# High Power RF Sources and TEX R&D

06/06/2022

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*On behalf of WA LINAC, WA RF Sources and TEX technical team*

# Comments from last review

An intensive R&D work is still necessary for several key components of the accelerator modules (Structures, waveguide components, BOC).

- CPI HE tube: tender near to sign phase
- Canon station: feasibility study for integration at TEX and technical specification defined. Waiting founds to start tender.
- Structures: intense prototyping activities ongoing.
- RF devices and WG component: survey with institutes and companies performed, in house R&D on-going. Procurement for some of them started for TEX.

In this context, the completion of the TEX Facility (TEst-stand for X-band) is essential, and the RC welcomes the significant progress and the upcoming availability of the test facility.

- RF Source, LLRF, vacuum and control systems commissioned.
- Basic layout completed. Pending final permissions from authorities.

Of particular importance for the operation of the facility will be the jitter in phase and amplitude of the RF stations. Pulse to pulse stability studies will have to be integrated early on in the TEX program.

- Fellow position open on this topic.

General comment: war and pandemic circumstances impact costs and delivery time.

# 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).

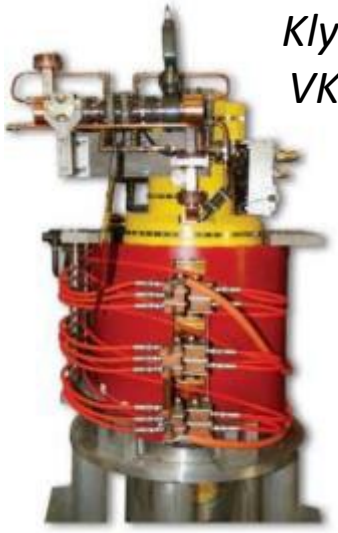
Test station based on the VKX8311A klystron at TEX already commissioned.

