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# THE STATUS OF NARROW MULTIBARYONIC RESONANCES STUDIES

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## 1. Introduction

The study of dibaryons is of great importance for different reasons. It is the simplest state of nuclear physics where two baryons interact through meson exchanges. It provides one of the best way to study the quark picture proposed for the description of NN short range interaction. Moreover it opens a natural way to look at possible hidden color states forbidden in the classical description of nuclear physics but allowed in quark models/1/. Broad dibaryons ($\Gamma \sim 150$ MeV) observed in NN and deuteron photodisintegration experiments, are usually related to N$\Delta$ interactions. We will therefore limitate our discussion to narrow ($\Gamma \sim 20$ MeV) non strange dibaryons.

The experimental results will be shared into three different paragraphs :

a) since a few years many studies have been carried on in different laboratories to look at narrow structures in two proton invariant masses or in missing masses spectra. These results have been already discussed/2/ in review talks We will use them in the discussion but skip their presentation.

b) They are "*old*" published data, measured in order to study other problems outside the scope of multibaryonic context. Therefore, they are less precise but also not suspected to be influenced. We will discuss some of these results after careful re-analysis to give evidence of positive or negative signals of dibaryonic states.

c) Finally some new, often preliminary and unpublished data, will be presented.

## 2. Dibaryons

### 2.1 B = 2, T = 0

There are very few results on experimental search for narrow isoscalar dibaryons. Our dd → dx results have been published without mention to structures/3/. Indeed there are bumps at $T_d$ = 2.29 and 1. 65 GeV which where located 6 MeV apart, and nothing at $T_d$ = 2.0 GeV. However it turned out recently that close to the maximum of

Saturne energy a correction of some MeV -depending on the energy- has to be done. This makes the centroid of the two bumps to lie at 2 MeV apart, with intermediate confidence level since at $T_d$ = 1.65 and 2.29 GeV the number of standard deviations is respectively S.D. = 3.3 and 3.1. There is then a possible candidate for an isoscalar dibaryon at Mx = 1.930 GeV with a width FWHM close to 11 MeV, corresponding to the experimental resolution (see Fig. 1).

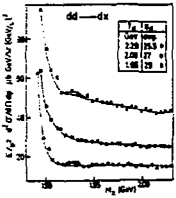

*Fig. 1 : Missing mass spectra for isoscalar dibaryon search*[3].

## 2.2 B = 2, T = 1

### 2.2.1 NN channels

The pp total cross sections versus incident energy, $\sigma_T(pp)$, have been measured by various authors[4], with sometimes large error bars, precluding any conclusion about the existence or not of any narrow structure. The same conclusion holds for $\sigma_{el.}(pp)$ and $\sigma_{inel.}(pp)$ likewise for $\sigma_T(pp \rightarrow \pi^+ d)$ and $\sigma_T(pp \rightarrow pn\,\pi^+)$ where in addition the number of measurements is not large enough. At Saturne in the NN group, F. Lehar et al.[39] determined directly 11 linearly independent amplitudes from p-p elastic scattering at eleven energies between 0.83 and 2.7 GeV ($30° \leq \theta_{C.M.} \leq 90°$). The results show a smooth angular dependence at all energies except at $T_p$ = 2.1 GeV where a dibaryonic resonance has been observed for $\sqrt{S} \cong 2.75$ GeV, FWHM ≤ 52 MeV. This is close to the structure observed in $\Delta\sigma_L$ measurements at Argonne[43].

### 2.2.2 *"Old experiments"*

Some years ago, Cverna et al.[5] measured the $pp \rightarrow \pi^+ X$ reaction at Lampf, using 800 MeV proton beam. A bump corresponding to the np final state interaction appears at all angles. The other structures which are mainly observed at small pion angles, do not correspond to stable missing masses except possibly at 2.04 GeV.

At LAMPF also, using the Epics Spectrometer, Källne et al. have measured $^3He(\pi^\pm,p)X$ reactions for different pion energies[6]. The data which are unprecise and must be shifted[7] have been published without error bar. The masses corresponding to possible structures are not stable for different pion energies.

