FERMI@ELETTRA: THE SINGLE-PASS FREE-ELECTRON LASER FOR THE VUV AND SOFT X-RAY SPECTRAL RANGE AT ELETTRA

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Abstract

The FERMI proposal is an initiative from ELETTRA, INFM and other Italian institutes, to construct a single-pass FEL user-facility, to be located next to the third-generation synchrotron radiation facility ELETTRA in Trieste, Italy. For the initial phase, the project aims for lasing from 100 nm to 10 nm, with the use of the existing 1.2-GeV S-band linac. As a next step, the accelerator system should be extended to reach 1.2 nm. In all stages, reliability and flexibility are of importance. That is, seeding schemes are considered to improve the SASE output. In addition, users of this new source will have full control over both wavelength and polarization of the radiation.

The initiative is a response to the Italian government's call for proposals for a multi-purpose pulsed laser X-ray source. In anticipation of a positive decision, the Sincrotrone Trieste has initiated the ELETTRA Linac FEL project (ELF), i.e., an R&D project to facilitate a quick and effective implementation of the first step of FERMI. Here, we describe the main features of the project. Emphasis is given to the implementation and initial steps and the ELF project.

INTRODUCTION

FERMI@ELETTRA is a research and development proposal for the construction of a single-pass FEL user-facility for the Vacuum Ultra-Violet (VUV) to the X-ray spectral region, i.e., from 100 nm (12 eV) to 1.24 nm (1 keV). It is foreseen to build-up this machine in three successive stages, aiming for lasing from 100 nm to 40 nm, from 40 nm to 10 nm, and from 10 nm to 1.24 nm, respectively. The first two stages are based on use of the existing 1.2-GeV linac. For the latter stage, the energy of the linac will be extended up to 3.0 GeV. An artist impression of project is given in Fig. 1.

The FEL is intended to operate as a user-facility. Hence, the target capabilities and specifications have been defined in close collaboration with potential users [1]. The most important machine properties are:

- An S-band accelerator with advanced feedback and feed-forward systems to improve the stability
- High-power short optical pulses (~100 fs) with a high pulse-to-pulse reproducibility
- APPLE II type undulators to enable flexible tuning of both the wavelength and the polarization
- Implementation of seeding schemes for further stabilization of the FEL process

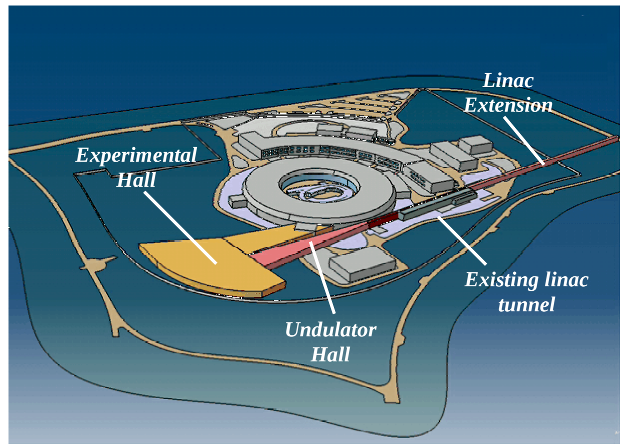

Figure 1: Overview of the ELETTRA laboratory-site after completion of the FERMI project. In the center and top are the buildings in place today. On the left, the undulator hall and the experimental hall are an extension of the existing linac tunnel. The linac extension on the right permits an extension of the spectral range from 10 to 1.2 nm.

Table 1: FERMI@ELETTRA machine parameters

	Stage 1+2	**Stage 3**
Wavelength (nm)	100/40/10	1.2
Peak brightness*	0.1/0.3/0.9	55
Peak power (GW)	2.3/1.8/0.75	3.0
Beam Energy (GeV)	1.2	3.0
Norm. emittance (mm-mrad)	2.0	2.0
Peak current (kA)	0.6	2.5
Rms e-beam pulse length (fs)	250	160
Charge per pulse (nC)	0.38	1
Energy spread (%)	0.05	0.05
Repetition frequency (Hz)	10	10 – 50
FEL parameter ρ (10^{-3})	4.8/3.2/1.6	1.2
Gain length (m)	0.7/0.8/1.3	2.6

* (ph/s/mm^2/mrad^2/0.1%BW)(×10^{30})

The key-parameters are summarized in Tab. 1. To ensure effective operation, the machine will be built using a progressive approach where users will gain access to the machine in an as early as possible stage. Feedback from this approach is then used to refine the design for the successive stages of the project.

While the project waits for funding the ELETTRA Linac FEL project (ELF) has been initiated. ELF is an R&D project to facilitate a quick and effective implementation of the first step of the FERMI proposal with the use of the existing 1.2-GeV linac. As a final goal, ELF aims to reach both lasing and initial user experiments in the wavelength range from 100 nm to 10 nm with a single undulator-line. For the longer wavelength-target, the electron beam energy will be reduced from 1.0 to 0.5 GeV as compared to the original proposal. The electron beam parameters for the shortest wavelength target remain identical to the ones quoted in Tab. 1.

