Radiation Sources

Stefano Lupi

Department of Physics and INFN – Roma, Sapienza University

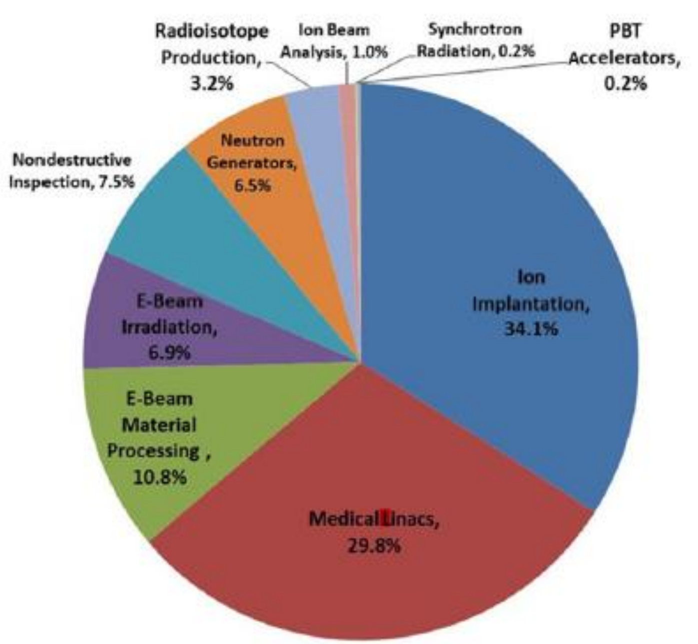
stefano.lupi@roma1.infn.it

Contributions from Sabina@SPARC_LAB and INFN-Ferrara

Outline

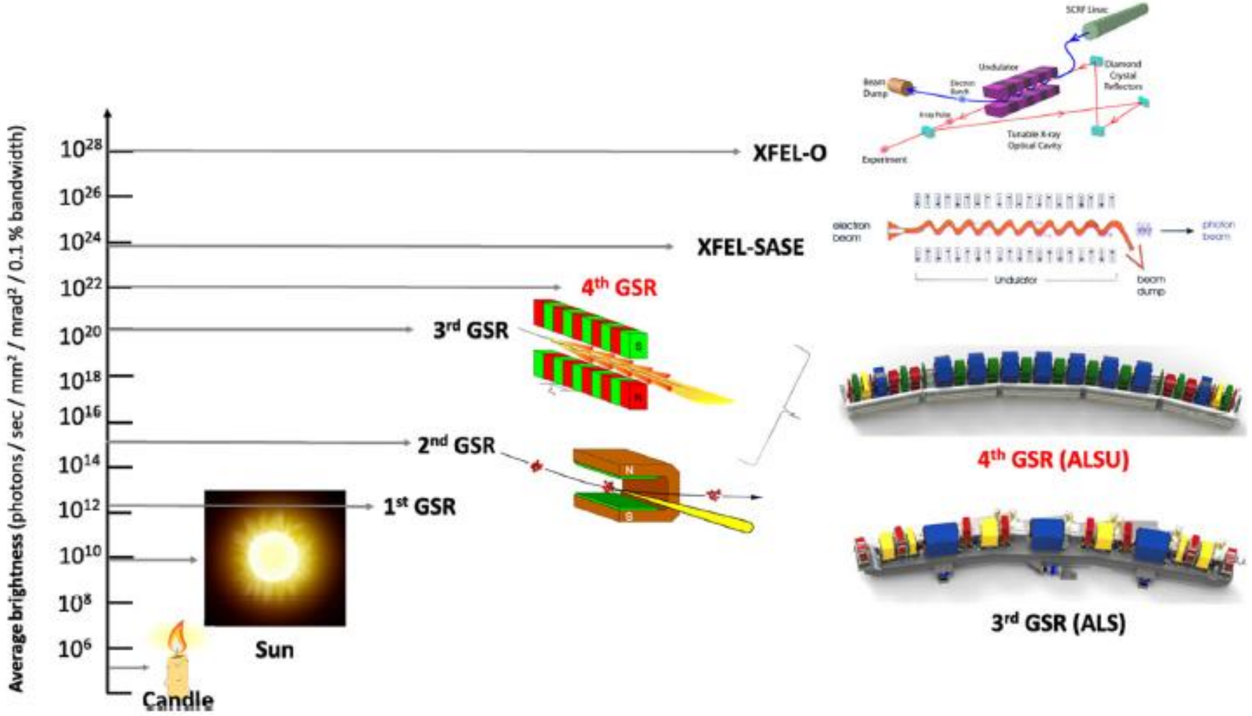
- Particle Accelerators as Radiation Sources;
- Production mechanisms of radiation generated by electron beams;
- Research activities on radiation sources at LNF (Sabina @SPARC-Lab), at Roma1 (SISSI2.0@Elettra), and INFN-Ferrara (THECNO-CLS);
- PhD thesis opportunities;

