(To be submitted to

Il Nuovo Cimento)

SLAC-PUB-389
HEPL 545

DECEMBER 1967

PI PAIR PRODUCTION WITH POLARIZED X-RAYS*

R. W. Morrison†

High Energy Physics Laboratory
Stanford University
Stanford, California

and

D. J. Drickey and R. F. Mozley‡

Stanford Linear Accelerator Center
and High Energy Physics Laboratory
Stanford University
Stanford, California

* Work supported in part by the U. S. Office of Naval Research Contract [Nonr 225(67)] and the U. S. Atomic Energy Commission. Distribution of this document is unlimited.

† Present address: Carleton University, Ottawa, Canada.

‡ Present address: Stanford Linear Accelerator Center, Stanford, California.

PI PAIR PRODUCTION WITH POLARIZED X-RAYS*

R. W. Morrison†, D. J. Drickey, and R. F. Mozley‡

High Energy Physics Laboratory and Stanford Linear Accelerator Center

Stanford University, Stanford, California

ABSTRACT

A study has been made of the reaction $\gamma + p \rightarrow \pi^- + N^{*++}(1238)$ using a polarized X-ray beam. The essentially null result obtained for the production asymmetry can assist in determining the OPE contribution to this reaction.

Introduction

Experiments by Allaby, <u>et al</u>[1] and by the DESY and CEA bubble chamber collaborations[2],[3] have indicated that in the region between 600 MeV and 1 GeV pi pair production is very much enhanced in the channel: $\gamma + p \rightarrow \pi^- + N^{*++}(1238)$. If one programs kinematically for a two-body final state of π^- and N^*, about 80% of the general reaction $\gamma + p \rightarrow \pi^- + \pi^+ + p$ will in fact proceed in this manner. If the momentum and angle of one final-state particle is measured, the polarized beam available at Stanford allows the determination of the photon energy and the reaction polarization asymmetry only for two-body final states. Therefore, the possibility of studying pi pair production exists for the quasi two-body final state $\pi^- N^*$ by observing solely the π^- with a spectrometer.

The use of polarized X-rays in photoproduction aids in determining parities and allows an evaluation of the possible presence of specific diagrams such as one pion exchange (OPE). Such a production process would in fact be entirely along the electric field vector and as a result photoproduction with polarized X-rays should be extremely sensitive to this.

The net result of the experiment described below was to find no asymmetry of greater than a few percent. The experimentally measured values are presented in table 1.

Experimental Technique

The Stanford polarized X-ray beam was used in the manner described in papers by Mozley, <u>et al</u>[4]. A partially polarized beam was produced by selecting the proper portion of a normal bremsstrahlung beam. The plane of polarization was changed from horizontal to vertical cyclically at intervals. The π^- mesons from a hydrogen target were deflected in a 90° spectrometer (fig. 1) and detected by a three counter scintillation telescope. The major background was from electrons and these, plus a small fraction of the pions, were largely rejected by a Čerenkov detector in anticoincidence.

The spectrometer had a resolution of about $\pm 2\%$ and when this was combined with the effects of target length and beam energy spread, an energy resolution of approximately $\pm 3\%$ was obtained. The photon beam was monitored by an ionization chamber. In operation a beam of one polarization direction was passed through the hydrogen target to give a predetermined integrated output from the ionization chamber, and the polarization was then shifted 90° cyclically.

The degree of polarization of the beam was calculated from a knowledge of the beam angle. Electron beam shape and multiple scattering in the radiator modified significantly the expected polarization. These effects were specifically taken into account by an experimental measurement of the beam distribution after passing through a half thickness radiator (0.0015" Al). This measurement was done by exposing a glass slide and measuring the darkening caused by the beam[4). The contribution to the total error introduced by these measurements is discussed below.

The principle problem with polarized photoproduction using the Stanford technique is that polarization exists only for the lower energy portion of the bremsstrahlung spectrum. At the peak of the spectrum, there is no polarization. (See fig. 2.) Since the peak beam energy readily available during this measurement was of the order of 1 GeV, the polarization available for the higher energy points was quite low (~ 8%).

