E-8

FERMILAB-PUB-76-157-E Phys Rev Letter

Λ° Hyperon Polarization in Inclusive Production by 300 GeV Protons on Beryllium

G. Bunce, R. Handler, R. March, P. Martin

L. Pondrom and M. Sheaff

Physics Department
University of Wisconsin
Madison, Wisconsin 53706*

K. Heller, O. Overseth, and P. Skubic

Physics Department
University of Michigan
Ann Arbor, Michigan 48104†

T. Devlin, B. Edelman, R. Edwards, J. Norem

L. Schachinger and P. Yamin

Physics Department
Rutgers University
New Brunswick, New Jersey 08903†

Abstract

Λ° polarization has been observed in $p + Be \rightarrow \Lambda^{\circ}$ + anything at 300 GeV. A total of 1.3×10^{6} Λ° decays were recorded at fixed lab angles between 0 and 9.5 mrad, covering a range of kinematic variables $.3 \leq x \leq .7$ and $0 \leq p_{\perp} \leq 1.5$ (GeV/c). The observed polarization conserved parity and increased monotonically with increasing $p_{\perp}$, independent of x, reaching $\langle \alpha P \rangle = .18 \pm .05$ at 1.5 GeV/c.

A search for Λ° polarization in inclusive production by 300 GeV protons $p + Be \rightarrow \Lambda^\circ$ + anything has been made in the Fermilab neutral hyperon beam. Figure 1 shows the apparatus. The 300 GeV protons were deflected vertically (positive angles upwards) with a magnet 150 m upstream of the Λ° production target, and then restored to the target with magnets 5 m upstream, to obtain production angles between 0 and 9.5 mrad in a vertical plane. The neutral beam was defined by a fixed collimator with its axis in the horizontal plane. The collimator was 5.3 m long, compared to the decay length for 150 GeV/c Λ°'s of 10.4 m. A vertical magnetic field (the sweeping magnet) of 21kg was applied to the collimator. A circular tungsten aperature 4 mm in diameter at 3.2 m defined a solid angle of 1.2 μsterad. The production target was a beryllium cylinder 6 mm in diameter and 15 cm long.

A multiwire proportional chamber system and spectrometer magnet of conventional design was used to reconstruct the decays $\Lambda^\circ \rightarrow p\pi^-$. The spectrometer system could record 220 events per 1 sec beam spill. At .5 mrad 40% of the triggers reconstructed as Λ°, with fwhm mass resolution of 6 MeV/c^2. At 9.5 mrad 10% of the triggers reconstructed as Λ°. The other triggers were $K^\circ_S \rightarrow \pi^+\pi^-$ along the vacuum decay length, and conversions $\gamma \rightarrow e^+e^-$ and neutron stars in the thin windows and other material in the neutral beam. A typical 80,000 trigger magnetic tape required about 1 hour. Data were taken at 9 production angles: -2.5, -1.5, -.5, +.5, +1.5, +3.5, +5.5, +7.5, and +9.5 mrad. At each angle data were taken for both polarities of the sweeping magnetic field. The analyzing magnet was periodically reversed. Beryllium target and "no target" data were interleaved. The Λ° (target out)/(target in) yield was 2%.

The Λ° hyperon is well suited to a high energy polarization search because of the large asymmetry in the parity violating decay $\Lambda^\circ \to p\pi^-$. In the rest frame of the Λ° the proton distribution is $dN/d\Omega = (1 + \alpha P \cos\theta)/4\pi$, where θ is the angle between the proton momentum and the Λ° spin, P is the magnitude of the polarization, and $\alpha = .647 \pm .013$.[1]

Right handed cartesian coordinates in the Λ° rest frame were chosen such that $\hat{z}$ was parallel to the Λ° momentum, $\hat{x}$ was horizontal, and $\hat{y}$ was in a vertical plane, positive upwards. Each component of the proton asymmetry was measured separately using the maximum likelihood method. For the z component the likelihood term for the ith event was $L_i = (1 + \alpha P_z \cos \psi_i)/(\int d\cos\psi\ (1 + \alpha P_z \cos\psi))$, where ψ_i is the polar angle between the Λ° momentum vector and the proton momentum vector in the Λ° rest frame. The denominator was evaluated over the acceptance of the spectrometer for each event separately by Monte Carlo techniques. The unknown parameter (αP_z) was then obtained by maximizing $L = \prod_i L_i$. The calculated acceptance agreed with the true acceptance observed in the apparatus.

