A study of reaction $K^-N \rightarrow (K^-\pi^+\pi^-)N$ at 28 GeV/c

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Abstract

Diffractive-like production of strange meson resonances have been studied on the statistics nearly 300 000 events, which exceeds statistics of previous experiments. Experimental data have been acquired by VES spectrometer, exposed in unseparated tagged beam off Serpukhov accelerator on Be target. Preliminary results of the standard 3-meson Partial Wave Analysis of $(K^-\pi^+\pi^-)$ system with masses below 2 GeV are presented. Apart from two established resonances with spin-parity $J^P = 1^+$, $K_1(1270)$ and $K_1(1400)$, we have indications on the 3-rd resonance with mass close to 1750 MeV. Also properties of pseudoscalar resonance, $K_0(1460)$ are discussed.

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1 Introduction.

The properties of $(K^-\pi^+\pi^-)$-system have been studied by several experiments, two of them are the most statistically significant: $K^{\pm}p$ at 13 GeV/c [1] ($\sim$ 138000 events in total) and K^-p at 63 GeV/c [2] ($\sim$ 191000 events). The total mass distribution has two wide bumps, near 1300 and 1800 MeV, called Q- and L-regions, respectively.

The wave with spin-parity $J^P = 1^+$ is dominant, particularly in the Q-region. There are two well known resonances here, K_1(1270 and K_1(1400), which are interpretted as a mixture of two $(s\bar{u})$-states with parallel and antiparallel spins of quarks. Looking for the number of events in another waves, the second and the 3-rd waves are the $J^P = 0^-$ and 2^- waves. A wide resonance with mass $\sim 1400 - 1460$ MeV has been observed in the 0^- wave, which is not yet considered as well established. Events in the 2^- wave are concentrated mainly in the L-region. It would be natural to expect two 2^- mesons, like two 1^+ resonances. There are published fit results for 2^- wave with one or two resonances in the L-region in the $(K^-\pi^+\pi^-)$-system [2], as well as for the $(K\omega)$-system [3]. The χ^2 probabilities are better for two resonance hypothesis, however the difference is not large and this question needs clarification.

This paper is limited to the study of 1^+ and 0^- waves, according to the present status of the analysis. The paper is organized as follows. Selection procedure is described in Sect. 2. The Partial Wave Analysis (PWA) of 3-meson system has been performed in 20 MeV bins by well known program by G.Acsoli et al. (Sect. 3). Then the obtained distributions of $J^P = 1^+$ events in 5 channels and phases between channels were fitted in the framework of a model, which contains 3 resonances and Deck rescattering amplitudes. Successful describtion of the 1^+ wave was obtained in the $(K\pi\pi)$ mass range from 1 to 2 GeV. Phases of two most important channels, $(1^+S\ K^*\pi)$ and $(1^+S\rho K)$, are used then as the reference phases in the analyss of 0^- wave in 4 channels, in the same mass range (Sect. 4,5). The main results are summarized in the Conclusions.

2 Experimental setup and the data selection.

VES facility is a large angle magnetic spectrometer designed for studies of light meson resonances. It is installed in a beam of unseparated negative particles with possible momentum range between 23 and 46 GeV/c off the IHEP accelerator. Reconstruction of charged tracks is provided by a system of proportional chambers and drift chambers. The spectrometer is equipped by a lead-glass electromagnetic calorimeter and by a gas Cherenkov detector, which is suitable for identification of secondary $K^{\pm}$ in the momentum range from $\sim$ 4.5 to $\sim$ 20 GeV/c. A system of three beam Cherenkov detectors provides the identification of initial π^-, K^- and $\overline{p}$. A minimum bias trigger, based on a system of scintilator hodoscopes, is used. The trigger selects events with charged multiplicity from 2 to 6.

The data sets acquired in 1992 and 1996 runs at 28 GeV/c with identified K^- beam particles are used in this study. The following selection criteria have been applied:

- kaon beam (no signals in two beam Cherenkov detectors tuned below K-threshold; but a signal seen in the 3-rd one, above K-threshold);
- there are 3 charged secondary tracks (one positive, two negative);
- the energy sum of charged tracks lies in the range (25.,30.) GeV;
- there is no π^0, η in the event and energy deposited in the Electromagnetic Calorimeter is less than 1 GeV (i.e. consistent with noise);
- the momentum transfer cut: $|t'| < 0.7\ GeV^2$;
- at least one secondary negative track is identified by the Cherenkov detector as K^- or π^-. The identification was found satisfactory in the momentum range from 4.5 to 16.0 GeV/c;
- there is no K^+ identified by the Cherenkov detector;
- if both negative tracks are identified, then one of them should be identified as a K^- and another one as a π^-.

