CHARM AND CHARMONIUM PHYSICS
AT BABAR

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Abstract

The BaBar experiment, located in SLAC at the PEPII asymmetric storage ring, achieved the luminosity of 477 fb$^{-1}$, so Spectroscopy studies are possible. The B-Factory BaBar offers an excellent opportunity in searching new states and their decay modes to understand their nature. Here below the states recently observed at BaBar are briefly presented.

1 Charm Spectroscopy

Only 4 $c\bar{s}$ quarks bound states were observed before B-factories started to work in this field, in perfect agreement with the theoretical models. BaBar observed $D^{*}(2317)^+$ and $D_{sj}(2460)^+$ in the decay modes $D_s^+\pi^0$ and $D_s^{*+}\pi^0$ respectively, at energies where the theory has not done predictions. New non-expected states were observed, making more rich the mass spectrum, most of them decaying to channels where $D_s$ got involved: $D_{sj}^{*}(2317)^+$ and $D_{s1}(2536)^+$. For these analyses, high precision measurements and high statistics were required [1]. These very narrow states were detected in inclusive decays of the $B$ meson.

A very interesting contribution of Babar was given in the measurement of the mass difference of $D_{s1}$ and $D^*$. In the PDG06 [2] the value was: $(525.0 \pm 0.6 \pm 0.1)$ MeV/$c^2$; BaBar obtained: $m(D_{s1} - m(D^*)) = (525.85 \pm 0.02 \pm 0.04)$MeV/$c^2$ [3,4], a large improvement in the error measurement. By searching in the inclusive modes: $e^+e^- \rightarrow D^{0,\pm}K^{0,\pm}X$, BaBar observed on 240 fb$^{-1}$ the values reported in the table below.

A new state in the mass spectrum was added: $\Omega_c^{*0}$ [5]. On 232 fb$^{-1}$ Babar searched this $c\bar{s}s$ state, $J^P = \frac{3}{2}^+$, decaying to $\Omega_c^{*0}\gamma$, with $\Omega_c^{*0}$ decaying in 4 different modes. By combining them, the mass difference of $\Omega_c^{*0}$ and $\Omega_c^{0}$ was
measured: \((70.8 \pm 1.0 \pm 1.1)\) MeV/c\(^2\). In addition, we report the measured value: \(\frac{\sigma(e^+e^-\rightarrow\Omega^0\bar{\Omega}^0)}{\sigma(e^+e^-\rightarrow\Omega^0\Omega^0)} = (1.01 \pm 0.23 \pm 0.11)\).

Another interesting contribution of \textit{BaBar} was given in the analysis of the invariant mass of \(D - \text{proton}\): a known state was confirmed, \(\Lambda_c(2880)^+\), and a new state was observed: \(\Lambda_c(2940)^+\) [6]. Evidence of excited charmed baryons was found: \(\Xi_c(2980)^+\), \(\Xi_c(3077)^+\), \(\Xi_c(3077)^0\), and the recent observations for \(\Xi_c(3055)^+\) and \(\Xi_c(3125)^+\) make this study more interesting [7]. They are in agreement with the corresponding values published by the \textit{Belle} collaboration, even if the measurements done in \textit{Belle} show to be slightly overestimated from the corresponding ones measured in \textit{BaBar}, the smaller values of mass and width in some cases due to the treatment of proximity to the threshold.

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>State</th>
<th>Mass(MeV/c(^2))</th>
<th>(\Gamma)(MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D^0 \rightarrow K^-\pi^+)</td>
<td>(X(2690))</td>
<td>2688 (\pm 4 \pm 3)</td>
<td>112 (\pm 7 \pm 36)</td>
</tr>
<tr>
<td>(D^0 \rightarrow K^-\pi^+)</td>
<td>(D^*_s(2573))</td>
<td>2572.2 (\pm 0.3 \pm 1.0)</td>
<td>27.1 (\pm 0.6 \pm 5.6)</td>
</tr>
<tr>
<td>(D^0 \rightarrow K^-\pi^+)</td>
<td>(X(2690))</td>
<td>2688 (\pm 4 \pm 3)</td>
<td>112 (\pm 7 \pm 36)</td>
</tr>
<tr>
<td>(D^0 \rightarrow K^-\pi^+)</td>
<td>(D^*_s(2860))</td>
<td>2856.6 (\pm 1.5 \pm 5.0)</td>
<td>47 (\pm 7 \pm 10)</td>
</tr>
<tr>
<td>(D \text{ proton})</td>
<td>(\Lambda_c(2880)^+)</td>
<td>2881.9 (\pm 0.1 \pm 0.5)</td>
<td>5.8 (\pm 1.5 \pm 1.1)</td>
</tr>
<tr>
<td>(D \text{ proton})</td>
<td>(\Lambda_c(2940)^+)</td>
<td>2939.8 (\pm 1.3 \pm 1.0)</td>
<td>17.5 (\pm 5.2 \pm 5.9)</td>
</tr>
</tbody>
</table>

## 2 Charmonium Spectroscopy

The \(c\bar{c}\) mass spectrum is not completely understood, and not full-filled yet. In fact, states below the \(DD\) threshold are well known, and some \(1^{--}\) states above; moreover they fit well theoretical models. Recently, some other states were observed but they do not fit well theoretical predictions. More than one prediction was done from theorists [11]. Here below are presented the results of the more recent \textit{charmonium} – like states observed in \textit{Babar}.

