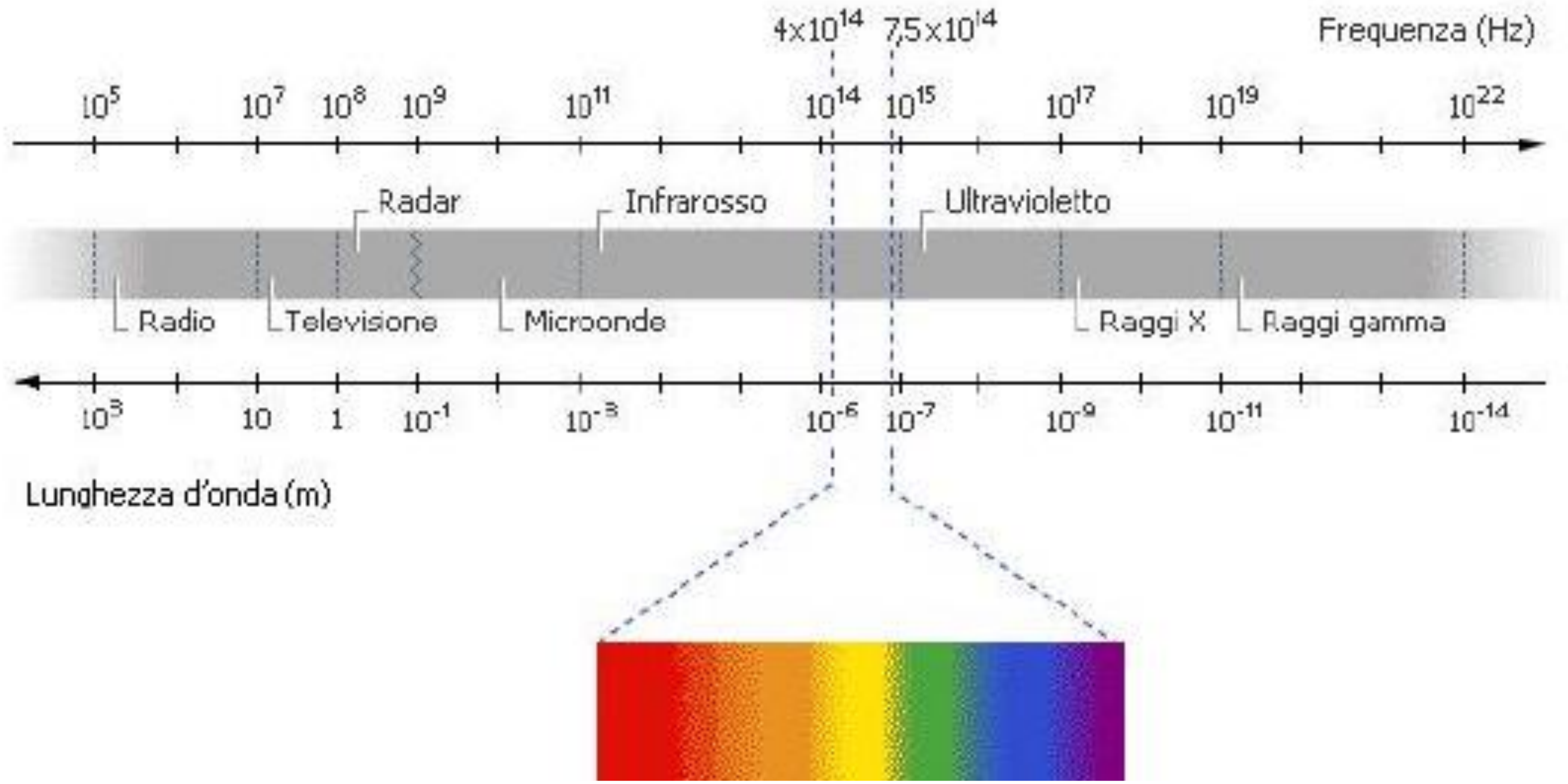
Radiation Sources from relativistic electron beams: Compton Back-scattering, Free Electron Lasers, THz radiators

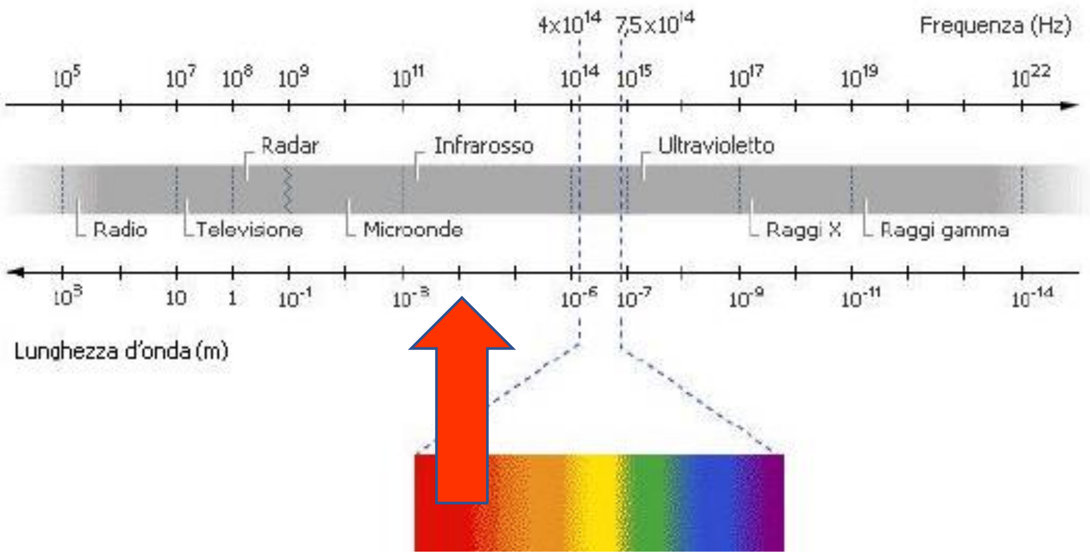
Presented by V.Petrillo– INFN-Milan

- Research activities on radiation sources at LNF (EupraXia, SPARC-Lab, Sabina), Roma1 (Sissi), Milan-LASA (Star, BriXinO)

- Emphasis on radiation sources generated by Electron Beams of High Phase Space
- Density (i.e. peak and/or average brightness,) such as Free-Electron laser, Compton
- Sources and Synchrotrons
- Contributions from L.Serafini, S. Lupi (La Sapienza), L. Bandiera (INFN-Ferrara), Sparc
- and EupraXia team

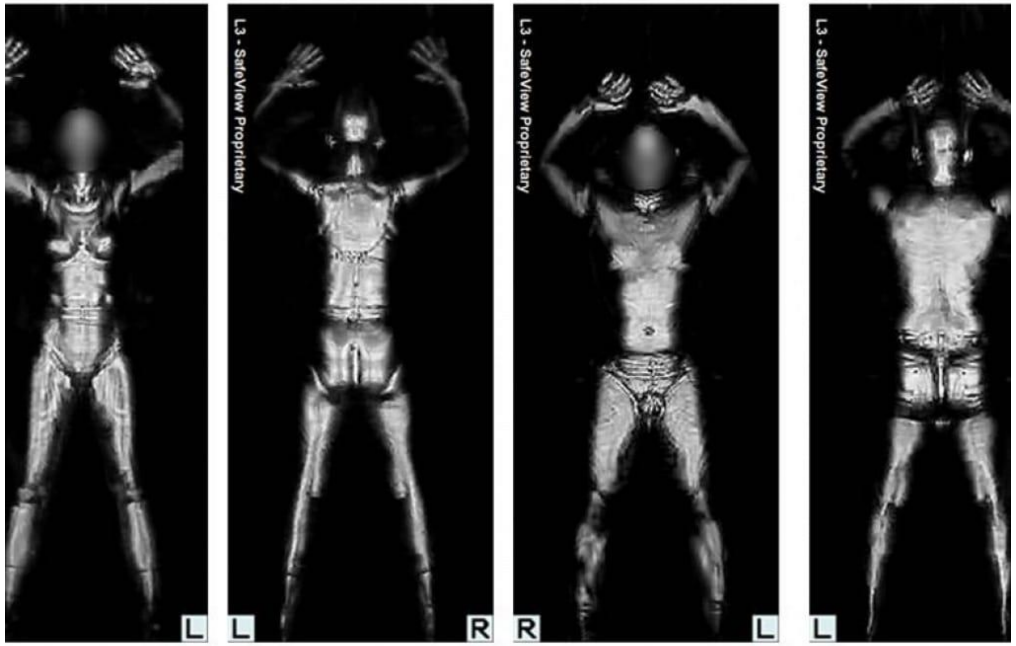
Radiation spectrum





Radiazione TeraHertz
1THz

λ=20 μm- qualche mm



SABINA (SOURCE OF ADVANCED BEAM IMAGING FOR NOVEL APPLICATIONS) : FEL in the terahertz range in commissioning @LNF

Project leader: Lucia.Sabbatini@lnf.infn.it

Other informations on possible experimental thesis:

Alberto.Petralia@enea.it

- **GOAL:** Enhancment of the SPARC_LAB research facility at **LNF INFN** (Frascati, Italy) → 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

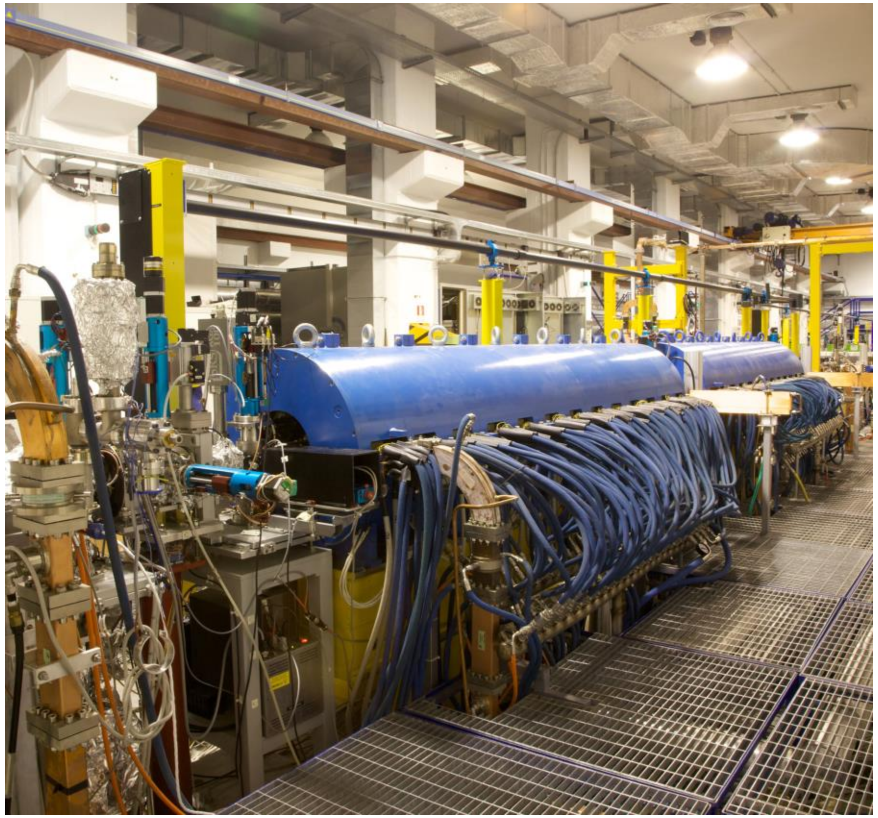
  III. Creation of two user facilities:

  FLAME: High power laser for solid target experiments

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

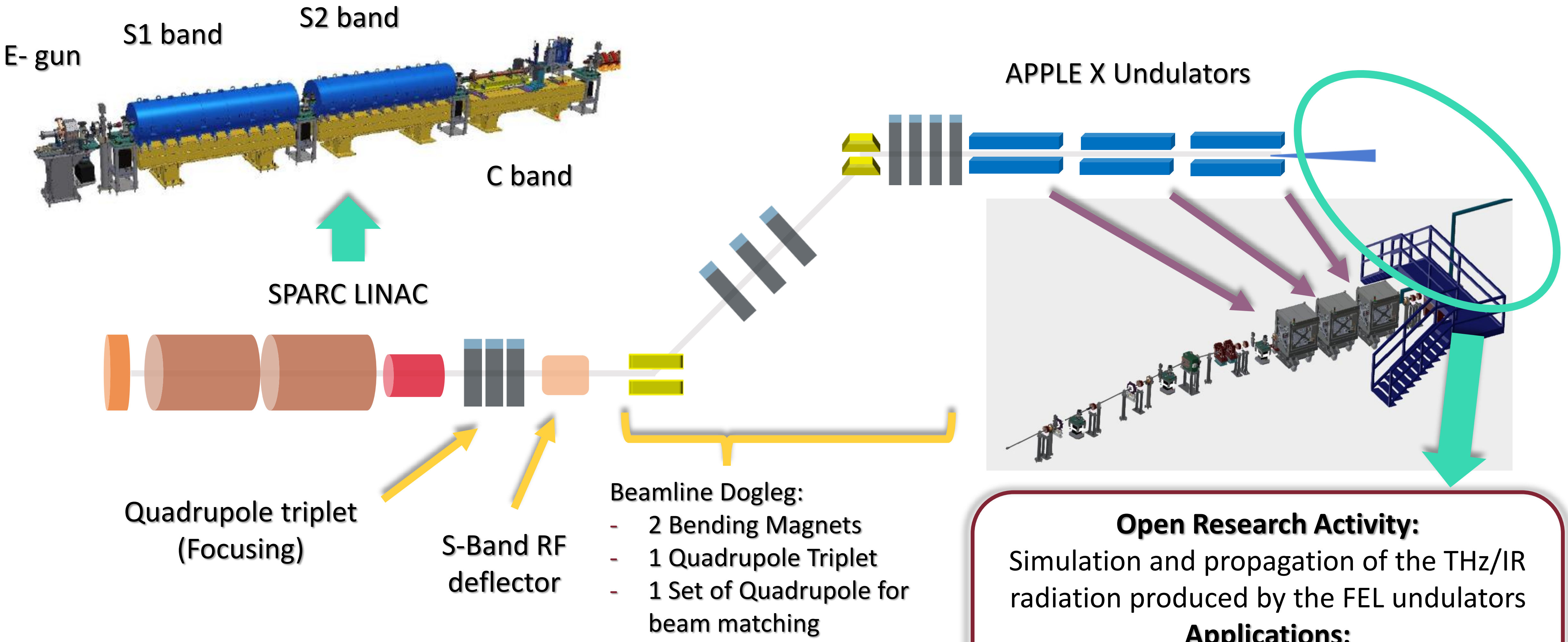
Monochromatic Light with ps/sub-ps time duration	Tunable Frequency between 3 – 30 THz	Tunable Polarization Linear, Circular and Elliptical

- **FUNDS:** *Project co-founded by Regione Lazio within POR-FESR 2014-2020 funds and INFN*



FEL Beamline Layout

Information: stefano.lupi@roma1.infn.it
Experimental and simulative PhD thesis



Open Research Activity:
Simulation and propagation of the THz/IR radiation produced by the FEL undulators
Applications:
Realization of a beamline to Transport THz/IR radiation to an external user facility

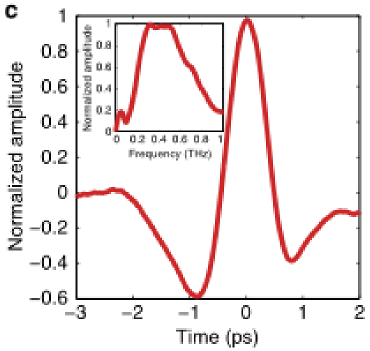
stefano.lupi@roma1.infn.it

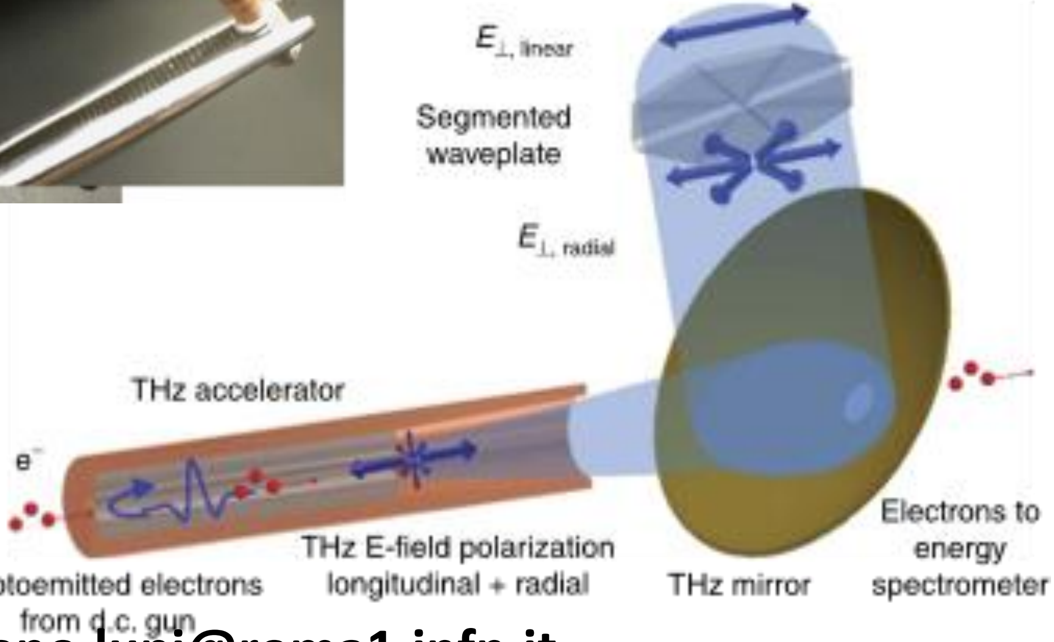
Other ways for producing terahertz radiation;:
Terahertz (THz) Radiation Projects

Stefano Lupi and Massimo Petrarca, INFN and Sapienza University

1) TERA (THz-ERA): THz Technology for Particle Acceleration

Acceleration Cavity





Why Terahertz

- λ_{THz}=100 microns>>$L_{e\text{-}beam}$

à Relaxed conditions with respect to NIR/VIS Laser

- Same laser for e-beam and THz production:

à Low jitter and good synchronization

- Surface Resistence increases with $\omega^{1/2}$

à Breakdown effects at higher electric field

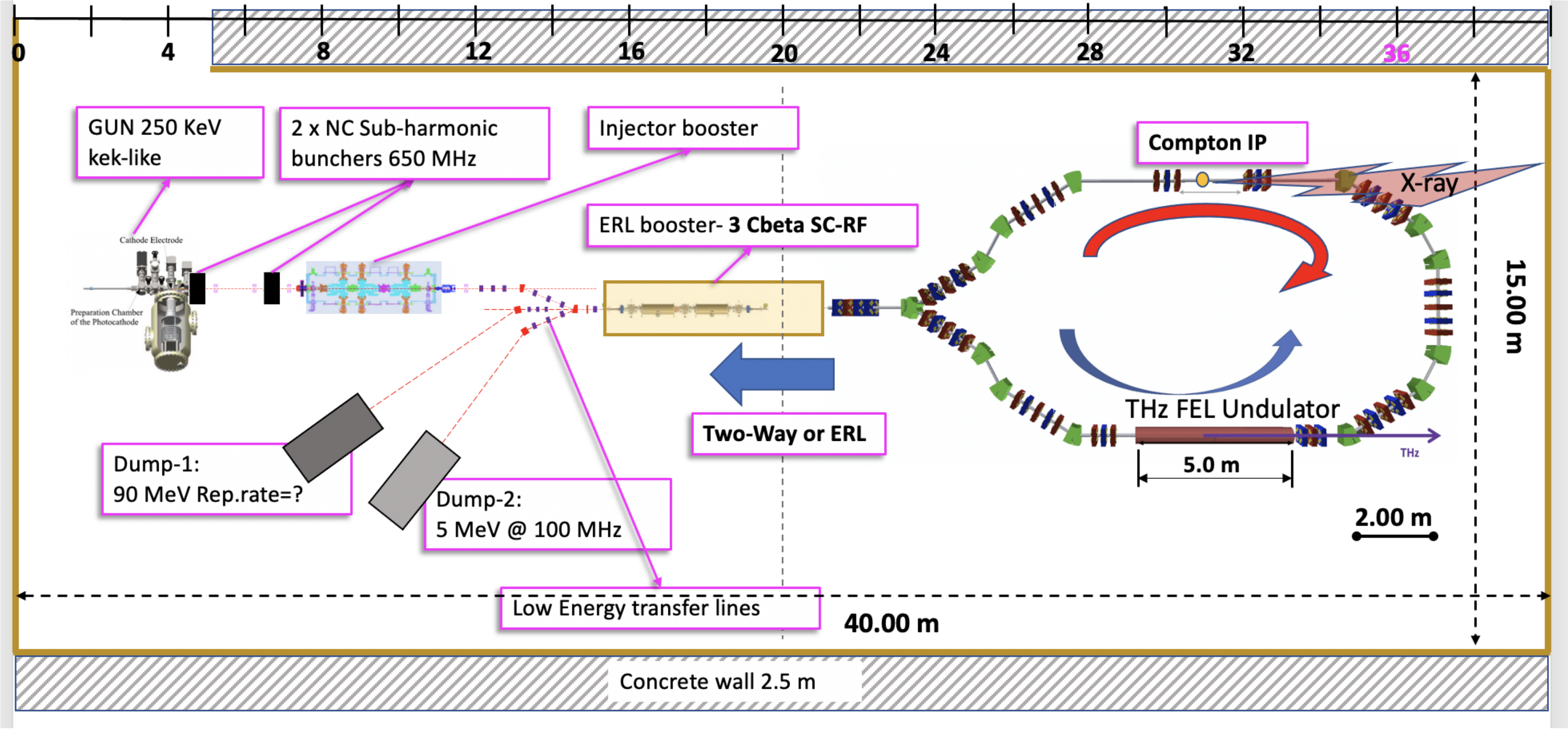
- Multiple THz production mechanisms

PhD Proposal (experimental and theoretical):
Development of THz Technology for THz Acceleration
From Acceleration Cavities to Detectors

