POLARIZATION IN INCLUSIVE LAMBDA PRODUCTION

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ABSTRACT

At high energies the reaction $p + N \to \Lambda^0 + X$ yields Λ^0s which are strongly polarized. The behavior of this polarization should give information about quark production mechanisms. The inclusive Λ^0 polarization is also compared with $\bar{\Lambda}^0$, Ξ^0, and proton polarization in the fragmentation region of the incident proton at Fermilab energies.

INTRODUCTION

The neutral hyperon beam collaboration at Fermilab is engaged in a program using polarization as a probe of the high energy production mechanisms. In this talk I will review results which have already been published and present some new data which are still preliminary. The people who have contributed to the acquisition, analysis, and understanding of this data are: R. Grobel, R. Handler, R. March, P. Martin*, L. Pondrom, M. Sheaff, C. Wilkenson: University of Wisconsin; T. Devlin, B. Edelman**, R. Edwards***, J. Norem****, L. Schachinger*****, P. Skubic+: Rutgers University; P. Cox, J. Dworkin, O. Overseth: University of Michigan; G. Bunce++, P. Yamin+++: Brookhaven National Laboratory; K. Heller+: University of Minnesota.

About three years ago this group reported that Λ^0 hyperons produced by 300 GeV protons in the interaction $p + Be \to \Lambda^0 + X$ were strongly polarized, as shown in Figure 1.[1] This was the first

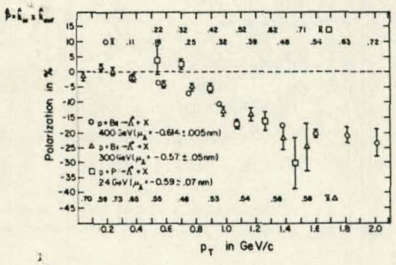

Figure 1: Polarization of Λ^0 for 3 incident proton energies plotted as a function of p_T. The average value of $x = P_L^*/(\sqrt{s}/2)$ is given for each point. The magnetic moment in nuclear magnetons, μ_Λ, for each data set is also shown.

evidence that all spin effects do not die off with energy as had been expected. Predictions available at the time were based on the triple Regge model.[2,3] These predictions called for inclusive Λ^0 polarization to be zero and the polarizations of other inclusively produced baryons to decrease with energy. In spite of its success in dealing with production cross-sections, the large Λ^0 polarization observed pointed out the failure, or at least irrelevancy, of this model.

Lambda production is an ideal tool to probe the structure of the strong interaction at high energies. Experimentally, its primary mode $\Lambda^0 \to p\pi^-$ is easily detected with a conventional charged particle spectrometer (Figure 2). Protons produce Λ^0's

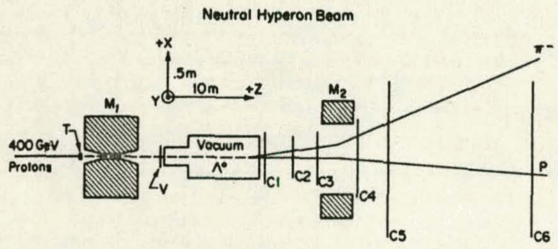

Figure 2: Fermilab neutral hyperon beam spectrometer. M_1 is the spin precession magnet, M_2 the spectrometer magnet, and C_i are MWPC's. A typical Λ^0 decay is shown.

with a reasonably high probability so that the production cross-section can be measured over a large region of phase space. At the same time, the spin direction of the Λ^0 sample can be determined from the asymmetry of the daughter proton distribution in the parity violating decay. The analyzing power of the decay is 65%. There is thus no need for rescattering, which reduces statistics and has a very small analyzing power above a few GeV. The long laboratory lifetime, 7 meters at 100 GeV, means that Λ^0s can be passed through a conventional magnet to precess the spin. Because the Λ^0 is neutral, its spin can be precessed through any desired angle, up to about 150° in our magnet, without changing the direction of the particle. The ability to control the spin direction allows the elimination of most asymmetries caused by the apparatus. In addition the magnitude of the precession must give the particle's magnetic moment and is thus a powerful test of the measurement.

Theoretically, lambda production by protons can be approached from the quark viewpoint. In the interaction to be investigated one and only one valence quark has changed. An up valence quark in the proton has been exchanged for a strange quark, giving rise to a Λ^0 in the framentation region of the proton (Figure 3).

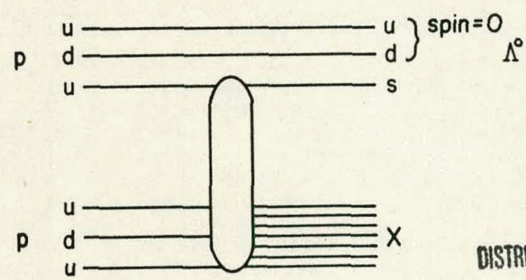

Figure 3: Quark "black box" diagram showing an incident proton (u,d,u valence quarks) becoming a lambda (u, d, s valence quarks) after an interaction with a target proton.

