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A SEARCH FOR T = 0 DIBARYONIC RESONANCES
Experimental results on the $d + d \to d + X$ reaction

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Abstract

A search for isoscalar dibaryonic resonances by means of missing mass spectra in the $d + d \rightarrow d + X$ reaction has been attempted using deuteron beams of T = 2.29, 2.00 and 1.65 GeV. The results do not show any evidence for a narrow peak with a limit of 0.03 pb/MeV^2 for a 15 MeV width or a broad enhancement which could be unambiguously attributed to a dibaryonic resonance.

NUCLEAR REACTION d(d,d)X, T = 1.65, 2.00 and 2.29 GeV, measured missing mass spectra, deduced limit for possible dibaryonic resonance formation.

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1. Introduction

The first suggestion of a dibaryonic resonance phenomenon came from the Argonne proton-proton scattering experiments with polarized protons (1). Unanticipated structures were observed in the cross section differences $\Delta\sigma_L$ and $\Delta\sigma_T$ as well as other spin parameters. Several authors (2) interpreted these structures as the manifestation of isovector dibaryonic resonances :

$^1D_2$ $m \cong 2.17$ GeV, $^3F_3$ $m \cong 2.22$ GeV,

$^1G_4$ $m \cong 2.43$ GeV.

Later, a group from Tokyo (3) measured the proton polarization in the $\gamma + d \to p + n$ reaction, and to interpret their data introduced two dibaryonic resonances (an isovector one with $J^\pi = 3^-$ or 2^- and $m = 2.25 - 2.30$ GeV, and an isoscalar one (3^+ or 0^+) with $m = 2.38$ GeV). However more recent differential cross section for the same process due to Baba et al. (4) show that the cross section does not exhibit a peak in the forward region. This behaviour is not predicted by any of the existing models, even including the effect of dibaryonic resonances.

Another channel has been studied at SIN,namely the $\pi + d$ channel. Measurements of the cross sections, analyzing powers iT_{11} and tensor polarizations T_{20} have been done (5,6). The iT_{11} data show an oscillating behaviour,which is strongly energy dependant. Locher and Sainio (7) reproduced this behaviour by introducing two isovector dibaryonic resonances $^1D_2$ with $m = 2.20$ GeV and $^1G_4$ (or $^1S_0$) with $m = 2.48$ GeV. More recent iT_{11} data do not display these oscillations, but on the contrary exhibit a smooth variation with energy (8). Moreover, if one performs a calculation à la Locher and Sainio for the pion production channel $\vec{p} + p \to d + \pi$ at the same energy, one finds that $\sigma_{00}(\theta)$ and $A_{yo}(\theta)$ develop strong oscillations in complete disagreement with experimental results (9) . The results on T_{20} from SIN are inconsistent with those from Los Alamos (10). One awaits the results of a $\vec{p} + p \to d + \pi$ experiment in progress at Triumf. It seems premature to draw any definite conclusions from the existing data.

On the theoretical side, the study of the six quark cluster configurations $q^2 - q^4$ and $q - q^5$ in the MIT bag model leads to prediction for a number of states (11). Although some of the previously seen structures could perhaps coincide with those predicted by theory, it is first necessary to be convinced that no "conventional" calculations, i.e. without explicity introducing dibaryonic resonances, could reproduce the observed structures. Some calculations (12,13) showed that, at intermediate energies, the coupling to the Δ production channel can induce a pseudo-resonant behaviour of some partial waves.

