

Asymmetry Studies in $\Lambda^0/\bar{\Lambda}^0$, Ξ^-/Ξ^+ and Ω^-/Ω^+ Production

J.C. Anjos, J. Magnin, F.R.A. Simão and J. Solano*

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

Abstract

We present a study on hyperon/anti-hyperon production asymmetries in the framework of the recombination model. The production asymmetries for $\Lambda^0/\bar{\Lambda}^0$, Ξ^-/Ξ^+ and Ω^-/Ω^+ are studied as a function of x_F . Predictions of the model are compared to preliminary data on hyperon/anti-hyperon production asymmetries in 500 GeV/c π^-p interactions from the Fermilab E791 experiment. The model predicts a growing asymmetry with the number of valence quarks shared by the target and the produced hyperons in the $x_F < 0$ region. In the positive x_F region, the model predicts constant asymmetries for $\Lambda^0/\bar{\Lambda}^0$ and Ω^-/Ω^+ production and a growing asymmetry with x_F for Ξ^-/Ξ^+ . We found a qualitatively good agreement between the model predictions and data, showing that recombination is a competitive mechanism in the hadronization process.

Key-words: Hyperons; Recombination; Leading particle effects.

* Supported by FAPERJ, Fundação de Amparo à Pesquisa do Estado de Rio de Janeiro.

I Introduction

In hadron interactions, the leading particle effect manifests as an enhancement in the production rate of particles which share valence quarks with the initial hadrons. As a consequence of the leading particle effect, strong asymmetries are expected in the $x_F (= 2p_L/\sqrt{s})$ inclusive differential cross sections for particles and anti-particles when the content of valence quarks shared by the produced particle and anti-particle with the initial hadrons is different.

This effect has been extensively studied, from both the experimental [1] and theoretical [2, 3] points of view in charm hadron production.

In the production of strange baryons, the same type of leading effects are expected. Indeed, there is some evidence of asymmetries in $\Lambda^0/\bar{\Lambda}^0$ production in π^- -Cu interactions at 230 GeV/c [4] and in $\Lambda^0/\bar{\Lambda}^0$ and Ξ^-/Ξ^+ production in 250 GeV/c π^-p interactions [5]. Some additional evidence for $\Lambda^0/\bar{\Lambda}^0$ asymmetry can be found in Ref. [6], but, in general, hyperon production asymmetries in π^-p interactions were not systematically studied until recently, when the Fermilab E791 experiment presented preliminary results on hyperon production in π^-p interactions at 500 GeV/c [7]. The E791 experiment has measured particle/anti-particle production asymmetries in both the small $x_F < 0$ and $x_F > 0$ regions for the $\Lambda^0/\bar{\Lambda}^0$, Ξ^-/Ξ^+ and Ω^-/Ω^+ hyperons.

The results obtained by the E791 experiment show a large asymmetry in the $x_F < 0$ region for $\Lambda^0/\bar{\Lambda}^0$ production and a lower asymmetry, in the same region, for Ξ^-/Ξ^+ production. In the $x_F > 0$ region, an approximately constant asymmetry with x_F is observed for Ξ^-/Ξ^+ and $\Lambda^0/\bar{\Lambda}^0$ hyperons. The asymmetry measured for Ω^-/Ω^+ production is approximately constant in the whole $-0.12 \leq x_F \leq 0.12$ region.

These results in the $x_F < 0$ region are consistent with the fact that Λ^0 hyperons share a ud diquark whereas the Ξ^- s share a d quark with the target particles (protons and neutrons), so a lower asymmetry is expected for the later since the Λ^0 is a double leading whereas the Ξ^- is a leading particle. In the $x_F > 0$ region, the Ξ^- share a d quark with the initial π^- , being a leading particle, while Ξ^+ shares none. Then a growing asymmetry with x_F is expected in Ξ^-/Ξ^+ production. The Λ^0 and $\bar{\Lambda}^0$ each have one valence quark in common with the beam π^- and, therefore, have equal enhancement i.e., no asymmetry is expected from this effect.

The Ω^-/Ω^+ hyperons are both non-leading in all the x_F regions studied and, consequently, no asymmetry is expected in Ω^-/Ω^+ production in π^-p interactions.

Due to the smallness of the strange quark mass and the p_T^2 values involved, hyperon production can not be accounted for in the usual framework of perturbative QCD.

The recombination scheme, initially introduced by Das and Hwa [8], appears to be a possible framework to deal with the non-perturbative QCD aspects involved in hadron and, in particular, in hyperon production. Indeed, this type of model has been used successfully to describe charmed particle/anti-particle asymmetries [3, 9] in hadroproduction.

In this work, we compare the predictions of a simple version of the recombination model on hyperon/anti-hyperon production asymmetries with the preliminary results of the E791 experiment. The good qualitative agreement found between model predictions and experimental data even at small values of x_F shows that it might be interesting to make efforts to improve the outcome of the model.

