SOURCES OF RADIATION ON ARC-EN-CIEL PROPOSAL

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Abstract

The ARC-EN-CIEL project [1] proposes a panoply of light sources for the scientific community. The choice to base the FEL sources on HGHG (High Gain Harmonic Generation) radiation and their Non Linear Harmonics seeded with the High order Harmonics generated in Gas (HHG) is further confirmed with the successful demonstration experiment of such a scheme at SCSS Prototype Accelerator in Japan [2]. In phase 1 (220 MeV), the radiation extends down to 30 nm, phase 1' (800 MeV) and phase 2 (1 GeV), the radiation reaches 1 nm, with 30-100 fs pulses. The first FEL "LEL1" utilizes in-vacuum undulators of period 26 mm for the modulator, and APPLE-type radiators of period 30 mm, close to the standard SOLEIL insertion devices. The second FEL branch "LEL2" uses in-vacuum planar U18 undulators as radiator. In addition, THz radiation from the magnets of the compression chicanes will be provided and has been calculated using SRW. ARC-EN-CIEL Phase 3 adds ERL loops at 1 GeV and 2 GeV where undulators emit conventional synchrotron radiation above 10 keV from short period in-vacuum undulators and soft X ray using a variable polarisation undulator. An FEL oscillator in the 40-8 nm spectral range is installed in the 1 GeV loop. The HHG seeded "LEL4" uses the electron beam from the 2 GeV loop and further accelerated to 3 GeV for producing coherent light production below 1 nm. Recent calculations and optimisations are presented.

INTRODUCTION

ARC-EN-CIEL (Accelerator-Radiation for Enhanced Coherent Intense Extended Light) aims at providing the user community with coherent femtosecond light pulses covering from UV to soft X ray spectral range in France [2]. It is based on a CW 1.3 GHz superconducting linear accelerator delivering high charge, subpicosecond, low emittance electron bunches at high repetition rate. The completion of ARC-EN-CIEL relies on different phases, according to the electron beam energy, the average current and the light sources available for the users. Phase 1 uses a 1 kHz high charge, short bunch electron beam, reaching an energy of 220 MeV with 3 cryomodules, and a first bunch compressor delivered by a modified Zeuthen RF gun [3], illuminated by a Ti:Sa laser. LEL1 is based on a FEL seeded with HHG with an APPLE-II type undulator as a radiator for adjustable polarisation radiation. Phase 1 (220 MeV, 30 nm) is now extended to 800 MeV (Phase1') with an additional bunch compressor and five cryomodules, and fits in the tunnel of the ALS (Accelerateur Linéaire de Saclay) allowing LEL1 radiation to be extended to shorter wavelengths for users applications. With two additional cryomodules on the Linac leading to 1 GeV (Phase 2), the FEL source "LEL2" will be installed, allowing stronger radiation to be achieved in the 1 nm range. Then, with the installation of an additional high average current gun (AES/JLab type [4]) illuminated by a Ytterbium diode pump fiber laser, two ERL loops at 1 and 2 GeV will be added. On the 1 GeV loop is planned LEL3 and FEL oscillator taking advantage of the mirror development for lithography, and an APPLE-II for subpicosecond radiation synchrotron radiation. On the 2 GeV loop, 6 in vacuum U20 (period of 20 mm) will be installed for hard X ray spontaneous emission. When the 2 GeV beams is not energy recovered but once again accelerated up to 3 GeV, it is sent to "LEL4", an FEL seeded with HHG and using cryogenic undulators. THz radiation is also produced in the bending magnets of the compression chicanes and of the arcs. The general scheme of ARC-EN-CIEL is shown in fig. 1.

Table 1: List of radiation sources on ARC-EN-CIEL. Phase: P. M for Modulator and R for Radiator. SR: Synchrotron Radiation. CSR: Coherent Synchrotron Radiation. BC Bunch Compressor. E: Energy. N: number of periods. Conf: configuration. BL: beam line.

	P	E GeV	Type	M/R, N	Spectral range
FEL radiation					
LEL1 Planar helical branch	1, 1', 2	0.22 - 1	HGHG conf 1-1 1-3 HHG seed	M :U26 200 R : HU30, N2=700	200-1.5 nm
LEL2 Planar branch	2	0.8-1.2	HGHG, conf 1-1 et 1-3 HHG seed	M : U26, N1=500 R : U18 N2=500	10-0.5 nm
LEL4 planar branch	3	3	HGHG conf 1-3and 1-5 HHG seed	M :U35, N1=700 R :U18, N2=1000	2-0.2 nm
LEL3	3	1	FEL oscillator	HU30, N=350	40-8 nm
Spontaneous emission					
VUV BL	3	1	SR	HU30	0.2-4 keV
X BL	3	2	SR	U 20, 100	1-20 keV
THz Radiation					
	1-1' 2, 3		CSR	BC1, 2, arc	0.1-10 THz

