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Experiments on the Nuclear Interactions of Pions and Electrons

Progress Report for the Dept. of Energy

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ABSTRACT

We have completed our analysis of the deuterium content in the CD target used in our experiment to study the $\pi + d \rightarrow 2p$ reaction at incident pion energies from 4 to 20 MeV. The final paper describing this experiment will be submitted for publication this summer. Analysis of LAMPF Exp. on pion absorption in ^{4}He is continuing. Preliminary results were reported at the Few Body Conference in Australia in January, 1992. In the summer of 1991 we collaborated with D. Pocanic from the Univ. of Virginia on a measurement at LAMPF of the π^0 production in π^+p interactions. This run proved the validity of the method and additional data have been obtained in a second run during the summer of 1992, using a new target.

We are fully involved in some major collaborations at LAMPF: the search for the decay $\mu^+ \rightarrow e^+ + \gamma$(MEGA), and a measurement of the Michel ρ parameter in the decay $\mu \rightarrow e + \nu + \nu$. We are taking part in a U.Va. - PSI collaboration to measure pion beta decay to an accuracy of less than 1%, using a large acceptance CsI detector to measure the π^0 following decay of stopped π^+ mesons.

We have published the results of an experiment to measure the longitudinal and transverse cross sections for electron scattering from nuclei in the quasi-free region. We have also joined a collaboration to measure the spin-content of the neutron using the 22 GeV electrons in Area A at SLAC.

In conjunction with the construction of the CEBAF accelerator, we are working on the CEBAF Large Acceptance Spectrometer (CLAS) program. We are contributing mainly to the construction of the CLAS forward calorimeter. We have built an apparatus to measure the properties of the scintillators with light from a N_2 laser. This apparatus was built in the spring of 1992, and debugged in May and June. Further modifications will be made, and we expect it to be fully operational by the end of the summer. We are also developing the electronic circuitry for the energy signal from the EGN detector, and the circuitry needed to route the signals from the all the photomultipliers to the TDC and ADC circuits. We continue to develop experimental proposals for the study of electroproduction of nucleon resonances at CEBAF, including measurements with polarized beam and targets.

1. Pion Nucleus Physics.

1 a) $\pi^+ + d \rightarrow 2p$.

LAMPF EXP., R. Minehart and Barry Ritchie, Spokesmen

R. Minehart, L.C. Smith, and collaborators from Arizona State U., U. Md., U. South Carolina.

Pion absorption on two nucleons is one of the fundamental nuclear reactions involving pions. At LAMPF we have been engaged for several years on a series of experiments[1,2] to measure the cross section for the reaction, $\pi^+ + d \rightarrow p + p$, with high precision over the entire energy range accessible there. During August and September of 1988, we measured the reaction at LAMPF with very low energy incident pions (5 - 20 MeV), in LAMPF experiment 1085.

In the π-d center of mass system, the emerging protons share the total energy equally. In the laboratory both have energies of the order of 80 to 100 MeV, so that they are conveniently detected in total absorption scintillation counters. When the energies of the two detected protons are combined, the reaction is easily separated from the background arising from pion absorption in carbon. At the low energies used for Exp. 1085, the intensity of the incident beam was low enough to count the particles with scintillation counters. Consequently, we used a deuterated scintillator (approximately CD) as an active target, which permitted us to measure the beam flux accurately. However, the beam consists of a mixture of positrons, muons and pions, and simple counting of the incident particles is insufficient to determine the pion flux. The measurement of the beam composition was the most difficult part of the experiment.

The fraction of pions in the beam was enhanced by using an electrostatic separator to deflect positrons and muons away from the target. However, the finite beam phase space prevented perfect separation of the three components. In general, we were able to obtain a beam with 50-70% pions, with the remainder primarily being muons. The residual positrons were easy to identify on the basis of their low energy loss in the target. The problem then was reduced to separation of pions and muons. At some energies it was possible to identify the particles in the momentum analyzed beam by inferring their velocities from their time-of-flight between the production target and the experimental reaction target. At some energies this time can be obtained by comparing the time of the pion signal in the experimental target to an accelerator RF reference pulse. Since the RF period is 5 ns, this method requires that the times-of-flight of the beam pions and muons not differ by a multiple of 5 ns, within an experimental resolution of about 1 ns. At energies where this method was useless, we were able to separate pions from muons by comparing the pulse heights in the target scintillator and in a second scintillator placed after the target. The pion and muon peaks in the pulse height spectra overlapped enough that accurate determination of the pion fraction requires reasonably accurate knowledge of the pulse height spectrum for each type of particle. Monte Carlo caculations were used to determine these spectra.

Preliminary results were reported at the Baltimore meeting of the American Physical Society in May, 1989, and an article[3] was published in Phys. Rev. Letters in 1991. A detailed article has been written and will be submitted shortly. A preprint is attached to this report. In the preparation of this paper, we re-worked the analysis of the beam composition (without significant changes from the Phys. Rev. Letter), and reviewed the chemical analysis of the CD target carried out for us at LANL. After consultation with chemists at the University of Virginia, we believe that the LANL analysis is as good as can be achieved with chemical procedures.

The principle results of our measurement are that the P-wave component of the absorption remains signficant down to the lowest measured energies, about 4 MeV, and that the cross section is in good agreement with the recent measurements of the pion production reaction, $n+p \rightarrow d + \pi^0$, which is related by time reversal and isotopic spin rotation. Some discrepancies with theoretical models are noted in the paper.

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1 b) Pion Absorption in ^{4}He

LAMPF Exp. 1126, R.C. Minehart, L.C. Smith, S. T. Thornton, R. Sealock, R. M. Marshall, D. Day, J. McCarthy, R. Lourie, in collaboration with Arizona State University, Hampton University, James Madison University, Renssalaer Polytechnic Institute.

We continued to analyze results from the LAMPF experiment "Two-nucleon absorption in ^{4}He at T_π=500 MeV" which received over 900 hours of beam time during the summer of 1990. This experiment was part of our continuing LAMPF program to study inelastic pion reaction mechanisms on light nuclei. Experiment 1126 was intended to study the effects of the high nucleon binding energy in ^{4}He on the systematics of two-body pion absorption on (pn),(pp) and (nn) pairs. The experiment was motivated by the results of a previous pion absorption measurement on ^{3}He at 500 MeV (Experiment 705) where a larger than expected quasideuteron cross section was observed. According to most models, the probability of absorption is sensitive to the amount of overlap between the absorbing nucleons. The ^{3}He result could be interpreted in this sense as resulting from absorption on a 'compressed' deuteron. If this is the case, one would expect to see an even stronger enhancement of quasideuteron absorption in the more tightly bound ^{4}He nucleus. Interestingly, such enhancements have not been seen in either isotope at the much lower energies of previous measurements. Therefore, the present measurement is crucial to establishing whether there is a systematic binding energy dependence of the two-nucleon absorption mechanism at higher energies.

Another important result expected from this measurement is an estimate of the importance of three- and four-body pion absorption. Such processes have only recently been unambiguously identified in the helium isotopes and the dynamical origin of these reaction channels is still speculative. Models involving both sequential Δ-excitation as well as $\Delta\Delta$ excitation have been proposed, but so far the only firm predictions are that such mechanisms are expected to contribute substantially to the total absorption cross section only for pion energies above 300 MeV. At the present time LAMPF is the only facility in which data needed to test these models can be obtained.

Our analysis of the ^{4}He(π^+,pp)pn reaction is nearly complete and preliminary results were presented in a paper given at the Fewbody XIII conference in Adelaide, Australia (see Appendix). These can be summarized as follows, 1) the two-body absorption yield is higher than expected from the quasideuteron model, but by the same amount seen in ^{3}He, indicating no significant density dependence, 2) the angular distribution of the quasifree absorption agrees closely with that for the free deuteron, 3) the four-body absorption is much lower than expected from the $\Delta\Delta$ model.

We are currently preparing to publish these results. Analysis of the other absorption reaction channels will continue for a possible later publication.

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R.E. Segel, G. Garino, D. Geesaman, J.P. Schiffer, G. Stephans, B. Zeidman, E. Ungricht, H. Jackson, R. Kowalczyk, D. Ashery, E. Piasetsky, M. Moinester, I. Navon, L.C. Smith, R.C. Minehart, G.S. Das, R.R. Whitney, R. McKeown, B. Anderson, R. Madey, J. Watson, *Phys. Rev.* **C43**, 957, (1991).

