DIBARYON RESONANCES IN PHOTON INDUCED REACTIONS

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I. Introduction

After the discovery of the J/ψ in 1974 QCD-motivated developments of the quark model proceeded rapidly and all exotic states became of special interest. Under this aspect, dibaryon states are particularly significant if the 6 quarks can not be grouped into two clusters of 3 quarks within which the colour forces are saturated. Such a state shall be called a hadron-like (or bag) dibaryon. In this context it is of fundamental interest why nature prefers the closure of the colour forces in 3q-systems rather than in 6q-systems.

In addition the existence of 6q-states in the nucleus or the excitation of B^2-states from a nucleus might give important contributions to the understanding of the nucleon-nucleon interaction and the nucleon structure. Here the interpretation of the repulsive core is one of the problems motivating the dibaryon search.

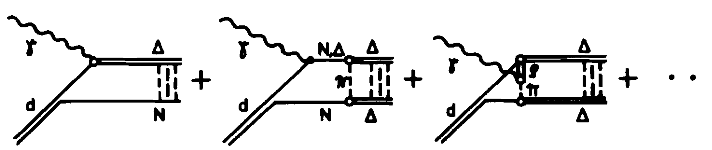
For reasons of simplicity under experimental and theoretical aspects mainly the deuteron has been investigated, although in principle more dense nuclei are preferable for the search of multiquark systems. According to the ideas of C. DeTar (1), V. Matveev, P. Sorba (2), H. Høgaasen, P. Sorba, R. Viollier (3) and others, the deuteron may have a 6q-bag admixture. In C. DeTar's calculations the "bag-deuteron" has a repulsive core due to a repulsive magnetic-gluon interaction.

In terms of the wave function of the deuteron V. Matveev, P. Sorba, H. Høgaasen, and R. Viollier calculate the composition of the deuteron:

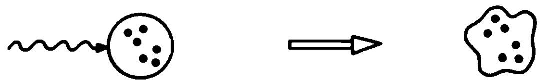
$$|d\rangle = \alpha|pn\rangle + \beta|6q\text{-state}\rangle$$
$$|6q\text{-state}\rangle = a|3q,[1]_c\rangle|3q,[1]_c\rangle + b|3q,[8]_c\rangle|3q,[8]_c\rangle .$$

Here the colour octet part is particularly interesting. The authors estimate its contribution to the deuteron to 5.6 %. There are two possibilities for the excitation of the deuteron to a B^2-state.

i) The excitation of a "deuteron like" dibaryon:



ii) The excitation of a "hadron like" bag dibaryon:



The experimental verification or exclusion of either possibility will help to clarify the above mentioned questions.

In photon induced reactions the first experimental motivation for the dibaryon search came from Tokyo measurements in 1975 (4). For the reaction $\gamma+d \to p+n$ they found a surprisingly high proton polarization $P \simeq -.8$ around $E_\gamma = 550$ MeV at $\Theta_{CM} = 90°$ [Fig. 1]. This behaviour can not be explained with conventional analyses of the reaction (see (4)). T. Kamae, T. Fujita (5) gave a first phenomenological explanation by postulating a bound $\Delta\Delta$-state at $m = 2.38$ GeV.

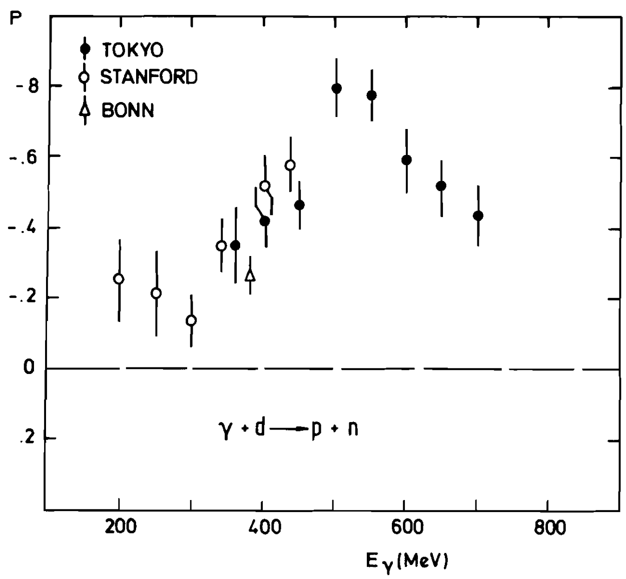


Fig. 1 Proton polarization in $\gamma+d \to p+n$ at $\Theta^{CM} = 90°$

II. Dibaryon Candidates from Non-Photon Induced Reactions

The general interest in B^2-resonances was strongly enhanced after the first publication of p-p scattering results from Argonne (7). Since then, most of the indications for B^2-candidates came from nucleon-nucleon scattering experiments. Here many data are available, cross section data as well as measurements of polarization parameters. These data allow rather reliable phase shift analyses. In spite of this, the discussion is still controversial mainly due to the question of cusp effect's influences (opening of the $N\Delta$-channel). For the purpose of this talk a list of those dibaryon candidates which are also under discussion in photon induced reactions will do.

Isospin I = 1 B^2_1-candidates

m [GeV]	Γ [MeV]	$^{2S+1}L_J$	J^P	Candidate in γd → pn analyses	Comment
≃ 2.14	50-100	$^1D_2$	2^+	Tokyo-Nagoya	cusp?
≃ 2.22	150	$^3F_3$	3^-	Tokyo, Tokyo-Nagoya	
≃ 2.43	150	$(^1G_4)$	(4^+)		

The situation is especially controversial with respect to the $^1D_2$ (2.14) candidate. Some authors (8), (9) claim the observed structures in the data to be due to cusp effects.

