EUROfusion

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Doppler Reflectometry for JT-60SA

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‘Basic’ functional diagram for the DR

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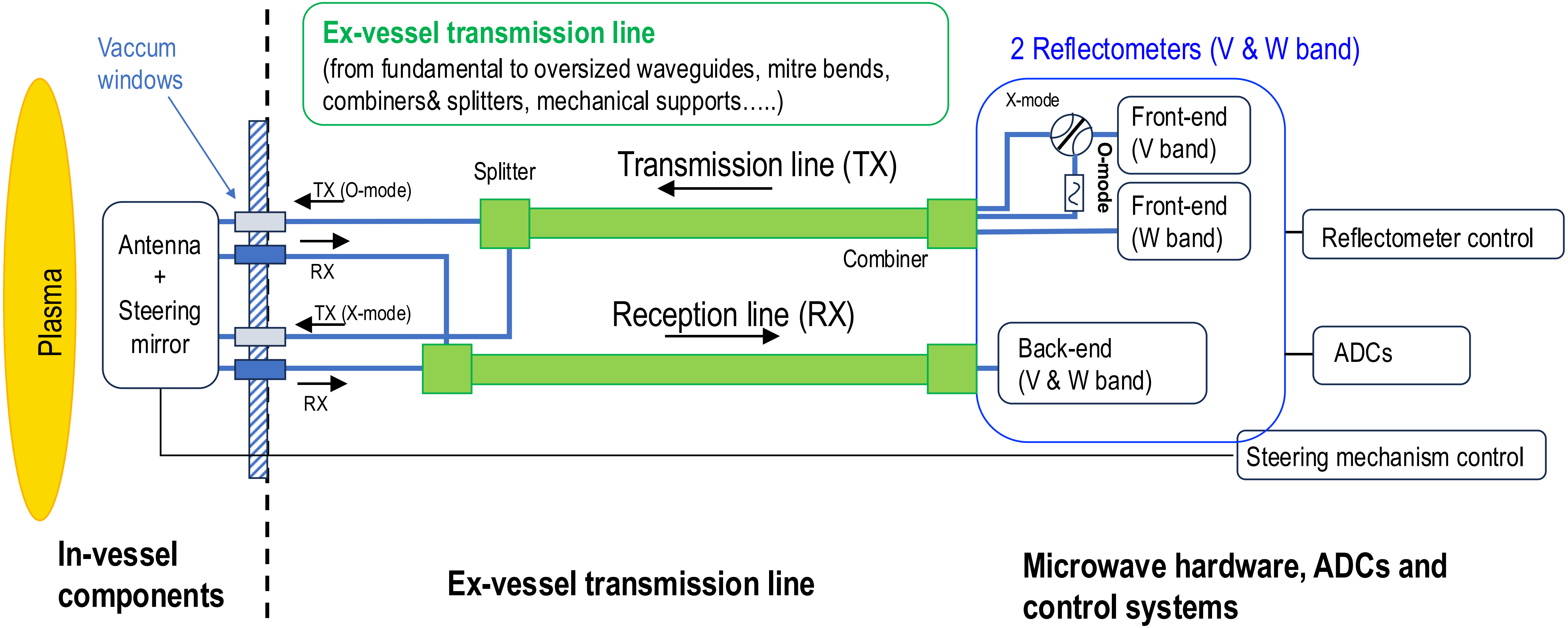

V band (50-75 GHz), W band (75-110 GHz)

Outline

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- Port allocation = EP09 (Nov-2024)
- Progress in 2025:
  - Optical design including space constraints in EP09
  - Engineering design
    - in-vessel
    - ex-vessel
- Plans for the second half of 2025 and beyond

EP09: space reservation for the DR system

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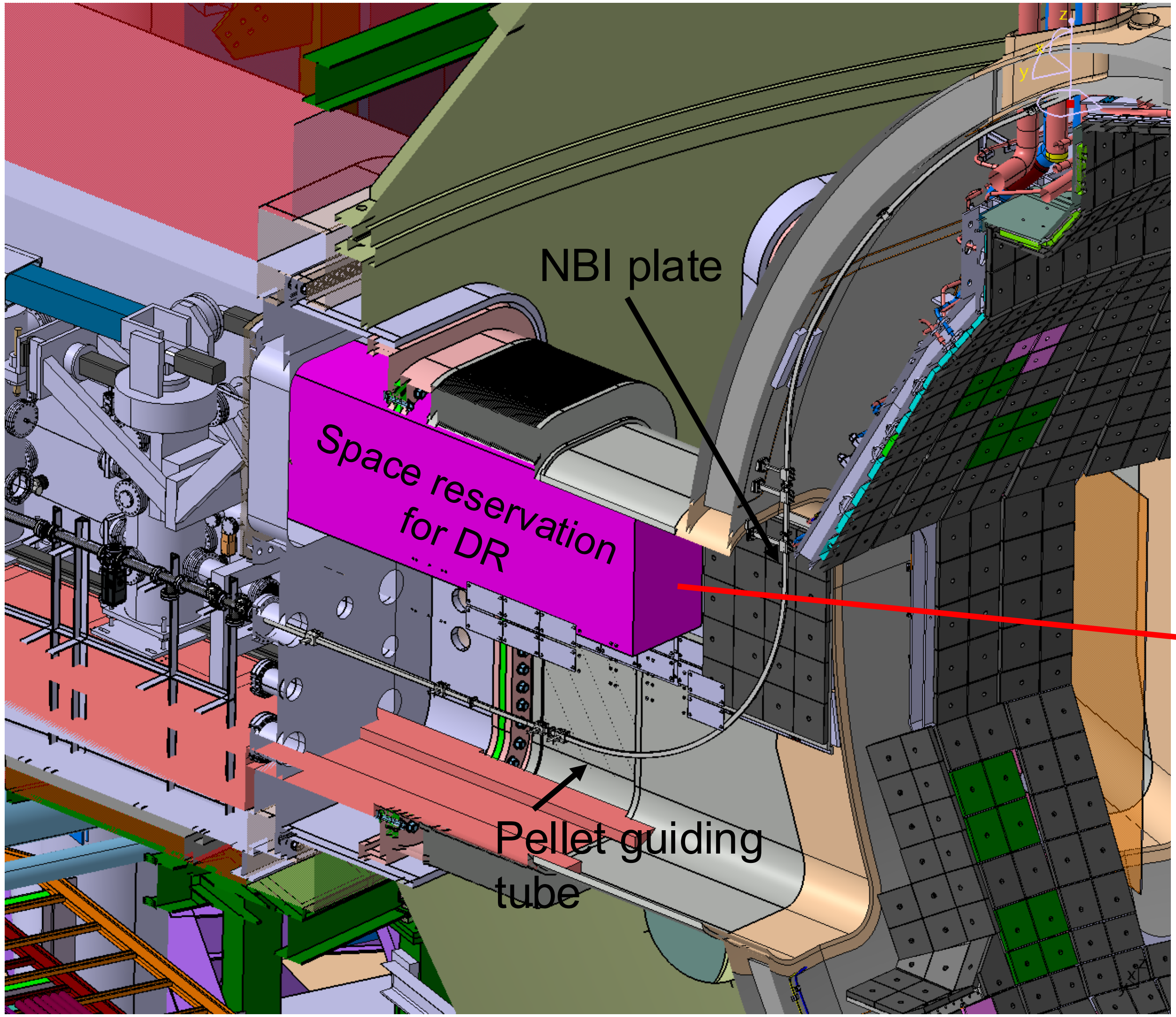
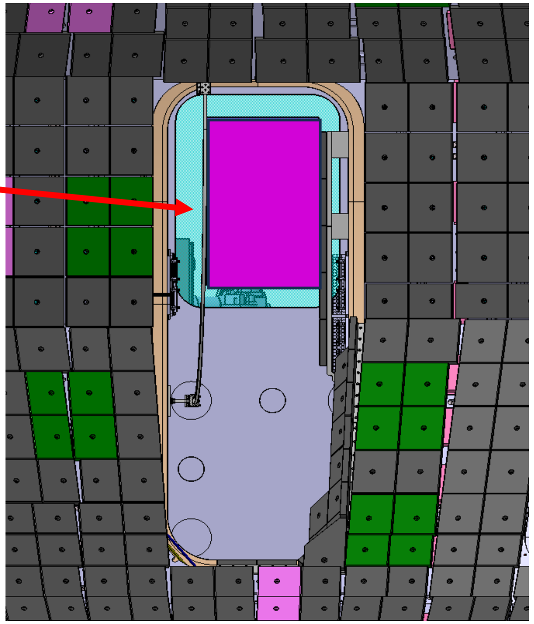


