14th International workshop on breakdown science and high gradient technology, HG2022
May 16 - 19, 2022

X-band activities at INFN-LNF

Fabio Cardelli

On behalf of the EupraXia and the TEX technical team
(National Institute of Nuclear Physics, INFN-LNF, Frascati, Italy)

Outline

1. **EuPRAXIA@SPARC_LAB project**
    - Introduction
    - Linac Overview
2. **Overview of the X-band LINAC**
    - Power stations
    - RF module layout
    - Accelerating structures design
        - prototyping activity
        - Thermo-mechanical analysis
3. **TEX (Frascati TEst stand for X-band)**
    - Description and main layout
    - Source commissioning and SAT
4. **Conclusions**

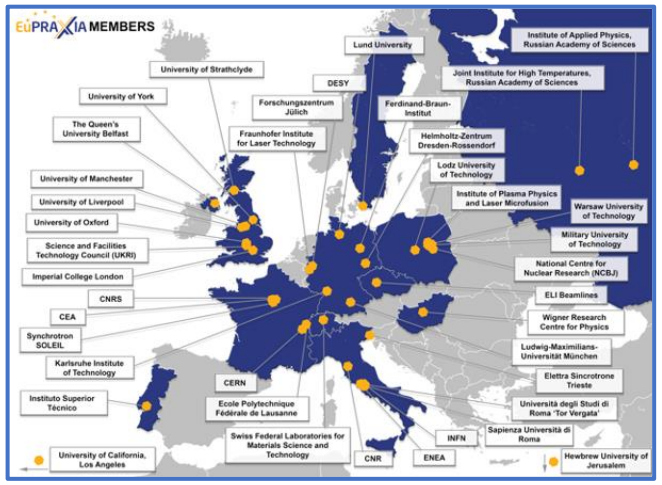
EupraXia@SPARC_LAB Project: Short Introduction

- The project EuPRAXIA@SPARC_LAB aims at constructing a FEL radiation source (λ_{FEL}=4 nm) 1GeV RF X-band Linac with Plasma Acceleration Stage (beam driven plasma acceleration)
- The project is currently in the preparatory phase of the Technical Design Report

TDR

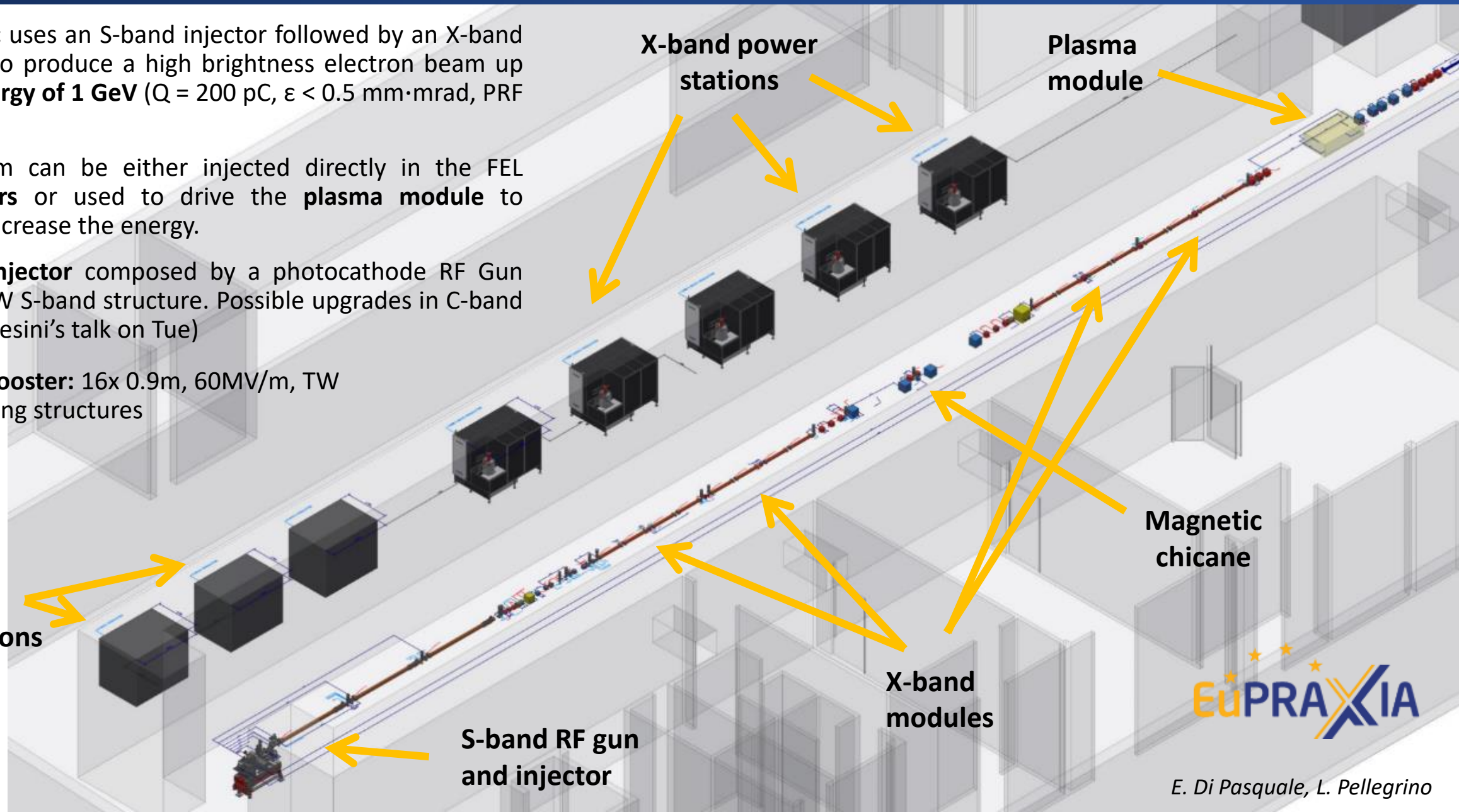
EuPRAXIA

- The project is one of the pillar of the **European Project EUPRAXIA** (coord. R. Assmann, http://www.eupraxia-project.eu/) – European Plasma Research Accelerator with excellence in Applications
- After a long and challenging evaluation process, EuPRAXIA has **been included in the ESFRI 2021 Roadmap**
- A **new building**, now under executive design phase, will host the new Facility at LNF.
- Main R&D Challenges:
  - 1 GeV RF X-band Linac
  - Plasma acceleration Stage