Particle Accelerators as Radiation Sources

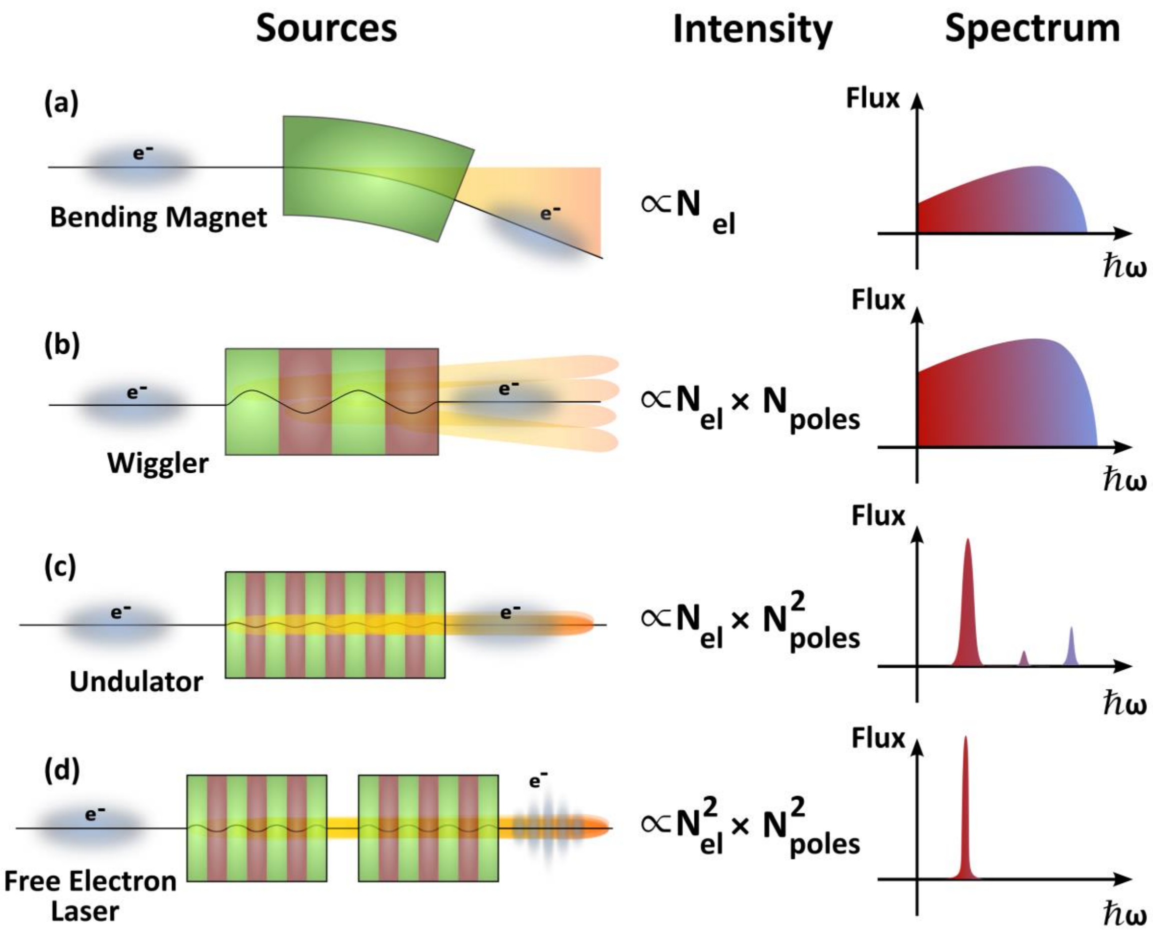


- About 50.000 particle accelerators operate worldwide (CERN info), mostly for scientific, industrial and medical applications.
- Among these, many of them accelerate electrons in the sub-GeV/GeV range to produce synchrotron radiation

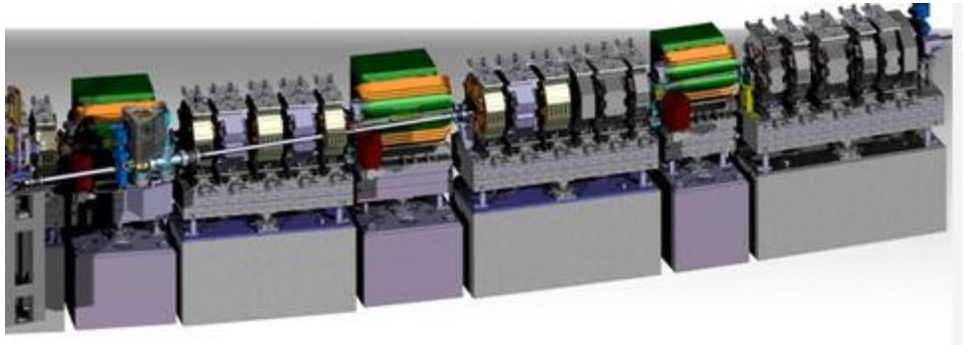
- Particle accelerators generate radiation in a broad spectral range (THz-X-Ray) with exceptional properties: **high brightness, temporal and spatial coherence, ps-pulsed structure, high repetition rate, and excellent stability.**
- Their outstanding performance enables experiments and cutting-edge research beyond the reach of conventional laboratory sources.
- The pursuit of ever-higher performance **has driven few generational advance** in accelerator physics and technology.



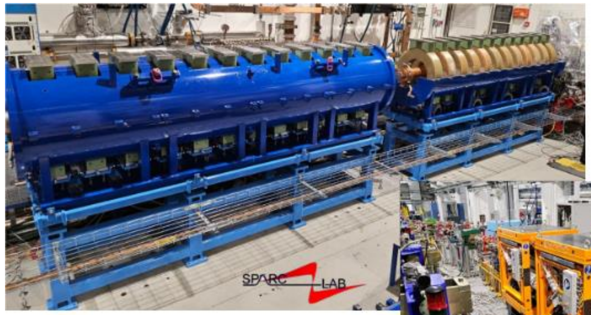
Particle Accelerators as Radiation Sources



- **Bending Magnets** in Storage Rings to produce bright broadband radiation from THz to hard X-rays

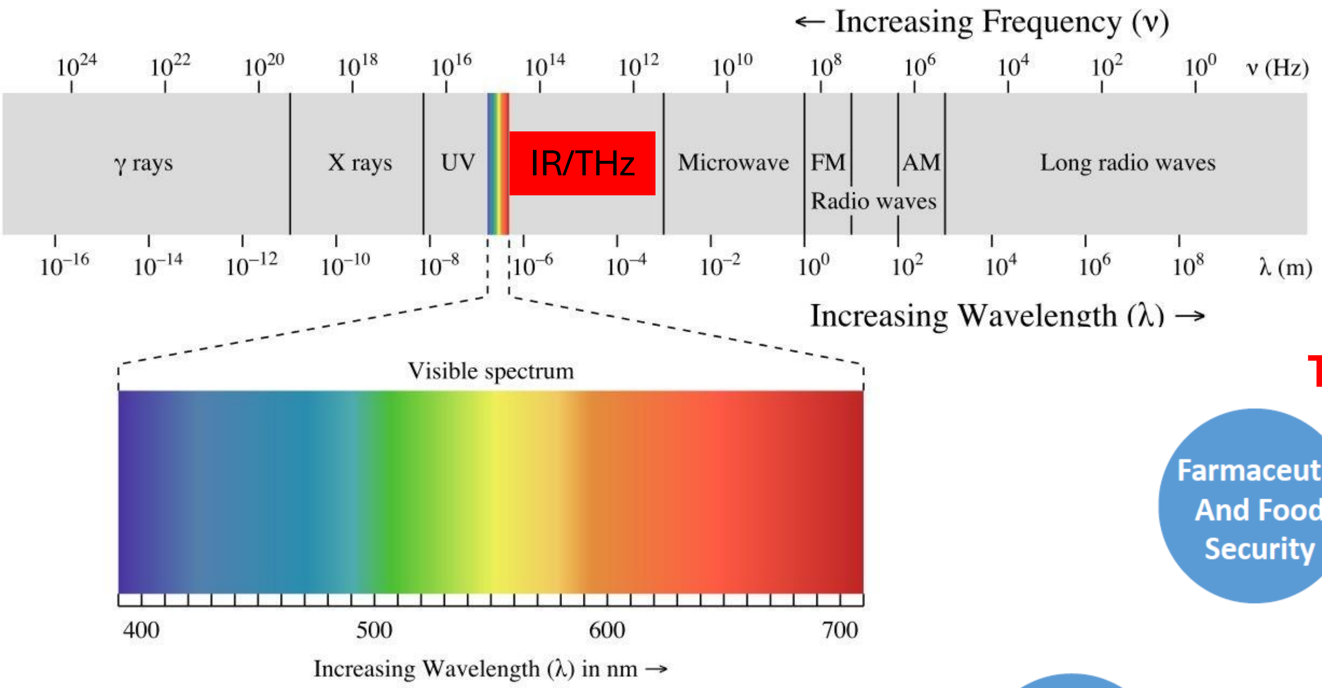


- **Insertion Devices** (Undulators and Wigglers) are meant and developed for SR production