Isospin I = 0 B^2_0-candidates

m [GeV]	Γ [MeV]	$^{2S+1}L_J$	J^P	Candidate in γd → pn analyses	Comment
≃ 2.25	≃ 100	$^3D_3(^3D_1)$	$3^+(1^+)$	Tokyo, Tokyo-Nagoya	with different m ≃ 2.36
≃ 2.19	≃ 50	$^1F_3$	3^-	Tokyo-Nagoya	

For a more detailed discussion on more candidates we refer to the review of A. Yokosawa (7) and the recent article of P. Kroll (33).

The pion-deuteron scattering experiments support dibaryons from N-N scattering analyses. K. Kanai et al. (12) additionally propose a ($J^P = 0^+$, m = 2.5 GeV) resonance, but it seems to be doubtful whether Glauber model calculations are reliable enough in the backward hemisphere. A SIN-group (13) has calculated the interference of B^2-resonances with Faddeev-amplitudes for elastic π-d scattering. They took into account the three I = 1 candidates mentioned above. New SIN target asymmetry data (14) at T_{π^+} = 256 MeV are consistent with a strong $^1G_4$ resonance (15) whereas the measurements at T_{π^+} = 142 MeV do not require the $^1D_2$ candidate [Fig. 2].

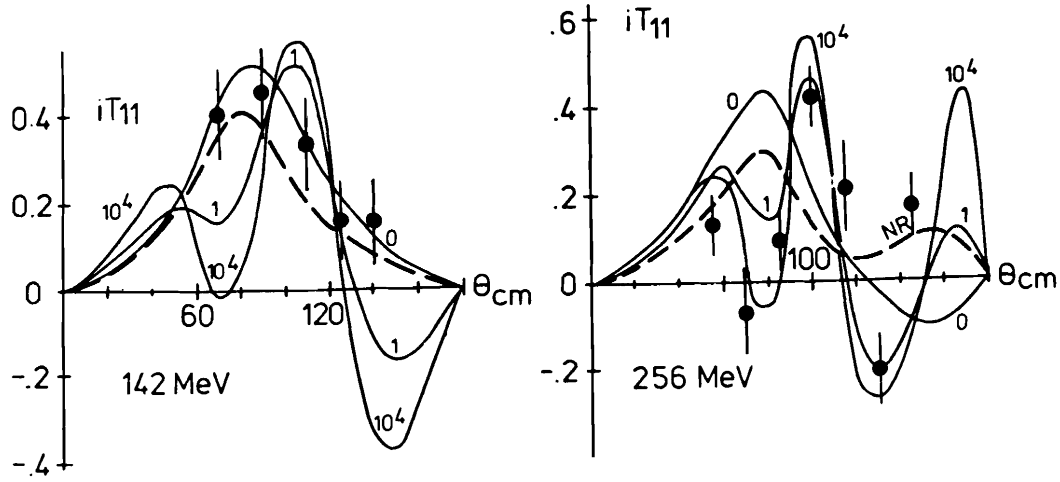


Fig. 2 The vector polarization in $\pi+\vec{d} \rightarrow \pi+d$ scattering at two pion energies. The curves are marked by the channel strength parameter (see (13)). Data points from (14).

III. Dibaryon Candidates in Photon Induced Interactions

Experimental activities in the dibaryon search in photon induced reactions are being done mainly at Tokyo, Saclay, Kharkov, and Bonn. The reactions under investigation are:

$$\gamma + d \rightarrow p + n$$

$$\gamma + d \rightarrow p + N + \pi \quad .$$

The covered mass range for B^2-candidates is between 2.05 and 2.5 GeV.

III.a) The Reaction $\gamma+d \rightarrow p+n$

This reaction is described in terms of 12 amplitudes. Most commonly used are the helicity amplitudes which are to be fixed via the measurements of the observables. For the relation between amplitudes and observables see Ref. 25. Measurements exist for the differential cross-section $d\sigma/d\Omega$ and three single-polarization observables:

The target asymmetry for the disintegration from a vector polarized d-target with unpolarized photons:

$$T = \frac{3}{2}\,\frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^0 + d\sigma^-}$$

where $d\sigma^+$ and $d\sigma^-$ are the cross sections for the reaction from deuterons polarized up and down perpendicularly to the production plane .

The beam asymmetry for the disintegration from unpolarized deuterons with linearly polarized photons:

$$\Sigma = \frac{d\sigma_{\perp} - d\sigma_{||}}{d\sigma_{\perp} + d\sigma_{||}}$$

where $d\sigma_{||}$ and $d\sigma_{\perp}$ are the cross sections for photon polarization parallel and perpendicular to the production plane;

The polarization of the proton with unpolarized particles in the initial state:

$$P = \frac{d\sigma^{+} - d\sigma^{-}}{d\sigma^{+} + d\sigma^{-}}$$

where $d\sigma^{+}$ and $d\sigma^{-}$ are the cross sections with the proton spin up and down perpendicular to the production plane, $d\sigma^{+}$ is defined by the direction $\vec{k}\times\vec{p}$.

Besides the measurements of these four observables no other experiments, for instance double polarization experiments, have been carried out. Compared to the number of observables the number of experiments is still deplorably small, too small to allow reliable analyses.

III.b) The Measurements of the Reaction $\gamma+d \rightarrow p+n$

A survey of the experimental status of the $\gamma+d \rightarrow p+n$ reaction together with the positions of B^2-candidates is shown in Fig. [3]. Each point in the kinematics plane represents a measurement of the corresponding observable.

Contributed papers to this conference come from Nagoya (16) and Bonn (17), new data exist in addition from Hiroshima and Bonn groups ((18), (19), (20), (21)). The new experiments are listed in table 1.

