PROBING STRONG INTERACTION AT BABAR (FORM FACTORS, DECAY PARAMETERS, ISR)

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Some results on strong interaction physics, recently obtained analysing the BABAR B-factory data, are presented. They include a) the first full measurement of the amplitudes of $B \to c\bar{c}K^*$, b) the first observation of the $C = +1$ processes $e^+e^- \to \rho\rho$, $e^+e^- \to \phi\rho$ around 10.5 GeV, c) the transition form factor of η, η' at $Q^2 = 112$ GeV^2, d) an overview of results of cross sections measured via ISR (Initial State Radiation) for a few channels of $e^+e^- \to$ hadrons up to $\sqrt{s} = 4.5$GeV, including a detailed study of $p\bar{p}$ production from threshold up to $\sqrt{s} \approx 4.5$ GeV.

1 Introduction

The BABAR B-factory [1] has been operating at SLAC since 1999 and has provided an integrated luminosity $\approx 340\,fb^{-1}$. All the results presented here are based on the data collected until October 2004 (Runs 1-4) which totals $\approx 232\,fb^{-1}$. These results can be grouped in three topics: section 2 reports analyses from decays of $B-$mesons produced on peak at the $\Upsilon(4S)$ resonance, sections 3 and 4 report on rare processes from e^+e^-annihilation which do not go through a resonant state, and section 5 reports on studies of processes with a hard photon emitted from the initial state (ISR) so that the effective e^+e^-collision is at $\sqrt{s} \leq 4.5$ GeV.

2 Amplitude and angular analysis of $B \to c\bar{c}K^*$

The decay $B \to c\bar{c}K^*$ is a pseudoscalar to two vectors decay. Therefore, three complex amplitudes and two phases are involved. Amplitude factorization of hadronic currents has proven effective in descriptions of decay process if only light final particles are present, and final state interactions are negligible; both simplifications do not apply in this decay, and more precise measurements are needed to understand non-factorizable contributions and select a suitable form factor model [3] The main measured parameters are reported in Table 1 for three $c\bar{c}$ states (J/ψ, $\Psi(2S)$ and χ_{c1})[2]. The measured strong phase difference $\delta_{\parallel} - \delta_{\perp} = 0.45 \pm 0.05 \pm 0.02$ is 8 standard

Table 1: BABAR measurements of amplitude parameters for $B \to c\bar{c}K^*$where $c\bar{c} = J/\Psi$, $\Psi(2S)$ or χ_{c1}.

Channel	$J/\psi\, K^*$	$\psi(2S)\, K^*$	$\chi_{c1}\, K^*$
A_0	$0.556 \pm 0.009 \pm 0.010$	$0.48 \pm 0.05 \pm 0.02$	$0.77 \pm 0.07 \pm 0.04$
$A_{\perp}$	$0.211 \pm 0.010 \pm 0.006$	$0.22 \pm 0.06 \pm 0.02$	$0.20 \pm 0.07 \pm 0.04$
$A_{\parallel}$	$0.233 \pm 0.010 \pm 0.005$	$0.30 \pm 0.06 \pm 0.02$	$0.03 \pm 0.04 \pm 0.02$
$\delta_{\parallel}$	$-2.93 \pm 0.08 \pm 0.04$	$-2.8 \pm 0.4 \pm 0.1$	$0.0 \pm 0.3 \pm 0.1$
$\delta_{\perp}$	$2.91 \pm 0.05 \pm 0.03$	$2.8 \pm 0.3 \pm 0.1$	...

deviations from zero, which is the value predicted by plain factorization. The angular analysis also allows a check of direct CP violation: no effect was observed with improved precision with respect to previous measurements.

3 First observation of the $C = +1$ processes $e^+e^- \to \rho\rho$ and $e^+e^- \to \phi\rho$ at 10.58 GeV

The search for exotic states or rare two-body processes at $\sqrt{s} \approx 10$ GeV has become feasible with the construction of high luminosity factories which provide huge data sets containing sizeble samples of very low cross section events. In this study [4], clean samples of fully reconstructed $2\pi^+2\pi^-$and $2\pi 2K$events have been selected among $e^+e^- \to 4$ charged tracks events at 10.58 GeV. The integrated luminosity is 205 fb^{-1} on-peak and 20 fb^{-1} off-peak, i.e. ≈ 40 MeV below the $\Upsilon(4S)$ mass. A clear signal is visible on the tail of 4-track mass distribution in the on-peak sample, as shown in Fig. 1a,1b left.

