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The LUNEX5 project in France

M. E. Couprie[1], C. Benabderrahmane[1], P. Betinelli[1], F. Bouvet[1], A. Buteau[1], L. Cassinari[1], J. Daillant[1], J. C. Denard[1], P. Eymard[1], B. Gagey[1], C. Herbeaux[1], M. Labat[1], B. Lagarde[1], A. Lestrade[1], A. Loulergue[1], P. Marchand[1], J. L. Marlats[1], C. Miron[1], P. Morin[1], A. Nadji[1], F. Polack[1], J. B. Pruvost[1], F. Ribeiro[1], J. P. Ricaud[1], P. Roy[1], T. Tanikawa[1], R. Roux[2], S. Bielawski[3], C. Evain[3], C. Szwaj[3], G. Lambert[4], A. Lifschitz[4], V. Malka[4], R. Lehe[4], A. Rousse[4], K. Ta Phuoc[4], C. Thaury[4], G. Devanz[5], M. Luong[5], B. Carré[6], G. LeBec[7], L. Farvacque[7], A. Dubois[8], J. Lüning[8]
[1] Synchrotron SOLEIL, Saint-Aubin, France
[2] Laboratoire de l'Accélérateur Linéaire, Orsay, France
[3] PhLAM/ CERLA, Lille, France
[4] Laboratoire d'Optique Appliquée, Palaiseau, France
[5] CEA/DSM/IRFU/SACM, Saclay, France
[6] CEA/DSM/IRAMIS/SPAM, Saclay, France
[7] ESRF, Grenoble, France
[8] LCPMR, Paris-VI, France
E-mail: couprie@synchrotron-soleil.fr

Abstract. The LUNEX5 (free electron Laser Using a New accelerator for the Exploitation of X-ray radiation of 5th generation) in France aims at investigating the generation of short, intense, and coherent pulses in the soft x-ray region (with two particular targeted wavelengths of 20 and 13 nm). It consists in a single Free Electron Laser (FEL) line with cryo-ready in-vacuum undulators using a Conventional Linear Accelerator (CLA) using the superconducting technology of 400 MeV or a Laser Wake Field Accelerator (LWFA) ranging from 0.4 to 1 GeV with multi-TW or PW lasers. The FEL line can be operated in the seeded (High order Harmonic in Gas seeding) and Echo Enable Harmonic Generation configurations, which performances will be compared. Two pilot user experiments for time-resolved studies of isolated species and magnetization dynamics will take benefit of LUNEX5 FEL radiation.

1. Introduction

Since the laser invention [1] and the first Free Electron Laser (FEL) [2], tuneable mJ X-ray lasers have become a reality, with the operation for users of LCLS [3] and SACLA [4] in the X-ray range. In the soft X-ray are also operating FLASH [5] down to 4.5 nm, FERMI@ELETTRA [6] (100-4 nm) in the seeded configuration, SCSS Test Accelerator [7] (40-60 nm). Transverse coherence results from the electron beam emittance and the temporal one from the FEL process. In the SASE configuration [8], the uncorrelated trains of radiation resulting from the interaction of electrons progressing jointly with the previously emitted spontaneous radiation lead to spiky longitudinal and temporal distributions, apart from single spike operation for low charge regime [9]. Seeding with an external laser or a short wavelength coherent light source, such as High order Harmonics generated in gas, allows the saturation length to be shortened, the jitter to be reduced, and the longitudinal coherence to be improved [10, 11, 12, 13, 14]. The self-seeding in which amplified spontaneous emission from first stage undulators is sent through a crystal monochromator, has been recently demonstrated at LCLS [15]. The Echo Enable Harmonic Generation (EEHG) scheme with a double electron–laser interaction can push the spectral range towards shorter wavelengths when operating on a high order harmonic of the seed wavelength [16, 17, 18]. A blooming of X-ray FEL (European XFEL [19], Korean FEL [20], SwissFEL [21]) projects is now arising worldwide. These powerful X-ray laser enable to explore new states of matter. LUNEX5 aims at providing at investigating the production of short, intense, and coherent pulses in the soft x-ray region via the FEL process employing the latest seeding schemes and accelerating concepts. It consists of a common FEL line fed either by a 400 MeV Conventional Linear Accelerator (CLA) for advanced fourth generation light sources (4GLS+) with the latest seeding schemes or by a 0.3-1 GeV LWFA for fifth generation light source as a LWFA qualification with a FEL application with ultrashort fs pulses generation. Pilot user experiments on isolated species and condensed matter will validate the LUNEX5 demonstrator radiation from a user point of view.

