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A.B.Kaidalov

# NARROW DIBARYON RESONANCES

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Experimental data indicating [illegible] resonances in pp-system [illegible] possible theoretical interpretations of [illegible] ed. Experimental signatures of the [illegible] I = 2 are considered.

Fig. - 3, ref. [illegible]

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## 1. Experimental situation

A possible existence of dibaryon resonances is widely discussed in recent years. Main experimental and theoretical efforts up to now have been devoted to a study of the broad ( $\Gamma \gtrsim$ 100 MeV) enhancements with masses $M \gtrsim 2.1$ GeV. Recently interesting experimental evidences for narrow dibaryon resonances ( $\Gamma \lesssim$ 20 MeV) at lower masses have been obtained. The most striking results have been obtained in refs. /2,9/ where very narrow structures in pp-mass spectra ( $\Gamma \lesssim 2 \div 5$ MeV) have been observed with masses 1.922, 1.936, 1.962 GeV. These results were obtained in bubble chamber experiments with good resolutions ( $\sim$ 5 MeV). At higher masses extra peaks at $M = 2.025$ GeV and $2.13 \div 2.14$ GeV have been found in refs. /3,6,7,9/ . The resonance at 2.025 GeV was first observed in 1964 /1/ .

The strongest evidence for narrow dibaryon resonances comes from the Dubna group /2/ working at neutron beam. The mass spectrum in pp-system, produced in the reaction

$np \to pp\pi^-$ at $p_n = 1.25$ GeV/c is shown in Fig. 1a). The data show a clear peak at $M_{pp} \approx 1.936$ MeV above a background, which has been calculated in OPE-model and well reproduces other characteristics of the data *) . A probability of the statistical fluctuation $P = 6 \cdot 10^{-6}$. The experimental width of the peak is (6.0 ± 1.4) MeV is consistent with experimental resolution. So the authors of ref. /2/ gave an estimate of the $\Gamma_{res} = |0.7^{+1.0}_{-0.7}|$ MeV. This state is produced mainly in the kimenatics, where $\pi^-$-meson moves in the direction of the initial neutron with $x_\pi = p_\pi/p_n > 0.1$, indicating to the importance of the baryon exchange (fig. 2). The cross section for the production of this state is $\sigma_{res} = (61 \pm 11)\,\mu b$ . This result is in an agreement (taking into account a footnote at page 1) with the results of experiments /4,5,9/ performed with $\pi^-$, p or $A_1$ (different types of nuclei) beams at propane bubble chambers, which observed peaks at $M_{pp} = 1922$ and 1938 MeV **) (fig. 1b,c). The cross sections for production of these states are $\sim 10^{-3}$ of the total reaction cross section. The widths of peaks are very narrow and are consistent with experimental resolutions. For each of the experiments the peaks are more than $4\sigma$ effects. Combination of the

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*) New analysis of the same group, based on improved statistics shows that this maximum actually consists of two peaks, - one at $M_{pp} \approx 1922$ MeV and the other one at $M_{pp} = 1938$ MeV.

**) The center of the peak, seen in ref. /4/ is at M = 1926 MeV, which within the errors agrees with the M = 1922 MeV quoted in ref. /9/ .

results [2,4,5,9] show that the probability of statistical fluctuation is negligible.

At larger energy of n-beam ( $p_n = 2.23$ GeV/c) a new peak at $M_{pp} \approx 1965$ MeV has been observed in the reaction $np \to pp\pi^-$ (fig. 3a). The width of a peak $\Gamma^{exp} = (9.0 \pm 2.0)$ MeV and $\Gamma_{res} = (1.0^{+2.0}_{-1.0})$ MeV. The backgrounds in figs. 2b),c) are calculated in OPE-model. The cross section $\sigma_{res} = (48 \pm 14)$ $\mu b$. This observation is confirmed by the data on the reaction $np \to pp\pi^+\pi^-\pi^-\pi^0$ at $p_n = 5.1$ GeV/c [2] (fig.3b) and the data on $\pi^- {}^{12}C \to ppX$ [6] (fig. 3c). A probability of statistical fluctuation from the data on two np-reactions is estimated to be $P \approx 2\cdot 10^{-7}$ [2]. Experimental cuts on two slow protons, observed in $\pi(p)\,C$ -interactions, , which select protons moving in opposite directions in laboratory frame, allows one to better investigate a high mass ($M_{pp} > 2$ GeV) tail of the distribution. In this way a strong evidence for a resonance in pp-system with $M \approx 2025$ MeV has been obtained in refs. [6,9] (fig. 3c). This agrees with the results of other experimental groups [3,7]. A possible width of this resonance $\approx$ 20 MeV.

