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Polarization of Σ^0 Hyperons from $\pi^- p \rightarrow \Sigma^0 K^0$ Near 1.3 BeV/c[*]

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ABSTRACT

Production of $\Sigma^0 + K^0$ by π^-'s incident on liquid hydrogen has been studied in the π^- momentum region from 1200 to 1400 MeV/c. By means of spark chambers, the Σ^0 polarization has been measured at four incident π^- momenta. Significant polarization, $\alpha_\Lambda P_\Sigma = -0.71^{+.33}_{-.25}$, exists in the backward hemisphere of Σ^0 production in the π^- momentum region from 1300 to 1350 MeV/c. Angular distributions have also been measured.

I. INTRODUCTION

We detected associated production of Σ^0's by π^- mesons incident on liquid hydrogen, recording the spark-chamber events photographically. Charged secondaries arising from the production and decay sequences

$$
\begin{aligned}
&\qquad\qquad\quad \ulcorner\!\rightarrow \pi^+ + \pi^- \\
&\pi^- + p \rightarrow K^0 + \Sigma^0 \\
&\qquad\qquad\qquad\qquad \rightarrow \Lambda^0 + \gamma \xrightarrow[\text{conversion}]{\text{lead}} e^+ + e^- \\
&\qquad\qquad\qquad\qquad\quad \llcorner\!\rightarrow p + \pi^-
\end{aligned}
$$

were detected in semicylindrical spark chambers. Topologically the events appear as two vees plus a γ-ray conversion pair. The primary goal of the experiment was to look for a region of large Σ^0 polarization, because with polarized Σ^0's the $\Sigma\Lambda$ relative parity can be measured by a method[1-3] independent of those used heretofore.[4-6] The polarization of the decay lambdas from $\Sigma^0 \rightarrow \Lambda^0$ + Dalitz pair, is correlated with the orientation of the plane of the Dalitz pair in a way that depends on the Σ^0 relative parity. Measurement of the Σ^0 parity using this technique does not depend in any essential way upon other results, as do other methods that have been used.[4-6]

II. EXPERIMENTAL METHOD

The incident π^- beam, with momentum in the range 1200 to 1400 MeV/c, was produced from an internal target at the Bevatron. A conventional beam-transport system was used to convey the π^- from the production target to a liquid-hydrogen secondary target. The hydrogen target was a 3-in.-diam 6-in.-long cylinder with its axis perpendicular to the beam direction. The target and detection apparatus were placed at the downstream end of a bending magnet, M (see Fig. 1), which dispersed the beam so that images of the internal target for various momenta were spread along the axis of the liquid-hydrogen target. The momentum of each beam particle could be determined by measuring tracks in beam-defining spark chambers placed at the entrance and exit of magnet M.

The primary particle detectors were two coaxial semicylindrical spark chambers viewed axially. Stereo information was provided by photographing spark images obtained by reflection of light circumferentially around the gaps.[7] (See Fig. 2.) The plates were 0.003-in. thick, hand-polished aluminum foil. A 1/16-in. -thick lead plate between the inner four-gap and outer six-gap chambers effected the conversion of γ-rays from the $\Sigma^0 \rightarrow \Lambda^0 + \gamma$ decays. Spark resolution was 0.75 mm for tracks normal to the spark-chamber plates.

From Fig. 2 it can be seen that a bona fide event is expected to lead to six charged particles in the final state, with two of them (electron pair) very close together. The triggering logic therefore demanded simultaneously (a) an incident pion, identified by scintillation and Cerenkov counters in the beam, and (b) five or more time-coincident particles emerging from the hydrogen target. This latter requirement was accomplished by surrounding the spark chambers with an array of 48 continuous scintillation counters whose signals provided the inputs to an adder-discriminator.

Figure 2 shows the experimental apparatus. Views of the various chambers have been taken from a photograph of an actual event and superimposed on the drawing. Sparks appeared to be twice as intense in the direct view of the semicylindrical chambers as in the stereo view. Hence, neutral-density filters were used to equalize apparent spark intensities.

III. DATA REDUCTION AND ANALYSIS

From 1.2 million photographs, 304 unambiguous $\Sigma^0 K^0$ events were obtained. The Λ^0 and K^0 decay vertices were not usually in the visible region of the chambers, so it was most practical to measure every event with four charged secondaries and an apparent conversion pair, unless the tracks formed a star or a kinematically impossible configuration. The SCAMP digitized measuring projectors with magnetic-tape storage were used for the film measurements.

It should be noted that track reconstruction is anomalous in this cylindrical geometry, because the straight particle tracks do not in general appear straight in the stereo view, where the sparks are seen after tangential reflections. The track images are sections of hyperbolas. Most tracks, however, appeared nearly straight, and were reconstructed by using the tangents at both ends of each track image.

