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## Temporal bunching of laser-driven ions by ultrafast phase-space rotation

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Laser-driven ion sources of picosecond duration enable new frontiers in the exploration of proton radiolysis, ultrafast atomic dynamics, and nanostructured dose distribution, providing unprecedented insights into how energy deposition influences chemical and structural change, with broad implications in medicine, chemistry, and materials science. However, ions produced by intense laser interactions, the most common and robust mechanism being the Target Normal Sheath Acceleration (TNSA), exhibit a broad energy spectrum and wide angular divergence. These factors result in significant dispersion and broadening of the ion pulses in both space and time as they propagate away from the source. A true game-changer would be a narrow-band, collimated proton beam that preserves its picosecond-scale duration well beyond the laser interaction point - yet no existing method has fully achieved this goal.

One method of generating a narrowband and collimated proton beam from a laser-plasma setup is through the use of a helical coil (HC) target design. In addition to focusing, energy selection and post-acceleration, the HC target induces simultaneous phase rotation of the proton bunch as it traverses through the HC. The phase rotation of proton beams on a picosecond timescale is demonstrated by measuring the bunch duration at a significant distance from the source using Chirped Optical streaking diagnostics. Our findings also show that this method is scalable, with simulations indicating efficient phase space rotation of protons of clinically relevant energies.

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