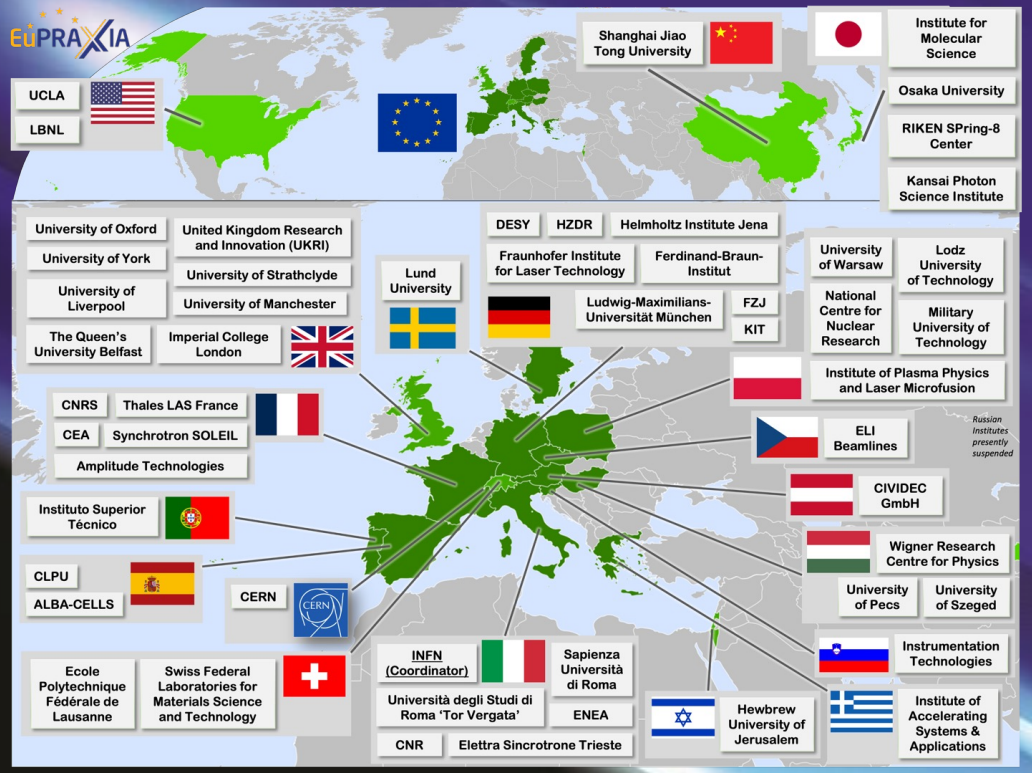
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

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



The EuPRAXIA Preparatory Phase Project

Arnd Specka,
Laboratoire Leprince-Ringuet
Ecole Polytechnique – CNRS/IN2P3

AG du GDR APPEL 13-15 Dec 2023
Orme des Merisiers, France

Based on slides by (AND thanks to):
Ralph Assmann, Massimo Ferrario, Alessio Del Dotto,Alessandro Cianchi, Rajeev Pattathil, Alexander Molodozhentsev,…

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

The EuPRAXIA Project

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

Funded by the European Union

- 1st ever design of a **plasma accelerator facility**. 1st **ESFRI** plasma acc. project. 1st ESFRI acc. project since 2016.
- **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**
- Next phase consortium: **> 50 institutes**
- Preparatory Phase project: **2022 – 2026** (ongoing)
- Start of 1st operation: **2028**

600+ page CDR, 240 scientists contributed

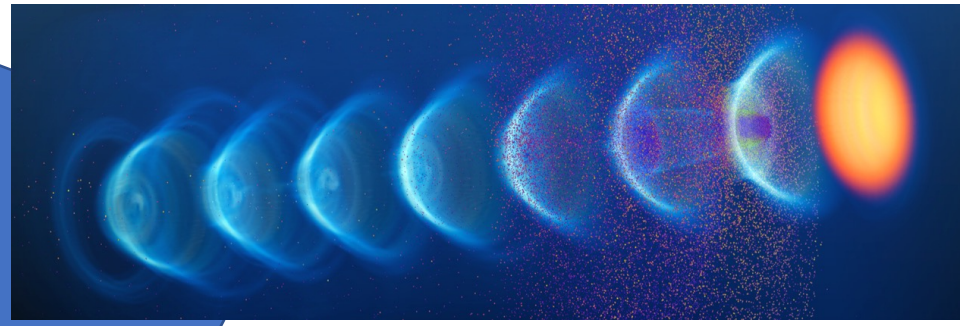
A New European High-Tech Research Facility Delivering Frontier Science

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

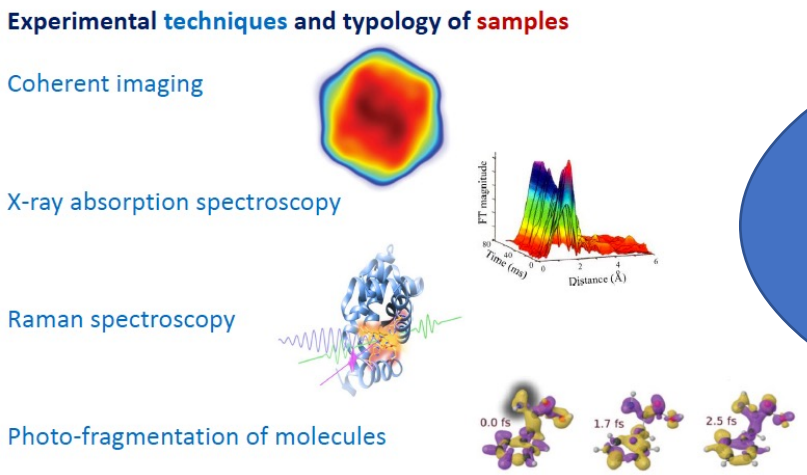
Shrink down the facility size



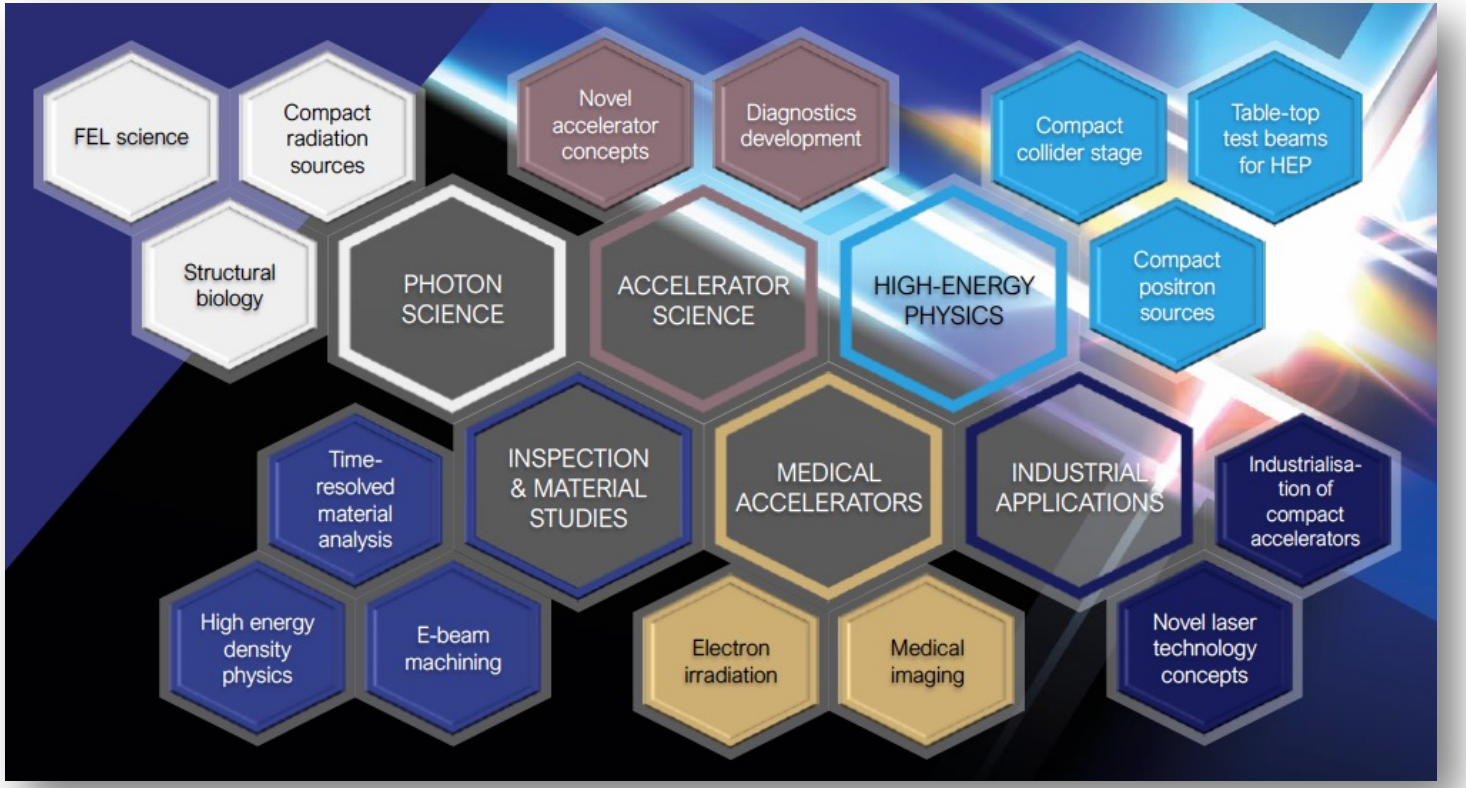
2

Producing particle and photon pulses to support several urgent and timely science cases

