Title

SPIN ANALYSIS OF CHARMED MESONS PRODUCED IN e+e~ ANNIHILATION

Permalink

https://escholarship.org/uc/item/9q2105hg

Author

Nguyen, H.K.

Publication Date

1977-05-01

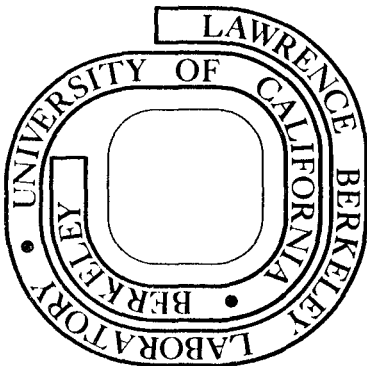# SPIN ANALYSIS OF CHARMED MESONS PRODUCED
IN e+e- ANNIHILATION

H.K. Nguyen, J.E. Wiss, G.S. Abrams, M.S. Alam,
A.M. Boyarski, M. Breidenbach, R.G. DeVoe, J. Dorfan,
G.J. Feldman, G. Goldhaber, G. Hanson, J.A. Jaros,
A.D. Johnson, J.A. Kadyk, R.R. Larsen, D. Lüke, V. Lüth,
H.L. Lynch, R.J. Madaras, J.M. Paterson, M.L. Perl,
I. Peruzzi, M. Piccolo, F.M. Pierre, T.P. Pun, P. Rapidis,
B. Richter, R.F. Schwitters, W. Tanenbaum, G.H. Trilling,

May 1977

DISCLAIMER

LBL-6424

SPIN ANALYSIS OF CHARMED MESONS PRODUCED IN e^+e^- ANNIHILATION[*]

H. K. Nguyen,[†] J. E. Wiss, G. S. Abrams, M. S. Alam,
A. M. Boyarski, M. Breidenbach, R. G. DeVoe, J. Dorfan,
G. J. Feldman, G. Goldhaber, G. Hanson, J. A. Jaros,
A. D. Johnson, J. A. Kadyk, R. R. Larsen, D. Lüke,[††]
V. Lüth, H. L. Lynch,[§] R. J. Madaras, J. M. Paterson, M. L. Perl,
I. Peruzzi,[‡] M. Piccolo,[‡] F. M. Pierre,[‡‡] T. P. Pun, P. Rapidis,
B. Richter, R. F. Schwitters, W. Tanenbaum, and G. H. Trilling

Lawrence Berkeley Laboratory and Department of Physics
University of California, Berkeley, California 94720

and

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

We have studied the threshold production and decay angular
distribution of neutral charmed mesons produced in e^+e^- annihila-
tion. We find consistency with the expected spin values of 0 and
1 for the ground and excited states D and D* respectively. We
rule out the alternative spin assignment of 1 for the D and 0 for
the D*.

We report on a study of the production and decay angular distributions
of neutral charmed mesons[1] produced in e^+e^- annihilation at center-of-mass
energies near 4.03 GeV.   Throughout this Letter, we identify the neutral
state decaying into $K\pi$ and $K3\pi$ at 1865 MeV/c^2 with the D^0 and the charged state
decaying into $K\pi\pi$ at 1875 MeV/c^2 with the D^+.[2] A study[3] of the threshold recoil
spectrum against the D^0 and D^+ has provided strong evidence for the existence
of excited charmed states: the $D^{*0}(2005)$ and the $D^{*+}(2010)$. Furthermore,
this study shows D^0 production near threshold is dominated by two-body reactions
such as:

$$e^+e^- \rightarrow D^0\bar{D}^{*0} \text{ or } \bar{D}^0 D^{*0} \tag{1}$$

$$\rightarrow D^{*0}\bar{D}^{*0} \tag{2}$$

$$\rightarrow D^{*+}D^- \text{ or } D^{*-}D^+ \tag{3}$$

where the D^{*0} and D^{*+} decay into D^0's via pion emission[4] and in the case of
the D^{*0}, by gamma emission. In this Letter we examine angular distributions
in reactions (1) and (2) in order to test the three possible D, D^* spin assign-
ments if one assumes that the sum of the spins for the D and the D^* is less
than two. We show that under this assumption the D is spinless, the D^* has
spin one and their relative parity is even.[5]