### 2.2.3 Recent and new data

The recent data have been already discussed in review talks[2], and the references given within. One work must be added to previous reviews. No structure has been found in two proton invariant masses in 7.5 GeV/c p on some nuclei[40] in the range $1.92 \leq M_I \leq 2.00$ GeV. The poor resolution ($\Delta M_I \sim 24$ MeV at $M_I$ = 1.97 GeV) could explain this negative result.

As concerns new data, since many experiments have been (and are presently) studied at Saturne, they are summarized in table 1. In the same table we present the measurements devoted to the search for 0 and 2 isospin dibaryons and search for narrow tribaryons. It is clear that many raw data are presently analyzed. Fig. 2 shows the last and most precise missing mass spectrum obtained in $^3He(p,d)X$ reaction[8]. Although the measurements are very precise (at 1.2 GeV, 33°, the statistical precision $\Delta\sigma/\sigma = \pm\ 0.7\ \%$) the structures have not been extracted at all angles. The corresponding cross sections are therefore poorly determined. Fig. 3 shows the comparison of the masses of these structures with those found previously[8]. At Lampf, very recently, a structure has been observed in the missing-mass spectra of the analyzing power for the $^3He\ (p,d)X$ reaction at 800 MeV. Preliminary results of the analysis indicate a correspondence between maxima in this structure and those we have observed at Saturne.

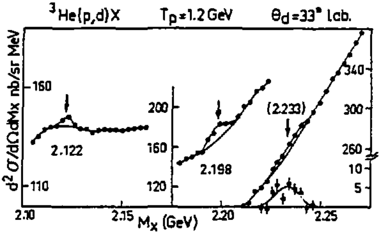

*Fig. 2 : Missing mass spectra for isovector dibaryon search*[3].

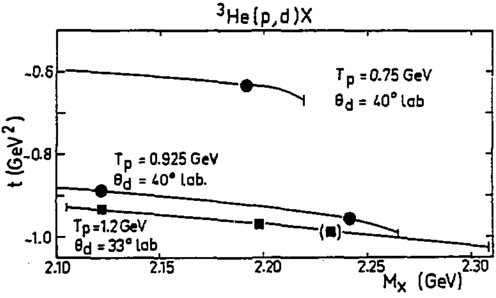

*Fig. 3 : Structures in $^3He(p,d)$ observed in different kinematical conditions.*

*Table 1:Summary of measurements done at Saturne to search for narrow multibaryons*

| Reaction | Beam line | Tinc. (GeV) | Reference | Results | T | B |
|---|---|---|---|---|---|---|
| $^{3}He(p,d)X$ | SPES 1 | 0.75<br>0.925<br>1.2 | B. Tatischeff et al. /8/ | Narrow structures<br>$M_X$ = 1.969 GeV<br>2.122 "<br>(2.155)?"<br>2.198 "<br>2.233 " | 1 | 2 |
| $p(^{3}He,d)X$ |  | 2.7 |  |  |  |  |
| $p(\vec{p},d)\pi^+$ | SPES 1<br>SPES 4 | $1.2<T_p<2.3$ | R. Bertini et al. /41/ | Broad resonance ($\Gamma \approx 150$ MeV), $\sqrt{s} \approx 2.7$ GeV |  |  |
| p(p,p)p | Internal gas jet 90° $d\sigma/d\Omega$ | $0.50<T_p<1.20$ | M. Garçon et al. /11/ | No narrow structure observed |  |  |
| $p(\vec{p},p)p$ | Ligne 5 Ay $17° < \theta < 35°$ | $0.655<T_p<1.017$ | M. Garçon et al. /12/ | No narrow structure observed |  |  |
| $\vec{p}(\vec{p},p)p$ | NN | 11 energies $0.83<T_p<2.7$ | F. Lehar et al to be published /39/ | Resonance at $\sqrt{s} \approx 2.73$ GeV<br>FWHM $\lesssim$ 52 MeV |  |  |
| $\sigma_T(pp \rightarrow pp\pi^\circ)$ | Ligne 8 | $0.48<T_p<0.56$ | J.P. Didelez et al. /42/ | Analysis not completed |  |  |
| $p(\vec{p},p)p$ | SD 2 | $0.13<T_p<0.26$ | R. Beurtey et al. | Very few data ; preliminary |  |  |
| $p(\vec{d},p\pi)X$ a)<br>$p(\vec{d},pp)X$ b) | SPES 3 | 2.1<br>2.0 | B. Tatischeff et al. | Data taking will start in July 88<br>a) $B_X = 2$<br>b) $B_I = 2$ |  |  |
| d(d,d)X | SPES 4 | 1.65<br>2.00<br>2.29 | M.P. Combes et al. /3/ | One candidate (see before)<br>$M_x$ = 1.930 GeV | 0 |  |
| $p(\vec{p},\pi^-)X$ | SPES 3 | 1.45<br>2.10<br>2.70 | N. Willis et al. /22/ | Analysis not completed | 2 |  |
| $d(\vec{p},\pi^-)X$ | SPES 3 | 1.45<br>2.10<br>2.70 | F. Hibou et al. /34/ | Analysis not completed | 3/2 | 3 |
| $p(p,K^+)X$ | SPES 4 | 2.3 | R. Frascaria et al. /23/ | Analysis not completed | S = − 1<br>B = 2 |  |