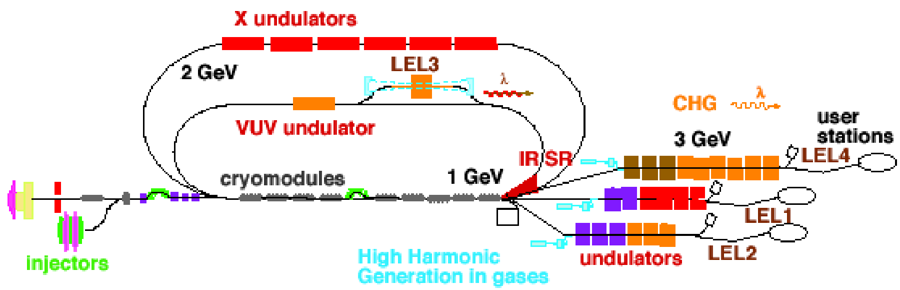

Fig. 1: General scheme of ARC-EN-CIEL, with the different phases and FEL sources

THE CONSTITUTING ELEMENTS

The different parts of the FEL and SR sources are here described, including accelerator parameters, insertion devices, HHG seed for LEL1, LEL2, LEL4 and optics.

The accelerator

A scheme of implementation of Phase1' in the ALS tunnel, showing the different accelerator components, is shown in fig. 2. Another site, the so-called "Mare du Vivier" at Saint-Aubin nearby SOLEIL and Orme des Merisiers, the French third generation synchrotron light source, is considered for Phases 2 and 3. The radiation from a SOLEIL beamline could be coupled to ARC-EN-CIEL radiation.

The beam dynamics has been studied starting from the gun using ASTRA, CSR-Track and TRAFFIC-4 for Phase 1 and 2, and using BETA and BU for Phase 3 [5]. The beam parameters taken for the FEL and radiation simulations are presented in Table 2.

The ERL mode relaxes the constraints with respect to the compression. In such a case, the beam will not go through the second bunch compressor bunch but will travel in a straight vacuum chamber installed at this position. ARC-EN-CIEL Phase 3 aims at achieving high average currents. Typically, 1 mA can be obtained for a repetition rate of 5 MHz. Two regimes depending on the charge level are envisaged, leading to different values of the emittance and peak current as shown in table 2. Higher average currents can be reached in enhancing the repetition rate up to 100 mA.

ARC-EN-CIEL should provide simultaneous electron beams in the accelerators for feeding the light sources for the users: the 1 kHz high peak current for LEL1 and LEL2 should coexist with the high repetition rate (1-100 MHz) recirculated beam in the ERL loops. Such an operation requires the electron beams to be recombined at low energy at the loop entrance and the beams to be separated at the exit of the accelerating structures thanks to kicker magnets.

The operating mode between the different phases relies on the temporal structure illustrated in figure 3.

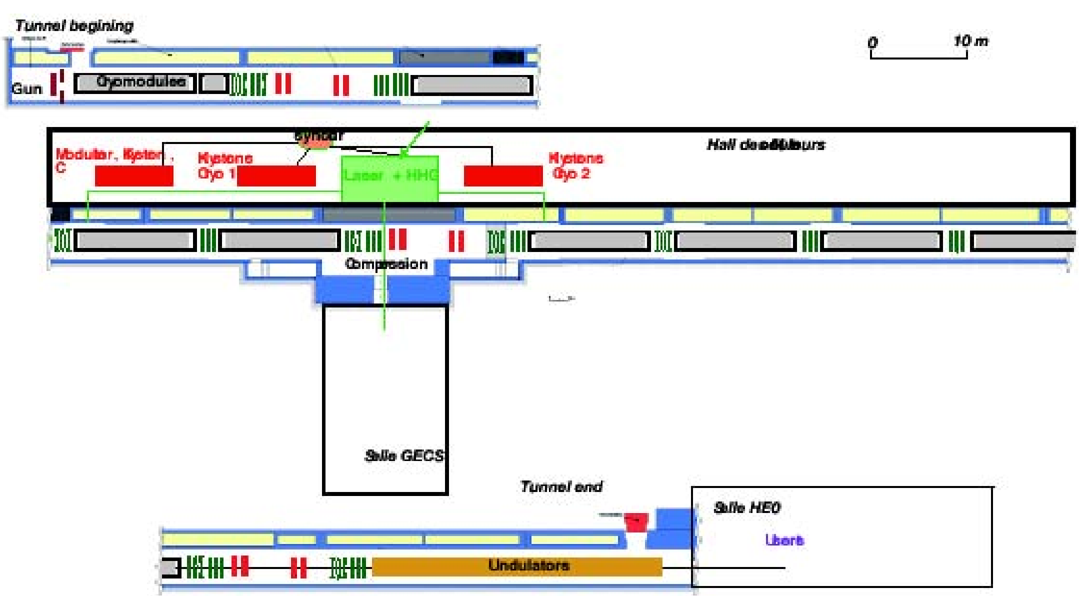

Fig. 2: Possible implementation of ARC-EN-CIEL phase 1' in the tunnel of the former Accelerateur Linéaire de Saclay (Linear Accelerator of Saclay) situated at Orme des Merisiers.

