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On Final State Polarization in Polarized Beam Experiments

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ABSTRACT

Strong polarization effects are observed for inclusive hyperon production in hadronic collisions. Also quarks which are conventionally regarded as spectators turn out to be polarized, e.g. in the reaction $K^+p \to \bar{\Lambda}X$. Thus the "spectators" can take a more active part in the reaction. In this paper we study how measurements of hyperon polarization in the fragmentation of polarized protons can clarify the rôle of the spectator quarks, in particular whether it is possible for the spin of the spectators to flip during the interaction.

1. Introduction.

Large polarization effects have been observed in inclusive baryon production from high energy, unpolarized hadron beams [1]. These observations came as a surprise, because spin effects were not expected to survive at these energies. Hard scattering processes do not give rise to large polarization effects according to conventional perturbative QCD. However, in case the polarization phenomena basically stem from a soft process, perturbative QCD should not be applicable. In that case we have presently to rely on phenomenological models. In the Lund model [2] polarization is a natural consequence of confinement. Satisfactory agreement with experimental data on e.g. Λ- and Σ-polarization have, for that model, been obtained in earlier papers [3,4].

In this paper we will first review some of the basic ideas, and then extend the discussion to the next generation of experiments, where the initial proton beam is polarized. We find that our predictions for the outcome of such experiments show a significant dependence on the detailed assumptions we make about the behaviour of the quarks etc. involved in the reaction. It is therefore our belief that the results of these experiments can give valuable contributions to our understanding of confined dynamics. In the additive quark model the hadronic constituents are partitioned into two groups, participants and spectators. One essential question is whether the spectator can flip or not during the process. This is very difficult to deduce from data on unpolarized beam experiments only. The general assumption [5] is that the spectator is totally unaffected, i.e. that it does not flip, but in our picture spectator flip is as natural as non-flip. A complete model should therefore cover both possibilities.

2. Review of previous ideas and results.

When a proton is hit in a collision, we expect it, within the frame-work of the Lund model, to stretch out in a stringlike manner

The idea is that a hadronic interaction is local in the sense that at first only one of the valence quarks (called I-quark - I for initial - in "standard Lund model jargon") gets involved. When all the energy of this quark is used up, the remaining quarks get involved, so that the next quark (J-quark, J for junction) will use up its energy and finally the third one (L-quark, L for leading) gets activated. Thus an essentially one dimensional force field is stretched out with the L-quark ahead, followed by the J- and the I-quark. Eventually the string breaks up by a quark-antiquark pair creation. If the quarks have mass and/or $\bar{k}_\perp$ they can, classically, only be produced a certain distance ℓ apart, so that the energy from the vanishing field between them is transformed into transverse mass (cf. fig. 1). Quantum mechanically this can be described as a tunneling phenomenon. Thus we have

$$\kappa \ell = 2\mu_\perp \qquad (2.1)$$

where $\kappa \approx 0.2$ GeV^2 is the energy per unit length in the string (the string tension), and

$$\mu_\perp = \sqrt{\mu^2 + k_\perp^2} \qquad (2.2)$$

is the transverse mass of the quark or the antiquark. Furthermore, in order to conserve transverse momentum, the pair must be produced with transverse momenta $\bar{k}_\perp$ and $-\bar{k}_\perp$ respectively. This induces an orbital angular momentum $\bar{L}$ of the size

$$|\bar{L}| = \ell k_\perp = \frac{2\mu_\perp k_\perp}{\kappa} \qquad (2.3)$$

In order to conserve the total angular momentum, the quark and the antiquark must therefore be polarized, resulting in a final-state-baryon polarization. For this picture to be consistent we note that we must have $L \lesssim 1$. However, the tunneling process will imply that $k_\perp \sim \sqrt{\kappa/\pi}$ and thus $L \sim 2/\pi$.

The situation is especially simple when the produced baryon is a Λ. In the Lund model for ordinary hadronic collisions, Λ-particles

at large x_F-values in proton fragmentation stem from a string with an effective ud-diquark (here called spectator) at the end and an s-quark created in a breakup of the string [3]. As the ud-diquark in a Λ-particle must be a spin-singlet, the Λ-polarization equals the polarization of the s-quark. In this picture a Λ with transverse momentum upwards (and the proton coming in from the left) is therefore expected to be polarized into the plane of the paper (see fig. 2), i.e. in the direction $-\bar{p}_p \times \bar{p}_\Lambda$.

