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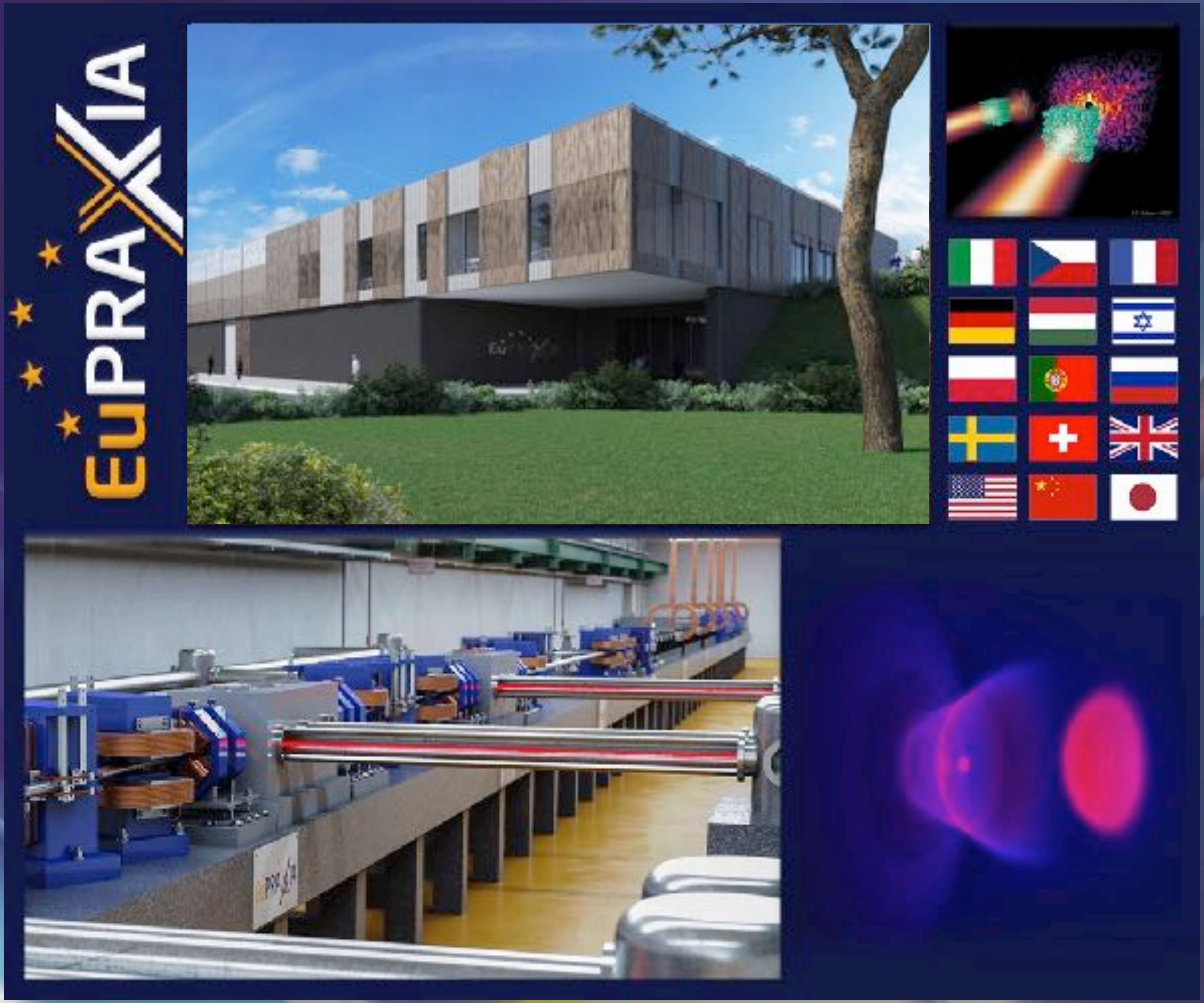
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS



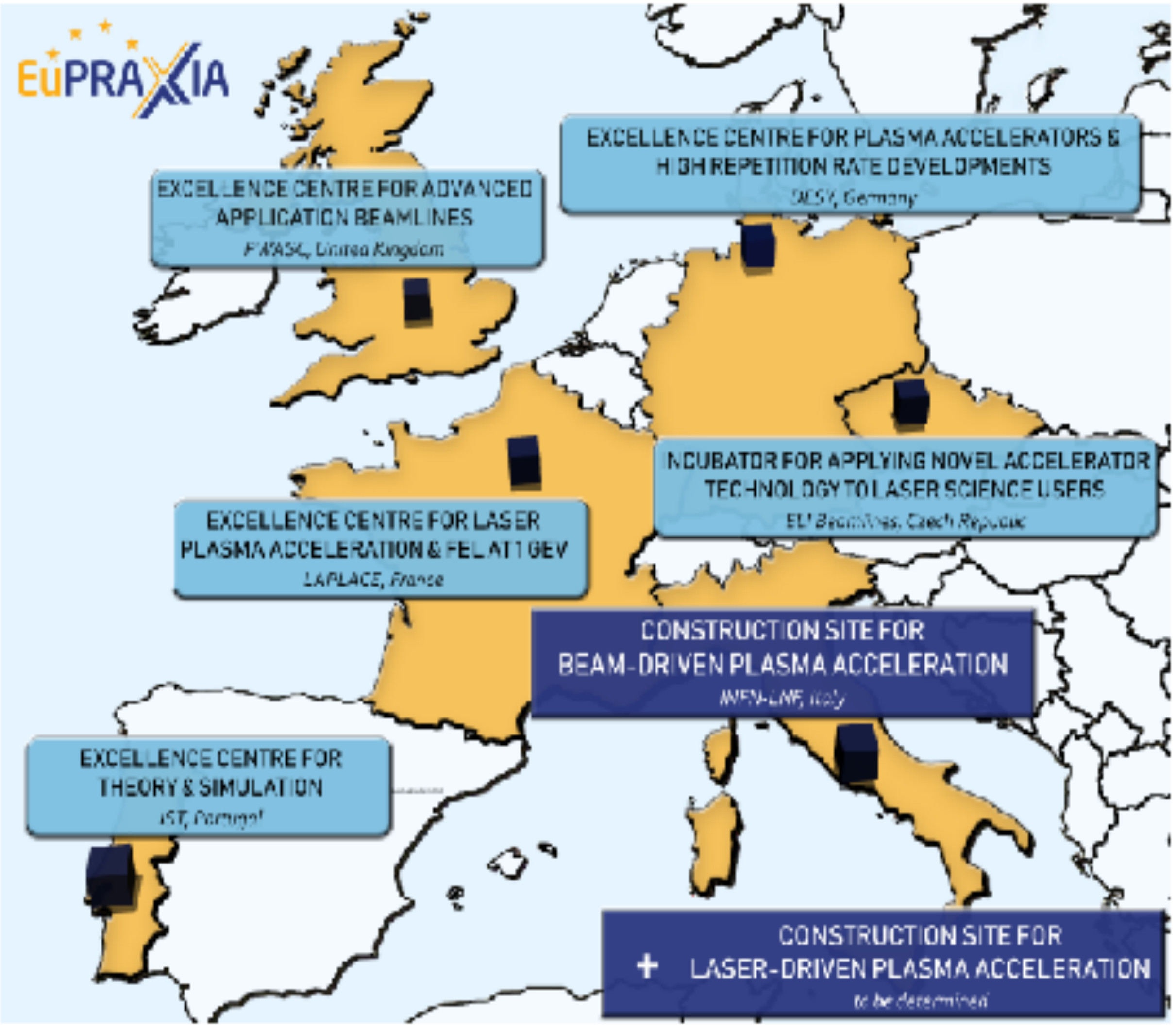
EuPRAXIA Advanced Photon Sources

Andrea R. Rossi

Consiglio di Sezione -14.07.2022

EuPRAXIA is an ESFRI Distributed Facility

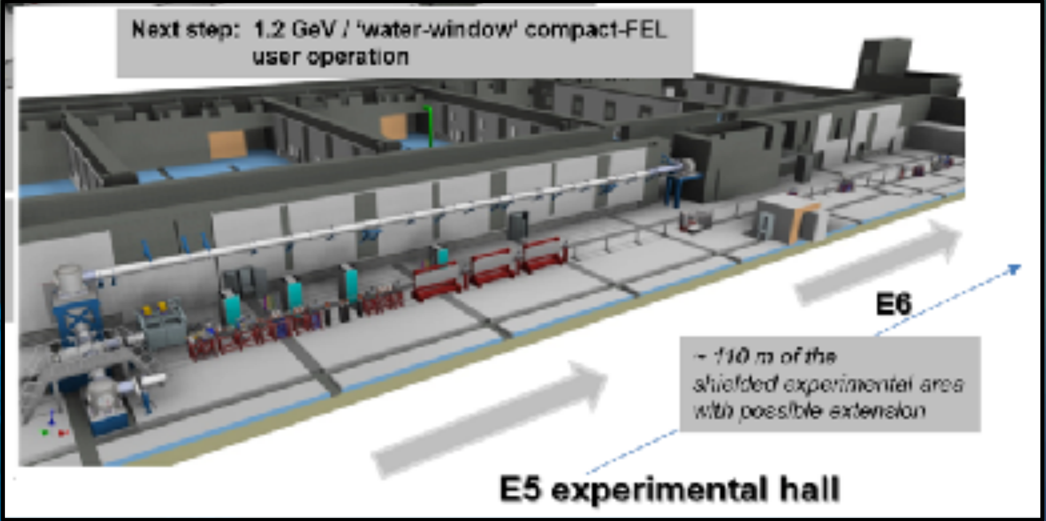
1. Lean overall **EuPRAXIA management**
2. **Ten clusters:** Collaborations of institutes on specific problems, developing solutions, technical designs, driving developments with EuPRAXIA generated funding → **expertise of Helmholtz centers required - opportunities**
3. **Five excellence centers** at existing facilities: Using pre-investment, support tests, prototyping, production with EuPRAXIA generated funding → **DESY excellence center**
4. **One or two construction sites** at existing facilities with EuPRAXIA generated funding:
   - **Beam-driven** at Frascati (Italy).
   - **Laser-driven** at CLF/STFC (UK), CNR/ INFN (Italy) or ELI-Beamlines.



Headquarter and Site 1: EuPRAXIA@SPARC_LAB

- Frascati`s future facility
- > 108 M€ invest funding
- Beam-driven plasma accelerator
- Europe`s most compact and most southern FEL
- The world`s most compact RF accelerator (X band with CERN)

Candidate 2nd Sites from CDR



From the EuPRAXIA CDR

The EuAPS proposal benefits from the preparatory work done in the conceptual design phase of EuPRAXIA, both for the scientific case and the technology. It focuses on an ambitious but technically achievable goal and builds on the pre-existing investments at the SPARC_LAB facilities. As stated in the EuPRAXIA CDR the following EuPRAXIA Flagship Goals will be addressed by the EuAPS Project:

Flagship Innovation Goal 2: EuPRAXIA will develop together with laser industry a **new generation of high peak power lasers**, advancing the presently leading technology into the regime of 20 - 100 Hz repetition rate […].

Flagship Science Goal 2*:* EuPRAXIA will deliver **betatron X rays with up to 10^{10} photons per pulse**, up to 100 Hz repetition rate and an energy of 5-18 keV to users from the medical area. […].

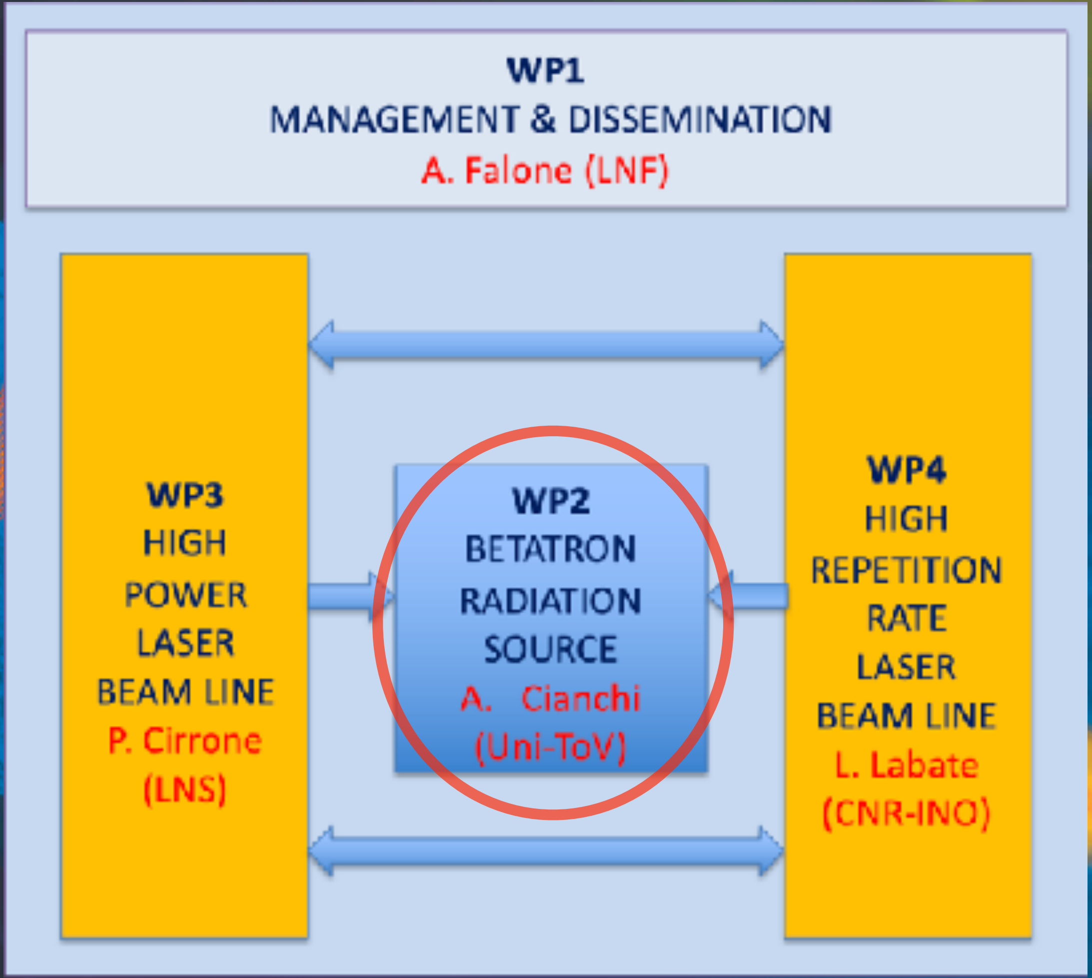
Flagship Science Goal 7*:* EuPRAXIA will provide access to cutting edge laser technology with **short pulse length in combination with high energy photon pulses** […].

