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The Λ_0 Polarization and the Recombination Function*

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Abstract

We study the Λ_0 polarization in the $p+p \rightarrow \Lambda_0+X$ reaction. In the framework of the Thomas precession model we use different recombination fuctions and see how their shape influences the polarization prediction.

Key-words: Λ_0 polarization; Recombination; Polarization; Theoretical models.

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1 Introduction

Although hyperon polarization is not well understood, several models have been proposed to explain the different aspects of this phenomenon.

An extensive review on polarization models and experimental data until 1990 can be found in ref.[1].

One of the most successful and quoted models is the so called Thomas precession model [2], which has been used extensively to describe hyperon polarization in several reactions.

The recombination of quarks to form baryons and mesons has been treated successfully at low p_T in the context of the parton model [3], [4]. However some doubts persist on the right form of the recombination function and multiquark structure functions used to describe quark recombination[5].

In this letter, we analyze the influence that the recombination function used to describe Λ_0 production in pp collisions has on the Λ_0 polarization prediction. In order to do that, we calculate $x_s\,(x_F)$, the momentum fraction of the $s-quark$ in the proton as a function of x_F, with a recombination model and we use this function to calculate the Λ_0 polarization in the Thomas precession model.

2 The Λ_0 polarization in the Thomas Precession Model

In the Thomas precession model, the fundamental observation is that the $s-quark$ involved in the recombination 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 Λ_0, it becomes a valence quark and must carry a very large fraction (of the order of $\frac{1}{3}$) of Λ_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 Λ_0,

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

where p is the momentum of the proton, $\xi = \frac{x_s}{x_F}$ and $x_F p = p_\Lambda$ is the Λ_0's momentum.

Since the $s-quark$ carries transverse momentum: on the average $p_T(s/p) \sim p_T(s/\Lambda) \sim \frac{1}{2}p_{T\Lambda}$, its velocity vector is not parallel to the change in momentum induced by recombination and it must feels the effect of Thomas precession.

The Hamiltonian describing the recombination process must contain the term

$$U = \overrightarrow{s} \cdot \overrightarrow{\omega}, \tag{2}$$

where $\overrightarrow{s}$ is the spin of $s-quark$ and $\overrightarrow{\omega}$ the Thomas frequency given by $\overrightarrow{\omega} = \frac{\gamma^2}{1+\gamma^2}\frac{\overrightarrow{F}}{m_s} \times \overrightarrow{v}$.

For the sea quarks, $\overrightarrow{\omega}$ points out and up the scattering plane defined by $\widehat{n} = \frac{\overrightarrow{p} \times \overrightarrow{p}_\Lambda}{\left|\overrightarrow{p} \times \overrightarrow{p}_\Lambda\right|}$ so, in order that the recombination potential be the more attractive as possible, $\overrightarrow{s} \cdot \overrightarrow{\omega} < 0$ and it brings about the following rule

Slow (sea) partons recombine preferentially with spin down in the scattering plane.

According with the Thomas precession model [2], the Λ_0 polarization in the reaction $p + p \to \Lambda_0 + X$ is given by

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

where

$$M^2 = \left[\frac{m_D^2 + p_{TD}^2}{1-\xi} + \frac{m_s^2 + p_{Ts}^2}{\xi} - m_\Lambda^2 - p_{T\Lambda}^2\right] \tag{4}$$

and ξ in ref. [2] is assumed to be given by

$$\xi = \left(\frac{1}{3} - x_F\right) + 0.1 x_F. \tag{5}$$

m_D, p_{TD}, m_s, p_{Ts}, m_Λ and $p_{T\Lambda}$ are respectively the masses and transverse momentum of the diquark, the $s - quark$ and the Λ_0. Eq. 3 was obtained assuming that the $s - quark$ in Λ_0 carries approximately $p(s/\Lambda) = \frac{1}{3} p_\Lambda = \frac{1}{3} x_F p$.

