SL_COMB

E. Chiadroni (Resp.), D. Alesini, M.P. Anania (Art. 36), M. Bellaveglia, A. Biagioni (Art. 36), S. Bini (Art. 36.), F. Ciocci (Ass.), M. Croia (Dott.), A. Curcio (Dott), M. Daniele (Dott.), M. Del Franco (Art. 36), D. Di Giovenale (Art. 36), G. Di Pirro, M. Ferrario, A. Gallo, A. Ghigo, D. Giulietti (Ass.), A. Marocchino (Art.36), R. Pompili (Art.36), S. Romeo (Dott.), V. Shpakov (Art. 36), J. Scifo (Ass. Ric.), B. Spataro (Ass.), C. Vaccarezza, F. Villa (Art. 23)

1 Experiment description

The experiment called SL_COMB aims at the acceleration, manipulation and transport of high brightness electron beams by resonant plasma wakefields [1]. At this regard, a train of high brightness bunches with THz repetition rate, so-called comb beam [2], is properly generated at the cathode, and manipulated through the velocity bunching technique [3, 4], in order to be injected in a H_2-filled plasma discharge capillary [5] with proper distance and length. A train of driver bunches separated by a plasma wavelength, λ_p, corresponding in our case to 1 ps, resonantly excites a plasma wake, which accelerates a trailing witness bunch injected at the accelerating phase. Going towards more compact facilities, also plasma-based focusing devices deserve deep investigation. In this regard at SPARC_LAB [6] we are performing theoretical and experimental studies on both active [7] and passive [8] plasma lenses to understand their effect on the beam quality and pave the way to their integration in conventional transport beam lines. For this reason different capillaries, in terms of size and material, are under investigation with a high voltage discharge circuit (20 kV, 200 A) to ionize the hydrogen gas filling the capillary. In addition, because of the nature of the gas-guiding structures used, detrimental effects on the beam stability due to wakefields might rise up requiring careful attention to minimize them.

2 Activity

The activity in 2017 was focused on the investigation of active plasma lenses under different conditions with the aim of characterizing the effect on the transverse emittance, which is of utmost importance if plasma lenses need to be integrated in conventional transport beam lines. With the 3 cm long capillary and the lower peak current (20 kV, 100 A) discharge circuit, we have observed, as reported in [7], a partial ionization of the gas, being maximum of 30% in close proximity to the axis. The partial ionization of the hydrogen results in an even more non-linear magnetic field, since the current is forced closer to the axes. To get rid of the non-linearities in the magnetic field, causing emittance degradation, we replaced the 3 cm long capillary with a shorter one, 1 cm length[1], and we modified the discharge circuit to produce a peak discharge current of 240 A with 20 kV, resulting in an unchanged focal length of 20 cm, where a YAG:Ce screen is placed for transverse beam size measurement. The one-dimensional model used confirms a higher and more uniform ionization degree within the capillary radius as depicted in Fig. 1 (red curve). The current is distributed approximately uniformly within the capillary aperture, resulting in a more linear magnetic field (Fig. 1 (blue curve)).

[1]The 1 cm-long capillary, with 1 mm hole diameter, is made by 3D printing; one inlet is open for gas flow at 1/2 of capillary.

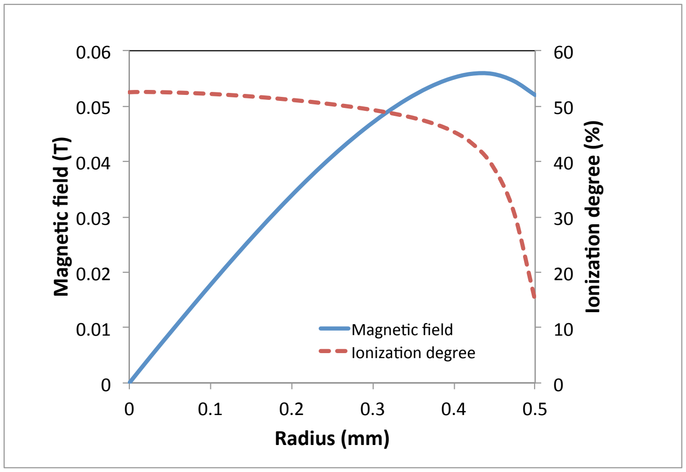

Figure 1: Calculated radial profiles of the azimuthal magnetic field (blue) and H_2 ionization degree (red) for 130 A discharge current, value at which the beam transverse size on the screen is minimized.