An additional problem in this experiment was that negative pions may be produced by the higher energy bremsstrahlung. These may be made by any of several reactions:

$$\gamma + p \rightarrow \pi^- + N^{*++}$$

$$\gamma + p \rightarrow \pi^- + \pi^+ + p$$

$$\gamma + p \rightarrow \pi^- + \pi^+ + \pi^0 + p$$

$$\gamma + p \rightarrow \pi^- + \pi^+ + \pi^+ + n \quad .$$

Fortunately the work of Allaby, et al[1)] evaluates the total amounts of these reactions in such a way as to be applicable to our measurements. Their measurements were as follows: Setting a spectrometer at a fixed momentum and angle for the π^-, the peak beam energy was varied and the resultant yield measured, as in fig. 3. For a fixed recoil mass, the initial rise would be very steep. In this case the width is due to the N^*, the continued rise being due to other processes. The analysis assumed a phase space distribution for the other processes and made a two parameter fit to the data. The resulting integral curves allow us to obtain the ratio of background to N^* production as a function of peak beam energy as may readily be seen from the figure.

It would have been desirable for us to make our own measurements of this ratio, but the data rate with polarized bremsstrahlung is much lower than in the Allaby configuration. As a result we have used their data to obtain our background estimates. These are unpublished, but are the data from which their published results derive. The fraction of $N^*(1238)$ at each experimental point is shown in table 1, together with a somewhat arbitrary 10% error.

Backgrounds and Errors

The major errors are random in nature, the dominant one being due to counting statistics. One evaluates the asymmetry parameter

$$\Sigma = \frac{d\sigma_\perp - d\sigma_\parallel}{d\sigma_\perp + d\sigma_\parallel} \quad ,$$

$d\sigma_\perp$ and $d\sigma_\parallel$ being the differential cross sections perpendicular and parallel to the electric field. The actual measurement is of $R = \mathrm{Yield}_\perp/\mathrm{Yield}_\parallel$, the ratio of the yields perpendicular and parallel to the electric field vector. The polarization $P = (N_\perp - N_\parallel)/(N_\perp + N_\parallel)$ (where $N_{\perp,\parallel}$ is the number of perpendicular and parallel photons) is calcualted from a measurement of beam size, angular divergence, and multiple scattering. In this experiment where a phase space background may contribute we may write

$$\mathrm{Yield}_\perp = N_\perp(d\sigma_\perp + dB) + N_\parallel(d\sigma_\parallel + dB)$$

$$\mathrm{Yield}_\parallel = N_\parallel(d\sigma_\perp + dB) + N_\perp(d\sigma_\parallel + dB) \quad ,$$

where dB is the non-N^* contribution to the yield and is assumed to have no polarization asymmetry. This leads to

$$\Sigma = \frac{1}{P}\,\frac{1}{f}\,\frac{R-1}{R+1} \qquad \text{where} \quad f = \frac{d\sigma_\perp + d\sigma_\parallel}{d\sigma_\perp + d\sigma_\parallel + 2dB} \quad .$$

The principle backgrounds were those due to the electron beam of the accelerator but not caused by the bremsstrahlung beam, and those due to the bremsstrahlung beam but not from the hydrogen target. Both backgrounds were of the order of a few percent and were evaluated by radiator out and target out runs. A more difficult error was involved in the separation of negative pions from a background of electrons.

Our detection system consisted of a three counter scintillation telescope with a Čerenkov detector in anticoincidence. Pion energies were in general high enough so that pulse height information was not sufficient to distinguish the pions. As a result it was necessary to know the efficiency of the Čerenkov detector. This counter was calibrated below meson threshold assuming that the only particles present were electrons, so that it was possible to use the scintillation telescope to determine the efficiency of the Čerenkov detector. We found a value of about 0.8 ± 0.05 which was used in correcting our data. The error contribution caused by the error in this value is less than $\pm 2\%$, since even in the worst case (the high energy points) the electrons are only about 30% of the pions.

