PROCEEDINGS OF SCIENCE

New exclusive cross section measurements for $e^+e^- \to$ hadrons

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The BABAR Collaboration has an intensive program studying hadronic cross sections in low-energy e^+e^- annihilations, which are accessible with data taken near the $\Upsilon(4S)$ via initial-state radiation. Our measurements allow significant improvements in the precision of the predicted value of the muon anomalous magnetic moment. These improvements are necessary for shedding light on the current ~ 3 sigma difference between the predicted and the experimental values. We have previously published results on a number of processes with two to six hadrons in the final state. Currently, the largest uncertainty on the calculation of the hadronic contribution in the energy region between 1 and 2 GeV stems from the $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ cross section. A new precise measurement of this process is presented here, together with measurement of other low-multiplicity channels, such as $e^+e^- \to \pi^+\pi^-\eta$.

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1. Introduction

Quantum Electrodynamics (QED) is tested to very high precision by comparing the electron anomalous magnetic moment $a_e = (g_e - 2)/2$ measurement with theoretical calculations. The anomalous magnetic moment of the muon, a_μ, however, shows a discrepancy between the most precise experimental determination [1] and recent theoretical evaluations [2, 3] of approximately 3 standard deviations: the difference between the theory value $a_\mu \cdot 10^{10} = 11659180.2 \pm 4.9$ [2] and the experimental result $a_\mu \cdot 10^{10} = 11659208.9 \pm 6.3$ is $\Delta a_\mu \cdot 10^{10} = 28.7 \pm 8.0$. This discrepancy may be due to new physics, but it may also be due to the contributions from Quantum Chromodynamics (QCD), mainly vacuum polarisation with hadrons. While ab initio QCD calculations are still not precise enough, these contributions can be reliably determined via dispersion relations connecting them to the cross section for $e^+e^- \to$ hadrons at low energies. These contribute with $a_\mu^{\text{had,LO}} \cdot 10^{10} = 692.3 \pm 4.2$ [2] or $a_\mu^{\text{had,LO}} \cdot 10^{10} = 694.9 \pm 4.3$, $a_\mu^{\text{had,NLO}} \cdot 10^{10} = -9.8 \pm 0.1$ [3] significantly to the theoretical uncertainty.

New and more precise experimental determinations of a_μ are expected within a few years from now from experiments at Fermilab and J-PARC. For the hadronic contributions to the theoretical value, experimental input from the measurement of the cross section $e^+e^- \to$ hadrons at low energies dominates. Therefore, precise measurements of exclusive cross sections are important to further improve our understanding of the discrepancy, either increasing its significance or, alternatively, reducing its value.

These cross sections have been obtained from scans at low-energy e^+e^- colliders. At the BABAR experiment [4], which took data at cms energies close to the $\Upsilon(4S)$ mass of 10.58 GeV, these cross sections are accessible through initial-state radiation (ISR).

2. The eta pion pion final state

The event selection at BABAR makes use of the good solid angle coverage of the detector and the well known beam energies. A full event $e^+e^- \to \pi^+\pi^-\eta + \gamma_{\text{ISR}}$ with $\eta \to \gamma\gamma$ [5] is submitted to a 4C fit, using energy and momentum conservation as constraints. The chisquare distribution of these fits shows a peaking density corresponding to the theoretical distribution with 4 degrees of freedom plus a rising distribution from background. A $\pi^+\pi^-\gamma\gamma$ signal is enhanced by a cut $\chi^2 < 25(15)$ for an energy in the cms of the hadronic final state $E_{\text{CM}\,\pi^+\pi^-\gamma\gamma} < (>) 2\,\text{GeV}$. In a fit to $m(\gamma\gamma)$, the number of $\pi^+\pi^-\eta$ events is determined in bins of E_{CM}. The resulting cross section is shown in Fig. 1. For $E_{\text{CM}} < 1.15\,\text{GeV}$, it is compatible with zero.

For the interval from threshold to $E_{\text{CM}} = 1.8\,\text{GeV}$, the new results correspond to $a_\mu^{\pi^+\pi^-\eta} \cdot 10^{10} = 1.19 \pm 0.02 \pm 0.06$, compared to the 2011 evaluation of 0.88 ± 0.10 [3].

The distribution of $m(\pi^+\pi^-)$ shows a pronounced $\rho(770)$ peak, indicating that this final state proceeds dominantly through $e^+e^- \to \rho^0\eta$. A slight shift to higher masses is observed which may indicate a $\rho(770)$-$\rho(1450)$-interference. The η helicity angle distribution $\propto 1 + (0.92 \pm 0.09)\cos^2\theta$ is in agreement with the vector pseudoscalar intermediate state.

