# EG-6
# Fusion technology developments

S. Brezinsek[(1)], C. Day[(2)], G. Dose[(3)] on behalf of the Expert Group-6 of the DTT Research Plan

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Kick-off Meeting

16-17 November 2022

# Expert Group-6

| | | | |
|---|---|---|---|
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Total of 19 people

- 7 from Italian Institutions
- 12 from European Institutions

**Different fields:**

- Plasma-facing components
- Plasma-Wall Interactions
- Heating systems
- Diagnostics
- Pumping systems
- Magnets
- Plasma physics
- Control and Operation

**The community response is not related to divertor technologies only.**

# EG6 objectives should attempt to address fusion technology as a whole

The capabilities of DTT are unique from the technological point of view:

- Steady-state/long pulse operation
- High field
- High power density
- High plasma density
- Reactor-relevant material (full W)

**Different fields:**

- Plasma-facing components
- Plasma-Wall Interactions
- Heating systems
- Diagnostics
- Pumping systems
- Magnets
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(proposal) **Objective of EG-6:**

Define ambitious, but realistic, scientific goals for DTT to bridge the technological gap to the realization of a fusion reactor.

# Integrating the inputs from different fields requires a proper planning

**Status:**

Experts have been contacted and first inputs have been received.

**Planning (November 2022 – February 2023):**

- First phase (November 2022 – Begin of January 2023):
  - **Definition of high-level goals.**

    Open questions:  do we focus only on heat and particle exhaust? or try and expand to other reactor-relevant objectives (e.g., steady state 3D magnetic sensor, HTS, fast ion diagnostics, travelling wave array antennas, ecc) ?

    Common comment from the fusion community is that DTT adopts just existing fusion technologies to "avoid risk". We must accept some risks to make advances in the field. **How much risk is acceptable?**

  - **Brainstorming.**

    After the main objectives have been agreed upon, we start to collect the proposal from the experts. The brainstorming should be carried out separately for all the different macroareas (if multiple), defined in the goals.

- Second Phase (end of January 2023 – February 2023):
  - **Definition of the scientific targets, together with a priority-driven strategy**

# Recommendations from the CTS set clear priorities

**Technical and Scientific Committee (CTS)** recommendations relevant for the Expert Group-6 (rephrased):

- The large ambition of the DTT scientific programme, may find **some limits**
- Clear role of **DTT contributing to ITER and DEMO**
- **Focus on divertor and plasma wall interaction studies**
- A **narrow down of the project missions** could be envisioned
- **In-depth definition of research targets** for the different phases
- Study future baffled configuration
- **Clearly state the limits of the flexibility**; no single machine can solve all problems
- Exploit synergy with **EXICTE/SHPD**