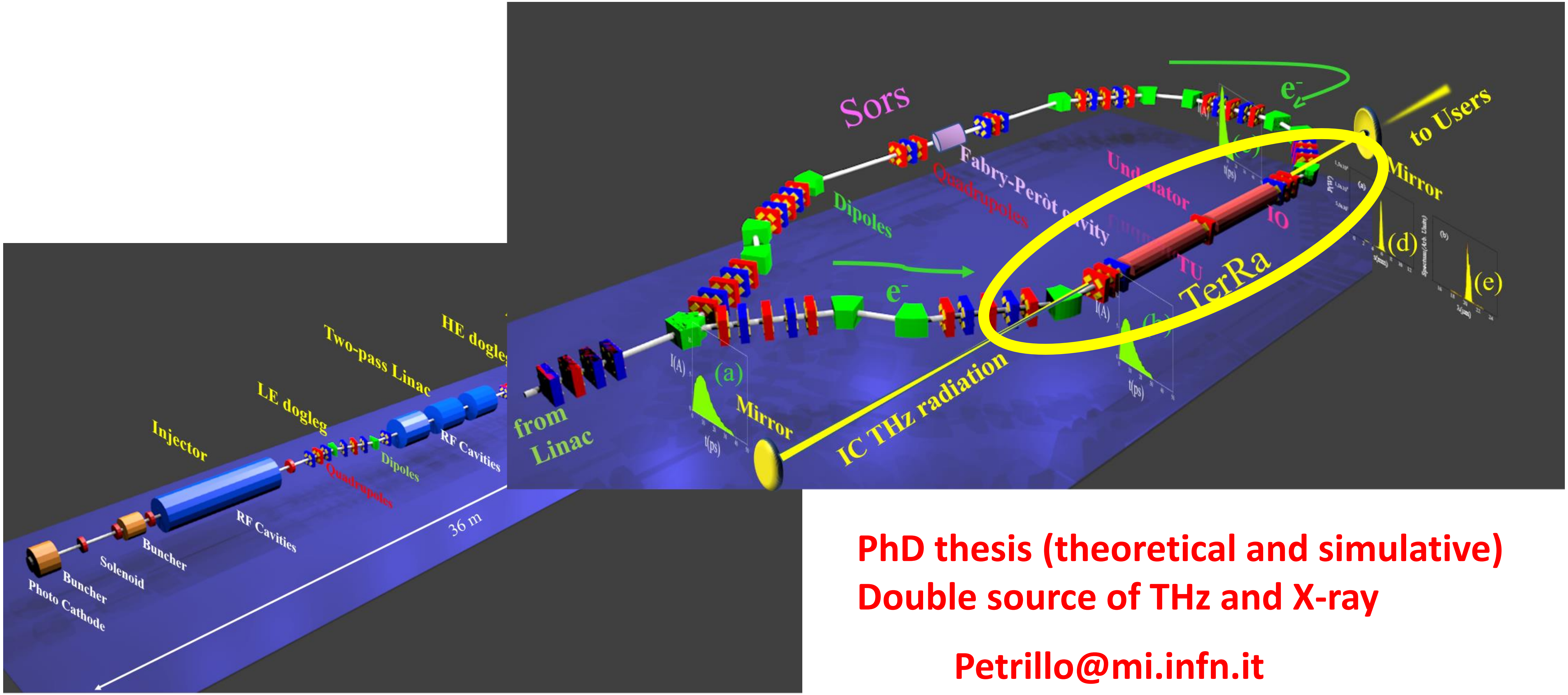
massimo.petrarca@uniroma1.it

stefano.lupi@roma1.infn.it

BriXSinO: Energy Recovery SC Linac @ LASA Milan (45 MeV, 5 mA CW, 225 kW) at the project stage

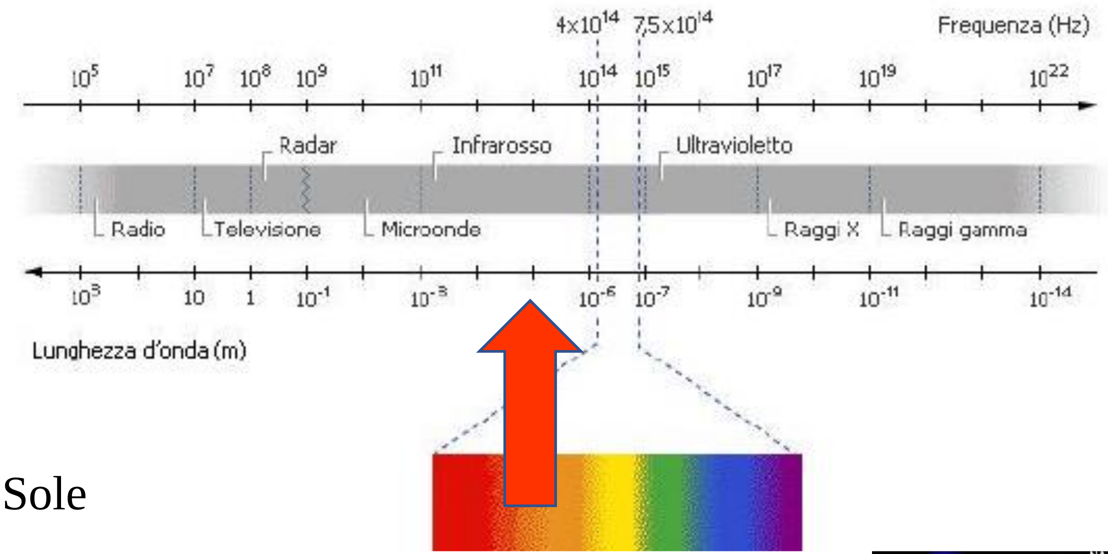


BriXSinO ERL TeraHertz Oscillator



PhD thesis (theoretical and simulative)
Double source of THz and X-ray

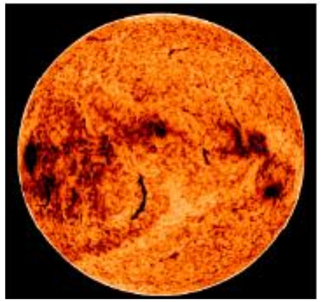
Petrillo@mi.infn.it

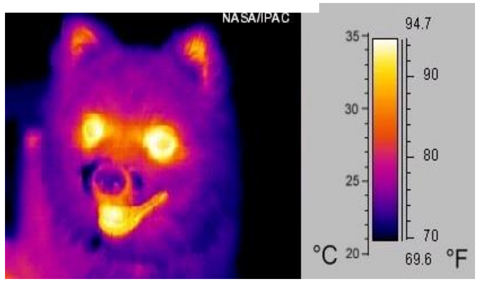


Infrarosso
10 THz-400 THz
λ=800 mn-20 μm

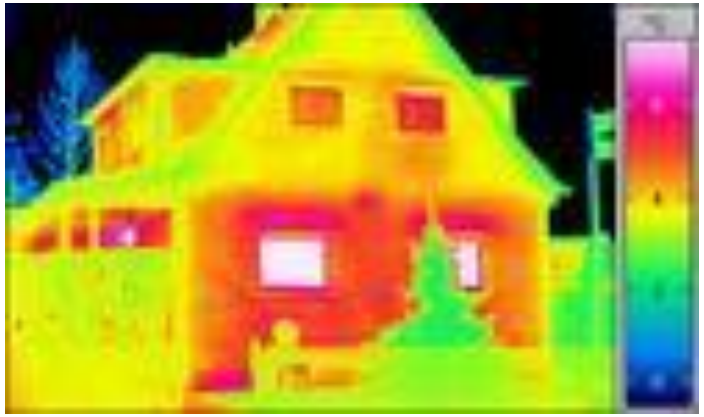
Generatori:
Corpi caldi

Sole





Rilevatori: Termocamere



Introduction to ELETTRA 2.0

- **Elettra** is a third generation synchrotron light source, located at Trieste,Italy, with:
  - a storage ring of 259.2 m
  - operation energy of 2 and 2.4 GeV
  - 28 beamlines available for external users

A **major upgrade** towards what is called the 'ultimate' light source is currently underway for this facility

The upgrade allows for a great reduction of transverse **emittance**

- Higher brilliance:

$$\mathcal{B} = \frac{\dot{N}_\gamma}{4\pi^2\sigma_x\sigma_y\sigma_{x'}\sigma_{y'}(0.1\%\mathrm{BW})}$$

- Increased coherence

$$C = [hc/(2h\nu)]^2[1/(\sigma_x\sigma_y\theta_x\theta_y)],$$

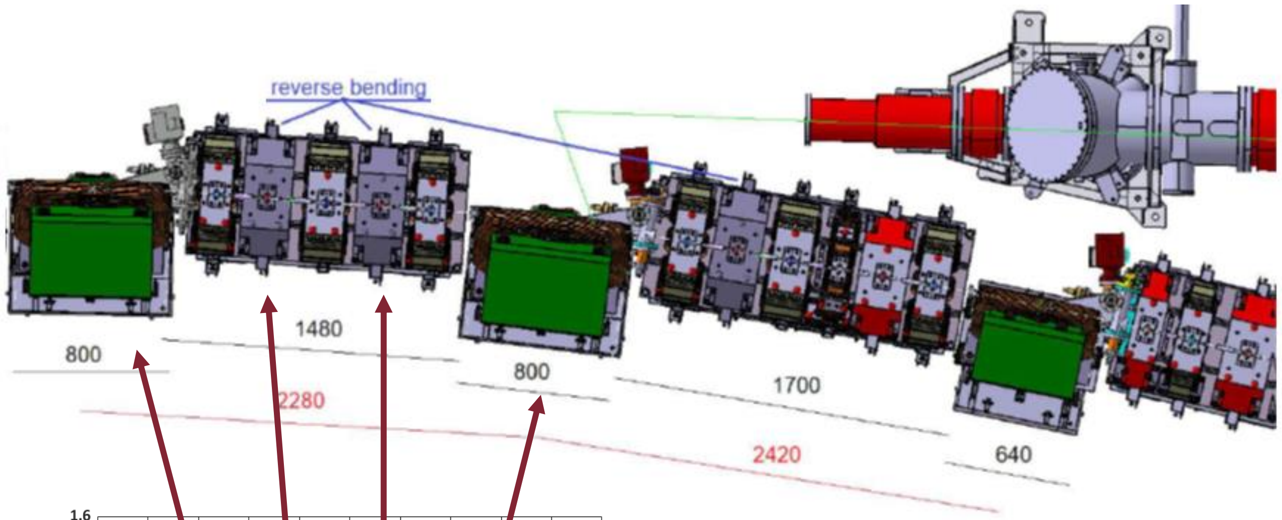
Replacement of **magnetic optics**:
new modified multi bend achromats dipoles with reverse bending

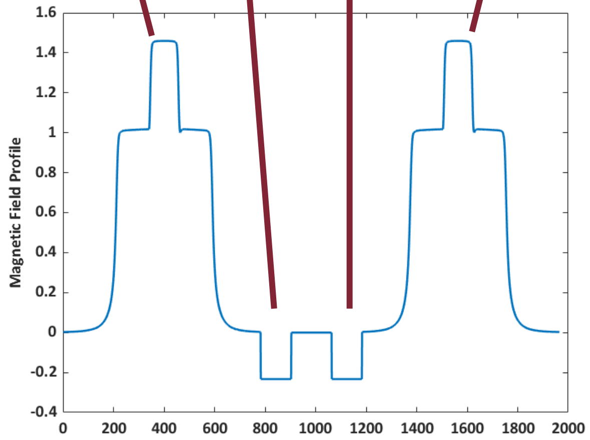
➢ **SISSI** (Synchrotron Infrared Source for Spectroscopy and Imaging): Beamline involved in the upgrade and one of the first to be funded

SAPIENZA UNIVERSITÀ DI ROMA

SISSI 2.0; project leader: stefano.lupi@roma1.infn.it

- The SISSI infrared beamline at Elettra extracts the IR and visible components of synchrotron radiation generated by bending magnets to perform spectroscopy, microspectroscopy and imaging. PhD experimental thesis at ELETTRA