Overview of the LINAC

- The Linac uses an S-band injector followed by an X-band booster to produce a high brightness electron beam up to an **energy of 1 GeV** (Q = 200 pC, ε < 0.5 mm·mrad, PRF = 100Hz).
- The beam can be either injected directly in the FEL **undulators** or used to drive the **plasma module** to further increase the energy.
- **S-band injector** composed by a photocathode RF Gun and 3x TW S-band structure. Possible upgrades in C-band (see D. Alesini's talk on Tue)
- **X-band booster:** 16x 0.9m, 60MV/m, TW accelerating structures



E. Di Pasquale, L. Pellegrino

X-band RF Power Station

The current **X-band power source** is based on the 50MW **CPI VKX8311A** klystron and k400 Scandinova Modulators. **5x X-band RF sources** for the LINAC (4 for the booster and 1 for the RFD).

Two other options are considered:

A. **CPI High efficiency VKX8311HE** klystron, developed in collaboration with CERN.
   - » High efficiency and Gain.
   - » Low modulator peak power requirement.
   - » Increased klystron lifetime.

B. **CANON E37119** which is currently in development and would allow to work at 400Hz (doubling the number of sources).
   - » Low modulator peak power requirement.
   - » Very high repetition rate.
   - » The Linac power sources need to be doubled (8x Source for the booster).

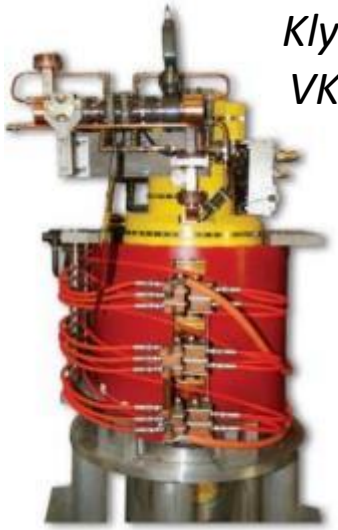
Test station based on the VKX8311A klystron at TEX already commissioned.

The **procurement of a VKX8311HE is already started**.

A **new X-band test station** based on the CANON E37119 klystron powered by a k300 modulator will be installed:

- Two conditioning stations available.
- Comparison and validation of the two sources performances.

Operational Parameters	*Unit*	*VKX8311A*	*VKX8311HE*	*E37119*
RF frequency	GHz	11.994	11.994	11.994
RF Peak Power	MW	50	50	25
Gain	dB	48	51	48
Modulator Peak Power	MW	140	90	90
Operational voltage	kV	430	430	335
Operational current	A	330	204	225
PRF	Hz	100	100	400
Pulse length (top)	us	1.5	1.5	1.5
Efficiency	%	40	60	40