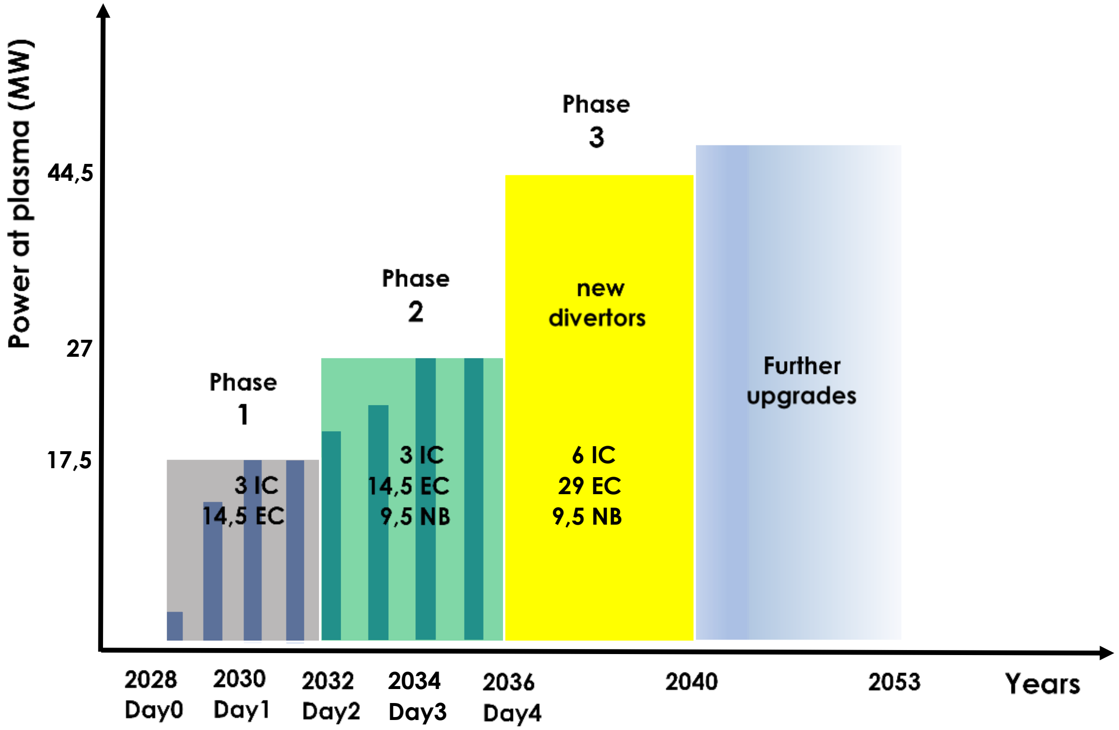
**ACTIONS FOR EG-6**

- **Define technological limits of DTT**
- **State DTT contributions to ITER (e.g., testbed for ITER 2nd divertor, detachment control, heat flux control,…)**
- **State DTT contribution to DEMO (e.g., PFC lifetime studies, divertor diagnostics, long-pulse operation of PFCs, PWI experiments…)**
- **Define, phase by phase, the priorities among the research objectives. Divertor and PWI studies should be prioritized.**
- **Exploit synergies also outside EU (EXCITE and DTT are remarkably similar machines)**

# Definitions of DTT limits and the inputs for the brainstorming phase

- Technological limits are defined in the **Plant Integration Document (PID)**, but will be summarized also in the Appendices of the RP

- Additionally, in order to define some research targets for each Phase, inputs are needed:




**What this chart translates into for the DTT divertor?**

- **Maximum power density**
- **Maximum particle flux/fluence**
- **Expected sputtering yield**

**For input definitions, required interaction with:**
**EG-3 for references scenario**
**EG-2 for plasma boundary conditions**

# Time schedule up to next DTT-RP meeting

- Discussion of high-level goals - **Hopefully Today / November 2022**
- 1st Meeting with experts and collection/discussion of proposals - **December 2022**
- 2nd Meeting with experts for priority definition – **End of January 2023 / Begin of February 2023**
- First report of Expert Group **- March 2023**
- 2nd Meeting of the DTT-RP team - **April 2023**

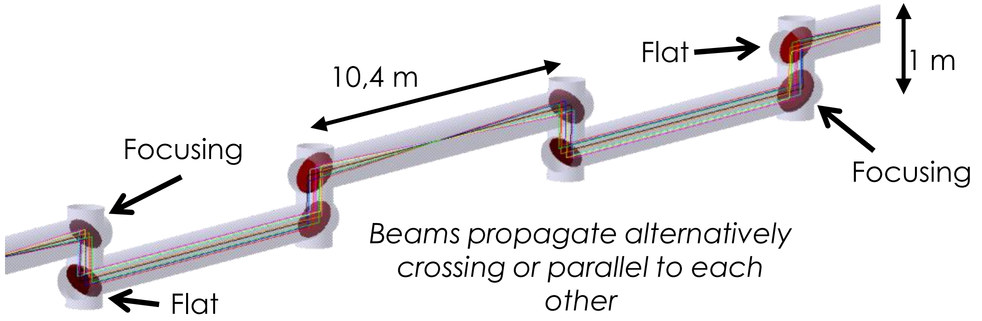
# What was done up to now: new technologies for DTT

**Heating systems:** (SOFT 2022, Granucci)

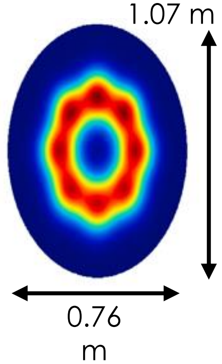
- **Evacuated quasi-optical transmission lines for ECRH**

  **DEMO relevance**: TL mirrors embodied in a vacuum enclosure to reduce losses due and avoid microwave leaks

  - **Efficiency target > 90%**
  - **Designed for up to 1.5 MW per beam**




Expected normalized heat load distribution of 8 overlap 1 MW beams on a MBTL mirror surface

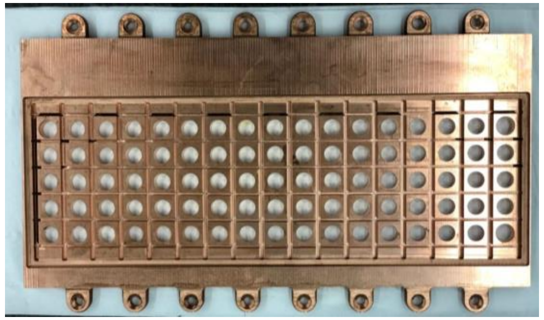



- **Solid state transmitter for ICRH**

  Low voltage PS: 400 V instead of 20 KV
  Wide Industrial market: vacuum tube production is a monopole
  Life time: more than 100 000 hours expected
  Strong Modularity

- **Additive Manufacturing for acceleration grid of NBI**

  Optimized shape and cooling design, as required in the proposed spherical grids and hyperlens.



