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INCLUSIVE PRODUCTION OF LAMBDA IN THE
PROTON FRAGMENTATION REGION FROM $K^-p \rightarrow \Lambda X$ AT 4.2 GeV/c

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ABSTRACT

A study of Λ production has been made for the process $p \xrightarrow{K^-} \Lambda$ from K^-p interactions at 4.2 GeV/c. The total Λ production cross section is (4.5 ± 0.2) mb and the cross section where Λ is associated with $K\bar{K}$ in the final state is found to be (0.44 ± 0.03) mb. A study of the polarization is made for the off-mass-shell strangeness annihilations ' $K\bar{K}$ ' $\rightarrow$ pions and strangeness non-annihilations ' $K\bar{K}$ ' $\rightarrow K\bar{K}$ + pions; the polarization when plotted as a function of x , p_T and $(\text{recoiling-mass})^2$ exhibits differences between the two processes. The polarisation observed in the strangeness non-annihilation process shows identical behaviour to that in $p\bar{p}$ reactions. An attempt has been made to understand the behaviour of the polarized and the unpolarized cross sections as a function of $(\text{recoiling-mass})^2$ in the triple Regge framework.

1. INTRODUCTION

It has been pointed out by Inami and Miettinen [1] that the inclusive production of Λ in the reaction

$$K^- + p \rightarrow \Lambda + \text{anything}, \quad (1)$$

when considered in the proton fragmentation region can be subdivided into two parts:

- (a) strangeness annihilation processes of the type

$$K^- + 'K^+' \rightarrow \text{pions}, \quad (2)$$

where the leading Regge trajectory (fig. 1(a)) is expected to be the exchange degenerate ϕ -f' trajectory, and

- (b) strangeness non-annihilation processes of the type

$$K^- + 'K^+' \rightarrow \bar{K}K + \text{pions}, \quad (3)$$

where the leading trajectories are expected to be the Pomeron and the normal meson trajectories.

In this paper we present a study of the Λ polarization associated with the two processes (2) and (3) based on the reactions

$$K^- + p \rightarrow \Lambda + n \text{ pions } (n = 1, 2, \dots) \quad (4)$$

$$K^- + p \rightarrow \Lambda + \bar{K}K + n \text{ pions } (n = 0, 1, 2, \dots), \quad (5)$$

Although several studies have been made in the past for the inclusive reaction (1) with incident K^- beam momentum in the range 3.9 to 32 GeV/c [2-11], no separate studies have been made for the Λ polarization from reactions (4) and (5).

In sect. 2 we describe the experimental data. The separation of events into the two categories (4) and (5) is described in sect. 3. Cross sections are presented in sect. 4. In sect. 5 we present x and p_T^2 distributions of the Λ . A detailed study of the Λ polarization is made

in sect. 6. In sect. 7 we discuss the M^2 dependence of the polarized and the unpolarized cross sections in the triple Regge framework. Finally, we summarize the results in sect. 8.

2. EXPERIMENTAL DETAILS

The data are taken from exposures of the CERN 2m hydrogen bubble chamber to a 4.2 GeV/c K^- beam. The present analysis is based on $\approx 2.4 \times 10^6$ pictures corresponding to 104 events/ μb . For this study only those events were considered which had at least one V^0 decay pointing to a production vertex. The events were measured and processed using the standard CERN programmes for bubble chamber analysis. Events giving rise to more than one kinematic fit were re-examined on scanning tables when ionization estimates could resolve mass ambiguities. This procedure yielded 296 032 events with an unambiguous Λ (we do not distinguish lambdas resulting from Σ^0 decay). From the decay angular distribution of these lambdas we estimated a loss of 0.7% as due to $\Lambda - K_s^0$ ambiguity.

To correct for Λ decay very near to the production vertex we have imposed a minimum projected separation of the Λ vertex from the production vertex of 0.3 cm. Within a restricted fiducial volume we were left with 279 796 events. These events were weighted to compensate for the above cut and also to take account of decays outside the fiducial volume. The average weight was found to be 1.10.

3. SELECTION OF THE FINAL STATE $\Lambda + K\bar{K} + \text{PIONS}$

In this section we describe the selection criteria adopted to separate reactions (4) and (5). The raw data after the cuts are listed in table I(a). Clearly the Λ events associated with K_s^0 belong to reaction (5). The basic problem is to identify reaction (5) among the events with no associated K_s^0 (column 2 of the table). We describe below the selection criteria that were adopted to separate the two reactions.

A large fraction of events with no visible K_S^0 was ambiguous between different hypotheses for reactions (4) and (5). Since $\sim 90\%$ of the events are expected^(*) to belong to reaction (4) we adopted the following procedure to resolve the ambiguity in the two and four-prong events:

(a) a higher constrained fit was given priority over a lower constrained fit (e.g. 4C over 1C), and (b) for equally constrained fits a pion hypothesis was given preference over a kaon hypothesis. This selection yielded $\approx 22\ 000$ events from the two-prongs and $\approx 1\ 400$ events from the four-prongs for reaction (5). Among the two-prongs $\approx 50\%$ of the events selected for reaction (5) were of the type $\Lambda K^\pm \pi^\mp (K^0)$ where a large contamination from the $\Lambda \pi^+ \pi^-$ (multi-neutral) channel is possible. This was carefully studied by looking at the probability distribution of these 1C fitted events and also by comparing the mass distributions of $(K^\pm \pi^\mp)$ from the $\Lambda K^\pm \pi^\mp (K^0)$ events with those from the 4C fitted events of the type $\Lambda K^\pm \pi^\mp K_S^0$. This study resulted in our putting a probability cut of 30% on these 1C fitted events. Similar studies were made for the other channels and it was found necessary to impose a probability cut of 10% and 20% for the 4C and 1C fitted events respectively.