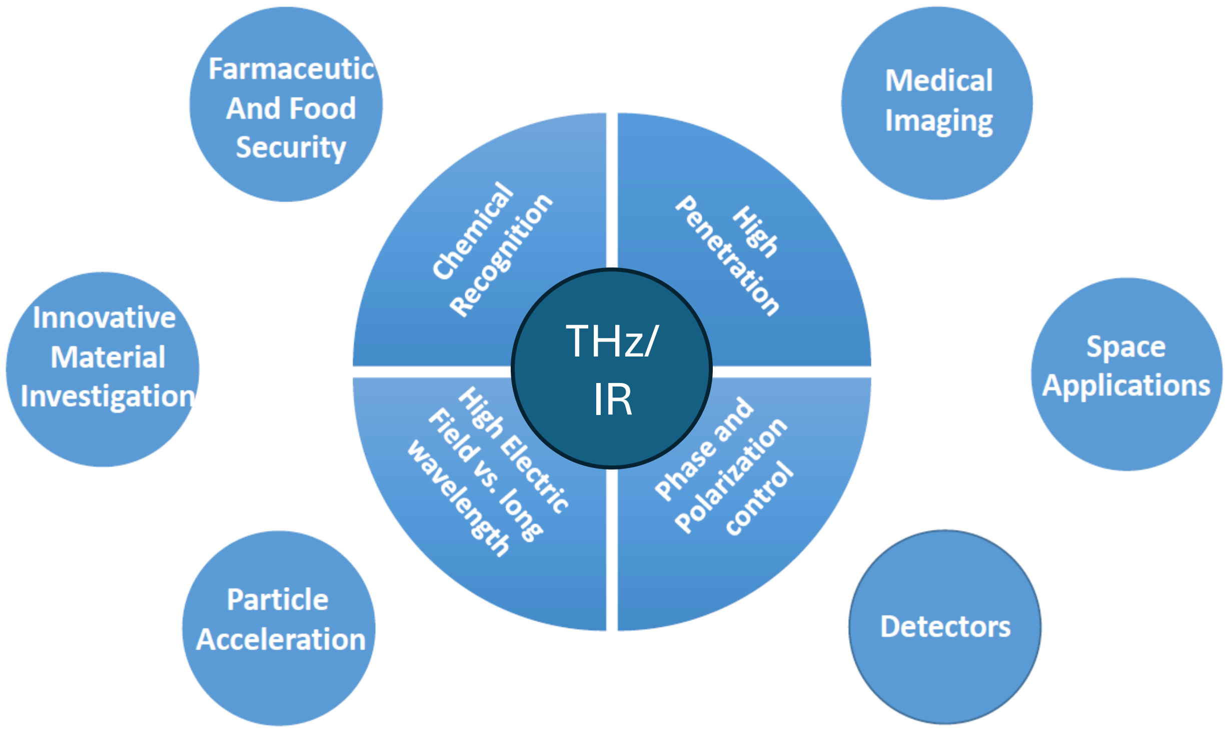
- In **Free Electron Lasers**, multiple undulators provide laser amplification using accelerated electrons as the gain medium

Terahertz/Infrared Radiation:
From the production to photonics applications



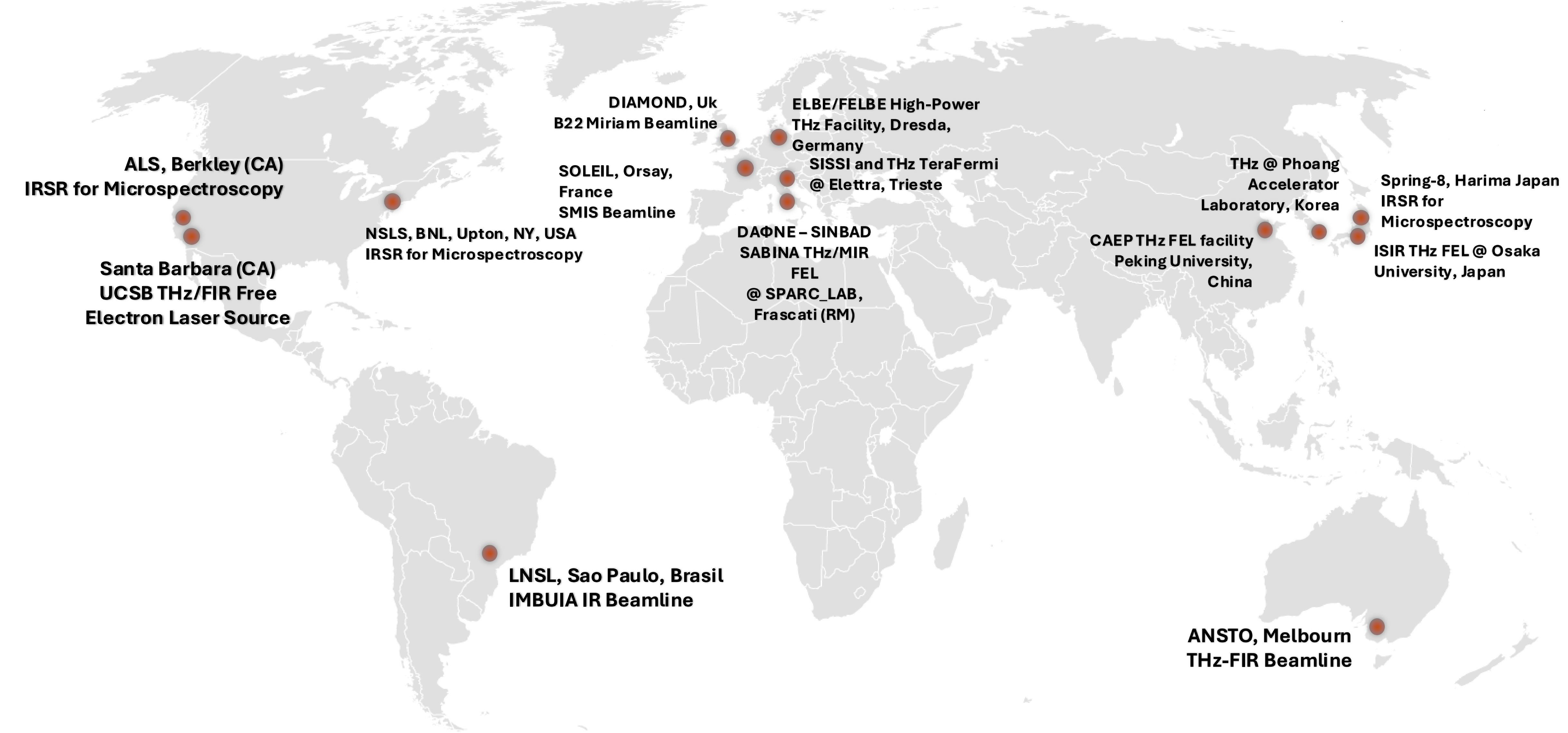
Frequency: 0.1 – 100 THz
Wavelength: 3 mm – 3 μm
Energy: 0.4 – 400 meV

THz/IR Multidisciplinarity



Dedicated THz/IR Facilities in the World

(Not Exhaustive List!)



