RECENT RESULTS AT THE SPARC_LAB FACILITY

M. Ferrario, D. Alesini, M. Anania, A. Bacci, M. Bellaveglia, R. Boni, M. Castellano, E. Chiadroni,
A. Cianchi, C. De Martinis, D. Di Giovenale, G. Di Pirro, U. Dosselli, A. Drago, A. Esposito, R. Faccini,
R. Fedele, A. Gallo, M. Gambaccini, C. Gatti, G. Gatti, A. Ghigo, D. Giulietti, P. Londrillo, S. Lupi,
A. Mostacci, E. Pace, L. Palumbo, G. Passaleva, L. Pellegrino, V. Petrillo, R. Pompili, A. R. Rossi,
L. Serafini, B. Spataro, P. Tomassini, G. Turchetti, C. Vaccarezza, F. Villa, INFN, Italy
G. Dattoli, E. Di Palma, L. Giannessi, A. Petralia, M. Quattromini, C. Ronsivalle, I. Spassovsky,
V. Surrenti, ENEA-CRE, Frascati, Italy
L. Gizzi, L. Labate , T. Levato, J.V. Rau, CNR, Italy

Abstract

A new facility named SPARC_LAB has been recently launched at the INFN National Laboratories in Frascati, merging the potentialities of the former projects SPARC and PLASMONX. We describe in this paper the status and the future perspectives at the SPARC_LAB facility.

INTRODUCTION

A new facility named SPARC_LAB (Sources for Plasma Accelerators and Radiation Compton with Lasers and Beams) has been recently launched at the INFN National Laboratories in Frascati, merging the potentialities of the former projects SPARC [1] and PLASMONX [2]. Ten years ago in fact, a robust R&D program on ultra-brilliant electron beam photoinjector and on FEL physics, the SPARC project, a collaboration among INFN, ENEA and CNR, was approved by the Italian Ministry of Research and located at the INFN National Laboratories in Frascati.

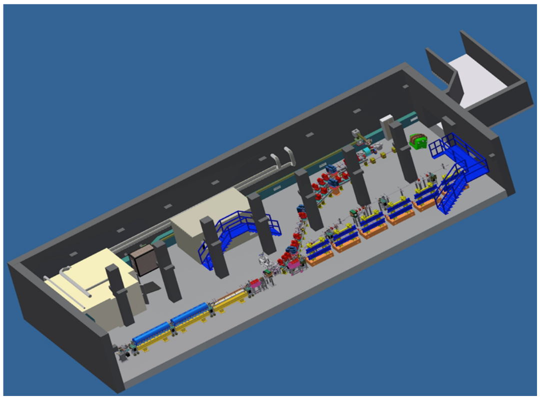

Figure 1: Layout of the SPARC_LAB facility.

The test facility is now operating, hosting a 150 MeV high brightness electron beam injector [3], able to operate also in the velocity bunching configuration [4], which feeds a 12 meters long undulator. Observations of FEL radiation in the SASE [5], Seeded [6] and HHG [7] modes have been performed from 500 nm down to 40 nm wavelength. A second beam line has been also installed and is now hosting a narrow band THz radiation source [8]. In parallel to that, INFN decided to host a 200 TW laser that will be linked to the linac and devoted to explore laser-matter interaction, in particular with regard to laser-plasma acceleration of electrons [9] (and protons) in the self injection and external injection modes, the PLASMONX experiments. The facility will be also used for particle driven plasma acceleration experiments, the COMB [10] experiment. A Thomson back-scattering experiment coupling the electron bunch to the high-power laser to generate coherent monochromatic X-ray radiation is also in the commissioning phase. An upgrade of the linac energy is also foreseen by the end of 2012 by installing two new high gradient C-band structures developed at LNF in the framework of the ELI_NP collaboration [11]. In Figure 1 a layout of the facility is shown.

THE HIGH POWER LASER SYSTEM

The SPARC_LAB high power laser system, named FLAME, has been recently fully commissioned. FLAME is based upon a Ti:Sa, chirped pulse amplification (CPA) laser able to deliver up to 220 TW laser pulses, 25 fs long, with a 10 Hz repetition rate at a fundamental wavelength of 800 nm, see Figure 2.

