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Constraining CP Invariance in Ortho-Positronium Decays at 7 T with NeuroSphere MR-Compatible PET Modules

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Positron Emission Tomography (PET) systems can measure the decay properties of ortho-positronium (oPs), an intermediate bound state often formed during positron-electron annihilation that decays to photons after a short lifetime. The lifetime and decay kinematics of oPs can be used to probe material properties, have potential to serve as a novel biomarker in disease, and can be used to test the Standard Model. Additional sources of charge conjugation-parity (CP) symmetry violation are required to explain the observed matter-antimatter imbalance in the Universe, and CP violation can be constrained by measuring decays under the reversal of an applied magnetic field. A dedicated physics measurement platform was constructed from the architecture of the NeuroSphere brain PET insert for 7-T MRI, including a PET detector array, positronium target with lifetime trigger, and motorized gantry for control of the system orientation inside the 7-T environment. GATE simulations were used to inform the development of a custom data analysis pipeline for oPs event selection and multi-coincidence processing. Systematics were mitigated by combining runs with various target and detector positions (to average out artificial asymmetries caused by assembly or detector efficiency) and by applying a baseline correction from events in a kinematic region with vanishing analyzing power (to account for drift and complex field- and material-related effects). Decays in polyvinyltoluene (PVT) were measured at 7 T, finding a long lifetime component near 100 ns and CP violation consistent with zero. This work demonstrates the unique opportunity provided by PET/MR instrumentation to perform high-field physics measurements and proof-of-concept for measuring positronium decays with the full NeuroSphere system.

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