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PROGRESS OF THE LUNEX5 DEMONSTRATOR PROJECT

M. E. Couprie, C. Benabderrahmane, P. Berteaud, C. Bourassin-Bouchet, F. Bouvet, L. Cassinari, L. Chapuis, M. Diop, J. Daillant, M. El Ajjouri, C. Herbeaux, N. Hubert, M. Labat, P. Lebasque, A. Lestrade, A. Loulergue, P. Marchand, J. L. Marlats, C. Miron, P. Morin, A. Nadji, F. Polack, F. Ribeiro, J. P. Ricaud, P. Roy, K. Tavakoli, M. Valléau, D. Zerbib, Synchrotron SOLEIL; S. Bielawski, C. Evain, E. Roussel, C. Szwaj, PhLAM/ CERLA, Lille, France G. Lambert, V. Malka, R. Lehe, A. Rousse, C. Thaury, Laboratoire d'Optique Appliquée, Palaiseau, France ; G. Devanz, C. Madec, A. Mosnier, CEA/DSM/IRFU/SACM, Saclay, France D. Garzella, B. Carré, CEA/DSM/IRAMIS/ LIDyL, Saclay, France, N. Delerue, Laboratoire de l'Accélérateur Linéaire, Orsay, France ; X. Davoine, CEA/DAM/DIF, Bruyère-Le-Châtel, France ; A. Dubois, J. Lüning ; LCPMR, Paris-VI, France

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 pulses in the 40-4 nm spectral range [1]. It comprises two types of accelerators connected to a single Free Electron Laser (FEL) for advanced seeding configurations (seeding with High order Harmonic in Gas, echo). A 400 MeV superconducting Linear Accelerator, adapted for studies of advanced FEL schemes, will enable future upgrade towards high repetition rate and multi-user operation by splitting part of the macropulse to different FEL lines. A 0.4 - 1 GeV Laser Wake Field Accelerator (LWFA) [2] will also be qualified by the FEL application. After the Conceptual Design Report, R&D has been launched on different sub components. Transport calculation of longitudinal and transverse manipulation of a LWFA electron beam enables to provide theoretical amplification, a test experiment is under preparation.

INTRODUCTION

More than 50 years after the lasers' discovery [3] and more than 30 years after the first FEL [4], VUVX light sources are actively developed around the word. Among accelerator laser light sources, FEL presently offer femtosecond tuneable radiation (LCLS [6], SACLA [7], FLASH [8] and FERMI [9]), FERMI being the first seeded FEL user facility.

Now, directions towards advanced and compact FELs are open in view of the fifth generation light sources. One path aims at approaching the diffraction and Fourier limits in a wide spectral range and with versatile properties, i.e. with a high level of flexibility to answer to users' needs (such as FEL oscillator in the X ray range, two-color operation, advanced seeding, multiple simultaneous operation, high repetition rate). Another direction aims at reducing the size either by exploring further seeding and / or by replacing the conventional linear accelerator by a compact alternative one, such as dielectric accelerator, inverse FEL and LWFA. Indeed, the rapidly developing LWFA are now able to generate synchrotron radiation. With an electron divergence of typically 1 mrad and an energy spread of the order of 1 %, an adequate beam manipulation through the transport to the undulator is needed for FEL amplification.

Several directions are explored within the LUNEX5 project (see Fig.1), aiming at investigating the production of short, intense, and coherent pulses in the soft X-ray region. It is composed of a 400 MeV superconducting linear accelerator for high repetition rate multiple user operation and a LWFA, a single FEL line with HHG and Echo Enable Harmonic Generation seeding (ECHO).

