EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA
Preparatory Phase

Overview of EuPRAXIA

Antonio Falone | INFN-LNF

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

EuPRAXIA

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.*

CERN COURIER MAY/JUNE 2023 25

Plasma Acceleration

Funded by the European Union

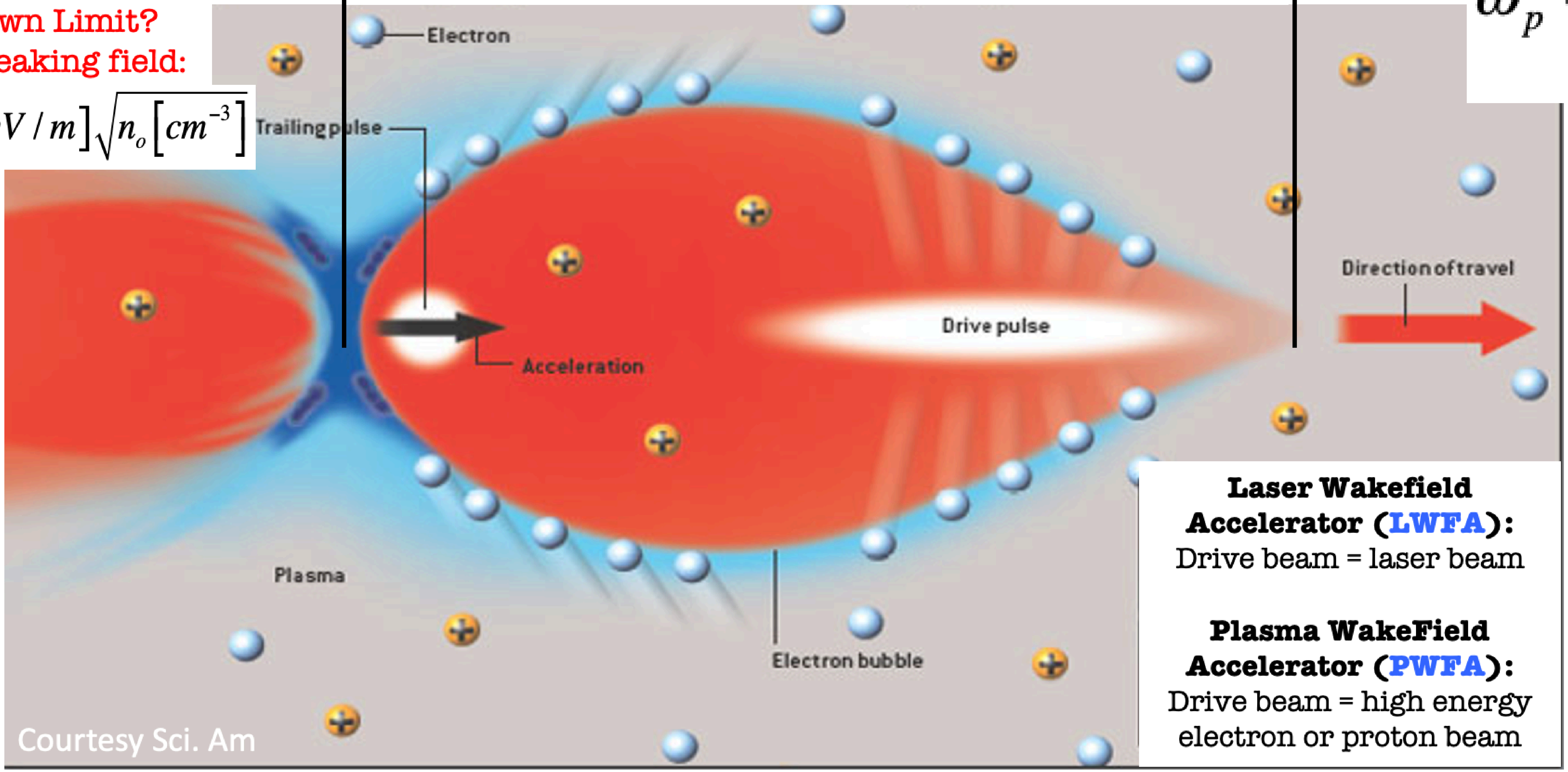
$$n_o = 10^{16}\,cm^{-3} \Rightarrow \lambda_p = 300\ \mu m$$

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

Break-Down Limit?

⇒ Wave-Breaking field:

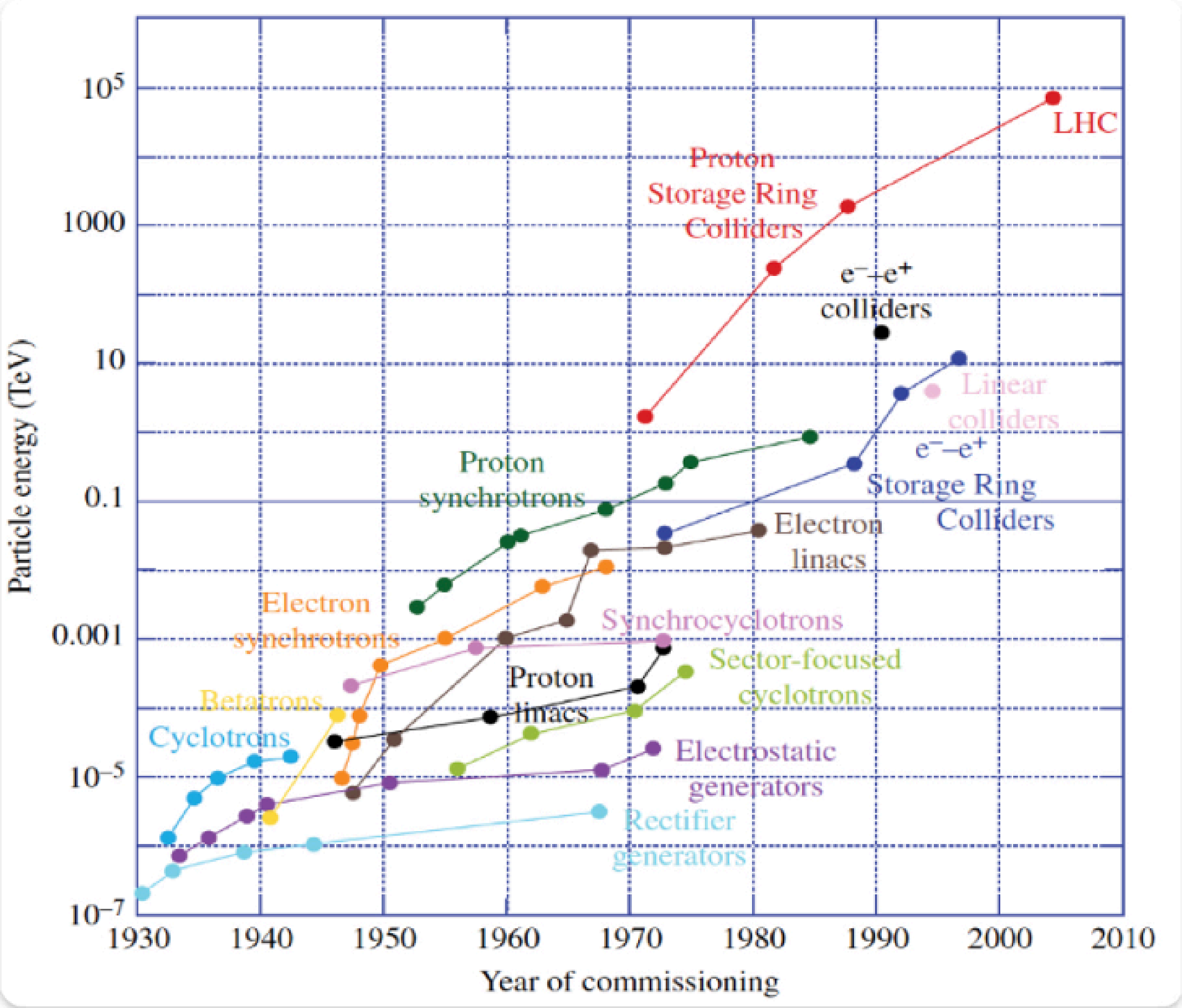
$$E_{wb} \approx 100\left[GeV/m\right]\sqrt{n_o\left[cm^{-3}\right]}$$

