CBPF - CENTRO BRASILEIRO DE PESQUISAS FÍSICAS

Rio de Janeiro

Notas de Física

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by

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## ABSTRACT

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

**Key-words:** $\Lambda_c^+$ polarization; Intrinsic charm; Fock states; Recombination; Fragmentation.

# 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 $\Lambda_c^+$ 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 $\Lambda_c^+$ should provide a signal of intrinsic charm Fock components in the proton. Here we give a quantitative prediction for the $\Lambda_c^+$ polarization in the framework of the recently proposed mechanism for $\Lambda_c^+$ 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 $\Lambda_c^+$'s produced via parton fusion in general would have the charateristic polarization present in those $\Lambda_c^+$'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 $\Lambda_0$ 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,

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

(1)

where $\Delta E_0$ 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 $\omega_T$ the polarization asymmetry is

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

(2)

with $\omega_T$ 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 $\Lambda_0$, $P$ is the proton momenta and $p_T$ the $\Lambda_0$ transverse momenta. $\Delta x_0$ 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 $\Lambda^0$ 's momentum.

For the process $pp \rightarrow \Lambda_c^\pm X$ we will take eqs. 2 and 3 to describe the $\Lambda_c^\pm$ 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 $\Lambda_c^+$ 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, $| uud \rangle$, $| uudg \rangle$, $| uudq\bar{q} \rangle$ ... 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 $\Lambda_c^+$ cross section at high $x_F$ [4]. The intrinsic charm of the proton can produce $\Lambda_c^+$'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 $\Lambda_c^+$. In the simple recombination mechanism proposed in [2], the $x_F$ distribution for the $\Lambda_c^+$ 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,

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

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], $\Delta E_0$ 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 $\Lambda_c^+$ 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 $\Lambda_c^+$ 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 $\Lambda_c^+$ 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 $\Lambda_c^+$ gives

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

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 $\Lambda_c^+$ the $\Delta E_0$ of eq. (2) is given by,

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

with the numerical values given before.

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

# 5 Summary and Conclusions

The fragmentation mechanism produces $\Lambda_c^+$ '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 $\Lambda_c^+$ s with the highest polarization at low $x_F$ values. The polarization for those $\Lambda_c^+$'s increases quickly with its transverse momenta.

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

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

The value of $r$ determines to what degree the $\Lambda_c^+$ polarization follows the upper or lower curves in fig.2. labeled with "fra" for fragmentation or with "rec" for recombination respectively. 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 $\Lambda_c^+$ polarization [6, 7] both with a very low statistics. They observed a $\Lambda_c^+$ polarization different from zero but with the accuracy achieved it is hard to reach a conclusion yet.

The first indications of $\Xi_c^+$ polarization have been reported by the the EXCHARM collaboration [8] which uses a neutron beam to produce the charm-strange baryon. $\Xi_c^+$ 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 $\Lambda_c^+$ 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 $\Lambda_c^+$ production and polarization in $pp$ collisions would provide interesting insights into the charm hadronization and charmed baryon production.

# 6   Acknowledgements

# Figure Captions

**Fig.1.** $\xi(x_F), z$ parametrizations; (solid line) used in [3] to describe the $\Lambda_0$ polarization, (dashed line) obtained from recombination of intrinsic charm to form a $\Lambda_c^+$ and (dot-dashed line) $z = 1/\xi$ from fragmentation of the intrinsic charm into a $\Lambda_c^+$.

