TECHNICAL PROGRESS REPORT
OF THE

INDIANA UNIVERSITY SPARK CHAMBER GROUP*

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During the year beginning Dec. 1, 1975 the activities of the Indiana high energy physics group were almost exclusively dedicated to executing various phases of four experiments initiated during previous contract years. Our SLAC effort, E103, involves a sensitive search for exotic mesons produced in non-exotic exchange reactions. At the internal target area of Fermilab we are measuring the polarization parameter for p-p elastic scattering. Also at Fermilab we are actively participating in the Multiparticle Spectrometer experimental program in the M6W beam line. Finally, we are searching for charmed particles produced at the CERN SPS. In addition, we are beginning to plan for an experiment at the PEP storage rings. A discussion of these projects follows, in rough chronological order.

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SLAC E103

The Exotic Meson Search, SLAC experiment E103 (Indiana, Vanderbilt, Purdue, SLAC), is designed to utilize the SLAC Streamer Chamber Facility together with a forward proton spectrometer to search in depth for backwards produced doubly-charged exotic mesons. Data were recorded for the six processes:

a) $\pi^- d \rightarrow p(\text{fwd}) + \dots$	160,000 pictures
b) $\pi^- d \rightarrow \pi^+(\text{fwd}) + \dots$	45,000 pictures
c) $\pi^+ d \rightarrow \bar{p}(\text{fwd}) + \dots$	12,000 pictures
d) $\pi^+ d \rightarrow \pi^-(\text{fwd}) + \dots$	18,000 pictures
e) $\pi^- p \rightarrow p(\text{fwd}) + \dots$	8,000 pictures
f) $\pi^- p \rightarrow \pi^+(\text{fwd}) + \dots$	4,000 pictures

at an incident beam energy of 14 GeV/c. The primary goal of this experiment is to study in detail the doubly charged system X^{--} in the reaction

$$\pi^- d \rightarrow p(\text{fwd}) + X^{--} + P_{\text{spectator}}$$

The data collection was completed between May 15 and July 15, 1975. Streamer chamber film measurement began immediately at both Indiana (PEPR) and Vanderbilt (hand machines). As of July, 1976, approximately 50% of the film had been measured. We estimate that the remainder of the measuring will be completed by February, 1977.

During the fall of 1975, a streamer chamber data analysis system was assembled at SLAC utilizing the SLAC computing complex. The hydrogen target events (from reactions e and f above) were measured on the Indiana PEPR and used to debug the analysis programs. By Spring, 1976, a larger sample of measured events on deuterium (~ 20% of total) were analyzed and preliminary results were reported at the APS Washington meeting.¹ No statistically

significant peaks were observed in exotic meson mass spectra at this stage in the analysis. However, the appearance of several well-known resonances assures us that the analysis procedure is correct.

Recently, we have implemented programs to exploit data from the proton spectrometer. The hybrid nature of E103 enables us to determine a missing mass off of the forward fast particle, and to examine in detail in the streamer chamber those events in a particular missing mass interval. One of the principal contributions of the Indiana group to the analysis system has been the joining of the downstream spectrometer data to streamer chamber measurements.

By the end of the contract year (November 30, 1976) we anticipate that results of the analysis of the majority of the exotic reactions a and c above will be published. These results will include a statement about exotic meson production at approximately the $0.1 \mu\text{b}$ level. (The cross section for backward exotic meson production is predicted to be comparable to the backward production for nonexotic mesons, about $\frac{1}{4} \mu\text{b}$ at 16 GeV/c incident momentum.)

FNAL E313

In June, 1974 the Indiana University High Energy Group received approval to conduct an experiment in the Internal Target Area at Fermilab to study spin effects in proton-proton interactions at high energies. Installation and testing of the apparatus required in this experiment formed one of the major efforts of the Group during the present contract year.

