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ANALYSIS OF THE PRODUCTION MECHANISM OF NARROW ENHANCEMENTS IN THE EFFECTIVE MASS SPECTRUM ($\pi^+\pi^-$) IN THE REACTION $np \to d\pi^+\pi^-$ AT A NEUTRON INCIDENT MOMENTUM OF P_n = 1.73 GeV/c

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Анализ механизма образования узких особенностей в спектре эффективных масс $(\pi^+\pi^-)$ реакции $np \to d\pi^+\pi^-$ при импульсе $P_n = 1,73$ ГэВ/с

Была наблюдена новая аномалия в спектре эффективных масс $M_{\pi^+\pi^-}$ для реакции $np \to d\pi^+\pi^-$ при $P_n = 1,73$ ГэВ/с. Положение пика находится при 0,40 ГэВ/с^2, а полная ширина $\Gamma \leq 0,03$ ГэВ/с^2. Ни одна из рассмотренных нами моделей не описывает совокупность экспериментальных данных этой реакции.

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Analysis of the Production Mechanism of Narrow Enhancements in the Effective Mass Spectrum $(\pi^+\pi^-)$ in the Reaction $np \to d\pi^+\pi^-$ at a Neutron Incident Momentum of $P_n = 1.73$ GeV/c

A new anomaly has been observed in the $M_{\pi^+\pi^-}$ effective mass spectrum for the reaction $np \to d\pi^+\pi^-$ at $P_n = 1.73$ GeV/c. The peak position is at 0.40 GeV/c and its full width is $\Gamma \leq 0.03$ GeV/c^2. None of the models studied here describes the bulk of the experimental data from this reaction.

The investigation has been performed at the Laboratory of High Energies, and Laboratory of Computing Techniques and Automation, JINR.

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1. INTRODUCTION

In the last years, nucleon-nucleon interactions with deuteron production in the final state have been studied in several experimental and theoretical works.

The reaction

$$pp \to d\pi^+ \quad (1)$$

has been best studied in a broad range of energies. The effective cross section of this reaction takes the form of a fastly increasing curve from the production threshold with a maximum of 3 mb at $P_p = 1.3$ GeV/c.

After this there follows a fast drop proportional to P_p^{-4}. Experimental data are described in terms of the OPE model[5,6] with the initial reaction

$$pp \to np\pi^+ \quad (2)$$

followed by the production of deuteron in the final state. In this model the maximum of the effective cross section is the result of the presence of the first isobar in the reaction (2).

The maximum observed in the spectrum of $(d\pi^{\pm})$ effective masses was also seen in the reaction with deuteron in the initial state[7-9], the so-called d^*.

The so-called ABC effect is directly related to this work as well[10-12]. This effect was clearly observed in the missing-mass spectrum of the reactions

$$np \to d + (mm)^\circ \text{ [13]} \quad (3)$$

$$dp \to {}^3He + (mm)^\circ \text{ [14]} \quad (4)$$

$$dd \to {}^4He + (mm)^\circ \text{ [15,16]}. \quad (5)$$

However, in the reactions

$$\pi N \to N + (\pi\pi) \tag{6}$$

$$pp \to d + (mm)^{+} \tag{7}$$

$$dp \to t + (mm)^{+} \tag{8}$$

the ABC effect was not observed.

This fact was the foundation for formal attribution of isospin $I=0$ to the ABC anomaly.

The experiments /13–16/ were performed at incident momenta per nucleon $P_0 = (1 \div 2)$ GeV/c.

The peak position shifts to the right from 0.30 GeV/c^2 to 0.36 GeV/c^2 with increasing momentum P_0, but the anomaly cross section fastly decreases, and around $P_0 \cong 2$ GeV/c the process practically disappears. The full width of the anomaly Γ is about 0.06 GeV/c^2.

The ABC effect was also studied in the reaction

$$np \to d\pi^{+}\pi^{-} \tag{9}$$

using the HBC from DESY. The irradiation of the chamber was performed with a continuous spectrum of neutrons having momenta between 1 and 4 GeV/c. The use of the bubble chamber methodics allows a more detailed analysis of the ABC anomaly to be carried out. However, a disadvantage of this experiment is that the neutron energy is unknown. This fact causes difficulties to study the structure of the $(\pi^{+}\pi^{-})$-system effective mass. It is interesting to note that in a study of the reaction

$$dp \to {}^{3}He + (mm)^{\circ}$$

in one of the missing-mass spectra /14/ at $P_d = 3.49$ GeV/c and a ^3He registration angle of $\Theta = 2.8^\circ$ an insignificant bump was observed around a mass of 0.45 GeV/c^2.