2. Medium Energy Particle Physics.

2 a) Search for heavy neutrinos.

SIN Exp., R. Minehart, K. Ziock, spokesmen

R. Minehart, R. Marshall, W. Stephens, B. Wright, K.O.H. Ziock, and SIN collaborators.

In this experiment we undertook to further reduce the upper limit for the branching ratio for the deay of a pion into a muon and a heavy (τ) neutrino, based on a proposal by R.E. Shrock[1]. The analysis of the data has been completed. We have decided that the data, while superior to those from our previous measurement in some mass regions, do not justify a new publication.

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2 b) The search for fractionally charged particles.

D.Allen, R. Marshall, and K.O.H.Ziock

In this experiment we endeavor to search for fractionally charged particles by measuring the residual charge on small (0.2 mm diam.) steel spheres with sub-electron sensitivity. We are in the process of building a completely new magnetic levitation electrometer with twice the distance between the field generating plates. The apparatus has been largely put together and should be ready for tests by the end of the year.

2 c) Search for the rare decay, $\mu^+ \rightarrow e^+ + \gamma$.

LAMPF Exp.

R.M. Marshall, B. Wright, K.O.H. Ziock and LAMPF collaborators.

The mu-e-gamma, or "MEGA", experiment is an attempt to reduce the limit on the branching ratio for the "forbidden" decay

$$\mu^+ \rightarrow e^+ + \gamma$$

to the lowest level achievable with current accelerator and detector technology.

The observation of such a decay would signal that the generation (or family) quantum number is not strictly conserved. The current upper limit on the branching ratio for this decay ($B < 5x10^{-11}$) was set by the Crystal Box experiment performed at LAMPF.

The design goal of the MEGA experiment is either to observe the decay or to reduce the upper limit on its branching ratio to

$$B < 2 \times 10^{-13}$$

The experiment uses a large (length = 2.9 m, i.d. = 2 m) superconducting solenoid with a field of 1.5T. The positive surface-muon beam from the low energy muon channel at LAMPF will be stopped in a thin target in the center of the magnet volume. The γ - rays from the forbidden decay will be observed by a set of pair spectrometers mounted concentrically with the target in the up- and down-stream direction. The energy of the decay positrons is measured with a set of wire chambers consisting of a large chamber concentric to the beam axis that is surrounded by a set of 7 smaller chambers. Inside the inner chamber and concentric with it are 2 sets of 87 scintillation detectors each that surround the beam entrance and beam exit pipes and that determine the arrival time of the decay positrons.

A significant fraction of the background events will be due to radiative muon decays, i.e. muon decays that are accompanied by the emission of an inner bremsstrahlung photon. If this photon has a high energy it can lead to a spurious γ - ray trigger. Such spurious events will, however, be accompanied by a low energy positron whereas the genuine events will be accompanied by a high energy positron. The low energy positrons will follow the magnetic field lines to the beam entrance and exit ports. Scintillation detectors, mounted where the low energy positrons leave the magnet can, therefore, be used to veto some of these spurious events, providing an "Inner Bremsstrahlung Veto", or IBV.

Our group has taken on the responsibility for the design, construction, and operation of the electron (e^+) scintillation detector, and of the inner bremsstrahlung veto.

The Electron Detector:

As of this writing, July 1992, we have installed all 174 electron scintillators as well as the IBV detectors. We have assembled the electronics and have connected the entire system to the data collection ADC's and TDC's. We have set the voltages for all the scintillators and are now in the process of testing the system in place with the muon beam.

2 d) A Precise Measurement of the $\pi^+ \to \pi^0 e^+ \nu$ Decay Rate

PSI Experiment R-89-01

D. Počanić, D. Day, E. Frlež, R.M. Marshall, J.S. McCarthy, R.C. Minehart, B.E. Norum, L.C. Smith, T.P. Welch, B.K. Wright, K.O.H. Ziock, and collaborators from Arizona State, Dubna, Swierk, Tbilisi, PSI, Zagreb, and Zurich. Switzerland.

As discussed in previous reports, Pion beta decay, $\pi^+ \rightarrow \pi^0 + e^+ + \nu$, can be related directly to the ft value for nuclear beta decay, through the use of the conserved-vector-current hypothesis of the unified theory of electromagnetic and weak interactions. The calculation of Sirlin[1] and Kallen[2] result in a formula expressing the inverse lifetime in terms of the weak interaction coupling constant for pure vector beta decay, and the difference in the mass of the charged and neutral pion, along with a radiative correction term. Nuclear beta decay contains the same coupling constant, so that the ratio of the two processes depends primarily on the pion mass difference and the radiative correction term. Sirlin obtained the rate, $1/\tau_{\pi\beta} = 0.403 \pm 0.003$ s^{-1}. Since 1978, several of the numbers that went into this calculation have been determined more precisely. Most important is the new value of the mass difference between the charged and neutral pion, as measured at PSI by Ziock, Marshall, and collaborators. With the corrected data, the decay rate is $1/\tau_{\pi\beta} = 0.3977 \pm 0.0008$ s^{-1}. The theoretical uncertainty is due in about equal parts to the uncertainty in the pion mass difference and to the uncertainty in the radiative corrections. This calculation can be compared to the results of Depommier *et al.*[2], who obtained $0.38^{+0.03}_{-0.04}$ s^{-1} in 1968 using stopped pions, and to McFarlane *et al.*[3] who reported 0.394 ± 0.015 s^{-1} in 1985 using pions in flight. The factor of 20 between the theoretical and experimental errors presents a strong challenge to the experimenters.

Believing that the Depommier measurement with stopped pions can be greatly improved by using modern techniques, we set ourselves the goal of designing an experiment to improve the accuracy from the 4% of McFarlane *et al.* to 0.5%. Specifically, measurement of the two photons from the decay of the π^0 in a large acceptance (nearly 4π) detector of CsI provides a reasonably economical method to obtain a significant improvement in the statistical and systematic errors. The CsI detector and a schematic plan of the experiment are shown in Figure 1. The task of determining the number of stopped pions to an accuracy of approximately 0.5% is perhaps the major problem.

The experiment has now been unconditionally accepted by the PSI PAC and our proposal for an equipment grant of $450,000 to the NSF has been fully funded.

The experiment requires a precisely constant and reproducible stopping distribution in the experimental target. In order to monitor this distribution continuously throughout the experiment we will use a "live target" consisting of 187 2 mm $\times$ 2 mm plastic scintillator fibers of 45 mm length. Each of these fibers will be read out by a photomultiplier with associated electronics to allow us to monitor not only counting rates in the individual fibers but also to study correlations in neighboring fibers. The active target has been constructed and has been partially (9 fibers) tested at LAMPF during a run in July 1992.

Two in-beam tests were conducted, in July and November 1989 at PSI, the latter just prior to the $1\frac{1}{2}$ year long shutdown of the ring accelerator. Rushed by the impending shutdown deadline, the November run was carried out with pure CsI detectors somewhat inferior to the best Bicron samples. We were able to instrument only one arm with CsI detectors, for the other arm we used an existing NaI detector. Nevertheless, the measurements demonstrated that detecting stopped pion decays was a sound method — a $\approx$30% measurement of the pion beta branching ratio was accomplished in about a day of beam time at the end of the run. Main results of this test run are summarized in Figure 2. During laboratory tests in 1989 it was determined that, contrary to previously reported results, pure CsI has a long intrinsic absorption length, $\geq$1 m. This led to a thorough redesign of the CsI calorimeter, making use of the significantly more favorable tower geometry. We were simultaneously encouraged by the PSI management to design a state-of-the-art detector system capable of reaching the 0.2 - 0.3% accuracy level. The ensuing Monte Carlo analysis of systematic uncertainties and detector design took well over a year of effort and resulted in the proposal which was approved by the PSI BV Program Committee in January 1992.

In April 1992, a two-week beam development run in the PIE1 channel using in-beam MWPC's demonstrated that sufficient pion rates could be obtained at 116 MeV/c beam momentum. Two different beam tunes were optimized, yielding a beam spot of about 10 - 12 mm diameter (FWHM), and with emittance of about 35 mr-cm. Combined positron and muon contamination was held under 0.3 using a degrader foil in the beam. We found that an acceptable beam can be achieved without an electrostatic separator, which will simplify the measurements. The properties of the measured beam were close to those used in the Monte Carlo simulations and design of the detectors. Further improvement of the beam spot parameters is possible, once the analysis of the April data is complete.

