Project Aim:

The aim of the project is to measure the effect of gravitational force on the positronium atom (Ps), the lightest matter-antimatter system, being composed by an electron and its antiparticle, the positron. The lifetime of Ps in the ground state is very short (142 ns). In order to perform gravitational measurements on this system, its lifetime has to be increased, at least, up to a microsecond. This is possible by laser excitation of Ps to metastable levels (for instance, levels with high principal quantum number, Rydberg levels). The availability of Ps atoms with longer lifetimes will allow to study their fall in the gravitational field of the Earth. During the implementation of the project, a sophisticated detection system made of plastic scintillators will be built and used in the AML laboratory in Trento (Italy), which has expertise in the production of Ps beams and the manipulation of their lifetimes using lasers.

Motivation for the proposed research project:

The studies proposed in this project address the simplest, but still open question for almost one century after the prediction of antimatter in 1928 by P. Dirac: "Does antimatter behave similarly to matter under the influence of gravitational force"? The answer to this question could solve the mystery of the absence of observed antimatter compared to matter in the Universe, and thus the matter-antimatter symmetry. For many decades, the main difficulty in pursuing this problem was that no objects/systems with antimatter were available for study. In recent decades, with the availability of anti-proton beams, several groups (ALPHA, AEgIS, GBAR) at CERN have begun to work on one of the most important problems, measuring the behavior of antimatter in the presence of a gravitational field. Ps constitutes a promising alternative to antihydrogen offering the advantage of an easier production and manipulation in a laboratory. However, to measure the gravitational effect, the lifetime of Ps must be manipulated in the order of microseconds, which can be done by using lasers to excite Ps to the metastable state.

Description of the research:

To achieve this ambitious goal, the research involves two major phases. In the first phase, Ps atoms will be created in the PsICO (Ps Interferometry and Correlation Observation) positron beam at AML and excited with lasers to a metastable state that has a lifetime ~an order of magnitude longer than the ground state. Laser cooling techniques will be also employed to collimate the Ps beam. A deflectometer/interferometer system will be used for the measurement of inertial sensing on Ps. The system consists of three equally spaced gratings and a stopper. The first two gratings, which may be material gratings or light gratings with fixed periodicity, give a fringe pattern in the plane of the third material grating whose vertical displacement depends on the acceleration experienced by Ps. At a distance of 1-2 cm from the third grating, a stopper intercepts the Ps crossing the material grating. The fringe pattern will be scanned by performing a series of measurements by moving the third grating along the force direction (perpendicular to the direction of the Ps beam) with a displacement in the range of sub-nm accuracy guaranteed by a commercial single-axis linear piezo nanopositioning system. Finally, to determine the strength of the gravitational force, the probability of annihilation of Ps on the third grating and the stopper is compared for each measured position of the grating. The second key phase requires a detection system to reconstruct the vertices of Ps atoms that interact and annihilate at the third physical grating or eventually at the stopper that crosses the grating. To this end, we will construct 4 modular detection units based on the expertise of the J- PET collaboration established at the Jagiellonian University. Each unit will consist of multiple plastic scintillators. Signals from each scintillator will be read out by silicon photomultipliers (SiPMs) at both ends. The digitization and acquisition of the signals will be entirely based on a FPGA (Field Programmable Gate Arrays) that can handle high count rates. The detection units will be placed around the third grating and the stopper, to separately register the annihilation photons coming from the grating and those coming from the stopper.

Expected Results:

The result of the project will be a direct test of the effect of gravity on Ps. This interdisciplinary project involves several interesting aspects, including the production of Ps, manipulation into long-lived states using lasers, customization of a dedicated deflectomer/interferometer, construction of detection modules based on plastic scintillators, and digital signal processing using FPGA. It will be a unique facility to perform the first direct test to measure the effect of gravitational force on Ps, a neutral matter-antimatter system in the pure leptonic sector.