SPARC-GE-03/001
09 September 2004

CONTRIBUTIONS TO EPAC 2002

(3-7 June 2002, Paris, France)

1) An R&D Program for a High Brightness Electron Beam Source at LNF

2) Beam Dynamics Study of an RF Bunch Compressor for High Brightness Beam Injectors

3) Design Study of a Soft X-Ray Sase-Fel Source

AN R&D PROGRAM FOR A HIGH BRIGHTNESS ELECTRON BEAM SOURCE AT LNF

D. Alesini, S. Bertolucci, M.E. Biagini, C. Biscari, R. Boni, M. Boscolo, M. Castellano, A. Clozza, G. Di Pirro, A. Drago, A. Esposito, M. Ferrario, V. Fusco, A. Gallo, A. Ghigo, S. Guiducci, M. Incurvati, P. Laurelli, C. Ligi, F. Marcellini, M. Migliorati, C. Milardi, L. Palumbo, L. Pellegrino, M. Preger, P. Raimondi, R. Ricci, C. Sanelli, F. Sgamma, B. Spataro, A. Stecchi, A. Stella, F. Tazzioli, C. Vaccarezza, M. Vescovi, V. Verzilov, C. Vicario, M. Zobov *(INFN/LNF)*;

F. Alessandria, G. Bellomo, I. Boscolo, F. Broggi, S. Cialdi, C. DeMartinis, D. Giove, C. Maroli, V. Petrillo, L. Serafini, *(INFN/Milano)*;

E. Chiadroni, G. Felici, D. Levi, M. Mastrucci, M. Mattioli, G. Medici, G. S. Petrarca *(INFN /Roma1)*;

L. Catani, A. Cianchi, A. D'Angelo, R. Di Salvo, A. Fantini, D. Moricciani, C. Schaerf, *(INFN /Roma2);*

R. Bartolini, F. Ciocci, G. Dattoli, A. Doria, F. Flora, G. P. Gallerano, L. Giannessi, E. Giovenale, G. Messina, L. Mezi, P.L. Ottaviani, L.Picardi, M. Quattromini, A. Renieri, C. Ronsivalle *(ENEA/FIS);*

L. Avaldi, C. Carbone, A. Cricenti, A. Pifferi, P. Perfetti, T. Prosperi, V. Rossi Albertini, C. Quaresima, N. Zema *(CNR)*

Abstract

The design of a high gradient S-band Photo-Injector system for the production and study of high brightness electron beams is in progress at the Frascati Laboratory, in the frame of a collaboration among INFN, ENEA, CNR, Univ. Roma TV, INFM and ST. This collaboration submitted last year a proposal to a dedicated call for proposals launched by our government, meant to be the first step of a R&D program strategically oriented to a large X-ray FEL initiative. This proposal was approved (December 2001), among others, for a total allocated budget of 9.5 M€ .The construction of the system is expected to start soon: it is comprised of a RF gun driven by a Ti:Sa laser to produce 10 ps flat-top pulses on the photocathode (up to a few nC bunch charge), injecting into two SLAC structures which boost the beam up to 150 MeV. We foresee to conduct investigations on the emittance correction technique and on the RF compression (velocity bunching) scheme, which is expected to increase the natural peak current (100 A) achievable at the gun exit up to a few kA level, with proper preservation of the transverse emittance. Although the system is expected to drive a FEL experiment in the UV region, it will be used also to investigate beam physics issues like surface roughness induced wake-fields, bunch length measurements in the sub-ps range, emittance degradation in magnetic compressors due to CSR and an eventual experiment of Compton backscattering to produce sub-ps X-ray pulses.

1 ORIGIN OF THE PROPOSAL

Driven by the large interest that 4th generation light sources, i.e. X-ray SASE FEL's, have raised world-wide in the synchrotron light scientific community, as well as in the particle accelerator community, and following solicitations arising from several Italian national research institutions, the Italian Government launched in 2001 a long-term initiative devoted to the realisation in Italy of a large scale ultra-brilliant and coherent X-ray source. The initiative was modulated into two phases, with anticipated budgets of 11 M€ and 96 M€ respectively: the first phase is meant to be a 3 year R&D program strategically oriented to explore the feasibility and the most crucial issues of the system which is expected to be designed and built in the second phase, aimed at the construction of the source in a 5-6 year time scale. To pursue this program, the Italian Government published two calls for proposals, in March 2001 and in December 2001 for the two phases respectively. In March 2002 the proposal SPARC, here described, was approved, among others, to be funded with 9.5 M€ over the available total budget of the first phase (11 M€): funding should be delivered soon, allowing a prompt start-up of the project. In the meanwhile, two proposals, submitted in February 2002 at the second phase of the call for proposals, are waiting a final decision of approval: one of these, SPARX, is tightly correlated to the approved project SPARC and is presented somewhere else at this conference[1].

SPARX has been submitted by a collaboration CNR-ENEA-INFN-Univ. Roma TV.

2 THE SPARC PROJECT

The overall SPARC project consists of 4 main lines of activity aiming at several goals: their common denominator is to explore the scientific and technological issues that set up the most crucial challenges on the way to the realisation of a SASE-FEL based X-ray source. These are:

1) Advanced Photo-Injector at 150 MeV

Since the performances of X-ray SASE-FEL's are critically dependent on the peak brightness of the electron beam delivered at the undulator entrance, we want to investigate two main issues - generation of the electron beam and bunch compression via magnetic and/or RF velocity bunching - by means of an advanced system delivering 150 MeV electrons, the minimum energy to avoid further emittance dilutions due to time-dependent space charge effects [2].

2) SASE-FEL Visible-VUV Experiment

In order to investigate the problems related to matching the beam into an undulator and keeping it well aligned to the radiation beam, as well as the generation of non-linear coherent higher harmonics, we want to perform a SASE FEL experiment with the 150 MeV beam, using a segmented undulator with additional strong focusing, to observe FEL radiation at 500 nm and below.

