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OBSERVATION OF A RESONANCE-LIKE STRUCTURE IN THE $pp \to pp\gamma\gamma$ REACTION AT PROTON ENERGY 198 MeV: IS THE DIBARYON OF MASS 1923 MeV FOUND?

The DIB-2γ Collaboration

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1 Introduction

In this paper we report further results of the first study of the reaction $pp \to pp\gamma\gamma$ at the proton energy ~200 MeV. We believe, that in addition to the ordinary bremsstrahlung, $pp \to pp\gamma$, the two-photon production process also deserves of a special investigation as a source, maybe, of an unique information on some important aspects of hadrodynamics, underlying the NN-interaction. In particular, our primary goal in this study is to probe of possible existence of exotic, narrow dibaryon resonances, that could escape distinct observation in the other reactions used earlier for the same aim.

The problem of narrow dibaryon resonances(FWHM $\ll$100 MeV) has attracted a lot of attention of both theorists and experimentalists in the past twenty years. Existence of narrow states with a baryon number equal to two(^2B) was predicted in several QCD-inspired models[1, 2, 3] and alternative standard models of the NN-interaction[4]. However, the available predictions for their masses and widths are model-dependent and, therefore, cannot be treated as reliable. The experimental situation has been somewhat confused. Although a number of claims were made for the observation of narrow structures[5, 6, 7, 8] some of them were not confirmed in later experiments[9].

Most of the dedicated experiments performed so far were aimed at looking for NN-coupled dibaryon resonances. Meanwhile, one might consider some processes leading to formation of dibaryons with quantum numbers for which the direct decay $^2B \to NN$ is either forbidden by the Pauli principle, or strongly suppressed by the isospin selection rule(NN-decoupled dibaryons). In this respect the process $pp \to \gamma^2 B \to pp\gamma\gamma$ has unique possibilities of searching for and investigating narrow, NN-decoupled dibaryon resonances with masses below the pion production threshold[11, 12]. The method of searching for these narrow dibaryon resonances is based on the measurement of the photon energy distribution in the $pp \to pp\gamma\gamma$ reaction by detecting both photons in coincidence. The narrow dibaryons, if they exist, should be seen as sharp γ-lines against a smooth background due to the photons from the radiative resonance decays($^2B \to \gamma pp$) and double pp-bremsstrahlung with an anticipated good signal-to-background ratio. The position of this line depends on the energy of the incident proton and the resonance mass M_B. Its width is determined by the total width of resonance Γ_{tot} and energy resolutions of the experimental setup. In a recent publication[10] we have reported the first results of searching for the narrow NN-decoupled dibaryons in the process $pp \to \gamma^2 B \to pp\gamma\gamma$ at the proton energy 203.4 MeV. Measurements of the γ-ray energy spectra of this reaction showed a well noticeable peak at the energy $E_\gamma \sim 47$ MeV, which was interpreted as evidence for the narrow dibaryon resonance with a mass ~1917 MeV. Unfortunately, no measurements were done then with the empty target and, therefore, estimation of the resonance parameters as well as its statistical significance depends on a hypothesis accepted for a background description. Moreover, the statistics of that experiment was insufficient to draw any firm conclusion on existence of the narrow dibaryon. In this paper we present the results of new measurements of the photon energy spectra for the process:

$$pp \to \gamma\, {}^2B \to \gamma\gamma pp \tag{1}$$

2 Experimental Details

The experiment was performed with a proton beam from the JINR phasotron with the proton energy 198 MeV and the energy spread about 1.5%. The schematic layout of the experimental setup is shown in Fig.1. It consists of a liquid hydrogen target(H_2), two detectors of γ-quanta (S_1 and S_2), veto counters($\overline{S_3}$ and $\overline{S_4}$) used to reject charged particles coming from the target, collimators($Pb's$) and a monitor of the proton beam(M). The liquid hydrogen target cell is designed to provide a high luminosity source. It is a horizontal cylindrical brass flask, 4.5 cm in diameter and 4.5 cm in length, with mylar windows of total thickness 100 μm. The target cell was mounted inside a vacuum can of diameter 8.5 cm having two mylar windows of total thickness 100 μm. Because the thickness of the liquid hydrogen was 0.3 g/cm^2, this target provided the luminosity $1.8 \cdot 10^{31} cm^{-2} \cdot s^{-1}$ with an intensity of the proton beam 10^8 p/s. The energy loss of a 200 MeV proton passing through the target was 2.8 MeV. At the target position the beam was found by radiography to be about 20 mm in diameter, and its energy was determined by range measurements in water. The beam intensity was monitored by a few ionization chambers. The γ-detector S_1 was composed of seven CsI(Tl) hexagonal