Table 2: ARC-EN-CIEL beam parameters. Total and slice energy spread $\sigma_\gamma/\gamma_{tot}$, and $\sigma_\gamma/\gamma_{slice}$, total and slice beam emittance ε_{tot} and ε_{slice}.

Phase	1	2	3, mode 1	3, mode 2	3
Energy (Gev)	0.2	1	1-2	1-2	3
Rep. rate (kHz)	1-10	1-10	10^3 – 10^5	10^3 – 10^5	1
Charge (nC)	1	1	0.2//1	0.2//1	0.75
ΔT(fs rms)	500-600	200-300	500-600	500-600	200
<I> (µA)	1-10	1-10	10^3-10^5	10^3-10^5	
I_{peak} (kA)	0.8	1.5	0.2	1	
$I_{peak,slice}$(kA)	1	2	1	1	1.5
ε_{tot}(□ mm mrad)	2.4	1.6	2	6	
ε_{slice} (□ mm mrad)	1	1.2	1	5	1.2
$\sigma_{□}/□_{tot}$ (%rms)	0.1	0.1	0.1	0.2	
$\sigma_{□}/□_{slice}$ (%rms)	0.04	0.04	0.04	0.08	0.02

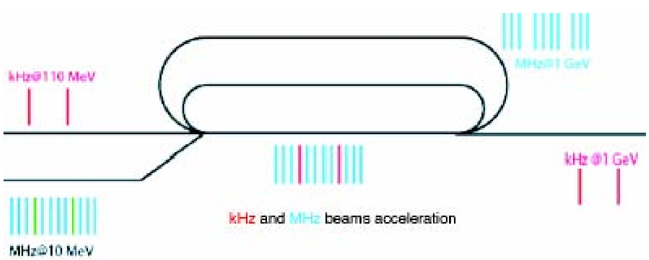

Fig. 3: Simultaneous operation of the electron beams in the different phases of ARC-EN-CIEL.

The undulators

Thanks to the experience on insertion devices acquired at SOLEIL [6], the choice of the undulators tends to select solutions not very different from the ones adopted at SOLEIL. For LEL1, 2, and 4, a conventional HGHG scheme comporting a modulator, a dispersive section and a radiator has been chosen. Different configurations are foreseen, from the 1-1 (modulator and radiator tuned on the seed wavelength), 1-2 (radiator tuned to the second harmonic of the modulator resonant wavelength), 1-3, 1-5 and harmonic cascade (resonant wavelength of the radiator equal to the resonant wavelength of the modulator multiplied by a ratio of integer numbers [7]). The resonant wavelength versus the undulator period has been calculated for different beam energies and the deflection parameter K values in planar and helical configuration. The accessible magnetic field B versus gap for a given undulator period $□_o$ has been evaluated using the analytical expression for NdFeB of remanent field 1.2T: $B=a\cdot\exp(b\cdot gap/□_o + c\cdot(gap/□_o)^2)$ where the coefficients a, b and c are derived for different cases of undulators types [8]. Further optimisations have been done then specifically with RADIA software [9], as in the example of the APPLE-II HU30. Such an undulator is adopted for the radiator of LEL1 and for the undulator of the FEL oscillator LEL3. At SOLEIL, after the installation of three HU80 on the ring, different APPLE-II types undulators are under construction or to be built, with periods ranging between 60 down to 34 mm. Since the vacuum chamber should be as wide in the horizontal direction and the vacuum constraints are soften with respect to storage ring, a period of 30 mm seems quite reasonable. Further analysis during the TDR phase will investigate the possible use of APPLE-III type undulators [10] and designs of in-vacuum APPLE-II undulators.

Standardization with respect to the different undulators sections of ARC-EN-CIEL and small deviations from the solutions adopted at SOLEIL are aimed. SOLEIL has already built several in vacuum U20 undulators, which type of insertion device has been adopted as the ones for the X ray synchrotron light sources on the 2 GeV loop. Further final adjustments will be made later according to the user requests. The periods for the in-vacuum undulators at SOLEIL range between 20 and 26 mm. An U26 has been chosen as a modulator for LEL1 and LEL2, allowing efficient bunching by the seed for the configuration 1-3 for example. The use of a short period high magnetic field in vacuum undulator allows the total length to be reduced and the system to be more compact. LEL2 aiming at operating even below 1 nm on the non-linear harmonics, the magnetic field has been pushed in this case with a radiator of 18 mm period.

