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Intrinsic Charm of the Proton and the Λ_c^+ Polarization*

by

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Abstract

We explore the possibility to resolve an intrinsic charm Fock state in the proton studying the Λ_c^+ polarization in proton proton collisions.

Key-words: Λ_c^+ polarization; Intrinsic charm; Fock states; Recombination; Fragmentation.

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1 Introduction

The gluon fusion ($gg \to Q\bar{Q}$) and quark-antiquark annihilation ($q\bar{q} \to Q\bar{Q}$) are expected to be the dominant processes for heavy quark production in QCD. QCD parton fusion, however, fails to explain important features of charm production [1]. This led to the suggestion [2] that the nucleon contains an intrinsic charm component at the level of 1%. In this letter we investigate the possibility to detect this component through the measurement of the Λ_c^+ polarization as it was first suggested by T. DeGrand and H. Miettinen [3].

In order to explain the presence of polarization in hyperons DeGrand and Miettinen [3] proposed a model which relates the polarization to a Thomas precession like term in the recombination process. They pointed out that the observation of positive polarization of Λ_c^+ should provide a signal of intrinsic charm Fock components in the proton. Here we give a quantitative prediction for the Λ_c^+ polarization in the framework of the recently proposed mechanism for Λ_c^+ production in proton proton collisions [4].

As in ref. [4] we assume that charmed hadron production occurs in two ways: via parton fusion and via fragmentation or recombination of intrinsic charm. Since polarization in the Thomas precession model is the result of an effective interaction originated by accelaration or deceleration of the $s-$ (in our case $c-$) quark in the moment when the baryon is build up, the fragmentation process of intrinsic charm or of charm produced by parton fusion would give the same polarization to the baryon formed. Therefore we will analyze the cases of intrinsic charm recombination and intrinsic charm fragmentation keeping in mind that Λ_c^+'s produced via parton fusion in general would have the charateristic polarization present in those Λ_c^+'s originated from intrinsic charm fragmentation.

2 The Polarization Model and the Intrinsic Charm

According to this model, in the process of recombination of quarks to produce a Λ_0 the quark s coming from the sea is accelerated in such a way that it feels the effect of Thomas precession in the presence of the diquark ud. This introduces an additional term in the Hamiltonian describing the recombination process.
The scattering amplitude for $pp \to \Lambda X$ is inversely proportional to the energy difference between intermediate and final states,

$$A \propto \frac{1}{\Delta E_0 + \vec{\omega_T} \cdot \vec{S}}, \tag{1}$$

where ΔE_0 is the energy difference in the absence of spin effects and $\vec{\omega_T} \cdot \vec{S}$ accounts for the spin dynamics with $\vec{\omega_T}$ being the Thomas frequency.

To leading order in ω_T the polarization asymmetry is

$$P(p \to \Lambda) = -\frac{\omega_T}{\Delta E_0}, \tag{2}$$

with ω_T given by

$$\omega_T = \frac{1}{2x_F P}\frac{3}{\Delta x_0}\frac{(1-3\xi)}{[(1+3\xi)/2]^2}P_T, \tag{3}$$

and $\xi = x_S/x_F$. x_S is the momentum fraction of the s quark in the proton and x_F the Feynman's x of the Λ_0, P is the proton momenta and p_T the Λ_0 transverse momenta. Δx_0 is the distance where the recombination takes place, we will use $\Delta x_0 = 5$ GeV^{-1}, which is the value obtained in ref. [3].
In order to get eq. (3) one assumes that $P_T^s \sim \frac{1}{2}P_T^{\Lambda}$ and that the quark s shares $\frac{1}{3}$ of the Λ^0 's momentum.
For the process $pp \rightarrow \Lambda_c^+ X$ we will take eqs. 2 and 3 to describe the Λ_c^+ polarization.

In order to obtain a prediction for the polarization it is important to have a parametrization for $\xi(x_F)$. In their paper [3] De Grand and Miettinen used a linear form for $\xi(x_F) = x_s/x_F$, here we will obtain a parametrization for $\xi(x_F) = x_c/x_F$ according with the production mechanisms described in [4] for the Λ_c^+ production, with x_c being the fraction of the proton momentum carried by the c-quark.

