EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

WP15 - TDR EuPRAXIA@SPARC_LAB (beam-driven plasma)

C. Vaccarezza-R. Pompili

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement No. 101079773

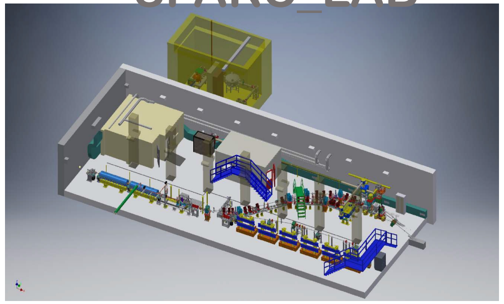
Beam Driven Pillar

- 1GeV full RF X-band Linac
- Plasma Acceleration Stage
- Ondulator Line
- + Brand New Building

Main Challenges:

- Plasma Acceleration stage
- 1 GeV full RF X-band Linac

SPARC_LAB



Full Upgrade supported by Regione Lazio through **SABINA** project

- Plasma acceleration stage
- RF Gun Prototype
- Diagnostics prototyping
- Synchronization

SPARC_LAB facility

TeX facility

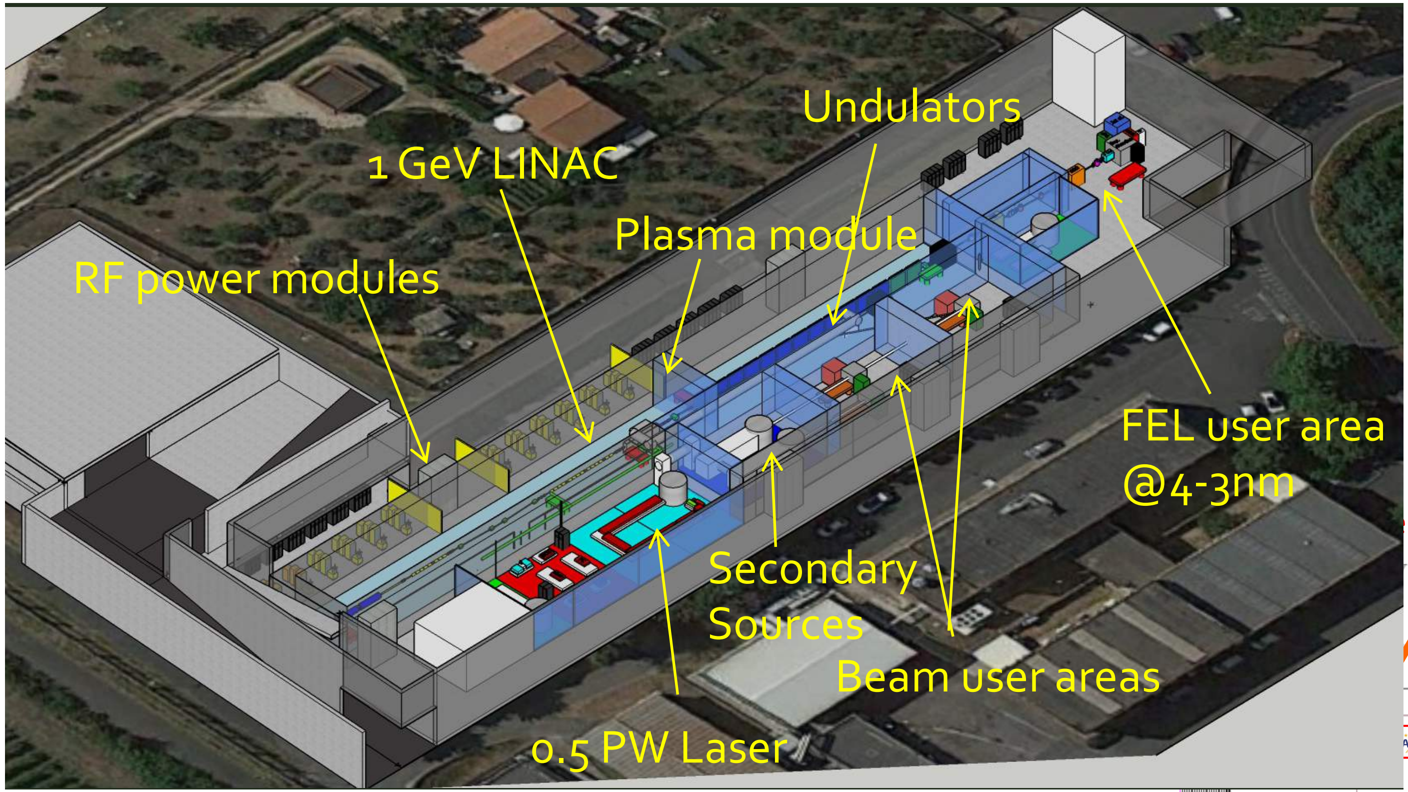
TEX- Test Stand X-band

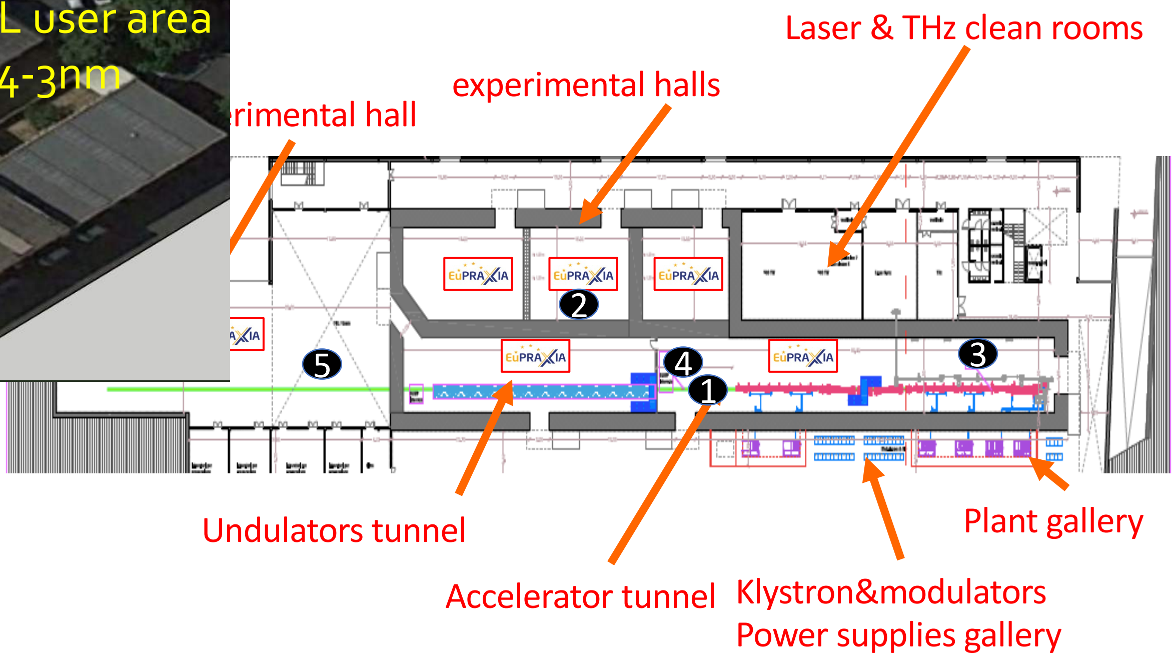
Supported by Regione Lazio through **LATINO** project

- X-band HP RF Technology
- X-band HP waveguide components & pulse compressor
- X-band structures conditioning