3 The $\xi\,(x_F)$ parametrization in a Recombination Picture

The behavior of ξ *as* a function of x_F is very important in order to obtain the Λ_0 polarization because it determines at which value the polarization becomes zero and if there is a change of sign in it when $\xi > \frac{1}{3}$ [6]. In view of it, we use the recombination model proposed in ref. [3], which has been extended to take into account quark recombination into a baryon [4], to obtain a parametrization for ξ as a function of x_F. In order to produce a Λ_0, a pair of u and d quarks, which are valence quarks in the proton, recombine with an $s - quark$ coming from the sea. The inclusive cross section for Λ_0 production [4] in the reaction $p + p \to \Lambda_0 + X$ is given by

$$\frac{d\sigma}{dx_F} = \int \frac{dx_u}{x_u} \frac{dx_d}{x_d} \frac{dx_s}{x_s} F\left(x_u, x_d, x_s\right) R\left(x_u, x_d, x_s\right), \tag{6}$$

where x_F is the Feynman x of the Λ_0, x_i; $i = u, d, s$; is the momentum fraction of quark i in the proton, $F\left(x_u, x_d, x_s\right)$ is the three quark distribution function and $R\left(x_u, x_d, x_s\right)$ is the recombination function.

For the three quark distribution function we use the form

$$F\left(x_u, x_d, x_s\right) = \beta F_{u,val}\left(x_u\right) F_{d,val}\left(x_d\right) F_{s,sea}\left(x_s\right) \left(1 - x_u - x_d - x_s\right)^\gamma \tag{7}$$

with $\gamma = -0.3$ as has been proposed in ref. [4] and $\beta = 0.075$. We used the Field and Feynman [7] parametrizations for the single quark distribution functions.

In order to see how the shape of the recombination function affects the prediction for Λ_0 polarization we use the two different forms:

$$R_1\left(x_u, x_d, x_s\right) = \kappa_1 \frac{x_u x_d x_s}{\left(x_F\right)^3} \delta\left(\frac{x_u + x_d + x_s}{x_F} - 1\right) \tag{8}$$

as in ref. [4] and

$$R_2(x_u, x_d, x_s) = \kappa_2 \left(\frac{x_u x_d}{x_F^2}\right) \left(\frac{x_s}{x_F}\right)^{\frac{3}{2}} \delta\left(\frac{x_u + x_d + x_s}{x_F} - 1\right), \tag{9}$$

inspired in the three valons recombination model proposed by R.C. Hwa [8]. $x_{u,d,s}$ are the momentum fraction carried by the quarks u, d and s in the proton. In R_2 the light u and d quarks are considered with different weight than the more massive s quark. κ_1 and κ_2 are normalization constants.

The inclusive cross sections obtained from eq. 6 with the two recombination functions R_1 and R_2 give a reasonable description of experimental data (see refs. [4], [5]).

The probability for Λ_0 production at x_F with an $s - quark$ from the sea of the proton at momentum fraction x_s is

$$\frac{d\sigma_i}{dx_s dx_F} = \int \frac{dx_u}{x_u} \frac{dx_d}{x_d} \frac{1}{x_s} F(x_u, x_d, x_s) R_i(x_u, x_d, x_s), \tag{10}$$

with $i = 1, 2$. The average value of x_s is given by

$$\langle x_s \rangle_i = \frac{\int dx_s x_s \frac{d\sigma_i}{dx_s dx_F}}{\frac{d\sigma_i}{dx_F}}. \tag{11}$$

In figure 1 we show the plots for $\xi_i = \frac{\langle x_s \rangle_i}{x_F}$; $i = 1, 2$; compared with the parametrization given in ref. [2]. Fig. 2 shows the Λ_0 polarization for the three different parametrizations of ξ at $p_T = 0.5$ GeV/c.

4 Conclusions

We obtained a parametrization for $\xi(x_F)$ using the recombination model for Λ_0 production. As can be seen in fig. 1, the two forms for ξ obtained with the two different recombination functions of eqs. 8 and 9 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 a recombination model are different to the simple form proposed in ref. [2].

As for the Λ_0 polarization, the curves obtained from eq. 3 with $\xi_{1,2}$ are different to the curve obtained with $\xi(x_F)$ given in eq. 5. In order to obtain a better fit to experimental data, we have taken $\Delta x = 7\ GeV^{-1}$and not $\Delta x = 5\ GeV^{-1}$ as in ref. [2]. We have seen that for small $p_{T\Lambda}$, our fit gives a good description of experimental data. It is reasonable since recombination models work better for small $p_{T\Lambda}$.

Within the precision of experimental data, it would be hard to decide which recombination function better describe Λ_0's production. It seems that, although the shape of the recombination functions is not crucial to inclusive cross section calculations [5], it does make a difference when applied to polarization. In this sense, a more accurate measurement of polarization at low p_T and low x_F can help to decide about the right form of the recombination function.