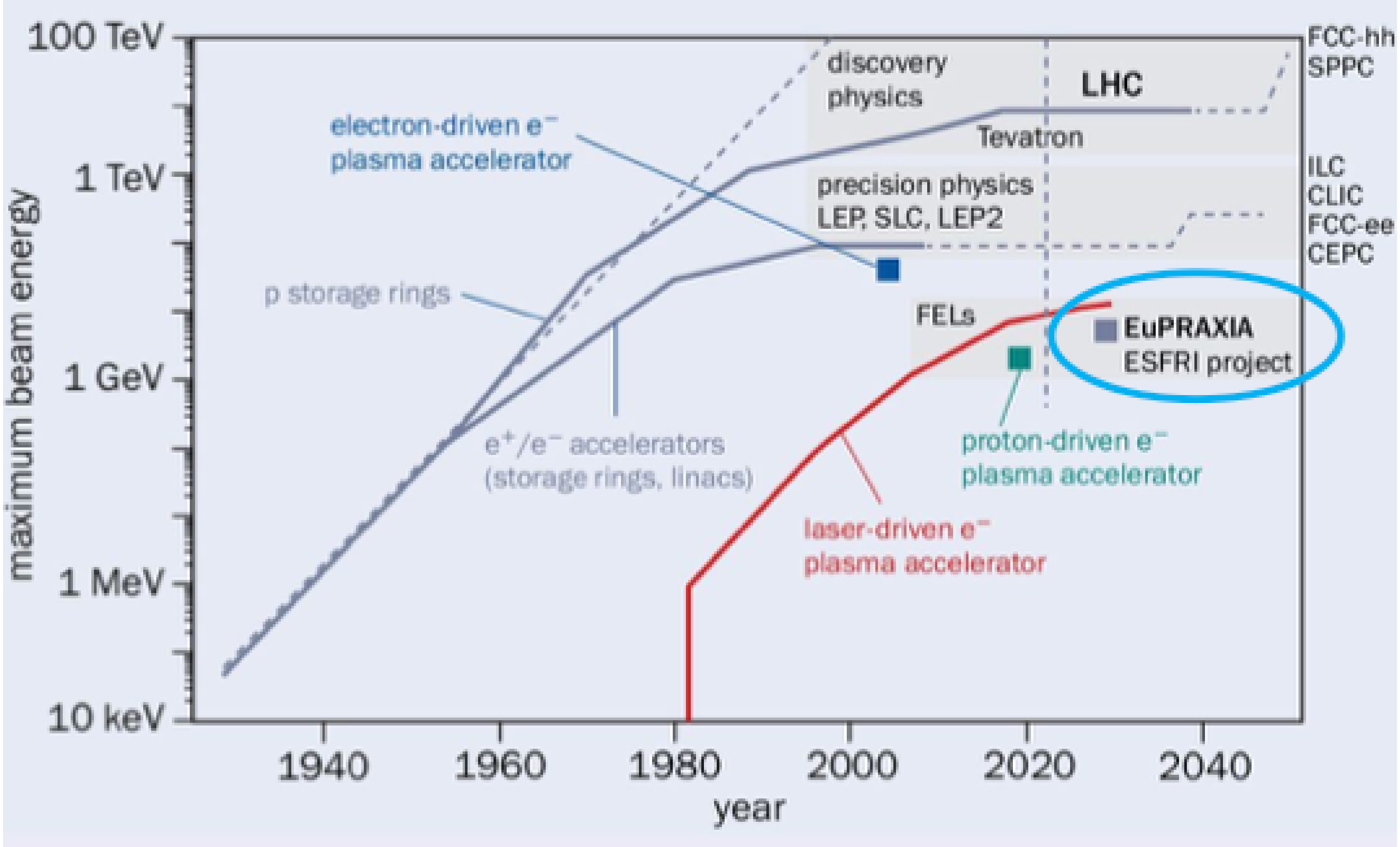


Laser Wakefield Accelerator (LWFA):
Drive beam = laser beam

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

Background





New frontier in particle accelerator → Technological steps

Plasma accelerator are now very promising to reach beam energy and quality able to be used for Free Electron Laser and light source in general.

Conceptual Design Report

- 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

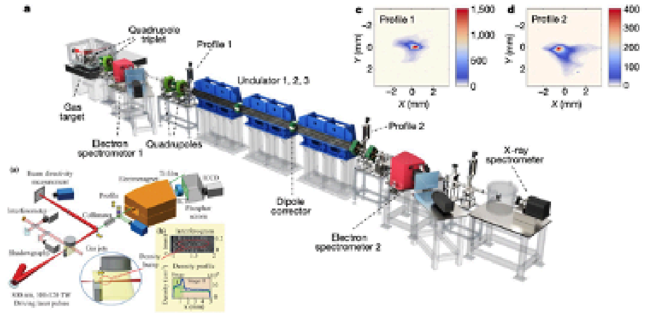
600+ page CDR, 240 scientists contributed

FEL Pilot 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

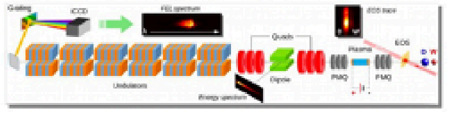
FEL lasing **amplification of 100** reached at 27 nm wavelength (average radiation energy 70 nJ, peak up to 150 nJ)

2021 Plasma FEL Feasibility Proven: Electron-driven

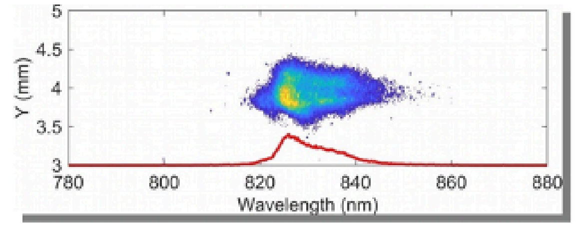
Recent ground-breaking results in Frascati:

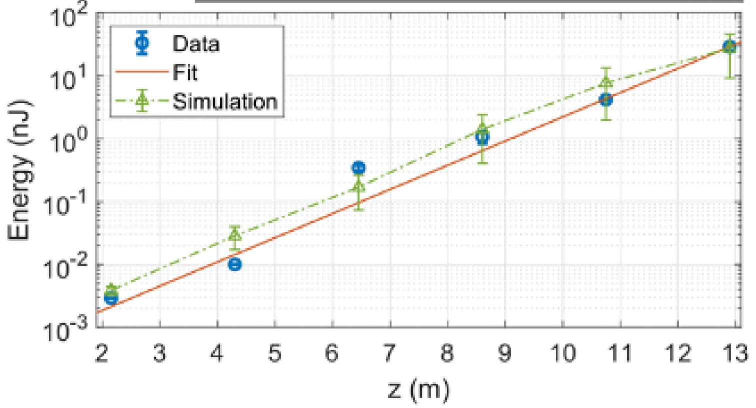
First FEL lasing from a beam-driven plasma accelerator