II Hyperon production by recombination in π^-p interactions

The recombination model was introduced long time ago by Das and Hwa [8] to describe meson production in hadron-hadron collisions. A simple extension of the model was made by Ranft [10]

to calculate baryon production. From those first attempts up to now, several modifications have been introduced trying to improve the outcome of the model [11]. Nevertheless, the recombination model remains a simple approach to deal with some non-perturbative aspects of QCD involved in hadron-hadron interactions.

The basic idea behind recombination is that the produced hadrons are formed from the debris of the fragmented beam (in the forward region) or target (in the backward direction) particles in such a way that partons initially in the incoming particles *recombine* into the final hadrons. All that is needed to deal with the problem is to know the distribution of partons in the initial particles, which are measured in Deep Inelastic Scattering experiments, and the so-called recombination function which will take into account all aspects involved in the recombination of partons into a hadron. Of course, the recombination function has a phenomenological origin, since no calculation from first principles is yet possible to obtain it.

For a generic hyperon H , the x_F inclusive distribution in recombination is given by

$$\frac{2E}{\sigma^{rec}\sqrt{s}} \frac{d\sigma^{rec}}{d|x_F|} = \int_0^1 \frac{dx_1}{x_1} \frac{dx_2}{x_2} \frac{dx_3}{x_3} F_3^H(x_1, x_2, x_3) R_3(x_1, x_2, x_3, x_F) , \quad (1)$$

where \sqrt{s} is the center of mass energy in the $\pi^-p \rightarrow H + X$ reaction, E is the energy of the outgoing hyperon and σ^{rec} is a normalization constant. In eq. (1), $F_3^H(x_1, x_2, x_3)$ is the three-quark distribution, which contains the distribution of valence quarks in the final particle inside the beam or target hadrons, $R_3(x_1, x_2, x_3, x_F)$ is the recombination function and x_i ; $i = 1, 2, 3$ is the momentum fraction of the i^{th} quark with respect to the initial particle.

Following the approach of Ref. [10], the three quark distribution function is assumed to be of the form

$$F_3^H(x_1, x_2, x_3) = \beta g(x_1, x_2, x_3) (1 - x_1 - x_2 - x_3)^\gamma , \quad (2)$$

where

$$g(x_1, x_2, x_3) = F_{q_1}(x_1) F_{q_2}(x_2) F_{q_3}(x_3) \quad (3)$$

contains the single quark distribution, $F_{q_i} = x_i q_i(x_i)$, of the q_i valence quark of the final hyperon in the initial particle. Note that F_{q_i} includes valence as well as sea quark contributions from the initial hadron. The coefficients β and γ are fixed using the consistency condition

$$F_q(x_i) = \int_0^{1-x_i} dx_j \int_0^{1-x_i-x_j} dx_k F_3^H(x_1, x_2, x_3) \quad (4)$$

$i, j, k = 1, 2, 3$

which must be valid for the valence quarks in the initial particle.

For the recombination function we use [13]

$$R_3(x_1, x_2, x_3) = \alpha \frac{(x_1 x_2)^{n_1} x_3^{n_2}}{x_F^{n_1+n_2-1}} \delta(x_1 + x_2 + x_3 - x_F) \quad (5)$$

allowing in this way a different weight for the heavier s (\bar{s}) quark than for the light u (\bar{u}) and d (\bar{d}) quarks.

The constant α in eq. (5) is fixed by the condition [14]

$$\frac{1}{\sigma^{rec}} \int_0^1 dx_F \frac{d\sigma^{rec}}{dx_F} = 1 , \quad (6)$$

then σ^{rec} is the recombination cross section of the hyperon H in $\pi^-p \rightarrow H + X$ in the forward ($x_F > 0$) or backward ($x_F < 0$) region. σ^{rec} may be fixed from experimental data.

Table 1: $g_H(x_1, x_2, x_3)$ and $g_{\bar{H}}(x_1, x_2, x_3)$ used in the calculation of asymmetries. q^n (\bar{q}^n) is the quark (anti-quark) distribution in nucleons, q^π (\bar{q}^π) is the quark (anti-quark) distribution in the π^- . The individual parton distributions were taken from Ref. [12].

