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OBSERVATION OF TWO STRANGENESS-ONE AXIAL VECTOR MESONS*

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ABSTRACT

A partial wave analysis of the $K^{\pm}\pi^{+}\pi^{-}$ system in $K^{\pm}p \rightarrow K^{\pm}\pi^{+}\pi^{-}p$ at 13 GeV is presented. Evidence is given for the existence of two $J^P = 1^+$ mesons: one at ~1300 MeV ($\Gamma \sim 200$ MeV) coupling principally to ρK and the other at ~1400 MeV ($\Gamma \sim 160$ MeV) coupling principally to $K^*\pi$.

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An outstanding problem of meson spectroscopy is the lack of positive identification of the axial vector mesons other than the B meson.[1,2] The quark model predicts two octets of such states, the A_1 octet with $J^{PC}=1^{++}$ and the B octet with $J^{PC}=1^{+-}$. In this paper evidence is given for the existence of two strange axial vector mesons, Q_1 and Q_2, with masses of ~1300 MeV and ~1400 MeV respectively. The evidence comes from a three body partial wave analysis of data from a spectrometer experiment studying the reactions $K^{\pm}p \rightarrow K^{\pm}\pi^{+}\pi^{-}p$ at 13 GeV.

Past searches for Q mesons in these reactions have been hampered by both experimental and interpretive problems. Previous partial wave analyses[3,4,5] of $K\pi\pi$ data have revealed no structure characteristic of resonance production, namely, comparatively narrow peaks in the mass spectrum accompanied by large phase variation. Statistics have limited these analyses to 100 MeV mass bins. The broad enhancements which have been observed in the $1^{+}K^{*}\pi$ system[3,4,5] may be qualitatively understood within the context of "Deck" models.[6]

The present experiment was performed at SLAC using 13 GeV rf separated $K^{\pm}$ beams incident on a 1 m hydrogen target. The spectrometer[7] used to detect the $K\pi\pi$ system consisted of nine magnetostrictive readout wire spark chambers and a dipole magnet with a 17.6 kg-m field integral. The secondary particles were identified in a multicell pressurized Cerenkov counter oriented to detect preferentially the beam charge K and π. The counter was filled with Freon 12 at 1.65 atm and gave K/π identification between 2.6 and 9.25 GeV. The data sample includes events in which the beam charge K and π were identified (~ 50%) together with events with only the K or the π positively identified (~25% each). Events for the present analysis are selected by requiring that the missing mass recoiling against the $K\pi\pi$ system lie in the range $0.74 < MM < 1.10$ GeV. The background within this interval is less than 5%. In the $K\pi\pi$ mass interval $1.0 < m(K\pi\pi) < 1.6$ GeV, there are 72,000 $K^+\pi^+\pi^-$ events and 56,000 $K^-\pi^+\pi^-$ events. For the much larger sample of $K^\pm \to \pi^\pm\pi^+\pi^-$ beam decays, used for apparatus efficiency studies and relative normalization checks, the 3π invariant mass resolution is 10 MeV FWHM.

At a given $K\pi\pi$ mass m and momentum transfer t (or $t' = t - t_{min}$), the $K\pi\pi$ system is defined by 5 variables, $\omega = (\alpha, \beta, \gamma, s_{K\pi}, s_{\pi\pi})$. The Euler angles α, β, γ describe the orientation of the $K\pi\pi$ decay plane coordinate system with respect to a production coordinate system which is taken to be the t-channel system. The Dalitz plot variables, $s_{K\pi}$ and $s_{\pi\pi}$, define the orientation of particles within the decay plane. The experimental data are not corrected for the spectrometer acceptance directly, but rather a model is made for the reaction, the effects of the spectrometer are introduced, and the result is compared with the experimental data through a maximum likelihood technique. Acceptance here includes not only the geometrical acceptance of the spectrometer but also the effects of K/π identification criteria, resolution, apparatus efficiencies, secondary particle absorption, and the cuts applied to the data. In general the apparatus provides good acceptance in the full range of ω.[9]

The isobar model[8, 9] is used to describe the decay of the $K\pi\pi$ system. Each partial wave is described by the quantum numbers $J^P M^\eta$ Iso (L), where J^P is the $K\pi\pi$ spin parity, M is the magnetic substate, η is the exchange naturality, Iso denotes the isobar $(K^*, \rho, \kappa, \epsilon)$, and L is the orbital angular momentum between the isobar and the remaining π or K. The isobars are in turn described by measured s and p wave $K\pi$ and $\pi\pi$ scattering phase shifts.

