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OPTIMISATION STUDY OF THE FABRY-PÉROT OPTICAL CAVITY FOR THE MARIX/BRIXS COMPTON XRAY SOURCE

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Abstract

We present the study of the optimization of the optical cavity parameters, in order to maximise the flux of scattered photons in the Compton scattering process. In the optimisation, we compensate the losses of the photon number due to the elliptical shape of the laser pulse in optical cavity with a high focusing electron beam.

INTRODUCTION

MariX (Multidisciplinary Advanced Research Infrastructure with X-rays) is a project of INFN and University of Milan [1, 2] and has to be constructed at the new scientific campus at the ex-EXPO site in Milan in the next years. The first component of the X-source MARIX is BriXS (Bright and compact X-ray Source), a double Compton X-ray source based on superconductive 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. The BriXS accelerator constitutes then the injector of a superconductive linac which drives a X-ray FEL at 1 MHz, for providing coherent, moderate flux radiation at 0.3-10 KeV at 1 MHz. The joint presence of a Compton source and of an hard and soft X-ray FEL will serve a multitude of users, in many fields of science while its characteristics are described in detail in [2].

A main characteristic of this machine is the very high average current. The double Compton X-ray sources will operate at 100 MHz, with 200 pC electron bunches that means 20 mA. These Compton sources are designed to operate with an electron maximum energy of 100 MeV, which for a 20 mA of current means 2 MW. Such a high beam power cannot be dumped without deceleration, and together with the CW (Continuous Wave) regime, it justifies an ERL (Energy Recovery Linac) machine. Our first analysis is based on a projects like CBETA ERL crymodule [3].

The focus on enabled applications by such an energy range and brilliance is on medical oriented research/investigations, mainly in the radio-diagnostics and radio-therapy fields, exploiting the unique features of monochromatic X-rays, as well as in micro-biological studies, and, within this mainstream, material studies, crystallography and museology for cultural heritage investigations. In this paper, the layout and the typical parameter of the BriXS X-ray source will be discussed.

LAYOUT

The BriXS layout, shown in Fig. 1, consists in two symmetric beam lines, fed from two independent photo injectors, where two symmetric (and coupled) Energy Recovery Linacs (ERL) accelerate the beams. The two ERLs are coupled, accelerating and decelerating (recovery) in a push-and-pull scheme. In this unconventional ERL scheme, beams are counter-propagating and bunches coming from guns are accelerated; those coming from the twins ERLs are decelerated and brought simultaneously to a single beam-dump. This push-and-pull coupled scheme permits to drive two Compton X-ray sources with the same degree of freedom of 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. Partial beam line modifications to host additional Compton source Interaction Points (IP) are still under study. CW electron guns capable to produce 20 mA average beam current, as BriXS needs, are not yet state of the art. Some of the most promising photo cathode guns [4] as the Cornell DC gun [5] and the RF CW Apex gun [6] have been compared by simulations.

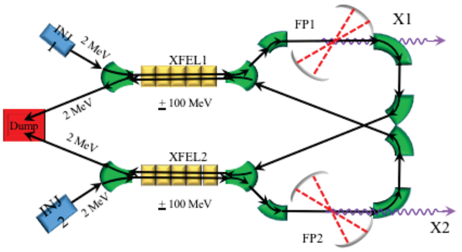

Figure 1: Scheme of BriXS layout.

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ELECTRON BEAM LINE

The beam lines of BriXS are presented in Fig. 2 and comprises: 1) a triplet of quadruples at the exit of superconductive linac matches the beam after the linac to the first dog-leg and permits a quadrupole-scan for emittance diagnostic; 2) chicane (dog-leg) with a 20° angle to make a translation of the beam to the IP region; the electron beam parameters at IP presented in Table 1; 3) the IP line is constituted by a pair a strong focusing quadruple triplets with a quite long distance in order to host Fabry-Pérot Optical Cavity; 4) Double bend achromat (DBA) section with two 90° dipole magnets; 5) long chicane (dog-leg) with a 20° angle to make a translation of the beam to the second superconductive linac.

