EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA
Preparatory Phase

EuPRAXIA within the European Context

Antonio Falone | INFN-LNF

Fundamental research and applications with the EuPRAXIA facility at LNF

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

Funded by the European Union

European **P**lasma **R**esearch **A**ccelerator with e**X**cellence **I**n **A**pplications

EuPRAXIA Mission

1

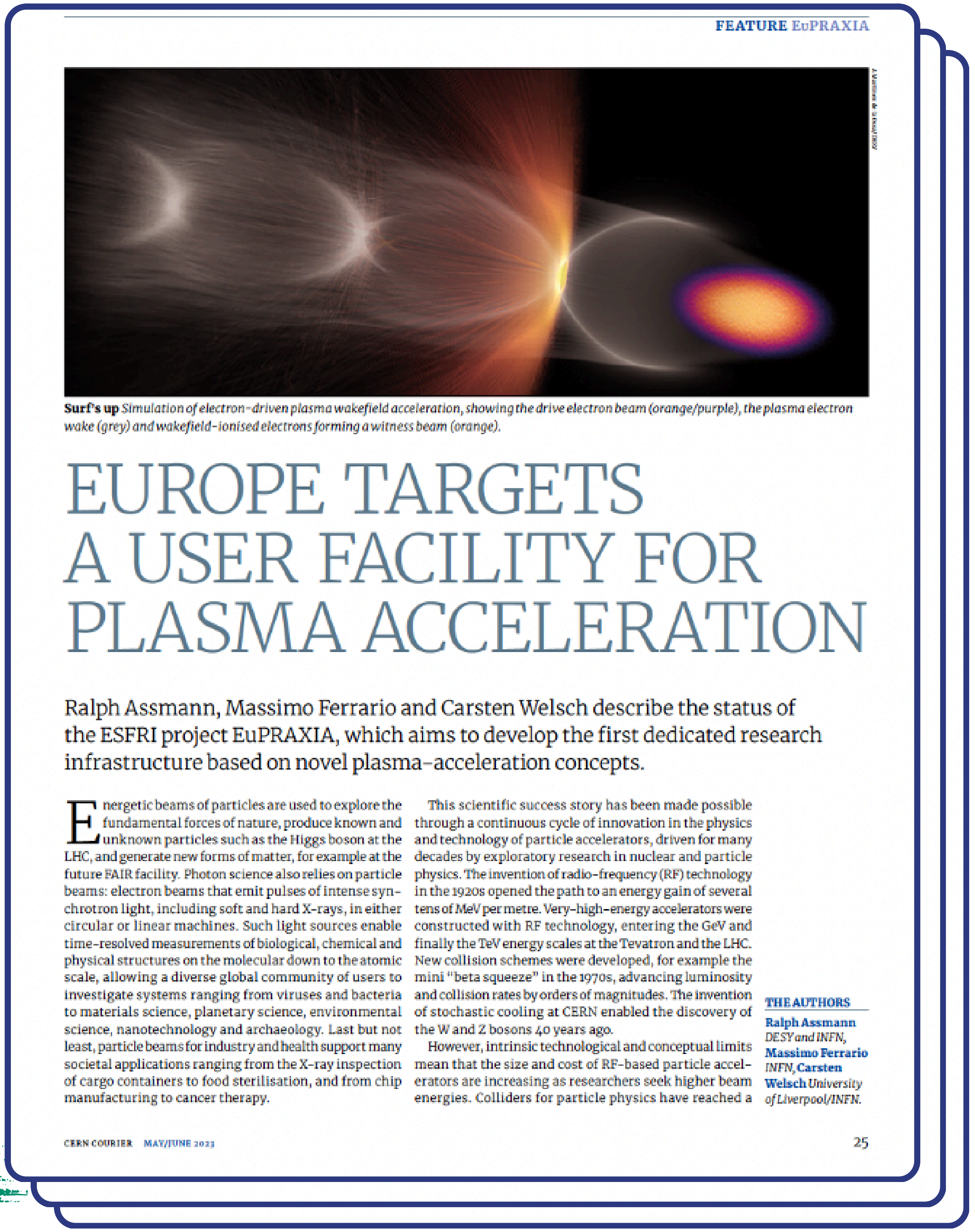
Building a distributed facility with very high field plasma accelerators, driven by lasers or beams
1 – 100 GV/m accelerating field

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



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.

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.*

Background

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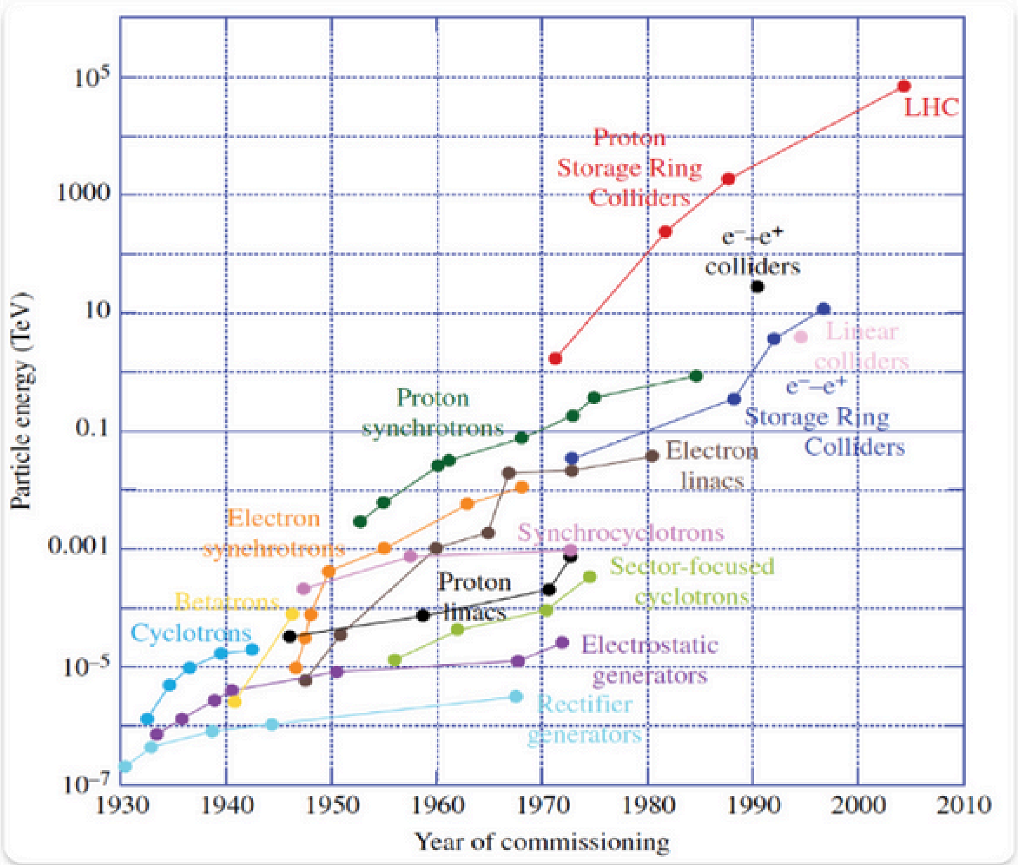

