

THE ELETTRA 2.0 PROJECT STATUS

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Abstract

After 31 years of serving the user community with excellent results, on July 2nd 2025 the removal of the Italian third generation synchrotron light source Elettra (www.elettra.eu) will start to be replaced by Elettra 2.0 a fourth-generation one. The project is in full development and, being a diffraction limited light source, Elettra 2.0 will provide ultra-high brilliance and coherence to the experiments while at the same time the machine is designed to provide very short pulses for time resolved experiments. The project status and its possibilities will be presented and discussed.

INTRODUCTION

Elettra 2.0 is a cutting-edge upgrade of the existing Elettra synchrotron light source facility with the aim to position it as one of the most advanced research infrastructures worldwide devoted to supporting a wide range of scientific fields. From advanced materials science to biology and medical applications, the new facility will provide researchers with access to vastly enhanced high-resolution imaging and spectroscopic capabilities. This project aims to significantly enhance the scientific output of the facility by upgrading the accelerator and beamline systems to meet the growing demands of scientific and industrial users.

OVERVIEW

Elettra 2.0 features several critical technological advancements that distinguish it from its predecessor:

1. **Storage Ring Upgrade:** The core of the Elettra 2.0 project is the replacement of the existing storage ring with a new low-emittance ring. This will significantly reduce the present beam emittance by a factor of 50, resulting in a photon source with higher brilliance and coherence. The storage ring will also include 2 superconducting bending magnets that will enhance production of photons with energy above 60 keV enabling in vitro imaging for high resolution morphological studies and clinical application to human patients. The design is compatible with providing in the future simultaneously short pulses of approximately 1 ps using superconducting deflecting rf cavities for time-resolved experiments requiring high repetition rate and standard single bunch charge, while preserving the transverse coherence

2. **Beamline Enhancements:** Elettra 2.0 will introduce new beamlines and upgrade existing ones to fully exploit the features of the upgraded storage ring. New beamlines will include several ones specifically designed for:

Advanced Spectroscopy: Enhanced capabilities in X-ray absorption spectroscopy, photoemission spectroscopy, and

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high-resolution diffraction will allow detailed analysis of material and electronic properties.

Coherent Diffraction Imaging: This technique will be expanded to provide higher-resolution 3D imaging, which is crucial for biological systems and advanced materials research.

Time-resolved Experiments: Enhanced ability to capture ultrafast processes will open new possibilities in studying dynamic systems such as chemical reactions and phase transitions in materials.

The new capabilities of Elettra 2.0 will enable transformative research in several scientific and industrial fields:

Nanotechnology and Materials Science: With enhanced resolution and imaging capabilities, Elettra 2.0 will foster innovations in nanomaterials, including the development of stronger, lighter, and more efficient materials for a variety of applications.

Quantum Materials: Elettra 2.0 will offer enhanced tools for studying quantum phenomena at high resolution, supporting the development of future quantum technologies.

Pharmaceuticals and Health Sciences: Enhanced imaging and spectroscopy techniques will aid drug discovery and development, particularly in understanding biological processes at the molecular level.

The Elettra 2.0 upgrade follows a well-defined project schedule, with several major milestones:

Decommissioning of the Current Storage Ring: This phase is scheduled to begin in July 2025, with completion expected by December 2025.

Installation of the New Storage Ring: The new storage ring installation will commence in September 2025, with completion expected by August 2026. This will include the assembly of magnets, RF, vacuum chambers, diagnostics and other critical components.

Beam Commissioning and User-mode Operations: Commissioning with beam is scheduled to start on September 15, 2026. Beamline commissioning will commence on November 15, 2026 in parallel with ring commissioning, to ensure that all systems are fully integrated and ready for user-mode operation. By January 2027, the new ring and an initial set of 15 beamlines will be fully operational and available to researchers.

Full Beamline Set: the number of beamlines available to users will be gradually increased to the final portfolio of 32 beamlines at the end of the project in 2029.

MACHINE DESCRIPTION

The enhanced symmetric six bend achromat (S6BA-E) lattice (Fig. 1) has specially been designed to meet all experiment / user requirements [1-11]. The ring has a total length equal to that of the present Elettra, i.e. 259.2 m, and

is made of 24 symmetric arcs, 12 long straights and 12 short straight sections, with a 12-fold symmetry. Each arc consists of 3-unit cells of the TME (theoretical minimum emittance) type i.e. :