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

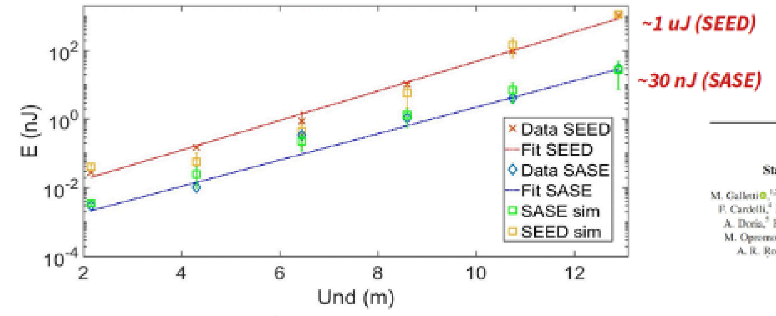


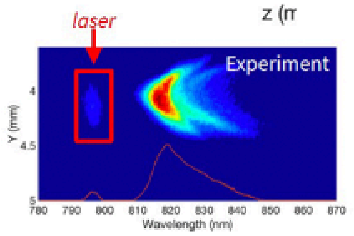
Single Spike SASE spectrum

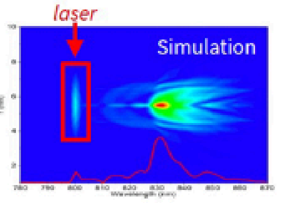




First Beam Driven SEEDED - FEL Lasing at SPARC_LAB (June 2021)







PHYSICAL REVIEW LETTERS 129, 234801 (2022)

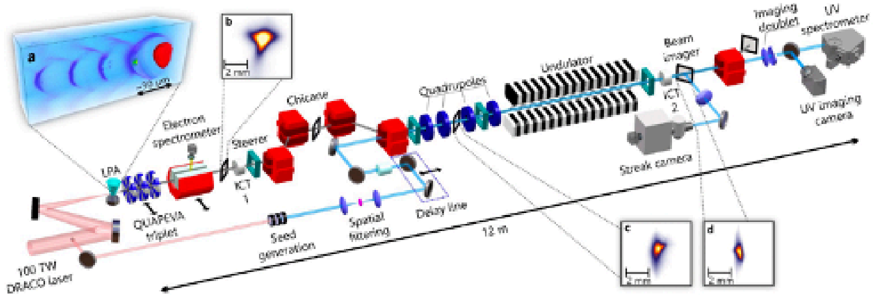
Stable Operation of a Free-Electron Laser Driven by a Plasma Accelerator

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



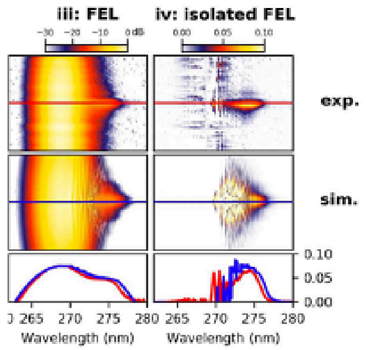


FIG. 1. **Experimental layout.** The electron beam generated in the LPA is first characterized using a removable electron spectrometer and then sent through a triplet of quadrupoles (QUAPEVAs) for beam transport to the undulator and FEL radiation generation. ICTs: Integrated Current Transformers. Non-labelled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

Timeline

Funded by the European Union

EuPRAXIA Consortium

Funded by the European Union

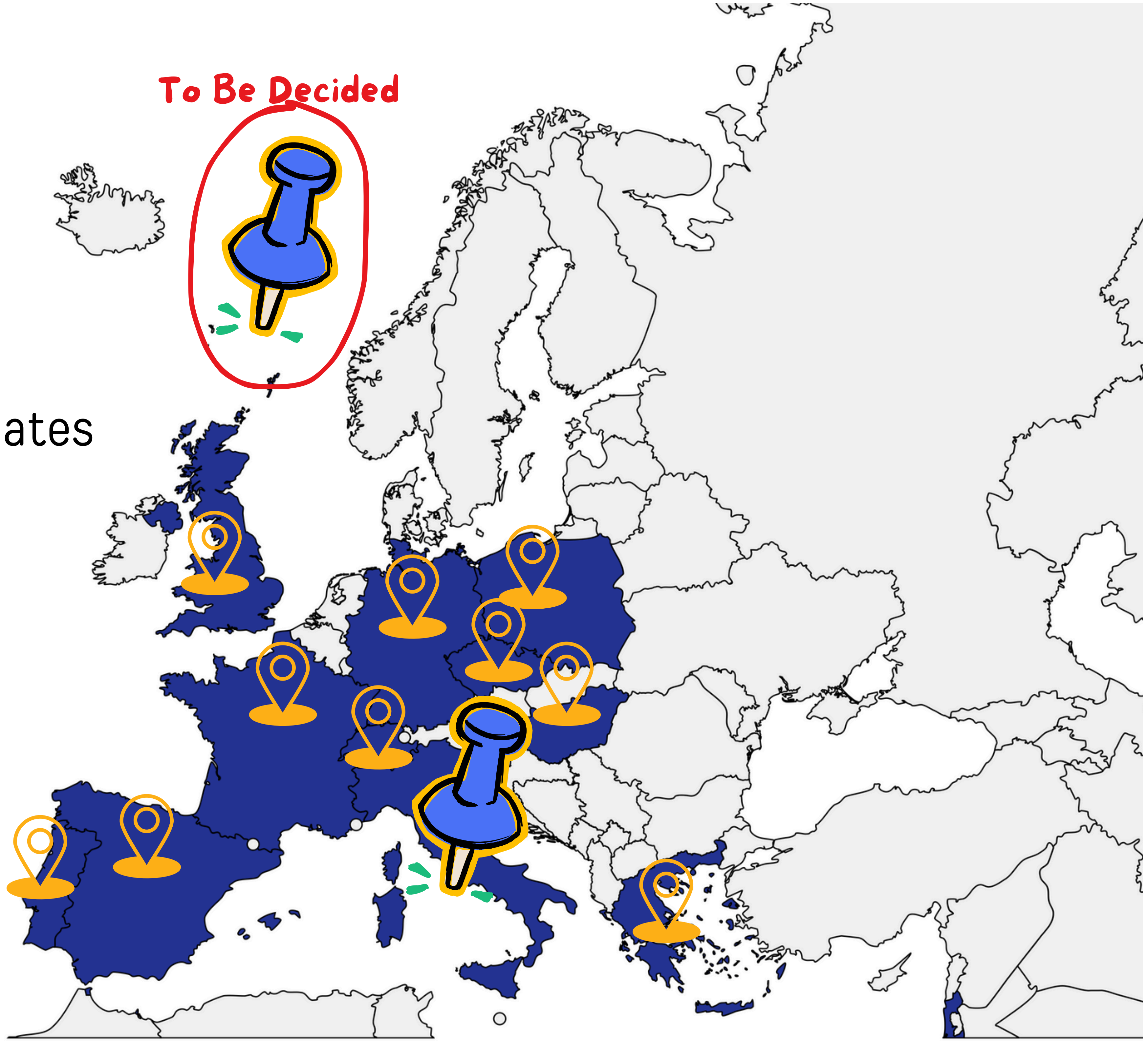
EuPRAXIA Preparatory Phase Consortium

38 institutes between members and observers
plus CERN

- 2 implementation sites:
  - Beam Driven Plasma @ INFN-LNF Frascati (Italy)
  - Laser Driven Plasma – To be decided among 4 candidates
    - ELI-ERIC (Czech Republic)
    - EPAC – CLF (UK)
    - CNR-INO (ITA)
    - CLPU (SP)

