{RMS}}=500$ ps.

A prototype was built and testing has begun. The prototype was constructed of 2 mm thickness NE118 scintillator. It is 5.9 cm wide by 24 cm long, with the triangular end curved to fit the 5.6 cm radius. It is not curved in the radial direction. Monte Carlo studies of the response of this counter indicate that for a minimum ionizing particle (MIP) we will get 100 photoelectrons from a phototube viewing the wide end and < 10 p.e. from a phototube viewing the narrow end. The performance of the prototype was measured using a simple test setup. The prototype was coupled to an RCA 8575 phototube via an adiabatic lightguide on the wide end and an RCA 83009E 10 mm diameter phototube on the narrow end. A ^{109}Ru beta source provided 1-3 MeV electrons which were collimated to a 1 cm diameter spot size on a fast timing TS counter. The ADC response was calibrated to be 700 channels for 1 MeV of energy deposited in NE118, using a ^{207}Bi source. Although the ^{109}Ru pulse height spectrum is poorly defined, due to the beta decay shape, the peak at low pulse height should correspond to approximately minimum ionizing electrons. Since this occurred at channel 70, the prediction of 100 p.e. is achieved. The pulse height was approximately independent of position, as expected. The pulse height from the smaller tube however, was position dependent, and had about 10% pedestal, indicating that the mean pulse height was < 10 p.e., perhaps as little as 2 p.e. on the average. This might indicate that the light transmission of the curved portion is bad, perhaps due to overheating during fabrication. The time spread is shown in Figs. 59 and 60. The RCA 8575 had a $\sigma = 500$ ps. using leading edge discrimination with no pulse height corrections. The time spectrum from the RCA 83009E approximates the rise and fall time constants of the scintillator, which would be expected if the light were only

Fig. 60. Time response of RCA 8575 for two positions of the source 15 cm apart. The separation of the peaks is 1.15 ns which corresponds to an effective transit time for the light of 75 ps/cm.

a few p.e. Fig. 60 also shows the effect of the light transmission time on the time response of the counter. The transit time is 75 ps/cm, which would lead to a time spread of 1.8 ns from the extreme ends of the counter. It is apparent that a great deal of work remains to be done. Future plans include the following steps.

- 1) More detailed study of the light transmission of the curved end.
- 2) Use of a faster scintillator, such as BC404, which has time constants about half those of NE118.
- 3) Comparison of leading edge timing with pulse height corrections and constant fraction discrimination.
- 4) Testing with faster phototubes, such as the Hamamatsu R3432.
- 5) Other schemes to extract the light, such as waveshifter bars or fiber optics, with the goal of reducing the time spread from the light transit time.
- 6) Monte Carlo the time spread due to flight path differences from the target to the start counter, and velocity spreads of typical charged particles to determine how well the counter must perform to achieve the design goal of $\sigma = 500$ ps.

The results of the preliminary prototype tests were presented at the CEBAF Users Meeting in June, 1992.

The Rice MOU calls for construction of a prototype by 6/92 and testing by 9/92. We are on schedule.

III. Publications, Presentations, Reports and Theses during the Present Grant: 1990 – 1992

Publications

.....1992.....

"Recent Results from E-810," BNL-46965, Nov. 1991, Proceedings of Quark Matter '91 (to be published in Nuclear Physics A), Gatlinburg, TN, Nov. 11-15, 1991. K.J. Foley and the BNL E810 Collaboration.

"Effects of High Beam Rates on TPC's," BNL-47201, Feb. 1992, Proceedings of the Wire Chamber Conf. (to be published), Vienna, Austria, Feb. 17-21, 1992. A. Etkin and the BNL E810 Collaboration.

"Rapidity Distributions and Nuclear Transparency in Heavy Ion Collisions," Submitted to Physics Letters B. S.E. Eiseman and the BNL E810 Collaboration.

"A Silicon Multiplicity Detector System for an Experiment on the Interaction of Antiprotons with Nuclei at BNL," IEEE Conference Record and IEEE Transactions on Nuclear Science (to be published). S. Ahmad and the BNL E854 Collaboration.

"Transverse Momentum Distributions of π^- from 14.6A GeV/c Silicon Ion Interactions in Copper and Gold," S. Ahmad and the BNL E810 Collaboration, Physics Letters **B281**, 29 (1992)

"Elastic scattering of N -, L -, and S -type polarized 794 MeV protons from an ND_3 target polarized in the S - L plane," E. Gülmez, D. L. Adams, S. Beedoe, M. Bleszynski, J. Bystricky, V. Ghazikhanian, G. Igo, T. Jaroszewicz, A. G. Ling, M. Nasser, M. W. McNaughton, S. Penttilä, G. Glass, G. Kahrmanis, W. F. Kielhorn, K. H. McNaughton, P. J. Riley, S. Sen, D. Wolf, Physical Review **C45**, 22 (1992)

"Measurement of the $\pi^+ \rightarrow e^+ \nu$ Branching Ratio," D. I. Britton, S. Ahmad, *et al.*, Phys. Rev. Letts. **68**, 3000, (1992)

.....1991.....

