Recent results from SPARC_LAB

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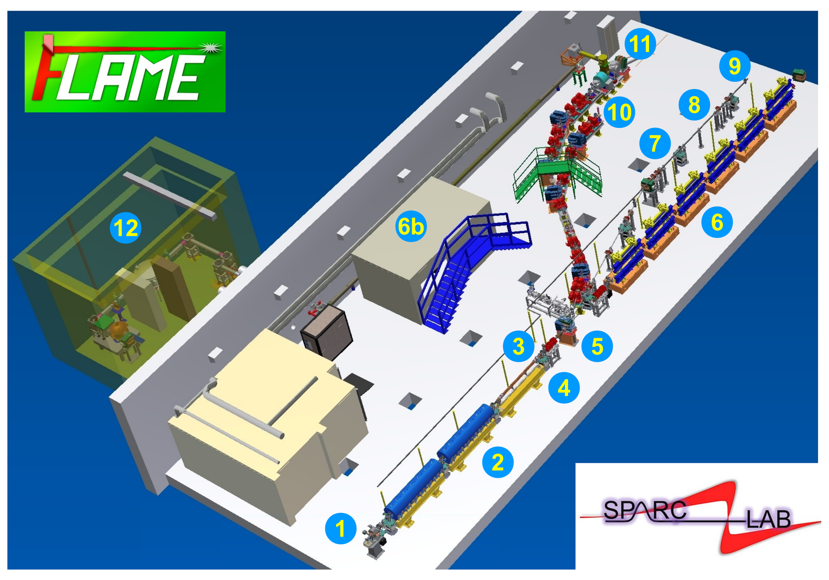
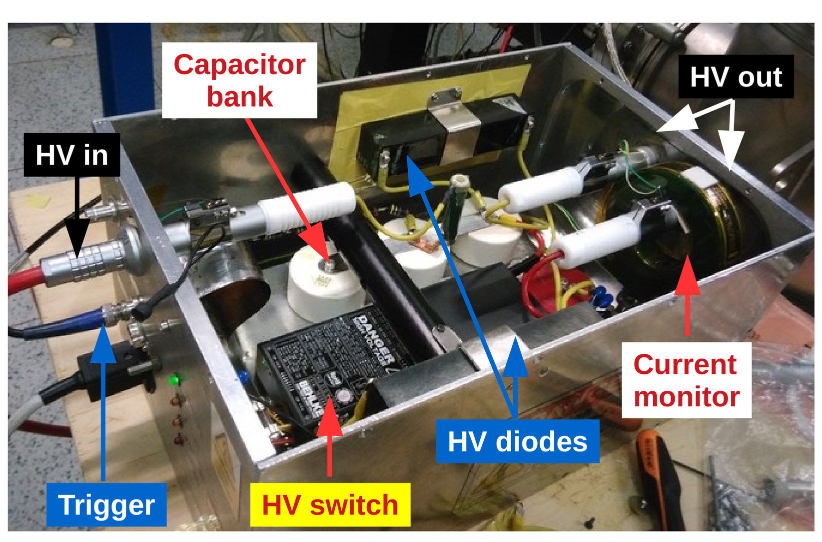
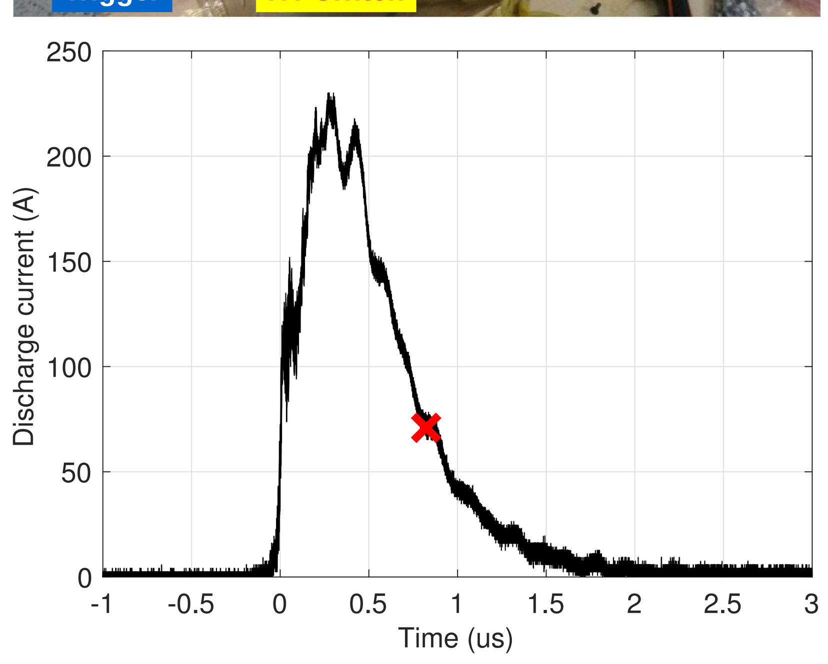
SPARC-LAB test-facility