Detailed analysis of the Cherenkov detector performance for secondary charged particles has been made, looking for the particle momentum and for the particle tracing through the detector. A crosscheck with $(\pi^-\pi^+\pi^-)$ and $(K^-K^+K^-)$ samples permited to find several photomultipliers with poor light yield. Only events with reliable K^-/π^- identification have been kept.

Selected sample contains 300895 events with mass $(K^-\pi^+\pi^-)$ in the range $(1.0, 2.1)$ GeV. An analysis of the sample purity has shown that the most serious impurity comes from the $(\pi^-\pi^+\pi^-)$ system, this admixture is of order of 5%. Admixtures due to the beam misidentification and from the $(K^-K^+K^-)$ channel are negligible.

3 Partial Wave Analysis of the three-meson system.

At the next step, the 3-meson PWA program was used (the program which has been developped by G.Ascoli et al, initially for 3π systems) [4, 5, 6, 7]. It is assumed in this approach that the $(K^-\pi^+\pi^-)$ system decays in two steps, first into an isobar (an intermediate resonance) and an odd pseudoscalar meson, then the isobar decays into two pseudoscalar mesons.

Notations used hereafter: $J^P\ L\ M^\eta$, where
J stands for the full angular momentum of $(K^-\pi^+\pi^-)$ system,
P is the parity of the $(K^-\pi^+\pi^-)$ system,
L is the orbital momentum between the isobar and the odd meson,
M is the projection of full angular momentum J to the quantization axis,
η is the parity of the $(K^-\pi^+\pi^-)$ system with respect to the reflection in the production plane, also called as "exchange naturality".

The following intermediate resonances are included into the PWA: 1)$K^*(890)$, 2)ρ, 3)ϵ (excluded $f_0(980)$), 4)κ or $K_0(1430)$, 5)$K^{**}(1430)$ or $K_2(1430)$, 6)$f_2(1270)$, 7)$K^{***}(1780)$ or $K_3(1780)$, 8)$f_0(980)$.

The following waves are used:

- FLAT (a phase space amplitude, not interfering with other waves)
- 1^+ waves: $J^PLM^\eta =$
  $1^+S0^+(K^*\pi)$, $1^+S0^+(\rho\, K)$, $1^+P0^+(\kappa\, \pi)$, $1^+P0^+(\epsilon\, K)$, $1^+D0^+(K^*\pi)$, $1^+P0^+(f_0(980)\, K)$, $1^+S1^+(K^*\pi)$, $1^+S1^+(\rho\, K)$, wave $1^+D0^+(K^*\pi)$ is switched on from 1.10 GeV, $1^+P0^+(f_0(980)\ K)$ – from 1.45 GeV.

- 0^- waves:
  $0^-P0^+(K^*\pi)$, $0^-P0^+(\rho\,K)$, $0^-S0^+(\epsilon\,K)$, $0^-S0^+(\kappa\,\pi)$, $0^-S0^+(f_0(980)\,K)$,
  wave $0^-S0^+(f_0(980)\,K)$ is switched on from 1.45 GeV.

- 2^- waves:
  $2^-P0^+(K^*\,\pi)$, $2^-P0^+(\rho\,K)$, $2^-S0^+(K^{**}\pi)$, $2^-S0^+(f_2\,K)$,
  waves $2^-S0^+(K^{**}\pi)$ and $2^-S0^+(f_2\,K)$ are switch on from 1.55 GeV.

- 3^+ waves:
  $3^+D0^+(K^*\pi)$, $3^+P0^+(K^{**}\pi)$, $3^+S0^+(K^{***}\,\pi)$, $3^+P0^+(f_2\,K)$,
  wave $3^+P0^+(K^{**}\pi)$ is switched on from 1.60 GeV, other waves from 1.65 GeV.

- 4^- waves:
  $4^-F0^+(K^*\pi)$, $4^-D0^+(K^{**}\pi)$, $4^-P0^+(K^{***}\,\pi)$, $4^-D0^+(f_2\,K)$,
  all waves are switched on from 1.70 GeV.

- 2^+ waves:
  $2^+D1^+(K^*\,\pi)$, $2^+D0^-(K^*\,\pi)$,
  wave $2^+D1^+(K^*\,\pi)$ is switched on from 1.10 GeV

- 1^- waves:
  $1^-P1^+(K^*\,\pi)$, $1^-P0^-(K^*\,\pi)$.

