# Divertor Tokamak Test facility diagnostic systems integration and design: current status and future perspectives

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DTT Consortium (DTT S.C.a r.l. Via E. Fermi 45 I-00044 Frascati (Roma) Italy)

# Outline

DTT in one slide

DTT diagnostic equipment organisation

Diagnostics design status

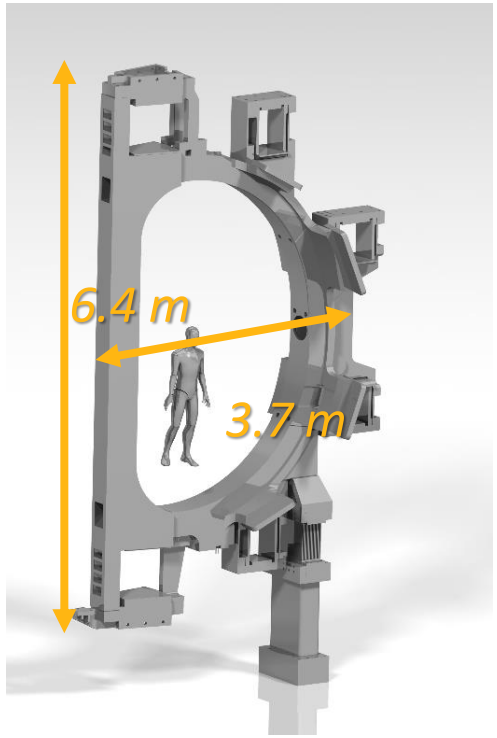
Diagnostics integration

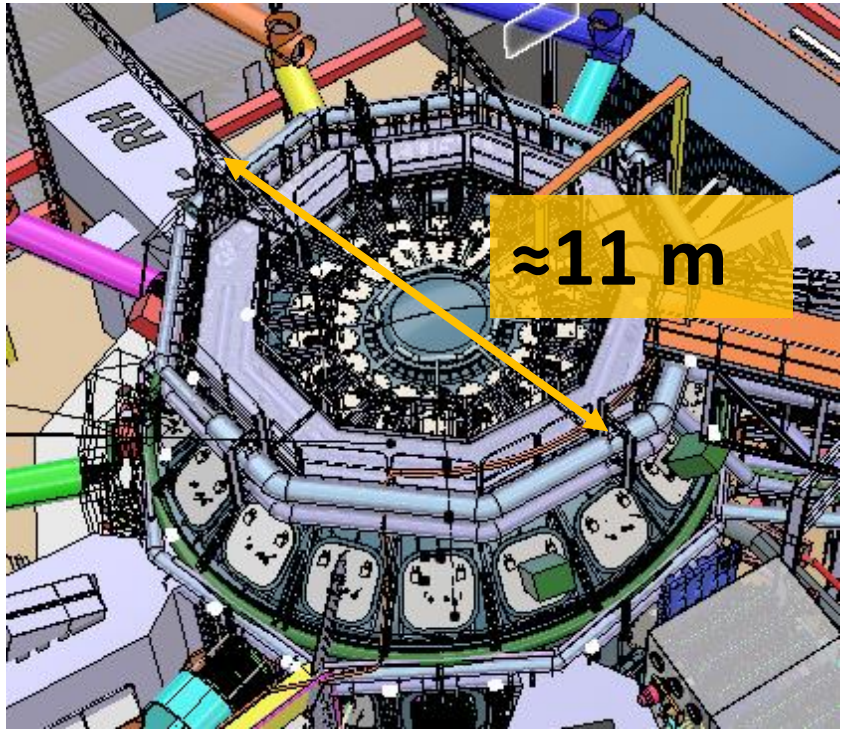
# The Divertor Tokamak Test facility in one slide

**DTT** (Divertor Tokamak Test) is a fully **superconducting medium-size tokamak** designed to address **power exhaust challenges** under **integrated, reactor-relevant conditions**, **currently under construction** in **ENEA research centre in Frascati, Italy**

DTT main design parameters

| Parameter | Units | |
|---|---|---|
| Major radius, $R$ | m | 2.19 |
| Minor radius, $a$ | m | 0.70 |
| Volume, $V$ | $m^3$ | 35 |
| $t_{pulse}$ | s | 100 |
| Plasma current, $I_p$ | MA | 5.5 |
| Toroidal field, $B_T$ | T | 5.85 |
| $P_{sep}/R$ | MW $m^{-1}$ | 15 |
| Total power, $P_{tot}$ | MW | 45 |
| $P_{ECRH}$ | MW | 29 |
| $P_{ICRH}$ | MW | 6 |
| $P_{NBH}$ | MW | 10 |




*G.M. Polli, this conference, plenary session* – ***DTT manufacturing and assembly plan***

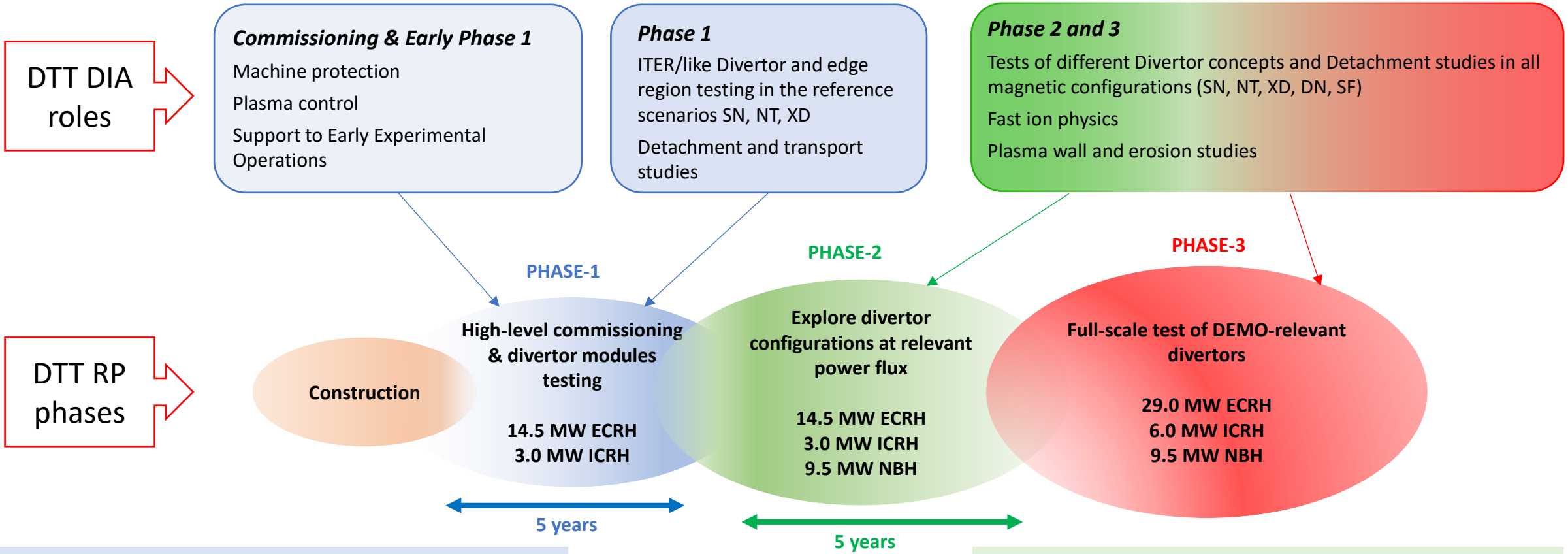
F. Romanelli *et al* 2024 *Nucl. Fusion* **64** 112015 - ***Status of DTT design***

F. Crisanti *et al* 2024 *Nucl. Fusion* **64** 106040 – ***DTT physics principles***

# DTT diagnostic equipment organisation



The construction and integration of a complete set of DTT diagnostics have been planned, organising them in three distinct groups according to the objectives of each experimental phase to undertake the goals of DTT Research Plan and to fulfil the requirements for machine protection and early operation phase. This strategy anticipates future diagnostic integration, minimizing constraints that could otherwise prevent installation during later operational phases and preserving the DTT experimental programme.




