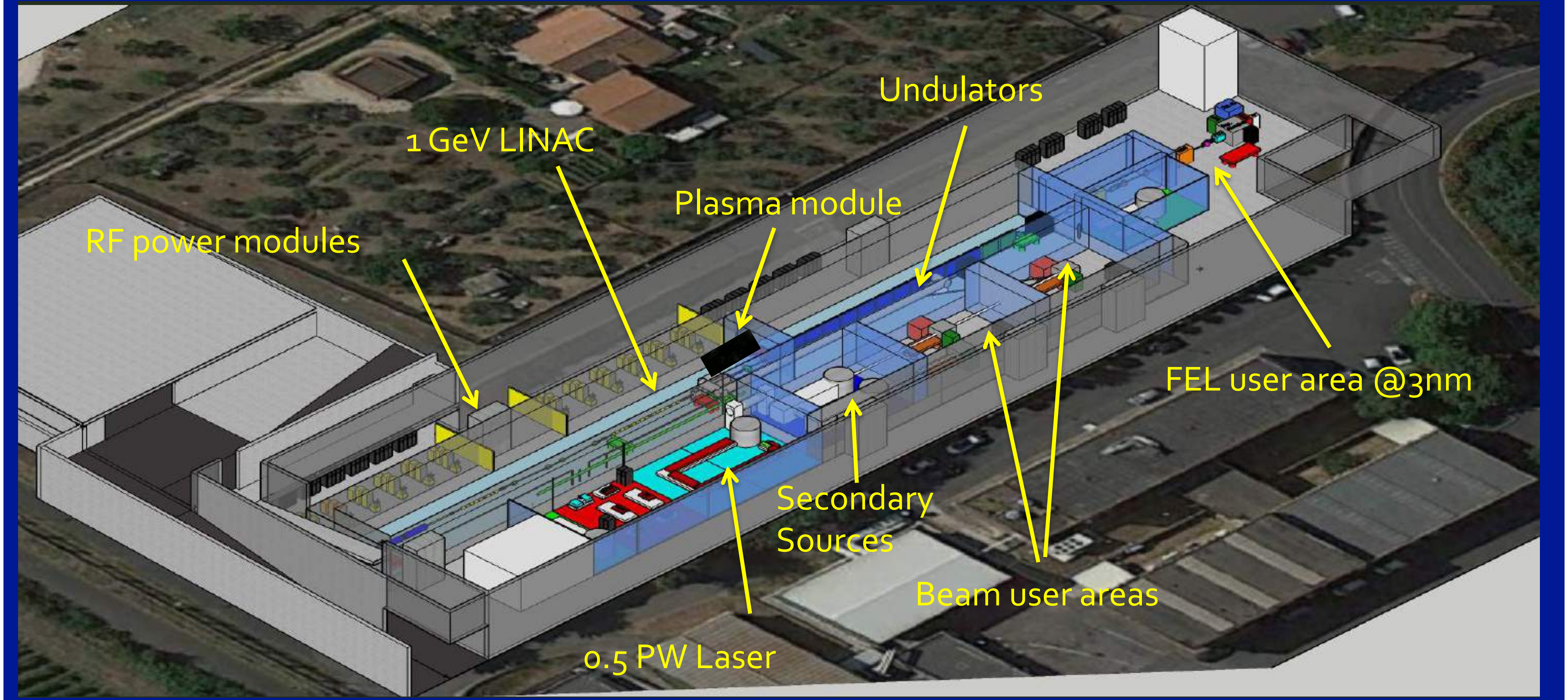
EuPRAXIA@SPARC_LAB

Massimo.Ferrario@lnf.infn.it

On behalf of the EuPRAXIA@SPARC_LAB team

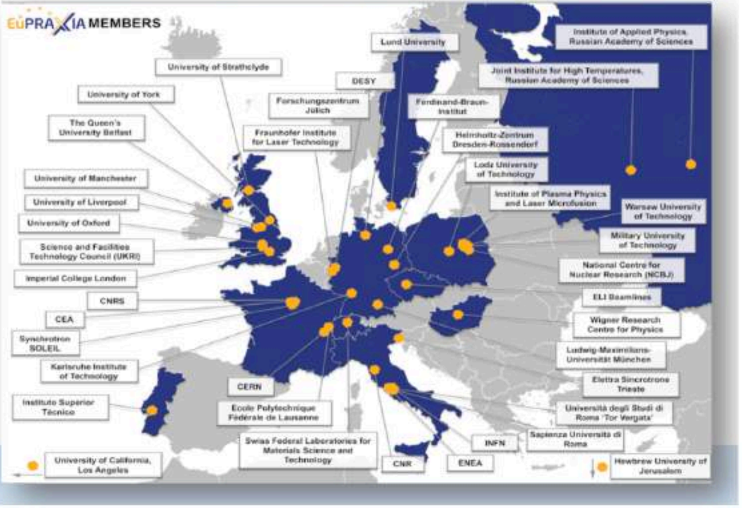


60th LNF Scientific Committee – November 16, 2020

ESFRI Proposal: Submitted on September 9

- EuPRAXIA strongly supported in European research landscape, it is **timely**, it offers **highly attractive opportunities** for innovation with industry, novel applications and pilot users.
- **Lead Country**: Italy (LNF/INFN)
  Political and financial support letter sent to ESFRI by Italian Ministry
- **Political support letters** (at least two needed from countries):
  - Hungary
  - Portugal
  - Czech Republic (ELI))
  - UK
- Note: All operational costs covered by host countries.

From political landscape it is seen that both Czech Republic and UK would be excellent sites for the second leg of EuPRAXIA, connecting to existing facilities with laser expertise and few 100 million € pre-invest.



Recent (November 4) message from ESFRI Policy Officer:

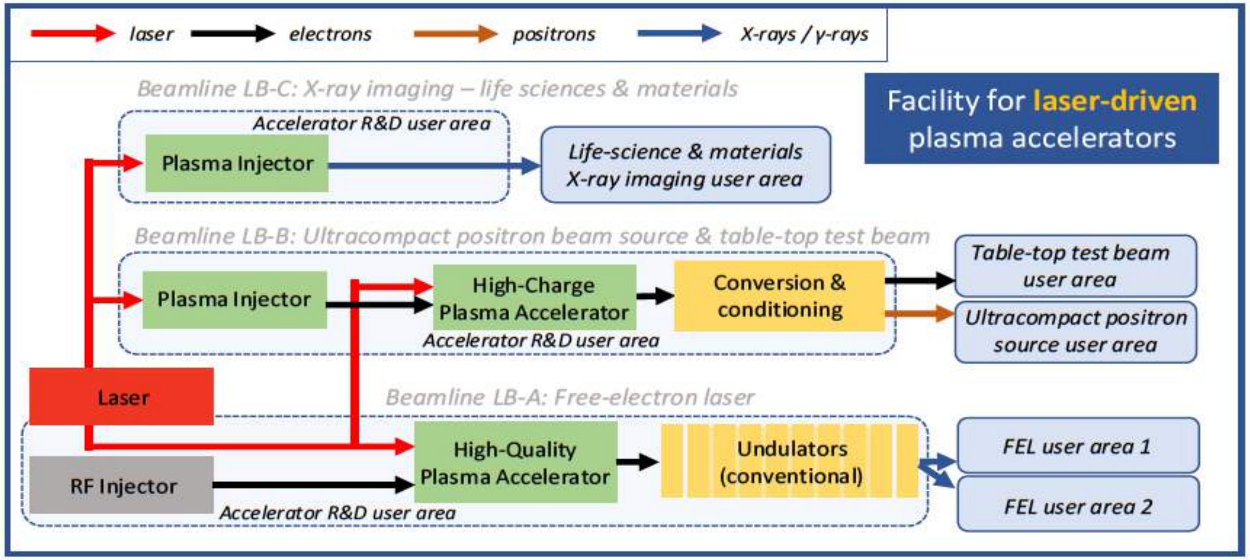
"We are glad to inform you that the proposal EuPRAXIA has been considered eligible and can now be assessed for entering the ESFRI Roadmap 2021."

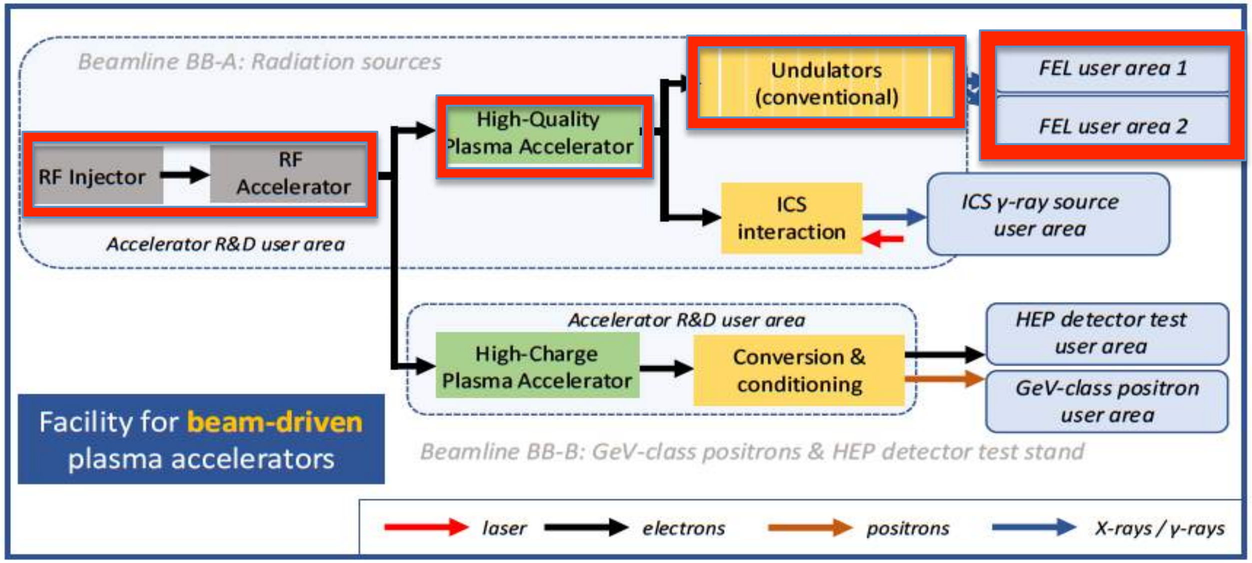
Next steps:

- Invitation for the hearing with list of critical questions: February-March 2021
- Hearing: April-May 2021

Horizon 2020

Conceptual Layout


laser
electrons
positrons
X-rays / γ-rays
Facility for **laser-driven** plasma accelerators
Beamline LB-C: X-ray imaging – life sciences & materials
Accelerator R&D user area
Plasma Injector
Life-science & materials X-ray imaging user area
Beamline LB-B: Ultracompact positron beam source & table-top test beam
Plasma Injector
High-Charge Plasma Accelerator
Conversion & conditioning
Accelerator R&D user area
Table-top test beam user area
Ultracompact positron source user area
Laser
Beamline LB-A: Free-electron laser
High-Quality Plasma Accelerator
Undulators (conventional)
RF Injector
Accelerator R&D user area
FEL user area 1
FEL user area 2

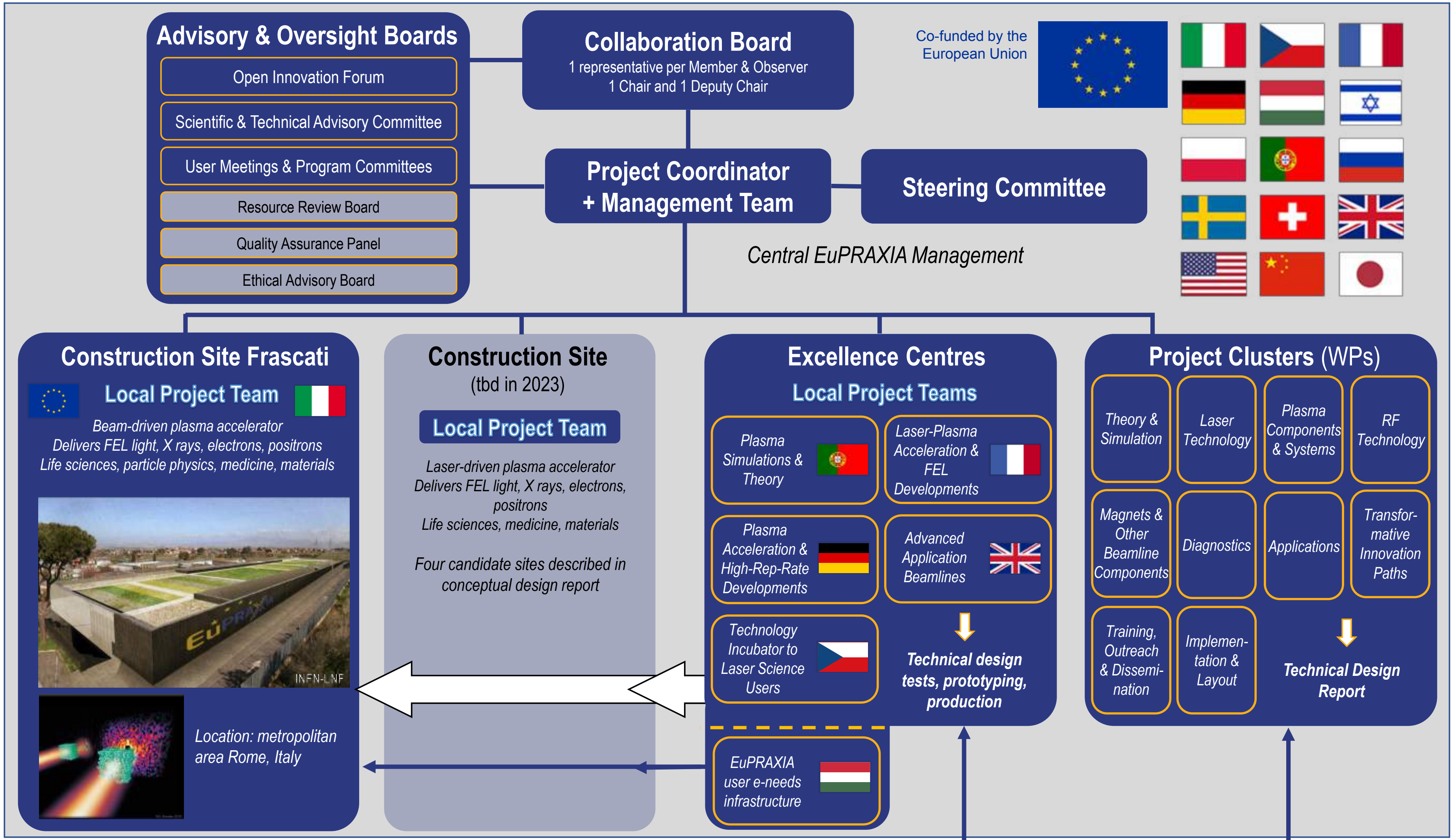

Beamline BB-A: Radiation sources
RF Injector
RF Accelerator
Accelerator R&D user area
High-Quality Plasma Accelerator
Undulators (conventional)
FEL user area 1
FEL user area 2
ICS interaction
ICS γ-ray source user area
Accelerator R&D user area
High-Charge Plasma Accelerator
Conversion & conditioning
HEP detector test user area
GeV-class positron user area
Beamline BB-B: GeV-class positrons & HEP detector test stand
Facility for **beam-driven** plasma accelerators
laser
electrons
positrons
X-rays / γ-rays

EuPRAXIA **lasers** will operate with high stability at 20 to 100 Hz, a modest advancement of a factor 2 to 10 over the current state of the art. In parallel, R&D activities will be pursued on the development of laser that can operate at kHz repetition rates and deliver peak-power at 100 TW or more.