If the final state particle instead is a Σ^+, things are rather similar, the main difference being that we now have a spin-triplet uu-diquark from the proton entering the new baryon. If the diquark-spectator was unpolarized, we would get $P_{\Sigma^+} = -\frac{1}{3}P_\Lambda$, which is not in very good agreement with the experimental observation $P_{\Sigma^+} \approx -P_\Lambda$. (This result stems, however, from not very large x_F-values but the trend seems to be the same for the whole observed range). The Λ polarization is certainly expected to be suppressed by decaying Σ^0:s and Σ^*:s, but probably not with a factor of three. However, there are strong experimental reasons to doubt that the spectator is unpolarized. In the reaction $K^+p \to \bar{\Lambda}X$ with the $\bar{\Lambda}$ in the K^+ fragmentation region, we expect that it will very often contain the $\bar{s}$-quark from the K^+. Then the $\bar{s}$-quark would take the rôle of spectator, and a $\overline{ud}$-diquark be produced in the field, as shown in fig. 3. Experimentally the $\bar{\Lambda}$ is polarized [6], and therefore the spectator $\bar{s}$-quark must have become polarized. The same conclusion should then apply to the uu_1-diquark in a Σ^+ stemming from the proton fragmentation region. A simple model accounting for this effect was recently proposed in [7] (diquark-polarization has also been discussed in [8]). In the proton rest frame the situation can look as in fig. 4a. When the d-quark in the proton is hit, the string will be bent and move as in fig. 4b. The uu-diquark and the attached string piece will get an angular momentum $\bar{J}$. Furthermore, the string tension will give it a transverse momentum $\bar{p}_\perp$ in the direction indicated in the figure. As the diquark in this picture never can be fully isolated from the confining colour field - i.e. a "constituent" quark must be regarded as a "bare" quark and an attached string piece - we can interpret this as a diquark polarization in the direction $\bar{p}_p \times \bar{p}_\Lambda$. The s-quark is polarized in the opposite direction, just as in the Λ-case. As

the spin of the Σ^+ is parallel to the spin of the uu-diquark and antiparallel to the s-quark spin, this effect will enhance the Σ^+-polarization in the experimentally observed direction.

Experimental data are also available on Σ^-, Σ^0-, Ξ^0- and Ξ^--particles [1]. Σ^0 is here produced in a way similar to Σ^+, while producing the others from proton fragmentation requires the production of (at least) two new quarks. The string is then stretched as shown in fig. 5 a and for large x_F:s it preferentially fragments with one quark-antiquark pair at each side of the J-quark. The quark behind the J-quark will according to the earlier described mechanism be polarized downwards, while the quark stemming from the string segment between the J- and L-quarks will be polarized upwards, by the same argument. Note that it is pulled in the opposite direction by the colour field. This is illustrated in fig. 5b. In the Lund model the LJ-segment of the string in general contains less available energy than the segment behind the J-quark. This implies that the transverse momentum of the quark (and antiquark) produced between L and J tends to be smaller than for the quark (antiquark) behind J. Quantitatively, Monte Carlo simulations have indicated [4] that

$$\langle k_\perp^2 \rangle_{\text{behind } J} \approx 2\langle k_\perp^2 \rangle_{\text{LJ-segment}} \qquad (2.4)$$

The quark produced in the LJ-segment should therefore be less polarized than the quark behind J. We further find it reasonable to expect that the J-quark, which goes into the final-state-baryon, behaves in a similar way to each of the quarks making up the diquark in the Σ^+-case. With this model it is possible to explain experimental data for various baryons. In the next section we continue with building up the formalism, which also is extended to include the case where the initial proton is polarized.

3. Σ^+-polarisation.

It is rather easy to extend the formalism to the case of polarized protons. There is, however, one possible effect we must be aware of. The quarks stemming from the proton may flip before they enter the final-state-baryon. This possibility is usually neglected in the literature, but we feel that it should be included in the treatment.

We have found it suitable to build up the formalism in connection with the Σ^+-case, which accounts for the main features of our ideas. In accordance with the earlier discussion we consider the Σ^+ to be constructed from a uu_1-diquark (spectator) from the proton and an s-quark produced in the confining field. Σ^0 is treated in the same way, the only difference being that the spectator now is a ud_1-diquark. We will all the time consider polarization effects with respect to the normal to the scattering plane.

We start by introducing some useful parameters:

- u = fraction of diquarks with spin +1 entering the Σ^+
- z = fraction of diquarks with spin 0 entering the Σ^+
- d = fraction of diquarks with spin -1 entering the Σ^+
- n_{s_+} = fraction of s-quarks with spin $+\frac{1}{2}$ entering the Σ^+
- n_{s_-} = fraction of s-quarks with spin $-\frac{1}{2}$ entering the Σ^+

Evidently, we must have $u + d + z = n_{s_+} + n_{s_-} = 1$

Convenient combinations of u, d and z are

$$V = u - d \tag{3.1}$$

and

$$T = u + d - 2z \,, \tag{3.2}$$

related to the vector and tensor polarization respectively. Furthermore, we introduce

S = polarization of the s-quark entering the Σ^+ and

a_{if} = *relative probability for a diquark with initial spin i and final spin f to end up in a* Σ^+.