**EOS CuCrZr Grid prototype Machined**

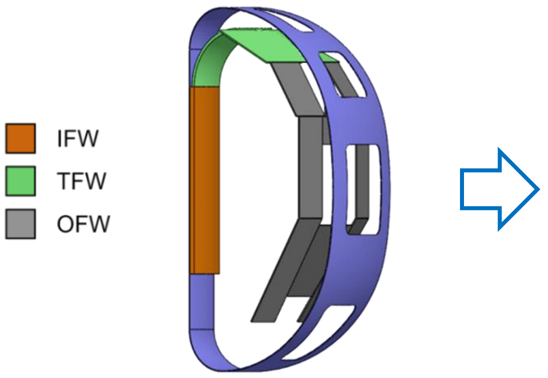
**Power Supplies:** (SOFT 2022, Zito)

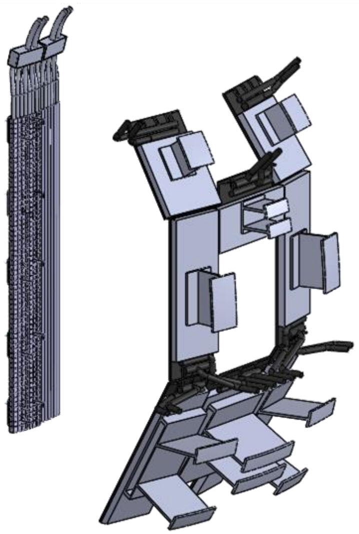
- **Silicon Carbide Varistors** for fast discharge units of TF

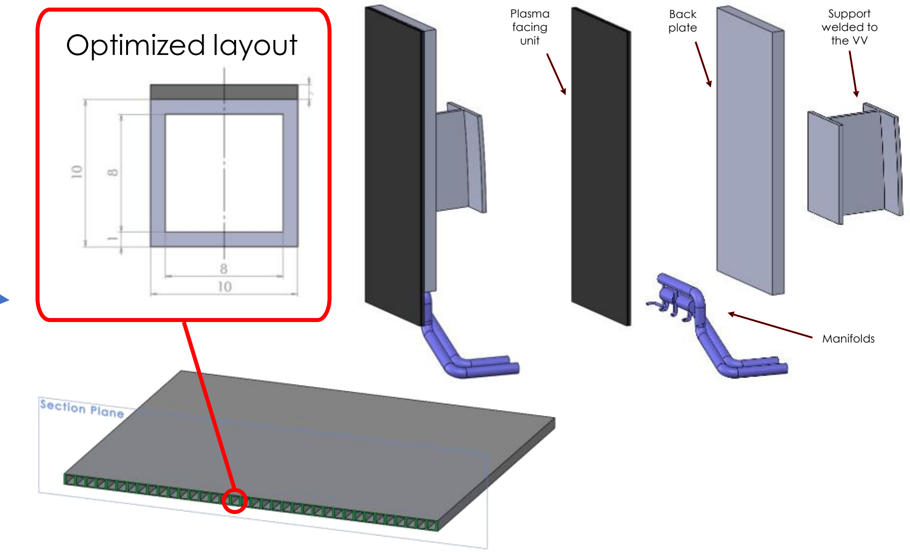
# What was done up to now: PFCs of the DTT First Wall

**DTT First Wall:** (SOFT 2022, De Sano)

**DEMO relevance**: Steel based PFC






Solution 1

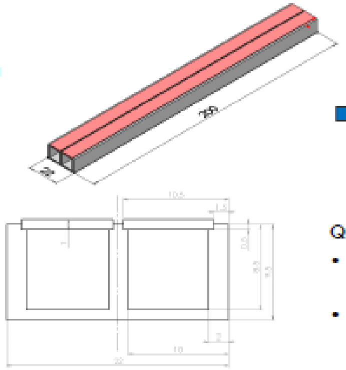
Solution 2

## Machining and welding

This manufacturing route leads to the distortion of the component. Therefore, thermal cycles are needed to relax the internal stresses. Small samples will be realized before fabricating the final prototype.

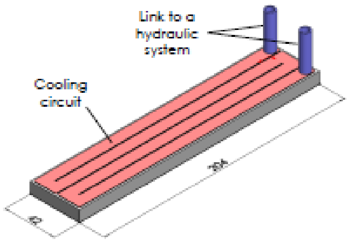
Mock-up #1

To verify the **full penetration welding** between the plate and the lids




Mock-up #2

To verify the full penetration and the **tightness of the weldings**




**Qualification tests:**

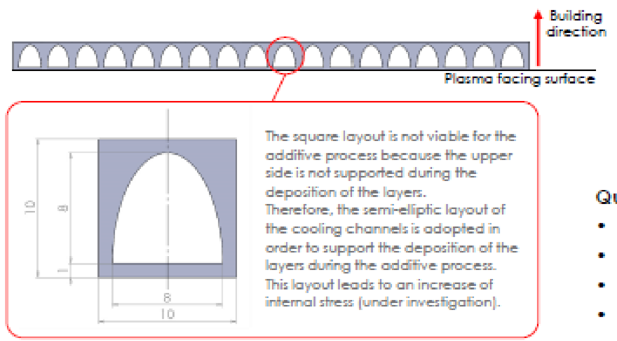
- For Mock-up #1: X-ray tomography and non-destructive ultrasonic inspection; metallographic inspection.
- For Mock-up #2: X-ray tomography and non-destructive ultrasonic inspection, leak and tightness assessment of the cooling circuit.

