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of Charmed Hadrons

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Spin Effects in Hadroproduction of Charmed Hadrons

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Abstract. We review the results on spin effects in the inclusive production of $D^{*+}(2010)$ and Λ_c^+ based on the CERN NA32 data. The spin alignment parameter of $D^{*+}(2010)$ meson is measured to be $\eta = 0.10_{-0.11}^{+0.12} \pm 0.01$. The angular distribution of decay products in the Gottfried-Jackson frame is consistent with the quark model assignment for Λ_c^+ spin. For Λ_c^+ $p_T > 1.1$ GeV/c, the product of the Λ_c^+ transverse polarization and the kaon type asymmetry for $\Lambda_c^+ \rightarrow pK^-\pi^+$ is measured to be $\alpha_K P_{\Lambda_c} = -0.65_{-0.18}^{+0.22}$ (anti-Basel). The Λ^0 polarization in the same experiment is measured to be $-0.28 \pm 0.09 \pm 0.02$ (Basel), for Λ^0 $p_T > 1$ GeV/c.

INTRODUCTION

Currently, in the charm sector, there are two particles² with nonzero spin for studying spin effects via exclusive decay channels with reasonable statistics. These are $D^{*+}(2010)$ and Λ_c^+ , with quark model assignments $J^P = 1^-$ and $J^P = \frac{1}{2}^+$, respectively. In both cases the spin measurements are lacking³ and studies of spin effects with these particles assume their quark model spin assignment.

This paper reviews the results of spin effects in the inclusive hadroproduction of $D^{*+}(2010)$ and Λ_c^+ . The results are based on data from the CERN NA32 fixed Cu target experiment, using the 230 GeV/c π^- beam, described elsewhere [Ref.(1)]. In addition, other spin effects involving charmed hadrons are listed.

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²Throughout the paper a charmed particle symbol stands for particle and antiparticle, i.e. any reference to a specific state implies the charge-conjugate state as well.

³In this paper we review the results on the measurement of the Λ_c^+ spin with the use of the $\Lambda_c^+ \rightarrow pK^-\pi^+$ channel.

THE $D^{*+}(2010)$ MESON [Ref.(2)]

The $D^{*+}(2010)$ sample consisted of 127 events. Using the same selection criteria 20 wrong sign events were found. The angular distribution for the $D^{*+}(2010) \rightarrow D^0 \pi_{ext}^+$ decay is given by

$$I(x) = \frac{1}{2} [1 + d_2 P_2(x)] \equiv \frac{1}{2} + \eta P_2(x), \quad (1)$$

where $P_2(x)$ is the second Legendre polynomial, $\eta = (3\rho_{00} - 1)/2$ is the spin alignment parameter, and the variable $x \equiv \cos \theta_{hel}$ stands for the cosine of the angle between the D^{*+} direction in the laboratory frame and the π_{ext}^+ direction in the D^{*+} rest frame.

The results of the maximum-likelihood fit, with the background subtracted, for the whole sample is $\eta = 0.10_{-0.11}^{+0.12} \pm 0.01$ [Ref.(2)]. In four equally populated subsamples, differing in x_F and p_T cuts, the spin alignment parameter η is consistent with zero.

The relative abundance of vector mesons $P_V^\sigma = V/(P + V)$, where P and V stands for the cross sections for the production of D^+ and $D^{*+}(2010)$ mesons, may be calculated using η within the statistical assumption (namely, for the spin dependent hadronization of the c quark combining with the sea antiquark to form a meson [Ref.(3)]). The P_V calculated within this picture

$$P_V^\eta = \frac{3}{4(1 - \eta)}, \quad (2)$$

should be equal to that from the cross section measurements, i.e. $P_V^\sigma = P_V^\eta$.

This simple picture works for a number of different production processes for π^0/ρ^0 and K_s^0/K^{*0} systems (see Ref.(4) for references). The only other measurements of the spin alignment parameter for the $D^{*+}(2010)$ come from e^+e^- collisions [Refs.(4), (5)]. For charm mesons the (e^+e^-) average, recalculated using the latest charm branching fractions (see Ref.(2) for details), is $P_V^\sigma = 0.70 \pm 0.07$, which is consistent with $P_V^\eta = 0.77 \pm 0.02 \pm 0.01$ [Ref.(4)]. Hence the e^+e^- results for charm mesons agree well with the statistical approach.