Each measured event was checked for consistency and for rough kinematical fit. The approximately 710 events surviving these preliminary checks were subjected to a χ^2 test. The chosen χ^2 function was based on a simple fitting procedure which adjusted the positions of the four tracks from the Λ^0 and K^0 decays. Because the momentum and position of the incident pion were well determined and because the kinematical fit is insensitive to the γ-ray parameters, these tracks were not adjusted in the fitting procedure. The χ^2 function was

$$\sum_{i-1,\,4} \left[\left(\frac{\theta_i - \theta^0{}_i}{\sigma_i\ (\theta_i)}\right)^2 + \left(\frac{\phi_i - \phi_i{}^0}{\rho_i\ (\phi_i)}\right)^2\right]$$

where $\phi_i{}^0$ and $\theta_i{}^0$ are respectively the measured azimuth and dip angles of the ith track, $(1 \leq i \leq 4)$, ϕ_i and θ_i are the adjusted angles, and ρ_i and σ_i were estimated as functions of plate-to-track angles in dip and azimuth.

Approximately one-seventh of the measured events were accepted for the Σ^0 polarization analysis. Of the events that failed to pass as $\Sigma^0 K^0$, approximately half were judged to have gross qualitative defects that made questionable their original selection by scanners. The rest were attributed mainly to stars with single secondary scatterings and to events with multiple beam tracks (the beam chambers had better time resolution than the semicylindrical chambers).

To avoid various scanning and triggering biases for the differential cross-section analysis, a geometrical cutoff was imposed on the events used in the polarization analysis. About 3/5 of the sample for the polarization measurement survived the cutoff and were used for the differential cross-section analysis. The detection efficiency of the system, which was particularly low for forward Σ^0 production, was found as a function of hyperon center-of-mass (c. m.) production angle and pion beam momentum by means of a Monte Carlo computer program; the results were used to correct the observed angular distributions to obtain the angular distributions presented here.

A substantial proportion of the events that fitted $\Sigma^0 K^0$ production and decay hypothesis had ambiguous solutions; that is, there were multiple solutions (more than one assignment of track labels gave a fit) within the resolution of the system. Such events were eliminated from both the real events and the Monte Carlo samples.

Events were checked for selection biases by comparing the observed events with events simulated by a Monte Carlo technique. A selection bias against certain decay configurations in the chambers was found, and was corrected in the angular-distribution analysis by eliminating such decays from both the real events and the Monte Carlo samples.

Contamination of the event samples by $\Lambda^0 K^0$ production with an accidental γ ray is expected to be less than 1% based on known cross sections, a search for accidental γ rays, and a Monte Carlo estimation of the probability that this type of event would be accepted as a $\Sigma^0 K^0$ event. Contamination of the sample by $\Lambda^0 K^0 \pi^0$ production is expected to be less than 1% based on known cross sections and a Monte Carlo study.

The polarization analysis was done by means of a maximum-likelihood function based on the decay Λ^0 polarization

$$\underset{\sim}{P}_\Lambda = - (\underset{\sim}{P}_\Sigma \cdot \hat{k})\, \hat{k},$$

where $\underset{\sim}{P}_\Sigma$ is the Σ^0 polarization and $\hat{k}$ is the direction of the decay γ ray in the Σ^0 c.m. system. The Λ^0-decay angular distribution is given by

$$I(\theta) = \frac{1}{2} (1 + \alpha_\Lambda P_\Lambda \cos\theta)$$

where θ is the angle between the Λ^0 polarization and the momentum of the decay pion; the current experimental value[8, 9] of α_Λ is -0.62±.05.

The likelihood function used was

$$\mathcal{L}(\alpha_\Lambda P_\Sigma) = \Pi_i \left[1 - (\alpha_\Lambda P_\Sigma)(\hat{N}_i \cdot \hat{k}_1)(\hat{k}_i \cdot \hat{k}_\pi)\right],$$

where i denotes the value for the $\underline{i}$th event, $\hat{N}_i$ is the direction of $\underset{\sim}{P}_\Sigma$, and $\hat{k}_\pi$ is the direction of the decay pion in the Λ c.m. system. Errors associated with values of $\alpha_\Lambda P_\Sigma$ found in this way were taken to be the half-widths of the likelihood functions at $e^{-1/2}$ of the maximum heights.

IV. RESULTS

A. Angular Distribution

Our angular distributions, along with those of other experimenters,[10-12] are shown in Fig. 3. The smooth curves represent cosine power-series fits. Our series have been carried to third order (even though in most cases fits to lower order give acceptable probabilities) because third order was required at 1225 MeV/c by Binford et al.[10] We obtained no total cross sections for the various beam-momentum bins. Our angular distributions have been normalized to 228 μb at 1275 MeV/c and to 225 μb at 1325 and 1365 MeV/c.[13] Table I lists the cosine series coefficients as functions of beam momentum (see Fig. 4).

B. Total Cross Section

We have obtained a total cross section for $\pi^- + p \rightarrow \Sigma^0 + K^0$ combining all of our events into one π^- momentum bin. The distribution in pion beam momentum of all events is shown in Fig. 5. The cross section obtained for these events is 0.22 ± .02 mb. This compares well with values found by Binford (Table I), and therefore we conclude that the triggering efficiency of the electronic adder-discriminator is near unity. The error cited is statistical only and the cross-section value is subject to electronic and scanning inefficiencies. Because the experiment was not designed to measure total production cross sections, we did not measure the momentum distribution of the pion beam, and for this reason we cannot determine the production cross sections as a function of momentum.