3) X-ray Optics/Monochromators

The X-ray FEL radiation will provide unique radiation beams to users in terms of peak brightness and pulse time duration (100 fs), posing at the same time severe challenges to the optics necessary to guide and handle such radiation. This project will pursue also a vigorous R&D activity on the analysis of radiaton-matter interactions in the spectral range typical of SASE X-ray FEL's (from 0.1 to 10 nm), as well as the design of new optics and monochromators compatible with these beams.

4) Soft X-ray table-top Source

In order to test these optics and to start the R&D on applications, the project will undertake an upgrade of the presently operated table-top source of X-rays at INFM-Politecnico Milano, delivering 10^7 soft X-ray photons in 10-20 fs pulses by means of high harmonic generation in a gas. This will be a very useful bench-test for the activities performed in item 3 above.

In the following, the lay-out and planned activities for items 1 and 2 will be presented in more details, being these more related to the particle accelerator field.

3 ADVANCED PHOTO-INJECTOR

Two are the main goals of this activity in the context of the SPARC project: acquiring an expertise in the construction, commissioning and characterisation of an advanced photo-injector system (which is today missing in the Italian particle accelerator community) and performing an experimental investigation of two theoretical predictions that have been recently conceived and presented by members of this study group. These are: the so-called Ferrario's working point[2] for high brightness RF photo-injectors and the velocity bunching technique to apply RF bunch compression[3] through the photo-injector, with emittance preservation.

The 150 MeV injector will be built inside an available bunker of the Frascati INFN National Laboratories: the general lay-out of the system is shown in Figure 1.

The proposed system to be built consists of: a 1.6 cell RF gun operated at S-band (2.856 GHz, of the BNL/UCLA/SLAC type [4]) and high peak field on the cathode (120-140 MeV/m) with incorporated metallic photo- cathode (Copper or Mg), generating a 6 MeV beam which is properly focused and matched into 2 accelerating sections of the SLAC type (S-band, travelling wave).

Our simulations using PARMELA indicate that we can generate with this system a beam like that needed by the FEL experiment at 150 MeV: in Figure 2 we report the longitudinal phase space distribution at the Linac exit. The rms correlated energy spread over the bunch is 0.14% with a rms normalized emittance of 1.2 mm·mrad (at 1.6 nC bunch charge, 150 peak current), but the slice energy spread, calculated over a 300 μm slice length (comparable to the anticipated slippage length), is well below 0.05 % all over the bunch.

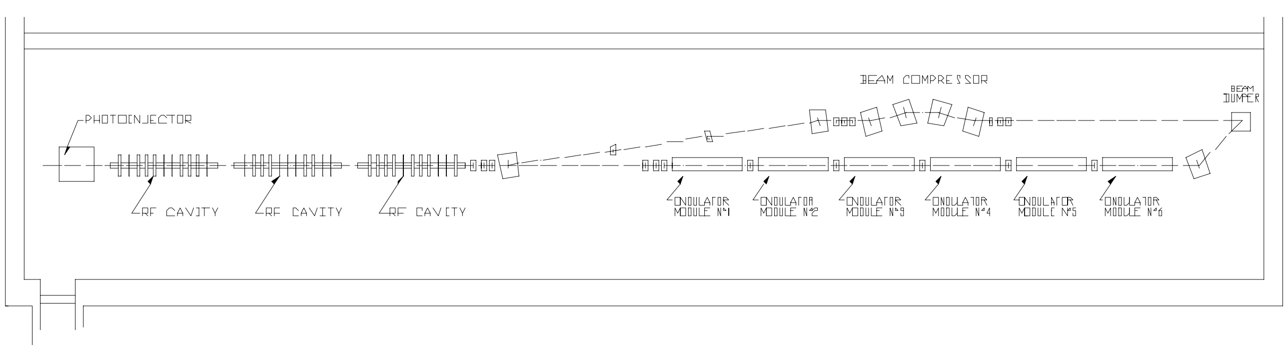

Figure 1 : Lay-out of the SPARC system.

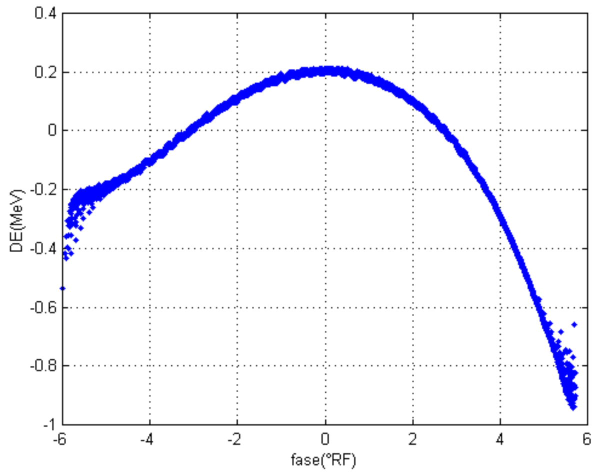

Figure 2: Longitudinal phase space distribution at Linac exit.

4 SASE-FEL EXPERIMENT

This will be conducted using a permanent magnet undulator made of 6 sections, each 2.5 m long, separated by 0.3 m gaps hosting single quadrupoles which focus in the horizontal plane. The undulator period is set at 3.3 cm, with an undulator parameter k_w= 1.88.

