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Searching for the double γ-decay of the $X(17)$ particle

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Summary. — The e^-e^+ decay of the candidate new particle $X(17)$ has already been confirmed by previous experiments. However, theoretical models give different predictions for the spin and the parity of this particle. The double γ-decay process could be an appropriate probe to shed light on such properties. Thus, for the first time, we searched for the $\gamma\gamma$ decay of $X(17)$ created in nuclear transitions. In this paper, we report preliminary results of two experiments on the $J^\pi = 0^- \to 0^+$ transition in ^{4}He.

1. – Introduction

Phenomenological models predict light neutral bosons (dark photons, axion-like particles, etc.) in the 10 MeV − 1 GeV range [1]. According to these models, the e^-e^+ decay of these particles is allowed. The first positive indications for such a light boson was published recently by Krasznahorkay *et al.* [2]. The $E_X = 17.6$ MeV and $E_X = 18.15$ MeV states of ^{8}Be were excited by using proton resonant capture on ^{7}Li. The de-excitation of these states ($J^\pi = 1^+$, $T = 1 \to 0^+$, $T = 0$; $J^\pi = 1^+$, $T = 0 \to 0^+$, $T = 0$) is allowed by internal pair creation. The angular correlation ($\sigma(\Theta)$) between the e^- and e^+ emitted in the process was measured. The experimental result for isovector transition ($E_X = 17.6$ MeV) is indeed in a good agreement with the theoretical expectations. However, in the case of the isoscalar transition, a significant enhancement has been observed at $\Theta \simeq 145°$, which was interpreted as a possible signature of a new particle, called $X(17)$, with a mass of $m_0c^2 = 16.70 \pm 0.35(\text{stat}) \pm 0.6(\text{sys})$ MeV.

Zhang and Miller have discussed in detail a possible nuclear physics origin of the observed anomaly [3]. They performed calculations considering interferences between E1, E2, and M1 multipoles and introducing important constraints from photon production measurements. The anomaly could not be explained by their modified model.

Feng and his co-workers analysed our results along with other previous measurements and gave a new interpretation of our experimental observations by proposing a new theory with a fifth, fundamental force [4]. According to their explanation, a vector-boson is created in the nuclear transition with a mass of $m_0c^2 = 16.7$ MeV and $J^\pi = 1^+$.

Very recently, Ellwanger and Moretti published another theoretical interpretation [5]. They assumed a hypothetical particle emitted with $L = 1$ orbital momentum. Thus, it implies that we observed a particle with $J^\pi = 0^-$.

We have performed two experiments to proof which is the right scenario. According to the Landau-Yang theorem, the $\gamma\gamma$-decay of a $m > 0$, $J = 1^+$ or $J = 1^-$ particle is strictly forbidden. Therefore, we searched for possible signatures of the $X(17) \rightarrow \gamma\gamma$ decay in the $J^\pi = 0^- \rightarrow 0^+$ transition of ^{4}He.

2. – Experimental results on ^{3}H(p, $\gamma\gamma$)^{4}He

We have investigated the ^{3}H(p, $\gamma\gamma$)^{4}He reaction at the new, 2-MV Tandetron Accelerator of MTA Atomki by impinging E=1 MeV protons on a 3 mg/cm^2 thick tritiated (^{3}H) Ti target layer evaporated on a 0.4 mm thick Mo disk and cooled by liquid N_2. The second excited state of ^{4}He with spin-parity, $J^\pi = 0^-$ and energy $E_X = 21.01$ MeV was populated by resonant proton capture. The beam energy has been chosen to be lower than the threshold energy of the (n,p) channel ($E_{thr} = 1.018$ MeV) to avoid any neutron-induced background. However, due to the large overlap of the first and second excited states and by applying $E_p = 1$ MeV, the first excited state was also populated with spin-parity, $J^\pi = 0^+$ and energy $E_X = 20.21$ MeV.

