DE-AS-5-76ER05096-7

HIGH ENERGY PHYSICS

PROGRESS REPORT

G. C. Phillips

J. B. Roberts

William Marsh Rice University

T. W. Bonner Nuclear Laboratories

April 1, 1979 - February 29, 1980

Prepared for the

U. S. DEPARTMENT OF ENERGY

DISCLAIMER

RICE UNIVERSITY

D.O.E. CONTRACT NO. DE-AS-5-76ERO5096 "High Energy"

PROGRESS REPORT 1979-1980

PROJECT ABSTRACT

During the contract year progress was made in data analysis of a number of ANL-ZGS experiments: E-418, Polarization in Large Angle n-p Elastic Scattering at 2, 3, and 6 GeV/c; E-407, Depolarization in $pp \rightarrow pN^*$ at 6 GeV/c; E-425, A_{nn} in n-p Elastic Scattering at 6 GeV/c; E-434, A_{nn}, A, and $\Delta\sigma_T$ in p-p Scattering from 1-12 GeV/c; E-460, $\Delta\sigma_T$ in $\bar{p}$-n Scattering from 1-2.5 GeV/c; and E-462, Spin Asymmetries in $pp \rightarrow p\pi^+n$ from 1-2 GeV/c. Three publications were made during the year.

In addition, three new experiments were undertaken and completed at the ZGS: E-445, Asymmetries in Inclusive Pion Production with a Polarized Beam and Target; E-460, Measurement of $\Delta\sigma_T$ in p-d and p-p Scattering from 1-2.5 GeV/c; E-462, Polarization Asymmetries in $pp \rightarrow p\pi^+n$ from 1.2-2.0 GeV/c.

During the year deuterated samples were polarized in PPT VI and the improvements necessary in the NMR system to detect the free deuteron polarization were made. PPT VI was disassembled at Argonne and transported to the Bonner Labs at Rice to be reassembled and improved for use in future experiments.

Our group has entered into a joint effort with the University of Michigan, Yale University, Argonne National Laboratory (ARF Division), and Brookhaven National Laboratory to implement an accelerated polarized beam at the AGS. In addition, our collaborative proposal to build a polarized beam facility, E-581, was approved at Fermilab.

PROGRESS REPORT

Contract No. DE-AS-5-76ERO5096

High Energy Physics

Rice University, Houston, Texas 77001

Personnel working on the project during the year to Feb.29,1980:

G. C. Phillips, Professor of Physics and Director, T. W. Bonner Nuclear Laboratories - Principal Investigator

J. B. Roberts, Associate Professor of Physics, Co-Principal Investigator

S. D. Baker, Professor of Physics

G. S. Mutchler, Associate Professor of Physics

H. E. Miettinen, Assistant Professor of Physics

T. A. Mulera (Ph.D., Purdue University) Senior Research Associate

M. D. Corcoran (Ph.D., Indiana University) Senior Research Associate

James D. Lesikar (B.S., M.A. Rice University) Research Assistant

Mark M. Calkin (B.S., Purdue University) Research Assistant

David A. Bell (B.S., University of Texas-Arlington) Research Assistant

Kenneth Johns, Research Assistant

J. A. Buchanan (B.S., University of Houston) Senior Research Engineer

J. M. Clement (Ph.D., Rensselaer Poly.Inst.) Research Engineer

Joe Windish, Mechanical Technican

Helen Viereck (M.A., University of Houston) Administrative Assistant

Physics Shop Personnel, Rice University

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EXPERIMENTS IN HIGH ENERGY PHYSICS

During the past year data analysis from five past experiments was continued and several efforts were completed, resulting in three publications.

Intensive efforts by all the Rice Group at ZGS occupied most of the past year. Three new experiments (E-445, E-460, and E-462) were started and completed during the year and new data was taken on several experiments started earlier. All but one of the experiments employed both the polarized ZGS beam and the PPT VI system. One experiment employed polarized deuterium in the PPT. Another experiment (E-462) was carried out in collaboration with an ANL group using only the polarized beam. We believe that the principal scientific highlights of this effort will be contributions to understanding the possibility of nucleon-nucleon resonances.

After the shutdown of ZGS (October 1, 1979), efforts to move the PPT to Rice were commenced and preparations for further polarization research at Brookhaven National Laboratory and Fermilab were intensified.

The following discussion summarizes the work during the past year on the topics

A. Spin Dependence of the Nucleon-Nucleon Interaction
B. Instrumentation
C. Theory

For each topic, the title and [ZGS experiment number] is listed.

A. Spin Dependence of the Nucleon-Nucleon Interaction

1. Depolarization in $pp \rightarrow pN^*$ at 6 GeV/c [E-407]

Preliminary data have been presented[1] which dramatically illustrate the dominance of pion exchange in small-t Δ^+ production, and we expect the final results to be submitted for publication before the end of this contract year.

[1] J. B. Roberts, "The ZGS Polarized Beam Program," History of the ZGS Symposium, AIP Conference Proceedings to be published.

2. Asymmetries in Inclusive p-nucleon Scattering at 11.75 GeV/c [E-408]

The final data on asymmetries in $p\uparrow p \rightarrow \pi^{\pm}$, $K^{\pm}$, p+anything have been published.[2]

[2]W. H. Dragoset *et al.*, Phys. Rev. D18, 3939 (1978).

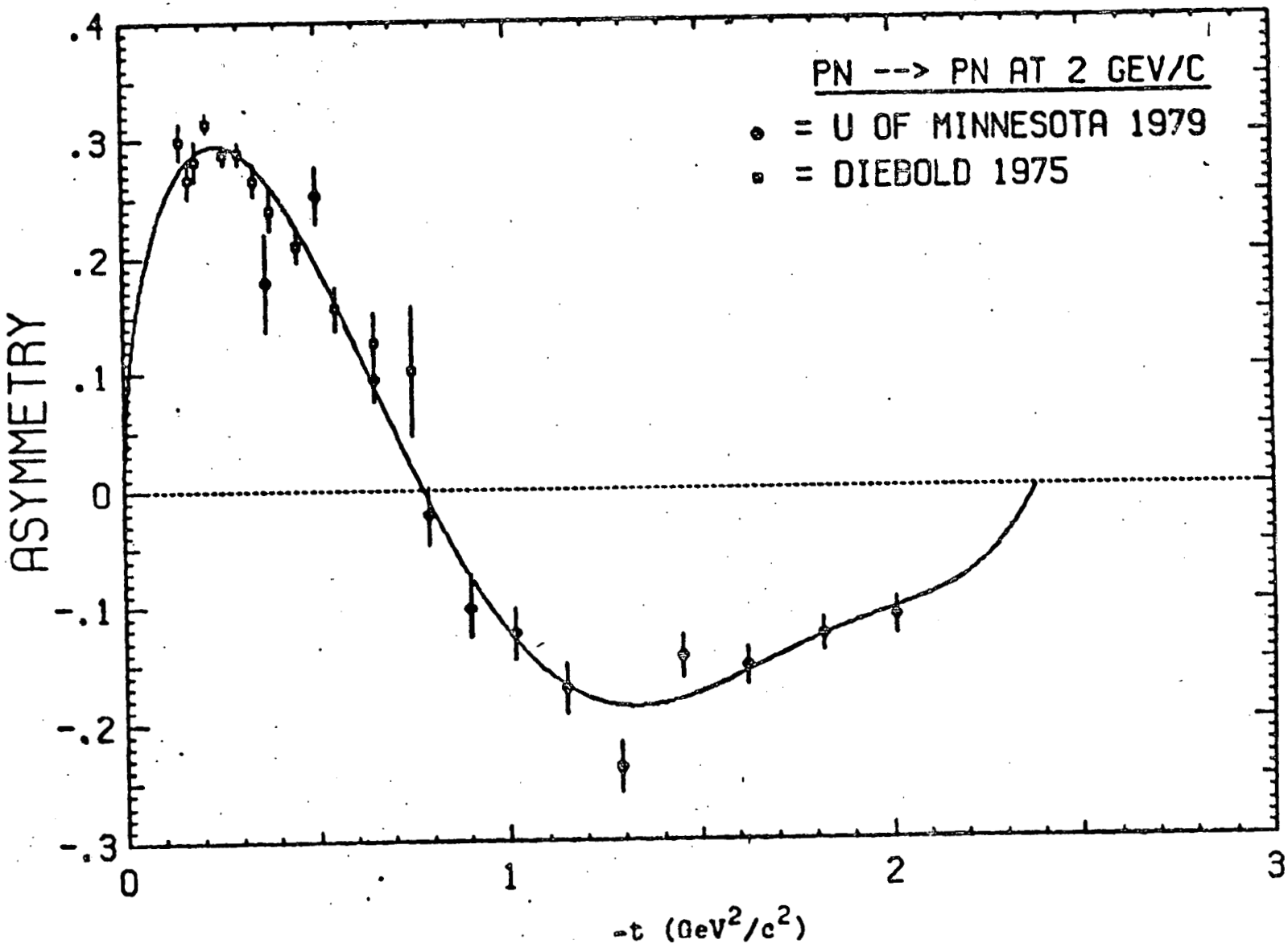
3. Polarization in Large Angle p-n Elastic Scattering [E-418]

