SPIN PARAMETER MEASUREMENTS IN INCLUSIVE HYPERON PRODUCTION

Marzio Nessi*
Rice University, Houston, TX 77251

Abstract

We have measured the spin parameters P, A and D in the inclusive Λ and Σ^0 production at 13.3 and 18.5 GeV/c. Our data cover a region of moderate p_T and Feynman x up to 0.75. The measured effects for A and D are generally smaller than predictions based on a simple parton-recombination model.

INTRODUCTION

Polarization effects tend to be always neglected among the interesting topics of high energy particle physics. This might be due to the fact that they tend to vanish in a perturbative QCD regime, or to the fact that up to now no experimental result seemed to be overwhelming enough to shake the fundaments of the theories that are generally accepted by the particle physics community. I would like to give first a brief summary of the rather broad collection of results that has been obtained up to now with unpolarized beams in inclusive hadron production at high values of Feynman x (x_F). I shall then describe in more detail with some preliminary results the work our collaboration is doing in expanding our knowledge to observables accessible with polarized beams. I would like to convince you that there is already a sufficiently exciting set of measurements to puzzle about. First pioneering measurements with unpolarized

*E817 Collaboration: B. E. Bonner, J. A. Buchanan, J. M. Clement, M. D. Corcoran, N. M. Krishna, J. W. Kruk, D. W. Lincoln, H. E. Miettinen, G. S. Mutchler, F. Nessi-Tedaldi, M. Nessi, G. C. Phillips, J. B. Roberts, P. M. Stevenson, S. R. Tonse, and J. L. White, *Rice University*; S. U. Chung, A. Etkin, R. C. Fernow, S. D. Protopopescu, H. Willutzki, *Brookhaven Natl. Lab.*; T. Hallman and L. Madansky, *Johns Hopkins University*; L. S. Pinsky, *University of Houston*.

beams gave very unexpected (non zero) results. Later, a systematic investigation of most hyperons was completed, and now, with the availability of high energy polarized beams both at Fermilab and Brookhaven we are stepping into a new era that shall provide the community with a very sensitive second generation of results. An expansion of such measurements into a kinematic region in which perturbative QCD is applicable might lead in the future to possibly severe statements, in line with those recently proposed by the EMC collaboration, in the measurement of the proton spin structure function.[1]

First non-zero effects were observed in the polarization P of inclusively produced Λ 's, but later also in the production of most hyperons.[2] I list here the facts that have emerged from a large number of experiments.

1. For proton induced production the Λ polarization is negative ($\parallel \vec{p}_\Lambda \times \vec{p}_B$). It increases with transverse momentum p_T , but appears to saturate for values of $p_T > 0.8$ GeV/c. Above this value, it increases linearly with x_F.

2. Measurements have been performed for nuclear targets and laboratory energies from 12 up to 2000 GeV. No important sensitivity to these parameters was found.

3. For proton beams,

$$P_{\Sigma^0} \simeq P_{\Sigma^-} \simeq P_{\Sigma^+} \simeq -P_\Lambda \simeq -P_{\Xi^0} \simeq -P_{\Xi^-}$$

$$P_{\bar{\Lambda}} \simeq P_p \simeq P_{\Omega^-} \simeq 0.$$

Also

$$P_\Lambda(p \to \Lambda) \simeq P_{\bar{\Lambda}}(\bar{p} \to \bar{\Lambda}).$$

4. For meson induced production, the pattern is substantially different.

$$P_\Lambda(K^- \to \Lambda) > 0,$$

$$| P_\Lambda(K^- \to \Lambda) | \gg | P_\Lambda(p \to \Lambda) | \quad and \quad | P_{\bar{\Lambda}}(K^+ \to \bar{\Lambda}) | \gg | P_{\bar{\Lambda}}(\bar{p} \to \bar{\Lambda}) |$$

Small and negative polarizations were observed in case of a pion beam.

