CBPF-NF-010/97

The Charm of the Proton and the Λ_c^+ Production*

J. dos Anjos, G. Herrera[†], *J. Magnin & F.R.A. Simão*

Centro Brasileiro de Pesquisas Físicas - CBPF
Rua Dr. Xavier Sigaud, 150
22290-180 – Rio de Janeiro, RJ – Brasil

Abstract

We propose a two component model for charmed baryon production in pp collisions consisting of the conventional parton fusion mechanism and fragmentation plus quarks recombination in which a ud valence diquark from the proton recombines with a c-sea quark to produce a Λ_c^+. Our two-component model is compared with the intrinsic charm two-component model and experimental data.

Key-words: Baryon production, Fragmentation into hadrons; Charmed baryons.

---

[*] This work was partially supported by Centro Latino Americano de Física (CLAF).
Talked presented at I Simposium Latinoamericano de Física de Altas Energias (SILAFAE), Merida, Mexico, November 1996.

[†] Permanent address: CINVESTAV, Apdo Postal 14-740 México 07000 DF,México.

Introduction

The production mechanism of hadrons containing heavy quarks is not well understood. Although the fusion reactions $gg \to Q\bar{Q}$ and $q\bar{q} \to Q\bar{Q}$ are supposed to be the dominant processes, they fail to explain important features of heavy quark hadro-production like the leading particle effects observed in $D^{\pm}$ produced in $\pi^- p$ collisions [1], Λ_c^+ production in pp interactions [2] [3] and in others baryons containing heavy quarks [4], the J/Ψ cross section at large x_F observed in πp collisions [5], etc.

The above mentioned effects have been explained using a two-component model [6] consisting of the parton fusion mechanism calculable in perturbative QCD plus the coalescence of intrinsic charm [7].

In hadron-hadron collisions the recombination of valence spectator quarks with c-quarks present in the sea of the initial hadron is a possible mechanism for charmed hadron production. Here we explore that possibility for the Λ_c^+'s production in pp interactions. We will assume that in addition to the usual parton fusion processes, a ud diquark recombines with c-sea quark both from the incident proton.

We compare our results with those of the intrinsic charm two-component model and the experimental data available.

Λ_c^+ Production *via* Parton Fusion

In the parton fusion mechanism the Λ_c^+ is produced via the subprocesses $q\bar{q}(gg) \to c\bar{c}$ with the subsequent fragmentation of the c quark. The inclusive x_F distribution of the Λ_c^+ in pp collisions is given by [8][9]

$$\frac{d\sigma^{pf}}{dx_F} = \frac{1}{2}\sqrt{s}\int H_{ab}(x_a, x_b, Q^2)\frac{1}{E}\frac{D_{\Lambda_c/c}(z)}{z}dz\,dp_T^2\,dy\ , \tag{1}$$

where

$$\begin{aligned} H_{ab}(x_a, x_b, Q^2) &= \Sigma_{a,b}\left(q_a(x_a, Q^2)\bar{q}_b(x_b, Q^2)\right. \\ &\quad \left. + \bar{q}_a(x_a, Q^2)q_b(x_b, Q^2)\right)\frac{d\hat{\sigma}}{d\hat{t}}\mid_{q\bar{q}} \\ &\quad + g_a(x_a, Q^2)g_b(x_b, Q^2)\frac{d\hat{\sigma}}{d\hat{t}}\mid_{gg} \end{aligned} \tag{2}$$

with x_a and x_b being the parton momentum fractions, $q(x, Q^2)$ and $g(x, Q^2)$ the quark and gluon distribution in the proton, E the energy of the produced c-quark and $D_{\Lambda_c/c}(z)$ the fragmentation function. In eq. 1, p_T^2 is the squared transverse momentum of the produced c-quark, y is the rapidity of the $\bar{c}$ quark and $z = x_F/x_c$ is the momentum fraction of the charm quark carried by the Λ_c^+. The sum in eq. 2 runs over $a, b = u, \bar{u}, d, \bar{d}, s, \bar{s}$.

