SE8200231

LU-TP--82-13
November 1982

HYPERON POLARIZATION AND TRANSVERSE MOMENTUM PROPERTIES IN PROTON FRAGMENTATION

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Abstract:

A dynamical mechanism for proton interaction in hadronic collisions is presented which provides a verification of the model with an essentially one-dimensional colour force field in the proton fragmentation region, proposed earlier. We include here a discussion of the transverse momentum properties of the final state particles and polarization properties for hyperons in proton fragmentation.

1. Introduction

In earlier publications we have presented a model for proton fragmentation in hadronic collisions [1] and also a mechanism for the polarization of inclusively produced Λ-particles [2,3]. In ref [1] only the distributions in the Feynman x_F-variable was discussed for various particles, including two-particle correlations. In the model an essentially linear colour field is stretched and in particular the model works in such a way that for very large x_F the final state baryon in a proton fragmentation region contains two of the original valence flavours while for smaller x_F-values it is more probable that the baryon contains only one such flavour. In ref [2] the variation of the Λ-polarization with $p_\perp$ was studied assuming that the Λ contains a ud_0-diquark from the proton and an s-quark produced in the field behind. These results should thus be regarded as the large-x_F limit.

In order to extend both the general fragmentation model to include transverse momentum predictions and to extend the Λ-polarization model to all x_F-values, it is necessary to have a more detailed dynamical picture of the original baryon wave function. We present a (semi-classical) model in which the three valence quarks of the proton are assumed to move at the end-points of a Y-shaped string. We show that this model will lead to an essentially linear colour field in the final state. We also exhibit some detailed predictions for the amount of energy available for $q\bar{q}$-pair production in the various parts of this field. We finally discuss the resulting polarization predictions for different hyperons (Λ, Σ, Ξ) in a proton fragmentation region as functions of x_F and $p_\perp$. We feel that the agreement between our model predictions and the observed Σ^--polarization direction is a strong indication for the essentially one-dimensional mechanism in our model.

II. Proton fragmentation model

In ref [1] we made the observation that the x_F-distribution of all particles (including both baryons and mesons) is very similar in proton-, meson- and quark-fragmentation regions. This can be understood if in all three cases new quark-antiquark pairs are produced in an essentially linear colour triplet field. We presented a dynamical reaction mechanism for hadronic collisions where in proton fragmentation a colour field is stretched as indicated in fig 1. The basic idea is that a hadronic interaction is local in the sense that to begin with only one of the valence-quarks (called the I-quark) is involved. Only when all the energy of the I-quark is used up, the remaining quarks will get involved in such a way that the next one (called the J-quark) will use up its energy and finally the third one gets involved. In that way an essentially one-dimensional force field is stretched in a piecewise manner so that the third valence flavour (called the L-quark) will be at the end of the force field followed by the J and finally the I quark flavours.

If the L-quark is red there will then be an $r\bar{r}$ field between J and L. If the J-quark is green the (LJ)-diquark is antiblue and to the left of J we have a $b\bar{b}$ field. We notice that the field changes direction at the J-quark position so that a produced quark is always pulled towards (and an antiquark away from) the J-quark. Thus when the field is divided into pieces by $q\bar{q}$-production, that piece which contains the J-quark will always become a baryon.

We will use the same production mechanism for quark-antiquark pairs as in the Lund model for a quark jet [4] and it is necessary at this point to recall a few properties of this model. If a quark-antiquark (or more generally a colour 3-$\bar{3}$) pair starts in one space-time point with large momenta in opposite directions, a colour force field is stretched between them. This field is broken by the production of colour 3-$\bar{3}$ pairs, $q\bar{q}$ (or $\overline{qq}$-qq) with zero energy, which can be pulled apart by the field, so that the final result with asymptotically emerging $q\bar{q}$ states (mesons) is as shown in fig 2a. We note that this is an inside-out cascade in the sense that in any Lorentz frame the mesons which are slow in that frame are produced first. With a large boost along the leading quark we may go to a Lorentz frame (see fig 2b) in which the "last" meson is produced first in time. Here the original quark, q_0, starts with fairly low momentum, and is soon stopped by the force field and follows $\bar{q}_0$. When one meson is taken away the remnant system looks just like the original one, and the fragmentation has an iterative structure as in a cascade jet model.

These pictures could also illustrate i.e. an inelastic electron-meson scattering event [5]. If the initial meson is described by a quark and an antiquark at the ends of a string (in a yo-yo mode), then fig 2b illustrates the situation in the rest frame of the initial meson when a quark (or antiquark) is hit by the electron. In this case the string is normally not completely in one space dimension. However in ref. [5] we have shown that the picture is essentially the same for the projection on the longitudinal i.e. the momentum transfer direction. The extension of the string in the transverse directions only provides some extra transverse momentum to the particles. (For a detailed description cf ref [5]).

For the corresponding baryon fragmentation field we note that in ref [1] it was assumed that when the J-quark has exhausted its energy it is retarded to a finite velocity in the total cms. Then the production of new $q\bar{q}$ pairs and the formation of hadrons will look as shown in fig. 3a. If we would make a boost to the rest frame of the initial proton this picture is changed into fig 3b where now the J-quark seems accelerated almost to the velocity of light.

The value of x_J is related to the wave function of the initial proton. In ref [1] we have assumed that x_J is distributed according to

$$\frac{dP}{dx_J} = 6x_J(1-x_J) \qquad (1)$$

With the Lund model recipe for dividing the force field into hadrons this implies around 50% probability for a break between the L- and J-quarks. This means that we have about equal probabilities that the baryon takes one or both of the initial quarks; it always takes at least one (the J-quark). For the I-quark, in ref. [1] we just assumed that the x_I-distribution is flat behind x_J. This implies that the x_I-distribution will be

$$\frac{dP}{dx_I} = 3(1-x_I)^2 \qquad (2)$$

In that way the probability to find an original proton flavour in a hadron in the center of the rapidity space will decrease as $\simeq \frac{3m_\perp}{\sqrt{s}}$. This number is compatible with the charge asymmetry between pp- and $p\bar{p}$-collisions at the ISR [6].

The model discussed above does not really give any indication of the size of the J-quark velocity. As will be demonstrated below this is essential for the energy available in the string segment between the J- and L-quarks and thus to the possibility to produce the heavier strange quarks or quarks with large $k_\perp$ in this segment. In order to amend that, we consider a more detailed (semi-classical) model for the motion of the three valence quarks in the proton. We will assume that the (massless) quarks move symmetrically at the ends of three string pieces. joined in a junction as shown in fig 4[7]. The junction itself will in this picture not carry any energy-momentum - it is only a device which moves in such a way that the total tension at rest of the three string pieces vanishes. It is not difficult to show that, on the average, half of the energy of the system is kinetic energy of the quarks and the other half potential energy in the strings ("glue"). In fig 5 we show the motion of this system if one of the valence quarks is made to move in the direction $\vec{V}$ due to an interaction with another hadron or with a lepton in a deep inelastic scattering event. When the quark (a) moves away a bend on its adjoining string piece will move towards the junction with the velocity of light. It reaches the junction at the same time as the other two quarks (provided the three quarks moved towards the junction at the moment of the collision). After this the junction will move with a constant velocity $\bar{v}_j$, which depends on the direction $\bar{V}$ of the quark (a). We note that the force from a string on a massless quark is always along the quark motion and the quarks (b) and (c) will continue to the "old" turning points (position 2). When they turn around they will however be accelerated in a new direction, such that in a Lorentz frame in which the adjoining string piece is at rest, the quark vill just move along the string. We note that when they stop, one of the quarks ((b) in fig 5) is close to the junction whereas the other one ((c)) is much further away. A simple calculation tells us that the energy available in the string piece adjoining (c) is in general large enough to produce $q\bar{q}$ pairs, thereby producing a meson containing the quark (c).

For the quark (b), however, the situation is always such that it will end up too close to the junction for any possible particle production. Thus the quark (b) and the junction will always end up in the same final state hadron which then becomes a baryon.

We have only discussed the situation when all the quarks were moving "inwards" at the time of the interaction with (a). The other situation when all move "outwards" will result in an almost identical final state situation.

We have evidently in this semi-classical model obtained a dynamical situation very similar to the one described above and in ref [1], with (a), (b) and (c) taking the roles of I, J and L respectively. There are, however, two differences. First, there will be a piece of the string between the quark (b) and the junction where the string cannot break. This will have the same effect as if the J-quark had a finite mass. If we interpret fig 3 as a picture in momentum space rather than in coordinate space, there will be a narrow region around the J-quark trajectory where new pairs cannot be produced. We will here neglect this effect.

More important is that the junction moves with a finite velocity. If the string does not break, the (b) quark will move back and forth through the junction a number of times, but after some time the (c) quark, which moves with the velocity of light, will catch up. If the string has not broken before, we will assume that it will no more be possible to break it between the (c) quark and the junction.

To see the significance of this effect it is useful to consider fig 6. We note that in order to produce a first rank π- or K-meson a new $q\bar{q}$-pair must be produced along the hyperbolas marked π and K respectively. If the J-quark (and the junction) moves with a velocity close to the velocity of light as in ref [1] (fig 6 a) then both pions and kaons can be produced with values of z between 0 and $(1 - x_J)$. When the junction moves with a finite velocity (fig 6b) then it is obvious that the more massive kaons will have a much more restricted z-range available.

In the string picture developed above there will be a correlation between the velocity of the junction (which depends on the direction $\bar{V}$ of the "kick" in fig 5) and the value of x_J (which however also depends on the phase in the quark motion at the time of the "kick"). We will study the string motion and these correlations in more detail in later work. For the purpose of this paper it is sufficient to give the junction a constant velocity $v_{effective}$ in the rest frame of the initial proton. After some algebra we find that the velocity v_j of the junction is given by the following expression, where θ and φ are the polar angles for the direction $\bar{V}$ of the kick in a frame where the kicked quark initially moved along the z-direction and the other two quarks in the xz-plane

$$v_j^2 = \frac{9\sin^2\theta\sin^2\varphi + \frac{9}{4}\sin^2\theta\cos^2\varphi + 1 + 2\cos\theta + \cos^2\theta}{(\cos\theta - 7/2)^2} \qquad (3)$$

Thus we find that the average value of v_j^2 is given by

$$\langle v_j^2 \rangle \cong (0.69)^2 \qquad (4)$$

In the following calculations we have consequently used this value instead of $v = 1$ as assumed in ref [1]. It turns out that the velocity change hardly affects the possibility to produce non-strange quarks with ordinary $p_\perp$. Thus the particle spectra in ref [1] will not be noticably changed; only the Λ-production spectrum will be a bit smaller. Only the small fraction of events with strange quark pair production or production of a pair with large $k_\perp$ between the J- and L-quarks will be suppressed.

