The $\Lambda_0$ Polarization and the Recombination Mechanism\textsuperscript{1}

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Abstract. We use the recombination and the Thomas Precession Model to obtain a prediction for the $\Lambda_0$ polarization in the $p + p \rightarrow \Lambda_0 + X$ reaction. We study the effect of the recombination function on the $\Lambda_0$ polarization.

INTRODUCTION

The unexpected discovery of large polarization in inclusive $\Lambda_0$ production by unpolarized protons has shown that important spin effects arise in the hadronization process. Several models have been proposed to explain hyperon polarization, being the Thomas Precession Model (TPM) [1] one of the most extensively used to describe polarization in a variety of reactions.

In order to obtain the $\Lambda_0$ polarization, we first calculate the momentum fraction of the recombining $s$-quark in the proton sea using a recombination model [2]. We use two different forms for the recombination function to see their influence on the predicted $\Lambda_0$ polarization.

THE $\Lambda_0$ POLARIZATION IN THE TPM

In $pp$ collisions the recombining $s$-quark resides in the sea of the proton and carries a very small fraction $x_s \simeq 0.1$ of the proton momentum. When the $s$-quark recombines to form a $\Lambda_0$, it becomes a valence quark and must carry a large fraction (of the order of $\frac{1}{3}$) of $\Lambda_0$'s momentum. Then one expects a large increase in the longitudinal momentum of the $s$-quark as it passes from the proton to the $\Lambda_0$,

$$\Delta p \simeq \left(\frac{1}{3} x_F - x_s\right)p = \left(\frac{1}{3} - \xi\right) x_F p,$$

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where $p$ is the proton’s momentum, $\xi = x_s/x_F$ and $x_F p = p_\Lambda$ is the momentum of the $\Lambda_0$ with $x_F$ the Feynman $x$.

Since the $s$-quark carries transverse momentum, on the average $p_T(s/p) \sim \frac{1}{2} p_{T\Lambda}$, its velocity vector is not parallel to the change in momentum induced by recombination and it must feel the effect of Thomas precession. Consequently, the $\Lambda_0$ is produced with net polarization perpendicular to the plane of the reaction.

According to the TPM the $\Lambda_0$ polarization in the reaction $p + p \to \Lambda_0 + X$ is given by [1]

$$P(p \to \Lambda) = -\frac{3}{M^2 \Delta x} \left( \frac{1 - 3\xi}{(1+3\xi)^2} \right)^{\frac{1}{2}} p_{T\Lambda},$$

where $M^2 = \left[ \frac{m_D^2 + p_{T\Lambda}^2}{1 - \xi} + \frac{m_s^2 + p_{T\Lambda}^2}{\xi} - m_\Lambda^2 - p_{T\Lambda}^2 \right]$ and $\xi = \frac{1}{3} (1 - x_F) + 0.1 x_F$ as was assumed in ref. [1]. $\Delta x = 0.5$ GeV is a characteristic recombination scale and $m_D$, $p_{T\Lambda}$, $m_s$, $p_{T\Lambda}$, $m_\Lambda$ and $p_{T\Lambda}$ are respectively the masses and transverse momentum of the diquark, the $s$-quark and the $\Lambda_0$.

THE $\xi(x_F)$ PARAMETRIZATION IN THE RECOMBINATION MODEL

We use the recombination model proposed in ref. [3], which has been extended to take into account baryon production [4], to obtain a parametrization for $\xi$ as a function of $x_F$ [2]. The inclusive $x_F$ distribution for $\Lambda_0$’s in $pp$ collisions is

$$\frac{d\sigma}{dx_F} = \int \frac{dx_u}{x_u} \frac{dx_d}{x_d} \frac{dx_s}{x_s} F(x_u, x_d, x_s) R(x_F, x_u, x_d, x_s),$$

where $F(x_u, x_d, x_s)$ and $R(x_F, x_u, x_d, x_s)$ are the three quark distribution and recombination functions respectively.

For the three quark distribution function we use the factorized form

$$F(x_u, x_d, x_s) = \beta F_{u, val}(x_u) F_{d, val}(x_d) F_{s, sea}(x_s) (1 - x_u - x_d - x_s)^\gamma$$

with $\gamma = -0.3$ as has been proposed in ref. [4] and $\beta = 0.75$. We used the Field and Feynman [5] parametrizations for the single quark distribution.

