BARYON-BARYON INTERACTION OU ”LE MYSTÈRE DE DIBARYON”

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Abstract
At the present conference there were about 40 contributions among which 11 oral presentations and several plenary talks which addressed the topic of baryon-baryon interactions or dibaryonic structures. In this summary an attempt is made to arrive at a definition of what constitutes a Dibaryon and to point out in which framework the discussion of dibaryonic structures are relevant. A fragmentary excerpt of some recent results is given.

I. Introduction
The issue of Dibaryons has a long and controversial history in strong interaction physics. It is characterized by many predictions, mainly based on some naive quark model of hadrons, and many experimental claims, mainly from inclusive reactions, few of which survived any scrutiny. It therefore seems appropriate to "go back to the basics" and try to define rather liberally, i.e. free of dogmatic prejudices concerning the physical interpretation, what really are dibaryons. This will be done in Section II. The next issue, i.e. the question how to establish dibaryons experimentally and a short discussion of the theoretical guidelines is the subject of Section III. Section IV is concerned with some of the recent results related to Dibaryons and the baryon-baryon interaction under the title: What did we learn about dibaryons at PARIS 90? Finally we will briefly review the ultimate motivation and the relevance of the investigation of dibaryonic structures or: Why should we care about dibaryons?
II. What really are Dibaryons?

As for any spectroscopic structure in strong interaction physics - whether one deals with simple hadronic systems such as mesons and baryons or with excitations of more complex systems such as nuclei - a Dibaryon is characterized by a set of quantum numbers which more or less also constitutes a "shopping list" of all one wants to know about a Dibaryon: First of all a Dibaryon is an object with baryon number $B = 2$; it has a more or less well defined excitation energy $E_x$ or mass $M$ and a total decay width $\Gamma_{tot}$. Most importantly it has a spin-parity assignment $J^P$ and a flavor assignment, like isospin $T$ or strangeness $S^*$. This should be backed by a phase shift analysis $\delta_p^F(E)$, showing a "counter-clock-wise" structure in the Argand-diagram, corresponding to a "pole in the 2nd-sheet", for some exclusive reaction. Finally this structure should preferentially be seen in different reaction channels, $|\psi\rangle$ like $NN, \pi\Delta, \gamma\delta$ etc., so that one can identify also the partial decay widths, $\Gamma_{\psi}$. Adopting this specification of what constitutes a Dibaryon we at least know two states, that meet these requirements, i.e. the ground state of the Dibaryonic spectrum: the deuteron with $J^P,T = 1^+,0$ and the proton-proton scattering resonance, also referred to as "$^3\text{He}^*$" with $J^P,T = 0^+,1$ with an excitation energy of less than 1 MeV.

III. How to establish a Dibaryon?

According to the "shopping list" given in the preceding section one can discern various stages on the way to establishing a dibaryon. Apart from a exploratory "Stage 0", which is just an orientation phase of "looking around for interesting features"

- **Stage I** should be the amplitude reconstruction for a given (exclusive) reaction to prove or disprove the existence of a "dibaryonic structure": $[\text{DB}]^\ast$.

- **Stage II** one should aim at a partial wave decomposition or a sufficiently detailed Dalitz-plot-type analysis of the decay products in order to establish spin and parity of this structure: $[\text{DB}]^{**}$. 

- The third phase, Stage III should confirm and enforce the quantum number assignments of stage II by an analysis of reactions with different entrance and/or exit channels in order to determine the partial decay widths, $\Gamma$. [DB]***.

IV. What did we learn about Dibaryon Resonances at PARIS 90?

According to the statements of the preceding two sections we can classify the status of the investigation of various exclusive reaction channels for dibaryonic excitations in the regime of excitation energies up to roughly 2 GeV as in Table I:

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<th>NN</th>
<th>$\pi d$</th>
<th>$\gamma d$</th>
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<td>NN</td>
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<tr>
<td>$\pi d$</td>
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<td>$\gamma d$</td>
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<tr>
<td>NN$\pi$</td>
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... ... ... ...

The best established structures, which according to our classification would be of the stage II/III-type, have been seen in the region of 250 MeV $< E_x < 350$ MeV in the reactions:

$pp \rightarrow pp$

$pp \rightarrow d\pi$

$\pi d \rightarrow \pi d$
analyzed by the Saclay/Geneva group [1], by Arndt et al. [2], N. Stevenson et al. [3] and by D. Bugg [4]. The Argand diagrams and the so-called speed plots for the NN-partial waves $^1D_2$ and $^3F_3$ are shown in Fig. 1.