One way to remove the ambiguity concerning the origin of the observed structures is to search for isoscalar dibaryons, whose mass is smaller than the $\Delta\Delta$ threshold.
The coupling to the $N\Delta$ channel is of course forbidden for isoscalar dibaryons. There has been until now no direct measurement of a reaction wich selects pure T = 0 dibaryon states, but only indirect inferences. For instance, the study of the $\gamma d \to \vec{p}n$ reaction led to simultaneous predictions for a T = 1 and a T = 0 state (3). Also $\Delta\sigma_L(pd)$ and $\Delta\sigma_L(pp)$ measurements allow one to extract $\Delta\sigma_L(pn)$ and hence $\Delta\sigma_L$ (T = 0). This indirect method led to the following states : $^1F_3$ with $m \cong 2.19$ GeV, 1^+, 3^+ with $m \cong 2.25$ GeV and $\Gamma \cong 100$ MeV (14). There are many theoretical predictions concerning isoscalar states. One can mention those of the MIT bag model (11,15) : $1^-(^1P_1)$, very unstable at 2.11 GeV ; $^3S_1$ at 2.15 GeV ; 1^+ at 2.16 GeV ; $(1^+, 2^+, 3^+)$, surely unstable, at 2.33 GeV ; $^3D_3$ at 2.34 GeV ; 3^+ at 2.36 GeV. A measurement in a pure T = 0 state was clearly needed, and was the object of the present experiment. Our method consists of the measurement of missing mass spectra for the $d + d \to d + X$ reaction (isospin $T_X = 0$), for missing mass values between 1.9 and 2.35 GeV under the following kinematical conditions :

incident kinetic energy	T (GeV)	2.29	2.00	1.65	1.65
or					
incident momentum	Pd (GeV/c)	3.72	3.39	2.98	2.98
deuteron angle	θ(°)	29	27	25.5	4

2. Description of the experiment

2.1. EXPERIMENTAL SET-UP

The experiment was performed at the Saturne National Laboratory. A liquid deuterium target of density 608 mg/cm^2 was used (16). The deuterons were analyzed with the SPES IV spectrometer. The momentum acceptance was $\frac{\Delta p}{p} = \pm 4$ % and the solid angle defined by a 40 cm lead collimator was $\Delta\Omega = 2.14\ 10^{-4}$ sr. The spectrometer is shown in fig. 1 and described in detail elsewhere (17).

The detection system (25) was composed of seven scintillation counters located in a plane orthogonal to the axis at the intermediate spectrometer image 16 meters from the target, an hodoscope of 44 scintillators, the momentum acceptance of each being 0.2 %, located at the final image (16 meters from the intermediate image), followed finally by 3 planes of seven scintillators each. A time of flight measurement over 16 meters (between the intermediate and the final images) and energy loss measurements in the five rows of scintillators lead to good particle identification.

The incident beam, the intensity of which is $1\text{-}2.10^{11}$ deuterons/burst, is monitored by three telescopes of three scintillators each. Two of the telescopes were aimed at an auxiliary target of 140 µm CH_2 located just below the D_0 dipole (see fig. 1). The third telescope was aimed at the liquid target ; a secondary emission chamber located between D_0 and Q_3 (below the auxiliary target) was used as well. The calibration of the monitors is done twice at each energy. For this purpose, a carbon target located near the liquid target was irradiated, and the decrease of ^{11}C from the $C(d,dn)^{11}C$ (natural target) reaction was studied (18).

Each measurement was performed with the liquid deuterium target and also with an empty target. This enabled us to deduce the back-ground due to the target walls, the windows and the air.

2.2. FOCAL RECOIL CORRECTIONS AND DISPERSION

Since a light target was used, there is a strong kinematical variation in the (horizontal) angular opening of the collimator.

The kinematical coefficient $K = \frac{1}{p} (\frac{dp}{d\theta})$ is large (a few units/rd) and the pseudo-focal moves back, goes to infinity, and comes back to the detection plane. As there is only one hodoscope in the final plane, it was necessary to bring the pseudo-focal back to the detection plane so as to improve the resolution and to be able to apply momentum independent and stable spectrometer geometrical cuts. These corrections have been done by modifying the strength of some quadrupoles (19). As foreseen, it was observed that the width of the elastic peak in $dp \to dp$ (at 2 GeV and 12° lab.) was reduced by half after the corrections. One consequence of these focal recoil corrections is that the dispersion D depends on k. The measured missing mass spectra are composed of several successive momentum bands. One gets these bands to overlap by varying the spectrometer field. Within one spectrum, K varies (from 0.89 to 1.40 at 2 GeV and 27° for example) ; the focal recoil corrections, as well as D, are different for each band. By fitting a linear form to the dispersion values measured by shifting the elastic peak throughout the focal plane, we obtained an analytical form for D as a function of K. By assumption, D has a constant value for one given band, but varies from one band to the next according to the formula :

$$D = 6.94 + 1.03\ K\ (\text{cm}/\%).$$

2.3. RELATIVE EFFICIENCY

The efficiency coefficients of each final hodoscope counter were determined in two different ways : i) via the sum of all the runs giving a continuous, regular and flat spectrum ; ii) via shifting of the elastic peak throughout the focal plane. Both methods gave very similar results : an inefficiency increasing gradually to 10 % for the extreme counters with respect to the central counters.

