Possible Dibaryon Resonance around 2.23 GeV/c^2 in $d(\gamma,p)X$

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(Received 14 May 1980)

The measured $d(\gamma,p)X$ cross section shows a rapid variation around a photon energy $k = 390$ MeV, not explained up to now by pion or nucleon rescattering processes. It is suggested that this and other related results could be explained by the existence of a dibaryonic resonance at a mass of 2.23 GeV/c^2.

PACS numbers: 14.20.-c, 13.60.Rj, 25.20.+y

One of the unanswered questions at the frontier between nuclear and particle physics is related to the possible existence of nonstrange dibaryon resonances. Such resonances are predicted by the existing models of strong interactions.[1] So far, the only available data which might show some evidence for such states come from N-N scattering experiments.[2]

We report in this paper two experiments that have looked for dibaryon resonances in the $NN\pi$ channel. They were performed with use of the bremsstrahlung photon beam of the linac at Saclay. In the first experiment, the reaction $d(\gamma,p\pi^-)p$ was investigated by detecting the emitted pion in coincidence with one of the two protons. The momenta of the particles were also measured so as to determine completely the kinematics of the reaction. The great advantage of this method lies in the possibility of reducing the contribution of the dominant process, namely the quasifree photoproduction, by considering different momenta P_R of the recoiling system. Similarly to previous works,[3] we detected the pion with the "400"-MeV/c magnetic spectrometer, but in order to achieve good resolution for P_R ($\Delta P_R \simeq 10$ MeV/c) and also to eliminate the large corrections brought in by the use of a range telescope, we detected the proton with the "700"-MeV/c magnetic spectrometer.[4] We kept constant the momentum P_R of the undetected proton ($P_R = 150$ MeV/c), the invariant mass Q of the pion-nucleon system ($Q = 1245$ MeV/c^2) and the angle ω of the pion relative to the incident photon in the pion-nucleon rest frame ($\omega = 105°$). We varied only the angle θ_R of the recoiling proton and hence the photon energy k, since these are kinematically related. In order to compare our new data with the previous results[3] obtained for various kinematical conditions ($1225 < Q < 1250$ MeV/c^2, $130 < P_R < 160$ MeV/c, $90° < \omega < 105°$), we have plotted on the same figure (Fig. 1) and as a function of k the measured counting rates divided by the prediction of the first-order quasifree model (impulse approximation). The new set of data thus confirms the rapid variation of the cross section around $k = 400$ MeV.

The results of a calculation[5] that takes into account the quasifree photoproduction process and the pion and proton rescattering up to the second order are also shown in Fig. 1. Although this model can successfully account for previous experimental results,[4] it fails to reproduce the observed bump ($\chi^2 = 43$ for $\nu = 11$ degrees of freedom). At the present time this discrepancy is very difficult to explain in terms of contributions from rescattering processes, such as the Δ-N scattering.[6] It should be pointed out here that this peculiar behavior of the energy distribution

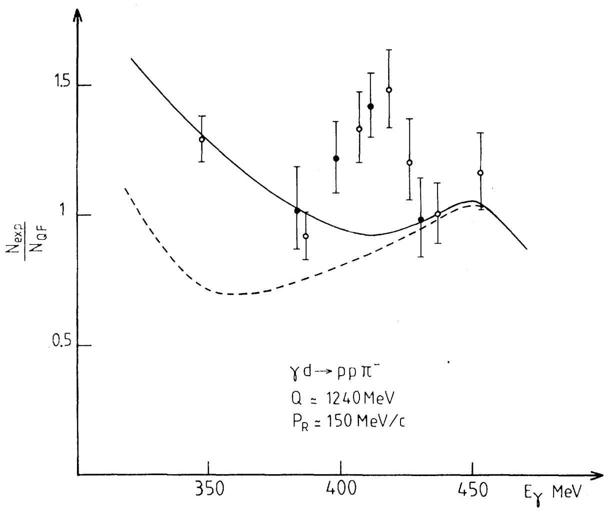

FIG. 1. Ratio of the experimental counting rate to the calculated quasifree contribution (impulse approximation as a function of the photon energy k). The open circles are the reanalyzed previous data whereas the full circles are the new data. The dotted curve is the prediction of the model (Ref. 5) taking into account the quasifree contribution plus pion and nucleon first-order rescatterings. The solid curve includes second-order scattering terms.