V and T can be expressed in terms of the probabilities a_{if}:

$$V = \frac{\Sigma a_{i1} - \Sigma a_{i-1}}{\Sigma a_{if}} \tag{3.3}$$

$$T = 1 - 3\frac{\Sigma a_{i0}}{\Sigma a_{if}} \tag{3.4}$$

The uu_1-part of the Σ^+ SU(6) wave function for $m_s = \pm\frac{1}{2}$ is given by

$$|\Sigma^+_\pm\rangle \sim \sqrt{2}|uu_1,\pm1\rangle|s\mp\rangle - |uu_1,0\rangle|s\pm\rangle \tag{3.5}$$

If semiclassical arguments can be used for the polarization along the normal to the scattering plane, it is reasonable to assume that interference effects are small when the spins are quantized along this direction. We therefore assume that in this situation the interference terms are small and all phases randomly distributed. This would not be expected if some other quantization axis was chosen. The probability Π to get a Σ^+ will then be

$$\Pi(\Sigma^+_\pm) \sim 2un_{s_\mp} + zn_{s_\pm} \sim 3(1 \pm V) \mp S(1 \pm 3V + 2T) \tag{3.6}$$

The resulting Σ^+-polarization is thus given by

$$P_{\Sigma^+} = \frac{1}{3}\,\frac{3V - S(1 + 2T)}{1 - SV} \tag{3.7}$$

We note that T does not enter this expression in a linear term. The exact behaviour of T will therefore, up to reasonable limits, be of secondary interest in our continued investigation.

If the incoming proton is polarized, the notations necessarily must become a bit more complicated. We need an extra index (±) for T and V, indicating the spin of the proton. Taking the SU(6) wave function for the proton into account, we then get

$$V_\pm = \frac{a_{01} + 2a_{\pm11} - a_{0-1} - 2a_{\pm1-1}}{\Sigma a_{0f} + 2\Sigma a_{\pm1f}} \tag{3.8}$$

$$T_\pm = 1 - 3\,\frac{a_{00} + 2a_{\pm10}}{\Sigma a_{0f} + 2\Sigma a_{\pm1f}} \tag{3.9}$$

For the relative cross-sections we have

	$\sigma\Sigma^+_+$ ~	$\sigma\Sigma^+_-$ ~	
p_+	$3(1+V_+) - S(1+3V_+ + 2T_+)$	$3(1-V_+) + S(1-3V_+ + 2T_+)$	(3.10a,b)
p_-	$c\{3(1+V_-) - S(1+3V_- + 2T_-)\}$	$c\{3(1-V_-) + S(1-3V_- + 2T_-)\}$	(3.10c,d)

where

$$c = \frac{\Sigma a_{0f} + 2\Sigma a_{-1f}}{\Sigma a_{0f} + 2\Sigma a_{1f}} \tag{3.11}$$

We can also calculate the polarization (analogous to eq. (3.7)):

$$P_{\Sigma^+_\pm} = \frac{1}{3}\,\frac{3V_\pm - S(1 + 2T_\pm)}{1 - SV_\pm} \tag{3.12}$$

In order to obtain quantitative predictions, we must estimate the relative size of the a_{if}:s. As we do not know whether the diquark flips or not we have performed the algebra for two general assumptions: one where spin-flip dominates (i) and one where non-flip controls the behaviour (ii):

$$\text{i)}\quad a_{if} = \alpha\delta_{if} + \beta(2 + f - i) \tag{3.13}$$

$$\text{ii)}\quad a_{if} = (1 + \beta f)\delta_{if}, \tag{3.14}$$

where α and β are positive constants.

Our first assumption is that non-flip is dominating for small $p_\perp$:s, but as $p_\perp$, or β (β is related to $p_\perp$ through V (cf. table 2)), increases, the spectator gets more and more inclined to flipping towards positive spin, while assumption (ii) corresponds to another possible mechanism: the spectators do not flip, but as $p_\perp$ is increased a larger fraction of those having positive spin from the beginning enters the final-state-baryon. These assumptions both lead to a positively polarized diquark (i.e. in the direction $\vec{p}_p \times \vec{p}_{\Sigma^+}$) for unpolarized protons, in concordance with the discussion in section 2. Our assumptions do, of course, not exclude other possibilities. The spectators may, for instance, flip more or less at random for small $p_\perp$:s, leading to much smaller correlations between the proton spin and the final-state-baryon spin.

