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$\Lambda_c/\overline{\Lambda}_c$ production asymmetries in pp and $\pi^- p$ collisions

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Abstract

We study $\Lambda_c/\overline{\Lambda}_c$ production asymmetries in pp and $\pi^- p$ collisions using a recently proposed two component model, which includes heavy baryon production by the usual mechanism of parton fusion and fragmentation plus recombination of valence and sea quarks from the beam and target hadrons. We compare our results with experimental data on asymmetries measured recently.

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

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1 Introduction

It is commonly accepted that charmed hadron production in hadronic interactions can not be explained by parton fusion alone. In fact, there is an important number of experimental indications that non perturbative phenomena occurs in addition to the parton fusion (perturbative) processes $q\bar{q} \to c\bar{c}$ and $gg \to c\bar{c}$ [1, 2].

One of the most notable experimental observation that supports the above statement is the leading effect in charmed hadron production in hadronic interactions. This effect is expected to appear also in beauty hadroproduction.
The leading effect manifests as an enhancement in the x_F distribution of particles that share valence quarks compared to the x_F distribution of particles that have no valence quarks in common with the initial hadrons.
A clear consequence of this effect is the large asymmetries observed in particle *vs* anti-particle production in hadron hadron collisions.

The above mentioned experimental results have been described by making use of models in which some non perturbative production mechanism is added to parton fusion processes. Among them it can be mentioned the model proposed by V.G. Kartvelishvili *et al.* [3], the intrinsic charm two component model [4] and the Lund string fragmentation model, which was implemented in the PYTHIA Monte Carlo program [5]. More recently it has been shown that a two component model combining the perturbative QCD processes of parton fusion and the recombination of the valence and sea quarks originally present in the initial hadrons describes very well the shape of the x_F inclusive distribution of Λ_cs produced in pp collisions [6].

In this paper, we give the predictions of the recombination two component model, where the non perturbative contribution is given by conventional recombination, for $\Lambda_c/\overline{\Lambda}_c$ production asymmetries in pp and $\pi^- p$ interactions. We compare the obtained result with recent measurements of the $\Lambda_c/\overline{\Lambda}_c$ asymmetry in pp [7] and $\pi^- p$ [8] collisions.

2 Λ_c and $\overline{\Lambda}_c$ production *via* parton fusion

In this section we briefly review $\Lambda_c/\overline{\Lambda}_c$ production in hadron hadron collisions by the usual mechanism of parton fusion followed by fragmentation. The calculation we present here is at Lowest Order (LO) in α_s. A constant factor $K \sim 2-3$ is included in the parton fusion cross section to take into account Next to Leading Order (NLO) contributions [9].

The inclusive $x_F\,(= 2p_L/\sqrt{s})$ distribution for Λ_c production in hadron hadron interactions, assuming factorization, has the form [10]

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

where

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

with x_a and x_b the parton momentum fractions in the inital hadrons A and B, $q(x, Q^2)$ and $g(x, Q^2)$ the quark and gluon distribution in the corresponding colliding hadrons, E the energy of the produced $c\,(\bar{c})$-quark and $D_{\Lambda_c/c}(z)$ the appropriated fragmentation function. In eq. 1, p_T^2 is the squared transverse momentum of the produced $c\,(\bar{c})$-quark, y is the rapidity of the $\bar{c}\,(c)$ quark and $z = x_F/x_c$ is the momentum fraction of the charm quark carried by the $\Lambda_c\,(\overline{\Lambda}_c)$. The sum in eq. 2 runs over $a, b = u, \bar{u}, d, \bar{d}, s, \bar{s}$. $d\hat{\sigma}/d\hat{t}\mid_{q\bar{q}}$ and $d\hat{\sigma}/d\hat{t}\mid_{gg}$ are the elementary cross sections for the hard processes $q\bar{q} \to c\bar{c}$ and $gg \to c\bar{c}$ calculated at LO. For consistency with the LO calculation, we use the GRV-LO parton distributions for both the proton [11] and the pion [12]. The hard momentum scale is fixed at $Q^2 = 2m_c^2$.

The fragmentation will be modeled by two different functions; the Peterson fragmentation function extracted from data in e^+e^- interactions [13]

$$D_{\Lambda_c/c}(z) = \frac{N}{z\left[1 - 1/z - \epsilon_c/(1-z)\right]^2} \qquad (3)$$

with $\epsilon_c = 0.06$ and the delta fragmentation function

$$D_{\Lambda_c/c}(z) = \delta(1 - z). \qquad (4)$$

The use of the delta fragmentation function implies that the Λ_c is produced with the same momentum carried by the fragmented c-quark. This mechanism for fragmentation has been used to simulate the coalescence of the c-quark, produced in a hard interaction, with light valence quarks coming from the initial hadrons [4].

