HADRONIZATION MECHANISMS AND SPIN EFFECTS IN HIGH ENERGY FRAGMENTATION PROCESSES

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Spin effects in high energy fragmentation processes can provide us with important information on hadronization mechanisms and spin structure of hadrons. It can in particular give new tests to the hadronization models. In this talk, we make a brief introduction to the different topics studied in this connection and a short summary of the available data. After that, we present a short summary of the main theoretical results we obtained in studying these different topics. The talk was mainly based on the publications [4-8] which have been finished in collaboration with C.Boros, Liu Chun-xiu and Xu Qing-hua.

1 Introduction

Spin effect is a powerful tool to study the properties of the hadronic interactions and hadron structures. Since the deep understanding of different aspects in spin physics of strong interaction almost always involves hadron production, spin effects in high energy fragmentation processes have attracted much attention recently, both experimentally and theoretically (see e.g. [1-13] and the references given there). There are two main aspects in this connection, i.e., the dependence of the polarization and the momentum distribution of the produced hadron on the spin of the fragmenting quark. The former is usually referred as the spin transfer in the fragmentation process. For the latter, if the fragmenting quark is transversely polarized, we study the azimuthal angle dependence of the produced hadrons, and if the fragmenting quark is longitudinally polarized, we study a quantity which is called “jet handedness”. I will concentrate on the first two problems in my talk.

The motivations for these studies are clear: They are important to understand the puzzling spin effects observed in high energy hadron-hadron collisions; they provide new tests to hadronization models and also a promising tool to detect the polarization of the quark before fragmentation.

2 Spin transfer in high energy fragmentation processes

Spin transfer in high energy fragmentation process is defined as the probability for the polarization of the fragmenting quark to be transferred to the produced hadron. Here, we consider \( q_0 \rightarrow h(q_0...) + X \). We suppose that the \( q_0 \) was
polarized before the fragmentation, and ask the following questions: (1) Will the \( q_0 \) keep its polarization? (2) How is the relation between the polarization of \( q_0 \) and that of the produced \( h \) which contains the \( q_0 \)? Clearly, the answers to these questions depend on the hadronization mechanism and on the spin structure of hadrons. The study can provide useful information for both aspects. In particular, there exist now two distinctively different pictures for the spin contents of the baryons: the static quark model using the SU(6) symmetric wave function [referred as the SU(6) picture], and the picture drawn from the data for polarized deeply inelastic lepton-nucleon scattering (DIS) and SU(3) flavor symmetry in hyperon decay [referred as the DIS picture]. It is natural to ask which picture is suitable to describe the question (2) mentioned above. Obviously, the answers to these questions are also essential in the description of the puzzling hyperon transverse polarization observed already in the 1970s in unpolarized hadron-hadron reactions.

2.1 Hyperon polarization in high energy reactions as a tool to study the spin transfer in fragmentation processes

It has been pointed out that measurements of the longitudinal \( \Lambda \) polarization in \( e^+e^- \) annihilations at the \( Z^0 \) pole provide a very special check to the validity of the SU(6) picture in connecting the spin of the constituent to the polarization of the hadron produced in the fragmentation processes. This is because the \( \Lambda \) polarization in this reaction obtained from the SU(6) picture should be the maximum among different models. Data are now available from both ALEPH and OPAL Collaborations. The results show that the SU(6) picture seems to agree better with the data compared with the DIS picture. (See Fig.1). This is rather surprising: the energy at LEP is very high hence the initial quarks and anti-quarks produced at the \( e^+e^- \) annihilation vertices are certainly current quarks and current anti-quarks. They cannot be the constituent quarks used in describing the static properties of hadrons using SU(6) symmetric wave functions. It is thus interesting and instructive to have further checks by making complementary measurements.

We note that, to study the spin transfer in fragmentation, we need to know the polarization of the \( q_0 \) before fragmentation and to measure the polarization of the produced \( h \). Hence, hyperon productions in lepton-induced reactions are ideal to study this problem. Here, the polarization of quark can easily be calculated using the standard model for electroweak interaction and the hyperon polarization can easily be determined by measuring the angular distribution of its decay products. We have thus made a systematic study of hyperon polarizations in different lepton-induced reactions. The obtained
results can be used as further checks of the different pictures. Now we give a brief summary of the calculation method and the obtained results.

