Technical Report

for

A Research Program in High Energy Accelerator Physics and LowLevel Counting Elementary Particle Physics

Contract AT(11-1)-1749

1 October 1969 to 30 September 1970

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 T. L. Jenkins, Principal Investigator,
 Professor of Physics

Case Western Reserve University

University Circle
 Cleveland, Ohio
 44106

June, 1970

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Atomic Energy Commission Contract AT(11-1)-1749

Research Program

MASTER

in

High Energy Accelerator Physics and Low Level Counting

Elementary Particle Physics

by

William R. Frisken
Thomas L. Jenkins
Charles R. Sullivan
William M. Smith
Alan G. Strelzoff

Associate Professor of Physics
Professor of Physics
Assistant Professor of Physics
Research Associate
Assistant Professor of Physics

History prior to present contract year

Experimental elementary particle physics at Case Western Reserve had its beginnings in the low and high energy neutrino work done by a group consisting of F. Reines, M. Crouch, T. Jenkins and R. Woods. This work received A.E.C. support from about 1959 to the present. In 1966 a major portion of the neutrino work was shifted to the University of California at Irvine. Some neutrino and double beta decay research remained at CWRU. In 1965 a new departure at Case Institute was made into the more conventional elementary particle physics performed at accelerators. This received A.E.C. funding from its inception but was primarily funded by an NSF grant made under the Science Development Program to Case Institute.

By the summer of 1966, faculty members of the group consisted of Professors Blanpied, Frisken, Jenkins and Liu (see biographical information in Appendix A). During the period 1966-67, various members of the group were still somewhat involved in collaborations elsewhere but we submitted two proposals to the Program Committee of the Zero Gradient Synchrotron in the Spring of 1967. The second of these, a proposal to study the radiative 2π decay mode of the K^+ ($K^+ \rightarrow \pi^+ + \pi^0 + \gamma$) was approved as experiment E-164 on July 31, 1967. Preparations for this experiment continued until the Spring of 1968 at which time approval for this, as well as other approved ZGS experiments, was withdrawn.

In May of 1968 we submitted a proposal to the ZGS to study charge exchange scattering, $\pi^- p \rightarrow \pi^0 n$, in the intermediate momentum transfer

region between the forward and backward peaks. This proposal was quickly approved as E-207 and the data-taking runs commenced in April, 1969. This experiment ran for a total of 143 shifts at π^- momenta of 3.67 and 4.83 BeV/c. Preliminary results of the experiment were reported at the January, 1970 APS Meeting and we expect to publish them in the early fall of 1970. Details of the experiment and its results to date are given in Appendix C.

The group presently consists of four faculty members, one post-doctoral Research Associate and four graduate students (one of whom is engaged in a double beta decay experiment. A full time technician and a secretary are shared by this and the bubble chamber group.

General purpose experimental equipment on hand consists of approximately 100 fast logic modules (mostly E. G. & G.) as well as the necessary ancillary apparatus for powering, triggering and photographing optical spark chamber arrays. An IBM 1800 system is shared by the counter and bubble chamber groups. This machine normally runs continuously 7 days a week. The day shift is devoted to general calculations and data handling for both groups. The night shifts and weekends are devoted to operation of an automatic flying spot digitizer which is presently analyzing the film from the 5.9 BeV/c charge exchange experiment. This digitizer was developed and built at CWRU under A.E.C. support. In addition to the 1800, time is available on the university computer (UNIVAC 1108).

π^- p Charge Exchange

Following the successful completion of E-207 a proposal was made and approved for extending the experiment to higher momenta, namely 5.9 BeV/c.

This second experiment (designated E-261 by ANL) used the same apparatus as E-207. It was run in the 17° meson beam of the ZGS. Initial operation began December 18, 1969 and continued through the first week in April, 1970. Much of this time was at low beam owing to the incompatibility of this and other experiments. Approximately one million triggers were obtained.

The film is being analyzed by means of the flying spot digitizer which scans and measures most of the frames. The output of this process consists of a scanning list for humans who are able to do the complicated pattern recognition problem of identifying two juxtaposed gamma ray showers.

Proton Stability Experiment

This experiment, an outgrowth of the solar neutrino search which was discontinued, was finished in 1969. The results are given in C00-1749-12. This will be submitted to the Physical Review shortly.

Double Beta Decay Experiment

Data taking for this experiment is complete. Preliminary results were reported at the January, 1970 APS Meeting.* It is anticipated that the final results can be published during the winter 1970-71.

