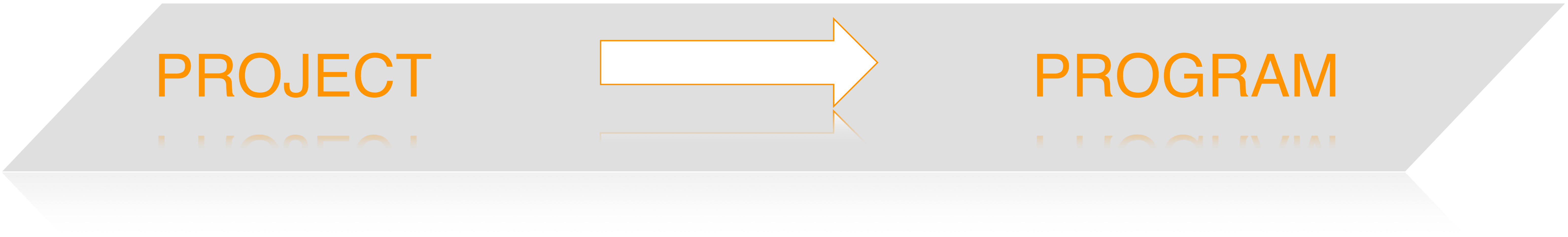
EuPRAXIA

Scientific Committee - 04/05/2023

Antonio Falone
On behalf of the EuPRAXIA Team

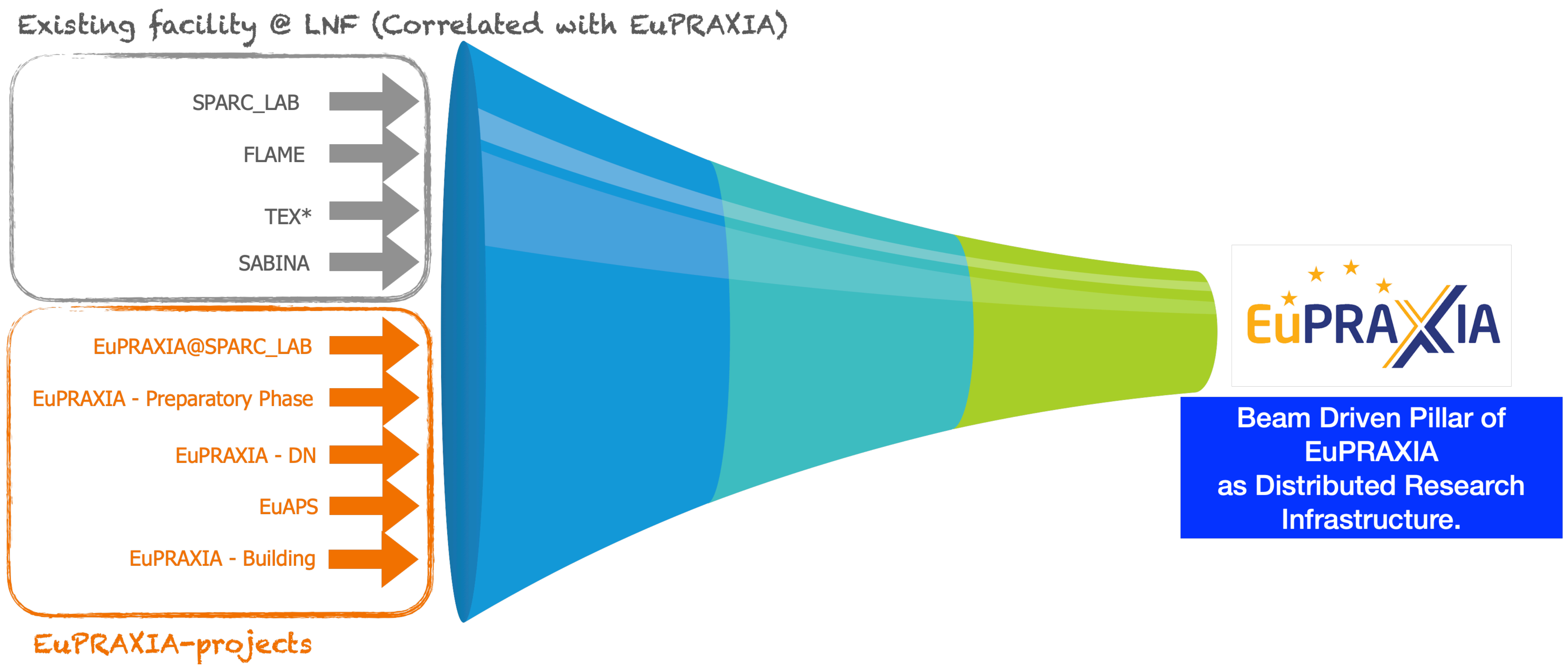
EuPRAXIA Galaxy

EuPRAXIA is naturally evolving from one single project to a program i.e. a set of correlated projects in order to achieve a common goal → Building a Research Infrastructure based on beam driven plasma acceleration and X-Band Linac.

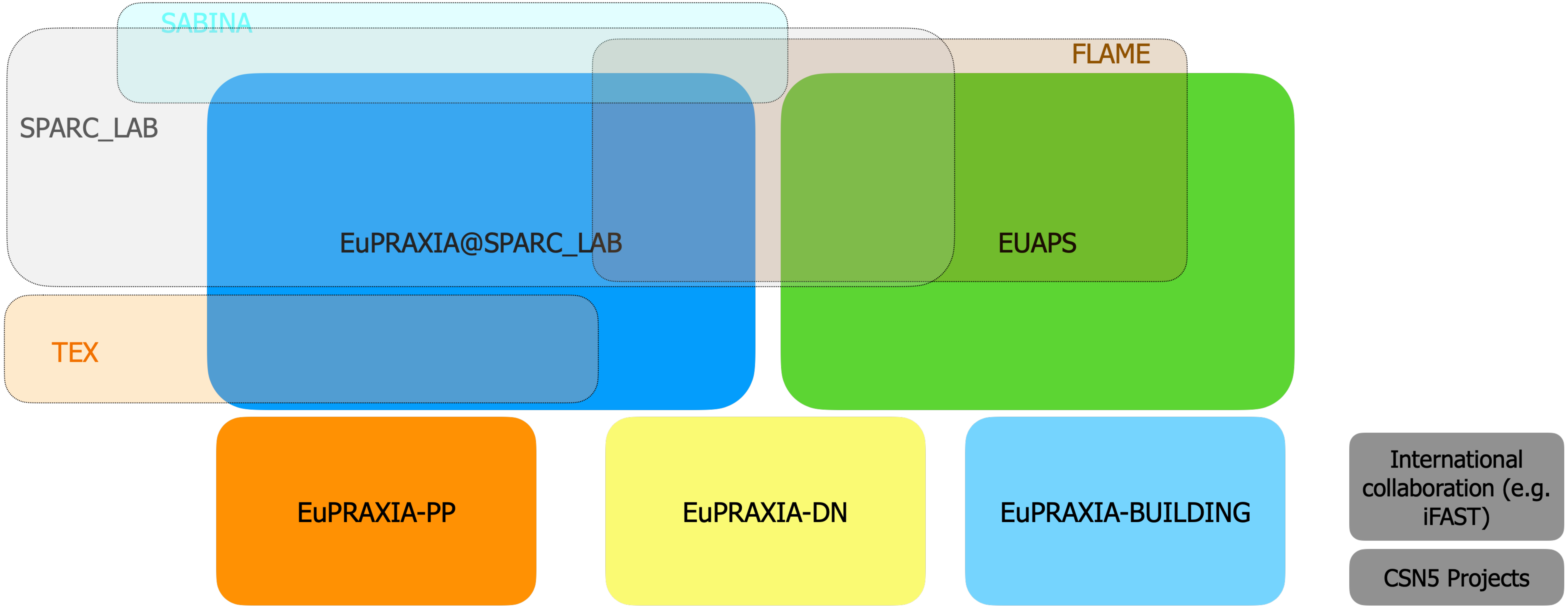


EuPRAXIA Galaxy

Existing facilities at LNF serve all EuPRAXIA projects



EuPRAXIA Galaxy

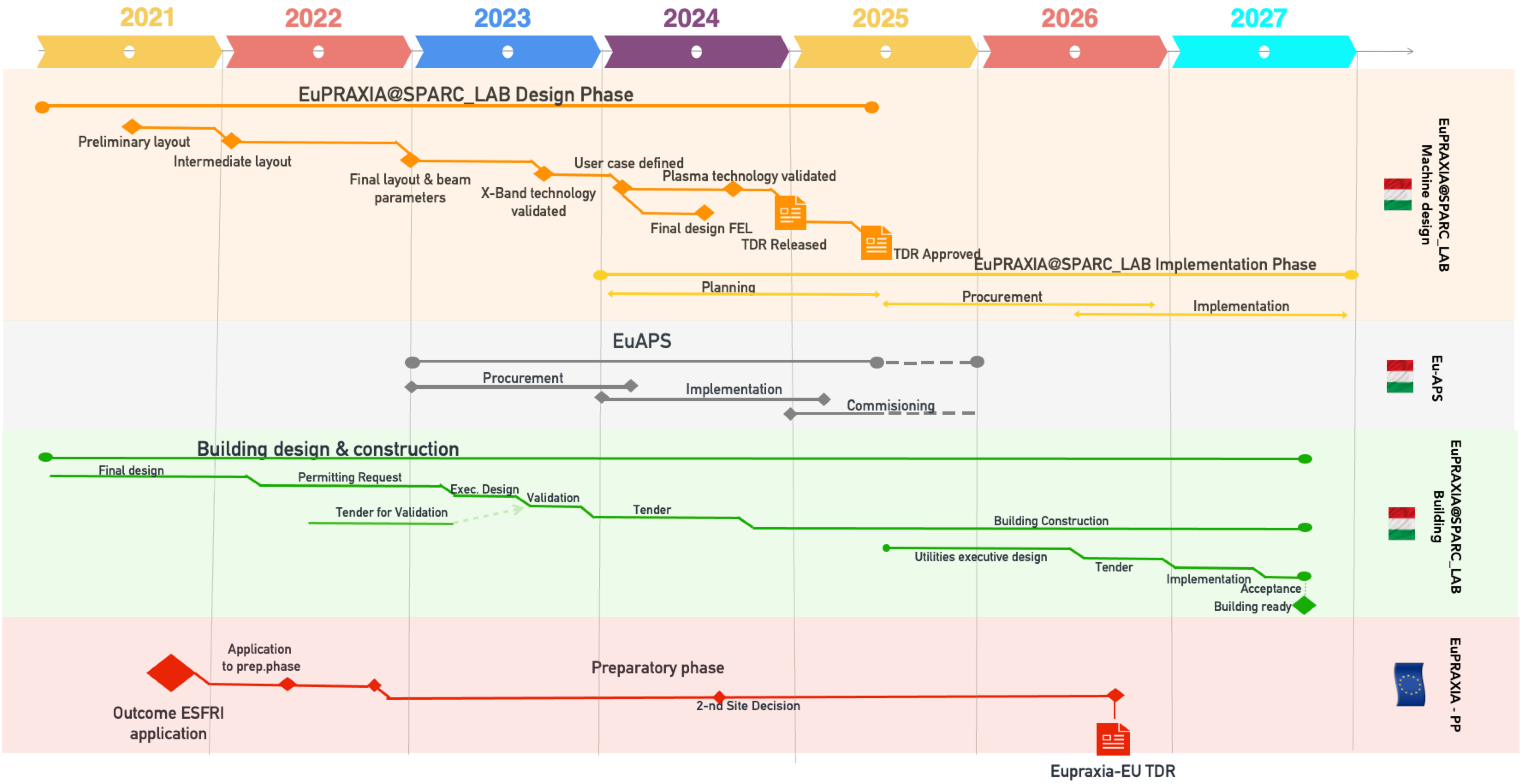


This is just a tentative visualization of the correlation between all EuPRAXIA related activities. The real world is even more complicated, all of them in fact share the same resources and we are not considering here other projects (e.g. STAR, ELI) and of course the activities carried out at the DAFNE Complex (Dafne + Linac + BTF).

EuPRAXIA Galaxy

	EuPRAXIA@SPARC_LAB	EuPRAXIA Building	EuAPS	EuPRAXIA-Preparatory Phase	EuPRAXIA - Doctoral network
Scope	Redaction of the TDR of the Beam Driven Pillar	Design and construction of the building that will house the facility	Betatrone Source High Power Laser High Repetition Rate Laser	Definition and design of EuPRAXIA as distributed RI (legal, governance, financial model)	10 PhD programs across Europe on plasma accelerator science
Duration	TDR is expected at the end of 2025	End of 2027 (approx)	30months (+6) Not later than 31/12/2025	48 months 30/10/2026	48 months 31/12/2026
Budget	9 M€	To be assessed. O(40M€)	22,3 M€	2,7 M€ (+ In kind contribution)	2,5 M€ (+ In kind contribution)
Funding source	Internal funding through GE	Internal funding through GE	PNRR	Horizon Europe	Horizon Europe
R&D required	Yes	NO	Some	NO	NO
Partner	Mainly internal LNF with some partnership with Elettra, ENEA UniTOV, Uniroma1, INFN-MI	Internal LNF	LNF, LNS, INFN-MI (INFN) CNR UniTOV	25 Partner + 9 Associated	23 Partner + 15 Associated

EuPRAXIA Galaxy



EuPRAXIA Galaxy

- Status EuPRAXIA Building

- Status EuPRAXIA@SPARC_LAB

- Status EuPRAXIA Advanced Photon Sources, EuAPS

Building Status

- Final design finalized
- «Conferenza dei Servizi» (Permitting authority commitee) closed (i.e. no further clarification required) waiting for the formal outcome.
- Frascati's townhall gave green light to the construction also considering the national interest of the investment. Final formalization from superintendency is expected soon.
- Cost updated (due to current geo-political and macroeconomic scenario) 42M€ based on final design.