C. Polarization

Figure 6 shows the Σ^0 polarization as a function of the c.m. production angle of the Σ^0 with the events divided into four momentum bins and two production angle bins. We note that the Σ^0 polarization averaged over all events is very small. Statistically significant polarization is seen, however, in the backward hemisphere of Σ^0 production at 1325 MeV/c; the value obtained is $\alpha_\Lambda P_\Sigma = -0.71^{+.33}_{-.25}$.

D. Discussion

The existence in the distribution at 1225 MeV/c (pion beam momentum) of large $\cos^3\theta$ terms that are not present at 1170 MeV/c has been attributed by Binford[10] to interference of $s_{1/2}$ and $f_{7/2}$ amplitudes. The $f_{7/2}$ amplitude is assumed to be large because of the 1920-MeV $N^*_{7/2}$ $(T=3/2)$ resonance, which is centered at 1480 MeV/c in π^- momentum and has a half-width of 200 MeV/c. Carayannopoulous et al. find a similar change in the odd cosine-series coefficients between 1111 and 1206-MeV/c pion momenta in $\pi^+ + p \rightarrow \Sigma^+ + K^+$ (pure $T = 3/2$).[14] This seems to support the above suggestion by Binford; unfortunately, Carayannopoulous et al. confine their partial-wave analysis to s, p, and d waves only. The angular distributions found in the present experiment also support Binford's suggestion, because the odd cosine-series coefficients continue to dominate up to 1376 MeV/c. We note, however, that the Σ^0 polarization seems to change rapidly in the 1200- to 1400-MeV/c region. Figure 7 shows the forward-backward asymmetry of the Σ^0 polarization (the difference between $\overline{P}_\Sigma$ averaged over the forward hemisphere and $\overline{P}_\Sigma$ averaged over the backward hemisphere.) Although the data are not statistically compelling, this function appears to vary greatly with energy. Because the polarization is not likely to vary rapidly with energy if the angular distribution is dominated by a single interference term involving a broad resonance, the data suggest that the interaction may be more complicated than simple $s_{1/2}$ - $f_{7/2}$ interference.

FOOTNOTES AND REFERENCES

[*] This work was done under the auspices of the U. S. Atomic Energy Commission.

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Table I. Coefficients of cosine power-series fits for $\pi^- + p \rightarrow \Sigma^0 + K^0$.

Momentum (MeV/c) Reference	1129 Binford[a]	1170 Anderson[b]	1235 Binford[a]	1277 Binford[a]	1275 This Exp't.	1325 This Exp't.	1326 Binford[a]	1365 This Exp't	1605 Schwartz[c]
A_0	13.2±1.4	12.8±1.5	14.2±2.2	13.3±1.8	17.7±5.7	13.4±3.0	12.6±2.2	15.5±3.6	4.4±1.2
A_1	0.72±2.0	3.8±2.2	17.7±6.1	24.1±5.8	8.1±15.9	23.3±9.7	19.0±7.3	19.9±11.8	0.7±6.3
A_2	22.8±4.1	20.8±4.3	20.4±6.6	14.8±4.8	1.4±23.9	13.4±11.6	12.1±5.9	7.0±11.8	12±11
A_3			-32.2±9.5	-42.2±9.5	-24.2±37.1	-33.5±19.2	-34.8±12.0	-36.8±22.8	49±29
A_4									6±15
A_5									-77±29
No. of events	738	322	257	315	44	78	168	50	117
Normalization	262±15	248	264±25	229±20	228[d]	225[d]	209±25	225[d]	121

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a. Reference 10.

b. Reference 11.

c. Reference 12.

d. Not a measured cross section.

FIGURE LEGENDS

Fig. 1. Plan view of apparatus and optical arrangement.

Fig. 2. Schematic diagram of counters and spark chambers, with a photograph of an event superimposed.

Fig. 3. Differential cross section for $\pi^- + p \rightarrow \Sigma^0 + K^0$. The solid curves represent cosine power-series fits from Table I.

Fig. 4. Coefficients A_n, from Table I, of cosine power-series $d\sigma/d\Omega = \sum_n A_n \cos^n\theta$ as a function of beam momentum; a denotes Anderson, b Binford, c this experiment, and d Schwartz.

Fig. 5. Momentum histogram of incident π^- for events used in the angular-distribution analysis and total-cross-section calculation.

Fig. 6. Sigma polarization in the form $\alpha_\Lambda P_\Sigma$ vs Σ^0 c.m. production angle for the π^-- beam momentum intervals shown.

Fig. 7. $\alpha_\Lambda P_\Sigma$ for the forward Σ^0 production hemisphere minus $\alpha_\Lambda P_\Sigma$ for the backward hemisphere as a function of pion beam momentum.

