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THRESHOLD PRODUCTION OF D AND B MESON PAIRS [redacted] IN $e^+ e^-$ ANNIHILATION

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The behavior of the $c\bar{c}$ and $b\bar{b}$ contributions to R in the threshold regions $\sqrt{s} = 3.68$ to 4.5 GeV $\sqrt{s} = 10.56$ to 11.1 GeV have been studied in various models based on the original Cornell model. The detailed energy behavior of the inclusive contributions to R and the exclusive cross sections for each of the two-body $B\bar{B}$ final states is presented. Implications for determining the strength of $B_s - \bar{B}_s$ mixing are briefly discussed.

1. INTRODUCTION

The Cornell model fits the mass spectrum and decay widths of the narrow charmonium and upsilon states below flavor threshold and gives an explanation for the relatively large leptonic width of the $\psi(3770)$ which is believed to be the triplet 1D $c\bar{c}$ state.[1] Light quark pair production matrix elements couple $Q\bar{Q}$ states to OZI-allowed mesonic decay channels. The parameters of the model are fixed by fitting the charmonium spectrum below charm threshold and without further adjustment the model fits the observed upsilon spectrum below beauty threshold. With these parameters the model then predicts charmed and beautiful meson productions above threshold. We report here results calculated from two such models.

2. THE MODELS

The Hamiltonian for these models is in a space consisting of $Q\bar{Q}$ and $Q\bar{q}\, q\bar{Q}$ states with Q = c or b and q = u, d, or s. In the $Q\bar{Q}$ subspace, the Hamiltonian has the form

$$H_{Q\bar{Q}} = \frac{p^2}{M} + V(r) + 2M \qquad (1)$$

with $M = M_Q$. We used the constituent quark masses originally chosen by the Cornell group and also the same form of the potential; viz.,

$$V(r) = -\frac{\kappa}{r} + C + \frac{r}{a^2} \quad . \qquad (2)$$

This potential both binds the quarks and is the source of pair production. It is flavor independent aside from a slow scale variation in κ owing to asymptotic freedom. In the original Cornell model only the linear part of the potential was used as the source of quark pairs. However the Coulombic part may also produce pairs and when this term is included in the analysis, the potential parameters which fit the narrow state spectroscopy are modified.[2] See Table 1. The original Cornell model we denote as (C), and the

Table 1

model	κ	a in GeV^{-1}
Cornell	0.483	2.12
Zambetakis	0.455	1.80

Potential parameters for the models; $m_b = 5.17$ GeV.

model in which both the Coulombic and confining parts of the potential produce pairs as the Zambetakis model (Z). We show results from both of these models to exhibit the model dependence.

3. THRESHOLDS

We have calculated threshold production cross sections

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for singlet and triplet ground state $q\bar{Q}$ and $Q\bar{q}$ meson pairs. We used the measured meson masses and estimated the B_s and B_s^* masses assuming the same hyperfine splitting for B_s as B_d and that the center of gravity of the singlet and triplet states of B_s mesons differs from that of B_d by the same amount as D_s and D_d. In Figs. 1(a) and (b) these thresholds are shown in the complex energy plane along with the positions of the observed resonance poles. It is clear from these diagrams that one cannot expect resonant cross sections to have simple Breit-Wigner energy dependence. The nearby thresholds significantly perturb that behavior.

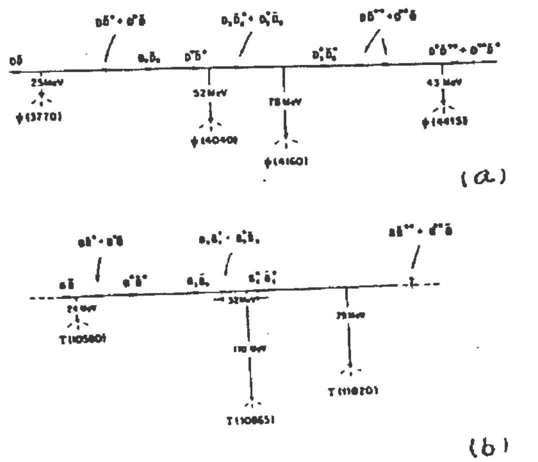


FIGURE 1

In our calculations we explicitly included only the nine ground state mesons. In principle all decay channels should be included; e.g., higher thresholds with radially excited mesons and mesons having nonzero orbital angular momenta. Decay channels whose thresholds are at energies above those for which the calculation is made contribute mass shifts. We have approximated their cumulative effect by including diagonal mass shifts that position the resonances at their observed energies. Consequently the positions of the resonance peaks are inputs. The outputs from our calculations are the energy dependence and magnitudes of the exclusive cross sections for the various channels as well as the widths of the resonances.

