## Nuova Proposta di Esperimento in CSN5 (INFN)

Istituto Nazionale di Fisica Nucleare

# ASTERIX

(**A**ccelerating **ST**ructures made of multipl**E** secto**R**s **I**n ***X***-Band)

3 anni (2025-2027)
Units: LNF, LNS, Roma1

Research line: Accelerators and related technologies

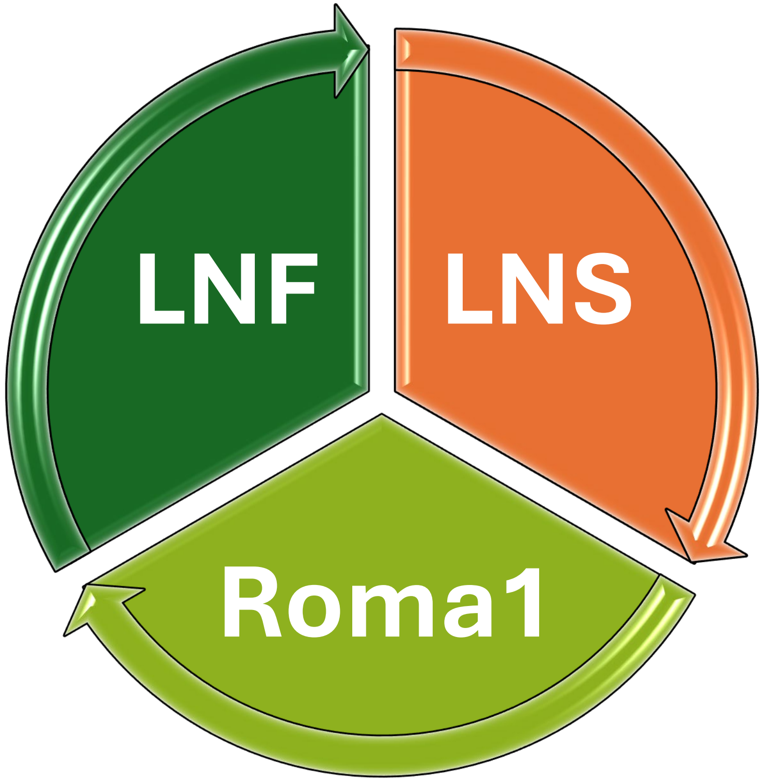
L. Faillace (Resp. Naz.) - LNF

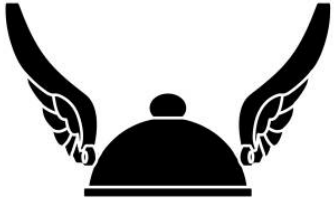
July 09, 2024

- Support from INFN-LNF Laboratory
- External Collaborators: V. Dolgashev (SLAC), Tetsuo Abe (KEK)
- PhD student from the University of Science and Technology of China (USTC)

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

# ASTERIX team



**Total FTE**
**5.35**

| LNF | FTE | LNS | FTE | Roma1 | FTE |
|---|---|---|---|---|---|
| L. Faillace (Resp. Naz.) | 0.4 | G. Torrisi (RL) | 0.1 | L. Ficcadenti (RL) | 0.3 |
| D. Alesini | 0.2 | D. Mascali | 0.05 | M. Petrarca | 0.2 |
| M. Bellaveglia | 0.05 | G. Mauro | 0.1 | M. Migliorati | 0.2 |
| S. Bini | 0.2 | G. Sorbello | 0.2 | G. Silvi | 0.2 |
| F. Cardelli | 0.3 | T. Isernia | 0.3 | L. Palumbo | 0.4 |
| M. Carillo | 0.2 | R. Palmeri | 0.3 | | |
| E. Chiadroni | 0.2 | A. Locatelli | 0.1 | | |
| A. Falone | 0.2 | C. De Angelis | 0.1 | | |
| A. Gallo | 0.15 | L. Vincetti | 0.1 | | |
| A. Giribono | 0.2 | | | | |
| A. Liedl | 0.1 | | | | |
| L. Piersanti | 0.1 | | | | |
| S. Pioli | 0.2 | | | | |
| B. Spataro | 0 | | | | |
| C. Vaccarezza | 0.2 | | | | |
| | | | | | |
| **Tot./Unit** | **2.7** | | **1.35** | | **1.3** |

# Motivation

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

↓

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

- World-wide 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**.