Presently, the ELF project focuses on: (1) a more detailed implementation of the plans proposed for the FERMI project, (2) a further build-up of expertise in areas beneficial to FEL development and (3) steps for implementation of the FEL. There is special attention to steps, necessary to enhance the parameters of the ELETTRA linac to a regime necessary to facilitate FEL R&D.

ELF PROJECT

The existing 65.5-m long, 1.2-GeV linac [2] forms an ideal starting-point for a linac-based FEL. It is located in a 110-m long underground tunnel and consists of S-band structures, each individually controlled. An overview of the infrastructure is given in Fig. 2.

The normal operating mode of the linac is a 10-Hz repetition of 800 ns RF-pulses. The maximum achievable energy is 1.2 GeV. Presently the linac serves as injector for the ELETTRA storage ring. Typically, this service requires 1.5 hours of dedicated operation per day. The remaining time is available for FEL development and operation. In addition, a full energy booster is under construction [3]. The present time-schedule foresees completion of this project in 2005, after which the linac will be dedicated to FEL activities only.

For the ELF project, we aim for lasing in successive steps at 100, 40 and 10 nm. Specifications are summarized in Tab. 2. To transform the linac into a suitable FEL driver, several tasks need to be performed: (1) replacement of the existing electron beam source with a low-emittance injector, (2) modification of the electron beam optics, including bunch compressor systems, to increase the peak current and performance, (3) installation of an undulator line, and (4) installation of additional electron-beam and photon-beam diagnostics to monitor the machine performance in each stage. Additionally there is a special interest in a FEL seeding scheme for the initial phase of the project.

Table 2: ELF target parameters

Wavelength Target (nm)	**100**	**40**	**10**
Peak brightness $^{*,\#}$	0.1	0.7	7.7
Peak power (GW) $^{\#}$	0.7	1.3	3.8
Beam Energy (GeV)	0.5	0.7	1.0
Norm. emittance (mm-mrad)	2.0	2.0	1.5
Peak current (kA)	0.6	1.0	2.5
Rms e-beam pulse length (fs)	667	400	160
Charge per pulse (nC)	1	1	1
Energy spread (%)	0.1	0.1	0.1
Repetition frequency (Hz)	10	10	10
RMS Undulator Strength $^{\#}$	1.95	2.6	4.0
Undulator Gap (mm) $^{\#}$	12	14	21
Average β function (m)	7.6	7.6	7.6
FEL parameter ρ (10^{-3}) $^{\#}$	2.0	1.8	1.6
Saturation Length (m) $^{\#}$	19	21	24

* (ph/s/mm^2/mrad^2/0.1%BW)($\times10^{30}$), $^{\#}$ Planar undulator field

RF Photo Injector

The present injector utilizes a thermionic triode, which does not perform sufficiently for lasing at even the longest wavelength. Hence, a second injector with improved capabilities will be installed. The original gun must remain operational to guarantee injection into the storage ring. For the new electron beam source, three rf photocathode guns are under consideration: (1) a high brightness photo-injector of the BNL/SLAC/UCLA type [4], a 2.6 cell gun developed at the TUE [5], and a higher-order mode 1-cell cavity presently developed by Lewellen at the APS [6]. For any of the options, both the timing-structure and the driving laser, are close to the ones chosen for the LCLS project [4], i.e., 1 nC with a 10 ps flat-top profile. For an optimum performance, there is emphasis on transverse and longitudinal laser pulse-shaping techniques. The driving laser will be located adjacent to the linac tunnel in an existing shielded area, see Fig. 2.

A schematic overview of the injector is presented in Fig. 3. Initially it can be installed as a stand-alone test stand and connected to the main linac during one of the regular shutdown periods. The design of the diagnostic section (emittance and energy spread) is such that it provides sufficient resolution and can be fitted into the space required for the emittance compensation scheme. Slight modifications to the design are still necessary and depend on the final choice of the RF photo cathode gun.

