Organizzato da

ILO Network Italia
Rete Industrial Liaison Officers

CENTRO ESTERO INTERNAZIONALIZZAZIONE PIEMONTE Agency for Investments, Export and Tourism

Finanziato da

TORINO CHAMBER OF COMMERCE INDUSTRY CRAFTS AND AGRICULTURE

Con il patrocinio di

REGIONE PIEMONTE

INFN Istituto Nazionale di Fisica Nucleare

EuPRAXIA

IOD – INDUSTRIAL OPPORTUNITY DAYS
Torino, 12 – 13 giugno 2025

Il progetto EuPRAXIA e le sue opportunità industriali

Antonio Falone - Istituto Nazionale di Fisica Nucleare

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

Organizzato da

ILO Network Italia
Rete Industrial Liaison Officers

CENTRO ESTERO INTERNAZIONALIZZAZIONE PIEMONTE

Finanziato da

TORINO CHAMBER OF COMMERCE INDUSTRY CRAFTS AND AGRICULTURE

Con il patrocinio di

REGIONE PIEMONTE

INFN Istituto Nazionale di Fisica Nucleare

EuPRAXIA

1

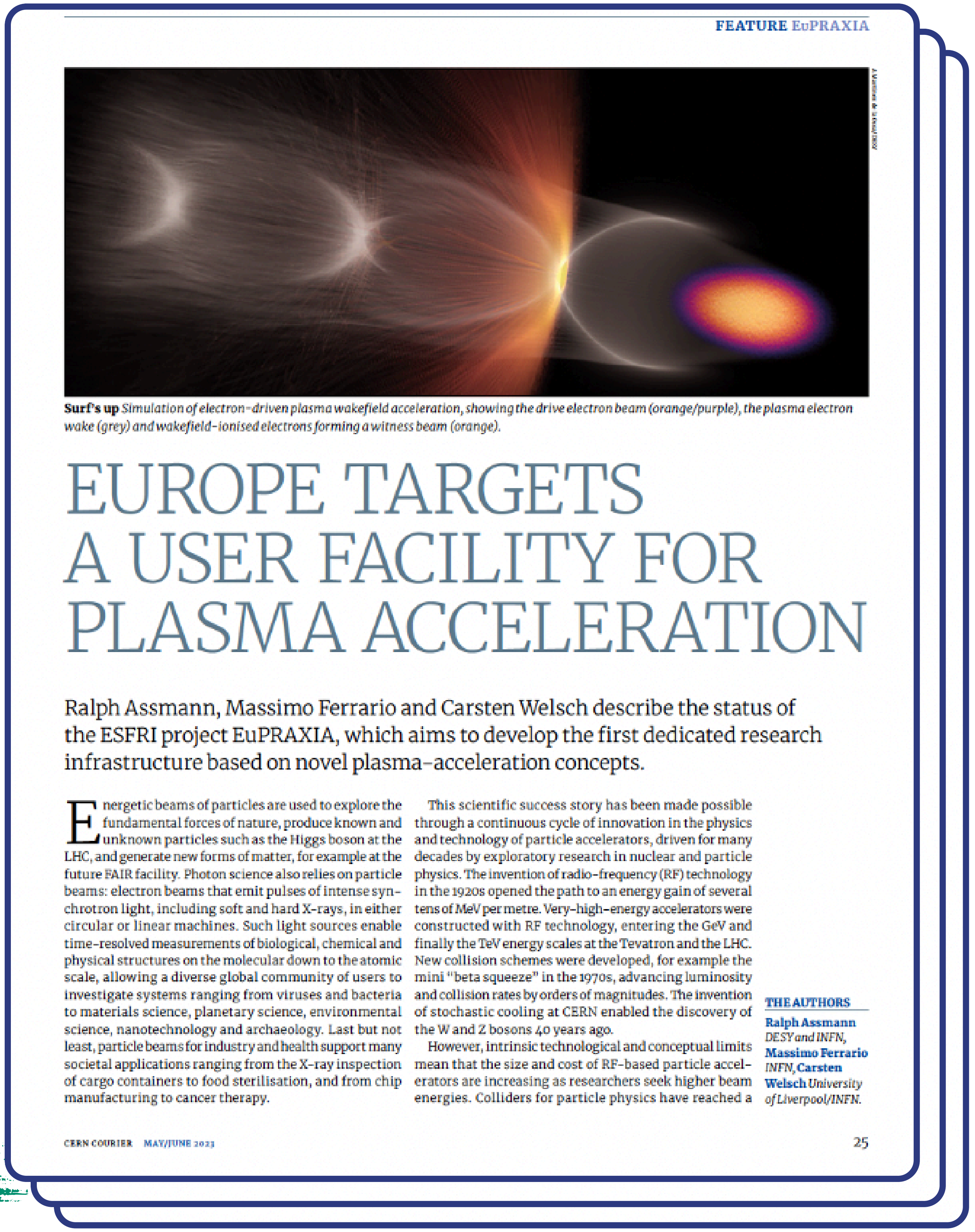
Building a distributed facility with very high field plasma accelerators, driven by lasers or beams
1 – 100 GV/m accelerating field

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.

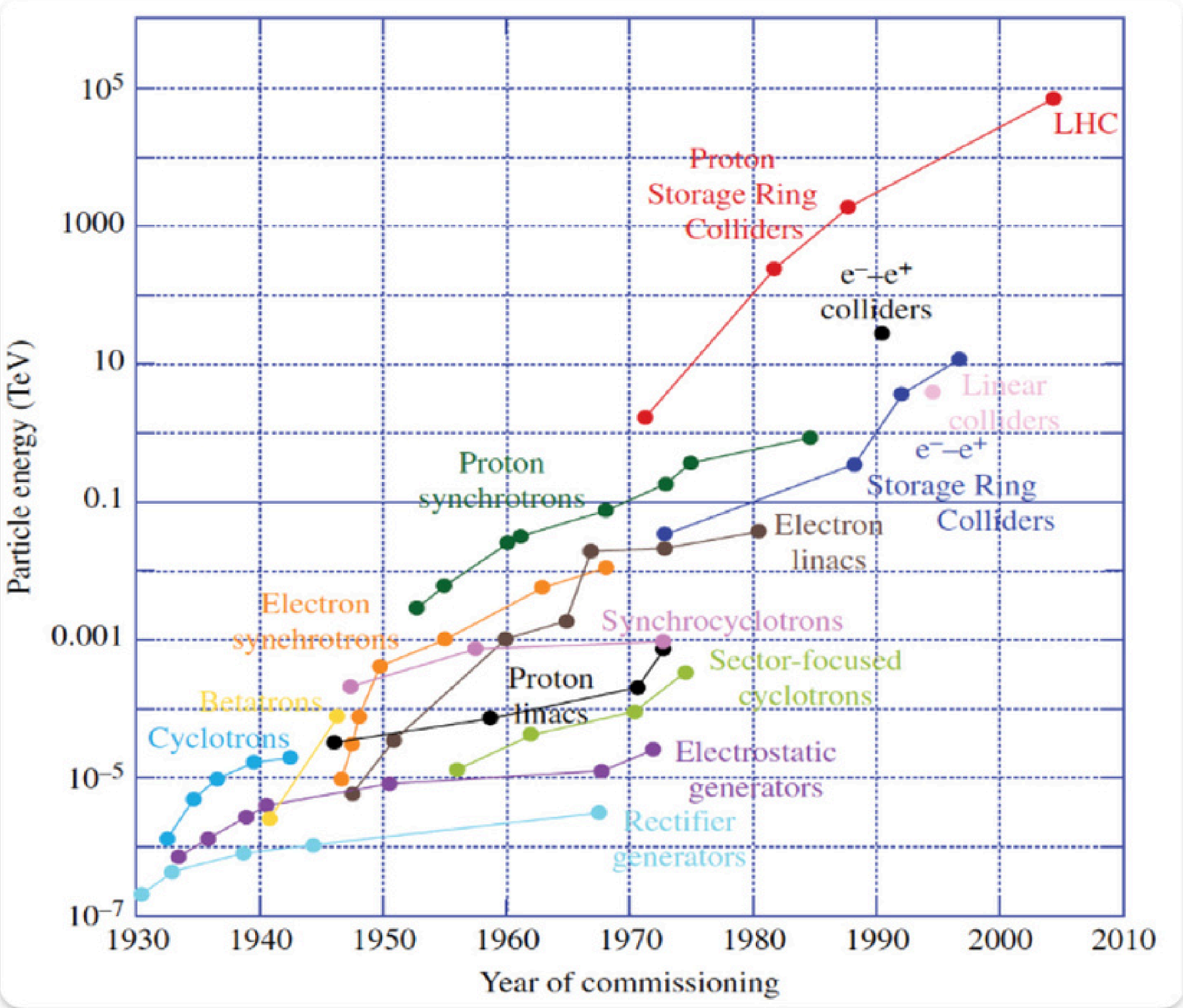
However, intrinsic technological and conceptual limits mean that the size and cost of RF-based particle accelerators are increasing as researchers seek higher beam energies. Colliders for particle physics have reached a