The analysis of the data of the Minnesota-Rice-Argonne collaboration on the polarization in large angle neutron-proton scattering has been completed, and a letter will be submitted shortly for publication. The data, which cover the full angular distribution at 2, 3, and 6 GeV/c are shown in Figs. 1,2,3. The agreement is good with the earlier small-t data of Diebold *et al.*,[3] at 2 and 3 GeV/c, but there is some disagreement at 6 GeV/c. Although our data at small-t are subject to greater systematic error than the large-t data, we can find nothing obviously wrong at 6 GeV/c and will stand by the result. The most striking result is that the large angle polarization parameter is large and increases with energy up to 6 GeV/c, contrary to its behavior at small-t.

[3] R. E. Diebold *et al.*, Phys.Rev.Lett. 35, 632 (1975).

4. Measurement of A and A_{nn} in n-p and p-p Elastic Scattering at 6 GeV/c [E-425]

E-425 which ran in November-December 1978, measured the spin parameters A and A_{nn} in n-p and p-p elastic scattering. The experiment utilized a 12 GeV/c transversely polarized deuteron beam, which provided 6 GeV/c polarized neutrons and protons incident on a polarized proton target, PPT VI. Coincident n-p and p-p events were detected with a double arm spectrometer to ensure clean (quasi-) elastic n-p events. The experiment covered a t range of 0.2 to 1.0 $(GeV/c)^2$.


PN --> PN AT 2 GEV/C
= U OF MINNESOTA 1979
= DIEBOLD 1975
ASYMMETRY
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.3
.2
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-.1
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1
2
3
-t (GeV²/c²)

Figure 1

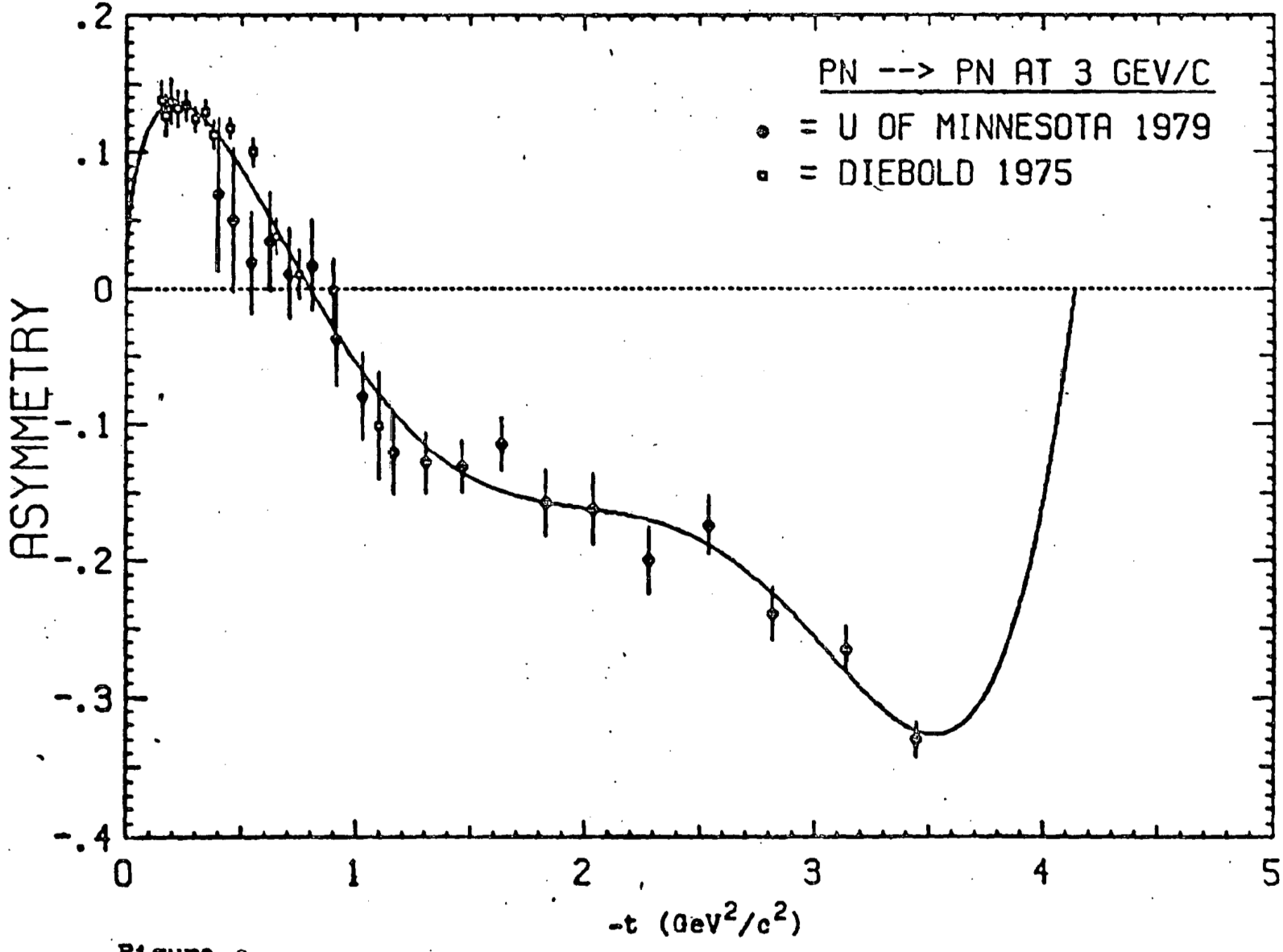
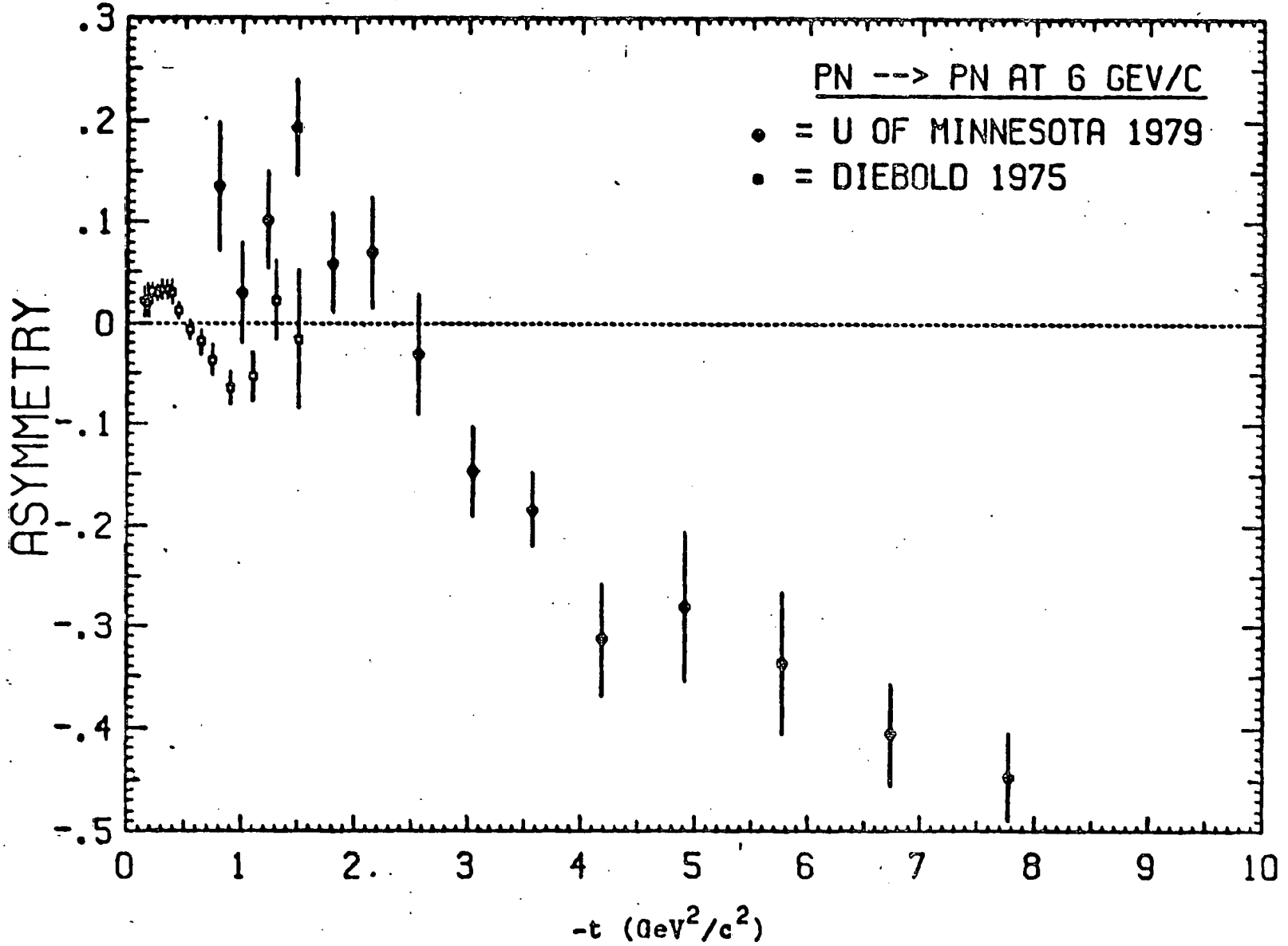