\textit{BaBar} searched for the narrow state \(X(3872)\) [8] (\(\Gamma < 2.3\) MeV and \(M = (3782.4 \pm 0.6)\) MeV/c\(^2\), world average) in \(B \rightarrow XK\), \(X \rightarrow J/\psi \pi^+\pi^-\), and also in the decay \(B \rightarrow J/\psi \gamma K\), on \(260 fb^{-1}\). Thanks to this decay mode observed, we could establish that the parity \(C\) of this state is positive [9]. An important implication concerning the decay modes of \(X \rightarrow J/\psi \pi^+\pi^-\) is that the invariant mass of \(\pi^+\pi^-\) is compatible with the \(\rho\) mass, so we should look at the charged partners of \(X\) (\(I = 1\)). But the search for \(X^+\) or \(X^-\) gave no evidence of signal [10]. So we can conclude that the resonance \(X\) is an isospin violating state (\(I = 0\)). That is the reason why we observed such a
narrow width. Recently, *BaBar* searched for the decay: $B \to \bar{D}^0 D^{*0} K$ [12]. By studying the invariant mass of $\bar{D}^0 D^{*0}$, with $D^{*0} \to D^0 \pi^0$ and $D^{*0} \to D^0 \gamma$, we observed an excess of events at $(3875.1 \pm 0.7 \pm 0.5)$ MeV/c$^2$. This important result confirms the measurement that *Belle* performed in $B \to \bar{D}^0 D^0 \pi^0 K$, even if this mass value is 4.5 $\sigma$ above the world average of $X \to J/\psi \pi^+ \pi^-$. The X(3872) is probably not a charmonium state. But we cannot exclude other interpretations, yet [11].

Searching in the decay $B \to J/\psi \omega K$ *BaBar* confirmed another important result: the discovery of the X(3940) [13]. *BaBar* analyzed the invariant mass of $J/\psi \omega$, where $\omega \to \pi^+ \pi^- \pi^0$, and $J/\psi \to l^+l^-$. In order to check the purity of the signal sample *BaBar* weighted each event with the appropriate function (Legendre polynomial of the second order $\times \cos \theta$, where $\theta$ is the $\omega$ Dalitz-plot helicity angle), so we can be sure that no contribution of non-resonant $\pi^+ \pi^- \pi^0$ can create a peak in the $J/\psi \omega$ invariant mass. By combining the charged and the neutral modes, *BaBar* found with 350 fb$^{-1}$ the mass value $M = (3914.3^{+3.8}_{-3.3}(\text{stat}) \pm 1.6(\text{sys}))$ MeV/c$^2$ and a width: $\Gamma = (33 \pm 0.7^{+12}_{-8}(\text{stat}) \pm 0.6(\text{sys}))$ MeV.

The B.R. of the $B \to J/\psi \omega K$ was measured, too. It it in good agreement with the *Belle* measurements, while the measurements of mass and width of the state X(3940) done in *Belle* are overestimated compared to what we observed in *BaBar*, because we obtained the measurement of a more narrow state and a mass value being 30 MeV/c$^2$ smaller.

The discovery of the state called Y(4260) [14] came from ISR events, and *Belle* confirmed by *CLEO*. The mass value is $(4258 \pm 8^{+6}_{-4})$ MeV/c$^2$ and the width is $(88 \pm 23^{+6}_{-4})$ MeV.

As it comes from ISR events, its quantum numbers are $J^{PC} = 1^{--}$. But in the plot of the ratio $R$ (the ratio between the cross section of $e^+e^- \to \text{hadrons}$ to the cross section of $e^+e^- \to \mu^+\mu^-$) we expected to look at a maximum corresponding to the energy in the center of mass of 4.26 GeV. Indeed, we looked at a local minimum there, that is a very peculiar behaviour. So, in order to reject some possibilities, we searched for the decay modes: $Y(4260) \to \pi^+ \pi^- \phi$, $Y(4260) \to D\bar{D}$ and $Y(4269) \to p\bar{p}$: we observed no yields, so probably it is not a glueball or charmonium state. There is also an evidence of this new state in the charged $B$ decay: the measurement of this B.R. $(B \to Y(J/\psi \pi^+ \pi^-)K)$ is $(2.0 \pm 0.7 \pm 0.2)10^{-5}$.

The search for the Y(4260) decay modes, and other searches in the inclusive
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$J\psi\pi^+\pi^-$ led to the discovery of another resonance, whose mass is $4324\pm24$ MeV/$c^2$ [15] and whose width is $172\pm33$ MeV. It is not compatible with the above mentioned $Y(4260)$, neither with $Y(4415)$ or S-waves-three-body-phase space. That is a new peak, confirmed now also from the Belle Collaboration.

Acknowledgments

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues, and for the substantial dedicated effort from the computing organizations that support BaBar.

References

[7] BABAR Collaboration, B. Aubert et al. hep-ex/0607042;

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