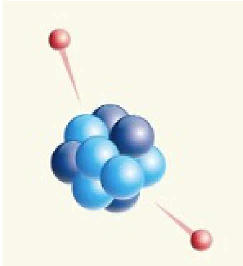

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A journey to ITACA

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High-pressure gaseous xenon time projection chambers with electroluminescence (HGXeTPC-EL), are among the leading technologies for the search of neutrinoless double beta decay. Their combination of excellent energy resolution and detailed topological reconstruction enables powerful discrimination between single-electron and double-electron tracks, the latter representing the characteristic signature of a $0\nu\beta\beta$ event near the decay energy. Background suppression in these detectors relies critically on this topological information, but its effectiveness is ultimately limited by the diffusion of drifting electrons and by the spatial blurring introduced during electroluminescent amplification.

Traditional approaches to mitigate diffusion, such as the addition of molecular cooling agents (e.g., CO_2, CH_4), are constrained by their strong quenching of xenon scintillation and electroluminescence. To overcome these limitations, we introduce ITACA (Ion Tracking with Ammonium Cations Apparatus), a novel concept that exploits both the prompt electron track and a delayed ion track to enhance event reconstruction. In this scheme, trace amounts of NH_3 (at ppb levels) convert xenon ions (Xe^+) into ammonium ions (NH_4^+) without affecting scintillation or EL yields. Electrons drift to the anode within milliseconds, forming the conventional EL image, while NH_4^+ ions drift slowly toward the cathode on a timescale of seconds. Using the primary scintillation (S1) signal as a timing reference, an electrostatic gate releases the ion cloud onto a sensor array of molecular detectors, which can be optically interrogated to reconstruct the ion track with sub-millimeter diffusion and without EL smearing.

By combining the electron and ion images, ITACA could significantly improve the topological background rejection of xenon TPCs, potentially by an order of magnitude. The applicability of this technique to liquid xenon detectors is also discussed, though the higher density and reduced track length in the liquid phase make ion tracking less practical in that regime.

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