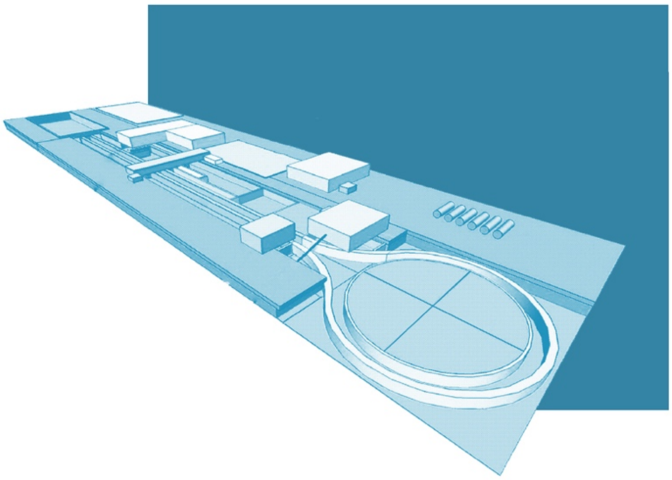
Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DEGLI STUDI DI MILANO



MariX

Multi-disciplinary Advanced Research Infrastructure for the generation and application of X-rays

An ultra-fast X-ray probe for atomic matter, ultra-precise for organic tissues

Foreword

MariX is a research infrastructure optimized for matter analysis carried out using techniques based on coherent X-ray diffusion and photo-electric effect, with a temporal resolution at the femtosecond level and MHz-class pulse repetition rate.

X-rays are the main probe to investigate the fine structure of matter, thanks to their characteristic interaction that allows high energy resolution, imaging with large structural contrast from nanometric to macroscopic scale as typically requested by bio-medical applications. The production of X-ray beams has achieved large efficiencies thanks to electron accelerator machines, either in the storage ring configuration of synchrotron light sources, capable to generate pulses with duration down to 10^{-11} s and repetition rates up to 500 MHz, or in the Linac configuration with Free Electron Lasers, achieving ultra high brilliances (up to 9 orders of magnitude larger than synchrotron light) together with ultra-fast pulses ($<10^{-14}$ s) and repetition rates within the 10 Hz - 10 kHz range.

Present X-ray sources in operation, or under construction, are not optimized for ultra-fast spectroscopy, since either the radiation pulses are not temporally short enough to follow the excitation and disexcitation of matter and its ordered configurations (electronic, magnetic and superconducting properties), yet with good energy resolution, polarization control and in linear regime with very large rep rate to quickly accumulate good statistics, or they are exceedingly intensive in the single pulse (10^{10}-10^{12} photons/pulse), inducing non-linear matter responses at a too low rep rate (10 Hz - 10 kHz), though in the ultra-fast time scale domain (10^{-14} - 10^{-13} s).

