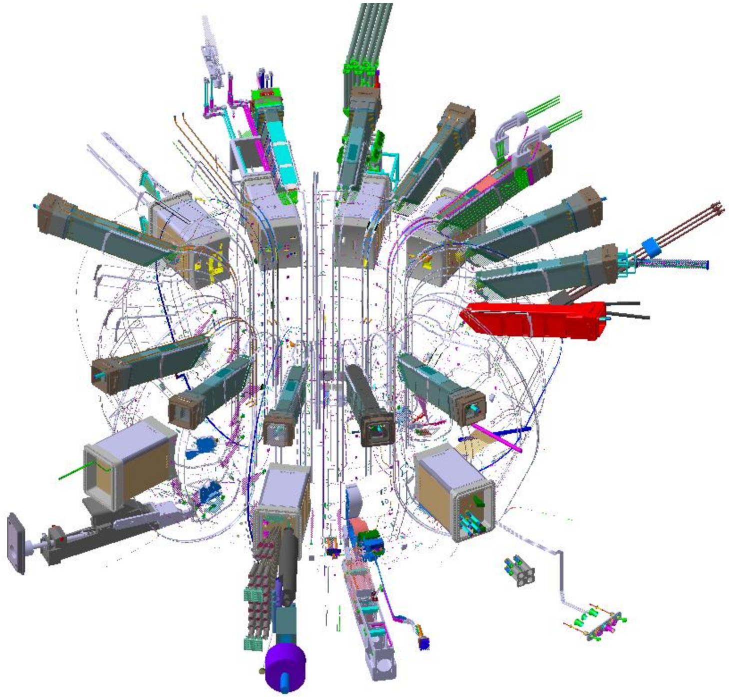
Progress in Integration of ITER Microwave Diagnostics



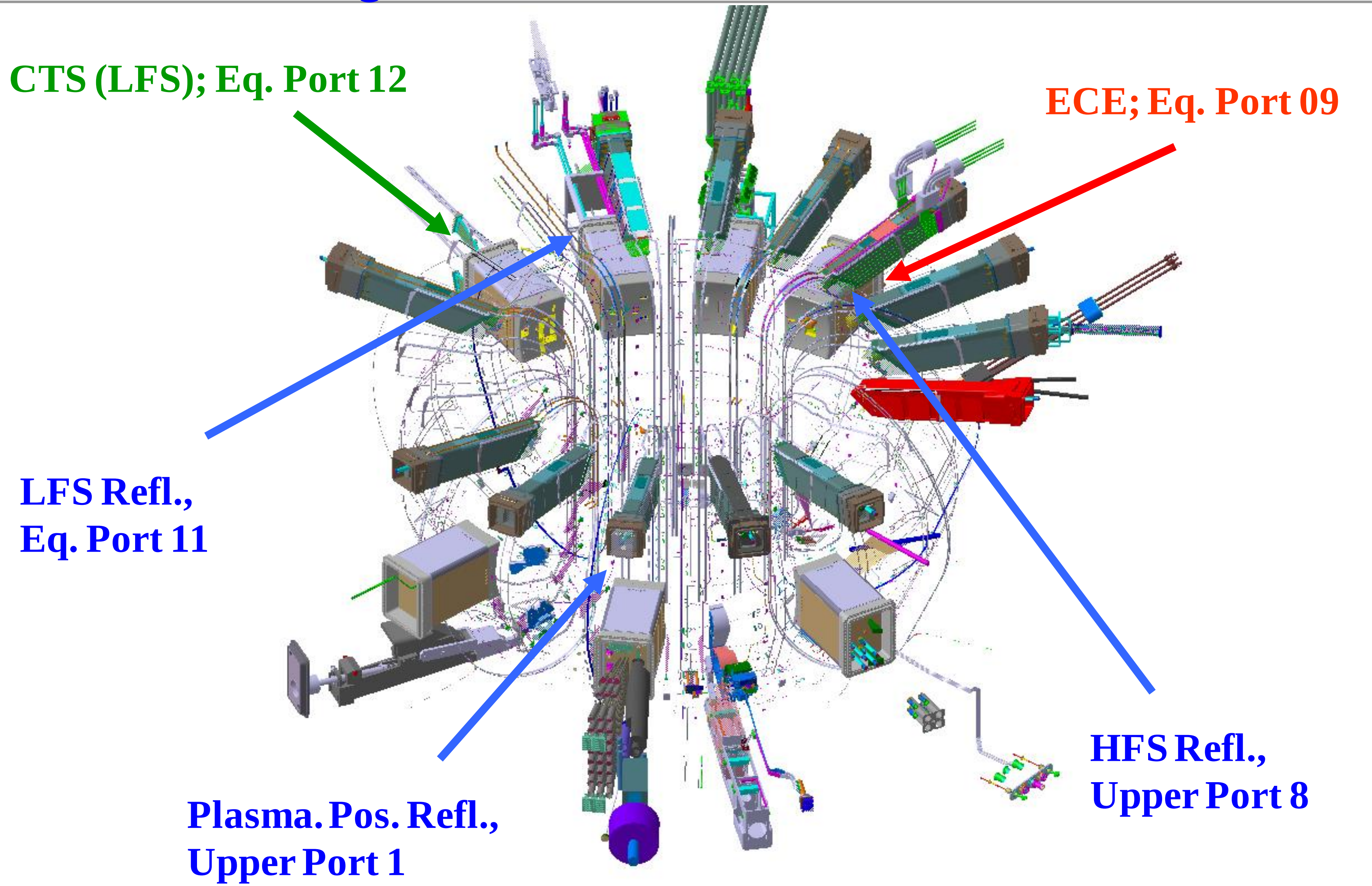
Victor S. Udintsev on behalf of ITER Team

ITER International Organization, CHD Department, Diagnostic Division

Outline

- Introduction
- Integration of microwave diagnostics on ITER
  - ECE
    - Measurement requirements
    - Integration of ECE: current design
    - Outstanding issues
  - Reflectometry
  - Collective Thomson Scattering
- Summary and Outlook

Diagnostics on ITER: Global Overview



Introduction: Microwave Diagnostics on ITER - responsibilities

- **ECE: Equatorial port 09, Front end: US; Transmission: IN; Receivers: IN and US**

- **Reflectometers: HFS, in-vessel and Upper Ports 08, 09 and 17: RF**

  LFS, EP11: US

  Plasma Position, in-vessel and UP01, 14 and EP09: EU

- **Collective Thomson scattering: LFS front end: EU**

Integration of all these diagnostics into ITER, taking into account all necessary interfaces, is a challenge

- **Measurement range: T_e = 0.5 – 40 keV**

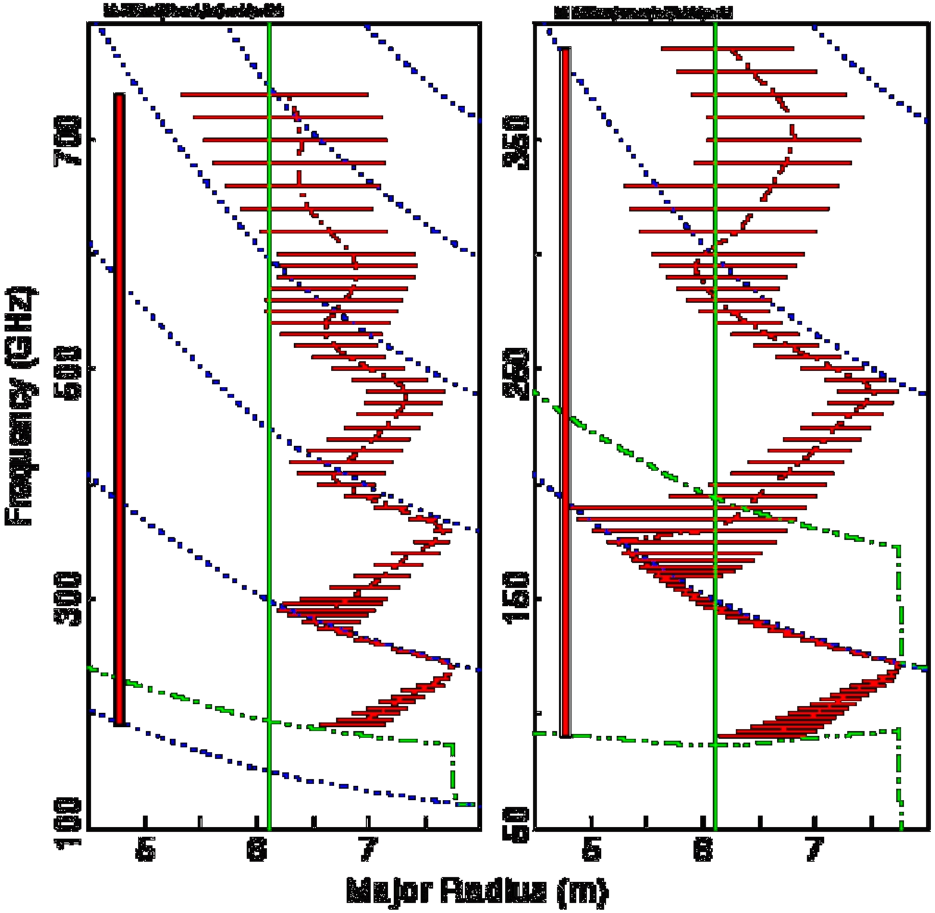
Radial resolution from the present Project Requirements on T_e:

- **Edge resolution: r/a > 0.85, 5 mm**
- **Core resolution: r/a < 0.85, 70 mm (~ a/30)**
- **Detection of MHD, TAE, NTM, turbulence**

Instruments: Michelson interferometry (O- and X-modes) and Heterodyne Radiometers (O (122-230 GHz) and X (244 – 355 GHz) modes; $B_t(0)$= 2 – 5.3 T)

Perpendicular and oblique lines-of-sight to allow studies of non-thermal populations

Integration of ECE: measurement range



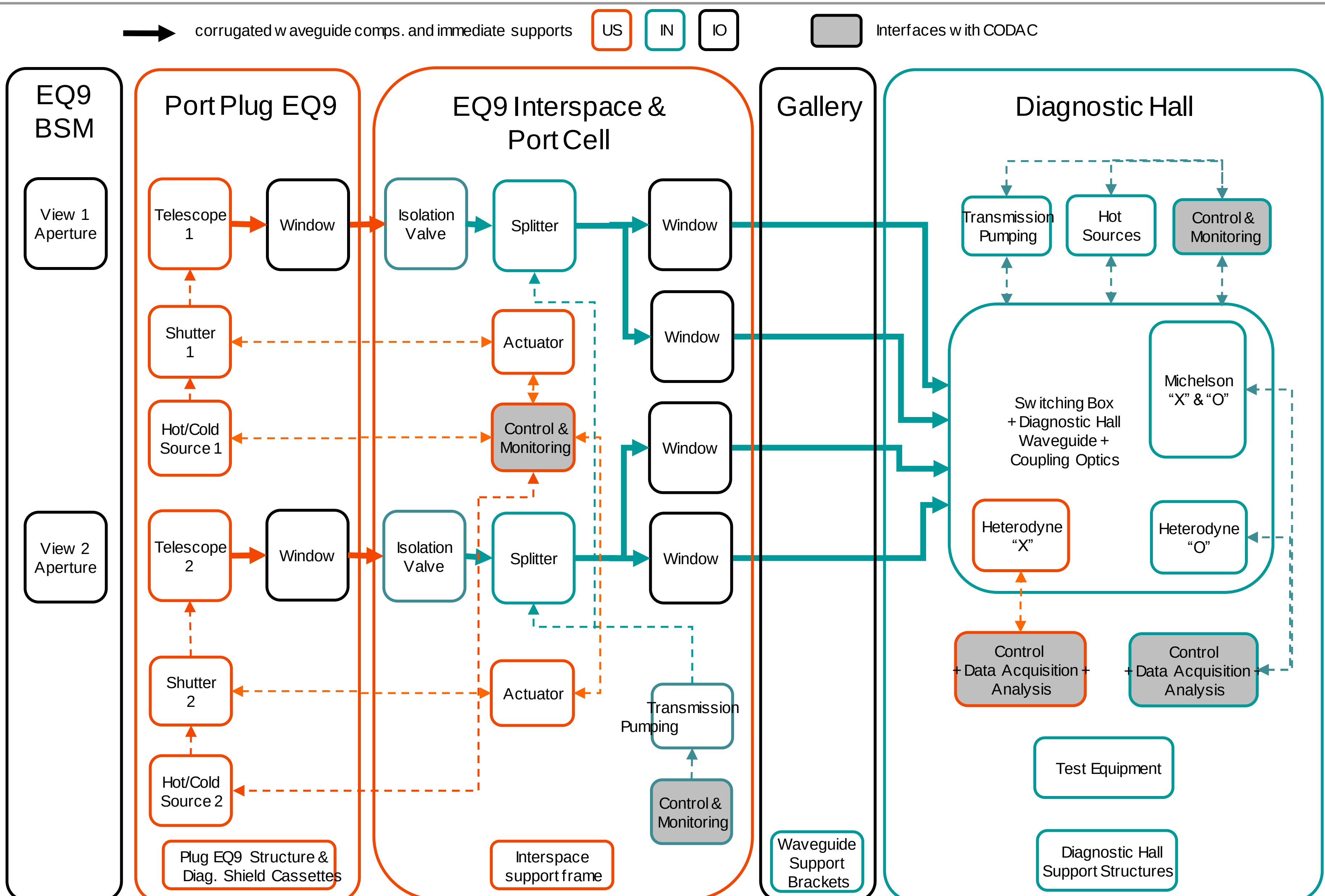
Overview of the X-mode (left) and O-mode (right) emission characteristics.

The horizontal bars represent the width of the emitting layer.

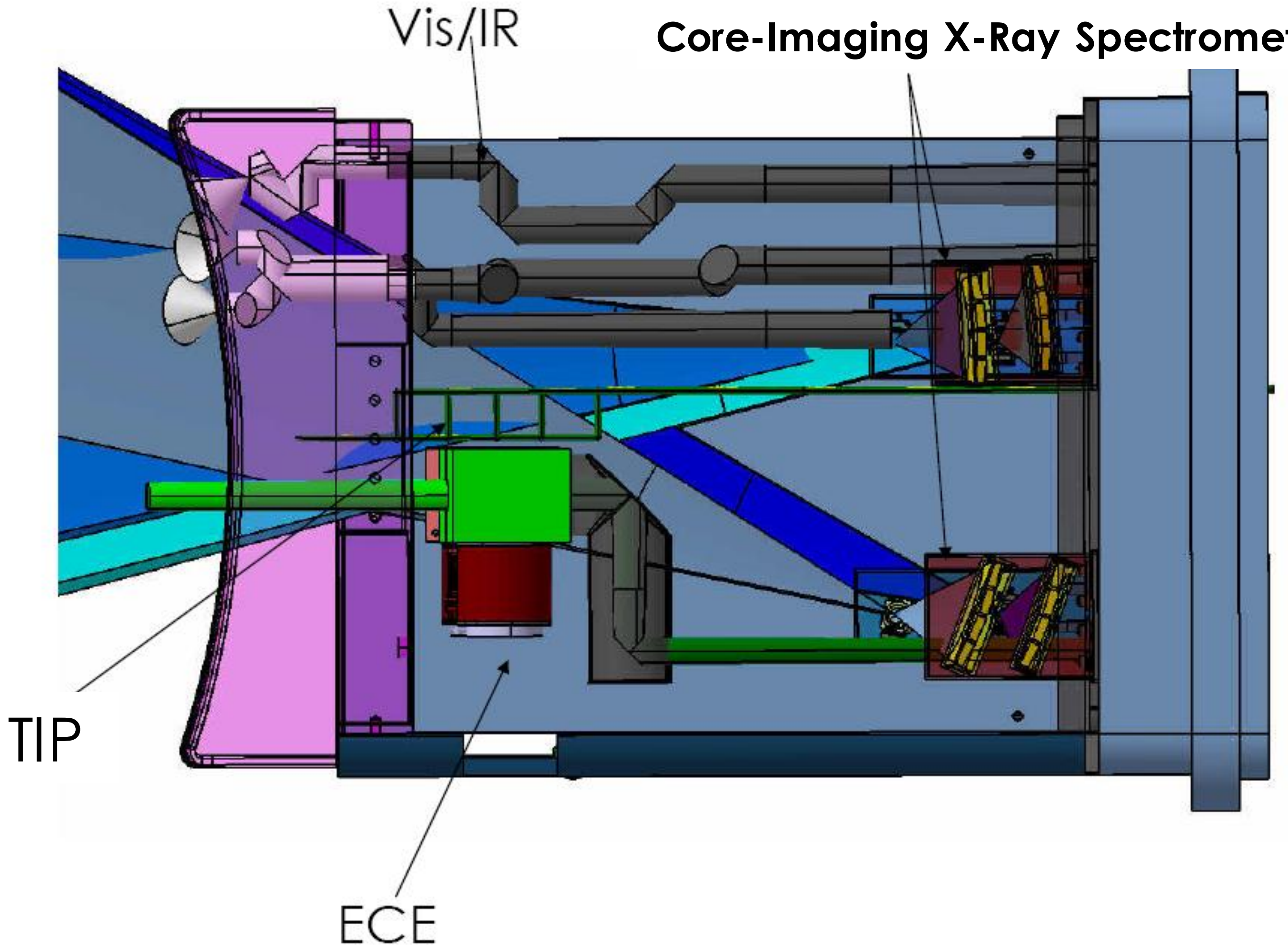
The vertical bar indicates the extent of the optically thick region. The vertical line indicates the magnetic axis. (ELMy H-mode case)

