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A new detection set-up to search the X17 boson

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ABSTRACT

An excess of electron-positron pairs at large relative angle emitted in the ^{3}H(p,e^{+}e^{-})^{4}He, ^{7}Li(p,e^{+}e^{-})^{8}Be, and^{11}B(p,e^{+}e^{-})^{12}C nuclear processes has been recently observed. These anomalies are compatible with the creation of a boson with mass of about 17 MeV, not foreseen in the standard model. To probe the possible existence of the so called X17 boson, we propose to study for the first time the ^{3}He(n,e^{+}e^{-})^{4}He reaction at the n_TOF facility at CERN. The experimental program and performance of the detector prototype are discussed.

1. The X17 experiment at n_TOF

Recently, a group of nuclear physicists operating at the ATOMKI laboratory observed an excess of electron-positron pairs at large relative angle emitted in the ^{7}Li(p,e^{+}e^{-})^{8}Be, ^{3}H(p,e^{+}e^{-})^{4}He and ^{11}B(p,e^{+}e^{-})^{12}C nuclear reactions [1–3]. As shown in Fig. 1, kinematics indicates that this anomaly might be due to the de-excitation of ^{4}He, ^{8}Be and ^{12}C nuclei with the emission of a boson with mass of about 17 MeV (here and after $c = \hbar = 1$), rapidly decaying into e^{+}e^{-} pairs. If confirmed, the existence of this new particle would be of extraordinary importance in particle physics and in cosmology. Indeed, the X17 boson could be a mediator of a fifth force, characterized by a strong suppression of the coupling with protons compared to neutrons (protophobic force) [4,5]. From the cosmological point of view, the X17 could be a "portal" between the ordinary matter and the dark sector.

To clarify the present scenario we have recently proposed to study for the first time a neutron induced reaction, namely the ^{3}He(n,e^{+}e^{-})^{4}He process, at the n_TOF facility at CERN [6]. This facility provides a pulsed neutron beam in a wide energy range (E_n = 0.01–10^9 eV) and with a FWHM ≈ 3 cm gaussian spatial profile. The prerequisite to study the ^{3}He(n,e^{+}e^{-})^{4}He reaction with a neutron beam is the use of a light detector, thus minimizing its sensitivity to photons and neutrons. Moreover, a large-acceptance detector is required to accumulate statistics as well as to derive the X17 boson quantum numbers J^{π}, which strongly affect the angular distribution of emitted X17 bosons [7]. Finally, to improve the event selection of data, an adequate reconstruction of the e^{+}e^{-} kinematics is also desirable.

Fig. 2 shows a sketch of the proposed setup for the ^{3}He(n,e^{+}e^{-})^{4}He experiment. It consists of a quasi-cylindrical ^{3}He target with a diameter of 2 cm and a volume of about 10 cm^{3}. The nominal pressure of the ^{3}He gas is 358 bar, corresponding to a density of approximately 10^{22} atoms/cm^{3} at room temperature. The ^{3}He is contained in a 0.3-mm thick capsule of an aluminium alloy (Scalmalloy), wrapped with a 1-mm thick carbon fiber. The relatively thin capsule containing the ^{3}He target is necessary to avoid a large impact of multiple scattering of e^{+}e^{-} pairs. A prototype of the capsule was successfully tested at CERN, where it was filled with ^{4}He at the intermediate pressure of 200 bar. As shown in Fig. 2, the target is surrounded by 4 μRwell detectors [8], with an active surface of 380×460 mm^2 each, and equipped with orthogonal readout strips. The distance between the cathode and μRwell plane is of 30 mm. Therefore, it is possible to make a 3D reconstruction of

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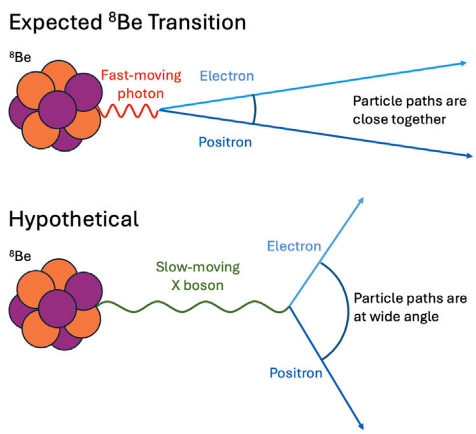

Fig. 1. Graphical representation of the X17 mechanism to produce e^+e^- at large angle.