- National nodes
- Techonological Clusters

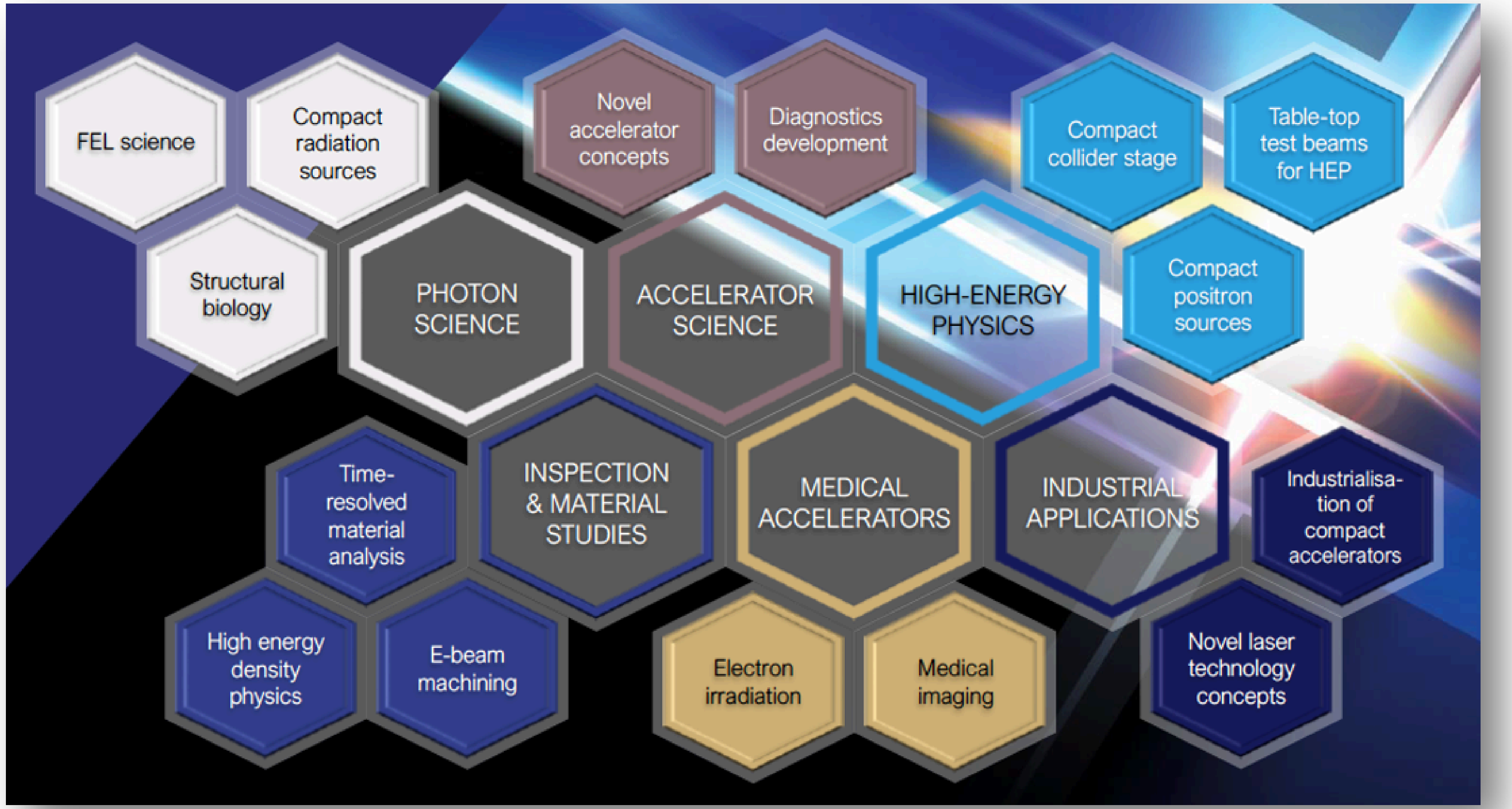
Observers also in China, Japan and US



R&D and wide user spectrum

- 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 on possible applications



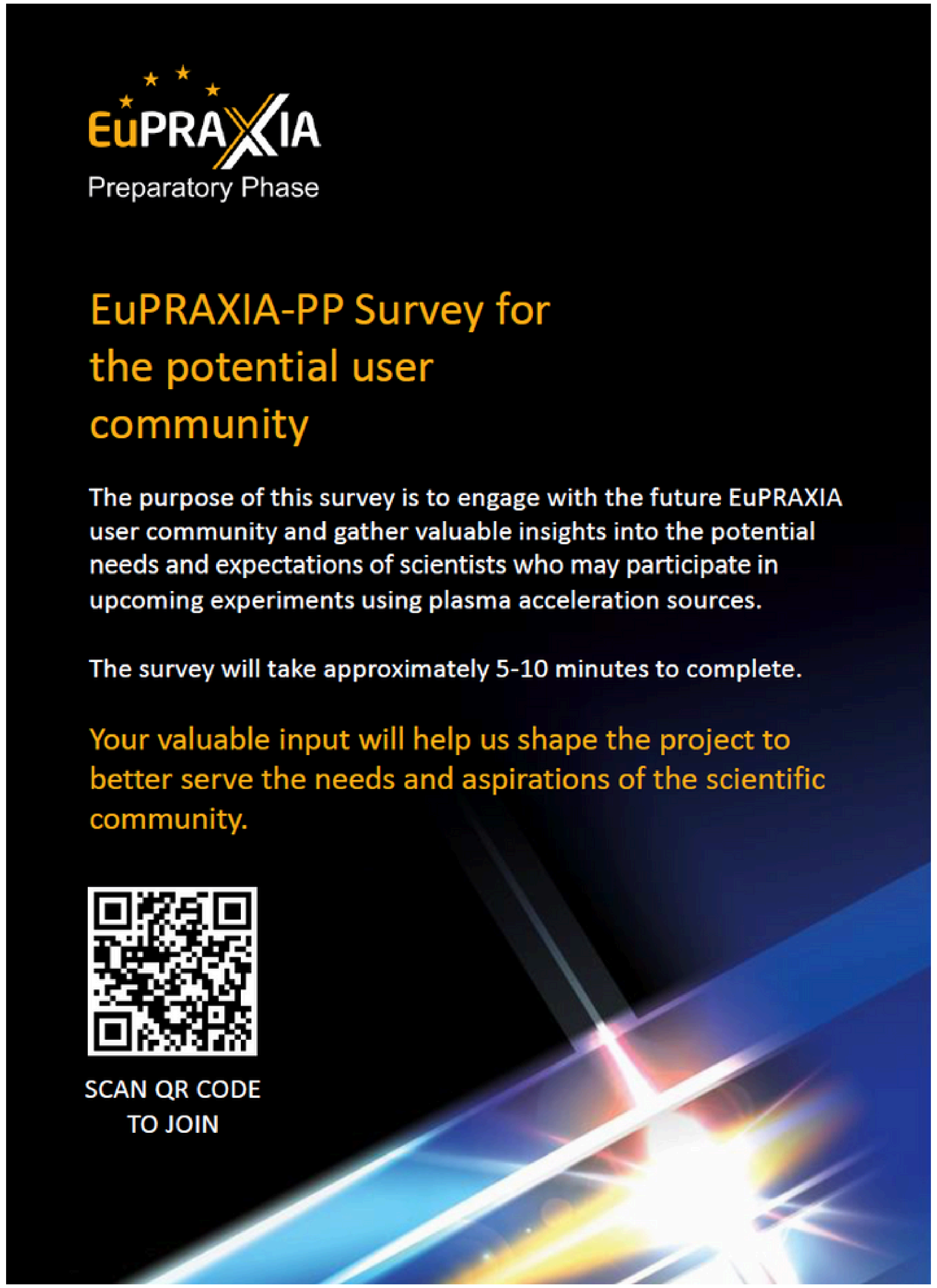
User Survey

Funded by the European Union

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

In order to offer the largest spectrum of possible application.