There are 30 waves in total. It worth mentioning that 5 most significant 1^+ waves are taken without assumming a factorization hypothesis (see [8]). Also four most significant 0^- waves and one $2^-(\rho\ K)$ wave are taken without factorization hypothesis. This approach increases the number of fitted parameters but allows to measure the coherence between different waves.

The PWA fit is performed in 20 MeV bins on m$(K^-\pi^+\pi^-)$, from 1.0 to 2.0 GeV. Preliminary results of this analysis after summation of individual decay channels are shown in Fig.1. In general, the pattern of 1^+, 0^- and 2^- waves is similar to the waves obtained in K^-p experiment at 63 GeV [2].

4 Wave 1^+.

It is known that the 1^+ wave below 1.6 GeV can be described as a sum of two resonances, $K_1(1270)$ and $K_1(1400)$, in conjunction with Deck background [2]. Like K^-p experiment at 63 GeV, we consider 5 most important decay channels with $M=0$, namely channels $(K^*\pi)$ (S- and D-waves), (ρK), $(\kappa\pi)$ and (ϵK). Our intention is to obtain a continious description of the 1^+ wave in the mass range from 1 to 2 GeV.

There is a complication with $K_1(1270)$ resonance: the dominant decay channel, (ρK), has a threshold near 1270 MeV. Therefore, this resonance should have deviations from simple Breit-Wigner shape. Looking for description of this deviation, we used formalism developped for other 1^+ meson, a_1 [9]. The analytically "correct" BW for the decay channel $Resonance \to ab$ can be written as

$$BW_{CORR}(s) = \frac{M\Gamma_{ab}}{(s-m^2(s))^2+(M\Gamma_{tot}(s))^2}; \qquad (1)$$

where

$$m^2(s) = M_0^2 + \delta^2(s) \qquad (2)$$

the mass shift emerges from the real part of the renormalization term in the propagator,

$$\delta^2(s) = Re\Pi(s) = \frac{1}{\pi}\int_{s^{th}}^{\infty}\frac{-Im\Pi(s)}{s-s'}ds' \qquad (3)$$

$$s^{th} = (m_a+m_b)^2 \qquad (4)$$

and the $Im\Pi(s)$ corresponds to the total width:

$$Im\Pi(s) = -M\Gamma_{tot}(s) = -M\sum_i \Gamma_i(s) \qquad (5)$$

At the case of decay in S-wave and if the decay products are stable particles, the Cauchy integration can be performed explicitly as shown in [9]. At the case of $K_1(1270)$ one of the decay products is a resonance, and calculations should be performed numerically, taking into account final width of the isobar. In estimation of the mass shift, we considered 6 most important decay channels, 5 of them are measured in this experiment and included in the fit. The 6-th channel is (ωK) which is not measured but can be estimated from isospin relations. The last channel is important, because of ω resonance is narrow and its contribution to the mass shift term has a sharp kink. As zero approximation, we calculated the mass shift and the expected line shapes for different channels starting from the mass, width and Branching Ratious given in the Table of Particle Properties [10]. Results of our calvulations are shown in Fig.2. The mass shift causes a rise of the low mass tale for the $(K^*\pi)$ channel and therefore amplifies the difference between (ρK) and $(K^*\pi)$ channels, which exists already due to the difference in thresholds.

Keeping the modified shape of $K_1(1270)$, we try to describe five channels of 1^+ wave as a superposition of three resonances ($K_1(1270)$, $K_1(1400)$ and the 3-rd one, which has been observed in K^-p experiment at 63 GeV and which is called $K_1(1650)$ in the Table of Particle Properties), and the Deck amplitudes. All resonances are taken in 5 decay channels. Every resonance should have be taken, in principle, with 9 free real parameters: mass, width, production amplitude, phase of production amplitude and 5 Branching Ratios[2]. One production amplitude (and one phase) can be fixed. The Deck rescattering amplitudes are calculated for the same five channels, using the Regge poles approach [11]. We keep the shape of mass dependence from this calculation, but leave the overall normalization and the phase shift for all channels as free parameters of the fit.

At the next step we assume that 3 resonances and Deck amplitudes are produced in coherent and uncoherent states. If complex production amplitudes for resonances and for Deck amplitude are A, B, C, D and corresponding coherence coefficients are $\alpha, \beta, \gamma, \delta$, then there are uncoherent sum of amplitudes,

$$S_u = \sqrt{(1-\alpha)^2|A|^2 + (1-\beta)^2|B|^2 + (1-\gamma)^2|C|^2 + (1-\delta)^2|D|^2} \qquad (6)$$

and the coherent sum:

$$S_c = (\alpha A + \beta B + \gamma C + \delta D) \qquad (7)$$

It is assumed that one correlation coeffitient is valid for all decay channels of resonance.

