The EuPRAXIA@SPARC_LAB Project

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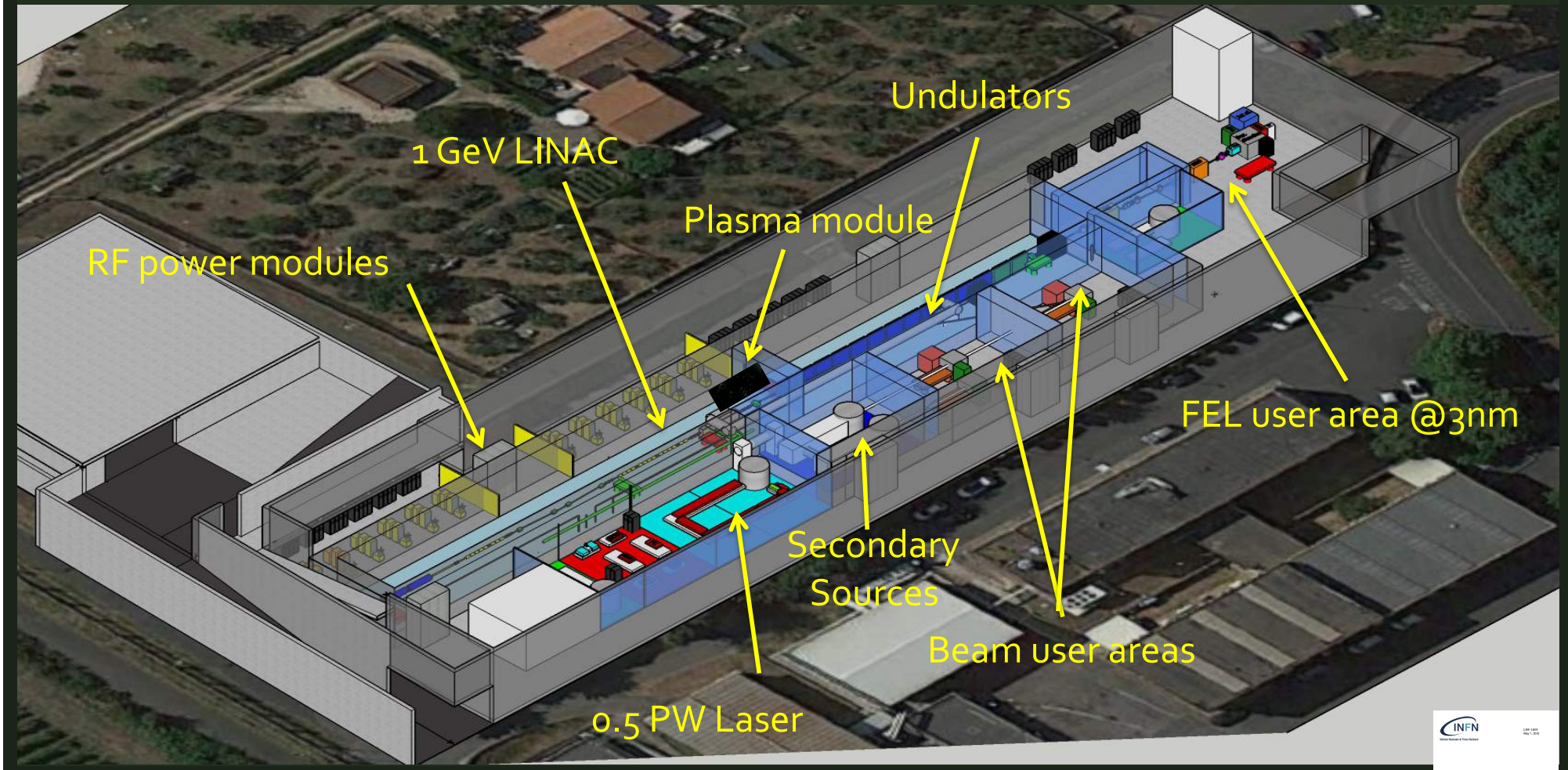
EuPRAXIA@SPARC_LAB Users Workshop, Zoom, October 14, 2021

INFN
Istituto Nazionale di Fisica Nucleare

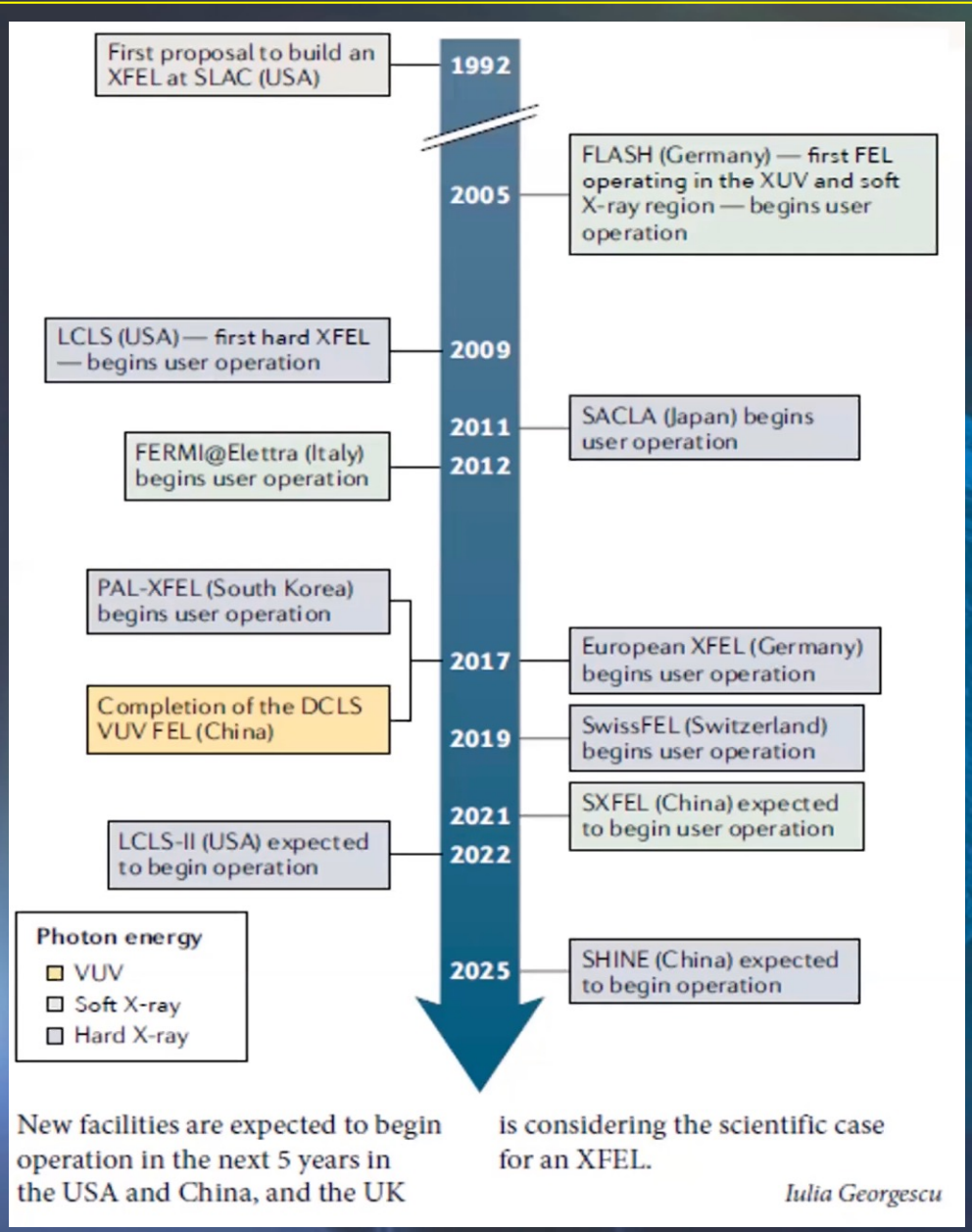
EuPRAXIA@SPARC_LAB



http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

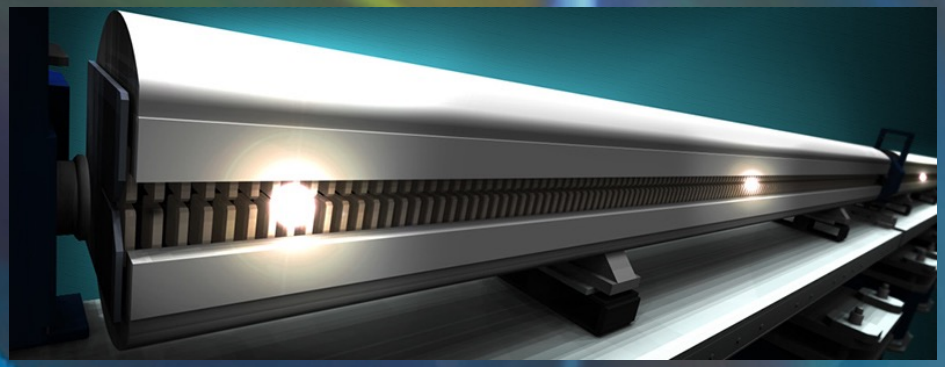
FEL is a well established technology

(But a widespread use of FEL is partially limited by size and costs)

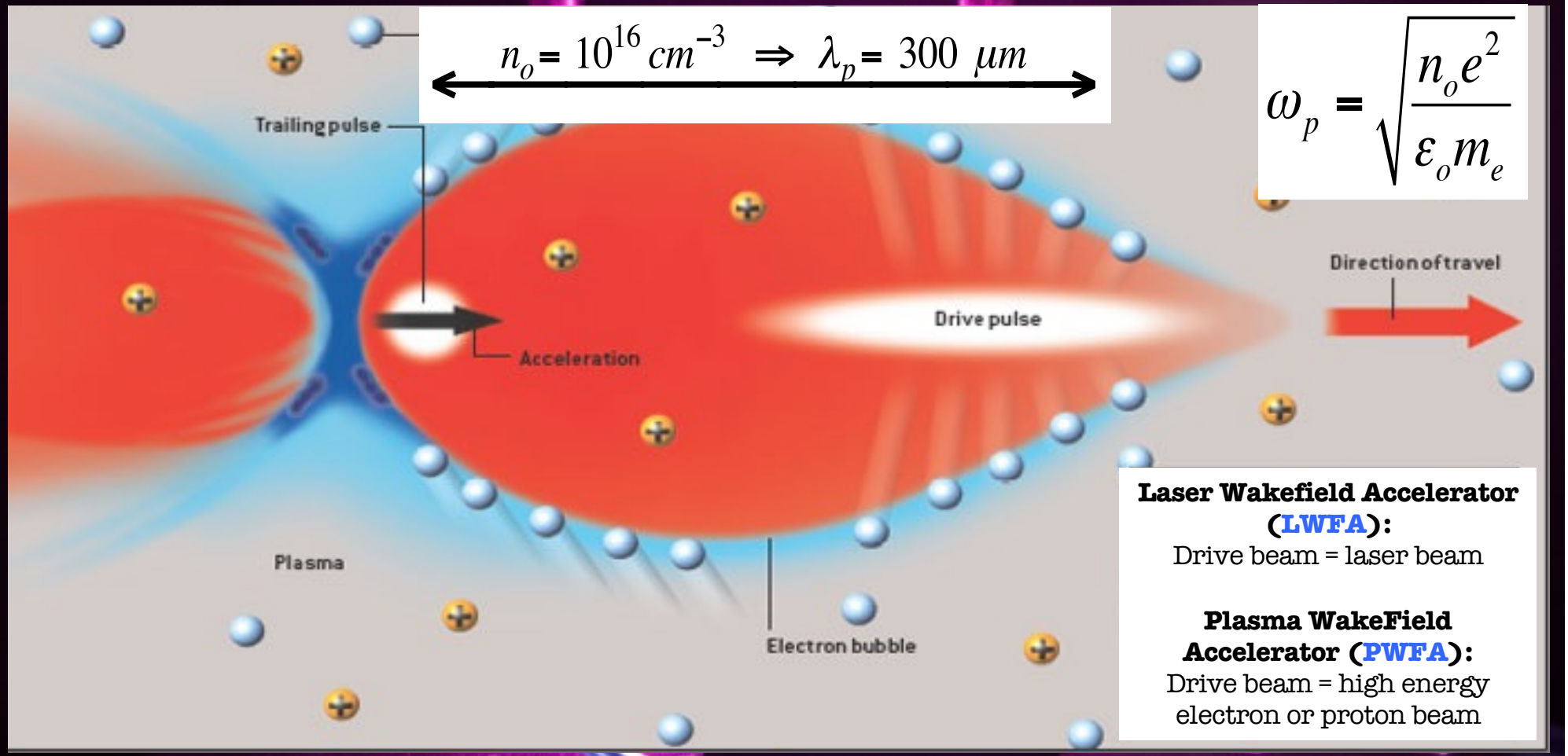


New facilities are expected to begin operation in the next 5 years in the USA and China, and the UK is considering the scientific case for an XFEL.