To explain the ABC effect, different theoretical models /18–21/ have been proposed. Probably, the OPE and baryon exchange models, proceeded by deuteron formation, should be considered as the main ones.

2. EXPERIMENTAL DATA ANALYSIS

Previously /22,23/, we presented experimental data on the reaction (9) obtained by irradiation of the 1m HBC with a neutron beam. The momentum neutron spread $\frac{\Delta p}{p}$ did not exceed 3% and the angular one ~0.3 mrad.

The reaction was selected by the χ^2-method with 4c-fit followed by visual particle identification. The experimental

data were obtained at four neutron momenta: $P_n = (1.73;\ 2.23;\ 3.83;\ 5.10)$ GeV/c. The cross sections of the reaction at the corresponding neutron momenta were:

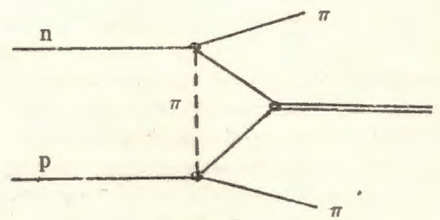
$$\sigma = (0.270 \pm 0.015;\ 0.33 \pm 0.02;\ 0.05 \pm 0.02;\ 0.03 \pm 0.02)\ \text{mb}.$$

The numbers of events from the reaction (9) at momenta $P_n = 1.73$ and 2.23 GeV/c were 1447 and 697, respectively. Two peaks were observed in the effective mass spectrum $M(\pi^{+}\pi^{-})$ at $P_n = 1.73$ GeV/c. The position and width of the first peak correspond to the ABC effect, the second one at $M(\pi^{+}\pi^{-}) = 0.40$ GeV/c^2 with a full width of $\Gamma \lesssim 0.03$ GeV/c^2 was a new anomaly. The cross section of the second anomaly was ~20 μb. To examine the assumption that the process (9) proceeds through the intermediate reaction

$$np \to np\pi^{+}\pi^{-} \tag{10}$$

with subsequent deutron formation, we used our experimental data from the reaction (10) /24/ using a part of the same material.

The number of events from the reaction (10) at $P_n = 1.73$ and 2.23 GeV/c was equal to 834 and 3585, respectively. The cross section of this reaction was $\sigma = (0.55 \pm 0.05;\ 4.05 \pm 0.25)$ 4.05±0.25) mb. We selected the events of the reaction (10) with an effective mass of $M_{np} < 1.95$ GeV/c^2. A further decrease of M_{np} did not change significantly the shape of the experimental distribution. This way qualitatively corresponds to theoretical calculation /19/ of the diagram



(I)

with a small relative motion between neutron and proton.

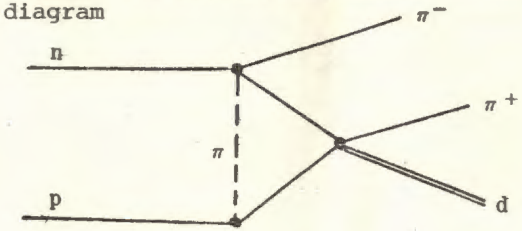
To check the next hypothesis that the process (9) proceeds through the intermediate reaction

$$np \to pp\pi^{-} \tag{11}$$

with subsequent deuteron production in the reaction $pp \to d\pi^{+}$ we also used experimental data from the reaction (11).

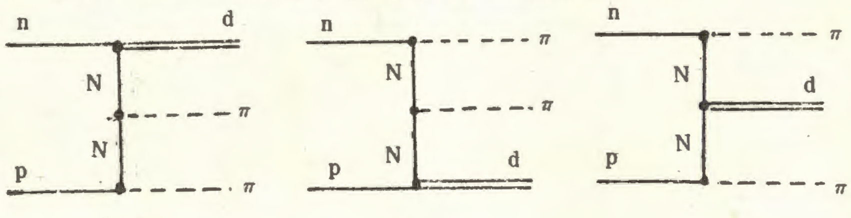
The number of events from the reaction (11) at $P_n = 1.73$ and 2.23 GeV/c was equal to 2675 and 2349, respectively.