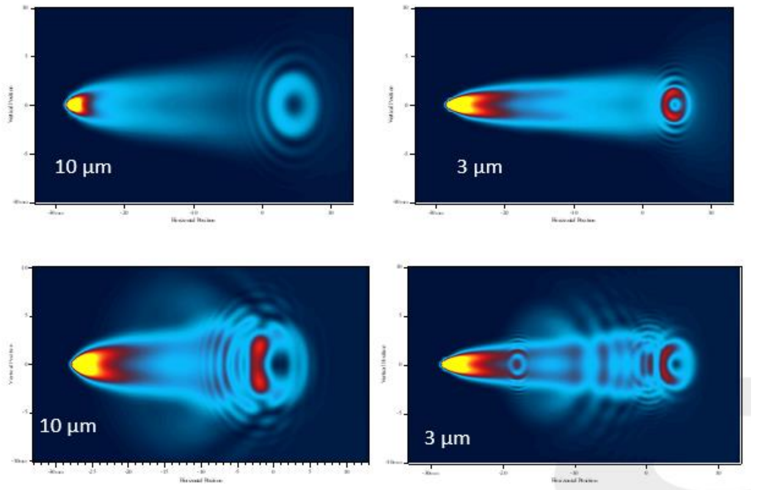


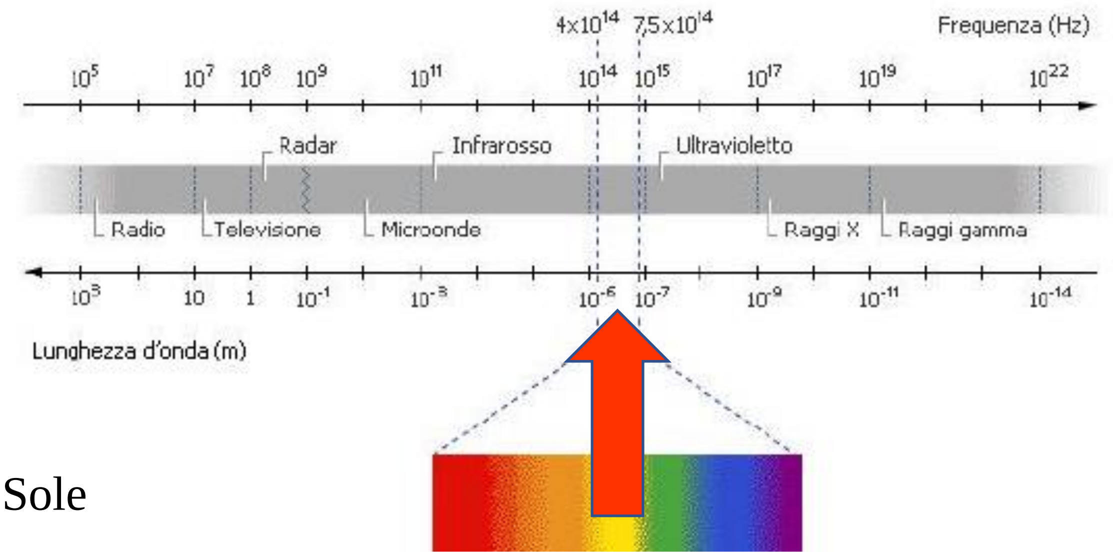


- The new magnetic layout introduces several steep variations in the magnetic field

Complicated interference effects between conventional synchrotron radiation and Edge radiation appear

Open Research Activity:
Analysis of the Interference effects by means of numerical simulations
Applications:
Radiation characterisation and optical beamline extraction design



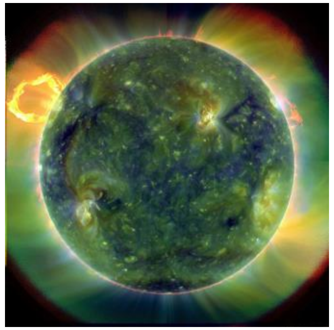


Visibile e Ultravioletto Vicino

10^{14} Hz-10^{17} Hz

λ=800 nm-10 nm

Sole



Lampada di Wood

SPARC_Lab

First demonstration of FEL light from plasma beam driven accelerator

Free-electron lasing with compact beam-driven plasma wakefield accelerator

Pompili, R; Alesini, D; Anania, M P; Arjmand, S; Behtouei, M; Bellaveglia, M; Biagioni, A; Buonomo, B; Cardelli, F; Carpanese, M; Chiadroni, E; Cianchi, A; Costa, G; Del Dotto, A; Del Giorno, M; Dipace, F; Doria, A; Filippi, F; Galletti, M; Giannessi, L

ISSN: 0028-0836 , 1476-4687; DOI: 10.1038/s41586-022-04589-1
Nature. , 2022, Vol.605(7911), p.659-662

PHYSICAL REVIEW LETTERS 129, 234801 (2022)

Stable Operation of a Free-Electron Laser Driven by a Plasma Accelerator

M. Galletti,[1,2,3,*] D. Alesini,[4] M. P. Anania,[4] S. Arjmand,[4] M. Behtouei,[4] M. Bellaveglia,[4] A. Biagioni,[4] B. Buonomo,[4] F. Cardelli,[4] M. Carpanese,[5] E. Chiadroni,[4,6] A. Cianchi,[1,2,3] G. Costa,[4] A. Del Dotto,[7] M. Del Giorno,[4] F. Dipace,[4] A. Doria,[5] F. Filippi,[5] G. Franzini,[4] L. Giannessi,[4] A. Giribono,[4] P. Iovine,[8] V. Lollo,[4] A. Mostacci,[6] F. Nguyen,[5] M. Opromolla,[9,10] L. Pellegrino,[4] A. Petralia,[5] V. Petrillo,[9,10] L. Piersanti,[4] G. Di Pirro,[4] R. Pompili,[4] S. Romeo,[4] A. R. Rossi,[10] A. Selce,[5,11] V. Shpakov,[4] A. Stella,[4] C. Vaccarezza,[4] F. Villa,[4] A. Zigler,[4,12] and M. Ferrario[4]

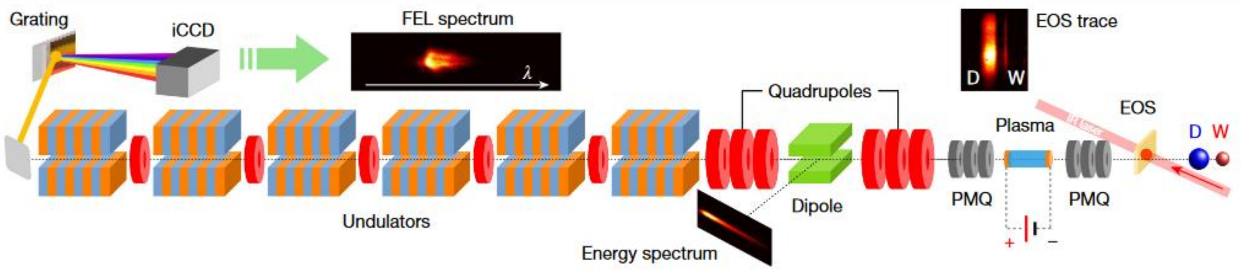
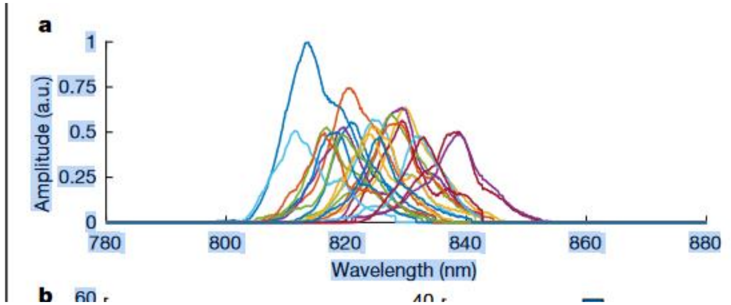
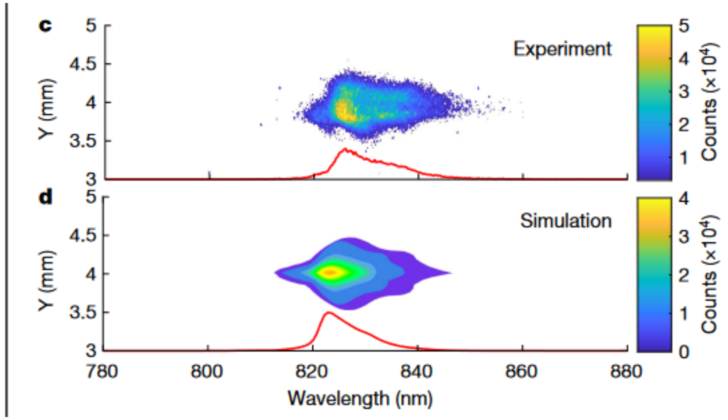


Fig. 1 | Experimental setup. The driver (D) and witness (W) electron bunches are produced by the photo-injector and their temporal separation is continuously monitored with a non-intercepting EOS diagnostics. The bunches are focused by a triplet of PMQs in a 3-cm-long capillary containing the plasma produced by ionizing hydrogen gas with a high-voltage discharge. The accelerated witness is extracted by a second triplet of PMQs and transported using six electromagnetic quadrupoles. A dipole spectrometer is used to measure its energy with a scintillator screen installed on a 14° beamline. The FEL beamline consists of six planar undulators with tunable gaps and five quadrupoles in between to transport the beam. The emitted FEL radiation is collected by an in-vacuum metallic mirror and measured with an imaging spectrometer equipped with a diffraction grating and a cooled intensified camera (iCCD).





Contact people:

Riccardo.Pompili@lnf.infn.it
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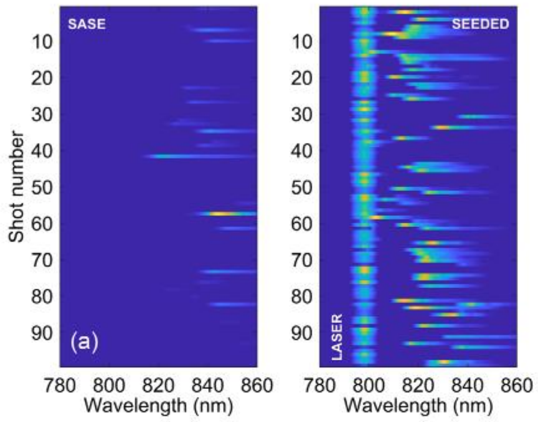
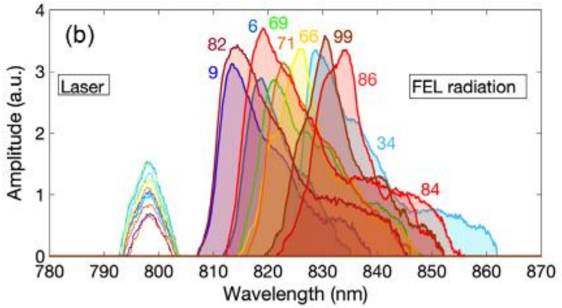




Betatron source: EuAbs

The motion of the electrons in the plasma waves produces
the **Betatron radiation,** with a spectrum extended from visible to X-rays.