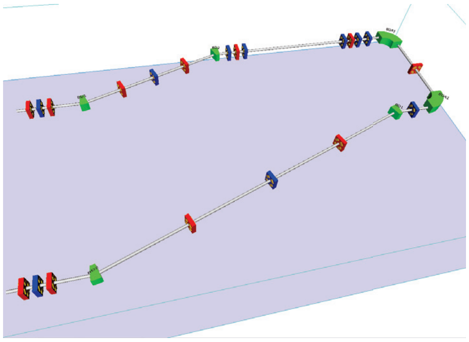

Figure 2: Principle scheme of magnetic elements of BriXS beam line.

The quadruple triplets in the IP region are equal and installed with a mirror symmetry. This structure have identity transport matrix which means that we can use different focusing at IP without modification the other magnetic elements after the IP region.

Table 1: Table of Electron Beam Parameters

Electrons mean energy [MeV]	70-100
Bunch charge [pC]	200
Bunch length rms [μm]	600
Nominal normalized ϵ_{nx}, ϵ_{ny} [mm·mrad]	0.99, 0.99
Nominal relative energy spread σ_e %	0.2
Focal spot size σ_x, σ_y μm	14.9, 14.9
Repetition rate [MHz]	100

LASER SYSTEM

The optical system of MariX is designed to guide both the Compton and the FEL sources with the use of a single laser oscillator. Concerning the Compton source, the laser system delivers the two 100 MHz outputs at 257.5 nm for the two RF-guns and that at 1030 nm for the high finesse cavity. The whole laser is based on Yb-fiber active medium in order to reach the high mean power due to the 100MHz reprate of the system. This system allow for direct pumping with semiconductor lasers at 975 nm, resulting in a high overall efficiency, relatively low cooling requirements, and compact footprint. The output dedicated for the FEL is based on the same technology but the reprate is reduced at 1MHz by a commercial amplitude modulator based on a integrated-optical waveguides Mach-Zender interferometer. In Fig. 3 is showed the scheme of the laser system. The oscillator is a commercial mode-locked Yb-fiber laser that delivers a train of pulses at 100 MHz and 1030 nm. Than we have three amplifier systems respectively dedicated to the high finesse cavity, the two RF-guns for the Compton, and the line for the FEL system that drive one of the two RF-guns. The amplifiers are based on the CPA (chiperd pulse amplification) scheme. The stretcher and the compressor are made by two CVBG (chirped volume Bragg grating) devices and the gain medium is based on a LMA (large mode area) fiber doped with Yb. With this scheme it is possible to reach the required mean power of 200 W with very high stability. The fiber technology, beside the thermal advantages, allows to obtain both optimal spatial quality and pointing stability, and this is of fundamental importance to coupling efficiently the high finesse cavity and to drive the RF-guns. In order to generate the electron bunches by photoemission the amplified radiation is upconverted up to the 4th harmonic (257.5 nm) by two nonlinear crystals, one LBO crystal in non-critical phase matching configuration, and a couple of CLBO crystals. Both the temporal and the spatial shaping of the laser pulse are implemented in order to reach the minimum level of the emittance in the electron bunches. The temporal shaping is obtained by the stacking method [7] with three alpha-BBO crystals and the spatial shaping is based on a commercial pi-shaper device and an imaging system. The reprate of the laser oscillator is stabilized respect to an external reference by a feedback system. In the case of the Compton the external reference could be an RF reference, but in the case of a pump and probe experiment with the FEL system, due to the demand of a timing at fs level [8], we need to stabilize the laser by a balanced cross correlator [8] with respect to an optical master oscillator. A second feedback system is needed in order to stabilize the high finesse cavity with respect to the laser oscillator. This second feedback is based on the PDH (Pound Drevel Hall) [9] method and a f2f system [10]. The first one is exploited in order to stabilize the reprate of the high finesse cavity, an the second one in order to remove the carrier-envelop-offset from the oscillator spectral comb and in turn to superimpose the oscillator spectral comb with that of the cavity.

HIGH FINESSE CAVITY

The high finesse cavity we are planing to use for the Compton is a 4 mirrors bow-tie cavity in the crossed configuration (see Fig. 4).

The mirrors M1, M4 are plane, and the mirrors M2 and M3 are concave with a radius of curvature of 750 mm. This kind of cavity allows to obtain a very high mechanical stability, an also provides high flexibility for the adjustments of the cavity round trip frequency (witch must be matched to that

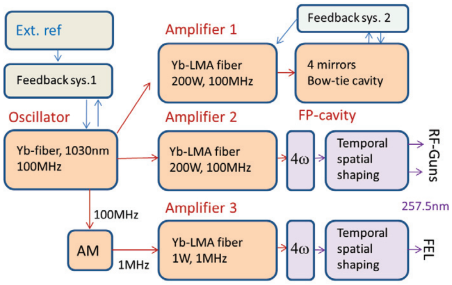

Figure 3: laser fig 1.