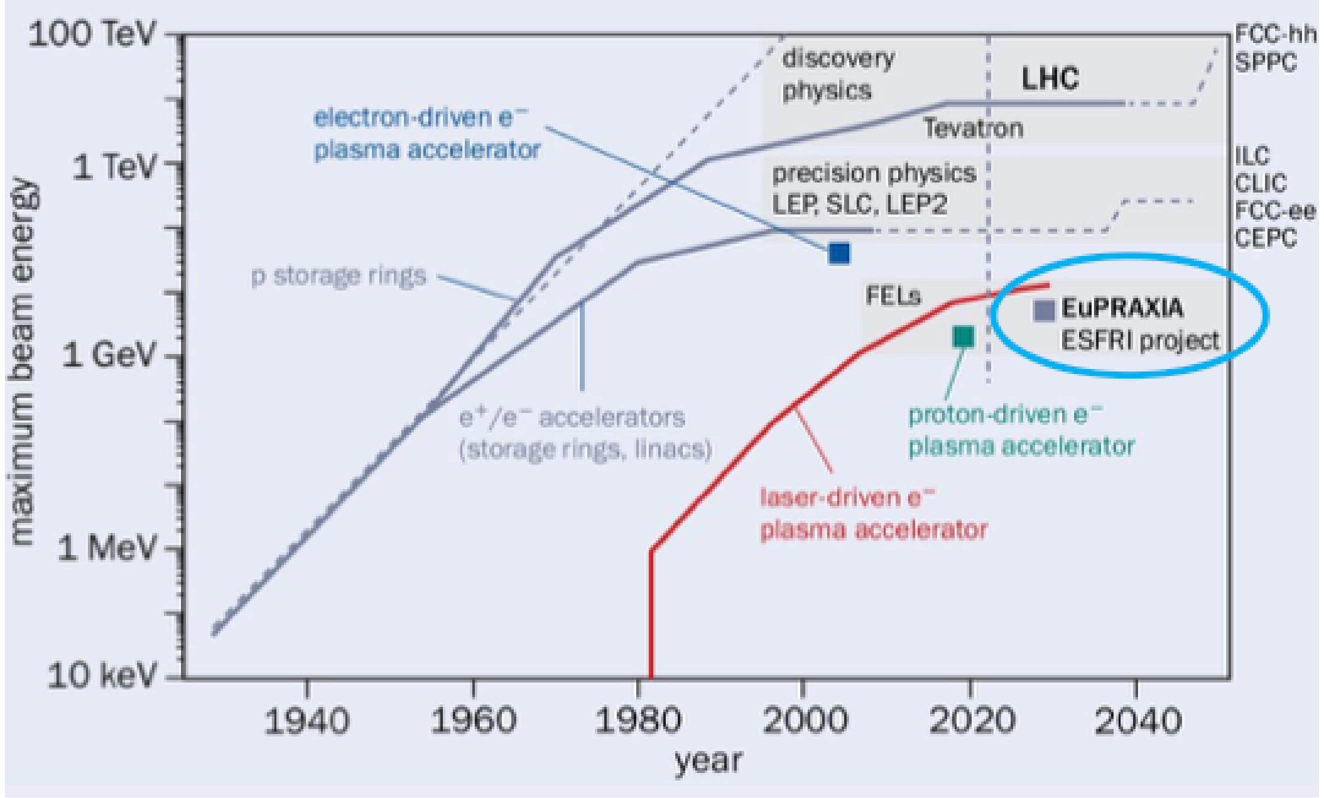

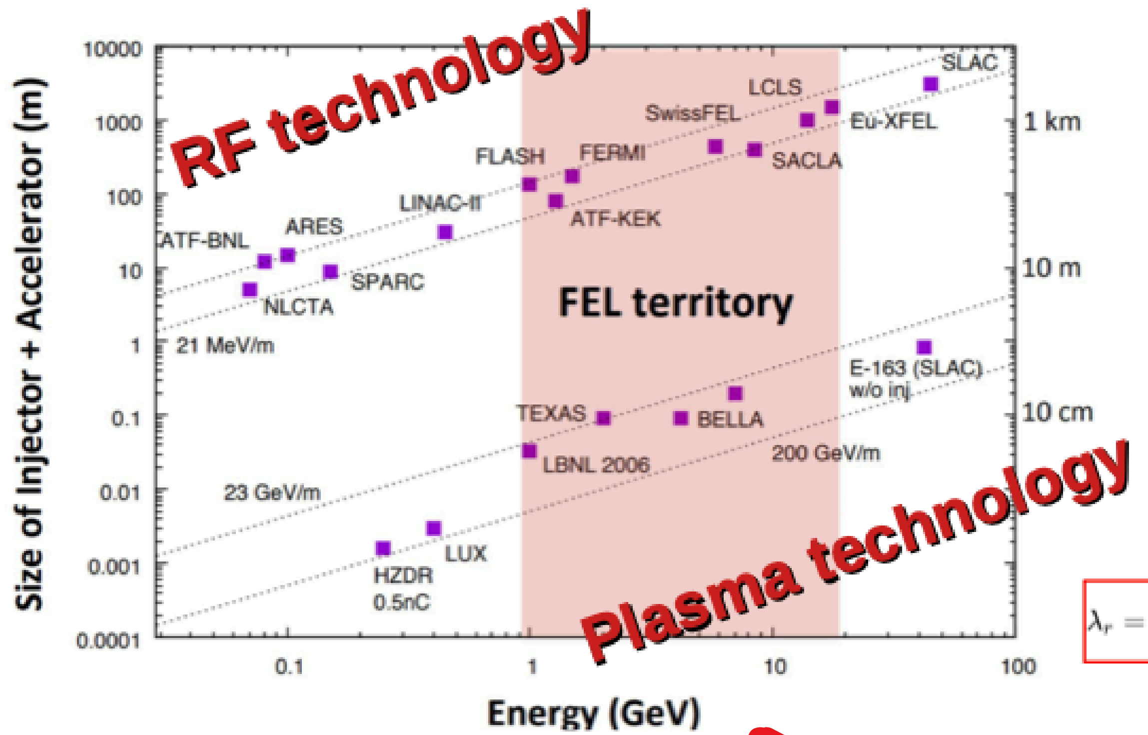

$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

Technological Steps → New frontier in particle accelerator

Plasma Accelerators are dramatically increasing their TRL and are now very close to be used as user facility → Free Electron Laser Region

The world around us

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• Recently, CERN started the process for the 2026 Update of the European Strategy for Particle Physics (ESPPU): a two-year process involving the whole community and aiming at **developing a common vision for the future of particle physics in Europe** within the international context. The process is expected to be concluded in June 2026, with the approval of the updated Strategy by the Council.

