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Searching for internal pair creation anomalies and the X17 boson at LNL

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Summary. — 2016, a breakthrough anomaly was reported in the isoscalar magnetic dipole transition in ^{8}Be via the Internal Pair Creation process. An unexpected angular distribution of the relative angle of the e^+e^- was measured at the Atomki Laboratory. This phenomenon was explained considering the assumption of an emission of a neutral boson, named X17, with a mass of 16.70±0.35(stat)±0.5(syst) MeV/c^2 and $J^\pi = 1^+$. This finding triggered a global campaign to search for the new boson claimed. In Italy, at the Legnaro National Laboratories, a novel scintillator detector array has been designed and built. The present work reports the status of the first in-beam experiments performed in 2023 and 2024.

1. – Introduction

In nature, physical systems look for lower energy configurations. The case of the atomic nucleus is of particular interest because the release of the energy contains information about its structure, spin, angular momentum, and internal dynamics. In the electromagnetic transitions, the emission of intermediate particles is observed. The most common case is the gamma-ray emission. Other processes become essential under certain conditions. For example, the internal conversion (IC) and the Internal Pair Creation (IPC) become relevant in $0^+_j \rightarrow 0^+_i$ transitions (i < j). The angular distribution of the emission of those particles contains information about the type of electromagnetic transition, spin, and parity. In the case of the IPC, a complete theoretical description was published by Rose in 1949 [1, 2]. The model had demonstrated consistency with the experiments performed in light nuclei since 1950 [3, 4]. But in 2016, Krasznahorkay et al. published the breakthrough of an anomaly in the IPC of ^{8}Be [5]. An unexpected behavior in the Internal Pair Creation Coefficient was found in the isoscalar magnetic dipole transition (18.15 MeV state ($J^\pi = 1^+$, $T=0^+$) $\rightarrow$ ground state ($J^\pi = 0^+$, $T=0^+$)). The Rose model predicts a quick drop with the relative emission angle of the leptons. In contrast, the Hungarian group found a peak-like behavior at large angles [5]. This result has been interpreted as the signature of the emission of a previously unknown neutral isoscalar particle, named X17, with a mass of 16.70±0.35(stat)±0.5(syst) MeV/c^2 and $J^\pi = 1^+$.

The present work reports the status of the first experiments performed at the Legnaro National Laboratories to study this anomaly. The project aims to measure the angular distribution of the relative angle of the emission of the e^+e^- in the IPC process in the isoscalar magnetic dipole transition in ^{8}Be.

2. – Method

The detector array was designed to be placed in the same reaction chamber as the target. This fact reduces the uncertainty of the incidence position determination of the leptons in the detector because of the absence of scattering material between the target and the detector. The material used to manufacture the detectors is the commercial plastic scintillator EJ-200 (polyvinyl toluene). The telescope configuration has been proposed since the coincidence among the different layers can reduce the gamma-ray background

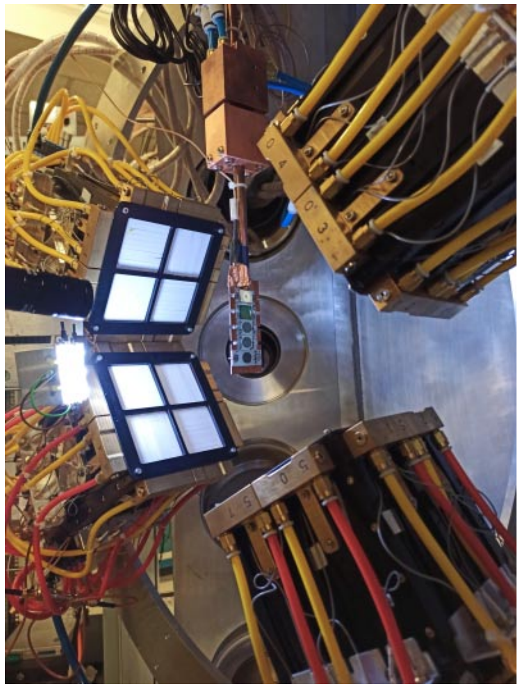

Fig. 1. – Picture of four clover detectors.

by up to 4 orders of magnitude, according to Geant4 simulations [6]. Moreover, since the ΔE layer cannot be used for particle identification, like in the case of other ions, it has been designed to be sensible to the incidence position of the leptons. Two sublayers of 10 bars of 5x50x2 mm^3 in a perpendicular configuration constitute the front part of the telescope. Every bar has been drilled through the longest part to create a 1 mm diameter canal. An optical fiber has been introduced inside this canal for better light collection. The light is read out by a 10x1 of 2x2 mm^2 SiPM array produced by the Fondazione Bruno Kessler (FBK). This system is cooling down at 0° for a better performance of the SiPM. On the other hand, a scintillator block of 50x50x100mm^3 is placed in the back of the telescope. This layer aims to measure energy in calorimeter mode. Two Hamamatsu SiPM of 6x6 mm^2 read out the scintillation light.

