EuPRAXIA@SPARC_LAB

Massimo.Ferrario@LNF.INFN.IT

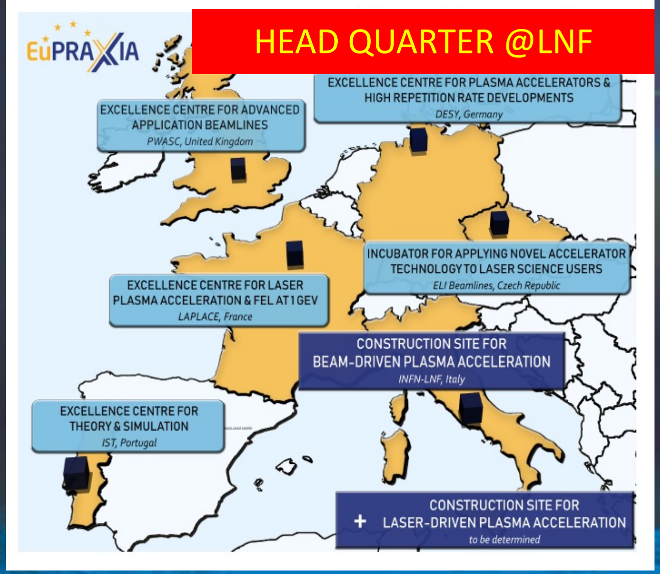
62nd LNF Scientific Committee Meeting, November 8, 2021

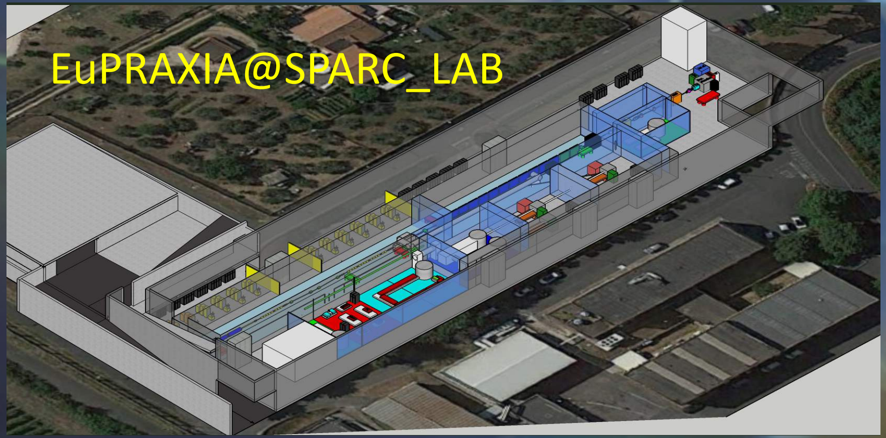
Istituto Nazionale di Fisica Nucleare

Process of ESFRI Road Map Application and Follow up

- Sep 2020 — **Submitted**
- Nov 2020 — Found eligible for ESFRI Roadmap

  Detailed assessment through ESFRI panels
- 15 Apr 2021 — ESFRI Hearing
- July 2021 — **Announcement of decision => We are in!**
- 16 Nov 2021 — Dead Line for HORIZON-MSCA-2021-DN-01 (2 PhD fellowships requested)
- 23 Nov 2021 — ESFRI Review Meeting
- 20 Jan 2022 — Dead Line for HORIZON-INFRA-2021-DEV-02-01 ("Preparatory Phase of new ESFRI research infrastructure projects")


EuPRAXIA
HEAD QUARTER @LNF
EXCELLENCE CENTRE FOR PLASMA ACCELERATORS & HIGH REPETITION RATE DEVELOPMENTS
DESY, Germany
EXCELLENCE CENTRE FOR ADVANCED APPLICATION BEAMLINES
PWASC, United Kingdom
INCUBATOR FOR APPLYING NOVEL ACCELERATOR TECHNOLOGY TO LASER SCIENCE USERS
ELI Beamlines, Czech Republic
EXCELLENCE CENTRE FOR LASER PLASMA ACCELERATION & FEL AT 1 GEV
LAPLACE, France
CONSTRUCTION SITE FOR BEAM-DRIVEN PLASMA ACCELERATION
INFN-LNF, Italy
EXCELLENCE CENTRE FOR THEORY & SIMULATION
IST, Portugal
+ CONSTRUCTION SITE FOR LASER-DRIVEN PLASMA ACCELERATION
to be determined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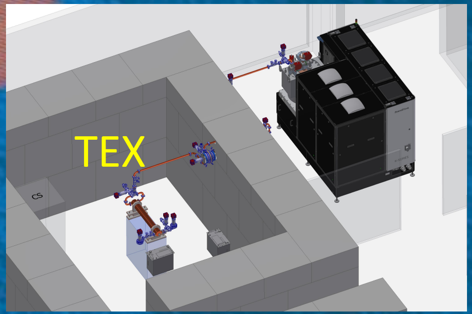
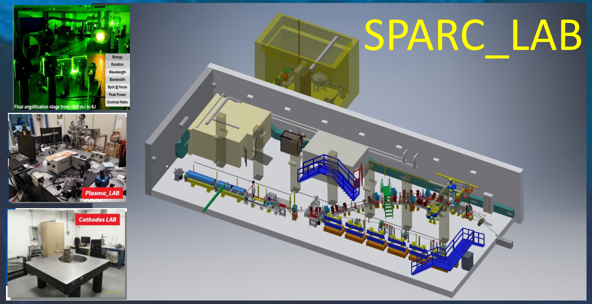
LATINO


TEX

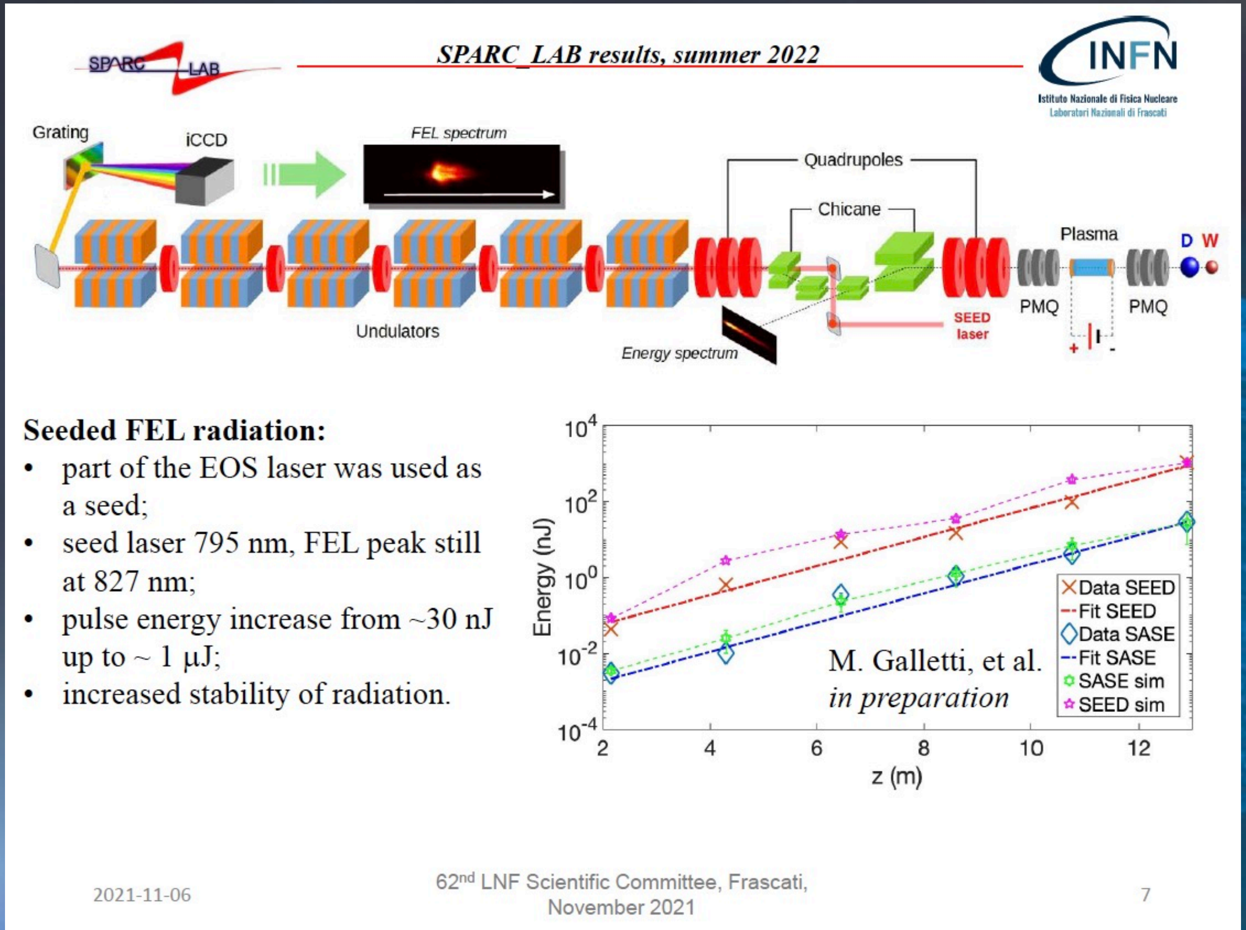
SABINA

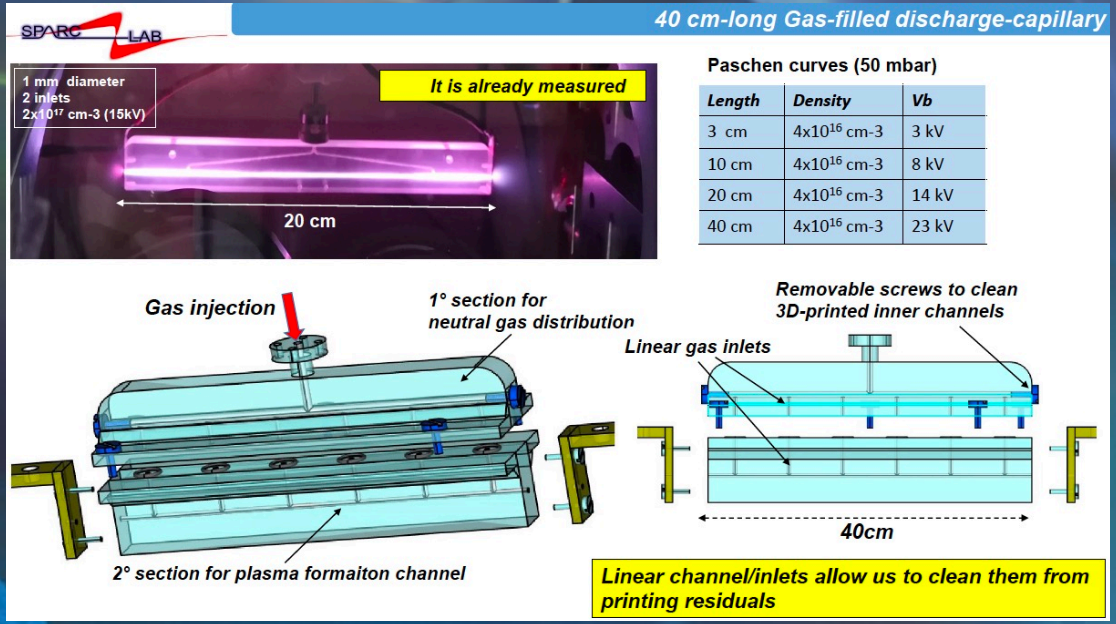

REGIONE
LAZIO


SPARC_LAB

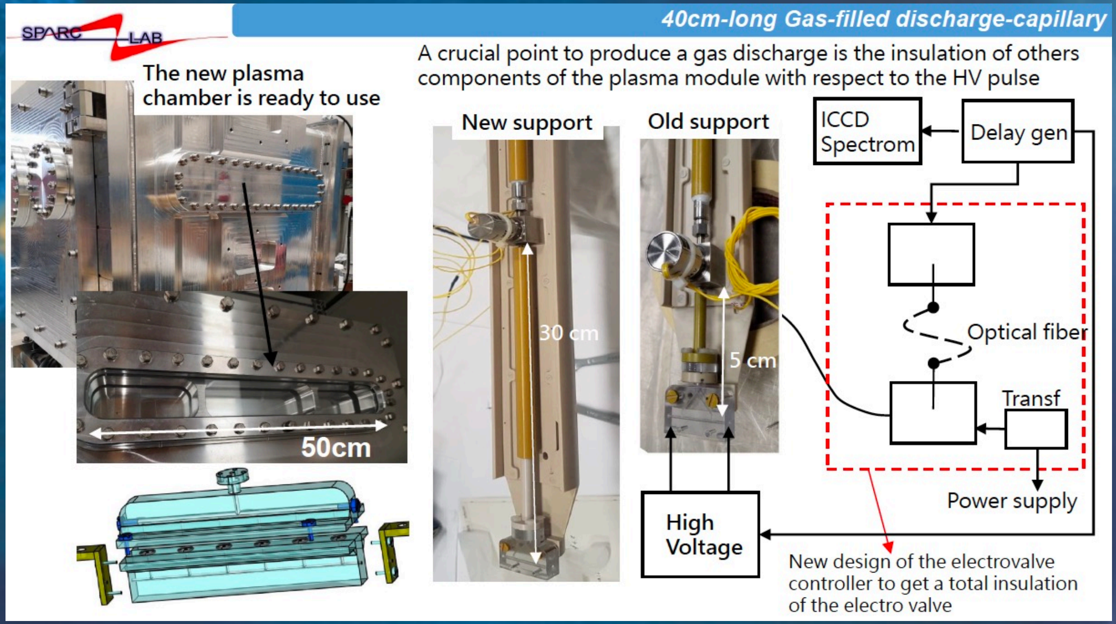

INFN
Istituto Nazionale di Fisica Nucleare
LNF–18/03
May 7, 2018
Technical Design Report