The reaction cross section was σ = (2.94±0.17;3.20±0.13)mb. The effective mass of the two protons was calculated for each event. Further experimental data[1] from the reaction (1) were used. The dependence was taken into account of the reaction (1) cross section on M_{pp} and on the shape of the angular distribution in the cms of the two protons. This approach qualitatively corresponds to theoretical analysis by the diagram



(II)

neglecting the off-mass-shell of two nucleons. Besides, we tried to describe the two-maximum structure in the effective mass spectrum $M(\pi^+\pi^-)$ at P_n = 1.73 GeV/c in terms of the reggeized double baryon exchange model DBEM. The calculation was performed according to the following diagrams:



(III) (IV) (V)

In order to write deuteron form factor, the Hulthen wave function was used as the basis. After this the deuteron vertex was described by π-meson exchange in the semi-relativistic model. For checking, we repeated the calculation that had been carried out by the authors[25] to describe the experimental data[13] from the reaction $np \to d + (mm)^\circ$. A good agreement was observed between the two calculations.

Experimental data for the reaction $np \to d\pi^+\pi^-$ (histograms) and the calculated curves are shown in figs. 1-6. The distributions in the c.m.s. are presented for $M(\pi^+\pi^-)$ effective masses (fig. 1), $M_{d\pi^\pm}$ effective masses (fig. 2), $\pi^\pm$-meson momenta $p^*_{\pi^\pm}$ (fig. 3), deuteron momenta P^*_d (fig. 4), cosines of the deuteron and $\pi^\pm$-meson angles $\cos\theta^*_d$ and $\cos\theta^*_{\pi^\pm}$ (fig. 5) and cosines of the angles between π-meson $\cos\phi^*$ (fig. 6).

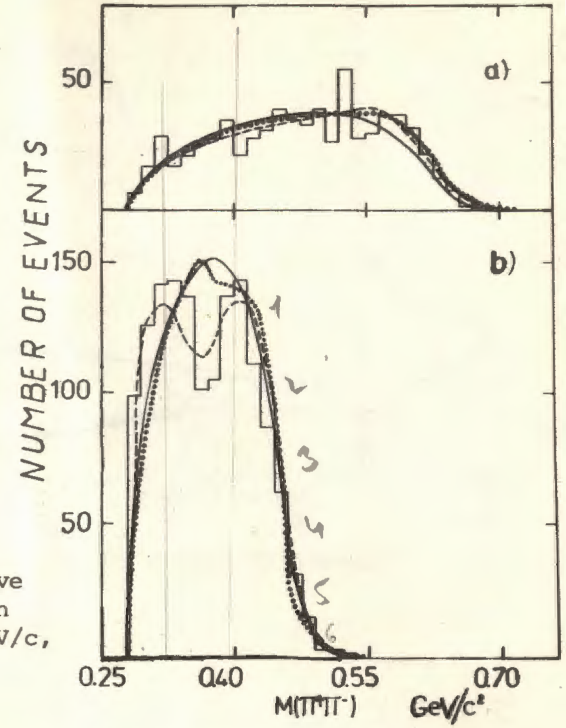


Fig. 1. $M_{\pi^+\pi^-}$ effective mass from the reaction $np \to d\pi^+\pi^-$ a) P_n=2.23 GeV/c, b) P_n = 1.73 GeV/c.

The upper distributions (a) correspond to the neutron momentum P_n = 2.23 GeV/c and the lower ones (b) to P_n = =1.73 GeV/c. The solid line corresponds to the phase space calculation. The dotted line corresponds to the hypothesis of intermediate reaction $np \to pp\pi^-$ and the dashed one to the calculation obtained by the baryon exchange model.

The experimenta distributions at P_n= 2.23 GeV/c are well described by the model which takes into account the intermediate reaction $np \to pp\pi^-$. The comparison of the experimental $M(\pi^+\pi^-)$ distribution with different calculated curves at P_n = 1.73 GeV/c shows that DBEM is the closest one to our data.

