EuPRAXIA @ SPARC_LAB

Scientific Committee - 16/05/2022

Antonio Falone
On behalf of the EuPRAXIA Team

EuPRAXIA @SPARC_LAB Follow up

- Consolidation EuPRAXIA iniative within EU Framework
- Progress on the EuPRAXIA@SPARC_LAB TDR activities
- Building Status
- Schedule Baseline
- System engineering
- Risk management
- Outcome of previous Sci-Com reccomendation

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 – Grant Agreement Phase
- 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, 27M€ (18M€ to INFN) – Under evaluation
- Apr 2022 – CREATE, Plasma and X-Band technology. Infradev - Horizon Europe, 10 M€ (3.8M€ to INFN) – Under evaluation
- Apr 2022 – EuPRAXIA Doctoral Network Program, 2 PhDs in Accelerator Physics
- More to come…

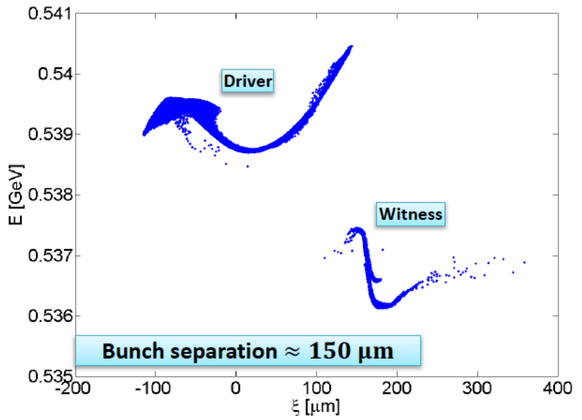
Progress on the TDR

Significant progress for ALL working areas and working packages

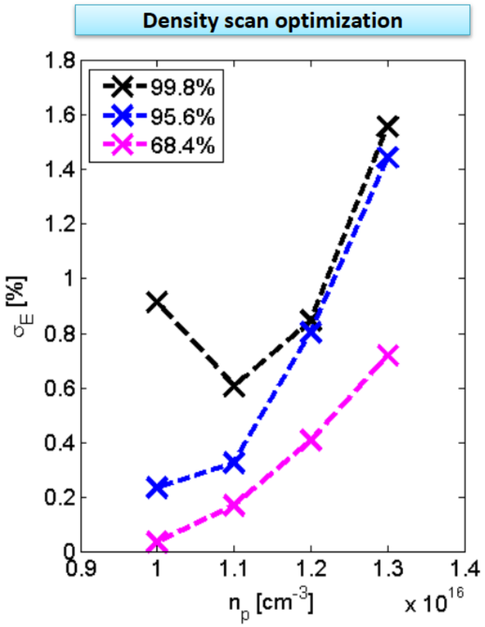
- Progress on the beam dynamics studies, approaching the critical milestone of the intermediate layout approval (end 2022)
- Realization of mechanical and RF X-Band section prototype (from CERN, on-schedule)
- Injector layout – Cost Benefit Analysis performed for different options
- Compact Beam Position Monitor prototype designed and built
- Full Upgrade (EuPRAXIA-Like) of the Low Level RF System ready to be commissioned
- Long plasma capillary (40cm) production and testing (under-schedule)
- User workshop (june 2021)
- Ondulator strategy concluded -> Possible 2 beamlines
- RF power source strategy concluded and procurement in progress
- SAT of X-Band tube completed successfully (50MW reached).

Beam Dynamics Studies – Machine Layout

- BD Analysis and comparison on injector scheme (4x2m S-Band vs 3m+3x2m S-Band)
- Plasma code optimization to speed up the simulation time
- Energy spread mitigation and overall quality of the beam at the plasma exit ➜ back and forth iteration between photoinjector and undulato simulation➜Plasma Wop stability

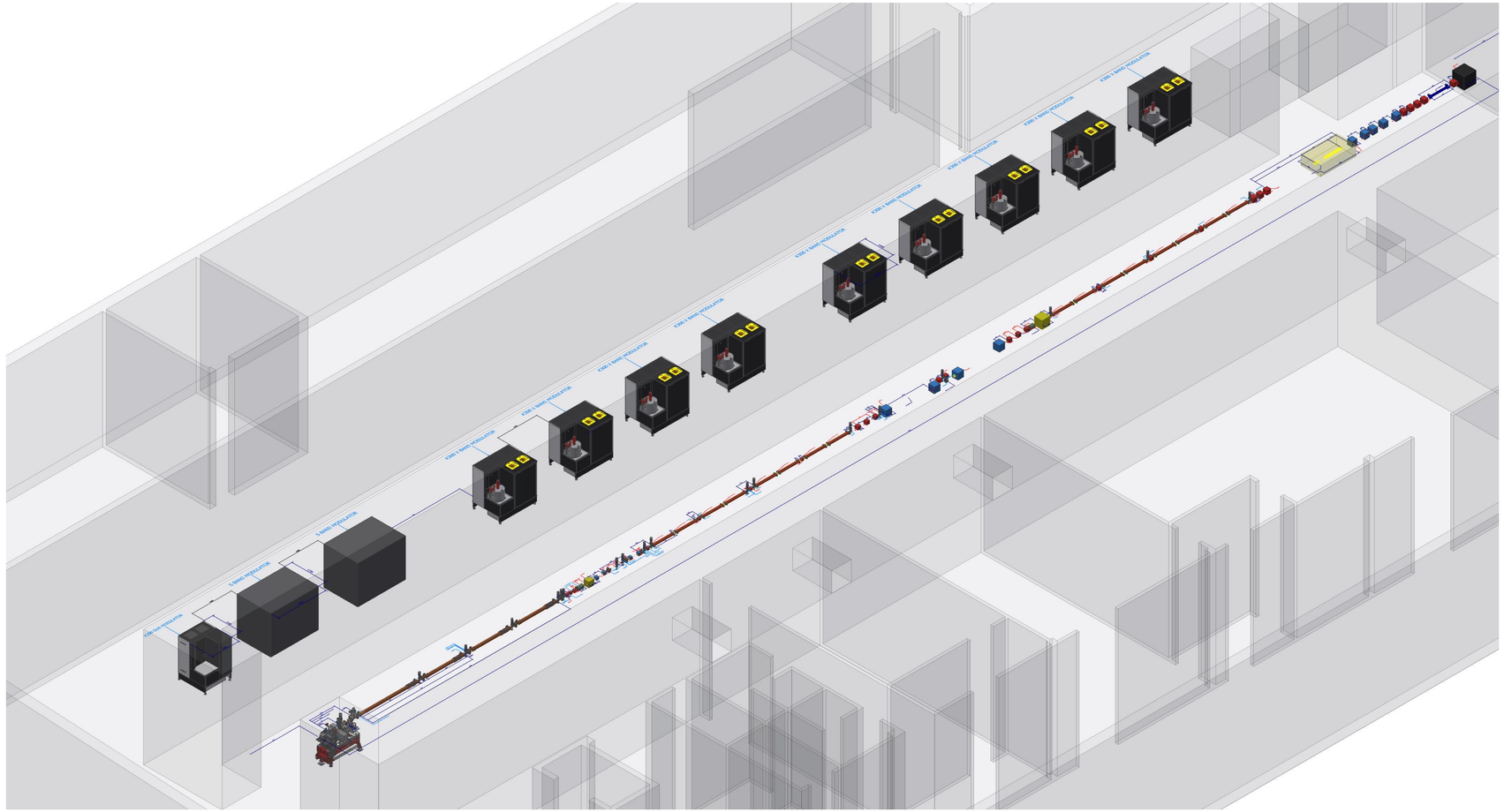


Driver parameters	Witness parameters
$\sigma_x = 4.6$ μm	$\sigma_{x,y} \approx 1.2$ μm
$\sigma_y = 7.2$ μm	$\sigma_z = 6.3$ μm
$\sigma_z = 52.2$ μm	$\varepsilon_{n(x,y)} \approx 0.6$ mm mrad
$\varepsilon_{n(x,y)} = 1.8, 2.0$ mm mrad	$\gamma = 1050$
$\gamma = 1055$	$\sigma_E = 0.05\%$
$\sigma_E = 0.06\%$	$I \approx 1.9$ kA



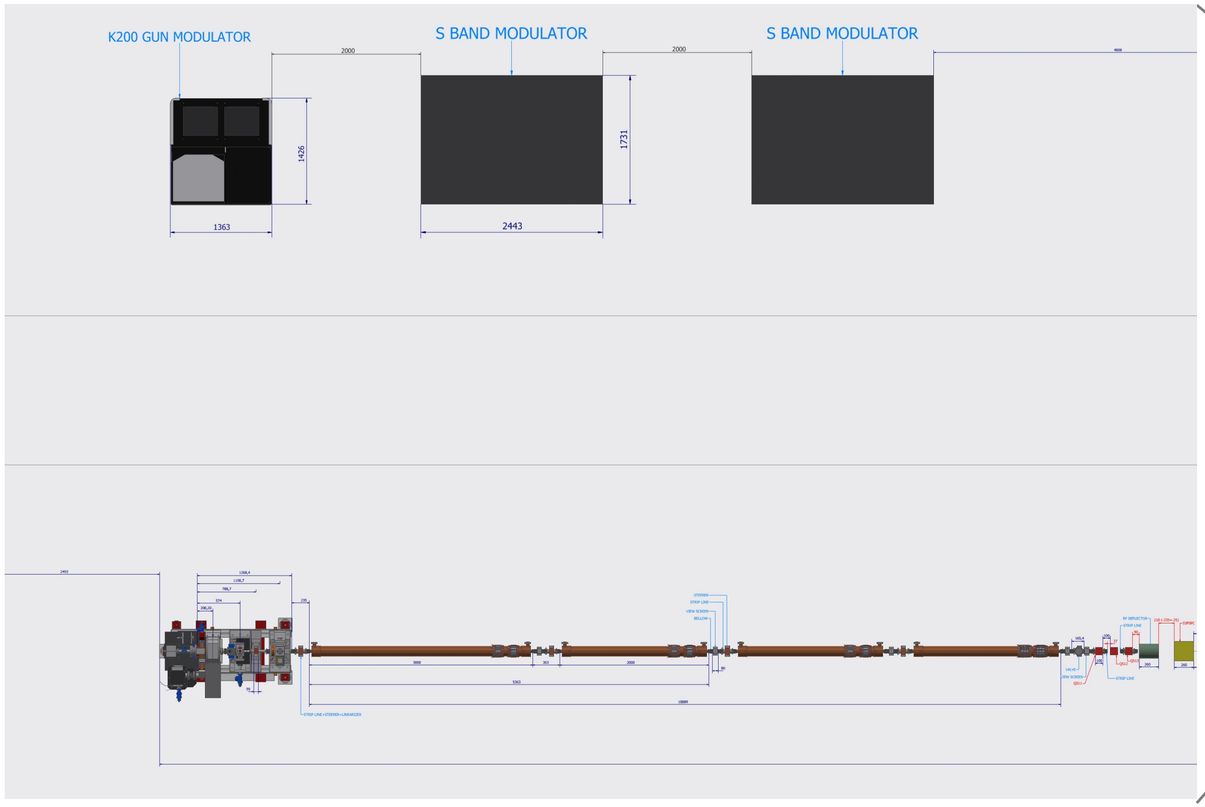
Courtesy C.Vaccarezza, A.Giribono, S.Romeo

