BROOKHAVEN NATIONAL LABORATORY

October, 1988

BNL-41988

**HYPERON POLARIZATION AND MULTIPLE QUARK
SCATTERING*****Jerzy SZWED**

BNL--41988

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Romuald WIT
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The quark scattering off external gluonic field, calculated to second order, and the quark recombination model are used to describe both the Λ inclusive production cross-section and the Λ polarization. The model gives good agreement with experimental data.

*Presented by J. Szwed at the International Symposium on High Energy Spin Physics, Minneapolis, Minn., September 1988.

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INTRODUCTION

Hyperon polarization has been one of the most discussed problems in spin physics in the last years. Since its surprising measurement¹ many attempts have been made to explain its strange behaviour. Its increase with the hyperon transverse momentum (see data in Fig. 1) contradicts the naive belief that the dominance of leading, hard scattering mechanism results in vanishing polarization. One lesson which follows from most of the proposed models²⁻⁵ is that the kinematical range of the hyperon polarization, as studied experimentally, is inbetween the soft and hard regions. This is probably the main reason for the lack of satisfactory, quantitative description of the effect — neither models of soft, multiparticle production, nor perturbative QCD can separately give the correct answer.

In this talk we study the quantitative consequences of the model proposed by one of us 7 years ago.⁴ The idea consists in the polarization of the massive strange quark in the course of multiple scattering off external gluonic field, which approximates the quark-quark and quark-gluon subprocesses. The model reproduced quantitatively all the features observed in proton and meson induced hyperon production. It was left however on the quark level. Here we present quantitative consequences of this polarization mechanism, “hadronized” with the use of the recombination model.⁶ In this way we take into account the intermediate character of the polarization effect: the second order perturbative QCD calculation is “married” with the soft, multiparticle production model.

MULTIPLE QUARK SCATTERING

Among many QCD subprocesses which contribute to high energy hadron- hadron collisions the scattering of massive quarks can lead to nonzero polarization. This interference effect appears already in the second order of perturbative calculus. In our approach we approximate the scattering off quarks and gluons by the scattering off external gluonic field, produced during the collision in the interaction region, of the form:

$$\Phi^a(\vec{q}) = \frac{4\pi g}{|\vec{q}|^2} I^a \quad a = 1, \dots, 8$$

with g - the quark-gluon coupling constant, $\vec{q}$ - the momentum transfer and I^a - an 8-component vector characterizing the external coloured field. In second order perturbation

calculus the polarization reads:

$$P_q = \frac{2C\alpha_s m_q |\vec{k}|}{E^2} \frac{\sin^3 \frac{\theta}{2} \log \sin \frac{\theta}{2}}{\left(1 - \frac{\vec{k}^2}{E^2} \sin^2 \frac{\theta}{2}\right) \cos \frac{\theta}{2}} \hat{\nu}$$

where

$$C = \frac{d_{abc} I^a I^b I^c}{I^a I^a}$$

m_q , $\vec{k}_{i/f}$, E and θ are the mass, initial/final momentum, energy and scattering angle of the quark. The unit vector

$$\hat{\nu} = \frac{\vec{k}_i \times \vec{k}_f}{|\vec{k}_i \times \vec{k}_f|}$$

points in the direction perpendicular to the scattering plane. The coupling constant $\alpha_s = g^2/4\pi$ is allowed to run for the transverse momentum greater than 1 GeV/c with $\Lambda_{QCD} = 200 \text{ MeV}$. Below this threshold it is kept constant.

The magnitude of the colour constant C which is given by the strength of the gluonic field can be compared to that of the scattering off another quark.⁷ In that case

$$C = \frac{1}{16} (d_{abc})^2 = \frac{5}{6}$$

One may expect that the effective external field which approximates in our approach the gluonic field of the interaction region is in general stronger than that following from quark-quark scattering.

There is no clear reason to break the calculation at second order. Instead of computing higher order diagrams the expression for P_q was compared numerically with the exact solution of the Dirac equation in external field.⁸ Both calculations give approximately the same result which encourages us to use the above expression for P_q in our polarization model.

The question of appropriate reference frame where the above approximation can be consistently formulated, was discussed in Ref. 9. Since the scattering off external field transfers only 3-momentum and not energy, one should apply the polarization formula in the frame in which the scattered quark fulfils this condition.