III. Transverse momentum properties

In this section we will consider the transverse momentum properties of the baryon fragmentation region in some detail.

We note firstly that in accordance with ref [8] the production of $q\bar{q}$- (or more generally colour $(3\ \bar{3})$) pairs along the force field can be treated as a tunneling phenomenon, which yields a Gaussian distribution of transverse momentum for the pair $(\bar{k}_\perp, -\bar{k}_\perp)$

$$dP \propto d^2k_\perp \exp(-k_\perp^2/\sigma^2) \qquad (5)$$

For quark jets in e^+e^--annihilation the value

$$\langle k_\perp^2 \rangle = \sigma^2 = (0.44\ \mathrm{GeV/c})^2 \qquad (6)$$

is found to reproduce the observed $p_\perp$ distributions, and we will use the same value of σ here. A produced meson will in that way obtain a transverse momentum given by the vector sum of the transverse momenta of its two constituents.

Another source of transverse momentum in a fragmentation region is the primordial $k_\perp$, i.e. the transverse momentum of the valence constituents in the original hadronic bound state. To account fully for the properties of these contributions one needs a complete picture of the baryon wave function.

Lacking such a picture we will be satisfied with the following simplified assumptions compatible with the Y-string baryon model presented above.

1) The three valence-constituents, which in accordance with the considerations in the first two sections will end up as the L, J and I quark along the force field, will each be given a Gaussian transverse momentum distribution

$$dP_j = d^2k_\perp \exp(-k_\perp^2/\sigma'^2) \qquad j = I,J,L \qquad (7)$$

with the constraint that

$$\bar{k}_{\perp I} + \bar{k}_{\perp J} + \bar{k}_{\perp L} = 0 \qquad (8)$$

We will in that way have a parametrization with in principle a parameter σ' at our disposal.

2) This primordial transverse momentum is transferred to the final state hadron in the same way as the tunneling contribution in eq.(5). Thus the $p_\perp$ of a hadron is the vector sum of the $\bar{k}_\perp$ of its two (for a meson) or three (for a baryon) constituents.

In fig 7 we present the $p_\perp$-spectrum for protons and Λ-particles obtained with a value of σ' such that

$$\langle k_\perp^2 \rangle_{I,J \text{ or } L} = 2/3\ \sigma'^2 = (0.4\ \text{GeV/c})^2 \qquad (9)$$

We note that this is consistent with the primordial $k_\perp$ carried by a quark in a DIS-event [9] (when also soft gluon emission is accounted for). As a further check of the x_F- and $p_\perp$-distributions we present in fig. 8 the baryonic jet profile defined in accordance with the Ochs-Stodolsky considerations [10]. The variable λ is defined as

$$\lambda = x_F/p_\perp \qquad (10)$$

with x_F the ordinary Feynman scaling variable.

We compare the results to experimental data and note a general good agreement.

IV. Polarization properties of the hyperons

In this section we will consider the polarization properties of the baryons, in particular the hyperons in a proton fragmentation region.

We have in earlier papers [2,3] shown that the production of quark-antiquark pairs in a uniform force-field imply strong polarization properties. We start by presenting a few relevant observations in that connection.

In a uniform force-field without concentrations of energy, transverse momentum or angular momentum, the production of a $q\bar{q}$-pair with transverse masses $\mu_\perp$ cannot occur in a point-like way. It is necessary to make use of a piece of the field of size ℓ such that (cf fig 9)

$$\kappa\ell = 2\mu_\perp \qquad (11)$$

where $\kappa \sim 1$ GeV/fm is the energy per unit length or the string tension. Further in order to conserve transverse momentum as discussed in section III, the pair is produced in a state with total transverse momentum zero, i.e. with $\vec{k}_\perp$ and $-\vec{k}_\perp$

respectively. From fig 9 it is obvious that the pair will be produced with an orbital angular momentum $\vec{L}$ in the direction indicated in the figure and with a size

$$|\vec{L}| \approx \ell \cdot k_{\perp} \approx \frac{2\mu_{\perp} k_{\perp}}{\kappa} \qquad (12)$$

(for $k_{\perp} \simeq 0.3 - 0.4$ GeV/c we find $L \sim 1$). Thus in order to conserve angular momentum the spins ought to be polarized in the opposite direction.

We have in ref [3] carried through a quantum mechanical treatment of pair production of spin 1/2 particles by a tunneling process. We find that the pair is always produced in a triplet state. Furthermore, if the pair is pulled apart by a confined colour field, such that all the flux ends at colour charges i.e. the quark or the antiquark, then the pair is strongly polarized in just the direction obtained by the simple argument above. The polarization is strong for $k_{\perp} \gtrsim .4$ GeV/c i.e. when $L \gtrsim 1$.

We note that the pair production in a homogeneous electric field would give polarization in the opposite direction [3]. This is so because in this case the particles traverse the electric field lines and thus there is an induced magnetic field in the particle rest frame which interacts with the magnetic moment. In this case also the external electric forces give a torque (see fig 10) and therefore the argument based on angular momentum conservation does not work.

In ref [2] we have applied this mechanism to the production of Λ-particles in a proton fragmentation region. We note that a Λ-particle is in the constituent quark model an (sud)-state such that the u- and d-quarks are in an isospin-spin = 0 state, $(ud)_0$. Therefore the polarization of a Λ-particle is entirely related to the s-quark. In ref [2] we assumed that the s-quark is produced according to the mechanism above in the colour field stretched behind a $(ud)_0$-diquark stemming from the original proton. In that way we obtained a prediction for the Λ-particle polarization as a function of the transverse momentum of the Λ which was in very good agreement both with respect to sign and size with the ISR-data corresponding to large x_F-values. With the more detailed baryon production model discussed above we will now extend our predictions to other values of x_F and also to other hyperon polarizations.

IV A. Λ-particle polarization.

In accordance with the model of this paper it is possible to predict the fractions of the produced Λ-particles which stem from the different possible production mechanisms. We note that the model contains Λ-production according to

(Ia) The Λ-particle stems from a $(ud)_0$ composed of the L- and J-quarks with the s-quark produced behind the J-quark.

(Ib) The Λ-particle stems from a $(ud)_0$ composed of the J-quark and another (u or d) quark from a piece produced between L and J together with an s-quark produced behind the J-quark.

(II) The Λ-particle stems from a $(ud)_0$ built from the J-quark and a u or d quark produced behind it (eventually the

I-quark) while the s-quark stems from the field in between the J- and L-quark.

(III) The Λ-particle stems from the decay of a primarily produced Σ^{0} or a Y^{*} .

(IV) The Λ-particle is one of a pair from baryon-antibaryon production along the force-field. $B\bar{B}$-pairs can be produced when a diquark-antidiquark pair (colour $\bar{3}$-3) is produced in the field. We assume that this occurs with the same probability as in a quark jet as described in ref [11].

In fig 11 we exhibit the fractional Λ-particle production according to the mechanisms (I)-(IV) (f_{I}-f_{IV}) as a function of x_F for large energies. (For this purpose we do not differ between (Ia) and (Ib)).

According to the production model in this paper the x_F- and the $p_{\perp}$-distributions do to a large extent factorize for a given production mechanism. Due to the Gaussian character of the $k_{\perp}$-distributions both for the tunneling production and for the primordial contributions the mean s-quark transverse momentum is proportional to the Λ transverse momentum. For the production mechanisms (Ia) and (Ib) the s-quark and therefore also the Λ-particle should be polarized along the direction $\vec{p}_{\Lambda} \times \vec{p}_{proton}$. For the production mechanism (II), where the s-quark will be pulled by the field in the opposite direction, the polarization should be opposite to $\vec{p}_{\Lambda} \times \vec{p}_{p}$.

Λ-particles stemming from the decay of Σ^{0} and Y^{*} should retain some part of the original particle polarization. This contribution will be rather small - although we expect it to be in the same directions as the one from production mechanisms (Ia) and (Ib) - and we will neglect it henceforth.

Finally, for the reaction mechanism (IV) we do not expect any Λ-polarization, at least not along the normal to the beam-Λ-plane. In fig 12 we plot the ratio

$$\frac{f_I - f_{II}}{f_I + f_{II} + f_{III} + f_{IV}} \qquad (13)$$

as a function of x_F and we expect that for a fixed $p_\perp$ and with the absolute size of Λ-polarization given at $x_F = 1$ this should provide a prediction for the Λ-polarization in the whole fragmentation region. We note that the dependence on x_F is almost linear, as is also indicated by the experimental data [12].

IVB. Σ^0,Σ^+-polarization

In the constituent quark model the Σ^0 and Σ^+ are $((ud)_1 s)$ and $((uu)_1 s)$ states respectively with the index on the diquark corresponding to spin and isospin 1. As the Σ^0 and Σ^+ are both spin 1/2 particles, the Σ^0-polarization will be opposite to the produced s-quark polarization and its size will depend upon to what extent the corresponding spin-1 diquark is polarized by itself. These diquarks are often "spectators" in the ordinary notation, i.e. may stem from the original proton wave functions, and therefore they should exhibit no polarization according to conventional wisdom. There are in our opinion, reasons to believe that the production mechanisms will favour spectator polarizations [13,14] but we will in this paper neglect the question of the absolute size of the Σ^0-polarization. We may, however, estimate the x_F-dependence just as for the Λ-particle. The production mechanisms (I) - (IV) discussed above are available also for the Σ^0 and Σ^+ particles and in fig 13 we depict the relative fractions for different x_F-values. We also show in fig 14 the ratio (13) as a measure of the expected Σ^0 and Σ^+ polarizations along the direction $\vec{p}_{proton} \times \vec{p}_{\Sigma}$.

IVC. Σ^--polarizations

In order to produce $\Sigma^-((dd)_1\ s)$ or $\Xi\ ((ss)_1\ d$ or $(ss)_1\ u)$ in a proton fragmentation region it is necessary to produce at least two new quarks for the hyperon. For Σ^- it is possible to take one of the d-quarks from the initial proton. In our model this quark is then the J-quark and we have the following possibilities

Ib. The s-quark stems from behind the J-quark and the new d-quark from the string segment between J and L.

V. The s-quark stems from between J and L and the new d-quark from behind J.

IV. It is also possible to produce Σ^- via the $B\bar{B}$-pair production mechanism.

According to our model the produced Σ^--particles will be polarized upwards (i.e. along $\bar{p}_{proton} \times \bar{p}_{\Sigma^-}$) as the combined effect of the following properties

1: The quark behind the J-quark (s or d in case Ib and V respectively) is polarized upwards and the quark between J and L (d or s) is polarized downwards, because it is pulled in the opposite direction by the colour field.