Beam Dynamics Studies – Machine Layout



Courtesy E.Di Pasquale

Beam Dynamics Studies – Machine Layout



Courtesy E.Di Pasquale

Injector

	Layout 3+2+2+2 (No x-band)		Layout 2+2+2+2 * (No x-band)		Layout 2+2+2+2 (x-band, 4 mm iris radius)		Layout 3+2+2+2 (No x-band) High witness charge	
Parameters	WITNESS 30 pC	DRIVER 200 pC	WITNESS 30 pC	DRIVER 200 pC	WITNESS 30 pC	DRIVER 200 pC	WITNESS 50 pC	DRIVER 200 pC
E (MeV)	124.3	125.8	145.07	146.17	164.9	166.5	124.3	125.8
$\varepsilon_{nx,y}$ (mm mrad)	0.7	1.85	0.6	1.2	0.32	2.68	0.89	2.2
σ_{z_rms} (µm)	6.97	55.6	3.6	55	3.2	55.4	9.5	55.2
ΔE/E (%)	0.132	0.498	0.105	0.494	0.064	0.423	0.15	0.46
Δt (µm)	150		140		150		150	

*AC1-AC2 30 cm drift case

- Several configurations has been studied.
- Cost Benefit Analysis – considering beam quality and space available.
- 3+2+2+2 S-Band sections seems to be the more adequate and it is now considered as baseline.
- Optimized design of the RF Structures is mandatory to take into account different filling times in order to optimize RF distribution.
- RF Power distribution has been designed.

Courtesy E.Chiadroni

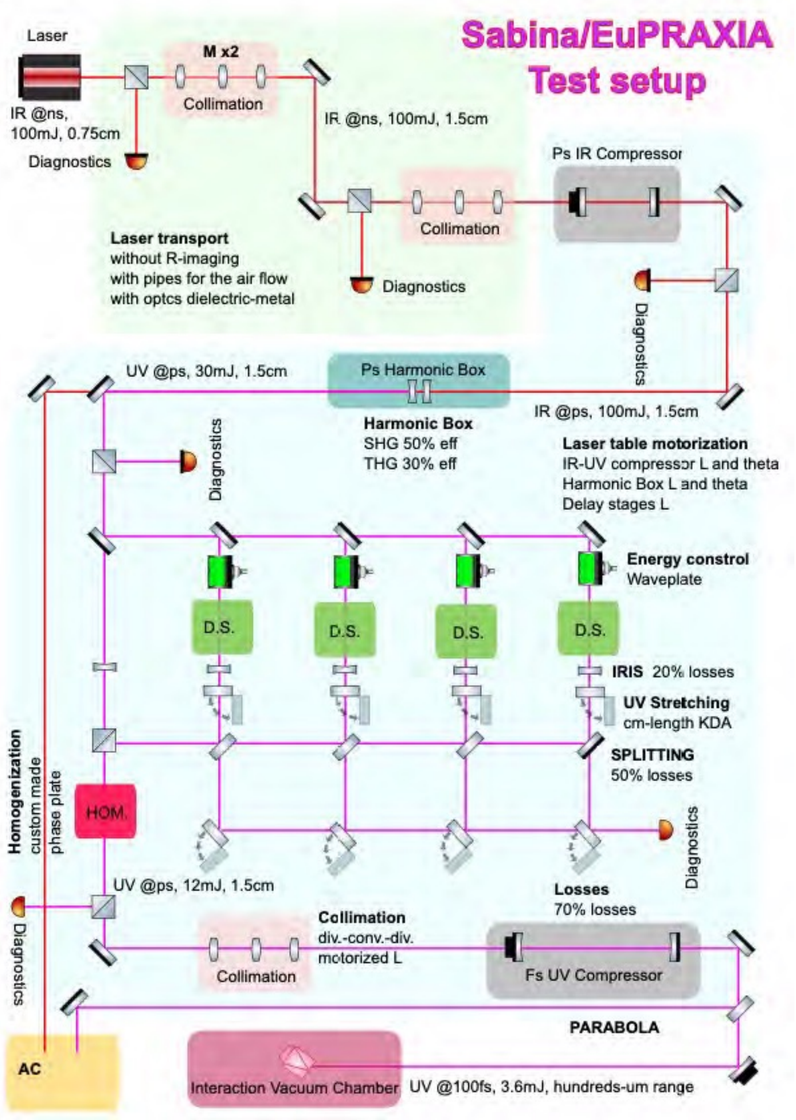
Injector

Photocathode laser: Study on the 400Hz option, which is feasible and requires small changes to the overall laser chain.

A test in SPARC is also possible, since SABINA laser has already a 1KHz exit.

To test the 400Hz in SPARC, some pieces will be needed (compressor and pockell cell)

Highest flexibility can be achieved on transverse profile and on longitudinal. Some tests need to be done (especially on dispersive materials).

