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Reviewing the study of narrow dibaryons

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REVIEWING THE STUDY OF NARROW DIBARYONS

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1. INTRODUCTION

The experimental evidence for narrow dibaryons has an essential importance if it can be associated to quark degrees of freedom in nuclei. The difficulty is double : first the corresponding structures have to be observed. When observed they are usually small, lying over a large background. They are not always observed. Second when observed these structures have to be dissociated as much as possible from any classical explanation as for example a threshold effect corresponding to the opening of a new channel of mesons and two baryons in interaction.

Extensive researches are done in some laboratories with emphasizes on the accuracy of the data : only such data, achieved in the two last years will be presented here[1]. The solution of the first difficulty needs data of high precision, both statistical and systematic. The second point : the identification of data with quark degrees of freedom is before all a theoretical problem although it will be clearly favoured by the narrowness of the observed dibaryons.

In opposition to experimental investigations for T = 1 and T = 2 dibaryons, where many experiments have been accomplished in the time range considered here, there have been no data concerning pure isoscalar dibaryon search. This is unfortunate since a calculation done by Goldmann et al.[2] in the framework of an effective one-gluon exchange inside the region of confinement, predicts that an I = 0 ($J^P = 3^+$) nonstrange dibaryon must exist.

2. SEARCHES FOR NARROW ISOVECTOR DIBARYONS

2.1

There are some data corresponding to different reactions where very small shoulders or even bumps are present although not discussed by the authors. The masses often fit the published masses [1] of isovector dibaryons.

Perhaps the best example of such situation can be found in one of our own data from Saturne, SPES1 facility. The results corresponding to ^{3}He(p,d)X reaction ($B_x = 2$, $T_x = 1$) have been published[3] with the same analysis for all energies and angles, and precisely with empty target subtraction and five MeV bins. At $T_p = 750$ MeV, $\theta_d = 40°$, there is a small bump at $M_x = 2.12$ GeV -whose confidence level is small. However when the same data are analyzed again in the same way than before except using three

MeV bins and without empty target subtraction in order to reduce partly the error bars, we get the data plotted on fiG. 1, where a bump appears clearly. It's mass is M_x = 2.122 GeV, $\Gamma_{1/2} \simeq$ 15 MeV and the number of standard deviations S.D. = 3.0. This data allows to fill one of the two missing points of fiG. 2 from reference 4.

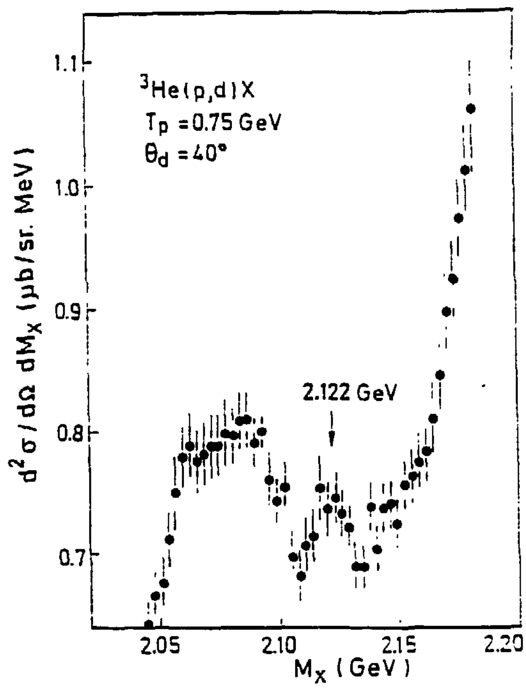


Fig. 1 : Missing mass spectra[3]. Data binned into 3 MeV intervals. No empty target subtraction.

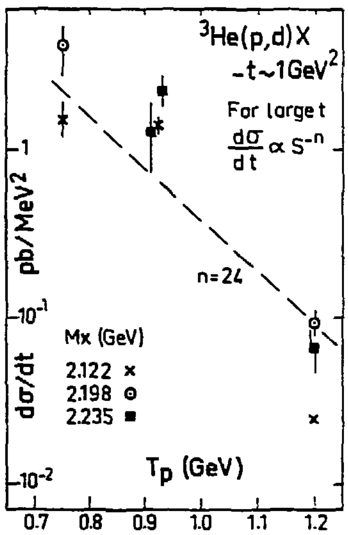
The ^{3}He(p,d)X reaction has been studied at three energies : T_p = 0.75, 0.925 and 1.2 GeV. We can then look at the energy variation for the production of the observed narrow dibaryons. Fig. 2 shows $d\sigma/dt = f(T_p)$ for structures at 2.122, 2.198 and 2.235 MeV for - t values close to 1 GeV^2. The tendancy is compared to the dashed line which is proportionnal to s^{-n} where n = 24 is the total number of participating quarks (n is larger if pions are considered). This is a high energy relation, not valid at energies considered here. The experimental FWHM are also shown in the fig. 2.