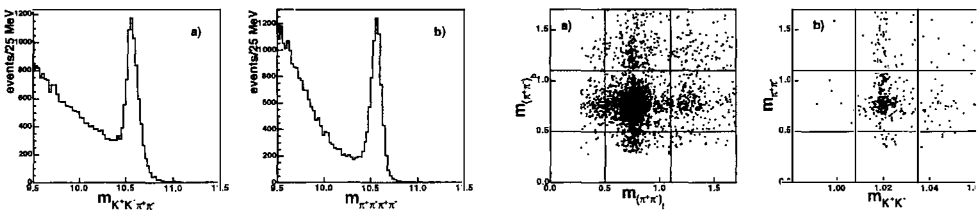

Figure 1: Reconstructed four track mass of $2\pi^+2\pi^-$and $K^-K^+\pi^-\pi^+$samples (plots a,b left). Scatter plot of $m(\pi^+\pi^-)$ (plot *a right*) and $m(K^+K^-)$ (plot *b right*) vs. the opposite pair $m(\pi^+\pi^-)$.

The same distribution is obtained off-peak, showing that the production mechanism is not the resonant process $\gamma^* \to \Upsilon(4S)$ which dominates the BABAR on-peak data. Clear correlated signals of ρ (and more) in $m(\pi^+\pi^-)$ and ϕ signal in $m(K^+K^-)$ are found in the mass plots, shown in fig. 1a,1b right; these ($C = +1$) final states confirms that the production is not through ($C = -1$) one-photon annihilation; a preliminary cut applied to raw data selection by present reconstruction software rejects $e^+e^- \to 2\phi$ events.

To understand the production mechanism, the $\cos(\theta^*)$ distributions of ρ and ϕ helicity angles θ^*, measured with respect to the e^- beam direction, have been studied; the comparison between data and theorical angular distribution of two virtual photon annihilation (TVPA), shown in Fig.2, strongly suggests this production mechanism. Data selection is limited to $|\cos(\theta^*)| \leq 0.8$ to reliably compare with theory, excluding the $|\cos(\theta^*)| \approx 1.0$ region where other processes may produce background.

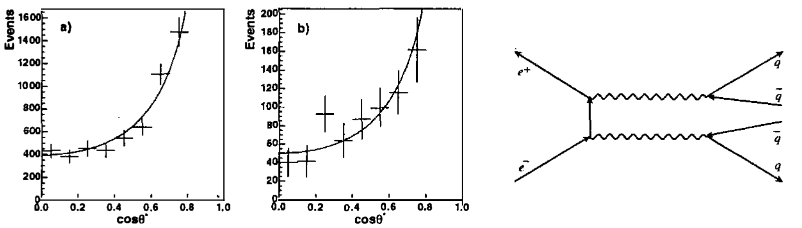

Figure 2: Angular distribution of ρ and ϕ production direction θ^* with respect to e^- beam direction (left and center); the Feynmann graph of two-virtual-photon-annihilation (right) .

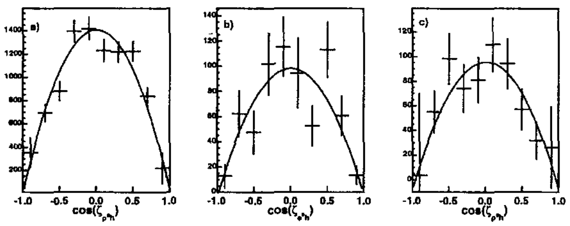

Figure 3: Angular distribution of $m(\pi^+\pi^-)$ in $e^+e^- \to \rho\rho$(fig. 3-a, and $m(\pi^+\pi^-)$, $m(\pi K)$ in $e^+e^- \to \phi\rho$(fig. 3-b,fig. 3-c respectively).