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2 e)The reaction $\pi^+p \to \pi^+\pi^0p$ near threshold

LAMPF Exp. 1179, R. Minehart, R. Marshall, L.C. Smith, and K. Ziock in collaboration with D. Pocanic (spokesman) et al., and LAMPF and Stanford.

The reaction $\pi^+p \to \pi^+\pi^0p$ near threshold is being investigated at LAMPF in Exp 1179. The goal is to obtain an improved constraint on the I=2 $\pi\pi$ scattering length. When

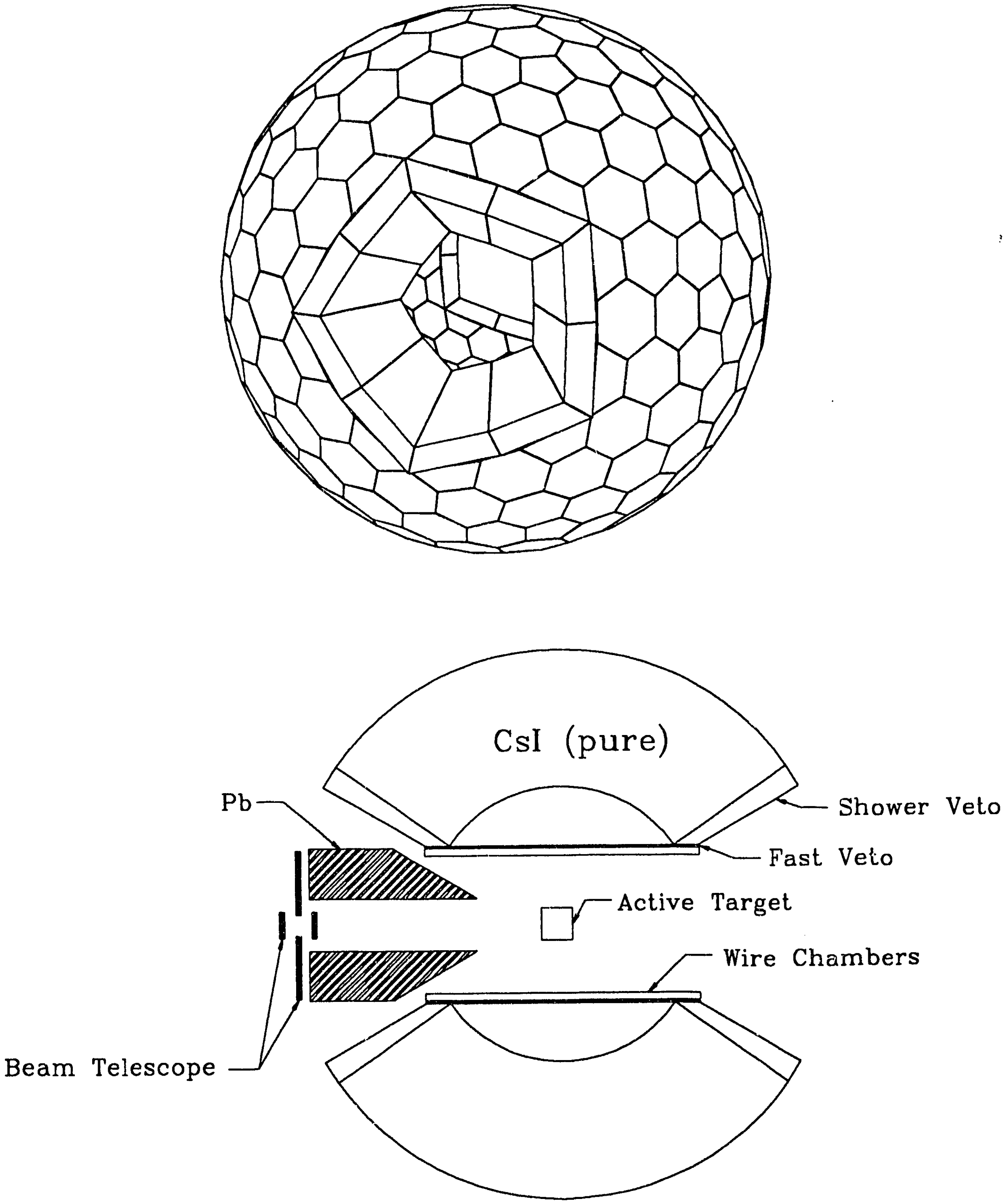

Figure 1. Top: a view of the 240-element pure CsI calorimeter. Bottom: schematic cross section through the $\pi\beta$ apparatus showing approximate locations of major components.

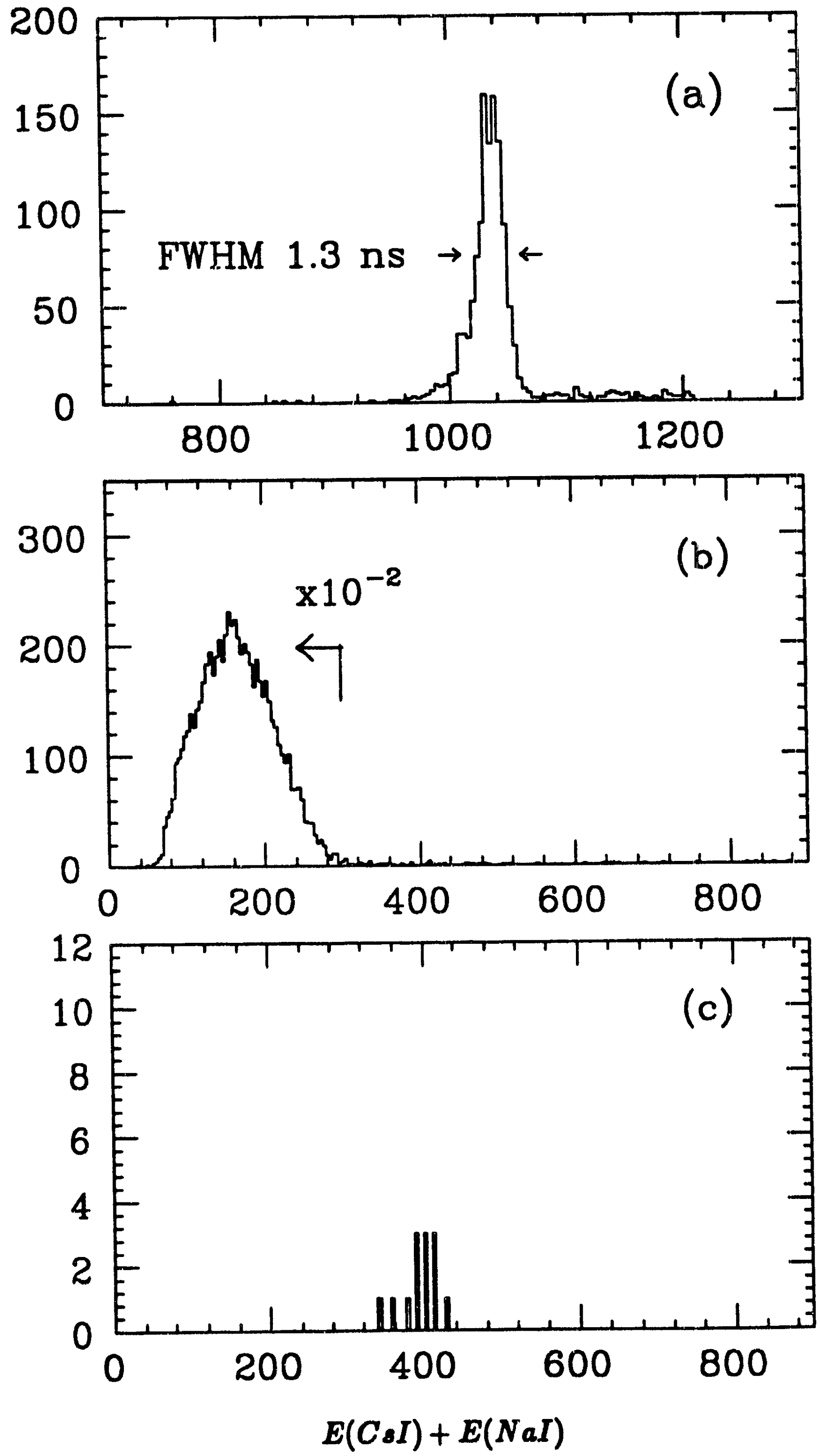

Figure 2. Spectra obtained during the pion beta development run in November 1989 at PSI: (a) timing of a CsI module relative to a plastic scintillator counter (scale: 20 ch/ns), (b) sum energy spectrum of the NaI and CsI arms, including charged particle events, and (c) same as (b) for neutral showers only, exceeding a ≈100 MeV threshold. The energy scale in (b) and (c) is approximately 3 channels/MeV.

combined with data available for other charge states of the pion production reaction the results will permit a more direct isospin decomposition of the $\pi\pi$N threshold amplitudes than previously possible.