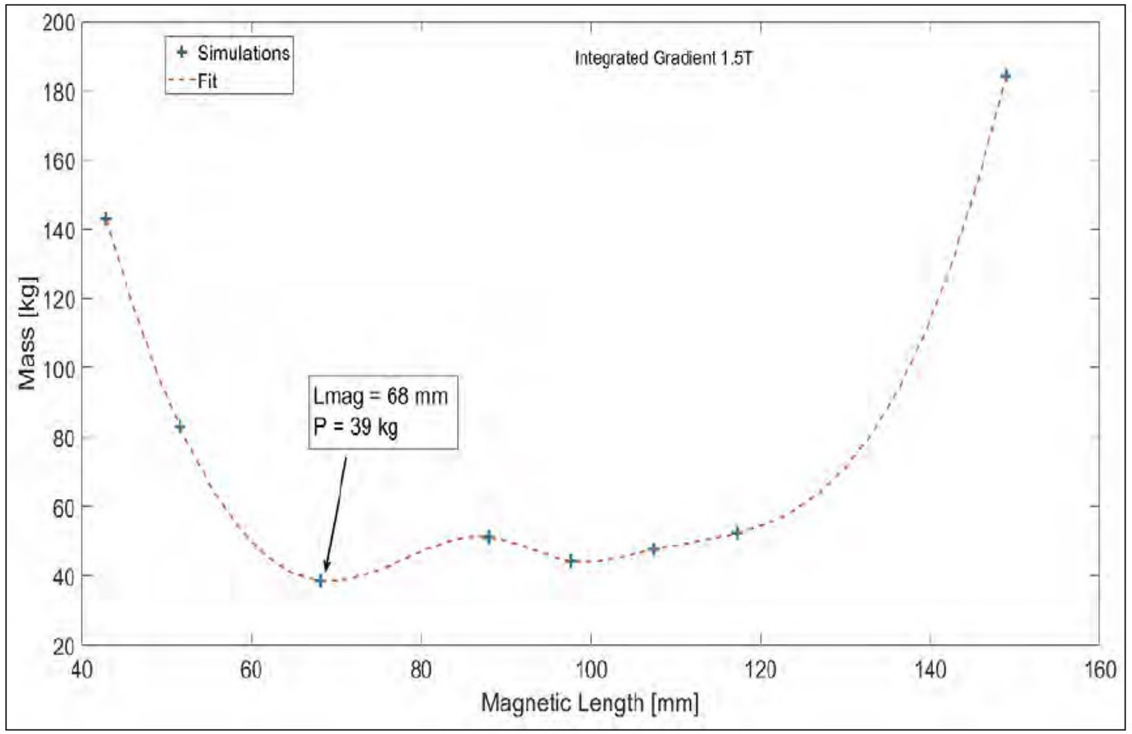


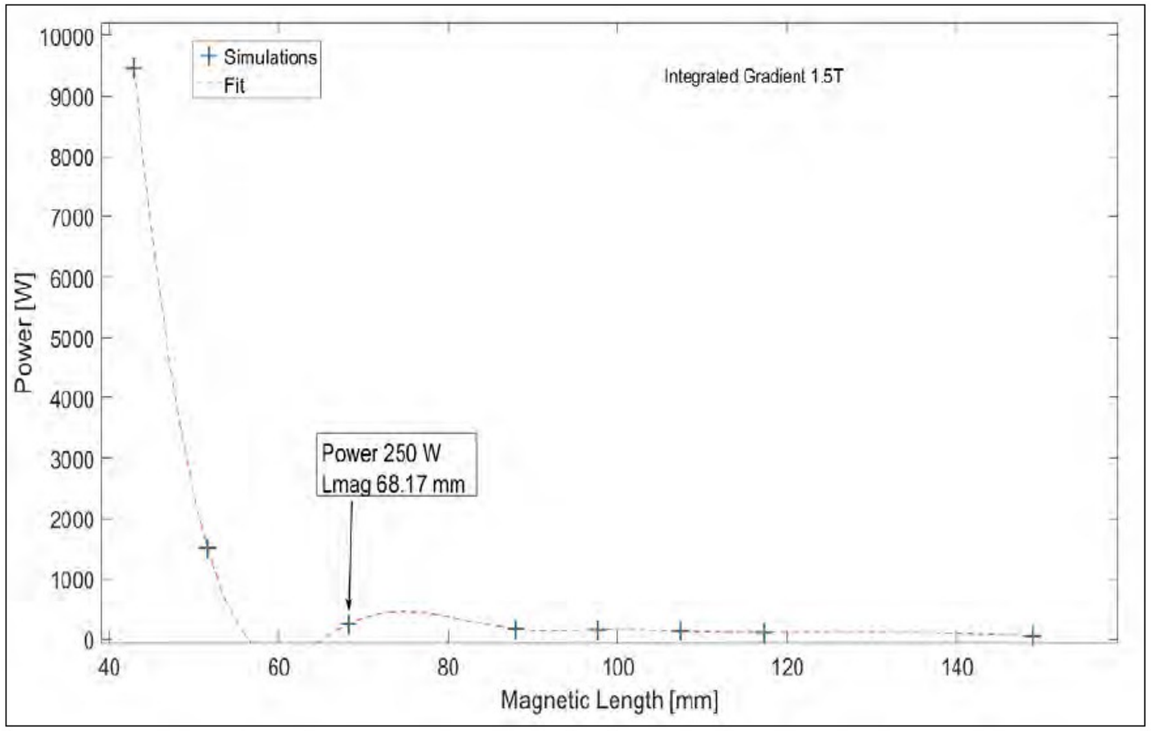
Courtesy M.Anania

Magnets Design

Quadrupoles Optimization

- A complete tool for the design has been developed
- Several simulations have been performed to find the power consumption and mass (installation costs) optimum
- An optimum was found for 1,5T integrated gradient quadrupole, optimization is ongoing for the other two families

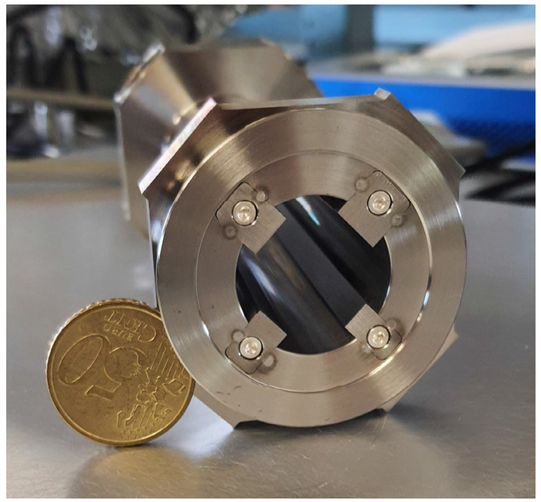




Courtesy L.Sabbatini, A.Vannozzi

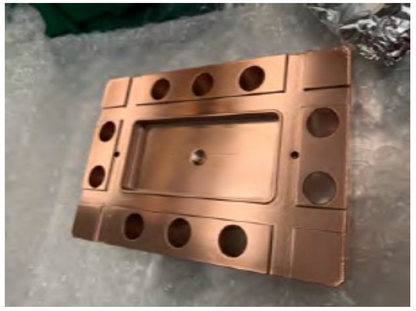
Prototyping activities

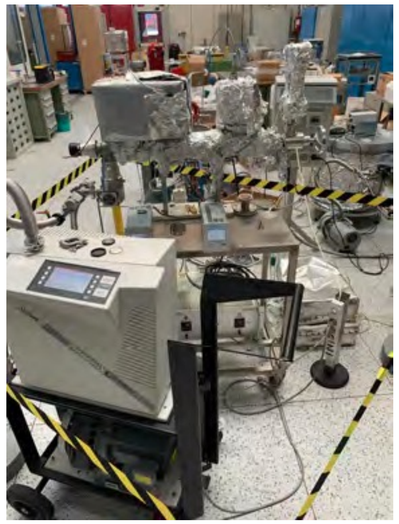
Compact Beam Position Monitor



Sized to be inserted in a 10cm long Quad
with 25mm aperture
Bench tests have been performed to verify :
- Impedance matching of the striplines
- BPM frequency response
- BPM pulse response to select
- proper strip width to match Z0=50ohm characteristic impedance

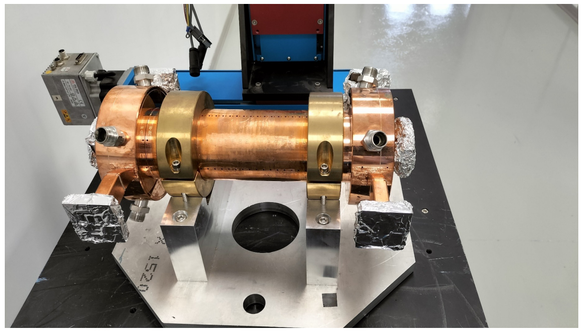
New S-band “DESY-like” flange



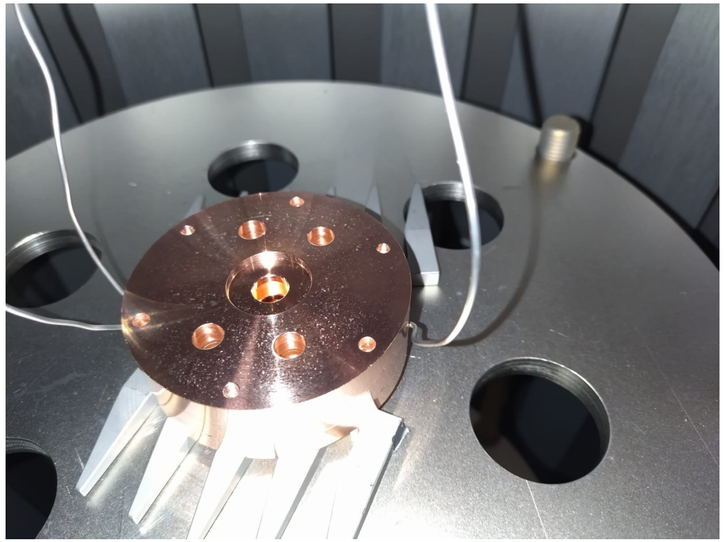


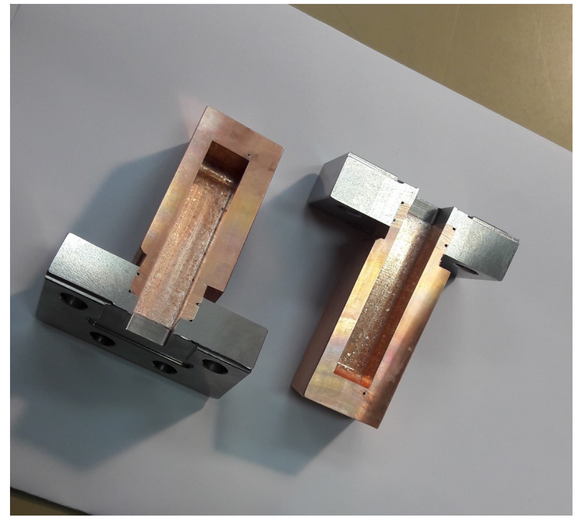
Setup for the thermal and vacuum leak tests

