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$e^+e^- \rightarrow$ HADRONS CROSS-SECTIONS AT BABAR*

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We present an overview of cross-section measurements at *BABAR*. In $e^\pm \rightarrow$ few-body processes at a center-of-mass energy $E_{\rm CM} = 10.6$ GeV we make new QCD tests and the first observation of two-virtual-photon annihilations into hadrons. Studies at lower $\sqrt{s}$, using radiative return, yield new/improved data on spectroscopy, form factors and the total hadronic cross section, an important input to calculations of $g_\mu - 2$ and $\alpha(M_Z)$. We also present an inclusive measurement of the running of α.

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1. Introduction

Electron-positron annihilations into hadrons have been studied at center-of-mass energies $E_{\rm CM}$ from $\pi^+\pi^-$ threshold to over 200 GeV [1]. Single-resonance and few-body processes dominate at low $E_{\rm CM}$, providing a wealth of strong interaction physics. At higher $E_{\rm CM}$, $e^+e^- \rightarrow q\overline{q}(g) \rightarrow$ jets events dominate and few-body processes are rare. The high luminosities and excellent detectors at the B factories allow their study, providing new QCD tests. We have begun systematic studies of such low-multiplicity final states.

We also study such reactions at low $\sqrt{s}$ via initial state radiation (ISR) [2], which has the advantage of covering a wide $\sqrt{s}$ range in a single experiment, in particular the threshold region with full angular acceptance. We make first or best measurements of many processes for $\sqrt{s}$ from threshold up to 4–5 GeV. The total hadronic cross-section $\sigma_{\rm had}$ is of current interest as input to calculations of the anomalous magnetic moment of the muon $g_\mu - 2$ and the fine structure constant α at the Z^0 mass scale. These need improved precision for $\sqrt{s} < 4$ and 10 GeV, respectively, and our exclusive ISR measurements make important contributions. We are also making an inclusive measurement of the contribution to $\alpha(M_Z)$ for $\sqrt{s} < 6.5$ GeV.

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2. Exclusive reactions at 10.6 GeV

To study an exclusive reaction of the form $e^+e^- \to f_1 f_2 ... f_n$, where f_j are specific final state particles, we select events containing a set of well measured charged tracks, identified as the desired types, and well measured photons. We require no additional good charged tracks and a limited amount of additional neutral energy. Invariant mass distributions for candidate $\pi^+\pi^-\pi^+\pi^-$ and $K^+K^-\pi^+\pi^-$ events [3] are shown in Fig. 1, along with that for $\pi^+\pi^-\pi^0\pi^0$ events after a requirement on the total momentum. All show clear signal peaks at 10.6 GeV/c^2. Backgrounds are small, but nonnegligible, and we focus here on specific quasi-2-body channels.

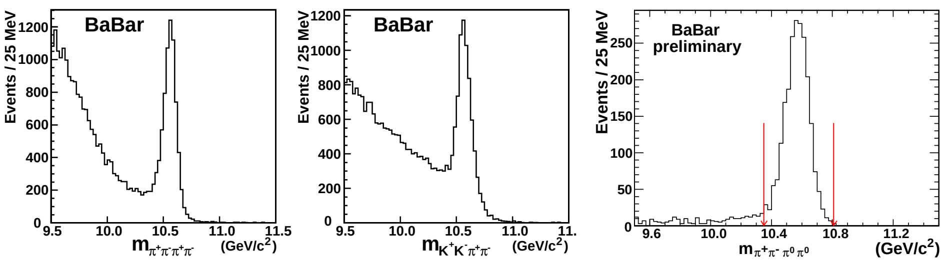

Fig. 1. Invariant mass distributions for candidate $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ (left) $K^+K^-\pi^+\pi^-$ (middle) and $\pi^+\pi^-\pi^0\pi^0$ (right) events.

We select $\pi^+\pi^-\pi^+\pi^-$ and $K^+K^-\pi^+\pi^-$ events within 170 MeV of our $\sqrt{s}$. They are dominated by the $\rho^0\rho^0$ and $\phi\rho^0$ channels, respectively, which have positive C-parity, so are forbidden in annihilations via a single virtual photon. The production and decay angular distributions and the slow $\sqrt{s}$ dependence implied by the absence of these events in the ISR samples (below) confirm that they result from a two-virtual-photon process that we observe for the first time. We measure cross-sections consistent with predictions of a simple vector dominance model [4] of this process.

We also study the $\rho^+\rho^-$ channel, which is allowed in one-γ^* annihilation. Two-γ^* processes could also contribute via final state rescattering, possibly giving an observable angular asymmetry. The cross-section is about half that of the $\rho^0\rho^0$ mode, but there are no theoretical predictions. This mode is present in our ISR data at a level consistent with one-γ^* annihilation, but the angular distributions indicate that the helicity state expected to dominate at this $\sqrt{s}$ can account for only $\sim$60% of the total rate.

In the reactions $e^+e^- \to \gamma\eta$ and $\gamma\eta'$ we measure [5] the η and η' transition form factors at $q^2 = 112$ GeV^2, in or near the asymptotic regime where there are theoretical predictions. They cover a wide range due to the uncertainty in η–η' mixing and our value for $\eta^{(\prime)}$ is at the upper (lower) end of the range, so improved measurements may help understand these particles.