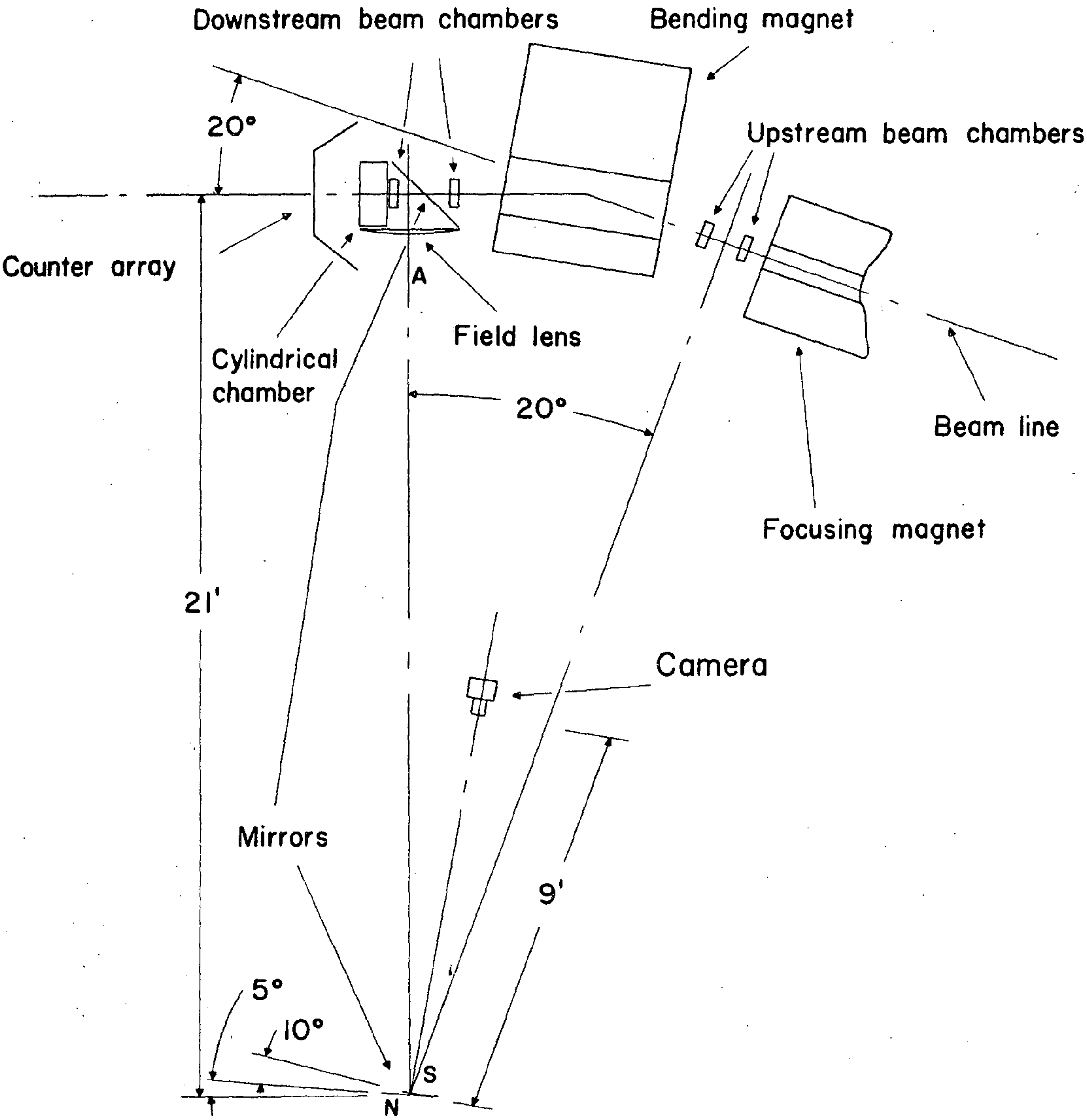

Downstream beam chambers
Bending magnet
20°
Upstream beam chambers
Counter array
A
Field lens
Cylindrical chamber
20°
Beam line
Focusing magnet
21'
Camera
9'
Mirrors
5°
10°
S
N
MUB-4699