Contact: Andrea.Rossi@mi.infn.it

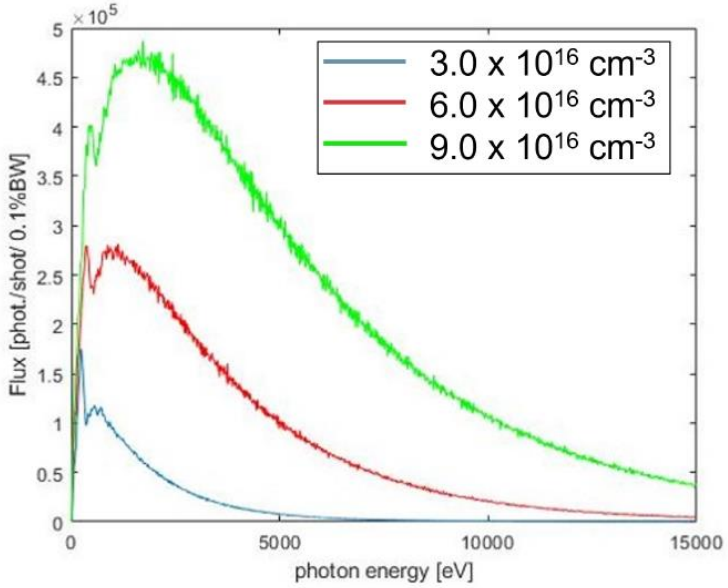
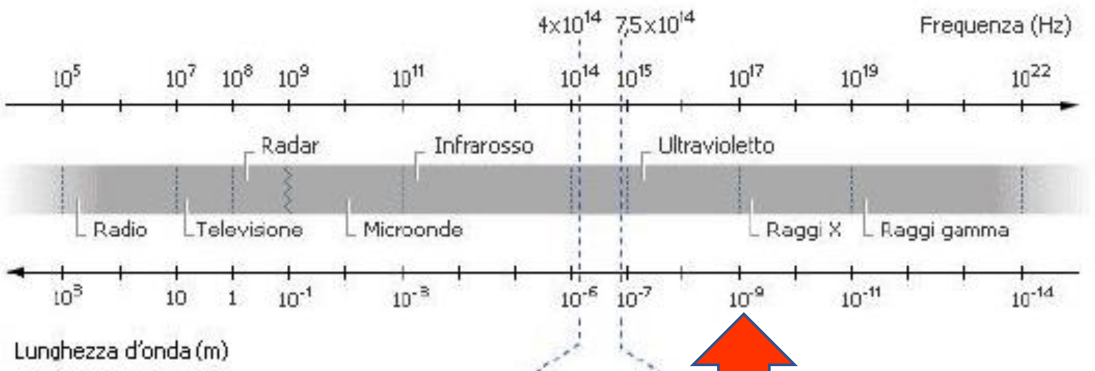


Figure 1. Betatron radiation spectra simulated for a source size of 3 μm and 3 different plasma densities. The total number of photons is 1.7 x ^{9} for the 9.0 x 10^{16} cm^{-3} density, 9.9 x ^{8} for the 6.0 x 10^{16} cm^{-3} density and 4.1 x ^{8} for the 3.0 x 10^{16} cm^{-3} density.

In the plasma wave electron can even undulate in a synchron way increasing the radiation coherence, already presented by

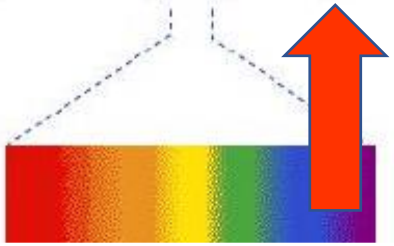
Enrica.Chiadroni@lnf.infn.it

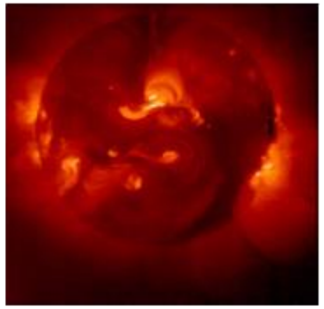


Ultravioletto Lontano e Raggi X

10^{17} Hz-10^{20} Hz

λ=10 nm-0.01 nm





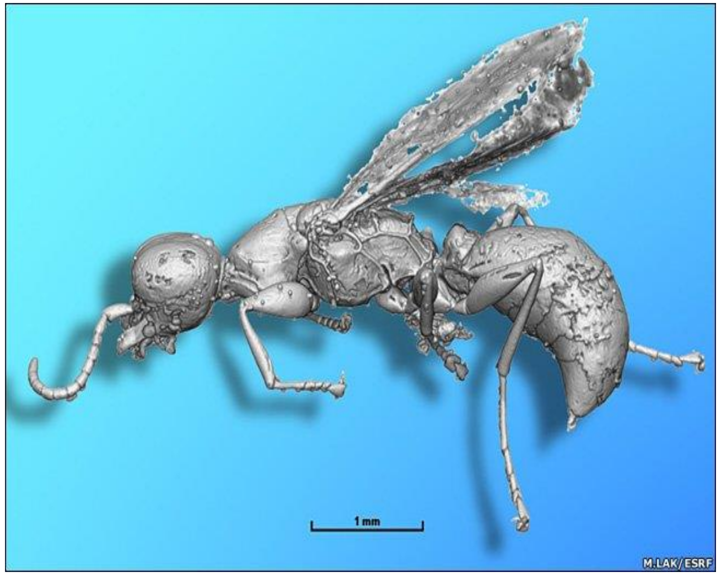
Generatori:

Tubi Roentgen

Sincrotroni

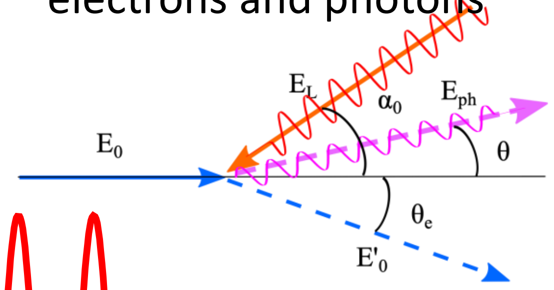
FEL

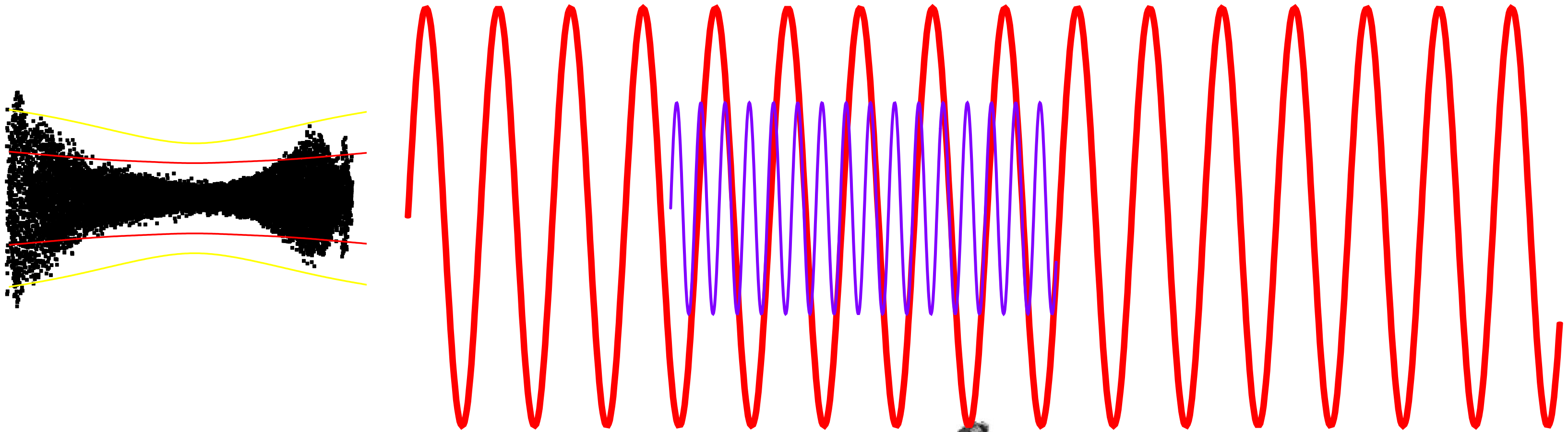
Betatrone



Inverse Compton Scattering

Collision between
electrons and photons





Progetti in costruzione: a Cosenza: STAR

Collisore elettrone-fotone altamente asimmetrico e compatto* (cfr. LHC)

***10 m, 10 M$**

Contact: Luca.Serafini@mi.infn.it

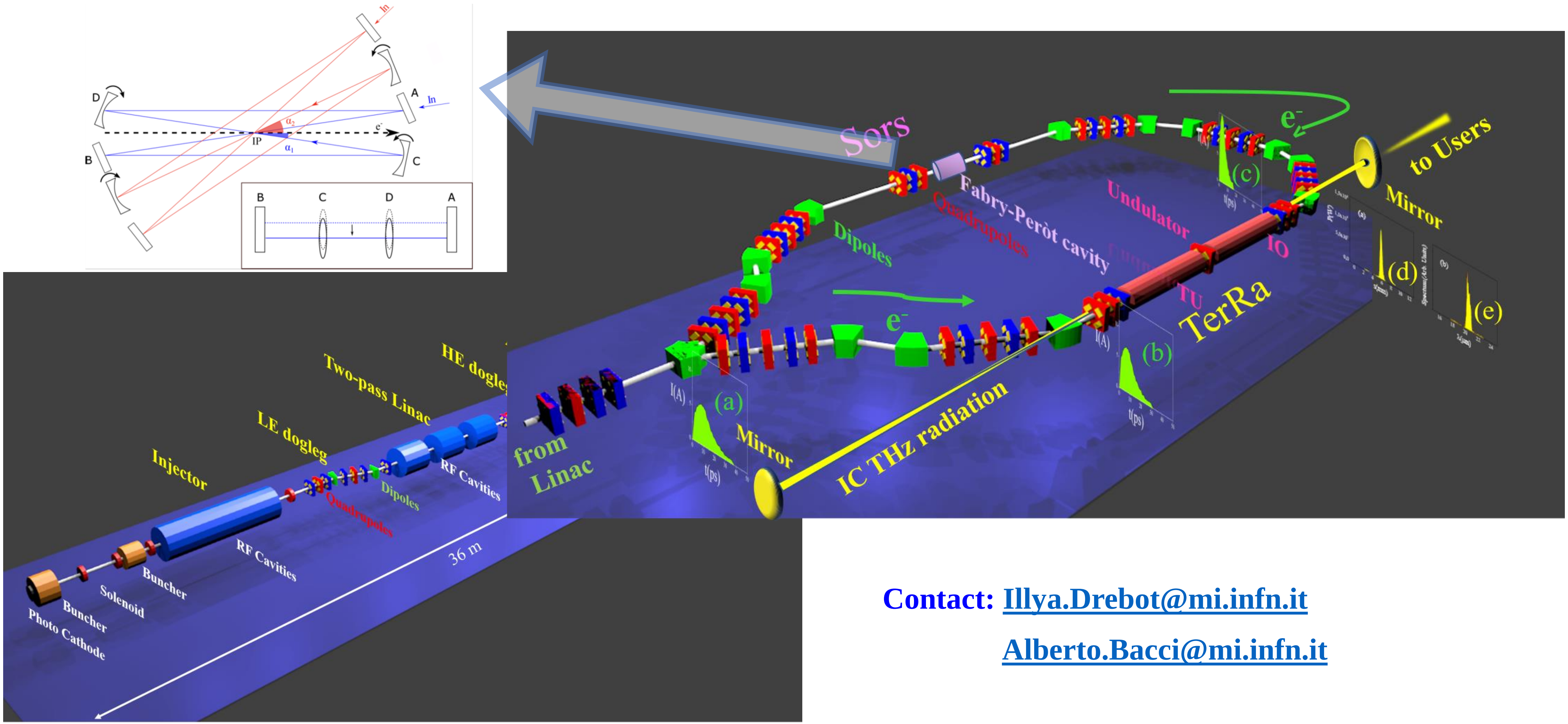
Alberto.Bacci@mi.infn.it

Fascio secondario di fotoni prodotto grazie al boost di Lorentz del sistema di riferimento del centro di massa elettrone-fotone.