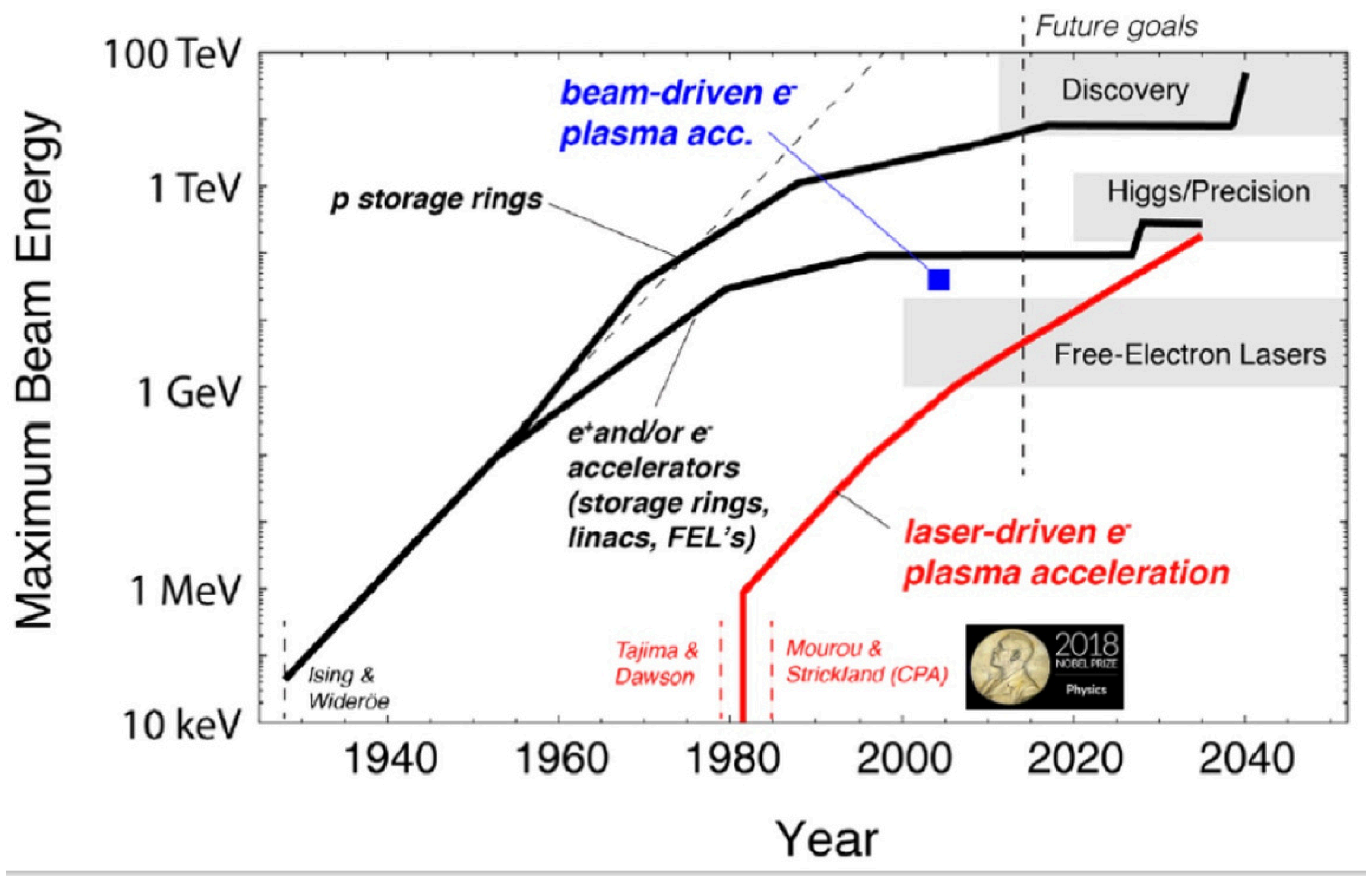
THE AUTHORS

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

CERN COURIER MAY/JUNE 2023

25





Nuove frontiere negli acceleratori → Salto tecnologico

L'accelerazione al plasma ha raggiunto un grado di maturità tecnica e scientifica molto vicina per essere implementata in una user facility.

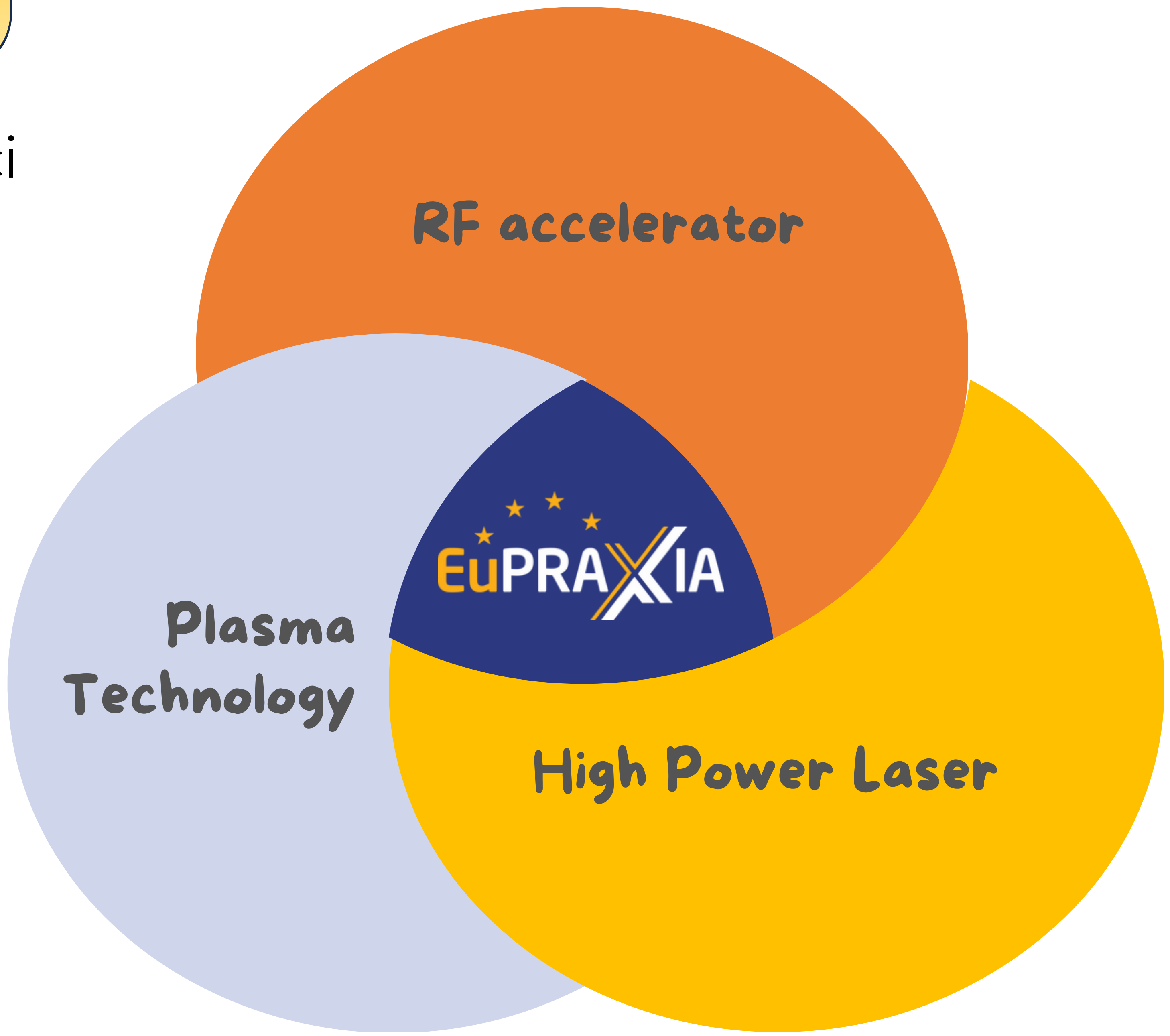
Ridurre le dimensioni (e conseguentemente i costi) di acceleratori per ampliare lo spettro delle possibili applicazioni.

EuPRAXIA si posiziona all'intersezione di 3 comparti tecnologici

- Standard RF accelerator
- Plasma technology
- High power lasers

2 soluzioni tecnologiche complementari

- Laser Driven Plasma Wakefield Accelerator (LPA)
- Beam Driven Plasma Wakefield Accelerator (BPA)



Organizzato da | Finanziato da | Con il patrocinio di

http://www.eupraxia-project.eu

Ampia collaborazione internazionale

- **Conceptual Design Report for a distributed research infrastructure** Finanziato da Horizon 2020. 16 instituti e 25 partner coinvolti, completato nel 2019.
- Inserito nella ESFRI Roadmap 2021 come infrastruttura strategica europea del prossimo decennio.
- EuPRAXIA@SPARC_LAB finanziato dal governo Italiano (108M€).
- Fund-raising: 164M€ ad oggi attraverso grant-europei e finanziamenti nazionali (incluso PNRR).
- Beam Driven Pillar : EuPRAXIA@SPARC_LAB Technical Design Report finalizzato e in fase di approvazione.
- Laser Driven Pillar: EuPRAXIA@ELI-ERIC recentemente selezionato e in fase di organizzazione per la redazione del TDR.

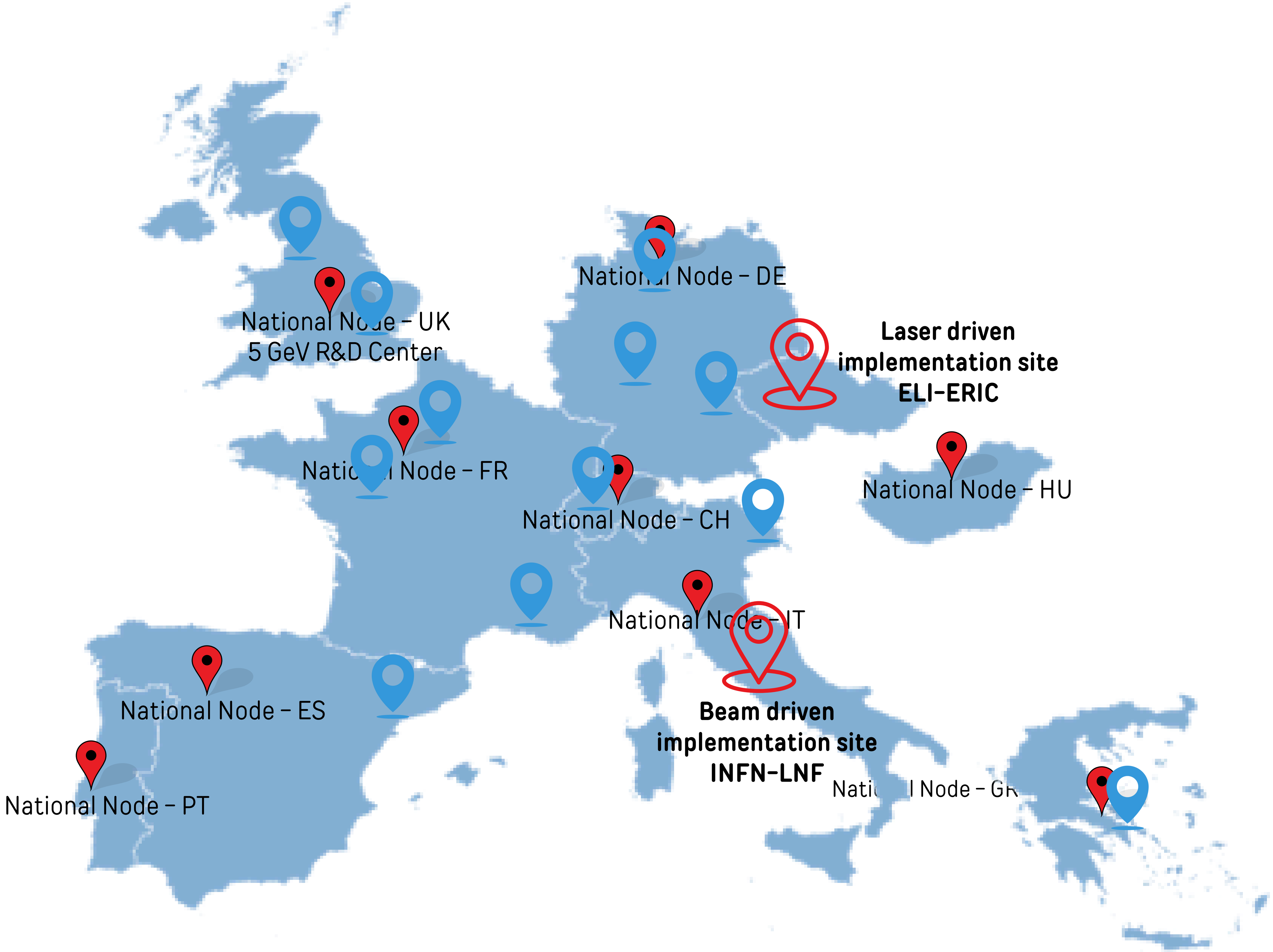
600+ page CDR, 240 scientists contributed

EuPRAXIA Distributed Research Infrastructure

2 Implementation Pillars

Several National Nodes

Project Clusters



- **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.*

600+ page CDR, 240 scientists contributed

- **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.*

Organizzato da

ILO Network Italia

Rete Industrial Liaison Officers

CENTRO ESTERO INTERNAZIONALIZZAZIONE PIEMONTE Agency for Investments, Export and Tourism