Towards the Fourth Generation Light Sources: Elettra 2.0 and SISSI 2.0 (Synchrotron Infrared Source for Spectroscopy and Imaging) Beamline

- **Elettra 1.0** is a third generation synchrotron light source with:
  - a storage ring of $259.2\ m$
  - operation energy of 2 and $2.4\ GeV$
  - 28 beamlines available for external users

Major upgrade towards the realization of a '*Diffraction Limited SR*' light source

- Higher brilliance:

$$B = \frac{\dot{N}_\gamma}{4\pi^2 \sigma_x \sigma_y \sigma'_x \sigma'_y (0.1\%BW)}$$

- Increased coherence:

$$C = \left(\frac{hc}{2h\nu}\right)^2 \frac{1}{\sigma_x \sigma_y \sigma'_x \sigma'_y}$$

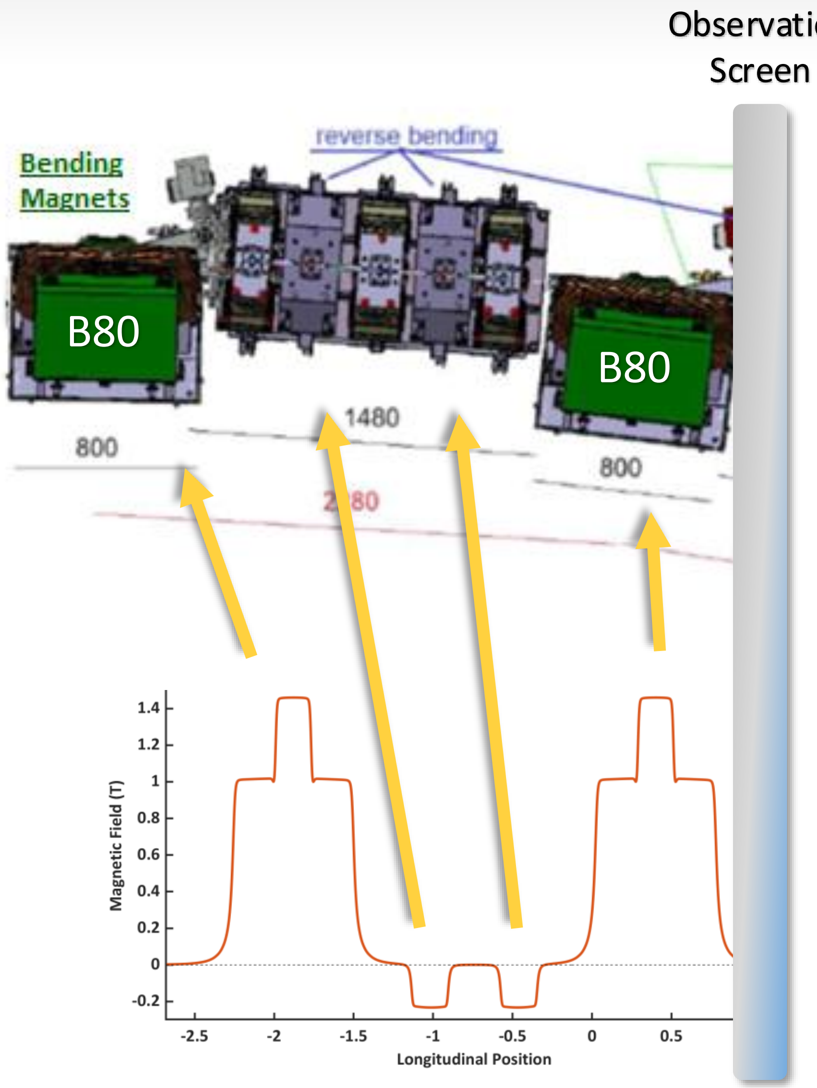
- Great reduction in transverse emittance (mainly horizontal)

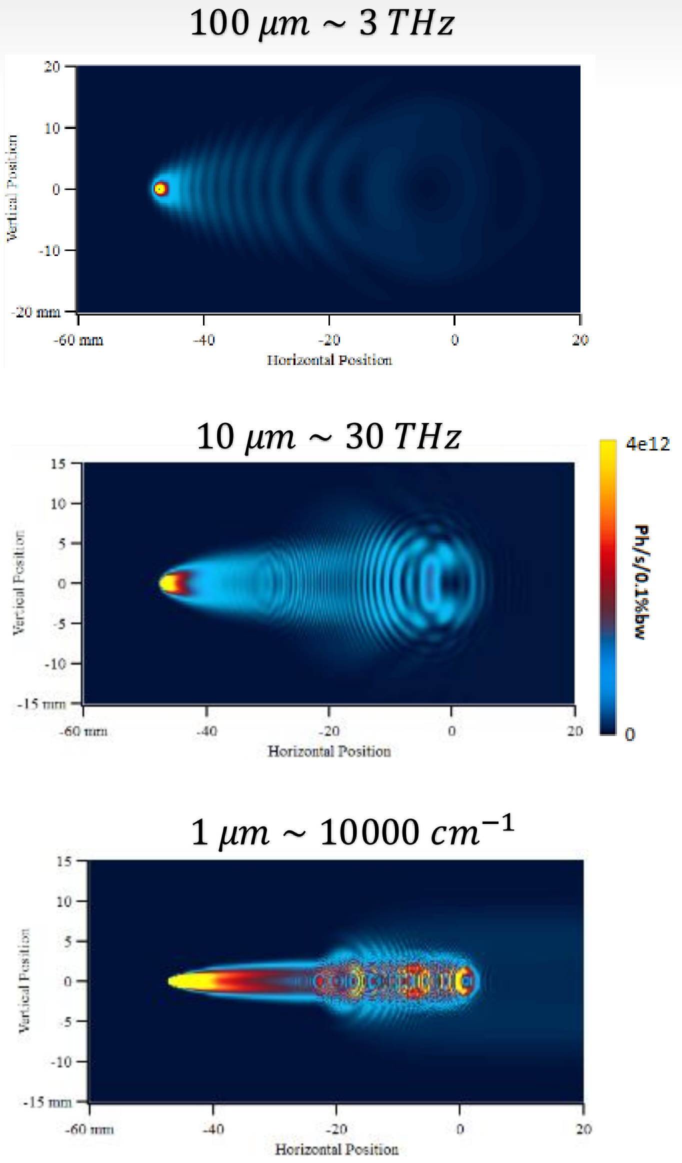
- Innovative design in magnetic optic: new modified multi-bend achromats dipoles (with Longitudinal Gradient and Reverse Bendings)