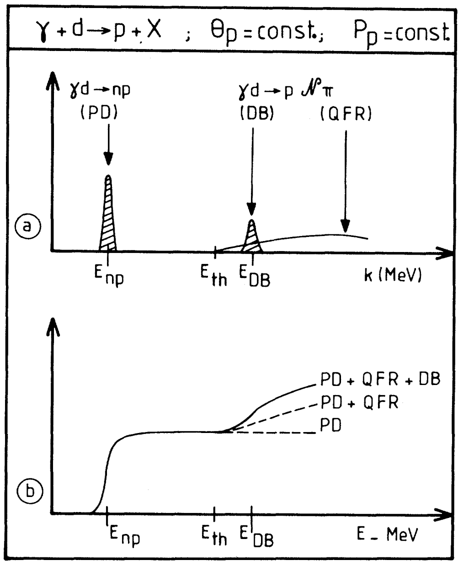

FIG. 2. Counting rate of the reaction $d(\gamma,p)X$ for a fixed momentum of the detected proton vs the proton energy: (a) for a monochromatic photon beam; (b) for a bremsstrahlung beam as a function of the end-point energy.

is reminiscent of an anomaly found in the study of the reaction $^4\mathrm{He}(\gamma,p\pi)$.[7] We were thus led to suspect the possible existence of a two-baryon resonance.

A second experiment more inclusive and less sensitive to possible interference effects had, therefore, to be designed. It consisted in studying the reaction $\gamma+d\rightarrow p+X$ with photon energies around 400 MeV. When the angle θ and the momentum p of the proton are determined, the cross section as a function of k is expected to behave as shown schematically in Fig. 2(a): (i) a peak corresponding to the photodisintegration (PD) centered at an energy $E_{np}(\theta,p)$; (ii) then, above the pion production threshold E_{th}, the contribution from the standard pion photoproduction including the quasifree production (minimized if the momentum and angle of the proton are large), as well as pion and proton rescatterings (QFR); (iii) above this usual π-production background, a bump at E_{DB} corresponding to the presence of a possible dibaryon resonance (DB) decaying with the emission of a pion. With the use of a bremsstrahlung beam, the observed counting rate is the convolution of the conitnuous bremsstrahlung spectrum with the above cross section. This yield, as shown in Fig. 2(b), is a function of the photon spectrum end-point energy E_-. A step in this yield around E_{DB} would be the signature for the dibaryonic resonance. As the effect is expected to be small (a few percent of PD), the experiment was designed so that it could provide measurements with a relative accuracy better than 1%.

The experimental setup was the same as the one used in the $(\gamma,p\pi^-)$ experiments,[3] but several precautions were taken in order to achieve the desired accuracy. Since the response of the gas quantameter which monitored the bremsstrahlung photon beam is dependent on the electron energy E_-, the momentum acceptance of the electron beam transport was reduced to 0.2%. In addition, the data were taken with the same quantameter output intensity in order to limit saturation effects to less than 0.1%. The beam was strongly collimated so that the center of the 17-mm-diam beam spot was stable enough to guarantee the constancy of the spectrometer solid angle to better than 0.1%. The contribution from the target walls (~5%) was measured for each run. Protons were detected with both magnetic spectrometers. The "700"-MeV/c spectrometer was fixed at $\theta = 60°$ and $p = 577$ MeV/c and was used to permanently check the stability of the liquid-deuterium-target thickness (0.47 g/cm^2). Its focal plane was split into four bins of $\Delta p/p = 0.03$. The "400"-MeV/c spectrometer was used for measurements done at three angles (90°, 105°, and 120°) and for two analyzed momentum bins (365–381 and 381–397 MeV/c). The data were taken by alternating high- and low-electron-energy measurements. With all these precautions, the total systematic uncertainty for a given bin was smaller than the statistical one, which was about 0.5%.

The number dN_γ of photons in the interval dk around the energy k is given by

$$dN_\gamma = \beta(k,E_-)\Lambda Q E_-^{-1} k^{-1} dk,$$

where Q is the total charge measured by the quantameter, Λ the constant of the quantameter, and $k^{-1}\beta(k,E_-)$ the energy dependence of the photon spectrum.