For the zero-prong events with no visible K_S^0 decay we require to estimate the contribution of reaction (5). Since the probability of observing either K^0 or $\bar{K}^0$ as $K_S^0 \rightarrow \pi^+ \pi^-$ is $1/3$ the relative fractions of final states containing a $K^0 \bar{K}^0$ pair should be $4/9$ with no K_S^0 visible, $4/9$ with one K_S^0 visible and $1/9$ with both K_S^0 visible. The ϕ meson^(**) however decays via $K_S^0 K_L^0$ and thus does not contribute to the final states with both visible K_S^0 . Thus by comparing the relative frequencies of the one and two visible K_S^0 events we are able to estimate (a) the amount of ϕ production and (b) the total contribution of $K\bar{K}$ pairs in the zero prong

(*) A crude estimate of the number of reaction (5) events among the $\Lambda +$ pions sample was made from the frequency of occurrence of single kinks in events with two V^0 and single and double kinks among events with no visible K_S^0 . This estimate yielded $(27\ 000 \pm 12\ 000)$.

(**) We have not considered the additional complication of other mesons, e.g. $A_2, f, f' \rightarrow K_S^0 K_S^0$ or $K_L^0 K_L^0$, since their cross section is known to be small compared with the ϕ .

events. This technique has been verified in the case of the 4C/1C production fits $K^- p \rightarrow \Lambda K_S^0 K_S^0 / \Lambda K_S^0 (K^0)$ via the $K\bar{K}$ effective mass spectrum. This procedure has also been applied in the two-prong events.

Results of the selection criteria are summarized in table I(b). The last two columns of the table give the estimated number of events of reactions (4) and (5) in the entire sample. For the analysis we used for reaction (4) only those events listed in column (2) of the table i.e., 249 496 events, while for reaction (5) we used only those events listed in column 4 i.e. 20 846 events (77% of the estimated sample); the latter contains 7620 vents with a visible K_S^0 decay or a visible kink on secondaries. The contamination due to events of reaction (5) with neutral K^0 decay could not be removed from reaction (4), this contamination being estimated to be $\approx 10\%$ among the zero-prong events and $\approx 1\%$ among the two-prong events.

In table II we list seven pairs of channels with $K^0 \bar{K}^0$ and $K^+ K^-$ pairs. It is generally assumed that the two reactions of each pair should occur with equal frequency. The observed small differences indicate the degree to which this general assumption may not be true.

4. CROSS SECTIONS

Topological cross sections for the reactions (4) and (5) are presented in table III. All the cross sections are corrected for the neutral decay mode of Λ and K^0 and for all cuts discussed above. The following values for the total cross sections are obtained:

$$\sigma_1(K^- p \rightarrow \Lambda + \text{anything}) = (4.54 \pm 0.22) \text{ mb} \quad (6a)$$

$$\sigma_2(K^- p \rightarrow \Lambda + \text{pions}) = (4.10 \pm 0.20) \text{ mb} \quad (6b)$$

$$\sigma_3(K^- p \rightarrow \Lambda + K\bar{K} + \text{pions}) = (0.44 \pm 0.03) \text{ mb}, \quad (6c)$$

where we have included a 5% systematic normalization uncertainty. The ratio σ_3/σ_1 is $(11 \pm 1)\%$. This is in agreement with the estimates reported earlier as $\approx 10\%$ at 4.2 GeV/c [3] and $(9 \pm 2)\%$ at 3.93 GeV/c [2]. It is worth mentioning that the cross section of Λ from reaction (4) is decreasing [7] as s^{-1} ,

where s is the square of the c.m. energy in GeV^2 , while that of the Λ from reaction (5) is continuously increasing from ≈ 0.4 mb at 4 GeV/c to ≈ 1.7 mb at 32 GeV/c [2-11].

5. THE x AND p_T^2 DISTRIBUTIONS

The invariant cross section for the production of Λ in terms of the variable x , where $x = p_L/p_L^{\max}$, and p_T is written as

$$\begin{aligned} f(x, p_T) &= E \frac{d^3\sigma}{d^3p} \\ &= \frac{E}{\pi p_L^{\max}} \frac{d^2\sigma}{dx dp_T^2}, \end{aligned} \quad (7)$$

where E , p_L and p_T are respectively the total energy, the longitudinal momentum and the transverse momentum of Λ in the c.m. system. $p_L^{\max}$ is the maximum longitudinal momentum available to the Λ (this is calculated by assuming the system recoiling against the Λ to be π^0 for reactions (1) and (4) and to be $K\bar{K}$ for reaction (5)). Integrating over p_T , we obtain the x distribution which we write as

$$F(x) = \int f(x, p_T) dp_T^2. \quad (8)$$

In fig. 2 we show the x distribution of Λ for the entire sample and compare it with that for the selected channel $K\bar{K} + \text{pions}$. The values of $F(x)$ are also listed in table IV. It can be seen that the fraction of events with $x \leq 0$ is larger for reaction (5) than for reaction (1). The average values of x for the reactions (1), (4) and (5) are respectively (-0.136 ± 0.001) , (-0.130 ± 0.001) and (-0.25 ± 0.01) .

