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NARROW DIPROTON RESONANCES IN THE $np \to pp\pi^-$ REACTION

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In paper[1] we mentioned the class of multiquark resonances (the namber of quarks is more than three) with comparatively smaller effective masses whose widths have been compared with experimental resolution. In following papers[2,3] dealing with six-quark system, a great number of narrow diproton resonances have been shown. Paper[4] made an attempt to systematize them in the model of rotating joint oriented strings (RJOSM).

If a large namber of diproton resonances can be predicted on the basis of QCD[5], then their widths, which are two orders less than those of ordinary hadron resonances, confirm the existence of some prohibition rules whose nature isn't clear yet and they prevent the decay on the strong channel.

Numerous works published since 1983 on the subject of narrow diproton resonances in most cases confirmed the existence of such effects[6,7,8,9,10,11,12,13,14]. However, in some experiments similar phenomena have not been observed[15,16,17].

In the present paper using a large statistical material. we shall show the existence of many narrow diproton resonances with high statistical reliability and estimate real widths of these resonances. The last question is passed over by the authors of all the works performed on this subject.

In the first part we shall consider the reaction $np \rightarrow pp\pi^-$ at P_n = 1.25 Gev/c on the example of which we shall discuss all the methodical questions, concerning the subject. In the second part the total spectra of two protons effective masses from the reaction $np \rightarrow pp\pi^-$ at P_n = 1.43, 1.72 and 2.23 GeV/c will be considered.

1. THE $np \rightarrow pp\pi^-$ REACTION AT P_n = 1.25 GeV/c

The reaction $np \rightarrow pp\pi^-$ at this energy as well as at other energies has been selected by the χ^2-method with 4-degrees of freedom using the data obtained in an exposure of the 1m HBC of the High Energy Laboratory, JINR to monochromatic neutrons from the synchrophasotron of the High Energy Laboratory. The beam spread of the momenta in all the cases is $\Delta P_n / P_n$ = 3%. Figure 1 presents the χ^2-distribution for the hypotheses of

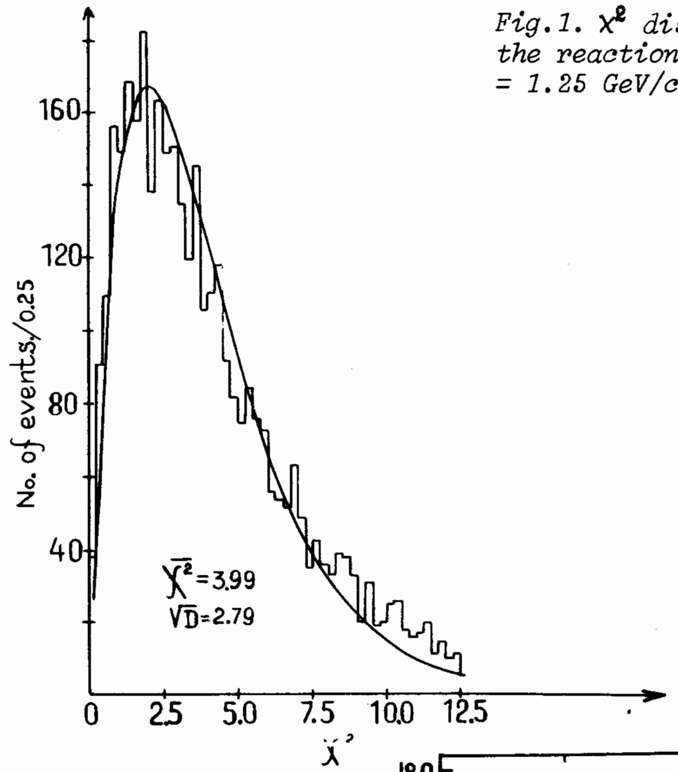
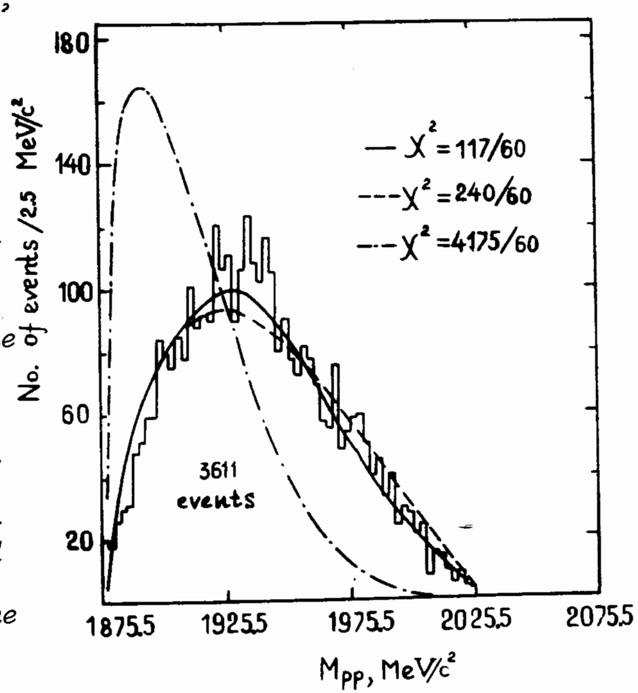