Since in the two-body photodisintegration reaction the energy k is only determined by θ and p, $k = E_{np}(\theta,p)$, the normalized counting rate $n(k,E_-) = NE_-/Q\beta(k,E_-)$ (where N is the number of events) must be a constant $C(E_{np})$ in the interval $E_{np} < E_- < E_{\mathrm{th}}$. From the ten different kinematical conditions, a total of 67 points satisfied this last condition. These were fitted with use of ten parameters $C(E_{np})$ and a quadratic function to compute $\beta(k,E_-)$ assuming that it depends on the ratio k/E_-. The fit gives a χ^2 of 63 for $\nu = 54$ [at 21%

confidence level (CL)]. We note that this function β is in excellent agreement with a calculation with use of the EGS code.[8]

The results indicate that the bremsstrahlung spectrum was correctly determined and confirm the good stability of the setup. So, we can confidently calculate above the pion production threshold the contribution of the photodisintegration process and we define the yield $Y(E_-)$ by

$$Y(E_-) = \frac{NE_-/Q - C(E_{np})\beta(E_{np}, E_-)}{\Lambda \mathfrak{N}_a \Delta\Omega \, \Delta P}$$

$$= \int_{E_{\mathrm{th}}}^{E_-} \frac{d\sigma(k)}{d\Omega dp}\, \beta(k, E_-) \frac{dk}{k},$$

$\mathfrak{N}_d$ being the number of target nuclei per square centimeter. We can compare its absolute value with the yield Y_π of the QFR model[5] using a Reid wave function. It should be noticed that in our kinematics the rescattering mechanisms are three times as large as the quasifree process and represent 20% of the (γ, np) yield 100 MeV above threshold. A fit was performed with one normalization parameter, a, for the points with $E_- > E_{\mathrm{th}}$, keeping only the cases where E_{th} was larger than 410 MeV (i.e., $\theta = 60°$ and $\theta = 120°$) in order to get rid of the anomaly described earlier. It yields a value $a = 0.98 \pm 0.05$ with $\chi^2 = 34$ for $\nu = 27$ (at $\simeq 17\%$ CL). This means that the angular distribution and the shape of the curves (Fig. 3) are well reproduced by the model in these cases.[10] Nevertheless, the QFR model is unable to account for the rapid variation of the cross section in the 370–410-MeV region. Indeed a fit performed for all the points with $E_- > E_{\mathrm{th}}$ yielded a value $a = 1.12 \pm 0.03$ with $\chi^2 = 150$ for $\nu = 76$ (at $< 10^{-4}$ CL). It remains bad even if the curves at $\theta = 90°$ and 105° are fitted separately: The smaller the E_{th} is, the larger the χ^2. In the case $\theta = 90°$ and $p = 379$ MeV/c, it is found that $a = 1.23 \pm 0.05$ with $\chi^2 = 37$ for $\nu = 12$ (at 2×10^{-4} CL; 2.7 standard deviations). The conclusion is that the shape is no longer correct when the threshold energy E_{th} is lower than 410 MeV. We therefore introduce a term to include the influence of the excitation of a resonance. For electron energies E_- such that the contribution of the resonance is saturated, we define $Y(E_-) = aY_\pi + Y_{\mathrm{DB}}$, where

$$Y_{\mathrm{DB}} = \int_{\mathrm{resonance}} (d\sigma_{\mathrm{DB}}/d\Omega\, dp)\beta(k, E_-) dk/k$$

$$= \bar{\beta}\, b / E_{\mathrm{DB}}.$$

$\beta(k, E_-)$ is almost a constant $\bar{\beta}$ in the resonance region, E_{DB} is the mean value of k over the resonance, and b is the resonance integrated cross