### 2.2.4 Discussion

There is a lot of results concerning narrow isovector dibaryons. The experimental situation is satisfactory above the pion production threshold since here the masses concentrate around some defined values. It has been shown/9/ that these masses can be displayed using a rotational like mass formula $M = M_0 + M_1 J(J+1)$ –see Fig. 4. Since for the two rotational bands $M_0$ corresponds precisely to $2M_N + M_\pi$ and $2M_N + 2M_\pi$ respectively, it has been speculated that in this range of masses, $M > 2.015$ GeV, the narrow structures correspond to quasi molecular model/10/ of two nucleons and pions. However since the observed masses correspond to experiments looking at two proton invariant masses (without pion) as well as to experiments studying missing masses, that assumption has to be eliminated. The observed dibaryons could correspond to quark degrees of freedom, in particular since they are narrow. However the calculated masses in earlier bag model studies/1/ were larger (by the order of 200 MeV) and this gap increased recently to 500 MeV as a result from cloudy bag model/24/. Moreover J = 1 and 3 states must be excluded from total antisymmetry for these L = 0 states, although they appear in the Fig. 4.

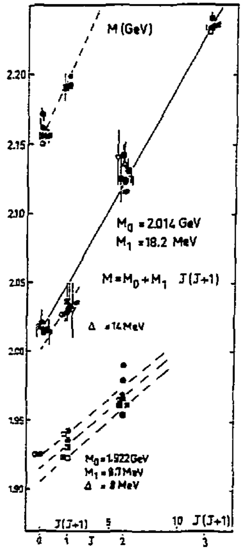

*Fig. 4 : Display of T = 1 dibaryons versus a J(J + 1) mass formula.*

The region of masses below M = 2.015 GeV is at the same time very important and experimentally more confused since the observed dibaryons do not concentrate at fixed masses. Very precise p–p elastic scattering data have to be performed, with high precision and small shifts in energy.

### 2.3 B = 2, T = 2

Many theoretical works have been devoted to the ($\pi^- nn$) system since several years, either using the Faddeev equations and a purely mesic assumption/13/ or in the framework of a model where short range interactions were parametrized by constituant quark forces/14/. The possibility of having one or several ($\pi^- nn$) bound states has been considered by several authors/15/. If there is such a T = 2 state at a mass lower than 2.018 GeV it will be bound by strong and electromagnetic interactions ; then it will be very narrow and could be detected (as is the pion).

Several experiments were performed in order to observe such states, but an upper limit of the cross sections could only be extracted :

- Bozzoli et al. using 200 GeV protons on Be[16] found an upper limit of 20 pb/sr·(MeV/c).

- de Boer et al. using 590 MeV protons on Be[17] have published very small upper limits for $(\pi^-)^Z\, n^N$ bound states, Z being equal to 1 or 2, and N varying from 2 to 6. The upper limit varied from $1.5 \times 10^{-34}$ to $6.1 \times 10^{-40}$ $\mathrm{cm}^2$/sr.(MeV/c).