2.2

The same reaction ^{3}He(p,d)X has been studied at Los Alamos[5] with 800 MeV polarized protons, at θ_d = 22°. The analyzing power data show structures for several masses M_X which correspond quite well to the masses where structures have been extracted in our cross section data -see Fig. 3.

2.3 $\pi d \rightarrow pp$ reaction

The relative yield for $\pi d \rightarrow pp$ at $\theta_{lab.} = 75°$ has been measured some



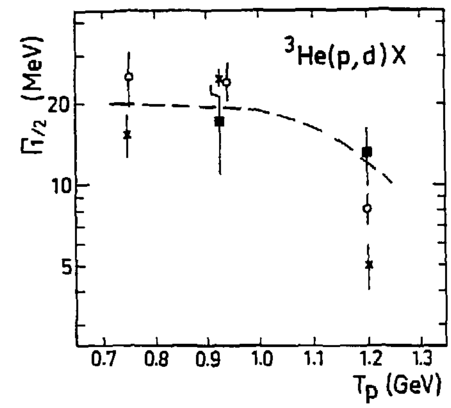


Fig. 2 : dσ/dt cross sections for the narrow structures observed in $^3He(p,d)X$ reactions/3,4/ at different incident energies. Corresponding FWHM values.

years ago at Los Alamos/6/. In the studied range $2.052 < M_{NN} < 2.277$ MeV there was no room for any structure. These data remain there smooth after the completion of the analysis/7/. Just as the data of $\vec{p}\, d \rightarrow pX$ reaction/7/.

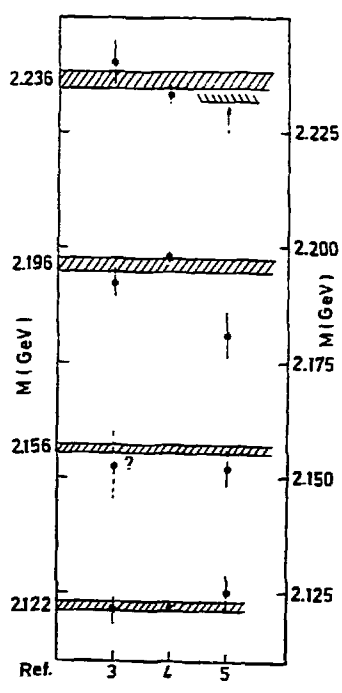


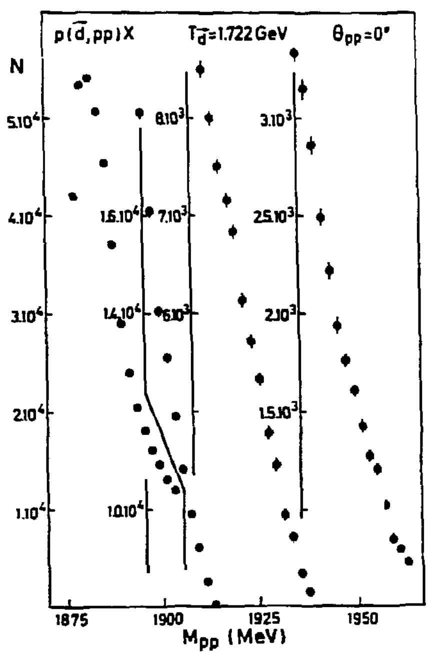
Fig. 3 : Masses of observed narrow structures using $^3He(p,d)X$ reaction at Saturne and Lampf.