The helicities of the ρ and ϕ, measured from the angular distributions of final π's and K's (Fig. 3a,b), indicate these vectors mesons are each produced through a transverse virtual photon, as schematically shown in the Feynmann graph shown in Fig. 2-right. The cross sections, measured within the fiducial region $|\cos(\theta^*)| \leq 0.8$, are

$$\begin{aligned} \sigma_{fid}(e^+e^- \to \rho\rho) &= 20.7 \pm 0.7\,(stat) \ \pm 2.7\,(sys)\ \text{fb} \\ \sigma_{fid}(e^+e^- \to \phi\rho) &= 5.7 \pm 0.5\,(stat) \ \pm 0.8\,(sys)\ \text{fb} \end{aligned} \tag{1}$$

4 Transition form factor of η, η' at $Q^2 = 112$ GeV^2

The transition form factor of $e^+e^- \to \gamma^* \to (\eta,\eta')\gamma$ is predicted by pQCD in the asymptotic limit; at $Q^2 = 112$ GeV^2, a very small cross section is expected, $\sigma \approx$ a few nb. Measurements by previous experiments were obtained only up to 15 GeV^2, before the full onset of asymptotic behaviour is expected. Tight event selection is required to reject background from $J/\psi \to \eta, \eta'+\gamma$ events; the knowledge gained in ISR studies proved valuable in carrying out this analysis. The distributions of $m(3\pi\,\gamma)$ and $m(2\pi\ 3\gamma)$, $m(\pi\ 5\gamma)$ clearly show the η and η' peaks respectively.

The measured cross sections are

$$\begin{aligned} \sigma(e^+e^- \to \eta\gamma) &= 4.48^{+1.25}_{-1.09} \pm 0.31\,\text{fb} \\ \sigma(e^+e^- \to \eta'\gamma) &= 5.40^{+0.84}_{-0.77} \pm 0.32\,\text{fb} \end{aligned} \tag{2}$$

From the measured cross sections, the values of the transition form factors have been extracted for $q^2 = 112$ GeV$/c^2$:

$$\begin{aligned} q^2|F_\eta(q^2)| &= 0.229 \pm 0.030 \pm 0.008\,\text{GeV} \\ q^2|F'_\eta(q^2)| &= 0.251 \pm 0.019 \pm 0.008\,\text{GeV} \end{aligned} \tag{3}$$

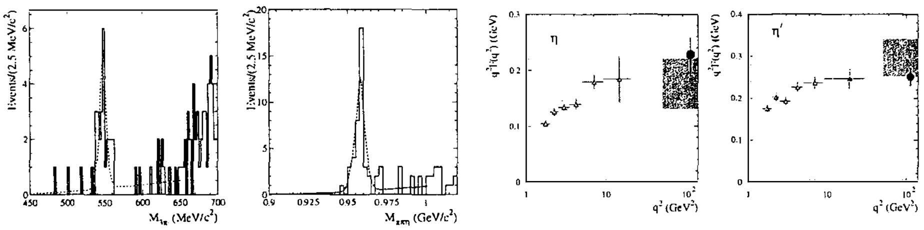

Figure 4: The $3\pi\gamma$ (left) and $2\pi3\gamma$ (center-left) invariant mass spectrum and corresponding η, η' fits for the selected events. BABAR measured transition form factor of η (center-right), η' (right) at $Q^2 = 112$ GeV^2 (full circle); the shaded areas indicate the theory expectation bands. Previous measurements at lower Q^2 from CLEO [6] are shown also (empty circles).

5 Studies of ISR process

The large statistical increase in the size of the data sample and the improvement of detector efficiency with respect to old e^+e^-experiment below 3 GeV allow disentangling the components of multihadronic production and searching for particular, *e.g.*, quasi two-body final states. A systematic study of ISR, including the effective luminosity scale factor from nominal BABAR luminosity, has been reported in previous works[?]. At present, a data sample related to 232 fb^{-1} total integrated luminosity has been analyzed.

5.1 $e^+e^- \to p\bar{p}$ from threshold to ≈ 4.5 GeV

A notable feature of ISR events is the boosting of particles produced near threshold, *i.e.*, with the lowest kinetic energy in the center of mass of the parent state. This boosting allows detection in the laboratory frame, even just above production threshold, with both high and nearly constant efficiency. The energy resolution of the measured $p\bar{p}$ pair is comparable to the e^+e^-storage ring CM energy spread, ISR is the best tool to study this processes, as shown by the cross section data plotted in Fig. 5. It is worthwhile noting two sudden drops in the cross section at ≈ 2.3 and 3.0 *GeV*. BABAR data allowed the first measurement of electric amd magnetic form factor G_E, G_M $vs\sqrt{s}$ in the $e^+e^- \to p\bar{p}$channel through fitting of proton angular distributions [?]. This behaviour is not in agreement with data from LEAR [11], which measured the inverse process $\bar{p}p \to e^+e^-$.

