ASTERIX (Accelerating STructures made of multiplE sectoRs In X-Band)

Responsabile Nazionale (L. Faillace, LNF), Resp. Locale LNS (Giuseppe Torrisi

3 anni (2025-2027)

Units: LNF, LNS, Roma1

- Dedicated PhD student from China
- External Collaborators: V. Dolgashev (SLAC), Tetsuo Abe (KEK)
- Letter for machine time from TEX facility at LNF

Esperimenti in CSN5 correlati:
MICRON (2022-2024)
DEMETRA (LNF/LNS)
ARYA (2020-2023)

Obiettivi generali

The ***Accelerating gradient*** is the key parameter
for the design, construction and cost of future linear accelerators

Linacs must be **reliable** and **cost-effective**

- Intense and systematic research (SLAC/INFN/KEK/CERN/Tsinghua Uni) on high-gradient accelerating RF structures started with the investment for the construction of normal-conducting linear colliders, new generation X-FELs, etc.

- In order to be feasible the design of linear colliders posed a minimum value on the accelerating gradient → **100 MV/m**.

Obiettivi generali

- Framework of a continuous more-than-two-decade-long collaboration on the study of RF structures with increasing accelerating gradients and the RF breakdown physics: SLAC (USA), INFN-LNF and KEK (Japan)
- Study of various geometries, materials, surface processing techniques and technological developments of **advanced accelerating structures working in X-band** (11 – 12 GHz):
  1. This research is strongly required by a demand for ever more ***advanced*** **accelerating structures**, with **accelerating gradients well-above 100 MV/m**, since higher efficiency and robust manufacturing play a major role for the next generation of linear particle accelerators for research;
  2. These structures are made of hard copper and **hard copper alloys** → better high-gradient performance;
  3. Different geometries, e.g. **"open-type" structures** (two halves, four quadrants, etc.)
  4. Alternative **"braze-free" joining techniques**, e.g. EBW and TIG welding.

Applications: existing and new-generation X-FELs, such as EuPRAXIA@SPARC_LAB [17]), industrial, and medical applications.

Obiettivi generali

The main goal of this experiment is the design, fabrication and high RF power testing of **four-quadrants (“open-type”) X-band RF accelerating structures** made of hard copper, joined and vacuum sealed by using **TIG welding** (**“braze-free” technique)** in order to achieve higher **accelerating gradients (>100 MV/m)**, higher efficiency, as well as **cost-effective and robust manufacturing**.

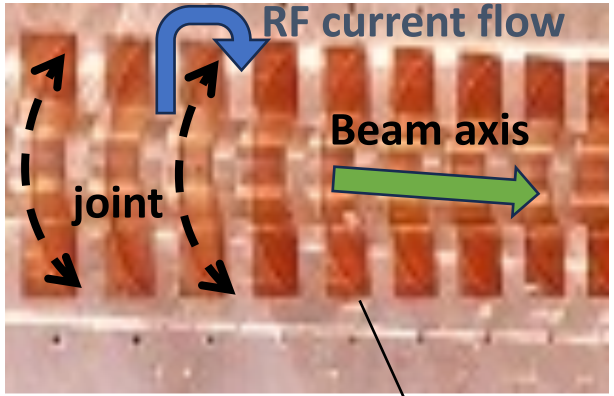
→difference from state-of-the-art: **to realize a practical (meter-long) linac for real linear accelerators.**

OBJECTIVES:

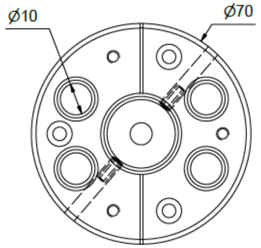
1. ***Radiofrequency (RF) Design and Wakefields/High-Order Modes (HOMs) Characterization and Optimization*** of a multi-cell, meter-long, TW X-band RF cavity made out of **hard copper** with an **open-type** geometry:
    - Structures for **single-bunch and multi-bunch operation**;
    - **Four quadrants** for the cancellation of the dipole and quadrupole EM field components, detrimental for the beam dynamics;
    - Mechanical engineering for joining with **TIG welding**;
    - RF power couplers will be **integrated four-port mode-launchers** [LNS/LNF] for compact power coupling and cancellation of the dipole and quadrupole field components;
    - **Secondary vacuum chamber** through the gap of the quadrants for improved pumping speed and **easy insertion of HOM absorbers** (if used for multi-bunch operation).
2. ***Fabrication*** of small-scale prototypes and full-scale structure for **single-bunch operation** (option for subsequent material R&D);
3. ***Low RF power tests*** (“cold-test”) of prototypes and full-scale structure at the LATINO Laboratory, INFN-LNF;
4. ***High RF-power tests*** of prototypes and full-scale structure at the TEX facility, INFN-LNF.

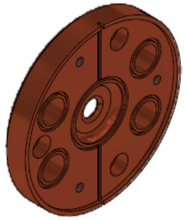
«Closed»

RF current flows through joints (brazing, diffusion bonding, welding)



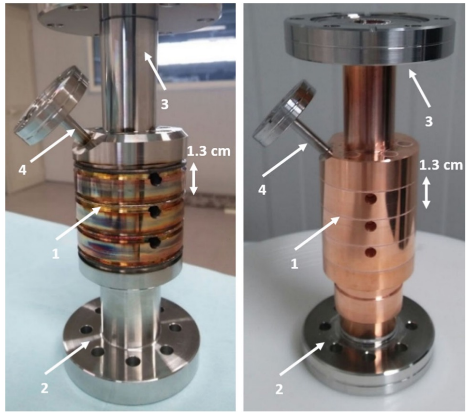
- Regular or pillbox-like cells





- Examples:

Brazed
EuPRAXIA, INFN-LNF

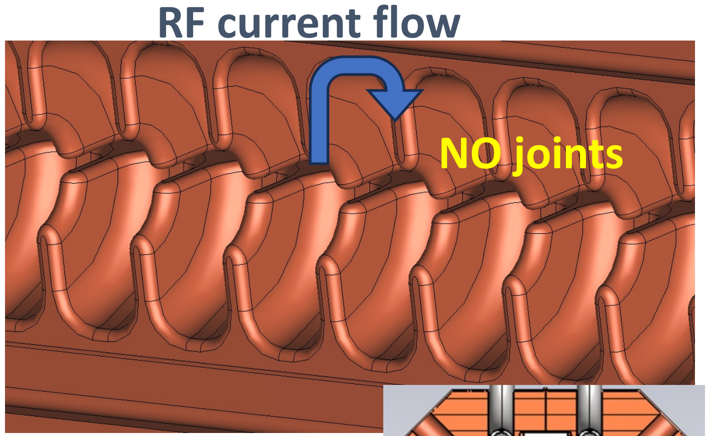


Welded INFN-LNF DEMETRA

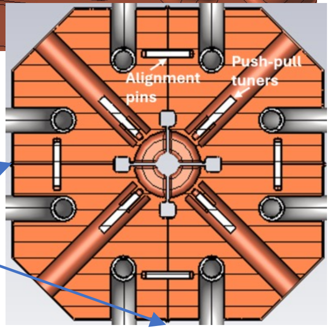
«Open»