Fig.1. χ^2 *distribution for the reaction* $np \to pp\pi^-$ *at* $P_n =$ *= 1.25 GeV/c.*

Fig.2. The effective mass distribution of two protons from the reaction $np\text{-}pp\pi^-$ *at* $P_n =$ *=1.25 GeV/c (3611 events). Stroke-dotted curve is obtained by the method of mixing up of some protons from different events;the dotted curve is the calculation in the frame of the model of one particle exchange; the solid curve is the modelling of the experiment in the lab.system (MELS).*



the reaction $np\text{-}pp\pi^-$ at P_n = 1.25 GeV/c. The solid line shows the theoretical χ^2-distribution with four degrees of freedom. There is a good agreement of theoretical and experimental distribution. The events with $\chi^2 \le 12.5$ concern the $np\text{-}pp\pi^-$ reaction. In such a way, 3611 events of this reaction have been selected.

The problem of background is one of the main problems on resonance studies. Figure 2 shows the effective mass distribution of two protons binned within 2.5 MeV/c^2 intervals. In the same figure one can see three background curves: a stroke-dotted line shows the backgroung obtained by the method of "mixing" which is usually used by experimentators and lies in the fact that a proton from one event combines with a proton from another event. The two-proton effective mass calculated in such a way is put down in the graphic for back-ground distribution. However, because of strong peripheral reactions[3] in this case there are lots of configurations where protons have close momenta, and angles, and, hence, small effective masses. χ^2 for the description of experimental distribution of such a background curve is equal to 4175 for 60 points, it shows that the given background does not deal with the matter.

The dotted line presents the background calculated on the basis of the model of one particle exchange[3]. The exchanges by π-mesons, nucleons, and Δ-isobars have been taken into account. Non-coherent mixture of 43% pion and 57% Δ-isobar exchange gives the best distribution of experimental data. χ^2 is considerably closer to the average value equal to 60 (χ^2 = 240) for the experiment description. But it is difficult to take into account the contribution of the other diagrams, the interference between them and so on. Besides, some corrections in the calculations of possible distortions brought by experimental material (e.g. lost of events with proton momentum 80 MeV/c and others) should be made.

The third possible backgroung is represented by a solid line - modelling taking into account the experimental distributions in the lab.system.(MELS). In this method a point from the plot P_1 vs P_2 in the lab.system (P_1 and P_2 are the two-proton momenta in the star) is casually confronted with a point on the plot of the angle between the two protons in the lab. system. After calculations the two-proton effective mass is plotted into the background distribution graphic. Background distributions obtained taking into account modelling experimental distributions in the total c.m.s. and in the rest frame system of $\pi^- p$ have been investigated. However, the smallest χ^2 (117 for 60 points), i.e. a background distribution closest to the experiment is obtained by the MELS method.

This conclusion is true for the reaction $np \to pp\pi^-$ at primary neutron momenta 1.43, 1.71 and 2.23 GeV/c.
Later on everywhere a distribution obtained by the MELS is used as a background.

The next question is connected with the shape of the resolution function on masses and, hence, with the shape of the resonance curves used for fitting of experimental data and for the procedure of definition of the real resonance width.