Our understanding of all these effects has been, up to now, very phenomenological, since in the considered region of moderate transverse momenta ($p_T \sim 1$ GeV/c)

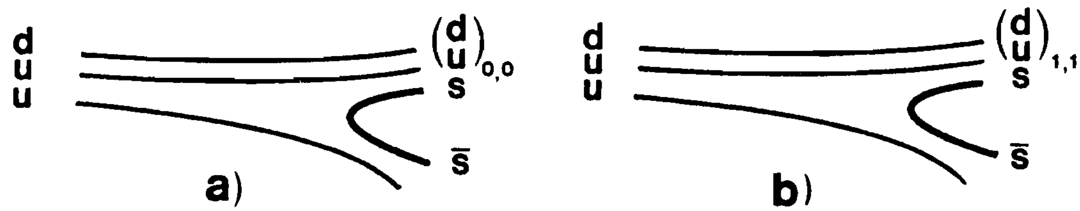


FIG. 1. Fragmentation and recombination diagrams for Λ (a) and Σ^0 (b) production.

perturbative QCD does not apply. It is evident from the data that inclusive polarization is strongly dependent on the incident and produced particle types. Is is natural to picture such processes in terms of a simple parton recombination in which one or two of the valence quarks in the projectile proceed forward, deflect only slightly and pick up extra quarks from the sea to make a large-x_F baryon. Therefore, it is plausible to describe the fragmentation and recombination using static wavefunctions, like those provided by SU(6), that give a description of the various spin-flavor components present in the hadrons. However, polarization might be due to a mechanism whose understanding doesn't teach us much about the spin dynamics. A better understanding can be achieved with measurements where the incoming particles are polarized. The polarization parameters that can be observed are not only polarization P, but also analyzing power A and polarization transfer D. They are determined as

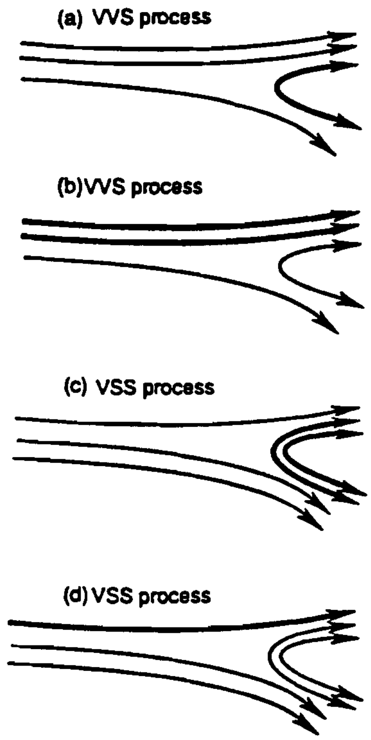
$$P = \frac{\sigma(f=\uparrow) - \sigma(f=\downarrow)}{2\sigma_0}$$

$$A = \frac{\sigma(i=\uparrow) - \sigma(i=\downarrow)}{2\sigma_0}$$

$$D = \frac{\sigma(i=f) - \sigma(i\neq f)}{2\sigma_0}$$

where σ indicates the production cross section, and i and f the intial and final spin states. The two last parameters enable us to test how the spin is transferred from the initial to the final state in the fragmentation and recombination. In this sense, such kind of measurements are sensitive tests for the spin-flavor structure of the wavefunctions.

The processes $p \to \Lambda$ and $p \to \Sigma^0$ represent particularly clean cases. In Λ production, a spinless (ud) diquark from the proton recombines with a strange sea parton, whose spin determines the spin of the Λ (see Fig. 1a). Since the diquark is spinless, the



Process	|Amplitude|^2
sea quark production	$\|B_\uparrow\|^2 = B(1 - \varepsilon)$ $\|B_\downarrow\|^2 = B(1 + \varepsilon)$
valence diquark of spin (S.M) transfer	$\|A_{1M}\|^2 = A(1 + M\delta)$ $\|A_{00}\|^2 = A$
sea diquark of spin (S.M) production	$\|A'_{1M}\|^2 = A'(1 - M\delta')$ $\|A'_{00}\|^2 = A'$
valence quark transfer	$\|B'_\uparrow\|^2 = B'(1 + \varepsilon')$ $\|B'_\downarrow\|^2 = B'(1 - \varepsilon')$

FIG. 2. Correlation between the various quark transfer and production processes and their corresponding amplitudes

spin of the proton should be irrelevant, and thus A and D are expected to be zero. For Σ^0's (Fig.1b), the transferred diquark is in a triplet state, and should therefore carry a memory of the incoming proton spin. Is is natural to expect non vanishing values for A and D.

