EuPRAXIA @ SPARC_LAB

Scientific Committee - 14/11/2022

Antonio Falone
On behalf of the EuPRAXIA Team

EuPRAXIA @SPARC_LAB Follow up

- Progress on the EuPRAXIA@SPARC_LAB TDR activities
- Schedule Baseline
- Other related projects

Consolidation EuPRAXIA EU framework

We have applied to several EU and National calls, to strengthen and consolidate EuPRAXIA Iniative

- June 2021- Approved ESFRI Roadmap 2021
- Jan 2022 – Application to the ESFRI Preparatory Phase, 3M€ (750k€ @ INFN) – Approved 12/04/2022 – Starting date 01/11/2022 - Kick off meeting 24-25 November 2022 - 4 years project
- Feb 2022 – Rome Technopole, 2.8M€ For the consolidation of RI – not directly related to EuPRAXIA but in synergy.
- Feb 2022 – EuAPS, EuPRAXIA Advanced Photon Source. PNRR, 22M€– 1° Ranking – Starting date 01/12/2022 30+6months in collaboration with CNR and University of Rome «Tor Vergata»
- Apr 2022 – EuPRAXIA Doctoral Network Program, 2 PhDs in Accelerator Physics

Progress on the TDR

Significant progress for ALL working areas and working packages

- Intermediate layout basically frozen (few minor issues to be further studied)
- Realization of X-Band accelerating section mechanical prototype full scale – in house
- Injector layout – Completed
- RF power source strategy concluded and procurement in progress → delay in the administrative procedure. CPI klystron kickoff in few weeks. Canon klystron expected begin 2023.
- Ondulator strategy concluded -> 2 Beamlines in the baseline prototyping activities are ongoing

In general the TDR work is advancing according to the schedule.
Additional Manpower is about to be hired (thanks also to the PNRR Funding).

TDR – Beam Dynamics | Machine Layout

Beam Dynamics Studies – Machine Layout

Photoinjector layout concluded (including X-Band 9 cells linearizer)

S2E Finalization for :

30+200pC at 1-1.2 GeV
50+230 pC at 1-1.2 GeV
X-Band @Gun finalization 200-300-500pC Beam

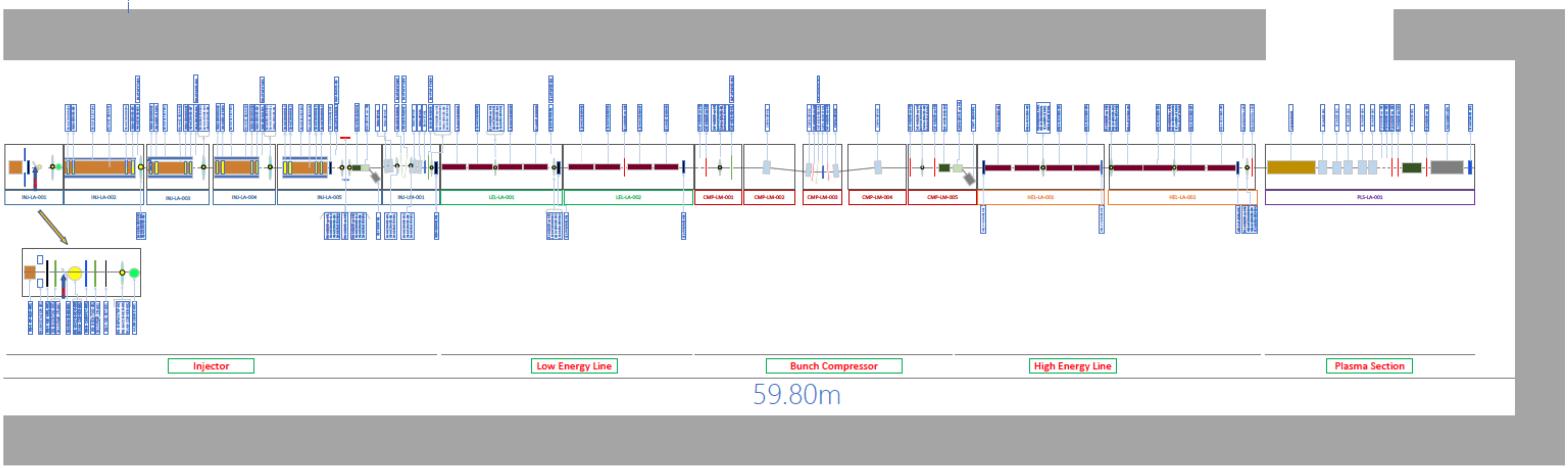
Jitter & Sensitivity analysis will be performed in Spring 2023 – according with the schedule

