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LAMBDA POLARIZATION IN THE K^- FRAGMENTATION REGION

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ABSTRACT

Results on Λ polarization in the inclusive reaction $K^-p \rightarrow \Lambda + X$ at 12 and 16 GeV/c for $0.6 < x < 1.0$, are presented. These results, obtained with the CERN Omega Spectrometer, show that the polarization is important at large x and increases with p_t over the covered range $0 < p_t < 1.2$ GeV/c. The average polarization for 31,857 lambdas with $x > 0.6$ is $P_\Lambda = 0.35 \pm 0.02$, along the direction $\vec{K}^- \times \vec{\Lambda}$. The polarization can be expressed as $P(x,p_t) = (0.66 \pm 0.03)p_t$ independent of x in the range covered by the experiment.

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1. INTRODUCTION

Polarization phenomena in strong interactions is a field of considerable interest although in the present situation there is little understanding of the peculiar features exhibited by experimental data. It is therefore important to perform experiments designed to cover special regions where polarization mechanisms are not overshadowed by a variety of other processes.

We have studied the polarization of lambdas inclusively produced at large x ($x > 0.6$) in K^-p interactions. In this kinematical region the polarization of the produced lambda could almost directly reflect the polarization acquired by the incident s quark and thus serve as a probe of the underlying scattering mechanism.

This is the first large statistics study of Λ polarization in this particular region.

Our main result, namely, the rise of lambda polarization with transverse momentum in the K^- fragmentation region is entirely new.

2. EXPERIMENTAL SET-UP

The experiment was performed at the CERN Omega Spectrometer exposed to an unseparated hadron beam of high intensity ($2-3 \times 10^7$ particles per burst) [1]. Beam particle identification was obtained using two Cerenkov counters in the beam line: one threshold Cerenkov counter and one differential Cerenkov counter (CEDAR) adjusted to identify K^-. The spectrometer was equipped with 16 MWPCs in the forward direction and eight MWPCs at each side of the 60 cm hydrogen target. In addition, two drift chambers, 4.5 and 5.7 m downstream, allowed the momentum measurement of forward tracks with an accuracy $\Delta p/p < 1\%$. Two threshold Cerenkov counters were used to select events with an outgoing proton. The momentum of the fast triggering particle was selected by MBNIM logic [2], assuming the vertex is at the centre of the target, and using the information of one MWPC plane and of two vertical hodoscopes of the lever arm. The trigger only accepted events with a fast proton (typically $x > 0.6$). The resulting acceptance for lambdas rises from about 10% at $x = 0.6$ to 70% at $x = 1.0$.

3. EVENT RECONSTRUCTION AND ANALYSIS

Events were reconstructed by the usual TRIDENT procedure [3]. For the inclusive lambda analysis, only events with a reconstructed V^0 decay pointing to the target and an identified forward proton were accepted. The invariant $p\pi^-$ mass was calculated leading to a clear lambda signal over negligible background (less than 0.5%) of width $\sigma_{M^2(\Lambda)} = 0.014\ \mathrm{GeV}^2/c^4$.

Most of the events did not have a reconstructed primary vertex (0-prong events or events with undetected slow charged particles). For these events, the point of minimum approach between the Λ line of flight and the incident beam was calculated; if found out of the target the event was rejected. This point of minimum approach was then used as a primary vertex. We checked that the results on lambda polarization were identical for events with and without a reconstructed primary vertex and found no bias.

A total of 16,630 lambdas at 12 GeV/c and 17,236 at 16 GeV/c were obtained; 15,836 (16,021) of these had $x = p^*_\ell / p^*_{\ell max} > 0.6$ and were finally used, our acceptance being too small below that limit.

The polarization of the produced lambdas was estimated [4] by $\langle\alpha P\rangle = \langle\cos\theta\rangle / \langle\cos^2\theta\rangle$, where $\alpha = 0.642$ and

$$\cos\theta = (\vec{K}^- \times \vec{\Lambda}) \cdot \vec{p}_{cm\Lambda} / |(\vec{K}^- \times \vec{\Lambda})| \cdot |\vec{p}_{cm\Lambda}| \ .$$

In this formula, $\vec{p}_{cm\Lambda}$ is the momentum of the decay proton in the Λ rest frame.