- Principal limitations
  - Restricted region of the plasma due to harmonic overlap
  - Degraded spatial resolution due to relativistic broadening.
- Target resolution can only be met in a limited region

Integration of ECE: Block-Diagram (from US DA)



Integration of ECE: Equatorial Port 09

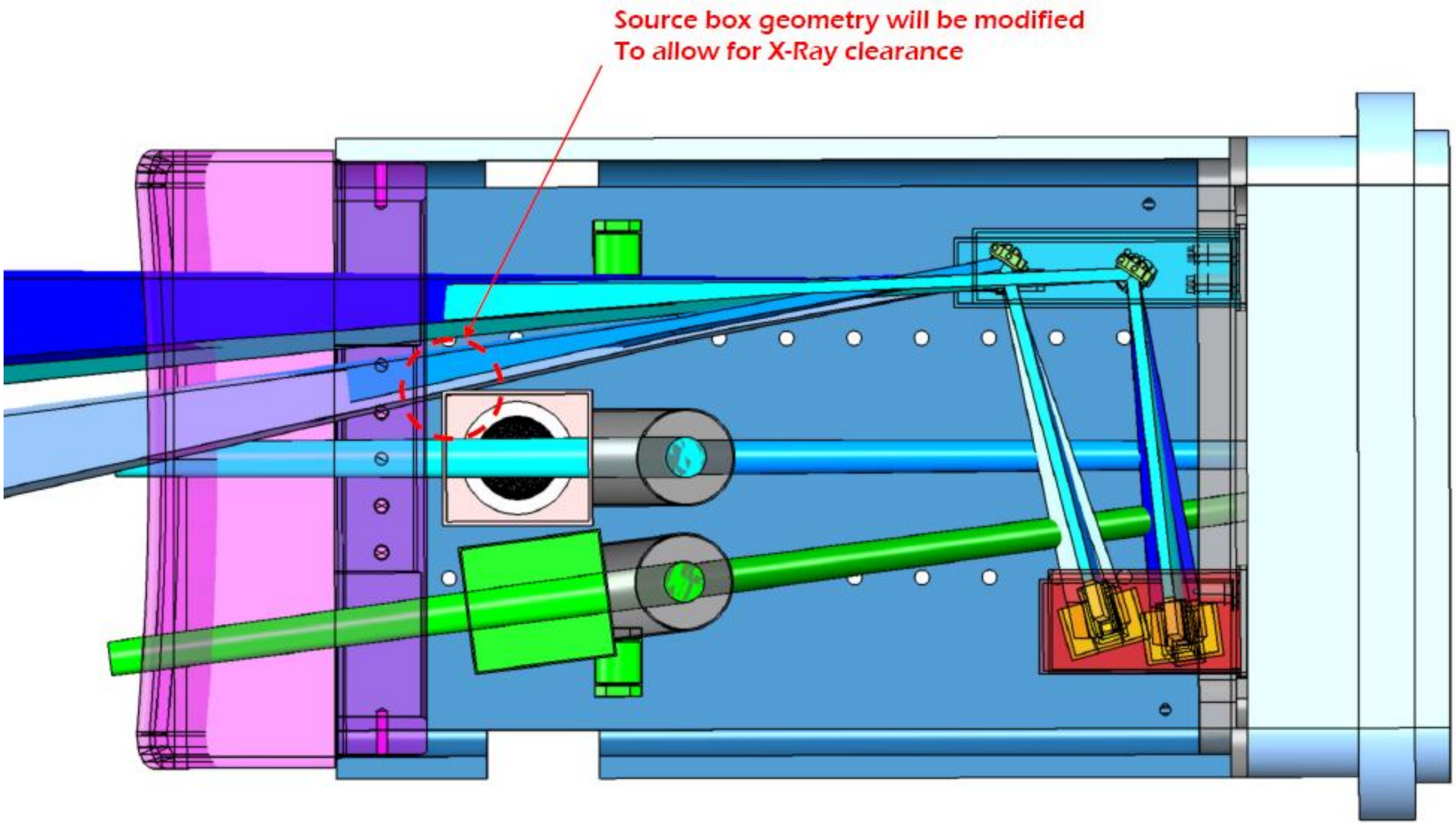


Courtesy: Russell Feder, PPPL, USA

See also: Max Austin, this Workshop

Angle and location of oblique ECE antenna is currently under discussion

Integration of ECE: Equatorial Port 09 (II)



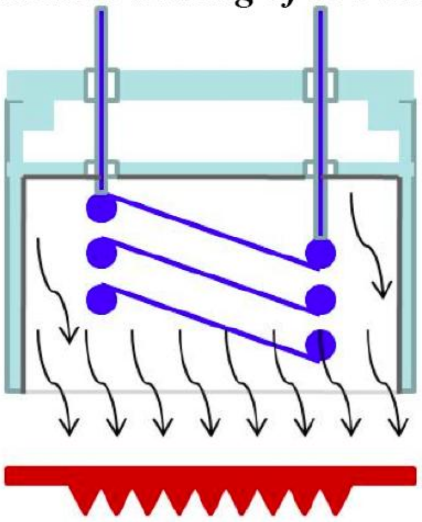
Courtesy: Russell Feder, PPPL, USA

Activity on source design and prototype is ongoing

Specifications

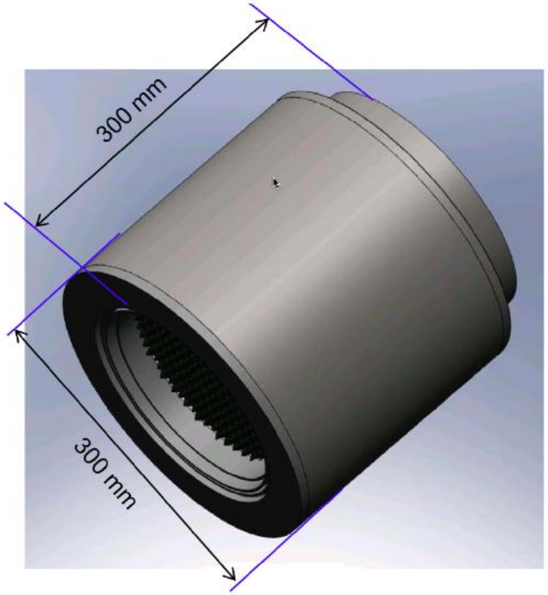
- High vacuum and high radiation flux environment
- Emissivity ~0.9 for 100 *GHz* to 1500 *GHz*
- Temperature >400 °*C* above background with ±10 °*C*
- 24 hrs stability

