THE FERMI PROJECT AT TRIESTE: A LINAC-BASED ULTRA BRIGHT PHOTON SOURCE

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Abstract

ELETTRA is a 2.0 to 2.4 GeV third generation Synchrotron Light Source operating since 1994 in Trieste. At the end of 2004, after the commissioning of the new full energy injection system now under construction, the present 1.2 GeV pre-injector Linac will be fully available to drive a high brightness short wavelength FEL. The goal of the FERMI project is to reach 40 to 10 nm in 3 to 4 years (phase I and II), with a further extension down to 1.5 to 1.2 nm after 2 more years (phase III). The project, articulated along these three lines of development, allows gradual improvement of systems and consolidation of technologies. An overview of the project together with the main upgrading phases is presented.

1 INTRODUCTION

Since 1992 a 1.2 GeV electron Linac has been in operation as injector of the Storage Ring ELETTRA, a third generation synchrotron light source in Trieste. For this purpose the linac use factor is less than 10%. Furthermore from the end of 2004, when the scheduled new full energy injector will come into operation, it will be completely free and available for other uses. On this basis, taking into account the rapid growth in interest for next generation light sources, it will be used as a Linac-based ultra bright photon source, to the great benefit of the scientific community and to the general growth of the facility and associated laboratories. Moreover at the end of 2001 the Italian Ministry of Education, Universities and Research announced a call for proposals for a “multipurpose, pulsed laser X-ray source”. In this context, considering also the *in-house* expertise in accelerators, insertion devices, beamlines and experimental systems, as well as a very strong Scientific Community and the ongoing Storage Ring FEL collaborations (EUFELE), Sincrotrone Trieste, together with INFM and other Italian institutes, has proposed the project FERMI@ELETTRA [1]. The primary objective of the FERMI project is to provide the User Community in the shortest time possible a photon source of outstanding characteristics and to develop and implement new experimental techniques requiring extraordinary flux and brilliance from the UV to the X-ray region. The project will be articulated along three lines of development:

I) use of the existing 1.2 GeV Linac with a new photoinjector and bunch compressor(s) to generate high quality beams for the production of 40 nm radiation (and if sufficient requested 100 nm). Commissioning of the 40 nm beamline after 2.5 years (due to on-site availability of the Linac) and open to Users after 3.5 years.

II) Use of the Linac with increased beam quality for a second beamline at 10 nm. Commissioning of the beamline after 3.5 years and open to Users after 4.5 years.

III) Extension of the Linac to an operation energy of 3.0 GeV and increased improvement of beam quality for the production of 1.2 - 1.5 nm radiation. All the activities will be done in parallel with other developments. Commissioning after 5.5 years and open to Users after 6.5 years.

The FEL scheme we plan to use, at least for the first two phases (40 to 10 nm), will be a seeded HGHG (High Gain Harmonic Generation) scheme [2,3]. This will allow the user to have controlled, polarized and synchronised light. The extension of the seeding scheme to the shorter wavelength of phase III (1.2 nm) has not been studied so far and will be part of the detailed design phase of the project. Preliminary SASE based calculations have however been performed to verify the feasibility of 1.2 nm generation. Table 1 summarizes the main parameters of the three different phases.

Table 1: Electron and photon beam parameters

Wavelength (nm)	100/40/10	1.2
Beam Energy (GeV)	1.0	3.0
Normal. emittance (mm-mrad)	2.0	2.0
Peak current (KA)	0.6	2.5
Pulse length (fs)	250	160
Charge per pulse (nC)	0.38	1
Energy spread (%)	0.05	0.05
Repetition frequency (Hz)	up to 50	
FEL parameter ρ (10^{-3})	4.8/3.2/1.6	1.2
Gain length (m)	.74/.83/1.3	2.6
Peak power at saturation (GW)	2.3/1.8/.75	3.0
Peak flux (ph/s/0.1%BW) (x10^{26})	2.4/1.1/.24	.2
Peak brightness (ph/s/mm^2/mrad^2/0.1%BW)(x10^{30})	.1/.28/.94	55

2 MACHINE LAYOUT AND UPGRADINGS

A complete description of the Trieste Linac can be found elsewhere [4,5]. To produce beams with suitable characteristics to drive a FEL in the energy range of interest it is necessary to implement on the existing machine the following upgrades:

- replacement of the present thermionic electron gun with a high brightness electron source (i.e. a photocathode gun);
- installation of one or more longitudinal compression systems to increase the peak current of the beam;

- review of the present RF system, in terms of phase and amplitude stability, to meet the project requirements;
- installation of an suitable diagnostic system, to preserve the high beam quality during the process of acceleration.

