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FINAL TECHNICAL REPORT
ON
RESEARCH IN HIGH ENERGY PHYSICS

1. PHOTOPRODUCTION OF PIONS
2. COLLIDING e^+e^- BEAM PHYSICS

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SUMMARY

This report describes research activities performed during the period June, 1969 to May, 1972 in two areas: Photoproduction of Pions and Colliding $e^+ e^-$ Beams. Results of several experiments on pion photoproduction with polarized photons are summarized and their significance is discussed. Progress in the construction and testing of a large magnetic detector facility (MAGNOLIA) is described. This facility was to be used in colliding $e^+ e^-$ beam experiments at the Cambridge Electron Accelerator.

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I. INTRODUCTION

Research in experimental high energy physics at Southeastern Massachusetts University (SMU)* was started in 1965. From an initial effort involving two faculty members with minimal financial support the high energy group developed into a viable research team with long-range programs and commitments. At present the group includes five faculty members, a graduate student working toward his Ph.D. and several graduate and undergraduate students during the summer.

The initial interest of the SMU group was in the area of pion photoproduction from nucleons. Our first experiment on single pion photoproduction from hydrogen and deuterium was completed in 1967. The results of this experiment generated considerable interest among groups active in photoproduction work at CEA, DESY and SLAC. Our own interest in pursuing this work further led to a comprehensive program of photoproduction experiments at CEA with polarized photons. These experiments were done during 1967-70 either by the SMU group, or the MIT group of Prof. Osborne, or a collaboration between these two groups. They are described in detail in Chapter II of this report.

After suspension of conventional physics experiments at CEA, the SMU group became involved in the design and construction of a magnetic detector facility - MAGNOLIA (magnetic on-line instrumentation analyzer) to be used for the study of processes initiated by e^+e^- collisions. This work was being done in collaboration with groups from MIT (Prof. Osborne and Prof. Frisch), CEA (Prof. Strauch), and members of the high energy group of Northeastern University. As of the summer of 1972, the MAGNOLIA detector was in an advanced state of construction with many of the subsystems assembled and tested. Completion of the assembly and testing was expected before the end of 1972. Features of the magnetic detector and its present status are presented in Chapter IV of this report.

Further work on the MAGNOLIA project was suspended in early fall of 1972 pending a decision on its future use in physics programs other than those originally planned at CEA.

* formerly called Southeastern Massachusetts Technological Institute (SMTI).

II. PHOTOPRODUCTION OF PIONS

A. General Considerations

The first experiment of the SMU group¹ involved measuring the π^-/π^+ cross section ratio of single pions produced in the reactions $\gamma d \rightarrow \pi^- pp_s$ and $\gamma p \rightarrow \pi^+ n$ at photon energies between 3.0 and 3.7 GeV and at pion center-of-mass angles between 30° and 90°.

The most significant result of this experiment was the observation that the π^-/π^+ ratio was substantially smaller than one. This fact eliminated any simple charge-symmetric model of π^+ and π^- production via one-particle exchange from the theorists' considerations. In addition, our measurements on the angular and γ -energy dependence of the π^-/π^+ ratio gave a first glimpse of the structure of the photoproduction amplitude at energies above the resonance region.

The observed asymmetry between π^- and π^+ raised many interesting questions. In the framework of exchange models, it was clear that at least two particles (or Regge poles) of opposite G-parity had to be exchanged, and that measurement of the π^-/π^+ ratio alone would not allow a determination of the number and relative amplitude of the exchanged objects. More detailed experimental information was needed to narrow down the choice between possible exchanges and their quantum numbers. This information could be supplied by experiments with polarized photons or polarized targets.

The reason for the importance of polarization experiments in pion photoproduction lies in a theorem due to Stichel². This theorem places restrictions on the quantum numbers of the objects exchanged in the t-channel in experiments using polarized photons of high energy. Only natural parity ($P(-1)^J = +1$) exchanges contribute to the cross section when the photon is polarized perpendicular ($\perp$) to the pion production plane, and only unnatural parity ($P(-1)^J = -1$) exchanges contribute for photons polarized parallel ($\parallel$) to the production plane.

The technique of producing polarized photons by coherent bremsstrahlung from a diamond monocrystal was well established in 1967 by the pioneering work of Überall³, Diambrini⁴, and others. Polarizations above 50% had been achieved at energies of about one half the incident electron energy.

Polarized targets, on the other hand, were considerably less developed at that time. Thus, the decision to initiate a long-range photoproduction program at the Cambridge Electron Accelerator focussed on the establishment of a polarized photon facility using the Überall effect.