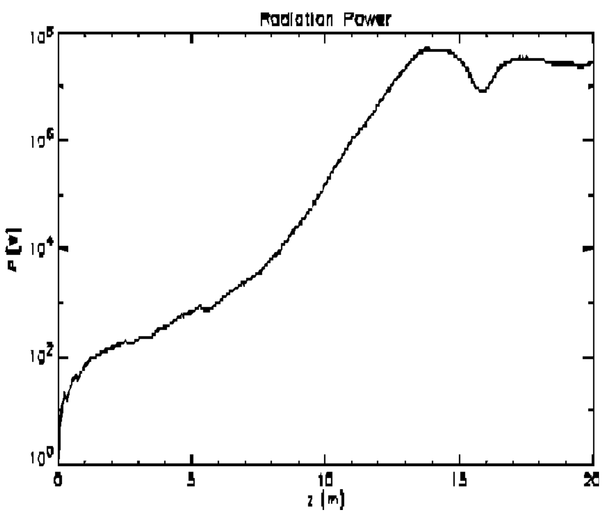

Figure 3 : Radiation Power growth along the undulator.

A simulation performed with GENESIS is reported in Figure 3, showing the exponential growth of the radiation power along the undulator: almost 10^8 Watts can be reached after 14 m of total undulator length, on the fundamental harmonic at 530 nm. Preliminary evaluations of the radiation power generated into the non-linear coherent odd higher harmonics show that 10^7 and $7x10^5$ W can be reached on the third and fifth harmonics, respectively.

5 FURTHER EXPERIMENTS

As shown in Figure 1, the SPARC lay-out anticipates two main upgrades that will be implemented in a second phase of the project: a third accelerating section which will be actually inserted between the RF gun and the 2 previous sections, and a parallel beam line containing a magnetic compressor.

The new section will be designed to study RF compression: it will support travelling waves at an adjustable phase velocity (from v=c down to v=0.999c) in order to exploit the full potentialities of the velocity bunching technique [3]. Its design and construction will proceed in parallel to the commissioning of the SPARC injector system (RF gun + 2 standard SLAC-type 3 m sections). These tests of RF compression assume great relevance in our R&D program[5] since the general lay-out for SPARX foresees the use of a mixed compression scheme, RF compression in the photoinjector up to 700 A and one single stage of magnetic compression at 1 GeV up to the final peak current of 2.5 kA.

The second beam line will allow to conduct experiments on magnetic compression: we want to experimentally investigate CSR induced effects on emittance degradation and surface roughness wake-field effects, without interfering with the ongoing FEL experiment.

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BEAM DYNAMICS STUDY OF AN RF BUNCH COMPRESSOR FOR HIGH BRIGHTNESS BEAM INJECTORS

M. Boscolo, M. Ferrario, INFN-LNF, Frascati (Roma); L. Picardi, C. Ronsivalle, ENEA, Frascati (Roma); L. Serafini, INFN-Milan, Milan

Abstract

A new method based on a rectilinear compressor scheme, utilizing the bunching properties of slow RF waves, has been recently proposed as an alternative to magnetic compressors in order to avoid beam quality degradation due to Coherent Synchrotron Radiation effects. We present here a theoretical and numerical study of the beam dynamics in an S-band photoinjector with rectilinear compressor, as proposed for the SPARC project.

1 TRANSVERSE BEAM DYNAMICS IN RADIO-FREQUENCY COMPRESSORS

Whenever a beam is injected into an RF structure at the zero acceleration phase and slips back up to the peak acceleration phase undergoing a quarter of synchrotron oscillation, it can be compressed [1].

In this section we present the theoretical description of transverse beam dynamics in RF compressors, and, in particular, the theoretical explanation on how the emittance correction process can be implemented in these devices. The analytical model is basically an extension of the invariant envelope theory [2], applicable to quasi-laminar beams carrying a constant current, to the case of currents variable along the beam line (i.e. growing together with energy along the RF compressor).

It is known that the invariant envelope is given by $\sigma_{INV} = \frac{1}{\gamma'}\sqrt{\frac{2I}{I_A\left(1+4\Omega^2\right)\gamma}}$, where the normalized beam kinetic energy is $\gamma = 1 + T/mc^2$ while the normalized accelerating gradient is defined by $\gamma = \gamma_0 + \gamma' z$ and $\gamma' \equiv \frac{E_{acc}}{mc^2}$, I is the beam peak current in the bunch, and the normalized focusing gradient is $\Omega^2 = \left(\frac{eB_{sol}}{mc\gamma'}\right)^2 + \left\{\begin{matrix} \approx 1/8\ SW \\ \approx 0\ \ TW \end{matrix}\right\}$ for a superposition of magnetic field of solenoids and RF ponderomotive focusing by Standing Wave or Traveling Wave sections. σ_{INV} is an exact analytical solution of the rms envelope equation for laminar beams

$$\sigma'' + \sigma'\frac{\gamma'}{\gamma} + \sigma\frac{\Omega^2\gamma'^2}{\gamma^2} - \frac{I}{2I_A\sigma\gamma^3} = \frac{\varepsilon_{n,sl}^2}{\sigma^3\gamma^2} \approx 0$$

where the emittance term (r.h.s.) is considered negligible (this is true in standard photo-injectors up to relevant energies, higher than 100 MeV): it corresponds to an equilibrium beam condition that assures emittance correction, i.e. a control of emittance oscillations associated to envelope oscillations such that the final emittance at the photoinjector exit is reduced to an absolute minimum. In order to assure this condition is necessary to match two types of flow along the photoinjector: the invariant envelope inside accelerating sections and Brillouin flow, given by $\sigma_{BRI} = \frac{mc}{eB_{sol}}\sqrt{\frac{I}{2I_A\gamma}}$, in intermediate drift spaces.

This analysis is valid only for beams carrying constant peak current I, as usual in photoinjectors when no compression mechanism is applied (or space charge debunching is negligible). In order to extend the model to the case of RF compression (where I grows by large factors) we have assumed that the current grows in the compressor at the same rate as the energy, i.e. $I = \frac{I_0\gamma}{\gamma_0}$, where I_0 and γ_0 are the initial values for the current and the energy, respectively, at injection into the compressor. This assumption is derived by observations performed in several simulations of the RF compressor, indicating that best results in terms of final beam brightness are achieved under this condition of adiabaticity, which indeed gives rise to a new beam equilibrium.