Table 1

Observable	Method	Photonenergy	θ_p^{CM}	Number of points	Institute	Reference
$d\sigma / d\Omega$	tagged γ, time of flight	200-460 MeV	24°-154°	$\approx$ 185	Bonn	(19)$^{+}$
$d\sigma / d\Omega$	tagged γ, magnet	180-600 MeV	15°-72°	$\approx$ 60	Hiroshima	(18)
$d\sigma / d\Omega$ $q^2 = -0.23$	missing mass spectrometer	280-520 MeV	$\theta_p^L = 90^{\circ}$	38	Bonn	(20)$^{+}$
T	deuterated butanol, magnet	300-700 MeV	$70^{\circ}, 100^{\circ}, 130^{\circ}$	$\approx$ 25	Tokyo-Nagoya	(16)
T	deuterated butanol, magnet	550 MeV	25°-60°	6	Bonn	(17)
Σ	goniometer, magnet	350-800 MeV	135°	$\approx$ 60	Bonn	(21)$^{+}$

$^{+}$: preliminary data

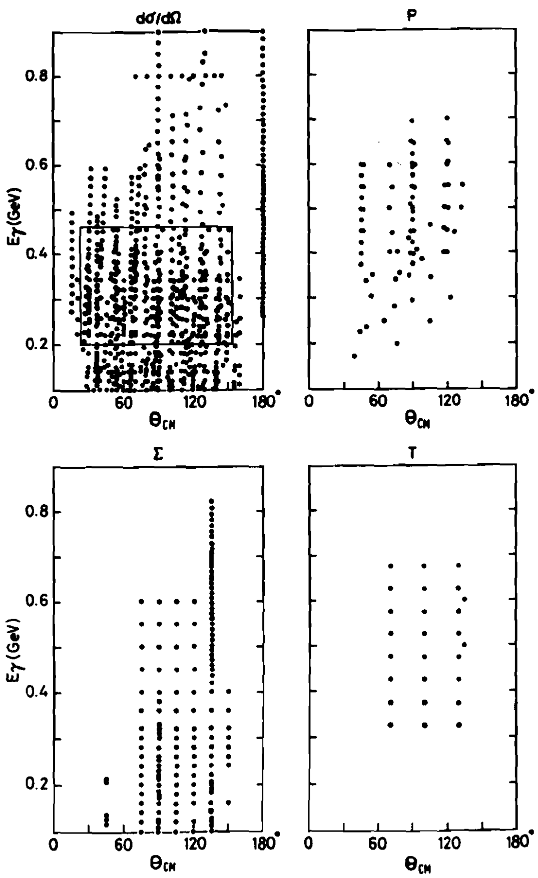


Fig. 3 Map of the measured data points for the observables dσ/dΩ, P, Σ, T for $\gamma + d \rightarrow p + n$. The shaded areas indicate the B^2-candidates under discussion. The framed area corresponds to the new Bonn measurements (19).

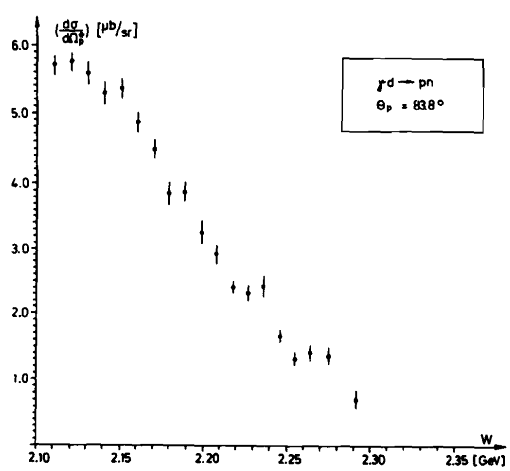


Fig. 4 Cross section data for $\gamma + d \rightarrow p + n$ with real photons

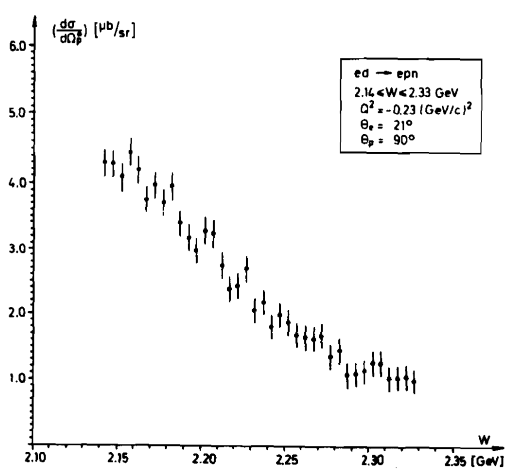


Fig. 5 Cross section data for $\gamma + d \rightarrow p + n$ with virtual photons

Results from these measurements together with different analyses are shown in the subsequent figures. The cross section data show no direct evidence for any dibaryon resonances. As an example new Bonn measurements with real and virtual photons are given in Fig. 4 and Fig. 5. Both excitation curves have obviously the same shape.

All analyses have in common the difficulties in fitting even the gross behaviour of the cross-section data for real photons, particularly at small and very large angles. Besides this, the number of data points for the polarization observables is still much too small to fix the analyses and to allow definitive statements about B^2-candidates.

Comparison of the analyses with the data

Here we will restrict ourselves to three analyses for the reaction $\gamma + d \rightarrow p + n$: the Tokyo analysis (24), the Bonn analysis (25), and the Tokyo-Nagoya analysis (16).

The Tokyo analysis is based on the work of K. Ogawa et al. (23) and takes into account the Feynman-graphs shown in Fig. 6 inside the dashed line: the nucleon pole, the pion reabsorption amplitude and two s-channel B^2-resonances. The pion reabsorption amplitude is calculated using the on-shell single pion photoproduction amplitudes given by Moorhouse, Oberlack and Rosenfeld (26). For the dibaryon contribution they tried to get a best fit with a minimal number of B^2-resonances and to determine the quantum numbers of the candidates from the fit. With two B^2-candidates they obtain the best fits with the following solutions:

Isospin $I = 1$: $J^P = 3^-$, $m = 2.26$ GeV, $\Gamma = 200$ MeV

Isospin $I = 0$: $J^P = 1^+$, $m = 2.35$ GeV, $\Gamma = 340$ MeV

or $J^P = 3^+$, $m = 2.36$ GeV, $\Gamma = 240$ MeV

(The $I = 0$ resonance was originally proposed by T. Kamae and T. Fujita to explain the first Tokyo measurements of the proton polarization.)

