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STUDY OF THE COHERENT REACTION $K^+d \to K^0\pi^+d$ AT 2 GeV/c *

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Abstract We have made a study of the coherent reaction $K^+d \to K^0\pi^+d$ at 2 GeV/c, using data obtained in the Lawrence Berkeley Laboratory 25 inch bubble chamber The cross section for this reaction is 324 ± 25 μb, after correction for invisible K^0 decays This reaction is dominated primarily by vector exchange We determine the parameters of the ω trajectory to be $\alpha_\omega = (0\ 33 + 0\ 04) + t$

1. Introduction

In this paper we present an analysis of the coherent reaction $K^+d \to K^0\pi^+d$ at 2 GeV/c, from data obtained with the Lawrence Berkeley Laboratory 25-inch deuterium-filled bubble chamber This reaction, in which the deuteron emerges intact in the final state, is particularly interesting in that the coherence acts as a filter in allowing only $I = 0$ non-spin-flip exchange at the deuteron vertex. The production of a natural spin-parity K* (890) from the unnatural spin-parity K^+ meson at the meson vertex precludes Pomeranchukon exchange, and thus the reaction $K^+d \to K^{*+}$ (890)d is expected to be dominated by ω exchange

Sect 2 outlines the experimental procedures used, and indicates how the sample of events in this analysis was obtained In sect 3 we present the analysis of the reaction $K^+d \to K^0\pi^+d$, and sect 4 treats in more detail the specific reaction $K^+d \to K^{*+}$ (890)d. Sect. 5 is a study of the ω trajectory, which compares these data with the results of other experiments.

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2. Data analysis

Approximately 780 000 photographs were taken in an exposure of the Lawrence Berkeley Laboratory 25-inch deuterium-filled bubble chamber to a 1.94 GeV/c separated K^+ meson beam. On the average, ten K^+ mesons were incident in the chamber per pulse. The film was scanned for events of all topologies, but the topologies of interest for this analysis are (i) two-pronged interactions with an associated vee, and (ii) one-prongs with a vee. The latter topology includes events in which the deuteron recoil is too short to be visible in the bubble chamber.

The reaction $K^+d \to K^0\pi^+d$ is dominated by $K^*(890)$ production, and at a value of $M(K^0\pi^+)$ equal to 890 MeV, the minimum allowed $|t|$ for the coherent reaction is about 0.023 $(\text{GeV}/c)^2$, which corresponds to a minimum momentum in the lab of about 150 MeV/c for the deuteron†. Since deuterons of momenta greater than about 120 MeV/c in the lab should leave visible tracks in the bubble chamber, the one-prong-plus-vee events contribute primarily to the low $K^0\pi^+$ mass region.

The reliability of the seven-constraint multivertex fit $K^+d \to K^0\pi^+d$, where the K^0 decays visibly in the bubble chamber, has been amply demonstrated through the use of the corresponding deuteron-breakup hypothesis, $K^+d \to K^0\pi^+pn$ (refs. [1, 2]), and will not be repeated here. All two-prong-plus-vee events kinematically consistent with the coherent hypothesis with chisquare probability greater than 0.1% are accepted. For the one-prong-plus-vee events, we also impose the criterion that the fitted deuteron momentum be less than 170 MeV/c. This requirement was determined from a study of the two-prong-plus-vee events, which indicate no scanning or measuring losses for deuterons of this momentum or greater. For the 60% of the film used in this analysis, we have a sample of 592 coherent $K^+d \to K^0\pi^+d$ events, of which 90% have the deuteron recoil visible in the bubble chamber. This implies a total cross section of 324 ± 25 μb for this reaction, after correction for K^0 decays which are not visible in the bubble chamber. This should be compared to a cross section of 228 ± 25 μb found for this reaction at 3 GeV/c (ref. [3]).

3. The reaction $K^+d \to K^0\pi^+d$

Fig. 1 shows the momentum distribution in the lab for the complete sample of coherent events. The shaded region represents the subsample of one-prong-plus-vee events. The distributions for the one-prong and two-prong events match reasonably well, with no apparent bias or loss of events.

Fig. 2 shows the distribution in $d\sigma/dt$ *versus* t for all coherent events. The data exhibit an approximate exponential form, $d\sigma/dt = A \exp(Bt)$ for $0.02 < |t| < 0.22$ $(\text{GeV}/c)^2$, with $B = 10.0 \pm 0.4$ $(\text{GeV}/c)^{-2}$. This slope is considerably less than that

† t is defined as the square of the four-momentum transfer from incident deuteron to final deuteron.