- 3 dipoles, of which one at 0.8 T with vertical field gradient and two with combined transverse (< 22 T/m), and longitudinal gradient (1 and 1.46 T) (Fig. 2)
- 7 quadrupoles (< 50 T/m) four of which are shifted at 5.16 mm to give the required reverse-bend angle of -0.4 deg each
- 10 combined sextupoles (< 4500 T/m²) (4 with correctors, 2 harmonic with correctors and 2 with skew quadrupole coils)
- 1 combined multipole (octupoles with corrector coils)
- 1 combined multipole (octupole with quadrupole coils)
- 1 pure corrector
- 3 correctors coils for fast orbit correction, cutoff at 6 kHz

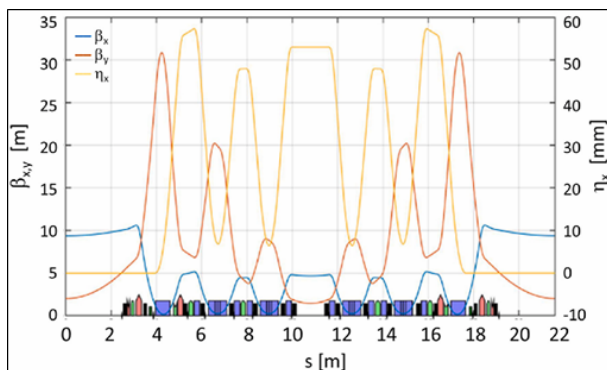


Figure 1: Elettra 2.0 S6BA-E lattice.

The working point is (33.25-33.27, 9.15-9.4) and the natural normalized chromaticity (-71 , -68) corrected to $+2$ for both planes. The two arcs are separated in the middle by a short straight section of 1.26 m free space. Those twelve spaces will be used for installing the rf cavities (4), for instrumentation (3) and for short undulators or wigglers (5). The free useful space of the long straights connecting the sections is 4.85 m long and it is dedicated to insertion devices (IDs) and to the feedbacks.

The total number of magnets is 552 with 192 corrector coils. For the fast correction (fast orbit feedback) 72 additional coils (6 per achromat) will be used. For the orbit control there are 14 BPMs (Beam Position Monitors)/achromat for a total of 168 with additional 4 BPMs for other uses [12-13].

The magnets [14] are specially designed with no protruding coils in the dipoles and quadrupoles. All magnets are independently powered, measured on site [15] and are mostly water cooled. The construction of the magnets is in course and the delivery has already started.

The vacuum chamber is rhomboidal with 17x27 mm internal dimensions. It is mainly made out of copper with some parts in aluminum (long straights) and also stainless steel (chambers in the dipoles). Most parts of the chamber

will be covered with 250 nm NEG (Non-Evaporable Getter) on the average [16].



Figure 2: The B80 magnet.

The power supplies [17] are reduced into 3 families for redundancy and simplicity. There are 74 unipolar 300 A for the dipoles, 504 bipolar 100 A for the multipoles and 676 bipolar 25 A for the correctors. The delivery of all types of power supplies has started and well advanced.

The same injector, consisting of a 100 MeV linac, a 2.5 GeV booster and a booster to storage ring transfer line, will be used also in Elettra 2.0. An injector upgrade program is running [18]. Due to the large dimensions of the beam coming from the booster (140 nm rad at 2.4 GeV) no pulsed multipole can be employed and the injection scheme will be similar to the present machine, i.e. off axis injection with a beam separation of 4 mm. The injection will be performed using the emittance swap technique having an efficiency of 97%.

For the RF system [19], the four Elettra 500 MHz RF cavities presently in operation will be re-used. Each cavity will be installed in a short straight section and each one will be powered by a 130 kW solid state amplifier (SSA). All SSAs are already installed and in operation.

SOME MACHINE PHYSICS DETAILS

The dynamic aperture (DA) including all (errors, chambers, IDs) [20] is about ± 6 mm horizontally and ± 2 mm vertically permitting off axis injection and at the same time permitting the tilted bunches (in case of installing crab cavities) having a vertical projection of ± 1.2 mm.

A passive superconductive third harmonic cavity (S-3HC) lengthens the bunch for stability and lifetime. The intra-beam scattering without the effect of the S-3HC at 400 mA will increase the emittance from 212 to 275 pm-rad (30% increase) while, including the effect of the S-3HC, the emittance will increase to 235 pm-rad (11% increase).

The impedance budget is comparable to that of the present machine, being about 0.85 Ohm longitudinal (about 0.24 Ohm effective) and 564 kOhm/m transverse giving a tune shift of about -0.8 kHz/mA (Elettra has -0.6 kHz/mA).

The single bunch microwave threshold is about 2.5 mA when CSR (Coherent Synchrotron Radiation) is included

and the TMC (Transverse Mode Coupling threshold) results at about 4 mA. Detailed studies have been performed and still are ongoing for exact impedance estimations and instability thresholds using different simulation programs [21-25].