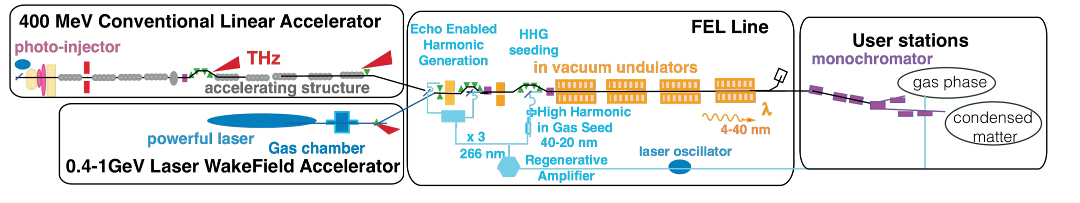

Figure 1. LUNEX5 scheme

2. LUNEX5 accelerator

2.1. The Conventional Linear Accelerator

The CLA includes a superconducting L band linac (with cryomodules designed for future CW operation fed by 1.3 GHz 20 kW CW solid state amplifiers) with a Desy-Zeuthen type photo-gun, a 1.3 GHz cryomodule for accelerating up to 200 MeV, a third harmonic cavity, a laser heater, a magnetic chicane, a diagnostic section, a second 1.3 GHz for accelerating module up to 400 MeV and the space for a possible additional third cryomodule.

2.2. The Laser Wakefield Linear Accelerator

Laser Wakefield Accelerator recent advances [22] in the colliding scheme in particular enable to control injected electrons that ensure both a very good reproducibility and a fine control of almost all the electron beam parameters. Using a 1 J-30 fs laser, the electron beam parameters reach typical values of up to 350 MeV for the electron energy, up to 100 pC for the charge, 1 to 10% for the relative energy spread, 1 to 3 fs for the bunch duration and up to 4 kA for the peak current. In LUNEX5, before using a dedicated laser, first 5GLS steps will be performed with existing lasers in the context of CILEX (Centre Interdisciplinaire de Lumière Extrême). A first implementation study in under way where an upgrade of the laser that will deliver two laser beams of 60 TW each will allow to explore new regime such as the cold injection scheme, with expected higher quality electron beams with parameters more suitable for FEL applications with hopefully a reduction of the relative energy spread. R&D starts for the variable permanent magnet quadrupoles insuring the transport to FEL line.

3. LUNEX5 FEL line

3.1. The undulators

The FEL line comprises transport magnetic elements, dump dipole and cryo-ready in-vacuum undulators with periods of 30 (modulators) or 15 mm (radiators). At 3 mm gap, a peak field of 1.7 T will be produced at 77K with PrFeB magnets for a 15 mm period. R&D will start on a prototype of 3 m long cryo-ready undulators, thanks to the experience acquired at SOLEIL [23] and at ESRF.

3.2. The seeding sources
Two types of seeding for the FEL will be available: seeding by High order Harmonics in Gas (HHG) and seeding using the Echo scheme. As illustrated on figure 1, the same laser will be used for both seeding scheme, it is composed of a Ti-Sa oscillator (30 fs @ 800 nm), followed by a regenerative and a multipass amplifier (30fs, 800nm, 10 mJ, 50 Hz, option at 1 kHz). For the Echo scheme the amplifier output is tripled (266 nm) and split in two parts. For the HHG scheme, the amplifier output injects directly the gas cell. Pump probe experiments of the pilot users require a laser signal perfectly synchronised with the seeding laser. This laser signal can be either provided by using part of the seeding laser and transporting it to the pilot experiments or by a dedicated laser (30fs, few mJ). In this later extremely tight synchronisation between lasers is required. All laser characteristics are within reach of commercially available lasers.