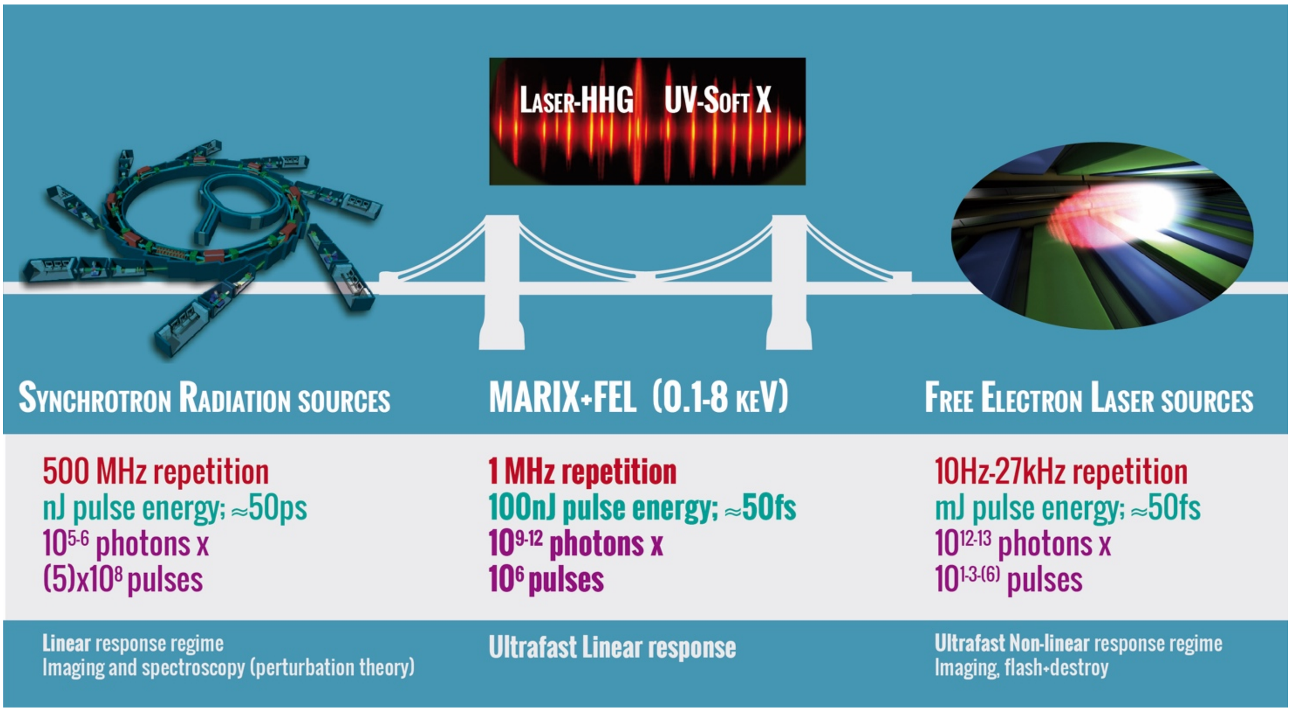


*Fig 1. **MariX** as a bridge joining merits of synchrotron light sources on one side and FELs on the other side*

As a matter of fact, science enabled by X-rays is in urgent quest of radiation sources capable to generate ultra-fast pulses (< 10^{-14} s), with intensity compatible to linear response regime (10^{8} photons per pulse), and repetition rates up to 1 MHz, ideal for high statistics and pump/probe experiments with full recovery of ground state in between successive pulses. These new kind of X-ray sources would build an ideal bridge linking synchrotron light sources and Free Electron Lasers, as simbolically depicted in Fig.1. They could marry in a single source their respective figures of merit.

These unique features will be exploited in several fields of life sciences, innovative materials, cultural heritage and paleontology, opening new scenarios and possibilities otherwise not accessible with present X-ray sources.

MariX is the first research infrastructure conceived for multi-disciplinary studies of matter based on an optimized source for ultrafast spectroscopy, which has also a very large energetic efficiency and a compact foopr int, minimizing the impact on real estate requeriments, besides an ideal distribution of spaces and utilities for research, optimally embedded in the frame of a scientific university campus.

MariX is based upon an originally conceived cutting-edge system of combined electron accelerators at the forefront of the world-wide scenario of X-ray sources, enabling the generation of X-rays over a large photon energy domain by exploiting two different physics mechanisms, the Free Electron Laser (FEL) and the Inverse Compton Scattering (ICS). The FEL generated X-ray beams, with photon energy in the 0.2-8 keV range, will have extremely short pulses (<10^{-14} s) with ultra-high brilliance, repeated at a regular frequency up to 1 MHz. At this temporal scale we can access visualization of excited states of proteins and macro-molecules, as well as spectroscopy of atoms and aggregated matter excited states in all time scales and phases.

X-rays generated by Inverse Compton effect will have larger photon energies, between 20 and 180 keV, easily tunable during measurements, either mono-chromatic or multi-color. Such properties will make them extremely effective in several medical and biological applications, for example in studying and developing early stage cancer diagnostics, and in many sectors of material science and cultural heritage (Ercolanus papyrus reading by virtual enrolling, non destructive diagnostics sensitive to elements of bronze and stone statues as well as canvas), studies of paleontological samples.

MariX source is optimized for a scientific case that has no chance of being performed elsewhere at present X-ray source facilities. A comparison can be drawn with other ongoing projects like LCLS-II, the new superconducting FEL at Stanford that will offer similar performances, although based on an accelerator complex quite more expensive and almost double in size than **MariX**. **MariX** compactness will result in much reduced costs of operation (almost 50%) with respect to other FELs in operation or in construction (EU-XFEL at Hamburg in Germany, or LCLS-II at Stanford in USA, or Shangai-FEL in China). Its technological concept is at all innovative since it conceives a two-fold use of RF Superconducting Cavities via a double pass of the electron beam through the Linac (back and forth). Such a lay-out allows to reduce by almost one half the number of cavities needed to boost the electron beam energy up to its maximum value foreseen at 3.8 GeV.
MariX conceptual study is extensively reported in its Conceptual Design Report, available for download at www.marix.eu, carried out, written and edited by a national collaboration among accelerator physicists and FEL/ICS users in matter science and spectroscopy, as well as representatives of the radio-logical and medical community belonging to several hospitals and medical research centers of the Milan metropolitan area (San Raffaele Hospital, Istituto Nazionale dei Tumori, Niguarda Hospital).
The well established expertise in accelerator physics and technology, consolidated since early '80s at INFN Milan Dept. and LASA Laboratory, that played a major role in designing and building key components of EU-XFEL and ESS accelerator systems, as well as in designing Compton Sources like SPARC-LAB, ELI-NP-GBS and STAR, has been the backbone of the design effort deployed in defining **MariX** project case and objectives, allowing also to set up a unique combination of know-how in the national context, capable to conceive and design an accelerator complex absolutely original in the global scenario. Actually, the preparation of **MariX** Conceptual Design Report has been carried out during almost one year of activity by such a collaborative group belonging to INFN-Milano (Department and LASA Laboratory) and University of Milan, with several contributions from Politecnico di Milano and many other Universities and Institutions in Italy and Europe (Ferrara, Napoli, Bologna, Roma Tor Vergata, Roma La Sapienza, Istituto di Fotonica e Nanotecnologie del CNR, Université de Paris Sud) and large European Laboratories (Orsay-LAL, DESY, Elettra Sincrotrone Trieste and CERN).

