e^+e^- PAIR SPECTROMETER FOR STUDYING THE INTERNAL PAIR CREATION IN ^{8}Be AT LNL-INFN*

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The founding of an anomaly by A. Krasznahorkay and collaborators in the Internal Pair Creation (IPC) in ^{8}Be triggered the worldwide effort to investigate this phenomenon. At the Laboratori Nazionali di Lengnaro (LNL-INFN), a new e^+e^- pair spectrometer was built, and the first experimental campaign was performed in 2023 and 2024. This work describes the methodology implemented to analyze the data collected, including the energy reconstruction of the e^+e^- and the relative angle at which they were emitted.

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1. Introduction

In 2016, the funding of an anomaly in the Internal Pair Creation (IPC) in the isoscalar magnetic dipole transition ($1^+_2 \to 0^+_1$) of ^{8}Be was reported at the Atomki Laboratories, Hungary [1]. According to the model of Rose [2], for an M1 electromagnetic transition, the angular correlation distribution of the e^+e^- pairs drops quickly by increasing the relative angle of the leptons. In contrast, a peak-like behavior was observed, centered at around 140°. This result was interpreted as the creation and subsequent decay of a previously unknown neutral boson named $X(17)$ with a mass of $16.70 \pm 0.35(\text{stat.}) \pm 0.5(\text{sys.})$.

A new e^+e^- pair spectrometer has been built at the Laboratori Nazionale di Legnaro (LNL). The project aims at measuring the angular correlation distribution of the e^+e^- pairs from the IPC process in the isoscalar magnetic dipole transition in ^{8}Be. The present work describes the apparatus and methodology used at the LNL to study this phenomenon.

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2. Detector array

The detector array comprises four cluster detectors (clovers) with four ΔE–E telescopes each. The material used in its construction is the plastic scintillator polyvinyl toluene (EJ-200, Eljen Technology Company). The telescope configuration consists of twenty $0.2 \times 0.5 \times 5.0$ cm^3 bars in the ΔE structure and a $10.0 \times 5.0 \times 5.0$ cm^3 block in the E structure (see figure 1).

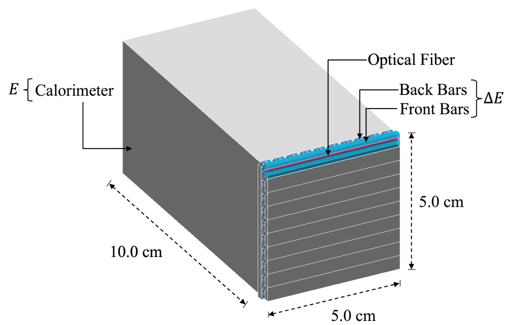

Fig. 1. Scheme of a ΔE–E telescope: Ten bars in front of the front face, ten behind them, and a calorimeter block. The paint has been removed in the top bar of the front face to show the optical fiber placed inside.

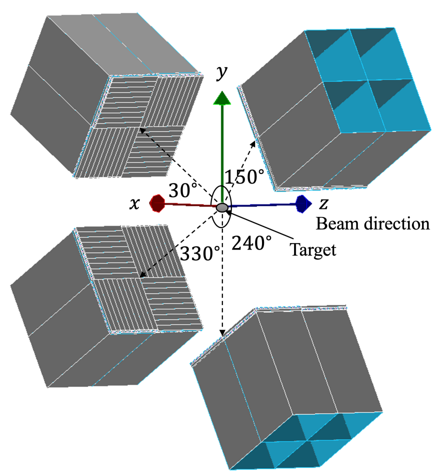

Fig. 2. Scheme of four clover detectors placed at 30°, 150°, 240°, and 330°.

The ΔE is a position detector, where the twenty bars are subdivided into two layers. Ten bars are in the front layer (parallel to each other) and ten are in the second one in a perpendicular direction to the ones in front. An optical fiber has been placed inside each bar through its axis for a better collection of the light generated in the scintillator material. All components were coated with the EJ-510 refractive paint to avoid the light diffusing out of the scintillator material. Two 6.0×6.0 mm^2 SiPM read out the light for the calorimeter and two sets of 10×1 SiPM (2.0×2.0 mm^2) arrays for the bars.

The clovers are built with four telescopes in a 2×2 configuration. They can be placed between 12.5 and 13.0 cm from the target and in the plane perpendicular to the beam direction. The angle of this plane can be decreased up to 45° (at smaller angles, the clovers could intercept the beam). Figure 2 shows an example of four clovers placed at 30°, 150°, 240°, and 330°.

3. Experiments

During 2023 and 2024, an experimental campaign to study the IPC process in ^{8}Be and ^{16}O took place at the AN2000 accelerator (LNL-INFN). LiF targets from 34 to 935 μg/cm^2 thickness were irradiated by a proton beam at 441 keV and 1.03 MeV (energy at the center of the target), with a typical current of 800 nA. The object of the experiment performed was the study of the e^+e^- pair from the IPC process in the $^7\mathrm{Li}(p, e^+e^-)^8\mathrm{Be}$ and $^{19}\mathrm{F}(p, \alpha e^+e^-)^{16}\mathrm{O}$ nuclear reactions. Three different detector configurations were used in the experiments. In the first one, corresponding to the commissioning of the setup, two clovers were placed at 30° and 315°. In the second, four clover detectors were placed at 30°, 165°, 240°, and 315°. In both cases, the detectors were set perpendicular to the beam. For the third experiment, the detectors were set in a plane at 45° from the beam direction. The angular coverage is shown in figure 2. The total data collected is equivalent to ~ 790 hours of the beam on target.

