Application of nuclear physics in studies of discrete symmetries, quantum entanglement and positronium imaging with the J-PET tomograph

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The newly constructed Jagiellonian Positron Emission Tomograph (J-PET) is a first PET tomograph built from plastic scintillators [1-8]. As a detector optimized for the registration of photons from the electron-positron annihilations, it also enables tests of discrete symmetries in decays of positronium atoms via the determination of the expectation values of the discrete-symmetries-odd operators, which may be constructed from the spin of ortho-positronium atom and the momenta and polarization vectors of photons originating from its annihilation [9-12]. J-PET is also a unique facility to study the entanglement of photons originating from positronium annihilations [13,14].

In the talk we will present the capability of the J-PET detector to improve the current precision of testing CP, T and CPT symmetries in the decays of positronium atoms and report on results from the first data-taking campaigns. With respect to the previous experiments performed with crystal based detectors, J-PET built of plastic scintillators provides superior time resolution, higher granularity, lower pile-ups, and opportunity of determining photon's polarization through the registration of primary and secondary Compton scatterings in the detector. These features makes J-PET capable of improving present experimental limits in tests of discrete symmetries in decays of positronium atom (a purely leptonic system).

We will also discuss the novel method of positronium imaging of the human body [15]. Positron injected to the human body create in more than 40% cases the bound state of electron and positron, the positronium atom. Currently, in the PET technique, the phenomenon of positronium production is neither recorded nor used for imaging. We will argue that properties of positronium atoms such as (environment modified) life time and production probability, as well as 3γ to 2γ rate ratio which can be obtained during a routine PET imaging may deliver information useful for the in-vivo cancer diagnosis and grading [15,16]. We present our progress in both the development of the diagnosis method and detector development and show operational prototypes.

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