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

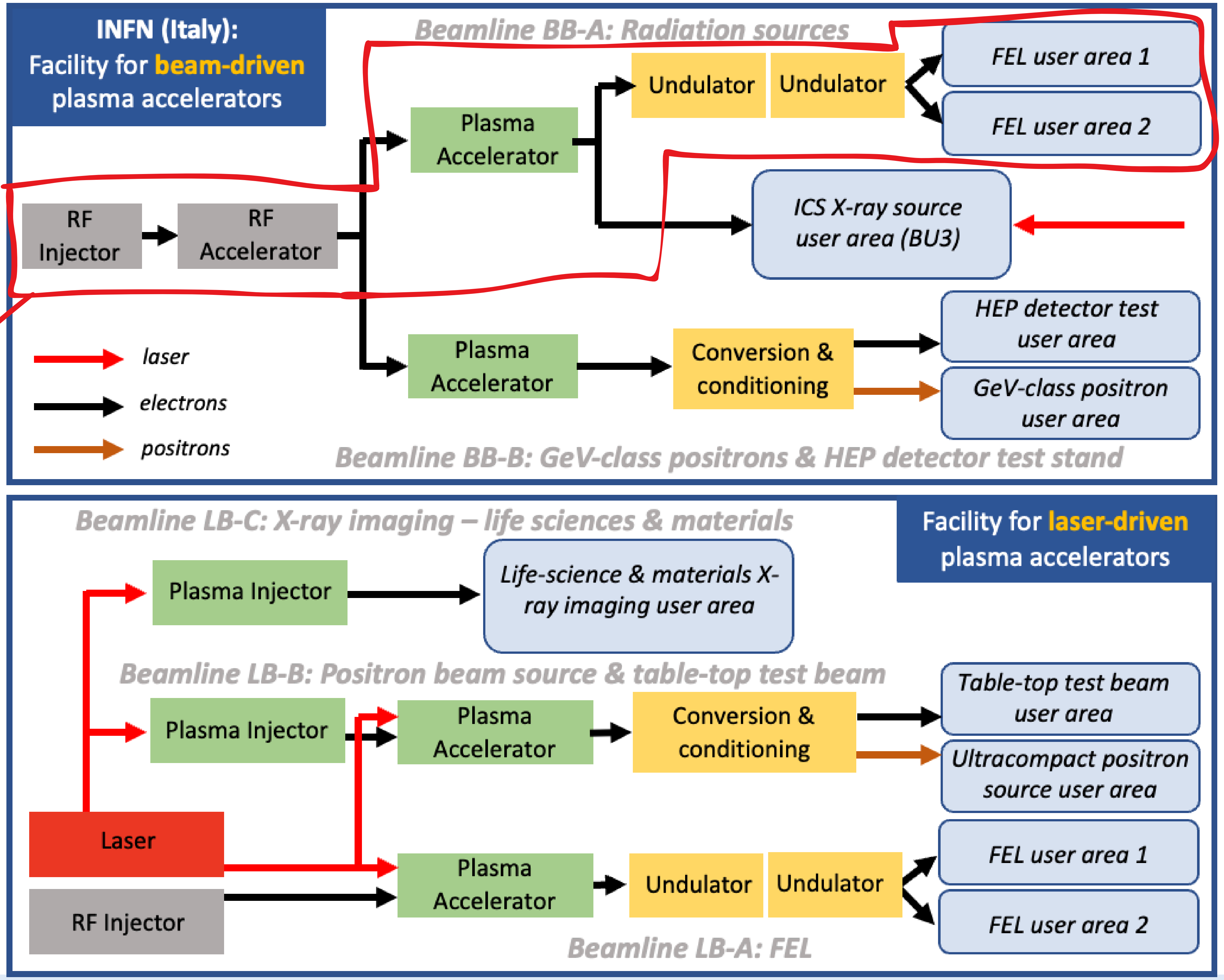


Implementation Phasing

Funded by the European Union

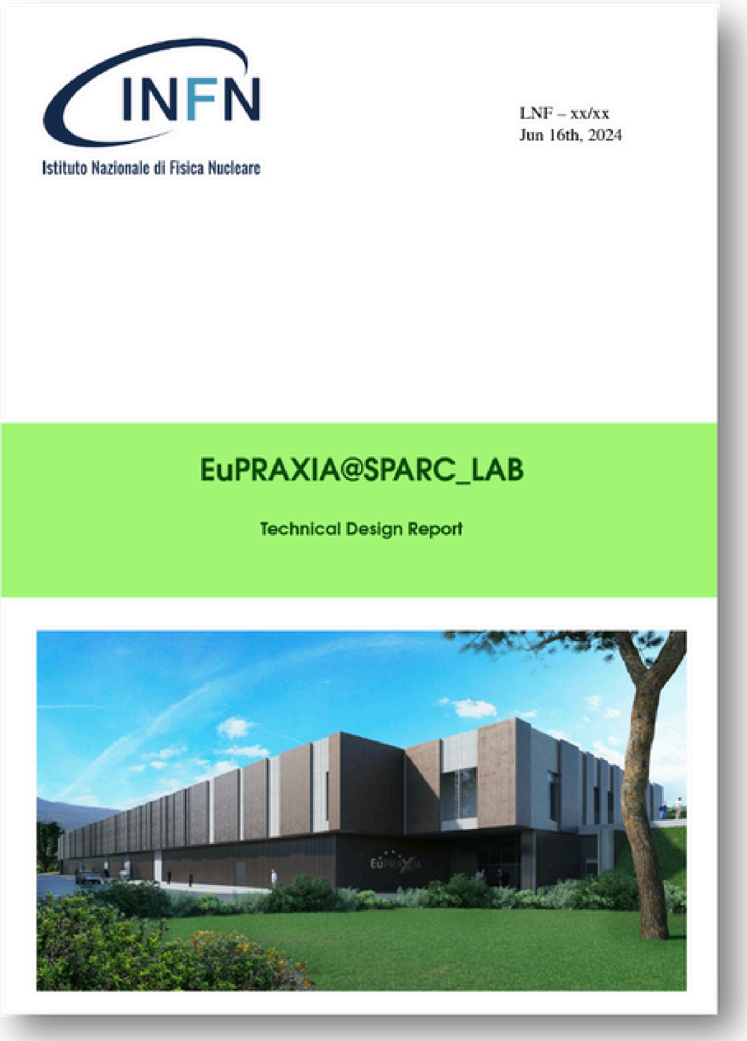
	Laser-driven	Beam-driven
Phase 1	✓ FEL beamline to 1 GeV + user area 1 ✓ Ultracompact positron source beamline + positron user area	✓ FEL beamline to 1 GeV + user area 1 ✓ GeV-class positrons beamline + positron user area
Phase 2	✓ X-ray imaging beamline + user area ✓ Table-top test beams user area ✓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

Fully Funded
130M€ approx



EuPRAXIA @ SPARC_LAB

Site 1 – Phase 0 Funded from Italian Government (108M€)