- a measurement has been carried out at Saturne, with the SPES 3 spectrometer[22] : using 2.7 GeV protons on a lead target an upper limit at 40° lab. for stable $(nn\pi^-)$ system has been obtained : $d^2\sigma/d\Omega\, dp \leq 0.1$ nb/sr. MeV/c (for $0.65 \leq pc \leq 1.35$ GeV).

- the double pion exchange reaction on d has been studied several times : Kyle et al.[18] measuring $d(\pi^+,\pi^-)X$ found an upper limit of 2 nb/sr.(MeV/c) for $(\pi^+ pp)$ bound states. Piasetzky et al.[19] also gave upper limits of 200 nb/sr and 300 to 500 nb/sr respectively for $(\pi^- nn)$ and $(\pi^+ pp)$ bound states, by studying $d(\pi^\pm,\pi^\mp)X$ with 256 and 331 MeV pions at Lampf.

Cverna et al. measured $pp \to \pi^-(\pi^+ pp)$ missing mass spectra using the 800 MeV proton beam from Lampf[5]. The measurements were performed for another purpose and were not very precise (no error bars were quoted). Nevertheless two structures appear in the spectra at more or less all angles for missing mass values around $M_x = 2.002$ and $M_x = 2.030$ GeV (Fig. 5).

Pion double charge exchange reactions on d have been recently measured by Ashery et al.[20] using $T_{\pi^-} = 256$ MeV and $T_{\pi^+} = 262$ MeV pion beams, at the EPICS channel (LAMPF). There are indications for peaks at 2.003 GeV missing mass for the $(\pi^+ pp)$ system and at 2.001 GeV for the $(\pi^- nn)$ system with 3 standard deviations -see Fig. 6.

An experiment has been carried out at Saturne using the SPES 3 facility[22]. The analyzing power and differential cross sections for the missing mass reaction $\vec{p}p \to \pi^- X$ have been measured at 1.45, 2.1 and 2.7 GeV incident energy. The analysis of the data is not yet completed.

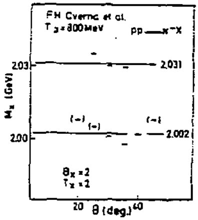

*Fig. 5 : Masses of structures in $pp \to \pi^- X$ data in Ref. 5.*

In conclusion, regarding all these data, structures could really be present at 2.00 and 2.03 GeV. It is clear that the available data have however to be confirmed (with better statistics) before claiming these structures for evident.

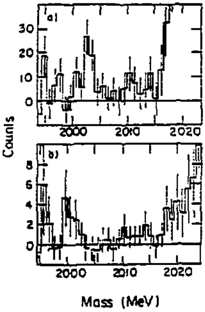

*Fig. 6 : Data from recent measurements at Lampf*[20] *:*
*a) $d(\pi^+,\pi^-)X$ and b) $d(\pi^-,\pi^+)X$.*

Finally long lived exotic dibaryons with charge − 2 (isospin T = 3) have been searched[21] at the laboratory of High Energies, Dubna. The fragmentation of 17.7 GeV/c alpha particles on carbon has been studied and an upper limit of $(E/p^2)\ d^2\sigma/d\Omega\ dp < 10^{-5}$ mb. GeV/ sr.(GeV/c)$^3$ was found for longlived ($\tau > 10^{-7}$ s) systems.

## 3. Tribaryons

It is well known since many years that three nucleon systems display a resonance − like behaviour at a few MeV excitation energy. This has been observed for instance in $^3H(p,n)ppn$ and $^3He(p,n)ppp$ reactions at 30 and 50 MeV[25] incident energies, or in $^3He(\pi^-,\pi^+)3n$[26] reaction at $T_\pi$ = 140 MeV. It was noticed[27] however that the attraction between two of the final nucleons can account for the observed structure which therefore has nothing to do with a three nucleon resonance. On the other hand multineutron systems have never been observed. There is a recent work[28] on transfer reactions studies with heavy ions incident beams, which concludes to an upper limit of 10 nb/sr.MeV for stable $^3n$. Again the SIN experiment[17] searching for $n^3\pi^-$ system was negative and upper limits published for $d^2\sigma/d\Omega\ dp$ are: $1.48 \times 10^{-38}$ cm$^2$/sr.(MeV/c) and $2.2 \times 10^{-38}$ cm$^2$/sr.(MeV/c) respectively for $n^3\pi^-$ and $n^3\pi^{-2}$.

