ULTRA-LOW EMITTANCE, HIGH CURRENT PROTON BEAMS PRODUCED WITH A LASER-VIRTUAL CATHODE SHEATH ACCELERATOR*

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High current multi-MeV protons and ions can be produced by irradiating thin foils with short-pulse, ultra-high intensity lasers (τ<ps, $I\lambda^2 > 10^{18}$ W/cm^2 μm^2). For many potential new applications, the high degree of beam laminarity is an important aspect, for example for table-top ion accelerators, high-resolution charged-particle radiography, or production of high energy density matter by isochoric heating. We understand the high laminarity, or low emittance, of these beams stems from the fact the acceleration process takes place on the cold rear (i.e. non-irradiated) surface of the thin foils. There, a dense relativistic electron sheath is formed by the laser-accelerated electrons that have propagated through the foil. This sheath produces an electrostatic field $>10^{12}$ V/m that ionizes the surface atoms almost instantaneously, forming a ~1 nm thick ion layer which, together with the electron sheath, resembles a virtual cathode.

By structuring the rear surface of this foil, we have succeeded to produce modulations in the transverse phase space, which resemble fiducial “beamlets” within the envelope of the expanding plasma. This allows us to map the expansion of the beam envelope during the latter, sheath expansion phase. Using this technique that allows to directly image the initial accelerating sheath, and we fully reconstruct the transverse phase space for protons of different energy. We find that for protons of up to 10 MeV, the transverse emittance is less than 0.004 mm.mrad [1], i.e. 100-fold better than typical RF accelerators and at a substantially higher ion current (kA range).

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