The differential cross section at a given $K\pi\pi$ mass m and t' is

$$\frac{d^7\sigma}{dm\,dt'\,d\omega} = \sum_\eta \left[\left| \sum_i N_i^\eta X_i^\eta(\omega) \right|^2 + \left| \sum_i F_i^\eta X_i^\eta(\omega) \right|^2 \right] ,$$

where i runs over all necessary waves and $X_i^\eta(\omega)$ is the decay amplitude.[8,9] N_i^η and F_i^η may be identified with nucleon helicity nonflip and flip amplitudes only up to a unitary transformation which leaves the differential cross section unchanged.[9,10] Results are given for the acceptance corrected cross section of a wave and its phase, ϕ_{rel}, as measured relative to $1^+0^+K^*\pi$.

The helicity nonflip waves used in this analysis were 0^-0^+, 1^+0^+ and 1^+1^+ coupling to each of the four isobar channels in the lowest allowed L; $2^+1^+K^*\pi(D)$; and $3^+0^+K^*\pi(D)$ above 1.43 GeV. The helicity flip waves were 1^+0^+, $1^+1^+\rho K(S)$ and $1^+0^+ \epsilon K(P)$. The only η odd wave was $2^+0^-K^*\pi(D)$. This wave set was arrived at by an iterative procedure in which many other waves were studied using the K^+ data in all mass bins. Only those waves giving significant increases in likelihood were retained.[9]

The results presented here correspond to an analysis of the data with ~3000 events in each mass interval for $|t'| < 0.3$ GeV^2. In each bin, searches for the parameters N_i^η and F_i^η were made for the K^+ and K^- data independently. In general, unique values for these parameters were found, with the exception that for the K^- data in the range $1.14 \leq m(K\pi\pi) \leq 1.25$ GeV, a restricted continuum of values was found. None of the conclusions made below is seriously affected by this ambiguity. In particular, the total cross section and total J^P contributions are in no way affected.

The observed mass distributions are shown in Fig. 1a,b; a significant break is seen at ~1.28 GeV. The points give the corrected cross section obtained by summing the contributions of all the waves present. In Fig. 1c, d, the contributions of each J^P state are shown. Spin parity 1^+ dominates the reaction over most of this mass region and accounts for the gross structure observed. The 0^- contribution becomes important at higher masses. In the region of the K*(1420), a small but distinct 2^+ signal is seen. It is only ~5% of the total cross section at this mass.

The intensity and relative phase of the principal $K^*\pi$ and ρK waves with $J^P = 1^+, 2^+$ and $\eta = +1$ are shown in Figs. 2 and 3. For regions of $m(K\pi\pi)$ where the intensity of a wave is small ($\lesssim 20\ \mu b/GeV^3$) and susceptible to fluctuations in measurement, its phase information is unreliable. The line shape of the $2^+1^+K^*\pi$ wave shown in Fig. 2e, f is well described by nominal mass and width parameters for the K*(1420).[2] Furthermore, the observed K*(1420) cross section is in excellent agreement with that expected from experiments detecting the $(K\pi)^\pm$ decay mode.[2,9]

The $1^+K^*\pi$ waves are shown in Fig. 2a-d. There are significant differences between the K^+ and K^- data. In the $1^+0^+K^*\pi$ waves, there are clearly two peaks in the K^- data but only a peak-shoulder structure in the K^+ data. The higher mass peak in the K^- data occurs at ~1380 MeV, well beyond the ambiguous region. As seen in Fig. 2e, f, there is little phase variation ($\lesssim 45^\circ$) of the $2^+1^+K^*\pi$ wave in the vicinity of 1420 MeV. The $1^+1^+K^*\pi$ waves are significant in the 1200 MeV region, but are $\lesssim 10\%$ of the $1^+0^+K^*\pi$ waves in intensity, indicative of t-channel helicity conservation (TCHC) for the $1^+K^*\pi$ waves.