Iulia Georgescu



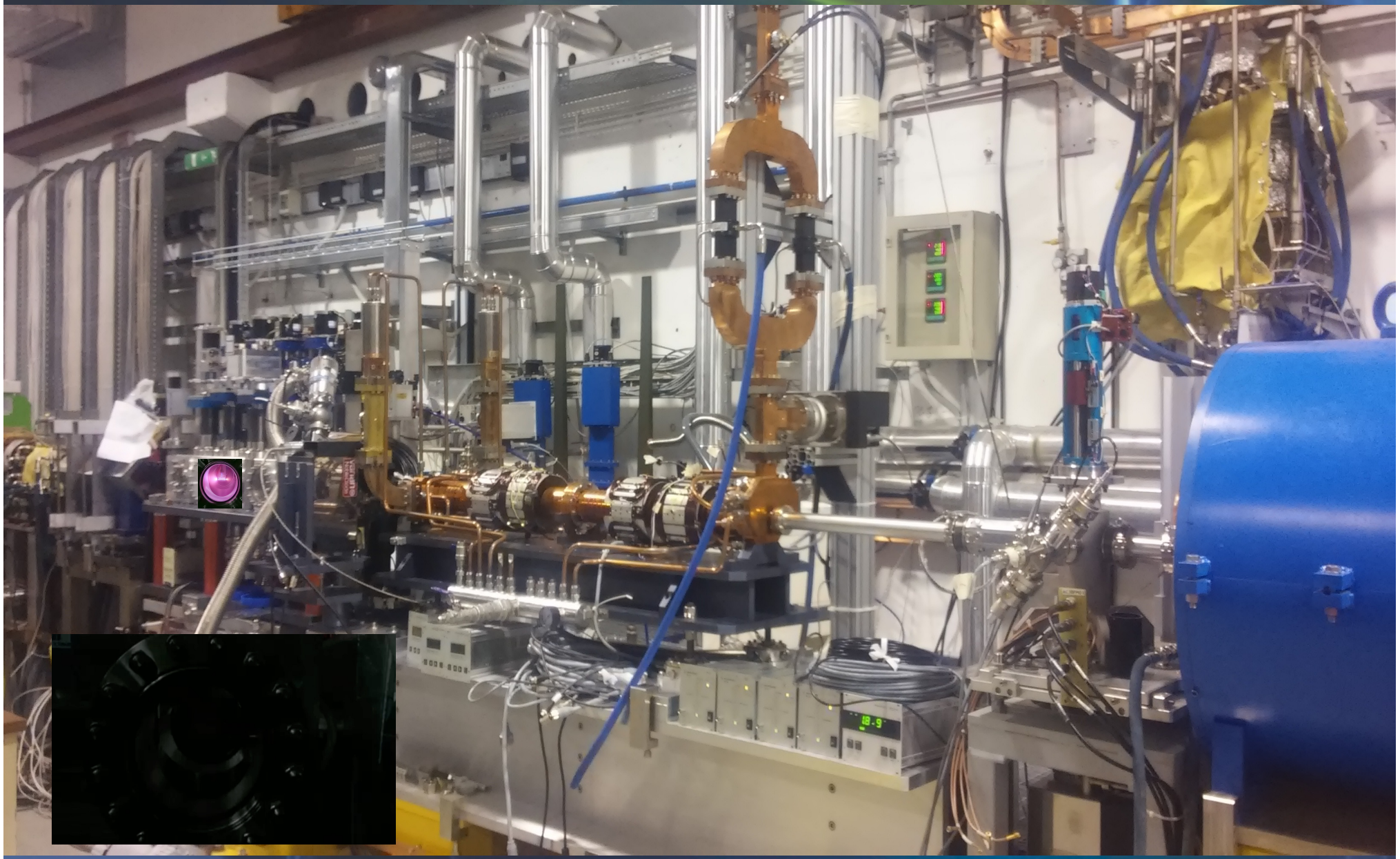
Principle of plasma acceleration



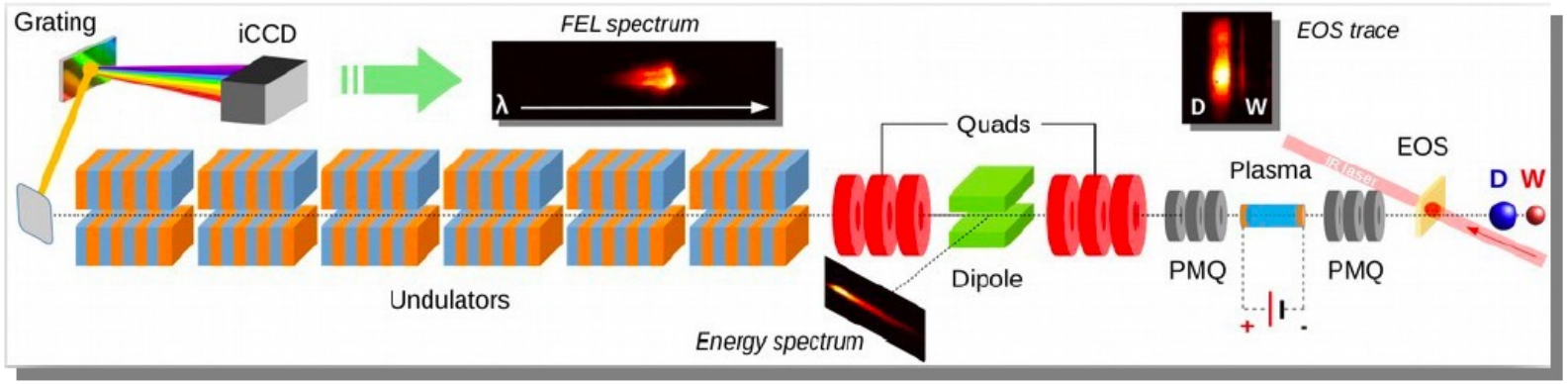
Laser Wakefield Accelerator (LWFA):
Drive beam = laser beam

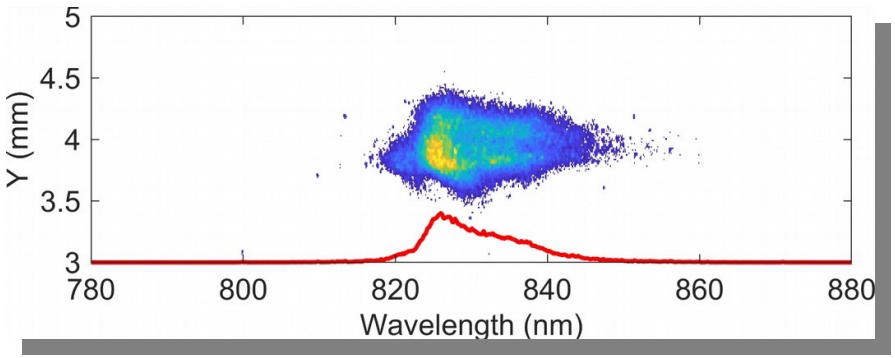
Plasma WakeField Accelerator (PWFA):
Drive beam = high energy electron or proton beam

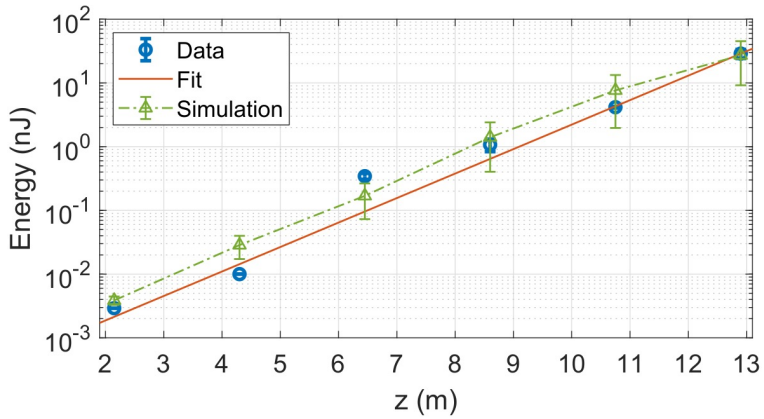
PWFA vacuum chamber at SPARC_LAB



First Beam Driven SASE-FEL Lasing at SPARC_LAB (May 2021)