DONE

- Tender for the validation of the executive design – to be started soon
- Executive design to be started soon after formalization of authorization

On Going

Courtesy S.Incremona, U.Rotundo

Building Status - rendering

Vista del nuovo complesso da Via Isaac Newton

Vista aerea del nuovo complesso dalla parte del nuovo parcheggio

Courtesy S.Incremona, U.Rotundo

EuPRAXIA@SPARC_LAB

EuPRAXIA
@SPARC_LAB

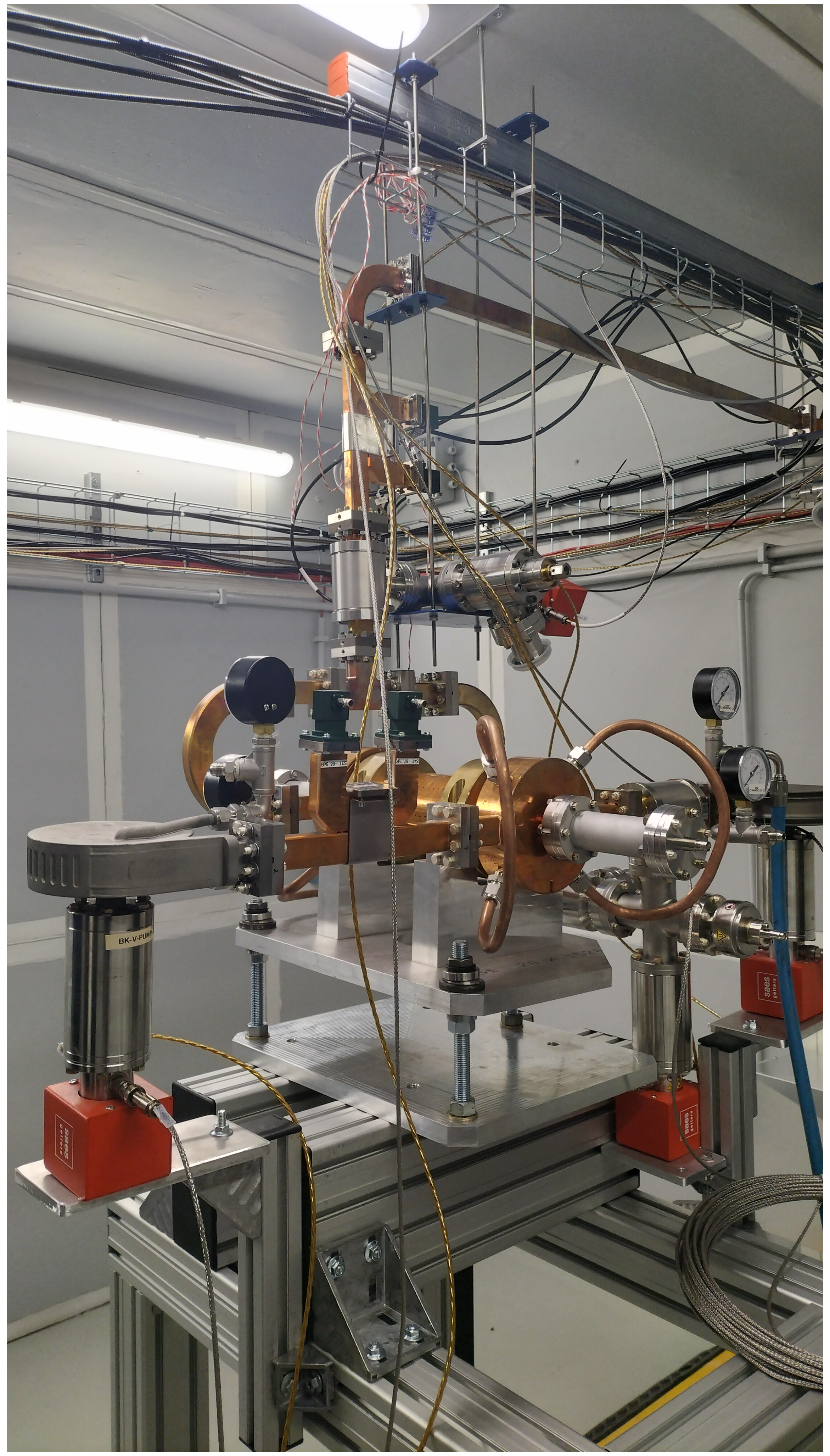
RF Power Source

- ✓ RF design of X-Band waveguide components is completed (e.g. mode converter and pumping port)
- ✓ Procurement High Efficiency High Power CPI Klystron (50MW) – Concluded. Critical design review in Dec 23. Delivery end of 2024
- ✓ Procurement High Repetition Rate Canon Klystron through Scandinova is ongoing – Delivery Feb.24
- ✓ TEX Facility – Operating. Test on CERN/ PSI X-Band section to be started soon (WG system already conditioned)
- ✓ Optimization of the RF Distribution on going (Choice on RF system for linearizer and deflector - dedicated RF station or distributed waveguide system)

Courtesy A.Gallo / S.Pioli

RF Power Source

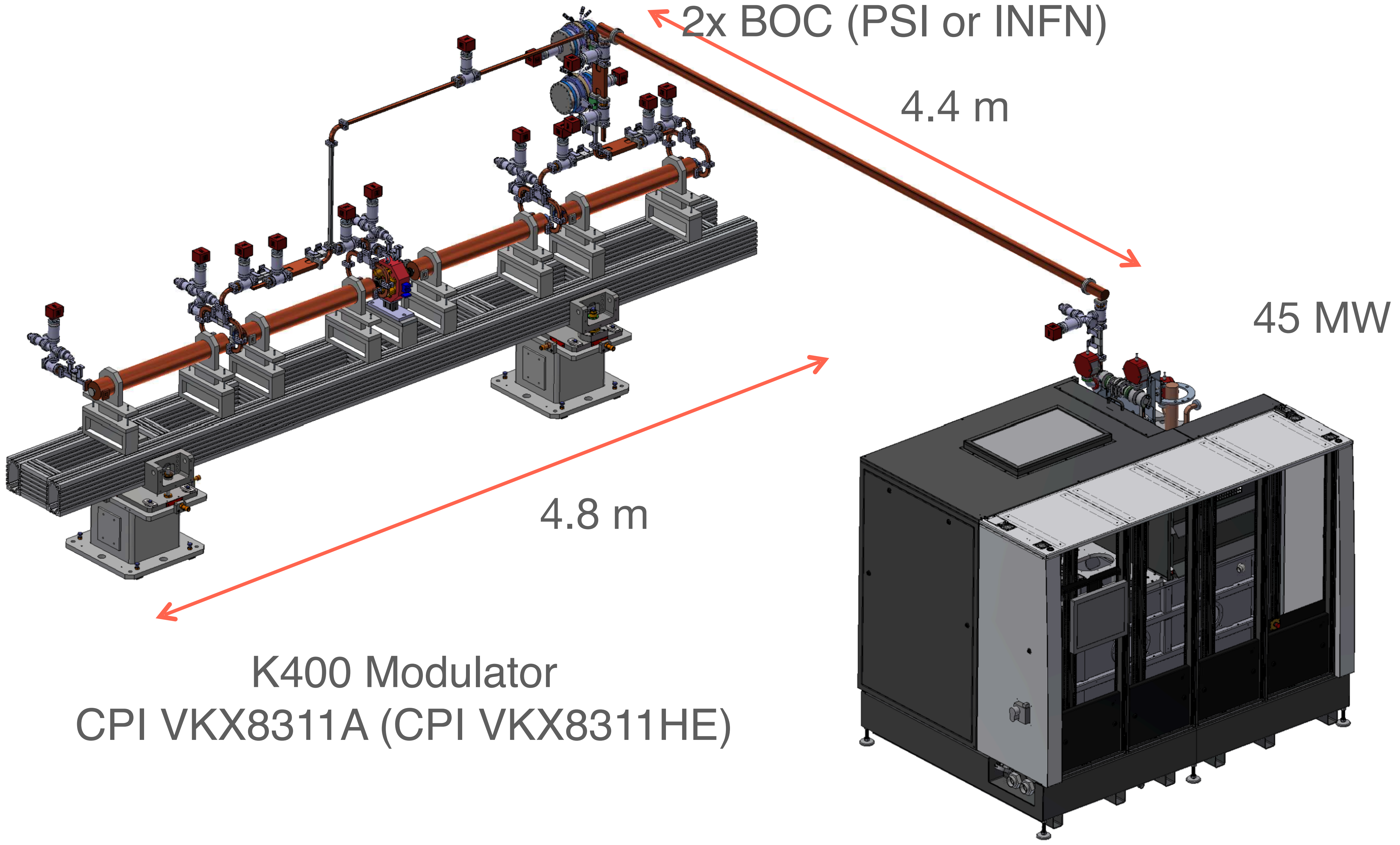
✓ TEX Facility – Operating. Test on CERN/ PSI X-Band section to be started soon (WG system already conditioned)



RF Power Source layout

CPI - OPTION

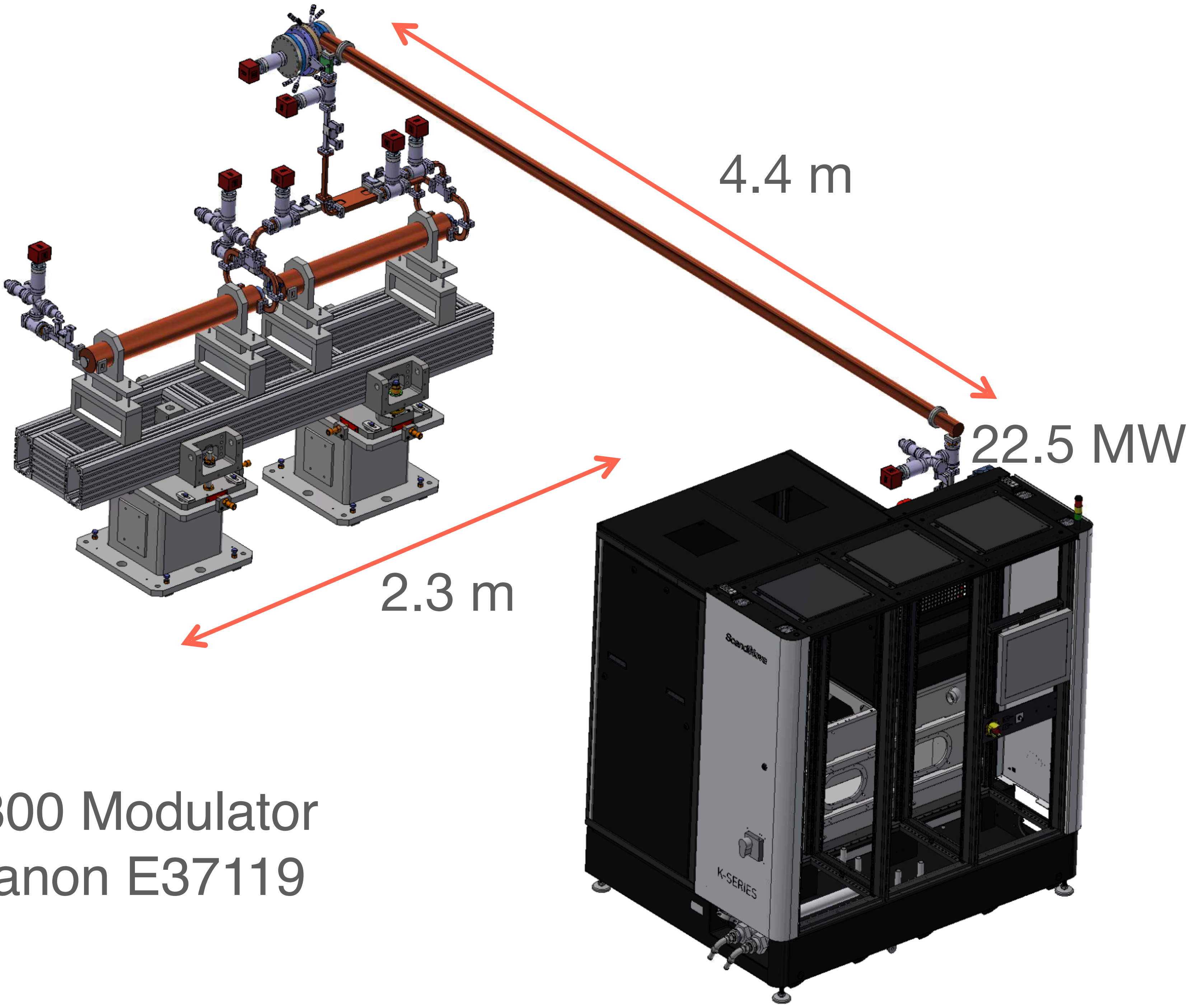
- 2x BOC on one line
- Less flexibility
- Different LE and HE module layout
- Lower power plants number



K400 Modulator
CPI VKX8311A (CPI VKX8311HE)

CANON - OPTION

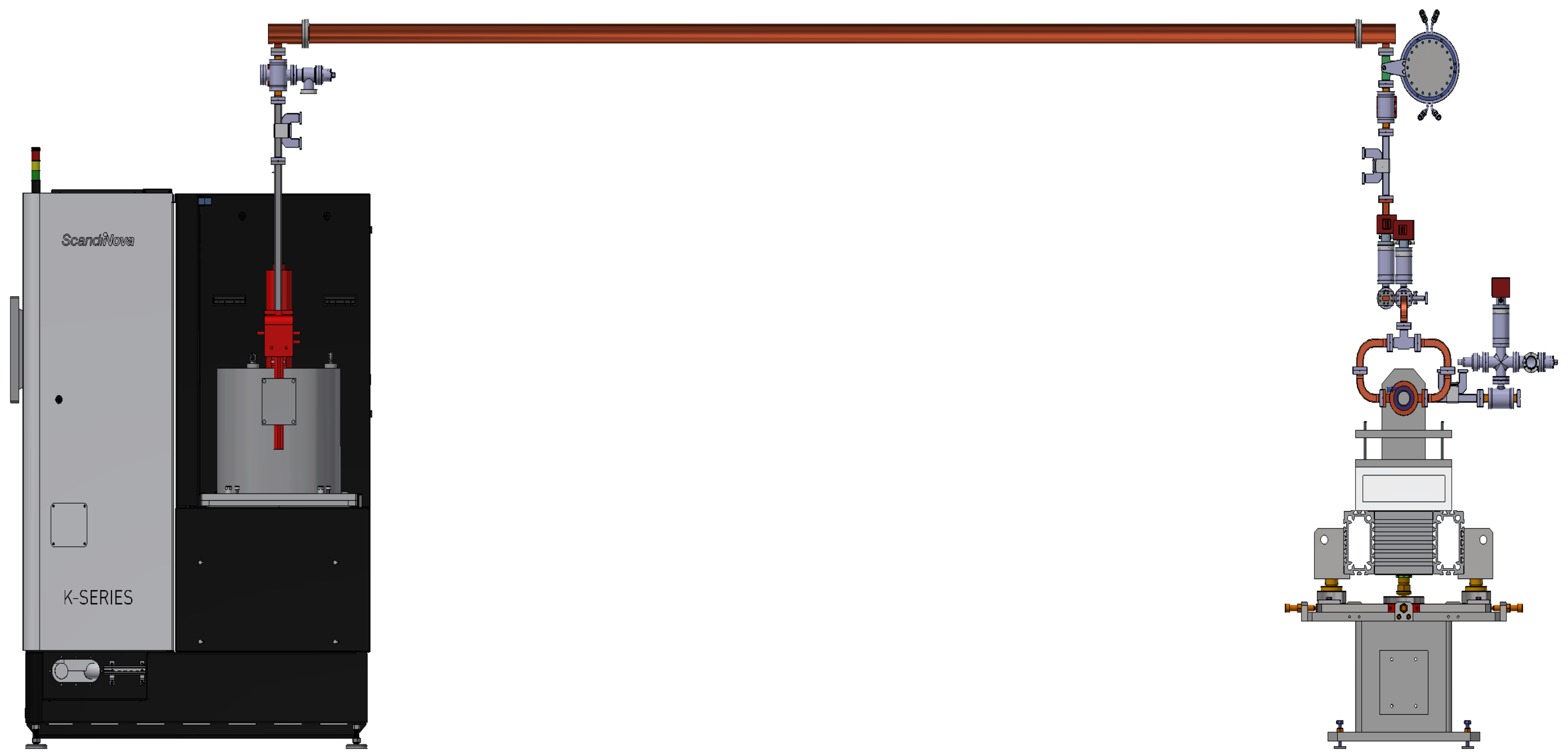
- 1x BOC on one line
- Higher flexibility
- Lower Modulator power requirements
- Possible upgrade at high rep. rate of the Linac