In the $1^+\rho K$ system (Fig. 3), peaks of width ~200 MeV are observed in all waves at ~1280 MeV. Furthermore, there are pronounced phase variations: a forward motion of $\sim 70^\circ$ for $1.20 < m(K\pi\pi) < 1.35$ GeV and a backward motion of $\sim 50^\circ$ for $1.35 < m(K\pi\pi) < 1.45$ GeV. The ratio of $1^+1^+\rho K$ to $1^+0^+\rho K$ (~1/3) is certainly <u>not</u> indicative of TCHC.[4,5] The measured coherence between the ρK and $1^+0^+K^*\pi$ waves is ~0.75 for the entire $K\pi\pi$ mass range.[9]

These features may be explained qualitatively in terms of two 1^+ resonances, Q_1 at ~1300 MeV coupling principally to ρK and Q_2 at ~1400 MeV coupling principally to $K^*\pi$, and a "Deck" background peaking at ~ 1200 MeV in the $1^+K^*\pi$ system. The evidence for such an interpretation is summarized as follows.

(a) There are comparatively narrow peaks in the partial wave mass spectra. Q_1 has a width of ~ 200 MeV and Q_2, a width of ~ 160 MeV. Such narrow peaks are not expected to result from "Deck" mechanisms.

(b) The large forward phase variation of the ρK waves would correspond to a resonance if the reference wave were approximately constant in phase. This would be the case if a significant background were present in $1^+K^*\pi$ and/or the Q_1 coupling to $K^*\pi$ were small.

(c) The suppressed phase variation of $K^*(1420)$ relative to $1^+0^+K^*\pi$ would indicate that this reference wave is also executing a Breit-Wigner phase variation in the region of 1400 MeV. In addition, if Q_2 couples weakly to ρK, a backward phase motion for the $1^+\rho K$ waves would then be expected.

(d) The residual low mass peaks in $1^+K^*\pi$ may be associated with a "Deck" background. Indeed little phase variation is observed between $1^+K^*\pi$ waves and the structureless $0^-0^+K^*\pi$ wave[9] as expected of "Deck" mechanisms.[6]

The large increase in statistics of the present experiment has enabled a partial wave analysis to be performed in much finer mass intervals, revealing distinct structure heretofore undetected. In particular intensity and phase variations with widths $\lesssim 200$ MeV have been observed. These effects may be interpreted as due to the existence of two 1^+ mesons Q_1 and Q_2, in accord with the multiplet structure implied by the quark model. These states would presumably be mixtures of Q_A and Q_B, the octet partners of the A_1 and B.