G. Giruzzi *et al* 2026 *Nucl. Fusion* **66** 116017 – ***DTT Research Plan***

F. Bagnato *et al* , accepted for publication in RSI – ***DTT diagnostics***

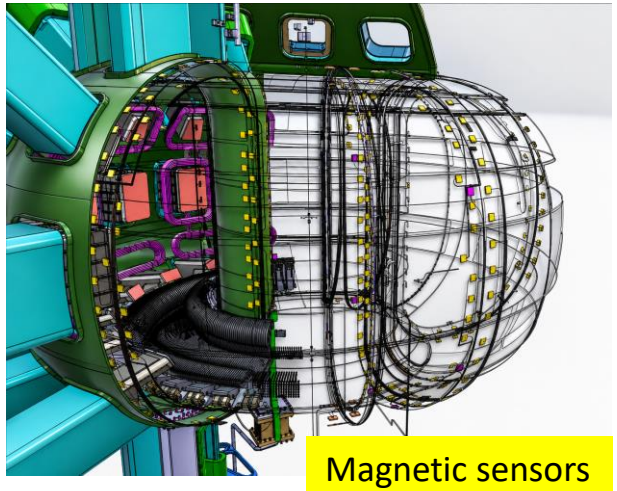
# DTT diagnostic equipment organisation

Assembly

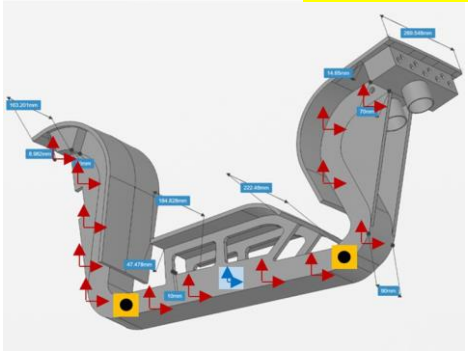
### *In-Cryostat diagnostics*

Include In-, Ex-Vessel, Divertor and FW diagnostics

- Mounted at DTT first assembly



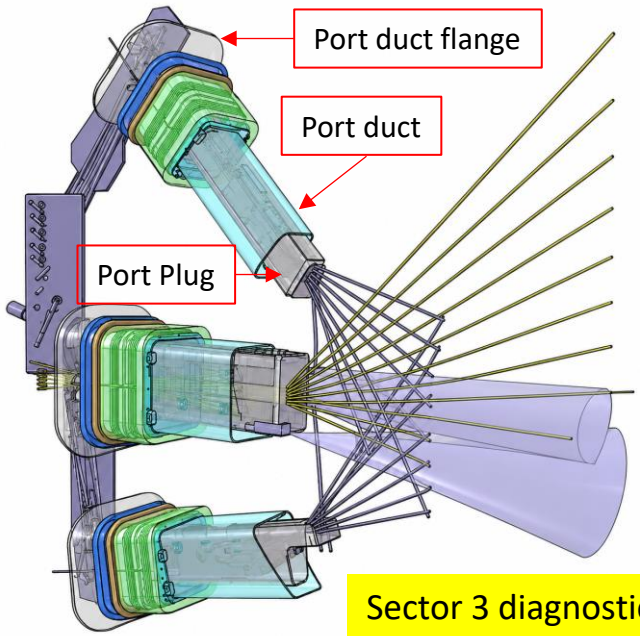
Magnetic sensors



### *Port duct diagnostics*

Include diagnostics located in the port ducts, PP or mechanically connected to the Port Duct flange

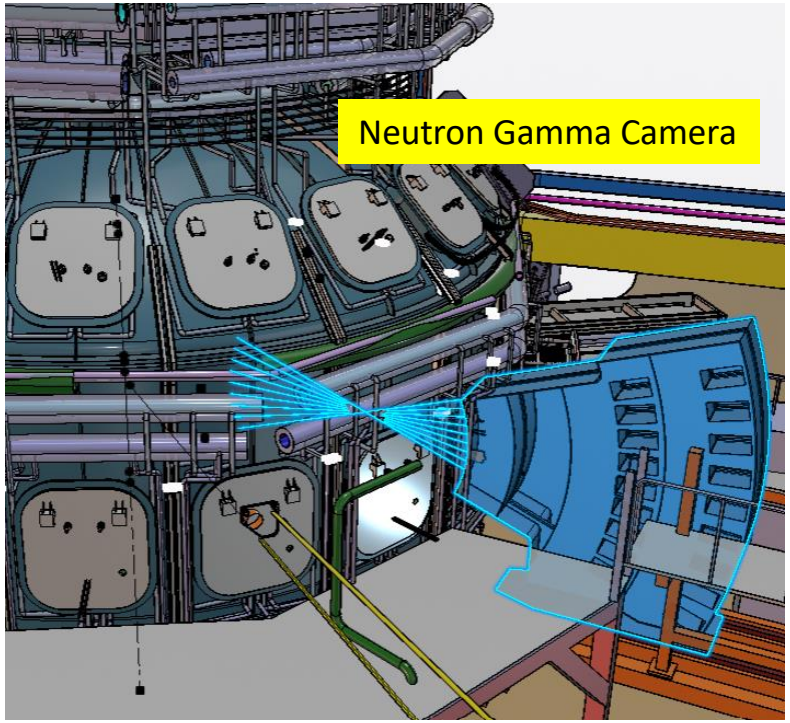
- **59/82** ports available for diagnostics
- **40** already assigned
- **19** equipped at Commissioning




Sector 3 diagnostics

### *Ex-Cryostat diagnostics*

Include sensors or diagnostics located outside the Cryostat and mechanically decoupled from it



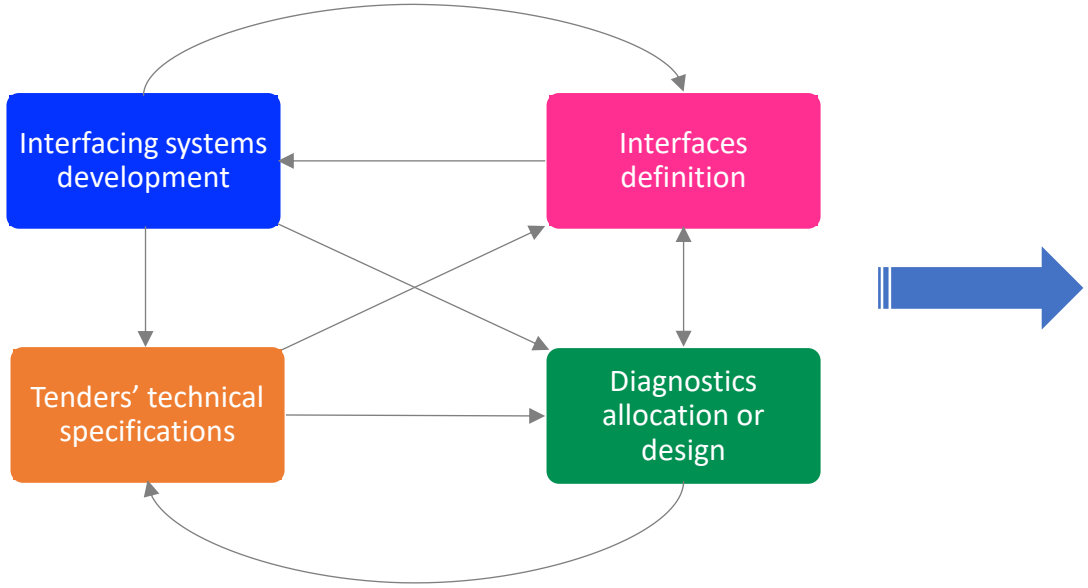
# Diagnostics design status

- DTT diagnostics are being developed by ENEA in partnership with the DTT Consortium members and with the active involvement of EUROfusion collaborators and industry.
- The conceptual design of Commissioning and Phase 1 diagnostics has been mostly completed in March 2024 according to their priority
- The engineering design of diagnostics that are critical for DTT schedule has already been performed; all the others will start in the next few months.
- Preliminary conceptual design of Phase 2 and newly added Commissioning & Early Experimental Operation diagnostics is in progress, focusing on interface and integration issues
- By the Kick-off Meeting of the Assembly call for tender, In-Cryostat diagnostics and diagnostic components design must reach a sufficient level of maturity:
  - all requirements must be defined ✓ **DONE**
  - integration and interface issues must be solved ✓ **ONGOING**

