Technical Progress Report
of the
Indiana University Spark Chamber Group[†]
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The Indiana Spark Chamber Group recently completed the running of a series of experiments at the Argonne National Laboratory ZGS to study the A_2 meson. The A_2 experiments involve a measurement of the missing-mass spectrum and proton polarization in $\pi^\pm p \rightarrow X^\pm p$ in the A_2 region at 4 BeV/c, and the rare $K\bar{K}$ decay mode of the A_2^- . Other major activities of the group during the current fiscal year include collaborative efforts at SLAC and the Brookhaven AGS. The SLAC experiment uses an optical spark chamber spectrometer in conjunction with the SLAC Rapid Cycling Bubble Chamber (RCBC) to study $\pi^+ p \rightarrow X^{++} n$. In addition, a proposal has been submitted to SLAC to study double charge exchange (DCEX) in reactions $K^- p \rightarrow \text{forward } \pi^+, p, \text{ or } K^+$ using the RCBC and a wire spark chamber spectrometer. The Brookhaven experiment, now in progress, is studying the threshold production of A_2 's, δ 's and R's.

The A_2 missing-mass experiment began tuning in September, 1971 after a three-month installation. This ZGS experiment, E-266, utilized a wire spark chamber magnetic spectrometer to analyze the final-state proton in the reaction $\pi^\pm p \rightarrow pX^\pm$. The momentum and direction of the incident π was measured with eight multiwire proportional chambers. The momentum resolution of the beam π had a FWHM of .4%. A gas cerenkov counter in the beam distinguished pions from heavier beam particles. The group's PDP-15 computer monitored the operation of the scintillators and chambers, on-line. More than 200,000 events, with X masses from 1.2 to 1.43 BeV, have been analyzed. Most of these data were collected during the A_2 polarization experiment, E-307, discussed below. The mass resolution for the mass of X has a standard deviation of about 4 MeV. We plan to publish these data soon.

The rare $K^- K_L^0$ decay mode of the A_2^- was studied by using a second magnetic spectrometer to analyze the K^- in $\pi^- p \rightarrow p K^- K_L^0$. This phase of our experiment was expeditiously performed during December, 1971. A novel trigger, never used previously, selected the $K^- K_L^0 p$ final state with $\geq 98\%$ efficiency while suppressing triggers due to other $\pi^- p$ interactions by about four orders of magnitude. The actual trigger rate was within 25% of our expected trigger rate. We purposely allowed a few triggers from $\pi^- p \rightarrow \pi^- p$ so that we would have a continual check on the performance of our spectrometers from the four-constraint measurement of this reaction. We expect to have about 500 $A_2^- \rightarrow K^- K_L^0$ events. The A_2 mass resolution, determined by our proton spectrometer, will be about 4 MeV. The analysis of these data will continue into the next calendar year. We do have some examples of elastic scattering and $A_2 \rightarrow K\bar{K}$ events; however, the software is yet not ready for production-type analysis on the Indiana University CDC 6600 computer.

In December 1971 the group began experiment E-307 at the Argonne National Laboratory ZGS. The purpose of this experiment was to make a study of the recoil proton polarization in the reaction $\pi p \rightarrow p X$ over several mass intervals from M_X equal to 900 up to 1600 MeV. We wished to determine the missing-mass variation of the recoil proton polarization at fixed values of t . Some theories predict that the variation of the inclusive polarization with missing mass could be small, even as the missing mass varied through resonances such as the A_2 meson. The polarization is predicted to be comparable in magnitude to the elastic polarization in $\pi p \rightarrow \pi p$. Moreover, some models for the A_2 production process lead to the prediction that

the recoil proton polarization would exhibit a t behavior similar to that of πp elastic scattering, with maxima, minima and double zeroes at well-defined values of t and with the A_2^+ and the A_2^- cases possessing mirror symmetric polarizations. Our data will allow some features of these models to be tested. The main effort in this experiment was spent in studying the recoil proton polarization in the A_2 mass region. We hope to determine a limit on the proton polarization in the reaction $\pi p \rightarrow A_2 p$ and to determine if any significant asymmetry exists in the polarization corresponding to the two "sides" of the A_2 . Over the A_2 mass region we anticipate having polarization measurements for $.2 \leq |t| \leq .5 \text{ (GeV/c)}^2$ at approximately eight mass points with an accuracy of $\pm .03$ per point.

Polarization data were taken in the A_2 region, as mentioned above, and in the δ , ρ and R regions. In addition, calibration data were taken utilizing the reaction $pp \rightarrow pp$ at 1.4 GeV/c. At the present all of the basic analysis routines have been written and checked and the production phase of the analysis is underway. It is anticipated that the analysis of the data will be completed in a few months.