The measured spin alignment $\eta = 0.10_{-0.11}^{+0.12} \pm 0.01$ gives $P_V^\eta = 0.83_{-0.10}^{+0.11} \pm 0.01$, which is inconsistent with the directly measured values of P_V^σ . The NA32 $\sigma(D^+)$ and $\sigma(D^{*+})$ cross sections yield $P_V^\sigma = 0.47 \pm 0.11$, and similarly using the same branching fractions, one obtains $P_V^\sigma = 0.46$ with a comparable error from the recent measurements of the E653 collaboration in $\pi^- Emuls.$ interactions at 600 GeV/c [Ref.(6)].

There is a definite discrepancy between P_V^η and P_V^σ for hadroproduction. A possible explanation is that contrary to the other processes, the hadroproduction of the $D^{*+}(2010)$ proceeds mainly via the decays of higher D^{**} mesons.

THE Λ_c^+ BARYON

The Λ_c^+ is the lowest mass charmed baryon and decays weakly. A natural decay channel to study production/decay spin effects for Λ_c^+ is the two-body channel $\Lambda_c^+ \rightarrow \Lambda^0 \pi^+$. There are interesting results from studies of the decay spin effects, namely the weak-cascade decay of an unpolarized $\Lambda_c^+ \rightarrow \Lambda^0 \pi^+ \rightarrow (p\pi^-)\pi^+$. A negative asymmetry $\alpha_{\Lambda_c^+}^{NL}$ of $-1.0_{-0.0}^{+0.4}$ and -0.96 ± 0.42 has been observed in this decay by CLEO and ARGUS [Ref.(7)], respectively. A similar cascade was used to measure the decay asymmetry parameter in the semileptonic decay of $\Lambda_c^+ \rightarrow \Lambda^0 l^+ \nu_l$, giving $\alpha_{\Lambda_c^+}^{SL}$ equal to $-0.89_{-0.11}^{+0.17+0.09}$ and -0.91 ± 0.49 from CLEO and ARGUS [Ref.(8)], respectively. The branching ratios for the above channels are few times smaller than for $\Lambda_c^+ \rightarrow pK^-\pi^+$ (being of order of 4% only). Besides that, the $\Lambda_c^+ \rightarrow pK^-\pi^+$ channel has a much better experimental signature than the above mentioned channels.

In the rest frame of the decaying particle, the angular orientation of the back-to-back two-body decay is specified by one direction only. For the three-body decay, the momenta of the final particles are bound to the decay plane, thus the three-body angular orientation is fixed by two directions that specify the decay plane and the rotation within it. These two directions may be chosen as: the normal to the decay plane and the direction of a final particle, or just the two directions of final particles. Thus, the resulting angular decay distributions have different decay coefficients, depending on the angular parameterization of the final state.

For the spin measurement, and the polarization & decay asymmetry studies the practically background free sample of 121 $\Lambda_c^+ \rightarrow pK^-\pi^+$ events with positive x_F of Λ_c^+ was used (see Refs.(9), (10)).

Testing Λ_c^+ Spin Hypothesis [Ref.(9)]

The $\cos\theta$ distribution, i.e. the angular decay distribution integrated over the decay plane rotation angle and the azimuthal angle of the first direction ϕ , has $(2J+1)$ parameters (d_l moments, see Ref.(9)) for the spin J . Choosing the Z direction of the reference frame to be the beam direction (the Gottfried-Jackson frame) their number is reduced by parity conservation (the d_l moments vanish for odd l). Thus, this frame is suitable for spin measurements with limited data samples, especially for higher spin hypotheses. On the other hand, among the different angular parameterizations of the final state, the one using the normal to the decay plane as the first direction (i.e. θ_n^{GJ} and ϕ_n^{GJ} , the polar and the azimuthal angle of the normal to the decay plane) appears to have a moderate acceptance dependence.

The experimental distribution of $\cos\theta_n^{GJ}$ was fit with the corresponding distribution for the Λ_c^+ spin $J=1/2$, $J=3/2$ and $J=5/2$ hypotheses [Ref.(9)]. The results of the maximum-likelihood fits for higher nonvanishing moments are consistent with zero, both for the whole sample and for the subsample of

$p_T(\Lambda_c^+) > 0.7$ GeV/c. It should be recalled here that the range of d_2 values for $J = 3/2$ is $[-1,1]$ and for both d_2 and d_4 , in the case of $J = 5/2$, is even wider. The integrated distribution in the azimuthal angle ϕ_n^{GJ} is essentially flat, both for the total sample and the $p_T > 0.7$ GeV/c subsample. Its coefficients $S_m^\pm$, which do not vanish identically for $J = 1/2$ or $J = 3/2$, are consistent with zero, within the statistical error of 0.13 for the whole sample and of 0.19 for the $p_T > 0.7$ GeV/c subsample.