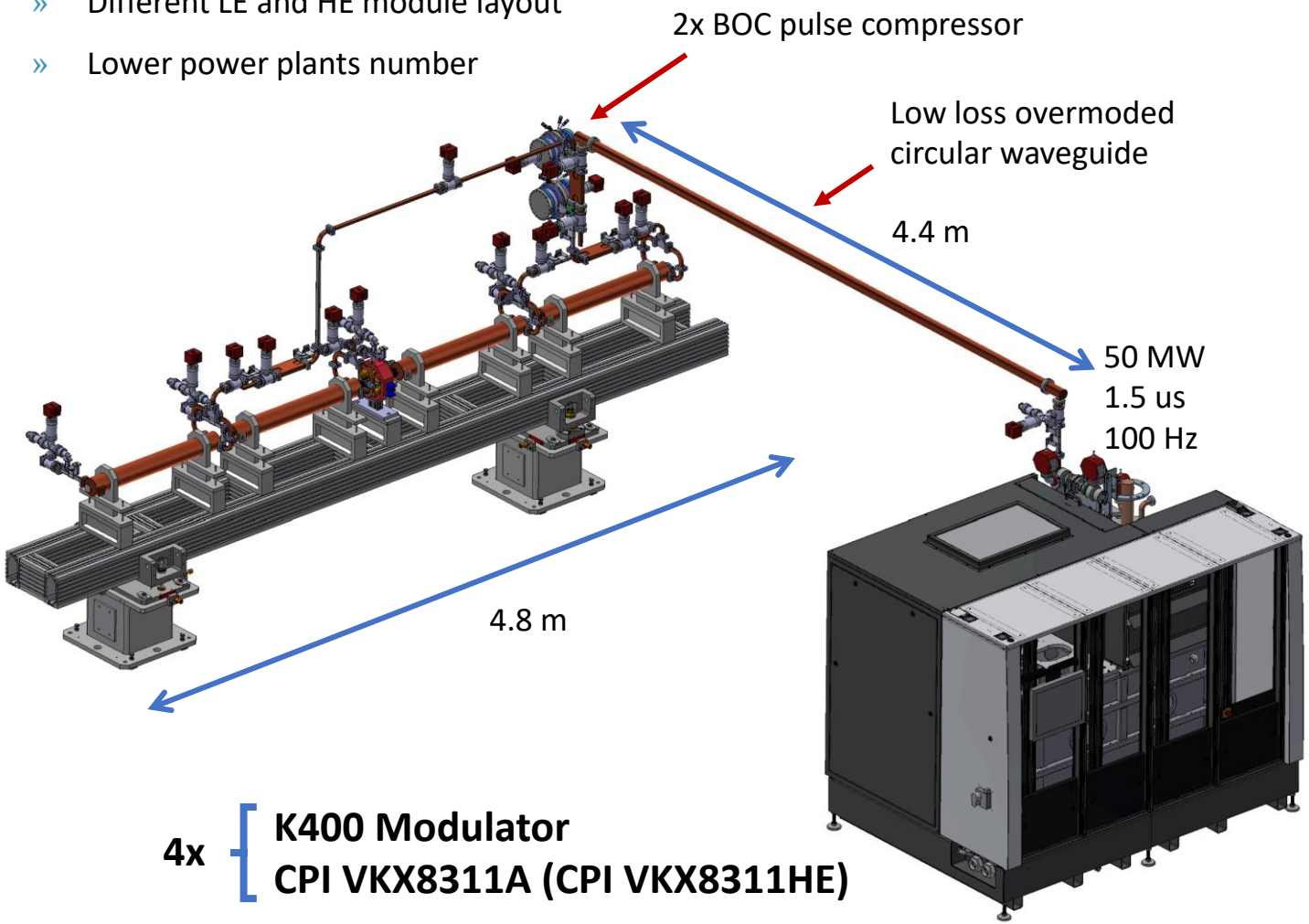
Klystron CPI VKX-8311A

Solid State Modulator Scandinova k400

X-band module layout

Module Option A:

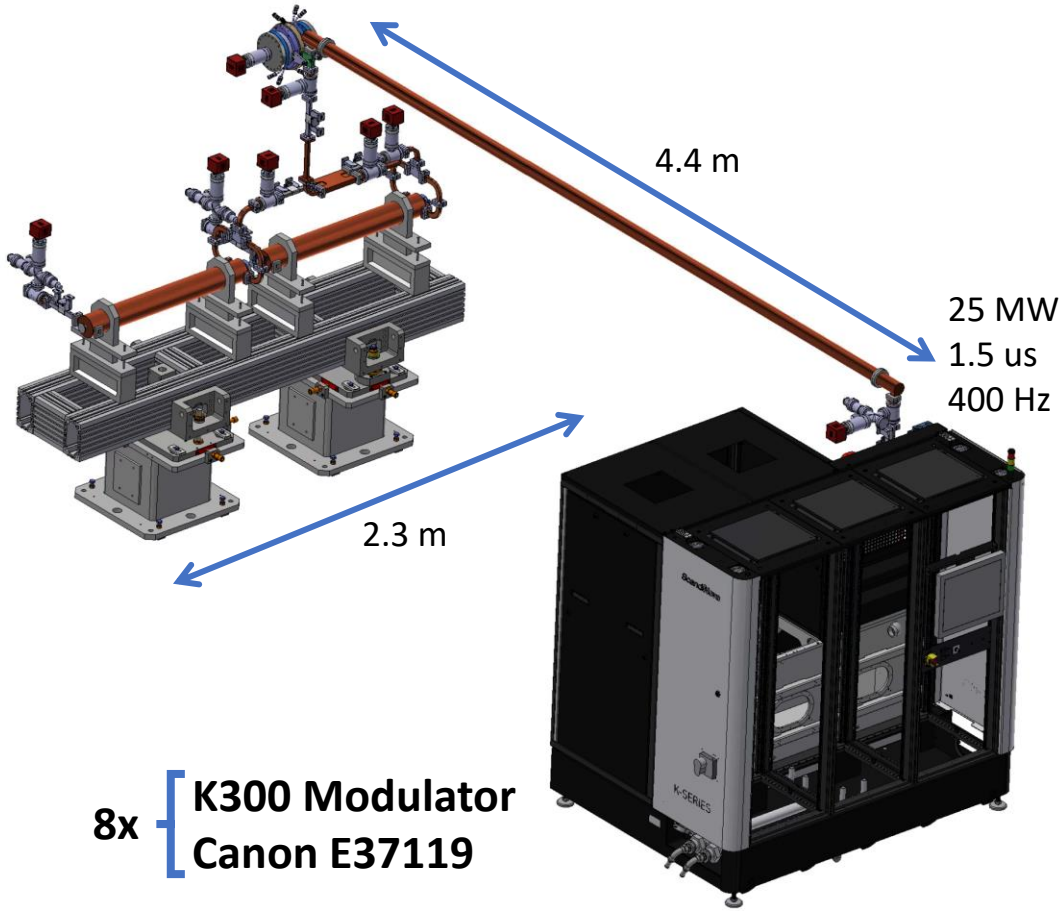
- 2x BOC on one line
- Less flexibility
- Different LE and HE module layout
- Lower power plants number



4x [**K400 Modulator**
CPI VKX8311A (CPI VKX8311HE)

Module Option B:

- Higher flexibility
- Lower Modulator power requirements
- Possible upgrade at high rep. rate of the Linac
- Double the number of the sources



8x [**K300 Modulator**
Canon E37119

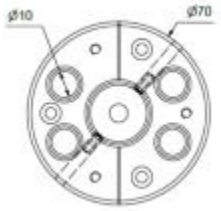
X-band Structure

- The EM design of the structure is completed: 0.9 m long structures with 3.5 mm average iris radius design to work with an average acceleration gradient of 60 MV/m.
- Synergies with other projects like the **I.FAST European project:** XLS/Compact-light accelerating structure (see M. Diomede's talk on Tue).
- **Thermo-mechanical simulations** of the structure have been completed to demonstrate the correct sizing of the cooling system.
- The **mechanical drawing** of the final X band structure is under constant review and is related to the result of the **prototyping activity**: brazing test, cell to cell alignment, etc.
- Three main 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 *(currently ongoing)*
  2. **Few cells-rf prototype for high power text**: 10 cell prototype with input/output coupler to be tested at low and high power *(currently ongoing)*
  3. **Final full scale structure prototype**.

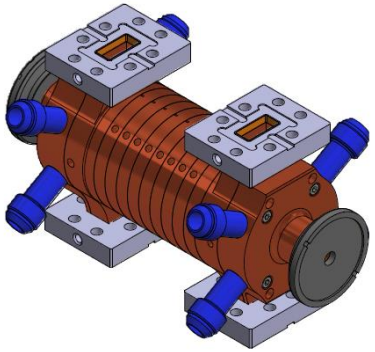
Parameter	Value
Frequency [GHz]	11.994
Average acc. gradient [MV/m]	**60**
Structures per module	**4**
Iris radius a (linear tapering) [mm] <a>=3.5	3.8-3.2
Tapering angle [deg]	0.04
Structure length L_s [m]	**0.9**
No. of cells	**108**
Shunt impedance R [MΩ/m]	94-107
Average dissipated power [kW]	1
Filling time [ns]	126
Effective shunt Imp. R_s [MΩ/m]	350
Peak Mod. Poynting Vector [W/μm^2]	3.5
RF pulse [μs]	**1.5**
Rep. Rate [Hz]	**100**

PhD Thesis M. Diomede

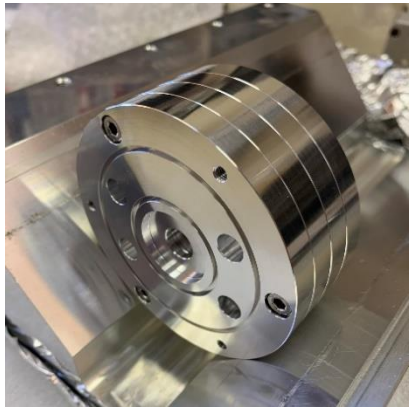
Single cell design



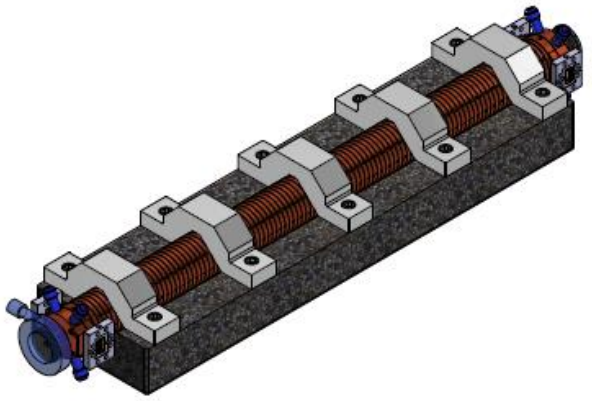
10 cells prototype



Cell to cell alignement tests



Copper cells for brazing tests



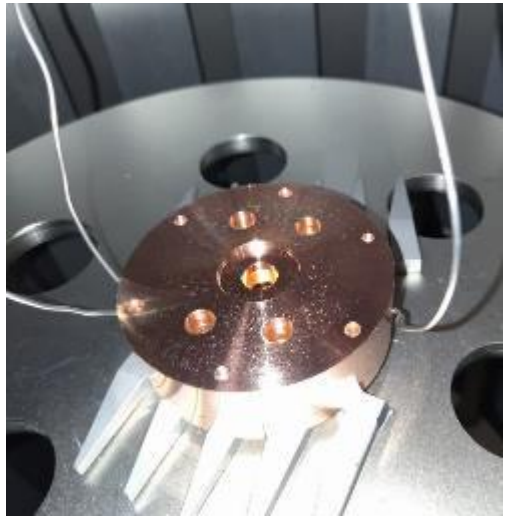
Courtesy of D. Alesini, V. Lollo, R. Di Raddo

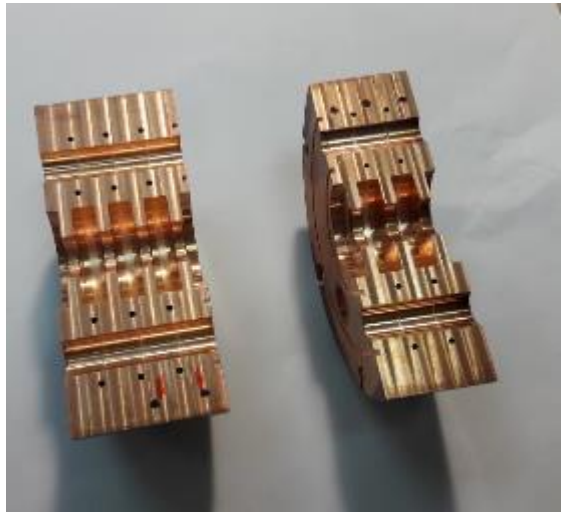
X-band Structure Prototyping Activities

- **New vacuum furnace** model (TAV TUVH 40-130) commissioned at INFN-LNF in the framework of the LATINO Project, that allows for in-house brazing of components.

Parameter	Unit	Value
Height	mm	1300
Diameter	mm	400
Max Temperature	°C	1200
Uniformity (@>700°C)	°C	±5

- Several 3-cells prototypes have been realized to optimize the brazing procedure.
- 0.9 m prototype made up of 3x three-cells module to test the brazing uniformity on the entire structure.
- All these activities also make it possible to train the technical staff in the use of the furnace and brazing.

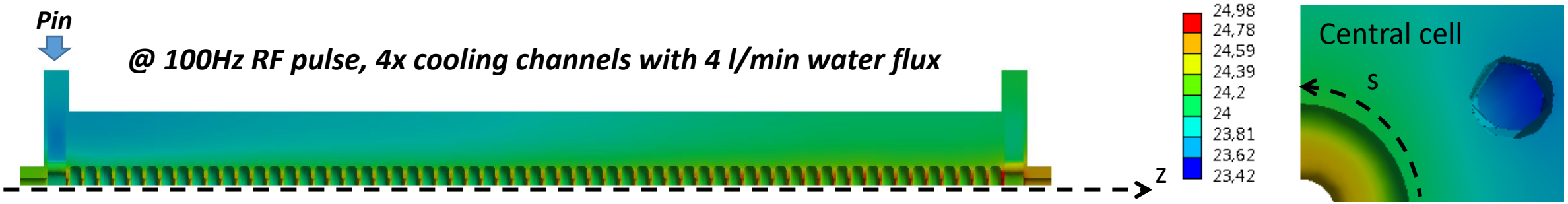


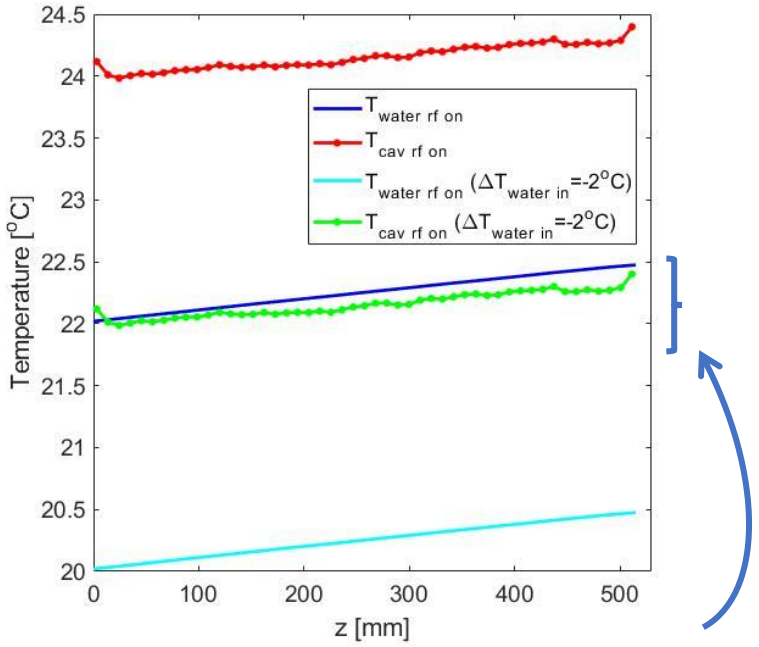


Courtesy of D. Alesini, A. Liedl, V. Lollo and R. Di Raddo

Thermo-Mechanical Analysis

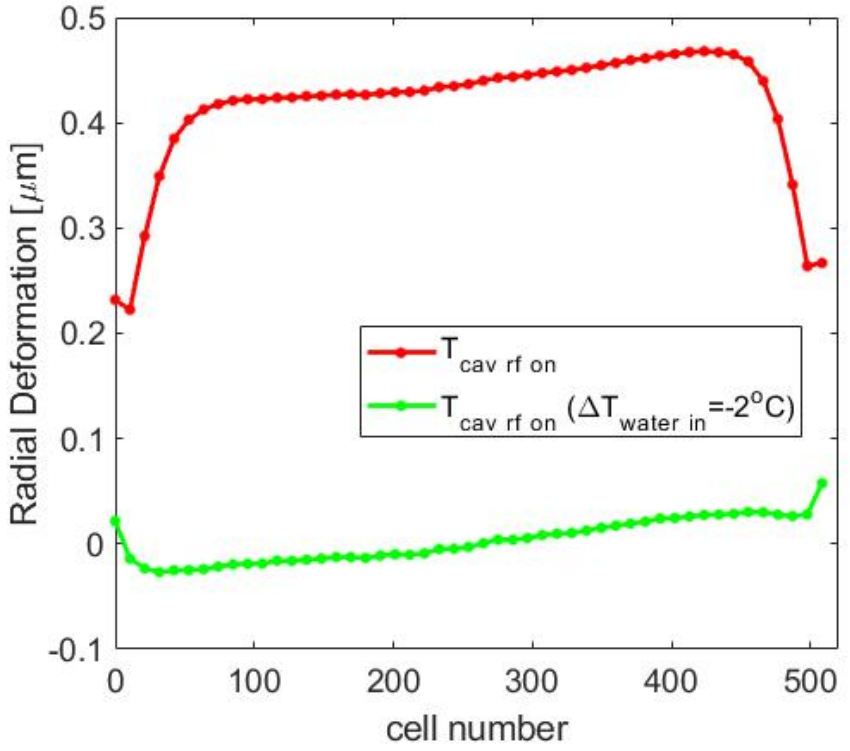
» The cavity temperature increase, and consequent deformation, has been evaluated by Ansys HFSS simulations with full RF input power

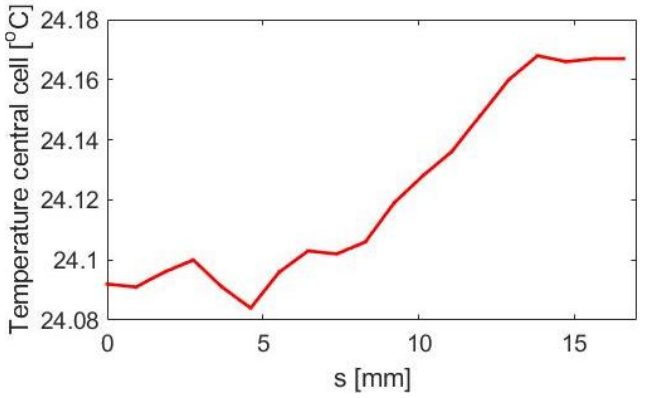


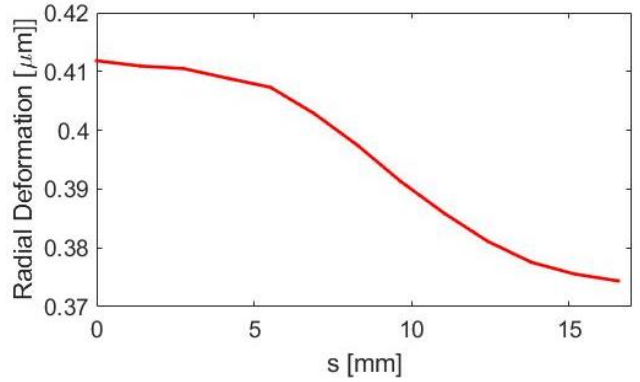


Analytical Calculation on 60 CELLS

ΔT_{diss_water}=0.475 °C







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. TEX is located in bld. 7 of LNF, which is being fully refurbished and upgraded to host the RF source and bunker.
- 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.
- Not only a facility for accelerator structures but also R&D for: high power tests on RF components, LLRF systems, Beam Diagnostics, Vacuum and Control System

Control room and Rack room

Concrete Bunker and Modulator Cage with the RF Source

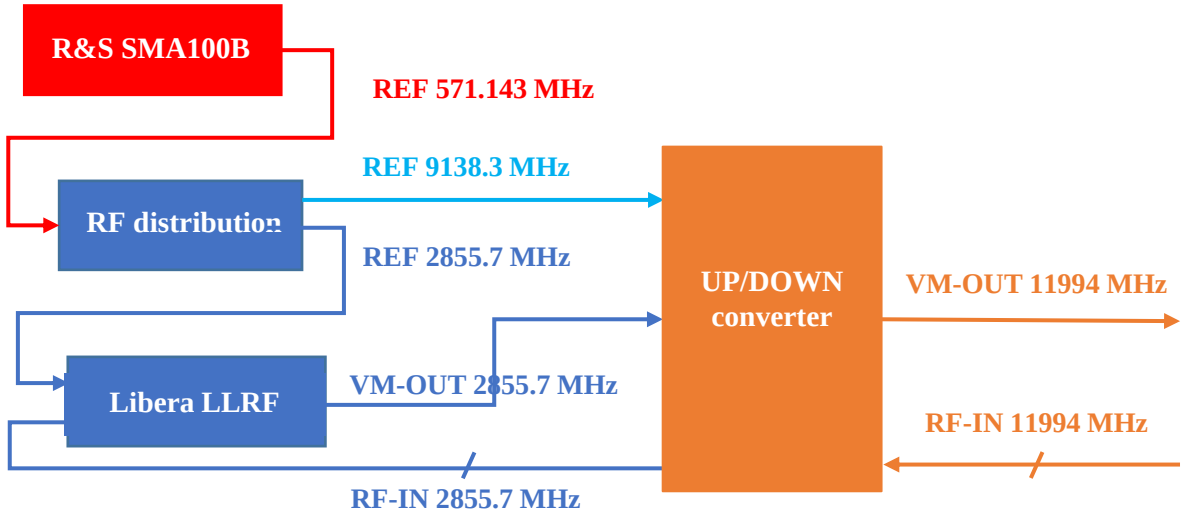


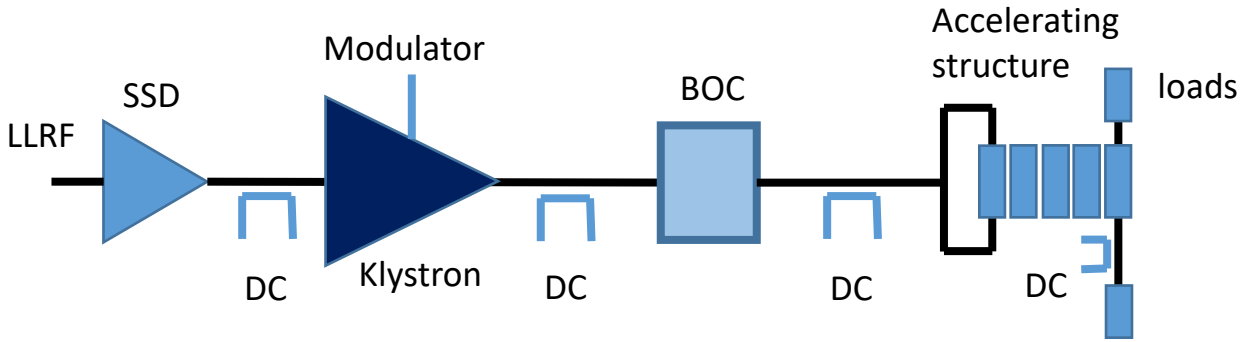


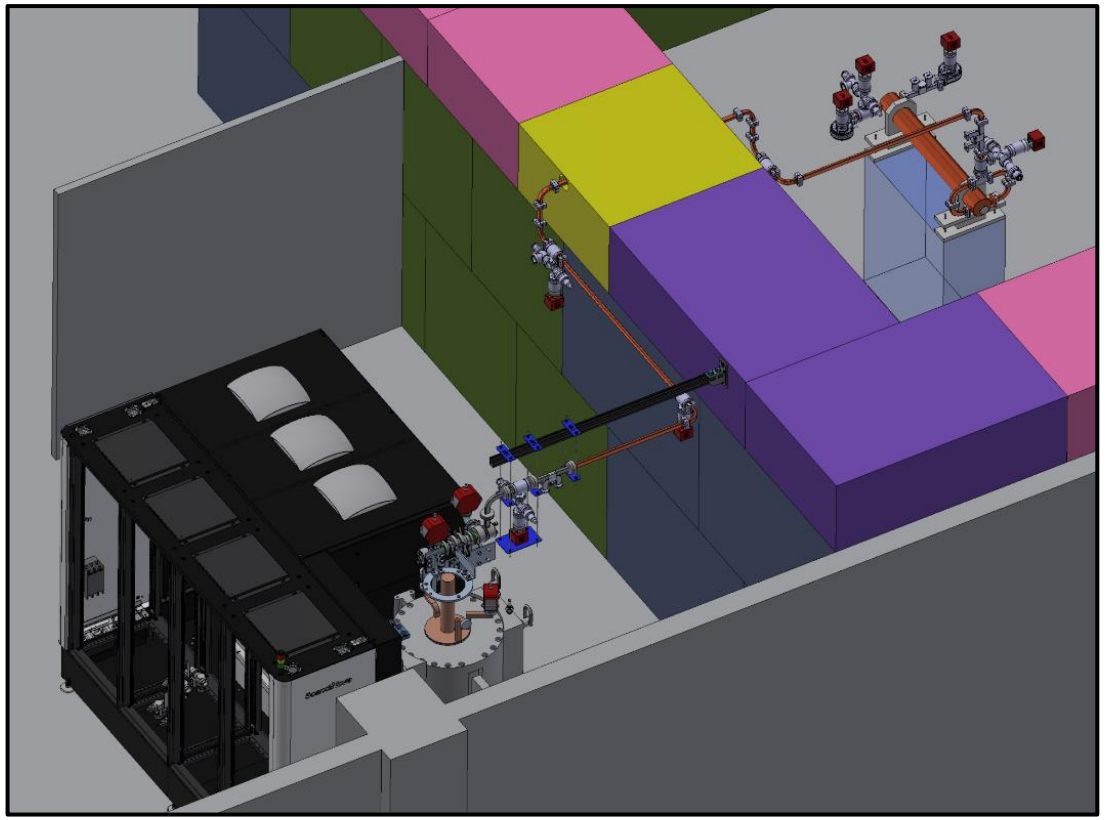



TEX facility – Layout

- 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 INFN-LNF.



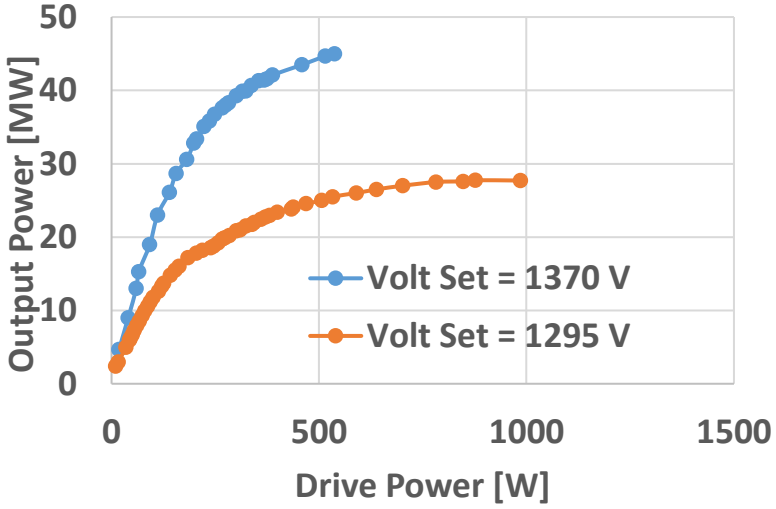




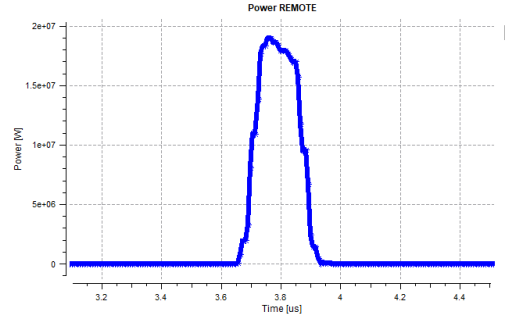
- In a second phase it will integrate also an X-band BOC pulse compressor.

SAT and commissioning of the X-band Source

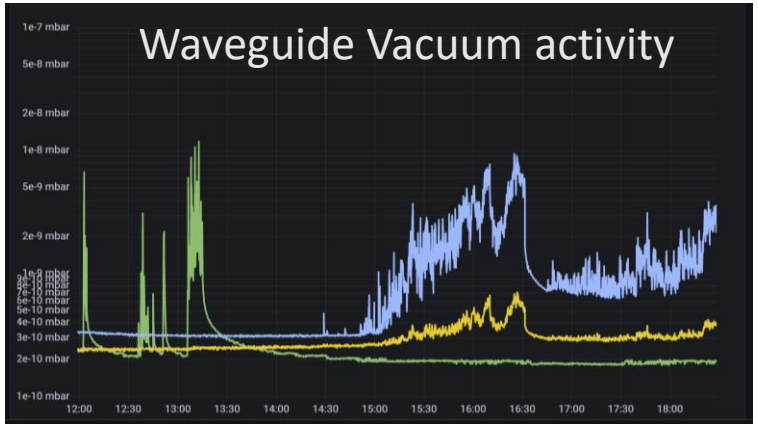
- The civil engineering works in the building has been concluded by the end of August 2021.
- LLRF system, EPICS control system have been commissioned.
- The SAT of the source with Scandinova has been completed reaching the design parameters (427 kV, 328 A):
  - Pulse Flatness tuning (<1.5%).
  - Pulse to pulse amplitude stability measurement (13 ppm).
- **Automatic conditioning** routine based on the algorithm developed at CERN and integrated in the EPICS control system



- During the SAT we perform some RF conditioning of the waveguide system reaching a RF peak output power of nearly 48 MW (150 ns pulse length, 50 Hz).