	$x_F < 0.$		$0. < x_F$	
	$g_H(x_1, x_2, x_3)$	$g_{\bar{H}}(x_1, x_2, x_3)$	$g_H(x_1, x_2, x_3)$	$g_{\bar{H}}(x_1, x_2, x_3)$
$\Lambda^0/\bar{\Lambda}^0$	$u^n(x_1)d^n(x_2)s^n(x_3)$	$\bar{u}^n(x_1)\bar{d}^n(x_2)\bar{s}^n(x_3)$	$u^\pi(x_1)d^\pi(x_2)s^\pi(x_3)$	$\bar{u}^\pi(x_1)\bar{d}^\pi(x_2)\bar{s}^\pi(x_3)$
$\Xi^-/\bar{\Xi}^+$	$d^n(x_1)s^n(x_2)s^n(x_3)$	$\bar{d}^n(x_1)\bar{s}^n(x_2)\bar{s}^n(x_3)$	$d^\pi(x_1)s^\pi(x_2)s^\pi(x_3)$	$\bar{d}^\pi(x_1)\bar{s}^\pi(x_2)\bar{s}^\pi(x_3)$
$\Omega^-/\bar{\Omega}^+$	$s^n(x_1)s^n(x_2)s^n(x_3)$	$\bar{s}^n(x_1)\bar{s}^n(x_2)\bar{s}^n(x_3)$	$s^\pi(x_1)s^\pi(x_2)s^\pi(x_3)$	$\bar{s}^\pi(x_1)\bar{s}^\pi(x_2)\bar{s}^\pi(x_3)$

The asymmetry as a function of x_F is defined by

$$A(x_F) = \frac{d\sigma_H/d|x_F| - d\sigma_{\bar{H}}/d|x_F|}{d\sigma_H/d|x_F| + d\sigma_{\bar{H}}/d|x_F|} \quad (7)$$

where H is the Hyperon and \bar{H} is the anti-Hyperon.

Replacing eq. (1), with eqs. (2) to (6), into eq. (7) for the hyperons and anti-hyperons we obtain

$$A(x_F) = \frac{\int_0^{|x_F|} dx_1 \int_0^{|x_F|-x_1} dx_2 [g_H(x_1, x_2, x_3) - \sigma g_{\bar{H}}(x_1, x_2, x_3)]}{\int_0^{|x_F|} dx_1 \int_0^{|x_F|-x_1} dx_2 [g_H(x_1, x_2, x_3) + \sigma g_{\bar{H}}(x_1, x_2, x_3)]}$$

$$x_3 = |x_F| - x_1 - x_2 \quad (8)$$

with $\sigma = \sigma^{\bar{H}}/\sigma^H$ the relative normalization between the hyperon and anti-hyperon distributions. The delta function of eq. (5) has been used to do one of the integrals in eq. (8).

As in Ref. [13], we have used $n_1 = 1$, $n_2 = 3/2$ and $\gamma = -0.3$ in our calculations.

In Figs. 1 and 2 we show the predictions of the recombination model compared to the E791 measurements. In order to obtain the theoretical curves shown in the figures, the asymmetry as given by eq. (8) has been calculated for each x_F region independently. In Table 1, the g_H and $g_{\bar{H}}$ distributions used in each region and for each one of the produced hyperons and anti-hyperons are displayed. The relative normalization between the particle and anti-particle x_F distributions, σ , has been chosen to fit the experimental data (See Table 2).

For $\Omega^-/\bar{\Omega}^+$ production, since both hyperon and anti-hyperon are non-leading in the $x_F < 0$ as well as in the $x_F > 0$ regions, the recombination model predicts a constant asymmetry arising only from the difference between the global normalization of the particle and anti-particle x_F distributions.

Table 2: Relative normalization, σ , between hyperon and anti-hyperon cross sections

	$x_F < 0.$	$0. < x_F$
$\Lambda^0/\bar{\Lambda}^0$	3.5	0.8
$\Xi^-/\bar{\Xi}^+$	1.9	2.2
$\Omega^-/\bar{\Omega}^+$	0.85	0.85

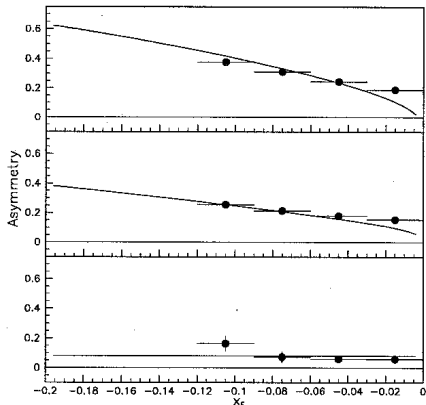


Figure 1: $\Lambda^0/\bar{\Lambda}^0$ (upper), Ξ^-/Ξ^+ (middle) and Ω^-/Ω^+ (lower) asymmetries as a function of x_F in the negative x_F region. Full line is the prediction from recombination model. Black dots are the preliminary E791 results taken from Ref. [7].