Recent development in cryogenics undulators permit to enhance the peak magnetic field by a factor 1.3 using a specific magnet variety operated at low temperature (typically 140 K). First proposed at SPring-8 [11], real advances have been achieved so far in particular at SPring-8, ESRF [12] and BNL [13]. R&D is launched on this subject at SOLEIL. So far, it has been demonstrated that the shimming can be done at normal temperature and the magnetic field properties remain at low temperature, as far as the girders mechanics is not modified. The cooling of the magnets can be performed either via cryocoolers or nitrogen circulation. The magnetic type allowing the highest magnetic field can not be baked for reaching low vacuum pressure, but this is less limiting on a Linac than on a storage ring. So cryogenic undulators are adopted for LEL2 and LEL4 of ARC-EN-CIEL project.

Table 3 summarizes the characteristics of the undulators considered for the simulations of the light sources. Mainly, simulations have been performed using PERSEO Time Dependent [14] considering a filling factor [15] of 0.1 in order to take into account the transverse overlap between the seed and the electron beam, considering average betatron functions of 2.6 m. The undulators are to be built in 2 meters length segments with a FODO lattice in between two segments. Compared to the values given in Table 3, the length will be slightly increased for being a multiple of the segment length. After each undulator module will be placed Optical Transition Radiator screens, Beam Position Monitors. These further optimizations (lattice, segmentations) will take place during the TDR phase of the project. Each segment comports four correctors for adjustment of the vertical and horizontal trajectories at its entrance and exit. After checking the magnetic axis, the module effect on the orbit will be measured versus gap and compared with the magnetic measurements. The natural focusing and the one resulting from defects of magnetic fields will be studied thanks to the quadrupoles located between two segments. In a further step, the radiation will be measured versus the electron beam position using a zone plate selecting the spatial distribution at a given energy, such as the DIAGON type measurements performed at SOLEIL [16].

Table 3: Undulators for ARC-EN-CIEL sources, M for Modulator and R for radiator, * for cryogenic undulators. In-vac for in-vacuum.

FEL	Type	□o mm	K_{max}	Gap_{min}	Length (m)
LEL1-M	In-vac	26	3.2	3.5	5.2
LEL1-R	Apple-II	30	P:2.16 H:1.5	10 8	21
LEL2-M	In-vac	26	3.2	3.5	13
LEL2-R	In-vac*	18	3.1*	3.7	9
LEL3	Apple-II	30	P:3.36 H:1.5	6 8	10.5
LEL4-M	In-vac *	35	4.8	3.5	24.5
LEL4-R	In-vac *	18	3.1*	3.7	18
VUV	Apple-II	30	P:1.1 H:0.7	15.5	2
X	In-vac	20	1.9	5.5	2x6

Simulations consider a dispersive section compression factor R_{56} of 1.5 µm maximum. The R_{56} can be expressed in terms of magnetic field as: $R_{56} = \frac{L_D}{\gamma^2}\left[1+\frac{e^2}{L_D m^2 c^2}\int_0^{L_D}\left[\int_0^s B_D(u)du\right]^2 ds\right]$ where L_D is the dispersive section total length, m the mass of the electron, c the speed of light, B_D the magnetic field of the dispersive section and s the longitudinal coordinate. Such a dispersive section can be realised with permanent magnets and modelised with RADIA [9]. In an example, R_{56} ranging between 33 µm at 500 MeV to 6 µm at 1.2 GeV, and 0.9 µm at 3 GeV were found.

HHG seed

The harmonic generation in gas results from the strong non-linear polarisation induced on the rare gases atoms, such as Ar, Xe, Ne and He, by the focused intense electromagnetic field E_{Laser} of a "pump" laser [17]. The radiation spectrum is tunable in the VUV-XUV region by frequency-mixing techniques applied on the pump laser. High order harmonics are linearly polarised sources from 266 nm down to the water window [18, 19, 20], of high temporal [21] and spatial [22] coherence, emitting very short pulses (attosecond pulses in a femtosecond envelope) in a small divergence (1 to 10 mrad), with a relatively high repetition rate (up to few kHz). The High Harmonics generated in Gas cover presently a wide spectral range with already significant intensities, as presented in fig. 4. Presently, in the short wavelength range, one can rely on a 10 fs pulse with peak powers of 10 MW at 30 nm, 1 MW at 10 nm, 1 kW at 4 nm (with further improvement foreseen in the next 3-4 years up to 10 kW) [23].

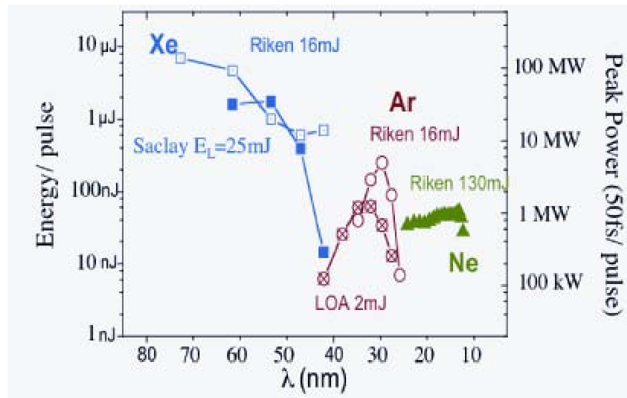

Fig. 4: Peak power and energy per pulse provided by High Harmonics generated in Gas.