4. RESULTS

Two model calculations for the inclusive charm contribution to R are compared with Figures 2(a) and (b). The curves are $R = \Delta R_c + 2.65$ and the data points are those given for R in the 1989 Review of Particle Properties (RPP).[3]

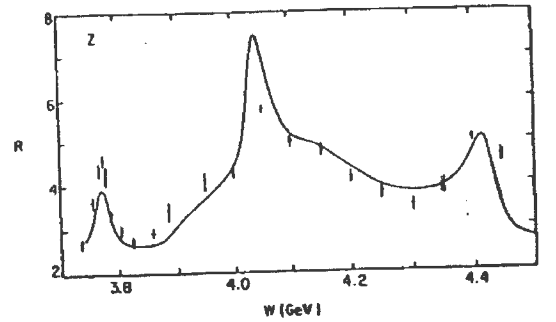
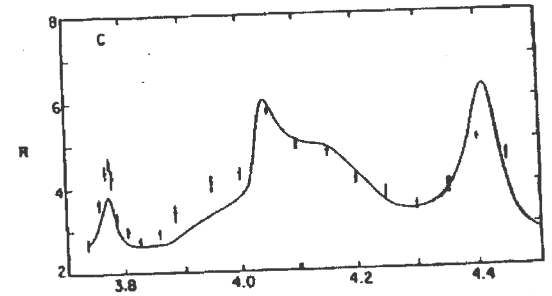


FIGURE 2 (a)



(b)

Neither model provides a quantitative fit to the data. However, both show the same qualitative properties. As explained above, the models have no adjustable parameters (aside from the mass shifts that position the resonance peaks). Neither model gives a large enough leptonic width for the $\psi(3770)$. The Zambetakis model does better in this regard than the Cornell model. Otherwise the Cornell model seems to fit the data better. We have also calculated the energy dependent contributions $\Delta R_c^{(f)}$ from all nine ground state meson channels f. However, we do not report those here. When better data available it may be possible to compare them with model predictions.

Model predictions for ΔR_b are shown in Figures 3(a) and (b). The curves are $R = \Delta R_b + 4.6$; the data points are CLEO data[4]. The models give the qualitative features of the data; a narrow 4S resonance; a satellite bump nearby; a broad 5S resonance; and a somewhat more distinct 6S resonance. The curves for R are rather flat over the region of the 5S or $\Upsilon(10865)$ resonance. Nevertheless there is a pole in the $b\bar{b}$ propagator as indicated in Fig. 2(b). In both models the eigenvector of that pole points clearly in the 5S direction.

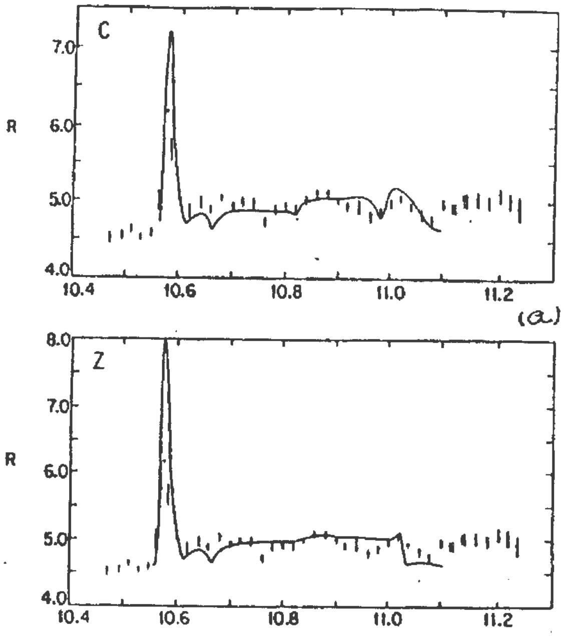


FIGURE 3

In Figs. 4-5 we show how the individual channels contribute to R. Only the B_d and B_u channels are open at the 4S [Υ(10580)] resonance. The $B_u\bar{B}_u^*$ threshold is just above this resonance at 10.61 GeV. The $B_u\bar{B}_u^* + \bar{B}_u B_u^*$ and $B_d\bar{B}_d^* + \bar{B}_d B_d^*$ channels are enhanced by the tail of this resonance and their contributions account for the satellite peak at 10.64 GeV. This shown in Fig. 4 where Cornell model calculations are exhibited. Results from the Zambetakis model are similar.

The 5S or Υ(10865) resonance region is complicated because many channels are open or opening. Qualitative features are similar in both models, but quantitatively they yield different results. As an example we show the results from the Cornell model in Fig. 5. The qualitative features are common to both models. They are that there is a resonance pole with eigenvector pointing mainly to 5^3S_1. The resonance is broad and decays mainly into nonstrange $B^*\bar{B}^*$ and $B\bar{B}^*+\bar{B}B^*$ channels with $B^*\bar{B}^*$ from 1.5 to 2 times more frequent. Of the strange channels the $B_s\bar{B}_s^*+\bar{B}_sB_s^*$ channel dominates (the $B_s^*\bar{B}_s^*$ is kinematically suppressed because its threshold is at the resonance mass); B_s productions are never larger than about 20 per cent of ΔR_b and tend to be considerably less. In both models there is a suppression of