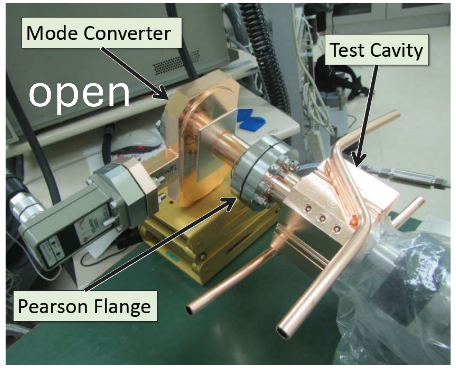
# Research Context

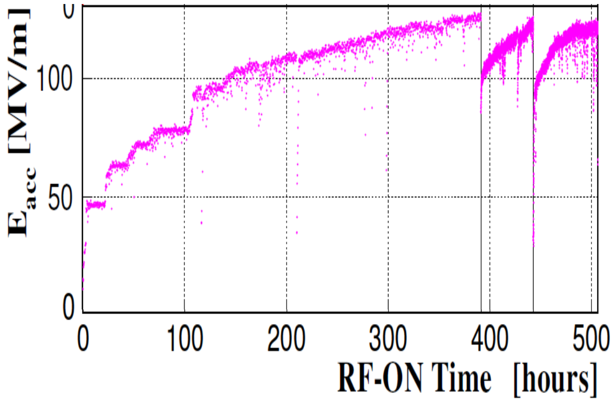
- Framework of a continuous more-than-two-decade-long collaboration on the study of RF structures with increasing accelerating gradients and the **RF breakdown physics**: SLAC (USA), INFN-LNF and KEK (Japan)
- Study of various geometries, materials, surface processing techniques and technological developments 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**: future linear colliders; existing and new-generation X-FELs, such as EuPRAXIA@SPARC_LAB; industrial, and medical applications.

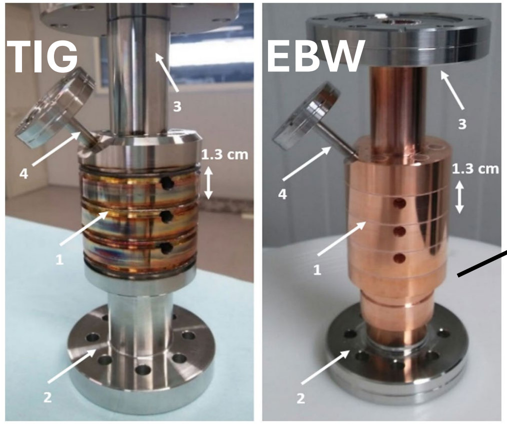
# State-of-the-art

1. “Single-cell” cavities (open and closed; disk-type and multi-sector)

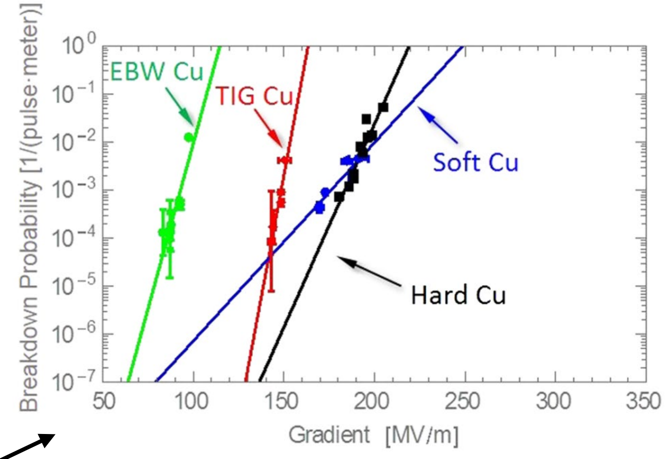


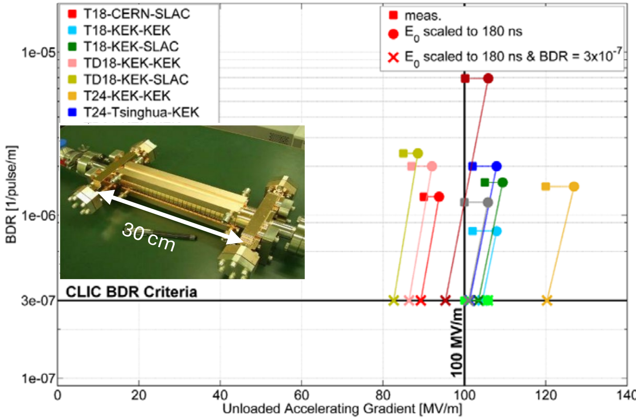

T. Abe, et al., High-gradient test results on a quadrant-type X-Band single-cell structure.




Dolgashev VA, Faillace L, Spataro B, Tantawi S, Bonifazi R. High-gradient rf tests of welded X-band accelerating cavities. Physical Review Accelerators and Beams. 2021 Aug 10;24(8):081002.



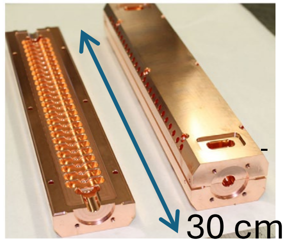

2. TW multi-cell structures (open and closed; disk-type and multi-sector)




3. Open-type multi-sector cavities, typically of small lengths (20- 25 cm).

SLAC/CERN 2018
- X-band
- 2 halves, open structure
- Brazed
- High-power tested:

→ Gradient: 100 MV/m with 200 ns pulse length.




CLIC-G-OPEN

KEK (Tetsuo Abe) 2023
- X-band
- 4 quadrants
- EBW welding

To be High-power tested.

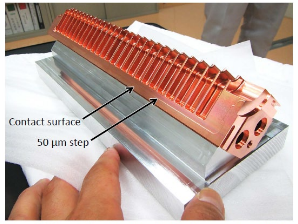



Figure 3: A quadrant fabricated with ultraprecision milling.

