EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA status (II)

Massimo Ferrario (INFN-LNF)

on behalf of the EuPRAXIA Collaboration

EuPRAXIA_PP Annual Meeting, September 22

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement No. 101079773

A New European High-Tech User Facility

Funded by the European Union

1

Building a facility with very high field plasma accelerators, driven by lasers or beams
1 – 100 GV/m accelerating field

Shrink down the facility size
Improve Sustainability

2

Producing particles and photons to support several urgent and timely science cases

Drive short wavelength FEL
Pave the way for future Linear Colliders

https://www.eupraxia-facility.org/

Surf's up *Simulation of electron-driven plasma wakefield acceleration, showing the drive electron beam (orange/purple), the plasma electron wake (grey) and wakefield-ionised electrons forming a witness beam (orange).*

EUROPE TARGETS A USER FACILITY FOR PLASMA ACCELERATION

Ralph Assmann, Massimo Ferrario and Carsten Welsch describe the status of the ESFRI project EuPRAXIA, which aims to develop the first dedicated research infrastructure based on novel plasma-acceleration concepts.

Energetic beams of particles are used to explore the fundamental forces of nature, produce known and unknown particles such as the Higgs boson at the LHC, and generate new forms of matter, for example at the future FAIR facility. Photon science also relies on particle beams: electron beams that emit pulses of intense synchrotron light, including soft and hard X-rays, in either circular or linear machines. Such light sources enable time-resolved measurements of biological, chemical and physical structures on the molecular down to the atomic scale, allowing a diverse global community of users to investigate systems ranging from viruses and bacteria to materials science, planetary science, environmental science, nanotechnology and archaeology. Last but not least, particle beams for industry and health support many societal applications ranging from the X-ray inspection of cargo containers to food sterilisation, and from chip manufacturing to cancer therapy.

This scientific success story has been made possible through a continuous cycle of innovation in the physics and technology of particle accelerators, driven for many decades by exploratory research in nuclear and particle physics. The invention of radio-frequency (RF) technology in the 1920s opened the path to an energy gain of several tens of MeV per metre. Very-high-energy accelerators were constructed with RF technology, entering the GeV and finally the TeV energy scales at the Tevatron and the LHC. New collision schemes were developed, for example the mini "beta squeeze" in the 1970s, advancing luminosity and collision rates by orders of magnitudes. The invention of stochastic cooling at CERN enabled the discovery of the W and Z bosons 40 years ago.

However, intrinsic technological and conceptual limits mean that the size and cost of RF-based particle accelerators are increasing as researchers seek higher beam energies. Colliders for particle physics have reached a

THE AUTHORS
Ralph Assmann *DESY and INFN,* **Massimo Ferrario** *INFN,* **Carsten Welsch** *University of Liverpool/INFN.*

The EuPRAXIA CDR

Funded by the
European Union

- First ever design of a **plasma accelerator facility**.
- **Conceptual Design Report for a distributed research infrastructure** funded by EU Horizon2020 program. Completed by 16+25 institutes.
- Challenges addressed by EuPRAXIA since 2015:
  - **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?
- Next phase consortium: **> 50 institutes**
- Preparatory Phase project: **2022 – 2026** (approved)
- Start of 1st operation: **2029**

http://www.eupraxia-project.eu

The European Physical Journal volume 229 · number 24 · December 2020

EPJ ST

EPS Recognized by European Physical Society

Special Topics

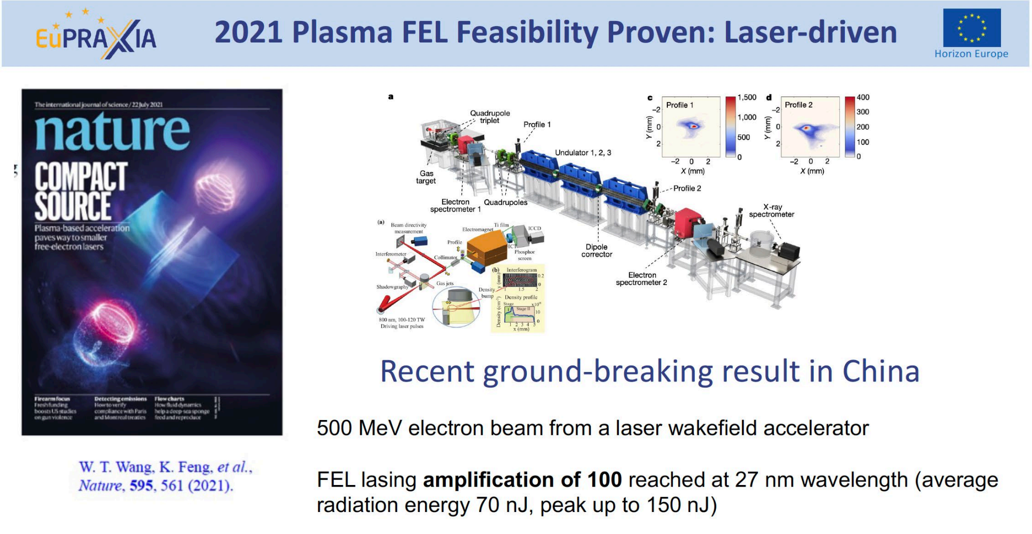
EuPRAXIA Conceptual Design Report

Ralph Assmann and Maria Weikum (Eds.)

edp sciences Springer

600+ page CDR, 240 scientists contributed

Basic beam quality achieved in pilot FEL experiments



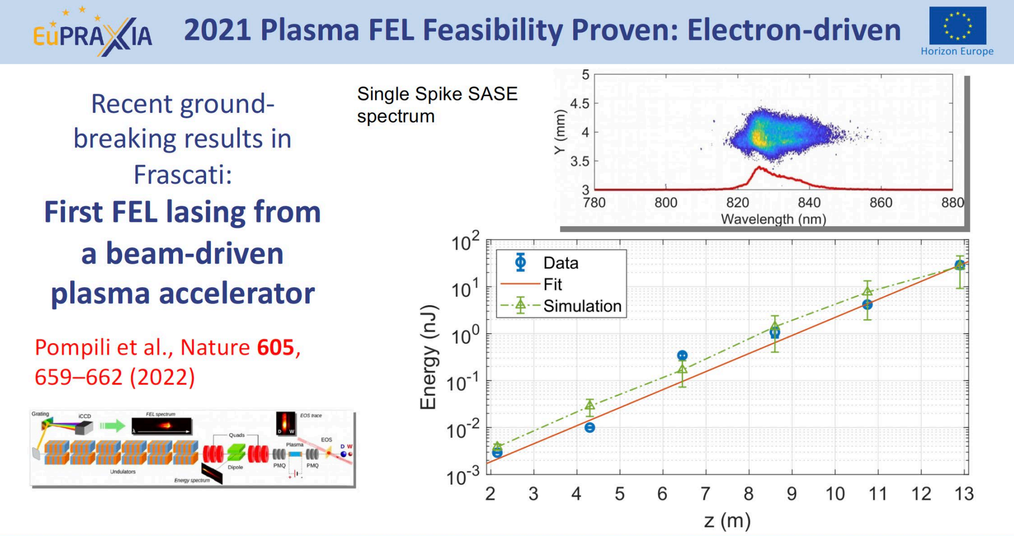
2021 Plasma FEL Feasibility Proven: Laser-driven

W. T. Wang, K. Feng, *et al.*, *Nature*, **595**, 561 (2021).

Recent ground-breaking result in China

500 MeV electron beam from a laser wakefield accelerator

FEL lasing **amplification of 100** reached at 27 nm wavelength (average radiation energy 70 nJ, peak up to 150 nJ)

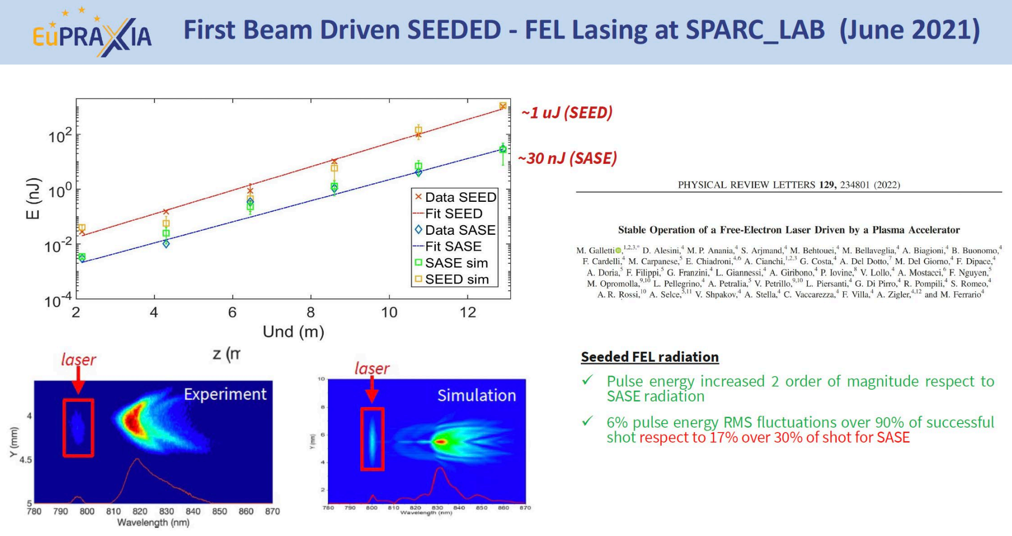


2021 Plasma FEL Feasibility Proven: Electron-driven

Recent ground-breaking results in Frascati:

First FEL lasing from a beam-driven plasma accelerator

Pompili et al., Nature **605**, 659–662 (2022)



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

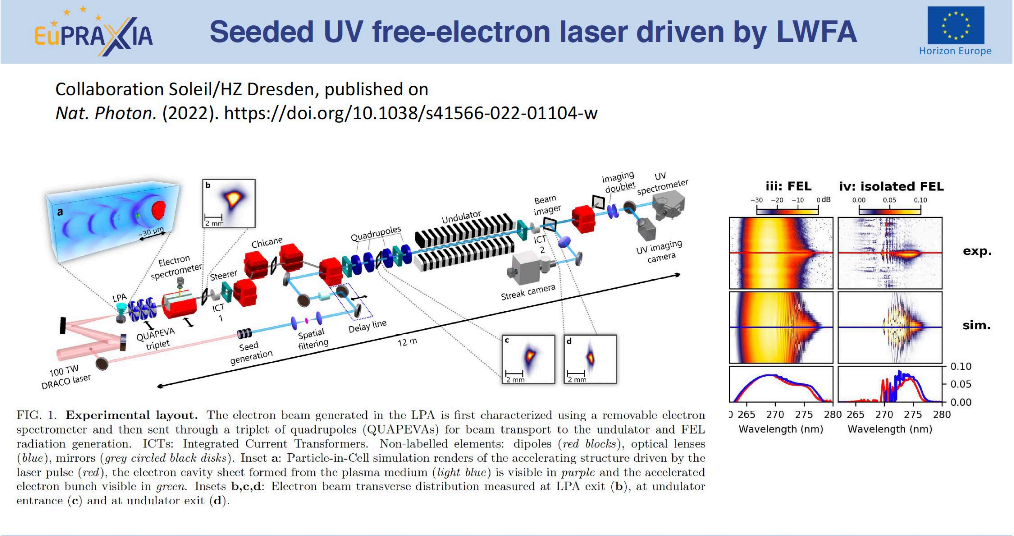
PHYSICAL REVIEW LETTERS **129,** 234801 (2022)

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]

Seeded FEL radiation

- ✓ Pulse energy increased 2 order of magnitude respect to SASE radiation
- ✓ 6% pulse energy RMS fluctuations over 90% of successful shot respect to 17% over 30% of shot for SASE



Seeded UV free-electron laser driven by LWFA

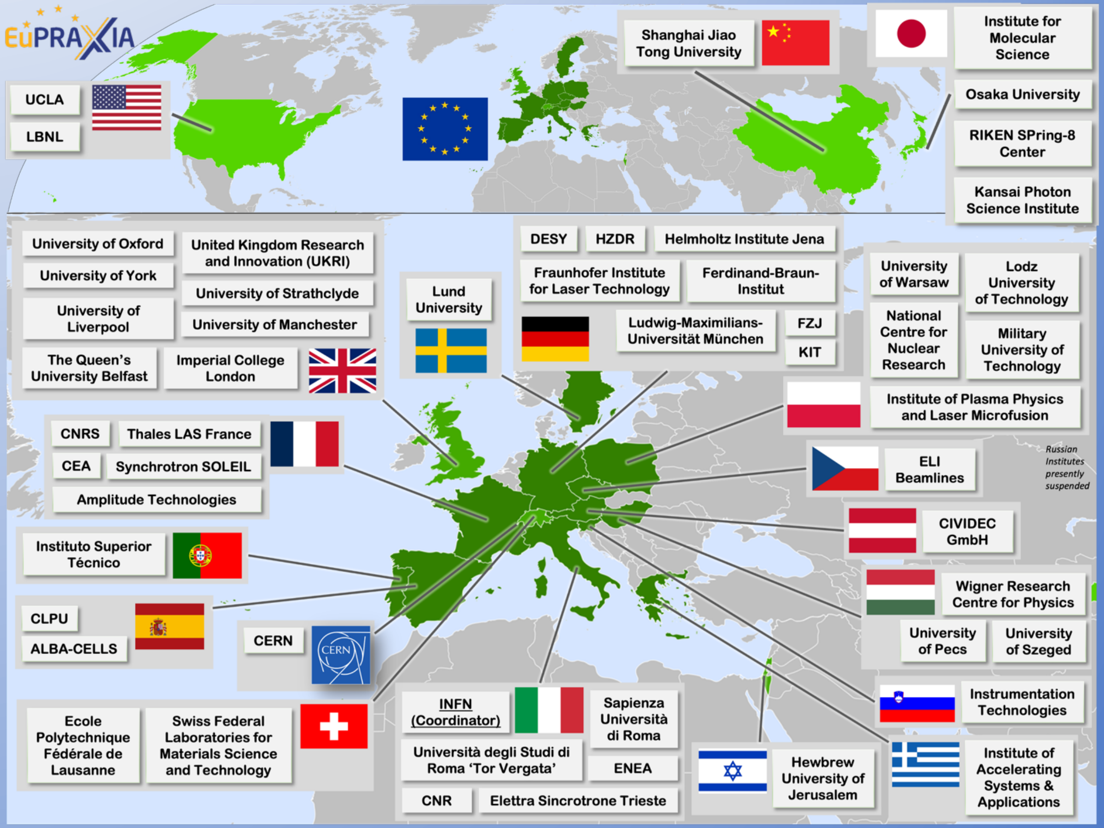
Collaboration Soleil/HZ Dresden, published on
Nat. Photon. (2022). https://doi.org/10.1038/s41566-022-01104-w

FIG. 1. **Experimental layout.** The electron beam generated in the LPA is first characterized using a removable electron spectrometer and then sent through a triplet of quadrupoles (QUAPEVAs) for beam transport to the undulator and FEL radiation generation. ICTs: Integrated Current Transformers. Non-labelled elements: dipoles (*red blocks*), optical lenses (*blue*), mirrors (*grey circled black disks*). Inset **a**: Particle-in-Cell simulation renders of the accelerating structure driven by the laser pulse (*red*), the electron cavity sheet formed from the plasma medium (*light blue*) is visible in *purple* and the accelerated electron bunch visible in *green*. Insets **b,c,d**: Electron beam transverse distribution measured at LPA exit (**b**), at undulator entrance (**c**) and at undulator exit (**d**).

Wide International Collaboration

Funded by the European Union

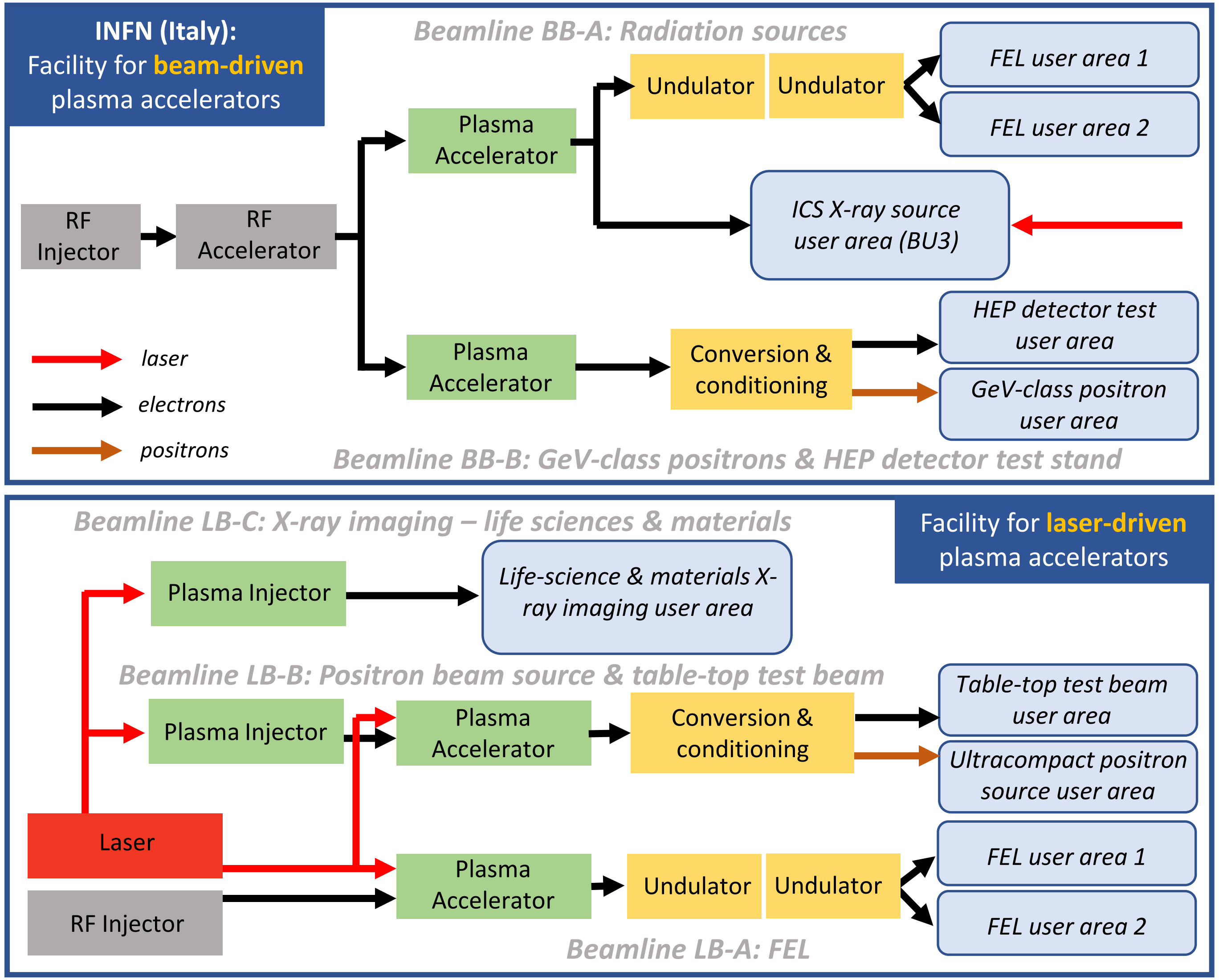
- **The EuPRAXIA Consortium today: 54 institutes** from **18 countries** plus CERN
- Included in the **ESFRI** Road Map
- **Efficient fund raising:**
  - –**Preparatory Phase** consortium (funding EU, UK, Switzerland, in-kind)
  - –**Doctoral Network** (funding EU, UK, in-kind)
  - –**EuPRAXIA@SPARC_LAB** (Italy, in-kind)
  - –**EuAPS Project** (Next Generation EU)
  - –**What Next? => PACRI !**



Phased Implementation of Construction Sites

Funded by the European Union

	Laser-driven	Beam-driven
Phase 1	✓ FEL beamline to 1 GeV + user area 1 ✓ Ultracompact positron source beamline + positron user area	✓ FEL beamline to 1 GeV + user area 1 ✓ GeV-class positrons beamline + positron user area
Phase 2	✓ X-ray imaging beamline + user area ✓ Table-top test beams user area ✓ FEL user area 2 ✓ FEL to 5 GeV	✓ ICS source beamline + user area ✓ HEP detector tests user area ✓ FEL user area 2 ✓ FEL to 5 GeV
Phase 3	✓ High-field physics beamline / user area ✓ Other future developments	✓ Medical imaging beamline / user area ✓ Other future developments



INFN (Italy):
Facility for **beam-driven** plasma accelerators

Beamline BB-A: Radiation sources

RF Injector → RF Accelerator → Plasma Accelerator → Undulator → Undulator → FEL user area 1 / FEL user area 2

Plasma Accelerator → ICS X-ray source user area (BU3)

RF Accelerator → Plasma Accelerator → Conversion & conditioning → HEP detector test user area / GeV-class positron user area

Beamline BB-B: GeV-class positrons & HEP detector test stand

laser
electrons
positrons

Facility for **laser-driven** plasma accelerators

Beamline LB-C: X-ray imaging – life sciences & materials

Laser → Plasma Injector → Life-science & materials X-ray imaging user area

Beamline LB-B: Positron beam source & table-top test beam

Laser → Plasma Injector → Plasma Accelerator → Conversion & conditioning → Table-top test beam user area / Ultracompact positron source user area

Laser, RF Injector → Plasma Accelerator → Undulator → Undulator → FEL user area 1 / FEL user area 2

Beamline LB-A: FEL

Preparatory Phase Main Goals

Funded by the
European Union

- Managerial WP`s
  - **Outreach** to public, users, EU decision makers and industry
  - **Define** legal model (how is EuPRAXIA governed?), financial model, rules, user services and membership extension for full implementation
  - Works with **project bodies and funding agencies** → Board of Financial Sponsors
- Technical WP‘s :
  - **Update of CDR** concepts and parameters, towards technical design (full technical design requires more funding)
  - Specify in detail **Excellence Centers and their required funding**: TDR related R&D, prototyping, contributions to construction
  - Help in defining funding applications for various agencies
- Output defined in **milestones & deliverables** with dates

EuPRAXIA_PP Project Coordinator: Pierluigi Campana (INFN)

Funded by the European Union

Coll. Board
M. Ferrario

Steering Committee

Scientific and Technical Advisory Board

Board of Financial Sponsors

WP1 - Coordination & Project Management
P. Campana, INFN
M. Ferrario, INFN

WP2 - Dissemination and Public Relations
C. Welsch, U Liverpool
S. Bertellii, INFN

WP3 - Organization and Rules
A. Specka, CNRS
A. Ghigo, INFN

WP4 - Financial & Legal Model. Economic Impact
A. Falone, INFN

WP5 - User Strategy and Services
F. Stellato, U Tor Vergata
E. Principi, ELETTRA

WP6 - Membership Extension Strategy
B. Cros, CNRS
A. Mostacci, U Sapienza

WP's on coordination & implementation as ESFRI RI (organization, legal model, financing, users)

WP7 - E-Needs and Data Policy
R. Fonseca, IST
S. Pioli, INFN

WP8 - Theory & Simulation
J. Vieria, IST
H. Vincenti, CEA

WP9 - RF, Magnets & Beamline Components
S. Antipov, DESY
F. Nguyen, ENEA

WP10 - Plasma Components & Systems
K. Cassou, CNRS
R. Shalloo, DESY

WP11 - Applications
G. Sarri, U Belfast
E. Chiadroni,U Sapienza

WP12 - Laser Technology, Liaison to Industry
L. Gizzi, CNR
P. Crump, FBH

WP13 - Diagnostics
A. Cianchi, U Tor Vergata
R. Ischebeck, EPFL

WP14 - Transformative Innovation Paths
B. Hidding, U Dusseldorf
S. Karsch, LMU

WP15 - TDR EuPRAXIA @SPARC-lab
C. Vaccarezza, INFN
R. Pompili, INFN

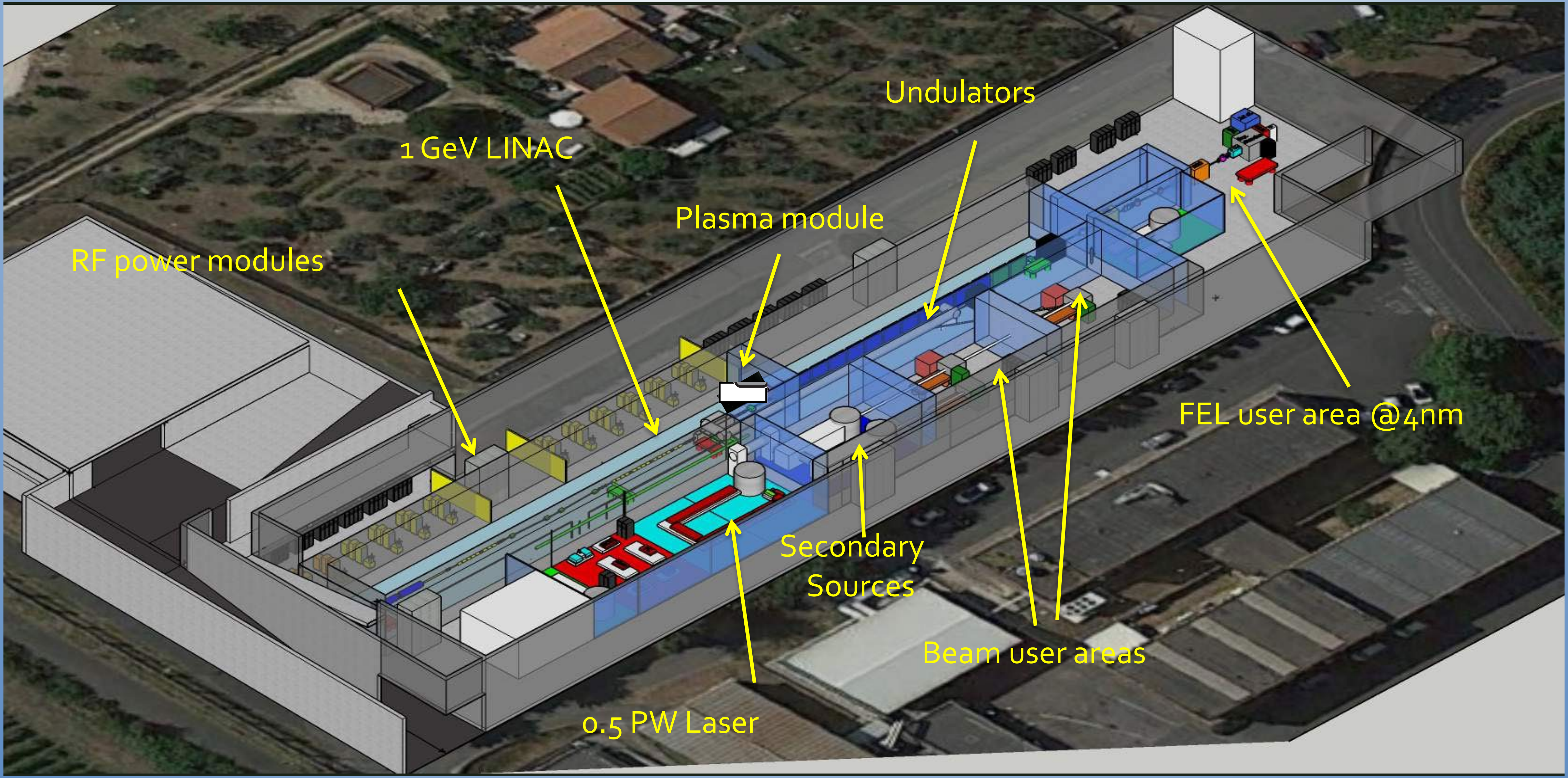
WP16 - TDR EuPRAXIA Site 2
A. Molodozhentsev, ELI-Beamlines
R. Pattahil, STFC

WPs on technical implementation and sites

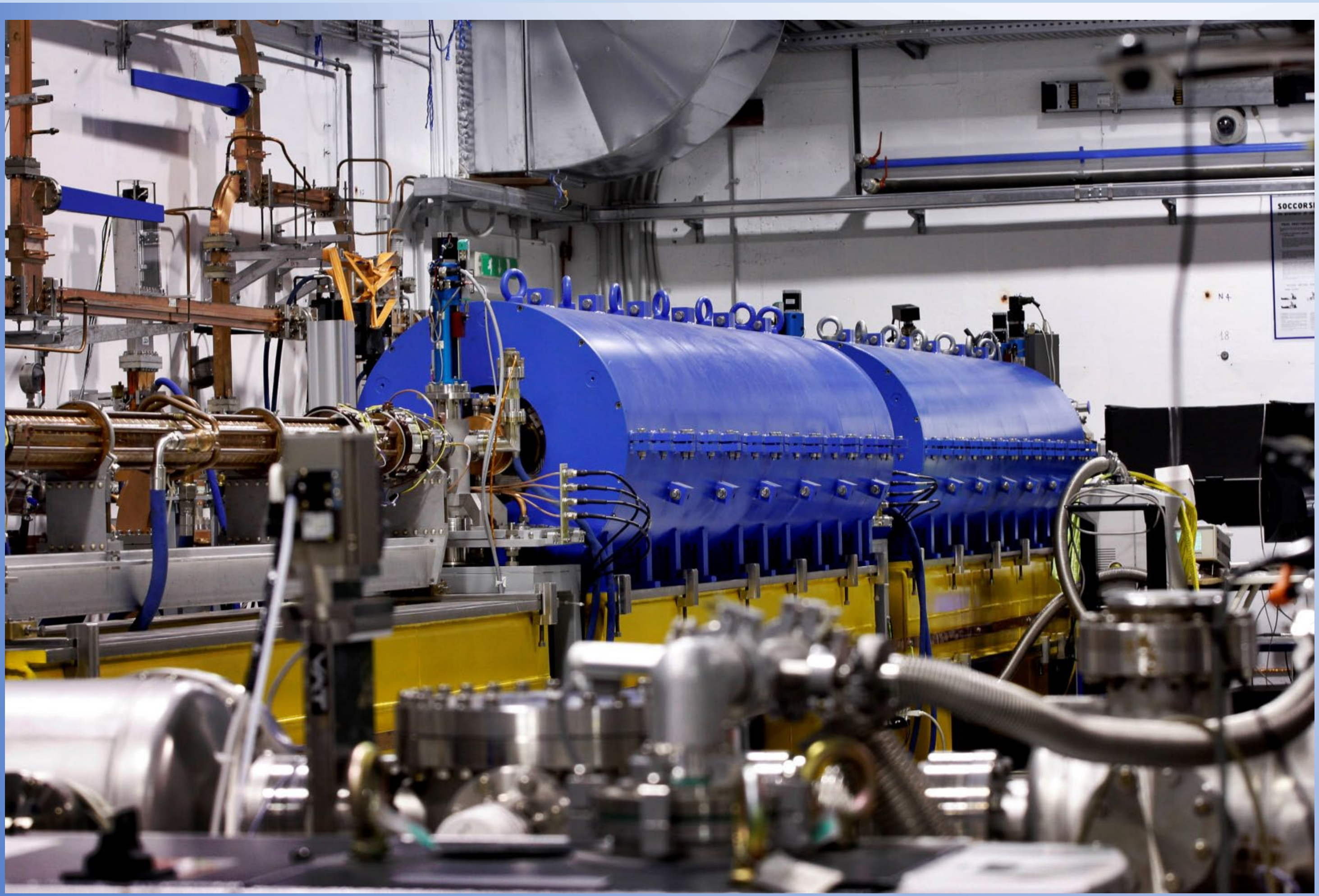
Headquarter and Site 1: EuPRAXIA@SPARC_LAB

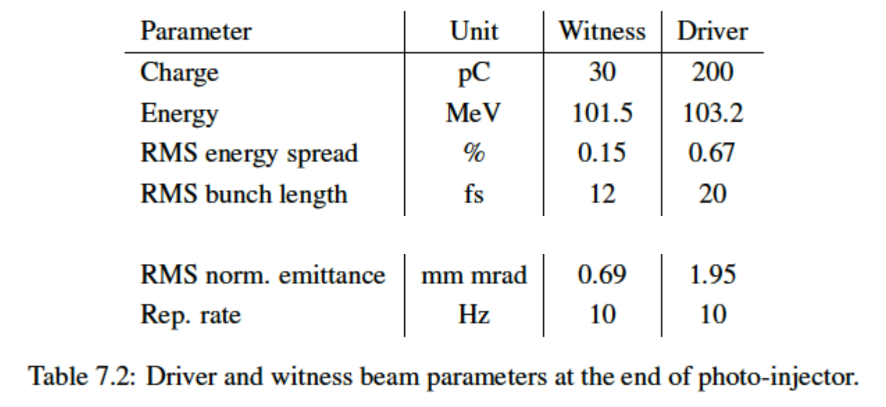
- Frascati`s future facility
- > 130 M€ invest funding
- Beam-driven plasma accelerator
- Europe`s most compact and most southern FEL
- The world`s most compact RF accelerator (X band with CERN)

EuPRAXIA@SPARC_LAB



High Quality Electron Beams



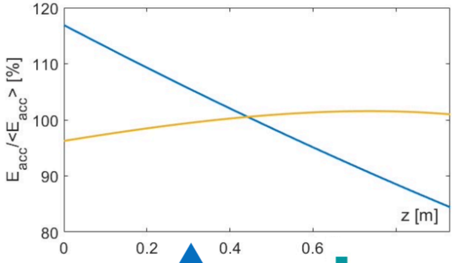


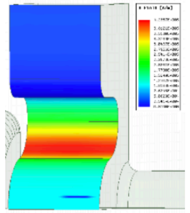
Parameter	Unit	Witness	Driver
Charge	pC	30	200
Energy	MeV	101.5	103.2
RMS energy spread	%	0.15	0.67
RMS bunch length	fs	12	20
RMS norm. emittance	mm mrad	0.69	1.95
Rep. rate	Hz	10	10

Table 7.2: Driver and witness beam parameters at the end of photo-injector.

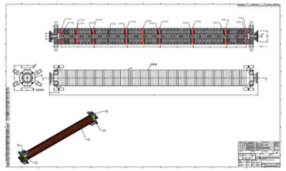
Courtesy E. Chiadroni

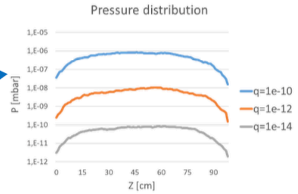
World`s Most Compact RF Linac: X Band

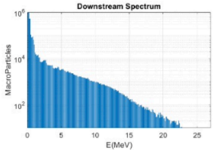




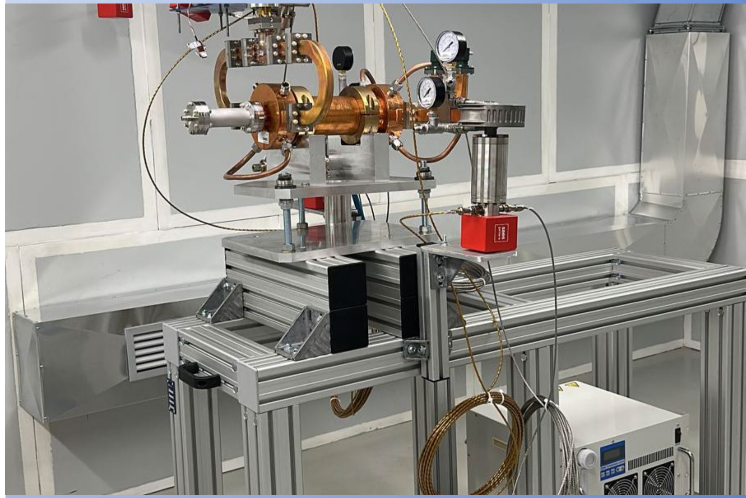
1. **E.m. design**: *done*
2. **Thermo-mechanical analysis**: *done*
3. **Mechanical design**: *done*
4. **Vacuum calculations**: *done*
5. **Dark current simulations**: *done*
6. **Waveguide distribution simulation with attenuation calculations**: *done*

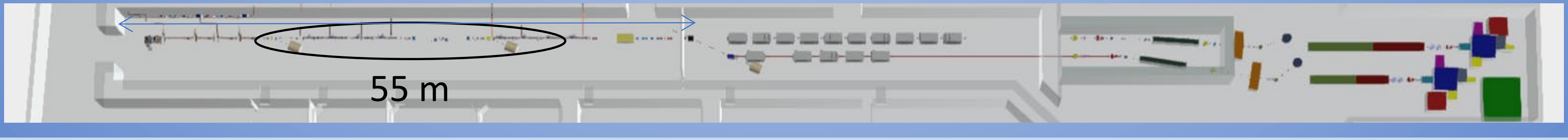






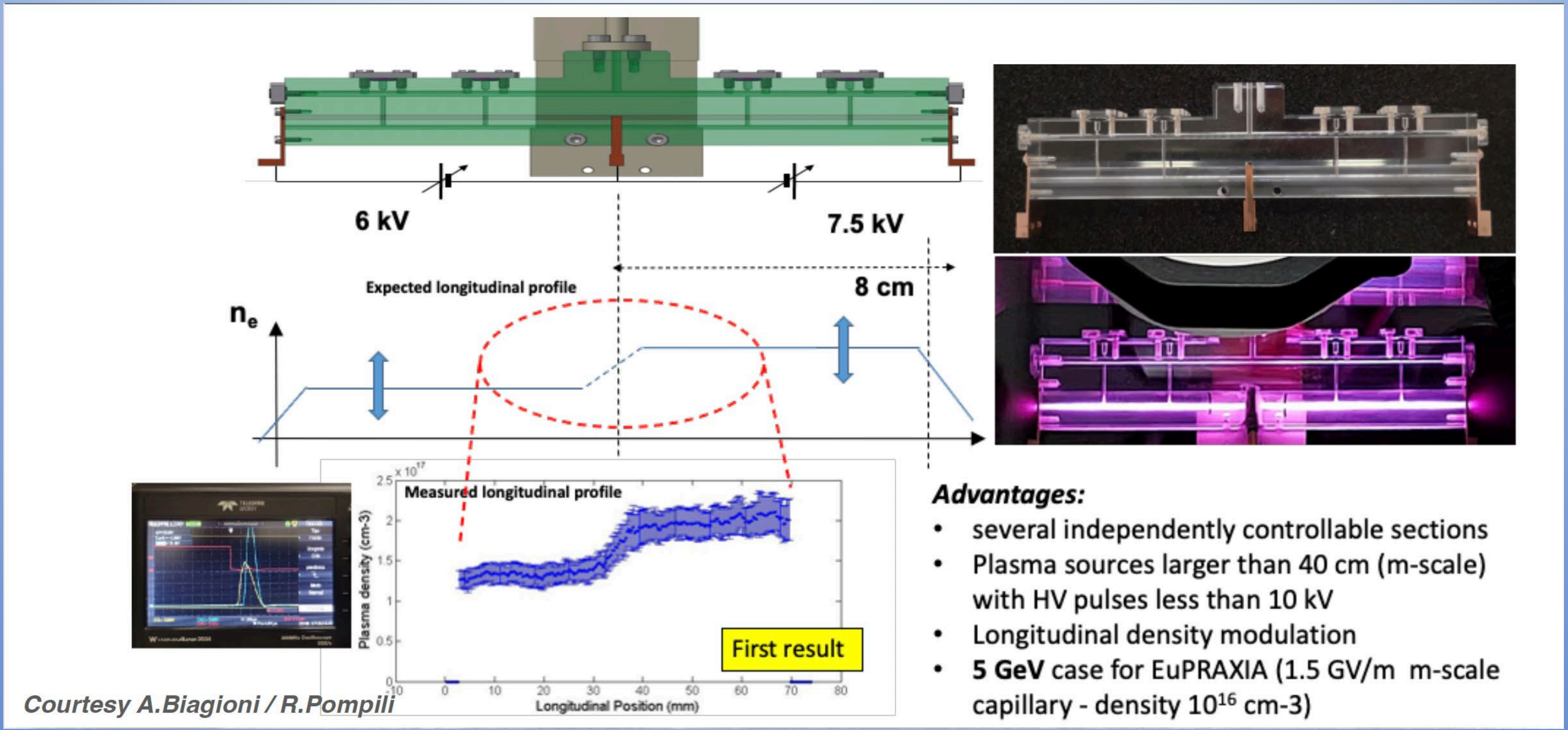
PARAMETER	Value	
	with linear tapering	w/o tapering
Frequency [GHz]	11.9942	
Average acc. gradient [MV/m]	**60**	
Structures per module	2	
Iris radius a [mm]	**3.85-3.15**	**3.5**
Tapering angle [deg]	0.04	0
Struct. length L_s act. Length (flange-to-flange) [m]	**0.94 (1.05)**	
No. of cells	112	
Shunt impedance R [MΩ/m]	93-107	100
Effective shunt Imp. $R_{sh\ eff}$ [MΩ/m]	350	347
Peak input power per structure [MW]	70	
Input power averaged over the pulse [MW]	51	
Average dissipated power [kW]	1	
P_{out}/P_{in} [%]	25	
Filling time [ns]	130	
Peak Modified Poynting Vector [W/μm²]	3.6	4.3
Peak surface electric field [MV/m]	160	190
Unloaded SLED/BOC Q-factor Q_0	150000	
External SLED/BOC Q-factor Q_E	21300	20700
Required Kly power per module [MW]	**20**	
RF pulse [μs]	**1.5**	
Rep. Rate [Hz]	**100**	





Courtesy D. Alesini

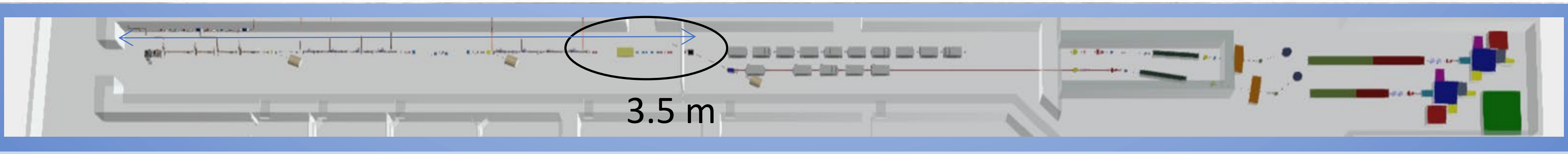
Plasma Module



Courtesy A.Biagioni / R.Pompili

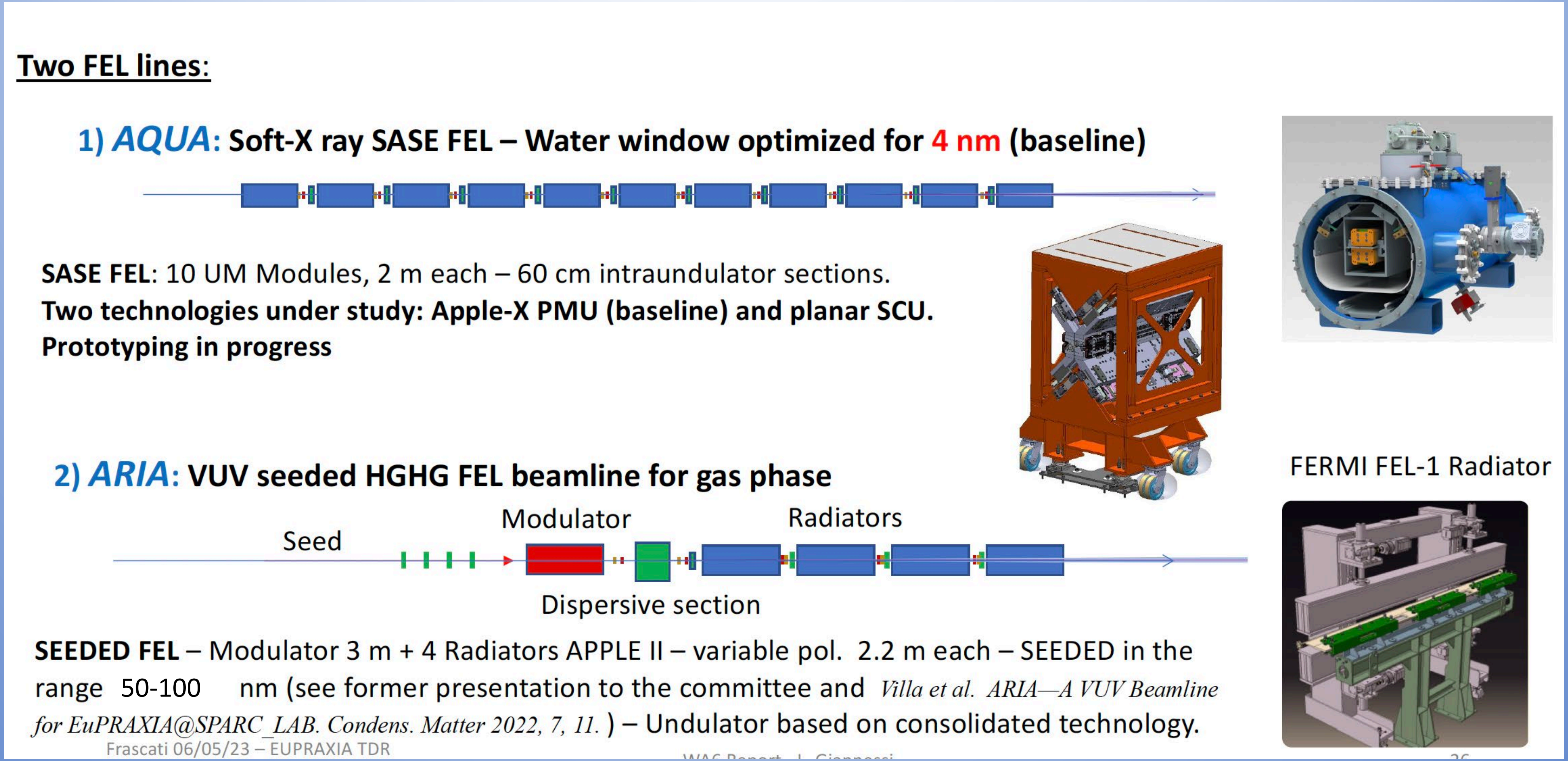
Advantages:

- several independently controllable sections
- Plasma sources larger than 40 cm (m-scale) with HV pulses less than 10 kV
- Longitudinal density modulation
- **5 GeV** case for EuPRAXIA (1.5 GV/m m-scale capillary - density 10^{16} cm-3)



Courtesy A. Biagioni, R. Pompili

Radiation Generation: FEL



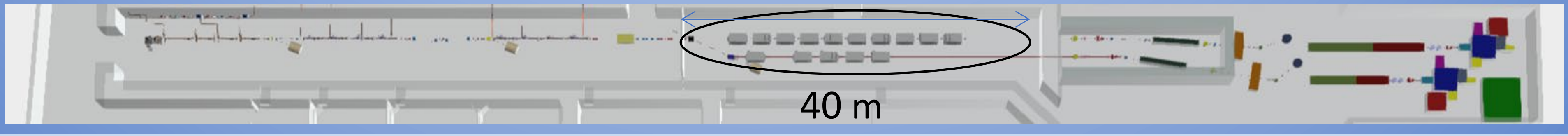
Two FEL lines:

1) ***AQUA*: Soft-X ray SASE FEL – Water window optimized for 4 nm (baseline)**

SASE FEL: 10 UM Modules, 2 m each – 60 cm intraundulator sections.
Two technologies under study: Apple-X PMU (baseline) and planar SCU.
Prototyping in progress

2) ***ARIA*: VUV seeded HGHG FEL beamline for gas phase**

SEEDED FEL – Modulator 3 m + 4 Radiators APPLE II – variable pol. 2.2 m each – SEEDED in the range 50-100 nm (see former presentation to the committee and *Villa et al. ARIA—A VUV Beamline for EuPRAXIA@SPARC_LAB. Condens. Matter 2022, 7, 11.*) – Undulator based on consolidated technology.



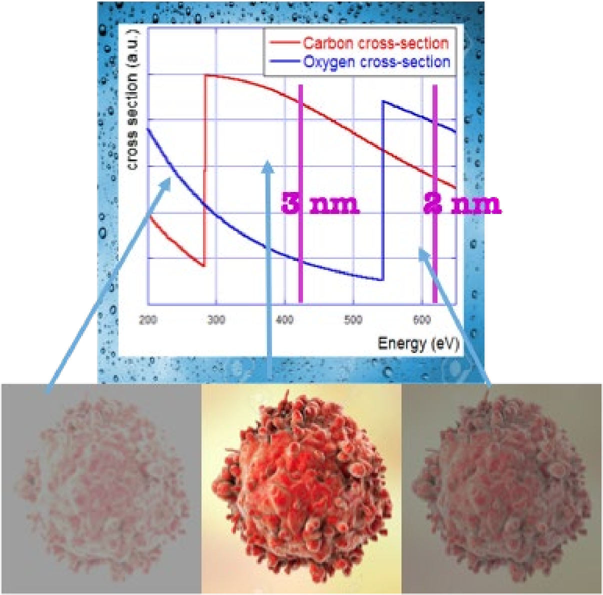
Courtesy L. Giannessi

Expected SASE FEL performances

Parameter	**Unit**	PWFA	Full X-band
Electron Energy	GeV	1-*1.2*	1
Bunch Charge	pC	**30-*50***	**200-*500***
Peak Current	kA	1-2	1-2
RMS Energy Spread	%	**0.1**	0.1
RMS Bunch Length	μm	6-3	24-20
RMS norm. Emittance	μm	1	1
Slice Energy Spread	%	≤0.05	≤0.05
Slice norm Emittance	mm-mrad	0.5	0.5

Parameter	**Unit**	PWFA	Full X-band
Radiation Wavelength	nm	**3-4**	**4**
Photons per Pulse	$\times 10^{12}$	**0.1- 0.25**	1
Photon Bandwith	%	**0.1**	0.5
Undulator Area Length	m	30	
ρ(1D/3D)	$\times 10^{-3}$	**2**	2
Photon Brilliance per shot	$s\,mm^2 mrad^2$ $bw(0.1\%)$	$\mathbf{1-2\ \times 10^{28}}$	$1\ \times 10^{27}$

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

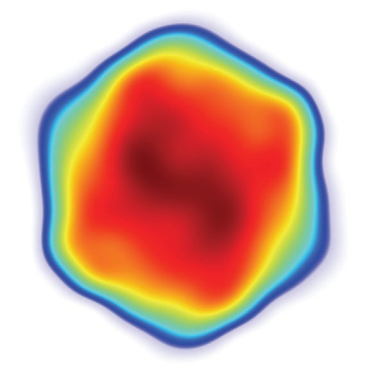
Courtesy F. Stellato, UniToV

Courtesy C. Vaccarezza/L. Giannessi

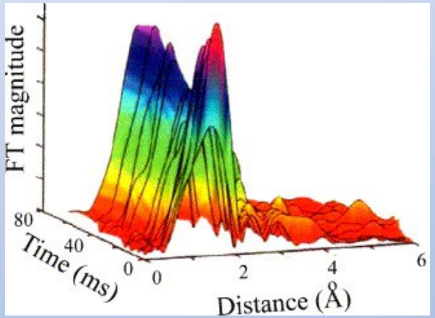
AQUA beamline scientific case

Experimental techniques and typology of samples

Coherent imaging



X-ray spectroscopy



Raman spectroscopy

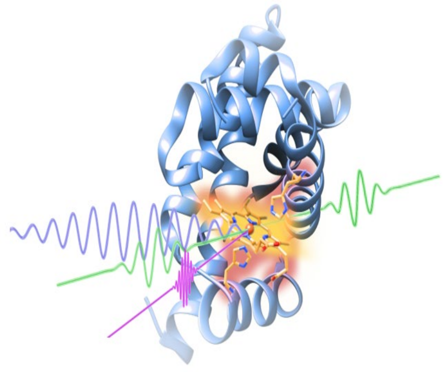
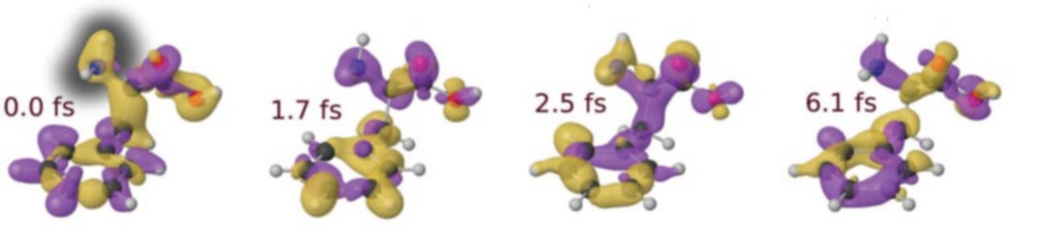


Photo-fragmentation of molecules



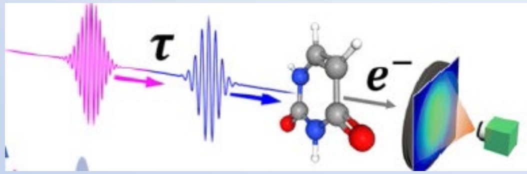
(Large) Viruses
Organelles
Bacteria/Cells
Metals
Semiconductors
Superconductors
Magnetic materials
Organic molecules

Courtesy F. Stellato

ARIA beamline scientific case

Defining experimental techniques and typology of samples (and applications)

Photoemission
Spectroscopy



Photoelectron Circular
Dichroism

Raman spectroscopy

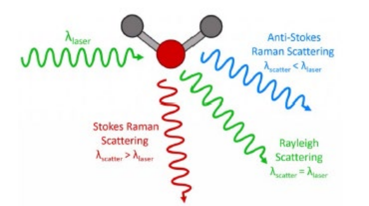
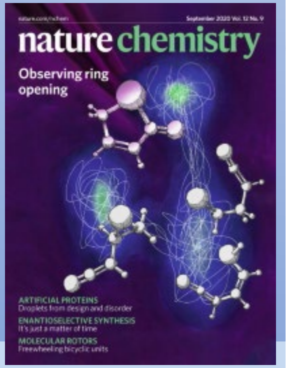
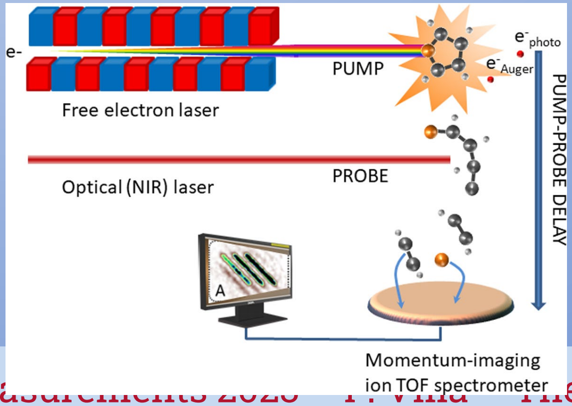


Photo-fragmentation of molecules
Time of Flight Spectroscopy



nature.com/natchem
September 2020 Vol. 12 No. 9
nature chemistry
Observing ring opening

ARTIFICIAL PROTEINS
Droplets from design and disorder
ENANTIOSELECTIVE SYNTHESIS
It's just a matter of time
MOLECULAR ROTORS
Freewheeling bicyclic units



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

Courtesy F. Stellato

Finanziato dall'Unione europea
NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

EuPRAXIA
Advanced Photon Sources

EuAPS: EuPRAXIA Advance Photon Sources

- Principal Investigator: M. Ferrario,
- Infrastructure Manager: C. Bortolin,
- Management and Dissemination: A. Falone

Research

The **EuPRAXIA Advanced Photon Sources** (**EuAPS**) project, led by INFN in collaboration with CNR and University of Tor Vergata, foresees the construction of a laser-driven "betatron" X Ray user facility at the LNF SPARC_LAB laboratory. EuAPS includes also the development of high power (up to 1 PW at LNS) and high repetition rate (up to 100 Hz at CNR Pisa) drive lasers for EuPRAXIA. EuAPS has received a financial support of 22.3 MEuro from the PNRR plan on "creation of a new RI among those listed in NPRI with medium or high priority" and has received the highest score for the action 3.1.1 of the ESFRI area "Physical Sciences and Engineering".

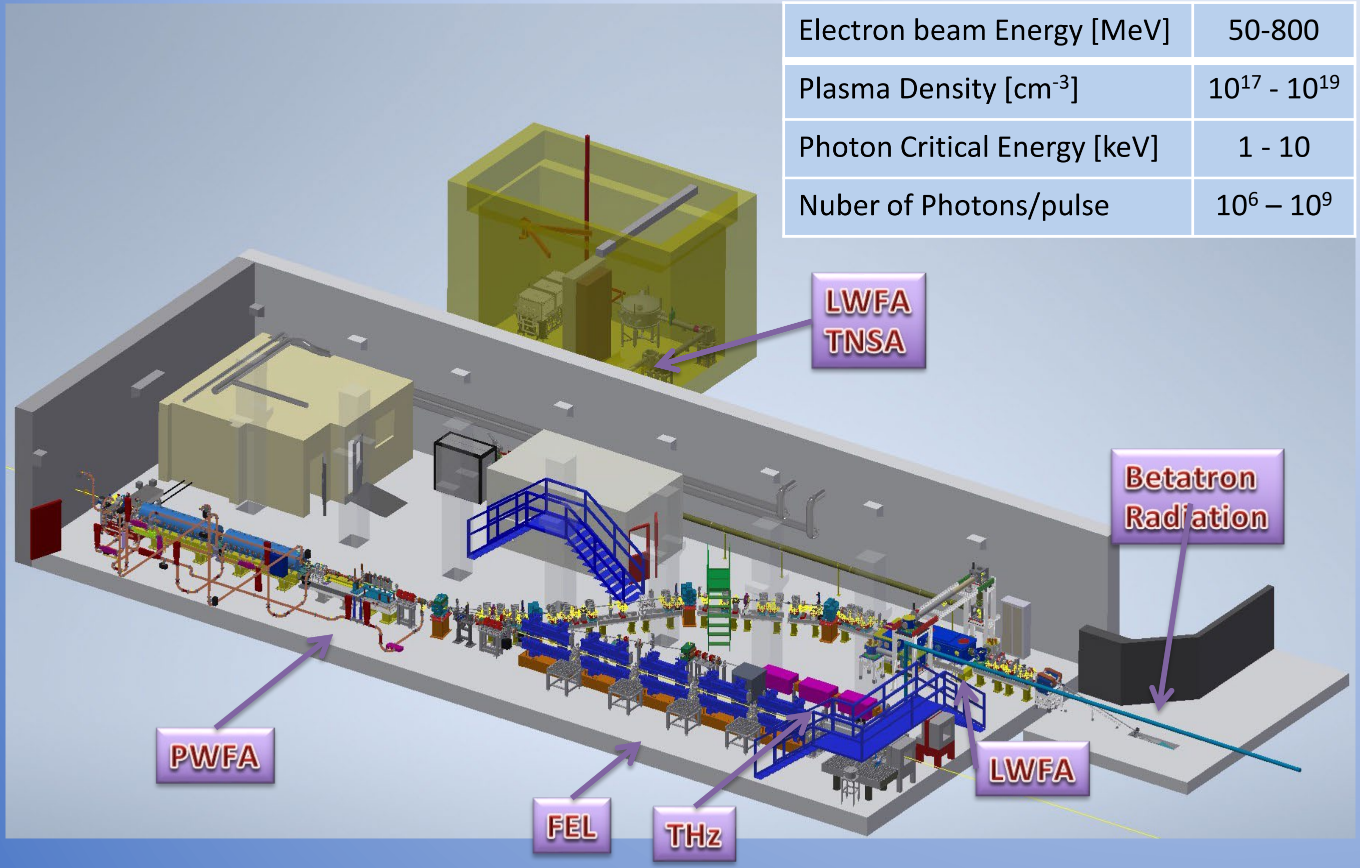
A. Cianchi (Uni ToV) — **Betatron Radiation Source**

P. Cirrone (INFN-LNS) — **High Power Laser Beamline**

L. Labate (CNR-INO) — **High Repetition Rate Laser Beamline**

M. Ferrario et al. INFN-23-12-LNF (2023)

Betatron Radiation Source at SPARC_LAB



Electron beam Energy [MeV]	50-800
Plasma Density [cm^{-3}]	10^{17} - 10^{19}
Photon Critical Energy [keV]	1 - 10
Nuber of Photons/pulse	10^{6} – 10^{9}

Courtesy J. Vieira, R. Fonseca/GoLP/IST Lisbon

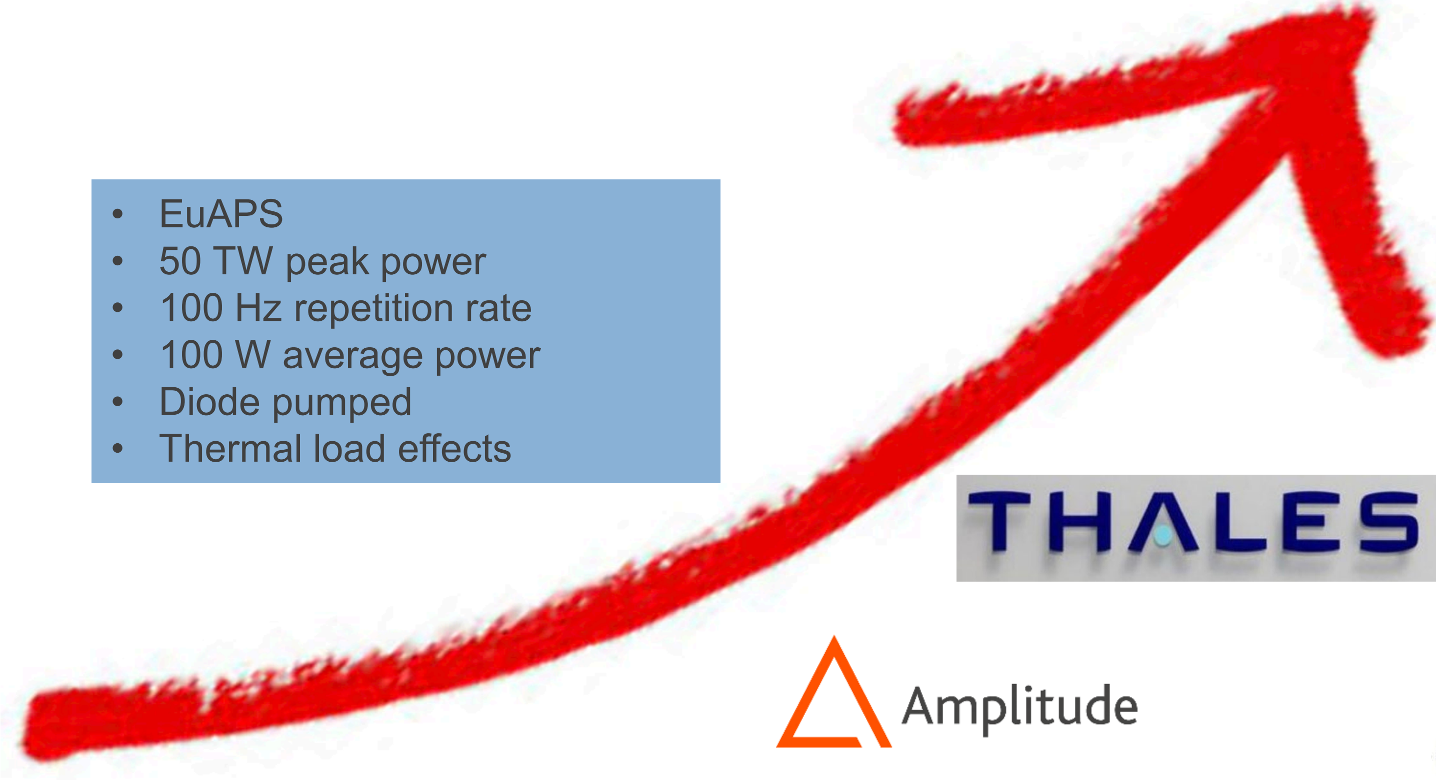
Towards EuPRAXIA Laser Specs

Funded by the European Union

Eupraxia laser development is aimed at delivering more efficient, kW class PW laser driver for plasma acceleration at >100 Hz rate

EuPRAXIA Advanced Photon Sources

- CURRENT
- PW class,
- Hz repetition rate,
- ≈10 W average power
- flashlamp pumped
- No thermal load transport



- EuAPS
- 50 TW peak power
- 100 Hz repetition rate
- 100 W average power
- Diode pumped
- Thermal load effects

- EuPRAXIA
- PW class,
- 100 Hz repetition rate,
- multi kW average power,
- diode pumped
- Full thermal load transport

THALES

Amplitude

EuPRAXIA

NEXT STEP: PACRI

Funded by the European Union

- **HORIZON-INFRA-2024-TECH-01-01: R&D for the next generation of scientific instrumentation, tools, methods, solutions for RI upgrade**

- **Dead line 12 March 2024**

- **Target Budget ~10 MEuro**

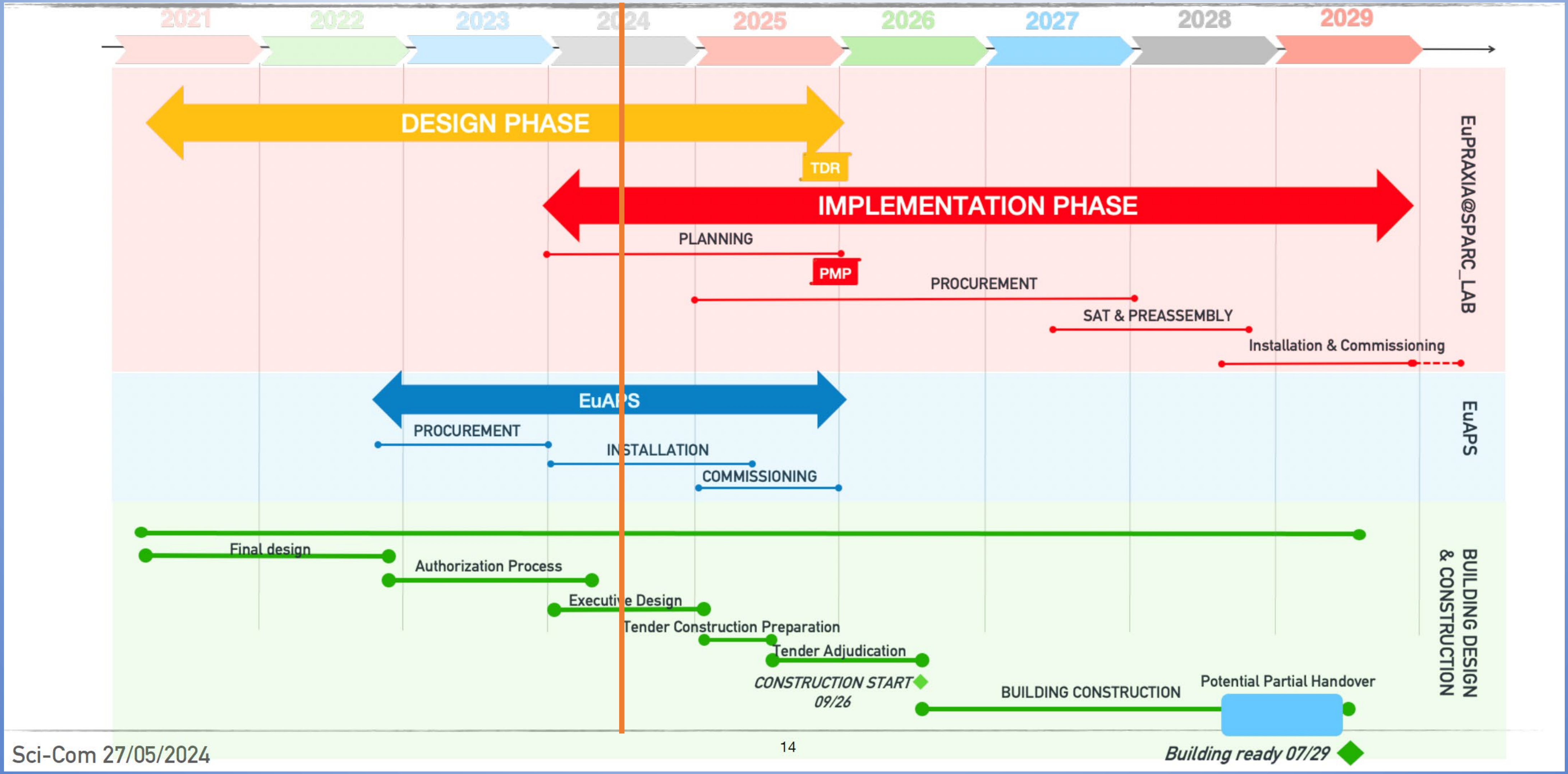
25 Members
+
1 Associated partner

19 Universities and Scientific Labs.
+
7 Industries

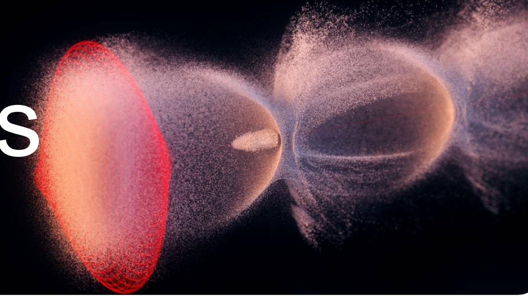
#	Partner	Acronym
1	Elettra - Sincrotrone Trieste SCpA (Coordinator)	ST
2	European Organization for Nuclear Research	CERN
3	Istituto Nazionale Fisica Nucleare	INFN
4	University of Liverpool	ULIV
5	Thales-MIS	Th-MIS
6	Scandinova Systems AB	SCND
7	VDL ETG Technology & Development BV	VDL
8	COMEB	COMEB
9	United Kingdom Research and Innovation	UKRI
10	Consiglio Nazionale delle Ricerche	CNR
11	Extreme Light Infrastructure ERIC	ELI-ERIC
12	Centre National de la Recherche Scientifique CNRS	CNRS
13	Thales LAS France SAS	Th-LAS
14	Amplitude	Amplitude
15	Centro de LÁSERES Pulsados	CLPU
16	Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Hoechstfrequenztechnik	FBH
17	Associacao do instituto superior Tecnico para a Investigacao e Desenvolvimento	IST
18	Università degli Studi di Roma La Sapienza	USAP
19	Heinrich-Heine-Universitaet Duesseldorf	UDUS
20	Deutsches Elektronen-Synchrotron DESY	DESY
21	The Chancellor, Masters and Scholars of the Univ. of Oxford	UOX
22	Ludwig-Maximilians-Universitaet Muenchen	LMU
23	GSI Helmholtz Centre for Heavy Ion Research	GSI
24	Università degli Studi di Roma Tor Vergata	UTOR
25	SourceLAB	SourceLAB
26	Paul Scherrer Institut (Associated partner)	PSI

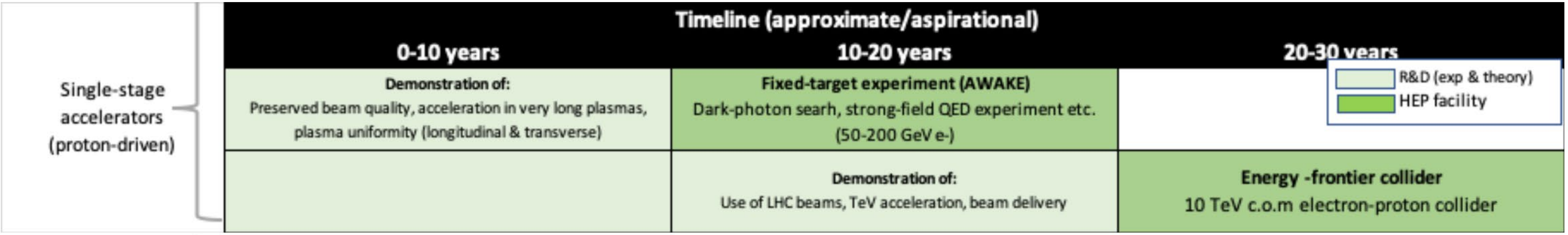
WP No.	**Work Package Title**	**Lead Partic. Short Name**
1	Coordination and project management	**ELETTRA**
2	Scientific and industrial exploitation	**ULIV**
3	Plasma accelerator theory and simulations	**IST**
4	High repetition rate plasma structures	**INFN**
5	Plasma acceleration diagnostics and instrumentation	**CNRS**
6	High efficiency RF generator	**Thales-MIS**
7	High repetition rate modulator	**Scandinova**
8	X-band RF Pulse Compressor (BOC)	**INFN**
9	RF tests and validation	**CERN**
10	High repetition rate high power Ti:Sa amplifier module	**UKRI**
11	Efficient kHz laser driver modules for plasma acceleration	**CNR**
12	High-rep rate pump sources for laser drivers	**ELI-ERIC**
13	Prototype of high average power optical compressor	**Thales-LAS**
14	Laser Driver System Architecture,transport and engineering	**CNRS**

EuPRAXIA@SPARC_LAB baseline updating



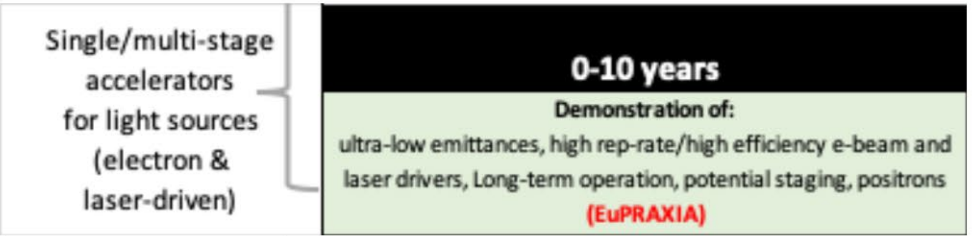
ESPP Roadmap Update – Plasma Accelerators





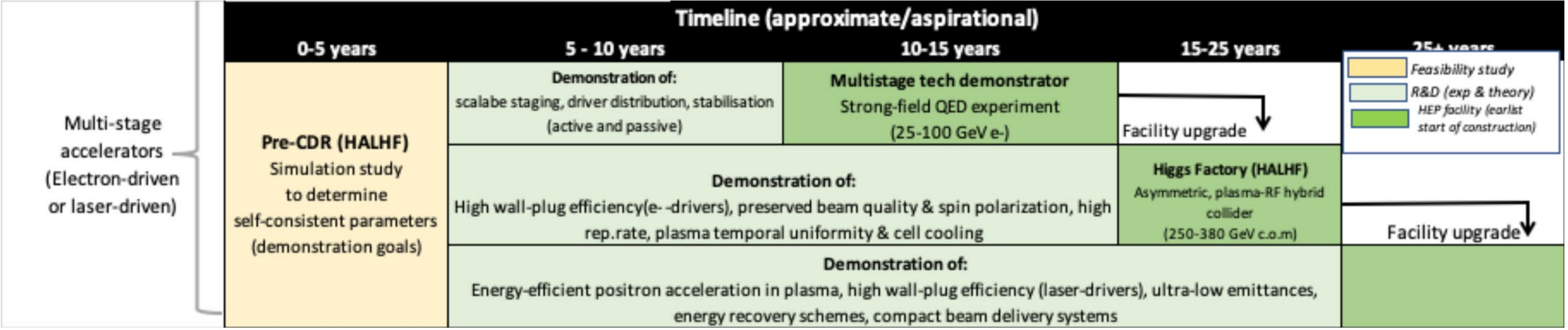
	Timeline (approximate/aspirational)		
	0-10 years	10-20 years	20-30 years
Single-stage accelerators (proton-driven)	**Demonstration of:** Preserved beam quality, acceleration in very long plasmas, plasma uniformity (longitudinal & transverse)	**Fixed-target experiment (AWAKE)** Dark-photon searh, strong-field QED experiment etc. (50-200 GeV e-)	
		Demonstration of: Use of LHC beams, TeV acceleration, beam delivery	**Energy -frontier collider** 10 TeV c.o.m electron-proton collider

R&D (exp & theory)
HEP facility



	0-10 years
Single/multi-stage accelerators for light sources (electron & laser-driven)	**Demonstration of:** ultra-low emittances, high rep-rate/high efficiency e-beam and laser drivers, Long-term operation, potential staging, positrons **(EuPRAXIA)**

R&D on EuPRAXIA will de-risk HALHF and other plasma-based collider concepts considerably



	Timeline (approximate/aspirational)				
	0-5 years	5 - 10 years	10-15 years	15-25 years	25+ years
Multi-stage accelerators (Electron-driven or laser-driven)	**Pre-CDR (HALHF)** Simulation study to determine self-consistent parameters (demonstration goals)	**Demonstration of:** scalabe staging, driver distribution, stabilisation (active and passive)	**Multistage tech demonstrator** Strong-field QED experiment (25-100 GeV e-)	Facility upgrade	
		Demonstration of: High wall-plug efficiency(e- -drivers), preserved beam quality & spin polarization, high rep.rate, plasma temporal uniformity & cell cooling		**Higgs Factory (HALHF)** Asymmetric, plasma-RF hybrid collider (250-380 GeV c.o.m)	Facility upgrade
		Demonstration of: Energy-efficient positron acceleration in plasma, high wall-plug efficiency (laser-drivers), ultra-low emittances, energy recovery schemes, compact beam delivery systems			

Feasibility study
R&D (exp & theory)
HEP facility (earlist start of construction)

Conclusions

Funded by the European Union

- Plasma accelerators have advanced considerably in beam quality, **achieving FEL lasing**.
- EuPRAXIA is a design and an ESFRI project for a distributed European Research Infrastructure, **building two plasma-driven FEL´s in Europe**.
- EuPRAXIA FEL site in Frascati LNF-INFN is sufficiently funded for **first FEL user operation in 2029**.
- Second EuPRAXIA FEL site will be selected in next months, among **4 excellent candidate sites**.
- Concept today **works in design and in reality**. Expect (solvable) problems in stability for **24/7 user operation**. Facility needed to demonstrate!
- Additional fund raising is continuosly going on

CERNCOURIER

May/June 2023 cerncourier.com

Reporting on international high-energy physics

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FEATURE EuPRAXIA

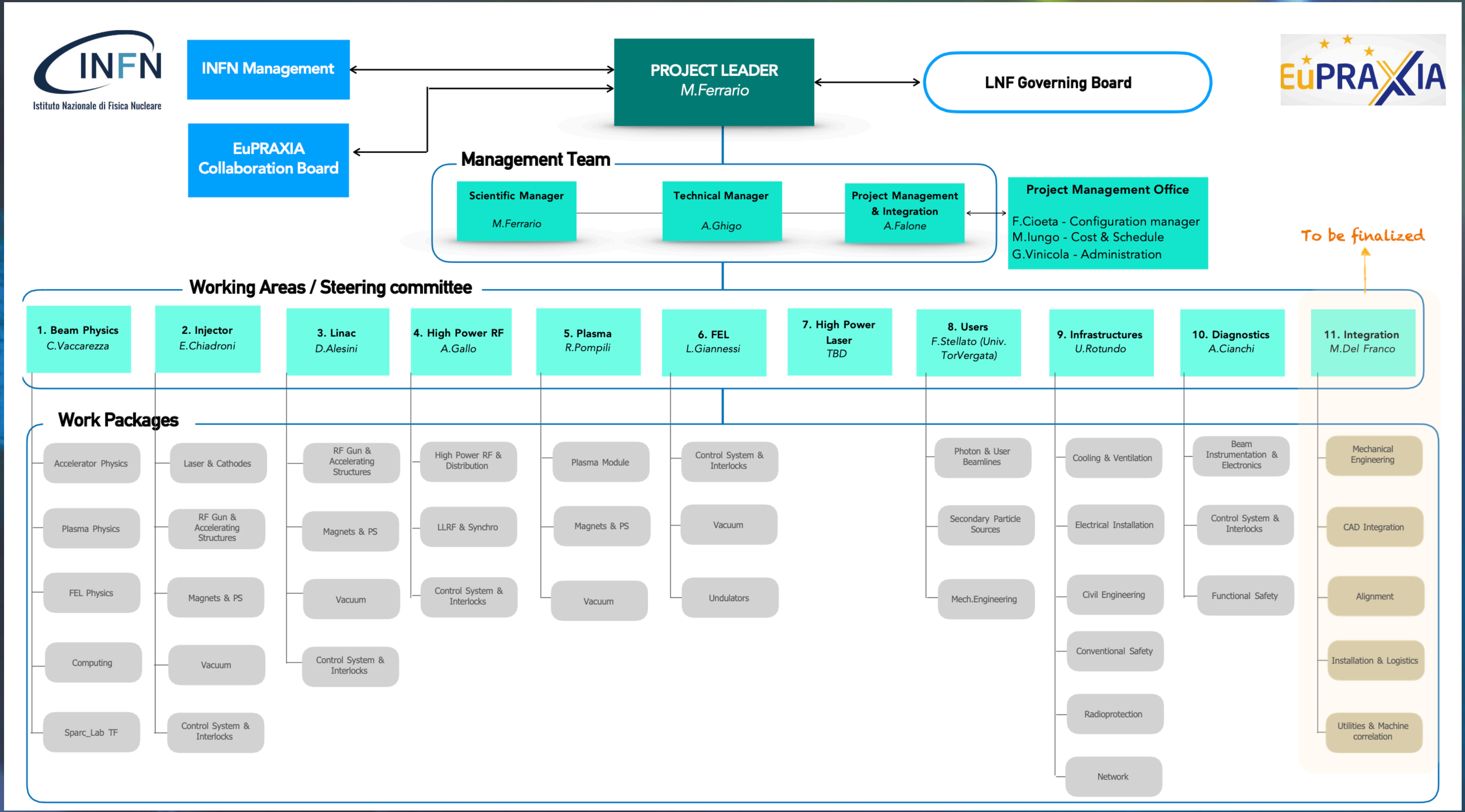
Surf's up *Simulation of electron-driven plasma wakefield acceleration, showing the drive electron beam (orange/purple), the plasma electron wake (grey) and wakefield-ionised electrons forming a witness beam (orange).*

EUROPE TARGETS A USER FACILITY FOR PLASMA ACCELERATION

Ralph Assmann, Massimo Ferrario and Carsten Welsch describe the status of the ESFRI project EuPRAXIA, which aims to develop the first dedicated research infrastructure based on novel plasma-acceleration concepts.

Thank for your attention

EuPRAXIA@SPARC_LAB Organization



INFN

Istituto Nazionale di Fisica Nucleare

INFN Management

EuPRAXIA Collaboration Board

PROJECT LEADER
M.Ferrario

LNF Governing Board

Management Team

Scientific Manager
M.Ferrario

Technical Manager
A.Ghigo

Project Management & Integration
A.Falone

Project Management Office

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

To be finalized

Working Areas / Steering committee

- **1. Beam Physics** *C.Vaccarezza*
  - Accelerator Physics
  - Plasma Physics
  - FEL Physics
  - Computing
  - Sparc_Lab TF
- **2. Injector** *E.Chiadroni*
  - Laser & Cathodes
  - RF Gun & Accelerating Structures
  - Magnets & PS
  - Vacuum
  - Control System & Interlocks
- **3. Linac** *D.Alesini*
  - RF Gun & Accelerating Structures
  - Magnets & PS
  - Vacuum
  - Control System & Interlocks
- **4. High Power RF** *A.Gallo*
  - High Power RF & Distribution
  - LLRF & Synchro
  - Control System & Interlocks
- **5. Plasma** *R.Pompili*
  - Plasma Module
  - Magnets & PS
  - Vacuum
- **6. FEL** *L.Giannessi*
  - Control System & Interlocks
  - Vacuum
  - Undulators
- **7. High Power Laser** TBD
- **8. Users** *F.Stellato (Univ. TorVergata)*
  - Photon & User Beamlines
  - Secondary Particle Sources
  - Mech.Engineering
- **9. Infrastructures** *U.Rotundo*
  - Cooling & Ventilation
  - Electrical Installation
  - Civil Engineering
  - Conventional Safety
  - Radioprotection
  - Network
- **10. Diagnostics** *A.Cianchi*
  - Beam Instrumentation & Electronics
  - Control System & Interlocks
  - Functional Safety
- **11. Integration** *M.Del Franco*
  - Mechanical Engineering
  - CAD Integration
  - Alignment
  - Installation & Logistics
  - Utilities & Machine correlation

Work Packages

WP12 Design study path for EuPRAXIA Laser-driver

Funded by the European Union

- **Baseline: proven technology based on Ti:Sa technology, pumped by diode-pumped lasers**
  - Strong R&D effort in place (e.g HAPLS@ELI **now entering into USER operation)**
  - ≈ 3-5 years to go to first industrial LWFA demonstrator [1]

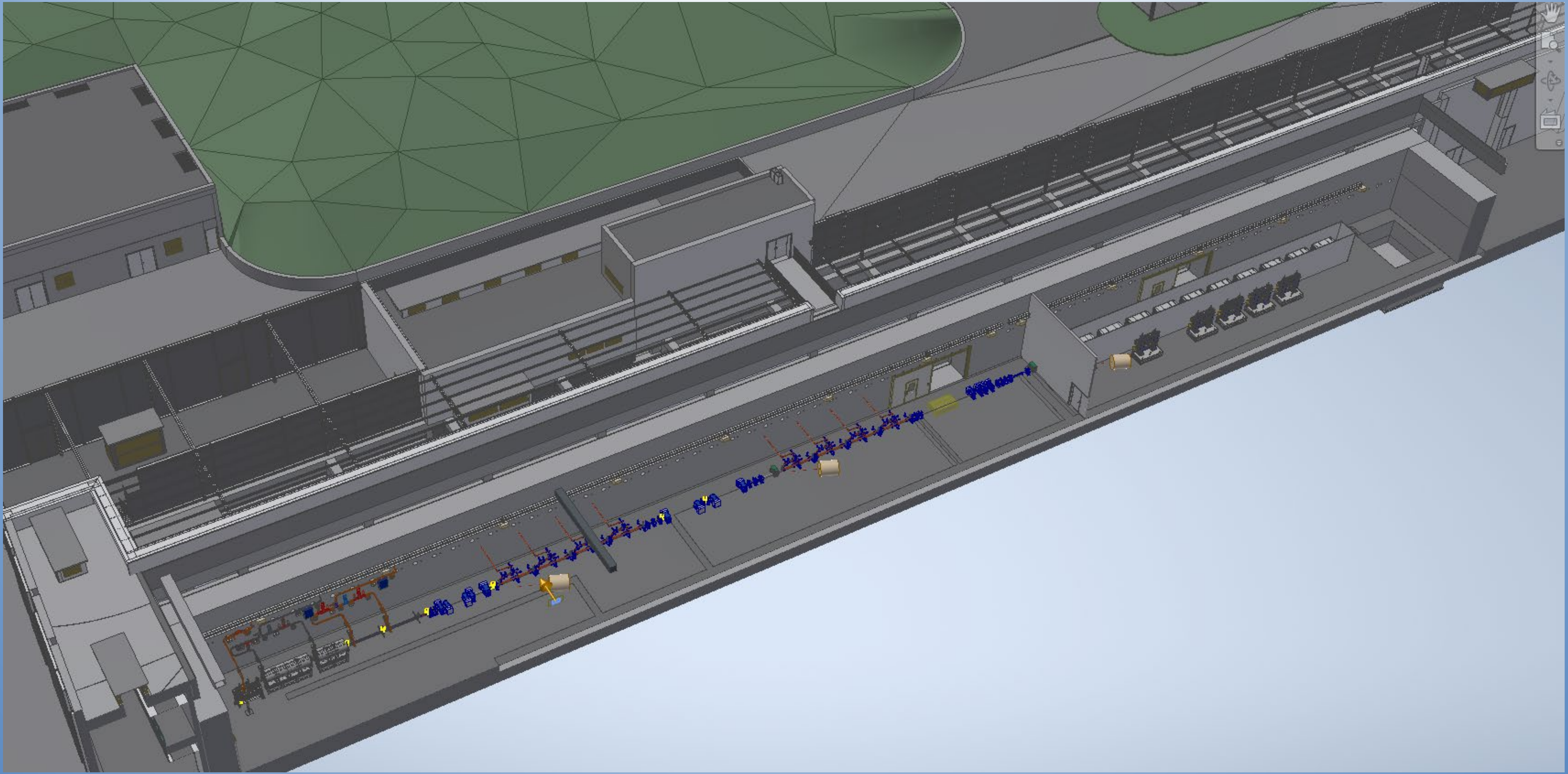
- **Fully diode pumped with Direct Chirped Pulse Amplification** with lasing media pumped directly by diodes is ideal for higher efficiency and higher rep-rate;
  - several materials under consideration, Yb:CaF2, Tm:YLF, **Tm:Lu2O3 (Pisa)** …
  - PENELOPE (Jena) 150 J, 1 Hz, at 1030 nm
  - Available ps kW thin disk lasers using plasma modulation (Oxford [2])

- **OPCPA** optical parametric amplification within large-aperture (LBO) crystals;
  - ELI-Beamlines facility, L2 DUHA (100 TW, 2 to 5 J between 20, 50, 100 Hz)

Partially addressed by new/pending proposal

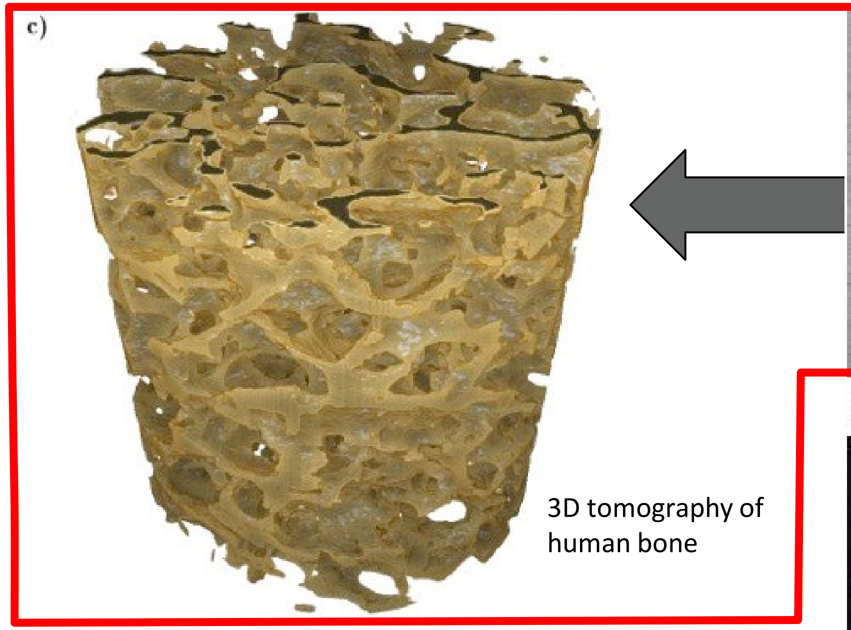
1. L.A Gizzi, F. Mathieu, P. Mason, P P Rajeev, *Laser drivers for Plasma Accelerators*, in Félicie Albert et al, *2020 roadmap on plasma accelerators*, 2021 New J. Phys. 23 031101, https://doi.org/10.1088/1367-2630/abcc62;
2. O. Jakobsson, S. M. Hooker and R. Walczak, PRL, 2021

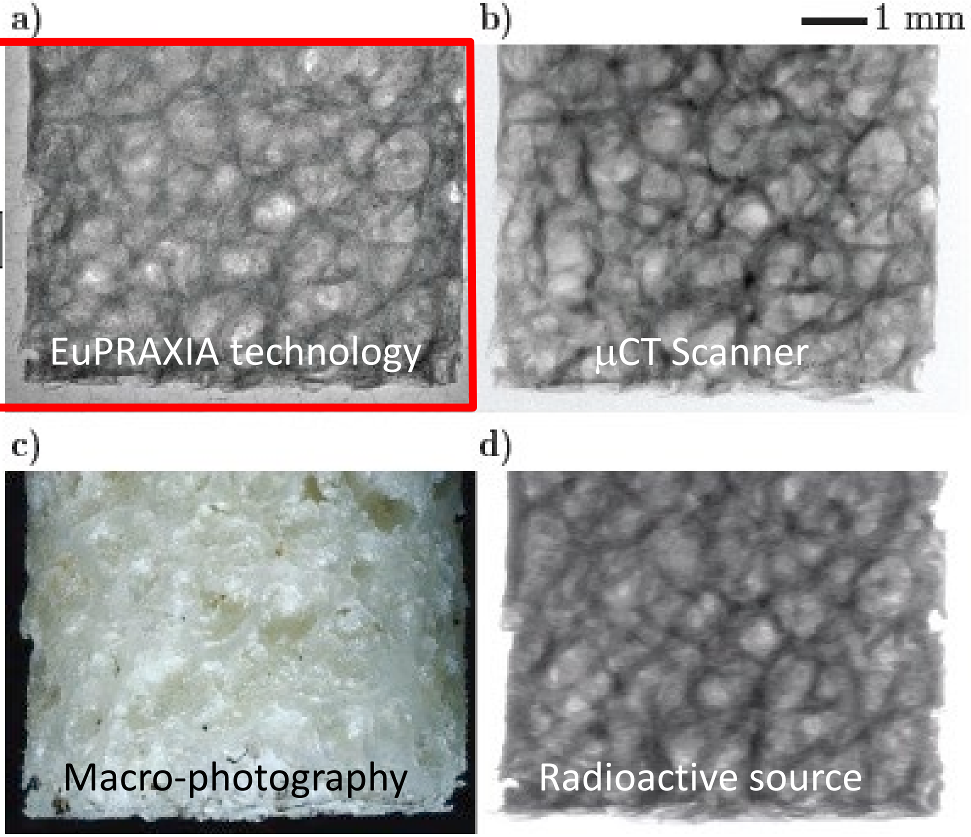
EuPRAXIA@SPARC_LAB



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)





- **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)

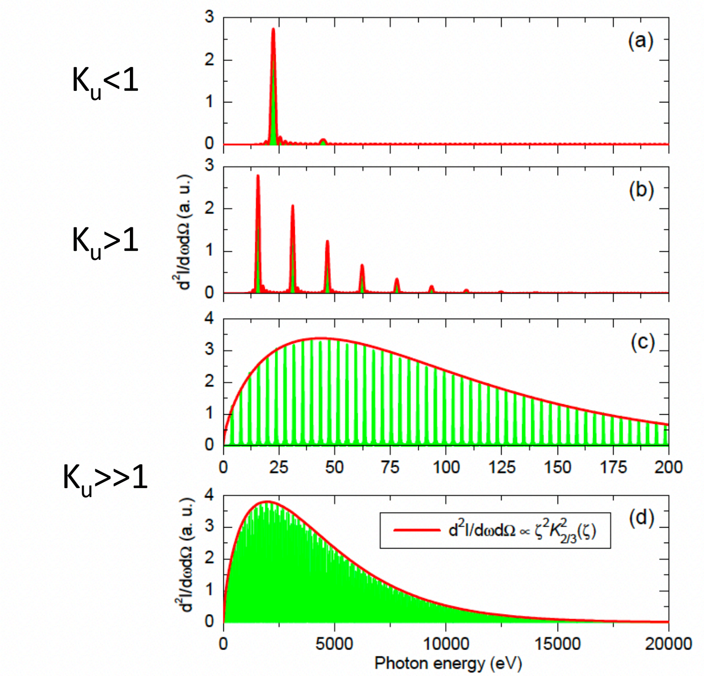
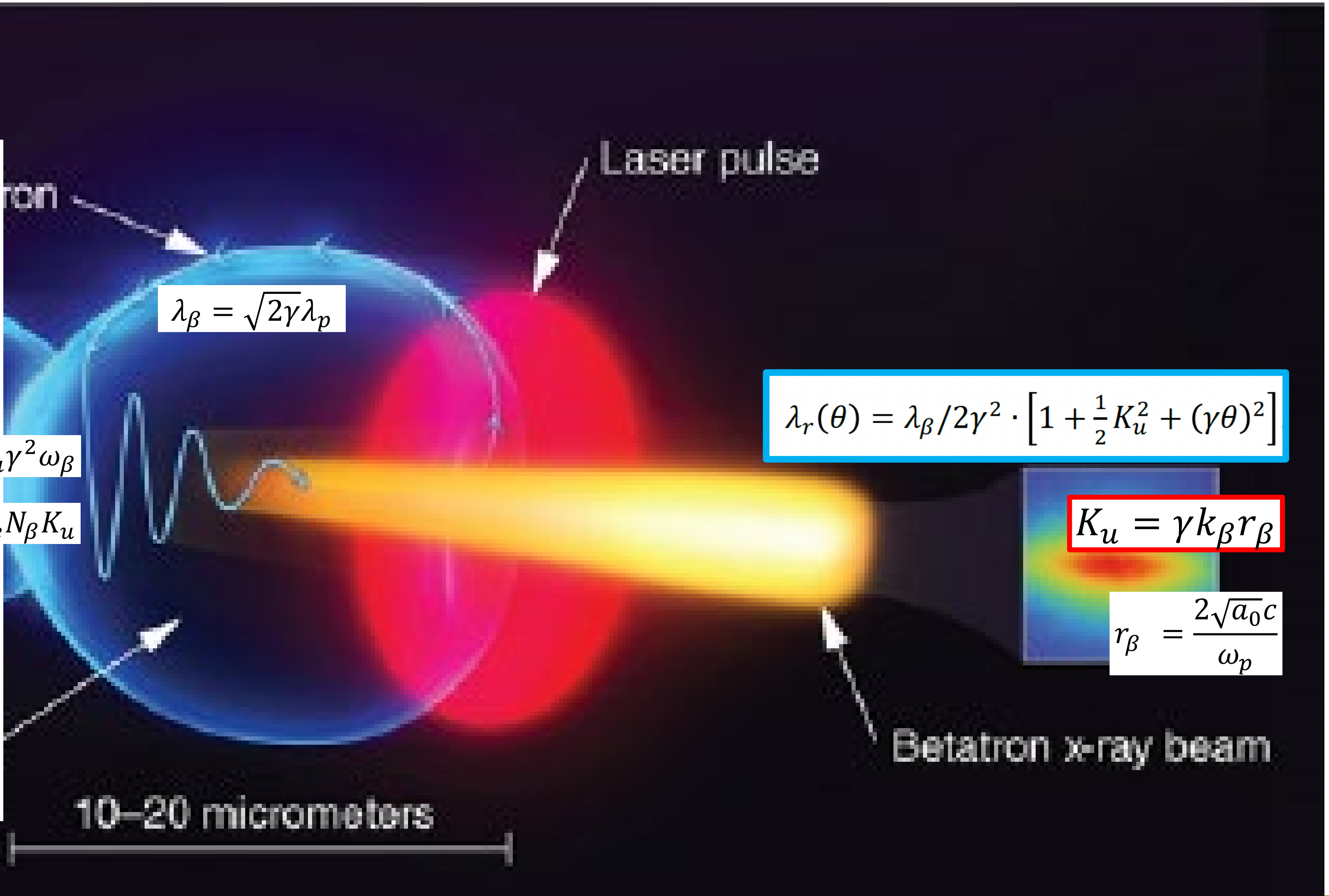


Figure 3.3: *Calculated betatron radiation spectra in a plasma column with density of 7×10^{18} cm^{-3}. The electron energy is 15 MeV, and oscillation amplitudes are (a) 0.1 μm, (b) 0.5 μm, and (c) 1.6 μm. (d) shows the case of a 100 MeV electron with an oscillation amplitude of 1.6 μm.*

$$\omega_c = 3K_u\gamma^2\omega_\beta$$

$$N_{ph} \propto N_e N_\beta K_u$$



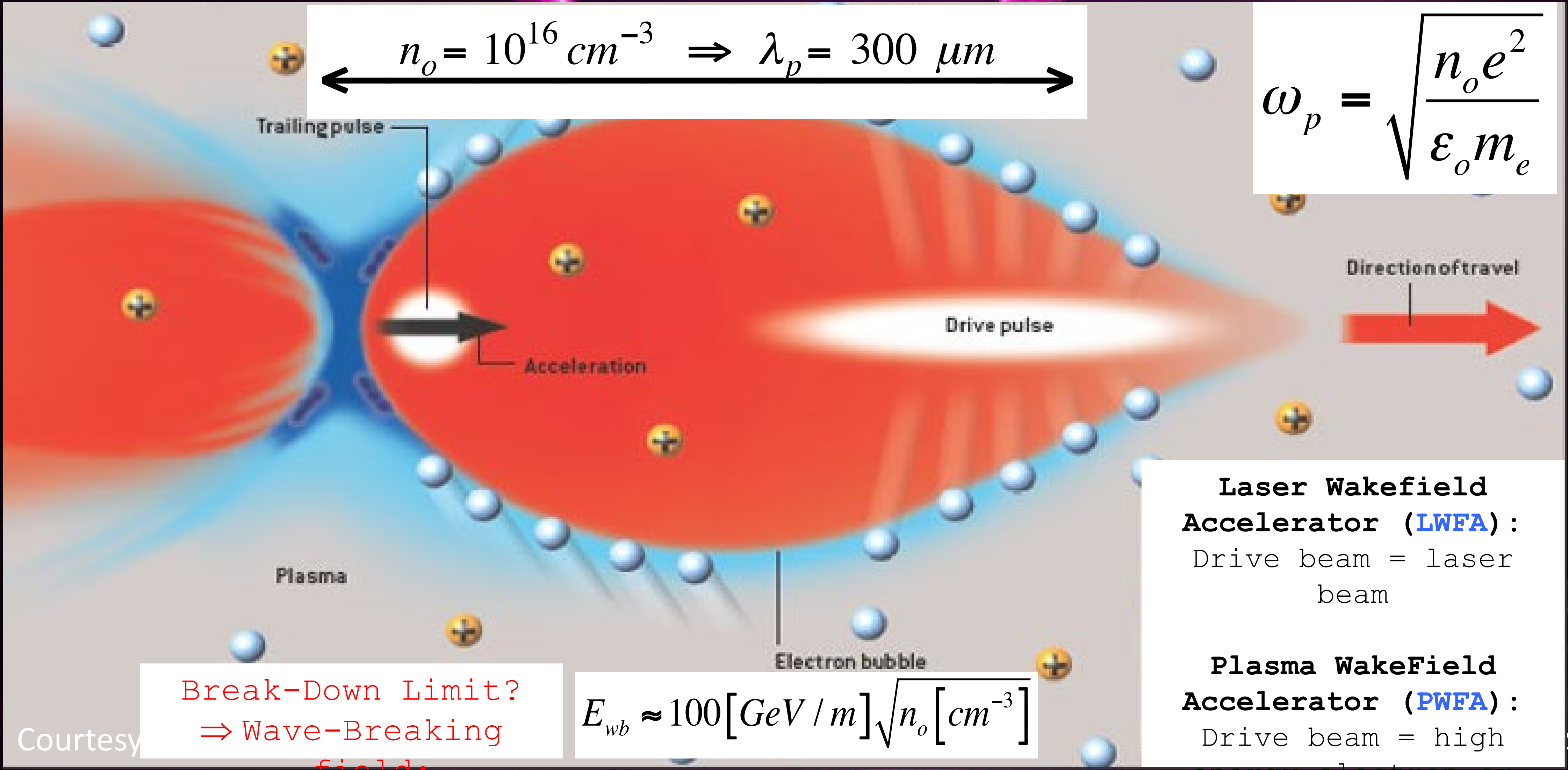
$$\lambda_\beta = \sqrt{2\gamma}\lambda_p$$

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

$$K_u = \gamma k_\beta r_\beta$$

$$r_\beta = \frac{2\sqrt{a_0}c}{\omega_p}$$

Principle of plasma acceleration



$$n_o = 10^{16}\, cm^{-3} \Rightarrow \lambda_p = 300\ \mu m$$

$$\omega_p = \sqrt{\frac{n_o e^2}{\varepsilon_o m_e}}$$

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

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

Break-Down Limit?
⇒ Wave-Breaking field:

$$E_{wb} \approx 100\left[GeV/m\right]\sqrt{n_o\left[cm^{-3}\right]}$$

Courtesy

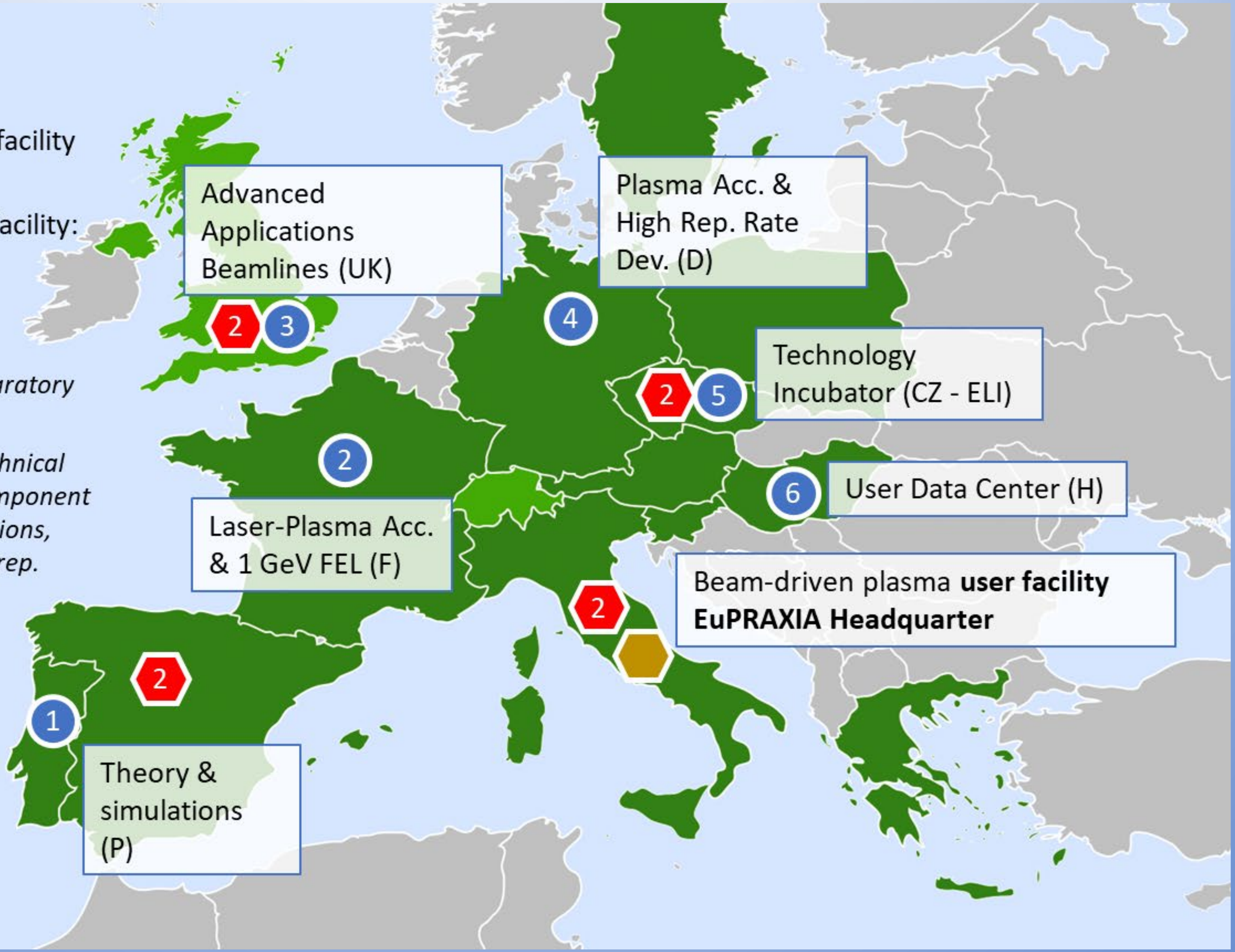
Distributed Research Infrastructure

Funded by the European Union

- ⬢ Beam-driven plasma user facility EuPRAXIA Headquarter
- 2 Laser-driven plasma user facility: candidates
- ● Excellence Center

Second site will be decided in Preparatory Phase project.

Excellence centers (EC) perform technical developments, prototyping and component construction. Number of EC's, locations, roles, responsibilities reviewed in Prep. Phase.



Advanced Applications Beamlines (UK)

Plasma Acc. & High Rep. Rate Dev. (D)

Technology Incubator (CZ - ELI)

User Data Center (H)

Laser-Plasma Acc. & 1 GeV FEL (F)

Beam-driven plasma **user facility EuPRAXIA Headquarter**

Theory & simulations (P)

Horizon Europe