Thus a strong experimental evidence exist that there are at least four (pp)-resonances with $M_{pp} < 2.1$ GeV, which have small widths $\Gamma_i \lesssim 10$ MeV.

## II. Possible interpretation of narrow dibaryon resonances

Existence of the low-mass dibaryon resonances, discussed in the previous section leads to several problems:

a) Why such resonances have not been observed in pp and np-scattering, where extensive data and phase shift analysis exist ?

b) Why these states are so narrow ?

c) What is the dynamical mechanism, which leads to such low-mass dibaryons ?

Note that in the standard bag models the dibaryon resonances are usually very broad and have masses $M \gtrsim 2.1$ GeV. A possible answer to the first question is that the resonances are so narrow ($\Gamma_i \lesssim 2 \div 5$ MeV) that they could have a chance to be observed only in experiments, where the steps in initial energy are very small. Most of the existing measurements do not satisfy to this condition.

The second question is more difficult. Small widths of these resonances indicate that there is some dynamical suppression for the decay of these states into two protons.

One of the possibilities that this suppression is due to the isotopic spin $I$ conservation in strong interactions. For example let us assume that narrow states have $I=2$ *) . Such states exist in 6 quark-systems (for example $N\Delta$ - bound state with $I=2$). Than the decay $X_{I=2} \to pp$ is forbidden by isospin conservation and is mediated by electromagnetic interaction. The decay $X_{I=2} \to NN\pi$ is allowed isotopically, but is forbidden kinematically for the states with $M < 2m_N + m_\pi$ . Such resonances have very small widths ( $\Gamma \lesssim 1$ keV, - see below) and would not be observed in elastic NN-scattering. On the other hand they are easily

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*) Such a possibility has been also mentioned by A.M.Baldin.

produced in inelastic reactions, by the mechanism shown in fig. 2 with $\Delta$ -exchange. Thus this hypothesis gives a natural explanation to the experimental observations /2/ .

There are no experimental information on the quantum numbers $J^P$ of the narrow resonances yet. The only limitations on $J^P$ comes from the observation of their decay into pp-system. So the following set of quantum numbers is possible: $0^+(^1S_0)$, $0^-(^3P_0)$, $1^-(^3P_1)$, $2^-(^3P_2)$, $2^+(^1D_2)$,... The $N\Delta$ - $S$ -wave bound state can have $1^+$ or $2^+$-quantum numbers and only $2^+$ state can decay into pp-system. In the following, for sake of definiteness, I shall consider the $J^P = 2^+$ quantum numbers for the resonance $X$ .

Let us estimate partial widths of $X_{++}$ resonance. It can decay into pp (with amplitude $T \sim \alpha$ ), into $pp\gamma$ -state ( $T \sim \sqrt{\alpha}$ ) and $ppe^+e^-$ ($T \sim \alpha$ ). The last channel $ppe^+e^-$ has a very small branching ratio, while the first two are of the same order of magnitude, because the pp-channel has smaller amplitude then $pp\gamma$ -channel, but larger phase space factor. It is possible to calculate the amplitudes for these decay channels, using the diagrams, shown in fig. 4. The verticies $X \to \Delta p$ , $\Delta \to p\gamma$ ,which enter into the diagrams of fig. 4 can be written in the form

$$V_{X\to\Delta p} = G\, X_{ik}\, \mathcal{X}_i^{\Delta} \sigma_k \varphi^{p} \tag{1}$$

$$V_{\Delta\to p\gamma} = e\, C\, \varepsilon_{ik\ell}\, \mathcal{X}_i^{\Delta} \varphi^{p} e_k^{\gamma} k_\ell^{\gamma}$$

The constant $C$ can be determined from the experimental data on $\Delta \to p\gamma$-decay and is equal to $C^2/4\pi \approx 1.85$. The dimensionless quantity $f \cong G^2/4\pi M_X^2 \sim 1$ is unknown and will be considered as a free parameter.