The differential cross section data from Lund (28) as input in these fits are reproduced rather well whereas new measurements from a Hiroshima group at the INS at Tokyo (18) and from Bonn (19) show strong deviations, especially at small angles. The analysis is in good agreement with the older proton polarization $P(\Theta)$ measurements (see (27)), whereas new target asymmetry $T(\Theta)$ data from Tokyo-Nagoya [Fig. 7] as well as from Bonn [Fig. 9] deviate substantially from either solution. The same holds for the new beam asymmetry $\Sigma(\Theta)$ data (21) from Bonn [Fig. 11].

The main intention of the Bonn analysis (25) is to investigate the reliability of deuteron photodisintegration calculations. For that reason this analysis avoids the use of on-shell MOR-amplitudes (26) and takes into account the graphs inside the full line in Fig. 6: the nucleon pole, the deuteron pole, and the pion reabsorption with nucleon and $\Delta(1232)$ exchange. The B^2-candidates under investiga-

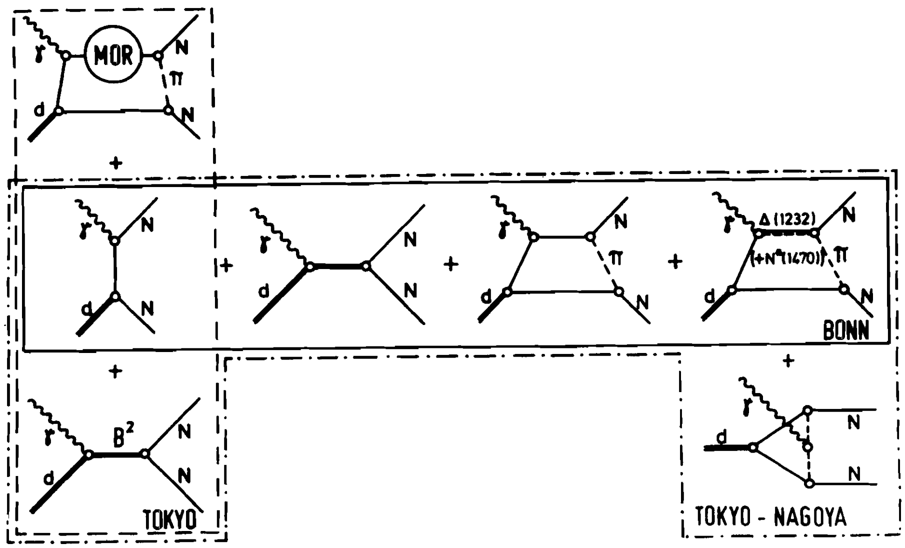


Fig. 6 The Feynman-graphs used in the various analyses discussed

tion are the same as used by the Tokyo analysis. This analysis is still in progress and considers especially the following questions:

How do the observables depend on the deuteron wave function?

Is an analysis without a correct relativistic implementation of the fermi motion reliable enough to determine B^2-candidates?

What influence do the different graphs have, in particular on the polarization observables?

At the present stage the analysis shows a fair agreement with the cross section data, the reproduction of the Σ- and P-values is not satisfactory. Target asymmetry predictions are rather good, even without B^2-contributions [Fig. 10].

The Tokyo-Nagoya analysis (16) follows the lines of Ogawa et al. (23) and the Bonn analysis, but includes additional graphs [Fig. 6] and the four dibaryon resonances given in table 2.

Table 2:

I	J^P	m[GeV]	Γ[MeV]
1	2^+	2.14	100
1	3^-	2.22	120
0	3^-	2.18	200
0	$1^+(3^+)$	2.38	200

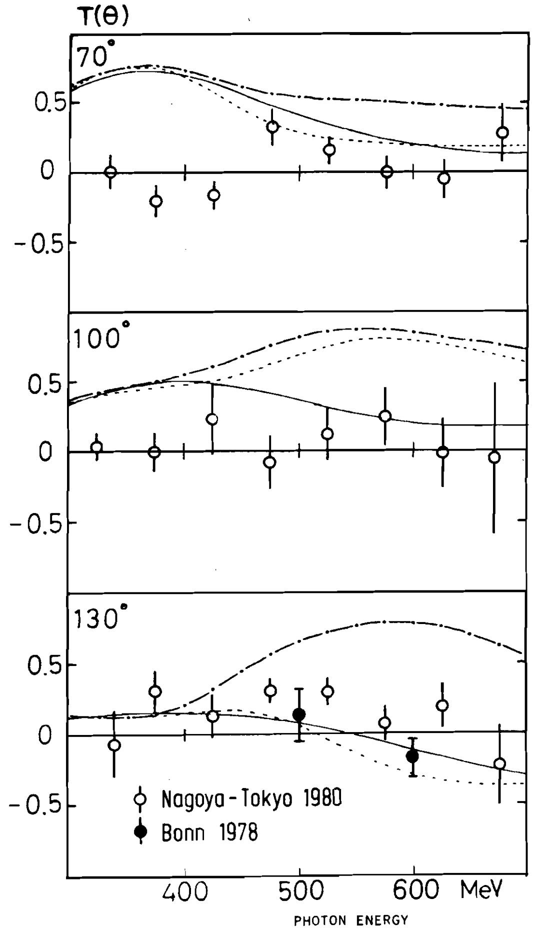


Fig. 7 Energy dependence of the target asymmetry T(Θ) (Ref. (16),(17)) compared with the Tokyo analysis (24):