We consider three sources of error in the polarization. The first arises because the polarization calculation involves a measurement of the undeflected electron beam size at the defining collimator after passing through a radiator one-half of the normal thickness. The beam causes darkening of a glass slide which is then measured on a densitometer. The error in such a measurement can be divided into the following:

a. Accuracy of measurement of single spot,

b. Accuracy of determination that the exposure is in linear region,

c. Variation of spot width at different times during data taking. The latter is the dominant error and the total error in spot width is estimated of the order of 6% , varying according to machine stability. We have assumed that two measurements of spot width at either end of a running period define the variation in running condition in between. As a result the contributions of error vary with running period. The approximate contribution to polarization error is tabulated separately for each run and varies from 2 to 11%. A second source of polarization error is the determination of the angle of the selected photons from that of the initial beam. Errors differ for different energies but are of the order of ±3%. The third contribution to the polarization error is related to the error in measuring the beam energy and the spectrometer setting. This error of about 2.5% affects the polarization error with greater effect for lower polarization and hence for the higher energy points. The contribution varies from 1.7% at 570 MeV to about 10% at 800 MeV. This error estimate is based on a narrow mass for the N^* . The polarization will vary approximately inversely with the mass of N^* produced, but should produce the central value on the average. The total polarization error was then found for each run by averaging effects from spot width, angle determination and energy determination as random. Values of $\frac{\Delta P}{P}$ varied between 0.05 and 0.14 , depending on the kinematic point and running conditions.

Possible systematic errors in the evaluation of the ratio R were negligible since in any measurement the polarization direction is cycled about 100 times and the same electronic circuits used. As a result the effects of any drift of sensitivity are small. The error in R is therefore considered as entirely due to counting statistics.

The fraction of the state going to N^* was evaluated by using unpublished data of Allaby, Lynch, and Ritson. Since our measurements have in all cases given a null result for $\frac{1}{P}\frac{R-1}{R+1}$, the error in the evaluation of $\sum = \frac{1}{f}\frac{1}{P}\frac{R-1}{R+1}$ is to a large extent independent of the error in f . An error of 10% in f , which we somewhat arbitrarily assign, contributes imperceptably to the total error.

Comparison with Theory

These results are particularly relevant to models that describe $N^*(1238)$ formation by photons in terms of a one pion exchange diagram (Drell process). If this process dominates, one expects the π^- to emerge predominantly along the electric field vector. The one pion exchange term is not gauge invariant by itself; however, a simple gauge invariant extension has been proposed by Stichel and Scholz[5] who considered the diagrams shown in fig. 4. This model has been extended to the case where linearly polarized photons are used in the production process by Böckmann, et al[6] who calculate explicitly the asymmetry $\sum$ to be expected with this model. They point out that the only contribution to a cross section perpendicular to the electric field comes from the contact graph, (no. 2). Their results are shown in fig. 5 for photon energies 1.0 GeV and 2.0 GeV . Our experimental points, although they were not taken at these energies, are also plotted. We conclude that our data do not support this model and are, in fact, more consistent with a multiresonant model.

The Cambridge Bubble Chamber Group[7] has interpreted its results for $N^*(1238)$ production in terms of such a model where higher nucleon isobar production in the S channel feeds the 1238 MeV channel via a decay into the $N^*(1238)$ and a negative pion. Although the detailed predictions have not been investigated, we feel our results are in qualitative agreement with this model since it provides the mechanism for production of the π^- meson without polarization asymmetry. We have looked only at the case of the interaction proceeding through either a $J = 3/2$ or $J = 1/2$ resonance.

A general phenomenological formulation of the angular distribution for decay from $3/2$ into the $N^* + \pi^-$ is given by[8)]

$$W(\theta\varphi) = [A|F_{3/2}|^2 + B|F_{1/2}|^2] (1 + 3 \cos^2\theta)$$

$$+ [A|F_{1/2}|^2 + B|F_{3/2}|^2] \, 3 \sin^2\theta$$

$$-2\sqrt{3} \, [\mathrm{Re}C] \sin^2\theta \, [|F_{3/2}|^2 - |F_{1/2}|^2] \cos^2\theta \cos 2\varphi \quad .$$

Here $F_{3/2}$ and $F_{1/2}$ are the two helicity amplitudes for the decay $N^{**} \rightarrow N^* + \pi$. A and B are real, while C is related to A and B by $AB = CC^*$. θ is the angle of the pion with respect to the photon, while φ is the angle between the electric field vector and the plane of pion emission.

A solution for pure S wave decay occurs when

$$|F_{3/2}|^2 = |F_{1/2}|^2 \quad .$$

There will also be no asymmetry for the case of a $J = 1/2$ intermediate state, $A = C = 0$.

In conclusion, it is quite possible to fit the existing data of polarization asymmetry by a theory requiring decay from other baryon resonances. There appears to be some discrepancy with the calculations assuming OPE dominance.