We expect that the focus on a mature part of the EuPRAXIA project strongly supports project completion on the timescales that are required by PNRR.

EuPRAXIA Advanced Photon Sources Proposal

Started on February 13th, 2022 - Submitted on February 28th, 2022

EuAPS Scientific Coordinator:
M. Ferrario (INFN-LNF)
EuPRAXIA/EuAPS Integration:
R. Assmann (DESY & INFN)



Scientific Advisory Committee

Operating Units Board

Scientific and Technical Board

LNF-LNS-MI

INO-ISM

The INFN-MI Operating Unit will take care of the betatron source numerical design and optimization and will help in delivering data analisys algorithms to be implemented in the control system

Budget Distribution among WPs

LNF-MI

ISM

LNS

INO

COSTS (€) WORK PACKAGE [WP 2 - Betatron Radiation Source]	Costs included in the request for funding		
	To be located within the eight southern Regions	To be located outside the eight southern Regions	Total requested grant
a. Fixed term personnel specifically hired for the project	120.000,00	878.000,00	998.000,00
b. Scientific instrumentation and technological equipment, software licenses and patent	1.000.000,00	6.840.400,00	7.840.400,00
c. Open Access, Trans National Access, FAI principal implementation	0,00	0,00	0,00
d. Civil infrastructures and related systems	0,00	0,00	0,00
e. Indirect costs, including running costs	76.400,00	540.283,00	616.683,00
f. Training activities	0,00	0,00	0,00
Total	1.196.400,00	8.258.683,00	[illegible]

COSTS (€) WORK PACKAGE [WP 3 - High Power Laser Beam Line]	Costs included in the request for funding		
	To be located within the eight southern Regions	To be located outside the eight southern Regions	Total requested grant
a. Fixed term personnel specifically hired for the project	150.000,00	0,00	150.000,00
b. Scientific instrumentation and technological equipment, software licenses and patent	5.917.812,47	0,00	5.917.812,47
c. Open Access, Trans National Access, FAI principal implementation	0,00	0,00	0,00
d. Civil infrastructures and related systems	1.300.006,38	0,00	1.300.006,38
e. Indirect costs, including running costs	496.651,15	0,00	496.651,15
f. Training activities	0,00	0,00	0,00
Total	[illegible]	0,00	7.864.470,00

COSTS (€) WORK PACKAGE [WP 4 - High Repetition Rate Laser Beam Line]	Costs included in the request for funding		
	To be located within the eight southern Regions	To be located outside the eight southern Regions	Total requested grant
a. Fixed term personnel specifically hired for the project	0,00	240.000,00	240.000,00
b. Scientific instrumentation and technological equipment, software licenses and patent	0,00	4.024.986,00	4.024.986,00
c. Open Access, Trans National Access, FAI principal implementation	0,00	0,00	0,00
d. Civil infrastructures and related systems	0,00	380.000,00	380.000,00
e. Indirect costs, including running costs	0,00	318.164,00	318.164,00
f. Training activities	0,00	0,00	0,00
Total	0,00	4.963.150,00	4.963.150,00

INFN-MI O.U. will receive about 500 k€ for fixed term personnel (4 FTE total) and high performance hardware

Betatron Radiation Source

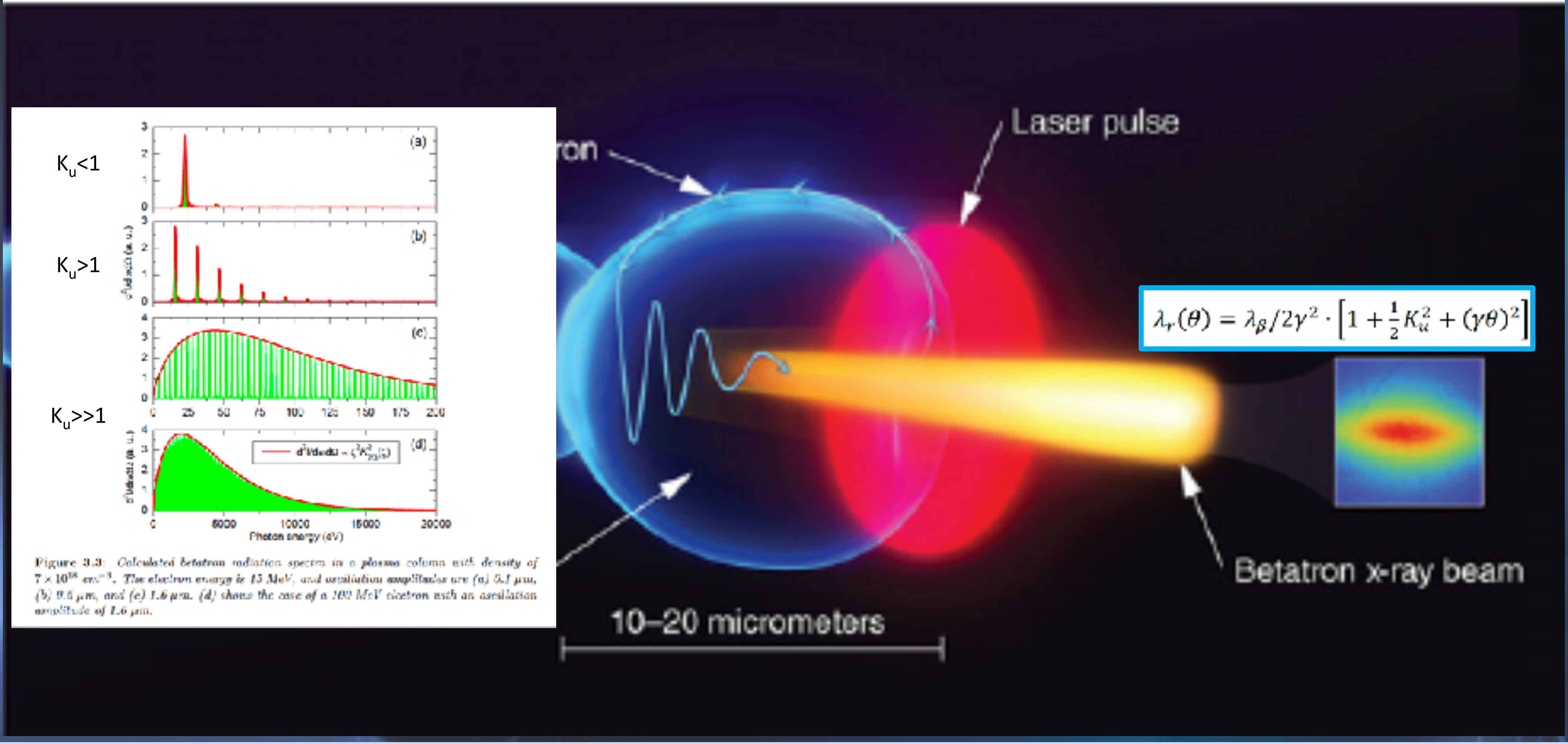
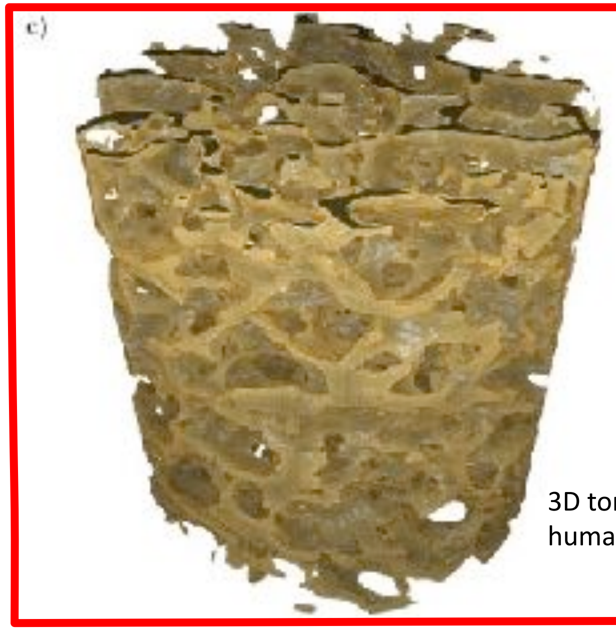