• The process will not only address the issue of what will be the next large machine to be built at CERN, but also plan identify the strategic technologies to be supported at CERN and in Member States' Laboratories: High Field Magnets, high gradient RF structures, **plasma-based accelerators**, energy recovery linacs, etc…

• A similar program ("The 2022 Snowmass process", finalized in the P5 2023 report) has been developed by DOE within the US HEP community for an R&D strategy for future colliders

• The plasma beam driven technology is identified as one of the **main component for stage 2 future linear colliders** (HAHLF proposal): there are plans to set-up a common facility for mul:-stage plasma studies. Other large international projects (Petra IV, DESY; CEPC, China) plan to build plasma-based injectors to operate large electron machines complex

• The EuPRAXIA community should make any effort to be involved in the scientific discussion, as the ESFRI RI will represent the first worldwide **TANGIBLE** example of plasma-based facility

Courtesy P.Campana

R&D and wide user spectrum

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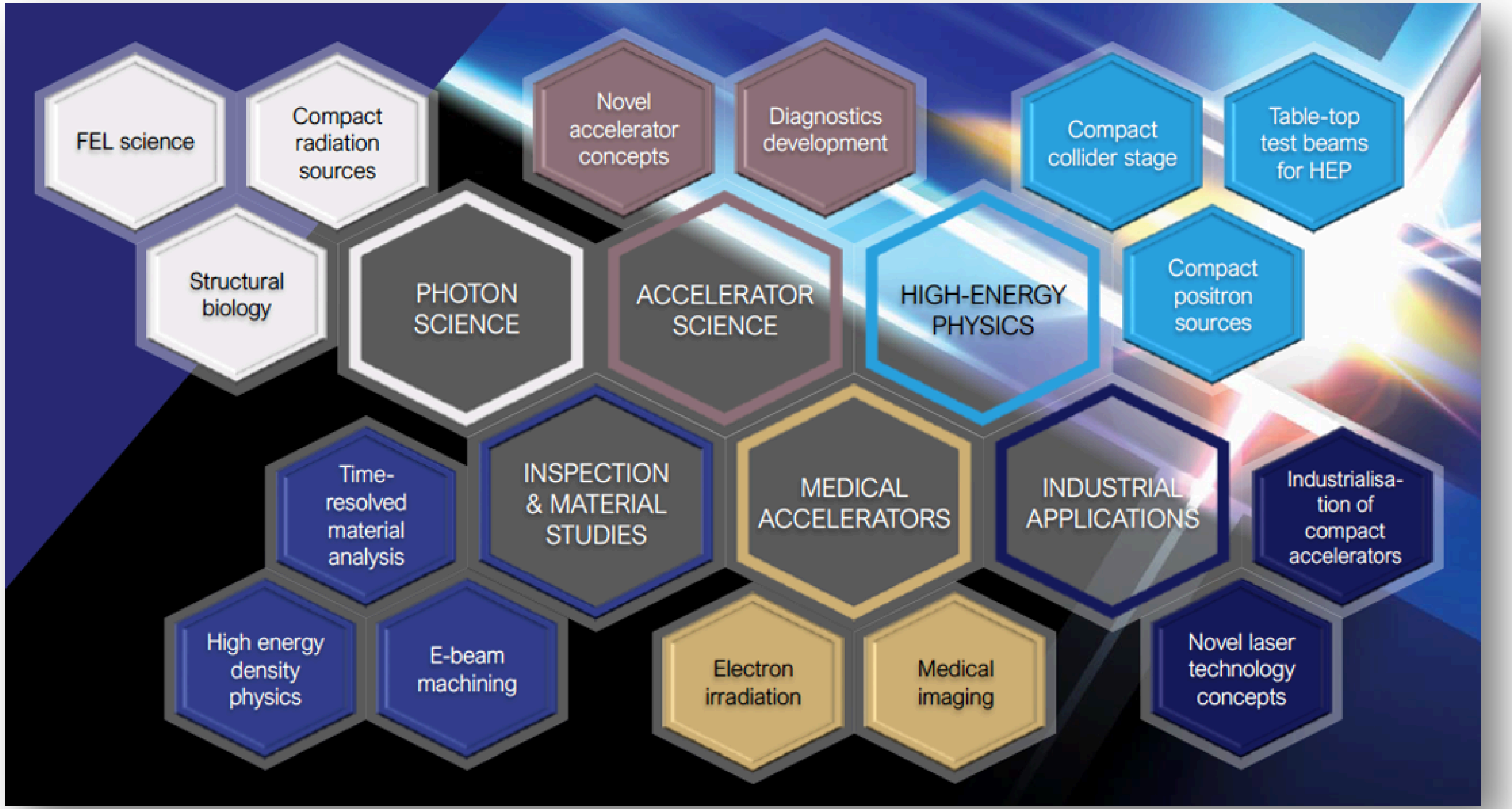
Charged Particle and Laser

- Electrons (0.1–5 GeV, 30 pC)
- Positrons (0.5–10 MeV, 106)
- Positrons (GeV source)
- Lasers (100 J, 50 fs, 10–100 Hz)
- X-band RF Linac (60 MV/m , up to 400 Hz)
- Plasma Targets
- Betatron X rays (1–10 keV, 1010)
- FEL light (0.2–36 nm, 109–1013)

Wide spectrum of possible application



Conceptual Design Report

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 (ongoing)
- Start of 1st operation: 2029

600+ page CDR, 240 scientists contributed

Science goals

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- **Free Electron Laser** → ***Flagship Science Goal 1***: *EuPRAXIA will deliver free-electron laser (FEL) X rays with 10^9-10^13 photons per pulse to user areas, covering wavelengths of 0.2 nm to 36 nm. The EuPRAXIA FEL pulses are naturally short (down to 0.4 fs) and will therefore provide users with tools for investigating processes and structures in ultra-fast photon science at a reduced facility foot print.*

- **Betatron Radiation Source** → ***Flagship Science Goal 2:*** *EuPRAXIA will deliver betatron X rays with about 10^10 photons per pulse, up to 100 Hz repetition rate and an energy of 5-18 keV to users from the medical area. The much reduced longitudinal length of the X ray emission area (point-like emission) leads to an important improvement in image resolution compared to other techniques.*

- **Positron Beams** — ***Flagship Science Goal 3***: *EuPRAXIA will deliver positron beams at energies from 0.5 MeV to 10 MeV and a repetition rate of 100 Hz for material science studies. Per pulse about 10^6 positrons will be produced in a time duration of 20-90 picoseconds on the sample, allowing time-resolved studies. EuPRAXIA will here advance the capabilities of existing positron sources in flux and time resolution.*