SPARC_LAB test facility





Length	Density	Vb
3 cm	$4x10^{16}$ cm-3	3 kV
10 cm	$4x10^{16}$ cm-3	8 kV
20 cm	$4x10^{16}$ cm-3	14 kV
40 cm	$4x10^{16}$ cm-3	23 kV

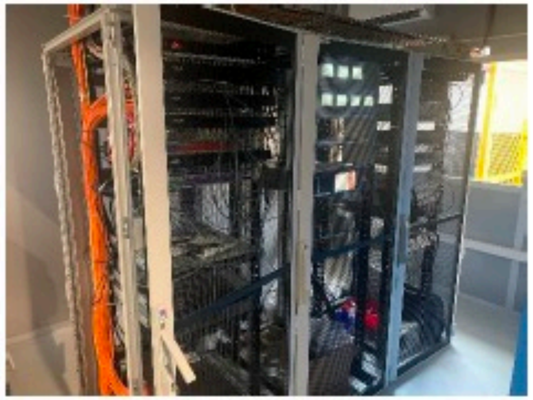


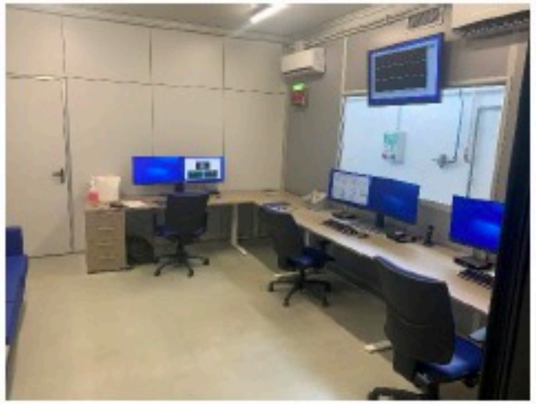
TEX facility – TEst stand for X-band at Frascati

- The *TEst-stand for X-band* (**TEX**) is a facility conceived for R&D on high gradient X-band accelerating structures and waveguide components in view of Eupraxia@SPARC_LAB project.
- It has been co-funded by Lazio regional government in the framework of **the LATINO project** (*Laboratory in Advanced Technologies for INnOvation*). The setup has been done in **collaboration with CERN** and it will be also used to test CLIC structures.
- TEX is located in bld. 7 of LNF, which is being fully refurbished and upgraded to host the high gradient facility and other labs.

Concrete shielded Bunker and Modulator Cage

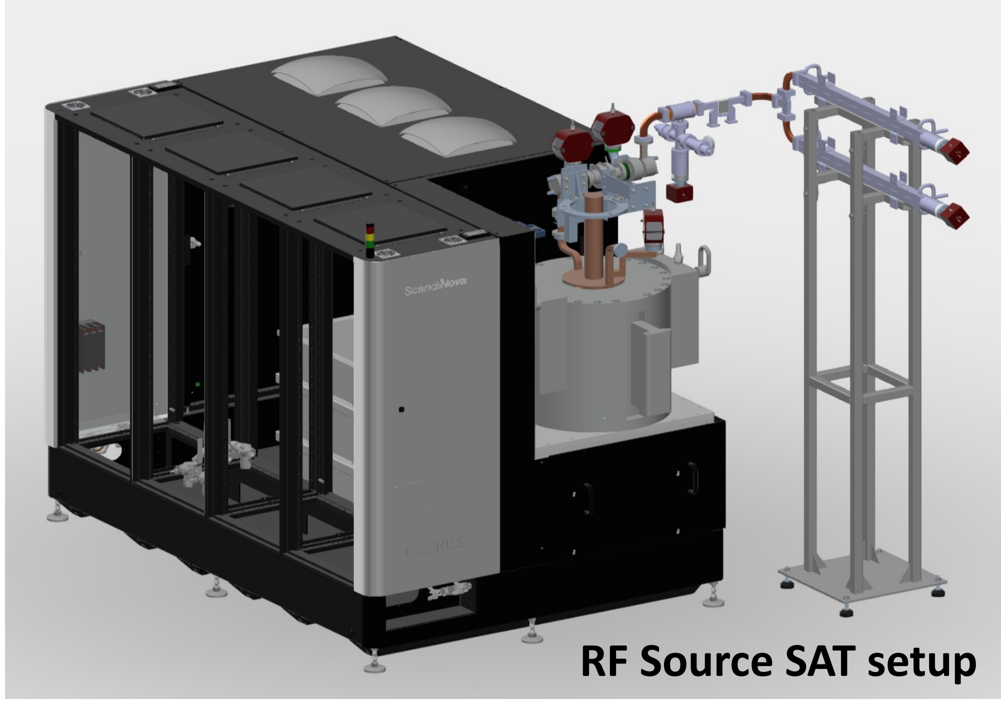
Control room and Rack room





Courtesy S. Pioli

TEX - TEst-stand for X-band



RF Source SAT setup

VKX-8311A CPI Klystron

- Cathode Voltage 428 kV
- Cathode Current 328 A
- Operating Frequency 11.994 GHz
- RF Drive power 865 W
- RF Output Power 51 MW

RF Source Site Acceptance on-going status:

- Setup with RF-Load (able to handle up to 25MW) installed.
- Baking at 150 °C performed for 5 days. Vacuum in 10^-11 mbar.
- LLRF, Controls, Timing, Safety and plants installed.
- Klystron conditioned in diode mode at 50Hz full-power.
- ScandiNova K400 Modulator SAT will finish this week.
- **WG and RF-Load currently conditioned at 21MW (50 Hz, 200ns pulse length) in 3 days.**

What next:

- Within end of 2021, final WG setup will be installed.
- Ready to start accelerating structures conditioning in early 2022.

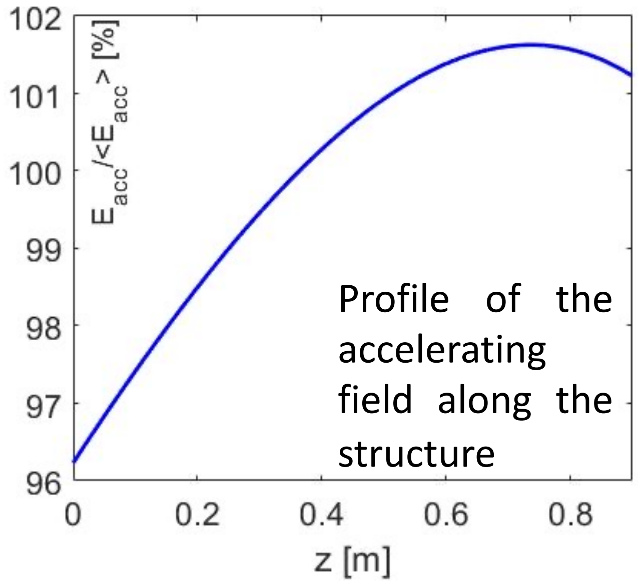
Courtesy S. Pioli

X BAND STRUCTURES: PARAMETERS

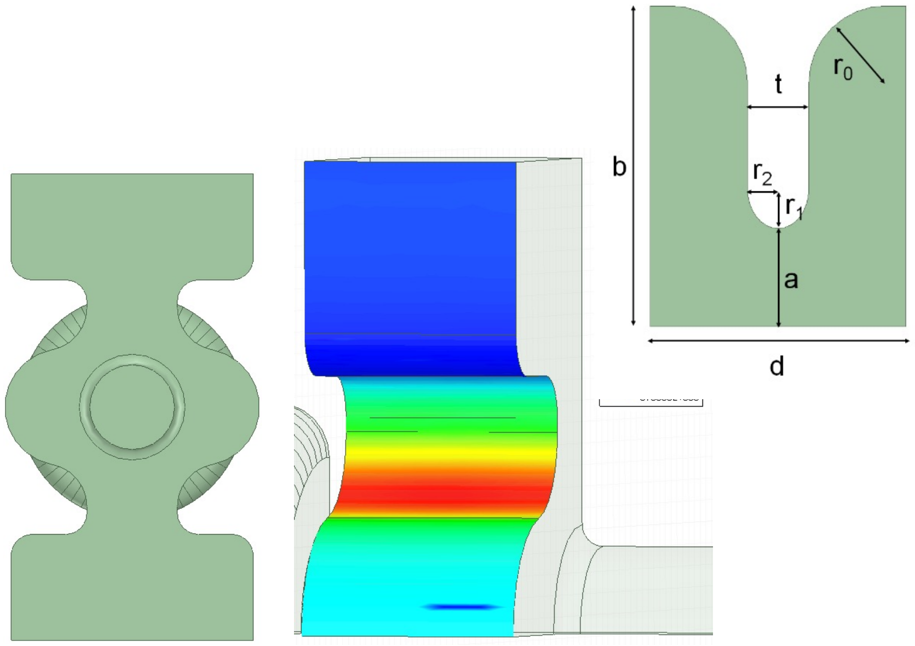
1. **e.m. design**: **linear tapering of the irises**, race track coupler to cancel the quadrupole field components (*PhD M. Diomede*);

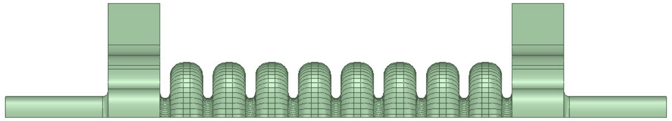
2. **0.9 m long** structures with 3.5 mm average iris radius

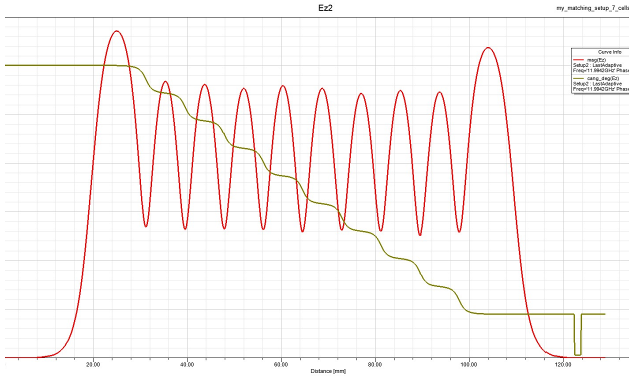
3. **60 MV/m** average accelerating field



Parameter	Value
Frequency [GHz]	11.9942
Average acc. gradient [MV/m]	**60**
Structures per module	4
Iris radius a (linear tapering) [mm] <a>=3.5	3.8-3.2
Tapering angle [deg]	0.04
Structure length L_s [m]	**0.9**
No. of cells	109
Shunt impedance R [MΩ/m]	94-107
Peak input power per structure [MW]	65
Input power averaged over the pulse [MW]	45
Average dissipated power [kW]	1
Filling time [ns]	126
Effective shunt Imp. R_s [MΩ/m]	350
Peak Modified Poynting Vector [W/μm²]	3.5
Unloaded SLED/BOC Q-factor Q_0	150000
External SLED/BOC Q-factor Q_E	21000
Required Kly power per module [MW]	**37/19**
RF pulse [μs]	**1.5**
Klystron power (available) [MW]	**50/25**
Rep. Rate [Hz]	**100**





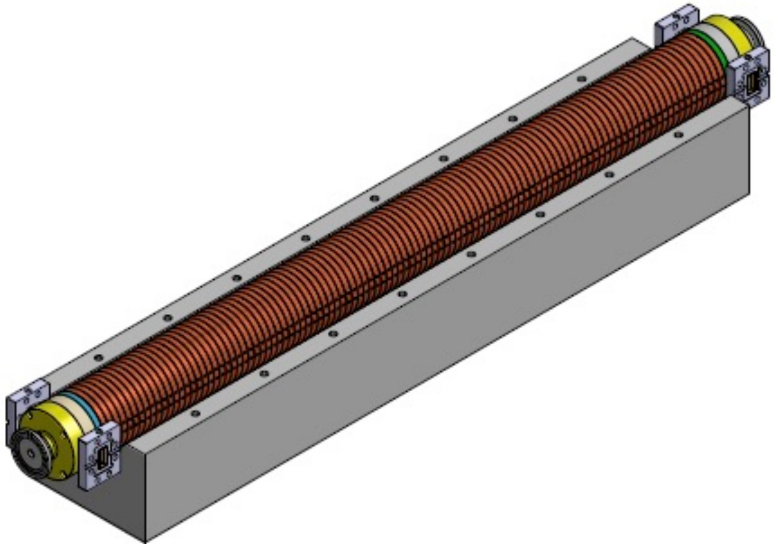


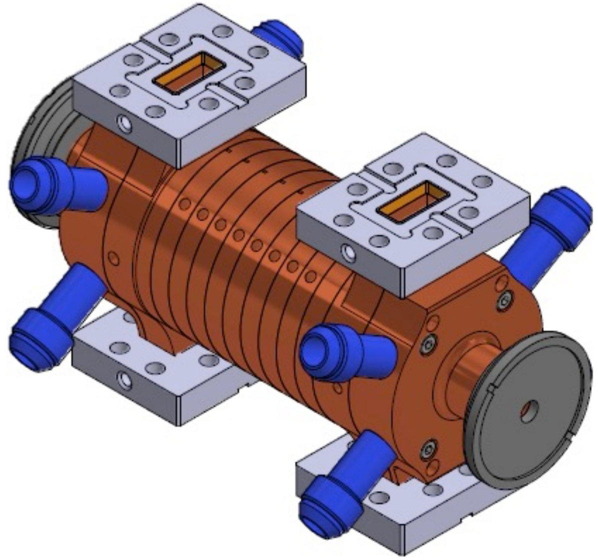
Courtesy M. Diomede

$$R_s = \frac{G^2 L}{P_{kly}}$$

G=average accelerating gradient
L=structure length
P_{kly}=klystron power (pre-sled pulse)

X-BAND STRUCTURE PROTOTYPING ACTIVITIES





- The **mechanical drawing** of the final X band structure is under constant review and is strongly related to the result of the **prototyping activity**: brazing test, cell to cell alignment, tuning-precision, etc.

