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Conceptual Design of a Modular EC System for EU-DEMO

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ABSTRACT

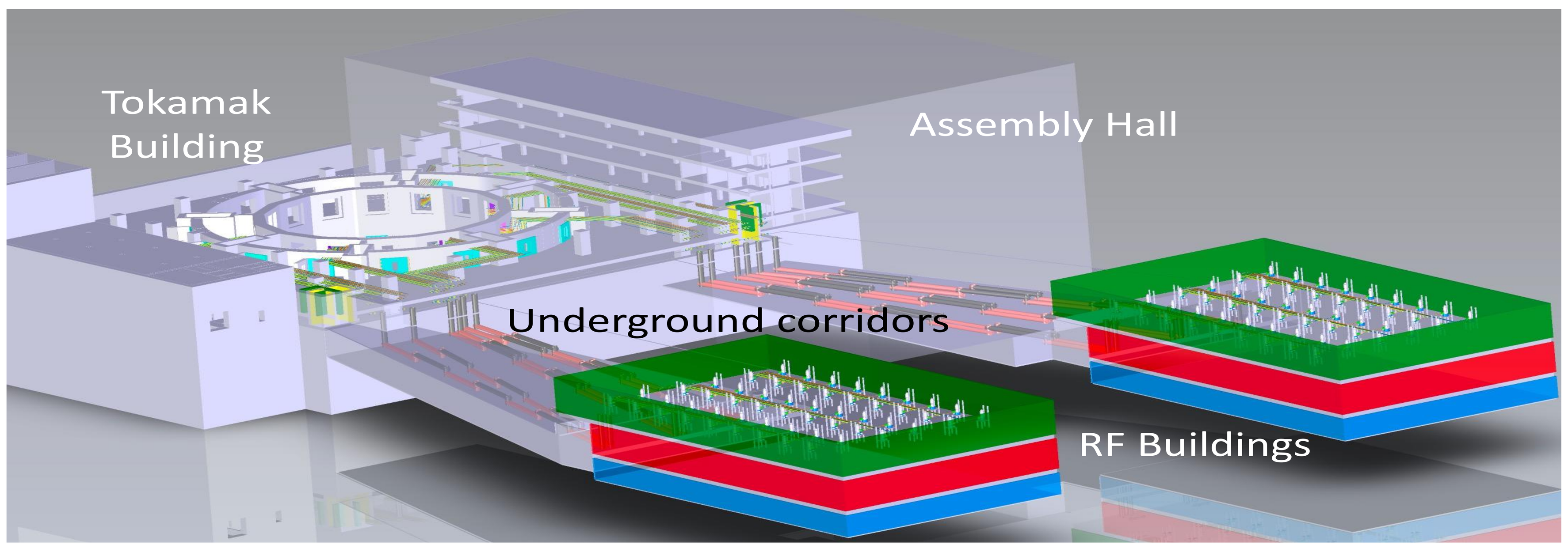
- EU-DEMO tokamak studies: fusion power plant concept with 2-hours pulse
  130 MW auxiliary heating by Electron Cyclotron (EC)[1].
- EC system delivers:
  - -30 MW for Bulk Heating (BH) in the plasma center,
  - -30 MW at the location of the main NTM instabilities,
  - -70 MW at plasma edge for preventing Radiative Instability (RI)[2].
- Design in clusters:
  - 9 x 2-MW coaxial-cavity gyrotrons
  - circular corrugated WG and evacuated QO multi-beam TL
  - 4 independent antennas in Equatorial ports
- The tunable (TF) and fixed (FF) frequencies variants have the flexibility to adapt to changing design guidelines, as the foreseen transition to a lower AR DEMO.

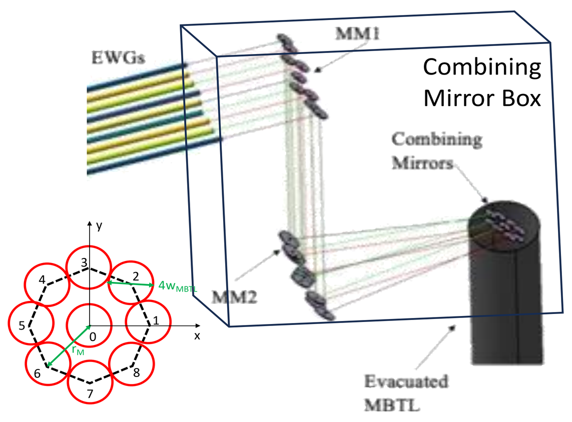
GYROTRON DESIGN AND DEVELOPMENTS

- 2 MW-class multi-purpose / multi-frequency coaxial-cavity gyrotrons developed in EU[3] will allow for operation at three different center frequencies (136/170/204 GHz).
- Test program on a modular gyrotron pre-prototype is ongoing at KIT FULGOR test facility to verify operation at pulses up to 1 s, multi-frequency and step-tunability and the possibility for an efficiency > 50 % by using a multi-stage depressed collector.