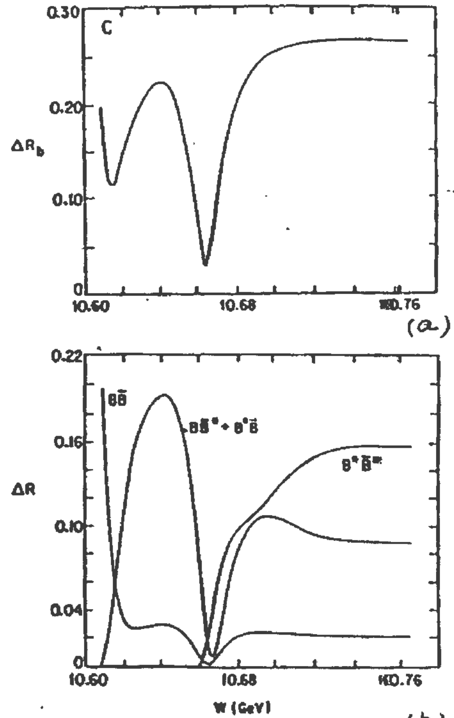


FIGURE 4

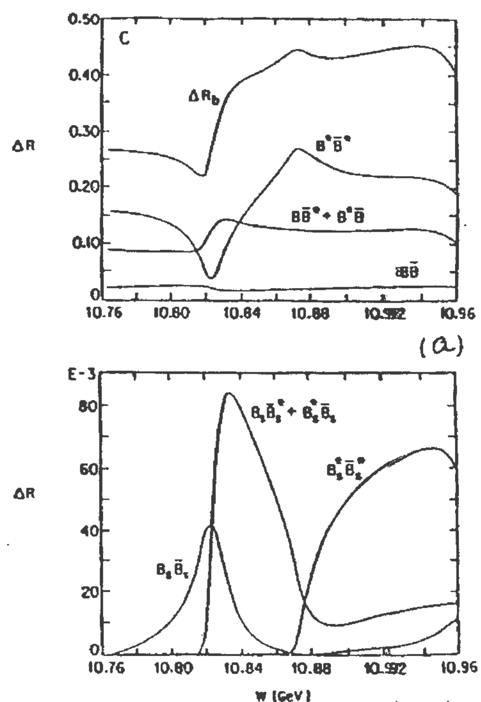


FIGURE 5

the $B_s\bar{B}_s^* + \bar{B}_s B_s^*$ channel around 10.88 GeV - apparently a $B_s^*\bar{B}_s^*$ threshold effect. The productions of psuedoscalar B meson pairs, strange and nonstrange, is small throughout this region. This is due to spin factors which, all other things being equal, would say $B\bar{B} : B\bar{B}^* + \bar{B}B^* : B^*\bar{B}^*$ is 1:4:7.

As regards the 6S or Υ(11019) resonance region, both models predict substantial (roughly 20 per cent) branching fraction to $B_s^*\bar{B}_s^*$ with nonstrange $B^*\bar{B}^*$ and $B\bar{B}^*+\bar{B}B^*$ branching fractions being resonant with branching fractions approximately in the ratio of 7:4. It is likely that some channels with thresholds higher than those we have explicitly included are opening up in the region of the 6S. Our results in this region therefore are less reliable than at the lower energies.

5. $B_s - \bar{B}_s$ MIXING

We have calculated the same sign dilepton signal in this resonance region assuming equal B_s and B_d semileptonic rates using the Argus value for the $B_d - \bar{B}_d$ mixing parameter $x_d = 0.7$. Model predictions for the ratio of same sign to opposite sign dileptons (SSDI) are shown in Fig. 6 for the extreme cases of no $B_s - \bar{B}_s$ mixing ($x_s = 0$) and strong mixing ($x_s = 3.5$). These curves show the model dependence of our results in the region from 10.85 to 11 GeV. If there is strong $B_s - \bar{B}_s$ mixing the dilepton signal will be a sensitive detector of B_s productions.

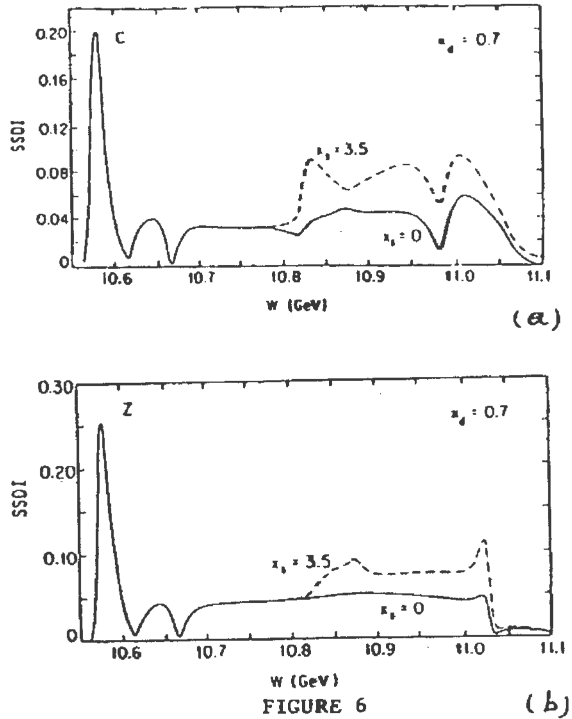


FIGURE 6

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