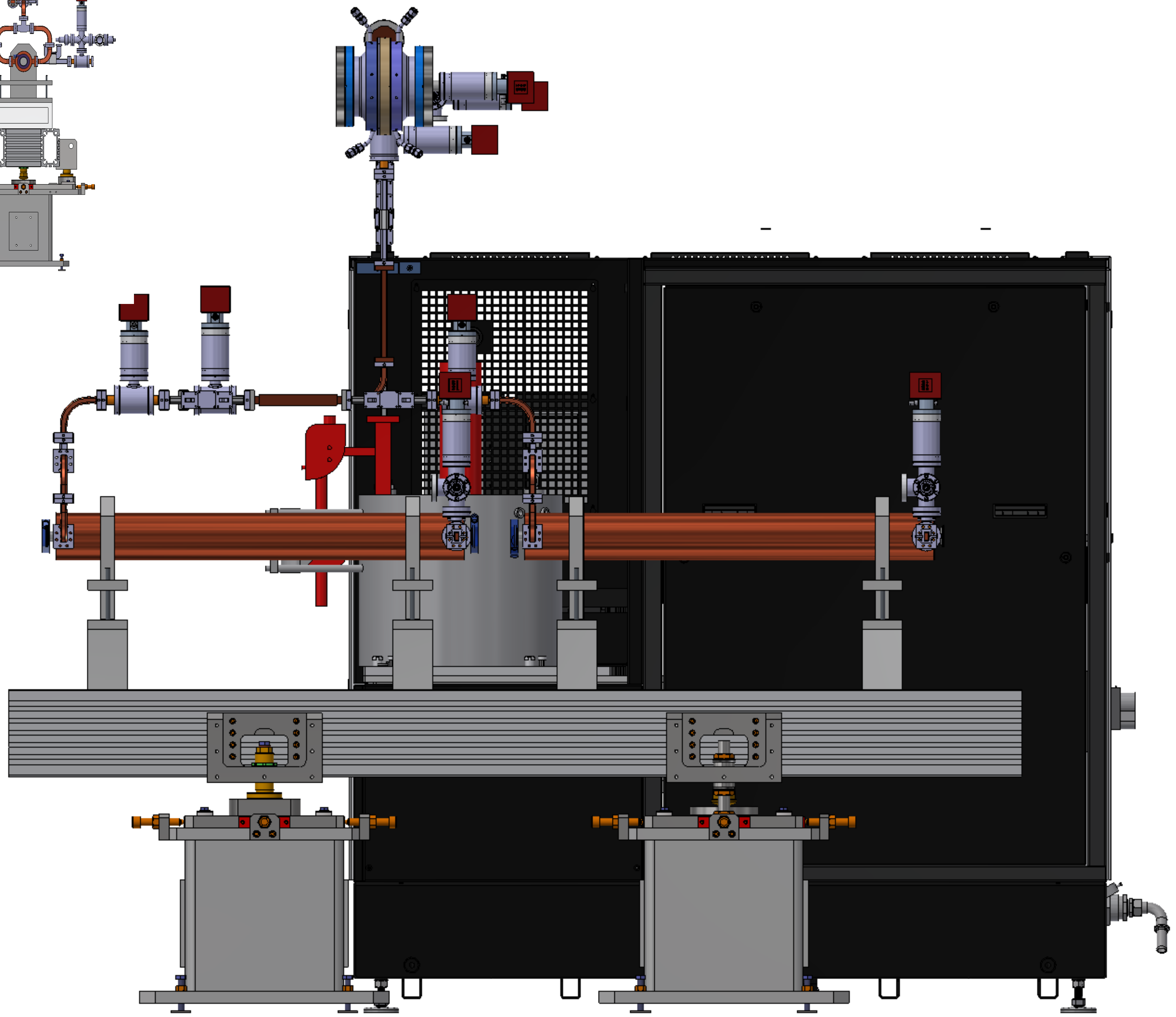


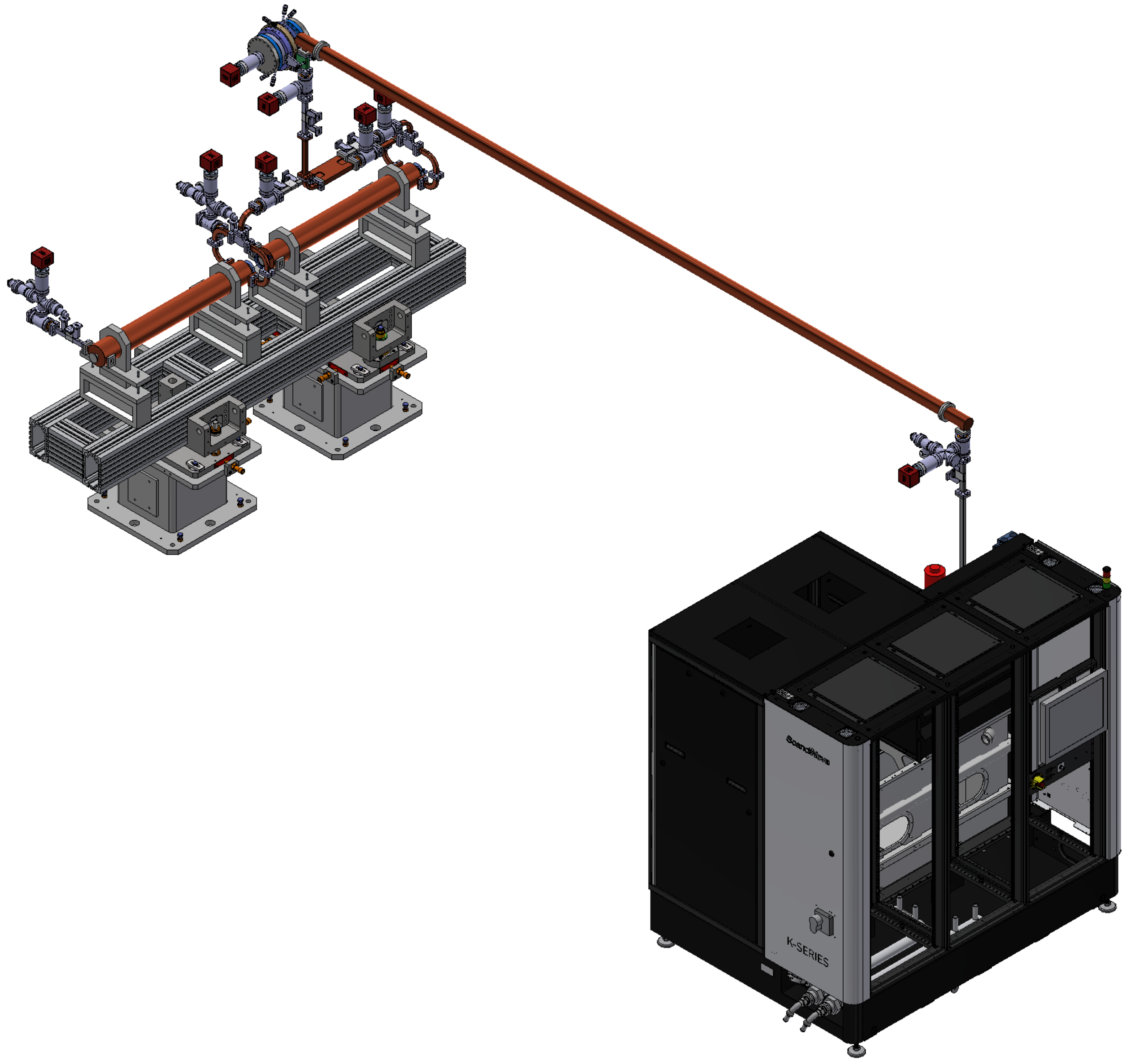
K300 Modulator
Canon E37119

Courtesy F.Cardelli

RF Power Source layout





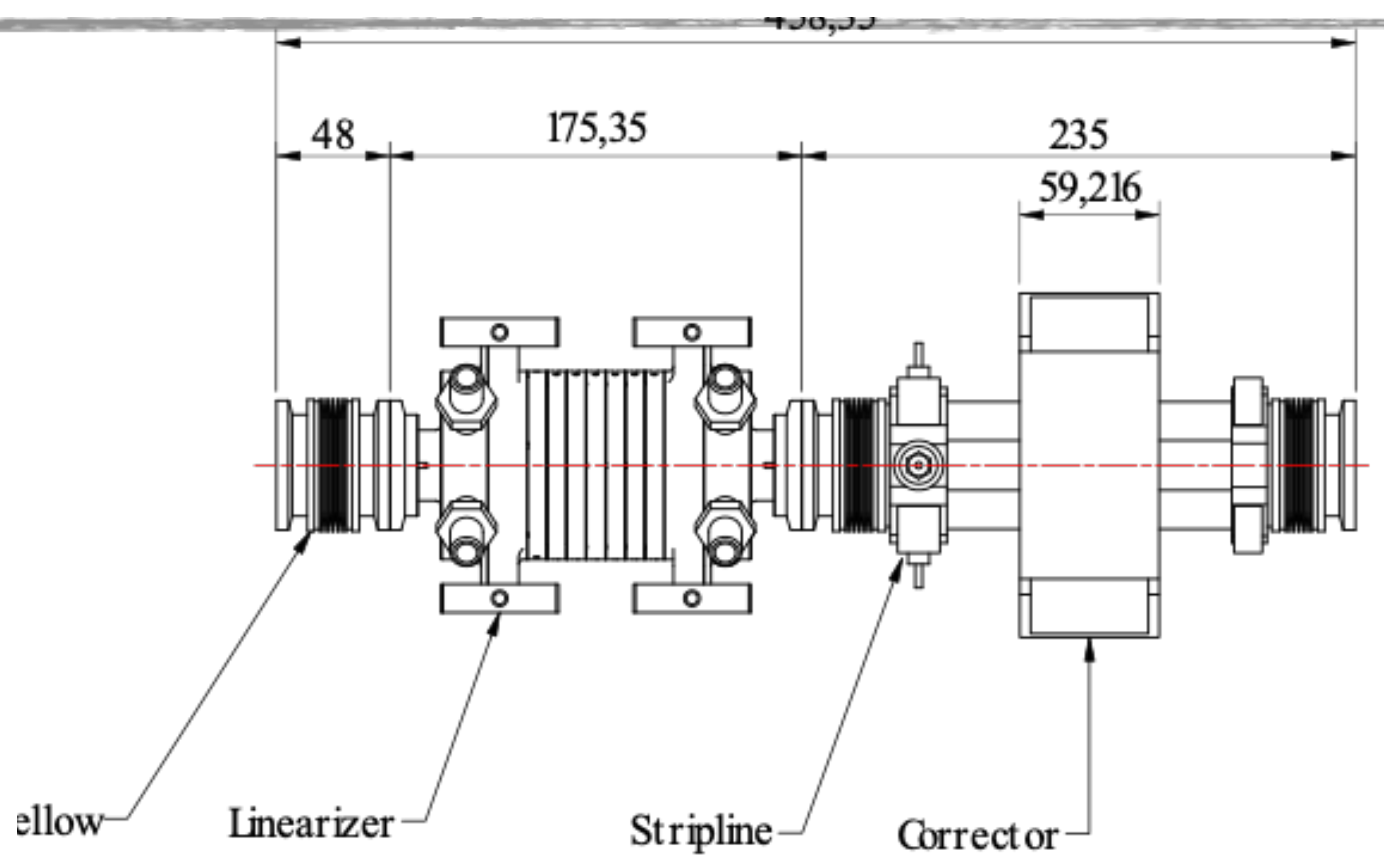


Courtesy F.Cardelli

Injector study is now frozen and approved

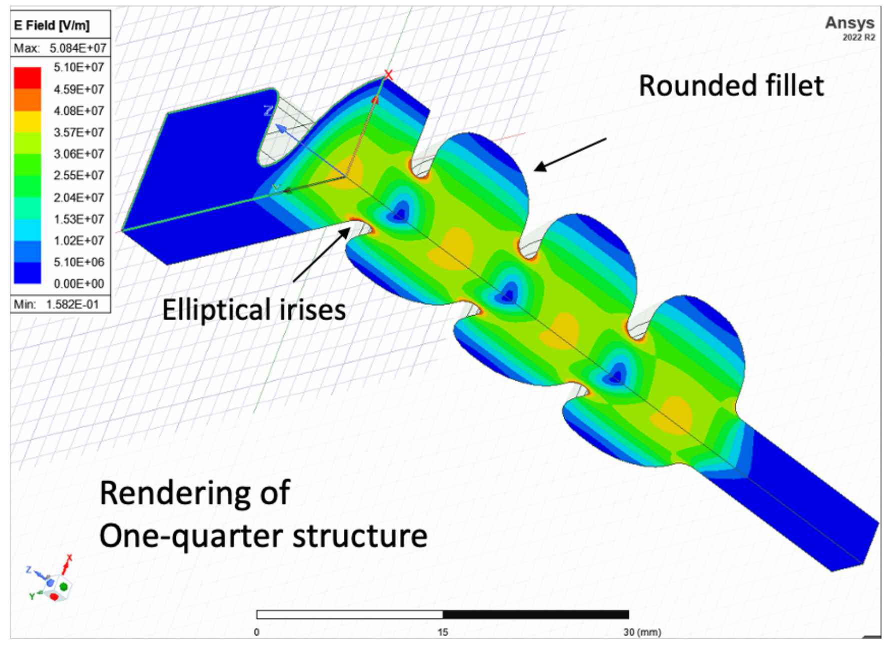
Optimization of the RF distribution taking into account the X-Band linearizer and the 4 S-Band sections are ongoing

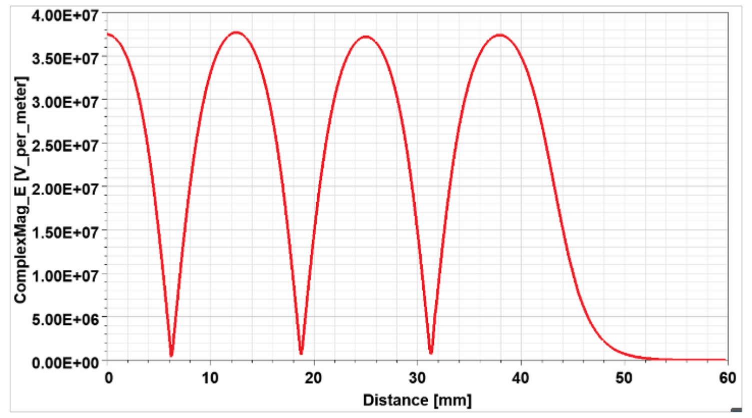
- ✓ Injector layout
- ✓ High charge working point
- ✓ RF distribution for the S-Band system (advanced layout agreed but still to be optmized)
- ✓ Jitter and sensitivity studies
- ✓ Comb Beam and S-Band optimization (3+2+2+2)



- iris aperture radius a = 4 mm
- Number of cells = 7
- Cavity Length (from rendering) = 12 cm
- pi mode
- Accelerating Gradient = 20 MV/m

a = 4 mm	
Resonant frequency, f	11.9942 GHz
Quality factor, Q	9,900
Eff. Shunt Impedance, r	83.5 MΩ/m
Eacc	20 MV/m
Epeak	38 MV/m
Number of cells	7
Coupling coefficient, β	1.23
Field build-up, τ	117 ns
Pin	400 kW

