SPARC_LAB RECENT RESULTS

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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 recent results obtained 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].

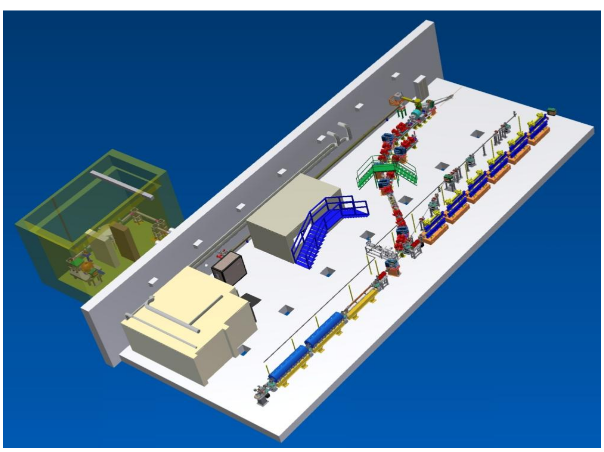

Figure 1: Layout of the SPARC_LAB facility

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] and an Electro-Optical Sampling test station. In parallel to that, INFN decided to host a 200 TW laser 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. An upgrade of the linac energy is also foreseen by installing two new high gradient C-band structures developed at LNF in the framework of the ELI_NP collaboration. In Figure 1 a layout of the facility is shown.

THE THOMSON SOURCE

The Thomson back-scattering (TS) X-ray source [11] 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 [12, 13] 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 electron beam parameter for the two interaction points are reported in Table 1.

Table 1 Expected Electron Beam Parameters at the Thomson Source Interaction Point

Parameter	Value
Bunch charge (nC)	**0.2 ÷ 1.0**
Energy (MeV)	28 ÷150
Length (ps)	15 ÷ 20
$\varepsilon_{n\ xy}$ (mm mrad)	1 ÷ 5
Energy spread (%)	0.1 ÷ 0.2
Spot size at int. point rms (mm)	05 ÷ 20

The installation of the beamline is now completed 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. The first collisions are expected by the end of the current year. 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 2, 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.

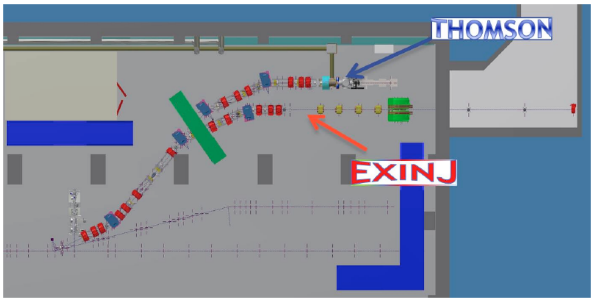

Figure 2: Details of the SPARC_LAB facility showing all the electron beam lines, downstream the injector from right to left: FEL undulators, THz source, Plasma Acceleration experiments, Thomson backscattering source.

The 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.

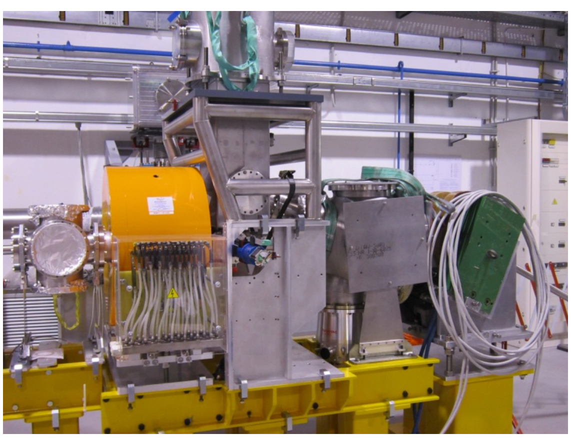

Figure 3: The Thomson scattering interaction chamber.

The Thomson interaction vacuum chamber, see Figure 3, 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 has been mounted to get the imaging of the electron and photon beam at the interaction point.

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 vacuum of the photon beam line is at the level of 10^{-6} Torr.

SYNCHRONIZATION UPGRADE

In order to achieve the specified performances of the next future experiments at SPARC_LAB a very demanding synchronization between the subsystems is required. In particular the two laser systems (SPARC photocathode and FLAME) have to be synchronized with a relative time jitter of <500 fs_{RMS} and <30 fs_{RMS} for the Thomson x-ray source and Plasma acceleration experiments respectively.

The synchronization reference is presently distributed through coaxial cables along the facility. The measured performances fully meet the Thomson experiment requirements. Figure 4 shows the schematics of the hardware configuration that synchronizes the two laser oscillators (and consequently the electron bunch and the FLAME amplified pulse at 10Hz rep. rate).