Finanziato da

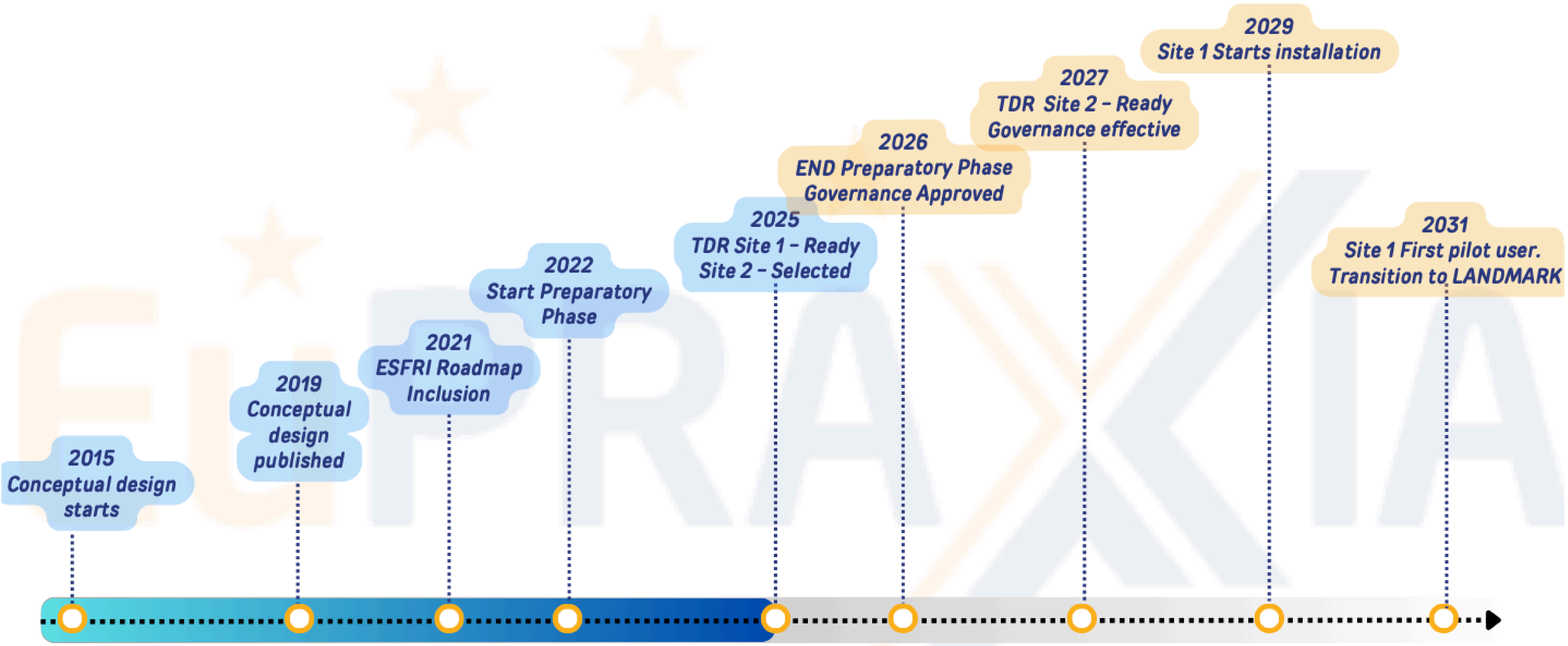
TORINO CHAMBER OF COMMERCE INDUSTRY CRAFTS AND AGRICULTURE

Con il patrocinio di

REGIONE PIEMONTE

INFN Istituto Nazionale di Fisica Nucleare

EuPRAXIA



EuPRAXIA@SPARC_LAB (presso INFN-LNF) è il "beam driven pillar" della facility EuPRAXIA e si propone di realizzare un Linac RF in banda X e un modulo di accelerazione al plasma fino a un'energia massima di 1.2GeV per pilotare due linee Free Electron Laser a differenti lunghezza d'onda (4nm e 290-430nm).

EuPRAXIA@SPARC_LAB ha ricevuto un finanziamento da parte del Governo Italiano per un totale di 108M€, un finanziamento da parte della Regione Lazio (20M€). EuPRAXIA è anche capofila dell'iniziativa PNRR EuAPS (EuPRAXIA Advanced Photon Source).

Progettazione, costruzione, installazione e commissioning di un acceleratore lineare di elettroni a un'energia di 1 GeV

Un modulo di accelerazione al plasma (energy doubling)

2 Linee di ondulatori per la produzione di radiazione coerente a diverse lunghezze d'onda

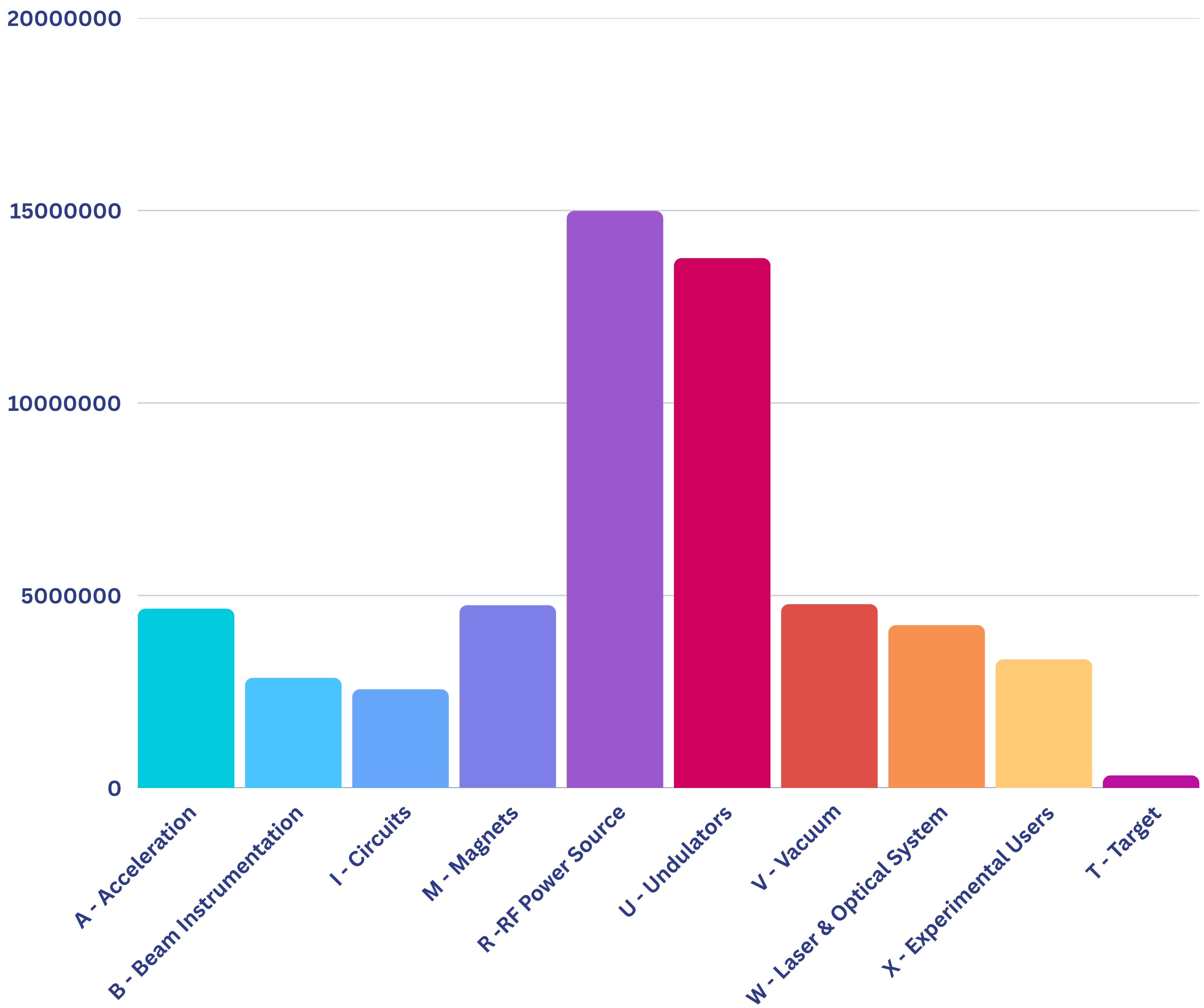
2 Linee sperimentali per utenti.

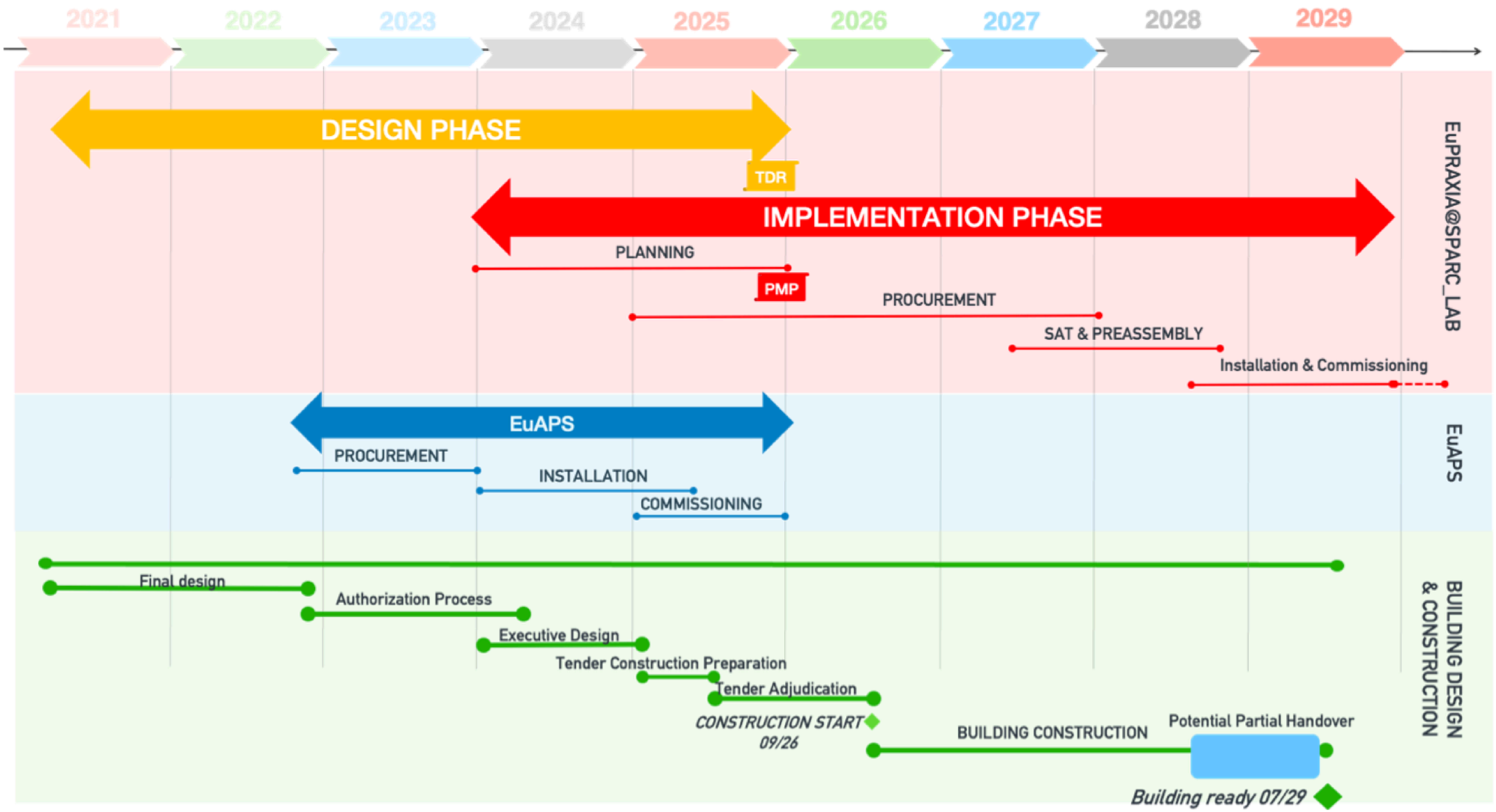
La costruzione di un edificio dedicato presso i Laboratori Nazionali di Frascati.

