Chapter 8

Concluding Remarks and Outlook

8.1 General Remarks for Seeded FELs

The operation of X-ray FELs relies on extremely high quality electron beams. Two FEL projects, LCLS at SLAC [33] and FLASH at DESY [157], employing the technique of SASE, define the state-of-the-art situation: peak current of few kiloamperes, normalized emittance of 1 mm mrad or less and an energy spread of 1 MeV or less [11]. The creation of electron bunches with these parameters is a difficult and elaborate process consisting of the electron bunch production, acceleration and compression. The main phenomena affecting the electron beam quality include chromatic aberrations, magnetic field errors and magnets misalignment, SC forces, wake fields and CSR. Demanding for the electron beam quality at least as much as, maybe more than, SASE FELs are those FELs that are designed to generate fully temporally coherent X-rays. Among these, the HGHG FELs employ a laser to seed the radiation at a lower harmonic of the FEL fundamental output. FERMI@Elettra belongs to this new generation of light sources. When the electron beam energy is not high enough to ensure a FEL fundamental emission resonant at the desired X-ray wavelength, two (or more) FEL cascades are adopted to reach the goal. So, FERMI FEL1 is a standard HGHG FEL, while FERMI FEL2 employs a double cascade. In this case the radiation produced in one cascade by one group of electrons proceeds ahead and interacts with other electrons from the same bunch in the next cascade. Thus, relatively long electron bunches are needed to accommodate this technique. The FEL gain is ensured by a high peak current that implies a constant value (flat profile) over most of the bunch length. At the same time, one must make sure that there is
no frequency chirp in the signal, or as little as possible. This chirp can be caused either by energy modulation along the electron bunch or by frequency chirp in the seeding laser. Thus, a flat longitudinal phase space of the electron beam has to be provided at the undulator entrance. At the end, in a HGHG FEL the goal is to obtain an electron beam with “flat-flat” distribution, i.e. flat in both peak current and energy.

It has been shown in this Thesis that in the presence of a longitudinal structural wake field, the degree of linearity of the final longitudinal phase space depends on the initial current profile. In FERMI, a flat longitudinal phase space is ensured by the linearity of the initial current ramp. If this is not perfect, residual higher order energy chirps might reduce the effective compression factor, enlarge the FEL spectral output bandwidth [158] (via a quadratic component of energy chirp) and create current spikes at the bunch edges during compression (via a cubic component of energy chirp) (see also [159]). These lead to further detrimental effects on the energy spread and emittance due to enhanced CSR and wake fields. It has been shown that these terms can be further minimized by adjusting the harmonic cavity RF voltage and phase.

At a scale much shorter than the bunch length, CSR, LSC and the dispersive motion in the magnetic chicanes lead to an amplification of initial small energy or density perturbations, even at the Schottky noise level, driving the microbunching instability. The final longitudinal phase space is typically modulated at wavelengths of the order of 1 \( \mu \text{m} \). In the presence of two-stage magnetic compression, the instability enters into the nonlinear regime that is the folded structure of the longitudinal phase space has important harmonic contents. Although the microbunching instability seems to be well suited to enforce the FEL amplification, there is not any practical way to keep it under control, yet. Instead, Landau damping induced by a large transverse emittance and large relative uncorrelated energy spread would allow partial or total suppression of the instability. In fact, they act as a low-pass filter for the spectral content of the final energy and current modulation. In FERMI, a laser heater has been adopted to increase the uncorrelated energy spread at low energy. Due to the relatively low beam energy at the undulator and to the FEL sensitivity to the relative energy spread, a careful control of the beam heating to a few keV level is required in order to reduce the instability strength. In practice, a compromise between strong heating to suppress the microbunching instability and small relative energy spread for an efficient FEL process has to be reached.