Enable frontier science in new regions and parameter regimes



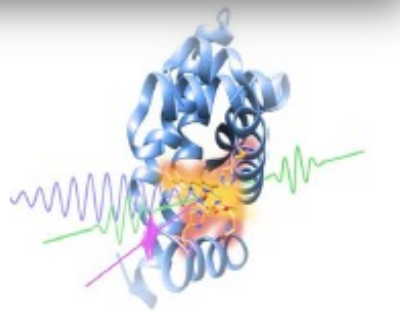
Versatile – Designed for Users in Multiple Science Fields



*Delivers 10-100 Hz **ultra-short** pulses*

- **Electrons** (0.1-5 GeV, 30 pC)
- **Positrons** (0.5-10 MeV, 10^6)
- **Positrons** (GeV source)
- **Lasers** (100 J, 50 fs, 10-100 Hz)
- **Betatron X rays** (1-110 keV, 10^{10})
- **FEL light** (0.2-36 nm, 10^9-10^{13})

Topics of research: proteins, viruses, bacteria, cells, metals, semiconductors, superconductors, magnetic materials, organic molecules

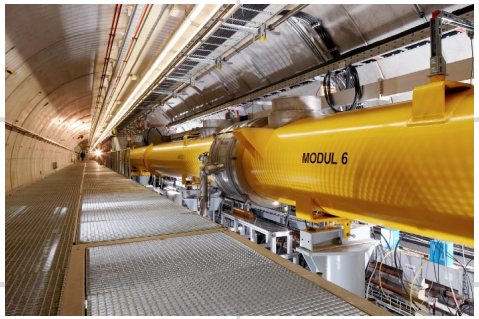


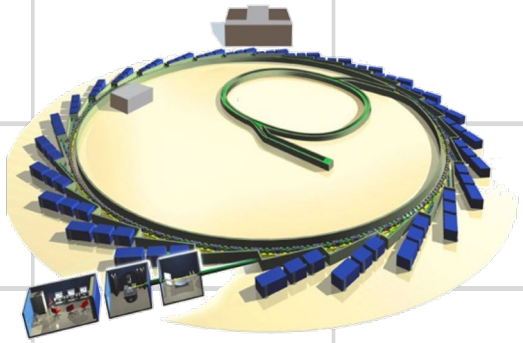
EuPRAXIA: Enabling Additional Science → FEL

Funded by the European Union

Visible light

Ultraviolet light





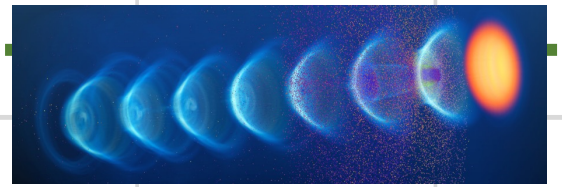
Soft X Rays

FELs OF EUROPE

- Beautiful and highly optimized **masterpieces of science**.
- Go here for **best possible performance**.
- Issue: Only few FEL´s can be built due to their size and cost. **Access to beam time is strongly limited**.

Hard X Rays

In **addition**: Compact plasma-based FEL´s



Gamma Rays

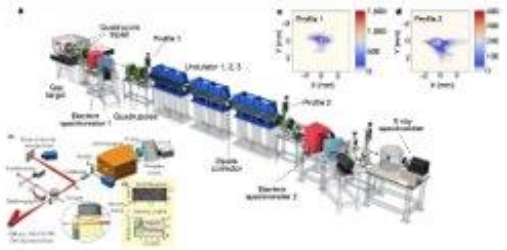
1 μm 100 nm 10 nm 1 nm 100 pm 10 pm 1 pm 100 fm 10 fm

Beam quality in pilot FEL experiments

Funded by the European Union

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

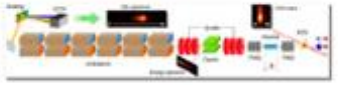
FEL lasing **amplification of 100** reached at 27 nm wavelength (average radiation energy 70 nJ, peak up to 150 nJ)

2021 Plasma FEL Feasibility Proven: Electron-driven

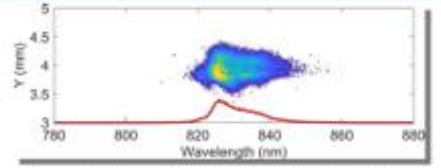
Recent ground-breaking results in Frascati:

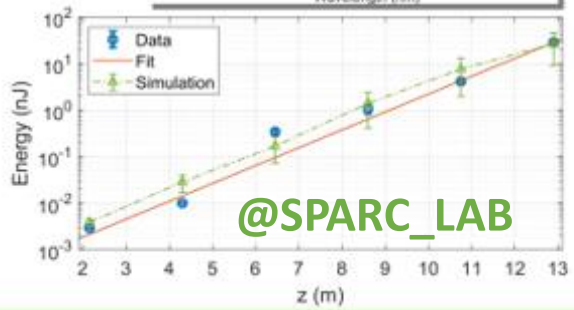
First FEL lasing from a beam-driven plasma accelerator

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



Single Spike SASE spectrum





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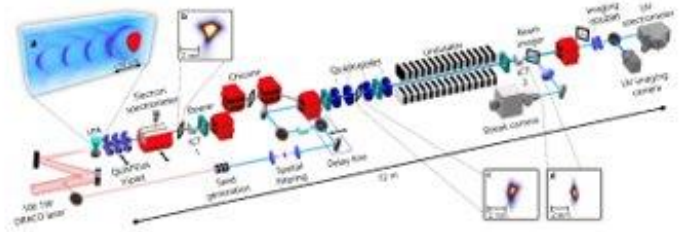
Seeded UV free-electron laser driven by LWFA

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



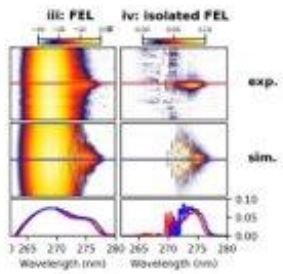
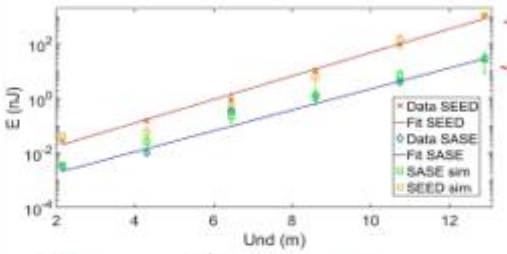
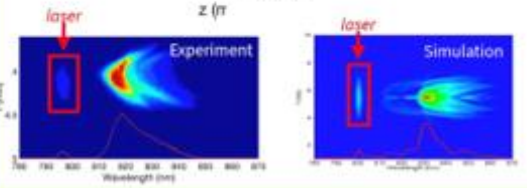
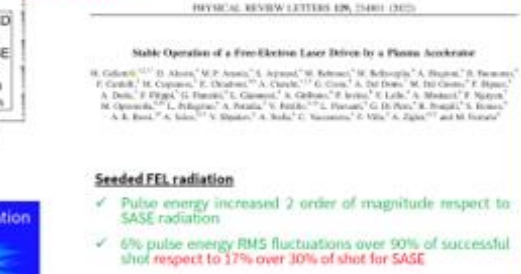


FIG. 1. **Experimental layout.** The electron beam generated in the LPA is first characterized using a removable electron spectrometer and then sent through a triplet of quadrupoles (QUAPEVAs) for beam transport to the undulator and FEL radiation generation. ICTs: Integrated Current Transformers. Non-labelled 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).

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







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

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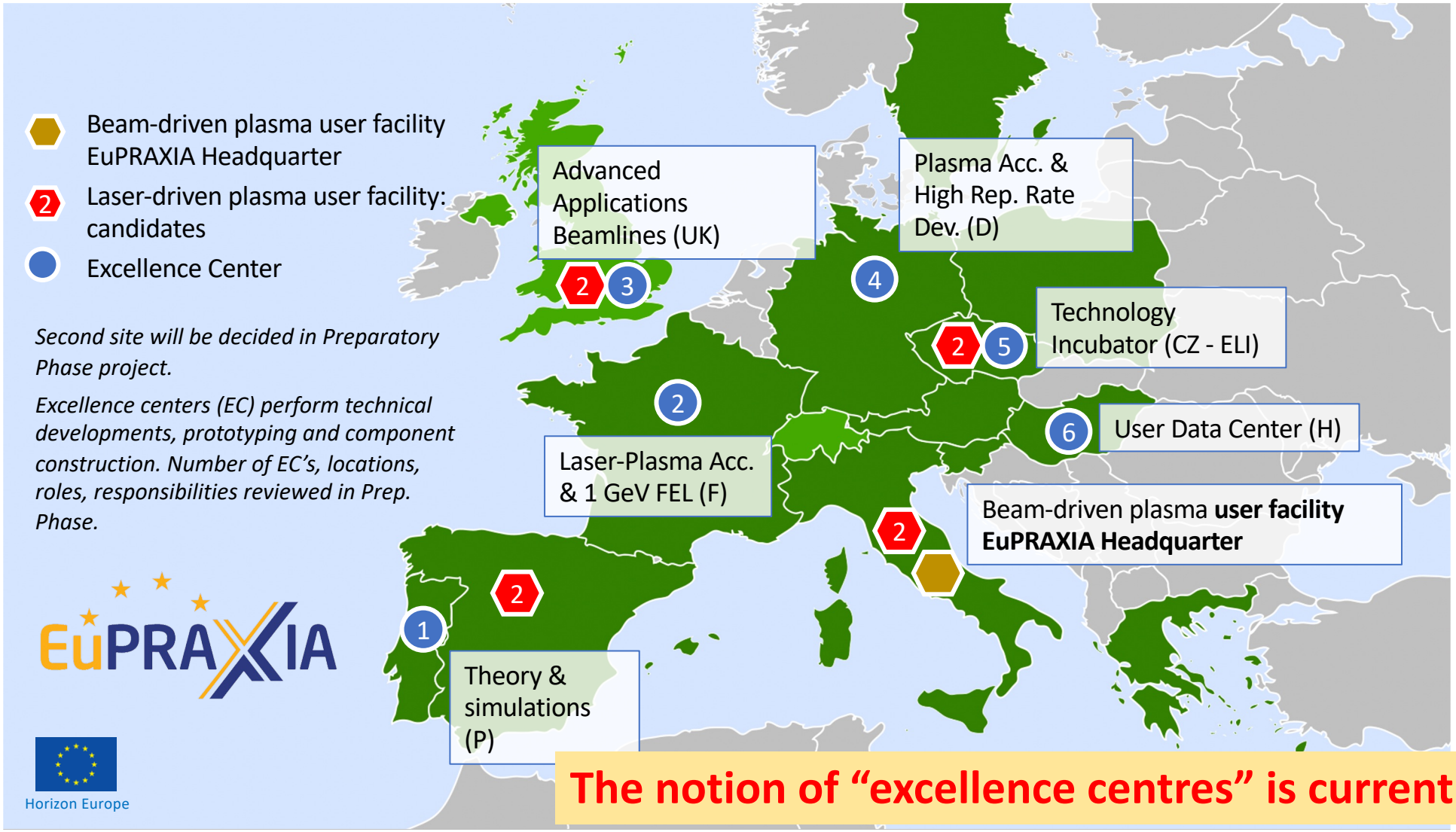
Distributed Research Infrastructure *(Sep 23)*