Finally, following assumptions made in [2], we assume that different decay channels can have an offset in phases. For example, the coherent amplitude for S-wave $(K^*\pi)$ channel is written as

$$S_{c1} = (\alpha A Br_{a1} + \beta B Br_{b1} + \gamma C Br_{c1} + \delta D_1)e^{i\phi_1}; \qquad (8)$$

where Br_{a1}, Br_{b1}, Br_{c1} are Branching Ratios of three resonances to $(K^*\pi)$ channel, D_1 is the Deck effect amplitude corresponding for this channel and

[2]Branching Ratios of $K_1(1270)$ and $K_1(1400)$ into S-wave $(K^*\pi)$ and (ρK) channels can be described by 3 parameters, as described in [2]

ϕ_1 is the "offset phase" of $(K^*\pi)$ channel. Since there are 5 channels in total, 4 "offset phases" are needed.

Fitted distributions are of the number of events (5 channels, 5 distributions) and relative phases (4 distrubutions). The phases are considered with respect to the S-wave $(K^*\pi)$ one, excepting the D-wave $(K^*\pi)$ which is taken with respect to the (ρK) channel.

Successful fit of all distribution is obtained, $\chi^2/ND = 217/352$. Fitted distributions and the results of the fit are shown in Fig.3. Preliminary parameters of 1^+ resonances are presented in Table 1.

Table 1.
Preliminary parameters of resonances in 1^+ wave.

	$K_1(1270)$	$K_1(1410)$	$K_1(1650)$
	V$\pm$ err. MeV	V$\pm$ err. MeV	V$\pm$ err. MeV
mass	1274 ± 9	1407 ± 10	1755 ± 50
width	45 ± 8	83 ± 10	269 ± 90
	V$\pm$ err. %	V$\pm$ err. %	V$\pm$ err. %
$Br(K^*\pi)_S$	16.1 ± 4.1	80.6 ± 9.1	9.7 ± 1.0
$Br(K\rho)$	65.7 ± 7.3	6.9 ± 5.7	26.5 ± 11.1
$Br(\kappa\pi)$	9.2 ± 0.9	1.4 ± 0.2	4.5 ± 1.8
$Br(\epsilon K)$	1.1 ± 0.4	3.6 ± 1.0	32.2 ± 6.8
$Br(K^*\pi)_D$	7.8 ± 1.2	7.8 ± 1.9	27.0 ± 3.9

For $K_1(1270)$ resonance, the "raw" values of mass and width are given. One can notice that the values of $K_1(1270)$ and $K_1(1400)$ masses are close to the values quoted in the Table of Particle Properties, while the values of width are significantly lower for both resonances. The values of Branching Ratios are given without (ωK) channel, which corresponds to $\sim 25\%$ of the (ρK) channel for $K_1(1270)$ and $\sim 33\%$ for higher masses. The Branching Ratios in Table 1 are corrected for other decay channels, different from $(K^-\pi^+\pi^-)$.

Errors given in the Table 1 are mainly systematical, including uncertainty from different binning and modifications of the model [3].

[3] A fit with Re and Im parts of non-diagonal matrix elements were tried, instead of phases between different decay channels.

5 Wave 0^-.

A similar model has been applied to 0^- waves, in 4 channels: $(K^*\pi)$, (ρK), (ϵK), $(\kappa\pi)$. Again, an attempt has been done to describe the 0^- wave in different channels in the mass range from 1 to 2 GeV and in $|t'| < 0.7\ GeV^2$. The model for 0^- waves includes one resonance, K_0(1460 which has been observed in previous experiments but still needs confirmation. All phases are measured with respect to $1^+S0+(K^*\pi)$ wave, excepting $0^-(K^*\pi)$ wave. The phase of this wave is measured with respect to $1^+S0^+(\rho K)$ wave.

Fit results are presented in Fig.4 and in Table 2 ($\chi^2/ND = 130./134$).

Table 2.
Preliminary parameters of resonance in 0^- wave.

	$K_0(1460)$ V$\pm$ err. MeV
mass	1450 ± 37
width	110 ± 25
	V$\pm$ err. %
$Br(K^*\pi)_S$	38.3 ± 4.1
$Br(K\rho)$	6.7 ± 0.8
$Br(\epsilon K)$	7.4 ± 1.2
$Br(\kappa\pi)$	47.7 ± 5.1

Like Table 1, here the Branching Ratios are corrected for other decay channels, different from $(K^-\pi^+\pi^-)$, and the errors are mainly systematical.