Radiative heating of SiC source



P. Philips, APS 2009

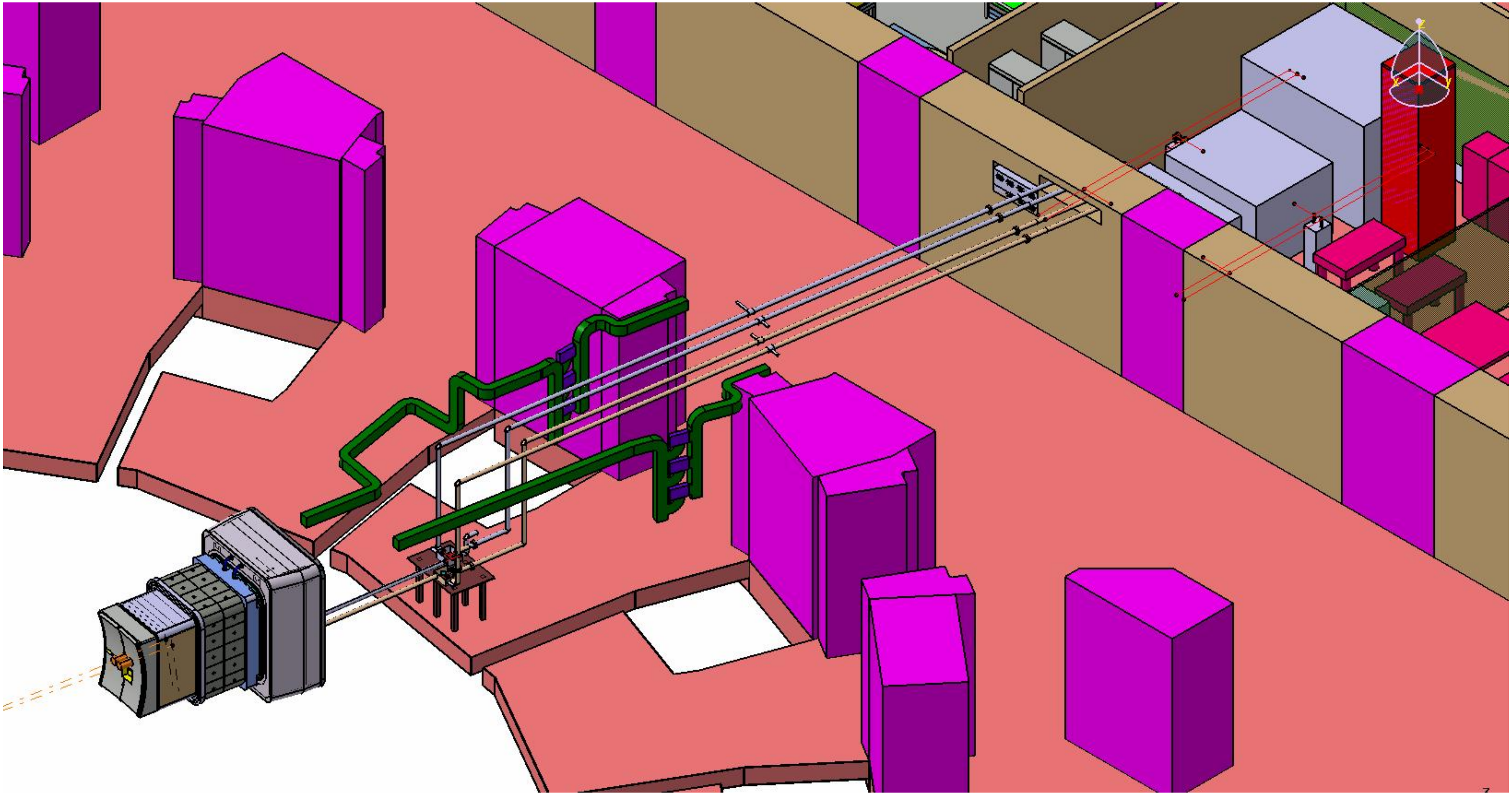
Approximate Size



Material: SiC - high temperature, high emissivity in frequency range of interest, low activation

Prototype test source (with non-ITER heating element) is being currently tested

Integration of ECE: Transmission lines and Cubicles



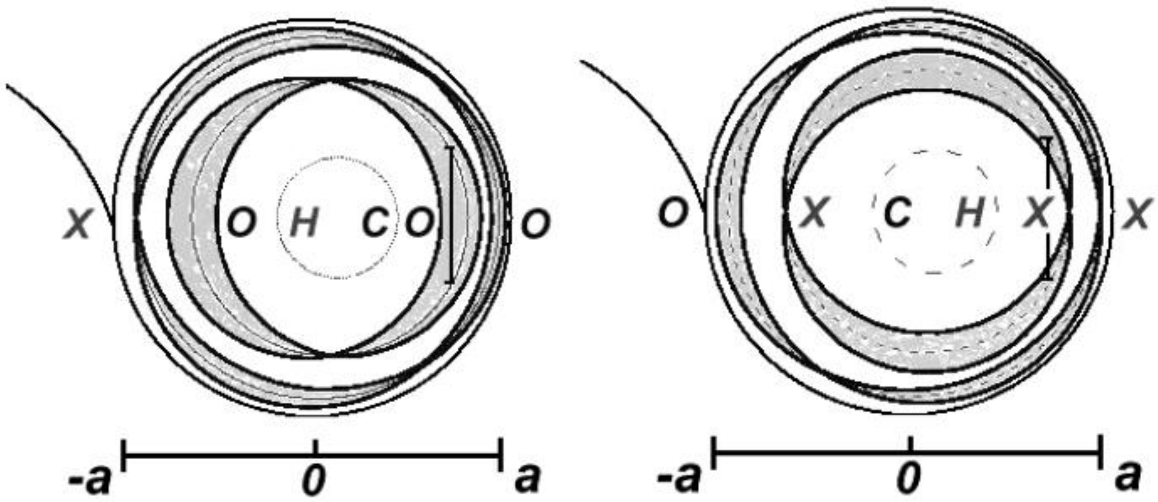
Design integration issues closely involve ITER Organization, US and IN DAs

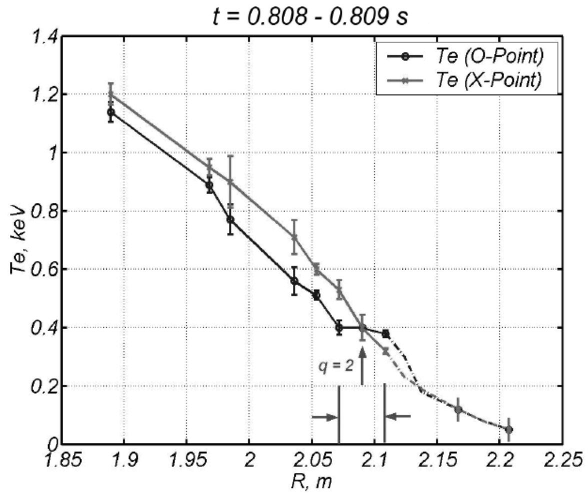
ECE: things to be thought about before Conceptual Design Review

- Present requirements for NTM detection:

$\Delta Te/Te = (0.1 - 5.0) \times 10^{-2}$, Δr = 50 mm

Is this enough, or higher radial resolution is needed?





TEXTOR; Udintsev, NF 2003

$$\Delta r = \frac{\Delta T_e}{dT_e / dr}$$

The critical island width on ITER is 20 – 40 mm; ECH deposition is 30 – 70 mm

This may affect the number of channels and their separation at NTM radii

ECE: things to be thought about before CDR (II)

- Calibration of the diagnostic:
  - hot/cold source (Equatorial Port 09) integration
  - "stability" check source in the transmission line
  - in-vessel calibration tooling

- Qualification and documentation of all components; pre-installation tests and mock-ups if necessary *(ITPA MWG work ongoing)*

- Consider a common confinement barrier strategy with other microwave systems on ITER (two windows or window + isolation valve) to provide confinement function in all situations: first confinement must withstand 2 bar peak pressure

- Refurbishment of the diagnostic

ITER Integrated Project Schedule: first plasma at late 2019!

ITER ECE: to attend at this Workshop!