We consider $q_0^f \to H_i + X$ and divide the produced $H_i$'s into the following groups: (a) directly produced and contain the $q_0^b$'s; (b) decay products of heavier hyperons which were polarized before their decays; (c) directly produced but do not contain the $q_0^b$; (d) decay products of heavier hyperons which were unpolarized before their decays. Obviously, hyperons from (a) and (b) can be polarized while those from (c) and (d) are not. We obtain,

$$P_{H_i} = \frac{\sum_f t_{H_i,f}^F P_f \langle n_{H_i,f}^a \rangle + \sum_j t_{H_i,H_j}^D P_{H_j} \langle n_{H_i,H_j}^b \rangle}{\langle n_{H_i}^a \rangle + \langle n_{H_i}^b \rangle + \langle n_{H_i}^c \rangle + \langle n_{H_i}^d \rangle}.$$ (1)

Here $P_f$ is the polarization of $q_0^f$ which is determined by the electroweak vertex; $\langle n_{H_i,f}^a \rangle$ is the average number of $H_i$'s which are directly produced and contain $q_0^b$ of flavor $f$, and $\langle n_{H_i,H_j}^b \rangle$ is that from the decay of $H_j$'s which were polarized; $P_{H_j}$ is the polarization of $H_j$; $\langle n_{H_i}^a \rangle$, $\langle n_{H_i}^b \rangle$, $\langle n_{H_i}^c \rangle$ and $\langle n_{H_i}^d \rangle$ are average numbers of $H_i$'s in group (a), (b), (c) and (d) respectively; $t_{H_i,f}^F$ is the probability for the polarization of $q_0^f$ to be transferred to $H_i$ in group (a) and is called the polarization transfer factor, where the superscript $F$ stands for fragmentation; $t_{H_i,H_j}^D$ is the probability for the polarization of $H_j$ to be transferred to $H_i$ in the decay process $H_j \to H_i + X$ and is called decay polarization transfer factor, where the superscript $D$ stands for decay. $t_{H_i,f}^F$ is equal to the fraction of spin carried by the $f$-flavor-quark divided by the average number of quark of flavor $f$ in $H_i$. This fractional contribution is different in the SU(6) or the DIS picture, and can be found in e.g. [4] or [5]. $t_{H_i,H_j}^D$ is determined by the decay process and is independent of the process in which $H_j$ is produced. For octet hyperon decays, they are extracted from
the materials in Review of Particle Properties, but for decuplet hyperons, we have to use an estimation based on the static quark model.

The average numbers of the hyperons of different origins mentioned above are determined by the hadronization mechanisms and should be independent of the polarization of the initial quarks. Hence, we can calculate them using a hadronization model which give a good description of the unpolarized data. We used Lund model implemented by JETSET or LEPTO in our calculations.

We applied the method to $e^+e^- \rightarrow H_i X$, $\mu^-p \rightarrow \mu^- H_i X$ and $\nu_\mu p \rightarrow \mu^- H_i X$ at high energies and calculated the polarization of different octet hyperons in these reactions. We now summarize the main results as follows.

For $e^+e^- \rightarrow H_i X$, we made the calculations at LEP I and LEP II energies. The results show that, all the octet hyperons should be significantly polarized and the polarizations are different in the SU(6) or the DIS picture. Measuring them can give further test to the pictures. We also tried to make flavor separation. We found that it is impossible to separate only contribution from $u$ or $d$ to $\Lambda$. But we can enhance the contribution from $s$ fragmentation by giving some criteria to the selected events. For details, see [5].

