THE INFLUENCE OF PARTONS ON SOFT HADRONIC REACTIONS- A REVIEW

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Abstract:
Data on soft hadron-hadron collisions are compared to each other and to deep inelastic lepton-hadron and e^+e^- collisions in the light of quark-parton pictures. Three basic observations are the success of quark statistics to explain different quantum number hadron yields, the reflection of the valence quark distribution in hadronic pion production, and the similarity of jets in hadron-hadron, deep inelastic lepton-hadron and e^+e^- collisions. The models evolving from these observations help to illuminate different aspects of the data. They allow to understand correlations in the proton fragmentation region. Quark and diquark fragmentation functions extracted from hadron-hadron collisions agree with those from neutrino-hadron collisions. Kaon and pion structure functions agree with those obtained from muon-pair production. Hyperon polarization at large energies, not understandable from reggeology, follows naturally from quark-fragmentation-recombination.

I. BASIC OBSERVATIONS

Three observations have recently been drawing increased attention to soft hadronic collisions:

1. Cross sections for resonance and particle production in central and fragmentation regions can be understood from quark statistics.
2. Pion production in the nucleon fragmentation region of soft hadron-hadron collisions seems to reflect the valence quark distribution in the nucleon as observed in moderately deep inelastic lepton-nucleon collisions.
3. Quark fragmentation jets from e^+e^- annihilation and deep inelastic collisions seem to resemble soft hadronic production in longitudinal, transverse and multiplicity behaviour of the produced hadrons.

These observations lead to the expection that the parton structure of hadrons also governs soft hadron-hadron collisions. To test this unifying concept and to use its far-reaching consequences to illuminate not only the complicated hadron-hadron collisions, but the (soft) quark fragmentation in general, is the basis of present experimental and theoretical effort in this field. Before discussing the status of this effort in the later section, we shall first review the three basic observations.

I.1. Quark Statistics

Early data[1)] give evidence for a two component picture of inclusive particle and resonance production. The fragmentation component depends on the produced particle or resonance and on the fragmenting incoming particle. The shape of the central component is universal, i.e. does neither depend on the incoming particles nor on the produced particle or resonance.

According to a simple additive quark model[2)], one quark of the beam particle reacts with one quark of the target to produce a large quark-antiquark ($q\bar{q}$) sea in the center. One or more quarks (or antiquarks) from the center join respectively the beam spectator and the target spectator quarks to produce hadrons in the fragmentation regions. The remaining quarks and antiquarks join to produce hadrons in the central region. SU(6) symmetry is assumed to be broken only by a relative suppression ($\lambda \approx 1/3$) of strange quark production. The probability of quark production in the sea does not depend on spin projection and charge. Furthermore, due to the large quark multiplicity at high energy, the probability of central quark production does not depend on the nature of the incoming quarks. In meson production in the fragmentation region, on the other hand, one spectator is joined by one quark from the sea, so that there the distribution depends on the nature of the spectator.

One of the main assumptions is that a "gas" of quarks and antiquarks with non-correlated spin projections is formed. As a consequence, the number of $q\bar{q}$ pairs with total spin s is proportional to the statistical weight 2s + 1. This gives an expected ratio 3:1 for ρ/π or $K^*(890)/K$, more generally for mesons containing the same quarks and belonging to the same SU(6) multiplet. The actually observed ratio depends on the contamination from decays of unobserved resonances. The ratio 3:1 has been verified[3] on K, K^* and K^{**} mesons (which appear in decay processes to a smaller extent and in a better controlled way than π and ρ) from pp and K^-p data.

The probability β for a spectator quark to pick up an antiquark (rather than a quark) from the sea has been estimated[4] to $\beta \approx 30\%$, consistently from $\bar{\Lambda}/K_s^o$ and Λ/K_s^o multiplicity ratios in π^- and K^- fragmentation.

The most detailed application of quark statistics is a systematic study of baryon production in the proton fragmentation region[5]. The data[5a] suggest that antibaryons can be attributed dominantly to the non-fragmentation type $B\bar{B}$ pair production with local compensation of quantum numbers. In that case, each valence quark of the incident proton either recombines with an antiquark to give an outgoing meson or recombines with other quarks, to give an outgoing baryon. From a consistent description of proton, Λ, Σ, Ξ and Ω^- production in proton fragmentation[5b], these two possibilities turn out to occur in an uncorrelated way for each valence quark of the incident proton, with the respective probabilities of about 40% and 60%[5c].

Furthermore, the probabilities a_i (i= 0, ...3) for the produced baryon to contain i valence spectator quarks can be consistently deduced from the same data to be

$$a_o = 0.05 \pm 0.03 \qquad a_1 = 0.20 \pm 0.04$$
$$a_2 = 0.30 \pm 0.16 \qquad a_3 = 0.45 \pm 0.17$$

We can conclude that pure quark statistics can give a consistent description of relative particle yields in central and fragmentation regions. This description is global, but it can be taken as a first hint that quarks may play a role also in soft hadronic reactions. If we want to know how, we have to go to more differential distributions.

I.2. Reflection of the Valence Quark Distribution

The analysis of lepton induced reactions has shown that only about half of the momentum of the proton is carried by quarks (q) and antiquarks ($\bar{q}$) and a small fraction by antiquarks alone. As $q(x)=\bar{q}(x)$ at x=0, the antiquark distribution is concentrated at small x (say x $\lesssim$ 0.2, the "sea" region) and the same is expected for gluons which could dissociate into a $q\bar{q}$ pair. The presence of a $\bar{q}$ component in the proton structure function implies that the proton, which primarily consists of three quarks, has dissociated into a state with many $q\bar{q}$ pairs if hit by the electron.

The suggestion of Ochs[6] is that the same process of dissociation into partons occurs if the proton fragments into hadrons in the field of another hadron at high energies. The longitudinal momenta of partons will be approximately conserved during the interaction and there is a correspondence between the hadron state and the parton state in the following way: A quark in the parton state outside the sea-region (x $\gtrsim$ 0.3) is a valence quark of a hadron of the final hadron state, and the momentum of the quark contributes to the momentum of the hadron.

