THE SPARX PROJECT: R&D ACTIVITY TOWARDS X-RAYS FEL SOURCES

D.Alesini, S.Bertolucci, M. Bellaveglia, M.E.Biagini, R.Boni, M.Boscolo, M.Castellano, A.Clozza, G.Di Pirro, A.Drago, A.Esposito, M.Ferrario, D. Filippetto, V.Fusco, A.Gallo, A.Ghigo, S.Guiducci, M.Incurvati, C.Ligi, F.Marcellini, M.Migliorati, A.Mostacci, L.Palumbo, L.Pellegrino, M.Preger, P. Raimondi, R.Ricci, C.Sanelli, M.Serio, F.Sgamma, B.Spataro, A.Stecchi, A.Stella, F.Tazzioli, C.Vaccarezza, M.Vescovi, C.Vicario, INFN-Frascati

F.Alessandria, A.Bacci, I.Boscolo, F.Broggi, S.Cialdi, C.De Martinis, D.Giove, C.Maroli, M. Mauri, V.Petrillo, M.Romè, L.Serafini, INFN-Milano

M.Mattioli, P. Musumeci, INFN-Roma1

L.Catani, E.Chiadroni, A. Cianchi, C. Schaerf, INFN-Roma2

F.Ciocci, G.Dattoli, A. Di Pace, A.Doria, F.Flora, G.P.Gallerano, L.Giannessi, E.Giovenale, G.Messina, L.Mezi, P.L.Ottaviani, S. Pagnutti G. Parisi, L.Picardi, M.Quattromini, A.Renieri, C.Ronsivalle, A. Torre, A. Zucchini, ENEA-Frascati

S. De Silvestri, M. Nisoli, S. Stagira, Politecnico/Milano

J.B. Rosenzweig, S. Reiche, UCLA - Dept. of Physics and Astronomy

P.Emma, SLAC

Abstract

SPARX is an evolutionary project proposed by a collaboration among ENEA-INFN-CNR-Universita` di Roma Tor Vergata aiming at the construction of a FEL-SASE X-ray source in the Tor Vergata Campus. The first phase of the SPARX project, funded by Government Agencies, will be focused on R&D activity on critical components and techniques for future X-ray facilities as described in this paper.

INTRODUCTION

SPARX is an evolutionary project proposed by a collaboration among ENEA-INFN-CNR-Universita` di Roma Tor Vergata aiming at the construction of a FEL-SASE X-ray source in the Tor Vergata Campus. The first phase of the SPARX project, funded by Government Agencies with 10 Million Euro plus a preliminary contribution of 2.35 Million Euro by INFN, will be focused on R&D activity on critical components and techniques for future X-ray facilities. A R&D program towards a high brightness photoinjector (SPARC project [1]) is already under way at LNF-INFN. Its aim is the generation of electron beams with ultra-high peak brightness to drive a SASE-FEL experiment at 500 nm, performed with a 14 m long undulator [2]. The R&D plans for the X-ray FEL source will be developed along two lines: (a) use of the SPARC high brightness photo-injector to develop experimental test on RF compression techniques and other beam physics issues, like emittance degradation in magnetic compressors due to CSR, (b) explore production of soft and hard X-rays in a SASE-FEL with harmonic generation, in the so called SPARXINO test facility, upgrading in energy and brightness the existing Frascati 800 MeV Linac at present working as injector for the DAΦNE ϕ-factory (Fig. 1).

Figure 1: View of the Frascati linac

A parallel program will be aimed at the development of other critical component for X-rays FEL sources like high repetition rate S-band gun, high Quantum Efficiency cathodes, high gradient X-band RF accelerating structures and harmonic generation in gas. In the next sections we describe preliminary start to end simulations for the SPARXINO test facility, the required R&D efforts and a possible solution for the DAΦNE linac upgrade.

THE SPARXINO TEST FACILITY

The spectral range from 10 nm to 1 nm, has been considered for the radiation source. In order to generate the SASE-FEL in this wavelength range, it is necessary to produce a high brightness beam to inject inside the undulators. A preliminary analysis of the beam parameters required for such a source leads to the values reported in Tab. 1.