Alta qualità del fascio di elettroni, ma basso repetition rate.

***Fig.2** – STAR machine as an example of Paradigm A. Overall length about 12 m.*

BriXSinO ERL Compton Scattering



Contact: Illya.Drebot@mi.infn.it

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Standard Magnetic Undulator for intense X-ray sources

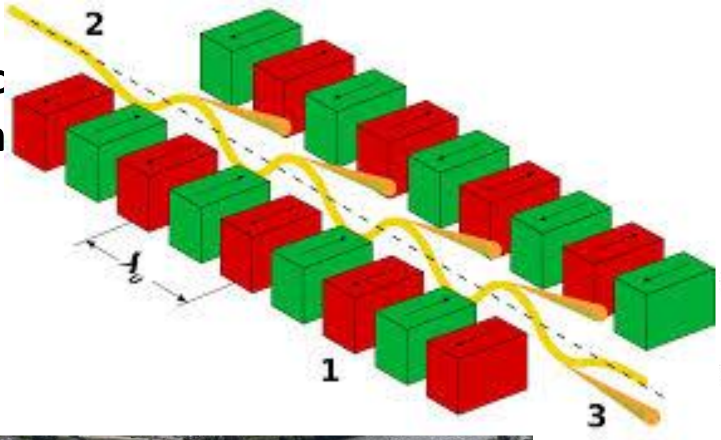
TECHNO-CLS

G.A. 101046458

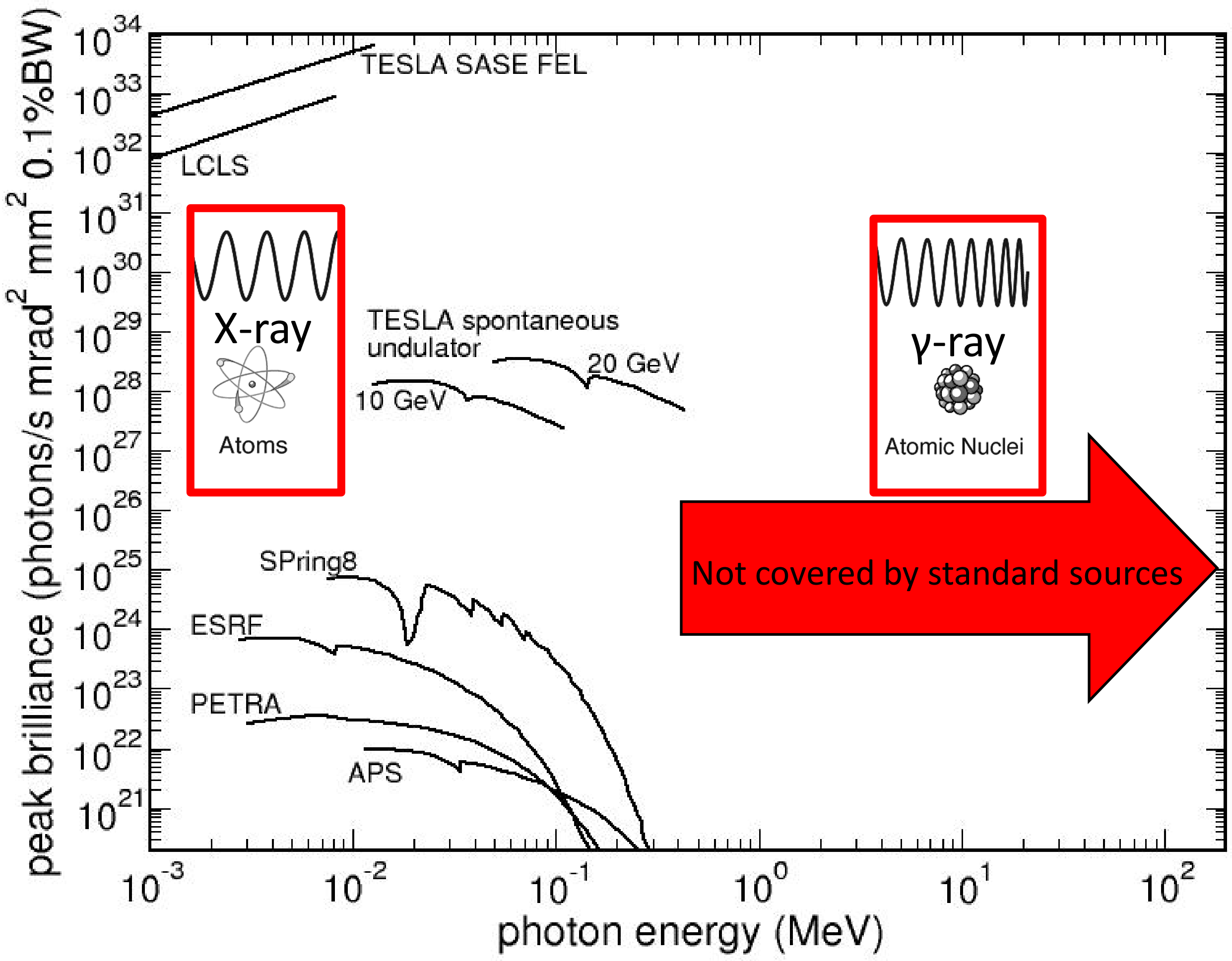
Classical scheme: magnetic undulator in a free electron laser

Soft X-rays (10 keV)

λ_u ~ cm

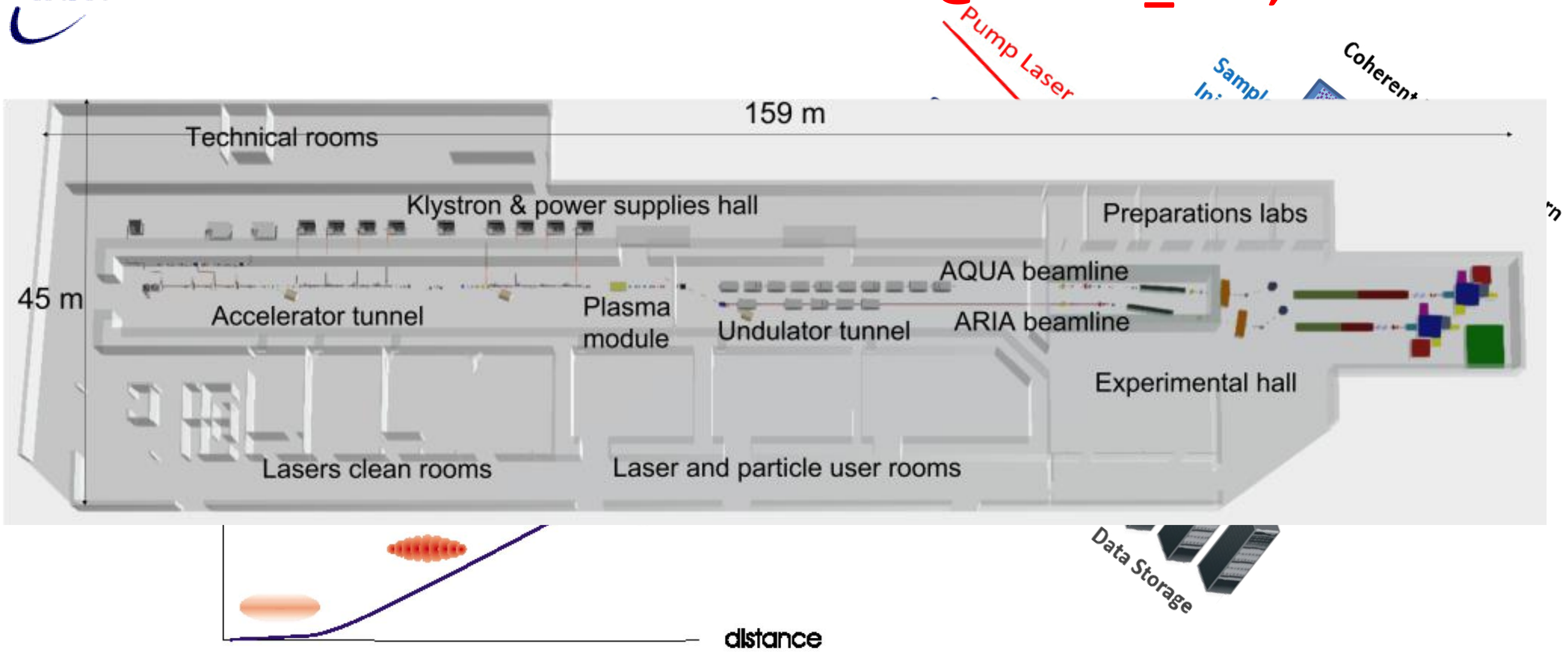


ESRF



To create a **powerful LS in the range λ<< 1Å,** new approaches and technologies are needed (ICS, Gamma factory ….)

Free Electron laser at EuPRAXIA@SPARC_LAB, LNF

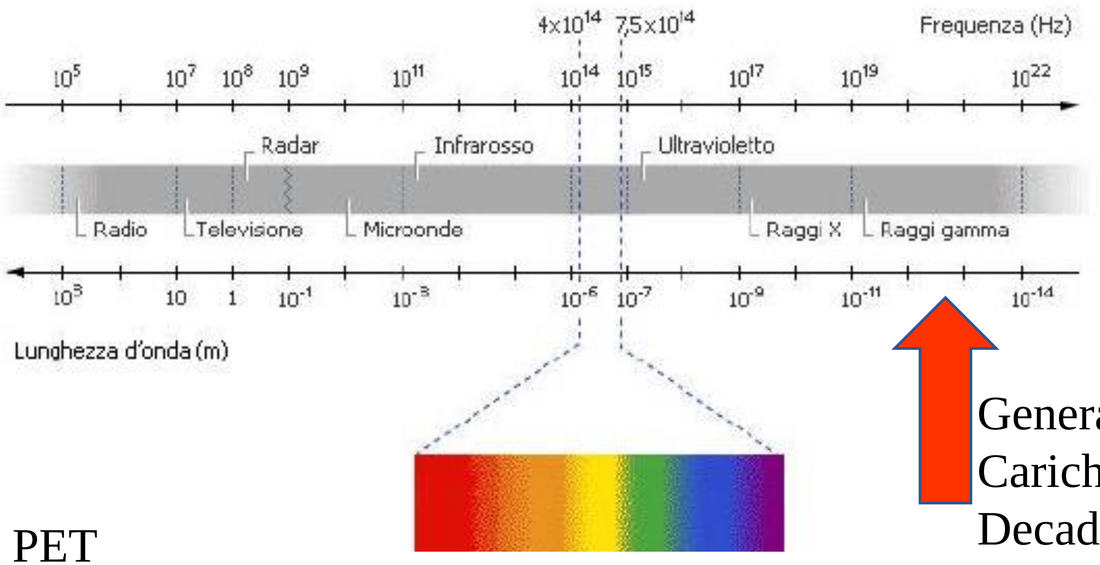


PhD Thesis Projects on FELs at EuPRAXIA@SPARC_LAB, LNF
Project leader: Massimo.Ferrario@lnf.infn.it

Massimo.Ferrario@lnf.infn.it Luca.Giannessi@lnf.infn.it
Petrillo@mi.infn.it
Alberto.Petralia@enea.it
Federico.nguyen@enea.it

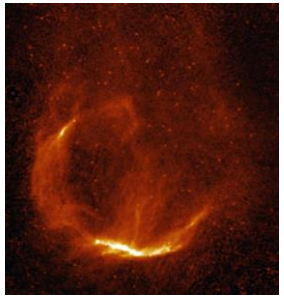
1) Seeded free-electron laser for the generation of UV ultrashort coherent pulses from a plasma-wake accelerator (ARIA)
2) Design of a narrow bandwidth, seeded free-electron laser for the generation of VUV light (ARIA)
3) Undulator design
4) Wakefield effect on radiation