Funded by the European Union



Today`s status

Excellence centers: **several** (6 – 10) assumed to be realized

Second site: **one** to be selected

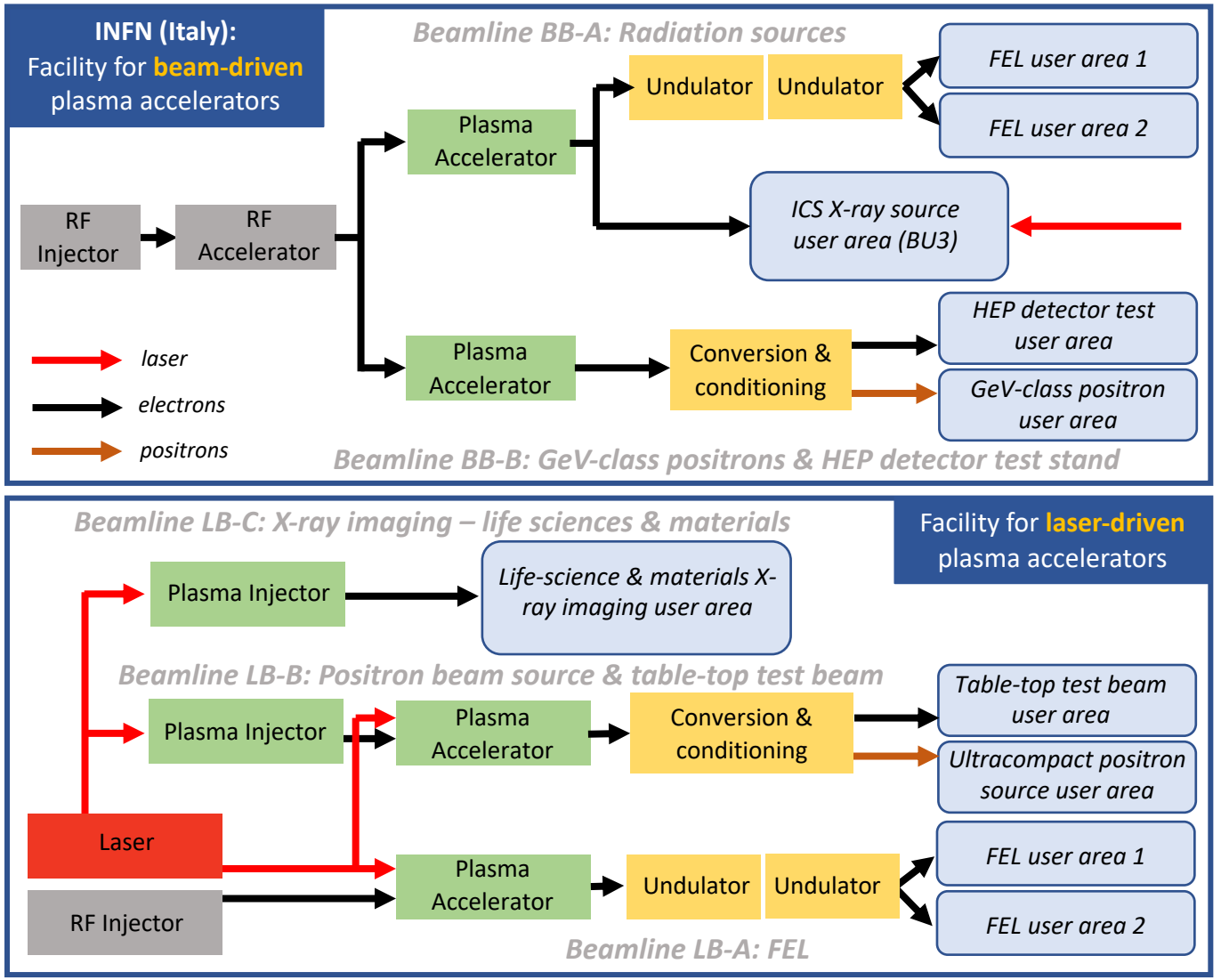
Connect with WP´s to Horizon Europe and national funding lines

The notion of "excellence centres" is currently being redefined

Phased Implementation of Construction Sites

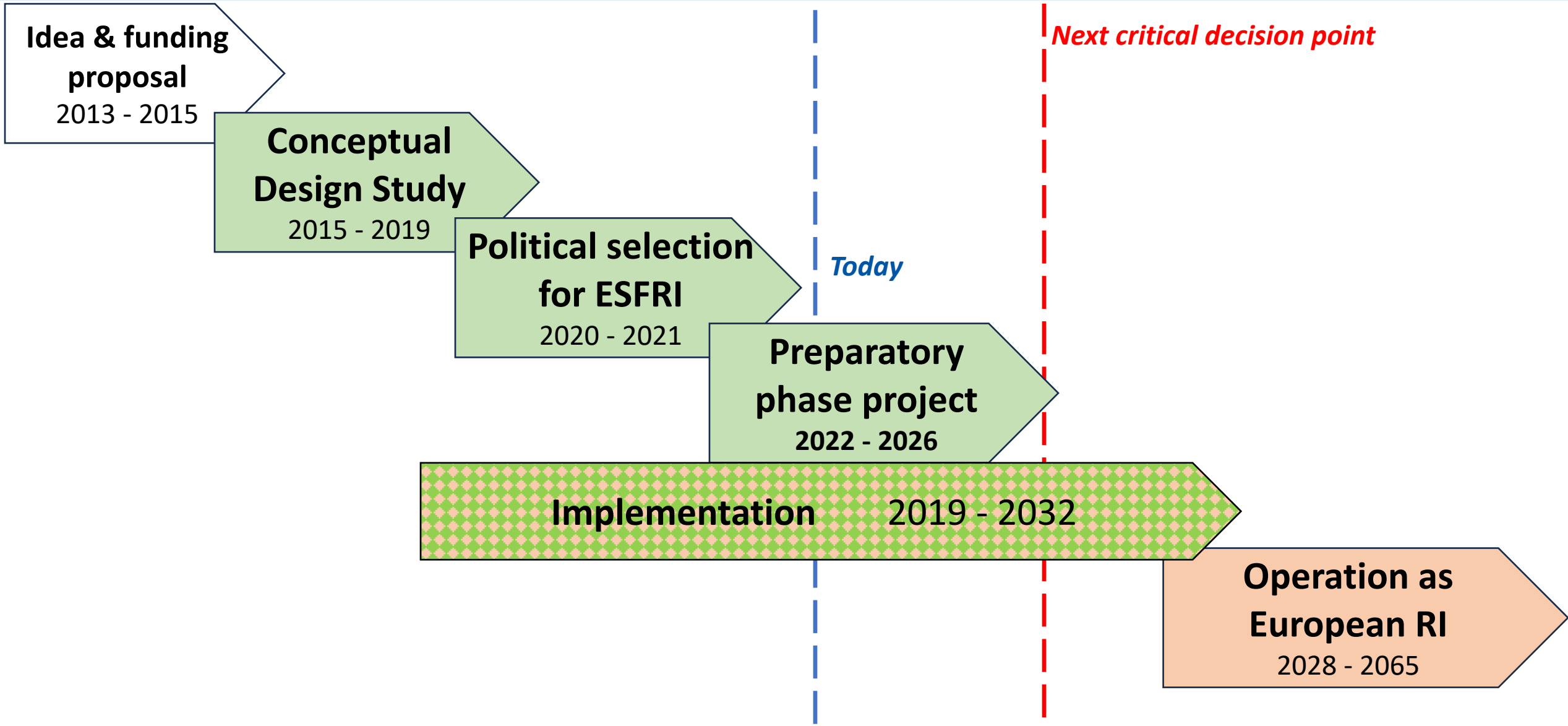
Funded by the European Union

	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



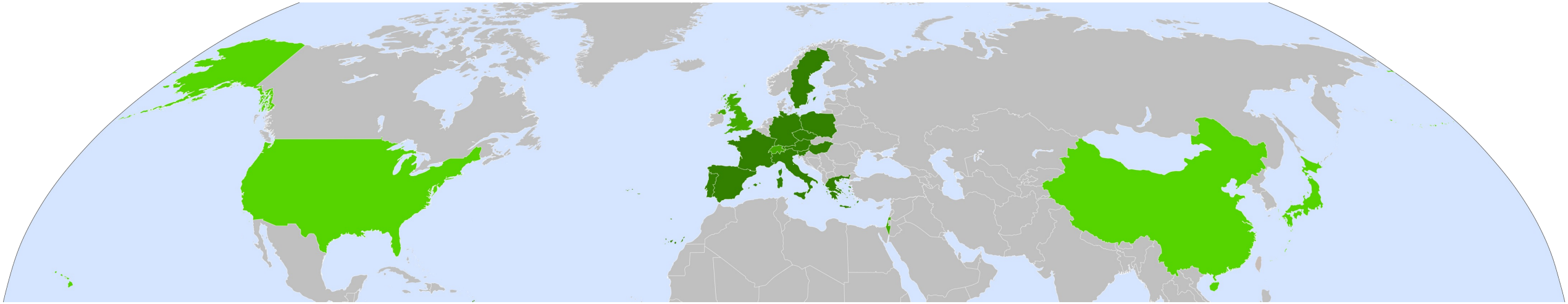
EuPRAXIA European Project: History and Today

Funded by the European Union

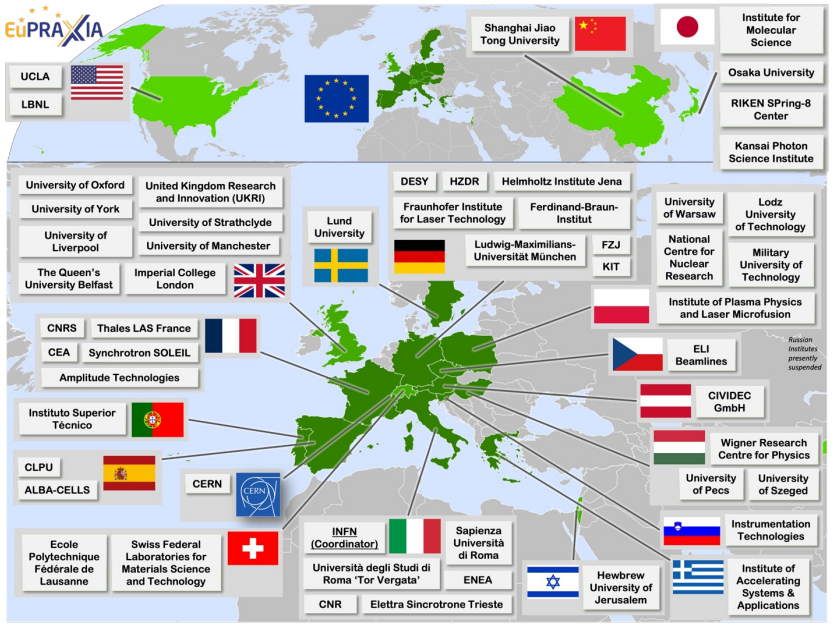


The EuPRAXIA Consortia Today

Funded by the European Union

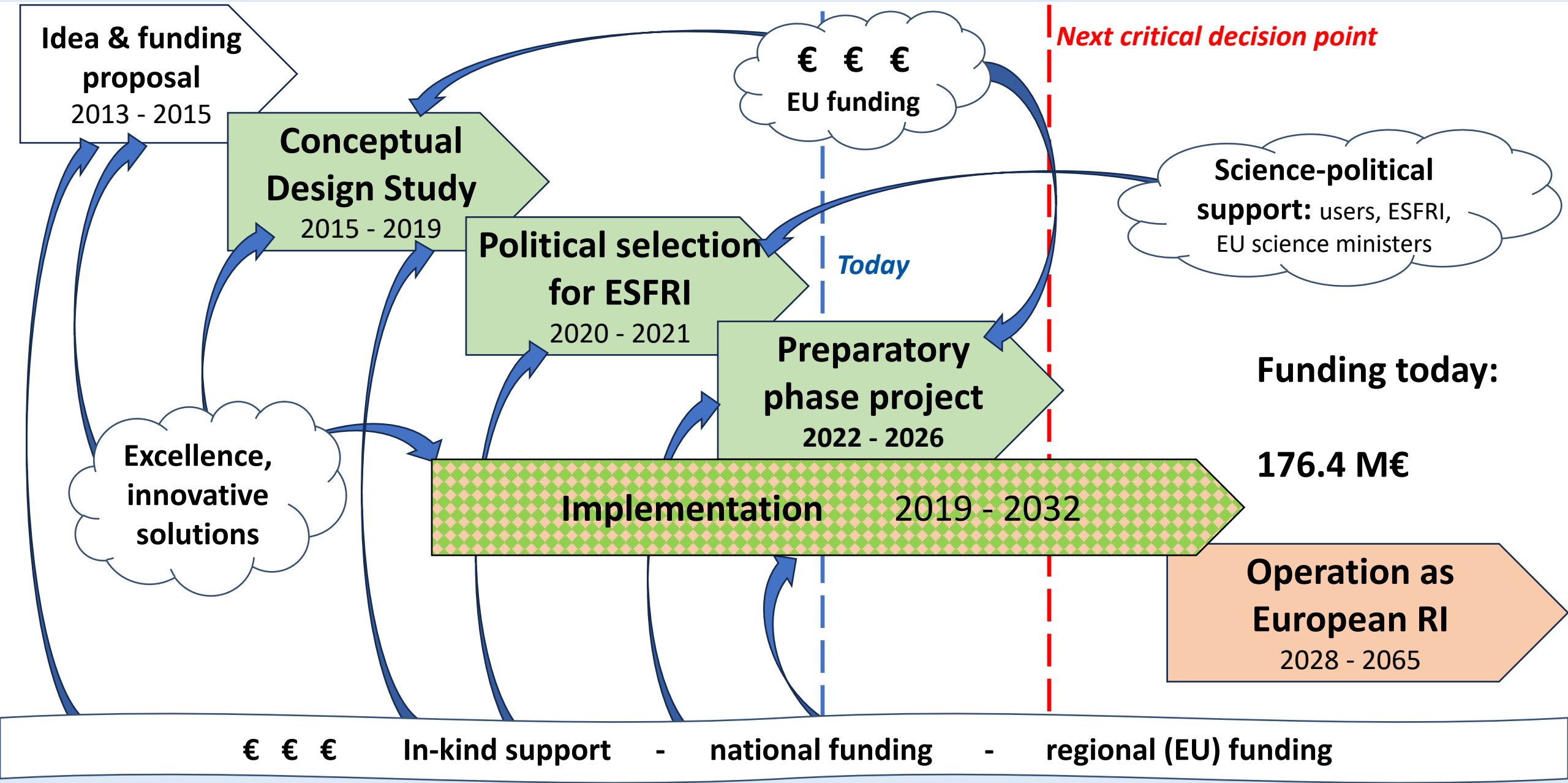


- **54 institutes** *(in addition > 6 asked to join us presently)*
- from **18 countries** plus CERN
- signed on one or several presently **active EuPRAXIA consortia**:
  - **ESFRI** consortium (funding in-kind)
    www.eupraxia-facility.org
  - **Preparatory Phase** consortium (funding EU, UK, Switzerland, in-kind)
    www.eupraxia-pp.org
  - **Doctoral Network** (funding EU, UK, in-kind)
    www.eupraxia-dn.org



EuPRAXIA European Project: History and Today

Funded by the European Union



EuPRAXIA: Cost/Budget Status Aug 2023

Funded by the European Union

Cost item	Invest (M€)	Personnel (M€)	Total cost (M€)	Obtained (M€)	Coverage (%)	Missing (§) (M€)
Site 1 (*), Frascati	151,0	23,0	174,0	**138,8**	**80%**	35,2
Site 2 (**), tbd	149,0	29,0	178,0	0,0	0%	**178,0**
Termination	*1,0*	*2,0*	*3,0*	*0,0*	*0%*	*3,0*
CDR	*0,2*	*2,8*	*3,0*	*3,0*	***100%***	*0,0*
Preparation, incl. excellence centers	137,0	74,0	211,0	34,6	16%	**176,4**
Total	438,2	130,8	**569,0**	**176,4**	**31%**	392,6

(*) includes estimate of 240 FTE-y of personpower from LNF-INFN

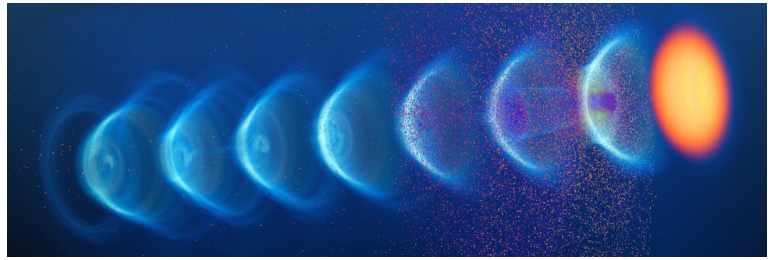
(**) cost will be reduced in case of relevant pre-invests (exisiting infrastructure, equipment)

*(§) for full implementation, phased EuRAXIA approach allows **user operation without full funding***

Outstanding Success in Funding so Far

Funded by the European Union

- It is highly unusual to have this **high funding rate** at this stage of the project.
- We have **sufficient funds to construct Phase 1 of EuPRAXIA at Site 1** = Frascati → construction process started
- But of course we want to build the full things:
  we can reduce the scope but we will loose some of our possible impact and we compromise leadership in the international landscape
- So **Preparatory Phase will work out details for the full EuPRAXIA proposal with two sites, excellence centers, laser leg, applications and clusters of institutes!**



We are on ESFRI Roadmap of 2021

Funded by the European Union

ESFRI = European Strategy Future Research Infrastructures

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ESFRI PROJECTS

PHYSICAL SCIENCES & ENGINEERING

NAME	FULL NAME	TYPE	LEGAL STATUS (Y)	ROADMAP ENTRY (Y)	OPERATION START (Y)	INVESTMENT COST (M€)	OPERATION COST (M€/Y)
EST	European Solar Telescope	single-sited		2016	2029*	200.0	12.0
ET	Einstein Telescope	single-sited		2021	2035*	1,912.0	37.0
EuPRAXIA	European Plasma Research Accelerator with Excellence in Applications	distributed		2021	2028*	569.0	30.0
KM3NeT 2.0	KM3 Neutrino Telescope 2.0	distributed		2016	2020	196.0	3.0

- Two new entries in 2021: **Einstein Telescope (ET)** and **EuPRAXIA**
- EuPRAXIA is the only accelerator facility selected in the last 6 years
- EuPRAXIA is the first plasma accelerator facility ever included

PHYSICAL SCIENCES & ENGINEERING

EuPRAXIA: Official Member of the Big Club

Funded by the European Union

PHYSICAL SCIENCES & ENGINEERING

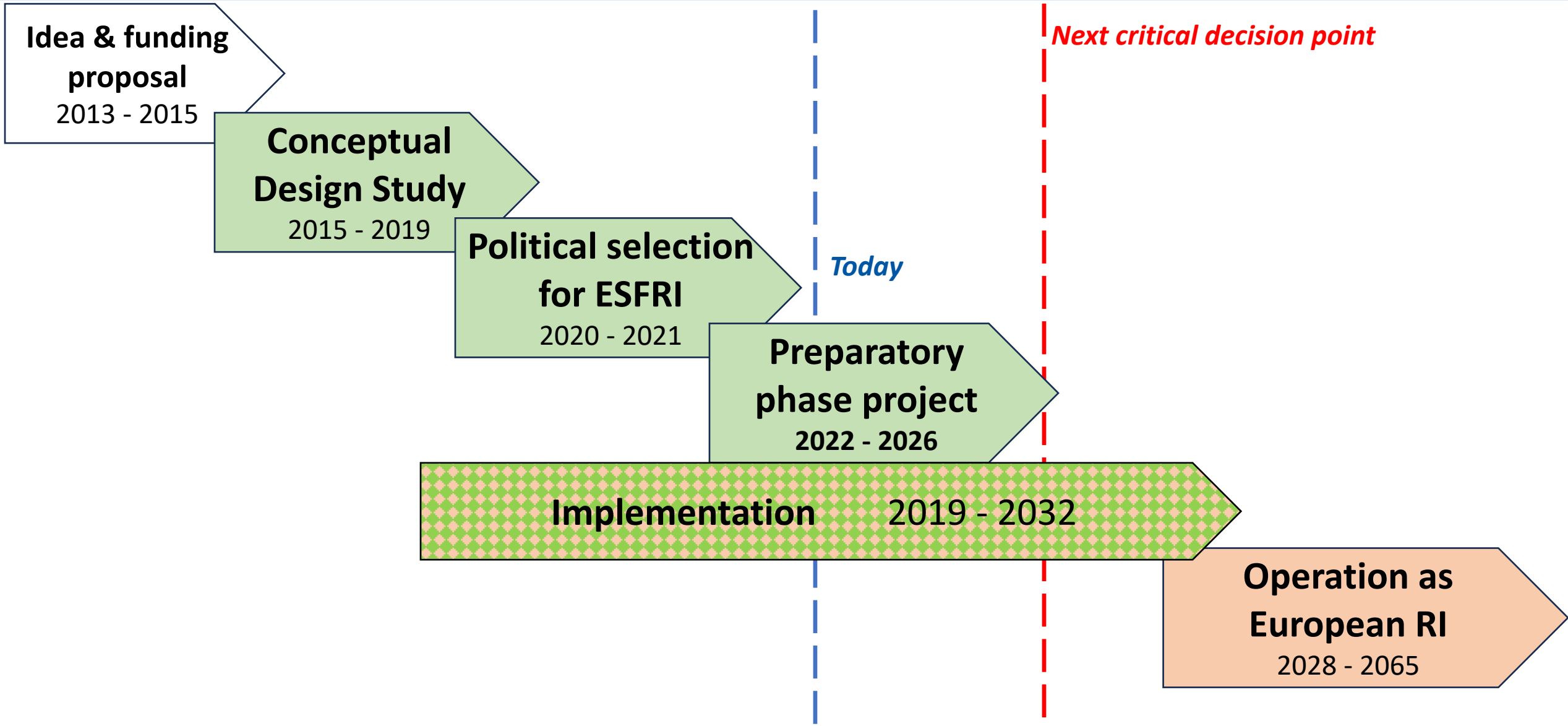
ESFRI LANDMARKS

NAME	FULL NAME	TYPE	LEGAL STATUS (Y)	ROADMAP ENTRY (Y)	OPERATION START (Y)	INVESTMENT COST (M€)	OPERATION COST (M€/Y)
CTA	Cherenkov Telescope Array	single-sited	gGmbH, 2014	2008	2024*	400.0	20.0
ELI ERIC	Extreme Light Infrastructure	single-sited	ERIC, 2021	2006	2018	850.0	80.0
ELT	Extremely Large Telescope	single-sited	ESO#	2006	2027*	1,309.0	48.0
EMFL	European Magnetic Field Laboratory	distributed	AISBL, 2015	2008	2014	170.0	20.0
ESRF EBS	European Synchrotron Radiation Facility Extremely Brilliant Source	single-sited	ESRF#	2016	2020	128.0	82.0
European Spallation Source ERIC	European Spallation Source	single-sited	ERIC, 2015	2006	2026*	3,009.0	140.0
European XFEL	European X-Ray Free-Electron Laser Facility	single-sited	European XFEL#	2006	2017	1,540.0	137.0
FAIR	Facility for Antiproton and Ion Research	single-sited	GmbH, 2010	2006	2025*	NA	NA
HL-LHC	High-Luminosity Large Hadron Collider	single-sited	CERN#	2016	2027*	1,408.0	136.0
ILL	Institut Max von Laue - Paul Langevin	single-sited	ILL#	2006	2012	188.0	100.0
SKAO	Square Kilometre Array Observatory	single-sited	SKAO, 2011	2006	2027*	1,986.0	77.0
SPIRAL2	Système de Production d'Ions Radioactifs en Ligne de 2e génération	single-sited	GANIL	2006	2019	307.3	5.2

https://roadmap2021.esfri.eu

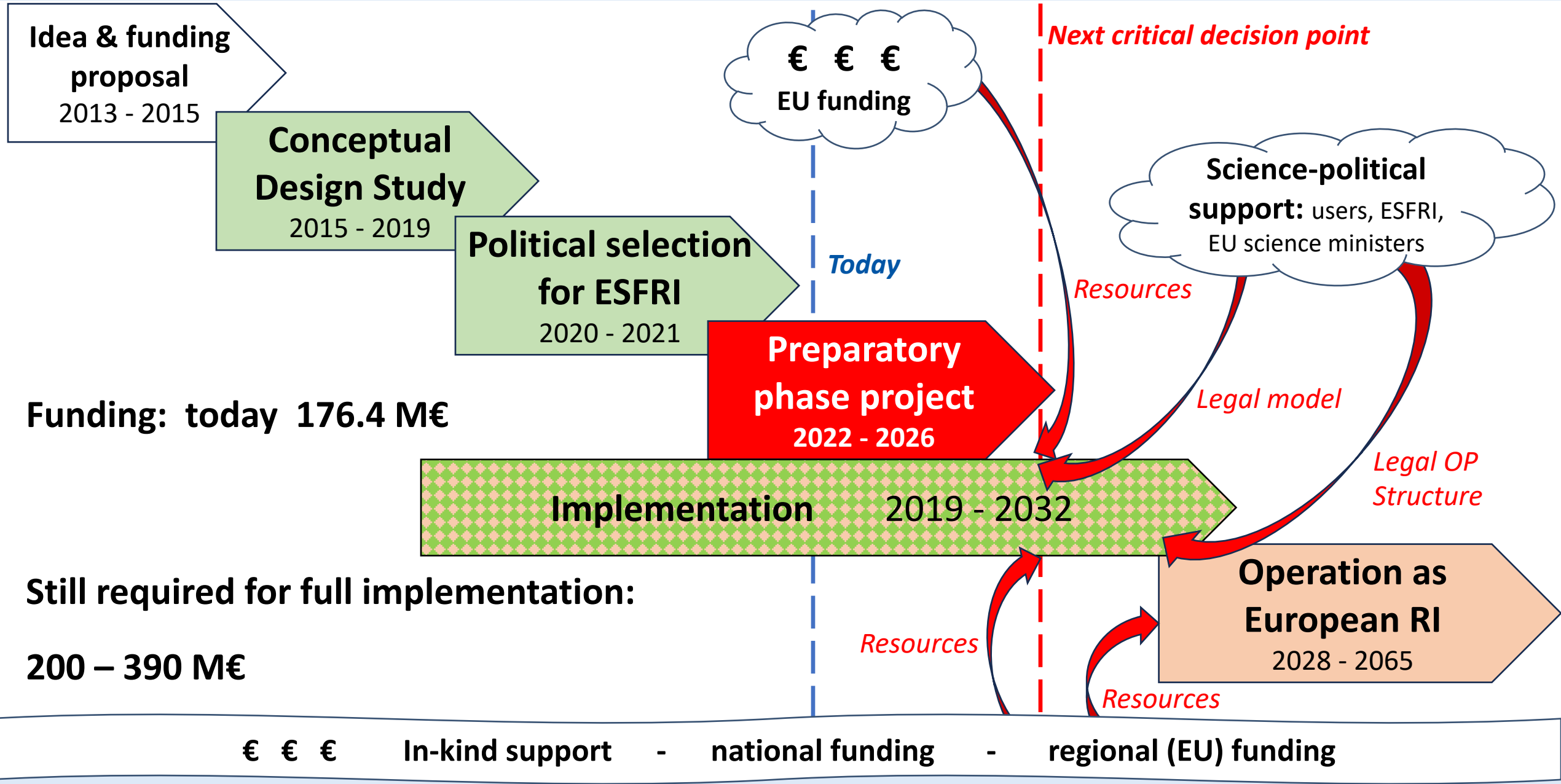
EuPRAXIA European Project: Next Step

Funded by the European Union



EuPRAXIA European Project: Next Step

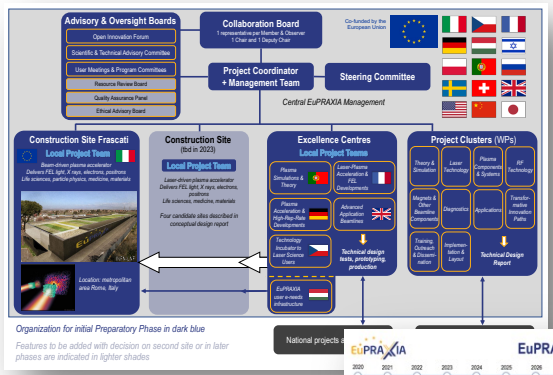
Funded by the European Union

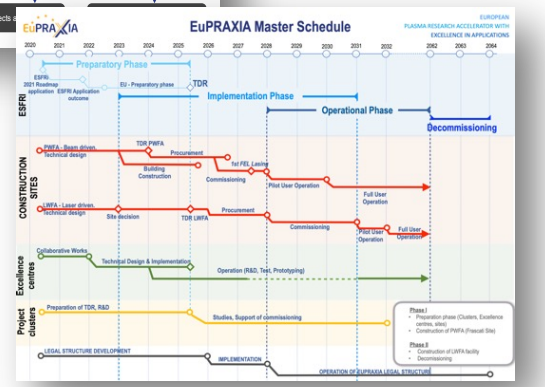


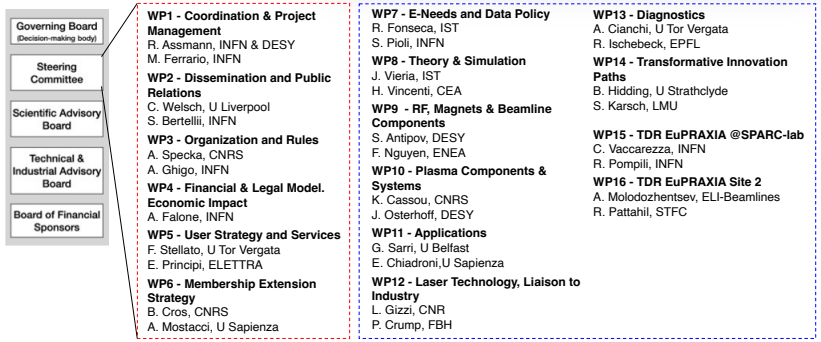
Preparatory Phase Main Goals

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 (correspond to Project Clusters):
  - **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







PP Steering Committee: Leaders Behind EuPRAXIA

Funded by the European Union

WP1 - Coordination & Project Management
R. Assmann, INFN & DESY
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

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
J. Osterhoff, 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 Strathclyde
S. Karsch, LMU

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

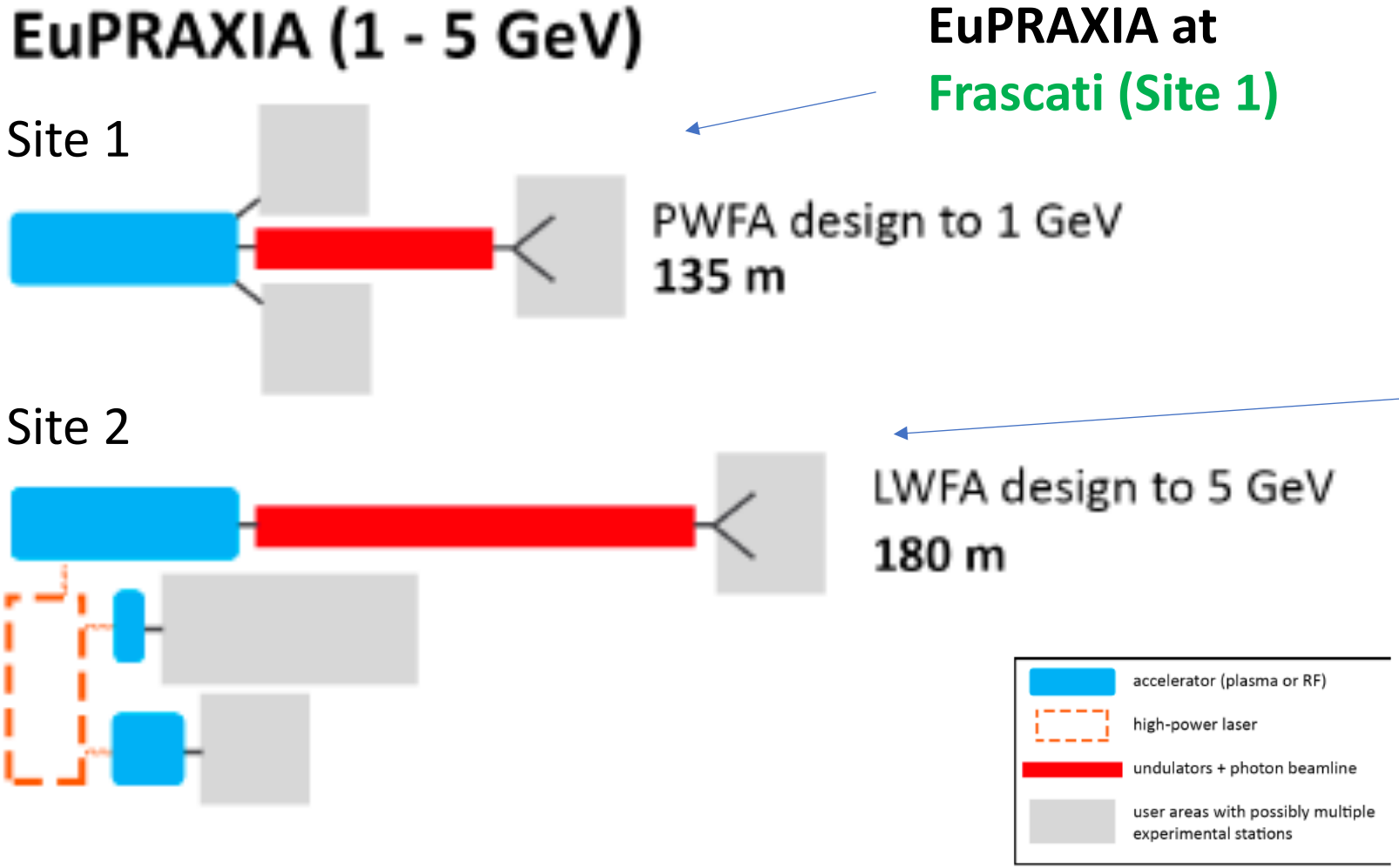
WP16 - TDR EuPRAXIA Site 2
A. Molodozhentsev, ELI-Beamlines
R. Pattahil, STFC

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

WPs on technical implementation and sites

Preparatory Phase: Decide 2nd FEL Site

Funded by the European Union



EuPRAXIA at Frascati (Site 1)

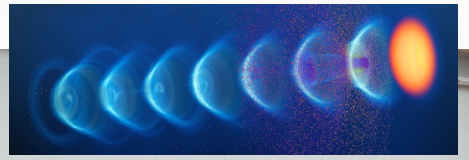
- Distributed RI
- **2 FEL Construction Sites**
- Several Excellence Centers

EuPRAXIA at *ELI-Beamlines or EPAC or Pisa or Salamanca or ?*

EuPRAXIA

135 – 175 m

~35 m

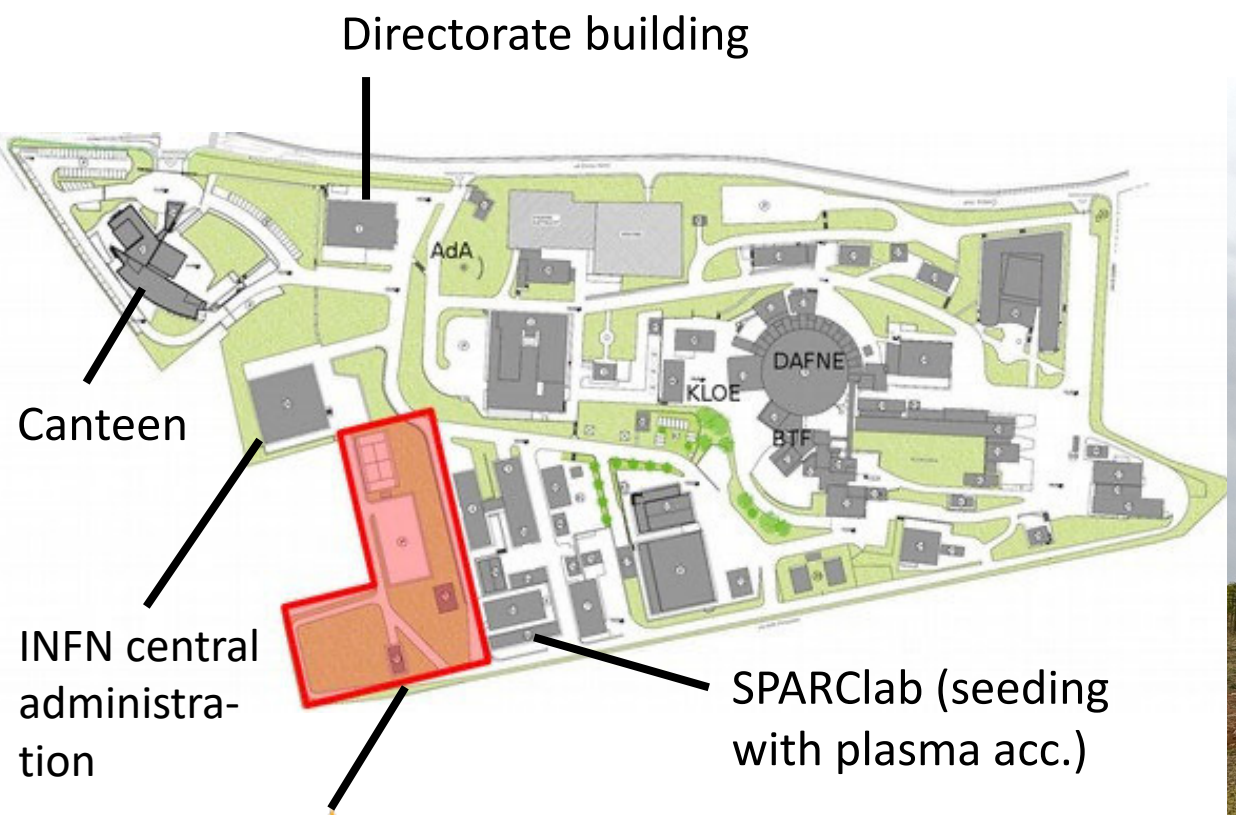


FOOTPRINT FROM CONCEPTUAL DESIGN REPORT

It Fits the Frascati Site

(also fits sites at a large university, hospital, company, …)

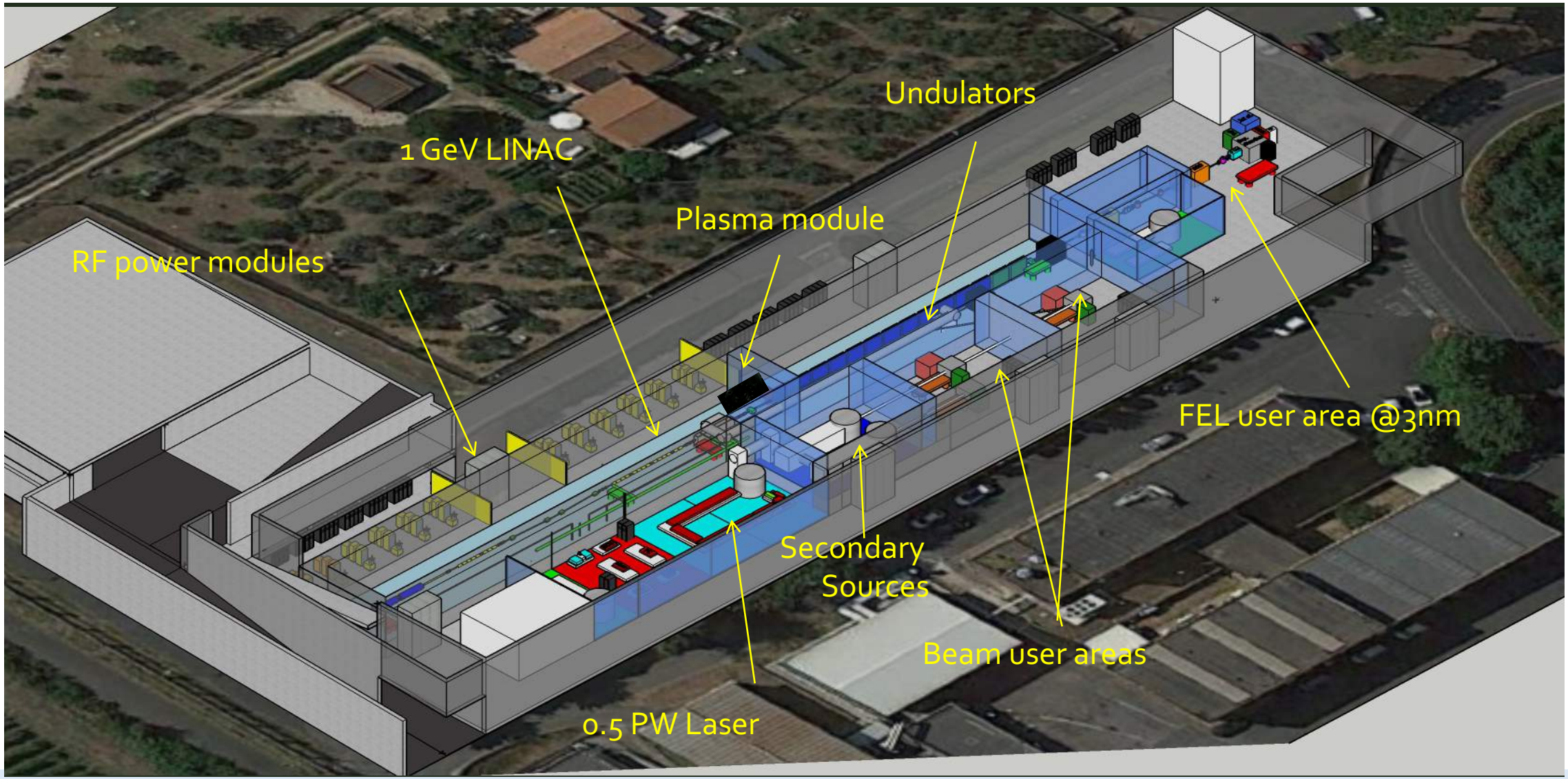
Funded by the European Union



EuPRAXIA @ SPARClab

(European site 1)

EuPRAXIA@SPARC_LAB (Site 1)



Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
EuPRAXIA Advanced Photon Sources

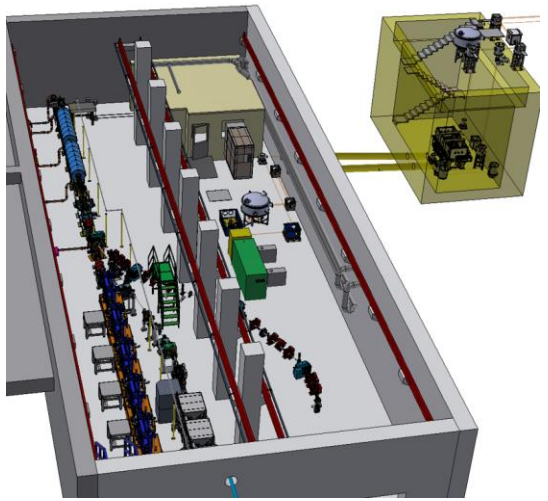
EuPRAXIA Advanced Photon Sources (EuAPS)

- Supported by PNRR funding
- Collaboration among INFN, CNR, University of Tor Vergata
- EuPRAXIA → *laser-driven betatron radiation source @SPARC_LAB*
  → development of high power (up to 1 PW at LNS) and high repetition rate (up to 100 Hz at CNR Pisa) laser
  → pre-cursor for user-facility

+ extra 22M€ (Italie)

Parameter	Value	unit
Electron beam Energy	100-500	MeV
Plasma Density	10^{18}-10^{19}	cm^{-3}
Photon Critical Energy	1 -10	keV
Number of Photons/pulse	10^{7}-10^{9}	
Repetition rate	1-5	Hz
Beam divergence	3-20	mrad

1) **Ultrafast** - laser pulse duration tens of fs useful for **time resolved experiments** (XFEL tens of fs, synchrotron tens to 100 ps).
2) **Broad energy spectrum** - important for **X-ray spectroscopy**.
3) **High brightness** - small source size and high photon flux for **fast processes**
4) **Large market** - 50 synchrotron light sources worldwide, 6 hard XFEL's and 3 soft-ray ones (many accelerators operational and some under construction).