The resolution function is determined as usual:

$$R(\Delta M) = \int \frac{1}{\sqrt{2\pi}\sigma} \exp[-(\Delta M)^2/2\sigma^2] P(\sigma) d\sigma / \int P(\sigma) d\sigma, \qquad (1)$$

where ΔM is the difference between the measured experimental value of the two-proton effective masses and the value of the mass obtained by smearing the measured track parameters, accordingly to the experimental errors. The errors are supposed to have Gauss distributions. σ is the experimental error of the mass.

Figure 3 presents the resolution function in the whole range of the two-proton masses in the reaction $np \to pp\pi^-$ at P_n = = 1.25 GeV/c. The resolution function was described by the Breit-Wigner curve (χ^2 = 72 for 66 points) and by the Gauss one (χ^2 = 162).

One can see that the Breit-Wigner shape well describes the resolution function. This holds for the description of resolution function for different ranges of the two-proton effective masses as well. A change of total widths of resolution functions in the reaction $np \to pp\pi^-$ at P_n = 1.25 GeV/c for various ranges of two-proton effective masses is shown in Fig.4.

It is known that the convolution of the true resonance curve, having the Breit-Wigner shape, with resolution function also having the same shape gives again the Breit-Wigner shape of the experimental resonance curve with $M_{0\,exp} = M_{0\,real}$ and $\Gamma_{exp} = \Gamma_{real} + \Gamma_{res}$. Thus, the fit to the experiments resonance curve should be given in the shape of the Breit-Wigner curves, and the real widths of the resonances could be determined as $\Gamma_{real} = \Gamma_{exp} - \Gamma_{res}$, where Γ_{exp} are the widths of the resonance curves, obtained by fitting the experiment.

Figure 5 presents the effective mass distribution of the two protons from the reaction $np \to pp\pi^-$ at P_n = 1.25 GeV/c.
In this figure the solid line is the experimental description

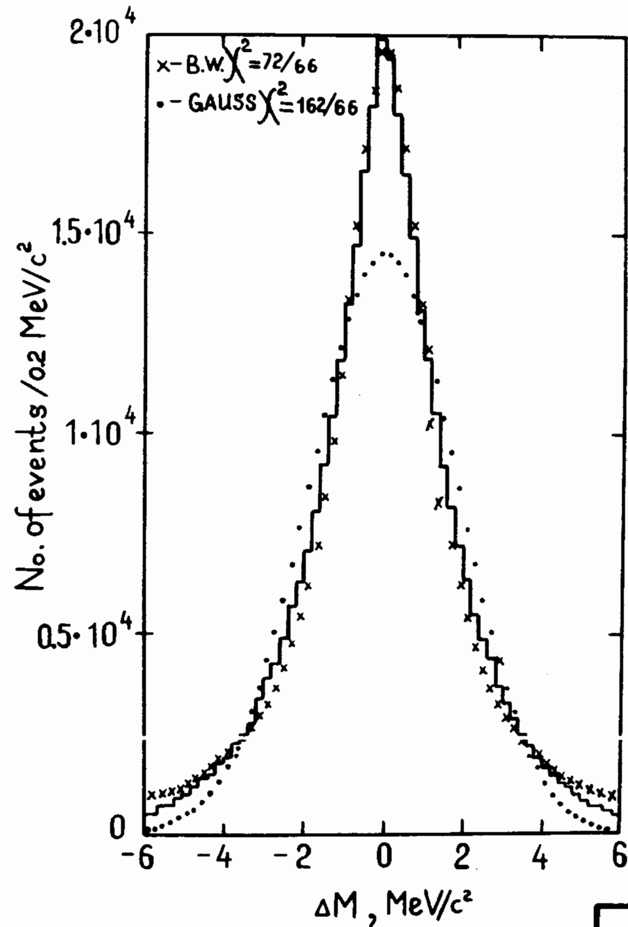


Fig.3. The shape of resolution function on masses over all the diapason of effective masses of two protons in the reaction $np \to pp\pi^-$ at P_n=1.25 Gev/c. The function width on the semiheight is $\langle\Gamma_{res}\rangle$=2.8 MeV/$c^2$.