A. Ghigo, A. Curcio
5) Possibility of using the betatron radiation to seed an X-ray FEL (AQUA)

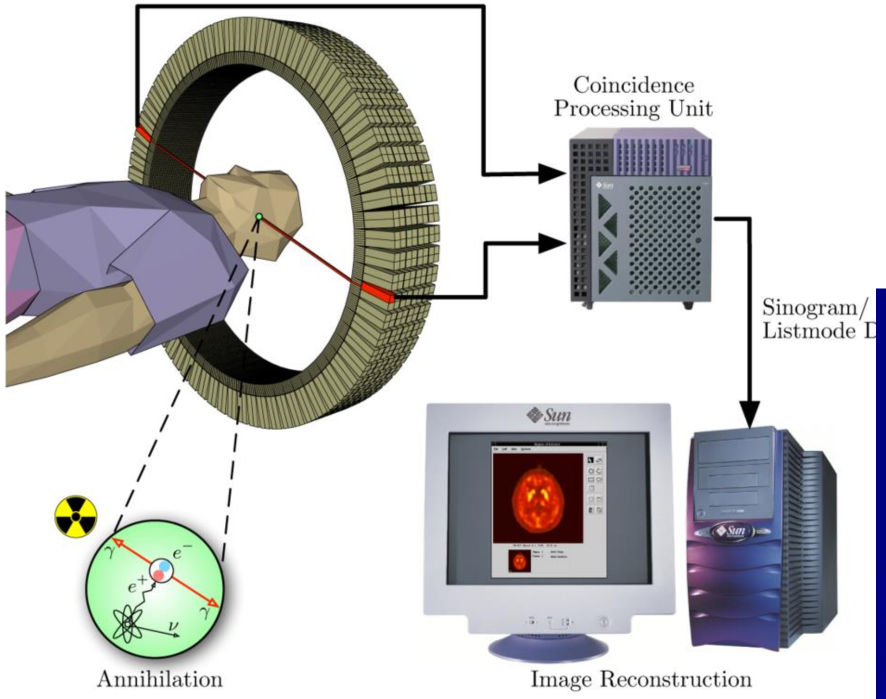


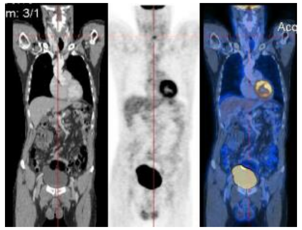
Raggi Gamma
$>10^{20}$ Hz
$\lambda<0.01$ nm

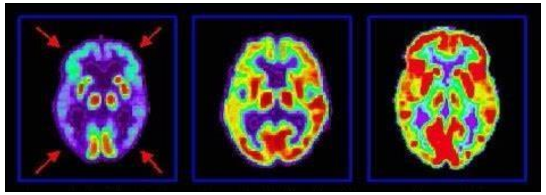
Generatori:
Cariche in moto
Decadimento e^+-e^-

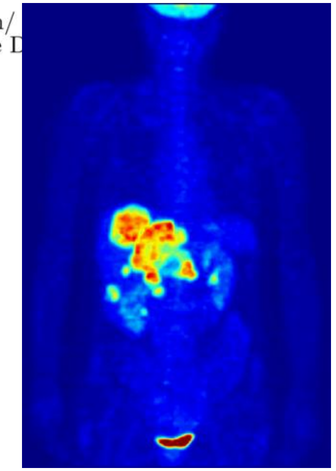


PET



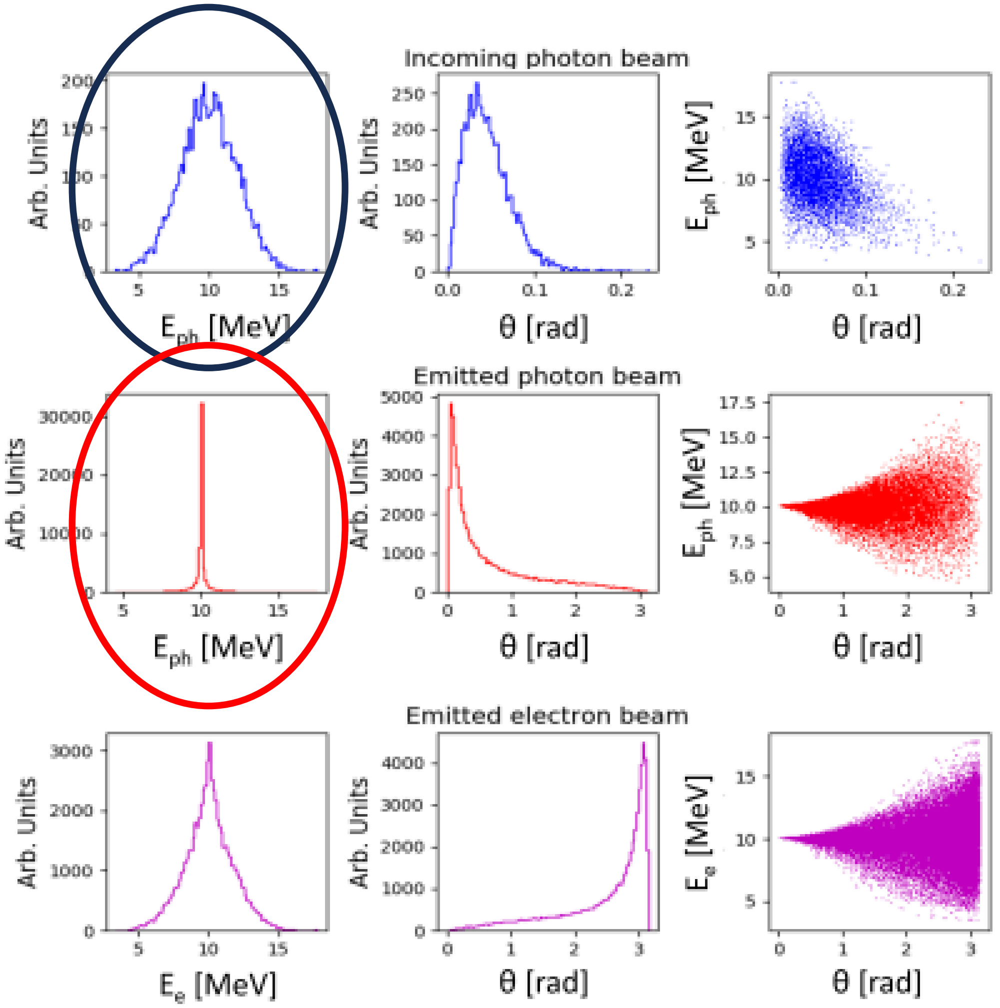






confronto tra depresso, normale, AD

Symmetric Compton Scattering



A new idea by L. Serafini
Luca.Serafini@mi.infn.it

A particular regime in ICS where the spectrum of the X or gamma-rays can be changed from white….

….to extremely monochromatic.

Other contacts:
Illya.Drebot@mi.infn.it

G.A. 101046458

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

TECHNO-CLS

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

INFN Contact: Laura Bandiera, bandiera@fe.infn.it

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

MBN Research Center

INFN Istituto Nazionale di Fisica Nucleare

ESRF

HELLENIC MEDITERRANEAN UNIVERSITY

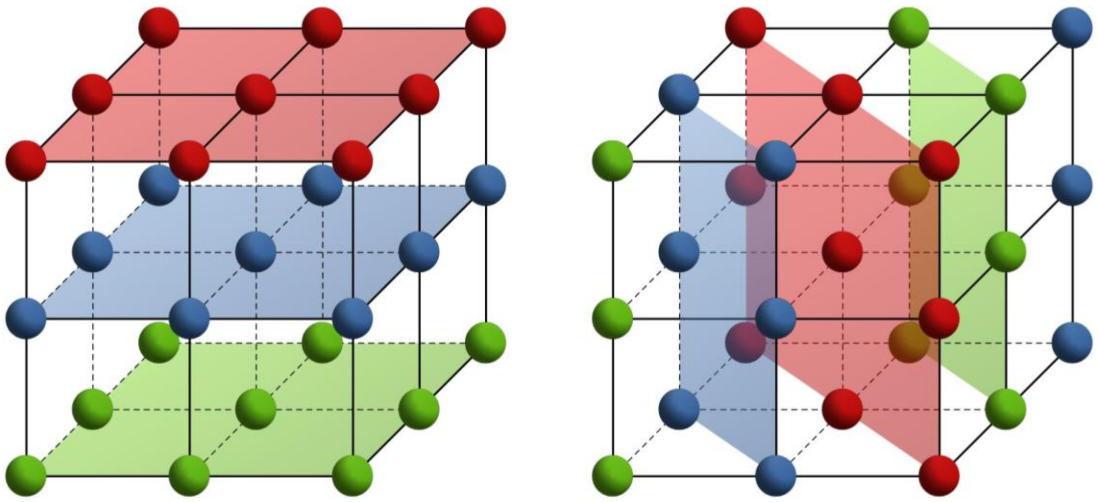
Università degli Studi di Padova

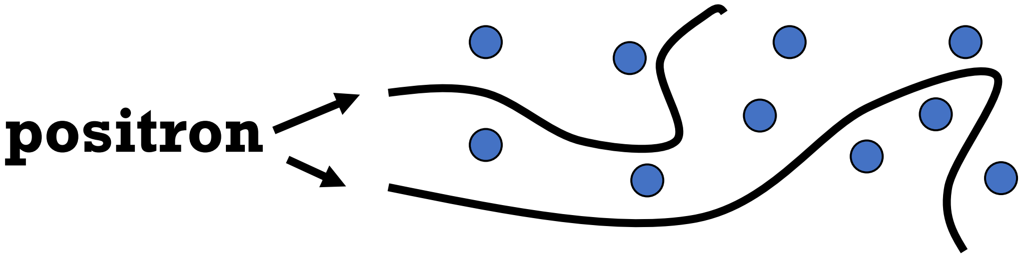
Università degli Studi di Ferrara

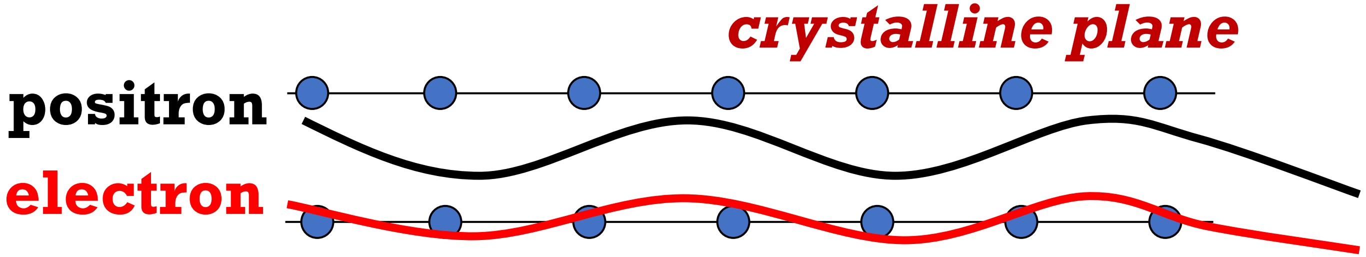
University of Kent

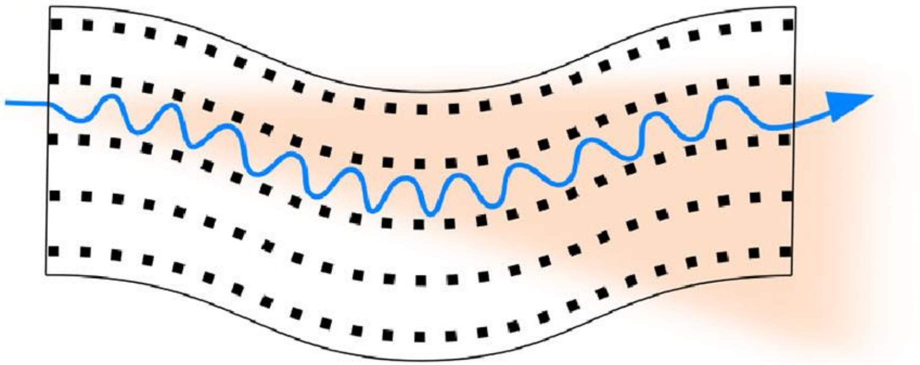
Trapping particles inside crystal channels