Acknowledgements

We wish to express our appreciation for the help received from E. Maninger and Professor F. F. Liu during the performance of the experiment. The excellent cooperation of the Mark III accelerator crew was essential. Dr. J. Allaby was of immense assistance in interpreting his unpublished data to allow us to evaluate the fraction of $N^{*}\pi^{-}$ two-body final state.

REFERENCES

* Work supported in part by the U. S. Office of Naval Research Contract [Nonr 225(67)] and the U. S. Atomic Energy Commission. Distribution of this document is unlimited.

† Present address: Carleton University, Ottawa, Canada.

‡ Present address: Stanford Linear Accelerator Center, Stanford, California.

1) J. V. Allaby, H. L. Lynch, and D. M. Ritson, Phys. Rev. 142 (1966) 887

2) CEA Bubble Chamber Collaboration, Phys. Rev. Letters 13 (1964) 640

3) DESY Bubble Chamber Collaboration, Physics Letters 23 (1966) 707

4) The best description of this beam is contained in two references: R. C. Smith and R. F. Mozley, Phys. Rev. 130 (1963) 2429; and R. E. Taylor and R. F. Mozley, Phys. Rev. 117 (1960) 835

5) P. Stichel and M. Scholz, Nuovo Cimento 34 (1964) 1381

6) K. Böckmann, W. Sandhas, and H. Wessel, University of Bonn Physical Institute, preprint, (1967)

7) Cambridge Bubble Chamber Group, "Production of the $N^*(1238)$ Nucleon Isobar by Photons of Energy up to 6 GeV," June 1967 (to be published)

8) S. Berman (private communication)