"Comparison of PWA Results of $K^+ K_S^0 \pi^-$ Final States Produced in 8-GeV/c K^-p , π^-p and $\bar{p}p$ Interactions," Proceedings of the 4th Int. Conf. on Hadron Spectroscopy, Hadron '91 (to be published), College Park, MD, Aug. 12-16, 1991. J. Dowd and the BNL E771 Collaboration.

"An Experiment to Observe Strange Particle Production in Ion Collisions at the AGS," BNL-46555, July, 1991, Proceedings of the Int. Symp. on High Energy Nuclear Collisions and Quark Gluon Plasma, Kyoto, Japan, Jun. 6-8, 1991, pp 62-68. E.D. Platner and the BNL E810 Collaboration.

"Behavior of TPC's in a High Particle Flux Environment," Proceedings of the Symposium on RHIC Detector R & D, Brookhaven National Laboratory, October 10-11, 1991, pp. 207-213. A. Etkin and the BNL E810 Collaboration.

"Evidence for Multiple Scattering of High Energy Partons in Nuclei", M. D. Corcoran, *et al.*, Physics Letters **B259**, 209 (1991).

- "Study of the Reaction $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ at 1.546 GeV/c and 1.695 GeV/c, P.D. Barnes, B. E. Bonner, *et al.*, Nuclear Physics A526, 575 (1991).
- "Silicon Ion Interactions: Measured in the E810 TPC at the AGS," Proceedings of QUARK MATTER 90, Menton, France, 7-11 May 1990. Nuclear Physics A525, 601c-604c (1991). B. E. Bonner, J. A. Buchanan, C. S. Chan, C. N. Chiou, J. M. Clement, M. D. Corcoran, S. E. Eiseman, A. Etkin, K. J. Foley, R. W. Hackenburg, T. J. Hallman, M. A. Kramer, J. W. Kruk, S. J. Lindenbaum, R. S. Longacre, W. A. Love, L. Madansky, T. W. Morris, G. S. Mutchler, M. Nessi, F. Nessi Tadaldi, E. D. Platner, J. B. Roberts, A. C. Saulys, K. Zhao.
- "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. Barlett, 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. Ferguson, G. W. Hoffmann, J. A. Marshall, L. Ray, J. F. Amann, B. E. Bonner, and J. B. McClelland, Physics Letters B264, 21, (1991).
- "Radiative muon capture on Carbon, Oxygen, and Calcium," D. S. Armstrong, S. Ahmad, *et al.*, Phys. Rev. C43, 1425 (1991).
- "np elastic spin transfer measurements at 788 MeV," M. W. McNaughton, K. Koch, I. Supek, N. Tanaka, K. H. McNaughton, P. J. Riley, D. A. Ambrose, J. D. Johnson, A. Smith, G. Glass, J. C. Hiebert, L. C. Northcliffe, A. J. Simon, D. L. Adams, R. D. Ransome, D. B. Clayton, H. M. Spinka, R. H. Jeppeson, G. E. Tripard, Physical Review C44, 2267 (1991)
- "Hard Scattering in Nuclei," M. D. Corcoran, Proceedings of the Fourth Conference on the Intersections Between Nuclear and Particle Physics, Tucson, 1991. Willem T. H. Van Oers, ed., p. 838-843.
-1990.....
- "Analyzing Power of Inclusive Production of π^+ , π^- and K_S^0 by Polarized Protons at 13.3 and 18.5 GeV/c," B. E. Bonner, F. Nessi-Tedaldi *et al.* Physical Review D41, 13 (1990).
- "Strangeness Production in Antiproton-Tantalum Interactions at 4 GeV/c," W. R. Gibbs and J. W. Kruk, Physics Letters B237, 317 (1990)
- "Neutral V Production with 14.6 x A GeV/c Silicon Beams," S. E. Eiseman, *et al.*, Physics Letters B 248, 254 (1990).
- "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).