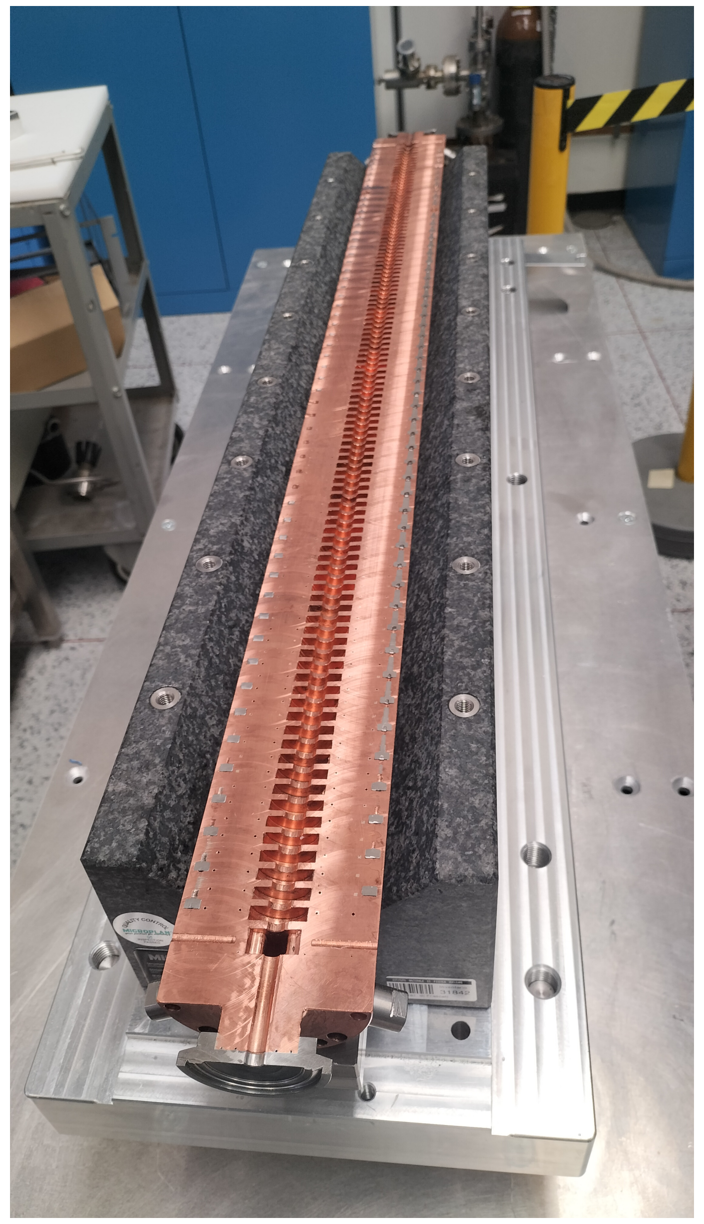




Courtesy E.Chiadroni

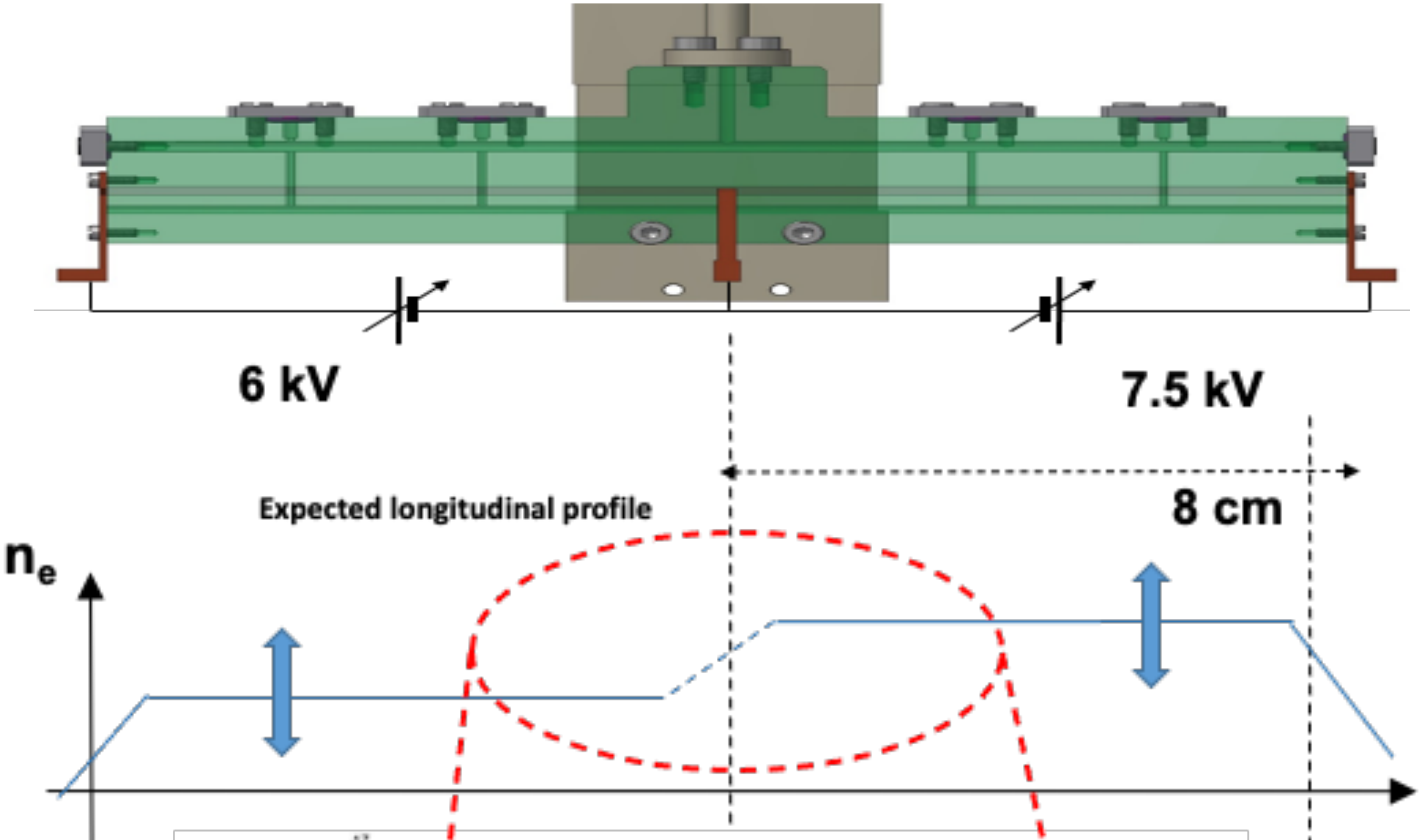
LINAC

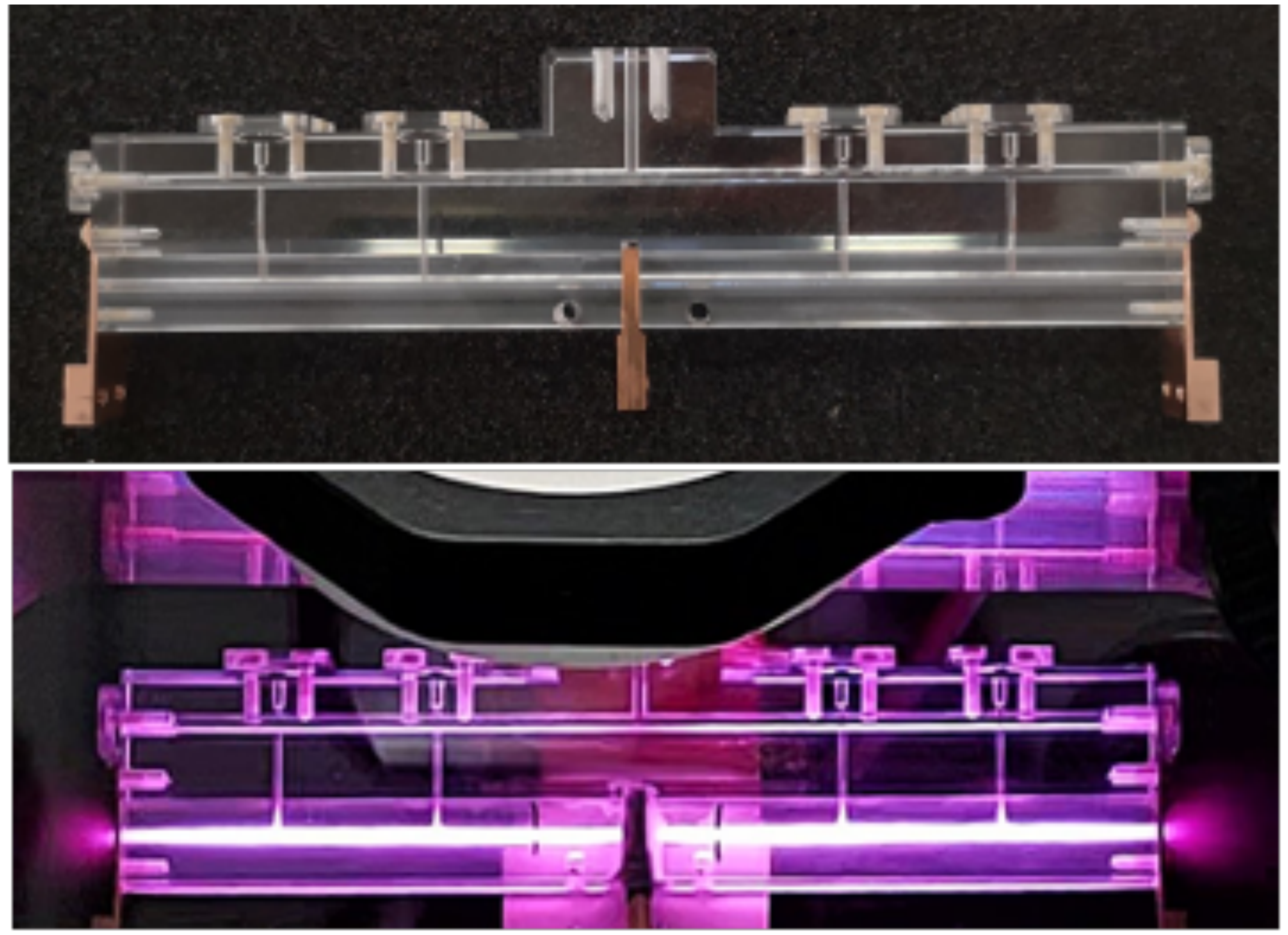
- ✓ Mechanical Prototype X-Band section successfully validated. No significant deformation after brazing and vacuum tightness.
- ✓ RF Prototype production in progress (expected in June)
- ✓ Magnets design definition in progress

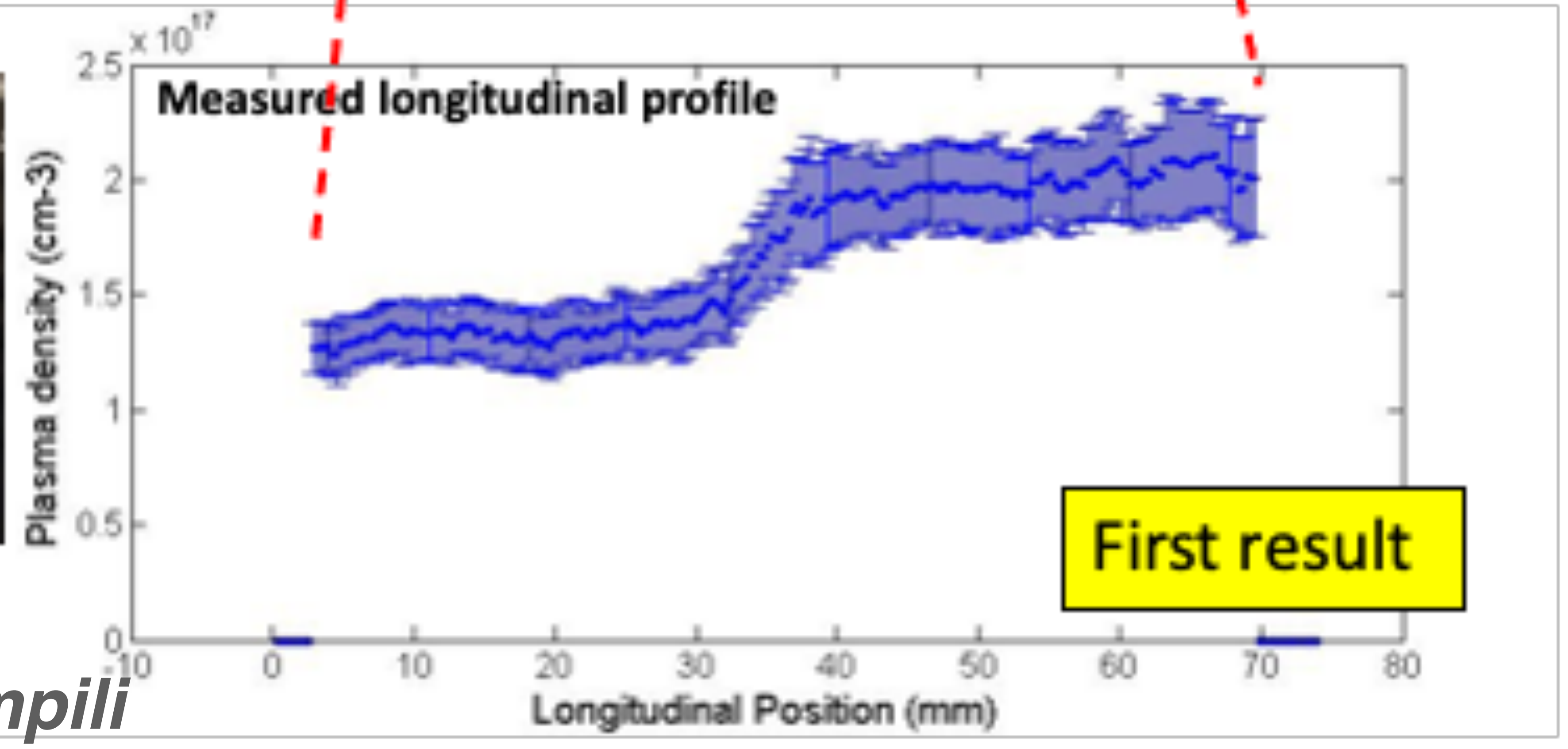


Courtesy D.Alesini

Plasma module







Advantages:

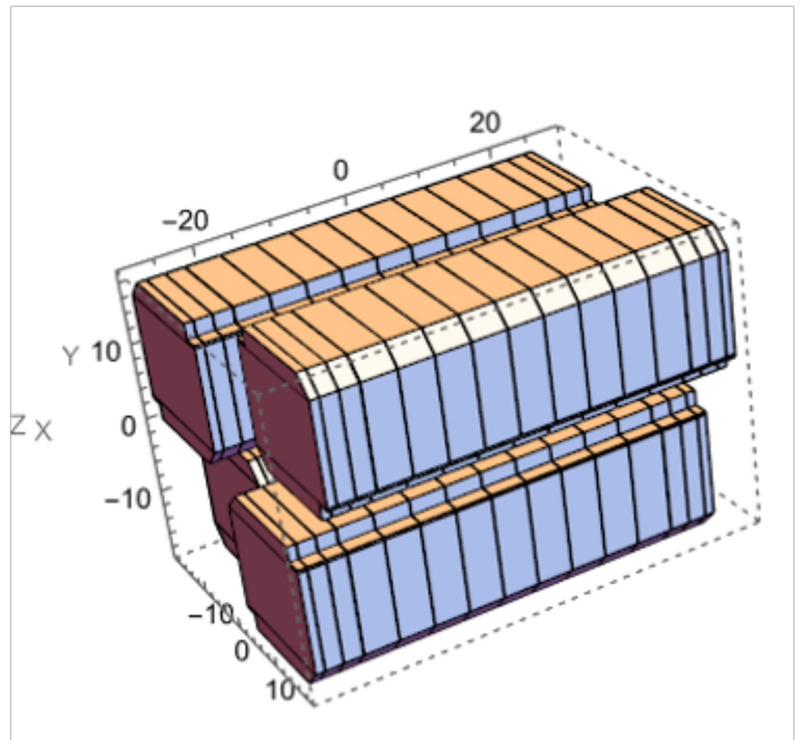
- several independently controllable sections
- Plasma sources larger than 40 cm (m-scale) with HV pulses less than 10 kV
- Longitudinal density modulation
- **5 GeV** case for EuPRAXIA (1.5 GV/m m-scale capillary - density 10^{16} cm-3)

Courtesy A.Biagioni / R.Pompili

Undulator design and prototyping for AQUA: Apple-X

Defining critical design aspects:
Minimum vacuum chamber size / vacuum - wake-fields (F. Bosco Un. Roma 3 – F. Nguyen, ENEA)
Magnetic field tolerances from prototype of Apple-X module (M. Opromolla, LNF)

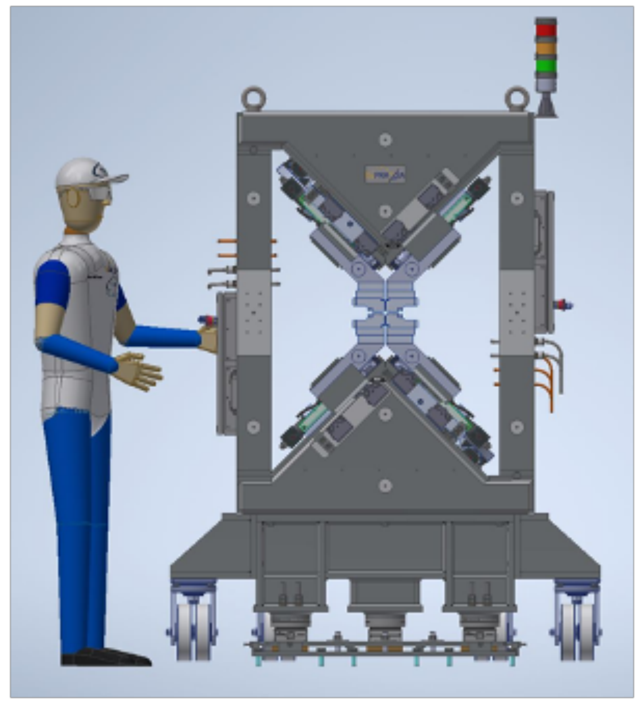
Apple-X undulator for ***SABINA*** (ref. L. Sabbatini) is a first prototype for ***AQUA*** FEL line



Magnetic design A. Petralia (ENEA)

LNF observer in LEAPS-INNOV:
setting up magnetic measurement bench (ref. L. Sabatini A. Vannozzi) in contact with M. Calvi / S. Karabekyan small size Hall probe and Hall probe bench.

Undulator mech. design adapted from **KYMA**- ***SABINA*** by M. Del Franco (LNF)



First ***SABINA*** undulator in FRASCATI March 29, 2023

Courtesy L.Giannessi

Undulator design and prototyping for AQUA 2: SCU

Prototype construction at FNAL (C. Boffo)

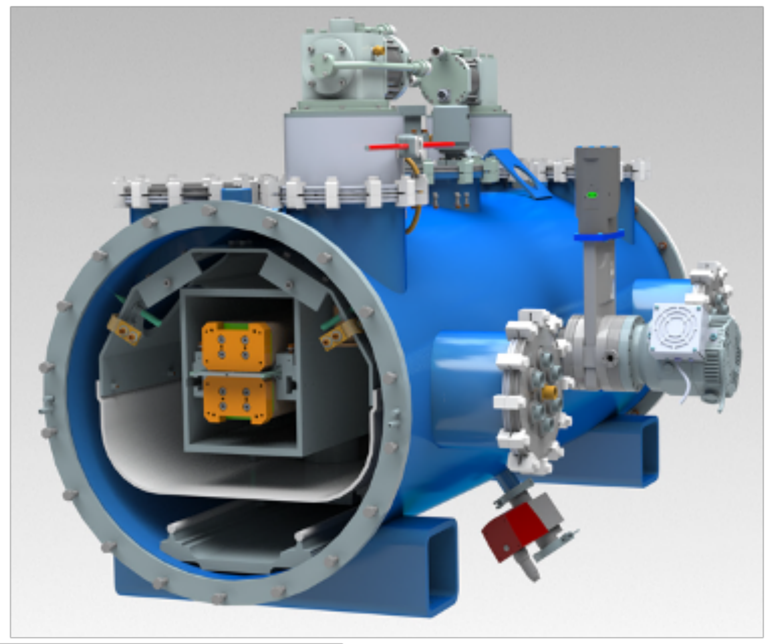
MODULAR DESIGN
Cooling: 2+2 1.8 W GM coolers

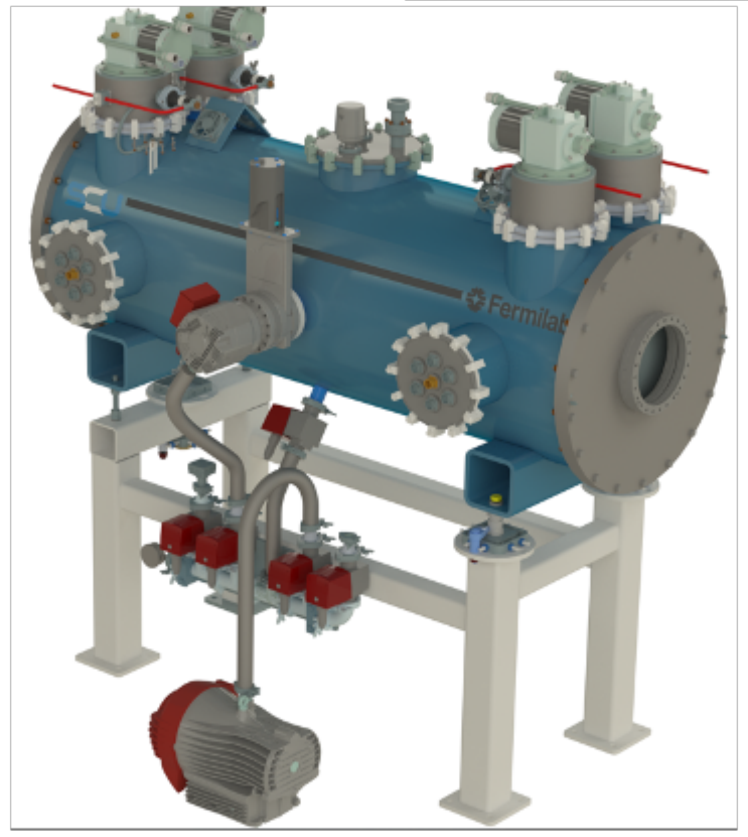
Reduced vessel diameter to minimize: costs, used space and radiation input at 50K

Current leads optimized for higher current/heat load. Hybrid HTS phosphor bronze system

Integrated G11 support posts as in LHC magnets combined with railing system as PIP-II cryomodules

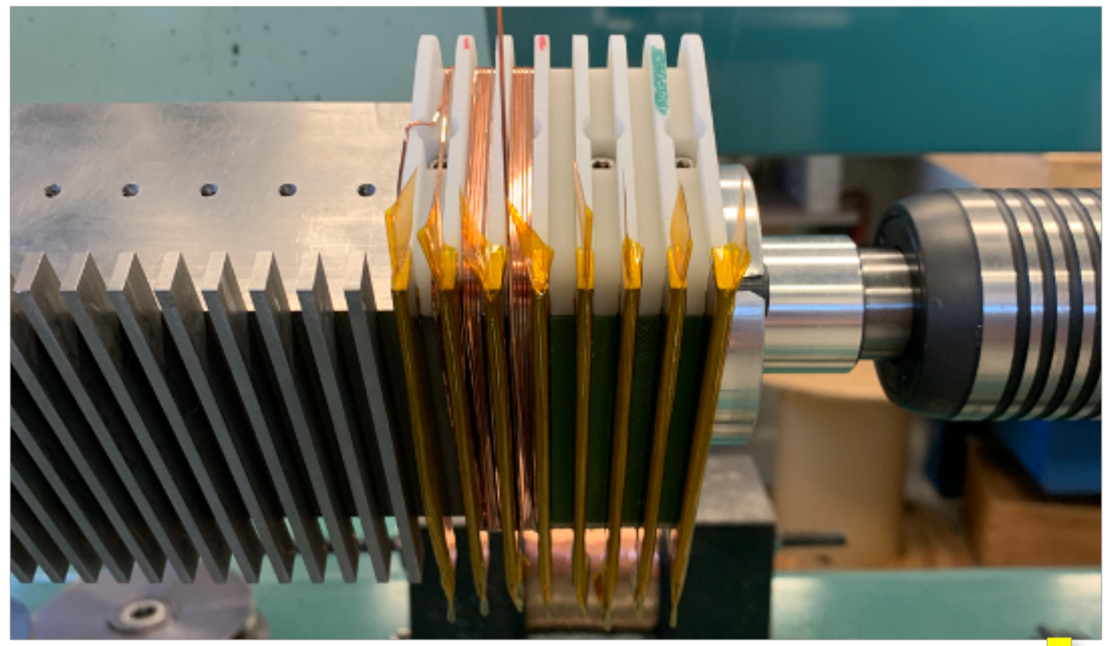
Parameter	Value	Unit
Period	< 16	Mm
Beam stay clear	5	mm
FEL wavelength	~3	Nm
K-value	>1.2	-
Beam heat load	TBD	W
Ramp to operating field	<600	s
Cooling	Cryocoolers	-
Operating temperature	4.2	K
Magnet length	1.5-1.6	m
Flange to flange length	2.0-2.5	m
Beam height	TBD	m
Vacuum vessel diameter	<1	m
Insulation vacuum	$1*10^{-5}$	mbar
Cooldown time	<7	days

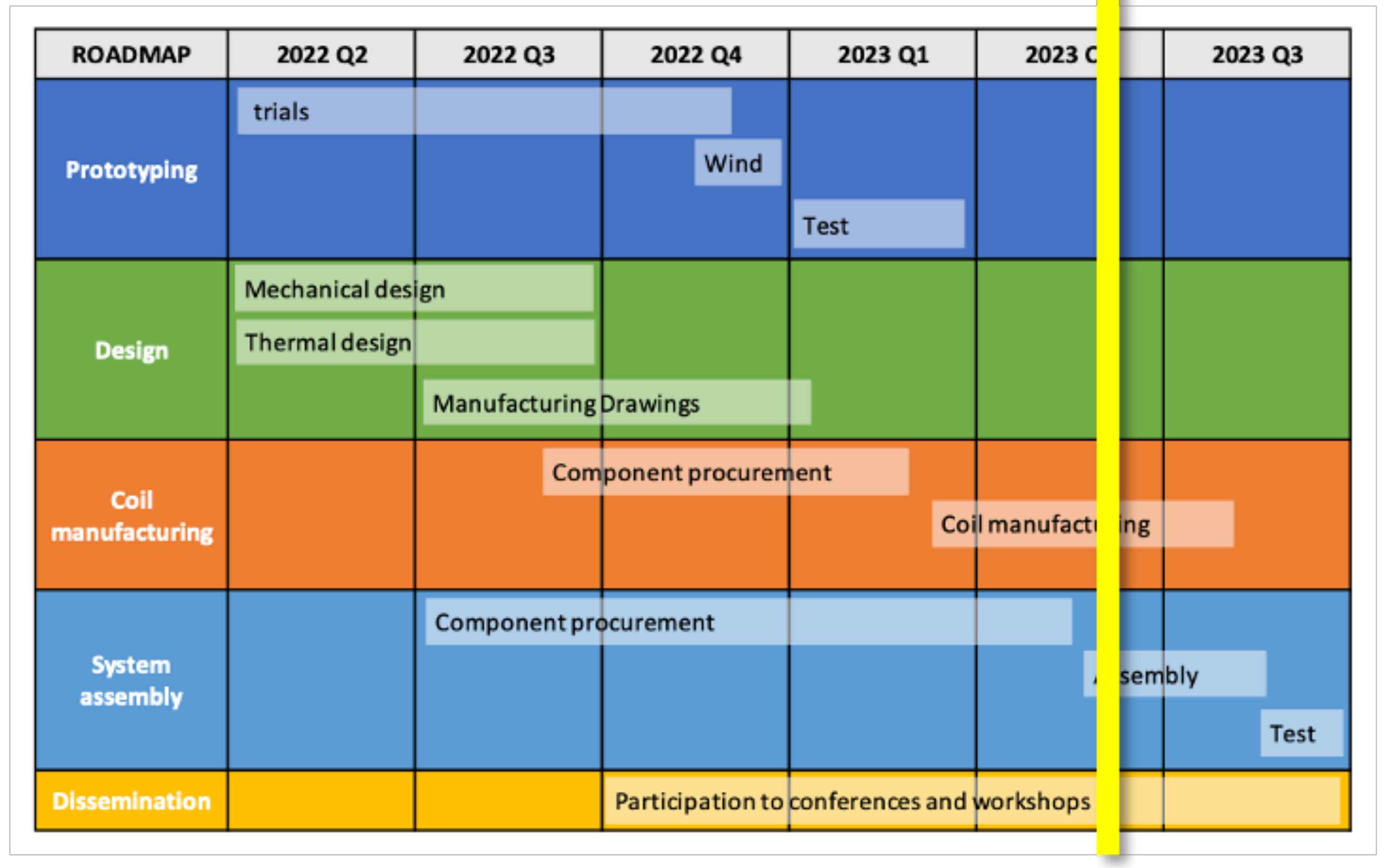




Q3 2023 the prototype undulator should be completed – delivery to LNF in 2024

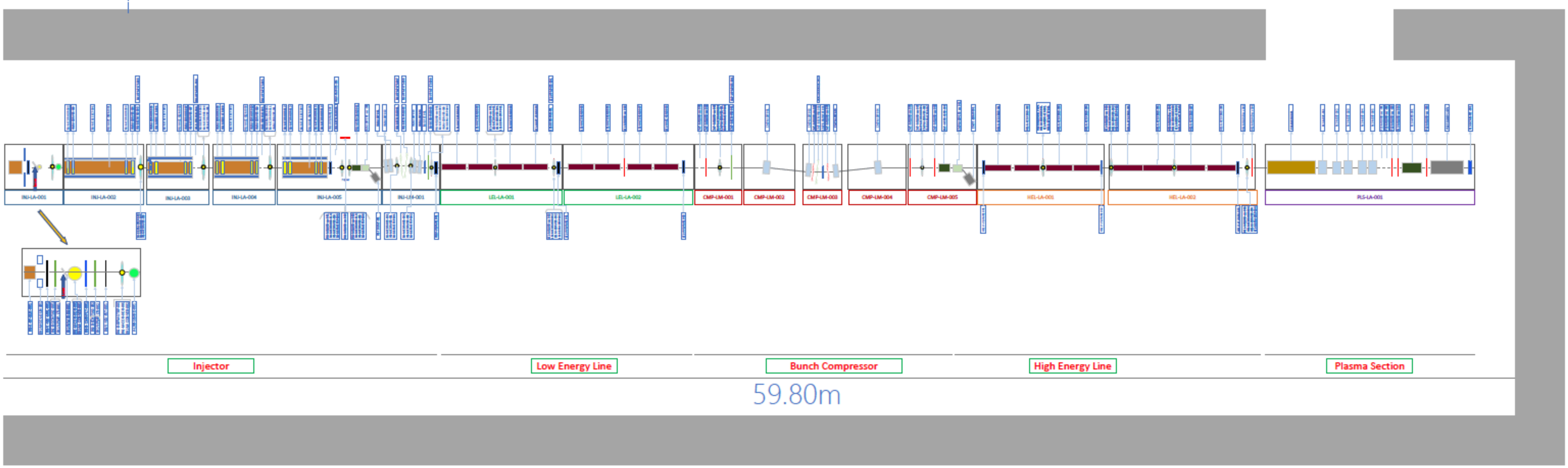
Fermilab U.S. DEPARTMENT OF ENERGY Office of Science