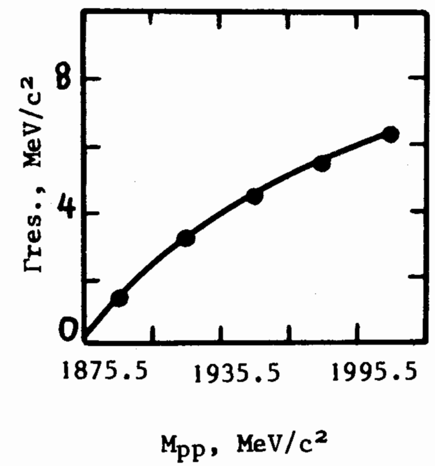


Fig.4.The change of the total width of resolution function depending on the value of the effective mass of two protons in the reaction $np \to pp\pi^-$ at P_n =1.25 GeV/c.

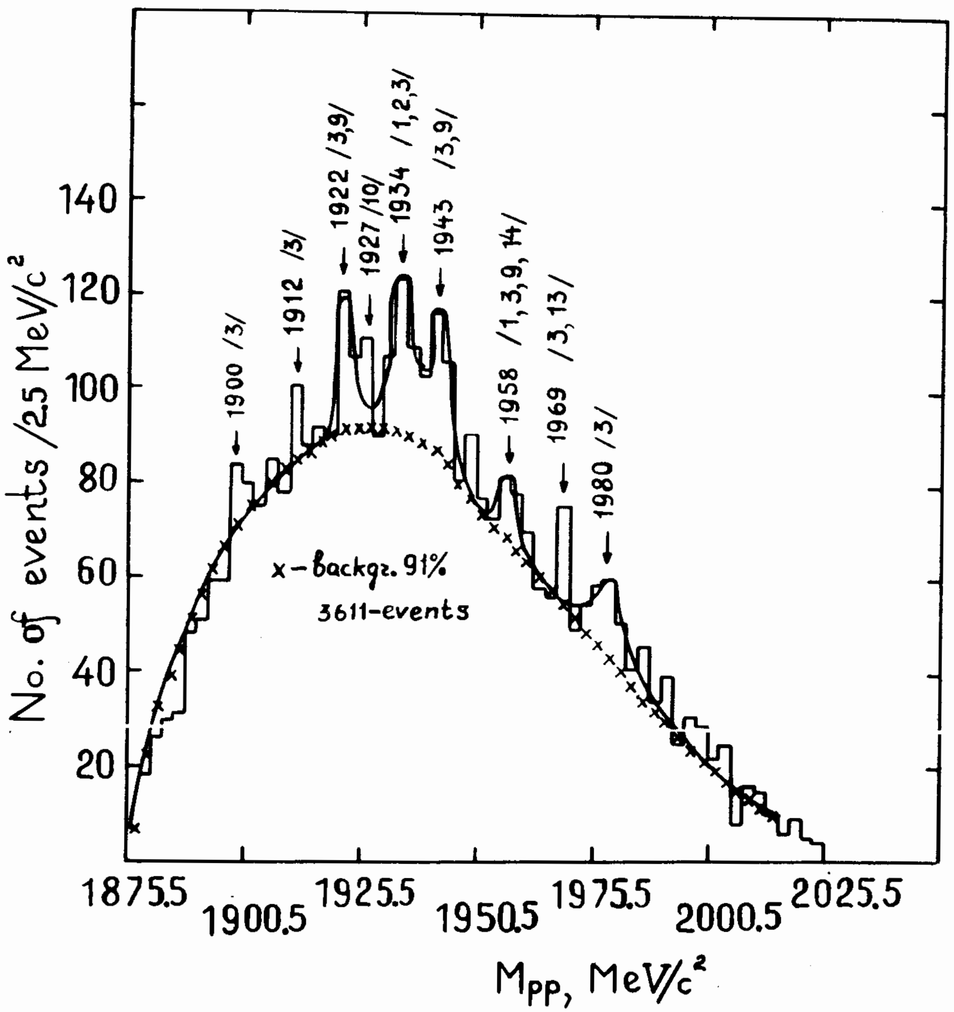


Fig.5 The effective mass distribution of two protons from the reaction $np \to pp\pi^-$ *at* P_n *= 1.25 GeV/c. The solid curve is uncoherent mixture of 5 Breit-Wigner resonance curves and a background curve in the shape of MELS. Crosses are the contribution of the background curve (91%).*

of the noncoherent sum of the fifth resonance curves and a background curve obtained by the MELS method; crosses show the contribution of the background curve left after fitting (91%). χ^2 = 1.3 for the first degree of freedom for the solid line.