- We will perform at least three steps of prototyping:
  1. **Full scale mechanical prototype**: to test the brazing process of the full structure and the cell-to-cell alignment we are able to achieve (ready for **March/April 2022**);
  2. **Few cells-rf prototype for high power text**: 10 cell prototype with input/output coupler to be tested at low and high power (ready for **March/April 2022**).
  3. **Final full scale structure prototype (ready for March 2023)**.

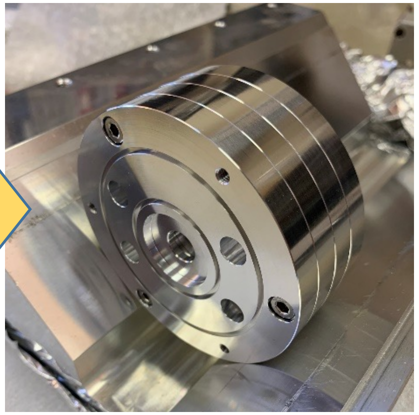
- Synergies with Int. projects: in the context of the **I.FAST European project** there is a Work Task on XLS-Compact light structure realization coordinated by G. D'Auria, to be fabricated in 2 years from May 2021. It is a structure very similar to the EuPRAXIA@SPARC_LAB one.

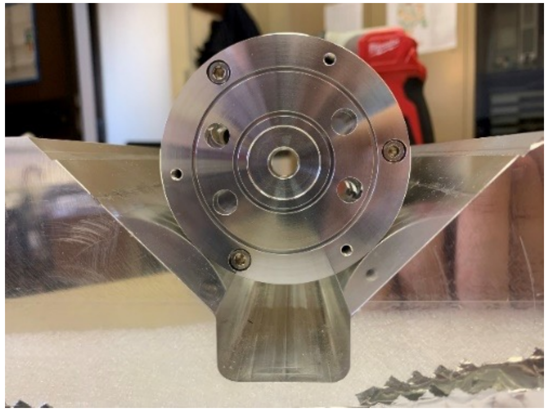
Courtesy G. Di Raddo, V. Lollo

X-BAND STRUCTURE PROTOTYPING ACTIVITIES: REALIZATIONS

Realization

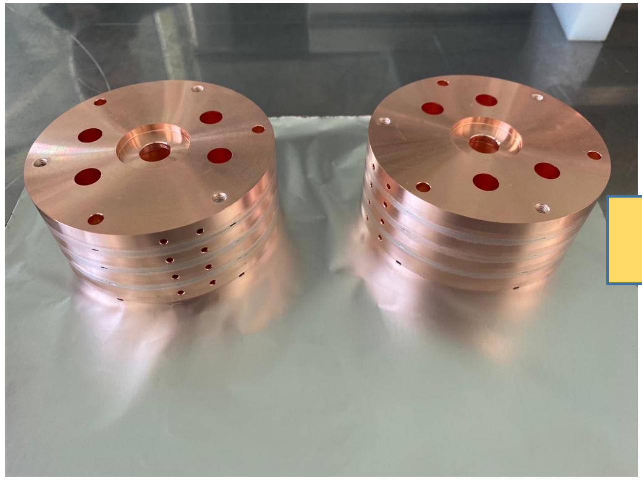
Assembly





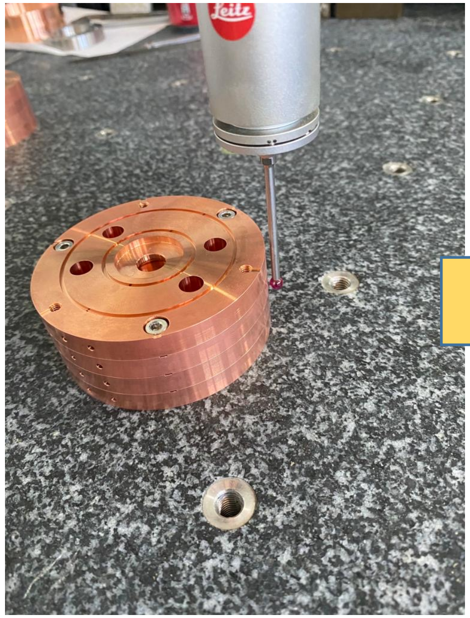
Characterization CMC

Brazing



Vacuum test

Characterization CMC



<+/-5 μm alignment (before/after brazing)

Realizations in parallel to all LNF activities…

Scicom Recommendations about EuPRAXIA

1) A key technical component for EuPRAXIA@SPARC_LAB is the Xband 50 MW klystron for the linear accelerator.

- For the foreseeable future only a single supplier with limited production capacity exists for this kind of tubes.

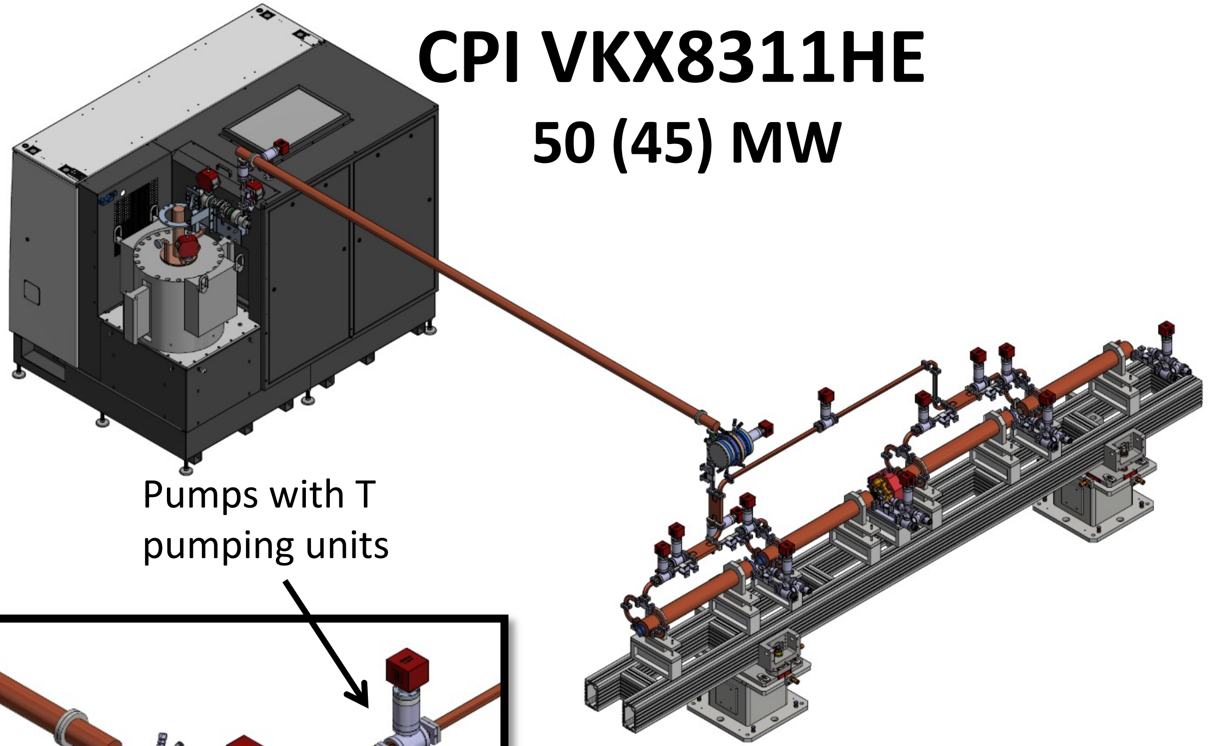
- Placing the order for a first tube, possibly with an option for all tubes required for EuPRAXIA@SPARC_LAB, as soon as possible, is of utmost importance for keeping the present EuPRAXIA@SPARC_LAB schedule.

Status of the activity

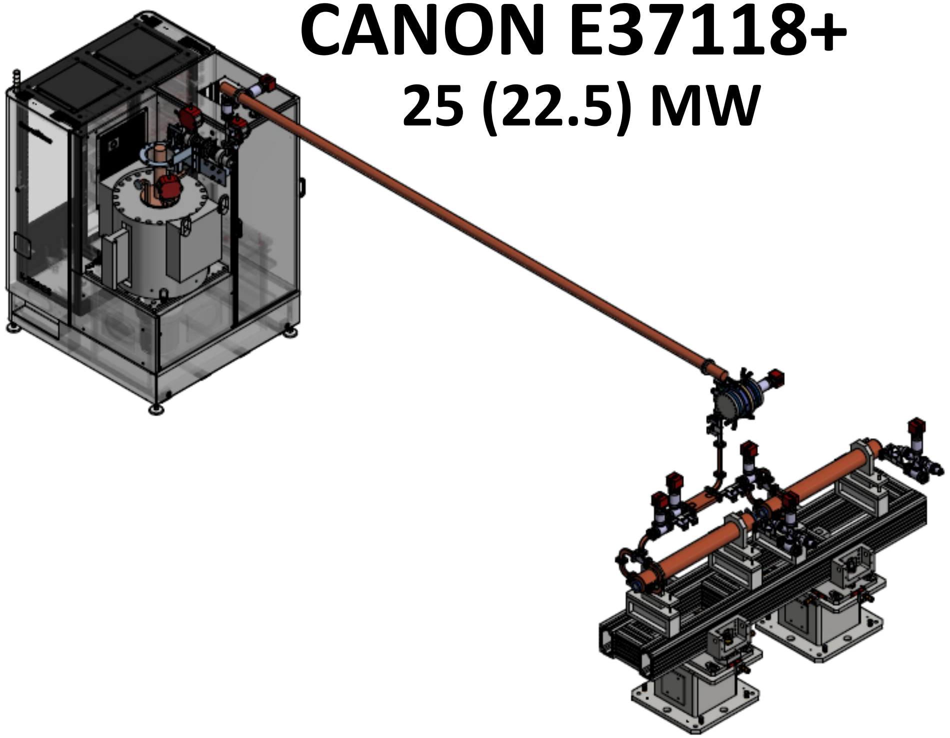
- The appearance of a second vendor as a possible commercial competitor has been certainly effective, and it has increased the companies “responsivity”;
- The two technical proposals can in principle fit the requirements of the project with some pros (CPI compactness, CANON rep. rate) and cons (CPI cost, CANON power consumption).
- CPI normalized cost (k€/MW_{peak}) still not completely understood. However, once the normalized costs of the full stations are considered, the two solutions are closely comparable.
- The 400 Hz provided by CANON is potentially a breakthrough feature. However many new aspects would need to be addressed, namely:
  - ✓ The definition of a high rep rate (HRR) WP, requiring a reduced gradient in the X-band structures;
  - ✓ New injector design for HRR operation. Many technical problems need to be solved (HRR Gun, C-band klystrons, …).
  - ✓ New specifications for the gallery services (AC power, cooling) compatible with the HRR requirements. Cooling should manage much different heat-loads (standard vs. HRR operation).
  - ✓ If plasma boost is included, then HRR related technical issues of the plasma-cell operation need to be considered.