The wave function of the proton in QCD has a decomposition in terms of color singlet eigenstates of the free Hamiltonian, $\mid uud\rangle$, $\mid uudg\rangle$, $\mid uudq\bar{q}\rangle$ ... The probability distribution corresponding to an n-particle Fock state is then given by [2],

$$\frac{d\sigma_{ic}}{dx_1 dx_2 ... dx_n} \propto \frac{\delta(1-\sum_{i=1}^n x_i)}{(m_h^2 - \sum_{i=1}^n(\hat{m}_i^2/x_i))^2} \tag{4}$$

where m_h is the hadron mass, $\hat{m}_i = \sqrt{\langle k_{T_i}^2\rangle + m_i^2}$ with m_i the masses and k_{T_i} and x_i the transverse and fractional longitudinal momentum carried by each constituent.

In our case $p \rightarrow uu'dc\bar{c}$ and as in [2] we will take the limit of heavy quarks, $m_c^2, m_{\bar{c}}^2 \gg m_i^2$ $(i = u, u', d)$, so that the momentum distribution of the intrinsic charm (ic) Fock state has the form

$$\frac{d\sigma_{ic}}{dx_u dx_{u'} dx_d dx_c dx_{\bar{c}}} = N\frac{x_c^2 x_{\bar{c}}^2}{(x_c + x_{\bar{c}})^2}\delta(1 - \sum_{i=uu'dc\bar{c}} x_i). \tag{5}$$

The charm present in the proton enhances the Λ_c^+ cross section at high x_F [4]. The intrinsic charm of the proton can produce Λ_c^+'s (and other charmed mesons and baryons) through recombination with the quarks from the proton and/or trough its own fragmentation.

Using these production mechanisms we will obtain a parametrization for $\xi(x_F)$ in eq. (3) and with this a polarization using eq. (2).

3 $\xi(x_F)$ and Intrinsic Charm Recombination

The $c-$quark can recombine with u and d quarks from the proton to form a Λ_c^+. In the simple recombination mechanism proposed in [2], the x_F distribution for the Λ_c^+ produced in this way is given by

$$\frac{d\sigma}{dx_F} = \int_0^1 dx_u dx_{u'} dx_d dx_c dx_{\bar{c}} \delta(x_F - x_u - x_d - x_c) \left(\frac{x_c x_{\bar{c}}}{x_c + x_{\bar{c}}} \right)^2 \delta(1 - \sum_{i=u,u',d,c,\bar{c}} x_i) \quad (6)$$

so that,

$$\frac{d\sigma}{dx_c dx_F} = \int_0^{x_F - x_{\bar{c}}} dx_{u'} \int_0^{1-x_F} dx_u \left(\frac{x_c(1 - x_u - x_F)}{x_c + 1 - x_u - x_F} \right)^2 . \quad (7)$$

The polarization is an average quantity. In order to parametrize $\xi(x_F)$ we calculate the mean value,

$$\langle \xi \rangle = \int \xi \frac{d\sigma}{dx_c dx_F} dx_c / \int \frac{d\sigma}{dx_c dx_F} dx_c . \quad (8)$$

Fig. 1 shows the resulting $\xi(x_F)$.

As in ref. [3], ΔE_0 of eq. (2) is given by,

$$\Delta E_0 = \frac{1}{2x_F P} \left[\frac{m_{qq}^2 + p_{Tqq}^2}{1 - \xi} + \frac{(m_c^2 + p_{Tc}^2)}{\xi} - m_{\Lambda_c^+}^2 - p_{T\Lambda_c^+}^2 \right], \quad (9)$$

where P is the proton momentum, $m_{\Lambda_c^+}$ the Λ_c^+ mass, m_{qq} the diquark (ud) and m_c the c-quark masses. p_{Tqq} and p_{Tc} are the transverse momentum of the diquark (ud) and the c-quark respectively. As in ref. [3] we use: $m_{qq} = \frac{2}{3} GeV$, $\langle p_T^2 \rangle_{c,qq} = \frac{1}{4} p_{T\Lambda_c^+}^2 + \langle k_T^2 \rangle$ with $\langle k_T^2 \rangle = 0.25$ GeV ^{2}. We take $m_c^2 = 1.5$ GeV and $m_{\Lambda_c^+} = 2.285$ GeV.