- **e+ / e- beams** — ***Flagship Science Goal 4***: *EuPRAXIA will deliver electron and positron beams at energies from a few 100 MeV up to 5 GeV for high energy physics related R&D (detectors, linear collider topics). R&D goals include the demonstration of a linear collider stage, a "table top" HEP test beam and studies on positron transport and acceleration towards a linear collider.*

- **ICS Photon Beams** — ***Flagship Science Goal 5:*** *EuPRAXIA will deliver photons from an inverse Compton scattering (ICS) source. The photons of up to 600 MeV and with narrow-band spectrum will enable precision nuclear physics and highly penetrative radiography for users.*

- **High Rep. Rate Laser** — ***Flagship Science Goal 6***: *EuPRAXIA will provide access to a multi-stage, high-repetition rate plasma accelerator in the GeV range to users from accelerator science. This R&D platform will allow the testing of novel ideas and concepts, full optimisation of a plasma collider stage, certain fixed target experiments (also in combination with lasers) and performance studies of conventional versus novel accelerator technology.*

- **Laser Technology** — ***Flagship Science Goal 7***: *EuPRAXIA will provide access to cutting edge laser technology with short pulse length in combination with high energy photon pulses and short electron/positron bunches. Novel schemes of pump probe configurations and ultra-precise timing will be researched, feeding back into laser science.*

Implementation Phasing

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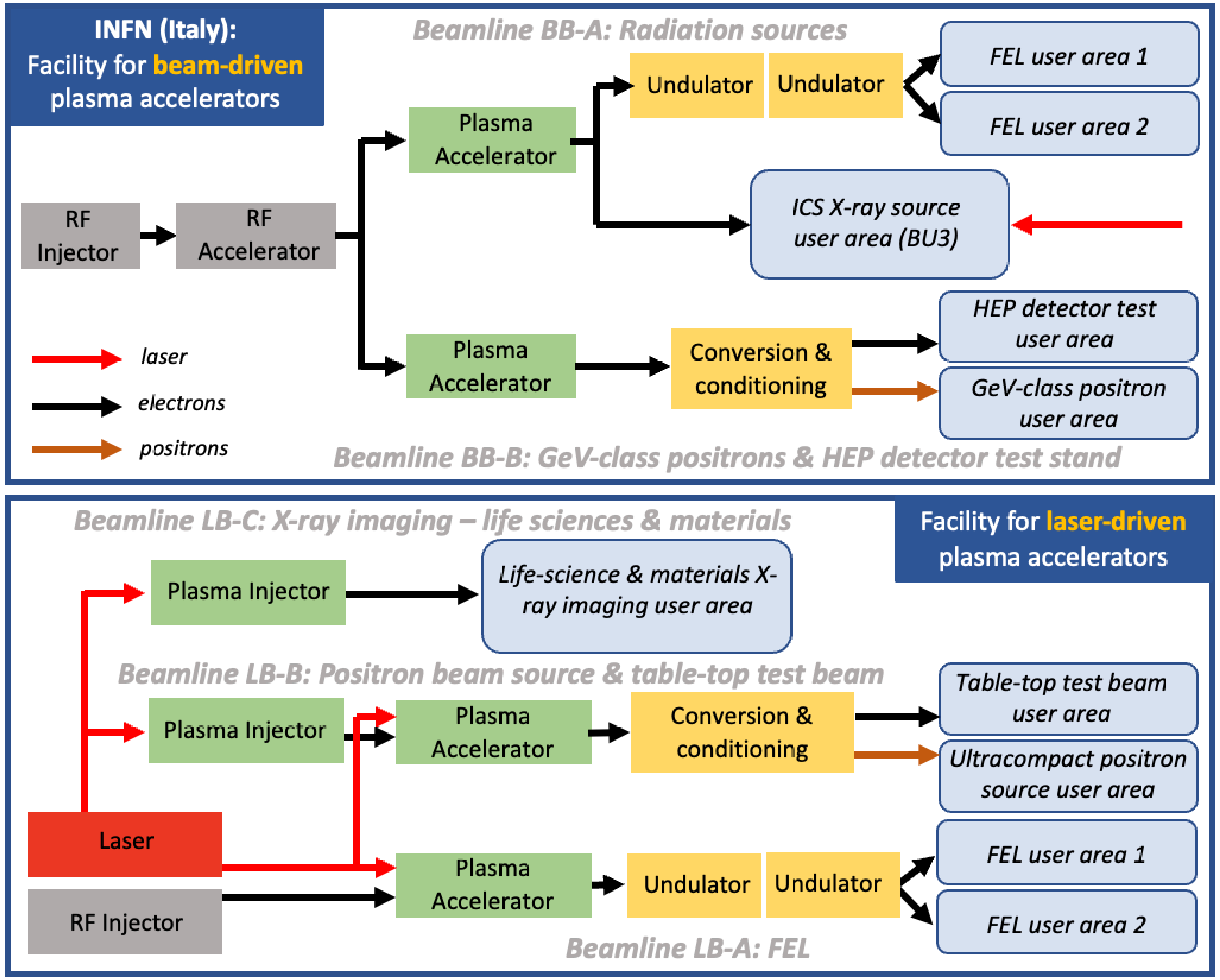
	Laser-driven	Beam-driven
Phase 1	✓ FEL beamline to 1 GeV + user area 1 ✓ Ultracompact positron source beamline + positron user area	✓ FEL beamline to 1 GeV + user area 1 ✓ GeV-class positrons beamline + positron user area
Phase 2	✓ X-ray imaging beamline + user area ✓ Table-top test beams user area ✓ 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