First step is to **optimise the optical design** to meet the spatial constraints within the port plug

- length limited by the NBI plate (to be confirmed by QST)
- width limited by the NBI plate and the pellet injector guiding tube

Dimensions (mm): 2000 (L) x 410 (W) x 650 (H)



Define the optical geometry for the DR system

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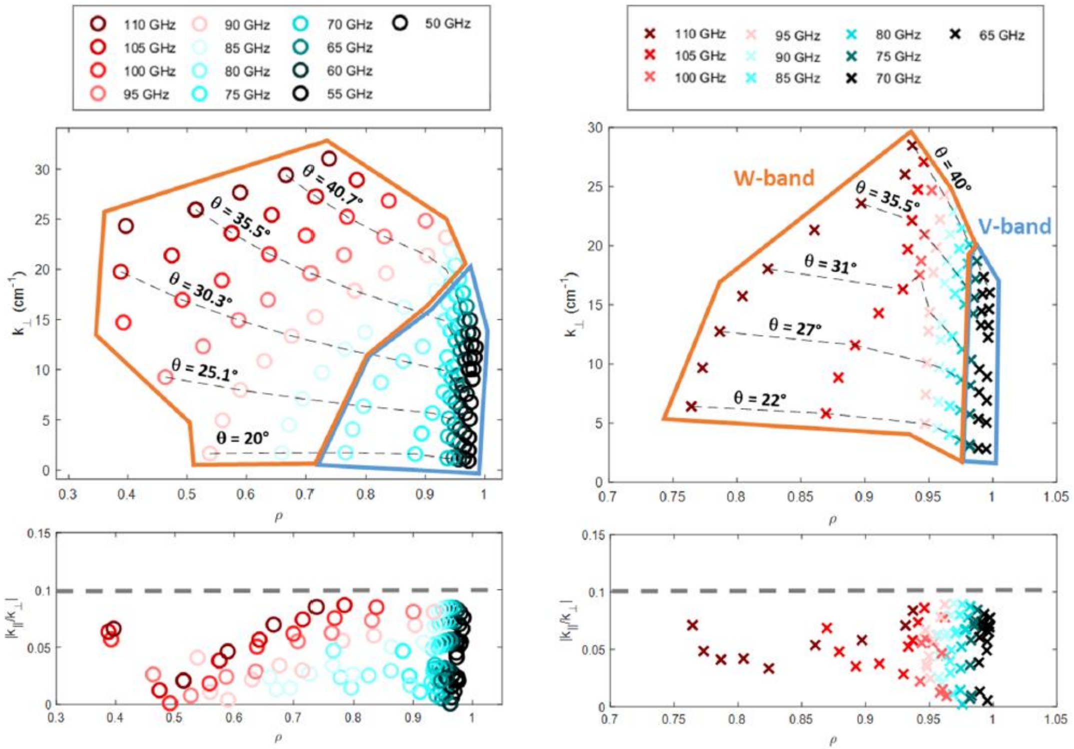
The ray tracing code TRAVIS is used to determine the optimal geometry for the DR
The analysis carried out in the previous feasibility analysis [Carralero et al., FED 2021]) has been repeated:

- using the realistic geometry of Upper Port EP09
- considering the most recent JT-60SA plasma operating scenarios (received at the end of Feb/2025)

The main steps carried out are:

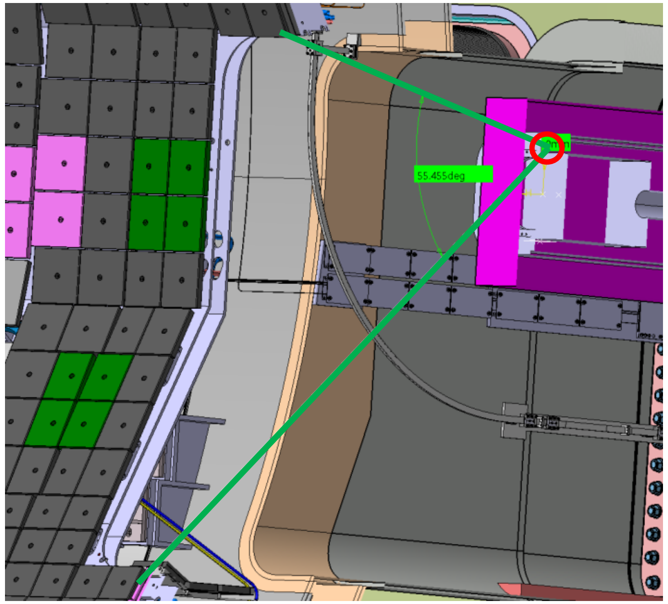
- Identify the radial region for measurements with the V and W bands, both in X and O mode polarisation
- Compare a number of potential launching points and select an optimal candidate
- Find a θ/ϕ (poloidal/toroidal) plane (single axis rotation to minimise the last mirror mechanical design complexity) for which the measurements are optimal in terms of accessible $k_\perp$ range:
  - minimize $k_{||}$ to at most $|k_{||}/k_\perp| < 0.1$ (required for acceptable S/N ratio)
  - $k_\perp \rho_i$ =1-10 for ITG/TEM turbulence

    (ρ_i is the ion gyroradius at the backscattering layer)