# Diagnostics integration

**Diagnostics integration in DTT is challenging**:

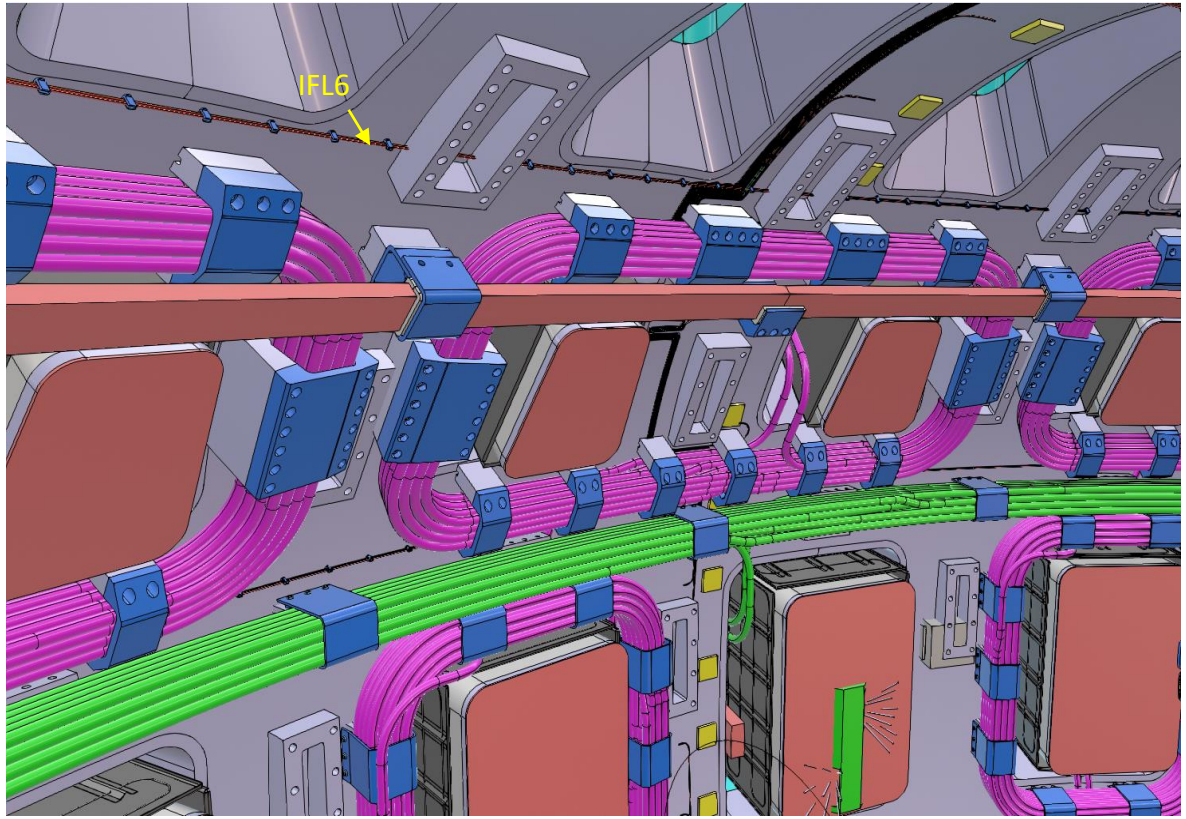
- **DTT is a compact and actively cooled device** → diagnostics will have to be integrated in a narrow, crowded space, especially in the Vacuum Vessel and within the Cryostat. Actively cooled walls may cause integration issues as well
- **The finalization of major DTT contracts** (e.g. Vacuum Vessel, Assembly) is progressively defining the interfaces, while diagnostics engineering design is still ongoing
- **Evolving interfacing DTT components** →
  - May require modifications to the diagnostics design to ensure compatibility with the final interfacing systems
  - May cause changes in diagnostics allocation, that propagate across multiple diagnostic systems requiring diagnostics redesign

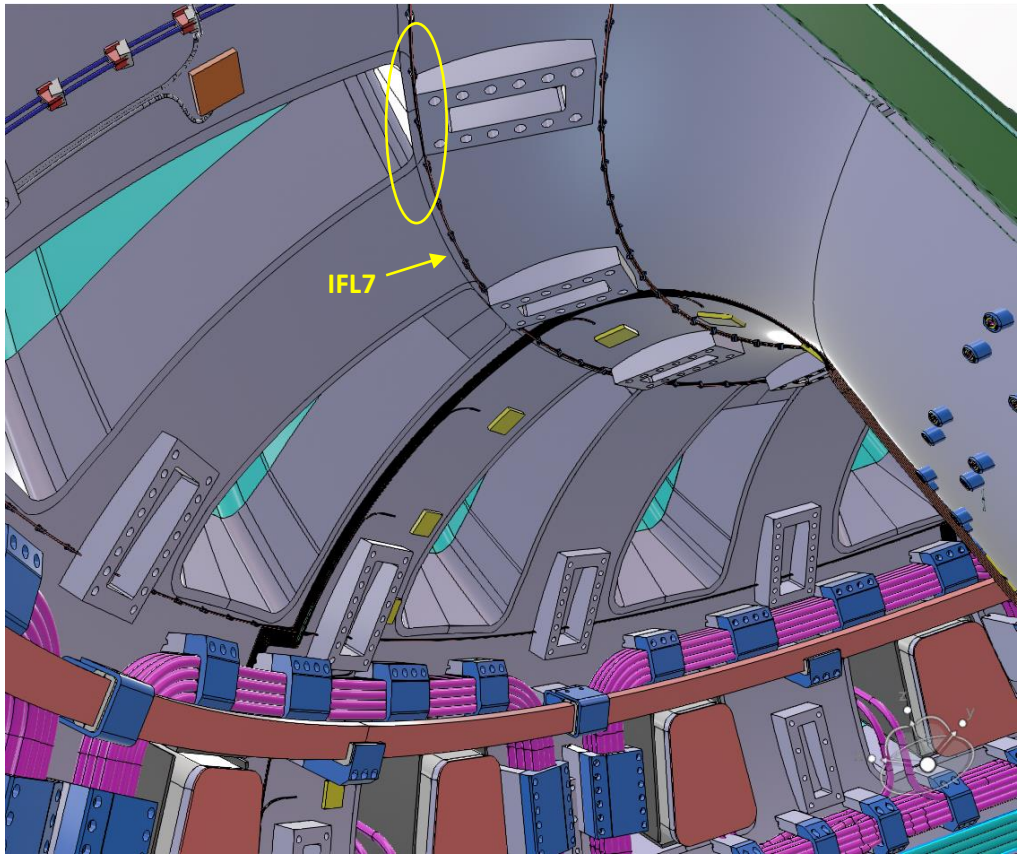



Complex interrelationships managed on a "case by case" basis

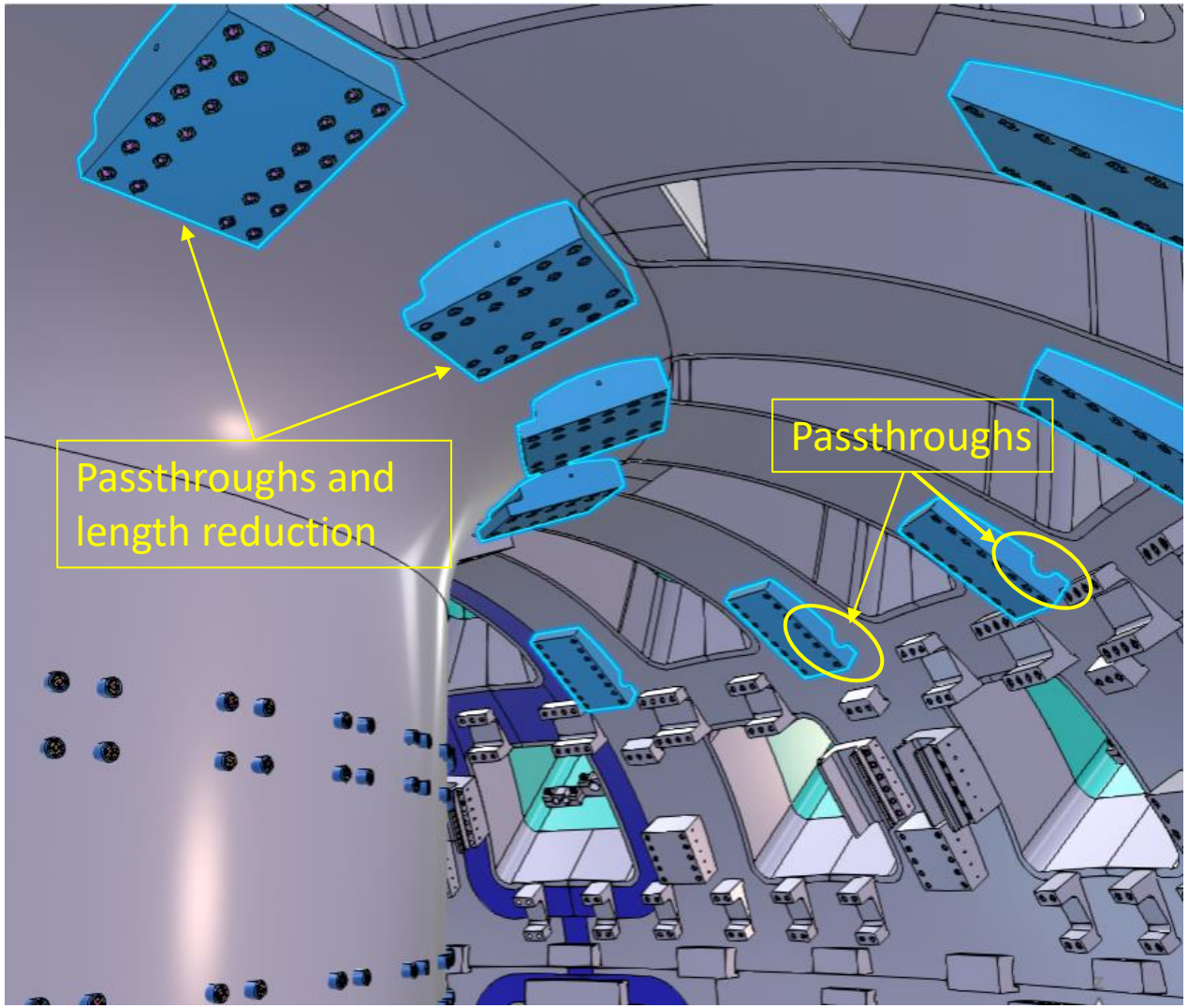
# Impact on/by DTT contracts – example: Internal Flux Loops

The poloidal position of the internal flux loops cannot be changed because of geometrical and reconstruction code constraints → interferences to be solved within the new design of the Top FW modules supports in the scope of the Vacuum Vessel contract