Understanding the mechanism of chiral symmetry breaking in strong interactions has remained an open question in medium-energy physics since the initial work of Weinberg[1] and Schwinger[2] in the mid-1960's. At least five different realizations of chiral symmetry breaking have been proposed since[3-9]. They can be constrained through the experimental study of π-π scattering at threshold. Since pion targets are not available, $\pi N \rightarrow \pi\pi N$ reactions are the closest accessible system[1], characterized, however, with considerable difficulties: theoretical above threshold, and experimental very near threshold.

In July 1989 a measurement of inclusive and exclusive cross sections of the reaction $\pi^+p \rightarrow \pi^+\pi^0p$ near threshold was proposed at LAMPF (experiment E1179), in order to obtain a new constraint on the I=2 s-wave $\pi\pi$ scattering length. Combined with data available for the other charge states of the $\pi N \rightarrow \pi\pi N$ reaction, these results will further constrain the global isospin decomposition of the $\pi\pi N$ threshold amplitudes. In addition to the usual soft-pion method, we plan to determine the I=2 $\pi\pi$ scattering length using Chew-Low extrapolation which is free of dynamic model assumptions.

Our experiment uses the LAMPF π^0 spectrometer along with eight E-ΔE scintillation detectors for protons and six E-ΔE scintillation detectors for the charged pions. The target is a specially constructed liquid hydrogen target enclosed in a vacuum chamber with many exit ports to allow the low energy charged particles to emerge in many different directions in a vertical plane that includes the target and beam. Each of the proton counters covers a solid angle of 10 msr and can stop protons of energies up to 180 MeV. The pion detectors are much larger (15 cm x 15 cm at the base), subtending a solid angle of 90 msr, and can stop pions with energies up to 90 MeV. The energy threshold for the charged particle detectors is about 25 MeV for protons and 15 MeV for pions.

The experiment was first run at the end of the summer of 1991. Part of the scheduled run time was lost due to a decision by the laboratory to turn off the accelerator earlier than planned. Measurements were, however, extended to energies below 260 MeV where a target-full background source was found, rendering the inclusive measurements uncertain near threshold. On the other hand, the exclusive channels π^0-π^0 and π^0-p which are measured independently, are free of this problem. The quality of our exclusive data is illustrated in Figure 4 which shows the missing invariant mass spectra at 260 MeV. In a preliminary analysis of the new exclusive measurements we have confirmed the quoted inclusive total cross section at 260 MeV, shown in Figure 3.

The final-pass analysis of the 1991 LAMPF data is in progress. The acceptance, detec-

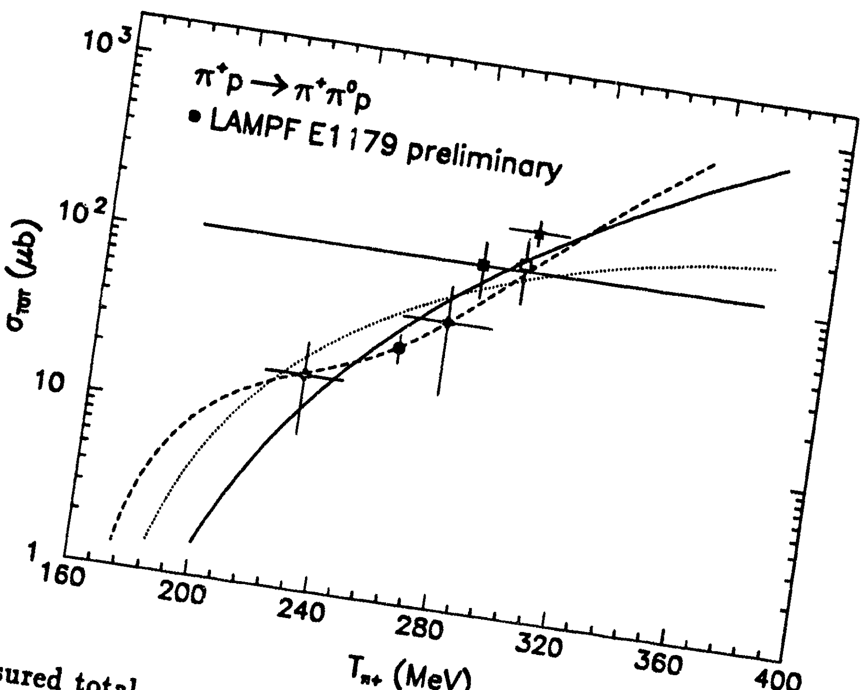

Figure 3. Measured total cross sections for $\pi^+ p \to \pi^+ \pi^0 p$ near threshold. The solid line shows the global fit using four isospin amplitudes [Low-91], including our preliminary point. The dotted line shows the effect of dropping the E1179 data point. The dashed line is a fit with quadratic dependence of amplitudes in total center-of-mass energy.

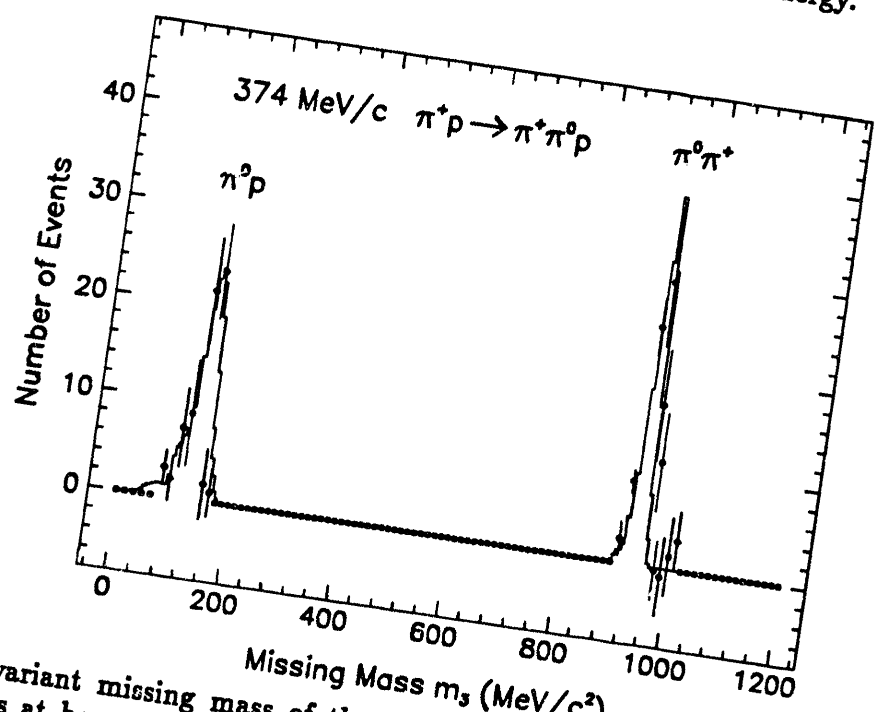

Figure 4. Invariant missing mass of the third particle from the analysis of $\pi^0\pi^+$ and $\pi^0 p$ coincidences at beam momentum 374 MeV/c (preliminary). The timing and particle identification cuts for selection of $\pi^+ p \to \pi^+ \pi^0 p$ events have been applied to the raw data sample. The result of the Monte Carlo simulation is also shown.

tion and tracing efficiency of π^0 spectrometer and charged-particle arm is being understood quantitatively at the few percent level. The full-fledged Monte Carlo simulation of the reaction in the realistic apparatus geometry has been performed using GEANT codes in order to cross-check the standard LAMPF π^0 spectrometer computer codes, giving satisfactory agreement.