All these considerations underline that a not so high electron energy of 1.5 GeV makes the FERMI HGHG FEL particularly sensitive to any nonlinear effect in the particle longitudinal phase space. As for the transverse dynamics, instead, the geometric emittance of the 100’s pC charged beam is adiabatically damped to the level of 0.3 nm rad so that, for an average betatron function of
10 m, the scale of the transverse beam size is 50 micron. This allows to relax the tolerances on the accelerator alignment and any source of transverse emittance growth (i.e., residual dispersion, magnets field quality, CSR effect, etc...) and trajectory jitter (i.e., ground and magnet vibrations, beam launching, etc...) with respect to much higher energy machines such as LCLS. However, because of the weaker beam rigidity, the transverse wake field instability, whose strength is made particularly important because of the small iris of the accelerating structures installed in FERMI, becomes a real issue, especially at the nominal high charge of 800 pC. A careful control of the beam trajectory along the linac and dedicated diagnostics with high resolution (screens, RF deflectors) are therefore required to minimize the projected emittance growth. If the head-tail instability is strong enough, any seeded FEL power emission would suffer of it because of the lack in the transverse overlap of the electron beam and the seed laser. The other major issue affecting the transverse emittance of the electron beam is the CSR emission in the bends of the magnetic chicanes and of the high energy transfer line. In this case, almost all the CSR effect can be recovered by a suitable optics arrangement, such as a high beam angular divergence at the single source point (in BC1 and BC2) and -I transport matrix between consecutive (and identical) sources of CSR emission (in the Spreader). When a quite linear compression is implemented and pretty far from the point of full-compression, the slice emittance is expected to be preserved as at the injector level, even for high compression factors.

8.2 Machine Design

The FERMI linac layout is designed in order to minimize any source of 6-D emittance dilution. The high impedance BTW accelerating structures are positioned in the last two linac sections L3 and L4, in the energy range 0.6–1.5 GeV, so that their longitudinal wake field is used to remove the energy chirp required upstream for bunch length compression and the effect of transverse wake field is minimized by the higher energy, shorter bunch obtained after compression. The electron energy at BC1 ranges between 330 and 310 MeV for a linear compression factor from 5 to 10. On the one hand, such energies are high enough to avoid repulsive nonlinear SC forces during compression that would otherwise degrade the 6-D beam emittance, on the other hand, BC1 is desired to be at as low energy as possible to enhance energy Landau damping in order to minimize the impact of the microbunching instability. In the two-stage compression scheme, the energy at BC2 is approximately 600 MeV. This choice balances the conflicting requirements of minimizing the CSR instability – by adopting small $R_{56} \approx -20$ mm and large energy spread $\sigma_\delta \approx 1\%$ – and that of can-
celing the correlated energy spread needed for compression in the two-stage scheme. The CSR effect in BC2 can be evaluated as in the following. Since the electron bunch emits in the long bunch, long magnet approximation, the CSR induced energy spread goes like $\sigma_{\delta,\text{CSR}} \sim \langle 4 \ln \gamma \theta - 2 \rangle / \gamma$. The CSR induced emittance growth has therefore the following dependence on the beam energy, $\Delta \epsilon / \epsilon \sim \gamma \sigma_{\delta,\text{CSR}}^2 \sim \langle 4 \ln \gamma \theta \rangle^2 / \gamma$ (for a Gaussian short bunch radiating in a long magnet we would have $\Delta \epsilon / \epsilon \sim 1 / \gamma$). So, we only gain a factor of 2 in emittance growth by ideally moving BC2 from 300 MeV to 1 GeV. The intermediate energy of 600 MeV has finally been chosen for the FERMI case. It primarily allows the beam to be fully compressed early enough to minimize the transverse wake field effect in L4. At the same time, all five BTW structures in L4 are run on-crest to maximize the final energy and, at the same time, their geometric longitudinal wake field removes the energy chirp required for compression in BC2. The threshold of 2% rms energy spread at the entrance of both chicanes sets tight but still realistic tolerances on the magnetic field homogeneity in the chicane dipole magnets. A good field homogeneity is required to avoid chromatic emittance dilution. The two-stage configuration allows FERMI@Elettra to extend the total compression factor up to 50, if needed. The chicane bending angle can reach a maximum operational value of 0.12 rad, so providing a (linear) compression factor of 10–30 in BC1 and 2–5 in BC2.

Owing to the combined action of LSC, CSR and dispersive motion in the compressors, FERMI@Elettra acts like a huge amplifier of small initial density and energy modulations. The frequency cutoff of the microbunching instability gain is determined by the uncorrelated energy spread and transverse emittance that allow particle phase mixing in the longitudinal and transverse phase space, respectively. Linear analysis of the instability starting from shot noise predicts a final slice energy spread of a few MeV's, which is one order of magnitude bigger than the FEL specification. The energy spread can be reduced to the 100 keV level (rms value) by using a laser heater at low energy, that is increasing the uncorrelated energy spread from the natural 2 keV level up to 10 keV. Owing to the sensitivity of FERMI FEL performance to the slice energy spread, the specified beam heating is a compromise between the effective reduction of the instability gain and the maximum energy spread tolerated by the FEL. The analysis shows that the efficiency in removing the beam microbunching by Landau damping is much more sensitive to the initial modulation wavelength than to the amplitude.