2: Mechanism Ib dominates over V.

As we have discussed in section II the LJ segment of the string in general contains less available energy and therefore less available "space" for the heavier $s\bar{s}$-pair production. A computer simulation also exhibits this property. In fig 15 we show the fractions of produced Σ^- according to the mechanisms Ib, IV and V.

Further, due to the same suppression mechanism the $k_\perp$-spectrum of the $q\bar{q}$-pairs produced in the LJ-segment is in general more narrow than the $k_\perp$-spectrum for the $q\bar{q}$-pairs produced behind the J-quark. In all relevant situations these spectra are effectively Gaussian according to our Monte Carlo simulations with widths such that

$$\begin{aligned} \langle k_\perp^2 \rangle_{\text{LJ-segment}} &= 0.09\ (\text{GeV/c})^2 \\ \langle k_\perp^2 \rangle_{\text{behind J}} &= 0.18\ (\text{GeV/c})^2 \end{aligned} \qquad (14)$$

Therefore the transverse momentum and thereby the polarizations of the produced quarks will increase linearly with the transverse momentum of the Σ^-. We note that according to the additive quark model the different possible quark polarizations will affect the final state Σ^- in different ways. To see that we assume that the three quarks, d (the J-quark), d (the produced d-quark) and s have polarizations α_1, α_2 and α_3 $(-1 \leq \alpha_i \leq 1\ ,\ i=1,2,3)$ respectively. The spin wave function for a Σ^- with spin up ($m_s = +1/2$) is given by

$$\psi_{\Sigma^-}(+) = \sqrt{2/3}\ |{+}{+}{-}\rangle - \sqrt{1/6}\ |{+}{-}{+}\rangle - \sqrt{1/6}\ |{-}{+}{+}\rangle \qquad (15)$$

in easily understood notation. With the quark polarization given above and with the assumption that all phases are randomly distributed, the probability that the spins add up to a total spin 1/2 pointing upwards, i.e. give a Σ^- with spin up is given by

$$\frac{2}{3}\left(\frac{1+\alpha_1}{2}\right)\left(\frac{1+\alpha_2}{2}\right)\left(\frac{1-\alpha_3}{2}\right) + \frac{1}{6}\left(\frac{1+\alpha_1}{2}\right)\left(\frac{1-\alpha_2}{2}\right)\left(\frac{1+\alpha_3}{2}\right) + \frac{1}{6}\left(\frac{1-\alpha_1}{2}\right)\left(\frac{1+\alpha_2}{2}\right)\left(\frac{1+\alpha_3}{2}\right) \qquad (16)$$

Consequently the resulting Σ^- polarization, P_{Σ^-}, is

$$P_{\Sigma^-} = \frac{2(\alpha_1+\alpha_2) - \alpha_3 - 3\alpha_1\alpha_2\alpha_3}{3 + \alpha_1\alpha_2 - 2(\alpha_1+\alpha_2)\alpha_3} \qquad (17)$$

This result is illustrated in fig 16. In fig 16a we assume that the spectator J-quark is unpolarized ($\alpha_1 = 0$) and show the Σ^--polarization, P_{Σ^-}, as a function of the polarization of the other two quarks, α_2 and α_3. We note that the production mechanism Ib ($\alpha_2 > 0, \alpha_3 < 0$) will give $P > 0$ and mechanism V ($\alpha_2 < 0, \alpha_3 > 0$) will give $P < 0$. We also note that the influence of the d-quark polarization (α_2) is stronger than that of the s-quark. If mechanism Ib dominates over V obviously Σ^- will be polarized upwards.

As mentioned above it is possible that the initial J-quark is polarized upwards. In fig 16 b we show the Σ^--polarization assuming that $\alpha_1 = 0.5$ (50% polarization). We note that this will increase the Σ^--polarization but it will not change the sign. Thus without a detailed model for the possible polarization of the J-quark it is not possible to give a quantitative prediction for the Σ^--polarization, although qualitatively we obtain Σ^--polarization in the same direction as for Σ^+ and Σ^0. This was pointed out already in ref [15].

We note that in case both the produced quarks for the Σ^- stem from a field behind the J-quark like in a recombination model [16], then a Thomas precession mechanism [14] would give both $\alpha_2 < 0$ and $\alpha_3 < 0$. According to fig 16 this mechanism would then result in a Σ^- polarization which is either very small or in the opposite direction to the one found for Σ^+ and Σ^0. Preliminary results show that this is not the case [17] and this fact provides a strong indication for the essentially one-dimensional force field production presented here, where the new quarks stem from both sides of the J-quark.

IVD. Ξ-polarization

To produce a Ξ it is necessary to produce two new s-quarks. In our model one is produced on each side of the J-quark, and therefore they tend to be polarized in opposite directions. On the other hand, to form a Ξ the s-quarks must form a triplet spin state, a $(ss)_1$. If one of the two s-quarks has larger $k_\perp$ it will thus have a stronger polarization effect and the whole ss-pair will be polarized accordingly. The combined polarization property of the pair is related to the sum of the orbital angular momenta obtained according to fig. 9 , i.e.

$$L_{1z} + L_{2z} = (\mu_{1\perp}k_{1x} - \mu_{2\perp}k_{2x})2/\kappa \tag{18}$$

Here the x-direction is chosen along $\bar{p}_{\perp\Xi}$ and z along $\bar{p}_{proton} \times \bar{p}_{\Xi}$. As $k_{\perp 1}$ and $k_{\perp 2}$ have approximately Gaussian distributions we obtain

$$\langle k_{1x} - k_{2x}\rangle_{p_{\perp\Xi}\ \text{fixed}} = \frac{\langle k_{\perp 1}^2\rangle - \langle k_{\perp 2}^2\rangle}{\langle k_{\perp 1}^2\rangle + \langle k_{\perp 2}^2\rangle} \cdot p_{\perp\Xi} \tag{19}$$

For Ξ we find approximately the same values of $\langle k_{\perp 1}^2\rangle$ and $\langle k_{\perp 2}^2\rangle$ as the ones for Σ^- given in eq. (14). Therefore an estimate of the angular momentum in accordance with eqs(18) and (19) would be a linear rise with $p_{\perp\Xi}$:

$$L_{1z} + L_{2z} \approx \frac{2}{3}\frac{\langle\mu_\perp\rangle\ p_{\perp\Xi}}{\kappa} \tag{20}$$

Thus due to the smaller mass available in the string segment between the L and J quark we expect the Ξ particle to be polarized in the same direction as a Λ-particle.

Once again in case the J-quark is polarized upwards the Ξ polarization will increase but not change its direction.

V. Concluding remarks

We have in this paper, based upon a more detailed dynamical mechanism for baryon interaction, provided both a verification of the results for proton fragmentation in ref.[1] and amended the model of that paper with transverse momentum properties for the final state particles and polarization properties for the hyperons in a baryon fragmentation region. The semiclassical dynamics of the Y-shaped baryon string provides an effective suppression mechanism for the production of heavy 3-$\bar{3}$ colour pairs and of pair production with large transverse momentum in the string segments between the L and J quarks. While this mechanism hardly affects meson production (there may be a small suppression of very fast vector mesons, in particular K^*) it will imply some changes in the different possible hyperon production mechanisms in the model. In particular the production of strangeness with large transverse momentum in the LJ segments is affected. This feature is noticeable for the hyperon polarizations when we make use of the results in ref [2,3] that $q\bar{q}$ production in a uniform force-field implies strong polarization of the produced pairs. We find that the Λ and Ξ particles will be polarized along the direction $\vec{p}_{hyperon} \times \vec{p}_{proton}$ while Σ^0, Σ^+ and Σ^- are polarized in the opposite direction. This is all in agreement with present experimental observations [17,18]. The size of the polarization is however difficult to predict for Σ and for Ξ particles without a better knowledge of a possible J-quark ("spectator") polarization.

References

1. B. Andersson, G. Gustafson, I. Holgersson, O. Månsson Nucl. Phys. B178 (1981) 242
2. B. Andersson, G. Gustafson, G. Ingelman, Phys. Lett. 85B(1979)41
3. B. Andersson, G. Gustafson, Polarization effects in jet fragmentation, Lund preprint LU TP 82-4
4. B. Andersson, G. Gustafson, C. Peterson, Z. Physik C1 (1979) 105
   B. Andersson, G. Gustafson, T. Sjöstrand, Z. Physik C6 (1980) 235
5. B. Andersson, G. Gustafson, Z. Physik C3 (1980) 223
6. Axial Field Spectrometer Collaboration, Phys. Lett. 108B (1982)58
7. X. Artru, Nucl. Phys. B85 (1975) 442
8. H. Bohr, H.B. Nielsen, NBI-HE-78-3
   B. Andersson, G. Gustafson, T. Sjöstrand ref. 4
9. G. Ingelman, B. Andersson, G. Gustafson, T. Sjöstrand Nucl. Phys. B206 (1982) 239
10. W. Ochs, L. Stodolsky, Phys. Lett. 69B (1977) 225
11. B. Andersson, G. Gustafson, T. Sjöstrand, Nucl. Phys. B197 (1982) 45
12. K. Heller, Talk presented at 5th International Symposium on High Energy Spin Physics, Brookhaven Sept. 1982,
13. G. Gustafson, Talk presented at 5th International Symposium on High Energy Spin Physics, Brookhaven Sept. 1982 LU TP 82-12
14. T. DeGrand, H. Miettinen, Phys. Rev. D23 (1981) 1227
15. G. Gustafson, Proceedings of the 1980 International Symposium on High Energy Physics with polarized beams and polarized targets, Lausanne,
16. K.P. Das, R.C. Hwa, Phys. Lett. 68B (1977) 459
17. B. Lundberg, Talk presented at 5th International Symposium on High Energy Spin Physics, Brookhaven Sept. 1982
18. O.E. Overseth, Proceedings of the 1980 International Symposium on High Energy Physics with polarized beams and polarized targets, Lausanne.
19. H. Fesefeldt, W. Ochs, L. Stodolsky, Phys. Lett. 74B (1978) 389
    W. Ochs, Tokuzo Shimada, Z. Physik C4 (1980) 141
20. D. Brick et al., Nucl. Phys. B164 (1980) 1.

Figure captions

1. The final state colour field (or colour flux tube) stretched out after an interaction on a baryon. One initial valence quark (L) is at the end of the field followed by the other two (J and I). If L is red and J green the field is antired-red between L and J and behind J it is blue-antiblue.

2. The breakup of the colour force-field built up from a high energetic pair $q_0\bar{q}_0$ into final state hadrons shown in the cms (fig 2a) and in a system boosted along the q_0-direction.