We start the calculation by expressing T, $V_\pm$, $T_\pm$ *and c in terms of* the single parameter V, the diquark polarization when the incoming proton is unpolarized. The result is shown in table 2, and in table 3 the relative cross-sections and polarizations are given. These are all expressed in S and V, i.e. no new parameters are needed when the proton is polarized. The parameter S can be found from data on Λ-polarization (cf. section 2), and should thus, for moderate $p_\perp$:s, increase linearly with $p_\perp$ [1]. If we include Σ^+-data, V can also be estimated. Eq.(3.7) can, for moderate S and V, to a good approximation be linearized:

$$P_{\Sigma^+} \approx V - \frac{S}{3} \tag{3.15}$$

Experimentally we have $P_{\Sigma^+} \approx -P_\Lambda$, giving $V \approx -\frac{2}{3}S$. If we include the the suppression effect from resonance decays, this ratio should be changed somewhat, and we therefore rather expect $V \approx -\frac{1}{2}S$. Thus for V, the mere parameter left, we also expect a linear rise with $p_\perp$, up to a certain limit, whereafter it should be more or less constant.

The variation of relative cross-sections is shown in figs. 6a and 6b. The largest cross-sections are, for both our assumptions, normalized to 1. The cross-sections in the two figures are therefore not to be compared with each other directly. In figs. 7a and 7b we can see the resulting polarization.

We see striking differences in the cross-sections when we increase

$p_\perp$ (or V). As a consequence the polarizations will also be different. This is in accordance with what one intuitively would expect from the assumptions we have made for the spectator. In (i) the spectators are expected to get an increasing propensity to flip, from negative to positive spin, when V is increased. If the protons have spin down, the Σ^+-polarization should therefore increase (from negative towards positive polarization) with V. In (ii) we do not expect such drastic effects.

We also note that the polarization effects are very large even for small $p_\perp$. This is a consequence of non-flip. On the other hand, if such effects will not be observed experimentally, this would naturally imply that the spectators flip even for very small final-state-baryon $p_\perp$:s.

4. Σ^--polarization.

In order to make a Σ^- in the proton fragmentation region at least two new quarks must be created. Large-x_F-Σ^-:s have been shown, in the Lund model, mainly to be built up from the J-quark (a d-quark) from the proton, an s-quark stemming from behind the J-quark, and a new d-quark from the string segment between J and L. We denote the corresponding polarizations J, S and D respectively. When we have polarized protons, an extra index (±) is needed for J, indicating the spin of the initial proton. The procedure we follow is now very similar to the one we used for Σ^+. We thus introduce a relative probability a_{if} for producing a Σ^- including a J-quark with initial spin i and final spin f. From the SU(6) wave function we can write down the probability to have a Σ^- with spin up (+) or down (-):

$$P(\Sigma^-_\pm) = 3 + JD - 2(J + D)S \pm 2(J + D) \mp S \mp 3JDS \qquad (4.1)$$

J is here expressable in the relative probabilities a_{if}:

$$J = \frac{a_{++} - a_{+-} + a_{-+} - a_{--}}{a_{++} + a_{+-} + a_{-+} + a_{--}} \qquad (4.2)$$

For the resulting Σ^--polarization we thus obtain:

$$P_{\Sigma^-} = \frac{2(J + D) - S - 3JDS}{3 + JD - 2(J + D)S} \qquad (4.3)$$

According to the discussion in section 2 we expect D to be smaller than S. If we furthermore assume that the ratio between the polarization of the spectator J and the s-quark S is the same as for Σ^+ (i.e. $J = -\frac{1}{2}S$), we do, in fact, get a Σ^--polarization that is in agreement with experimental data (if we e.g. put $D = -0.7S$ we get, to lowest order, $P_{\Sigma^-} = -\frac{4}{3}S$). However, data on Σ^- are very scarce [1] and have large errors, so one should be careful about making too extensive conclusions from this fact.

With polarized protons we thus arrive at the following relative cross-sections:

	$\sigma\Sigma^-_+$ ~	$\sigma\Sigma^-_-$ ~	
P_+	$P(\Sigma^-_+, J_+)$	$P(\Sigma^-_-, J_+)$	(4.4 a,b)
P_-	$cP(\Sigma^-_+, J_-)$	$cP(\Sigma^-_-, J_-)$	(4.4 c,d)

where

$$J_+ = \frac{a_{++} - a_{+-} + 2(a_{-+} - a_{--})}{a_{++} + a_{+-} + 2(a_{-+} + a_{--})}, \qquad (4.5\ a)$$

$$J_- = \frac{2(a_{++} - a_{+-}) + a_{-+} - a_{--}}{2(a_{++} + a_{+-}) + a_{-+} + a_{--}} \qquad (4.5\ b)$$

and

$$c = \frac{2(a_{++} + a_{+-}) + a_{-+} + a_{--}}{a_{++} + a_{+-} + 2(a_{-+} + a_{--})} \qquad (4.6)$$

As for Σ^+, our next step must now be to estimate the relative probabilities a_{if}. A natural approach is to assume that the J-quark

behaves in a way similar to each of the quarks in a corresponding Σ^+-diquark. The implications for the a_{if}:s are seen in table 4. Naturally, these choices will also here give a positively polarized spectator. This is in agreement with data, as discussed above.