The distribution of $d\sigma/dp_T^2$ in the region $-1.0 < x < -0.2$ for the reactions (1), (4) and (5) are well fitted by the following expression:

$$\frac{d\sigma}{dp_T^2} = A \exp(-B p_T^2), \quad (9)$$

for $p_T^2 \leq 0.5 \text{ GeV}^2$. The values of B are found to be (4.4 ± 0.1) , (4.4 ± 0.1) and $(4.5 \pm 0.1) \text{ GeV}^{-2}$ for the reactions (1), (4) and (5) respectively. The slope parameters are therefore the same within errors.

6. POLARIZATION OF Λ

In this section we describe the polarization (P_Λ) of lambdas from reactions (4) and (5) as functions of variables x , p_T and M^2 , where p_T is the transverse momentum of Λ and the recoiling-mass-squared M^2 is defined as,

$$M^2 = (q_K + q_p - q_\Lambda)^2, \quad (10)$$

where q_K , q_p and q_Λ are the four momenta of the incident kaon, the target proton and the Λ respectively. The variation of P_Λ with x will be described for the entire x region while the variation of P_Λ with p_T and M^2 will be described in the appropriate proton fragmentation region.

6.1 Definition of polarization

The polarization of the Λ is measured through its weak decay into a proton and a pion, and is defined as

$$P_\Lambda = \frac{3}{\alpha N} \sum_{i=1}^N \vec{q}_i \cdot \vec{n}_i \quad (11)$$

with expected error

$$\Delta P_\Lambda = \frac{1}{\alpha} \left[\frac{3 - (\alpha P_\Lambda)^2}{N} \right]^{1/2},$$

where $\vec{q}$ is the unit vector along the direction of the proton in the rest frame of the Λ , and $\vec{n}$ is the unit vector along the direction perpendicular to the production plane

$$\vec{n} = (\vec{q}_{\text{tar}} \times \vec{q}_\Lambda) / (|\vec{q}_{\text{tar}} \times \vec{q}_\Lambda|), \quad (12)$$

where $\vec{q}_\Lambda$ and $\vec{q}_{\text{tar}}$ are respectively the momentum in the overall c.m. system of the Λ and the target proton α is the decay asymmetry parameter of the Λ taken as 0.647 and N is the total number of observed events.

6.2 Polarization as a function of x and p_T

Fig. 3 shows the polarization P_Λ as a function of the variable x for the two processes (4) and (5). The variation of P_Λ with x for the reaction (4) which forms $\approx 90\%$ of the total sample has the same trend as had been noticed in earlier K^-p experiments in the momentum range 3.9 to 14.3 GeV/c [2,5]. There is a striking difference in P_Λ for the two processes (4) and (5) in the region $x < -0.5$; it is positive for reaction (4) whilst it is negative for reaction (5). The difference in P_Λ is marginal for $x > -0.5$. Because of large statistics for reaction (4) it is clear from the figure that P_Λ changes sign at $x \approx -0.5$ and it is negative for $x \geq -0.5$. Thus the basic difference in the two reactions lies in the proton fragmentation region. Within statistical errors there is no difference in P_Λ for the two reactions in the beam fragmentation region as expected because the leading Regge trajectories remain the same for the two reactions.

In fig. 4 the Λ polarization is plotted as a function of the Λ transverse momentum p_T . For this plot we have selected the events from the proton fragmentation region by restricting to $x < -0.2$. It is seen from the figure that for reaction (4) the value of P_Λ is positive and increases as p_T increases [12] while for reaction (5) P_Λ becomes negative as p_T increases.

6.3 Polarization as a function of (recoiling-mass)²

We describe here the Λ polarization in the proton fragmentation region as a function of M^2 . The events from the proton fragmentation region are selected by requiring $t \geq -1.0$ (GeV/c)², where t refers to the square of the four-momentum transfer from the target proton to the Λ .

Fig. 5 shows the plots of $d\sigma/dM^2$, P_Λ and $P_\Lambda d\sigma/dM^2$ as a function of M^2 for three different t-bins. It is seen from the figure that there is a difference in P_Λ for reactions (4) and (5) in the region $1.0 \leq M^2 \leq 2.0 \text{ GeV}^2$; it is positive for reaction (4) while it is negative for reaction (5). For $M^2 > 2 \text{ GeV}^2$ in reaction (4) there is a trend for P_Λ and $P_\Lambda d\sigma/dM^2$ to become negative. This behaviour is particularly clear for the t-range -1.0 to -0.6 (GeV/c)^2 ; this basically reflects the negative polarization seen in fig. 3 for $x \geq -0.5$.