2.4. UNCERTAINTIES

There are two types of uncertainties :

i) those appropriate to each point or group of points in one spectrum. These result in statistical errors of order 2-3 %, relative monitor fluctuations of about 2 %, and target density fluctuations which are negligible (< 1 %).

ii) those which are global over a whole spectrum. They result from the uncertainty in the collimator size and the target-collimator outface length (± 2 % in the solid angle), the target thickness d(± 1 %), the uncertainty in the carbon target activity measurement and in the C(d,dn)^{11}C cross section (± 6 %). All these errors are independent. The linear sum of all the non-statistical errors leads to a systematic error ± 9 %, which is not included in the figures.

2.5. ABSCISSA CORRECTIONS

The missing mass spectra display an elastic peak which is not centered on the deuteron mass, but is shifted by a small quantity (< 10 MeV). The value of this shift can be understood by recalling the uncertainty in the incident energy (± 1 %), the angle (± 0.1°) and the absolute spectrometer calibration. Each spectrum in the aggregate was shifted by the same missing mass interval, equal to the difference between the elastic peak abscissa and the deuteron mass.

2.6. FINAL ANALYSIS STAGE

The measured spectra are presented as a function of the missing mass squared Mx^2. In each spectrum, consecutive momentum bands have been overlapped without any noticeable systematic effect. An average of all the data in an interval $\Delta Mx^2 = 0.02\ (\mathrm{GeV})^2$ was carried out taking into account the statistical uncertainty.

3. Experimental results

3.1. PRESENTATION

In figure 2,we show the missing mass spectra corresponding to the following kinematical conditions :

$T = 2.29$ GeV , $\theta = 25.5°$; $T = 2.00$ GeV , $\theta = 27°$ and $T = 1.65$ GeV, $\theta = 29°$. In figure 3, the missing mass spectrum corresponding to $T = 1.65$ GeV, $\theta = 4°$ is displayed. Tables of these results are found in ref. (19).

The invariant cross sections $\frac{E}{p^2} \frac{d^2\sigma}{d\Omega dp}$ (E and p are the deuteron total energy and momentum)empty target substracted, are shown as a function of Mx^2. The error bars are only statistical (without the effect of relative monitor fluctuations).

In the spectra of fig. 2, one observes the elastic peak as Mx^2 increases, as well as the quasi-free peak (the deuteron scatters on one of the two target nucleons, the other being a spectator in the laboratory). The quasi-free peak sometimes shows an irregular top. The two Δ production threshold is situated in this mass bin and may be responsible for this irregularity. Although the free $(\Delta\Delta)$ mass is about 600 MeV above the deuteron mass, it is conceivable that $\Delta\Delta$ bound states could appear in the mass region we have studied. Such $\Delta\Delta$ bound states have been anticipated by H. Sato and K. Saito, who calculated $\Delta\Delta$ binding energies with a one boson exchange potential including a tensor term (20).

For small angles (fig. 3), the quasi-free peak is very near the elastic peak. Small angle measurements are then more appropriate to the study of missing masses above 2.2 GeV ($Mx^2 = 4.84$ GeV^2). Some of the experimental data was omitted. These data involved deuterons which lost around 600 MeV in the 40 cm lead collimator. These deuterons were found on the focal plane. Apart from the elastic and quasi-free peaks, this spectrum is dominated by a large asymmetrical bump above the one pion production threshold. This bump is reminiscent of the one observed,by Baldini et al.(21)

in the dp $\to$ dX reaction and attributed to single Δ formation. In analogy to this, we could also try to attribute our bump to single Δ formation. If one evaluates the ratio of the elastic peak height to the height of the bump for both reactions, under similar kinematical conditions, one finds the same order of magnitude. However in this missing mass region, there is considerable interference between different orders of multiple scattering (22), and great care is required before attributing the 4.4 GeV^2 bump to one Δ excitation.