The question arises how to use the available polarization data to obtain predictions for A and D. The qualitative behavior of polarization results can be explained with some simple phenomenological arguments. Λ polarization mechanisms are proposed by two groups, in terms of either a spin-orbit coupling (Thomas precession, DeGrand and Miettinen, Ref. 3) or as a trigger bias effect in the production of a strange quark-antiquark pair, which is described as string breaking in a color field (Andersson, Gustafson, Ingelman, Ref. 4). DeGrand and Miettinen have introduced a rather successful general framework to describe the polarization results introducing spin dependent parameters in the production probabilities. This parametrization can be used to calculate cross

TABLE I

Spin-observable predictions using the method of DeGrand and Miettinen

Reaction	P	A	D
$p \to \Lambda$	$-\epsilon$	0	0
$p \to \Sigma^+$	$+\frac{1}{3}\epsilon + \frac{2}{3}\delta$	$+\frac{2}{3}\epsilon + \frac{2}{3}\delta$	$+\frac{2}{3}$
$p \to \Sigma^0$	$+\frac{1}{3}\epsilon + \frac{2}{3}\delta$	$+\frac{2}{3}\epsilon + \frac{2}{3}\delta$	$+\frac{2}{3}$
$p \to \Sigma^-$	$+\frac{2}{3}\epsilon' - \frac{1}{6}\delta'$	$-\frac{1}{3}\epsilon' - \frac{1}{18}\delta'$	$-\frac{2}{9}$
$p \to \Xi^-$	$-\frac{1}{3}\epsilon' - \frac{2}{3}\delta'$	$-\frac{1}{3}\epsilon' - \frac{2}{9}\delta'$	$+\frac{1}{9}$
$p \to \Xi^0$	$-\frac{1}{3}\epsilon' - \frac{2}{3}\delta'$	$+\frac{2}{3}\epsilon' + \frac{4}{9}\delta'$	$-\frac{2}{9}$
$p \to \pi^+$ *or* K^+		$+\frac{2}{3}\epsilon + \frac{2}{3}\epsilon'$	
$p \to \pi^-$ *or* K^0		$-\frac{1}{3}\epsilon - \frac{1}{3}\epsilon'$	
$K^- \to \Lambda$	ϵ'		
$K^+ \to \bar{\Lambda}$	ϵ'		
$K^- \to \Sigma^+$, Σ^0 *or* Σ^-	$-\frac{1}{3}\epsilon' - \frac{2}{3}\epsilon'$		
$K^- \to \Xi^-$	$+\frac{2}{3}\epsilon' - \frac{1}{6}\delta'$		
$\pi^+ \to \Lambda$	$-\frac{1}{2}\delta'$		
$\pi^- \to \Lambda$	$-\frac{1}{2}\delta'$		

sections between different intial and final spin states, and thus predictions for other observables, like A and D, combining these amplitudes with SU(6) wavefunctions for the incoming and outgoing hadron. As usual in quark models, different spin configurations are summed incoherently. Based on the diagrams shown in Fig.2, one obtains predictions as shown in Table I. Using the parameters ϵ and δ as determined from Λ polarization measurements in proton and kaon production ($\epsilon \simeq \delta \simeq 0.15$), one obtains a prediction for $A \simeq 20\%$ and $D \simeq 67\%$ in Σ^0 production. For Λ's the simple predictions are slightly complicated by the fact that some of them arise indirecly from Σ^0 decay and others might be produced by a subdominant VSS process. The predictions are therefore modified[5] to be $A = 6\%$ and $D = -6\%$. The expected magnitudes of A and D for Σ^0's make this measurement particularly attractive, whereas the small ones for

Λ's are a crucial test of all models of this type. Our collaboration chose to investigate these two production processes as the most representative ones.

EXPERIMENTAL PROCEDURE

We have performed a first experiment[5] during the 1986 polarized beam run at the Brookhaven AGS, looking at Λ production at 13.3 and 18.5 GeV/c. In a subsequent experiment (polarized run of 1988, 18.3 GeV/c beam momentum) we have studied Σ^0 production through its decay into $\Lambda\gamma$. In both experiments, a Beryllium target was used.