In deeply inelastic lepton-nucleon scatterings, at sufficiently high $Q^2$ and hadronic energy $W$, hadrons in the current fragmentation region can be considered as the pure results of the fragmentation of the struck quarks. There are two advantages to study hyperon polarization in $\mu^-p \rightarrow \mu^- H_i X$: Here, flavor separation can be achieved by selecting events in certain kinematic regions; and we can study the spin transfer both in longitudinally and in transversely polarized cases. We made the calculations for different combinations of beam and target polarizations. The results show the following characteristics: (A), hyperons are polarized quite significantly if the beam is polarized but $\Lambda$ polarization is quite small in the case of unpolarized beam and polarized target. (B), there is significant contribution from heavier hyperon decay to $\Lambda$, it is even higher than the directly produced in most kinematic regions. (C), for $\Sigma^+$, the decay contribution is very small and the polarization is higher than that for $\Lambda$ and the differences from the different pictures are also larger. (D), the transverse polarization of the outgoing struck quark is achieved only in the case of using transversely polarized target. But the obtained $\Lambda$ transverse polarization is very small and the decay influence is large. In contrast, the $\Sigma^+$ polarization is larger and there is almost no decay contribution.

We made similar calculations for $\nu_\mu p \rightarrow \mu^- H_i X$. We found that there is a complete flavor separation for $\Sigma^+$ production. It comes almost completely from $u$ quark fragmentation. This leads to a quite high $\Sigma^+$ polarization. (See Fig.2, where the solid and dashed lines are the results obtained using the SU(6) and the DIS pictures). However, for $\Lambda$ production, contribution from
charmed baryon decay is very significant. It can completely destroy even the qualitative feature of the \( \Lambda \) polarization. We thus reached the conclusion that, in deeply inelastic lepton-nucleon scattering, \( \Sigma^+ \) production is much more suitable to study the spin transfer in fragmentation processes.

Last but not least, we note that the method can also be applied to hyperon polarization in high \( p_\perp \) jets in polarized pp collisions such as those at RHIC. They can also be used to study the spin transfer in fragmentation processes. Such calculations have also been done and the results can be found in [7].

2.2 Spin alignment of vector mesons in high energy reactions

Another aspect which is related to the problem of spin transfer in fragmentation is the spin alignment of vector meson in high energy reactions. It is clear that the polarization of the fragmenting quark can also be transferred to the vector meson \( V \). This effect can be studied by measuring \( \rho_{00}^V \), the 00 component of the helicity density matrix of \( V \) which is just the probability for \( V \) to be in the helicity zero state. Data are available for \( e^+e^- \) annihilation at the \( Z^0 \)-pole at LEP. It shows that \( \rho_{00}^V \) is much larger than \( 1/3 \), the result expected in the unpolarized case, for vector mesons with high momentum fraction.

After the calculations, we found out that these data imply a significant polarization of the anti-quark that is created in the fragmentation and combines with the polarized \( q_0^f \) to form the vector meson. The polarization has a simple relation to that of \( q_0^f \). It can be given by \( P(\bar{q}) = -\alpha P(q_0^f) \), where \( \alpha \approx 0.5 \) is a positive constant. Using this we get a good fit to the available data. (See Fig.3). It should be interesting to see whether this relation is also true in other processes where polarized \( q_0^f \) is produced. We thus apply it to other reactions and made predictions for the spin alignments of vector mesons in these processes. They can be checked by future experiments.

3 Azimuthal asymmetry in the fragmentation of a transversely polarized quark

In the fragmentation of a transversely polarized quark, the products can have an azimuthal asymmetry. HERMES has published the first measurement in this connection. Their results show that such an effect indeed exists at the HERMES energies. What we would like to point out here is the following: The existence of such an azimuthal asymmetry in fragmentation is a direct consequence of Lund string fragmentation model due to conservation of energy-momentum and angular momentum. The picture was first used to polarization effects in by Andersson, Gustafson and Ingelman in 1979 to
explain the unexpected Λ polarization in unpolarized pp collisions. By applying it to the fragmentation of a transversely polarized quark, we obtain a significant azimuthal asymmetry. We are now working on the numerical calculations along this line in collaboration with the Lund group. Predictions for semi-inclusive deeply inelastic lepton-nucleon scattering and hadrons in high $p_{\perp}$ jets in transversely polarized pp collisions will be available soon.

Fig.3: Spin alignment of $K^{*0}$ in $e^+e^- \rightarrow K^{*0}X$ at $Z^0$-pole. The data are taken from [2].

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