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OVERVIEW OF THE SOFT X-RAY LINE ATHOS AT SwissFEL

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Abstract

SwissFEL Athos line [1] will cover the photon energy range from 250 to 1900 eV and will operate in parallel to the hard X ray line Aramis. Athos consists of a fast kicker magnet, a dog leg transfer line, a small linac and 16 APPLE undulators. The Athos undulators follow a new design: the so called APPLE X design where the 4 magnet arrays can be moved radially in a symmetric way. Besides mechanical advantages of such a symmetric distribution of forces, this design allows for easy photon energy scans at a constant polarization or for the generation of transverse magnetic gradients. Another particularity of the Athos FEL line is the inclusion of a short magnetic chicane between every undulator segment. These chicanes will allow the FEL to operate in optical klystron mode, high brightness SASE mode, or superradiance mode. A larger delay chicane will split the Athos line into two sections such that two colors can be produced with adjustable delay. Finally a post undulator transverse deflecting cavity will be the key tool for the commissioning of the FEL modes. The project started in 2017 is expected to be completed by the end of 2020.

INTRODUCTION

Athos photon energy ranges from 250 eV to 1900 eV (or 6.5 – 49 Å) (Fig. 1) when assuming a maximum K value of 3.65. Such large range requires both a K variation and an electron energy variation. The electron energy at extraction point (270 m downstream electron source, Fig. 2) can be varied between 2.9 and 3.15 GeV. In addition, a small linac in the Athos branch can extend the beam energy range to 2.65 – 3.4 GeV.

The Athos undulator line is linked to the main linac of SwissFEL via a dogleg section (see Fig. 2). The SwissFEL injector will produce two bunches with 28 ns delay. The dogleg starts with the beam switching system, consisting of two kickers and three compensating dipoles. These kickers deflect the second beam vertically up by 1.75 mrad so that it enters a Lambertson septum magnets 10 mm above the Aramis axis [2]. The septum magnet deflects then the Athos bunch by 35 mrad horizontally. Kickers and septum deflecting angle must be very stable from bunch to bunch and a jitter of less than 0.3 µrad is expected. The rest of the dogleg should then close the vertical dispersion, collimate the beam in energy, compensate possible CSR kicks, align the beam tilt and energy acceptance by means of sextupoles and finally inject back the beam in the Athos undulator line parallel to the Aramis line at 3.75 m distance (Fig. 3). Downstream the dogleg, the beam can be accelerated / decelerated by four C-band structures (+/- 250 MeV) followed by diagnostics (screens, wire scanner, beam arrival monitor) to characterize the beam before entering the undulator section. Sixteen undulator segments are distributed in a FODO period of 5.6 m length. Finally an X band deflecting transverse cavity [3] will be installed before the beam dump allowing a permanent monitoring of the electron energy loss when lasing [4] or to measure the slice emittance.

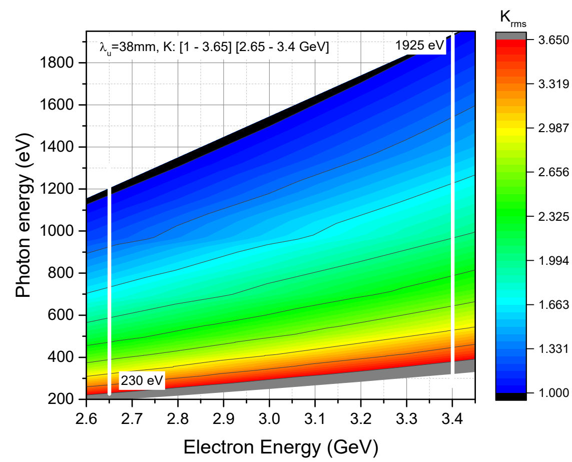

Figure 1: Photon energy range covered by the Athos FEL line (SIMPLEX [5]).