The instrumentation for experiment E-307 consisted of a carbon polarimeter in addition to the equipment used in experiment E-266. The carbon polarimeter was added after the downstream element of the proton arm of experiment E-266. The polarimeter consisted of four graphite plates, each being followed by two wire spark chambers with magnetostrictive readout. The same trigger logic used in E-266 was employed in E-307. Indeed, experiment E-307 should be viewed as an extension of E-266 during which information about the proton spin

was recorded.

An experiment to utilize the SLAC 15-Inch Rapid Cycling Bubble Chamber to study baryon exchange processes has been approved by the SLAC Program Committee and scheduled for execution in the fall of 1972. The experiment (SLAC #82) will be a collaborative effort by Indiana University, SLAC, Purdue University and Vanderbilt University. Both the Spark Chamber and Bubble Chamber Groups at Indiana are involved in this experiment.

The principal interest of the experiment is the examination of baryon exchange processes which produce a forward going neutron. The forward neutron is detected in neutron counters and chambers which are placed downstream of the rapid cycling chamber. The reaction is $\pi^+ p \rightarrow X^{++} + n(\text{forward})$ for $p_{\text{Lab}} = 5$ and 10 GeV/c. Events of this class are selected by a fast logic counter system. A search for resonances in the manifestly exotic X^{++} system will be of particular interest. The yield of events within the system's fiducial volume will be 144 events/ μb at 5 GeV/c and 276 events/ μb at 10 GeV/c.

The Indiana University Spark Chamber Group has had primary responsibility for the spark chamber and counter components for this experiment. During the present contract year all required neutron counters and spark chambers were designed and fabricated. Test runs of the experiment are scheduled for brief periods in August and September. The main data acquisition run should occur in November and will require approximately two weeks. The film from the 15-inch bubble chamber will be measured at Indiana University on its PEPR Facility. An additional experiment using the RCBC is now under consideration. This experiment would search for the production of exotics in $K^+ p$ reactions using similar techniques.

The second SLAC experiment, a collaborative effort between the Indiana Spark Chamber and Bubble Chamber Groups, will utilize the RCBC to study the DCEX reactions

$$\begin{aligned}
 K^- p &\rightarrow \pi^+ \Sigma^- \\
 &\rightarrow \pi^+ \Sigma^- (1385) \\
 &\rightarrow K^+ \Xi^- \\
 &\rightarrow K^+ \Xi^- (1530) \\
 &\rightarrow p K^- \\
 &\rightarrow p K^{*-} (890).
 \end{aligned}$$

The beam momentum will be 6 BeV/c. There is considerable theoretical interest in these "exotic" exchange reactions. The exchanged particle, or Regge trajectory, has a charge +2, strangeness +1 or +2 and baryon number 0 or 1. To study these reactions, a wire spark chamber magnetic spectrometer downstream of the RCBC will detect a fast, forward, positive particle and inform the RCBC that its lights should be flashed. The negative particle will be analyzed in the RCBC. We expect to obtain about 1000 events/ μb , in the interval $0 \geq t \geq -.45 (\text{BeV}/c)^2$, for each reaction. A proposal has been submitted to SLAC. We plan to run this experiment in summer or fall, 1973.

Brookhaven AGS Expt. 570 is a collaboration among BNL (Kalbfleisch & Vanderburgh), Rutgers (Alspector, Cohen, Harrisson, Maglich, & Sannes), Upsala (Oostens), and Indiana (Ankenbrandt). The experiment is a high-statistics, high mass resolution study of the threshold production properties of mesons (A_2 , δ , R , etc.) in $\pi^\pm p$ interactions. Much of the apparatus is that of Expt. 528, a prior Rutgers-BNL collaboration; hence preparation for E-570 was simplified.

About 100 hours of scheduled running was completed in June, 1972

to test and tune the apparatus and to acquire data in the A_2^+ and A_2^- mass regions. Further approved running, likely to occur in fall and winter, 1972-1973, will be used to look at other mass regions as well as to improve statistics in the A_2 region.

Two years ago the group proposed a ZGS experiment (E-280) to make a high statistics study of the polarization parameter in p-p scattering at high momenta and large angles. Because a new technique was to be employed, that of utilizing a polarized proton target in an external proton beam, the experiment required a significant modification of an existing beam line. This modification, which was scheduled to take place during the six-month ZGS titanium vacuum tank shutdown, is now essentially complete. Installation of the experimental equipment is scheduled for September, 1972 and the data taking phase is expected to begin in November, 1972.