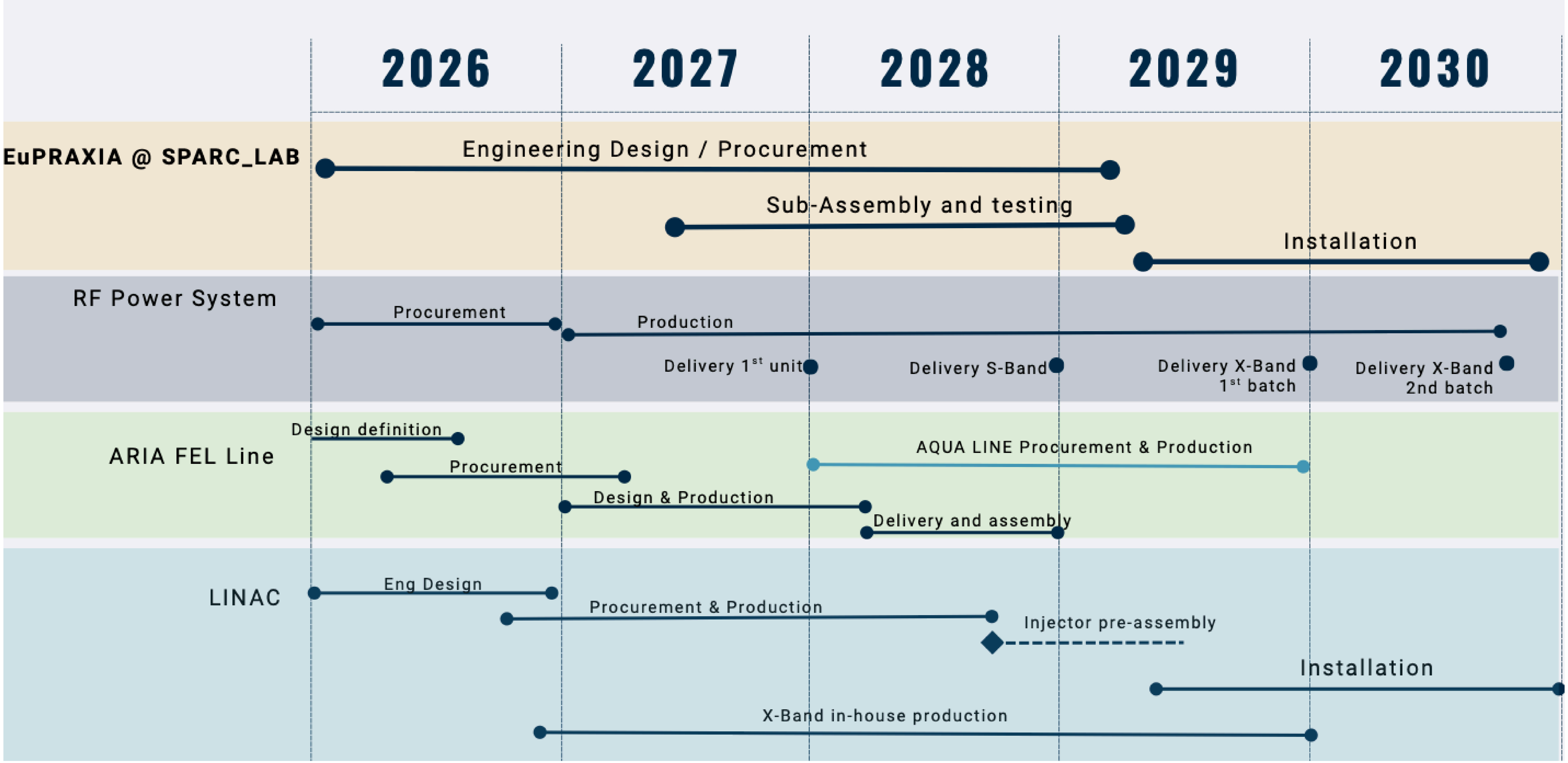
Il tutto oltre lo stato dell'arte!

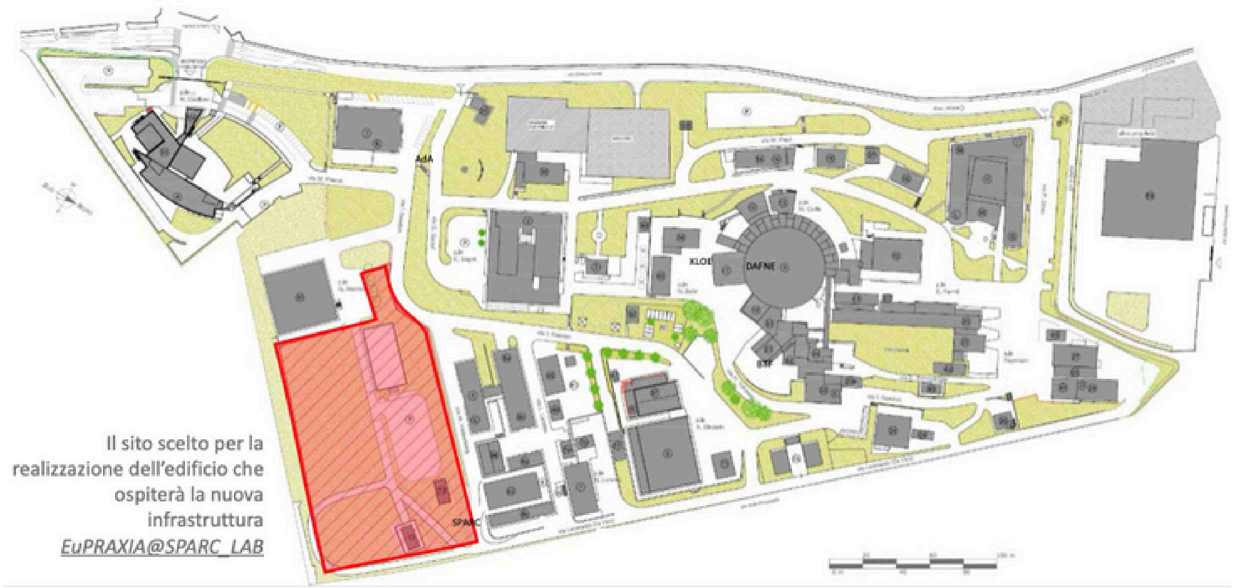
Ambiti Tecnologici

- Sistemi di potenza RF in banda X e relativa distribuzione (sistemi in guida d'onda).
- Magneti (convenzionali) e relativi alimentatori di potenza
- Meccanica di precisione e UHV
- Sistemi da vuoto (pompe, driver etc...)
- Elementi di trasporto ottico e manipolazione radiazione FEL
- Diagnostica di elettroni e DAQ.




2021
2022
2023
2024
2025
2026
2027
2028
2029
DESIGN PHASE
TDR
IMPLEMENTATION PHASE
PLANNING
PMP
PROCUREMENT
SAT & PREASSEMBLY
Installation & Commissioning
EuPRAXIA@SPARC_LAB
EuAPS
PROCUREMENT
INSTALLATION
COMMISSIONING
EuAPS
Final design
Authorization Process
Executive Design
Tender Construction Preparation
Tender Adjudication
CONSTRUCTION START 09/26
BUILDING CONSTRUCTION
Potential Partial Handover
Building ready 07/29
BUILDING DESIGN & CONSTRUCTION


2026
2027
2028
2029
2030
EuPRAXIA @ SPARC_LAB
Engineering Design / Procurement
Sub-Assembly and testing
Installation
RF Power System
Procurement
Production
Delivery 1st unit
Delivery S-Band
Delivery X-Band 1st batch
Delivery X-Band 2nd batch
ARIA FEL Line
Design definition
Procurement
Design & Production
Delivery and assembly
AQUA LINE Procurement & Production
LINAC
Eng Design
Procurement & Production
Injector pre-assembly
Installation
X-Band in-house production