# Impact on/by DTT contracts – example: Internal Flux Loops




New design of the Top FW supports, with **changed geometry** to:

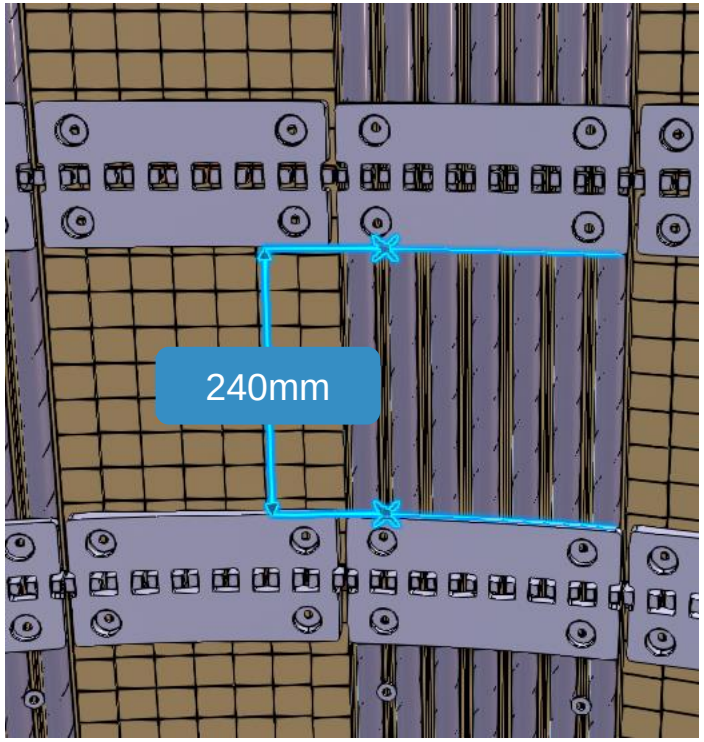
- **Remove clashes** with Internal Flux Loops
- **Satisfy welding inspection requirements** asked by the VV contractor

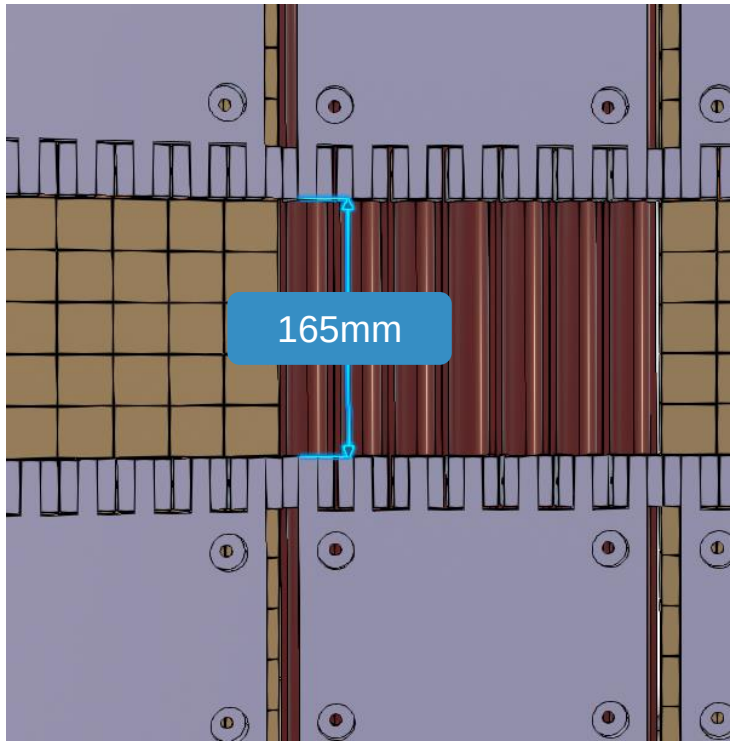
***M. Dalla Palma**, this conference, Topic H: Progress in the design and the verification of the DTT vacuum vessel*

# Effects of interfacing components design updates

## HFS First Wall modules backplates

Mechanical and thermal analyses have shown that the former design of the High Field Side First Wall modules backplates could not prevent the onset of high stresses on the FW pipes under EM loads. Hence the backplates' design has been changed (*), preserving the interfaces with the Vacuum Vessel but increasing their vertical size, thus reducing the interspace between two adjacent locations.




This change has an impact on the diagnostics (or diagnostics parts) located behind the First Wall modules, causing modifications in their design

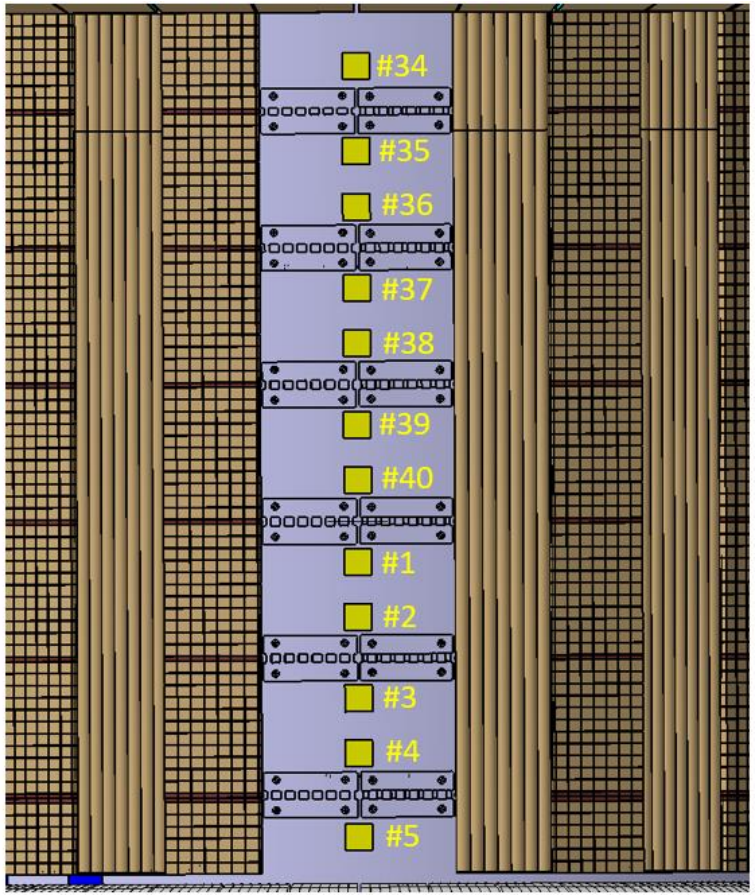
**Examples**:

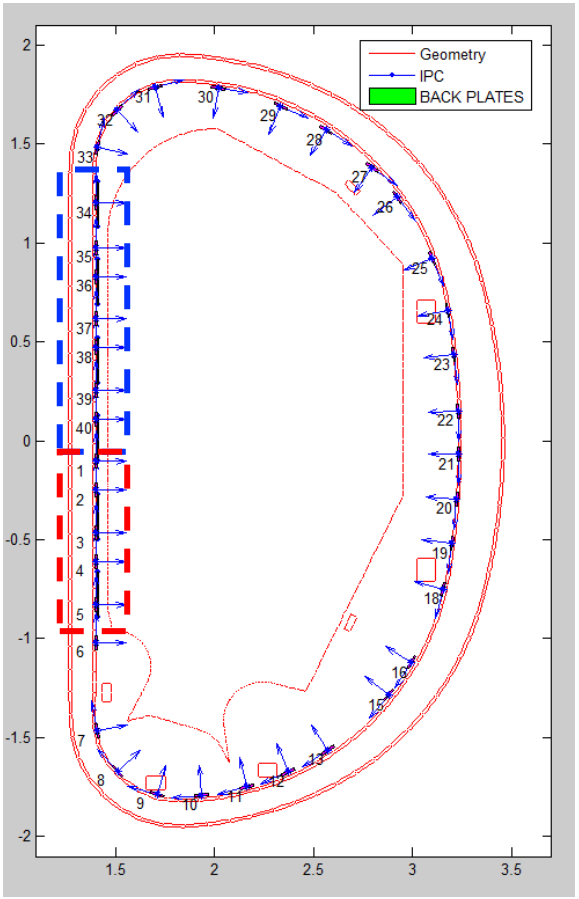
- Biaxial Pick-Up coils
- Plasma Position Reflectometer

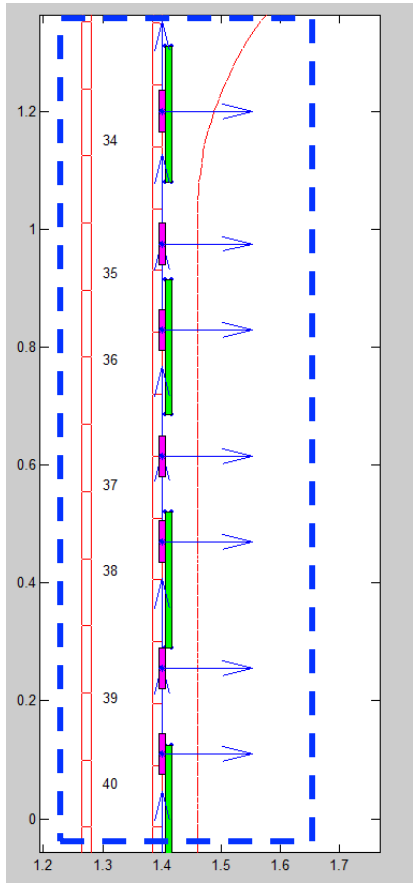
*(*) see D. Paoletti, this conference, poster BO-104*