Figure 3.3: Calculated betatron radiation spectra in a plasma column with density of 7×10^{18} cm^{-3}. The electron energy is 15 MeV, and oscillation amplitudes are (a) 0.1 μm, (b) 0.6 μm, and (c) 1.6 μm. (d) shows the case of a 100 MeV electron with an oscillation amplitude of 1.6 μm.

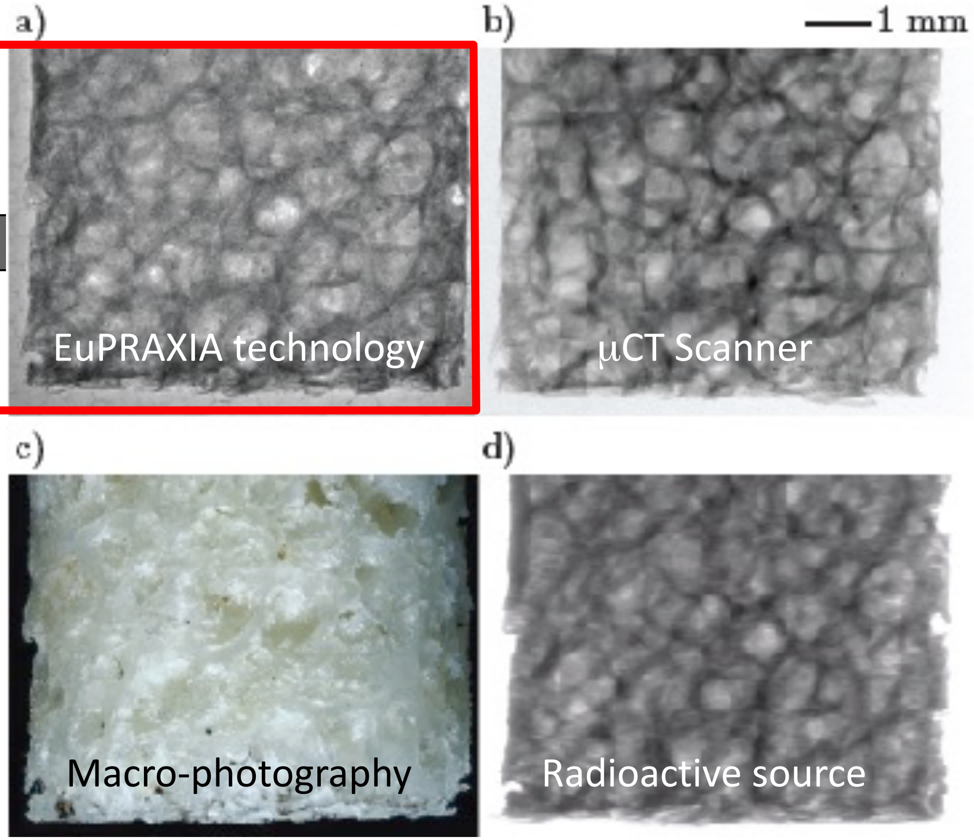
$$\lambda_r(\theta) = \lambda_\beta / 2\gamma^2 \cdot \left[1 + \tfrac{1}{2}K_u^2 + (\gamma\theta)^2\right]$$

Betatron X Rays: Compact Medical Imaging

J.M. Cole et al, "Laser-wakefield accelerators as hard x-ray sources for 3D medical imaging of human bone". Nature Scientific Reports 5, 13244 (2015)



3D tomography of human bone



- EuPRAXIA laser advance (industry) will push rate from 1/min to 100 Hz.
- **Ultra-compact source of hard X rays → exposing from various directions simultaneously is possible in upgrades**

Physics & Technology Background:

- Small EuPRAXIA accelerator → small emission volume for betatron X rays.
- **Quasi-pointlike** emission of X rays.
- **Sharper image from base optical principle.**
- Quality demonstrated and published, but takes a few hours for one image.
- Advancing flux rate with EuPRAXIA laser by factor > 1,000!