3.3. Synchronisation
LUNEX5 requires a very tight synchronization of many devices. To achieve a few femtosecond or tens of femtosecond jitter and an excellent stability, an optical synchronization will be used. Particularly, the user laser, the electron gun, the cryomodules and the harmonic cavities will be synchronized by this system with less than 10 fs jitter over 8 h.

3.4. The monochromator
The FEL light will hit a first toroidal mirror (to be interchanged with a second one for the echo source point) for focusing on the exit slit; it will then pass through a double rotation monochromator operating in the Petersen mode to select and stabilise the photon energy and through two focusing mirror systems to be dispatched on the two experimental set-ups.

4. LUNEX5 FEL performances
The LUNEX5 spectrum (see fig. 2) covers the 4-40 nm range with the first, third and fifth harmonics, a fundamental peak power between 10 and 100 MW, corresponding to more than 10^{11} photons/pulse and 10^{27} peak brightness and harmonic peak power from 1 MW down to a few hundreds W. Each wavelength can be obtained with different configurations (amplifier, cascade with a High Order Harmonic seed, echo with 266 nm lasers…). The FEL saturates earlier in the echo case than in the cascade one (7 versus 11 m), with slightly lower power (65 MW versus 0.27 GW), longer pulses (24 versus 17 fs) at the Fourier limit. 5G FEL performances critically depend on the electron beam quality and on the optimisation of the transport line.

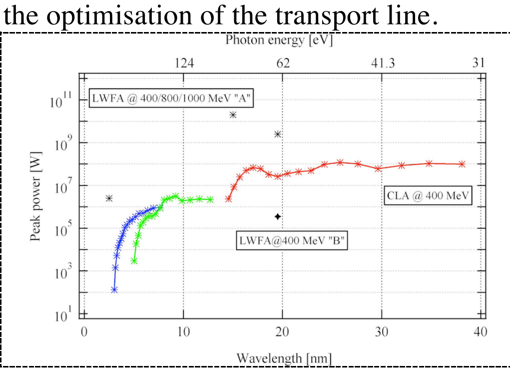

Figure 2. FEL peak power versus wavelength. Calculations with an 400 MeV electron beam, with a 1.5 π mm.mrad emittance, a peak current of 400 A, a slice energy spread of 0.02% (CLA) and case A :0.1, case B:0.5 % (LWFA), a bunch duration of 1 ps (CLA) and case A : 2, case B : 20) fs-RMS (LWFA)

5. LUNEX5 user stations for pilot experiments

5.1. Time resolved pump-probe studies of isolated species (TR-AMO)

The TR-AMO end station will consist in a high resolution velocity map imaging (VMI) spectrometer allowing for spectroscopy of cold atoms/molecules, clusters or nanoparticles, issued from a multi-purpose source, combined with the full momenta characterisation of both electrons and ions using a COLTRIMS type of spectrometer based on time-of-flight and particle 2D position detection (covariance mapping will be used for data analysis).

5.2. Condensed matter imaging exploiting the coherence

The first solid state experiments will aim at obtaining spatially resolved information on ultrafast magnetization dynamics following a non-thermal excitation of a ferromagnetic thin film by an intense, fs short IR laser pulse. Studying non-reproducible aspects of these phenomena will be possible by single X-ray pulse based resonant magnetic small angle scattering at the transition metal's M-edges. These experiments will fully exploit -and characterize- the expected high temporal resolution and energy stability of the X-ray pulses. The coherence of the radiation will allow to obtain single shot X-ray images of the magnetic domain structure [24], for example, to follow in real space and real time the evolution of the magnetization during the recently discovered all-optical process [25].

6. Conclusion

LUNEX5 is coupled CLA-LWFA based test facility for complementary use and test of new ideas aiming for ultra short FEL pulses quest, production and use. It will pave the way towards the next generation of light source (4GLS+, 5GLS). The CDR has been completed, and R&D is starting.

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