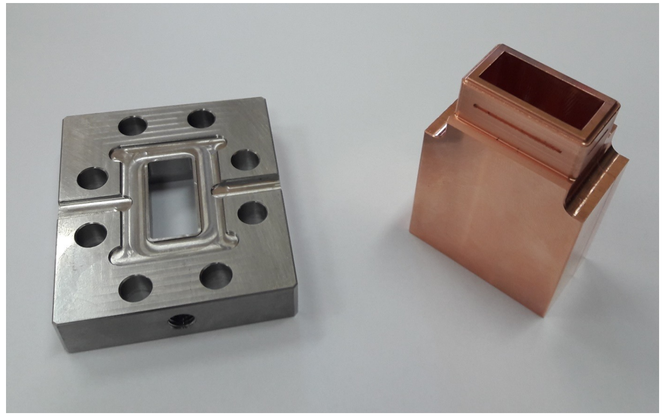
1° X-Band Acc. Section prototype

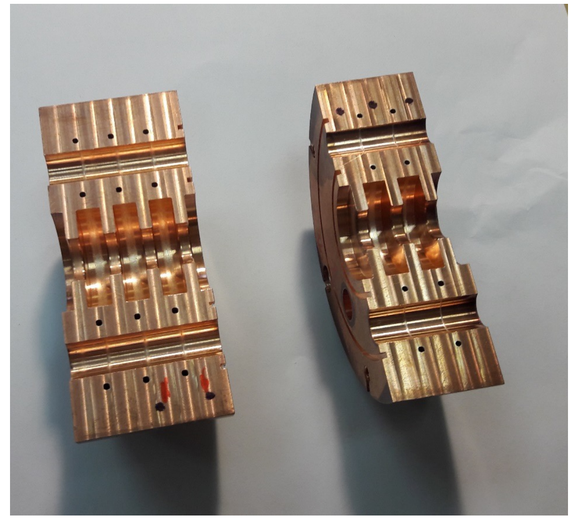


Prototyping activities | X-Band





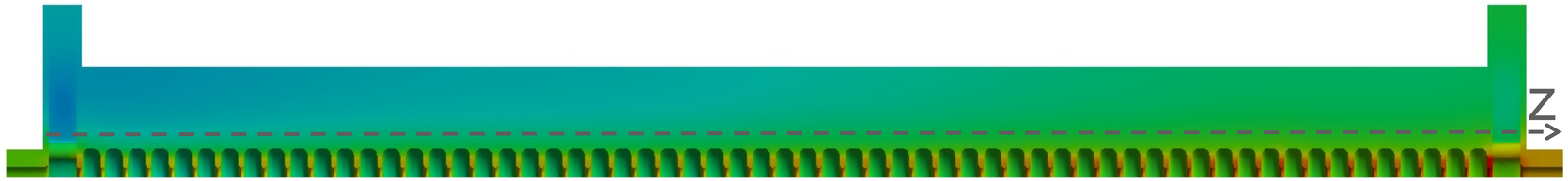


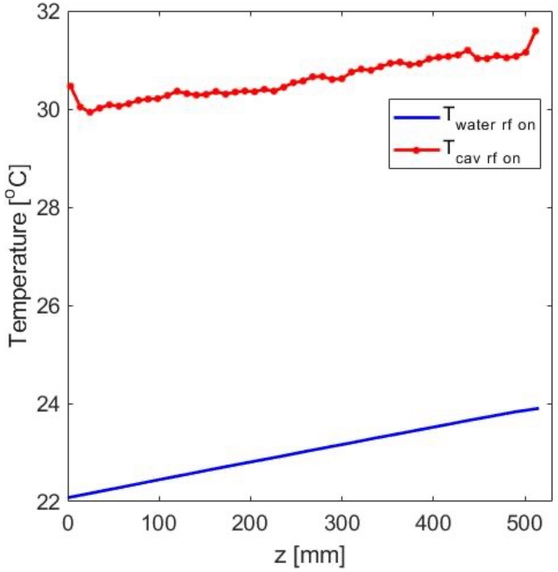


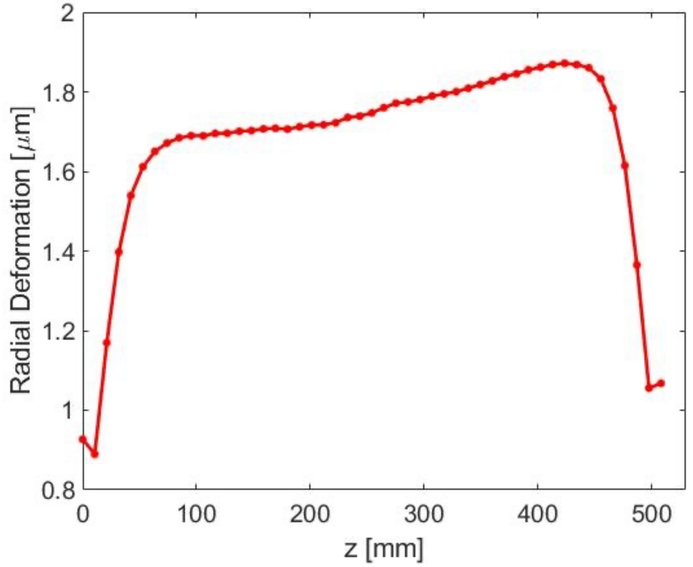
X-Band Development (400Hz studies)

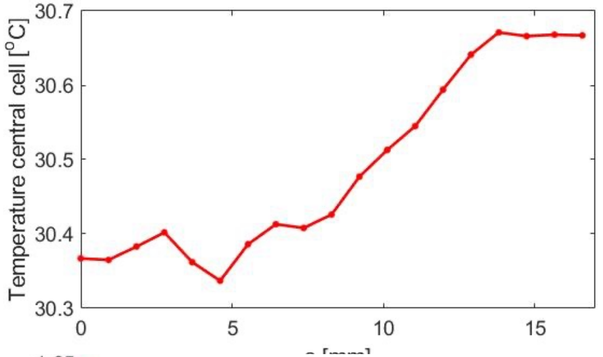
Pin

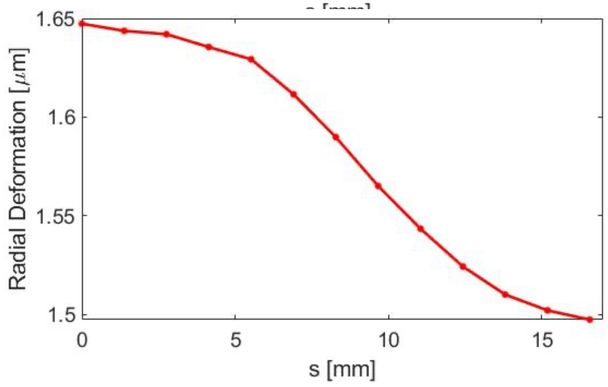
CAVITY TEMPERATURE INCREASE AND DEFORMATIONS (400 Hz): SIMULATIONS RESULTS











ANALYTICAL CALCULATION 60 CELLS

F_{tube}=4 l/min ⇒ ΔT_{diss_water}=1.9 °C

Courtesy D.Alesini

X-Band Development

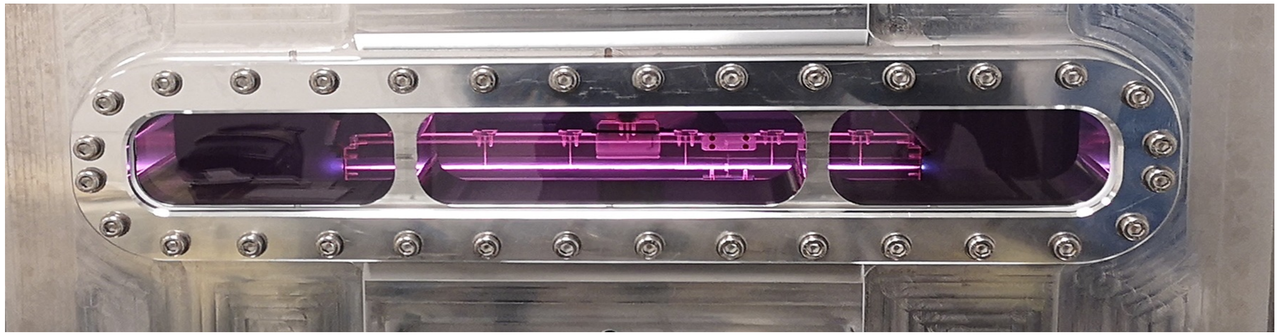
- Realization of mechanical prototype (on schedule)
- Realization of RF prototype (on-schedule)
- Design of waveguide components: Mode converter, Pumping units.
- Vacuum waveguide calculations. Set-up at TEX showed very good performances in terms of vacuum along the waveguide (smoothly conditioned in few days).
- Double high waveguide to minimize power losses - possibility under discussion with CERN.
- Thermo-mechanical calculations on the X-Band prototype (up to 400Hz).
- LNF will host High Gradient workshop in 2023.

Plasma module development

Production of the first prototype of long capillary (40cm).

- The new vacuum chamber for Plasma lab is completely tested
- Tests with high-current pulses (>2kA) for very long capillaries are on going. (New design and first tests of the electro valve controller have been done)
- First plasma stabilization studies are completed:
  - External laser source
  - Electrovalve insulation
- New capillary 40cm is working
  - New gas injection system (inlets design/e-valve insulation)

- Rep rate at 1 Hz
- 9 kV – 480 A minimum values to have the ionization (3 kV – 140 A for 3cmx2mm)
- Aperture time E-valve/Voltage delay is 8ms/12 ms (3-4 ms/5-6 ms for 3cmx2mm)
- 6 inlets of 1 mm in diameter separated by 60mm/80mm (1 or 2 inlets for 3cmx2mm)



Courtesy A.Biagioni

Plasma module development

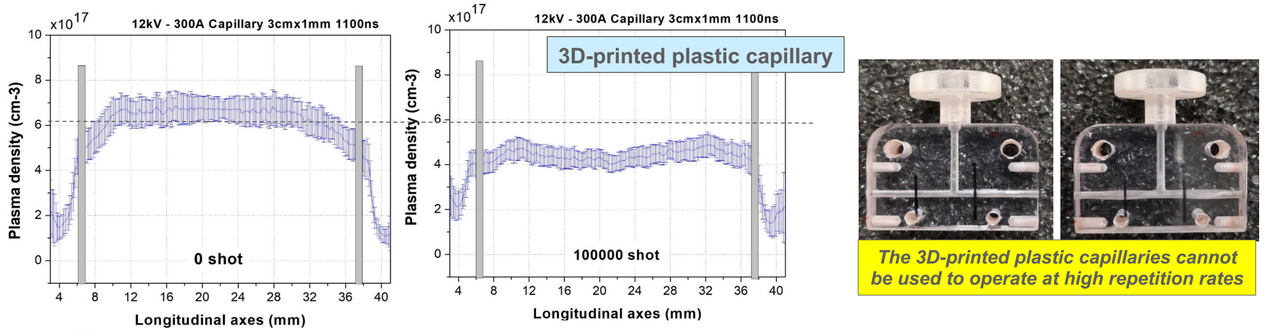
On-Going Activities

- Test of long capillaries (40 cm-10^{16} cm^{-3})
  - *Density* characterization of 40 cm long capillary
  - Tests of segmented capillaries
- High rep rate capillaries (100-400Hz):
  - Tests of new material and capillary design to avoid a plasma properties degradation (3D printing with like-glass materials) * see next slide
  - Requirements for the vacuum system (gas injection at 100 Hz)
  - Redesign of the HV-pulser
- Segmented capillaries design and tests have started
- Study of plasma instabilities with beam-based measurements

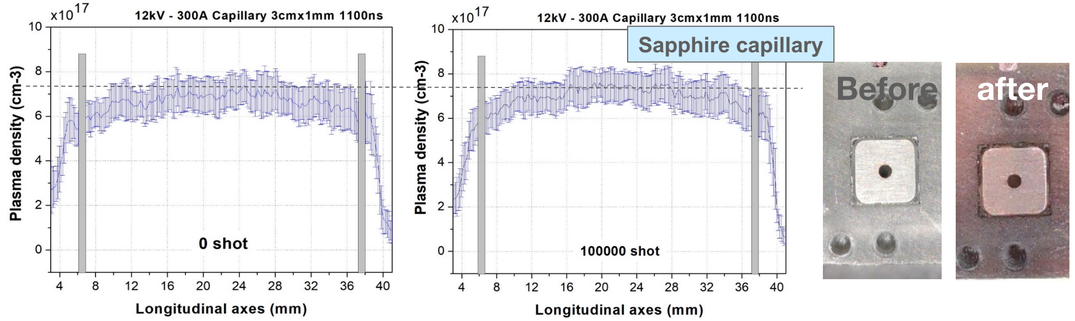
Courtesy A.Biagioni

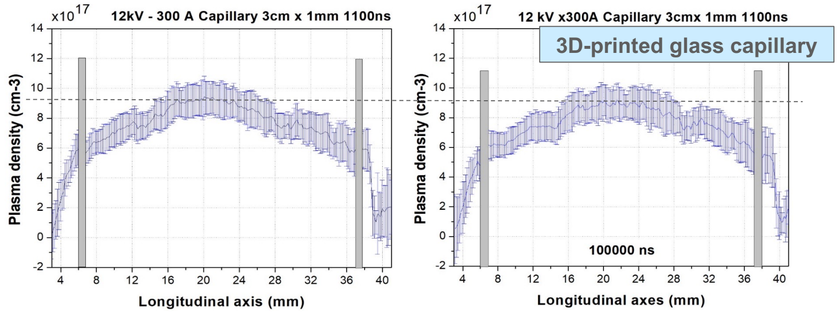
Plasma module development

Capillary longevity



The 3D-printed plastic capillaries cannot be used to operate at high repetition rates