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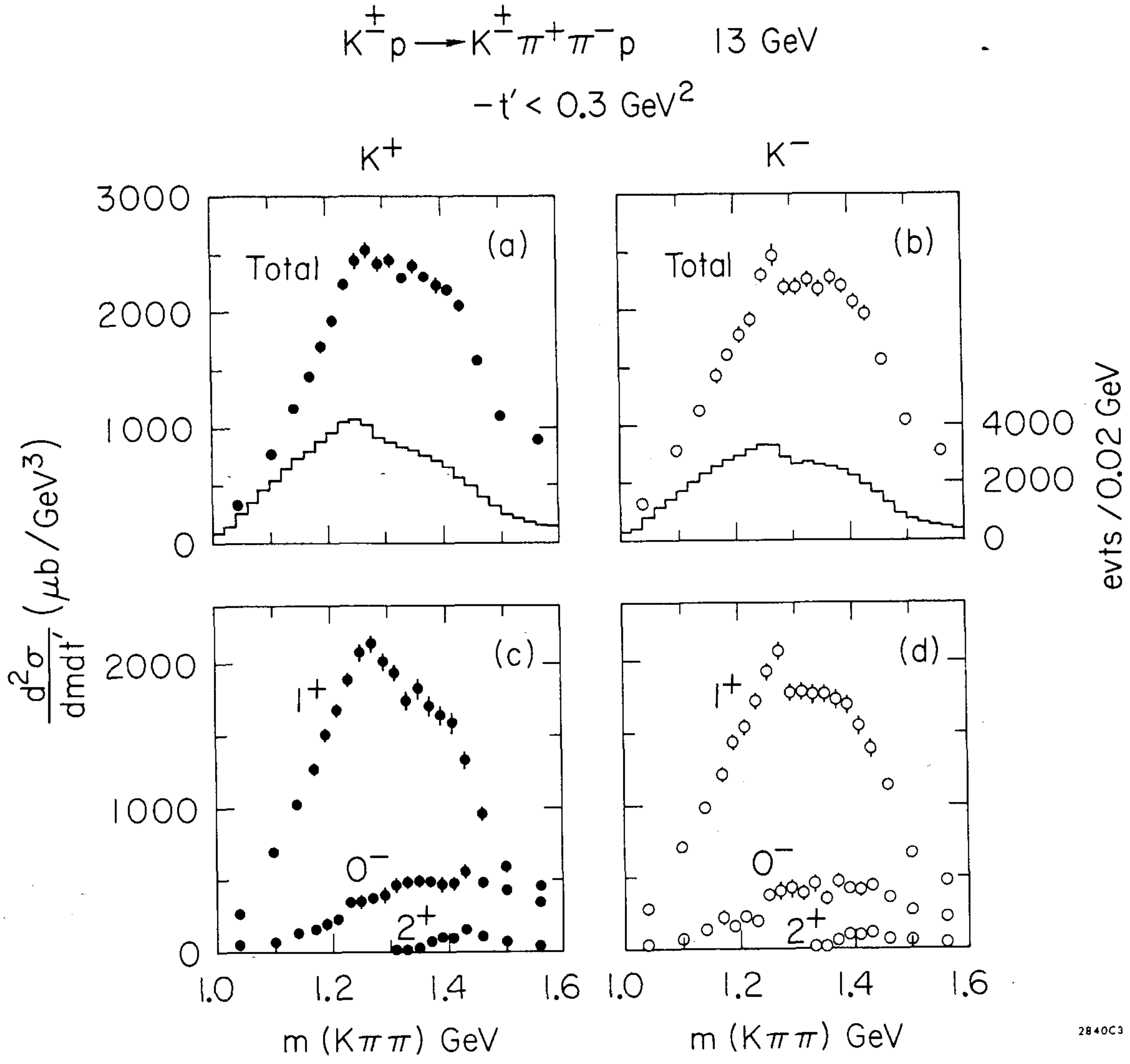