Table 1

$M_R \pm \Delta M$	$\Gamma_{exp} \pm \Delta\Gamma$	$\Gamma_R = \Gamma_{exp} - \Gamma_{res}$	$\sigma(\mu b)$	SD	P
1922 ± 1	$4.0 {}^{+1.5}_{-0.5}$	$0.6 {}^{+1.5}_{-0.5}$	15 ± 5	3.2	$3.5 \cdot 10^{-2}$
1934 ± 1	$5.0 {}^{+1.5}_{-1.0}$	$1.0 {}^{+1.5}_{-1.0}$	19 ± 5	3.6	$7.1 \cdot 10^{-3}$
1943 ± 1	$5.0 {}^{+1.5}_{-1.0}$	$0.8 {}^{+1.5}_{-0.8}$	16 ± 5	3.6	$8.1 \cdot 10^{-3}$
1958 ± 1	$4.6 {}^{+3.0}_{-2.0}$	0.0 + 3.0	6 ± 3	2.1	$1.7 \cdot 10^{-1}$
1980 ± 2	$6.0 {}^{+6.0}_{-4.0}$	$0.6 {}^{+6.0}_{-0.6}$	14 ± 4	4.0	$1.3 \cdot 10^{-3}$

All the data obtained are summed up in Table 1: the first column gives the value of resonance masses; the second one, the value of the experimental width obtained by fitting, the third one is the real width of the resonance (all the values at MeV/c); the fourth one, the cross section of resonance production (the cross section of the reaction $np \to pp\pi^-$ at P_n= = 1.25 GeV/c is equal to (0.89 ± 0.15) mb[18]). The fifth coloumn of the Table shows the number of standard deviations from the background; the sixth one, the probability of accidental overshooting of the given effect.

The probability of accidental overshooting is defined by the method devised in[19], where the influence on the effect of all points of distribution in study is taken into consideration.

Figure 5 presents the position of four more bumps with masses of 1903, 1911, 1926 and 1969 MeV/c² observed in papers[3,10,13].

References to the works with peaks at close (within measurement errors) mass values are given by each value.

II. THE $np \to pp\pi^-$ REACTION AT P_n = 1.43, 1.72 AND 2.23 GeV/c

The aim of this part is to prove the existence of a large number of narrow diproton resonances. The events of the reactions $np \to pp\pi^-$ at given momenta of primary neutrons have been selected using the method of χ^2 with four degrees of freedom like in part 1. The total number of events with the reactions $np \to pp\pi^-$ at P_n = 1.43, 1.72 and 2.23 GeV/c is 4847, 4568 and 5521, respectively.