In table 5 $J_\pm$ and c are expressed in J, and in table 6 we can see the resulting relative cross-sections. We see that the J-independent terms are the same for both our assumptions. As this part of the expressions is the dominating one (at least for moderate $p_\perp$:s), it will be rather difficult to distinguish the predominating mechanism (i.e. (i) or (ii)) from experimental data.

The expressions for the polarizations are not very enlightening, and we therefore do not write them down explicitely. (They are easily found from the cross-sections). They have, quantitatively, been checked to be of the same order of magnitude as they are for unpolarized protons. One interesting thing to note is, though, that the sign of the polarization is opposite to the sign of the proton spin.

5. Ξ^-- and Ξ^0-polarization.

Production of a Ξ-particle requires the creation of two s-quarks. In the Lund model one quark is produced on each side of the J-quark. We thus have a picture almost in accordance with the one in the last section, the only difference being the entrance of some new SU(6)-factors in the wave-functions. If we want to produce a Ξ^0 we must supplement the s-quarks with a u-quark from the proton (thus taking the rôle of the J-quark), while a Ξ^- calls for a d-quark from the proton. For unpolarized protons this will not have any influence on our formulas, i.e. we do not expect any difference in polarization for Ξ^0 and Ξ^-. This is consistent with experimental data. We can therefore suppress the index, and refer to these particles as a Ξ.

Following the steps in section 4 we first write down the probability Π to have a Ξ with spin up (+) or spin down (-) (for simplicity we denote the s-quark in the L-segment with D).

$$\Pi(\Xi_\pm) = 3 + SD - 2(D + S)J \pm 2(S + D) \mp J \mp 3JDS \qquad (5.1)$$

Consequently the Ξ-polarization is given by

$$P_\Xi = \frac{2(S + D) - J(1 + 3DS)}{3 + SD - 2(S + D)J} \qquad (5.2)$$

Eqs. (5.1) and (5.2) are analogous to eqs. (4.1) and (4.2) with J *and S interchanged.*

With the same ratio between J, D and S as in the previous section for Σ^-, the Ξ-particle will be polarized in the same direction as a Λ-particle, in agreement with data. The magnitude of the polarization will be a bit smaller than experimental data give, but we must remember that these ratios are only estimates. We can increase the magnitude of the Ξ-polarization by decreasing D and/or increasing J relative to S.

The formal expressions for the relative cross-sections will be identical to eqs. (4.4). For Ξ^- eqs. 4.5a,b and 4.6 also still hold, but for Ξ^0 $J_\pm$ and c will, due to other SU(6)-factors, look somewhat different when expressed in the probabilities a_{if}:

$$J_+ = \frac{5(a_{++} - a_{+-}) + a_{-+} - a_{--}}{5(a_{++} + a_{+-}) + a_{-+} + a_{--}}, \qquad (5.2\ a)$$

$$J_- = \frac{a_{++} - a_{+-} + 5(a_{-+} - a_{--})}{a_{++} + a_{+-} + 5(a_{-+} + a_{--})} \qquad (5.2\ b)$$

and

$$c = \frac{a_{++} + a_{+-} + 5(a_{-+} + a_{--})}{5(a_{++} + a_{+-}) + a_{-+} + a_{--}} \qquad (5.3)$$

Using the same probabilities a_{if} as before, we arrive at the results in table 8. These are very similar to those for Σ^- (cf. table 6). So are the expressions for Ξ^-, which are the same as for

Σ^- with J and S interchanged. The conclusions we made for Σ^- in section 4 should therefore be valid for Ξ as well.