Presentations

- "The μ Polarimeter for SMC Experiment at CERN SPS," The Spin Muon Collaboration, *Adriatico Research Conference: Polarization Dynamics in Nuclear and Particle Physics*, Miramare-Trieste, January, 1992.
- "Hard Scattering in Nuclei," M. D. Corcoran, *9th Conf. on the Intersections between Nuclear and Particle Physics*, Tucson, May 1991.
- "Behavior of TPC's in a High Particle Flux Environment," A. Etkin, S. Ahmad *et al.*, *IEEE Nuclear Science Symposium*, Santa Fe, Conference Record p. 537 (1991)
- "Radiative Decays of the Low-Lying Hyperons," G. S. Mutchler, CEBAF, March 19, 1990.
- "First Observation of Λ , $\bar{\Lambda}$, and K_S^0 Production in Relativistic Heavy Ion Collisions at the AGS, *Heavy Ion Physics at the AGS*, Brookhaven, March 1990, AIP Conference Proceedings (to be published), T. Hallman, B. E. Bonner, G. S. Mutchler *et al.*
- "AGS Silicon Gold Collisions Measured in the E-810 TPC," *Ibid.*, W. A. Love, B. E. Bonner, G. S. Mutchler *et al.*
- " V^0 Production with 14.5 GeV/c Silicon Beams," *Ibid.*, A. C. Saulys, B. E. Bonner, G. S. Mutchler *et al.*
- "810 Future Plans," *Ibid.*, E. D. Platner, B. E. Bonner, G. S. Mutchler *et al.*
- "Partial-Wave Analysis of the $K^+K_S^-\pi^-$ System Produced in π^-p and K^-p Interactions at 8 GeV/c," *MIT PANIC XII*, Boston, June 1990, AIP Conference Proceedings (to be published), S. U. Chung, B. E. Bonner, G. S. Mutchler *et al.*
- "Studies of Central Interactions of Si Ions at 14.5 x A GeV/c in Au and Cu," *Ibid.*, K. J. Foley, B. E. Bonner, G. S. Mutchler *et al.*
- "Search for a Quark - Gluon Plasma and Other New Phenomena with A 4π Tracking TPC Magnetic Spectrometer at RHIC: Letter of Intent," BNL-RLOI-3, Sept 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, S. J. Lindenbaum, C. S. Chan, M.A. Kramer, K. Zhao, Y. Zhu, A. Aprahamian, N. Biswas, U. Garg, P. Kenney, J. Piekarz, 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.

Reports

- "Tests of a 5 meter long Scintillating Fiber Counter using a pion beam at TRIUMF," STAR Note #46, S. Ahmad *et al.*, 1992.
- "Mechanical Design for the Time of Flight System of the STAR Detector," STAR Note #49, S. Ahmad *et al.*, 1992.
- "Test of Proximity Mesh Dynode Tubes and Evaluation of Shingle Counters," STAR Note #50, S. Ahmad *et al.*, 1992.

"Annulus Scintillator Trigger Detector at High Eta," STAR Note #51, S. Ahmad *et al.*, 1992.

"Use of Time of Flight Detectors in the Trigger," STAR Note #52, S. Ahmad *et al.*, 1992.

Theses

"Time-of Flight Particle Identification Results from Central Si-Si and Si-W Collisions at 14.6xA GeV/c," Chengnan Chiou, Ph.D., Rice University, May, 1992.

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

"Spin Effects in Inclusive Strange Particle Production," Nety M. Krishna, Ph.D., Rice University, May 1990.

"Design and Construction of a Beam Calorimeter for E683 at FNAL," Donald W. Lincoln, M.A., Rice University, May 1990.

"Construction of the E683 Hodoscope and Preliminary Calibration of the E683 Main Calorimeter," Michael M. Traynor, M.A., Rice University, May 1990.

"Particle Identification by Time-of-Flight for Heavy Ion Interactions," Chengnan Chiou, M.A., Rice University, May 1990.

IV. Face Pages from Selected Documents

*All Face Pages
removed*

1. Proposal for AGS E854: "Antiproton-Nucleus Interactions at 5-10 GeV/c," January, 1989.
2. Paper to be presented at the Second Biennial Conference on Low-Energy Antiproton Physics: LEAP '92, "A Silicon Multiplicity Detector System for an Experiment on the Interaction of Antiprotons with Nuclei at BNL," September, 1992.
3. E810 paper on "Transverse momentum distributions of π^- from 14.6A GeV/c silicon ion interactions in copper and gold," Phys. Letts. B281 (1992) 29.
4. E810 paper on "Recent Results from E810," to be published in Quark Matter 1991, Gatlinberg, TN.
5. Draft Conceptual Design Report for the Solenoidal Tracker at RHIC, June, 1992.
6. Updated SMC Name List, February, 1992.
7. SMC paper presented at the *Adriatico Reserch Conference*, "The μ Polarimeter for Experiment SMC at CERN SPS," January, 1992.

Removed