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Dipartimento Energia "Galileo Ferraris"

Karlsruher Institut für Technologie

Analysis of the flow distribution in the Back Supporting Structure manifolds of the HCPB Breeding Blanket for the EU DEMO fusion reactor

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EUROfusion

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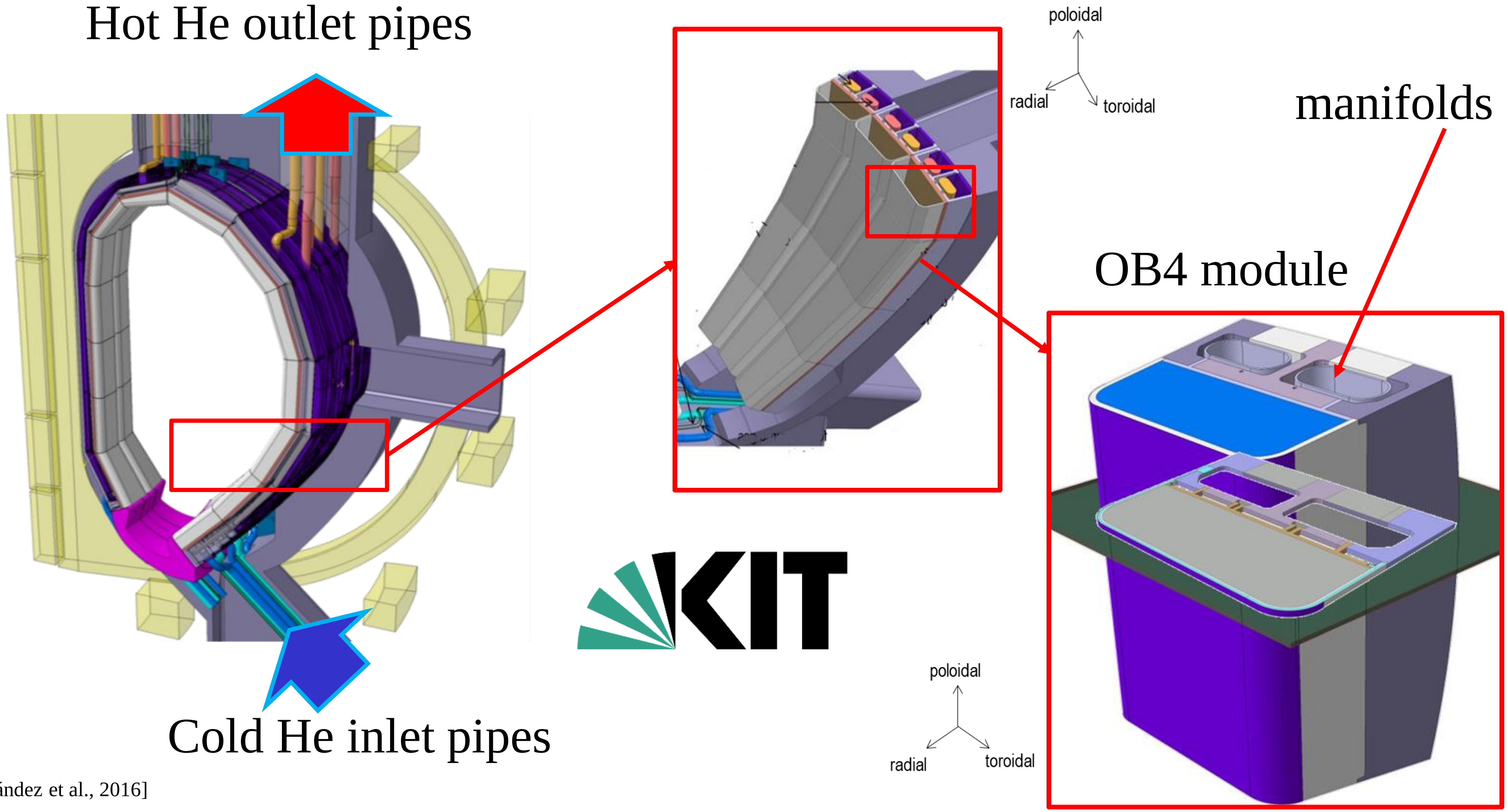
Outline

- Layout of the Helium-Cooled Pebble Bed Back Supporting Structure
- Introduction
- The need for a 1D hydraulic model of the manifolds
- 1D model development
- Results
- Conclusions & perspective