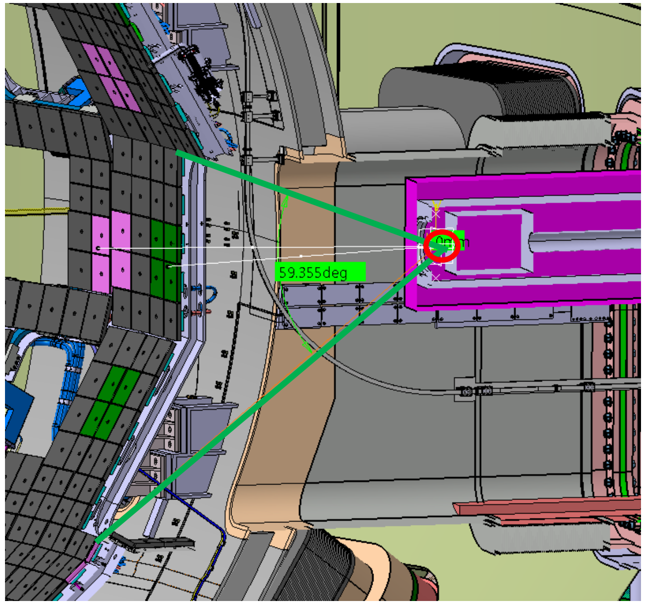


Carralero et al., FED 2021

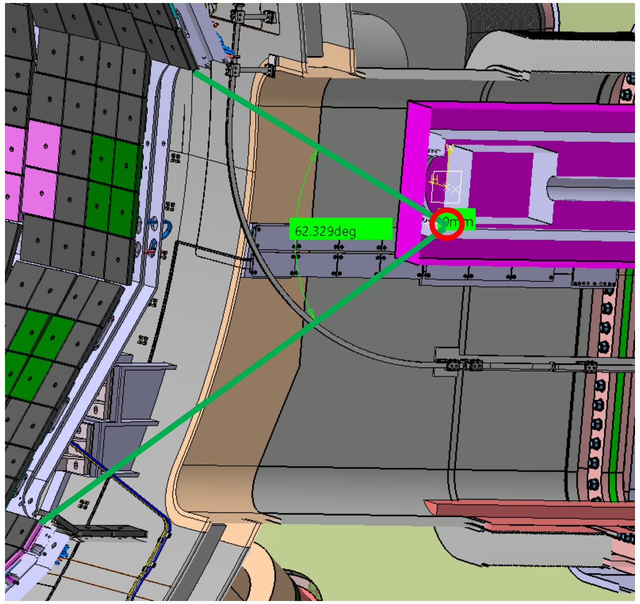
Define the optimal launching position



upper

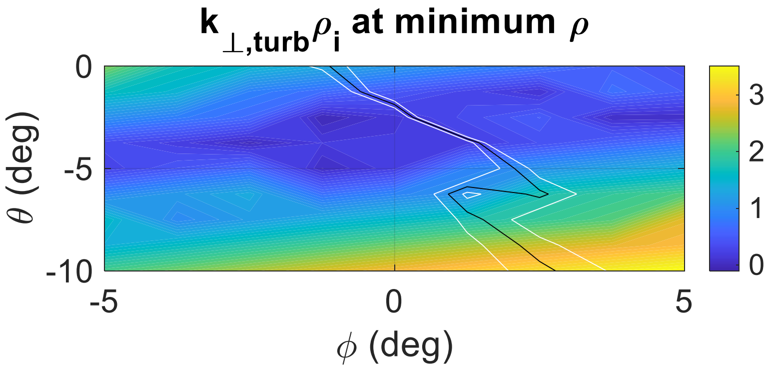


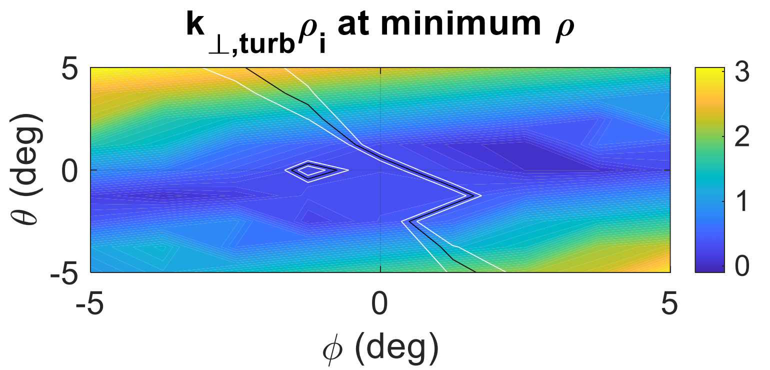
middle

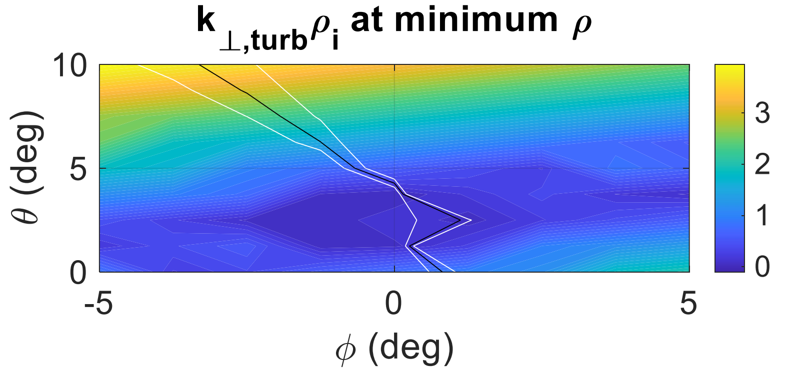


lower

High power, baseline, X-mode, 100 GHz, ρ_{min}=0.84







Feasibility analysis for port EP09. Where are we?

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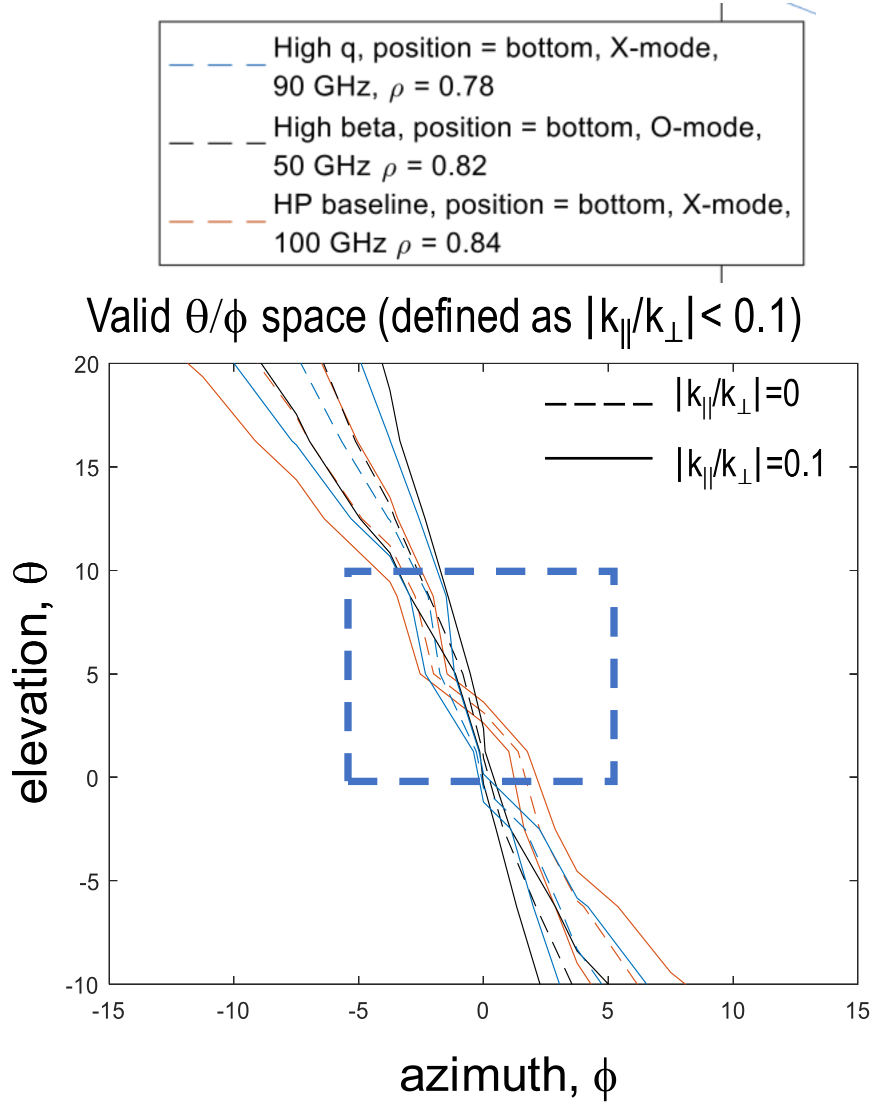
A number of conclusions can be achieved after carrying out a preliminary analysis of the different scenarios:

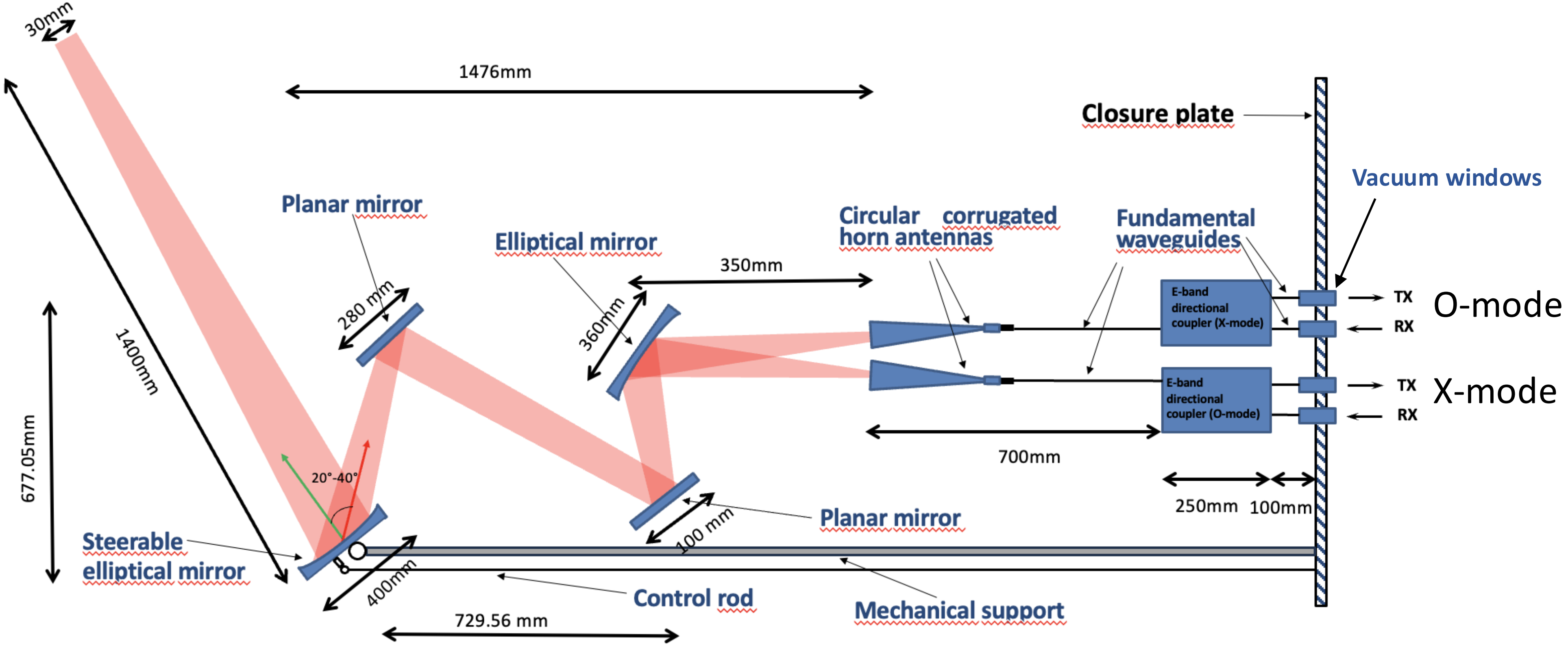
- 4 scenarios considered (OP-2):
  - baseline low/high power
  - high beta
  - high q_{95}