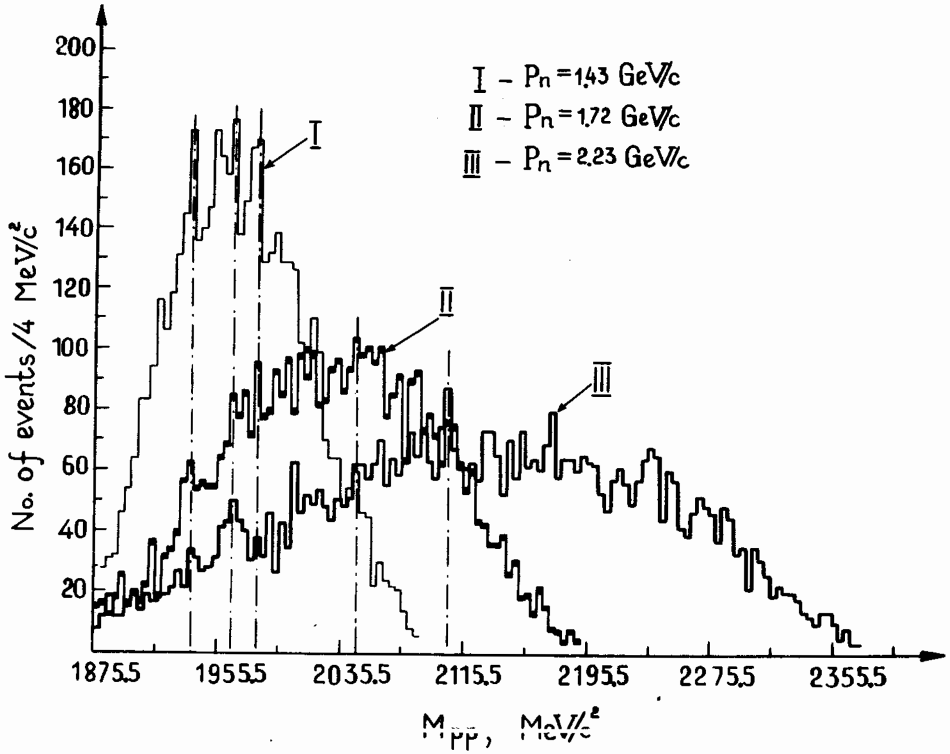


Fig.6. The effective mass distribution of two protons from the reaction $np \to pp\pi^-$ *for* P_n *= 1.43 (histogram I),* P_n *= 1.72 (histogram II),* P_n *= 2.23 (histogtam III).*

Figure 6 presents the effective mass distribution of the two protons separately for each energy. Histogram I is for P_n = 1.43; II, for P_n = 1.72; III, for P_n = 2.23 GeV/c. Several regions of the two proton effective masses, where overshooting at all three energies has been observed are marked by vertical lines. The coincidence effects strongly prove their resonance origin and give a good reason to sum all three distributions.

Figure 7 shows the effective mass distribution of the two protons summed at all three energies. The solid line is a fitting one, constructed from uncoherent mixture of the background curve, obtained by MELS method separately for each energy and summed with the corresponding weight proportional to the number of experimental events at each energy, and 13 resonance

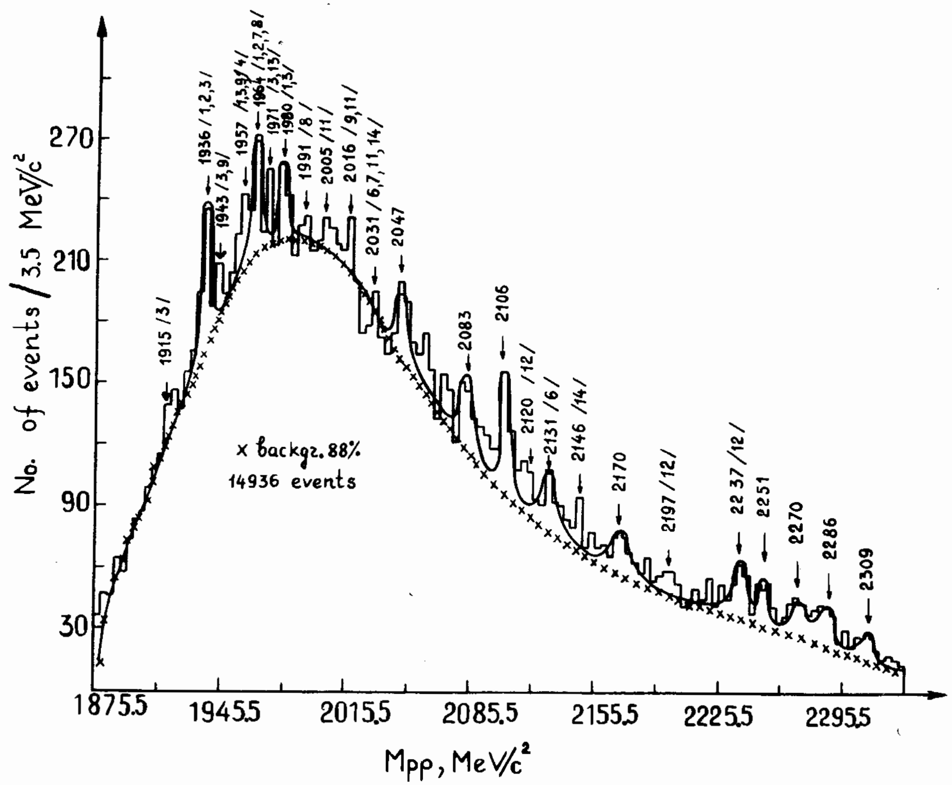
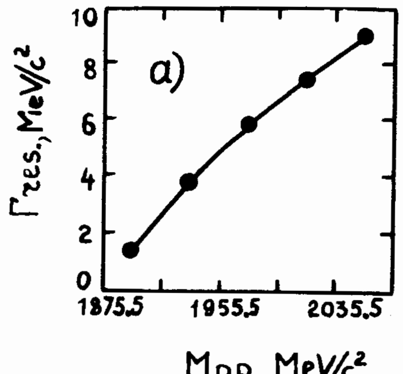