SISSI 2.0 Beamline Design: Source Properties

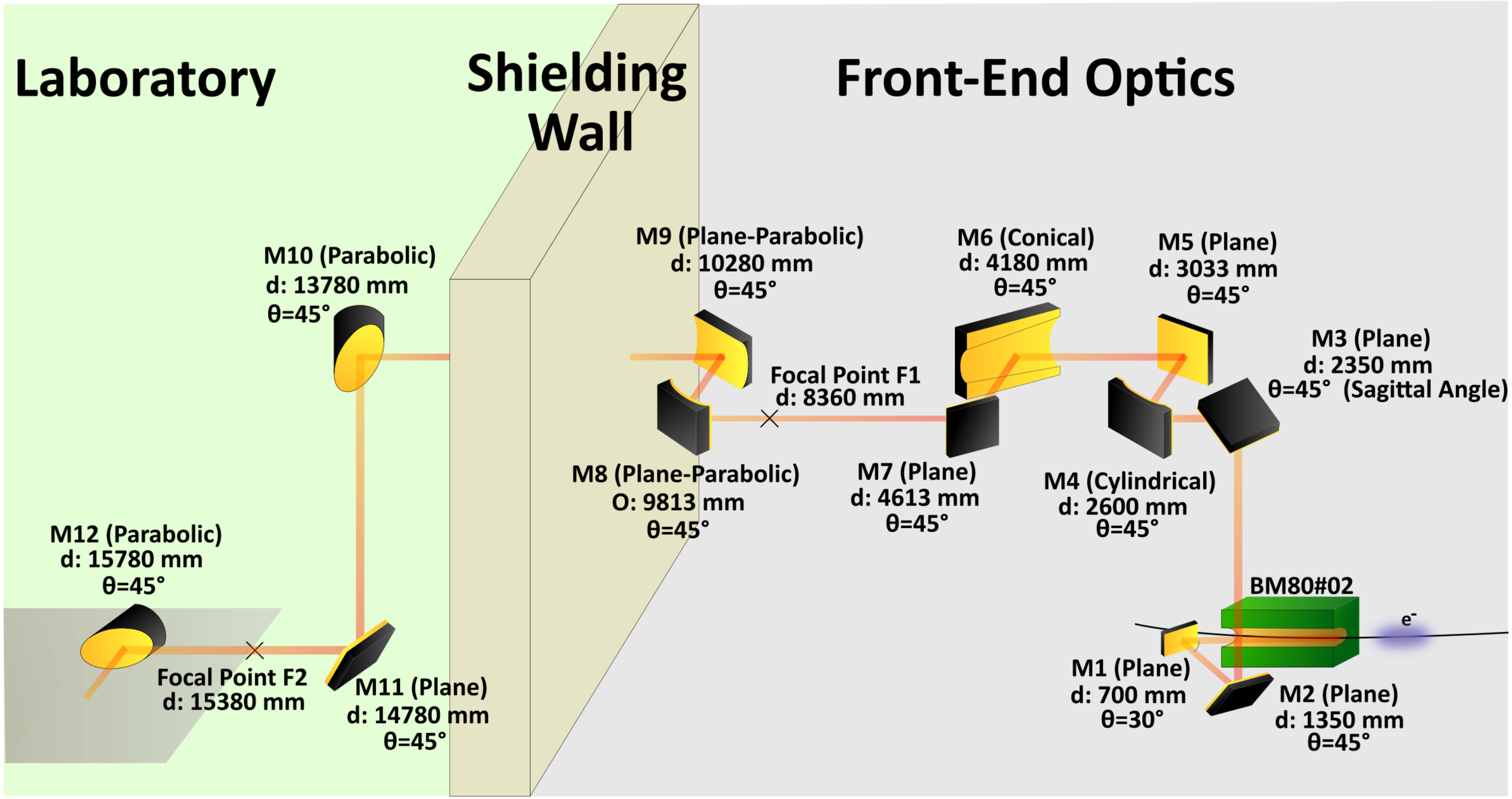
- Section of the Storage Ring dedicated to SISSI 2.0
- Dipolar contribution of the magnetic lattice provided with:
  - Longitudinal Gradient Bending Dipoles
  - Reverse Bendings

SRW Simulations to calculate the SR **Electric Field** in Near Field Regime





Design of the Optical Beamline: SISSI 2.0 Beamline



SABINA: THz/IR Beamline @ SPARC_LAB

SABINA:

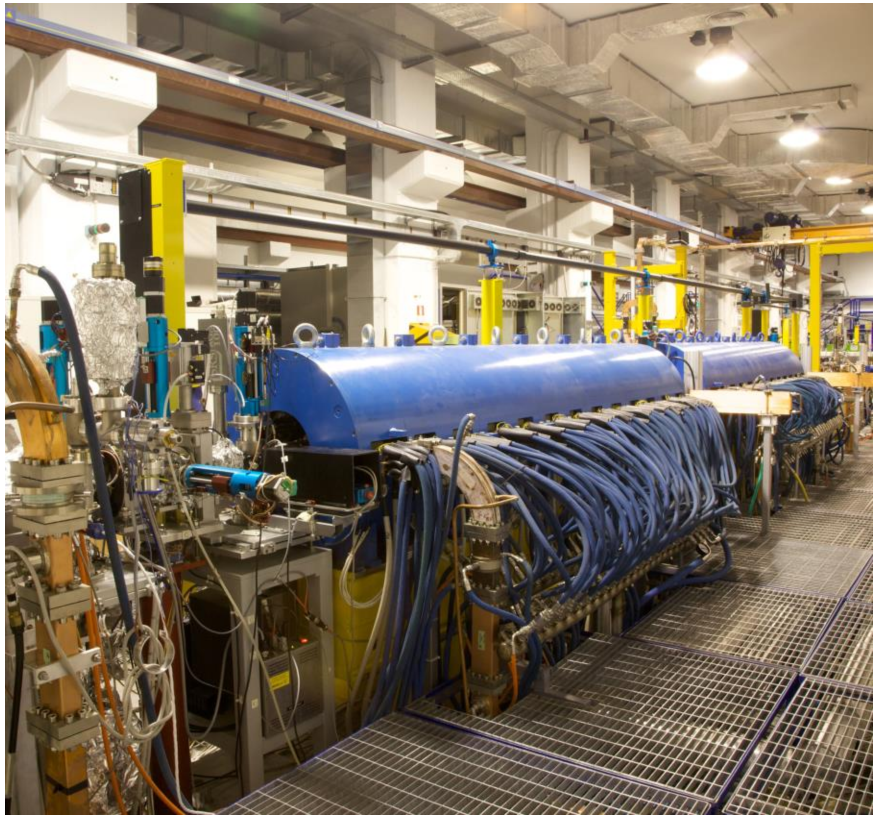
SOURCE OF ADVANCED BEAM IMAGING FOR NOVEL APPLICATIONS

Project co-founded by Regione Lazio within POR-FESR 2014-2020 funds and INFN
Scientific Responsibility: Lucia Sabbatini and Ilaria Balossino (INFN-LNF) and the SPARC_LAB group