—— NO B^2

-·- $1(3^-) + 0(1^+)$

--- $1(3^-) + 0(3^+)$

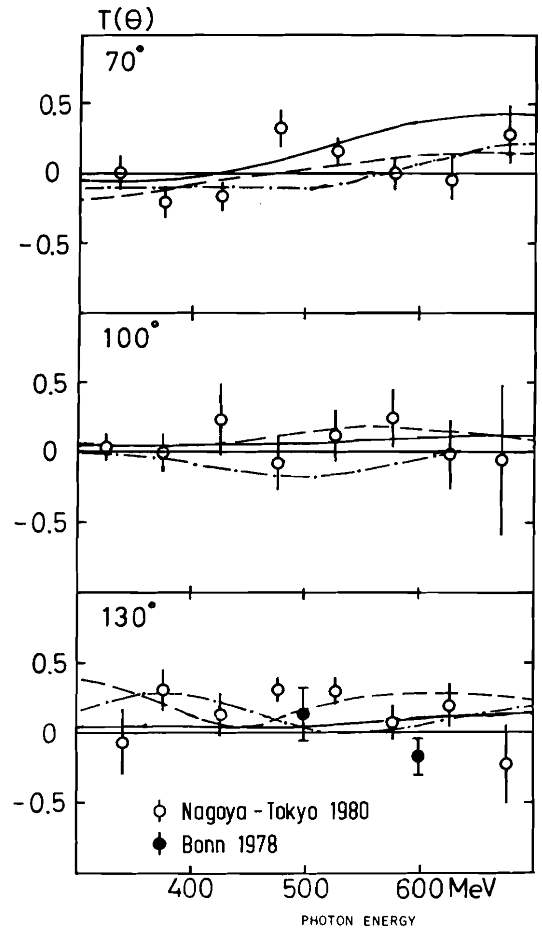


Fig. 8 Energy dependence of the target asymmetry T(Θ) (Ref. (16), (17)) compared with the Tokyo-Nagoya analysis (16):

—— NO B^2

-·- $1(3^-)+1(3^-)+0(3^-)+0(1^+)$

--- $1(2^+)+1(3^-)+0(3^-)+0(3^+)$

The first three candidates in table 2 are known from N-N scattering analyses, the fourth is the one proposed by T. Kamae and T. Fujita (5).

The agreement with $d\sigma/d\Omega$ - data can be seen in Fig. 12. Neither this analysis, nor the others lead to a solution, that really agrees consistently with the data. The energy dependence of the target asymmetry T(Θ) [Fig. 8] is, however, in good agreement with the existing data. The angular distribution of T(Θ) at 550 MeV [Fig. 10] can be matched only if B^2-contributions are introduced, in contrast to the Bonn analysis which fits at least the forward hemisphere without dibaryons. For the Σ(Θ)-behaviour [Fig. 11] the analysis is not so far away from the data as

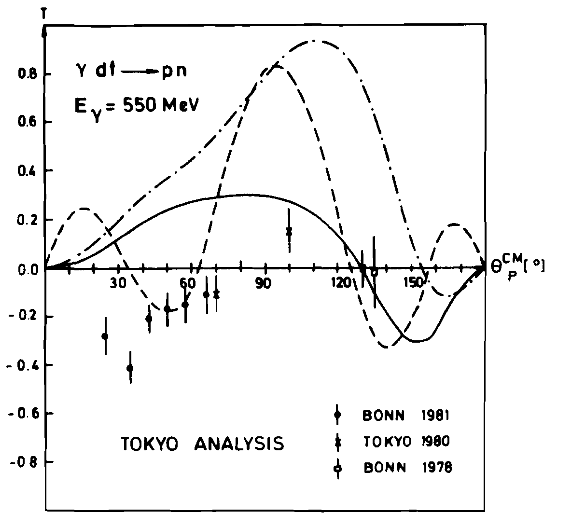


Fig. 9 Angular distribution of the target asymmetry T(Θ) for γ+d↑ → p+n (data points from (16),(17)) in comparison with the Tokyo analysis (24):

—— NO B^2

–·– $1(3^-) + 0(1^+)$

––– $1(3^-) + 0(3^+)$

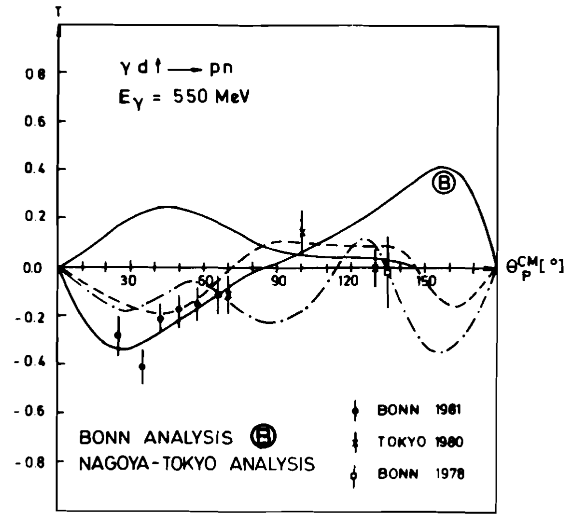


Fig. 10 Angular distribution of the target asymmetry T(Θ) for γ+d↑ → p+n (data points from (16),(17)) in comparison with the Bonn analysis (25) and the Tokyo-Nagoya analysis (16):

—— NO B^2

–·– $1(2^+)+1(3^-)+0(3^-)+0(1^+)$

––– $1(2^+)+1(3^-)+0(3^-)+0(3^+)$

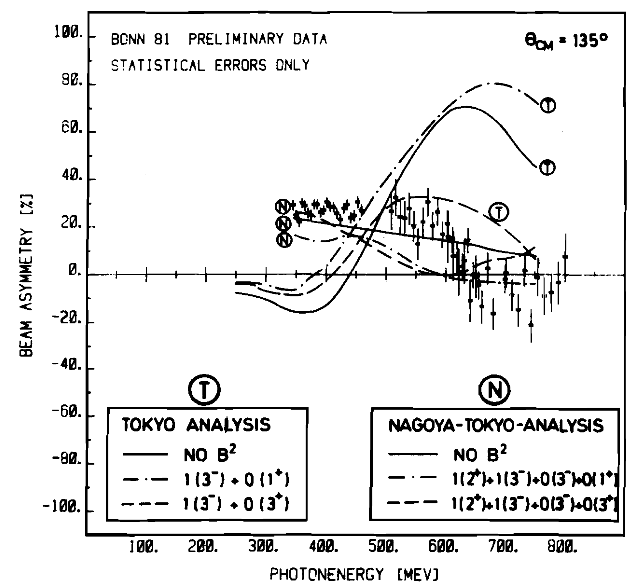


Fig. 11

Energy dependence of the beam asymmetry Σ for γd → pn for linearly polarized photons. Data points from Bonn (21). Analyses from Tokyo (24) and Tokyo-Nagoya (16).