EuPRAXIA@SPARC_LAB

Funded by the European Union



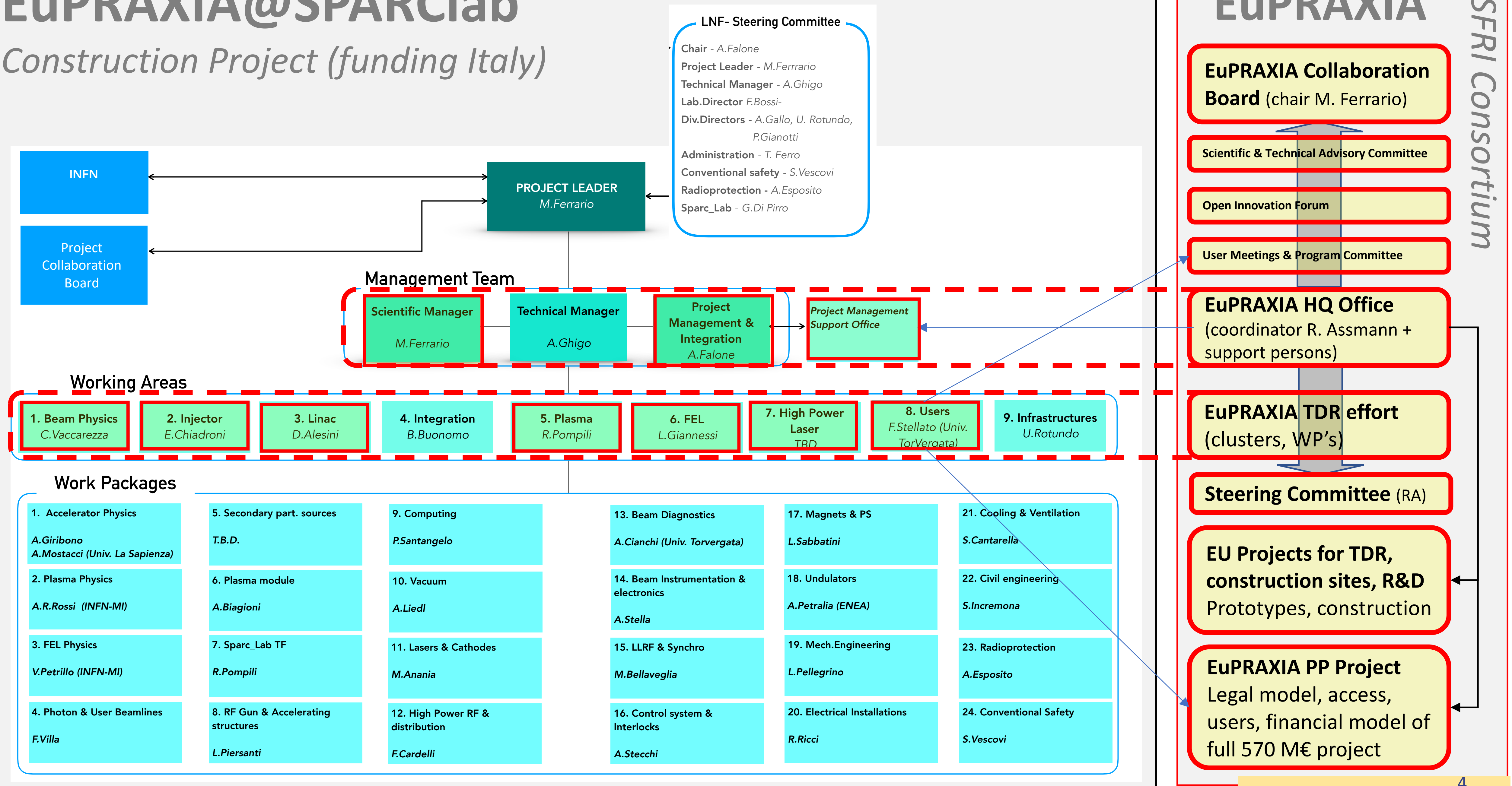


1. Plasma structure designs, devices
2. Compact positron source
3. HQ 150 MeV laser plasma injector
4. HQ laser driver
   - Hybrid concepts
   - Simulations
5. User experiments and lines

To be detailed in TDR phase.

EuPRAXIA@SPARClab

Construction Project (funding Italy)