Our γ-ray coincidence spectrometer consisted of 14 $LaBr_3$ scintillators. Twelve detectors had a volume of 3" $\times$ 3" and two detectors had a volume of 6.5" $\times$ 3.5". The smaller detectors were placed on a surface of a sphere with a radius of 30 cm. The two larger detectors were located behind the target. The energy resolution of the $LaBr_3$ detectors was 0.5% at $E = 17$ MeV.

The γ spectrometer was calibrated by the γ cascade de-exciting the second excited state of ^{12}C ($E^* = 16.6$ MeV, $J^\pi = 2^-$) which was populated in the ^{11}B(p,γ)^{12}C reaction by a proton beam at $E_p = 0.685$ MeV. The 2^- state can decay to the first excited state at $E = 4.43$ MeV, thus the two gamma photons of the cascade with $E_{\gamma 1} = 12.17$ MeV and $E_{\gamma 2} = 4.43$ MeV could be detected in coincidence. The single gamma energy spectrum of the calibration measurement is shown in Fig. 1a. Single escape (SE) and double escape (DE) peaks are indicated by arrows. In Fig. 1b, the $E = 16.6$ MeV energy sum of the two cascade gammas can be clearly seen as well as the corresponding single and double escape peaks and their combinations.

In the experiment on ^{3}H(p, $\gamma\gamma$)^{4}He, we measured the energy sum of the detected γ photons in coincidence. To reduce the effect of the scattering between the detectors, we set a strict condition on the energy symmetry parameter $y = (E_{\gamma i} - E_{\gamma j})/(E_{\gamma i} + E_{\gamma j})$, where $E_{\gamma i}$ and $E_{\gamma j}$ denote the detected γ-energies. The energy sum spectrum is shown in Fig. 2a. Random events and cosmic background events were subtracted. The contribution of the background to the γ spectrum is relatively high since the cross section for the direct capture γ rays is large. However, a peak clearly shows up at $E = 20.6$ MeV. A large Compton edge is also visible at the low–energy side of the energy spectrum.

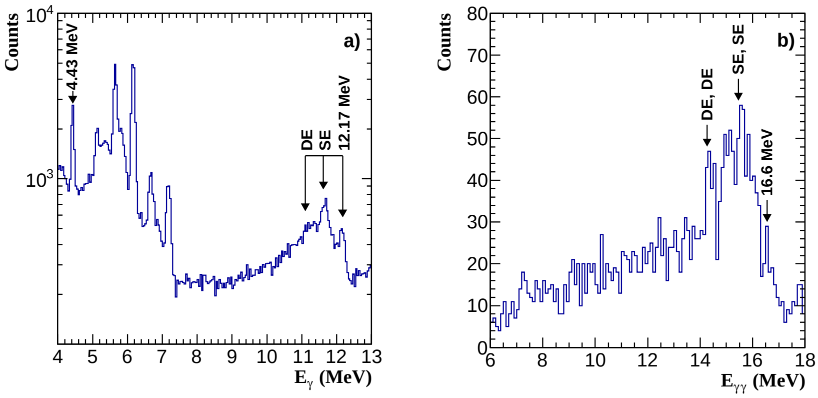

Fig. 1. – a) γ energy spectrum of ^{12}C showing the 12.17 and 4.43 MeV cascade transitions, which are excepted in coincidence and b) the sum energy spectrum of detectors fired in coincidence. The response of the spectrometer shows the energy summing of the 4.443 and 12.17 MeV transitions. The escape peaks are indicated.

3. – Experimental results on ^{3}He(n, $\gamma\gamma$)^{4}He

In the second experiment, we investigated the ^{3}He(n, $\gamma\gamma$)^{4}He reaction at the cold neutron beamline of the high-flux reactor Research Neutron Source Heinz Maier-Leibnitz (FRM II) of the Technical University Munich (Munich, Germany) in order to search for any signature of the $X(17) \to \gamma\gamma$ decay channel. The Q-value of the reaction is very large (Q=20.6 MeV), so the neutron resonance absorption populates the $E_X = 20.21$ MeV ($\Gamma = 0.50$ MeV) as well as the $E_X = 21.01$ MeV ($\Gamma = 0.84$ MeV) state of ^{4}He due to their significant overlap. These states can decay by the emission of one or two γ photons with a branching ratio of $\sigma(1\gamma)/\sigma(2\gamma) = 0.28$ [6].