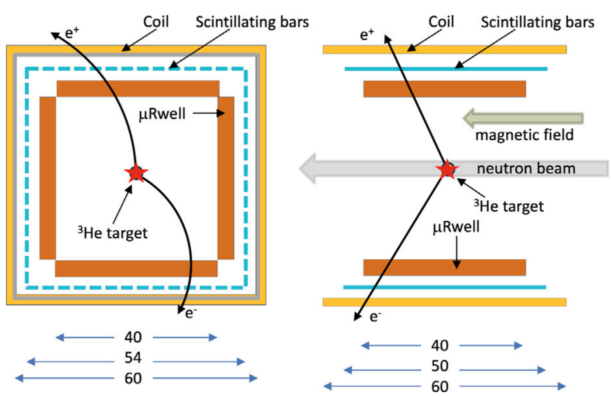

Fig. 2. Sketch of the X17 detector setup. Dimensions are in cm.

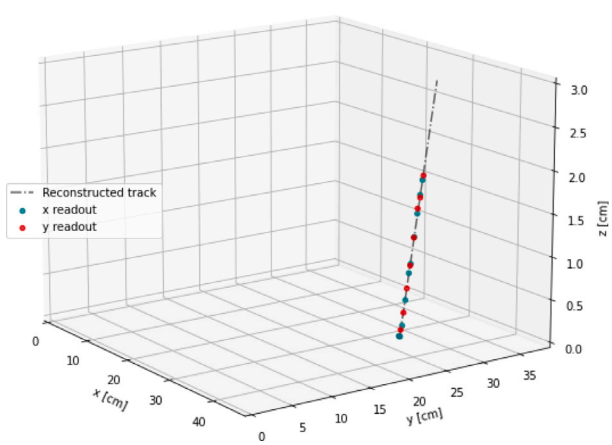

Fig. 3. Example of an electron track reconstructed with the large μRwell operated in μTPC mode. The electron is produced by the ^{7}Li(p,e^+e^-)^{8}Be reaction at E_p = 0.450 MeV.

electrons and positrons tracks, operating the μRwells in the μTPC mode. The trigger for the μRwells is provided by 4 planes of scintillating bars. Each plane is made of 32 bars of $3\times17\times500$ mm^3. The bars also provide the time of flight of neutrons to deduce their energy. Finally, the target and the active detectors are inserted into a coil with a square section which provides a magnetic field of 500 Gauss (see Fig. 2), to reconstruct the charge and the momentum of e^+e^- pairs.

The performance of the detector has been evaluated with GEANT4 simulations, in which is reproduced the experimental setup, the beam characteristics and the production of e^+e^- pairs due to the internal pair convertion (IPC) process and due to the decay of a vector X17 boson (see Fig. 1), assuming the branching ratio provided by the ATOMKI result [7]. In particular, the simulation provides the beam induced background on the detector. It is also found that the magnetic field provides the charge of e^+e^- ejectiles, as well as their momentum with a typical accuracy of about 20%. Other details about the detector performance are reported in the conceptual design report (CDR) [9], in which are also discussed the results obtained with the demonstrator, composed by a single μRwell backed with a set of scintillator bars. For instance, Fig. 3 shows the track generated by an electron (or positron) in the test performed at ATOMKI. It can be noted that the track is reconstructed only for a projected length of 2 cm out of the 3 cm maximum drift length. However, this is due to the limited time window (675 ns) of the APV25 electronics.

2. Conclusions

The experimental goal is to perform the first measurement of the ^{3}He(n,e^+e^-)^{4}He process at the n_TOF facility in the second half of 2025, to shed light on the X17 boson claim and to investigate its quantum numbers. The proposed detection setup is well suited for proton-induced reactions as well. For instance, it can be used to repeat the ATOMKI experiment with improved kinematic reconstruction. Finally, low sensitivity to neutrons suggests its use to study for the first time the ^{2}H(n,e^+e^-)^{3}H and ^{2}H(p,e^+e^-)^{3}He reactions. In these latter cases, the specular structure of the ^{3}He and ^{3}H nuclei and the different numbers of neutrons and protons involved in the two reactions can be studied to investigate the isospin dependency of the X17-nucleon interaction, as the alleged "proto-phobicity".

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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