Since the inclusive process is a sum of all n-body processes, with $n \geq 2$, structures in $(\text{recoiling-mass})^2$ due to two-body processes at low energies can be expected. In K^-p reactions some of the two-body final states are $\pi^0\Lambda$, $\rho^0\Lambda$, $\omega^0\Lambda$, $\eta'\Lambda$, $\phi\Lambda$ and $A_2\Lambda$, and in general their production cross sections decrease with increasing mass [13]; the cross section is $\approx 60 \text{ } \mu\text{b}$ for $\pi^0\Lambda$ and $\approx 15 \text{ } \mu\text{b}$ for $A_2\Lambda$ in the forward direction ($t \geq -1.0 \text{ (GeV/c)}^2$) at the present energy. These two-body processes are known to involve large Λ polarization [13] and therefore one expects to see their effects in P_Λ over and above a general trend. The prominent structures seen in P_Λ and $P_\Lambda d\sigma/dM^2$ for both reactions (4) and (5) are primarily due to this effect.

6.4 Comparison of polarization from K^-p and $\bar{p}p$

It is interesting to note that the leading Regge trajectories involved in the strangeness non-annihilation process of reaction (5) and in the reaction

$$p + \bar{p} \rightarrow \Lambda + \text{anything} \quad (13)$$

are the same (figs 1(a) and 1(b)). One might therefore expect similar polarization properties in the two reactions. We have therefore compared the lambda polarization from reaction (5) with that from reaction (13) at 5.7 GeV/c [14].

Fig. 6(a) shows a comparison of P_Λ vs. p_T for events in the proton fragmentation regions (selected by restricting to $-1.0 < x < -0.2$) in the two reactions. Fig. 6(b) shows a comparison of P_Λ vs. x for events with

the selection $x < 0.0$. As expected, the figures show identical behaviour for the two reactions. It is to be remarked that even the exclusive quasi two-body reactions, $K^- p \rightarrow \phi \Lambda$ and $\bar{p} p \rightarrow \bar{\Lambda} \Lambda$ show a similar behaviour in P_Λ when plotted as a function of t [15].

7. DISCUSSION

In this section we discuss the polarized and the unpolarized Λ cross section in the triple Regge framework. The similarity of the Λ polarization from reactions (5) and (13) is discussed in the framework of the quark model.

(a) Polarized Λ cross sections

The triple Regge model has been applied [16] to high energy inclusive reactions at the kinematic boundaries of the target and the beam fragmentation regions. This model is also expected to apply at lower energies, in a semi-local sense, through finite mass sum rules giving an average description through the resonance production region. This is found to be valid in reactions with low incident momenta [4,14]. Some of the implications of the triple Regge model for polarization measurements and its importance in inclusive reactions have been discussed by several authors [5,17]. The polarized cross section for reaction (1) in this framework can be written as,

$$P_\Lambda(s, t, M^2) \cdot \tilde{\sigma} = \frac{1}{s} \sum_{ijk} P_{ijk}(t) \cdot \left(\frac{s}{M^2} \right)^{\alpha_i(t) + \alpha_j(t)} \cdot (M^2)^{\alpha_k(0)}, \quad (14)$$

where $\tilde{\sigma} = \frac{d^2\sigma}{dtd(M^2/s)}$.

$P_{ijk}(t)$ contains the Regge residues and the signature factors [17(a)] and $\alpha(t)$ are the relevant Regge trajectories in fig. 1(a). From the parity invariance of the Regge residues it has been shown [17(a)-(b)] that $P_\Lambda \tilde{\sigma}$ can be written as the sum of two terms

$$P_\Lambda \tilde{\sigma} = P_\Lambda^{N/U} \tilde{\sigma}^N + P_\Lambda^{U/U} \tilde{\sigma}^U, \quad (15)$$

where N/U refers to natural/unnatural parity exchanges at the $p\Lambda$ vertex.

The M^2 dependence of $P_{\Lambda}^{\sim}$ for a fixed value of the incident beam momentum is obtained from eq. (14)

$$P_{\Lambda}(t, M^2)^{\sim} \sim \sum_{ijk} P_{ijk}(t) \cdot (M^2)^{\alpha_k(0) - \alpha_i(t) - \alpha_j(t)}, \quad (16)$$

where the summation has to be taken over the natural and the unnatural exchanges separately. We now assume that the natural parity exchanges coupling to the $p\Lambda$ vertex are K^* and K^{**} while the unnatural parity exchanges are K and K_A . The values of the intercepts and the slopes that we have assumed for these trajectories are given in table V(a). We have summarized in table V(b) the M^2 dependence of $P_{\Lambda}^{\sim}$, as expected from eq. (16), for three typical t values. It is seen from the table that $P_{\Lambda}^{\sim}$ rises with M^2 for $|t| \gtrsim 0.1 \text{ (GeV/c)}^2$ for both natural and unnatural exchanges.

In the case of the strangeness annihilation process the Regge trajectories that are expected to couple to the $K^- K^-$ vertex are the ϕ , f' trajectories and we correspondingly take $\alpha_k(0) = 0$. The general trend of the experimental $P_{\Lambda}^{\sim}$, shown in fig. 5, is that it decreases with increasing M^2 and, for high M^2 and high $|t|$ values, it becomes negative. This general trend can be qualitatively understood if we assume that the natural and the unnatural exchanges contribute with opposite sign.

