Exclusive Hadronic Final States in e^+e^- Interactions at BABAR

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The first observation of e^+e^- annihilation into states of positive C parity, $\rho^0\rho^0$ and $\phi\rho^0$ is reported. It is shown that these final states are produced through two-virtual-photon annihilation. This is based on the distributions of $cos\theta^*$, where θ^* is the center-of-mass polar angle of ϕ or ρ^0. The cross sections for the $|cos\theta^*| < 0.8$ are measured. In addition, the observation of another channel, $e^+e^- \to \phi\eta$ near $\sqrt{s} = 10.58$ GeV with a significance of 6.5σ is discussed. The cross section of the later channel for $|cos\theta^*| < 0.8$ is measured, where θ^* is the center-of-mass polar angle of ϕ meson.

1 Observation of e^+e^- annihilation into states of positive C parity, $\rho^0\rho^0$ and $\phi\rho^0$

The BABAR experiment has measured some rare, low multiplicity final states that have C= +1. These final states are produced through a two-virtual-photon annihilation (TVPA) process which is shown in Figure 1.

The channels measured by the BABAR experiment [2] are the exclusive reactions $e^+e^- \to \rho^0\rho^0$ and $e^+e^- \to \phi\rho^0$. The final state in both these channels is even under charge conjugation and cannot be produced by single-photon annihilation. The data sample used in this analysis consists of 205 fb^{-1} of data collected on the $\Upsilon(4S)$ resonance and 20 fb^{-1} collected 40 MeV below.

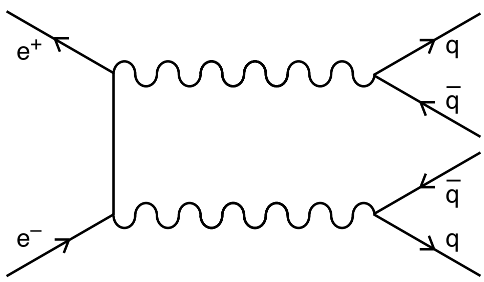

Figure 1: Two-virtual-photon annihilation diagram.

The event selection requires four well-reconstructed charged tracks with a total charge of zero. Two oppositely charged tracks must be identified as pions and the other two must be both pions or kaons.

The four tracks are fitted to a common vertex and we require the χ^2 probability to exceed 0.1%. We select events that have a reconstructed invariant mass within 170 MeV/c of the nominal c.m. energy as shown in Figure 2.

The analysis is performed using a binned maximum-likelihood fit. The fit is performed in nine rectangular regions of the two-dimensional mass distributions. The signal region is considered to be the $0.5 < m_{\pi^+\pi^-} < 1.1$ GeV/c^2 and $1.008 < m_{K^+K^-} < 1.035$ GeV/c^2 mass regions.

The number of signal events for the $\rho^0\rho^0$ and $\phi\rho^0$ channels are 1243 ± 43 and 147 ± 13 respectively with a χ^2/dof (degrees of freedom) of 6.4/4 and 2.0/3. There are a total of 1508 $\pi^+\pi^-\pi^+\pi^-$ ($\sim$ 18% background) and 163 $K^+K^-\pi^+\pi^-$ ($\sim$ 10% background) events in the signal box, respectively.

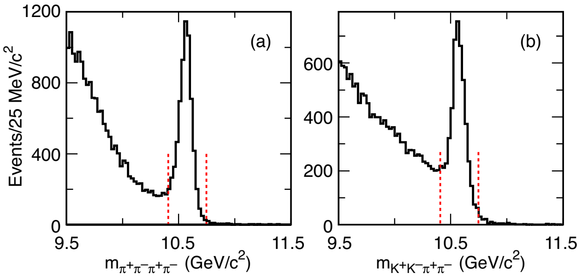

Figure 2: The invariant mass for the (a) $\pi^+\pi^-\pi^+\pi^-$ and (b) $K^+K^-\pi^+\pi^-$ final states. The dashed lines show the signal regions.

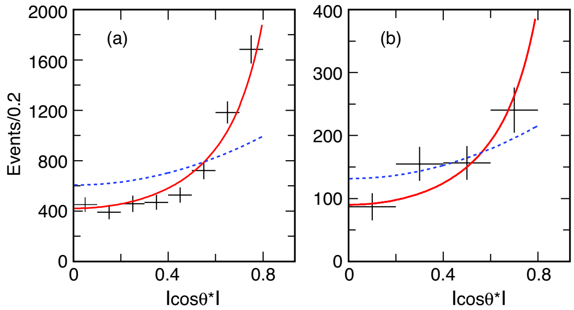

Figure 3: Distributions of the production angle for a) $\rho^0\rho^0$ and b) $\phi\rho^0$. The solid and dashed lines are the normalized $\frac{1+\cos^2\theta^*}{1-\cos^2\theta^*}$ and $1+\cos^2\theta^*$ distributions, respectively.

One can study the production mechanism by using the production angle θ^*, which is defined as the angle between the ρ^0 (ϕ) direction and the e^- beam direction in the CM frame. Figure 3 shows the $|\cos\theta^*|$ distributions after MC efficiency correction. The measurements are restricted to the fiducial region $|\cos\theta^*| < 0.8$, since the efficiency drops rapidly beyond 0.8. These forward peaking $\cos\theta^*$ distributions are consistent with the TVPA expectation [3], which can be approximated by:

$$\frac{d\sigma}{d\cos\theta^*} \propto \frac{1+\cos^2\theta^*}{1-\cos^2\theta^*}$$

in the fiducial region. The fit for TVPA hypothesis gives a χ^2/dof of 11.8/7 ($\rho^0\rho^0$) and 3.5/3 ($\phi\rho^0$). However, fitting by $1+\cos^2\theta^*$, will give a χ^2/dof of 112/7 for $\rho^0\rho^0$ and 6.3/3 for $\phi\rho^0$ respectively.