The three components of asymmetry were measured in the hyperon rest frame downstream of the sweeping magnet channel, after the Λ°'s have passed through a vertical magnetic field with $\int B d\ell = 117 \pm 3$ kg-m. Λ°'s polarized in the horizontal plane should precess through an angle greater than 90° between the beryllium target and the decay region. The advantage of this precession was that the z component of the asymmetry would change sign as the sweeper was reversed, giving a useful handle on the presence of polarized Λ°'s. This is shown schematically in Fig. 2a. The polarity of the sweeper did not affect the detection efficiency of the apparatus in any way. Experimental evidence for a sweeper dependent asymmetry is presented in Fig. 2b, where αP_z vs. production angle θ_Λ is plotted for the 150 GeV/c Λ° momentum bin. The separation between sweeper + and sweeper - is attributed to a reversal of αP_z. Neighboring momentum bins showed the same trend. Plots similar to Fig. 2b were made for all three components of the asymmetry in momentum bins 20 GeV/c wide between 70 GeV/c and 210 GeV/c. The data were consistent with the initial spin along $\hat{x} = (\vec{p}_\Lambda \times \vec{p}_p)/|\vec{p}_\Lambda \times \vec{p}_p|$. Thus the z component reversed as the sweeper polarity was reversed, while the x and y components remained unchanged. One half the difference between sweeper + and sweeper - was taken as αP_z, while the two polarities were averaged to obtain αP_x and αP_y. No statistically significant asymmetry was observed at any momentum in any of the three components for angles less than 3.5 mrad. In particular 157,000 events at ±.5 mrad showed no effect in any component of the asymmetry, serving to check for parity violating polarization in production, Λ° polarization due to a polarization of the incident diffractively scattered proton beam, and geometrical biases in the apparatus. As a further check on geometrical biases, the data sample for the decay $K^\circ_s \rightarrow \pi^+\pi^-$ (156,000 events) was analyzed for a "polarization" in the same way as $\Lambda^\circ \rightarrow p\pi^-$, and showed no statistically significant effect. From αP_z vs. θ_Λ in various p_Λ momentum bins αP_z vs. $p_\perp$ in various x bins was obtained by using $p_\perp = p_\Lambda \theta_\Lambda$, $x \cong p_\Lambda/300$ GeV/c. No x dependence was found throughout the range $0.3 \leq x \leq 0.7$. The asymmetries summed over x as a function of $p_\perp$ are shown in Fig. 3.

The vectors in Fig. 2a show that an initial Λ° spin parallel to $+\hat{x}$ will result in general in two non-vanishing components of the asymmetry after precession: (αP_x) and (αP_z). The ratio $(\alpha P_x)/(\alpha P_z)$ gives the tangent of the precession angle, and hence the magnetic moment of the Λ°, provided that the sign and approximate magnitude of μ_Λ are assumed known. The ratio $(\alpha P_x)/(\alpha P_z)$ should remain constant. Comparing the data in Figs. 3a and 3b shows that this is indeed the case for $p_\perp \geq .8$ GeV/c, where the magnitude of the observed polarization is statistically different from zero. The average precession angle is $\Omega = \pi/2 + \tan^{-1} (\alpha P_x/\alpha P_z) = 122° \pm 10°$, where the error includes an estimate of of possible systematic error. Combining this with the field integral quoted above gives $\mu_\Lambda = -.57 \pm .05$ proton magnetons.[2] From Fig. 3c the average value of the parity violating component $\alpha P_y = -.009 \pm .003$. The other parity violating component at the point 0 in Fig. 2a, the z component, can be obtained by comparing sweeper + and sweeper - data, with the result that if ω is the angle between $\vec{P}$ and $\hat{x}$ at production, $P \sin \omega = .005 \pm .003$.[3]

Figure 3d shows the $p_\perp$ dependence of $|\alpha P| = ((\alpha\vec{P} \cdot \hat{x})^2 + (\alpha P \cdot \hat{z})^2)^{1/2}$. The polarization increases monotonically with increasing $p_\perp$ over the range of $p_\perp$ observed. At $p_\perp = 1.5$ (GeV/c) the observed value is $\alpha P = .18 \pm .05$, corresponding to $P = .28 \pm .08$. For $p_\perp \geq .8$ GeV/c, $\langle\alpha P\rangle = .100 \pm .007$. To design a polarized Λ° beam, the relevant parameter is the average polarization at fixed angle. At 8 mrad for 150 GeV/c $\leq p_\Lambda \leq$ 210 GeV/c, the average $\langle\alpha P\rangle = .10 \pm .015$. In the solid angle defined by the collimator this corresponds to 1.5 polarized Λ° per 10^6 protons on target.

We wish to thank Dr. P. Koehler and Dr. C. Brown and the staff of the Fermilab Meson Laboratory for their support and cooperation, which made this experiment possible. Much of the equipment was built by G. Ott and E. Behr.

