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AN EVIDENCE FOR THE BARYON RESONANCE WITH ISOTOPIC SPIN 5/2 IN n-p INTERACTIONS AT ENERGIES OF 4 ÷ 5 GeV

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In 1964 S.Goldhaber reported on the observation of the anomaly in the effective mass spectrum of $p\pi^+\pi^+$ combinations from the reaction $\pi^+ p \to p\pi^+\pi^+\pi^-$ at $P_{\pi^+} = 3.65$ GeV/c. The anomaly had a mass of 1560 MeV/c ^{2} and a width of about 200 MeV/c ^{2}. The baryon resonance with such a decay mode must be an exotic state with isotopic spin I = 5/2 that may be constructed using four quarks and one anti-quark /1/.

The search for exotic baryon resonances with isotopic spin I = 5/2 has been described in a number of experimental articles/2/. Results are the following: firstly, the effect observed by Goldhaber may be explained by the kinematical reflection on the joint production of Δ_{33} - resonance and ρ°-meson, and, secondly, the existence of baryon resonance with isotopic spin I = 5/2 has not been rather well established experimentally.

In the present paper we study the reaction

$$np \to p\pi^+\pi^+\pi^-\pi^- n \qquad (1)$$

at three incident neutron momenta (5.10 $\pm$ 0.17), (4.35 $\pm$ 0.16) and (3.83 $\pm$ 0.15) GeV/c.

The events of the reaction (1) were registered on the films obtained in an exposure of the 1-m hydrogen bubble chamber to monochromatic neutron beams produced by the Dubna synchrophasotron /3/.

1249, 785 and 77 events of the reaction (1) were selected at the three above-mentioned neutron momenta, respectively. The cross sections of the reaction (1) were obtained using our topological cross sections /4/ and were equal to (0.49 $\pm$ 0.04), (0.26 $\pm$ 0.02) and (0.12 $\pm$ 0.01) mb. The events of the reaction (1) were selected from 5-prong stars of n-p interactions using χ^2-procedure, missing mass analysis, particle identification according to visible ionization, particle range and $\pi \to \mu \to e$ decay and some consequences of the isotopic symmetry of n-p interactions /5/.

The quality of the data obtained is characterized by missing mass squared distributions at the three incident neutron momenta for the reaction (1) (Fig.1). The distributions are symmetrical near the value of neutron mass (pointed).

Figure 2 shows the angular distributions of protons, neutrons, π^+ and π^- mesons in the CMS of the reaction (1). The left scale is for nucleons and the right scale is for mesons in this figure.

The asymmetry coefficients $\alpha = (N_f - N_b)/(N_f + N_b)$ are calculated for these distributions, where N_f is the number of events flying in the forward hemisphere in the CMS and N_b, in the backward hemisphere. The values of the asymmetry coefficients are shown in Table 1.

Table 1

P_n, GeV/c	5.10	4.35	3.83
Protons	-0.11 ± 0.04	-0.05 ± 0.05	-0.12 ± 0.16
Neutrons	0.09 ± 0.04	0.05 ± 0.05	0.14 ± 0.16
π^+ -mesons	-0.07 ± 0.03	-0.06 ± 0.04	-0.04 ± 0.16
π^- -mesons	0.08 ± 0.03	0.08 ± 0.04	0.07 ± 0.16

It is seen that for all three incident neutron momenta the coefficients for isotopic conjugated particles coincide in module and are opposite in sign within the errors as needed for the isotopic symmetry of the reaction (1).

The analysis of the two-dimensional plot of $M_{p\pi^+}$ vs $M_{n\pi^-}$ shows that the reaction (1) proceeds via the subreactions:

$$np \to p\pi^+\pi^+\pi^-\pi^- n \qquad (1a)$$

$$\to \Delta^{++}\pi^+\pi^-\pi^- n \qquad (1b)$$

$$\to p\pi^+\pi^+\pi^-\Delta^- \qquad (1c)$$

$$\to \Delta^{++}\pi^+\pi^-\Delta^- . \qquad (1d)$$

The percentage of each subreaction is shown in Table 2 for three values of incident neutron momenta.