3.2. THE QUASI-FREE PEAK REGION

One can evaluate the quasi-free scattering differential cross-section via a macroscopic approach in the PWI approximation, following the formula of Van Oers (23). Since particle X is not detected, one performs the integration over the corresponding variable. Taking an Hulthen momentum density for the deuteron S state, and

$$\frac{d\sigma}{d\Omega}\Big|_{pd}^{CM} \cong 4\ \mu b/sr \quad (Tp = 1\ \text{GeV},\ \theta_{CM} = 103.2°) \qquad (24),$$

one gets 140 μb/sr. GeV^2 for the maximum of the 2 GeV and 27° quasi-free peak ; the experimental value is 150 μb/sr.(GeV)^2. As can be seen from fig. 4, the shape of the curve is also not unreasonable. This process corresponds to first and second orders in the Glauber multiple scattering expansion. In the following article (22), it is shown that first and second order processes are indeed dominant in this mass region 5.3 - 6.3 GeV^2.

3.3. EXPERIMENTAL LIMITS FOR RESONANCE CROSS SECTIONS

Our experimental spectra show narrow discontinuities as large as five standard deviations involving a maximum of one or two points. These discontinuities don't appear at the same masses for the different incident energies, so no conclusions can be drawn. However, a cross section limit for possible dibaryonic resonance formation can be evaluated. To this end, let us choose the 2 GeV and 27° spectrum, close to Mx^2 = 4.67 GeV^2 (Mx = 2.16 GeV). These are theoretical suggestions for a resonance in this mass region. Let us suppose that a bump consisting of four consecutive points exists if these points are at least at three standard deviations from the average data. For a 15 MeV width (the elastic peak width), one gets the limit 0.03 pb/MeV^2 for resonance production.

4. Conclusion

We did not observe any narrow (less than several tens of MeV braod) structures in the missing mass spectrum for $d + d \rightarrow d + X$ with a limit of 0.03 pb/MeV^2.

The structures found by other authors (1,3) were very broad (100 - 200 MeV). It is difficult to estimate a cross section limit for the production of such a broad structure in our data. This is because the measured spectrum is not regular and it is first necessary to extract the purely nuclear contribution ($d + d \rightarrow d + p + n$). This has been done in the context of the Glauber model (22). The comparison of the theory and the data yield the following conclusions :

i) at small angles, the spectrum, in addition to the nuclear part, is composed of an asymmetrical bump which can be attributed to a one pion mechanism ;

ii) at large angles, one can hope that a purely nuclear model, more realistic than the one used here, can account for the observed spectrum. Here one also needs to estimate the contribution of the one pion mechanism, which appears clearly at small angle.

We have obtained no evidence for the existence of narrow isoscalar dibaryonic resonances. If this result is corroborated by more detailed studies, it could be a very important indication in favour of the thesis many authors maintain that the structures observed in isovector states are due to the $N\Delta$ coupling.

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FIGURE CAPTION

Figure 1 : Experimental lay out.

Legend : D = dipoles, S = sextupoles, MF = mobil frame, IFP = intermediate focal plane, TOF = time of flight, Q = quadrupoles, M = monitors, T_o, T_1 = two target positions, FFP = final focal plane

Figure 2 : Missing mass spectra corresponding to :
$T = 1.65$ GeV, $\theta = 29°$; $T = 2.00$ GeV, $\theta = 27°$;
$T = 2.29$ GeV, $\theta = 25.5°$

Data have been binned into 0.02 $(GeV)^2$ intervals. Error bars are only statistical.

Figure 3 : Missing mass spectra 1.65 GeV and 4°. Statistical error bars are smaller than the size of the points.

Figure 4 : Extract of the 2 GeV, 27° missing mass spectrum corresponding to the quasi-free peak region.
The continuous curve shows the result of a macroscopic calculation of the quasi-free diffusion and has been normalized on the top of the experimental quasi-free peak.

