SPIN ALIGNMENT OF $D^{*+}(2010)$ PRODUCED IN 230 GeV/c π^-Cu INTERACTIONS

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We study the spin alignment of $D^{*+}(2010)$ in its helicity frame for a very clean sample of 127 $D^{*+}(2010)$ mesons produced in 230 GeV/c π^-–Cu interactions. We measure the spin alignment parameter to be equal to $\eta = 0.10^{+0.12}_{-0.11} \pm 0.01$. This parameter, within our statistics, does not depend on x_F or p_T. We compare our results with statistical aproach.

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1. Introduction

Although the production properties of charmed hadrons are reasonably well known, there is very little information about their polarization and the spin alignment in hadroproduction. In a recent paper [1] we have demonstrated the transverse polarization of (Λ_c^+) [1] produced at high p_T in 230 GeV/c π^-–Cu meson interactions. Now we describe a study of spin alignment for another charmed spinning particle, namely for the $D^{*+}(2010)$. The study is based on a clean sample of $D^{*+}(2010)$ observed in the same experiment (NA32 of the ACCMOR collaboration). The sample has already been used [2] for the precise measurement of the mass and width of the $D^{*+}(2010)$. The paper is organized as follows: In Section 2 and Section

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

3 we briefly review the ACCMOR experiment, data processing and acceptance corrections. The spin dependent hadronization of the charm quark is briefly described in Section 4, while the results are given in Section 5. Some implications of the results are discussed in Section 6 and concluded in Section 7.

2. The experiment and data analysis

The data used in this study come from the second phase of the NA32 experiment which was performed at the CERN-SPS using a negative 230 GeV/c beam (96% pions and 4% kaons) and a 2.5 mm Cu target. Charm decays were reconstructed with an improved silicon vertex detector and a large-acceptance spectrometer. The latter consisted of two magnets, 48 planes of drift chambers and three multicellular Cherenkov counters allowing pion, kaon and proton identification in the momentum range $(4 \div 80)$ GeV/c. The vertex detector consisted of a beam telescope with seven microstrip planes and a vertex telescope with two charge-coupled devices and eight microstrip planes. The overall precision of our vertex detector allowed a purely topological charm search, which was restricted neither to a limited number of decay modes nor to any mass window.

Event reconstruction is done in several steps (see Ref. [3] for more details). First, all tracks are reconstructed in the drift chambers and particle identification is performed. Independently, the beam track and the secondary tracks are reconstructed in the beam and vertex telescopes, respectively. Then, tracks found in the drift chambers and in the vertex telescope are matched. Finally, the reconstruction of the primary vertex is performed. We only accept events with the primary vertex inside the target and at least two tracks not originating from the vertex. These tracks are then used as a seed for the search for one or more secondary vertices. The vertices should be between the target and the second CCD plane (20 mm from the target). In addition we require the vector sum of the momenta of all particles originating from the secondary vertex to pass through the primary one. This results in about 1200 fully reconstructed decays of D^0, D^+, D_s^+, Λ_c^+, Ξ_c^+ and Ξ_c^0 (see Refs. [3, 4, 5]).

3. Signal, background and acceptance corrections

As in Ref. [2] we select the $D^{*+}(2010) \to D^0 \pi^+_{ext}$ events where $D^0 \to K^- \pi^+$ or $D^0 \to K^- \pi^+ \pi^+ \pi^-$, requiring

— a decay vertex including an identified K^- and one or three pions,

— the effective mass of the $K^- \pi^+$ or $K^- \pi^+ \pi^+ \pi^-$ system to be within 2 sigma of D^0 mass,

— an additional pion π^+_{ext} originating from the primary vertex and not identified as K^+ or proton,

— $m(D^0\pi^+_{ext}) < 2015$ MeV.