The Λ_c^+ polarization for this process and for different values of $p_{T\Lambda_c^+}$ is shown in fig. 2.

4 $\xi(x_F)$ and Intrinsic Charm Fragmentation

The charm present in the proton could produce a Λ_c^+ by way of fragmentation. Fragmentation of the intrinsic charm using the Peterson fragmentation function with $\epsilon_c = (m_q/m_c)^2 = 0.06$ to form a Λ_c^+ gives

$$\frac{d\sigma}{dx_F} = \int dx_c dz \frac{P(x_c)\delta(x_F - x_c z)}{z\left[1 - 1/z - \epsilon_c/(1-z)\right]^2}, \quad (10)$$

with $P(x_c) = \frac{d\sigma_{ic}}{dx_c}$. One obtains $P(x_c)$ by integrating the Fock state cross section (eq. 5) over the x-distributions of the light valence quarks and the $\bar{c}$ quark. It is given by,

$$P(x_c) = 3600 \frac{x_c^2}{2} \left[\frac{1}{3}(1 - x_c)(1 + 10x_c + x_c^2) - 2x_c(1 + x_c) ln(1/x_c) \right], \quad (11)$$

see ref. [2]. In eq.(9) z is the fraction of the charm quark momentum carried by the produced hadron, *i.e.* $z = x_F/x_c$. Hence,

$$\frac{d\sigma}{dx_c dx_F} = \frac{P(x_c)}{x_F[1 - \frac{x_c}{x_F} - \frac{\epsilon x_c}{x_c - x_F}]^2} \Big|_{x_c \geq x_F}$$

Fig. 1 shows the $z = 1/\xi(x_F)$ obtained from a fragmentation process after evaluation of eq.(8).
In the case when the intrinsic charm fragments to form a Λ_c^+ the ΔE_0 of eq. (2) is given by,

$$\Delta E_0 = \frac{1}{2x_F P}\left[\frac{m^2_{\Lambda_c^+} + p^2_{T\Lambda_c^+}}{z} + \frac{m^2_{qq} + p^2_{Tqq}}{1-z} - (m_c^2 + p^2_{Tc})\right], \qquad (12)$$

with the numerical values given before.

The Λ_c^+ polarization for this process and for different values of $p_{T\Lambda_c^+}$ is shown in fig. 2 together with the polarization of Λ_c^+ 's produced via recombination.

5 Summary and Conclusions

The fragmentation mechanism produces Λ_c^+ 's with a small polarization. It remains almost constant for all x_F and grows slowly with the baryon transverse momentum. Recombination of the intrinsic charm on the other side, would produce Λ_c^+ s with the highest polarization at low x_F values. The polarization for those Λ_c^+'s increases quickly with its transverse momenta.

As pointed out in [4], the two mechanisms contribute to the Λ_c^+ production in such a way that,

$$\frac{d\sigma_{ic}^{\Lambda_c^+}}{dx_F} = \frac{d\sigma_{ic}^{frag}}{dx_F} + r\frac{d\sigma_{ic}^{rec}}{dx_F}. \qquad (13)$$

The value of r determines to what degree the Λ_c^+ polarization follows the upper or lower curves in fig.2. labeled with "fra" for fragmentation or with "rec" for recombination respectivelly. A value extracted from other measurements (see ref. [4]) would provide a prediction for the polarization and viceversa a precise measurement of polarization would provide a value for r.

Unfortunately there are only two measurements of Λ_c^+ polarization [6, 7] both with a very low statistics. They observed a Λ_c^+ polarization different from zero but with the accuracy achieved it is hard to reach a conclusion yet.
The first indications of Ξ_c^+ polarization have been reported by the the EXCHARM collaboration [8] which uses a neutron beam to produce the charm-strange baryon. Ξ_c^+ however contains a strange quark which from the point of view of recombination would come from the sea of the proton. A more extensive treatment of polarization to consider this fact is underway.

A detailed study of the Λ_c^+ polarization would provide an indication of the existence of charm Fock states in the proton. In this way the existence of unusual Fock states in the proton closely related to intrinsic charm would be supported [5].