Added value

Sharper images with outstanding **contrast**

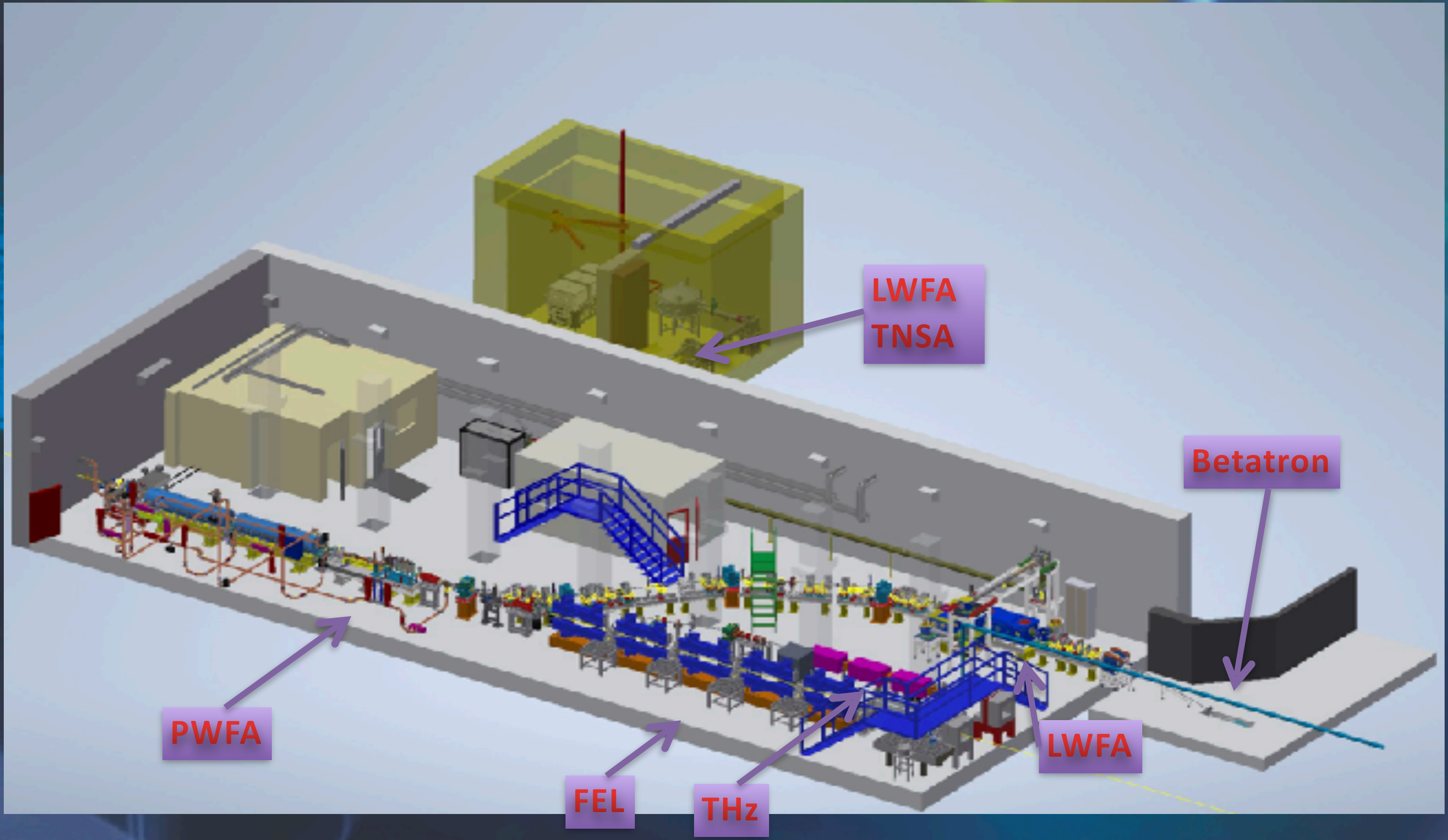
Identify smaller features (e.g. early detection of cancer at micron-scale – calcification)

Laser advance in EuPRAXIA → **fast imaging** (e.g. following moving organs during surgery)