Two events for which ambiguous D^0 vertices are found have been discarded. Contrary to the e^+e^- experiments we do not need kinematical cuts to clean our signal. Among our 127 $D^{*+}(2010)$ events there are 26 with $D^0 \to K^-\pi^+$ and 101 with $D^0 \to K^-\pi^+\pi^+\pi^-$. The $\Delta m = m(D^0\pi^+_{ext}) - m(D^0)$ distribution for these events is shown in Fig.1.

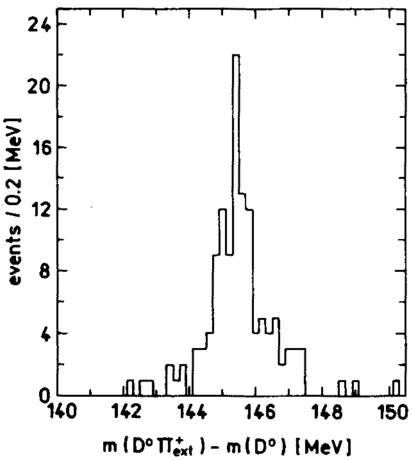

Fig. 1. Experimental distribution of $\Delta m = m(D^0\pi^+_{ext}) - m(D^0)$.

Using the same selection criteria we find 20 "wrong sign" ($D^0\ \pi^-_{ext}$) events in the signal region. We assume the same amount of background of accidental $D^0\pi^+_{ext}$ combinations in our "right sign" $D^0\pi^+_{ext}$ sample.

Acceptance corrections are calculated using a Monte Carlo program which generates an uncorrelated pair of charmed particles in the reaction $\pi^-\mathrm{Cu} \to D^{*+}\overline{D}X$, where $\overline{D}$ is a 2:1 mixture of $\overline{D}^0$ and D^- while X stands for other particles produced in the interaction. $D^{*+}(2010)$ decays into $D^0\pi^+_{ext}$ with subsequent decay $D^0 \to K^-\pi^+$ or $D^0 \to K^-\pi^+\pi^+\pi^-$ while $\overline{D}$ decays according to known branching fractions. The branching fractions and lifetimes of $\overline{D}$ are taken from the RPP tables [6]; for the production parameters of all charmed mesons we use the results of the same experiment [7]. The parameters of other particles X are read from the sample of interaction-trigger events recorded during the experiment. Then the generated and real tracks are merged and resulting signals are used to simulate our trigger, particle identification and selection criteria. The acceptance does not depend on any of the decay angles in the $D^{*+}(2010)$ rest frame.

The relative statistical errors of acceptance are about 2% in each of 10 bins in $\cos\theta_{\rm hel}$ and the systematic errors are of similar magnitude.

4. Basic spin formalism and the relative abundance of vector and pseudoscalar mesons

The angular distribution for the $D^{*+}(2010) \to D^0\pi^+$ decay, described in terms of spherical moments d_l (see *e.g.* Ref. [8]), is given by

$$I(x) = \tfrac{1}{2}\left[1 + d_2 P_2(x)\right] \equiv \tfrac{1}{2} + \eta P_2(x)\,, \tag{1}$$

where $P_2(x)$ is the second Legendre polynomial and the variable $x \equiv \cos\theta_{\rm hel}$ stands for the cosine of the angle between the $D^{*+}(2010)$ momentum in the laboratory frame and the $\pi^+_{\rm ext}$ momentum in the $D^{*+}(2010)$ rest frame. The spin alignment parameter η (given in terms of the spin density matrix ϱ for the $D^{*+}(2010)$ production) reads

$$\eta \equiv \tfrac{1}{2} d_2 = \tfrac{1}{2}(3\varrho_{00} - 1)\,. \tag{2}$$

Thus η is limited to the range $-1/2 \leq \eta \leq 1$.