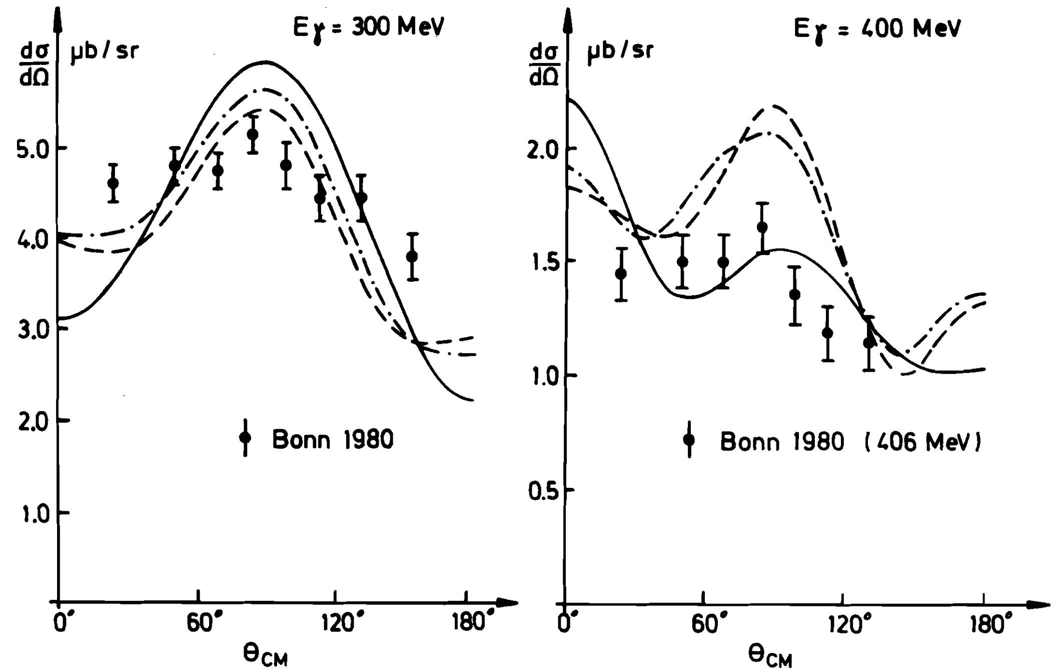


Fig. 12 Cross section data (19) for the reaction $\gamma d \to pn$ in comparison with the Tokyo-Nagoya analysis (16):

—— NO B^2

–·– $1(2^+) + 1(3^-) + 0(3^-) + 0(1^+)$

--- $1(2^+) + 1(3^-) + 0(3^-) + 0(3^+)$

for instance the Tokyo analysis.

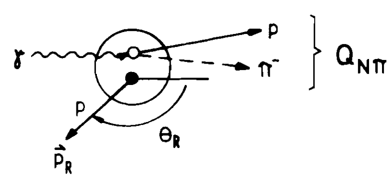
Conclusion for Dibaryon Candidates from Analyses of the Reaction $\gamma+d \to p+n$

The new Tokyo-Nagoya analysis gives the most reasonable fit to the data but includes the greatest number of dibaryon resonances. If one keeps in mind, that none of the analyses is able to fit even the cross section data in a convincing way and if in addition one looks at the big differences in the results of the analyses without B^2-contributions, - see for example Fig. 10 and Fig. 11 - then it is questionable whether an introduction of B^2-candidates is sensible on this basis or not. Despite the obvious inadequacy of all existing analyses, there probably are regions in the different observables where there is no way to fit the data by conventional means, thus indicating the existence of something exotic. The well known P(Θ) bump at 90° around E_γ = 550 MeV is an example. But in order to obtain reliable statements on B^2-candidates much more work about the approximations used in the analyses and much more experimental data are needed. So at the moment the introduction of more B^2-candidates results primarily in more parameters and does not increase the reliability of the conclusions. In summary, we are still far away from a really conclusive statement about B^2-resonances in the reaction $\gamma+d \rightarrow p+n$.

III.c) Inclusive Measurements $\gamma+d \rightarrow p+X$ and the Reaction $\gamma+d \rightarrow p+p+\pi^-$

Measurements with more than two particles in the final state have been performed by Saclay, Bonn and Hiroshima groups. There are essential differences between these measurements and the deuteron photodisintegration. In the $\gamma+d \rightarrow p+n$ experiments hints for dibaryons come mainly from the polarization data, whereas in these experiments the cross section data and mass distributions give direct indications for B^2-states.

First results came from a Saclay measurement (30) of the reaction $\gamma+d \rightarrow p+p+\pi^-$. This experiment was performed by detecting the pion and the proton with the higher momentum. The momentum of the recoil proton p_R and the mass $Q_{N\pi}$ of the pion-fast proton-system were kept constant. Under these conditions a change of the recoil angle Θ_R leads to a variation of the photon energy E_γ. Fig. 13 shows the result for $Q_{N\pi}$ = 1245 MeV and p_R = 150 MeV/c. A destinct bump around $E_\gamma \simeq 410$ MeV can not be explained in the framework of quasifree production. For a small



value of p_R = 50 MeV/c the quasifree approximation is excellent. The authors take this behaviour as an indication for a dibaryon candidate. In principle, it might point also to the existence of an exotic resonance in the recoil proton-pion system as well.