Seeding optics and FEL oscillator mirrors

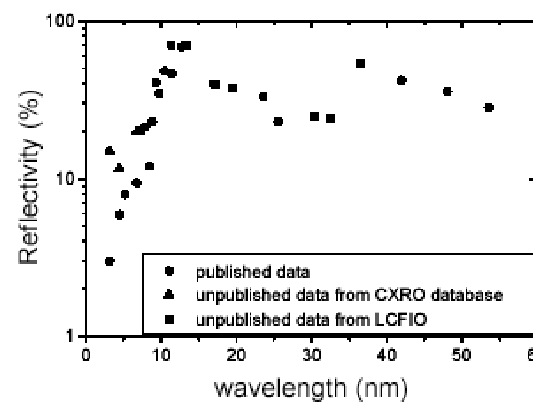

Fig. 5: Normal incidence reflectivity of multilayer mirrors.

The HHG seed can be injected inside the modulator via a set of two spherical mirrors for being able to adjust the focusing inside the undulator, and two periscope mirrors for introducing the light on axis on a dogleg of the accelerator. One can also consider using toroidal and grazing incidence mirrors. For the first, third and fifth harmonics, high reflectivity multilayer mirrors (oxides and fluorides) can be employed. In the VUV, Al metallic and then SiC mirror can be used. In the soft X ray, X ray multilayers are available [24]. In normal incidence, the performances of multilayers around 13 nm benefit from the development carried out for lithography and high reflectivity has been achieved. Such reflectors, currently developed at Institut d'Optique, will be employed for LEL3 (see fig. 5).

ARC-EN-CIEL SEEDED FEL SOURCES

After comparisons of saturation lengths were performed between PERSEO and GENESIS in the steady state regime, the design, characteristics evaluation of the ARC-EN-CIEL FEL sources has been mainly performed using PERSEO Time Dependent adapted to the ARC-EN-CIEL case. Such a code present the advantage of providing also the radiation on the odd non linear harmonics in the planar undulator case. A Filling factor of 0.1 was applied in the modulator in order to approximate the transverse overlap between the electron and the seed beam. Specific calculations (such as short wavelength case, emittance effects) were also studied with GENESIS1.3 (without the non linear harmonics) [25] coupled to SRW [26]. The GENESIS-SRW combination permits the further propagation of the FEL wavefront to the beamlines and deeper insight on transverse coherence issues. Non linear harmonics in the helical undulator configuration and even harmonics produced on the UVSOR-II FEL seeded with a 1 kHz Ti:Sa laser [27] are under analysis with MEDUSA [28]. Following these studies, one plans to proceed to simulations of even harmonics and non linear harmonics produced in the helical configuration for ARC-EN-CIEL FEL sources.

Power and Spectral range

The spectral range covered by LEL1, LEL2 and LEL4 of ARC-EN-CIEL is shown in fig. 6. In seeded FEL sources, different wavelengths will be provided via various electron beam energies: a kicker will extract the 500 MeV beam after Bunch Compressor 2 for being sent to LEL1 for example, the phase tuning of the LINAC allows the energy to be varied between 0.8 and 1.2 GeV for LEL2 and the 3 GeV will be obtained after the 2 GeV loop after a further injector. A slow adiabatic change of the energy in operating the different beams produced by the two guns will be studied in details in the TDR phase. Fine tuning will result from a simultaneous gap change of the undulators and wavelength modification of the Ti-Sa laser illuminating the gas cell for the HHG production, coupled to a change in the monochromators for allowing the users to scan the energy during the measurements on their samples. Compared to the usual "gap scan" on synchrotron radiation facilities, the coupling with the change of the Ti-Sa laser should be added. At short wavelength, the wavelength of the harmonics produced in gas are very close (they are separated by 0.3 nm at 10 nm), a relatively small change wavelength is required to pass from one to the other. Spectral tuneability performed by means a combined chirp on the laser and the electron beam can also be applied [29].

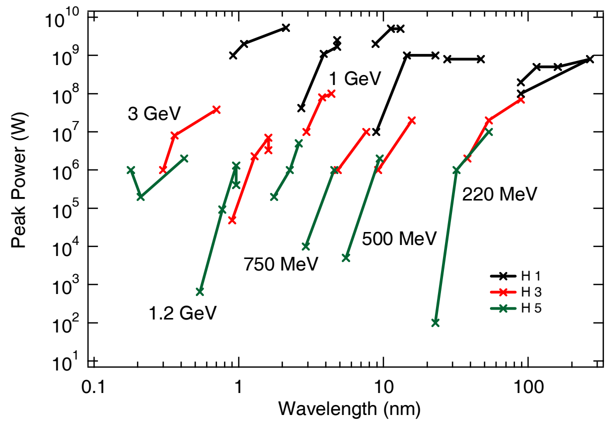

Fig. 6. Spectral range covered by the HHG seeded FEL sources of ARC-EN-CIEL on the fundamental (black), third (red) and fifth (green) harmonics of the radiator.