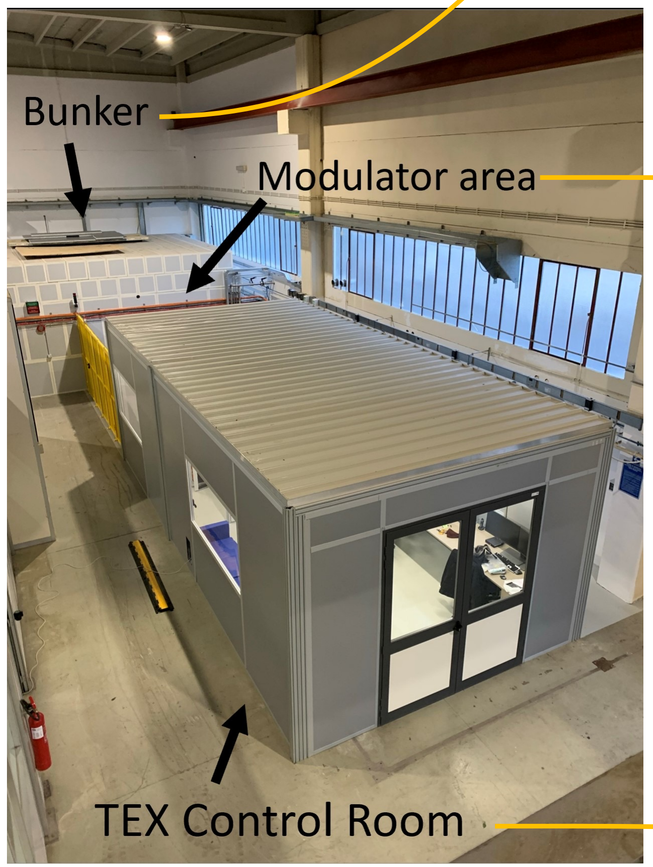


- Any shape of the channel can be done (3D printing)
- Glass materials are stronger than Plastic ones
-
- Different Glass materials can be produced (K=2-3)
- Low precision of the 3D-printers

- Short capillaries (max 5 cm) and small diameter (min 0.5 mm) can be produced
- Sapphire materials (k=40) are stronger than glass materials

Courtesy A.Biagioni

TEX – TEst stand for X-Band



X-Band RF Source SAT
Successfully accomplished

Courtesy F.Cardelli & S.Pioli

- The present TEX setup is based on:
  - K400 ScandiNova Modulator (HV pulses 430kV, 3.5us, 100Hz)
  - CPI VKX8311 Klystron (RF pulse 50MW, 1.5us, 50Hz)
  - Microwave Amplifier 1300 W solid state driver (SSD) amplifier
  - Commercial S-band LLRF system (ITech) adapted to work at 11.994 GHz with an Up/Down converter developed at LNF.

RF Power Source

EuPRAXIA@SPARC_LAB has two main technological challenges:

- PLASMA Module
- X-Band RF Technology

TEX facility is currently working with a CPI Klystron on loan from CERN. An additional (at least) spare klystron is needed in order to guarantee continuity.

Opportunity to explore other solutions, better performances and possible upgrades in order to choose the baseline option.

TEX is also becoming a EOSC facility under FAIR principles (as requested by ESFRI for EuPRAXIA).

Collaboration with CNAF for data archiving

Development of a configuration tool (with LNL).

Cost & Performances comparison analysis

Parameter	Unit	Canon	CPI
Max Peak Power	MW	25	50
Max Repetition Rate	Hz	400	100
Number of station	#	20	10
Efficiency	%	40	60
Unit Cost *	k€	320	1085
RF Station Cost **	k€	975	1800
Cost / Peak power	k€/MW	39	35,6
Cost / Avg Power	k€/kW	65	237

* To be updated as the procurement process ends with the current price.

** For CANON case the number of total RF Stations is twice the CPI case.

- CANON : 350k€ but additional K300 modulator + auxiliary utilities needed - tot. 1700k€
- CPI : 1250 k€. Can be marginally co-funded through CERN collaboration

RF Power Source SWOT Analysis

	STRENGTH	WEAKNESS	OPPORTUNITY	THREAT
CPI	1 High Effiency 2 Lower Running cost 3 Longer life time 4 Smaller number of units	1 Higher cost per avg power 2 More complicated WG Network 3 Rep.Rate 100Hz maximum 4 Too high EM field in the WG. 5 Demanding HV modulator	1 CERN Collaboration	1 Monopolistic approach as result of being a unique supplier.
CANON	1 Higher Repetition Rate 2 Simpler Configuration 3 Lower Peak field in the WG 4 Unit cost lower 5 Smaller footprint (k300)	1 Larger number of RF Stations 2 Limited in peak power	1 Towards high rep.rate LINAC - Beyond the state of the art 2 Other R&D activities related to EuPRAXIA	1 Difficult relationship with CANON

Procurement in progress. Signature of the contracts expected in 1 month

Slight preference to the CANON option, nevertheless it is worth to point out that NONE of them have been tested so far (i.e. they are essentially prototype).

General consensus among the reviewer and colleagues to explore and test experimentally the two solutions before choosing which one will be the baseline.

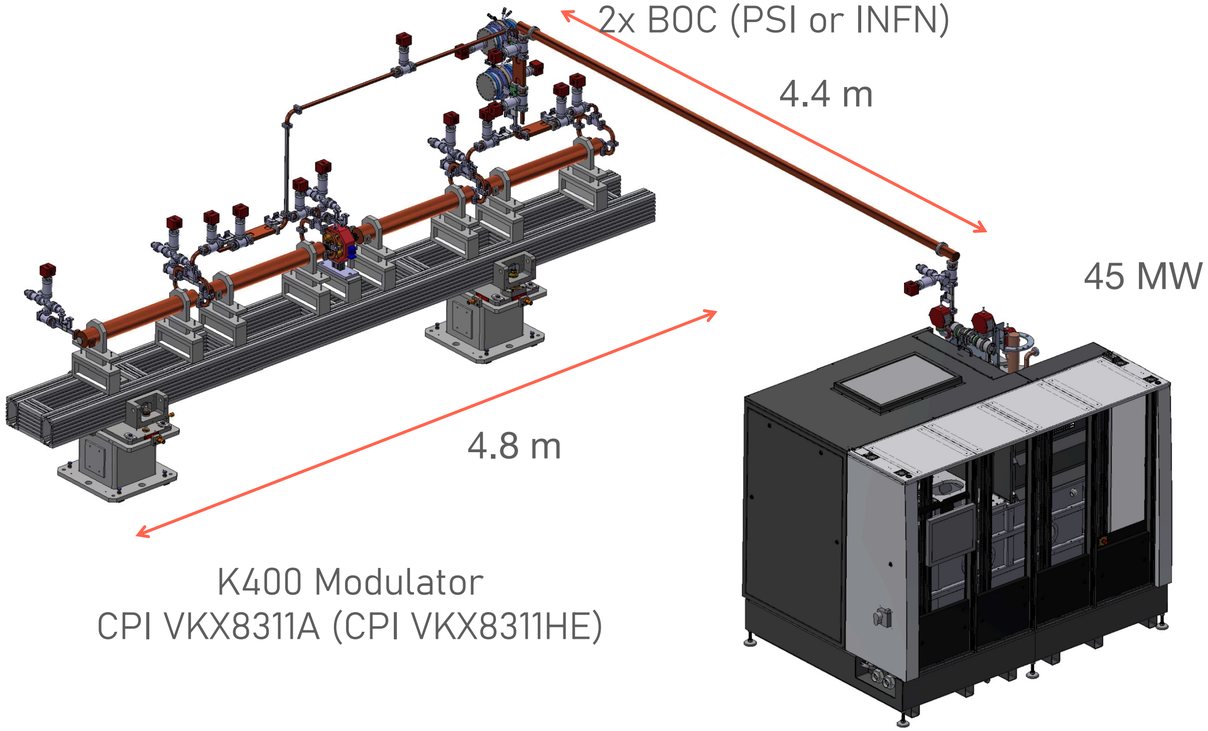
In addition this will make TEX a unique facility in the world:

- 2 X-Band tubes at different repetition rate
- Possible extension to other frequency band (e.g. C-BAND)
- Dedicated bunker, beam irradiation up to 20 MeV also possible (electron beam diffraction?)
- Other R&D activities can be performed and therefore becoming attractive for users and additional funding schemes.