THE RECOMBINATION MODEL

The basic idea of the model follows from the similarity of the distribution of mesons produced in hadronic collisions and the distribution of quarks common to the incoming and

produced hadrons.¹⁰ The model states that the quarks of the projectile hadron just “fly through” without significant change of their momenta. Quantitatively this means that the cross-section for e.g. baryon inclusive production (in which we are interested in) reads^{6,11}

$$\frac{x d\sigma}{\sigma dx} = \gamma \int dx_1 dx_2 x_1 q(x_1) x_2 D(x_2) (1 - x_1 - x_2) R(x_1, x_2, x)$$

where $q(x_1)$ and $D(x_2)$ denote the quark and diquark distributions respectively, $(1 - x_1 - x_2)$ is the phase space factor and the recombination function takes the form

$$R(x_1, x_2, x) = \beta \frac{x_1 x_2}{x^2} \delta(x_1 + x_2 - x).$$

The constants β and γ are left free. There is no explicit transverse momentum dependence in the model and the above cross-section is usually compared with the experimental data integrated over transverse momentum.

The model is quite succesful in describing the inclusive meson production.¹² It has been also extended to the inclusive baryon production,¹¹ in particular the Λ production has been fitted in Ref. 13. In the following we are using the resulting¹³ fixed quark and diquark distributions to calculate the Λ polarization.

THE LAMBDA POLARIZATION

Having introduced two basic ingredients of our model — the multiple quark scattering and the recombination procedure, we are able to calculate the hyperon polarization. The only additional assumption follows from the lack of p_T dependence in the recombination model. We assume therefore the strange quark momentum to be parallel to the hyperon momentum.

In this talk we concentrate on the Λ hyperon which spin is given in the $SU(6)$ symmetric case by the strange quark spin. Having performed the integral over x_2 the Λ polarization dependence on Feynman x and transverse momentum p_T is given by

$$P_\Lambda(x, p_T) = \frac{\int dx_1 x_1 D(x_1) (x - x_1) q(x - x_1) P_q(x - x_1, x p_T)}{\int dx_1 x_1 D(x_1) (x - x_1) q(x - x_1)}$$

where $D(x_1)$ and $q(x - x_1)$ are now the $(ud)_{S=0}$ diquark and s-quark distributions respectively. The above formula is compared in Fig. 1. with the data on Λ production off beryllium target at 400 GeV/c.¹⁴ The solid line corresponds to the model as described in

the text with the coupling constant α_s running for $p_T \geq 1 \text{ GeV}/c$, the broken one — with α_s fixed. The agreement with the data is quite good.

To estimate the strength of the coloured field C we have to take into account the fact that the model should be used for the directly produced Λ hyperons which means that the data should be multiplied by a factor of 1.4.¹⁴ In this case $C = 1.9$ as compared to $5/6$ suggested by the gluon field resulting from a single quark. If however the scale of the transverse polarization is given not by the quark mass ($m_s = .5 \text{ GeV}$) but by the hadron mass¹⁵ — the constant C comes out close to 1.

CONCLUSIONS

We have presented a quantitative model of hyperon polarization. Since the transverse momentum covered by experiments is inbetween soft and hard regions we have “borrowed” from one region the soft recombination model and from the other — the hard scattering off external gluonic field. This we consider as the best we could use in the area where perturbative and nonperturbative effects interfere. We are aware of the fact that the above calculation is a QCD — inspired and compatible model rather than a QCD result. Keeping this in mind we claim good agreement of the model with the data.

The polarization of other hyperons requires additional knowledge concerning the wave functions. One knows that $SU(6)$ symmetry is broken in the structure functions of baryons, one has also to take into account possible diquark polarization. Work along these lines is in progress.

To summarize, the QCD picture where the massive quark scatters off external gluonic field in the interaction region seems to be responsible for the Λ polarization at high transverse momentum.

ACKNOWLEDGEMENTS

This paper was finished and written up during the visit of one of us (J.S.) to Brookhaven National Laboratory. He would like to thank William Marciano and the Theory Group of BNL for their hospitality. Discussions with Krzysztof Fiałkowski are also acknowledged.

Fig. 1: The data on Λ polarization¹⁴ compared with the model described in the text.

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