Overview of the design and procurement of ECRH system for DTT

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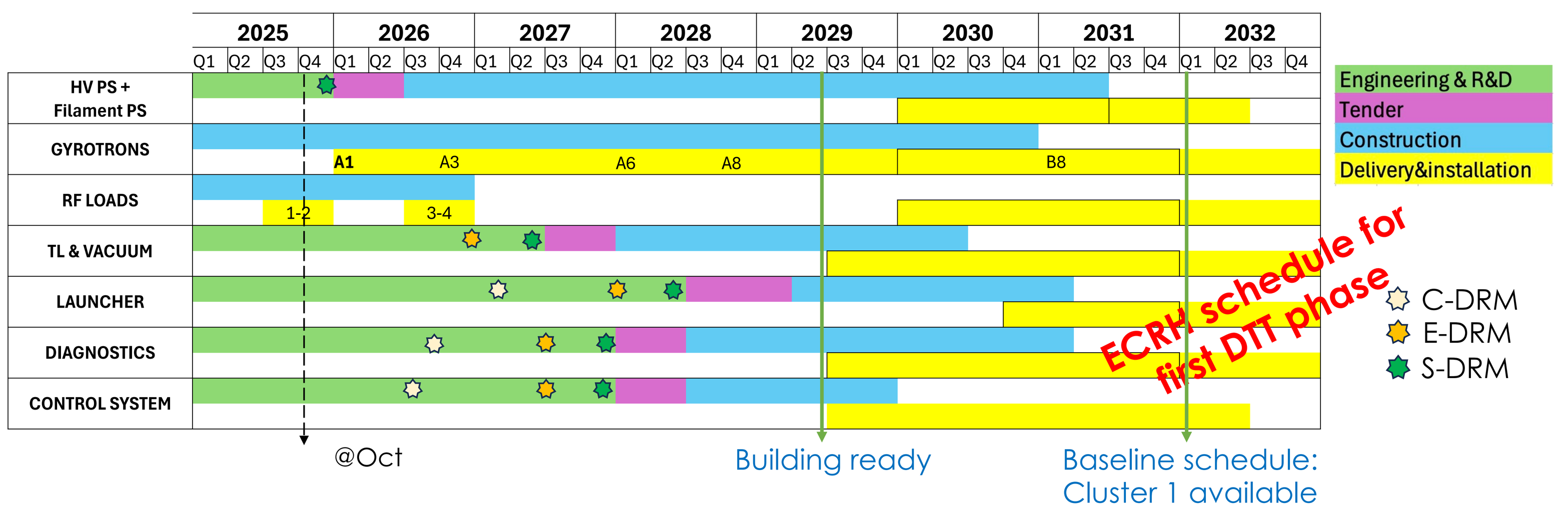
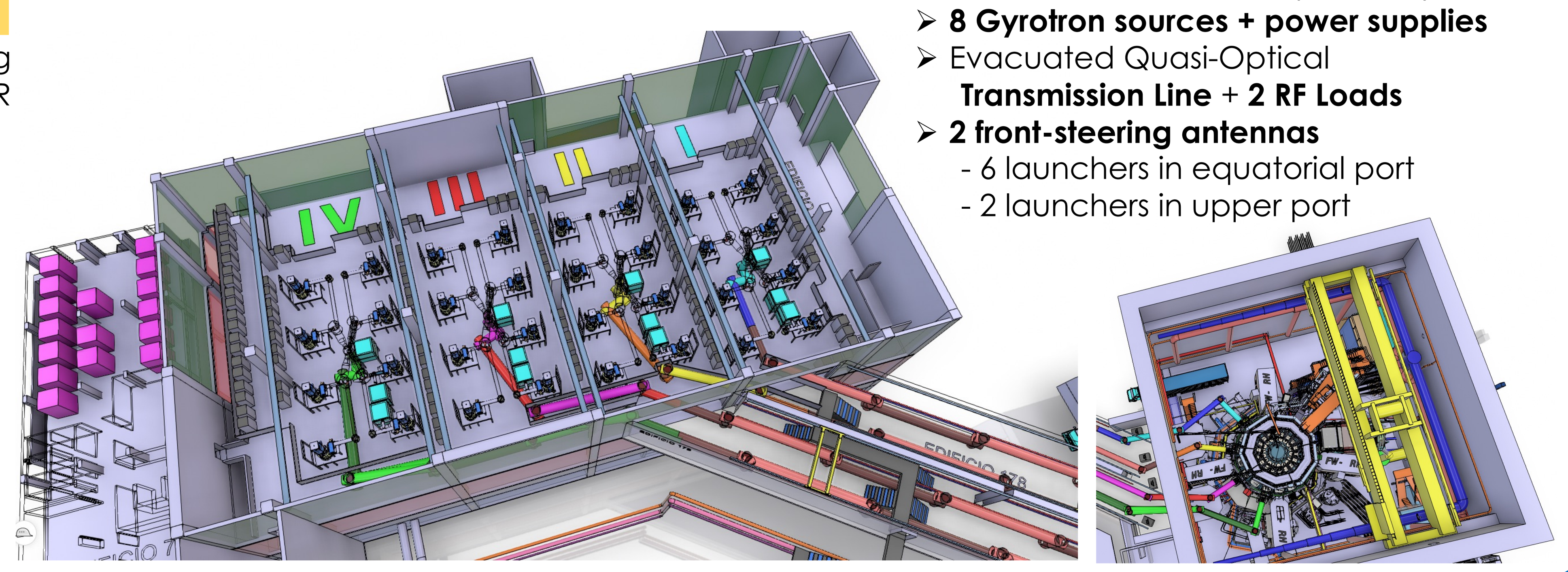
Introduction