PN --> PN AT 3 GEV/C
= U OF MINNESOTA 1979
= DIEBOLD 1975
ASYMMETRY
.2
.1
0
-.1
-.2
-.3
-.4
0
1
2
3
4
5
-t (GeV²/c²)

Figure 2


PN --> PN AT 6 GEV/C
• = U OF MINNESOTA 1979
• = DIEBOLD 1975
ASYMMETRY
.3
.2
.1
0
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-.2
-.3
-.4
-.5
0
1
2
3
4
5
6
7
8
9
10
-t (GeV²/c²)

Figure 3

A schematic of the experimental setup is shown in Fig. 4. The recoil protons were measured with a conventional magnetic spectrometer containing scintillation counters and multiwire proportional chambers (MWPCs). The scattering angles of the neutron (or proton) were measured with a neutron detector system. The detector consisted of (1) a $2L_{rad}$ lead plate, (2) a veto scintillator, (3) two 1" brass plates, (4) trigger scintillators, and (5) MWPCs. A neutron incident on the brass produces charged particle(s), which are observed by the scintillators and MWPCs. These are used to determine the neutrons conversion vertex in the brass, which is traced back to the target to get the neutron's scattering angles.

The lead plate converted photons which were tagged by the veto scintillator along with charged particles. A fraction of the spectator protons from the deuteron were also detected by a downstream telescope to further tag the event.

The running of the experiment was marred by poor RF structure in the beam due to the necessity of using $\sqrt{x}$=1 resonant extraction to avoid an unexpected depolarizing resonance. This resulted in unacceptable accidental rates for most of the experiment. These problems were eventually corrected and we were able to collect 15-20,000 n-p elastic events during the last ten days of the run. A clear neutron signal was seen in the on-line analysis. Fig. 5, which represents 10% of the data, is the opening angle distribution (Θ_2-$\Theta_2$calculated) for protons and neutrons. The neutrons and protons have different peaks because the protons are bent to larger angles in the PPT's magnetic field. This makes Θ_2 calculated too small, which in turn offsets the $\Delta\Theta_2$ distribution to larger values.

Design work on this experiment included a Monte Carlo study of the neutron detection efficiency. This study which is part of M. M. Calkin's M.A. thesis, also indicated a 3.7% neutron detection efficiency and a 95% single track topology with the remainder being double tract events.

The analysis, which is part of M. M. Calkin's M.A. thesis, is now in progress and should be completed early next year.

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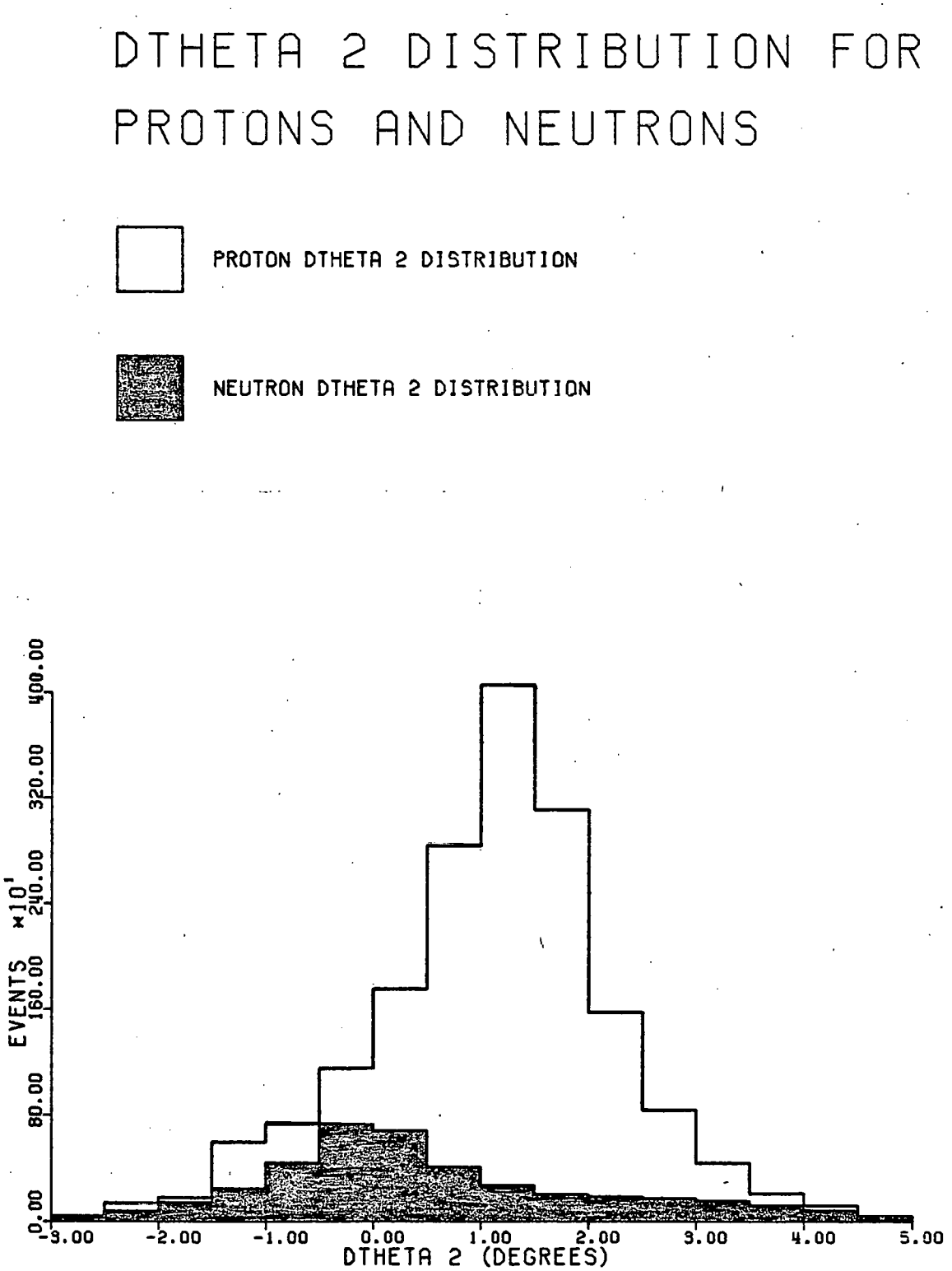
DTHETA 2 DISTRIBUTION FOR PROTONS AND NEUTRONS
PROTON DTHETA 2 DISTRIBUTION
NEUTRON DTHETA 2 DISTRIBUTION
EVENTS ×10¹
0.00
80.00
160.00
240.00
320.00
400.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
DTHETA 2 (DEGREES)