EuPRAXIA also includes the development and construction of a compact **X-band RF** accelerator based on technology from CERN with up to 100 MV/m gradients to realise a beam-driven plasma accelerator.

EuPRAXIA Organisation Chart

EUROPEAN
PLASMA RESEARCH ACCELERATOR WITH
EXCELLENCE IN APPLICATIONS



Advisory & Oversight Boards

- Open Innovation Forum
- Scientific & Technical Advisory Committee
- User Meetings & Program Committees
- Resource Review Board
- Quality Assurance Panel
- Ethical Advisory Board

Collaboration Board

1 representative per Member & Observer
1 Chair and 1 Deputy Chair

Project Coordinator + Management Team

Steering Committee

Central EuPRAXIA Management

Co-funded by the
European Union

Construction Site Frascati

Local Project Team

Beam-driven plasma accelerator
Delivers FEL light, X rays, electrons, positrons
Life sciences, particle physics, medicine, materials

Location: metropolitan area Rome, Italy

Construction Site

(tbd in 2023)

Local Project Team

Laser-driven plasma accelerator
Delivers FEL light, X rays, electrons, positrons
Life sciences, medicine, materials

Four candidate sites described in conceptual design report

Excellence Centres

Local Project Teams

- *Plasma Simulations & Theory*
- *Laser-Plasma Acceleration & FEL Developments*
- *Plasma Acceleration & High-Rep-Rate Developments*
- *Advanced Application Beamlines*
- *Technology Incubator to Laser Science Users*
- *EuPRAXIA user e-needs infrastructure*

Technical design tests, prototyping, production

Project Clusters (WPs)

- *Theory & Simulation*
- *Laser Technology*
- *Plasma Components & Systems*
- *RF Technology*
- *Magnets & Other Beamline Components*
- *Diagnostics*
- *Applications*
- *Transformative Innovation Paths*
- *Training, Outreach & Dissemination*
- *Implementation & Layout*

Technical Design Report

National projects and facilities

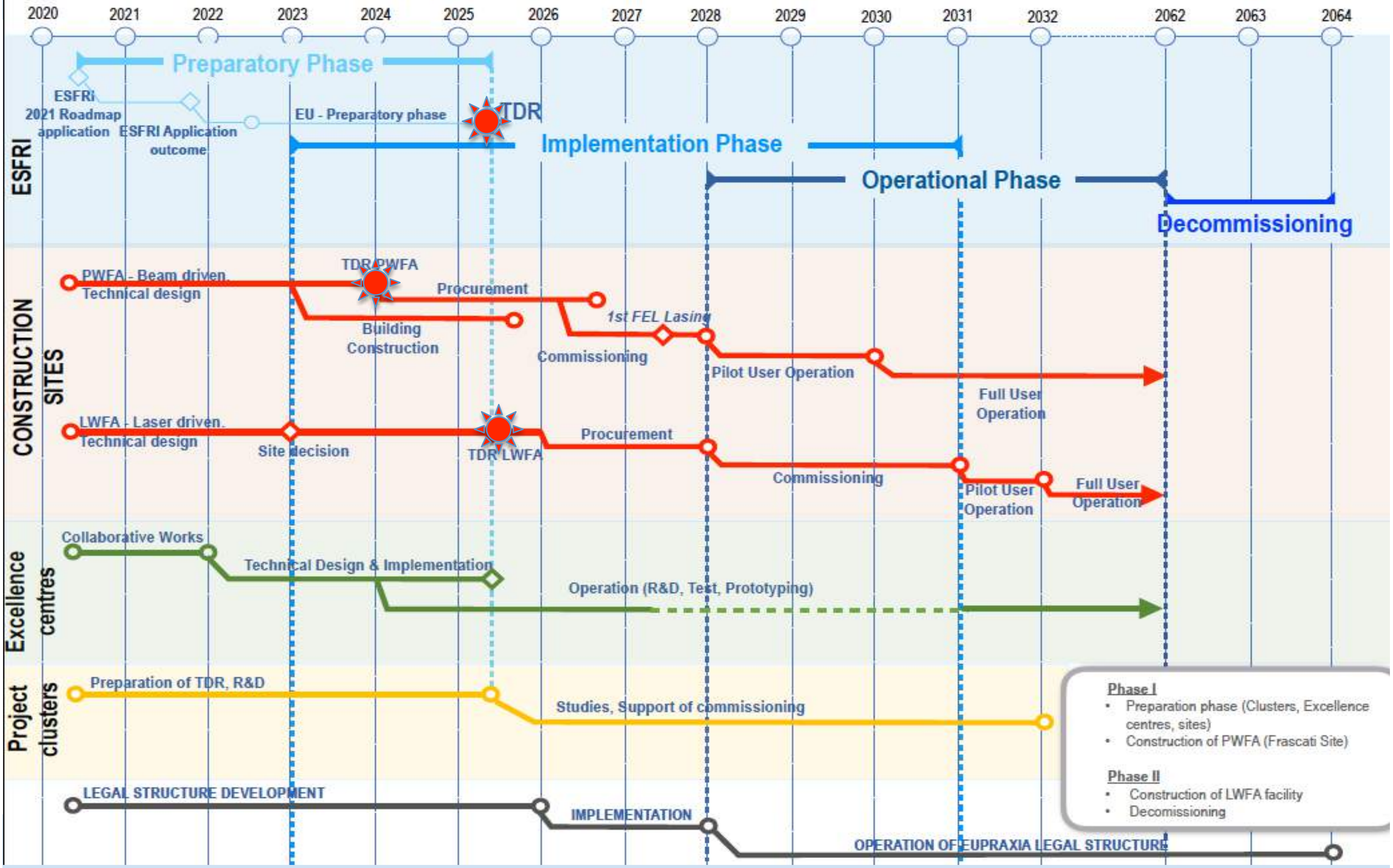
Individual groups at universities and laboratories

Organization for initial Preparatory Phase in dark blue

Features to be added with decision on second site or in later phases are indicated in lighter shades

EuPRAXIA Master Schedule

EUROPEAN
PLASMA RESEARCH ACCELERATOR WITH
EXCELLENCE IN APPLICATIONS



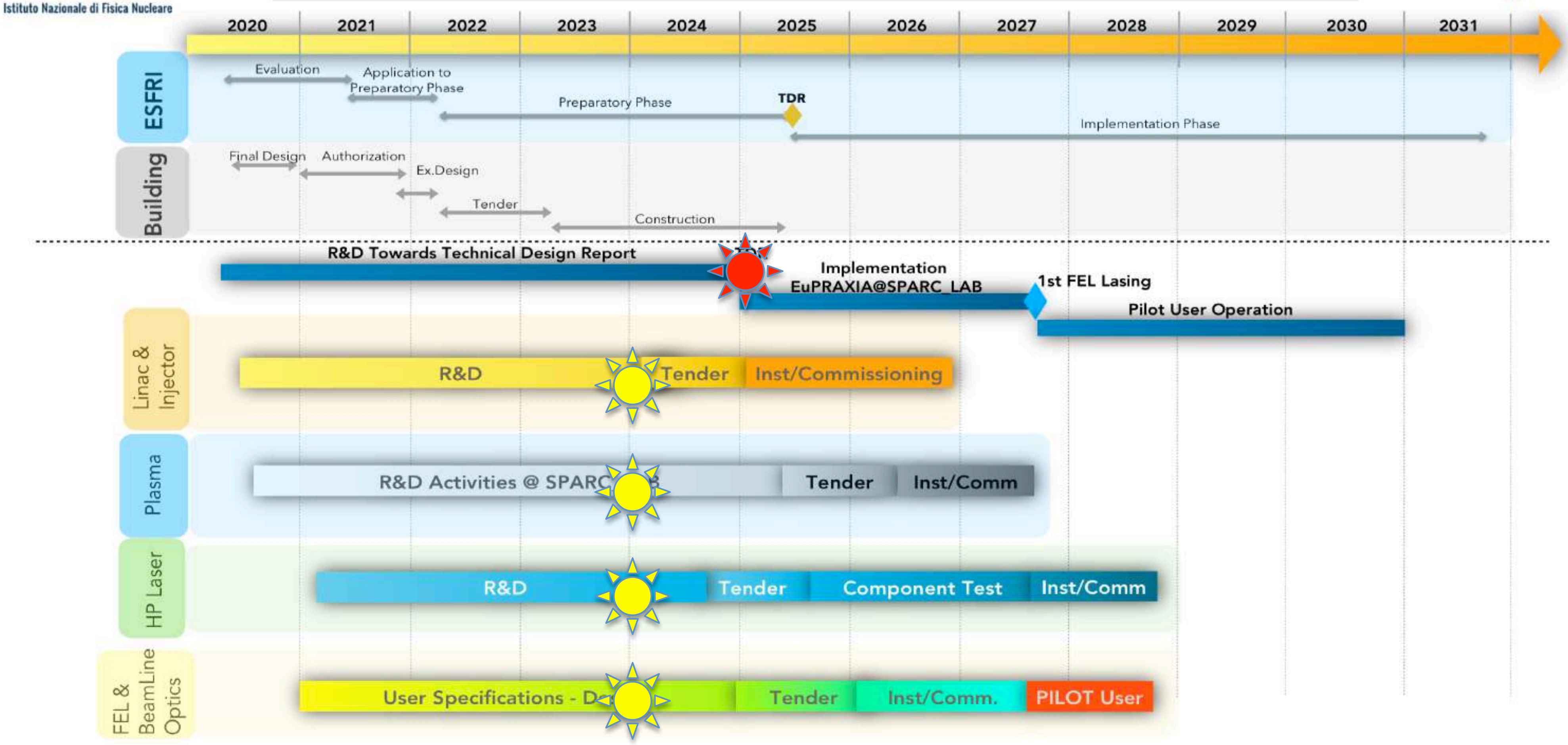
Phase I
- Preparation phase (Clusters, Excellence centres, sites)
- Construction of PWFA (Frascati Site)

Phase II
- Construction of LWFA facility
- Decomissioning

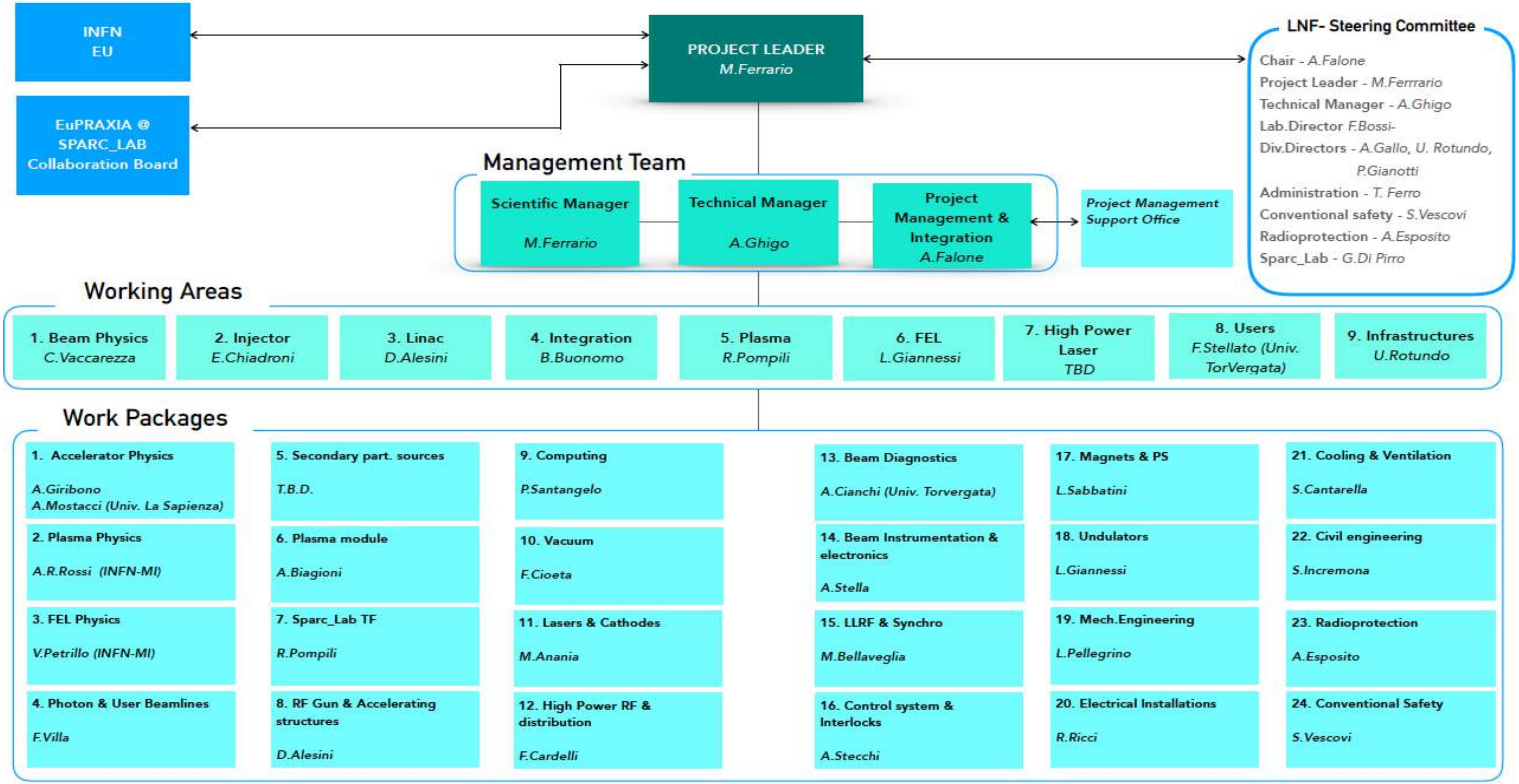
INFN LNF Istituto Nazionale di Fisica Nucleare

EuPRAXIA @ SPARC_LAB Master Schedule

EuPRAXIA



Courtesy A. Falone



INFN
EU

EuPRAXIA @
SPARC_LAB
Collaboration Board

PROJECT LEADER
M.Ferrario

LNF- Steering Committee

- Chair - *A.Falone*
- Project Leader - *M.Ferrrario*
- Technical Manager - *A.Ghigo*
- Lab.Director *F.Bossi-*
- Div.Directors - *A.Gallo, U. Rotundo, P.Gianotti*
- Administration - *T. Ferro*
- Conventional safety - *S.Vescovi*
- Radioprotection - *A.Esposito*
- Sparc_Lab - *G.Di Pirro*

Management Team

Scientific Manager
M.Ferrario

Technical Manager
A.Ghigo

Project Management & Integration
A.Falone

Project Management Support Office

Working Areas

1. Beam Physics — *C.Vaccarezza*
2. Injector — *E.Chiadroni*
3. Linac — *D.Alesini*
4. Integration — *B.Buonomo*
5. Plasma — *R.Pompili*
6. FEL — *L.Giannessi*
7. High Power Laser — *TBD*
8. Users — *F.Stellato (Univ. TorVergata)*
9. Infrastructures — *U.Rotundo*