High statistics measurements of Λ_c^+ production and polarization in pp collisions would provide interesting insights into the charm hadronization and charmed baryon production.

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Fig. 1

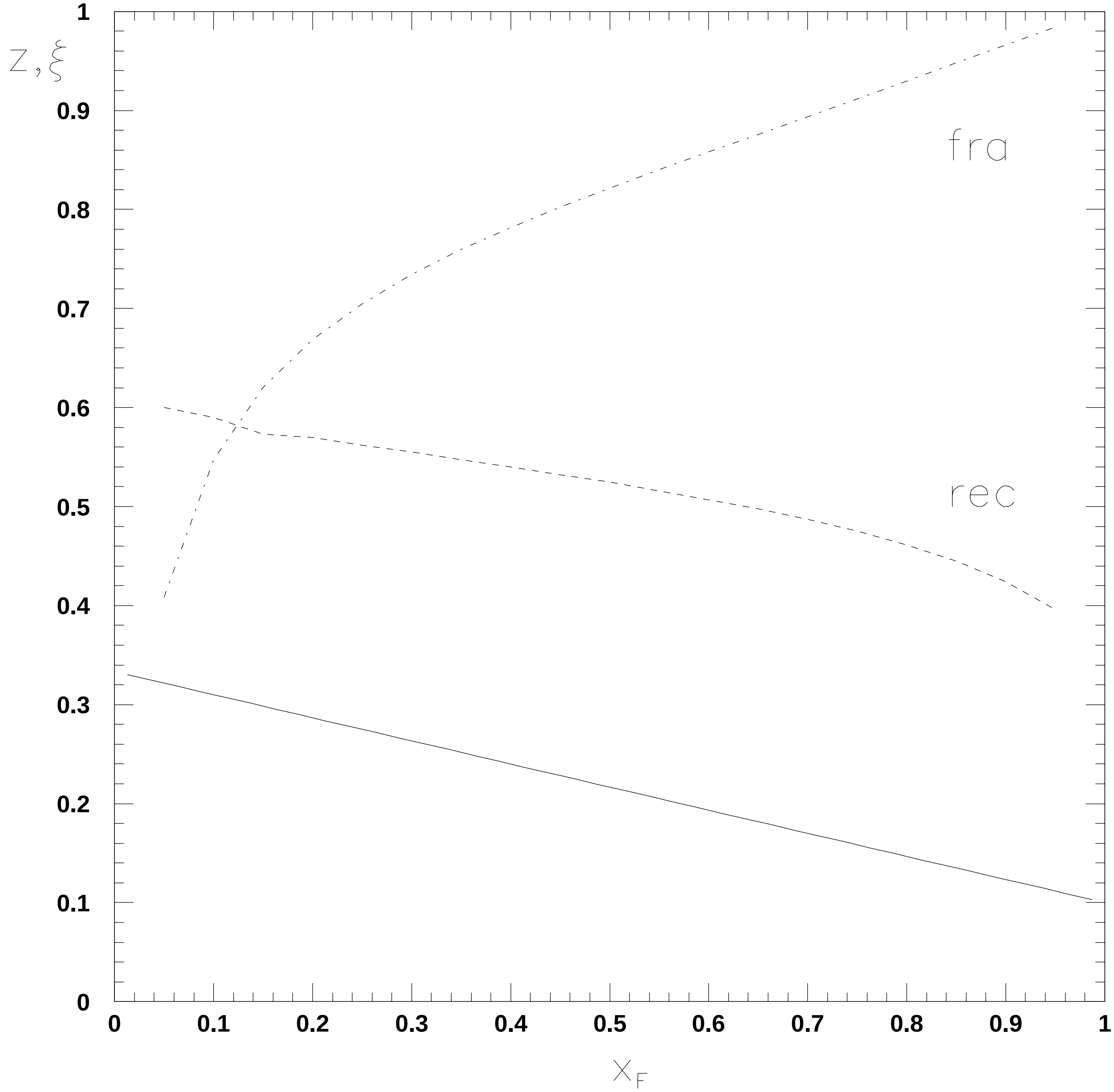

Fig.1. $\xi(x_F), z$ parametrizations; (solid line) used in [3] to describe the Λ_0 polarization, (dashed line) obtained from recombination of intrinsic charm to form a Λ_c^+ and (dot-dashed line) $z = 1/\xi$ from fragmentation of the intrinsic charm into a Λ_c^+.