The second Saclay experiment (30) tries to be more insensitive to possible interference effects and looks therefore at the photon-energy dependent rate of the process

$$\gamma + d \rightarrow p + X .$$

Here the momentum and production angle of the detected proton were fixed. The photon energy was varied by changing the endpoint energy of the linac. Since only a bremsstrahl-spectrum and no monochromatic photon beam was available, a s-channel B^2-resonance will lead to a step in the cross section data. The results are presented in Fig. 14. The arrow indicates the detection threshold for the one pion production at the chosen kinematics. At lower energies only the photodisintegration contributes. For the photodisintegration no step is to be seen, but in the $\gamma+d \rightarrow p+\pi+N$ case there are indications for a step in the yield. The deviation of the data (solid curve) from the quasifree calculation (dashed curve) is taken as

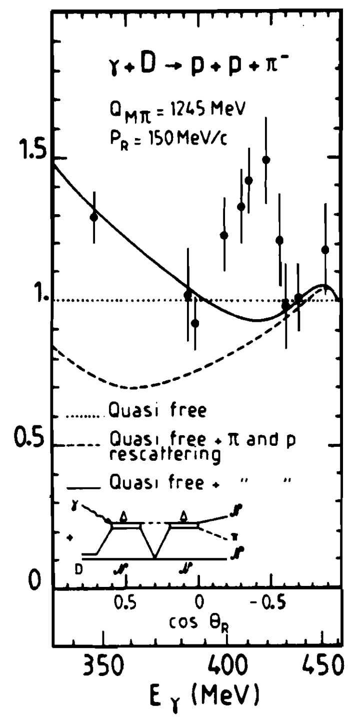


Fig. 13

Ratio of measured counting rate to the first order quasi-free calculation of Laget (see ref. 30)

an argument for a B^2-resonance at E_γ = 390 MeV with a width of about 40 MeV. The energy integrated cross section over the resonance is given as .39 ± .039 MeV·μb/sr·(MeV/c) corresponding to a total cross section of ≈ 38 μb for Γ = 40 MeV, assuming phase space decay.

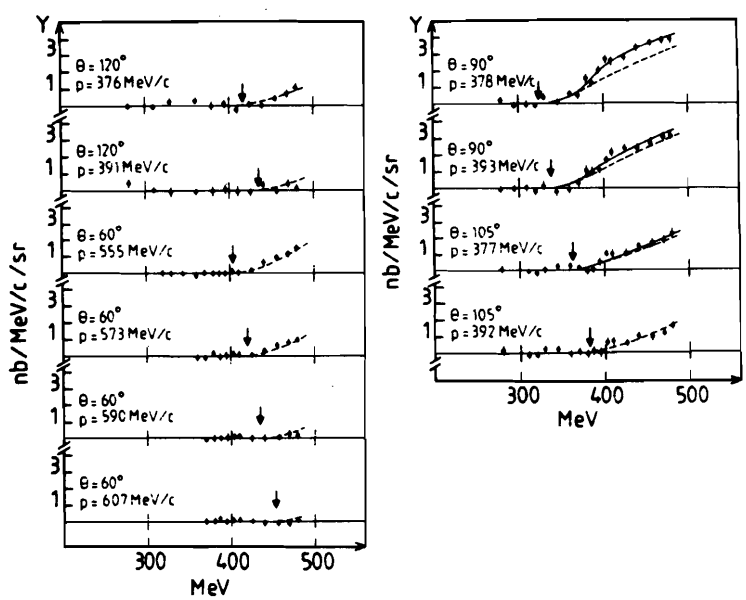


Fig. 14

Measured yield of the reaction γ+d → p+X as a function of the bremsstrahlung end point energy

A SIN-Saclay-Grenoble (30) collaboration has performed a corresponding experiment with pions instead of photons in the initial state:

$$\pi^+ + d \rightarrow p + X .$$

The result [Fig. 15] shows no indication for a B^2-contribution. The small bump in the region of the expected resonance moves with the momentum of the detected proton and can not be connected with a s-channel B^2-contribution, but a pion-recoil proton resonance can not be excluded. Bonn group (31) has measured the differential cross section for $\gamma+d \rightarrow \pi+N+N$ with tagged photon beam in the kinematical region $200\ \text{MeV} \le E_\gamma \le 460\ \text{MeV}$, $18° \le \Theta_p^{Lab} \le 145°$. For the reaction $\gamma+d \rightarrow B^2(2.23,\ \Gamma=40) \rightarrow p+X$ they give the upper limit: $\sigma_T \le 30\ \mu b$.
The Hiroshima group (18) measured the inclusive reaction $\gamma+d \rightarrow p+X$ at $\Theta_p^{Lab} = (30 \pm 5)°$ but can give no statistically significant conclusions.

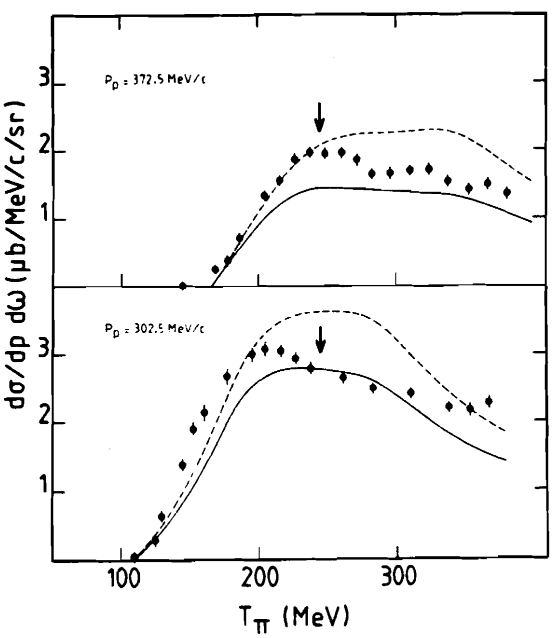
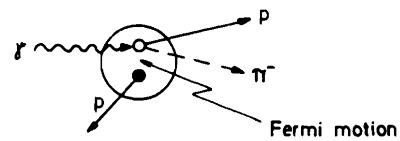


Fig. 15

Differential cross section for the reaction $\pi+d \rightarrow p+X$ vs. the pion kinetic energy at $\Theta_p^{Lab} = 90°$. The arrows indicate the pion energy corresponding to the total mass 2.23 GeV. The theoretical curves are calculations with different deuteron wave functions (34).