5.2 $e^+e^- \to 3\pi^+3\pi^-$,$e^+e^- \to 2\pi^+2\pi^-2\pi^0$ and $e^+e^- \to K^+K^-2(\pi^+\pi^-)$ cross sections

The analysis of $e^+e^- \to 3\pi^+3\pi^-$and $e^+e^- \to 2\pi^+2\pi^-2\pi^0$data has been reported more extensively elsewhere [8]; here it is worthwhile noting that both 6π cross sections show clear dips at $\sqrt{s} \approx 1920$ MeV, matching similar behaviour observed by other experiments [9,10]. Although no specific interpretation can be given at this time, the overall behaviour of $p\bar{p}$ and high multiplicity $e^+e^- \to$ hadrons channels around the $p\bar{p}$ production threshold is far from being a smooth, phase space dominated cross section.

The search for quasi two-body processes has given a clear indication of ρ production, and nothing additional in $e^+e^- \to 3\pi^+3\pi^-$; however, the channel $e^+e^- \to 2\pi^+2\pi^-2\pi^0$shows clear, correlated production of $\eta\omega$ at $\sqrt{s} \approx 1.68$ GeV.

The analysis of $e^+e^- \to K^+K^-2(\pi^+\pi^-)$data is under way. The cross section, shown in fig. 6 (right) is reported as a preliminary result. The search for quasi two-body processes will be carried out as already done for $e^+e^- \to 3\pi^+3\pi^-$and $e^+e^- \to 2\pi^+2\pi^-2\pi^0$.

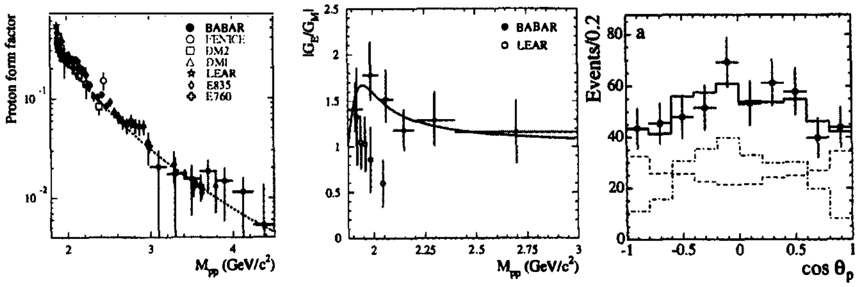

Figure 5: $e^+e^- \to p\bar{p}$cross section from threshold to $\approx 4.5\,GeV$ measured at BABAR, shown togheter with previous measurements (left). Electric and magnetic form factor ratio $\frac{G_E}{G_M}$ from threshold to $\approx 3\,GeV$ measured at BABAR from $e^+e^- \to p\bar{p}$and at LEAR from the inverse reaction $\bar{p}p \to e^+e^-$(center). One of the plots of the experimental and theoretical angular distribution of protons in a $100\,MeV$ wide energy bin; data points of the center frame in this figure were obtained by similar fits (right).

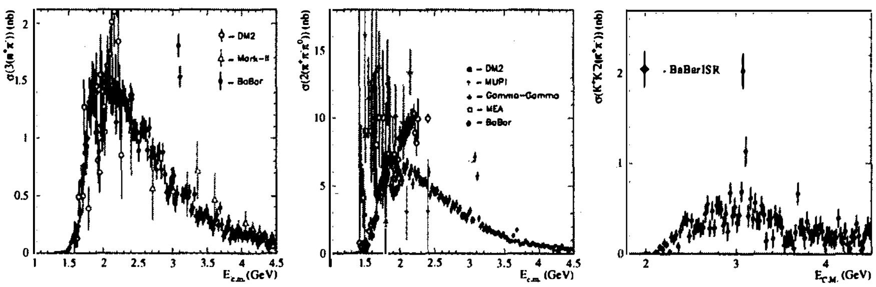

Figure 6: Cross section of $e^+e^- \to 3\pi^+3\pi^-$(left) and $e^+e^- \to 2\pi^+2\pi^-2\pi^0$(center) from threshold to ≈ 4.5 GeV measured at BABAR, shown togheter with previous measurements, mainly carried out in the 80's. The cross section of $e^+e^- \to K^+K^-2(\pi^+\pi^-)$(right) has first been measured at BABAR.

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