SPARC-LAB (*Sources for Plasma Accelerators and Radiation Compton with Lasers and Beams*) is a test-facility based on the 180 MeV SPARC electron linac and the 300 TW FLAME laser system [1]. Bunch up to 1 nC charge are produced by a laser hitting on the photo-cathode of a RF-gun (1). The RF-gun is followed by three accelerating sections (2) and a THz radiation source (3). A Plasma Wakefield Acceleration (PWFA) experiment is located upstream the THz station. Four beamlines follow the RF Deflector (4) and the main dipole (5). They are devoted to Free Electron Laser (FEL, 6) both in SASE and seeded (6b) schemes; beam diagnostics (7) based on THz radiation (8) and Electro-Optical Sampling (9); Laser Wakefield Acceleration (LWFA) by external injection (10); X-rays source by Thomson scattering (11) between the e-beam and the FLAME laser (12).

HV Discharge Pulser





The discharge circuit prototype we have realized provides currents up to 600 A with a capacitor bank of $C = 10.8$ nF in series with a resistance $R = 7\ \Omega$. The core is represented by a HV thyristor switch providing up to 12 kA peak current when operating at 44 kV voltage. A second capacitor is used as a low-pass filter and cut the high-frequency ($f > 40$ MHz) oscillations. Two HV diodes prevent negative current overshoot and protect the HV switch.

References

[1] M Ferrario, et al. SPARC_LAB present and future. *Nuclear Instruments and Methods B*, 309:183–188, 2013.

[2] V Shpakov, et al. Longitudinal phase-space manipulation with beam-driven plasma wakefields. *Physical review letters*, 122(11):114801, 2019.

[3] R Pompili, et al. Experimental characterization of active plasma lensing for electron beams. *Applied Physics Letters*, 110(10):104101, 2017.

[4] J Van Tilborg, et al. Active plasma lensing for relativistic laser-plasma-accelerated electron beams. *Physical review letters*, 115(18):184802, 2015.

[5] R Pompili, et al. Focusing of high-brightness electron beams with active-plasma lenses. *Physical review letters*, 121(17):174801, 2018.

[6] Carl A Lindstrøm, et al. Emittance preservation in an aberration-free active plasma lens. *Physical review letters*, 121(19):194801, 2018.