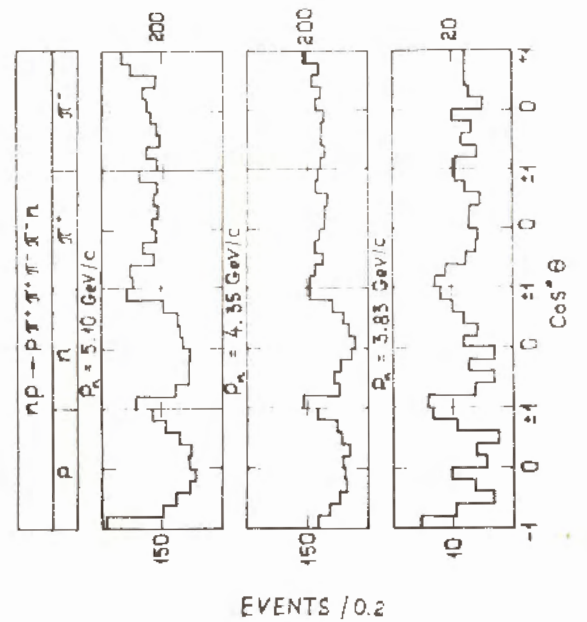


Fig.2. Particle angular distributions in the rest system of the reaction $np \to p\pi^+\pi^+\pi^-\pi^- n$.

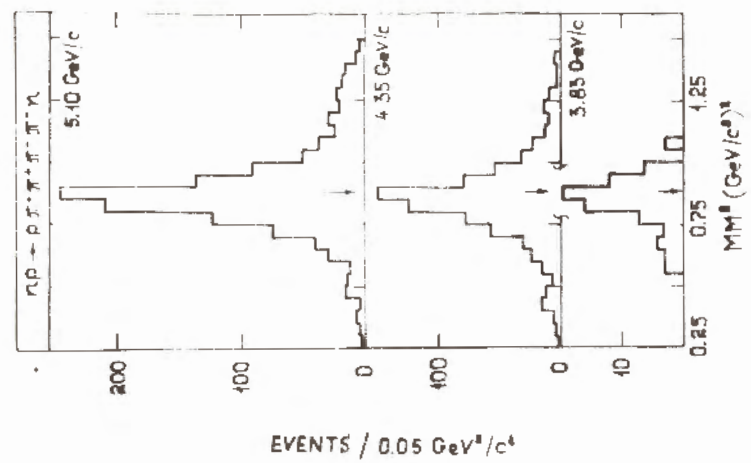


Fig.1. Missing mass distributions squared for the reaction $np \to p\pi^+\pi^+\pi^-\pi^- n$.

Table 2

Reaction \ P_n, GeV/c	5.10	4.35	3.83
$np \to p\pi^+\pi^+\pi^-\pi^-n$	16 ± 2	30 ± 3	30 ± 12
$\Delta^{++}\pi^+\pi^-\pi^-n$	37 ± 3	18 ± 3	25 ± 10
$p\pi^+\pi^+\pi^-\Delta^-$	37 ± 3	18 ± 3	25 ± 10
$\Delta^{++}\pi^+\pi^-\Delta^-$	10 ± 2	34 ± 3	20 ± 9

The approximation of the two-dimensional plot was carried out by means of subreactions (1a - 1d). Each of them was modelled for corresponding phase space using the program FOWL. The Δ-resonance was described by the Breight-Wigner distribution with M_Δ = 1232 MeV/c^2 and Γ_Δ = 110 MeV/c^2. Each subreaction with corresponding weight (see Table 2) was then used to describe the one-dimensional effective mass distributions $M_{p\pi^+}$ (added to $M_{n\pi^-}$), $M_{p\pi^-}$ (added to $M_{n\pi^+}$) (Fig.3), and $M_{\pi^+\pi^-}$ (Fig.4). It is seen that description of all these distributions (solid line) is satisfactory, i.e., subreactions (1a - 1d) modelled in this manner are sufficient to describe the effective mass distributions of various particle combinations.

Note that ρ^0-meson is not seen in the experimental effective mass distributions $M_{\pi^+\pi^-}$.

Figure 5 shows the effective mass distributions of $p\pi^+\pi^+$ (added to $n\pi^-\pi^-$) combinations. The $M_{p\pi^+\pi^+}$ and $M_{n\pi^-\pi^-}$ distributions are in coincidence within the errors (not shown, see [6]). The solid curves are the background obtained from subreactions (1a - 1d); each of them is taken with its own weight. It is very interesting to pay attention to the anomaly at 1420 MeV/c^2 that looks as an excess over the background at all energies of incident neutrons.