3. Exclusive reactions at lower energies via ISR

For our lower-energy studies we select events as above, with an additional high-energy photon. We perform a set of kinematic fits that are used both to select events and measure backgrounds with similar topologies. We have published [2] measurements in several channels, including: the best measurement of the proton form factor, confirming the threshold enhancement and showing structures near 2.25 and 3 GeV; improved studies of the ω' and ω'' mesons in the $\pi^+\pi^-\pi^0$ channel; a measurement of the $\pi^+\pi^-\pi^+\pi^-$ cross-section that improves the uncertainty on the total cross-section; and improved studies of the $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$ channels showing considerable internal structure.

In an improved study of the $K^+K^-\pi^+\pi^-$ and $K^+K^-\pi^0\pi^0$ channels [6], we isolate the $\phi f_0(980)$ submode, and its cross-section is shown in Fig. 2(a). A structure is evident near threshold in both f_0 decay modes; a threshold function (red line) cannot describe the data. Including a single resonance in the fit gives a mass of 2175±18 MeV/c^2 and a width of 58±26 MeV. This mass region, close to $\Lambda^0\overline{\Lambda}^0$ threshold, is quite interesting.

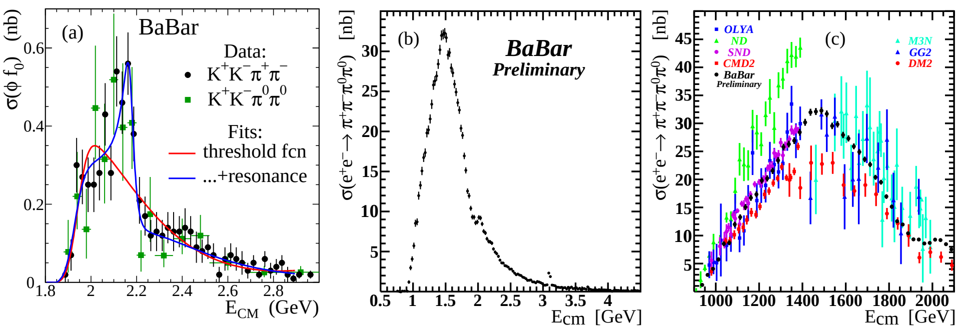

Fig. 2. (a) Cross-section for $e^+e^-\to\phi f_0$; the lines represent fits with and without a resonant contribution. Preliminary cross-section for $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$ over (b) our full energy range and (c) compared with previous measurements at low energies.

We show a new measurement of the $\pi^+\pi^-\pi^0\pi^0$ cross-section, along with previous results, in Figs. 2(b), (c). It covers a wide $\sqrt{s}$ range and shows structure attributable to ρ and J/ψ resonances. This final state has the largest cross-section in the 1.1–2.5 GeV region, so is very important for $g_\mu-2$. The five measurements below 1.4 GeV are consistent within their 5–25% normalization errors (not shown), and can be combined to give an error of ∼3%. Our preliminary error is 8%, but we expect to achieve ∼5% and further measurements are expected from other experiments. At higher $\sqrt{s}$ our point-to-point systematic errors are small, so the uncertainty from the data below 1.4 GeV can be used across the full range in calculating g_μ–2.

4. $\alpha(M_Z)$ from an inclusive ISR measurement

One can measure $\sigma_{\rm had}$ inclusively using hard photons recoiling against a hadronic system. Our energy resolution obscures narrow structure, see Fig. 3(a), but we can measure its integral up to a high $\sqrt{s}$ value. To calculate $g_\mu-2$ or $\alpha(M_Z)$, we must convolve with the appropriate kernel. True and reconstructed convolutions for $\alpha(M_Z)$ converge for $\sqrt{s}>4$ GeV, see Fig. 3(b), but the $g_\mu-2$ kernel peaks too strongly at low $\sqrt{s}$. We reject events with identified $e^\pm$, but subtract the well understood radiative μ- and τ-pair events. Background from $e^+e^-\to q\bar{q}$ events at 10.6 GeV with a hard π^0 faking a photon grows exponentially as $\sqrt{s}$ increases. Extensive studies of these events in the data allow us to reduce them to a well understood, low level, shown in Fig. 3(c). We expect a $\sim$4% measurement of the contribution from $\sqrt{s}<6.5$ GeV, improving the overall uncertainty on $\alpha(M_Z)$.

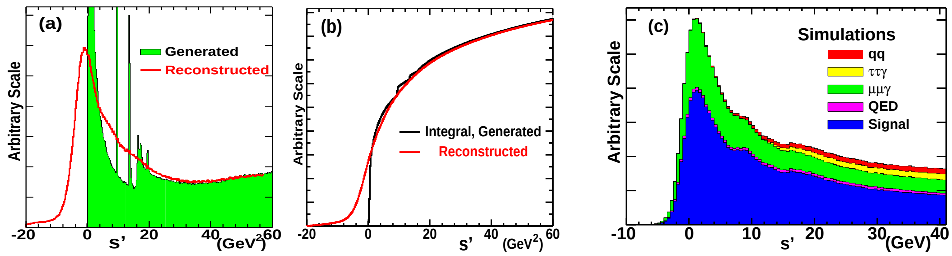

Fig. 3. (a) Cross-sections generated and reconstructed from simulated ISR photons; (b) integrals with the $\alpha(M_Z)$ kernel. (c) Simulated signal and background events.

5. Summary

BABAR has made many new and improved studies of e^+e^- annihilation physics at our c.m. energy of 10.6 GeV, and from threshold up to 4–7 GeV using ISR. With the full data set and improved analysis, we expect excellent measurements of these and many more channels in the future.

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