SL_COMB

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

1. Experiment description

The experiment called SL$_$COMB aims at the acceleration of high brightness electron beams by resonant plasma wakefields. At this regard, a train of high brightness bunches with THz repetition rate, so-called comb beam, is properly generated at the cathode, and manipulated through the velocity bunching technique, in order to be injected in a H_2-filled plasma discharge capillary. 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.

The SL_COMB experiment at SPARC_LAB will operate in the so-called quasi-nonlinear regime, defined by the dimensionless charge quantity

$$\tilde{Q} \equiv \frac{N_b k_p^3}{n_0} < 1 \tag{1}$$

being N_b the driver number of particles, $k_p=2\pi / \lambda_p$ the plasma wavenumber.

At SPARC LAB, a 3-5 cm long sapphire capillary (1 mm diameter) will be used and operated with a high voltage discharge circuit (20 kV, 200 A) to ionize the hydrogen gas filling the capillary. Assuming a plasma density $n_0=10^{16}$ cm^{-3}, the plasma wavelength is λ_p = 330 μm, corresponding to an oscillation period of 1 ps. The goal of the experiment is to provide an adequate accelerating gradient of the order of 1 GV/m, while preserving the brightness of the accelerated witness beam, i.e. low energy spread ($\Delta E/E < 1\%$) and transverse normalized emittance of the order of 1 mm mrad.

2. Activity

The activity in 2015 was focused on the preparation of the experiment as a whole, spanning from experimental studies on electron beam dynamics, simulations to investigate beam transport, beam-plasma interaction and extraction of the accelerated beam, and preparation of advanced electron beam and plasma diagnostics.

2.1 Experimental beam dynamics and simulation studies

A train of multiple bunches is directly produced at the photo-cathode through a comb-like laser pulse, as generated by birefringent crystals. In addition, a delay line has been set up to take full control of the witness temporal position with respect to the last driver. Finally half wave plates have been used for producing an unbalance of laser intensity, which turns into a ramp of charge.

By combining the laser comb technique, to produce train of bunches at the cathode, with the velocity bunching regime, to rotate the longitudinal phase space allowing the generation of a train of ultra-short (few tens of femtosecond scale) electron bunches, we succeeded in experimentally manipulating and characterizing trains of up to five bunches, 4 drivers with ramped charge and 1 witness, whose parameters are listed in Table 1 and both the longitudinal phase space and the current distributions are shown in Fig. 1.

Table 1: Measured driver and witness beams parameters

	Beam Energy (MeV)	Energy spread (%)	Position (ps)	Bunch duration (ps)	Charge (pC)
Witness Beam	112.584(0.009)	0.084(0.001)	2.36(0.03)	<0.088(0.001)	24.0 (0.3)
Drive Beam 4	112.281(0.009)	0.159(0.001)	3.93 (0.03)	0.042(0.001)	74.9 (0.5)
Drive Beam 3	112.170(0.009)	0.112(0.001)	5.31(0.03)	0.092(0.001)	69.4(0.4)
Drive Beam 2	112.255(0.008)	0.087(0.001)	6.10 (0.03)	0.113(0.001)	36.3(0.2)
Drive Beam 1	112.197(0.008)	0.045(0.013)	7.01 (0.02)	<0.100(0.024)	15.0 (0.2)
Whole Beam	112.269(0.009)	0.162(0.001)	4.77(0.03)	1.275(0.003)	220 (1)

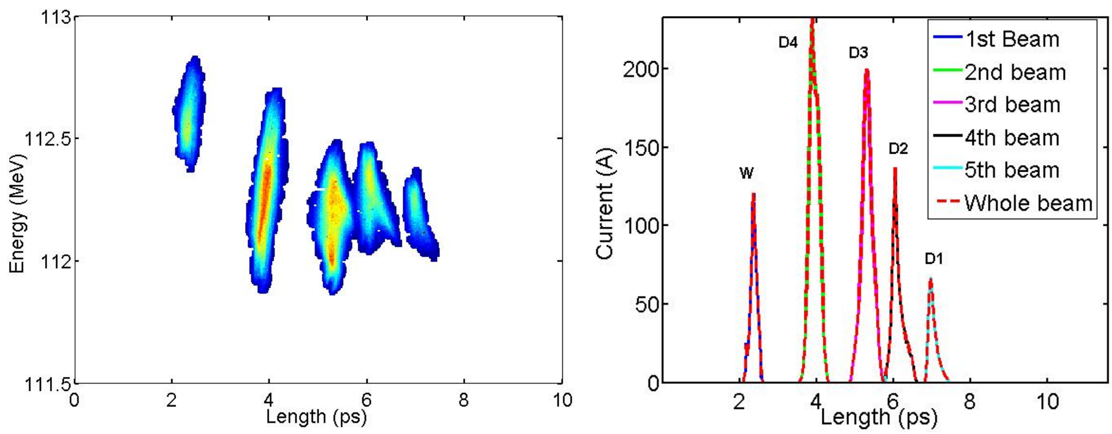

Figure 1: Longitudinal phase space (left) and current distribution (right) for the 4 ramp drivers and 1 witness beam.

