Possible Evidence for Narrow States in Missing-Mass Spectra of the $B = 2$, $T = 1$ System

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The missing-mass spectra for the transfer reactions $p(^3\mathrm{He},d)X$ and $^3\mathrm{He}(p,d)X$ ($B=2$, $T=1$) have been measured at, respectively, $T_{^3\mathrm{He}}=2.7$ GeV and $T_p=0.925$ GeV. The data show a narrow structure lying on top of an important continuum, with a mass $M=2.240\pm0.005$ GeV and a width $\Gamma_{1/2}=0.016\pm0.003$ GeV.

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Since the measurements performed by Hidaka *et al.* and Kamae *et al.*[1] revealing structures in the polarization observables of protons resulting from deuteron photodisintegration, the analysis[2] of corresponding data and of many others has triggered interest in the question of the existence of dibaryonic resonances. During past years, several authors analyzing various experimental results have reached positive conclusions on the existence of broad ($\Gamma_{1/2}\sim 0.1$–0.2 GeV) resonances, assigning corresponding masses and quantum numbers. However, more recently, new experiments[3-11] or discussions came to contradictory conclusions.

All these studies have been clearly stimulated by the predictions[12] of the Massachusetts Institute of Technology bag model and the resulting spectroscopy of many levels, generated by six confined quarks. The widths were not calculated. However, since the primary analysis of several measurements indicated large widths, experiments were developed to look for wide resonances in the initial state, in this instance, with large steps (a few tens of megaelectronvolts) in the variation of the incident energy.

It is generally believed that conventional calculations of the three-body problem using the Faddeev approach[13] for $NN\rightarrow NN$, $NN\rightarrow NN\pi$, and $NN\rightleftarrows \pi d$ describe more or less quantitatively the data. According to this belief we have to conclude that, since these models do not take into account possible color degrees of freedom, these—if any—could manifest themselves in the experimental results through narrow and weakly excited structures.

A few experiments have been devoted to the search for eventual narrow resonances ($\Gamma\lesssim 0.02$ GeV). The n-p total-cross-section measurement[14] with a missing-mass resolution $\Delta M=0.0014$ GeV has not been able to show any narrow structure. A broad anomaly was attributed to the $^3F_3(T=1)$ resonance. Neither the reaction $d(p_{\mathrm{pol}},p')np$ at $\theta_{\mathrm{lab}}=18°$ and $T_p=0.7$ GeV nor the reaction $\pi+d\rightarrow p+p$ at $\theta_{\mathrm{lab}}=75°$ have revealed[15] a narrow dibaryon resonance. However, in backward π-d scattering[16] the t_{20} data from the Swiss Institute for Nuclear Research present a peak located around 2.137 GeV and a width $\Gamma_{1/2}\leq 0.020$ GeV. In the study of deuteron breakup reaction at 3.3 GeV/c for nonspectator events, structures have been found at 2.020 GeV ($\Gamma_{1/2}=0.045$ GeV) and 2.13 GeV ($\Gamma_{1/2}=0.02$ GeV).[17] In the case of the search for narrow structures, some conditions have to be satisfied. Among them, we can enumerate the following: (a) inelastic scattering with large momentum transfers, needed to favor some new color distribution among the substructures of the $B=2$ system; (b) a high energy-resolution experiment; and (c) precise measurements with high statistics in order to pin down the eventual structures above a large background due to nonexotic processes. These conditions are fulfilled in a missing-mass experiment and one-nucleon–transfer process on light nuclei.

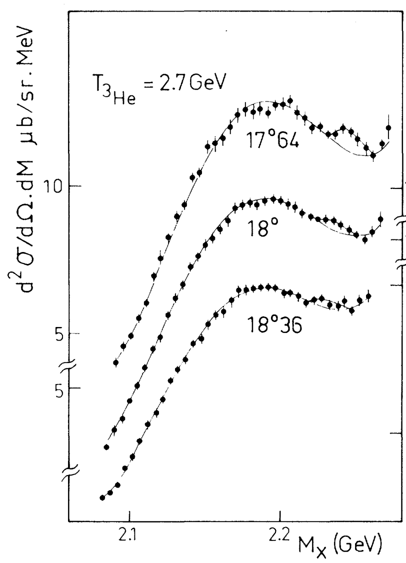

FIG. 1. Missing-mass spectra in doubly differential cross sections measured in the reaction $p(^3He,d)X$ (laboratory system). Data have been binned into 5-MeV intervals.