Fig. 1

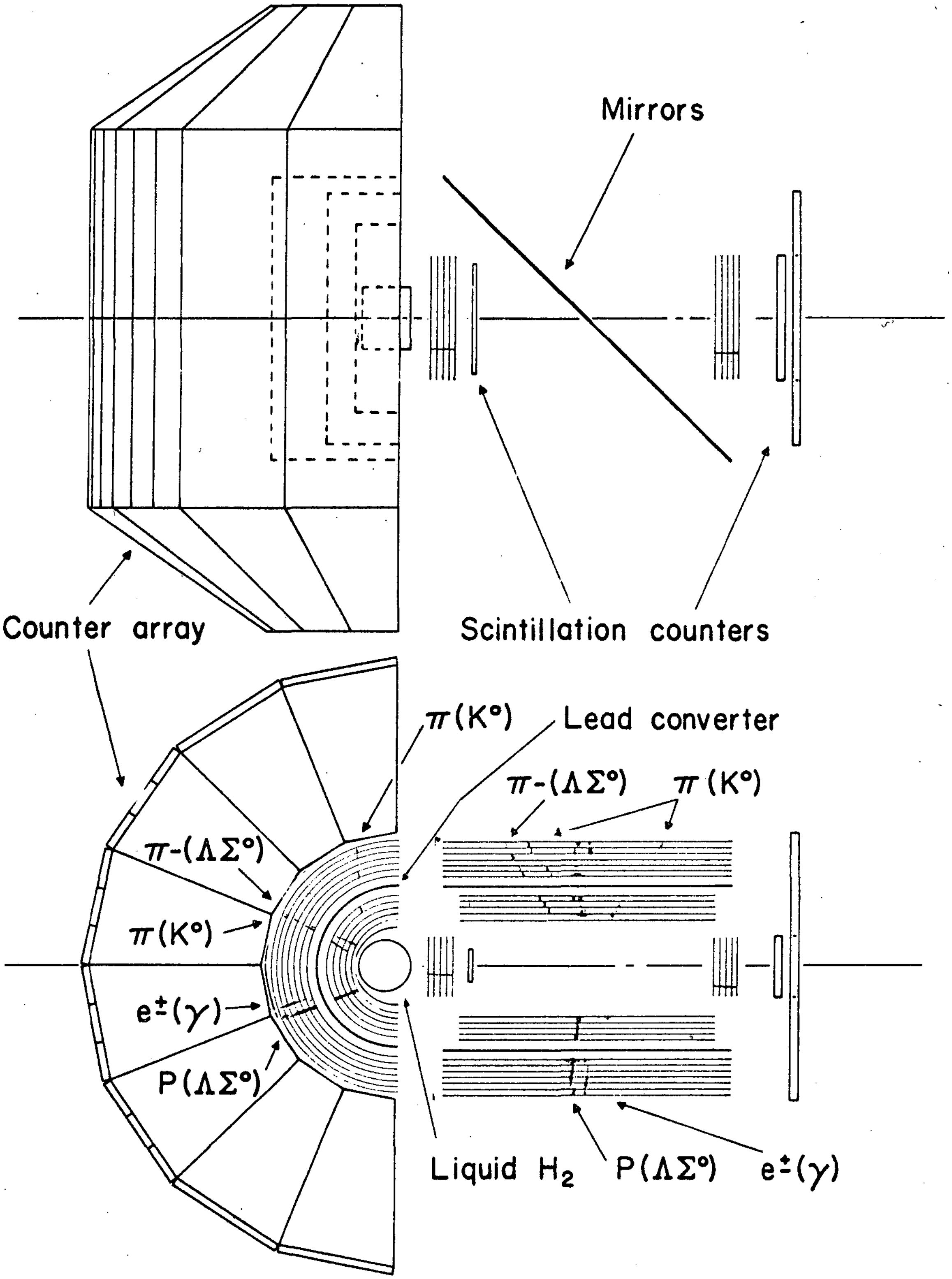