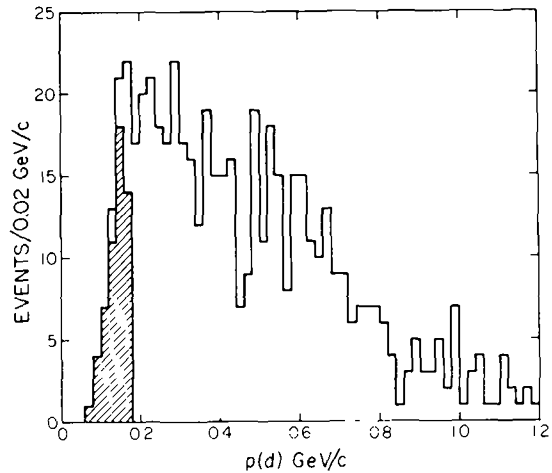

Fig. 1. Lab momentum distribution of the recoil deuteron. The shaded region refers to the events with unmeasured deuterons.

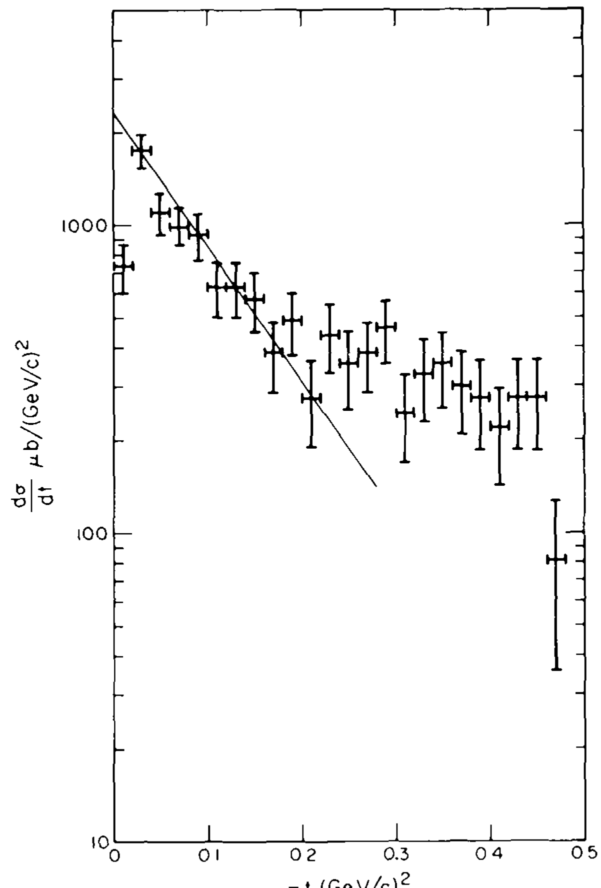

Fig 2 $d\sigma/dt$ *versus* t for all coherent events

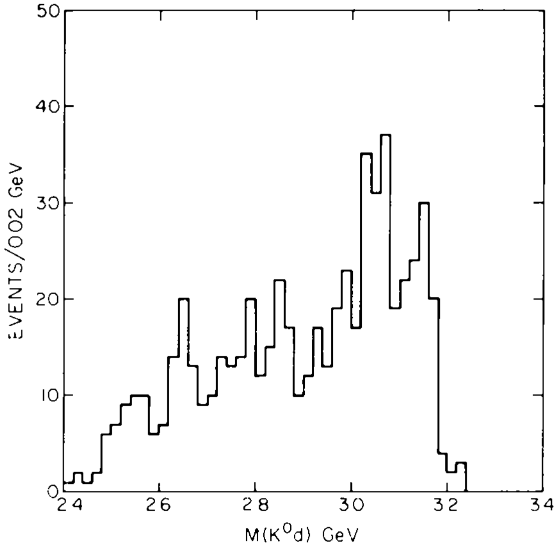

Fig. 3 Distribution in $M(dK^0)$

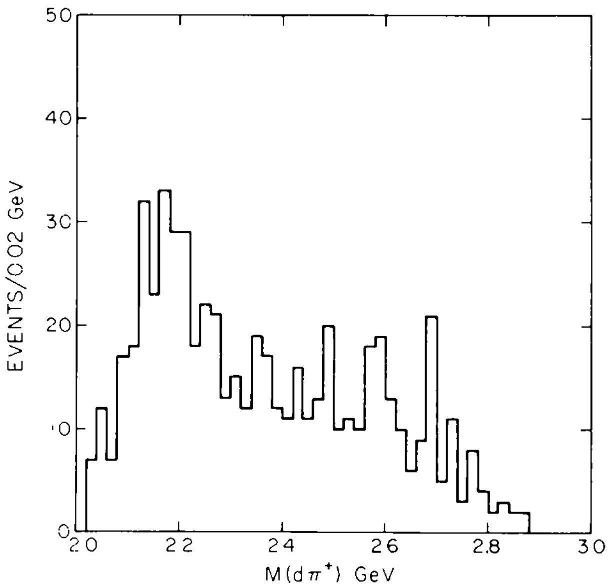

Fig. 4 Distribution in $M(d\pi^+)$

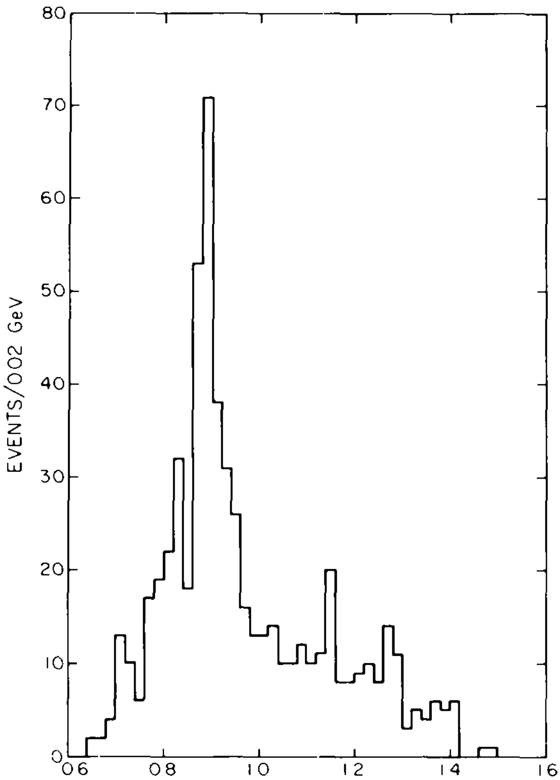

Fig 5 Distribution in $M(K^0\pi^+)$

frequently observed for coherent reactions in deuterium, but other experiments at these energies show similar effects [3, 4]. The turnover in the forward direction is due to the effects of the Chew-Low boundary. The cross sections quoted in this paper have not been corrected for the effects of this kinematic boundary

Figs 3, 4, and 5 show the three invariant mass distributions, $M(dK^0)$, $M(d\pi^+)$ and $M(K^0\pi^+)$ for the complete sample of coherent events There is no evidence for any structure in the $M(dK^0)$ distribution, nor is there any significant evidence for d^{*++} production in the $M(d\pi^+)$ distribution The reaction is completely dominated by K^* (890) production