The incident neutron flux was collimated down to a slit of 8x18 mm^2. The total flux on the target was around 10^{10}/s (thermal equivalent). We used a ^{3}He gas target at a pressure of p=2 bar contained in a 90 cm long cylinder and closed by 50 μm thick aluminized Mylar foil at both ends. By adopting such a geometry, 90% of the incident neutron flux was absorbed via the ^{3}He(n,p) reaction, which has a very large cross section (σ=5400 barn). The photons were detected in coincidence by an array of twelve 3" $\times$ 3" $LaBr_3$ scintillators placed perpendicularly to the beam direction at 30 degree between each other. In addition, we used a plastic scintillator array above our spectrometer to reject the cosmic-ray coincidences in the region of interest.

Fig. 2b shows the energy sum spectrum of the $\gamma\gamma$ coincidences. The γ energy distribution is very similar to the one measured at Atomki, but the background is much smaller since the direct capture of the cold neutrons has much smaller cross section. Although, a peak can be clearly seen at $E \approx 20$ MeV, no conclusive angular correlation could be extracted for the $\gamma\gamma$ pairs. Unfortunately, the experiment was limited in terms of counting rate due to the scattering of the neutron beam halo on the Al wall of the ^{3}He gas container. Thus, only 25% of the available neutron flux could be used in the experiment. According to our data, the plastic veto detector array could reduce the cosmic ray background only by a factor of 0.5 resulting in a significant cosmic ray contribution to the coincidence events. We plan to revisit the experiment soon with an improved setup.

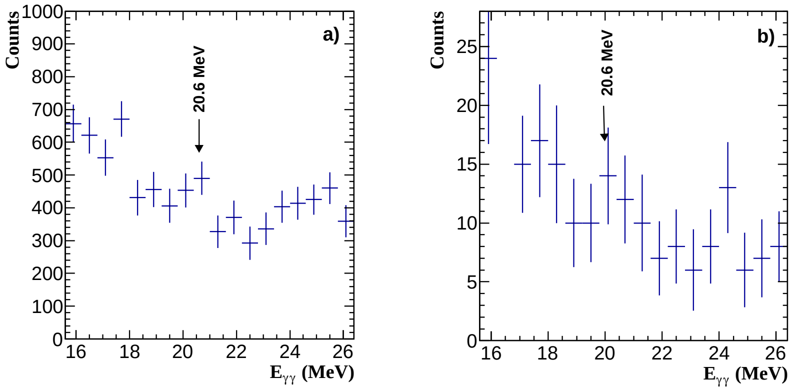

Fig. 2. – a) Energy sum spectrum of the detected γ photons in ^{3}H(p, $\gamma\gamma$)^{4}He and b) in ^{3}He(n, $\gamma\gamma$)^{4}He. Both histogram were random event and cosmic background subtracted.

4. – Conclusion

We studied the $\gamma\gamma$ decay of the 17-MeV particle candidate in order to distinguish between the vector or the pseudoscalar boson scenario, both of which have been suggested recently by different theoretical groups interpreting our previous experimental observations. Employing the ^{3}H(p, $\gamma\gamma$)^{4}He and the ^{3}He(n, $\gamma\gamma$)^{4}He reactions in different experiments, we measured the sum energy and the angular correlation of the γ pairs by using a $LaBr_3$ spectrometer array. We recorded true $\gamma\gamma$ coincidences in both experiments, however, no clear indication of a boson decay was observed. It may be due to the large cosmic ray background and the limited statistics, hence, we plan to repeat both experiments with an improved setup.

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