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Laser-acceleration and all-optical structuring of energetic proton beams from renewable cryogenic hydrogen jets[1]

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Laser-accelerated proton beams have received increasing attention due to their potential multidisciplinary applications to laser-driven radio-oncology, fusion energy and material sciences among others. These applications demand well controlled ion beam quality, specifically high particle energies and sufficient particle yields, both delivered in a stable and reliable fashion. So far, best laser-acceleration performance was achieved when applying micrometer thick foils as interaction targets in the focus of the high-power laser pulses. This contribution presents the first demonstration of equally efficient laser-proton acceleration from renewable cryogenic hydrogen jets. Due to their continuous and debris-free operation, these targets are credible candidates to enable transitioning from proof-of-principle experiments to application-ready ion sources as they meet critical demands arising from high shot rates (up to 10 Hz) of modern Petawatt laser systems. When operated at the 150 TW laser DRACO of Helmholtz-Zentrum Dresden-Rossendorf (HZDR) in collaboration with SLAC and EuropeanXFEL, high-quality pure proton beams with energies up to 20 MeV and particle yields of $>10^9$ /MeV/sr were detected from hydrogen micro-jets, comparable to proton beams obtained from reference metal foils. Furthermore, investigation of the accelerated proton beam profiles revealed a so far unrecognized effect of the polarized background gas in the interaction chamber. At millimeter distances from the initial laser-target interaction, the transmitted laser pulse ionized residual gas molecules and lead to the formation of quasi-static electric deflection fields in the shape of the laser beam profile. As the trailing proton pulse propagated through the field map, laser intensity features were imprinted on its beam profile, allowing for deliberate tailoring of profile structures and offering an alternative explanation for beam profile modulations observed in previous experiments in the field.

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