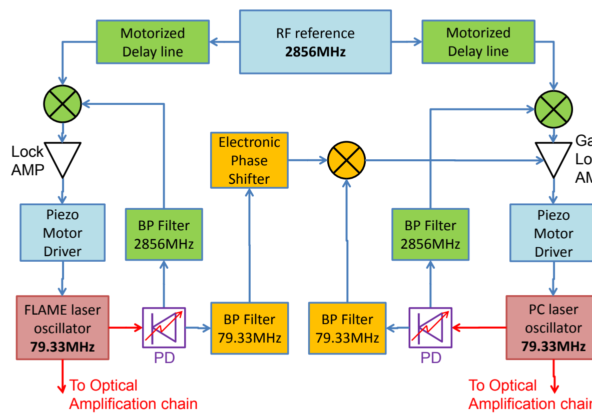

Figure 4: Sketch of the lasers synchronization scheme used in the Thomson scattering experiment.

Two Phase Locked Loops working at 2856 MHz (the SPARC linac frequency, equal to the 36th harmonics of the rep rate of the lasers) represented by the green boxes are used to independently synchronize the two laser oscillators to the RF reference with a time jitter <100 fs_{RMS}.

The harmonic loop could lock the 2 lasers at any of 36 different relative time separations within one period of the laser rep rate T_{Las} = 12.6 ns. To select only one lock position and reject the others we added an ancillary PLL working at the laser fundamental frequency (orange boxes). This acts on the error amplifier of one harmonic loop opening a time window whose duration is only 1/36 of T_{Las}. A 360° electronic phase shifter in the fundamental loop allows moving the gating window along an entire laser period for a coarse control of the relative position of the pulses, while the fine positioning is obtained by moving the motorized delay lines transporting the reference signal to the harmonic loops.

To achieve better performances, especially in the phase detection process, we need to migrate towards an

ISBN 978-3-95450-122-9

optical reference signal distribution architecture. We have already purchased and installed an Optical Master Oscillator (OMO) which is now under test. Also we have partially installed the fiber links to bring the signal to the clients (laser oscillators, RF power station, diagnostics). Next step is to characterize the high resolution optical phase detectors (cross-correlators) that will guarantee a minimal time jitter resolution of the order of 1 fs.

To guarantee a stable operation in both electrical and optical reference signal distribution, we are designing the system including a link stabilization apparatus. The optical stabilized links are nowadays available on the market, providing residual drifts of the order of 10 fs_{RMS} in point-to-point reference distribution. Concerning the coaxial cable distribution, we are developing a link monitor that can diagnose the drifts of the signal path length. We will use this information to close a pulse-to-pulse feedback loop, compensating the drift using the motorized delay lines.

TWO COLOURS FEL 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 [14]. 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.

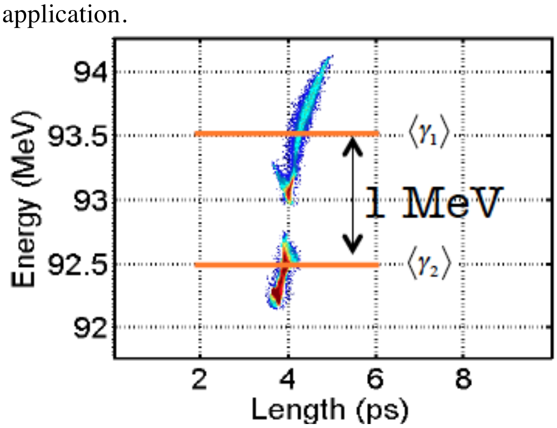

Figure 5: Measured longitudinal phase space of the double electron pulse showing the time overlapping and the energy separation of the two bunches.

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 [15]. Recently two electron beam pulses with a relative energy difference of about 1 MeV and overlapped in time see Figure 5, have been injected in the undulator and a characteristic two colours spectrum produced by the SASE FEL interaction in this new configuration has been observed, see Figure 6, confirming that both pulses have been correctly matched to the undulator and were both lasing [16].

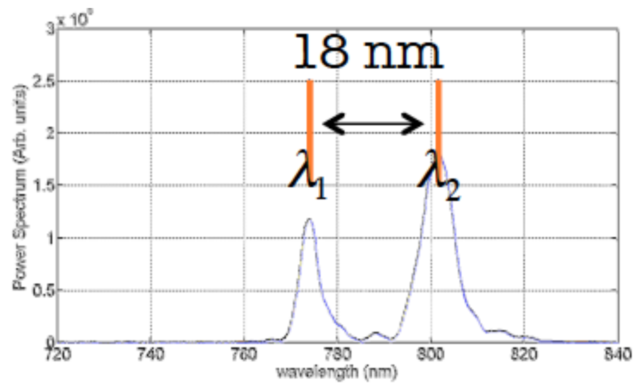

Figure 6: Two colours SASE FEL spectrum obtained with the double electron pulse shown in figure 5.

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