  ❖ Lower density (lower I_p) than those analysed in Carralero, FED 2021
- **The lower position is selected**, as it admits greater clearance with respect to the space constraints within the port
- Radial range of measurements covers the outer half of the plasma (2X absorption might be a problem for X-mode operation in high q_{95} scenarios, as already found in previous analysis)
- Azimuth and elevation angles should not be close to clearance limits (θ/ϕ= [-10,20] / [-5,5] respectively)
- **Detailed analysis and scenario prioritisation will be required to determine the optimal θ/ϕ plane (mirror axis rotation).**



Doppler Reflectometer conceptual design (2024)

- **2 microwave bands** (V & W) and two polarizations (O-mode and X-mode) to cover the different JT-60SA scenarios, from the edge to the core ($\rho > 0.5$) region (depending on the density profile in each scenario)
  - best polarization and frequency coverage can be selected remotely depending on the scenario
- **1 steerable mirror** is used to control the launching angle for both bands and polarizations:
  - $k_\perp$ can be selected, allowing the measurement of wavenumber spectra



Doppler Reflectometer conceptual design (2025)

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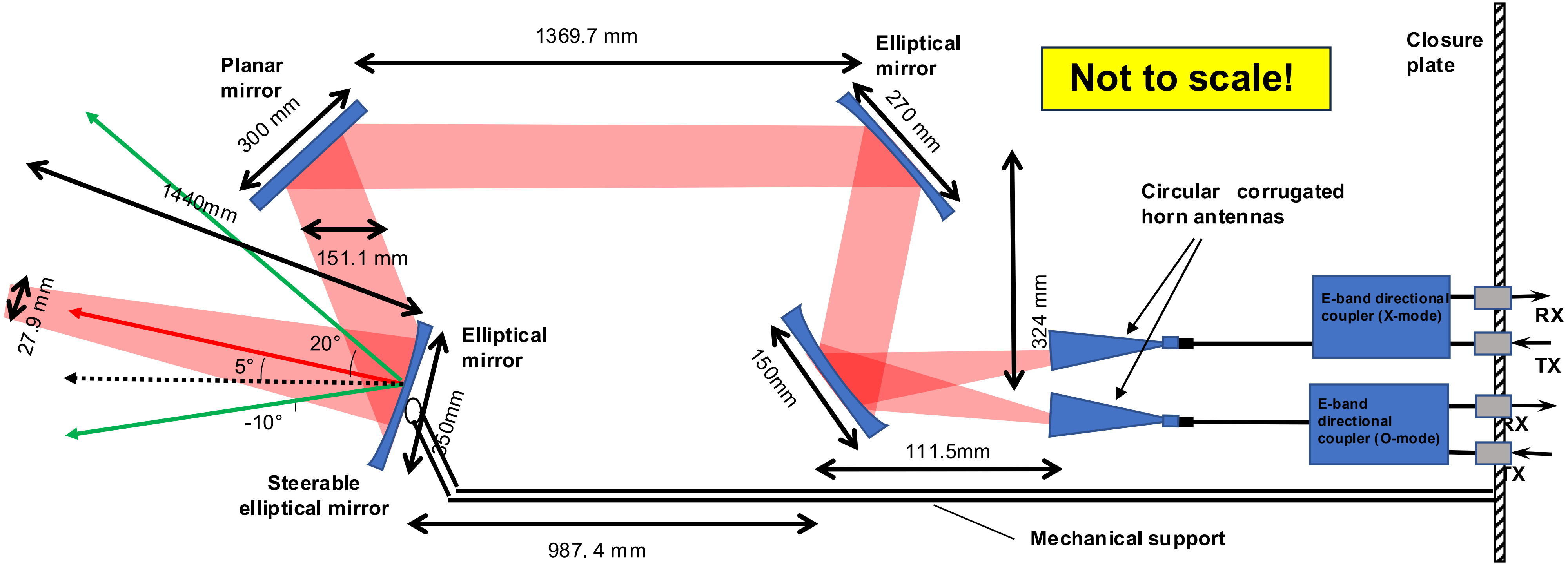
- 2024: Gaussian beam telescope (2 elliptical mirrors & 2 plane mirrors)
  - ❖ the beam waist is displaced towards the plasma edge for higher frequencies
- **2025**: Include space constraints imposed by the EP09 & new optical design
  - ❖ **3 elliptical mirrors + 1 plane mirror: the beam waist moves towards the plasma core for higher frequencies**, consistent with the change in the location of the reflecting layer