The experiment was run again in the summer of 1992. The liquid-hydrogen target vessel was redesigned in order to improve the π^0 detection efficiency. The online analysis of the data has been very encouraging. Although the accelerator operating efficiency was not as high as we had hoped, we will have about 1100 events at 260 MeV and of the order of 100 events at each of the energies, 190, 200, 220, and 240 MeV. The extracted total cross sections with $\approx$10 % uncertainties will cover the energy range sensitive to higher order terms in the phenomenological $\pi\pi N$ Lagrangian, and thus fill the remaining gap in the total cross section data needed for a new and definitive global soft-pion isospin amplitude analysis.

In collaboration with J. Lowe we shall combine our data with the BNL E857 $\pi^- p \rightarrow \pi^0\pi^0 n$ data (9785 exclusive events) in order to determine elastic $\pi\pi$ cross-sections and phase shifts using the method of Alekseeva *et al.* [10] which is based on the well known Chew-Low extrapolation. High-statistics data samples will allow us to study the stability of the results due to different extrapolation procedures. This analysis is particularly important since it is expected to yield much improved model-independent values for the s-wave $\pi\pi$ scattering lengths (especially the I=2 one which is presently determined with $\pm$ 100% uncertainty[10]), and in this way distinguish in a definitive manner between the various realizations of chiral symmetry breaking.

It is possible that our measurements can be improved by using the new NMS spectrometer at LAMPF; it will be evaluated once the 1992 data are analyzed.

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3. Electro-Nuclear Physics.

3 a) Transverse and Longitudinal Response Functions for several nuclei near $Q^2 = 1\ (\mathrm{GeV/c})^2$.

SLAC Experiment NE9, Z. Meziani, spokesman

R. Minehart, J.P. Chen, and L. Chinitz,with collaborators from U. Va., Stanford, Florida State U. and SACLAY.

Because the longitudinal cross section for inelastic electron scattering from nuclei is expected to be small outside the electron- nucleon quasielastic region, it has been thought that quasi-free electron-nucleon scattering models would be especially successful at predicting the longitudinal response function. Measurements[1-3] were made at Bates and SACLAY to obtain the separated longitudinal and transverse response functions for several nuclei ranging from ^4He to Fe. These experiments generally yielded transverse response functions in reasonable agreement with theory, but obtained a longitudinal response signficantly less than the theoretical[4-6] results. The disagreement between theory and experiment has elicited a large variety of theoretical explanations, some of them being rather exotic.

When the longitudinal response function, $R_L(Q^2,\nu)$, is integrated over the energy loss, ν, one obtains the "Coulomb sum rule". Except at low Q^2, non-relativistic calculations predict that the result will be the electric form factor, G_E, of the proton times the number of protons in the nucleus. For ^4He at $Q^2 \approx 6\ \mathrm{fm}^{-2}$, the sum rule is satisfied, but with increasing nucleon number, A, the longitudinal response is suppressed more and more, so that in ^{40}Ca, the data fail to saturate the sum rule by 40%. Data from SACLAY[13] also report a failure at the 30% level for ^4He at Q^2 of 0.5 $(\mathrm{GeV})^2$.

Among the proposed explanations, perhaps the most interesting require modification of the nucleon by the nuclear medium. This approach is illustrated by the work of Celenza *et al.*[7,8] This method can improve the agreement between theory and experiment for the longitudinal response, but at the expense of removing the agreement for the transverse response function. Another approach[9-12] has been to modify the nucleon current through an effective mass. This has had better success in bringing the theory and experiment into agreement, but the explanation of the effective mass is uncertain. A change in the effective mass can be expected to alter the the intrinsic nucleon form factors in nuclear matter, but other factors may also affect the structure of the nucleon in nuclear matter. The Q^2 dependence of the structure functions is therefore an important feature, so that data at higher Q^2 was needed.

In Oct. and Nov., 1987, we measured the quasi-elastic cross sections in the region of $Q^2 = 1\ (\mathrm{GeV/c})^2$ at SLAC using the 8 GeV/c magnetic spectrometer in the SLAC-NPAS facility. Measurements were made on ^3He, ^4He, ^{12}C, and Fe at two angles, 15^0 and 80^0, with incident electron energies ranging from 600 MeV to 4 GeV. A minimum of two angles are needed to make the Rosenbluth separation of the cross section into its longitudinal and transverse parts. Additional measurements were not possible due to the limited time available at SLAC. To minimize the systematic errors, the measurements were all made with the SLAC 8 GeV/c spectrometer.

J.P. Chen, R.Minehart, and Z.-E. Meziani at Stanford, have been working together on the analysis of the data. The analysis of the iron data was published[7] in Phys. Rev. Letters, in March, 1991. The analysis of the helium data was completed this year, and has been published in the Phys. Rev. Letters of July 6, 1992. A copy of the paper is appended to the progress report.

The main results reported in the paper are that on the low energy loss side of the quasi-free peak, the ratio of the reduced longitudinal and transverse response functions is approximately 1, in contrast to results at lower momentum transfer, where the ratio is 1 for ^3He but about 0.75 for ^4He. When plotted against the scaling variable, y, there appears to be a relative shift of the peak positions, with the transverse response appearing to move to relatively higher y values. This shift may be at least partly explained by the contributions at high momentum transfer from exchange currents and pion electroproduction to the transverse response function. Within large uncertainties the Coulomb sum rule is satisfied by our data.

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3 b) Measurements of the Nucleon Spin Structure at SLAC

R. Minehart, L.C. Smith, Todd Averett, and E143 Collaboration

Experiment E143 has been approved for running at SLAC. This experiment is designed to measure spin structure of the proton and neutron using the facilities of End Station A, a polarized electron beam and a polarized target being built by the University of Virginia group under the direction of Don Crabb. A collaboration from Virginia, SLAC, American University, Wisconsin, Basel, CEBAF, Harvard, Livermore, Massachusetts, Michigan, Ohio U., U. Pa., Rochester, Saclay, Stanford, Tel Aviv has been formed to do this experiment. The University of Virginia has taken responsibility for the polarized target, and a graduate student, Todd Averett, working under the supervision of R. Minehart, will be using this project as a thesis project.

The measurements will be made with a beam energy of 22.66 GeV, and will cover the range $0.03 \leq x \leq 1$ at momentum transfers greater than 1 $(GeV/c)^2$. Polarized NH_3 and ND_3 targets will be used. The neutron spin structure will be extracted from the polarized deuteron in the ND_3 target. The results are intended to measure the Ellis-Jaffee[1] sum rule to about 8% for the proton and about 20% for the neutron. The Bjorken[10] sum rule will be measured to about 15%. The main new feature in the measurements will be recent advances in polarized beam and polarized target technology.

By measuring the electron scattering cross sections with longitudinally polarized electrons incident on both longitudinally and transversely polarized nucleons a variety of spin asymmetries can be measured. These asymmetries are differences of cross sections measured with two orientations of the target spin, divided by the sum. Systematic errors tend to cancel out in these ratios, so that the asymmetries, although small, can be measured to high precision. It is possible to extract two spin structure functions, $G_1(Q^2, \nu)$ and $G_2(Q^2, \nu)$ from these measurements. In the scaling region, i.e. large Q^2 and large ν, these functions can be related to the the helicity distributions $g_1(x)$ and $g_2(x)$ for the partons in the nucleon.

Measurements of the spin asymmetry on the proton have been carried out at SLAC and CERN. While a variety of models tend to be in agreement with the experiments in the range of $0.1 < x < 0.7$, the experimental uncertainties are large enough for the the comparisons to be rather inconclusive. In the range $0.01 < x < 0.1$, the EMC[3] results lie below the predictions of all the models. The experiment result, $\int_0^1 g_1^p(x)dx = 0.126 \pm 0.01 \pm 0.015$, from the combined data falls well short of the value, $0.198 \pm .005$ predicted by Ellis and

Jaffee[1].

Also of considerable importance is the determination of the difference integral for the proton and the neutron, known as the Bjorken[2] sum rule,

$$\int (g_1^p - g_1^n)dx = \frac{1}{6}|\frac{g_A}{g_V}|_{n\to pe^-\nu}(1 - \frac{\alpha_s(Q^2)}{\pi})$$

The measurements will be carried out in Area A at SLAC using two non-focussing spectrometers, basically the same as used in Exp. E142, at 4.5° and 7°. The results expected from the measurement are shown in the figures given in the appended proposal. The time needed for check-out and data taking is 3 months. Todd Averett is expected to move to SLAC at the end of the Fall, 1992, term. He will then be supported by this contract for a period of 1 to 2 years, while he is at SLAC.