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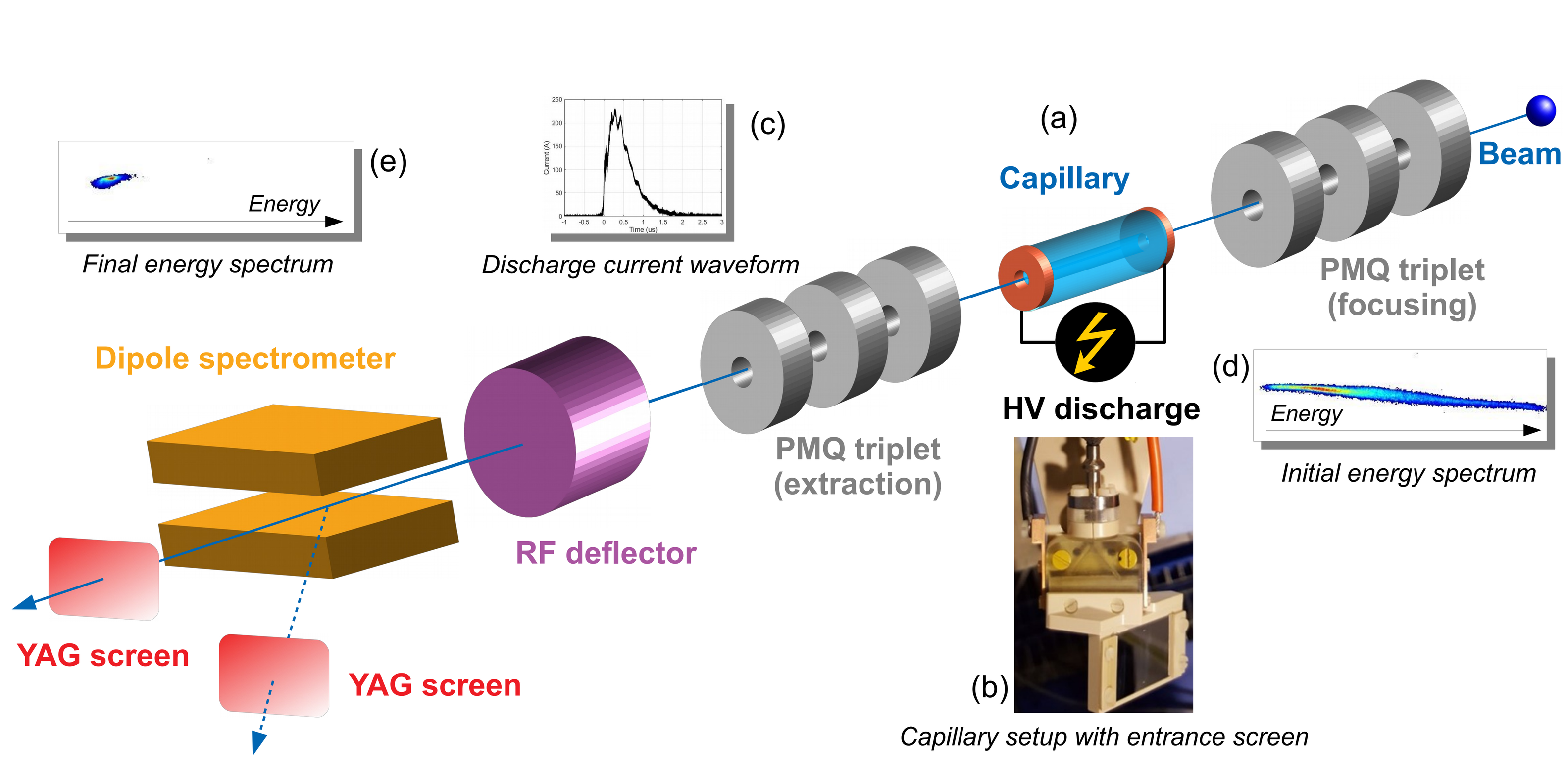