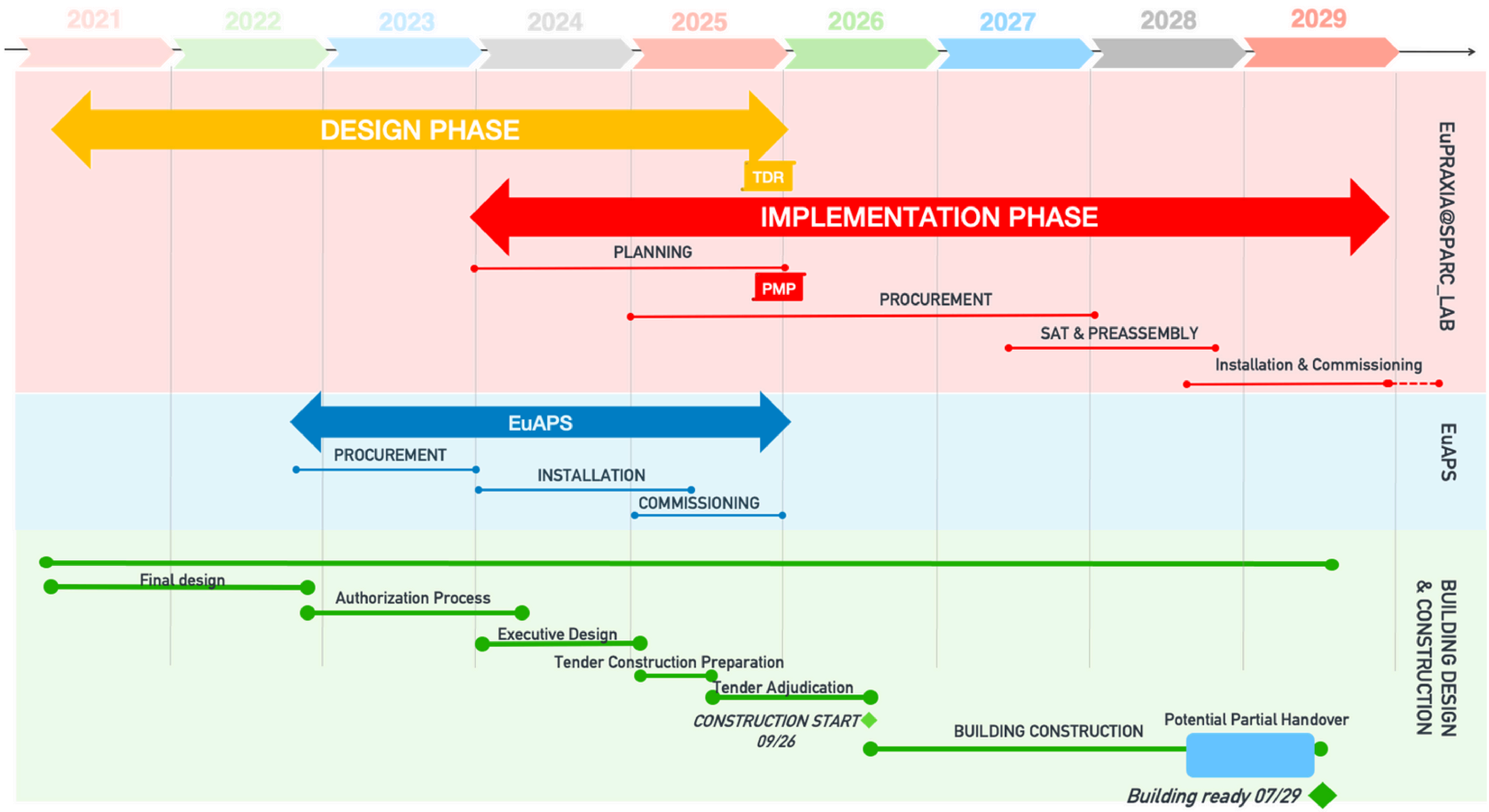

INFN
Istituto Nazionale di Fisica Nucleare

LNF – xx/xx
Jun 16th, 2024

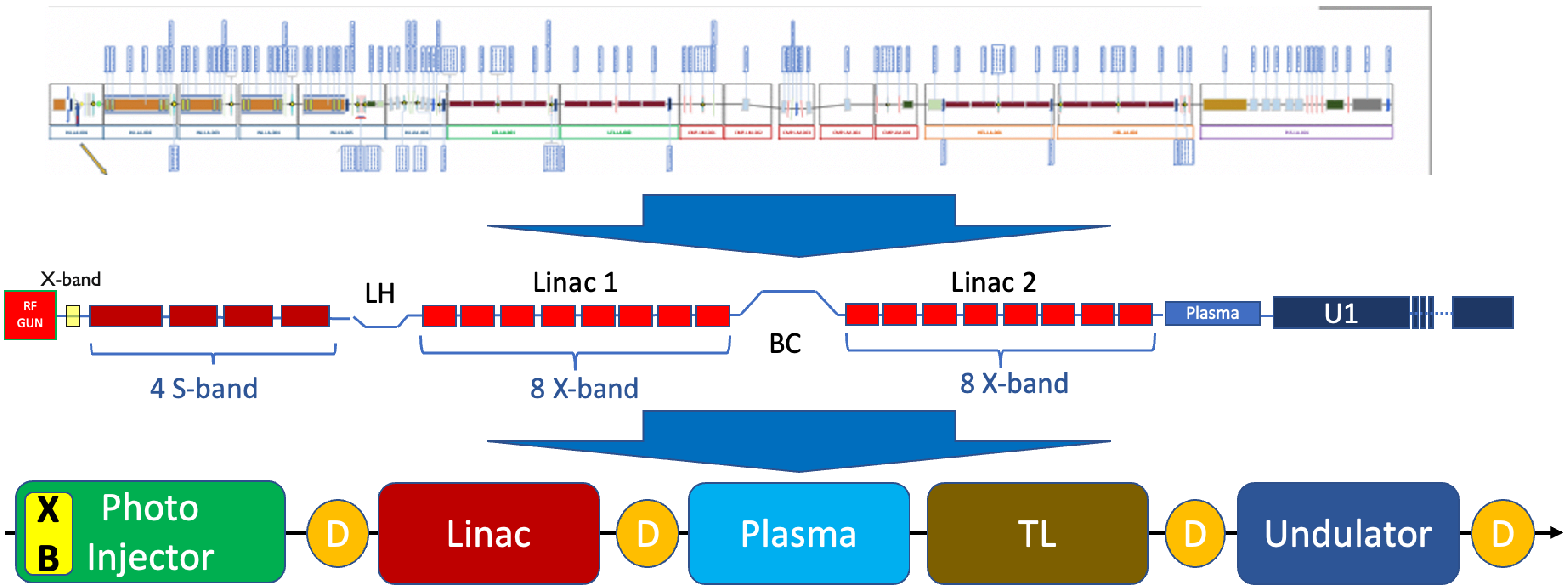
EuPRAXIA@SPARC_LAB

Technical Design Report

TDR finalization on going



Beam Driven Plasma – Site 1



- **Baseline : Plasma acceleration operation scheme = WoP1**
- **Suitable for the High Charge Single Bunch operation boosted by an All-RF Linac up to 1 GeV = WoP2**

