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Laser-Produced and Accelerated High Energy Protons[1]

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Ultra-low emittance, multi-MeV proton beams have recently been produced by the interaction of high-intensity short-pulse lasers with thin metallic foils [1]. The acceleration process proceeds in two steps. First the laser ponderomotively accelerates huge, MA currents of $\sim$MeV electrons which propagate through the foil and form a dense relativistic electron sheath on the non-irradiated rear surface. This sheath produces an electrostatic field $>10^{12}$ V/m that ionizes the surface atoms almost instantaneously, forming a $\sim$1 nm thick ion layer which, together with the electron sheath, resembles a virtual cathode. The ions are accelerated initially normal to the foil surface, followed by a diverging plasma expansion phase driven by the electron plasma pressure. By structuring the rear surface of the foil, we have succeeded to produce modulations in the transverse phase space of the ions, which resemble fiducial "beamlets" within the envelope of the expanding plasma. This allows one to image the initial accelerating sheath, and map the plasma expansion of the beam envelope, to fully reconstruct the transverse phase space. We find that for protons of 10 MeV, the normalized transverse rms emittance is less than 0.004 π mm.mrad [1], i.e. 100-fold better than typical RF accelerators and at substantially higher ion currents exceeding 10 kA. Recent results will be reported on stripping the electrons while maintaining the low emittance from experiments at the LULI 100 TW laser, and theoretical estimates of the lowest emittance which can be expected based on ion heating mechanisms during the initial sheath formation and ion acceleration processes, will be presented. [1] T.E. Cowan, J. Fuchs, H. Ruhl *et al.*, *Phys. Rev. L*ett. 92, 204801 (2004).

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