Doubly differential cross sections $d^2\sigma/d\Omega\, dM$ corresponding to the reaction $p(^3He,d)X$ ($B=2$, $T=1$) have been measured at the Saturne National Laboratory with use of the SPESI facility and standard detection.[18] The ^3He beam had typically an intensity of $(2\text{–}4)\times 10^9$ particles per burst. The calibration was done by means of the activation reaction $C(^3He,X)^{11}C$,[19] with use of $\sigma=57$ mb for the total cross section at this energy. Because of the extrapolation from low-energy calibration,[20] this last value is known with poor precision. There is also an overall absolute uncertainty due to the poor knowledge of the target bulging. These two effects produce an overall uncertainty of $\pm 30\%$. Continuous monitoring was accomplished by two telescopes and a secondary electron emission chamber. The relative stability between different runs was very good. For example the ratio of counts between a monitor and the secondary-emission chamber, for adjacent runs, was always better than $\pm 1.3\%$. The overall energy resolution is $\Delta M_X \approx 0.0022$ GeV, mainly due to the angular divergence of the incident beam on target (± 2.5 mrad). A cryogenic hydrogen target ($\rho d = 0.20$ g/cm^2) was used, and the contributions of the windows (empty target) were systematically subtracted. The ratio of empty to full target spectra, at $M_X = 2.24$ GeV, is typically 14%. The window spectra are flat and do not present any structure. The horizontal opening angle $\Delta\theta = \pm 0.179°$ was determined by cuts introduced during the analysis of raw data. The results are presented in Fig. 1. The errors are purely statistical. The information extracted from the spectra is summarized in Table I. First a large structure is clearly seen. Its precise mass and width values depend on the assumption made about background. The phase-space curves are smooth for pp, $p\Delta$ ($\Gamma_{1/2}=0.115$ GeV), or $pn\pi^+$ final states, but are unable to reproduce the broad structure. However, as the mass of this large structure is close to that of the ΔN system, it suggests to us that a more complete dynamical calculation should be done.

Second, a small and narrow structure is observed at 2.24 GeV. Since the momentum acceptance of the detection is close to 3.5%, each spectrum has been obtained by superposition of many measurements with slightly different central momenta corresponding to appropriate magnetic field settings of the spectrometer. We have checked that the removal of each individual run from the overall data leaves the results more or less unchanged, the structure remaining always there. To express the statistical significance of this narrow structure, and then to extract its location, width, and cross section,

TABLE I. Number of standard deviations (SD) from the background of the narrow structure and corresponding confidence levels (CL). The masses (M_X), total widths at half maximum ($\Gamma_{1/2}$), and cross sections ($d\sigma/dt$) correspond to the structure found at 2.24 GeV (see the text).

	Angle	SD	CL	M_X (GeV)	$\Gamma_{1/2}$ (GeV)	$d\sigma/dt$ (µb/GeV^2)
$p(^3He,d)X$,	17°64	3.10	99.8%	2.245 ± 0.002	0.016 ± 0.003	7.3 ± 2.0
$T_{^3He} = 2.7$ GeV	18°	1.40	83.8%	2.237 ± 0.002	0.015 ± 0.004	2.8 ± 1.1
	18°36	0.74	54.1%	2.232 ± 0.003	0.18 ± 0.007	2.5 ± 1.4
$^3He(p,d)X$, $T_p = 0.925$ GeV	40°	2.73	99.4%	2.243 ± 0.003	0.17 ± 0.006	1.3 ± 0.57

we have used the procedure usually followed in particle physics for resonance search.[21] After removal of the five data points lying in the narrow peak region (2.230 to 2.255 GeV), a fourth-order polynomial fit has been carried out for the whole spectra giving a value ≤ 0.45 for the normalized χ^2. Then without making any assumption on the shape of the bump, we have computed the number of standard deviations of the structure from the background. Finally, when we put back the data corresponding to the narrow structure, a Gaussian fit allows the determination of values (and precisions) of masses, widths, and cross sections given in Table I.

