SLAC-PUB-13256
June 2008

INITIAL STATE RADIATION PHYSICS AT THE B FACTORIES [a]

EUGENI GRAUGÉS (*BaBar* collaboration)
Universitat de Barcelona. Departament d'Estructura i Constituents de la Matèria. Facultat de Física. Avda. Diagonal 647. E-08028 Barcelona, Spain

A mini-review of the recent *BaBar* and *Belle* results on the process $e^+e^- \to hadrons$ using the initial state radiation (ISR) technique, is presented. ISR studies at the $\Upsilon(4s)$ resonance (B-Factories) can yield to the same observables as the low energy e^+e^- experiments: Precise cross-section measurements, the R ratio (ratio of cross-sections of hadron production to di-muon production) measurement, form factors measurements (from hadron pair production such as $e^+e^- \to p\bar{p}, \Lambda\bar{\Lambda}, \Lambda\bar{\Sigma}, \Sigma\bar{\Sigma}$), as well as $J^{PC} = 1^{--}$ hadron spectroscopy that can lead to the discovery of new states.

1 Introduction

The extraordinary performance of the B meson factories which was required for the study of CP violation in the b quark sector has made them, both BaBar and Belle, an excellent place to study hadronic final states in e^+e^- anihilation. Making use the so-called radiative return, where a photon is emitted by either the initial electron or positron, it is possible to study not only the produced events at the collider nominal centre-of-mass energy, but also at lower energies, from the production threshold up to the 4-5 GeV region.

2 Cross-section measurements

The measurement, using the ISR method [1], of the cross-section for $e^+e^- \to hadrons$ at low energy allows the precise determination of the ratio $R = \sigma(e^+e^- \to hadrons)/\sigma(e^+e^- \to \mu^+\mu^-)$, which is of key importance to calculate the hadronic contribution in the theoretical prediction of [2] the muon anomalous magnetic moment $(g-2)$ and [3] the running QED coupling constant α. The advantage of using ISR events is that a scan of the entire effective centre-of-mass energy range (the available energy after the initial state radiation of a hard photon), is performed in the same experiment, avoiding uncertainties in the relative normalization when combining data from different experiments. In addition, the B-factories high luminosity and detector performances (specially their particle identification capabilities) allow the ISR data to be very competitive againsts low energy e^+e^- machines.

Contributed to 43rd Rencontres De Moriond On QCD And Hadronic Interactions, 3/8/2008-/15/2008, La Thuile, Italy

Work supported in part by US Department of Energy contract DE-AC02-76SF00515

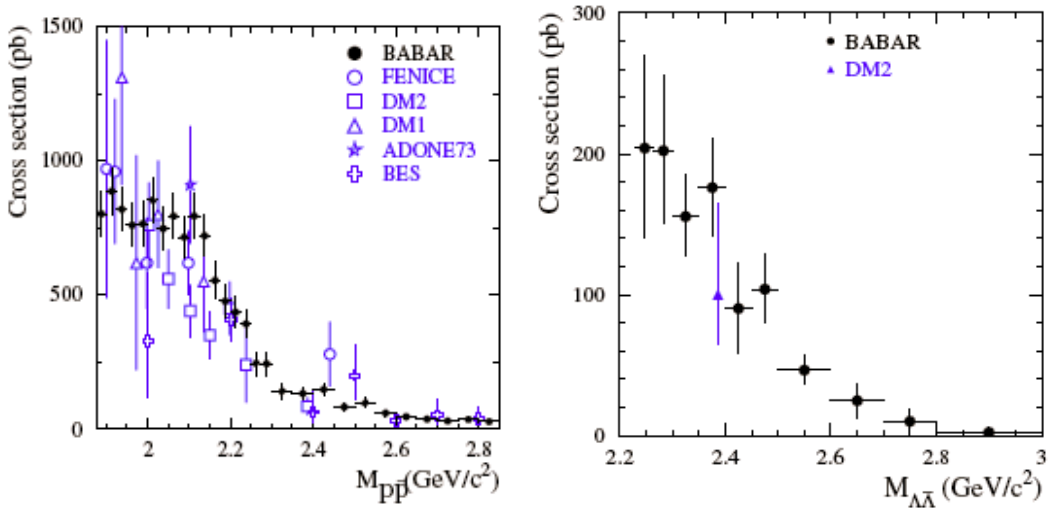

Figure 1: The $e^+e^- \to p\bar{p}$ (left) and $e^+e^- \to \Lambda\bar{\Lambda}$ (right) cross sections near threshold measured from e^+e^- experiments: BaBar [12] [13] , FENICE [16], DM2 [15], DM1 [14], ADONE73 [17] and BES [18].