Considerable information on the spin and parity of the D and D^* comes from
a study of the D^* production and decay modes. Our observation of either
$D^{*0} \rightarrow D^0\gamma$ or $D^{*0} \rightarrow \pi^0 D^0$ produced in $e^+e^- \rightarrow D^0\bar{D}^{*0}$ or $\bar{D}^0 D^{*0}$ implies that
the D and D^* cannot both be spinless.[7] Observation of $D^* \rightarrow D\pi$ implies that
the D and D^* must have even relative parity if one meson has spin zero and the
other has spin one. This last observation is quite helpful for it allows unique
predictions for the production and decay angular distributions of $D \rightarrow K\pi$ in
reaction (1) under the two spin assignments we will further consider, $J_D = 0$,
$J_{D^*} = 1$ or $J_D = 1$, $J_{D^*} = 0$.

We   express the expected joint D^o production and decay distributions

in terms of the three angles Θ, θ, φ where Θ is the polar production angle of

the D^o with respect to the annihilation axis, and (θ, φ) are the spherical angles

of the decay kaon in the D^o helicity frame.[8] In the limit of nonrelativistic

D^{*o}'s, one computes from symmetry considerations the distributions below[9]:

$$\frac{d^3\sigma}{d\cos\Theta\, d\cos\theta\, d\varphi} \propto 1 + \cos^2\Theta \qquad\qquad (a)$$

$$\frac{d^3\sigma}{d\cos\Theta\, d\cos\theta\, d\varphi} \propto \sin^2\theta(\cos^2\varphi + \cos^2\Theta\,\sin^2\varphi) \qquad (b)$$

where Eq. (a) is for $J_D^P = 0^\mp$, $J_{D*}^P = 1^\mp$, and Eq. (b) is for $J_D^P = 1^\mp$, $J_{D*}^P = 0^\mp$.

We shall compare these distributions to the data.

The present analysis is based on about 35,000 hadron events produced in

e^+e^- annihilation at center-of-mass energies between 3.9 and 4.15 GeV   . The

data were taken with the SLAC-LBL magnetic detector at SPEAR. Descriptions of

the detector and event selection procedures using time-of-flight information

have been published.[1,10] All neutral two-prong combinations are considered as

potential D^o candidates with the track having time-of-flight information most

consistent with the kaon hypothesis called the kaon.[11] The other track is

called the pion. For approximately 40% of the real D^o events this amounts to little

more than a random selection. For the production angular distribution this

K-π ambiguity is irrelevant; however it could matter in analyzing the decay

distribution of the kaon in the D^o helicity frame. Fortunately we find that

it does not, since K-π interchange effectively reverses the direction of the

kaon in the D^o helicity frame, and the angular distributions we are testing

are invariant under this transformation.

A relatively clean sample of D^o's produced against $\bar{D}^{*o}$'s in reaction (1)

can be selected by cutting on the invariant mass of the Kπ system and the

corresponding recoil mass. We have obtained a sample of 153 D^o candidates

by cutting on invariant mass from 1820 to 1920 MeV/c^2 and on recoil mass, computed with a fixed D^O mass of 1865 MeV/c^2, from 1970 to 2030 MeV/c^2. About 70% of these D^O candidates were obtained at the fixed center-of-mass energy of 4.028 GeV. We estimate that approximately 15% of the D^O candidates satisfying these cuts are not D^O's but are background two-prong combinations. Furthermore, we estimate that (64 ± 4)% of the real D^O's within this cut are primary D^O's recoiling against $\bar{D}^{*O}$'s. The remaining D^O's come from either pion or gamma decays of the D^{*O}'s produced via reaction (1), or pion decays of the D^{*+} produced in reaction (3). The primary fraction exceeds 50% because direct D^O's are partially resolvable from secondary D^O's on the basis of recoil mass. The conservative 4% error on the primary fraction is mainly due to uncertainties in the number of D^O's arising from D^{*+} decays.

Figures 1a and 1b show the observed cos Θ and cos θ distributions for D^O candidates satisfying the above mass and recoil mass cuts. The normalized distributions expected for our two spin assignments are also shown. In both figures the solid curve is computed from Eq. (a) and the dashed curve is computed from Eq. (b). Both curves are calculated by a Monte-Carlo program incorporating the acceptance and resolution appropriate to the SPEAR Magnetic Detector. The theoretical distributions have been corrected for the presence of the 15% background[12] and the presence of secondary D^O's.[13] The difference between the solid and dashed curves of Fig. 1a is entirely due to the effects of geometrical acceptance for the different D $\rightarrow$ Kπ decay distributions of Eqs. (a) and (b).