FULLY FUNDED – 140M€ approx



User Survey

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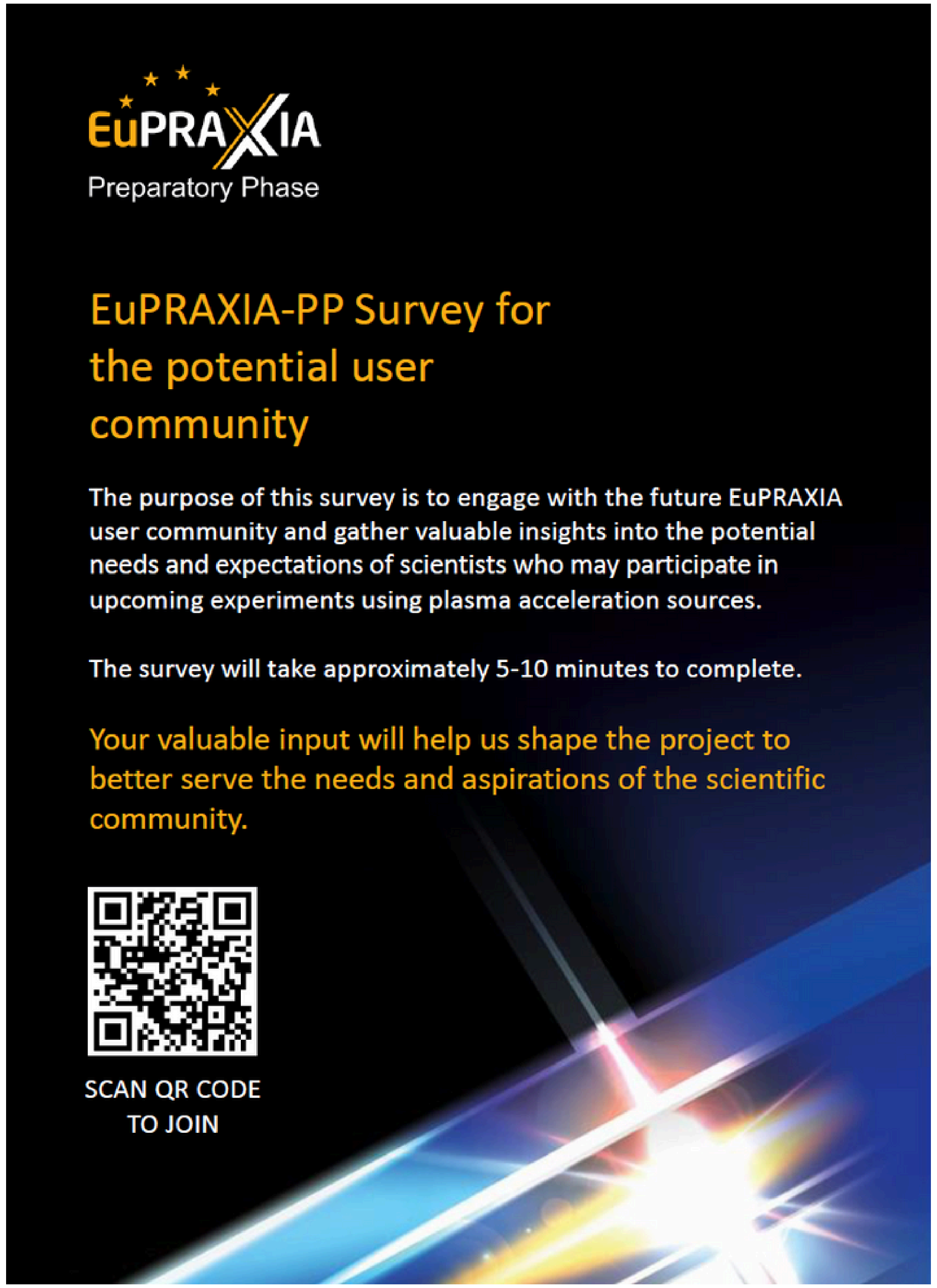
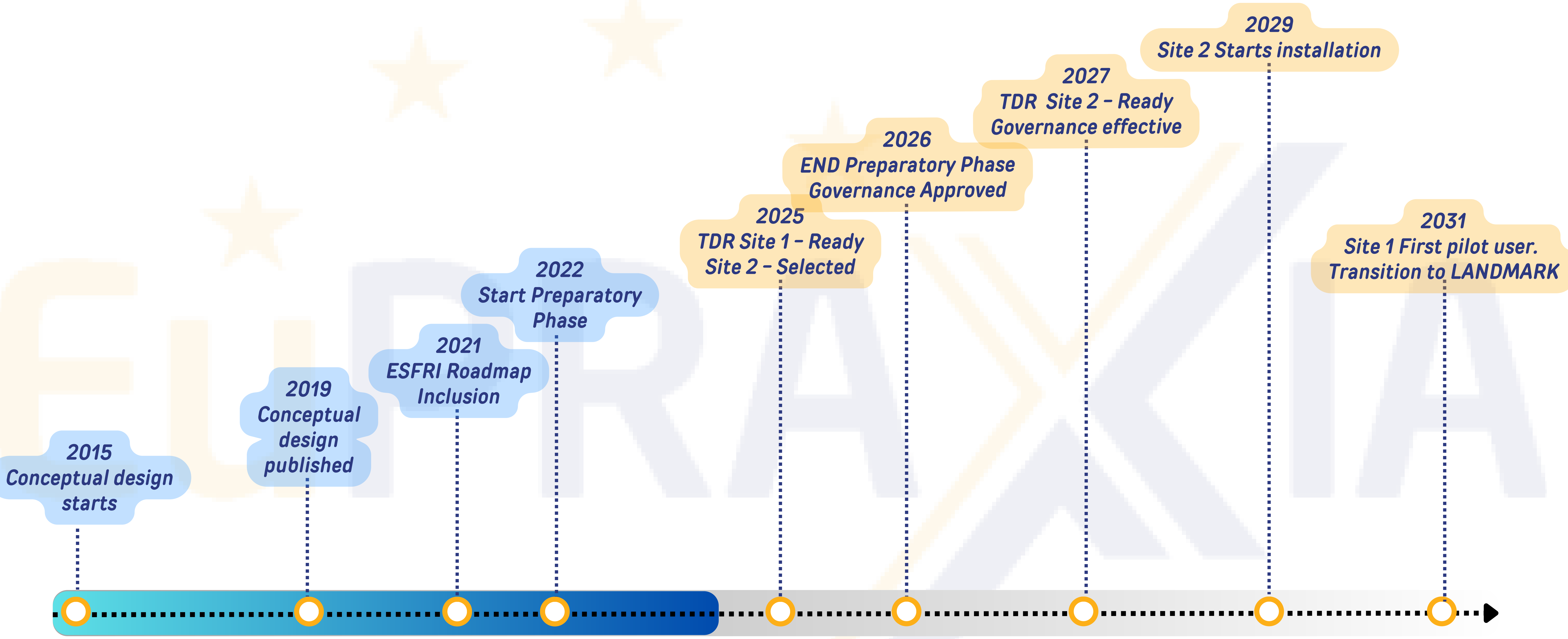
In order to offer the largest spectrum of possible application:

Open Survey to better understand needs and requirements from potential users.

https://surveys.infn.it/index.php/718177?lang=en



Timeline


2015
Conceptual design starts
2019
Conceptual design published
2021
ESFRI Roadmap Inclusion
2022
Start Preparatory Phase
2025
TDR Site 1 – Ready
Site 2 – Selected
2026
END Preparatory Phase
Governance Approved
2027
TDR Site 2 – Ready
Governance effective
2029
Site 2 Starts installation
2031
Site 1 First pilot user.
Transition to LANDMARK

EuPRAXIA Preparatory Phase

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- HE Grant (2022-2026), gathering 38 institutes plus observers, with the goal to bring the EuPRAXIA iniative to a level of maturity able to start the implementation phase.