Work Packages

1. Accelerator Physics
A.Giribono
A.Mostacci (Univ. La Sapienza)

2. Plasma Physics
A.R.Rossi (INFN-MI)

3. FEL Physics
V.Petrillo (INFN-MI)

4. Photon & User Beamlines
F.Villa

5. Secondary part. sources
T.B.D.

6. Plasma module
A.Biagioni

7. Sparc_Lab TF
R.Pompili

8. RF Gun & Accelerating structures
D.Alesini

9. Computing
P.Santangelo

10. Vacuum
F.Cioeta

11. Lasers & Cathodes
M.Anania

12. High Power RF & distribution
F.Cardelli

13. Beam Diagnostics
A.Cianchi (Univ. Torvergata)

14. Beam Instrumentation & electronics
A.Stella

15. LLRF & Synchro
M.Bellaveglia

16. Control system & Interlocks
A.Stecchi

17. Magnets & PS
L.Sabbatini

18. Undulators
L.Giannessi

19. Mech.Engineering
L.Pellegrino

20. Electrical Installations
R.Ricci

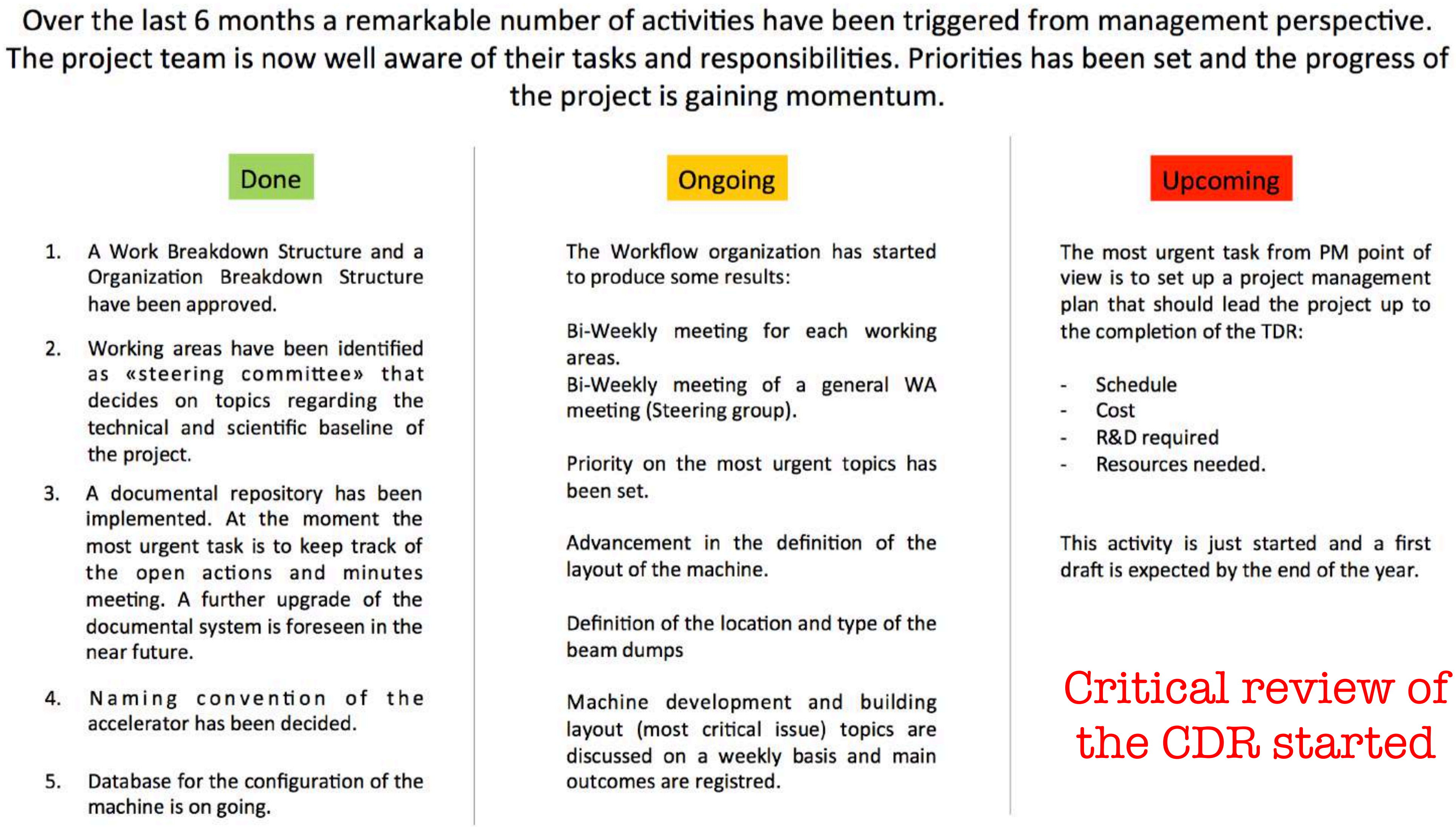
21. Cooling & Ventilation
S.Cantarella

22. Civil engineering
S.Incremona

23. Radioprotection
A.Esposito

24. Conventional Safety
S.Vescovi

Management Activities



Over the last 6 months a remarkable number of activities have been triggered from management perspective. The project team is now well aware of their tasks and responsibilities. Priorities has been set and the progress of the project is gaining momentum.

Done

1. A Work Breakdown Structure and a Organization Breakdown Structure have been approved.
2. Working areas have been identified as «steering committee» that decides on topics regarding the technical and scientific baseline of the project.
3. A documental repository has been implemented. At the moment the most urgent task is to keep track of the open actions and minutes meeting. A further upgrade of the documental system is foreseen in the near future.
4. Naming convention of the accelerator has been decided.
5. Database for the configuration of the machine is on going.

Ongoing

The Workflow organization has started to produce some results:

Bi-Weekly meeting for each working areas.
Bi-Weekly meeting of a general WA meeting (Steering group).

Priority on the most urgent topics has been set.

Advancement in the definition of the layout of the machine.

Definition of the location and type of the beam dumps

Machine development and building layout (most critical issue) topics are discussed on a weekly basis and main outcomes are registred.

Upcoming

The most urgent task from PM point of view is to set up a project management plan that should lead the project up to the completion of the TDR:

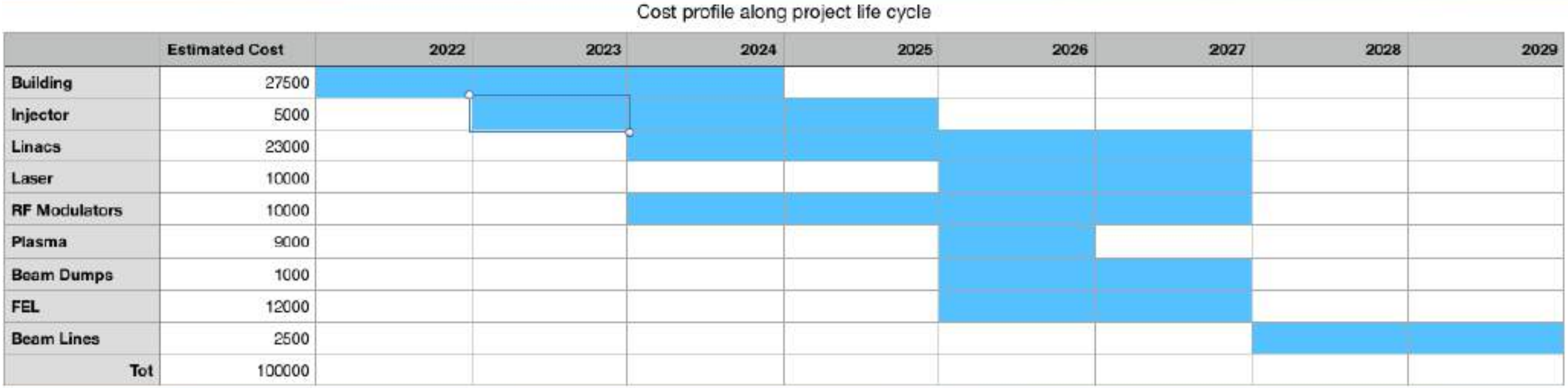
- Schedule
- Cost
- R&D required
- Resources needed.

This activity is just started and a first draft is expected by the end of the year.

Critical review of the CDR started

Courtesy A. Falone

Cost Estimation



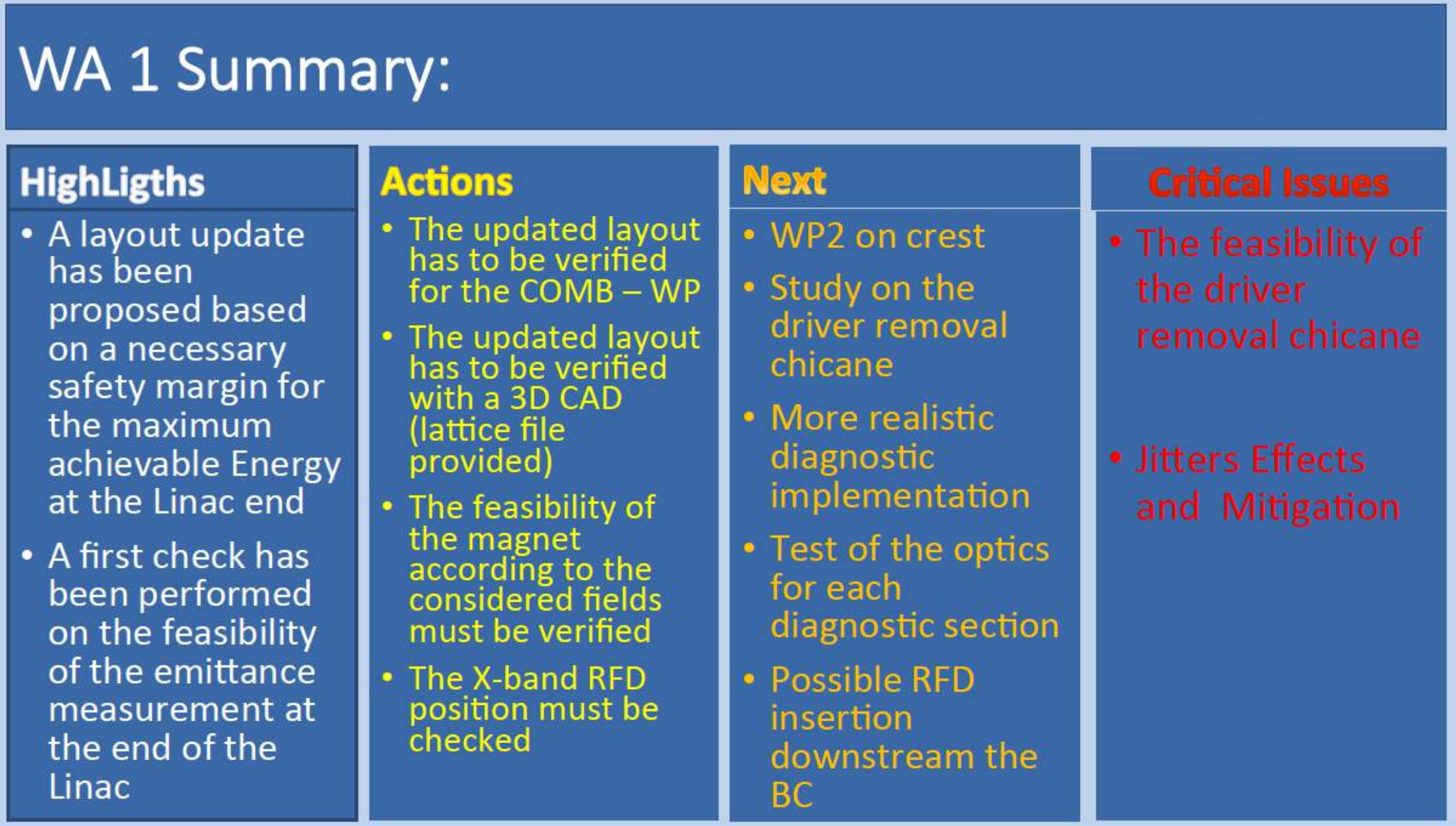
Cost profile along project life cycle

	Estimated Cost	2022	2023	2024	2025	2026	2027	2028	2029
Building	27500	■	■	■					
Injector	5000		■	■	■				
Linacs	23000			■	■	■	■		
Laser	10000					■	■		
RF Modulators	10000			■	■	■	■		
Plasma	9000					■			
Beam Dumps	1000					■	■		
FEL	12000					■	■		
Beam Lines	2500							■	■
Tot	100000								

Around 10% contingencies

No R&D and Manpower included

WA 1 – Beam Physics



WA 1 Summary:

HighLigths

- A layout update has been proposed based on a necessary safety margin for the maximum achievable Energy at the Linac end
- A first check has been performed on the feasibility of the emittance measurement at the end of the Linac

Actions

- The updated layout has to be verified for the COMB – WP
- The updated layout has to be verified with a 3D CAD (lattice file provided)
- The feasibility of the magnet according to the considered fields must be verified
- The X-band RFD position must be checked

Next

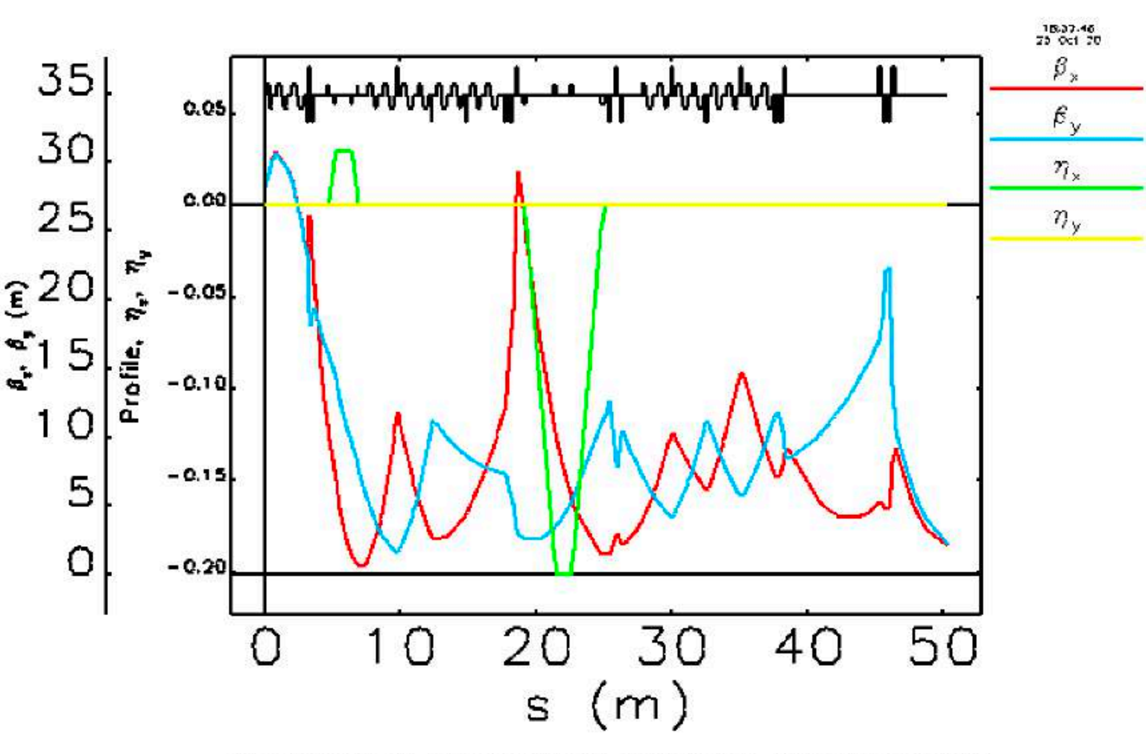
- WP2 on crest
- Study on the driver removal chicane
- More realistic diagnostic implementation
- Test of the optics for each diagnostic section
- Possible RFD insertion downstream the BC