Both the solid and dashed curves are acceptable fits to the data of Fig. 1a with the solid curve having a χ^2 of 5.6 for 9 degrees of freedom (CL = 76%) and the dashed curve having a χ^2 of 11 for 9 degrees of freedom (CL = 28%). The dashed and dotted curve of Fig. 1a is the sin$^2 \Theta$ distribution appropriate for the case of spinless D's and D*'s, corrected for acceptance, background,

and the presence of secondaries. This spin assignment is clearly ruled out by the data of Fig. 1a with a χ^2 of 74 for 9 degrees of freedom. The main discrimination between Eqs. (a) and (b) comes from the kaon polar helicity distribution shown in Fig. 1b. The solid curve of Fig. 1b is consistent with the data with a χ^2 of 8.2 for 9 degrees of freedom (CL = 51%) while the dashed curve is inconsistent with a χ^2 of 23 for 9 degrees of freedom (CL = 6×10^{-3}).[14] On the basis of this analysis the expected spin assignment 0 and 1 for D and D^* respectively is preferred over the alternative assignment 1 and 0.

We have devised an alternative method for comparing the data to the distribution of Eqs. (a) and (b) which makes use of all three angular variables and handles backgrounds differently. The technique displays the invariant mass plot for events satisfying the recoil mass cut and having variables within one of two angular regions chosen to insure discrimination between Eqs. (a) and (b) by dividing the space of angular variables by a surface of constant $I = \sin^2 \theta (\cos^2 \varphi + \cos^2 \Theta \sin^2 \varphi)$. Figures 2a and 2b show the $K^{\mp} \pi^{\pm}$ invariant mass distribution for events satisfying $I < 0.32$ and $I > 0.32$ respectively. The fit of Figs. 2a and 2b, consisting of a Gaussian signal over an exponentially falling background, gives 58 ± 8 and 73 ± 10 signal events respectively.[15] Defining an asymmetry variable A_s equal to the difference in the number of signal events over their sum, we obtain $A_s = 0.11 \pm 0.10$ which is in good agreement with 0.11 ± 0.01, the value expected for spin 0 D's and spin 1 D^*'s, but inconsistent with 0.41 ± 0.03, the value obtained for spin 1 D's and spin 0 D^*'s ($\chi^2 = 8.3$ for one degree of freedom, CL = 3.5×10^{-3}). The errors on the expected asymmetries under the two hypotheses reflect mainly the errors on the fraction of primary D^o's from reaction (1).

In Fig. 1c we present the production polar distribution for D^o's from the reaction $e^+ e^- \to D^{*o} \bar{D}^{*o}$ chosen by selecting an appropriate range in D^o momentum. About 75% of D^o's selected come from the fixed center-of-mass energy of 4.028 GeV. We estimate 15% of the D^o candidates satisfying this selection are back-

ground with 75% of the r e a l D^O's arising from $D^{*O} \rightarrow D^O \pi^O$ and 25% arising

from radiative D^{*O} decays.   A D^O background sample taken from sidebands in the

πK invariant mass plot is consistent with isotropy.

The D^* polar distribution for the reaction $e^+ e^- \rightarrow D^* \bar{D}^*$ is of the form

$$(d\sigma)/(d \cos \theta) \propto 1 + \alpha \cos^2 \theta \ , \hspace{2cm} (c)$$

where unique predictions for α cannot be made by symmetry arguments except for

spin 0 for which $\alpha = -1$.

The production polar distribution of D^O from $D^{*O} \rightarrow D^O \pi^O$ closely follows

Eq. (c) owing to the low D^{*O}, D^O relative momentum, whereas that of D^O's arising

from radiative D^{*O} decays is a broad convolution over Eq. (c) owing to the

larger D, D^* relative momentum.   We estimate that $\alpha = -0.30 \pm 0.33$ by fitting

the data of Fig. 1c to a linear combination of Eq. (c) for pionic decays, the

convoluted form of Eq. (c) for radiative decays, and an isotropic background.

The curve superimposed on Fig. 1c represents the above fit.   This result is

2.1 standard deviations from the value expected for spinless D^*'s.