We observed Λ 's through their decay mode $p\pi^-$ in the Brookhaven National Laboratory Multiparticle Spectrometer (MPS)[6], placed on the left side of the incoming beam. The setup for the two experiments was very similar, and we show therefore (Fig.3) only the one used for Σ^0's (also the numbers we quote are for that measurement, unless specified otherwise). During the Λ experiment, a Čerenkov counter and matching hodoscope were used behind the spectrometer, to identify the decay protons and suppress pions. They were replaced by a leadglass calorimeter during the second experiment to detect the γ's arising from Σ^0 decays. The calorimeter was offset vertically with respect to the spectrometer axis, in order to favor the acceptance of transverse decays, where the polarization transfer from Σ^0 to Λ in the decay has the largest magnitude.[7] The leadglass was calibrated with 1 and 2 GeV/c electrons, a range that corresponds to the γ energies in the Σ^0 decay. The stability was continuously monitored with a constant light source in form of a LED system coupled to each module via fiberoptics. ^{241}Am doped scintillator was used for absolute monitoring.

The incident polarized proton beam was defined by scintillator S2 and a hole scintillator S3. The average intensity was 3x10^6 per 500-ms AGS pulse. The most powerful element of the Λ trigger consisted of the first level requirement of a neutral going through scintillator S4 decaying into two charged particles before scintillator S5, achieved with the first scintillator in veto and requiring two or more minimum ionizing particles in the second one. In a second level trigger, the proportional chambers P1-P3 were used for

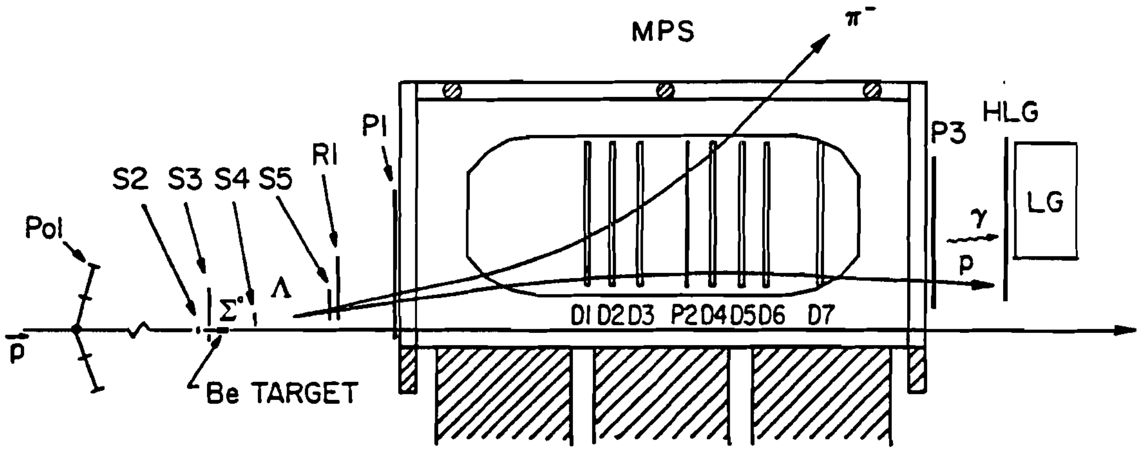


FIG. 3. Plan view of the experimental apparatus for the Σ^0 experiment showing the polarized proton beam and the Multiparticle Spectrometer at the AGS.

multiplicity requirements to enhance the acceptance of a fast proton and to suppress photon showers produced inside the spectrometer.[5] The basic Σ^0 trigger was defined with the additional requirement of a minimum energy deposition in the leadglass. A segmented hodoscope covered the whole MPS aperture upstream of the leadglass. It was used to suppress hadronic showers by vetoing charged particles hitting the layer in which an energy deposition in the calorimeter was observed. It also favored events in which a fast proton traversed all the chambers by requiring at least one charged particle hit. The differences between the time a beam particle hit the target and an energy deposition in each layer of leadglass were fed into TDC's, for accidentals suppression. Charged particle tracking was achieved with a set of 49 drift planes clustered into 7 chambers (D1-D7) and four proportional chamber planes (R1 and P1-P3). The tracks were reconstructed inside the 0.5 Tesla magnetic field and then extrapolated into the field free upstream region to the proportional chambers $P1(x)$ and $R1(x,u,v)$ for vertex reconstruction. The transverse components of the beam polarization P_B were monitored with a polarimeter located a few meters upstream of the beryllium target. It consisted of a polyethylene target viewed by four scintillator telescopes and whose analyzing power was periodically recalibrated against the University of Michigan absolute polarimeter[8] located in another beamline. At 18 GeV/c we observed that P_B was rotated from the vertical in a direction transverse to the beam momentum by $29^0 \pm 1^0$