Optical design: where we are and plans for 2025/26

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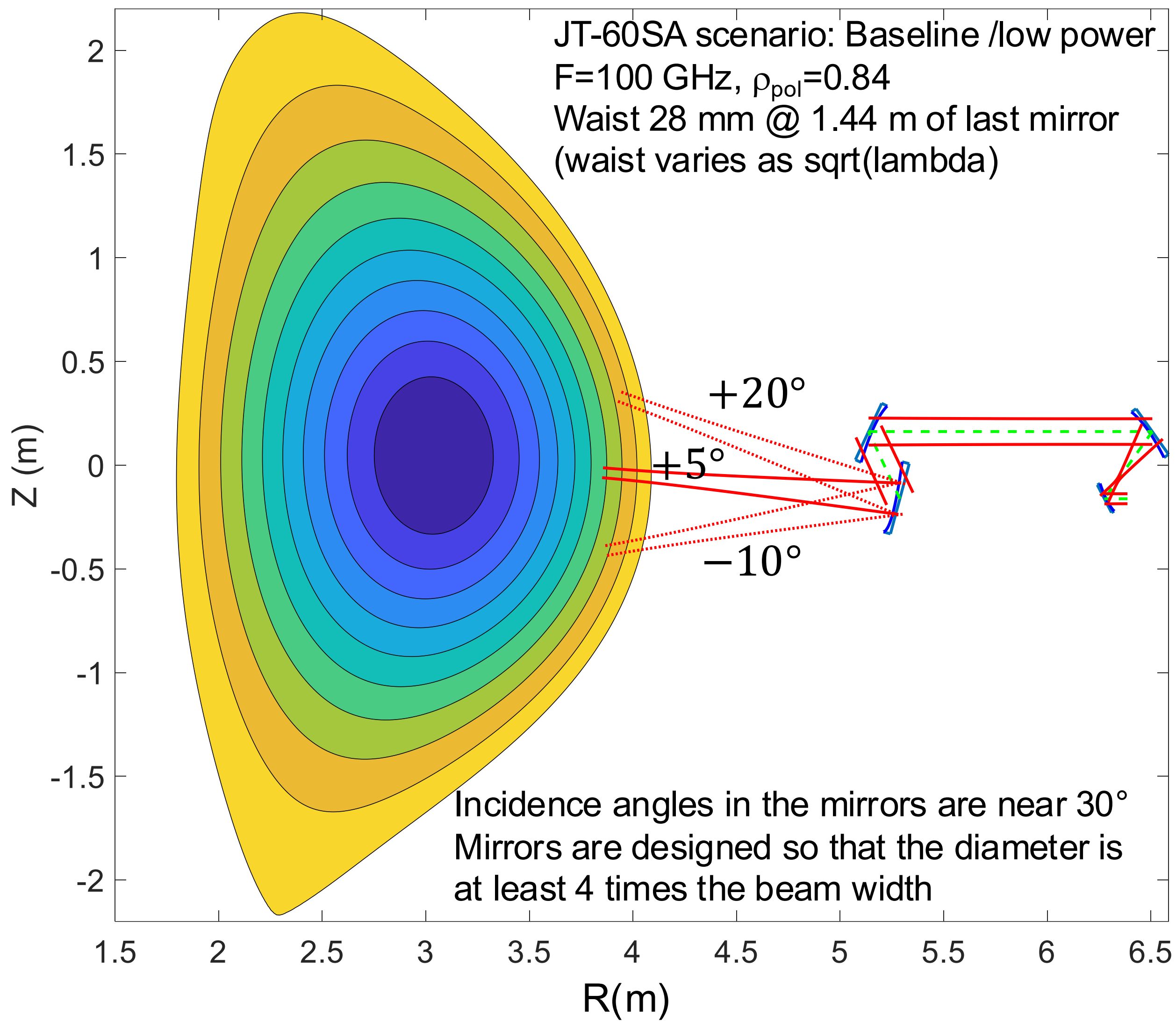
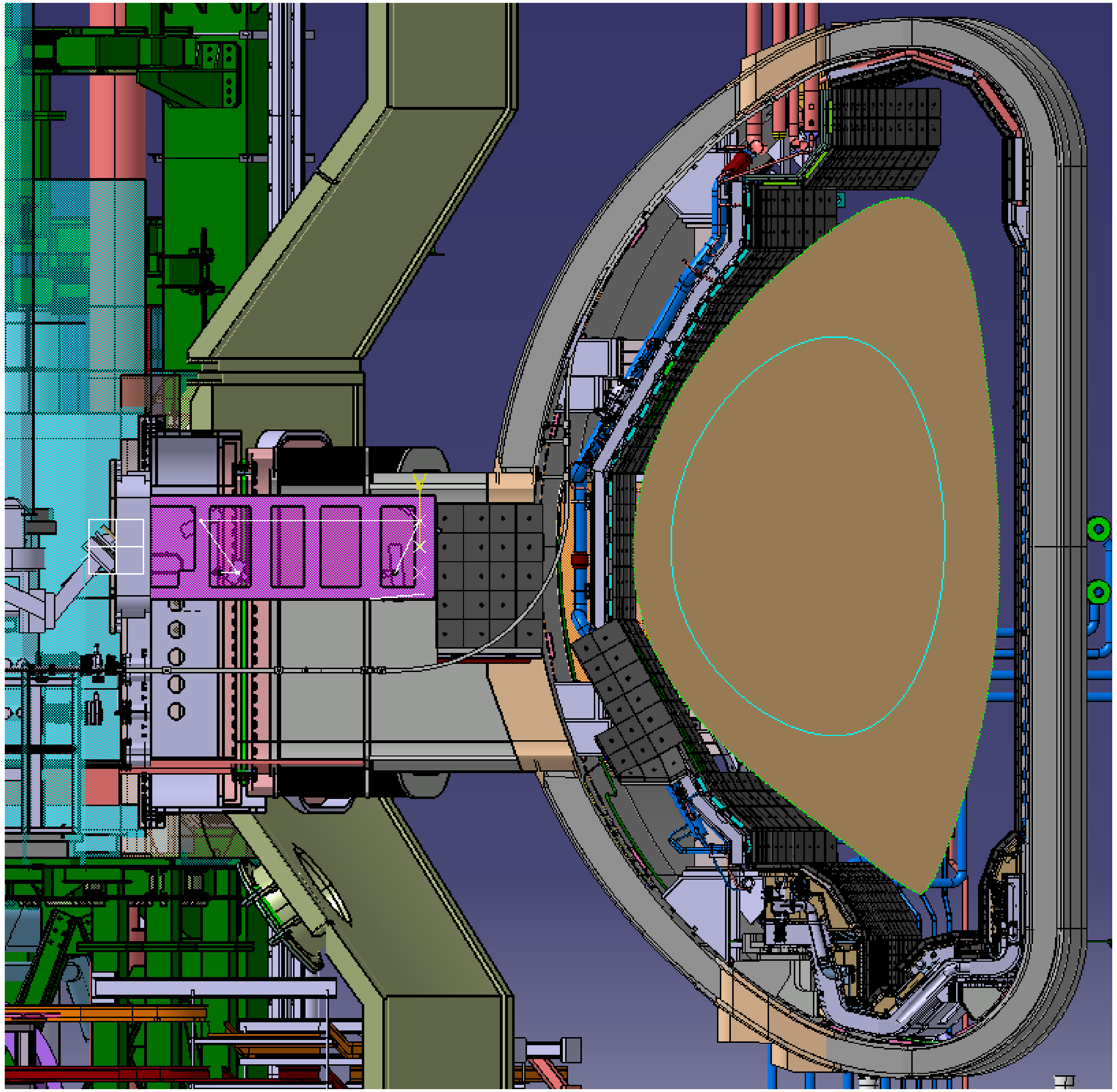


1. Define microwave beam launching position (last mirror). **DONE**
2. Re-build the conceptual design (3 elliptical mirrors) and account for space constraints within the EP09 port. **DONE**
3. Detailed analysis of the radial and $k_\perp$ accessible range using the final beam launching position: **IN PROGRESS (2025)**
   - Conduct a detailed analysis of the $k_\perp$ vs radial position vs scenario
   - Based on the analysis, prioritise scenarios in order to fix the geometry in a final design, including the rotation plane of the last mirror
4. Finalise the optical design. **IN PROGRESS (2025)**

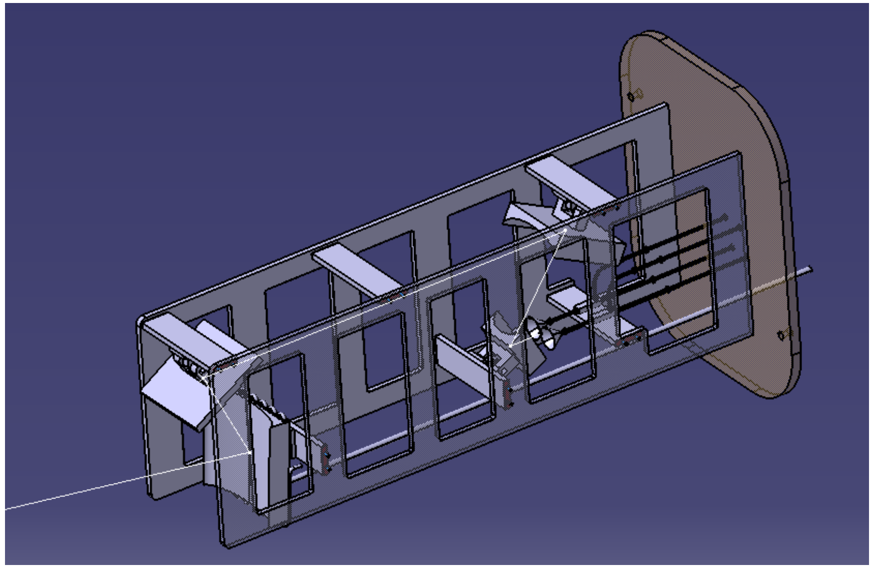
In-vessel engineering design: where we are and plans 2025/26



EP09 is used for access to the vaccum vessel

✓ A "port-plug-like" design (similar to that installed in W7-X) is proposed to allow removing the system to free EP09 as a manhole

1. Conceptual design of the in-vessel frame for the optical system, taking into account the 2025 optical design dimensions. **DONE**



In-vessel engineering design: where we are and plans 2025/26

1. Conceptual design of the in-vessel frame for the optical system, taking into account the 2025 optical design dimensions. **DONE**
2. Prepare preliminary design. **IN PROGRESS (2025)**
   - For long-pulse operation, the optics should be prepared to be water-cooled with cooling pipes integrated in the last two mirrors
3. Define interface & load definition. **IN PROGRESS (2025)**
4. Engineering analysis:
   - Thermal analysis. **IN PROGRESS (2025)**
   - EM analysis **CONTINUES in 2026 (?)**
   - Mechanical analysis. **CONTINUES in 2026 (?)**

Input required:

- Restrictions imposed by the NBI plate within the port (Request: (1) Minimum clearance required between the last mirror and the NBI plate, and (2) NBI footprint) *Pending since TCM in Nov-2024*
- Vacuum window specifications & required tests (*first contact by email with Tokuzawa; so far, not enough information*!)
- Any specific requirements concerning the sequence of installation/removal of diagnostics systems installed in EP09 (for access to the vacuum vessel)
- Inputs (interfaces & loads) for the engineering analysis (reference: PID_222UJY_v4_6):
  – What materials are allowed in the port plug?
  – Heat loads
  – Seismic loads
  – EM forces due to disruptions
  – ……