6. Summary and conclusions.

Large polarization effects observed in inclusive hyperon production in hadronic collisions have earlier, in the frame-work of the Lund model, been explained as a natural consequence of confinement. In this paper we have extended the discussion to account for what we believe is the next generation of experiments, experiments with polarized beams. We find that our predictions for such experiments are highly dependent on the assumptions we make about the constituent quarks. These are in our picture divided into two cathegories: spectators, stemming from the proton, and participants, produced from the confining force field during the reaction. Data indicate that both these cathegories are polarized. In particular, data on the reaction $K^-p \to \bar{\Lambda}X$ clearly indicate that also the spectator must be polarized. This can be understood if the quarks are considered together with their attached string. In this picture it is quite natural to expect that the spectators flip during the process, and they are therefore perhaps not as passive during the reaction as generally has been assumed before. This will give noticable effects in cross-sections and polarization. For comparison we have also performed the algebra for the case when the spectators do not flip. The study of Σ^+-production is seen to be particulary useful as a way to investigate the behaviour of the spectator quarks, while for Σ^-- and Ξ-particles the effects are expected to be less dramatic.

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Table 1: SU(6) wave functions for some of the particles discussed in the text. The wave functions of the spin-down states are obtained by reversing the signs of all spins as well as the signs of the spin-singlet components.

$$|p_+\rangle = \frac{\sqrt{2}}{3}|uu_1 1\rangle|d-\rangle - \frac{1}{3}|uu_1 0\rangle|d+\rangle - \frac{1}{3}|ud_1 1\rangle|u-\rangle + \frac{1}{\sqrt{18}}|ud_1 0\rangle|u+\rangle + \frac{1}{\sqrt{2}}|ud_0 0\rangle|u+\rangle$$

$$|\Sigma^+_+\rangle = \frac{\sqrt{2}}{3}|uu_1 1\rangle|s-\rangle - \frac{1}{3}|uu_1 0\rangle|s+\rangle - \frac{1}{3}|us_1 1\rangle|u-\rangle + \frac{1}{\sqrt{18}}|us_1 0\rangle|u+\rangle + \frac{1}{\sqrt{2}}|us_0 0\rangle|u+\rangle$$

$$|\Sigma^-_+\rangle = \frac{\sqrt{2}}{3}|dd_1 1\rangle|s-\rangle - \frac{1}{3}|dd_1 0\rangle|s+\rangle - \frac{1}{3}|ds_1 1\rangle|d-\rangle + \frac{1}{\sqrt{18}}|ds_1 0\rangle|d+\rangle + \frac{1}{\sqrt{2}}|ds_0 0\rangle|d+\rangle$$

$$|\Xi^0_+\rangle = -\frac{\sqrt{2}}{3}|ss_1 1\rangle|u-\rangle + \frac{1}{3}|ss_1 0\rangle|u+\rangle + \frac{1}{3}|us_1 1\rangle|s-\rangle - \frac{1}{\sqrt{18}}|us_1 0\rangle|s+\rangle - \frac{1}{\sqrt{2}}|us_0 0\rangle|s+\rangle$$

$$|\Xi^-_+\rangle = -\frac{\sqrt{2}}{3}|ss_1 1\rangle|d-\rangle + \frac{1}{3}|ss_1 0\rangle|d+\rangle + \frac{1}{3}|ds_1 1\rangle|s-\rangle - \frac{1}{\sqrt{18}}|ds_1 0\rangle|s+\rangle - \frac{1}{\sqrt{2}}|ds_0 0\rangle|s+\rangle$$

$$|\Sigma^0_+\rangle = \frac{\sqrt{2}}{3}|ud_1 1\rangle|s-\rangle - \frac{1}{3}|ud_1 0\rangle|s+\rangle - \frac{1}{\sqrt{18}}|us_1 0\rangle|d+\rangle - \frac{1}{6}|us_1 0\rangle|d+\rangle + \frac{1}{2}|us_0 0\rangle|d+\rangle - \frac{1}{\sqrt{18}}|ds_1 0\rangle|u+\rangle - \frac{1}{6}|ds_1 0\rangle|u+\rangle + \frac{1}{2}|ds_0 0\rangle|u+\rangle$$

Table 2: $V_\pm$, T, $T_\pm$ and c expressed in V, for the two assumptions 3.13 (i) and 3.14 (ii). The last column shows the relation between V and the parameters α ((i) only) and β.

	V_+	V_-	T	T_+	T_-	c	V
(i)	$\frac{1}{3}\frac{2-3V}{1-V}$	$\frac{1}{3}\frac{3V-2}{1+V}$	0	0	0	$\frac{1+V}{1-V}$	$\frac{2\beta}{\alpha+4\beta}$
(ii)	$\frac{1}{3}\frac{2+3V}{1+V}$	$\frac{1}{3}\frac{3V-2}{1-V}$	0	$\frac{V}{1+V}$	$\frac{-V}{1-V}$	$\frac{1-V}{1+V}$	$\frac{2}{3}\beta$

Table 3: Relative cross-sections and polarization P_{Σ^+} obtained with the assumptions 3.13 (i) and 3.14 (ii). Common factors have been extracted from the cross-sections.