## Additive manufacturing

This technique provides an higher design flexibility. The powder bed based process will be adopted. On the other hand, the component will be characterized by the worst mechanical performances of the material (that will be evaluated) and an higher roughness ε in the cooling circuits.

Hydraulic parameters

| | | | |
|---|---|---|---|
| $\dot{m}$ | 0.39 | kg/s | |
| $\bar{u}$ | 7.9 | m/s | +28% |
| $\varepsilon$ | 12.0 | μm | |
| $\Delta p/L$ | 1.04 | bar/m | +120% |
| $\Delta p_c$ | 0.50 | bar | +29% |

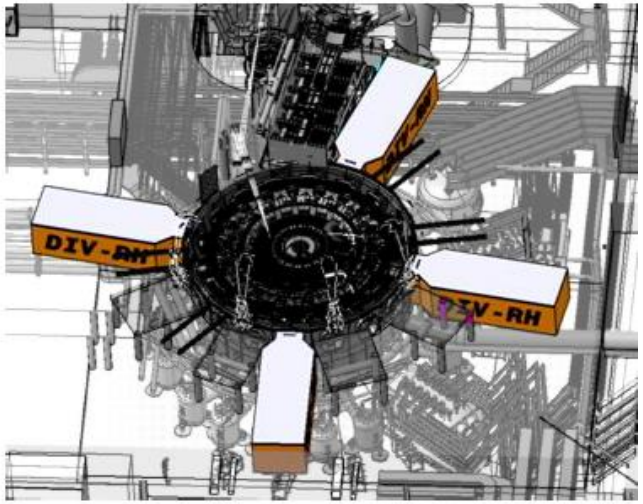



**Qualification tests:**

- Characterization of the AISI 316L powder.
- Realization of small samples.
- Mechanical assessment of the small samples.
- Tightness assessment of the cooling circuits.

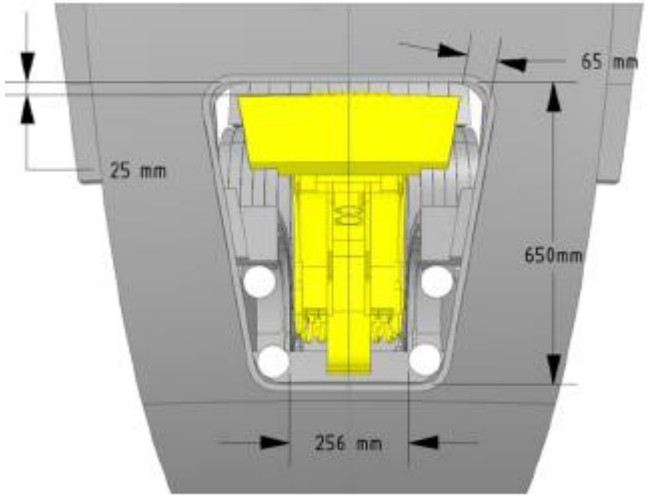
# What was done up to now: Divertor studies

**DTT Divertor:** (SOFT 2022, Roccella)




- **4 ports** are dedicated to the **Remote Handling of the divertor**
- 4 divertor cassettes benefits from a preferential position to be extracted
- These divertor modules, called **Divertor Test Modules**, will be dedicated to divertor studies
  - New PFC technology
  - Special Diagnostics
  - Post mortem studies between phases
  - …
- The divertor WCS is designed to accommodate future **dedicated cooling system** for technology study on Test Modules

| Cooling system parameters | Standard Modules | Test Modules |
|---|---|---|
| Temperature | Up to 130°C | Up to 250°C |
| Pressure | 5 MPa | Up to 15 MPa |
| Tot mass flow | 577 kg/s | 43 kg/s |