The partial width of the pp and pp$\gamma$ -decay channels, calculated, using the diagrams of fig. 4 have theform

$$\Gamma_{X\to pp} \simeq \frac{\alpha^2 f C^2}{5\cdot 27}\,\frac{p^5}{M_X^2 m_N^2}$$

$$\Gamma_{X\to pp\gamma} = \frac{3\alpha f C^2}{5\cdot 4\pi}\,\frac{\omega_{max}^4 \widetilde{K}_p}{[(m_N+\omega_{max})^2 - m_\Delta^2]^2} \tag{2}$$

where p is the momentum of protons in the $X\to pp$ decay and $\omega_{max}$ is the maximum energy of the photon in the pp$\gamma$ -decay. For a $X$ state with the mass 1936 MeV $\Gamma_{X\to pp\gamma} \simeq 0.1$ keV$\cdot f$ and $\Gamma_{X\to pp} \simeq 0.15$ keV $f$ . So the characteristic width of such a state (0.1 + 1) keV and the branching ratio $\Gamma(X\to pp\gamma)/\Gamma(tot) \simeq 40\%$. This can serve as a definite signature for such a state. If there are several states with I=2 then the cascade transitions from higher to lower states with $\gamma$ -emission can exist. These transitions would lead to a monochromatic $\gamma$ -lines. The experimental search for the low energy direct photons, associated with dibaryon resonances is carried out in Dubna now. First attempt to look for such photons /2/ indicates to a possible resonance structure in the pp$\gamma$ -mass spectrum (fig. 5) at 1936 MeV.

For a dibaryonic state with I=2 there should be five members of the isomultiplet with electric charges Q =-1, 0,1, 2, 3. The states with Q=-1 and +3 and $M<2m_N+m_\pi$ could not decay strongly or electromagnetically and have only weak decays

$$X_- \to n n e^- \bar{\nu}$$
$$X_{+++} \to p p e^+ \nu \qquad (3)$$

The lifetime for such decays is estimated to be $\sim 10^{-3} \div 10^{-5}$ sec. Thus such states live long enough and can be produced in interactions of hadrons with proton and nuclei (figs. 6,7). It follows from isospin invariance that

$$\sigma_{np\to\pi^- X^{++}} / \sigma_{pp\to\pi^- X^{+++}} = \frac{1}{2} \qquad (4)$$

So the cross section of the $X^{+++}$ production in pp collisions at energies $p_L = (1\div5)$ GeV is of order of $10\,\mu b$.

Strong experimental limit on the production cross section of the states with $Q = -1$ and $M \sim 2$ GeV, $\tau > 10^{-8}$ sec. has been obtained in ref. /11/ – $\frac{d^2\sigma}{dp\,d\Omega} < 10^{-42}\,\frac{sm^2}{MeV\cdot sr}$.

Thus the interpretation of the narrow resonances as states with isotopic spin $I = 2$ seems to be in contradiction with the experimental result obtained in ref. /11/.

Another possibility to explain the narrow width of resonances is to assume that they have such quantum numbers that they decay into pp system with large angular momentum l. For example the 5 -wave $N\Delta$ bound state, discussed above (but now with $I = 1$) decays into pp-system in D-wave and has a strong centrifugal barrier. The vertex for such a decay has the form

$$V_{X\to pp} = \frac{g}{m_p} X_{ik}\, p_i\, p_k\, \varphi_1 \cdot \varphi_2 \qquad (5)$$

A natural value of the width for a state with M = 1936 MeV ( $p \simeq$ 240 MeV) is ~ 1 MeV (for $g^2/4\pi$ = 1 ÷ 10). So the centrifugal suppression of the decay for high partial waves can lead to widths of the states with M $\lesssim$ 2 GeV $\Gamma_i \lesssim$ 10 MeV.