P5-3447 by G. M. Polli | P5-3323 by P. Martin | P3-2816 by A. Romano

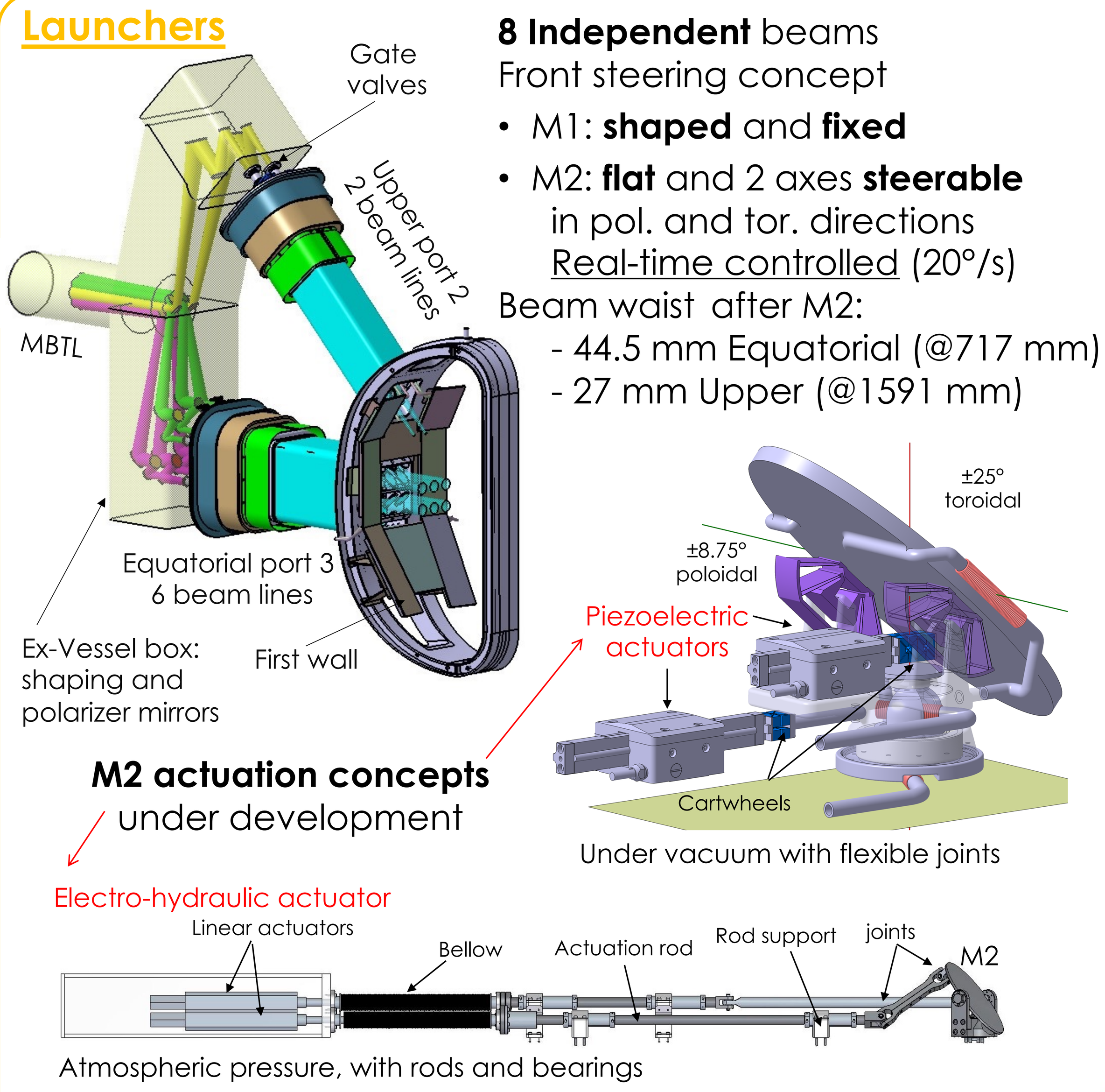
The **Divertor Tokamak Test (DTT)** facility will be equipped with an **ECH system** providing **~28.8 MW** to the plasma to reproduce the level of divertor heat loads foreseen in ITER and DEMO and to address the power exhaust issue.