A closer zoom of the radiation produced by LEL 1 in the short wavelength region for planar and helical configuration is shown in fig. 7. Saturation length depends on the seed wavelength, the number of undulator modules or the dispersive section which can be adjusted.

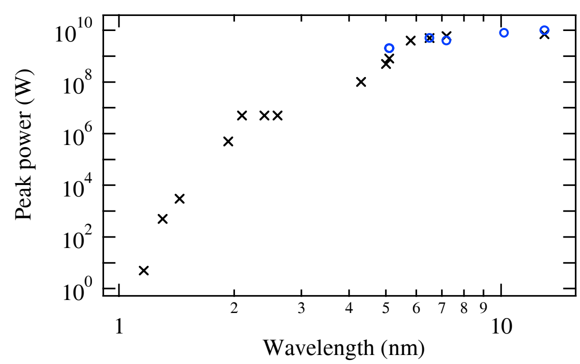

Figure 7: Radiation produced by LEL1 in ARC-EN-CIEL Phase 2. Calculations with 1.5 kA. Seeding power is 30 kW, 50 fs-fwhm, U26 Modulator (100 to 200 periods, depending on seeded wavelength); HU30 Radiator: in (x) planar and (o) helical configuration (400 to 700 periods).

LEL2 allows the spectral range to be extended below 1 nm in the linear polarisation case, as illustrated in fig. 8. Note that in both cases, the calculations were performed with a conservative peak power of 1.5 kA.

LEL4 is more prospective. It allows the spectral range to be extended down to 0.2 nm in the linear polarisation case in configuration 1-5, as illustrated in fig. 9. It exploits the energy enhancement in the loops and the accelerating structures up to 3 GeV and cryogenic undulators technology. The seed ranges between 6.3 and 4 nm, with 30 kW as expected in a near future.

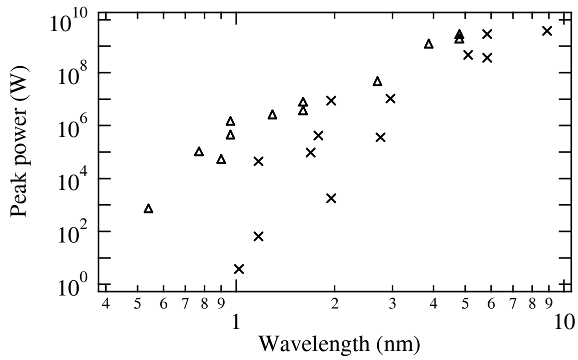

Fig. 8 : Peak power delivered by LEL 2 in ARC-EN-CIEL Phase 2. Seeding power is 50 kW, 50 fs fwhm. Beam parameters of phase 2 with 1.5 kA and (x) E=1 GeV, (Δ) E=1.2 GeV. U26 Modulator (400 to 500 periods), U18 Radiator (400 to 500 periods).

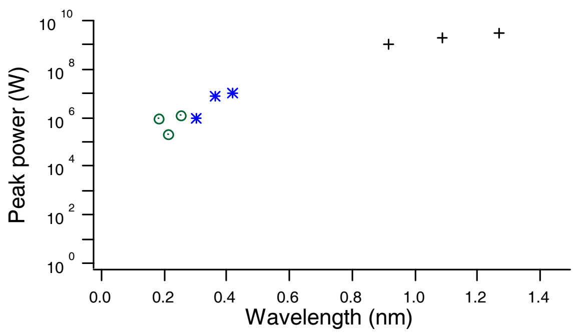

Figure 9: Radiation produced by LEL4 in ARC-EN-CIEL Phase 3. Seeding power is 30 kW, 50 fs-fwhm. U35 Modulator (up to 700 periods), cryogenic U18 radiator (1000 periods).

Longitudinal dynamics, pulse duration and linewidth

Fig. 10 shows the longitudinal dynamics of the FEL radiation followed using evolution diagrams showing the pulse temporal distribution along the progression in the undulators. In the modulator, the seeded fundamental wavelength radiates strongly, with a short, nearly Fourier transformed limited pulse. The non-linear harmonics radiation in contrast are very noisy, wide spectrally and temporally and weak in intensity. The energy modulation of the electrons due to the seed interaction can be seen in phase space, it is transformed into density modulation after the dispersive section. The electrons rotate in phase space when the end of the radiator is reached and some of them escape the separatrix.