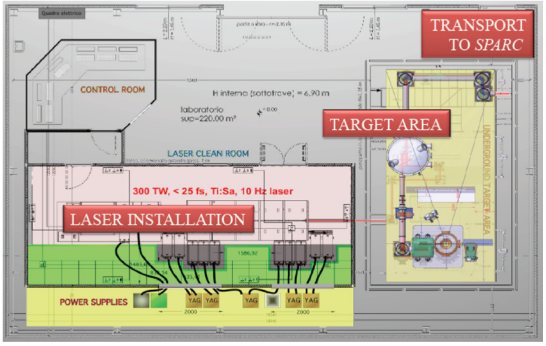

Figure 2: Layout of the FLAME laser with the target area for self-injection plasma acceleration experiments.

The system features a high contrast ratio ($>10^{10}$) and has a fully remotely controlled operation mode. It includes a front-end with pulse contrast enhancement, bandwidth control and regenerative amplifier and yields pulses with 0.7 mJ in 80 nm bandwidth. These pulses are then further amplified by the first amplifier up to 25 mJ while the second amplifier brings the energy up to the 600 mJ. The third cryogenic amplifier is based on a 50 mm Ti:Sa crystal pumped by 10 frequency doubled Nd:YAG laser pulses, reaching an energy up to 20 J at 532 nm. The extraction energy is as high as 35%, leading to a final energy in the stretched pulses in excess of 7 J. The pulse is then compressed to a minimum pulse duration below 30 fs. Once compressed, the pulse is transported under vacuum to the target area via remotely controlled beam steering mirrors. In the typical experimental conditions of laser wakefield acceleration in self-injection configuration, the laser pulse is focused at peak intensities exceeding 10^{18} W/cm^2 which, with our ASE contrast, gives a precursor laser intensity on target below 10^9 W/cm^2.

Among the different uses of FLAME, the scientific program includes self-injection and external injection [12] experiments and the realisation of an X-ray source based on the Thomson backscattering process. To this purpose, a careful characterization of FLAME performances, with particular reference to the transverse beam quality was carried out during the commissioning. The measured Strehl ratio is greater than 50% up to pulse energies of approximately 6J. For energies between 6 and 7 J, the phase front distortion increases leading to a reduction of the Strehl ratio to a minimum value of 35%. Our measurements show that the phase front pattern remains very stable from shot to shot at a given pulse energy. This makes the phase front correction with adaptive optics (planned for installation by the end of 2012) a reliable and complete solution to achieve a high quality focal spot.

THE THOMSON SOURCE

The Thomson back-scattering (TS) X-ray source [13] is foreseen to work in three different operating modes: the high-flux- moderate-monochromaticity-mode (HFM2), suitable for medical imaging, the moderate-flux- monochromatic-mode (MFM) suitable to improve the detection/dose performance [14, 15] and the short-and-monochromatic-mode (SM) useful for pump-and-probe experiments e.g. in physical-chemistry when tens of femtosecond long monochromatic pulses are needed.

The installation of the beamline will be completed by the 2012 summer with a transfer line for the electron beam together with a photon beamline that brings the laser pulse from FLAME target area to the interaction with the electron beam. In this configuration the electron beam energy can range from 28 MeV up to 150 MeV, and the electron beam transport is meant to preserve the high brightness coming from the linac and to ensure a very tight focusing and a longitudinal phase space optimization for the whole energy span. The general layout is showed in Figure 3, where the electron transfer line departs from a three way vacuum chamber inside the first dipole downstream the RF deflector that is used for the six-dimensional phase space analysis of the electron beam. This dipole is also part of the 14 degrees dogleg that brings the electron beam up to the SPARC THz source.

The electron beamline consists in a 30 m double dogleg starting, as mentioned, downstream the SPARC photoinjector; they ends in a two branch beam delivery line that provides two separate interaction regions with the possibility to host two different experiments at the same time: the Thomson source and the external injection in a plasma accelerator experiment.