A compromise has also to be reached about the optics design of BC1 and BC2, in which the magnitude of the $H$-function in the last bend of the chicane can vary within at least a factor of four. This will give us some flexibility to maneuver between such tasks as containing the emittance excitation due to CSR that benefits from smaller $H$ and containing energy spread growth due to the
microbunching instability that benefits from larger $H$. Numerical simulations of the microbunching instability support and complete the linear analysis. They are a multi-scale dynamics problem because even fluctuations on a small scale can lead to global instabilities and fine-scale structure formation. "elegant" tracking demonstrates the high sensitivity of FERMI to even very small initial density modulations and confirms that most of the instability gain is cumulated just after BC2. In addition to the linear analysis, it also shows that the instability enters into the nonlinear regime after BC2. IMPACT and Vlasov solver predict that a minimum beam heating of $\sim 10$ keV is necessary to suppress the instability in the two-stage compression scheme, whereas 12 keV rms was predicted by the analytical treatment of the instability. So, the final slice energy spread would be in the range 80–150 keV rms, which is still compatible with the FEL production. The substantial agreement of 1-D and 3-D codes simulating the CSR instability in BC1 and the microbunching instability along the whole linac suggests that the 3-D SC effect, if present, is small and probably masked by the differences in the computational methods of the numerical noise.

We have also investigated compression schemes alternative to the two-stage, in order to more effectively suppress the microbunching instability and compatible with the present FERMI layout. They are the one-stage compression and the so-called enhanced phase mixing. The feasibility of one-stage compression and its compatibility with the FERMI@Elettra FEL requirements is demonstrated by means of 1-D and 3-D particle tracking, with promising results for the preservation of the beam quality. In addition to this, a different promising configuration shows up. If the linear energy chirp at the exit of BC1 is removed by dedicated accelerating structures, then particle longitudinal crossover in BC2 is enhanced. The effect is optimized by two chicanes, BC1 and BC2, with the same sign of $R_{56}$. As a result, the energy modulation is damped, together with the associated current spikes. The beam transport has been verified with "elegant" particle tracking, including collective effects, for a compression factor of 10 in BC1. The study shows that the enhanced phase mixing is successful and even more efficient than the one-stage compression for initial modulations whose wavelength is of the order of tens of $\mu$m. It may even be applicable to longer wavelengths and/or higher compression factors, although these more extreme situations need to be confirmed by further investigations.

The diagnostic part of the FERMI linac layout relies on the design of a compact multi-purpose optics insertion. This aims to reach a satisfactory compromise between beam diagnostic, production, collimation and space saving. It is based on a low-beta symmetric optics over $2\pi/3$ betatron phase advance. A betatron mismatch parameter $\leq 1.05$ and maximum residual dispersion of the order of $\eta \approx 1$ mm, $\eta' \approx 1$ mrad are expected. Total shadowing of the undulator vacuum chamber, including 20% safety margin on the 7 mm gap, is ensured.
by the definitively small collimators’ iris radius of 2 mm. A dedicated optics for collimation with bigger $\beta_{x,y}$ would have been desired. However, a different arrangement of quadrupole magnets would have required more space or, alternatively, the CS should have to be moved further downstream in a dedicated optics insertion. In general, modifications to the present magnetic lattice are possible but probably not in the picture of a sole optics for beam diagnostic and transport. The straight line is intersected by a spectrometer line for the characterization of the beam longitudinal phase space. Here, an energy resolution in the range $10^{-4} - 10^{-5}$ is available.

8.3 Electron Beam Quality and Control

In the nominal design, to be fully implemented by the end of 2011, the final electron bunch duration is fixed to 900 fs fwhm to accommodate 150 fs rms arrival time jitter between the seed laser and the electron beam [29] and an up to 200 fs long seed pulse. A peak current of 800 A is achieved by compressing the bunch length of the initial 0.8 nC charged beam by a factor of 11. The compression efficiency is limited by nonlinearities in the longitudinal phase space, mostly due to the geometric longitudinal wake field in the accelerating structures (for a parabolic current profile, a quadratic energy chirp $\approx 0.02 \text{ MV/ps}^2$ and a cubic energy chirp $\approx 165 \text{ MV/ps}^3$ are induced at the entrance of BC1) and the second-order energy/path length dependence in the magnetic chicane ($T_{566} \leq 60 \text{ mm}$).