The same experiment had also been done with different kinematical conditions and background by inverting the incident particle with the target: $^3\mathrm{He}(p,d)X$. Some preliminary data have already been presented.[22] These data have been obtained with use of the same facility and detection. A more complete description of the experiment and of the data will be presented later.[23] The results with purely statistical errors are presented in Fig. 2. The information extracted from the spectra is summarized in Table I. A small structure is again observed at $M_X = 2.243$ GeV.

For both experiments, the angles were chosen in order to avoid the production of deuterons having a momentum in the investigated range from substructures of ^{3}He projectiles, as $p(d,d)p$ or

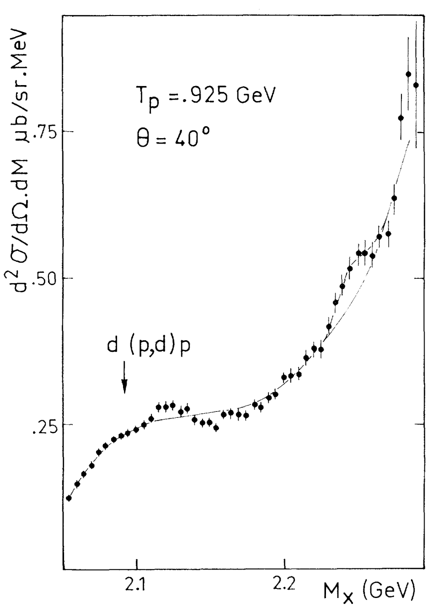

FIG. 2. Missing-mass spectra in doubly differential cross sections measured in the reaction $^3\mathrm{He}(p,d)X$ (laboratory system). Data have been binned into 5-MeV intervals.

$p(p,d)\pi^+$, for the first reaction and from substructures of the ^{3}He target, as $d(p,d)p$, for the inverse reaction. Our kinematical choices, angles and energies, do not allow the possibility of a hypothetical final-state interaction, the deuteron (which is identified) being emitted at the same angle and same speed as one of the undetected particles. The observed narrow structure can then only be produced by an interaction between the undetected particles designated as $X(B=2,\ T=1)$. This experiment has not been performed before, and the other studies of narrow dibaryons—as described previously—have never found structure at this mass. From Fig. 2, we see an indication for a narrow structure at 2.12 GeV.[23] Similar mass and width ($\Gamma_{1/2} \sim 0.02$ GeV) have been found in the deuteron breakup study.[17]

In conclusion, by using the missing-mass experiments $p(^3\mathrm{He},d)X$ and $^3\mathrm{He}(p,d)X$ we have observed in the $B=2$, $T=1$ final state a narrow structure at $M_X = 2.240 \pm 0.005$, $\Gamma_{1/2} = 0.016 \pm 0.003$ GeV. The corresponding cross section is $d\sigma/dt = 3.4 \pm 0.8$ μb/GeV^2 at $\theta_{\mathrm{lab}} = 18°$ for the reaction $p(^3\mathrm{He},d)X$, and $d\sigma/dt = 1.32 \pm 0.57$ μb/GeV^2 at $\theta_{\mathrm{lab}} = 40°$ for the reaction $^3\mathrm{He}(p,d)X$. It is not possible to make definite statements concerning the origin of these structures. Although the common belief is that conventional $NN\pi$ models describe the experimental data in $NN \to NN$, $NN \to NN\pi$, $NN \rightleftarrows \pi d$, and $\pi d \to \pi d$ reactions, the agreement with the data is not very good. We cannot therefore exclude an unpredicted manifestation of the strong $N\Delta$ coupling. However, the structure observed being narrow, we also cannot exclude completely a possible manifestation of an exotic process dealing with either color degrees of freedom or quantum numbers forbidden for the pp state but allowed for six quarks.

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