Beam Driven Plasma – Site 1

Funded by the European Union

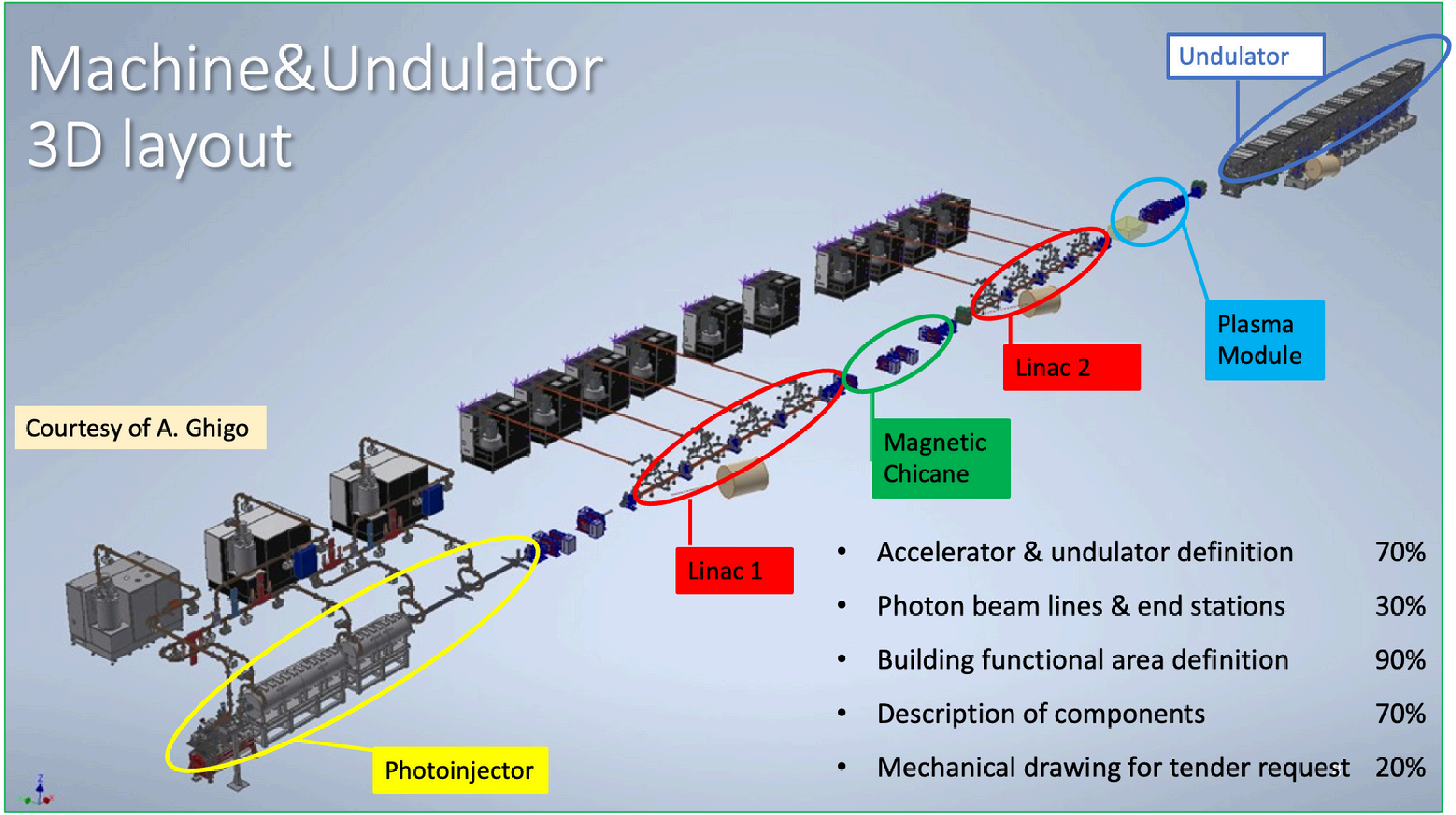
S-Band Injector

X-Band Linac

X-Band RF power stations

2 FEL Lines (4nm and 180nm)

Innovative design to compress the space. (1GeV in approximately 55m)



Beam Driven Plasma – Site 1

Brand new building to be constructed in the south area of the LNF Campus.

- Executive design almost completed.
- Authorization ok.
- Tender for construction will be out in 2025.

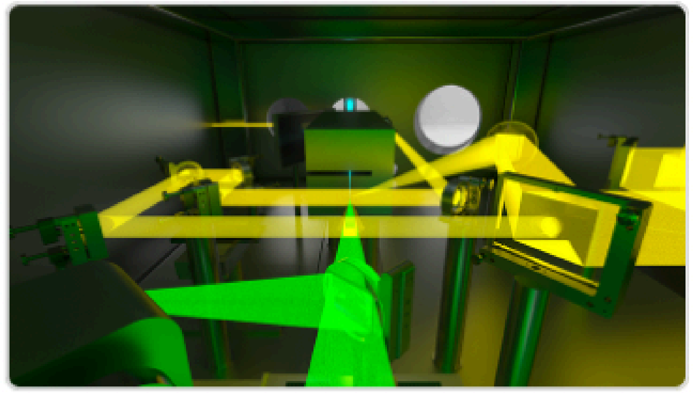
Courtesy of S. Incremona

EuPRAXIA Advanced Photon Source

EuAPS: EuPRAXIA Advance Photon Sources - Principal Investigator: M. Ferrario,
- Infrastructure Manager: C. Bortolin,
- Management and Dissemination: A. Falone

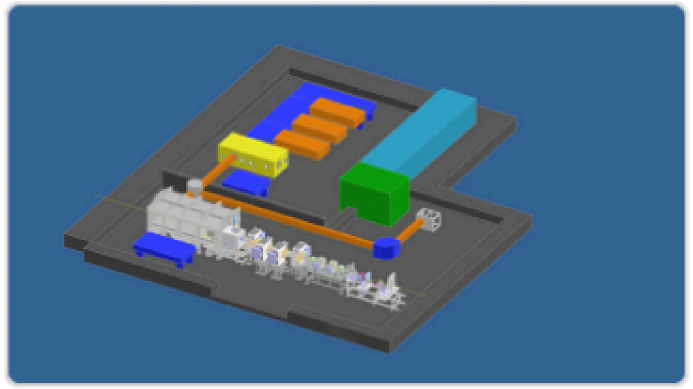
Research

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".



Betatron Radiation Source

READ MORE



High Power Laser Beamline

READ MORE

High Repetition Rate Laser Beamline

READ MORE

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

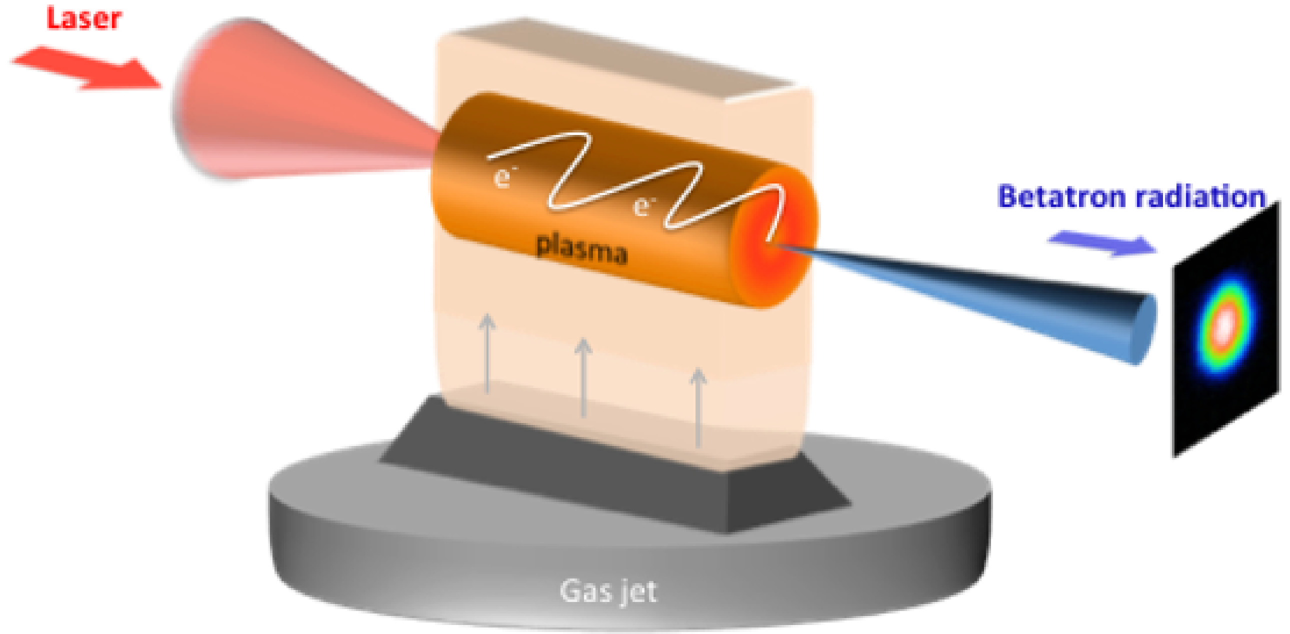
- CURRENT
- PW class,
- Hz repetition rate,
- ≈10 W average power
- flashlamp pumped
- No thermal load transport