Compression inefficiency translates into high order energy chirp, large correlated energy spread and current spikes at the bunch edges of the final beam. On the bunch length scale, CSR corrupts the longitudinal phase space much less than the longitudinal wake field: 0.5 MeV energy loss induced by CSR can effectively be neglected with respect to 15.6 MeV dissipated by the linac wake field. The flatness in the current profile, $\Delta I/I \leq 12\%$, and in the longitudinal phase space, $\sigma_{\delta,\text{tot}} \leq \rho = 1.5 \cdot 10^{-3}$, are simultaneously recovered by means of a linearly ramped current profile at the gun exit to generate linear longitudinal wake potential in the succeeding linac, while an RF X-band structure shall be used in decelerating mode to cancel the quadratic and cubic energy chirp during compression in BC1. An additional fine manipulation of the current profile is possible through $R_{56}$ tuning, at the mm level, in the Spreader.

After accurate machine tuning, an rms projected emittance smaller than 2 mm mrad is expected at the entrance of the undulator. This is computed over 100% of the charge. A value closer to 1 mm mrad is predicted for approximately 80% of the charge in the bunch core. The initial 0.8 mm mrad emittance [29], provided by the injector at 100 MeV, is primarily affected by the geometric transverse wake field in the accelerating structures of L3 and L4, which have the re-
markably small iris radius of 5 mm. Trajectory bumps must be implemented along the linac to cancel the banana shape at the end of acceleration. Approximately 50% projected emittance blow up due to wake field can be tolerated by the FEL process. Simulation studies show that most of this blow up concerns trailing electrons, which occupy only 20% of bunch duration and therefore are not necessary involved in the interaction with a 100 fs long seed laser. Trajectory jitter smaller than 20 \( \mu \text{m} \) rms is tolerated in order not to corrupt the trajectory manipulation that counteracts the transverse wake field instability.

The second main source of emittance dilution is CSR emission in the compressors. This happens as in free space since there is no radiation shielding from the 70 mm wide vacuum chamber for a bunch duration equal or shorter than 1 ps. Theoretical evaluations and simulation results agree on a maximum emittance blow up of 20% once the horizontal betatron function in the second half of the chicane is shrunk to the 1 m level. It is important to notice that such projected emittance growth is essentially due to the slice emittance blow up in the bunch edges, where current spikes may appear corresponding to high slice energy spread and slice mismatched optics. A dedicated \(-I\) transport matrix is implemented in the Spreader to cancel any CSR effect on the transverse emittance. Chromatic aberrations dilute the vertical emittance up to 15% (the main source is quadrupole focusing in the BC1 area) in the conservative scenario of complete filamentation that, however, is not expected to develop in the FERMI lattice. All other sources of emittance dilution are forced to a negligible level by the specifications of the magnet field quality and alignment. The specifications are computed for producing 1% projected emittance growth from each independent error source. Unlike the projected emittance, the slice emittance in the bunch core – we define a slice 30 fs long so that the seed pulse covers from one to three of them – is preserved as at the 0.8 mm mrad injector level. A safety value of 1 mm mrad is kept as the reference since it is still compatible with HGHG FEL production even at 4 nm fundamental output wavelength.

During one year of commissioning, from September 2009 to December 2010, a 350 pC electron beam has been generated, transported through the whole beam line with \( \geq 97\% \) efficiency and seeded to generate the first FEL output signal in the coherent harmonic generation mode. A peak signal at the fundamental wavelength of 43 nm has been detected, as well as signals up to the 15th harmonic, with the narrowest fwhm bandwidth of 21 meV. Although priority was given to the RF conditioning and simple beam transport to ensure generation of an FEL signal within the deadline of December 2010, rough machine tuning and preliminary studies of electron beam dynamics have been carried out. Our initial contribution has concerned the characterization of the longitudinal phase space of the initial beam by means of projection imaging in the LH spectrometer line. So, bunch length, mean energy and energy spread are
measured on the basis of the beam line design optics. Then, we focused on the development of methods for slow (∼ 1 Hz) trajectory correction and feedback. A MATLAB-based tool manipulates the trajectory with theoretical as well as experimental response matrices. The tool ensures freedom in setting correction algorithms, weights on the eigenvalues of the inverted matrices, speed of convergence of the correction loop and merging different matrices. Trajectory manipulation by imposing several constraints on the BPMs reading and correctors strength was successful, even using a global matrix correcting from the injector to the linac end as well as three parallel feedback loops covering from the injector to the FEL1 undulator line. Trajectory bumps along the linac are routinely implemented. They limit the projected emittance dilution to 20% downstream of L1 and reduce the normalized emittances from ∼ 10 mm mrad to ∼ 3–4 mm mrad at the linac end (∼ 2 mm mrad emittances are measured in the BC1 area). So, a strong sensitivity of the projected emittances to the trajectory is experimentally confirmed. Trajectory correction to 20 µm level is normally achieved, with trajectory short-term jitter at 10 µm level.