At the entrance of the radiator in fig. 10, the radiation first results from the one emitted in the modulator, shifted towards the head of the bunch because of slippage. Then, the emission from the bunched electrons starts and reaches an asymmetric bifurcation, where the light slips along the electron bunch mainly in the forward direction. The electrons situated where the radiation was previously emitted are strongly heated (as seen on phase space analysis) and the radiation starts from the lateral electrons which still have sufficient bunching, exhibiting a thiner pulse duration than the main central pulse. When the heated electrons refresh, the radiation can start again from the center. The behaviour on the harmonics is similar, with a larger number of bifurcation when the harmonic number is higher. The change of slope in the evolution diagram here results the process of saturation of the electrons in the middle of the pulse. The pulse in the modulator appears as a vertical line since slippage here is small with respect to the pulse duration. For this reason the process appears different the one previously observed in the case of a super-radiant regime [30].

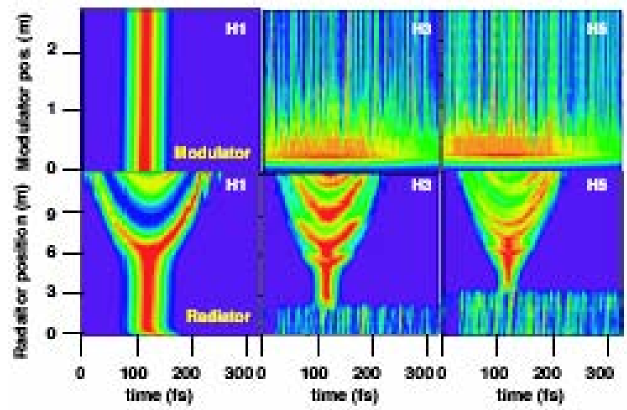

Fig. 10: Evolution of the radiation longitudinal distribution along the position in the modulator (top) and radiator (bottom) for the fundamental (H1), the third (H3) and the fifth harmonic. Case of LEL1, seed at 12.3 nm, 50 fs and 50 kW.

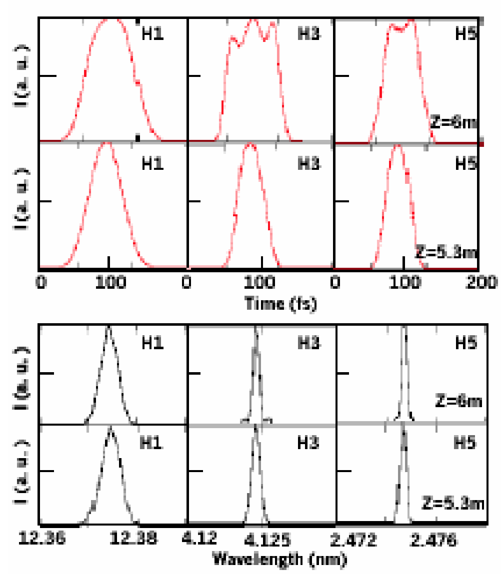

Fig.11 : Temporal and spectral profiles of LEL2 (case of fig. 11) after 6 m in the radiator : H1 : 26 fs rms, 0.014%, 0.38 mJ, H3 : 25 fs, 0.009%, 1.2 µJ, H5 : 20 fs, 0.006%, 30.5 nJ, 2 MW. After 5.1 m in the radiator: H1 : 23 fs fwhm, 0.015%, 0.15 mJ, H3 : 16 fs, 0.0075%, 0.56 µJ, H5 : 14 fs, 0.0054%, 3.7 nJ.

Pulse duration and width decrease along the path in the radiator and start to increase again after saturation. The minimum of pulse duration is reached earlier on the harmonics than on the fundamental. The FEL pulse duration and spectral width does not vary significantly when the seed pulse is changed from 150 fs to 50 fs.

Tolerances Sensitivity to parameters

The sensitivity to the different parameters (electron beam, seed) has been studied in order to evaluate tolerances. They have been mainly carried out in the case of LEL2, more sensitive than LEL1.

The influence of the emittance has been studied with GENESIS coupled to SRW, and is illustrated in fig. 11. In case of peak current, the peak power drops by one order of mzagnitude from 1.5 kA to 2 kA. Higher peak current permit a more efficient power extraction on the harmonics. An increase of energy spread leads to a significant reduction of the peak power, in particular on the non linear harmonics (from 0.06% to 0.08%, one order of magnitude is lost on H1, more than 1 on H2 and 2 on H5).

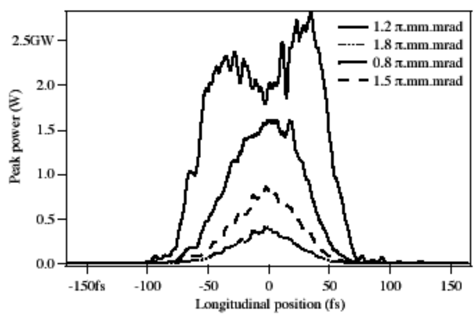

Fig. 11: GENESIS study on the influence of the emittance on the LEL1 on fundamental radiation peak power and pulse duration. LEL1 seeded at 12 nm in the 1-1 configuration.