However, this model does not describe other experimental histograms, particularly the angular distributions in the c.m.s. The $d\pi^\pm$ effective mass distributions are qualitatively described by the model taking into account the intermediate reaction $np \to pp\pi^-$. Experimental data from the reaction $np \to np\pi^+\pi^-$ are presented in figs. 7-9. Here the upper histograms (a) also correspond to P_n = 2.23 GeV/c and

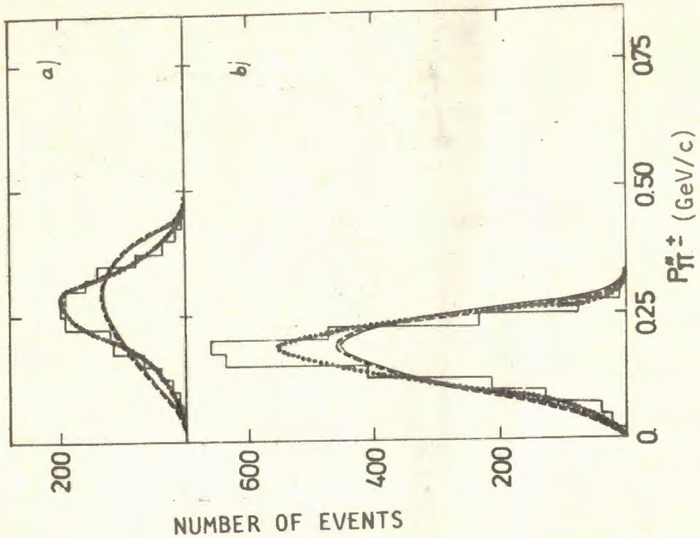


Fig. 3. $\pi^\pm$-momentum distributions in the c.m.s. of the reaction $np \to d\pi^+\pi^-$ a) P_n = 2.23 GeV/c, b) P_n = 1.73 GeV/c.

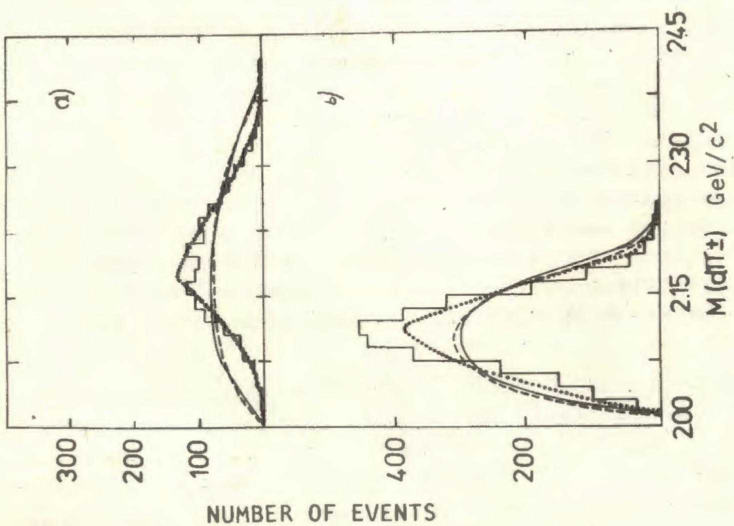


Fig. 2. $M_{d\pi^\pm}$ effective mass from the reaction $np \to d\pi^+\pi^-$ a) P_n = 2.23 GeV/c, b) P_n = 1.73 GeV/c.

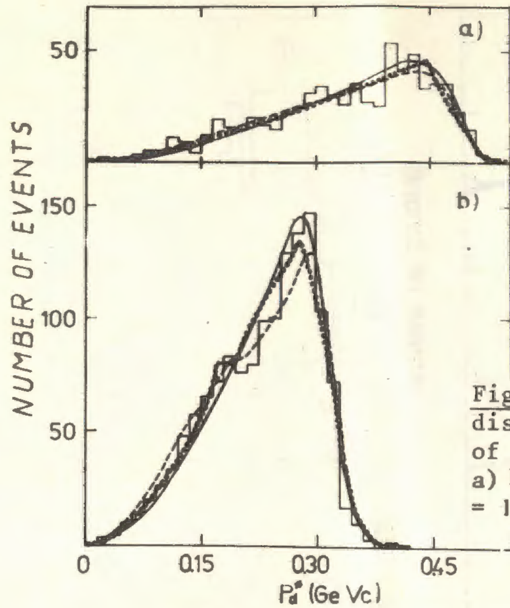


Fig. 4. Deutron momentum distributions in the c.m.s. of the reaction $np \to d\pi^+\pi^-$, a) P_n = 2.23 GeV/c, b) P_n = 1.73 GeV/c.