EWG AND MULTI-BEAM TRANSMISSION LINE

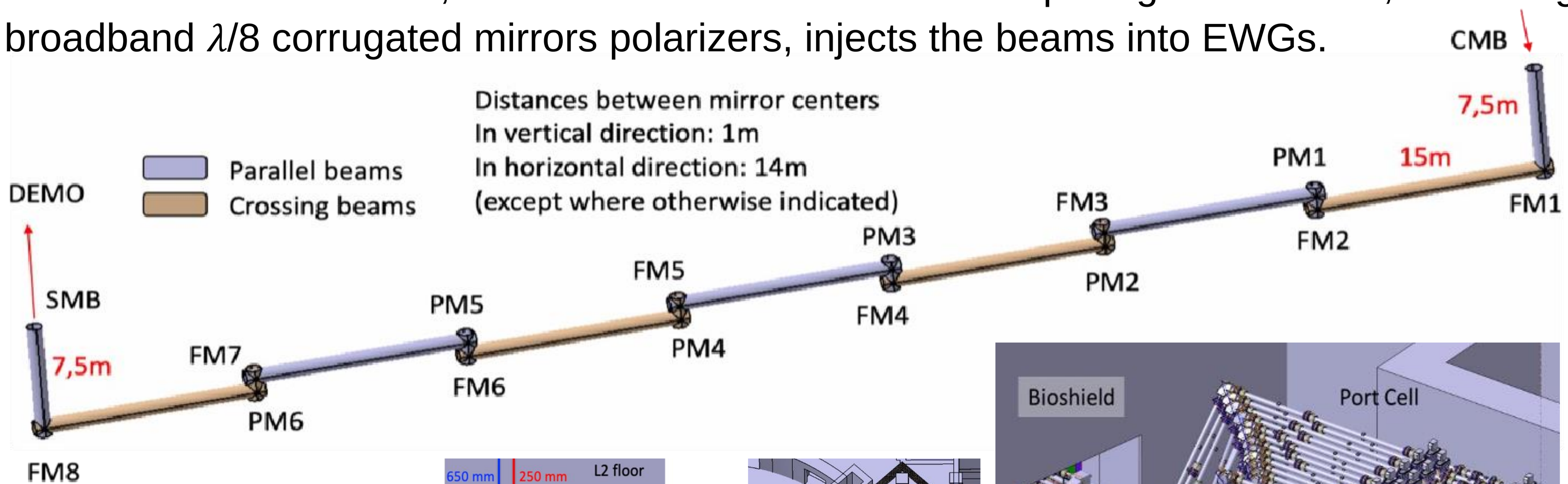
Two gyrotron buildings are located ~140 m away from tokamak. Power is carried by HE_{11} evacuated waveguides (EWG) inside the RF and Tokamak Buildings (safety and tritium confinement granted with RF windows and valves) and by multi-beam transmission lines (MBTL) running in underground corridors between the two buildings.