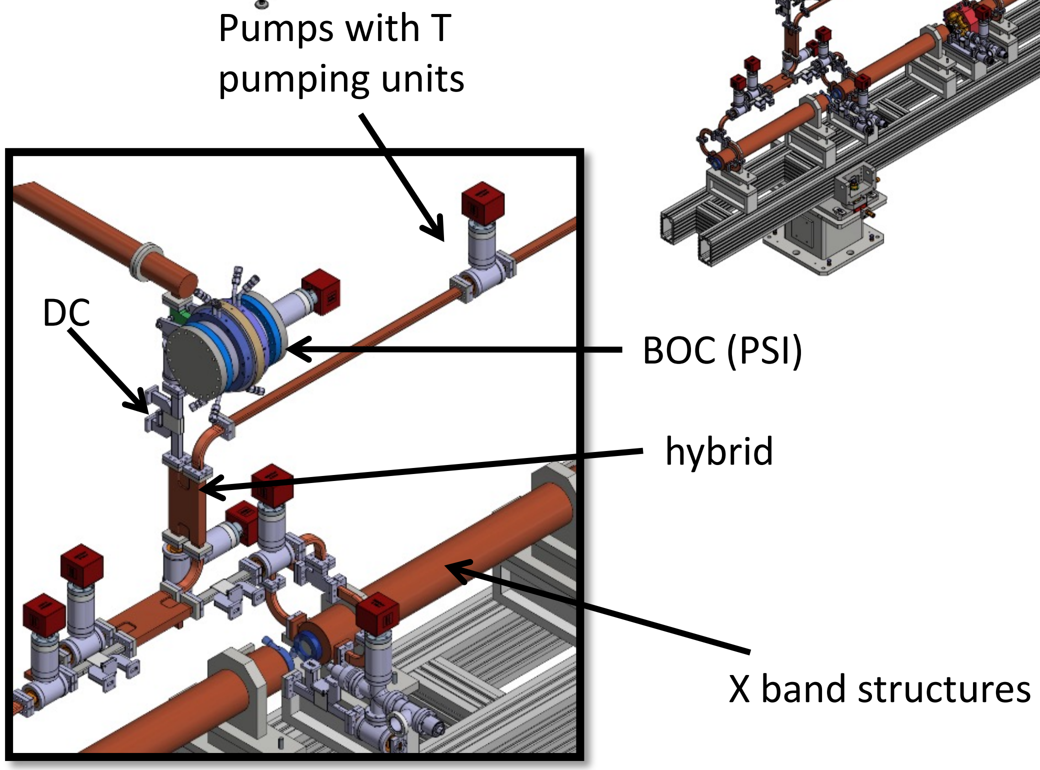
RF MODULE LAYOUT

CPI VKX8311HE
50 (45) MW



CANON E37118+
25 (22.5) MW





Courtesy G. Di Raddo,
E. Di Pasquale, F. Cardelli

⇒ **Waveguide components** (DC, T pumping, hybrids,…) **CERN design** but there are some components for which we have to fix the design (circular-rectangular waveguide mode converter, pumping unit on circular waveguide)

⇒ **Pulse compressor: BOC (PSI) or INFN Design**

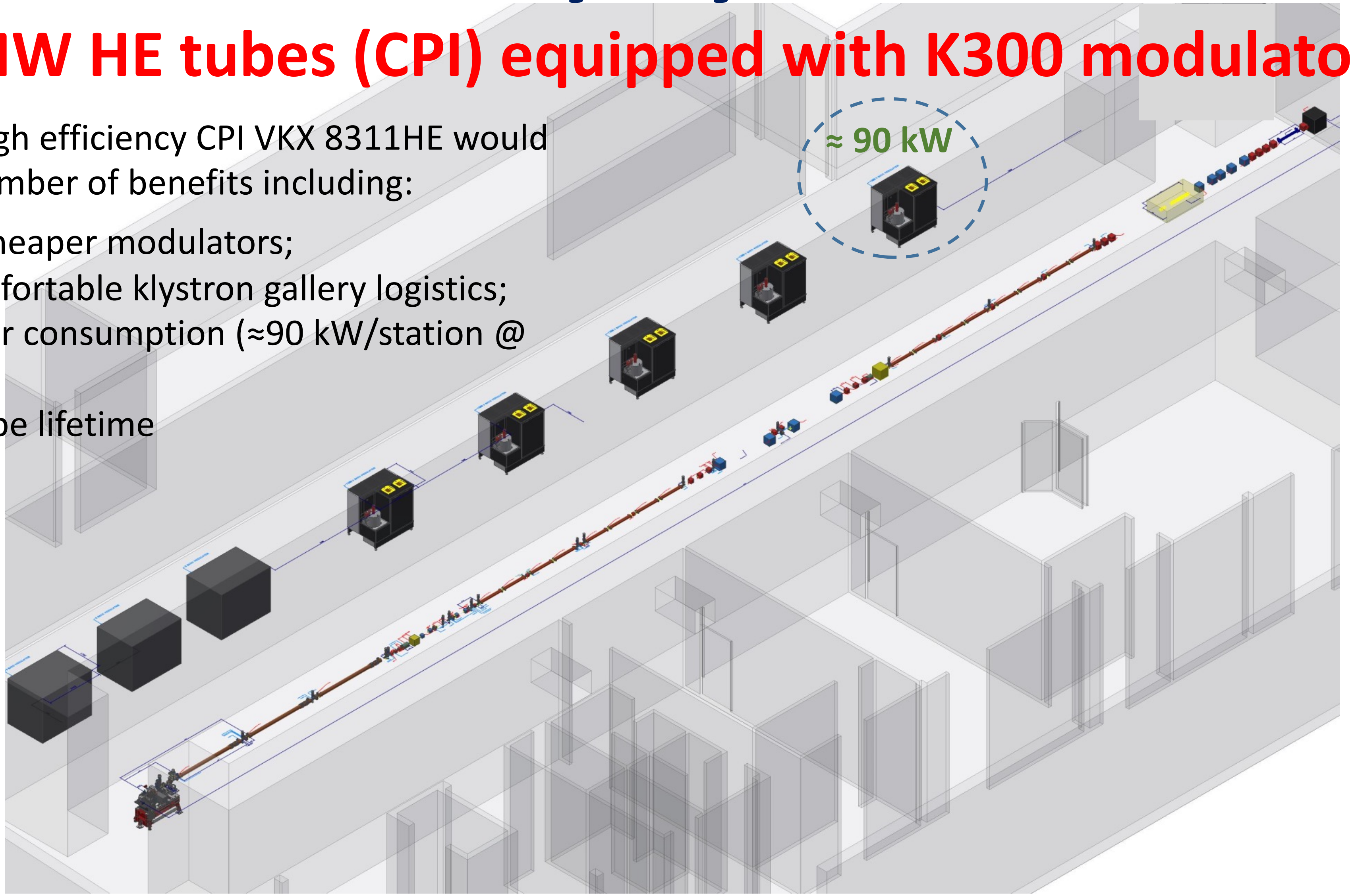
⇒ **Asymmetric waveguide distribution system to take into account the RF propagation time**

Gallery layout 1

50 MW HE tubes (CPI) equipped with K300 modulators

The use of high efficiency CPI VKX 8311HE would result in a number of benefits including:

- Smaller/cheaper modulators;
- More comfortable klystron gallery logistics;
- Less power consumption (≈90 kW/station @ 100 Hz);
- Longer tube lifetime

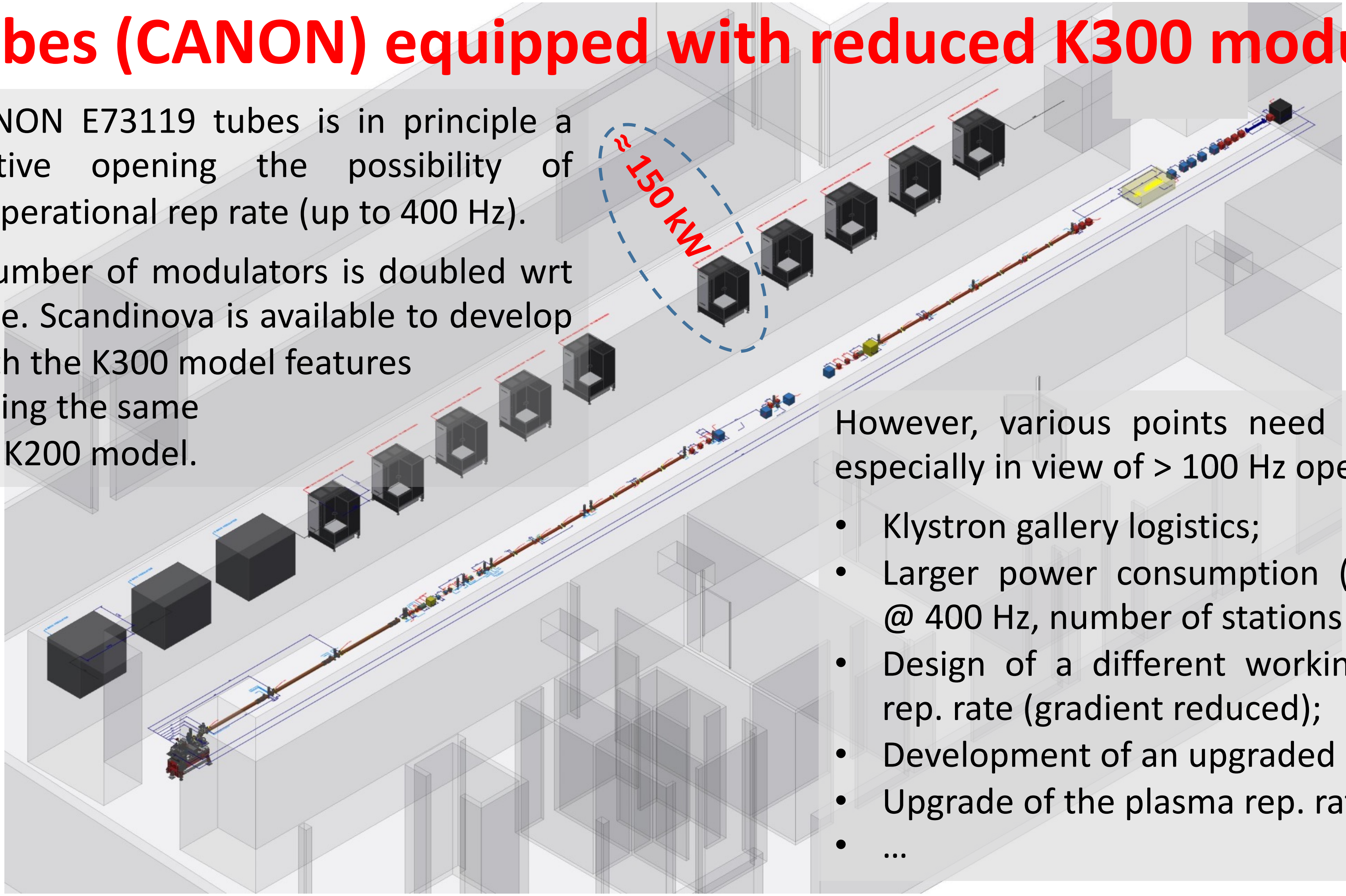


Gallery layout 2

25 MW tubes (CANON) equipped with reduced K300 modulators

The use of CANON E73119 tubes is in principle a viable alternative opening the possibility of increasing the operational rep rate (up to 400 Hz).

The required number of modulators is doubled wrt the CDR baseline. Scandinova is available to develop a modulator with the K300 model features in a module having the same footprint as the K200 model.



However, various points need to be addressed especially in view of > 100 Hz operation:

- Klystron gallery logistics;
- Larger power consumption (≈150 kW/station @ 400 Hz, number of stations doubled);
- Design of a different working point for high rep. rate (gradient reduced);
- Development of an upgraded injector;
- Upgrade of the plasma rep. rate;
- …

Perspectives

- Continuing discussion with both producers for technical and commercial aspects;
- Define (soon) a procurement strategy for the evaluation phase. At the moment we believe we have to continue stimulating both vendors by placing orders for the 2 most interesting models: CPI VKX 8311HE and CANON E73119 provided with a dedicated modulator. Development times are similar, both in the 2 years range.
- Define a roadmap for the project baseline choice. This point remain crucial. It is clear from the presentation that probably **the X-band klystron**, i.e. the core of the EuPRAXIA@SPARC_Lab linac RF system, **does not exist yet**.

Scicom Recommendations about EuPRAXIA

2) The beam dynamics design team still has to perform very substantial simulation campaigns for optimizing and consolidating in particular the plasma acceleration part of the EuPRAXIA@SPARC_LAB beam dynamics design.

- For this a dedicated, state-of-the-art computing infrastructure is required.

Computing resources-WP9 (F. Fortugno)

- The installation of the new five AC922 units for the plasma simulations is on going from **Sept. 10th 2021**
- The infiniband connection cards and switches for the cluster setup must be purchased.
- The purchase procedure of the WS rack module for Linac simulations has been finalized on **Oct. 20th 2021**, delivery in one month.

- 6 Power 9 768 core
- 6 GPU V100

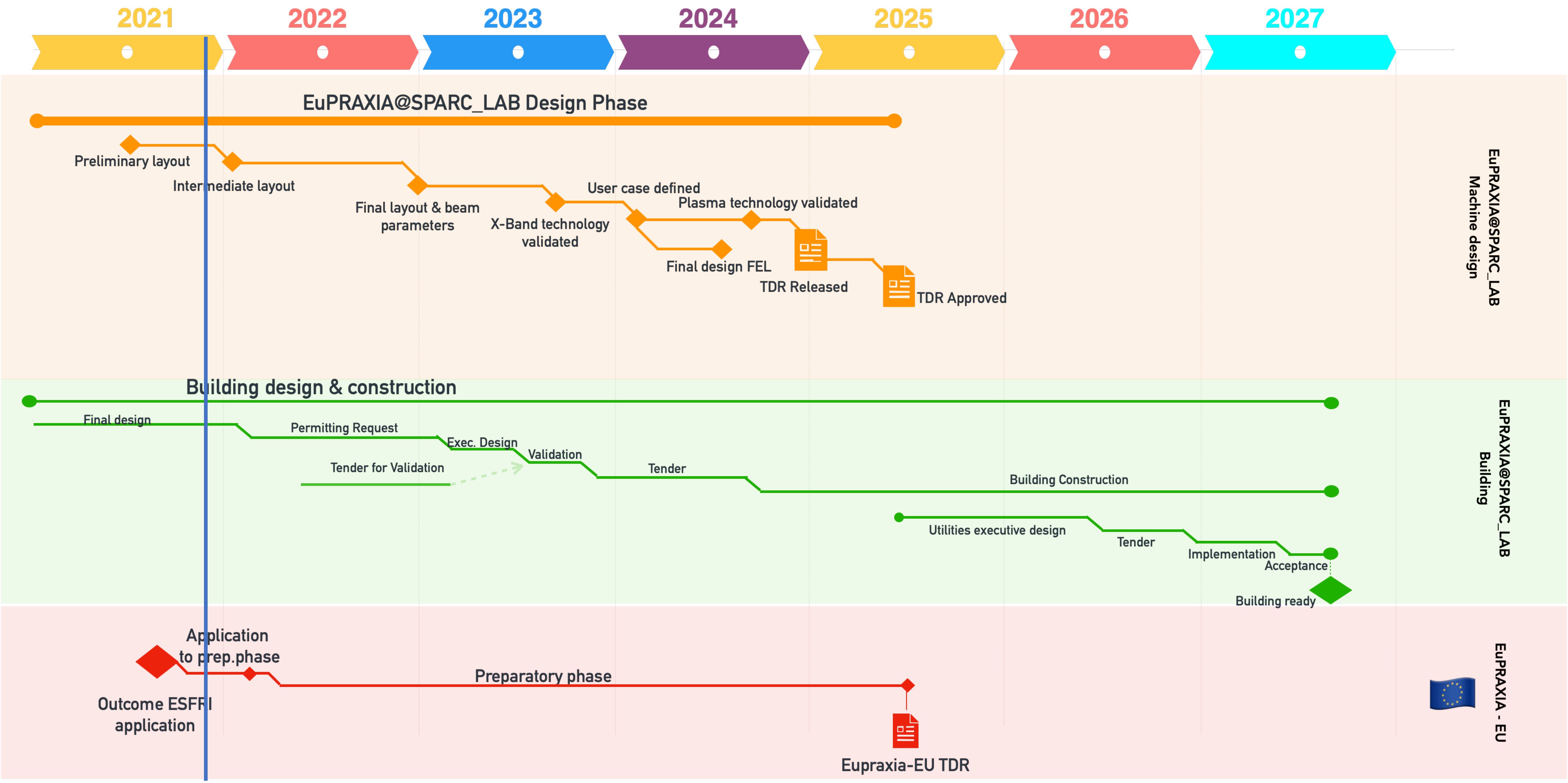
Expected CPU speed (6 time faster)