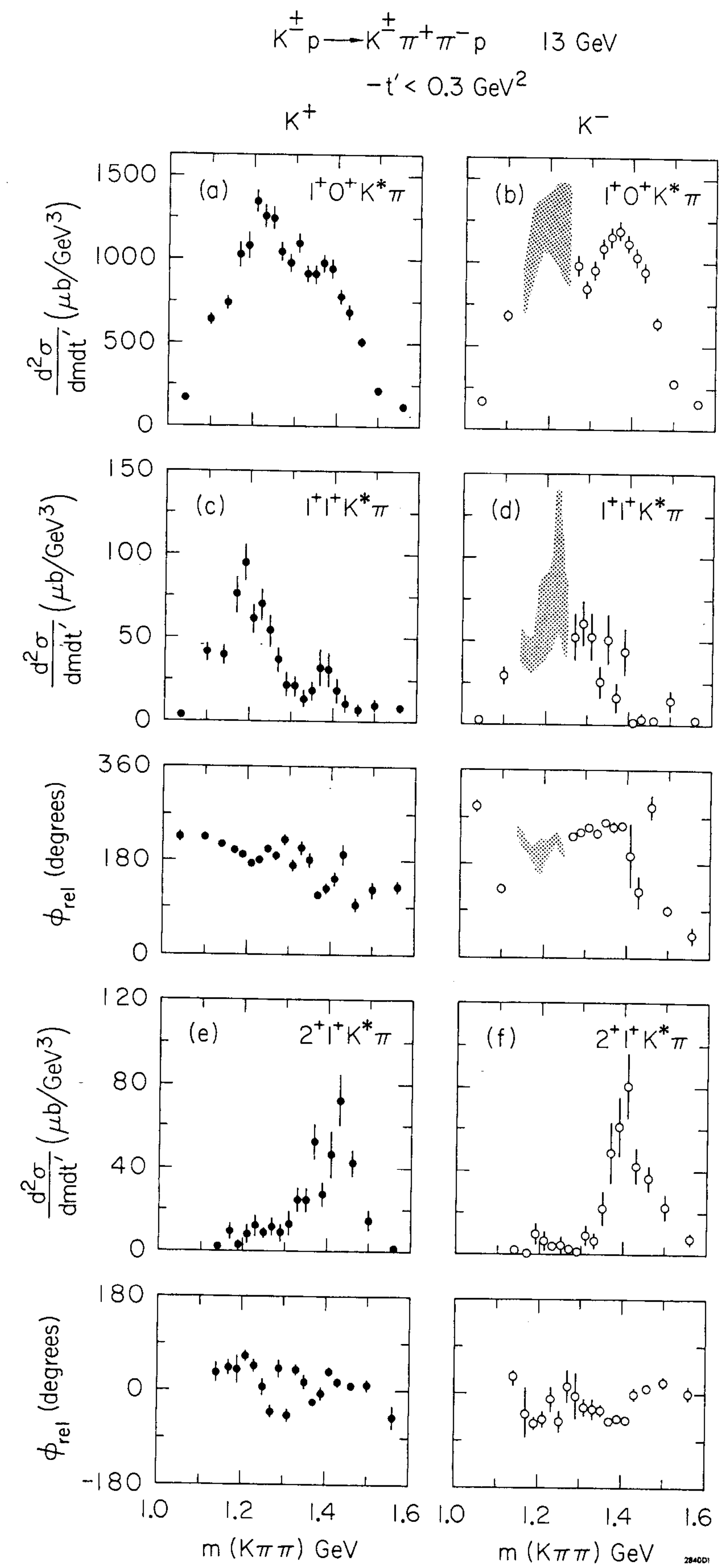
FIGURE CAPTIONS