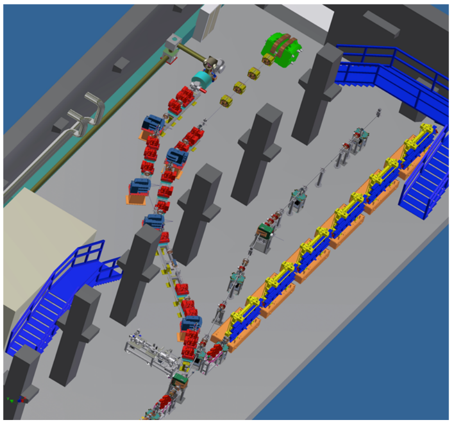

Figure 3: Details of the SPARC_LAB facility showing all the electron beam lines, downstream the injector from right to left: FEL undulators, THz source, Plasma Acceleration experiments, Thomson backscattering source.

The Thomson interaction vacuum chamber, see Figure 4, consists in two mirror stations that will determine the in and out trajectory of the photon beam, plus an interaction chamber in the middle that hosts the diagnostic for both the electron and photon beams. The parabolic mirror located downstream the interaction point will focus the photon beam at the interaction point down to a 10 μm spot size, its spatial adjustment is obtained with its x-y movable support that can be also remotely controlled. The interaction chamber is a tee-vacuum chamber where a double screen movement will be mounted to get the imaging of the electron and photon beam at the interaction point.

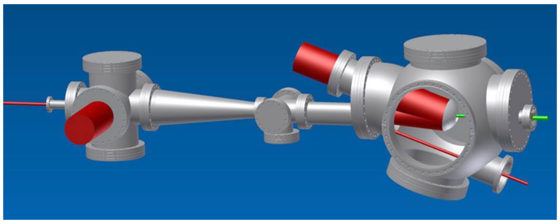

Figure 4: Final drawing of the Thomson scattering interaction chamber.

The laser beam transfer line to the interaction region is composed by a series of high reflectivity mirrors inserted in a vacuum pipe 50 m long. The mirrors, 8 inches diameter, are supported by motorized gimbal mounts in order to assure the alignment up to the off-axis parabola that focus the laser pulse on the electron beam. The vacuum of the photon beam line is a the level of 10^{-6} Torr.

The Thomson scattering experiment needs an extremely precise synchronization between electron bunch and laser pulse. The relative time of arrival jitter of the two beams is fundamental to obtain a repeatable and efficient interaction. The electrons and photons have to be synchronized with a relative jitter < 500 fs. This can be obtained with a standard electrical distribution of the reference signal. Anyway an optical distribution is preferable to obtain precise time of arrival measurement resolution (equal or less than 5fs) and to obtain better synchronization between the two beams, a necessary requirement for the external injection in the plasma accelerator experiments. This can be achieved by means of an optical cross-correlation between short laser pulses (100-200 fs). In particular the electrical (or optical) master oscillator in our project will serve two laser oscillator clients: the photo injector laser for the production of electrons and the FLAME laser. The RF system phase will be also locked to the master oscillator using low noise phase detection; and the phase feedback loops will be implemented too.