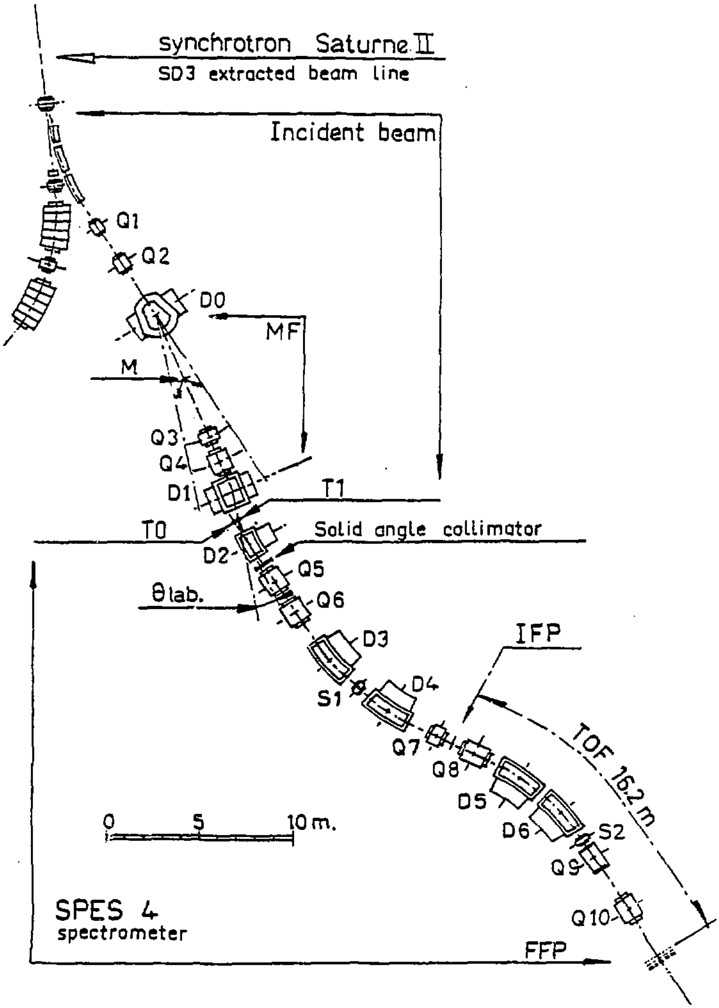
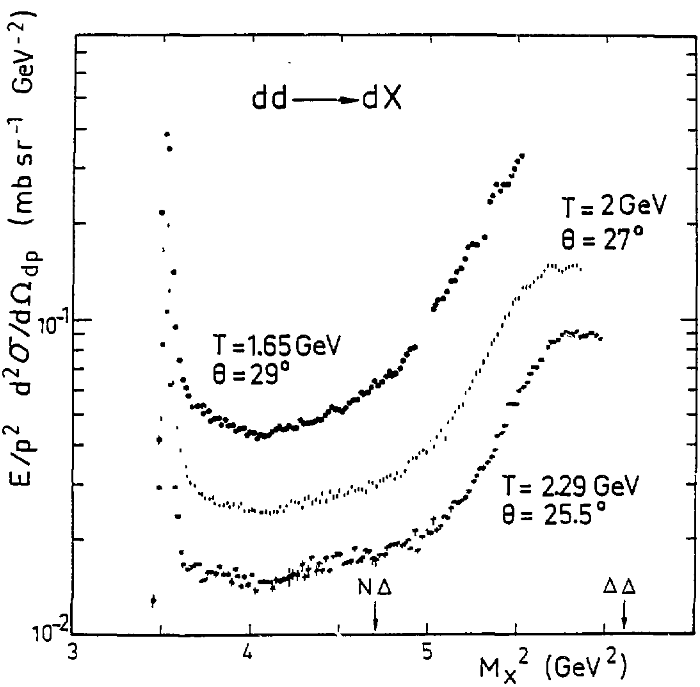

synchrotron Saturne II
SD3 extracted beam line
Incident beam
Q1
Q2
D0
MF
M
Q3
Q4
D1
T1
T0
Solid angle collimator
D2
Q5
θ lab.
Q6
D3
IFP
S1
D4
TOF 16.2 m
Q7
Q8
D5
0
5
10 m.
D6
S2
Q9
SPES 4
spectrometer
Q10
FFP

