An alternative fit to Belle mass spectra for $D\bar{D}$, $D^{*}\bar{D}^{*}$ and $\Lambda_{C}\bar{\Lambda}_{C}$

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Abstract

Peaks observed by Belle in $D\bar{D}$ at 3.878 GeV and in $D^{*}\bar{D}^{*}$ at 4.156 GeV may be fitted by phase space multiplied by a form factor with an RMS radius of interaction 0.63 fm. The peak observed in $\Lambda_{C}\bar{\Lambda}_{C}$ at 4.63 GeV may be explained by $Y(4660)$, multiplied by a corresponding form factor with RMS radius $\sim 0.94$ fm.

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Belle find a broad bump in $D\bar{D}$ with mass $M = 3878 \pm 48$ MeV, $\Gamma = 347^{+316}_{-143}$ MeV [1]. The data are reproduced in Fig. 1(a) after a subtraction of experimental background. Belle tentatively interpret this as a broad resonance denoted $X(3880)$ with $3.8\sigma$ significance. They conclude that 'the observed threshold enhancement is not consistent with non-resonant $e^{+}e^{-} \rightarrow J/\Psi D\bar{D}$.'

The proposal made here is that this spectrum has an intensity proportional to $D\bar{D}$ phase space $\rho(s)$ multiplied by the square of a form factor $\exp(-q^{2}R^{2}/6)$ for a Gaussian source; $q$ is the momentum of $D$ and $\bar{D}$ in their centre of mass and $R$ is the radius of interaction of the $D\bar{D}$ pair:

$$I(s) = \rho(s)e^{-2Aq^{2}},$$

$$A = \frac{1}{6}\left(\frac{R(fm)}{\hbar c}\right)^{2},$$

with $\hbar c = 0.19732$ GeV/c. The assumption being made here is that the final-state interaction is fairly weak and that the amplitude may be parametrised by a scattering length, with the exponential providing an effective range. No resonance is involved and the data are not particularly sensitive to small phase shifts.

The full curve in Fig. 1(a) uses $A = 1.7$ (GeV/c)$^{-2}$, corresponding to a reasonable RMS radius $R = 0.63$ fm for the combined $D\bar{D}$ pair or $R' = R/\sqrt{2} = 0.45$ fm for each $D$. Although the fit looks slightly ragged, it is in fact very close to that made by Belle with a broad resonance. It may appear surprising that the form factor has a strong effect; the reason is that momenta increase rapidly from threshold because of the high masses of the two $D$.

Secondly, Belle also observe a peak in $D^{*}\bar{D}^{*}$ with $M = 4156^{+29}_{-26}(stat) \pm 15(syst)$ MeV, $\Gamma = 139^{+111}_{-61} \pm 21$ MeV, reproduced in Fig. 1(b) after subtracting a very small experimental background. The full curve shows a fit using Eqs. (1) and (2) with exactly the same radius parameter as for Fig. 1(a). There is some scatter in experimental points, but the fit is reasonable in view of present statistics. Belle point out that the peak of Fig. 1(b) is too strong to be explained by $\Psi(4160)$, for which $< 1$ event is to be expected. One should also note that $\Psi(4160)$ is observed in five other sets of data [2], [3], [4], in all of which there are strong interferences with

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Figure 1: Fits to Belle data on (a) $D\bar{D}$, (b) $D^*\bar{D}^*$, (c) $\Lambda_C\bar{\Lambda}_C$ and (d) $D\bar{D}^*$. In (b), the full curve is for S-wave $D^*\bar{D}^*$ and the dashed curve shows the perturbation due to a P-state centrifugal barrier. In (c), the full curve shows the line-shape of $Y(4663)$ after modulation by a form factor; the dashed curve is the result without the form factor. In (d), the full curve shows the Belle fit with $Y(3942)$ and the dashed curve the fit with phase space and a form factor.

$\Psi(4040)$ and $X(4260)$, which has $J^{PC}1^{--}$. Belle say: 'We interpret the observed enhancement, which has a statistical significance of 5.5$\sigma$, as a new resonance and denote it as $X(4160)$', i.e. distinct from $\Psi(4160)$.

There are two further sets of data where a relation between them can be explained by a form factor related to that given above. Firstly Belle report a sharp peak in $e^+e^-\rightarrow \gamma_{ISR}\Psi'(3686)\pi\pi$ with $M = 4664\pm11\pm5$ MeV, $\Gamma = 48\pm15\pm3$ MeV [5]. As Guo, Hanhart and Meissner point out [6], this coincides with the sharp $\Psi'(3686)f_0(980)$ threshold. Guo et al. favour interpretation as a dynamically generated molecular state. There is a well established mechanism by which a shape threshold can generate a resonance or attract a pre-existing state [7]. An alternative explanation of $Y(4664)$ is the $\Psi(5S)$ state or $\Psi(3D)$ [8], though it is then rather narrow.

Secondly, Belle data on $e^+e^-\rightarrow \gamma_{ISR}\Lambda_C\bar{\Lambda}_C$ reveal a narrow peak with $M = 4634^{+8}_{-7}^{+5}_{-8}$ MeV, $\Gamma = 92^{+40}_{-24}^{+10}_{-21}$ MeV [9]. These data are reproduced in Fig. 1(c). The dashed curve shows a fit using parameters of $Y(4664)$, except that the width is increased by one standard deviation. Clearly the dashed curve disagrees with the data.

It seems likely that $Y(4664)$ and $Y(4634)$ are related. What happens if a form factor is introduced? For $Y(4664)$, there is rather little effect, since the signal is centred at the threshold
for $\Psi'f_0(980)$. However, for $Y(4634)$ some effect is to be expected. Because the $\Lambda_C$ contains three quarks, one expects the radius of interaction in this case to be larger than for $D\bar{D}$ and $D^*\bar{D}^*$. It is well known that the total cross section for $NN$ is asymptotically larger than for $\pi N$ by a factor $\sim 1.5$. This increase arises from changing 2 quarks to three in one particle. For $\Lambda_C\bar{\Lambda}_C$ both particles contain 3 quarks. The full curve of Fig. 1(c) shows a fit assuming $R^2$ increases between $D\bar{D}$ and $\Lambda_C\bar{\Lambda}_C$ by a factor $(1.5)^2$. This curve approximately reproduces the peak mass in $\Lambda_C\bar{\Lambda}_C$ and also the increase in width. To achieve this result, it is necessary to increase the width of $Y(4664)$ by one standard deviation. A further possible source of a large radius of interaction is that it is well known that $p\bar{p}$ and $K^-p$ total cross sections increase rapidly near threshold. A similar effect for $\Lambda_C\bar{\Lambda}_C$ would account for the threshold peak in that channel.

A final point concerns Belle data for $D\bar{D}^*$ [10]. The full curve of Fig. 1(d) shows their fit. The data require $M = 3942^{+7}_{-5} \pm 6$ MeV, $\Gamma = 37^{+26}_{-18} \pm 8$ MeV. In this case, the fit with phase space and a simple form factor (shown by the dashed curve) does not reproduce the data accurately. So this does look like a resonance. Confirmation of this peak in $D\bar{D}^*$ and its spin-parity is important.

In conclusion, experimentalists and phenomenologists should keep a watchful eye open for simple non-resonant explanations of bumps in data. A form factor of reasonable radius of interaction can produce two of the peaks reported by Belle and provide an explanation of the shift of mass between peaks they observe in $\Psi'f_0(980)$ and $\Lambda_C\bar{\Lambda}_C$.

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