In the fragmentation region of the proton, the π^+ can be assumed to be composed of a u valence and a $\bar{d}$ sea quark. Since the latter carries very little momentum, we expect to find a u quark with similar momentum to that of the $\pi^+ = |u\bar{d}\rangle$. The same holds for a d quark and the $\pi^- = |d\bar{u}\rangle$. As a consequence, the x-distribution of a pion in the fragmentation region of an incident proton is expected to be similar to that of the valence quark which it shares with the proton. Fig.1a-b shows that the x-distribution of π^+ is indeed similar to the u-quark distribution u(x) derived from SLAC data on electron-nucleon deep inelastic scattering[7]. The π^- distribution agrees with d(x) up to x~ 0.7, and is only slightly above d(x) for larger x-values.

We conclude that the quantum numbers and the distribution of the target proton valence quarks can be found back in the particles produced in the target fragmentation region.

What is the role of the beam quantum numbers? Fig.1c gives a comparison of the ratio of the inclusive invariant cross sections for π^+ and π^- production as a function of x in the target fragmentation region for the reactions $\pi^{\pm} p \rightarrow \pi^{\pm} X$ at 16 GeV/c to that for $p \rightarrow \pi^{\pm} X$ (scaling between 19 and 2000 GeV/c). The ratio R is considerably larger for 16 GeV/c π^+p than for pp reactions. On the other hand, R falls below the proton curve for π^-p collisions.

At higher energies, however, the $\pi^{\pm}$ p ratios tend to converge. The approach of R to a high energy limit is given in fig.2 for $\pi^{\pm}$ p collisions[9], as a function of $s^{-1/2}$, for several x intervals. The energy dependence agrees with an $s^{-1/2}$ term, the asymptotic limit is consistent with the ratio R for pp reactions. A similar conclusion can be drawn for $K^{\pm}p$ collisions. This means that at $p_{lab} \gtrsim$ 200 GeV/c, the influence of the proton valence quarks alone is observed to govern proton fragmentation in soft hadronic collisions.

This second basic observation supports the quark recombination picture[10] of hadron production in the fragmentation region. In the framework of this picture a fast meson with small p_t is formed by a two step process:

i) a quark-antiquark pair is picked out from a proton,

ii) this pair recombines to form the meson.

Neglecting many-body recombination the inclusive x distribution of a meson M is therefore given by

$$\frac{x}{\sigma_t}\frac{d\sigma}{dx} = \int f_{v\bar{s}}(x_v,x_s)\, R(x_v,x_s)\, \delta\left(\frac{x_v}{x}+\frac{x_s}{x}-1\right) dx_v dx_s$$

where $f_{v\bar{s}}(x_v,x_s)$ is the probability density of finding simultaneously within the proton two partons v and $\bar{s}$ with respective momentum fractions x_v and x_s (the two-quark structure function) and $R(x_v,x_s)$ is the recombination probability for the v and $\bar{s}$ quarks to form the meson M. The δ-function assures momentum conservation for the process.

Justification[11] for the particular form of $f_{v\bar{s}}$ and $R(x_v,x_s)$ comes from the so-called "valons" (kind of dressed quarks). The distribution of quarks in a valon and of the valons in the proton can be completely determined in shape and normalization by ensuring that they reproduce the quark distribution from low Q^2 lepton-nucleon collisions.

I.3 Jet Universality

The decrease in average sphericity <S>, thrust <1-T> and spherocity <S'> with increasing energy, generally interpreted as evidence for jet production, is not only a feature of reactions in which single quark effects are expected to dominate[12], but also of low p_t hadron-hadron collisions[13]. As is shown in fig.3a-c the average shape of the hadronic system is the same in all three types of collision at given hadronic energy, as is its change with energy.

The energy dependence of the shape of the sphericity distribution itself[13a,c] is shown in fig.3d,e. As for e^+e^- collisions, one observes a change from a dip at S=0 at low energy to a sharp peak at S=0 at higher energies. The shape of the 16 GeV/c K^-p S distribution (E_{cm}=5.6 GeV) is peaked at rather lower S values than the SPEAR data at 6.2 GeV. Very good agreement is observed between the S distribution in K^-p at 110 GeV/c (E_{cm} = 14.8 GeV) with the PLUTO result at 17 GeV, and the h^+p data at 147 GeV/c with the TASSO distribution (the TASSO S distribution at 17 GeV is similar to the PLUTO data). Diffractive events contribute only at the most "jet-like" values, i.e. low S. The agreement between the shape of the K^-p and the leptonic distributions is improved when the diffractive events are removed. The only major difference in the shapes of S and T distributions in K^-p and in published leptonic data remains the above mentioned peaking at lower S values in the K^-p data at 16 GeV/c, when compared with the SPEAR data. This probably results from the problems in defining the sphericity axis in low E_{cm} e^+e^- events.

The normalized 70 GeV/c K^+p rapidity distribution, evaluated with respect to the thrust axis[13c] is compared to e^+e^- results at 13 GeV/c (TASSO)[14] in fig.4a,b. At similar energy, the two rapidity distributions agree remarkably well and it can be expected from the insert (and from old results on hadronic rapidity plateaus) that hadron-hadron and e^+e^- data show a similar ln $\sqrt{s}$ increase of the plateau hight and, above all, the same plateau hight at the same energy!

Also the normalized p_t^2 distributions relative to the sphericity axis fig.4c show agreement at 13 GeV/c, even though there may be indication of a larger cross section in the high p_t tail for the e^+e^- results.

The conclusion of jet universality is further supported from a comparison[13] of the energy dependence of $\langle n \rangle$, as well as of $\langle p_t \rangle$ and $\langle p_{//} \rangle$ relative to the thrust axis (not shown). Again, the hp and e^+e^- data have essentially the same values and the same energy behaviour. In particular, the rise in $\langle p_t^2 \rangle$ with E_{cm} felt to be a characteristic feature of single quark jets is in fact also a feature of hadronic low p_t particle production.