In summary, we have shown that the production and decay angular distribu-

tions for D^O's produced near threshold via the reaction $e^+ e^- \rightarrow D^O \bar{D}^{*O}$ or $\bar{D}^O D^{*O}$

are incompatible with D^O, D^* spin-parity assignments of $1^{\mp}$, $0^{\mp}$ and compatible

with $0^{\mp}$, $1^{\mp}$.   In addition the angular distribution of D^{*O}'s produced in reaction

$e^+ e^- \rightarrow D^{*O} \bar{D}^{*O}$ is incompatible with spinless D^* on the 2 standard deviation

level.   In the conventional quark model, one constructs the light neutral

charmed mesons from an S-wave combination of a c and $\bar{u}$ quark.   In light of

experience with the conventional, uncharmed mesons, one expects the $^1S_0$ pesudo-

scalar charmed state to lie lower in mass than the $^3S_1$ vector state.   In this

model the D^O is a pseudoscalar and the D^{*O} is a vector.[16]   Our data are consis-

tent with this assignment.   Several theorists, however, have contemplated the

alternative possibility that the D^O is a vector and the D^{*O} is a pseudoscalar.[17]

This possibility has now been ruled out.

We wish to thank J. D. Jackson and F. Gilman for useful discussions.
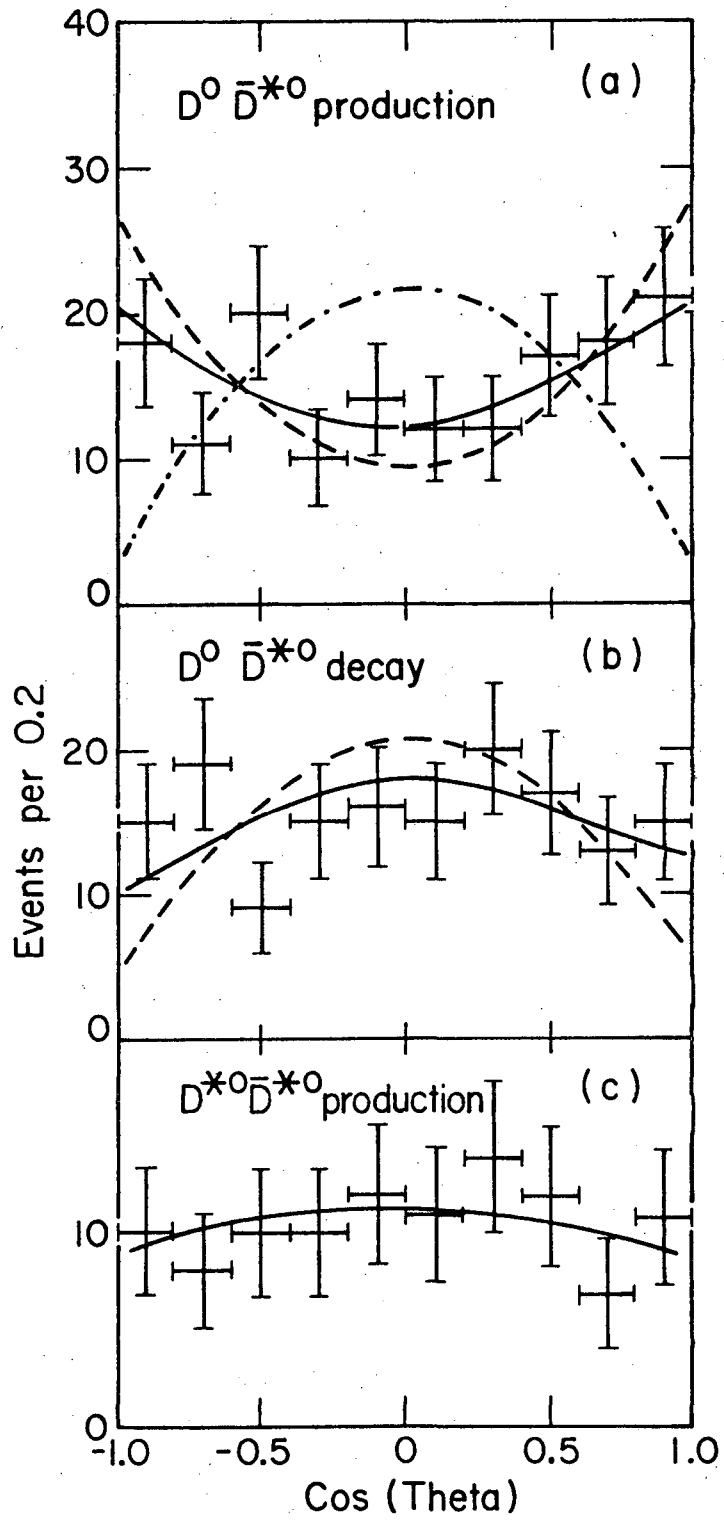
FOOTNOTES AND REFERENCES