The experiment utilizes a hydrogen jet target, a superconducting magnetic spectrometer, and a sophisticated carbon polarimeter. Recoil protons from elastic p-p scattering are momentum analyzed in the spectrometer and spin analyzed in the carbon double scatterer. Elastic polarization will be measured

for $20 \text{ GeV}/c < p_{\text{LAB}} < 400 \text{ GeV}/c$ for $|t|$ between 0.2 and $2(\text{GeV}/c)^2$. The statistical accuracy at the smaller $|t|$ values will typically be $\sim .75\%$. The capability of pulsing the jet at arbitrary points along the machine ramp permits an extensive fixed- t variable p_{LAB} study to be made of spin effects in p - p scattering. Because of the kinematics at high energies, a fixed laboratory angle setting of the spectrometer corresponds very nearly to a fixed t independently of p_{LAB} . We also intend to study polarization effects in inclusive p - p interactions where the final state proton polarization in $p + p \rightarrow p + X$ is measured. The elastic measurements should provide useful tests on various optical and Regge models. The inclusive measurements could have a direct impact on the triple-Regge models and on our general understanding of how inclusive processes proceed.

The spectrometer consists of two superconducting quadrupoles and one superconducting dipole. These magnets are on loan to Fermilab from Berkeley. Our group assumed major responsibility for the cryogenics work required to adapt these magnets for use at Fermilab. Special transfer lines had to be fabricated; special coils were required for mapping the magnets and extensive cryogenics plumbing had to be installed. A massive program was undertaken (and is continually in progress) to minimize the helium losses so that the highest possible operational duty cycle is obtained within the limitations of the available liquifiers. Parts of the spectrometer support were fabricated at Indiana and shipped to Fermilab. The particle detectors (multiwire proportional chambers and scintillation counters) in the spectrometer are jointly read-out by our group and by E198 (Rochester-Rutgers collaboration). The latter experiment will utilize the spectrometer to measure the cross section in various p - p interactions. The spectrometer has now been made operational.

Elastic peaks have been observed with the momentum resolution of $\sim \pm 1\%$ at all pertinent energies and $|t|$ values within the scope of the experiment and at the expected rate.

The polarimeter, which was completely fabricated at Indiana, consists of multiwire proportional chambers to determine the incoming and outgoing proton trajectories associated with a double scatter in a carbon block, a hodoscope array to aid in the chamber filtering, trigger and timing counters, and a range telescope to check the elasticity of the double scatter. The trigger for the polarimeter is controlled by a sophisticated hardwired computer which examines, for each possible trigger, the status of the proportional chamber wires to determine if a useful double scatter occurred. This device prevents the recording of small angle double scatters, which are of no use for polarization analysis but which, if ignored, would dominate the data acquisition rate and fill each data buffer with primarily useless information. This hardwired computer is one of the principal unique features of the polarimeter. We have devoted a large effort in recent test runs to verify that the device accomplishes the vetoing of small angle scatters in a completely symmetric fashion and that it does not perturb in any way the important large angle scatters. Another unique feature of the polarimeter is that it is a chamber polarimeter which can be remotely rotated so that as far as the detectors are concerned, left and right can be exchanged. Since it is the left-right scattering asymmetry that is used to determine the magnitude of the recoil beam polarization, it is important that the apparatus be completely symmetric. By averaging results taken in two supplementary orientations we can thereby guarantee, to a high order, effective symmetry of the apparatus. The carbon analyzer has been previously calibrated in the ZGS polarized beam.

Our first runs of the experiment with all magnets powered occurred at

the end of June, 1976. These few days of running resulted in some 600K triggers and approximately 120K useful double scatters. This represents a 2% polarization measurement at $t = -.3(\text{GeV}/c)^2$ at $p_{\text{LAB}} = 20, 100, \text{ and } 200 \text{ GeV}/c$. The major running period for the experiment will occur after July, 1976. Because of the helium liquifier limitations at the Fermilab Internal Target Area, and also the need for E198 to operate the spectrometer at different settings from those of interest in E313, we anticipate receiving only approximately 10 days of priority running per month. At this rate we expect that the execution stage of the experiment will extend through most of the coming contract year. We plan to present preliminary results from the experiment at the Argonne Polarization Symposium in August, 1976.