At this stage we may ask whether the agreement between the data is accidental, e.g. due to longitudinal phase space, or has any more fundamental dynamical origin. In ref.13c the sphericity, thrust, spherocity and other distributions are compared to mere longitudinal phase space and the Field and Feynman parametrization of quark-parton jets[15]. In all cases, both the FF parametrization as well as LPS more or less describe the data. One may conclude that FF is a somewhat complicated way to parametrize longitudinal phase space. Jet universality may well turn out to reduce to the equal p_t distributions and the equal average multiplicities, the rest may follow from independent emission + conservation laws. But the point is, if this will turn out to be the case, it will hold equally for hadronic, deeply inelastic and e^+e^- hadron production. In all cases the same mechanism is at work, governing multiplicities and transverse momenta in an identical way.

If quark fragmentation is indeed governed by longitudinal phase space, it will be interesting to look for the trivial differences expected from the quantum numbers or excitation modes of the fragmenting quarks, as well as for (non-trivial) flavour correlations within the fragmentation jet.

One difference of the hadron system produced in e^+e^- annihilation and pp collisions is that the baryon number is zero in the first case and two in the second. In other words, there are more interacting valence quarks in pp collisions than in e^+e^- hadron production. A CERN-Bologna-Frascati Collaboration[16] using the CERN Split-Field Magnet at $\sqrt{s}$=62 GeV has attempted to remove the expected effects of baryon-number conservation by selecting events with a leading proton and redefining the fractional variables of the particle after removal of that proton.

The pp data (normalized to the mean charge multiplicity) are compared to (normalized) e^+e^- data from the Tasso Collaboration[17)] at three different energies E_{had}. The agreement between the two distributions at all three E_{had} values, both in shape and absolute value (mean charged multiplicity), suggests that the mechanism for transforming energy into particles in these two processes must be the same. This would be surprising if the fragmentation process would not be governed by longitudinal phase space, since excluding the leading proton means excluding the leading parton plus its companion. To be fair, one would have to exclude the leading quark and its companion in e^+e^- annihilation, as well.

The 147 GeV/c h^+p collaboration studied the effect on <S> and <T> when removing the leading particle. As expected, <S> and 1- <T> increase, but the available hadron energy E_{had} decreases. Both values are compared to the e^+e^- and νN data at the corresponding values of E_{had}. Removing the proton does not improve the agreement. I would suggest to forget this approach and to look for expected differences rather than to exclude them before they are shown to exist.

The better approach seems to me to select certain events where the jet is expected to derive from $q\bar{q}$ separation as in e^+e^- jet production. A possible laboratory for this study is meson or photon diffraction dissociation[18)]. The diffractive dissociation can be assumed to be a two-step process. First, the meson dissociates into a $q\bar{q}$ pair, then this $q\bar{q}$ system hadronizes in the same manner as hadronization takes place of neutral quark-antiquark pairs during e^+e^- annihilation to two jets of hadrons. Diffraction dissociation may have the enormous advantage over e^+e^- annihilation that the $q\bar{q}$ pair is known and not a mixture of $u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$ or $b\bar{b}$. This may provide the unique opportunity to investigate jets of known flavour!

The fact that jets produced in e^+e^- annihilation and deep inelastic lepto-production are very similar to these produced along the beam direction in ordinary hadron-hadron collisions has led to the assumption of parton fragmentation as a common underlying dynamical mechanism. In the quark fragmentation view[19)], inelastic (non diffrative) scattering is dominated by events where one valence quark of the baryon with low momentum interacts with the other hadron and is fixed in the central region. The remaining diquark system will carry almost all the original baryon momentum and subsequently fragment into hadrons in the baryon fragmentation region. The rapidity density of the fragmentation chain is universal, i.e. it depends only on the nature of the system at the chain end and not on the nature (hard or soft) of the process which produces them. The inclusive one-particle distribution of hadron H in the fragmentation region of hadron h is given by the convolution integral

$$\frac{1}{\sigma}\frac{d\sigma}{dx} = \sum_q \int_x^1 dy\,dz\, f_q^h(y)\, D_q^H(z)\, \delta(yz-x)$$

between the probability distribution $f_q^h(x)$ of the constituents of h to carry momentum fraction x and the fragmentation $D_q^H(z)$ of constituent q into the hadron H, as obtained from leptonic reactions.

The important assumption is that the mechanism responsible for hadronic interactions favours configurations of valence quarks different from those measured in lepto-production. Only configurations in which the diquark carries almost all the momentum are assumed to be responsible for pion production in the proton fragmentation region. This amounts to

$$f_q^h(x) = k_q^h\, \delta(x-x_o)$$

with k being a statistical factor corresponding to the additive quark model and $x_o \simeq 1$. So, hadronic spectra are given by the fragmentation functions $D_q^H(x)$ in a parameter free form.

II. SELECTED APPLICATIONS

The recombination and fragmentation pictures have been designed to describe single particle distributions from a different point of view. Attempts to show the duality or complementarity of the two views have been started[20] and should be continued. Rather than trying to prove one of the pictures and disprove the other, we shall here use their complementarity to illuminate different aspects of the data.

II.1 Target Fragmentation

According to the fragmentation model[19], pion production in the proton fragmentation region can be written in terms of the diquark fragmentation functions D_{qq}^{π} as

$$\frac{1}{\sigma}\frac{d\sigma}{dx}^{p\to\pi^\pm}(x) \simeq \frac{1}{3} D_{uu}^{\pi^\pm}(x) + \frac{2}{3} D_{ud}^{\pi^\pm}(x).$$

From isospin invariance follows $D_{ud}^{\pi^-} = D_{\bar{ud}}^{\pi^+}$, so that three independent functions remain: $H_1 = D_{uu}^{\pi^+}$, $H_2 = D_{ud}^{\pi^+} = D_{u\bar{d}}^{\pi^-}$ and $H_3 = D_{uu}^{\pi^-}$. One can expect $H_1 > H_2 > H_3$ for large x since in H_1 both u-quarks can contribute to the creation of a π^+, while in H_2 only one quark contributes, and in H_3 none of the two u-quarks contributes to π^- production.