LIST OF FIGURES

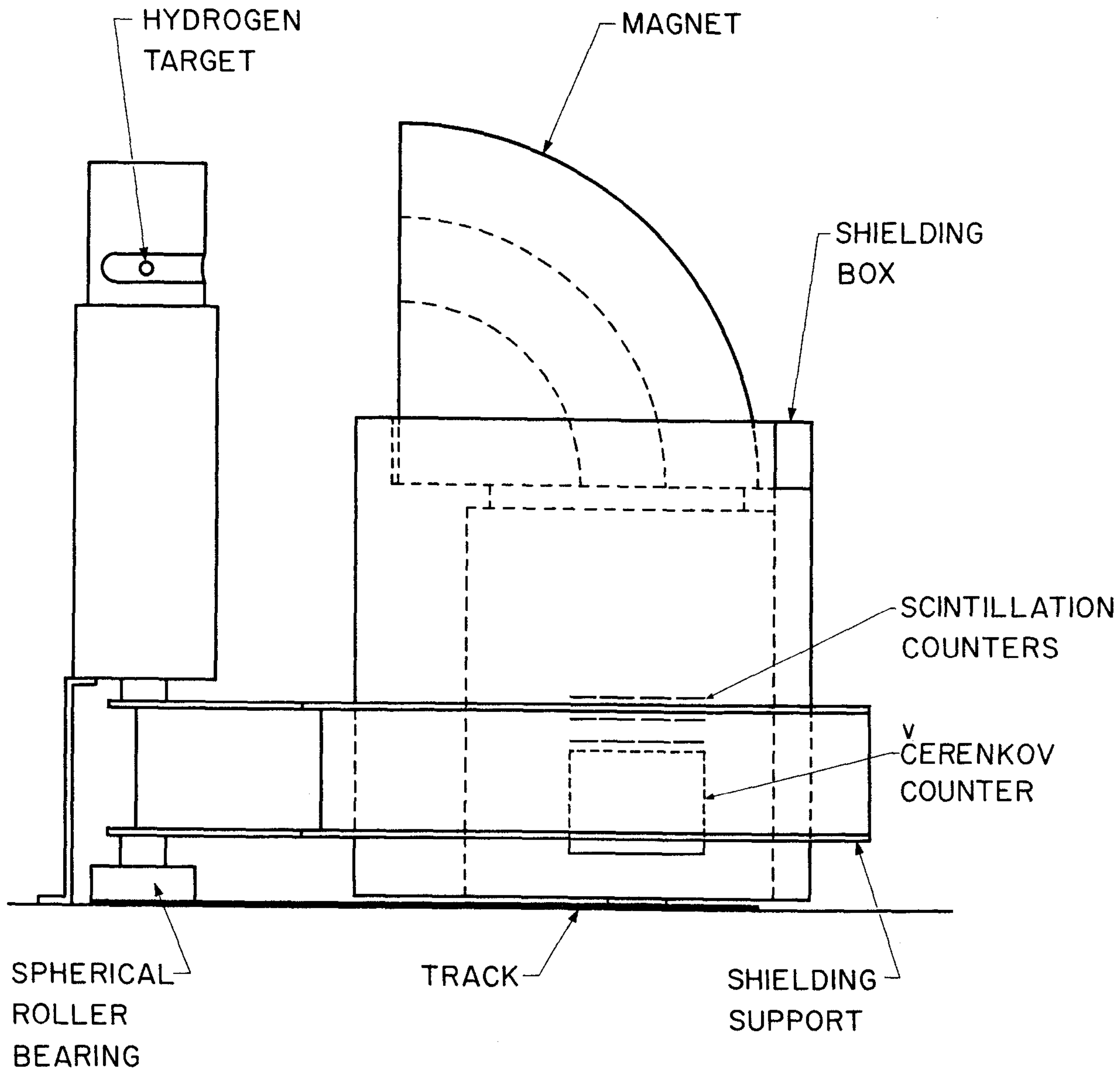

HYDROGEN
TARGET
MAGNET
SHIELDING
BOX
SCINTILLATION
COUNTERS
ČERENKOV
COUNTER
SPHERICAL
ROLLER
BEARING
TRACK
SHIELDING
SUPPORT