3 Λ_c and $\overline{\Lambda}_c$ production *via* recombination

In pp interactions, Λ_cs are produced in both the beam ($x_F > 0$) and target fragmentation ($x_F < 0$) regions through the recombination of an ud-valence diquark with a c-sea quark.

This is a Valence-Valence-Sea (VVS) recombination process. On the other hand, $\overline{\Lambda}_c$s are produced by the recombination of the $\bar{u}$, $\bar{d}$ and $\bar{c}$-sea quarks of the proton, *i.e.* by Sea-Sea-Sea recombination (SSS). The invariant x_F distribution for the Λ_c *via* recombination in the reaction $p + p \to \Lambda_c + X$ is,

$$\frac{2E}{\sqrt{s}\sigma}\frac{d\sigma^{rec}}{dx_F} = \int_0^{x_F} \frac{dx_1}{x_1}\frac{dx_2}{x_2}\frac{dx_3}{x_3} F_3\left(x_1, x_2, x_3\right) R_3\left(x_1, x_2, x_3, x_F\right) \tag{5}$$

where

$$R_3\left(x_u, x_d, x_c\right) = \alpha \frac{x_u x_d x_c}{x_F^2} \delta\left(x_u + x_d + x_c - x_F\right) \tag{6}$$

is the recombination function and

$$F_3\left(x_1, x_2, x_3\right) = \beta_p F^p_{u,val}\left(x_1\right) F^p_{d,val}\left(x_2\right) F^p_{c,sea}\left(x_3\right)\left(1 - x_1 - x_2 - x_3\right)^{\gamma_p} \tag{7}$$

is the three quark distribution in the proton [14]. In eq. 7, $F^p_q\left(x_i\right) = x_i q\left(x_i\right)$ $1 \leq i \leq 3$ are the single quark distributions in the proton with F^p_u normalized to one valence u-quark. The constants $\beta_p = 75$ and $\gamma_p = -0.1$ [6] are fixed by the consistency condition

$$\begin{aligned} F_q\left(x_i\right) \quad = \quad & \int_0^{1-x_i} dx_j \int_0^{1-x_i-x_j} dx_k \, F_3\left(x_1, x_2, x_3\right), \\ & i, j, k = 1, 2, 3 \, . \end{aligned} \tag{8}$$

The three quark distribution of eq. 7 depends on Q^2 through the dependence on Q^2 of the single quark distributions. We take $Q^2 = 4m_c^2$ as the recombination scale [6].

The constant α in eq. 6 was fixed at the ISR energy $\sqrt{s} = 63$ GeV in ref. [6] using the condition

$$\frac{1}{\sigma}\int_0^1 dx_F \frac{d\sigma^{rec}}{dx_F} = 1 \, . \tag{9}$$

In this way a value for α was found and σ was interpreted as the Λ_c recombination cross section at the ISR energy.

In order to obtain the recombination cross section at different energies we assume that the ratio of the parton fusion to recombination cross sections is independent of the energy. This assumption is supported by the experimental fact that no energy dependence has been observed in hadron anti-hadron production asymmetries.

We will assume that $\overline{\Lambda}_c$ production by recombination is negligible compared to Λ_c. This is a reasonable hypothesis since, in *pp* collisions, the first is produced in SSS recombination processes while the later proceeds through VVS recombination.

Λ_c ($\overline{\Lambda}_c$) production by recombination in $\pi^- p$ collisions is different in the beam than in the target fragmentation region. Indeed, in the target fragmentation region, the mechanism for Λ_c and $\overline{\Lambda}_c$ production is the same than in the case of pp interactions since they are formed from the debris of the proton. Then, Λ_c production by recombination in the target fragmentation region is described by eqs. 5, 6 and 7 with the same normalization than in pp collisions.
We neglect $\overline{\Lambda}_c$ production as it was done in pp collisions and it is assumed that the recombination function is the same for both pp and $\pi^- p$ interactions.

On the other hand, in the (π^-) beam fragmentation region, both Λ_cs and $\overline{\Lambda}_c$s are produced through VSS recombination processes. Since $\bar{u}$ and d valence and sea quark and anti-quark distributions in pions are equal [12], at least up to our actual knowledge of the pion structure, Λ_cs and $\overline{\Lambda}_c$s are produced at the same rate.

