DYNAMICAL CALCULATION OF HYPERON POLARIZATION

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Abstract

We compute polarizations for inclusively produced hyperons in pN scattering at high energy by considering interferences between different resonances. Our predictions agree with experiment at small transverse momentum $p_\perp$ and large X_F but fail to explain the data at large $p_\perp$.

Introduction

Since the pionnering Fermilab experiment [1] in 1976 where a large transverse polarization has been observed in the inclusive reaction $pN \rightarrow \Lambda X$ all measurements[2] have confirmed a negative and large Λ polarization which at fixed X_F increases with $p_\perp$ up to 1 GeV and becomes flat in the high $p_\perp$ region. For Σ production the polarization is positive whereas there is no polarization for inclusively produced protons. Using the optical theorem the transvese polarization for hyperon B reads:

$$P_B = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow} = \frac{\mathrm{Im} F_B^{+-}}{F_B^{++}} \qquad (1)$$

where
$$F_B^{\lambda\lambda'} = \bar{\sum_{\lambda_p,\lambda_N}} \mathrm{disc}_M 2 \ \langle p(\lambda_p)\, N(\lambda_N)\, \bar{\Lambda}(\lambda)\, | p(\lambda_p) N(\lambda_N) \bar{\Lambda}(\lambda') \rangle \qquad (2)$$

λ_p (resp. λ_N) being the proton (resp. nucleon) helicity. Equation (1) shows that one needs both an helicity flip and a phase to get a non zero polarization.

The phenomenological models [3),4)] which explain the features of the data are semiclassical and not based on a dynamical calculation from a fundamental theory. It has been suggested[5)] that polarization arises from strange quark scattering off the color field generated by quarks and gluons inside the target. Unfortunately for reasonable values of color field intensity it leads to a polarization of roughly 1%.

I will mainly discuss the possibility of generating a phase by two different hadronic amplitudes[6)]. I will describe a dynamical calculation[7)] of hyperon polarization based on interferences between different resonances Y and Y* producing the hyperon B.

Description of the model and results

The amplitude (2) reads

$$F_B^{\lambda\lambda'} = \int ds_2\, R(s_2)\, \mathrm{disc}_{M^2} \langle pN\bar{Y}(\lambda)|pN\bar{Y}^*(\lambda')\rangle \quad P_Y(s_2)\ P_{Y^*}(s_2)$$
$$A(Y\to B(\lambda)\pi)\ A(Y^*\to B(\lambda')\pi) \qquad (3)$$

where $R(s_2)$ is the phase space factor for the decay $Y^{(*)} \to B\pi$, P_Y (resp. P_{Y^*}) is the propagator of Y (resp. Y*) resonance and A is the decay amplitude. The imaginary part is obtained from the different structure of the two propagators (for Λ polarization only a virtual Σ can decay into $\Lambda\pi$).

We have now to produce a non zero helicity flip amplitude :

$$\mathcal{A} = \mathrm{disc}_{M^2} \langle pN\bar{Y}\,(+)\,|\,pN\,\bar{Y}^*\,(-)\rangle \qquad (4)$$

We will consider two distinct kinematical regions : the low $p_\perp$ one ($p_\perp \leq 1$ GeV and $X_F \geq .6$) and the large $p_\perp$ one ($p_\perp > 1$ GeV). In the first region the theoretical scheme we will use [7)] to compute $\mathcal{A}$ is the triple Regge mechanism. For Λ production the relevant trajectories are the K* and K** and the residues are extracted from phenomenology[8)]. The total Λ polarization is obtained after addition of the contribution due to Σ° decaying into $\Lambda\gamma$. As shown in figure 1 we get [7)] $p_\Lambda \cong -10\%$ in agreement with low $p_\perp$

experimental data. Moreover we obtain [7] for the ratio $R = \sigma_{\Sigma^\circ} / (\sigma_{\Sigma^\circ} + \sigma_\Lambda)$ the result .27 in perfect agreement with the experimental value R = .28±.06 . This mechanism predicts that protons are unpolarized since the resonances N and Δ cannot interfere as they have different isospin values.