The Athos branch of SwissFEL is designed to operate in various modes of operation slightly different to standard SASE operation. The particularity of the Athos FEL lies in the permanent magnet chicanes present between every undulator segment. These chicanes allow operation in the optical klystron mode in which the microbunching process is speed up [6]. To generate terawatt – attosecond FEL pulses, a transversely tilted beam can also be shifted and delayed between every undulator segment thanks to the chicanes. In this mode, only a small portion of the beam is on the lasing trajectory and fresh electrons are supplied after a beam portion saturates [7]. The same chicanes can also be used to simply delay the bunch (without transverse shift) such that a given radiation slice (spike) will slip over a longer portion of the bunch and increase the cooperation length. This corresponds to the so called high-brightness mode [8,9] or purified SASE mode [10]. A larger magnetic chicane (2 meters length), with electromagnets, placed after the 8th undulator segment, will give the possibility to split the line and to generate two colors with adjustable time delay (0 to 500 fs). The Apple X undulator design can easily produce a transverse gradient which when used with a transversely tilted beam can produce a broadband FEL radiation of up to 10% bandwidth.

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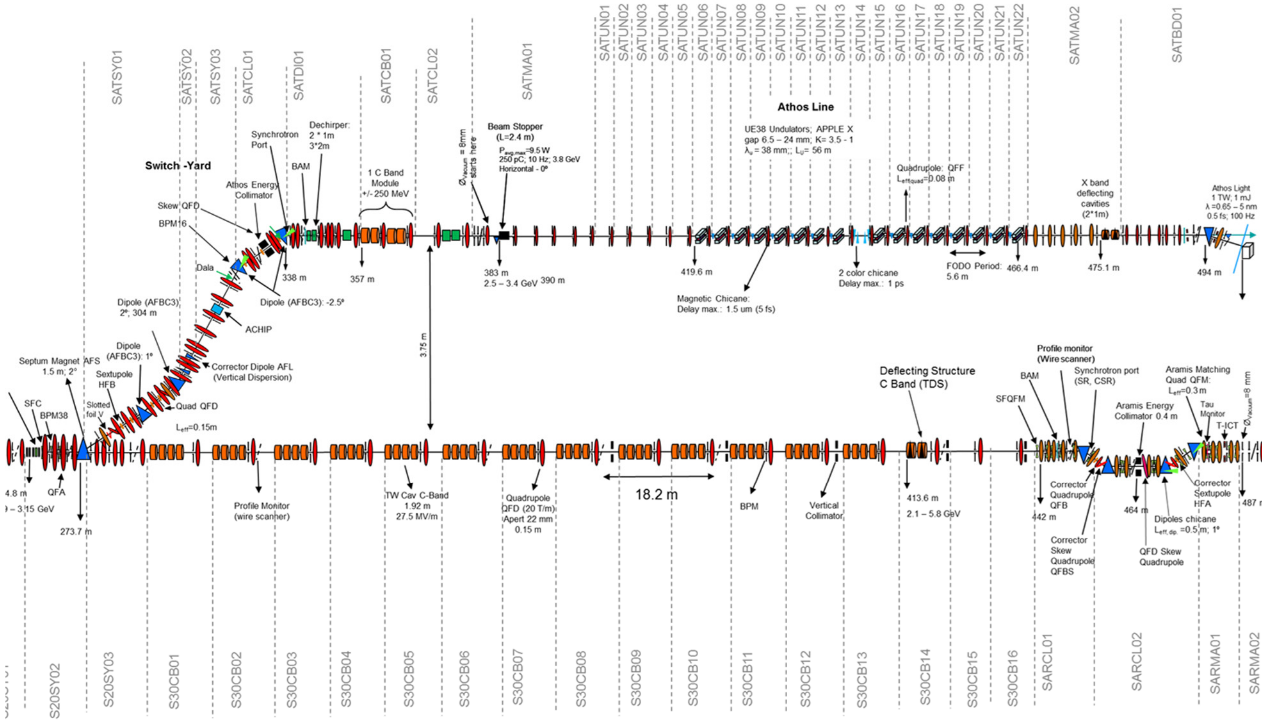

Figure 2: Layout of the Athos FEL line with the main electron beam components going from z ~270m to z~500m (electron source photocathode is at z~0m). Athos is parallel to the linac 3 of SwissFEL.

Figure 3: View of the SwissFEL tunnel with the linac 3 towards Aramis on the right and the footprint of the future Athos undulator line on the left.