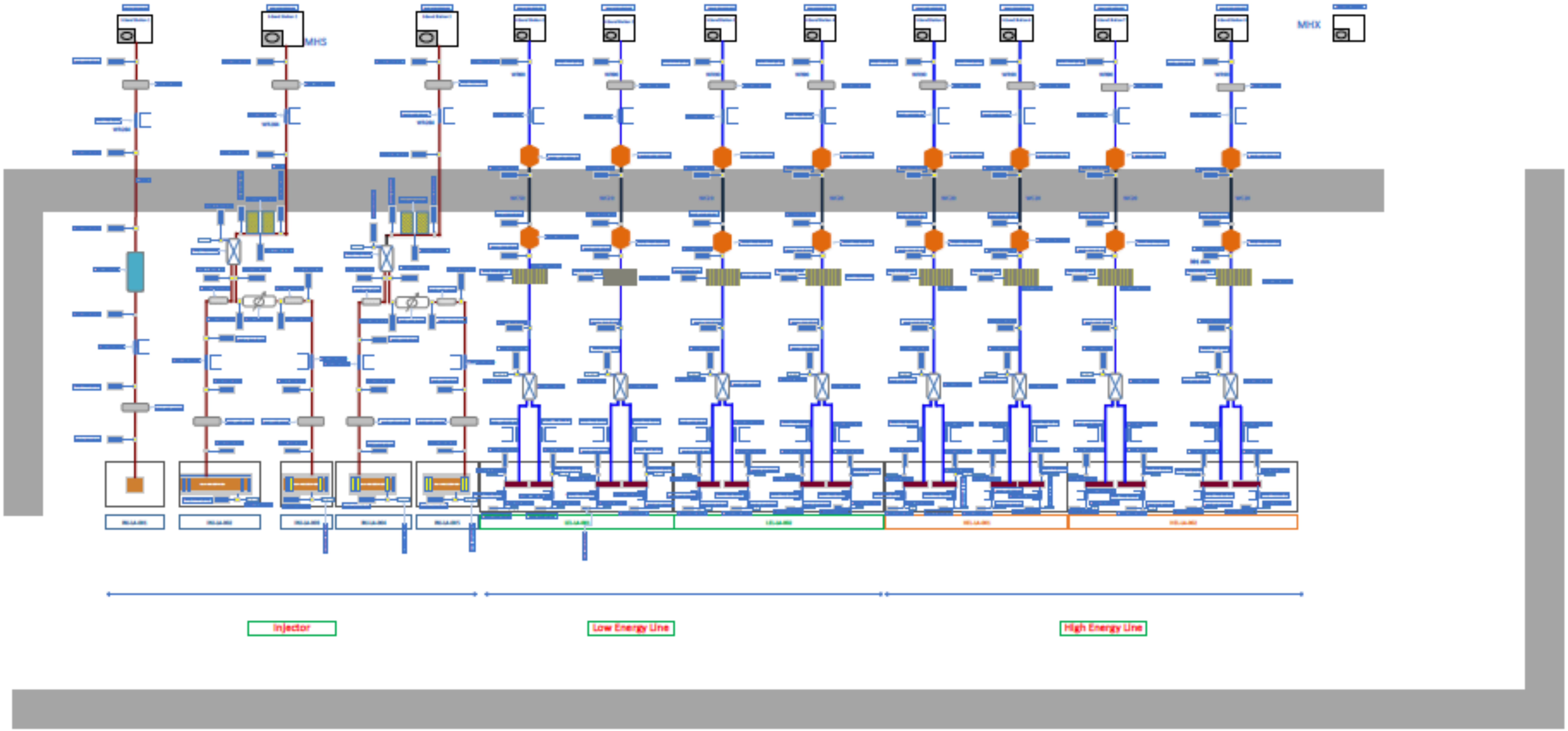
Courtesy L.Giannessi

Machine Layout



Courtesy F.Cioeta & E.Di Pasquale

RF Power Source layout



Courtesy F.Cioeta

Transition to Implementation Phase

✓ Starting the planning of the implementation phase

1 additional Working Area - INTEGRATION to help in the definition of the implementation phase:

- Installation and commissioning strategy
- Procurement strategy and planning
- Ancillary systems to be organized (pre-assembly area, alignment, logistics etc…).

✓ TDR Structure to be discussed at the next review committee

Transition to Implementation Phase

✓ Detailed cost estimation on going based on the existing layout. To be finalized in few weeks.

Machine
- Linac
- Ondulators
- Photon Beamline
- User End Station
- RF & Power Supplies
- Laser system
- Ancillary System (DAQ, Controls)

Utilities
- Cabling
- Secondary cooling system

Civil Engineer
- Building
- HVAC
- Electrical Distribution

EuPRAXIA Advanced Photon Sources

EuPRAXIA

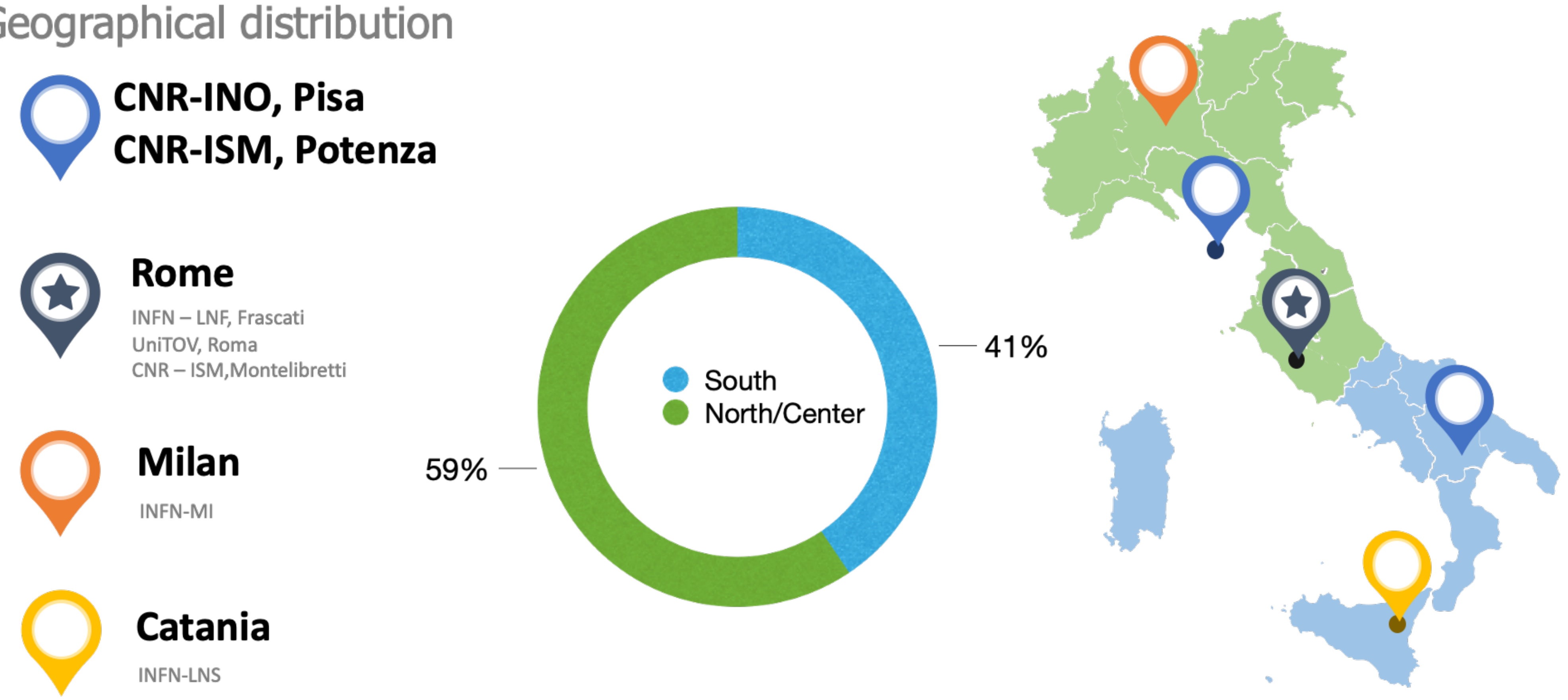
Advanced Photon Sources

EuPRAXIA Advanced Photon Sources

- Ranking 1° in ESFRI Research Infrastructure call for Next Generation EU (PNRR).
- Phase 1 EuPRAXIA Implementation Phase
- Betatron Radiation Source for x-ray imaging (INFN- LNF)
- High Power Laser [1 PW] (INFN-LNS)
- High Repetition Rate Laser [100Hz] (CNR-INO)

Kick off meeting on the 28th Feb. 2023

Geographical distribution



ISTITUTO NAZIONALE DI FISICA NUCLEARE

Laboratori Nazionali di Frascati

INFN-23-12-LNF
6 Aprile 2023

EuPRAXIA Advanced Photon Sources

PNRR_EuAPS Project

M. Ferrario[1], R. Assmann[1,2], L. Avaldi[3], P. Bolognesi[3], R. Catalano[4], A. Cianchi[5], P. Cirrone[4,6], A. Falone[1], T. Ferro[1], L. Gizzi[7], M. G. Iungo[1], L. Labate[7], C. Mustarelli[8], G. Petringa[4], A. R. Rossi[9]

[1] *INFN, Laboratori Nazionali di Frascati, Frascati, Italy*
[2] *Deutsche Elektronen-Synchrotron DESY, Hamburg, Germany*
[3] *CNR - Istituto di Struttura della Materia , Montelibretti, Italy*
[4] *INFN, Laboratori Nazionali del Sud, Catania, Italy*
[5] *University of Roma "Tor Vergata", Physics Department, Italy*
[6] *Centro Siciliano di Fisica Nucleare e Struttura della Materia (CSFNSM), Catania, Italy*
[7] *CNR - Istituto Nazionale di Ottica , Pisa, Italy*
[8] *CNR - Istituto Nazionale di Ottica , Firenze, Italy*
[9] *INFN, Sezione di Milano, Milano, Italy*

Abstract

The EuPRAXIA Advanced Photon Sources (EuAPS) project, led by INFN in collaboration with CNR and University of Roma "Tor Vergata", foresees the construction of a laser-driven "betatron" X Ray user facility at the LNF SPARC_LAB laboratory. EuAPS also includes 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 M€ from the PNRR plan, Mission 4 "Education and Research", Action 3.1.1 "Creation of new research infrastructures strengthening of existing ones and their networking for Scientific Excellence under Horizon Europe" and has received the highest score among the submitted projects of the ESFRI area "Physical Sciences and Engineering".

The EuAPS project starting date has been fixed on December 1st, 2022 and will last 30 months (with a possible extension of additional 6 months).

In this paper we report the introductory part of the submitted proposal.

EuPRAXIA Advanced Photon Sources

EuAPS Scientific Coordinator: M. Ferrario (INFN-LNF)
EuPRAXIA/EuAPS Integration: R. Assmann (DESY & INFN)

Consiglio Nazionale Ricerche

Istituto Nazionale di Fisica Nucleare

Università di Roma Tor Vergata

WP1
MANAGEMENT & DISSEMINATION
A. Falone (LNF)

WP3
HIGH POWER LASER BEAM LINE
P. Cirrone (LNS)

WP2
BETATRON RADIATION SOURCE
A. Cianchi (Uni-ToV)

WP4
HIGH REPETITION RATE LASER BEAM LINE
L. Labate (CNR-INO)

Scientific Advisory Committee

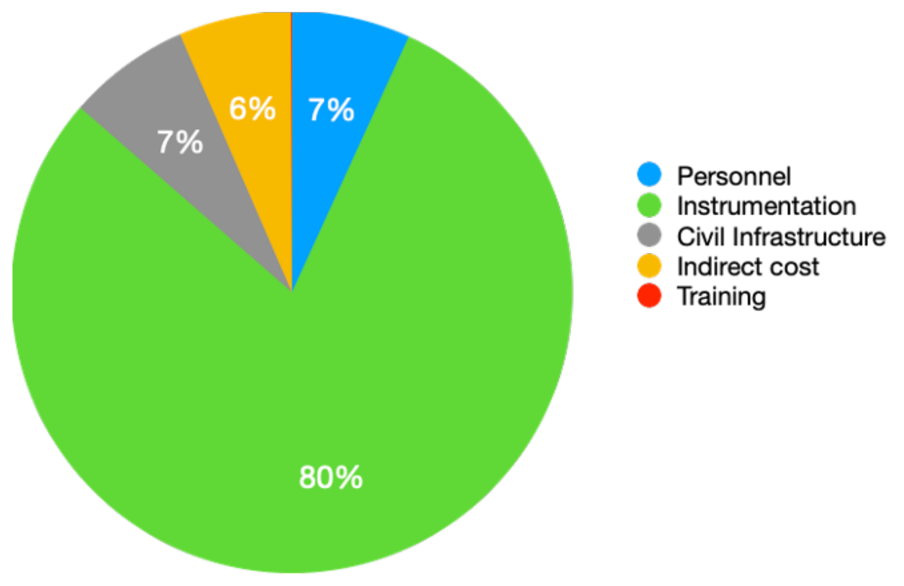
Operating Units Board

Scientific and Technical Board

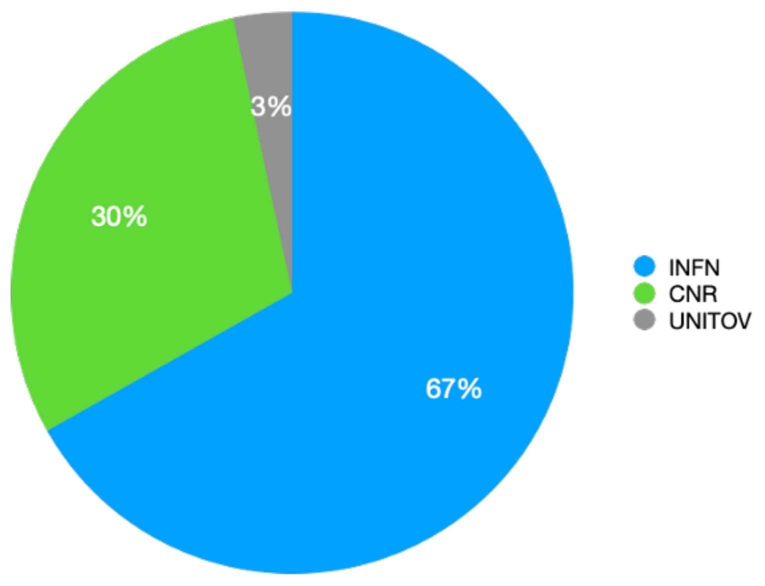
EuPRAXIA Advanced Photon Sources

Costs included in the request for funding (€)			
	To be located within the eight southern regions	To be located outside the eight southern Regions	Total requested grant
Fixed term personnel specifically hired for the project	270.000,00	1.258.000,00	1.528.000,00
Scientific instrumentation and technological equipment,software licenses and patent	6.917.812,47	10.865.386,00	17.783.198,47
Open Access,Trans National Access, FAIR principle implementation	0,00	0,00	0,00
Civil infrastructures and related systems	1.300.006,38	280.000,00	1.580.006,38
Indirect costs, including running costs	575.081,15	869.302,00	1.444.383,15
Training activities	0,00	15.000,00	15.000,00
Total	**9.062.900,00**	**13.287.688,00**	**22.350.588,00**