2.4 $\vec{p}p \to pp$ reaction

The existence of narrow dibaryons is better established in the mass range $2.1 < M < 2.25$ GeV although many experiments have studied and are presently studying the range of masses below pion production. Above this threshold the elasticity for narrow dibaryons is expected to be small, however a very precise study of the elastic $pp \to pp$ scattering is needed. Such experiment has been recently fulfilled[8] using Saturne polarized proton beam and SPES3 beam line whose detection has been slighly modified. The analyzed power of two proton invariant mass M_{pp} was studied in the range $2115 \leqslant M_{pp} \leqslant 2210$ MeV using polarized protons $510 \leqslant T_p \leqslant 725$ MeV. The effect of the $\gamma G = 3$ resonance was studied and appeared to be very narrow ($\pm$ 3 MeV). Thirteen different proton energies between 564 and 725 MeV have been used, each energy allowing the study of $\Delta T_p \approx 40$ MeV, by use of a rotating wheel with 16 different thicknesses. Both protons were detected using SPES3 and a recoil telescope. The background was very small ($\approx 10^{-3}$) with nearly the same polarization. The statistical precision obtained $\Delta Ay \lesssim 1.2\ 10^{-3}$ is much better than that from recent KEK results[9] where structures at $M_{pp}(\Gamma_{1/2}) = 2160$ (14) and 2192 (13) MeV have been extracted with a number of standard deviations S.D. $\geqslant 3.5$. We have to notice that $\gamma G = 3$ resonance corresponds to $M_{pp} = 2170$ MeV. Although the angles were different (19.1 degree for the forward p in Saturne experiment and 16.7 degree at KEK) and also the angular acceptances ($\pm$ 50 mrd at Saturne and $\pm$ 21 mrd at KEK), the Saturne data are so precise that it is difficult to believe that the structures will totally disappear if present at nearby angle. We should rather conclude that narrow structures are up to now not present in pp system. We shall notice that all experiments where narrow structures have been observed and identified to dibaryons had either for beam, or target, or both, a nucleus heavier than a single nucleon. We must therefore consider with attention the theoretical findings [10] that the repulsive core of the NN system prevents it to be a good candidate to study their multiquark structure.

2.5 $p(\vec{d}, pp)X$ reaction

Although several results are available for isovector dibaryon study in the range $2\ M_N < M_{pp} < 2\ M_N + M_\pi$, they have been usually provided by experiments studying bubble chamber pictures. Precise electronical experiments devoted to the study of two proton invariant mass in this range are needful. The study of $p(\vec{d}, pp)X$ reaction has been performed[11] using the tensor polarized deuteron beam from SATURNE ($T_d = 1.722$ GeV), and SPES3 facility. Both protons were detected at zero degree allowing a two proton invariant mass range : $2\ M_N < M_{pp} < 1.963$MeV owing to the SPES3 large values of solid angle and momentum ranges ($\Delta\Omega = 10^{-2}$ sr and $p_{max}/p_{min} \approx 2.5$). The FWHM of the experimental width for M_{pp} is close to 1 MeV. The data -in order to improve the statistical uncertainties have been binned into two MeV intervals. There is no discontinuity presenting a number of standard deviations (S.D.) larger than 2.2 in the M_{pp} histogram (fig. 4). The vector analyzing power iT_{11} is equal to zero within statistics since the data correspond to zero degree. Another combination of the four polarization states -which should be zero- is indeed compatible to zero inside statistical error bars. In the tensor asymmetry data on the other hand, there is -see fig. 4- either an oscillation around 1944 MeV, either a narrow hole at M_{pp} = 1941 MeV (FWHM $\approx$ 6 MeV). The corresponding T_{20} histogram for the missing mass M_X does not show such an oscillation. S.D. for a hole at 1941 MeV is close to 4.3. Other raw data corresponding to the same reaction but for T_d = 2.1 GeV deuteron energy and θ_{pp} = 17° are presently under analysis.



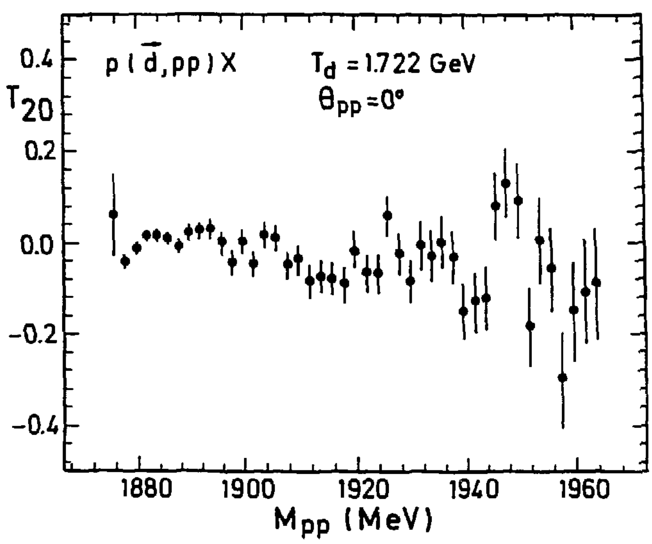


Fig. 4 : $p(\vec{d},pp)X$ reaction study. Histogram of two proton invariant mass M_{pp} and corresponding tensor analyzing power[11].