Furthermore, if baryon production is dominant in the diquark fragmentation, the approximate relation $2H_2 \sim H_1 + H_3$ is valid[19]. For the pion cross section in proton fragmentation then follows

$$\frac{1}{\sigma}\frac{d\sigma}{dx}^{p\to\pi^+}(x) \simeq \frac{2}{3}H_1(x) + \frac{1}{3}H_3(x) \quad \text{and} \quad \frac{1}{\sigma}\frac{d\sigma}{dx}^{p\to\pi^-}(x) \simeq \frac{1}{3}H_1(x) + \frac{2}{3}H_3(x) \ .$$

K^-p data at 70 GeV/c[20] are compared to νp and $\bar{\nu}p$ data[21] in fig.5. The following observations can be made:

- $H_1(x)$ from νp data indeed agrees with $H_1(x)$ from K^-p data.
- $2H_2(x)$ from $\bar{\nu}p$ data agrees with $H_1(x)$, giving support to the above approximation.
- $H_3(x)$ from νp data is much smaller than $H_1(x)$. It is compatible with zero for the K^-p data (not shown).

Of particular interest in connection with the influence of the valence spectators are various types of quantum number correlations between the two different fragmentation regions and within one fragmentation region itself. Long range correlation of pions, each coming from a different one of the two incident protons, has been measured[22] in the form of the two pion correlation function $R(x_1,x_2) = \sigma N(\pi_1\pi_2)/N(\pi_1).N(\pi_2)$ for $pp \to \pi\pi X$ at $\sqrt{s} = 62.3$ GeV ($0.2<x_1,x_2<0.95$, $0.2<p_{t_1}, p_{t_2}<1.2$ GeV/c). Over most of the x range, the $\pi^+\pi^+$, $\pi^+\pi^-$ and $\pi^-\pi^-$ data are essentially uncorrelated ($R\simeq1$), in agreement with factorization of the two fragmentation processes, as is expected for gluon exchange.

For comparison to single particle production in the proton fragmentation region, the ratio R of π^+ to π^- production can be studied in association with various triggers. With a π^+ trigger, the spectator system ($u_v d_v d_s$) should produce equal amounts of π^+'s and π^-'s at fixed $\tilde{x}_\pi = x_\pi/(1-x_{tr})$. This is confirmed by the data[23] in fig.6: Whereas the untriggered π^+/π^- ratio rises with increasing x, the ratio for a π^+ trigger is compatible with unity for $x \gtrsim 0.4$. In comparing this associated ratio to the π^+/π^- ratio measured in charged current $\bar{\nu}p$ collisions where the spectator system is the same, the agreement is indeed striking.

For a π^- trigger, the spectator system is ($u_v u_v u_s$) and a strong increase of the ratio R is expected with increasing x. Also this is indeed observed in fig.6.

We conclude that proton fragmentation is well behaved and understood, so that one can go further and apply the same ideas to extract new information from meson fragmentation.

II.2 Meson Fragmentation

The 70 GeV/c K^-p data were used to extract $D_u^{\pi^+}$ and $D_u^{\pi^-}$ from the π^+, π^- and π^o distribution in the K^- fragmentation region[20] (see fig.7). The contamination from charged kaons has been estimated from K^n production and has been removed. The study of π^- production is restricted to the region $x \lesssim 0.7$ to avoid contamination from leading K^-. The authors claim rather good agreement with the $\nu(\bar{\nu})p$ data with W>4 GeV and with the Field and Feynman $D_u^{\pi^\pm}$ functions[15]. This is certainly true for the comparison of $D_u^{h^-}$. Note that the difference between νp and hp data for $D_u^{h^-}$ is smaller than between (the isospin symmetric) $D_u^{h^-}$ and $D_{\bar{d}}^{h^+}$ from $\nu(\bar{\nu})p$ data. $D_u^{\pi^+}$ seems consistently steeper for hp collisions, but one has to take into account that

- in the $\nu(\bar{\nu})p$ data it is only at high values of z (where the contribution of the sea is negligible) that the functions D^h represent the fragmentation of a pure u(d) quark (in addition they represent production of hadrons $h^\pm$ rather than just $\pi^\pm$);
- it is not clear that diffraction dissociation (Q, L ..) has been sufficiently removed. There may be a contribution $K^- \to \pi^-$ ...below x=0.7.

With these limitations in mind, one can conclude that one can extract the single quark fragmentation function to a very good approximation from hadronic collisions.

Alternatively, the recombination picture[10,11] can be used to determine[24] the valence quark distribution in mesons, for which there is no direct information from deep inelastic lepton interactions. The results can be given in terms of the power n of the (1-x) distribution of the valence quarks. For a pion it follows from charge conjugation and isospin invariance that the quark distribution function is the same for both valence quarks. For a kaon the situation is expected to be non-symmetric. A value of n=1.0±0.1 has been obtained for the pion structure function. The power n is indeed larger than unity for the non-strange valence quark in the kaon while it is smaller than unity for the strange valence quark. These results are compatible with those extracted via the Drell-Yan model from μ-pair production[25]. One can conclude that meson valence quarks are harder than those in the nucleon and that strange valence quarks are harder than non-strange ones.

II.3 Meson Resonances

Of particular interest in connection with partons is inclusive production of resonances. One can assume that resonances are more abundantly and more directly produced than pions and kaons, represent a larger variety of quantum numbers and allow for conclusions about their production from their decay density matrix.

In the quark picture the ϕ is of central interest because of its hidden strangeness quantum numbers. In particular, it has a valence quark in common with an incoming kaon, but not with an incoming pion, proton or antiproton. The x-distribution is therefore flatter for kaon induced production than in the other cases[26].