WP2 - Betaron Radiation Source at SPARC_LAB

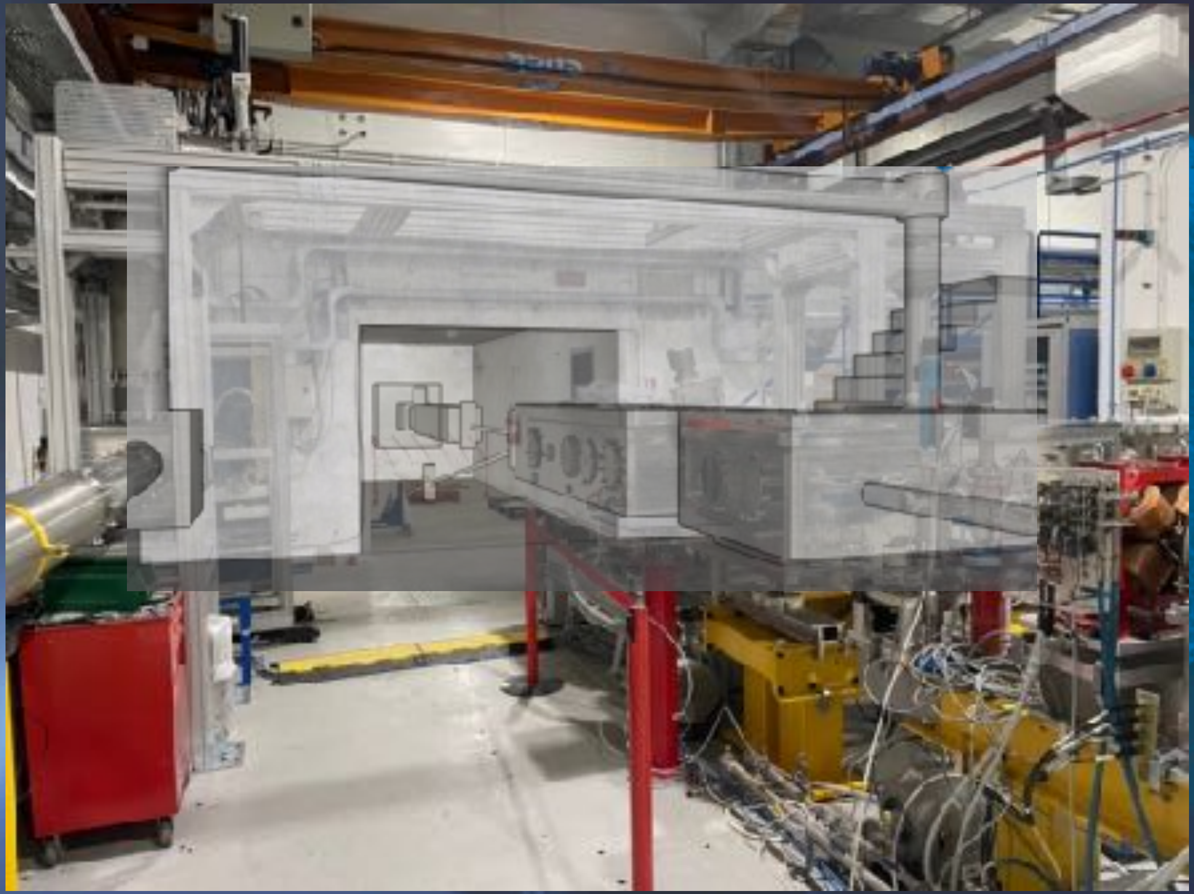
LNF-MI

ISM

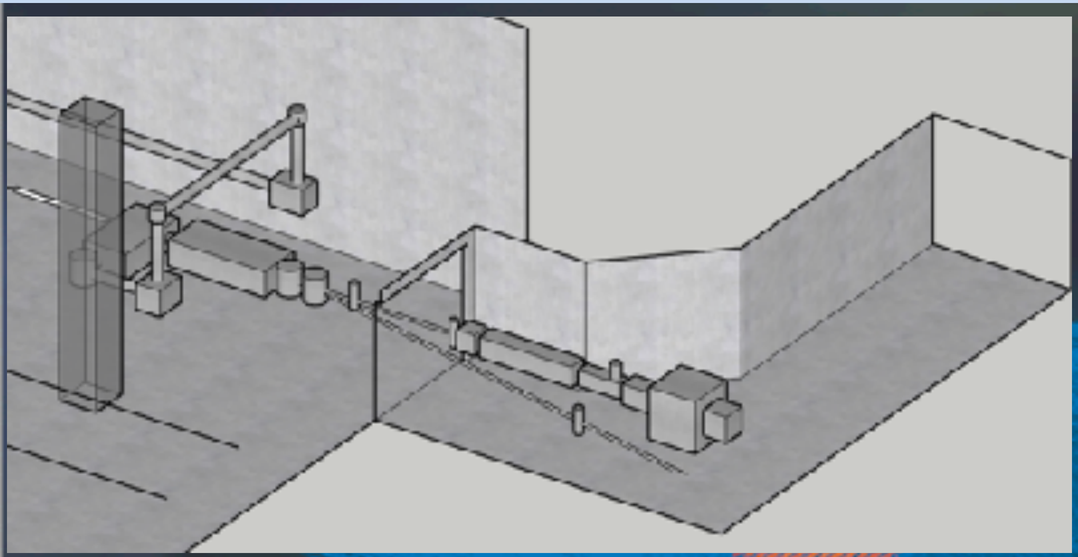


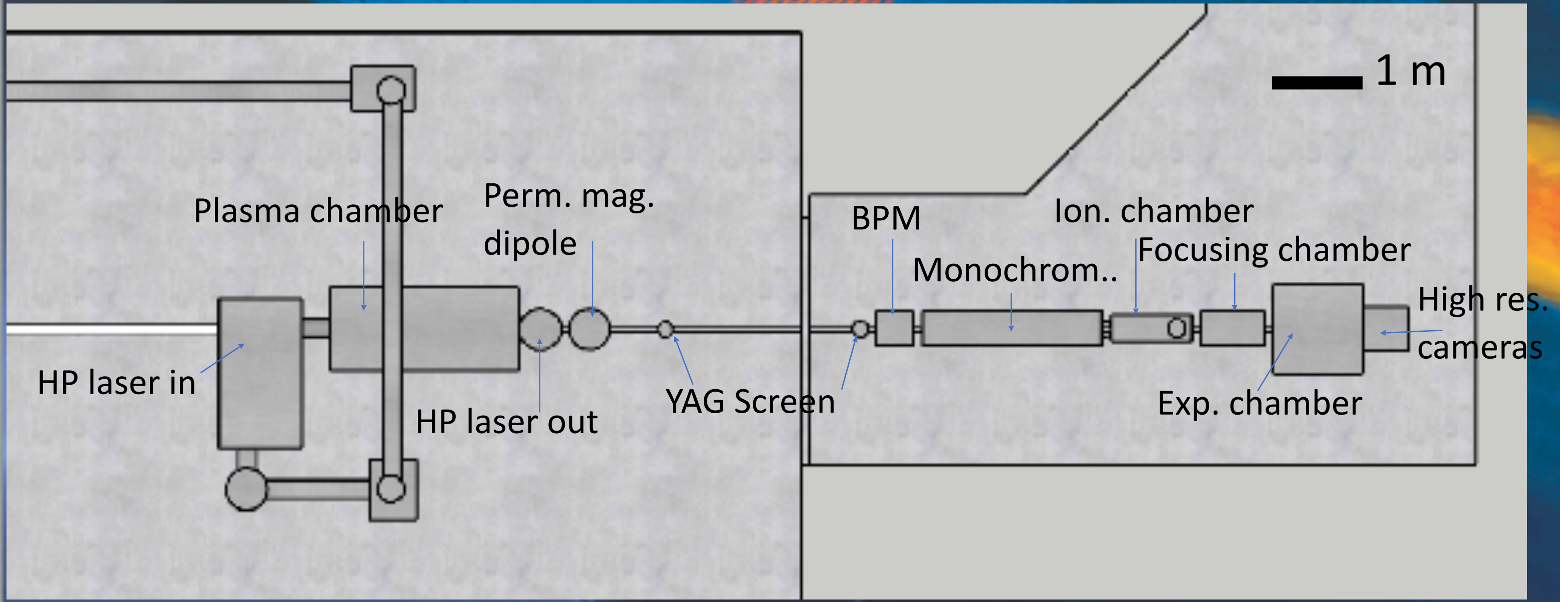
WP2 - Betaron Radiation Source at SPARC_LAB

- Laser/Plasma interaction chamber at SPARC_LAB just intalled and possible betatron radition user's beam line



WP2 - Betaron Radiation Source at SPARC_LAB





First measurements of betatron radiation at FLAME laser facility

A. Curcio, M. Anania, F. Bisesto, E. Chiadroni, A. Cianchi, M. Ferrario, F. Filippi, D. Giulietti, A. Marocchino, F. Mira, M. Petrarca, V. Shpakov, A. Zigler