Critical Issues

- The feasibility of the driver removal chicane
- Jitters Effects and Mitigation

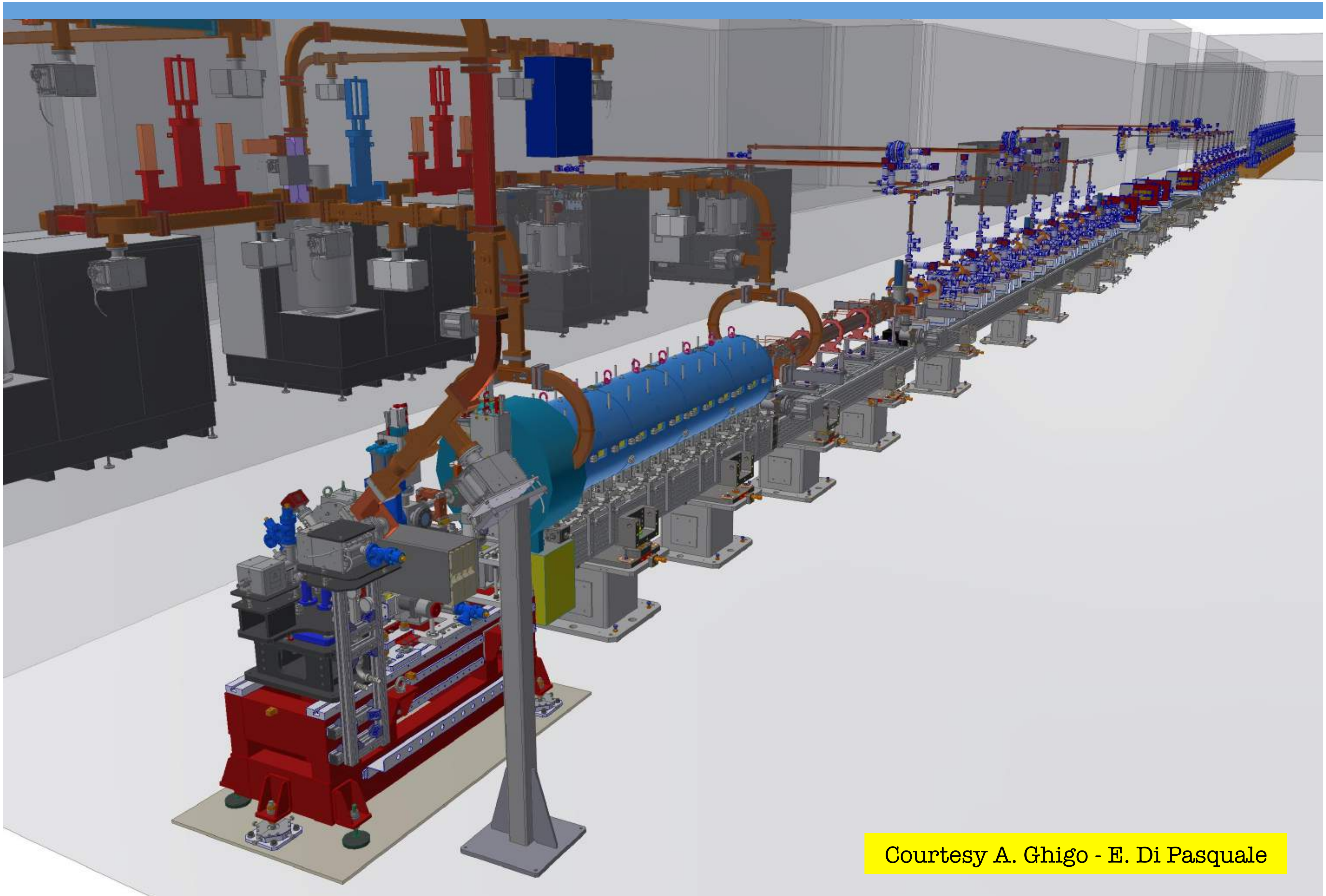
Courtesy C. Vaccarezza

A conservative value for the accelerating field in the accelerating sections is identified as **E_{acc}=60 MV/m**, corresponding to a 10% reduction of the RF power coming from the Klystron, i.e. 53.9 MV integrated for each X-band section, L=0.89856 m . With these premises and the old layout the maximum achievable energy at the Linac 2 end, turns out to be lower than 1 GeV, E_{max} = 0 .95 GeV



Twiss parameters for 200pC_1GeV_X_90cm_update_short_LH_4b_up_check_new_Oct_20

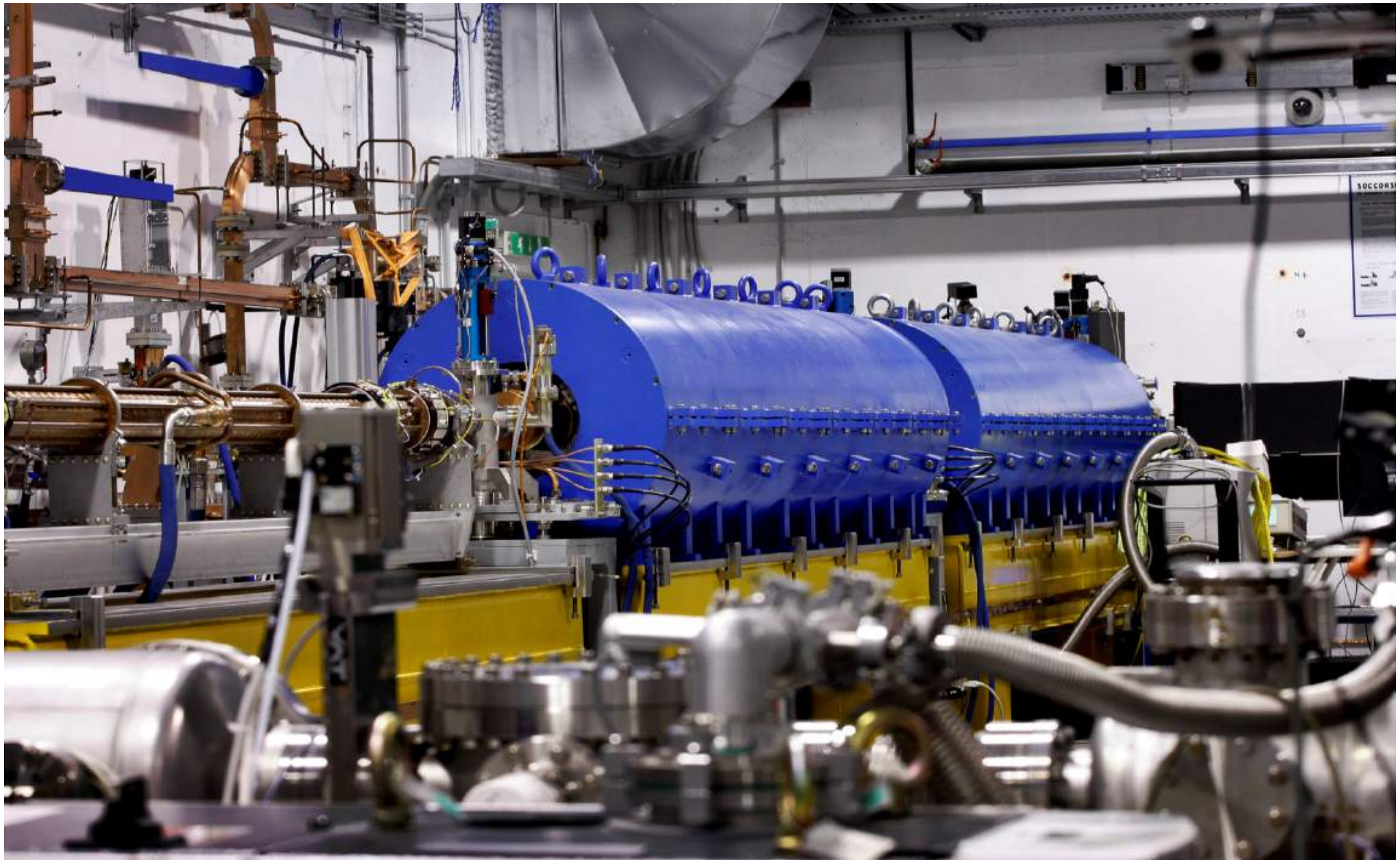
Courtesy C. Vaccarezza

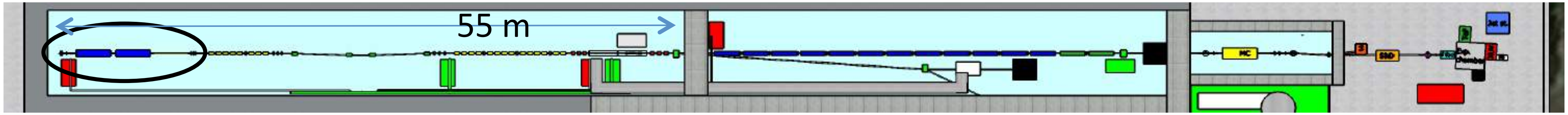


Courtesy A. Ghigo - E. Di Pasquale

WA 2 - Injector

SPARC_LAB HB photo- injector





Work in Progress

- Need for a CAD 3D layout including all the elements and the laser transport beamline
- Evaluate the feasibility of a load lock system from the beginning, even for copper cathodes (PSI model)
- Two main working points should be identified, in particular:
  - Without plasma (Full RF)
  - With plasma (and with a comb-like beam)

  To evaluate:
  - The compatibility of the diagnostics (since they may have very different beam parameters)
  - The maximum available charge
  - The laser heater studies
  - Sensitivity studies on the effect of the RF phase jitter

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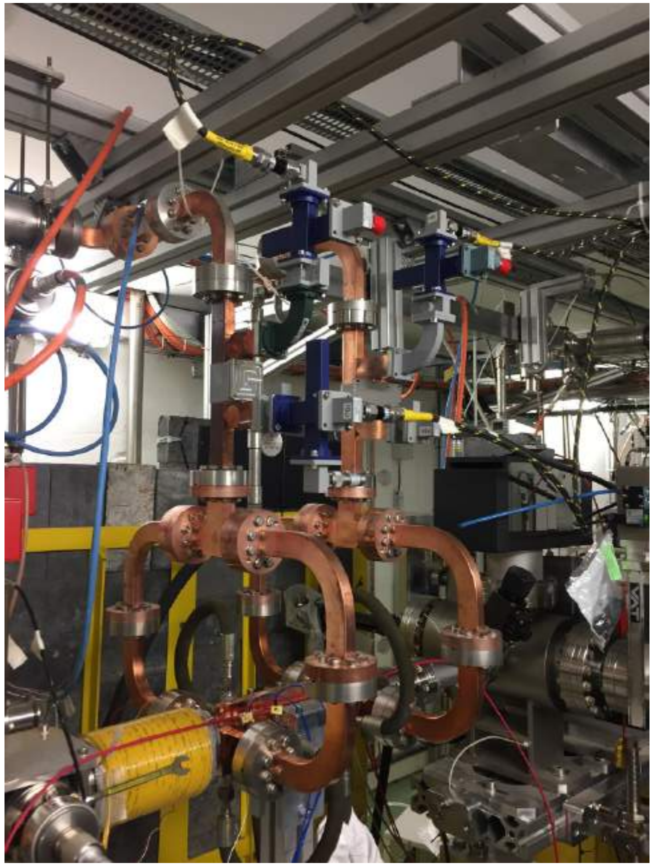
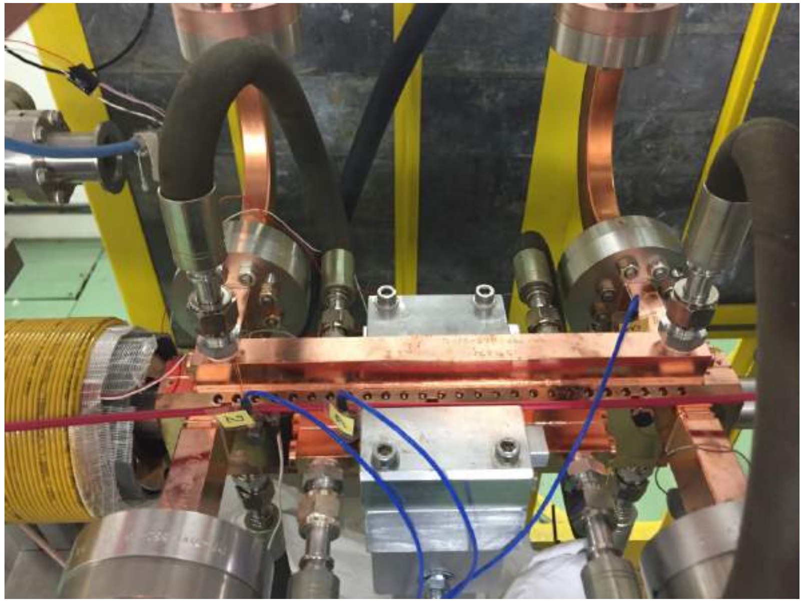
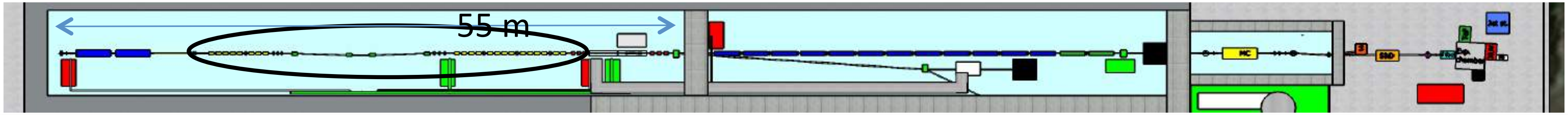
WA 3 - Linac