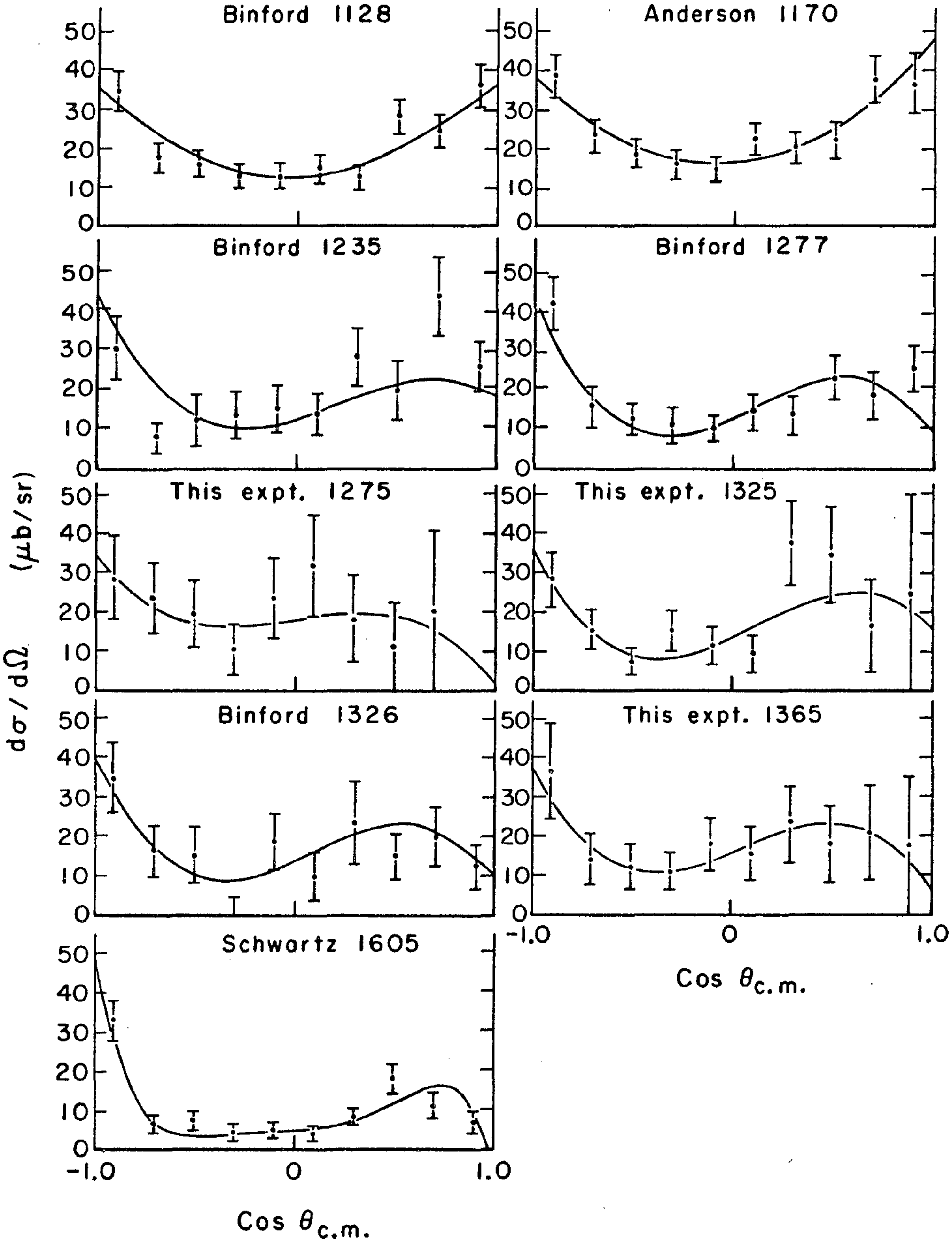
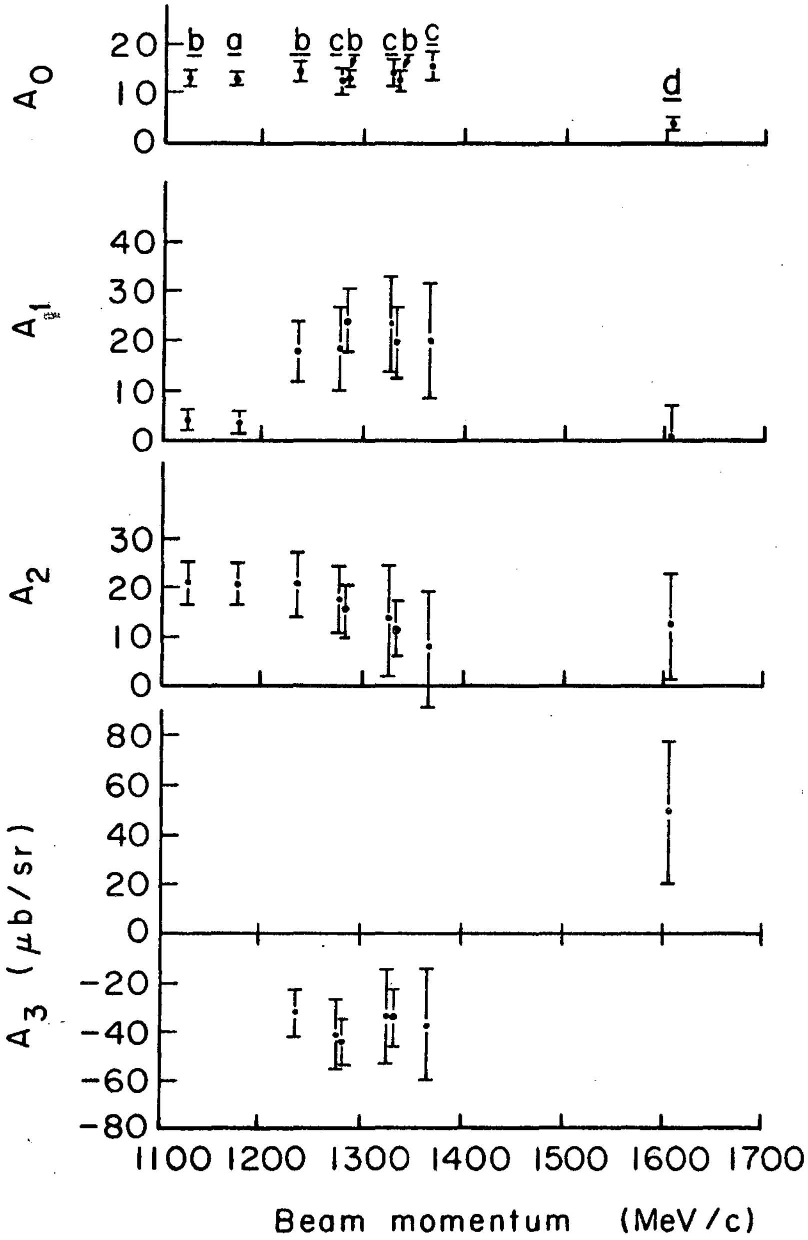