Fig. 1

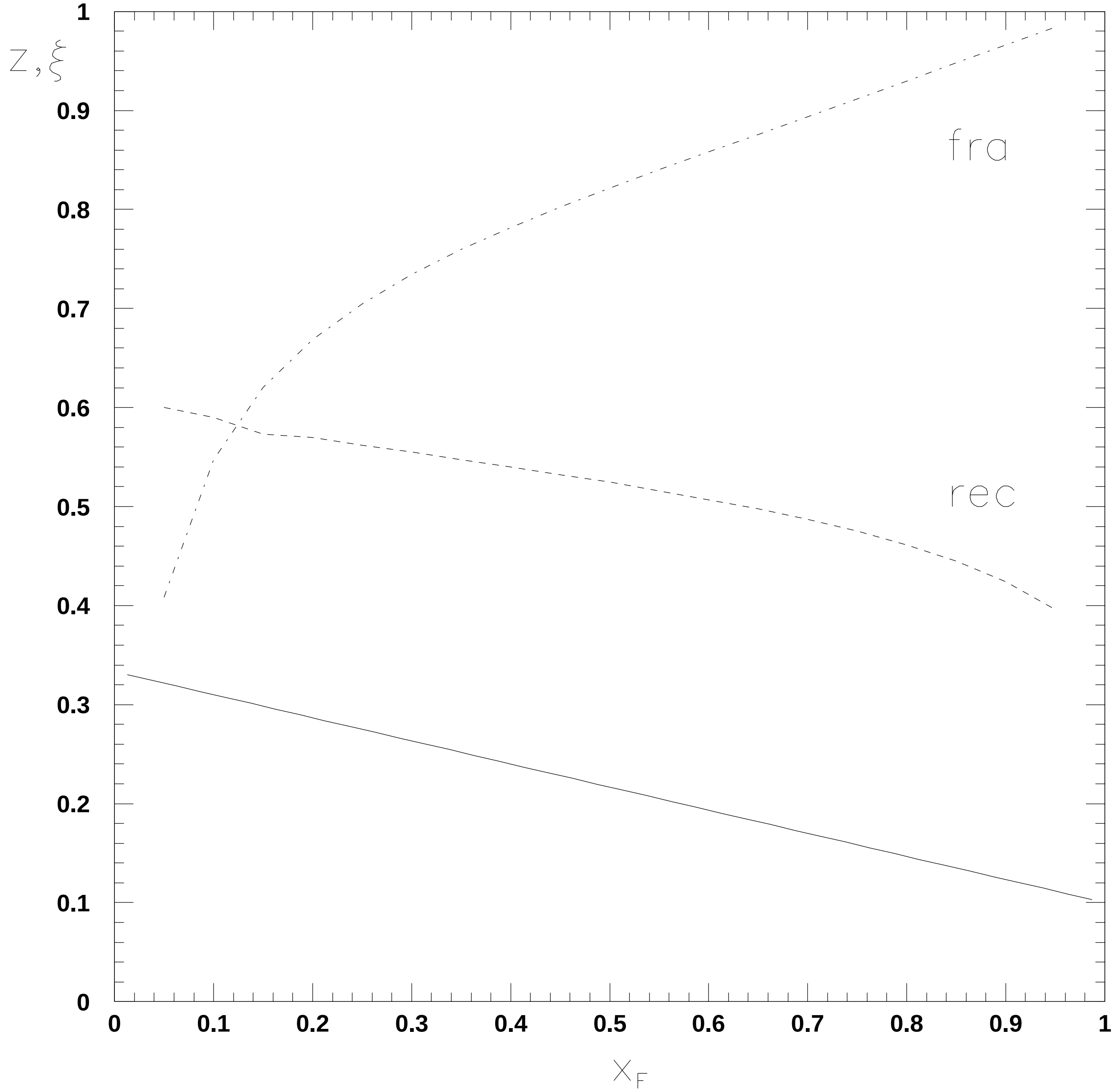

Fig.2. Λ_c^+ polarization as a function of x_F for different values of p_T and both recombination and fragmentation mechanisms.

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