At present the polarization in p-p elastic scattering has been measured only over the t range $0 \lesssim -t < 3(\text{GeV}/c)^2$. The limitation on extending the measurements to high $|t|$ values has been the attendant lower cross sections and the unavailability of proton beam intensities of greater than a few million protons per second for such measurements. We propose to conduct measurements, not in a secondary proton beam as has been done in all previous polarized target p-p polarization experiments, but in an external proton beam. It is anticipated that beam intensities of up to 5×10^{10} protons per second can be utilized in the experiment without difficulty. This gain of a factor of $\sim 10^4$ in intensity will allow us to make high accuracy measurements over the entire t region $0 \lesssim -t < 10(\text{GeV}/c)^2$ while maintaining a good rejection factor for inelastic and quasi-elastic events.

Even over the limited t range $0 \lesssim -t < 3(\text{GeV}/c)^2$ the p-p polarization has exhibited remarkable structure. Minima in the polarization have been discovered near $t = -1(\text{GeV}/c)^2$ and near $t = -2.5(\text{GeV}/c)^2$. These t values correspond also to the values at which slope changes in the fixed angle cross section have been observed by us in a previous experiment (ZGS experiment E-199). This enhances our original speculation that breaks in the fixed angle cross section are closely correlated with structure in the polarization. A high statistics systematic study of the polarization in p-p elastic scattering over the proposed t range $0 \lesssim -t \lesssim 10(\text{GeV}/c)^2$ may provide some insight into the mechanism of slope changes in the fixed angle cross sections. The polarization in the region of $t = -7(\text{GeV}/c)^2$ will be of special interest because of the dramatic break in the 90° cross section observed by Akerlof, *et al* (Phys. Rev. 159, 1138 (1967)) near this t value. Moreover, our measurements are expected to provide crucial tests for several phenomenological models. One model, developed by Chu and Hendry, is able to account well for the existing p-p polarization and cross section data and it makes definite predictions about the behavior of the p-p polarization over the entire angular region. If the prediction of this model over the rather vast unexplored t region is found to be correct, unprecedented success toward understanding the basic parameters of p-p elastic scattering will have been attained.

The experiment will utilize a butanol polarized proton target. Measurements will be made at the momenta 3.0, 5.0, 7.0 and 12.5 GeV/c at ~ 12 c.m. angles between 30° and 90° . The typical statistical error in the polarization will be ± 0.1 . The scattered protons will

be momentum analyzed in a two-arm proportional chamber spectrometer. A PDP-15 on-line computer system will be used to monitor all phases of the experiment.

During the present contract year all design work for the experiment was completed. The construction and testing of the required proportional chambers and the scintillation counters is in progress. Hardware has been designed and constructed to allow our on-line computer system to exercise a high level of monitoring and control of the polarized proton target system.

The experiment has been scheduled to run at the Argonne ZGS over the period November, 1972 through March, 1973. It is anticipated that approximately four months of time will be required to finish the data analysis after the completion of the experimental run.

During the present contract year the final publication associated with our ZGS experiment E-235 was completed. This experiment resulted in a comprehensive set of data on π^+p elastic scattering at intermediate angles from 3.0 to 5.0 GeV/c. The article will appear in the journal Nuclear Physics (H. W. Paik, et al., Intermediate angle π^+p elastic scattering from 3.0 to 5.0 GeV/c, COO-2009-32).

There are five faculty members associated with the Indiana Spark Chamber Group. They are Asst. Prof. C. M. Ankenbrandt, Assoc. Prof. B. B. Brabson, Prof. R. R. Crittenden, Prof. R. M. Heinz, and Prof. H. A. Neal. They devoted 100% of their time during two summer months and 40% of their time during the academic year to this project. There is one faculty-level research scientist, D. Rust, who joined the group August 1, 1972. Beginning December 1, 1972 eighteen percent

of his salary will be paid by the AEC contract. (Indiana University provides the remaining support for Dr. Rust.) The university also contributes a research physicist (J. Krider) and a technician (B. Martin) to the group. The group has, at present, one postdoctoral associate, S. I. Levy. He replaces our previous postdoc, A. J. Pawlicki, who is now employed at the Argonne National Laboratory ZGS. There are two graduate students, G. Abshire and M. Alam, working with us. The group recently hired an electronics engineer, S. Ems, using funds from a departmental NSF Science Development Program renewal. The SDP also financed floating point hardware, a disc, and additional core for our PDP-15 on-line computing facility as well as a computer-electronics trailer. Prof. Crittenden is spending the 1972-73 academic year on sabbatical leave at the Los Alamos Meson Physics Facility. Prof. Neal currently serves on the Board of Trustees of Argonne Universities Association and is chairman of the Board's Committee on High Energy Physics.