Mirrors
Counter array
Scintillation counters
$\pi(K^0)$
Lead converter
π-$(\Lambda\Sigma^0)$
$\pi(K^0)$
π-$(\Lambda\Sigma^0)$
$\pi(K^0)$
$e^{\pm}(\gamma)$
$P(\Lambda\Sigma^0)$
Liquid H_2
$P(\Lambda\Sigma^0)$
$e^{\pm}(\gamma)$

Fig. 2



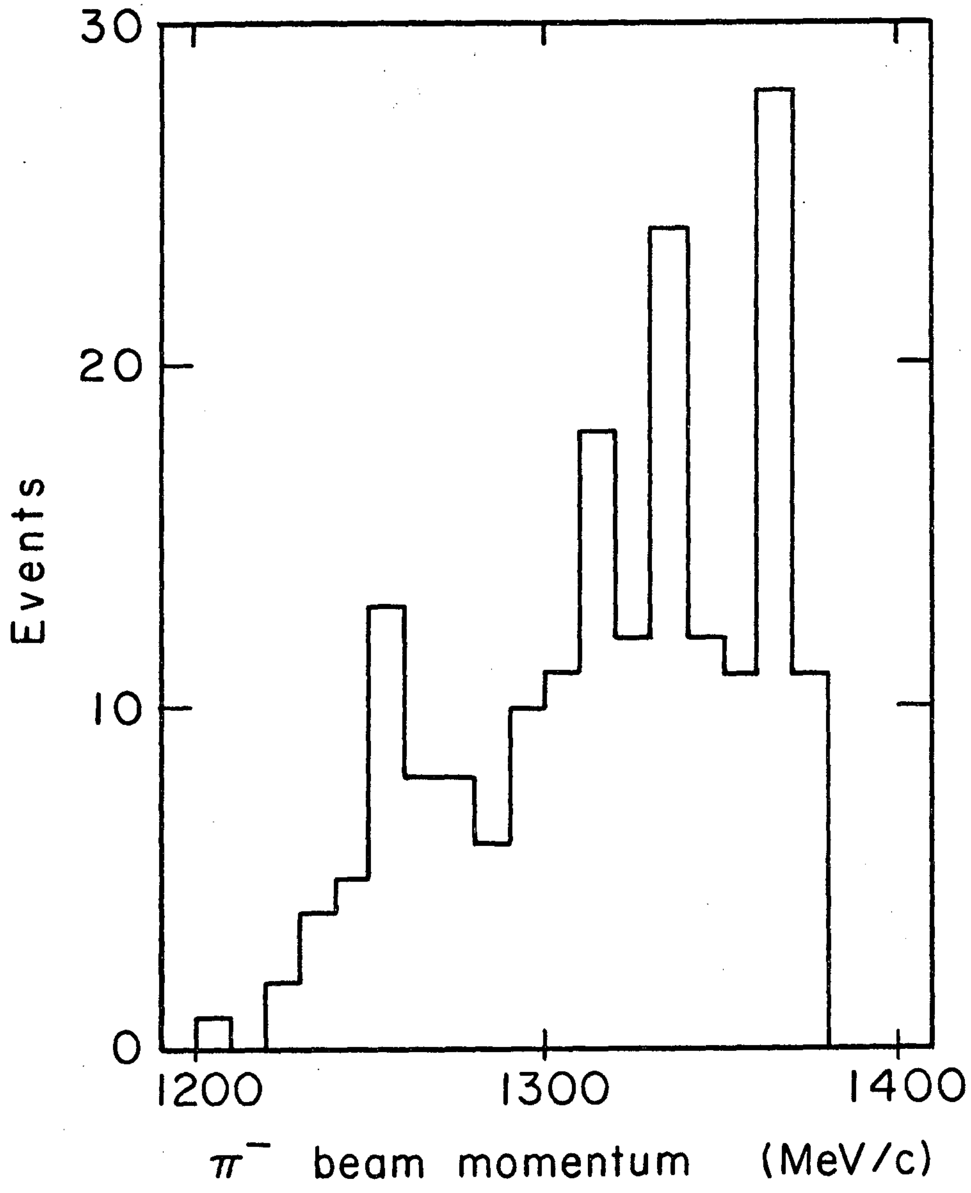