as can be seen in fig 5. We estimate the cross section for K^{*+} (890) production in this reaction to be 195 ± 15 μb, where this cross section has been corrected for the effects of invisible decays of the K^0, and for the $K^+\pi^0$ decay mode of the K^{*+} (890), but no correction has been applied for the effects of the Chew-Low boundary.

4. The reaction $K^+d \to K^{*+}$ (890)d

We select the events in the region $0.84 < M(K^0\pi^+) < 0.96$ GeV as approximating the sample of K* (890) events There are 237 such events, and the remainder of this analysis is concerned solely with this sample. Fig. 6 shows the t-distribution for the K* sample These data are listed in table 1 The data with $|t| > 0.02$ $(GeV/c)^2$ may be fit to an exponential distribution of slope $B = 9.4 \pm 0.5$ $(GeV/c)^{-2}$ Fig 7 shows the distribution in t', where $t' = |t - t_{min}|$ and t_{min} is the kinematic limit for t In this case, the forward turnover does not appear, and the slope is $B = 10.4 \pm 0.6$ $(GeV/c)^{-2}$

Fig 8 shows the distributions in $\cos\theta$ and ϕ for the K* (890) events, where θ and ϕ are the polar and azimuthal angles of the K* (890) decay in the Gottfried-Jackson