Figure 6 shows the effective mass distributions of combinations when the histogram includes only the events for which the effective masses of protons (neutrons) and even though one $\pi^+(\pi^-)$ from two $\pi^+(\pi^-)$ are within $1160 \le M_{p\pi^+(n\pi^-)} \le 1300$ MeV/c^2, i.e., within the Δ-resonance range.

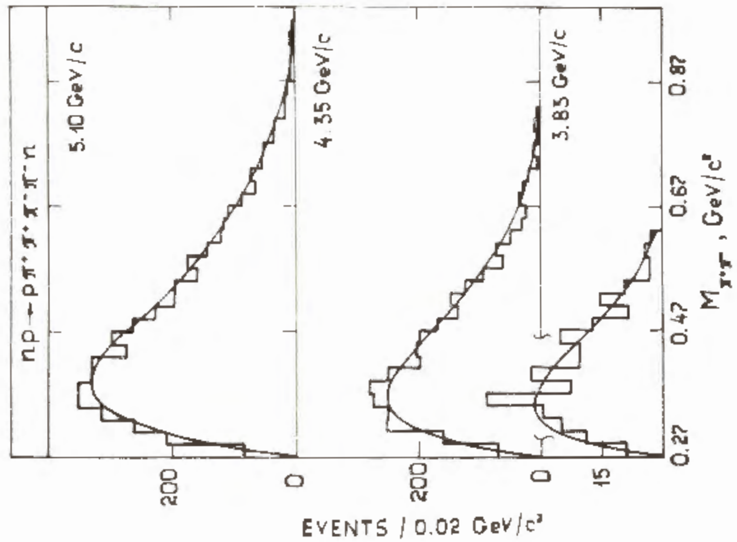


Fig.4. Effective mass distributions of $\pi^+\pi^-$-combinations.

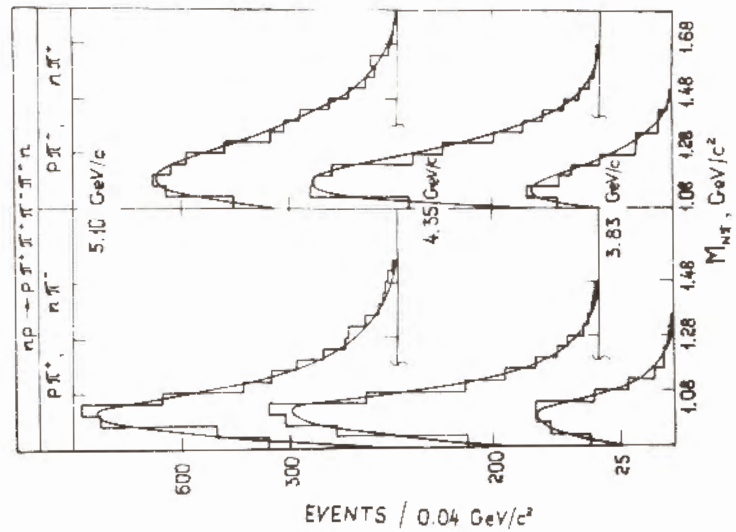


Fig.3. Effective mass distributions of $N\pi$-combinations.

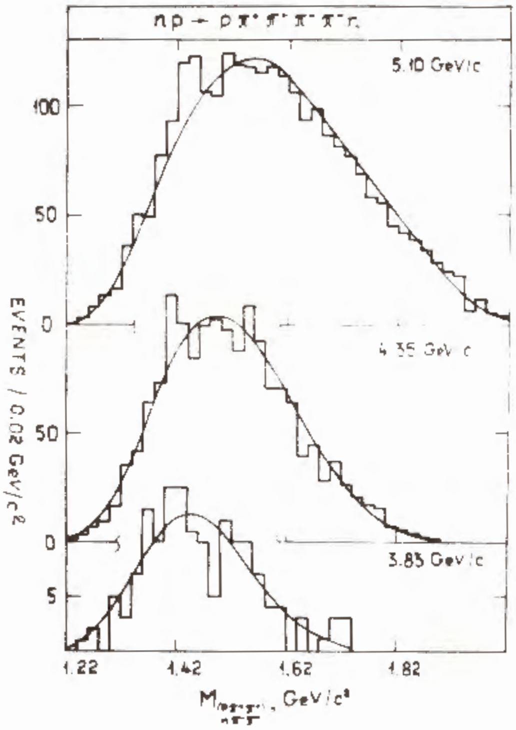
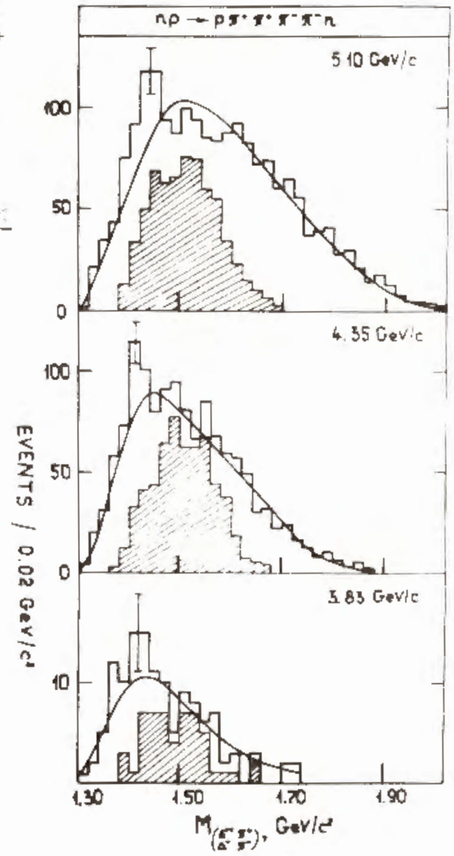