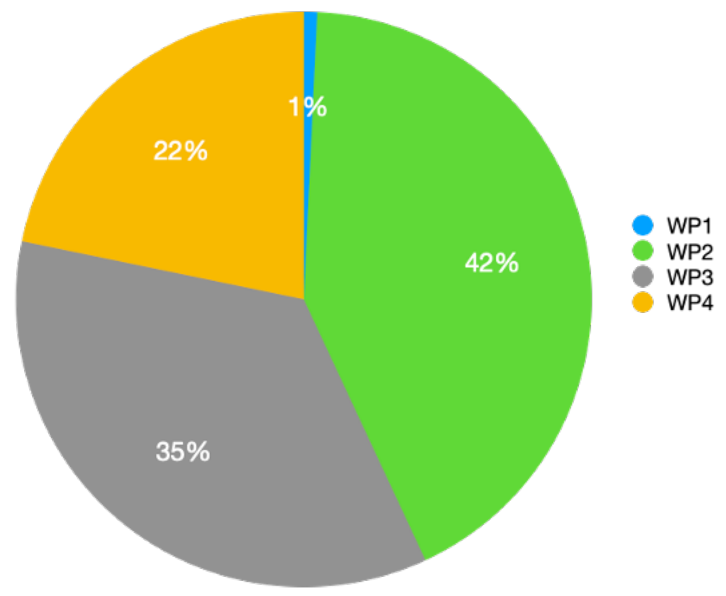
Distribution per item



Distribution per institution



Distribution per WP

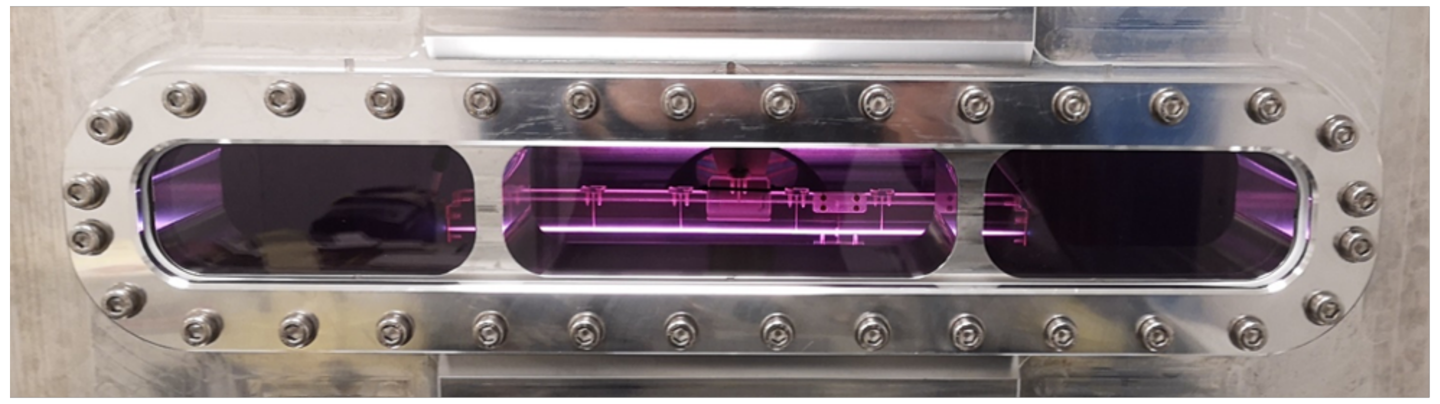


EuPRAXIA Advanced Photon Sources

Plasma-Generated X-ray Pulses: Betatron Radiation Opportunities at EuPRAXIA@SPARC_LAB

Francesco Stellato [1,2,*], Maria Pia Anania [3], Antonella Balerna [3], Simone Botticelli [2], Marcello Coreno [3,4], Gemma Costa [3], Mario Galletti [1,2], Massimo Ferrario [3], Augusto Marcelli [3,5,6], Velia Minicozzi [1,2], Silvia Morante [1,2], Riccardo Pompili [3], Giancarlo Rossi [1,2,7], Vladimir Shpakov [3], Fabio Villa [3] and Alessandro Cianchi [1,2]

$$\frac{d^2I}{d\omega d\Omega}(\theta=0) \cong \frac{N_\beta 3e^2}{2\,\pi^3\epsilon_0 c}\,\gamma^2\left(\frac{\omega}{\omega_c}\right)^2 K_{\frac{2}{3}}^2\left(\frac{\omega}{\omega_c}\right)$$



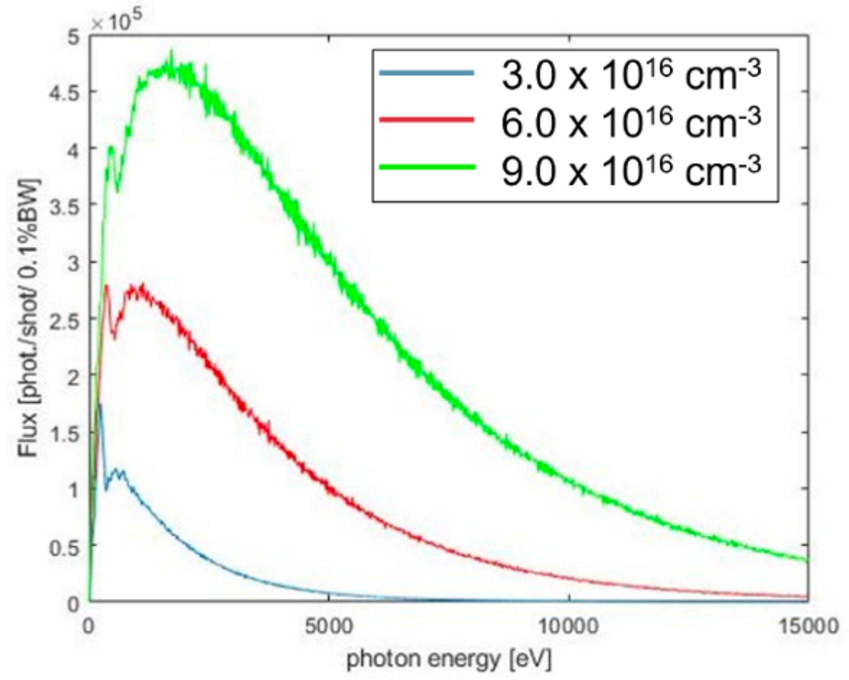
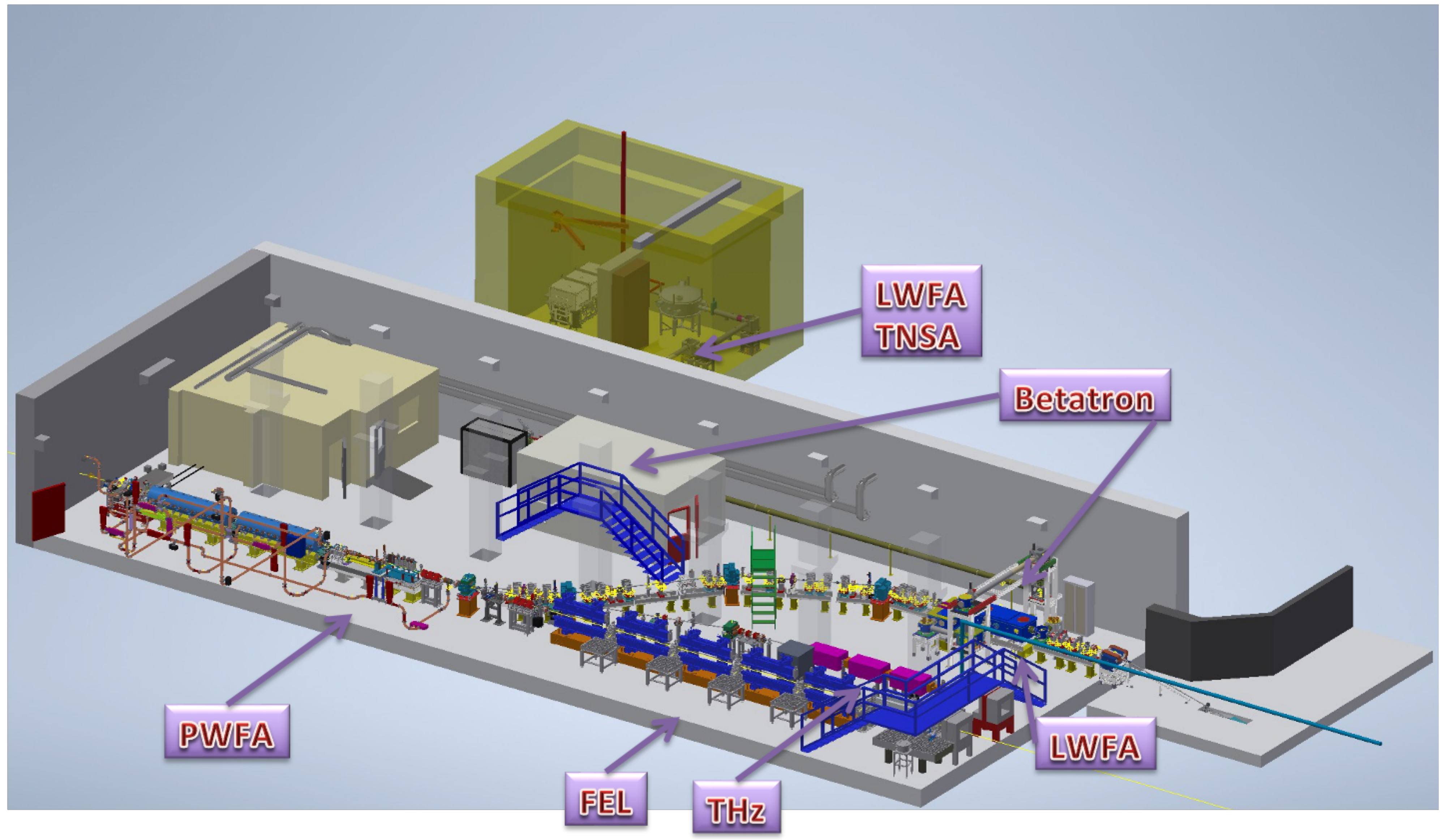
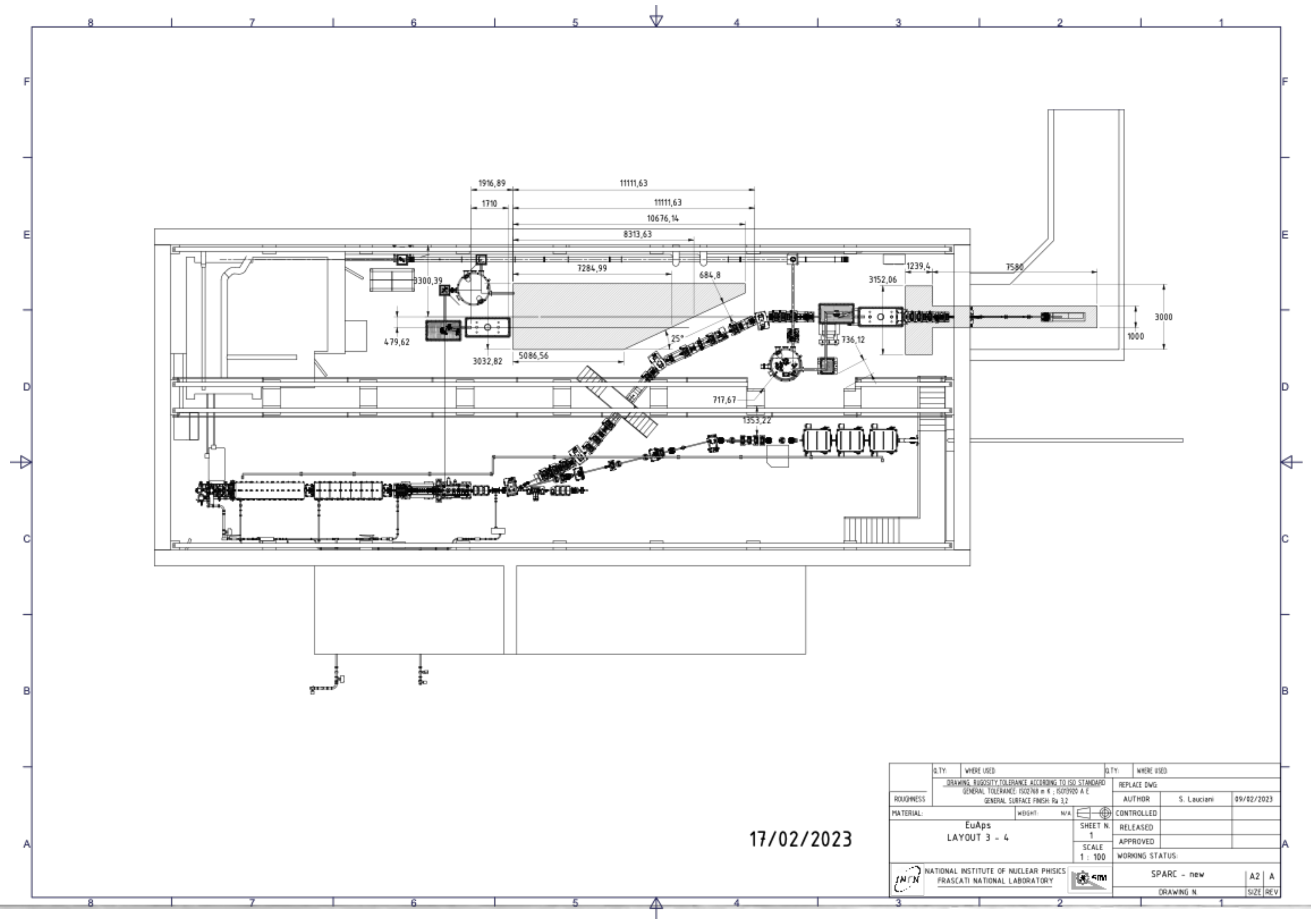


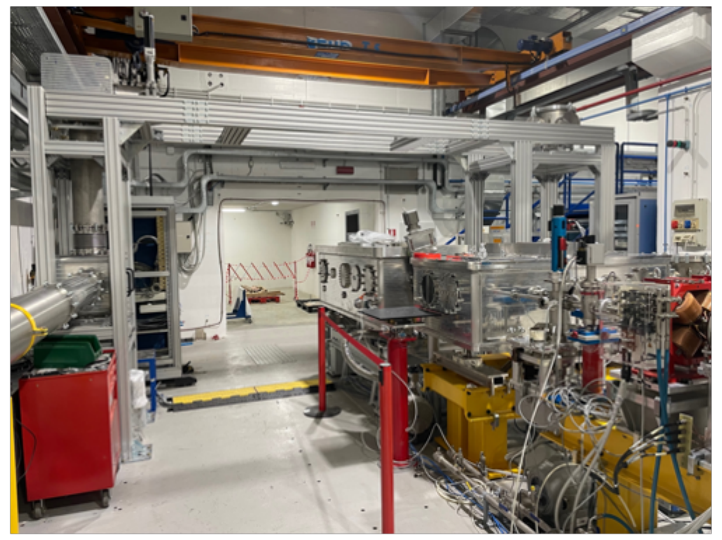
Figure 1. Betatron radiation spectra simulated for a source size of 3 μm and 3 different plasma densities. The total number of photons is 1.7 x ^{9} for the 9.0 x 10^{16} cm^{-3} density, 9.9 x ^{8} for the 6.0 x 10^{16} cm^{-3} density and 4.1 x ^{8} for the 3.0 x 10^{16} cm^{-3} density.