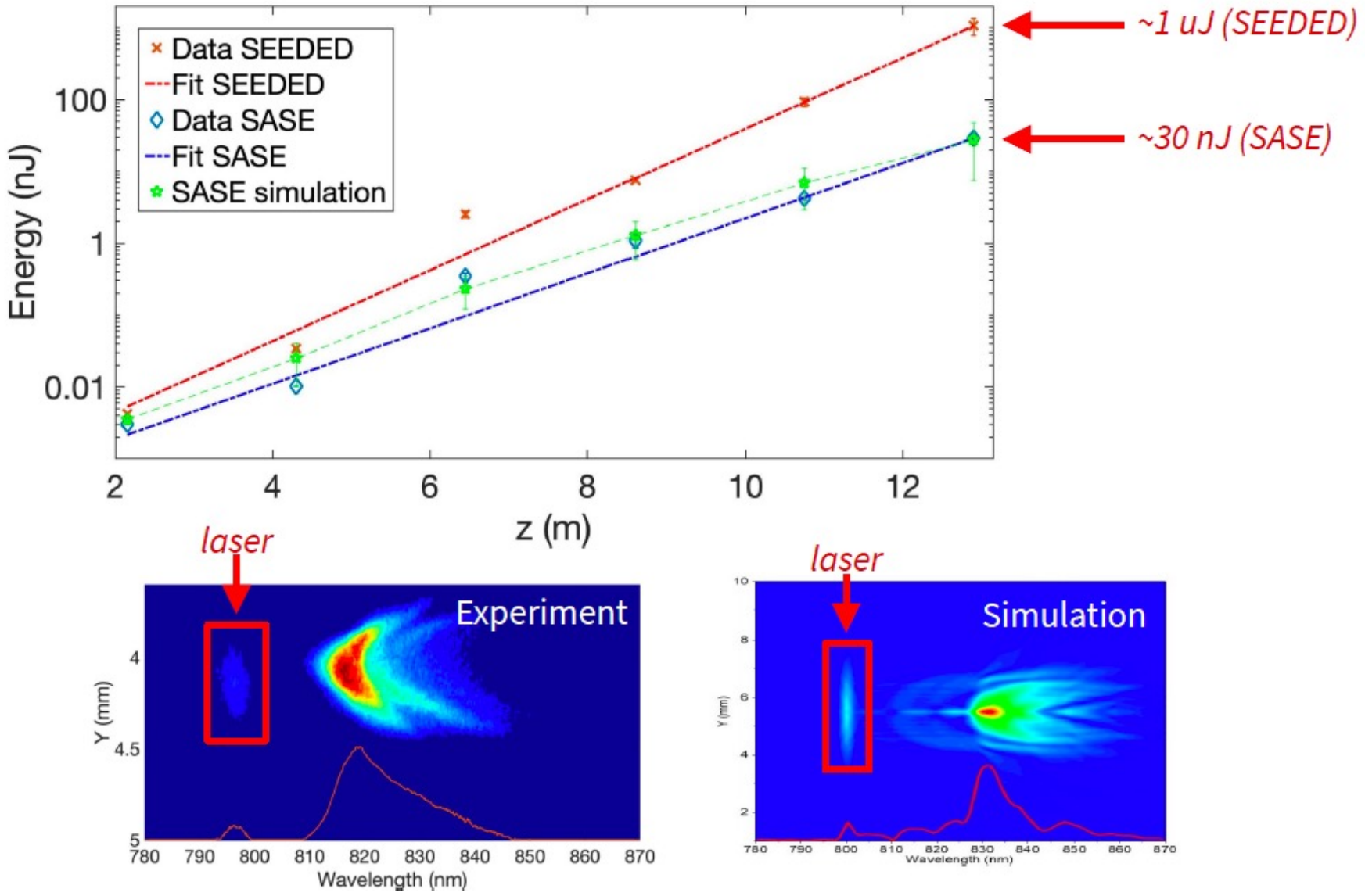




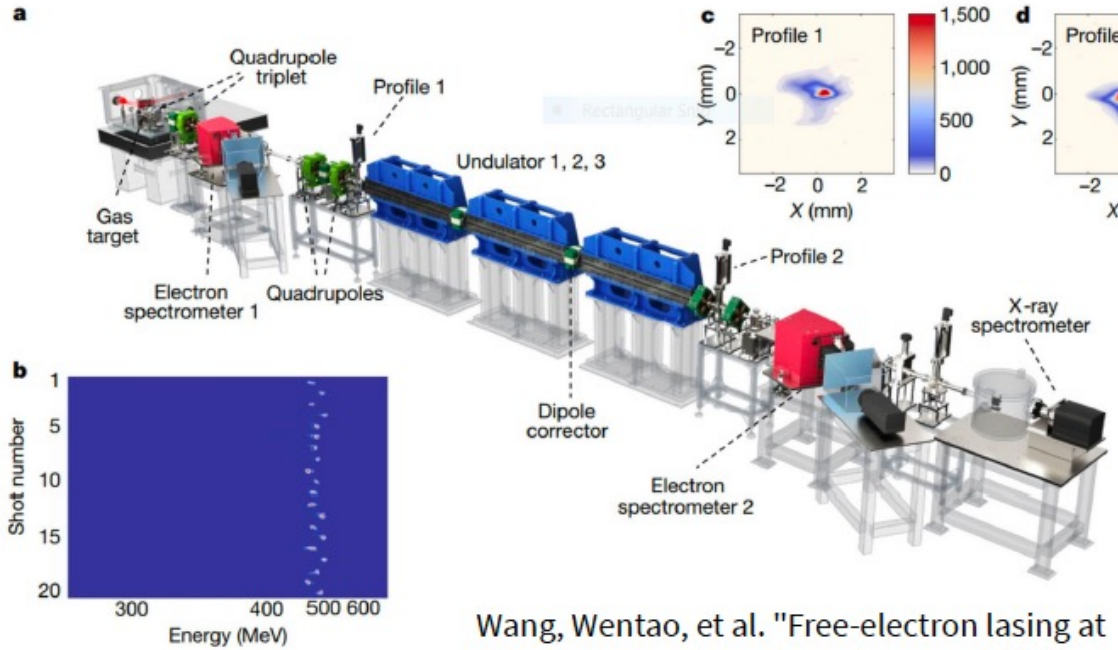


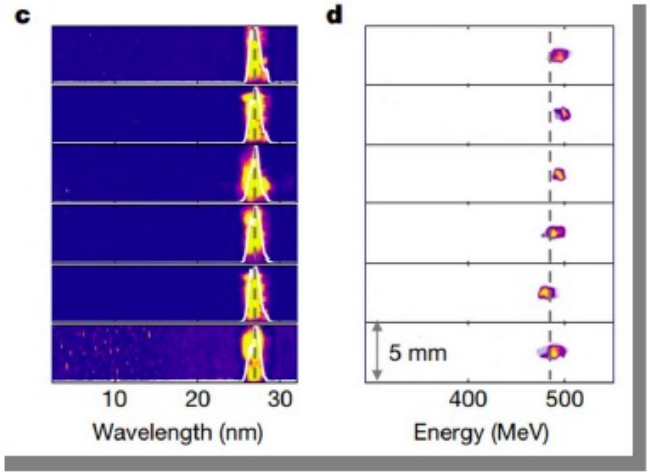
Submitted to Nature

First Beam Driven SEEDED - FEL Lasing at SPARC_LAB (June 2021)



First Lasing with LWFA at SIOM





Wang, Wentao, et al. "Free-electron lasing at 27 nanometres based on a laser wakefield accelerator." Nature 595.7868 (2021): 516-520.

Observation of FEL radiation @ 27 nm using LWFA

Electron beam generated from a 200 TW ($I \sim 4 \times 10^{18}$ W/cm^2) laser focused on a gas-jet

Peak energy ~ 490 MeV, 0.5% spread (measured), emittance 0.5 um (estimated)

Radiation energy from 0.5 to 150 nJ

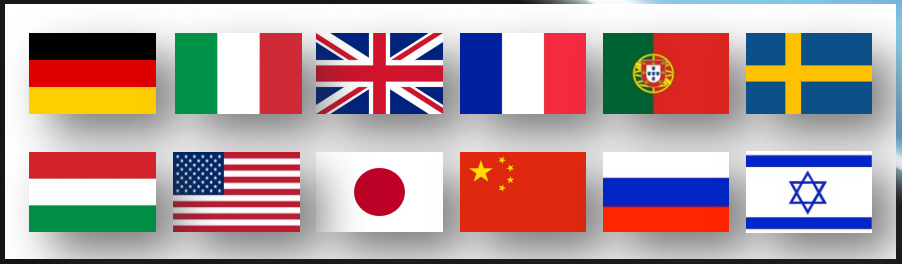
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

EuPRAXIA Design Study started on Novemebr 2015

Approved as HORIZON 2020 INFRADEV, 4 years, 3 M€

Coordinator: Ralph Assmann (DESY)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

http://eupraxia-project.eu

The EuPRAXIA Project

http://www.eupraxia-project.eu/

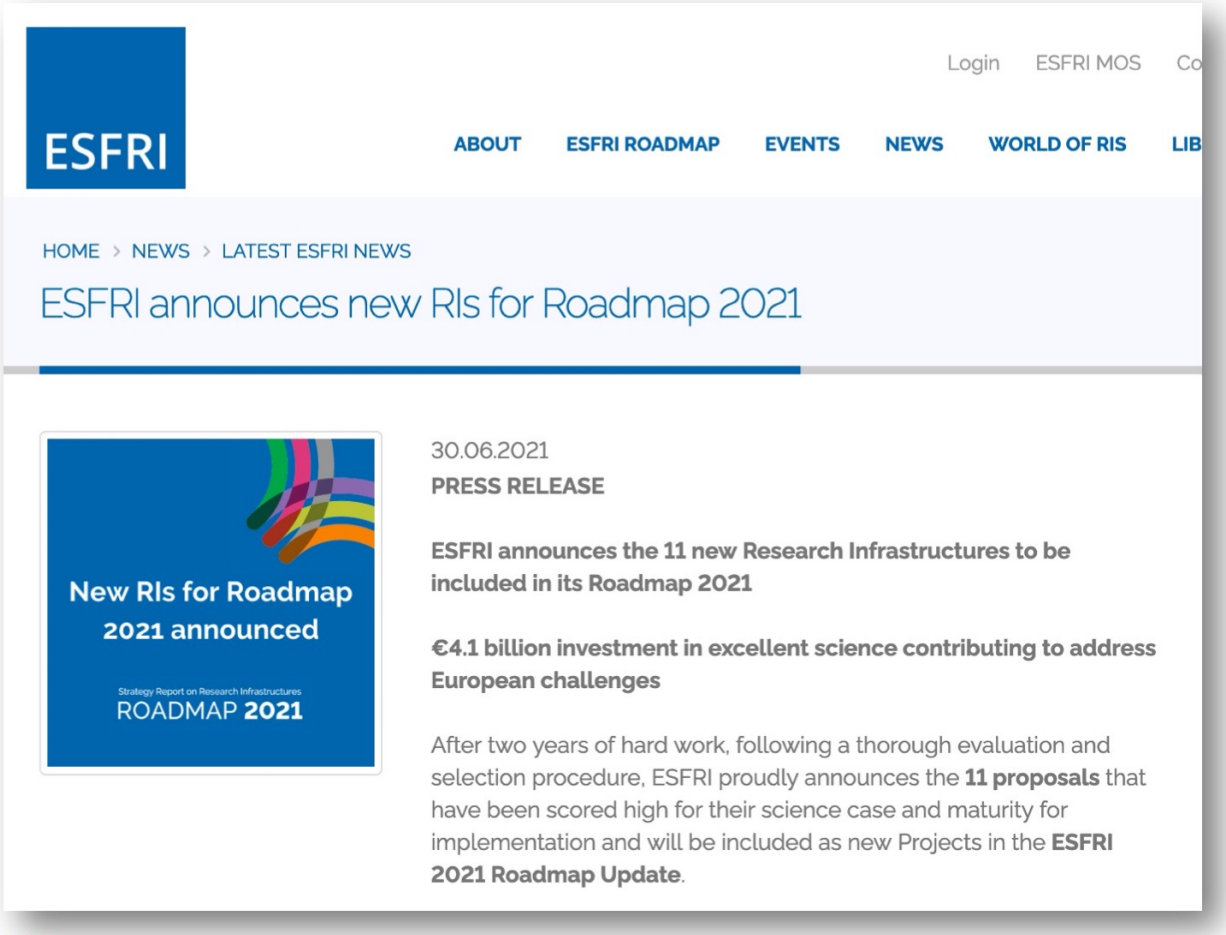
Horizon 2020

- First ever international design of a **plasma accelerator facility**.
- Challenges addressed by EuPRAXIA since 2015:
  - How **can plasma accelerators produce usable electron beams**?
  - **For what can we use those beams** while we increase the beam energy towards HEP and collider usages?
- **CDR for a distributed research infrastructure** funded by EU Horizon2020 program. Completed by 16+25 institutes.
- **Next phase consortium** with 40 partners, 10 observers.
- **Applied to ESFRI roadmap update 2021** with government support in Sep 2020.
- **Successful** and and placed on ESFRI roadma.