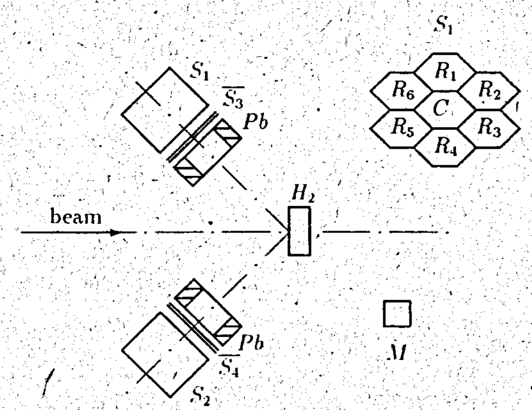

Figure 1: Schematic layout of the experimental setup.

crystals, each with an outer diameter 10 cm and length 15 cm. It consisted of(see fig.1) a central crystal C and six crystals $R_1 - R_6$ in the external ring. The energy of each γ ray is determined by summing up the energy deposited in the crystal C and the energies deposited in the crystals $R_1 - R_6$. Besides this, the crystals $R_1 - R_6$ served as an active shielding to reject the background from cosmic ray muons. The γ-detector S_2 was a cylindrical NaI(Tl) crystal of diameter 15 cm and length 10 cm. The veto counters $\overline{S_3}$ and $\overline{S_4}$ were 0.5 cm thick plastic scintillators. To reduce a large background of protons scattered by the target, both the S_1 and S_2 γ-detectors were set on either side of the beam to detect backward emitted photons at angles of 111^0 and 240^0, respectively. The solid angles covered by S_1 and S_2 were 35 msr and 70 msr, respectively. Prompt particles from the target were attenuated by 20 cm polyethylene bars placed in between the target and each detector. The γ-detectors were surrounded by a 10 cm lead shield and a 5 cm borated paraffin shield.

The energy calibration of the γ-ray detectors was done using γ-rays from a $Pu - Be$ source(E_γ = 4.43 MeV), the reaction $p + ^{12}C \to \gamma + ^{13}N^*$ (E_γ = 15.1 MeV) and a peak produced by cosmic ray muons. The energy threshold for both γ-detectors was set at about 9 MeV. The amplitude and time signals from the S_1 and S_2 γ-detectors were sent to ADCs and TDCs. Besides, the phasotron radio-frequency(RF) signal was also sent to TDC. All TDCs were started by a signal from the central detector C and stopped each separately by the S_2 detector, each of the ring $R_1 - R_6$ detectors and the RF signal. In parallel, the time signals from the detectors S_1, S_2, $\overline{S_3}$ and $\overline{S_4}$ were sent to a coincidence circuit to select those events which had signals from both γ-detectors and did not have signals from both veto counters within a 500 ns time interval. Events satisfying the above criteria were recorded in the event-by-event mode on a hard disk of an IBM PC-486 computer. A further analysis of these data was done during off-line data processing. The energy spectra of γ-rays were measured in the energy range from 10 to 100 MeV. The measurements for the empty target and the full one were performed in two successive runs. Data were taken with a proton beam of energy T_{kin}= 198.0 MeV and average intensity $5.5 \cdot 10^8$ p/s for about 10 hours and 20 hours, respectively.