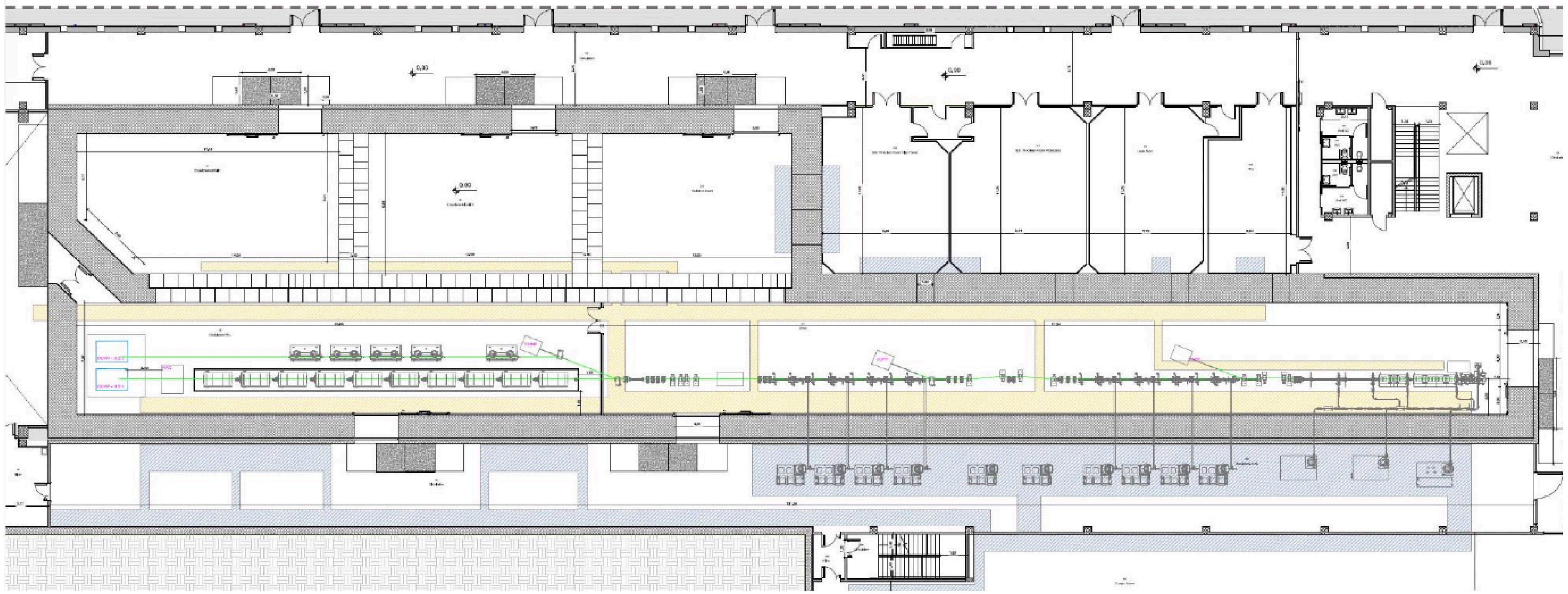


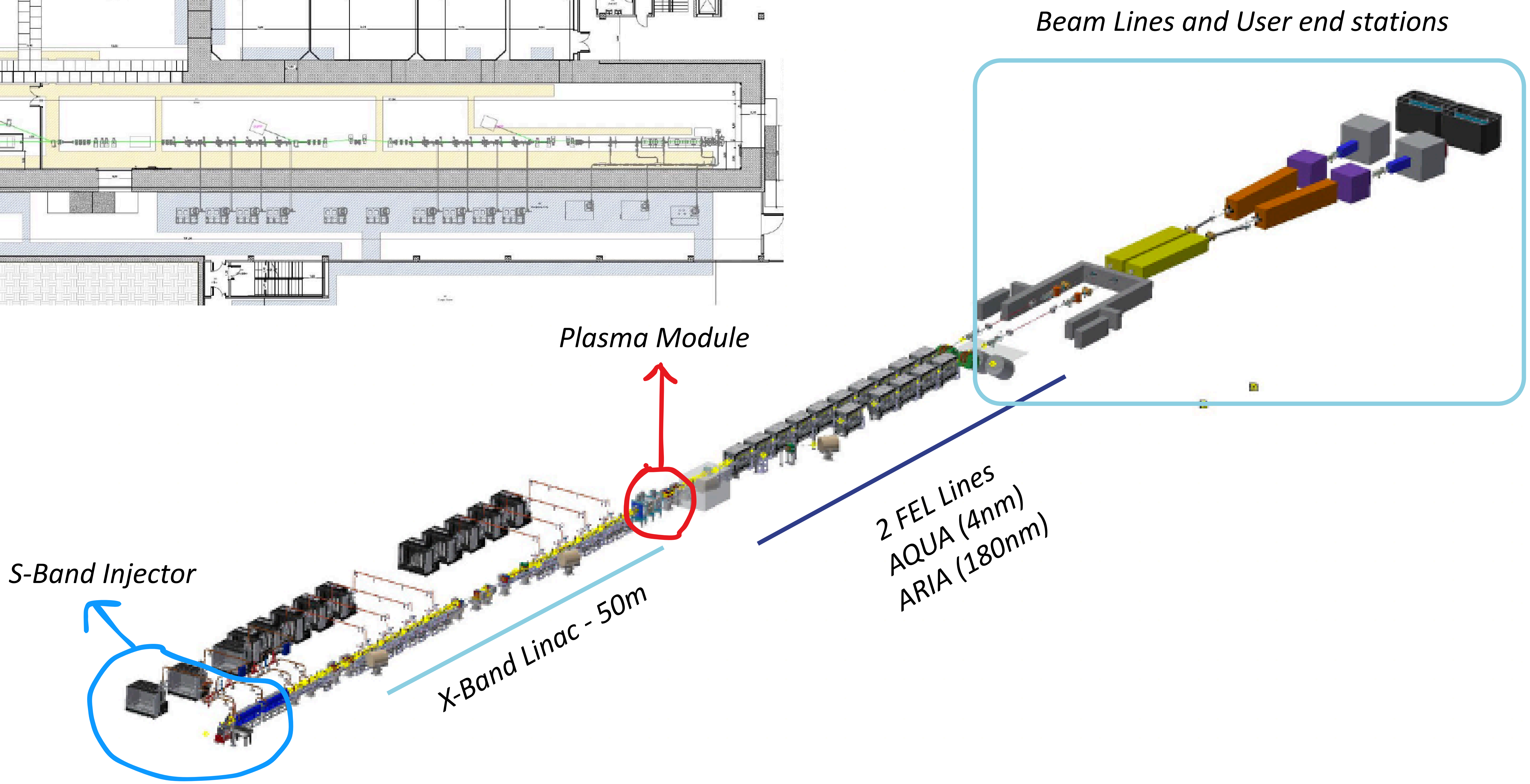
Progettazione definitiva ed esecutiva è terminata e in fase di validazione. I procedimenti autorizzativi sono stati positivamente conclusi e si aprirà la gara per la realizzazione a settembre 2025.

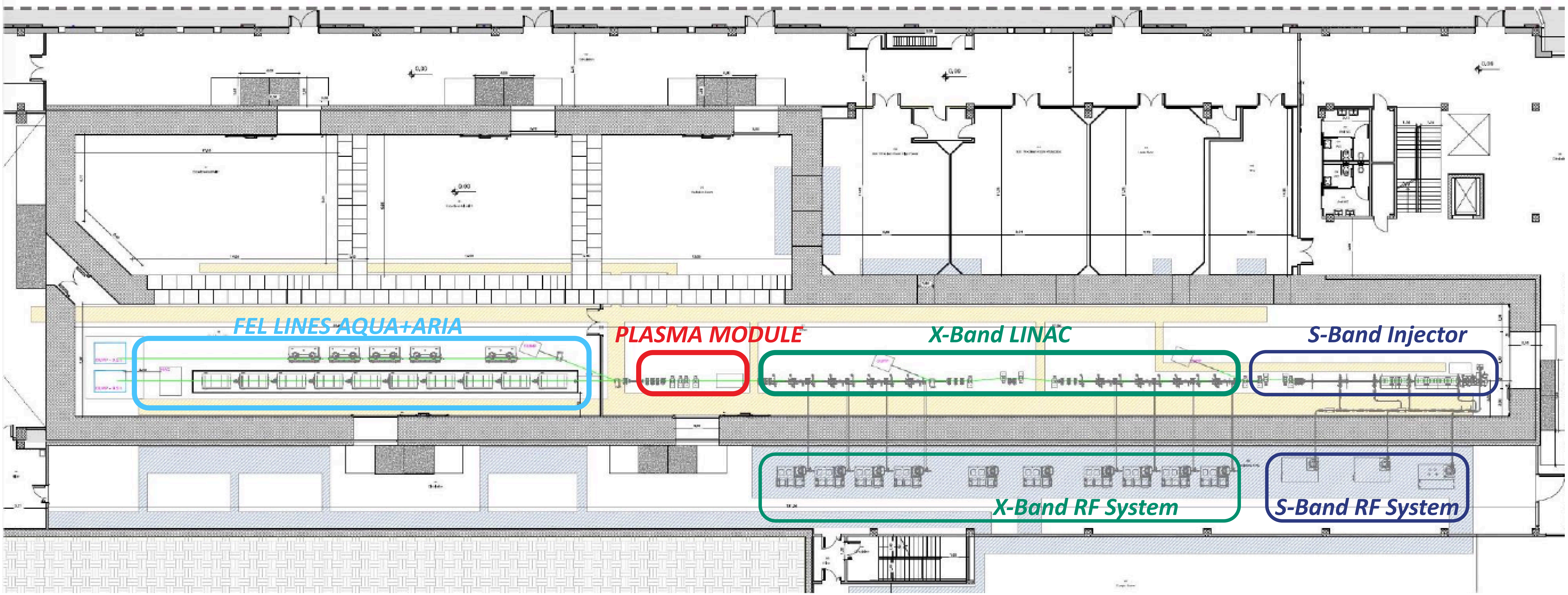
Organizzato da

Finanziato da

Con il patrocinio di






FEL LINES AQUA+ARIA
PLASMA MODULE
X-Band LINAC
S-Band Injector
X-Band RF System
S-Band RF System

PARAMETRI RADIAZIONE FEL

Radiation Parameter	**Unit**	PWFA	Full X-band
Wavelength	nm	**3-5**	4
Pulse length (fwhm)	fs	10.0	-
Photons per Pulse	$\times 10^{12}$	**0.1- 0.25**	1
Photon Bandwidth	%	**0.1**	0.5
Undulator Area Length	m	26	
ρ(1D/3D)	$\times 10^{-3}$	**1**	1
Photon Brilliance per shot	$\left(\frac{s\ mm^2 mrad^2}{bw(0.1\%)}\right)$	$\mathbf{1{-}2 \times 10^{28}}$	1×10^{27}

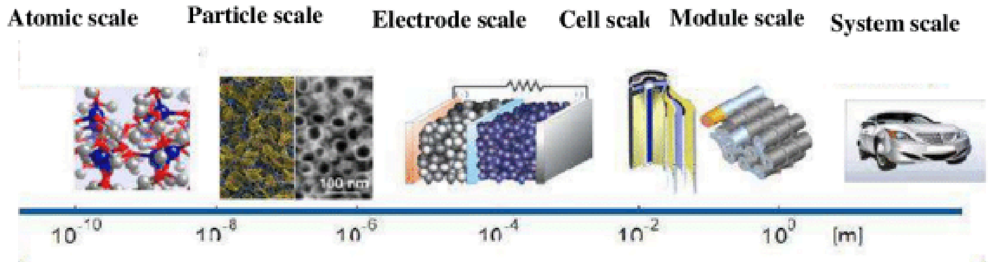
PARAMETRI LINAC

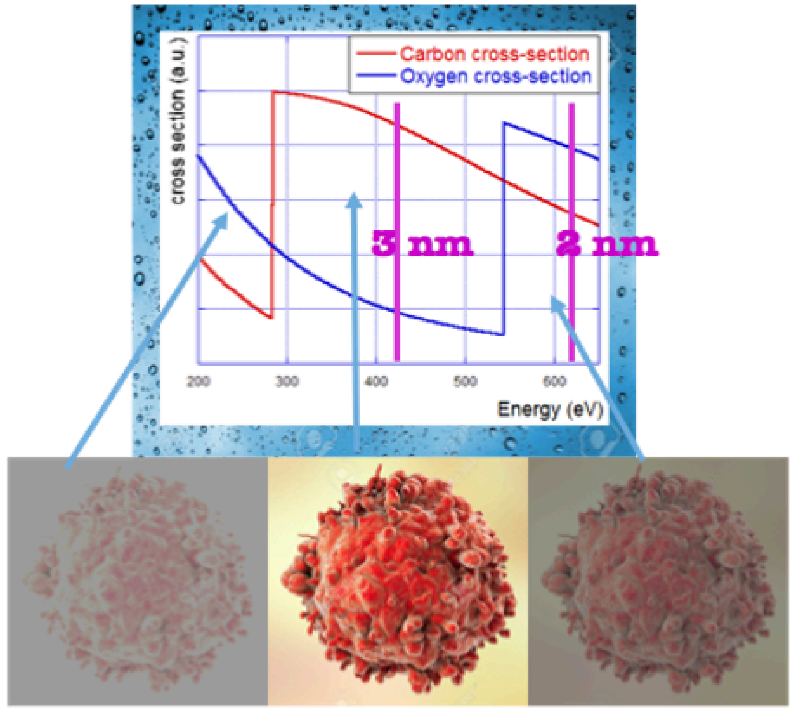
Electron Beam Parameter	**Unit**	PWFA	Full X-band
Electron Energy	GeV	**1-1.2**	1.2
Bunch Charge	pC	**30 - 50**	200-500
Peak Current	kA	~ 2.2	1-2
RMS Energy Spread	%	**< 1**	0.1
RMS Bunch Length	μm	**3-6**	24-20
RMS norm. Emittance	μm	**0.7 – 1.2**	1
Slice Energy Spread	%	**≤0.05**	≤0.05
Slice norm Emittance	mm-mrad	**0.5 – 0.8**	0.5
Energy jitter	%	**< 1**	0.1