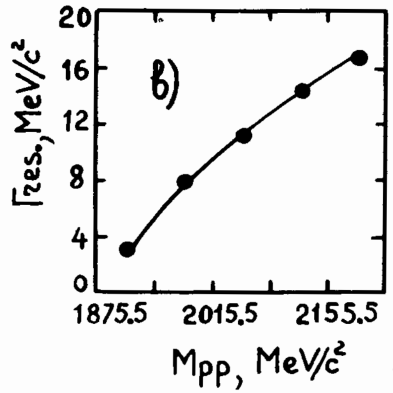
Fig.7. The effective mass distribution of two protons from the reaction $np\text{-}pp\pi^-$ *at* P_n *= 1.43, 1.72 and 2.23 GeV/c (the sum at all energies). The solid curve is a coherent sum of 13 Breit-Wigner resonance curves and a background one in the shape of MELS. Crosses are the contribution of the background curve (86%).*

curves in the Breit-Wigner shape. The background curve left after fitting (its contribution is 88%) is marked by crosses.

The effective mass positions with overshootings are statistically unvaluable in the given distribution and that is why not included into the procedure of fitting, but earlier discussed in other experiments are marked in the graphic too. References to other authors' papers in which overshootings have been observed at similar mass values are indicated over each mass value.

Graphics of changes of resolution function total width depending on the effective mass of the two protons at three





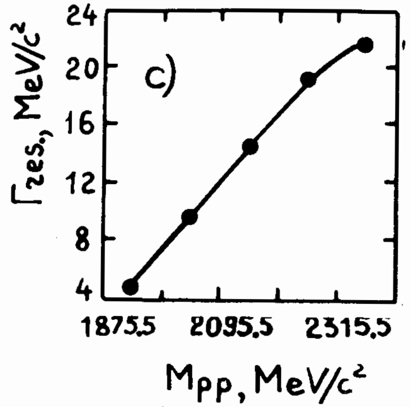


Fig.8. The change of the total width of function resolution depending on the value of the effective masses of two protons in the reaction $np\to pp\pi^-$*: a) for* P_n = =1.43 GeV/c*; b) for* P_n=1.72 GeV/c*; c) for* P_n=2.23 GeV/c.

values of primary neutron momentum are given in Fig.8. Later when determining the real resonance widths the width of resolution function was calculated as a mean value from widths at each energy with weight proportional to the contribution on the number of events in the present mass interval from each energy.

All resolution functions have a shape close to the Breit-Wigher ones, so the procedure of real width determination is the same as in part 1, i.e., $\Gamma_{real} = \Gamma_{exp} - \Gamma_{resolution}$.

The data obtained are summed up in Table II. The marks are the same as in Table I.

CONCLUSIONS

The present paper indicates the existence of a large number of narrow diproton resonances. A wide range of masses (from 1876 to 2300 MeV/c²) has been investigated. The statistical value of the effects observed is rather high, particu-