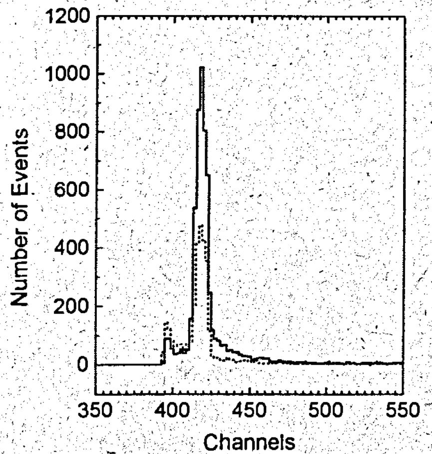

Figure 2: The spectrum of the time of the RF signals with respect to the signal from central detector. The solid and the dotted lines correspond to the target filled with liquid hydrogen and the empty one, respectively. One channel equals 1.0 ns.

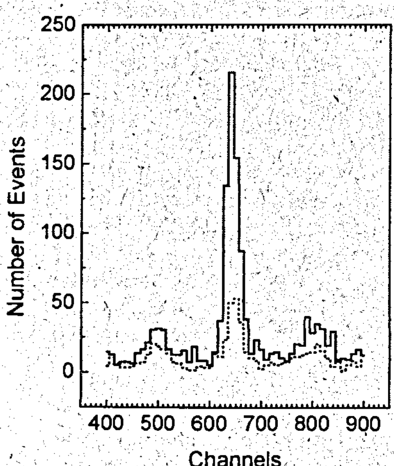

Figure 3: The coincidence time spectrum. The solid and the dotted lines correspond to the target filled with liquid hydrogen and the empty one, respectively. One channel equals 0.5 ns.

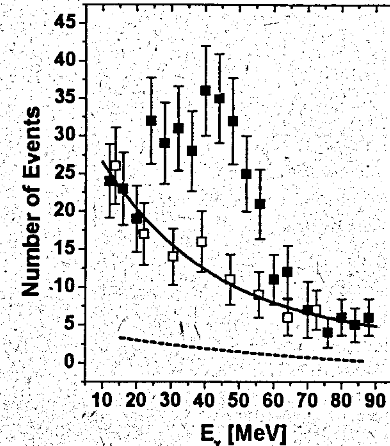

Figure 4: The photon energy spectra for the S_1 γ-ray detector. The solid squares correspond to the target filled with liquid hydrogen and the open squares to the empty one. The solid line represents an exponential fit to the empty target data points. The dashed line shows the bacground of accidental coincidences.

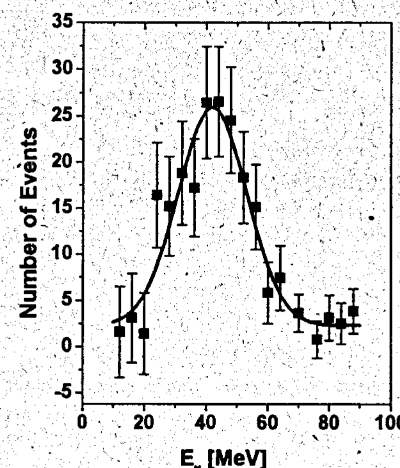

Figure 5: The photon energy spectrum for the S_1 γ-ray detector after subtracting the empty target contribution. The solid line is the result of a gaussian fit to the data points

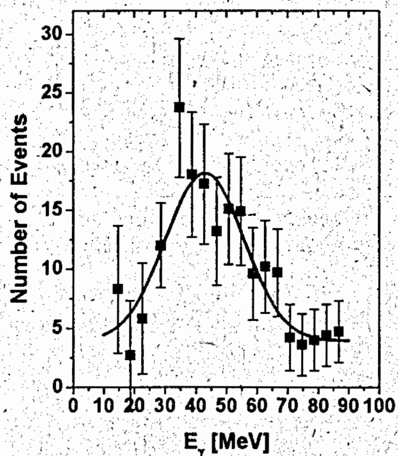

Figure 6: The photon energy spectrum for the S_2 γ-ray detector after subtracting the empty target contribution. The solid line is the result of a gaussian fit to the data points