Furthermore, $K^-p \rightarrow \bar{K}^{*0}_-$, $K^+p \rightarrow K^{*0}_+$ and $Kp \rightarrow \phi$ all have the same x dependence[27] and are definitely more forward peaked than $Kp \rightarrow \rho^0$. This is a direct consequence of the fact that the strange quark in the incident kaon is harder than the nonstrange quark. The ratio of ϕ and ρ^0 is plotted in fig.8a for K^-p at 32 GeV/c[26b] and compares well to the ratio of s and $\bar{u}$ distribution functions.

Fig.8b gives the forward ρ^0 distribution from $\pi^\pm p$ collisions at 147 GeV/c[28]. The curves shown correspond to a power law fit[29] (DCR), a recombination fit (QRM) and fragmentation predictions (QFM) with Field and Feynman[15] (dashed) and Lund[19] (dot-dashed) parametrizations of the fragmentation functions. The Lund prediction works very well, so do DCR and QRM. In the latter two cases, the distribution function comes out consistently slightly flatter than for pions. This observation does not change after exclusion of diffractive events and should be checked with good statistics.

Fig.9 shows the results for the density matrix for $K^+p \rightarrow K^{*+}X$ at 32 and 70 GeV/c[30] as a function of t and M^2/s. Distributions like these should be a challenge to the quark pictures.

II.4 Hyperon Polarization

Non-zero Λ polarization is known since 1976 from pBe collisions at 400 GeV/c[31a] and has been observed in π^-p collisions at NAL[31b] and pp collisions at ISR[31c]. This observation cannot be explained from the Regge model since at these energies RPR terms dominate and these terms do not give rise to polarization. Non-zero polarization has also been observed in ep scattering[32]. In fig.10a the pp and ep points show an increasing polarization for $p_t>0$. Furthermore, from scattering off deuterium and other nuclei, no difference is found in polarization between proton and neutron targets[33].

The best recent data come from the Michigan-Minnesota-Rutgers-Wisconsin Collaboration[34] (see fig.10b,c). One can conclude that:

- Λ^0's produced in hh, hA and ep scattering are polarized transverse to the production plane, along the $(\vec{p}_\Lambda \times \vec{p}_p)$ axis).

- This polarization is probably independent of the beam energy, the projectile type and largely also of the x value of the Λ^0.
- The polarization increases linearly with the transverse momentum of the Λ^0.
- $\bar{\Lambda}$ and protons are not polarized.
- Ξ^0, Ξ^- have the same polarization as the Λ^0.
- Σ^+ has the same polarization as Λ^0 in magnitude but with opposite sign.

A semi-classical model for basically soft Λ^0-production able to explain the observed polarization effect is suggested in the quark fragmentation picture[35]. In this picture, a diquark continues forward as a unit after the collision and a string-shaped colour dipole field is stretched between the diquark and the central collision region. This field can break up by the production of quark-antiquark pairs (as in e^+e^- hadron production). A Λ^0-particle can be formed if an $s\bar{s}$-pair is produced in the field of a (ud)-diquark (of isospin and spin I=S=0), so that the spin of the Λ^0 is determined by the spin of the s-quark.

The transverse momentum p_t of the Λ^0 with respect to the beam direction is made up of two contributions, the transverse momentum $\vec{q}_t$ of the diquark (the direction of the field string) and the (locally conserved) transverse momentum $\vec{k}_t$ of the s quark with respect to the string direction. A pair of massless quark-antiquarks can be produced point-like, but massive quarks have to be produced at a certain distance from each other. Therefore, the pair will obtain an orbital angular momentum perpendicular to the string; this is assumed to be compensated by the spin of the $s\bar{s}$-pair. In a Λ sample of definite p_t, we obtain an enhanced number of events where $\vec{k}_t$ and $\vec{p}_t$ point in the same direction. So the observed effect is explained by a sort of trigger bias. The curves in fig.10a show the model prediction and its upper and lower limits (without inclusion of the effect of Λ production via Σ^0 and Σ^*).

A somewhat similar picture has recently been developed[36] in the framework of the recombination model. Here, the polarization arises via Thomas precession of the quarks' spin in the recombination process. The description accounts for all presently known qualitative features of the baryon and antibaryon polarization as stated above. Also this picture can be extended to e^+e^- annihilation and deep inelastic scattering. Of special interest in this context is further the prediction for polarization of baryons (and vector mesons) in e^+e^- annihilation by Bartl et al.[37]

We conclude that hyperon polarization which cannot be explained by the triple Regge model, may find an explanation from the quark composition of incident and produced particles.

III. CONCLUSION AND OUTLOOK

With the help of quark statistics one can get to a consistent understanding of various particle yields. This first basic observation is taken as a hint that partons may play a role also in soft hadronic reactions.

The similarity of pion production in the nucleon fragmentation region to the valence quark distribution in the nucleon as measured from deep inelastic collisions suggests that valence quarks are governing pion production in proton fragmentation. This observation has led to a recombination and valon picture.

Particle production in soft hadronic collisions shows features very similar to those in e^+e^- and lepton-hadron collisions. This third observation has led to the quark fragmentation picture.

Particle production and correlation in proton fragmentation is well understood in terms of these two pictures. Extracted di-quark fragmentation functions are identical to those from deep inelastic neutrino scattering.

Application of the two pictures to meson fragmentation allows to extract meson structure functions similar to those obtained from μ-pair production on one hand, and quark fragmentation functions similar to those obtained from deep inelastic neutrino scattering on the other.

Differential distribution for resonances start to become available at high energies. They allow to check the results on more directly produced particles, to compare a larger variety of quantum numbers and to challenge models on their decay density matrix.

Hyperon polarization at high energies, not understood from triple Regge exchanges, seems to be explained from both the recombination and fragmentation pictures of hadron production.