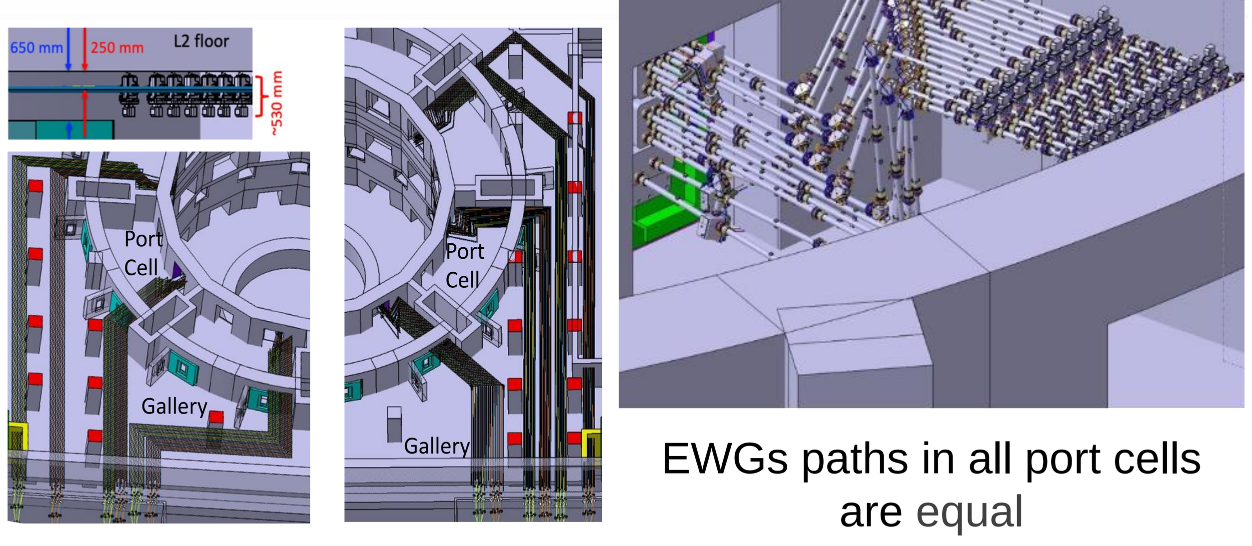


Coupling of the EWGs of each cluster to one MBTL is realized by a set of mirrors in the Combining Mirror Box (left), matching the beams from the EWGs in a packed octagonal bundle for the MBTL transmission. Plane "combiner" mirrors near the beam waist couple all beams of the cluster down with parallel axes at the MBTL entrance.

Under the Assembly Hall the quasi-optical MBTL guides the beams with 99.9% purity by means of single large focusing (FM#) and plane (PM#) mirrors in evacuated enclosures to reduce maintenance, losses and risk of arcs. A Splitting Mirror Box, including broadband $\lambda/8$ corrugated mirrors polarizers, injects the beams into EWGs.

