ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF058

THE MariX SOURCE (MULTIDISCIPLINARY ADVANCED RESEARCH INFRASTRUCTURE WITH X-RAYS)

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Abstract

MariX (Multidisciplinary advanced research infrastructure with X-rays) is a joint project of INFN and University of Milan, aiming at developing a twin X-ray Source of advanced characteristics for the future Scientific Campus of the University of Milan. Presently in its design study phase, it will be built in the post Expo area located in north-west Milan district. The first component of the X-source MariX is BriXS (Bright and compact X-ray Source), a Compton X-ray source based on superconducting cavities technology for the electron beam with energy recirculation and on a laser system in Fabry-Pérot cavity at a repetition rate of 100 MHz, producing 20-180 keV radiation for medical applications. The BriXS accelerator is also serving as injector of a 3.8 GeV superconductive linac, driving a X-ray FEL at 1 MHz, for providing coherent, moderate flux radiation at 0.3-10 KeV at 1 MHz. Scientific case, layout and typical parameters of MariX will be discussed.

INTRODUCTION

MariX (Multidisciplinary advanced research infrastructure with X-rays) is a project of INFN and University of Milan, and has to be constructed at the new scientific campus at the former EXPO site in Milan in the next years.

The joint presence of a Compton source and of an soft and hard X-ray FEL will serve a multitude of users, in many fields of science. The first component of the X-source MariX is BriXS (Bright and compact X-ray Source), a Compton X-ray source based on superconducting cavities technology for the electron beam with energy recirculation and on a laser system in Fabry-Pérot cavity at a repetition rate of 100 MHz, producing 20-100 keV radiation for medical applications.

Few parameters of the Compton source are presented in Table 1, while its characteristics are described in detail in Ref [1] . The BriXS accelerator will also work as injector of a superconductive linac driving a X-ray FEL at 1 MHz, for providing coherent, moderate flux radiation at 0.3-10 KeV at 1 MHz.

In this paper, the scientific case, the layout and the typical parameter of the MariX FEL line will be discussed.

SCIENTIFIC CASE

The MariX FEL project is set up as a FEL in the X-rays range with moderate flux per pulse and high repetition rate.The extremely innovative characteristic of the layout allows to operate with relatively low electron energy, with contained dimension and costs.

Table 2 shows electron and photon energy ranges, number of photons per pulse and per second for MariX and for FELs (operating and projected) in a similar X-ray range.

As can be seen, while the performances of MariX are not competitive as regards the number of photons per pulse at 10 keV, the average flux is instead in the highest range.

Table 1: Parameter and Performance of the Compton Source BriXS

Quantity	Value	Units
Photon energy	20-180	keV
Bandwidth	5	%
Number of photon	$1.5\ 10^{5}$	per shot
Number of photon	$1.5\ 10^{13}$	per second

MACHINE LAYOUT

The machine consists of the injector (BriXS), described in Ref [1], followed by the superconductive accelerator bringing the electron beam at 1.5-1.8 GeV (depending on the cavity gradient). At the exit of the accelerator, an arc compressor is placed [2,3]. The electron beam, after a round turn of 240° retraces the accelerator, gaining another 1.5-1.8 GeV. A delay line permits to change the phase of the electrons between the accelerator and the arc

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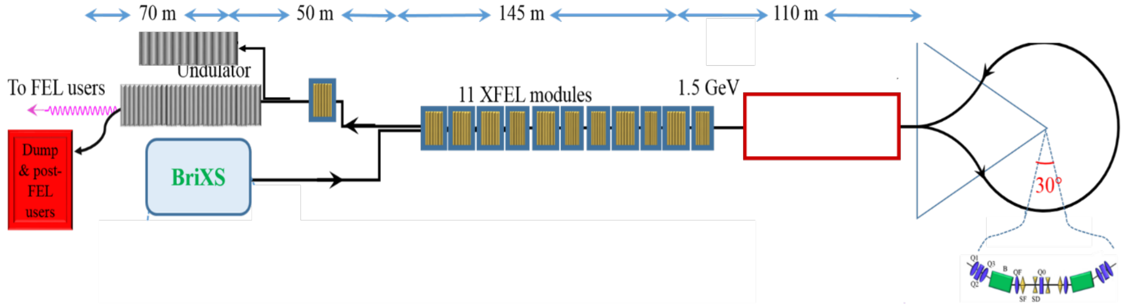

Figure 2: Scheme of MariX.

compressor.

An independent acceleration cavity leads the electron beam to a final energy of 3.2-3.8 GeV. After the acceleration stage, the electron beam is matched to the undulators.

Injector

BriXS [1] (see Fig. 3) is itself a backscattering Compton machine that will drive two X-Ray sources with 100 MeV electron bunches. Furthermore, it will be used as MariX FEL electron beam injector.