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







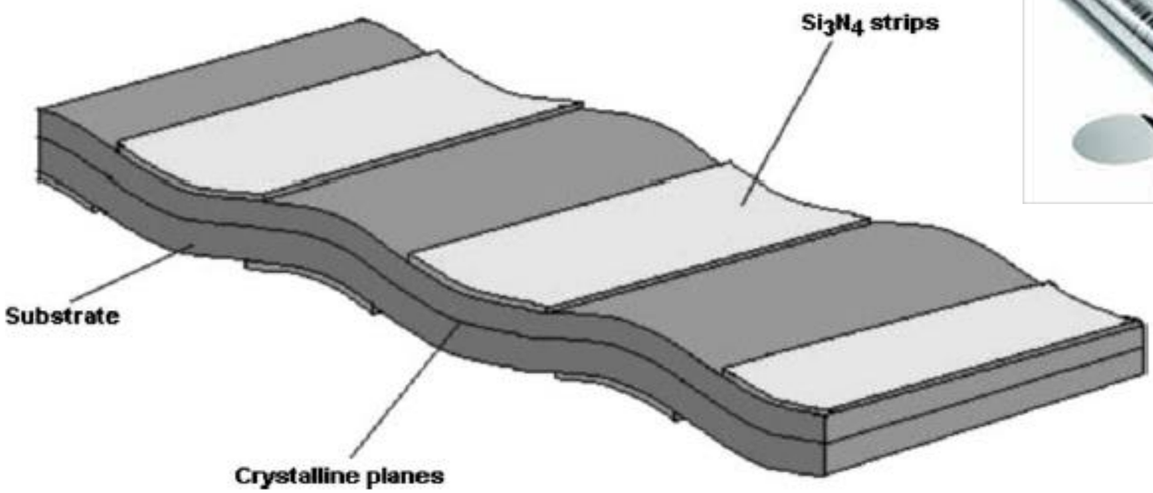


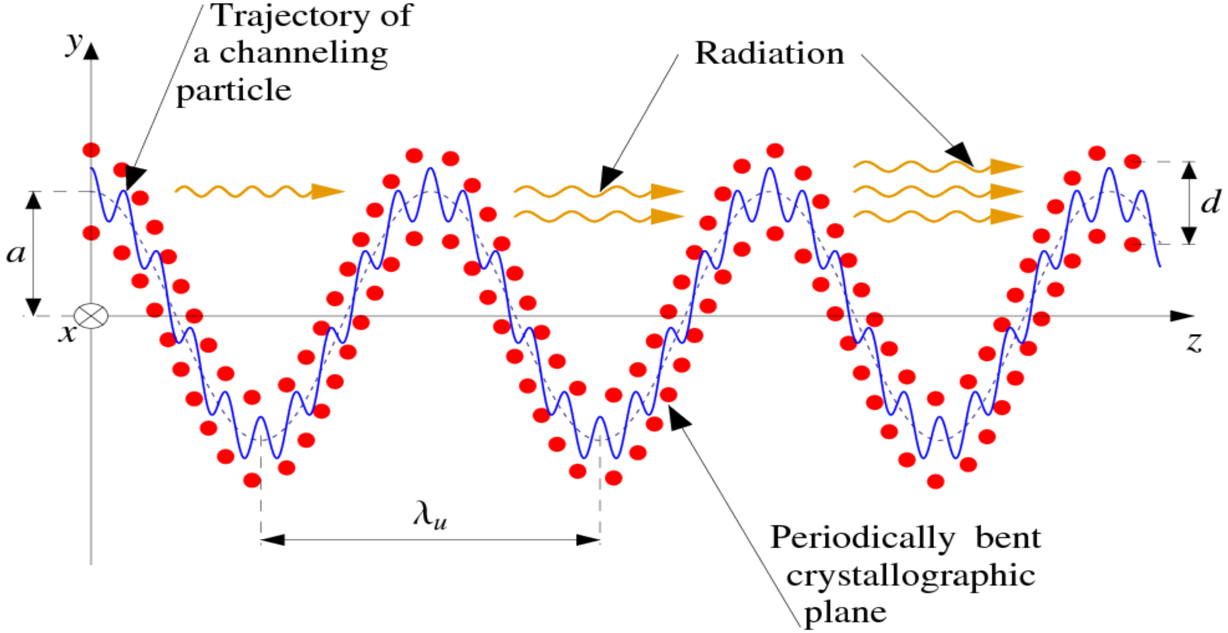
If the crystal is periodically bent, the particle beam follows the bending

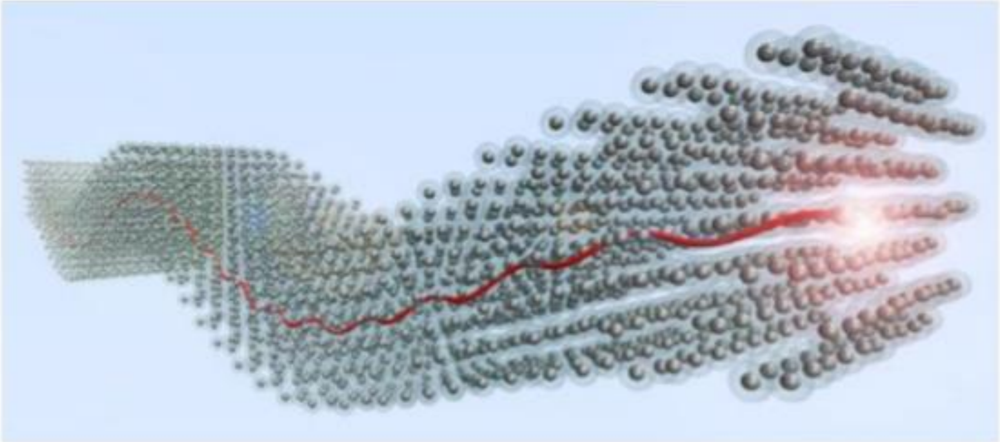
A Crystalline Undulator

A periodically bent crystal can be realized via thin film deposition

Silicon and Germanium







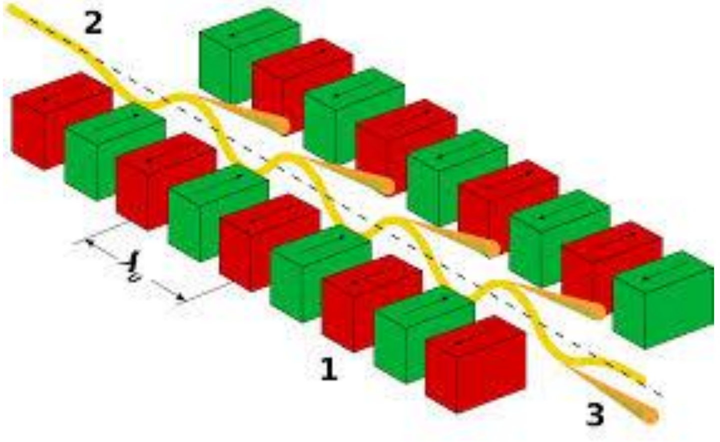
Artistic view of a Crystal-based Light Source (CLS)

Standard Magnetic Undulator vs Crystal Light Source

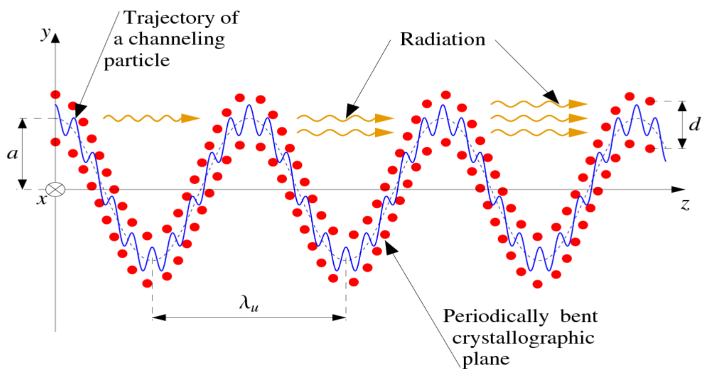
G.A. 101046458

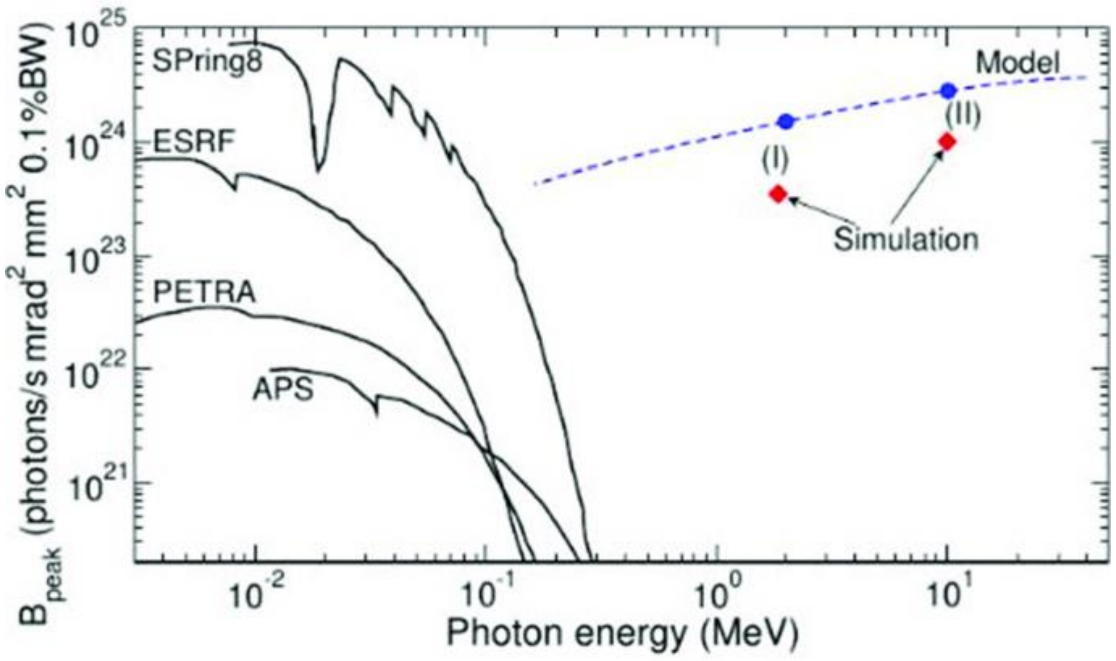
Korol, A.V., Solov'yov, A.V. Eur. Phys. J. D 74, 201 (2020).

Classical scheme: magnetic undulator in a free electron laser
Soft X-rays (10 keV)
λ_u ~ 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.

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