Under these conditions, and with beam parameters at the plasma entrance listed in Table 1, we have observed a more uniform beam transverse distribution as shown in Fig. 2 for the two cases. In particular, at the current of maximum defocalization, the beam distribution is not affected by spherical aberrations (Fig. 2b), signature of non-linear magnetic field and responsible of the emittance growth observed in [7]. Figure 2 shows a comparison between measured transverse

Table 1: Measured beam parameters at the plasma entrance.

Q (pC)	50 (5)
E (MeV)	126.5 (0.04)
$\Delta E/E$ (%)	0.06
ε_{nx} (mm mrad)	0.9 (0.1)
ε_{ny} (mm mrad)	1.15 (0.05)
σ_z (μm)	303 (6)
σ_x (μm)	79 (2)
σ_y (μm)	86 (2)

distributions in case of an ionization degree of about 30% mainly on axis (a) and of 50% over a larger fraction of the capillary radius (b).

Simulations have been performed to validated our hypothesis and cross-check the measurements. The magnetic profile, retrieved from the 1D simulation, has been included in the simulations performed using GPT [10] and Architect [9], showing very good agreement with measured data, as shown in Fig. 3. An emittance growth between 30 and 40% has been registered in the plasma, with respect to the case without plasma, probably due to non linearities in the magnetic field, explored by the outer particles of the bunch. The horizontal axis, in Fig. 3 shows a relative longitudinal coordinate along the linac. In this relative coordinate system, the plasma lens is placed at approximately z=5 cm, where the emittance (solid line) starts increasing in the 1 cm long capillary. This is the result of a beam dynamics simulation with the GPT code, assuming in the plasma capillary a radial profile of the azimuthal magnetic field as shown in Fig. 1. The dashed line in Fig. 3 represents the simulated emittance value in case of free space (no plasma in the capillary).

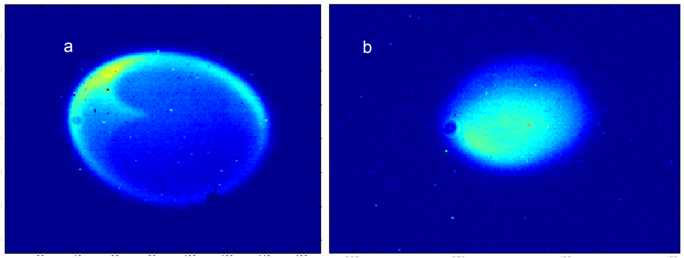

Figure 2: Beam transverse distribution measured on the YAG screen at 20 cm from the capillary for the maximum current: (a) 100 A and 3 cm length, (b) 240 A and 1 cm length.

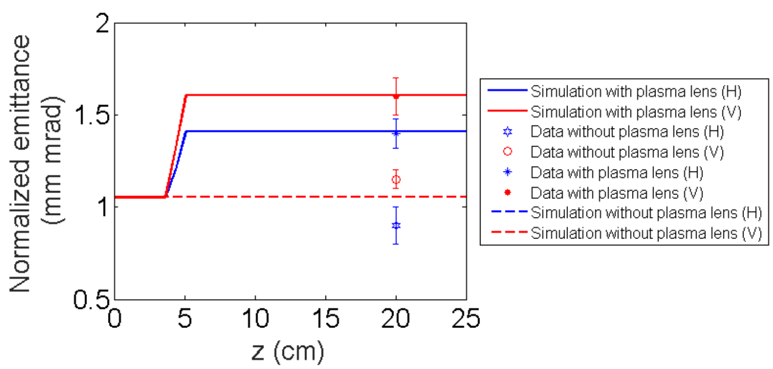

Figure 3: Normalized transverse emittance as function of z. The numerically computed emittance is plotted with solid lines, and the experimental values are overlapped with stars (ε_{nx}) and circles (ε_{ny}).

Since the the emittance is measured through the conventional quadrupole scan technique about 5 m downstream from the plasma lens and the Twiss parameters are backtracked to the flag at about 20 cm from the plasma, the data of measured emittance (x and y) with (star and dot) and without plasma (hexagon and circle) are both drawn at z=20 cm.