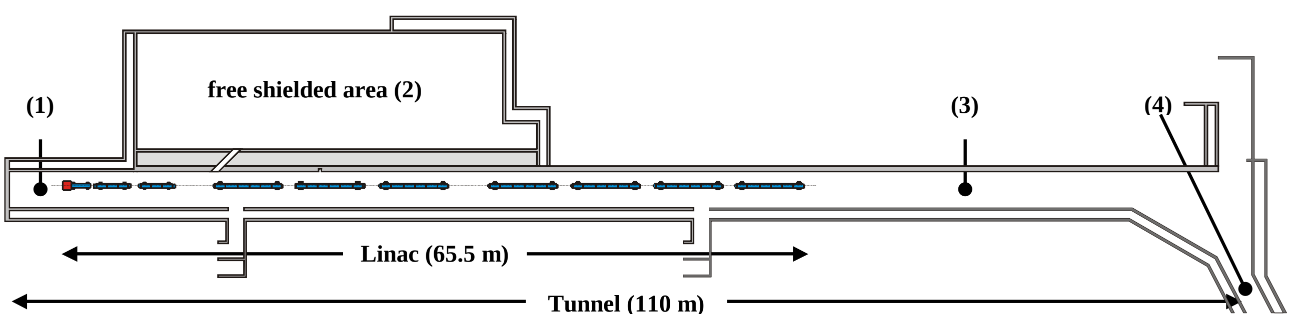

Figure 2: Overview of the existing linac tunnel. The marked areas are: location of a RF photo-injector test stand (1), a shielded area for the driving laser (2), and free area to facilitate the installation of an undulator and moving of accelerator modules (3). The area on the bottom right (4) leads to the injection point of the storage ring. The klystron area is located above the linac tunnel.

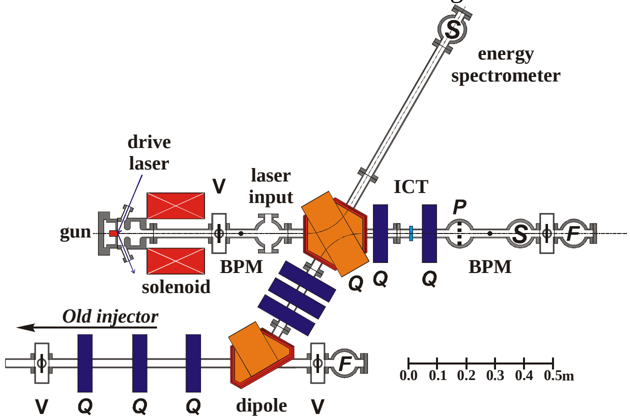

Figure 3: Schematic layout of the injector: (F) faraday cup, (P) pepper pot, (Q) quadrupoles, (S) screens, and (V) vacuum valves. The Faraday cup on the right indicates the position of the first accelerator cavity. The beam-line at the bottom enables use of the present thermionic gun.

Linear Accelerator Section

The only modifications to the structure of the linac are the relocation of one accelerating section to allow for the introduction of magnetic bunch-compressors and additional diagnostics. Similar to the photo-injector, all activities can be executed during normal shutdown periods without interfering with ELETTRA operations.

For initial lasing at 100 nm, it is foreseen to start with modest peak-currents. Hence, the demands for the magnetic bunch compression system are relaxed and a single compression-stage at an energy of 120 MeV is sufficient. In this phase, even a third harmonic cavity to enhance the compression efficiency is not strictly necessary though it would permit a more flexible manipulation of the electron beam. For lasing at shorter wavelengths, it will be necessary to install such a system. Especially for lasing at 10 nm the target peak current is more challenging and a 3rd harmonic cavity in combination with a second compression stage is mandatory.

Undulator Section and Seeding

The undulator section will consist of a 6.5-m period pure FODO lattice with 2.48-m long, 4-cm period undulators. The undulator period is chosen identical to the undulator designated for the second phase of the FERMI proposal. Consequently, the electron beam energy for the initial phase of the project will be reduced to allow lasing at 100 nm.

The final undulator design is still under consideration. For the downstream sections, APPLE II type of undulators will be used to allow a flexible tuning of both the wavelength and polarization. The period is a compromise between a compact design (shorter period) and the complexity of manufacturing (longer period). The choice of the upstream sections of the undulator depends on the desired operational mode of the FEL which is still under discussion: (1) a pure SASE mode of operation or seeding with a conventional low-power laser on a sub-harmonic, or (2) lasing with the aid of a HGHG seeding scheme [7]. For the former option, a variable gap planar undulator with identical period can be used. The latter requires the construction of a sub-harmonic undulator.

For both types of seeding schemes, conventional laser systems are available. Seeding on a sub-harmonic is compatible with a pure SASE mode of operation and, hence, more straightforward for the initial phase of the project. The HGHG scheme might prove to be more cost effective. Both seeding-schemes might suffer from the initially anticipated pulse-to-pulse jitter of the central energy of the electron beam that exceeds the gain bandwidth of the FEL and hence, the effectiveness of the seeding process. This effect can be counter-acted with the use of a sufficiently large energy-chirped beam. Studies indicate that such options are feasible within the parameter range of the ELF project. In such a case, the third harmonic RF cavity will also be mandatory for the initial phase of the project since it permits a sufficient flexible control of the electron beam.

FERMI PROJECT

Since the target parameters of the ELF project are compatible with the FERMI@ELETTRA proposal, the projects can be merged effectively without loss of capital. The space available in the present linac tunnel does not permit the ELF to develop to the status of user-facility. For this, it is necessary to construct a user-hall, such as depicted in Fig. 1. Construction of such a hall, as described in the FERMI proposal [1], would thus form the first natural transformation step. This would also permit a further development towards of a full-scale next-generation light-source user facility, e.g., by constructing parallel undulator beam-lines and implementing an increased repetition rate of the system.

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