Courtesy C.Vaccarezza, A.Giribono, S.Romeo

Machine Layout

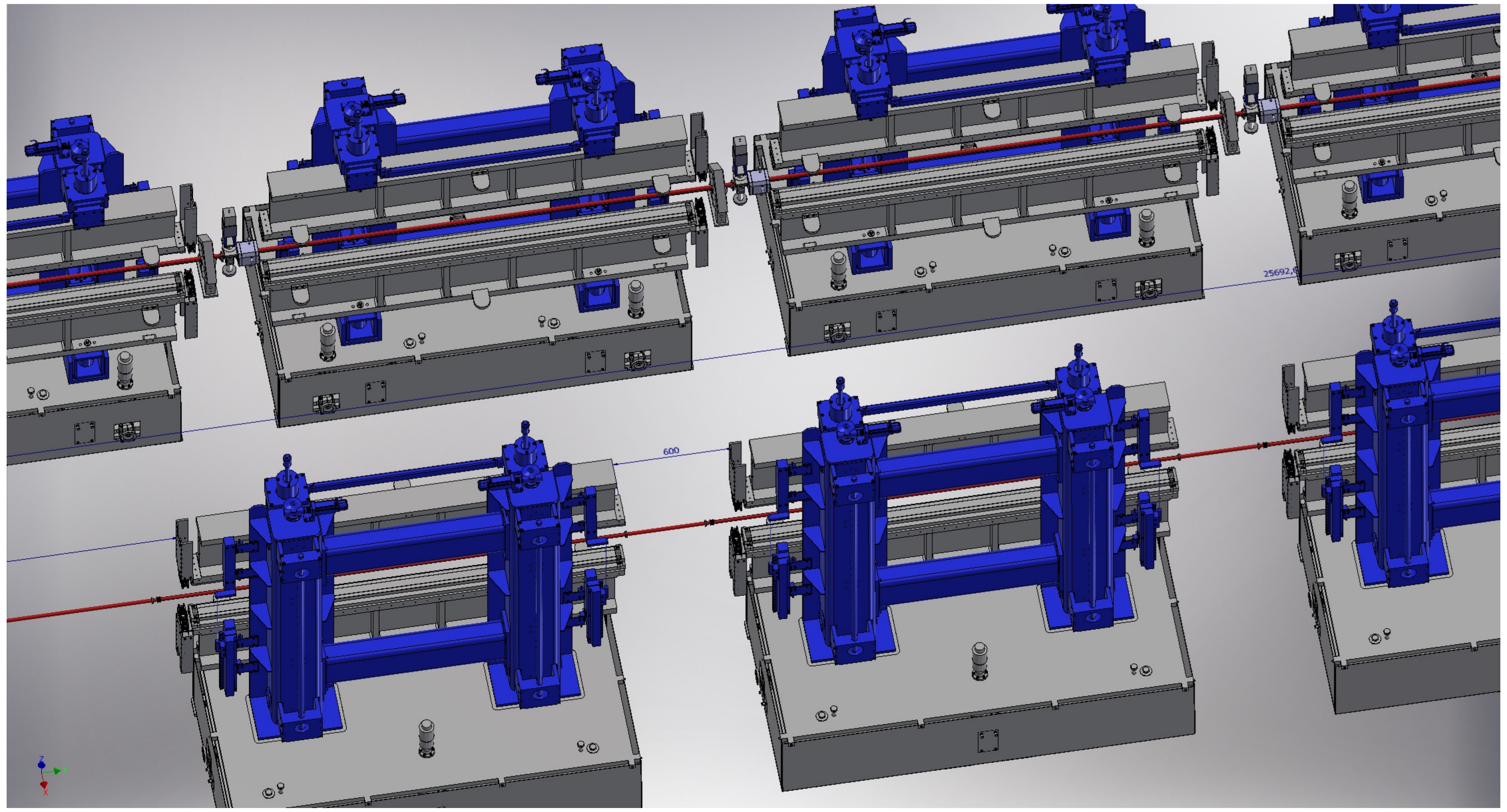
Courtesy F.Cioeta & E.Di Pasquale

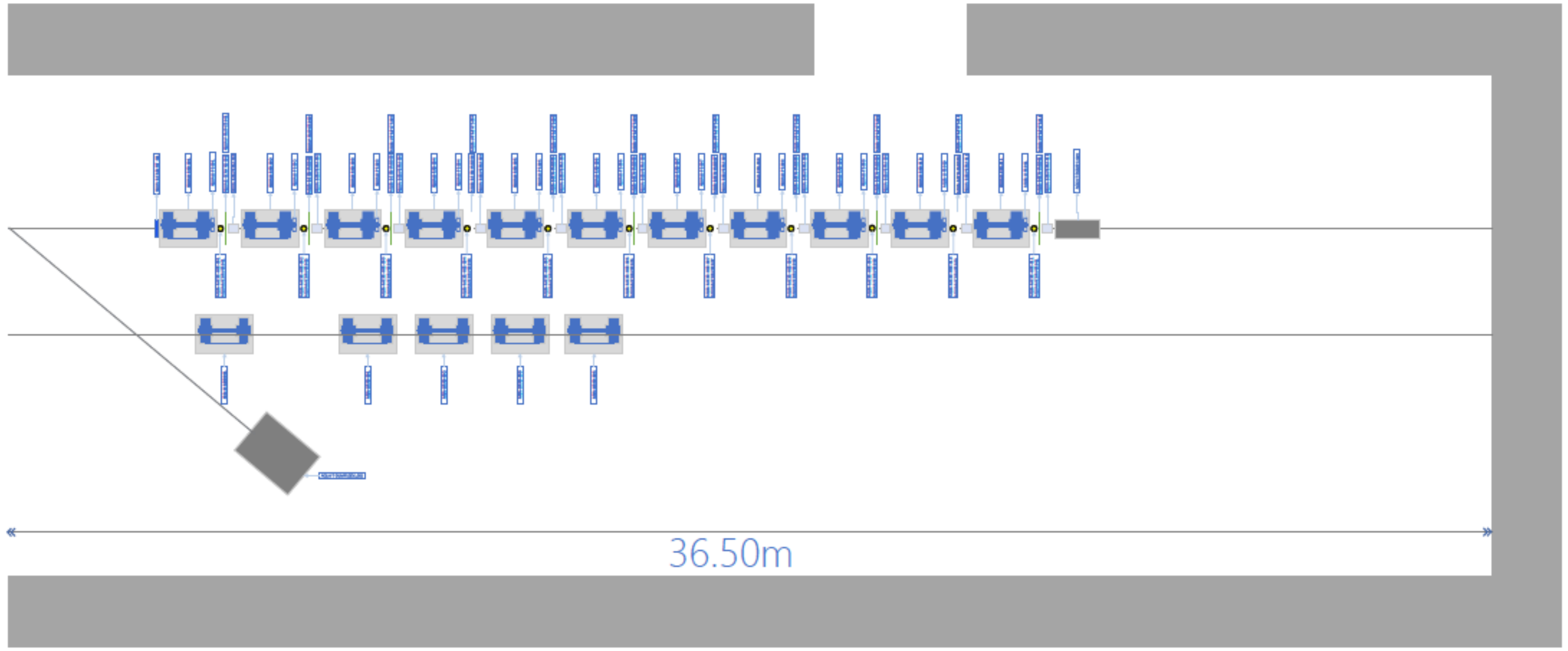
Machine Layout



Courtesy F.Cioeta & E.Di Pasquale

Machine Layout





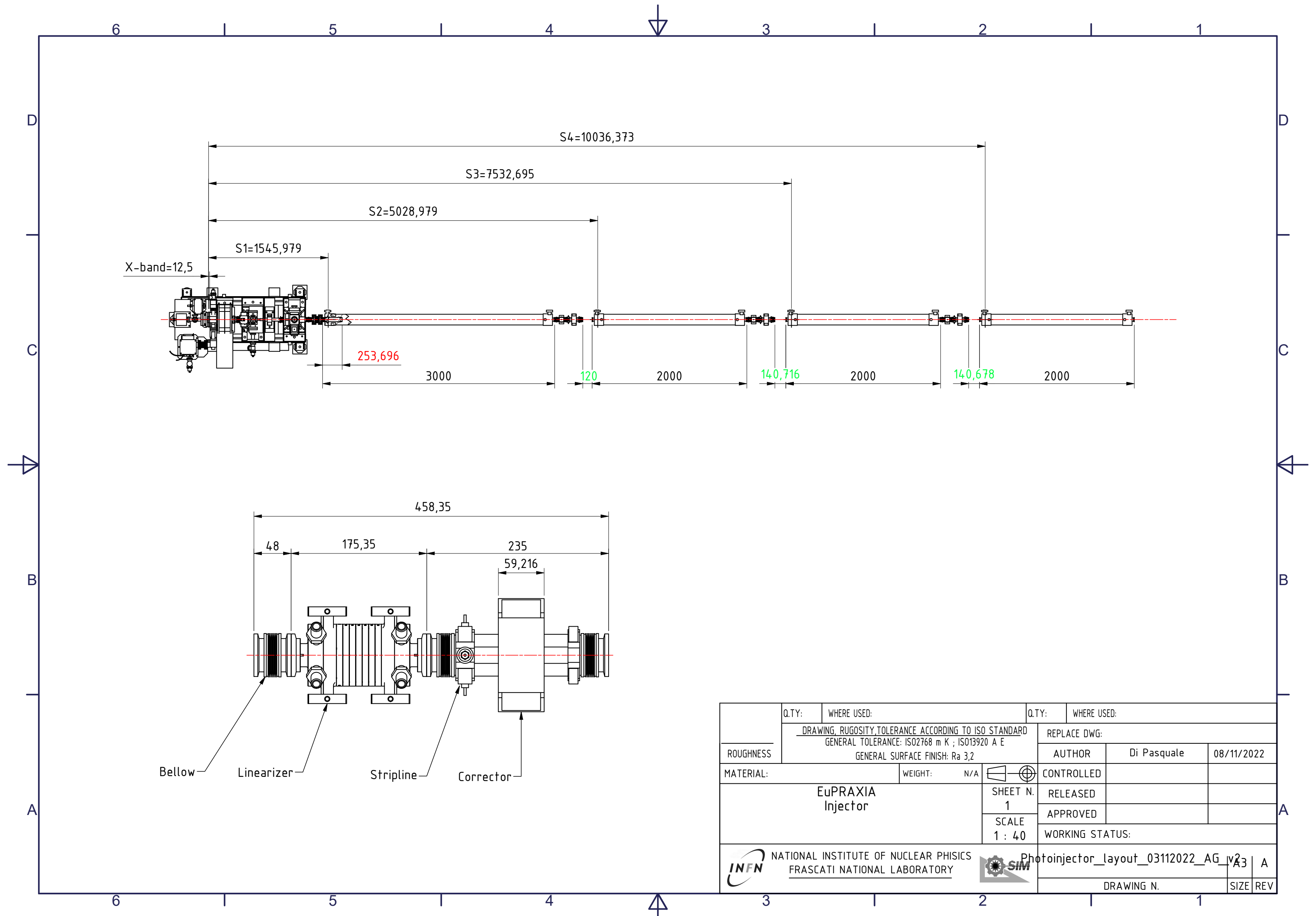
Courtesy F.Cioeta & E.Di Pasquale

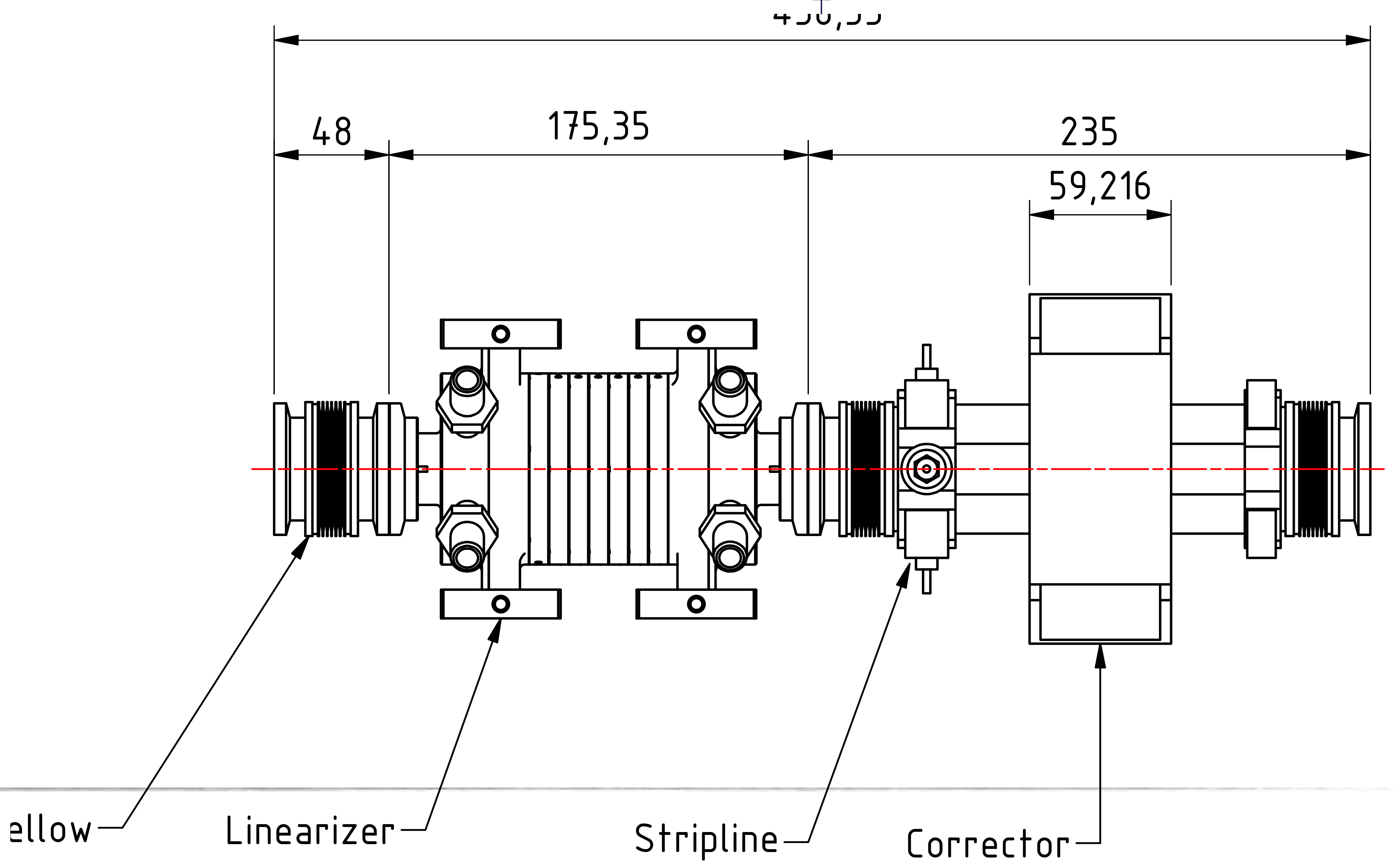
Injector

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

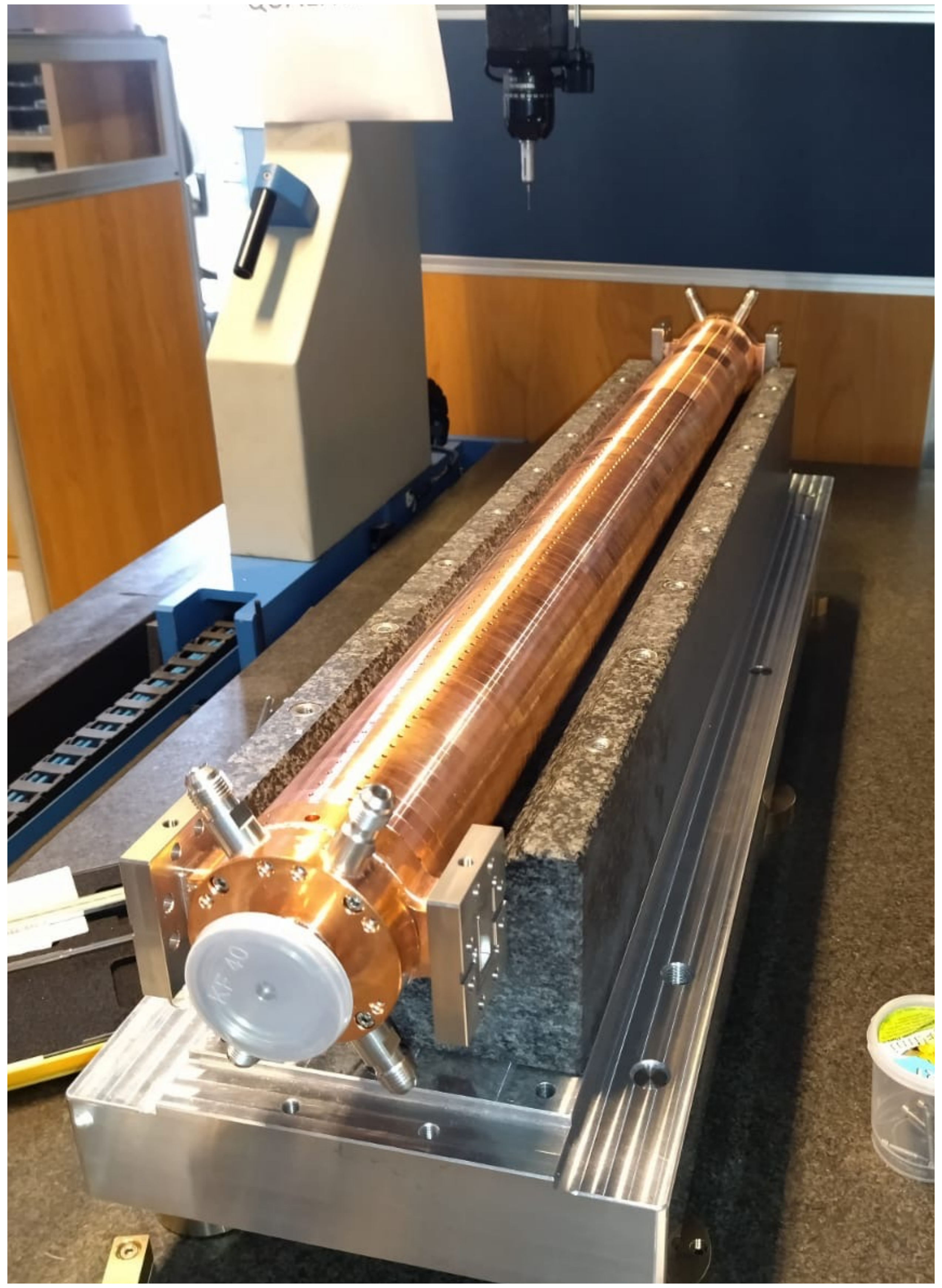
- ✓ Injector layout
- ✓ High charge working point
- ✓ Comb Beam and S-Band optimization (3+2+2+2)
- ✓ RF distribution for the S-Band system (advanced layout agreed but still to be optmized)
- ✓ SW vs TW X-Band linearizer in terms of power distribution
- ✓ Jitter and sensitivity studies