*G. R. Smith, T. L. Jenkins, Bulletin of the A.P.S. 15, 24 (1970).
COO-1749-15

Appendix A

Biographical Information

The following Ph.D. physicists have been members of the CWRU counter group:

William A. Blanpied, Associate Professor, 1966 - 1969
presently on leave with NSF/AID program in India.

William R. Frisken, Associate Professor, 1966 - present.

Thomas L. Jenkins, Professor, 1960 - present.

F. F. Liu, Assistant Professor, 1966 - 1968, now at SLAC

William M. Smith, Research Associate, 1969 - present.

Alan G. Strelzoff, Assistant Professor, 1969 - present.

Charles R. Sullivan, Assistant Professor, 1967 - present.

John A. Todoroff, Research Associate, 1967 - 1969, now with IBM.

Appendix B

Publications by members of the CWRU counter group during the period July 1966 to present.

1. Enriched Low Momentum K Beam for E.P.B., Argonne. Report to TAP Enriched Beam Subcommittee, June 1967. W. R. Frisken, CWRU.
2. Low Momentum Enriched K^+ Beams. Report to TAP enriched Beam Subcommittee, July 1967. W. R. Frisken, CWRU, E. W. Jenkins, U. of Arizona.
3. Bubble Chambers. Yu. A. Aleksandrov, G. S. Voronov, V. M. Gorbunkov, N. B. Delone, Yu. I. Nechayev. English Translation edited by W. R. Frisken, published by University of Indiana Press 1967. 371 pages.
4. Muon Pair Decay Modes of the Vector Mesons, W. A. Blanpied, A. Wehmann, E. Engels, Jr., C. M. Hoffman, P. G. Innocenti, R. Wilson, D. J. Drickey, L. N. Hand, and D. G. Stairs, Phys. Rev. Letters, 18, 929 (1967).
5. High Energy π^-p , $k^- - p$, $\bar{p} - p$ Elastic Scattering. A. Ashmore, C. J. S. Damerell, W. R. Frisken, R. Rubinstein, J. Orear, D. P. Owen, F. C. Peterson, A. L. Read, D. G. Ryan, D. H. White, Phys. Rev. Letters, 21, 387 (1968).
6. Structure in Backward Pion-Proton Elastic Scattering from 6 to 17 GeV/c. J. Orear, D. P. Owen, F. C. Peterson, A. L. Read, D. G. Ryan, D. H. White, A. Ashmore, C.J.S. Damerell, W. R. Frisken, R. Rubinstein, Phys. Rev. Letters, 21, 389 (1968).
7. Elastic Scattering of π^- , K^- and $\bar{p}$ from Protons at 9.8 and 13.6 GeV/c*. J. Orear, D. P. Owen, F. C. Peterson, A. L. Read, D. G. Ryan, D. H. White, A. Ashmore, C.J.S. Damerell, W. R. Frisken, and R. Rubinstein, Phys. Letters 28B, 61 (1968).
8. Some Rare Decay Modes in Interactions of π^- and K-mesons with Carbon and Iron, W. A. Blanpied, A. W. Wehmann, E. Engels, Jr., C. M. Hoffman, P. G. Innocenti, R. Wilson, D. J. Drickey, L. N. Hand, and D. G. Stairs, Phys. Rev. Letters, 20, 748 (1968). COO-1749-3
9. Momentum Measurements at 100 MCs of Particles in a High Energy Beam with Large Angular Divergence and Spatial Extent, W. A. Blanpied, C. Zajde, E. Engels, Jr., C. Hoffman, P. G. Innocenti, A. Liberman, R. Wilson, D. G. Stairs, and D. Drickey, Nuclear Instruments and Methods, 65, 93 (1968). COO-1749-1

