

PROGRESS ON THE LUNEX5 PROJECT

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Abstract

LUNEX5 (free electron Laser Using a New accelerator for the Exploitation of X-ray radiation of 5th generation) aims at investigating the production of short, intense, coherent Free Electron Laser (FEL) pulses in the 40-4 nm spectral range. It comprises a 400 MeV superconducting Linear Accelerator for high repetition rate operation (10 kHz), multi-FEL lines adapted for studies of advanced FEL schemes, a 0.4 - 1 GeV Laser Wake Field Accelerator (LWFA) for its qualification by a FEL application, a single undulator line enabling advanced seeding and pilot user applications. Different studies and R&D programs have been launched. A test experiment for the demonstration of 180 MeV LWFA based FEL amplification at 200 nm is under preparation, thanks to a proper electron beam manipulation. Specific hardware is also under development such as a cryo-ready 3 m long undulator of 15 mm period.

INTRODUCTION

Since the laser discovery [1] and the first FEL [2] in the infra-red in Stanford on MARK III, followed by the ACO FEL at Orsay [3] in the visible and harmonic generation [4] in the VUV, VUVX light sources are actively developed around the world [5-8]. After the early FEL times, France has remained quite active, with the Super-ACO FEL [9-11] and first user applications [12-14], collaborations on UVSOR [15] and ELETTRA [16]. Besides the CLIO infra-red FEL [17] moved from oscillator to single pass configuration, with a particular interest on seeding schemes (influence of the undulator helicity [18], pulse splitting [19], sidebands [20], seeding with high order harmonics in gas (HHG) [21-23]) and on the transverse properties [24].

The LUNEX5 [25-28] demonstrator (see Fig. 1) aims at exploring several directions for the production of short, intense, and coherent FEL pulses between 40 to 4 nm on the first, third and fifth harmonics.

A 400 MeV superconducting (SC) linac with 2-3 modified XFEL type cryomodules at 1.3 GHz (fed with solid state amplifiers) will enable a CW operation for high repetition rate and multiple users. The qualification of an elementary RF unit with SC cavity, low level RF and solid state amplifier for CW operation is under study. The electron bunch is compressed thanks to a dogleg with sextupoles, enabling phase space linearization and cancellation of the second order dispersion [28]. The gun will be either superconducting [29] or APEX type [30]. In addition, an LWFA [31] based FEL configuration will be explored, requiring a specific beam transfer line able to handle the divergence (1 mrad) and energy spread (1 %) [32-35].

The single FEL line with different cryo-ready undulator segments of 15 and 30 mm period will allow Echo Enable Harmonic Generation (echo) [36] and HHG seeding to be compared for further handling of the spectral and temporal properties. SC linac based FEL calculations anticipate more than 10^{11} photons/pulse and 10^{27} peak brightness on the fundamental wavelength. Two pilot user experiments in gas phase and condensed matter will qualify the FEL performance in the different cases.

After the completion of the LUNEX5 Conceptual design Report at the end of 2011 [25], complementary studies and R&D have been launched.

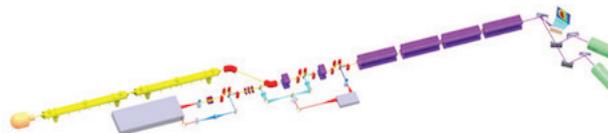


Figure 1: LUNEX5 sketch: cryomodules (yellow), LWFA laser hutch (grey), undulators (4 radiators and 2 echo modulators) (purple), pilot user experimental sections (green).

R&D ON THE EQUIPMENT

Cryo-ready U15 Undulator

A cryo-ready 15 mm period undulator is under construction [37]. The selected $\text{Pr}_2\text{Fe}_{14}\text{B}$ magnets with a coercivity of 1671 kA/m at 300 K and a remanence of 1.31 T enable operation at room temperature with a peak magnetic field of 1.59 T, and a cold regime at 77 K with a field of 1.74 T at 3 mm gap thanks to the increase of the remanence up to 1.55 T, without occurrence of the spin transition reorientation as for $\text{N}_2\text{Fe}_{14}\text{B}$ magnets (see Fig. 2). The modules consist of magnets surrounded by two half poles, with the possibility to insert a thermal sensor. The carriage that should handle 10 tons has three columns. The taper required for the FEL will be applied thanks to a modification of the girder handling, leading to reversal girder deformation. A low temperature in-vacuum measurement bench will be embedded in the final vacuum chamber, the transverse positions and the angle of the Hall probe will be corrected by piezo motors.

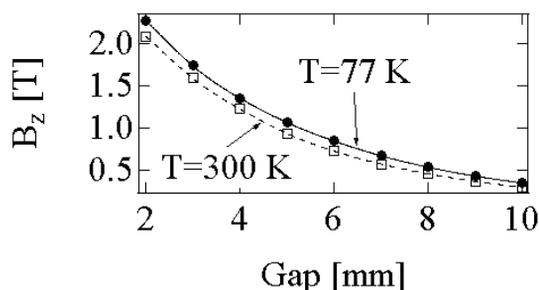


Figure 2: U15 field dependence versus the gap from the calculated field using RADIA [38]. Hybrid design with vanadium-Permendur poles and $\text{Pr}_2\text{Fe}_{14}\text{B}$ magnets.