More details of the experiment and references to the literature may be found in the attached proposal to SLAC.

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3 c) Activities at LEGS

L. C. Smith

Our time-of-flight nucleon detection system remains set up at the Laser Electron Gamma Source (LEGS) at Brookhaven National Lab. This facility creates beams of polarized high energy gamma photons to probe polarization observables in breakup reactions on few-body nuclei. The detector system is part of Virginia's contribution to the LEGS collaboration. An experiment proposed by Rensselaer Polytechnic Institute and which concluded in September measured photodisintegration of ^{3}He over a large range of photon energies up to 300 MeV. The isospin dependence of both two- and three-body breakup modes will be studied and angular distributions of the photon asymmetry (Σ), which is the ratio of the difference to the sum of cross sections obtained with the photon's electric vector parallel and perpendicular to the reaction plane, will be compared to a just completed photodisintegration measurement on the deuteron. Results from that experiment showed that (Σ) is sensitive to the short range behavior of the tensor interaction in models of the nuclear force. Comparisons between ^{3}He and deuterium should be particularly revealing in light of the difference in binding energy. The measurement required detection of both (pp) and (pn) pairs, which was done using an array of phoswich E-ΔE detectors on one side of the beam and on the other side a similar array of the sixteen pairs of neutron detector bars provided by Virginia.

Another LEGS experiment proposed by RPI was conducted in October and November of 1991. This measured the reaction $D(\vec{\gamma},pn)\pi^o$ to study the deviations from the predictions of the spectator nucleon model, particularly those caused by ΔN rescattering. The creation and propagation of the Δ in nuclei is the only way to reach the ΔN interaction. The reaction $D(\vec{\gamma},pn)\pi^o$ is particularly well suited to this purpose since π^o photoproduction proceeds mostly through the delta channel and the requirement of a π^o in the final state ensures that a delta has been formed. Also, theorists are able to calculate the multiple scattering series explicitly in the two nucleon system.

Our activity in this experiment during 1991 involved installation of the neutron bars, setting up the CAMAC electronics and calibration of the data acquisition software, as well as participation in the experimental runs.

3 d) CEBAF Experiments

R. Minehart, R. M. Marshall, L. C. Smith, T. Averett

Several proposals for an extensive program to study electroproduction of nucleon resonances with the proposed 4π CLAS detector were approved by the first CEBAF Program Advisory Committee meeting. R. Minehart was co-spokesman for three of these. During the past year, another proposal, the study of inclusive polarized electron scattering from polarized NH_3 and ND_3 targets was proposed and accepted by the PAC.

Identification of the scattered electron is an important requirement of the CLAS detector. This identification will require a combination of a threshold Cerenkov detector and a total absorption electron calorimeter. The CLAS is building an electron calorimeter for the forward angle region, $\theta < 45^0$, that will also be useful for detection of photon pairs (for π^0 and η detection) and neutrons. The calorimeter is called the electron-gamma-neutron (EGN) detector.

The calorimeter is made of alternating layers of lead and scintillator. It has a triangular cross section and is approximately 14 r.l. thick. Each scintillator layer consists of strips approximately 10 cm wide and 1 cm thick running parallel to one side of the triangle. Successive layers consist of scintillator strips parallel to successive sides of the triangle. The read-out system will permit the shower to be localized to a triangular cell approximately 10 cm on a side formed by the intersections of the three scintillator orientations. This scheme can resolve two particles in the same detector and measure the energy deposited by each. The calorimeter should provide an energy resolution of about $8\%/\sqrt{E(GeV)}$. The U.Va. group, primarily R. Minehart, R. Sealock, and R. Marshall, took on the major responsibility for the construction and testing of a prototype version of this detector, which was successfully tested at the Brookhaven National Laboratory in the spring and summer of 1990.

3 e) Scintillator measurements

A laser-driven gain calibration and monitoring system to be used in the evaluation of the CEBAF EGN calorimeter scintillators is under development at the University of Virginia. The complete setup will be able to measure simultaneously the positional dependence of light-collection efficiency of as many as six scintillators of varying lengths (up to 3 meters). The system is depicted schematically in Figure 5.

A nitrogen laser is used as a pulsed light source. The laser has a peak power of 250 kW in a 300 psec pulse and a maximum repetition rate of 10 Hz. The output wavelength of the laser is 337.1 nm.

The laser pulses are transmitted via an optical fiber with a quartz core of diameter 1 mm, then fanned out to 30 optical fibers of core diameter 400 microns. Twenty-nine of the 400-micron fibers feed into shutter/splitter systems and the remaining fiber is used for monitoring by a photodiode, providing a stable pulse-by-pulse measurement of the laser light output.

There are 29 shutter/splitter systems consisting of a solenoid-activated shutter and a Bakelite housing with one 400-micron fiber coming in and six 400-micron fibers fanning out. The solenoids are computer-controlled to pull the shutter out of the light path between the incoming and outgoing fibers. For each shutter/splitter system, the six outgoing fibers vary in length and are mounted on an aluminum bar such that each will illuminate a different scintillator. Up to six scintillators may be placed above the aluminum bar at one time. The complete system has 29 such aluminum bars placed at 10 cm intervals along a long scintillator to measure the positional dependency of light-collection efficiency.

3 f) Development of Electronics for the EGN Detector

W. Stephens

W. Stephens is developing the electronic circuitry to split the signal from each EGN

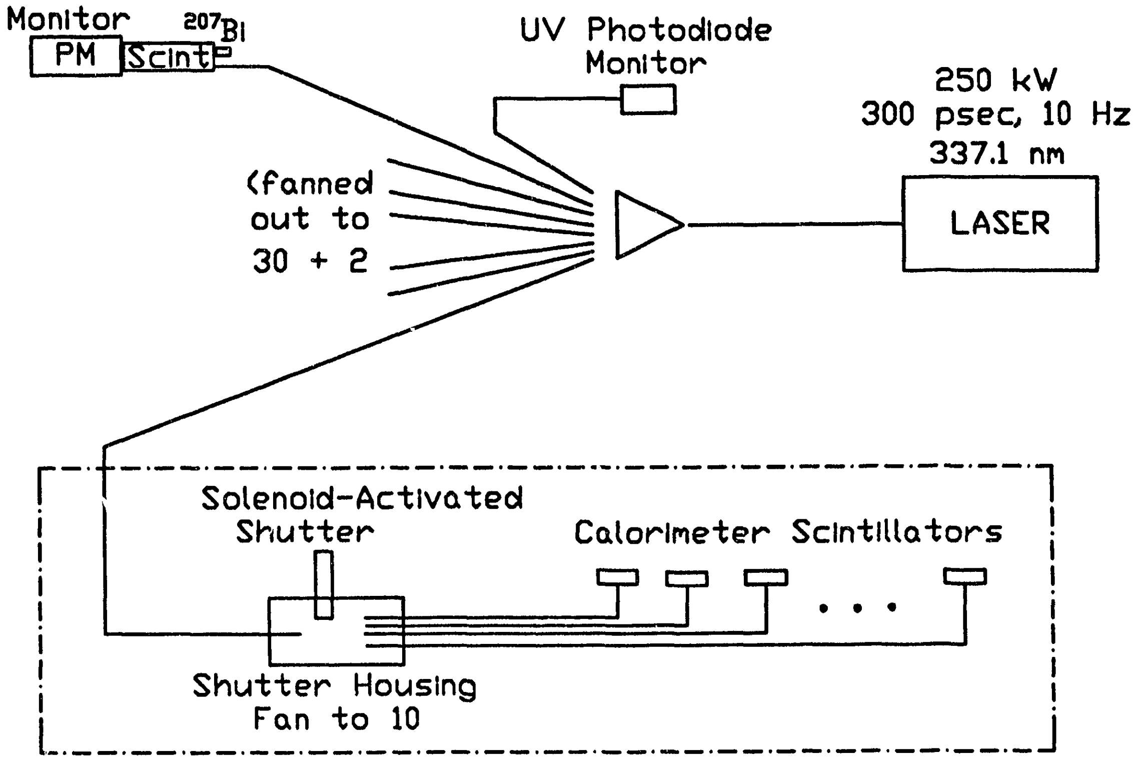

Figure 5. Schematic diagram of the laser-driven gain calibration system for the CEBAF EGN calorimeter

photomultiplier into three signals, one that can be used to measure the time of the signal, one that can be used to measure the pulse height, and one that can be used in another circuit he is developing to to form a total energy signal for incorporation into the CLAS Level 1 trigger.