H. Pandya, talk on Tuesday at 14:10

ECE session: Wednesday at 10:30, incl. M. Austin's talk

G. Taylor, summary talk on Thursday at 10:30

S. Danani, poster session 1 (presented by H. Pandya)

Reflectometry on ITER: overview

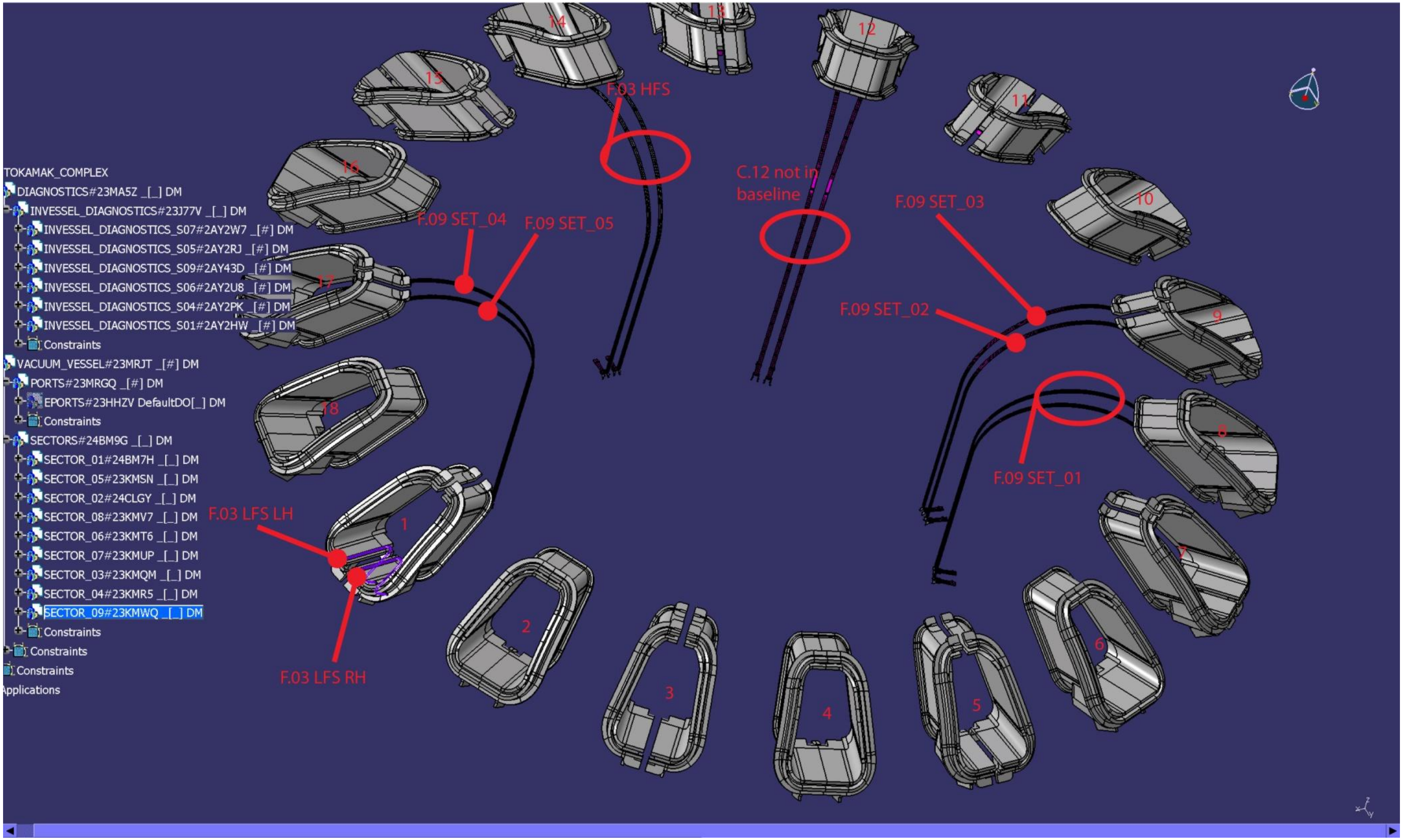
- Density profiles (core and edge)
- MHD (incl. TAEs), turbulence, ELMs
- Plasma position
- Both O- and X-mode reflectometry are planned

G. Vayakis et al., 7th Int. Refl. Workshop, Garching, 2005

Together with ECE, valuable information on T_e and n_e profiles, MHD and turbulence can be obtained; also in real-time

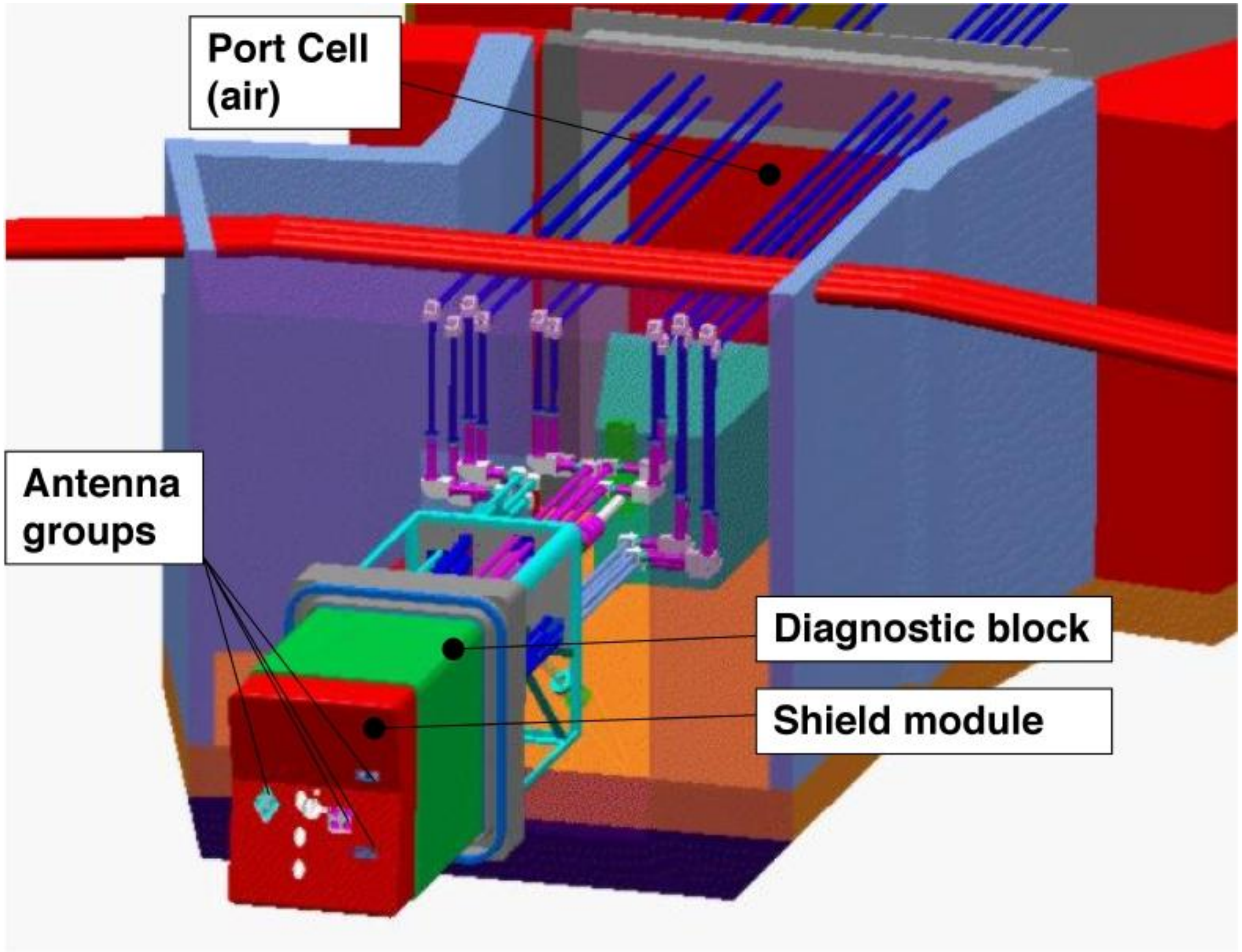
Integration of the reflectometry systems in- and ex-vessel without affecting the performance of the diagnostics is a major challenge; *in general, similar considerations for alignment/maintenance and confinement as for ECE*

Reflectometry on ITER: locations (HFS and Plasma Position)



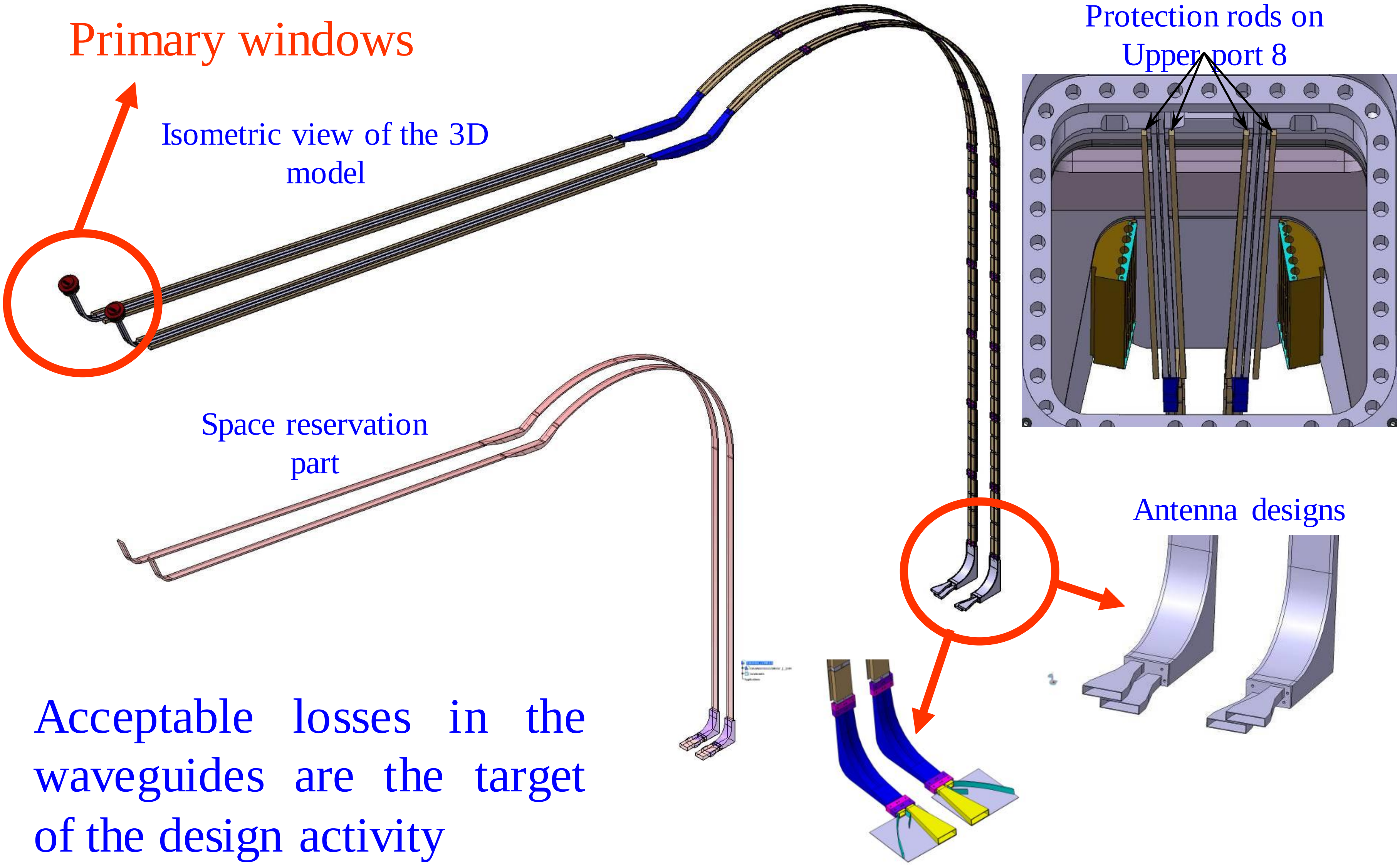
Number of waveguide pairs for each system is under study