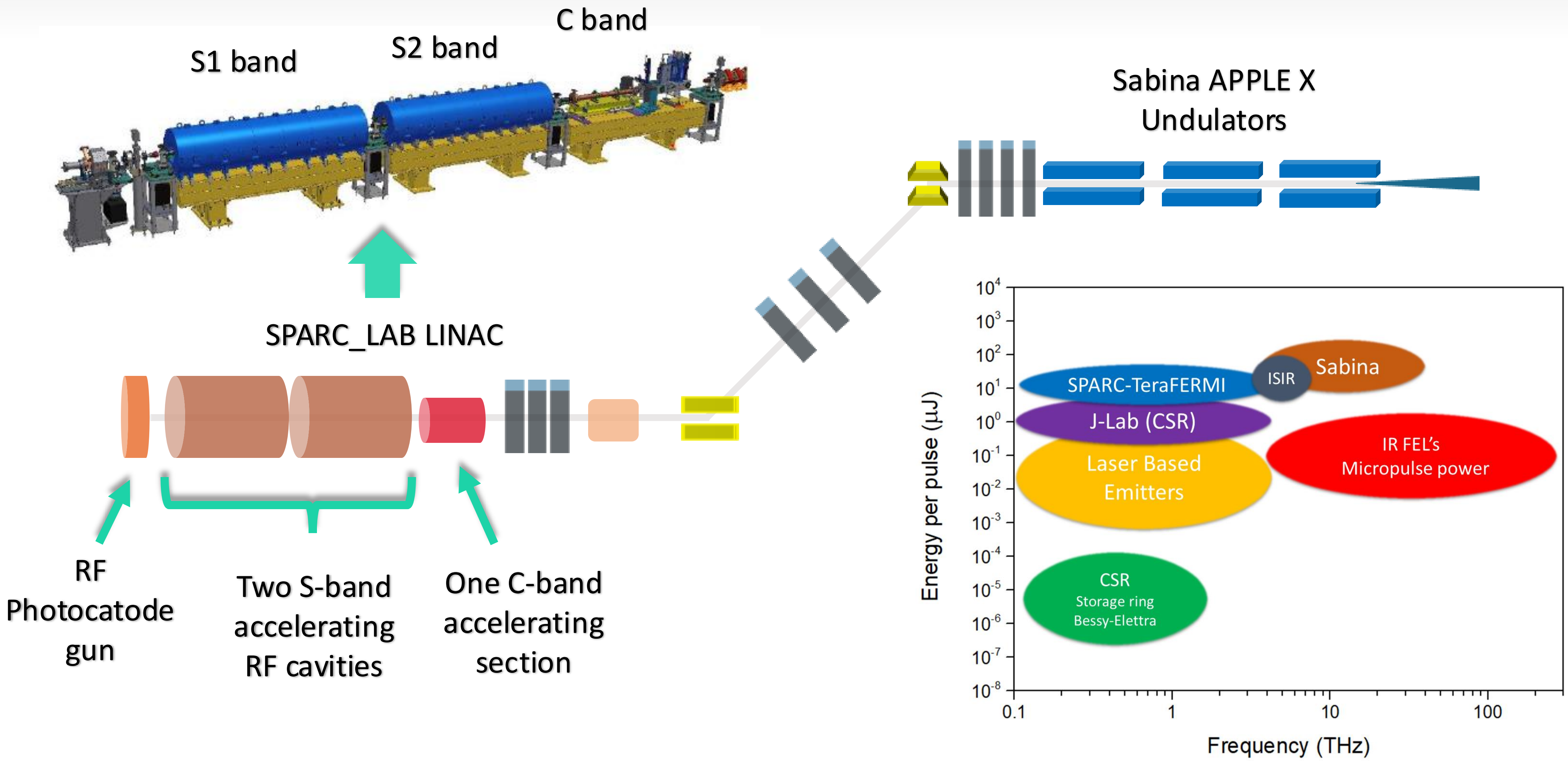
- **GOAL:** Enhancement of the SPARC_LAB research facility – increase of the uptime and improvement of the accelerator performances:
  I. Technological plant renewal
  II. Substitution of the ancillary systems and upgrade of the facility in terms of technology
  III. Development of a Spectroscopy and Imaging user facility:

     THz/IR FEL: radiation source for optical spectroscopy (pump-probe technque), also at cryogenic T

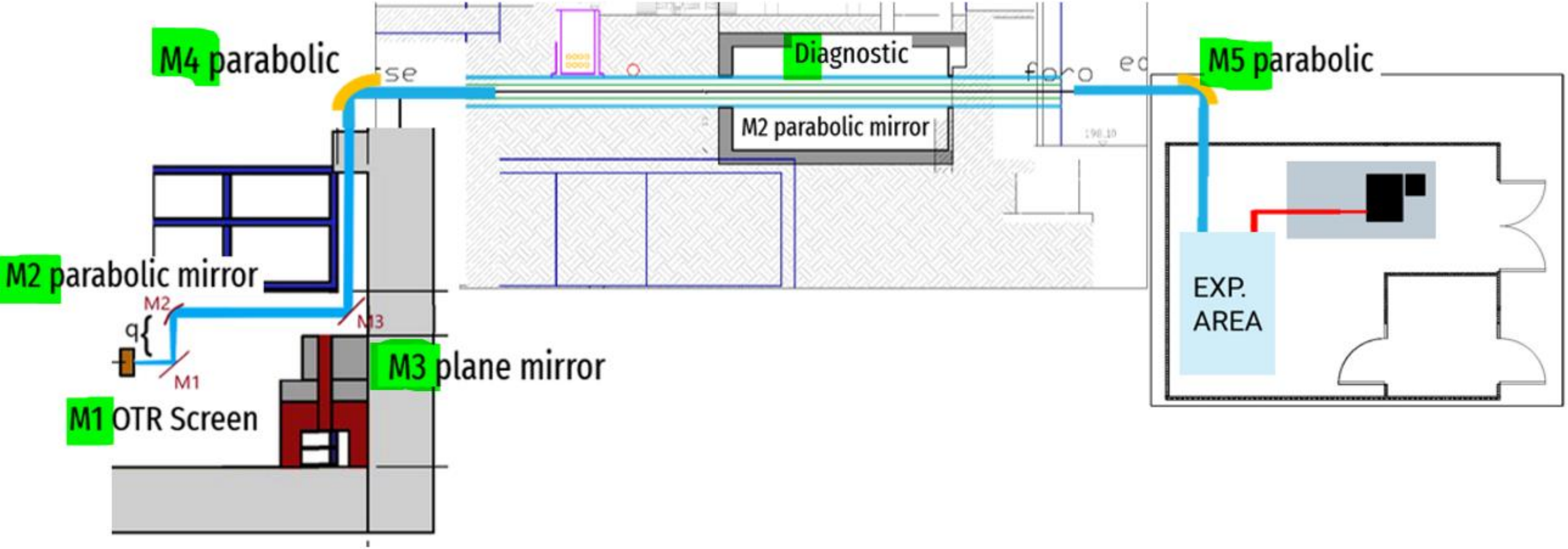
- **STATUS:** kick off Sept. 2019, project finalization: end of 2026



FEL Beamline Layout



Sabina Optical Scheme



Experimental doctoral theses available on SISSI 2.0 and Sabina projects:
Development of the beamlines, their performances characterizations and first optical experiments
contact: stefano.lupi@roma1.infn.it

EIC PATHFINDER OPEN TECHNO-CLS
"Crystal-based gamma-ray light sources"

G.A. 101046458

TECHNO-CLS

- The project started on 1 June 2022 and has a duration of 5 years.