Code	Tipologia	Serial = S Parallel = P	3 cm plasma	40 cm plasma days	Grid (resolution 1 x 0.5 x 0.5)
AlaDyn	PIC 3D	P (CPU)	1.5 giorni	23 (instead of 138)	1200x400x400 micron
FBPIC	PIC quasi-3D (cilindrico spettrale)	P (GPU)	6 ore	3 (not usable)	1200x400 micron
Architect	Modello Fluido	S (CPU)	1 giorno	21 (parallelization in progress)	1200x400 micron

Review Committees Season

- 2^{nd} TDR Review Committee Oct 26-27
- LNF Scientific Committee Nov 8
- INFN Machine Advisory Committee Nov 11
- ESFRI Review Meeting Nov 23
- Building Review Committee Dec ~15

https://agenda.infn.it/event/28572/timetable/

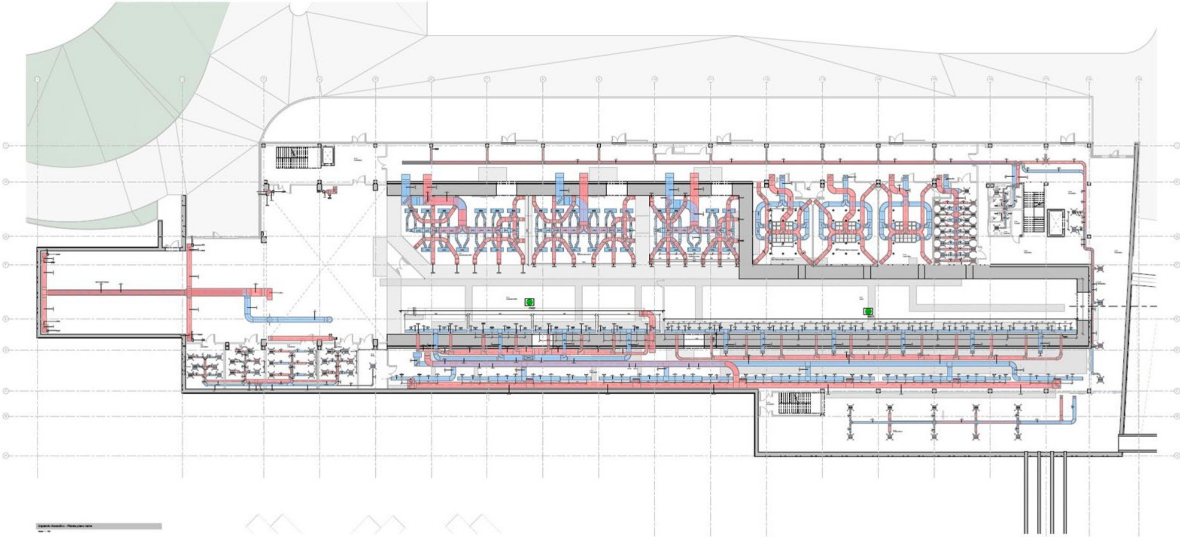


Courtesy A. Falone

Short term outlook - upcoming milestones

Intermediate Milestone	Expected date	Status	Risk
Project Management Plan ready	Feb21	Accomplished	n.a.
Preliminary layout	Jun -21	Accomplished	n.a.
Injector preliminary layout	Jun -21	Accomplished	n.a.
Building final design	Jun -21	Accomplished	n.a.
Outcome ESFRI Application	Oct-21	Accomplished	n.a.
2021 Progress Report	Dec-21	On time	None
Intermediate machine baseline	Dec-21	Ongoing	High Risk of long delay (not quantified) due to lack of manpower
Magnets Specifications	Dec-21	Ongoing	Risk of delay HIGH due to lack of manpower
S-Band Waveguide design	Dec-21	On time	None
X-Band Waveguide design	Dec-21	On going	Depending on the final RF Station choice. It might be delayed
X-Band mech prototype	Dec-21	On time	To be validated
X-Band RF Prototype	Dec-21	On time	To be validated
Funcitonal layout and configuration framework	Dec-21	Accomplished	n.a.
TEX Fully operational	Dec-21	On time	None

EuPRAXIA@SPARC_LAB Building

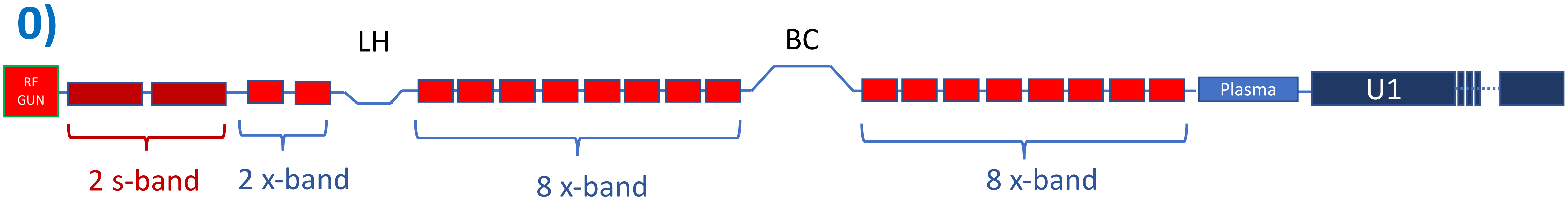


Courtesy U. Rotundo

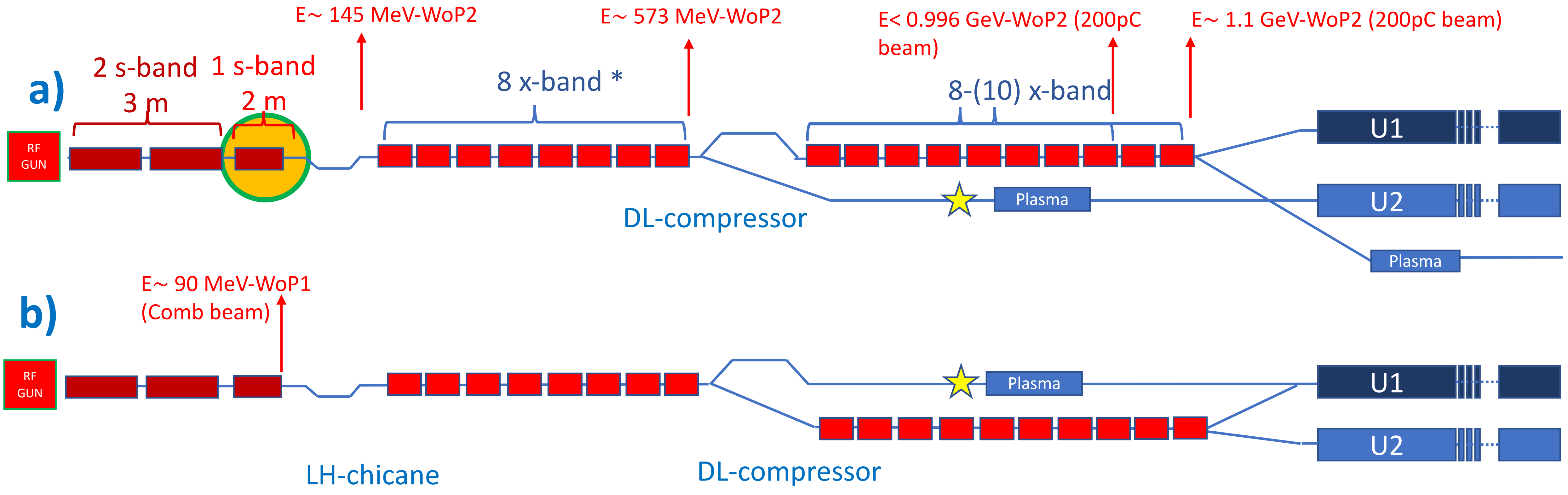
EuPRAXIA@SPARC_LAB Building

- Building Final Draft was officially delivered by the engineering company (Mythos)
- INFN review process was carried out
- AfterFD validation the building permitting request process will start (already started preliminary activities, in order to accelerate and save time)
- A dedicated review meeting with an expert panel (chaired by L. Scibile) will take place by the end of the year to validate the main technical choices for civil works and plants

Courtesy U. Rotundo



From Baseline Single Beamline Design to the Double Beamline option

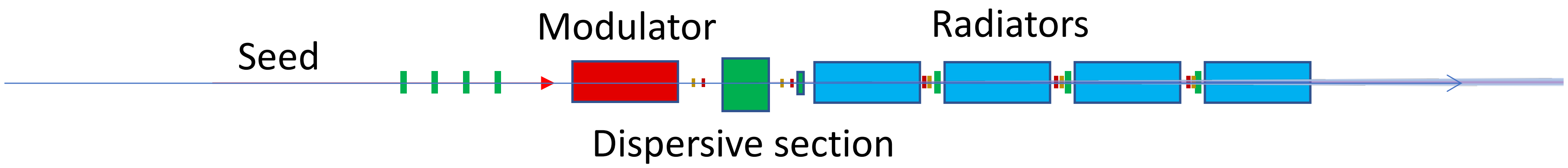


Operation at 400 Hz is under investigation

Two FEL beamlines option:

1) AQUA: Soft-X ray SASE FEL – Water window 4 nm shortest wavelength

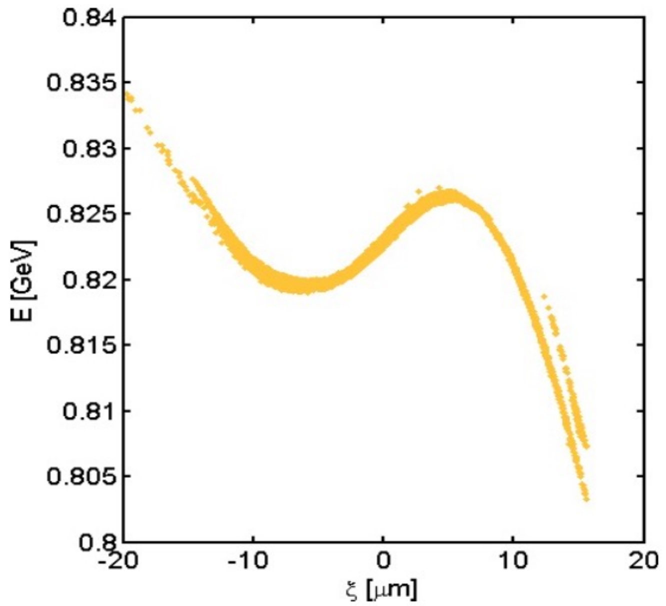
2) ARIA: VUV seeded HGHG FEL beamline for gas phase (not in the baseline)



Beam parameters investigation

	High charge High current Short pulse	High charge Low Current Flat-top	Low charge Ultrashort (linac)	Low charge Ultrashort (plasma)
AQUA	A	Not interesting	C	D,E
ARIA	Not interesting	B	C	D,E

			LINAC			PWA	
Parameter	**Symbol**	**Units**	**A**	**B**	**C**	**D (CDR)**	**E**
Charge	Q	pC	200	200	30	30	30
Energy	E	GeV	**0.996**	**1**	1	1	1
Peak current	I_{peak}	kA	**1.6**	**0.7**	?	**1.8**	**800**
Bunch length	σ_z	µm	**18.3**	**100**	?	**4**	**5**
Proj. norm. emittances (x/y)	$\varepsilon_{n,x,y}$	mm-mrad	1.85	?	?	**1.7**	3/4
Slice, norm. emittances (x/y)	$\varepsilon_{n,x,y}$	mm-mrad	**0.5**	**0.5**	?	0.8	3/4 **(1/1.2 at linac)**
Proj. energy spread	$\sigma_{\delta p}$	%	0.09	?	?	0.95	1.5
Slice Energy spread	$\sigma_{\delta s}$	%	**0.02**	**0.01**	?	**0.05**	**0.06**
			AQUA	ARIA	AQUA/ARIA		