ELECTRON BEAM KEY COMPONENTS

As mentioned in the introduction, beam quality corrections are foreseen in the dogleg section before entering the Athos line which is parallel to Aramis. For example, the residual beam energy chirp after bunch compressor 2 will be removed with dechirper systems.

Dechirper

The Athos dechirper consists of two adjustable (vertically and horizontally) dechirper units of one meter length each and a nominal gap of 2.5 mm followed by 3 long units of 2 meters length. The long dechirpers have a square section with a fixed aperture of 2.5 mm. In the adjustable dechirper, two parallel corrugated structures (like gratings) are used to control the wakefields generated by the beam. By properly selecting the gap and the geometry of the structure it is possible to compensate the residual energy chirp left after bunch compressor 2. The short dechirpers are shown in Figure 4. Only the gap / slit and a transverse vertical / horizontal shift can be remotely controlled. Three different corrugation geometries are available and each can be manually translated into the beam axis (during shutdown). Indeed the short dechirper units will first be used in 2018 for various test of beam manipulation on the fs time scale like deflection or dechirping [11].

Apple X Undulator UE38

The undulator segments of the Athos line have a period of 38 mm with permanent magnet situated outside vacuum. These undulators are built in the so called Apple X configuration where X comes from the possibility to move each magnet arrays radially at 45 degrees angle (see Fig. 5). In this symmetric design, gap and slit can be open simultaneously keeping the horizontal and vertical forces identical. In addition each magnet array can be moved longitudinally in order to change the polarisation from circular to linear or inclined linear. In other words, the polarisation control (shift change) is independent of the photon energy control (radial gap change). Another possible feature is to open only the left gap (or the right gap) so that the electron beam sees a transverse magnetic gradient. This offers new operation possibilities like lasing with a large bandwidth beam [12]. Permanent magnets are hold in a flexible support where the position height of each half period can be adjusted to the sub micrometer level by moving a small wedge (Fig. 5). The wedge-

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screw will later be automatically adjusted by a robot according to the magnetic field measured at that particular location [13].

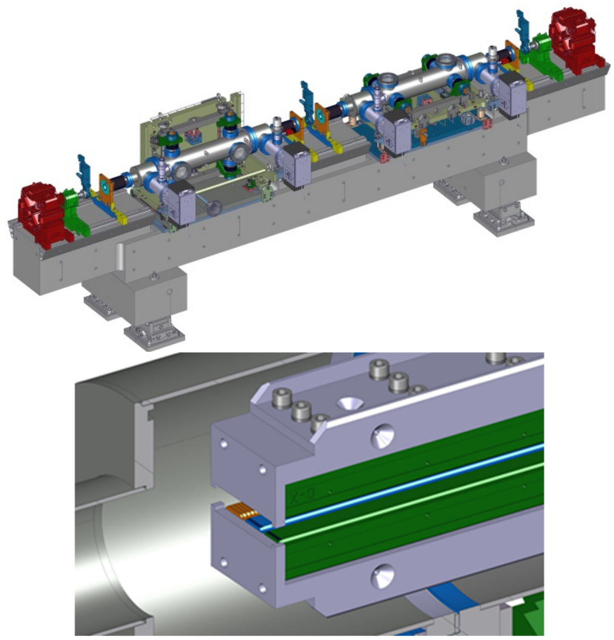

Figure 4: The vertically and horizontally adjustable dechirper on a girder (Top) Three different corrugation geometries can be installed and aligned on the axis.

Samarium cobalt will be used for the magnets since it has a permeability closer to one than NdFeB and thus less nonlinear effects. This is an important parameter for Apple undulator where the magnet field profile changes with each polarisation. Hysteresis in the magnet field leads to error in the polarisation and /or photon energy prediction. In order to boost the magnetic field near the apex of the "spade" magnets, tests of non-uniform magnetisation is currently performed by Arnold Magnetics and PSI [14]. The vacuum chamber will be produced by galvanic techniques such that the inner vacuum chamber will be 5 mm for 0.2 mm wall thickness and a minimum UE38 aperture of 6 mm.