Figure 5

5. Measurement of A_{nn} in p-p Elastic Scattering in the 1-3 GeV/c Region [E-434]

In August and September 1978 we measured the spin parameters A and A_{nn} in p-p elastic scattering at nine different energies in the range p_{lab}=1.14-2.75 MeV/c. The measurements were made using the ZGS polarized proton beam and the Argonne PPT VI, and elastic events were detected with the E-434 double arm spectrometer. Full angular distributions of A and A_{nn} were obtained at each energy.

The analysis of these data is now in progress, and five out of the nine energies have been analyzed as this report is being written. As examples, our results on the θ-dependences of A and A_{nn} at p_{lab}=2.25 GeV/c and on the energy dependence of A_{nn} (θ_{cm}=90°) are shown in Fig. 6 and 7.[4] The full analysis of these data is expected to be carried out by early 1980.

Our detailed measurements on A_{nn} in this energy range will provide valuable new input data for N-N phase shift analyses, and should help clarify the controversy regarding the existence of dibaryon resonances. We anticipate carrying out a phenomenological analysis of these data in 1980.

[4]D. Besset *et al.*, AIP Conf.Proc. 51, 424 (1979); H. B. Willard *et al.*, AIP Conf.Proc. 51, 420 (1979); D. Miller *et al.*, Phys.Rev. *D16*, 2016 (1977); and A. Lin *et al.*, Phys.Lett. *74B*, 273 (1978).

6. Measurement of $\Delta\sigma_T$ in p-p Scattering [E-434, E-460].

We have measured $\Delta\sigma_T$ in p-p scattering using PPT VI during August-September 1978 [E-434] and August-September 1979 [E-460]. Our initial measurements at 1.2, 1.5, 1.75, 2.9, and 2.5 GeV made in E-395[5] indicated interesting structure at about 2 GeV/c and possible structure near 1.2 GeV/c. Our more recent measurements at the same and additional momenta (which are just now being analyzed) indicate more structure at the lower momenta