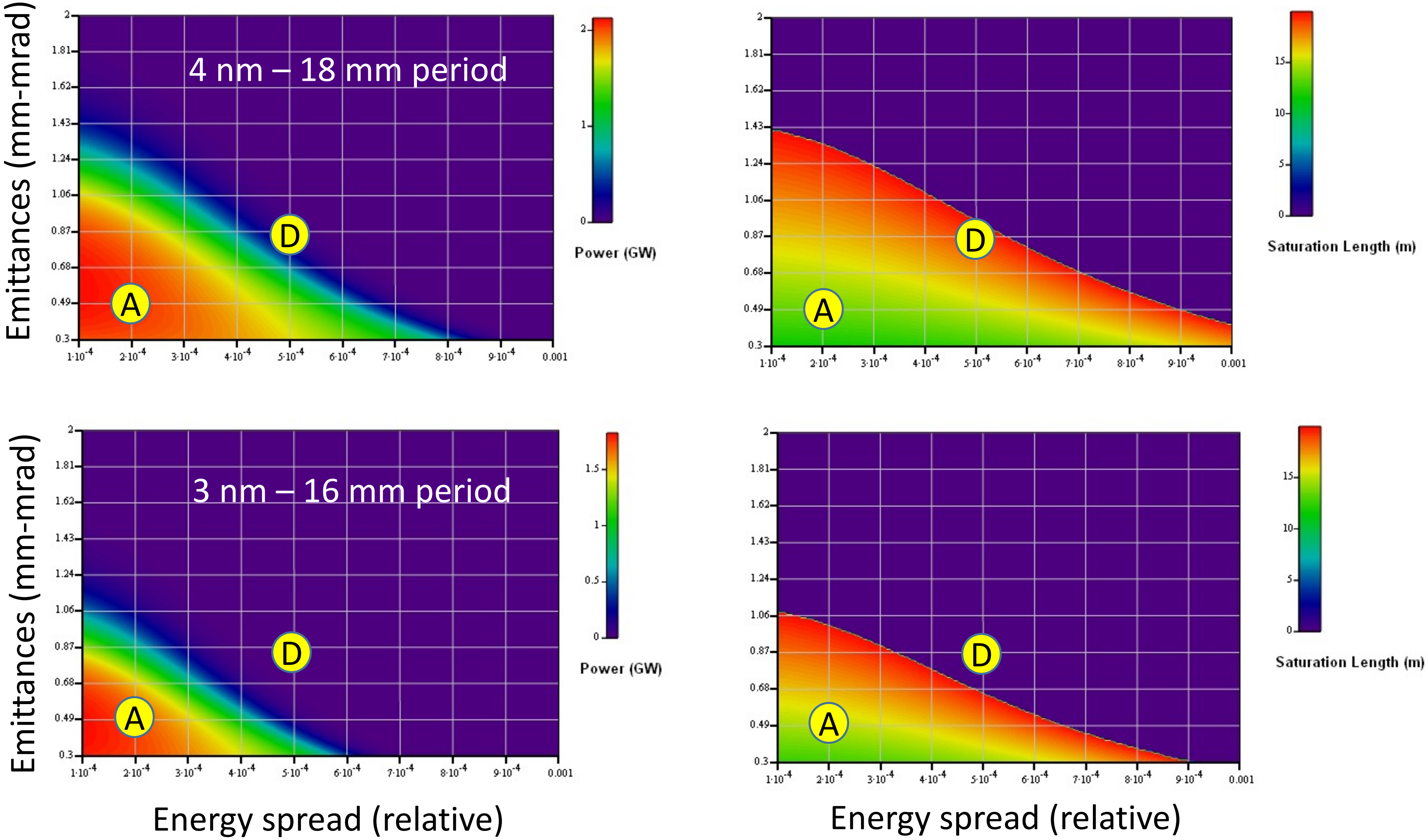


FEL performance map

Other parameters:

- Polarization Linear
- Peak current 1.6 kA
- Beta functions 8 m

- Case A ensures lasing in both conditions
- Case D (CDR parameters with current 1.6 kA): energy spread critical



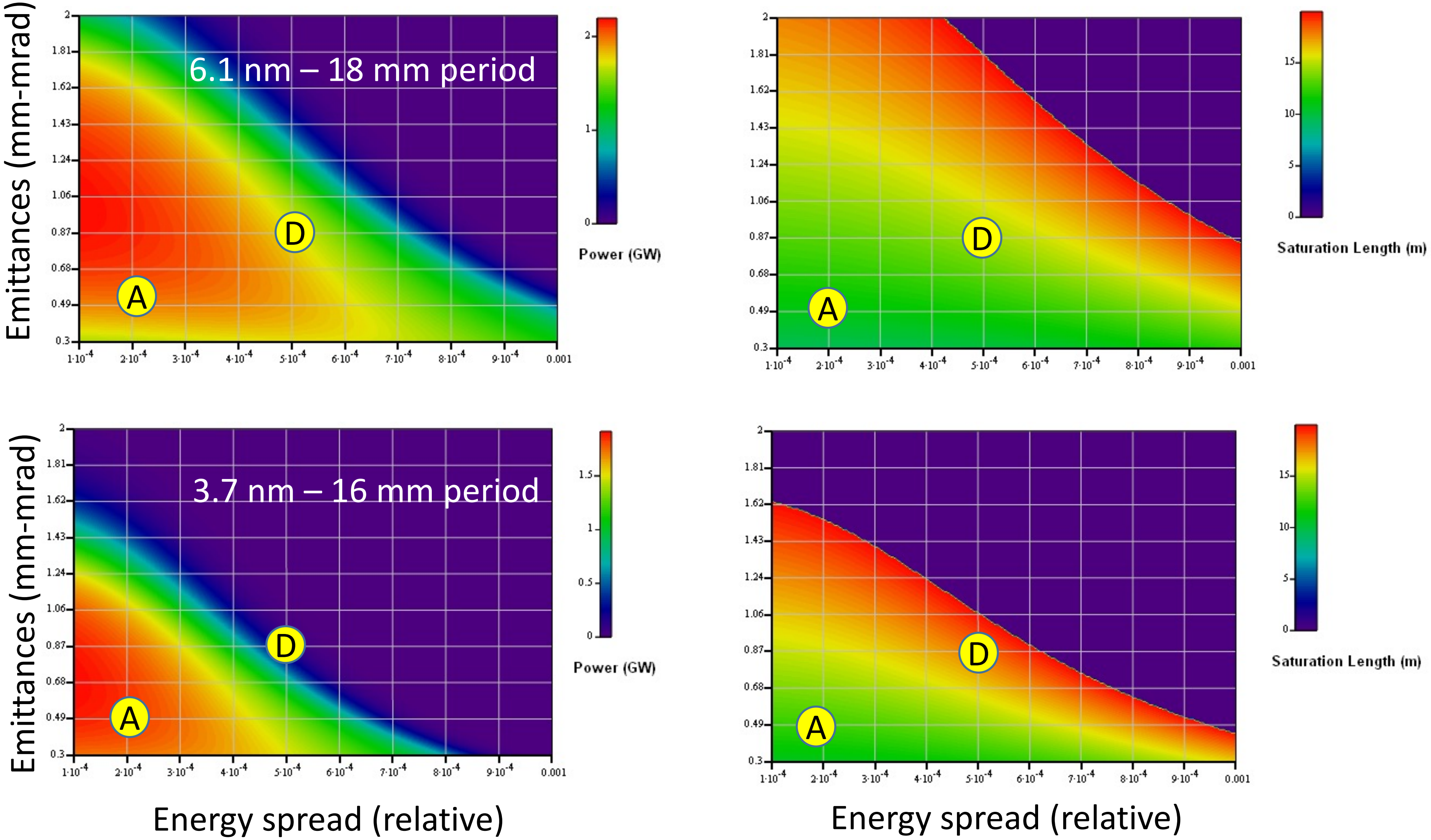
FEL performance map at longest wavelength (1 GeV)

The longest wavelength that can be achieved:

with 18 mm period is 6.1 nm

with 16 mm period is 3.7 nm

18 mm period solution is less sensitive to e-beam parameters

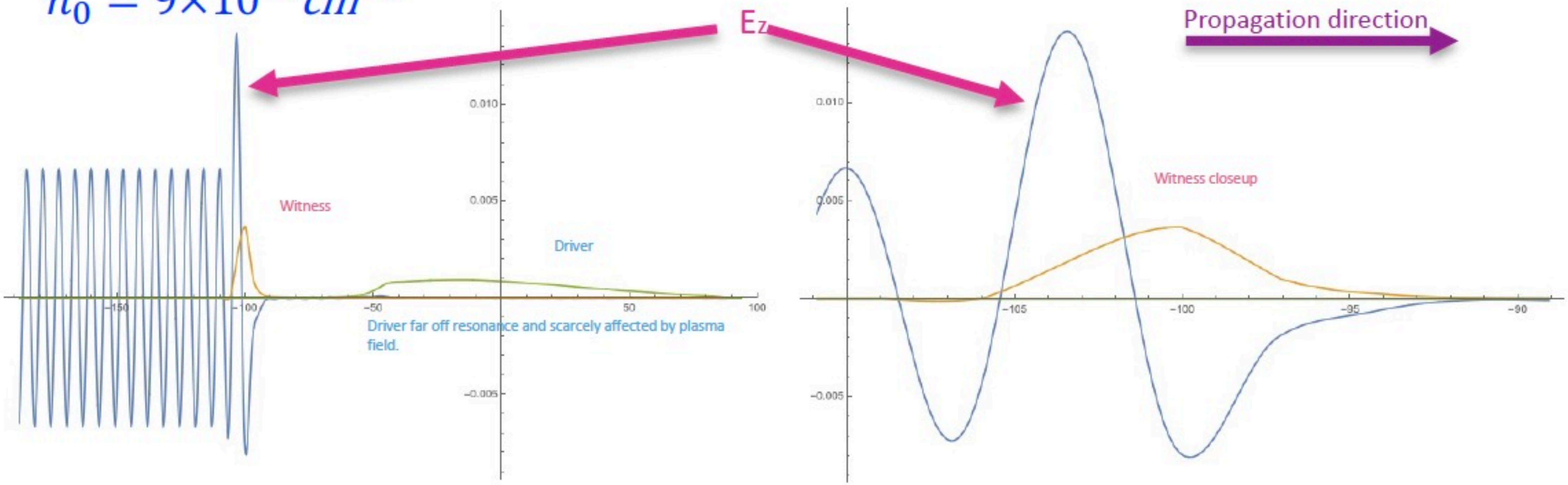


Option 2: Plasma pre-chirper (A.R. Rossi)

We are investigating the possibility to pre-compensate the energy chirp by using a higher plasma density stage. Back of the envelope, 1D evaluations seem to qualitatively confirm the possibility to pre-compensate energy chirp.

Pre-compensation for the excess beam loading case

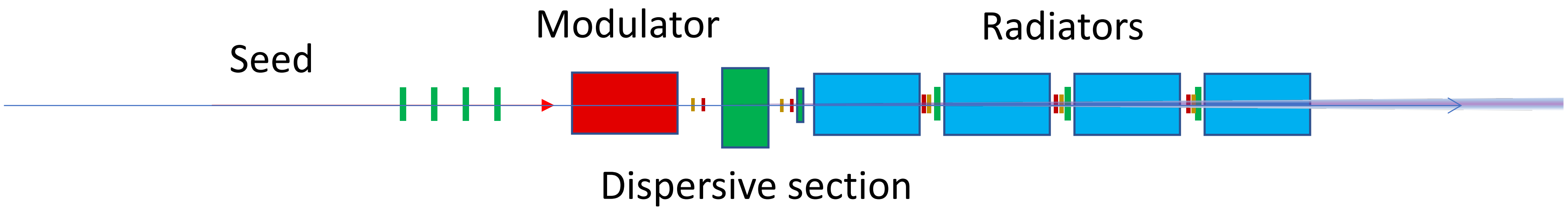
$$n_0 = 9\times10^{18}\,cm^{-3}$$



NB: all units are normalized. Current profiles are in a.u. D and W profiles are do not have the same scale.

ARIA

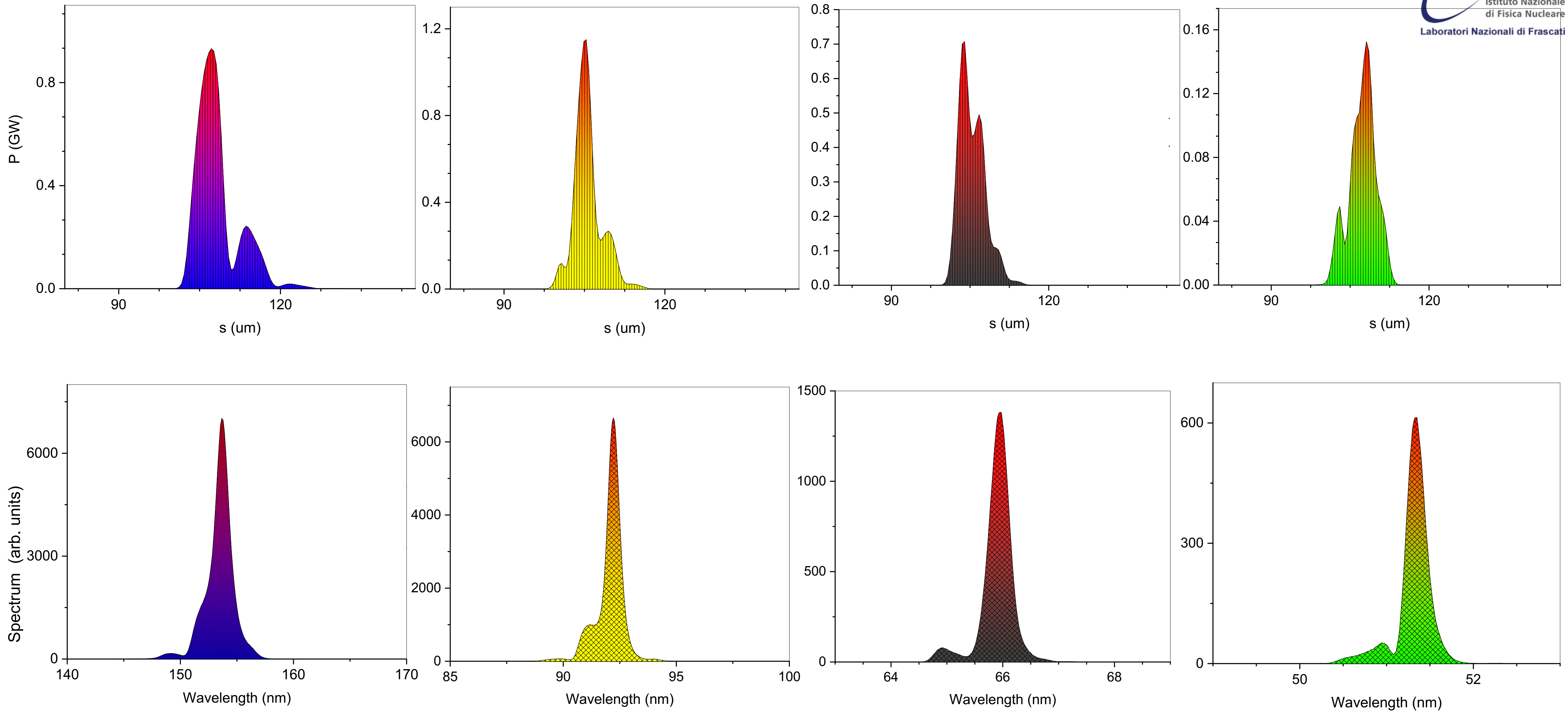
SEEDED FEL line – Full coherence – Short/Long pulses – Close to FT Limit



- High-Gain Harmonic Generation seeded FEL: modulator – dispersive section – 4 radiators
- Wavelength range 50 nm (then 30 nm) – 180 nm – continuously tunable – 10-100 uJ pulse energy
- Apple II Undulators: variable polarization (circular left/right, horizontal and vertical)
- Ready for users since the first commissioning phase. Would contribute to establish a user community for the EupraXia at SparcLab user facility

GENESIS 1.3 simulations (courtesy of M. Opromolla/V. Petrillo ~beam D parameters)

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati



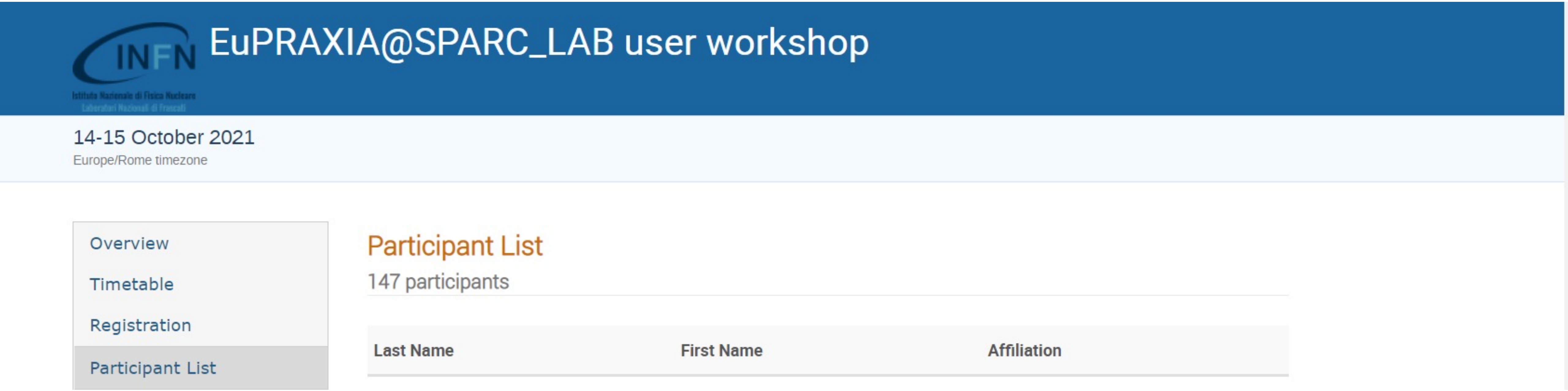
153nm (nh=3)

92nm (nh=5)

66nm (nh=7)

51nm (nh=9)

AQUA/ARIA - A growing community



The first EuPRAXIA@○SPARC_LAB user workshop

More than 140 registrants from 9 countries and ~30 institutions

https://agenda.infn.it/event/27926/overview

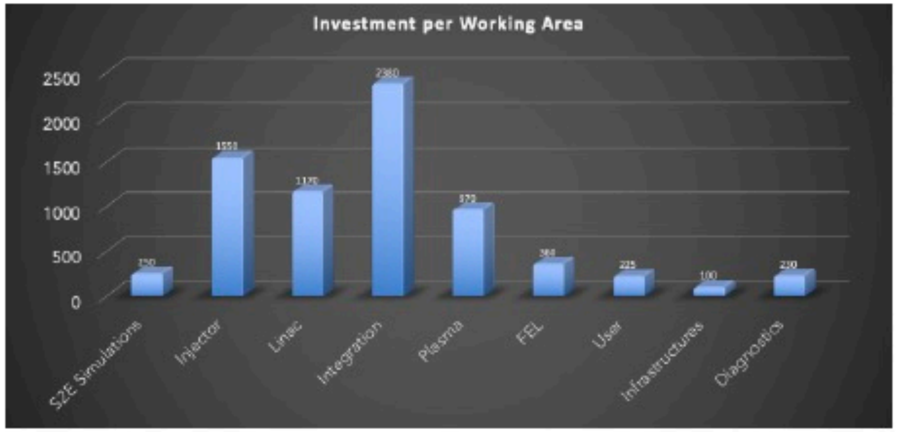
Summary

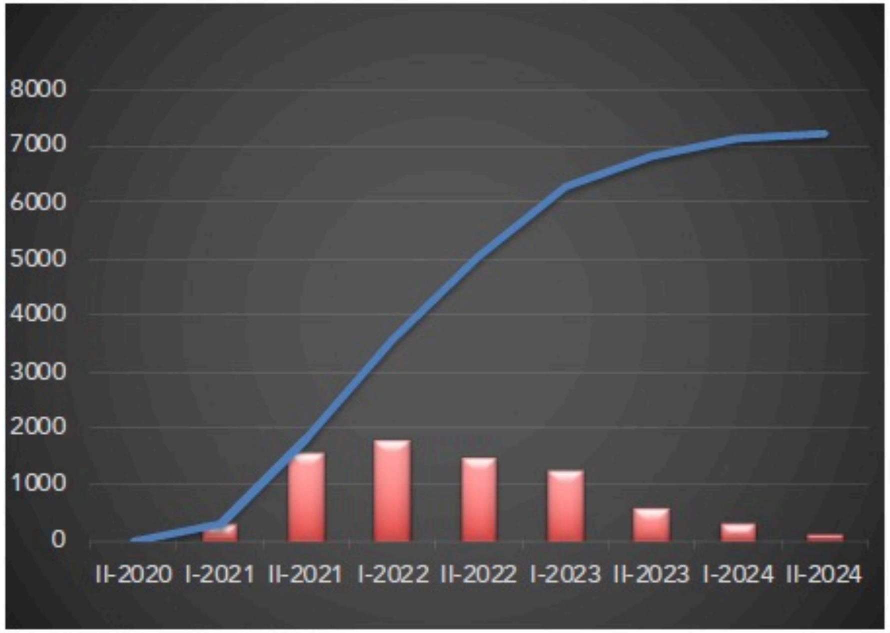
- AQUA – FEL in the water window requires high quality beam
- Simulation work is in progress: freezing the configuration still requires some work on the layout
- This beamline is also demanding from the point of view of the undulator technology. A SC undulator would ensure best performances and photon energy range extension.
- An Apple X PM undulator would still provide a sufficient tuning range, but is technologicaly challenging. The beam stay clear region would also be reduced.

- ARIA - The VUV FEL in a seeded configuration is more tolerant in terms of beam quality.
- ARIA is seeded by near UV/blue laser. A tuneable seed source delivering few tens of microjoules in the range 410-560 nm covers the full range required by the source (operating at harmonics 3 - 9 of the seed)
- ARIA can be combined to a synchronized HHG Source for UV-pump UV-probe experiments, and is a promising resource to build a user community from the early startup of the facility.
- From the ESUW21 workshop: The ARIA FEL fills a niche in the world FELs scenario

Financial Requests for the R&D effort

Working Area	Amount (k€)
WA1- Beam Physics	250
WA2 - Injector	1550
WA3 - Linac	1170
WA4 - Integration	2380
WA5 - Plasma	970
WA6 - FEL	360
WA8 - Users	225
WA9 - Infrastructures	100
WA.10 - Diagnostics	230
Subtotal	7235
Contingencies	360
TOTAL	7595





- Cost Baseline for TDR already presented at the last meeting. Few modification in the meanwhile.
- Presented to the INFN management board (GE) which informally approved but waiting for your final feedback.
- Some funds already allocated to cover some urgent procurement.

Current resources allocation [FTE]

	Accelerator Division										
	Diag.	Magnets	Mech Eng	Linac	RF	Controls	Vacuum	Laser	STAFF	Secret.	TOT
Staff	2	1,5	2	2	2	2	3	2	7	1	24,5
Technician	2	1	2	3	2	1	3	1	0	0	15

	Technical Division						
	Civ.eng.	HVAC	Electrical	Gen.Serv	Warehouse	Mech.	TOT
Staff	1	2,7	1			0,3	5
Technician	0	1,5	1	0,5	0,5	1	4,5

	Others
AdR / Post-Doc	6
INFN-MI	1
UniRoma1	1
UniRoma2	2
ENEA	2
TOT	12

First estimation to evaluate the current FTEs allocated to the project.

Total: 61 FTE

Estimation required additional manpower

WP	Description	Staff *	Post-Doc	Technician	Comment
1	Beam Physics	2	2		
2	Plasma Physics	1	1		
3	FEL Physics		1		INFN-MI
6	Plasma Module		1		
8	RF-Gun &				
10	Vacuum		1	2	
11	Laser & Cathodes	1	1		
14	Diagnostics	1	1		
15	LLRF & Synchronization	1			
16	Controls	2		2	
17	Magnets & PS		1		
18	Undulators		2		1 @ ENEA
19	Mech Engineer	1			
20	Electrical Installation			2	
21	Cooling & Ventilation			1	
22	Civil Engineering			1	
23	Radioprotection	1			
24	Conventional Safety	1			
25	Network	1			
PO	Project Office	1	2		
	TOTAL	**13**	**13**	**8**	
	TOT. FTE	**34**			

This would bring up to <u>95 FTE</u> allocated

- This does not take into account PhD students (around 10).
- Estimated cost/year = 1M€ (approx)
- These FTEs could come from different sources:
  - Already present in the Lab but working on other topics
  - Turnover
  - New hiring
  - In-kind contribution
- Request to be submitted at the INFN-Management.
- Strategy to be decided at Management level

INFN
Istituto Nazionale di Fisica Nucleare

EuPRAXIA

- INFN Management
- EuPRAXIA Collaboration Board
- PROJECT LEADER — *M.Ferrario*
- LNF Governing Board

Management Team

- Scientific Manager — *M.Ferrario*
- Technical Manager — *A.Ghigo*
- Project Management & Integration — *A.Falone*

Project Management Office

F.Cioeta - Configuration manager
M.lungo - Cost & Schedule
G.Vinicola - Administration

Working Areas / Steering committee

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

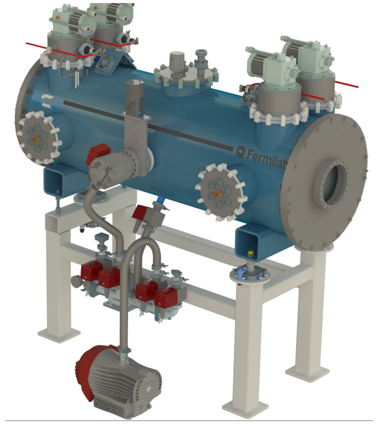
Work Packages

1. Accelerator Physics — *A.Giribono*
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 — *L.Piersanti*
9. Computing — *P.Santangelo*
10. Vacuum — *A.Liedl*
11. Lasers & Cathodes — *M.Anania*
12. High Power RF & distribution — *F.Cardelli*
13. Functional Safety — *TBD*
14. Beam Instrumentation & electronics — *A.Stella*
15. LLRF & Synchro — *M.Bellaveglia*
16. Control system & Interlocks — *A.Stecchi*
17. Magnets & PS — *L.Sabbatini*
18. Undulators — *A.Petralia (ENEA)*
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*
25. Network — *G.Di Pirro*

thanks for your attention

Undulator technology

Superconducting Undulator

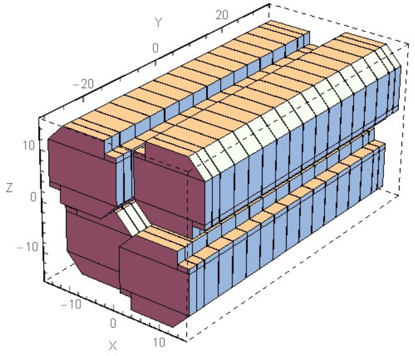


Responsible C. Boffo (FNAL)

Agreement with FNAL signed 1y ago
Development plan 4 ys – 2024
prototype in Frascati

Costs for the entire undulator in excess of the baseline for the project

Permanent Magnet Undulator



Respons. A. Petralia (ENEA)

Apple X - Variable gap, variable polarization
New poles design, scaled from SABINA (LNF- THz FEL) undulator

Period increased to 18 mm to increase tuning range.