Between the motivations for studies of $(K^-\pi^+\pi^-)$ system, it was a search for the 2-nd resonance in 0^- wave, a strange partner of the $\pi(1800)$. There is no significant indications for this object at the present level of sensitivity.

6 Conclusions

- Partial Wave Analysis of $(K^-\pi^+\pi^-)$ system is performed on the statistics of ~ 300000 events. The general pattern of large waves is similar to the pattern observed in K^-p experiment at 63 GeV/c.

- A complex of 5 most significant 1^+ waves in the mass range from 1 to 2 GeV can be desribed as a superposition of 3 resonances and Deck rescattering amplitudes. Existence of 1^+ resonance with mass close to 1750 MeV is confirmed. Preliminary values of mass, width and Branching ratios of this object are determined.

- Satisfactory description of 4 most significant 0^- waves below m_{tot}=2 GeV requires one resonance, $K_0(1460)$ and Deck effect. Preliminary measurements of $K_0(1460)$ parameters are presented. There is no evidence for 2-nd resonance in this wave, a strange partner of $\pi(1800)$.

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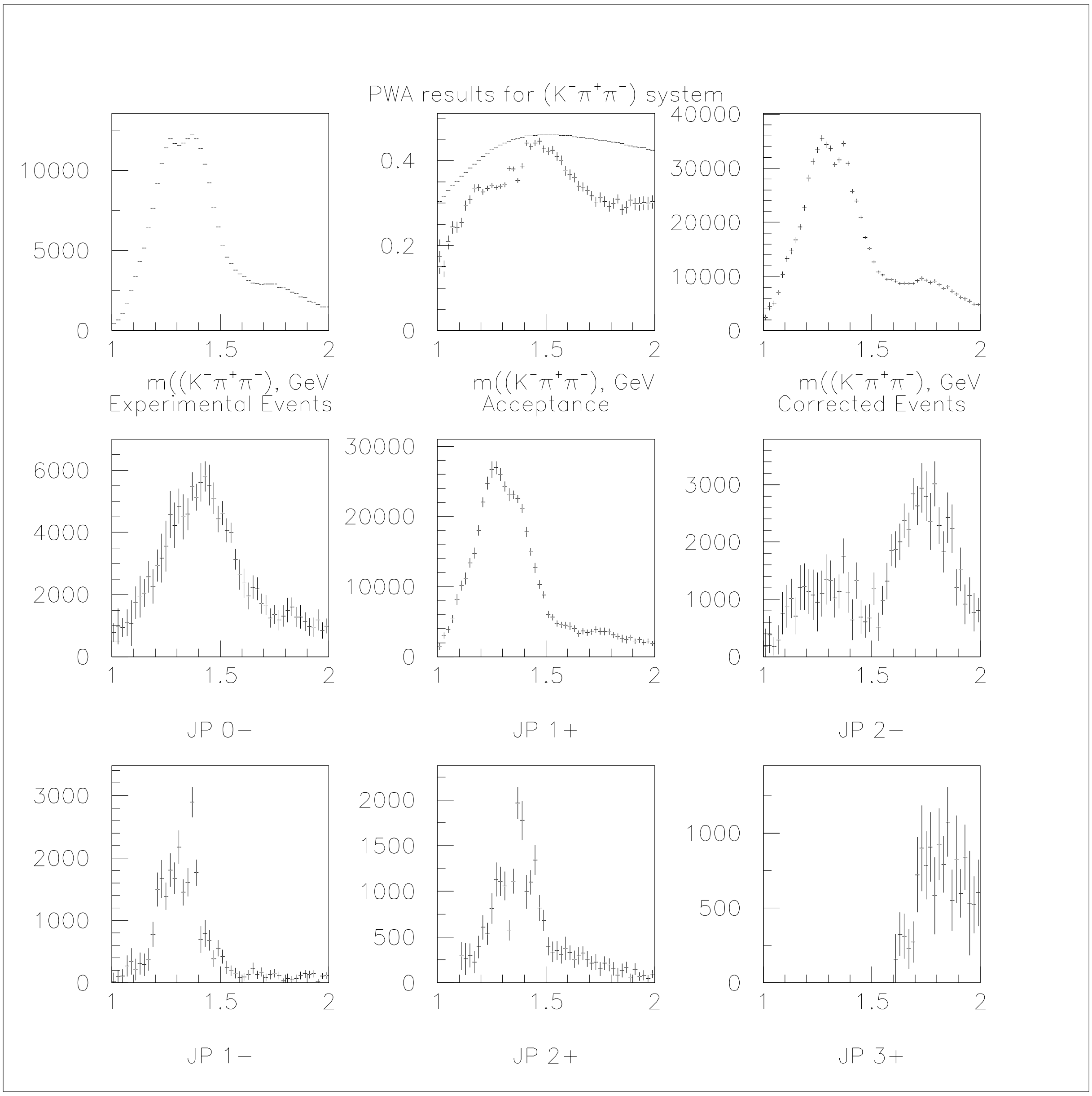