In the project's first stage, 2 cluster detectors (called "clover") of 4 telescopes were installed in the reaction chamber. They were placed perpendicular to the beam direction at 30° and 315°, at a 12.5 cm distance from the target. LiF targets from 60 to 900 μm/cm^2 on Cu/C backing (20-50 μm/cm^2 thickness) were irradiated with a proton beam of 450 keV energy. The latest configuration of the setup consists of 4 clover detectors. A two-part experiment has been carried out in the last six months. Two configurations were used to cover the angular range of the anomaly. In the first one, the clovers were placed at 35°, 165°, 240°, and 315°. While in the second at 30°, 150°, 240°, and 300° (see fig. 1). A 1.036 MeV proton beam impinging on LiF targets from 30-100 μm/cm^2 on 20-50 μm/cm^2 thickness C backing was the object of study in this stage.

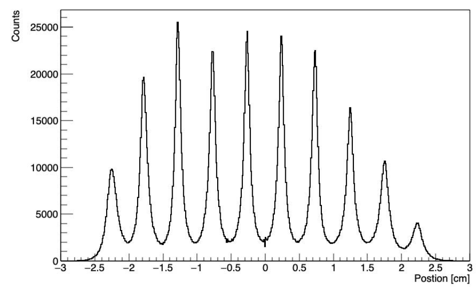

Fig. 2. – Position spectrum of the bar front layer.

3. – Results.

The position determination of the scintillator bar system showed a well-separate peak spectrum in correspondence to one bar fired in one of the sublayers (see fig. 2). The position in the 3D space was accomplished by considering the coincide of the two sublayers. The primary validation statement of the events is the coincidence in the three layers of two telescopes inside a 10 ns time window. The interaction of leptons with matter causes a tortuous path. To avoid those events that produce a wrong position determination, a high energy limit of 1 MeV has been set in every sublayer of the ΔE. This restriction allows us to select the straightest paths.

In the 451 MeV proton beam irradiation, the population of the 0_2^+ in ^{16}O via the nuclear reaction ^{19}F(p,α)^{16}O and the 1^+ in ^{8}Be via ^{7}Li(p,γ)^{8}Be were observed. The reconstruction of the transition energy of the populated states was calculated via the sum of the energy of the pair detected in coincidence. The energy spectrum as a function of the asymmetry of the deposited energy (see fig. 3) shows three structures along the

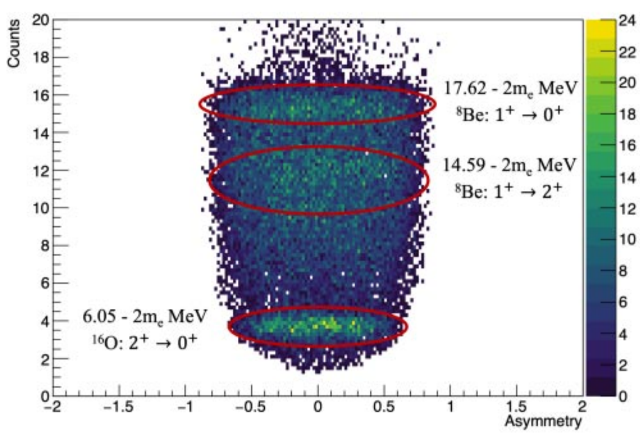

Fig. 3. – Lepton pair sum energy spectrum at 451 MeV proton beam irradiation as a function of the energy asymmetry of the pair detected.

Y-axis. The bottom corresponds to the transition to the ground state in ^{16}O. The second one looks less defined due to the wall effect in the detectors and the intrinsic width of the 2_1^+ state in ^{8}Be. The transition to the ground state in ^{8}Be is at the top of the matrix. These results indicate that the setup and the analysis method can be used to study the anomaly reported in the isoscalar magnetic dipole transition [5].

4. – Conclusions.

A new lepton spectrometer has been commissioned at the Legnaro National Laboratories, and its performance indicates that it can be used to study the anomaly found at the Atomki laboratories in 2016. The setup can determine the incidence position of the leptons in coincidence and measure their energy with a limit close to 20 MeV per lepton. The analysis of the former experiments is in progress, and it will be of relevant importance to understand the anomaly reported.

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