ISSN: 0094-243X/79/510542-07$1.50

A strange valence quark did not exist before the interaction, so it must have been "created" by some mechanism during the interaction. The Λ^0 is not simply a rearrangement of the already existing valence quarks. Because the Λ^0 is an isosinglet, the symmetry of the standard s-wave quark wave function requires that the spin of the Λ^0 be just that of the s quark. These wave functions have been successfully used to predict baryon magnetic moments if the quarks are given masses consistent with hadron mass splittings.[4] If the Λ^0 emerges polarized, which it does, the "created" s quark must be polarized. The basic mechanism involved is thus spin dependent. The properties of the quark interaction mechanism can then be systematically investigated by finding the kinematic dependence of the polarization and its dependence on the quarks involved.

EXPERIMENTAL RESULTS

The published polarization properties of high energy Λ^0s produced by protons[1,4,5] are:

1. The Λ^0 polarization increases monotonically with p_t to over 20% at p_t = 2 GeV/c. Because of the $\Sigma^0 \rightarrow \Lambda^0\gamma$ contribution to the sample which dilutes the polarization, this is a lower limit of the Λ^0 polarization.
2. The Λ^0 polarization is perpendicular to the production plane in the direction $-(\hat{k}_{in} \times \hat{k}_{out})$.
3. The Λ^0 polarization appears to be energy independent between proton energies of 24 and 400 GeV (Figure 1).
4. The parity violating components of Λ^0 polarization are both consistant with zero to a part in 10^{-3}.

The only other high energy inclusive polarization data published show that $\bar{\Lambda}^0$s produced by protons are unpolarized over the same kinematic region in which Λ^0s show substantial polarization (Figure 4).[6]

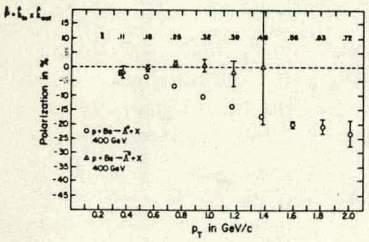

Figure 4: Polarization of $\bar{\Lambda}^0$ and Λ^0 produced by 400 GeV incident protons. The data for both sets of points were taken at the same time. At a given p_T, the $\bar{\Lambda}^0$ point represents the same average value of x as the corresponding Λ^0 point.

In addition our group has preliminary data which indicate:

5. The Λ^0 polarization is probably also dependent on the longitudinal momentum (Figure 5). Increasing with increasing $X = P_L^* / (\sqrt{s}/2)$.

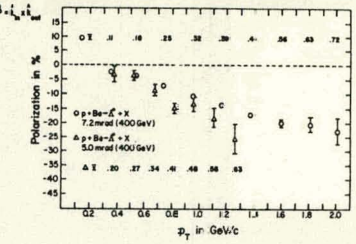

Figure 5: The magnitude of the Λ^0 polarization at 5 mrad appears systematically greater than that at 7.2 mrad. This behavior indicates that at a given p_T the polarization increases with increasing x.

6. The Λ^0 polarization from H_2 is the same as from Be (Figure 6), indicating that the production mechanism is independent of target.

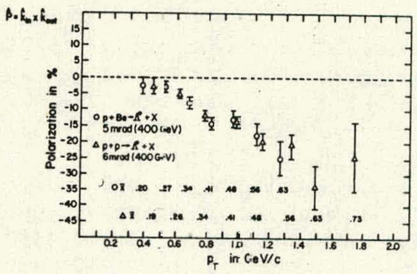

Figure 6: Polarization of Λ^0 produced by 400 GeV protons from a Be target at 5 mrad and as H_2 target at 6 mrad.

The H_2 data are still being analyzed by R. Grobel. Data exist at many incident angles so the analysis should also determine the dependence of the polarization on both transverse and longitudinal kinematic variables.

In another experiment our group examined the polarization of Λ^0s produced at 0° by a 320 GeV secondary proton beam. The secondary proton beam was produced at 3 mrad from a primary proton beam of 400 GeV on a Be target. The reaction was

$$p + Be \rightarrow p + X$$
$$\hookrightarrow + Be \rightarrow \Lambda^0 + X.$$

An observed Λ^0 polarization would mean the produced protons were polarized. A null result on the other hand would not exclude the possibility of proton polarization. The data in Figure 7 show no Λ^0 polarization. This is inconclusive but consistent with the results of the Indiana group to be reported at this conference.[7] Their more direct measurement of inclusively produced protons at p_t = 1 GeV/c shows protons are not polarized to the same extent as the Λ^0.