CONTACTS: L. Bandiera (bandiera@fe.infn.it) and G. Paternò (paterno@fe.infn.it)

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

MBN Research Center

INFN Istituto Nazionale di Fisica Nucleare

ESRF

HELLENIC MEDITERRANEAN UNIVERSITY

University of Kent

Università degli Studi di Padova

Università degli Studi di Ferrara

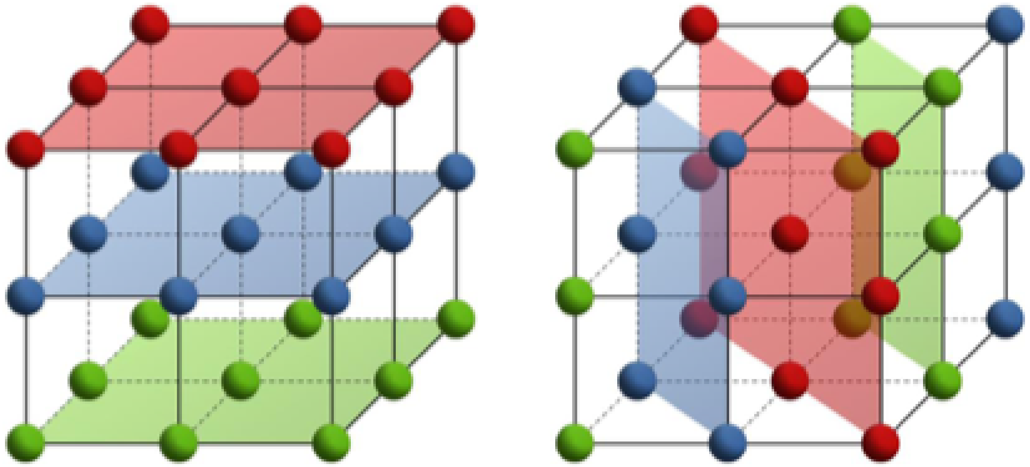
The INFN **CORAL** experiment: *Crystal RadiatOrs for AcceLerators*

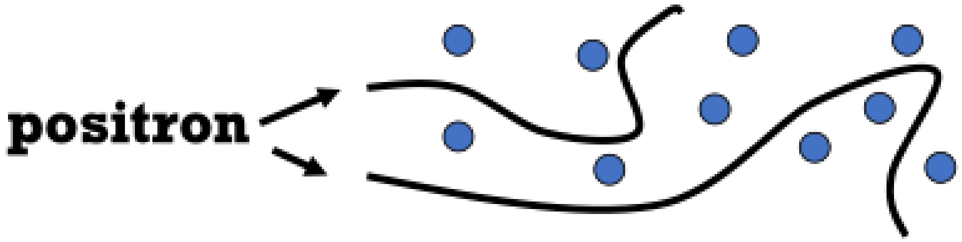
The **main objective of CORAL** is to **design, fabricate,** and **experimentally validate optimized crystalline radiators** capable of generating photon fluxes **exceeding 10^{10} γ/s** within selected energy bands ranging from **hundreds of keV to several hundreds of MeV**—an upper energy range that remains **beyond the reach of current state-of-the-art technologies**.

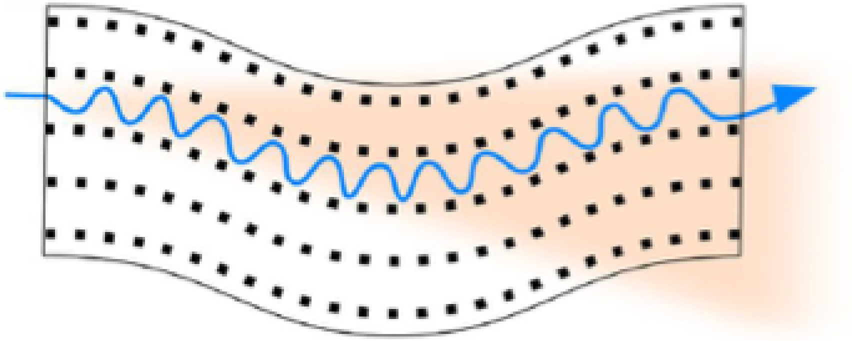
CSN5 Ricerca Tecnologica

Trapping particles inside crystal channels

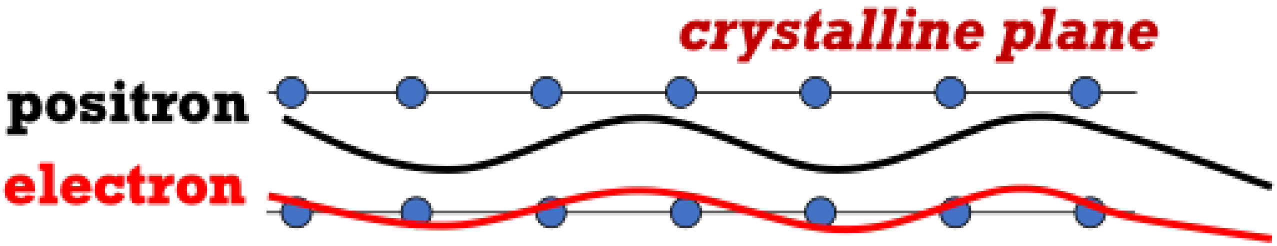
If the particle beam is nearly parallel to the crystallographic planes, it can be trapped in the planar potential well







Channeling Radiation



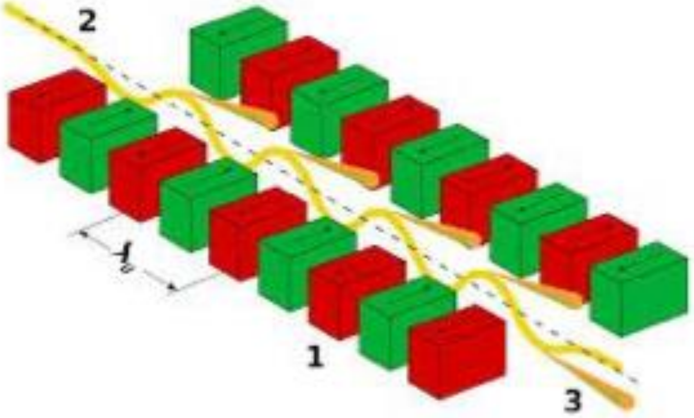
If the crystal is periodically bent, the particle beam follows the bending