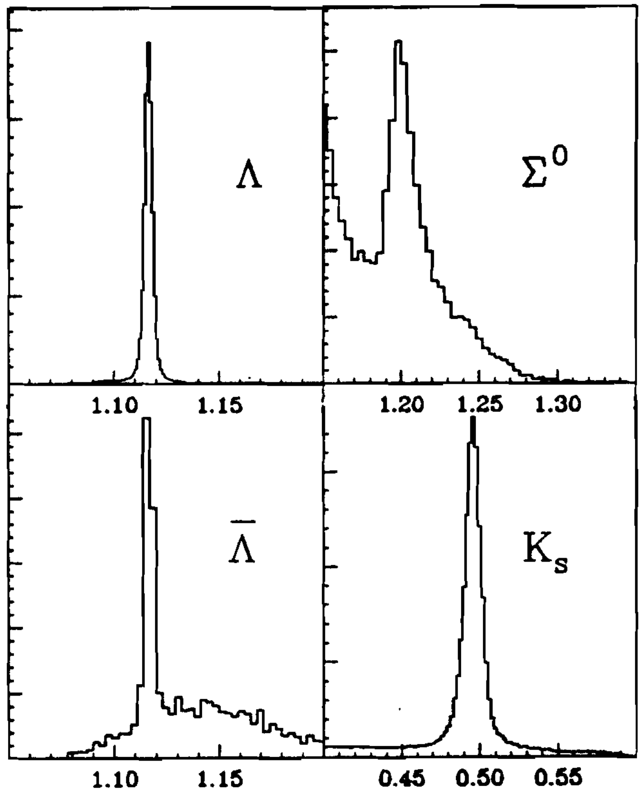


FIG. 4. Effective mass distributions [GeV/c^2] for Λ , Σ^0 , K_s^0 and $\bar{\Lambda}$ events.

in the azimuthal angle Φ in agreement with spin precession calculations in the magnets of the extracted proton beam lines.[9] The beam polarization was 44.3% $\pm$ 1.4%. The polarization direction was reversed after each AGS pulse.

The off line event reconstruction was performed on an IBM 3090 system. In the analysis several cuts were applied: The neutral decay vertex was required to fall inside the field free region between S4 and S5, the produced particle momentum had to extrapolate back to the target. We also required proton and pion to reconstruct a Λ effective mass within 2σ (1σ=2.9 MeV/c^2) of the mean value. In the Σ^0 analysis, the $\Lambda\gamma$ invariant mass was determined for all the events having a $\Lambda \rightarrow p\pi^-$ decay satisfying all the cuts above. In addition, the charged particle tracks reconstructed inside the spectrometer were extrapolated to the leadglass position, and showers closer than 13 cm to any track were rejected. This was done to suppress showers induced by charged hadrons hitting the leadglass. Accidental showers were eliminated applying TDC cuts. During the Λ experiment, a total of 321K (243K) events at 13.3 (18.5) GeV/c passed vertex and target cuts as well as the $(p\pi^-)$ invariant mass cut, and were taken to be Λ's (see Fig.4). In the second experiment, 171K events reconstructed to Λ 's and 10K among them reconstructed to a Σ^0. The background underneath the Σ^0 mass peak, which is due to Λ production together with uncorrelated γ's, had to be taken into account, and the results corrected accordingly. The kinematical range covered by these measurements extends in x_F up to 0.75 and in p_T between 0.5 and 2.0 GeV/c. A considerable sample of $K_s^0 \to \pi^+\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$ were also reconstructed in both experiments.