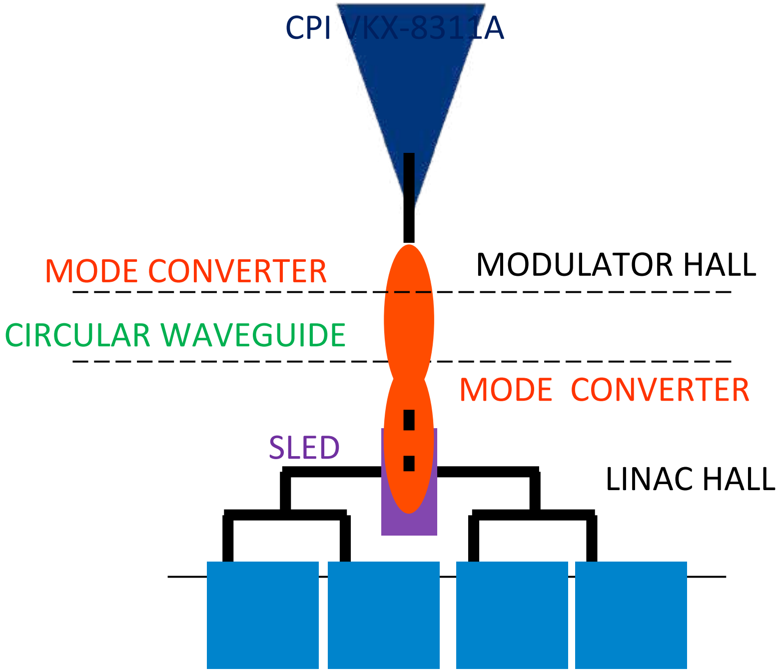
X-band Linac







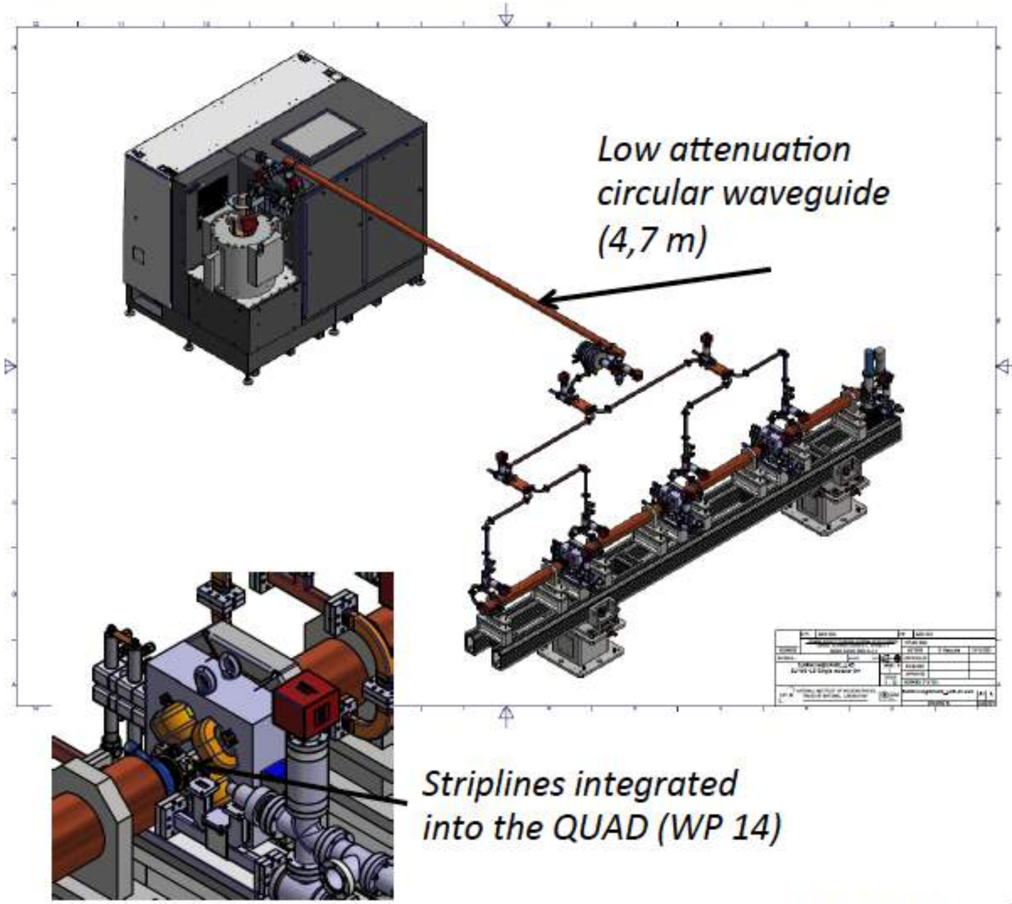
Compact



Parameter	Value
Frequency [GHz]	11.9942
RF pulse [µs]	1.5
Kly. power [MW]	50
Average iris radius <a>	3.5
Iris radius a [mm]	4.3-2.7
Average gradient <G> [MV/m]	65->60
Structure length L_s [m]	0.9
Linac active length L_{act} [m]	18
Unloaded SLED Q-factor Q_0	180000
External SLED Q-factor Q_E	23100
Shunt impedance R [MΩ/m]	85-117
Effective shunt Imp. R_s [MΩ/m]	356
Number of modules	5
Structures per module N_m	4
Klystron power per module Pk_m [MW]	43
Peak input power [MW]	74
Input power averaged over the pulse [MW]	48
Total number of structures N_{tot}	20
Total number of klystrons N_k	5

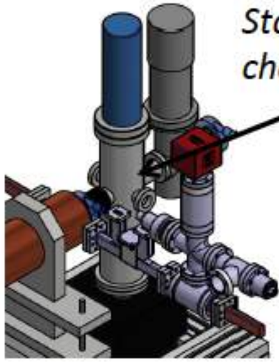
Courtesy M. Diomede

X BAND MODULE LAYOUT

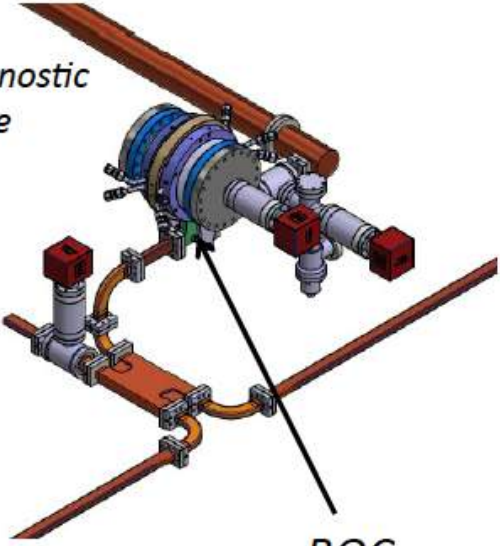


Low attenuation circular waveguide (4,7 m)

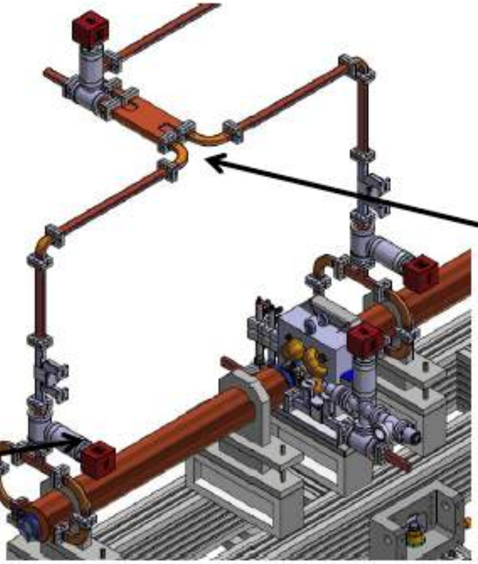
Striplines integrated into the QUAD (WP 14)



Standard Diagnostic chamber+valve



BOC



hybrid

pumps

NB: two version of the module: Low and High Energy (QUAD length)

E. Di Pasquale, G. Di Raddo

Courtesy D. Alesini

X BAND MODULE: RF STRUCTURES

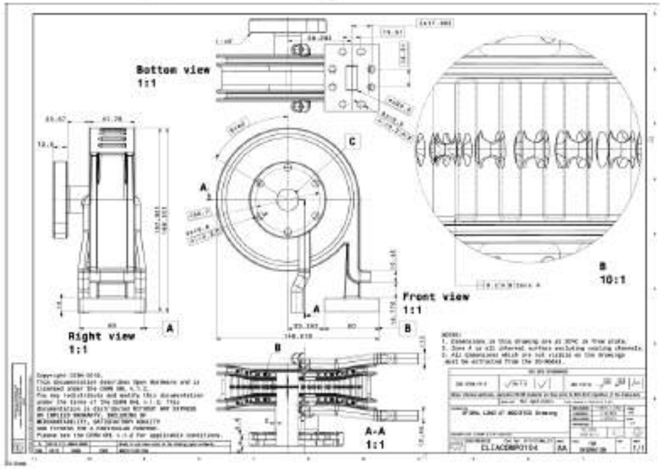
- X Band structure prototyping phase to do:
  - Mechanical prototype
  - RF prototype

- RDA submitted (40k+40k)
- Mechanical design (mechanical prototype) exp. March 21
- RF prototype (mechanical design) exp. May 21
- Realizations Fall 21

NB: Also the IFAST proposal has been funded and it foreseen the realization of the XLS structure (24 Months)

- Dark current estimation to do: CST license acquisition in progress

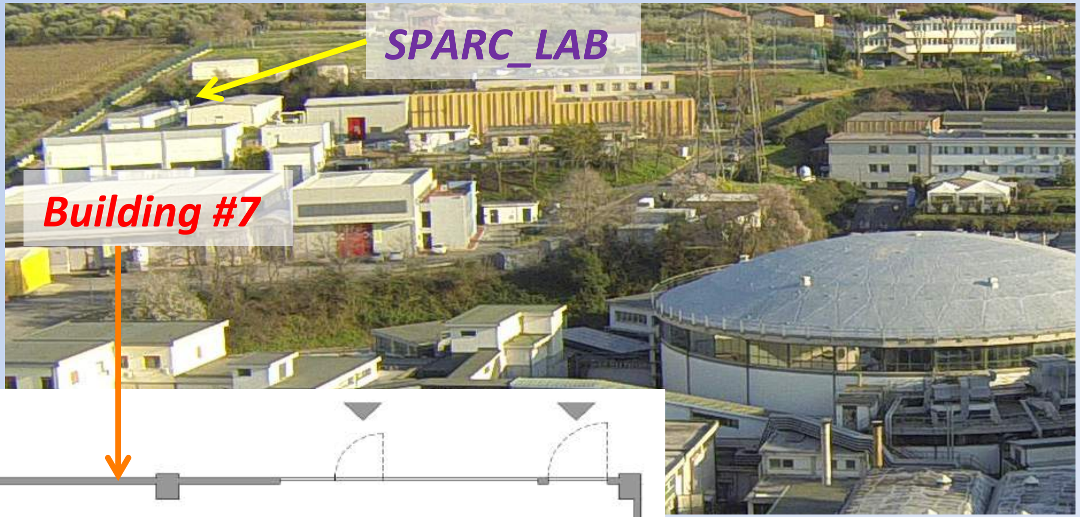
- RF load (spiral one, Titanium): Additive manufacturing up to now. TSC would like to developed a version “machined”.