Different bubble chamber data have been recently presented. When these data are compared to those presented before and obtained with electronical detections, two differences at least can be noticed :

- first the statistics is poor even if it increases year after year for some reactions (for example, Ref.[18]).
- second the ratio of peak -if any- over background is larger. This can be due to cuts applied to reject low momenta protons (favouring non spectator events) and to kinematics which consider large solid angle when the spectrometer experiment like that described in 2-5 consider both protons emitted in the same solid angle -the corresponding phase space being small.

When combining both effects, the number of S.D. found is sometimes $\geqslant 3$. The five next experiments have been obtained using beams from Dubna.

2.6

After analysis of $2.25.10^4$ inelastic nuclear collisions of 5 GeV/c π^- beam impinging on propane (propane-fréon) 1 m JINR bubble chamber, structures have been observed in $pp\gamma$ spectra[12] corresponding to the following masses M(MeV), (FWHM (MeV) and S.D.) : 1915 (< 3 ; > 2), 1959(8 ; 4.6), 2014 (15 ; 4.8), 2052(15 ; 2.6) and 2159(20 ; 3.5).

2.7

2 m JINR propane bubble chamber has been used to study pp correlations in pC, dC, αC and CC interactions[13]. Two structures have been observed at 1903(4.8 ; 3.05) and 1915(1.2 ; 3.0) MeV.

2.8

1 m JINR HBC has been used to study pp correlations using dp interactions. Two structures have been extracted[14] at 1939(27 ; 2.2) and 2090(10 ; 2.0) MeV. These data have poor energy resolution although the statistical precision is not high.

2.9

Concerning the np $\rightarrow pp\pi^-$ data, things are getting clearer. Two years ago many structures were advocated[15] though in the data corresponding to P_n = 1.257 GeV/c, only one structure at 1977 MeV has a not negligeable S.D. (S.D. $\approx$ 2.1) and in the data obtained using P_n = 2.23 GeV/c only one structure again has a not too small S.D. at 2232 MeV (14 ; 2.2.). This gave rise to conflicting analysis[17]. Statistics has been improved recently by adding results from p_n = 1.43, 1.72, 2.23 and 3.83 GeV/c. Structures are now extracted[18] by the authors at the following masses, (full width half maximum after extraction of experimental contributions to widths, and S.D.) : M_{pp}(FWHM ; S.D.) (in MeV) : 1886(3.6 ; 4.4), 1937(1.8 ; 3.7), 1965(1.4 ; 4.4), 1981(0.7 ; 4.3), 2017(0.6 ; 2.8), 2047(1.7 ; 3.1), 2083(0.1 ; 3.1), 2105(0.0 ; 3.1), 2237(6.8 ; 5.8), 2278(5.2 ; 7.0). It is clear that a further increase of statistics will be desirable.

2.10

Elastic pp $\rightarrow$ pp scattering has been studied in the range 116 < T_p < 199 MeV. The differential cross section relative to inelastic p-p and p-d scattering shows four peaks[19] identified as structures having the following masses and statistical significances : 1936(93 %), 1951(80 %), 1958(99.4 %) and 1971(97 %). When looking to data however, it appears that the statistics should indeed be increased -even by integrating the results which are at the moment binned into 0.4 MeV intervals.

2.11

An experiment has been performed at DORISII using 5 GeV $e^{\pm}$ impinging on ^{16}O gas target[20]. The ratio of correlated over uncorrelated protons was plotted versus two proton invariant mass, and no narrow dibaryon found in the range $1875 \leqslant M_{pp} < 2360$ MeV. Notice that the statistics is not very rich specially for M_{pp} above 2.05 GeV, although this is an experiment with electronical detection.