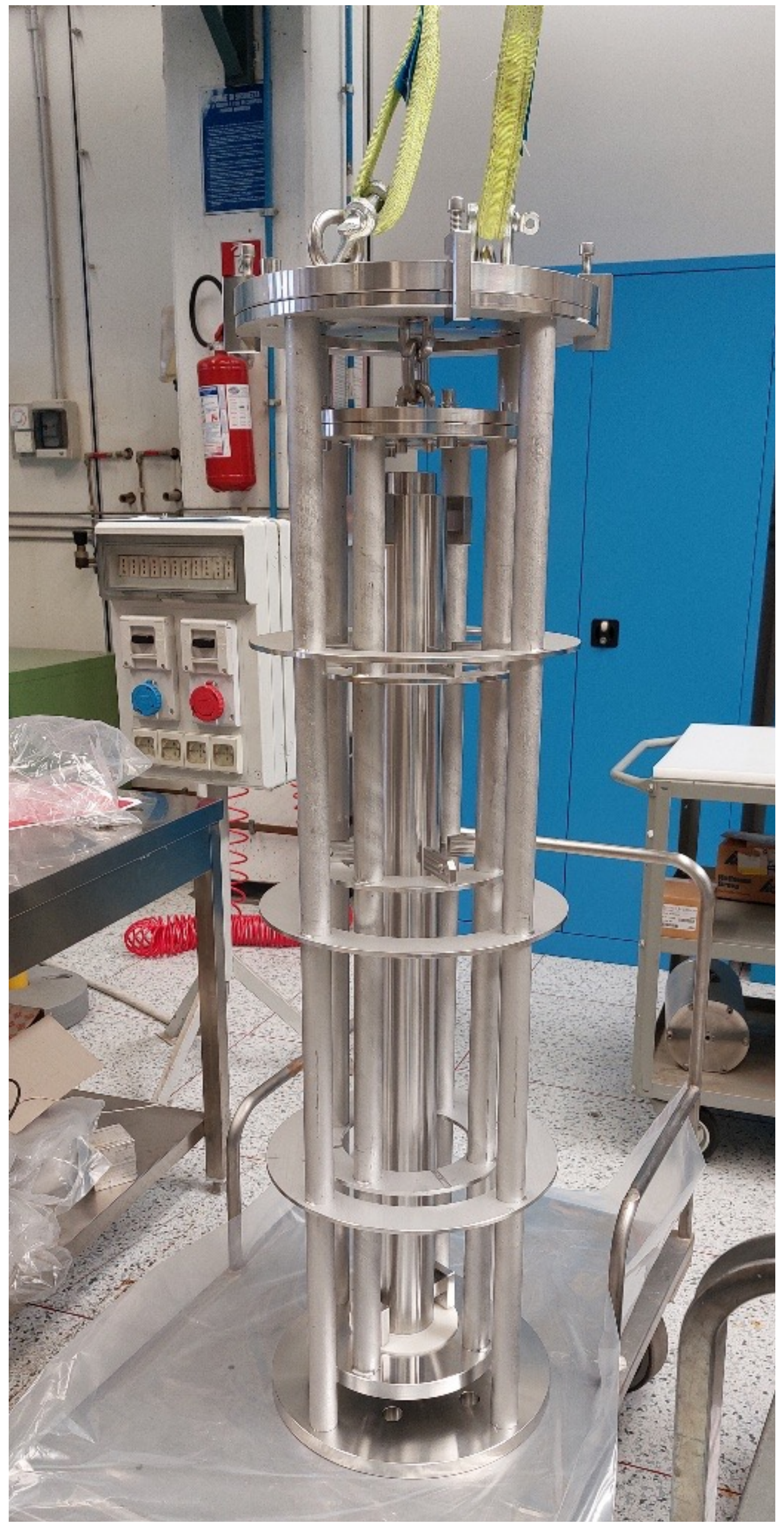




LINAC

- X-Band Accelerating section. Mechanical prototype full scale built.
- Dimensional check and quality control ongoing
- Design of the RF full scale X-Band structure (C.I.) is completed
- Procurement of material for the realization of the RF prototype has started (to be concluded late spring 2023).
- LINAC Layout complete (except Laser heater and bunch compressor design still to be finalized).





Courtesy D.Alesini

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. Kickoff in the following weeks.
- ✓ Procurement High Repetition Rate Canon Klystron through Scandinova is ongoing – to be finalized begininning of 2023
- ✓ Optimization of the RF Distribution on going (including X-band deflector and linearizer).
- ✓ TEX Facility – Radioprotection authorization process completed. It should be able to start the scientific program soon (waiting for the formalization of the authorization).

Courtesy A.Gallo

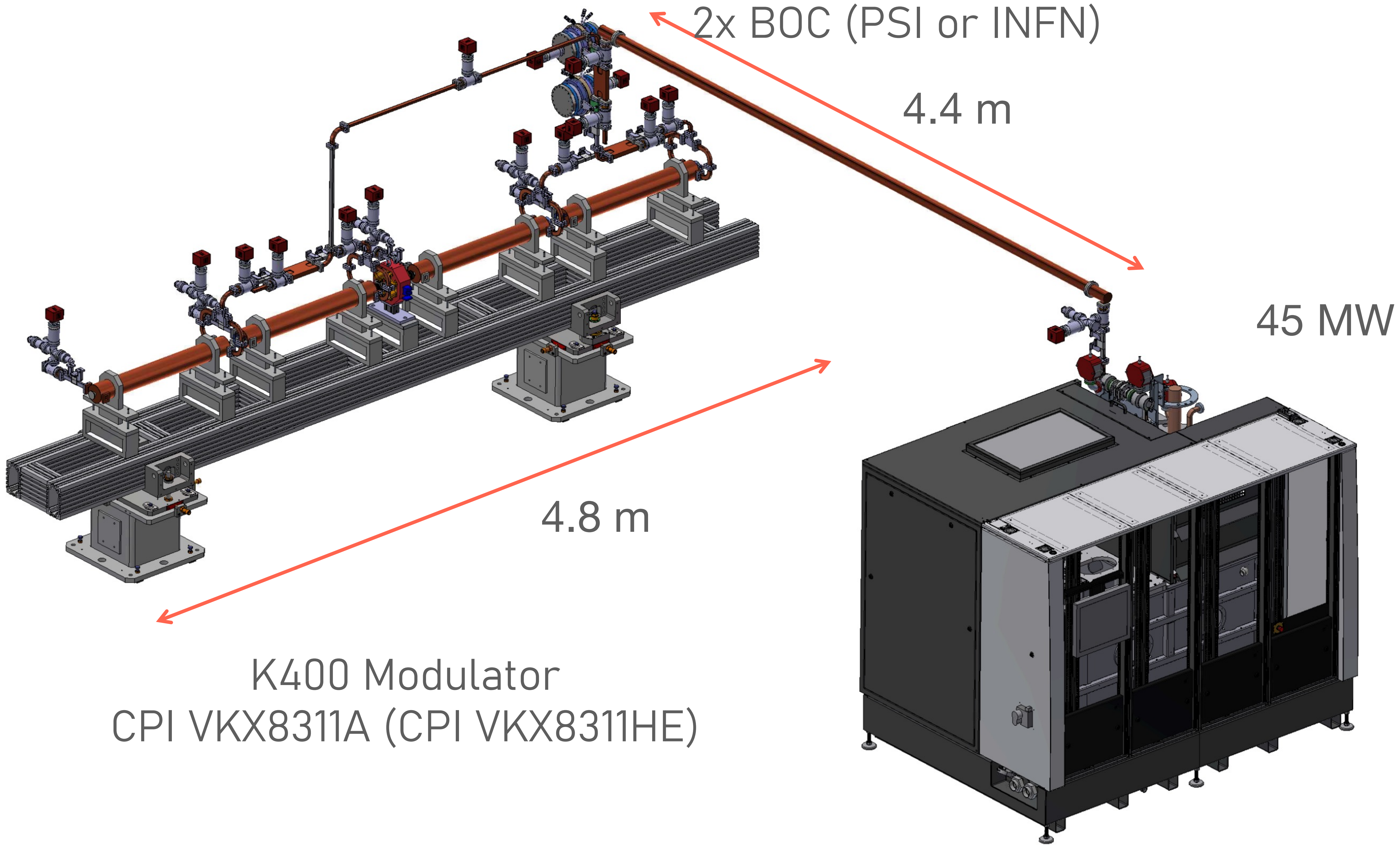
High Efficiency Klystron Specs

No	Parameter		Unit
		nominal	
1	RF Frequency	11,9942	GHz
2	Peak RF power	50	MW
3	Average RF Power	7,5	
4	RF pulse width (at -3dB)	1,5	µs
5	Pulse repetion rate *	50 / 100	Hz
6	Klystron peak voltage	430	kV
7	Klystron peak current	212	A
8	Perveance	0,75	$\mu A/V^{1.5}$
9	Gain at peak power	50	dB
10	Bandwidth (at -3 dB)	50	MHz
11	Efficiency at saturation	55	%
12	Maximum output VSWR	1.10 : 1	
13	Variation of anodic current (at klystron peak power) within +/- 5% cathode heater power variation		
14	Fraction of RF powr in 2nd harmonic		dBc
15	Pulse failures (arcs etc) during 12 hours continuous test period	< 1	
16	Heater voltage DC	TBD	V
17	Heater current DC	TBD	A
18	Preheating period stable operation full compliant		Hours
19	RF drive power	500	W
20	Magnet current (Main Top)	TBD	A
21	Magnet current (Main Bottom)	TBD	A
22	Magnet current (Gun Coil)	10	A
23	Water flow rate (Collector)	10	GPM
24	Water flow rate (Body)	2	GPM
25	Water flow rate (Magnet)	10	GPM
26	X-ray radiation	0,5	µSv/hr
27	RF output WR-90 flange	TBD	
28	RF input WR-90 flange	TBD	
	* depending on the RF pulse length		

RF Power Source layout

CPI - OPTION

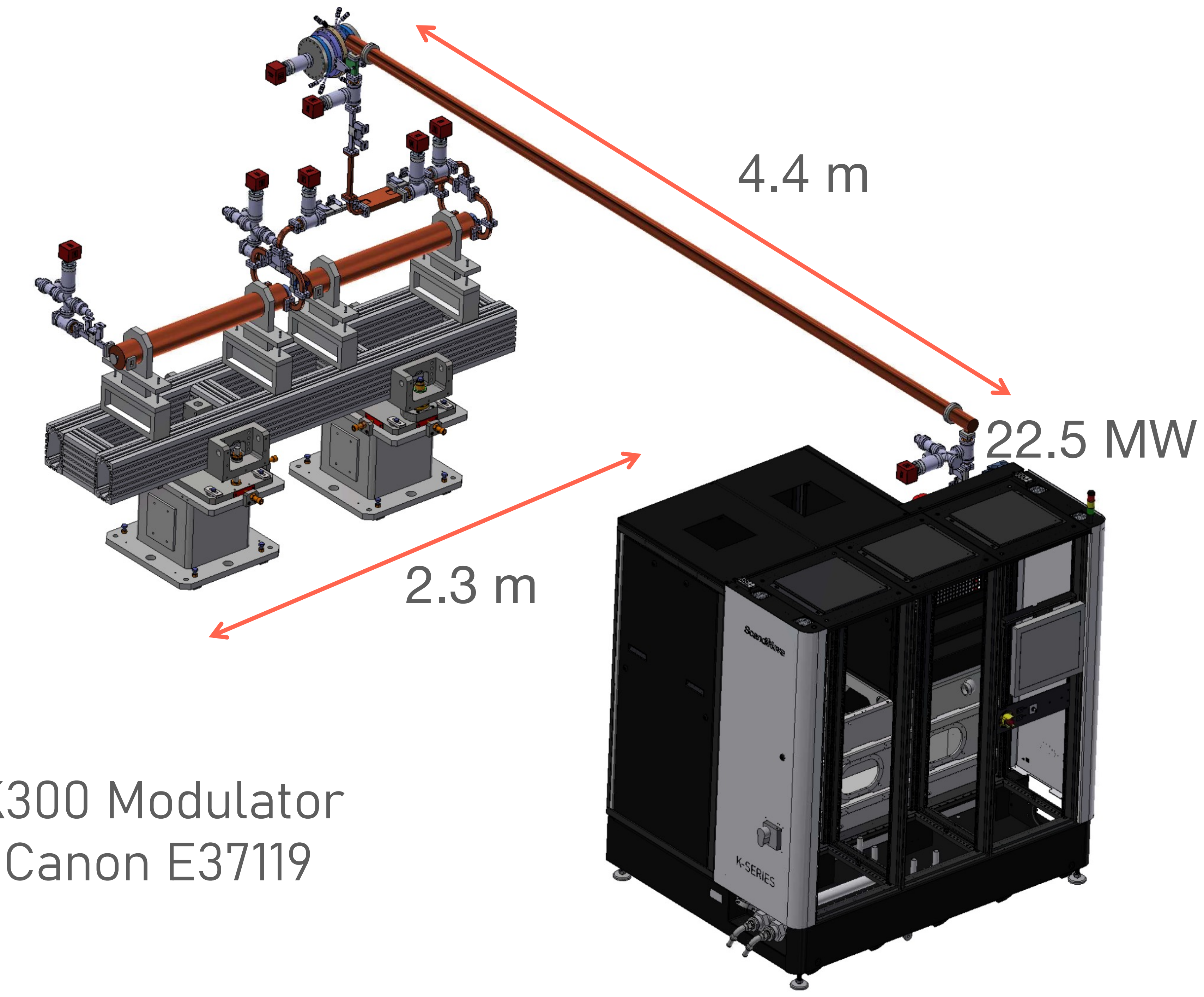
- 2x BOC on one line
- Less flexibility
- Different LE and HE module layout
- Lower power plants number