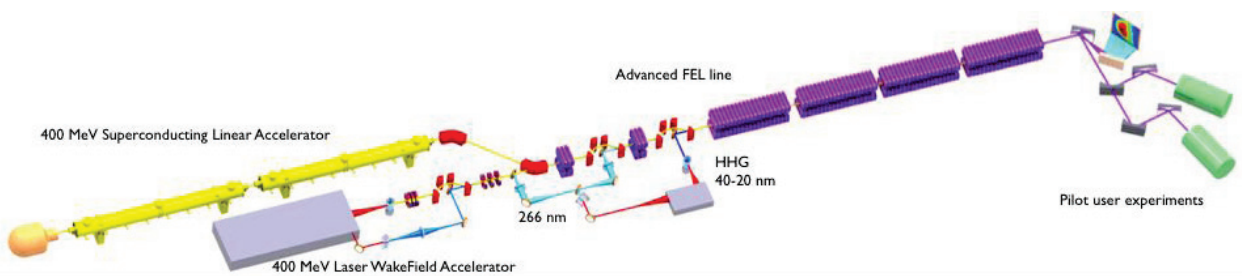

Figure 1: LUNEX5 sketch: cryomodules (yellow), laser hutch for LWFA (grey), undulators (four radiators and two ECHO modulators) (purple), pilot user experimental sections (green).

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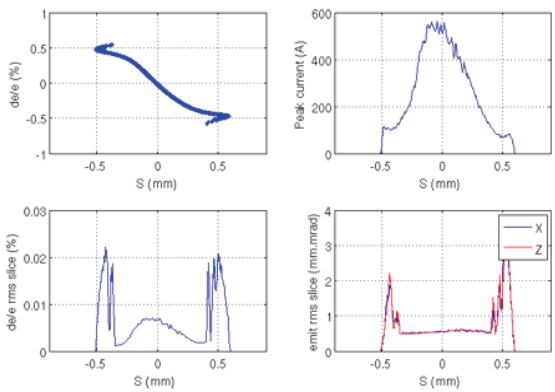
LUNEX5 STUDIES WITH THE SUPERCONDUCTING LINAC

Different choices of the Conceptual Design Report [10] are revisited.

Concerning the temporal structure, discussions with pilot users led to consider a 10 kHz repetition rate. It is of interest for experiments requiring the high repetition rate such as coincidence, photo-emission and in a longer term, imaging (Coherent diffraction Imaging).

Besides, the superconducting linac choice, adopted for E XFEL [11] and LCLS II, will enable at term to dispatch electrons towards different FEL lines, for a reduced operating cost.



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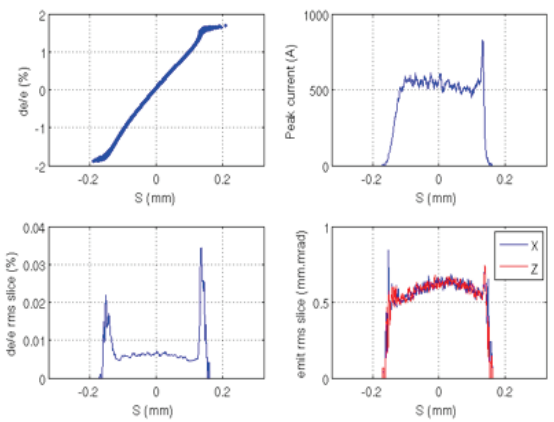

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Figure 2: Energy spread (top left), slice energy spread (bottom left), peak current (top right), slice emittance (bottom right) in a) the harmonic cavity and chicane case b) the dogleg and sextupole case.

For the gun, a superconducting one [12] or an APEX type one [13] is considered. The study and test of an elementary RF unit with sc cavity, low level RF and solid state amplifier for CW operation is also under discussion.

Recent electron beam simulations [14] led to a cheaper and simpler lay-out shortening the accelerator chain : the standard compression scheme with a third harmonic cavity and a compression chicane (see Fig. 2a) has been replaced by a dogleg with sextupoles (see Fig. 2b), enabling to linearize the phase space, to compress the beam and to cancel the second order dispersion. In both cases, the electron bunch experience a compression by typically a factor 10, leading to a peak current increase from 50 to roughly 500 at the undulator entrance. The phase space plots are very similar. The energy chirp is reversed.