Courtesy of R. Assmann

EuPRAXIA

Timeline

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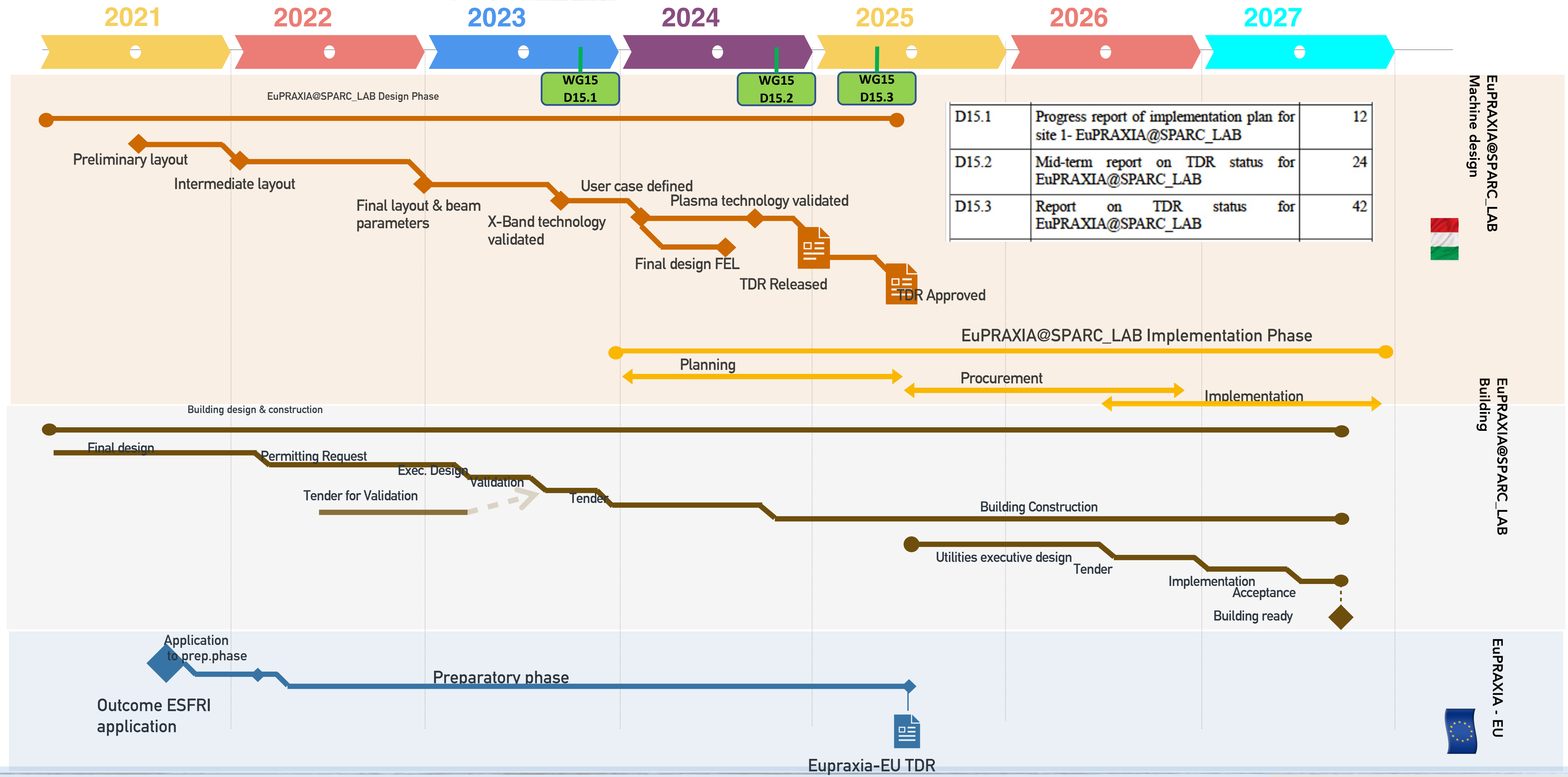


D15.1	Progress report of implementation plan for site 1- EuPRAXIA@SPARC_LAB	12
D15.2	Mid-term report on TDR status for EuPRAXIA@SPARC_LAB	24
D15.3	Report on TDR status for EuPRAXIA@SPARC_LAB	42

X-BAND LINAC OPERATION:

- WoP1 : PWFA

The 500 MeV Witness+Driver scheme is adopted with a lattice able to drive the two bunches at the plasma entrance with the required characteristics

- WoP2 : Full X-band

The 1 GeV energy is achieved by means of 16 X-band RF sections the beam is compressed with a Hybryd scheme: VB + Mag. chicane