K400 Modulator
CPI VKX8311A (CPI VKX8311HE)

CANON - OPTION

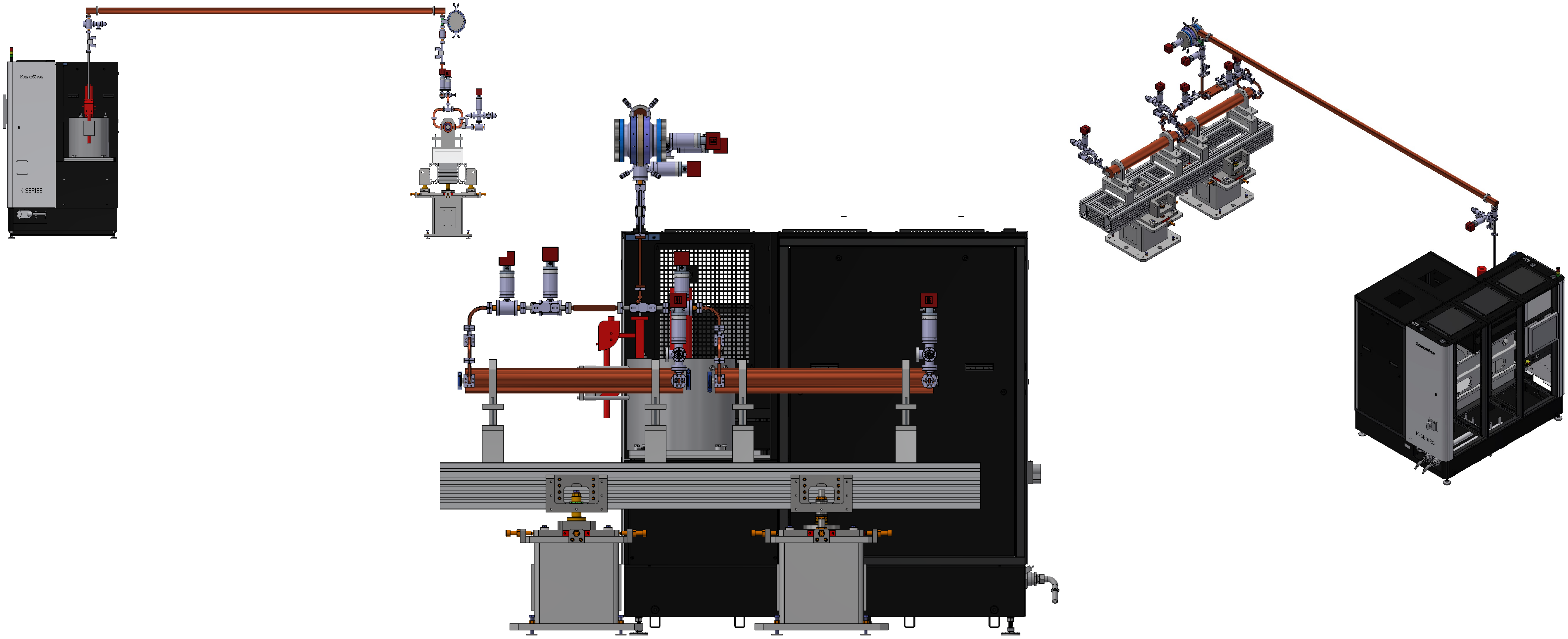
- 1x BOC on one line
- Higher flexibility
- Lower Modulator power requirements
- Possible upgrade at high rep. rate of the Linac