Figure 1



dd ⟶ dX
$E/p^2 \ d^2\sigma/d\Omega_{dp}$ (mb sr^{-1} GeV^{-2})
10^{-1}
10^{-2}
T = 2 GeV
θ = 27°
T = 1.65 GeV
θ = 29°
T = 2.29 GeV
θ = 25.5°
NΔ
ΔΔ
3
4
5
M_X^2 (GeV^2)

figure 2

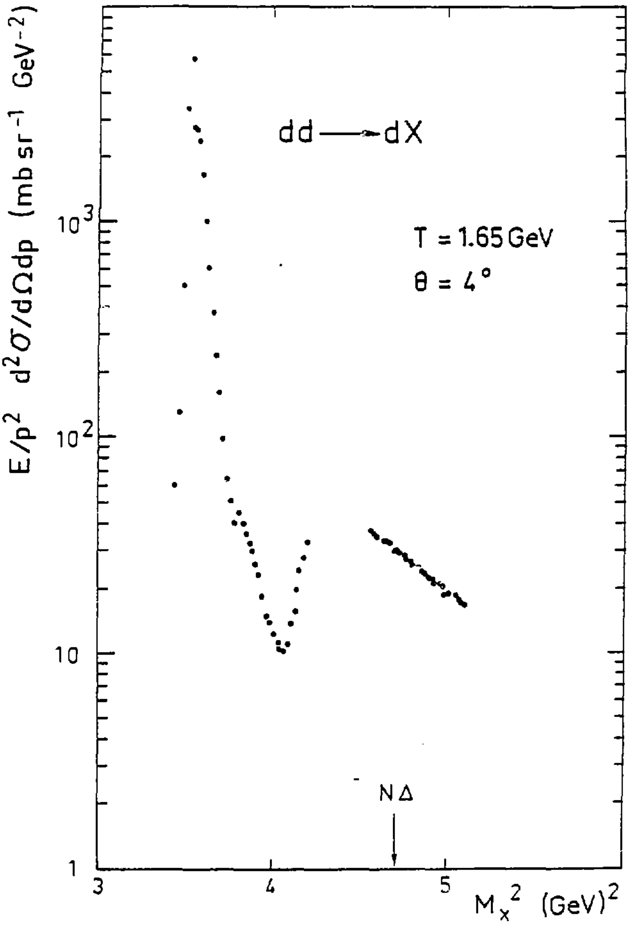

dd ⟶ dX
T = 1.65 GeV
θ = 4°
E/p² d²σ/dΩdp (mb sr⁻¹ GeV⁻²)
10³
10²
10
1
3
4
5
NΔ
Mx² (GeV)²

figure 3

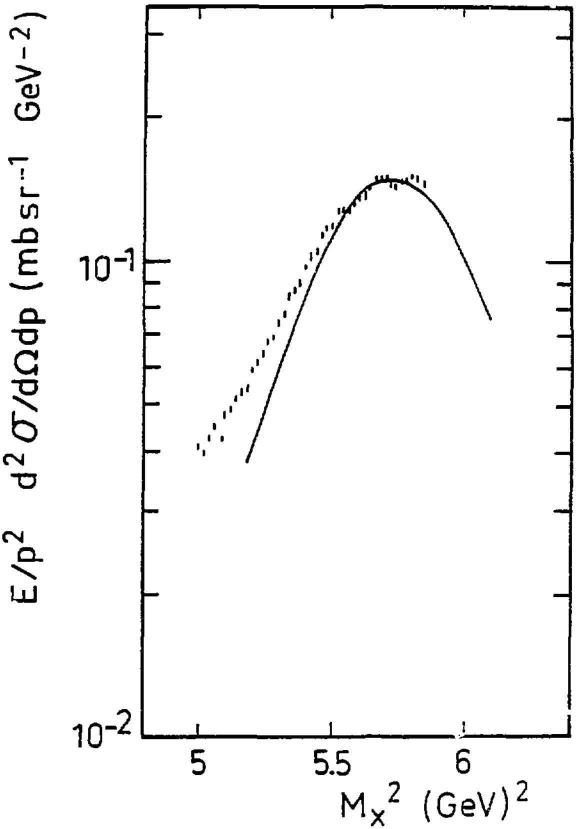


figure 4