RF currents never cross joints

- Chocke-mode cavity
- Multi-sector

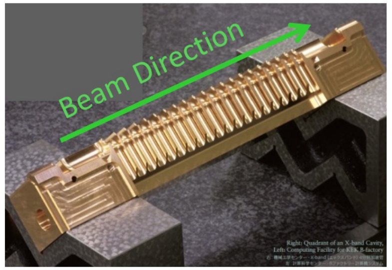


Joints away from RF surfaces

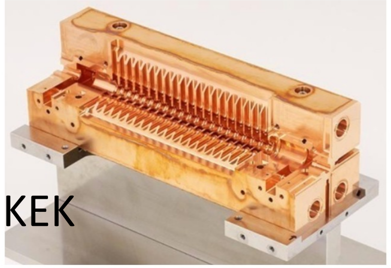


- Examples:

INFN-LNF
DEMETRA
ARYA (1xtwo halves and 2xfour quadrants)

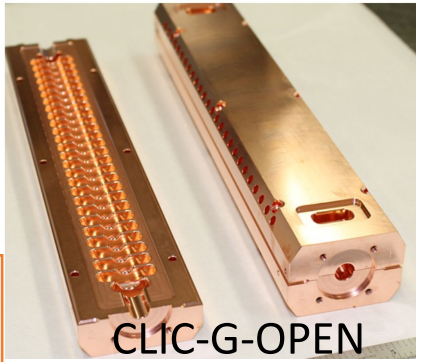


A Quadrant



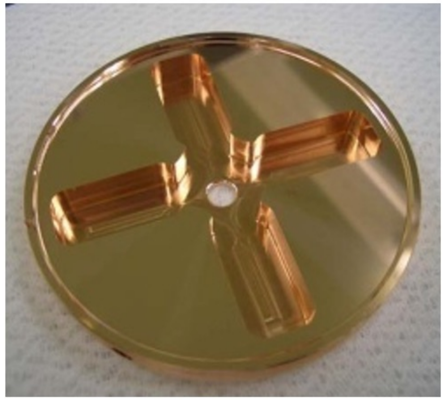
Three Quadrants

3x quadrant-structures fabricated and sent to SLAC and KEK for high-power testing

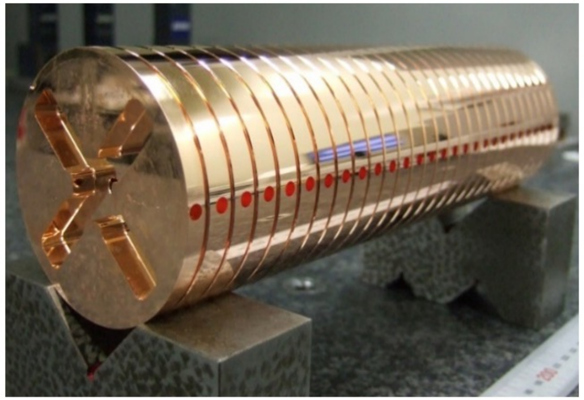


Disk-type vs Multi-sector type

Disk type



A damped disk

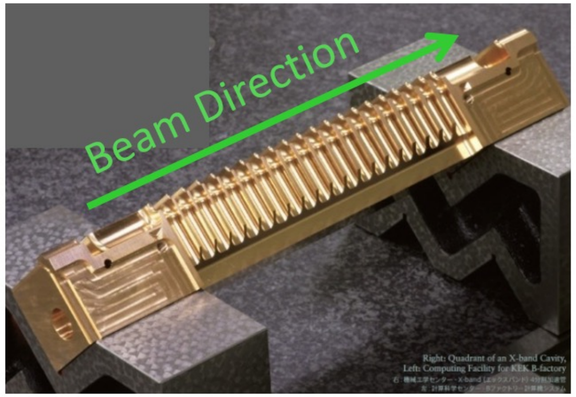


Disks stacked and bonded

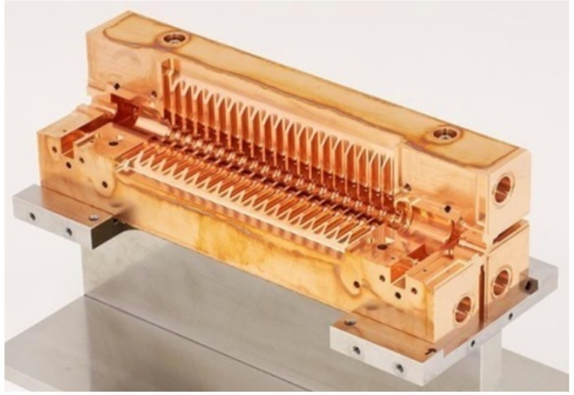
- Pros
  - ✓ Machining by turning (1 micron)
  - ✓ Very smooth surface (roughness about 30nm)

- Cons (Need special care)
  - Ultra-high-precision machining of dozen of disks
    →Stack and bonding
  - **Surface currents flow across disk-to-disk junctions.**