Fig.5. Effective mass distributions of $p\pi^+\pi^+$ (added with $n\pi^-\pi^-$) combinations.

Fig.6. Effective mass distributions of $p\pi^+\pi^+$ ($n\pi^-\pi^-$) combinations with the effective mass of proton (neutron) and even though one $\pi^+(\pi^-)$-meson within $1160 \leq M_{p\pi^+(n\pi^-)} \leq 1300$ MeV/c^2.



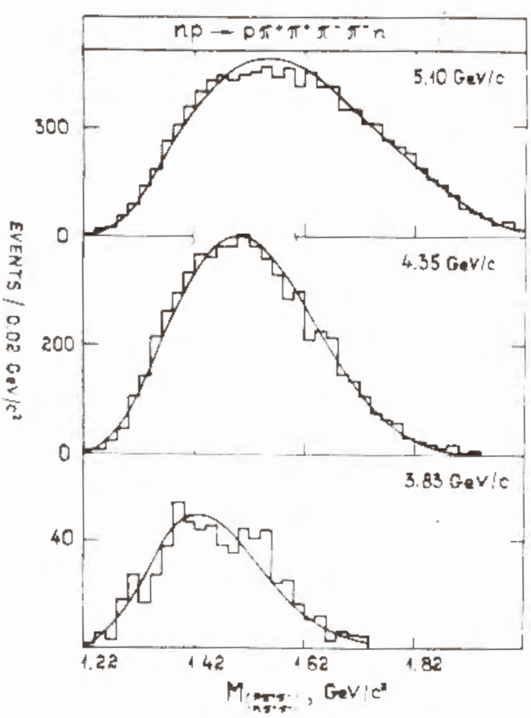
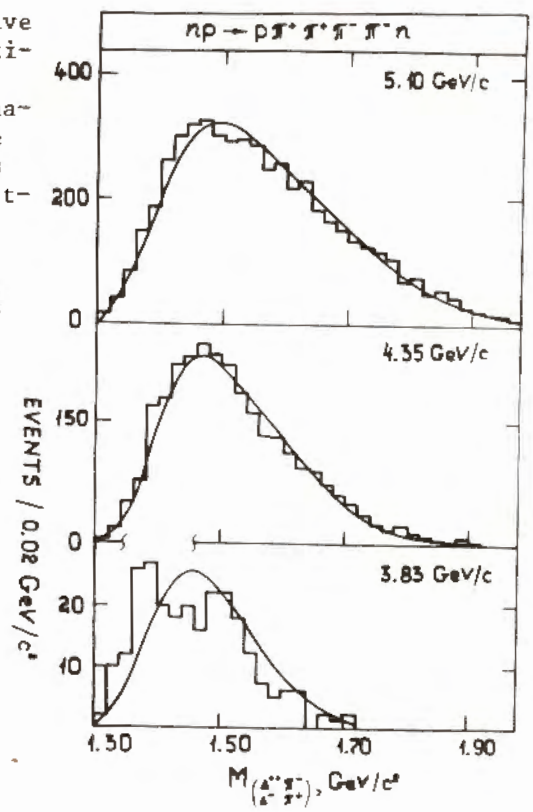


Fig.7. Effective mass distributions of $p\pi^+\pi^-$ (added to $n\pi^+\pi^-$) combinations.

Fig.8. Effective mass distributions of $p\pi^+\pi^-$ ($n\pi^+\pi^-$) combinations with the effective mass of proton (neutron) and even though $\pi^+(\pi^-)$ meson within $1160 \leq M_{p\pi^+(n\pi^-)} \leq 1300$ MeV/c^2.



The background curves are plotted again for subreactions (1a - 1d) only with the events for which the effective mass of nucleon and even though π-meson is within $1160 \le M \le 1300$ MeV/c^2, i.e., in the same manner as for the experiment. The events with nucleon from Λ-decay (e.g., in subreaction (1b)) and with π-meson not from Δ-decay, which have the effective mass within the above limit, are also taken into account. Using these limitations on $M_{p\pi^+(n\pi^-)}$, the effect increases at a mass of 1420 MeV/c^2 because the number of experimental events does not vary in this region and the background decreases.

The events with the effective mass of proton (neutron) and both $\pi^+(\pi^-)$-mesons within the Δ-resonance region are shaded in fig.6. This leads to limitations on the effective mass of $p\pi^+\pi^+(n\pi^-\pi^-)$ combinations and could imitate a peak in some effective mass region. One can see that these events are outside the observed anomaly.

The effective mass distributions of $p\pi^+\pi^-$ (added to $n\pi^+\pi^-$) combinations are shown in fig.7. The solid curves are the background from the subreactions (1a - 1d). One can see no noticeable generation of resonances the decay of which may somehow imitate the effect observed in $p\pi^+\pi^+(n\pi^-\pi^-)$ combinations.

Figure 8 shows the effective mass distributions of $p\pi^+\pi^-$ $(n\pi^+\pi^-)$ combinations with the effective mass of proton (neutron) and $\pi^+(\pi^-)$-meson within the Δ-resonance range. No significant peak can be observed near a mass of 1420 MeV/c^2.

Thus, one can conclude from our data that the effect observed in the effective mass distribution of $p\pi^+\pi^+(n\pi^-\pi^-)$ combinations is not a kinematical imitation of the considered phenomena such as ρ^0-meson generation, the production, of heavier resonances with decay mode $\Delta^{++}\pi^-(\Delta^-\pi^+)$, some kinematical limitations. If we deal with a new resonance, then the most probable mode of its decay is likely to be $N^*_{5/2} \to \Delta_{3/2} + \pi$.

In 1978 A.B.Kaidalov and A.A.Grigorian [7] published the theoretical article devoted to the investigation of the SSR for reggeon-particle scattering. It is shown that the saturation of equations obtained needs the existence of the whole sequence of resonances with increasing isotopic spins I, spins J = I and decay mode $(I,J) \to (I-1, J-1) + \pi$. The masses of these resonances are not very high, and the widths are about some tens of MeV/c^2.

To estimate the spin of the probable resonance, the angular distribution of protons (neutrons) was constructed in the rest system of the $\Delta^{++}(\Delta^-)$ resonance included in $N^{*+++}(N^{*--})$ relative to the direction of $\Delta^{++}(\Delta^-)$ in the new resonance rest system (fig.9). The events were chosen from the range of the

effective masses of $p\pi^+\pi^+(n\pi^-\pi^-)$ combinations 1420÷1460 MeV/c^2 at P_0 = 5.10 GeV/c and 1400÷1440 MeV/c^2 at P_0 = 4.35 and 3.83 GeV/c. The distributions are similar to isotropic ones at all momenta that is an evidence for the spin of $N^{*+++} > 1/2$.

V.L.Lyuboshitz has obtained a number of isotopic correlations [8] for observation probabilities of various projections of isotopic spin I = 5/2 in different reactions. For reaction (1) it is shown that the probability to observe the resonance decay through the modes $p\pi^+\pi^-(n\pi^+\pi^-)$ and $p\pi^-\pi^-(n\pi^+\pi^+)$ is considerably less than through the mode $p\pi^+\pi^+(n\pi^-\pi^-)$.

Figure 10 shows the effective mass distribution of $p\pi^-\pi^-$ $(n\pi^+\pi^+)$ combinations for reaction (1). No noticeable effect

Table 3

P_n, GeV/c	5.10±0.17	4.35±0.18	3.83±0.15	SSR
$M_{res.}$, (GeV/c)^2	1.42±0.01	1.41±0.01	1.42±0.01	1.40+1.70
$\Gamma_{\Delta^{++}\pi^+}$, GeV/c^2	0.043	0.032	0.040	0.036
J^P	>1/2	>1/2	>1/2	$5/2^+$
Probable decay	$\Delta\pi$	$\Delta\pi$	$\Delta\pi$	$\Delta\pi$
$\sigma_{\Delta^{++}\pi^+}$, μb	21±3	11±3	7±4	some μb
I	5/2	5/2	5/2	5/2

can be observed near a mass of 1420 MeV/c^2 as expected for the available statistics of events.

We have determined the production cross sections of the probable resonance with I = 5/2 decaying, presumably, through the mode $N^{*+++} \to \Delta^{++} + \pi^+$ and its width (after background subtraction). The results and SSR predictions [7] are presented in Table 3.

There is a good agreement between the experimental data and SSR predictions [7].

The exotic states constructed of four colour quarks and one colour antiquark were considered in various modifications of the "quark bag" model [9,10]. The predictions of the model

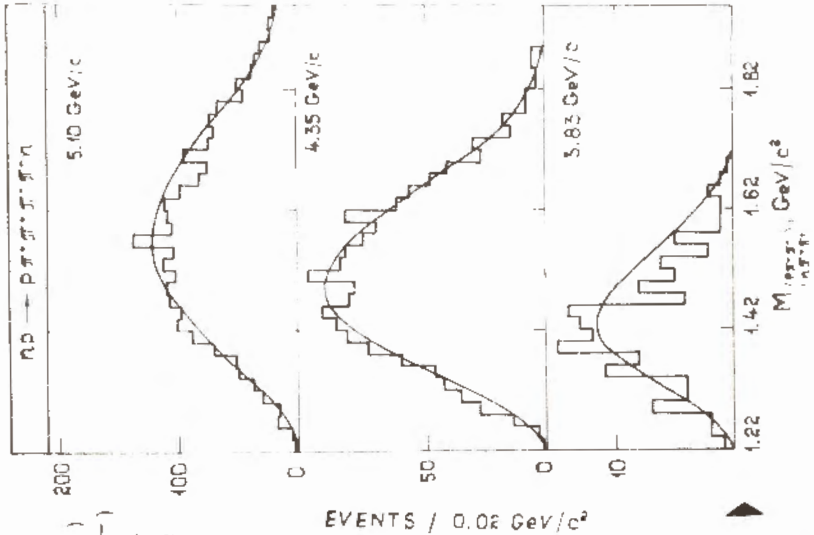


Fig.10. Effective mass distribution of $p\pi^-\pi^-$ (added to $n\pi^+\pi^+$) combinations.

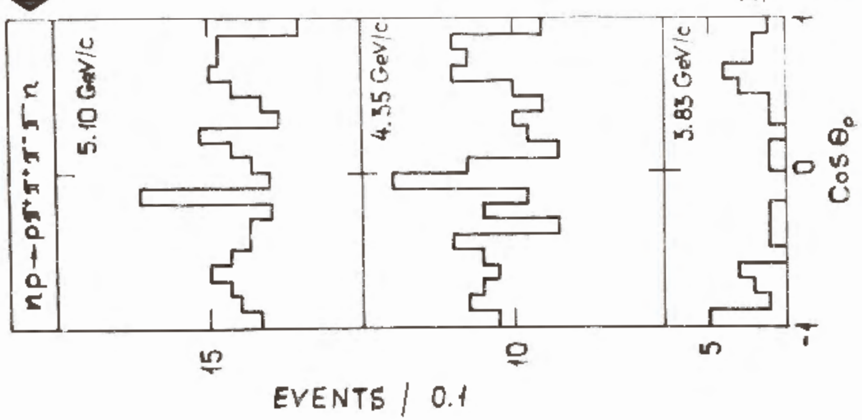


Fig.9. Angular distribution of protons (neutrons) from $\Delta^{++}(\Delta^-)$ included in $N^{*+++}(N^{*---})$ relative to the direction of $\Delta^{++}(\Delta^-)$ in the system of N^*.

of two colour "quark bags" connected by angular momentum has been obtained for the resonance state with isotopic spin $I = 5/2$ near a mass of 2.44 GeV/c^2. This is considerably greater than the values observed in our experiment and predicted by SSR. Therefore a reliable evidence for the above exotic resonance state may lead to a number of essential problems connected with mass calculation methods for this state in the quark approach.

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