Reflectometry on ITER: LFS System



Observation: edge / gradient region optimized; core when possible

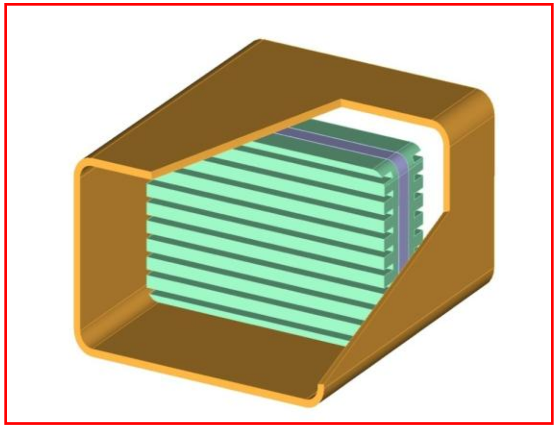
Reflectometry on ITER (HFS/Pl. Position): ongoing design activity



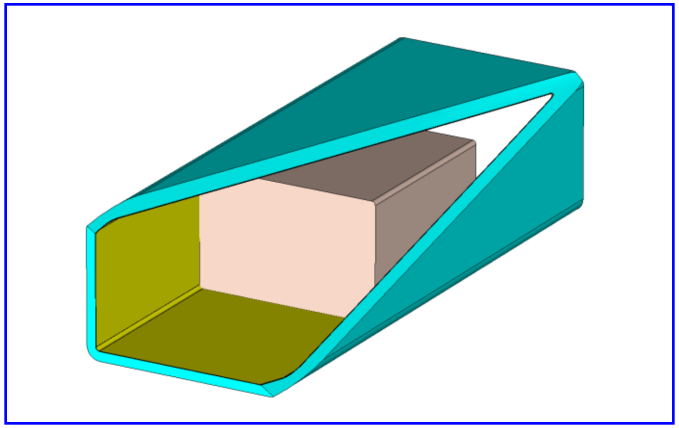
Acceptable losses in the waveguides are the target of the design activity

Reflectometry on ITER: confinement barriers

Primary vacuum window

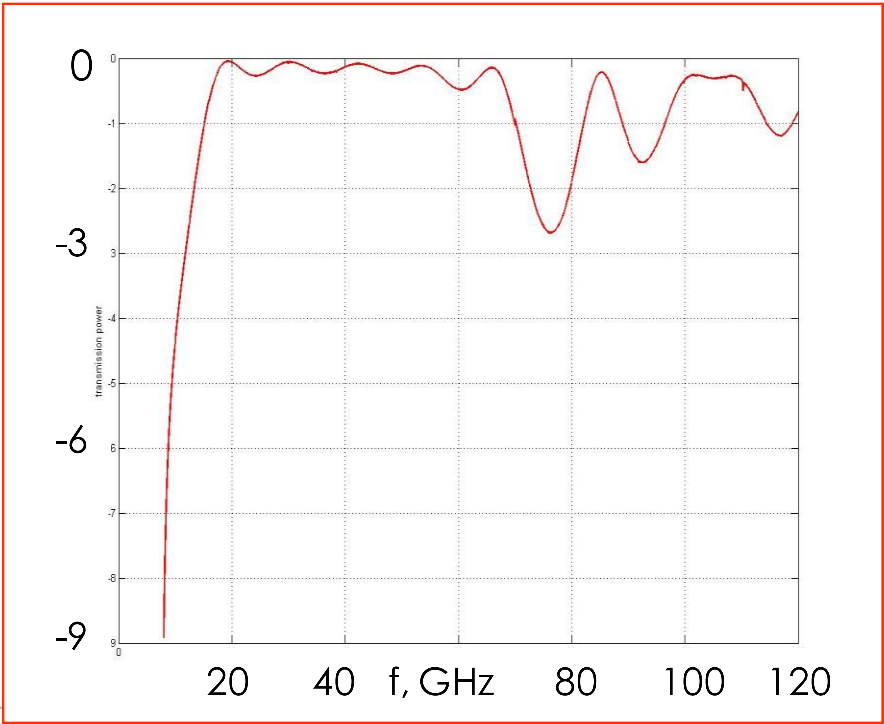


Secondary vacuum window



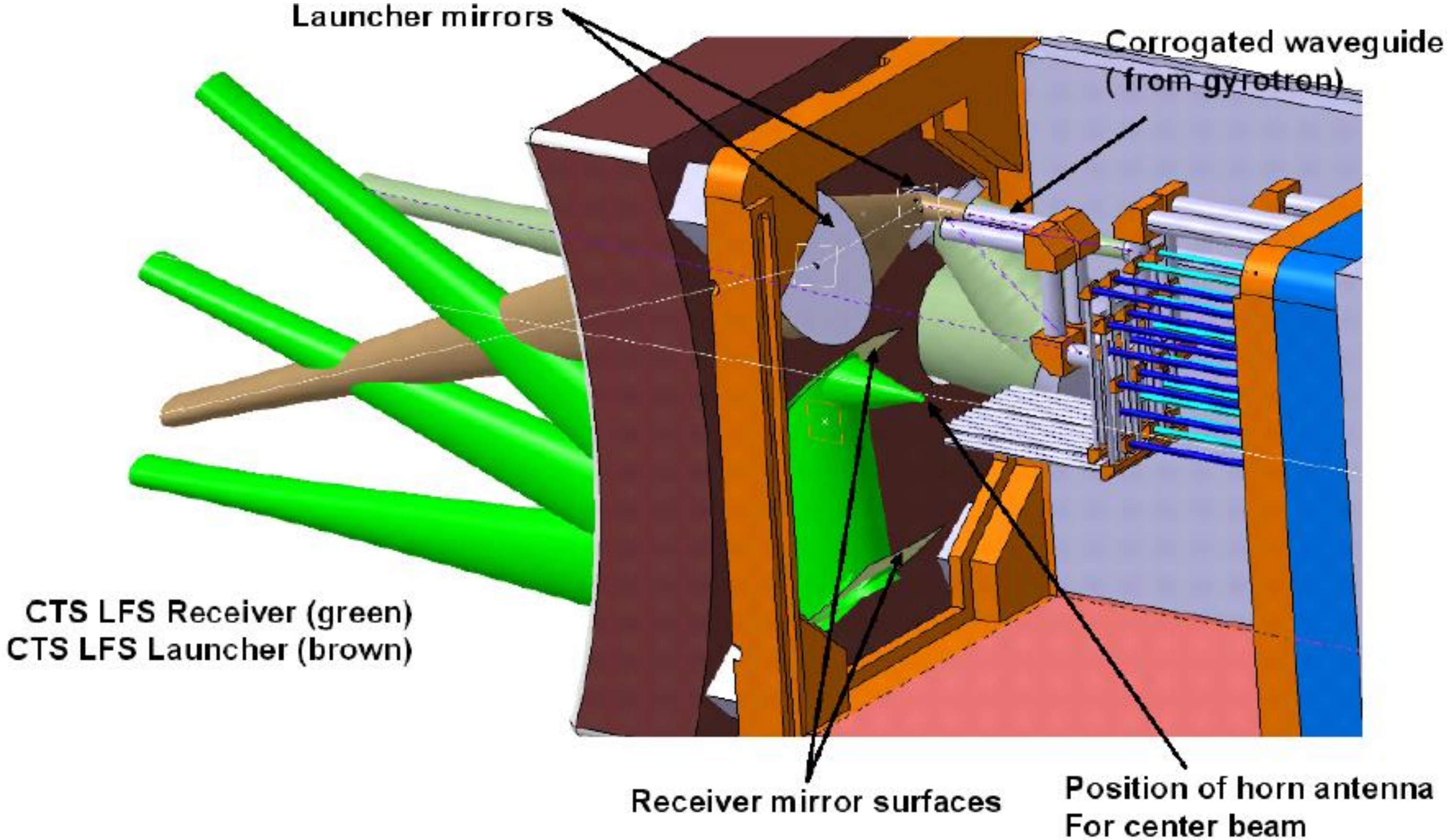
2 cm thick ROHACELL® foam with $\varepsilon < 1.1$ and low RF absorption