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

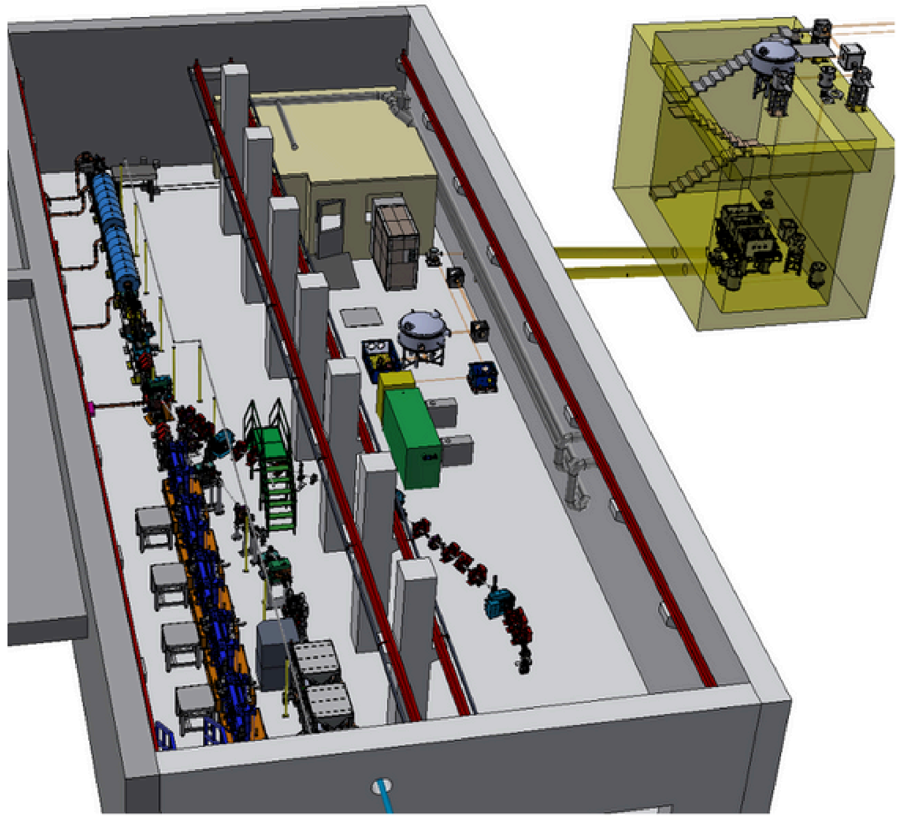
- EuPRAXIA
- PW class,
- 100 Hz repetition rate,
- multi kW average power,
- diode pumped
- Full thermal load transport

THALES

Amplitude



Full Funded by Next-Gen EU , PNRR Italian Program (22,4M€)



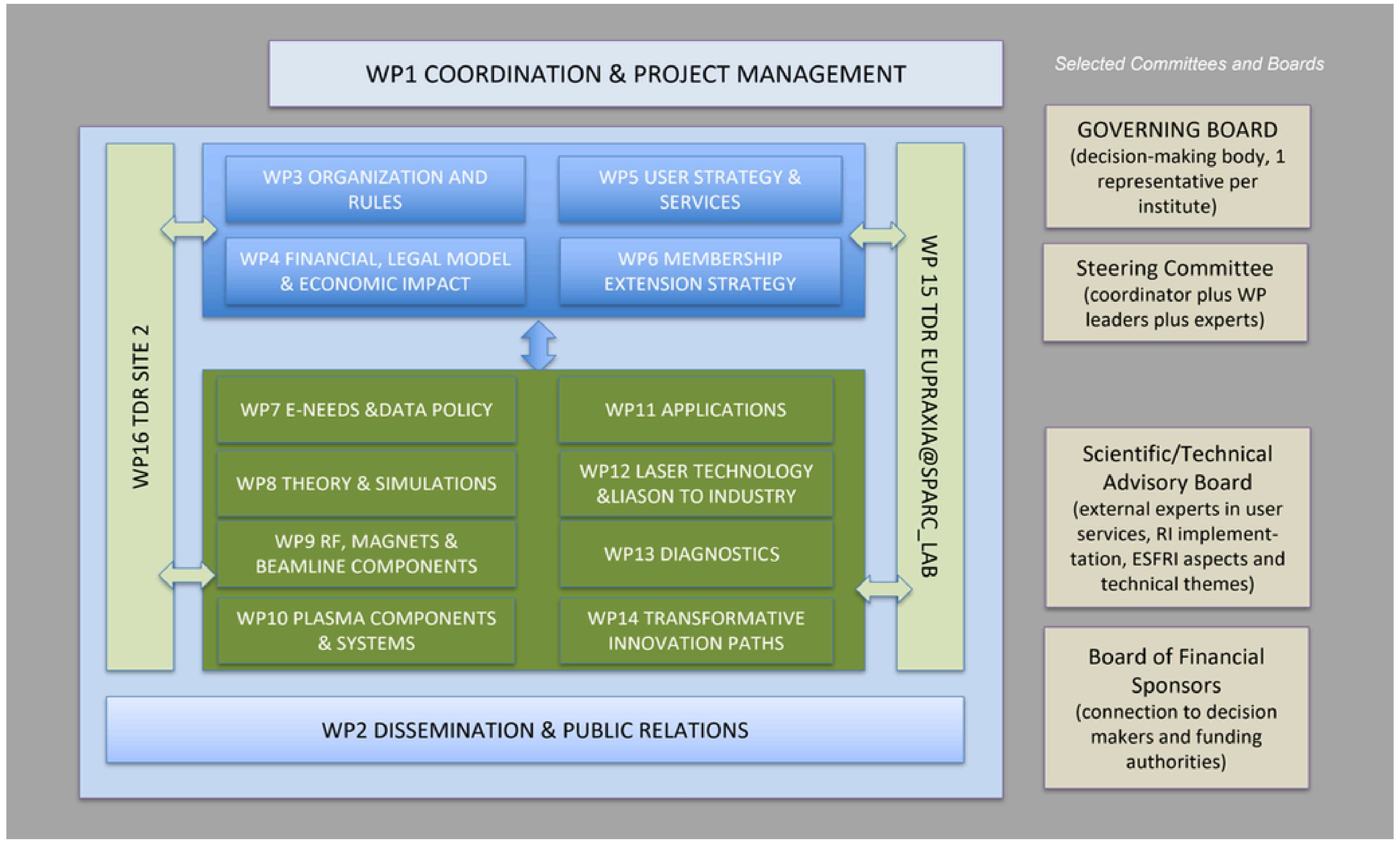
Electron Beam Energy	50- 800 MeV
Plasma Density	10^17-10^19 (cm^-3)
Photon Critical Energy	1-10 keV
Number of photon per pulse	10^6 10^9

Preparatory Phase

Funded by the European Union

Infradev – Horizon Europe Grant aimed to bring the overall iniative to a level of maturity able to guarantee a smooth transition towards the implementation and operational phase.

- 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



2022-2026. We are now in the middle of the preparatory phase

Preparatory Phase

Funded by the European Union

EuPRAXIA community gathered last week in the beautiful location of ELBA Island to discuss the status and future progress of EuPRAXIA.

Conclusions

Funded by the European Union

- EuPRAXIA aims to become a reference world class distributed Research infrastructure in the field of Particle Accelerator, Plasma Technology and High power laser.
- From the conceptual design to the start of operation (2029 approx).
- Fund raising successfull --> ESFRI Roadmap
- Large collaboration – Bottom up approach
- Exciting time ahead: 2nd Site Decision, Definition of the future governance and legal framework, R&D outcome…
- Start the implementation of EuPRAXIA@SPARC_LAB (site 1) in 2026.

Funded by the European Union

THANK YOU!

EuPRAXIA

EuPRAXIA-PP Consortium

Funded by the European Union

Coordinator

INFN Istituto Nazionale di Fisica Nucleare

Consiglio Nazionale delle Ricerche

Elettra Sincrotrone Trieste

ENEA Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

SAPIENZA Università di Roma

Università di Roma Tor Vergata

Imperial College London

Queen's University Belfast

UK Research and Innovation

University of Liverpool

University of Oxford

University of Strathclyde Glasgow

CERN

DESY.

Leibniz Ferdinand Braun Institut

Fraunhofer ILT

GSI

hhu Heinrich Heine Universität Düsseldorf

HZDR Helmholtz Zentrum Dresden Rossendorf

Jülich Forschungszentrum

LMU Ludwig-Maximilians-Universität München

Amplitude

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