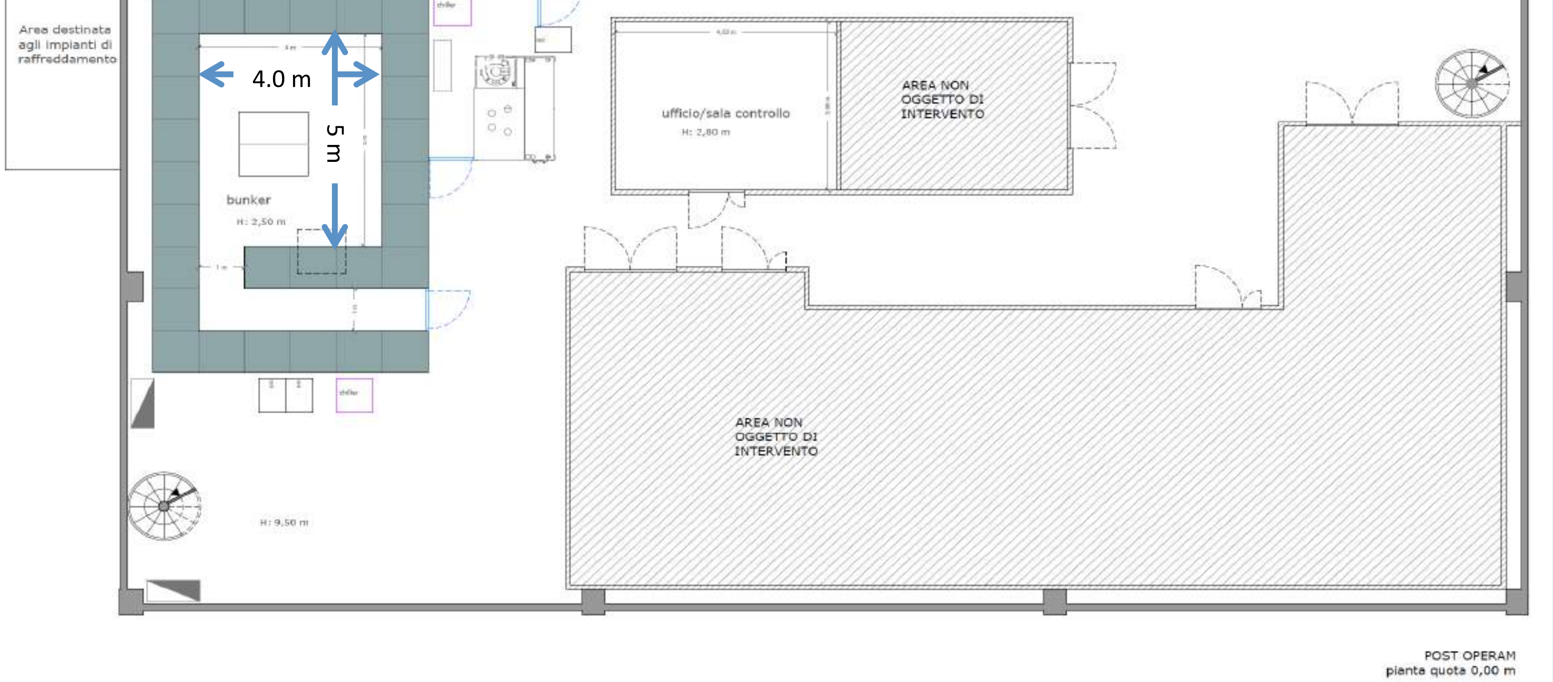


Courtesy D. Alesini

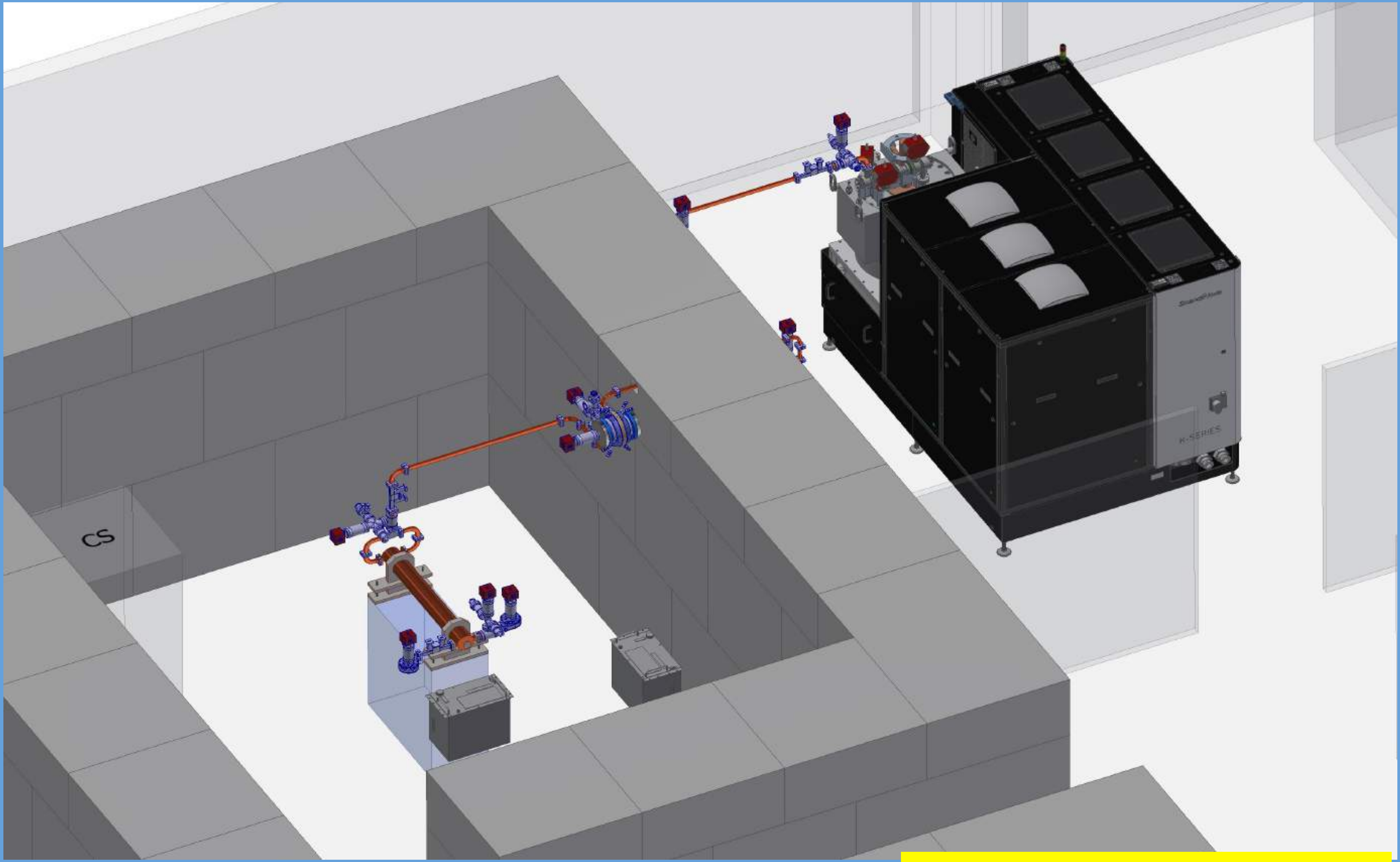
The Frascati X-box

The LATINO high-power RF Lab is based on the **INFN X-box**, a test stand under construction to test **X-band** high gradient RF structure similar to the 3 X-boxes installed at CERN. The CERN **CLIC RF group** is supporting this program through a **dedicated addendum** to the general **CERN-INFN MoU**.





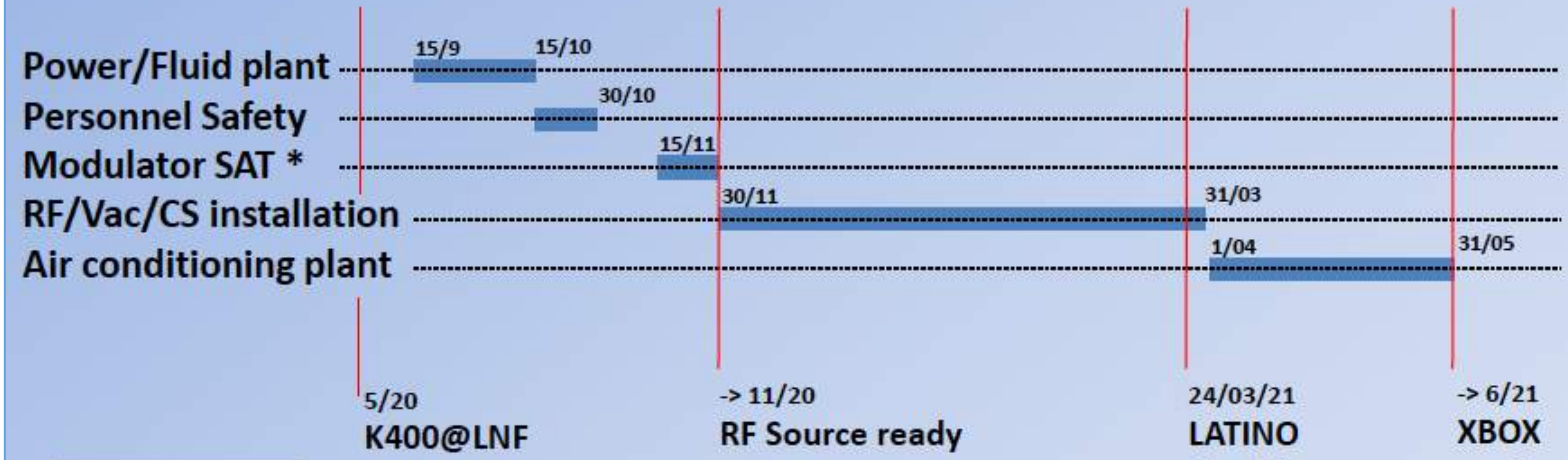
X-BOX@LNF



Courtesy E. Di Pasquale

X-band Test Stand completion schedule

(based on the tentative assumption of having the klystron delivered by early November 2020)



Power/Fluid plant 15/9 15/10

Personnel Safety 30/10

Modulator SAT * 15/11

RF/Vac/CS installation 30/11 31/03

Air conditioning plant 1/04 31/05

5/20
K400@LNF

-> 11/20
RF Source ready

24/03/21
LATINO deadline
proposed to be extended to -> 12/21

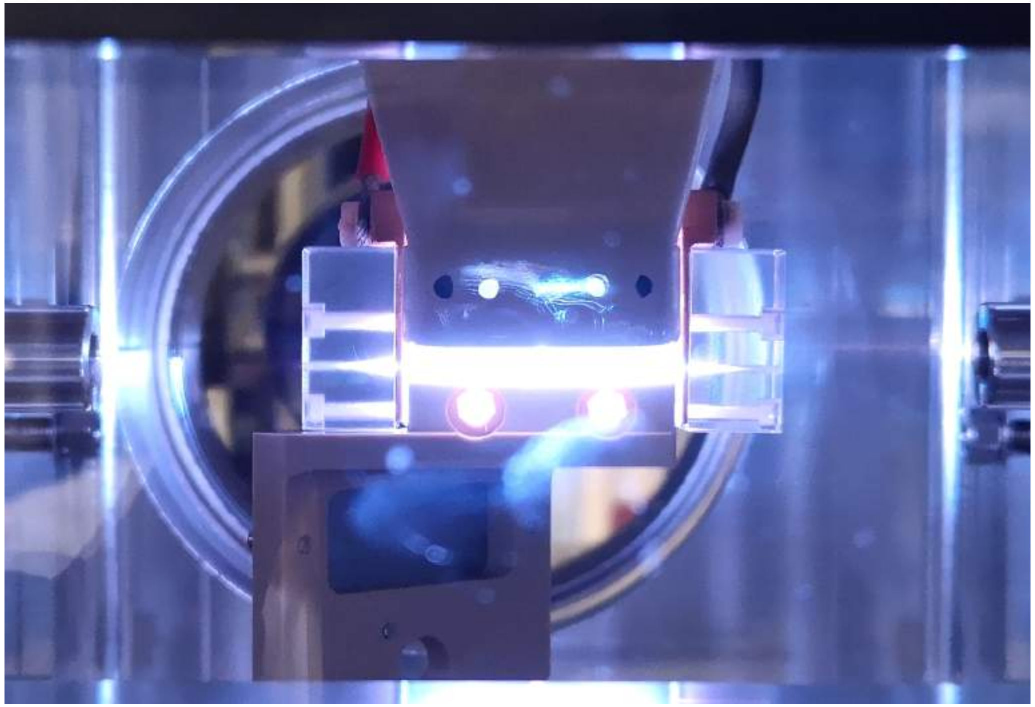
-> 6/21
XBOX ready


VKX-8311A

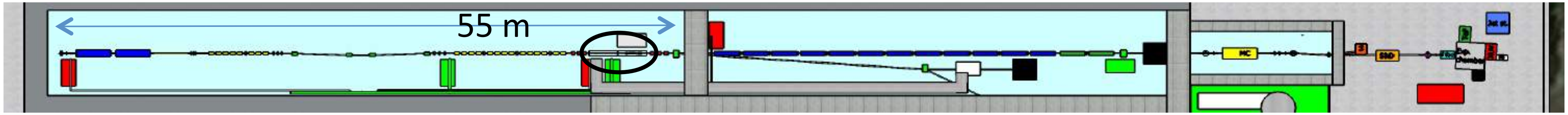
CPI klystron delivery @LNF originally expected early November 2020 CERN (repaired, tested in diode-mode, RF conditioning on going)

WA 5 - Plasma

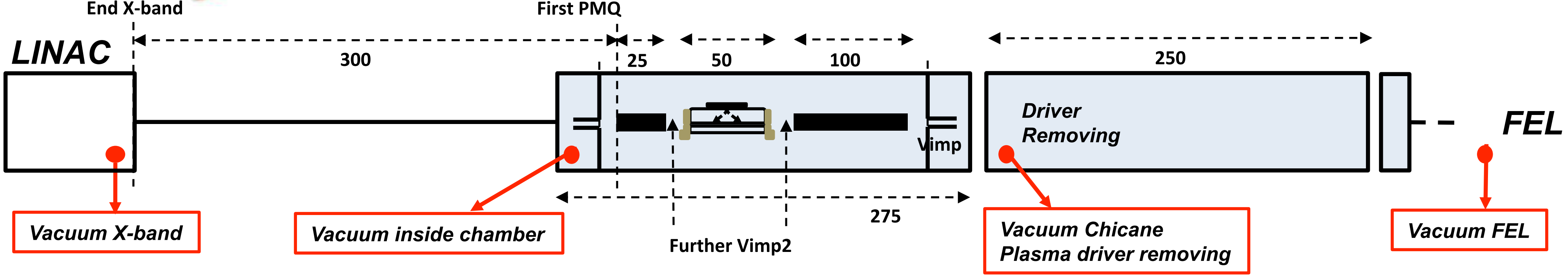
Plasma WakeField Acceleration



Capillary discharge at SPARC_LAB



Plasma module layout



End X-band

First PMQ

LINAC

300

25

50

100

250

Driver Removing

Vimp

FEL

275

Further Vimp2

Vacuum X-band

Vacuum inside chamber

Vacuum Chicane
Plasma driver removing

Vacuum FEL

1. *Chamber sizing depends on the vacuum constrains and capillary dimensions*
2. *Eupraxia chamber sizing starts from the current plasma chamber*
3. *Minimum length is 215 cm*
4. *Driver removing chamber properties depend on the technique used to remove the driver (Plasma or chicane)*
5. *Chamber/capillary factor is 5.5*
6. *New solutions will be studied to reduce the chamber/capillary factor by means of vacuum test and simulation*

3 cm-long capillary@ne = 10^{16} - 10^{17} cm^{-3}

	Vgas (cm^3)	*VimpEXT*	*VimpINT*	*Tpumps*	$V_{C\text{-}band}$	$V_{chamber}$	*Wtime*
1 Hz	0.0236	2 x 6mm/15cm	2 x 6mm/10cm	1780 l/s	10^{-7} mbar	10^{-8} mbar	No limits
10 Hz	0.236	2 x 6mm/15cm	2 x 6mm/10cm	1780 l/s	10^{-7} mbar	10^{-8} mbar	1 hour
100Hz	2.36						

50 cm-long capillary@ne = 10^{16} - 10^{17} cm^{-3}

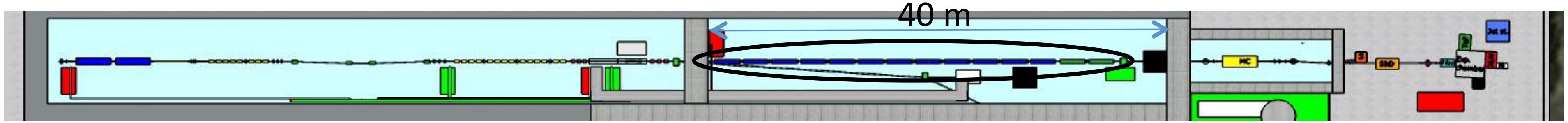
x15	*Vgas* (cm^3)	*Vimp*	*Vimp2*	*Tpumps*	$V_{X\text{-}band}$	$V_{Chamber}$	*Wtime*
1 Hz	0.314	2 x 6mm/15cm	2 x 6mm/10cm	7000 l/s			
10 Hz	3.14	2 x 6mm/15cm	2 x 6mm/10cm	7000 l/s			
100Hz	31.4 *x100*						

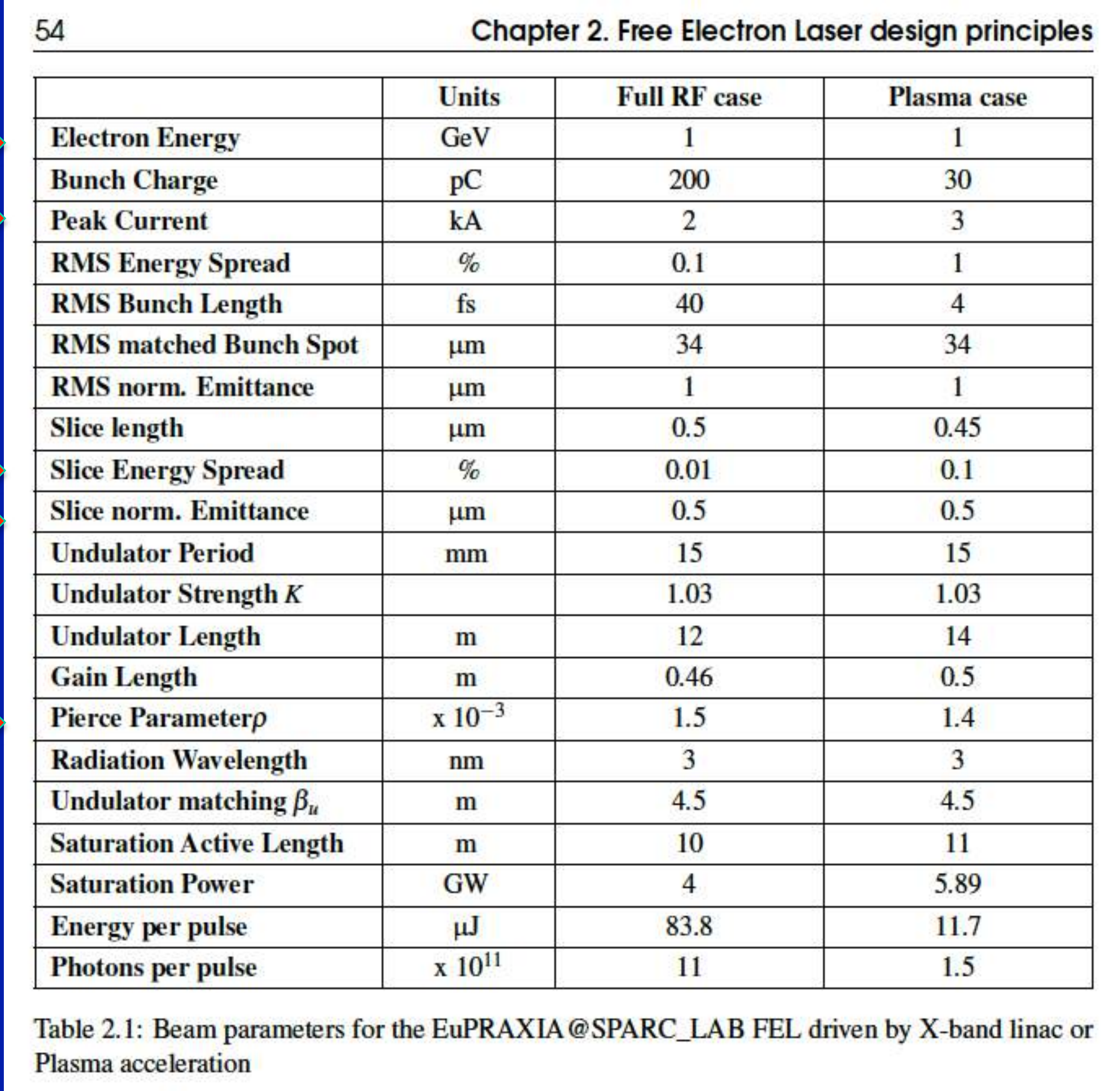
Courtesy R. Pompili , A. Biagioni

WA 6 - FEL

Undulators

KYMA Δ udulator at SPARC_LAB: $\lambda=1.4$ cm, K1





	Units	Full RF case	Plasma case
Electron Energy	GeV	1	1
Bunch Charge	pC	200	30
Peak Current	kA	2	3
RMS Energy Spread	%	0.1	1
RMS Bunch Length	fs	40	4
RMS matched Bunch Spot	µm	34	34
RMS norm. Emittance	µm	1	1
Slice length	µm	0.5	0.45
Slice Energy Spread	%	0.01	0.1
Slice norm. Emittance	µm	0.5	0.5
Undulator Period	mm	15	15
Undulator Strength K		1.03	1.03
Undulator Length	m	12	14
Gain Length	m	0.46	0.5
Pierce Parameterρ	x 10^{-3}	1.5	1.4
Radiation Wavelength	nm	3	3
Undulator matching β_u	m	4.5	4.5
Saturation Active Length	m	10	11
Saturation Power	GW	4	5.89
Energy per pulse	µJ	83.8	11.7
Photons per pulse	x 10^{11}	11	1.5