Quadrant type



A Quadrant

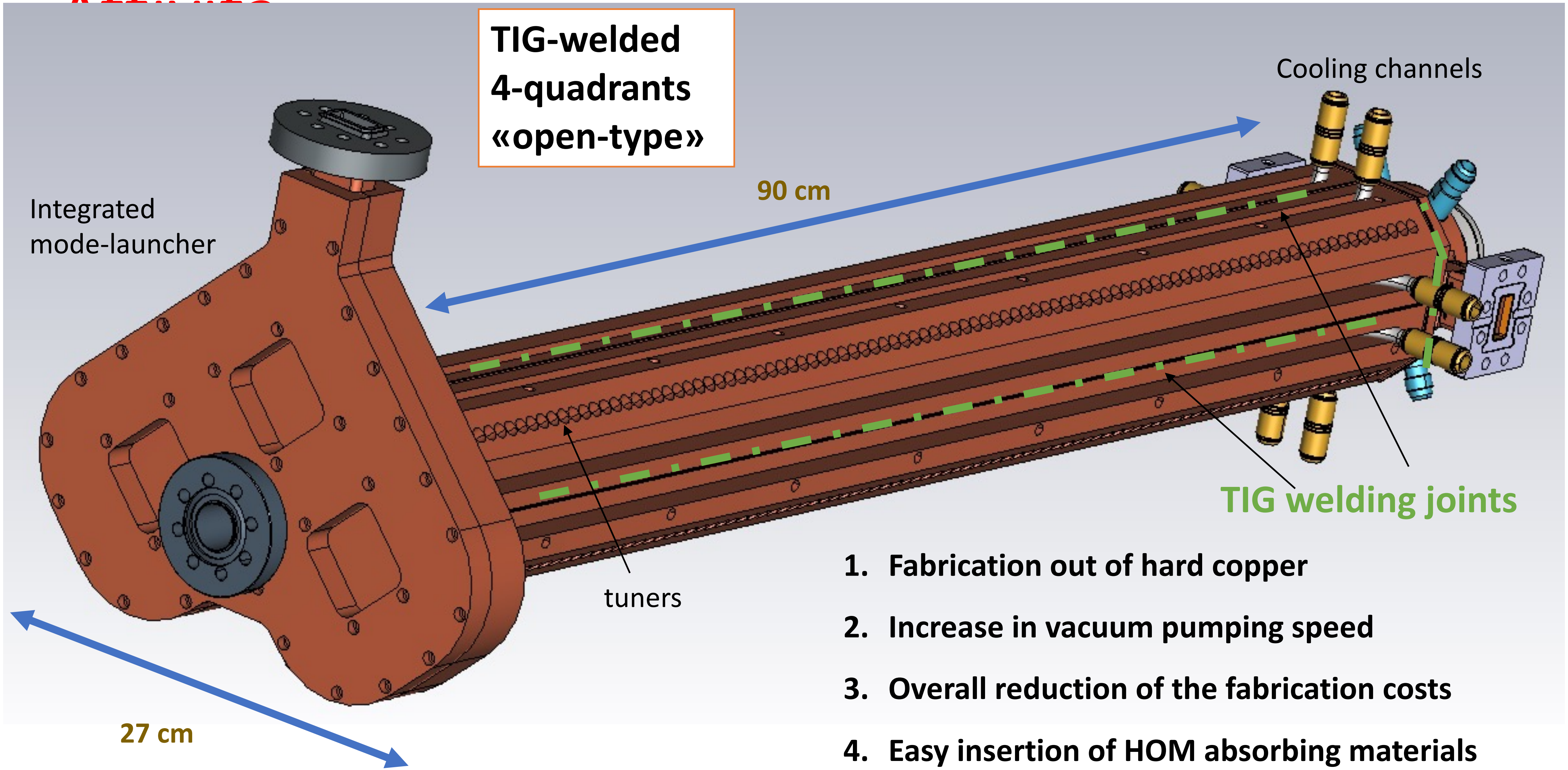


Three Quadrants

- Pros
  - ✓ **No surface current flows across any junction or bonding plane.**
  - ✓ Simple assembly process → Significant cost reduction
  - ✓ 3-axis CNC milling machine with higher precision +/- 1.5 microns with a repeatability of +/- 1.0 micron.
  - ✓ very smooth surface (roughness 50- 100 nm)

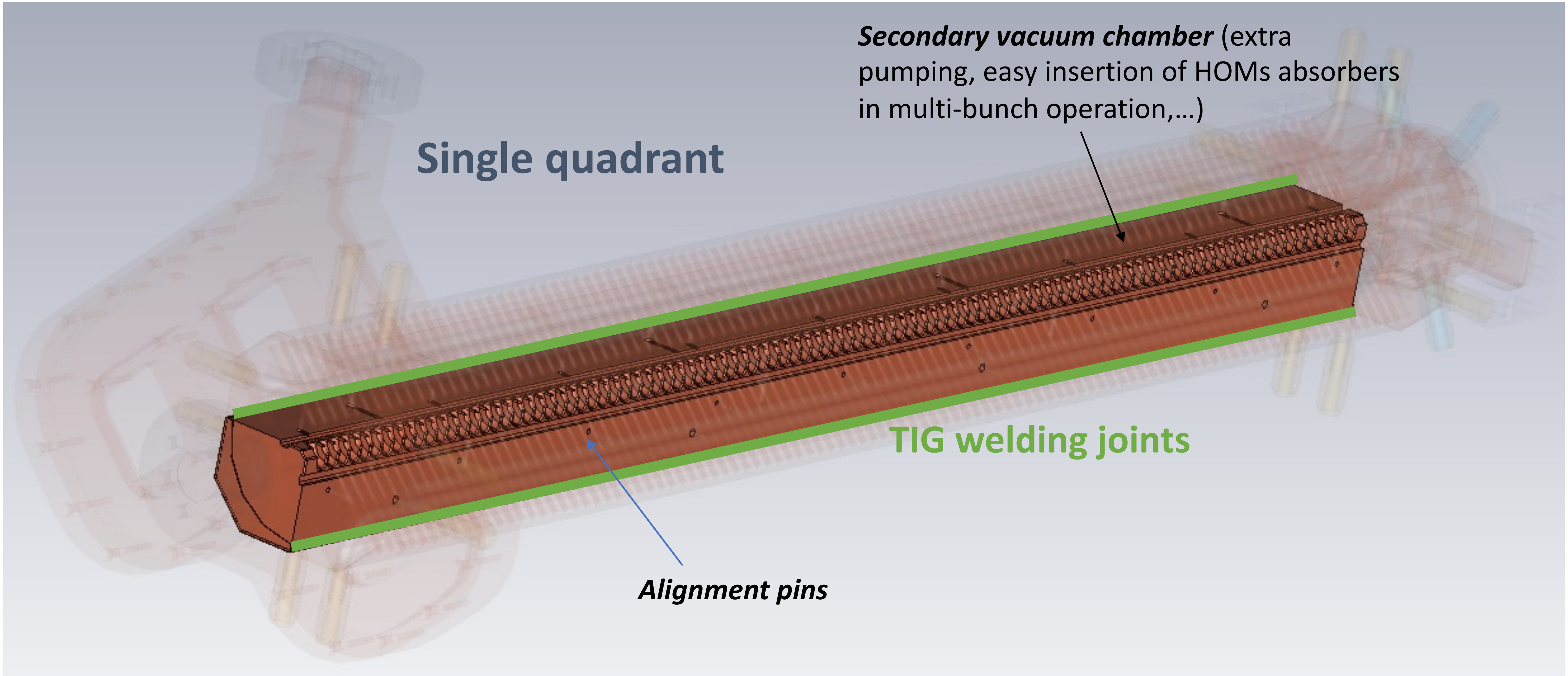
- Cons (Need special care)
  - Need GAP (~1 mm) among quadrants to avoid virtual leaks
  - Field enhancements at the corners of quadrants