DATA ANALYSIS AND RESULTS

The Λ polarization P_Λ appears in the parity-nonconserving angular distribution of decay protons in the Λ rest frame:

$$dN/d\cos\Theta^* = N_0(1 + \alpha P_\Lambda \cos\Theta^*)$$

where the analyzing power[10] $\alpha = 0.645 \pm 0.017$, and Θ^* is the angle of the decay proton momentum with respect to the Λ polarization vector in the Λ restframe. The polarization in the Λ experiment was determined therefore from the $\cos\Theta^*$ distribution

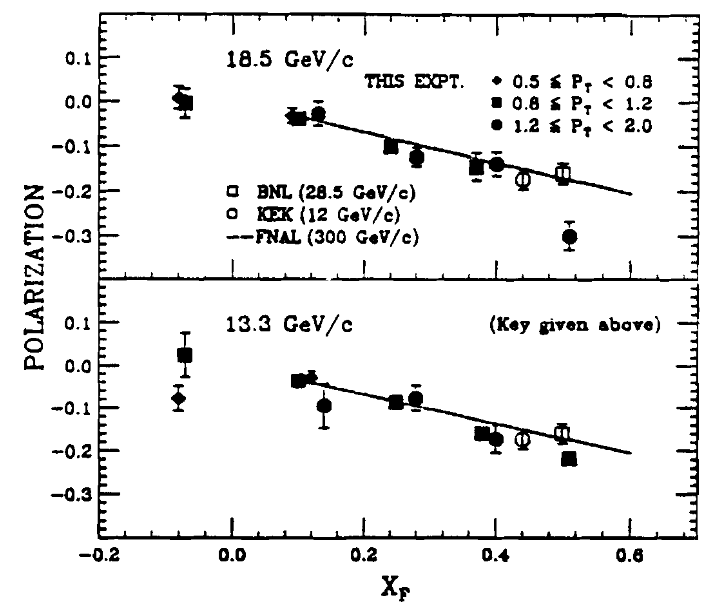


FIG. 5. Λ polarization as a function x_F , compared to data from Refs. 11

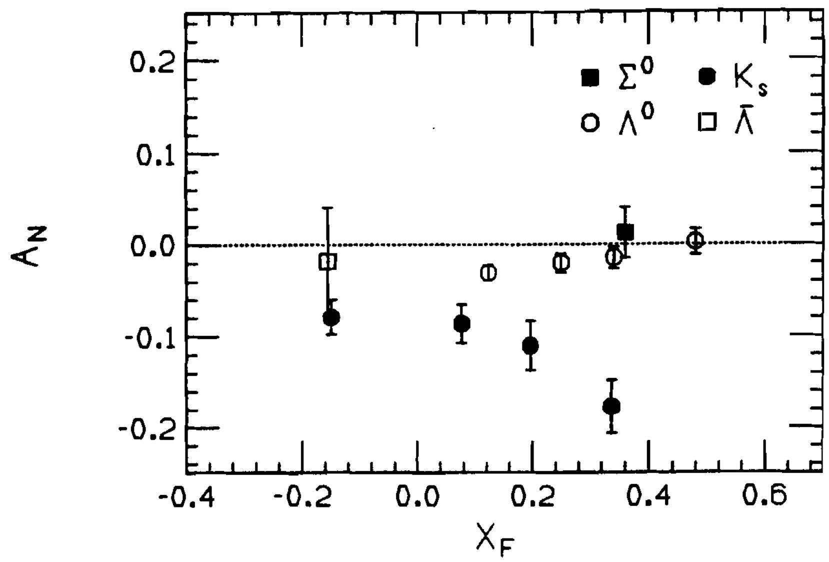


FIG. 6. Analyzing power results for Λ , Σ^0 , K_s^0 and $\bar{\Lambda}$ production as a function x_F .

of the decay protons. The effect on the results due to the limited detector acceptance were studied thoroughly in Ref. 5, and are negligible within the statistical accuracy of our measurement. The results are presented in Fig.5. Our data are in good agreement with previous experiments, showing a polarization that increases linearly with x_F and extending far into the region where the parton-recombination picture of Ref. 3 should be applicable. The Σ^0 polarization P_{Σ^0} can be determined from the decay Λ polarization through the complete reconstruction of the decay kinematics, since in the Σ^0 restframe

$$\vec{P}_\Lambda = -(\vec{P}_{\Sigma^0} \cdot \hat{p}_\Lambda)\hat{p}_\Lambda,$$

where $\hat{p}_\Lambda$ is a unit vector in the direction of the Λ momentum in the Σ^0 restframe. This analysis is still in progress; we already see an agreement in sign and magnitude with the results of Ref. 12.