References

*Work supported in part by the Energy Research and Development Administration.

†Work supported in part by the National Science Foundation.

1. O. Overseth and R. Roth, Phys. Rev. Letters <u>19</u>, 391 (1967).
2. The average of two previously published measurements of $\mu_{\Lambda}' = -.67 \pm .06$ proton magnetons. See D. Hill, et al., Phys. Rev., <u>D4</u>, 1979 (1971), and Dahl-Jensen, et al., Nuovo cimento, <u>3A</u>, 1 (1971).
3. A sample of 130,000 Λ°'s have been analyzed which were produced by 300 GeV protons on a copper target at 0, 5, and 10 mrad production angles in a <u>horizontal</u> plane. In this case the polarization was vertical, parallel to $-\hat{y}$, unaffected by the sweeper field, with $\langle \alpha p_y \rangle = -.088 \pm .010$ for $p_{\perp} \geq .8$ GeV/c. The corresponding parity violating components at production were $\alpha P_x = .017 \pm .007$ and $\alpha P_z = 0.006 \pm .005$.

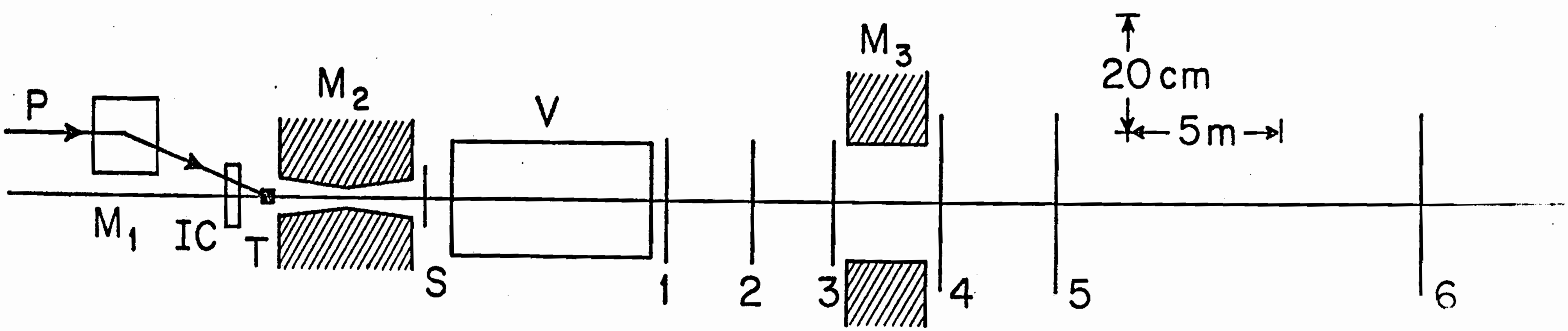
Figure Captions

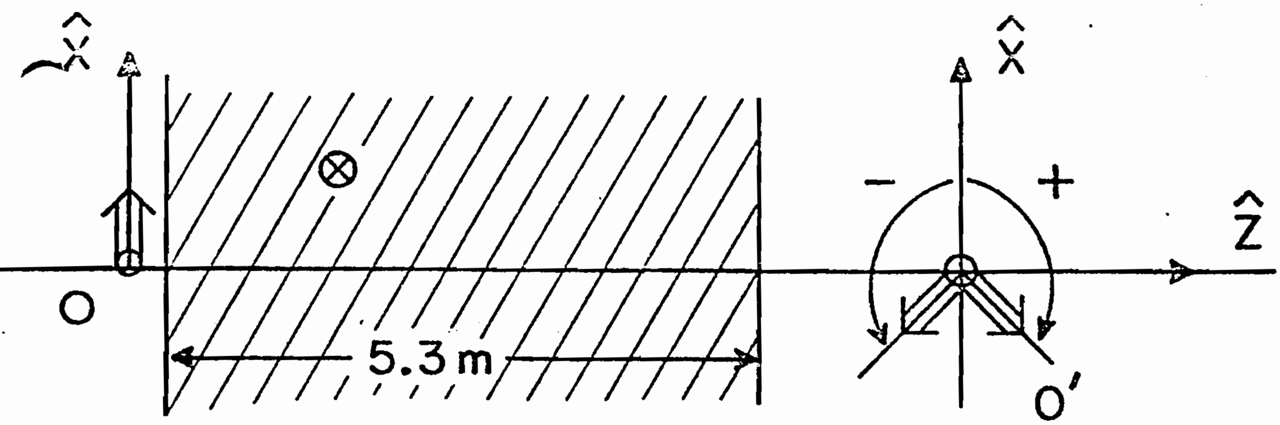
1. Elevation view of the FNAL neutral hyperon beam. 300 GeV protons were incident from the left. M1 is the restoring magnet for production angle variation. IC and T are ion chamber and Be target. M2 is the collimator and sweeper. S is a veto counter; V is the decay vacuum; and 1 → 6 are MWPC's. M3 is the analyzing magnet.