We use the LO results for the elementary cross-sections $\frac{d\hat{\sigma}}{d\hat{t}}\mid_{q\bar{q}}$ and $\frac{d\hat{\sigma}}{d\hat{t}}\mid_{gg}$ [8].

$$\frac{d\hat{\sigma}}{d\hat{t}}\mid_{q\bar{q}}= \frac{\pi\alpha_s^2(Q^2)}{9\hat{m}_c^4}\,\frac{cosh\,(\Delta y)+m_c^2/\hat{m}_c^2}{[1+cosh\,(\Delta y)]^3} \tag{3}$$

$$\frac{d\hat{\sigma}}{d\hat{t}}\mid_{gg}= \frac{\pi\alpha_s^2(Q^2)}{96\hat{m}_c^4}\,\frac{8cosh\,(\Delta y)-1}{[1+cosh\,(\Delta y)]^3}\left[cosh\,(\Delta y)+\frac{2m_c^2}{\hat{m}_c^2}+\frac{2m_c^4}{\hat{m}_c^4}\right] \tag{4}$$

where Δy is the rapidity gap between the produced c and $\bar{c}$ quarks and $\hat{m}_c^2 = m_c^2 + p_T^2$.

In order to be consistent with the LO calculation of the elementary cross sections, we use the GRV-LO parton distribution functions [10], allowing by a global factor $K \sim 2-3$ in eq. 1 to take into account NLO contributions [6].

We take $m_c = 1.5\ GeV$ for the c-quark mass and fix the scale of the interaction at $Q^2 = 2m_c^2$ [8]. Following [6], we use two fragmentation functions to describe the hadronization of the charm quark;

$$D_{\Lambda_c/c}(z) = \delta(1-z) \tag{5}$$

and the Peterson fragmentation function [11]

$$D_{\Lambda_c/c}(z) = \frac{N}{z\left[1-1/z-\epsilon_c/(1-z)\right]^2} \tag{6}$$

with $\epsilon_c = 0.06$ and the normalization defined by $\sum_H \int D_{H/c}(z)dz = 1$.

Λ_c^+ Production *via* Recombination

The production of leading mesons at low p_T by recombination of quarks was proposed long time ago [12]. The method introduced by Das and Hwa for mesons was extended by Ranft [13] to describe single particle distributions of leading baryons in pp collisions.

In recombination models one assumes that the outgoing hadron is produced in the beam fragmentation region through the recombination of the maximun number of valence and the minimun number of sea quarks coming from the projectile according to the flavor content of the final hadron. Thus, *e.g.* Λ_c^+'s produced in pp collisions are formed by the ud valence diquark and a c-quark from the sea of the incident proton. One ignores other type of contributions involving more than one sea flavor recombination.
The invariant inclusive x_F distribution for leading baryons is given by

$$\frac{2E}{\sqrt{S}\sigma}\,\frac{d\sigma^{rec}}{dx_F} = \int_0^{x_F}\frac{dx_1}{x_1}\frac{dx_2}{x_2}\frac{dx_3}{x_3}F_3\,(x_1,x_2,x_3)\,R_3\,(x_1,x_2,x_3,x_F) \tag{7}$$

where x_i, $i = 1,2,3$, is the momentum fraction of the i^{th} quark, $F_3\,(x_1,x_2,x_3)$ is the three-quark distribution function in the incident hadron and $R_3\,(x_1,x_2,\ x_3,x_F)$ is the three-quark recombination function.

We use a parametrization containing explicitly the single quark distributions for the three-quark distribution function

$$F_3\left(x_1,x_2,x_3\right)=\beta F_{u,val}\left(x_1\right)F_{d,val}\left(x_2\right)F_{c,sea}\left(x_3\right)\left(1-x_1-x_2-x_3\right)^{\gamma} \tag{8}$$

with $F_q\left(x_i\right)=x_i q\left(x_i\right)$ and F_u normalized to one valence u quark. The parameters β and γ are constants fixed by the consistency condition

$$\begin{aligned} F_q\left(x_i\right) &= \int_0^{1-x_i} dx_j \int_0^{1-x_i-x_j} dx_k\, F_3\left(x_1,x_2,x_3\right), \\ & i,j,k=1,2,3 \end{aligned} \tag{9}$$

for the valence quarks of the incoming proton as in ref. [13].

We use the GRV-LO parametrization for the single quark distributions in eq. 8. It must be noted that since the GRV-LO distributions are functions of x and Q^2, then our $F_3\left(x_1,x_2,x_3\right)$ also depends on Q^2.