K300 Modulator
Canon E37119

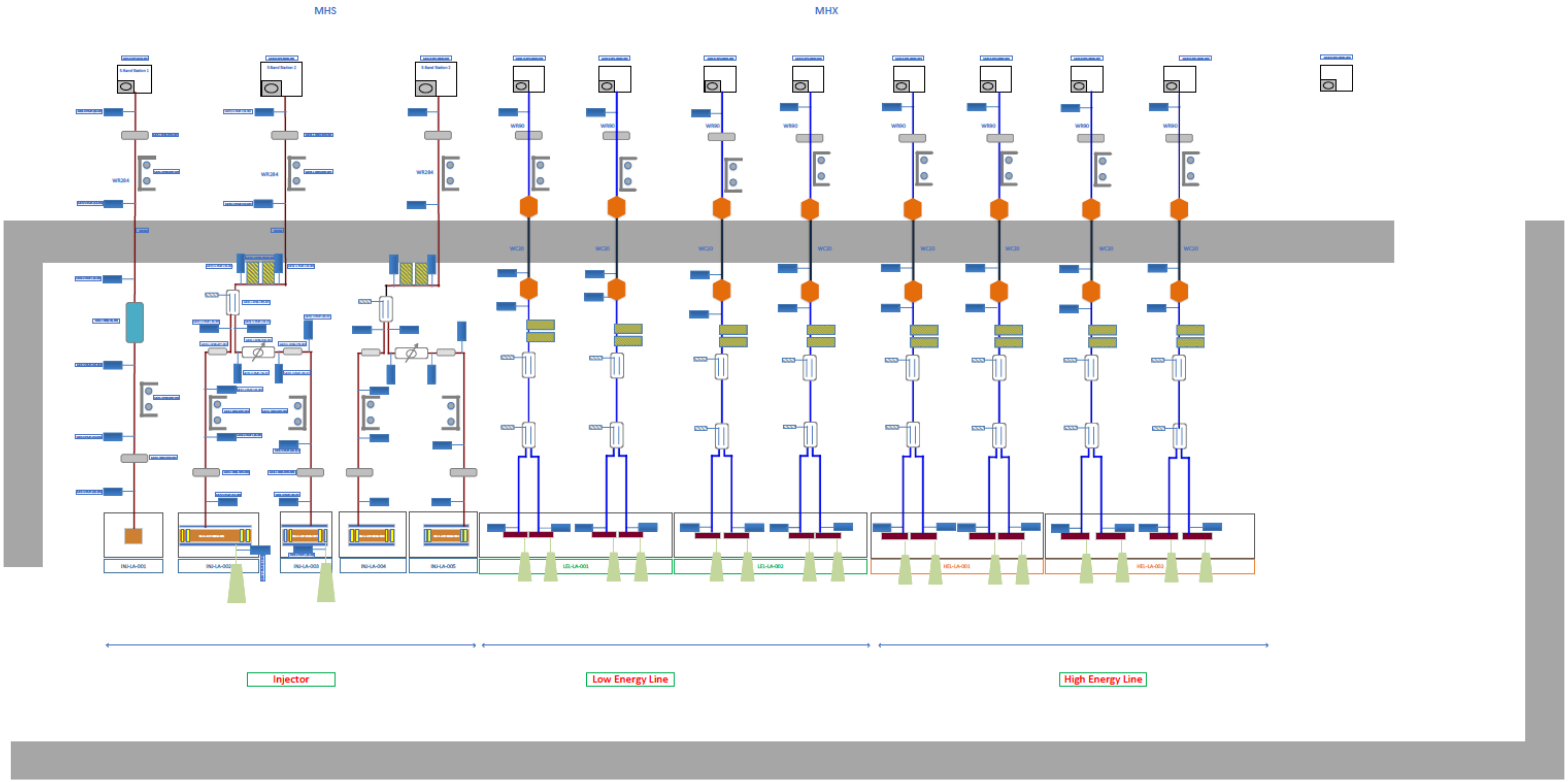
Courtesy F.Cardelli

RF Power Source layout



Courtesy F.Cardelli

RF Power Source layout

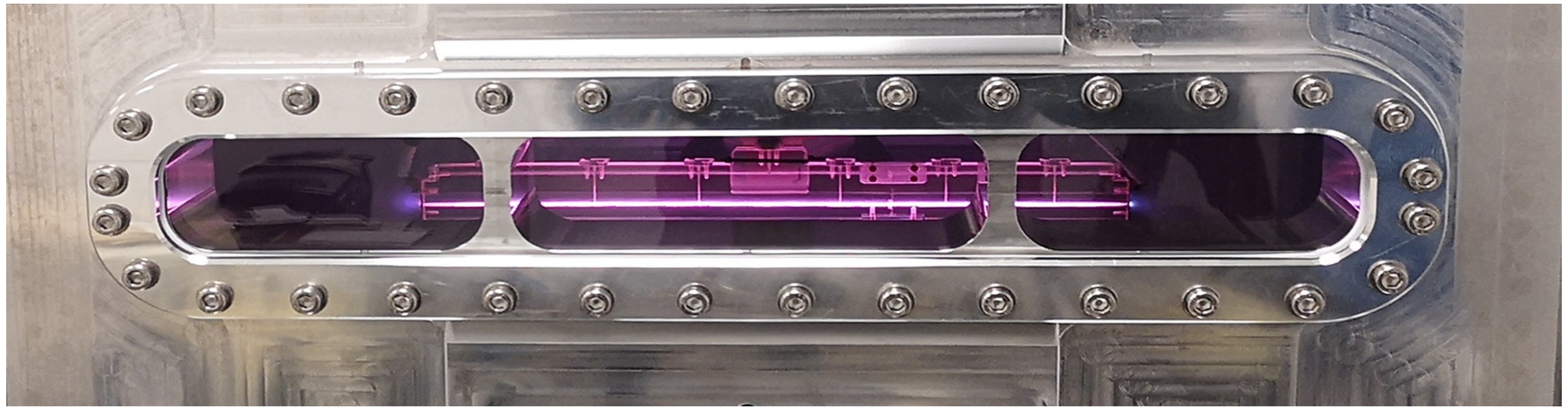


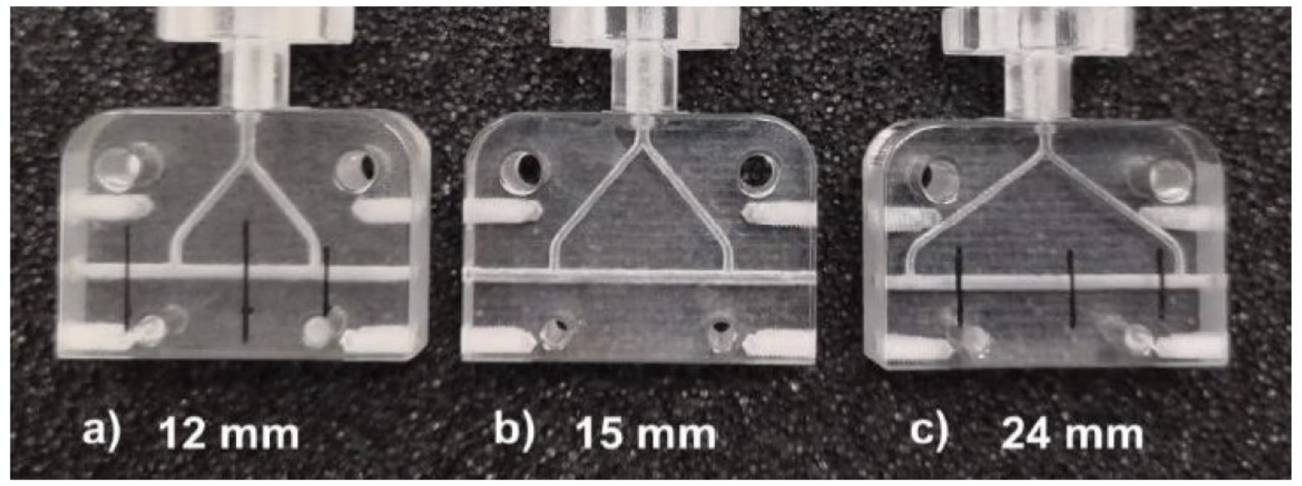
Courtesy F.Cioeta

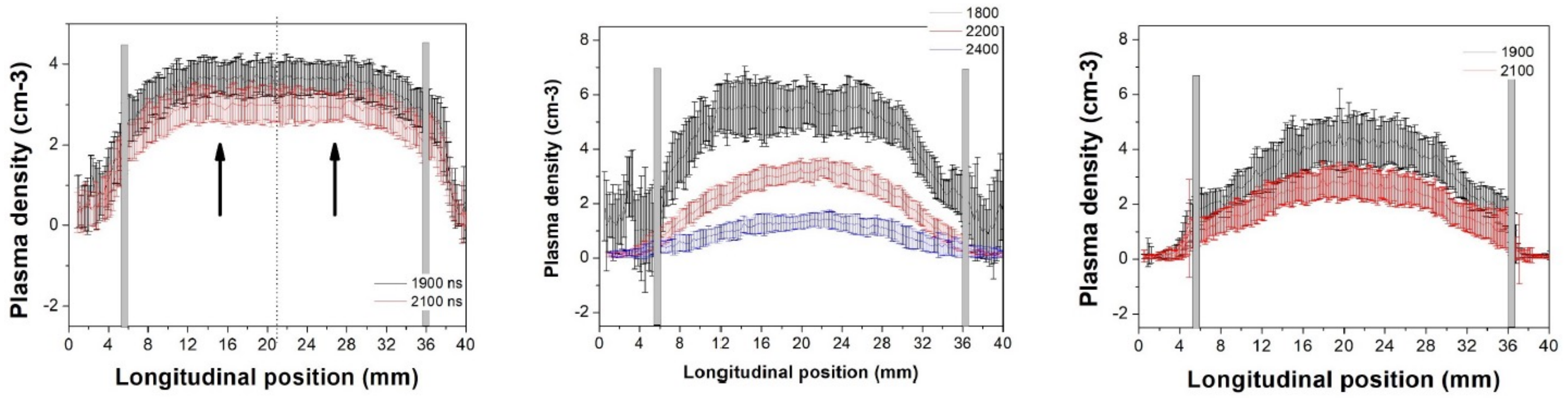
Plasma Module

Production of the first prototype of long capillary (40cm) - Already presented at the last Sci-Com meeting.

- ✓ 40 Cm Discharge was successfully achieved in a plastic capillary.
- ✓ Plasma density completely characterized
- ✓ Vacuum tests with plasma at 100Hz have been reached .
- ✓ Transverse matching tests ongoing
- ✓ 40cm sapphire capillary tests to be performed



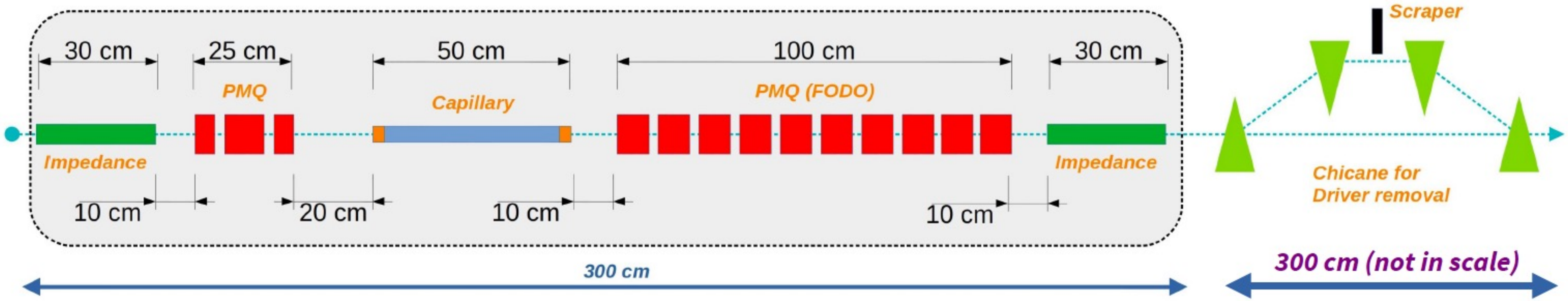




Courtesy R.Pompili, A.Biagioni

Plasma Module

Plasma module layout – Different options under investigations.



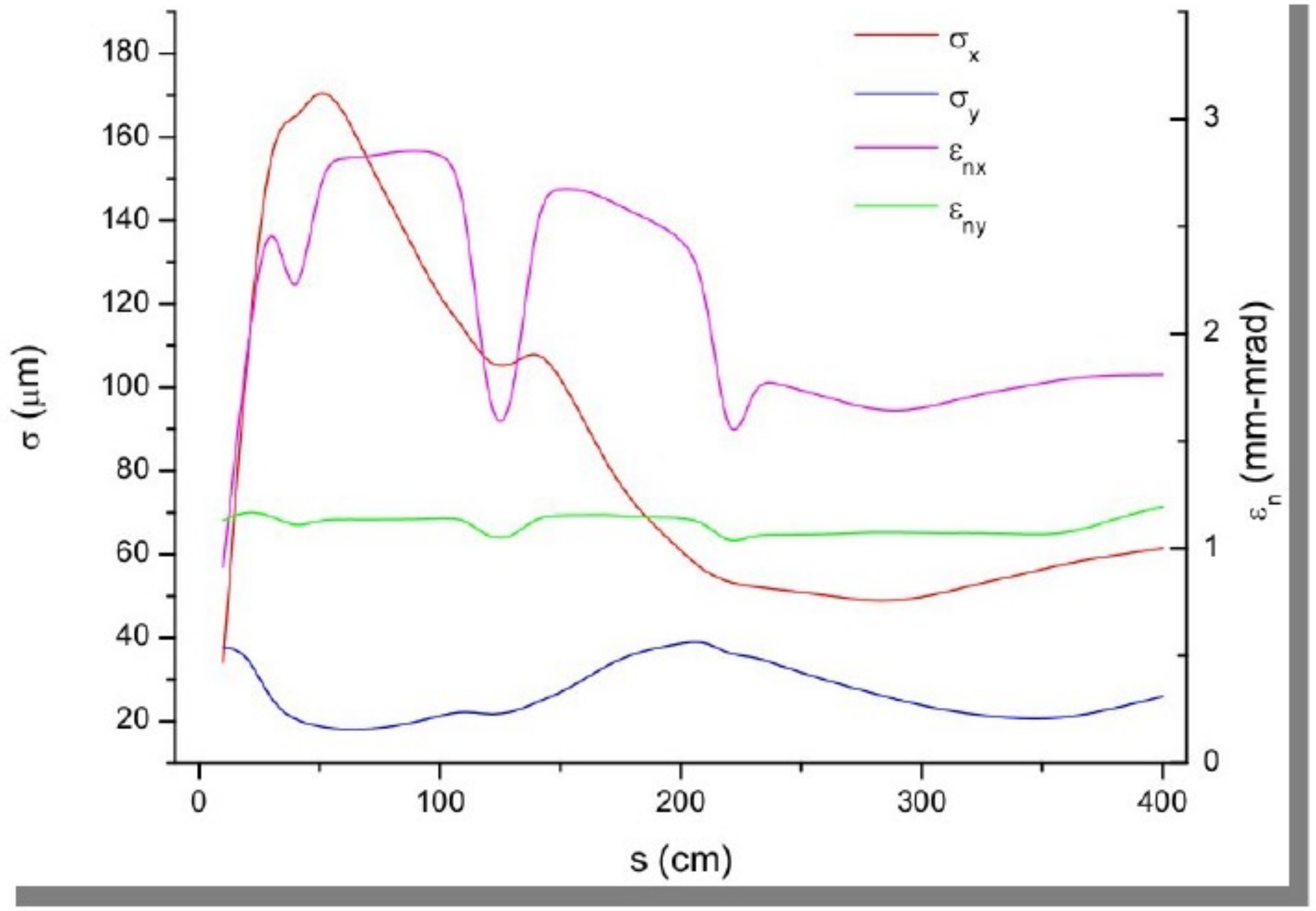
Option 1

From CDR, first idea is to use a long "gentle" FODO to extract the witness.

Major part of the driver is still transported

A magnetic chicane must be used to separate witness and driver in energy and cut the latter with a scraper

Simple solution but require some space and single independent tuning for each PMQ

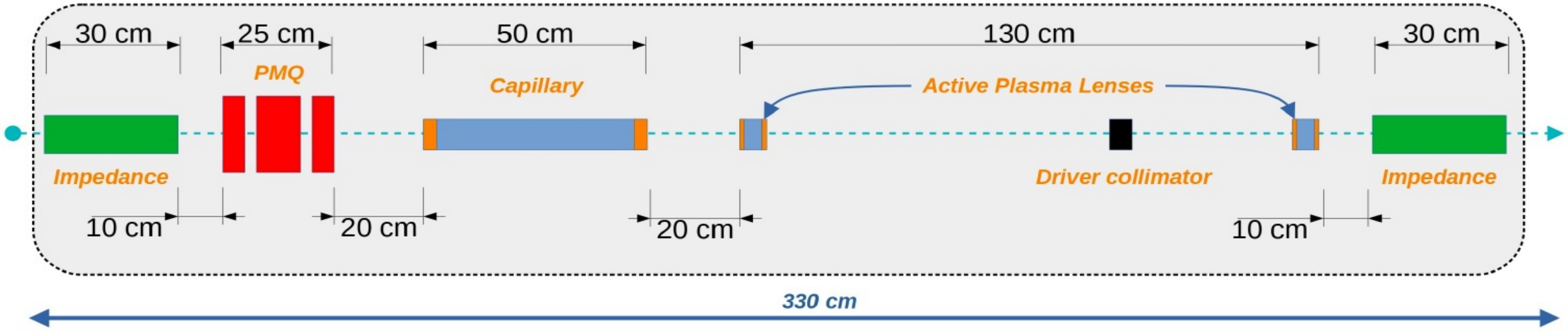


Courtesy R.Pompili, A.Biagioni

Plasma Module

Plasma module layout – Different options under investigations.