3. The analogue of fig 2 for baryon fragmentation. The trajectory of the J-quark is indicated. In this case it happens to go into the second rank hadron, which thus becomes a baryon.

4. A Y-shaped baryon string model in the rest-system. The quarks are at the end-points of the strings.

5. The motion of the Y-shaped baryon string in case the quark marked a is made to move along the direction $\vec{V}$ by an interaction (fig 5a). In this example the angles θ and φ in eq.(3) are $\pi/2$ and 0 respectively. In fig. 5b the quark (a) moves away along $\vec{V}$ with an adjoining string segment, and a corner moves with the velocity of light towards the junction. In fig. 5c a set of positions in time are marked out with the strings marked by full lines, the quark trajectories with dashed lines and the trajectory of the junction by a dotted line. In position 2 the quarks (b) and (c) are at the "old" turnings points and will henceforth be accelerated in new directions.

6. A final state pion or kaon can be formed by the L-quark and and antiquark produced along the hyperbola marked π or K respectively. If the J-quark moves with very large velocity in the initial proton rest frame (fig 6a), both pions and kaons can be produced with z-values between 0 and $1-x_J$. If the J-quark moves with lower velocity (fig 6b) the z-range for kaons in particular is more restricted.

7. The transverse momentum distribution of the protons, Λ- and Ξ^--particles in a baryon fragmentation region according to the model. Experimental results for Λ from ref [20] are normalized with $\sigma_{\text{non-diff,inelastic}} = 26$ mb.

8. The Ochs-Stodolsky jet profiles for baryon number $dB/d\lambda$, energy fraction $\frac{d\varepsilon}{d\lambda}$ and charge (displayed as $dQ/d\varepsilon$) with $\lambda = x_F/p_\perp$. Experimental data from [10,19]. The curves are calculated for the experimental beam momentum, 24 GeV/c.

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

10a. If the colour flux of a confined field ends at the particle and the antiparticle like vortex lines, the external forces, $\bar{F}$ and $-\bar{F}$ act along the same line and give no torque.

10b. For a particle-antiparticle pair produced in an external homogeneous field, the forces $\bar{F}$ and $-\bar{F}$ do give a torque.

11. The fractions of Λ-particles produced with the mechanisms I-IV described in the main text as functions of x_F in a proton fragmentation region. (The calculations are for 400 GeV/c proton lab. momentum.)

12. The ratio in eq. (13) is shown as the full line corresponding to the model prediction for Λ-polarization normalized to 1 at $x_F = 1$. In e.g. a proton-proton interaction Λ's stemming from the opposite hemisphere ($x_F < 0$) are polarized oppositely and the resulting subtracted prediction is shown by a dashed line.

13. The fractions for Σ^0 and Σ^+ corresponding to fig. 11 for the Λ-particles.

14. The ratio in fig. 12 for the Λ-particles shown for Σ^0 and Σ^+.

15. The fractions for Σ^- from the different reaction mechanisms described in the main text.

16. Levelcurves for fixed polarisation of Σ^- as functions of the polarisation of the produced d- (α_2) and s-quarks (α_3) when the polarization of the J-quark is $\alpha_1 = 0$ (fig. 16a) and $\alpha_1 = 0.5$ (fig. 16b).