653 page CDR, 240 scientists contributed

Great News 30.6.2021

Building the first plasma accelerator facility

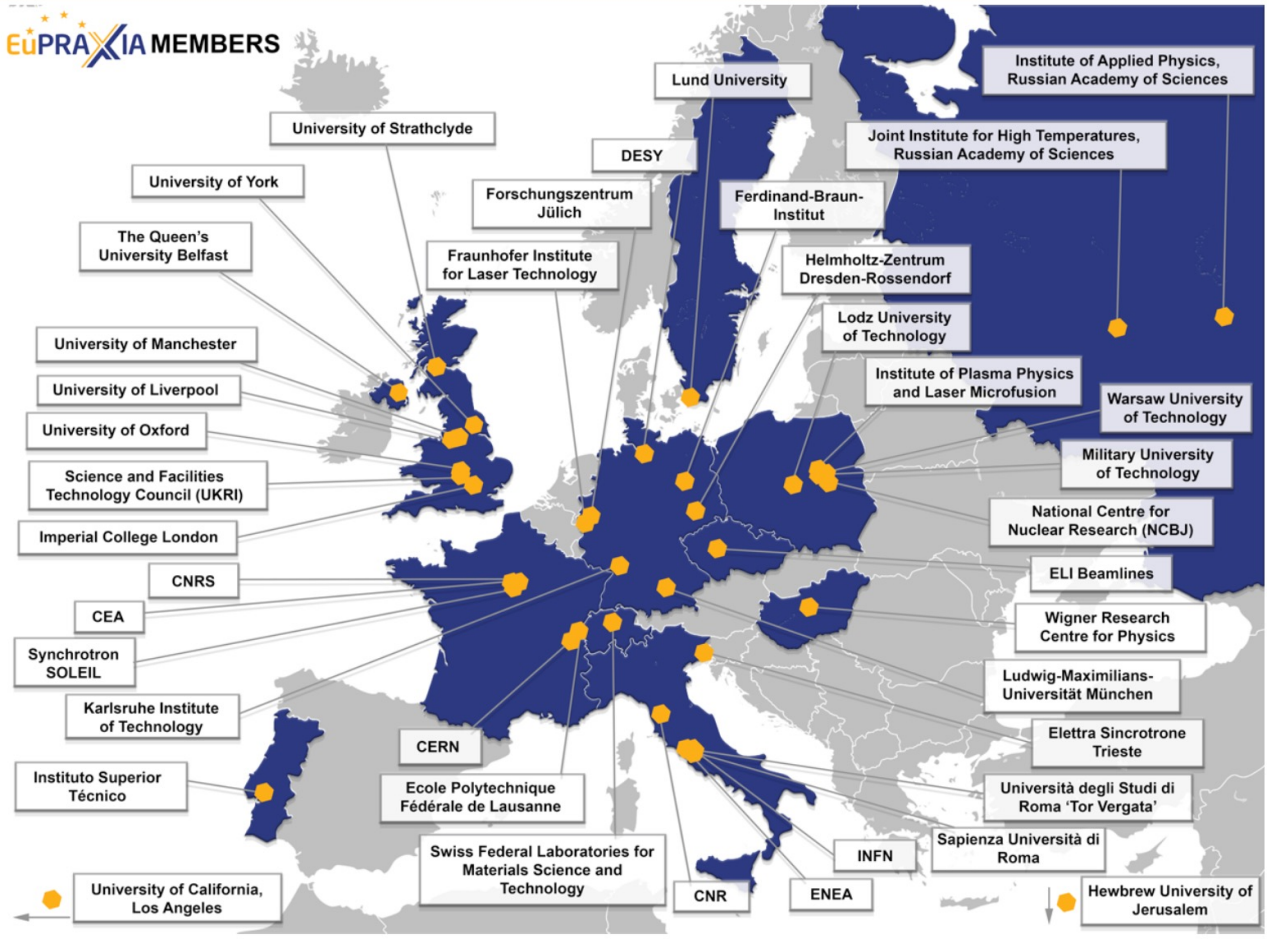


About the ESFRI Roadmap

ESFRI has established a European Roadmap for Research Infrastructures (new and major upgrades, pan-European interest) for the next 10-20 years, stimulates the implementation of these facilities, and updates the roadmap as needed. The ESFRI Roadmap arguably contains the best European science facilities based on a thorough evaluation and selection procedure. It combines ESFRI Projects, which are new Research Infrastructures in progress towards implementation, and ESFRI Landmarks successfully implemented Research Infrastructures enabling excellent science.

The Consortium Members for the Next Phase

(from 16 to 40)



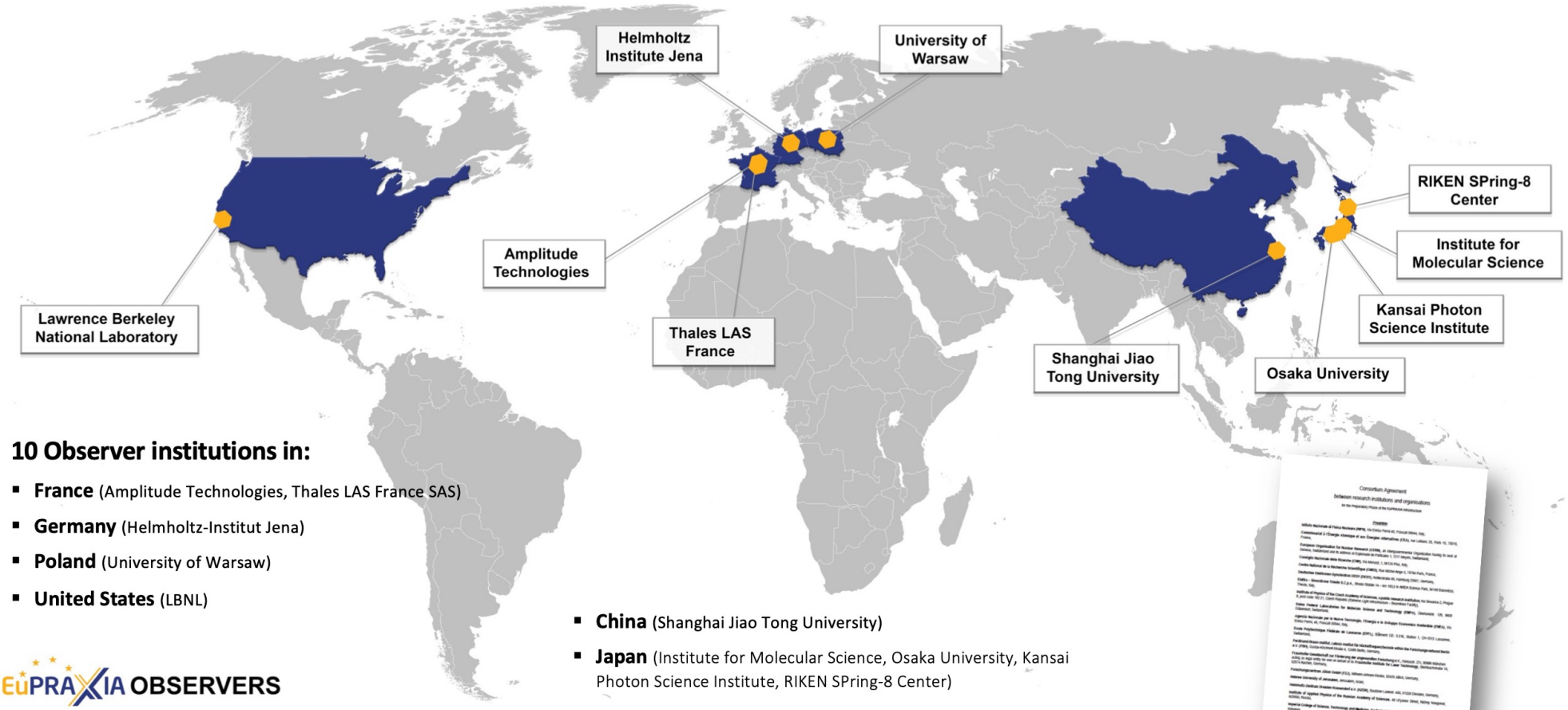
40 Member institutions in:

- **Italy** (INFN, CNR, Elettra, ENEA, Sapienza Università di Roma, Università degli Studi di Roma "Tor Vergata")
- **France** (CEA, SOLEIL, CNRS)
- **Switzerland** (EMPA, Ecole Polytechnique Fédérale de Lausanne)
- **Germany** (DESY, Ferdinand-Braun-Institut, Fraunhofer Institute for Laser Technology, Forschungszentrum Jülich, HZDR, KIT, LMU München)
- **United Kingdom** (Imperial College London, Queen's University of Belfast, STFC, University of Liverpool, University of Manchester, University of Oxford, University of Strathclyde, University of York)
- **Poland** (Institute of Plasma Physics and Laser Microfusion, Lodz University of Technology, Military University of Technology, NCBJ, Warsaw University of Technology)
- **Portugal** (IST)
- **Hungary** (Wigner Research Centre for Physics)
- **Sweden** (Lund University)
- **Israel** (Hebrew University of Jerusalem)
- **Russia** (Institute of Applied Physics, Joint Institute for High Temperatures)
- ***United States*** (UCLA)
- **CERN**
- **ELI Beamlines**

The Consortium Observers for the Next Phase

(from 25 to 10, Consortium Agreement signed)

Horizon 2020



10 Observer institutions in:

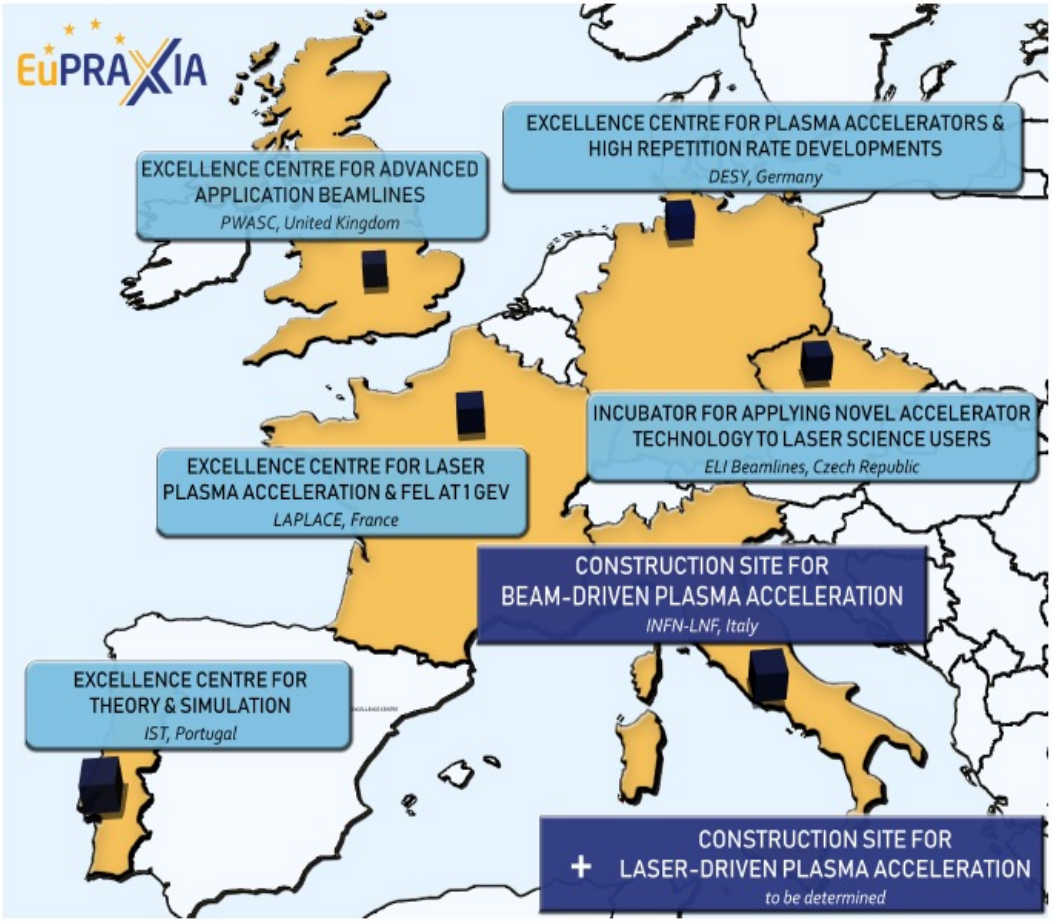
- **France** (Amplitude Technologies, Thales LAS France SAS)
- **Germany** (Helmholtz-Institut Jena)
- **Poland** (University of Warsaw)
- **United States** (LBNL)
- **China** (Shanghai Jiao Tong University)
- **Japan** (Institute for Molecular Science, Osaka University, Kansai Photon Science Institute, RIKEN SPring-8 Center)

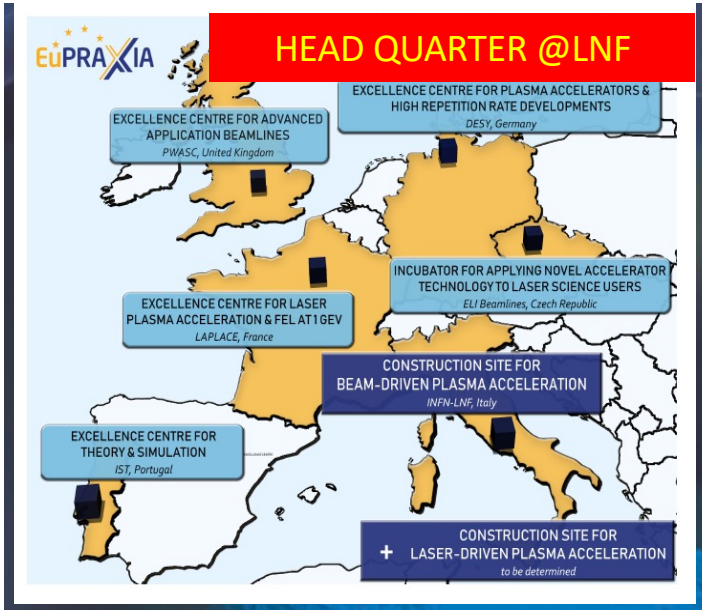
EuPRAXIA OBSERVERS

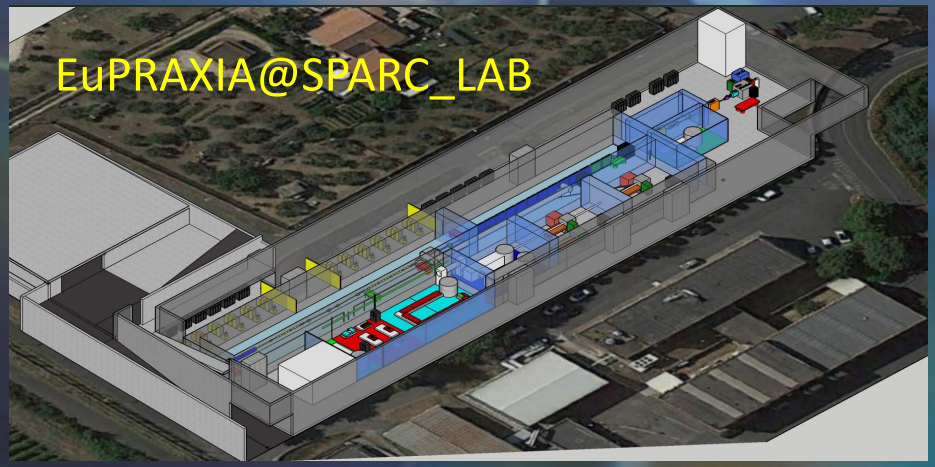
… and Builds a European Distributed Facility

Position Europe as a Leader in the Global Context

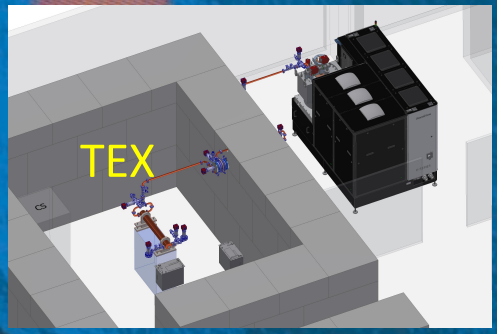
1. Lean overall **EuPRAXIA management**
2. **Ten clusters:** Collaborations of institutes on specific problems, developing solutions, technical designs, driving developments with EuPRAXIA generated funding → **expertise of Helmholtz centers required - opportunities**
3. **Five excellence centers** at 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.





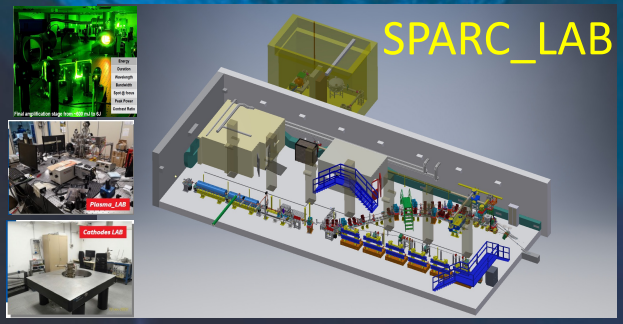


LATINO



SABINA

REGIONE LAZIO



EuPRAXIA Organisation Chart

EUROPEAN
PLASMA RESEARCH ACCELERATOR WITH
EXCELLENCE IN APPLICATIONS

Advisory & Oversight Boards

- Open Innovation Forum
- Scientific & Technical Advisory Committee
- User Meetings & Program Committees
- Resource Review Board
- Quality Assurance Panel
- Ethical Advisory Board

Collaboration Board

1 representative per Member & Observer
1 Chair and 1 Deputy Chair

Project Coordinator + Management Team

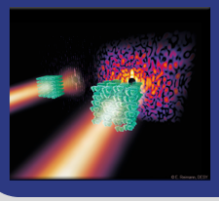
Steering Committee

Central EuPRAXIA Management

Construction Site Frascati

Local Project Team

Beam-driven plasma accelerator
Delivers FEL light, X rays, electrons, positrons
Life sciences, particle physics, medicine, materials



Location: metropolitan area Rome, Italy

INFN Istituto Nazionale di Fisica Nucleare

INFN Management

EuPRAXIA Collaboration Board

PROJECT LEADER
M.Ferrario

LNF Governing Board

Management Team

Scientific Manager	Technical Manager	Project Management & Integration
M.Ferrario	*A.Ghigo*	*A.Falone*

Project Management Office

F.Cioeta - Configuration manager
M.Iungo - Cost & Schedule
G.Vinicola - Administration

Working Areas / Steering committee

1. Beam Physics	2. Injector	3. Linac	4. High Power RF	5. Plasma	6. FEL	7. High Power Laser	8. Users	9. Infrastructures	10. Diagnostics
C.Vaccarezza	*E.Chiadroni*	*D.Alesini*	*A.Gallo*	*R.Pompili*	*L.Giannessi*	*TBD*	*F.Stellato (Univ. TorVergata)*	*U.Rotundo*	*A.Cianchi*

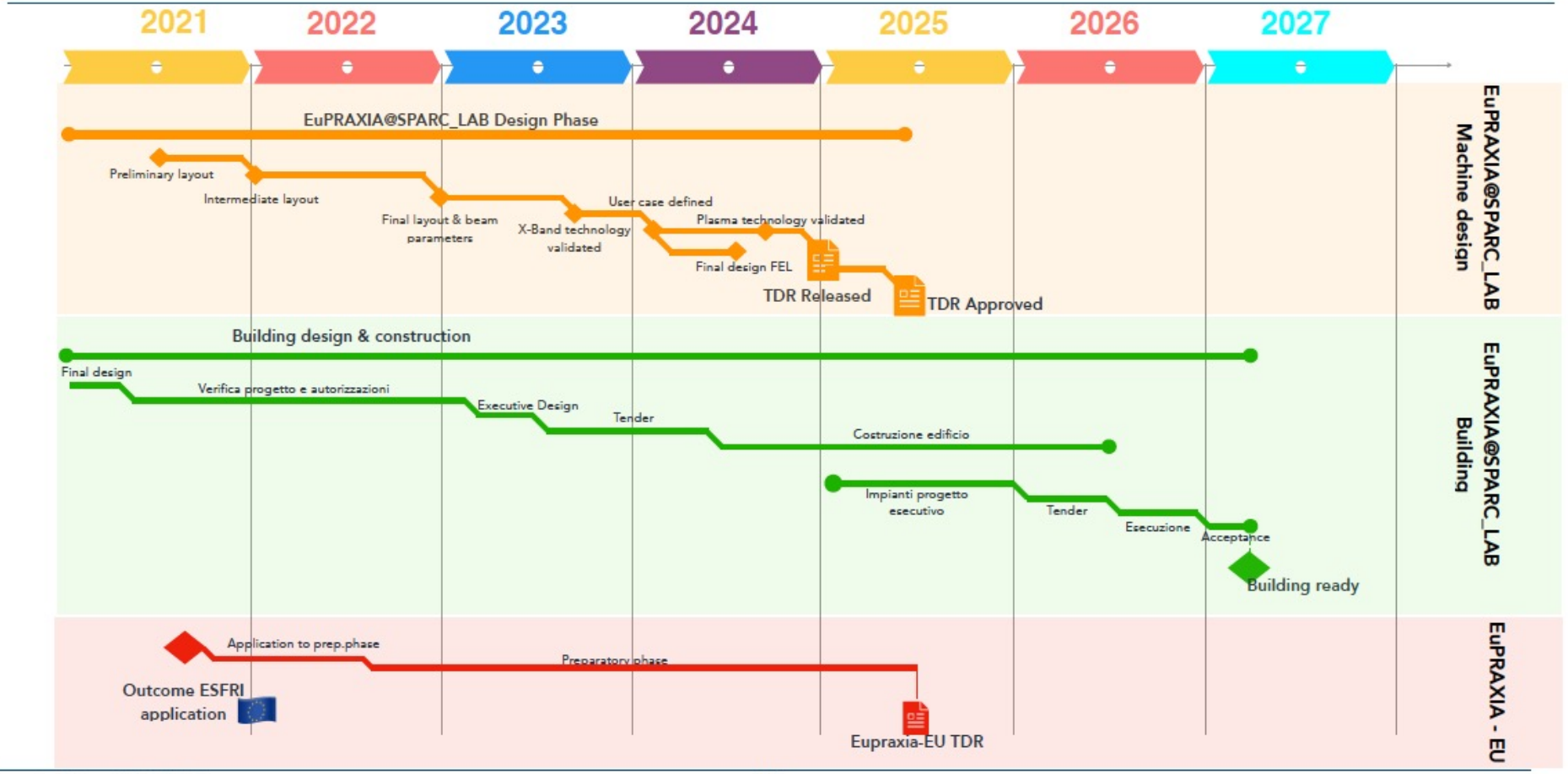
Work Packages

1. Accelerator Physics *A.Giribono*	6. Plasma module *A.Biagioni*	11. Lasers & Cathodes *M.Anania*	16. Control system & Interlocks *A.Stecchi*	21. Cooling & Ventilation *S.Cantarella*
2. Plasma Physics *A.R.Rossi (INFN-MI)*	7. Sparc_Lab TF *R.Pompili*	12. High Power RF & distribution *F.Cardelli*	17. Magnets & PS *L.Sabbatini*	22. Civil engineering *S.Incremona*
3. FEL Physics *V.Petrillo (INFN-MI)*	8. RF Gun & Accelerating structures *L.Piersanti*	13. Functional Safety *TBD*	18. Undulators *A.Petralia (ENEA)*	23. Radioprotection *A.Esposito*
4. Photon & User Beamlines *F.Villa*	9. Computing *P.Santangelo*	14. Beam Instrumentation & electronics *A.Stella*	19. Mech.Engineering *L.Pellegrino*	24. Conventional Safety *S.Vescovi*
5. Secondary part. sources *T.B.D.*	10. Vacuum *A.Liedl*	15. LLRF & Synchro *M.Bellaveglia*	20. Electrical Installations *R.Ricci*	25. Network *G.Di Pirro*

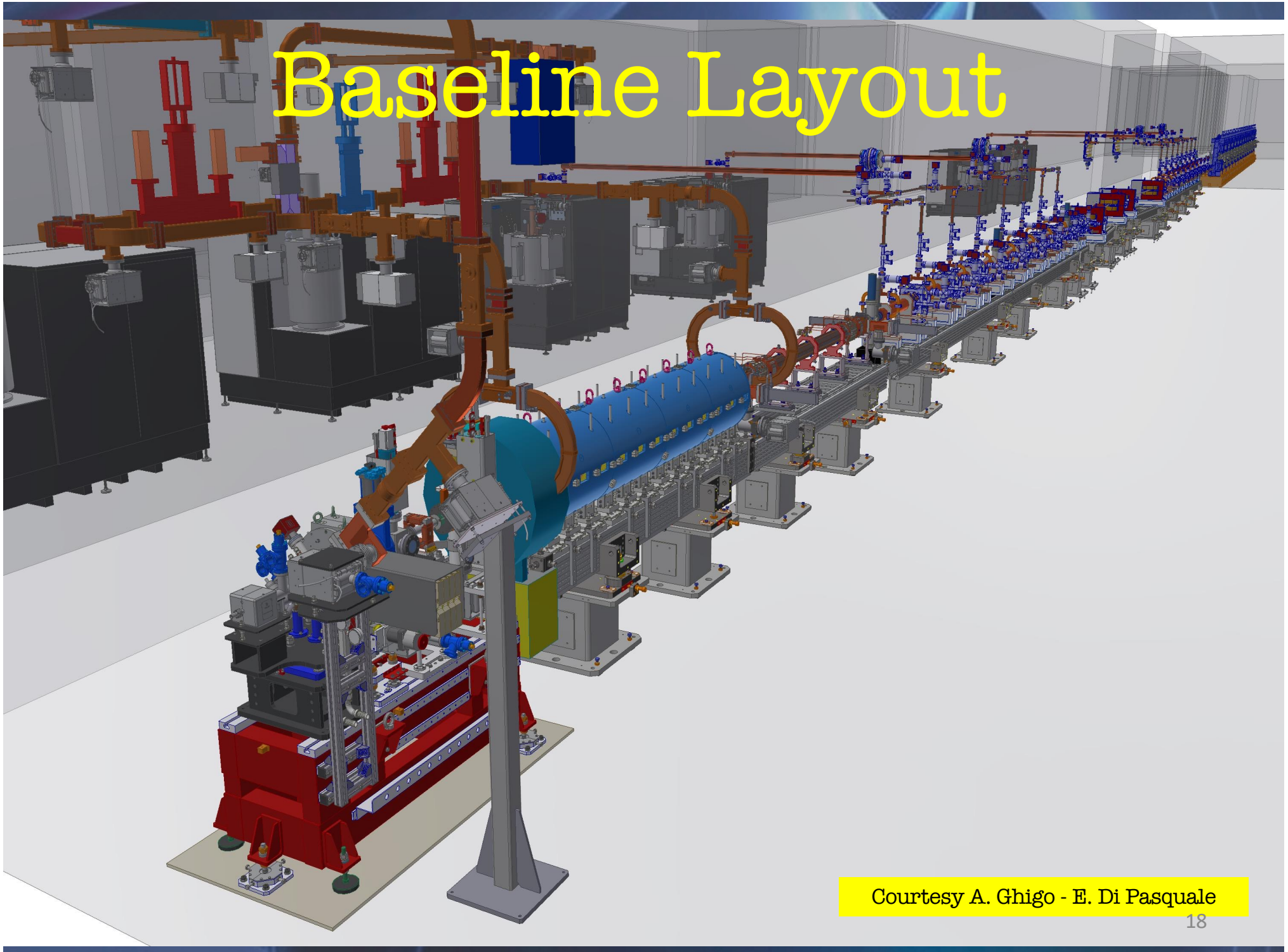
Organization for initial Preparatory I

Features to be added with decision phases are indicated in lighter shades

Road map

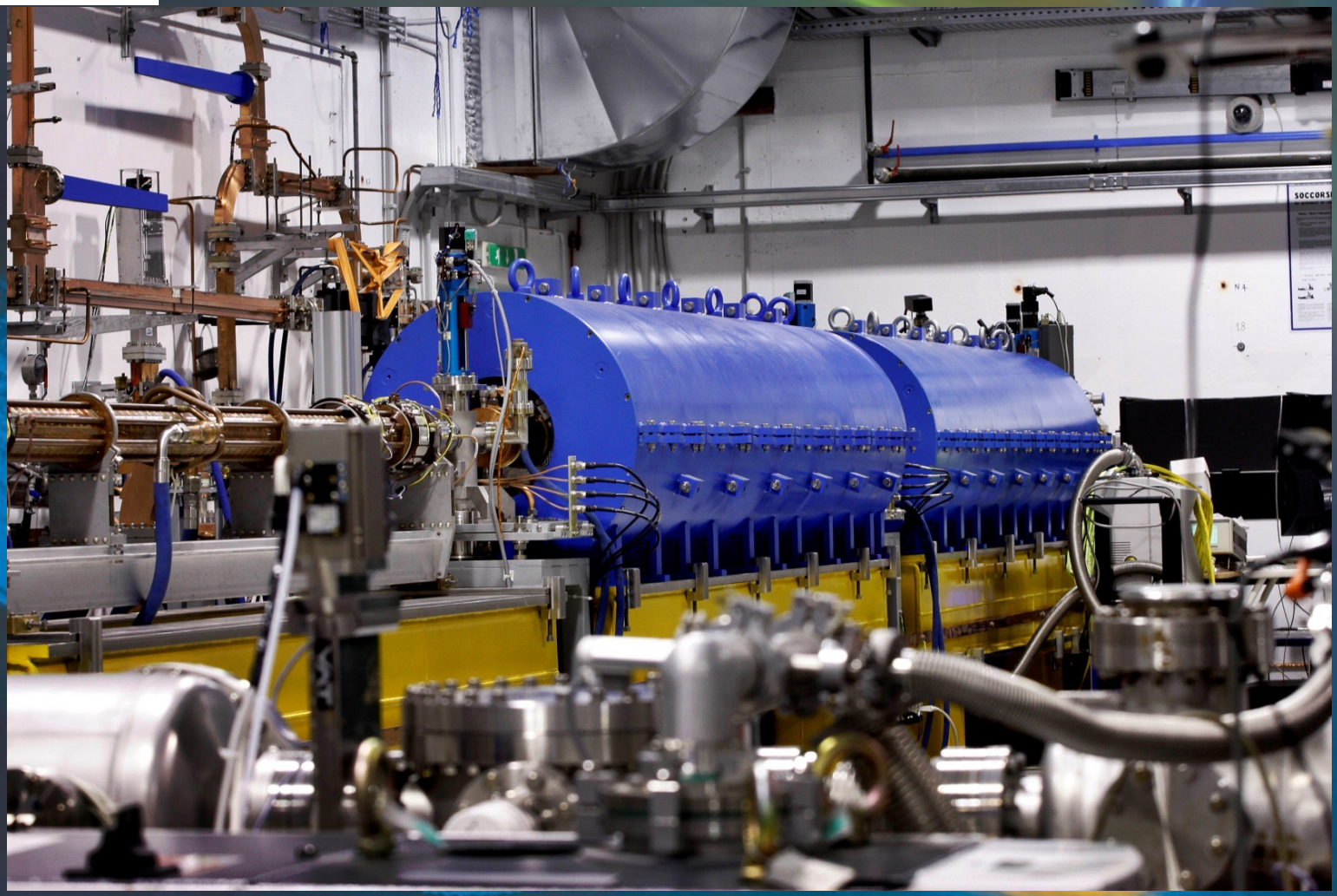

2021
2022
2023
2024
2025
2026
2027
EuPRAXIA@SPARC_LAB Design Phase
Preliminary layout
Intermediate layout
Final layout & beam parameters
X-Band technology validated
User case defined
Plasma technology validated
Final design FEL
TDR Released
TDR Approved
EuPRAXIA@SPARC_LAB Machine design
Building design & construction
Final design
Verifica progetto e autorizzazioni
Executive Design
Tender
Costruzione edificio
Impianti progetto esecutivo
Tender
Esecuzione
Acceptance
Building ready
EuPRAXIA@SPARC_LAB Building
Application to prep.phase
Preparatory phase
Outcome ESFRI application
Eupraxia-EU TDR
EuPRAXIA - EU

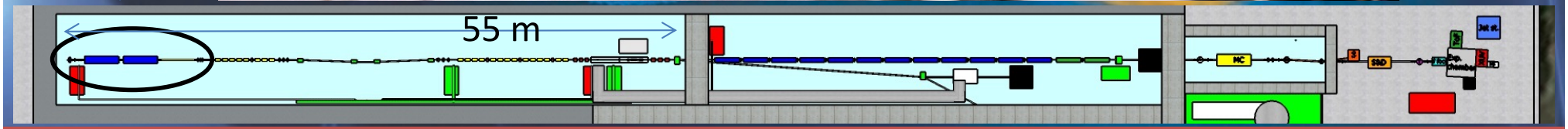
Baseline Layout



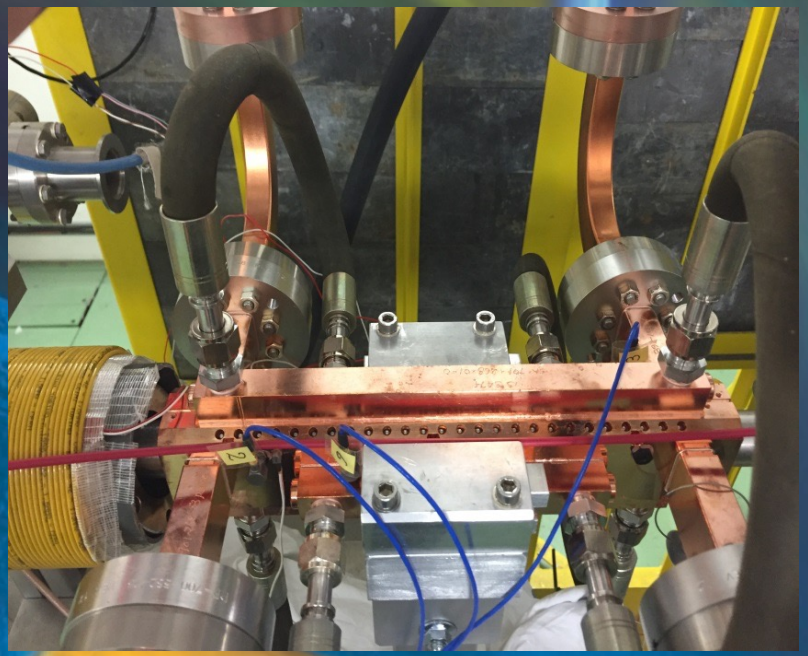
Courtesy A. Ghigo - E. Di Pasquale

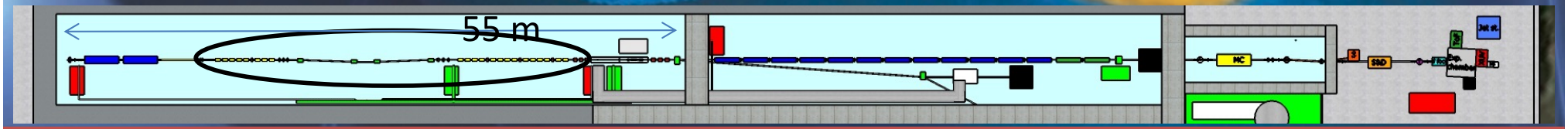
SPARC_LAB HB photo- injector



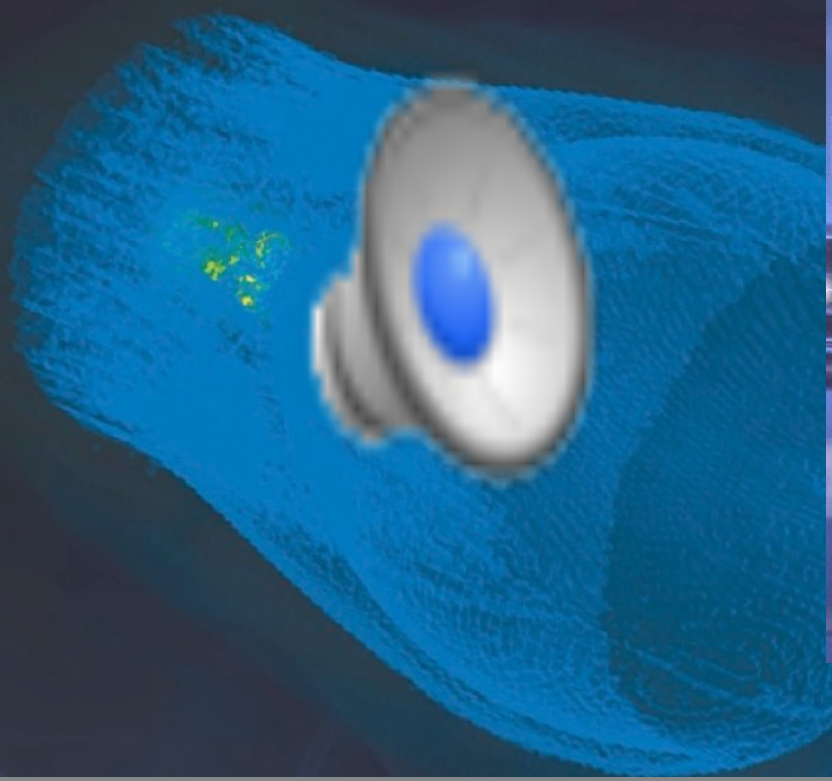


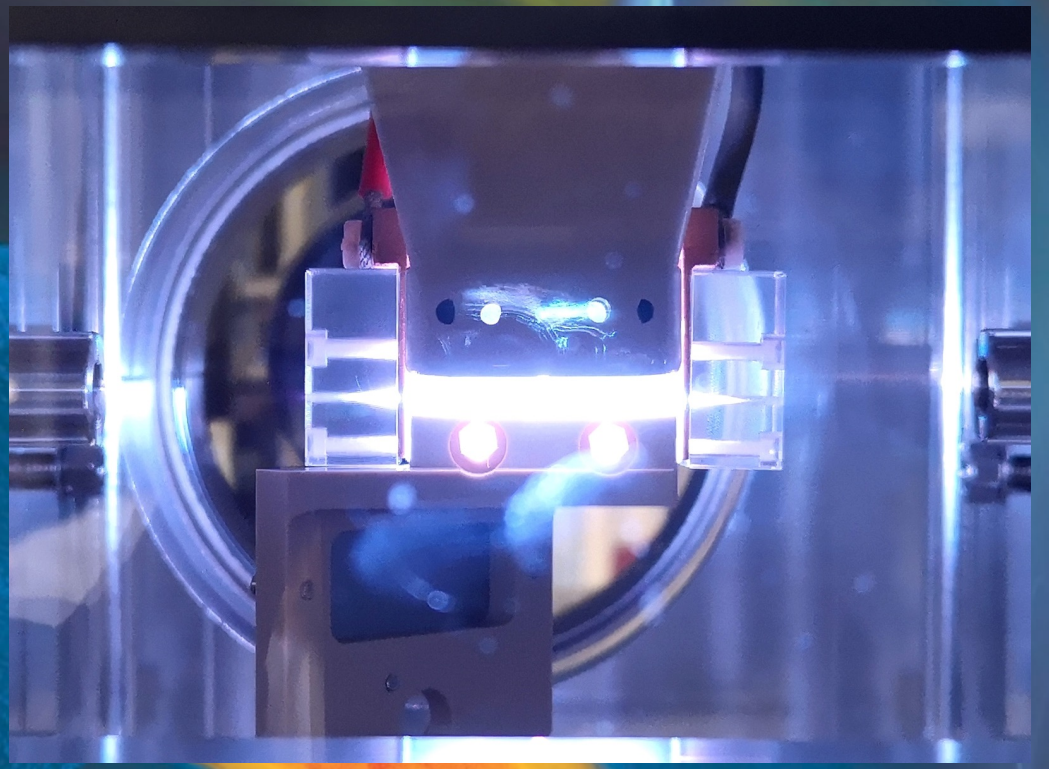
X-band Linac



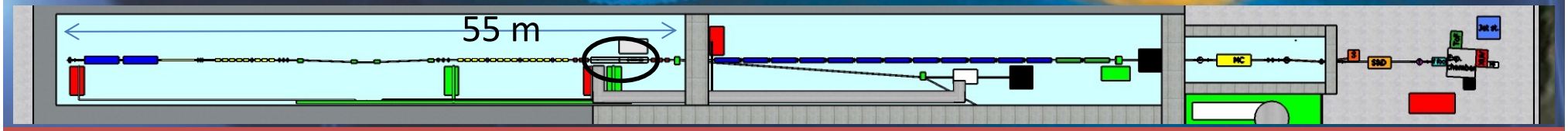


Plasma WakeField Acceleration

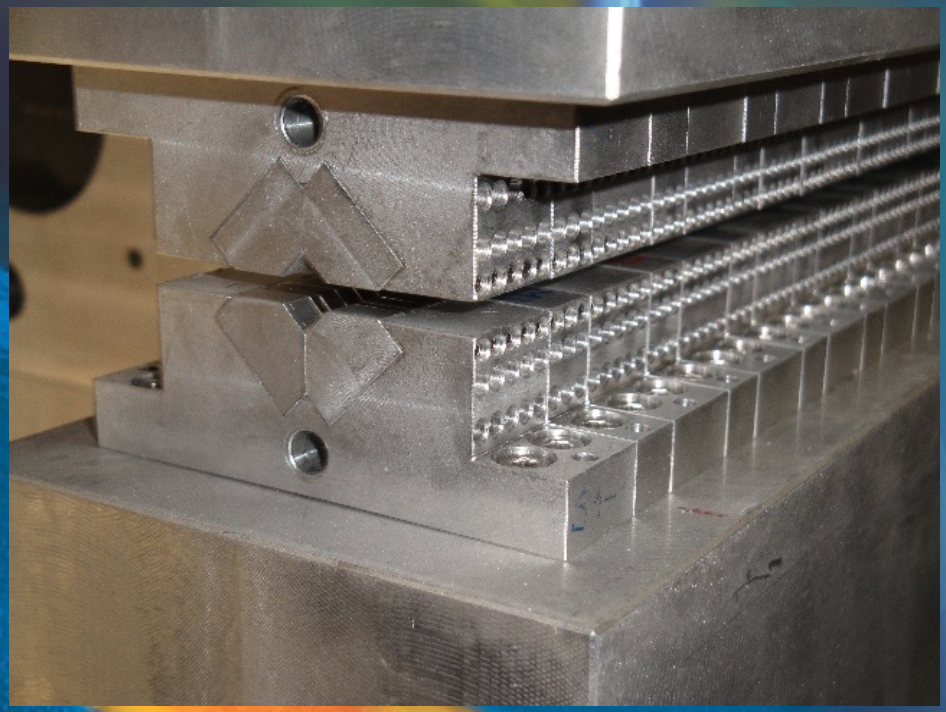




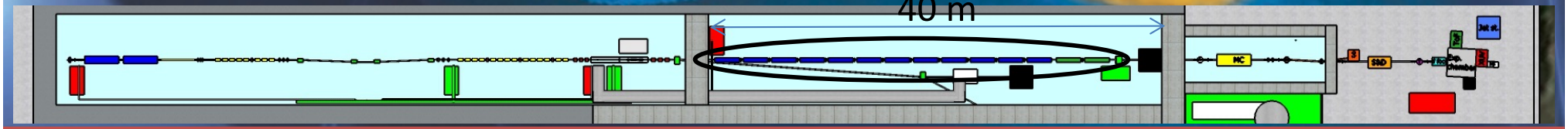
Capillary discharge at SPARC_LAB



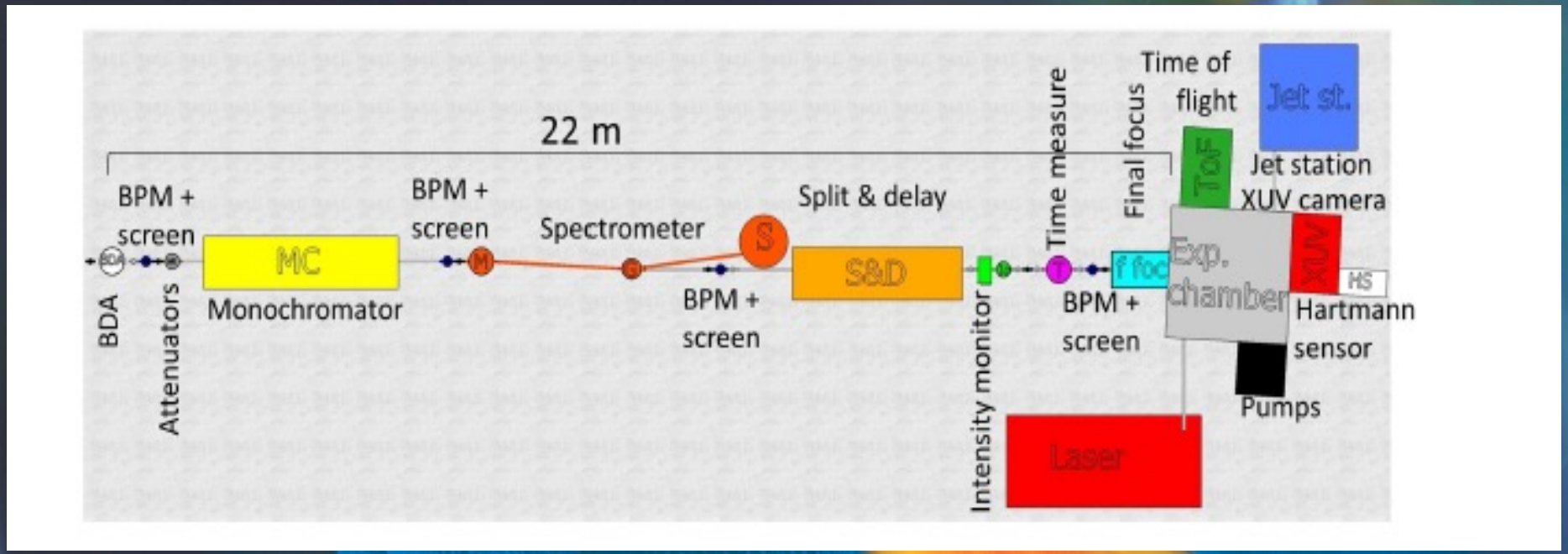
Undulators

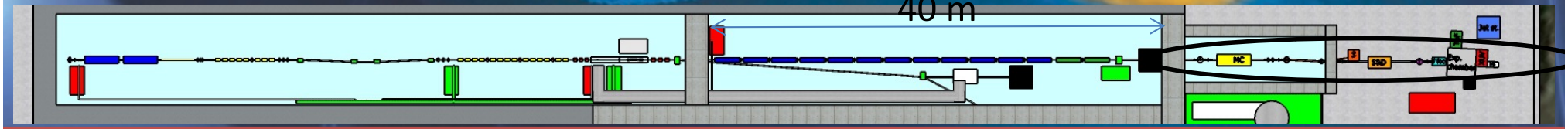


KYMA Δ udulator at SPARC_LAB: λ=1.4 cm, K1



Photon beam line



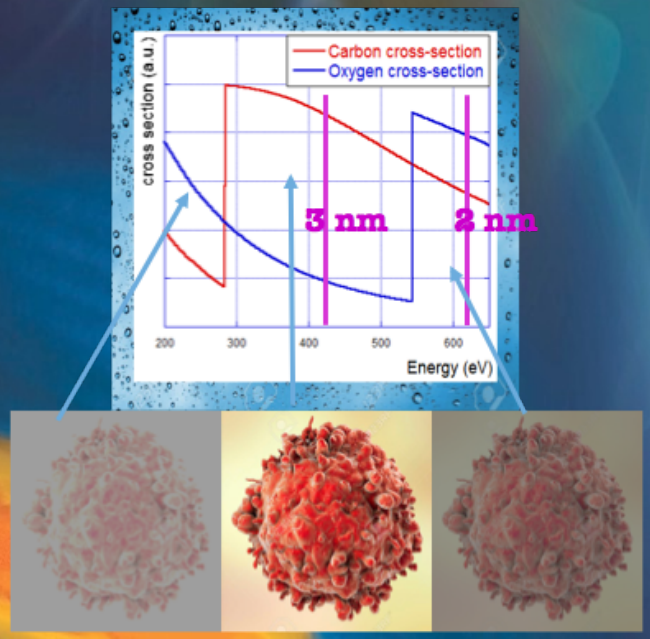


Expected SASE FEL performances

	Units	Full RF case	Plasma case
Electron Energy	GeV	1	1
Bunch Charge	pC	200	30
Peak Current	kA	2	3
RMS Energy Spread	%	0.1	1
RMS Bunch Length	fs	40	4
RMS matched Bunch Spot	μm	34	34
RMS norm. Emittance	μm	1	1
Slice length	μm	0.5	0.45
Slice Energy Spread	%	0.01	0.1
Slice norm. Emittance	μm	0.5	0.5
Undulator Period	mm	15	15
Undulator Strength K		1.03	1.03
Undulator Length	m	12	14
Gain Length	m	0.46	0.5
Pierce Parameter ρ	x 10^{-3}	1.5	1.4
Radiation Wavelength	nm	3	3
Undulator matching β_u	m	4.5	4.5
Saturation Active Length	m	10	11
Saturation Power	GW	4	5.89
Energy per pulse	μJ	83.8	11.7
Photons per pulse	x 10^{11}	11	1.5

Table 2.1: Beam parameters for the EuPRAXIA@SPARC_LAB FEL driven by X-band linac or Plasma acceleration

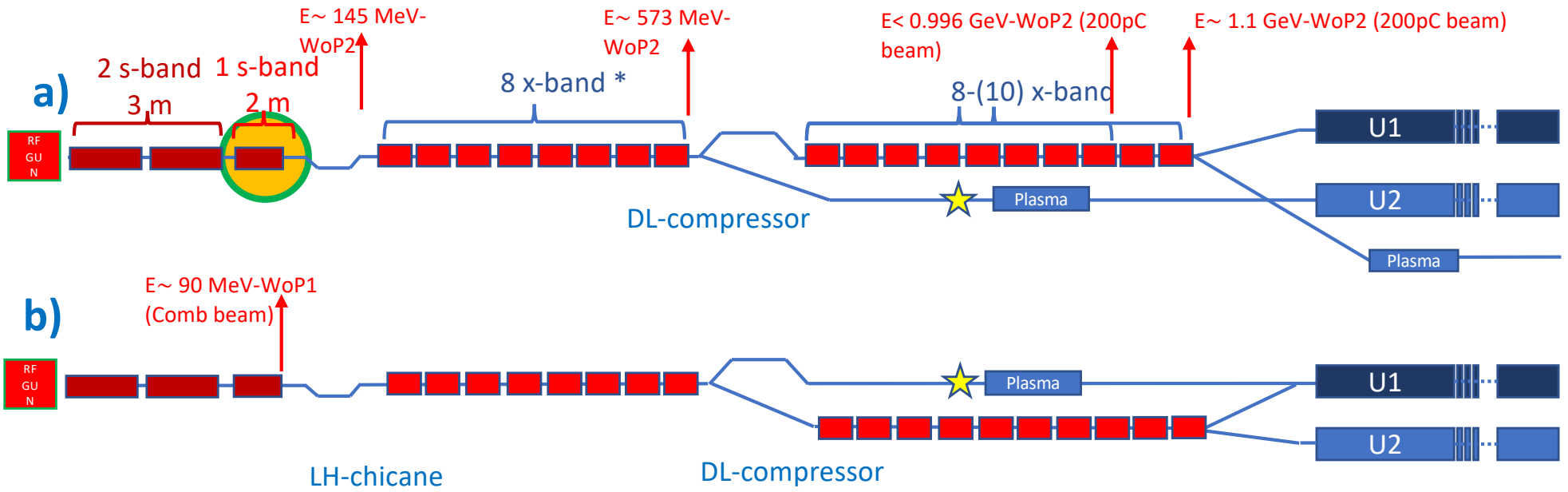
In the Energy region between Oxygen and Carbon K-edge 2.34 nm – 4.4 nm (530 eV -280 eV) water is almost transparent to radiation while nitrogen and carbon are absorbing (and scattering)



Coherent Imaging of biological samples protein clusters, VIRUSES and cells living in their native state
Possibility to study dynamics
~10 ^{11} photons/pulse needed

Courtesy F. Stellato, UniToV

WA1-Beam Physics: Layout brainstorming two layouts for comparison up to now (Apr 2021)….



* The location of the 10 x-band linac downstream or upstream the chicane is under study

AQUA - Techniques & Samples @ 3 nm

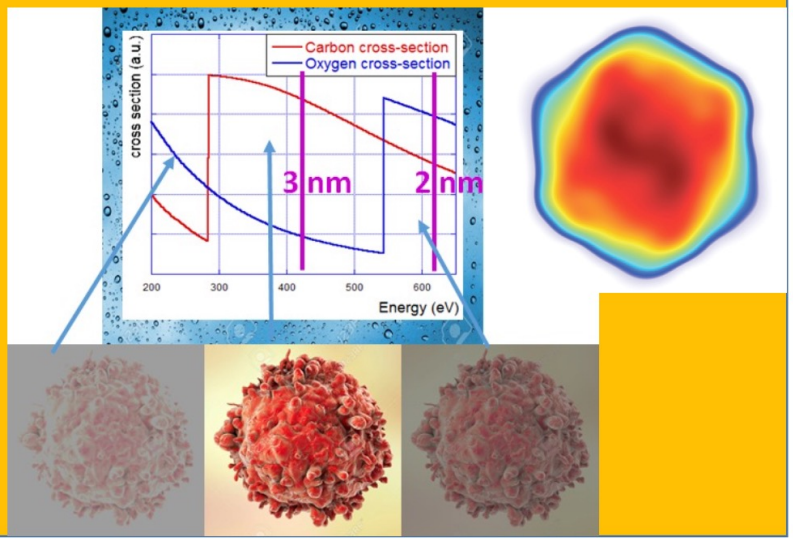
Scientific case assembled and published.
Contributions from >15 different institutions

Balerna *et al.* Condensed Matter 4, 30 (2019)

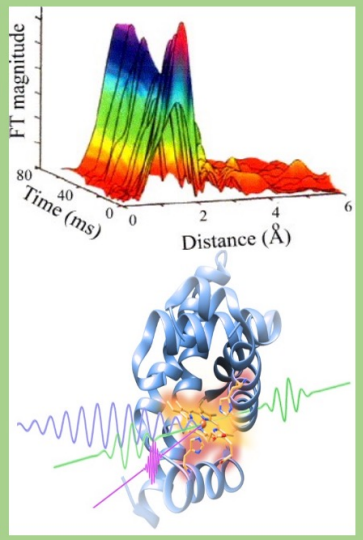
Bio & Inorganic Samples

Proteins - Viruses
Bacteria- Cells
Metals – Magnetic materials
Superconductors -Semiconductors

Coherent imaging



X-ray absorption spectroscopy



Raman spectroscopy

ARIA - Techniques & Samples @ 50-180 nm

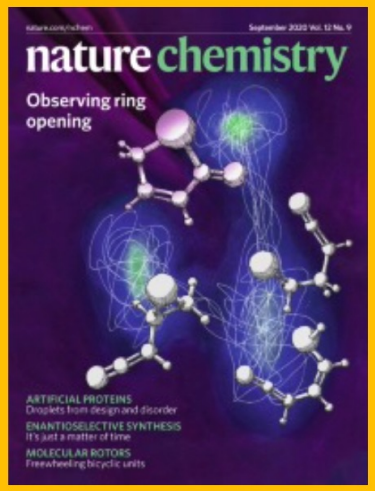
Scientific case in the DUV (DeepUV) and VUV (VacuumUV) is being assembled
Wavelength interval **complementary** with FEL1 @ Fermi

Samples & (techniques)

Gas phase & Atmosphere (Earth & Planets)
Aerosols (Pollution, nanoparticles)
Molecules & gases (spectroscopies, time-of-flight)
Proteins (spectroscopies)
Surfaces (ablation e deposition)

Photoemission Spectroscopy

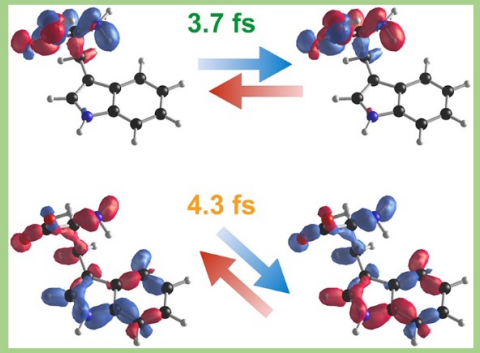
Ring opening in organic molecules
Pathak *et al. Nature Chemistry* 2020



Raman spectroscopy

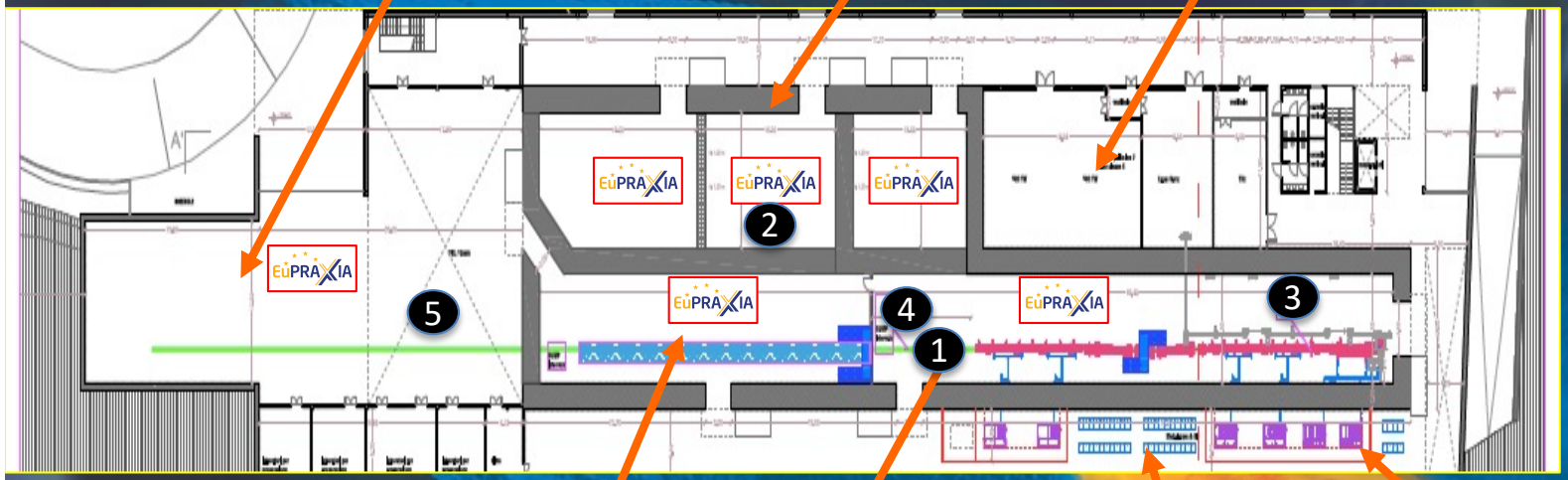
Photo-fragmentation of molecules

Ultrafast Quantum Interference in the Charge Migration of Tryptophan.
J Phys Chem Lett 2020



Time of Flight Spectroscopy

Opportunities for Collaborations at EuPRAXIA@SPARC_LAB



European interests & possible contributions to Frascati site:

1. Plasma structure designs, devices
2. Compact positron source
3. HQ 150 MeV laser plasma injector
4. HQ laser driver
   - Hybrid concepts
   - Simulations
5. User experiments and lines

To be detailed in TDR phase.


Thank for your attention