10. Search for a CP-Nonconserving Asymmetry in the Decay $K_L^0 \rightarrow \pi^+ \pi^- \pi^0$, W. A. Blanpied, L. B. Levit, E. Engels, Jr., M. Goitein, T. Kirk, D. G. Ryan, and D. G. Stairs, Phys. Rev. Letters, 21, 1650 (1968). COO-1749-8.
11. Electron Antineutrino Interactions with Deuterons. T. L. Jenkins, F. E. Kinard, F. Reines, Phys. Rev. 185, 1599 (1969). COO-1749-9.
12. High Energy Elastic Scattering of $\pi^\pm$, $K^\pm$, $\bar{p}$ on Hydrogen at c.m. Angles from 22° to 180° . D. Owen, F. C. Peterson, J. Orear, A. L. Read, D. G. Ryan, D. H. White, A. Ashmore, C.J.S. Damerell, W. R. Frisken, R. Rubinstein, Phys. Rev. 181, 1794, 1969 May 25th.
13. High-Energy Muon Inelastic Scattering, W. A. Blanpied, C. M. Hoffman, A. D. Liberman, E. Engels, Jr., D. C. Imrie, P. G. Innocenti, R. Wilson, C. Zajde, D. G. Stairs, and D. Drickey, Phys. Rev. Letters 22, 659 (1969). COO-1749-10
14. Experimental Test of Quantum Electrodynamics by Muon Bremsstrahlung, W. A. Blanpied, A. D. Liberman, C. M. Hoffman, E. Engels, Jr., D. C. Imrie, P. G. Innocenti, R. Wilson, C. Zajde, D. G. Stairs, and D. Drickey, Phys. Rev. Letters 22, 663 (1969). COO-1749-7.
15. Muon Pair Production by 12 GeV/c Negative π and K mesons on Carbon and Iron, W. A. Blanpied, A. Wehmann, E. Engels, Jr., C. M. Hoffman, P. G. Innocenti, R. Wilson, D. J. Drickey, L. N. Hand, and D. G. Stairs, Phys. Rev. 178, 2095 (1969). COO-1749-6.
16. Physics: Its Structure and Evolution, W. A. Blanpied. Blaisdell publishing Co., Waltham, Mass., June 1969.

APPENDIX C

A Preliminary Report on the Study of the Reaction

$$\pi^- p \rightarrow \pi^0 n \text{ at } 3.67 \text{ and } 4.83 \text{ GeV}/c^*$$

W. S. Brockett, G. T. Corlew, W. R. Friksen, T. L.

Jenkins, A. R. Kirby, C. R. Sullivan, J. A. Todoroff†

Case Western Reserve University

W. B. Richards

Oberlin College

This experiment was performed in the 17° meson beam of the ZGS at the Argonne National Laboratory. The experimental apparatus, shown in Figure 1, consisted of a liquid hydrogen target surrounded, in almost 4π geometry, by anticoincidence counters. Downstream of the target and on opposite sides of the beam line were two symmetric arrays of spark chambers interspersed with lead plates. These served as converters for both the γ 's resulting from the π^0 decay and the neutrons. Vertex locations for these conversions and beam particle direction provided one more piece of data than was necessary to reconstruct the event on the $\pi^- p \rightarrow \pi^0 n$ hypothesis (i.e., a 1-C fit). The chambers could be triggered in one of two possible modes namely a "neutral trigger" (a beam particle in and no charged particle out) or a neutral trigger plus the requirement that a charged particle be observed in at least one

of the Γ counters located in the spark chamber array. Usually this Γ counter trigger signal was produced by a shower in the array. About equal running time was spent on both trigger modes and on both π^- momenta. The laboratory angles of $\sim 15^\circ$ to $\sim 70^\circ$ covered by the detectors corresponded to four-momentum transfers of $1.5 < |t| < 4.5$ $(\text{GeV}/c)^2$ at 3.67 GeV/c incident momentum and $1.5 < |t| < 6.5$ at 4.83 GeV/c. Two different target (and anticoincidence counter) locations were used during the run.

The experiment was run for a total of 143 shifts during the late spring of 1969. A total of about 5×10^5 triggers were obtained. At this writing a large fraction of the 3.67 GeV/c data and nearly all of the 4.83 data have been scanned and measured. Scanning consisted of identifying events with the correct "topology", that is, two gamma ray showers on one side of the beam and a neutral particle conversion deep within the array on the other side of the beam. Measured vertex positions were analysed in a program adapted from the bubble chamber fitting program GUTS.¹ In the reconstruction program unmeasured variables such as event vertex location and final particle momenta are calculated and the directly measured variables are adjusted such that four-momentum conservation is satisfied with a minimum value of χ^2 . The calculations yield a t value for every event as well as a calculated error of t (which averaged $0.15 (\text{GeV}/c)^2$ at both momenta), χ^2 and event vertex location along the

incoming beam track, z_v . Verification that true $\pi^-p \rightarrow \pi^0n$ events were being observed derives mainly from the distribution of these last two quantities χ^2 and z_v . These distributions are shown in Figures 2 and 3. In addition, other data are presented in Figures 4 and 5 to show that the distributions of depth of conversion points of the γ 's and neutrons were consistent with what one would expect for these particles. Additional verification is provided by the π^0 decay opening angle distribution shown in Figure 6, although it must be recognized that this is not a completely unbiased test of the data since the reconstruction program forces the γ vertex positions to be consistent with π^0 decay.