The transverse normalized emittance in the horizontal plane has been measured for each bunch in the train by means of the RF deflecting cavity, which deflects the beam vertically, combined with the well-known quadrupole scan technique, resulting in 1 mm mrad for the witness beam.

From the numerical point of view, we started to simulate the case of one driver (200 pC, 190 fs) and one witness (20 pC, 40 fs), whose results are reported in Fig.2: the witness experiences about 1.1 GV/m accelerating field with an energy spread around 1.5% (left plot) thanks to its longitudinal matching and short duration. The witness envelope and emittance are depicted in Fig. 2 (right plot), showing a mitigation of envelope oscillations and the preservation of emittance along the capillary. Simulations of beam driven plasma wakefield acceleration (PWFA) have been performed by means of a hybrid kinetic fluid code, named as Architect [ref].

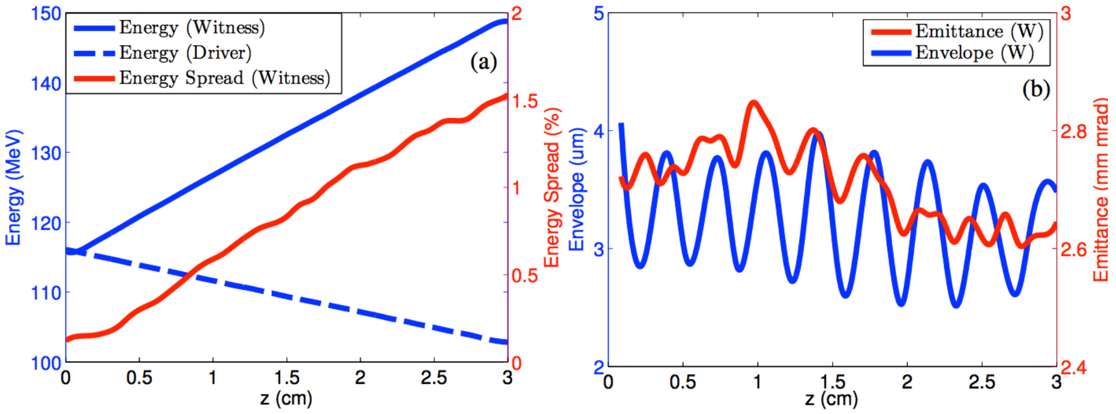

Figure 2: Beam evolution along the capillary: (a) Energy gain and witness energy spread; (b) envelope (blue) and emittance (red) of the witness bunch.

2.2 Experimental apparatus for plasma acceleration experiment

The vacuum chamber for PWFA experiments has been finalized, vacuum tested and installed on the main line right after the third accelerating structure (Fig. 3). The chamber, beyond the H_2-filled 3D printed capillary, hosts longitudinal diagnostics, based on Electro-Optical Sampling, for properly setting bunches inter-distance and duration, permanent magnets to proper match the beam into the plasma and capture it at the exit from plasma, and transverse diagnostics to validate the matching.

The vacuum chamber has been designed to have the best vacuum performances, in order to guarantee the ultra-high vacuum level, i.e. 5 10^{-8} mbar, at the exit of the last accelerating structure. The vacuum tests guarantee the operation with the plasma at 5 Hz satisfying the vacuum requirements.

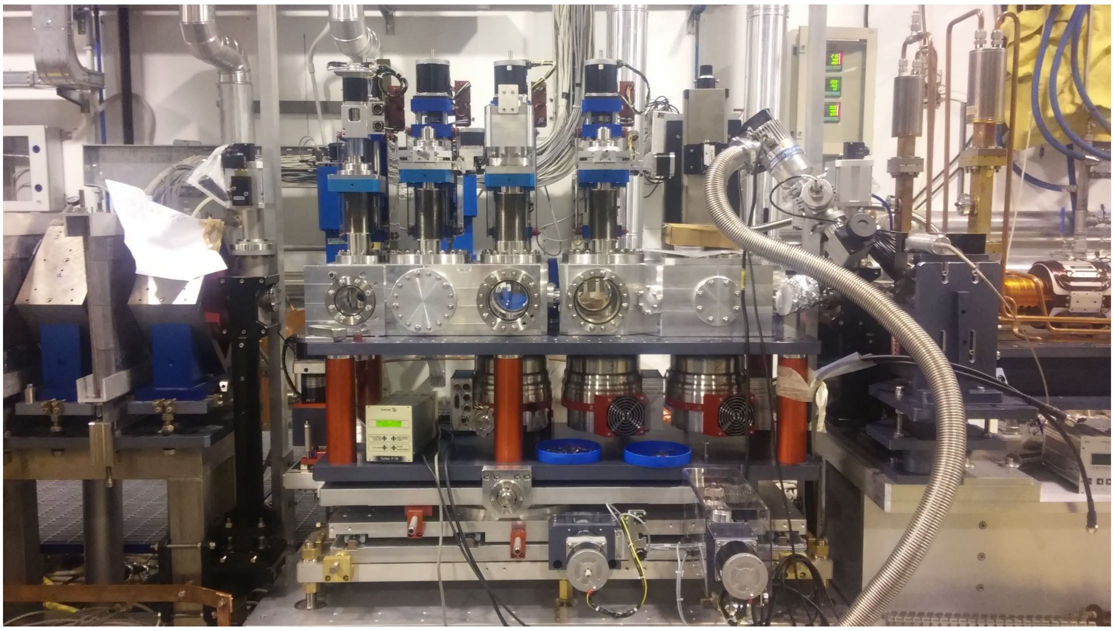

Figure 3: PWFA chamber installed at the end of the linac.