- Window material: diamond brazed to the copper waveguide section
- The profiled quartz plates enhance the window transmission
- The losses versus frequency are shown at the right graph



Courtesy: V. Vershkov, RRC Kurchatov Institute, RF

Collective Thomson scattering on ITER (60 GHz): the goal is to measure fast ion distribution (100 keV to 3.5 MeV, a/10 ~ 20 cm, 100 ms) near parallel and near perpendicular to the magnetic field at different radii



Eq. port #12

LFS CTS launcher and receiver beams, rear view

Courtesy: F4E

CTS on ITER: major challenges

Needs for high-power transmission lines and their assembly should be defined (similarity to ITER ECH systems?)

Engineering design of the front-end quasi-optical components in the Port Plug is needed

Minimisation of the neutron streaming should be investigated

Design study of the window assemblies needed for the large number of waveguides

Specifications for the gyrotron (60 GHz, several MW of power?)

Summary and outlook

- **The present status of design and open issues for ECE, reflectometry and CTS on ITER have been discussed**

- **The milestones are defined by ITER Integrated Project Schedule**

- **IO and Domestic Agencies need to work together to ensure that the diagnostics meet measurement requirements and delivered on time**

- **At the same time, new ideas on expanding the physics programme within the present requirements and designs are welcome**

Back-Up Slides

1. Electron Cyclotron Emission ECE		
O & X-mode Michelson	70 GHz – 1 THz	Quasi-optic
O-mode Radiometer	122 – 230 GHz	4 bands: F, D, G +
X-mode Radiometer	244 – 355 GHz	4 bands. QO?
2. Reflectometers		
O-mode plasma position	15 – 60 GHz	3 bands: K, Ka, U
LFS O-mode profile	15 – 60 GHz +	3 bands as above
LFS O-mode profile	40 – 160 GHz	4 bands: U, E, F or W, D
LFS Xu-mode profile	76 – 180GHz	2(or 3) bands: W, D, (G)
HFS Xl-mode profile	8 – 78 GHz	3-5 bands: (X), K, Ka, U, (V or E)
HFS O-mode profile	15 – 127 GHz	5-6 bands: K, Ka, U, E, F

Test Tanks Area

ITER_D_2UWPKM v 1.0

4.3 Level L1

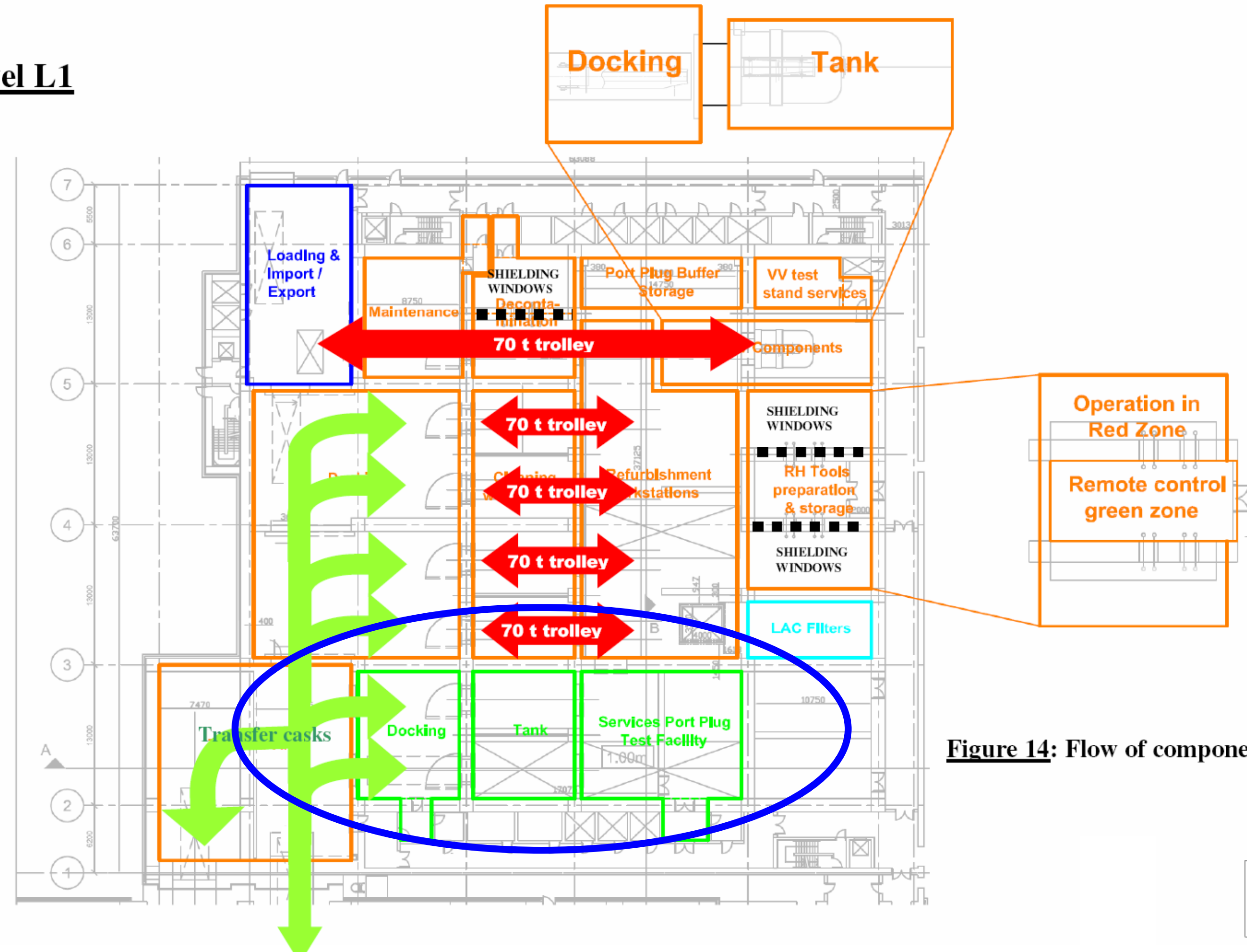
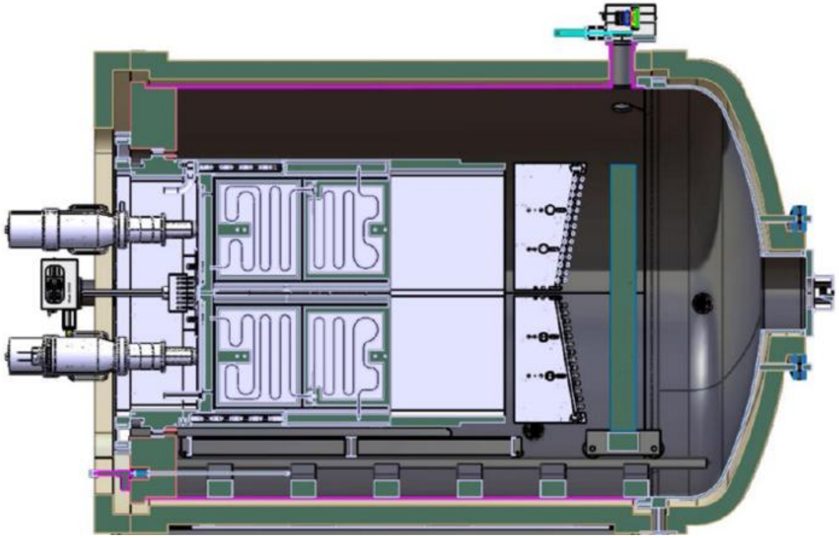
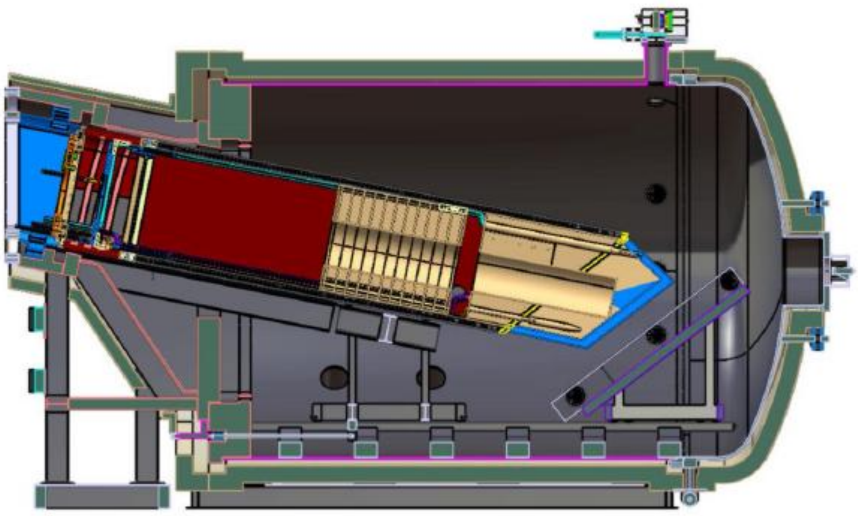