Table 1: Electron beam parameter

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

The basic scheme is shown in Fig. 2 and consits of an advanced high brightness photoinjector followed by a first linac driving the beam up to 350 MeV with the correlated energy spread required to compress it in a following magnetic chicane. The second linac drives the beam up to 1 GeV while damping the correlated energy spread taking profit of the effective contribution of the longitudinal wake fields provided by the S-band accelerating structures.

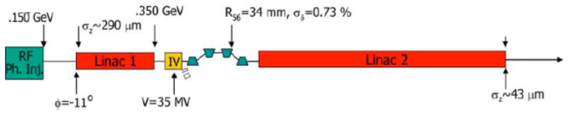

Figure 2: Scheme of the SPARXINO test facility.

A peculiarity of this linac design is the choice to integrate a rectilinear RF compressor in a high brightness photoinjector, as proposed in [3], thus producing a 300-500 A beam in the early stage of the acceleration. The SPARXINO linac will be the first SASE FEL experiment operating with RF and magnetic compressors in the same linac. The potentially dangerous choice to compress the beam at low energy (<150 MeV) when it is still in the space charge dominated regime, results from simulations not too difficult provided a proper emittance compensation technique is adopted [4], a possibility that is not viable in a magnetic chicane. In addition the propagation of a shorter bunch in the first linac reduces the potential emittance degradation caused by transverse wake fields and longitudinal wake fields result to be under control by a proper phasing of the linac. A comparison between the two compression techniques is scheduled during the SPARC phase II operation.

The preliminary design of the injector for the SPARXINO test facility is a copy of the SPARC high brightness photoinjector [1]. It considers a 1 nC bunch 10 ps long (flat top) with 1 mm radius, generated inside a 1.6-cell S-band RF gun of the same type of the BNL-SLAC-UCLA one [5] operating at 120 MV/m peak field equipped with an emittance compensating solenoid. Three standard SLAC 3-m TW structures each one embedded in a solenoid boost the beam up to 150 MeV.

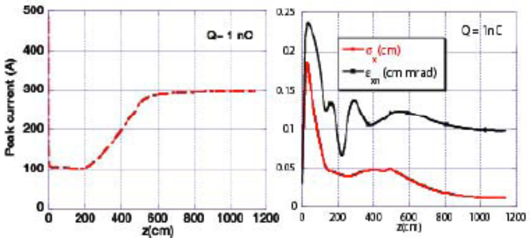

Figure 3: rms current (left), rms norm. emittance and rms beam envelope (right) along the injector, up to 150 MeV.

With a proper setting of the accelerating section phase and solenoids strength it is possible to increase the peak current preserving the beam transverse emittance. In the present case we have got with PARMELA simulation a bunch average current of 300 A with a normalized rms emittance below 1 mm-mrad.

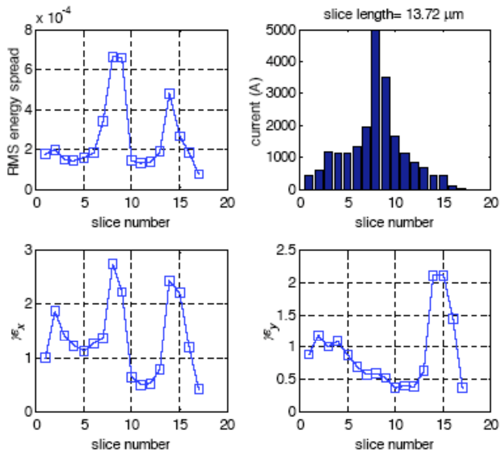

Figure 4: Energy spread, peak current and transverse emittances along the bunch, at the linac exit.

The low compression ratio (a factor 3) has been choosen to keep the longitudinal and transverse emittances as low as possible in order to simplify the second compression stage. We used the first two TW sections as compressor stages in order to achieve a gradual and controlled bunching, the current has to grow at about the same rate of the energy, and we increased the focusing magnetic field during the compression process. Fig. 3 (left) shows the current growth during bunch compression until 150 MeV, envelope and emittance evolution are also reported (right), showing the emittance compensation process driven by the solenoids around the accelerating section that keep the bunch envelope close to an equilibrium size during compression.