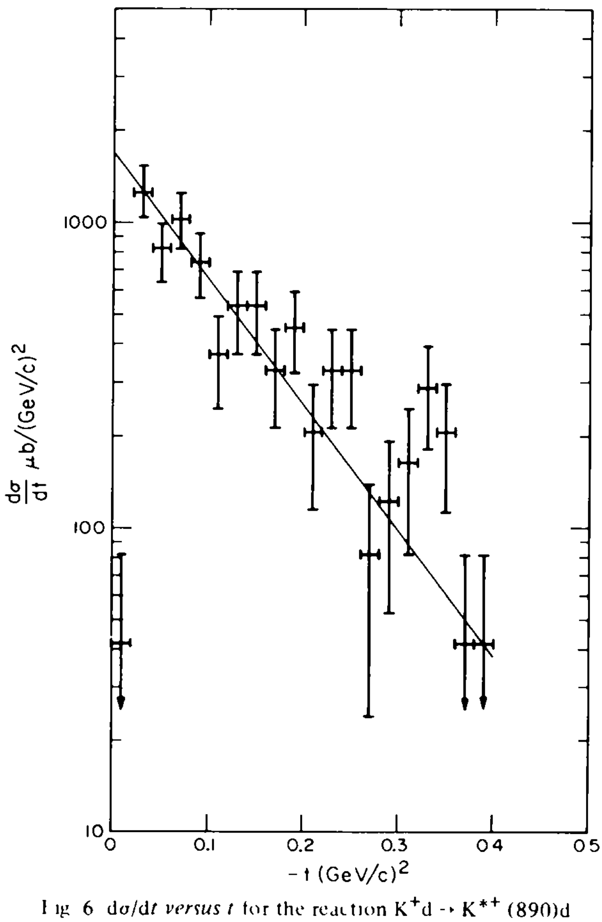

Fig 6 $d\sigma/dt$ *versus* t for the reaction $K^+d \to K^{*+}$ (890)d

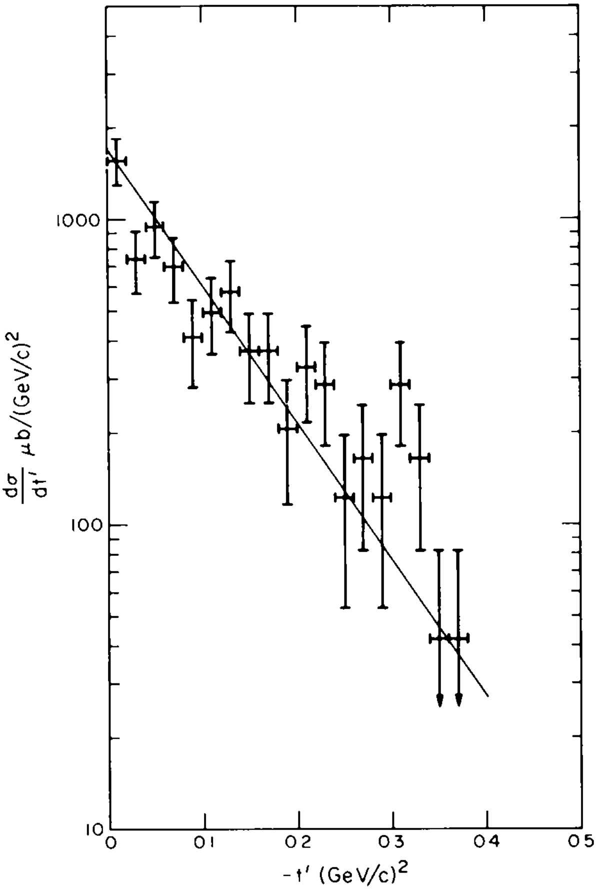

Fig. 7. $d\sigma/dt'$ *versus* t' for the reaction $K^+d \to K^{*+}(890)d$

Table 1
Differential cross section for $K^+d \to K^{*+}(890)d$

$-t$ (GeV/c)^2	$d\sigma/dt$ μb/(GeV/c)^2	$-t$ (GeV/c)^2	$d\sigma/dt$ μb/(GeV/c)^2
0.00 – 0.02	41 ± 41	0.20 – 0.22	206 ± 90
0.02 – 0.04	1274 ± 234	0.22 – 0.24	329 ± 115
0.04 – 0.06	822 ± 185	0.24 – 0.26	329 ± 115
0.06 – 0.08	1028 ± 206	0.26 – 0.28	82 ± 58
0.08 – 0.10	740 ± 173	0.28 – 0.30	123 ± 70
0.10 – 0.12	370 ± 123	0.30 – 0.32	164 ± 82
0.12 – 0.14	534 ± 148	0.32 – 0.34	288 ± 107
0.14 – 0.16	534 ± 148	0.34 – 0.36	206 ± 90
0.16 – 0.18	329 ± 115	0.36 – 0.38	41 ± 41
0.18 – 0.20	452 ± 136	0.38 – 0.40	41 ± 41