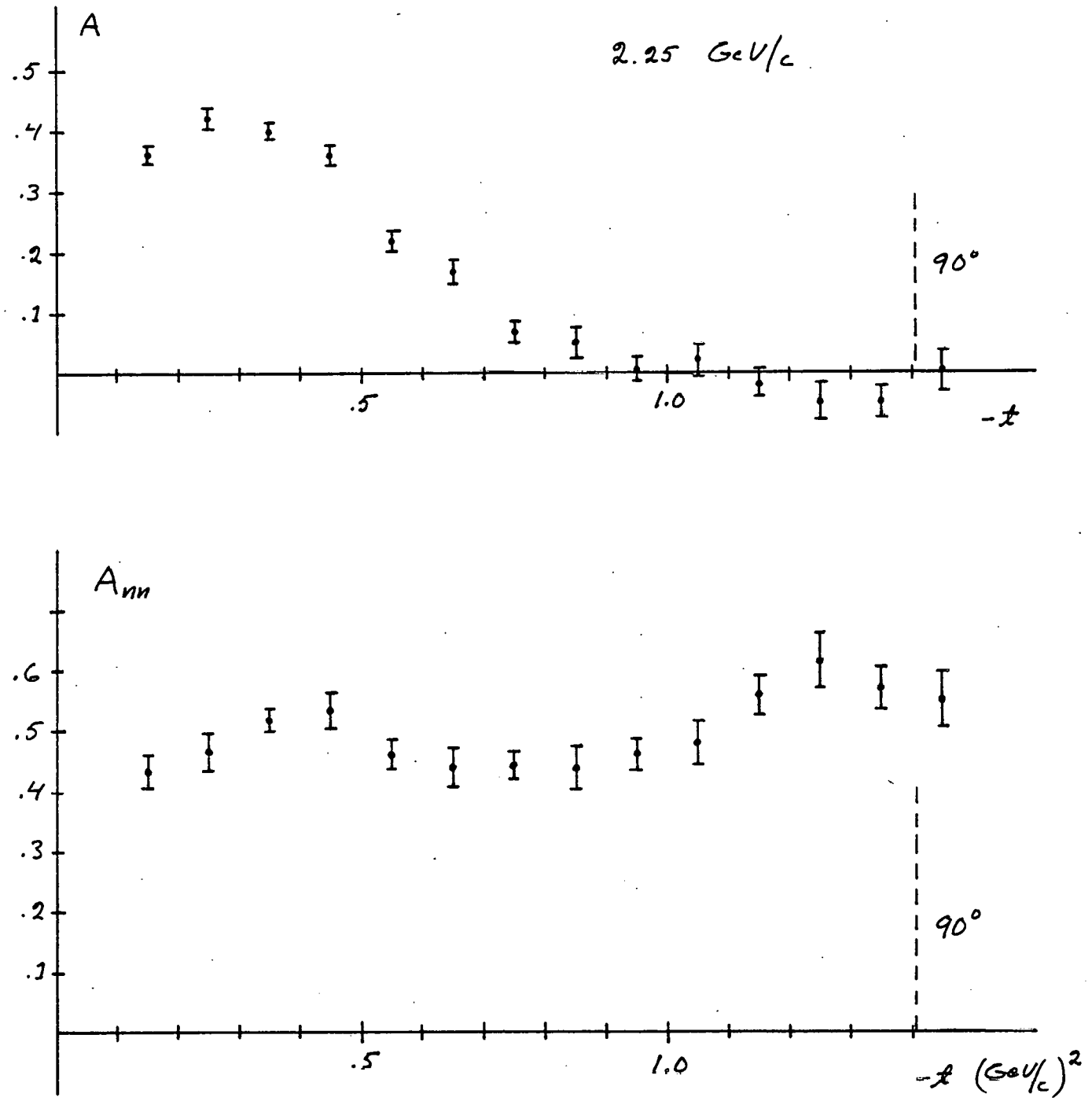

Figure 6: A and A_{nn} in p-p elastic scattering at p_{lab}=2.25 GeV.c

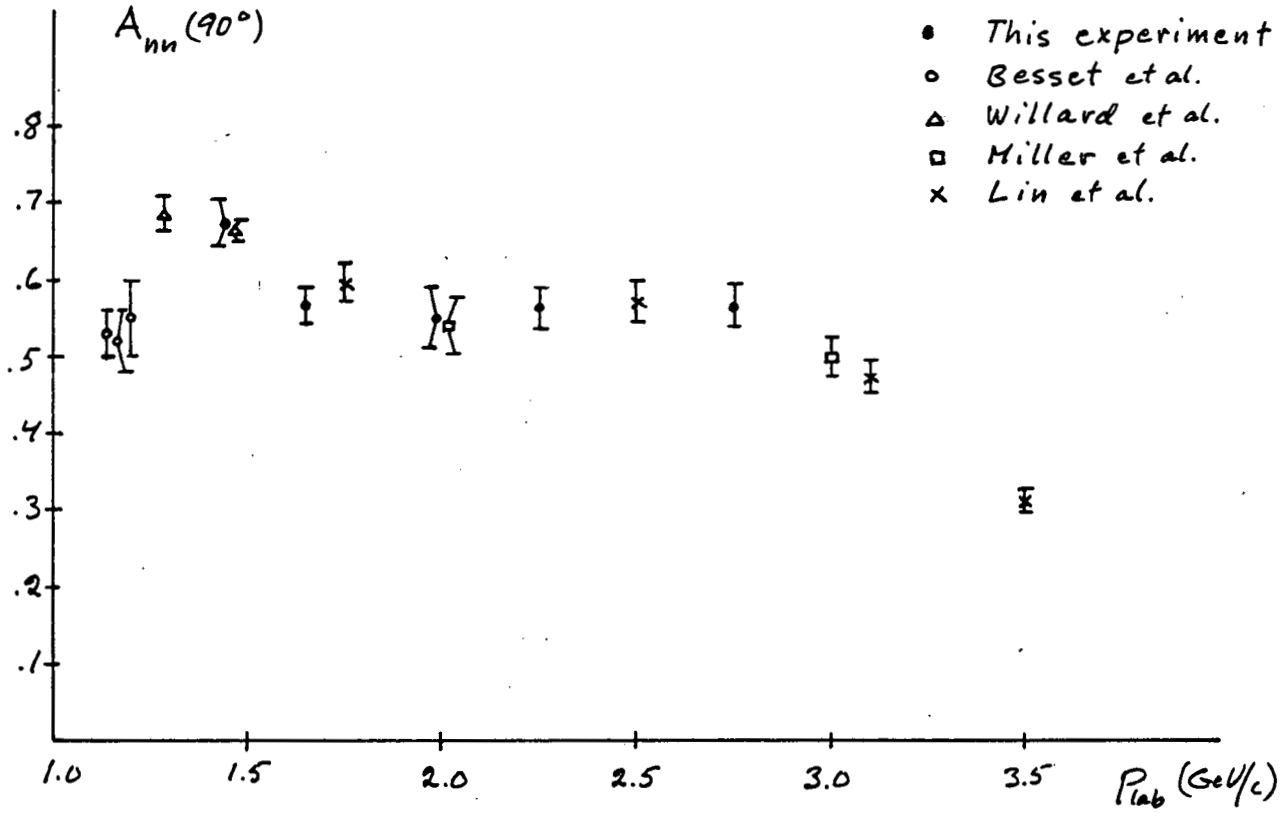

Figure 7: A_{nn} in p-p elastic scattering at $\Theta_{cm}=90°$

than we had previously observed. Some of these on-line results are shown in Fig. 8. In particular, it appears that the E-395 point at 1.2 GeV/c was low by 2-3 mb, and the 1.5 GeV/c point was also low. The higher momentum points seem to reproduce to within errors. We are engaged in a detailed study of possible systematic errors, but all the data taken with PPT VI are in agreement to within on-line errors. E-434 data points repeated in 1979 during E-460 reproduce to within errors, as do E-460 points repeated within the run. We expect the data to be analyzed and systematic effects to be studied by early 1980.

There is also a correction to $\Delta\sigma_T$ due to Coulomb scattering which is dependent on the geometry of the transmission detectors, because A_{nn} and A_{ss} are unknown but probably non-zero in the Coulomb-nuclear interference region. Calculation of these effects depends on a knowledge of only partially known strong amplitudes in this energy region, and therefore an iterative procedure must be used to estimate the corrections. Estimates have been made by Watanabe[6] for both $\Delta\sigma_T$ and $\Delta\sigma_L$, and give corrections as large as 2 mb at the lowest ZGS energies. We also will attempt to analyze these effects for our geometry with some theoretical assistance.

We will perform a "second generation" experiment measuring $\Delta\sigma_T$ in five energy steps up to 1.5 GeV/c at LAMPF [E-505] in the summer-fall of 1980. We believe that the very high beam quality and very accurate beam polarization measurement at LAMPF will considerably reduce the systematic errors in the data. We hope these results will help resolve the question of the existence of dibaryon resonances.

[5]Ed. K. Biegert *et al.*, Phys.Lett. *73B*, 235 (1978).
[6]Y. Watanabe, Phys.Rev. *D19*, 1022 (1979).

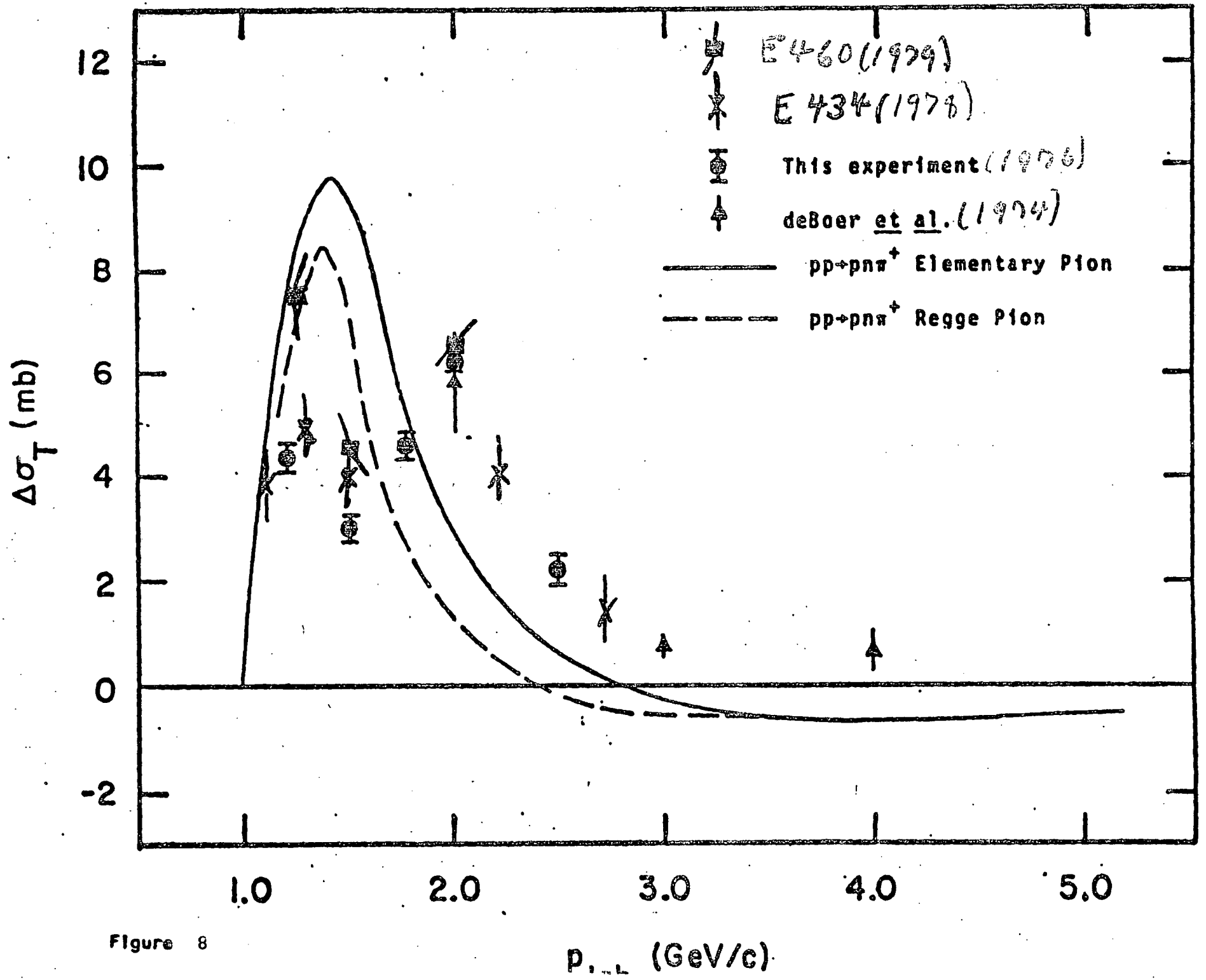
E 460 (1979)
E 434 (1978)
This experiment (1978)
deBoer et al. (1974)
pp→pnπ+ Elementary Pion
pp→pnπ+ Regge Pion
Δσ_T (mb)
12
10
8
6
4
2
0
-2
1.0
2.0
3.0
4.0
5.0
p_lab (GeV/c)