An important question - whether 6-quark resonances with such small masses can exist has no definite answer up to now. The stretched bags or molecular type 6-quark configuration (analogs of deuteron) can in principle have masses smaller than the states of a spherical bag.

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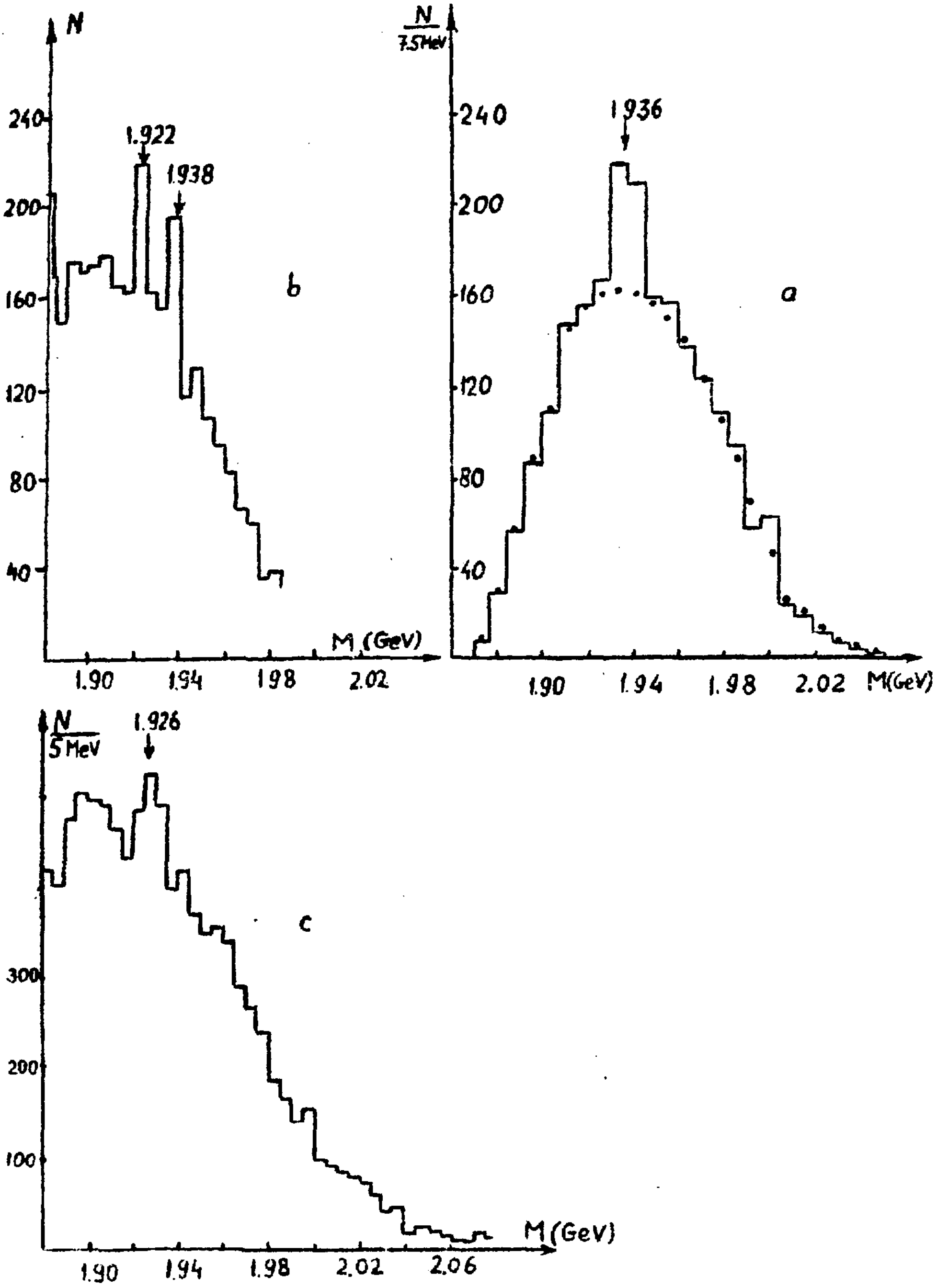