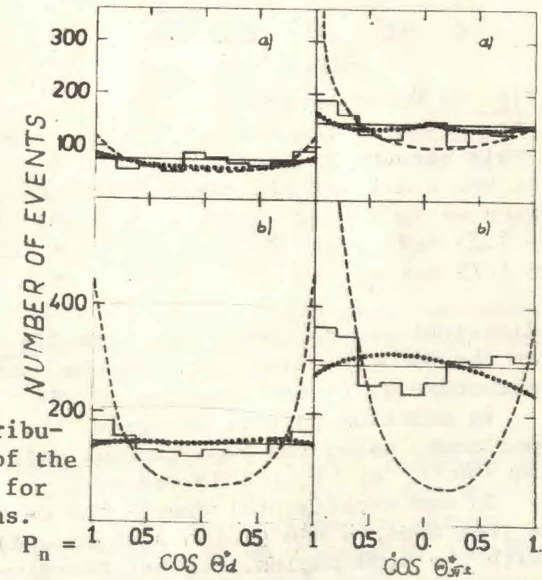


Fig. 5. Angular distributions in the c.m.s. of the reaction $np \to d\pi^+\pi^-$ for deutrons and $\pi^\pm$-mesons. a) P_n = 2.23 GeV/c, b) P_n = 1.73 GeV/c.

the lower ones (b) to P_n = 1.73 GeV/c. The dashed histogram corresponds to the cut-distribution for M_{np} 1.95 GeV/c^2. Figures 7,8 and 9 show respectively the $M(\pi^+\pi^-)$, $P^*_{\pi^\pm}$ and $\cos\theta^*_{\pi^\pm}$

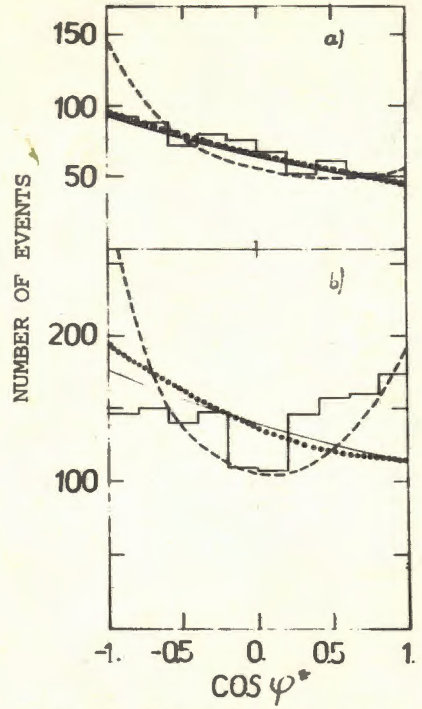


Fig. 6. Distributions over the cosine of the flying angle between π^+ and π^- in the c.m.s. of the reaction $np \to d\pi^+\pi^-$. a) P_n = = 2.23 GeV/c, b) P_n = = 1.73 GeV/c.

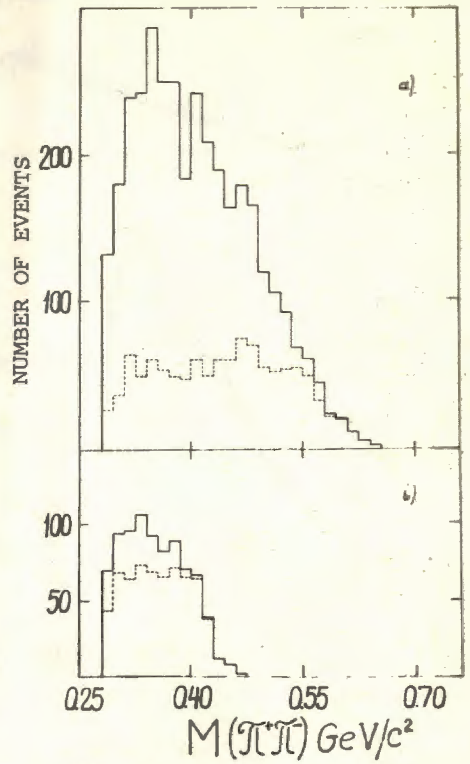


Fig. 7. $M_{\pi^+\pi^-}$ effective mass from the reaction $np \to np\pi^+\pi^-$ a) P_n = = 2.23 GeV/c, b) P_n = = 1.73 GeV/c.

distributions in the c.m.s. From fig. 7 it is seen that in the $M(\pi^+\pi^-)$ distributions one cannot observe a clear structure as in the reaction $np \to d\pi^+\pi^-$.

In addition to this analysis, the modelling has been performed using the experimental material from the reaction $np \to d\pi^+\pi^-$ at P_n = 1.73 GeV/c.