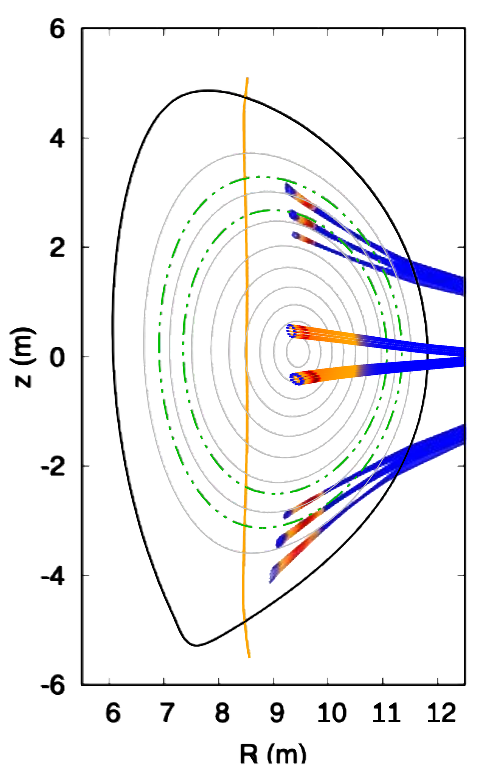


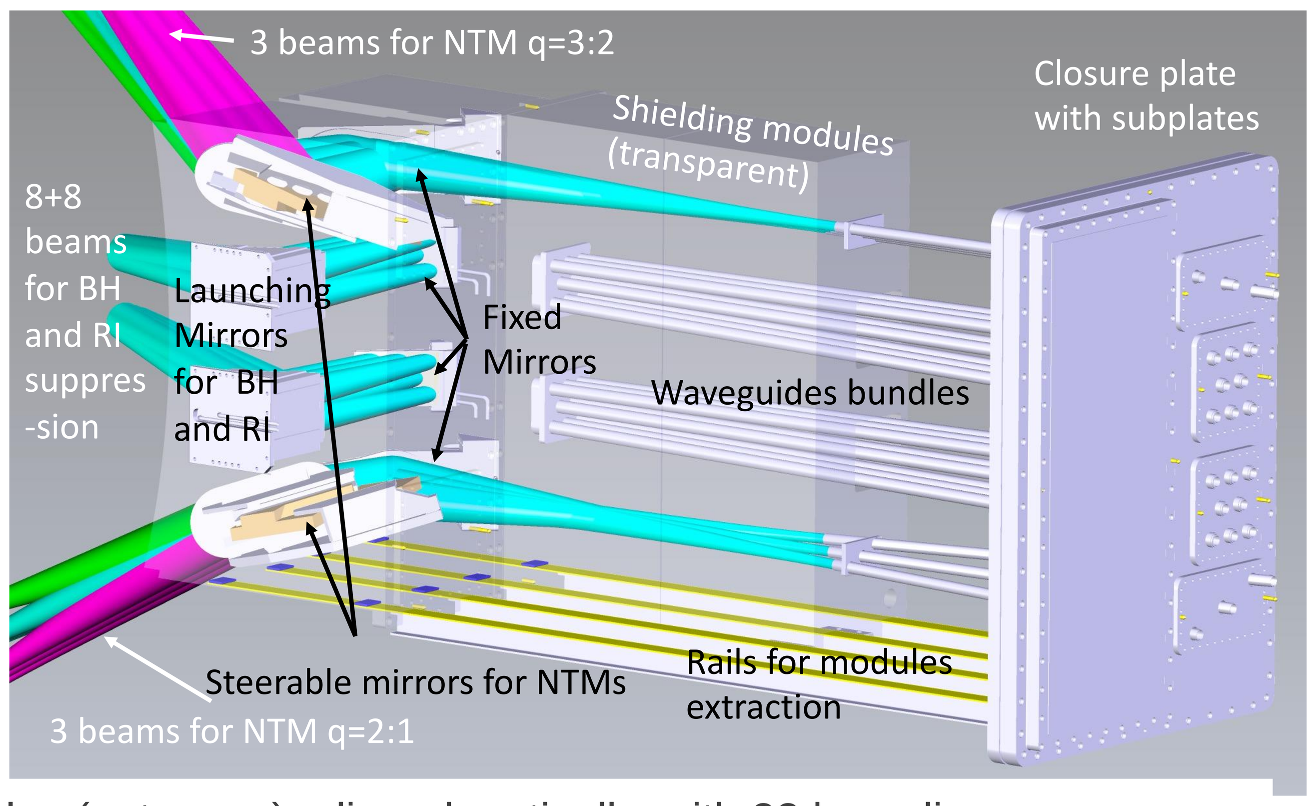
The EWGs run from the south wall of tokamak building to the ports dedicated to the EC close to the ceiling of equatorial level in the gallery.



EWGs paths in all port cells are equal

EC LAUNCHER

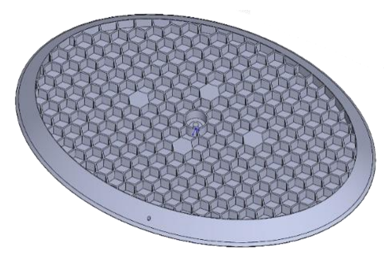


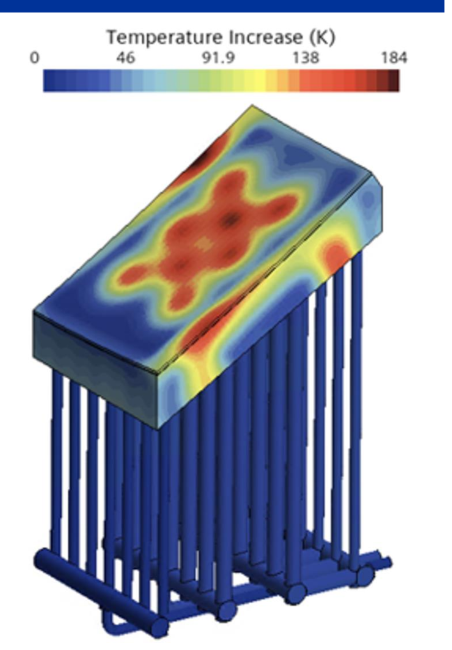


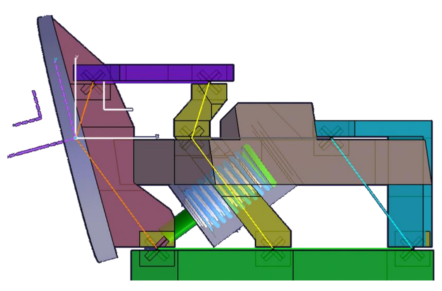
- 4 independent modules (antennas), aligned vertically, with 22 beamlines.
- 3+3 beams on top and bottom antennas (movable in the FF, fixed in the TF variants) for NTMs. Optics is studied to have 3 beams equivalent in toroidal symmetry, with equal trajectories and deposition profiles independently on plasma shape.
- The BH and RI beams share two symmetric fixed antennas, close to the equatorial plane each with 8 beams, that travel partially superimposed and are refocused at the plasma side in order to require the minimum aperture on the Breeding Blanket. Different resonant frequencies are used to inject power in the plasma center (170/204 GHz) or at the edge (136 GHz).
- Launcher is in two parts: on one side launching mirror antennas, on the opposite, fixed mirrors, shielding and input waveguides.
- Launching mirror block can be extracted and replaced leaving in place fixed mirrors block, shielding and waveguides, easing maintenance of the critical parts.