In order to see how the shape of the recombination function affects the prediction for the $\Lambda_0$ polarization, we use two different forms for $R(x_u, x_d, x_s)$:

$$R_1(x_u, x_d, x_s) = \kappa_1 \frac{x_u x_d x_s}{(x_F)^3} \delta \left( \frac{x_u + x_d + x_s}{x_F} - 1 \right)$$

as in ref. [4] and
\[ R_2(x_u, x_d, x_s) = \kappa_2 \left( \frac{x_u x_d}{x_F^2} \right)^a \left( \frac{x_s}{x_F} \right)^b \delta \left( \frac{x_u + x_d + x_s}{x_F} - 1 \right), \]  

which is inspired in the three valons recombination model proposed by R.C. Hwa [6]. In \( R_2 \), unlike \( R_1 \), the light quarks are considered with different weight than the more massive \( s \) quark introducing two distinct exponents \( a \) and \( b \). Indeed, in the recombination model proposed in ref. [6], a recombination function for hyperons is derived and a ratio \( \frac{a}{b} = \frac{2}{3} \) is used. We choose \( a = 1 \), \( b = \frac{3}{2} \) by fitting experimental data. \( \kappa_1 \) and \( \kappa_2 \) are normalization constants.

The probability for \( \Lambda_0 \) production at \( x_F \) with an \( s \)-quark from the sea of the proton at momentum fraction \( x_s \) is

\[ \frac{d\sigma_i}{dx_s dx_F} = \int \frac{dx_u dx_d}{x_u x_d} \frac{1}{x_s} F(x_u, x_d, x_s) R_i(x_F, x_u, x_d, x_s) \]  

with \( i = 1, 2 \). The average value of \( x_s \) is therefore [2]

\[ \langle x_s \rangle_i = \left[ \int d x_s x_s \frac{d\sigma_i}{dx_s dx_F} \right] \frac{d\sigma_i}{dx_F}. \]  

We have taken \( m_D = \frac{2}{3} \) GeV, \( m_s = \frac{1}{2} \) GeV and \( \langle p_T^2 \rangle_{s,D} = \frac{1}{4} p_{T\Lambda}^2 + \langle k_T^2 \rangle \) with \( \langle k_T^2 \rangle = 0.25 \) GeV\(^2\) [1]. The figure 1 shows the \( \Lambda_0 \) polarization for the three different parametrizations of \( \xi(x_F) \) at \( p_T = 0.5 \) GeV/c.

**CONCLUSIONS**

The two forms for \( \xi \) obtained with the two different recombination functions of eqs. 5 and 6 are very similar in shape for large \( x_F \). For small \( x_F \) however, the difference grows slightly and \( \xi_1(x_F = 0) = \frac{1}{3} \) while \( \xi_2(x_F = 0) \neq \frac{1}{3} \).

The parametrizations for \( \xi(x_F) \) obtained from the recombination model are different to the simple form proposed in ref. [1]. Our calculation of \( \xi(x_F) \) shows that, for \( x_F \rightarrow 1 \), \( \xi(x_F) \rightarrow 0.15 \) approximately for both recombination functions. This is consistent with our actual knowledge of the sea structure functions in the proton.

We have seen that for small \( p_{T\Lambda} \) our fit gives a good description of experimental data. This is reasonable since recombination models work better for small \( p_T \).

Within the precision of experimental data [3][7], it would be hard to decide which recombination function better describe \( \Lambda_0 \)'s production. A more accurate measurement of polarization at low \( p_T \) and low \( x_F \) can help to clarify the right form of the recombination function. It is interesting to note that, although the shape of the recombination function is not important for cross section calculations, it does make a difference when applied to polarization. In this sense, polarization measurements can help to understand the underlying mechanisms in hadroproduction.
FIGURE 1. $A_0$ polarization at $p_T = 0.5\text{GeV}/c$ obtained with $\xi(x_F)$ determined with the recombination functions $R_1$ (a), and $R_2$ (b). (c) is the polarization prediction of ref. [1]. Experimental data are taken from refs. [1] and [7].

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