In fact, the rms envelope equation becomes in this case:

$$\sigma'' + \sigma'\frac{\gamma'}{\gamma} + \sigma\frac{\Omega^2\gamma'^2}{\gamma^2} - \frac{I_0}{2I_A\sigma\gamma_0\gamma^2} = 0$$

whose new exact analytical solution is $\sigma_{RFC} = \frac{1}{\Omega\gamma'}\sqrt{\frac{I_0}{2I_A\gamma_0}}$, i.e. a beam flow at constant envelope (instead of $1/\sqrt{\gamma}$ as for the invariant envelope). This is dictated by a new equilibrium between the space charge defocusing term (decreasing now as $1/\gamma^2$) and the focusing and acceleration terms (imparting restoring forces to the beam): while for the invariant envelope equilibrium is achieved even in absence of external focusing, i.e. at $\Omega = 0$, in this case we need to provide external focusing.

Just for sake of comparison we notice that the solution for Brillouin flow (i.e. drifting beam at constant energy and constant current undergoing a rigid rotation in the solenoid field B_{sol}) becomes $\sigma_{BRI}^{BAC} = \frac{mc}{eB_0}\sqrt{\frac{I_0}{2I_A\gamma_0}}$ in the case of current increasing linearly along the drift ($I = (\mu z)I_0$) for a corresponding growing solenoid field of the type $B_{sol} = \sqrt{\mu z} B_0$ (also in this case we obtain a constant envelope matched beam through the system, like for the case of RF compression). σ_{BRI}^{BAC} describes what typically happens in ballistic bunching to the beam envelope, which needs to be taken under control by providing a ramped solenoid field to avoid envelope instability.

What is relevant for the emittance correction process is the behavior of the envelope and associated emittance oscillations due to envelope mismatches at injection: let us assume that the injecting envelope is mismatched with respect to the equilibriuum condition such that $\delta\sigma_{INV0} = \sigma_{INV} - \sigma_0$, or $\delta\sigma_{RFC0} = \sigma_{RFC} - \sigma_0$, or $\delta\sigma_{BRI0}^{BAC} = \sigma_{BRI}^{BAC} - \sigma_0$, depending on the type of equilibrium flow that the beam has to be matched on. A perturbative linear analysis of the rms envelope equations reported above (together with $\sigma'' + \sigma\left(\frac{eB_0\sqrt{\mu z}}{mc\gamma_0}\right)^2 - \frac{(\mu z)I_0}{2I_A\sigma\gamma_0^3} = 0$ for the ballistic bunching case) brings to these solutions for the evelope mismatches:

$$\delta\sigma_{INV} = \delta\sigma_{INV0} \cos\left[\sqrt{1/4 + 2\Omega^2}\, \ln\left(\frac{\gamma}{\gamma_0}\right) + \psi_0\right]$$

for the invariant envelope,

$$\delta\sigma_{RFC} = \delta\sigma_{RFC0} \cos\left[\Omega \ln\left(\frac{\gamma}{\gamma_0}\right) + \psi_0\right]$$

for its generalization in RF compressors, and

$$\delta\sigma_{BRI}^{BAC} = \delta\sigma_{BRI0}^{BAC} \cos\left[\left(\frac{eB_0\sqrt{\mu z}}{mc\gamma}\right) z + \psi_0\right]$$

for the ballistic bunching case.

These envelope mismatches produce emittance oscillations in laminar beams because of the spread in initial mismatches due to different slice currents [2]. The emittance behaviors for the three flow conditions come out to be

$$\varepsilon_n^{INV}(z) \approx \sqrt{\varepsilon_{off}^2 + \frac{I\left\langle \delta\sigma_{INV}^2 \right\rangle}{\left(\frac{1}{4} + \Omega^2\right)\gamma'^2\gamma}}$$

$$\varepsilon_n^{RFC}(z) \approx \sqrt{\varepsilon_{off}^2 + \frac{I_0\left\langle \delta\sigma_{RFC}^2 \right\rangle}{\Omega^2\gamma'^2\gamma_0}}$$

$$\varepsilon_n^{BAC}(z) \propto \sqrt{\varepsilon_{off}^2 + \frac{I_0\left\langle \delta\sigma_{BRI0}^{BAC\,2} \cos^2\left[\left(\frac{eB_0\sqrt{\mu z}}{mc\gamma}\right)z + \psi_0\right]\right\rangle}{B_0^2\gamma_0}}$$

where the average $\left\langle \delta\sigma^2 \right\rangle$ is performed over the initial spread of mismatches in different bunch slices and ε_{off} accounts for the non linear and thermal contributions.

While the rms normalized emittance oscillates and adiabatically damps as $1/\sqrt{\gamma}$ in the invariant envelope case (ε_n^{INV}, constant current), it oscillates at constant amplitude along the RF compressor (ε_n^{RFC}), and with a frequency scaling like the invariant envelope case, i.e. $\frac{\Omega}{z}\ln\left(1 + \frac{\gamma' z}{\gamma_0}\right)$ compared to $\frac{\sqrt{1/4 + 2\Omega^2}}{z}\ln\left(1 + \frac{\gamma' z}{\gamma_0}\right)$. In the case of ballistic bunching the emittance ε_n^{BAC} exhibits on the other hand a completely different scaling, with constant amplitude but an increasing frequency like $\left(\frac{eB_0\sqrt{\mu z}}{mc\gamma}\right)$. This the basis why the transverse emittance can be corrected succesfully in the RF compressor: by connecting the two types of flow carefully (proper matching) we can make the emittance oscillates at constant amplitude in the RF compressor and connect adiabatically these oscillations to a damped oscillatory behavior in the accelerating sections following the RF compressor, where the beam is propagated under invariant envelope conditions - this is possible because of the similar frequency behavior of the two flows. It seems hardly achievable in the ballistic bunching, where the increase of the emittance oscillation frequency prevents a good matching to the invariant envelope regime, and induces the onset of non-linear space charge effects that prevent the emittance oscillations to be fully reversible (each minimum in the oscillations is slightly larger than the previous ones).