Figure 8

7. Measurement of A_{nn} in p-p Elastic Scattering at 11.75 GeV/c [E-434]

In May of 1978 a Rice University-University of Houston collaboration measured the spin parameters A and A_{nn} in p-p elastic scattering at small angles at p_{lab}=11.75 GeV/c, using the ZGS polarized proton beam, the Argonne PPT VI, and the E-434 double arm spectrometer. The main motivation for this experiment was to provide input data for a model-independent amplitude analysis in p-p elastic scattering at 12 GeV/c.

The analysis of these data has now been completed and our final results are shown in Fig. 9. Our results are in good agreement with previous data[7] and indicate that A_{nn} is small and positive at small t. We expect to publish these results together with our forthcoming 6 GeV/c data on A_{nn} at small t [E-425].

[7] S. L. Kramer *et al.*, Phys.Rev. *D17*, 1709 (1978); K. Abe *et al.*, Phys.Lett. *63B*, 239 (1976).

8. Asymmetries in Inclusive Pion Production with a Polarized Beam and Polarized Target [E-445]

E-445, the measurement of spin-spin asymmetries in pion production at 11.8 GeV/c, was run March-April 1979. We studied only the reaction $pp\rightarrow\pi^-X$ at 90° C.M. as a function of $p_\perp$, which simplified particle detection and the experimental procedure considerably. Large spin-spin asymmetries have been observed in p-p elastic scattering near 90° C.M. at 11.8 GeV/c[8] and large single-spin asymmetries are seen in $pp\rightarrow\pi^\circ X$ at $p_\perp\sim$1-2 GeV/c at 24 GeV/c.[9] A study of spin-spin asymmetries in inclusive pion production in this same $p_\perp$ range thus seems quite compelling although the large background intrinsic to such a measurement may place severe restrictions on the accuracy of the results.

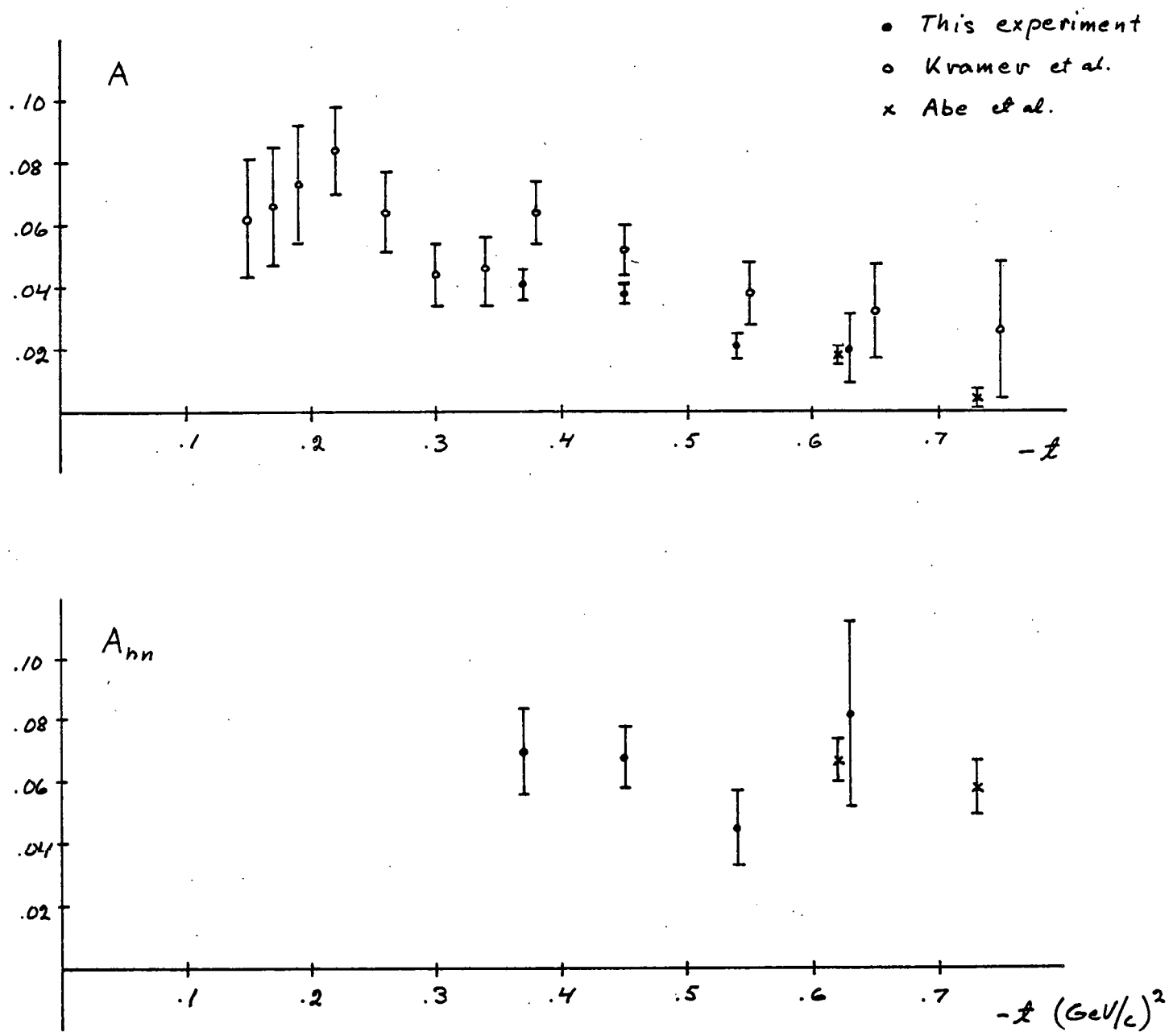

Figure 9: A and A_{nn} in p-p elastic scattering at p_{lab}=11.75 GeV/c.

The apparatus consisted of a single arm magnetic spectrometer viewing the PPT. The detectors were scintillation counter hodoscopes enabling the taking of the necessary high statistics without writing excessive amounts of magnetic tape. The π^- were identified by the momentum and time of flight measurements, and the backgrounds from e^-, $\bar{p}$, and K^- were negligible. Data were taken with the target flask empty and filled with dummy targets at each magnet setting to help determine the C-CH subtraction. Some significant asymmetries were observed on-line, and progress will be made on the analysis of this data within the coming year.

[8]D. G. Crabb *et al.*, Phys.Rev.Lett.

[9]AIP Conf.Proc. No. 51, p. 527 [originally presented by J. Antille].