The 10k macro-particles beam generated by PARMELA [6] has been propagated through Linac1, Magnetic Compressor and Linac2 with the code ELEGANT [7]. The correlated energy spread induced by Linac1 is 0.7% in order to compress the beam by a factor 6 in the 10 m long magnetic chicane with R_{56} = 34 mm. At the exit of Linac2 the required parameters for FEL operation have been achieved over more than 30% of the bunch length, as shown in Fig. 4. A further improvement is expected by fully optimizing the compression scheme and by using a 4th harmonic cavity [8] for the linearization of the longitudinal phase space distribution

THE SASE FEL SOURCE

Time dependent FEL simulations, performed with the code GENESIS [9] using the particle distributions produced by the Linac simulations presented in the previous section are in progress showing saturation for 30% of bunch slices after 16 m of active undulator length. We assume to use the same undulator of the SPARC project [2] with two additional 2.13 m long modules required to saturate at 10 nm, see Fig. 5. These first preliminary results are encouraging and will be the starting point for further optimizations

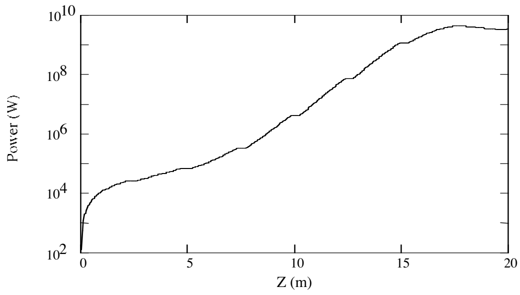

Figure 5: Power vs. z for the 10 nm SPARXINO SASE-FEL source, GENESIS simulation (slice energy spread $8*10^{-4}$, slice norm. emittance 1 mm mrad, slice peak current 2 kA , undulator parameter K=2.2)

DAΦNE LINAC UPGRADE

The DAΦNE injection system is a 60 m long. LINAC equipped with 15 S-band (2.865 GHz) SLAC-type 3 m long accelerating structures driven by four 45 MW klystrons each followed by a SLED peak power doubling system. At present it delivers 0.8 μs RF pulses at a repetition rate of 50 Hz as required for DAΦNE operation. A quadrupole FODO focusing system is distributed along the entire linac. It accelerates the positron bunches emerging by the Positron Converter, up to the maximum energy of 550 MeV and the electron bunches up to 800 MeV. A drift space of about 15 m is available at the linac output for the installation of the undulator.

The Linac energy upgrade to 1 GeV can be achieved, as shown in figure 6, by pushing the accelerating field of the existing units up to 26 MV/m, which is today easily attainable and by adding 2 new SLAC-type sections to reach 1.1 GeV. The Linac waveguide network must also be modified in order to supply two accelerating units per RF station. This system configuration requires two new 45 MW klystrons.

High beam brightness can be achieved by installing a copy of the 12 m long SPARC photoinjector upstream the DAFNE linac with a minor modification of the existing building and a magnetic compressor at 350 MeV in the area of the Positron Converter, thus keeping the possibility to operate the linac as DAΦNE injector. A detailed analysis of the SPARXINO test facility compatibility with the proposed DAΦNE energy upgrade operation is under way [10].

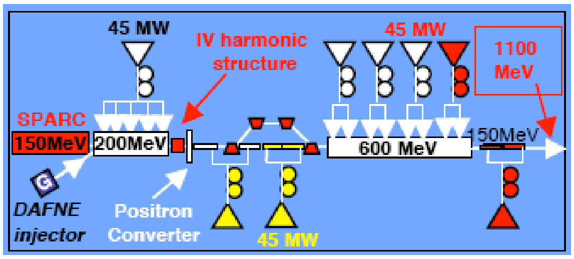

Figure 6:Scheme of the Frascati linac upgrade for SPARXINO and DAΦNE operation. Existing elements (white). Additional SPARXINO elements (red). Additional elements for positron acceleration (yellow).

CONCLUSIONS

The SPARX R&D project has been approved by the Italian Government and funded in June 2004 with a schedule of three years. The critical components for an X-ray FEL source will be tested during phase II of the SPARC project and assembled in a high energy and high brightness linac, the SPARXINO test facility, by upgrading the existing Frascati linac.

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