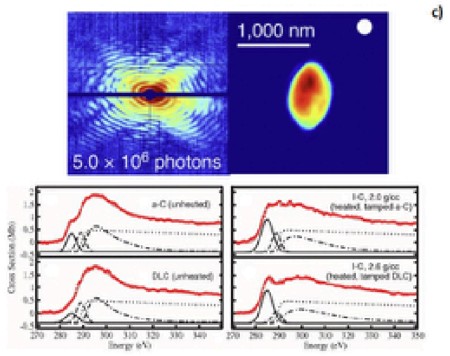
Organizzato da
ILO Network Italia
Rete Industrial Liaison Officers
Finanziato da
TORINO CHAMBER OF COMMERCE INDUSTRY CRAFTS AND AGRICULTURE
Con il patrocinio di
REGIONE PIEMONTE
INFN Istituto Nazionale di Fisica Nucleare
EuPRAXIA

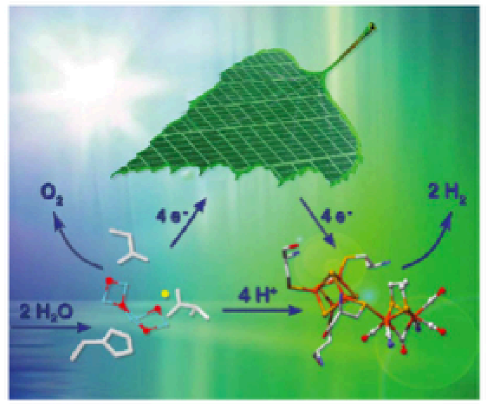
Campo di applicazione

Application Area	Scientific Focus	Techniques	Key Impact
Renewable Energy	• Charge transport in solar cells & catalysts • Photocatalytic H_2 production • PFAS/PClAS analysis	XAS, XES, PI-MS	• Efficient solar materials • Clean hydrogen production • Environmental remediation
Warm Dense Matter (WDM)	• Extreme temperature/density • Astrophysics & fusion	Time-resolved XAS, TR-XES	• Stellar/planetary modeling • Fusion research support
Battery Technology	• Ion migration & interfaces • Solid-state battery study	XAS, non-linear X-ray spectroscopy	• Safer, longer-life batteries • High energy density
Structural Biology	• Live-cell imaging • Cellular processes (stress, DNA damage)	CDI, XAS, CEI	• Real-time biomolecular studies • Disease mechanism insight
Health & Radiobiology	• DNA damage by radiation	X-ray pump–probe, photo-fragmentation	• Radioprotection • Cancer treatment improvement
Atmospheric Chemistry	• VOC/NOx oxidation • Aerosol dynamics	PI-MS, ion spectroscopy	• Pollution models • Climate studies
Astrochemistry	• Radiation chemistry in space • Organic molecule formation	XAS, photochemistry	• Space molecular evolution









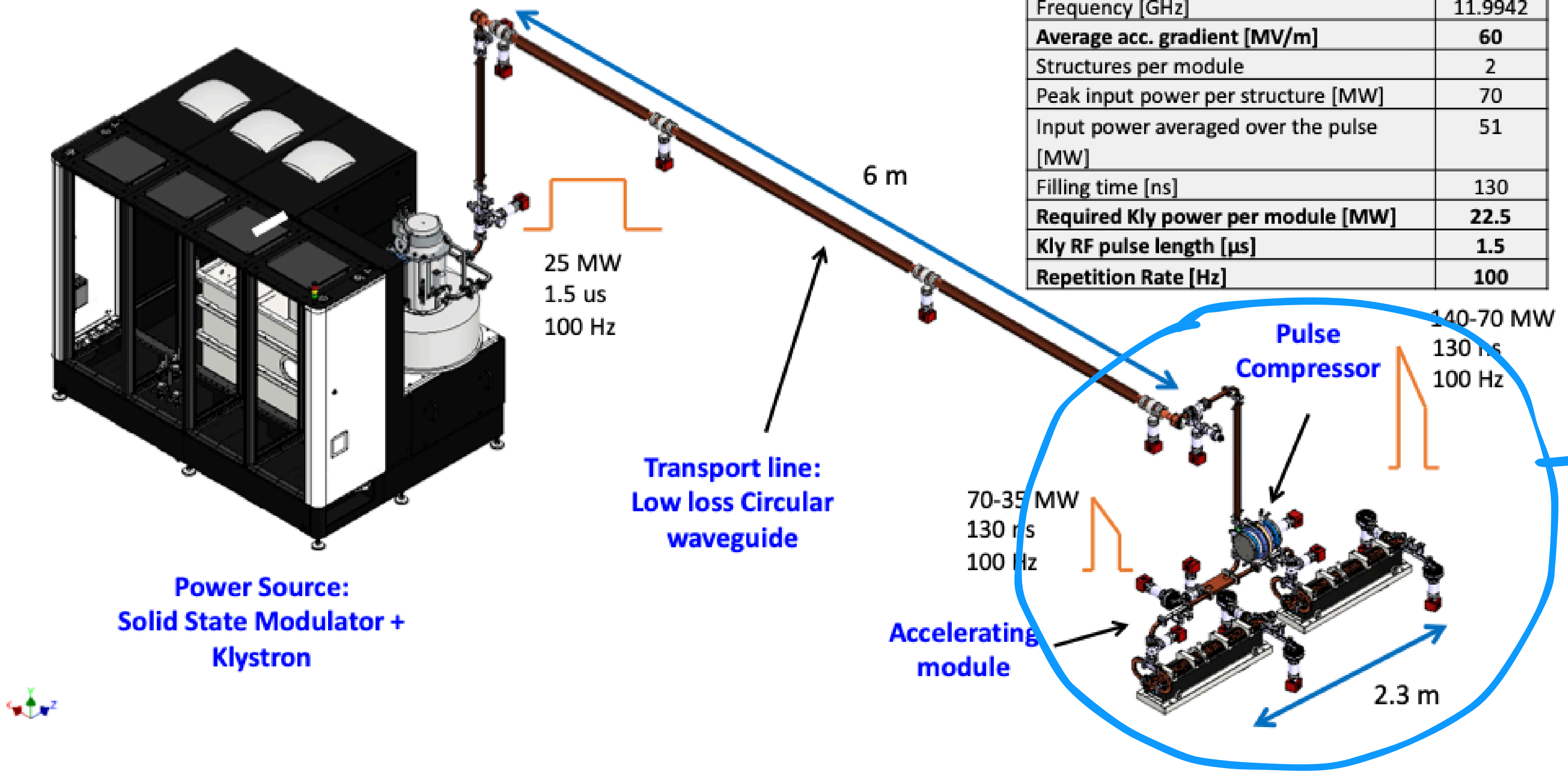
RF Linac in Banda X (12GHz):

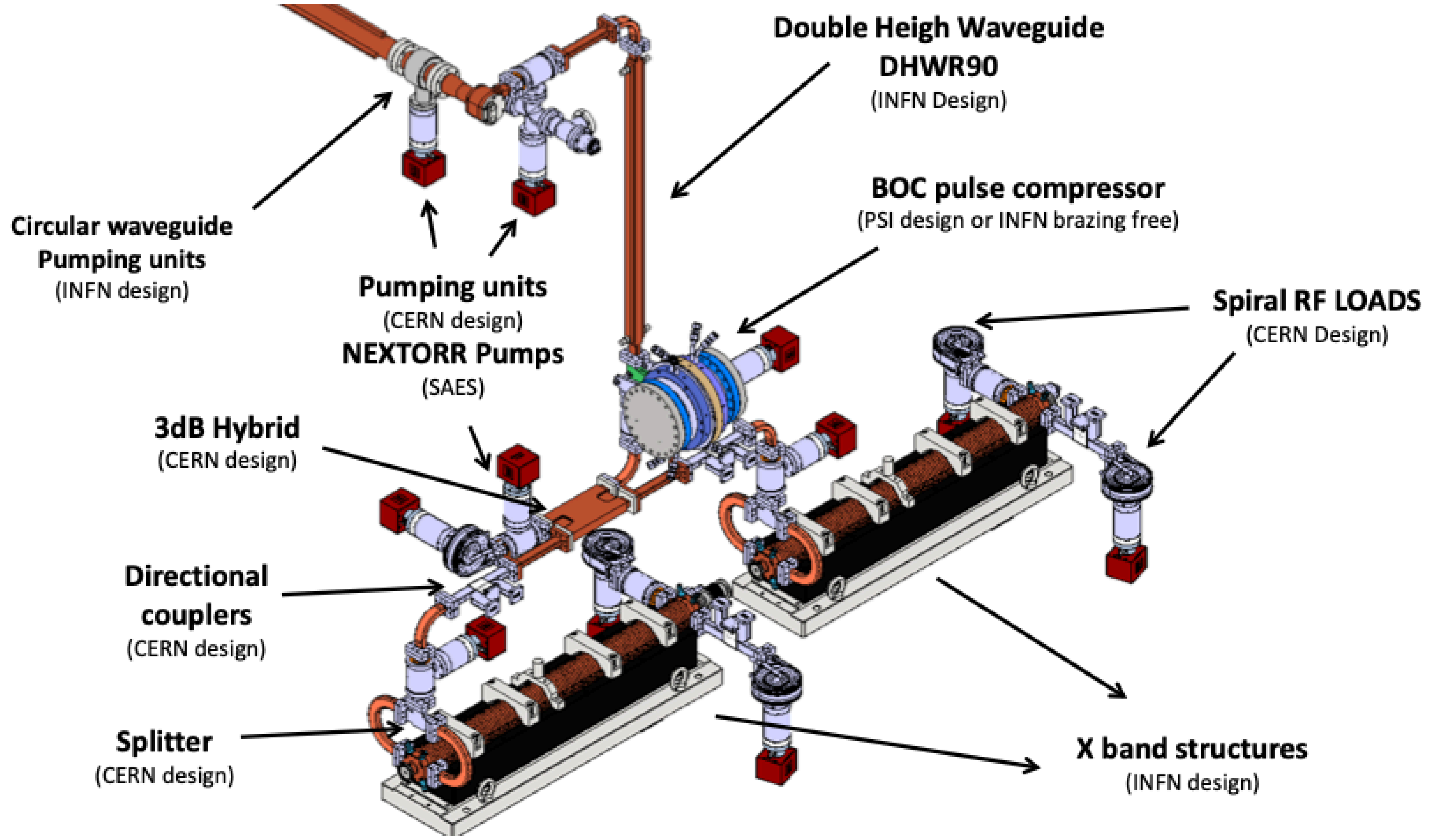
Sorgenti di potenza RF (Klystron + modulatore) ad alta potenza (25M€) e alto repetition rate (<= 400Hz)

Componentistica in guida d'onda (bidirectional couplers, pumping ports, BOC, loads)

