HYPERON POLARIZATION IN INCLUSIVE AND EXCLUSIVE PROCESSES

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Abstract

Hyperon polarization in inclusive and exclusive processes is explained by multiple scattering of the strange quark. Energy, Feynmann x and transverse momentum dependence is discussed, relations between polarizations of different hyperons in various processes ~~is~~ are given. The charmed and bottom baryons are predicted to be analogically polarized.

I would like to report in the idea which explains qualitatively why the hyperons are polarized when produced in high energy processes at non zero transverse momentum. The subject causes some excitement since the measurements [1] of the Λ polarization which is essentially independent of energy and decreases from zero with increasing transverse momentum (Fig. 1). Similarly behaves the polarization of Ξ, the Σ gets polarized in the opposite direction. The axis with respect to which the polarization is measured points in the direction perpendicular to the scattering plane and is defined by

$$\hat{\nu} = \frac{\vec{p}_P \times \vec{p}_H}{|\vec{p}_P \times \vec{p}_H|}$$

where $\vec{p}_P$ and $\vec{p}_H$ are the c.m. momenta of the incoming proton and the hyperon, respectively. Similar measurements showed no sign of polarization for the protons and $\bar{\Lambda}$. To summarize the experimental facts one can say that there exists quite a complete set of information. At the same time we have no convincing explanation of this phenomenon. The data were a surprise - many people did not expect important spin effects at high energies, the more at higher transverse momentum where a real, hard amplitude dominates.

Let me start to present the model with the Λ polarization. Here the situation is the clearest. The Λ wave function consists of ud diquark in spin zero state so the spin projection of the Λ is entirely given by that of the s-quark and consequently their polarizations are equal: $\mathcal{P}(\Lambda) = \mathcal{P}(s)$.

Looking into the proton hemisphere one already has an $ud|_{s=0}$ diquark originating from the proton. The source of the s-quarks which are needed to recombine into the Λ are twofold: they either come from the proton sea or are produced in the interaction region by gluons in the subprocess $g \rightarrow s\bar{s}$. In both cases its energy in the c.m. system is low. The Λ energy is essentially given by that of the ud-diquark.

Looking for the Λ's with a given transverse momentum $p_\perp$ one automatically chooses states in which the s-quark has considerable transverse momentum $k_\perp$ pointing in most cases in the direction of $p_\perp$. Our main assumption is that the s-quark gets its required $k_\perp$ by multiple scattering off quarks and gluons. Many diagrams contribute to this process and there is no clear suming technique due to rather low momentum transfers. We approximate the procedure by assuming the scattering off external gluonic field

$$\phi^a(\vec{q}) = \frac{4\pi g I^a}{\vec{q}^{\,2}} ,$$

g is the quark-gluon coupling constant, $\vec{q}$ - the momentum transfer and I^a, a = 1,...,8 is the vector representing the external field. Polarization appears already in the second order of perturbation theory and reads then [2]

$$\mathcal{P} = \frac{C g^2 m |\vec{k}|}{2\pi E^2} \frac{\sin^3\theta/2 \, \ln \sin\theta/2}{\left(1 - \frac{k^2}{E^2}\sin^2\theta/2\right)\cos\theta/2} \cdot \hat{y} \qquad (1)$$

where m, k, E and θ are the mass, momentum, energy and scattering angle of the quark. The unit vector $\hat{\nu} = \frac{\vec{k}_i \times \vec{k}_f}{\sin\theta}$ points in the direction perpendicular to the scattering plane. The colour factor $C = \frac{1}{2}(d^{abc}I^aI^bI^c)/(I^a)^2$. For positive C the expression multiplying $\hat{\nu}$ is negative, thus the polarization is opposite to $\hat{\nu}$ (Fig. 2). Another way of calculating $\mathcal{P}(q)$ is to solve the Dirac equation in external field. The exact answer [3] looks then qualitatively the same as in Fig. 2. Many required features follow immediately. Increasing $k_\perp$ means increasing θ between $0°$ and $90°$ – one sees that the polarization increases then in magnitude with $p_\perp$. The polarization increases with the quark mass. We thus expect stronger polarization of baryons containing charmed and bottom quarks (e.g. Λ_c) if the c- or b-quark sea is not much different from the s-quark sea. This is also the reason why we do not expect the protons to be polarized.

Because x_Λ comes predominately from the x_{ud} there is no strong x_Λ dependence of polarization. This statement concerns however directly produced Λ's, the total sample which contains Λ's being resonance decay products may show some increase of $\mathcal{P}(\Lambda)$ with x_Λ.