RF Power Source layout

CPI - OPTION

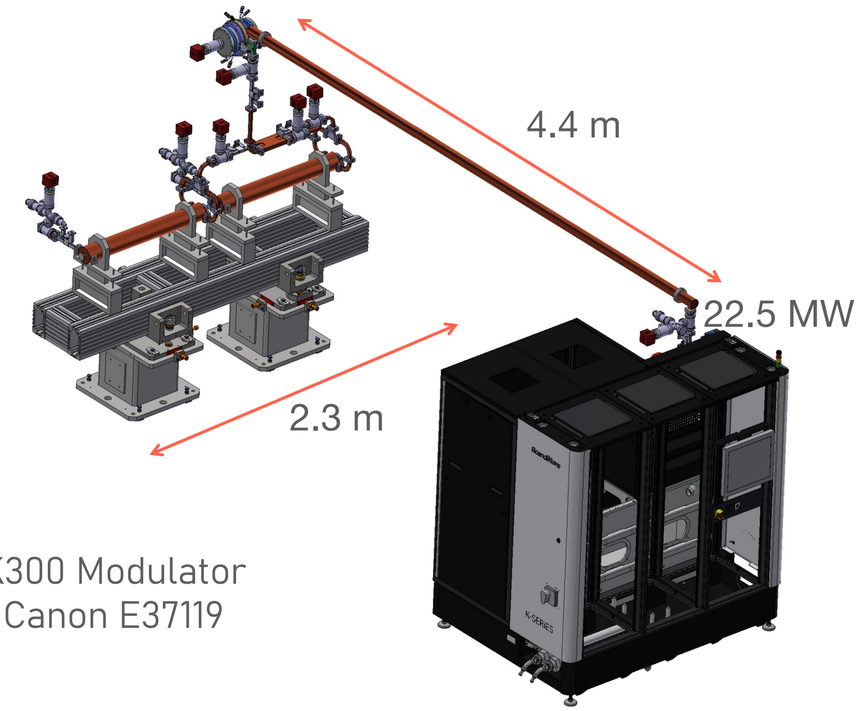
- 2x BOC on one line
- Less flexibility
- Different LE and HE module layout
- Lower power plants number



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



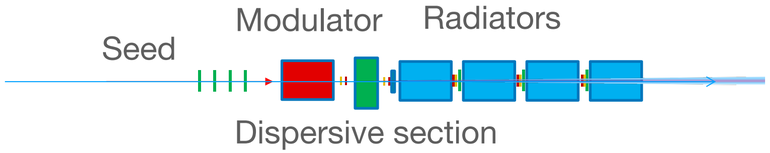
K300 Modulator
Canon E37119

Courtesy F.Cardelli

FEL | Ondulators

AQUA: Soft-X ray SASE FEL – Water window 4 nm

ARIA: VUV seeded HGHG FEL beamline for gas phase (not in the baseline)

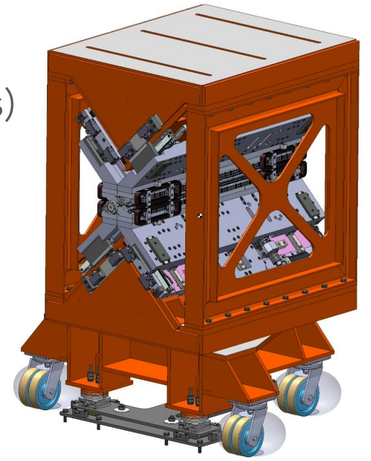


Phase 1 –Apple X undulator for AQUA

- Baseline solution is an APPLE X Undulator / Period 18mm / 10 modules / 2m each
- Magnetic design studying:
  - Increasing #magnet per period 4 →6/8
  - Effect of mechanical deformation
  - Set-up appropriate magnetic measurement system.

- Prototyping (from Sabina undulators – KYMA design)
  - Define upper limits for acceptable deformation
  - Mitigate mechanical deformations associated to stresses

- Simulations
- Definition of intraundulators sections (e.g. diagnostics)



Prototype – Sabina ondulator (Kyma)

FEL Line	Configuration
AQUA	FEL Amplifier APPLE-X 18 mm period (+ SCU 1 module)
ARIA	HGHG FEL Modulator 3 m 10 cm period planar + 4 Apple 2 radiators, 6 cm period

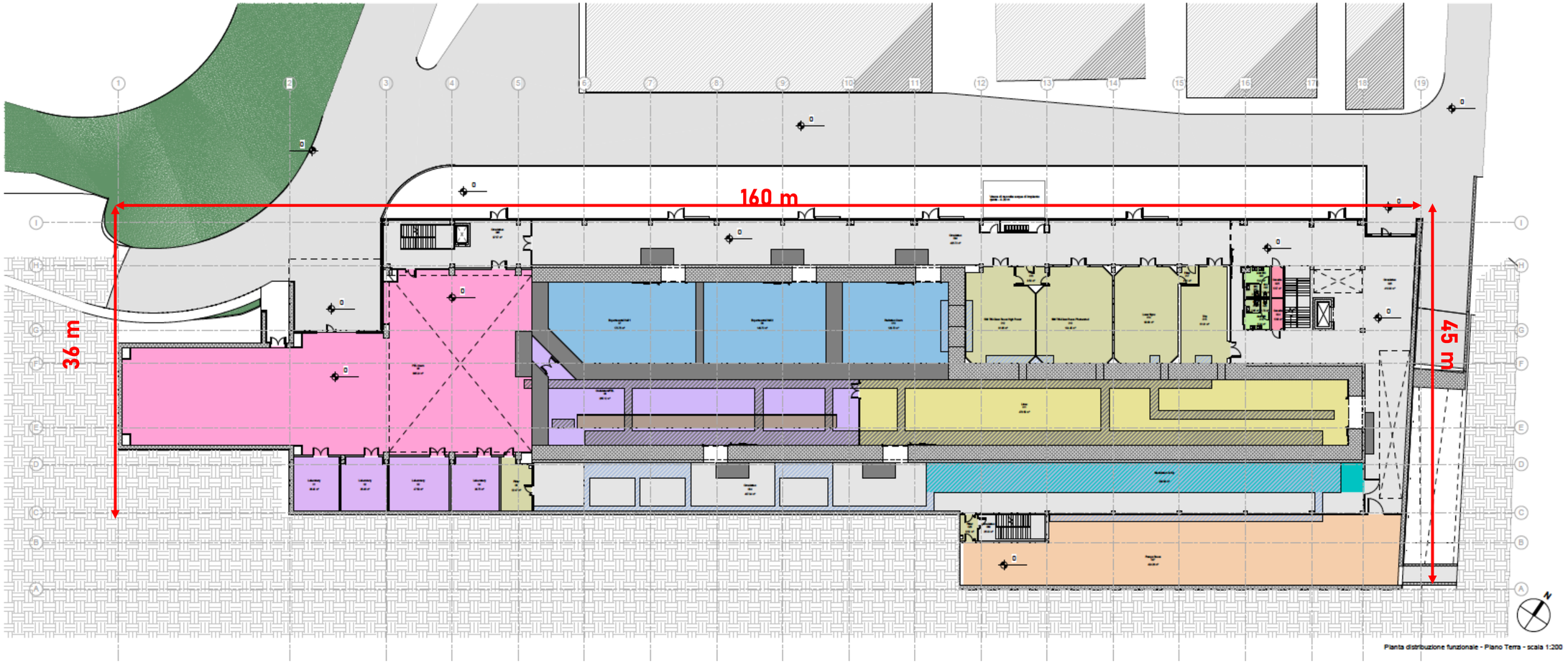
Courtesy L.Giannessi

Building Status

Progress in the design finalization and authorization process.

- Several modifications have been included, taking into account an iterative refinment of the machine and building interfaces.
- Successfull external review in December.
- Definitive design close to completion. Integration and implementation of reviewers' reccomendation is in progress.
- Preliminary activities for triggering the authorization process has already started.

Building Status



Courtesy S.Incremona

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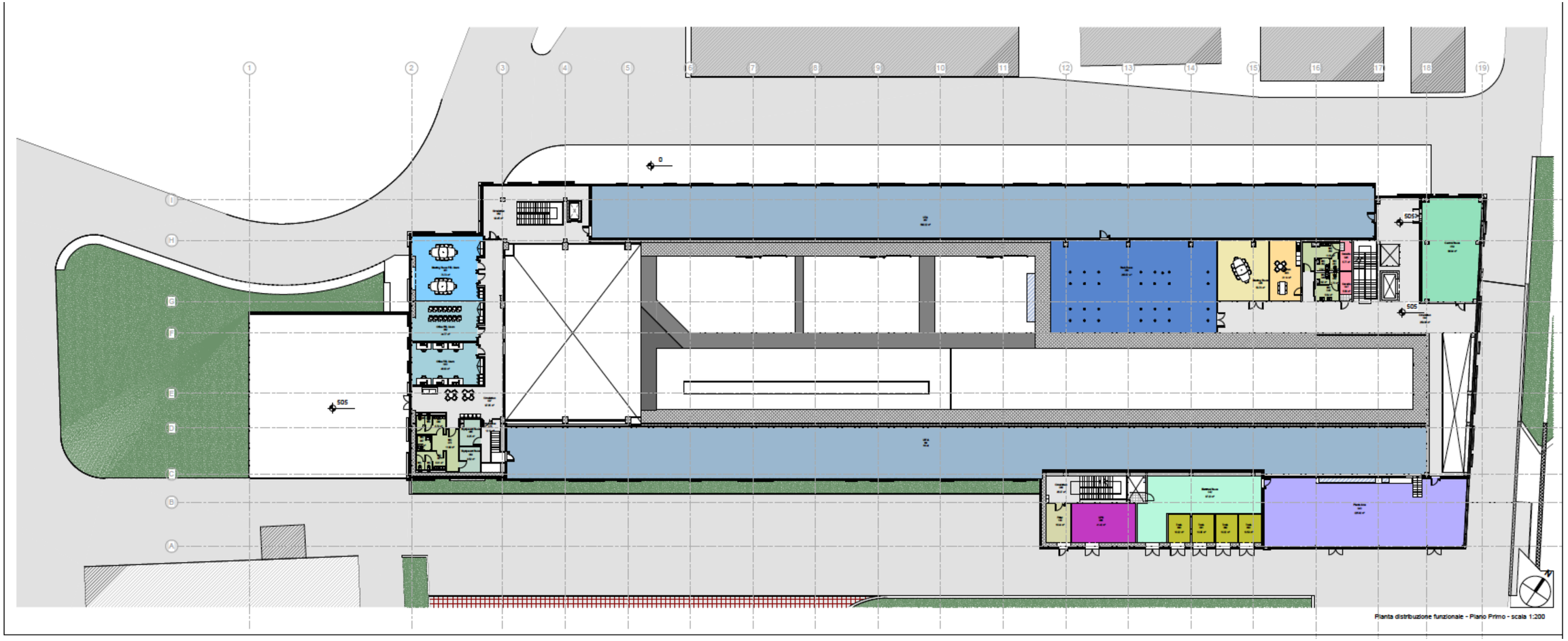