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 |



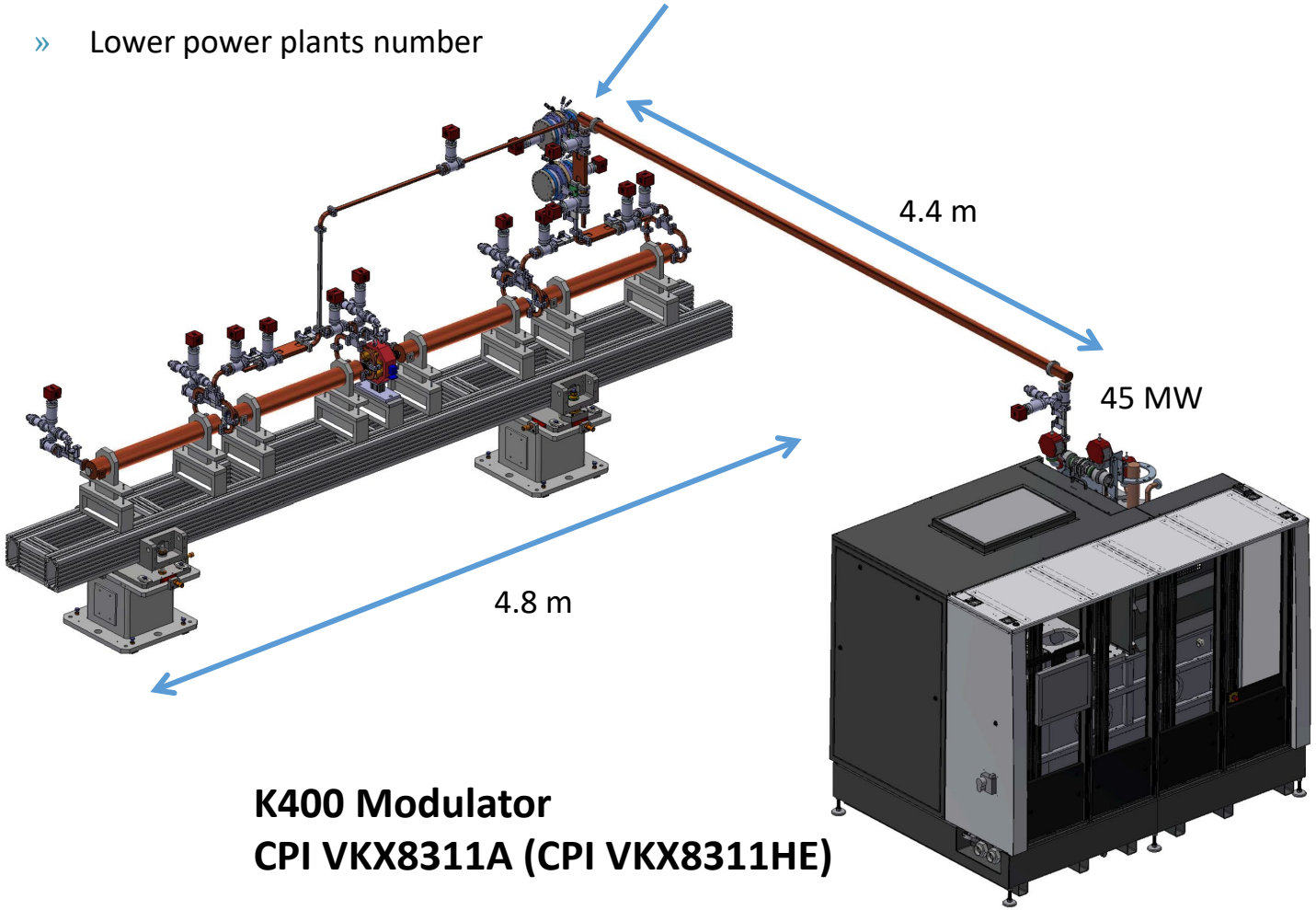
*Klystron CPI VKX-8311A*

*Solid State Modulator Scandinova k400*

# X-band module layout

## Module Option A:

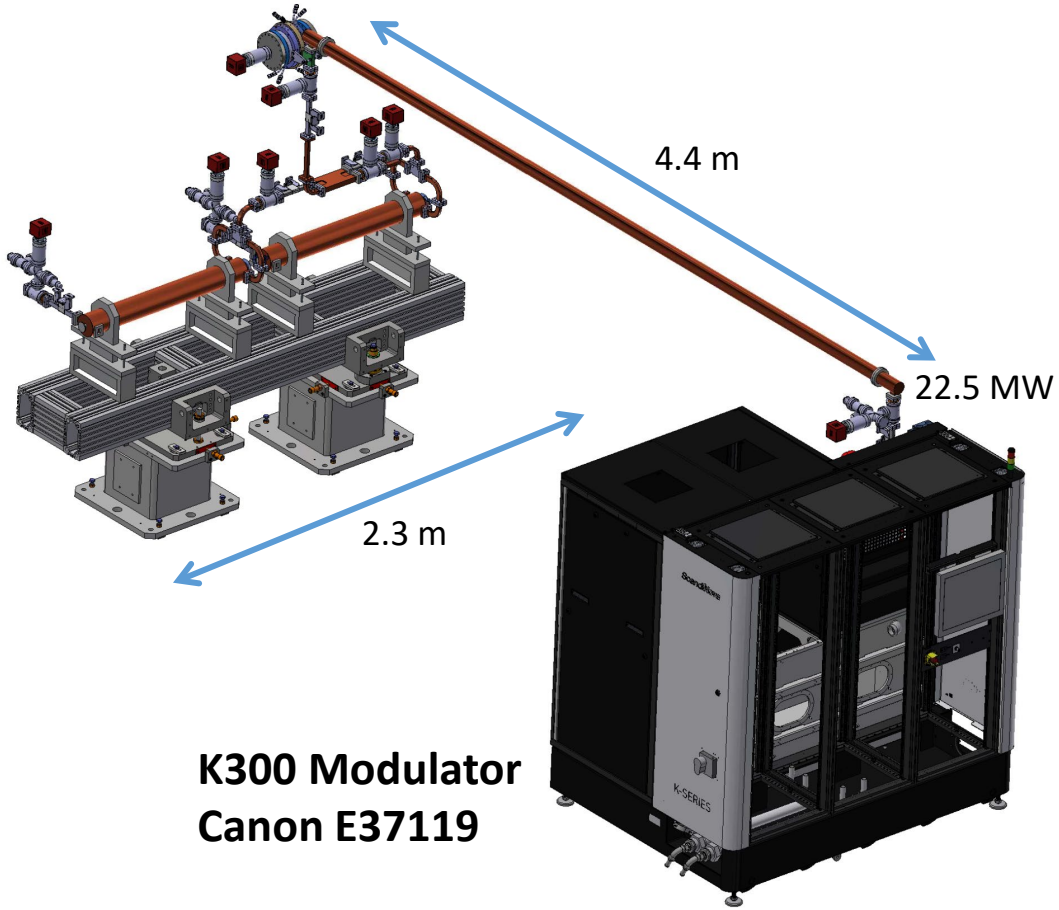
- 2x BOC on one line
- Less flexibility
- Different LE and HE module layout
- Lower power plants number




**K400 Modulator**
**CPI VKX8311A (CPI VKX8311HE)**

## Module Option B:

- 1x BOC on one line
- Higher flexibility
- Lower Modulator power requirements
- Possible upgrade at high rep. rate of the Linac



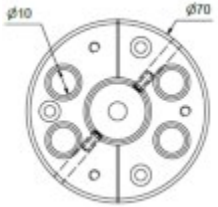

**K300 Modulator**
**Canon E37119**

# X-band Structure

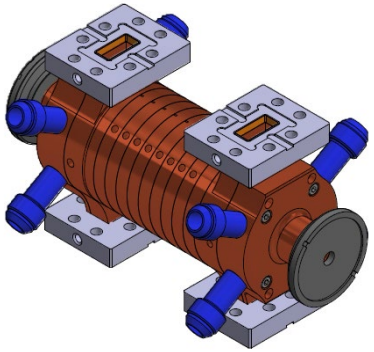
- The EM design of the structure is completed: 0.9 m long structures with 3.5 mm average iris radius design to work with an average acceleration gradient of 60 MV/m.
- Synergies with other projects like the **I.FAST European project:** XLS/Compact-light structure realization coordinated by G. D'Auria.
- Thermo-mechanical simulations of the structure have been completed.
- 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/μm²] | 3.5 |
| RF pulse [μs] | 1.5 |
| Rep. Rate [Hz] | 100 |

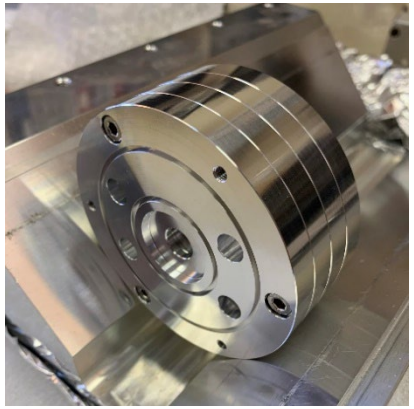
*Single cell design*



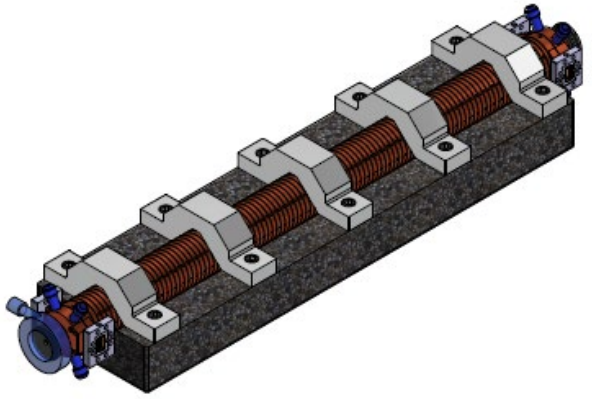

*10 cells prototype*



*Cell to cell alignement tests*



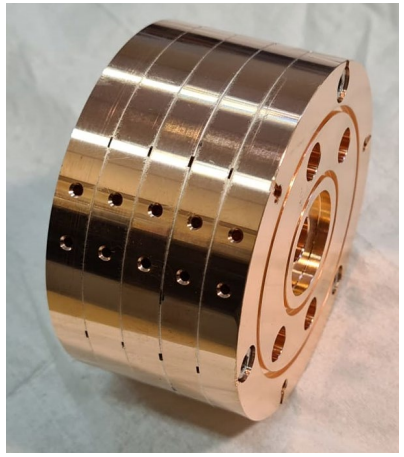
*Copper cells for brazing tests*

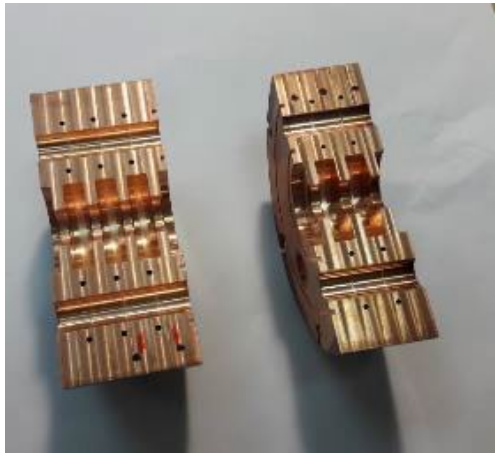


# X-band Structure Prototyping Activities

- 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 |

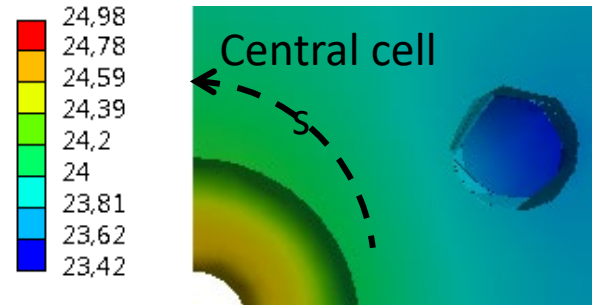


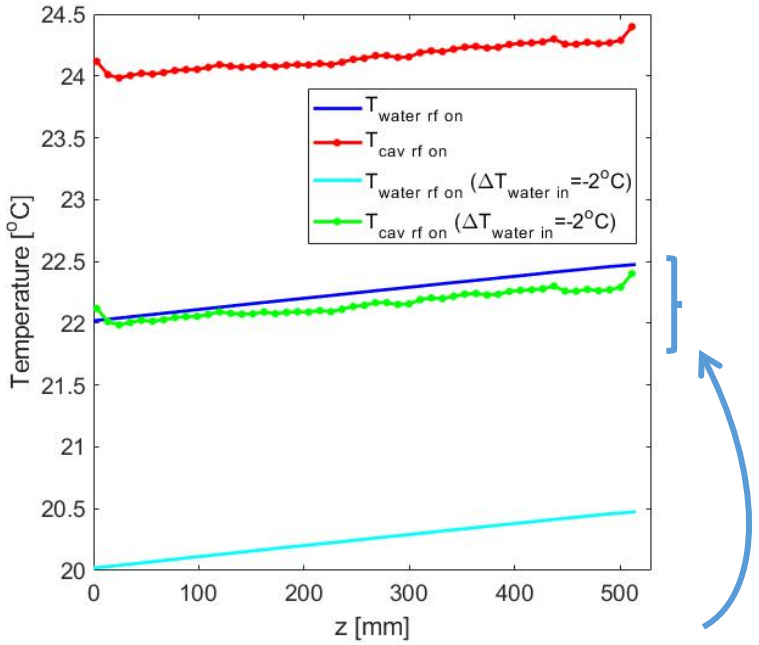


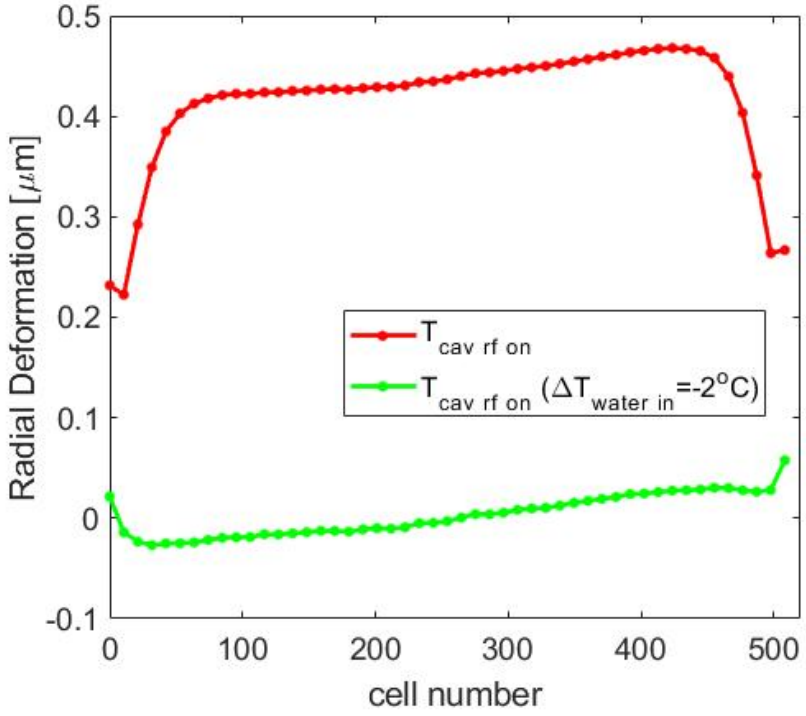
- Several 3/6-cells prototypes have been realized to optimize the brazing procedure
- 0.9 m prototype
- All these activities also make it possible to train the technical staff in the use of the furnace and brazing
- Mechanical prototype ready by October 22
- RF prototype by January 2023

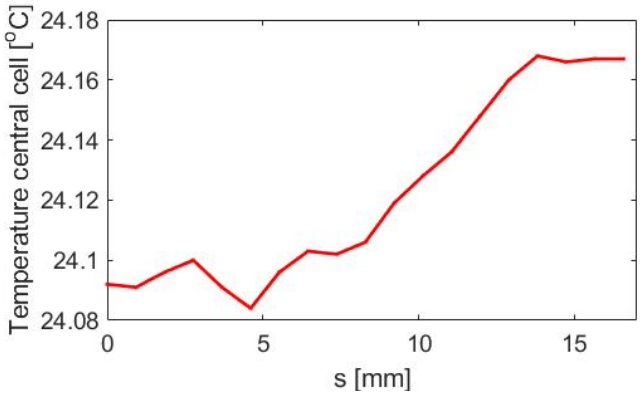
# Thermo-Mechanical Analysis

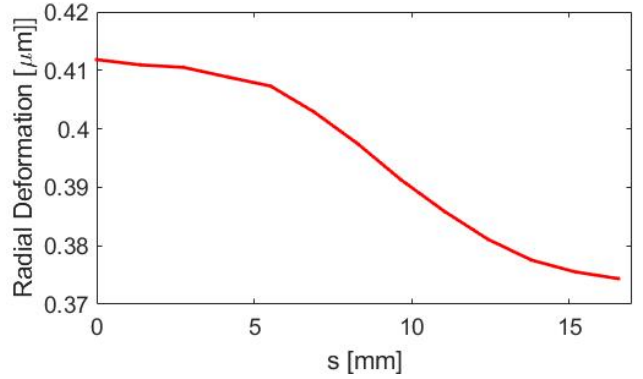
» The cavity temperature increase and consequent deformation has been evaluated by Ansys HFSS simulations with full RF input power: both the 100 Hz and the 400 Hz operation have been simulated and the current cooling design is compatible also with this last operation mode (CANON klystron)


***Analytical Calculation on 60 CELLS***

$\Delta T_{diss\ water}$=0.475 °C

# TEX facility – TEst stand for X-band at Frascati

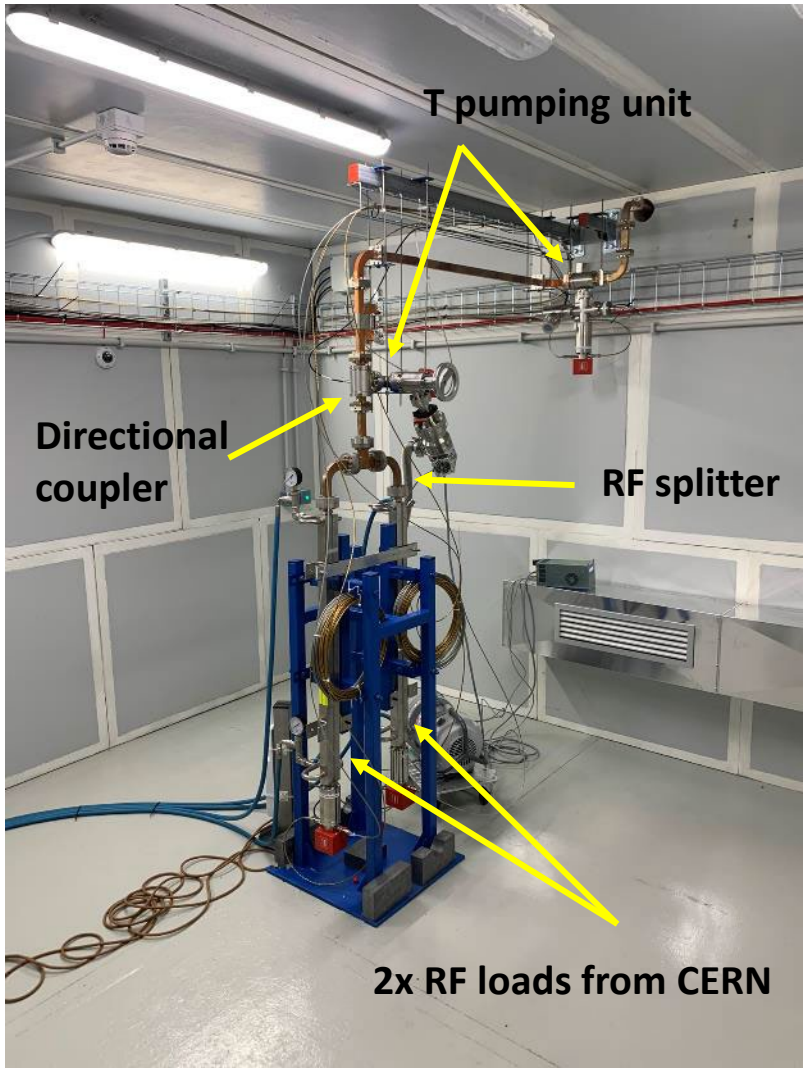
- The ***TEst-stand for X-band*** (**TEX**) is a facility conceived for R&D on high gradient X-band accelerating structures and waveguide components in view of Eupraxia@SPARC_LAB project. TEX is located in bld. 7 of LNF, which is being fully refurbished and upgraded to host the RF source and bunker.
- 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***

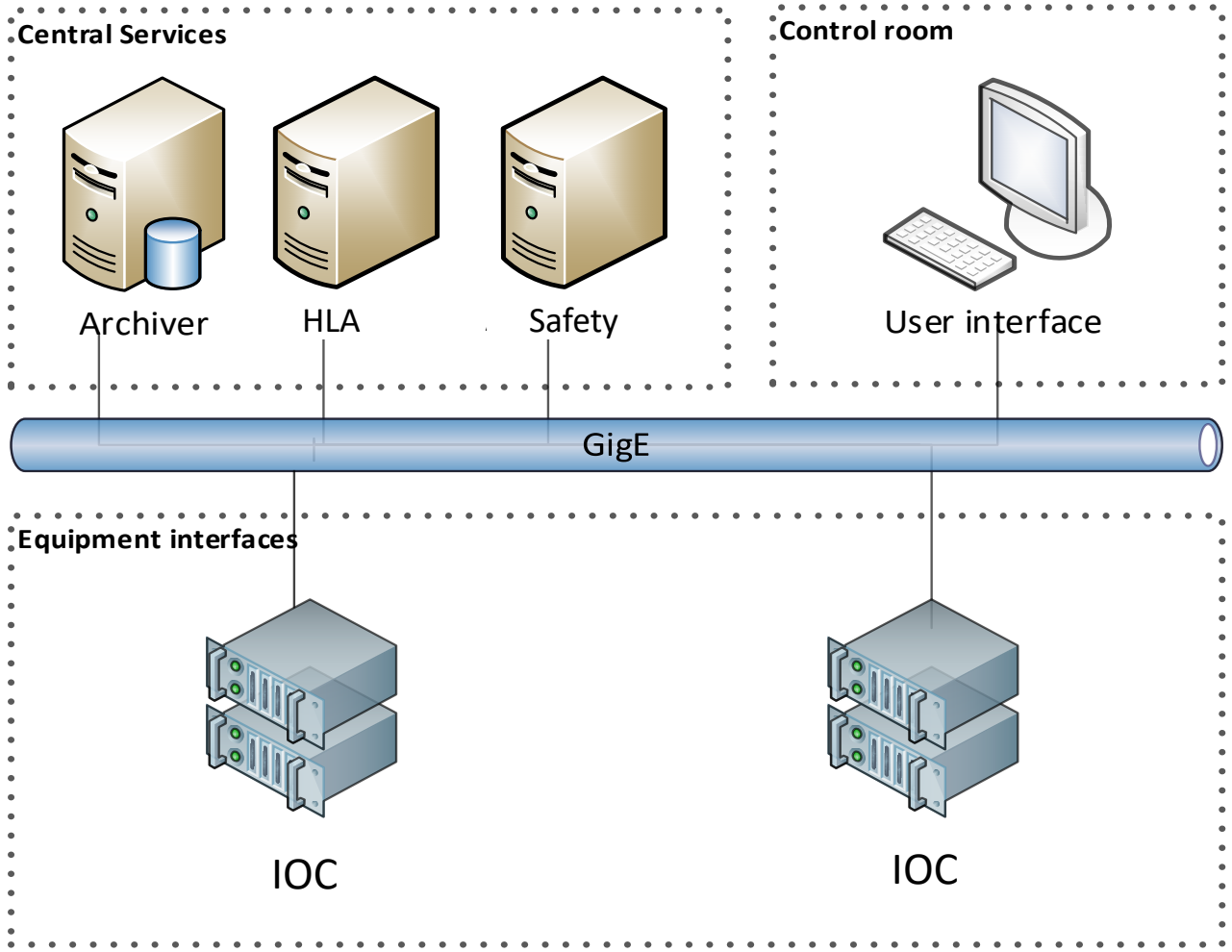
***Concrete Bunker and Modulator Cage with the RF Source***

# 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.

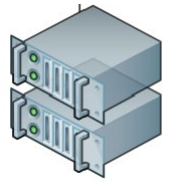
# TEX Control System




**Standardized field-proven controls framework:**

- ✓ **Scalability**
- ✓ **Performance**
- ✓ **Maintainability**
- ✓ **Reliability**
- ✓ **Usability**
- ✓ **Longevity**

# TEX Control System – Resource Tier



| Device Families | |
|---|---|
| RF Modulator | Fluid Plant |
| LLRF | Faraday Cups |
| RF Driver Amplifier | Motors |
| Vacuum Gauges | Camera |
| Vacuum Ion-Pumps | Magnets |
| Timing System | Machine Protection System |
| RTD sensors | Personnel Safety System |
| Chiller | |

**12 Families integrated and 3 Families under testing.**
**Strong collaboration with ScandiNova, Instrumentation Technologies and Agilent.**

# TEX Control System – Services Tier

| Functional Safety | Archiver | Autonomous Operation | High Level Application and Tools | Asset Management |
|---|---|---|---|---|

**Personnel Safety (PSS) and Machine Protection (MPS) Systems**

Safety life-cycle assessment based on statistical methods allow the estimation of the mean time between failure (MTBF), system reliability and availability and compliance with:

- IEC-61508 standard on “Functional Safety”
- NCRP reports 88 on “Radiation Alarms and Access Control Systems”
- ANSI reports 43.1 on “Radiation Safety for the Design and Operation of Particle Accelerator”

Systems capabilities:

- Real-Time intervention (with rep. rate up to 10 kHz)
- Dual Modular Redundancy
- Scalable and distributed design
- Fail-safe and fool-proof design

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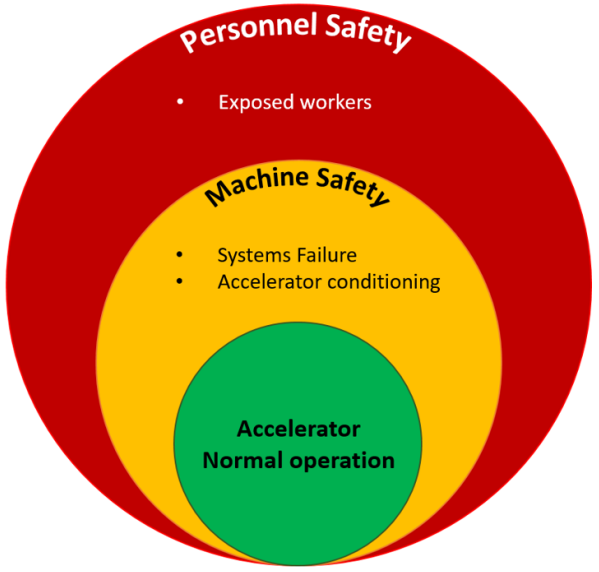
SINGULARITY



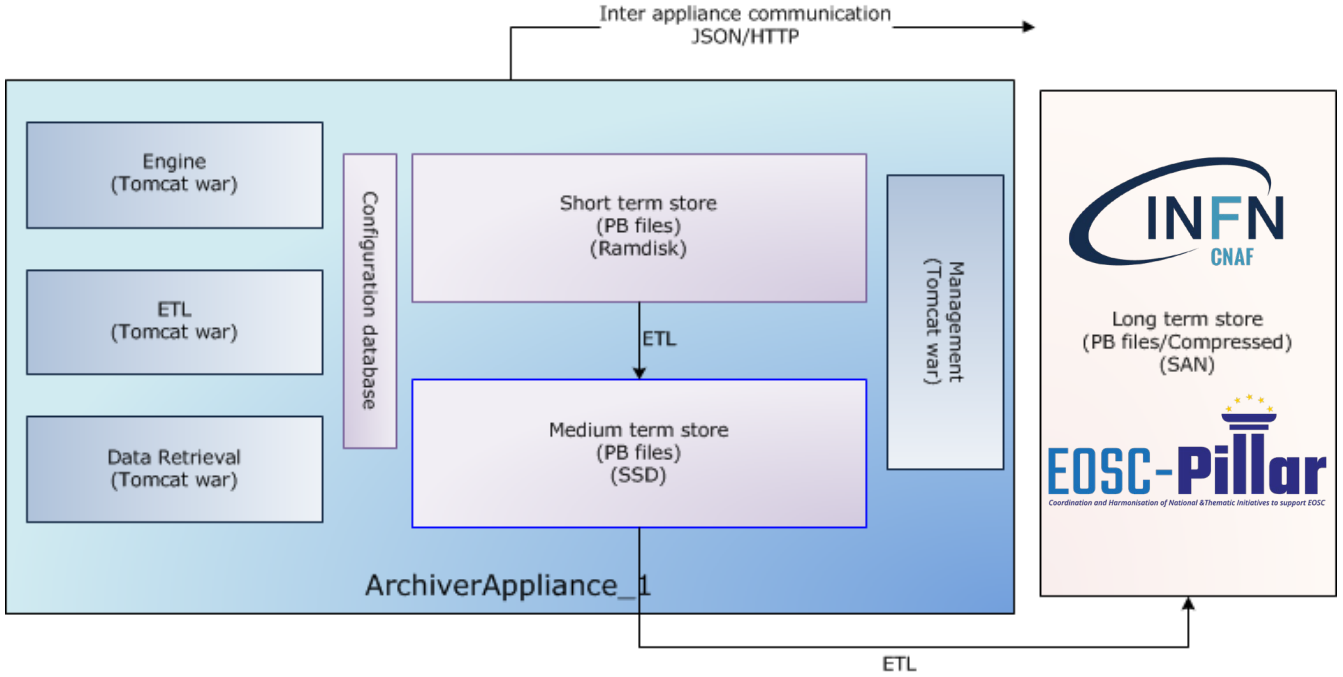

Risk assessment and reduction

- IEC-61508
- ANSI report N43.1
- NCRP report N88

# TEX Control System – Services Tier

| Functional Safety | **Archiver** | Autonomous Operation | High Level Application and Tools | Asset Management |
|---|---|---|---|---|

**EPICS Archiver Appliance** SLAC




**ESFRI Roadmap requirements for EUPRAXIA_PP:**

- Data management plans shaped to **maximize data and scientific software reuse** across scientific domains and across institutional boundaries
- Store only absolutely necessary primary data, use online analysis for data reduction and derived data generation: **Stored data must make experiment and simulation reproducible**
- Long-term, **F.A.I.R.-compliant data object storage, work together with EOSC projects**. International best practices for data and metadata standards (ISO), in line with other European RI's.

# TEX Control System – Services Tier

| Functional Safety | Archiver | Autonomous Operation | High Level Application and Tools | Asset Management |
|---|---|---|---|---|

**Automatic conditioning routine**

Main capabilities:

- Increase the RF feedback set level following a sigmoid curve.
- Detect generic modulator ilks.
- Handle BD events from:
  - Modulator RF Digitizer
  - LLRF
  - vacuum gauges
  - ML-based vacuum anomaly detection
  - ML-based BD real-time detection from RF signals
- Handle mean vacuum level rising trends
- After a breakdown, it makes a step down, decreasing the power and turns on RF after vacuum restoring.
- Identify and handle clusters of BDs.

**HLA and CS Tools**

- Modulator data analysis
- LLRF signal analysis
- Diagnostic instruments post-processing
- Alarm handling
- Post-mortem

SINGULARITY

# TEX Control System – Services Tier

| Functional Safety | Archiver | Autonomous Operation | High Level Application and Tools | Asset Management |
|---|---|---|---|---|

**GEMINI - Generate Experimental Machine Interface Naming Items**

Asset Management tool for LINAC:

- Track device history and changes
- Web-based interface
- Store configuration data
- Provide device information:
  - Machine schematic (equipment name, description, module, …)
  - Cabling (routing, destination, plug, …)
  - Documentation (certification, warranty, manual)
  - EPICS IOC parameters
- Handle UUID device identification
- Fast db query from operation team (QR-code on each device)
- Manage user permissions (create, edit, visualize)

INFN LNL
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

# TEX Control System – Presentation Tier

- Engineering consoles: LabView
- Archive Viewer: Grafana
- Archiver Data Retrieval: web-based
- Logbook: ELog
- Reference Manual: Confluence
- Alarm Notification: Telegram

# TEX Control System

*Strengths:*

- A lot of hardware integrated in EPICS from native or open-access sources (other INFN projects, PSI, STFC, ESS, SLAC, BNL repositories) as suggested in ESFRI roadmap.
- Share software with other research-infrastructure allow better device integration and sw troubleshooting.
- Device integration and user-friendly interfaces developed with sub-systems experts and operators.
- EPICS framework with EOSC compliant data policy empower the interaction bewtween TEX facility and users.

*Weaknesses*:

- *Lack of manpower*

*Opportunities*:

- Easily scalable infrastrcuture and methodology (on going integration of services and EPICS IOCs for SPARC_LAB and DAFNE LINAC sub-systems).
- Avoid full-integration of Resource Tier in out-sourcing (tipically 10-15% of facility budget) with limited knowledge transfer to customer.

*Threats:*

- Involve state-of-the-art framework and reuse open-access software, allow to focus CS group effort on high level software, feedback, algorithms. CS expert for such applications should be young IT/Automation profiles to be found and trained in time.