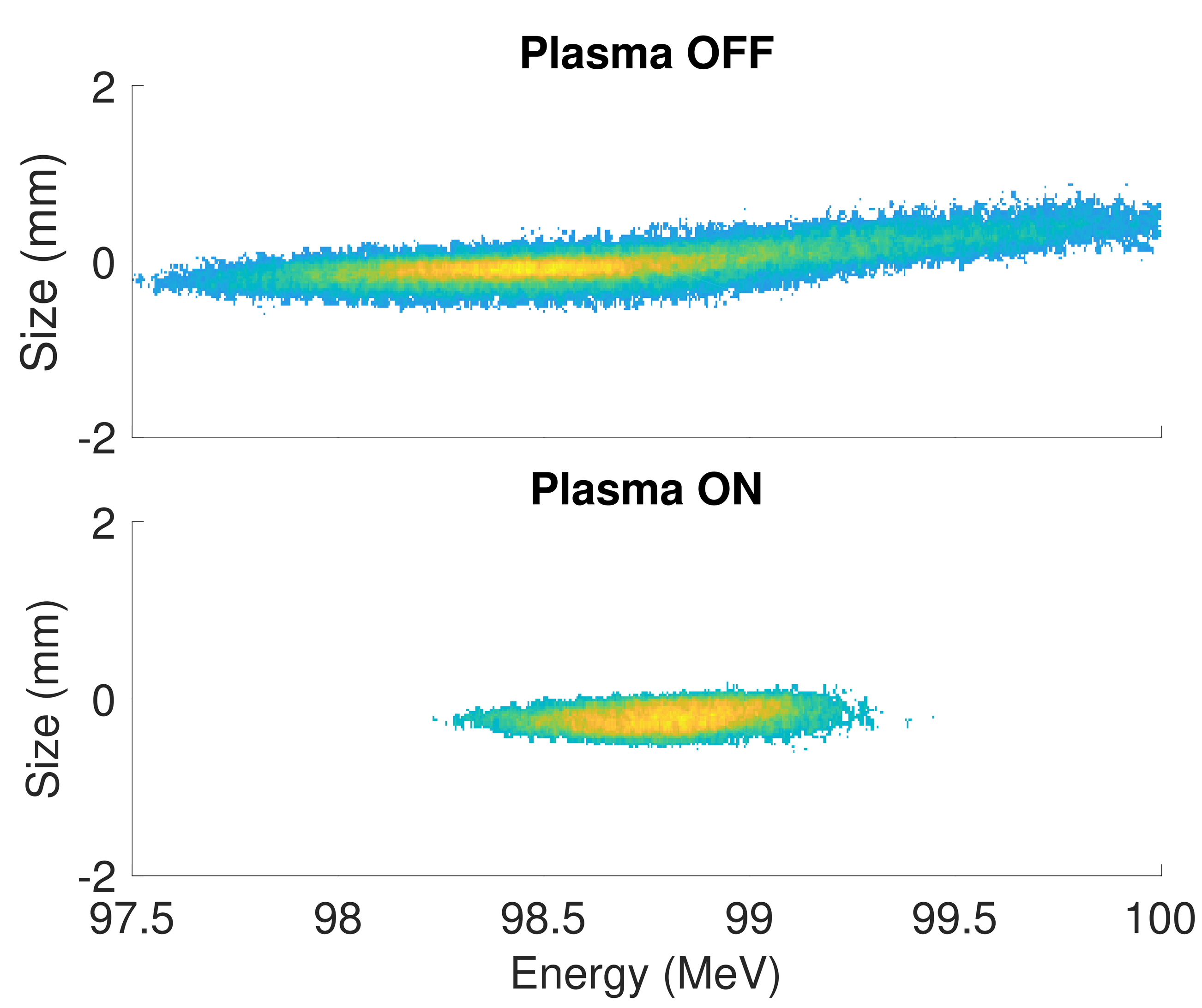
Longitudinal phase-space manipulation with plasma wakefields