2.12

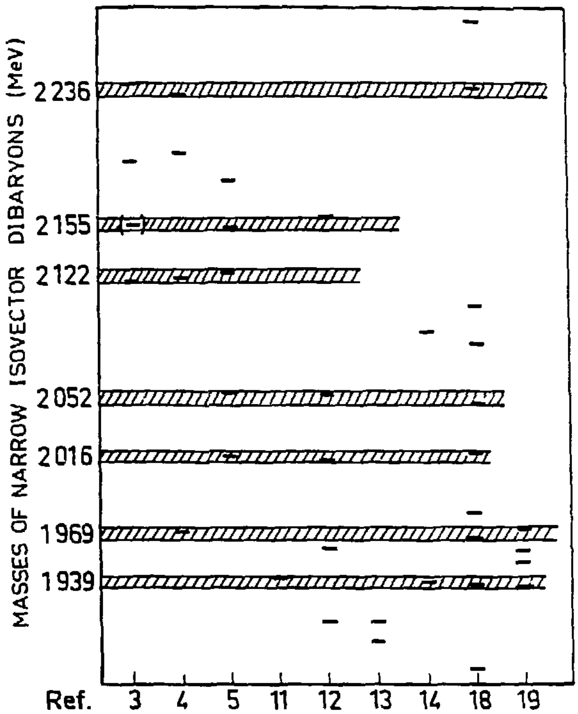
Another electronical experiment with a negative result has been performed at ITEP using 7.5 GeV/c incident protons and C, Cu and Pb targets. Two protons were detected with thick scintillators[21]. Measurements have been done in the range $1.9 < M_{pp} < 2.0$ GeV but with a low statistics and poor energy resolution (from $\approx$ 2 MeV at 1.9 GeV, till $\approx$ 5 MeV at 1.93 GeV and $\approx$ 13.5 MeV at 2.0 GeV).

All the data discussed previously, corresponding to narrow isovector dibaryons are displayed on fig. 5. If we select those masses M where a narrow structure has been observed at least in three different experiments at the same value within ± 4 MeV, we get the numbers drawn on the fig. 5 : 1939, 1969, 2016, 2052, 2122, 2155 and 2236 MeV. In some other cases a structure with the same mass within ± 4 MeV has been observed in two different experiments (1915, 1959, 2086, 2195 MeV). Remember that the data published or completed more than two years ago, are not discussed in this article and are not considered in Fig. 5.

3. SEARCHES FOR NARROW DIBARYONS WITH ISOSPIN T = 2

Positive results with very poor statistics have been found at Lampf in $d(\pi^{\pm}, \pi^{\mp})X$ missing mass experiments[26]. These results were not confirmed. On the contrary different data have been published from Saturne, Triumf and LAMPF without any narrow structure. Likewise theoretical calculations within three body isobar model, after a better choice of the vertex function value ν, concluded[31] on the non existence of isospin 2 πNN bound state.

Fig. 5 : Masses of isovector narrow structures observed recently (see text).



3.1 $\vec{p}\,p \to \pi^- X$ reaction

Analyzing powers and differential cross sections have been studied at T_p = 1.45, 2.1 and 2.7 GeV proton energies at Saturne/27/.SPES3 facility was used. The missing mass range extended from 1.8 to 2.65 GeV. Only one structure could be extracted at 2.164 GeV (FWHM = 15 MeV ; S.D. = 2.6) when T_p = 2.1 GeV. Since this mass is close to the $M_\Delta + M_N$ mass, it is difficult to eliminate a threshold effect. Upper limits for 3 S.D. structure have been extracted, increasing from 8 to 90 nb/sr. MeV when M_X increases from 2.0 to 2.2 GeV (fig. 6).

3.2

The yield of γ rays (10-20 MeV) has been studied at Triumf/28/, for π^- stopping in D_2. A transition from a π^-d atom to a neutral $\pi^\circ nn$ or $\pi^- pn$ will give a peak if a bound T = 2 dibaryon will exist. No peak was observed around the expected energy.

3.3 $d(\pi^-, \pi^+)\pi^- nn$ reaction

It was studied using 291.2 MeV pion beam, at LAMPF/29/. No peak was observed in the range 2.02 < M_X < 2.07 GeV.

4. THEORETICAL WORKS

Different theoretical results have been proposed recently :

- Within a constituent quark model[22] the masses of multiquark states have been calculated and found much larger than the observed masses, as well for N = 3 as for N = 6 (by ≈ 370 MeV), N = 9 or N = 12 quarks.