Fig. 1

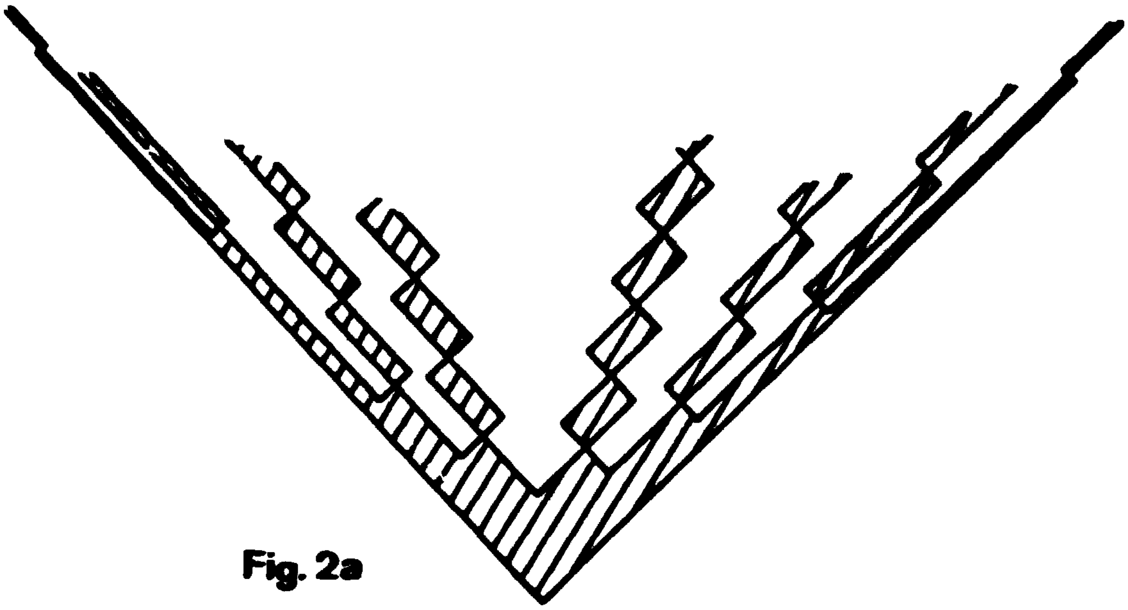


Fig. 2a

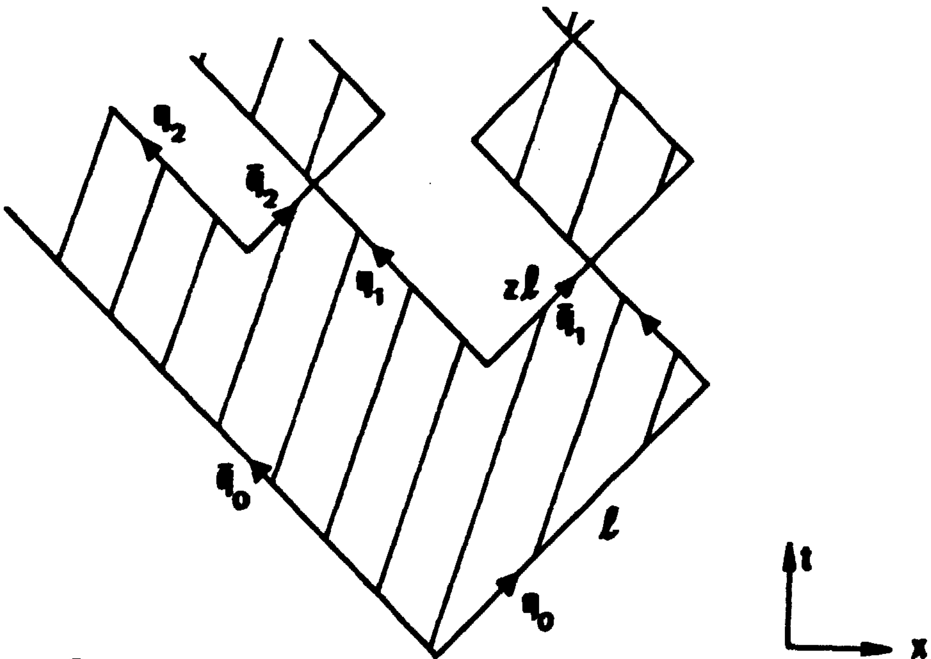


Fig. 2b

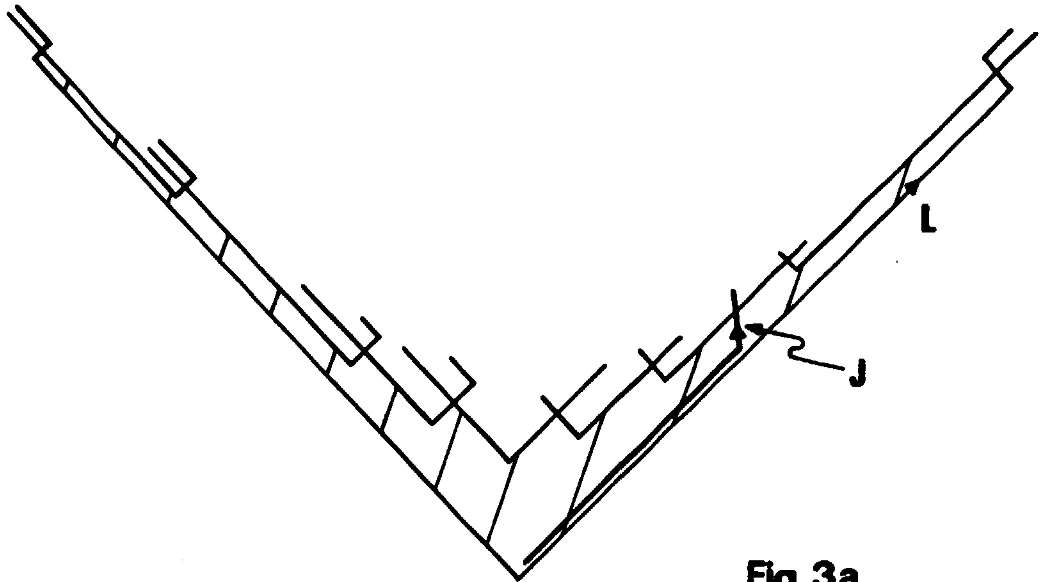


Fig. 3a

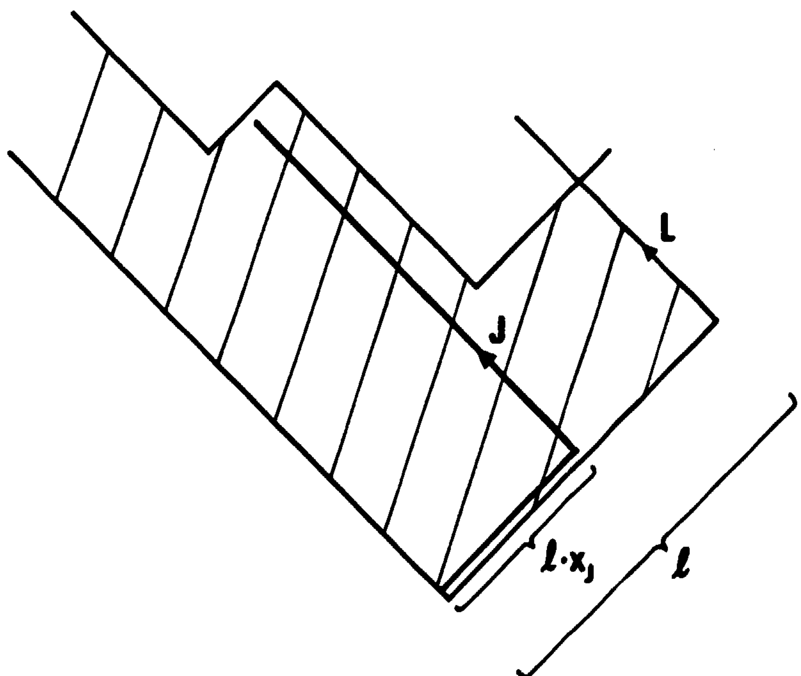


Fig. 3b

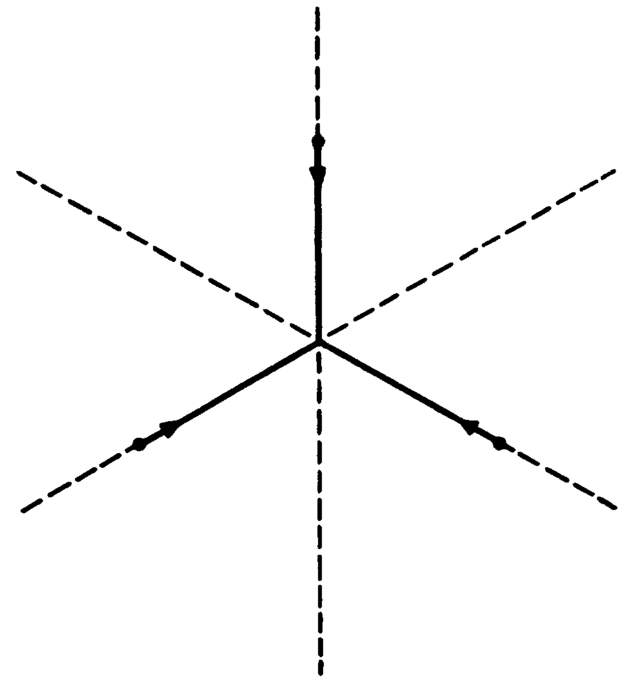
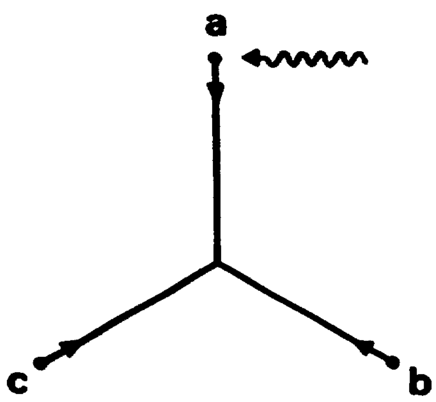
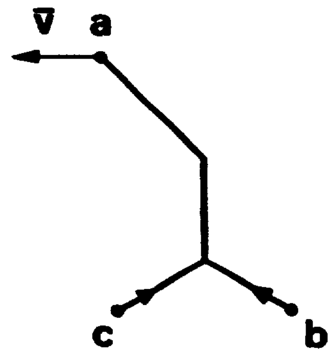