![Argand- and speed-plots of the $^1D_2$ and $^3F_3$ NN-partial waves](image_url)

**Fig. 1:** Argand- and speed-plots of the $^1D_2$ and $^3F_3$ NN-partial waves. Data are from [a,b].

Supported by amplitude and partial wave analyses of the other two reactions, a tentative interpretation of these resonances is provided in terms of $\Delta N$-quasi molecular states with quantum numbers $[\Delta N]^{1S_0}$ at $E_x \approx 245$ MeV and $[\Delta N]^{5P_3}$ at $E_x \approx 325$ MeV, i.e. shifted downward by $\Delta E_{2^+} \approx 55$ MeV and upward by $\Delta E_{3^+} \approx 25$ MeV compared to the $\Delta N$ total mass, respectively. Those two dibaryon resonances correspond to a total mass of approximately 2120 MeV/c$^2$ and 2200 MeV/c$^2$, respectively.

From the very same reactions there are also some indications for a structure at roughly $M \approx 2730$ MeV/c$^2$, which, however, at the present are still of the Stage I type. First of all a prominent energy dependence is found for the analyzing power at constant momentum transfer $t=0$ in the pp $\rightarrow d\pi$ reaction [5].
(see Fig. 2); secondly, at almost the same total energy also an anomaly in the
phases of the NN-elastic scattering amplitudes is found [1] (see Fig. 3); finally, also a slight bump in the total cross section at constant momentum
transfer $t=0$ is observed [5].

$$p (p, d) \pi^+$$

Fig. 2: Analyzing power $A_{\gamma o}(t=0)$ for the $pp\rightarrow d\pi^+$ reaction [5]

The interpretation of the structure(s?) is still an open question. At first
face they nicely coincide with a prediction made by Lomon [6] on the basis of
a calculation of NN-scattering where, within an R-matrix approach,
[\sigma^2]-configurations are used to describe the short range behavior of the
hadronic wave functions. There still remains, however, the problem of the
coupling to other channels, like e.g. the $\pi\pi$-channel.

There also was some indication for a structure in the analyzing power for
elastic proton-proton scattering at $T_p^{(ab)} \approx 610$ MeV, observed at KEK by
Shimizu et.al.[7]. This, however could not be confirmed by a very recent, high
resolution, high statistics experiment at Saclay [8].
Finally, we turn to the results of "Stage 0"-type experiments. They mainly stem from missing mass measurements in the $^3\text{He}(p,d)X$-reaction, performed by Taticheff et al.[9], who reported indications of interesting structures at $M_X = 2122, 2156, 2196$ and $2236$ MeV/c^2. We also like to mention the interesting change in the angular distribution of the analyzing power with increasing energy in the $p p \rightarrow d \pi^+$-reaction as observed by Mayer et al.[10] and Bertini et al.[11].

V. Why should we care about dibaryons?

It is not very hard to prove that, as long as gluonic degrees of freedom are not relevant, every $B=2$ state can be described in terms of (properly anti-symmetrized) baryon-baryon states, where every baryon is (per definition) a $[q^3]$-color-singulett state. If one neglects in a first approximation, all effects of the baryon-baryon interaction and the possible effects stemming
from the quark Pauli-principle, one can depict the non-strange dibaryonic excitation structure as in Fig. 4.

Fig. 4: Unperturbed baryon-baryon spectrum.

From this picture it is clear that, apart from the $\Delta N$-resonances (discussed in section IV), due to moderately strong interactions (roughly of the order of the $\Delta N$-interaction) an appreciable mixture of various baryon-baryon configurations is to be expected. As a consequence of this, or also because of the Pauli-principle, the description in terms of baryon-baryon configurations might not be a very efficient one and it might be simpler to describe these excitations in terms of $[q^6]$-configurations. This is essentially a dynamical issue and, of course, intimately related to the nature of hadronic confinement. The key question, whether interacting baryons conserve their hadronic identity is something which can not be settled by the study of isolated simple hadrons. In my opinion this is the ultimate motivation for the study of dibaryonic systems. It should perhaps be remarked, that there might be no unique answer to this question: the relevance of the description in terms of dibaryonic molecules opposed to the $[q^6]$-"bag" treatment might vary with excitation energy or moreover even from state to state, analogously to the situation in nuclei where the coexistence of single-particle and collective excitat-
ions has been established.

As far as the theoretical predictions of dibaryonic structures are concerned we notice that of course there are no a priori results from QCD. Quark model calculations involve the R-Matrix method with a cloudy bag description of the short range $q^6$-wave function [6] or the resonating group method [12] based on potential models of hadrons. Coupled channel meson-exchange models [13,14] have been applied up to now only to the relatively low-energy $\Delta N$-resonances.

In any way, as a guideline for future investigations it is absolutely mandatory that such model calculations aim at a consistent description of the dibaryonic spectra, the decay properties and the related scattering observables, such that a comparison to sufficiently detailed data on the level of a partial wave analysis is possible.

It is evident that this major undertaking is not easily settled, because it heavily relies on systematic investigations, and requires a lot of physical intuition, high technical competence and perseverance. In this sense it also needs open minded PAC's.

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