1. G. Goldhaber et al., Phys. Rev. Lett. **37**, 255 (1976).

2. I. Peruzzi et al., Phys. Rev. Lett. **37**, 569 (1976).

3. G. Goldhaber, Invited Talk at the Annual Meeting of the American Physical Society, Chicago, February 1977; G. Goldhaber et al., to be published.

4. G. J. Feldman et al., Phys. Rev. Lett. (in press).

5. Because charmed mesons are associatively produced by the strong or electromagnetic interaction, and are known to decay weakly[6] with parity violation, the absolute parity of the D^o cannot be determined and thus can be set to -1 by convention.

6. J. E. Wiss et al., Phys. Rev. Lett. **37**, 1531 (1976).

7. The presence of the decay $D^* \rightarrow D\pi$ implies that the D and D^* have odd relative parity if both are spinless, but then they could not couple to a photon in a P-wave without violating parity conservation in electromagnetic production reaction $e^+e^- \rightarrow D^oD^{*o}$ or $\bar{D}^oD^{*o}$. This seems to be one of the dominant production modes for charmed mesons near threshold.[3]

8. The helicity frame is oriented with its z axis (polar axis) along the direction of the D momentum in the overall c.m. and its y axis along the production plane normal.

9. J. D. Jackson, Lawrence Berkeley Laboratory Internal Note JDJ/76-1.

10. J.-E. Augustin et al., Phys. Rev. Lett. **34**, 233 (1975).

11. Neutral two-body combinations with both tracks lacking time-of-flight are dropped from the analysis. This occurs for about 10% of the combinations.

12. Background effects were included by the addition of a 15% isotropic background in both production and decay angular distributions. The assumption of background isotropy was checked by background events from 50 MeV/c^2 sidebands in the Kπ invariant mass distribution.

13. The presence of secondary D^0's only slightly distorts the cos Θ distribution of Fig. 1a owing to the small momentum of the D^0's in the D^{*0} rest frame for D^* pion decays.   We estimate the direction of D^0's from $D^{*0} \to D^0 \pi^0$ lies within 5° of the $D - D^*$ axis. The largest effect of secondary D^0's is the addition of a nearly isotropic contribution to the cos θ distribution of Fig. 1b for the curve appropriate to Eq. (b).

14. Errors in the calculation of the expected curves are not included in these χ^2 calculations.

15. We note that there is a 1.5 standard deviation inconsistency in the widths of the peaks of Fig. 2.

16. S. L. Glashow, I. Iliopoulos and L. Maiani, Phys. Rev. D2, 1285 (1970); A. De Rujula, H. Georgi and S. L. Glashow, Phys. Rev. D12, 147 (1975); M. K. Gaillard, B. W. Lee and J. L. Rosner, Rev. Mod. Phys. 47, 277 (1975).