In the experimental events the deuteron was presented as a free neutron and proton with momenta equal to $P_d/2$ and with the same angles. Further two-dimensional plots were constructed of the effective masses ($M_{p\pi^+}, M_{n\pi^-}$) and of the angle cosines in the Jackson's system for $p\pi^+$ and $n\pi^-$ combinations ($\cos\theta^J_{\pi^+}$, $\cos\theta^J_{\pi^-}$). In the modelled events of the reaction $np \to d\pi^+\pi^-$ these characteristics were

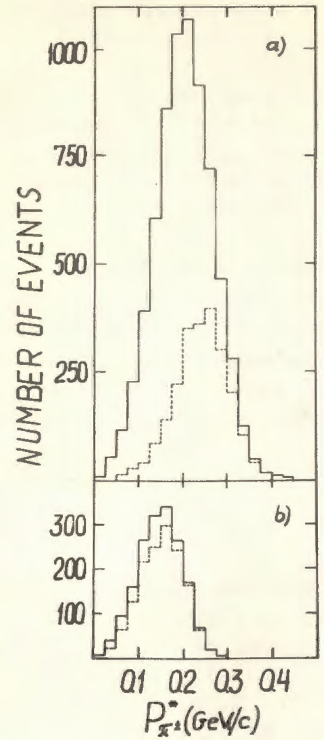


Fig. 8. $\pi^\pm$ -momentum distributions in the c.m.s. of the reaction $np \to np\pi^+\pi^-$. a) P_n = 2.23 GeV/c, b) P_n = = 1.73 GeV/c.

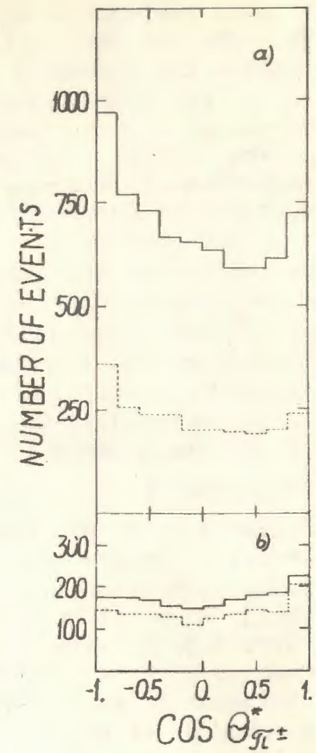


Fig. 9. Angular distributions in the c.m.s. of the reaction $np \to np\pi^+\pi^-$ for $\pi^\pm$ -mesons. a) P_n = 2.23 GeV/c, b) P_n = 1.73 GeV/c.

completely coincident with the experimental ones. In this approach we failed to describe the two-peak structure in the mass spectrum $M(\pi^+\pi^-)$ as well.

3. CONCLUSIONS

The peak near a mass of 0.40 GeV/c^2 is not observed in the reactions $np \to d + (mm)^o$ /13/ at P_n = 1.88 GeV/c and $np \to d\pi^+\pi^-$ /17/ at P_n < 1.83 GeV/c. For the first reaction the missing mass spectrum is preliminary and can be changed by (10-20)%. Moreover, the experimental resolution mass $(mm)^o$ is likely to be insufficient to observe the two anomalies. In the second reaction the absence of the anomaly can be explained by a wide momentum spectrum of incident neutrons, i.e., the position of the ABC-anomaly is shifted with changing momentum P_n . For our data at $P_n = 2.23$ GeV/c it is necessary to increase the number of events.

None of the models studied here describes the bulk of the experimental data from the reaction $np \to d\pi^+\pi^-$. Probably, it is necessary to take into account more exotic effects of the mechanism of this reaction. The $M_{d\pi^\pm}$ effective mass distribution is described in terms of the model taking account of the intermediate reaction $np \to pp\pi^-$.

Thus, a new anomaly has been observed in the $M(\pi^+\pi^-)$ effective mass spectrum for the reaction $np \to d\pi^+\pi^-$ at $P_n = 1.73$ GeV/c. The peak position is at 0.40 GeV/c^2 and its full width is $\Gamma \leq 0.03$ GeV/c^2. The angular distribution in the $(\pi^+\pi^-)$ combination c.m.s. around a mass of 0.40 GeV/c^2 is nearly isotropical which formally does not contradict the set of quantum numbers $I^G(J)^P = 0^+(0^+)$.

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