SL_COMB

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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, in the framework of SL_COMB we have performed at SPARC_LAB [6] theoretical and experimental studies on both active [7, 8] and passive [9] 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, have been investigated with different high voltage discharge circuits [10] to ionize the hydrogen gas filling the capillary. The discharge phenomenon deserves deep investigation in particular in case of plasma-filled capillaries for plasma lenses, setting the initial conditions and therefore the uniformity of the plasma density, which in turn manifests itself in the linearity of the magnetic field. 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 2018 was focused on the demonstration of the acceleration of high quality electron bunches through particle driven plasma acceleration. Preparatory studies, both theoretical and experimental, have been performed on beam dynamics and matching and transport by means of permanent magnet quadrupoles (PMQ) and plasma devices. The preparatory beam dynamics studies based on start-to-end simulations resulted also in the writing of the Conceptual Design Report for the EuPRAXIA@SPARC_LAB project. To optimize the final focus and extraction with both PMQs and active plasma lenses, we have modified the plasma interaction chamber to gain more flexibility of the final focus system, allowing a better adjustment with the beam energy. In addition, we have performed a deep measurement campaign to optimize the alignment through the PMQ triplets used for the injection and extraction, from the plasma accelerating module. The impact of plasma jets, gas partial ionization and passive plasma lens has been extensively studied both theoretically and experimentally to get rid of the preservation of the emittance in plasma-based focusing devices. This study has also led to the first benchmark between codes and experimental data. In this regard, we have demonstrated how to minimize the non-linearities in the magnetic field, thus improving the lens effect and preserving the beam emittance (Fig. 1). This achievement represents a major breakthrough toward the miniaturization of next-generation

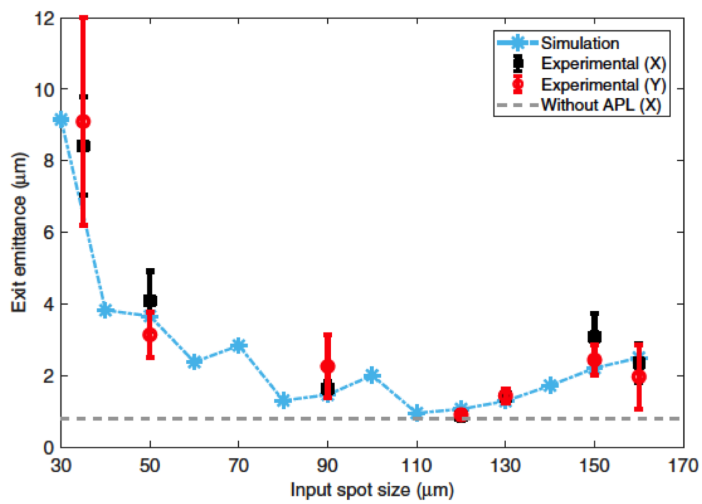

Figure 1: Resulting emittance as a function of the beam spot size at capillary entrance. The black (red) data points refer to the experimentally measured X(Y) emittances. The blue line reports the expected emittance obtained with numerical simulations. The gray line shows the unperturbed (X) beam emittance without active plasma lens.

focusing devices.

Finally, we have started an experimental campaign for the characterization of the interaction of a single bunch beam, i.e. a driver-like (200 pC, 97 MeV, 50 μm (rms) bunch length, 0.5 MeV energy spread), with the plasma to maximize the energy loss in view of the two-beams PWFA experiments. Preliminary measurements have been compared with simulations performed with Architect [11] and reported in Fig. 2. The maximum decelerating field, i.e. 200 MV/m, corresponds to a plasma density $n_0 \simeq$1.4 10^{15} cm^{-3}; as a result, a witness bunch injected at the proper phase would experience an accelerating field of 300 MV/m.

Beam-driven plasma wakefields can be also used to tune, in particular reduce, the beam energy-chirp. Indeed, being the tail of the beam decelerated with respect to the head, several knobs allow to adjust the energy-time correlation: for instance the plasma density, bunch charge/density, bunch length, capillary length. In this regard, we have performed a deep experimental investigation, which demonstrates how to remove such correlation and reduce the overall energy spread to its uncorrelated term. The results reported in [12] are sketched in Fig. 3.

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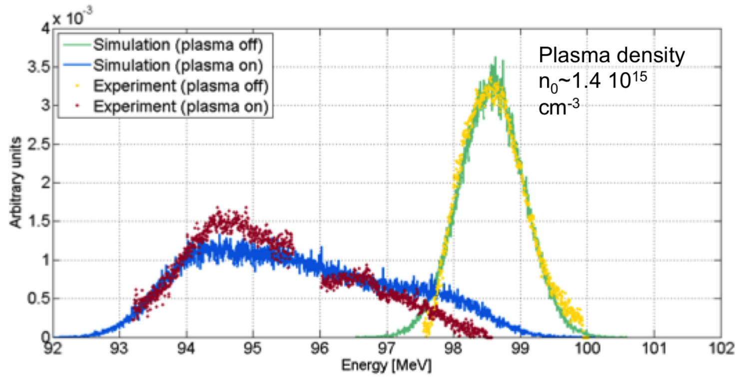

Figure 2: Beam energy profile with plasma discharge off (yellow dots: data, green line: simulation) and on (red dots: data, blue line: simulation). The tail of the bunch loses about 4 MeV in 3 cm capillary length, which corresponds to a maximum decelerating field of 300 MV/m for a plasma density of $n_0 \simeq$1.4 10^{15} cm^{-3}.