EuPRAXIA@SPARC_LAB Parameter List

Funded by the European Union

- FEL parameters

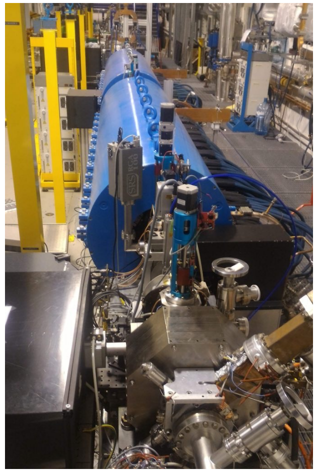
Parameter	Unit	PWFA	Full X-band
Radiation Wavelength	nm	3-4	4
Photon per Pulse	$\times 10^{12}$	0.1-0.2	1
Photon Bandwith	%	0.1	0.2
Undulator Length	m	30	
$\rho(1D/3D)$	$\times 10^{-3}$	1	2
Photon Brilliance per shot	$\left(\frac{s\, mm^2 mrad^2}{bw(0.1\%)}\right)$	10^{26}	

- Electron Beam Parameters

Parameter	Unit	PWFA	Full X-band
Electron Energy	GeV	1-1.2	1
Bunch Charge	pC	30-50	200
Peak Current	kA	1-2	1-2
RMS Energy Spread	%	0.1	0.1
RMS Bunch Length	μm	6-3	24-20
RMS norm. Emittance	μm	1	1
Slice Energy Spread	%	≤5E-04	≤5E-04
Slice norm Emittance	mm-mrad	0.5	0.5

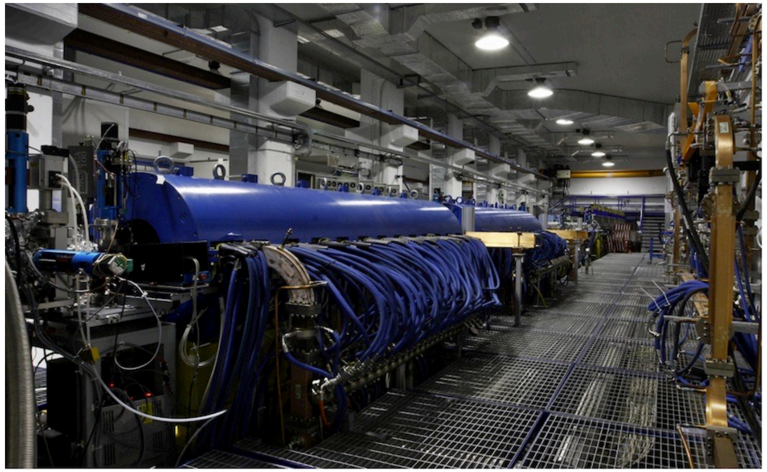
SPARC_LAB in more detail

Funded by the European Union



The Photoinjector

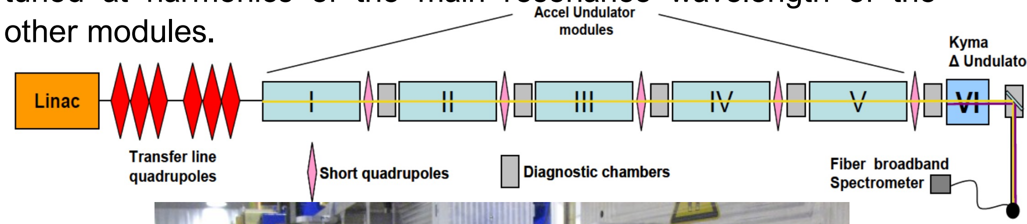
The SPARC_LAB photoinjector is based on a 1.6 cell S-band RF gun which operates at ~120 MV/m peak on cathode. At the gun exit a solenoid is located for the emittance compensation and downstram two 3 m long S-band accelerating structures plus a 1.5 m C-band, are located providing a total energy of ~200 MeV on crest.



The SPARC_LAB photocathode laser system is based on a Titanium-Sapphire laser at 800 nm, the laser system is synchronized with the RF system with a compressed pulse energy of about 50 mJ. We split the laser pulses from the oscillator to two CPA systems, one used for the photocathode and one for FEL seeding and diagnostics

The Undulator

The Undulator consists of six permanent magnet modules made by 77periods with λ_u=2.8 cm. Each module allows a variable gap in the range from 25 to 8.4 mm in order to achieve an undulator strength parameter variation up to K_u=2.2 at the minimum gap. The intersections between the undulator modules host quadrupoles and diagnostic stations for electron beam and radiation. More recently a novel type of short period undulator with λ_u=1.4 cm and K_u=1, has been installed and tested. This undulator acts as an afterburner to have emission of radiation tuned at harmonics of the main resonance wavelength of the other modules.