Figure 1: Results of the Partial Wave Analysis of $(K^-\pi^+\pi^-)$-system. Number of experimental events in 20 MeV bins, acceptance, number of corrected events and number of fitted events in different spin-parity waves are shown. The acceptance is estimated for two assumptions, for distribution of decay products simply according to the phase space and for fitted ρ-matrix.

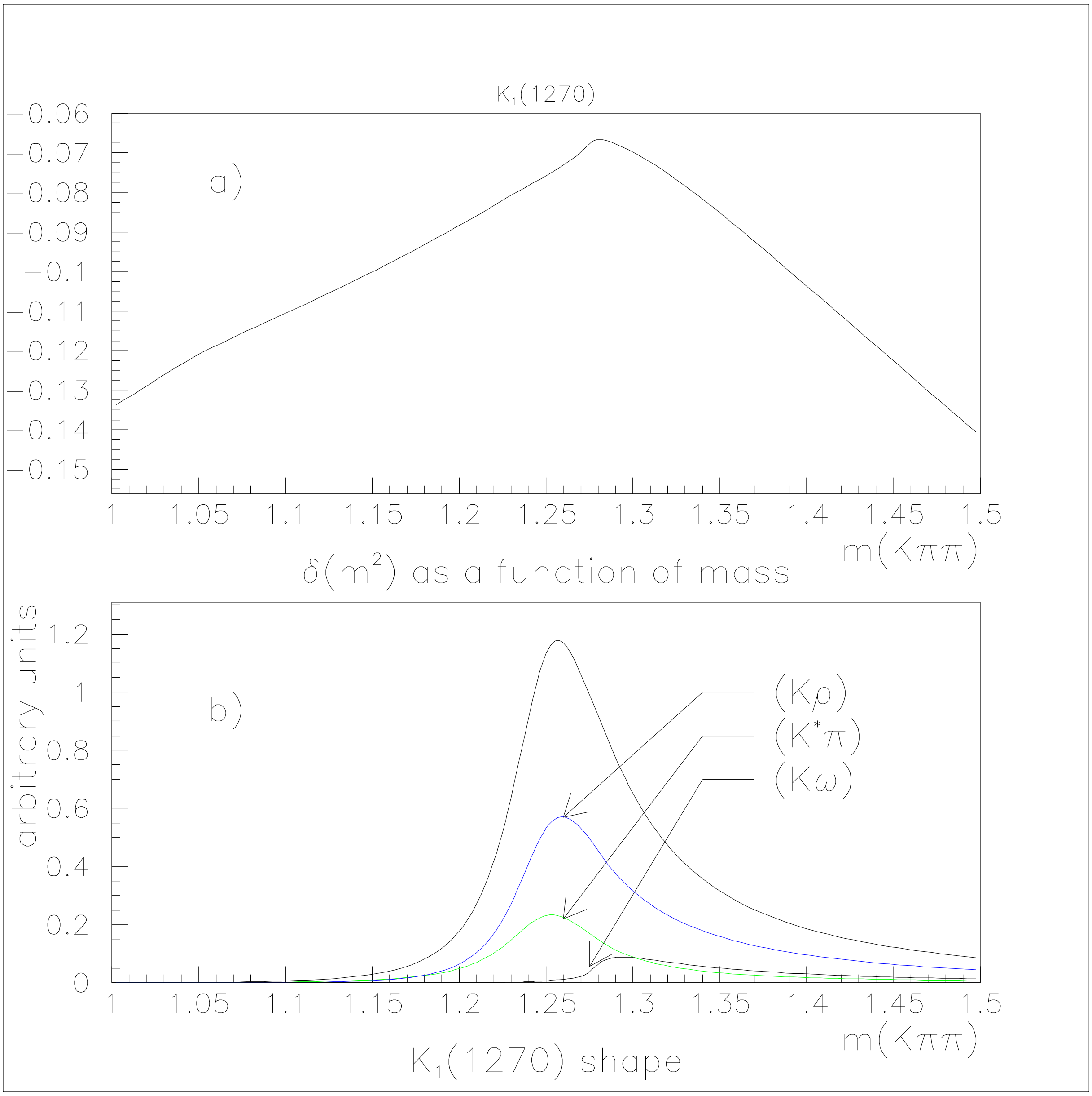

Figure 2: Influence of the threshold effects on the shape of $K_1(1270)$ resonance: a) estimated $\delta(m^2)$, mass sqared shift (see text); b) shapes of the $(K^*\pi)$(S-wave), (ρK), (ωK) channels and the sum of all channels.