Detection efficiency calculations have been performed using an artificial set of data generated by a Monte Carlo program. The results of this calculation are shown in Figure 7. Finally, the cross section values as a function of t are shown in Figures 8 and 9 along with the results of other experiments and a theoretical prediction calculated from parameters given by Barger and Phillips.² The errors shown are statistical only. The data have yet to be corrected for a number of effects such as scanning losses resulting from invisible neutron stars (see Figure 10) as well as other sources. These corrections are t -dependent and will tend to increase the measured cross section by possibly as much as a factor of two near the low $|t|$ end. Less correction will be necessary in the middle and high $|t|$ region.

The authors wish to acknowledge the support of the Argonne National Laboratory and the cooperation and assistance of its staff members. Professors W. A. Blanpied, F. F. Liu and A. G. Strelzoff have contributed to planning and other aspects of the experiment.

Footnotes

* Work supported by the A. E. C. and N. S. F.

† Now at I. B. M., Endicott, New York.

1. J. P. Berge, F. T. Solmitz and H D. Taft, R.S.I. 32, 538 (1961).
2. V. Barger and R. J. N. Phillips, Phys. Rev. Letters 22, 116 (1969).
3. P. Sonderegger, et al., Physics Letters 20, 75 (1966).
4. R. C. Chase, et al., Phys. Rev. Letters 22, 1137 (1969).
5. J. H. Atkinson, et al. Phys. Rev. 123, 1850 (1961).

Figure 1. Plan view of the apparatus showing incoming π^- direction and a typical disposition of gamma ray and neutron conversion vertices. Cross hatched areas represent shower counters. A1, A5 and A6 were charged particle anticoincidence counters. S1 and S2 are lead plate - spark chamber arrays each consisting of 25 2 gap spark chamber modules viewed in 90° stereo. Not shown are upstream beam counters B1, B2, B3, a pair of thin plate beam chambers, and some shower anticoincidence counters above and below the target.

Figure 2. χ^2 distributions resulting from event reconstruction with 1-C fit. The triangles show the expected form of the distributions.

Figure 3. Calculated z coordinate of reaction vertex. Only events for which $\chi^2 < 3.0$ are included in the above figures. Since the target location and size nowhere entered the reconstruction calculation, the clustering of these points about the actual target position is verification that we are observing elastic charge exchange events.

Figure 4. Distribution of gamma conversion points as a function of depth in the chamber array.

Figure 5. Distribution of neutron conversion points as a function of depth within the chamber array. The 18.2 cm mean free path corresponds to the neutron reaction cross section in lead of reference 5.

Figure 6. Opening angle distribution of π^0 decay in C. of M. for reconstructed events. Solid curve shows theoretical distribution normalized to total events.

DETECTION EFFICIENCY FOR $\pi^-p \rightarrow \pi^0n$ EVENTS

AS A FUNCTION OF 4-MOMENTUM TRANSFER SQUARED.

E207 - OCT. 1969.

FIGURE 7A.

INCIDENT MOMENTUM = 3.67 BEV/C
MARGIN ON CHAMBERS = 0.5 INCH.

30%

20%

10%

0%

FIGURE 7B.

INCIDENT MOMENTUM = 4.83 BEV/C
MARGIN ON CHAMBERS = 0.5 INCH.

30%

20%

10%

0%

$t, (\text{BEV}/c)^2$

Figure 8. Differential cross section, $d\sigma/dt$ for $\pi^-p \rightarrow \pi^0n$ at incident π^- momentum of 3.67 BeV/c. Open circles on the left are the data of Sonderegger et al. (ref. 3), on the right, of Chase et al. (ref. 4) at 4 BeV/c. Solid circles are the preliminary results of this experiment. Dashed curve is from reference.2.

Figure 9. Differential cross section, $d\sigma/dt$ for $\pi^- p \rightarrow \pi^0 n$ at incident π^- momentum of 4.67 BeV/c. Points on the left are the data of Sonderegger et al., (ref. 3), on the right, of Chase et al. (ref. 4) at 5 BeV/c. Open circles are the preliminary results of this experiment.

Figure 10

DEPENDENCE OF NEUTRON STAR "LENGTH" ON t
FOR INCIDENT MOMENTUM = 3.67 GEV/C.

NUMBER OF STARS