2 AN RF COMPRESSOR FOR SPARC

The SPARC [3] design assumes a 1.6-cell S-band RF gun of the same type of the BNL-UCLA one equipped with an emittance compensating solenoid and followed by three standard SLAC 3-m TW each one embedded in a solenoid. The preliminary results of the first simulations show that with a proper setting of accelerating sections phase and solenoids strength it is possible, applying the compression method described above, to increase the peak current preserving the beam transverse emittance. An optimized parameters set is shown in table 1.

In order to get a slow bunching of the beam (the current grows about at the same rate of the energy) and to increase the focusing magnetic field with the current during the compression process, we used the first two sections as compressor stages.

Table 1: RF compressor parameters

TW Section	**I**	**II**	**III**
Gradient (MV/m)	15	25	25
Phase (Deg)	-88.5	-64.3	0 (on crest)
Solenoid field (Gauss)	1120	1400	0

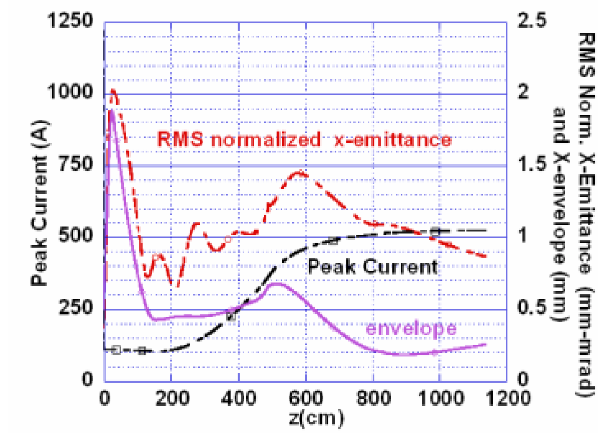

Figure 1: RMS normalized emittance, beam envelope and peak current vs the distance from the cathode.

The plots in fig. 1 of the peak current and the transverse normalized rms emittance (a thermal emittance of 0.3 mm mrad is included) as a function of the distance from the cathode computed by PARMELA for 10K particles show that a peak current of 510 A can be reached with a transverse rms normalized emittance of 0.9 mm mrad. The final beam energy is 120 MeV. The plots of figures 2 and 3 show the evolution of the bunch during the compression as derived from PARMELA computations. One can see that the bunch temporal distribution that is uniform at the beginning tends to a triangular shape: so the value of the peak current in the plot of fig.1, that is simply scaled with the rms bunch length, in reality is an average current in the bunch corresponding to a larger value in the peak (almost doubled respect to the average).

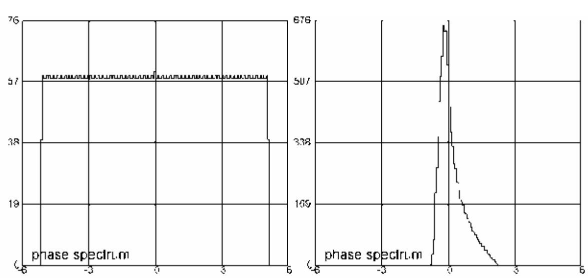

Figure 2: initial and final phase spectrum.

From the point of view of the beam transverse dynamics, during the compression slices with different longitudinal position within the bunch undergo different focusing strengths: in particular the head of the bunch which contains the maximum charge is defocused, while the tail tends to be focused or overfocused, as it shown in figure 3 which shows the plot x-phi in different points of the compressor line.
According to PARMELA convention in the plots of figure 3 and figure 4 the head of the bunch is on the left.

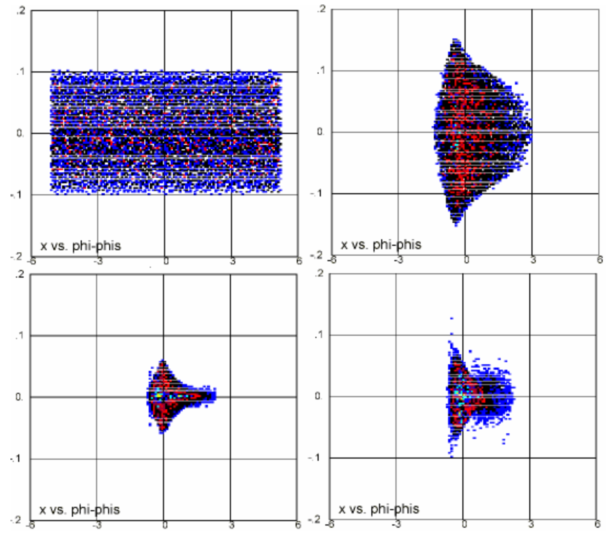

Figure 3: x-phi plot Top: left plot: initial RF gun, right plot: output Section 1, Bottom: right plot: output Section 2, left plot: output Section 3.

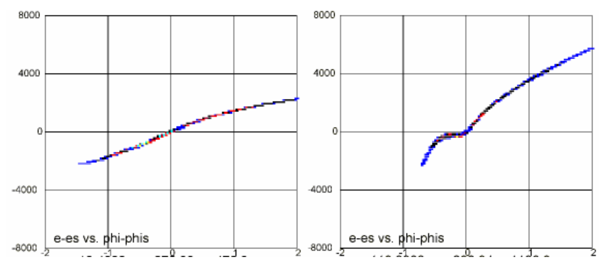

Figure 4: Energy-phase space: left: output Section 1 I=330 A, left: output Section 3 I=510 A.