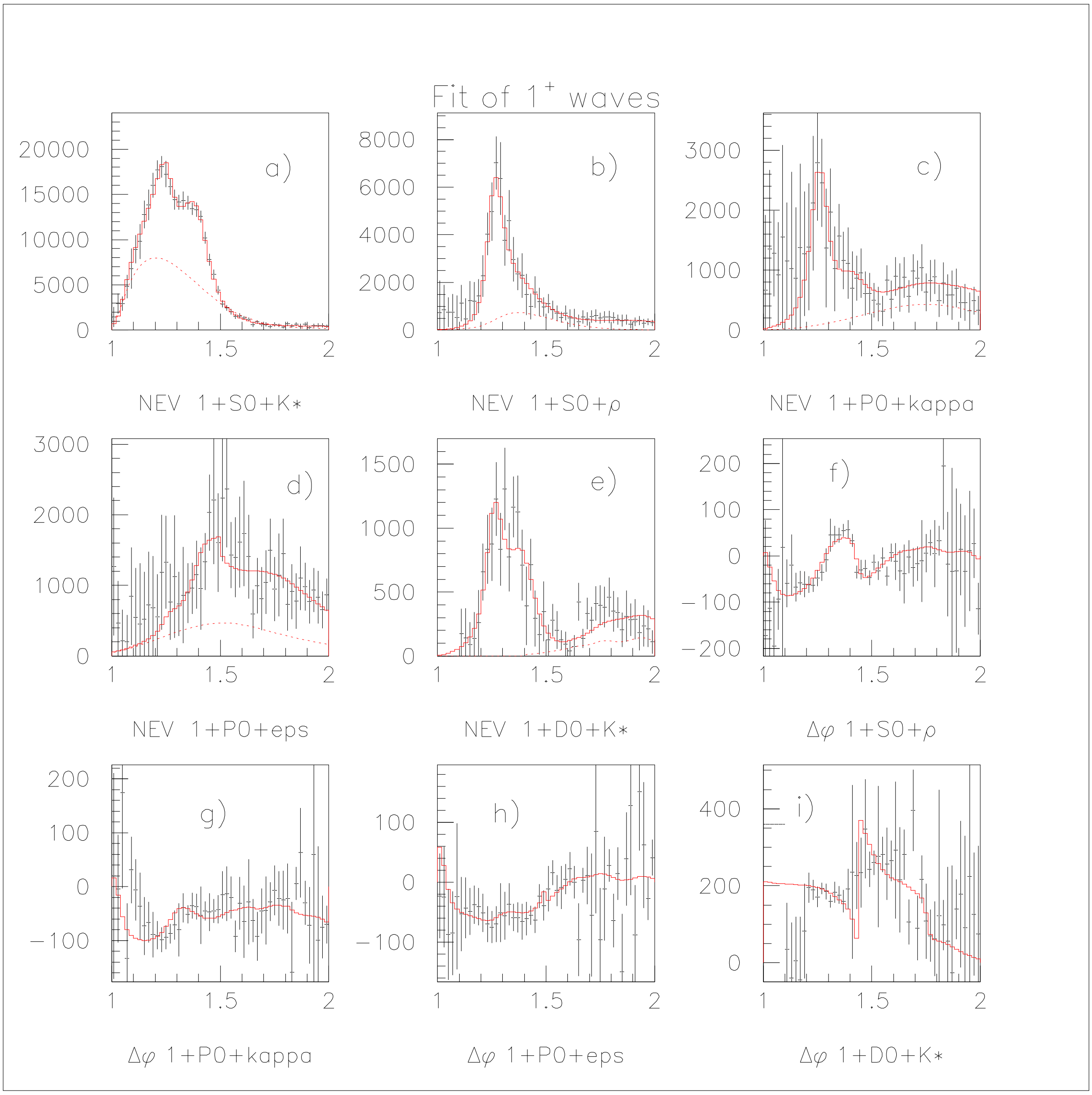

Figure 3: Results of Partial Wave Analysis for $J^P M^\eta = 1^+0^+$ waves, $1.0 < m(K\pi\pi) < 2.0\ GeV$, $0 < |t| < 0.7\ GeV^2$. Number of events in 20 MeV bins for individual channels (a-e) and relative phases with respect to S-wave $(K^*\pi)$ (f-h) or (ρK) (i) channels are shown. Dashed lines demonstrate the contributions from Deck effect.