Electro-optical Sampling

The usual electron bunch length measurement technique based on the spectrally encoded electro-optic sampling (EOS) detection [39,40] is limited in terms of acquisition rate by the current camera speed. Applying the photonic time-stretch strategy [41] to the EOS technique, single-shot recordings up to 88 MHz of Coherent Synchrotron Radiation pulses have been demonstrated on the AILES beamline at Synchrotron SOLEIL [42]. The temporal waveform containing the spectrally encoded signal is stretched in time so that it is slow enough to be detected using a photodetector instead of a spectrometer. This technique allows us to overcome the speed of classical camera and will be applied to the SC linac based LUNEX5 FEL.

EXPERIMENT PREPARATION TOWARDS A LWFA BASED FEL

In order to explore the possibility to achieve FEL amplification with a LWFA, a test experiment is under preparation with an existing 2x60 TW laser at Lab. d'Optique Appliquée and equipment from SOLEIL. The

designed transfer line [34-35,43] properly manipulates longitudinal and transverse electron beam distributions down to the undulator: strong permanent magnet quadrupoles handle the beam divergence, a “demixing” chicane sorts the electrons in energy and reduces the slice energy spread and the transverse density is maintained constant all along the undulator. Seeding will be applied to ease the amplification.

The magnetic elements are under final construction (permanent magnet quadrupoles of variable gradient) or measurement (chicane, steerers). The power supplies are prepared and are under test. Their specific control system (Ethernet for TANGO) is under test. First, an existing 2 m long U20 undulator will be employed, until the U15 will be available. A compact permanent magnet dipole for the beam dump is under study. Beam position and charge measurements are optimized for low charge (typically 10 pC) and single bunch operation: a Turbo-Integrated Current Transformer from Bergoz [44], a Cavity Beam Position Monitor (CBPM) from Paul Scherrer Institute [45] with a sub μm resolution at low charge. One unit of each system is currently installed on the SOLEIL LINAC-to-Booster transfer line, TL1 (see fig. 3) for testing purposes. Both are mounted on an X/Z plane translation stage for CBPM commissioning and calibration. Beam profile diagnostics are also under preparation. General integration of the equipment with specific girders, vacuum chambers and pumping systems is under finalisation. The experiment will be started at 200 nm, with a spectrometer (iHR320 from Horiba). A larger spectral range spectrometer is still under investigation, while handling the limited allowed space constraints.

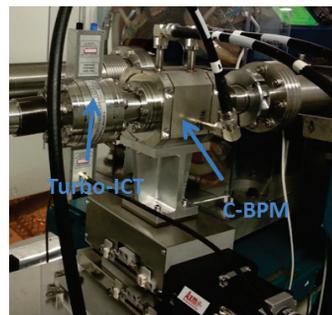


Figure 3 : COXINEL cavity BPM and charge monitor being tested on SOLEIL TL1.

TOWARDS MEASUREMENTS OF FEL COHERENCE PROPERTIES

Measuring and controlling the temporal properties of the emitted radiation emitted by LUNEX5 is essential. Therefore, a new method has been developed for characterizing these properties even in the presence of partial longitudinal coherence [46]. The measurement scheme relies on laser-dressed XUV photoionization: the evolution of the shot-averaged photoelectron spectrum with the laser/XUV delay provides a two-dimensional spectrogram (see Fig. 4a). The statistical properties of the XUV pulses accumulated during the measurement are

then extracted from this spectrogram using a phase-retrieval algorithm. This method is an extension of the well-known FROG (Frequency Resolved Optical Gating) technique and therefore also applies to the temporal characterization of XUV attosecond pulses [47] and near visible femtosecond waveforms [48]. The ability of the technique to measure the pulses produced by LUNEX5 has been validated numerically. Fig. 4a shows the expected spectrogram in the EEHG configuration of LUNEX5 [49]. In this regime, partial longitudinal coherence will arise from the unavoidable arrival time jitter that exists between the laser and FEL pulses. The simulations show a severe impact of jitter on the spectrogram. The proposed technique however properly retrieves the LUNEX5 pulse, (see Fig. 4b), as well as the laser pulse and the envelope of the arrival time jitter (see Fig. 4c).

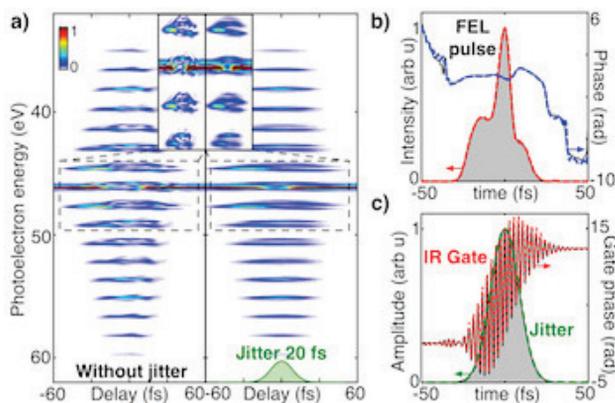


Figure 4: a) Photoelectrons spectra vs laser/FEL delay with and without arrival time jitter. In the presence of jitter, the new technique allows for the retrieval of b) the LUNEX5 pulse and of c) the laser pulse and the jitter envelop.

This technique provides a diagnostic for shot-to-shot pulse fluctuations, but it also enables the characterization of other phenomena that can reduce the pulse coherence, including the spatio-temporal pulse distortions or the limited resolution of the detection device.

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