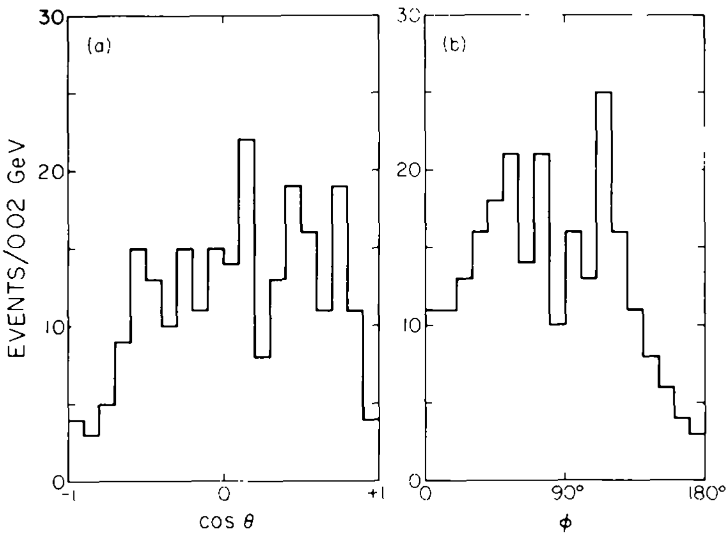

Fig. 8. Distributions in the Gottfried-Jackson frame for the reaction $K^+d \to K^{*+}(890)d$ of (a) $\cos\theta$, the polar angle and (b) ϕ, the azimuth.

frame, i.e., θ is the angle between the incident K^+ and the final K^0 in the $K^*(890)$ rest frame, and ϕ is the azimuth about the incident K^+ direction of the final K^0, all in the $K^*(890)$ rest frame. The spin-density-matrix elements as functions of t' are shown in fig. 9 and listed in table 2.

Pure pseudoscalar exchange would predict $\rho_{00} = 1$ and $\rho_{11} = 0$. (We use the normalization $\rho_{00} + 2\rho_{11} = 1$.), while pure vector exchange predicts $\rho_{00} = 0$ and $\rho_{11} = 0.5$. We see from table 1 that, although vector exchange dominates the reaction, there is contamination from other exchanges, particularly at low t. Averaged over all t, $\rho_{00} = 0.15 \pm 0.05$, which implies some 85% vector exchange; at 12 GeV/c it was found that $\rho_{00} \simeq 0.15 \pm 0.1$ (ref. [2]).

Table 2
Spin-density matrix elements for $K^+d \to K^{*+}(890)d$

t' (GeV/c)^2	ρ_{00}	ρ_{1-1}	Re ρ_{10}
0.0–0.1	0.25 ± 0.07	0.20 ± 0.06	0.08 ± 0.08
0.1–0.2	0.06 ± 0.09	0.22 ± 0.10	0.10 ± 0.10
0.2–0.3	0.11 ± 0.08	0.37 ± 0.13	0.18 ± 0.14
0.3–0.4	0.19 ± 0.21	0.05 ± 0.13	0.53 ± 0.21

