Fermi National Accelerator Laboratory

FERMILAB-Pub-94/071-E

E687

Search for CP Violation in Charm Meson Decay

P.L. Frabetti et al
The E687 Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

March 1994

Submitted to *Physical Review Letters*

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

Search for CP Violation in Charm Meson Decay

P. L. Frabetti[1], H. W. K. Cheung[2], J. P. Cumalat[2], C. Dallapiccola[*,2], J. F. Ginkel[2], S. V. Greene[2], W. E. Johns[2], M. S. Nehring[2], J. N. Butler[3], S. Cihangir[3], I. Gaines[3], P. H. Garbincius[3], L. Garren[3], S. A. Gourlay[3], D. J. Harding[3], P. Kasper[3], A. Kreymer[3], P. Lebrun[3], S. Shukla[3], M. Vittone[3], S. Bianco[4], F. L. Fabbri[4], S. Sarwar[4], A. Zallo[4], R. Culbertson[5], R. W. Gardner[5], R. Greene[5], J. Wiss[5], G. Alimonti[6], G. Bellini[6], B. Caccianiga[6], L. Cinquini[†,6] M. Di Corato[6], M. Giammarchi[6], P. Inzani[6], F. Leveraro[6], S. Malvezzi[‡,6] D. Menasce[6], E. Meroni[6], L. Moroni[6], D. Pedrini[6], L. Perasso[6], A. Sala[6], S. Sala[6], D. Torretta[§,6] D. Buchholz[7], D. Claes[**,7] B. Gobbi[7], B. O'Reilly[7], J. M. Bishop[8], N. M. Cason[8], C. J. Kennedy[††,8] G. N. Kim[8], T. F. Lin[8], D. L. Pušeljić[8], R. C. Ruchti[8], W. D. Shephard[8], J. A. Swiatek[8], Z. Y. Wu[8], V. Arena[9], G. Boca[9], C. Castoldi[9], G. Gianini[9], S. P. Ratti[9], C. Riccardi[9], P. Vitulo[9], A. Lopez[10], G. P. Grim[11], V. S. Paolone[11], P. M. Yager[11], J. R. Wilson[12], P. D. Sheldon[13], F. Davenport[14], J. F. Filasetta[15], G. R. Blackett[16], M. Pisharody[16], T. Handler[16], B. G. Cheon[17], J. S. Kang[17], K. Y. Kim[17]

(E687 Collaboration)

[1] *Dip. di Fisica dell'Università and INFN - Bologna, I-40126 Bologna, Italy.*
[2] *University of Colorado, Boulder, CO 80309.*
[3] *Fermilab, Batavia, IL 60510.*
[4] *Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy.*
[5] *University of Illinois at Urbana-Champaign, Urbana, IL 61801.*
[6] *Dip. di Fisica dell'Università and INFN - Milano, I-20133 Milan, Italy.*
[7] *Northwestern University, Evanston, IL 60208.*
[8] *University of Notre Dame, Notre Dame, IN 46556.*
[9] *Dip. di Fisica Nucleare e Teorica dell'Università and INFN - Pavia, I-27100 Pavia, Italy.*
[10] *University of Puerto Rico at Mayaguez, Puerto Rico.*
[11] *University of California-Davis, Davis, CA 95616.*
[12] *University of South Carolina, Columbia, SC 29208.*
[13] *Vanderbilt University, Nashville, TN 37235.*
[14] *University of North Carolina-Asheville, Asheville, NC 28804.*
[15] *Northern Kentucky University, Highland Heights, KY 41076.*
[16] *University of Tennessee, Knoxville, TN 37996.*
[17] *Korea University, Seoul 136-701, Korea.*

Abstract

We report the results of a search for CP violating decay rate asymmetries (A_{CP}) in the charm decay modes $D^+ \to K^-K^+\pi^+$, $D^+ \to \overline{K}^{*0}K^+$, $D^+ \to \phi\pi^+$, and $D^0 \to K^+K^-$. Our measurements are all consistent with zero asymmetry: $A_{CP}(KK\pi) = -0.031 \pm 0.068$, $A_{CP}(K^*K) = -0.12 \pm 0.13$, $A_{CP}(\phi\pi) = 0.066 \pm 0.086$, and $A_{CP}(KK) = 0.024 \pm 0.084$. The data were accumulated by the Fermilab high energy photoproduction experiment E687.