Sezioni acceleranti in banda X

PARAMETER	Value
Frequency [GHz]	11.9942
Average acc. gradient [MV/m]	**60**
Structures per module	2
Peak input power per structure [MW]	70
Input power averaged over the pulse [MW]	51
Filling time [ns]	130
Required Kly power per module [MW]	**22.5**
Kly RF pulse length [μs]	**1.5**
Repetition Rate [Hz]	**100**





Courtesy F.Cardelli

TEX Test facility

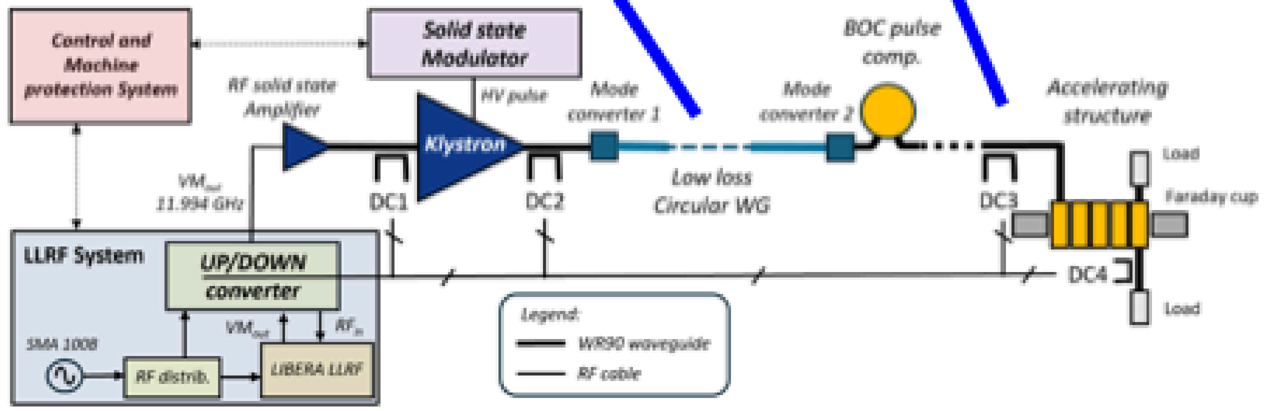
Test stand to validate X-Band Technology & open infrastructure for external users.

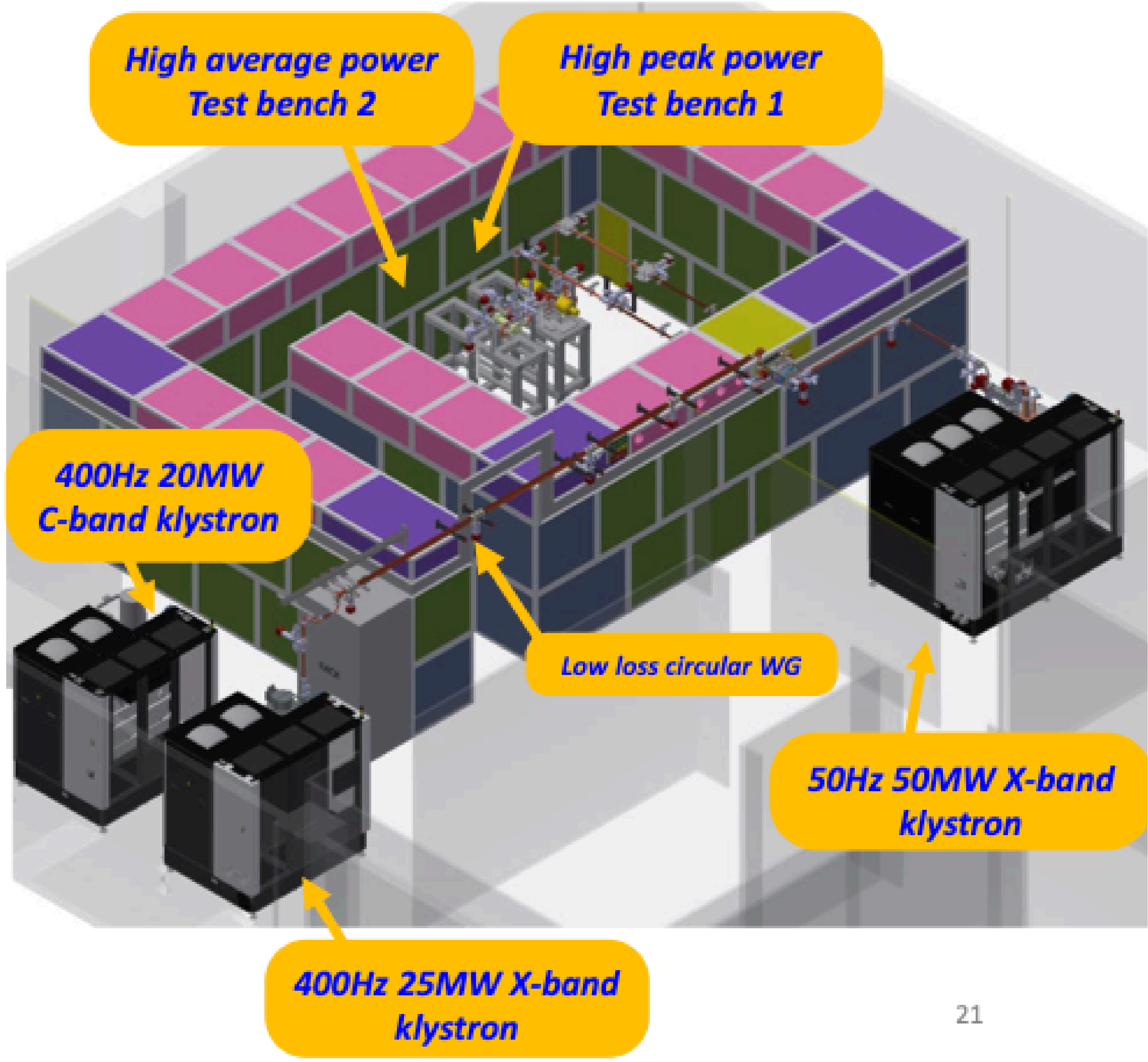
2 X-Band RF Stations

1 C-Band RF Station

1 Dedicated bunker

- The 2nd **test bench will double the TEX X-band testing capabilities** and will allow for high average power test of X-band components.
- The 1st test bench has been moved and the waveguide network modified.
- **All the waveguide system has been already designed and procured and his installation is ongoing:**

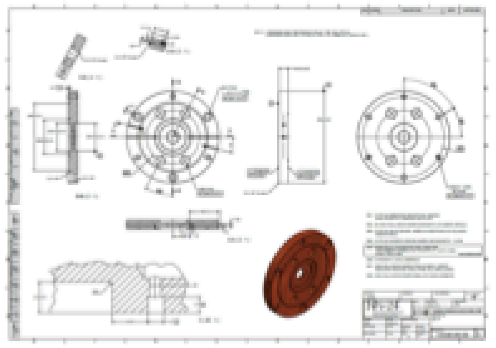


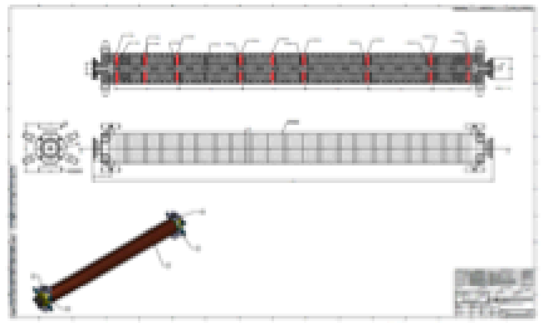


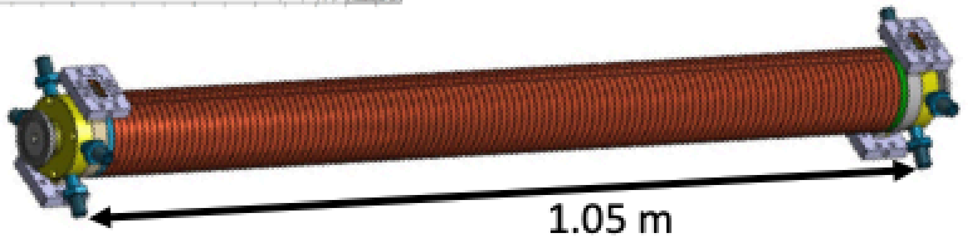
Courtesy F.Cardelli

Sezioni acceleranti in banda X

- The **EM design of the structure is completed**: **1.05 m long** structures with **3.5 mm average iris radius** design to work with an average acceleration gradient of **60 MV/m.** The single cell and RF structure optimization has been completed developing a semi-analytical code to consider also the power gain from the BOC pulse compressor: ***done***
- **Thermo-mechanical simulations** to demonstrate the correct sizing of the cooling system (at 100 Hz and 400 Hz): ***done***
- **Dark current simulations** (CST Particle in cell) have been performed to evaluate the background radiation together with **vacuum calculation** to verify the pression distribution along the structure: ***done***
- The final **mechanical design** of the final X-band structure has been under constant review, related to the result of the **pre-prototyping activity**: brazing test, cell to cell alignment, etc: ***done***



