1 Goal of the Project

Have you ever wondered why our universe is made almost entirely of matter, with hardly any antimatter in sight? According to the Big Bang theory, the matter and anti-matter should have been created in equal proportion. However, this is not the case. So why do we see such an imbalance?

Physicist Andrei Sakharov has put forward a list of conditions responsible for such an anomaly in the Nature. One of the conditions includes the violation of Charge conjugation symmetry (C-Symmetry). Under C-symmetry invariance particle (matter) and anti-particle (anti-matter) should be treated equally under the laws of Standard Model (SM) of Physics. However, in reality the Nature appears to differ from our narrative. While there is a concrete proof that one of the fundamental forces, the weak interaction, already violates this symmetry, it is still intact in electromagnetic (EM) interactions. In the proposed project we aim to test C-symmetry in EM interaction using the cutting-edge J-PET detector.

2 Reasons for attempting particular research topic

This project proposes a novel and precise approach to investigating one of the most fundamental mysteries in physics. We will search for events where four photons are emitted in the specific angular arrangement of a regular tetrahedron—a rare and theoretically significant pattern. This method offers a unique way to detect signs of C-symmetry violation in the annihilation of a matter–antimatter system. By analyzing the angular distribution of the photons, we can gain deeper insight into the fundamental behavior of nature.

Additionally, the study has the potential to introduce a new methodology for distinguishing between para-positronium (pPs) and ortho-positronium (oPs) states in high-photon decay processes. Overall, this research represents one of the most precise experimental tests of C-symmetry in EM interactions to date.

3 Description of research

The J-PET detector is specifically designed to detect and reconstruct the paths of multiple photons simultaneously, making it highly suitable for multi-photon experiments. In our experiment, we will use a radioactive material, sodium-22, which gives positron while decaying. The positron picks an electron from the surrounding forming positronium, which decays into photons. We are particularly interested in searching for events where four photons are emitted in the exact shape of a regular tetrahedron, a very specific and rare configuration in the already collected data using the modular detector. To make our search faster and more reliable, we will use machine learning algorithms to help identify the right patterns in the data.

4 Substantial results expected

From the proposed research study, primarily we expect to test the possibility of C-symmetry violation study in matter-antimatter system using modular J-PET detector. With the proposed method, this will be one of the most stringent test of C-symmetry violation. Basically we will be able to see if C-symmetry is violated and the level of its violation in EM interactions. This will also serve as a test of the theoretical predictions and might improve the results for such violation from previous experiments. Additionally, the proposed study will serve as a methodology to differentiate between the pPs and oPs apart from their lifetimes. Finally, since the major part of the proposal revolves around the hypothesis of the tetrahedral configuration of the emitted photons during oPs decay as a result of Bose Einstein statistics, this study should also test the validity of this statistics at a very fundamental level potentially offering new insights into quantum behavior of photons.