The estimator $\langle\cos\theta\rangle / \langle\cos^2\theta\rangle$ was found to agree within errors with $3\langle\cos\theta\rangle$. Statistical errors on $\langle\alpha P\rangle$ were calculated according to

$$\sigma(\alpha P) = \{[3 - (\alpha P)^2]/N\}^{1/2} \ .$$

We checked that the results obtained with this expression were identical to those calculated using

$$\sigma(\alpha P) = [\Sigma \cos^2\theta_i (1 - \alpha P \cos\theta_i)^2]^{1/2} / \Sigma \cos^2\theta_i \ .$$

The polarization in the production plane was also measured and was found to be compatible with zero along the direction normal to the Λ. A careful check was performed to identify possible bias due to the trigger or the apparatus acceptance, using a Monte Carlo program. Lambdas were generated according to their measured x and p_t distributions, followed in the spectrometer and allowed to decay. All trigger and geometrical cuts were imposed. No transverse polarization arises from these cuts when the decay of the lambdas is generated assuming zero polarization. The x and p_t measured dependence of the polarization were then introduced in the Monte Carlo and we checked that neither this dependence nor the polarization values were distorted by the trigger or the geometrical acceptance in the analysed x,p_t region.

The ratio Σ^o/Λ has been measured in bubble chamber experiments in this energy range and is about 25% [5]. This means that our results on Σ^o/Λ inclusive production will be slightly modified if applied to prompt lambdas [6]. If P_{seen} is the polarization of all Λ's produced and P_Λ the polarization of prompt lambdas, then $P_\Lambda = 4/3\ P_{seen} + 1/3\ P_{\Sigma^o}$. The polarization of prompt lambdas can therefore be obtained multiplying our results of Tables 1 and 2 and Figs. 1 to 3, by 4/3 and adding to the error bars a systematic uncertainty of 1/9.

4. x AND p_t DEPENDENCE OF THE INCLUSIVE CROSS-SECTIONS

We have used our final samples at 12 and 16 GeV/c to estimate the inclusive differential cross-sections $d\sigma/dx$ and $d\sigma/dp_t^2$, using a Monte Carlo program to compensate for all geometrical and reconstruction losses as well as for trigger inefficiencies. The study of the reaction $\pi^- p \to p_{fast} + X$ (accepted by the same trigger) at 12 and 16 GeV/c allowed us to calculate trigger and detection inefficiencies.

The p_t dependence of the cross-section for the inclusive reactions $K^- p \to \Lambda + X$ at 12 and 16 GeV/c, for $x > 0.6$, was parametrized with the formula $d\sigma/dp_t^2 \sim \exp(-bp_t^2)$ with the results:

$$b = 2.82 \pm 0.08\ (\text{GeV/c})^{-2} \text{ at } 12 \text{ GeV/c}$$

$$b = 2.94 \pm 0.18\ (\text{GeV/c})^{-2} \text{ at } 16 \text{ GeV/c}\ .$$

The $d\sigma/dx$ and $E^* d\sigma/dx$ distributions for the same reactions were parametrized by the form $(1-x)^a$. Results for the exponent a are shown in Table 3, together with those obtained by other experiments at 110 GeV/c ($x > 0.4$) [7], and at 200 GeV/c ($x > 0.27$) [8].

Systematic errors have little influence on the parameters a and b. Our results at 12 and 16 GeV/c are in agreement with the results obtained at 110 GeV/c [7]. The apparent disagreement with the results obtained at 200 GeV/c disappears if we restrict the fit to the range $x > 0.62$, using the published data of Ref. 8. This is shown in the last column of Table 3.

We remark that these results for the $d\sigma/dx \sim (1-x)^a$ dependence in $K^- \to \Lambda$ reactions are against the predictions of a proposed quark counting rule model [9] which foresees a value of two or bigger for the exponent.

5. RESULTS ON Λ POLARIZATION

Results on Λ polarization are summarized in Table 1 and 2 and in Figs. 1 to 3. Lambdas are polarized along the direction $K^- \times \Lambda$. This polarization increases with p_t and is rather insensitive to x for $x > 0.6$ (Tables 1 and 2). Results obtained at 12 GeV/c and at 16 GeV/c are compatible with each other. A fit of the form $P(p_t) = Bp_t$ was performed on the combined 12 + 16 GeV/c data with the result $B = 0.66 \pm 0.03$ ($\chi^2 = 6.0/ND = 3$). A fit using the (more realistic) form $P(p_t) = 1 - \exp(-p_t/A)$ was also performed, with the result $A = 1.08 \pm 0.07$ ($\chi^2 = 2.0/ND = 3$).