Layout of the 2015 HCPB BSS



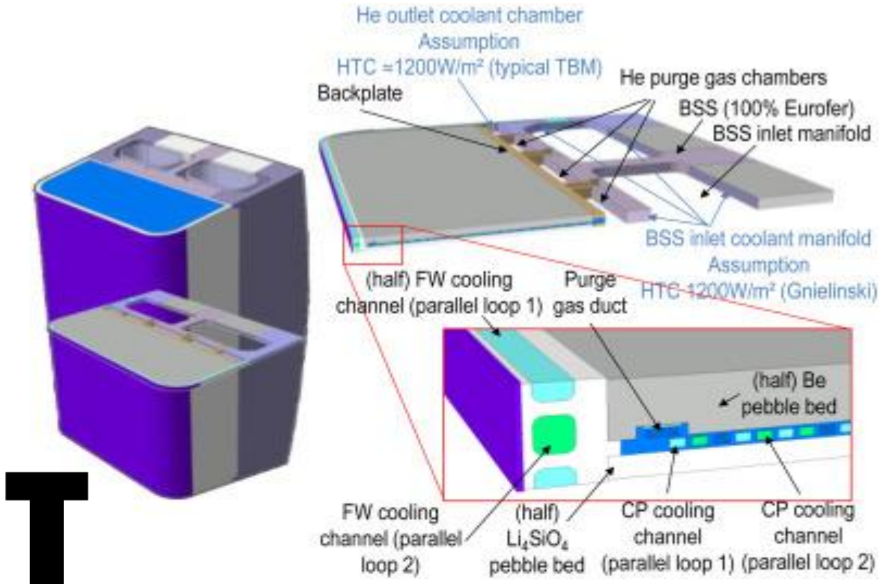
[F. A. Hernández et al., 2016]

Introduction: CFD analyses of the BB

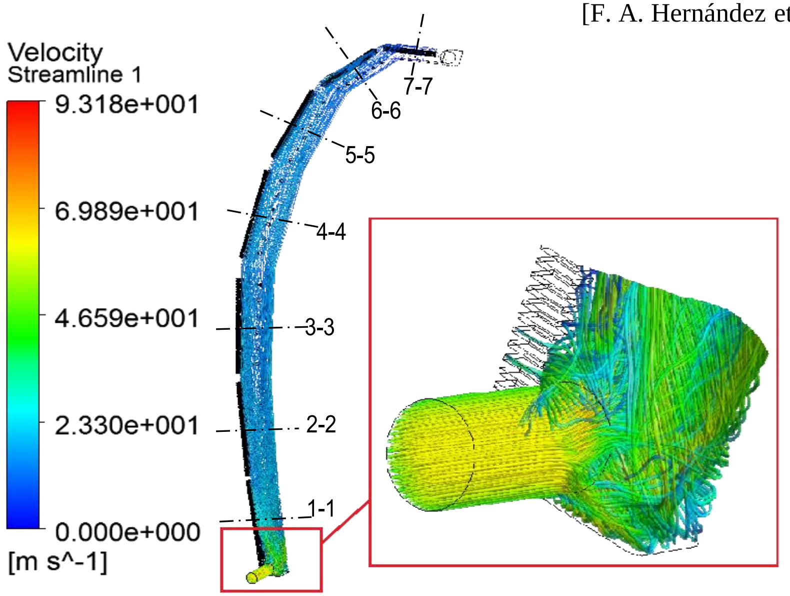
Due to computational cost, CFD analyses can focus on:

- Blanket module elementary unit OR
- BSS 3D analysis

→ Either manifolds or BM are treated as BCs → detailed results, but not representative BCs

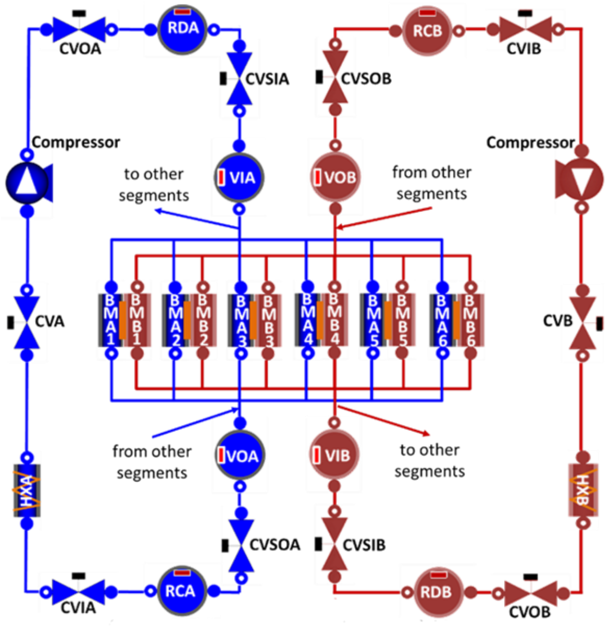


[F. A. Hernández et al., 2016]