17. G. Altarelli, N. Cabbibo and L. Maiani, Phys. Rev. Lett. 36, 1287 (1976); S. R. Borchardt and V. S. Mathur, Phys. Rev. Lett. 36, 1287 (1976).
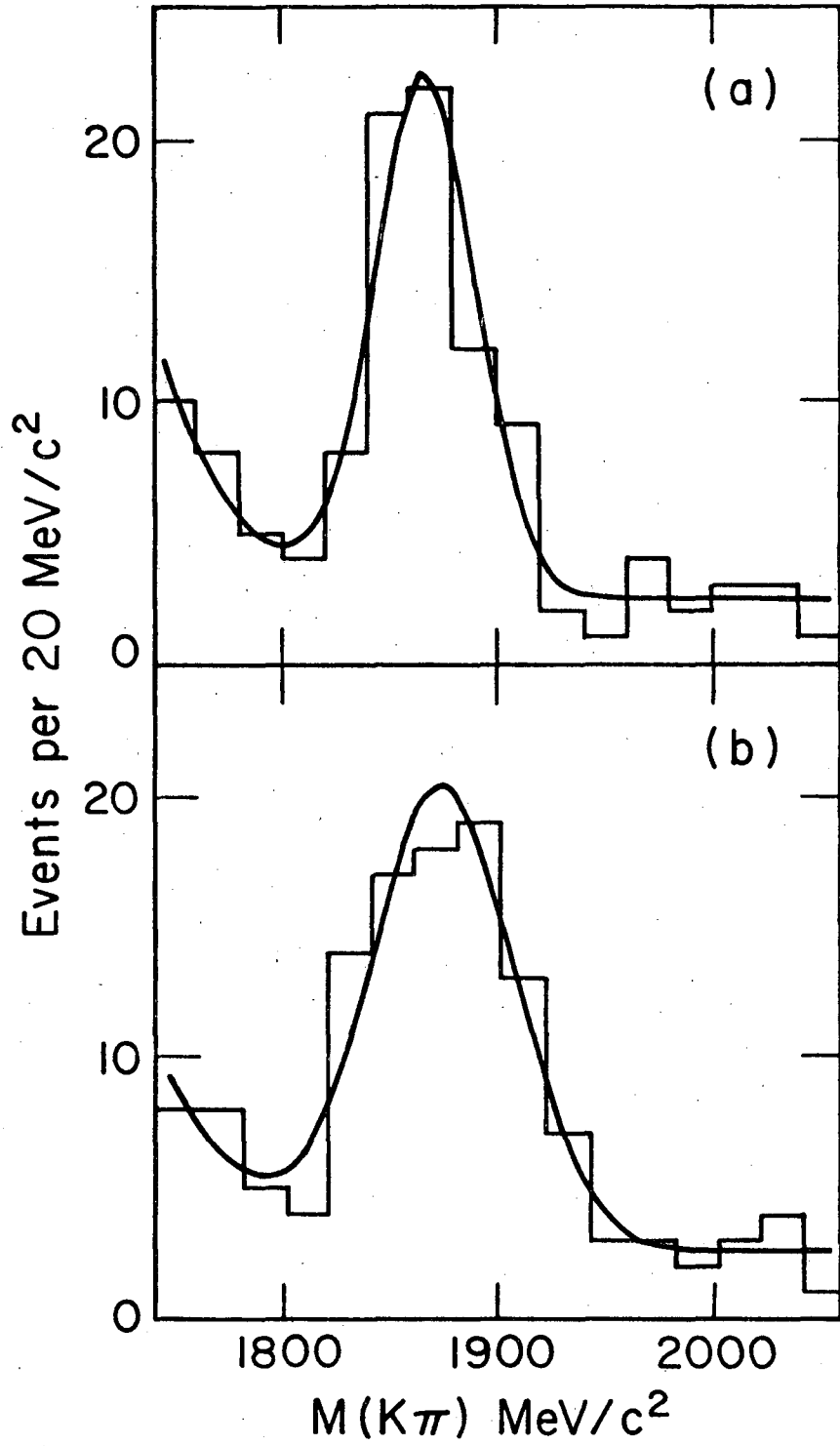
FIGURE CAPTIONS

Fig. 1. (a) Production polar distribution of D^0 in reaction (1). Solid curve corresponds to $J_D^P = 0^\pm$ and $J_{D*}^P = 1^\pm$. Dashed curve corresponds to $J_D = 1^\pm$ and $J_{D*}^P = 0^\pm$. Dashed and dotted curve corresponds to spinless D and D^*; here "theta" = Θ (see text). (b) Helicity polar distribution for D^0 in reaction (1). Solid curve corresponds to $J_D^P = 0^\pm$ and $J_{D*}^P = 1^\pm$. Dashed curve corresponds to $J_D^P = 1^\pm$ and $J_{D*}^P = 0^\pm$; here "theta" = θ. (c) Production polar distribution for D^0 in reaction (2). Solid curve is deduced from fit; here "theta" = Θ.

Fig. 2. Invariant mass spectra of $K^\pm \pi^\mp$ system for $I < 0.32$ and $I > 0.32$.

Fig. 1

XBL 775-936

XBL775-937

Fig. 2