If required it will be also possible to increase the average beam current extending the beam repetition rate from the present 10 Hz up to 50/100 Hz and/or modulating the RF pulse with a high repetition rate microbunch beam (i.e. up to 100 MHz).

To obtain the required values of brilliance, for the electron source and the low energy part of the machine we have considered two possible solutions with two different compression schemes.

Scheme A:

- production of a 6-7 MeV electron beam, with a peak current of about 100 A and a transverse normalized emittance less than 2 mm mrad (i.e. adopting the LCLS photoinjector) [6];
- a compression stage of the electron bunch to the required values (200 fs/0.6 kA) by means of an RF compression scheme: a slow-wave RF accelerating structure followed by a third harmonic structure [7];
- further acceleration of the beam up to 1.0 GeV.

Scheme B:

- production of a 150 MeV electron beam utilizing the same layout adopted by the LCLS project (photoinjector +Linac 0);
- injection of the beam in the two 3.2 m long accelerating structures of the present pre-injector operated off crest to chirp the beam energy before bunch compression;
- use of an X-band structure to linearize the bunch charge [8];
- a magnetic compression stage at 150 MeV (250 fs/0.6 kA);
- further acceleration of the beam up to 1.0 GeV.

The implementation of phase III will require the addition of a second compression stage between 1.0 and 1.6 GeV to increase the peak beam current up to the 2.5 kA as requested. The 3.0 GeV energy upgrade will be implemented adding 36 new accelerating sections (i.e. 3 m long SLAC type) fed with 9 additional RF plants, equipped with TH2132A klystrons and SLED compression systems (i.e. 4 sections per klystron).

Figure 1 shows a layout of scheme B.

Regarding the RF upgrading plans, as well as the implementation of a proper diagnostic and feedback systems, they will be organized taking into account the bunch compression scheme and the emittance preservation.

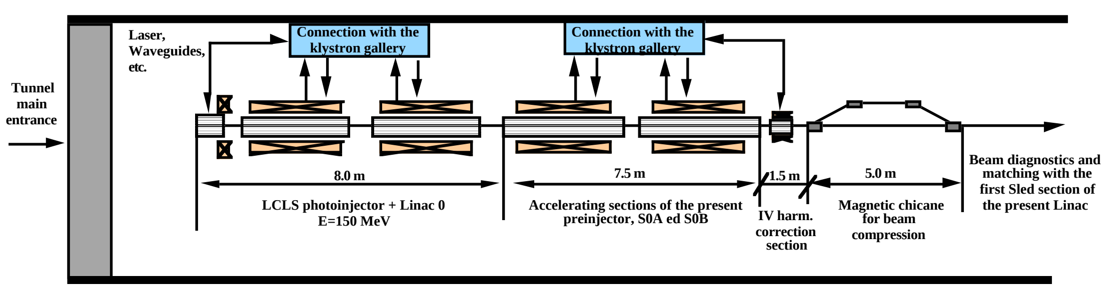

Figure 1: Photoinjector and magnetic compressor layout.

3 SCHEME B: 1.0 GeV START TO END SIMULATIONS

A start-to-end simulation using the program 'ELEGANT' [9] has been performed for scheme B to optimize the magnetic compression chicane [10]. As shown in fig. (1) the proposed layout foresees the replacement of the present gun and bunching elements with a LCLS pre-injector made up of a 6.7 MeV photoinjector and a 150 MeV booster linac. The overall length of the system is a little less than 8 m and will fit in the space available in the present tunnel. It can be installed before the first of the two existing 3.2 m long accelerating sections.

The full simulation used the phase space output from a 'PARMELA' run for the LCLS photoinjector [11], using 0.1 million particles, representing 1 nC charge with a duration of roughly 10 ps, an initial relative energy spread of 0.4% and an emittance of 0.75 mm mrad. The distribution was then re-sampled to remove numerical noise from the time distribution and increased to 0.5 million particles. A more conservative emittance was assumed doubling the previous value to 1.5 mm mrad. An X-band section placed before the magnetic compressor is used to linearise the bunch avoiding non-uniformity of the charge distribution and enhancement of coherent synchrotron radiation effects in the chicane. The specifications for the X-band structure are those of the LCLS. The system, however, is not yet full optimized and further studies will be necessary to minimize the CSR emission especially if we have to further compress the beam with a second magnetic chicane (Phase III).