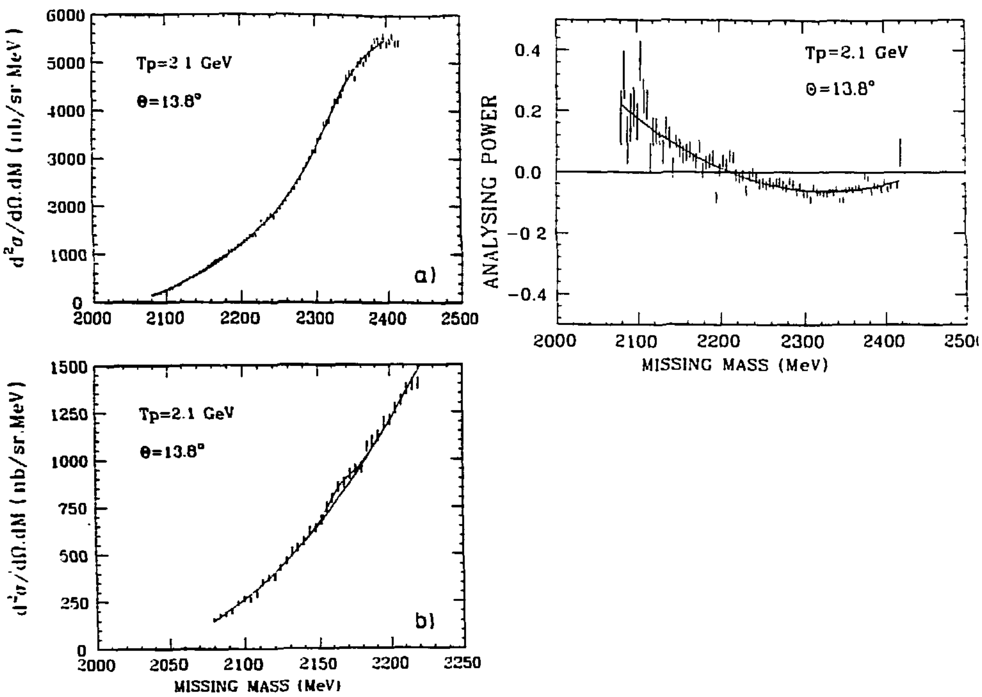


Fig. 6 : Search for isospin 2 dibaryons using $p(\vec{p},\pi^-)X$ reaction at T_p = 2.1 GeV. Differential cross section and analyzing power[27].

- Long range meson-baryon strong interaction can lead to quasi nuclear NΔ systems[23] with excitation energies of 10-70 MeV/N, and a width of 10^{-3} - 10' MeV.
- A calculation describing non perturbative effects inside conventional QED has been proposed[24], where many narrow resonances are predicted in the pp system and also in the e^+e^- system (c.f. GSI narrow peaks). If such description and predictions are right, then the level density of pp resonances is large, specially below pion production threshold

(one resonance every 3.7 MeV in the average) and therefore resonance fluctuations[30] should be considered, depending on their widths $\Gamma_{res.}$.

- Within a QCD quark potential model[25] many nonstrange dibaryons have been calculated with masses equal or larger then 2.495 GeV.
- A calculation[2] already mentionned concluded that a nonstrange dibaryon having quantum numbers $J^P = 3^+$, $I = 0$, must exist.

5. CONCLUSION

Experimentally evidence for isovector dibaryons has been strengthened, especially in the range above $M = 2\, M_N + M_\pi$. Intensive works are presently carried out below this threshold. There is still no signature in the isoscalar dibaryon sector. Different experiments have been accomplished in the search of T = 2 narrow dibaryons, at Saturne, Triumf and Lampf. In any case a narrow structure has been observed. That negative result can be commented as follow :

- the precisions obtained in these experiments are usually worse than the precisions of the best data obtained in the isovector dibaryon studies,
- we can speculate also on the smaller peak over background ratio in the production cross section. Notice that in each case a different reaction has been studied.

The most important and new result is the lack of any signal in pp analyzing power data, although very precise measurements have been done at Saturne. As already noticed recent theoretical work[10] pointed out that a NN system is badly appropriated to study the multiquark structure of the hadrons and that the non repulsive, nonstrange dibaryon study is more appropriate.

Finally if very precise experiments -to be done- will not be able to observe narrow structures corresponding to dibaryons with isospin T = 0 and T = 2, this clearly will be considered as an argument against the assumption associating the observed narrow dibaryons with quark degrees of freedom. Then an explanation should be found inside baryons and mesons in interaction. Presently such last description does not exist, and quark degrees of freedom remain the simplest assumption for the observed data.

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