Fig.4





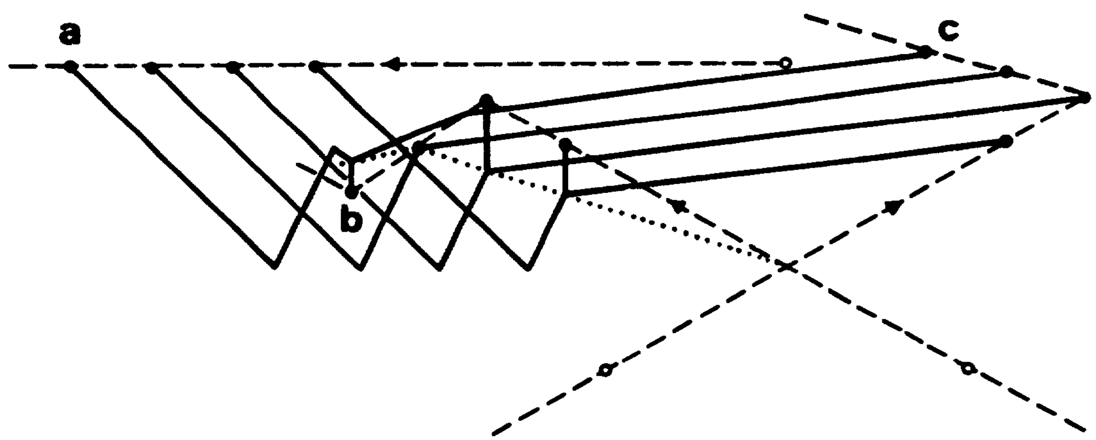


Fig.5a b c

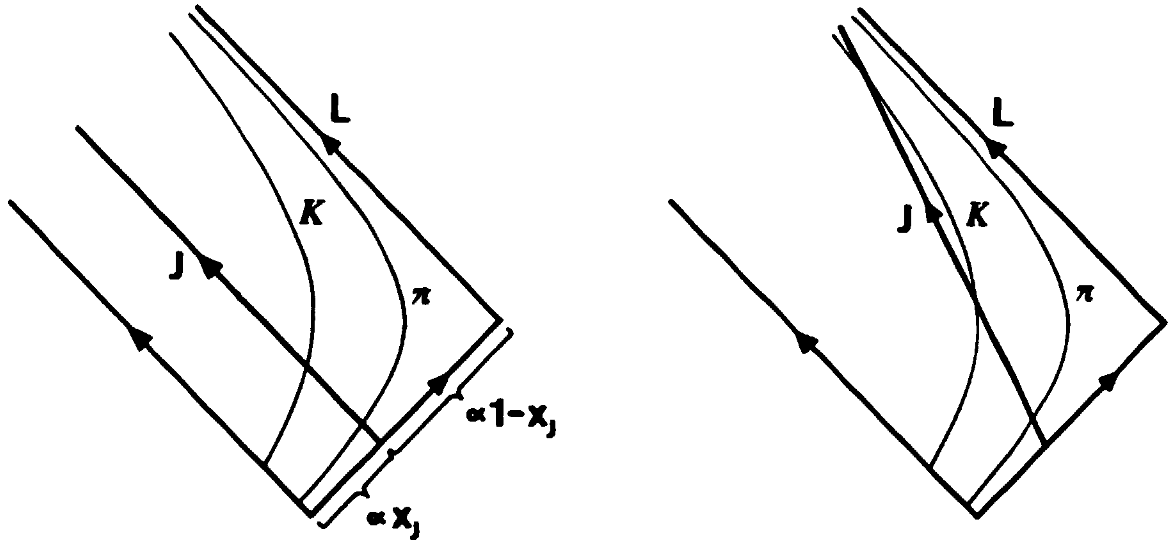


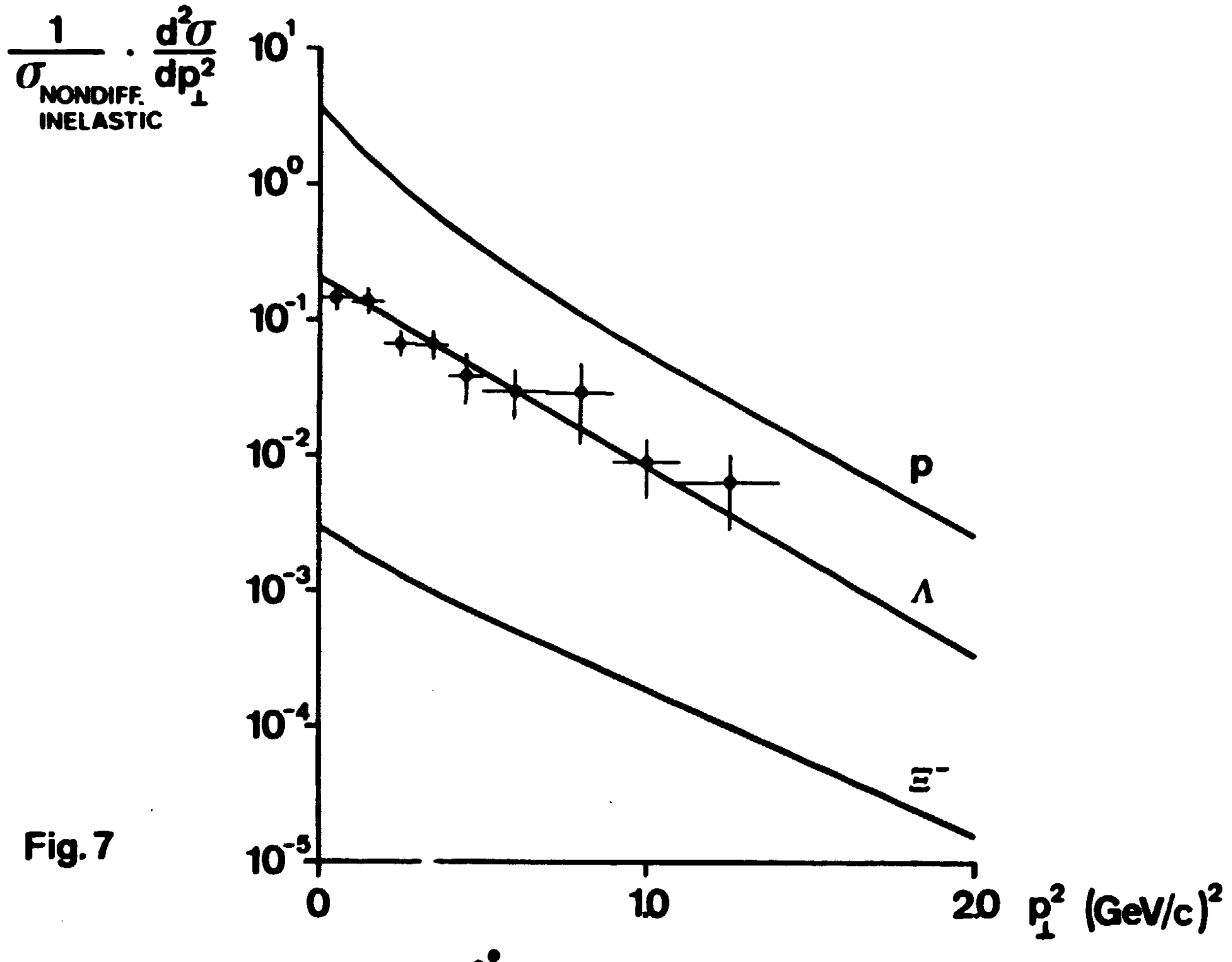
Fig. 6a

6b

c

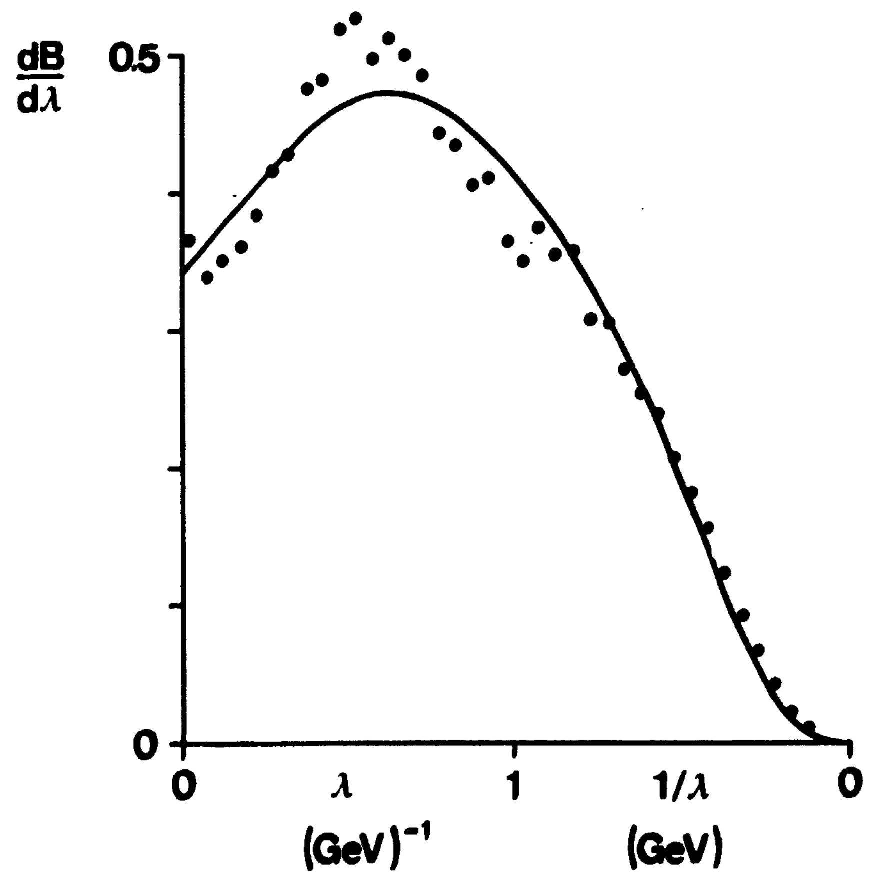
b

Fig.5a



$\frac{1}{\sigma_{NONDIFF. INELASTIC}} \cdot \frac{d^2\sigma}{dp_\perp^2}$
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
p
Λ
Ξ⁻
0
1.0
2.0
$p_\perp^2$ (GeV/c)^2

Fig. 7



$\frac{dB}{d\lambda}$
0.5
0
0
λ
1
1/λ
0
(GeV)$^{-1}$
(GeV)