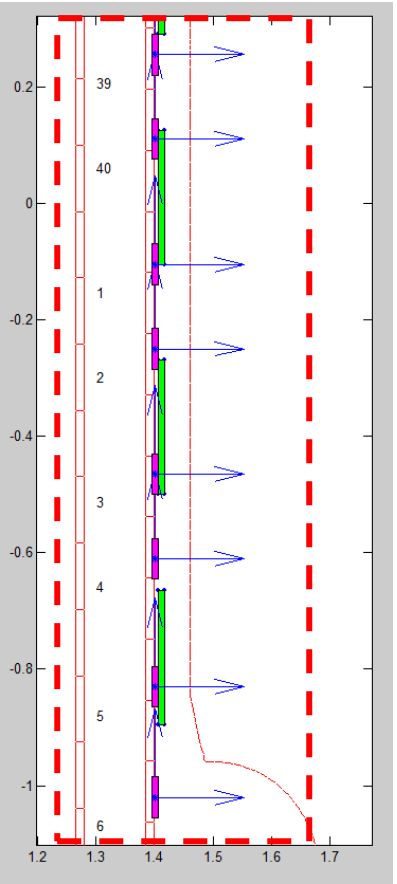
# Biaxial Pick-up Coils

- The In-Vessel Biaxial Pick-Up Coils diagnostic was originally composed of six poloidal arrays of 38 sensors, 12 of which between the backplates in the HFS
- The increased vertical size of the IFW backplates caused an overlap with the HFS IPC

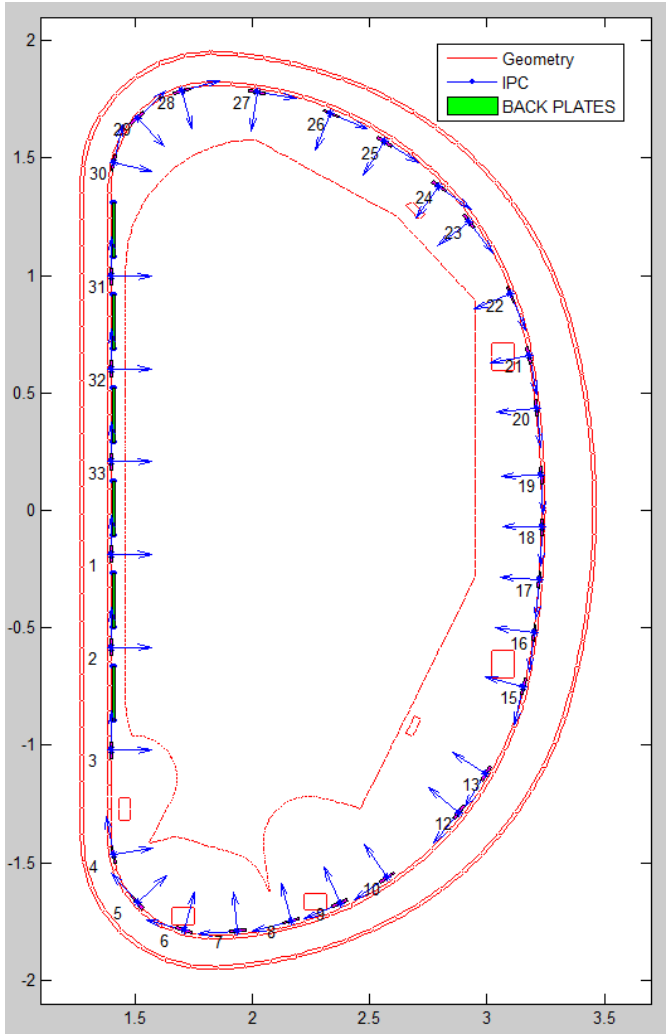


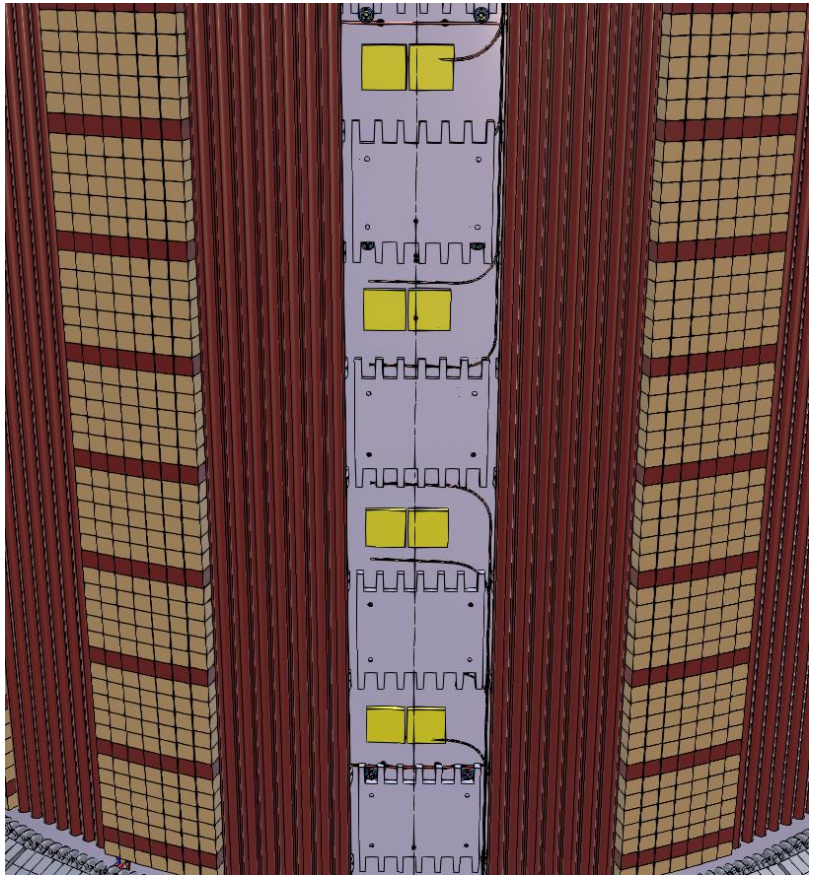





# Biaxial Pick-up Coils




The number of HFS Biaxial IPC was **reduced to 31** to fit into backplates' interspace. Extra IPC were added on one side for redundancy.



***Impact on plasma control***

The reduction of the IPC may cause a possible downgrade in magnetic equilibrium reconstruction accuracy and may affect the identification of MHD modes → **possible impact on plasma control performance**.

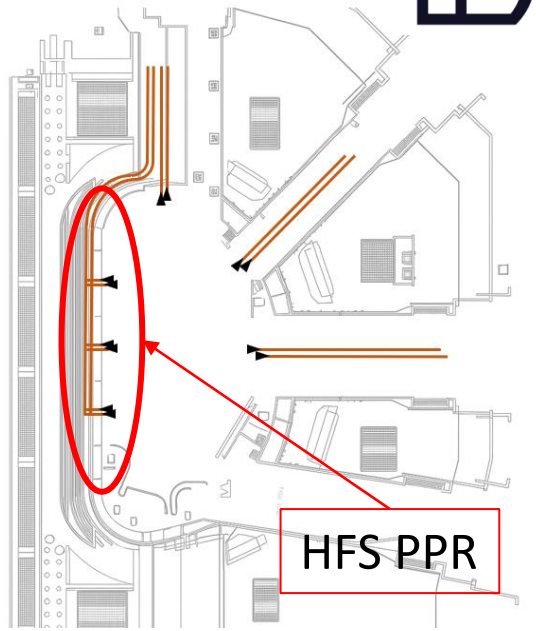
The extent of the downgrade must be evaluated to confirm that the accuracy remains within the limits required by the PCS

***Impact on VV contract***

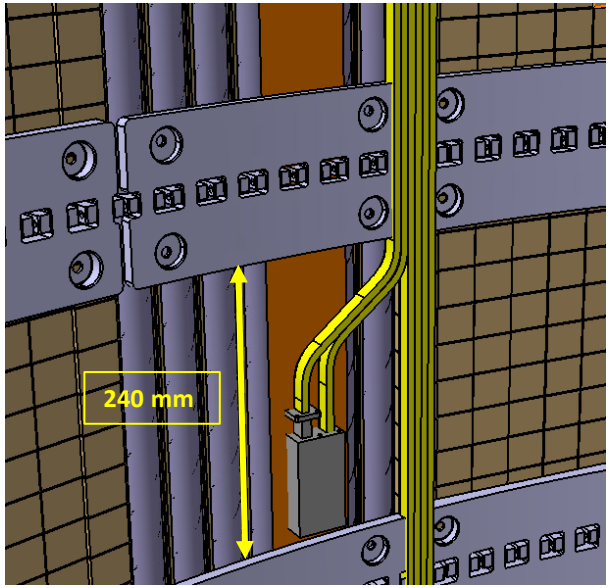
The VV contractor is in charge of installing the IPC supports on the VV inner shell → once the validity of the new layout is assessed, the new IPC coordinates must be provided to the VV contractor