From the point of view of the longitudinal phase space, as it can be seen in Figure 4, when the current becomes greater than 400 A the bunch head tends to loose the energy-phase correlation differently from the tail that contains less charge, which could be a problem for a further compression of the bunch at higher energy. This point will be investigated more carefully in the future.

3 REFERENCES

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DESIGN STUDY OF A SOFT X-RAY SASE-FEL SOURCE

L. Palumbo on behalf of the SPARX design study group*†‡§

Abstract

FEL's based on SASE (Self Amplified Spontaneous Emission) effect are able to generate coherent radiation with unique features. In principle the brilliance of the source is several order of magnitudes higher than the Synchrotron Radiation Sources of third generation, and it is possible to reach the x-ray spectrum region with ultra-short pulses of hundreds femto-seconds. This source is believed to be a powerful tool to explore the frontiers of basic sciences, from physics to chemistry to biology. Intense R&D programs have started in USA and Europe, in order to understand the SASE physics and to proof the feasibility of these sources. The allocation of considerable resources in the Italian National Research Plan (PNR) brought to the formation of a CNR-ENEA-INFN-"Tor Vergata" University study group. An R&D program (SPARC Project) at LNF has been recently approved and close to start while schemes of a soft-X rays source ranging from 1.5 to 13 nm (SPARX Project) have been investigated and proposed to the Italian Government.

1 SCIENTIFIC CASE

X-rays from synchrotron light sources are today widely used in atomic physics, plasma and warm dense matter, femto-second chemistry, life science, single biological molecules and clusters, imaging/holography, micro and nano lithography. The X-rays are the ideal probe for determining the structure on the atomic and molecular scale. The big step in the peak brilliance, several orders of magnitude, expected with the FEL-SASE sources will open new frontiers of research. New techniques in X-imaging, time resolved spectroscopy can be applied in the field of material science, biology, non linear optics. Of particular relevance are the diffractive techniques with coherent radiation on biologic tissues that allow the crystallography of macro-molecules with single pulses.

2 FEL-SASE SOURCE

Two spectral complementary regions around 13.5 nm and 1 nm, are considered for the source. In order to generate the SASE-FEL at these wavelengths, it is necessary to produce a high brilliance beam to inject inside two long undulators. A preliminary analysis of the beam parameters required for such a source leads to values reported in Table 1.

Table 1: Beam parameters

Beam Energy	2.5	GeV
Peak current	2.5	kA
Emittance (average)	2	mm-mrad
Emittance (slice)	1	mm-mrad
Energy spread (correlated)	0.1	%

We envisage to use the same beam to feed two undulators whose characteristics are discussed in Table 2-3.

Table 2: Undulator characteristics (first undulator)

Undulator 1 – UM1	
Type	Halbach
Period	3 cm
K	1.67 (@ 1.5 nm)
Gap	12.67 mm (@ 1.5 nm)
Residual field	1.25 T

Table 3: Undulator characteristics (second undulator)

Undulator 2 – UM2	
Type	Halbach
Period	5 cm
K	4.88 (@ 13.5 nm)
Gap	12.16 mm (@ 13.5 nm)
Residual Field	1.25 T

As in all laser systems, the FEL-SASE signal starts from chaotic noise which is then amplified (exponential growth) and eventually saturates. Those three different phases are clearly shown in Figs. 1-2 concerning the generation of radiation at 1.5nm and 13.5nm respectively. The typical "steps" in the exponential rise are due to beam focusing regions where there are no undulators (and therefore the light beam is not amplified).

The characteristics of the FEL-SASE radiation up to the 5th harmonics, have been investigated by means of several codes: GINGER, GENESIS, MEDUSA, PROMETEO, PERSEO, and the results are shown in Table 4.

* D. Alesini, S. Bertolucci, M.E. Biagini, C. Biscari, R. Boni, M. Boscolo, M. Castellano, A. Clozza, G. Di Pirro, A. Drago, A. Esposito, M. Ferrario, V. Fusco, A. Gallo, A. Ghigo, S. Guiducci, M. Incurvati, P. Laurelli, C. Ligi, F. Marcellini, M. Migliorati, C. Milardi, L. Palumbo, L. Pellegrino, M. Preger, P. Raimondi, R. Ricci, C. Sanelli, F. Sgamma, B.Spataro, A. Stecchi, A. Stella, F. Tazzioli, C. Vaccarezza, M. Vescovi, V.Verzilov, C. Vicario, M. Zobov *(INFN /LNF)*; E. Acerbi, F. Alessandria, D. Barni, G. Bellomo, C. Birattari, M. Bonardi, I. Boscolo, A. Bosotti, F. Broggi, S.Cialdi, C. DeMartinis, D. Giove, C. Maroli, P. Michelato, L. Monaco, C. Pagani, V. Petrillo, P. Pierini, L. Serafini, D. Sertore, G. Volpini *(INFN /Milano)*; E. Chiadroni, G. Felici, D. Levi, M. Mastrucci, M. Mattioli, G. Medici, G. S. Petrarca *(INFN /Roma1)*; L. Catani, *(INFN /Roma2)*.

† R. Bartolini, F. Ciocci, G. Dattoli, A. Doria, F. Flora, G. P. Gallerano, L. Giannessi, E. Giovenale, G. Messina, L.Mezi, P.L.Ottaviani, L. Picardi, M. Quattromini, A.Renieri, C. Ronsivalle *(ENEA/FIS)*.

‡ L.Avaldi, R.Camilloni, C.Carbone, S.Colonna, A.Cricenti, I.P.DePadova, S.Lagomarsino, C.Ottaviani, P.Perfetti, A.Pifferi, T.Prosperi, C.Quaresima, V.Rossi Albertini, N.Zema *(CNR)*.