Option 2



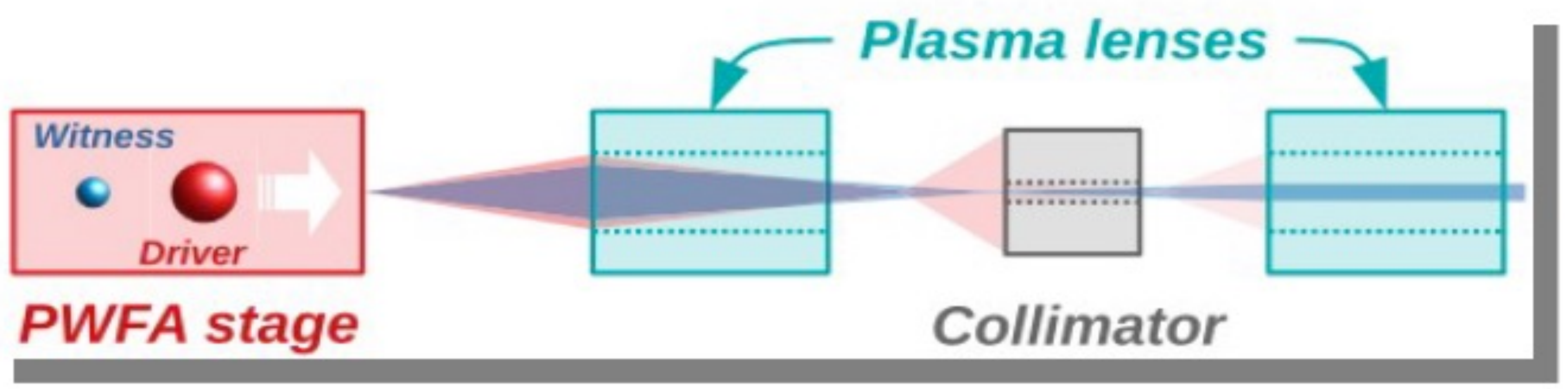
Active-Plasma lenses to extract the witness and remove driver

- Witness is catch and transported without loss of charge
- Driver is over-focused at the collimator entrance and its charge removed

Pompili, R., et al. "Plasma lens-based beam extraction and removal system for plasma wakefield acceleration experiments." Physical Review Accelerators and Beams 22.12 (2019): 121302.

Study performed on the EuPRAXIA@SPARC_LAB reference working point

- It requires two active-plasma lenses and a lead collimator.
- Solution would benefit of compactness and tunability.
- However puts more load on the vacuum



Courtesy R.Pompili, A.Biagioni

FEL | Ondulators

- **ARIA** - No news
- **AQUA**
  - Undulator design – Study of undulator termination and minimization wake fields
  - Undulator prototyping: drawing of a model from the Sabina STEP file in progress. No updates since last meeting (MDF involved in othe activities).
  - Design study of short period undulator. After delivery of SABINA Undulator, to be assigned through contract ?
  - Pulsed wire measurement system under study (A. Selce, A. Petralia)
  - Intrasection design (L. Sabatini, A. Vannozzi, A. Selce, F. Nguyen) Quadrupole field integral defined/discussion ongoing on having correctors embedded in quadrupoles, impedances and feedback frequency cutoff (L. Sabatini, A. Selce, A. Vannozzi)
  - Simulations: testing wake fields models as also suggested by TDR Committee (F. Nguyen & N. Mirian)
  - Recent S2E simulations from WA1 are showing peak currents in excess of 1.9-2kA. FEL simulations show saturation at wavelengths < 4 nm (V. Petrillo). New working point parameters ?

Courtesy L.Giannessi

User & Beamlines

- ✓ Proposal for development and characterization of novel optics for focusing X-rays @Elettra

- ✓ Coordination with the corresponding WP for EuPRAXIA- Preparatory Phase

Upcoming Milestones

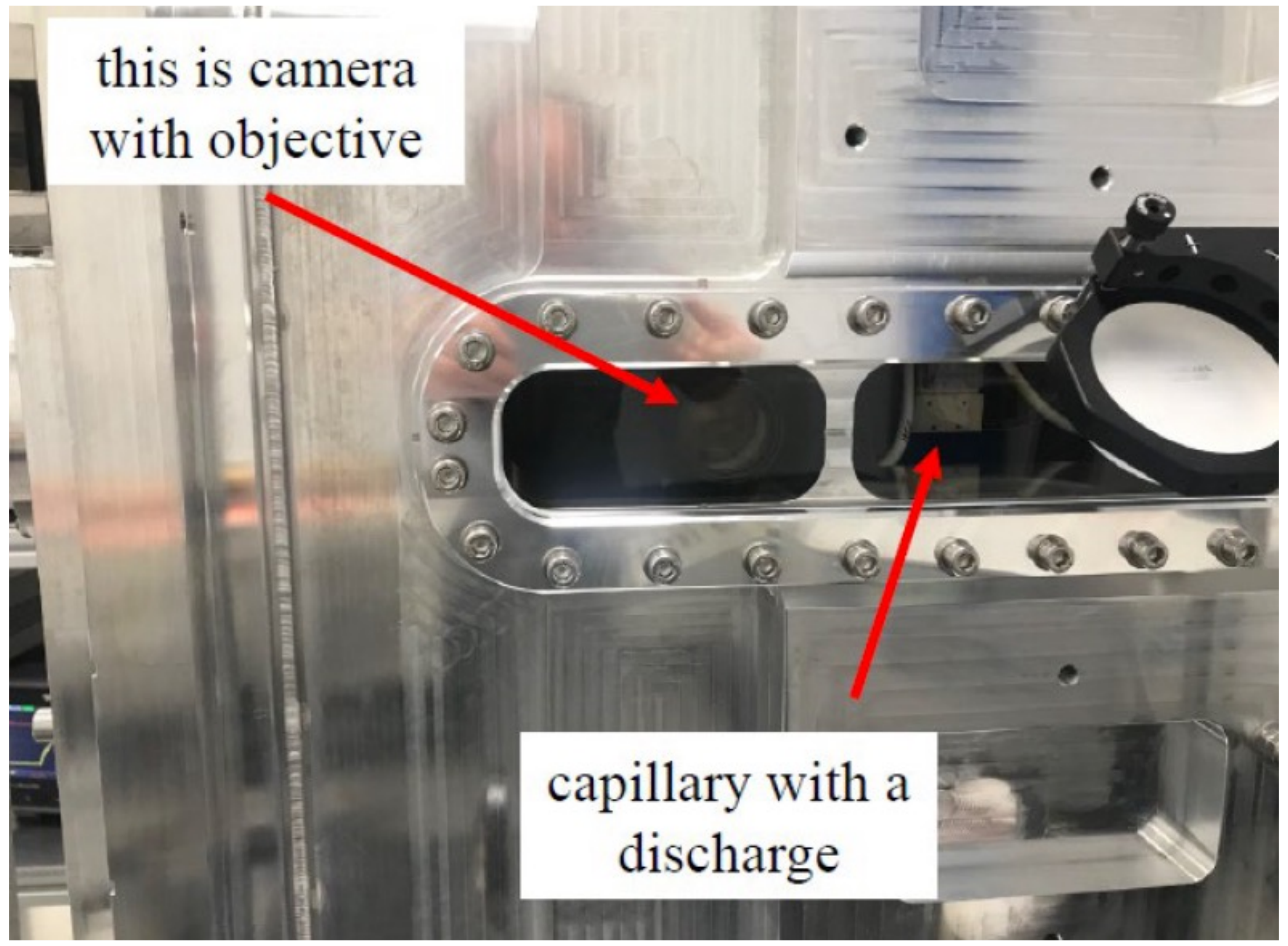
31/12/22 *Preliminary optical simulation of the beamlines*

31/12/22 *Evaluation of Scientific Case for other wavelengths (ARIA)*

Courtesy F.Stellato

Diagnostics

Test on CCD Camera in the plasma chamber - done



Conclusions:

- Camera can work inside the vacuum without problems with the temperature
- Discharge does not create problems with the camera or the trigger

CBPM – PSI Choice for intra ondulator diagnostics

Read-out electronics development under discussion

	PSI CBPM5/8	FMB Oxford
Material	Stainless Steel (outside) – Copper (inside)	Stainless Steel
Length [mm]	100 mm	100 mm
Inner Aperture [mm]	5 / 8 mm	20 mm (custom)
Res. frequency	4.9266 GHz	6.474 GHz
QL	1000	610
Decay Constant	64.6 ns	30 ns
Charge Range	10-200 pC	10-100 pC
Typical Position Range	±1 mm	
Position Sensitivity (CBPM5)	4.5 V/mm/nC	1 V/mm/nC
Charge Sensitivity (CBPM5)	62.8 V/nC	

Stripline prototype

STATUS: Strip-Lines BPM
10cm between flanges and 25mm aperture

- BPM prototype (delivered Feb2022) ✓
- RF Bench tests (march 2022) ✓
- **BPM realization for beam tests including minor modification to design**

Vacuum feedthroughs procurement (qty:16)
Purchase order (PMB, May2022) ✓
Delivery: 4 weeks (estimated)

Tender for mechanical realization (with vacuum group) before 12/2022

Installation @ SPARC (before 03/23)

Beam Tests@ Sparc (before 09/23)

Courtesy A.Cianchi, A.Biagioni,A.Stella

Building Status

Progress in the design finalization and authorization process.

- Final design is basically frozen with many further implementations in the last months.

- Informal authorization from different stakeholders to proceed with the formal «Conferenza dei Servizi» (Permitting authority commitee) :

  - ✓ Archeological survey
  - ✓ Landscape
  - ✓ Fire Dept.

- Cost updated (due to current geo-political and macroeconomic scenario) to be discussed at management level

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

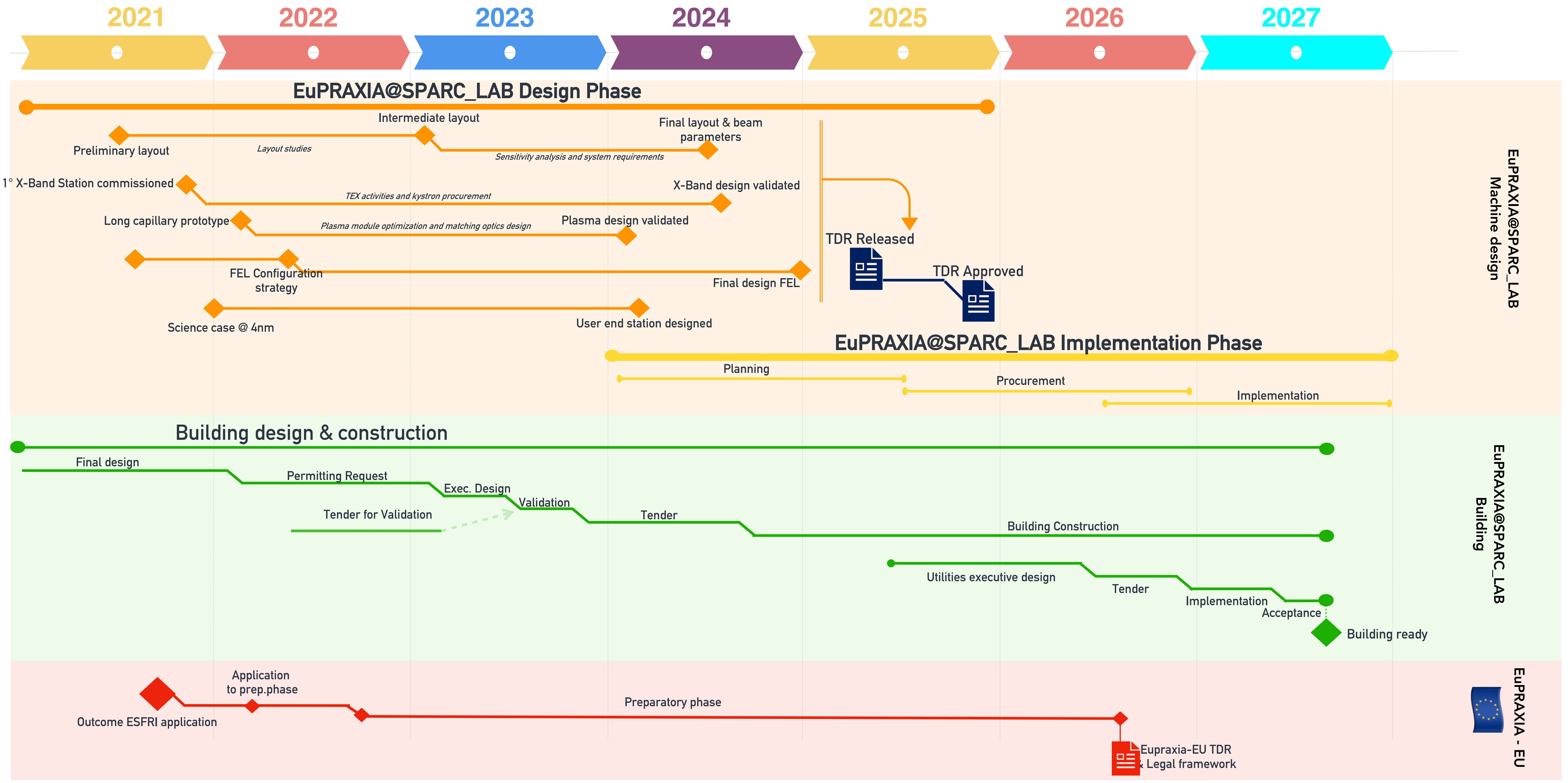
System Engineering

- Functional layout aligned to optic and mechanical layout.
- Nomenclature in place
- Framework for configuration database done.