PACS numbers: 13.25.+m, 14.40.Jz

It has been argued [1], [2] that CP violation in the decays of charm mesons may be significantly enhanced, without requiring physics beyond the standard model. One signature for CP violation would be an asymmetry (A_{CP}) in the decay rate of a charm decay mode and its CP conjugate. In order to exhibit such an asymmetry, there must be two independent weak decay amplitudes that contribute to the same final state (*e.g.* Cabibbo suppressed decays). In addition, final state interactions must induce a strong phase shift between the two weak amplitudes (direct CP violation) or mixing must be present (indirect CP violation, possible for neutral D mesons only). Existing limits on mixing in the charm sector [3] also put upper limits on indirect CP violation, which are somewhat lower than the searches reported here. We report on searches which are sensitive to direct CP violation.

The decay modes $D^0 \to K^+K^-$ and $D^+ \to K^-K^+\pi^+$ (CP conjugates are implied throughout this letter) provide a clean high statistics sample of Cabibbo suppressed decays. The $D^+ \to K^+K^-\pi^+$ mode is complicated by the possibility of intermediate resonant states ($\overline{K}^{*0}K^+$ and $\phi\pi^+$). The CP asymmetry could be different for each decay mode, since the strong phase shift and relative size of the two weak decay amplitudes may vary. We therefore look separately for an asymmetry in the exclusive resonant decay modes as well as in the $K^+K^-\pi^+$ mode. The only existing limit for CP violation in charm meson decay [4] is for the Cabibbo suppressed mode $D^0 \to K^+K^-$: $A_{CP} < 45\%$.

The data for this analysis were collected in the 1990–91 run of the Fermilab photoproduction experiment E687. A photon beam (mean energy $\sim$ 220 GeV for triggered events) interacts in a beryllium target. Immediately downstream of the production target is a high resolution microvertex detector consisting of 12 planes of silicon microstrips arranged in three views. Further downstream are two analysing magnets of opposite polarity, and five stations of multiwire proportional chambers (MWPC's). There are three MWPC stations between the two magnets and two stations downstream of the second magnet. Three gas Čerenkov counters provide particle identification. A more detailed description of the E687 detector can be found in reference [5].

Before searching for a CP decay rate asymmetry, we must account for the differing D and $\overline{D}$ production rates in photoproduction. This is done using Cabibbo allowed decays ($D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$). The CP decay rate asymmetry, correcting for D and $\overline{D}$ production rates, can then be written as

$$A_{CP} = \frac{\eta(\mathrm{D})-\eta(\overline{\mathrm{D}})}{\eta(\mathrm{D})+\eta(\overline{\mathrm{D}})}$$

where, for example,

$$\eta(D) = \frac{\mathrm{N}(\mathrm{D}^0 \to \mathrm{K}^+\mathrm{K}^-)}{\mathrm{N}(\mathrm{D}^0 \to \mathrm{K}^-\pi^+)}$$

and $N(D^0 \to K^+K^-)$ is the efficiency corrected number of candidate decays. Normalizing production rates via Cabibbo allowed decays has the added benefit of cancelling potential sources of systematic error.

The signals for $D^0 \to K^+K^-$ and $D^0 \to K^-\pi^+$ are extracted through the decay chain $D^{*+} \to D^0\pi^+$ with the charge of the D^* daughter pion used to differentiate between D^0 and $\overline{D^0}$. A candidate driven vertexing algorithm [5] is used to identify the primary and secondary vertices of the decay. The significance of detachment of the vertices, ℓ/σ_ℓ, is defined as the distance (ℓ) between the two vertices divided by the error (σ_ℓ) on ℓ. For this neutral D analysis ℓ/σ_ℓ is required to be greater than 4.0. In addition the kaon candidate track must be consistent with a Čerenkov hypothesis of kaon or kaon/proton ambiguous. The D^* daughter pion must be inconsistent with a Čerenkov hypothesis of electron. The invariant mass plots for $D^0 \to K^-\pi^+$ and $D^0 \to K^+K^-$, separated between D^0 and $\overline{D^0}$, are shown in Figure 1 and Figure 2. Before determining the CP decay rate asymmetry we correct our yields for detection efficiency. The spectrometer acceptance and Čerenkov identification efficiency are both dependent on the charm meson momentum. Monte Carlo is used to determine momentum dependent efficiencies for each mode, and each event is weighted by the inverse of its efficiency. We use a momentum dependent efficiency to avoid any bias arising from the D momentum spectra assumed by the Monte Carlo. The resulting mass plots are fit with a Gaussian combined with a second order polynomial. In all such fits in this letter, the masses are in good agreement with world averages [6], and the widths are consistent with our Monte Carlo predicted resolutions. The CP decay rate asymmetry we measure is $A_{CP}(KK) = 0.024 \pm 0.084$ (consistent with zero).