2a. Horizontal plane view of the motion of Λ° spin in the magnetic field of the collimator. Hyperons were produced at O. Double arrows represent the spin directions. Positive polarity precesses a negative moment clockwise. The polarization components were measured at O'.

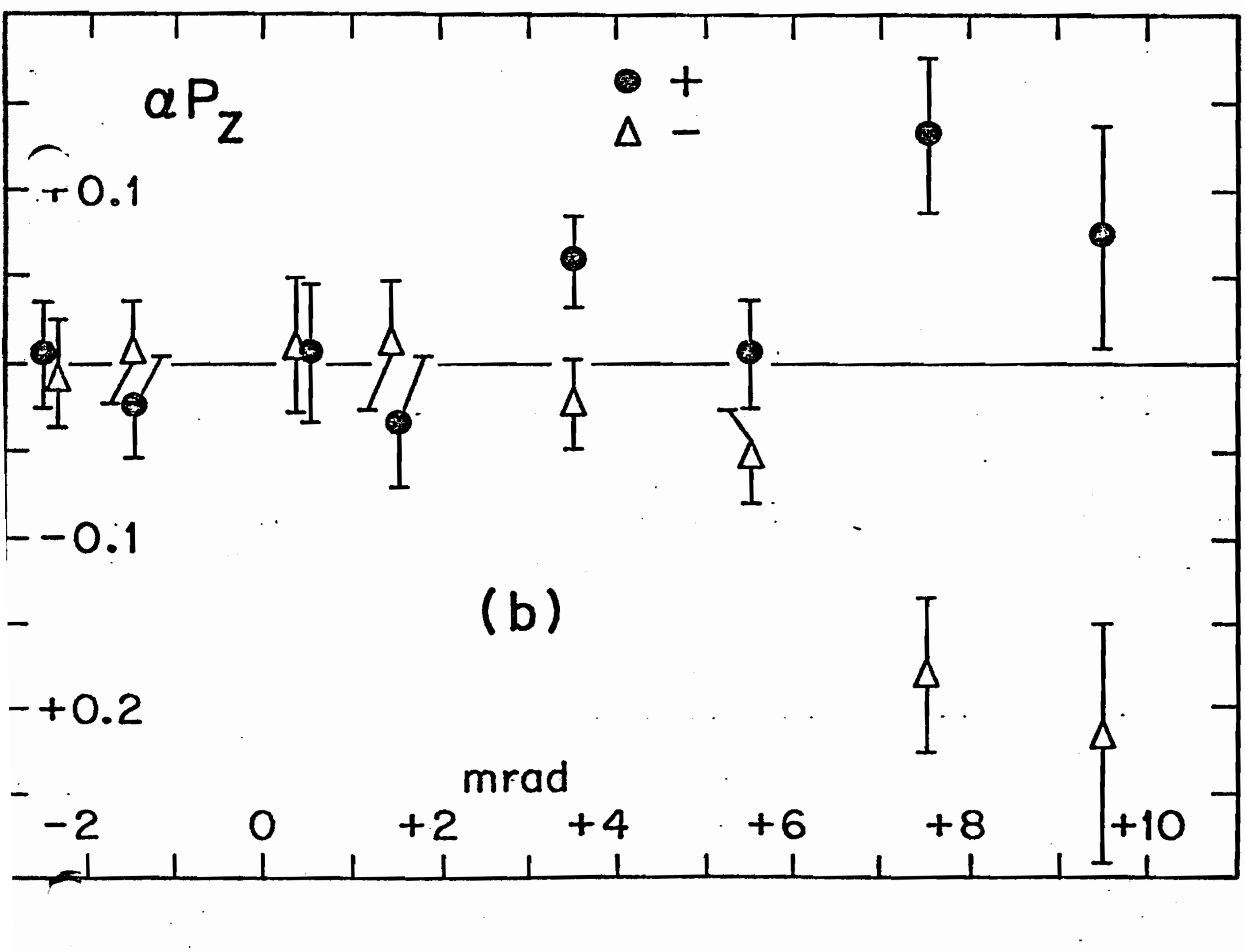
2b. αP_z as a function of θ_Λ for 140 GeV/c $\leq p_\Lambda \leq$ 160 GeV/c. A sweeper dependent asymmetry appears for $\theta_\Lambda \geq 3$ mrad.