Comparison with results of other experiments is presented in Fig. 3 showing the integrated polarization defined as

$$P(x) = \int P(x,p_t)(d^2\sigma/dxdp_t)dp_t / \int (d^2\sigma/dxdp_t)dp_t \ .$$

In the K^- fragmentation region covered by our experiment ($x > 0.6$) all published data comes from bubble chamber experiments mostly with poor statistics [10-15]. The compatibility of our results in particular with 4.2 GeV/c data excludes a strong energy dependence of Λ polarization in the considered x region.

6. DISCUSSION

The most prominent feature of our data is the increase of polarization with p_t. This has not been observed by other K^-p experiments at lower positive x values and thus appears to be characteristic of the K^- fragmentation region.

For the comparison of our data with models for Λ polarization one should bear in mind the experimental situation in $pp \to \Lambda + X$ reactions where a (almost linear) dependence of the Λ polarization with p_t has been measured from $\sqrt{s}$ = 4.9 GeV up to 62 GeV. This dependence ranges from $\sim 0.15\ p_t$ to $\sim 0.4\ p_t$ in the different experiments. At large x values ($x > 0.7$) the polarization is about 0.24 for p_t = 2 GeV/c in reactions with 400 GeV/c incident protons [16]. The <u>sign</u> of polarization is opposite in $p \to \Lambda$ and $K^- \to \Lambda$ reactions.

The De Grand and Miettinen model [17] describes Λ polarization as a result of Thomas precession of the quarks' spins in the recombination process and predicts P_Λ to be roughly energy independent and of the same order of magnitude but opposite signs in $K^- \to \Lambda$ and $p \to \Lambda$ processes at large x. Qualitatively, our data supports this prediction, although the experimental values for P_Λ are significantly lower in $p \to \Lambda$ than in $K^- \to \Lambda$ at equal p_t (typically, at p_t = 1 GeV, $P_\Lambda = -0.2$ for $p \to \Lambda$ and $P_\Lambda = 0.6$ for $K^- \to \Lambda$).

The semiclassical model of Andersson et al. [18] is based on an angular momentum conservation argument and concerns the case where the s quark of the Λ is not present in the valence of the incident hadron, the argument requiring the creation of an $s\bar{s}$ pair, as occurs in $p \to \Lambda$ but not in $K^- \to \Lambda$.

The model of Szwed [19] based on a kind of "effective" multiple Coulomb scattering of the s quark in the strong field requires the scattered quark to remain slow in the centre of mass system in order to acquire a significant polarization. This, again, could be the case in $p \to \Lambda$ processes but certainly not in $K^- \to \Lambda$ at large x.

Moreover, one can easily check if a naive Mott polarization mechanism [20], as it occurs, for instance, in the QED polarization of electrons scattered by a nucleus, could account for the polarization of the s quark in the scattering process. The answer is negative for two reasons. First, P_Λ $(x > 0.6)$ is independent of energy between 4.2 and 16 GeV/c except in the last bin $(x > 0.9)$ where the polarization seems to increase with energy in the range 4.2 GeV/c to 12-16 GeV/c; this excludes an energy dependence of the form $\sim 1/k$ as required by a naive Mott mechanism. Secondly, the dependence of $|P_\Lambda|$ on $\cos\theta_{CM}$, where θ_{CM} is the s quark scattering angle in the c.m.s. of the scattering has positive curvature near $\theta_{CM} = 0$ in the Mott formula but our 12 + 16 GeV/c values are well parametrized by the formula $P_\Lambda = B + A \ln(1 - \cos^2\theta_{CM})$ with $B = 93 \pm 2$ and $A = 21.2 \pm 0.7$ $(\chi^2 = 0.94/ND = 4)$ in the range $\cos\theta_{CM} > 0.850$ and $x > 0.6$ showing clearly a negative curvature if one admits that the scattering angle is essentially the same for the s quark and for the Λ itself near $x = 1$.

We conclude that the peculiar features of Λ polarization in $K^- \to \Lambda$ processes here reported do not find a satisfactory explanation in the framework of the existent models.

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Table 1

$K^- p \to \Lambda + X$ at 12 GeV/c
Λ polarization as a function of x and p_t

p_t (GeV/c)	P_Λ $0.6 \leq x < 0.7$	$0.7 \leq x < 0.8$	$0.8 \leq x < 0.9$	$0.9 \leq x \leq 1.0$
0.8–1.2	0.62 ± 0.09 (949)	0.59 ± 0.07 (1411)	0.69 ± 0.09 (841)	0.96 ± 0.24 (127)
0.6–0.8	0.46 ± 0.10 (770)	0.38 ± 0.07 (1563)	0.49 ± 0.08 (1269)	0.65 ± 0.15 (326)
0.4–0.6	0.41 ± 0.12 (541)	0.34 ± 0.07 (1553)	0.33 ± 0.07 (1609)	0.32 ± 0.11 (578)
0.0–0.4	0.20 ± 0.15 (316)	0.16 ± 0.08 (1251)	0.12 ± 0.06 (1859)	0.17 ± 0.09 (873)

Numbers in brackets refer to the number of (unweighted) events in each cell.