Fig. 1. a) Distribution on the pp-mass in the reaction $np \to pp\pi^-$ at $P_n$ = 1.25 GeV/c /2/, b) same for $\pi^- C$ and $pC$ interactions at different energies /9/, c) same for $\pi^- C$, $AC$ /4/

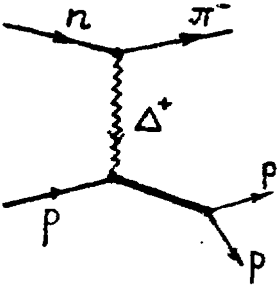


Fig. 2. The $\Delta$ -exchange diagram for $X_{++}$ production in the reaction $np \rightarrow pp\pi^-$

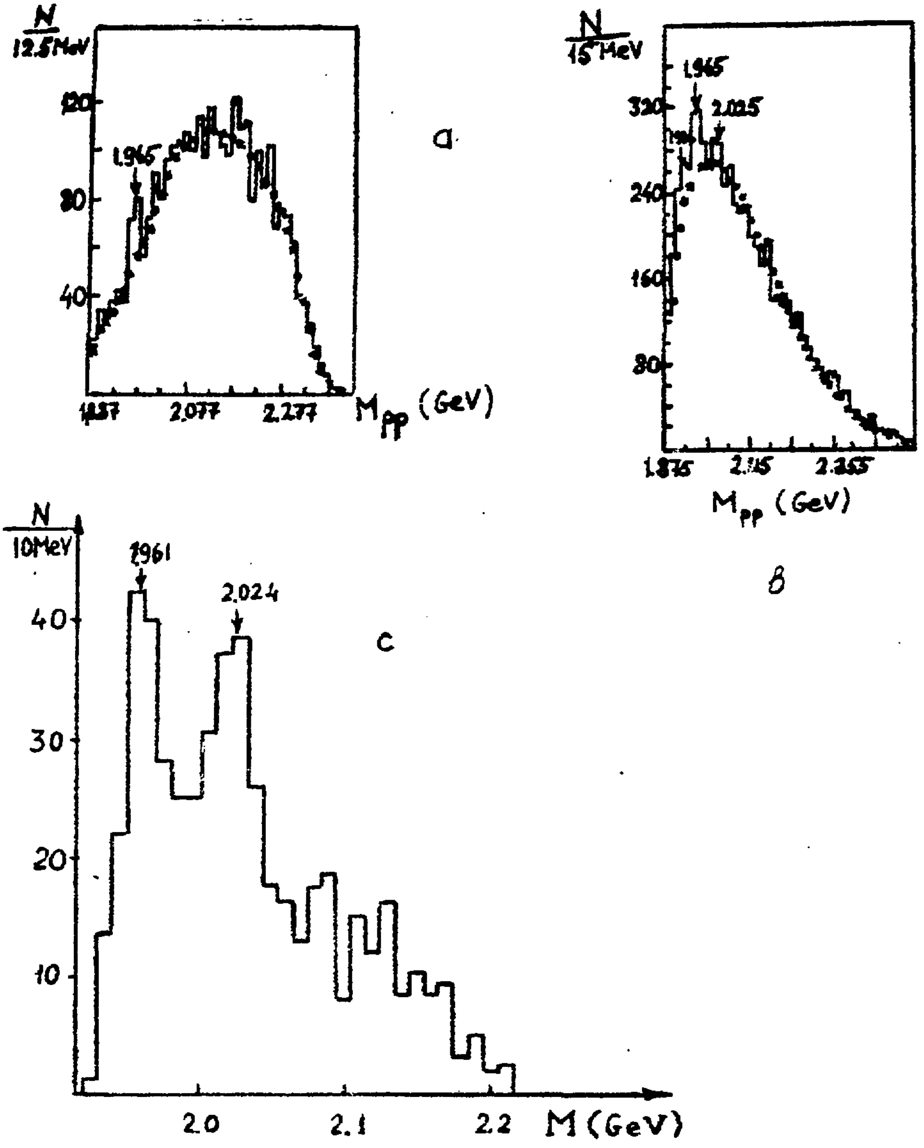


Fig. 3. a) $pp$ – mass distribution in the reaction $np \to pp\pi^-$ at $p_n$ = 2.23 GeV/c and $np \to pp\pi^+\pi^-\pi\pi^0$ at $p_n$ = 5.1 GeV/c /2/ – b): c) same for $\pi^-C$ interaction /6/.