We conclude that a new field has evolved in the last 3 years and that partons do play a role in soft hadronic reactions. Work to be done on the theoretical side is on a solid foundation of the two pictures as well as on an explanation of the apparent complementarity of the two views. On the experimental side, high statistics is needed on hydrogen and on higher nuclei at $p_{lab} > 200$ GeV/c in combination with good momentum resolution and particle identification. This will allow to study flavor correlations and resonance production more conclusively than was possible until now and, in particular, to isolate the influence of longitudinal phase space in quark fragmentation.

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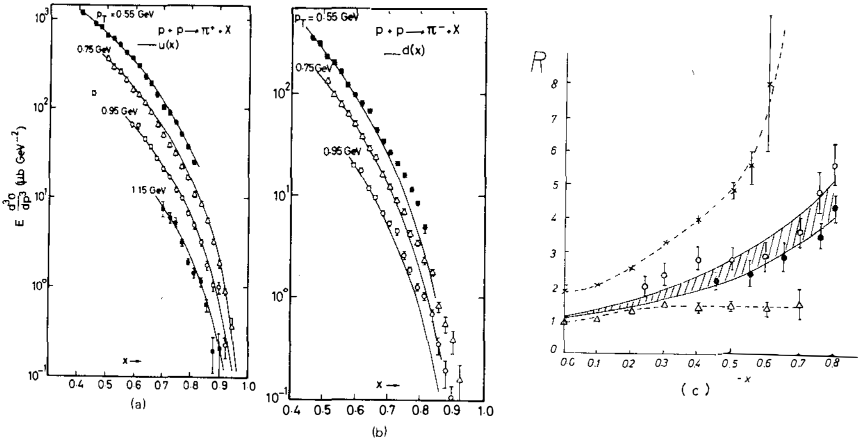


Fig. 1 (a)-(b) Comparison of the invariant π^+ and π^- cross section from pp collisions at $\sqrt{s}$=45 GeV to the u and d quark distribution functions u(x) and d(x), respectively[7],
(c) π^+/π^- ratio[8] in the proton fragmentation region of 16 GeV/c π^+p collisions (crosses) 16 GeV/c π^-p collisions (triangles) and pp collisions (shaded area and circles).

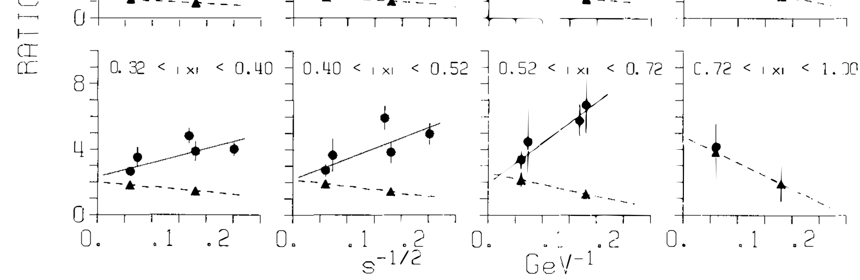


Fig. 2 The π^+/π^- ratio in the proton fragmentation region for $\pi^\pm$p collisions as a function of $s^{-\frac{1}{2}}$, for different x-intervals, as indicated[9].

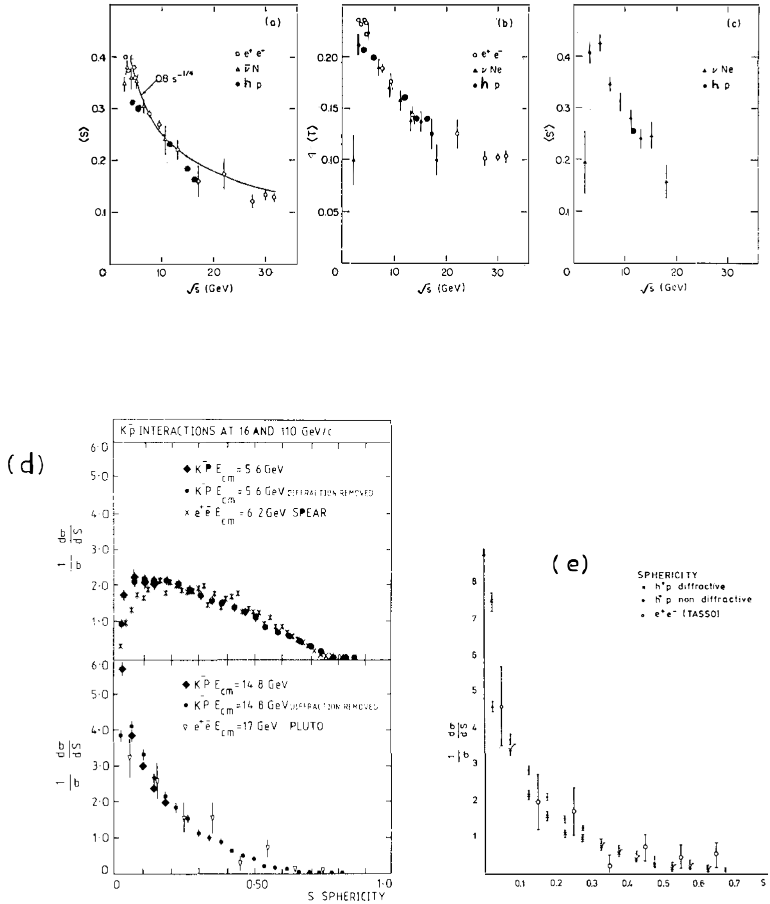


Fig. 3 (a)-(c) Average sphericity, thrust and spherocity as a function of cms energy for e^+e^-, neutrino and hadron-hadron interactions,
(d) sphericity distribution for K^-p at 16 and 110 GeV/c compared to e^+e^- at corresponding energies[13a),]
(e) same for h^+p at 147 GeV/c[13b)].