	Spin		Relative cross-section	P_{Σ^+}
	p	Σ^+		
(i)	+	+	5 − 6V − 3S + 4SV	$\frac{2-3V-S+SV}{3-3V-2S+3SV}$
		−	1 − S + 2SV	
	−	+	1 + 12V + S − 10SV	$-\frac{2-9V+S+SV}{3+3V+2S-9SV}$
		−	5 − 6V + 3S − 3SV	
(ii)	+	+	5 + 6V − 3S − 4SV	$\frac{2+3V-S-3SV}{3+3V-2S-3SV}$
		−	1 − S	
	−	+	1 + S	$-\frac{2-3V+S-3SV}{3-3V+2S-3SV}$
		−	5 − 6V + 3S − 4SV	

Table 4: The relative probabilities a_{if} for the J-quark, obtained using the same assumptions as for the diquark in Σ^{+}.

	(i)	(ii)
a_{++}	$5\alpha + 19\beta$	$5 + 4\beta$
a_{+-}	$\alpha + 5\beta$	1
a_{-+}	$\alpha - 3\beta$	1
a_{--}	$5\alpha + 19\beta$	$5 - 4\beta$

Table 5: $J_{\pm}$ and c expressed in J, for the two assumptions about the J-quark (see previous table). These expressions are valid for Σ^{+}. The last column shows the relation between J and the parameters α ((i) only) and β.

	J_+	J_-	c	J
(i)	$\frac{1}{3}\frac{15J-2}{3+J}$	$\frac{1}{3}\frac{9J-2}{3-J}$	$\frac{3-J}{3+J}$	$\frac{7\beta}{\alpha+6\beta}$
(ii)	$\frac{1}{3}\frac{2+3J}{3-J}$	$\frac{1}{3}\frac{9J+2}{3+J}$	$\frac{3+J}{3-J}$	$\frac{2}{3}\beta$

Table 6: Relative cross-sections ($p \to \Sigma^{+}$) obtained with the a_{if}:s in table 4. Common factors are extracted.

	Spin		
	p	Σ^{+}	Relative cross-section
(i)	+	+	23+16D− 5S−12DS+3J(13+ 7D−11S−17DS)
		−	31−20D+13S−24DS−3J(7− 3D+ 9S−13DS)
	−	+	31+20D−13S−24DS−3J(1+ D+ 5+ DS)
		−	23−16D+ 5S−12DS−3J(5− 3D+ 3S− 5DS)
(ii)	+	+	23+16D− 5S−12DS+3J(3+ D− 5S− 7DS)
		−	31−20D+13S−24DS−3J(9− 5D+ 7S−11DS)
	−	+	31+20D−13S−24DS−3J(9+ 5D− 7S−11DS)
		−	23−16D+ 5S−12DS−3J(3− D+ 5S− 7DS)

Table 7: $J_{\pm}$ and c expressed in J, for the two assumptions about the J-quark (see table 4). These expressions are valid for Ξ^{0}. The relation between J and the parameters α ((i) only) and β is the same as in table 5.

	J_+	J_-	c
(i)	$\frac{1}{3}\frac{4-3J}{3-2J}$	$\frac{1}{3}\frac{9J+4}{3+2J}$	$\frac{3+2J}{3-2J}$
(ii)	$\frac{1}{3}\frac{21J-4}{3+2J}$	$\frac{1}{3}\frac{9J-4}{3-2J}$	$\frac{3-2J}{3+2J}$

Table 8: Relative cross-sections ($p \to \Xi^{0}$) obtained with the a_{if}:s in table 4. Common factors are extracted.

	Spin		
	p	Ξ^{0}	Relative cross-section
(i)	+	+	23+10(D+S)− 3DS−3J(5+ 2(D+S)− DS)
		−	31−26(D+S)+21DS−3J(7− 6(D+S)+ 5DS)
	−	+	31+26(D+S)+21DS−3J(1+10(D+S)+19DS)
		−	23−10(D+S)− 3DS+3J(13−18(D+S)+23DS)
(ii)	+	+	23+10(D+S)− 3DS+3J(3− 2(D+S)− 7DS)
		−	31−26(D+S)+21DS+3J(9−10(D+S)+11DS)
	−	+	31+26(D+S)+21DS−3J(9+10(D+S)+11DS)
		−	23−10(D+S)− 3DS−3J(3+ 2(D+S)− 7DS)

Figure captions:

1. A quark and an antiquark with transverse momenta $\bar{k}_{\perp}$ and $-\bar{k}_{\perp}$ are produced at a distance $\frac{2\mu_{\perp}}{\kappa}$ from each other. They carry an orbital angular momentum $\bar{L}$ which is compensated if the spins are polarized in the opposite direction.