An experiment has been performed at Saturne using a 2.7 GeV incident proton beam impinging on a lead target and the SPES 3 spectrometer. No negative charged particle with a mass close to 3 $M_N$ has been observed with an upper limit of 0.015 nb/sr/MeV (in the range $0.65 < pc < 1.35$ GeV)[22].

This leaves room for possible tribaryonic unstable resonances at excitation energies larger than 10−20 MeV. Such resonances have been predicted[1] within MIT bag model calculations. Some experiments have been carried on to look for such resonances. Table 2 summarizes these measurements. In an old experiment devoted to the study of $pd \to \pi^- X$ reaction[29], the authors assume the narrow peak observed at $p_{\pi^-}$ = 0.36 GeV/c to be a signature of a narrow dibaryon M = 2.161 ± 0.002 GeV ($\Gamma_{1/2}$ = 0.020 GeV) from a $p + n(p) \to \pi^- + X^{++} + (p)$ reaction. However, the Fermi momentum should extend this width ; a width of ± 150 MeV/c will contribute to ± 100 MeV for $\Delta M_x$. Since $\Gamma_x$ = 20 MeV here, we have to conclude that a tribaryon has really been observed at $M_x$ = 3.30 ± 0.003 GeV, $B_x$ = 3, $T_x$ = 3/2. The data corresponding to $^4He(\pi^\pm,p)X$ measurements[6] are not very precise (no error bars). If however we try to point out structures in these data (some shifts have to be done[7] between published and

*Table 2* : *Experimental studies for tribaryon search.*

| *Reaction* | $T_x$ | $M_x$ *(GeV)* | *Authors* | *Location* | *Ref.* |
|---|---|---|---|---|---|
| $pd \to \pi^- X$ | 3/2 | 3.30 ± 0.003 | J.H. Hall et al. | Birmingham | 29 |
| $^4He(\pi^\pm,p)X$ | 1/2 , 3/2 | 2.915 | J. Källne et al. | Lampf | 6 |
| $\pi^- C \to pppX$<br>$AC \to pppX$<br>$(A=p\ ,\ d,\ ^4He, C)$ | 3/2 | 2.91 ; 2.94 | H.N. Agakiskiev et al. | JINR | 31 |
| $\pi^- C \to pppX$ | 3/2 | 3.27 | O.B. Abdinov et al. | JINR | 32 |
| $^3He\ p \to n_F ppp$ | 3/2 | 3.05 | A.V. Blinov et al. | JINR | 33 |
| $pd \to \pi^- X$ | 3/2 | Analysis not completed | F. Hibou et al. | Saturne | 34 |

corrected data), a striking stability for a given missing mass appears at $M_X \simeq 2.915$ GeV. We have to remember however that in $^3He(\pi^\pm,p)X$ data the spread of the missing masses corresponding to the observed structures was important. Blinov et al.[30] -using 2.5 GeV/c tritons impinging on p- have studied invariant masses of $(p_F nn)$ and $(p_s nn)$ systems and found structures at 2.90, 2.94 and 3.01 GeV. They concluded however that these structures were not resonances since they were too strongly dependent on kinematical variations. Structures in the effective mass spectrum of three protons have also been observed for $M_t \approx 2.91$ and 2.94 GeV by Agakishiev et al.[31]. They used 40 GeV/c incident pions to study $\pi^- C \to ppp + X$ reaction, and 4.2 GeV/c/A p , d, $^4He$ and $^{12}C$ on $C \to ppp + X$ $(200 \leq p_p \leq 600$ MeV/c). A structure was also observed in the three proton invariant mass by Abdinov et al.[32] in the analyzis of 5 GeV/c $\pi^- + C \to ppp + X$ reaction, at $M_t = 3.27 \pm 0.02$ GeV, $\Gamma = 70 \pm 40$ MeV. Blinov et al.[33], using 2.5 and 5 GeV/c $^3He$ impinging on p, observed a structure in the three proton mass spectrum for 5 GeV/c incident $^3He$ particles. Since they were not able to describe it by the theoretical pole model calculation, they concluded that the structure at 3.05 GeV was not due to nucleonic degrees of freedom. Finally at Saturne, using the SPES 3 spectrometer, the $\vec{p}d \to \pi^- X$ reaction has been measured[34] using polarized protons at $T_p = 1.45$, 2.10 and 2.70 GeV. The final analysis of the differential cross sections for missing mass spectra and analyzing powers is not yet terminated. The masses of all previously quoted structures, candidates for tribaryons, are displayed in Fig. 7. The confidence we can have in tribaryon studies is clearly smaller than for isovector dibaryons. The precision is perhaps better for $M_t = 2.91$, 2.94 and 3.29 GeV.