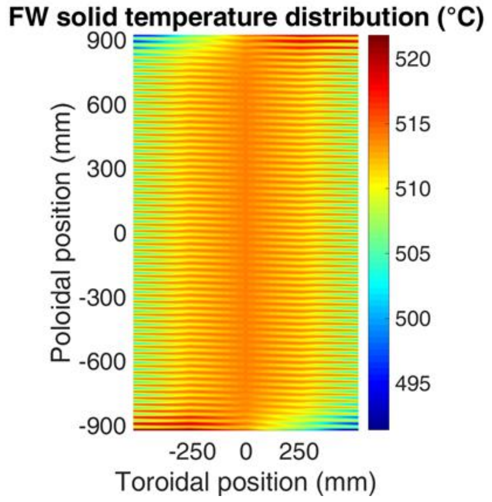


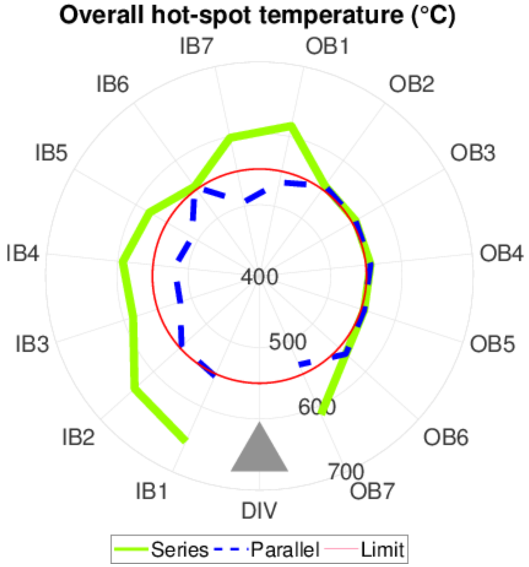
Introduction: system-level analyses of the BB

- System-level analyses can bring information on the entire plant and sometimes reach good level of details
- BUT they are based on physics simplifications (e.g. 0D modelling of manifolds)



[A. Froio et al., 2018]





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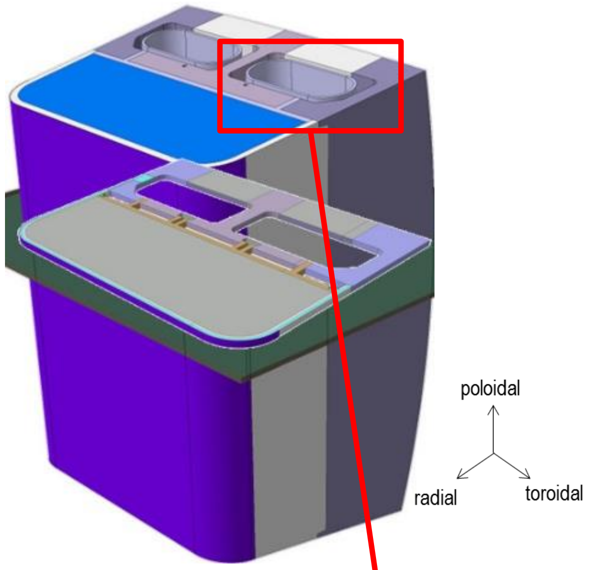
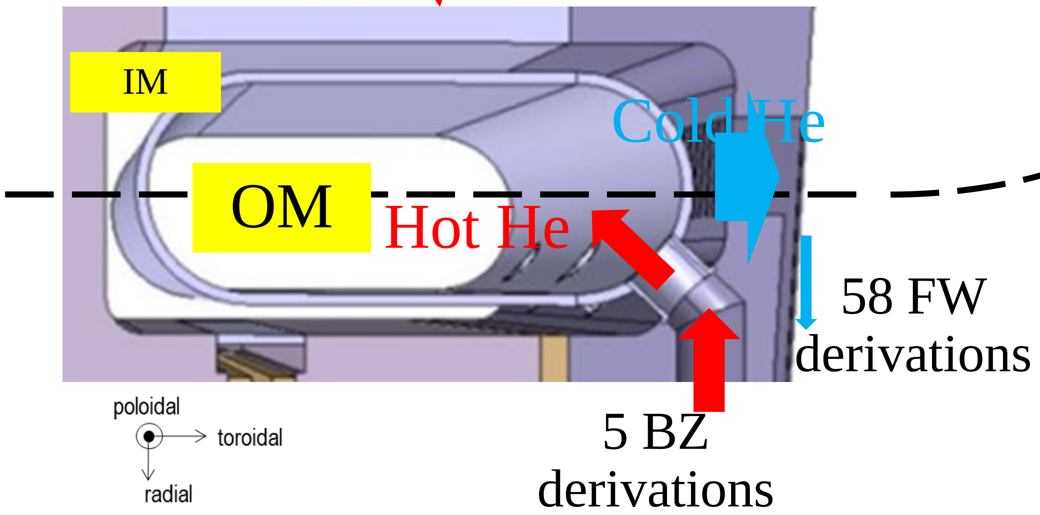
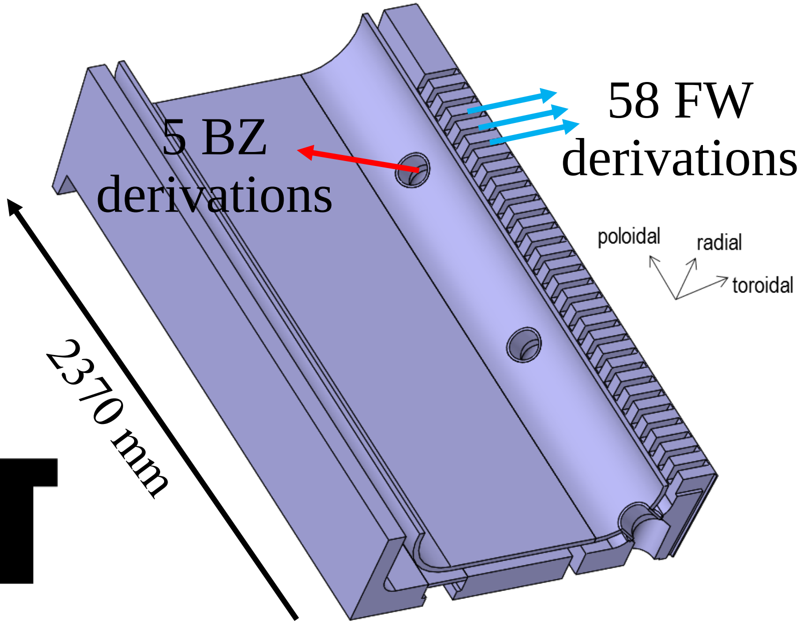
HCPB BSS design