The inclusive x_F distributions for Λ_cs and $\overline{\Lambda}_c$s in the pion fragmentation region are given by expressions formally identical to eq. 5 with the obvious replacement of the corresponding single quark distributions. The normalization of the $\Lambda_c/\overline{\Lambda}_c$ x_F distributions must be fixed from experimental data.

4 $\Lambda_c/\overline{\Lambda}_c$ production asymmetry

The total inclusive x_F distributions are obtained by adding the contributions of parton fusion, eq. 1, to recombination, eq. 5. Then in pp collisions we have

$$\frac{d\sigma^{tot}}{dx_F}\mid_{\Lambda_c}=\frac{d\sigma_p^{pf}}{dx_F}+\frac{d\sigma_p^{rec}}{dx_F} \tag{10}$$

and

$$\frac{d\sigma^{tot}}{dx_F}\mid_{\overline{\Lambda}_c}=\frac{d\sigma_p^{pf}}{dx_F} \tag{11}$$

in the entire interval $-1 \leq x_F \leq 1$. The parton fusion cross sections evaluated at LO are equal for both Λ_c and $\overline{\Lambda}_c$. It must be noted that at NLO a small asymmetry appears in Λ_c and $\overline{\Lambda}_c$ production since to this order in perturbation theory the cross section for the production of a quark differs from the cross section for the production of an antiquark [10]. However, this asymmetry is too small to account for the observed leading effect.

On the other hand, in $\pi^- p$ interactions, the total inclusive distributions for Λ_c and $\overline{\Lambda}_c$ are given by

$$\frac{d\sigma^{tot}}{dx_F}\mid_{\Lambda_c(\overline{\Lambda}_c)}=\frac{d\sigma_\pi^{pf}}{dx_F}+\frac{d\sigma_\pi^{rec}}{dx_F} \tag{12}$$

in the π^- fragmentation region and

$$\frac{d\sigma^{tot}}{dx_F}\Big|_{\Lambda_c} = \frac{d\sigma_\pi^{pf}}{dx_F} + \frac{d\sigma_p^{rec}}{dx_F} \tag{13}$$

$$\frac{d\sigma^{tot}}{dx_F}\Big|_{\overline{\Lambda}_c} = \frac{d\sigma_\pi^{pf}}{dx_F} \tag{14}$$

in the target fragmentation region because of the difference on the production mechanisms between the two regions.

The asymmetry parameter is defined as

$$A_{L/NL}^{AB}(x_F) = \frac{d\sigma_L/dx - d\sigma_{NL}/dx}{d\sigma_L/dx + d\sigma_{NL}/dx}\,, \tag{15}$$

where $d\sigma_L/dx$ and $d\sigma_{NL}/dx$ are the Leading and Non Leading inclusive x_F distributions, the indices A and B indicate the beam and target colliding hadrons respectively and $N(NL)$ are the produced Leading (Non Leading) particles.

Λ_cs produced in *pp* collisions are leading in the whole interval $-1 \leq x_F \leq 1$ whereas $\overline{\Lambda}_c$ are non leading, then a growing asymmetry with $|x_F|$ is expected. The asymmetry for $\Lambda_c/\overline{\Lambda}_c$ in *pp* collisions is given by

$$A^{pp}_{\Lambda_c/\overline{\Lambda}_c}(x_F) = \frac{d\sigma_p^{rec}/dx_F}{2d\sigma_p^{pf}/dx_F + d\sigma_p^{rec}/dx_F}\,. \tag{16}$$

In order to compare our result with available experimental data, we define an integrated asymmetry in the interval $x_0 \leq x_F \leq x_1$ by an analogue formula to that of eq. 15 in which the x_F inclusive distributions are integrated over the above mentioned x_F region. The E769 experiment [7] found a lower limit of 0.6 on the integrated asymmetry in *pp* collisions at 250 GeV in the beam fragmentation region. This lower limit indicates a quite pronounced enhancement of Λ_c over $\overline{\Lambda}_c$ production, which in the framework of our model implies that the Λ_c recombination cross section must be at least three times the corresponding parton fusion cross section in the forward hemisphere.

Fig. 1 shows the asymmetry prediction for the recombination cross section normalization given in ref. [6] and $\sigma^{rec} = 3\sigma^{pf}$, as indicated by the lower limit obtained in the E769 experiment, for both Peterson and delta fragmentation.