Figure 1

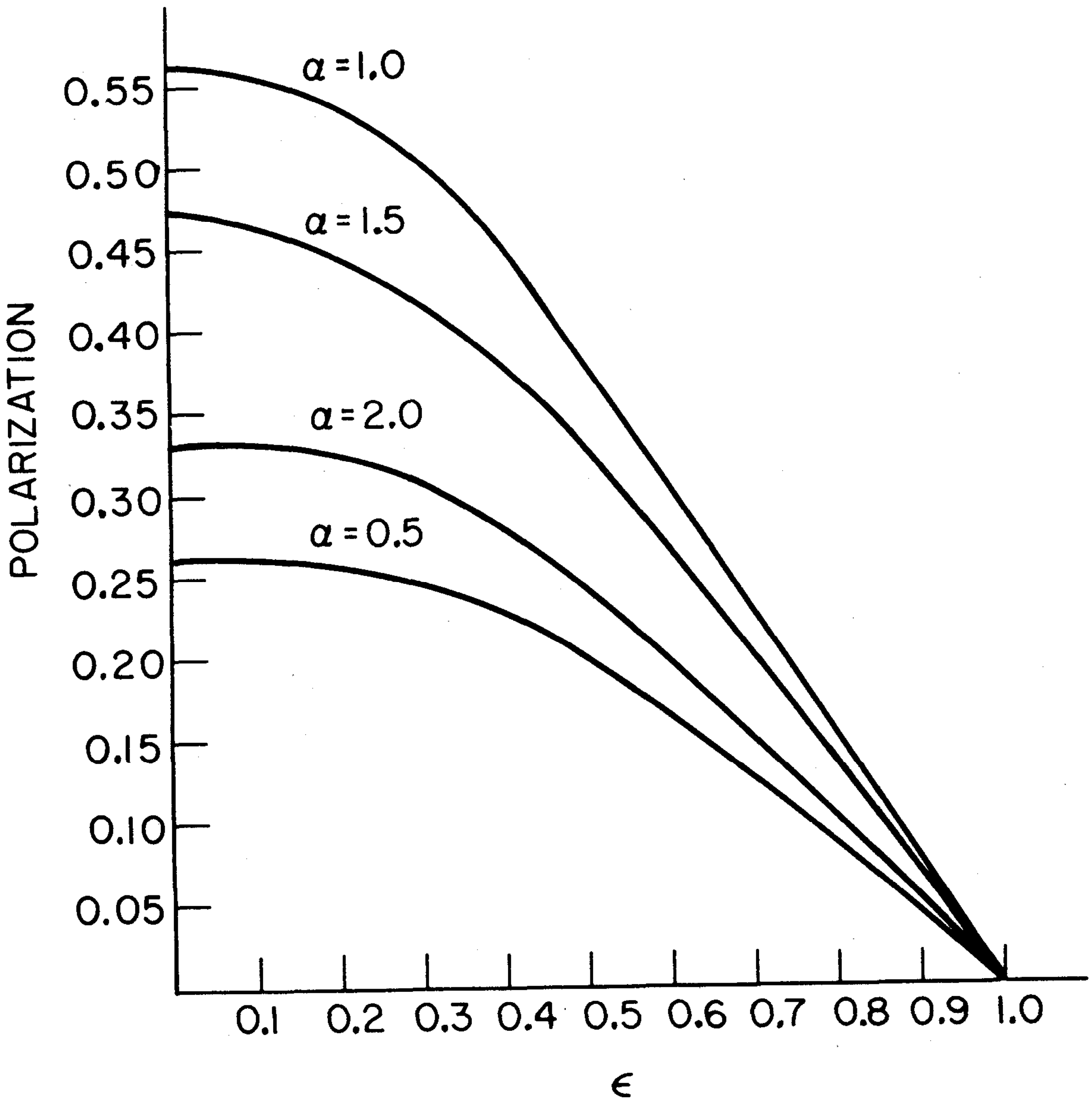