2. Predominating production mechanism for Λ at large x_F:s. A ud_0-diquark is scattered with a certain transverse momentum and an $s\bar{s}$-pair is created in the colour force field.

3. Production of an $\bar{\Lambda}$ in a $K^{+}p$-reaction. $\bar{\Lambda}$ consists of an $\bar{s}$-quark from the K^{+}, and an $\overline{ud}_0$-diquark from the colour force field.

4a. A proton consisting of a u-quark and an effective uu_1-diquark, here seen in the proton rest frame, is to be hit by a particle coming in from the right.

4b. After the collision the string will be bent and move as in this figure. The uu_1-diquark and the attached string piece will have an angular momentum $\bar{L}$, and furthermore the tension in the string will give it a transverse momentum $\bar{p}_{\perp}$ in the direction indicated. The uu_1-diquark, here taking the rôle of a "spectator", will thus be polarized.

4c. Production of a Σ^{+} from proton fragmentation. The Σ^{+} consists of a uu_1-spectator, polarized in concordance with fig. 4b, and a s-quark produced in the field.

5a. When a Σ or a Ξ is to be produced, the colour field is supposed to stretch in this manner.

5b. One quark-antiquark pair will be created at each side of the spectator-J-quark. These are pulled in opposite directions by the colour field, and are therefore also opposite polarized.

6a. Relative cross-sections ($p_{\pm} \to \Sigma^{+}_{\pm}$) obtained with assumption (3.13). The largest cross-section is normalized to 1 for all V.

6b. As fig. 6a, but with assumption (3.14).

7a. Σ^{+}-polarization obtained from the cross-sections in 6a.

7b. Σ^{+}-polarization obtained from the cross-sections in 6b.

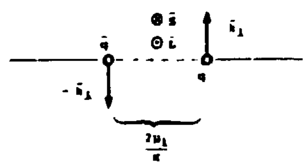

Fig. 1

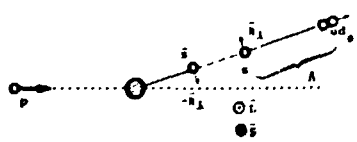

Fig. 2

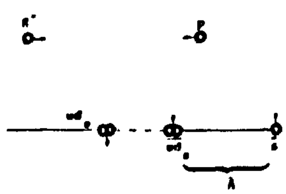

Fig. 3

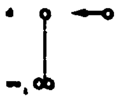

Fig. 4a

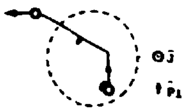

Fig. 4b

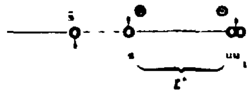

Fig. 4c

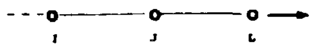

Fig. 5a

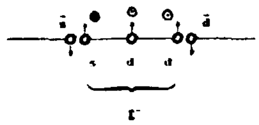

Fig. 5b

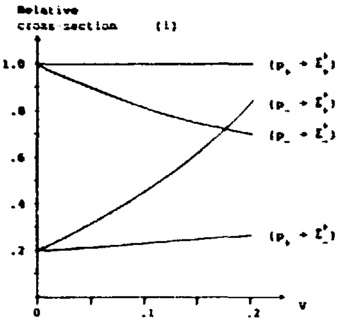

Fig. 6 a

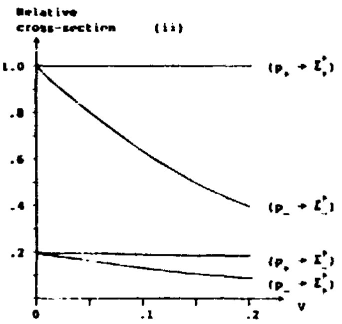

Fig. 6 b

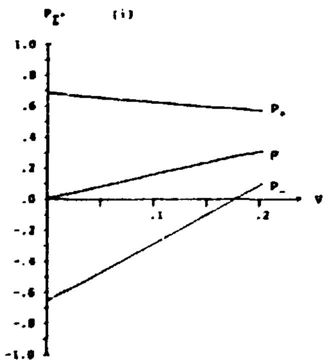

Fig. 7 a

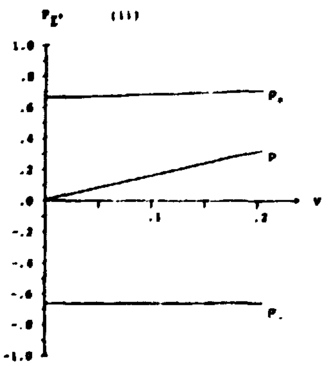

Fig. 7 b