BriXS exploits a completely new Energy Recovery Linac (ERL) scheme: two symmetric beam lines, fed from two independent photo injectors, with two coupled ERLs that accelerate and decelerate (recovery) beams in a push-and-pull scheme. In this unconventional scheme, the beams are counter-propagating; bunches coming from guns are accelerated while those coming from the twin ERLs are decelerated and brought simultaneously to a single beam-dump. This scheme permits to drive the Compton X-ray sources with the same degrees of freedom as a linac driven source, in terms of energy and electron beam quality. Furthermore, the coupled ERL fed by two independent RF system is more stable.

A main peculiarity of the whole machine, as shown in Tabs 1 and 2, is the huge X-Ray average flux, connected to the very high electron beam current. Such a high current can be produced by using CW (Continuous Waves) accelerating cavities. BriXS will work at 20 mA, i.e. 200 pC bunches at 100 MHz repetition rate. One BriXS bunch every hundred will be extracted by a fast kicker and injected in the MariX beam line to drive the FEL. This beam will have 50 pC for an average current of 50 mA. These different bunches, 200 pC and 50 pC, will be extracted from the cathode by laser pulses with different intensities and shapes.

The photocathode gun technology is extremely challenging. The most promising set ups at the state of the art are the Cornell DC gun [4] and the RF CW Apex gun [5]. The very high power stored in the BriXS beam, about 2MW (20 mA at 100MeV), cannot be dumped without a beam deceleration, which results by the ERL working mode; first analyses show that our linac should be very similar to the Cornell CBETA cryomodule [6]. The DC gun operates at high voltage (routinely at about 400kV) with a beam energy output of about 300 keV, while the Apex-type RF gun works at a higher accelerating gradient, producing a beam with an energy of about 800 keV. Both photoinjectors confirm the possibility to achieve very good emittance values at the ERL exit, <1mm-mrad, as proved by beam dynamics simulations performed with ASTRA and PARMELA. Both guns are so far good candidates for BriXS.

The superconductive accelerator will bring the electron beam to an energy whose maximum value will be about 1.5-1.8 GeV (depending on the cavity gradient).

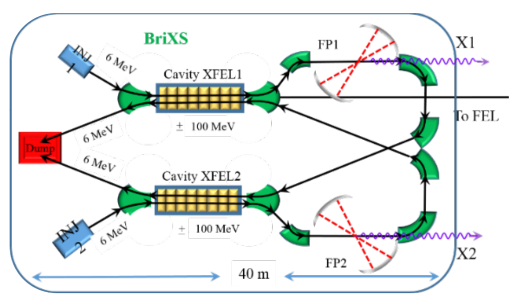

Figure 3: scheme of BriXS.

Arc Compressor

The arc compressor here presented, Figure 2, named bubble arc compressor, represents an extremely innovative layout, able to provide the re-injection of the beam into the booster as well as a high longitudinal compression factor, while preserving the transverse emittance. As it is known, Standing Wave (SW) accelerating cavities, by symmetry, can accelerate in both directions, so the bubble arc compressor gives back the bunches (boosted and compressed) to be re-boosted a second time in the SW linac. During the second boosting, due to the much shorter longitudinal bunch dimension, the energy spread is preserved, as requested by the FEL. It possible to avoid electron bunch collisions inside the linac by properly tuning the inter-bunch distance of about 300 m due to the machine periodicity -1 MHz- with the linac and bubble arc lengths, that together again are about 300 meters.

Coherent Synchrotron Radiation (CSR) effects are nowadays well covered in literature by analytical models and experimental results [7,8]. CSR induces an emittance dilution that strongly limits the final performances of magnetic compressors. The arc compressor is born from a revisiting of a synchrotron achromatic periodic cell, initially thought, at constant bunch length, to preserve the beam quality. The knobs usually used to compensate CSR

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emittance degradation in rings can be successfully used during a strong bunch compression; the key point is a correct setting of the lattice sextupoles, able to fully compensate the CSR chromatic effects.

Table 2: X ray FELs Working Parameters

	E_e, GeV	E_{ph} (Max, keV)	N pulse/ sec	N_{ph} /pulse x 10^{11}	N_{ph}/ sec x 10^{13}
LCLS	14.3	12.8	120	5.7	6.8
SACLA	8.5	17	60	0.05	0.03
PAL	10	12.8	60	0.83	0.5
SwissFEL	17.55.	12.5	100	0.73	0.73
EuXFEL	8	12.4	2.7 10^4	12	3.3 10^3
LCLS_II	15	12.5	10^6	0.7	7 10^3
MariX	3.8	10	10^6	0.05	5 10^2

Undulators

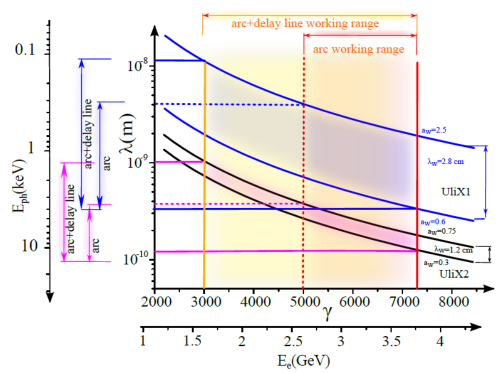

Figure 4: Energy of the photon as a function of the energy of the electrons, for the two undulators.