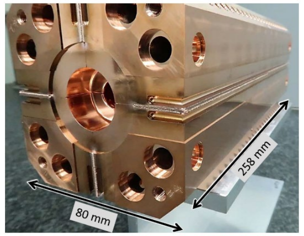
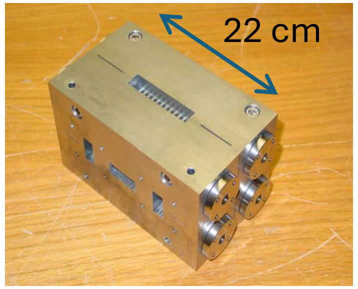



Figure 4: Photograph of the quadrants after the EBW.




CERN 2007
- X-band
- 4 quadrants
- Clamped, high T-treated
- High-power Tested:
- → Gradient: 80 MV/m with 40 ns pulse length.

# Goal

ASTERIX stands apart from state-of-the-art

First-time demonstration of **practical, meter-long,** X-band RF accelerating structure for real linear accelerators:

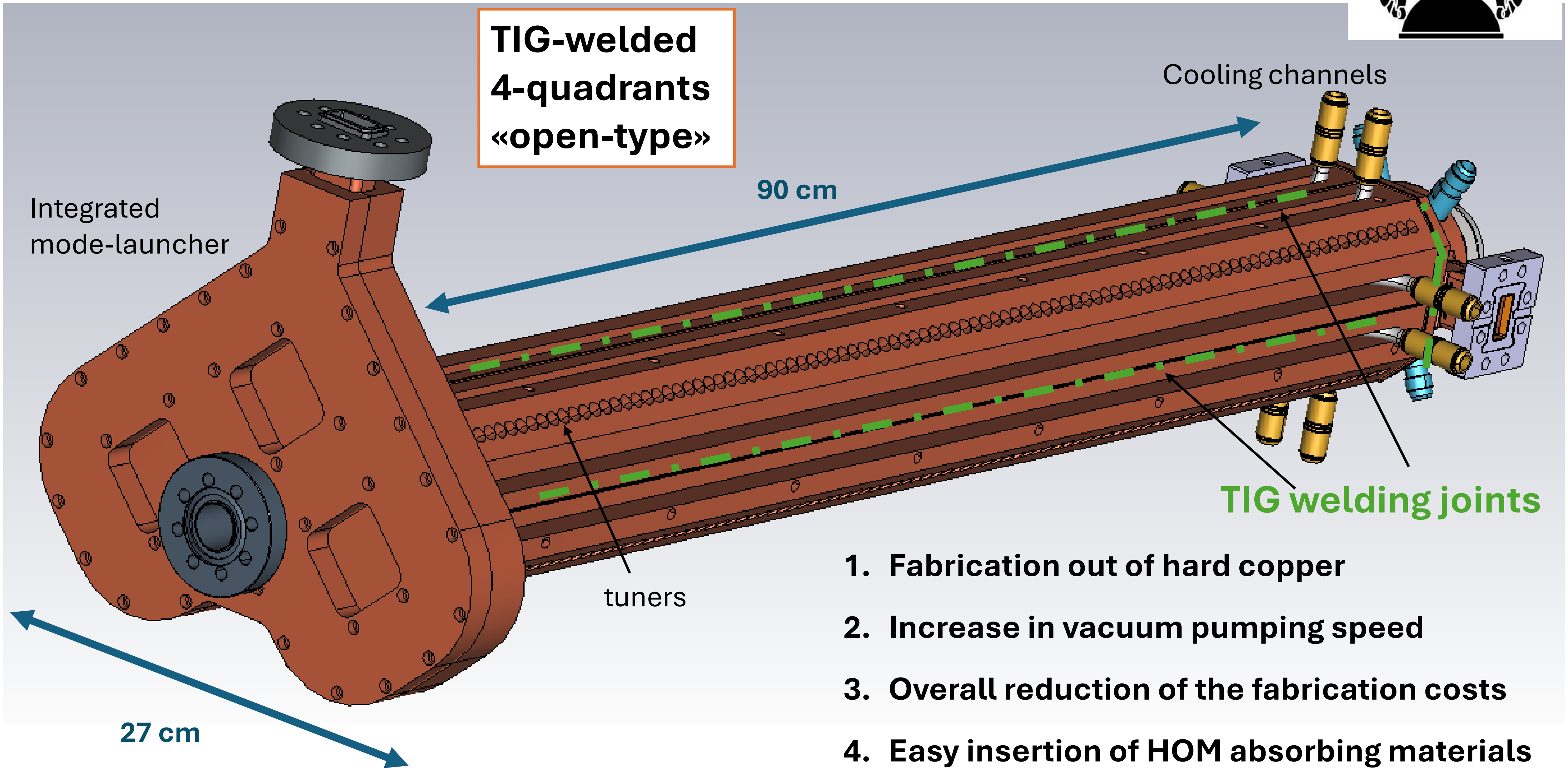
Requirement to be competitive among the world-wide collaboration

- high **accelerating gradients (>100 MV/m)**;
- composed of **four-quadrants** ("open-type");
  - cancellation of the dipole and quadrupole EM field components, detrimental for the beam dynamics
  - improved pumping speed and easy insertion of HOM absorbers (in case of multi-bunch operation)
- made out **hard copper;**

  Superior high-gradient performance, compared with soft copper
- joined and vacuum sealed by using **TIG welding** ("braze-free" technique).