Donogue [9] suggested an interesting relation between the spin alignment η and the relative abundance of pseudoscalar P and vector V mesons. This is based on statistical assumptions for the spin dependent hadronization of the c quark. The latter can combine with the sea antiquark to form a meson. If the spins of c and $\overline{q}$ are parallel there is a 50% chance for a vector meson V with $J_z = \pm 1$ to be formed. On the other hand, if the spins are antiparallel there is a probability f for a pseudoscalar meson P to be created and the remaining probability $(1 - f)$ refers to the formation of a vector meson V with $J_z = 0$. In this picture the alignment is given by

$$\eta = \frac{1 - 2f}{4 - 2f}\,. \tag{3}$$

Further, assuming simple spin counting one expects $f = 1/2$ *i.e.* $\eta = 0$, while *e.g.*. Field and Feynman [10] assumed $f = 1$ i. e. $\eta = -1/2$.

Now, let us define the quantity

$$P_i^\sigma = \frac{\sigma(V)}{\sigma(P) + \sigma(V)}\,, \tag{4}$$

where $\sigma(P)$ and $\sigma(V)$ are production cross sections of pseudoscalar P and vector V mesons in which i denotes the heavier of the valence quarks in the meson while P_i^σ represents the quantity obtained by direct measurements of $\sigma(P)$ and $\sigma(V)$. On the other hand, using Eq. (2) and Eq. (3) one obtains

$$P_i^\eta = \frac{3}{4(1-\eta)}. \quad (5)$$

Thus, simple spin counting yields $P_i^\eta = 3/4$ while $f = 1$ leads to $P_i^\eta = 1/2$. If the above statistical approach is valid one expects

$$P_i^\sigma = P_i^\eta \quad (6)$$

and consequently

$$P_i^\sigma \geq \tfrac{1}{2}. \quad (7)$$

This problem was investigated in e^+e^- collisions. The HRS collaboration [11] has measured $P_d^\sigma = 0.54 \pm 0.06$ from the relative abundance of π^0 and ρ^0. Similarly, they measured $P_s^\sigma = 0.66 \pm 0.08$. For P_c^σ we recalculate the average reported by Mättig [12] using the latest charm branching fractions (see Sec.6). This yields $P_c^\sigma = 0.70 \pm 0.07$. The last result is certainly consistent with $P_c^\eta = 0.77 \pm 0.02 \pm 0.01$ measured by the CLEO collaboration [13]. As shown *e.g.* in Ref. [13] the increase of relative abudance of vector mesons with the quark mass is reasonably consistent with the Lund string model [14]. Thus the results from the e^+e^- collisions are certainly consistent with the statistical approach.

Our results allow a measurement of P_c^η and its comparison with P_c^σ, both being determined in the same hadroproduction experiment (see Sec.6).

5. Results

The distribution of $|\cos\theta_{\rm hel}|$ is shown in Fig. 2 for our signal (solid line) and background (dashed line) samples.

We have fitted the η parameter using the method of maximum likelihood. The $\cos\theta_{\rm hel}$ distribution coming from the background was subtracted. We have also fitted the spin alignment parameter for various equally populated subsamples differing by x_F and p_T cuts. The results are collected in Table I, the errors of η being statistical ones. The systematic error of η was estimated by varying the background and the acceptance within one standard deviation limits. This error equals 0.01 in each case. The χ^2 values are calculated for 9 degrees of freedom, on the assumption of $\eta \equiv 0$.

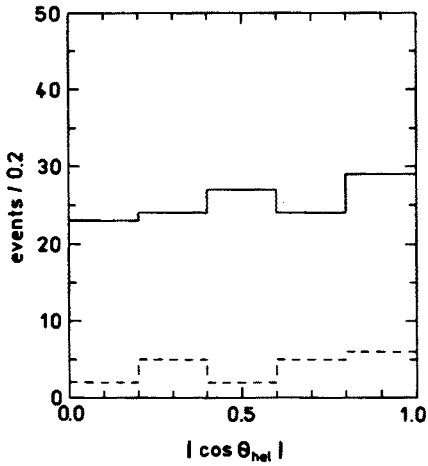

Fig. 2. The distribution of $|\cos\theta_{hel}|$ from $D^{*+}(2010)\to D^0\pi^+_{ext}$ decay for all x_F and p_T (solid line). The dashed line stands for "wrong sign" background events.