In contrast with the parton fusion calculation, in which the scale Q^2 of the interaction is fixed at the vertices of the appropriated Feynman diagrams, in recombination there is not clear way to fix the value of the parameter Q^2, which in this case is not properly a scale parameter and should be used to give adequately the content of the recombining quarks in the initial hadron.

Since the charm content in the proton sea increases rapidly for Q^2 growing from m_c^2 to Q^2 of the order of some m_c^2's when it become approximately constant, we take $Q^2=4m_c^2$, a conservative value, but sufficiently far from the charm threshold in order to avoid a highly depressed charm sea which surely does not represent the real charm content of the proton. At this value of Q^2 we found that the condition of eq. 9 is fulfilled approximately with $\gamma=-0.1$ and $\beta=75$. We have verified that the recombination cross section does not change appreciably at higher values of Q^2.

For the three-quark recombination function for Λ_c^+ production we take the simple form [13]

$$R_3\left(x_u,x_d,x_c\right)=\alpha\frac{x_u x_d x_c}{x_F^2}\delta\left(x_u+x_d+x_c-x_F\right) \tag{10}$$

with α fixed by the condition $\int_0^1 dx_F(1/\sigma)d\sigma^{rec}/dx_F=1$, then σ is the cross section for Λ_c^+'s inclusively produced in pp collisions. From eqs 7 and 8, the invariant x_F distribution for Λ_c is

$$\begin{aligned} \frac{2E}{\sqrt{s}\sigma}\frac{d\sigma^{rec}_{\Lambda_c^+}}{dx_F} &= 75\alpha\frac{\left(1-x_F\right)^{-0.1}}{x_F^2}\int_0^{x_F} dx_1 F_{u,val}(x_1) \\ & \times\int_0^{x_F-x_1} dx_2 F_{d,val}(x_2)F_{c,sea}(x_F-x_1-x_2) \end{aligned} \tag{11}$$

where we already integrated over x_3. The parameter σ will be fixed with experimental data.

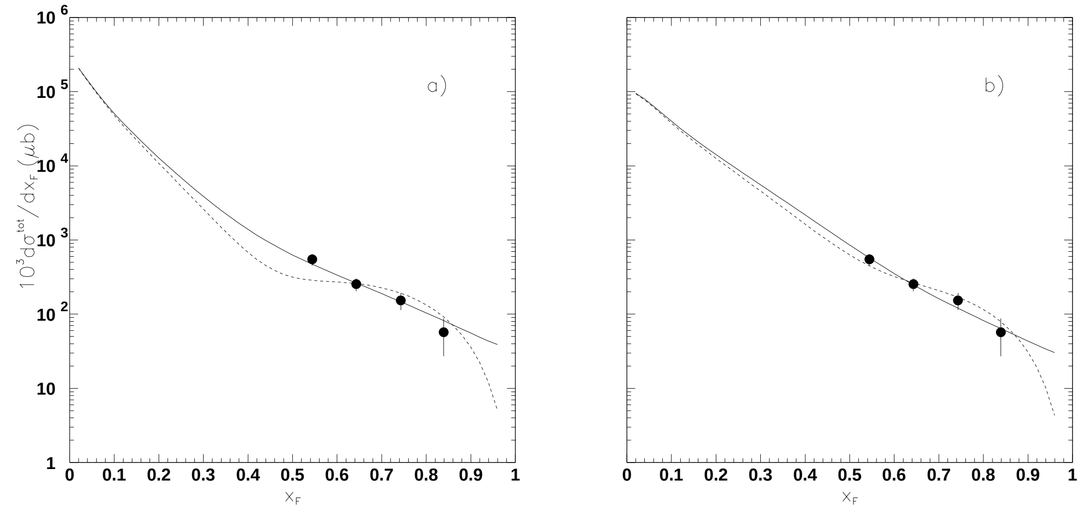

Figure 1: x_F distribution predicted by parton fusion plus recombination (full line) and parton fusion plus IC coalescence (dashed line) for Peterson fragmentation (a) and delta fragmentation function (b). Experimental data (black dots) are taken from ref. 3.