The analyzing power A_N is given[13] by

$$A_N = \frac{1}{P_B \cos\phi} \cdot \frac{N_\uparrow(\phi) - N_\downarrow(\phi)}{N_\uparrow(\phi) + N_\downarrow(\phi)}$$

The azimuthal angle ϕ is that between the beam polarization direction and the normal to the production plane. $N_{\uparrow,(\downarrow)}$ is the number of particles produced for positive (negative) beam polarization. P_B is the average beam polarization. We have carefully investigated the p_T and x_F dependence of the Λ analyzing power in Ref. 5. All results are compatible with zero within a few percent, and show no energy or other kinematical dependence (Fig.6). We have also measured A_S, the analyzing power for the component of beam polarization in the scattering plane, which is expected to be zero due to parity conservation. We observed $A_S = -0.003 \pm 0.005$. In the Σ^0 data, the up-down asymmetry in our acceptance due to the leadglass and hodoscope positions, together with the non-zero horizontal polarization component of the beam produced a systematic shift. It was taken into account with a correction factor that was determined to be ~0.9. The average analyzing power (see Fig.6) for $x_F > 0.2$ ($< x_F >= 0.3$, $< p_T >= 1.2\, GeV/c$) is $A_N = 0.013 \pm 0.028$, where both, statistical and systematic errors due to the background correction are contained in the quoted uncertainty. We have determined an analyzing power also for those events that reconstruct to a K^0_s. Averaged over all p_T and x_F we obtained a value for $A_N(K^0_s) = -0.094 \pm 0.012$ and -0.076 ± 0.015 at 13.3 and 18.5 GeV/c beam energy respectively in the first run. During the second run, we obtained a mean value of -0.101 ± 0.010. The consistency between these results confirms the reliability of our understanding of the different detector acceptances. It should be noticed that even at small and negative x_F this analyzing power remains large and negative. For $\bar{\Lambda}$ production, the average over both experiments gives $A_N = -0.013 \pm 0.059$.

The polarization transfer D in Λ production is given by

$$D = \frac{1}{2P_B \cos\phi}[P_{\Lambda\uparrow}(1 + P_B A_N \cos\phi) - P_{\Lambda\downarrow}(1 - P_B A_N \cos\phi)]$$

where $P_{\Lambda\uparrow}$ ($P_{\Lambda\downarrow}$) is the measured Λ polarization for beam spin up (down). The polarization tranfer can also be determined in a fully acceptance independent way[5] subdividing the whole phase space into single elements of $d(\cos\Theta^*)$, each one yielding a measurement of D. The weighted average of all these measurements leads to the results we present. This method is not so relevant in the Λ experiment, where the measured distributions were not heavily affected by the detector acceptance, but it is very important in the case of Σ^0 's. In this second analysis, the phase space is subdivided into single elements $d(\cos\delta_i)d(\cos\Theta^*_j)$, where δ is the angle between Σ^0 polarization and Λ direction in the Σ^0 restframe. This is necessary because the spin transfer from the Σ^0 to the decay Λ is proportional to $\cos\delta$. For each bin a measurement D_{ij} is determined, and the result for D is calculated from the average over all D_{ij}, weighted with their statistical errors. For Λ production, the polarization transfer results are shown in Fig.7. There is no

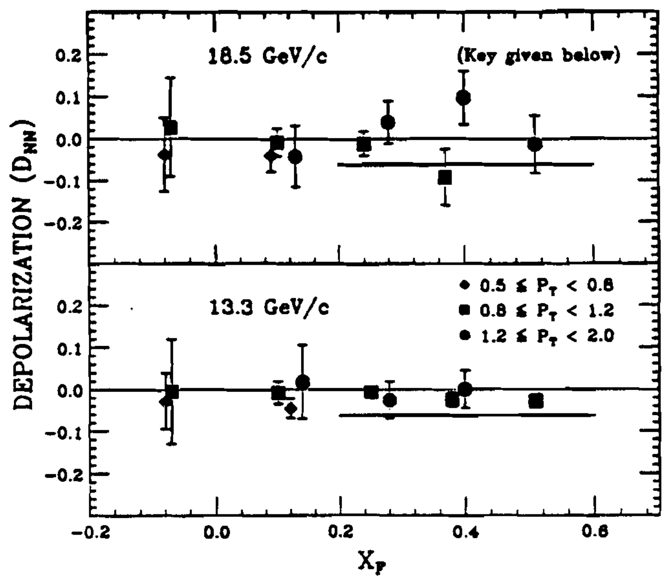


FIG. 7. Polarization transfer results for Λ production as a function of x_F, for different bins of transverse momentum.

significant deviation from zero, implying that the spin of the Λ is not dependent on the spin of the incident proton. Our Σ^0 data yield $D = 0.26 \pm 0.16$.