4 Clusters, each one composed by:
- **8 Gyrotron sources + power supplies**
- Evacuated Quasi-Optical **Transmission Line** + **2 RF Loads**
- **2 front-steering antennas**
  - 6 launchers in equatorial port
  - 2 launchers in upper port



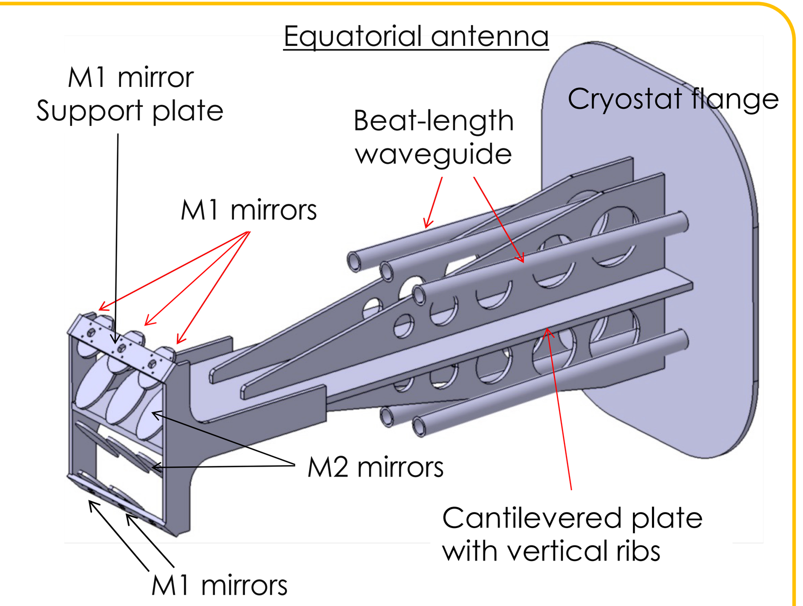
Launchers



8 Independent beams
Front steering concept
- M1: **shaped** and **fixed**
- M2: **flat** and 2 axes **steerable** in pol. and tor. directions Real-time controlled (20°/s)

Beam waist after M2:
- 44.5 mm Equatorial (@717 mm)
- 27 mm Upper (@1591 mm)

M2 actuation concepts under development



- Analyzed under **plasma disruption events** using **FE simulations**.
- Max. reaction forces and torques → torsional deformation up to **49 mm**
- **New design** with a boxed structure and bracing elements to **enhance rigidity**.
- Reduced deformation to **~11 mm**.