In $\pi^- p$ interactions an asymmetry is expected in the target fragmentation region, where Λ_cs are leading. No asymmetry is expected in the beam fragmentation region in which Λ_cs and $\overline{\Lambda}_c$s are produced at the same rate *via* recombination.

The $\Lambda_c/\overline{\Lambda}_c$ production asymmetry in $\pi^- p$ collisions is given by a formula formally identical to that of eq. 16, in which the pp parton fusion cross section must be replaced by the corresponding $\pi^- p$ one, in the interval $-1 \leq x_F \leq 0$. In the region $0 \leq x_F \leq 1$, zero asymmetry is obtained with the convencional recombination scheme within the two component model.

The prediction of our model in the forward region is consistent with the ratio $N(\Lambda_c)/N(\overline{\Lambda}_c) = 0.99 \pm 0.16$ measured by the ACCMOR Collaboration [15], which indicates no asymmetry. Also a preliminary analysis from the E791 Collaboration [8] shows an asymmetry consistent with zero for $0 \leq x_F \leq 0.55$.
In the backward region, the same E791 data set shows a high asymmetry, reaching a value of the order of 40% at $x_F \simeq -0.13$ but with large errors. The ratio $N(\Lambda_c)/N(\overline{\Lambda}_c) = 1.17 \pm 0.08$ measured by the E791 Collaboration in the whole interval $-0.13 \leq x_F \leq 0.55$ is described by our model but taken the normalization of the recombination component as $\sigma^{rec} = 1.25\sigma^{pf}$.

In fig. 2 the asymmetry for $\Lambda_c/\overline{\Lambda}_c$ production obtained in $\pi^- p$ interactions is shown for both Peterson and delta fragmentation functions with the two different normalization for the recombination cross section in the backward region as discussed in the case of pp interactions. The asymmetry curve with the recombination normalization suggested by the E791 preliminary results is between the curves corresponding to the two normalization shown slightly closer to the upper one.

5 Summary and discussion

In this work we have studied the asymmetries in $\Lambda_c/\overline{\Lambda}_c$ production in pp and $\pi^- p$ collisions within the recently proposed scheme of conventional recombination in a two component model [6].

This two component model describes charmed hadron production as the superposition of two mechanisms: parton fusion and the recombination of valence and sea quarks originally present in the initial hadrons.

Assuming that Λ_cs are produced by a mixture of parton fusion and recombination and that $\overline{\Lambda}_c$s are produced through parton fusion alone, we have obtained the asymmetries for two different normalizations of the recombination component. The experimental evidence of a high $\Lambda_c/\overline{\Lambda}_c$ asymmetry in the forward region in pp interactions [7] is consistent with a high contribution of recombination. Such high asymmetry has been observed also in $\Lambda_c/\overline{\Lambda}_c$ production in $\pi^- p$ collisions [8] in the backward region at small values of x_F.

Our model can account for high asymmetries in a completely natural way. In effect, taking a recombination contribution as high as three times the parton fusion cross section, the model gives an integrated asymmetry of the order of the lower limit found in the E769 experiment [7] for the $\Lambda_c/\overline{\Lambda}_c$ asymmetry in pp collisions and still it can fit the ISR Λ_c production at the center of mass energy $\sqrt{s} = 63$ GeV [2] diminishing the global normalization factor used in ref. [6] to a value around 10.

It is important to note that, although all models can give similar predictions for the $\Lambda_c/\overline{\Lambda}_c$ asymmetry in pp and $\pi^- p$ collisions, all of them predict different x_F distributions as was shown in refs. [4, 6]. So, in order to do a meaningful comparison between model predictions and experimental data, both asymmetry and x_F distributions of leading and non leading particles must be taken into account.

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References

[1] E791 Collaboration (E.M. Aitala *et al.*), Phys. Lett. **B 371**,157 (1996); A.N. Aleev *et al.*, Z. Phys. **C 23**, 333 (1984); G. Bari *et al.*, Nuovo Cimento, **104 A**, 57 (1991) and Nuovo Cimento **104 A**, 787 (1991); S.F. Biagi *et al.*, Z. Phys. **C 28**, 175 (1985); R. Werding, WA89 Collaboration, in proceedings of ICHEP94, Glasgow

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

[3] V.G. Kartvelishvili, A.K. Likhoded and S.R. Slobospitskii, Sov. J. Nucl. Phys. **33**, 434 (1981), V.A. Bednyakov, Mod. Phys. Lett. **A 10**, 61 (1995).