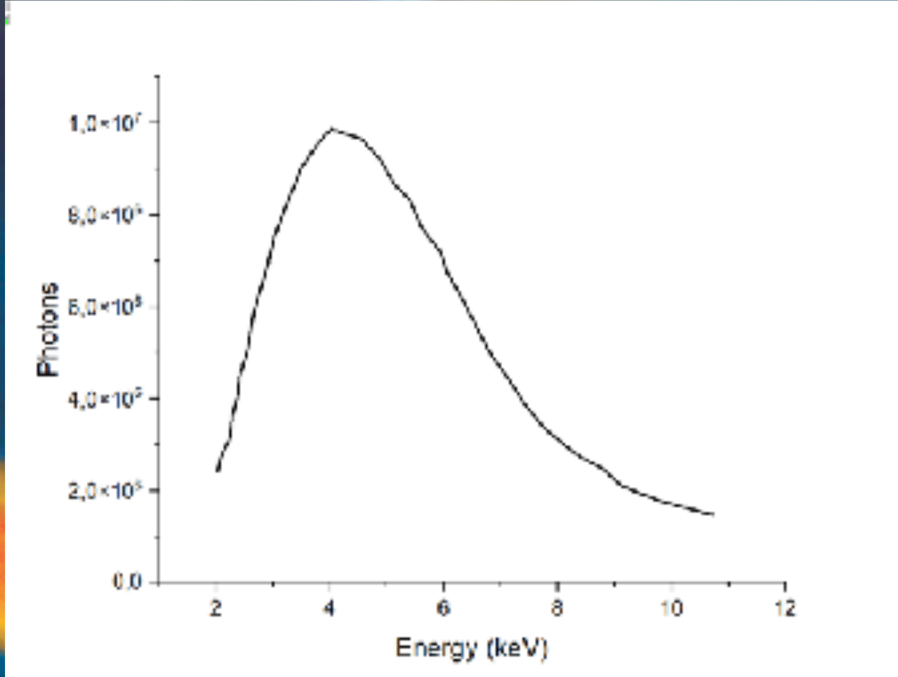
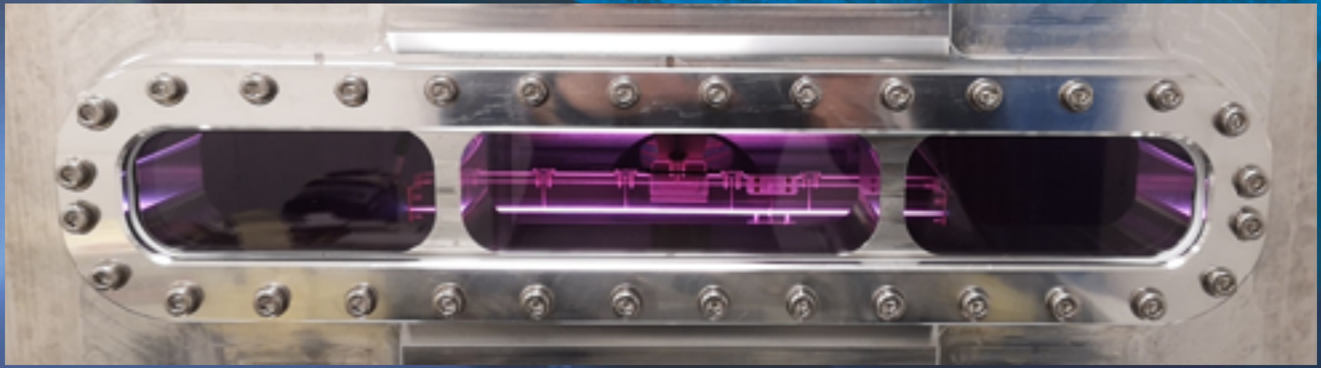


Fig. 6. Betatron radiation spectrum detected by the CdTe spectrometer. Laser, plasma and electron parameters: energy per pulse $E_L = 1.5$ J, pulse duration $\tau = 35$ fs, focus rms radius $\sigma_r \sim 5$ µm. Electron plasma density $n_e \sim 6 \pm 1 \times 10^{18}$ cm^{-3}, electron mean energy 200 MeV, energy spread 30%, electron beam divergence 12 mrad, bunch charge 20 pC. The acceleration length was 1 mm.

WP1 - Betaron Radiation Source at EuPRAXIA@SPARC_LAB

Plasma-Generated X-ray Pulses: Betatron Radiation Opportunities at EuPRAXIA@SPARC_LAB

Francesco Stellato [1,2,*], Maria Pia Anania [3], Antonella Balerna [3], Simone Botticelli [3], Marcello Coreno [3,4], Gemma Costa [3], Mario Galletti [1,2], Massimo Ferrario [3], Augusto Marcelli [3,5,6], Velia Minicozzi [1,2], Silvia Morante [1,2], Riccardo Pompili [3], Giancarlo Rossi [1,2,7], Vladimir Shpakov [3], Fabio Villa [3] and Alessandro Cianchi [1,2]



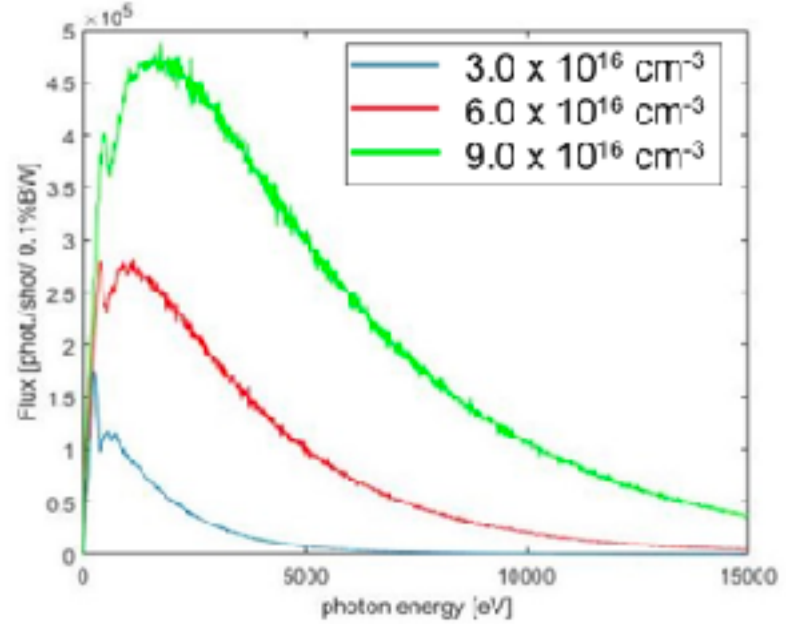
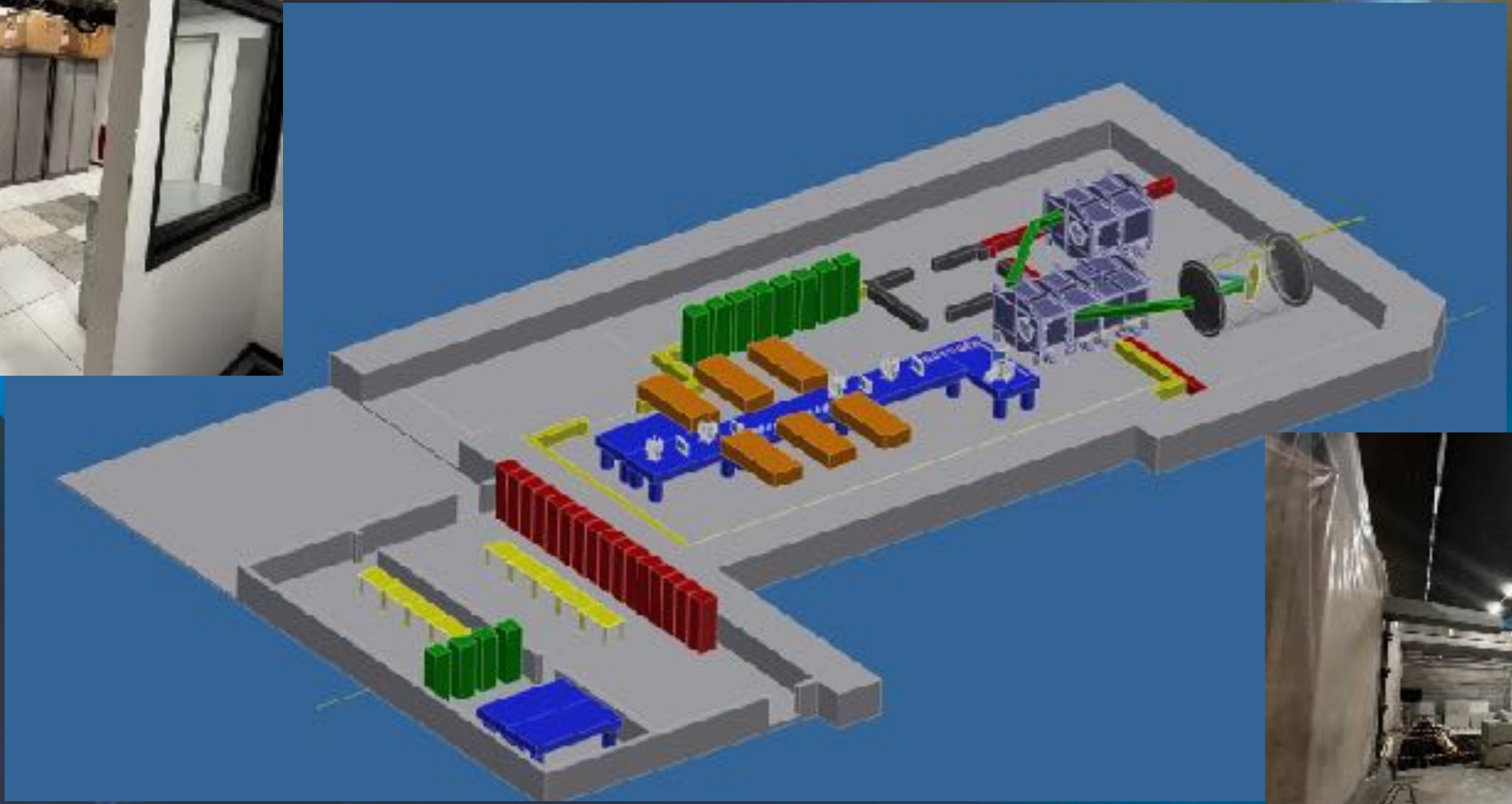