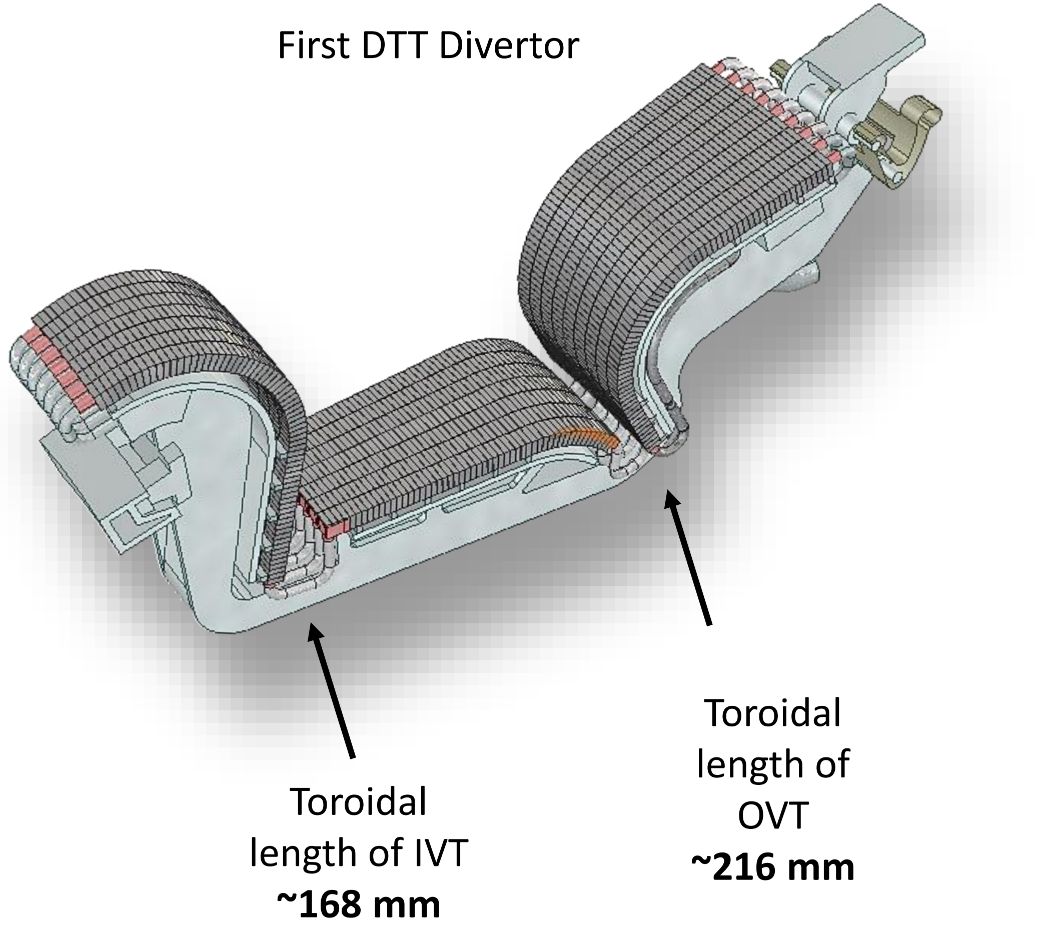


# What was done up to now: Material studies

**DTT Divertor:**

- **First DTT divertor will use W monoblocks**
  This is currently the baseline reference for both the ITER and EU-DEMO divertor targets
  + Manufacturing Technology already established in-house in ENEA

- What do we need **beyond the W monoblock?**



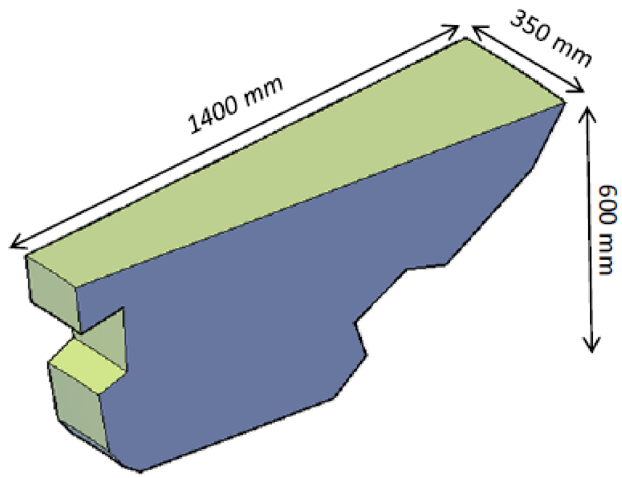

DTT will provide a testbed where a **large area dedicated to material studies** in tokamaks (currently missing in EU)

Do we want to start from Day0?
Do we have a list of promising candidates ready to be integrated in a Test Module?