- Configuration Management
- Cost –book
- Integration
- Utility Matrix and systems interface definition

- Functional layout is being transformed in a Project Breakdown Structure database.
- Each component is now broken down into a number of subsystems and hierarchically ordered.

Schedule update – critical milestones



Schedule update and conclusions

- Significant progress on the machine layout development
- Still a number of open points to be more investigated
- Prototyping activities on track. X-Band LLRF System prototype is under investigation
- Several other EuPRAXIA related projects to be started soon will reinforce EuPRAXIA@SPARC_LAB activities.
- Additional manpower will hopefully be hired in the next months (3 Through EuAPS Funding + others from funding sources) and hiring for other project can alleviate the workload to EuPRAXIA team.
- In the next weeks we will start the process to structure the TDR chapters and connect them to the intermediate milestones we are performing.

Other EuPRAXIA Related Project

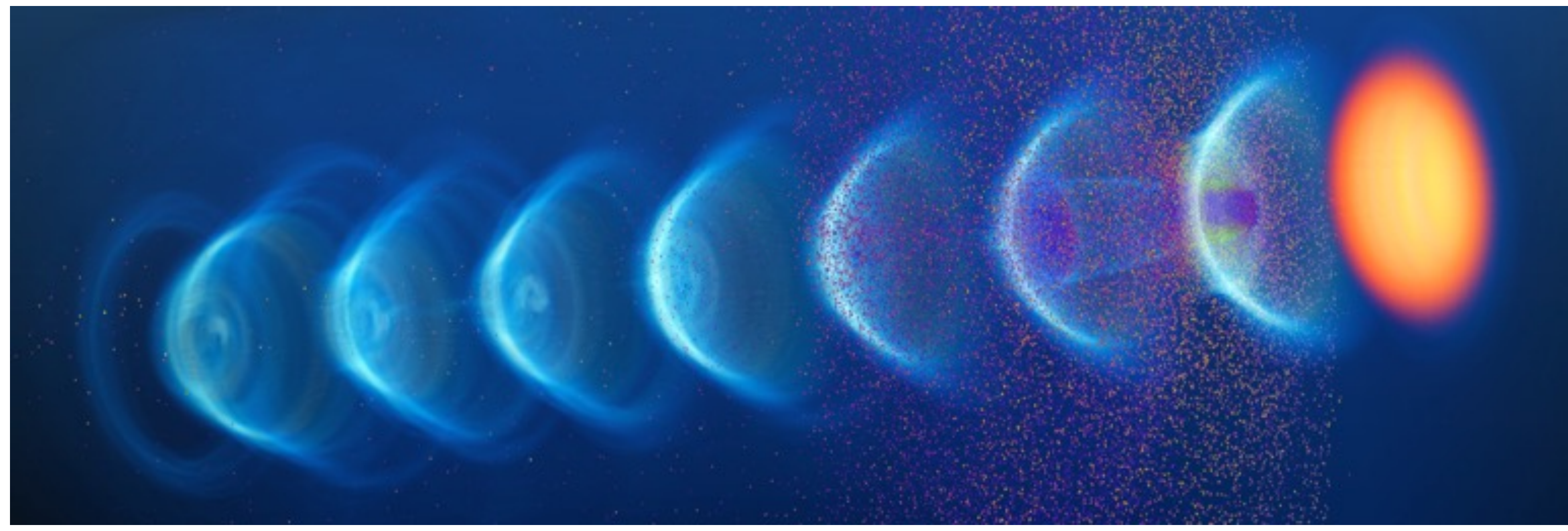
- EuPRAXIA – Preparatory Phase. Horizon Europe Infradev- ESFRI Project

- EuPRAXIA Advanced Photon Source – EuAPS – PNNR funding

EuPRAXIA-PP (Preparatory Phase) Key Facts

Prepares the implementation of the full RI in Europe

- Total project volume (including in-kind): **8.3 M€**
  - EU funding: **2.49 M€** (EU without in-kind)
  - Outside EU **0.69 M€** (Switzerland)
    0.51 M€ (UK)
- Work organized in 16 Work Packages
- Project dates: **1 Nov 2022 – 31 Oct 2026**
- Coordinator and location of headquarters: **INFN**
- **34** participating organizations from 12 countries
- Will establish a "Board of Financial Sponsors" with representatives of funding agencies.
- So far ~ **25%** of total M&P funding (**569 M€**) secured. Site 1 is essentially financed → Massimo.



PP Steering Committee: Leaders Behind EuPRAXIA

Horizon Europe

- Governing Board (Decision-making body)
- Steering Committee
- Scientific Advisory Board
- Technical & Industrial Advisory Board
- Board of Financial Sponsors

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

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

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

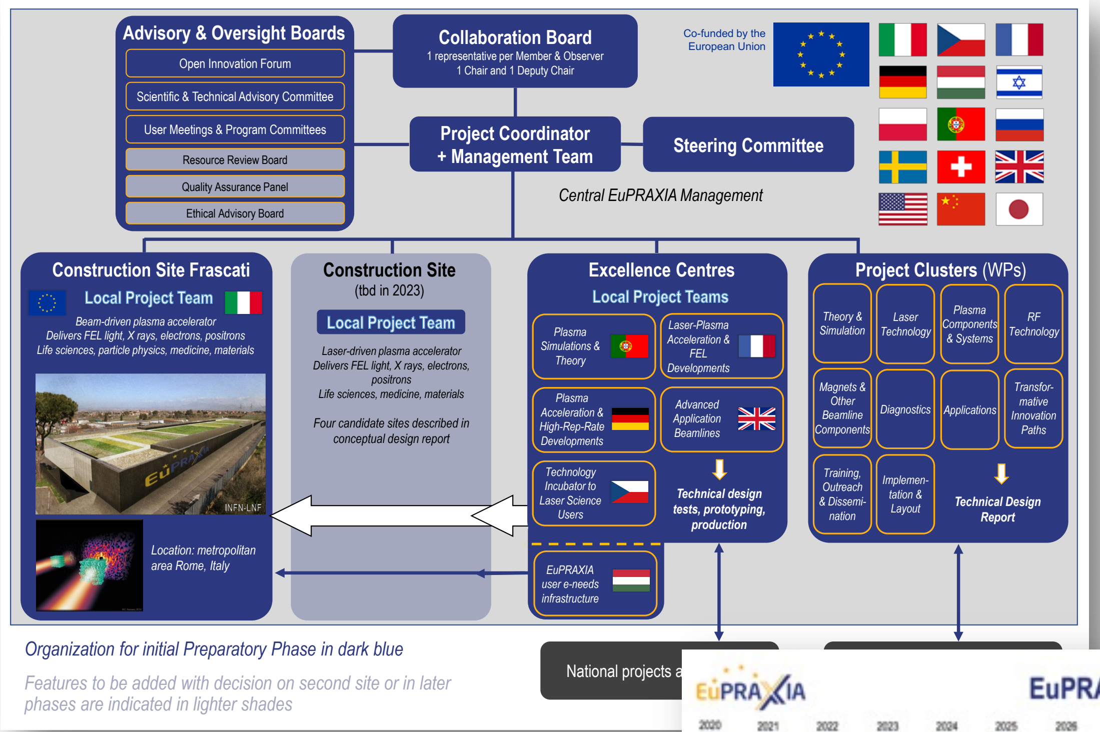
WP16 - TDR EuPRAXIA Site 2
A. Molodozhentsev, ELI-Beamlines
R. Pattahil, STFC

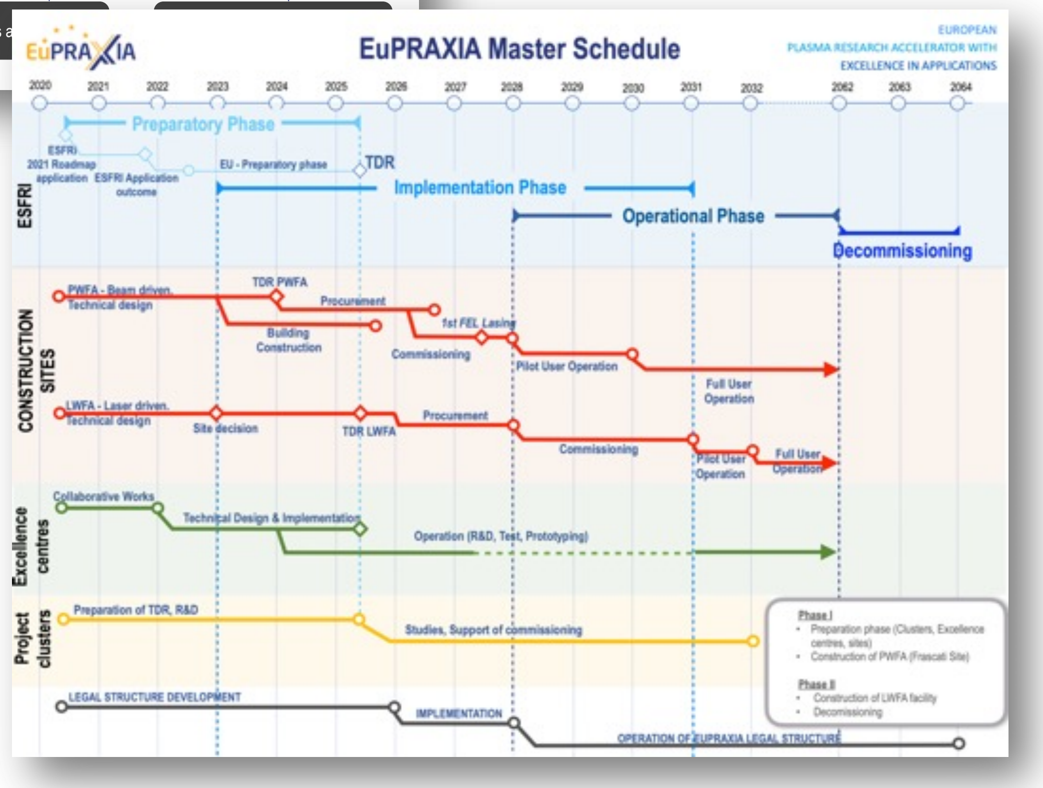
WPs on technical implementation and sites