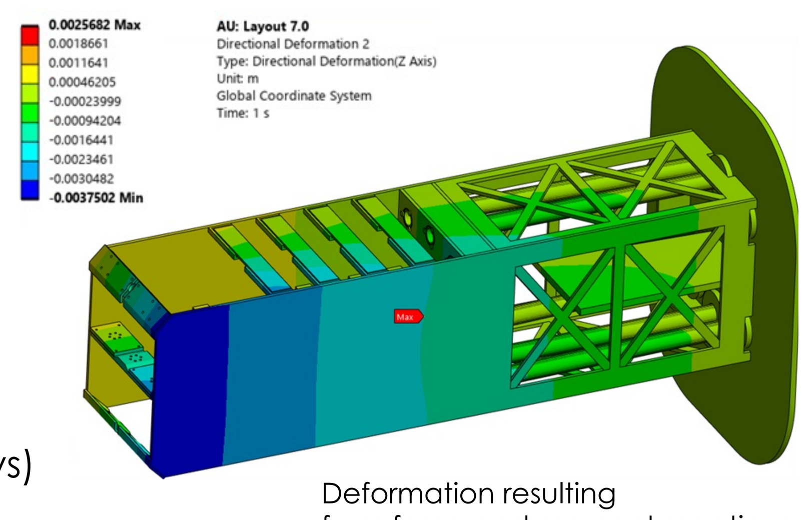
Further reduction expected with electrical insulation (ceramic bushings, insulating plates) to prevent current loops.

M1 & M2 additive manufactured
Active cooled with spiral channel

Study ongoing to achieve **efficient cooling** to **reduce surface deformation and stress** under high thermal loads (1 MW beam, plasma, and stray radiation).
Variable depth complementary spiral channel option proposed as efficient and simply cooling solution

M2 material choice:
- optimal cooling → high-thermal conductivity (copper alloys)
- minimizing induced currents → low electrical conductivity.

Thermomechanical studies show AISI 316 has limits → **AISI 316 + Cu inserts** or the high-strength Nickel alloy (**Inconel 718**) as possible alternative.



Deformation resulting from force and moment reactions extracted by EM analysis loads generated during VDE II scenario.

Ray-tracing (GRAY code) simulations show **~1% of XM coupling** can cause **reflected power** (>3 MW/m²) at the first wall. **Beam polarization** control is essential to ensure safe operation and protect diagnostics.

Transmission Lines

Quasi-optical propagation of **8** Gaussian beams in a **multi-beam (MB)** confocal layout, minimizing distortion and operating under vacuum to reduce arcing risk. **Single-beam (SB)** sections connect **MB** to the gyrotrons/antennas with combiner/splitter mirrors.

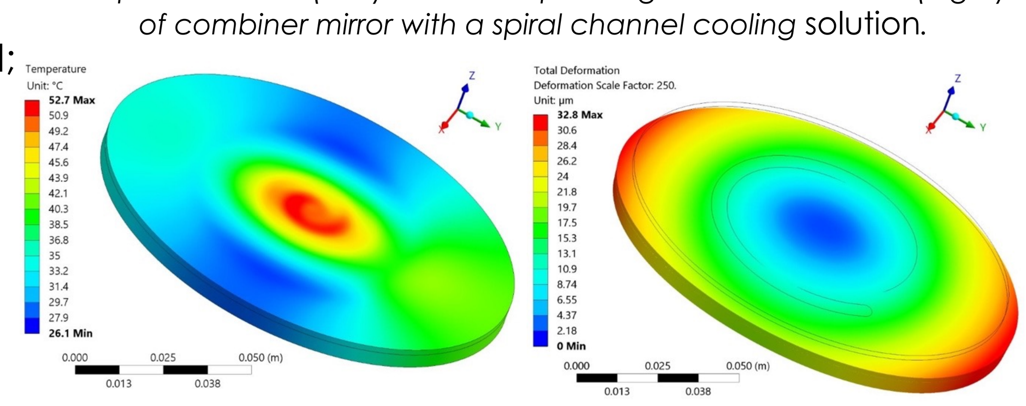
- **~80 mirrors per cluster** over ~100 m of beam path.
- Transmission efficiency **>90%**.
- Universal polarizer system (P1–P2) for matching the injected wave to the plasma.

Analytical sinusoidal-grating polarizer model was validated (≈ 0.5% error vs. HFSS) and enables real-time polarization control. All required angle coverage can be obtained with two elliptical polarizers.

Cooling solutions tested: **spiral channels** and **TPMS structures** .
- **SB mirrors:** max deformation ≈ 30 µm.
- **Combiner/splitter mirrors (TPMS):** deformation ≈ 60 µm.

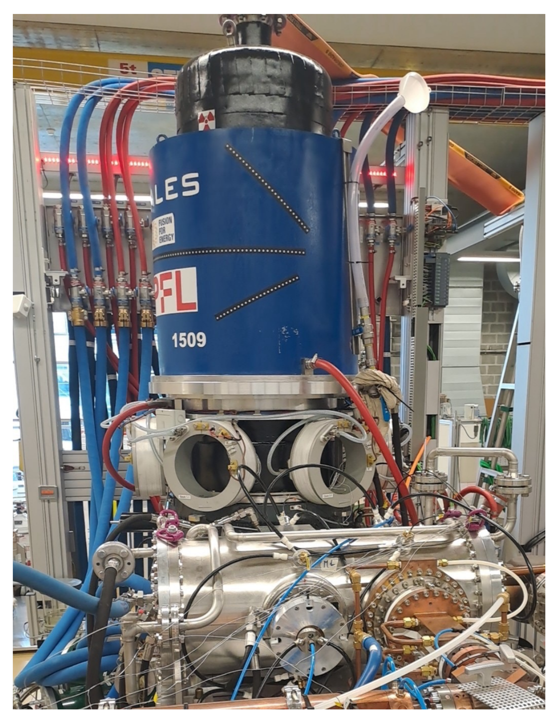
- Two **CuCrZr prototypes** additive manufactured; spiral channels selected as baseline, TPMS option for polarizers.
- **MB mirrors:**
  - **multi-spiral cooling** deformation ≈ 60–90 µm;
  - simpler **single-spiral design** under study for easier fabrication and monitoring.

Temperature field (Left) and corresponding total deformation (Right) of combiner mirror with a spiral channel cooling solution.

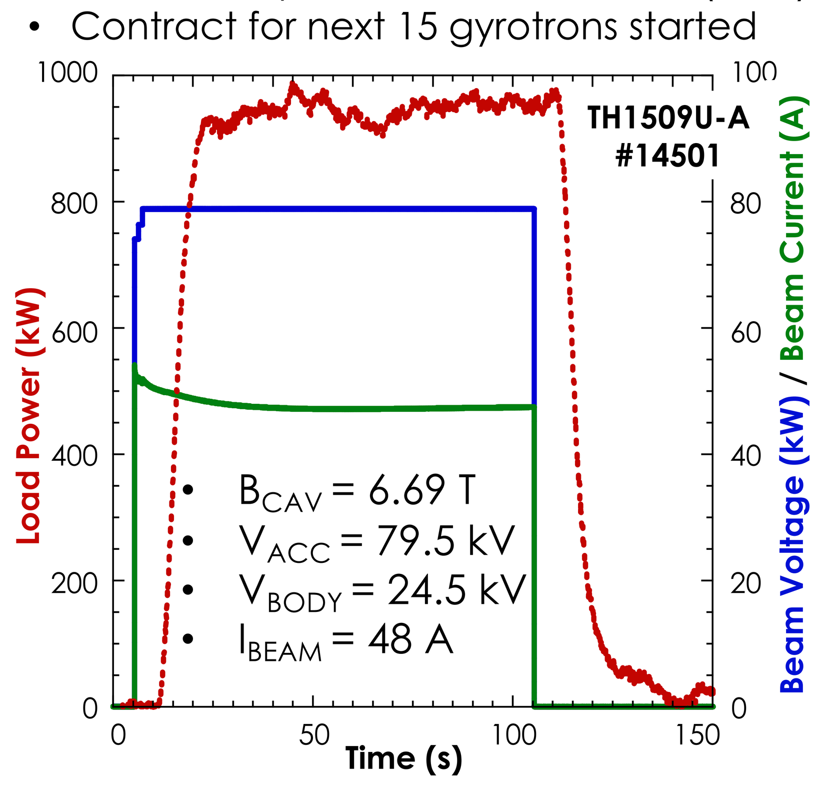


Gyrotron and HV Power Supplies

Gyrotron specifications:
- Frequency: **170 ± 0.3 GHz**
- Power: **≥ 1 MW**
- Pulse length: **≥ 100 s**
- Duty cycle: **> 10%**
- TEM_{00} purity mode: **> 98%**
- Efficiency: **≥ 40%**
- Reliability: **~ 95%**
- He-free SCM, B_{AXIAL}=**6.78 T**



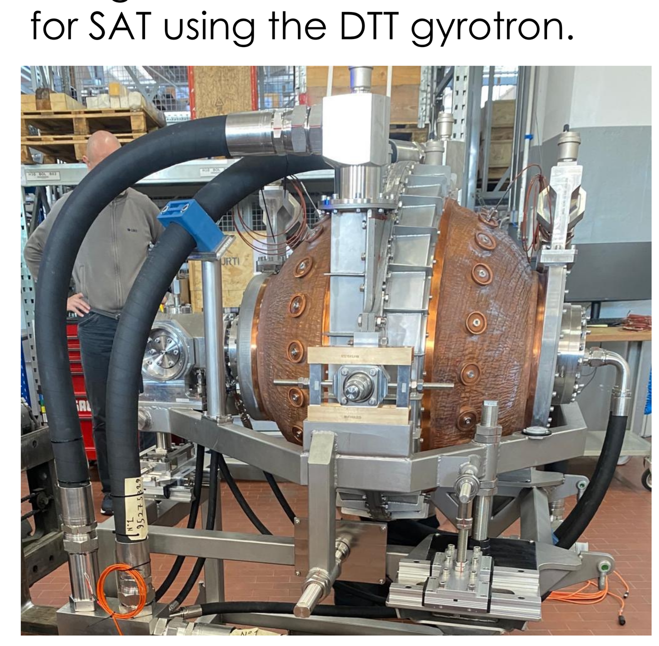
- International procurement with the F4E
- Supplier chosen: **Thales**
- Interim FAT performed at FALCON (EPFL)
- Contract for next 15 gyrotrons started



- 4 **RF loads** procurement in progress
- Supplier chosen: **Curti–LT Calcoli**
- Completion in 2026.
- First RF load FAT completed
- Being delivered to FALCON for SAT using the DTT gyrotron.

Power supplies:
- 1 x Main HVPS: **-60kV, 110A** (2 gyrotrons fed in pair)
- 1 x Body PS: **+30kV, 100mA**
- 1 filament heater: **-25A, 35 V**

- Conceptual design completed
- Technical specifications defined
- First 8 sets on site in **2031**

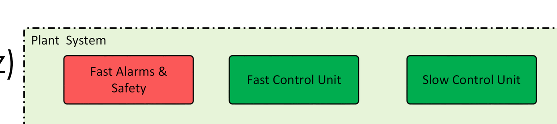


Short evacuated **Connection Line** to connect the gyrotron with RF load
Designed to enable the tests of:
- the output beam of the gyrotron (FAT)
- different mirror technologies for R&D

Control system

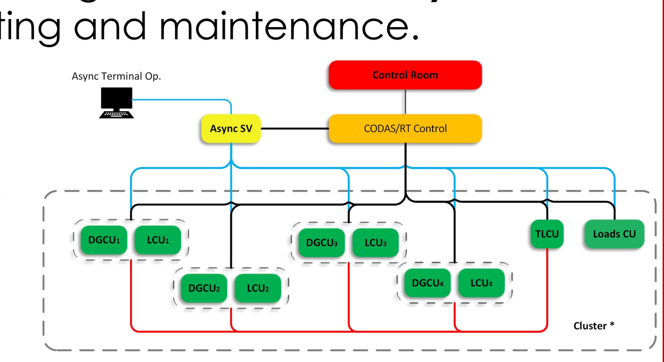
Network of **Plant Systems Units (PSU)** connecting CODAS, Plasma Control System (PCS) and ECRH components.

PSU structure:
- **SCU**: PLC-based, Protections + slow communications (≤1kHz)
- **FCU**: PC-based, RT control + HVPS references generator.
- **FA&SU**: Arc detection + fast interlocks.



In CODAS/PCS, the **ECRH plant supervisor** manages all **PSUs**; an ***Asyn**chronous **SuperVisor*** handles independent gyrotron testing and maintenance.

PSU types:
- **D**ouble **G**yrotron **CU**: gyrotron pair, PS + auxiliaries + thermal/hydraulic monitoring.
- **T**ransmission **L**ine **CU**: RF transmission, vacuum, mirror alignment, temperature + arc detection.
- **L**auncher **CU**: manage mirrors + polarizers, temperature + arc detection.
- **LoadCU**: RF Load, monitors RF power (bolometric) + safety



Single Cluster PSU organization