PROCEEDINGS OF SCIENCE

Study of three-body charmonium decays in *BABAR*

Sandrine Emery-Schrenk on behalf of the *BABAR* collaboration*
DRF/IRFU/SPP, CEA centre de Saclay, France
E-mail: `sandrine.emery@cea.fr`

The processes $\gamma\gamma \rightarrow K^0_S K^{\pm}\pi^{\mp}$ and $\gamma\gamma \rightarrow K^+K^-\pi^0$ are studied using a data sample of 519 fb^{-1} recorded with the *BABAR* detector operating at the SLAC PEP-II asymmetric-energy e^+e^- collider at center of mass energies at and near the Υ(n = 2, 3, 4) resonances. In both final states we observe η_c decays and Dalitz plot analyses are performed using a model-independent partial wave technique. This allows a model-independent measurement of the mass-dependence of the $I = \frac{1}{2}$ Kπ S-wave amplitude and phase. This measurement is compared to those from previous experiments and the phase shows similar behavior for up to a mass of 1.5 GeV/c^2 but the amplitudes exhibit very marked differences. The presence of a new a$_0$(1950) resonance is required by the data with $m = 1931 \pm 14 \pm 22$ MeV/c^2 and $\Gamma = 271 \pm 22 \pm 29$ MeV.

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*Speaker.

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1. Physics motivations

The study of scalar mesons has long been a puzzle, since many states have been observed in a picture apparently inconsistent with the $q\overline{q}$ quark model. The structure of the $I=\frac{1}{2}$ $K\pi$ S-wave is poorly known. It represents a source of large systematic errors in three or four-body decays of heavy flavored mesons, useful for CP violation measurements, such as the $B\to K^{*}\rho$ decay. Previous mesurements of the isospin $I=\frac{1}{2}$ $K\pi$ S-wave from the LASS [1] and E791 [2] experiments are limited to values of $K\pi$ mass below the D^{+} mass, and are also contaminated by a contribution from isospin $I=\frac{3}{2}$. The LASS (E791) experiments are based on studies of $K^{-}p\to K^{-}\pi^{+}n$ ($D^{+}\to K^{-}\pi^{+}\pi^{+}$). The new measurement presented here of the $I=\frac{1}{2}$ $K\pi$ S-wave using $\eta_c\to K\overline{K}\pi$ decays allows one to determine the $K\pi$ S-wave amplitude for $K\pi$ mass values up to 2.5 GeV/c^{2}. Also the isospin conservation (the η_c isospin is zero) implies no $I=\frac{3}{2}$ contribution in the $K\pi$ S-wave.

2. the BABAR experiment and the data sample

The studies of $\eta_c\to K\overline{K}\pi$ decays at BABAR presented here have been published in [3] [4]. The BABAR experiment has collected data until 2008 at the SLAC PEP-II asymmetric-energy $e^{+}e^{-}$ collider, at center of mass energies at and near the Υ(n = 2, 3, 4) resonances. The BABAR detector provides a large solid angle coverage, excellent tracking, electromagnetic calorimetry, and particle identification. Two photon scattering events $\gamma\gamma\to\eta_c\to K^0_S K^{\pm}\pi^{\mp}$ and $\gamma\gamma\to\eta_c\to K^{+}K^{-}\pi^{0}$ are selected from the full 519 fb^{-1} BABAR dataset taken on and off the Υ(n = 2, 3, 4) resonances.

A low scattering angle and quasi-real photons are requested by vetoing the detection of the scattered electron and positron. Selecting η_c production from two photon scattering avoids the contamination from vector charmonium states, and allows clean and low multiplicity samples. This selection requires a low transverse momentum for the η_c candidate, compared to the beam axis. To suppress the Initial State Radiation background (ISR), mostly from $e^{+}e^{-}\to\gamma_{ISR}J/\Psi$, a large missing mass is required.

The selection of the $K^0_S K^{\pm}\pi^{\mp}$ final state requires exactly four charged tracks, particle identification, and a cut on the reconstructed K^0_S mass. A sample of 12849 events with a 64.3 % η_c purity is obtained. The selection of the $K^{+}K^{-}\pi^{0}$ final state is more difficult due to the π_0 selection, leading to a sample of 6710 events with a η_c purity of 55.2 %. The $K^0_S K^{\pm}\pi^{\mp}$ [3] and $K^{+}K^{-}\pi^{0}$ [4] mass spectra in the η_c mass region are shown in Fig. 1. In the Dalitz plot analysis, both the signal and the sidebands regions are used to constrain the backgrounds ($e^{+}e^{-}$ annihilation, other $\gamma\gamma$ processes, and ISR). The Dalitz plots obtained in the η_c signal region for $\eta_c\to K^0_S K^{\pm}\pi^{\mp}$ [3] and $\eta_c\to K^{+}K^{-}\pi^{0}$ [4] are shown in Fig. 2. Both η_c decay channels show the dominance of the $\eta_c\to pseudoscalar+scalar$ contributions.

