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Is the Axial Vector Charmed Meson Found ?

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It is argued that the charmed meson of $J^P = 1^+$ is produced copiously at the center-of-mass energy 4.028 GeV in electron-positron annihilation.

Goldhaber et al. have reported evidences for charmed mesons in a recent Letter,[1] in which they have shown among others the recoil mass spectrum against D^0 ($\bar{D}^0$) . De Rujula et al.[2] have subsequently attributed the higher peak in the recoil mass spectrum to the kinematic reflection of the $D^{0*}(1^-)$ $\bar{D}^{0*}(1^-)$ production. With more accurate values[1,3] for the masses involved and with the actual beam energy ($\sqrt{s} = 4.028 \pm 0.005$ GeV), however, the ratio of the $D^0(0^-)\,\bar{D}^{0*}(1^-)$ + $\bar{D}^0(0^-)\,D^{0*}(1^-)$ and $D^{0*}(1^-)\,\bar{D}^{0*}(1^-)$ production cross sections turns out to be

$$\sigma(D^{0*}\bar{D}^{0*})/\{\sigma(D^0\bar{D}^{0*}) + \sigma(\bar{D}^0 D^{0*})\} \simeq 0.052 \qquad (1)$$

aside from possible form factor effects, provided that the quark model based on statistical spin weight be valid.[2] The small number in (1) is due to the vanishingly small Q value available for the $D^{0*}\bar{D}^{0*}$ channel. To explain the height of the higher recoil mass peak, this has to be close to the order of unity.

An alternative interpretation, probably more faithful to the experiment, is that the higher recoil mass peak is due to the production of $D^0(0^-)\,\bar{D}^{0**}(1^+)$ and its charge-conjugate state. In this case the mass is estimated from the momentum spectrum of D^0 ($\bar{D}^0$) to be 2.147 GeV. Since the production takes place in an s-wave, the small Q value suppresses less severely the $(0^-,1^+)$ production than the $(1^-,1^-)$ production. This value of the 1^+ charmed meson mass is considerably smaller than 2.33 GeV of a quark mass spectroscopy[4] and 2.5 GeV of a linearly rising potential model.[5] It does not fit in linear mass formulas, but it satisfies approximately the quadratic mass formulas,

$$\begin{aligned} m^2(D^{0**}) - m^2(D^{0*}) &\simeq 0.59\ \mathrm{GeV}^2 , \\ m^2(A_1) - m^2(\rho) &\simeq 0.62\ \mathrm{GeV}^2 , \\ m^2(K_A) - m^2(K^*) &\simeq 0.74\ \mathrm{GeV}^2 . \end{aligned} \qquad (2)$$

Treating the production at $\sqrt{s} = 4.028$ GeV as "γ" $\longrightarrow \psi_{4.03} \longrightarrow$ charmed mesons, one can get some idea of the relative magnitude of the $D^0(0^-)\,\bar{D}^{0**}(1^+)$ and $D^0(0^-)\,\bar{D}^{0*}(1^-)$ production cross sections from the $A_1\rho\pi$ and $\omega\rho\pi$ couplings as follows: Let us assume that the $\psi_{4.03}$ state, as a member of an excited hexadecimet vector multiplet of SU(4), couples with the 0^-, 1^-, and 1^+ mesons as the $\psi_{3.1}$ state does, namely,

$$g(\psi_{4.03}D\bar{D}^*)/g(\psi_{4.03}D\bar{D}^{**}) \approx g(\psi_{3.1}D\bar{D}^*)/g(\psi_{3.1}D\bar{D}^{**}). \qquad (3)$$

The right-hand side of (3) is related to $g(\omega\rho\pi)/g(A_1\rho\pi)$ through SU(4) in the ideal mixing.[6] If we make Q value corrections to the decay rates as $\Gamma \propto p^{2\ell+1}/m^{2\ell}$, where m is the mass of a decaying meson, we find with $\Gamma(A_1 \to \rho\pi) \simeq 100$ MeV and $\Gamma(\omega \to \pi^0\gamma) \simeq 0.87$ MeV that

$$\sigma(D^0\bar{D}^{0**})/\sigma(D^0\bar{D}^{0*}) \simeq 0.96\ . \qquad (4)$$

Though this number should not be taken too seriously, it indicates that the $D^0\bar{D}^{0**}$ production can easily be of the order of the $D^0\bar{D}^{0*}$ production at $\sqrt{s} = 4.028$ GeV.