1. Observed and corrected mass spectrum and principal total J^P contributions. The right hand scale refers only to the observed spectrum; the left hand, only to the corrected spectrum.
2. Mass dependence of the 1^+0^+, 1^+1^+, and $2^+1^+K^*\pi$ waves. The phase, ϕ_{rel}, is measured with respect to $1^+0^+K^*\pi$. The shaded area indicates the range of ambiguity.
3. Mass dependence of the 1^+0^+ and $1^+1^+\rho K$ waves. The phase, ϕ_{rel}, is measured with respect to $1^+0^+K^*\pi$. The shaded area indicates the range of ambiguity.



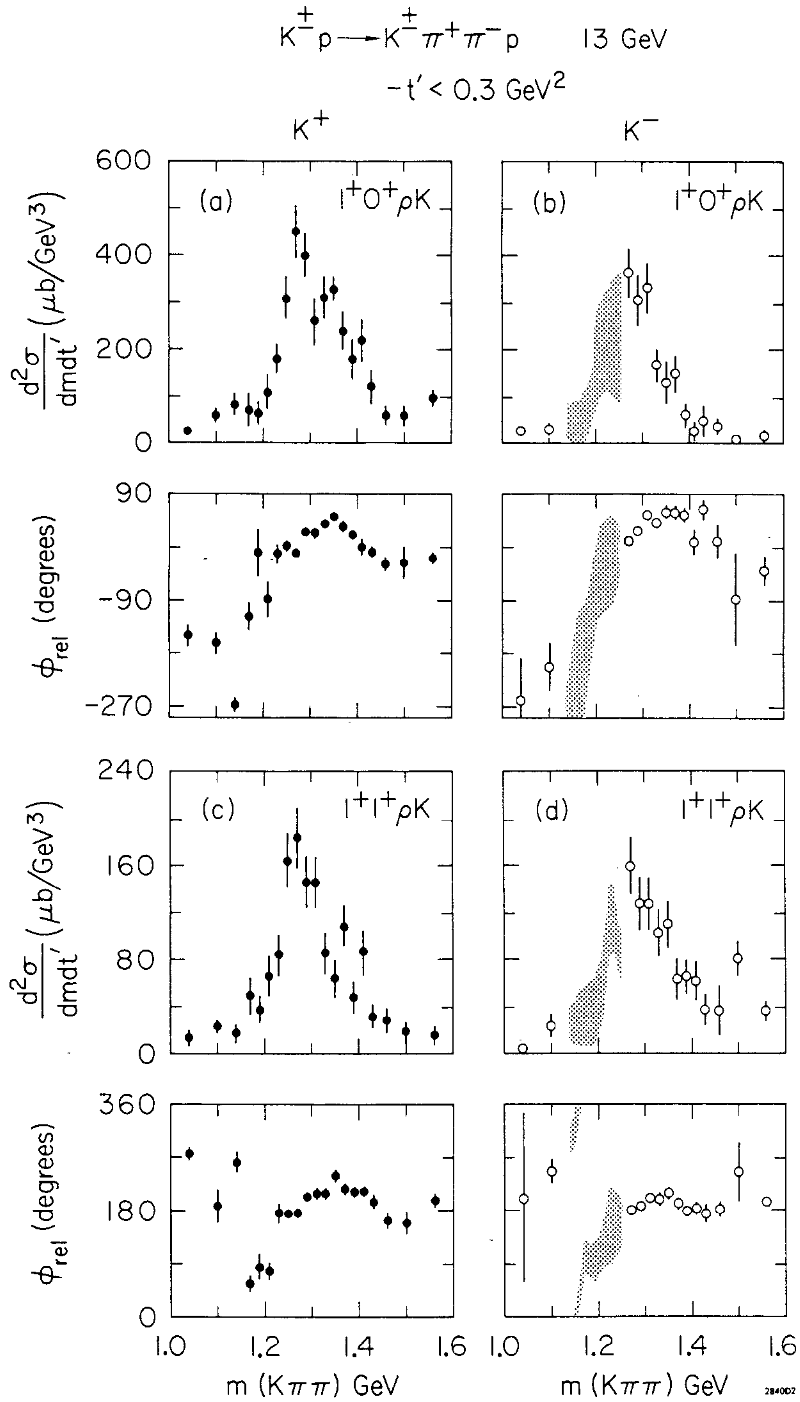
$K^{\pm}p \rightarrow K^{\pm}\pi^{+}\pi^{-}p$ 13 GeV
$-t' < 0.3$ GeV^2
K^+
K^-
Total
(a)
(b)
(c)
(d)
1^+
0^-
2^+
$\frac{d^2\sigma}{dmdt'}$ (μb/GeV^3)
evts/0.02 GeV
m (K$\pi\pi$) GeV
2840C3

Fig. 1



$K^{\pm}p \rightarrow K^{\pm}\pi^{+}\pi^{-}p$ 13 GeV
$-t' < 0.3$ GeV^2
K^+
K^-
(a) $1^+0^+K^*\pi$
(b) $1^+0^+K^*\pi$
(c) $1^+1^+K^*\pi$
(d) $1^+1^+K^*\pi$
(e) $2^+1^+K^*\pi$
(f) $2^+1^+K^*\pi$
$\frac{d^2\sigma}{dmdt'}$ (μb/GeV^3)
ϕ_{rel} (degrees)
m ($K\pi\pi$) GeV
2840D1

Fig. 2



$K^{\pm}p \rightarrow K^{\pm}\pi^{+}\pi^{-}p$ 13 GeV
$-t' < 0.3$ GeV^2
K^+
K^-
(a)
$1^+0^+\rho K$
(b)
$1^+0^+\rho K$
(c)
$1^+1^+\rho K$
(d)
$1^+1^+\rho K$
$\frac{d^2\sigma}{dmdt'}$ (μb/GeV^3)
ϕ_{rel} (degrees)
600
400
200
0
90
-90
-270
240
160
80
360
180
1.0
1.2
1.4
1.6
m ($K\pi\pi$) GeV

Fig. 3