Table II

$M_R \pm \Delta M$	$\Gamma_{exp} \pm \Delta\Gamma$	$\Gamma_R = \Gamma_{exp} - \Gamma_{res}$	SD	P
1936±1	$7 {}^{+1}_{-1.5}$	$2.6 {}^{+1}_{-1.5}$	5.2	$1.4 \cdot 10^{-5}$
1964±1	$7 {}^{+0.5}_{-1.0}$	$1.0 {}^{+0.5}_{-1.0}$	3.5	$2.0 \cdot 10^{-2}$
1980±1	$7 {}^{+0.5}_{-1.0}$	$0.2 {}^{+0.5}_{-0.2}$	2.7	$2.4 \cdot 10^{-1}$
2047±1	9 ± 2.0	0.0 + 2.0	3.8	$1.1 \cdot 10^{-2}$
2083±2	$14 {}^{+2.5}_{-1.5}$	$1.8 {}^{+2.5}_{-1.5}$	3.7	$1.5 \cdot 10^{-2}$
2106±1	$12.3 {}^{+2.0}_{-1.5}$	0.0 + 2.0	5.8	$9.7 \cdot 10^{-8}$
2130±2	17.0±3.5	$2.0 {}^{+3.5}_{-2.0}$	4.2	$2.3 \cdot 10^{-3}$
2171±2	$16.0 {}^{+5.0}_{-3.5}$	$0.8 {}^{+5.0}_{-0.8}$	4.1	$2.2 \cdot 10^{-3}$
2237±1	$18.0 {}^{+3.0}_{-4.0}$	0.0 + 3.0	5.8	$9.2 \cdot 10^{-7}$
2251±1	$18.0 {}^{+2.0}_{-1.5}$	0.0 + 2.0	3.3	$8.3 \cdot 10^{-2}$
2270±2	$18.0 {}^{+4.0}_{-3.0}$	0.0 + 4.0	3.8	$1.1 \cdot 10^{-2}$
2286±2	21.0±3.0	1.0 + 3.0	5.3	$1.4 \cdot 10^{-5}$
2310±2	21.0±3.5	1.0 + 3.5	3.7	$1.5 \cdot 10^{-2}$

larly if the repetition of effects in different experiments is taken into account and if to multiply the corresponding probabilities of accidental overshootings (e.g., for the resonance with the mass equal to 1935 $P = P_{1,26} \cdot P_{1,43;\,1,72;\,2,23} = 10^{-7}$ as is seen in Tables I and II of the present work).

The total contribution of such resonances to the $np\to pp\pi^-$ reaction is 10% of the energies under study. The resonance widths are of an order of the error in their definition.

Thus, one can think that we deal with new physical phenomenon the nature of which is not clear. The hypothesis relative to the fact that small widths of such resonances could be explained by the production of a state with izotopic spin $\bar{I}$=2 in the intermediate stage of the reaction which then realises narrow resonance γ-transition in the two proton system, is not corrobarated, probably, by the experiments under study [20]. On the other hand, if this hypothesis is true the question should be replaced to the other plane, or else how to explain a large number of such resonances to be in the states with other izotopic spin.

Thereby, it is natural to distort the solving of the problem taking coloured degrees of freedom into consideration. It can give many such states and rules of prohibition of their decay.

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Троян Ю.А. и др. Д1-88-329
Узкие дипротонные резонансы в реакции $np \to pp\pi^-$

Представлены распределения эффективных масс двух протонов из реакции $np \to pp\pi^-$ при P_n = 1,25; 1,43; 1,72 и 2,23 ГэВ/с (всего около 19 тыс. событий). Материал получен с однометровой водородной камеры ЛВЭ ОИЯИ, облученной монохроматическими нейтронами ($\Delta P_n/P_n \approx 3\%$) от синхрофазотрона ЛВЭ. С достаточно высокой статистической достоверностью обнаружены 16 дипротонных резонансов с истинными ширинами порядка 1 МэВ/с^2. Вклад резонансов составляет около 10% при каждой энергии. Исследован диапазон эффективных масс от 1876 до ~ 2300 МэВ/с^2. Резонансные эффекты существуют во всем этом диапазоне.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1988

Troyan Yu.A. et al. D1-88-329
Narrow Diproton Resonances
in the Reaction of $np \to pp\pi^-$

The effective mass distributions of two protons from the reaction $np \to pp\pi^-$ at P_n = 1.25, 1.43, 1,72 and 2.23 GeV/c (about 19000 events) are presented. The data have been obtained in an exposure of the 1m HBC of the High Energy Laboratory, JINR to monochromatic neutrons ($\Delta P_n/P_n \approx 3\%$). Sixteen diproton resonances with the true width of 1 MeV/c^2 are found out using rather high statistics. The effective mass range from 1876 to ~2300 MeV/c^2 has been investigated. Resonance effects are present in the whole range.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1988