Ex-vessel design: where we are and plans 2025/26

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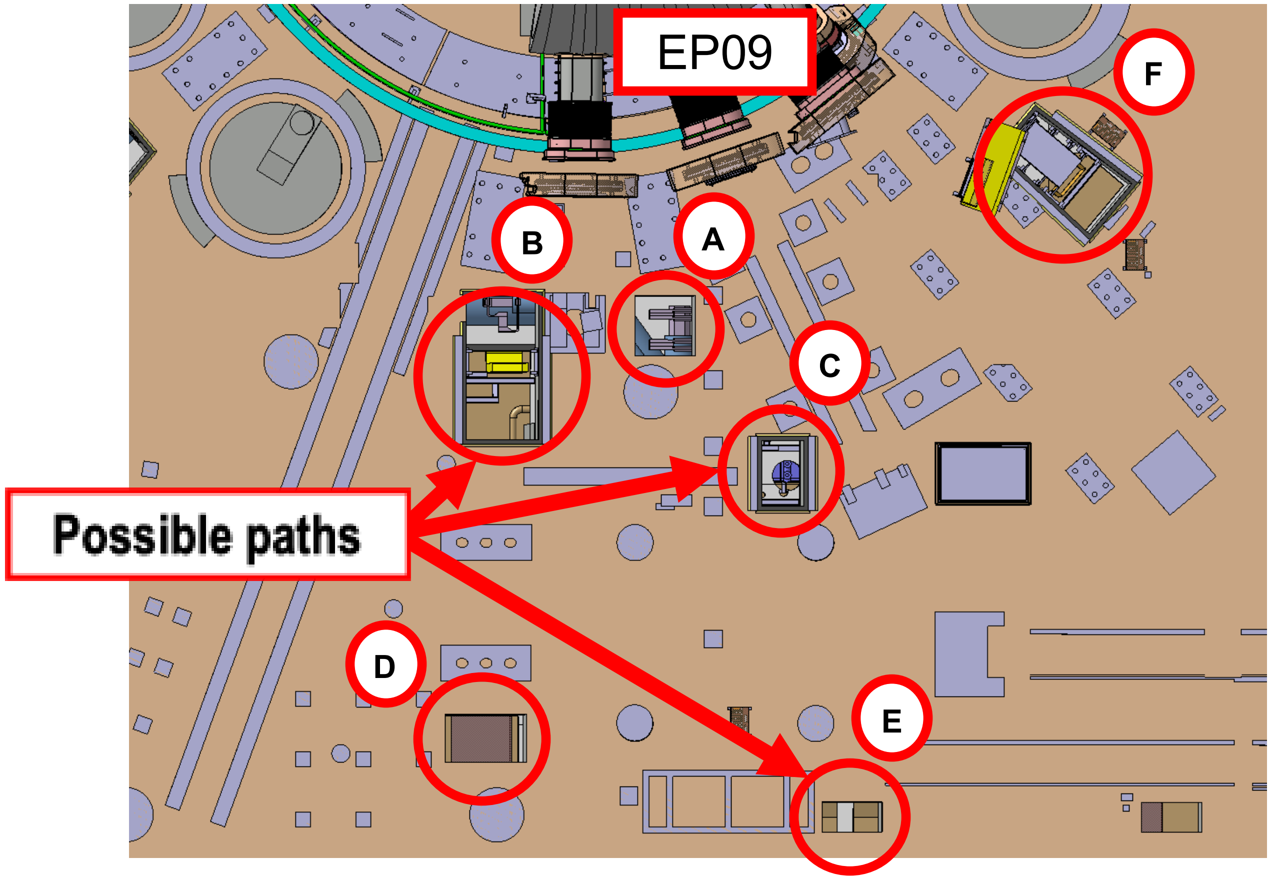

- Space requirement in the penetrations:
  - 2 circular oversized waveguides (~ 40 mm diameter, allowing for 50 mm including flanges)

❖ Minimize transmission path length and number of bends is a critical design requirement (to reduce signal losses) ➔ long path lengths will require the use of oversized corrugated WG (costly option)

- **Visit to Japan in September** (E. de la Luna, S. Cabrera)

Input required:
- Which of the nearby penetrations can be used?
- What are the suitable locations in the basement for installing the instrumentation?

Based on current CAD data, possible routing paths include B, C, and E
Final selection pending receiving further information from QST

Ex-vessel engineering design. Input required

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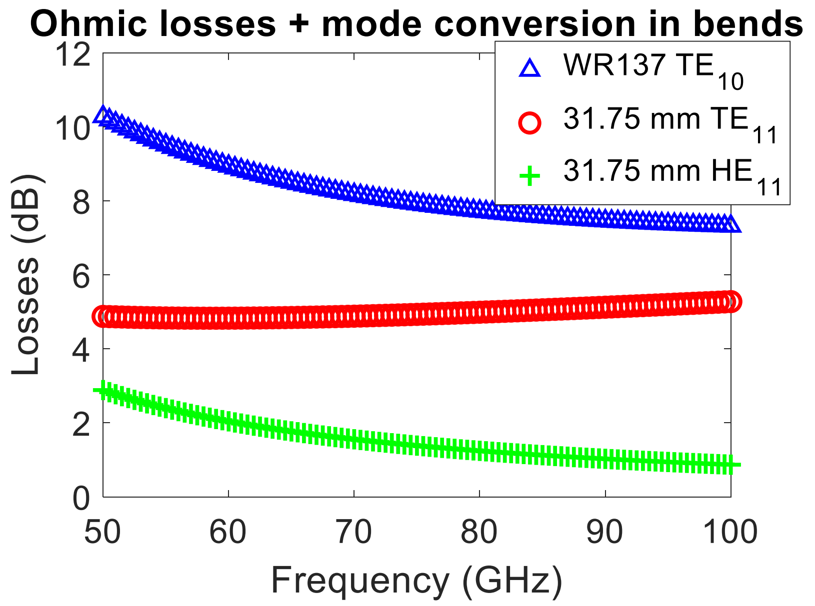
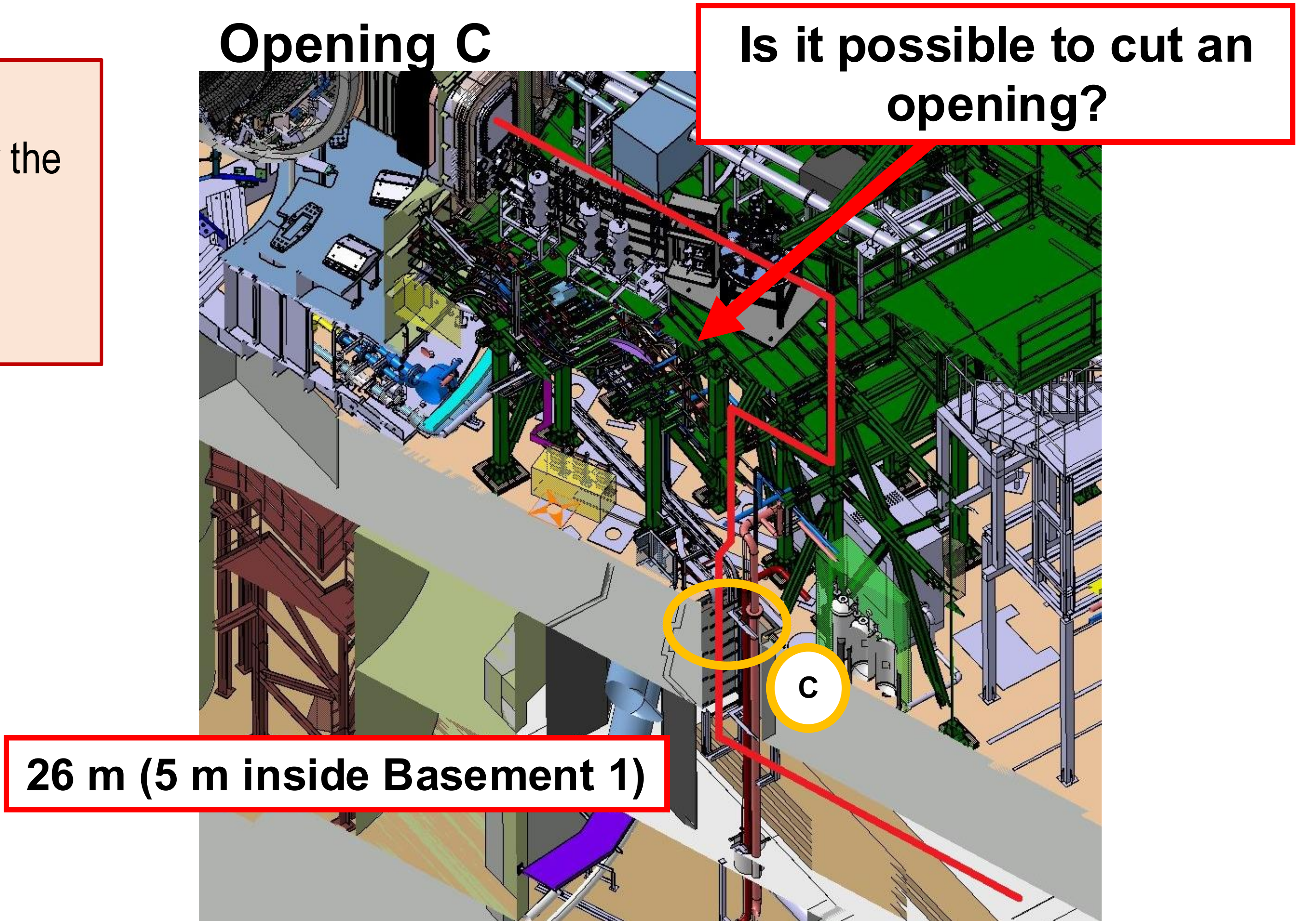
Input required:
- How to support the ex-vessel waveguides, particularly the first meters near the port flange?
- Is it possible to cut an opening in the 'common stage' (saving 5 m and a few bends in path C)?