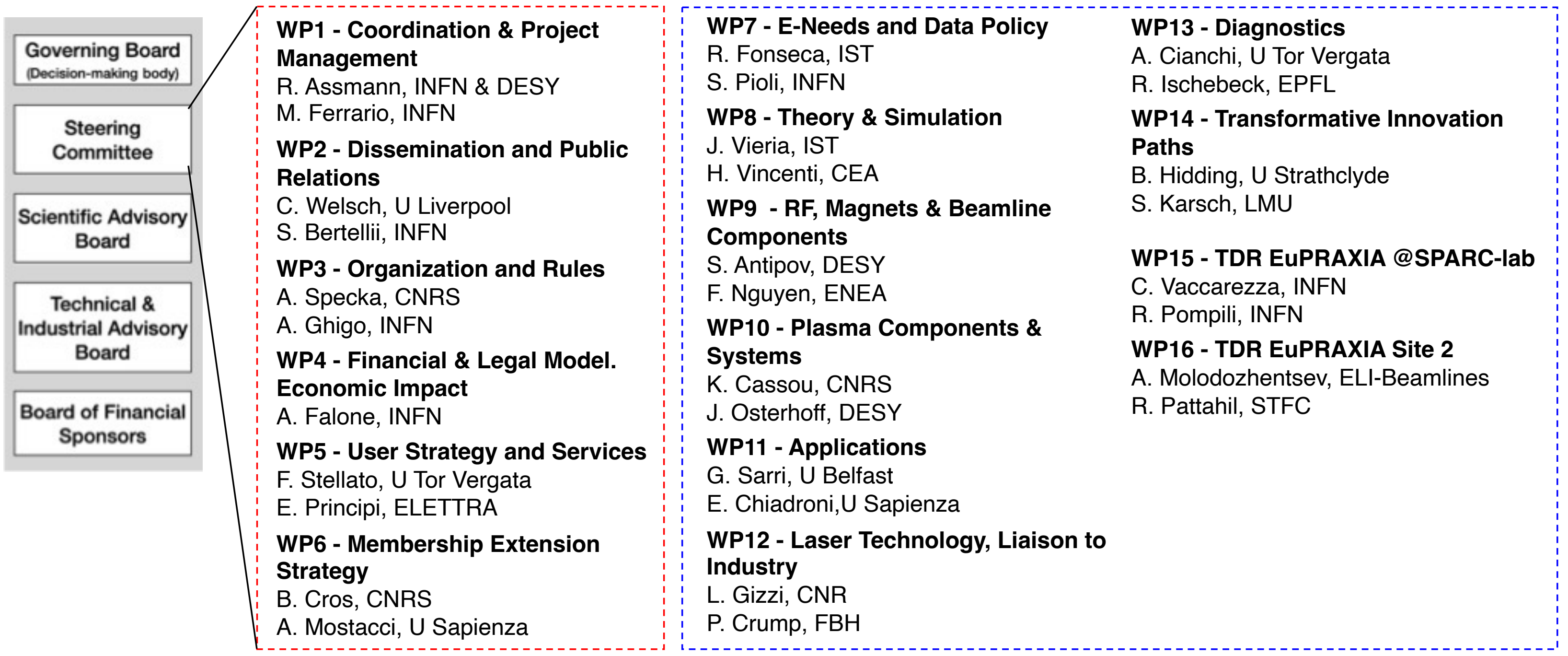
Preparatory Phase Main Goals

Horizon Europe

- 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







EuPRAXIA Advanced Photon Source

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

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]

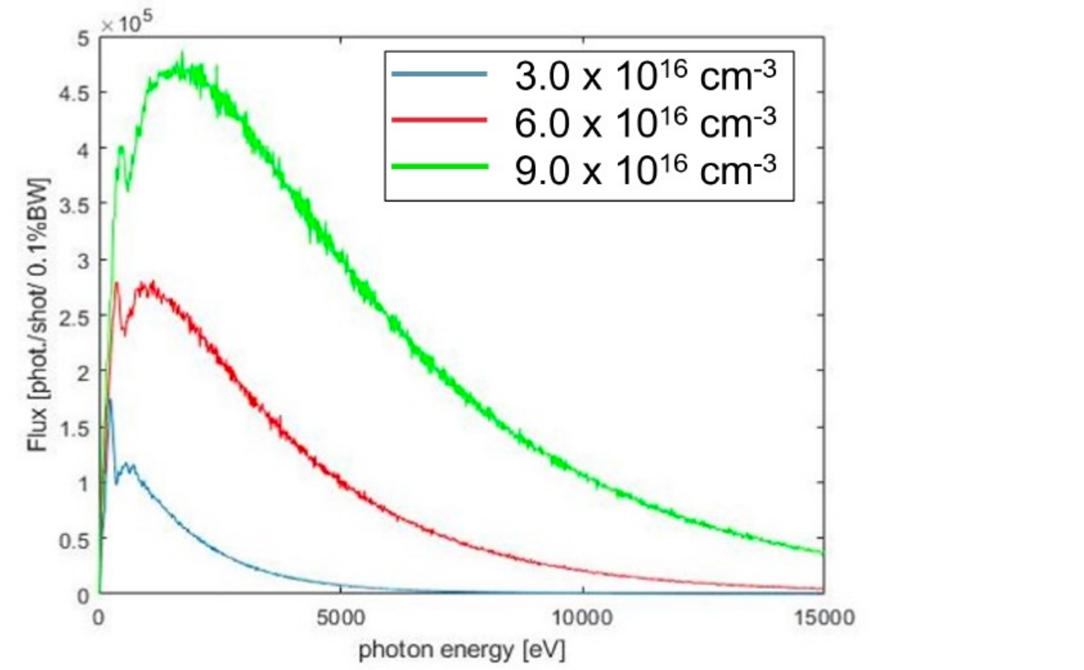


Figure 1. Betatron radiation spectra simulated for a source size of 3 μm and 3 different plasma densities. The total number of photons is 1.7 x ^{9} for the 9.0 x 10^{16} cm^{-3} density, 9.9 x ^{8} for the 6.0 x 10^{16} cm^{-3} density and 4.1 x ^{8} for the 3.0 x 10^{16} cm^{-3} density.

The EuAPS proposal benefits from the preparatory work done in the conceptual design phase of EuPRAXIA, both for the scientific case and the technology. It focuses on an ambitious but technically achievable goal and builds on the pre-existing investments at the SPARC_LAB facilities. As stated in the EuPRAXIA CDR the following EuPRAXIA Flagship Goals will be addressed by the EuAPS Project:

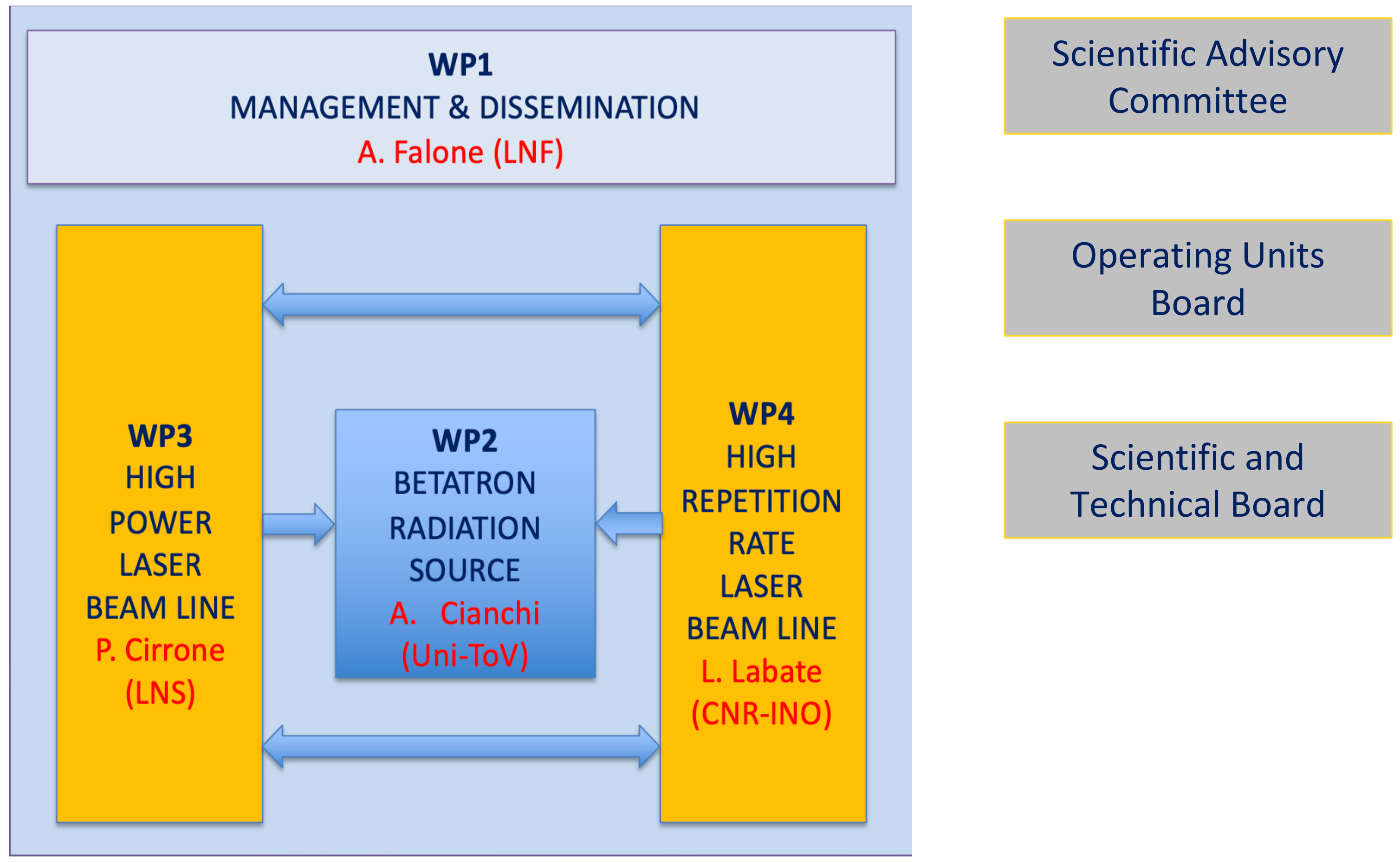
Flagship Innovation Goal 2: EuPRAXIA will develop together with laser industry a **new generation of high peak power lasers**, advancing the presently leading technology into the regime of 20 – 100 Hz repetition rate […].

Flagship Science Goal 2: EuPRAXIA will deliver **betatron X rays with up to 10^{10} photons per pulse**, up to 100 Hz repetition rate and an energy of 5-18 keV to users from the medical area. […].

Flagship Science Goal 7: EuPRAXIA will provide access to cutting edge laser technology with **short pulse length in combination with high energy photon pulses** […].

We expect that the focus on a mature part of the EuPRAXIA project strongly supports project completion on the timescales that are required by PNRR.

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



Findings & Reccomendation (I)

The implementation part of the EuPRAXIA@SPARC_LAB schedule needs further refinement. In particular, the assumptions on procurement have to be adjusted for sufficient margins. Typical procurement times for long lead items as well as the current issues with supply chains need to be considered in this context.

This certainly will be taken into account. The detailed planning of the implementation phase looks a bit early to be developed, also considering a number of boundary conditions that need to be clarified. As example the Legal Framework and the Financial models that will be adopted (which are main deliverables of WP.4 EuPRAXIA – Preparatory Phase) for the implementation of the distributed RI might have a remarkable impact on the procurement strategy and hence on the overall planning.

Findings & Reccomendation (II)

The efforts to develop the future photon user community of EuPRAXIA@SPARC_LAB have to continue.

User community will be strenghten through EuAPS and EuPRAXIA-Preparatory Phase projects that have a dedicated WP for the user exploitation. Workshop and school are foreseen in the next years.

Implementation of the staffing plan for EuPRAXIA@SPARC_LAB needs the full attention of the LNF management. This is not only a question of funding but also needs efforts to make project posts attractive for highly qualified experts. In particular, clarifying the perspectives for long-term employment early on in the hiring process could facilitate this process

We noticed a growing interest in the community on EuPRAXIA initiative. EuPRAXIA is becoming an attractive project. Of course salary and perspectives not always are aligned with the expectations of the candidates and the time needed for hiring sometime is a problem. However PNRR opportunity give us a bit of flexibility in hiring also highly qualified personnell. E.g. 1 Laser Scientist and 1 Plasma Scientist will be hired soon. The personnel hired for other PNRR project altough are not strictly correlated with EuPRAXIA they will help to alleviate the workload on the EuPRAXIA team.