Our group has also taken data of Ξ^0 production by protons; detecting both the Λ^0 and the π^0 (via 2γ decay). These data

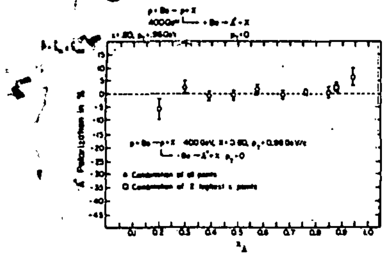

Figure 7: Polarization of Λ^0 produced by 320 GeV protons at 0 mrad as a function of x of the Λ^0. The Λ^0 polarization represents the product of the proton polarization and the spin transfer in Λ^0 production.

are undergoing preliminary analysis for polarization by P. Cox, and should yield about 10^5 fully reconstructed Ξ^0s with P_t above 1 GeV/c. These Ξ^0s will then be used to determine P_{Ξ^0} from $p + Be \rightarrow \Xi^0 + X$, and the magnetic moment of the Ξ^0.

Another approach to investigating the Ξ^0 polarization has been taken by our group. In our previous data on Λ^0 production, most of the Λ^0s reconstructed by our spectrometer point back precisely to the production target (Figure 8). A small fraction

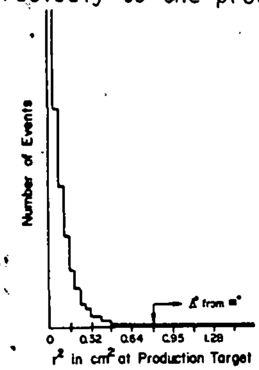

Figure 8: When the reconstructed Λ^0 trajectory is extrapolated back to the plane containing the production target, r is the distance from that point of intersection to the target center. The radius of the target is 3 mm.

do not. These large r^2 Λ^0s were analyzed by G. Bunce and O. Overseth to determine if they could be daughter Λ^0s from $\Xi^0 \rightarrow \Lambda^0 \pi^0$. In that decay the Λ^0 retains a substantial fraction of the Ξ^0 polarization in the laboratory frame. The vertex distribution of the large r^2 Λ^0s (Figure 9) is consistent with a parent-daughter decay such as $\Xi^0 \rightarrow \Lambda^0 \pi^0$, $\Lambda^0 \rightarrow p\pi^-$. This analysis gives the preliminary result that $p + Be \rightarrow \Xi^0 + X$ yields polarized Ξ^0s. The polarization is consistent in magnitude and direction with that of the Λ^0s, $P_{\Xi^0} = -0.09 \pm 0.02$ at $p_T = 0.73$ GeV/c, $x = .26$. These data give a magnetic moment of the Ξ^0 of -1.20 ± 0.06 nm.

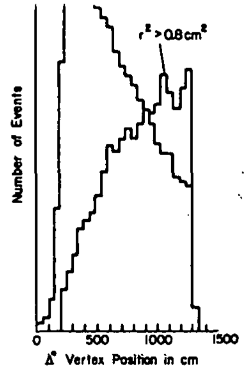

Figure 9: Vertex distribution for Λ^0s which point back to the production target (small r^2) and vertex distribution for Λ^0s which do not point back to the production target (large r^2).

CONCLUSIONS

Lambdas and Ξ^0s produced by protons are polarized at $p_T > 1$ GeV/c while $\bar{\Lambda}^0$s and protons are not (Figure 10). Both

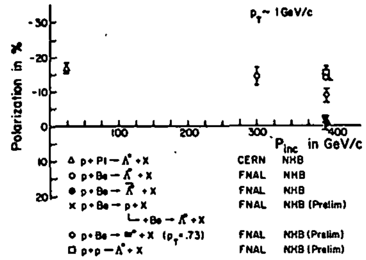

Figure 10: Summary of high energy polarization from inclusive production of baryons at $p_T \sim 1$ GeV/c by protons.

polarized particles are baryons, presumably manifestations of the incident proton with a quark change. The Λ^0 has nothing in common with the incident proton and the proton does not necessarily involve the creation of any new valence quarks.

A theory of quark interactions should explain the large polarizations observed. QCD gives promise of being such a theory. However, an analysis of Kane, Pumplin and Repko, which will be discussed at this conference, shows that a QCD perturbation expansion would not allow the large observed polarizations.[8] They conclude that if the effect does not die off at transverse momenta where the theory is expected to be valid, either QCD or their analysis method is incorrect. An experiment by our group to extend the measurement into that region will be run at Fermilab within a year.

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