9. Measurement of $\Delta\sigma_T$ in p-d Scattering [E-460]

We have measured $\Delta\sigma_T$ in p-d scattering using the ZGS polarized proton beam and a sample of fully deuterated (98%) ethylene glycol polarized in PPT VI. Some of the on-line results are shown in Fig. 10.

Measurements were made at seven momenta between 1.2 and 2.5 GeV/c, with both deuteron and proton samples polarized in the PPT, so that an identical-geometry subtraction can be made to extract $\Delta\sigma_T$ for p-n scattering, and thus by an additional subtraction $\Delta\sigma_T(I=0)$. The extraction of $\Delta\sigma_T(I=0)$ from $\Delta\sigma_T(pd)$ involves corrections due to shadowing and rescattering which include the real and imaginary parts of several of the pp and pn scattering amplitudes which are unknown. The subtraction of the p-p partial cross sections with identical geometry at least eliminates the need for Coulomb corrections to first order. This entire analysis is rather difficult and complex and will constitute a doctoral thesis for James Lesikar.

There have been indications from the $\Delta\sigma_L(pd)$ measurements of Auer *et al.*[10] of interesting structure in the I=0 spin-dependent cross sections near 1.5 GeV/c, so the $\Delta\sigma_T(I=0)$ results,

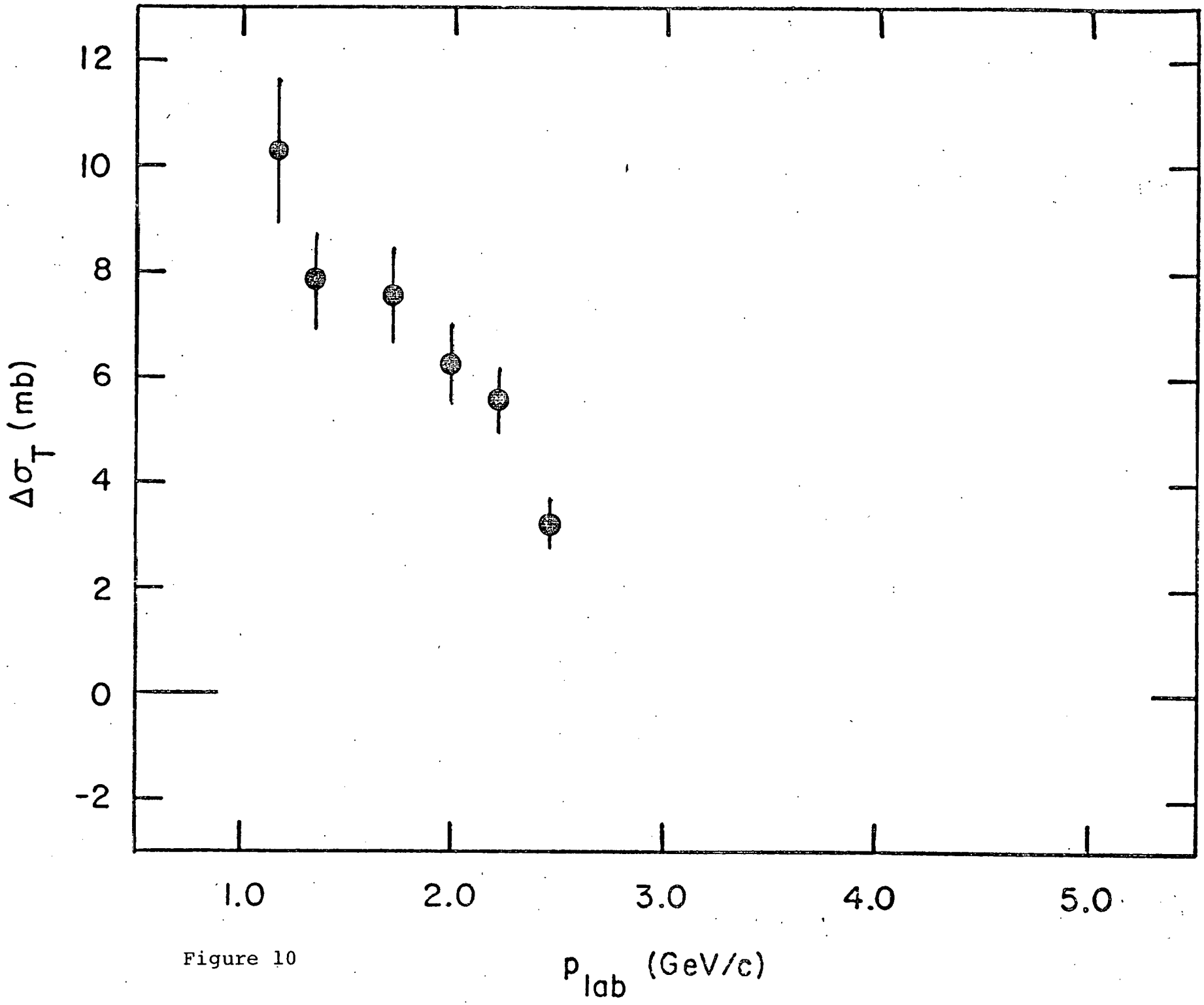

Figure 10

although difficult to obtain may prove to be of considerable interest.

[10] I. P. Auer, Nucleon-Nucleon Resonances, ANL-HEP-CP-79-64.

10. Energy Dependent Study of $pp \to pn\pi^+$ Using Polarized Proton Beams [E-462]

The inelastic reaction $pp \to p\pi^+n$ was studied at 1.2, 1.5, 1.75, and 2.0 GeV/c using the ZGS polarized proton beam and the Effective Mass Spectrometer. The EMS contains a large solid angle spectrometer magnet and a vertex detector surrounding the liquid hydrogen target. This system will allow the measurement of the density matrix elements and polarization correlations (including longitudinal and transverse spin correlations) for $\vec{p}+p \to \Delta^{++}n$ over the full range of Δ^{++} production angle (i.e., 0° to 180° in the center of mass).

The system was set to trigger rather loosely on final states with two charged particles. Off line analysis will identify $pp \to p\pi^+n$ events. Elastic scattering events will be used for solid angle and efficiency calibrations. Approximately 600,000 events per energy were accumulated during the experiment. Between 150,000 and 200,000 of these are expected to be $pp \to p\pi^+n$ events. The running time was divided into approximately 75% transversely polarized beam and 25% longitudinally polarized beam. Summary data tapes have been prepared at Argonne, and the analysis of these tapes has begun at Rice.

B. Instrumentation

1. Computer Systems

There has been continuing work on the upgrading of both the data acquisition and analysis computer systems. Additional memory (65K words) has been installed in the PDP 11/34 system and replacement memory (96K words) has been installed in the PDP 11/45

system. An 8-input serial multiplexor has been ordered to increase user utilization of the analysis computer by allowing more terminals to be installed. The faster PDP 11/45 system is being moved from the trailer to the Bonner Labs' computer location, while the PDP 11/34 system is being installed in the renovated trailer. This will allow more rapid data analysis, with still adequate data-acquisition speed. A new control panel arrangement with new features to better monitor data acquisition have been designed and is being installed.

2. Portable Laboratory Renovations

The trailer that has been used by Bonner Labs for six years now has become rather worn and required renovation. This necessary work was started during the contract year. It consists of repairs to the ceilings, walls, floors, and lighting fixtures. After the renovations the computer changeout (see above) will be carried out. The new floor layout of equipment is expected to improve the efficiency of operations.

3. Computer Control for NMR System of PPT VI: Deuteron Polarization

A paper, "Microprocessor-Controlled Target Polarization Monitor" was presented at the Topical Conference on Computerized Data-Acquisition Systems in Particle and Nuclear Physics which was held in Sante Fe, New Mexico on May 14-17, 1979.

Modifications to the NMR system to enable determination of the deuteron polarization were accomplished for experiment E-460 at the Argonne ZGS.