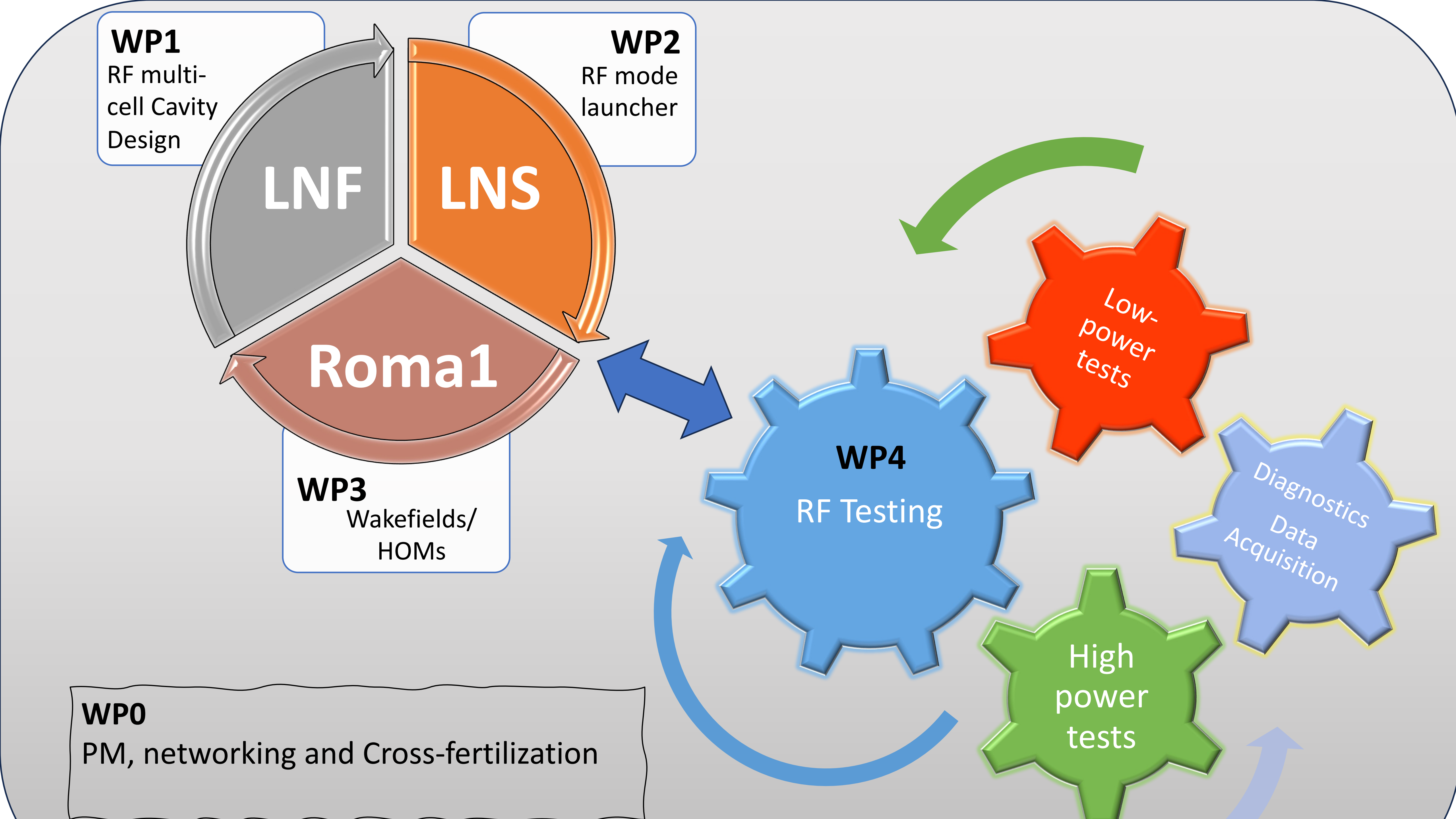
Full TW multi-cell X-band structure



1. **Fabrication out of hard copper**
2. **Increase in vacuum pumping speed**
3. **Overall reduction of the fabrication costs**
4. **Easy insertion of HOM absorbing materials**

Full TW multi-cell X-band structure




WP1
RF multi-cell Cavity Design
WP2
RF mode launcher
LNF
LNS
Roma1
WP3
Wakefields/ HOMs
WP4
RF Testing
Low-power tests
Diagnostics Data Acquisition
High power tests
WP0
PM, networking and Cross-fertilization

Working Packages and Tasks

- **WP1 RF Design, Engineering and Fabrication of the multiple-sector RF cavity (<u>LNF</u>, LNS, Roma1)**

Local Responsible: F. Cardelli

- Task1.1 RF design of the multiple-sector RF cavity (<u>LNF</u>)
- Task1.2 Vacuum System Desing of the RF cavity (LNF)
- Task1.3 Engineering and fabrication of the RF cavity, and mode-launcher from WP2 (LNF)

- **WP2 RF Design, Engineering and Fabrication of the RF power mode launcher (<u>LNS</u>, LNF, Roma1)**

Local Responsible: G. Torrisi

- Task2.1 RF design of the RF power mode launcher (<u>LNS</u>)
- Task2.2 Fabrication the RF power mode launcher (<u>LNS</u>)

- **WP3 Wakefields/HOMs Characterization and Optimization (<u>Roma1</u>, LNF, LNS)**

Local Responsible: L. Ficcadenti

- **WP4 RF low- and high-power testing at INFN-LNF (<u>LNF</u>, Roma1, LNS)**

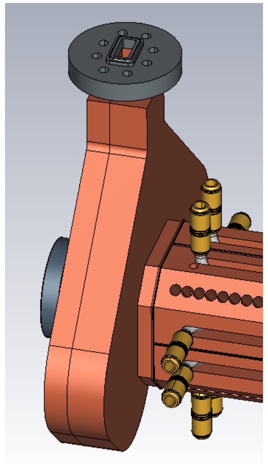
Local Responsible: L. Piersanti, S. Pioli

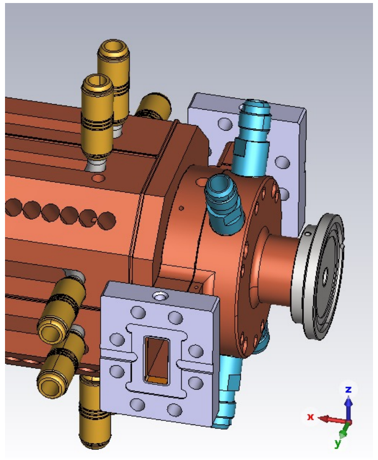
- Task4.1 Low-power RF testing at LATINO Lab at INFN-LNF (LNF)
- Task4.2 High-power RF testing at TEX facility at INFN-LNF (LNF)
- Task4.3 Diagnostics and data acquisition (LNF)