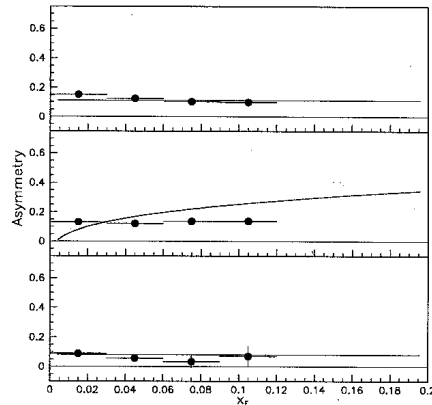


Figure 2: $\Lambda^0/\bar{\Lambda}^0$ (upper), Ξ^-/Ξ^+ (middle) and Ω^-/Ω^+ (lower) asymmetries as a function of x_F in the positive x_F region. Full line is the prediction from recombination model. Black dots are the preliminary E791 results taken from Ref. [7].

III Conclusions

As can be seen in Figs. 1 and 2, the predictions of the recombination model agree qualitatively well with the experimental data.

In the negative x_F region, the growth of the asymmetry predicted by the model with the number of valence quarks shared by the leading hyperons and the target particles is in a remarkable agreement with the E791 data. In this region, the asymmetry as a function of x_F is also qualitatively well described by the model. The agreement between data and model predictions is better as $|x_F|$ rises. This is possibly due to the fact that, at very low values of $|x_F|$, other mechanisms than recombination are competitive in the hadronization.

In the positive x_F region, although the leading effect in Ξ^-/Ξ^+ production is qualitatively accounted for by the model, in general, the agreement between data and recombination model predictions is poorer than in the negative x_F region. Note, however, that the quark distributions in pions are not as well known as in nucleons, being one of the possible causes of the discrepancies between model prediction and data in this region.

The asymmetry predicted for Ω^-/Ω^+ production is constant over all the x_F region under study. This is consistent with the fact that the Ω^- and the Ω^+ are both non-leading particles over the whole x_F region from -1 to 1 .

In conclusion, the recombination model, although simple, is able to reproduce qualitatively the behaviour of the experimental data on hyperon/anti-hyperon asymmetries, so it might be possibly of interest to make efforts in order to improve the outcome of the model.

For a meaningful quantitative comparison between data and model predictions, however, the individual inclusive x_F distributions for leading and non-leading particles must be taken into account.

Acknowledgements

Two of us, J.C.A. and F.R.A.S. would like to thank the organizing committee and the Centro Latino Americano de Física, CLAF, for financial support to attend the SILAF AE II. The authors also would like to acknowledge J.A. Appel, B. Meadows and D.A. Sanders for useful comments.

References

- [1] WA92 Collaboration (M. Adamovich *et al.*), Nucl. Phys. **B495**, 3 (1997); E791 Collaboration (E.M. Aitala *et al.*), Phys. Lett. **B371**, 157 (1996); E769 Collaboration (G. A. Alves *et al.*), Phys. Rev. Lett. **77**, 2388 (1996) and Phys. Rev. Lett. **72**, 812 (1994); WA82 Collaboration (M. Adamovich *et al.*), Phys. Lett. **B305**, 402 (1993),
- [2] R. Vogt and S.J. Brodsky, Nucl. Phys. **B478**, 311 (1996)
- [3] G. Herrera and J. Magnin, Eur. Phys. J. **C2**, 477 (1998), E. Cuautle, G. Herrera and J. Magnin, *ibid.* 473.
- [4] S. Barlag *et al.*, Phys. Lett. **B325**, 531 (1994).
- [5] D. Bogert *et al.*, Phys. Rev. **D16**, 2098 (1977).
- [6] S. Mikocki *et al.*, Phys. Rev. **D34**, 42 (1986), R.T. Edwards *et al.*, Phys. Rev. **D18**, 76, (1978) and N.N. Biswas, Nucl. Phys. **B167**, 41 (1980).
- [7] E791 Collaboration and J. Solano, J. Magnin and F.R.A. Simão, Fermilab-Conf-97/368-E and CBPF-NF-No 072/97, to be published in the RANP97 proceedings (hep-ex/9710033).
- [8] K.P. Das and R.C. Hwa, Phys. Lett. **B68**, 459 (1977).
- [9] R.C. Hwa, Phys. Rev. **D51**, 85 (1995).
- [10] J. Ranft, Phys. Rev. **D18**, 1491 (1978).
- [11] E. Takasugi and X. Tata, Phys. Rev. **D23**, 2573 (1981), R.C. Hwa, Phys. Rev. **D22**, 759 (1980), R.C. Hwa, Phys. Rev. **D22**, 1593 (1980).
- [12] R.D. Field and R.P. Feynman, Phys. Rev. **D15**, 2590 (1977).
- [13] G. Herrera, J. Magnin, Luis M. Montaño and F.R.A. Simão, Phys. Lett. **B382**, 201 (1996).
- [14] J.C. Anjos, G. Herrera, J. Magnin and F.R.A. Simão, Phys. Rev. **D56**, 394 (1997).