Fig. 8a

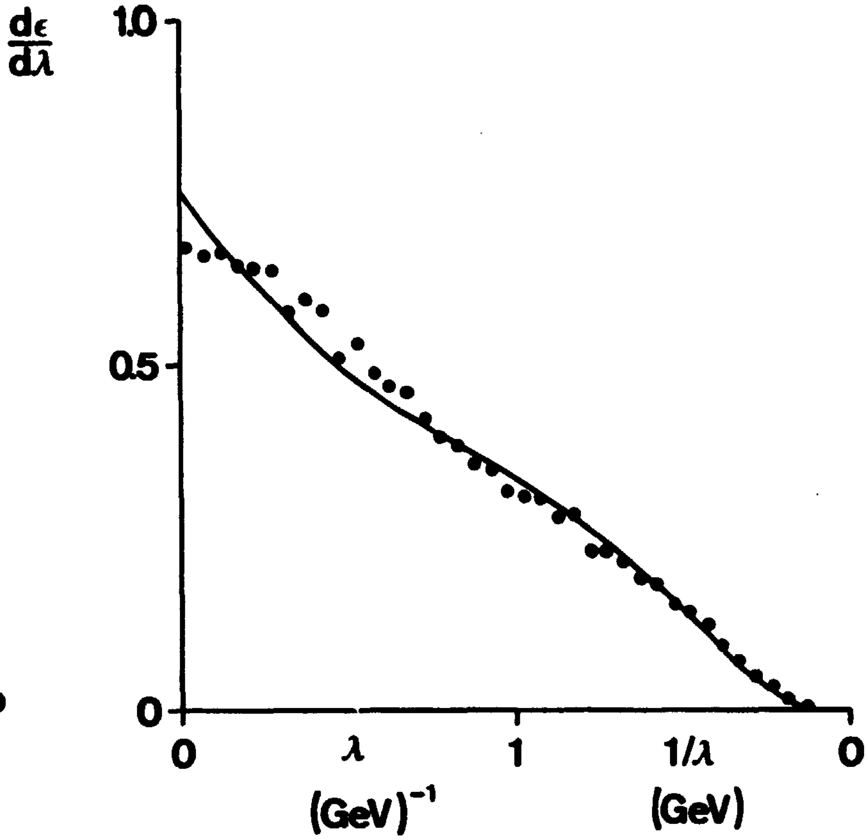


Fig. 8b

² (GeV/c)²

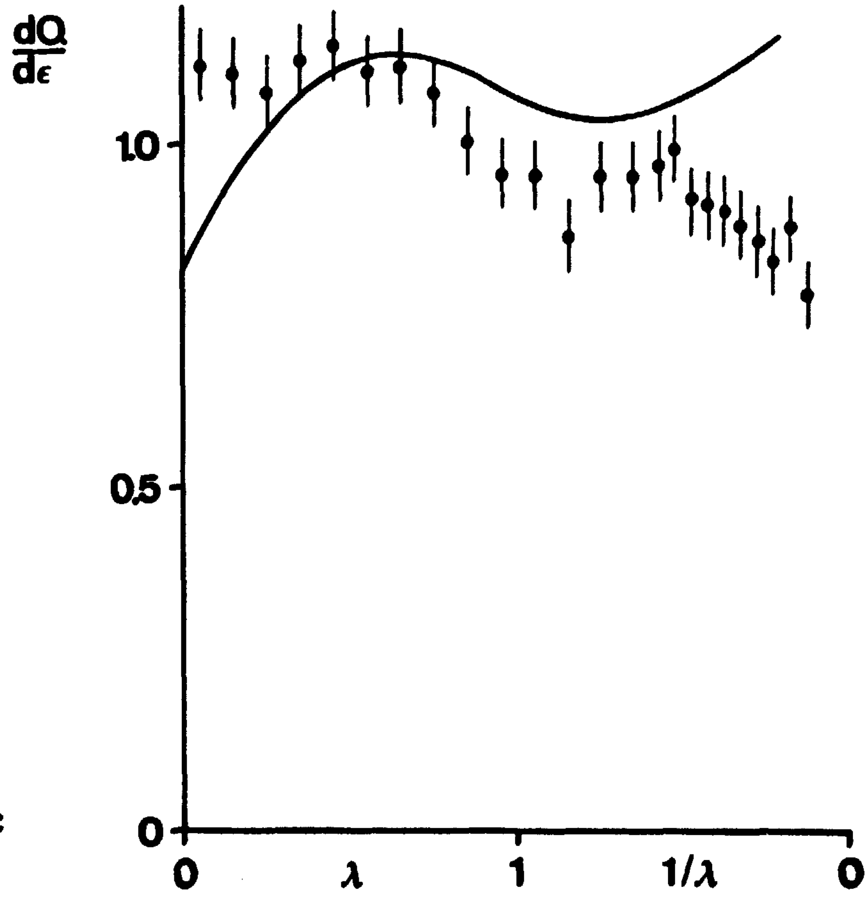


Fig. 8c

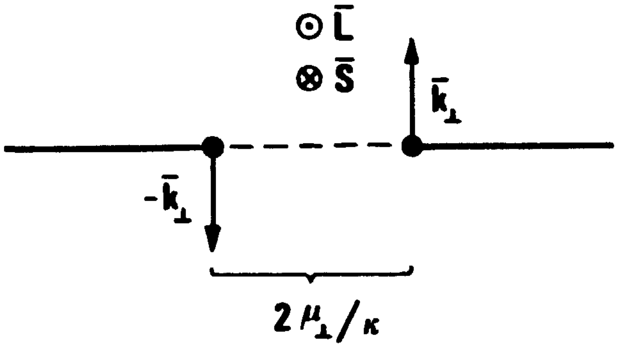


Fig. 9

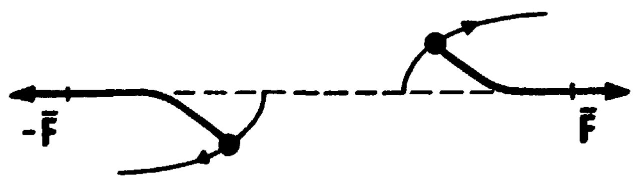


Fig.10a

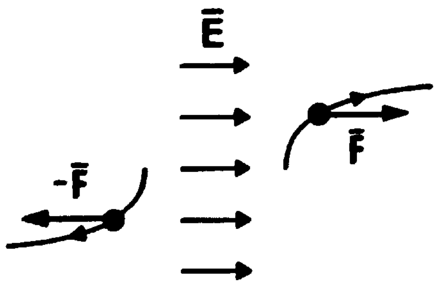


Fig.10b

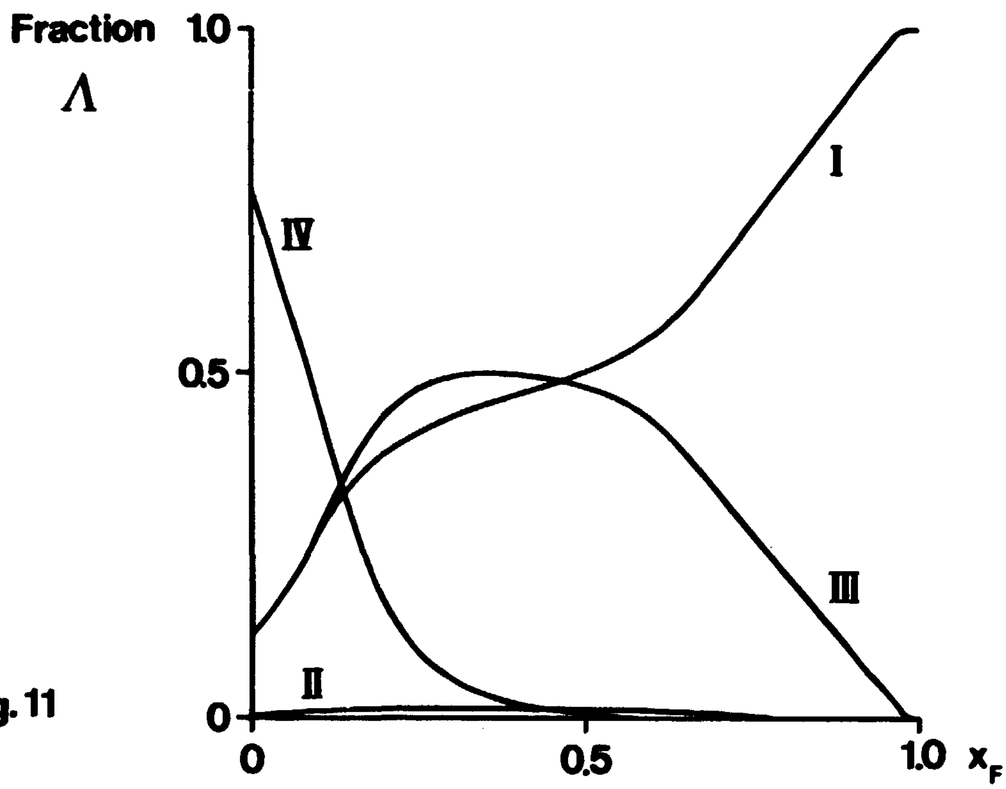


Fig. 11

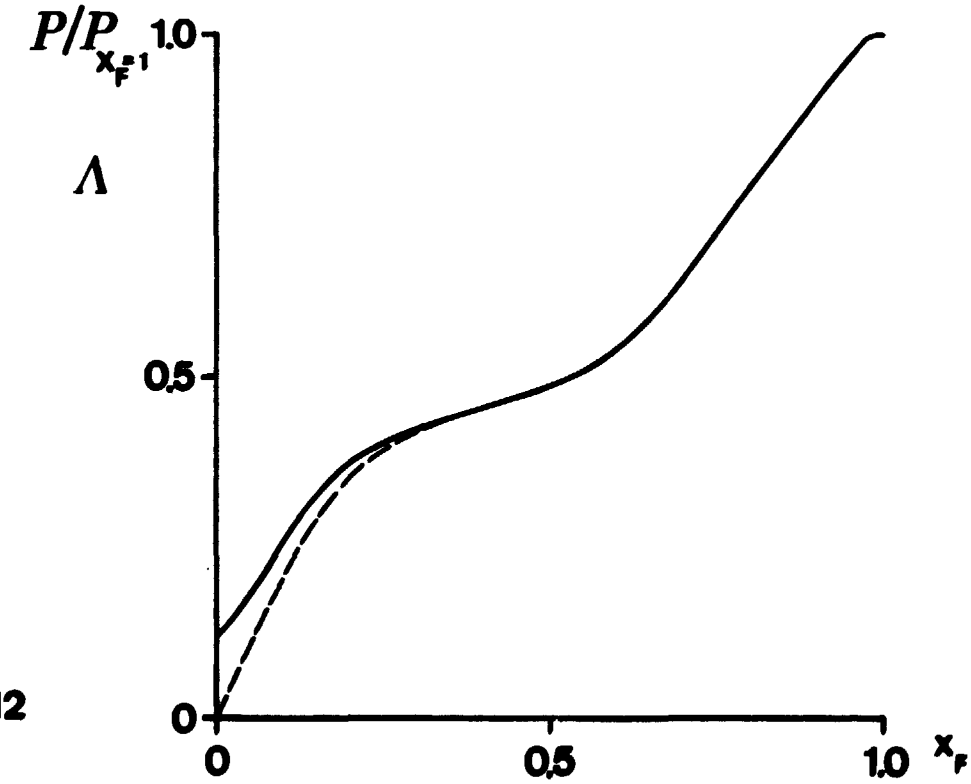