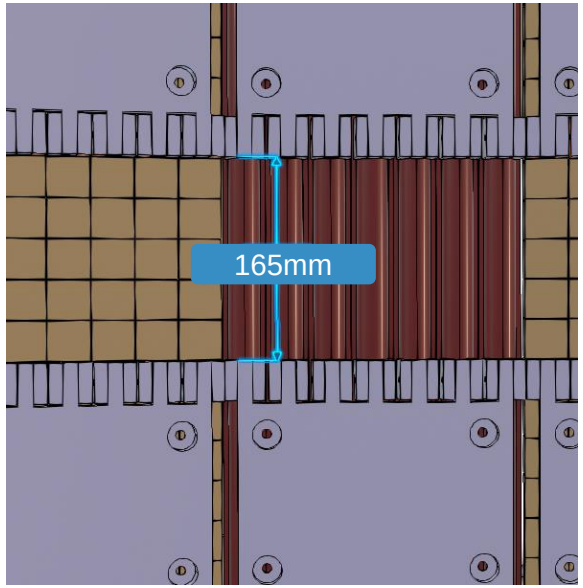
# Plasma Position Reflectometer

- 3 HFS, 1 Vertical and 2 LFS Lines of Sight, each LoS featuring two oversized waveguides (transmitter and receiver) and hoghorn bistatic antennas. The transmitter propagates O-mode frequencies in the range 18-110 GHz (K-W frequency band).
- The PPR diagnostic will be active during Phase 2, but **its HFS components must be installed at DTT first assembly**




- Oversized WG required carefully optimized bends (hyperbolic secant) to overcome integration challenges and to prevent mode conversion.
- The reduction of the available space between the backplates would require instead 90° bends to allocate the antennas



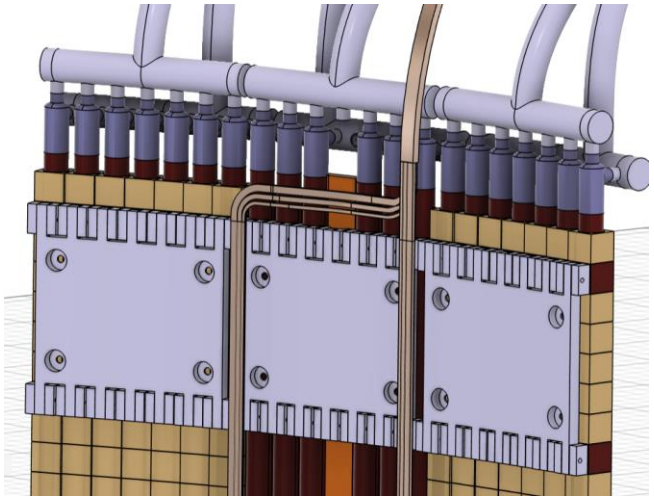

PPR High Field Side lines of sight (waveguides + antennas) could no longer be integrated

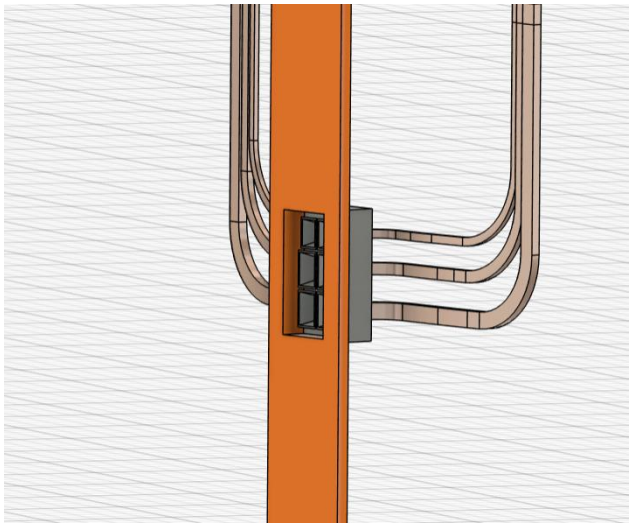
The new constraints required a **change in the PPR design**

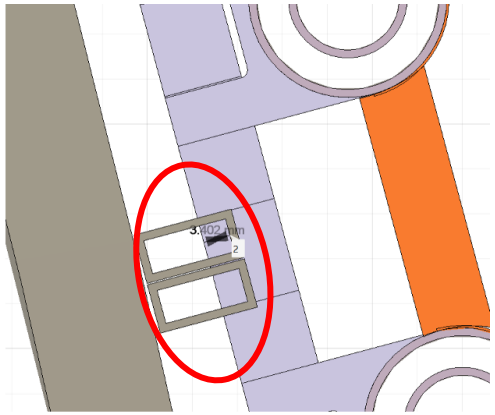
F. Ruffini *et al* , 2025, Journal of Instrumentation, 20(5) C05030

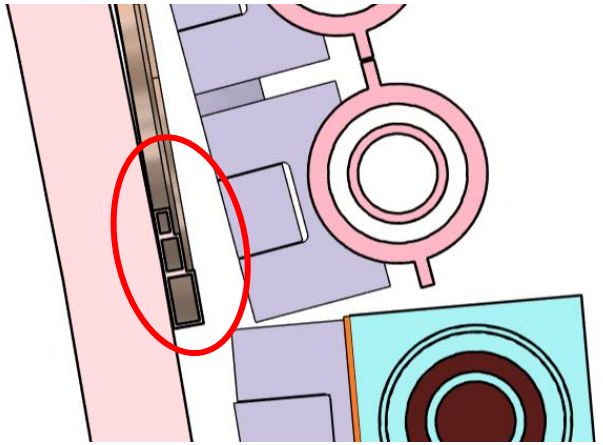
# Plasma Position Reflectometer

New proposal solving integration issues: using fundamental WGs instead of oversized ones, WG fixed on the VV, and distributing the LOS over three DTT sectors









… but this requires the modification of three standard FW modules on the HFS with an adapted thermal bridge

To progress with the integration and the design, **simulations for the reconstruction of the plasma position** and **mechanical and thermal analyses** on HFS standard first wall modules **will be performed** to prove the feasibility of the new layout

# Effects of interfacing components design updates

## Port Plugs 3 and 4

- Among other key functions (*), DTT Port Plugs provide diagnostics with protection from thermal, radiation and plasma loads and mechanical support, also enabling remote extraction for maintenance purposes.
- A preliminary allocation of the diagnostics in the Port Plugs has been performed at the completion of their conceptual design, based on the design of P3 and P4 available at the time.
- The conceptual design of Port Plugs is currently being updated to take into account the required tolerance with respect to the Port Duct during disruptions and to comply with the RHS requirements, leading to a reduction of the section of PP3 and the reshaping of the profile of PP4
- Port plug sizing is highly critical for equipment allocation, and its consolidation is essential for enabling integration activities

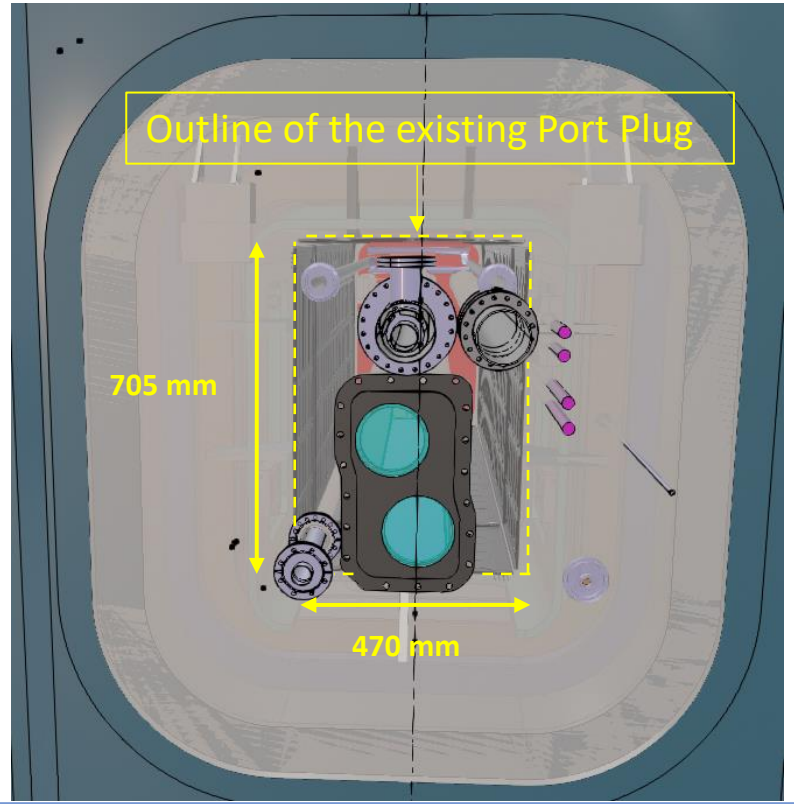


A diagnostics reallocation campaign will start as soon as the PP3 and PP4 design is consolidated