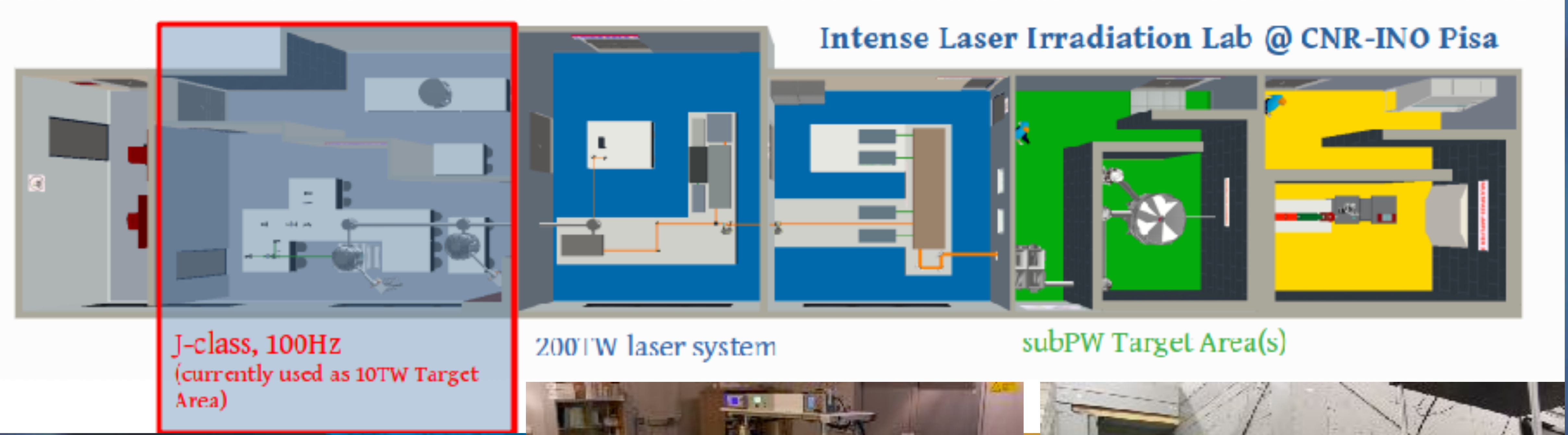
Figure 1. Betatron radiation spectra simulated for a source size of 3 μm and 3 different plasma densities. The total number of photons is 1.7 x ^{9} for the 9.0 x 10^{16} cm^{-3} density, 9.9 x ^{3} for the 6.0 x 10^{16} cm^{-3} density and 4.1 x ^{8} for the 3.0 x 10^{16} cm^{-3} density.

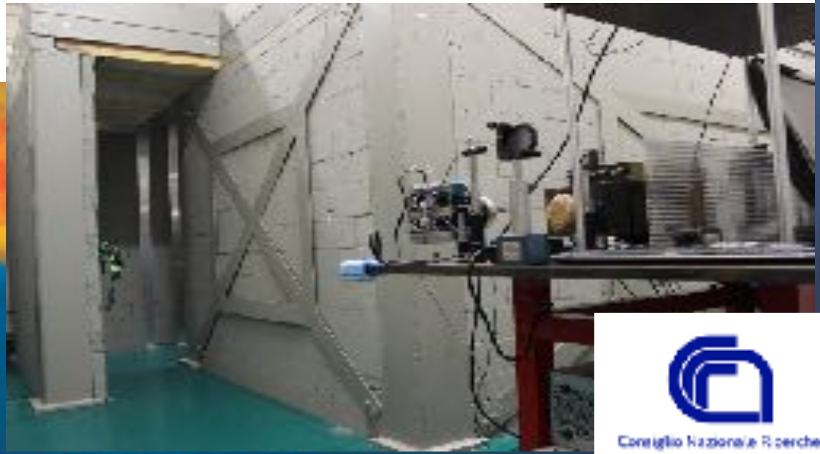
WP3 - I-LUCE INFN-Laser indUced radiation acCEleration



LNS

WP4 - ILIL@CNR-INO High Repetition Rate Laser





INO

Conclusions

- One of the ambitions of EuAPS is to be the first operating brick of the EuPRAXIA project well in advance compared to the EuPRAXIA time scale.

- Thus bringing together laser, plasma and advanced accelerator scientists with radiation user's experts to promote the blooming of a new scientific community well prepared to efficiently exploit the scientific opportunities of EuPRAXIA.

- Significant advancement in Laser Technology for EuPRAXIA

- X-ray users beam line scientific case in preparation, medical applications

- A lot of new interesting beam physics still possible (various plasma configurations, plasma undulator and FEL, beam diagnostics, limitation for LC)

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Thank you for your attention