FNAL E110/260

During the past year, physicists from the E110/260 collaboration have been engaged in using the Multiparticle Spectrometer in the M6W beamline at Fermilab to study reactions (E260) in which a single particle, or a group of particles, is produced with large transverse momentum (p_t). The physics goals are to gather data on the types of particles produced in high p_t reactions as a function of particle type inducing the reaction in order to understand high- p_t "quarkology". In addition, the collaboration has been building instrumentation to surround the target region in preparation for E110, which is a general study of low-momentum-transfer, quasi-two-body processes.

The E260 spectrometer is based around a superconducting magnet and utilizes multiwire proportional chambers (PWC's), magnetostrictive spark chambers, two large Cerenkov counters, and calorimeters. The two calorimeters can distinguish hadrons from electrons and photons. For E110, the calorimeters

will be removed and the target region will be surrounded by cylindrical PWC's, shower counters, and neutron counters. The E110/260 collaboration, which designed and built the Multiparticle Spectrometer, includes physicists from Caltech, Fermilab, UCLA, U. of Illinois at Chicago Circle, and Indiana.

The collaboration has completed two data runs on E260 since December, 1975 yielding a total of 430,000 triggers. Another run is scheduled to begin in mid-August. The data were collected using the calorimeters in the trigger. The trigger electronics allows for various trigger configurations:

- a) single particle high p_t - one segment of one calorimeter has an electron-hadron signal which exceeds a given threshold;
- b) "Jet" trigger - the sum of p_t signals over the four modules for either calorimeter exceeds threshold;
- c) " ψ " trigger - a p_t signal over threshold in one of the left electron modules along with a p_t signal over threshold in one of the right electron modules, i.e., an e^+e^- pair trigger.

These three triggers were run in a series of single-trigger runs during the first data-taking cycle (January, 1976 run) and in a multiple-trigger configuration during the second cycle (July, 1976 run). The p_t thresholds were chosen so as to optimize data collection at p_t well above threshold, i.e., the threshold was set low enough to minimize the effect of the calorimeter energy resolution on the p_t region of interest but not so low as to lose too much of the high p_t data in system dead time. For the multiple-trigger runs, the single-particle-high p_t and "jet" thresholds were chosen so as to give approximately equal trigger rates. The " ψ " triggers were contained in the single-particle-high p_t triggers. The beam momentum was 200 GeV/c. We ran with both positive and negative beam. (Beam Cerenkov counters separated π 's from K's from protons.)

During the January run, most of the data were taken using a 6cm beryllium target. A 12-inch long liquid hydrogen target was used for the July run.

The offline analysis of the January run was carried out by three subgroups of the E260 collaboration. The three subgroups worked independently although with much software in common. The comparison of different approaches has been very valuable. The analysis of the January run has just reached the physics stage with track finding and reconstruction of these complex events (average 9 tracks through the magnet) now understood. Preliminary physics results are currently being studied.

In preparation for E110, A. Dzierba and Kevin Komisarck, an Indiana U. student, worked on the design of the shower counters and mounts which will cover the region just upstream and downstream of the target area. This array of counters, called "jaw" counters, in conjunction with cylindrical shower counters, will be used to indicate the presence of slow π^0 's from Δ and N^* produced at low momentum transfer. The counters have been completed with construction taking place in the Indiana University Physics Department machine shop. During the next year we plan to actively participate in the physics analysis of E260 and to interface the "jaw" counters into the spectrometer system for E110 data-taking.

In addition to participation in the E110/260 experiments we plan to submit a proposal to use the Multiparticle Spectrometer to search for events which have a prompt lepton produced in association with a neutral strange particle to search for charm particle production in hadron-induced reactions. We are currently studying the data in hand to decide on a scheme for triggering on the production of a neutral-strange particle. This proposal will be submitted in time for a Multiparticle Spectrometer Facility Workshop which is as yet

unscheduled but will likely take place at the end of 1976. If approved, the experiment would follow E110/260 approved running which should end sometime in the fall of 1977.

CERN. WA11

Since early 1975 our group has been working collaboratively with Saclay in an experimental effort at the CERN SPS. Until December, 1975 we had intended to study backward pi meson-proton elastic scattering at beam momenta up to 150 GeV/c. This experiment, WA5, was approved by CERN and we were scheduled to run in the West Area beam H3 soon after the SPS was operational (late 1976).