The inclusive production cross section of the Λ_c^+ is obtained by adding the contribution of recombination eq. 11 to the QCD processes of eq. 7, then

$$\frac{d\sigma^{tot}}{dx_F} = \frac{d\sigma^{pf}}{dx_F} + \frac{d\sigma^{rec}}{dx_F}. \tag{12}$$

The resulting inclusive Λ_c^+ production cross section $d\sigma^{tot}/dx_F$ is plotted in fig. 1 using the two fragmentation function of eqs. 5 and 6 and compared with experimental data in pp collisions from the ISR [3]. As we can see, the shape of the experimental data is very well described by our model. We use a factor $\sigma = 0.92(0.72)\mu bar$ for Peterson (delta) fragmentation respectively.

In a similar approach R. Vogt *et al.* [6] calculated the Λ_c^+ production in pp and πp collisions. The two component model used by them consists of a parton fusion mechanism plus coalescence of the intrinsic charm in the proton. Their results are shown in fig.1. The normalization however has been modified to make a proper comparison to our result.

Conclusions

We have studied the Λ_c^+ production in pp collisions with a two component model. We show that both the intrinsic charm model and the conventional recombination of quarks can describe the shape of the x_F distribution for Λ_c^+'s produced in pp collisions. None of them, however, can describe the abnormally high normalization of the ISR data quoted in ref. [3]. This discrepancy between theory and experiment does not exist for charmed

meson production, which is well described both in shape and normalization with the parton fusion mechanisn plus intrinsic charm coalescence [9] and with the conventional recombination as proposed here [14].
An interesting test to rule out one of the two models would come from a measurement of the Λ_c polarization as proposed in [15].

Acknowledgments

We would like to thank the organizers for financial support to participate in the I Simposium Latino Americano de Física de Altas Energías and for the kind hospitality extended to us during the event.

References

[1] E791 Collaboration (E.M. Aitala *et al.*), Phys. Lett. **B 371**,157 (1996).

[2] A.N. Aleev *et al.*, Z. Phys. **C 23**, 333 (1984), G. Bari *et al.*, Nuovo Cimento, **104 A**, 57 (1991).

[3] P. Chauvat *et al.* Phys. Lett. **B 199**, 304 (1987).

[4] S.F. Biagi *et al.*, Z. Phys. **C 28**, 175 (1985), G. Bari *et al.*, Nuovo Cimento **104 A**, 787 (1991), R. Werding, WA89 Collaboration, in proceeding of ICHEP94, Glasgow.

[5] NA3 Collaboration (J. Badier *et al.*), Z. Phys. **C 20**, 101 (1983).

[6] R. Vogt and S.J. Brodsky, Nucl. Phys. **B 478**, 311 (1996).

[7] S.J. Brodsky, P. Hoyer, C. Peterson and N. Sakai, Phys Lett. **B 93**, 451 (1980) and S.J. Brodsky, C. Peterson and N. Sakai, Phys. Rev. **D 23**, 2745 (1981).

[8] J. Babcock, D. Sivers and S. Wolfram, Phys. Rev. **D 18**, 162 (1978), B.L. Combridge, Nucl. Phys. **B 151**, 429 (1979), P. Nason, S. Dawson and R.K. Ellis, Nucl. Phys. **B 327**, 49 (1989), R.K. Ellis, Fermilab-Conf-89/168-T (198 9), I. Inchiliffe, Lectures at the 1989 SLAC Summer Institute, LBL-28468 (1989).

[9] R. Vogt, S.J. Brodsky and P. Hoyer, Nucl. Phys **B 383**, 643 (1992).

[10] M. Glük, E. Reya and A. Vogt, Z. Phys. **C 53**, 127 (1992).

[11] C. Peterson, D. Schlatter, J. Schmitt and P. Zerwas, Phys. Rev. **D 27**, 105 (1983).

[12] K.P. Das and R.C. Hwa, Phys. Lett. **B 68**, 459 (1977).

[13] J. Ranft, Phys. Rev. **D 18**, 1491 (1978).

[14] E. Cuautle, G. Herrera and J. Magnin in preparation.

[15] G. Herrera and L. Montano, *Phys. Lett.* **B 381** 337(1996), J. dos Anjos, G. Herrera, J. Magnin and F.R.A. Simão, in preparation.