3. Dalitz plot analysis

The Dalitz plot analysis is based on the full interference between ampitudes of different contributions. It has been performed recently using the isobar model for the $\eta_c\to K^0_S K^{\pm}\pi^{\mp}$ channel [3], and had been done previously for the $\eta_c\to K^{+}K^{-}\pi^{0}$ channel [4]. A Model Independent Partial

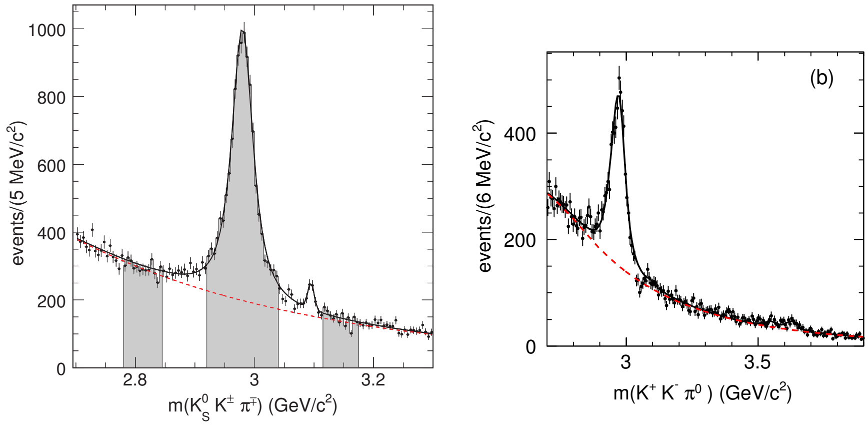

Figure 1: The $K^0_S K^{\pm}\pi^{\mp}$ [3] (left) and $K^+K^-\pi^0$ [4] (right) mass spectra in the η_c mass region. The solid curve shows the total fitted function, and the dashed curve shows the fitted background contribution. On the left plot, the shaded areas show signal and sideband regions.

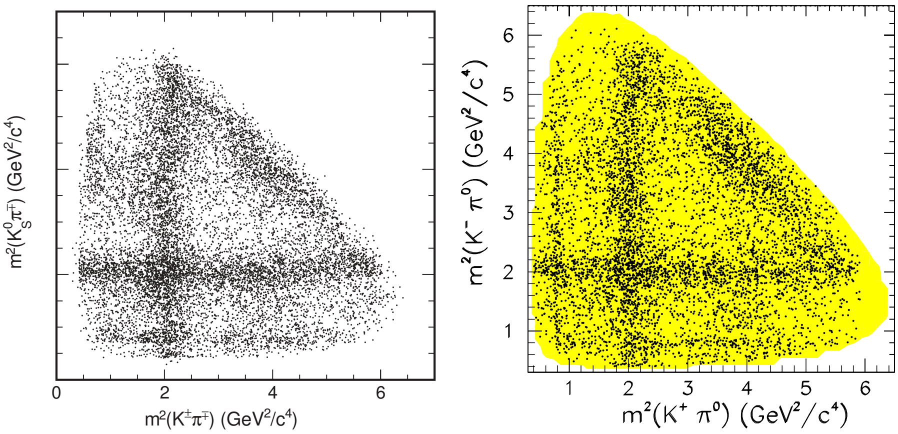

Figure 2: Dalitz plot in the η_c signal region for $\eta_c \to K^0_S K^{\pm}\pi^{\mp}$ [3] (left) and $\eta_c \to K^+K^-\pi^0$ [4] (right) events.

Wave Analysis (MIPWA) of the Dalitz plot has been used recently in [3] for both η_c decay modes. The MIPWA analysis also allows a measurement of the $I = \frac{1}{2}$ $K\pi$ S-wave. In the isobar model the $I = \frac{1}{2}$ $K\pi$ S-wave is not measured as a whole but is a sum of several contributions: $K^*_0(1430)\overline{K}$, $K^*_0(1950)\overline{K}$, and a uniform non-resonant contibution.