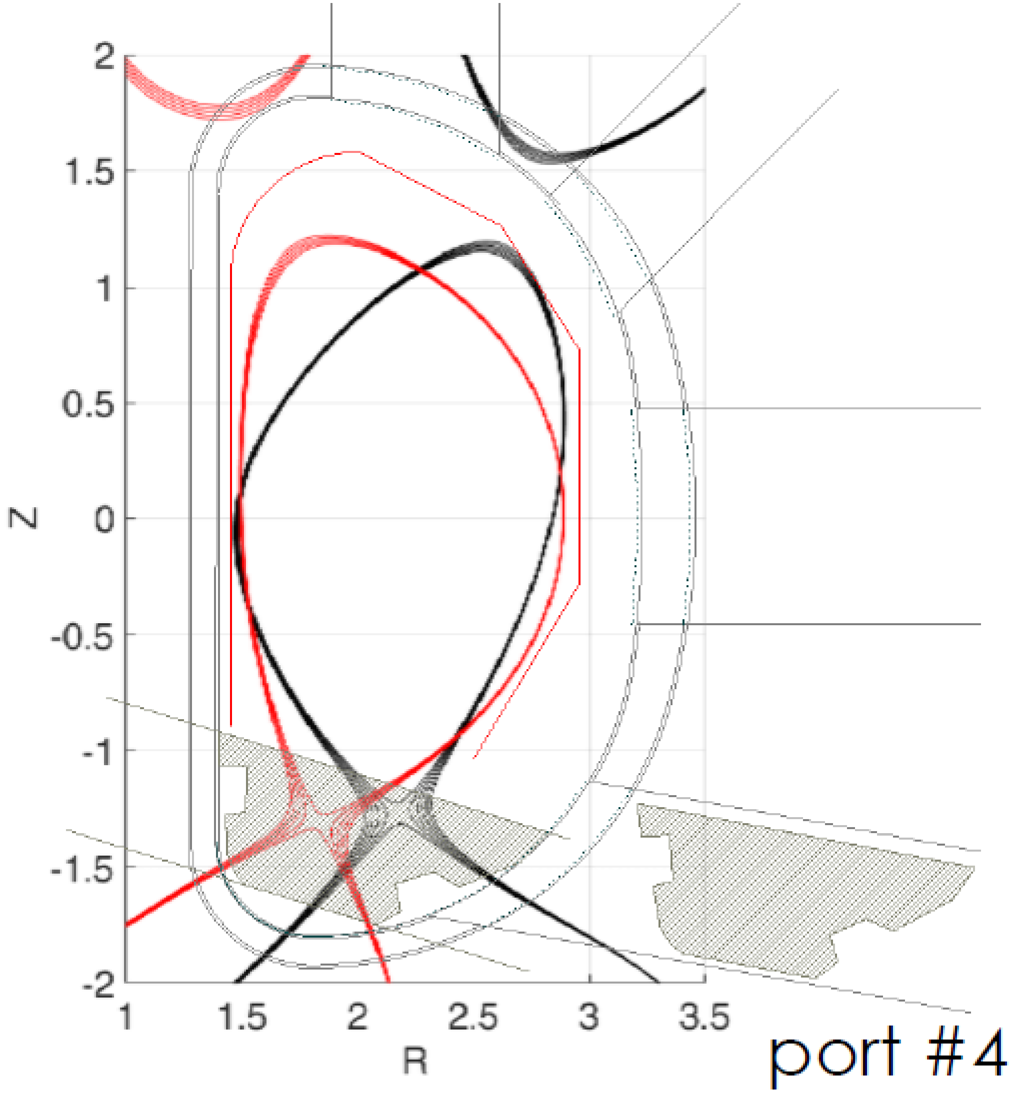
# What was done up to now: Testbed for new divertors

**DTT Divertor:** (SOFT 2022, Roccella)

- DTT can accommodate **new divertors**, as long as they satisfy the engineering requirements (mainly from the remote handling), and they are compatible with the expected magnetic equilibria