Courtesy S.Incremona

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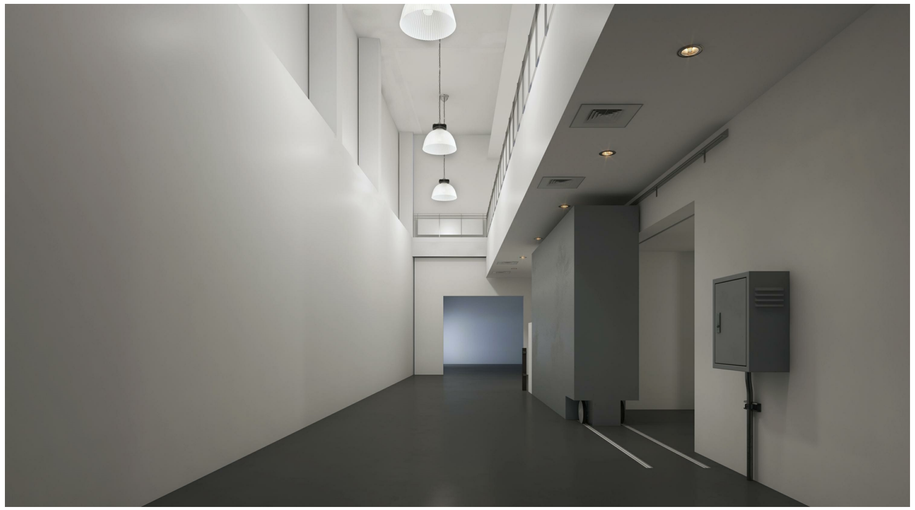
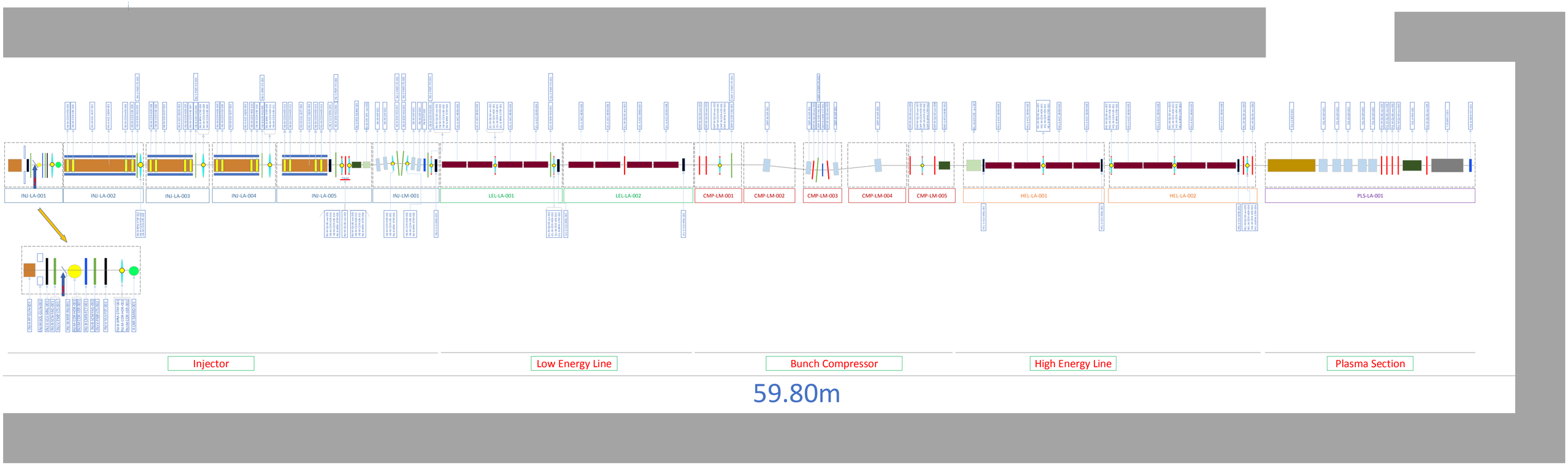


Courtesy S.Incremona

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



System Engineering

GEMINI - Generate Experimental Machine Interface Naming Items

- In-house tool for configuration management under development (in collaboration with LNL):

Gemini is an asset Management tool for LINACs for:

- Track instruments history and user actions over those instruments
- Web-based interface
- Stores data used by different clients
  - Graphical user interfaces
  - Finite state machines
  - IOCs
  - Utility management tool
  - Beam dynamic management tools
  - Automatic Logbook creation.
- Handle UUID device identification
- Provide Information on utility metrics:
  - Schematic (equipment name, description, accelerator module, room, vacuum region, sub-system, …)
  - Cabling (routing, destination rack & controller, cable type, connector type, …)
  - Archived PV values stored with EPICS Archiver Applliance over EOSC infrastructure (ESFRI roadmap)
- Enabling fast DB query from operation team (QR-code on each device)
- Manage user permissions (create, edit, visualize)

Courtesy D.Moriggi

Schedule update – critical milestones

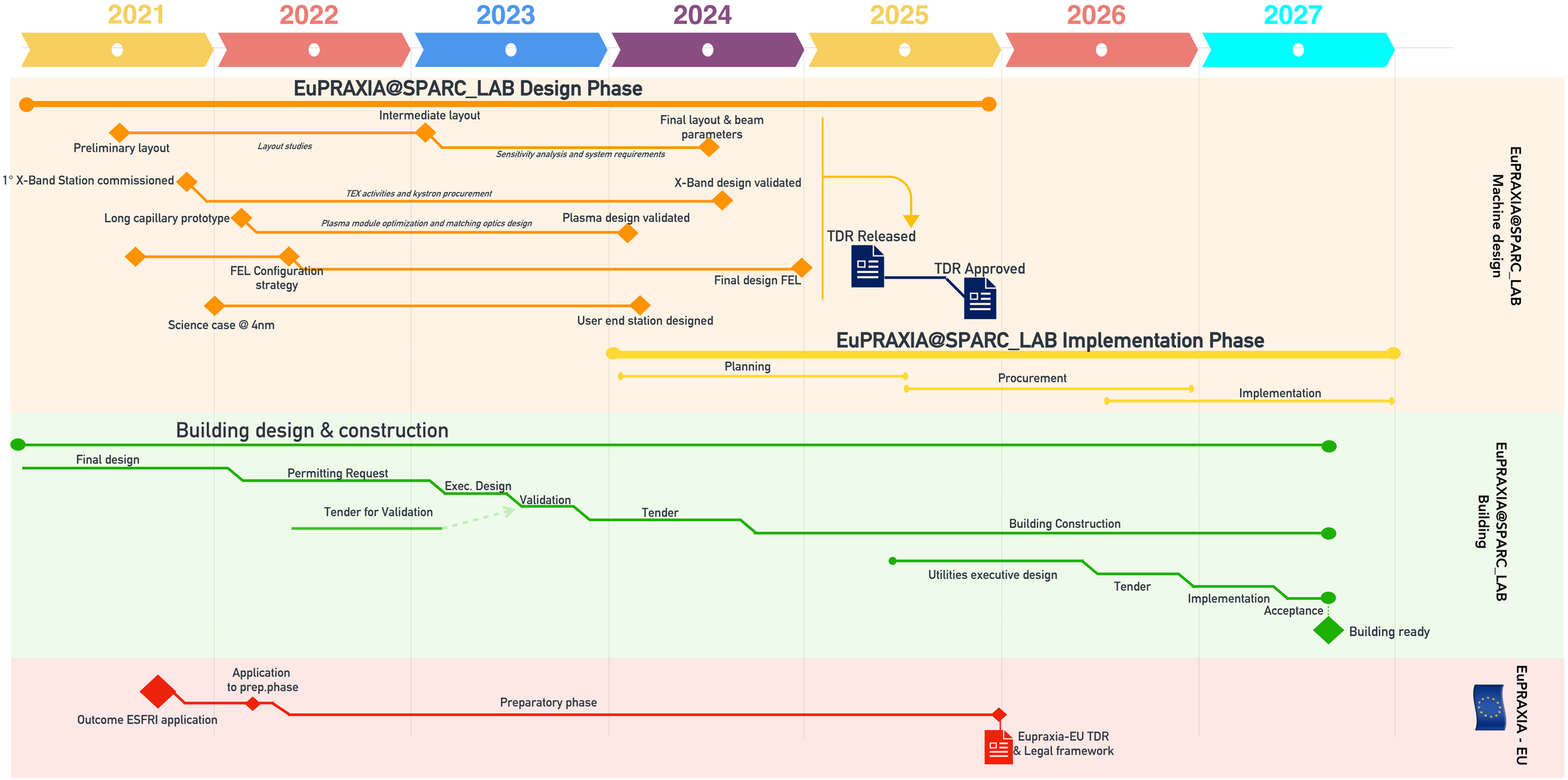
Necessity to update the time-baseline due to several factors

- RF Source solution to be chosen as baseline must be tested experimentally. Procurement of the HE tube (CPI) and HRR tube (CANON) is long (around 24 months for CPI and 18 months for CANON).
- Resource loaded schedule
- Alignment w.r.t. EuPRAXIA Preparatory Phase
- Alignment w.r.t. building construction
- Hardware delivery time is becoming risky (war et. Pandemic), additional contingencies are needed to accept and manage the risk.