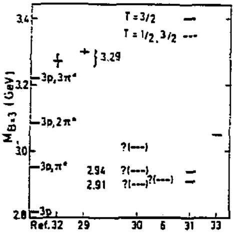

*Fig. 7 : Masses of structures candidate for tribaryons.*

## 4. Theoretical survey

In the framework of the cloudy bag model/24/, the masses found for six-quark resonances (M ≈ 2.6-2.7 GeV) are larger than those discussed in the present work. The width also are larger (≈ 50 MeV). A different calculation within a non relativistic quark model, has been recently presented/35/. Here again the found masses are larger than the predicted ones using the MIT bag model/1/, by 400 MeV for 6 quarks and 800 MeV for 9 quarks. Using a semiphenomenological diquark cluster model Konno and Nakamura/36/ found many states which degenerate to a single energy level. There is also degeneracy for isospin. In this model, the resonating energies and widths of the dibaryons with T = 1, $J^P = 1^-$ and $0^-$ are close to the masses and widths of the narrow dibaryons observed experimentally and discussed in the present paper. The model of stretched rotating (string-like) bags -with coloured quark clusters at both ends (a diquark and a four quark clusters) proposed by Kondratyuk et al./37/ predict many levels and particularly a T = 0 $J^P = 2^-$ with a low mass 1.95 - 2.05 GeV -not far from our candidate at 1.93 GeV. Bazhanskij et al./38/ within the assumption that many dibaryonic resonances exist with a width close to 20 MeV, developed a statistical calculation showing that interferences -depending on the observables-lead to narrow peaks. Such description leaves some unexplained questions : why are similar narrow peaks not observed in NN data ? And why is the spread observed under 2 GeV, not really observed above ?

## 5. Conclusion

There is experimental evidence for narrow structures at well defined masses in the T = 1 dibaryon sector. The evidence is not strong enough for the T = 0 or 2 dibaryons and for tribaryons. The structures observed in all cases are often tinny effects lying over large physical background NN, NNπ, NΔ... It is then important to confirm the first observations by independent measurements. We have to increase the number of experiments and vary their nature in particular by measuring spin-dependent observables. We need :

1- angular distributions for some of the mostly excited $T = 1$ dibaryons ;

2- precise pp elastic scattering in the range $50 \leq T_p \leq 280$ MeV with small steps in energy ($\Delta T_p \cong 3$ MeV) in order to clarify the region $M < 2.015$ GeV. These two type of measurements 1 an 2 are important and should be performed as soon as possible ;

3- a search for possible dibaryons with larger masses, and particularly in the region $M \cong 2\ M_N + 3\ M\pi$ and $M \cong 2.7$ GeV ;

4- experiments in pure $T = 0$, 2 and 3 states ;

5- experiments in tribaryon sector.

We need also theoretical studies to specify masses and widths of multibaryonic states as well as dynamical calculations of the relative size of the multibaryon signal and of the background to explain why the structures appear for different reactions and incident energies.

Some narrow structures are really observed. Their identification to quark degrees of freedom remains the simplest explanation but it is still a working hypothesis.

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