The dominant hadronic channel below 1 GeV is $\pi^+\pi^-$, but other hadronic channels are dominant at larger centre-of-mass energies, and the total hadronic rate is obtained by summing up all the exclusive cross-sections. The majority of them have recently been measured by BaBar: $\pi^+\pi^-\pi^0$ [4], $2\pi^+2\pi^-$,$2K^+2K^-$ [5], $\pi^+\pi^-K^+K^-$, $\pi^0\pi^0K^+K^-$, $2K^+2K^-$[6], $2\pi^+2\pi^-\pi^0$, $2\pi^+2\pi^-\eta$, $K\bar{K}\pi^+\pi^-\pi^0$, $K\bar{K}\pi^+\pi^-\eta$ [7], $3\pi^+3\pi^-$, $2\pi^+2\pi^-2\pi^0$, $K^+K^-2\pi^+2\pi^-$ [8], $p\bar{p}$ [9], $\Lambda\bar{\Lambda}$, $\Lambda\bar{\Sigma}$, $\Sigma\bar{\Sigma}$ [10], and $K^+K^-\eta, K^+K^-\pi^0, K^0_sK^+\pi-$ [11]. There is also a preliminary measurement of the channel $\pi^+\pi^-\pi^0\pi^0$, and work is in progress to measure from the same data sample the cross-section of the processes $\pi^+\pi^-$, K^+K^-, $\pi^+\pi^-3\pi^0$, $p\bar{p}p\bar{p}$, as well as the inclusive measurement of the aformentioned R ratio.

3 Form factor measurements

BaBar has measured with unprecedented accuracy the $e^+e^- \to p\bar{p}$ [12] and $e^+e^- \to \Lambda\bar{\Lambda}$ [13] processes cross-sections, as well as the mass dependence of the ratio of the electric and magnetic form factors, $\|G_E/G_M\|$. These measurements, as summarized in figure 1, have been made by means of the ISR technique, which has the advantadges of good efficiency, an energy resolution of around 1 MeV and full angular acceptance when the radiated photon is detected. A surprising feature of these cross sections is their non-vanishing values at threshold. In principle, due to the finite energy-bin width, it cannot be excluded from data vanishing cross-sections at threshold with extremely sharp rise. If that was not the case, for charged baryons ($p\bar{p}$ case), this phenomenon could be explained in terms of the Coulomb interaction between the outgoing baryon and antibaryon. However such an effect is not expected for neutral baryons ($\Lambda\bar{\Lambda}$ case), and alternative explanations might be suggested, such as sub-threshold resonances among others. Concerning the measurement of the $\|G_E/G_M\|$ form factor ratio, for $p\bar{p}$ case it is found to be significantly greater than unity near threshold, whereas for the $\Lambda\bar{\Lambda}$ case, it is consistent both with unity and with the results for $e^+e^- \to p\bar{p}$.

4 Study of charmonium-like states via ISR

Observations of charmonium-like states recoiling from a J/ψ in the inclusive process $e^+e^- \to J/\psi +$ *anything* have been made by the Belle collaboration [19] [20], using also the ISR

technique. In the case of the X(3940) state its decay into $D^*\bar{D}$ final states is used to determine their intrisic width. Similarly, in the process $e^+e^- \to J/\psi D^{*+}D^{*-}$, another charmonium-like state, denoted as X(4160) has been observed [20]. The observation of this X(4160) state has also been hinted at the cross-section measurement (using also the ISR technique) of the process $e^+e^- \to D^{*+}D^{*-}$ [21]. In addition, the ISR method based measurements [22] of the exclusive cross section for $e^+e^- \to D^0D^-\pi^+$ process show the first observation of the state Y(4415) ($\psi(4415)$) decaying into $D\bar{D}_2^*(2460)$.

B meson factories have also studied the invariant mass distribution of $(\pi^+\pi^- + charmonium)$ in the processes $e^+e^- \to (\gamma_{ISR})\ \pi^+\pi^- + charmonium$. Both Babar and Belle found for the case $e^+e^- \to \pi^+\pi^- + \psi(2s)$ evidence a new resonance [23][24]. The exact mass and width values are slightly different between the measurements made by the different collaborations since the mass spectrum is parametrized as a single Breit-Wigner (BW) function (BaBar) or as the coherent sum of two BW's (Belle). In particular, this new resonance appears to be uncompatible with the Y(4260) state, observed earlier by Babar [25] and confirmed afterwards by Belle [26], in the process $e^+e^- \to \pi^+\pi^- + J/\psi$. The CLEO-c experiment has confirmed the Y(4260) in direct $e^+e^- \to Y(4260)$ interactions [27]. The Y(4260) has also been detected in CLEO-c to decay into $\pi^0\pi^0 J/\psi$ and a ratio of BR($e^+e^- \to \pi^-\pi^+ J/\psi$)/BR($e^+e^- \to \pi^0\pi^0 J/\psi$) has been measured to be around 0.5, which implies that the Y(4260) has isospin zero, as expected for a charmonium state. Observations of states such as the Y(4260) (and also X(3872) [28]) have complicated the picture in which charmonium spectroscopy was well described by potential models. Therefore at the B factories search for charmonium and other new states has also been performed in the study of exclusive ISR production of $e^+e^- \to D\bar{D}$. The $D\bar{D}$ mass spectrum shows clear evidence of the $\psi(3770)$ plus other structures near 3.9, 4.1, and 4.4 GeV/c2, but no evidence for $Y(4260) \to D\bar{D}$ is observed [29][30]. Moreover, no evidence has been found of Y(4260) decays into $\phi\pi\pi$ in the $e^+e^- \to KK\pi\pi$ process [31][32], but the sub-resonant structure shows hints of a new resonance, denoted as X(2175), in the invariant mass distribution of $\phi(1020)f_0(980)$ of the $e^+e^- \to \phi(1020)f_0(980)$ process. Such observation of the X(2175) resonance seems to be supported in the analysis of the invariant mass distribution of $\phi\eta$ in the $e^+e^- \to \phi\eta$, where ϕ decays into K^+K^- and η decays into either a $\gamma\gamma$ pair or $\pi^+\pi^-\pi^0$ final state [33][34].