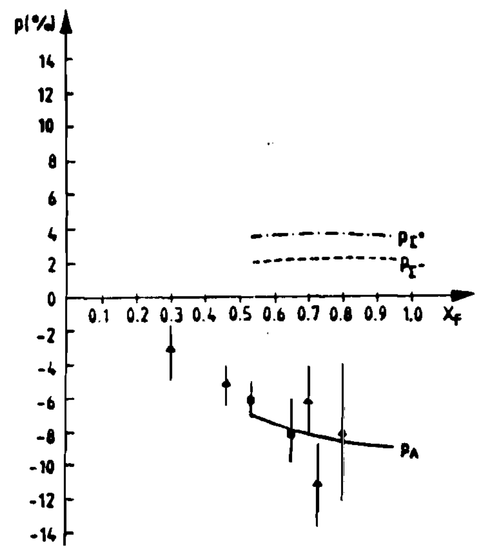

Fig.1

Theoretical predictions for Λ, Σ^+, Σ^- polarizations for $0.45\ \text{GeV} < p_\perp \le 0.55\ \text{GeV}$, compared to experimental data.

Since the Regge description cannot be applied to large $p_\perp$ values we have [9] to find another mechanism to produce the spin flip amplitude. It will be provided by perturbative QCD. Assuming factorization, we get :

$$F_B^{++} = \int dx_p\, dx_N\, dx_c^{-1} \frac{\hat{s}}{\pi}\ \delta(\hat{s}+\hat{t}+\hat{u}) \sum_{a,b,c} F_a^p\ (x_p)\ F_b^N\ (x_N)$$

$$D_c^Y(x_c)\ \frac{d\hat{\sigma}}{dt}(ab \to cX) \qquad (5)$$

where F_a^H (x) (resp. D_a^H) is the structure function (resp. fragmentation function) of parton a and $\frac{d\hat{\sigma}}{dt}$ is the partonic cross section.

Similarly :

$$F^{-+}_{Y^*Y} = \int dx_p\, dx_N\, dx_c^{-1} \frac{\hat{s}}{\pi} \delta(\hat{s}+\hat{t}+\hat{u}) \sum_{a,b,c} F_a^p(x_p)\, F_b^N(x_N) \sum_{h,h'} D_{c\,c\,,\,hh'}^{Y^*Y,-+}\, a_{hh'} \tag{6}$$

where $D_{c\,c'\,,\,hh'}^{Y^*Y,HH'}$ is the amplitude depicted in fig.2 that we evaluate using SU(6) wavefunctions and $a_{hh'}$ the partonic spin flip cross section.

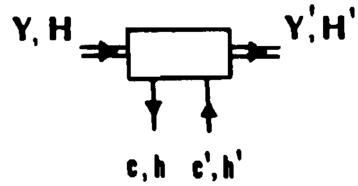

Fig.2

The $q\bar{q}$ YY' amplitude. h,h' (resp. H,H') are helicities of quarks (resp. Y,Y*) whereas c and c' are the quark flavor indices.

In QCD since the gluon coupling to quarks preserves helicity for massless quarks the naive calculation would predict[10] that a_{-+} is proportional to the quark mass. It has been shown[11] by applying angular momentum conservation and Bjorken sum rule that the mass parameter has to be identified with the mass of the polarized hadron. Therefore, we will replace in a_{-+} m_q by M_B. The largest contribution arises from gq→gq scattering. We get at the partonic level :

$$\hat{p}_B = \frac{0.1}{32} \frac{M_B\, p_\perp\, \hat{s}}{\hat{t}\;\hat{u}} \frac{1}{\left(\frac{9}{4}\frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2} - \frac{\hat{u}^2+\hat{s}^2}{\hat{u}\;\hat{s}}\right)} \tag{7}$$

A rough estimate of the magnitude of $\hat{p}_B$ in the central region gives $\hat{p}_B \sim 10^{-2}$ at $p_\perp \sim 1$ GeV. After inclusion of fragmentation and decay of resonances we get a smaller result.

Our analysis shows that the resonance interference model for hyperon polarization in high energy inclusive pN scattering which was successful in explaining low $p_\perp$ data fails to reproduce the data in the large $p_\perp$ region.

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