Unconventional undulator design: Is prototyping required ?
(Advice from the committee welcome)
Observers in the LEAPS – INNOV: several labs investing in this kind of devices.

Alternative: sacrifice the tuning range - fixed gap PMU – less expensive, but poor flexibility

SUMMARY of the available information

		CANON E37118		CANON E37119		CPI VKX-8311A		CPI VKX-8311HE	
		single piece	series	single piece	series	single piece	series	single piece	series
Peak RF Output Power	**MW**	**20**		**25**		**50**		**50**	
Average RF Ouput Power	kW	12		15		7,5		7,5	
Peak beam Voltage Vk	kV	270		335		420		420	
Peak beam Current Ik	A	182		225		320		204	
Peak Drive power	W	400		400		900		400 (?)	
Gain	dB	47		48		48		51 (?)	
Rep rate	Hz	400		400		100		100	
Efficiency	%	40		40		40		60	
Cost (with solenoid, no VAT)	**k€**	**250**	**212,50**	**320**	**272**	**900**	**765**	**1050**	**892,5**
Cost/Peak_power	**k€/MW**	**12,5**	**10,63**	**12,8**	**10,88**	**18**	**15,3**	**18**	**17,85**
Cost/Ave_power	k€/kW	20.8	17,71	21,33	18,13	120	102	140	119
Delivery time	**months**	**10 ?**		**22** (first), **10** mass prod.		**15**		**26** (first), **15** mass prod.	
Reference Modulator	**Model**	**K200**		**K300**		**K400**		**K300**	
Modulator price	**k€**	**375**	**315**	**485**	**395**	**560**	**475**	**485**	**395**
SS Driver Power	**kW**	**0,5**		**0,5**		**1**		**0,5**	
SS Driver cost	**k€**	**50**		**50**		**100**		**50**	
LLRF cost	**k€**	**120**		**120**		**160**		**160**	
Station cost	**k€**	**795**	**697,50**	**975**	**837,0**	**1720**	**1500**	**1745**	**1497,5**
Station cost/ Peak_power	**k€/MW**	**39,75**	**34,875**	**39**	**33,5**	**34,4**	**30**	**34,9**	**29,95**
Station cost/ Ave_power	k€/kW	66,25	58,13	65,0	55,8	229,3	200,00	232,67	199,67

Notes:
For series production Scandinova discounts K200 and K400 by about 15%, K300 about 18%
A guessed 15% discount is considered also for the tubes, without confirmation from the producers
Waveguides components have not been included since the network configuration is expeted to be independent on the station configuration

WP16 • Control System
State of play

Training
Two courses (on EPICS and AGILE) – aimed at the EuPRAXIA@SPARC_LAB project – have been organized and attended

Survey on Work Packeges requirements
A first collection of specifications for machine hardware was completed

Activities planned in collaboration with others
Time synchronization and trigger distribution

Control framework definition
The final structure is being defined and will be discussed with management within the year (as stated in the previous review)

Control framework definition

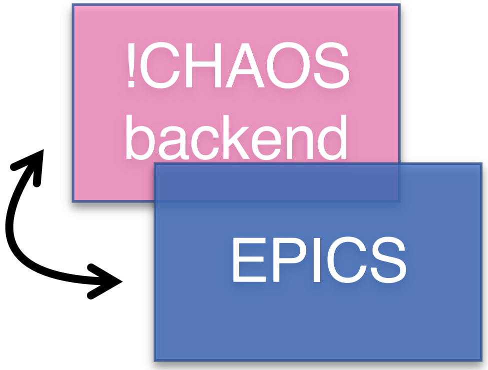
During the last review we said that the control framework would be finalized **by the end of 2021**.

The two hypotheses at stake were:

1. control **entirely made in !CHAOS**;
2. control **implemented in an already established framework** (EPICS, TANGO) **with !CHAOS as backend service** (PaaS, SaaS) for: storage, data analisys, data presentation, etc.

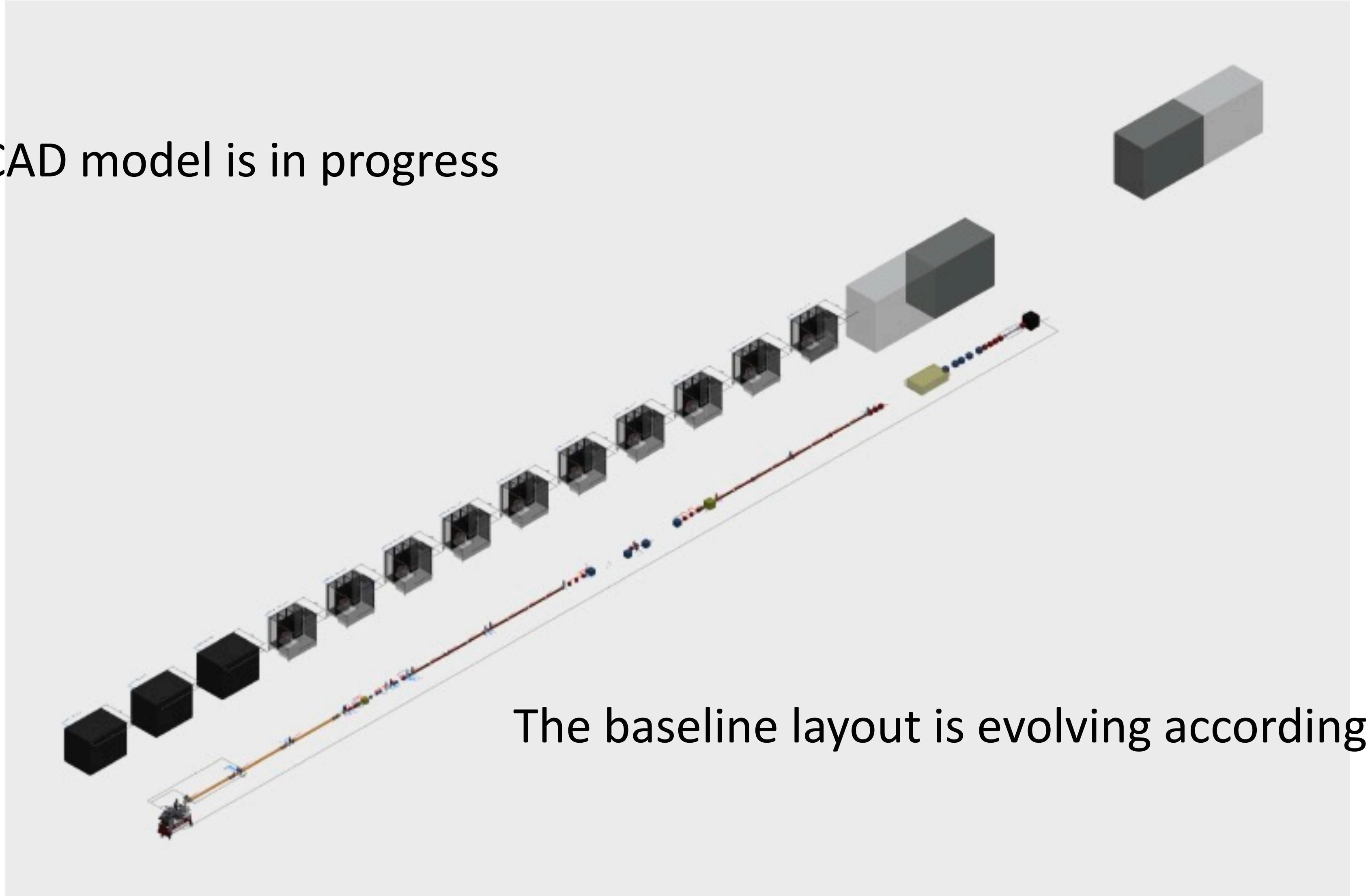
At the moment, the scenario that is being defined **is the second one**, using EPICS as control framework. This is going to be discussed with our management and defined within the set deadline.

An interfacement method between the two systems is under development and we are going to test it on the TEX facility.



Preliminary baseline layout in progress

A detailed CAD model is in progress



The baseline layout is evolving according to the BD results

Two operating modes

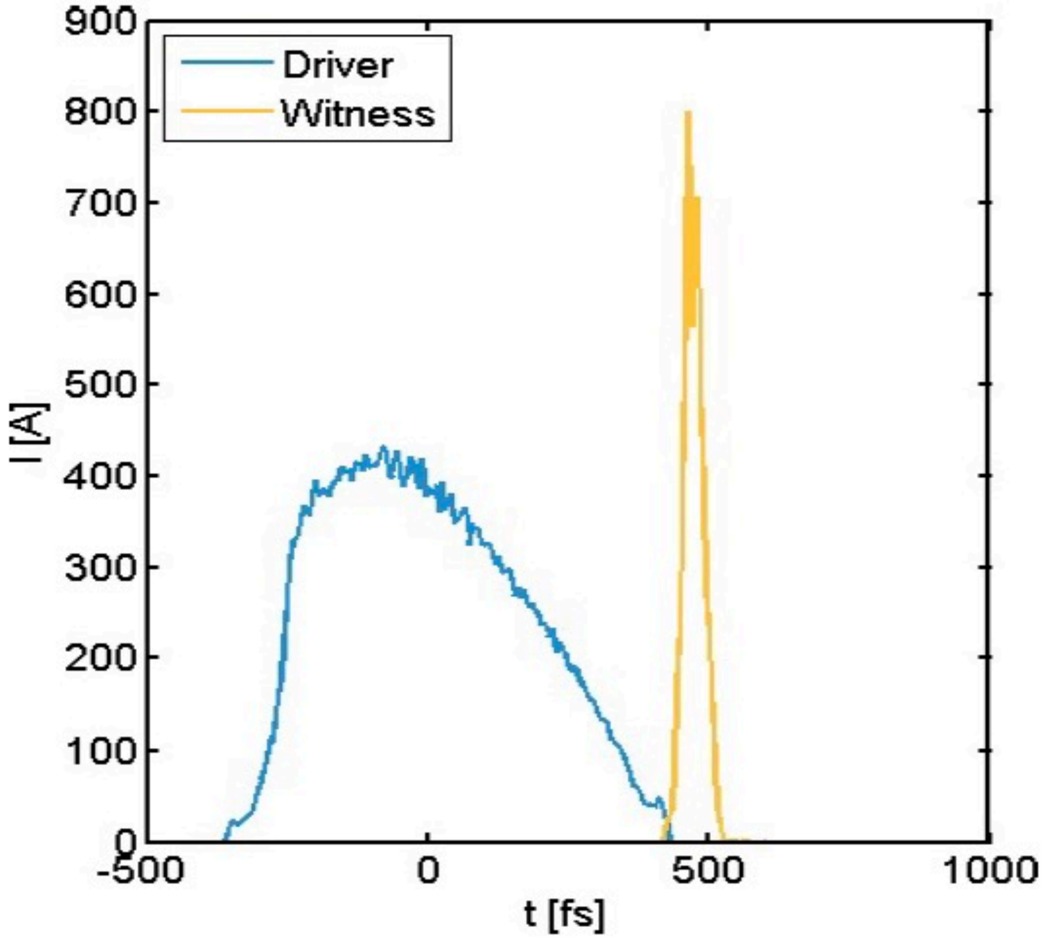
- **Long seed/ Long e-bunch mode:**
  - Narrow linewidth, eventually in combination with a monochromator.
  - The presence of a "long" seed transfers seed coherence properties to the e–beam and maximizes the coupling with the spectral acceptance of the monochromator
- **Short e-bunch mode:**
  - Electron bunch shorter than the coop. length: single long. mode
  - Pulse duration limited by gain bandwidth ~10 fs
  - Deterministic system, second order coherence provided by the seed - > stable in intensity and central wavelength

The gain bandwidth in a FEL amplifier is proportional to the ρ_{3D} parameter and to the ratio $\sqrt{\frac{L_{sat}^{SASE}}{L_u}}$ when $L_u < L_{sat}^{SASE}$

- **ARIA** operates in the VUV with a beam "designed" for the water window" -> ρ_{3D} large
- **ARIA** is seeded: the presence of the seed ensures: $L_u < L_{sat}^{SASE}$

The ARIA seeded FEL can generate ultrashort pulses in the VUV when driven by a high current, high brightness, short electron bunch

WoP1 I_w=800 A (S. Romeo)



Start to end simulation from Elegant data:

- Simulation with Architect code
- 40 cm propagation in plasma channel
- Density scan to optimize the energy spread

Witness parameters

$\sigma_{x,y} = 2.6\ ,2.8\ \mu\text{m}$

$\sigma_z = 5.11\ \mu\text{m}$

$\varepsilon_{n\ (x,y\ )} = 1.2\ ,1.0$ mm mrad

$\gamma = 921$

$\sigma_E = 0.076\%$

$I \approx 800$ A