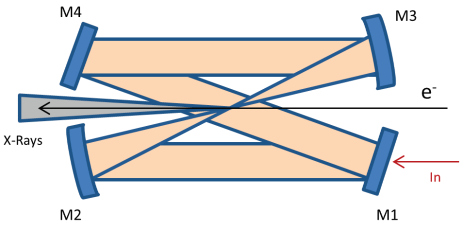

Figure 4: laser fig 2.

of the electrons, that is fixed at 100 MHz) and the laser beam waist. Indeed, it turns out that a length variation between the two flat mirrors changes the cavity round trip length without changing noticeably the laser beam waist. The laser beam waist can thus be set by tuning the distance between the two spherical mirrors independently of the cavity round-trip length. Moreover when this cavity operates near the edge of the confocal configuration we obtain at the same time the minimum dimension in the focal point and the maximum dimension on all the 4 mirrors allowing the working at the very high mean power required for the Compton, staying below the damage threshold of the mirrors. We plain to inject the cavity with 200 W in order to obtain an internal mean power of 500 kW by a gain factor of 2500. In order to minimize the thermal deformation [11], and in turn the variation of the mirrors radius of curvature, the substrate of the mirrors M2, M3, M4 is made of ULE (ultra low expansion material) and that of the M1 mirror of Sapphire to transmit efficiently the input beam. Due to the mirrors encumbrance the collision angle will be around 7 degree and this introduces an ellipticity in the cavity as function of spatial shift δH between two curved mirrors mode as showed in the Fig. 5. due to the incidence angle on the curved mirrors.

Table 2: Table of Laser Parameters

Laser pulse energy (mJ)	5
Laser pulse length [$psec$]	2
Laser focal spot size w0 RMS [μm]	50
Laser papameter α_0	0.2
Collision angle [deg]	7-10

RADIATION SPECTRA

The number of scattered photons (flux) depends on the transverse size of interacting beams. Due to the fact the laser spot size in the waist has an elliptical profile, we try to focus as much as possible the electron beam at IP with a round or a similar elliptical profile. Results of simulations are presented in Fig. 5. One of the main goal of this study is that electron beam with $\sigma_x = 25\ \mu m$, $\sigma_y = 15\ \mu m$ has almost the same flux as $\sigma_x = 15\ \mu m$, $\sigma_y = 15\ \mu m$. It means that we can have not so strong focusing in the horizontal dimension of electron beam at IP obtaining the same number of scattered photons.

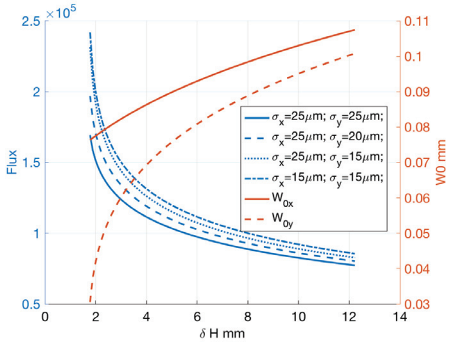

Figure 5: (Blue) Photon flux as function of spatial shift δH between two curved mirrors. (Red) Laser waists as function of δH.

Compton back scattering radiation has energy angular distribution. This quantity make possible to get a monochromatic radiation by using a collimator. The parameters of the scattered radiadion are presented in Table 3.

Table 3: Table of Photon Parameters

Peak spectrum [keV]	88
Mean spectrum [keV]	85
Collimation angle θ_{max} [μrad]	2.9
Bandwidth [keV]	4.3
Bandwidth %	5
# photons per shot N_{ph_tot}	1.5 10^5
# photons per shot after collimation N_{ph}	2.7 10^4
Source rms divergence θ_{RMS} [mrad]	1.94 10^3
Spot Size at 10 m [mm]	14.3, 13.1
Rad. pulse length $\sigma_{\gamma z}$ [psec]	1.49

CONCLUSION

In this paper conceptual design study are presented. We have demonstrated that optimizing a focusing triplet get an elliptical electron spot profile. Using elliptical profile we are in profit.

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