The sequential decay pattern is as follows:

$$\begin{array}{l} D^0(0^-) \ + \ \bar{D}^{0**}(1^+) \\ \qquad\qquad \hookrightarrow \ \pi^0 \ + \bar{D}^{0*}(1^-) \\ \qquad\qquad\qquad\qquad \hookrightarrow \ \pi^0 \ + \bar{D}^0(0^-) \end{array} \qquad (5)$$

and its charge-conjugate process. The charged decay modes are either forbidden or highly suppressed kinematically. The D^0 ($\bar{D}^0$) meson produced directly has a sharp value of momentum while the $\bar{D}^0$ (D^0) meson emitted in the decay has a width in momentum due to the two steps of decay. This is in contrast to the momentum spectrum of D^0 ($\bar{D}^0$) meson in the $D^{0*}\bar{D}^{0*}$ production, in which case the momenta of both D^0 and $\bar{D}^0$ are smeared only by the final decay momenta.

The angular distribution of the D^0 ($\bar{D}^0$) emission is spherically symmetric for the directly produced D^0 ($\bar{D}^0$) and for the decay product $\bar{D}^0(D^0)$, too, if one ignores the decay momenta as compared with the momentum of the 1^+ meson. This is to be compared with the angular distribution of the D^0 ($\bar{D}^0$) produced through the $D^{0*}(1^-)\bar{D}^{0*}(1^-)$ emission, $1 + \frac{1}{4}\sin^2\theta$, which results if one retains only the charge coupling of the charmed quark with the time-like photon. The latter is modified in the presence of the magnetic and/ or quadrupole moment coupling of the $D^{0*}(\bar{D}^{0*})$ meson.[7]

Another test for the present interpretation is to measure the energy dependence of the two peaks in the recoil mass spectrum. If the higher peak is really due to the $D^{0*}\bar{D}^{0*}$ reflection, its location shifts and its width broadens as the beam energy increases. At the present moment, the clear peaks have been observed in the recoil mass spectrum only at $\sqrt{s} = 4.028$ GeV. They disappear at $\sqrt{s} = 4.4$ GeV, the next lowest energy where there are sufficient data on the charmed meson production.[8] To distinguish between the $D^{0*}\bar{D}^{0*}$ reflection and the $D^0\bar{D}^{0**}$ pair production, it is sufficient to measure the recoil masses in the region of $\sqrt{s} = 4.1 \sim 4.2$ GeV, where the location of the higher peak shifts upwards by $10 \sim 20$ MeV and its width broadens by as much as $30 \sim 60$ MeV in the case of the $D^{0*}\bar{D}^{0*}$ reflection. If the peak is due to the $D^0\bar{D}^{0**}$ pair production, the location nor the width does not change as the energy is varied. In this case the height of the higher peak increases far less rapidly than that of the lower peak at energies corresponding to the same value of the center-of-mass momentum. This will clearly distinguish between s-wave and p-wave productions.

The 1^+ charmed meson can be of either $^3P_1$ or $^1P_1$. If the D^{0**} here is a $^3P_1$ state, there should exist a 0^+ charmed meson state below 2.147 GeV, which may be produced with D^{0*} ($\bar{D}^{0*}$) of 1^- in pair above $\sqrt{s} \simeq 4.1$ GeV.

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References

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1. G. Goldhaber et al., Phys. Rev. Letters 37, 255 (1976).

2. A. De Rujula, H. Georgi, and S. L. Glashow, Phys. Rev. Letters 37, 398 (1976). See also Reference 5.

3. G. Goldhaber, a talk at SLAC Summer Conference on Particle Physics, August, 1976. $m(D^o) = 1866.5$ MeV and $m(D^{o*}) - m(D^o) = 138.9$ MeV.

4. A. De Rujula, H. Georgi, and S. L. Glashow, Phys. Rev. D12, 147 (1975).

5. K. Lane and E. Eichten, Phys. Rev. Letters 37, 477 (1976).

6. The D^{o**} meson is assumed here to be a $^3P_1$ state.

7. N. Cabibbo and R. Gatto, Phys. Rev. 124, 1577 (1961).

8. Some data are available at $\sqrt{s} = 4.1$ GeV, but they are not sufficient statistically to plot the recoil mass spectrum.

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