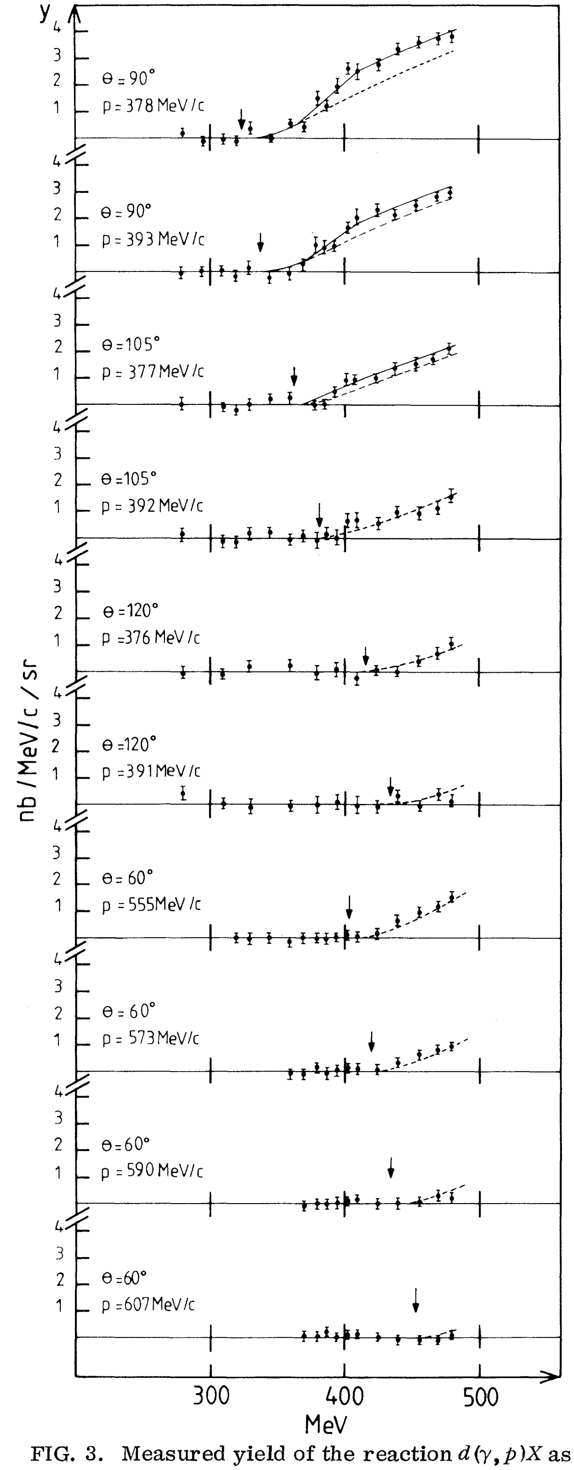

FIG. 3. Measured yield of the reaction $d(\gamma, p)X$ as a function of the bremsstrahlung end-point energy E_- after subtraction of the $d(\gamma, p)n$ contribution. The arrows indicate the threshold pion-production energy E_{th} for the various kinematical conditions. The dotted curve represents the calculated (Ref. 5) nonresonant contribution only. The solid curve includes a resonance at 390 MeV with a width of 40 MeV.

section.

The data suggest $E_{\mathrm{DB}} = 390$ MeV and a width of the order of 40 MeV. We can thus extract the integrated cross section from the data above 410 MeV. We obtain

$$a = 0.94 \pm 0.03,$$

with $\chi^2 = 85$, for $\nu = 72$ (at 14% CL) and with b given in Table I.

TABLE I. The resonance integrated cross section b as a function of the center-of-mass momentum $P_{\mathrm{c.m.}}$ of the detected proton for the various experimental conditions.

θ_{lab}	P_{lab} (MeV/c)	$P_{\mathrm{c.m.}}$ (MeV/c)	b [MeV μb/(sr · MeV/c)]
90°	378	417	0.389 ± 0.039
90°	393	431	0.147 ± 0.036
105°	377	466	0.111 ± 0.033
105°	392	482	0.024 ± 0.033

We make two additional remarks: (i) The decreasing behavior of the integrated cross section, as a function of the c.m. momentum $P_{\mathrm{c.m.}}$ of the detected proton, is similar to the phase-space variation of a three-body system of total mass 2.23 GeV/c^2 vanishing at $P_{\mathrm{c.m.}} = 481$ MeV/c. (ii) The maximum of the cross section observed in Fig. 1 for the reaction $d(\gamma, p\pi^-)$ is located around 410 MeV instead of 390 MeV. This may be an indication of an interference with a nonresonant background, this shift being of the order of magnitude of the width.

In conclusion, these results give a clear indication of an excess of cross section in the vicinity of 390 MeV. In conjunction with other $(\gamma, p\pi^-)$ experiments,[7] the data, which in the present state of the art are not explained by rescattering contributions, may be interpreted as a dibaryon resonance located at a mass $Q_{\mathrm{DB}} = 2.23$ GeV/c^2 and with a width of 40 MeV/c^2.

We thank Dr. J. M. Laget for having extended his calculations to our kinematical conditions.

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[10] We have checked that choosing a different wave function [K. Holinde and R. Machleidt, Nucl. Phys. A256, 479 (1976)] and including the contribution from double pion photoproduction does not affect the shape of the yield; only its amplitude is slightly modified.