The capillary is filled with hydrogen set at 10 mbar (~100mbar outside the chamber). A valve opens for few ms (~5 ms) letting gas flow inside the capillary. A discharge of ~20kV and 200A ionizes the gas. First tests of the discharge circuit for plasma generation from H_2-filled capillaries have been performed in laboratory (Fig. 4).

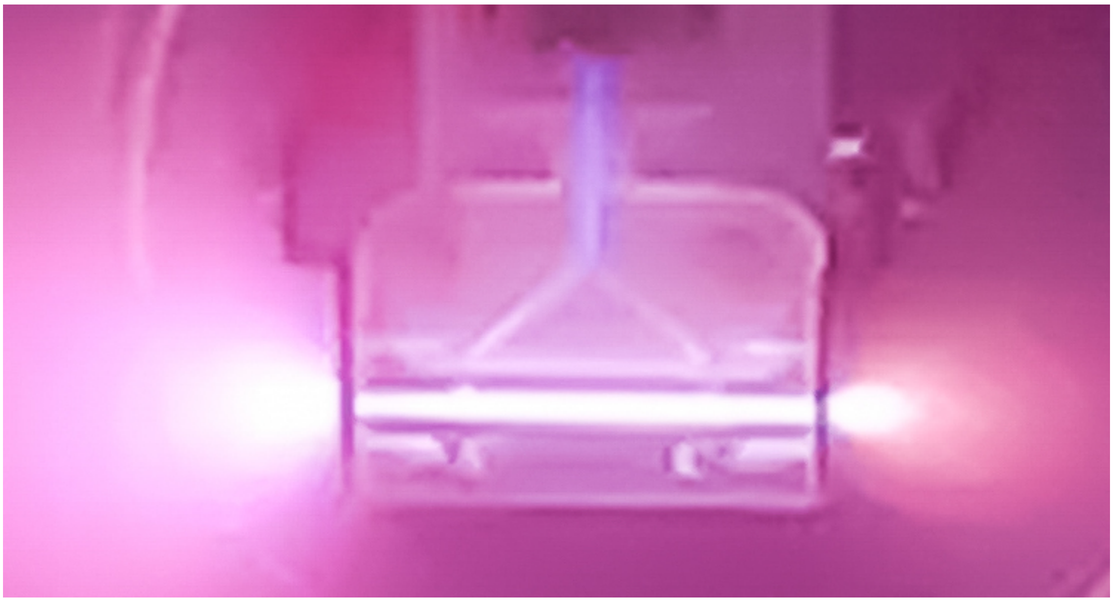

Figure 4: Screenshot of the discharge-driven plasma.

Preliminary plasma diagnostics has been set up to retrieve plasma density by measuring the widening of K-alpha line of Hydrogen through Stark effect. The light emitted from the capillary is imaged on the spectrometer slit and its spectrum measured by means of a gated ICCD camera. Preliminary results have shown the capability of the system of retrieving plasma density of the order of 10^{16} cm^{-3}.

3. List of Conference Talks by LNF Authors in Year 2015

1. R. Pompili, Beam manipulation with Velocity Bunching for PWFA applications, 2nd European Advanced Acceleration Conference, La Biodola - Isola d'Elba (2015)

2. A. Biagioni, Opto-acoustic measurements of the plasma density within a gas-filled capillary plasma source, 2nd European Advanced Acceleration Conference, La Biodola - Isola d'Elba (2015)

3. S. Romeo, Beam dynamics in resonant plasma wakefield acceleration at SPARC LAB, 2nd European Advanced Acceleration Conference, La Biodola - Isola d'Elba (2015)

4. E. Chiadroni, Longitudinal Electron Beam Diagnostics, Beam Dynamics meets Diagnostics, EuCard2, Firenze (2015)

5. F. Ciocci, Segmented undulator operation at the SPARC-FEL test facility, SPIE Optics + Optoelectronics, Prague 2015

6. M. Bellaveglia, The SPARC_LAB femtosecond synchronization for electron and photon pulsed beams, SPIE Optics + Optoelectronics, Prague 2015

7. F. Villa, Seeded FEL with two energy level electron beam distribution at SPARC_LAB, SPIE Optics + Optoelectronics, Prague 2015

4. Publication

1. A. Cianchi et al., Six-dimensional measurements of trains of high brightness electron bunches, PRST AB **18**, 082804 (2015).

2. V. Shpakov, Pre-wave zone studies of Coherent Transition and Diffraction Radiation, http://dx.doi.org/10.1016/j.nimb.2015.03.047 (2015)