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Intense laser-driven ion beams in the relativistic-transparency regime: acceleration, control and applications[1]

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Laser-plasma interactions in the novel regime of relativistically-induced transparency have been harnessed to generate efficiently intense ion beams with average energies exceeding 10 MeV/nucleon (>100 MeV for protons) at "table-top" scales. We have discovered and utilized a self-organizing scheme that exploits persisting self-generated plasma electric (˜0.1 TV/m) and magnetic (˜10^4 Tesla) fields to reduce the ion-energy (E_i) spread after the laser exits the plasma [1], thus separating acceleration from spread reduction. In this way we routinely generate aluminum and carbon beams with narrow spectral peaks at E_i up to 310 MeV and 220 MeV, respectively, with high efficiency ($\approx 5\%$). The experimental demonstration has been done at the LANL Trident laser with 0.12 PW, high-contrast, 0.65 ps Gaussian laser pulses irradiating planar foils up to 250 nm thick. In this regime, E_i scales empirically with laser intensity (I) as $I^{1/2}$. Our progress is enabled by high-fidelity, massive computer simulations of the experiments. This work advances next-generation compact accelerators suitable for new applications. *E.g.*, a carbon beam with $E_\mathrm{i} \approx 400$ MeV and 10% energy spread is suitable for fast ignition (FI) of compressed DT [2]. The observed scaling suggests that is feasible with existing target fabrication and PW-laser technologies, using a sub-ps laser pulse with $I \approx 2.5\ 10^{21}$ W/cm^2. These beams have been used on Trident to generate warm-dense matter at solid-densities [3], enabling us to investigate its equation of state and mixing of heterogeneous interfaces purely by plasma effects distinct from hydrodynamics. They also drive an intense neutron-beam source [4] with great promise for important applications such as active interrogation of shielded nuclear materials. Considerations on controlling ion-beam divergence for their increased utility are discussed. [1] S. Palaniyappan, C. Huang, *et al.,* Nature Comm. **6**, 10170 (2015) [2] J. C. Fernández, *et al.,* Nucl. Fus. **54**, 054006 (2014) [3] W. Bang, *et al.*, Sci. Rep. **5**, 14318 (2015) [4] M. Roth, *et al.*, PRL **110**, 044802 (2013)

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