4. PPT Engineering

The polarized proton target PPT VI that was built jointly with ANL and used successfully there by the Rice Group was moved to the Bonner Labs during the contract year. The committee (R. Woods, Chairman) in charge of disposition of ZGS equipment transferred custody of this equipment to Rice University. During November 1979 the system was moved to Rice for re-engineering to effect a plan of making the target portable for use at Los

Alamos, AGS, and possibly other laboratories. Mr. James Bywater and his staff from ANL agreed to aid in this re-engineering as consultants. A "sea-container" was purchased for installation of most of the auxillary equipment.

5. Progress on Multiwire Proportional Chamber Development

Work has been completed on a new design for an improved model multiwire proportional chamber for use in experimental medium and high energy physics at Rice University.

A variety of different plastic materials was obtained and tested for strength and chemical resistance, and a suitable replacement for the present construction material, G-10 fiberglass, was found that was less expensive, more easily machined, and of lighter weight.

The new design eliminated many of the old design difficulties and incorporated several desirable features excluded in the old design. It is expected to increase the detection efficiency and nearly eliminate experimental "down" time for plane repair.

The development of this new design and the construction and testing of a working model scheduled for early 1980 are expected to partially fulfill the requirements of a Master of Arts degree in physics at Rice University for D. A. Bell, the graduate student assigned to the project.

In addition, plans are being made to study the feasibility of adapting this new design to the building of a multistep avalanche chamber, as developed by G. Charpak at CERN. An undergraduate student assistant has been assigned to this project for his senior thesis.

Should this new design fulfill its expectations, plans will be formulated to gradually replace all the old chambers with entirely new models. Attempts will be made to improve the old chambers until they are phased out of usage in the future.

C. Theory

A large amount of the theory work carried out by Professor I. M. Duck and Dr. Miroslav Furić, and their students on the Rice Medium Energy physics contract is very pertinent to the work reported here. For that reason that Progress Report is appended.

CHANGES IN PERSONNEL

During this contract year, valuable personnel have been added to our High Energy program, and several faculty have received recognition from Rice University. Professor S. D. Baker joined in the summer's research work at Argonne [he shares research with the High Energy contract 20% and the Medium Energy work 30%]. J. B. Roberts, Jr. was promoted to Associate Professor of Physics with tenure by Rice University. H. E. Miettinen, who joined the research work as a two-year Visiting Assistant Professor of Physics, was appointed to a tenure-track Assistant Professorship by Rice.

T. A. Mulera, the Senior Research Associate, resigned in September to return to California and a position at Berkeley.

Marjorie D. Corcoran joined the group as the Senior Research Associate in October; she comes to the group from research work with the University of Wisconsin. Her curriculum vitae is attached. Dr. Corcoran has assumed responsibility for data analysis of some of our prior experiments.

One graduate student was added during the past year, Kenneth Johns, who has worked with Dr. Roberts the past two summers as an undergraduate laboratory assistant. Mr. Johns was accepted as a graduate student by the Physics Department after three years of undergraduate work in which he completed four years of required Physics courses.

OTHER FINANCIAL ASSISTANCE: No support external to Rice University and this contract for the work reported here occurred during the year.

PUBLICATIONS:

1. T. A. Mulera, "Measurement of the Energy Dependence of $\Delta\sigma_T$ and A_{nn} for pp Scattering in the 1-3 GeV/c Region," Third International Symposium on High Energy Physics with Polarized Beams and Targets-Argonne (1978), AIP Conference Proceedings, No. 51 (1979), ed. G. H. Thomas, p. 428-433.

2. J. A. Buchanan, "Microprocessor-Controlled Target Polarization Monitor," Topical Conference on Computerized Data-Acquisition Systems in Particle and Nuclear Physics-Sante Fe, 1979 [to be published].

3. J. B. Roberts, Jr., "The ZGS Polarized Beam Program," History of the ZGS Symposium-ANL,1979, to be published in AIP Conference Proceedings.

INCIDENT REPORT: No incidents such as those outlined in attachment "A" have occurred during the contract year.

G. C. Phillips, Principal Investigator

November 30, 1979

MARJORIE D. BLASIUS CORCORAN

2306 Prairie Road
Madison, Wisconsin 53711
608/273-0057 (Home)
608/262-2486 (Lab)

Born 21 July 1950
Married, no children
U.S. Citizen

EDUCATION

Doctorate in Physics, Indiana University, 1977.
- Major in Physics, minor in Mathematics.
- G.P.A. 4.0
- Advisor: Professor Homer A. Neal.
- Dissertation title: Measurement of the Polarization Parameter in Proton-Proton Elastic Scattering for Beam Momenta Ranging from 20 to 200 GeV/c.

Bachelor of Science in Physics, University of Dayton, 1972.
- Major in Physics, minors in Mathematics and German.
- G.P.A. 3.93

Goethe Institut, Radolfzell, West Germany, 1971.
- Completed an intensive two-month course in the German language.

PROFESSIONAL EXPERIENCE

Project Associate in experimental High Energy Physics, University of Wisconsin, September 1977 to present.
- Participated in Wisconsin-Fermilab-Lehigh-Penn experiment conducted at Fermilab, using a double-arm calorimeter to study hadron jets.
  - Aided in construction of large drift chamber array.
  - Worked extensively on off-line data analysis.
  - Carried out detailed Monte Carlo calculations designed to aid in understanding instrumental effects.
- Involved in developmental work on large multiwire proportional chamber with charge division read-out.

Research Associate in experimental High Energy Physics, Indiana University, January 1973 to September 1977.
- Deeply involved in all phases of an experiment conducted at Fermilab which measured the polarization parameter in proton-proton elastic scattering.
  - Worked extensively on the design and construction of multiwire proportional chamber array.
  - Involved in the design and construction of scintillation counter hodoscopes and trigger counters, fast logic systems, and read-out systems for multiwire proportional chambers.
  - Worked extensively on all aspects of the data analysis.
- Participated in two experiments conducted at Argonne which measured spin parameters in proton-proton interactions.

Associate Instructor, Indiana University Physics Department, August 1972 to December 1972.

Research Assistant in Nuclear and Environmental Physics Laboratory, University of Dayton Physics Department, September 1969 to July 1972.

Instructor, Good Samaritan Hospital, Dayton Ohio, Summer 1970.
- Taught elementary physics course to x-ray technician students.

Engineering Assistant, U.S. Army Corps of Engineers, Wright Patterson Air Force Base, Dayton Ohio, July 1969 to August 1969.

Laboratory Assistant, University of Dayton Research Institute, Cryogenics Laboratory, Aerospace Research Laboratories, Wright Patterson Air Force Base, Dayton Ohio, May 1969 to June 1969.

HONORS AND AWARDS

Outstanding Physics Graduate Student, Indiana University, April 1976.
Indiana University Fellow, August 1975 to May 1976 and August 1972 to June 1973.
Alpha Sigma Tau Honor Society, University of Dayton, 1972.
Graduated Summa Cum Laude (second in class of over 1000), University of Dayton, 1972.
Sigma Pi Sigma Physics Honor Society, University of Dayton, 1971.
Caesar Castro Award in Elementary Physics, University of Dayton, 1970.

REFERENCES

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Professor Homer A. Neal, Department of Physics, Indiana University, Bloomington, Indiana 47401.

Professor Richard M. Heinz, Department of Physics, Indiana University, Bloomington, Indiana 47401.

Dr. C. Richard Cothern, Environmental Protection Agency, Office of Toxic Substances (TS-793), Washington, D.C. 20460.

PUBLICATIONS

Trace Metal Analysis Using X-ray Fluorescence and Electron Spectroscopy, with C. R. Cothern and C. D. Brown, Proceedings of the Sixth Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, Missouri, June 1972.

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π^+ Structure Information from a Jet Experiment, with M. Dris, A. Erwin, P. Gollon, E. Harvey, A. Kanofsky, W. Kononenko, B. Robinson, W. Selove, M. Thompson and B. Yost, submitted for publication.