COMPONENT DESIGN

MBTL mirror, with a honeycomb structure and spiral cooling channels below the copper surface.

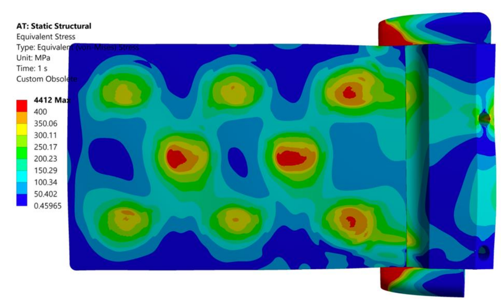




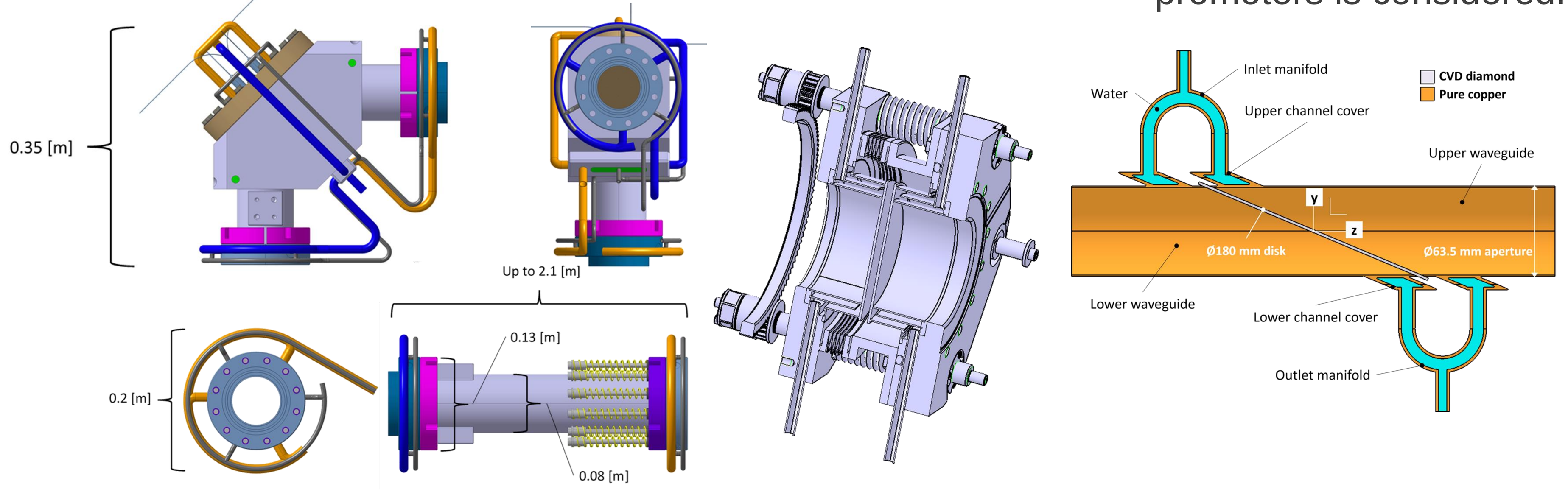


Steering mechanism (FF variant) is realized behind launching mirror for radiation protection, with pneumatic-actuated new pantograph structure.

Cooled mirror structures designed and analyzed at highest power densities of BH modules (smaller beam footprints)



Use of helium as coolant and v-ribs as turbulence promoters is considered.



Design of components for primary vacuum is ongoing. Major challenges are the remote handling and the broadband double-disk or Brewster-angle windows for the TF variant.

CONCLUSIONS

The conceptual design of DEMO EC system is addressing the main challenges: high-power generation and transmission with efficiency, low losses and reliability, installation and (remote) maintenance of complex components in a restricted space, and design of components at high power, requiring materials resistant to irradiation damage.

[1]FEDERICI, G. et al., The EU DEMO staged design approach in the Pre-Concept Design Phase, Fusion Engineering and Design 173 (2021) 112959
[2]TRAN, M.Q.T. et al., Status and future development of Heating and Current Drive for the EU DEMO, Fusion Engineering and Design 180 (2022) 113159
[3]JELONNEK, J. et al., Design considerations for future DEMO gyrotrons: a review on related gyrotron activities within EUROfusion, Fusion engineering and design 123, (2017) 241.

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