A change of synchronisation between the seed and the electron bunch leads to a reduction of the saturation length and to a deformation of the pulse shape. At given undulatro length, a tolerance of ±35 fs is found for a 10% change in peak power, while temporal and spectral distribution remain similar.

The maximum of peak power is obtained when the seed wavelength is slightly higher than the undulator resonant one. The influence of the spectral detuning is not symmetrical and becomes much more drastic at short wavelength. Tolerances for 10% peak power change are ±0.025 nm @38 nm, ±0.022 nm (resp. ±0.012nm)@14 nm for a 1-1 (resp. 1-3) configuration.

ARC-EN-CIEL FEL OSCILLATOR SOURCE

The length of the optical resonator is given by the synchronism condition with the electron bunch spacing ($d=c/2f$) with f frequency of the electrons. A 34 m long resonator corresponds to a repetition rate of 4.5 MHz for the 1 GeV loop. In fact, two series of electrons bunches (from the first pass in the 1 GeV loop or from the return pass from the 2 GeV loop in the 1 GeV one) will generate two FELs. For the calculations presented here, a macropulse of 10 ms is considered.

The optical resonator consists of two spherical mirrors with a hole for extraction of the radiation (10 % efficiency assumed for the calculations). For a symmetrical cavity, the waist w_o which minimises the volume of mode along the undulator of length L_{ond} is $w_o = \sqrt{L_{ond}\lambda / 2\pi\sqrt{3}}$ with □ the wavelength. For LEL3 at 10 nm, it is of the order of 100 µm, leading to mirror radius of curvature of 16 m at 10 nm. The corresponding mode divergence $\theta = \frac{\lambda}{\pi w_o}$ is 35 µm at 10 nm. A slight asymmetry of the resonator is better in order to reduce the heat load on the front mirror, so radii of curvature of 16 and 20 m are taken. PERSEO calculations have been carried out for this configuration with the two modes (low and high charge) of operation at 1 GeV. The HU30 undulator allows variable polarisation to be produced. At 1 GeV, the spectral range in circular polarisation on the fundamental covers from 20 to 8.5 nm, with peak power of 120 MW and average power of 90-550 W. In planar polarisation, the spectral range covers from 40 to 10 nm, with peak powers of 50 MW and average power of 200 MW. The absorbed power by the mirrors has been limited to 2 kW, assuming cryogenic cooling as usually done on the SOLEIL beamlines. The use of deformable mirrors is foreseen. Further optimisation of the duty cycle, cavity length and mirror position will be performed during the TDR phase for enhancing the extracted power. Indeed, a longer cavity length allows the mirror to handle a larger laser spot and the power density to be reduced. Pulses are typically 300 fs and 0.5% spectral width. LEL3 is complementary to LEL1, since it provides to the users a source with higher average and lower peak power.

ARC-EN-CIEL SYNCHROTRON RADIATION SOURCES

Radiation from the spontaneous emission undulator sources has been calculated using SRW. The peak brilliance is plotted in fig. 12.

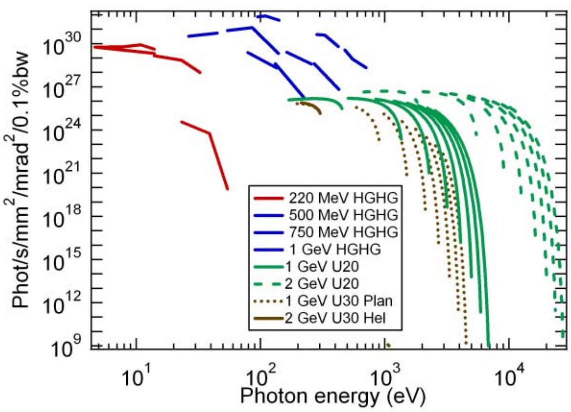

Fig. 12 : Peak Brillance by LEL1 operated at 10 kHz and the spontaneous emission sources for 20 mA in the loops.

ARC-EN-CIEL THZ SOURCES

Figure 13 presents the spectral energy per pulse and the average spectral power of the terahertz emission, calculated for angular apertures of 60 mrad (H) x 40 mrad (V) for three different phases of ARC-EN-CIEL.

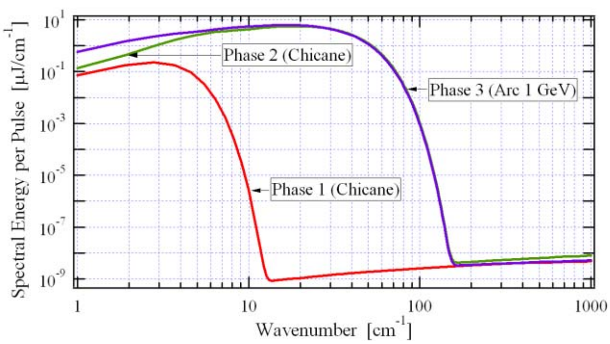

Fig. 13: Pulse energy spectra of terahertz range emission collected by 60 mrad (H) x 40 mrad (V) aperture ports.

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