Fig. 12

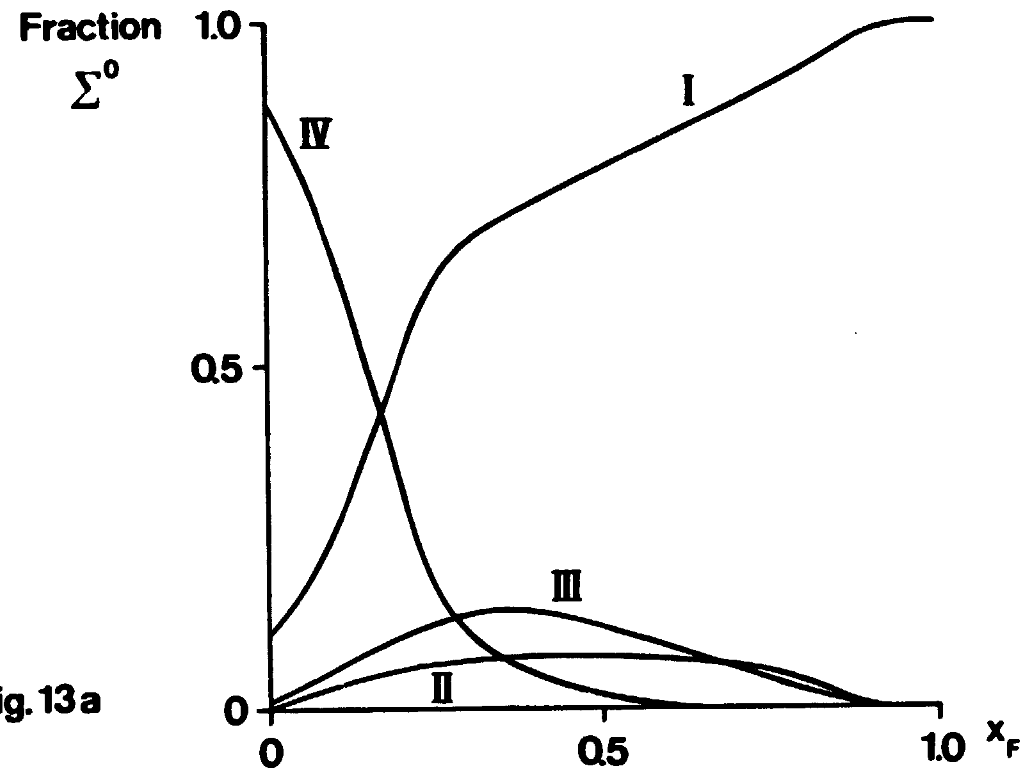


Fig. 13 a

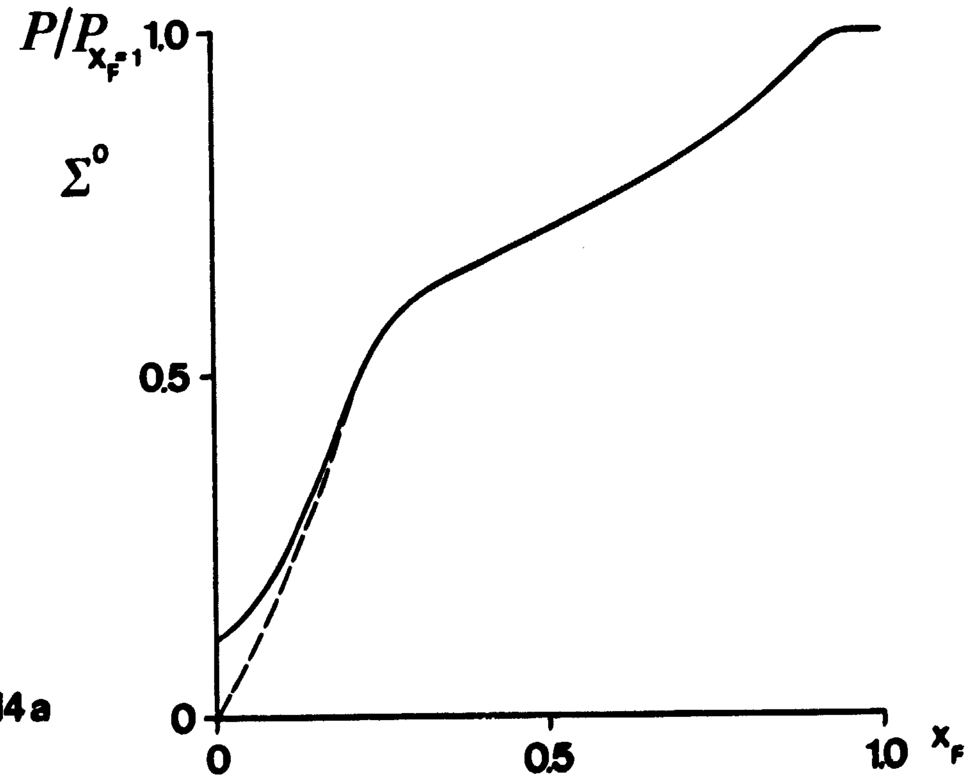


Fig. 14 a

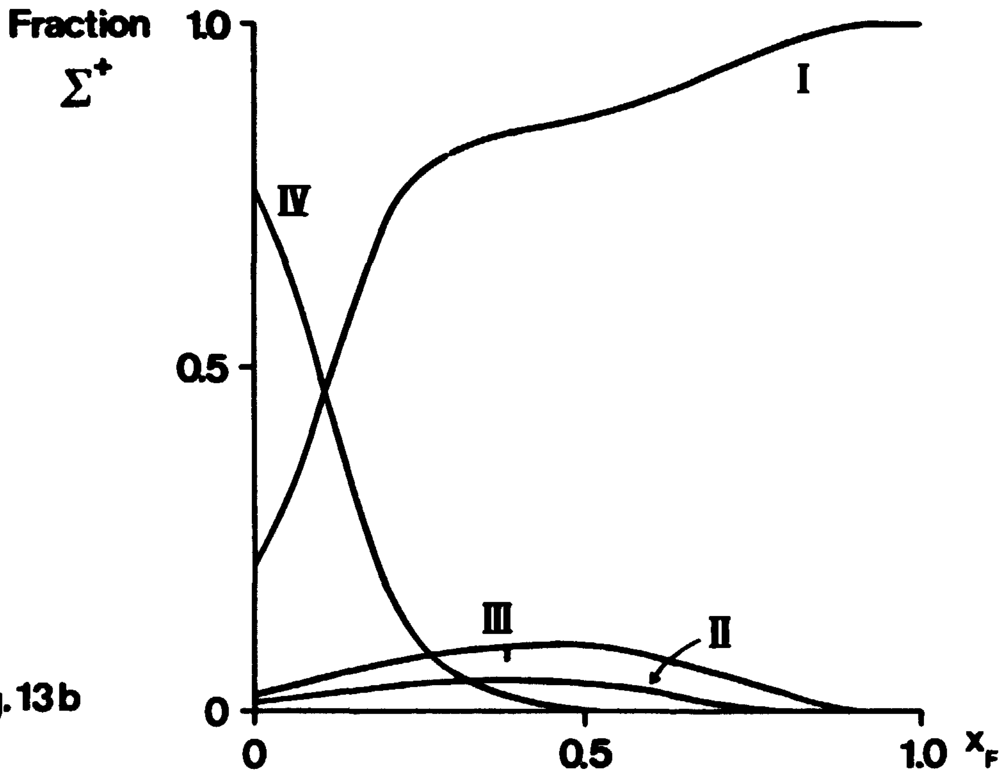


Fig. 13b

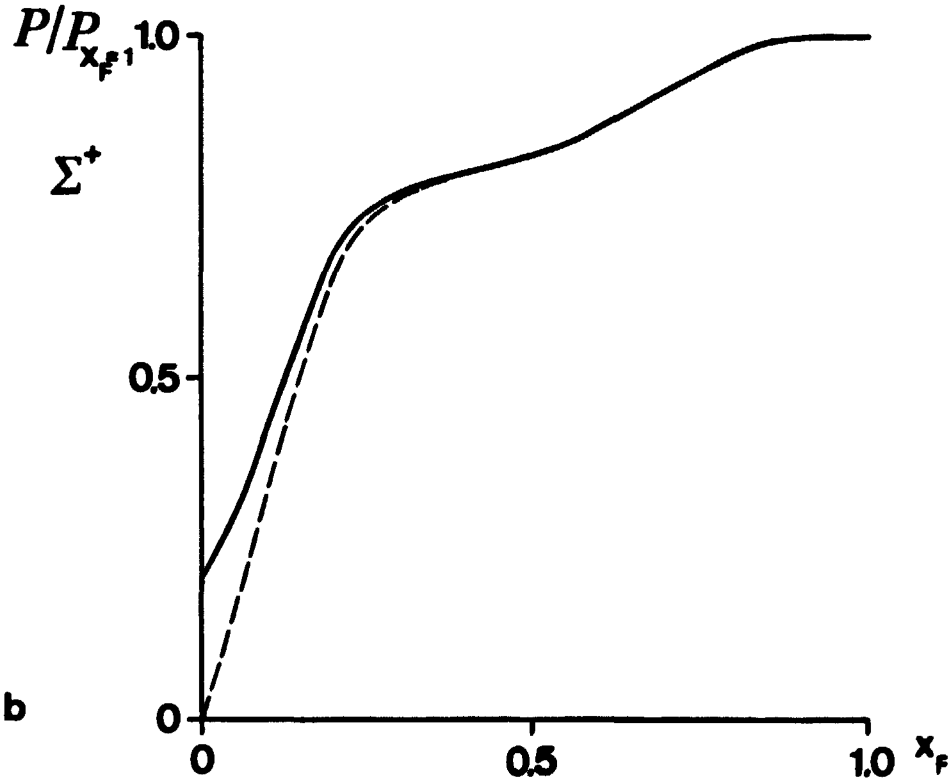


Fig. 14b

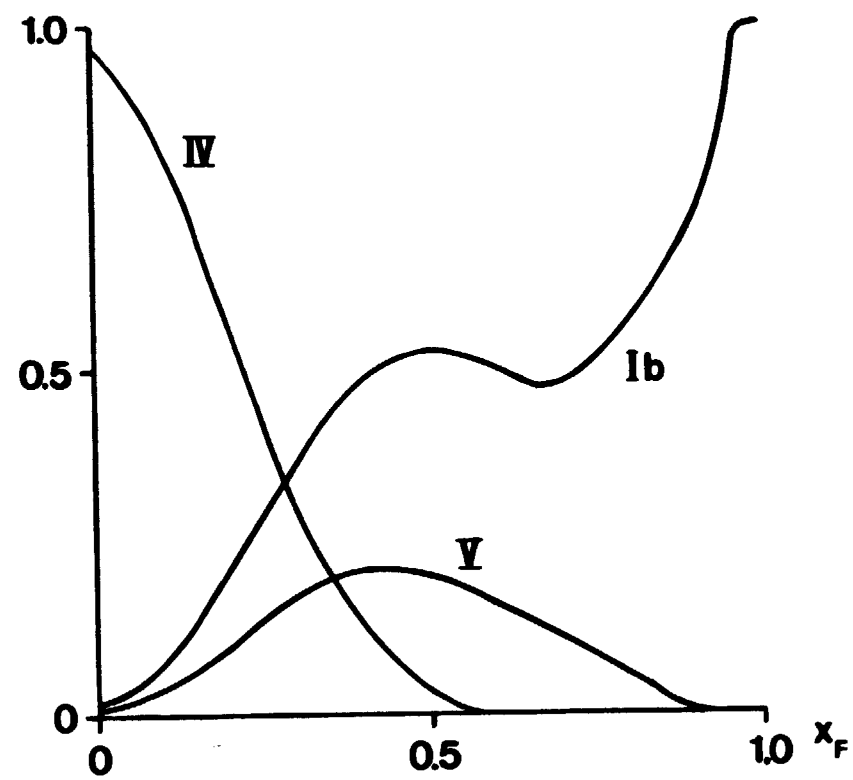


Fig. 15

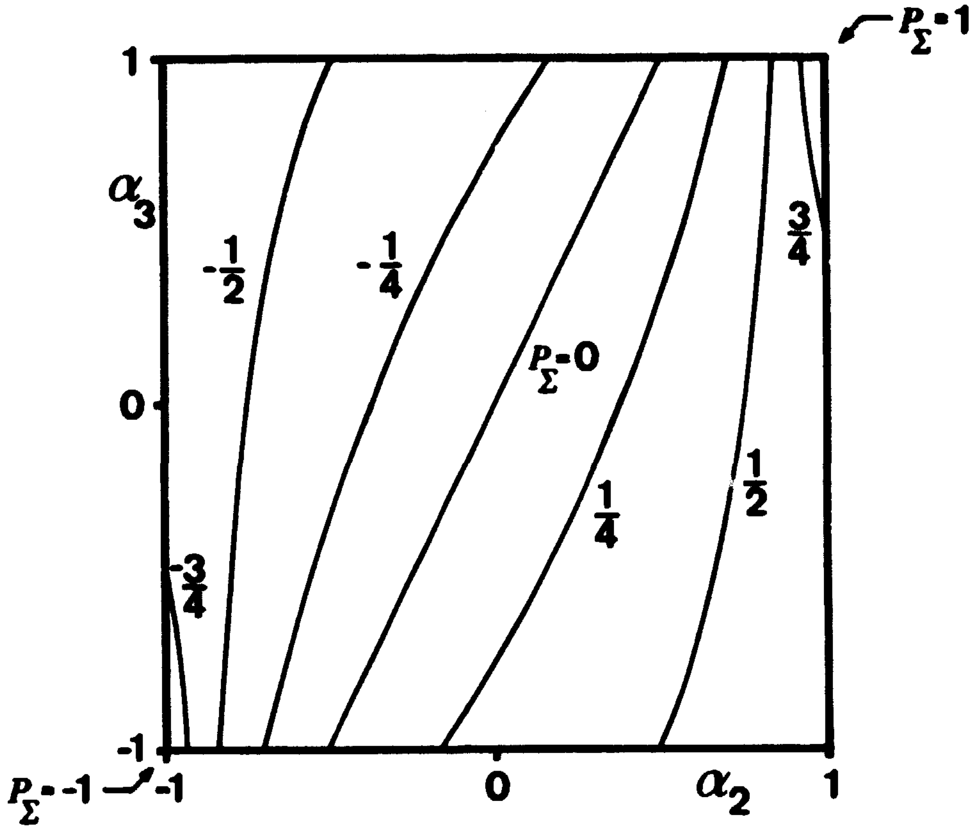


Fig. 16a

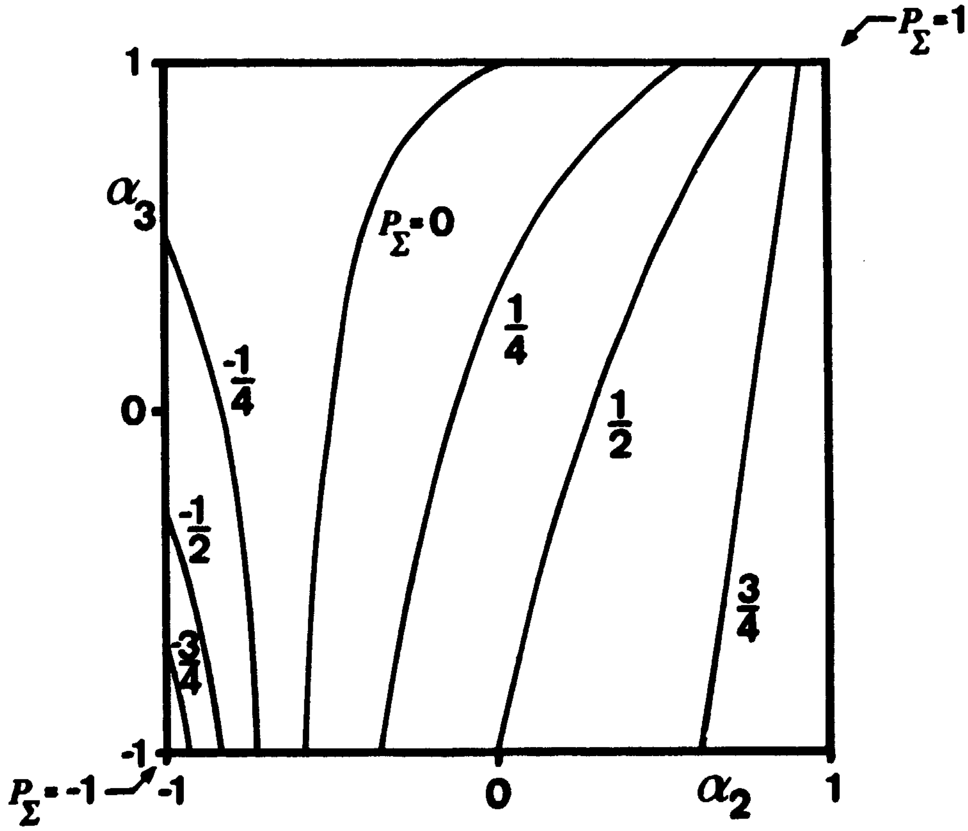


Fig. 16b