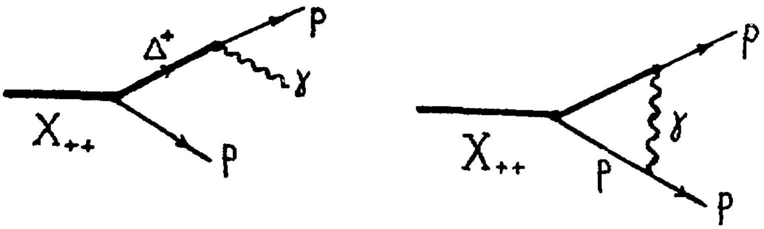


Fig. 4. Diagrams for decays $X_{++} \to pp\gamma$ and $X_{++} \to pp$

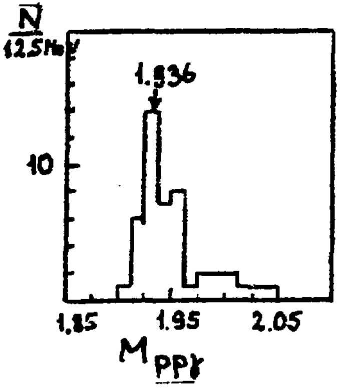


Fig. 5. $pp\gamma$ - mass distribution in $\pi^- C$ interactions ($10 < \varepsilon_\gamma < 50$ MeV) /2/

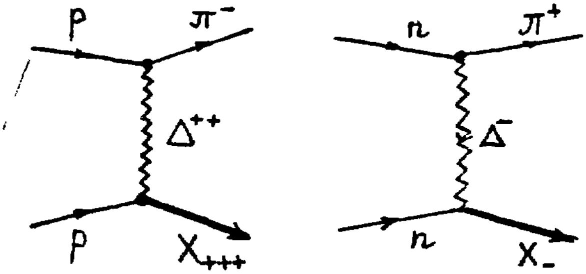
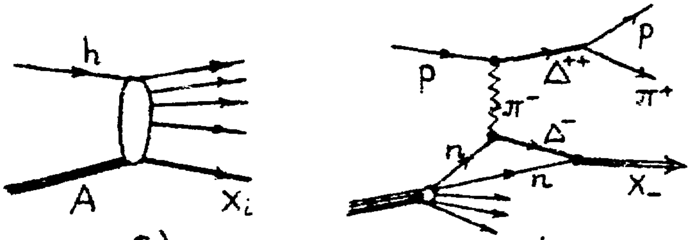


Fig. 6. Diagrams for $X_{+++}$ and $X_-$ production



a) b)

Fig. 7. Diagrams for $X$ -states production in hadron-nuclei interactions.

# REFERENCES

[illegible] V.S. et al. M., Preprint ITEP, 1984, N 77.

[illegible] K. et al. Dubna, Preprint JINR D1-83-815; [illegible] JINR D1-85-433, Dubna, 1985.

[illegible] V. et al. Dubna, Preprint JINR E1-83-59, 1983.

[illegible] M.N. et al. Dubna, Preprint JINR E1-84-492; [illegible] E1-84-448.

[illegible] Warsaw-Dubna-... - Yad.Fiz., 1984, 40, p.482.

[illegible] A.A. et al. - Yad.Fiz., 1984, 39, p.44.

[illegible] P. et al. - Phys.Lett., 1984, 128B, 397.

[illegible] A.S. et al. - Nucl.Phys., 1976, A274, [illegible]

[illegible] V.A. et al. - Yad.Fiz., 1985, 42, p.913.

[illegible] V.V. et al. Preprint LIYF, 1985, N 1083.

[illegible] M. et al. - Phys.Rev.Lett., 1984, 53, 421.

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