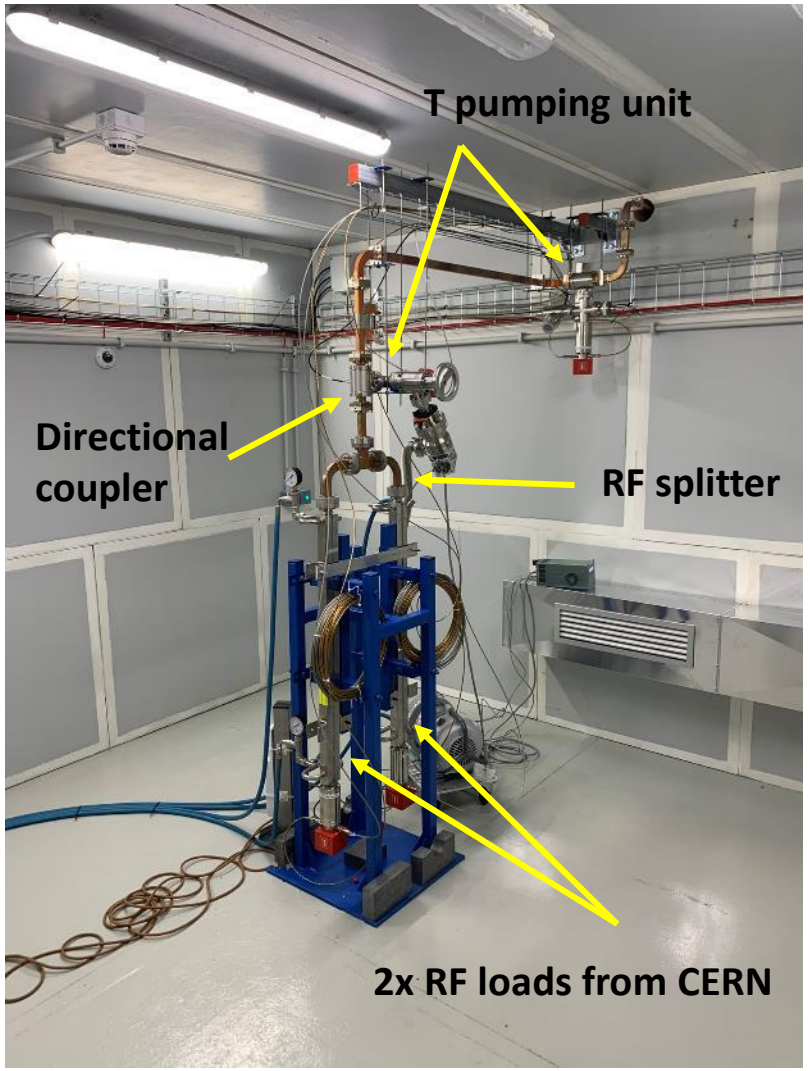


- The complete **waveguide network** up to inside the bunker has been procured and installed (terminated on two RF loads).
- We are working on the procurement of all the RF X-band elements for the EUPRAXIA@SPARC_LAB project: Spiral Loads (3t am), Mode converter (SLAC), BOC (PSI of INFN), etc.
- The design of the girder and of the beam diagnostics for the structure conditioning has to be completed.
- We are waiting for radioprotection authority permissions. Then the source will be available for accelerating structures conditioning and tests.



Current TEX waveguide layout

» The mechanical support and the waveguide system up to the position of the accelerating structure inside the bunker have been installed.



Conclusions

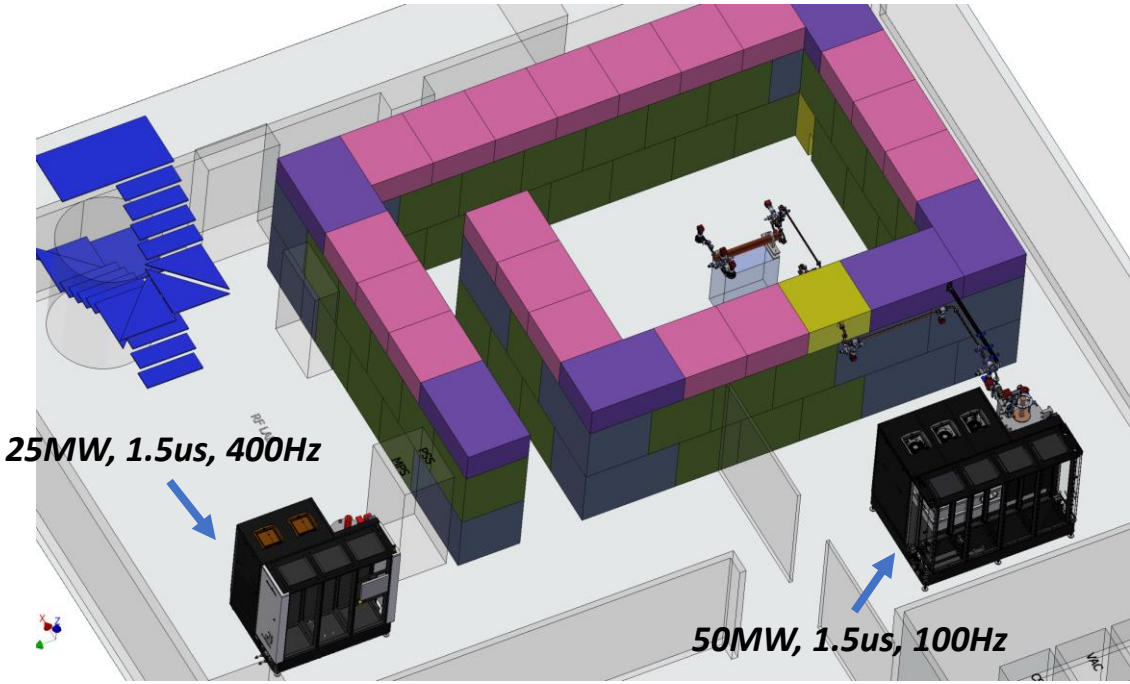
- **EuPRAXIA@SPARC_LAB** is the next INFN-LNF project: FEL radiation source based on RF linear accelerator (X-band) combined with a plasma module. It is one pillar of the Eu project EUPRAXIA, that has **been included in the ESFRI 2021 Roadmap**

- **X-band source and module**: The basic layout is based on the CPI VKX8311A Klystron, but other solution are investigated. Two different X-band sources based on different klystrons will be compared. The procurement of a high efficiency CPI klystron (VKX8311HE) has been started. We are completing the technical specifications for a completely new RF source to integrate in the TEX facility based on a 25MW high rep. rate Canon Klystron.

- **X-band structures**: EM design defined (including vacuum, dark current), the thermo-mechanical analysis demonstrate the efficiency of the cooling system. An intensive prototyping activity is ongoing exploiting the new vacuum furnace at LNF. The mechanical prototype and the few cell RF prototype will be ready by Autumn 2022.

- **TEX (Frascati Test stand for X-band)**: extremely important facility to test all RF components and X band prototypes at the nominal power/gradient. It has been commissioned performing the Source SAT. We procure all the element and the subsystem for the operation. We are waiting for radioprotection authority permissions in order to start the accelerating structures tests.

TEX Facility Upgrade



THANK YOU FOR YOUR ATTENTION