Permanent Magnet Chicane

Most of the operation modes of Athos rely on the magnetic chicanes which will be installed between every UE38 segment. The chicane will be capable to delay the electrons by up to 8 fs (2.5 µm longitudinal delay) or to shift the beam transversally up to 350 µm. Also a combination of 5 fs (1.5 µm) delay together with a 250 µm shift will be possible. This requires however a very strong magnetic field of 2.5 T and the possibility to control each half of the chicane separately. This is achieved with the design presented in Fig. 6 where 4 motors can control the two halves of the chicane. The chicane has a magnetic length of 200 mm and a minimum gap of 6 mm. Each magnet block is an assembly of several small magnets surrounding one pole to maximize the field above this pole. The chicane should also be used as normal phase shifter when operating in normal SASE mode. In this case, the electron beam is longitudinally delayed by less than 10 nm corresponding to a chicane gap of roughly 9 mm.

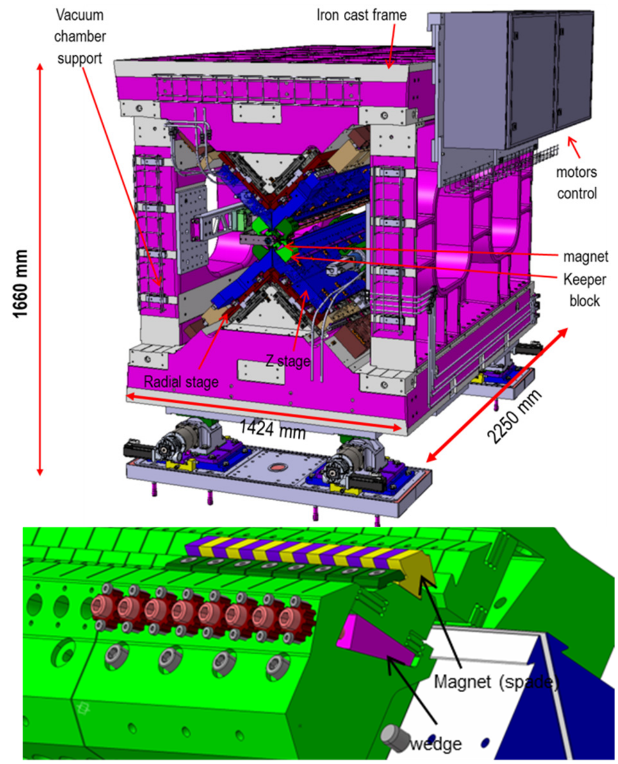

Figure 5: Apple X undulator where magnet arrays move radially along a 45-degree angle (top). Magnet keeper adjustable to sub-micrometer level (bottom).

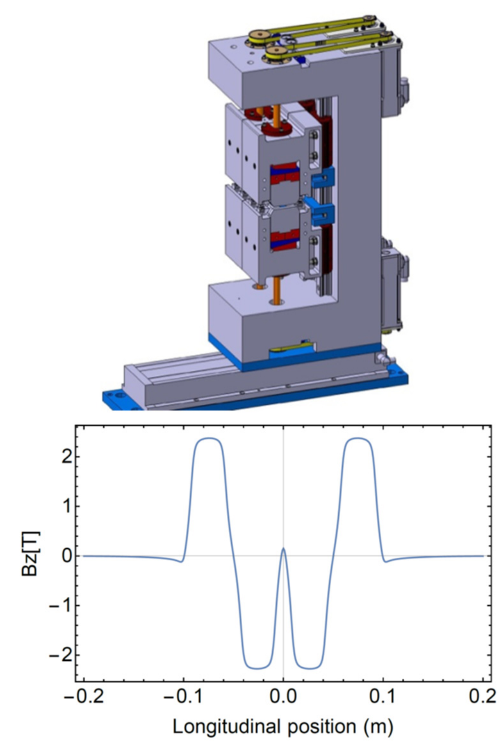

Figure 6: Magnetic chicane to shift and / or delay the electrons between every undulator segment (top) and magnetic field profile along the chicane axis (bottom).