The case of the strangeness non-annihilation is more complicated because of the expected coupling of both the Pomeron as well as the ordinary meson trajectories ($\alpha_k(0) \approx 0.5$) to the $K^- K^-$ vertex. The coupling of the Pomeron to the natural exchanges, $PK^* K^{**}$, is expected to be zero by generalized C-parity [5] and therefore yields no polarization. The experimental observation is that $P_{\Lambda}^{\sim}$ is consistent with zero for all values of M^2 except for $M^2 \approx 1 \text{ GeV}^2$ with $t < -0.2 \text{ (GeV/c)}^2$, see fig. 5. This negative and large value of $P_{\Lambda}^{\sim}$ at $M^2 \approx 1 \text{ GeV}^2$ is due to the two-body reaction $K^- p \rightarrow \phi \Lambda$.

(b) Unpolarized Λ cross sections

We now discuss the M^2 dependence of the unpolarized invariant cross sections for reactions (4) and (5). To do this it is convenient to replace M^2 by the antisymmetric variable $v = M^2 - t - m_K^2$, where m_K is the rest mass of the kaon. The invariant cross section for reaction (4) or (5) can be written as

$$\frac{d^2\sigma}{dt d(v/s)} = G(t) \cdot s^{\alpha_K(0)-1} (v/s)^{\alpha_K(0)-\alpha_i(t)-\alpha_j(t)} \quad (17)$$

The intercept $\alpha_K(0)$ refers to the effective ϕ , f' trajectory for reaction (4), and to the effective Pomeron + meson trajectory for reaction (5). Because of the copious production of resonances in reaction (4) we have used the first moment integral [18]

$$I_1(x, t) = \int_0^x \left(\frac{v}{s}\right) \frac{d^2\sigma}{dt d(v/s)} \cdot d(v/s), \quad (18)$$

which gives

$$I_1(x, t) = g(t) \cdot \frac{x^{a(t)+2}}{a(t)+2}, \quad (19)$$

where

$$a(t) = \alpha_K(0) - \alpha_i(t) - \alpha_j(t) \quad (20)$$

and

$$g(t) = G(t) s^{\alpha_K(0)-1}. \quad (21)$$

For the sake of clarity we now label $a(t)$ as $a_4(t)$ for reaction (4) and $a_5(t)$ for reaction (5); similarly we re-name the leading Regge trajectory intercept $\alpha_K(0)$ as $\alpha_4(0)$ and $\alpha_5(0)$. Thus we have

$$a_4(t) = \alpha_4(0) - [\alpha_i(t) + \alpha_j(t)], \quad (22)$$

$$a_5(t) = \alpha_5(0) - [\alpha_i(t) + \alpha_j(t)]. \quad (23)$$

It is reasonable to assume that on the average $(\alpha_i(t) + \alpha_j(t))$ is the same for both reactions (4) and (5) and it then follows from eqs (22) and (23)

$$\Delta = a_5(t) - a_4(t) = \alpha_5(0) - \alpha_4(0). \quad (24)$$

Thus, by determining $a_4(t)$ and $a_5(t)$ from the experimental data it is in principle possible to measure the difference of the intercepts of the two effective trajectories responsible for reactions (4) and (5).

Since the variable v becomes negative for $t > -0.3 \text{ (GeV/c)}^2$ in the case of reaction (4), we have therefore restricted our analysis to the t -range -1.0 to -0.3 (GeV/c)^2 . The experimental distributions $I_1(x,t)$ for reactions (4) were fitted by using eq. (19) and the values of $a_4(t)$ were determined for different t -bins. We show in figs 7(a) and (b) a sample fit to reaction (4) for the t -interval -0.6 to -0.5 (GeV/c)^2 . The solid curves represent the result of the fit to eq. (19) and they reproduce in an average sense the low mass regions of fig. 7(a) as expected from finite mass sum rules. The fitted values of $a_4(t)$ are listed in table VI and they are in good agreement with those determined previously [4] with one-third of the present data.

In the case of reaction (5) there is a high mass threshold of $M^2 = 4m_k^2$. We have adopted two methods to determine $a_5(t)$ and they are discussed below.

- (i) We ignore the threshold effect and determine $a_5(t)$ using eq. (19). We show in fig. 7(d) a sample fit to reaction (5) for $-0.6 < t < -0.5 \text{ (GeV/c)}^2$ by the solid curve. Its projection to the invariant cross section eq. (17) is shown in fig. 7(c) by a solid curve. The fitted values are listed in column 3 of table VI.
- (ii) We have attempted to take care of the threshold effect by replacing v by v'

$$v' = v - v_{th}, \quad v_{th} = 3m_k^2$$

in eq. (19). The experimental data for $-0.6 < t < -0.5 \text{ (GeV/c)}^2$ in terms of (v'/s) is shown in fig. 7(d) by a dotted histogram and the fit by a dotted curve. Its projection to the invariant cross section eq. (17), is shown in fig. 7(c) by a dotted curve. The fitted values are listed in column 4 of table VI.

The projected curves from (i) and (ii) to the invariant cross section are both equally good, but the values of $a_5(t)$ as deduced from the two methods are systematically different by 0.8. The values of Δ as deduced by using the two methods are listed in columns 5 and 6 of table VI. Because of the large enhancement right at the threshold due to the reaction $K^- p \rightarrow \phi \Lambda$ and a comparatively small range of (v/s) available at the present energy, it is not possible to draw a conclusion on the difference of the intercepts of the two effective trajectories responsible for reactions (4) and (5).