**Fig.2.** $\Lambda_c^+$ polarization as a function of $x_F$ for different values of $p_T$ and both recombination and fragmentation mechanisms.
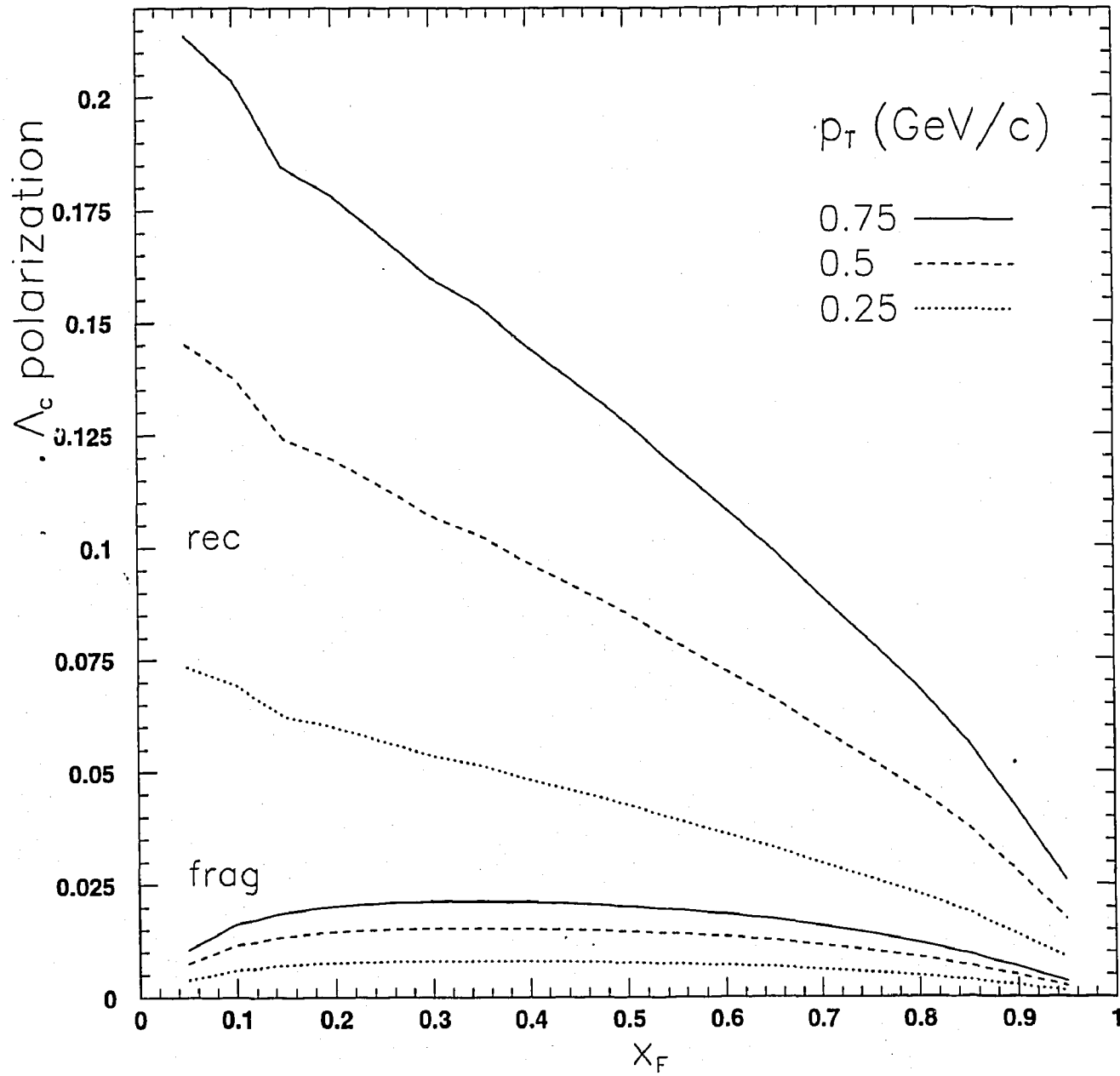
# Fig. 1
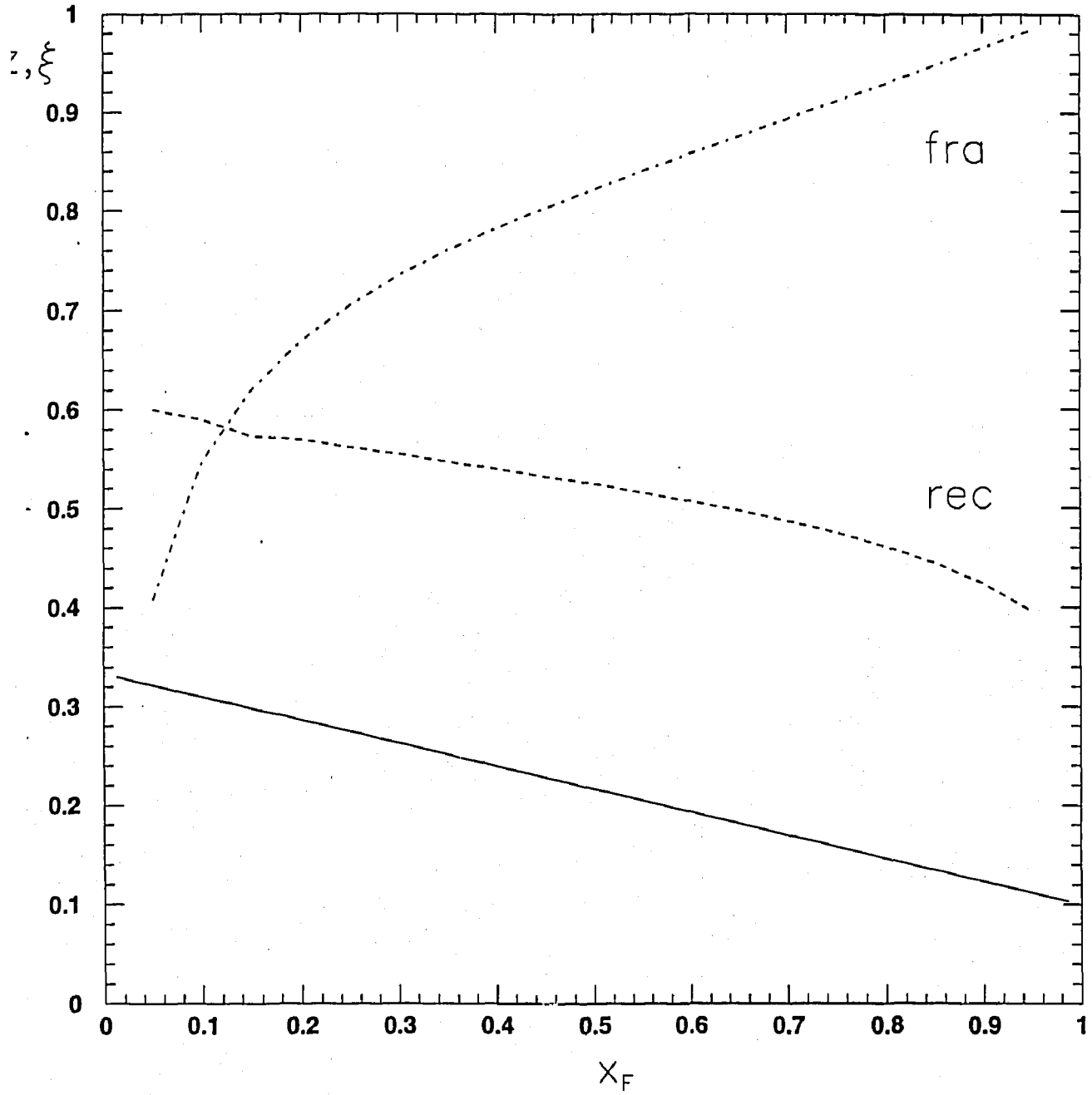
# Fig. 2

# References

[1] R. Vogt, S.J. Brodsky and P. Hoyer, *Nucl. Phys.* **B383** (1992)643

[2] S. J Brodsky, P Hoyer, C. Peterson and N. Sakai, *Phys. Lett.* **B93** (1980)451 and
S. J Brodsky, C. Peterson and N. Sakai, *Phys. Rev.* **D23** (1981)2745

[3] A. DeGrand and H.I. Miettinen, *Phys. Rev.* **D24** (1981)2419

[4] R. Vogt and S.J. Brodsky, SLAC-PUB-95-7068, Dec. 1995.
Submitted to *Nucl. Phys. B*

[5] R. Vogt and S.J. Brodsky, *Phys. Lett.* **B349** (1995)569

[6] A. N. Aleev, *et al.* EXCHARM Collaboration, *Yad. Fiz.* **43**(1986)619, *Sov. J. Nucl. Phys.* **43** (1986)395

[7] P. Chauvat *et al.*, *Phys. Lett.* **B199** (1987)304

[8] A. N. Aleev, *et al.* EXCHARM Collaboration, JINR-D1-93-36 submitted to *Zeitschrift für Physik* **C**