Table 1 shows the results of the two fits based on an isobar model for the $K^0_S K^{\pm}\pi^{\mp}$ and $K^+K^-\pi^0$ η_c decay modes. The agreement between the fit results for the two modes is not very good, and the values of the fit χ^2 show that the isobar model does not agree very well either with the data. In the MIPWA analysis based on a technique developped in [2], the total amplitude A is a sum of partial waves including the A_1 $K\pi$ S-wave amplitude: $A = A_1 + c_2 A_2 e^{\phi_2} + c_3 A_3 e^{\phi_3} + ...$ The A_1 $K\pi$ S-wave amplitude is symmetrized for the $(K\pi)K$ systems, as the isospin conservation in the η_c and K^* decays leads to a constructive interference for $(K\pi)K$ systems. For example, for the

Table 1: Isobar model fit results

	$\eta_c \to K^0_S K^\pm \pi^\mp$ [3]		$\eta_c \to K^+K^-\pi^0$ [4]	
Final state	Fraction (%)	Phase (rad)	Fraction (%)	Phase (rad)
		$K\pi$ S-wave		
$K_0^*(1430)\overline{K}$	40.8 ± 2.2	0.	$33.8 \pm 1.9 \pm 0.4$	0.
$K_0^*(1950)\overline{K}$	14.8 ± 1.7	-1.00 ± 0.07	$6.7 \pm 1.0 \pm 0.3$	$-0.67 \pm 0.07 \pm 0.03$
Non resonant	18.0 ± 2.5	1.94 ± 0.09	$24.4 \pm 2.5 \pm 0.6$	$1.49 \pm 0.07 \pm 0.03$
$a_0(980)\pi$	10.5 ± 1.2	0.94 ± 0.12	$1.9 \pm 0.1 \pm 0.2$	$0.38 \pm 0.24 \pm 0.02$
$a_0(1450)\pi$	1.7 ± 0.5	2.94 ± 0.13	$10.0 \pm 2.4 \pm 0.8$	$-2.40 \pm 0.05 \pm 0.03$
$a_0(1950)\pi$	0.7 ± 0.2	-1.76 ± 0.24	–	–
$a_0(1320)\pi$	0.2 ± 0.2	-0.53 ± 0.42	$2.1 \pm 0.1 \pm 0.2$	$0.77 \pm 0.20 \pm 0.04$
$K_2^*(1430)\overline{K}$	2.3 ± 0.7	-1.55 ± 0.11	$6.8 \pm 1.4 \pm 0.3$	$-1.67 \pm 0.07 \pm 0.03$
Total	88.8 ± 4.3		$85.8 \pm 3.6 \pm 1.2$	
χ^2/N_{cells}	467/256= 1.82		212/130= 1.63	

$\eta_c \to K^0_S K^+\pi^-$ decay $A_j^{S-wave} = \frac{1}{\sqrt{2}}[a_j^{K^+\pi^-} e^{i\phi_j K^+\pi^-} + a_j^{\bar{K}^0\pi^-} e^{i\phi_j \bar{K}^0\pi^-}]$, $a_j^{K^+\pi^-}(m_{K\pi}) = a_j^{\bar{K}^0\pi^-}(m_{K\pi})$ and $\phi_j^{K^+\pi^-}(m_{K\pi}) = \phi_j^{\bar{K}^0\pi^-}(m_{K\pi})$. The $(K\pi)$ mass spectrum is divided into 30 mass intervals (j), each associated with two free parameters A_j and ϕ_j, except for one arbitrary bin for which they are fixed to $A = 1$ and $\phi = \frac{\pi}{2}$. The other resonance contributions A_2, A_3, etc. are described by Breit-Wigner amplitudes multiplied by their associtated angular functions. The Background contribution is estimated using the η_c sidebands regions. The results of the MIPWA Dalitz plot analysis show in