Plans for 2025 and beyond

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- Detailed analysis of $k_\perp$ vs radial position across JT-60SA plasma scenarios (see *D. Carralero et al, Fusion Engineering and Design 73, 112803 (2021)* for the previous feasibility study) — **In progress (2025)**
- Finalisation of the optical design (mirrors & antennas) — **In progress (2025)**
- Start defining the technical instrumentation specifications (independent of the mechanical design) — **In progress (2025)**
- **Visit to Naka planned for September 2025** to assess ex-vessel waveguide routing and discuss further design requirements
- Preliminary engineering design — **In progress (2025)**
  - Includes both ex-vessel & in-vessel components; can proceed in parallel if enough information about the ex-vessel path is gathered in the visit to Naka
- Final engineering design, including thermal, EM, and mechanical analysis — **To be completed in 2026**
- Timely receipt of all the required input data from QST is essential to prevent delays in the design work (requests outlined in the presentation)

Work scheduled for 2025 is contingent upon finding/receiving the required input data

Work in 2026 is contingent upon the availability of financial support

THANKs for you attention

Preliminary Project Planning (resource-dependent)

- Original plan assumed design work starting in 2024 (presented by C. Sozzi in the TCM, 28 Nov 2024)

Y1 (2024)	Y2 (2025)	Y3 (2026)	Y4 (2027)	Y5 (2028)
Finalize optical design (EP09) & mechanical design	Design validation	Final design review & call for PA	Procurement, manufacturing & testing ???	

- Where we are as of today

Y1 (2024)	Y2 (2025)	Y3 (2026)	Y4 (2027)	Y5 (2028)	
Finalize conceptual design (EP15 not suitable)	Finalize optical design (EP09) & mechanical design ??	Design validation ??	Final design review & call for PA	Procurement, manufacturing & testing ???	M3

EP09 port allocation (28 Nov 2024)

- Plan for installation in ME3 (end of 2028), very tight schedule !!!!
  - Mitigation action: performed activities in parallel (e.g. ex-vessel & in-vessel components) whenever possible to accelerate progress (resource-dependent).
  - Timely receipt of all the required input data from QST is essential to prevent delays in the design work

JT60-SA scenarios-OP2 (2024)

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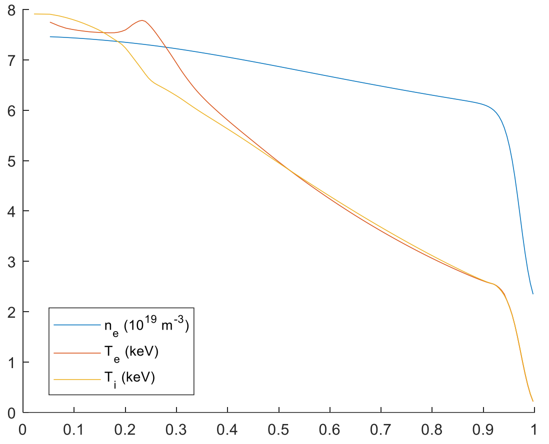
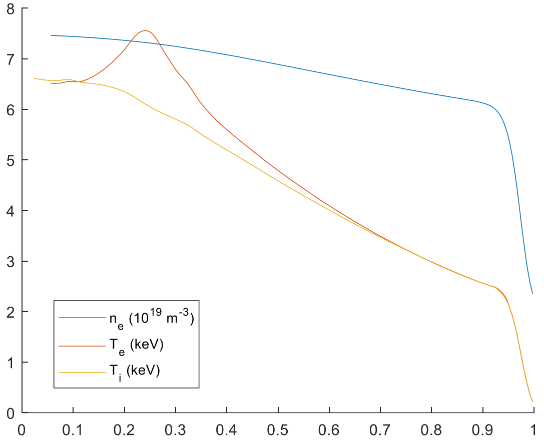
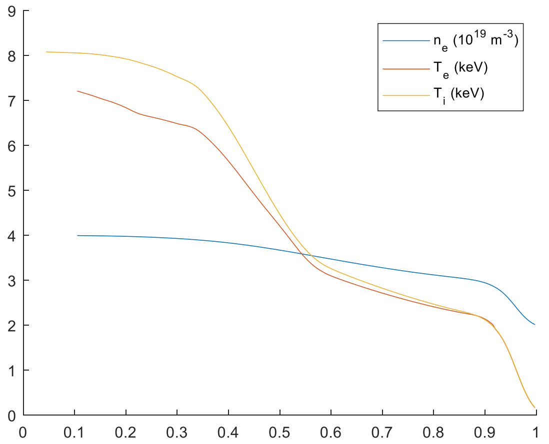
baseline high power



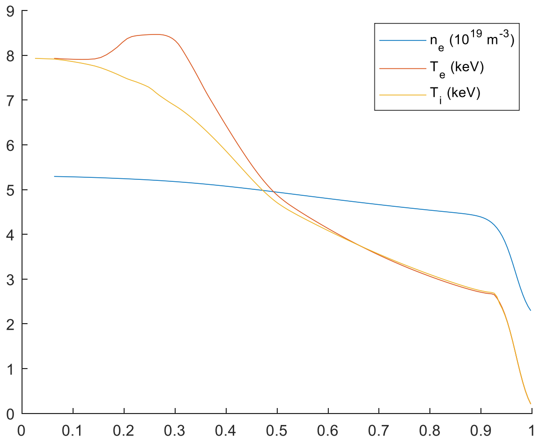
baseline low power



high beta



high q



We have considered four scenarios provided by QST:

- Baseline (q_{95}=3, f_{GW}=0.6):
  - low power (16 MW+3 MW)
  - high power (23.5 MW+3 MW)
- High beta (q_{95}~6.5, 14 MW+1.5 MW, f_{GW}=0.7)
- High q_{95} (q_{95}~5, 16 MW+3 MW, f_{GW}=0.6)

Scenarios in OP2 were prepared at a lower I_p, resulting in slightly lower density than those at full performance, which were used in the previous feasibility analysis [*D. Carralero et al, Fusion Engineering and Design 73, 112803 (2021)*])