ADVANCED BEAM DYNAMICS EXPERIMENTS

The SPARC photoinjector is a 1.6 cell S-band RF gun, followed by 3 S-band accelerating sections, which boost the beam energy up to 150–200 MeV. With this machine configuration a new technique called Laser Comb [10], aiming to produce a train of short electron bunches, has been tested [16]. In this operating mode the photocathode is illuminated by a comb-like laser pulse to extract a train of electron bunches which are injected into the same RF bucket of the gun. The SPARC laser system, based on a Ti:Sa oscillator has been upgraded for this specific application. The technique used relies on a α-cut beta barium borate (α-BBO) birefringent crystal, where the input pulse is decomposed in two orthogonally polarized pulses with a time separation proportional to the crystal length. In the first accelerating structure operating in the VB mode, i.e. injecting the bunch train near the zero crossing of the RF wave, the bunch train is compressed by the longitudinal focusing effect of the RF wave and with a proper choice of injection phase is possible to keep under control both the intra-bunch distance as well as the single bunch length. This method preserves all the extracted charge and it is different from other passive tecniques [17], where the train is produced by using a mask that stops a significant fraction of the charge. Up to four electron beam pulses shorter than 300 fs and separated by less than 1 ps have been characterized and a narrowing THz spectrum produced by the bunch train has been measured [8]. In addition two electron beam pulses have been injected in the undulator and a characteristic interference spectrum produced by the FEL interaction in this new configuration has been observed, confirming that both pulses have been correctly matched to the undulator and were both lasing [18]. Coherent excitation of plasma waves in plasma accelerators [17] can be also performed with this technique. Preliminary simulations [19] shown that a train of 3 electron drive bunches, each of them 25 μm long, with 200 pC at 150 MeV and 1 μm rms normalized emittance, could accelerate up to 250 MeV a 20 pC, 10 μm long witness bunch, injected at the same initial energy, in a 10 cm long plasma of wavelength 383 μm. As shown in Figure 5 the drive bunches will loose energy to excite the plasma accelerating field up to 1 GV/m. Simulations show also that the witness bunch can preserve a high quality with a final energy spread less than 1 % and 1.6 μm rms normalized emittance. A test experiment is foreseen at SPARC_LAB, aiming to produce a high quality plasma accelerated beam able to drive a FEL in the SASE mode.

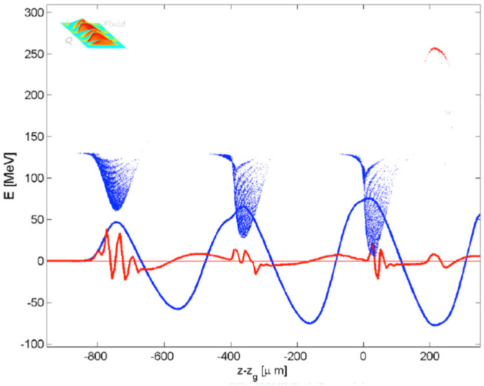

Figure 5: Longitudinal phase space of the COMB beam at the end of the acceleration process. The accelerating field is also plotted in arbitrary units.

REFERENCES

[1] D. Alesini et al., Nucl. Instrum. Meth. A 507 (2003) 345.
[2] D. Giulietti et al., Proc. of PAC 2005, Knoxville, Tennessee, USA.
[3] M. Ferrario et al., Phys. Rev. Lett. 99 (2007) 234801.
[4] M. Ferrario et al., Phys. Rev. Lett. 104 (2010) 054801.
[5] L. Giannessi et al., Phys. Rev. Lett. 106 (2011) 144801.
[6] M. Labat et al., Phys. Rev. Lett. 107 (2011) 224801.
[7] L. Giannessi et al., Phys. Rev. Lett. 108 (2012) 164801.
[8] E. Chiadroni et al., Journal of Physics: Conference Series 357 (2012) 012034.
[9] L. A. Gizzi et al., Europ. Phys. Journal - Special Topics 175 (2009) 3.
[10] M. Ferrario et al., Nucl. Instrum. Meth. A 637(1), (2011) S43-S46.
[11] C. Vaccarezza, TUOBB01, these proceedings.
[12] A. R. Rossi, WEEPPB002, these proceedings.
[13] P. Oliva et al., Nucl. Instrum. Meth. A 615 (2010) 93.
[14] A. Bacci et al., Nucl. Instrum. Meth. A 608 (2009) S90.
[15] U. Bottigli et al., Il Nuovo Cimento 29C, N.2 (2006).
[16] A. Mostacci et al., TUPPD055, these proceedings.
[17] P. Muggli, Proc. of PAC 2009, Vancouver, Canada.
[18] A. Bacci et al., Proc. of FEL Conf. 2011, Shanghai, China.
[19] P. Tomassini, private communication.