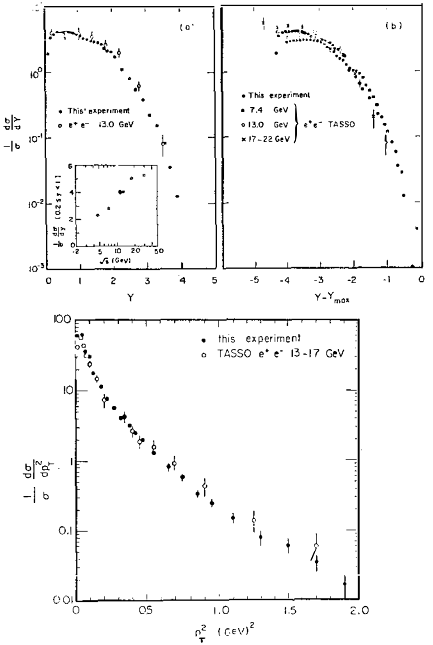


Fig. 4 Rapidity and p_t^2 distributions for 70 GeV/c K^+p collisions, evaluated relative to the thrust axis, compared to e^+e^- collisions at similar and different energies[13c].

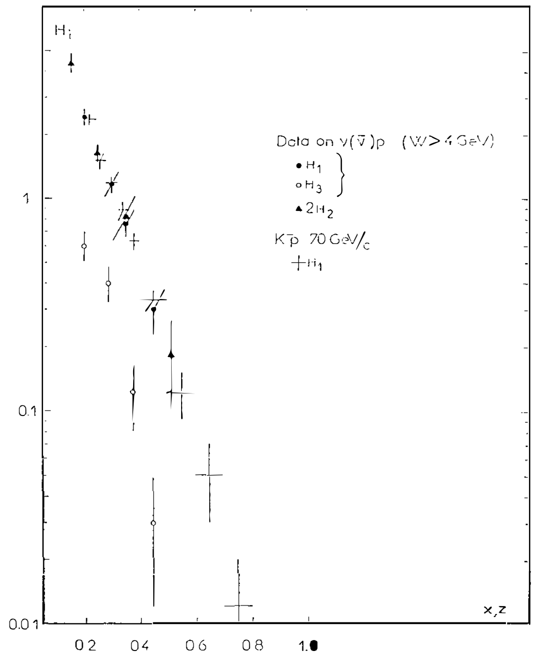


Fig. 5 Diquark fragmentation function $H_1(x)=D^{\pi^+}_{uu}(x)$ obtained in K^-p collisions at 70 GeV/c[20]. Data on $H_1(x)$, $H_2(x)=D^{\pi^+}_{ud}(x)$, $H_3(x)=D^{h^-}_{uu}(x)$ from $\nu(\bar{\nu})p$ experiments are also reported.

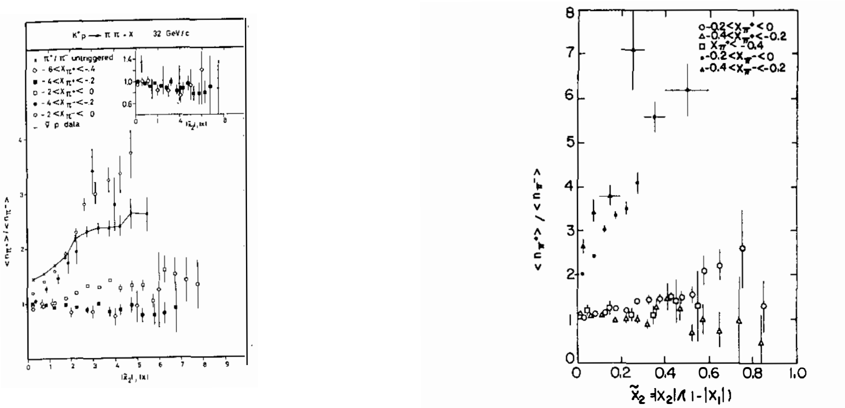


Fig. 6 The π^+/π^- ratio as a function of $\tilde{x}_2$ in the proton fragmentation region of 32 and 70 GeV/c K^+p collisions, associated with a π^- or π^+ trigger, for several trigger momentum intervals[23a,b].

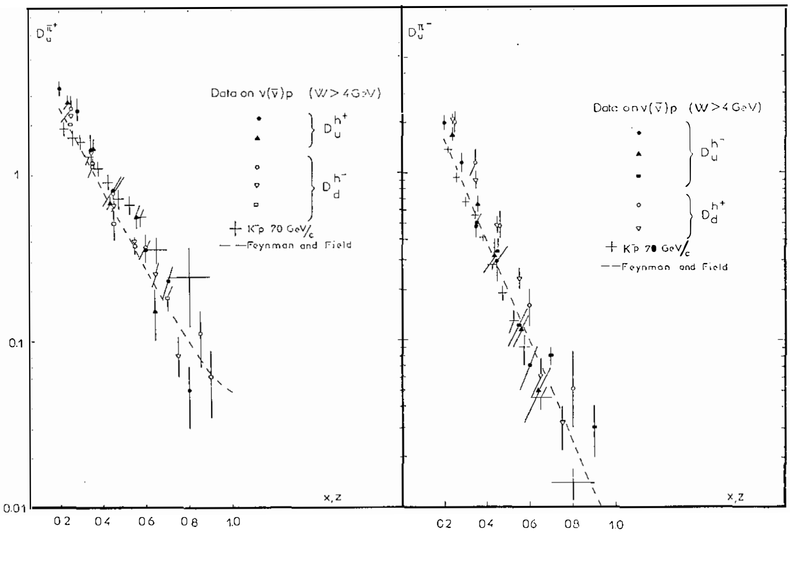
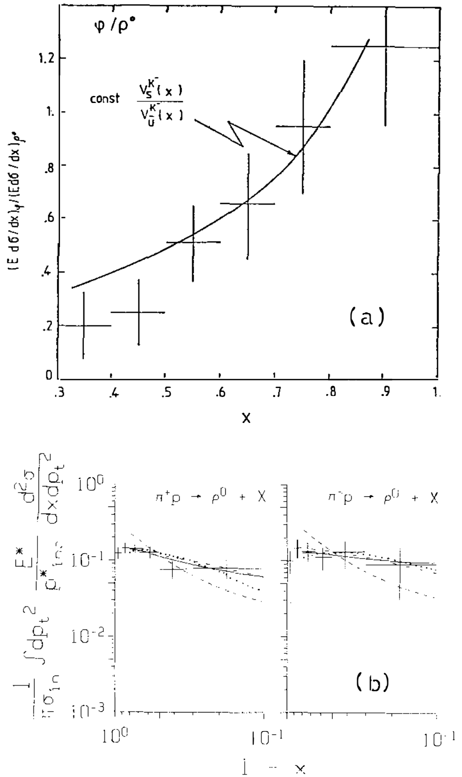