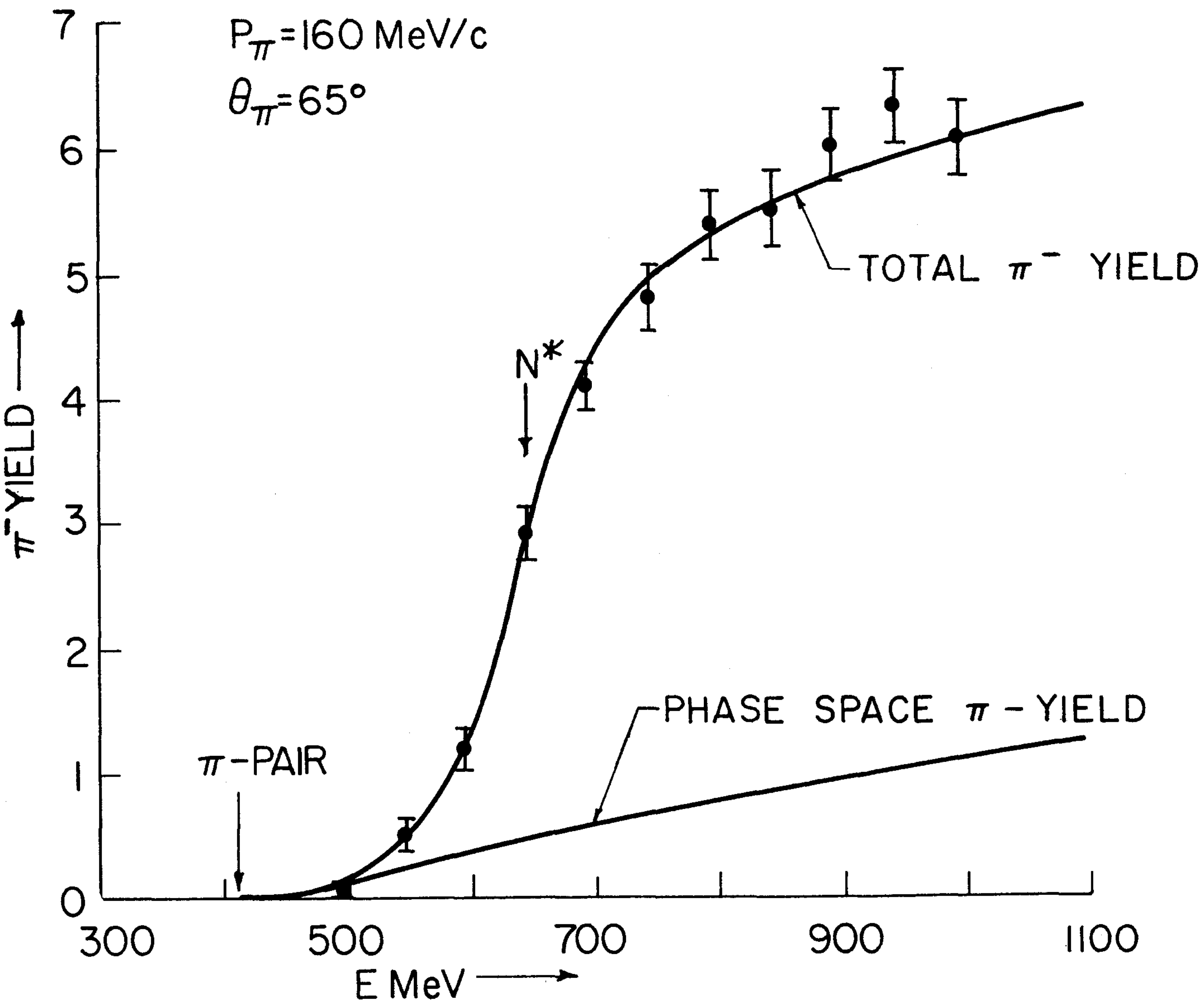