§ S.Stucchi, D.Flamini, C.Schaerf, A Cianchi, A.Desideri, S.Morante, S.Piccirillo, N.Rosato, V.Sessa, M.L.Terranova (*Univeristy of Rome "Tor Vergata"*)

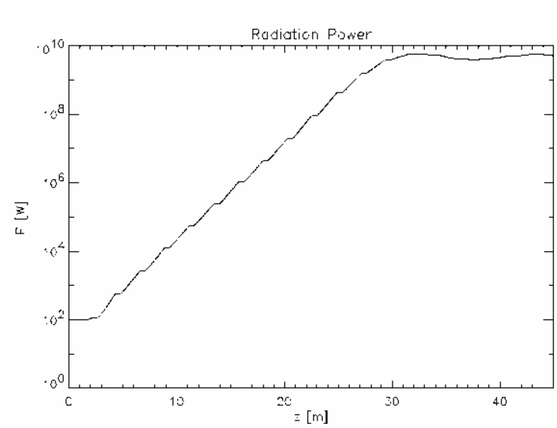

Figure 1: FEL signal evolution (λ=1.5 nm) along the undulator 1 (see Table 2).

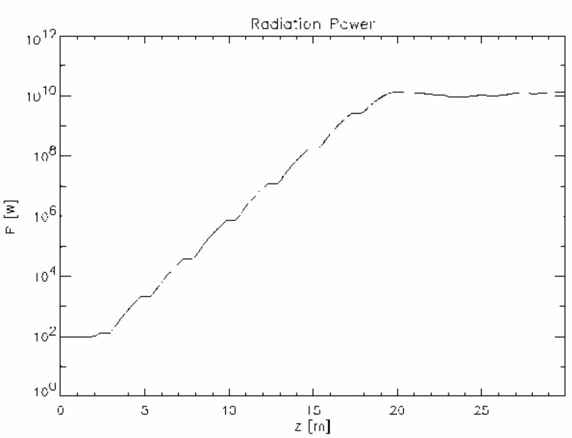

Figure 2: FEL signal evolution (λ=13.5 nm) along the undulator 2(see Table 3).

Table 4: FEL-SASE expected performances

Wavelength (λ)	1.5 nm	13.5 nm
Saturation length	24.5 m	14.5 m
Peak Power	10^{10} W	4 10^{10} W
Peak Power 3rd harm.	2 10^{8} W	5 10^{9} W
Peak Power 5th harm.	3 10^{7} W	2 10^{8} W
Brilliance**	1.8 10^{31}	2 10^{32}
Brilliance** 3rd harm.	10^{29}	10^{31}
Brilliance** 5th harm.	9 10^{28}	3 10^{29}

With the two undulators it is possible to cover a bandwidth from 1.2nm to 13.5nm, with the first harmonic, and a bandwidth from about 0.4nm to 4nm, using the 3rd harmonic, which exhibits still a considerable peak power, as shown in Fig. 3.

It is worth noting that the spontaneous synchrotron radiation power emitted by the beam inside the two undulators is (at least) two orders of magnitude higher than in the 3rd generation light sources (see for example Fig. 4).

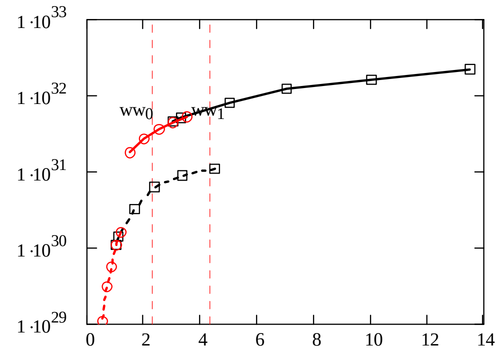

Figure 3: Brilliance** as a function of the λ (nm) at constant energy.

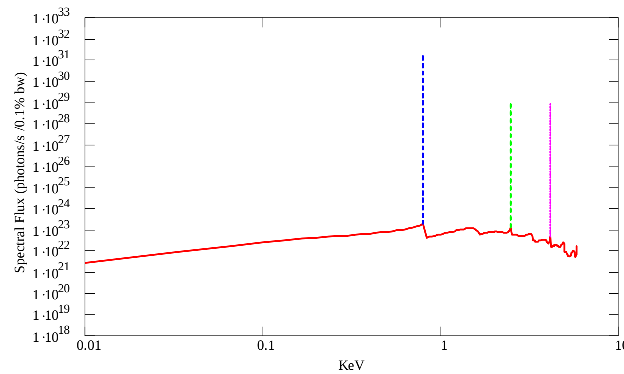

Figure 4: Spectral flux for three FEL harmonics compared to the synchrotron light contribution (see Table 2, 2.5 kA).

3. LINAC R&D AND LAY-OUT

The accelerator dedicated to the FEL-SASE source has the task of accelerating ultra-brilliant electron bunches up to the energy of 2.5 GeV. Given the charge Q in the bunch and the r.m.s. dimensions σ_x, σ_y, σ_z, the brilliance is defined as: $B_n = 2I/\varepsilon_n^2$, where $I= cQ/\sqrt{2\pi}\sigma_z$ is the peak current and $\varepsilon_n=\gamma\sigma_x\sigma_y$ the normalized emittance.

The nominal values for the proposed source are: energy E=2.5 GeV (γ=4892), peak current 2.5 kA, normalized emittance 2 µm, energy spread 0.1%. A beam with these characteristics hasn't yet been generated; however, it is believed to be achievable with the current R&D world-wide activity on photo-injectors and bunch compressor schemes.