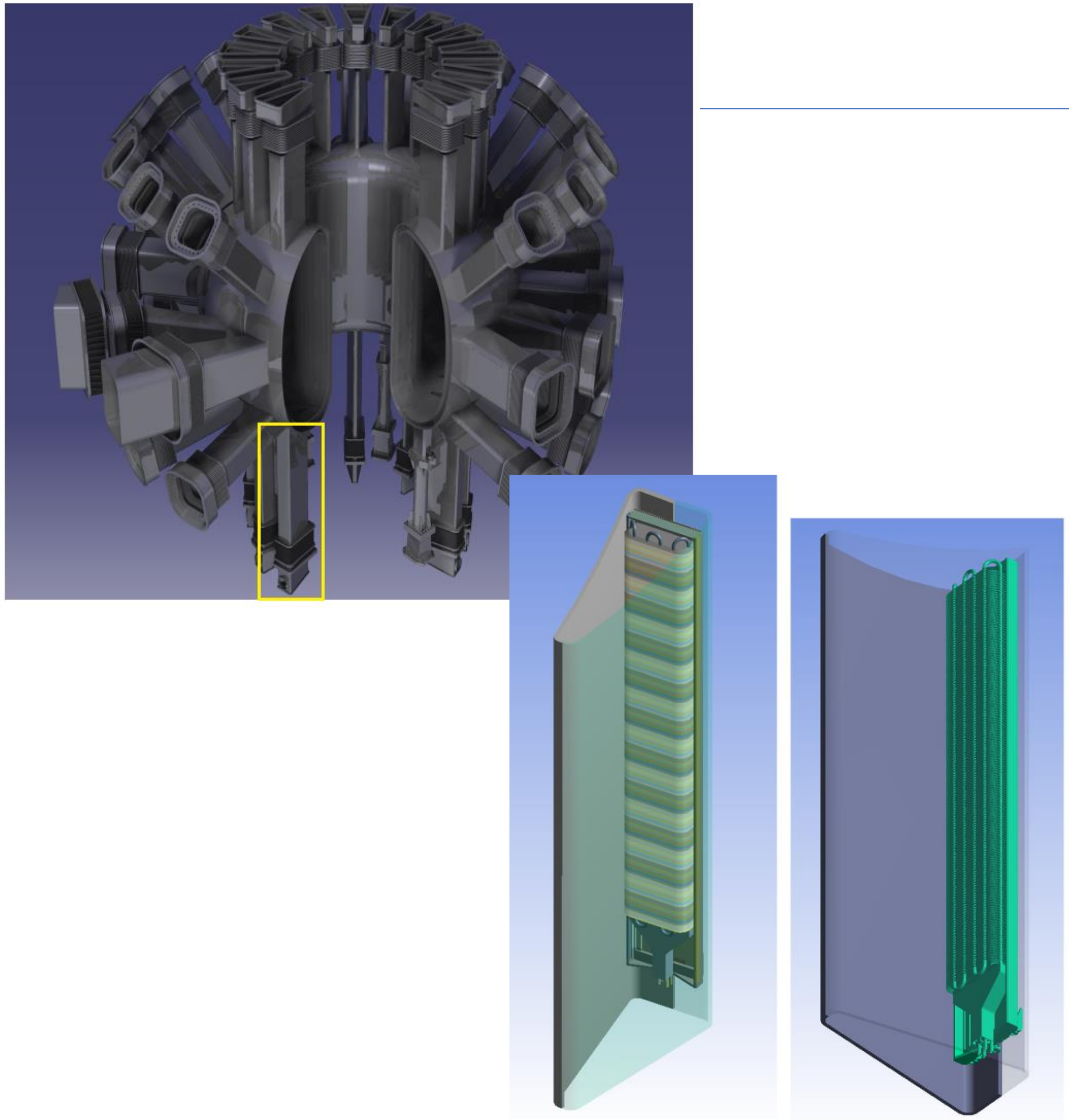



Maximum Size of a divertor module in DTT




- Possibility of investigating **baffled configuration** (are they reactor relevant, though???)

# Divertor pumping

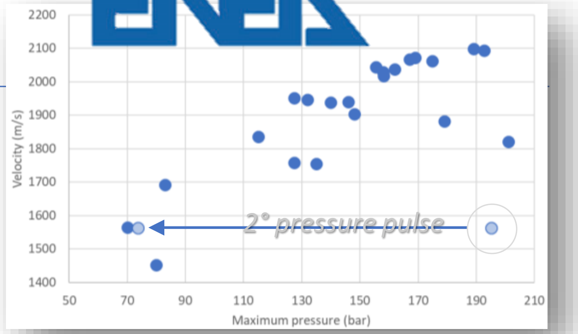


**DTT Pumping:**

- DTT will be equipped with a pumping speed of ~ 100 $m^3/s$ by tailor-made cryopumps located in a number of lower vertical (#5) ports.
- This pumping technology is not long pulse (DEMO) relevant, but was the only one matching the requirements if to be located in the #5 ports.

- Regarding the DTT timeline, DTT would provide a **perfect option to further increase the technical readiness of the new DEMO pump technologies** in relevant size and under representative conditions (such as external magnetic field).
- However, due to its limited cross-section and low conductance towards the bottom side, the port #5 is not a very good testing environment.
- Option to define a port #4 as suitable test port (at some time)?

# Pellet Injection

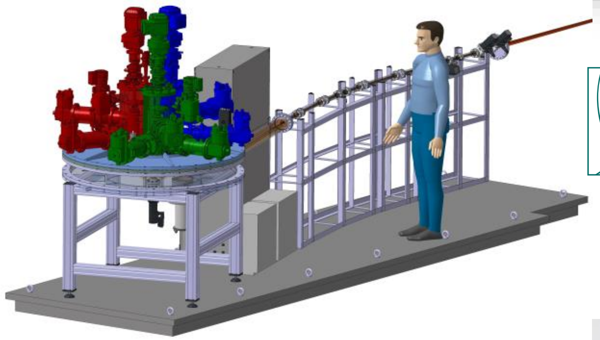



**DTT pellet Injector:**

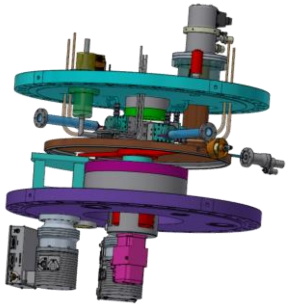
- The pellet injection system(s) for EU-DEMO is currently under definition in a multi-RU activity involving ENEA, IPP, CEA, EK-CER, KIT.

- A pellet test bed (PET) is under build at KIT, the configuration of the pellet injector will be defined by end 2023.

- DTT (with plasma) and PET (without plasma) could ideally **define a joint pellet injection development programme**, to be as much as possible complementary (repeatability, and high repetition long pulse performance)



For JT-60SA



# Background – EU-DEMO Maturation programme

- EUROfusion Technology Department is conducting in each work package a yearly multi-dimensional maturity review of critical technologies.
- This shall cover three aspects: technology readiness, integration readiness, and system readiness.
- A strong cross-relation with potential DTT contributions is obvious, if DTT wants it.

| Technology readiness level (TRL) | Description |
|---|---|
| 1 Basic principles observed and reported | Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties. |
| 2 Technology concept and/or application formulated | Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies. |
| 3 Analytical and experimental critical function and/or characteristic proof of concept | Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. |
| 4 Component and/or breadboard validation in | Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of |
| | ...nificantly. The basic technological ...listic supporting elements so they can be ...clude high fidelity laboratory integration of |
| | ...ch is well beyond that of TRL 5, is tested in ...tep up in a technology's demonstrated ...e in a high-fidelity laboratory environment or |
| | ...n. Represents a major step up from TRL 6 ...em prototype in an operational environment |
| | ...form and under expected conditions. In ...f true system development. Examples ...e system in its intended weapon system to |
| | ...orm and under mission conditions, such as ...uation. Examples include using the system |

| Level | SRL Definition |
|---|---|
| 9 | System has achieved initial operational capability and can satisfy mission objectives |
| 8 | System interoperability should have been demonstrated in an operational environment |
| 7 | System threshold capability should have been demonstrated at operational performance level using operational interfaces |
| 6 | System component integrability should have been validated |
| 5 | System high-risk component technology development should have been complete; low-risk system components identified |
| 4 | System performance specifications and constraints should have been defined and the baseline has been allocated |
| 3 | System high-risk immature technologies should have been identified and prototyped |
| 2 | System materiel solution should have been identified |
| 1 | System alternative materiel solutions should have been considered |

| IRL | Definition | Evidence Description |
|---|---|---|
| 0 | No integration | No integration between specified components has been planned c |
| 1 | A high-level concept for integration has been identified. | Principle integration technologies have been identified<br>Top-level functional architecture and interface points have been d<br>High-level concept of operations and principal use cased has been |
| 2 | There is some level of specificity of requirements to characterize the interaction between components | Inputs/outputs for principal integration technologies/mediums are characterized and documented |
| 3 | The detailed integration design has been defined to include all interface details | Detailed interface design has been documented<br>System interface diagrams have been completed<br>Inventory of external interfaces is completed and data engineering |
| 4 | Validation of interrelated functions between integrating components in a laboratory environment | Functionality of integrating technologies (modules/functions/asse been successfully demonstrated in a laboratory/synthetic environ<br>Data transport method(s) and specifications have been defined |
| 5 | Validation of interrelated functions between integrating components in a relevant environment | Individual modules tested to verify that the module components (f together |
| 6 | Validation of interrelated functions between integrating components in a relevant end-to-end environment | End-to-end Functionality of Systems Integration has been validated<br>Data transmission tests completed successfully |
| 7 | System prototype integration demonstration in an operational high-fidelity environment | Fully integrated prototype has been successfully demonstrated in a simulated operational environment |
| 8 | System integration completed and mission qualified through test and demonstration in an operational environment | Fully integrated system able to meet overall mission requirements operational environment<br>System interfaces qualified and functioning correctly in an operati |
| 9 | System integration is proven through successful mission proven operations capabilities | Fully integrated system has demonstrated operational effectiveness and suitability in its intended or a representative operational environment<br>Integration performance has been fully characterized and is consistent with user |

# Inputs from experts

- **Heating systems:**
  - Performant Antennas (e.g., Travelling Wave Array Antennas)
- **Plasma Diagnostics:**
  - Steady state 3D magnetic sensors
  - Imaging diagnostics for fast ions
  - LIF-based diagnostics
- **Magnets:**
  - Operational straegies for transients (e.g. active cooling or not during the baking, effectiveness of different strategies to discharge the energy from the magnet system, etc.)
  - Automatic operational strategies for the whole cryoplant
  - Exploit the bore of the CS (e.g. HTS)
  - Model validation
- **PFCs**
  - Strategies to recover plasma wall damage
  - Smart W alloys for PFCs

# Discussion