4. Analysis method

The analysis begins by selecting the events in which the front and back layers, together with the calorimeter, were in coincidence. This condition strongly decreases the γ-ray detection due to the low-Z material used in the detector construction, making the interaction with the three structures unlikely by the same γ-ray. Then, considering events where only two telescopes achieved this condition, some events with scattered e^+ or e^- are rejected, as well as random coincidence with cosmic muons.

In the results published by Krasznahorkay and collaborators [1], e^+e^- pairs with energy symmetry of 50% were selected from the data. For this purpose, a disparity parameter was defined as

$$y = \frac{E_{e^-} - E_{e^+}}{E_{e^-} + E_{e^+}}\,, \tag{1}$$

where E_{e^+} and E_{e^-} are the energy that positrons and electrons deposit in the detectors, respectively. The e^+e^- symmetric pairs can be selected by gating on $|y| < 0.5$. In our case, a larger gate was set in $|y| < 0.75$ to study the dependence on this parameter.

In addition, the sum energy deposited in the ΔE of the telescopes in coincidence was restricted from 1.2 to 2.2 MeV to select e^+e^- traveling in straight paths. Finally, better performance was observed using the add-back technique. It consists of summing up the energy deposited in the four calorimeters of the clover fired. Applying this technique and according to Geant4 simulations, the P/T improves from 25% to 39% for an 18.15 MeV transition (see figure 3), which corresponds to the energy of the isoscalar dipole transition in ^{8}Be.

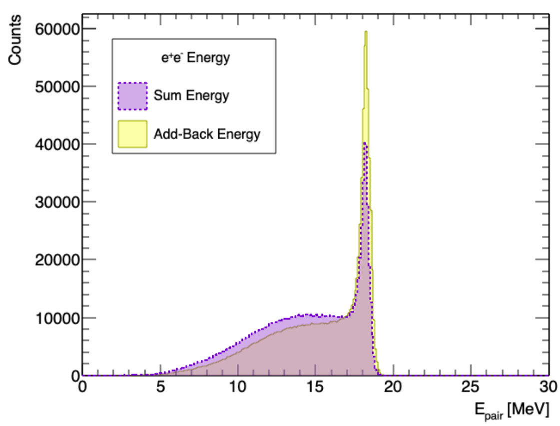

Fig. 3. (Color online) Energy deposited by the e^+e^- in the calorimeters of the two telescopes (violet/gray) and the calorimeters of the clover fired (add-back, yellow/light gray) for a Geant4 simulation of the IPC in an electromagnetic transition at 18.15 MeV.

The reconstruction of the transition energy allows us to selectively choose the electromagnetic transition and determine the angular distribution of the e^+e^- pairs for that transition. Figure 4 shows the matrix of the energy deposited by the e^+e^- in the clovers *versus* the relative angle measured between them for e^+e^- random emission pairs in a Geant4 simulation at 18.15 MeV transition. The measured angular distribution is shown at the top of the matrix, considering the energy gate on the right. In the region between 120° and 160°, drastic drops are not observed. Those drops can produce artifacts in the final angular distribution, which will be obtained after correcting the efficiency of the detector array.

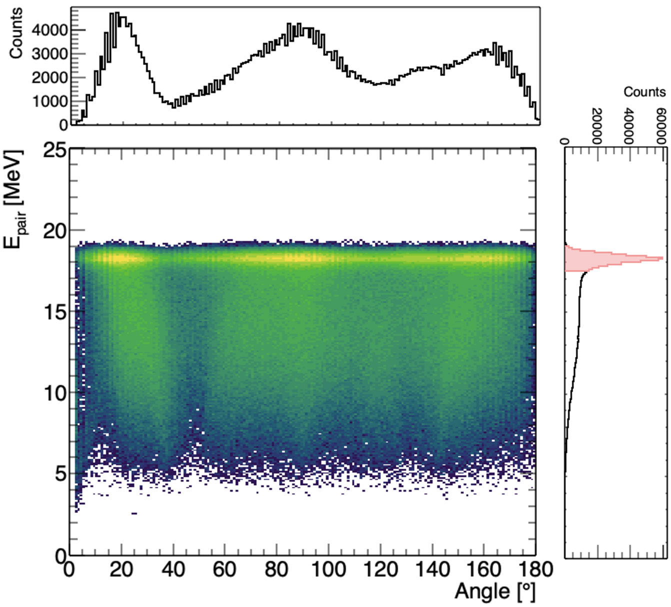

Fig. 4. e^+e^- energy measured *versus* their relative angle measured for a Geant4 simulation of the IPC in an electromagnetic transition at 18.15 MeV. The angular distribution uncorrected is shown at the top of the matrix, considering the energy gate on the right.

5. Conclusions and future work

At LNL-INFN, a new e^+e^- pair spectrometer has been built, and the first experimental campaign was performed in 2023 and 2024. A methodology to selectively determine the angle between the e^+e^- pair has been developed, and the analysis of the experimental data is ongoing. This methodology is being implemented to study the anomaly found by A. Krasznahorkay and collaborators in the isoscalar magnetic dipole transition in ^{8}Be, and the results obtained will be released soon.

REFERENCES

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