Table 2: MIPWA fit results

	$\eta_c \to K^0_S K^\pm \pi^\mp$ [3]		$\eta_c \to K^+K^-\pi^0$ [3]	
Amplitude	Fraction (%)	Phase (rad)	Fraction (%)	Phase (rad)
$K\pi$ S-wave	$107.3 \pm 2.6 \pm 17.9$	fixed	$125.5 \pm 2.4 \pm 4.2$	fixed
$a_0(980)\pi$	$0.8 \pm 0.5 \pm 0.8$	$1.08 \pm 0.18 \pm 0.18$	$0.0 \pm 0.1 \pm 1.7$	...
$a_0(1450)\pi$	$0.7 \pm 0.2 \pm 1.4$	$2.63 \pm 0.13 \pm 0.17$	$1.2 \pm 0.4 \pm 0.7$	$2.90 \pm 0.12 \pm 0.25$
$a_0(1950)\pi$	$3.1 \pm 0.4 \pm 1.2$	$-1.04 \pm 0.08 \pm 0.77$	$4.4 \pm 0.8 \pm 0.8$	$-1.45 \pm 0.08 \pm 0.27$
$a_0(1320)\pi$	$0.2 \pm 0.1 \pm 0.1$	$1.85 \pm 0.20 \pm 0.20$	$0.6 \pm 0.2 \pm 0.3$	$1.75 \pm 0.23 \pm 0.42$
$K_2^*(1430)\overline{K}$	$4.7 \pm 0.9 \pm 1.4$	$4.92 \pm 0.05 \pm 0.10$	$3.0 \pm 0.8 \pm 4.4$	$5.07 \pm 0.09 \pm 0.30$
Total	$116.8 \pm 2.8 \pm 18.1$		$134.8 \pm 2.7 \pm 6.4$	
χ^2/N_{cells}	301/254= 1.17		283.2/233= 1.22	

Table 2 shows an agreement between the two $\eta_c \to K\overline{K}\pi$ decay modes. The values of the fit χ^2 also indicate a better agreement with the data, compared to the isobar model. The values of the sum of the fractions are greater than 100%, due to interference effects. Table 2 also indicates that the $K\pi$ S-wave contribution is dominant, but a $K_2^*(1430)\overline{K}$ as well as some $a_0\pi$ contributions are observed. Including a new resonance $a_0(1950)$ improves the agreement with the data, as shown on Fig. 3. This represents a 2.5 σ (4.2 σ) effect for the $K_S^0K^\pm\pi^\mp$ ($K^+K^-\pi^0$) mode. The two channels agree and the weighted means for the parameters $m = 1931 \pm 14 \pm 22$ MeV/c^2 and $\Gamma = 271 \pm 22 \pm 29$ MeV are obtained when combining the two results. The measurement of the $(K\pi)$ mass dependence of the $I = \frac{1}{2}$ Kπ S-wave amplitude and phase (Fig. 4) indicates a good agreement between the two η_c decay modes. A clear $K_0^*(1430)$ peak is visible on the amplitude plot, as well as a broad structure probably associated to the $K_0^*(1950)$ resonance. A phase variation by about π is seen around the $K_0^*(1430)$ peak, but the phase drops at about 1.7 GeV/c^2 due to the interference with the $K_0^*(1950)$.

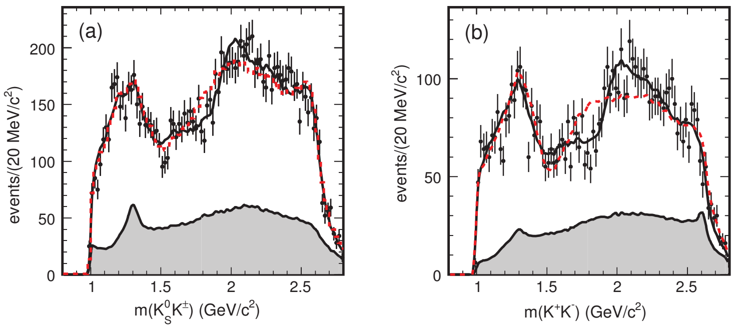

Figure 3: The mass projections (a) $K_S^0K^\pm$ from $\eta_c \to K_S^0K^\pm\pi^\mp$ and (b) K^+K^- from $\eta_c \to K^+K^-\pi^0$. The histograms show the MIPWA fit projections with (solid, black) and without (dashed, red) the presence of the $a_0(1950)$ resonance. The shaded regions show the background estimates obtained by interpolating the results of the Dalitz plot analyses of the sideband regions.