For the D^+ decay modes, tracks are defined as candidate kaons if they are consistent with a Čerenkov hypothesis of kaon or kaon/proton ambiguous. If the track momentum is greater than 60 GeV/c, the Čerenkov system cannot discriminate between pions and kaons. If such tracks are kaon/pion ambiguous, they are also accepted as kaon candidates. No Čerenkov requirements are made on pions. A cut on ℓ/σ_ℓ is made ($\ell/\sigma_\ell > 20$ for the $K^+K^-\pi^+$ mode, $\ell/\sigma_\ell > 7$ for the $\overline{K}^{*0}K^+$ and $\phi\pi^+$ modes). In addition, requirements are placed on the isolation of the primary and secondary vertices. Tracks not assigned to either the primary or secondary vertex are added one at a time to the secondary vertex. The D^+ candidate is rejected if the confidence level of the fit to any of the resulting vertices is greater than 0.1%. Tracks assigned to the secondary vertex are each added to the primary vertex, and the candidate is cut if the confidence level of any fit is greater than 5%. The invariant mass plots for $D^+ \to K^-\pi^+\pi^+$ and $D^+ \to K^-K^+\pi^+$, separated between D^+ and D^-, are shown in Figure 3 and Figure 4. In Figure 4, the Gaussian peak at 1.86 GeV/c^2 is the D^+, and the large bump at 1.97 GeV/c^2 is from both D_s^+ decays to $K^+K^-\pi^+$ and kinematic reflection from $D^+ \to K^-\pi^+\pi^+$. The reflection occurs at a large rate because of the relatively loose Čerenkov requirements made on kaons for this mode. The asymmetry we measure for this mode is $A_{CP}(KK\pi) = -0.031 \pm 0.068$.

Candidates for the decay modes $D^+ \to \overline{K}^{*0}K^+$ and $D^+ \to \phi\pi^+$ are selected by cutting on the reconstructed $\overline{K}^{*0}$ and ϕ mass, respectively. The $\overline{K}^{*0}K^+$ candidates are required to have a $K^-\pi^+$ invariant mass between 840 MeV/c^2 and 940 MeV/c^2 and $\phi\pi^+$ candidates must have a K^+K^- mass between 1014 MeV/c^2 and 1025 MeV/c^2. A sideband subtraction is performed in order to find the number of candidates for each mode. For the $\overline{K}^{*0}$ candidates the sidebands used are $K^-\pi^+$ mass from 690 to 790 MeV/c^2 and 990 to 1090 MeV/c^2. The ϕ sidebands are K^+K^- mass from 992 to 1003 MeV/c^2 and 1036 to 1047 MeV/c^2. Figure 5 shows the invariant mass plots, after sideband subtraction, for the two resonant decay modes separated between charge conjugates. For the $D^+ \to \overline{K}^{*0}K^+$ mode we measure $A_{CP}(K^*K) = -0.12 \pm 0.13$. For the $D^+ \to \phi\pi^+$ mode we find $A_{CP}(\phi\pi) = 0.066 \pm 0.086$.

Several sources of systematic error were considered: choice of sidebands for the resonant modes, possible false D^{*+} tags for the D^0 mode, fit proceedures, method of acceptance correction, and choice of cuts. All were found to be much smaller than our statistical errors.

Our results are summarized in Table I. All measured asymmetries are consistent with zero. We find with 90% confidence that each asymmetry lies in the interval shown in the table. (These intervals are centered on our measured value.) The results for $D^+ \to K^-K^+\pi^+$ (including two resonant decay modes) are the first for D^+ mesons. We have also improved on the existing limit for $D^0 \to K^+K^-$.