CONCLUSIONS

All this different spin parameter measurements allow us to make some general remarks. The first measured values,A and D in Λ production, appeared to be smaller than what we expected due to Σ^0 contamination using the simple parametrization above. However, the measured values for A are different from zero and negative, even at small values of x_F. Our Σ^0 data confirm this behavior, with results that in this sense can be considered consistent with the ones for Λ's. The result for $A(\Sigma^0)$ is $\sim 7\sigma$ away from the prediction. The polarization transfer $D(\Sigma^0)$ has the predicted sign, but is smaller than expected. The statistical significance of this result should however be improved. The analyzing power we observe in K^0_s production is large and negative, with a trend to increasing magnitude at larger p_T and x_F. Including in the prediction an estimate for the contribution from K^* to K^0_s production[5], we obtain an expectation of -7%, which is smaller than the measured values. In the target fragmentation region the value of $A(K_s^0)$ is still unexpectedly large.

The disagreement of our Λ and Σ^0 results can not easily be understood in terms of a parametrization like the one of Ref.3. Either this scheme does not apply, or some important elements are still missing. We notice however that an inclusion that we are currently investigating of a spin-spin term, based on other measurements on hyperon production[14], might improve the overall agreement with the data. Further measurements are very compelling at this point. An investigation of all this processes at higher energies is already planned, within our E704 collaboration at Fermilab.

This experiment was supported by the U.S. Department of Energy. We are grateful to Dr. L. Ratner and the entire staffs of the AGS Department, the MPS group and the BNL-Applied Mathematics Department.

References

1. EM Collab., J. Ashman *et al.*, Phys. Lett. **206B**, 364 (1988); S. J. Brodsky, J. Ellis, M. Karliner, Phys. Lett. **206B**, 309 (1988); F. Close and R. G. Roberts, Phys. Rev. Lett. **60**, 1471 (1988).

2. For a review, see e.g. L. G. Pondrom, Phys. Rep. **122**, 57 (1985) or K. Heller, 7th Int. Symp. on High Energy Spin Physics, Protvino (1986).

3. T. A. DeGrand and H. I. Miettinen, Phys. Rev. **D 24**, 2419 (1981).

4. B. Anderson, G. Gustafson, A. Ingelman, Phys. Lett. **85B**, 417 (1979).

5. B. E. Bonner et al., Phys. Rev. Lett. **58**, 447 (1987) and B. E. Bonner *et al.*, to be publ. in Phys. Rev. **D 38** n.3 (1 August 1988).

6. S. Eiseman *et al.*, Nucl. Instr. Methods Phys. Res. **217**, 140 (1983)

7. R. Gatto, Phys. Rev. **109**, 610 (1957)

8. G. R. Court *et al.*, Phys. Rev. Lett. **142B**, 451 (1984)

9. G. Bunce, Brookhaven National Laboratory report BNL-29856 (1981)

10. O. E. Overseth and F. Roth, Phys. Rev. Lett. **51**, 2025 (1983), and references therein

11. G. Bunce *et al.*, Phys. Rev. Lett. **36**, 1113 (1976); K. Heller *et al.*, Phys. Lett. **68B**, 480 (1977); K. Heller *et al.*, Phys. Rev. Lett. **41**, 607 (1978); F. Lomanno *et al.*, Phys. Rev. Lett. **43**, 1905 (1979); S. Erhan *et al.*, Phys. Lett. **82B**, 301 (1979) F. Abe *et al.*, Phys. Rev. Lett. **50**, 1102 (1983).

12. E. C. Dukes *et al.*, Phys. Lett. **193B**, 135 (1987)

13. J. Ashkin *et al.*, in Higher-Energy Polarized Proton Beams- 1977, edited by A. D. Krisch and A. J. Salthouse, AIP Conference Proceedings No. 42 (American Institute of Physics, New York, 1978), p.142

14. M. W. Sullivan et al., Phys. Rev. **D 36**, 674 (1987).