[4] R. Vogt and S.J. Brodsky, Nucl. Phys. **B 478**, 311(1996), R. Vogt, S.J. Brodsky and P. Hoyer, Nucl. Phys **B 383**, 643 (1992).

[5] T. Sjöstrand, Comput. Phys. Commun **39**, 347 (1986) and T. Sjöstrand and M. Bengtsson, Comput. Phys. Commun **43**, 367 (1987).

[6] J. dos Anjos, G. Herrera, J. Magnin and F.R.A. Simão, hep No.: hep-ph 9702256, submited to Phys. Rev. **D** and talk presented at the 1^{st} Latin American Symposium

on High Energy Physics, I SILAFAE, Mérida, México, October 30^{th} - November 3^{rd}, 1996, hep No.: hep-ph 9702257, to be published in proceedings.

[7] E769 Collaboration (G. Alves *et al.*), Phys. Rev. Lett. **77**, 2388 (1996).

[8] A.M. Halling, Il Nuovo Cim. **109 A**, 617 (1996) and S. Kwan (E791 Collaboration), private communication.

[9] R. Vogt, Z. Phys. **C 71**, 475 (1996).

[10] 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. **N 327**, 49 (1989), R.K. Ellis, Fermilab-Conf-89/168-T (1989), I. Inchiliffe, Lectures at the 1989 SLAC Summer Institute, LBL-28468 (1989).

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

[12] M. Glük, E. Reya and A. Vogt, Z. Phys. **C 53**, 651 (1992).

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

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

[15] ACCMOR Collaboration (S. Barlag *et al.*), Phys. Lett. **B 247**, 113 (1990).

Figure Captions

Fig. 1: $\Lambda_c/\overline{\Lambda}_c$ asymmetries in pp interactions for Peterson (full line) and delta fragmentation function (dashed line). The thin lines are the corresponding predictions for the recombination normalization given in ref. [6], the thick lines are the predictions with a normalization of $\sigma^{rec} = 3\sigma^{pf}$ (see discusion in the text).