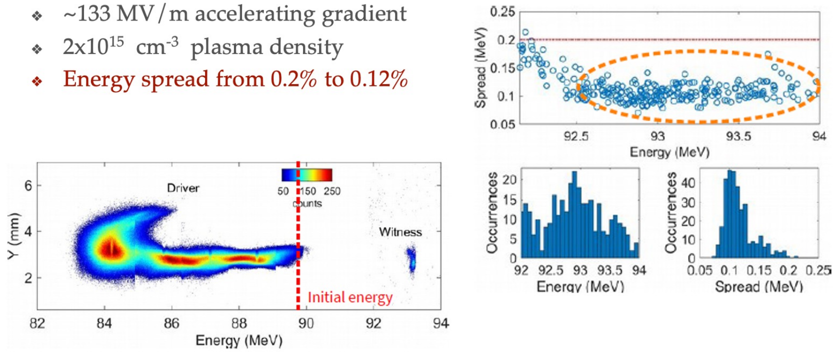
SPARC_LAB results

Funded by the European Union

Energy spread reduction in the beam driven PWFA experiment

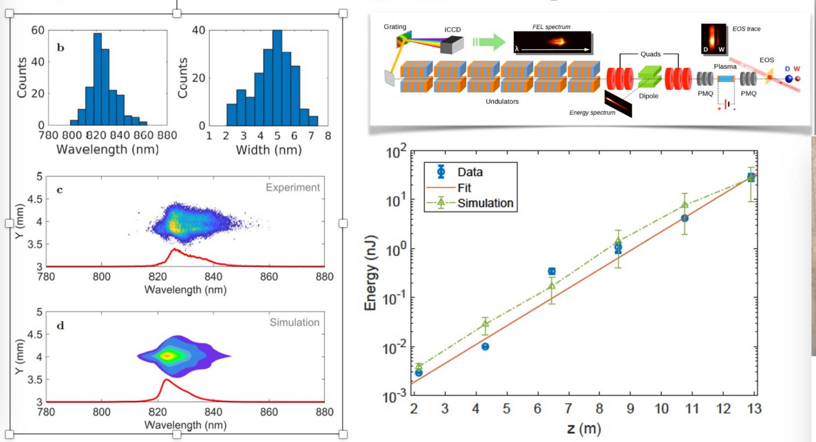
2020

- 4 MeV acceleration in 3 cm plasma with 200 pC driver
  - ~133 MV/m accelerating gradient
  - 2×10^{15} cm^{-3} plasma density
  - Energy spread from 0.2% to 0.12%



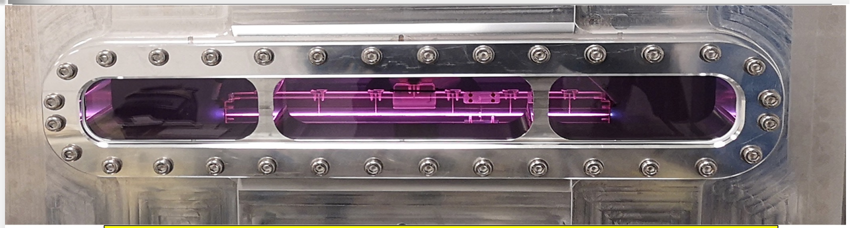
R. Pompili et al., *Energy spread minimization in a beam-driven plasma wakefield accelerator* (2021), Nature Physics, **17** (4), pp. 499-503

First experimental observation of the gain growth of a plasma-driven SASE FEL



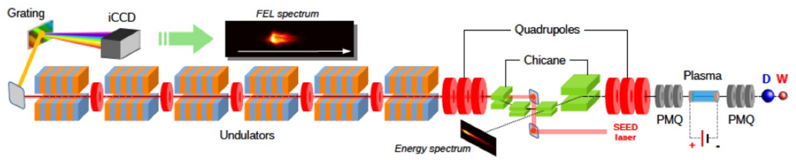
R. Pompili et al., *First lasing of a free-electron laser with a compact beam-driven plasma accelerator*, (2021), accepted in Nature