Once the mechanism of the quark polarization is fixed many relations among polarizations of different hyperons are given by their spin-flavour wave functions. So one expects e.g. $\mathcal{P}(\Xi) = -1/3\,\mathcal{P}(\Lambda)$ a relation which holds experimentally [4] but without the factor 1/3. This can again be attributed to the resonance decays which predominately "polute" the Λ sample.

It is crucial that the s-quark is relatively slow, otherwise the polarization would be negligible. This is the reason why $\bar{\Lambda}$ is not polarized in proton induced reactions, for its finite $x_{\bar{\Lambda}}$ one needs finite x_s. It can be however polarized in the π induced reactions in the π hemisphere.

Our idea can be easily implemented in exclusive processes. Strong Λ and Σ polarizations analogical to these in inclusive production was observed in $pp \to \Lambda\bar{\Lambda}$ and $pp \to \Sigma\bar{\Sigma}$ [5]. An interesting effect appears when comparing two processes

$$K^- p \to K\bar{K}\Lambda + \text{pions} \qquad (2a)$$

$$K^- p \to \Lambda + \text{pions} \qquad (2b)$$

In both cases one looks at the Λ polarization in the proton hemisphere. In the first process the kaon scatters predominately by a small angle so the Λ gets the s-quark in the usual way from the proton - one expects thus no difference as comparing to inclusive production. In the second case however the s-quark turns by a large angle to form the Λ in the proton hemisphere ($p_\perp = 0$ corresponds to the scattering by 180^o). Increasing $p_\perp$ means again an increase in $\mathcal{P}(\Lambda)$, but the question is with respect to which axis. Looking at $\hat{\nu} \sim \vec{k}_i \times \vec{k}_f$ one sees that it changes sign when going from the process (2a) to (2b) because k_i changes its direction. Consequently one expects in both processes analogical behaviour of polarization but of opposite sign. This is in fact what is seen experimentally [6].

To summarize, we have shown how a single idea is able to account qualitatively for all known facts of hyperon polarization. It would be interesting to check the predictions which were made in this talk.

It is worth noting that this idea can be easily implemented in the known models of low and intermediate $p_\perp$. A quantitative description requires only the knowledge of the quark structure functions.

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Figure captions

Fig. 1. Polarization as a function of the transverse momentum $p_\perp$ (from Ref. [1]).

Fig. 2. Polarization of the quark in external gluonic field (arbitrary normalization).

Fig. 3. Λ polarization in the process $K^- p \to KK\Lambda$ + pions (cricles) and $K^- p \to \Lambda$ + pions (squares) at 4.2 GeV/c (from Ref. [6]).

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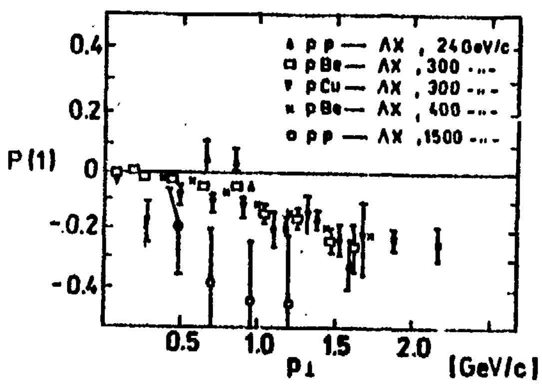

Fig.1

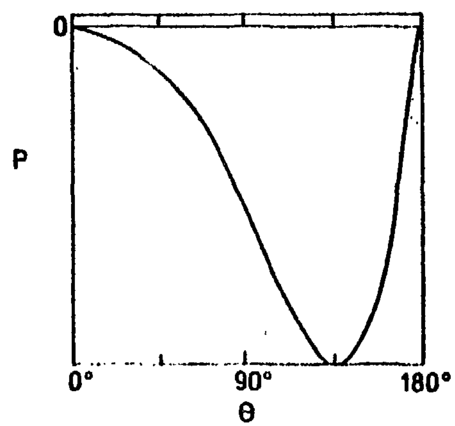

Fig.2

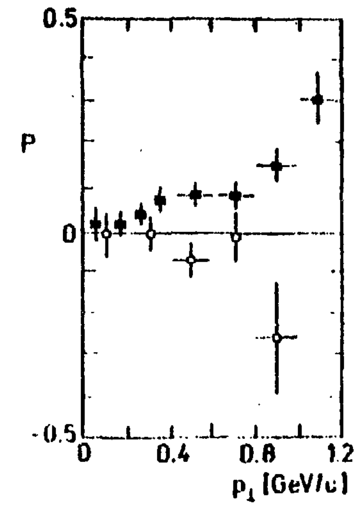

Fig.3