The proposed signal splitter is shown in Figure 6. The signals are first split at the photomultiplier anode. One signal is sent to the TDC discriminator, whose output will be used to determine the timing of the signal. The other signal is split again in a splitter box, with one output used for amplitude measurement in an ADC, and with another for use in the energy summing amplifier that we will describe in the next paragraph.

The Level 1 trigger will be used to make fast decisions on whether an interesting event has occurred. It is intended that this level be completed within 50-100 nsec after the electron interaction in the target. The Level 1 decision will include a test on the energy deposited in the EGN calorimeter. For this test each sector will be considered independently. The energy deposited in a sector will be determined by adding the outputs of all the photomultiplier tubes in the forward portion of the detector. Since there are 108 tubes per sector, summing their outputs presents some non-trivial challenges.

First, it is necessary to take into account that the signals from each photomultiplier will not be simultaneous. With some of the bars being as long as 4.5 m, the time spread can be as great as 30 nsec. Thus, some integration to keep the early pulses from drooping while waiting for the late pulses is required. On the other hand this integration is limited by the need to operate the system at event rates up to 2 MHz. The need for high rates dictates the use of DC coupling so that base lines can be restored quickly.

Second, the summed noise from 108 tubes can be overwhelming when there is only one actual signal. This problem is exacerbated by the large dynamical range (20:1) in the size of the energy signal. The most serious noise problem is coherent low frequency noise (60 Hz, switching power supplies, etc.) which with DC coupling will be multiplied by a factor of 108 if all tubes were summed in a simple way.

The circuit that we are developing is shown in Figure 7. Six photomultiplier signals are combined in a summing amplifier and the outputs of six of these are again taken to another summing amplifier, to give a total sum of 36 photomultiplier signals, which is the total number along one edge of a sector. Resistors can be used to select only a fraction of each signal in the final sum of six. In this way we can compensate for the fact that long scintillators will tend to suffer more signal attenutation than short ones, and thereby achieve an output signal more nearly proportional to the shower energy. The summing amplifier is a Comlinear CLC404, a current feedback amplifier that has a very high bandwidth independent of gain. A shorted delay line is used to provide a reflected signal out-of-phase and delayed by

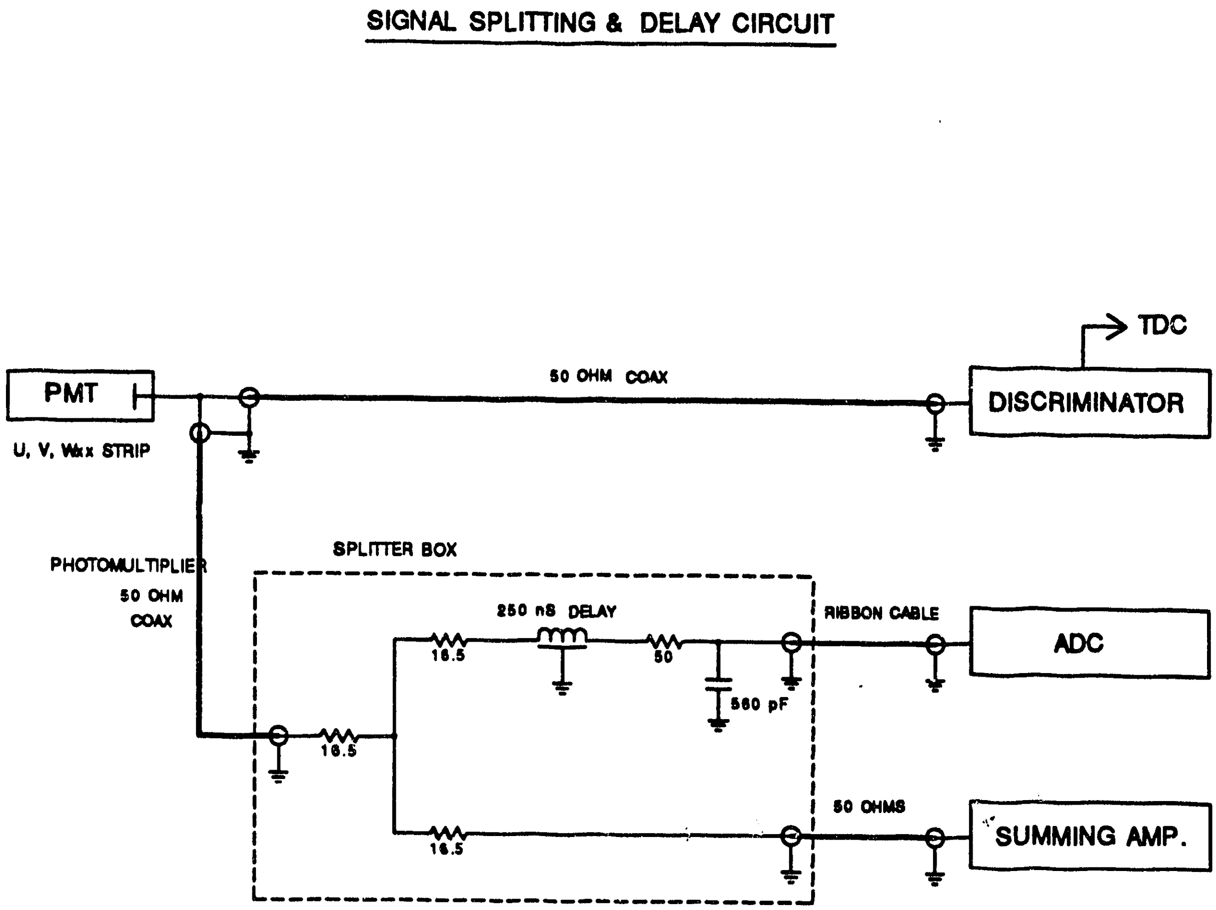

Figure 6. Schematic of the proposed signal splitter.