Fig. 7 Quark fragmentation functions $D_u^{\pi^+}(x)$ and $D_u^{\pi^-}(x)$ obtained from K^-p collisions at 70 GeV/c[20]. Data on $D_u^{h\pm}$ and $D_d^{h\mp}$ from $\nu(\bar{\nu})p$ experiments are also reported.



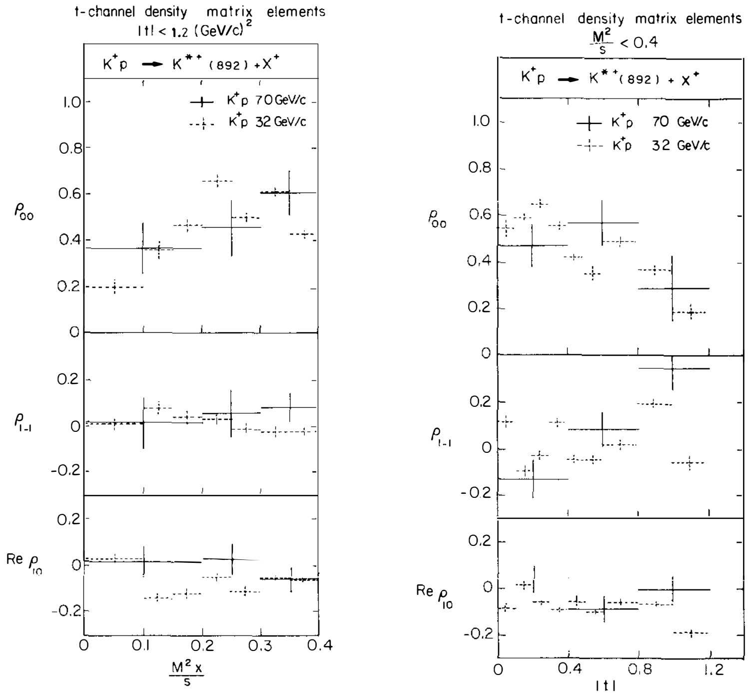


Fig. 9 Density matrix elements in the t-channel for K^{*+} production from K^+p collisions at 32 and 70 GeV/c, as functions of M^2/s and t.[30c)]

Fig.8a) The ϕ/ρ^0 ratio as a function of x for K^-p collisions at 32 GeV/c, compared to ratio of the strange to non-strange valence distribution functions,[26b)]
b) the (1-x) dependence of ρ^0 production in the pion fragmentation region of $\pi^\pm p$ collisions at 147 GeV/c[28)]. The curves are explained in the text.

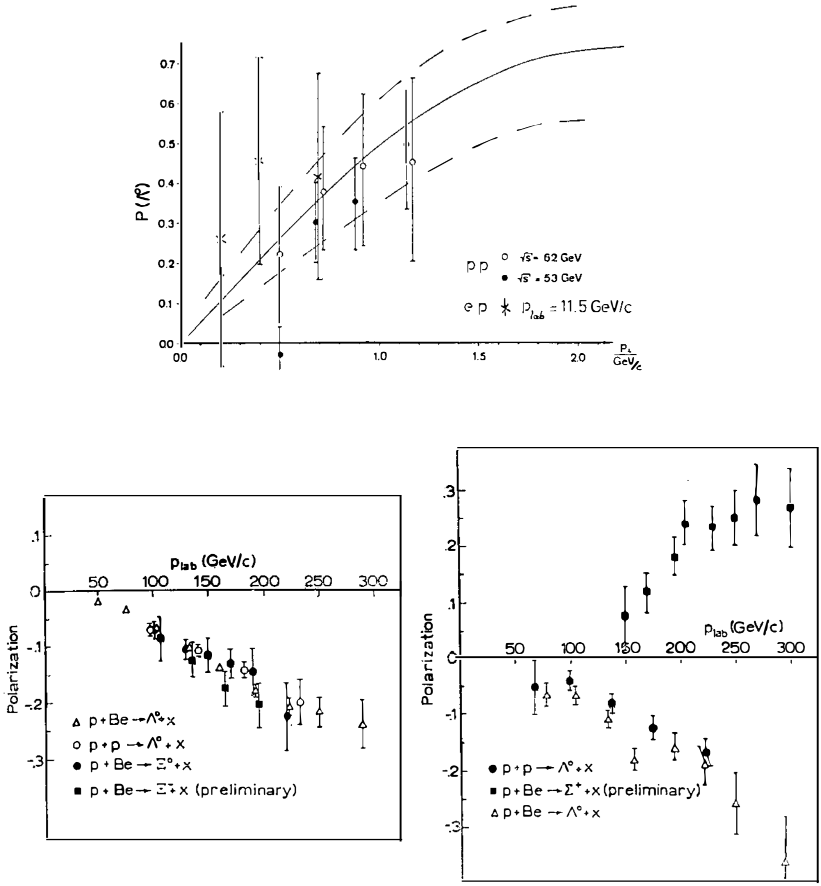


Fig. 10 (a) Λ polarization as a function of p_t for pp collisions at $\sqrt{s}$=53 and 62 GeV[31c] and ep collisions at p_{lab} = 11.5 GeV[32]. The lines are the expectation and its limits from the fragmentation model [35].
(b) Hyperon polarization for pp and pBe collisions at 400 GeV/c, as a function of the hyperon lab momentum[34].