Ex-vessel engineering design. Possible paths

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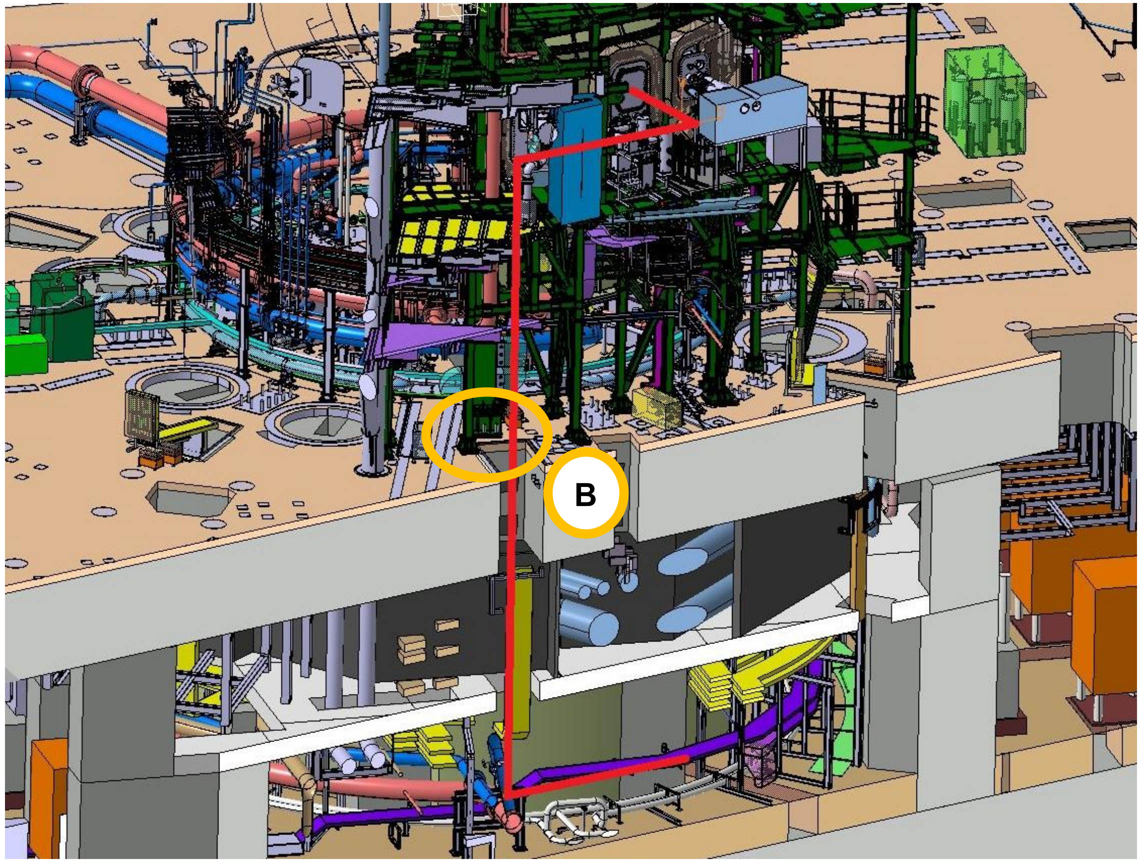
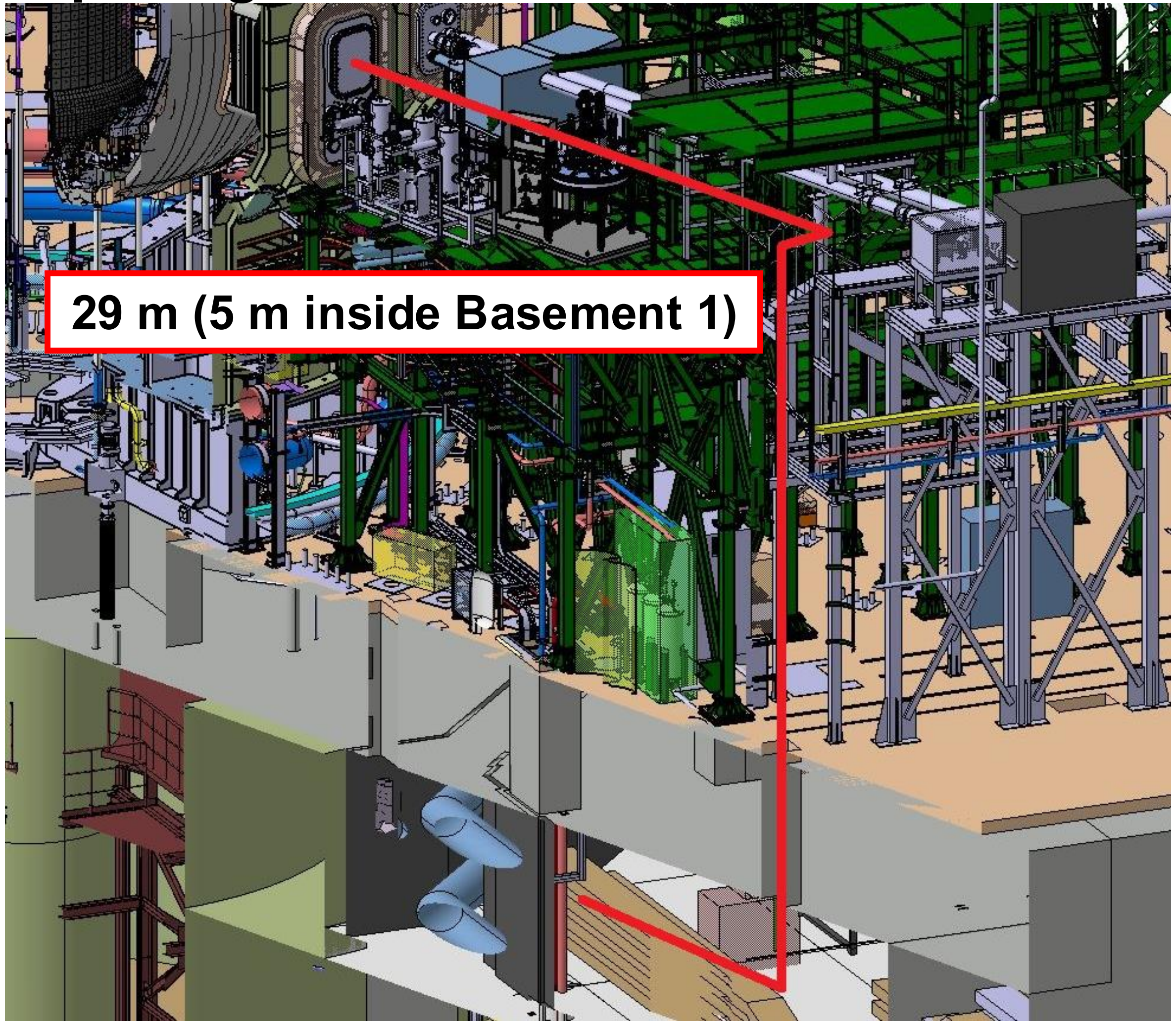
Opening B



29 m (5 m inside Basement 2)

Opening E



Feasibility analysis done in 2021 used a different port!

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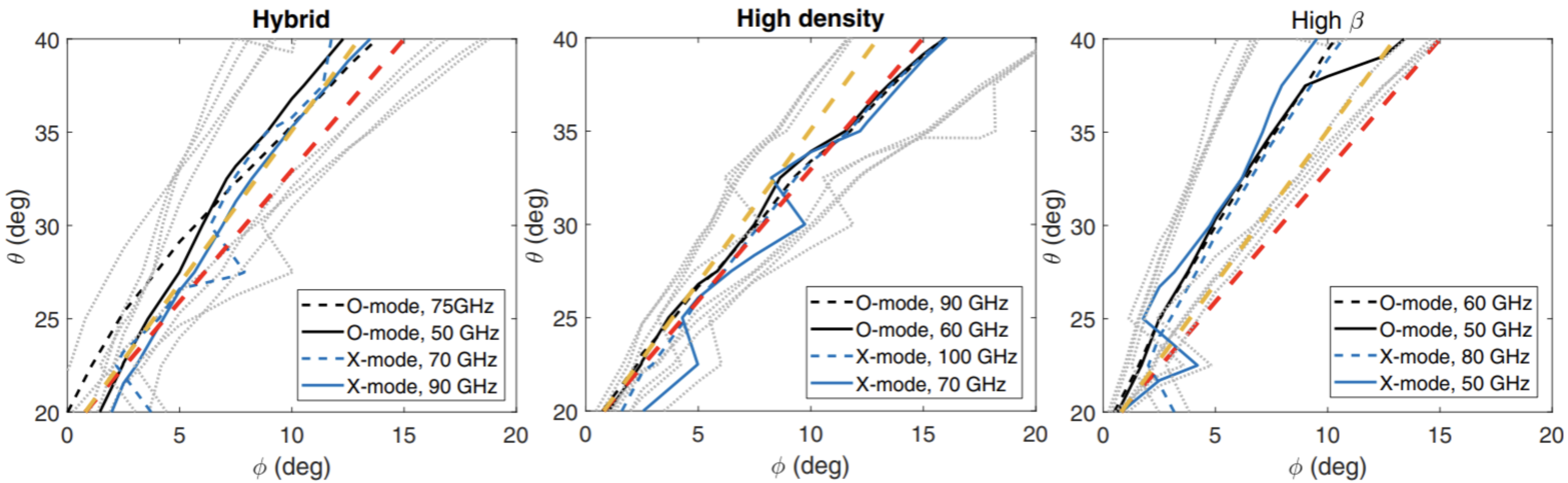

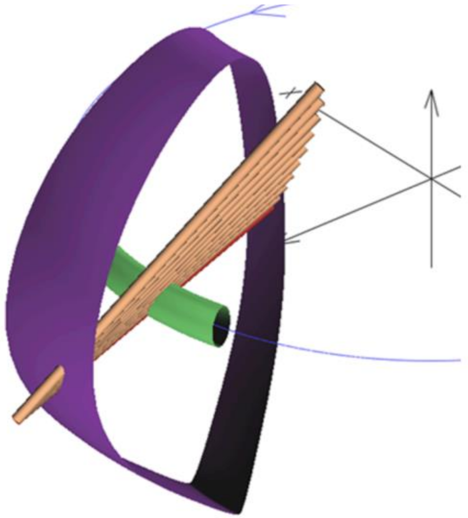

Optimal angle comparison is done to determine the **optimal θ/ϕ plane** that defines the single rotation plane of the last mirror.

This require repeating the ray tracing calculations for:

- different scenarios
- different backscattering positions (different frequencies/polarisation)

D. Carralero et al, Fusion Engineering and Design 73, 112803 (2021)