

Abstract for General Public (English)

Deuteron–deuteron (DD) fusion reactions are of fundamental importance in nuclear physics nuclear astrophysics as well as in nuclear energy production. Typically, the probability of such reactions occurring (i.e., the reaction cross section) decreases rapidly with decreasing deuteron projectile energy. However, accelerator experiments conducted at very low projectile energies using metallic targets have shown a significantly higher reaction cross section than expected. This enhancement cannot be fully explained by the well-known electron screening effect alone, where electrons surrounding the reacting nuclei reduce the Coulomb barrier and increase the reaction probability. Recent studies suggest that an additional contribution can come from a narrow 0^+ resonance state in the ^4He nucleus, located just above the DD reaction threshold (23.85 MeV). This resonance is predicted to decay predominantly through Internal Pair Creation (IPC), a rare electromagnetic decay process in which an electron–positron pair is emitted. Theoretical models predict that the IPC contribution becomes more significant at lower deuteron energies and may account for the enhanced reaction cross sections observed in metallic environments. However, detecting IPC signals at these ultra-low energies (from 5 keV down to ~ 1 keV) is experimentally challenging due to the very low reaction cross sections and the presence of background radiation from terrestrial sources and cosmic rays, especially in surface-based laboratories.

The primary aim of this project is to carry out the first ever measurement of IPC decay in DD fusion at deuteron energies below 5 keV, extending experimental studies down to approximately 1 keV. A key goal is to determine the electron–proton branching ratio and compare it with theoretical predictions. To achieve this, the project will use a dual-detection strategy: direct detection of electron–positron pairs using a silicon detector telescope in ΔE – E configuration, and indirect detection of 511 keV annihilation photons and bremsstrahlung radiation using large-volume NaI(Tl) detectors operating in coincidence mode. These methods are expected to offer significant background suppression and enable measurements at lower energies. The experiments will be conducted at the Ultra High Vacuum (UHV) accelerator facility at the University of Szczecin, equipped with a high-current Electron Cyclotron Resonance (ECR) ion source and a dedicated electrostatic deceleration lens system. This setup allows the delivery of stable, high-current deuteron beams at energies as low as 1 keV under UHV conditions. A central part of the project involves detailed background characterization, supported by GEANT4 Monte Carlo simulations, to model and minimize the effects of environmental and cosmic-ray-induced radiation on the measurements. Accurate background modeling is essential for isolating IPC signals at these low energies.

The results of this project are expected to contribute significantly to the understanding of energy generation in compact astrophysical objects, such as brown dwarfs and giant exoplanets (often referred to as "super-Jupiters"). The enhanced DD fusion rates observed in laboratory metallic targets can help to explain the excess energy production and anomalous radii observed in these stellar bodies. The project will provide important experimental input for refining astrophysical models related to their thermal evolution. Furthermore, the background suppression methods and detection techniques developed in this project will be relevant to other rare-event nuclear experiments, including those in particle and astroparticle physics. By pushing experimental limits, this project is expected to deliver the first-ever measurements of DD fusion cross sections below 5 keV under ultra-high vacuum conditions.