(c) Similarity of Λ polarization from $K^- p$ and $\bar{p} p$

We have demonstrated in sect. 6.4 the similarity of the Λ polarization in the proton fragmentation region from reactions (5) and (13). In the simple quark model this similarity can be qualitatively understood as demonstrated in fig. 8. The quark line s in the K^- vertex and the quark lines $\bar{d}$, $\bar{u}$ in the $\bar{p}$ vertex act as spectator quarks. It can be easily checked that the above argument is not true if we replace reaction (5) by reaction (4); in the latter case the quark diagram has to be non planar and therefore the configuration becomes different compared to the $\bar{p} p$ case.

The similarity in the exclusive reactions $K^- p \rightarrow \phi \Lambda$ and $\bar{p} p \rightarrow \bar{\Lambda} \Lambda$ can also be understood in this simple quark picture, see fig. 8(b).

8. CONCLUSIONS

We have made a study of lambda production from 4.2 GeV/c $K^- p$ interactions. The main motivation has been to study differences in the proton fragmentation region between the off-mass-shell $K\bar{K}$ interaction leading to Strangeness Annihilation Processes (SAP) and Strangeness Non-Annihilation Processes (SNAP). These two processes are expected to involve exchange of different leading Regge trajectories, namely ϕ , f' exchange in SAP and exchange of P plus normal meson trajectories in SNAP. The present analysis has brought out the following important features of the two

processes:

- (a) The Λ polarization is positive in the case of SAP while it is negative for the SNAP in the region $-1.0 < x < -0.5$. In the former case the polarization changes sign for $x \gtrsim -0.5$.
- (b) The dependence of P_Λ on p_T is found to be very different for the two processes: namely for SAP P_Λ is positive and increases with p_T while for SNAP P_Λ is consistent with zero for $p_T < 0.5$ GeV/c and becomes negative for $p_T > 0.5$ GeV/c.
- (c) The general trend of the polarized cross section for both SAP and SNAP is that its absolute value on the average decreases as M^2 increases. In the case of SAP it becomes negative at high M^2 and high $|t|$ values. In the case of SNAP it is consistent with zero for $M^2 > 1.2$ GeV² and for all t -values.
- (d) A similarity was demonstrated between the strangeness non-annihilation processes and the production of Λ in $\bar{p}p$ interactions; the Λ polarization when plotted as a function of x and p_T is found to be remarkably similar for the two reactions. This similarity is understood within the context of simple quark diagrams.

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TABLE CAPTIONS

- Table I(a) Topological break-down of the raw data.
- (b) Topological separation of events in terms of two final states $\Lambda + \text{pions}$ and $\Lambda + K\bar{K} + \text{pions}$.
- Table II Comparison of number of events for reaction channels with $K^0\bar{K}^0$ and K^+K^- pairs in the final state.
- Table III Topological cross section of $K^-p \rightarrow \Lambda + \text{pions}$ and $K^-p \rightarrow \Lambda + K\bar{K} + \text{pions}$.
- Table IV Invariant x distribution $F(x)$ for all Λ and for $K^-p \rightarrow \Lambda + K\bar{K} + \text{pions}$.
- Table V(a) Regge trajectories.
- (b) M^2 dependence of $P_{\Lambda} \cdot \tilde{\sigma}$ from the interference of natural trajectories ($K^* K^{**}$) and from unnatural trajectories (KK_{Λ}).
- Table VI Result of a triple Regge fit to the experimental data of $K^-p \rightarrow \Lambda + \text{pions}$ and $K^-p \rightarrow \Lambda + K\bar{K} + \text{pions}$.

TABLE I(a)

Event type	One V^0 Λ	Two V^0 's $\Lambda + K_S^0$	Three V^0 's $\Lambda + K_S^0 + K_S^0$	TOTAL
Zero prong	38 748	3 383	421	42 552
Two prongs	182 457 (1073)*	2 581 (73)*	41	185 079
Four prongs	51 679 (114)*	7	0	51 686
Six prongs	479	0	0	479
Total	273 363	5 971	462	279 796

(*) Number of events in the previous total which have a visible kink on a secondary track.

TABLE I(b)*

Event Type	After hypothesis selection		After cut on probability	Estimated No. of events in the total Λ sample	
	$\Lambda + \text{pions}$	$\Lambda + K\bar{K} + \text{pions}$	$\Lambda + K\bar{K} + \text{pions}$	$\Lambda + \text{pions}$	$\Lambda + K\bar{K} + \text{pions}$
Zero prong	38 748	(3804)	(3804)	34 592	7 960
Two prongs	159 970	22 487 +(2622)	13 409 +(2622)	166 992	18 087
Four prongs	50 299	1 380 +(7)	1 004 + (7)	50 543	1 143
Six prongs	479	0	0	479	0
Total	249 496	23 867+(6433)	14 413+(6433)	252 606	27 190

(*) Bracketed numbers refer to the events with K_S^0 . They are not included in the previous total.