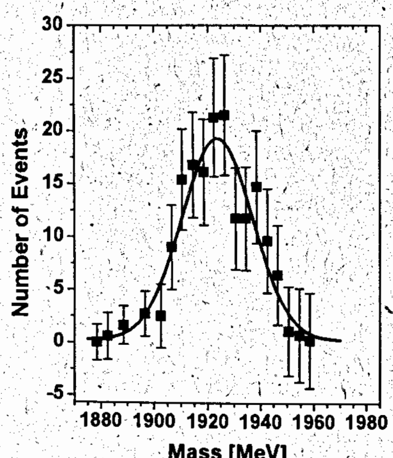

Figure 7: Distribution of the reconstructed dibaryon mass for the S_1 γ-detector. The solid line is the result of a gaussian fit to the data points

3 Data analysis and results

The off-line selection of useful events associated with process (1) was carried out in several steps. At the first step, events related to proton bursts of the beam(ones of 7 ns duration follow each other with an interval about 70 ns) were selected. This was done using the time spectrum of the RF signals(see Fig. 2.) in which the useful events are concentrated within a peak superimposed on the background of accidental coincidences. This peak was confined within a 20 ns time window and events were only selected if they fell within the time interval chosen. At the second step, events corresponding to $\gamma-\gamma$ coincidences were selected. In order to do this a coincidence time spectrum was obtained. It contained a peak of useful events and a background of accidental coincidences. A part of this spectrum which includes three proton bunches of the beam microstructure is shown in Fig. 3. The width of the peak of the useful events depends only on the time resolution of the setup, which was about 15 ns(FWHM). This peak was limited within a 30 ns time window and events out of it were treated as a background of accidental coincidences and were rejected. Finally, since the maximum of the photon energy distribution due to the presumed resonance decay($M_B \sim 1920$ MeV) is located near ~ 40 MeV[12] that, for the $S_1(S_2)\gamma$-detector events were only retained if $E_{\gamma_1} \geq 10$ MeV($E_{\gamma_2} \geq 10$ MeV) and $E_{\gamma_2} \geq 16$ MeV($E_{\gamma_1} \geq 16$ MeV). The γ-ray energy spectra for the γ-detector S_1 measured for the full target as well as empty one are presented in fig. 4. The solid line in this figure is the result of a fit of the exponential form function to the empty target data and the dashed one shows the background of accidental coincidences. The spectrum obtained as a result of subtraction of the empty target contribution is shown in Fig.5.

A structure at energy near 42 MeV is clearly seen in this spectrum. A fit to a gaussian gave the energy of this peak 42.0±4.5 MeV with width(FWHM) 26.3±4.0 MeV. This fit yielded a χ^2 value of 6.7 for 14 degrees of freedom. The γ-ray energy spectrum for the γ-detector S_2 obtained after the corresponding subtraction of the empty target contribution is shown in Fig.6. An analogous peak at the energy about **42 MeV** is also well seen in this spectrum. For the energy and the width of this peak the fit to a gaussian gave the values 42.5± 6.5 MeV and 31.3 ± 7.0 MeV. The χ^2 for the fit is 5.6 for 13 degrees of freedom. However the length of this detector(only 4.9 radiation lengths) is insufficient to measure the energy of γ-rays above 10 MeV with a desired accuracy.

If one assumes that a narrow dibaryon resonance is responsible for the peak observed one can reconstruct a corresponding dibaryon mass distribution[12]. This distribution for the γ-detector S_1 is presented in fig. 7. It has a peak at $M_B \sim 1923$ MeV. The distribution of fig. 7, when fitted with a gaussian, gave a fitted mass 1923.5±1.5 MeV and a width 31.3±5.0 MeV. The chi-squared for the fit is 5.0 for 14 degrees of freedom. The significance of the effect exceeds 8 standard deviation.

4 Conclusions

The γ-ray energy spectrum for the $pp \to pp\gamma\gamma$ reaction at the proton energy 198 MeV has been measured. A narrow peak at the photon energy about 42 MeV was observed in this spectra. It can be interpreted as a signal due to a narrow, exotic dibaryon ^2B formation and decay in the $pp \to \gamma^2B \to pp\gamma\gamma$ processes. Distribution of the dibaryon mass obtained under this assumption shows a narrow peak with mass M_B=1923.5±4.5 MeV and width FWHM=31.3±5.0 MeV. The statistical significance of this peak exceeds 8σ. The results presented are in agreement with our previous ones[10].

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