Table 2

$K^- p \to \Lambda + X$ at 16 GeV/c
Λ polarization as a function of x and p_t

p_t (GeV/c)	P_Λ $0.6 \leq x < 0.7$	$0.7 \leq x < 0.8$	$0.8 \leq x < 0.9$	$0.9 \leq x \leq 1.0$
0.8–1.2	0.58 ± 0.08 (1115)	0.63 ± 0.08 (1239)	0.55 ± 0.11 (633)	0.80 ± 0.30 (82)
0.6–0.8	0.45 ± 0.08 (1219)	0.45 ± 0.07 (1550)	0.49 ± 0.09 (937)	0.50 ± 0.18 (217)
0.4–0.6	0.43 ± 0.08 (1047)	0.44 ± 0.07 (1713)	0.37 ± 0.08 (1193)	0.38 ± 0.15 (322)
0.0–0.4	0.17 ± 0.09 (884)	0.08 ± 0.06 (1760)	0.20 ± 0.07 (1416)	0.03 ± 0.12 (475)

Numbers in brackets refer to the number of (unweighted) events in each cell.

Table 3

x dependence of the inclusive cross-sections
for the reactions $K^-p \rightarrow \Lambda + X$ (fitted exponents)

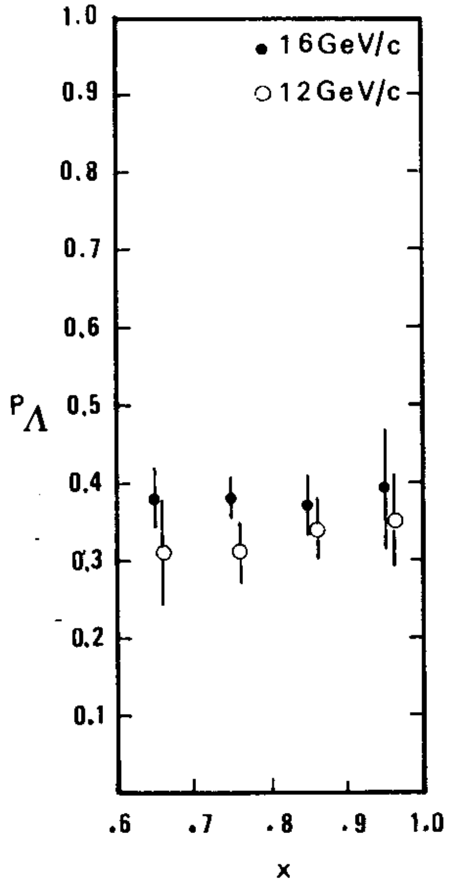
	12 (GeV/c) x > 0.6	16 (GeV/c) x > 0.6	110 [7] (GeV/c) x > 0.4	200 [8] (GeV/c) x > 0.27	200 [8] (GeV/c) Our fit for x > 0.67
$d\sigma/dx \sim (1-x)^a$	1.32±0.04	1.34±0.04	–	–	–
$E^* d\sigma/dx \sim (1-x)^a$	1.13±0.02	1.15±0.02	1.7±0.9	2.02±0.20	1.13±0.29

Figure captions

Fig. 1 : Lambda polarization as a function of $x = p_{\ell}^{*}/p_{\ell max}^{*}$ at 12 GeV/c and 16 GeV/c.