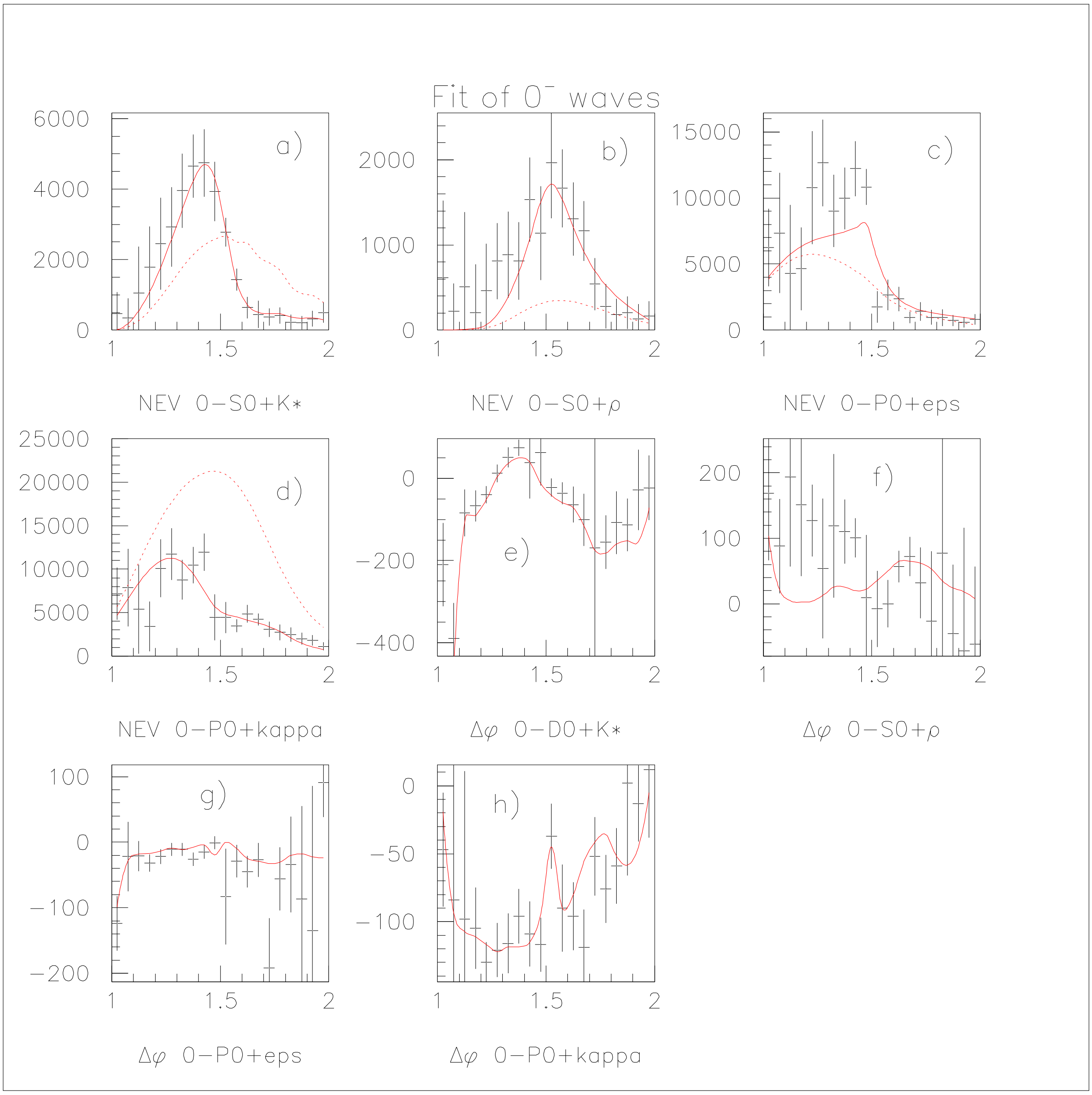

Figure 4: Results of Partial Wave Analysis for $J^P M^\eta = 0^- 0^+$ waves, $1.0 < m(K\pi\pi) < 2.0$ GeV, $0 < |t| < 0.7$ GeV^2. Number of events in 50 MeV bins for individual channels (a-d) and relative phases with respect to $1^+ S(\rho K)$ (e) or $1^+(K^*\pi)$ (f-h) channels are shown. Dashed lines demonstrate the contributions from Deck effect.