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3 List of Conference Talks by LNF Authors in Year 2017

1. E. Chiadroni, *Overview of Plasma Lens Experiments and Recent Results*, 3^{rd} European Advanced Accelerator Concepts Workshop (EAAC), La Biodola, Isola d'Elba - September 24-30, 2017

2. E. Chiadroni, *Plasma-based Experiments at the SPARC_LAB Test Facility*, IFAE XVI Incontri di Fisica delle Alte Energie, April 19 - 21, 2017 - Università degli Studi di Trieste

3. F. Filippi, *Plasma ramps generation by outflow in gas-filled capillaries*, 3^{rd} European Advanced Accelerator Concepts Workshop (EAAC), La Biodola, Isola d'Elba - September 24-30, 2017

4. R. Pompili, *Recent results from SPARC_LAB*, 3^{rd} European Advanced Accelerator Concepts Workshop (EAAC), La Biodola, Isola d'Elba - September 24-30, 2017

5. R. Pompili, *High-brightness electron beams focusing with plasma lenses: recent results at SPARC_LAB*, Conference on High Intensity Laser and attosecond science in Israel (CHILI) , December 11 - 13, 2017, Tel Aviv

6. S. Romeo, *High quality plasma wakefield acceleration experiment in linear regime at SPARC_LAB*, 3^{rd} European Advanced Accelerator Concepts Workshop (EAAC), La Biodola, Isola d'Elba - September 24-30, 2017

7. J. Scifo, *n-machining, surface analysis and characterization measurements of a copper photocathode at SPARC_LAB*, 3^{rd} European Advanced Accelerator Concepts Workshop (EAAC), La Biodola, Isola d'Elba - September 24-30, 2017

8. V. Shpakov *Plasma acceleration limitations due to betatron radiation*, 3^{rd} European Advanced Accelerator Concepts Workshop (EAAC), La Biodola, Isola d'Elba - September 24-30, 2017

4 List of Publications in Year 2017

1. Lorusso, A., ..., Chiadroni, E. et al.,

   Pulsed laser deposition of yttrium photocathode suitable for use in radio- frequency guns

   Appl. Phys. A-Material Science & Processing **123**(12), 779 (2017)

   doi: 10.1007/s00339-017-1396-1

2. Filippi, F., Anania, M. P. et al.,

   Gas-filled capillaries for plasma-based accelerators

   Journal of Physics: Conference Series **874**(1), 012036 (2017)

3. Marocchino, A. et al.,

   Experimental characterization of the effects induced by passive plasma lens on high brightness electron bunches

   Appl. Phys. Lett. **111**, 184101 (2017)

   doi: 10.1063/1.4999010

4. Curcio, A. et al.,

   Single-shot non-intercepting profile monitor of plasma-accelerated electron beams with nanometric resolution

   Appl. Phys. Lett. **111**, 133105 (2017)

   doi: 10.1063/1.4998932

5. Villa, F. et al.,

   Generation and characterization of ultra-short electron beams for single spike infrared FEL radiation at SPARC_LAB

   Nucl. Instr. and Methods in Physics Research A **865**, 43-46 (2017)

   doi: 10.1016/j.nima.2017.02.042

6. Cianchi, A., Anania M. P., Bellaveglia, M. et al.,

   Transverse emittance diagnostics for high brightness electron beams

   Nucl. Instr. and Methods in Physics Research A **865**, 63-66 (2017)

   doi: 10.1016/j.nima.2016.11.063

7. Chiadroni, E. et al.,

   Beam manipulation for resonant plasma wakefield acceleration

   Nucl. Instr. and Methods in Physics Research A **865**, 139-143 (2017)

   doi: 10.1016/j.nima.2017.01.017

8. Shpakov, V. et al.,

   Study of the beam tolerance for plasma based ion channel lasers

   Nucl. Instr. and Methods in Physics Research B **402**, 384-387 (2017)

   doi: 10.1016/j.nimb.2017.03.107

9. Zhu, J., Chiadroni, E. et al.,

   Misalignment measurement of femtosecond electron bunches with THz repetition rate

   Phys. Rev. Accel. and Beams **20**, 042801 (2017)

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10. Pompili, R. et al.,

    Experimental characterization of active plasma lensing for electron beams

    Appl. Phys. Lett. **110**, 104101 (2017)

    doi: 10.1063/1.4977894