Betatron Imaging (PCI, CT) => sub-μ resolution
Betatron X-ray tme-resoved spectroscopy (XAS)
Beam Diagnostics
FEL Seeding
Betatron coherence



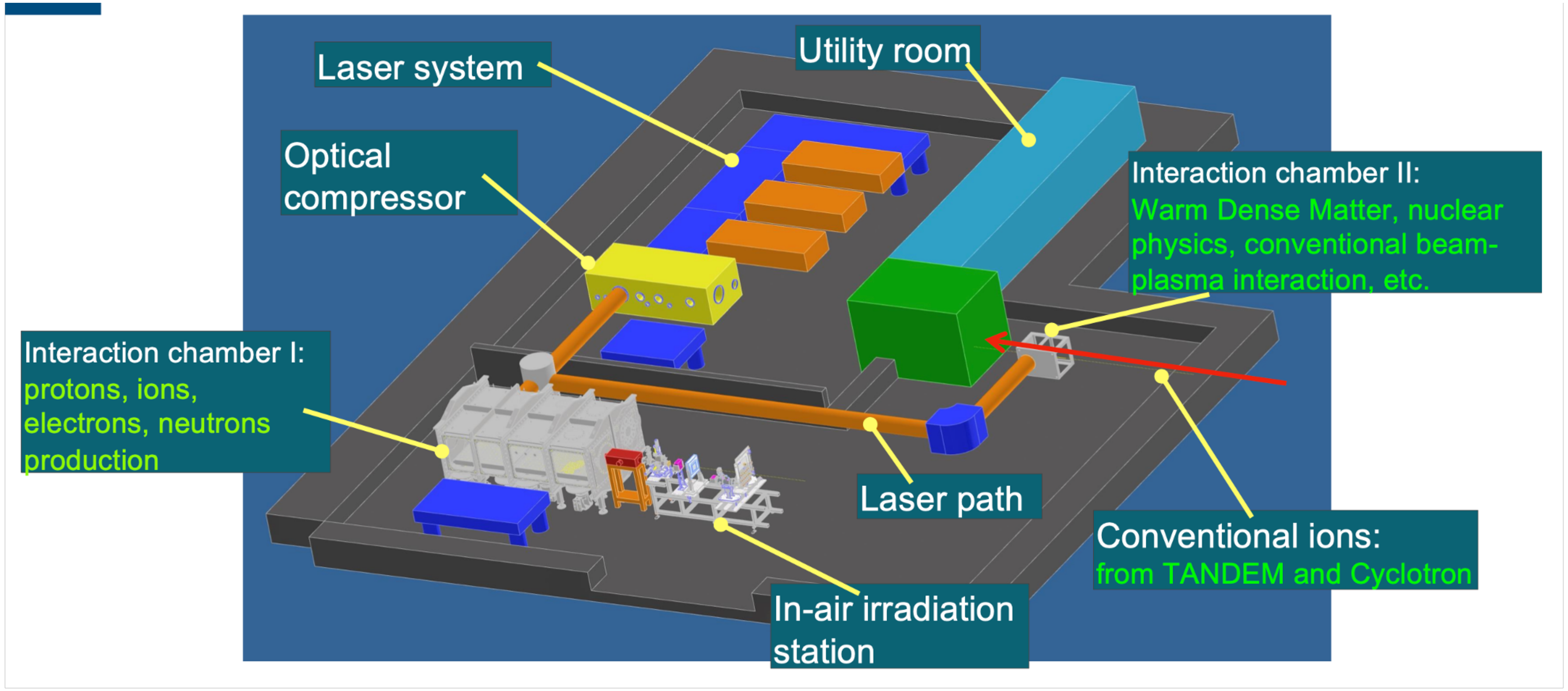
From scratch to reality in 30 (+6) months.





Other activities extra-LNF:

Development of high power laser at INFN-LNS (I-LUCE Facility)

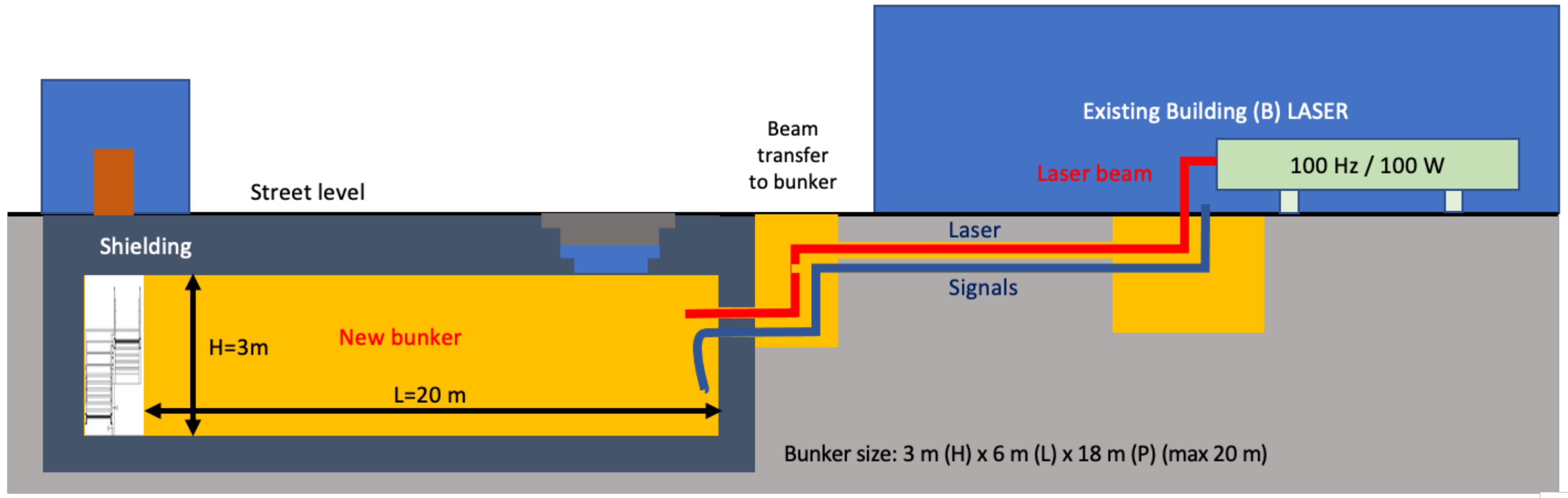


Other activities extra-LNF:

WP.4 High Repetition Rate Laser at CNR-INO (Pisa)

Full 100 Hz system at Joule level will allow to tackle operational issues and mechanical stability

New bunker
Designed for high dose irradiation (100 Hz)



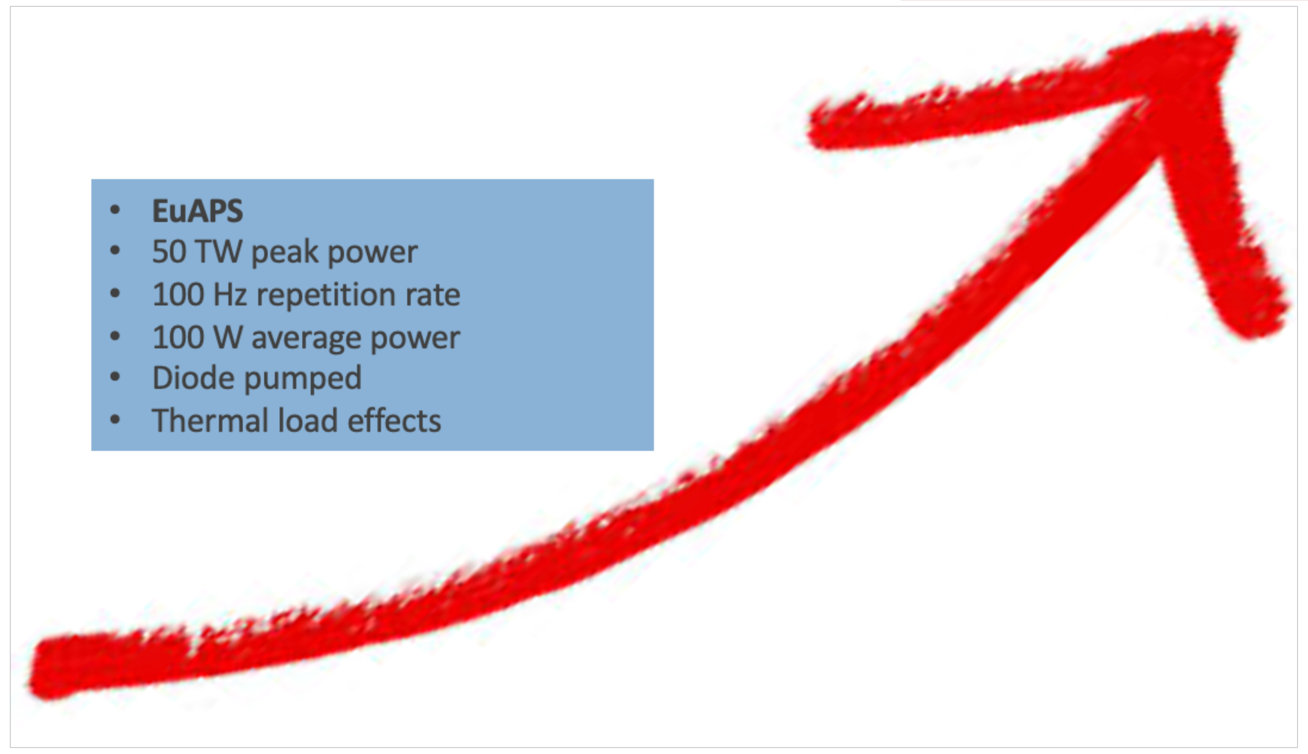
Part of the IPHOQS (ELI/LENS/CUSBO Photonics Infrastructure), and Tuscan Health Ecosystem 4.5 M€ dedicated funding @ CNR-Pisa)

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

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

EuPRAXIA Advanced Photon Sources

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



Courtesy L.Gizzi (CNR-INO)

EuPRAXIA Advanced Photon Sources

A seguito della selezione, ciascun Soggetto Attuatore delle progettualità connesse all'investimento PNRR oggetto del presente Avviso, si obbliga:

a) …….

t) ad individuare entro il 31 dicembre 2023, ai sensi del decreto legislativo 18 aprile 2016, n. 50, del decreto-legge 31 maggio 2021, n. 77, nonché di tutte le altre norme di settore applicabili, i soggetti Realizzatori;

x)…….

In other words ALL the tenders must be adjudicated by December 2023.
Current Status: tenders preparation even if in some cases it is still unclear what we have to buy.

Comments & Recommendation - Follow up

- The SC re-iterates that further clarifications of the long-term schedule and resource needs of all LNF accelerators are a boundary condition for a successful EuPRAXIA@SPARC_LAB project execution.
- Though EuAPS can be a door opener for future EuPRAXIA@SPARC_LAB users, it bears the risk that some of the already scarce resources for EuPRAXIA@SPARC_LAB preparation are diverted to EuAPS realization. EuAPS uses a very different approach to X-ray generation and is therefore of limited relevance for the technical progress of EuPRAXIA@SPARC_LAB.

This is certainly true. The impact of EuAPS on the progress of EuPRAXIA@SPARC_LAB might be relevant, at the moment is not too critical and hopefully in the near future this can be further mitigated. It should be added that EuAPS **IS** part of EuPRAXIA in the wide sense, so it should not be seen as a competing project.

A intense recruitment process is ongoing, during 2023 we will have (or already have in some cases):

- **4 Post-Doc:**
  FEL
  Magnets
  Controls
  Virtual RF Diagnostics through ML application
- **4 Technicians:**
  Magnets (2)
  Diagnostics
  RF
- **4 Researcher and Technologists in several areas:**
  Project Management support
  Infrastructure Manager
  Plasma Scientist
  Laser Scientists (to be found)

- **1 Permanent Position** (laser scientist) started few weeks ago.

In addition several positions will be covered for other projects and from other funding lines, although not directly linked to EuPRAXIA those resources can certainly alleviate the workload on the EuPRAXIA core team.

Comments & Recommendation - Follow up

- *An anticipated procurement of one of the S-band modulators and installation in SPARC_LAB K2 slot would provide early RF system tests.*
- *The recent experience with the SPARC_LAB triplet emphasizes the need of well-established quality control procedures for all critical components of EuPRAXIA@SPARC_LAB.*
- *Continue with the two-pronged approach for X-band klystrons, and monitor progress with both companies closely. This is probably the most time critical procurement item for EuPRAXIA@SPARC_LAB.*

- The decision to procure 2 S-Band SS modulators for SPARC_LAB is now taken. Preliminary discussion already started to start up the procurement procedure.

- For the implementation phase and especially for the most critical tenders we will involve a quality engineer (already found and available).

- The 2 X-Band tube approach is now fully in the production phase. In the 2024 we hopefully receive both Canon and CPI tubes.

Conclusions

- EuPRAXIA transition to single project to multiple correlated projects (Program)

- EuPRAXIA@SPARC_LAB is gradually converging to solid conclusions- on time w.r.t. original baseline. TDR is expected to be written at beginning of 2025.
    - X-Band Sections development is ongoing
    - TEX facility is now operating. 2 additional RF station will upgrade the facility by 2024.
    - Ondulators prototype SABINA ready.
    - Plasma R&D is proceeding towards high performances solutions
    - Transition to the implementation phase is now ongoing

- EuAPS is a new challenge that will complete the EuPRAXIA phase 1
    - Very demanding project from management perspectives (all tenders to be adjudicated by Dec23).
    - Additional manpower was possible (including an infrastructure manager).
    - Opportunity to laser upgrade
    - Synergy with EuPRAXIA@SPARC_LAB for beam line and user end station.

- EuPRAXIA Building has now passed the authorization phase and executive design could be ready by the end of the year.