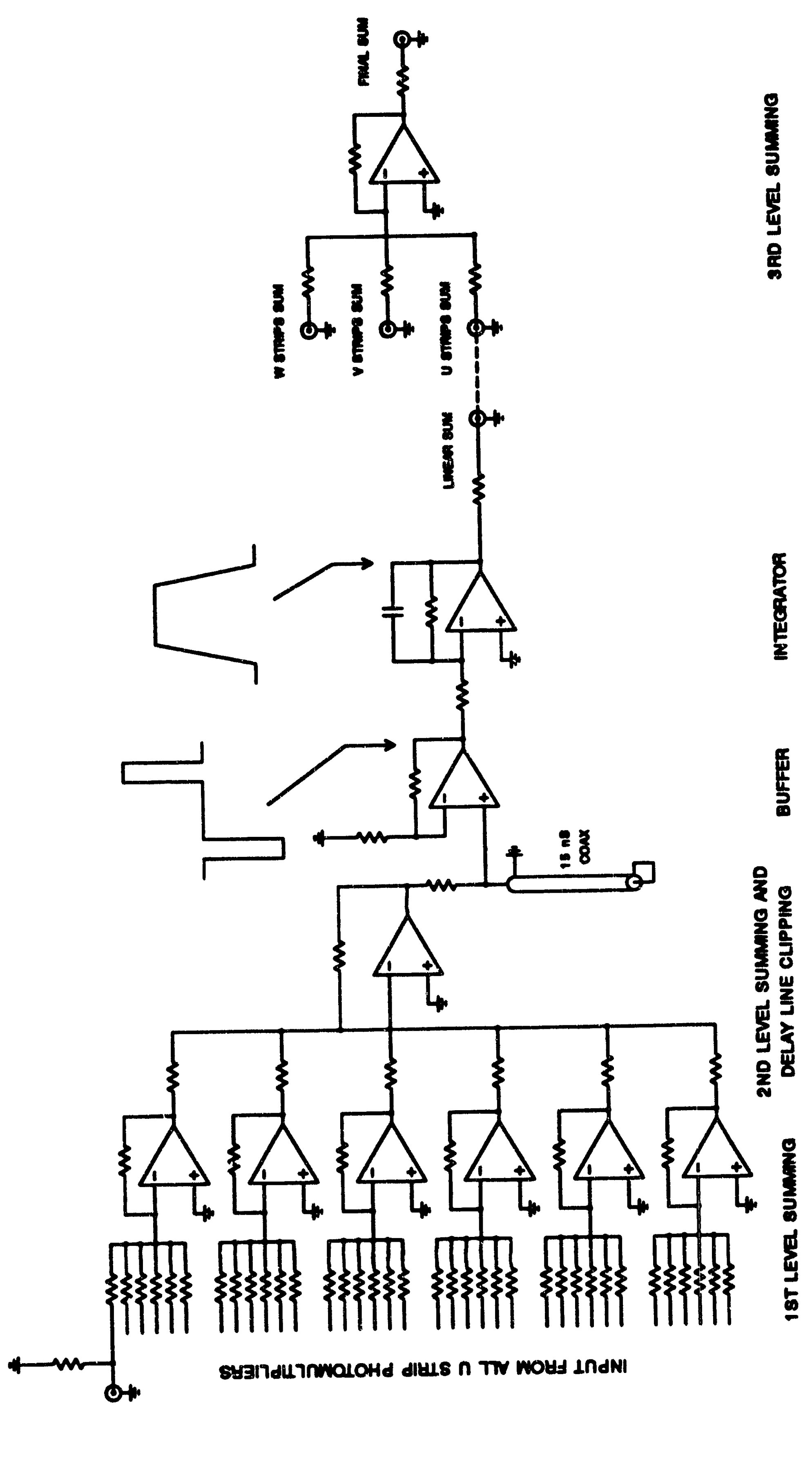

Figure 7. Energy summer for the Level 1 Trigger.

30 nsec relative to the direct signal. The inverted reflection will restore the base line at the output of the amplifier. This delay line also progressively attenuates noise as it decreases in frequency below 10 MHz. After passing through a buffer amplifier, the signal and its delayed reflection are integrated in a CLC420 op-amp circuit that gives a stretched signal of 30 ns duration. Finally, the output of this circuit is summed with two other outputs, which are the sums of the signals from the other two sides of the EGN triangular detector, and which will overlap in time because of the signal stretching.

We have also examined the question of how best to delay the signals to the ADC's and TDC's, which must be held back for approximately 250 ns to allow time for the trigger signal to be generated and returned to the ADC and TDC gate inputs. A brute force method is to use a long cable for each signal. This involves an enormous amount of cable and non-trivial expense. We have found an economical solution for the ADC delay based on the use of commercial lumped delay lines. It also may be possible to take the TDC signal directly to an ECL discriminator. The output of the discriminator, which is on a wire pair, can be coupled with a BALUN transformer to relatively inexpensive 100Ω coaxial cable and then recoupled by another BALUN transformer to the ECL input of the TDC circuits. This technique should give timing resolution of the order of 250 ps, which should be adequate for the EGN detector.

CEBAF is providing some funds to cover incremental costs of these projects. This includes funds for undergraduate summer students to measure scintillator properties, and funds for the proto-type electronics.

3 g) Development of computer programs for nucleon resonance study.

Todd Averett, a Virginia graduate student, spent last summer incorporating amplitudes for resonant excitation of neutrons into a program developed at CEBAF. This program calculates amplitudes and cross sections for electroproduction of mesons from the nucleon. It has been shown by Volker Burkert at CEBAF to give a realistic representation of existing data for a proton target. The calculation includes Breit-Wigner resonance terms and Born amplitudes for single meson production. When it works satisfactorily for free neutrons, we plan to combine the proton and neutron amplitudes via the Hulthen wave function into a realistic calculation for electroproduction on the deuteron.

The program is being used extensively to help with the design of polarization measurements in CLAS, proposals which we had hoped to be ready for last fall's PAC. However, it turned out that the measurements were rather complex so that additional study was required. Following calculations made during the winter and spring of 1992, it now appears that measurement of polarized production of exclusive π^0 production will be very sensitive at testing the presence of small components, such as the Roper amplitudes, in the electroproduction of nucleon resonances. We now hope to prepare a proposal for the next PAC meeting in 1993. This project is expected to be coordinated with activities of Henry Weller's group at Duke. They will concentrate on the study of charged pion production.

4. Talks

1."Nucleon Structure Program at CLAS", R. C. Minehart, Duke University Seminar, April, 1992.

5. Publications

1."High Momentum Transfer $R_{T,L}$ Inclusive Response Functions for ^{3,4}He", Z.-E. Meziani, J.P. Chen, D. Beck, G. Boyd, L.M. Chinitz, D.B.Day, L.C. Dennis, G.E. Dodge, B.W. Fillipone, K.L. Giovanetti, J. Jourdan, K.W. Kemper, T.Koh, W. Lorenzon, J.S. McCarthy, R.D. McKeown, R.G. Milner, R.C. Minehart, J. Morgenstern, J. Mougey, D. H. Potterveld, O.A. Rondon-Aramayo, R.M. Sealock, I.Sick, L.C. Smith, S.T. Thornton, R.C. Walker, and C. Woodward, *Phys. Rev. Letters*, **69**, 41 (1992).

2. "Nuclear Structure functions at x> 1", B.W. Filippone, R.D. McKeown, R.G. Milner, D.H. Potterveld, D.B. Day, J.S. McCarthy, Z. Meziani, R. Minehart, R. Sealock, S.T. Thornton, J. Jourdan, I. Sick, Z. Szalata, *Phys. Rev. C*, **45**, 1582 (1992).

3." Measurement of the reaction ^{4}He(π^+,pp)pn at T_π=500 MeV", L.C. Smith, R.C. Minehart, D. Day, R. Lourie, R.M. Marshall, J. McCarthy, R. Sealock, S.T. Thornton, B.G. Ritchie, K. Giovanetti, K. Baker, D. Tedeschi, Abstract and paper submitted to the Few Body XIII, Adelaide, Australia, Jan 6-11, 1992.

4. "Polarization in Photonuclear Reactions on ^{3}He", G.S. Adams, H. Baghaei, A. Caracappa, W. Clayton, A. D'Angelo, M-A. Duval, S. Hoblit, R. Lindgren, G. Matone, L. Miceli, W.K. Mize, M. Moineser, C. Ruth, A.M. Sandorfi, C. Schaerf, R. M. Sealock, L.C. Smith, P. Stoler, D.J. Tedeschi, P.K. Teng, C.E. Thorn, S.T. Thornton, K. Vaziri, C.S. Whisnant, E.J. Winhold, abstract submitted to Gordon Conference on Photonuclear Reactions, August, 1992.

5. "Neutral Pion Production on Deuterium with Polarized Photons away from Quasifree Kinematics", G.S. Adams, H. Baghaei, A. Caracappa, W. Clayton, A. D'Angelo, S. Hoblit, T. Kobayashi, R. Lindgren, L. Miceli, C. Ruth, A.M. Sandorfi, C. Schaerf, R. M. Sealock,L.C. Smith, P. Stoler, D.J. Tedeschi, C.E. Thorn, S.T. Thornton, K. Vaziri, C.S. Whisnant, E.J. Winhold, abstract submitted to Gordon Conference on Photonuclear Reactions, August, 1992.

6."Measurement of Polarized Structure Functins in Inelastic Electron Proton scattering using

the CEBAF Large Acceptance Spectrometer", by the N* collaboration, submitted to Baryons '92, June 1-4, 1992, New Haven, CT.

7. "Measurements of the Transverse and Longitudinal Response Functions for ^{3}He and ^{4}He at q near 1 GeV/c", J.P. Chen, L. Chinitz, D. Day, K. Giovanetti, J.S. McCarthy, R.C. Minehart, O. Rondon-Aramayo, R.M. Sealock, L.C. Smith, S.T. Thornton, Z.E. Meziani, G. Dodge, D. Beck, G. Boyd, B.W. Filippone, J. Jourdan, R.D. McKeown, R.G. Milner, D. Potterveld, R. Walker, C. Woodward, L.D. Dennis, K.W. Kemper, W. Lorenzon, I.Sick, J. Morgenstern, and J. Mougey. Abstract submitted to the Annual Fall Meeting of the American Physical Society, Division of Nuclear Physics, 24-26 October, 1991.

8. "Reaction $\pi^+ p \rightarrow \pi^+ \pi^0 p$ at 375 MeV/c", D. Počanić, E. Frlež, K.A. Assamagan, K.J. Keeter, R.M. Marshall, L.C. Smith, W.J. Cummings, G.E. Dodge, S.S. Hanna, B.H. King, S.E. Kuhn, J.D. Bowman and J.N. Knudson, *Bull. Am. Phys. Soc.* **36**, 1274 (1991).

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