The generation of high-brightness electron beams requires the manipulations of their longitudinal phase space (LPS) in order to achieve peak currents as large as required by the specific task. The ability to shape the energy and temporal profiles is thus of paramount importance. The development of new compact machines that exploit advanced acceleration techniques based on plasma wakefields, in particular, would benefit of such a manipulation. Plasma acceleration, indeed, can generate electric fields up to tens of GV/m, allowing to produce GeV level beams in few centimeters. However, due to the shortness of the accelerating field wavelength, a large correlated energy spread is imprinted on the accelerated beam, making it difficult to transport the beam using conventional magnetic optics (like solenoids and quadrupoles), due to chromatic effects.



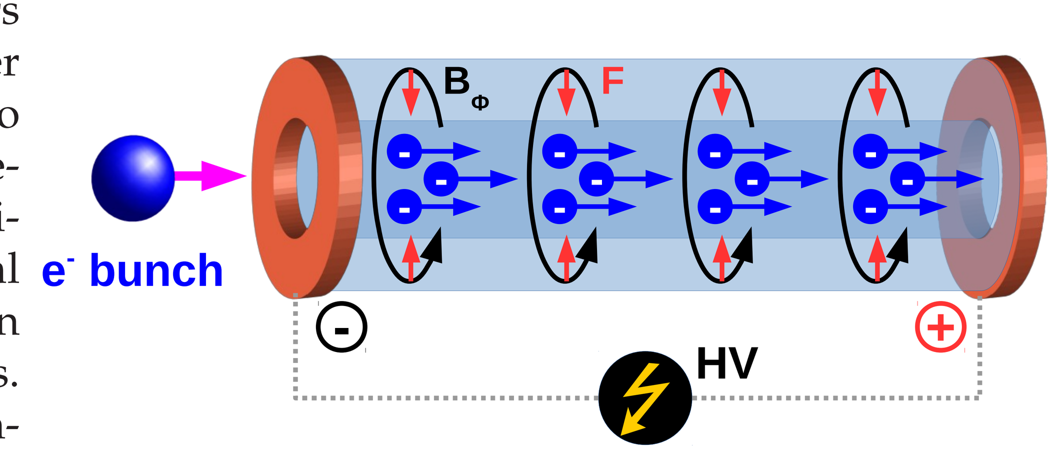
Experimental results



A technique able to remove such an energy chirp must be foreseen. We demonstrated a new approach that allowed to tune the beam LPS by using the wakefields excited in a plasma channel [2]. The solution is based on the use of the self-wakefields created by the beam in the plasma and can be employed both to remove the energy chirp (acting like a *dechirper*) or tune it by adjusting the plasma density. Once injected into the plasma, the electron bunch starts to create the wakefield. The strength of that field depends on plasma density and the density of the beam itself. In our configuration, the tail of the beam experiences a decelerating electric field and loses its energy, while the head moves along an unperturbed plasma, keeping its energy actually constant. This is equivalent to a rotation of the beam LPS.
In our specific case, being the wakefield approximately 50 MV/m, we expect that the energy chirp of the beam ($\approx 10^4$ MeV/m) can be completely removed by employing a few-cm-long structure. To measure the effect on the beam energy spectrum, we transported the beam (200 pC, 99 MeV, 0.6 MeV energy spread) into the magnetic spectrometer downstream the capillary (with the RF deflector turned off) and made several measurements at different plasma densities. When the plasma is turned on and its density tuned to $n_p \approx 1.8 \times 10^{14}$ cm^{-3} (corresponding to a delay on the order of $4.5\ \mu s$), we achieved the maximum reduction of the beam energy spread, down to 0.1 MeV.

Active-plasma lenses as focusing devices

Plasma-based technology promises a tremendous reduction in size of accelerators allowing to develop table-top machines. By pushing particles to larger and larger energies, the availability of strong and tunable focusing optics is mandatory also because plasma-accelerated beams usually have large angular divergences. Active-plasma lenses (APL) [3] represent a compact and affordable tool to generate radially symmetric magnetic fields several order of magnitude larger than conventional quadrupoles and solenoids. Recent experiments demonstrated kT/m focusing on relativistic electron beams coming from laser-plasma [4] and RF [5, 6] accelerators. These devices consist of a discharge-current (flowing through a capillary) that generates an azimuthal magnetic field with radially increasing strength.



Experimental results

To test the APL we used a 50 pC electron beam with 127 MeV energy, 1.3 ps duration and $0.8\ \mu m$ (rms) normalized emittance. The bunch spot size at the capillary entrance is varied from $\sigma_{x,y} \approx 35\ \mu m$ to $\sigma_{x,y} \approx 160\ \mu m$. The resulting emittance is measured downstream the capillary. For small spot sizes there is a strong effect of the plasma wakefields due to the larger bunch densities and the emittance increases up to $\epsilon_n \approx 9\ \mu m$. Conversely, for large spot sizes their effect is minimized but the nonlinearities of the active lensing also increase the emittance (up to $\epsilon_n \approx 3\ \mu m$). The best compromise is obtained by entering into the plasma with a transverse spot size of about $110\ \mu m$. When the discharge is turned on, the beam is squeezed to $17\ \mu m$. This point corresponds also to the smallest emittance ($\approx 0.9\ \mu m$).