We wish to acknowledge the assistance of the staffs of the Fermi National Accelerator Laboratory, the INFN of Italy, and the physics departments of the collaborating institutions. This research was supported in part by the National Science Foundation, the U.S. Department of Energy, the Italian Istituto Nazionale di Fisica Nucleare and Ministero dell'Università e della Ricerca Scientifica e Tecnologica, the Korean Science and Engineering Foundation, and the Vanderbilt University Research Council.

REFERENCES

* Present address: University of Maryland, College Park, MD, 20742,USA
† Present address: University of Colorado, Boulder, CO 80309, USA
‡ Present address: Dip. di Fisica Nucleare e Teorica and INFN - Pavia, I-27100 Pavia, Italy
§ Present address: Fermilab, Batavia, IL 60510, USA.
** Present address: University of New York, Stony Brook, NY 11794, USA.
†† Present address: Yale University, New Haven, CN 06511, USA.
[1] M. Golden and B. Grinstein, Phys. Lett. B **222**, 501 (1989)
[2] F. Buccella *et al.*, Phys. Lett. B **302**, 319 (1993)
[3] J. C. Anjos *et al.*, Phys. Rev. Lett., **60**, 1239 (1988)
[4] J. C. Anjos *et al.*, Phys. Rev. D Rapid Comm. **44**, R3371 (1991)
[5] P. L. Frabetti *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **320**, 519 (1992).
[6] Particle Data Group, K. Hikasa *et al*, Phys. Rev. D **45** (1992).

TABLE I. CP Violating Asymmetry and 90% Confidence Level Limits

Decay Mode	Measured Asymmetry	90% C.L. limit
$D^0 \to K^+K^-$	0.024 ± 0.084	$-11\% < A_{CP} < 16\%$
$D^+ \to K^-K^+\pi^+$	-0.031 ± 0.068	$-14\% < A_{CP} < 8.1\%$
$D^+ \to \overline{K}^{*0}K^+$	-0.12 ± 0.13	$-33\% < A_{CP} < 9.4\%$
$D^+ \to \phi\pi^+$	0.066 ± 0.086	$-7.5\% < A_{CP} < 21\%$

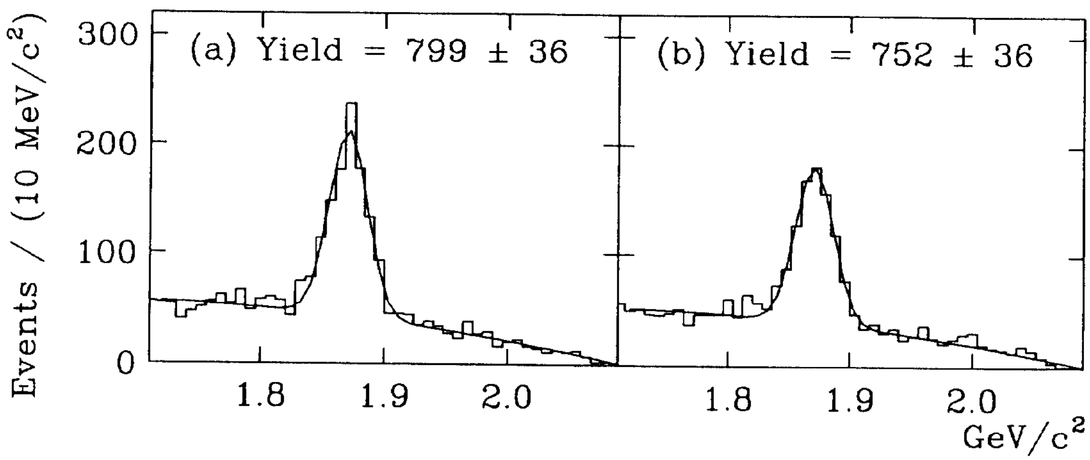

FIG. 1. Invariant mass plots: a) $K^+\pi^-$ with $\overline{D^0}$ tag; b) $K^-\pi^+$ with D^0 tag.

