1. Goal of the project

Quantum physics, the study of universe at its most fundamental level, is full of mind-bending mysteries. One of the most intriguing is quantum entanglement, a phenomenon where two particles become inexplicably linked with each other, even when separated by vast distances. They act as if sharing an unseen bond, and with the change in state of one particle instantly influencing the other. Einstein himself described this as "spooky action at a distance," highlighting its seemingly paradoxical nature.

This research project will leverage the J-PET detector, a state-of-the-art instrument, to study the entanglement of photons produced in matter-antimatter (electron-positron) annihilation. By analysing the polarization of these photons, the project aims to determine the strength of entanglement and investigate whether it varies across different annihilation processes. This unique experimental approach, combined with advanced machine learning techniques, could provide unprecedented insights into the nature of quantum entanglement.

2. Reasons for attempting particular research topic.

This is the first study of its kind to systematically explore how entangled photons are when produced through different types of matter-antimatter annihilation. We're not just confirming existing theories; we're pushing the boundaries of our understanding of entanglement at high energies, where the rules of quantum physics can be especially surprising.

In addition to exploring this fundamental scientific question, our work could have real-world impact. Medical imaging techniques like PET scans rely on detecting photons from positron annihilation. By better understanding the entangled nature of these photons, we could open the door to new ways to improve the accuracy and sensitivity of these scans, leading to earlier and more precise diagnoses.

3. Description of research

The J-PET detector, a cutting-edge PET (positron emission tomography) scanner designed for precise measurement of photon interactions. By observing how pairs of photons from electron-positron annihilation scatter off within the detector, we can deduce their polarization, a key property related to entanglement.

To analyse the data generated by our experiments, we will employ advanced machine learning algorithms. By using these algorithms, we can enhance our ability to differentiate between the various photon creation processes, ultimately leading to more precise measurements of their quantum entanglement.

4. Substantial results expected.

We anticipate our research will reveal a detailed picture of how strongly photons are entangled when they originate from different annihilation processes. This will not only test theoretical predictions but may also uncover new and unexpected quantum behaviours. We're particularly interested in seeing if the degree of entanglement varies depending on how the photons are produced. If so, this could provide valuable insights about the interaction of atomic particle leading to entanglement, and potentially offer new ways to control and manipulate entangled particles for future quantum technologies. We're also hopeful that our findings could lead to innovations in medical imaging. For example, if we discover that entanglement patterns can act as unique signatures for different types of tissues, we could develop more sensitive and specific diagnostic tools.

This project probes the fundamental nature of quantum particles, with the potential to transform both our understanding of the fundamental laws of nature and our ability to harness them for practical applications.