Table 2.1: Beam parameters for the EuPRAXIA@SPARC_LAB FEL driven by X-band linac or Plasma acceleration

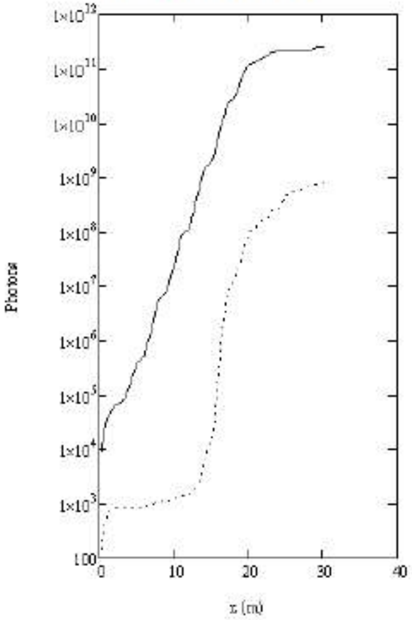
$$\frac{\Delta E}{E} \approx \rho$$

Undulator for Eupraxia FEL

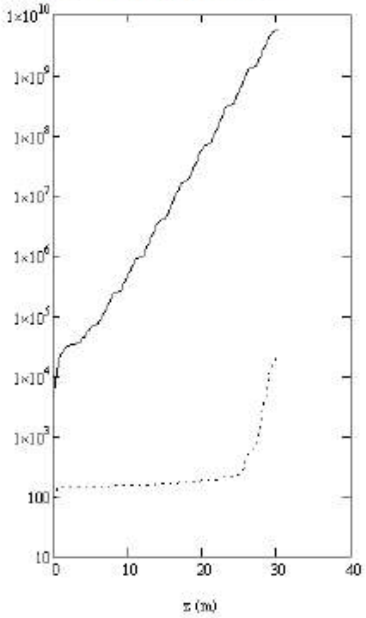
- Working Point @3 nm is critical
  - gain length strongly dependent on the beam energy spread
  - An Undulator based on Permanent Magnet technology (PMU) aiming at a final wavelength of 3 nm has a period of 15-16 mm of length and should be operated at minimum gap with low K parameter. Practically no tuning range.
- Solutions:
  - High field helical undulator
  - Superconducting Undulator Technology

Or both together (even better).

200 keV
0.5 mm-mrad



800 keV
0.5 mm-mrad



Courtesy L. Giannessi

Tuning range - period 16 mm

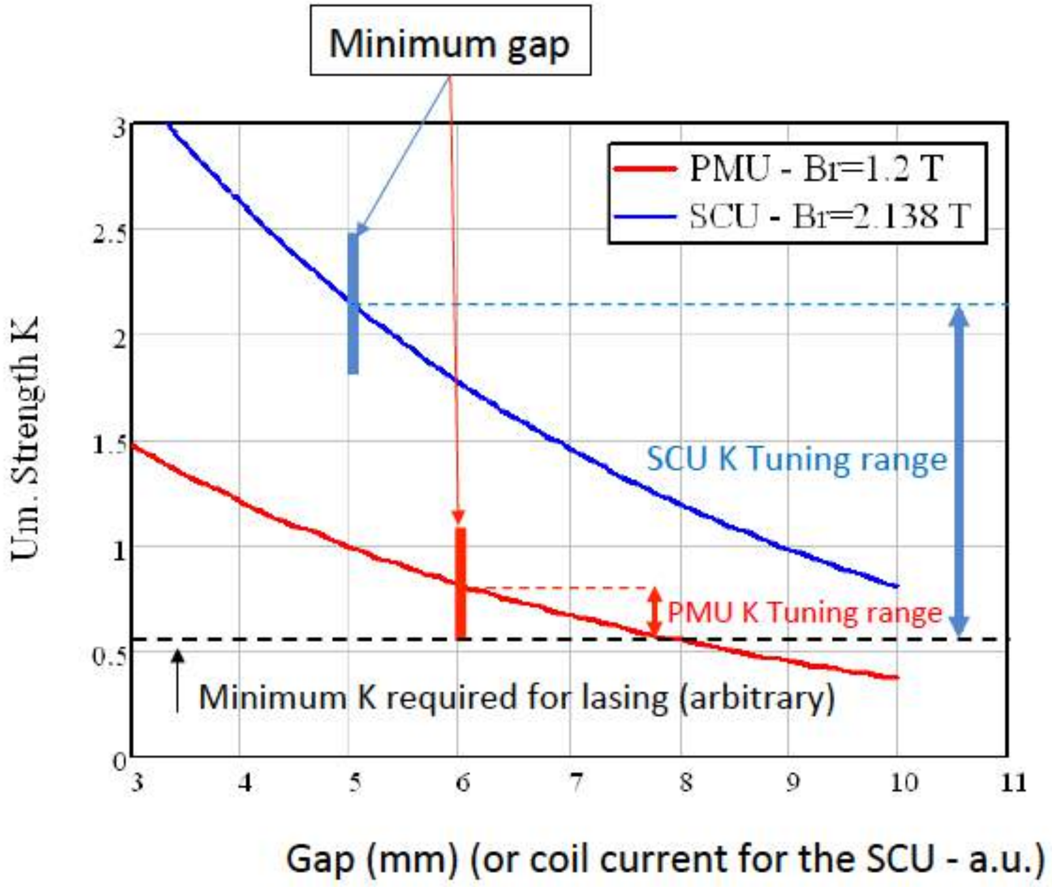
Right plot: Undulator strength (planar undulator) vs the gap (or coil current)

Period set to 16 mm

The SCU allows resonant wavelength tuning varying the undulator K parameter.

This tuning possibility is very limited with a PMU optimised for 3 nm @ 1 GeV

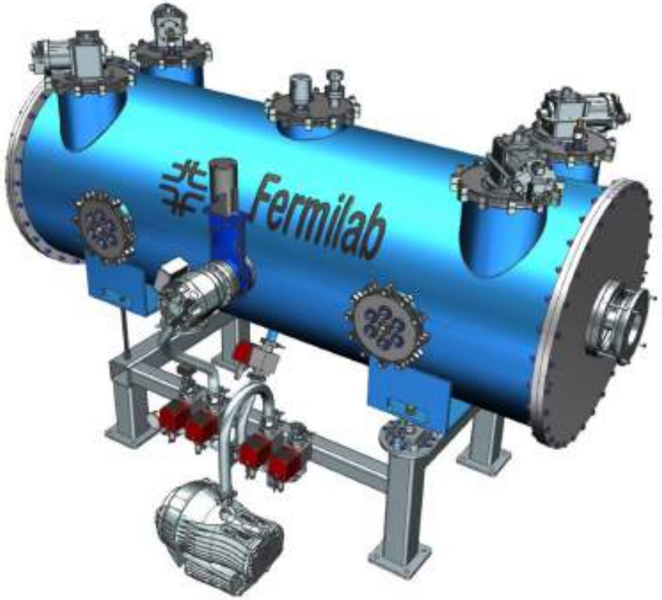
Tuning is still possible by reducing the beam energy, but unless the other beam parameters are not improved, it cannot be achieved by increasing the beam energy

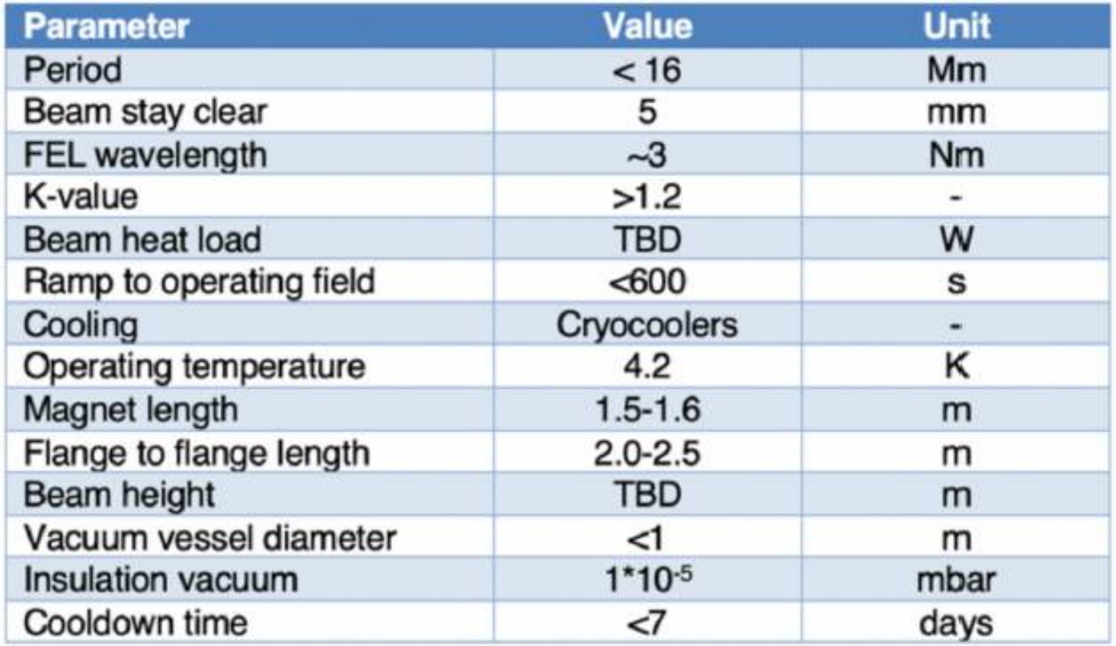


Courtesy L. Giannessi

Collaboration with FNAL (C. Boffo)

Prototype SCU undulator
Development in progress





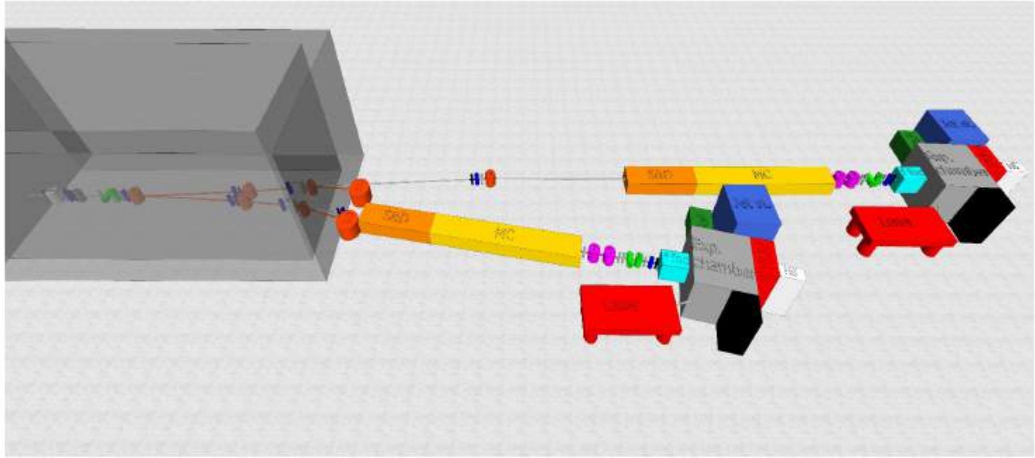
Parameter	Value	Unit
Period	< 16	Mm
Beam stay clear	5	mm
FEL wavelength	~3	Nm
K-value	>1.2	-
Beam heat load	TBD	W
Ramp to operating field	<600	s
Cooling	Cryocoolers	-
Operating temperature	4.2	K
Magnet length	1.5-1.6	m
Flange to flange length	2.0-2.5	m
Beam height	TBD	m
Vacuum vessel diameter	<1	m
Insulation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

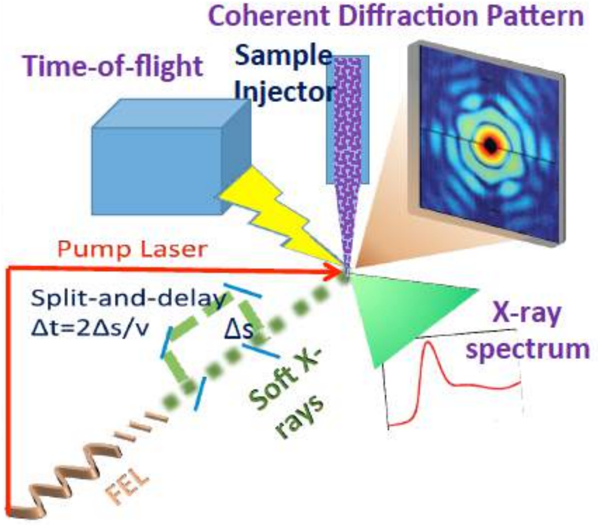
Courtesy L. Giannessi

WA 8 - Users

Photon beam line

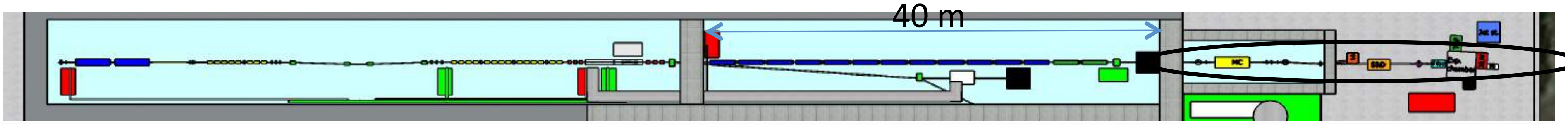
Conceptual design of the beamlines and of the connected instruments