The dispersion function has been measured along the linac for several configurations of magnetic focusing and RF acceleration. The dispersion in the middle of BC1 is in good agreement with the theoretical value. Closure of the BC1 dispersion bump has also been verified. A large 100 mm vertical dispersion propagates parasitically along the linac. We suspect the main source of this effect is a time-dependent RF kick given by the vertical coupler of the injector. If so, a suitable steering at low energy would allow to compensate for these unexpected dispersion bumps.

A MATLAB-based tool for optics matching and transport has been developed that also takes advantage of specific SDDS-to-TANGO MATLAB scripts to interface elegant with the real magnet devices. The matching procedure is routinely performed in LH, BC1 and TLS area and it works reliably. A theoretical solution is obtained in a few tens of seconds. Graphical and text data are provided by the tool to the user to check the level of convergence and the accuracy of the matching loop. By virtue of the low-β symmetric optics downstream of each matching section, the user can immediately verify whether the theoretical solution is correctly applied to the machine by looking to the beam sizes at three consecutive screens. Statistics of the experimental mismatch parameter, mainly collected during measurements in LH and BC1 area, gives the horizontal one in the range [1.005 ± 0.001, 1.075 ± 0.020], with mean value of 1.03. The vertical mismatch parameter is in the range [1.002 ± 0.002, 1.117 ± 0.124], with mean value of 1.05. In general, we notice that the quality of the matching depends mainly on the goodness of the initial emittance and beam parameters measurement. Noisy or odd-shaped beams are more difficult to match. After having matched the beam, we load the theoretical optics on the lattice. Once the optics
is matched in the LH area, the beam is transported to the BC1 section almost instantly, requiring only small trajectory adjustments with the correctors. In one of the best cases of simple optics transport, the experimental mismatch parameter in BC1 area is 1.011 and 1.004 in the horizontal and in the vertical plane, respectively. Since the model is also including the vertical focusing of the BC1 dipole magnets and cavity end RF focusing, the good optics transport is also a confirmation of the correct modeling of such effects on the particle motion. A good week-by-week reproducibility of the machine optics has been confirmed.

Projected emittance studies have been carried out in the BC1 area, for several configurations of the magnetic chicane. While elegant simulations do not predict any important emittance growth during compression, we have measured some emittance blow up due to energy and/or optically mismatched beam passing through the compressor. Second order simulations with mismatched optics show that CSR and chromatic aberration seem to justify the measurement results. In addition to this, we guess some head-tail effect is coming form the injector, in both planes. Trajectory manipulation allows to minimize the emittance blow up downstream of L1 with no compression. As for the BC1 area, the CSR instability would dominate the horizontal beam dynamics providing an emittance growth by a factor of 2 for $C = 6.4$, while chromatic aberration would dominate the vertical with a blow up of a factor of 5 for $\sigma_\delta \sim 1\%$. This interpretation is supported by several measurement campaigns with BC1 on, off and in bunch lengthening mode. A residual dispersion effect in the horizontal plane is not excluded at all, but, in this case, it would invalidate the emittance measurement itself that assumes a pure betatron particle motion. More in detail, $\epsilon_{n,x}$ grows by 20% for $C < 3$, in agreement with simulations. But, for $C > 6$, up to a factor of 1.8 is gained. Since the CSR instability depends on the initial emittance as $\sim 1/\epsilon_x$, we have normalized the relative growth to the initial value for different measurements at different compression factors and found that the measured absolute emittance growth coincide with 0.1 mm mrad error. Finally, we expect that a new optics with smaller $\beta_x$ across BC1 chicane, smaller $\beta_y$ over the BC1 matching quadrupoles, BC1 bending angle of 0.052 rad, 1.5% energy spread and a compression factor of 5, would allow a large reduction of the emittance growth (we expect <20%) with respect to the present status.