During 1975 the excitement generated by the discovery of the ψ meson at SLAC and BNL pervaded the high energy physics community. There exists strong support for the idea that the ψ consists of a charmed quark (c) bound with its antiquark. If this is so, there should exist hadrons which contain a single charmed quark and which exhibit the charm quantum number. The discovery of these charmed particles (which we will call D) is probably at least as important as finding the ψ . There exists indirect evidence for charmed particles in the production of anomalous leptons which could be coming from D decays. Also, data from SLAC indicate that charmed particles may be produced in e^+e^- interactions. During 1975 we designed our WA5 apparatus with enough versatility so that we could consider doing a charm search experiment with a modest additional effort. In Dec., 1975 we decided to devote our efforts entirely to the charm search and submitted a proposal, WA11, to CERN. WA11 has been approved by CERN and we have withdrawn the backward scattering proposal WA5.

There is a phenomenon (called Zweig's rule) that in hadron-hadron collisions there is a suppression of processes in which a quark line (in a quark

diagram) starts and stops in the same particle. Thus it is expected that ψ mesons will be produced in association with charmed particles. We intend to enrich the charmed particle component of our data sample by only considering events in which there is a ψ meson. Indeed, our apparatus will be triggered on ψ events so that the chaff is eliminated at the outset.

This novel idea of using a ψ trigger for a charm search can be applied in an analogous situation involving strange quarks s . The ϕ meson consists primarily of $s\bar{s}$, much like the ψ is thought to be $c\bar{c}$. In an unpublished CERN experiment involving 19 GeV/c π^-p interactions, events with ϕ mesons do contain two additional strange particles (K mesons) about 50% of the time. In ψDD production a very large mass (~ 7 GeV) must be created and this will happen only at very small x (i.e., with the ψ c.m. longitudinal momentum near 0) and at large energies. Our π^- beam momentum will be 150 GeV/c and our acceptance will be large near $x = 0$.

Our apparatus consists of beam multiwire proportional chambers (MWPC), a 1m long H_2 target, a large vertex spectrometer, and a forward spectrometer. The vertex spectrometer consists of a 2m diameter, 1m gap, 16kG magnet (Goliath) filled with MWPC's. Hadron decay products of the D are hoped to be observed here. Downstream of Goliath is the forward spectrometer which contains MWPC's, a multicellular Cerenkov counter, and an iron-scintillator array to trigger the system on two μ mesons coming from the ψ decay. We expect to obtain about 7,000 ψ events in 1400 hours of running.

All of our equipment is either built or in the final stage of assembly. Most of the sophisticated detectors have been tested at the CERN PS during the last 8 months. Goliath is already in place and powered. We are currently installing our apparatus in anticipation of our first beam, which we should get in Oct., 1976.

Future PEP Project

Physicists from Indiana University and the University of Michigan have begun discussions on a proposal for construction of an experimental facility at PEP, the e^+e^- storage ring project at SLAC. By December, 1976 we plan to jointly submit this project to the experimental program committee.

The detector design that we are considering will be capable of complete particle identification (e , π , K , p) over an appreciable fraction of the solid angle. This capability together with fine spatial resolution will allow a detailed study of the jet phenomena unveiled at SPEAR. In addition, a direct identification of high multiplicity decay states of the newly-discovered (and yet to be discovered) charmed particles will be possible.

The principal investigators covered by this contract (R. Heinz and H. Neal) have devoted 100% of their time for 11 summer weeks and approximately 40% of their time during the academic year to this research project. It is anticipated that these percentages will apply for the remainder of the contract year. To the best of our knowledge compliance with the contract requirements has been complete.

References

1. A. Kreymer, et al., "The SLAC 2-meter Streamer Chamber with Downstream Spectrometer for Analysis of Backwards-Produced Exotic Mesons", p. 688, BAPS, April, 1976; S. Jones et al., "Investigation of Final States in the 13 GeV/c Baryon Exchange Reaction $\pi^- + d \rightarrow (p_t) + p_{\text{forward}} + \text{Anything}$ ", p. 688, BAPS, April, 1976.