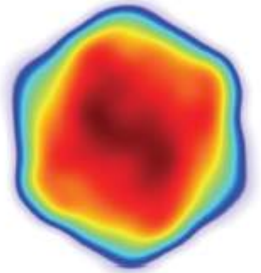
pump-probe
Time-resolved experiments

Balerna *et al.* Cond Matt (2019)
Villa *et al.* J Phys Conf Ser (2020)

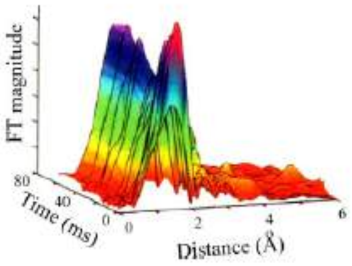


Defining the experimental techniques and the typology of samples

Coherent imaging



VUV spectroscopy



Raman spectroscopy

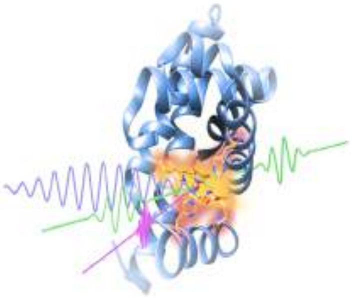
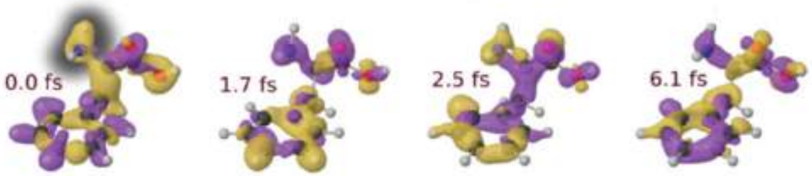


Photo-fragmentation of molecules



Proteins
Viruses
Bacteria
Cells
Metals
Semiconductors
Superconductors
Magnetic materials
Organic molecules

Courtesy F. Stellato

Next future plans

- Upgrade of the scientific case

    Expansion to other experimental techniques (RIXS, TOF, X-ray emission)
    & exploring extra experimental possibilities @ different wavelengths

- Dissemination: building up the users' community

    3 published papers dedicated to the beamline & the possible experiments
    +
    Presentations @ national & international conferences (more to come)
    +
    Planning pilot experiments @ various FEL sources

- People

    1 dedicated AdR → selection process in progress

- Paving the road for the TDR

    Intercation with "upstream" Was; gathering technical details on novel instrumentation

Courtesy F. Stellato

WA 9 - Infrastructures

EuPRAXIA@SPARC_LAB building _ render

Courtesy S. Incremona – U. rotundo

EuPRAXIA@SPARC_LAB building _ render

Courtesy S. Incremona – U. rotundo

EUPRAXIA@SPARC_Lab – WA9 Infrastructures

Final and executive design awarded to MYTHOS.

Kick off Feb 2020
Then stop due to COVID restrictions
Actual start of the project: 17.06.2020

Definitive design is currently in progress.

Main milestones reached so far:

- Space management and allocation of the volumes
- Primary utilities requirements
- Radioprotection requirements
- First interaction with local authorities (VV.FF. – F.D.) to determine main constraints from conventional safety point of view.

A final review of the building design is expected to be in January 2021.

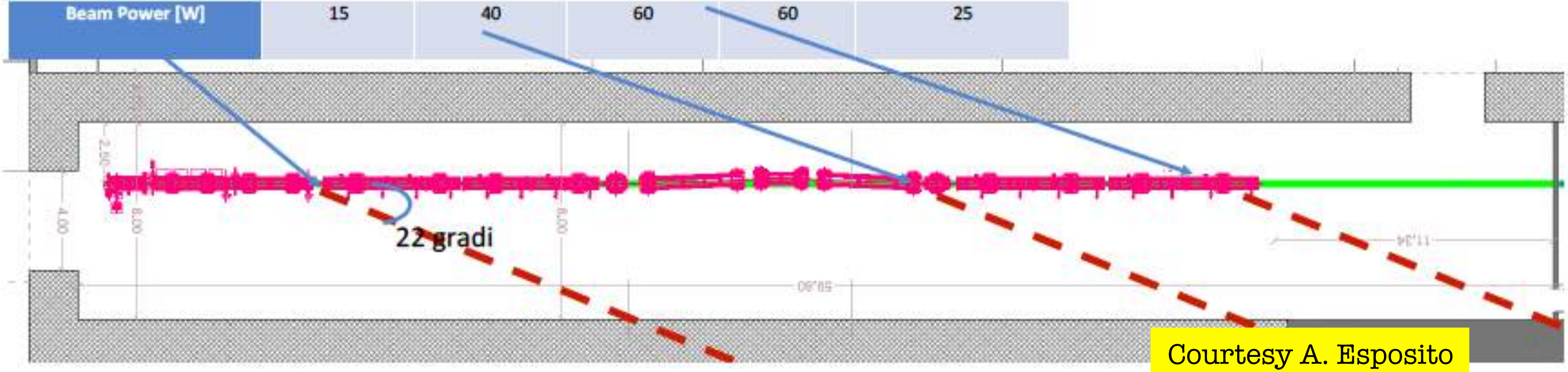
The mutual interaction between building engineering decision and machine development is the most critical factor that has been addressed through dedicated meeting (weekly based).
Design effort for flexibility in order to accommodate further upgrading of the machine.

Courtesy S. Incremona – U. Rotundo

Beam Dumps

Max Values	DUMP_1.1	DUMP_1.2	DUMP_1.3	DUMP_2	DUMP_3
Location	Injector Exit	Compressor Exit	Plasma Exit	FEL Exit	Compton/Positron Sources Exit?
Energy [GeV]	0.3	0.8	1.2	1.2	5
Q [pC]	500	500	500	500	50
Peak Current [kA]	3	3	3	3	3
Rep. Rate [Hz]	100	100	100	100	100
Average Current [nA]	50	50	50	50	5
Beam Power [W]	15	40	60	60	25

Il Dump serve ad evitare che il fascio primario colpisca le pareti schermanti e ad assorbire la cascata elettromagnetica prodotta nonche' a ridurre la produzione dei neutroni, responsabili delle attivazioni e piu' difficili da schermare.



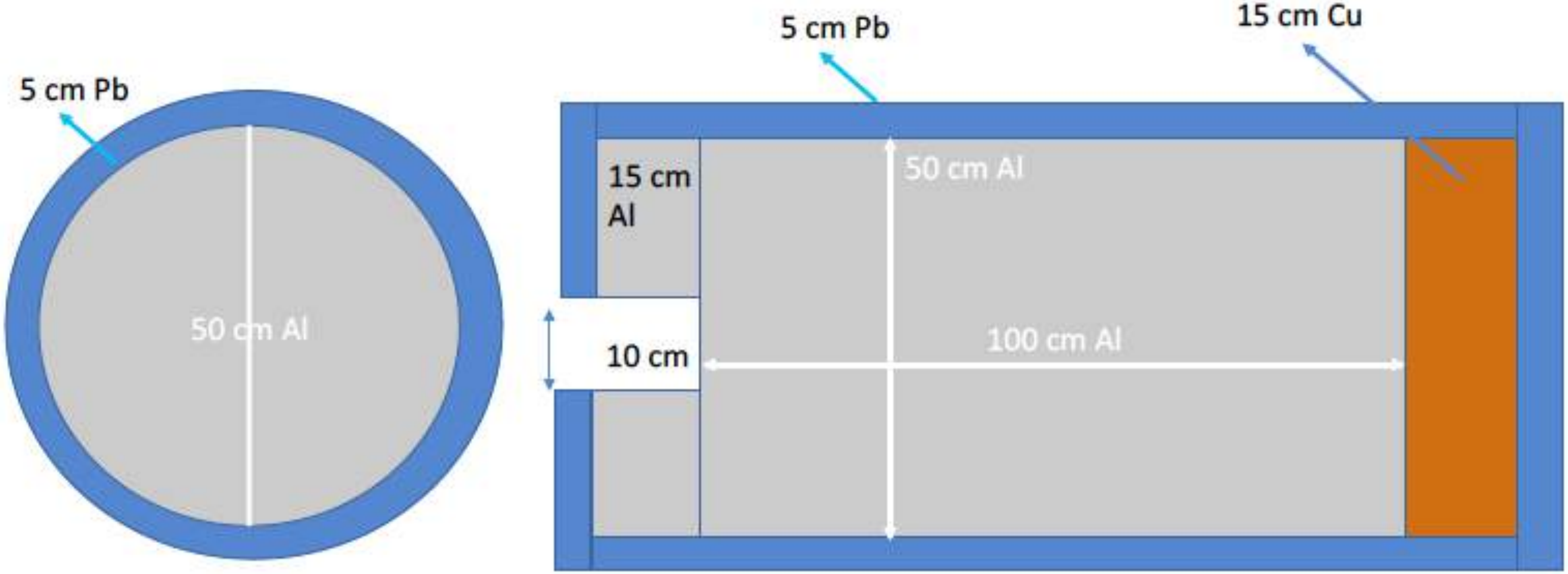
Courtesy A. Esposito

Dump caso 1000 e 5000 MeV

60 watt 25 watt

Si sta pensando anche a dumps con grafite all'interno dell'alluminio

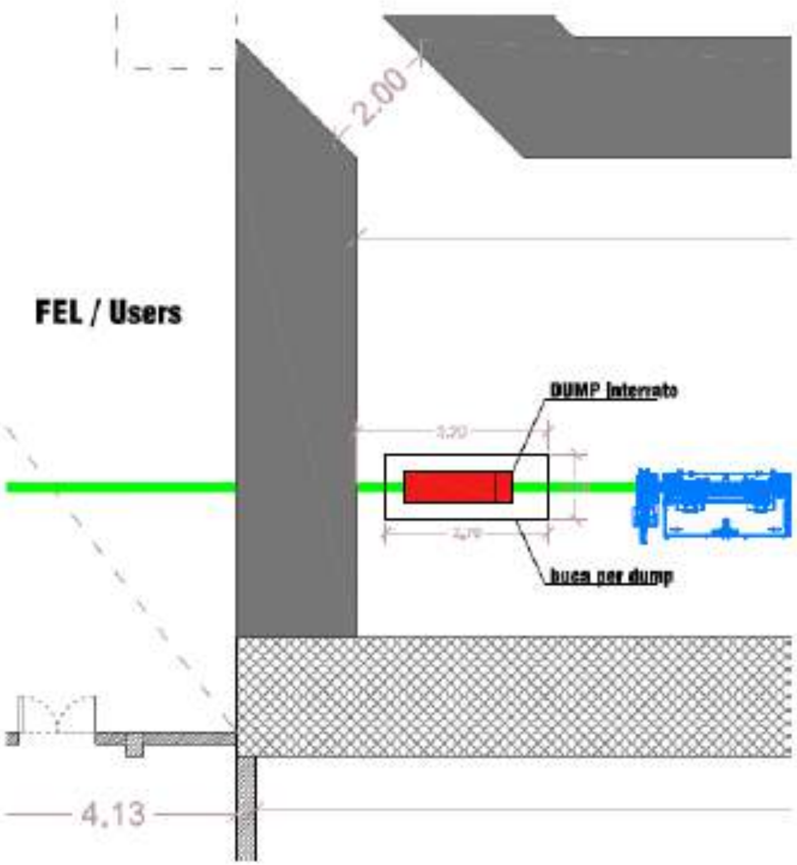
Non dovrebbe essere necessario alcun raffreddamento tenuto conto delle potenze in gioco ma un calcolo con Ansys dovrebbe essere fatto

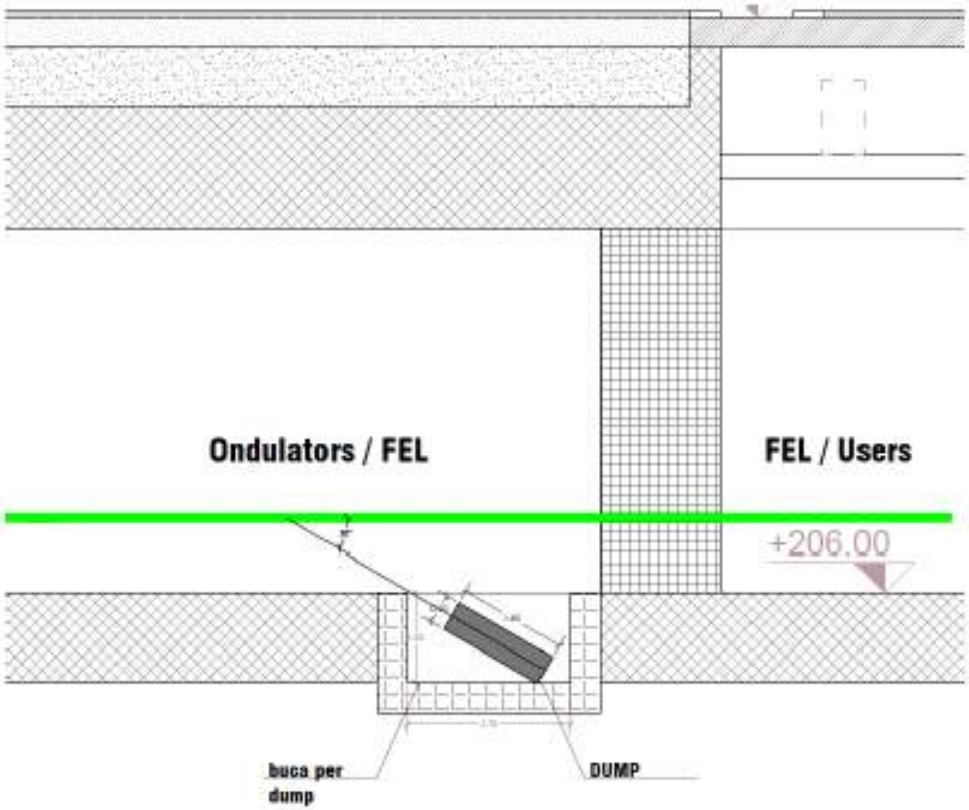


Peso complessivo kg 2400

Nei casi a piu' bassa energia si e' usato uno spessore di Al pari a 50 cm e 25 cm pesi 1680 e 1300

Courtesy A. Esposito





Courtesy A. Esposito

Conclusions

- **A Critical Review of the CDR is ongoing**
- A detailed **schedule and cost estimate** towards the completion of the TDR is in progress.
- The technology readiness level of the main components is high but it requires **additional R&D effort** (with particular emphasis to the **stability, reproducibility** and **quality** of the accelerated electron beam) to have a fully proven engineering design of the X-band Linac and Plasma Module.
- The current funding **do not include Manpower and the R&D** needed for the TDR. Additional funding must be found.
- Laser Heater/Magnetic Compressor optimization is in progress, including alternative schemes for Driver and Witness generation. **Energy Jitters investigation and mitigation in progress.**
- **Adjust the optimal energy/wavelength for FEL operation** with and without Plasma compatible **with realistic accelerating gradients** (X-band 60 MV/m, Plasma 1 GV/m).
- Plasma beam line optimized to **remove the driver** beam and preserve the the witness beam parameters .
- FEL Baseline and advanced configurations.
- Extend the Users Scientific Case including lower wavelength.
- Demonstration of the main beam requirements at SPARC_LAB (**spread, emittance, stability**)