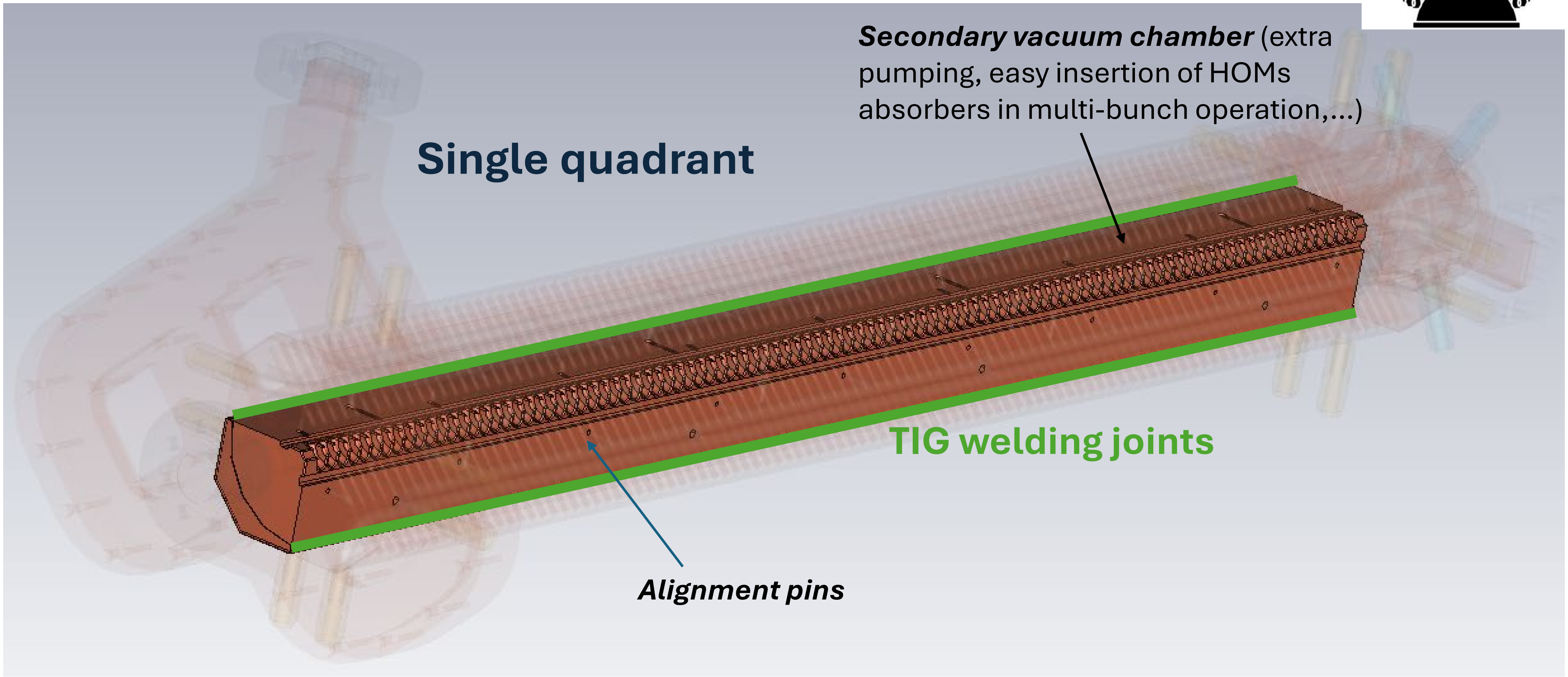
  cost-effective and robust manufacturing.

# 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**

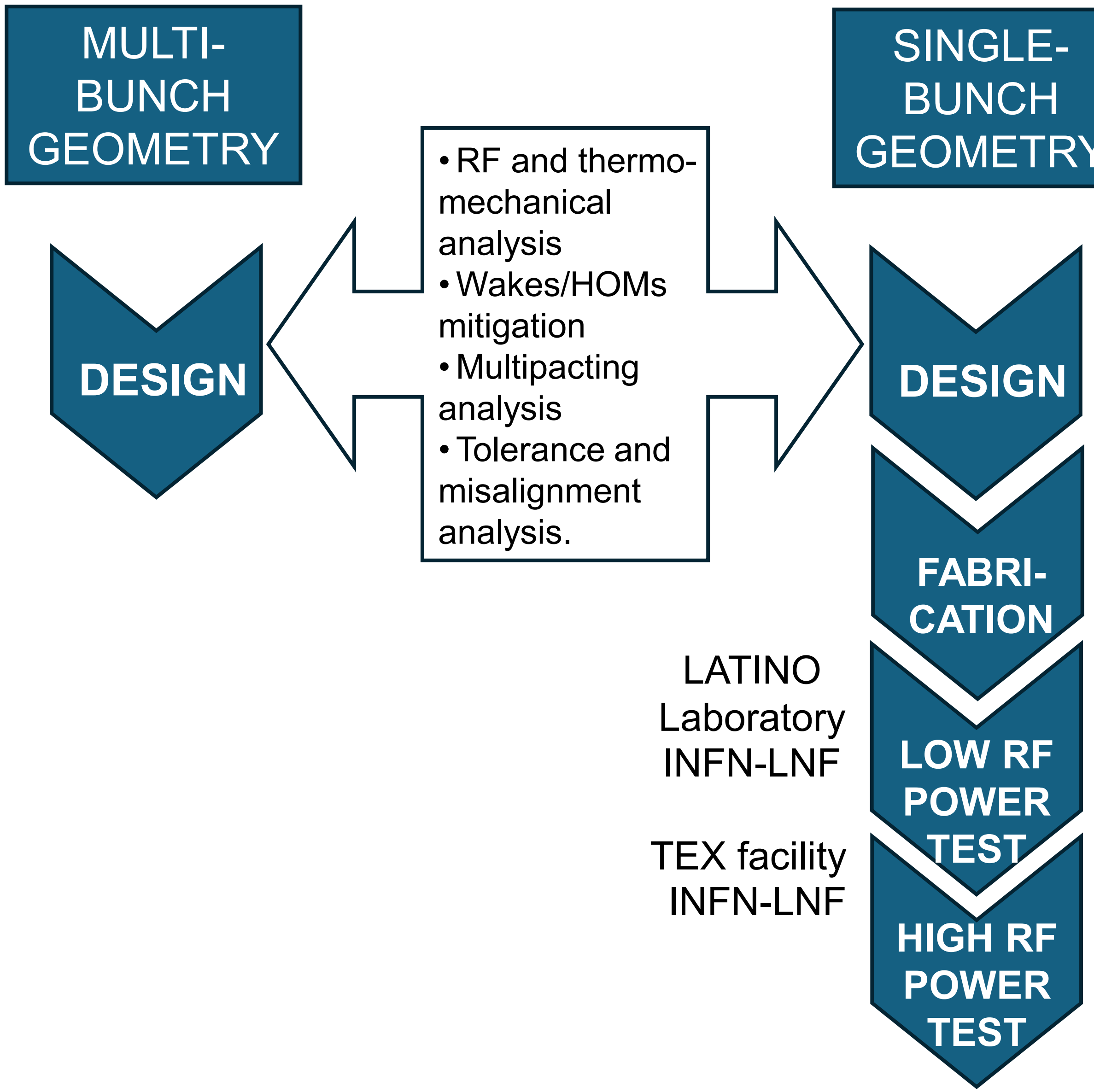
# Full TW multi-cell X-band structure



# Objectives

World-wide collaboration
&
EuPRAXIA@SPARC_LAB scenario

Reasonable scope, time and budget



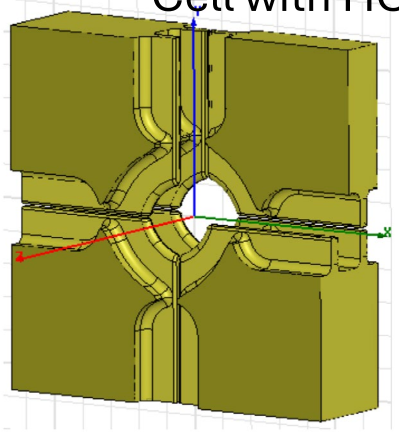

- Low-precision full model for mechanical tests (quadrant straightness and alignment, TIG welding process, vacuum tightness) → 1° year
- Prototyping activity, nominal precisions (small-scale structure, 30 cm and 20 cells) → 2° year
- Full-scale structure with four-port RF mode-launchers → 3° year

Validate the structure's fabrication within required tolerances for tuning:
- measure key RF parameters (resonant frequency, quality factor, and coupling coefficient ← scattering parameters.
- Bead-pull for on-axis electric field amplitude and phase.

High-gradient performance (compressed pulse up to 200 MW from VKX8311A 50 MW X-band klystron by CPI and BOC-type compressor):
- Accelerating gradient
- RF breakdown probability
- Dark current (surface field emitted electrons)

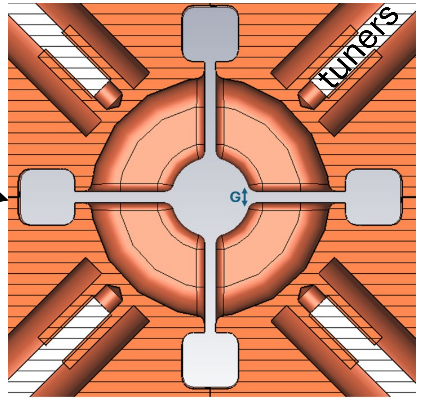
# Objectives

Cell with HOM WGs



Cell without HOM WGs

Secondary vacuum chamber




World-wide collaboration
&
EuPRAXIA@SPARC_LAB scenario

Reasonable scope, time and budget

**DESIGN**

- RF and thermo-mechanical analysis
- Wakes/HOMs mitigation
- Multipacting analysis
- Tolerance and misalignment analysis.

**DESIGN**

**FABRI-CATION**

- Low-precision full model for mechanical tests (quadrant straightness and alignment, TIG welding process, vacuum tightness) → 1° year
- Prototyping activity, nominal precisions (small-scale structure, 30 cm and 20 cells) → 2° year
- Full-scale structure with four-port RF mode-launchers → 3° year

**LOW RF POWER TEST**

LATINO Laboratory INFN-LNF

Validate the structure's fabrication within required tolerances for tuning:
- measure key RF parameters (resonant frequency, quality factor, and coupling coefficient ← scattering parameters.
- Bead-pull for on-axis electric field amplitude and phase.

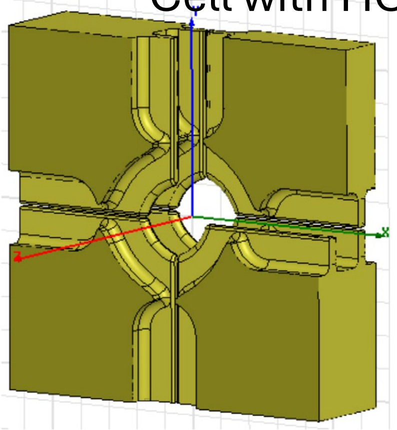
**HIGH RF POWER TEST**

TEX facility INFN-LNF

High-gradient performance (compressed pulse up to 200 MW from VKX8311A 50 MW X-band klystron by CPI and BOC-type compressor):
- Accelerating gradient
- RF breakdown probability
- Dark current (surface field emitted electrons)

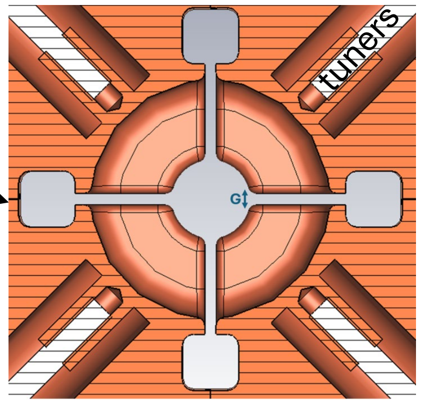
# Objectives

Cell with HOM WGs



Cell without HOM WGs

Secondary vacuum chamber




World-wide collaboration
&
EuPRAXIA@SPARC_LAB scenario

Reasonable scope, time and budget

**DESIGN**

- Limited time, budget
- Future experiments
- Version 2.0
- Asterix &Obelix

- RF and thermo-mechanical analysis
- Wakes/HOMs mitigation
- Multipacting analysis
- Tolerance and misalignment analysis.

**DESIGN**

**FABRI-CATION**

- Low-precision full model for mechanical tests (quadrant straightness and alignment, TIG welding process, vacuum tightness) → 1° year
- Prototyping activity, nominal precisions (small-scale structure, 30 cm and 20 cells) → 2° year
- Full-scale structure with four-port RF mode-launchers → 3° year

LATINO Laboratory INFN-LNF

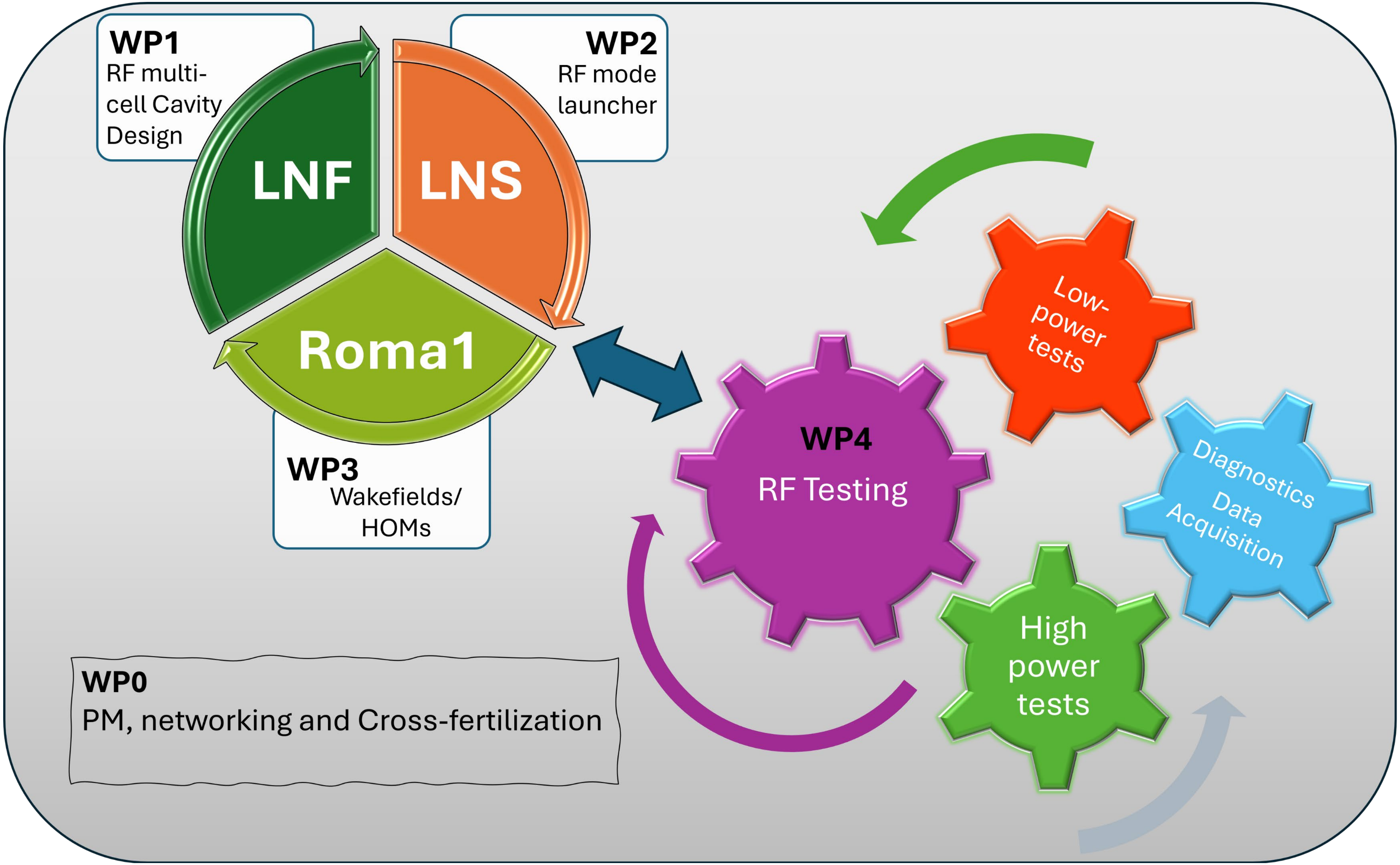
**LOW RF POWER TEST**

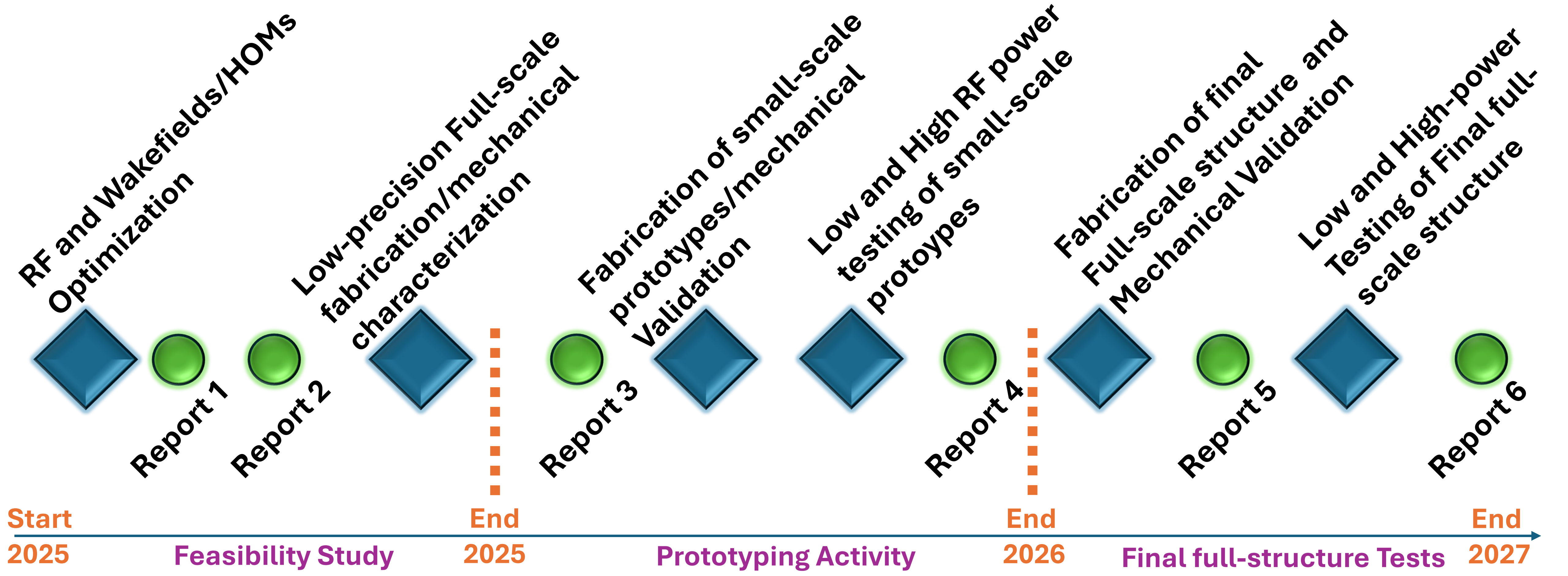
Validate the structure's fabrication within required tolerances for tuning:
- measure key RF parameters (resonant frequency, quality factor, and coupling coefficient ← scattering parameters.
- Bead-pull for on-axis electric field amplitude and phase.

TEX facility INFN-LNF

**HIGH RF POWER TEST**

High-gradient performance (compressed pulse up to 200 MW from VKX8311A 50 MW X-band klystron by CPI and BOC-type compressor):
- Accelerating gradient
- RF breakdown probability
- Dark current (surface field emitted electrons)

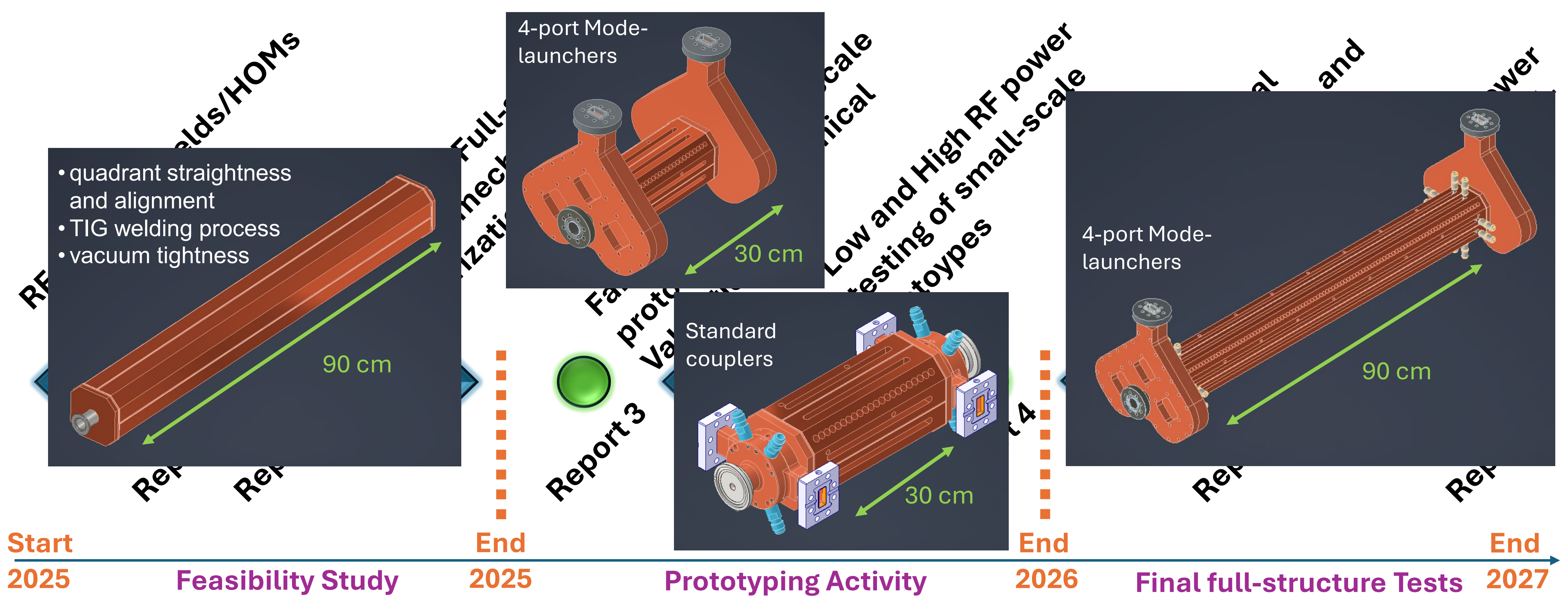

WP1
RF multi-cell Cavity Design
WP2
RF mode launcher
LNF
LNS
Roma1
WP3
Wakefields/ HOMs
WP4
RF Testing
Low-power tests
Diagnostics Data Acquisition
High power tests
WP0
PM, networking and Cross-fertilization




7 Milestones

6 Deliverables

1. Report of the Feasibility Study (RF and Wakefields/HOMs);
2. Report of the Mechanical Engineering of the low-precision prototype with standard RF couplers for Mechanical, TIG welding and vacuum testing;
3. Report of the Mechanical Engineering of the small-scale structures with ad-hoc integrated RF Mode Launcher couplers;
4. Report of the low/high RF power testing of the small-scale structures;
5. Report of the Mechanical Engineering of the Full Structure with with ad-hoc integrated RF Mode Launcher couplers;
6. Final Report of low and High RF power testing of final full-scale structure.




**7 Milestones**

**6 Deliverables**

1. Report of the Feasibility Study (RF and Wakefields/HOMs);
2. Report of the Mechanical Engineering of the low-precision prototype with standard RF couplers for Mechanical, TIG welding and vacuum testing;
3. Report of the Mechanical Engineering of the small-scale structures with ad-hoc integrated RF Mode Launcher couplers;
4. Report of the low/high RF power testing of the small-scale structures;
5. Report of the Mechanical Engineering of the Full Structure with with ad-hoc integrated RF Mode Launcher couplers;
6. Final Report of low and High RF power testing of final full-scale structure.

# Budget

| YEAR | | Cost | Quantity | INFN Units | |
|---|---|---|---|---|---|
| 1 | Software License – CST Microwave Studio | € 31,000.00 | 2.00 | LNF/LNS | Ask for advance |
| | Inventariabile (Workstation) | € 6,000.00 | | LNF | Ask for advance |
| | Consumabili | € 35,000.00 | | | |
| | Missions | € 4,500.00 | | LNF/LNS/Roma1 | |
| | **TOT. 1st year** | **€ 76,500.00** | | | |
| 2 | Consumabili | € 70,000.00 | | LNF | Prototyping (max 30 cm) |
| | Cavi+WG adapters, 2xRF power loads | € 56,500.00 | | LNF | Activity: Cavity+MLs |
| | 2xFCs | € 4,800.00 | | LNF | |
| | Turbopump and Scroll | € 8,000.00 | | LNF | |
| | Missions | € 12,000.00 | | LNF/LNS/Roma1 | |
| | **TOT. 2nd year** | **€ 151,300.00** | | | |
| 3 | Consumabili | € 130,000.00 | | LNF | Full structure (90 cm) |
| | Missions | € 12,000.00 | | LNF/LNS/Roma1 | |
| | **TOT. 3rd year** | **€ 142,000.00** | | | |
| | | | | | |
| **TOT** | | **€ 369,800.00** | | | |

# Thanks for your attention!