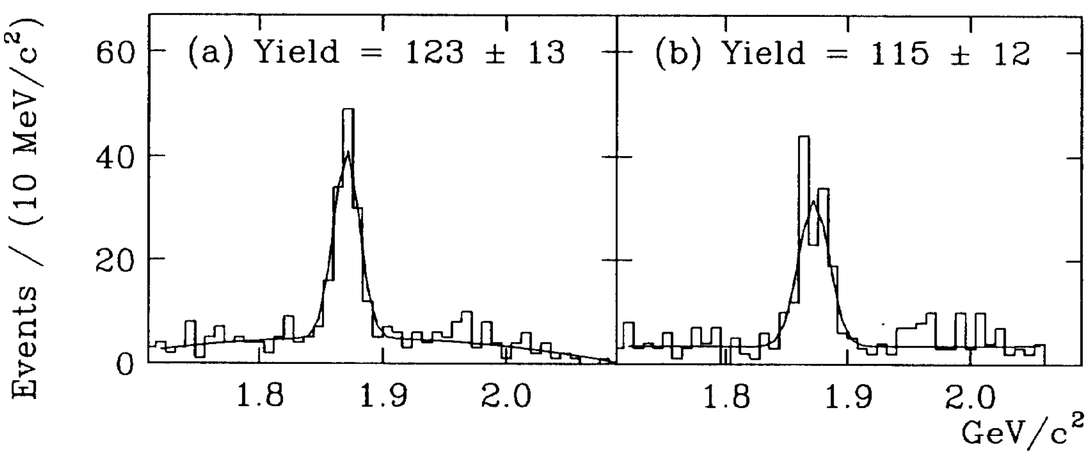

FIG. 2. Invariant mass plots: a) K^+K^- with $\overline{D^0}$ tag; b) K^+K^- with D^0 tag.

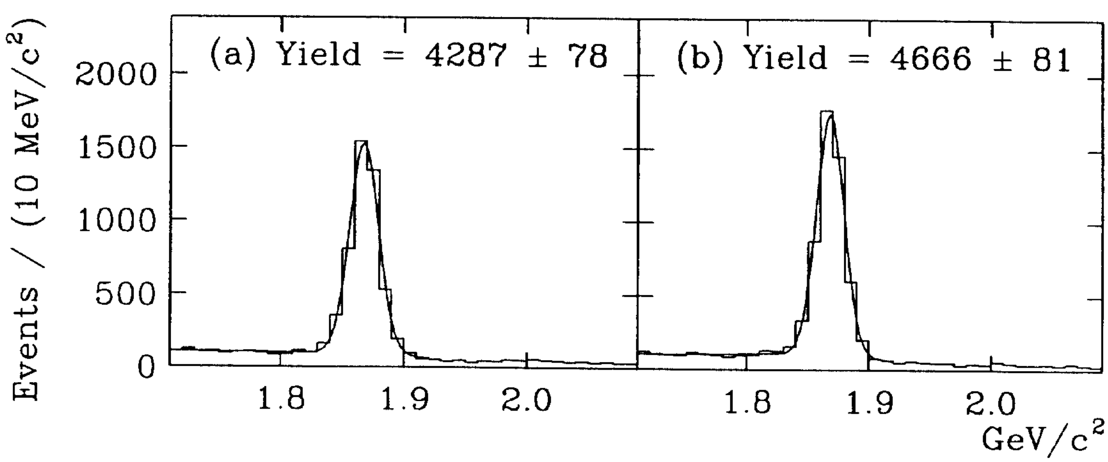

FIG. 3. Invariant mass plots: a) $K^-\pi^+\pi^+$; b) $K^+\pi^-\pi^-$.