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3 List of Conference Talks by LNF Authors in Year 2018

1. 9^{th} International Particle Accelerator Conference - IPAC2018 (April 30th - May 4th, 2018 - Vancouver, BC - Canada)

   - E. Chiadroni, *Status of Plasma-based Experiments at the SPARC_LAB Test Facility*

2. 7^{th} International Beam Instrumentation Conference - IBIC 2018 (9-13 September 2018, Shanghai - China)

   - A. Cianchi, Frontiers of Beam Diagnostics in Plasma Accelerators

3. 104^{th} Congresso Nazionale SIF (17-21 Sept. 2018 - University of Calabria)

   - R. Pompili, *Advanced beam manipulation with plasma based devices*

4. 29^{th} Linear Accelerator Conference - LINAC18 (16-21 Sept. 2018 - Beijing)

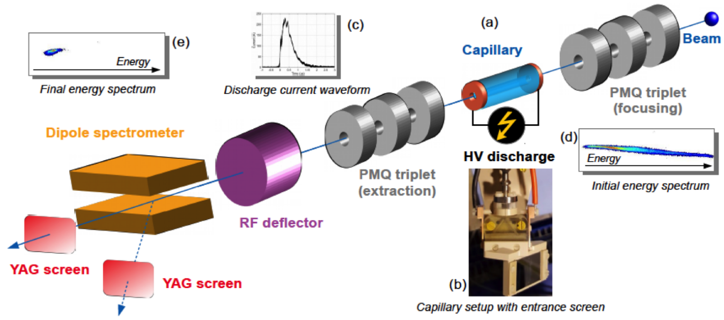

Figure 3: Experimental setup. The electron beam is tightly focused by the PMQ triplet into a 3 cm-long plastic capillary (a) filled by H_2 gas through two inlets (b) connected to an electrolytic generator. Below the capillary and in correspondence of its entrance, a screen has been installed to measure the beam transverse profile. At the capillary ends there are two copper electrodes connected to a 20 kV power supply producing 230 A peak current (c). The whole system is mounted on a movable actuator allowing to adjust its position with respect to the beam. The exiting beam is then captured by a second PMQ triplet. The diagnostics of the experiment is completed by a RF-deflector and two screens downstream the dipole spectrometer. The second screen is located at 14 with respect to the initial beam path, allowing to measure the beam energy spectrum without (d) and with (e) plasma.

- A. Cianchi, *Frontiers of Beam Diagnostics in Plasma Accelerators*
- A. Marocchino, *High brightness electron beams from plasma-based acceleration*

5. 8^{th} International Conference Channeling 2018 - Charged & Neutral Particles Channeling Phenomena (23-28 Sept. 2018 - Ischia)

   - R. Pompili, *Guiding of Charged Particle Beams in Curved Capillary-Discharge Waveguides*
   - M. Ferrario, *Advanced Accelerator Developments at EuPRAXIA@SPARC_LAB*

4 List of Publications in Year 2018

1. Pompili, R. et al.

   Focusing of high-brightness electron beams with active-plasma lenses

   Physical Review Letters **121**.17 (2018): 174801

2. Filippi, F. et al.,

   3D-printed capillary for hydrogen filled discharge for plasma based experiments in RF-based electron linac accelerator

   Review of Scientific Instruments **89**.8 (2018): 083502

3. Filippi, F. et al.,

   Tapering of plasma density ramp profiles for adiabatic lens experiments

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4. Cianchi, A. et al.,
Frontiers of beam diagnostics in plasma accelerators: Measuring the ultra-fast and ultra-cold
Physics of Plasmas **25**.5 (2018): 056704.

5. Chiadroni, E. et al.,
Overview of plasma lens experiments and recent results at SPARC_LAB
Nucl. Instr. and Methods in Physics Research A, in press (2018)
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6. Ferrario, M. et al.,
EuPRAXIA@SPARC_LAB Design study towards a compact FEL facility at LNF
arXiv. No. arXiv: 1801.08717. 2018

7. Pompili, R. et al.,
Recent results at SPARC_LAB
arXiv preprint arXiv:1801.05990 (2018)

8. Biagioni, A. et al.,
Wake fields effects in dielectric capillary
arXiv preprint arXiv:1801.04200 (2018)

9. Scifo, J. et al.,
Nano-machining, surface analysis and emittance measurements of a copper photocathode at SPARC_LAB
arXiv preprint arXiv:1801.03823 (2018)

10. Giribono, A. et al.,
RF injector design studies for the trailing witness bunch for a plasma-based user facility
arXiv preprint arXiv:1801.02878 (2018)

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Preliminary RF design of an X-band linac for the EuPRAXIA@SPARC_LAB project
arXiv preprint arXiv:1801.00707 (2018)

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Numerical studies on capillary discharges as focusing elements for electron beams
Nucl. Instr. and Methods in Physics Research A, in press (2018)
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13. Filippi, F. et al.,
Plasma ramps caused by outflow in gas-filled capillaries
arXiv preprint arXiv:1802.10030 (2018)

14. Vaccarezza, C. et al.,
EuPRAXIA@SPARC_LAB: Beam Dynamics studies for the X-band Linac
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15. Giribono, A. et al.,
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16. Rossi, A. R. et al.,
Plasma boosted electron beams for driving Free Electron Lasers
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17. Petrillo, V. et al.,
Free Electron Laser in the water window with plasma driven electron beams
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18. Pompili, R. et al.,
Ultrafast evolution of electric fields from high-intensity laser-matter interactions
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19. Rosenzweig, J. B. et al.,
Adiabatic plasma lens experiments at SPARC
Nucl. Instr. and Methods in Physics Research A, in press (2018)
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20. Bisesto, F. G., M. Castellano, E. Chiadroni, and A. Cianchi
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