TABLE II ^(a)

Sets	Final states	Estimated No of events
1	$\Lambda K^0 \bar{K}^0$	2749 ± 300
	$\Lambda K^+ K^-$	3409 ± 150
2	$\Lambda K^0 \bar{K}^0 (\pi^0)$	2954 ± 300
	$\Lambda K^+ K^- (\pi^0)$	2383 ± 120
3	$\Lambda K^0 \bar{K}^0 (MM)$	2257 ± 250
	$\Lambda K^+ K^- (MM)$	2454 ± 120
4	$\Lambda \pi^+ K^+ K_S^0$	1888 ± 100
	$\Lambda \pi^+ K^+ (K^0)^{(b)}$	5108 ± 300 $(3776 \pm 200)^{(c)}$
5	$\Lambda \pi^+ K^+ K_S^0 (\geq 1\pi^0)$	649 ± 50
	$\Lambda \pi^+ K^+ (MM)$	1106 ± 70 $(1298 \pm 100)^{(c)}$
6	$\Lambda \pi^+ \pi^- K^0 \bar{K}^0$	890 ± 120
	$\Lambda \pi^+ \pi^- K^+ K^-$	767 ± 60
7	$\Lambda \pi^+ \pi^- K^0 \bar{K}^0 (\geq 1\pi^0)$	200 ± 30
	$\Lambda \pi^+ \pi^- K^+ K^- (\geq 1\pi^0)$	243 ± 30

- (a) K_S^0 refers to only charged decay into $\pi^+ \pi^-$.
Unseen decay modes are corrected in K^0 or $\bar{K}^0$.
- (b) This final state refers to 1C fit and (K^0) refers to unseen K^0 only.
- (c) The numbers within brackets refer to the expectation based on the ratio of the probability of seeing a K^0 decay to that of not seeing a K^0 decay, which is 2.

TABLE III

Topology	$\sigma(\mu\text{b})$		Total
	$\Lambda + \text{pions}$	$\Lambda + \text{K}\bar{\text{K}} + \text{pions}$	
Zero prong	570 ± 30	130 ± 10	700 ± 33
Two prongs	2682 ± 125	295 ± 22	2977 ± 130
Four prongs	835 ± 40	19 ± 3	854 ± 41
Six prongs	9 ± 1	-	9 ± 1
Total	4096 ± 200	444 ± 30	4540 ± 220

TABLE IV

x interval	$K^- p \rightarrow \Lambda + X$		$K^- p \rightarrow \Lambda + K\bar{K} + \text{pions}$	
	No of events	F(x) (μb)	No of events	F(x) (μb)
-1.00 -0.95	1973	293 ± 7	297	58 ± 3
-0.95 -0.90	2542	357 ± 7	562	105 ± 4
-0.90 -0.85	3406	459 ± 8	547	99 ± 4
-0.85 -0.80	6089	788 ± 10	585	106 ± 4
-0.80 -0.75	7095	893 ± 11	616	108 ± 4
-0.75 -0.70	7114	874 ± 10	718	126 ± 5
-0.70 -0.65	7616	910 ± 10	776	134 ± 5
-0.65 -0.60	8052	939 ± 10	816	148 ± 5
-0.60 -0.55	8464	964 ± 10	803	142 ± 5
-0.55 -0.50	9045	1005 ± 11	775	142 ± 5
-0.50 -0.45	9421	1022 ± 10	821	139 ± 5
-0.45 -0.40	9590	1017 ± 10	758	136 ± 5
-0.40 -0.35	9970	1037 ± 10	740	123 ± 5
-0.35 -0.30	10293	1049 ± 10	811	131 ± 5
-0.30 -0.25	10822	1085 ± 10	755	118 ± 4
-0.25 -0.20	10916	1082 ± 10	757	115 ± 4
-0.20 -0.15	11249	1104 ± 10	759	108 ± 4
-0.15 -0.10	11431	1116 ± 10	721	109 ± 4
-0.10 -0.05	11535	1123 ± 10	732	103 ± 4
-0.05 0.00	11776	1149 ± 11	744	107 ± 4
0.00 0.05	11511	1125 ± 10	765	111 ± 4
0.05 0.10	11334	1112 ± 10	746	107 ± 4
0.10 0.15	11024	1095 ± 10	680	102 ± 4
0.15 0.20	10603	1070 ± 10	658	94 ± 4
0.20 0.25	9933	1013 ± 10	633	91 ± 4
0.25 0.30	9130	947 ± 10	599	88 ± 4
0.30 0.35	8338	884 ± 10	508	78 ± 4
0.35 0.40	7313	795 ± 9	443	68 ± 3
0.40 0.45	6375	708 ± 9	388	62 ± 3
0.45 0.50	5447	624 ± 8	345	55 ± 3
0.50 0.55	4512	532 ± 8	278	44 ± 3
0.55 0.60	3939	479 ± 8	203	34 ± 2
0.60 0.65	3212	399 ± 7	169	30 ± 2
0.65 0.70	2530	321 ± 6	127	22 ± 2
0.70 0.75	2062	273 ± 6	80	17 ± 2
0.75 0.80	1590	213 ± 5	55	12 ± 2
0.80 0.85	1098	155 ± 5	39	9 ± 2
0.85 0.90	856	123 ± 4	26	6 ± 1
0.90 0.95	345	51 ± 3	13	2 ± 1
0.95 1.00	229	38 ± 3	5	1 ± 0.5

TABLE V(a)