Schedule update

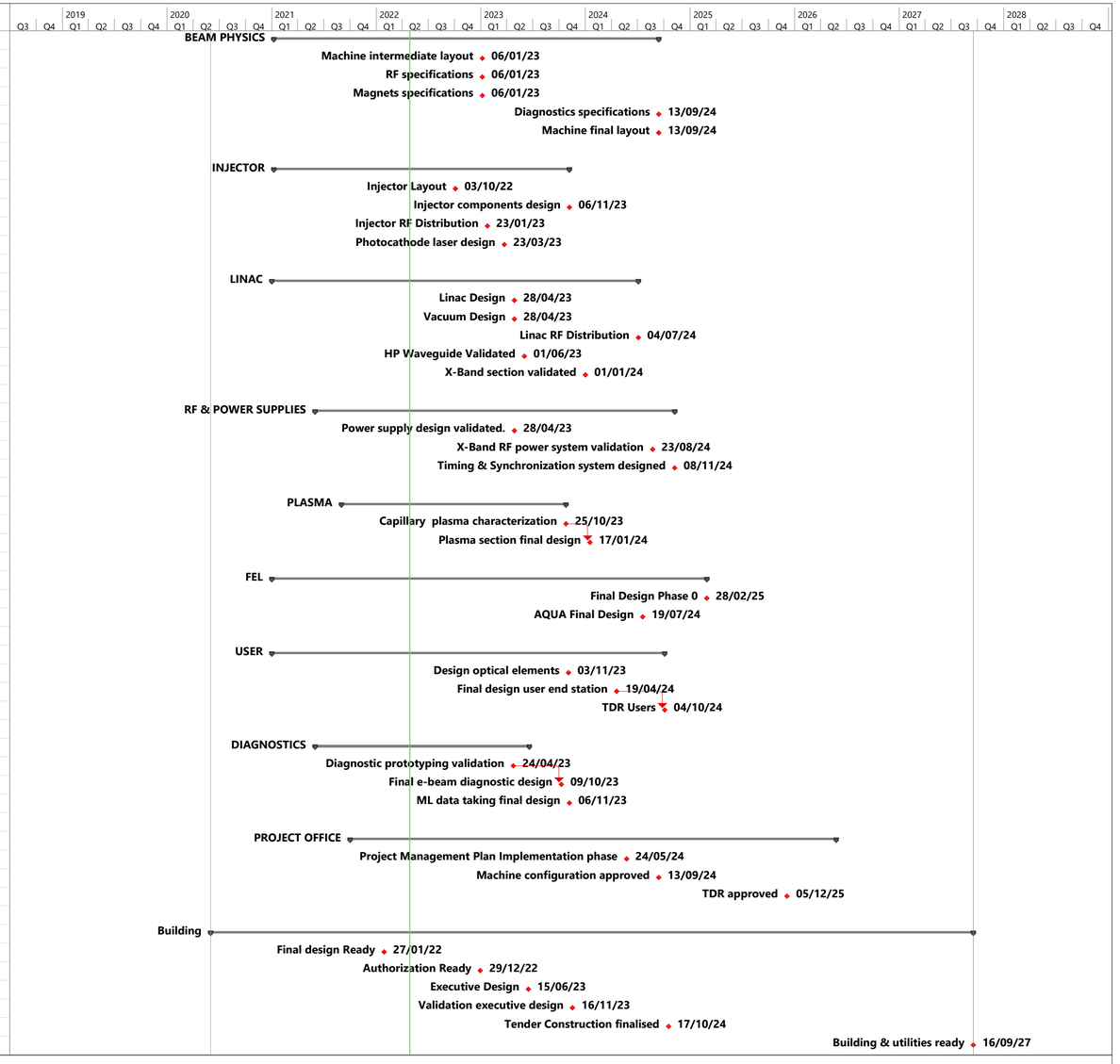
- Intermediate milestones are now achievable (all of them are on time now and on good track),
- Additional intermediate milestones added to have a better control on the progress
- Some adjustments (e.g. Diagnostics is now a WA which include also photon diagnostics).
- Building timeline is on track.
- Delivery of the X-Band Klystrons are aligned with the procurement status.

Schedule update – critical milestones



Schedule update

ID	Task Mode	WA ID	Task Name
1		**WA1**	**BEAM PHYSICS**
6		M1.1	Machine intermediate layout
7		M1.2	RF specifications
8		M1.3	Magnets specifications
9		M1.4	Diagnostics specifications
10		M1.5	Machine final layout
11			
12		**WA2**	**INJECTOR**
21		M2.1	Injector Layout
22		M2.2	Injector components design
23		M2.3	Injector RF Distribution
24		M2.4	Photocathode laser design
25			
26		**WA3**	**LINAC**
44		M3.1	Linac Design
45		M3.2	Vacuum Design
46		M3.3	Linac RF Distribution
47		M3.4	HP Waveguide Validated
48		M3.5	X-Band section validated
49			
50		**WA.04**	**RF & POWER SUPPLIES**
60		M4.1	Power supply design validated.
61		M4.2	X-Band RF power system validation
62		M4.3	Timing & Synchronization system designed
63			
64		**WA.05**	**PLASMA**
71		M5.1	Capillary plasma characterization
72		M5.2	Plasma section final design
73			
74		**WA.06**	**FEL**
88		M6.1	Final Design Phase 0
89		M6.2	AQUA Final Design
90			
91		**WA.08**	**USER**
100		WA8.M1	Design optical elements
101		WA8.M2	Final design user end station
102		WA8.M3	TDR Users
103			
104		**WA.10**	**DIAGNOSTICS**
116		M10.1	Diagnostic prototyping validation
117		M10.2	Final e-beam diagnostic design
118		M10.3	ML data taking final design
119			
120		**PO**	**PROJECT OFFICE**
132		MPO.3	Project Management Plan Implementation phase
133		MPO.4	Machine configuration approved
134		MPO.5	TDR approved
135			
136		**BLDG**	**Building**
155		BLDG.M1	Final design Ready
156		BLDG.M3	Authorization Ready
157		BLDG.M4	Executive Design
158		BLDG.M5	Validation executive design
159		BLDG.M6	Tender Construction finalised
160		BLDG.M7	Building & utilities ready



Page 1

Risk Management update

The Project Management Plan included a comprehensive section concerning Risk Management: Methodology, Risk assessment, Mitigation actions.

- Mitigation actions have been implemented, wheareas not possible contingencies have been added (e.g. new baseline).
- Shortage of Manpower was considered a critical risk and it is being addressed at the management level
- Additional risks are now on the table → Post Pandemic situation & War → Significant increase of costs and additional delays in procurement (already visible for the RF Power source) are expected in the next months /years. This will affect the R&D Phase and most importantly the implementation phase. By end of 2022 a comprehensive cost estimation of the implemenation phase will be done.
- Additional mitigation actions must be put in place and will be discussed at management level soon.

Sci-Com Reccomendation Nov 2021

Recommendations EuPRAXIA

• The staffing plan for EuPRAXIA needs further consolidation and integration with the resource planning for all LNF accelerator activities. To keep the ambitious schedule of EuPRAXIA@SPARC_LAB, the LNF management needs to allocate soon the staff and budget for the project preparation phase.

• The 400 Hz option can provide a unique feature for the FEL user facility. The SC recommends a thorough study what is required to make all facility components compatible with 400 Hz operation.

Sci-Com Reccomendation Nov 2021

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• *The staffing plan for EuPRAXIA needs further consolidation and integration with the resource planning for all LNF accelerator activities. To keep the ambitious schedule of EuPRAXIA@SPARC_LAB, the LNF management needs to allocate soon the staff and budget for the project preparation phase.*

At the moment there are around 35 FTE working at EuPRAXIA-wide activities (which includes Sparc_lab, TEX, building, administration and general services) within the Lab. A recruitment plan will be presented at the management level soon (18/05/2022) that will cover the time frame 2022-2026.

2026: transition from Design Phase to Implementation Phase.

- The recruitment plan has the ambition to raise the total number of FTE actually working from 35 to 60 (approx).
- Synergies with other Lab activities have been included in the plan.
- External contributors (INFN-MI, UniRoma1, UniRoma2, ENEA) have been considered and effort the keep the collaboration alive will be implemented.

Sci-Com Reccomendation Nov 2021

- *The staffing plan for EuPRAXIA needs further consolidation and integration with the resource planning for all LNF accelerator activities. To keep the ambitious schedule of EuPRAXIA@SPARC_LAB, the LNF management needs to allocate soon the staff and budget for the project preparation phase.*

AREA	Staff increment	Temporary contract / Fellow Increment
Accelerator Division		
High Brightness / Plasma acceleration	2	1
FEL Physics	2	2
Beam line design & Maintenance	2	-
Plasma cell & Diagnostics	1	1
Beam Diagnostics	-	1
Laser	2	1
Magnets	1	1
Control system	2	1
Mechanics		2
Vacuum	2	1
RF	2	1
Linac / Power RF	1	1
Project Management	1	1
-TOTAL Accelerator Division	14+4	11+2
Technical Division		
Cooling & Electrical Plant	2 engineers + 2 technicians	-
Civil Engineering	1 engineer	-
Safety & Radioprotection	2	-
-TOTAL Technical Division	7	

Note: in RED personell already present in the lab, but currently working in other projects.

- Acc.Div 90 → 104 15% increment
- Tec.Div 40 → 45 12,5% increment

LNF → 7% total increment

Sci-Com Reccomendation Nov 2021

Recommendations EuPRAXIA

- *The 400 Hz option can provide a unique feature for the FEL user facility. The SC recommends a thorough study what is required to make all facility components compatible with 400 Hz operation.*

This is ongoing. Preliminary calculation on cooling capabilities of Acc.Sections in X-Band at 400Hz are promising. Also PC laser studies are on-going and seems feasible.
RF Gun thermal studies at 400Hz are also foreseen (in synergy with other projects).

However, at the moment, outcomes are not mature enough to conclude that 400Hz option can be used as baseline. It will be likely seriously considered after a comprehensive test at 400Hz of the RF power source.

Design of the subsystems will be made anyway considering 400Hz option.

A decision if 400Hz option can be considered as baseline will be made in 2024 (after Canon tube test)

Conclusions

- Last months have been quite busy with the application to EU and National calls to consolidate the project ambition to build up a reference EU facility.
- Significant technical progress in all the working areas.
- Prototyping activities is well on track, testing will be made throughout 2022.
- New schedule baseline looks more reasonable and feasible. Building is on the critical path but at the moment on schedule.
- Recruitment plan is now being addressed at management level
- Additional new risks will be taken seriously under consideration. Further mitigation actions will be implemented.
- 1° November will start officially the EuPRAXIA Preparatory Phase which will pave the way for the implementation of the EuPRAXIA distributed research facility (48months).