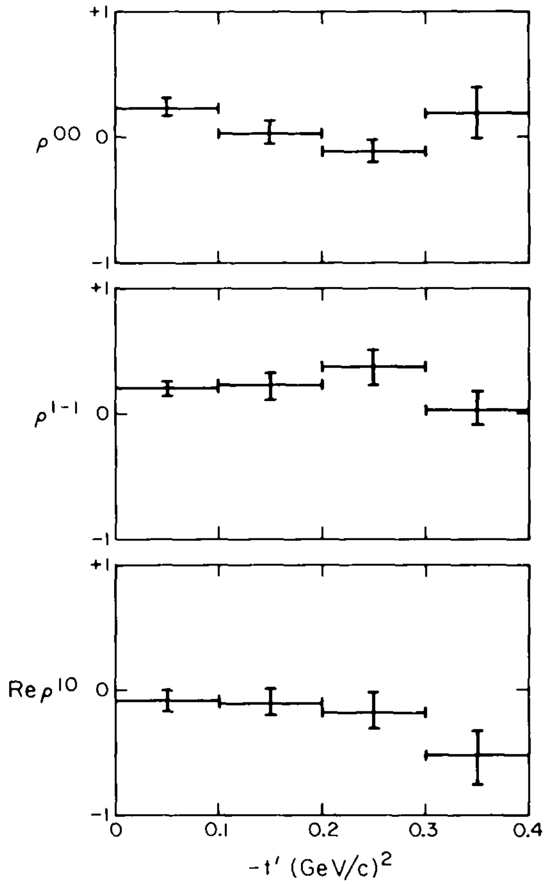

Fig. 9. Distributions of spin-density-matrix elements versus t' in the Gottfried-Jackson frame for the reaction $K^+d \to K^{*+}(890)d$. (a) ρ_{00}, (b) ρ_{1-1} and (c) Re ρ_{10}.

5. The ω trajectory

In order to determine the parameters of the ω trajectory, we have collected the available published data on the coherent reactions $K^{\pm}d \to K^{*\pm}(890)d$. These include the present experiment of 2 GeV/c K^+d, 3 GeV/c K^+d (ref. [3]), 12 GeV/c K^+d (refs. [1, 2]), 3 GeV/c K^-d (ref. [4]), 4.5 GeV/c K^-d (ref. [5]), 4.9 GeV/c K^-d (ref. [6]) and 12.6 GeV/c K^-d (ref. [7]). The parameterization used to extract the trajectory, α, is

$$(1 - \rho^{00})\,\frac{d\sigma}{dt} = \frac{A}{p_{\rm lab}^2}\,(s - u)^{2\alpha},$$

where A is the normalization constant and α is the ω trajectory. We have assumed a linear trajectory with unit slope, i.e., $\alpha = \alpha_0 + t$, and thus have two free parameters, A and α_0. We find that the minimum chisquare is 124 for 50 data points, and occurs for $A = 515 \pm 25$ μb and $\alpha_0 = 0.33 \pm 0.04$. If only the K^+ data are used, then the minimum chisquare is 57 for 30 data points, and occurs for $A = 410 \pm 25$ μb and $\alpha_0 = 0.35 \pm 0.06$. We also find that the minimum chisquares occur for a unit slope for the trajectory. The relatively low values of chisquare per degree of freedom appear to be due to normalization inconsistencies among the various experiments, but this effect does not significantly affect the trajectory. The errors quoted in the various experiments appear to be underestimated by about $\frac{1}{2}$ standard deviation.

These results should be compared to the results of Barger et al. [8], who obtained $\alpha_\omega(0) = 0.38 \pm 0.04$ from a fit to total cross section data, Brody et al. [9], who obtained $\alpha_\omega(0) = 0.47 \pm 0.09$ from a study of the reaction $K_L^0 p \to K_S^0 p$, and Michael et al. [10], who determined that the ω-trajectory passed through zero at $-t = 0.40 \pm 0.05$ $(\mathrm{GeV}/c)^2$ from a study of the reaction $\pi N \to \rho N$. Gidal [11] has summarized the previous results on the trajectory, and has concluded that $\alpha_\omega = 0.4 + t$.

It is worth pointing out that in this experiment ρ^{1-1} is significantly less than ρ^{11}. The same effect is seen in other experiments at 3 GeV/c on the coherent reactions $K^+d \to K^{*+}(890)d$ (refs. [3, 4]), but at higher energies (refs. [5, 6]) ρ^{11} and ρ^{1-1} are within errors equal. This implies that at least at low energies some unnatural parity exchange in the helicity one state must also be present. Present statistical precision does not permit further investigation of this question.

6. Conclusions

We have measured the cross section for the coherent reaction $K^+d \to K^0\pi^+d$ to be 324 ± 25 μb at 2 GeV/c. This reaction is dominated by $K^*(890)$ production and the cross section for the reaction $K^+d \to K^{*+}(890)d$ is 195 ± 15 μb. The $K^*(890)$ is produced predominantly through vector, i.e. ω, exchange. We determine the ω trajectory to be of the form $\alpha_\omega = (0.33 \pm 0.04) + t$.

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