Courtesy of A. Cianchi

'EuPRAXIA Advanced Photon Sources PNRR_EuAPS Project', M. Ferrario et al. INFN-23-12-LNF (2023)

2nd site candidates

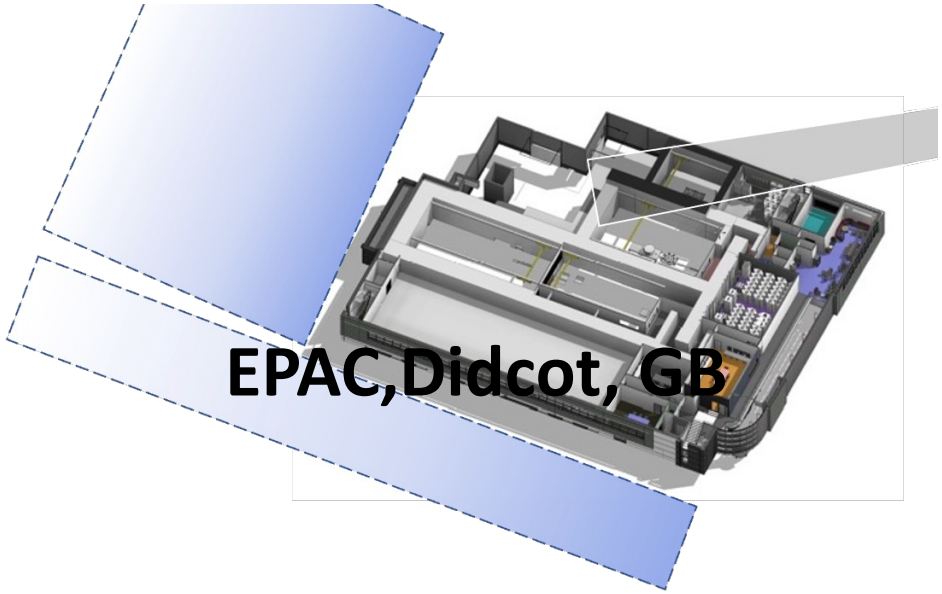
Selection Criteria 2nd EuPRAXIA Site

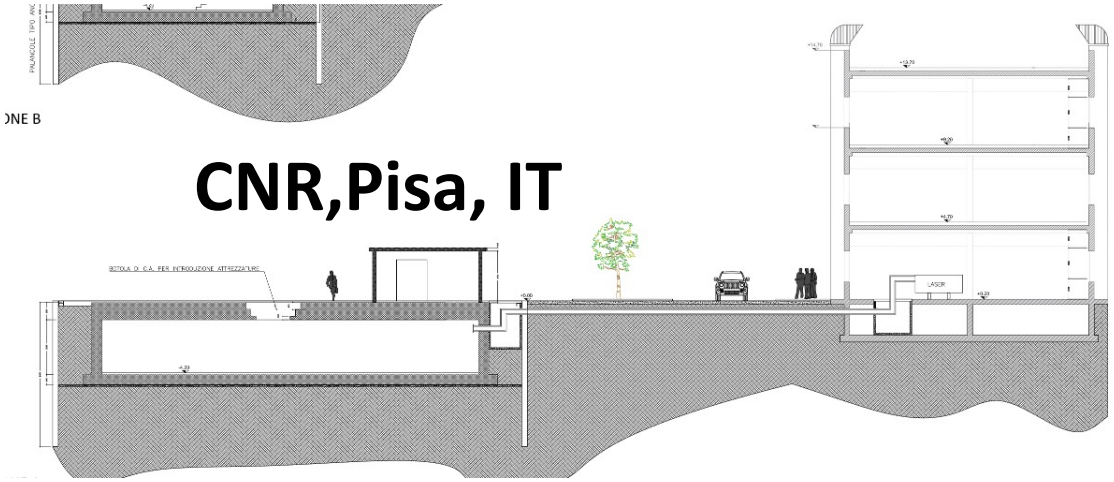
(from CDR, fulfilled by 1st Site LNF/INFN)

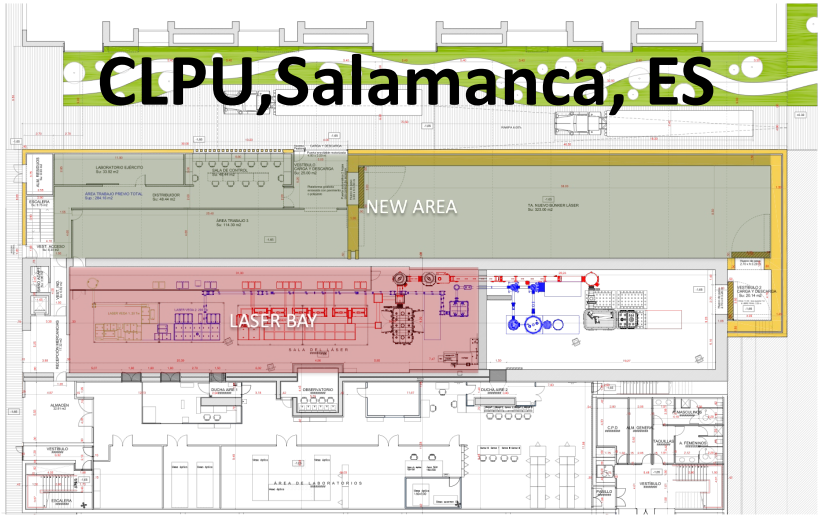
Funded by the European Union

Legal/Political	Technical	Financial
Compliance of host institution with **EuPRAXIA Access** Policy	Site provides sufficient **space** (about 175 m x 35 m)	Commitment to **sustainability** of EuPRAXIA (host lab covers site operation costs)
Compliance of host institution with **EuPRAXIA Open Innovation** and **Open Science** Policy	Laboratory has **infrastructures** in one or several of RF accelerators, laser installations, user access.	**Previous investments** into local infrastructures of relevance for EuPRAXIA (leverage effect)
Agreement of host institution with the **long-term scientific agenda** of EuPRAXIA	Site provides required **services** and facilities for support of external users, including E infrastructure	Existence of one or a mix of **funding sources** able to finance implementation of the site
Laboratory has existing groups in place to guarantee **safety** requirements (laser, radio-protection, access control) and rules		*Note: approach reduces cost (pre-invest) and risks of cost-overun.*

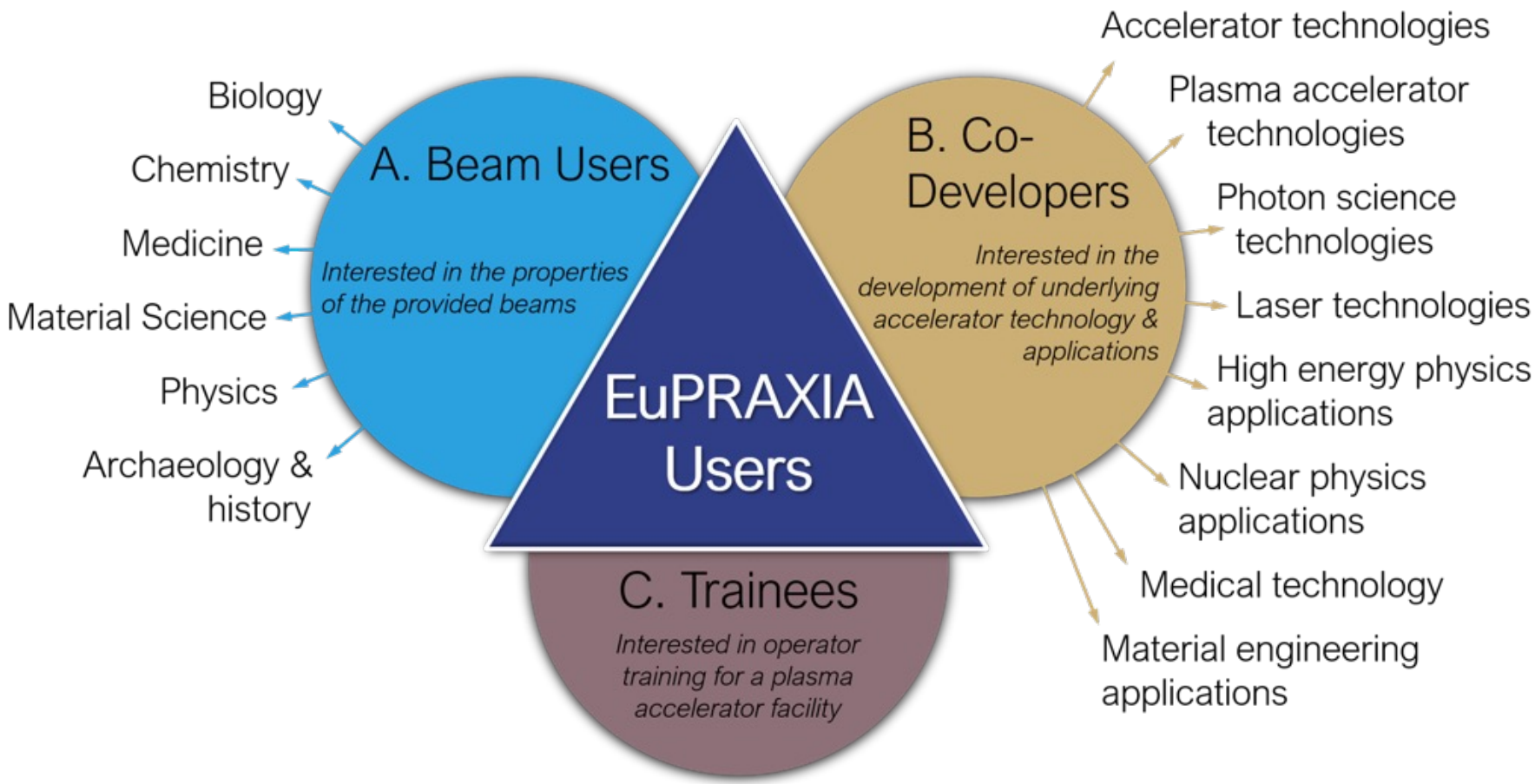
Ground area for extensions identified







User Categories: collbaorative approach



Conclusion

- 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 2028**.
- Second EuPRAXIA FEL site will be selected in next 18 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!