From the FEL point of view, besides the comparison between ECHO and seeding with High order Harmonics generated in Gas [15] carried out in the frame of the DYNACO ANR contract, studies on the FEL property manipulations are considered, with in particular, the two-color operation, the optical post-compression (FELShaping, OPT2X contracts).

TOWARDS THE DEMONSTRATION OF FEL AMPLIFICATION WITH A LWFA ELECTRON BEAM

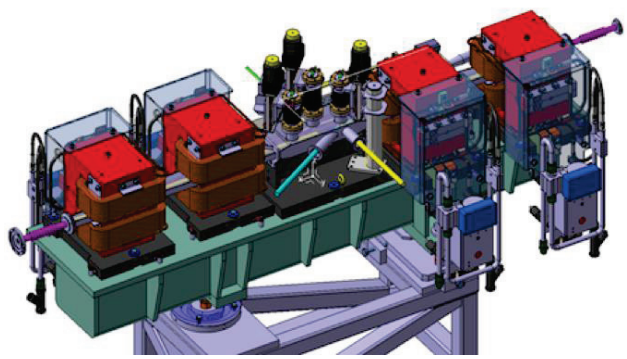

Figure 3: Chicane implementation with the dipoles of the chicane (in red), the diagnostics, and the seeding ports (blue, yellow).

COXINEL grant aims at demonstrating an appropriate electron beam transport from the source to the undulator. The key concept relies on an innovative electron beam longitudinal and transverse manipulation in the transport towards an undulator: a “demixing” chicane sorts the electrons in energy and reduces the spread from 1 % to a slice one of 0.1 % and the transverse density is maintained constant all along the undulator (supermatching) by a proper synchronisation of the electron beam focusing and the progress of the optical wave along the undulator [16]. An example of the baseline implementation is shown in Fig. 3.

Equipment is under preparation at Synchrotron SOLEIL.

Besides, the X-Five grant concerns the optimisation of the LWFA electron beam with a 2x60 TW laser of the

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Laboratoire d'Optique Appliquée. Coupling both programs enables to prepare a demonstration experiment to observe FEL amplification at 200 nm first and then at shorter wavelength. Provided a successful amplification, further study and potential control of the FEL properties will then follow.

PROGRESS ON THE EQUIPMENT

Studies on the most critical hardware are launched. Indeed, in the frame of "Triangle de la Physique" contract QUAPEVA, the magnetic design of a permanent magnet quadrupole with variable strength for the focusing of the LWFA diverging electron beam is finalised.

A R&D program on the construction of a cryo-ready 3 m long 15 mm period undulator is under way in the frame of a French Swedish collaboration. The use of a specific grade of $Pr_2Fe_{14}B$ with poles in Vanadium-Permendur enables operation both at room temperature and at 77 K. A magnetic field of 1.67 T is expected at 3 mm gap. The module scheme has been modified for using half-poles, enabling an easier swapping. It has been magnetically validated with a four period system, as shown in Fig. 4.

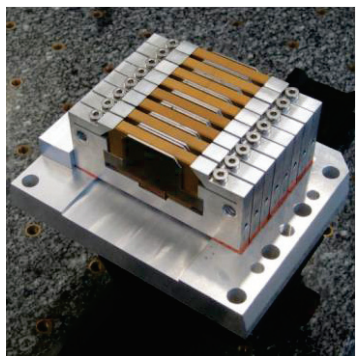

Figure 4: Picture of a four period assembly with half poles.

Studies on diagnostics concern in particular electro-optical sampling [17], Smith-Purcell radiation [18]. Specific development for the electron part is also in progress.

CONCLUSION

Some R&D and complementary studies for the LUNEX5 project have been launched. The choice of the superconducting linac is confirmed by the need of high repetition rate operation for scientific application and for multi-FEL operation. Besides, a test experiment for the demonstration of FEL amplification with a LWFA is under preparation. Important funding is still necessary for the LUNEX5 demonstrator.

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