First EuPRAXIA plasma source to reach 1.1 GeV (1.5 GV/m) - 40 cm long



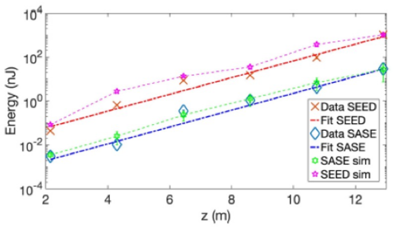
- **Rep rate at 1 Hz**
- **9 kV – 480 A minimum values to have the ionization (3 kV – 140 A for 3cmx2mm)**
- **Aperture time E-valve/Voltage delay is 9ms/12 ms (3-4 ms/5-6 ms for 3cmx2mm)**
- **6 inlets of 1 mm in diameter separated by 60mm/80mm (1 or 2 inlets for 3cmx2mm)**

First plasma-driven Seeded FEL



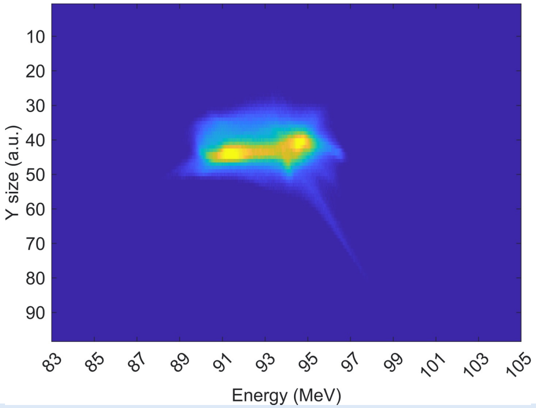
Seeded FEL Radiation

- Part of the EOS laser used as seed
- Seed laser ~ 795 nm, FEL peak 827 nm
- Pulse energy increase from 30 nJ up to 1 μJ
- Increased stability of emitted radiation

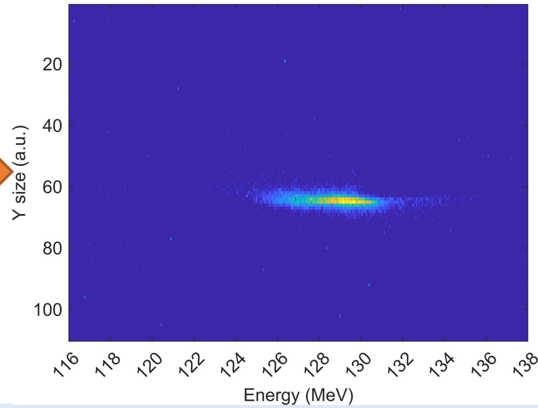


M. Galletti et al., *Stable operation of a free-electron laser driven by a plasma accelerator*, (2022), submittedi to Nature