For calculating the cross section we take the branching fraction of $\phi \to K^+K^-$ to be 49.1% and that of $\rho^0 \to \pi^+\pi^-$ as 100% [4]. The TVPA cross sections within $|\cos\theta^*| <0.8$ near $\sqrt{s} = 10.58$ GeV are:

$$\sigma_{\text{fid}}(e^+e^- \to \rho^0\rho^0) = 20.7 \pm 0.7(\text{stat}) \pm 2.7(\text{syst})\ \text{fb}$$
$$\sigma_{\text{fid}}(e^+e^- \to \phi\rho^0) = 5.7 \pm 0.5(\text{stat}) \pm 0.8(\text{syst})\ \text{fb}.$$

These measured cross sections are in good agreement with the calculation from a vector-dominance two-photon exchange model [3].

2 Observation of the $e^+e^- \to \phi\eta$ reaction at $\sqrt{s} = 10.58$ GeV

The most likely mechanism for the $e^+e^- \to \phi\eta$ reaction is the Feynman diagram in Figure 4. Different QCD-based models predict different s dependences for the production rates of e^+e^- annihilations to vector-pseudoscalar (VP) final states like $\phi\eta$. The CLEO experiment has measured the cross section for $e^+e^- \to \phi\eta$ at $\sqrt{s} = 3.67$ GeV [5]. Our measurement at $\sqrt{s} = 10.58$ GeV [6] provides a meaningful test of the s dependence.

Our analysis uses 204 fb^{-1} of data collected on the $\Upsilon(4S)$ resonance at $\sqrt{s} = 10.58$ GeV and 20 fb^{-1} collected 40 MeV below the $\Upsilon(4S)$ mass. To $\phi\eta$ final state is reconstructed in the $K^+K^-\gamma\gamma$ mode, by selecting two well-reconstructed oppositely charged tracks and at least two well-identified photons.

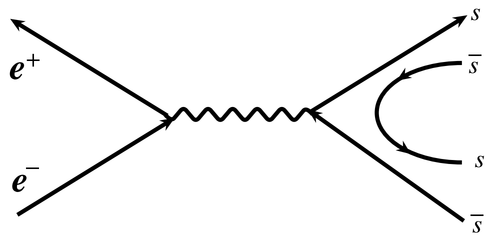

Figure 4: Two-virtual-photon annihilation diagram.

The two tracks are fitted to a common vertex with a requirement on the χ^2 probability to exceed 0.1%. The photon candidates are required to have a minimum energy of 500 MeV in the laboratory frame. We accept events with a reconstructed invariant mass of $K^+K^-\gamma\gamma$ within 230 MeV/c^{2}of the e^+e^- CM energy. In addition we require the invariant mass of K^+K^- to be close to the ϕ mass ($m_{KK} < 1.1$ GeV/c^2) and that of $\gamma\gamma$ to be near the η mass ($0.4 < m_{\gamma\gamma} < 0.8$ GeV/c^2).

The number of signal events are derived using a two-dimensional log-likelihood fit. The number of $\phi\eta$ signal events is 24 ± 5 in the ϕ mass window, where the ϕ mass window is defined as $1.008 < m_{KK} < 1.035$ GeV/c^2. This corresponds to a significance of 6.5 standard deviations. The significance is estimated by using the log-likelihood difference between signal and null hypotheses (no $\phi\eta$ signal component), $\sqrt{2ln(L_s/L_n)}$, where L_s and L_n refer to the likelihoods of the signal and null hypotheses respectively.

The cross section is calculated by taking the branching fraction of $\phi \to K^+K^-$ to be 49.1% and that of $\eta \to \gamma\gamma$ equal to 39.4% [4]. The cross section within $|\cos\theta^*| < 0.8$ near $\sqrt{s} = 10.58$ GeV is:

$$\sigma_{\text{fid}}(e^+e^- \to \phi\eta) = 2.1 \pm 0.4(\text{stat}) \pm 0.1(\text{syst})\ \text{fb}.$$

There is no direct prediction for the cross section of this process at this energy. Some QCD-based models predict the $e^+e^- \to$ VP cross section to have $1/s^4$ [7, 8] dependence. Our result and that of CLEO, ($\sigma = 2.1^{+1.9}_{-1.2} \pm 0.2$ pb) at $\sqrt{s} = 3.67$ GeV (continuum) [5], favors a $1/s^3$ dependence as depicted in Figure 5.

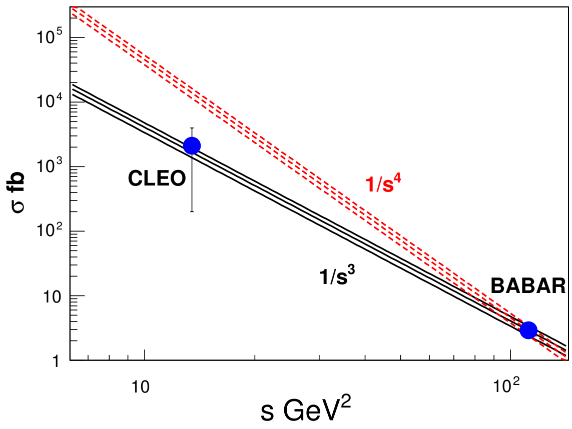

Figure 5: Extrapolations of cross sections using BABAR's measurement at $\sqrt{s} = 10.58$ GeVassuming $1/s^3$ (solid) or $1/s^4$ (dashed) energy dependence. The bands show one standard deviation uncertainties in the extrapolations. The CLEO measurement at $\sqrt{s} = 3.67$ GeV is also shown.

References

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