At this stage of the project, the foreseen undulators are two, of different periods and with variable gaps: a first undulator ULIX 1 (Undulator Light InfraStructure for X-rays 1) with period=2.8 cm and stregth up to a_w=2.5 , 30 meters long, and a second one, ULIX 2, with period 1.2 cm and stregth up to a_w=0.75, with total length of 60 m. The working region of the FEL as function of the electron energy and undulator characteristics is shown in Fig.4.

CHARACTERISTICS, WORKING POINTS AND PERFORMANCES

A summary of some working points, simulated with the FEL radiation code GENESIS 1.3 [10], is presented in Table 3. The properties of the FEL radiation could be summarized as follows :

Energy Range Between 0.1 keV and 10 keV

The access to the energy regime above 5 keV provides resolution and allows the analysis of elements needed for deployment of photocatalysts for fuel production. This regime allows also studies on strong spin-orbit coupling and on the K-edges used for protein crystallography.

Repetition Rate at 1 MHz

The high repetition rate, ultrafast hard X-Rays from MariX will permit to detect rare events with the simultaneous measure of electronic structures and nuclear displacements. Fundamental timescales (femtosecond and longer) and operative regimes requiring hard X-ray penetration and sensitivity of high repetition rate could be analysed.

Temporal Resolution Down to 10 fs

MariX will deliver coherent X-Rays on the fastest timescales. The typical limit for synchrotron sources is ~100 ps, whereas the performance of MariX will be from 200 fs down to 10 fs, coupled to the capability for double pulses with independent control of energy, bandwidth, and timing.

High Temporal Coherence Degree

The sensible bandwidth control could be exploited for high-resolution inelastic X-Ray scattering and spectroscopy in the hard X-Ray range (RIXS and IXS). The actual scientific impact of RIXS and IXS is so far substantially limited by the available spectral flux (ph/s/meV) from temporally incoherent synchrotron sources. The possibility of a seeded mode operation, as well as the use of momochromators, is under study.

Total Spatial Coherence

The high average coherent power of MariX with programmable pulses at high repetition rate, will enable studies of spontaneous ground-state fluctuations and heterogeneity at the atomic scales using the X-Ray photon correlation spectroscopy (XPCS). The non-equilibrium dynamics and fluctuations could be studied via time-domain inelastic X-Ray scattering (FT-IXS) and X-Ray Fourier-transform spectroscopy approaches using Bragg crystal interferometers.

Table 3: Summary of Working Points

Quantity	A	B	C
E_e (GeV)	2.97	3.2	3.8
Q(pC)	50	50	50
λ_w	2.8	1.2	1.2
a_w	2.5	0.75	0.5
λ(nm)	3	0.23	0.17
E_{ph} (keV)	0.41	0.54	7.35
N_{ph}/shot	2 10^{12}	4.6$10^{10}$	2.6$10^{10}$
bw(0.1%)	1	2	1.5
N_{ph}/shot/bw	2$10^{12}$	2.3 10^{12}	1.7$10^{10}$
N/s	3$10^{18}$	2.3 10^{18}	2.6$10^{16}$

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REFERENCES

[1] I. Drebot et al. 'Optimization study of the Fabry-Pérot cavity for the MariX Compton X-ray source', IPAC 2018, MOPAB065

[2] S. Dimitri and M. Cornacchia, "Transverse emittance-preserving arc compressor for high-brihgtness electron beam-based light sources and colliders", *EPL*, vol. 109, p. 62002, March 2015, doi:10.1209/0295-5075/109/62002

[3] S. Dimitri, "Feasibility study of a periodic arc compressor in the presence of coherent synchrotron radiation", *Nuclear Instrumentation and Methods in Physics Research A*, vol. 806, p. 184-192, 2016, doi:10.1016/j.nima.2015.10.015

[4] C. Gulliford, et al. "Demonstration of cathode emittance dominated high bunch charge beams in a DC gun-based photoinjector", Appl. Phys. Lett. 106, 094101 (2015).

[5] F. Sannibale, et al. "Upgrade Options Towards Higher Fields and Beam Energies for Continuous-Wave Room-Temperature Vhf Rf Guns", MOPIK019, Proceedings of IPAC2017, Copenhagen, Denmark.

[6] G. Hoffstaetter, et al. "CBETA Design Report", BNL-114549-3027-IR, CBETA/015b, June 2017.

[7] R. Talman,Physical Review Letters 56 (1986) 1429.

[8] C. C. Hall, et al., Physical Review Special Topics Accelerators and Beams 18 (2015) 030706.

[9] F. Ciocci et al.: Conference: SPIE 9512, Advances in X-ray Free-Electron Lasers Instrumentation III, At Prague, Czech Republic , April 13, 2015, Volume: 9512

[10] S. Reiche, Nucl. Instrum. and Meth. in Phys. Res. A "GENESIS 1.3: a fully 3D time-dependent FEL simulation code" 429, 243 (1999).