*(*) see A. Salvitti, this conference, poster 071*

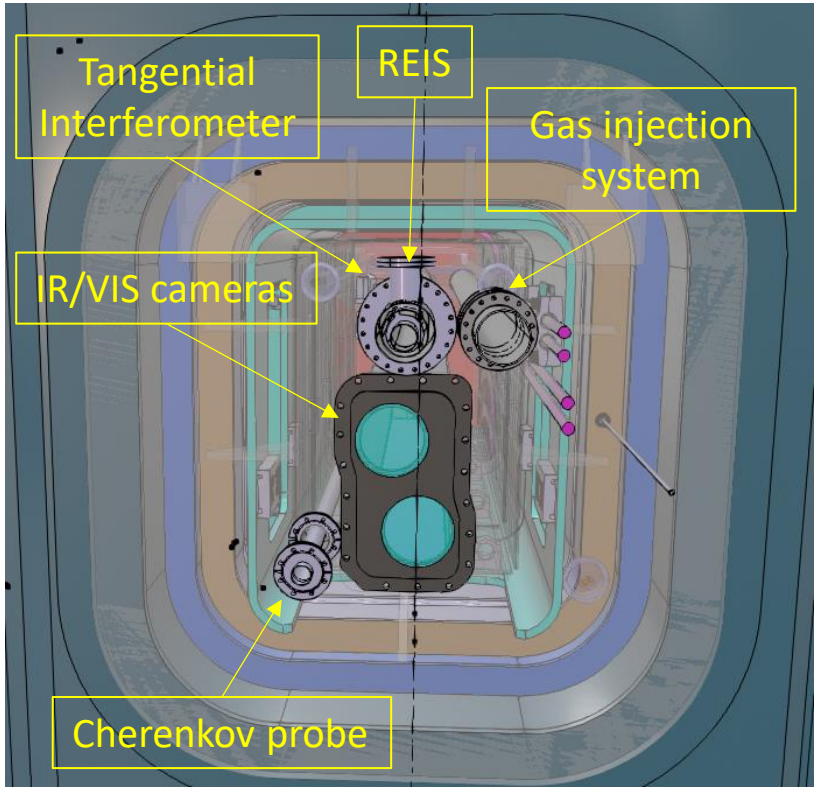
# Equatorial Port Integration Challenges

- Equatorial ports are the most advantageous location for diagnostics, since they provide an excellent view of the plasma core and a suitable view of the divertor region → they are already congested



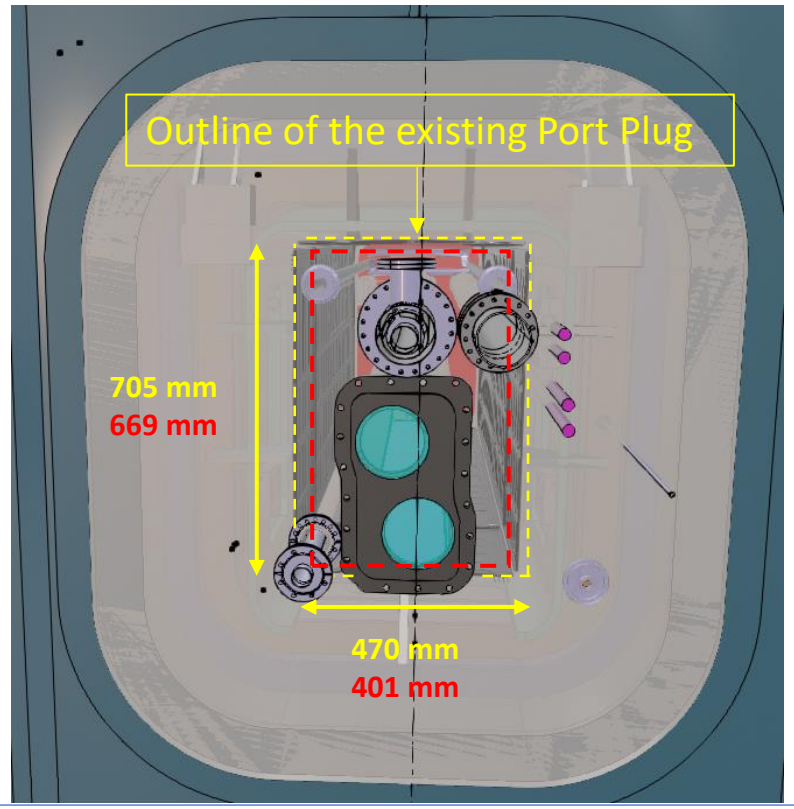

Sector 9 equatorial port current status with the existing port plug cross-section, prior to resizing

Not all diagnostics allocated in the ports have been actually drawn in the CAD



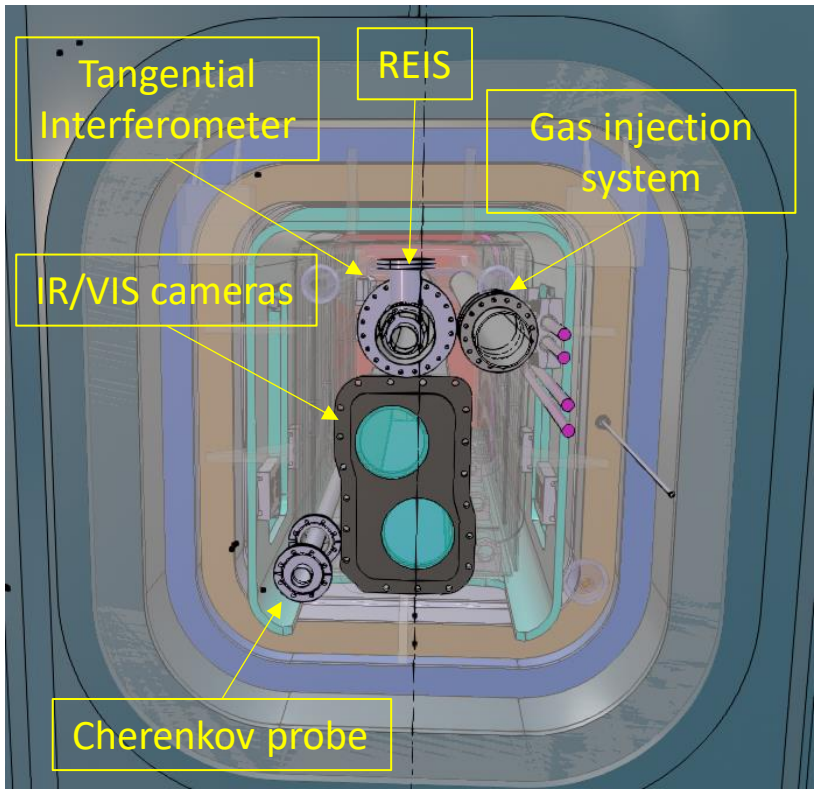
# Equatorial Port Integration Challenges

- Equatorial ports are the most advantageous location for diagnostics, since they provide an excellent view of the plasma core and a suitable view of the divertor region → they are already congested
- The reduction of the PP3 section affects dramatically diagnostics and other systems (ex. Massive Gas and Pellet injection) currently allocated in Equatorial Ports → Diagnostics reallocation is mandatory but highly challenging, having a cascade effect on systems allocated in multiple ports, and may ultimately have an effect also on the definition of the diagnostics set




Sector 9 equatorial port current status with the existing port plug cross-section, prior to resizing

Not all diagnostics allocated in the ports have been actually drawn in the CAD



# Conclusions and future work

- A robust **diagnostics set** has been **defined and organized** to pursue the objectives of DTT Research Plan
- Diagnostics **design is progressing**, giving priority to systems required for the Commissioning and Early Experimental Operations, and **adopting a flexible framework** to allow staged installation and to prevent future allocation issues
- Diagnostic **integration is challenging**, and deeply intertwined with the progress of the design of diagnostics and of the interfacing subsystems
- A huge effort has been made to **provide finalized interface data** for the technical specifications of current and incoming contracts
- Progress is being made on the design of In-Vessel diagnostics experiencing **integration issues**
- A comprehensive **diagnostic reallocation campaign** will start as soon as the revised design of port plugs 3 and 4 will be stable

Thank you!