- Several Aspects are considered:
  - Communication strategic plan
  - Governance, Legal framework, Rules & Financial model
  - e-needs & Data Management
  - User strategy
  - TRL improvement on several scientific domains
  - 2nd site decision

EMPA*	CH
EPFL*	CH
PSI*	**CH**
DESY	DE
FBH Berlin	DE
FHG-ILT Aachen	DE
FZ Julich	DE
HZ Dresden	DE
LMU Muenchen	DE
HHU Dusseldorf	**DE**
GSI-FAIR Darmstadt	**DE**
ELI Beamline ERIC	CZ
CEA	FR
CNRS	FR
THALES	FR
AMPLITUDE	**FR**
IASA Athens	GR
WIGNER	HUN
Uni. Szeged	HUN
Uni. Pecs	HUN

* associate partners

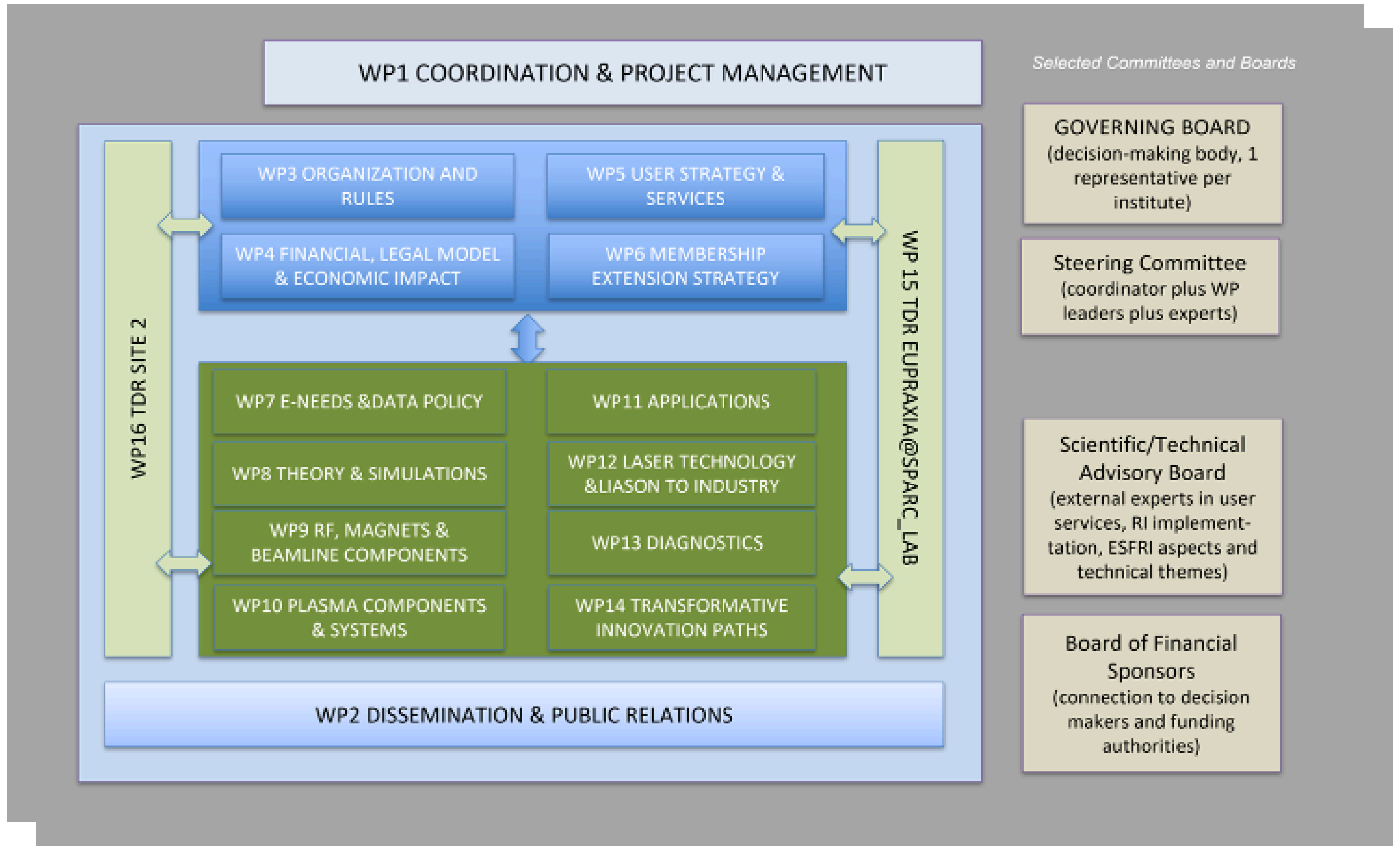
CERN	INT. ORG.
H. Univ. Jerusalem	ISR
CNR	IT
ELETTRA Trieste	IT
ENEA Frascati	IT
INFN	IT
U. Roma Sapienza	IT
U. Roma Tor Vergata	IT
IST Lisbon	P
ALBA Cells	SP
CLPU Salamanca	SP
IC London*	UK
QU Belfast*	UK
STFC*	UK
U. Liverpool*	UK
U. Oxford*	UK
U. Strathclyde*	UK
UCLA*	US

UJT Shanghai (observer)	CN
HZ Jena (observer)	DE
U. Cote d'Azur Nice (observe	FR
NTUA Athens (observer)	GR
U. Milano Bicocca (observer)	IT
U. Palermo (observer)	IT
NCBJ Otwock (observer)	PL
U. Manchester (observer)	UK

- 38 Members
- 8 observers
- 2 private industries
- 16 workpackages

CRITICAL milestone : Laser Driven Implementation Site

- 2nd site (laser driven site) decision:
  - 3 outstanding candidates: ELI - ERIC (CZ), CNR-INO (IT), EPAC (UK)
- Bid book in preparation.
- Approval from Collaboration Board in Spring 2025.
- Several deliverables correlated (including financial package)



European Initiatives

Funded by the European Union

ESFRI

ESFRI Roadmap inclusion boosted the overall visibility of EuPRAXIA Initiative and its funding attractivity.