This facility was established by a collaboration between our group and the MIT photoproduction group of Prof. Osborne during 1967-68.

The next few years saw an active research program being pursued by these groups, partly independently and partly in collaboration with each other. During the period covered by this report (June 1969 - May 1972), a total of six experiments were completed and published by the SMU group and the SMU/MIT collaboration. In addition we have published a paper on a gas threshold Cerenkov counter developed and built by the SMU group as an independent contribution to the spectrometer facility at CEA. Detailed descriptions of the various experiments and projects are contained in the following sections.

B. Production of Single Negative Pions with Polarized Photons

This experiment⁵ measured the cross section asymmetry, A^- , defined as

$$A^- = (\sigma_{\perp} - \sigma_{||}) / (\sigma_{\perp} + \sigma_{||})$$

in the reaction $\gamma p \rightarrow \pi^- p p_s$ for photons of energy 3.0 GeV linearly polarized parallel ($||$) or perpendicular ($\perp$) to the pion production plane. The range of four-momentum-transfers covered extended from $-t = 0.15$ to 2.0 (GeV/c)^2 .

The experimental technique used in this and the following photoproduction experiments consisted in measuring coincidence yields between pions and one of the recoil nucleons. The other "spectator" nucleon (p_s) remained unobserved. The pions were detected in a magnetic spectrometer which measured their production angle and momentum using trigger counters and digitized spark chambers; the recoil nucleon was detected by a simple counter telescope. The detailed configuration of this telescope depended on the nature and momentum of the detected recoil particle.

The asymmetry, A^- , showed considerable structure as a function of four-momentum-transfer $-t$, dropping from positive values at small $-t$ to a minimum at about $-t = 0.5 \text{ (GeV/c)}^2$ and rising slowly again at $-t$ values above 0.6 (GeV/c)^2 . The last point measured⁶, at $-t = 2.4 \text{ (GeV)}^2$ showed again a strongly negative asymmetry, a fact which was verified in a later experiment by our collaboration.¹⁰

Thus, the essential conclusions from this experiment were that natural-parity exchange dominates the cross section both at small $-t$ ($\approx 0.2 \text{ (GeV/c)}^2$) and at large $-t$ ($1.0 \leq -t \leq 1.8 \text{ (GeV/c)}^2$) while at intermediate $-t$ values unnatural and natural parity exchange contribute about equally.

The data from this experiment also showed for the first time the limitations of a Regge-Pole model proposed by Frøylund and Gordon.⁷ This model had been very successful in fitting our earlier π^-/π^+ ratio as well as predicting correctly the π^-/π^+ ratio up to 16 GeV measured at SLAC and the positive pion polarization asymmetry A^+ measured at DESY⁸. However, our π^- data indicated strong disagreement with this model between $-t = 1.0$ and 2.0 (GeV/c)^2 .

C. π^+ Photoproduction from Hydrogen with Polarized Photons

This experiment⁹, conducted in collaboration with the MIT group of Prof. Osborne, measured the positive pion asymmetry, A^+ ,

$$A^+ = \frac{d\sigma_{\perp} - d\sigma_{\parallel}}{d\sigma_{\perp} + d\sigma_{\parallel}} (\gamma_{\perp}, p \rightarrow \pi^+ n)$$

for polarized photons of energy 3.0 GeV in the $-t$ range from 0.15 to 1.2 (GeV/c)^2 . The asymmetry was found to be positive throughout this momentum-transfer interval, indicating the dominance of natural-parity exchange in this reaction.

Our data were in excellent agreement with DESY data⁸ in the region $0.2 \leq -t \leq 0.6 \text{ (GeV/c)}^2$ and extended the range of data to larger $-t$ values.

Another important conclusion resulted from combining results of this experiment with those of the previous one⁵ (cf. II B., above). It was established that the dip in the π^-/π^+ cross section ratio measured in the first experiment¹ of our group (cf. II A.) was caused by strong

isoscalar-isovector photon interference in the perpendicular cross section, $d\sigma_{\perp}$. In terms of known particle exchanges, ρ - A_2 interference might be a prominent candidate for this effect.

Comparisons of our data from both π^- and π^+ polarization experiments with the vector dominance model (VDM) were less conclusive due to the ambiguity of evaluating spin-density matrix elements in various frames and because of a possible D-wave contribution to the ρ_{1-1} matrix element. This aspect of the experiment is reported in some detail in our paper⁹ and in the literature cited there.