# Backup slides

# DTT diagnostic equipment organisation

Commissioning and Early Exp. Operations

| Magnetic Measurements |
|---|
| IN & EX Vessel Biaxial and Mono-Axial Pick-Up Coils |
| IN & EX Vessel Diamagnetic and Flux Loops |
| EX Vessel Hall Sensors Bi-Axial Poloidal Set |
| EX Vessel Rogowski coils and Fiber Optic Current Sensors |
| EX Vessel Saddle Loops |
| IN Vessel High Frequency Pick-up coils |
| First Wall Halo Current Partial Rogowski Coils and Wall Shunt Sensors |
| Divertor Biaxial Pick-up Coils and Mono-Axial Toroidal Pick-Up Coils |
| Divertor Halo Current Partial Rogowski Coils and Wall Shunt Sensors |
| Divertor Hybrid Hall probe Sensors |
| **Plasma Wall interaction** |
| Electron Cyclotron Stray Detection Bolometers |
| Langmuir probes and Fast Thermocouples (First Wall and Divertor) |
| Microbalance probes redeposition |
| Electron Cyclotron Stray Detection Sniffer Probes |
| IR and Visible "WIDE ANGLE" Cameras |
| Event detection FAST Visible Camera |
| Neutrals Gas Analyzer and Optical Gas Spectroscopy |
| **Scattering techniques and Spectroscopic Measurements** |
| Visible spectrometer survey and Divertor and Zeff Bremsstrahlung |
| Visible D alpha array and Divertor (Reduced number of LoS) |
| SXR and VUV spectrometers |
| Bolometric Tomography (Reduced number of bolometer cameras) |
| SXR Tomography (Reduced number of LoS) |
| LIDAR Thomson Scattering |
| **Interferometric and Microwave Techniques** |
| Tangential Interferometer |
| ECE Electron Cyclotron Emission Heterodyne Radiometer |
| ECE Michelson Interferometer Spectrometer |
| Vertical Interferometer/Polarimeter (Reduced number of LoS) |
| *Plasma Position Reflectometry (PPR) (HFS Waveguides & Antennas)* |
| Thomson and Interferometer rails under Divertor |
| **Neutron, γ, REs, Fast particle Measurements** |
| Neutron Activation System |
| Runaway Electron Imaging Spectrometer (REIS) |
| Neutron Yield and Hard-X-Rays/Gammas Monitors |

Phase 1

| Plasma Wall interaction |
|---|
| Divertor Langmuir probes and Fast Thermocouples (Full system) |
| Divertor Optical sensors of deformation-strain sensors (FOS) |
| Electron Cyclotron Stray Detection Sniffer probes (Full system) |
| Gas Puffing Imaging |
| IR cameras (science) |
| Langmuir probes reciprocating |
| Neutrals Gas Analyzer and Optical Gas Spectroscopy (Full system) |
| Sample Introduction System (SIS) |
| **Scattering techniques and Spectroscopic Measurements** |
| Bolometer cameras, toroidal asymmetries studies |
| Bolometer Tomography (System installation completion) |
| SXR Tomography (Full system) |
| Charge Exchange Recombination Spectroscopy (CXRS) |
| Diagnostic Neutral Beam Injection (DNBI) |
| Motional Stark Effect Optics |
| Multi-spectral Imaging system Divertor (Visible Filtered Camera) |
| X-Ray Crystal Spectrometer (XRCS) |
| Divertor and External Edge Thomson Scattering |
| Visible D alpha array and Divertor (Full system) |
| Visible Zeff Bremsstrahlung (Full system) |
| VUV spectrometer imaging Divertor |
| BES beam emission spectroscopy |
| **Interferometric and Microwave Techniques** |
| Divertor Interferometer |
| Interferometer/Polarimeter Vertical (Full system) |
| Reflectometry Density Profile Reconstruction (DPR) |
| Reflectometry Turbulence (TR) |

Phase 2 and 3

| Magnetic Measurements |
|---|
| Toroidal Alfven Eigenmodes diagnostic heads (TAE) |
| **Plasma Wall interaction** |
| Laser Induced Breakdown Spectroscopy (LIBS) |
| Laser Induced Breakdown Spectroscopy-(LIBS-Divertor) |
| Laser Induced Desorption Spectroscopy (LIDS) Wall and DIVERTOR |
| **Scattering techniques and Spectroscopic Measurements** |
| Polarimetric Thomson Scattering (PTS) |
| Tangential GEM SXR Imaging |
| Thermal He Beam |
| **Interferometric and Microwave Techniques** |
| Correlation ECE (CECE) |
| ECE Imaging (ECEI) |
| Phase Contrast Imaging (PCI) |
| Plasma Position Reflectometry (PPR) (Full system) |
| **Neutron, γ, REs, Fast particle Measurements** |
| Cherenkov probe |
| Fast ions Deuterium alpha (FIDA-CX) |
| Fast-Ion Loss Detector (FILD) |
| Imaging Neutral Particle Analyzer |
| Runaway Electron Imaging Spectrometer (REIS) (Rad-Hard version) |
| Neutron Gamma Camera |
| Time-Of-Flight (TOF) neutron and HXR gammas spectrometers |

In-Cryostat diagnostics

Port Duct or Port 1 diagnostics

Out/Cryostat diagnostics

Red text — Only IN-Vessel diagnostic parts

# Equatorial Port Integration Challenges

| DTT-WBS Owner | Diagnostic (Equatorial Port) | SECTOR | New allocation | Allocation Change Required | Integration Feasibility Assessment |
|---|---|---|---|---|---|
| DIA-DWL | Cameras IR and Visible WIDE ANGLE | 3 | 3 | | Integration unlikely to be feasible |
| DIA-DIM | Interferometer/Polarimeter Vertical (=> 17/3) | 3 | 17 | Required | |
| DIA-DTR | Visible Spectrometer Survey and Divertor & Visible Zeff-Bremmsthralung | 3 | 3 | | Integration unlikely to be feasible |
| DIA-DIM | Electron Cyclotron Emission Heterodyne Radiometer | 5 | 5 | | |
| DIA-DIM | Electron Cyclotron Emission Michelson | 5 | 5 | | |
| DIA-DIM | ECE Advanced Systems | 5 | 5 | | Integration unlikely to be feasible |
| DIA-DWL | Event Detection FAST Visible Camera | 5 | 5 | | Integration unlikely to be feasible |
| DIA-DIM | Phase Contrast Imaging In (PCI) | 5 | 5 | | |
| DIA-DWL | Cameras IR and Visible WIDE ANGLE | 9 | 9 | | |
| DIA-DNF | Cherenkov Probe | 9 | 9 | | |
| DIA-DIM | Interferometer Tangential (CCR) | 9 | 5 | Required | |
| OVC- VAU | Massive Gas Injection (MGI) | 9 | 9 | | Integration unlikely to be feasible |
| DIA-DWL | Neutral Gas Analyzer (NGA) & Optical Gas Spectroscopy | 9 | 9 | | |
| DIA-DNF | Runaway Electron Imaging Spectrometer (REIS) | 9 | 9 | | |
| OVC- VAU | Shattered Pellet Injection | 9 | 9 | | Integration unlikely to be feasible |
| DIA-DTR | Diagnostic Neutral Beam Injector (DNBI) | 10 | 10 | | Integration unlikely to be feasible |
| DIA-DTR | Interferometer Tangential (CCR) | 10 | 3 | Required | |
| OVC- VAU | Pellet ELM pacing and fueling | 10 | 10 | | Integration unlikely to be feasible |
| DIA-DTR | Reflectometry Density Profile Reconstruction (DPR) | 10 | 10 | | Integration unlikely to be feasible |
| DIA-DTR | Cameras IR and Visible WIDE ANGLE | 15 | 15 | | |
| DIA-DTR | Interferometer Tangential | 15 | 17 | Required | |
| DIA-DTR | SXR Tomography | 15 | 15 | | |
| DIA-DTR | Total Radiate Power Tomography | 15 | 15 | | |
| OVC- VAU | Massive Gas Injection (MGI) | 17 | 17 | | Integration unlikely to be feasible |
| DIA-DTR | Phase Contrast Imaging Out (PCI) | 17 | 17 | | |
| OVC- VAU | Shattered Pellet Injection | 17 | 17 | | Integration unlikely to be feasible |
| DIA-DTR | SXR Spectrometer | 17 | 9 | Required | |
| DIA-DMN | Time-Of-Flight neutron spectrometer | 17 | 17 | | Integration unlikely to be feasible |
| DIA-DTR | VUV Spectrometer Survey | 17 | 9 | Required | |

# DTT diagnostic equipment organisation guidelines

A **flexible framework** has been adopted to allow DTT diagnostic set future optimization and enhancements, and its staged completion along DTT operational phases

No significant time gap between Commissioning and Phase 1 → the **commissioning set must** include diagnostics to **support the first experiments**, as well as plasma control and machine protection

An international panel of experts helped **defining diagnostic priorities** with respect to Commissioning, Phase 1, and subsequent DTT operational phases

The Commissioning priority list has been further refined through several iterations with DTT **operation experts**

# Impact on/by DTT contracts

*Done*

DTT Vacuum vessel →

- In-Vessel diagnostics physical interfaces finalization and identification of clashes
- In- and Ex-Vessel cables paths and EC stray radiation protection conduits requirements collection

DTT Assembly →

- Preliminary assessment of the diagnostics assembly sequences and schedule
- Mapping of In-Cryostat cable types and number for:
  - allocation of the FTs on the Cryostat and Port Ducts walls
  - cable routing and cable conduits dimensioning

*Planned*

DTT Cryostat →

- Mapping of the diagnostics' viewports and services (sub-flanges) on port ducts flanges
- Calculation of bending stresses for Cryostat flange cantilevered diagnostics