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Figure captions

Figure 1: Parametrizations for $\xi(x_F)$ obtained with the recombination functions R_1 (a), R_2 (b) and $\xi(x_F)$ given by T. De Grand and H. Miettinen (c) [2].

Figure 2: Λ_0 polarization at $p_T = 0.5 GeV/c$ obtained with $\xi(x_F)$ determined with the recombination functions R_1 (a), and R_2 (b) from recombination model. (c) is the polarization prediction of ref. 2. Experimental data are taken from ref. [2].

Fig. 1

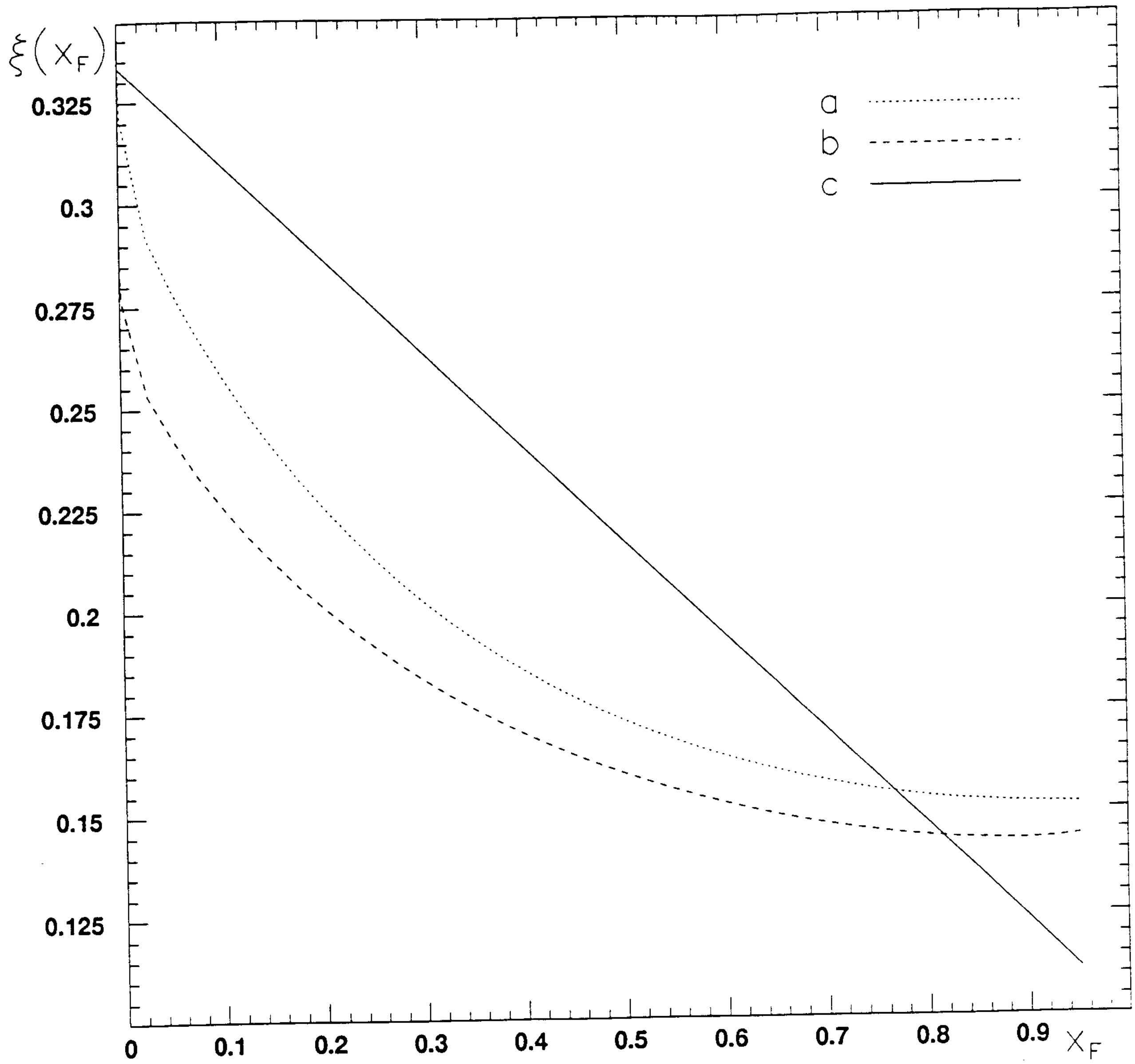
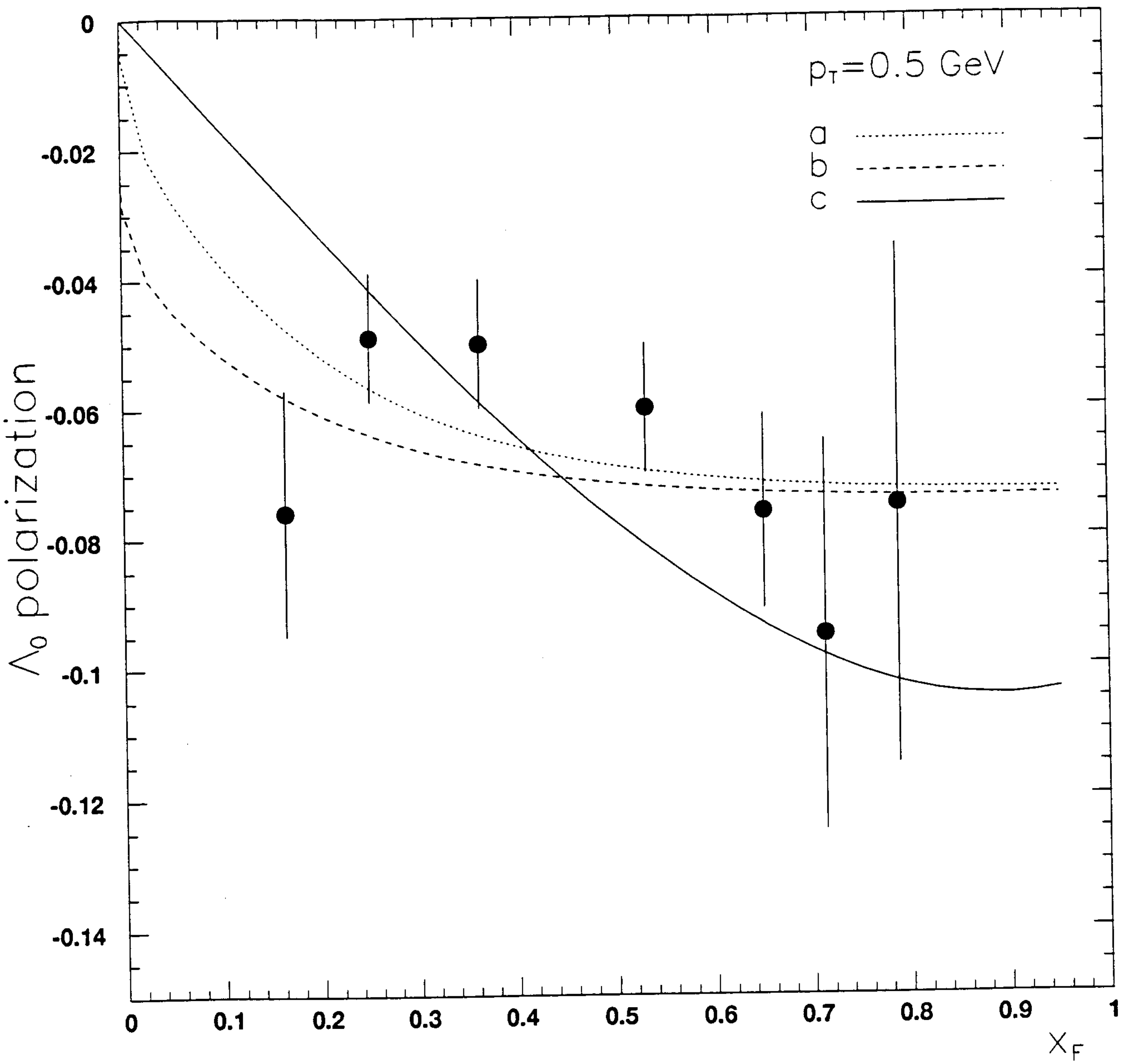

ξ(X_F)
0.325
0.3
0.275
0.25
0.225
0.2
0.175
0.15
0.125
a
b
c
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
X_F

Fig. 2


p_T=0.5 GeV
a
b
c
Λ_0 polarization
x_F
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

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