TABLE I

$D^{*+}(2010)$ spin alignment for various x_F and p_T intervals (always $x_F > 0$)

x_F range	p_T range [GeV/c]	No of events	No of "wrong sign" events	η	$\chi^2(\eta\equiv 0)$
full	full	137	20	$0.10^{+0.12}_{-0.11}$	4.4
≤ 0.2	full	58	9	$0.04^{+0.18}_{-0.17}$	7.1
> 0.2	full	69	11	0.14 ± 0.15	3.4
full	≤ 0.9	61	13	0.17 ± 0.18	5.9
full	> 0.9	66	7	$0.05^{+0.15}_{-0.14}$	3.2

Table I shows that the spin alignment parameter is well consistent with zero for all the x_F and p_T intervals under consideration. Several e^+e^- experiments [13, 15 16] have measured the $D^{*+}(2010)$ spin alignment to be consistent with zero; we find the same in hadroproduction.

Interpretation of our results depends on the assumption that there is no polarization of the D^* meson in decays of higher D^{**} mesons which could be its source. Let us recall that in the e^+e^- collisions, only ≈12% of D^* mesons come from this source [17]. Furthermore, only ≈4% of the D^* produced from D^{**} decays are polarized [17]. Not much is known about the hadroproduction of D^{**} mesons but it seems reasonable to assume that their relative abundance is not greater than in e^+e^- collisions.

From the spin alignment value $\eta = 0.10^{+0.12}_{-0.11} \pm 0.01$ we determine $P_c^\eta = 0.83^{+0.11}_{-0.10} \pm 0.01$ using Eq. (5).

6. Hadroproduction of pseudoscalar and vector mesons

In the same experiment the ACCMOR Collaboration [18] has determined $\sigma(D^+)$ and $\sigma(D^{*+})$ using charm branching fractions (BF) from the '88 edition of Review of Particle Properties [19]. Now we recalculate the cross sections using the latest values of the $BF's$ [20]. Of particular importance is the recent result of the CLEO II collaboration [21], namely $BF(D^{*+} \to D^0\pi^+) = (68.1 \pm 1.0 \pm 1.3)\%$. Now the ACCMOR results yield $P_c^\sigma = 0.47 \pm 0.11$. Using the same branching fractions one can obtain $P_c^\sigma = 0.46$ with a comparable error from the recent measurements of the E653 Collaboration [22] in 600 GeV/c π^- emulsion interactions. Thus there is a definite discrepancy between P_c^η and P_c^σ measured in hadroproduction.

Let us recall here the results of the EHS-NA22 Collaboration [23, 24, 25] studying meson production in 250 GeV/c π^+ p interactions. Combining their results for π^0 and ρ^0 one obtains $P_d^\sigma = 0.13 \pm 0.01$ while their cross sections for K_s^0 and K^{*0} yield $P_s^\sigma = 0.37 \pm 0.04$. Thus the EHS-NA22 results for light quarks violate Eq. (7) while our results on P_c^η and P_c^σ do not obey Eq. (6). The statistical approach seems to fail in hadroproduction while working fairly well in e^+e^- collisions.

7. Conclusions

We have measured the spin alignment parameter with respect to the helicity axis of D^{*+}(2010) mesons produced in π^-–Cu interactions at 230 GeV/c. The alignment is consistent with zero, both for whole sample and for such x_F and p_T cuts as were possible in our sample of only 127 events. In the framework of the statistical approach we have determined the relative abundance of D^{*+} mesons to be $P_c^\eta = 0.83^{+0.11}_{-0.10} \pm 0.01$. This value disagrees with $P_c^\sigma = 0.47 \pm 0.11$ obtained from direct measurements.

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