MENU 2007
11th International Conference
on Meson-Nucleon Physics and
the Structure of the Nucleon
September10-14, 2007
IKP, Forschungzentrum Jülich, Germany

CHARM AND CHARMONIUM PHYSICS AT *BABAR*

Elisabetta Prencipe
prencipe@slac.stanford.edu
University of Ferrara & INFN
via Saragat, 1 - 44100 Ferrara (IT)

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: $e^+e^- \to D^{0,\pm}K^{0,\pm}X$, *BaBar* observed on 240 fb^{-1} the values reported in the table below.

A new state in the mass spectrum was added: Ω_c^{*0} [5]. On 232 fb^{-1} *BaBar* searched this *css* state, $J^P = \frac{3}{2}^+$, decaying to $\Omega_c^0\gamma$, with Ω_c^0 decaying in 4 different modes. By combining them, the mass difference of Ω_c^{*0} and Ω_c^0 was

measured: $(70.8 \pm 1.0 \pm 1.1)$ MeV/c^2. In addition, we report the measured value: $\frac{\sigma(e^+e^- \to \Omega_c^{*0})}{\sigma(e^+e^- \to \Omega_c^0)} = (1.01 \pm 0.23 \pm 0.11)$.
Another interesting contribution of *BaBar* was given in the analysis of the invariant mass of $D - proton$: 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 *Belle* collaboration, even if the measurements done in *Belle* show to be slightly overestimated from the corresponding ones measured in *BaBar*, the smaller values of mass and width in some cases due to the treatment of proximity to the threshold.

Decay mode	*State*	$Mass(MeV/c^2)$	$\Gamma(MeV)$
$D^0 \to K^-\pi^+$	$D^*_{s2}(2573)$	$2572.2 \pm 0.3 \pm 1.0$	$27.1 \pm 0.6 \pm 5.6$
$D^0 \to K^-\pi^+$	$X(2690)$	$2688 \pm 4 \pm 3$	$112 \pm 7 \pm 36$
$D^0 \to K^-\pi^+$	$D^*_{sj}(2860)$	$2856.6 \pm 1.5 \pm 5.0$	$47 \pm 7 \pm 10$
$D\ proton$	$\Lambda_c(2880)^+$	$2881.9 \pm 0.1 \pm 0.5$	$5.8 \pm 1.5 \pm 1.1$
$D\ proton$	$\Lambda_c(2940)^+$	$2939.8 \pm 1.3 \pm 1.0$	$17.5 \pm 5.2 \pm 5.9$

2 Charmonium Spectroscopy

The $c\bar{c}$ mass spectrum is not completely understood, and not full-filled yet. In fact, states below the $D\overline{D}$ 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 $charmonium - like$ states observed in *Babar*.

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 $B \to XK$, $X \to J/\psi\pi^+\pi^-$, and also in the decay $B \to J/\psi\gamma K$, 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 $X \to J/\psi\pi^+\pi^-$is that the invariant mass of $\pi^+\pi^-$ is compatible with the ρ 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 a isospin violating state (I = 0). That is the reason why we observed such a

narrow width.
Recently, *BaBar* searched for the decay: $B \to \overline{D}^0 D^{*0} K$ [12]. By studying the invariant mass of $\overline{D}^0 D^{*0}$, 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 $B \to \overline{D}^0 D^0 \pi^0 K$, even if this mass value is 4.5 σ 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 $J/\psi \to l^+l^-$, $\pi^0 \to \gamma\gamma$, $K_s \to \pi^+\pi^-$. 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 θ is the ω 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 = $(3914.3^{+3.8}_{-3.4}(stat) \pm 1.6(sys))$ MeV/c^2 and a width: $\Gamma = (33 \pm 0.7^{+12}_{-8}(stat) \pm 0.6(sys))$ 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 $e^+e^- \to hadrons$ 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: $Y(4260) \to \pi^+\pi^-\phi$, $Y(4260) \to D\overline{D}$ and $Y(4269) \to p\overline{p}$: 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

$J\psi\pi^+\pi^-$ led to the discovery of another resonance, whose mass is (4324 ± 24) MeV/c^2 [15] and whose width is (172 ± 33) 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

[1] BABAR Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **74** 032007;

[2] D. E. Groom *et al.* [Particle Data Group Coll.], *" Review of particle physics,"* Eur. Phys. J. C **15**;

[3] BABAR Collaboration, B. Aubert *et al.* hep-ex/0607084 ;

[4] BABAR Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **97** 222001;

[5] BABAR Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **97** 232001;

[6] BABAR Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **98** 012001;

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

[8] Belle Collaboration, Phys. Rev. Lett. **91** 262003; BABAR Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **73** 011101; Phys. Rev. Lett. **74** 071101;

[9] BABAR Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **71** 031501;

[10] BABAR Collaboration, B. Aubert *et al.* hep-ex. arXiv:0708.1565;

[11] Phys. Rev. D. **71** 074005; Phys. Rev. D. **71** 014028;

[12] BABAR Collaboration, B. Aubert *et al.* arXiv: hep-ex/0708.1565

[13] BABAR Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **95** 142001;

[14] BABAR Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **73** 011101; Phys. Rev. Lett. **73** 012005;

[15] BABAR Collaboration, B. Aubert *et al.* Phys. Rev. Lett. **98** 212001;