Phase	Project Name	Funding Source	Topic	Years
Preparatory Phase	Design Study	Horizon 2020 Grant	Conceptual Design Report	2015-2019
Preparatory Phase	EuPRAXIA Preparatory Phase	Horizon Europe Grant	RI infrastruture preparation	2022-2026
Preparatory Phase	EuPRAXIA Doctoral Network	Horizon Europe Grant	Marie Curie Doctoral students	2022-2026
R&D	PACRI	Horizon Europe Grant	R&D	2025-2029
Implementation	EuPRAXIA@SPARC_LAB	IT- National Funding	Beam Driven pillar	2019-2031
Implementation	EuPRIAXA Advanced Photon Sources EuAPS	Next Gen EU, PNRR IT prograrm	Betatron Source / High Power Laser / High Rep. rate Laser	2022.2025
Implementation	EuPRAXIA Aria Beam Line	Regione Lazio	Aria beam Line	2026-2029

EuPRAXIA architecture

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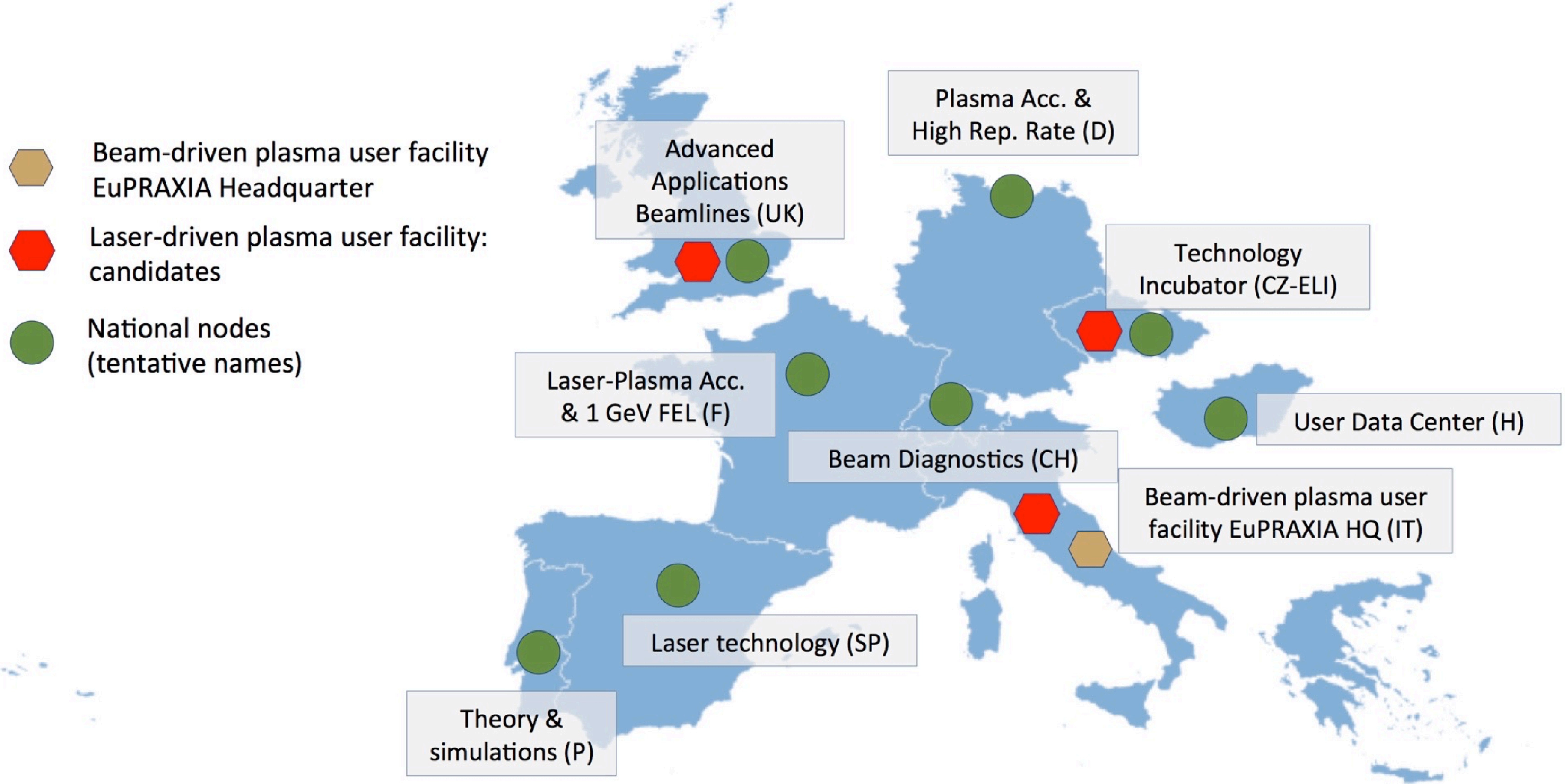


EuPRAXIA architecture

- **Implementation Sites**
  Beam Driven (@LNF) and Laser Driven (to be decided soon)

- **National Nodes**
  Technological clusters for development and in-kind contribution
  Coordination at National Level

- **Project Clusters**
  Units that performs dedicated R&D / prototyping / subsystem

Funded by the European Union

Future Governance and Legal Model

Funded by the European Union

EuPRAXIA Community has been ruled so far through Collaboration Agreements (largely based on the typical DESCA model of HE grants) which are consequence of the funding model driven by dedicated grants.

The role of the Preparatory Phase is to identify the most suitable legal framework, governance model and funding scheme to guarantee a sustainable implementation and operation of the future Research Infrastructure

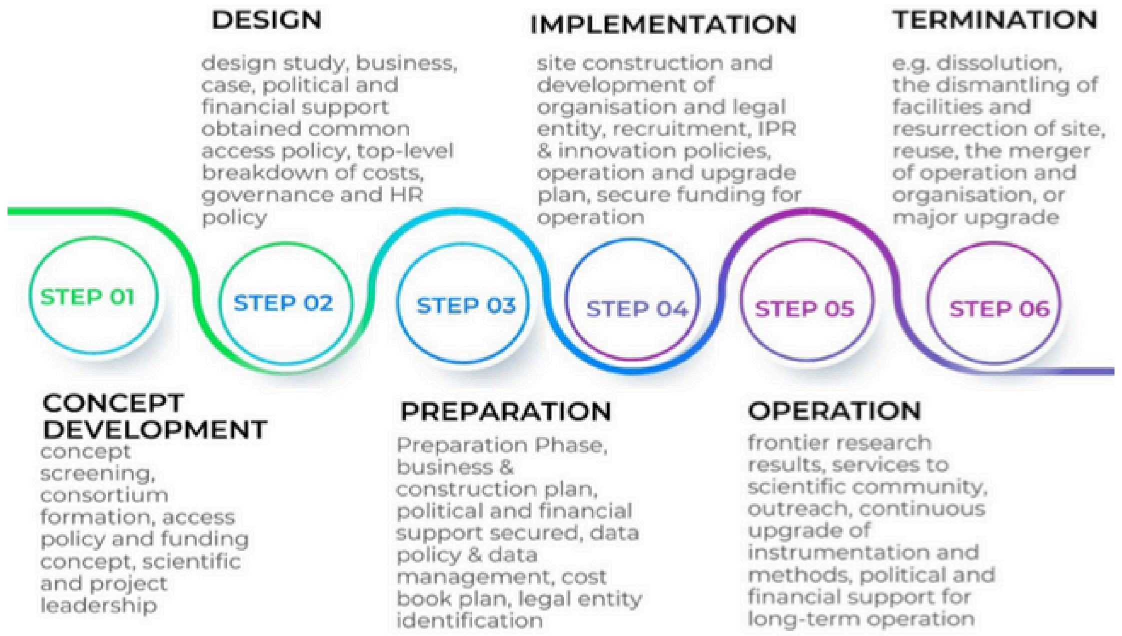
The goal and ambition of EuPRAXIA is to create a solid collaboration, based on a common vision, mission and strategy capable to attract funding and become a reference for the Plasma, Laser and Accelerator community and eventually create a brand new legal entity capable to operate autonomously in grant & funding enhancing the overall sustainability.