Standard Magnetic Undulator vs Crystal Light Source

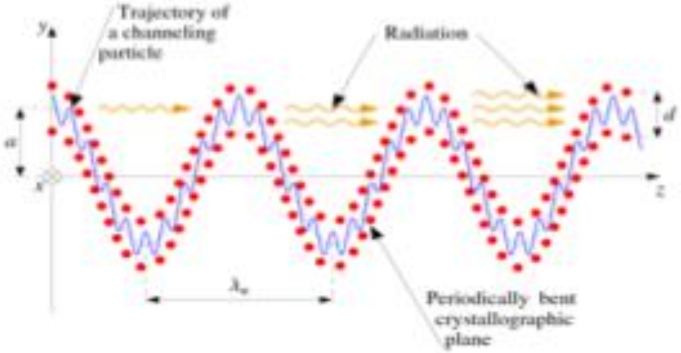
G.A. 101046458

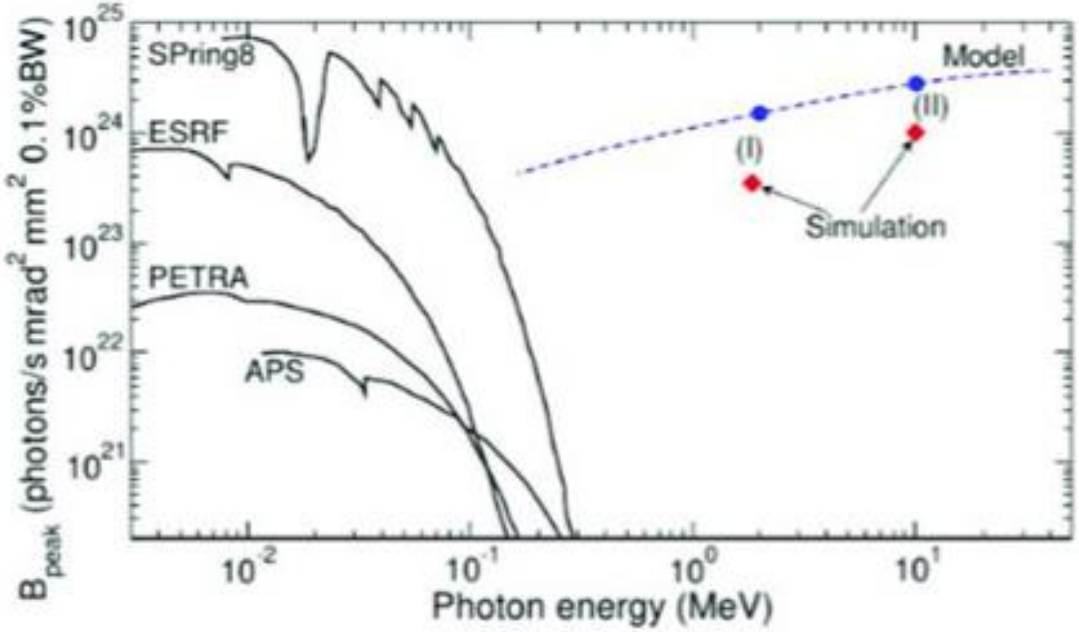
Korol, A.V., Solov'yov, A.V. Eur. Phys. J. D 74, 201 (2020).

Classical scheme: magnetic undulator in a free electron laser
Soft X-rays (10 keV)
$\lambda_u \sim$ cm



Innovative scheme: Crystalline undulator->
Hard X-rays and gamma rays (100 keV - 10 MeV)
λ_u << mm





A Crystal Undulator is a small, passive and sustainable element that does not require either magnets or power supply

PhD thesis:

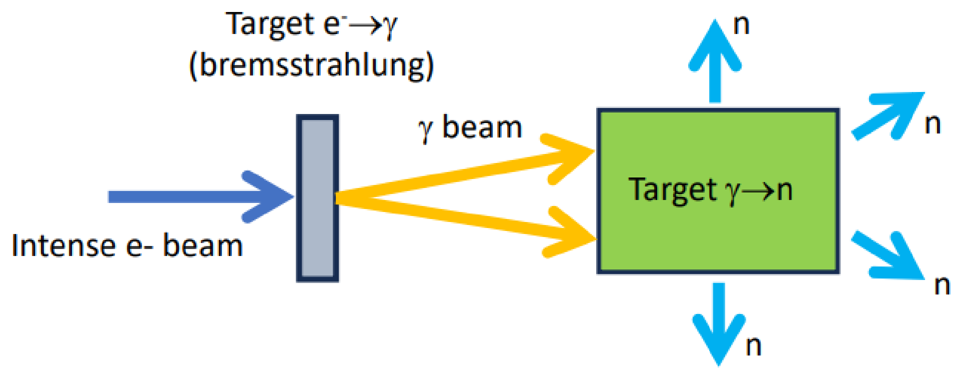
- Monte Carlo simulation for CLS optimization; Mechanical design and realization of Periodically Bent Crystals;
- Experimental tests on beam and data analysis.

Contact: bandiera@fe.infn.it

Application 1: High-intensity gamma beams @ 1–20 MeV obtained with e-beam up to 200 MeV.

Photon-induced fission, nuclear waste transmutation and energy production, production of medical and industrial isotopes.

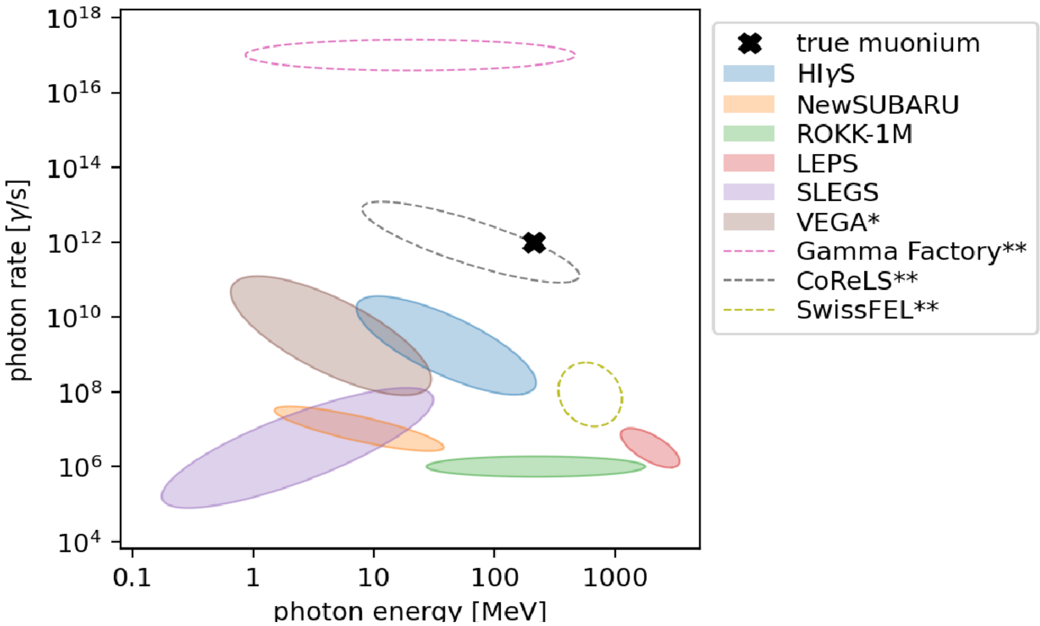
Crystal targets are ideal companions of plasma wakefield accelerators to realize intense **table-top photon sources**.



D. Alesini, INFN Workshop Transizione Energetica 2024 «Prospettive di trasmutazione, fissione controllata e caratterizzazione di materiali con acceleratori di elettroni di alta intensità»

Application 2: Gamma fluxes above 10^{10} γ/s at energy > 100 MeV, well beyond the capabilities of current sources.

High-energy nuclear physics, **searches beyond the Standard Model**, and muon pair production above the 211 MeV threshold, for next-generation **muon sources** (*collaboration with ETH Zurich*).



Possibility of thesis:

- Simulation of radiation emission and/or thermo-mechanical stress induced in crystalline target
- Experimental tests on beam and data analysis
- Conceptual design of a scheme for interaction of channeling radiation with e-beam from MESA accelerator

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