A dedicated R&D program (SPARC project) is envisaged at LNF-INFN, in collaboration with CNR and ENEA. Its aim is the generation of electron beams with ultra-high peak brightness and the generation of resonant higher harmonics in the SASE-FEL process. The proposed scheme (Fig. 5) consists of a RF gun operated at

** The brilliance is given in photons/sec/0.1%bw/(mm mrad)^2

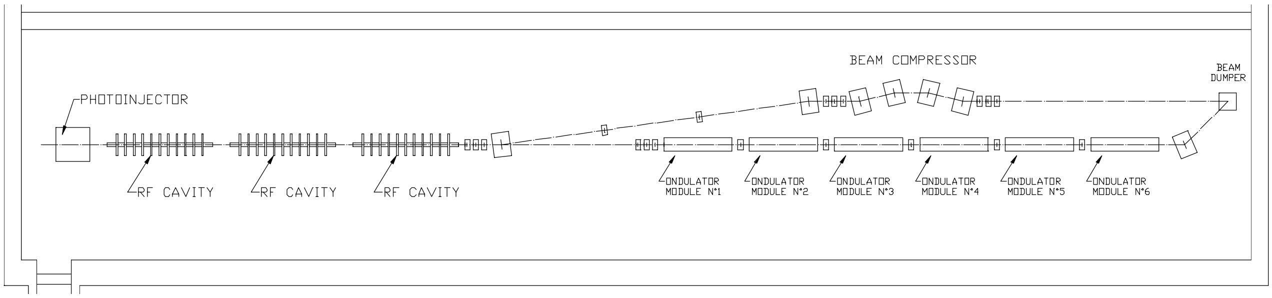

Figure 5: Schematic layout of SPARC R&D project

S-band (2.856 GHz) and high peak field on the cathode (120-140 MeV/m) with incorporated metallic photo-cathode (Copper or Mg), generating a 6 MeV beam which is properly focused and matched into 3 accelerating sections of the SLAC type (S-band, travelling wave).

The peak current will be in excess of 150-200 A and will drive a SASE-FEL experiment at 520 nm, performed with a 12m undulator following the linac. The normalised emittance and the peak beam current along the injector are shown in Fig. 6. The project has been approved by the Italian Government and expected to be founded soon.

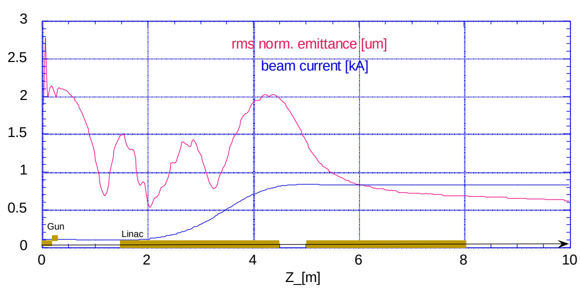

Figure 6: Beam current and normalised transverse emittance along the injector (with RF compression).

The soft X-ray project, SPARX, has been recently proposed with the schematic layout given in Fig.7. After the SPARC injector, a first 60m long accelerating section will accelerates the beam up to 1 GeV, before entering in a magnetic bunch compressor to increase the current intensity (Fig. 7). The last 90 m section will then produce the 2.5 GeV beam to be injected in the undulators. The beam parameters evolution along the whole SPARX machine is shown in Fig. 8.

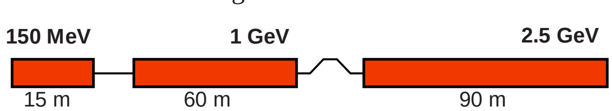

Figure 7: Linac scheme of SPARX project.

4 CONCLUSIONS

A coherent soft X ray source based on the FEL-SASE mechanism, is of great interest for many fields of applications, from basic science to industrial and medical applications. A study group gathering researchers from the major Italian research institutions (CNR, ENEA, INFN) started a conceptual design of such a source. The conceptual design was proposed to the Italian

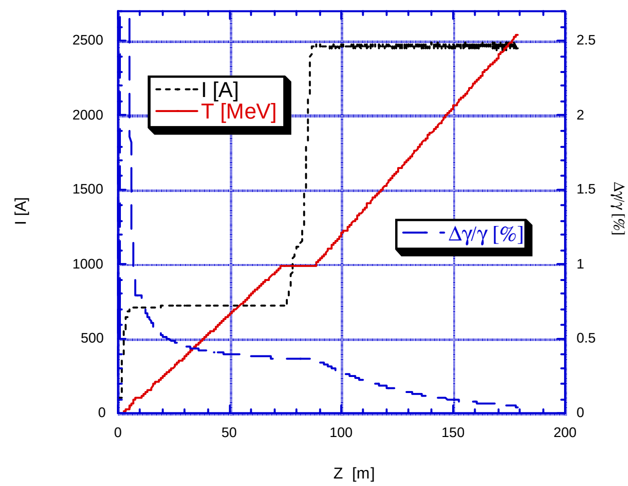

Figure 8: Beam parameters along the SPARX machine.

Government following a call for proposals issued in December 2001. The source will consist of a high brilliance photo-injector optimised for the production of very low emittance (2 μm) beams at150 MeV, and whose first accelerating section is used as RF bunch compressor,able to reach a peak current of the order of 700-800A. The R&D program for such an injector (SPARC) has already been approved and it is expected to be funded soon. After the injector, two Linacs and a magnetic compressor at 1 GeV allow a high peak current and a high quality beam, to reach the energy of 2.5 GeV. The beam is then injected into two undulators in order to generate FEL-SASE radiation (from 1.5 to 13 nm). Eventually five radiation lines bring the radiation inside an experimental area. The proposed site is the campus of the University of Rome "Tor Vergata".

5 ACKNOWLEDGEMENTS

The SPARX project profits from the collaboration of many scientists worldwide. We wish to thank all the colleagues who helped us to prepare the scientific case. Concerning the source proposal, we are in debt with W.B. Fawley (LBNL), H.P. Freund (NRL), S.G. Biedron S.V. Milton (ARGONNE) and the EXOTICA international workgroup.

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