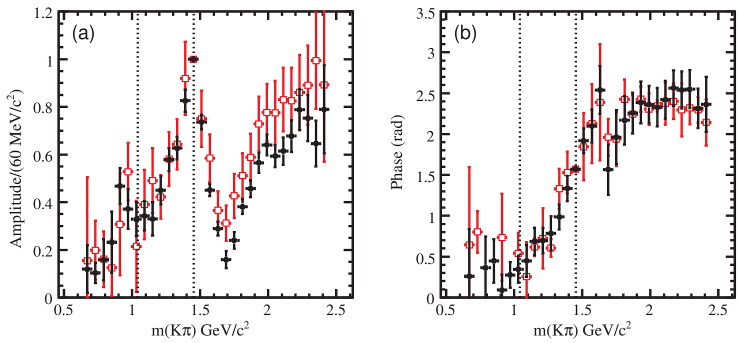

Figure 4: The $I = \frac{1}{2}$ $K\pi$ S-wave amplitude (a) and phase (b) from $\eta_c \to K_S^0K^\pm\pi^\mp$ [solid (black) points] and $\eta_c \to K^+K^-\pi^0$ [open (red) points]; only statistical uncertainties are shown. The dotted lines indicate the $K\eta$ and $K\eta$' thresholds.

Fig. 5 shows the comparaison between this new *BABAR* result and the measurements obtained by the LASS [1] and E791 [2] experiments. The phase measurements are consistent to a $m_{K\pi}$ value of about 1.7 GeV/c^2, which is the upper limit for E791 and the starting point for a two fold ambiguity for LASS. However, a large difference is seen in the $K\pi$ mass dependence of the amplitudes for the BABAR result, compared to LASS and E791 experiments. Note that in the LASS and E791 measurements, the $I = \frac{1}{2}$ component of the $K\pi$ S-wave is difficult to disentangle from the $I = \frac{3}{2}$ component. The BABAR measurement is not contaminated by the $I = \frac{3}{2}$ component.

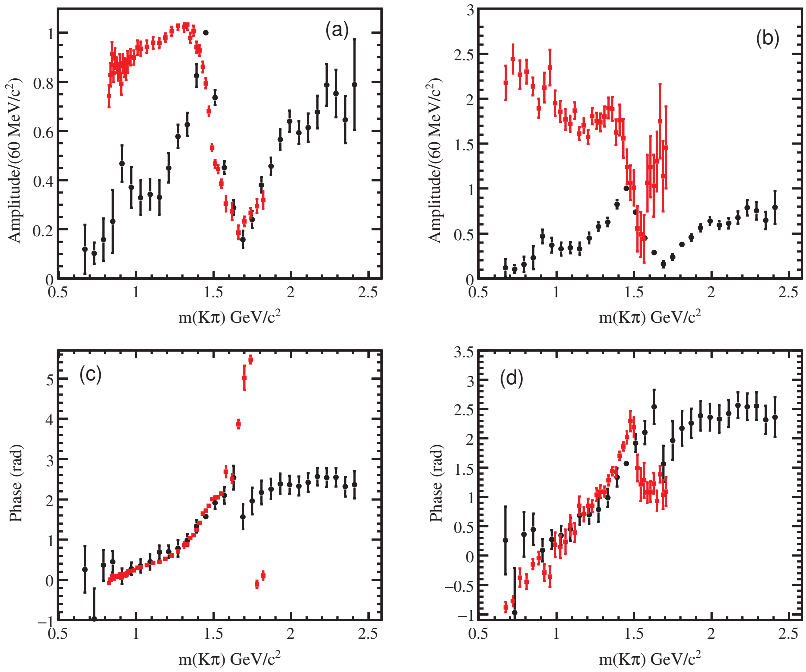

Figure 5: The $I = \frac{1}{2}$ $K\pi$ S-wave amplitude measurements from $\eta_c \to K^0_S K^{\pm}\pi^{\mp}$ compared to the (a) LASS and (b) E791 results: the corresponding $I = \frac{1}{2}$ $K\pi$ S-wave phase measurements compared to the (c) LASS and (d) E791 measurements. Black dots indicate the results from the present analysis; square (red) points indicate the LASS or E791 results. The LASS data are plotted in the region having only one solution.

4. Conclusion

The Dalitz plot of the $\eta_c \to K\overline{K}\pi$ has been fitted using an isobar model and a Model Independent Partial Analysis (MIPWA). The MIPWA fits the data better than the isobar model.

A new measurement of the $I = \frac{1}{2}$ Kπ S-wave amplitude has been performed, up to a $K\pi$ invariant mass of 2.5 GeV/c^2 which is higher than the previous measurements from LASS and E791 experiments. A large difference is seen in the $K\pi$ mass dependence of the amplitudes, compared to LASS and E791 experiments.

References

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