Regge trajectories	Naturality
$\alpha_K(t) = -0.2 + 0.9 t$	Unnatural
$\alpha_{K_A}(t) = -0.5 + 0.9 t$	Unnatural
$\alpha_{K^*}(t) = 0.3 + 0.9 t$	Natural
$\alpha_{K^{**}}(t) = 0.2 + 0.9 t$	Natural
$\alpha_\phi(0) = 0.0$	Natural
$\alpha_M(0) = 0.5$	Natural
where M refers to normal meson trajectories	

TABLE V(b)

t (GeV/c) ²	$\alpha_K(0) = 0.0$		$\alpha_K(0) = 0.5$	
	$K^* K^{**}$	$K K_A$	$K^* K^{**}$	$K K_A$
-0.1	$(M^2)^{-0.3}$	$(M^2)^{0.9}$	$(M^2)^{0.2}$	$(M^2)^{1.4}$
-0.4	$(M^2)^{0.2}$	$(M^2)^{1.4}$	$(M^2)^{0.7}$	$(M^2)^{1.9}$
-0.8	$(M^2)^{0.9}$	$(M^2)^{2.1}$	$(M^2)^{1.4}$	$(M^2)^{2.6}$

TABLE VI

t-intervals (GeV/c) ²	$a_4(t)$	$a_5(t)$		Δ	
		Method (i)	Method (ii)	Method (i)	Method (ii)
-0.3 -0.4	0.70 ± 0.04	1.10 ± 0.09	0.26 ± 0.09	0.4 ± 0.1	-0.4 ± 0.1
-0.4 -0.5	0.90 ± 0.04	1.10 ± 0.08	0.42 ± 0.09	0.2 ± 0.1	-0.5 ± 0.1
-0.5 -0.6	1.10 ± 0.04	1.70 ± 0.07	0.87 ± 0.08	0.6 ± 0.1	-0.2 ± 0.1
-0.6 -0.7	1.40 ± 0.04	1.70 ± 0.06	0.95 ± 0.07	0.3 ± 0.1	-0.5 ± 0.1
-0.7 -0.8	1.60 ± 0.04	1.80 ± 0.06	1.05 ± 0.07	0.2 ± 0.1	-0.6 ± 0.1
-0.8 -0.9	1.90 ± 0.04	2.30 ± 0.07	1.51 ± 0.07	0.4 ± 0.1	-0.4 ± 0.1
-0.9 -1.0	2.00 ± 0.04	2.50 ± 0.07	1.69 ± 0.07	0.5 ± 0.1	-0.3 ± 0.1

FIGURE CAPTIONS

- Fig. 1 Triple Regge diagrams for the target fragmentation process $p \rightarrow \Lambda$: (a) for the incident beam as K^- and (b) for the incident beam as antiproton.
- Fig. 2 Invariant cross sections as a function of x .
- Fig. 3 Λ polarization as a function of x for the reactions $K^- + p \rightarrow \Lambda + \text{pions}$ and $K^- + p \rightarrow \Lambda + K\bar{K} + \text{pions}$.
- Fig. 4 Comparison of Λ polarization as a function of the transverse momentum for the two processes $K^-p \rightarrow \Lambda + \text{pions}$ (data points as $\square$) and $K^-p \rightarrow \Lambda + K\bar{K} + \text{pions}$ (data points as $\blacksquare$) in the target fragmentation region $-1.0 < x < -0.2$.
- Fig. 5 Plots for $d\sigma/dM^2$, polarization and $P_\Lambda d\sigma/dM^2$ versus (recoiling-mass) 2 are shown in three t -intervals for the reactions $K^-p \rightarrow \Lambda + \text{pions}$ and $K^-p \rightarrow \Lambda + K\bar{K} + \text{pions}$. Dotted curves through the data points are drawn to aid the eye.
- Fig. 6(a) Comparison of Λ polarization as a function of the transverse momentum for the two processes $K^-p \rightarrow \Lambda + K\bar{K} + \text{pions}$ and $\bar{p}p \rightarrow \Lambda + \text{anything}$ in the target fragmentation region $-1.0 < x < -0.2$.
- (b) Comparison of Λ polarization as a function of x for the two processes $K^-p \rightarrow \Lambda + K\bar{K} + \text{pions}$ and $\bar{p}p \rightarrow \Lambda + \text{anything}$ in the region $x < 0.0$.
- Fig. 7 Solid histograms are the experimental data: (a) and (c) refer to $d^2\sigma/dt d(v/s)$ as a function of v/s , and (b) and (d) are $I_1(x,t)$ as a function of v/s . Dotted histogram refers to the experimental $I_1(x,t)$ by replacing v by $v' = v - v_{th}$. Curves on (b) and (d) are the fitted ones while those on (a) and (c) are the deduced ones. For details see the text.
- Fig. 8(a) Quark diagrams for $p \rightarrow \Lambda$ in $K^-p \rightarrow \Lambda K\bar{K} + \text{pions}$ and $\bar{p}p \rightarrow \Lambda + \text{anything}$.
- (b) Quark diagrams for $K^-p \rightarrow \phi\Lambda$ and $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$.

FIG. 1a

FIG. 1b

FIG. 2

FIG. 3

Fig. 4

Fig. 5

Fig. 6

$K^-p \rightarrow \Lambda + \text{pions} \ , \ -0.6 < t < -0.5$

$K^-p \rightarrow \Lambda + K \bar{K} + \text{pions} \ , \ -0.6 < t < -0.5$

Fig. 7

Fig. 8