Figure 14: Flow of components level L1

Hot Cell Facility: Test Tanks Area

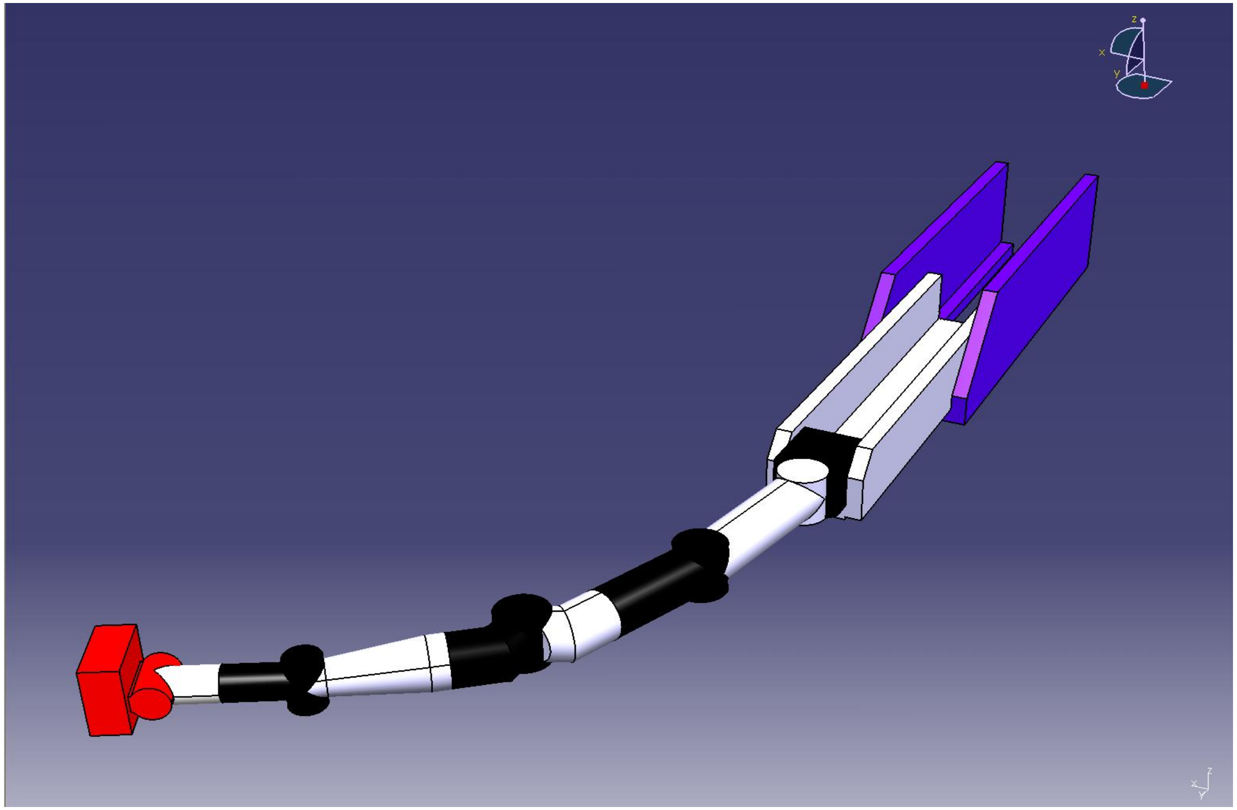


Tank for EPP



Tank for Upper PP

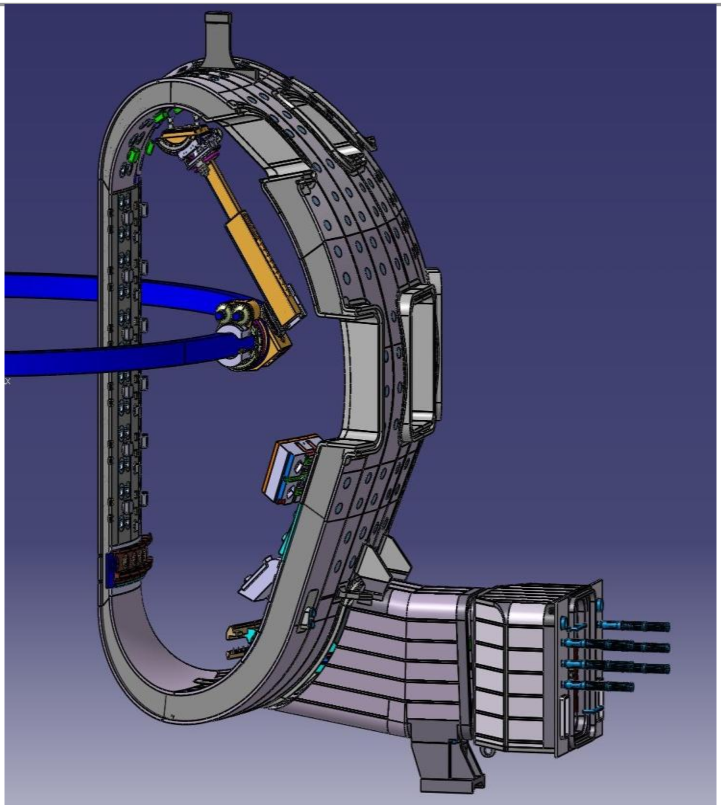
ITER Transport systems: MPD

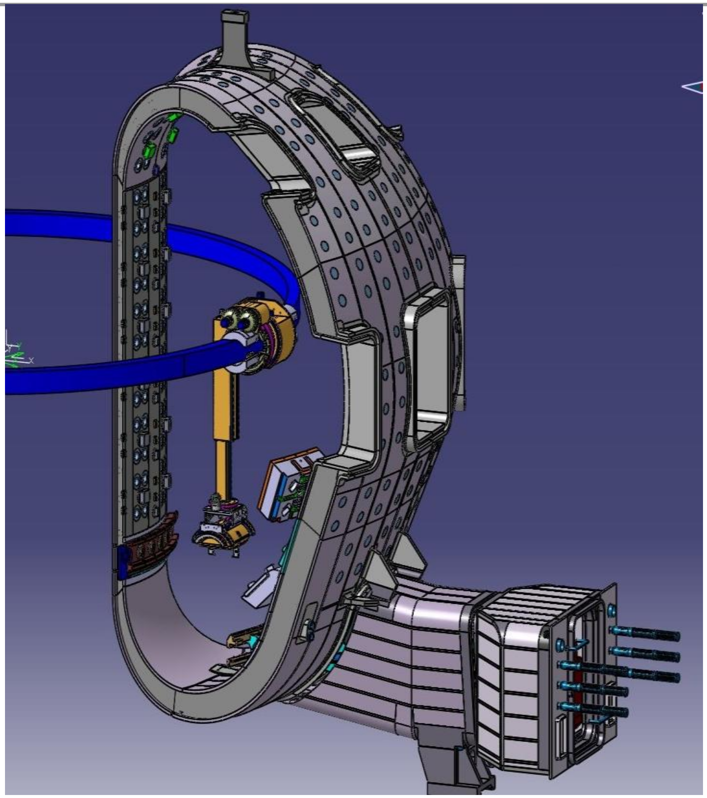


Multi-Purpose Deployer

• More appropriate for most diagnostics, less disturbing diag. calibration/alignment line of sights, less reflections

ITER Transport systems: IVT





IVT equatorial rail :

- can be used for the optical Diag. Calibration/Alignment lines of sight, but with increased reflections (background);
- unworkable for neutron calibration because of rail position and of massive scattering contribution.