Fig. 2: Same as in Fig. 1 for $\pi^- p$ interactions

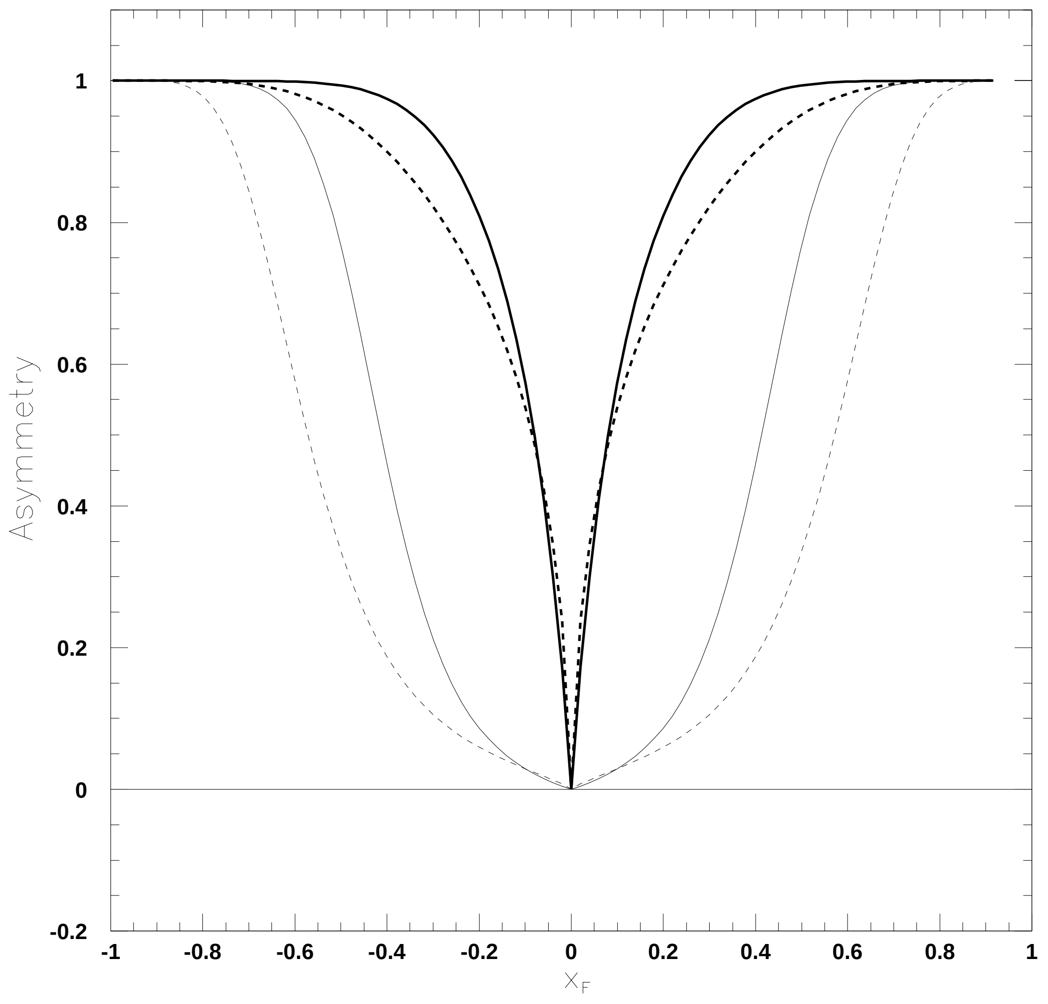

Figure 1:

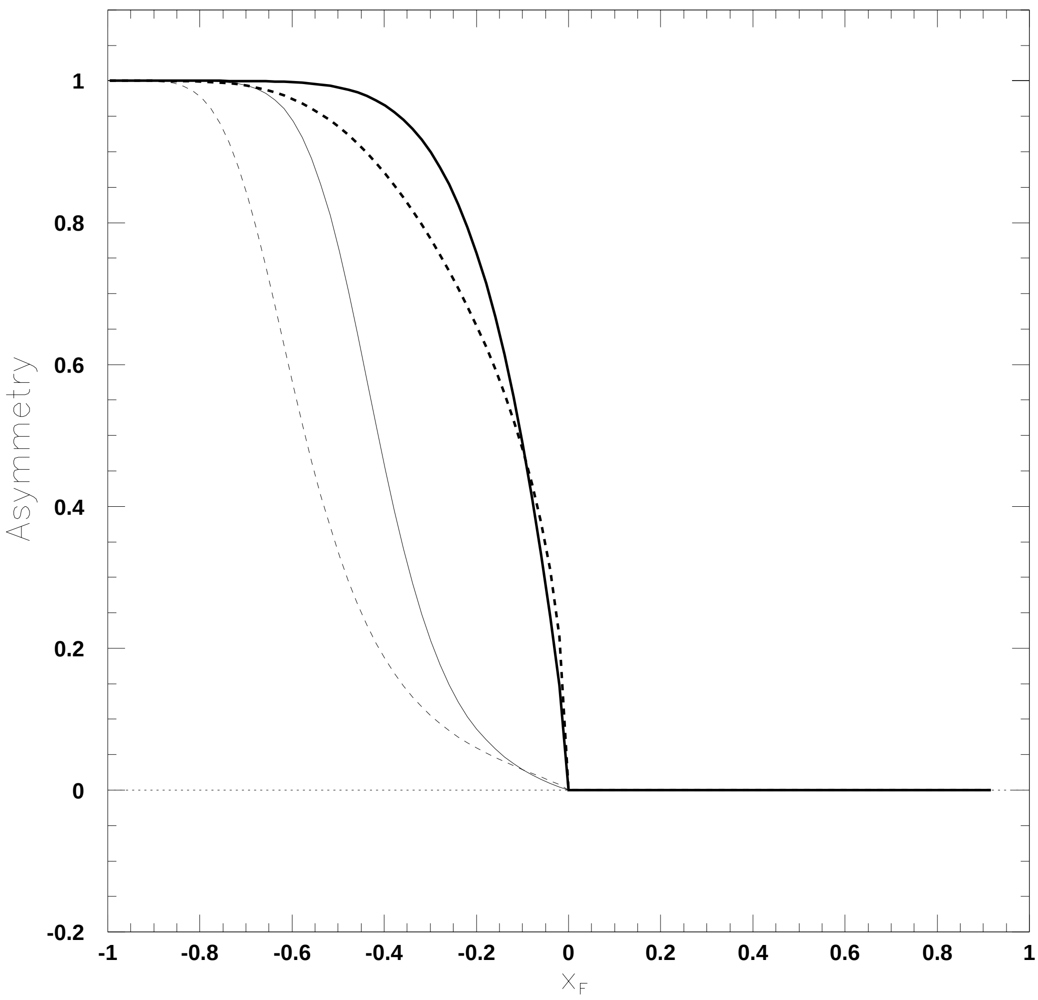

Figure 2: