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The reaction p p $\Rightarrow$ p $\pi^+ N$ has been studied at 3 energies (T_p=1520, 1805 and 2100 MeV) and 6 angles from 0° up to 17° (lab.) . Several narrow states have been observed in missing mass spectra at : 1004, 1044 and 1094 MeV. Their widths are typically one order of magnitude smaller than the widths of N^* or Δ. Possible biases are discussed. These masses are in good agreement with those calculated within a simple phenomenological mass formula based on color magnetic interaction between two colored quark clusters.

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The study of exotic hadrons (mesons and baryons) is carried out since several years, motivated by the hope to relate these states to multiquarks, hybrids or glueballs. The experimental studies can be separated into two classes. The first one concerns studies of exotic mesons mainly - but also in a few cases of exotic baryons -, with explicit exotic quantum numbers, or their exotic combinations. The second class of studies concerns low energy, narrow exotic states with hidden exotic properties (strangeness or color ...) [1]. The main observable here is the small width of the observed structures. Even if such narrowness is not a firm signature [2], that characteristic is essential from the experimental point of view. Some candidates exist with relatively large masses, which have been seen at Protvino, CERN and Argonne, although the existence of some of them, is still a subject of debate. The corresponding masses are upper 1000 MeV for mesons and 1950 MeV for baryons. For experimental reasons (resolution and counting rates), nearly all results of low mass narrow hadrons, concern isovector dibaryons which masses concentrate around some values [3]. Different authors, in several laboratories, have observed many candidates for such isovector narrow dibaryons. This mass spectrum agrees surprisingly well with a simple phenomenological mass formula [3] derived for two colored clusters in a diquark-quadriquark assumption inside a MIT bag. Different theoretical works have been performed on dibaryons. The first approaches within MIT spherical bags [4], have been improved using cloudy bags [5]. In these last calculations, dibaryons were found at masses close to 2.7 GeV. The same authors predict the existence of molecular states [2] in lower mass region.

The experiment presented below is the study of p p $\Rightarrow$ pπ^+N reaction. It was carried out using the proton beam from Saturne synchrotron and SPES3 facility [6]. The incident proton energies were 1520, 1805 and 2100 MeV. The measurements have been performed at six angles (at each energy), from 0° up to 17° [7]. The cryogenic H_2 target was 393 mg/cm^2 thick. Both particles, p and π^+ were detected in coincidence in the solid angle of 10^{-2} sr ($\Delta\theta = \Delta\phi = \pm$ 50 mrd) of the magnetic spectrometer . The broad range of momenta studied by the detection, $600<pc<1400$ MeV at B=3.07 T, allowed the simultaneous study of large range of missing masses ($939 < M_x < 1520$ MeV). The particle trajectories were localized using drift chambers. The trigger consisted of four planes of scintillating hodoscopes. Time of flight measurements on a 3 meters basis (and energy loss) allowed the identification of detected particles. Events were lost when both trajectories intersected on each plane of the detection. A simulation code describing the detection has been written in order to correct such inefficiencies. These corrections, normalizing the data by a factor $\sim$ 1.25, are smooth functions, except in a narrow range of pπ^+ invariant masses corresponding to trajectories intersecting the focal plane at the same position. Inside such invariant mass range the data have been removed, since a peak on the correction function, makes any eventual structure at the same mass doubtful.

The randoms and eventual wrong identifications coming from real pp $\rightarrow$ ppX events, have been eliminated using a second time of flight between both particles. The total coincidence window common for all time of flight channels was ± 2 ns. Since some random events from pp $\rightarrow$ ppX reaction, if badly identified, could simulate real pp $\rightarrow$ pπ^+X events, checks have been done and have shown that the corresponding number of events is very small, and that they are randomly distributed in the two-dimensional plot of invariant mass against missing mass. In a very small number of cases (0.6% of events), the data reduction code, makes a wrong assignement of trigger and chamber informations . These events have been removed.

The necessary conditions required for narrow and small structures study, were fullfilled in this experiment. These are :

- good mass resolution; the σ on missing mass increases from 2.5 MeV up to 9.4 MeV for spectrometer angles varying from 0° up to 17°.
- high statistics ($\geq 10^3$ events per channel),
- good particle identification,
- studies in different kinematical conditions, in order to check mass stability of eventual narrow structures, from data obtained at different angles and incident energies .

The pπ^+ invariant mass versus the missing mass of events (before normalizations) obtained at 1805 MeV, 0.75° is presented in fig.1. The limits of the plot are produced by the cuts on momenta : (600 and 1400 MeV/c), applied on both particles during the analysis, since they correspond to well defined acceptance of SPES3. The empty zone corresponds to the same intersection of the two trajectories on focal plane, where the first drift chamber was located. No other empty (intense) line appears which would correspond to dead (hot) region in this chamber. The neutron peak is clearly seen on the left of the figure. It corresponds to events produced with a Δ in invariant mass, partly cut when they lie outside the acceptance, and above, heavier Δ and not resonant $p\pi^+$ phase space events. The region with large number of events at M_x ~1220 MeV, $M_{p\pi^+}$ ~1200 MeV corresponds to double deltas production, Δ^0 and Δ^{++}, respectively in missing mass and invariant mass. Some weakly excited vertical lines appear in the region $1000 < M_x < 1100$ MeV.

The second figure shows the result of the projection of the previous two-dimensional plot normalized to constant $\Delta p_p.\Delta p_\pi$ and the same data for the three lowest angles at 1520 and 1805 MeV, selected for missing masses larger than 960 MeV, in order to set off the narrow structures. The decrease of the cross sections and the broadening of the resolution explain the structures vanishing for increasing angle values. The weakly excited lines, seen in fig. 1, are clearly identified in fig.2. Empty target measurements have been performed for the same number of incident protons. Small ($< 5\%$) and flat countings (without structure) have been observed.

A careful study has been undertaken in order to make sure that the structures were not produced by events from $pp \rightarrow p\pi^+ n$ reaction, with p or π^+ emitted at large vertical angles, outside the useful solid angle acceptance, with a momentum eventually larger than 1400 MeV/c, then slowed down by lead slits and stainless steel rings at the entrance of the spectrometer. Such eventuality has been introduced in the simulation code, showing a small and smooth contribution up to 1060 MeV, and a peak arising at masses above and broader than the observed structures. At the missing mass of 1004 (1044) MeV, where the first (second) structure has been observed, the effect of the slits and stainless steel rings is small and vary monotonously with mass (see [8] for more detailed discussion). We conclude therefore on the lack of such possible contamination for the 1004 and 1044 MeV structures, but a doubt remains around 1094 MeV.

The cross-sections of these structures have been extracted, using polynomials fits for background and gaussians for peaks. The structure masses are well defined, but their cross sections and widths are inaccurate, since they depend in a large amount on the shape of the background and on the experimental resolution. Table 1 summarizes these results. The lab. cross sections have been normalized to constant momenta ranges. An overall systematic error of 20% can be estimated, mainly due to large background subtraction uncertainties .

Although many experiments devoted to various other studies, have explored the baryonic excitation function between neutron and delta, and have often observed some shoulders or discontinuities in that region, none of them was accurate enough in order to be able to ascertain the real presence of new states . A (not exhaustive) list of such experiments is presented in table 2.

As pointed out before, narrow baryons which are sometimes still subject of debate, have already been observed in different laboratories. They appear as candidates for exotic baryons with hidden strangeness, in invariant masses of strange baryon and strange meson [22-25].

Although it is not proved that these structures are a manifestation of colored quark clusters, we have considered such assumption. The mass formula for two clusters of quarks at the ends of a stretched bag has been derived some years ago in terms of color magnetic interactions [4,26] :

$$M = M_0 + M_1[i_1(i_1+1) + i_2(i_2+1) + (1/3)s_1(s_1+1) + (1/3)s_2(s_2+1)] , \tag{1}$$

where M_0 and M_1 are parameters deduced from mesonic and baryonic mass spectra and $i_1(i_2)$, $s_1(s_2)$ are isospin, spin of the first (second) quark cluster. We do the assumption that the clusters are $q^2 - q$ or $(q\overline{q})^2 - q^3$. The spin (isospin) values for a diquark $(q\overline{q})$ cluster are 0 or 1 and for a 3 quarks cluster 1/2 or 3/2. Since the masses correspond to zero radial excitation, all parities are positive.

In order to define the two parameters, we first assume that the nucleon mass is obtained when i_1=s_1=0, and i_2=s_2=1/2, giving therefore the nucleon quantum numbers S=I=1/2. We assume also that the Roper resonance at 1440 MeV (the first excited state of the nucleon) is obtained with i_1=1, s_1=0, i_2=3/2 and s_2=1/2 giving - among degeneracy - possible experimental quantum numbers S=I=1/2. Such assumptions allow to predict the masses of the two first possible S=I=3/2 states at 1206 (i_1=s_1=1 and i_2=s_2=1/2) and 1239 MeV (i_1=1, s_1=0, i_2=1/2 and s_2=3/2), close to the mass of the first delta resonance. Such assumptions determine the values of M_0=838.2 MeV and M_1=100.3 MeV. The corresponding mass spectra obtained using relation (1) without any adjustable parameter, is shown in figure 3. As it was for the narrow isovector dibaryons [3], a good agreement is observed between the experimentally and calculated masses. Masses, spins and isospins for additional levels are predicted, with usually - but not always - several possible spin and isospin values due to the degeneracy mentioned above. It is not excluded that more precise experiments will in the future observe these levels. Below the pion emission thresholds, 1075 MeV for baryons and 2012 MeV for dibaryons, the only possible decay channel is the radiative one. Below and above the pion emission thresholds, the assumption that they are states of two colored quark clusters gives a good agreement between the color magnetic mass formula and the experimental observations.

In conclusion, three narrow baryonic states have been observed at the following masses : 1004 MeV, 1044 MeV and with a smaller confidence at 1094 MeV, without any anomalous experimental behavior. The latter state is only 19 MeV above the pion threshold mass. The widths of these three observed states are in the range 4-15 MeV, that is narrow enough to consider them as a possible manifestation of quark degrees of freedom in the nucleon.

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TABLE I. Narrow structures cross sections (lab.) in μb/(sr.GeV/c)^2, absolute errors, widths(σ) and number of standard deviations (S.D.).

M_x (MeV)	Tp(MeV)	angle	cross sec.(err.)	width(MeV)	S.D.
1004	1520	0°	271(42)	5.3	5.9
		2°	260(29)	4.8	8.6
		5°	223(34)	11.6	3.6
		17°	observed		
	1805	0.75°	360(29)	6.5	16.9
		3.75°	120(23)	7.5	5.1
	2100	0.3°	606(178)	4.5	2.9
1044	1520	5°	59(27)	3.6	2
		17°	observed		
	1805	0.75°	144(15)	5.4	9.1
		3.75°	95(18)	5.3	5.1
		6.7°	59(14)	7.7	4.1
		13°	observed		
	2100	0.3°	560(87)	10.4	6.2
		3°	631(72)	14.8	6.1
1094	1520	0°	231(44)	7.1	5
		2°	212(44)	4.9	4.3
		5°	112(39)	4	2.4
		9°	97(29)	7.9	3.1
	1805	0.75°	253(20)	8.1	11.6
		3.75°	261(23)	7.7	10.6
		6.7°	81(16)	5	4.8
		9°	37(10)	6.2	3.5
	2100	0.3°	251(49)	6.8	4.7
		3°	223(45)	6.6	4.1

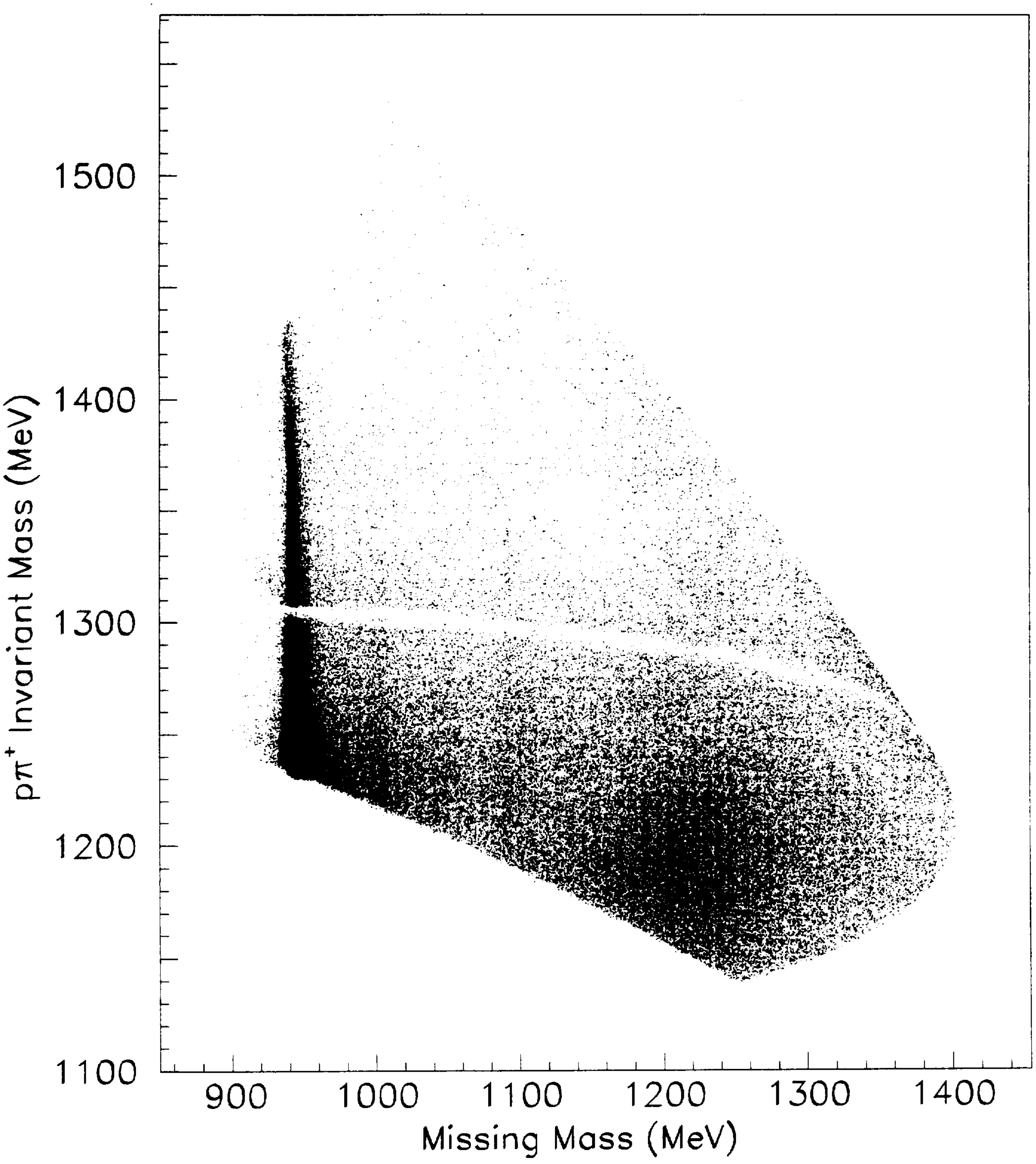
TABLE II. Experiments having studied the baryonic mass region between nucleon and delta.

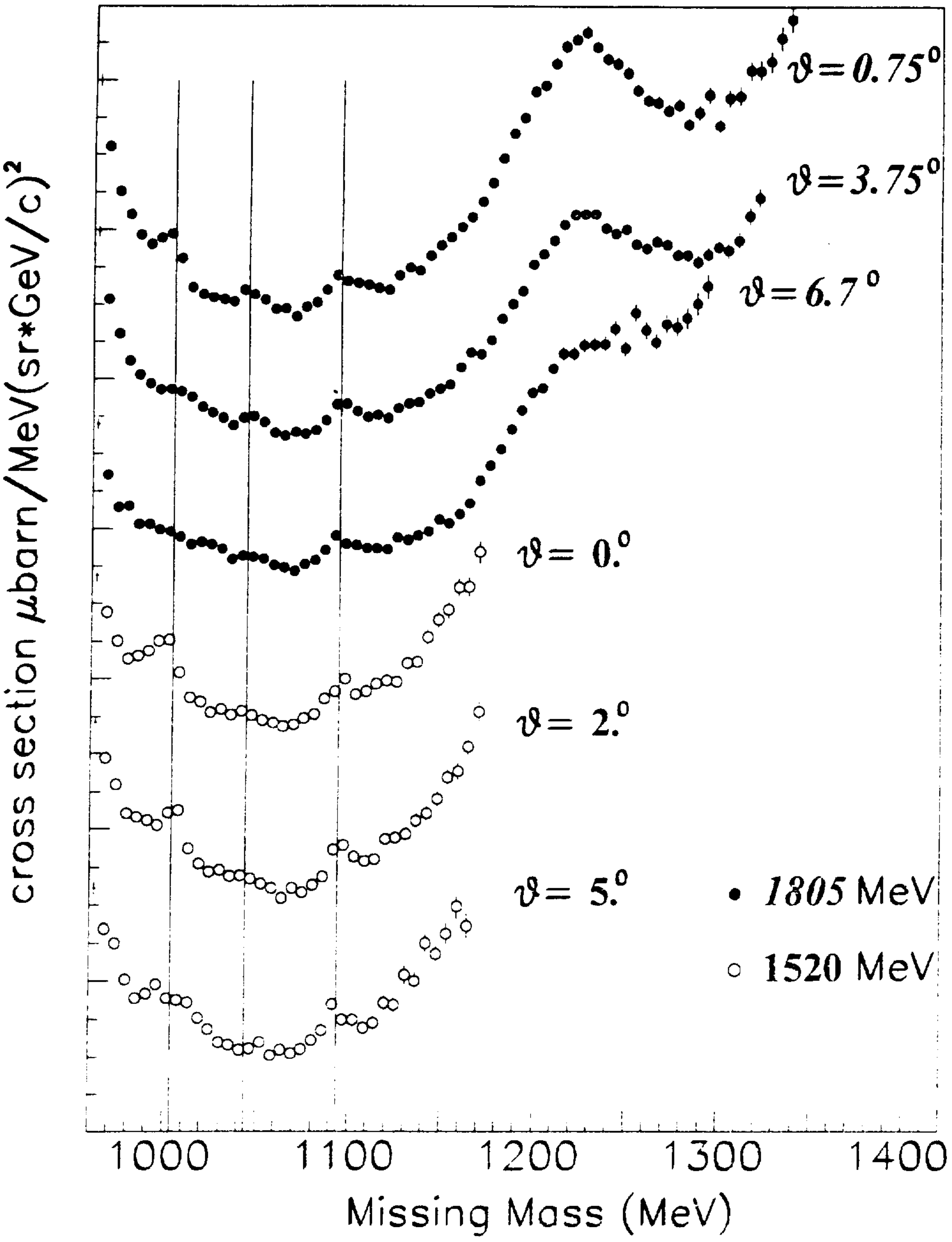
Particles	accelerator	reaction	reference
nucleons	LAMPF	np→ pX (0°)	B.E.Bonner *et al.* (1983) [9]
		pp→ $p\pi^+n$ (800 MeV)	A.D.Hancock *et al.* (1983) [10]
		pp→ $p\pi^+n$ (800 MeV)	J.Hudomalj-G. *et al.* (1978) [11]
	Saturne	$p(^3He,t)X$	D.Contardo *et al.* (1986) [12]
		$^3He(p,t)X$	B.Tatischeff *et al.* (1978) [13]
		np→ pX	G.Bizard *et al.* (1976) [14]
photons	MAMI	γ p→ π^0X	M.Fuchs *et al.* (1996) [15]
		γ p→ γ X (90°)	C.Molinari *et al.* (1996) [16]
		γ p→ $p\pi^+\pi^-$	A.Braghieri *et al.* (1995) [17]
		γ p→ $p\pi^0\pi^0$	"
		γ n→ $p\pi^+\pi^0$	"
	Saskatchevan	γ p→ γX	E.L.Hallin *et al.* (1993) [18]
	Brookhaven	γ p→ π^0X	G.Blanpied *et al.* (1992) [19]
	Saclay-ALS	γ p→ π^0X	E.Mazzucato *et al.* (1986) [20]
	Bonn	γ d→ pX	J.Arends *et al.* (1996) [21]

FIG. 1. Two-dimensional plot at 1805 MeV proton energy and 0.75° for the mean value of both detected particles. The data exhibit clearly the production of delta-neutron and two deltas events, and between them an indication of some narrow and small structures.

FIG. 2. Missing mass differential cross-sections for pp$\rightarrow$ pπ^+X reaction for the three lowest angles at T_p=1520 and 1805 MeV, selected for missing masses larger than 960 MeV. Data have been bined into 5.6 MeV mass intervals, shifted and amplified in order to allow the presentation of all six angles inside the same figure. Vertical lines indicate the mean position of the structures.

FIG. 3. Baryonic experimental and calculated masses.


1500
1400
1300
1200
1100
pπ+ Invariant Mass (MeV)
900
1000
1100
1200
1300
1400
Missing Mass (MeV)


cross section μbarn/MeV(sr*GeV/c)²
Missing Mass (MeV)
1000
1100
1200
1300
1400
ϑ=0.75°
ϑ=3.75°
ϑ=6.7°
ϑ= 0.°
ϑ= 2.°
ϑ= 5.°
● 1805 MeV
○ 1520 MeV

Experimental **BARYONIC MASSES (MeV)** **Calculated**

Spin		Isospin	Mass
1/2	N(P_{11})	1/2	1440.
3/2	Δ	3/2	1232.
			(1094.)
			1044.
			1004.
1/2	N	1/2	939.

Mass	Spin	Isospin
1440.	1/2...7/2 3/2,5/2 1/2	1/2,3/2 3/2 1/2...5/2
1407.	1/2...5/2 5/2	3/2 1/2,3/2
1340.	3/2,5/2 3/2 5/2	1/2,3/2 3/2 1/2
1306.	1/2,3/2 1/2...5/2	3/2 1/2,3/2
1273.	3/2...7/2	1/2
1239.	1/2...7/2 1/2 3/2	1/2 3/2 1/2,3/2
1206.	1/2,3/2	1/2,3/2
1139.	3/2,5/2 1/2	1/2 1/2,3/2
1106.	1/2...5/2	1/2
1039.	3/2	1/2
1005.	1/2,3/2	1/2
939.	1/2	1/2