Λ_c^+ Polarization and Decay Asymmetry [Ref.(10)]

The Λ_c^+ polarization was studied with respect to the normal to the production plane, within the anti-Basel convention $\vec{p}_{\Lambda_c} \times \vec{p}_{beam}$ used in Ref.(10). Assuming the $J=1/2$ spin assignment for the Λ_c^+ , the integrated distribution of the polar angle of the first direction reads

$$I(\cos \theta_i^T) = \frac{1}{2} [1 + d_1^i \cos \theta_i^T] \equiv \frac{1}{2} [1 + \alpha_i P_{\Lambda_c} \cos \theta_i^T], \quad (3)$$

where P_{Λ_c} is the Λ_c^+ polarization with respect to the normal to the *production* plane and α_i are the decay asymmetry parameters depending on the choice of the angular parameterization of the final state. The θ_n^T , θ_p^T , θ_π^T and θ_K^T refer, respectively, to the angle between the normal to the *production* plane and: the normal to the *decay* plane, the proton, the pion and the kaon direction.

The results of maximum-likelihood fits of the d_1^p and d_1^π are consistent with zero, regardless of p_T . The d_1^n is consistent with zero within two standard deviations for Λ_c^+ $p_T > 1.1$ GeV/c. For the distribution of $\cos \theta_K^T$ and $p_T > 1.1$ GeV/c, the product of the Λ_c^+ polarization and the kaon type $\Lambda_c^+ \rightarrow pK^-\pi^+$ asymmetry is measured to be $\alpha_K P_{\Lambda_c} = -0.65_{-0.18}^{+0.22}$. The systematic error estimated by varying the acceptance within one standard deviation is of order of 0.02, for high p_T fits. Assuming the suggestion in Ref.(11) for the $\Lambda_c^+ \rightarrow pK^-\pi^+$ decay and the heavy quark effective theory predictions and first results [Refs.(7), (8)], the kaon type decay asymmetry should be negative, thus the Λ_c^+ polarization should be positive (negative) within the anti-Basel (Basel) convention and of order of 0.6-0.8.

Comparison of Λ_c^+ and Λ^0 Polarization [Ref.(12)]

There is a different production mechanism for Λ_c^+ and Λ^0 . For positive x_F , the measured $N(\Lambda_c^+)/N(\Lambda_c^-)=0.99\pm0.16$, while $N(\Lambda^0)/N(\bar{\Lambda}^0)=1.27\pm0.03$ [Refs.(1), (12)]. Thus, the Λ_c^+ is expected to be oppositely polarized to the Λ_c^- and, neglecting the CP violation in the decay, the angular decay distributions look the same for both. This is not the case with the hyperon, where the hadronization effects have more impact on the light s quark. Nevertheless, it is interesting to compare the polarization of the two baryons in the same production process.

The hyperon polarization was studied with respect to the normal to the production plane, with the more widely used Basel convention $\vec{p}_{beam} \times \vec{p}_\Lambda$, for a very clean sample of 27217 Λ hyperons produced in 230 GeV/c π^-Cu interactions [Ref.(12)]. For negative x_F there is basically low p_T data, thus the measured polarization is consistent with zero. For $x_F > 0$ and $p_T > 1$ GeV/c we find $P(\Lambda^0) = -0.28 \pm 0.09(\text{stat.}) \pm 0.02(\text{syst.})$.

CONCLUSIONS

We have shown that interesting spin effects arise for inclusive $D^{*+}(2010)$ and Λ_c^+ hadroproduction. The spin effects in $D^{*+}(2010)$ hadroproduction do not support the statistical picture of spin dependent c quark hadronization, possibly indicating the importance of higher resonance contribution to the $D^{*+}(2010)$ hadroproduction. The $\Lambda_c^+ \rightarrow pK^- \pi^+$ decay channel has been shown to be useful for the Λ_c^+ spin measurements and the polarization & decay asymmetry measurements. Evidence has been shown for the high p_T Λ_c^+ transverse polarization and the kaon type $\Lambda_c^+ \rightarrow pK^- \pi^+$ asymmetry.

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