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INITIAL STATE RADIATION PHYSICS AT THE B FACTORIES [a]

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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.

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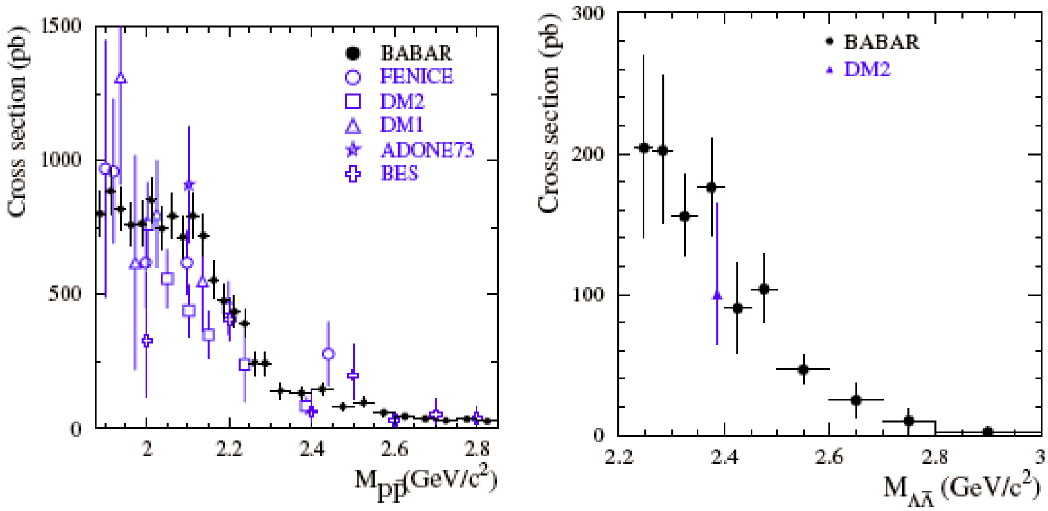

Figure 1: The $e^+e^- \rightarrow p\bar{p}$ (left) and $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ (right) cross sections near threshold measured from e^+e^- experiments: BaBar [12] [13] , FENICE [16], DM2 [15], DM1 [14], ADONE73 [17] and BES [18].

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 $e^+e^- \rightarrow p\bar{p}$ [12] and $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ [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 $e^+e^- \rightarrow p\bar{p}$.

4 Study of charmonium-like states via ISR

Observations of charmonium-like states recoiling from a J/ψ in the inclusive process $e^+e^- \rightarrow J/\psi +$ *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 $e^+e^- \rightarrow J/\psi D^{*+}D^{*-}$, 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 $e^+e^- \rightarrow D^{*+}D^{*-}$ [21]. In addition, the ISR method based measurements [22] of the exclusive cross section for $e^+e^- \rightarrow D^0D^-\pi^+$ process show the first observation of the state Y(4415) (ψ(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 $e^+e^- \rightarrow (\gamma_{ISR})\ \pi^+\pi^- + charmonium$. Both Babar and Belle found for the case $e^+e^- \rightarrow \pi^+\pi^- + \psi(2s)$ 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 $e^+e^- \rightarrow \pi^+\pi^- + J/\psi$. The CLEO-c experiment has confirmed the Y(4260) in direct $e^+e^- \rightarrow Y(4260)$ 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($e^+e^- \rightarrow \pi^-\pi^+ J/\psi$)/BR($e^+e^- \rightarrow \pi^0\pi^0 J/\psi$) 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 $e^+e^- \rightarrow D\bar{D}$. The $D\bar{D}$ mass spectrum shows clear evidence of the ψ(3770) plus other structures near 3.9, 4.1, and 4.4 GeV/c2, but no evidence for $Y(4260) \rightarrow D\bar{D}$ is observed [29][30]. Moreover, no evidence has been found of Y(4260) decays into $\phi\pi\pi$ in the $e^+e^- \rightarrow KK\pi\pi$ 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 $e^+e^- \rightarrow \phi(1020)f_0(980)$ 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 $e^+e^- \rightarrow \phi\eta$, 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.

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