3. Three components and magnitude of the $\Lambda^\circ \to p\pi^-$ asymmetry as a function of Λ° transverse momentum.

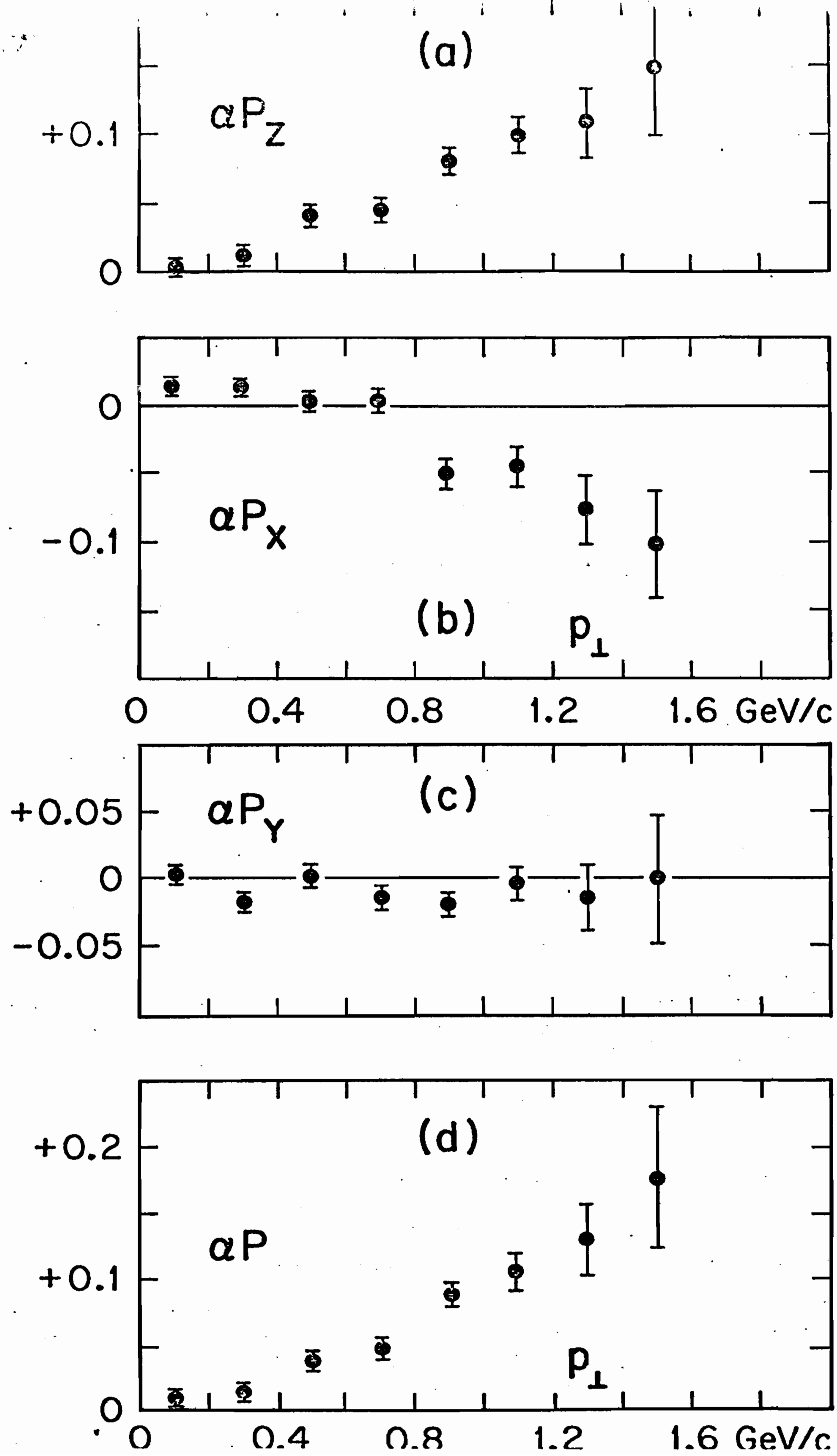

P
M_1
IC
T
M_2
S
V
1
2
3
M_3
4
5
20 cm
5 m
6



(a)



(b)



(a)
αP_Z
+0.1
0
(b)
αP_X
0
-0.1
p_⊥
0
0.4
0.8
1.2
1.6 GeV/c
(c)
αP_Y
+0.05
0
-0.05
(d)
αP
+0.2
+0.1
0
p_⊥
0
0.4
0.8
1.2
1.6 GeV/c