5 Conclusions

In this mini-review, it has been shown that the B meson factories are also $q\bar{q}$ factories and, that what is commonly thought to be background to b-quark physics, is actually a very rich and fruitful source of physics results. The ISR technique, properly applied to Babar and Belle, has revealed as a very powerful tool to obtain *effective* low energy e^+e^- experiments with unprecedented statistics. Many more new results might be expected from new and updated analysis from the B factories in the near future.

References

[1] Benayoun M., Eidelman S. I. *et al*, *Mod. Phys. Lett.* A **14**, 2605-2614 (1999).

[2] M. Davier *et al* , *Eur. Phys. J.* **C27**, 497 (2003).

[3] H. Burkhardt and B. Pietrzyk, *Phys. Lett.* B **513**, 46 (2001).

[4] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **70**, 072004 (2004).

[5] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **71**, 052001 (2005).

[6] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **76**, 012008 (2007).

[7] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **76**, 092005 (2007).

[8] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **73**, 052003 (2006).

[9] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **73**, 012005 (2006).

[10] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **76**, 092006 (2008).

[11] BaBar Collaboration. B. Aubert *et al.* SLAC-PUB-12968, BABAR-PUB-07-052, arXiv:0710.4451 [hep-ex]. Submitted to *Phys. Rev.* D.

[12] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **73**, 012005 (2006).

[13] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **76**, 092006 (2007).

[14] B. Delcourt *et al.* (DM1 Collaboration), *Phys. Lett.* B **86**, 395 (1979).

[15] D. Bisello *et al.* (DM2 Coll.), *Nucl. Phys.* B **224**, 379 (1983); *Z. Phys.* C **48**, 23 (1990).

[16] A. Antonelli *et al.* (FENICE Collaboration), *Nucl. Phys.* B **517**, 3 (1998).

[17] M. Castellano *et al*, *Nuovo Cimento* **14**, 1 (1973).

[18] M. Ablikim *et al.* (BES Collaboration), *Phys. Lett.* B **630**, 14 (2005).

[19] Belle Collaboration: K. Abe *et al*, *Phys. Rev. Lett.* **98**, 082001 (2007)

[20] Belle Collaboration: I. Adachi *et al*, arxiv:0708.3812

[21] Belle Collaboration: G. Pakhlova *et al*, *Phys. Rev. Lett.* **98**, 092001 (2007)

[22] Belle Collaboration: G. Pakhlova *et al*, *Phys. Rev. Lett.* **100**, 062001 (2008)

[23] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev. Lett.* **99**, 212001 (2007).

[24] Belle Collaboration: X. L. Wang *et al*, *Phys. Rev. Lett.* **99**, 142002 (2007)

[25] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev. Lett.* **95**, 142001 (2005).

[26] Belle Collaboration: Yuan *et al*, *Phys. Rev. Lett.* **99**, 182004 (2007)

[27] CLEO Collaboration, T. E. Coan *et al*, *Phys. Rev. Lett.* **96**, 162003 (2006)

[28] S. K. Choi et al. (Belle Collaboration), Phys. Rev. Lett. 91, 262001 (2003); D. Acosta et al. (CDF Collaboration), Phys. Rev. Lett. 93, 072001 (2004); V. M. Abazov et al. (D0 Collaboration), Phys. Rev. Lett. 93, 162002 (2004); B. Aubert et al. (BABAR Collaboration), Phys. Rev. D 71, 071103(R) (2005).

[29] BaBar Collaboration. B. Aubert *et al.* SLAC-PUB-12818, BABAR-PUB-07-060, arXiv:0710.1371v2 [hep-ex].

[30] Belle Collaboration: G. Pakhlova *et al*, arxiv:0708.0082v3

[31] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **74**, 091103 (2006).

[32] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **76**, 012008 (2007).

[33] BaBar Collaboration. B. Aubert *et al* , *Phys. Rev.* D **76**, 092005 (2007).

[34] BaBar Collaboration. B. Aubert *et al.* BABAR-PUB-07-052, arXiv:0710.4451 [hep-ex].