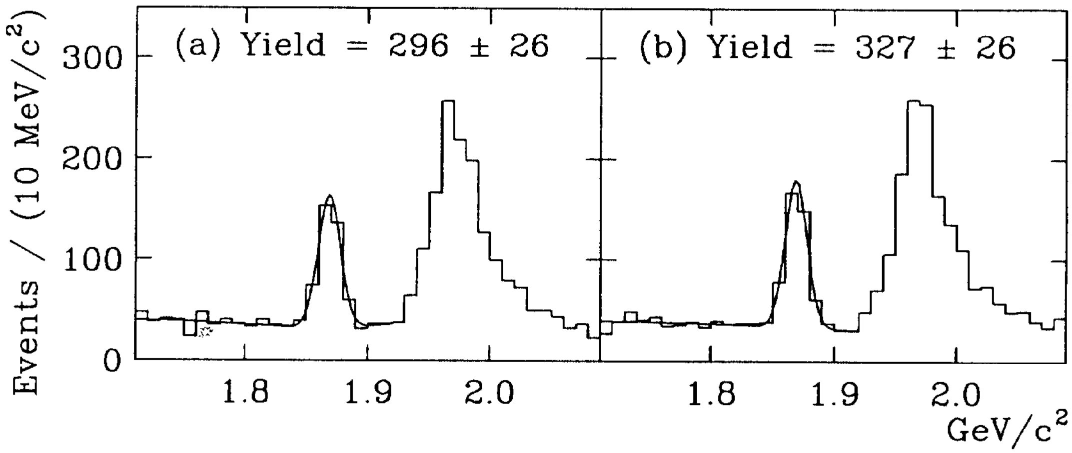

FIG. 4. Invariant mass plots: a) $K^-K^+\pi^+$; b) $K^+K^-\pi^-$.

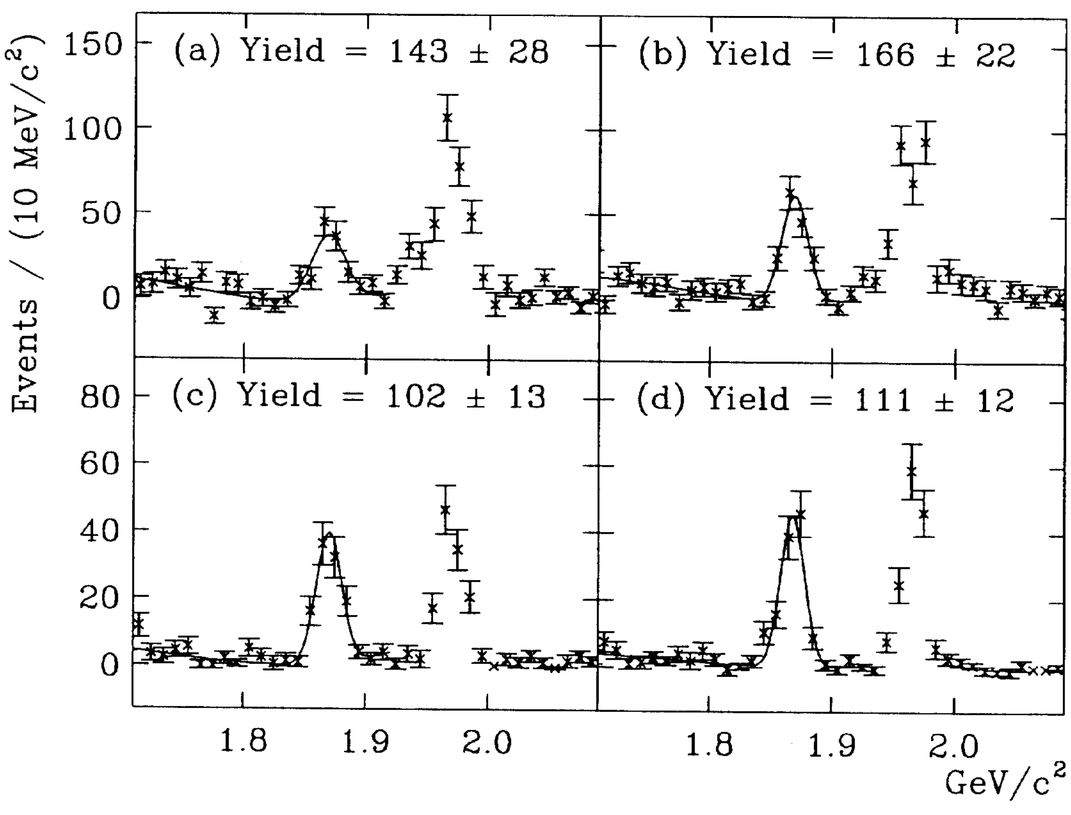

FIG. 5. Invariant mass plots: a) $\overline{K}^{*0}K^+$; b) $K^{*0}K^-$; c) $\phi\pi^+$; d) $\phi\pi^-$.