A second Bonn group (32) has measured the invariant mass distribution $M_{pp\pi^-}$ for the reaction $\gamma+d \rightarrow p+p+\pi^-$ in the mass region between 2.18 and 2.45 GeV. One proton was detected with a magnetic spectrometer at an angle of $\Theta_{p_1} \approx (60 \pm 6)°$ and the second proton with a time of flight hodoscope in the range $51° \le \Theta_{p_2} \le 87°$. The momentum of the first proton was 0.483 GeV ± 6%, that of the second proton $p_{p_2} \ge .300$ GeV.

Due to the kinematical setting and the $1/E_\gamma$ decrease of the bremsstrahlspectrum the acceptance of the apparatus has a maximum around $m = 2.21$ GeV. Therefore a possible B^2-contribution at $m = 2.23$ can not be seen directly, since it would only increase the maximum and shift its position by 10 MeV or so. For that reason a Monte-Carlo calculation of the background distribution from quasifree production has been performed, taking into account cross section data from $\gamma+n \rightarrow p+\pi^-$, the Fermi motion and the experimental acceptance.



It turned out that it was impossible to fit the measured mass distribution with the simulation by applying an overall normalization factor. In this case, a remarkable inconsistency always occured around $m = 2.23$ GeV.

The best fit of the measured distribution was obtained by adding the non-resonant background with an overall normalization factor and a B^2-contribution at $m = 2.23$ GeV with $\Gamma = 40$ MeV. The strength of this B^2-contribution resulted in $\sigma_T \simeq 3\mu b$, phase space behaviour presumed. Fig. 16 shows the measured $M_{pp\pi^-}$-mass distribution (upper curve), the overall normalized non-resonant background simulation (dashed line) and the resulting difference. Because of the uncertainties in the background simulation and in particular because of the acceptance behaviour further investigation is necessary. The group has therefore performed new measurements of the same type but with a different acceptance structure. The data are still under evaluation, the results will hopefully clarify the situation.

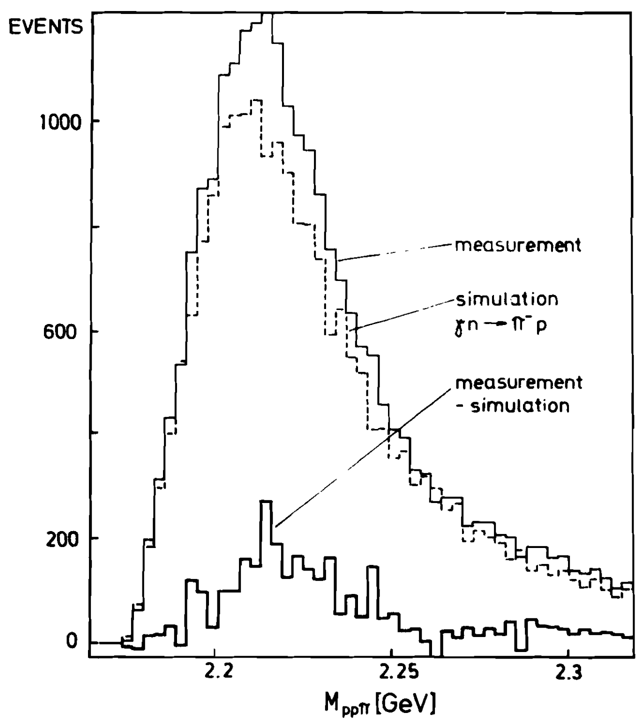


Fig. 16

Invariant mass distribution $M_{pp\pi^-}$ for the reaction $\gamma+d \rightarrow p+p+\pi^-$. The lower distribution gives the difference between the measured date and the background simulation.

Combining the Bonn and Saclay measurements there is some indication for a dibaryon at m ≈ 2.23 GeV with Γ ≈ 40 MeV. Since the SIN πd scattering experiment gives no positive result, an isospin I = 0 assignment seems plausible.

Conclusion for γ+d → p+N+π experiments

The B^2 (m ≈ 2.23 GeV, Γ ≈ 40 MeV)-candidate has now support from Saclay and Bonn but needs further confirmation. Their "first generation" experiments suffer from experimental limitations in particular from the small duty-cycles of the existing machines and the limited acceptance of the detectors. The open questions can be solved with large solid angle detectors which allow to take statistically relevant mass spectra without phase space limitations. That again requires a new generation of electron machines with high duty cycle for energy marked photon beams with sufficient intensity. This effort is necessary since the question is of fundamental interest for the dynamics of quark confinement and for the understanding of nuclear structure.

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Discussion

V. Hepp, Univ. Heidelberg: Concerning the search of γ-induced dibaryons in $\gamma d \rightarrow pp\pi^-$, I would like to ask: are there plans for 2^{nd} generation experiments at Bonn, where the outgoing π^- is identified and measured and the incoming photons are tagged?

W.J. Schwille: Yes indeed, there are projects of that type at Bonn. The main project is a multipurpose large solid angle detector together with a tagged photon beam. But this will take some years before going into operation. At short sight the group which has done the $\gamma d \rightarrow pp\pi$ experiments will try to improve the accuracy of the proton identification and additionally identify at least the direction of the produced pion by drift chambers.

G. Barbiellini, CERN: Is the proton-proton scattering an adequate channel for dibaryon search?

W.J. Schwille: In nucleon-nucleon scattering experiments Argonne has done a good job for the dibaryon search. I think experiments of that type should be continued, in addition here as well as in photon induced reactions one should look into the inelastic channels. In my opinion that might be a very promising task independent from any bag model predictions.