The total longitudinal loss factor when the effect of the third harmonic cavity is included, is 13.5 V/pC giving a parasitic power loss of 4.7 kW with 400 mA.

The average Touschek lifetime, including errors and all, is about 4 h with 1 mA/bunch, 2 MV total rf voltage and 5% coupling, while including the effect of S-3HC it becomes 12 h for a factor of three bunch lengthening resulting from an exact study of the transient beam loading effects [26], using a code developed and calibrated on the present machine.

FURTHER DETAILS

The 3-D detailed design including all insertion devices and front ends is completed and frozen. In Fig. 3 the view of an achromat is shown together with the girder configuration [27].

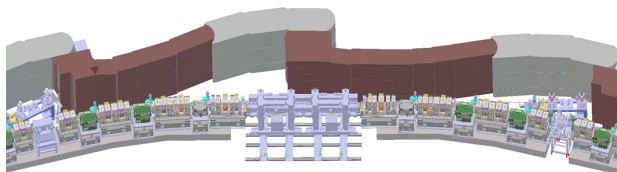


Figure 3: 3D view of an achromat with IDs (long and short) a rf cavity and a front end.

Elettra 2.0 will serve up to 32 beamlines. Many of the already existing ones will be upgraded. In general 12 beamlines will keep their present position, 9 beam lines will be moved from their present position and 11 will be new. Amongst the new beamlines, there is a coherent diffraction imaging (CDI) and three new micro-spot beam lines that the present machine cannot support.

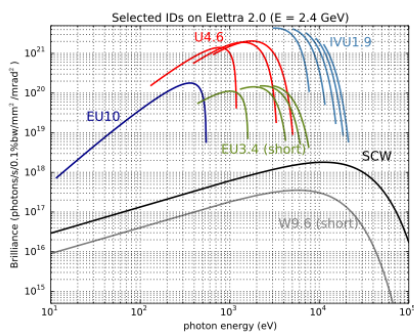


Figure 4: Old and new IDs brilliance.

To meet the requested performance, in-vacuum undulators (IVU) of 5 mm aperture will be installed and provide the 7th, 9th, 11th and 13th harmonics with the required flux of 10^{14} ph/s/0.1%bw on the sample and energy range, while the brilliance is $> 10^{21}$ ph/s/mm²/mrad²/0.1% BW (Fig. 4) at 10 keV.

We intend to reuse some already existing IDs including the super conducting 3.5 T wiggler. Also short IDs i.e. 2 mini wigglers and 3 undulators will be installed in the

short straight sections. The short IDs are already in production [28].

The hard X-ray imaging (life and material science) requires 10^{13} ph/s at above 50 keV and can be satisfied using two super-bends (SB) [29] with peak field at 6 T.

Regarding the short pulse option, the use of crab cavities will allow both long pulses at 400 mA for the majority of the users plus short photon pulses of few tilted bunches for the beamlines that request time resolved capability [30, 31].

In Fig. 5 the shortest photon pulse duration and single pulse relative flux are summarized, for 10 keV photon energy. DR and IM mean drift optics and imaging optics respectively. For many beamlines the pulse durations is ≤ 3.5 ps fwhm. The minimum slit half-aperture is 5 μ m in drift mode and 2 μ m in imaging mode.

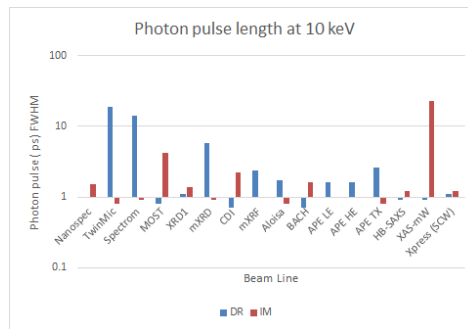


Figure 5: Pulse length at each beamline.

The project organization is well structured and is divided mainly into 5 areas dedicated to machine, beam lines, infrastructures, executive management and removal and installations, the latter being an area of particular importance due to the fact that the new machine and most beamlines will replace the old ones presently installed [32, 33]. Already two temporary buildings are constructed: one to store the old machine components and the other one to provide space for the assembly of the new machine and beamlines. A very detailed scheduling of all activities has been developed including detailed activities for the removal and installation works.

Elettra 2.0 will consume about 20 % less energy than the present machine. Future measures to reduce the CO₂ footprint include getting energy from renewable sources (already looking for implementing a photovoltaic plant) and also reducing consumption by using permanent magnets (a task that initially is impossible due to the requirement of two operating energies for some years).

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