The first two sections of the linac will also be used to strongly energy chirp the beam before it enters the X-band structure. Very little acceleration occurs through these sections but the beam quality is maintained after the compressor. A compression factor up to 8 and a peak current approaching 800 A in 250 fs have been obtained. The compression occurs at roughly 150 MeV and the magnetic compression chicane has an overall length of 5 m to reduce the effects of coherent synchrotron radiation. Voltages and phases downstream the chicane were optimized to reduce the energy spread.

Optics were matched throughout the accelerator and extraction line to the surface. The horizontal beta function is kept to low values at the exit of the compression chicane to minimise degradation due to coherent synchrotron radiation. Two double bend achromats were used to deflect the beam out of the tunnel and towards the undulators. The tracking took into account longitudinal wakefields in the structures, coherent and incoherent synchrotron radiation effects in all dipoles and second order chromatic effects in the quadrupoles. Transport through dipoles included non-linear terms due to curvature and the energy dependence was taken into account to all orders. The simulation of RF effects included the exact sinusoidal dependence.

Beam parameters at the exit of the linac are shown in figure 2. The four bending magnets transporting the beam in the final vertical dogleg have 2.5° deflections and induce a slight amount of energy micro-bunching of the beam due to coherent synchrotron radiation. Future studies will re-optimize the transfer line to maximise the extraction angle. The final beam parameters at the start of the undulator chains is given in the following table.

Energy [GeV]	1.0
Relative energy spread [%]	< 0.04
Norm. transv. emittance [mm-mrad]	< 1.5
Pulse length (with 0.6 kA) [fs]	~ 500
Peak current [kA]	> 0.8

4 CONCLUSIONS

The main characteristics of the FERMI project at ELETTRA have been outlined. The proposal has been guided by User requirements on the high peak brilliance light and on its applications in Material Science and Technology. The layout proposed and the technical solutions adopted will allow to generate light with controllable polarization and time structure applicable also for pump-and-probe techniques in a stable and reproducible mode in connection with the existing Storage Ring source. Moreover the project has been strongly polarised towards the earliest availability of this new kind of infrastructure.

5 REFERENCES

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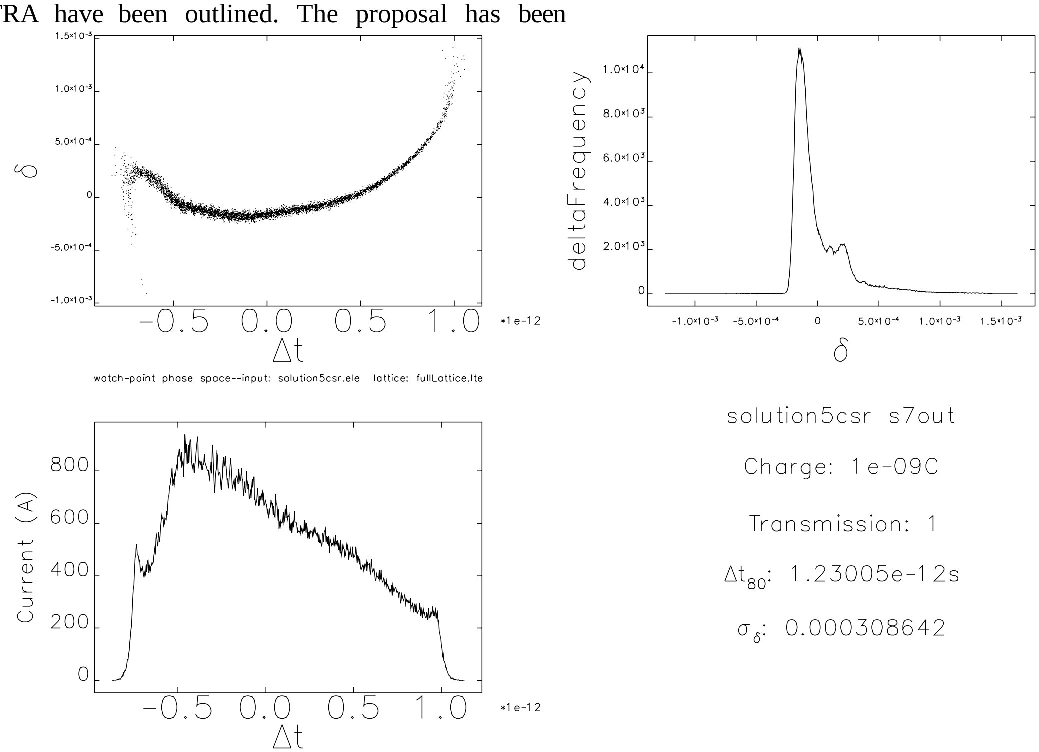

Figure 2: Charge and energy distribution at the exit of the Linac (1.0 GeV). *(Courtesy M. Borland)*