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OPTICAL LAYOUT AND ENDSTATIONS

Due to the variety of the operation modes, the X ray optical component have to cope with a large range of photon beam properties. Three beamlines are foreseen for photon energies going from 170 eV to 2000 eV (see Fig. 7). To be compatible with the spatial requirements at other synchrotron facilities, especially the SLS, the height above the floor should be approximately 1400 mm at the location of the experiments. The beamline thus transports the beam from 1200 mm height at the exit of the undulator to the required 1400 mm at the experimental stations. The three endstations will share a common monochromator. The beam transport to a height of 1400 mm above floor is accomplished by operating the grating at a higher deflection angle as the subsequent plan mirror.

The changeover from monochromatized to pink beam operation is accomplished by a roll rotation of the first mirror and a translation of the second mirror out of the beam. The photon beam divergence is varying from 5 urad to 40 urad depending on the photon energy and the mode of operation. Whenever possible, the beam transport system should accept the whole FEL beam, i.e. five times the rms-value of the beam cross section.

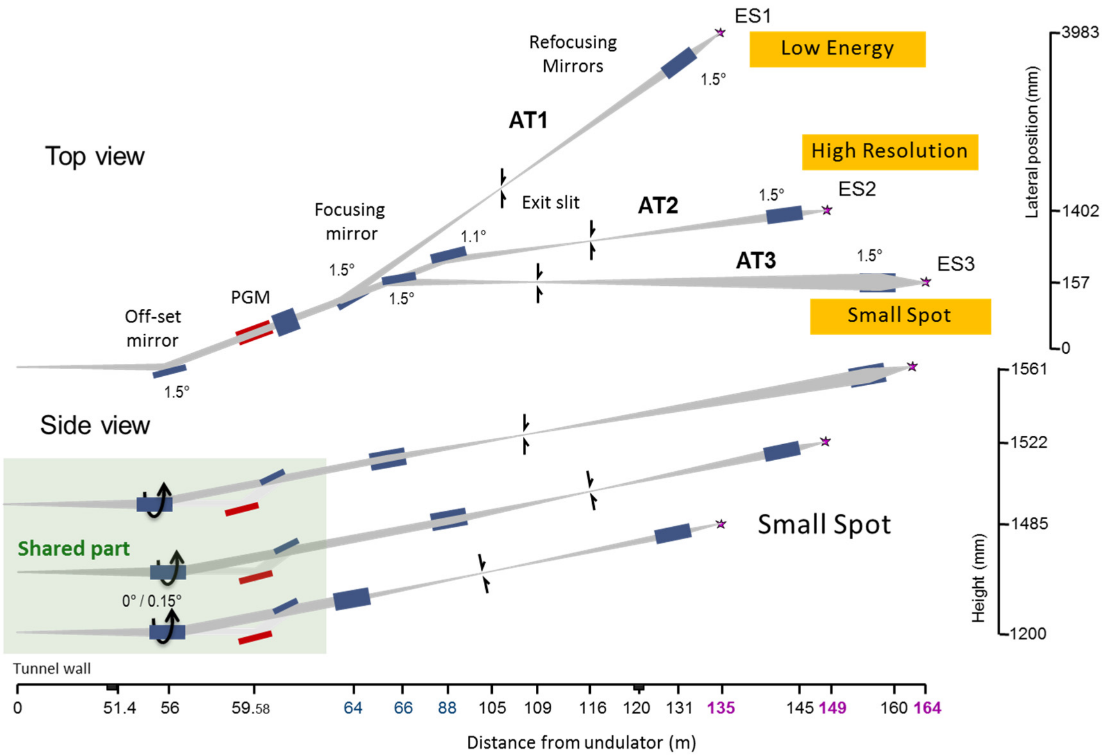

Figure 7: Optical layout of the 3 Athos photon beamlines.

The endstations are all located in the same large experimental hall for maximum flexibility. The specialty of each end station is still under discussion but as it is shown on Figure 7, ES1 should focused more on experiment using low energy photons like in catalysis and biochemistry studies. ES2 should allow higher photon energy resolution which is more suited for spectroscopy of correlated electron systems or ultrafast magnetisation dynamics. ES3 would be dedicate to experiment requiring tight focussing.

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