Future governance will guarantee a fair representation of the collaboration, the implementation sites and national nodes. It will be lean and effective to provide an efficient decision making process.

Collaboration agreement → Legal entity (AISBL?)

Governance & Phasing Approach

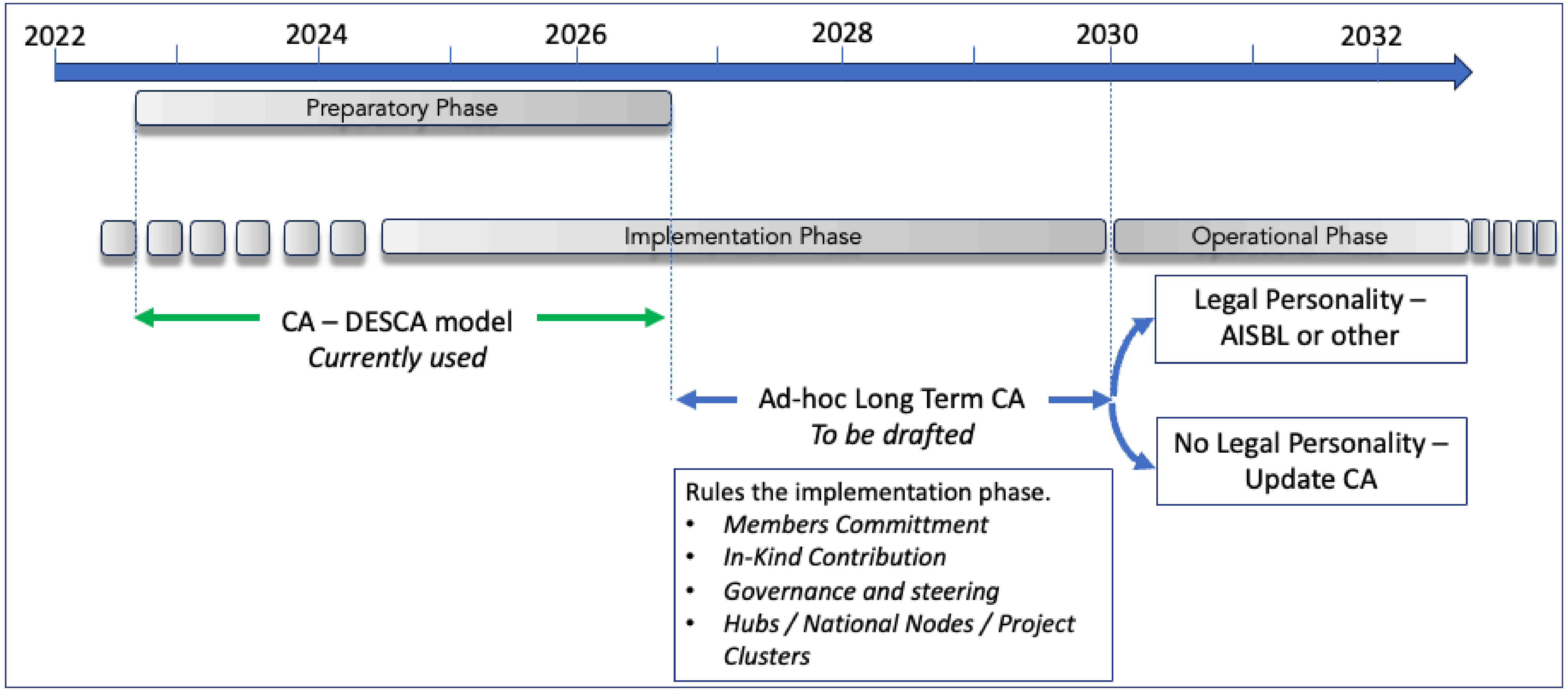
Funded by the European Union



Typical Lifecycle of a ESFRI project. In reality phases might overlap (as EuPRAXIA case)

Governance model adapting the maturity and project lifecycle.

Operational phase needs a long term agreement for its sustainability



Financial model

Funded by the European Union

EuPRAXIA initiative is an ambitious project that requires a substantial amount of resources. So far the fund raising has been quite effective along the project lifecycle.

Eu GRANTS (through national institutes)

National Funding

Financial model

Funded by the European Union

Eu Funding Distribution

Country	Acronym	Funding received
Italy	IT	4.228.312,80
France	FR	3.918.060,00
Germany	DE	2.380.328,00
United Kingdom	UK	2.376.590,00
Czech Republic*	CZ	1.626.051,80
Hungary	HU	270.348,00
Spain	ES	401.000,00
Portugal	PT	808.103,20
CERN	CERN	450.500,00
Netherlands	NL	138.750,00
Sweden	SE	888.959,60
Slovenia	SI	242.179,20
Austria	AT	270.331,20
Israel	IL	10.000,00
Greece	EL	10.000,00
EUROPE	TOT	18.019.513,80

National Funding Distribution

Country	Acronym	Funding allocated
Italy	IT	140.400.000
Switzerland	CH (matching funds)	1.670.880
France	FR	2.500.000
United Kingdom	UK (matching funds)	1.116.000
	TOT	145.686.880

Project phase funding

Project Phase	Funding
Design	2.999.900
Preparatory	6.841.360
R&D	13.465.133
Implementation	140.400.000
TOT	163.706.393

~164 M€ raised so far.

Financial model / In Kind Contribution

Funded by the European Union

Sites funding: based on in-kind contributions from institutes/country + regional funding + EU calls+national funding

• Operational costs: basically relying on hosting Institution (other schemes possible, although difficult)
• National nodes/ technology clusters: based on in-kind contributions from institutes/country + regional funding + EU calls. They are expected to contribute to specific technical parts of sites

National nodes and project clusters can provide a significant contribution on specific topics and arranged on point to point basis as example:

- INFN – ENEA : Undulators development
- INFN – PSI : Electron beam diagnostics
- INFN – CERN: X-Band Technology
- INFN – ELETTRA: under discussion (beam lines?)
- INFN – ESRF: to be discussed

Conclusions

EuPRAXIA is a fascinating project at the junction of three scientific communities: accelerator, laser and plasma.

It is a truly international and European endeavour under the ESFRI umbrella similar to HEP style collaboration.
Unusual multi-stakeholder funding scheme and large collaboration.

Exciting times ahead – In the next year(s) many milestones will be accomplished:

- 2nd site decision
- Conclusion of the preparatory phase and governance approval
- EuPRAXIA@SPARC_LAB start of the implementation phase
- EuAPS in the commissioning and operational phase

and many more…