Fig 2. Rendering di MIND (Milan INnovation District)

MariX infrastructure has been conceived as a pivotal element of competence and actractiveness for the future innovation district MIND, which is in its design phase at the Milan post-Expo area, and in sinergy with the future Scientific Campus of University of Milan (see Fig.2). Nevertheless, its Conceptual Design Report has been developed as a site-independent project.

The whole infrastructure has a footprint about 500 m long and 100 m wide, mainly 8-10 m underground, leaving most of the surface available for green areas and light installations. It is characterized by a rectilinear radio-shielded tunnel containing the superconducting linear accelerator, as well as a structure with a shape of a bubble-arc containing the arc compressor (see Fig.3) whose diameter is about 80 m, containing the magnetic beam transport lines needed to deflect the electron beam exiting the accelerator after the first passage and re-inject it into the Linac for the second passage with further acceleration. Its CAD-3D representation is shown in Figure 3.

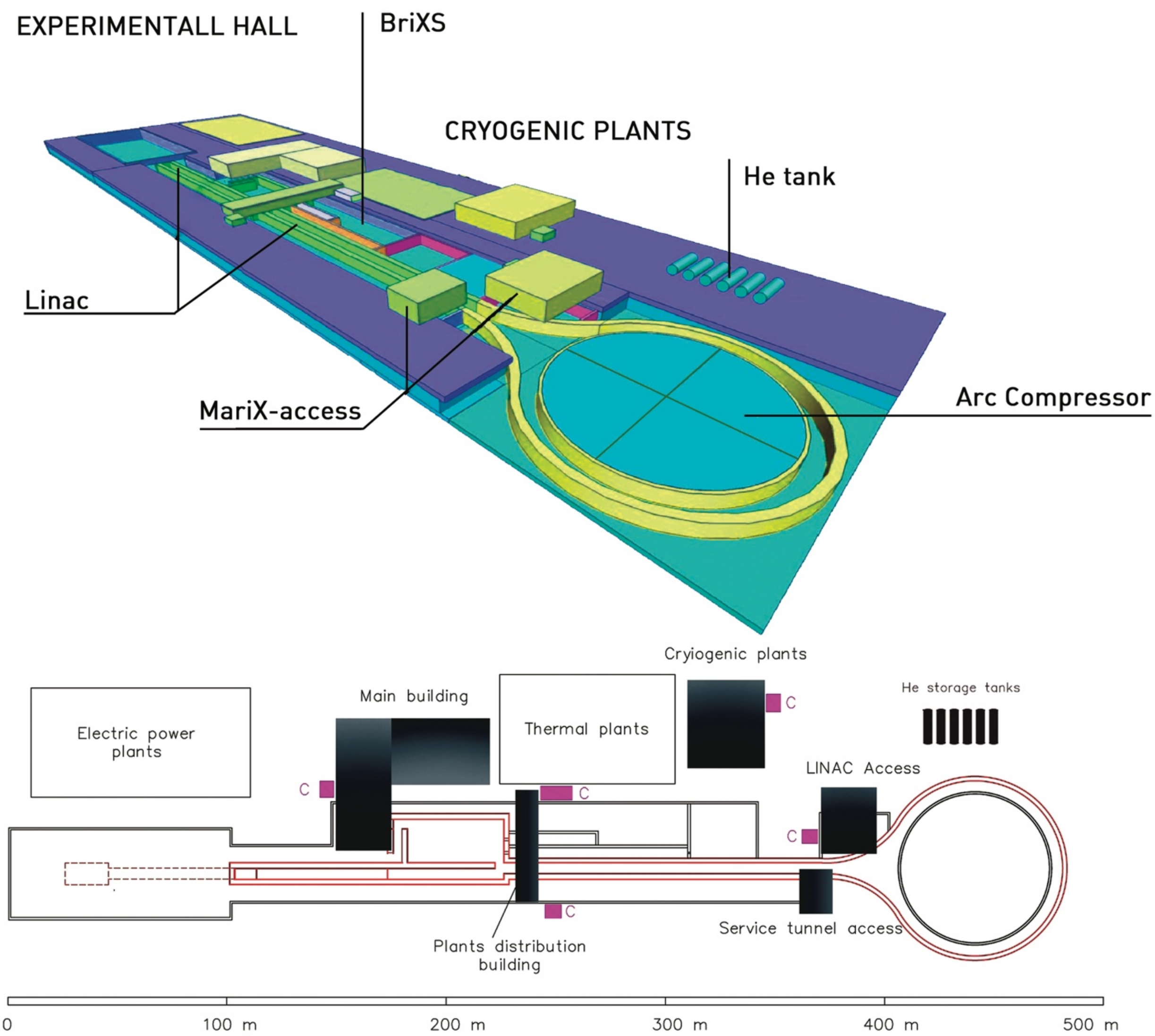


Fig 3. Map view and 3D-CAD of MariX