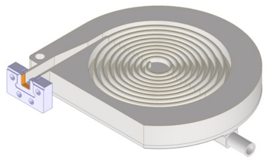
-WP2 RF Design, Engineering and Fabrication of the RF power mode launcher (LNS)

Local Responsible: G. Torrisi

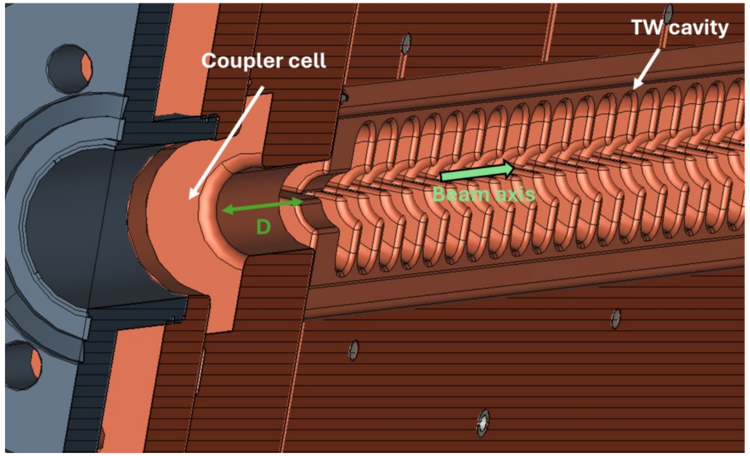
- **Close collaboration with WP1 and WP3**
- **Mode launcher**:
  - Single and double four-port mode launchers;
  - Input mode launcher and two output spiral loads;
  - “open” launcher as HOM-free RF power coupler.
- **Integrated**:
  - Ideally D → 0
  - D > 0
- **Stand-alone, separate mode launcher**:
  - Connected to the multi-cell TW cavity through an RF flange.

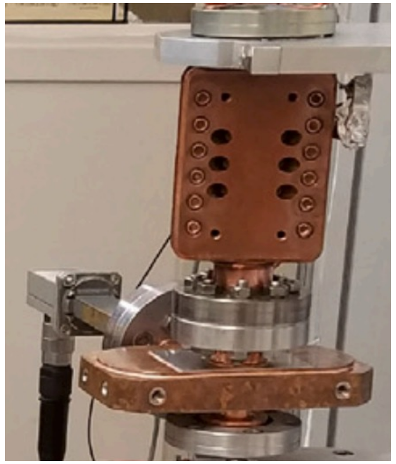




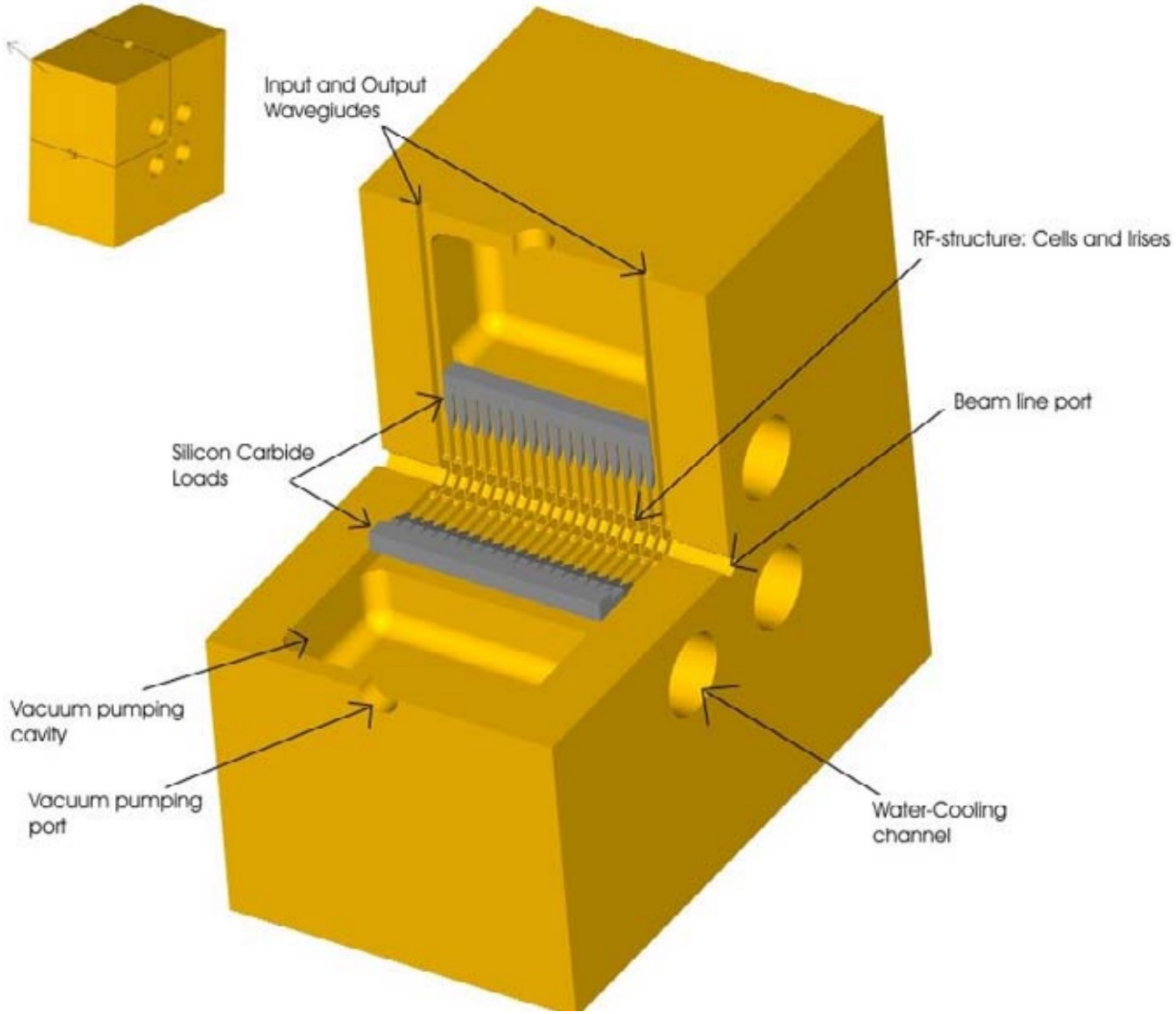


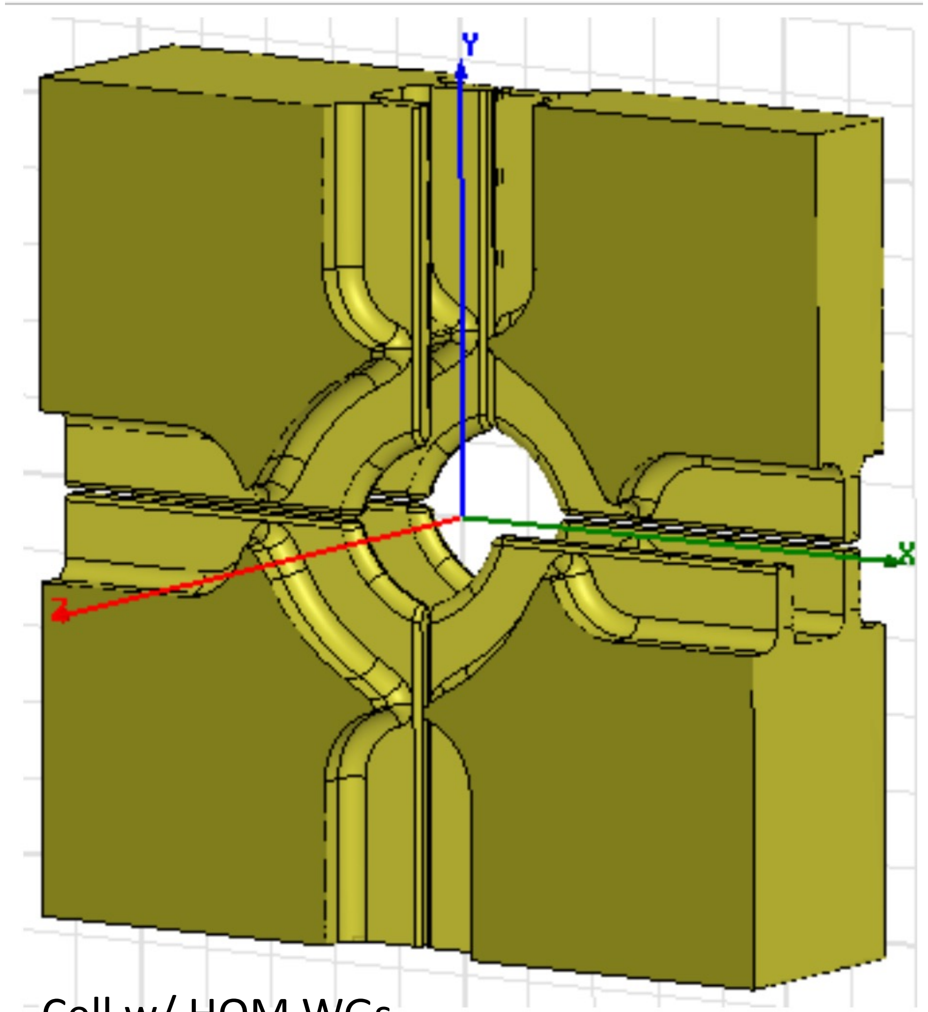
X-band high-power metallic load





X-band Slotted-Iris Accelerator Structure

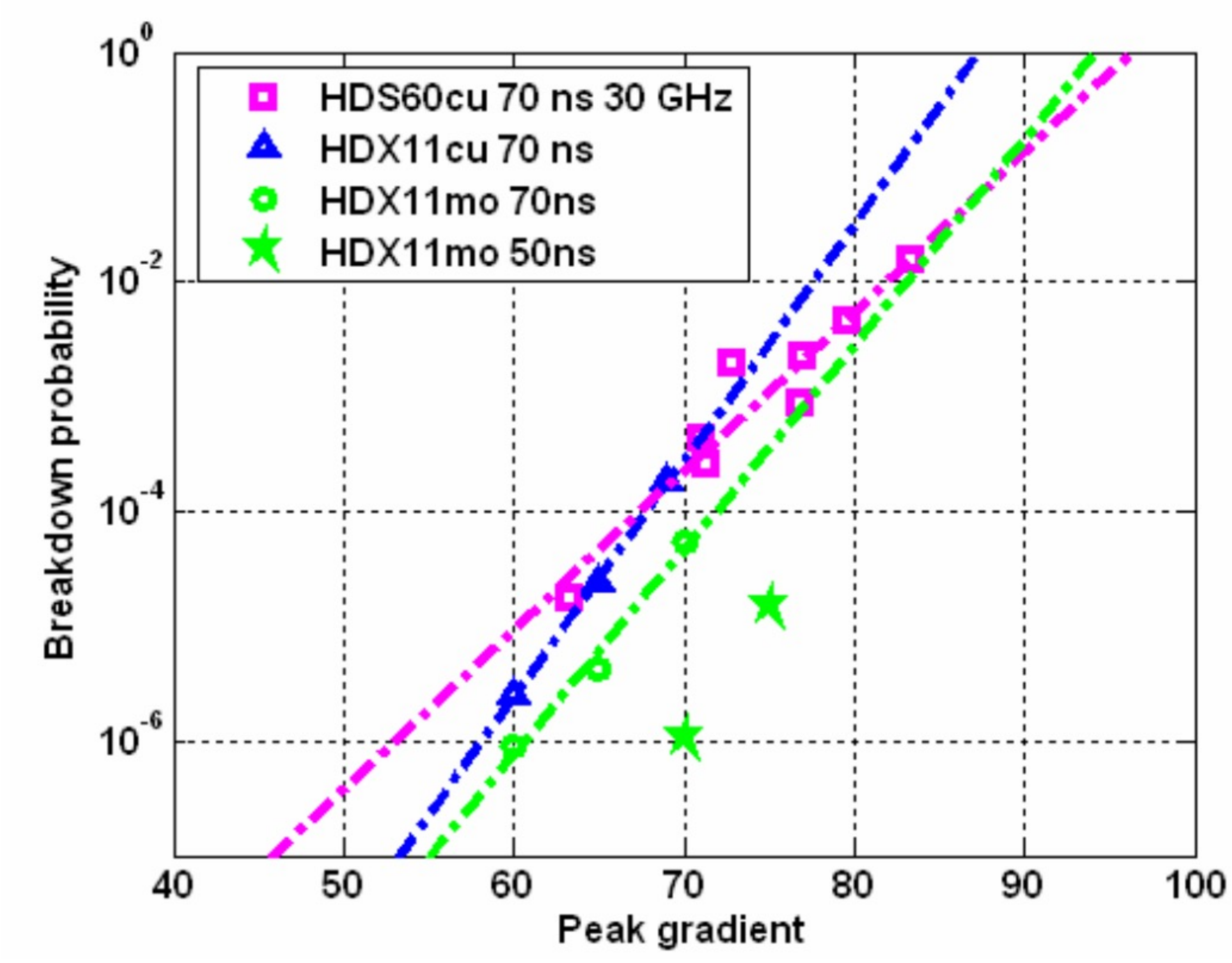




Cell w/ HOM WGs

- Grudiev, A. and Wuensch, W., 2004. A newly designed and optimized CLIC main linac accelerating structure (No. CERN-AB-2004-041-RF).
-Adolphsen, C., Rodríguez, J.A., Laurent, L., Fandos, R., Heikkinen, S., Taborelli, M., Döbert, S., Wuensch, W. and Grudiev, A., 2007. High Power Test on an x-Band Slotted-Iris Accelerator Structure at NLCTA (No. CERN-AB-2007-060).

X-band Slotted-Iris Accelerator Structure



- Grudiev, A. and Wuensch, W., 2004. A newly designed and optimized CLIC main linac accelerating structure (No. CERN-AB-2004-041-RF).
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Synthesis of open structures starting from closed-cross-section waveguide devices

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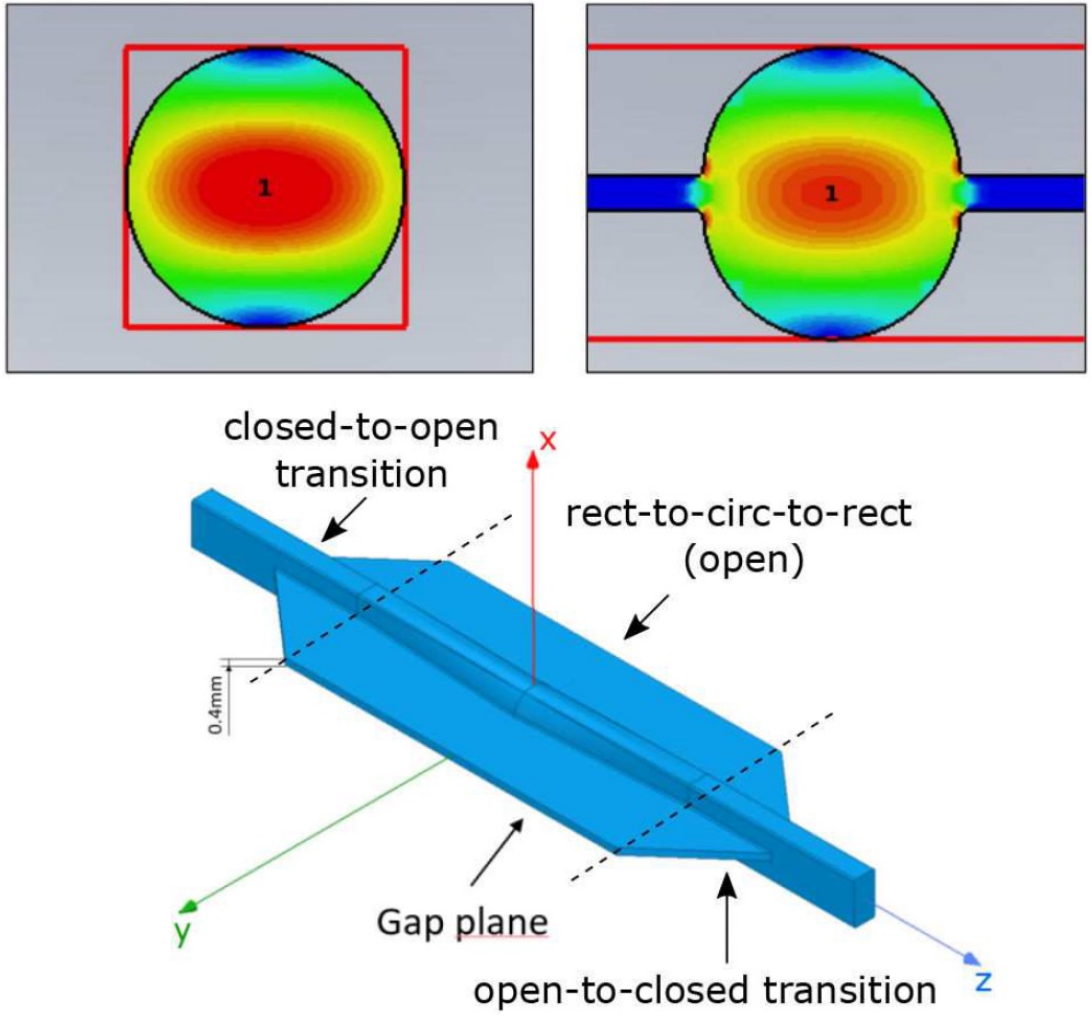
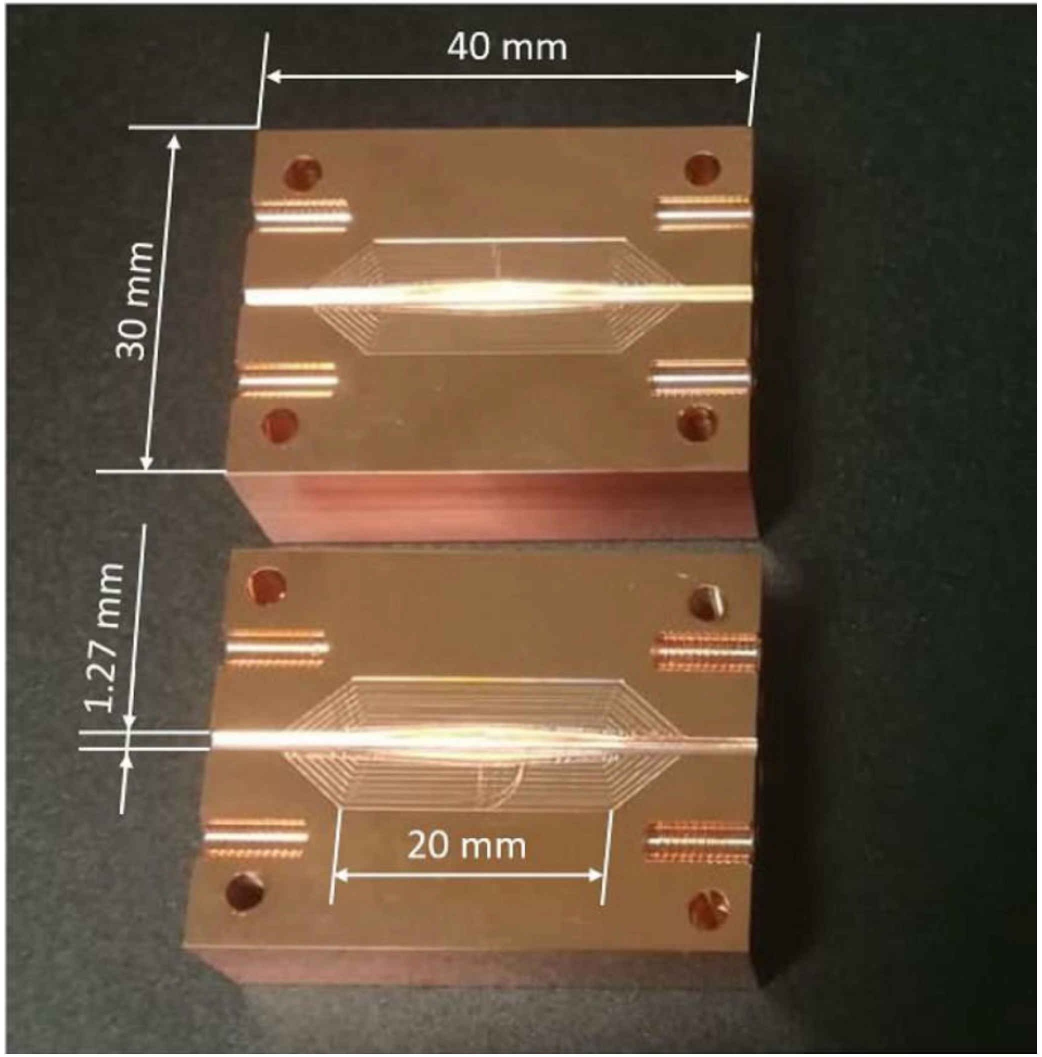