Vector meson dominance is tested via fits to the E_{CM} distribution, using four models:

- $\rho(770)$ and $\rho(1450)$ fit data below 1.7 GeV,

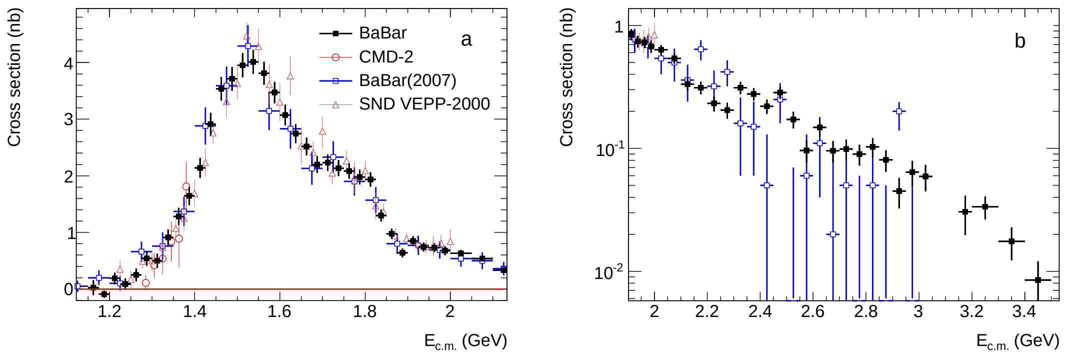

Figure 1: Cross section for $e^+e^- \to \pi^+\pi^-\eta$ from *BABAR* compared to previous measurements [6, 7, 8]. The main contributions are below 2.2 GeV (a), while we also measured the tails up to 3.5 GeV shown in a logarithmic scale (b).

- $\rho(770)$, $\rho(1450)$ plus a $\rho(1700)$ with a relative phase of 180° fit data below 1.9 GeV,
- The same with a $\rho(1700)$ with a relative phase of 0° fit the same interval equally well,
- $\rho(770)$, $\rho(1450)$, $\rho(1700)$ and $\rho(2150)$ fit data up to 2.2 GeV.

Beyond 2.3 GeV, the cross section is larger than the vector dominance models' tails.

Our cross section is also used to test CVC (conserved vector current hypothesis) calculating the branching fraction of the tau lepton, $\mathscr{B}(\tau^- \to \nu_\tau\pi^+\pi^-\eta) = (0.160 \pm 0.009)\%$. Adding our previous result [8] with $\eta \to \pi^+\pi^-\pi^0$, we predict $\mathscr{B}(\tau^- \to \nu_\tau\pi^+\pi^-\eta) = (0.162 \pm 0.008)\%$. The measured value, $\mathscr{B}(\tau^- \to \nu_\tau\pi^+\pi^-\eta) = (0.139 \pm 0.010)\%$, is lower, which may be a statistical fluctuation (about 1.5σ) but could also be due to isospin breaking contributions.

3. Four pion final states

The final state $\pi^+\pi^-\pi^0\pi^0$ was one with a large contribution to the error on a_μ^{had}. The new *BABAR* results [9] have reduced the errors considerably.

Our result is achieved by subtracting exclusive background using calibrated Monte Carlo predictions. This method is cross-checked via the chisquare distribution of a 6C fit, using as constraints in addition to overall energy and momentum conservation also the two π^0 mass constraints on the photon pairs. The resulting cross section is shown in Fig. 2, it is compatible with zero below 0.85 GeV. For the interval from threshold to $E_{\text{CM}} = 1.8$ GeV, the new results correspond to $a_\mu^{\pi^+\pi^-2\pi^0} \cdot 10^{10} = 18.1 \pm 0.1 \pm 0.6$, compared to the 2011 evaluation of 18.62 ± 1.15 [3].

A comparison with the $\pi^+\pi^-\pi^+\pi^-$ cross section [10] reveals a different E_{CM} distribution due to different resonant subchannels, in particular $\omega\pi^0$ which can only contribute to $\pi^+\pi^-\pi^0\pi^0$.

4. Other new final states

More final states have been recently measured by *BABAR*, which are presented in a poster contribution to this conference [12]. They comprise the final states $K_S^0K_L^0\pi^0$, $K_S^0K_L^0\pi^0\pi^0$, and $K_S^0K_L^0\eta$, the latter being almost completely a $\phi\eta$ state.

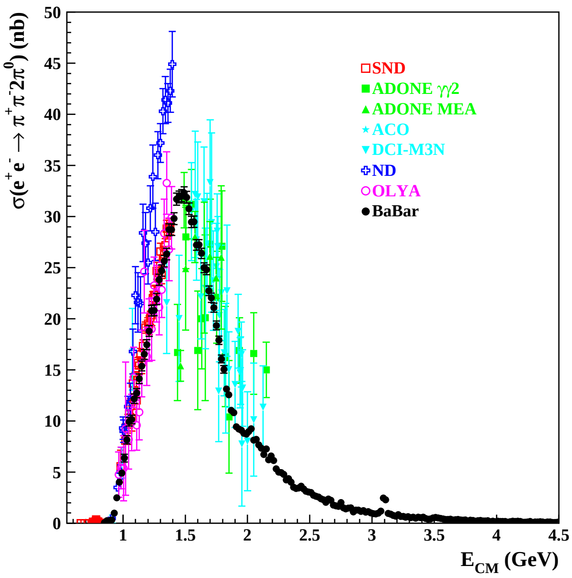

Figure 2: Cross section for $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ from *BABAR* compared to previous measurements [11].

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