2022



Nov 2022: 1.2 GV/m in a 3cm capillary 50+500 pC



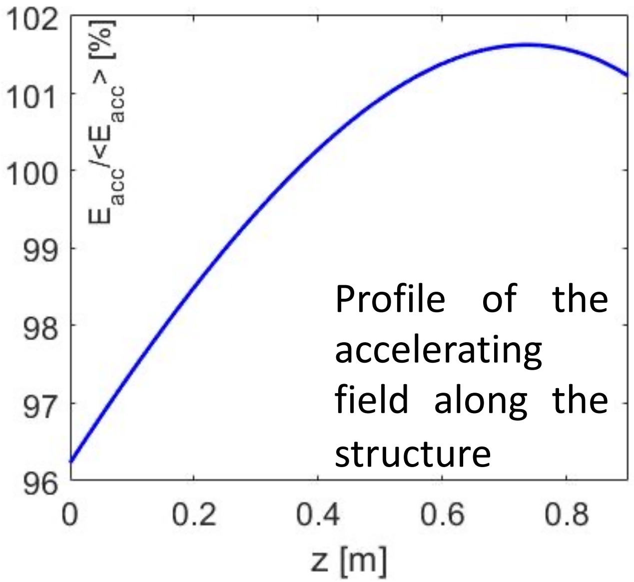
X BAND STRUCTURES: PARAMETERS

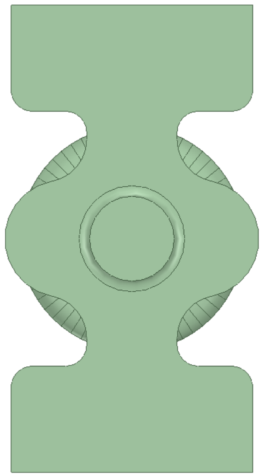
1. **e.m. design**: **linear tapering of the irises**, race track coupler to cancel the quadrupole field components (*PhD M. Diomede*);

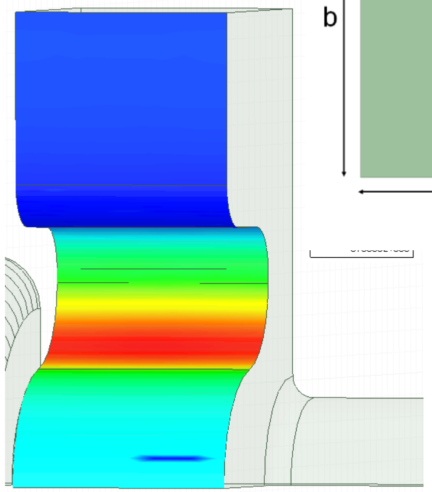
2. **0.9 m long** structures with 3.5 mm average iris radius

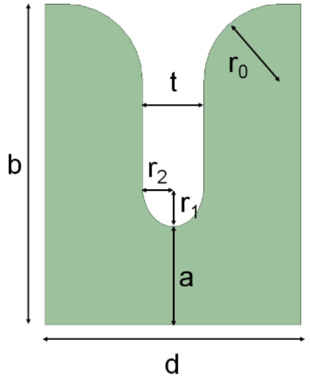
3. **60 MV/m** average accelerating field

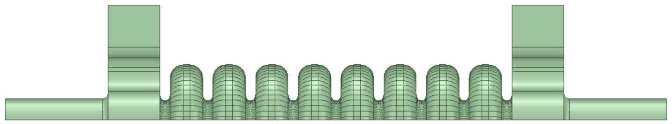
4. **Final full scale structure prototype (March 2023)**.

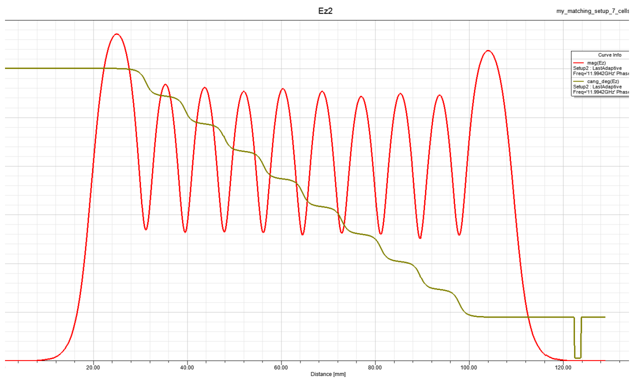












Courtesy M. Diomede

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**

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

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

TEX facility

TEX, AN X-BAND TEST FACILITY AT LNF

6 May 2022 Featured, News

TEX (TEst stand for X-band) is the new infrastructure at LNF, co-funded by the **LATINO** project, devoted to the radiofrequency (RF) in X-band and, in general, to the development of all the technologies and systems related to a particle accelerator.

The X-band (11.994 GHz) is at present the most advanced RF technology, with demonstrated capability of providing accelerating gradients up to 100 MV/m and beyond.
TEX features measurement laboratories, assembly laboratories and a bunker for high power testing to characterize accelerating structures and validate them for the operation on future particle accelerators for medical, industrial and research applications. At this aim, TEX is directly involved in the LNF leading project EuPRAXIA@SPARC_Lab and CLIC at CERN.
The facility is accessible to external users, including national and international laboratories and companies. The open-access to TEX is one of the services offered by INFN to the external community through LATINO, a project approved and funded by the government of "Regione Lazio" aimed at promoting and increasing the technology transfer between research centres of excellence and the surrounding economic framework.

THANKS
for your
attention