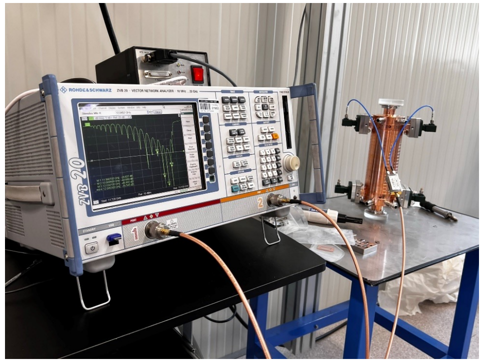
-WP4 RF low- and high-power testing at INFN-LNF (<u>LNF)</u>

Local Responsible: L. Piersanti, S. Pioli

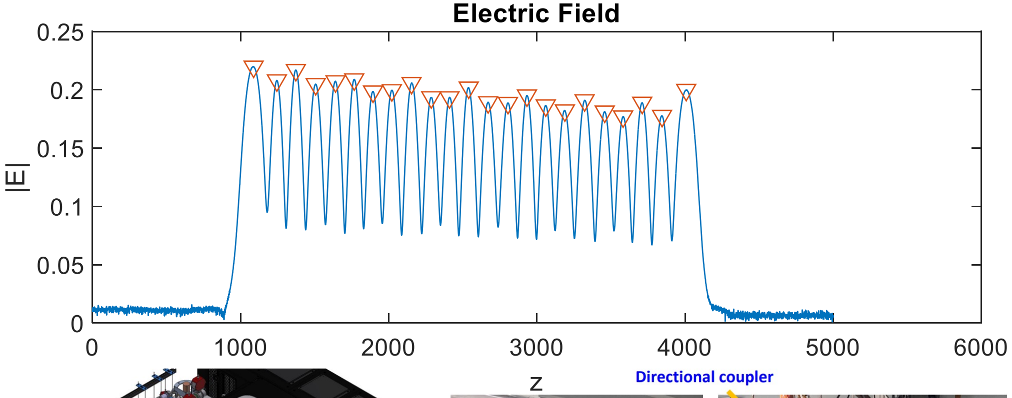
- **Low-power measurements**: to validate the structure's fabrication within required tolerances for tuning.
  - Using a Vector Network Analyzer (VNA)
  - to measure key RF parameters such as resonant frequency, quality factor, and coupling coefficient, typically observed through the reflection coefficient (S_{11}).
  - Bead-pull for on-axis electric field amplitude and phase.

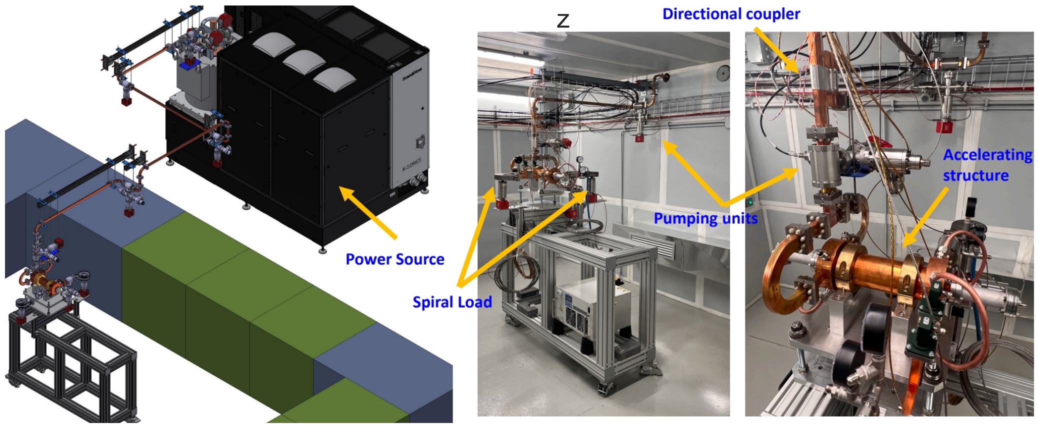
- **High-power conditioning** at the TEX facility at INFN-LNF. The rf power source is a VKX8311A klystron by CPI (50 MW, operating with a pulse repetition rate of up to 50 Hz and pulse duration of up to 1.5 us)

- **Diagnostics and Data Acquisition**:
  - Two current monitors positioned on either side of the cavity intercepted field emission electrons and linked to a digitizer through coaxial cables.
  - High-gradient tests comprised two phases: conditioning, during which the RF breakdown rate varied, and measurement of RF breakdowns, during which this rate remained stable.
  - Conditioning starts by pulsing the accelerating structure with low-power RF at a short pulse length of 100 ns. RF power was gradually increases during conditioning.



Bead-pull setup with VNA and accelerating structure under test.





Budget (LNS)

Year		Cost	Notes
1	Software-CST	**€ 15,000.00**	simulazioni RF coupler design
	Missions	**€ 1,500.00**	Partecipazioni misure in collaborazione meccaniche e vuoto sul primo prototipo (LNF)
2	Missions	€ 4,000.00	Partecipazioni misure dei primi prototipi sia a bassa che alta potenza RF a TEX (LNF)
3	Missions	€ 4,000.00	Partecipazione misure in collaborazione del prototipo finale sia a bassa che alta potenza RF a TEX (LNF)
TOT		**€ 24,500.00**	

FTE

LNS	FTE
G. Torrisi (RL)	0.1
D. Mascali	0.05
G. Mauro	0.1
G. Sorbello	0.2

Impatto su divisioni e servizi LNS, eventuali necessità di spazi

S. Passarello