MUB-9539

Fig. 3



MUB-9538

Fig. 4



MUB-9540

Fig. 5

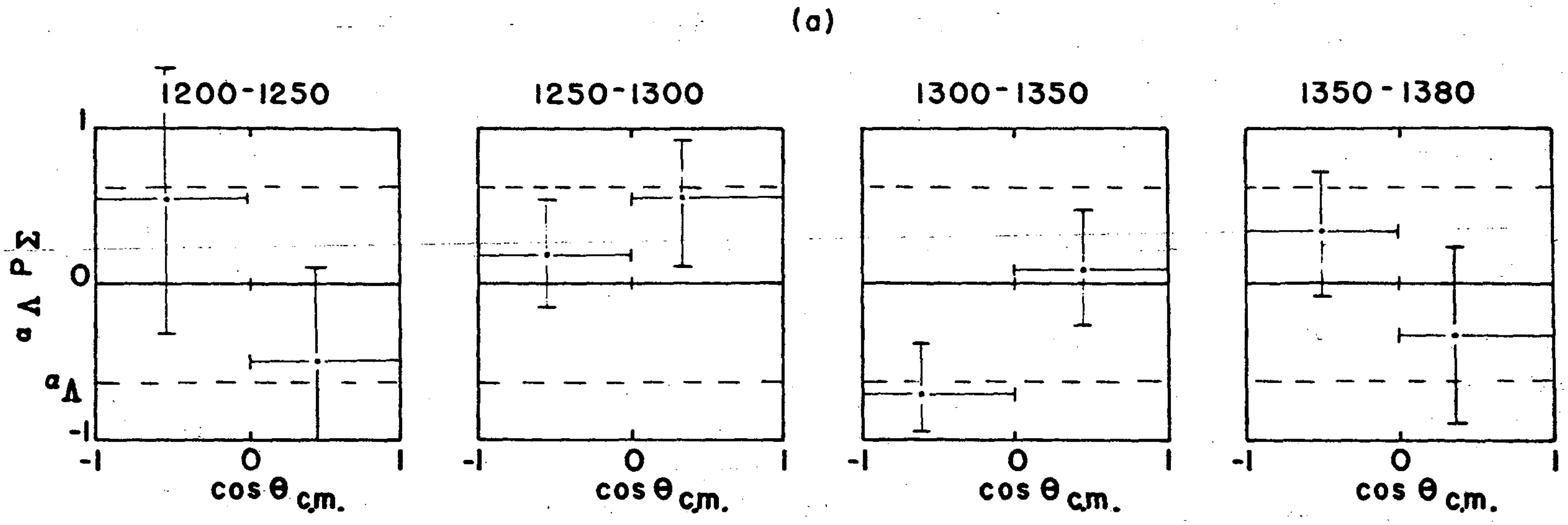
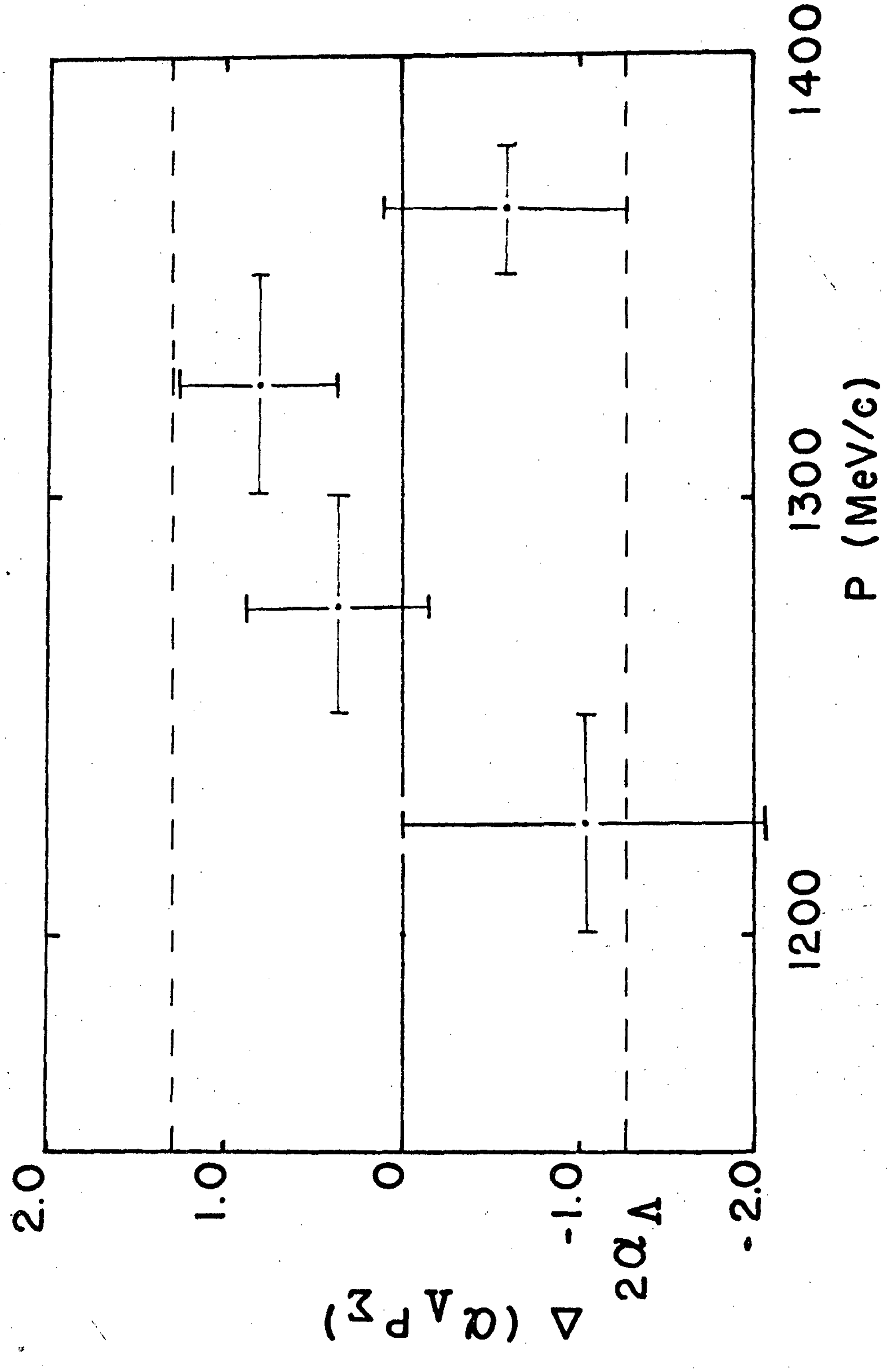

(a)
1200-1250
1250-1300
1300-1350
1350-1380
$\alpha_\Lambda P_\Sigma$
α_Λ
1
0
-1
-1
0
1
$\cos\theta_{c.m.}$

Fig. 6



MU-36117

Fig. 7