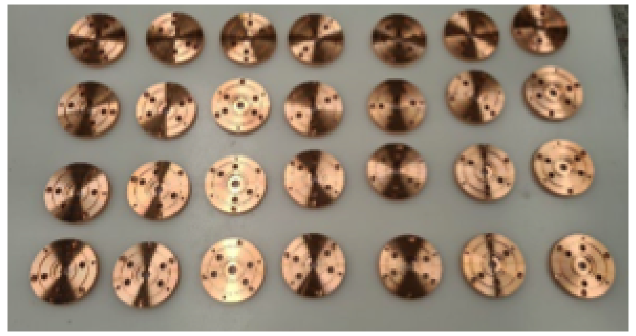


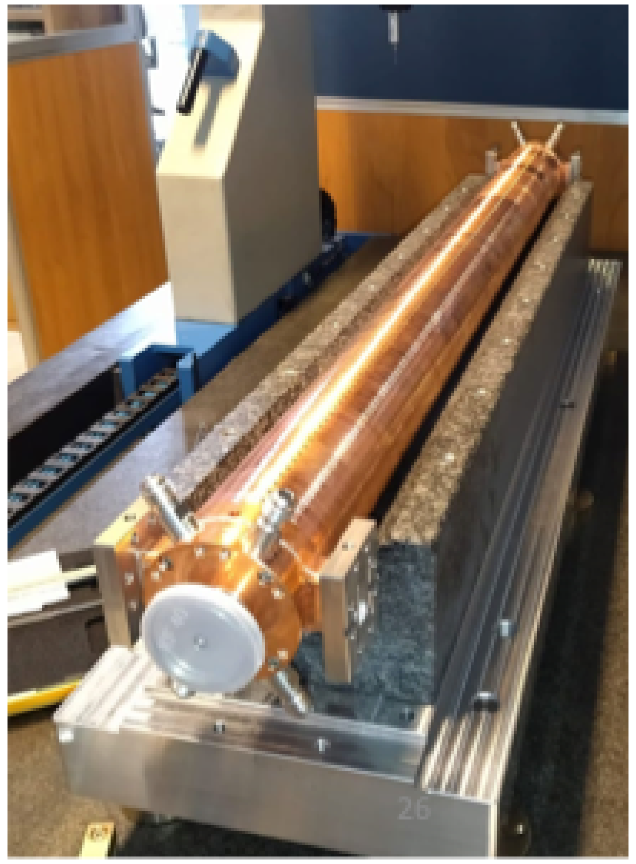


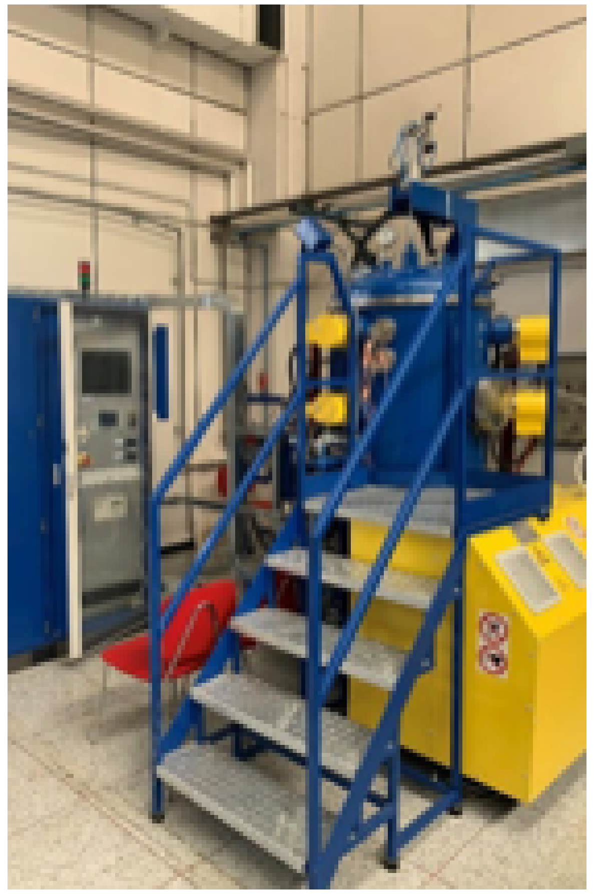
PARAMETER	Value	
	Quasi-Constant Gradient	Constant Impedance
Frequency [GHz]	11.9942	
Average acc. gradient [MV/m]	**60**	
Structures per module	2	
Iris radius a [mm]	**3.85 - 3.15**	**3.5**
Tapering angle [deg]	0.04	0
Struct. length L_s act. Length [m]	**1.05**	
No. of cells	112	
Shunt impedance R [MΩ/m]	93-107	100
Effective shunt Imp. R_{sh_eff} [MΩ/m]	350	347
Peak input power per structure [MW]	70	
Input power aver. 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
Required Kly power per module [MW]	**22.5**	
Kly RF pulse length [µs]	**1.5**	
Repetition Rate [Hz]	**100**	

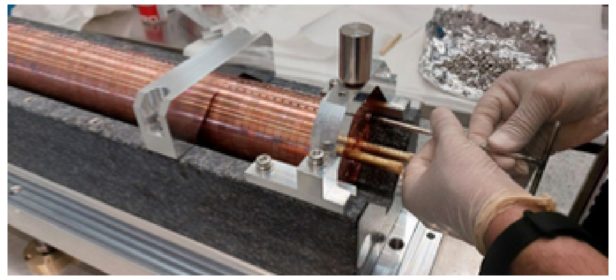
25

M. Diomede et al. NIM A 909 (2018) 243–246









Courtesy F.Cardelli

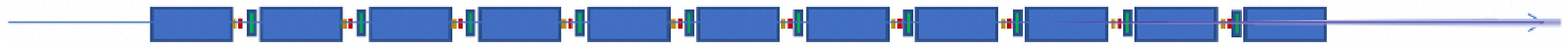
Free Electron Laser - baseline

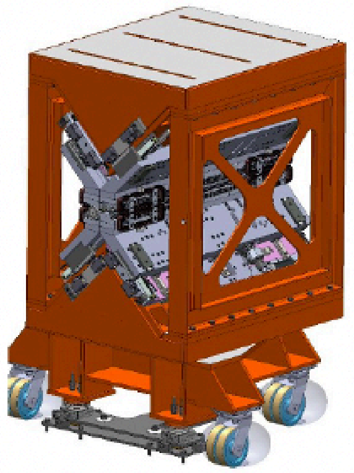
2 FEL Lines in the baseline

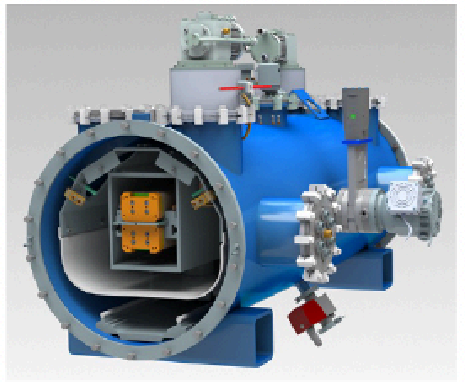
- **AQUA** – Soft X–ray SASE (4nm) APPLE X PMU
- **ARIA** (290–430nm) APPLE II PMU variable polarization

Two FEL lines:

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



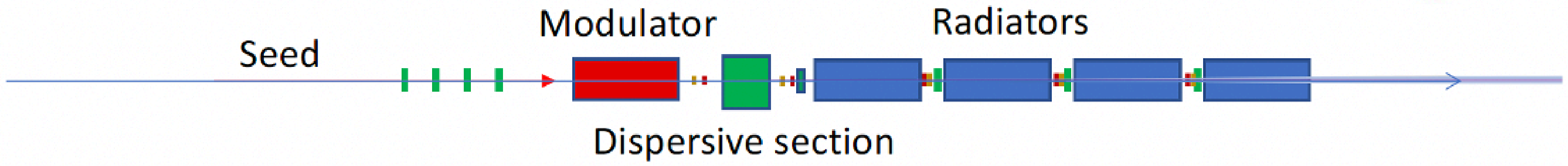


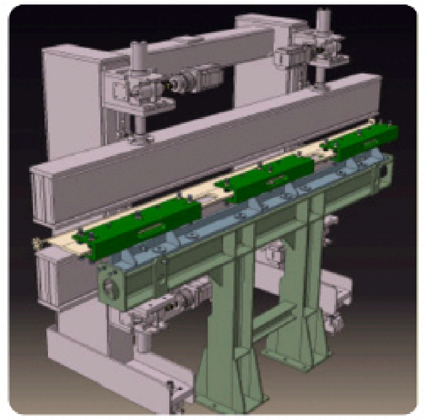


SASE FEL: 10 UM Modules, 2 m each – 60 cm intraundulator sections.
Two technologies under study: Apple-X PMU (baseline) and planar SCU.
Prototyping in progress

FERMI FEL-1 Radiator

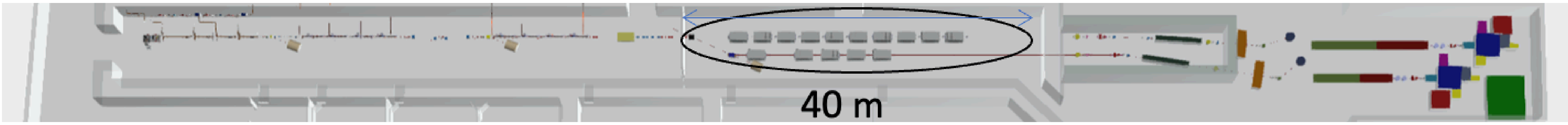
2) ***ARIA*: VUV seeded HGHG FEL beamline for gas phase**





SEEDED FEL – Modulator 3 m + 4 Radiators APPLE II – variable pol. 2.2 m each – SEEDED in the range 290 – 430 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.

Frascati 06/05/23 – EUPRAXIA TDR



Courtesy -L.Giannessi

Organizzato da

ILO Network Italia
Rete Industrial Liaison Officers

Finanziato da

TORINO CHAMBER OF COMMERCE INDUSTRY CRAFTS AND AGRICULTURE

Con il patrocinio di

REGIONE PIEMONTE

INFN Istituto Nazionale di Fisica Nucleare

EuPRAXIA Advanced Photon Sources

EuPRAXIA Advanced Photon Source – EuAPS

PNRR Missione 4 Investimento totale – 22.3 M€

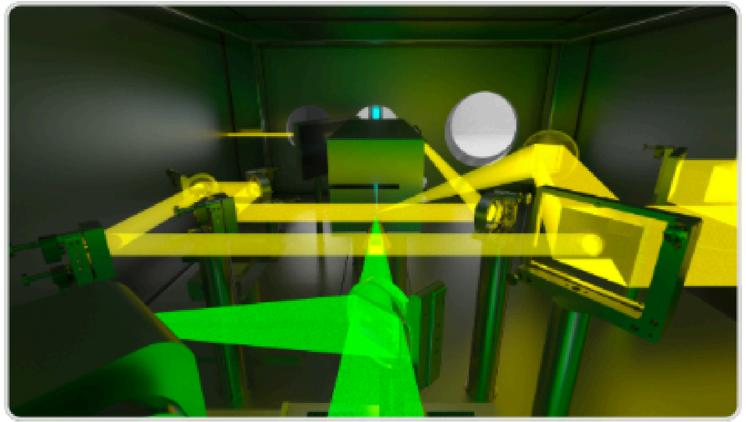
Ranking 1st – Infrastrutture di Ricerca

Unità operative:
INFN-LNF, INFN-LNS, UniTOV, CNR-INO

Flagship goals 2, 6 & 7

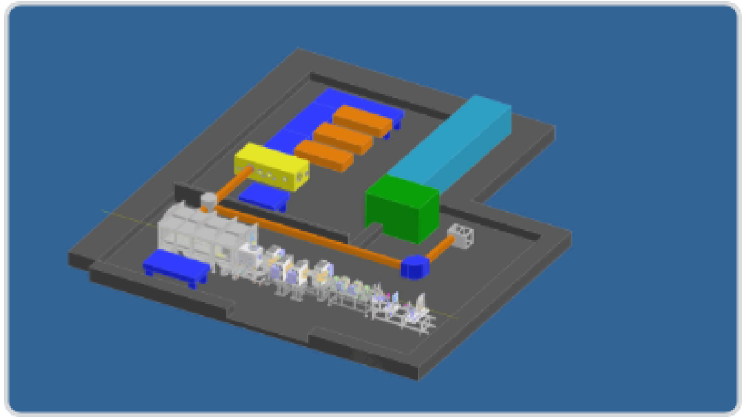
Research

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

www.euaps.infn.it

L'implementazione si concludera a Novembre 2025 e nel 2026 inizierà la fase di commissioning e operativa per utenti esterni

EuPRAXIA è un'iniziativa europea inserita nella roadmap di ESFRI nel 2021 ed è attivamente impegnata per realizzare una facility distribuita europea basata su due siti di implementazione e nodi nazionali. L'INFN è capofila e ospita l'headquarter.

EuPRAXIA@SPARC_LAB ha ottenuto un finanziamento di 108M€ (+20M€) per la sua realizzazione.
Il primo obiettivo è la realizzazione dell'edificio (gara aggiudicata 2026) e immediatamente dopo la realizzazione della macchina con l'obiettivo di arrivare al 2031 con una facility in fase avanzata di commissioning.

Le tecnologie usate e le loro applicazioni sono di sicuro interesse e impatto per il tessuto industriale.
Uno studio accurato sull'impatto socio-economico è in corso e verrà pubblicato entro fine 2025.


Thank you