α=1.0
α=1.5
α=2.0
α=0.5
POLARIZATION
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
ϵ

Figure 2



P_π = 160 MeV/c
θ_π = 65°
π⁻ YIELD
E MeV
N*
π-PAIR
TOTAL π⁻ YIELD
PHASE SPACE π - YIELD
0
1
2
3
4
5
6
7
300
500
700
900
1100

Figure 3

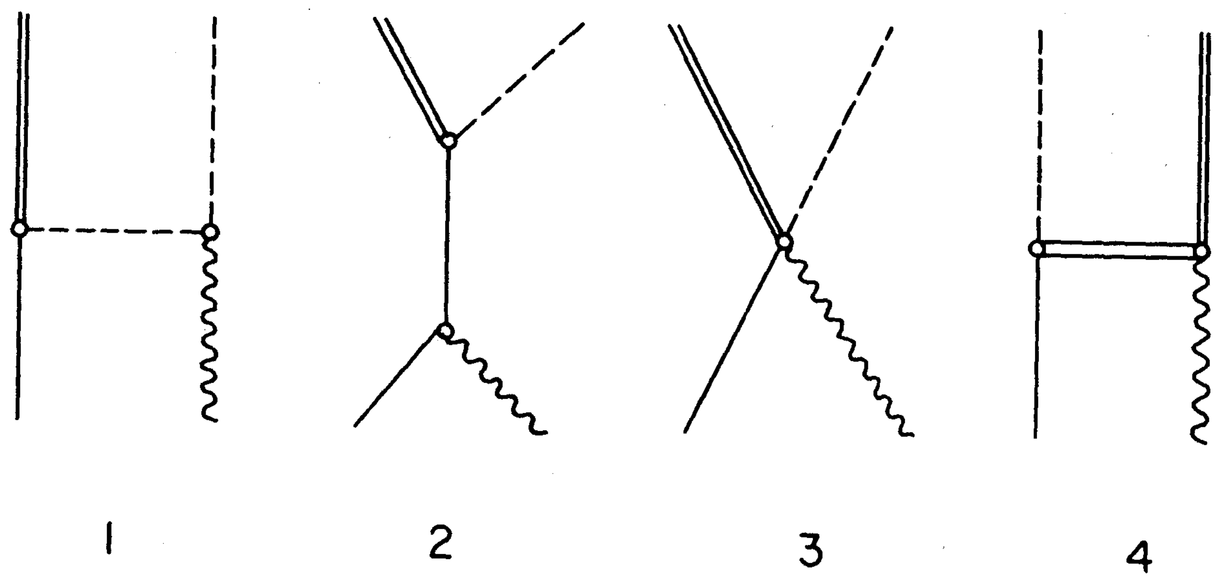


Figure 4

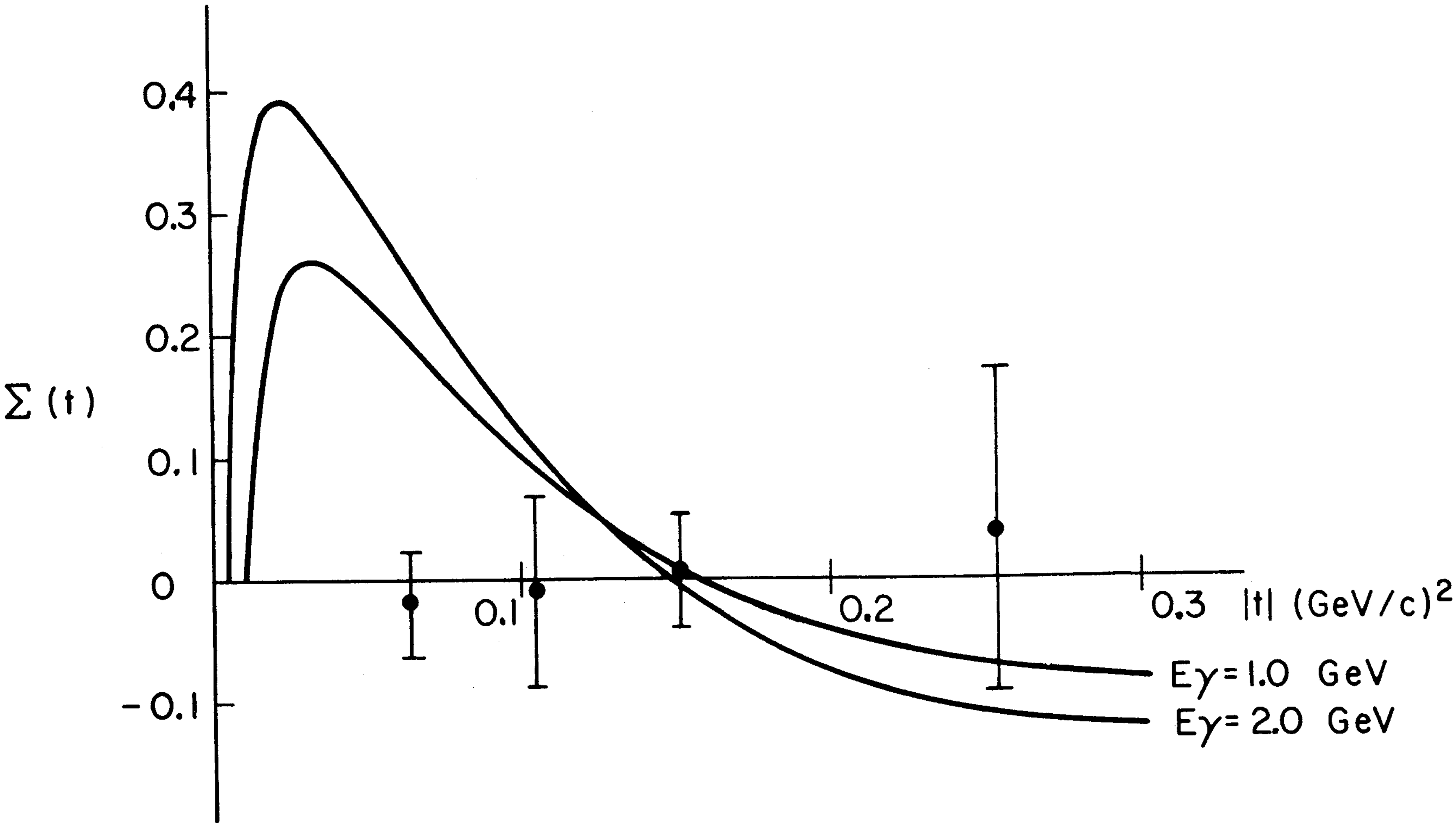


Figure 5

TABLE I

Summary of Data and Associated Errors

E_γ^* lab	$\theta^*_{\pi^-}$ c.m.	Peak Beam Energy	P^*	$\frac{1}{P^*}\frac{R-1}{R+1}$	f	t^* $(GeV/c)^2$	Σ^*
570 MeV	90°	1000 MeV	0.22 ± 0.015	-0.0075 ± 0.051	0.69 ± 0.07	0.10	-0.0109 ± 0.074
650 MeV	90°	975 MeV	0.16 ± 0.011	0.0059 ± 0.035	0.78 ± 0.08	0.15	+0.0076 ± 0.045
650 MeV	45°	900 MeV	0.15 ± 0.011	-0.015 ± 0.034	0.82 ± 0.08	0.06	-0.018 ± 0.041
800 MeV	90°	1050 MeV	0.11 ± 0.012	0.026 ± 0.091	0.71 ± 0.07	0.25	+0.037 ± 0.13

*Starred quantities are significant only for the $\pi^- N^*$ two-body final state.