Evidence of the microbunching instability has been collected downstream of BC1 for $C \geq 3$. COTR appears in this case, it is smeared by a YAG target or by inserting an OTR foil upstream. Also, some energy modulation has been detected in the dispersive line in front of the main beam dump. Since the laser heater is not implemented yet, some bunching development is expected to happen along the machine even starting from shot noise.
8.4 Outlook

In the last 20 years, an important part of the accelerator physics community has been focusing on the design, optimization and construction of VUV, soft and hard X-ray FELs. These powerful light sources, driven by linacs, show enough flexibility in the output photon properties to cover a broad range of experimental programs. Two big families of FEL generation schemes can be recognized in the SASE and seeded FEL production. Although both these schemes can be in principle implemented in the same facility, every laboratory involved in this business starts with specializing its own project on the basis of the requirements expressed by its own science case. SASE FEL might be considered a good choice to achieve very short pulses at wavelengths in the nm range and below with a 10’s GeV energy linac. HGHG FEL is intended to be an improvement with respect to SASE in terms of spectral purity, but it is currently limited to a few nm output wavelength in the fundamental because of the available seed laser technology. The HGHG scheme could become a practical choice for much shorter wavelengths, as in the SASE case, if and when a seed laser became available at 10’s nm wavelength. Some recent scientific programs are already looking to the High Harmonic Generation technique to make this possibility a reality. At the moment, the harmonic cascade implemented in a HGHG FEL is probably the only way to allow a 1 GeV machine reaching 1–5 nm fundamental output wavelength with hundreds of MW peak power and more than $10^{12}$ photons per pulse. Of course, also a SASE FEL might have an important harmonic content, but in this case the undulator must be much longer than in a seeded FEL (we can estimate at least by a factor of 2 to reach saturation, with the same electron beam) and therefore with higher costs. In a seeded FEL, the time and spectral properties of the output photon pulse are dominated by the seed laser quality. Unfortunately, the higher the harmonic up-shifting from the seed laser wavelength, the tighter is the constraint on the slice relative energy spread at the undulator entrance. We have the impression this is the most critical issue on which a 1 GeV, X-ray HGHG FEL design should be focused.

The most challenging FEL option of FERMI@Elettra implements the HGHG with fresh bunch technique. This requires a bunch length of approximately 1 ps and, for 800 A peak current, 800 pC total charge. This unavoidable high charge for the double cascade scheme might reveal as a limiting factor for the ultimate FEL performance because it seems to be quite difficult to ensure a high brightness and uniform particle distribution over such duration at the undulator entrance. An arrival time jitter between the seed laser and the electron beam possibly to 10 fs level would reduce the final bunch duration and thus relax the electron beam quality requirements, especially in terms of energy and current flatness. Also, there are some expectations about the potential success of the
optics design to suppress the CSR induced emittance growth in the presence of large bending angles. This special optics arrangement (-I transport matrix) can reveal particularly useful for the design of the high energy transfer line that, in all linac-based FEL projects, brings the electron beam to the undulator line(s) with at least one dog-leg lattice. If the CSR effect is canceled, the electron beam quality is totally preserved and large bending angles would become allowed thus reducing the total length of the undulator and experimental hall buildings. The impact on the total cost of a FEL project would then be really important. A major uncertainty that future FEL projects could be facing is the impact of the microbunching instability on the FEL performance. The instability mechanism is already known, but the nonlinear development of it is not treated analytically yet (time consuming and complex numerical methods are currently used). As already mentioned, lower energy machines are more sensitive to the growth of energy spread induced by this instability and the implementation of a laser heater at low energy seems now to be mandatory for almost all this kind of projects. However, the scheme of enhanced phase mixing could be one possible, simpler and cheaper solution than the laser heater to suppress the energy and current modulation. This scheme is thought to be feasible for moderate compression factors in one-stage, but it also gives an FEL project the possibility of achieving full compression with a two-stage compression. As a bottom line, we think that one really new and challenging goal for the next future linac-based FELs is to drive the microbunching instability on purpose and keep it under control in order to enhance the desired bunching at the undulator entrance.