D. $\pi^{\pm}$ and π^0 Production by Polarized Photons in the Resonance Region

The SMU-MIT collaboration conducted a series of experiments¹⁰ on pion photoproduction with polarized photons in the nuclear resonance region. The energy range covered in these experiments extended from 0.8 to 2.2 GeV and pion center-of-mass angles studied were 45°, 50°, and 90°. All charge states of the pion were investigated in this series by measuring yields for the reactions

$$\gamma_{\perp, ||} p \rightarrow \pi^+ n$$

$$\gamma_{\perp, ||} p \rightarrow \pi^0 p$$

$$\gamma_{\perp, ||} d \rightarrow \pi^- pp_s$$

The principal purpose of these experiments was i) to conduct a comprehensive survey of the photoproduction amplitude in an energy region where several nuclear resonances, in particular the D_{15} (1670), F_{15} (1688), and F_{37} (1950) are expected to contribute substantially to the cross-section, and ii) to compare the data to quark model predictions¹¹ on baryonic excitations.

The c.m. angle of 90° was chosen to maximize the contribution of resonance excitation compared to t- and u-channel exchange contributions, and the 45° - 50° points were chosen to supply us with some initial information regarding the angular distribution of the resonances excited.

Further exploration of the angular distribution was planned, but could not be pursued due to the conversion of the C.E.A. to a colliding beam facility.

The principal result of these experiments can be summarized as follows: Bumps are seen in the region of the F_{15} (or D_{15}) resonance in the cross section for π^+ and π^0 , but not for π^- production; this is in agreement with quark model predictions.¹¹ The π^+ data on the asymmetry, A , are compatible with the quark model prediction that A be zero for the F_{15} ; but the π^0 data would require strong interference effects to be compatible with this prediction. The magnitude of the measured cross section bumps seems to be higher than predicted by the model¹¹, but more data will be needed to obtain a clear picture of this region.

III. INSTRUMENTATION FOR PHOTOPRODUCTION EXPERIMENTS

A. Gas Cerenkov Counter

The SMU group contributed to the instrumentation of the photoproduction facility at C.E.A. by designing, building and testing a threshold gas Cerenkov counter¹². Its primary purpose was to distinguish between pions and protons traveling along the MOBY DICK magnetic spectrometer. Design constraints due to the large beam cross section and the short space on the spectrometer platform were successfully overcome. Maximum light utilization along the whole flight path of the particles resulted in an efficiency for pion detection of over 99% - see Appendix I.

B. Polarized Photon Beam Facility

The SMU group collaborated with MIT and CEA to develop and test the polarized beam facility. Our primary contribution was in setting up and testing the high precision goniometer¹³ built at CEA, surveying the quality of several diamond crystals by X-ray diffraction methods, selecting suitable specimens, developing the mounting techniques for the diamond in its goniometer holder, and measuring the resulting overall spectra. The goniometer performed reliably and with good reproducibility over several thousand hours of operation.

IV. MAGNETIC DETECTOR PROJECT "MAGNOLIA"

A. Development and SMU Contribution

In the fall of 1970, the SMU group was invited to assume a major role in the development of a magnetic detector to be used in the second-generation experiments planned for the CEA colliding e^+e^- beam facility. This detector, called MAGNOLIA, was being designed by groups from MIT (Prof. Osborne), CEA (Prof. Stranch) and members of the high energy group from Northeastern University.

Upon joining this collaboration we assumed responsibility for developing an extensive testing system to measure the spatial resolution and the efficiency of a large number of spark chambers that were being built by the collaboration. In addition, the SMU group assumed responsibility for designing the magnetic field measuring device to survey the field of the large-volume solenoid of MAGNOLIA and for measuring a detailed field map with high precision. Members of the SMU group also took part in the construction of some of the component parts of the apparatus, and in their subsequent assembly into subsystems.

During 1971 and 1972 the SMU group built and operated several spark chamber test facilities. One was used to measure the spatial resolution of prototype shower chambers and utilized a set of four reference chambers of known resolution. Another one measured efficiency and spatial resolution of successively larger arrays of production spark chambers up to full quadrant size.

To analyze the chamber test data we utilized a data recording system and computer programs that had been developed earlier for a photoproduction experiment at CEA by one of the members of the SMU group and collaborators. This system was successfully adapted to our purposes and has operated over long test periods without any trouble.

The device to measure the magnetic field of the large solenoid was designed by a member of the SMU group. Engineering and programming aid was provided by members of the collaboration from MIT and Northeastern University, and construction of the mechanical parts and assembly has been proceeding at the CEA shop.

B. Status Report

The present status of the MAGNOLIA detector is described in detail in CEAL - Report No. 3063-04, which has been submitted to the Atomic Energy Commission. This report is included as Appendix 1 to this report.

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