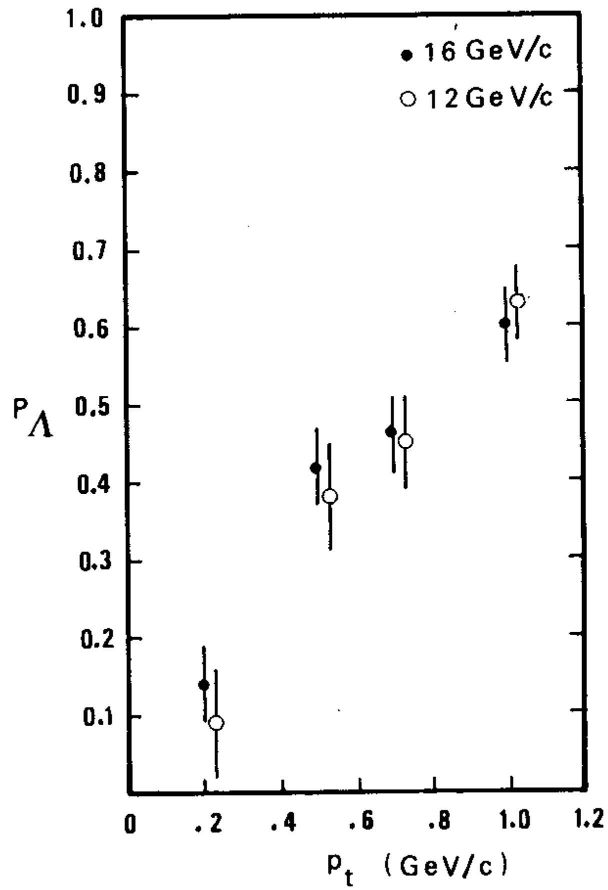
Fig. 2 : Lambda polarization as a function of the transverse momentum of the lambda at 12 GeV/c and 16 GeV/c.

Fig. 3 : Comparison with other experiments. Lambda polarization as a function of x for x > 0.6. Our data on the figure is the combined 12 + 16 GeV/c data (shown separately in Fig. 1). Data at 10 + 16 GeV/c [13] is not shown in the figure as only the average for 0.6 < x < 1.0 is published (0.34 ± 0.13). The same occurs with the 32 GeV/c data [15] where the average for 0.6 < x < 1.0 is 0.73 ± 0.13. The sign of polarization for all experiments has been (re)calculated using the definition given in the text (see Section 3).



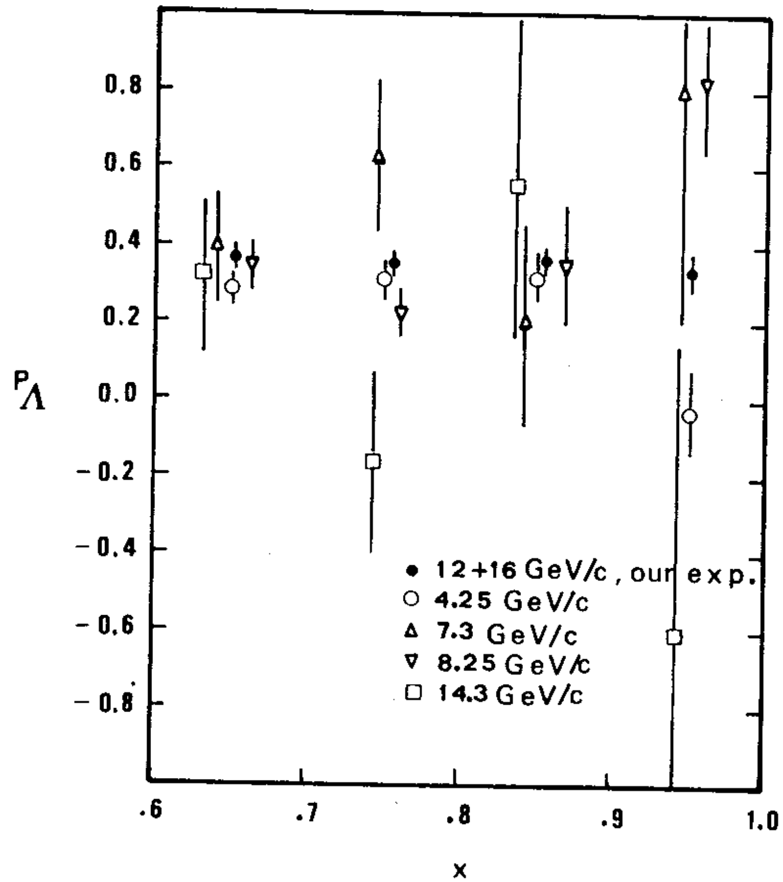
● 16GeV/c
○ 12GeV/c
P_Λ
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
.6
.7
.8
.9
1.0
x

Fig.1



● 16 GeV/c
○ 12 GeV/c
P_Λ
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
.2
.4
.6
.8
1.0
1.2
p_t (GeV/c)

Fig.2



0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
P_Λ
.6
.7
.8
.9
1.0
x
● 12+16 GeV/c, our exp.
○ 4.25 GeV/c
△ 7.3 GeV/c
▽ 8.25 GeV/c
□ 14.3 GeV/c

Fig. 3