- 2 identical sets of coaxial I/O manifolds
- FW derivations: one per FW channel, outflowing from inlet manifold (IM)
- BZ derivations: grouped, inflowing into the outlet manifold (OM)





[F. A. Hernández et al., 2016]

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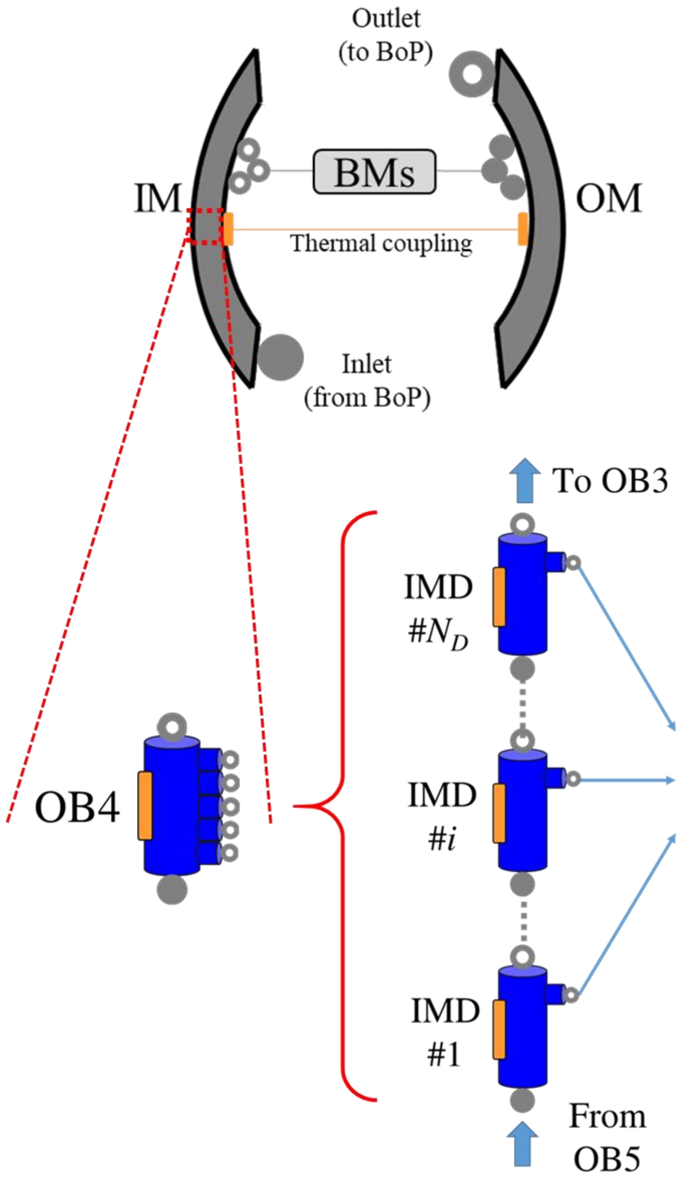
The need for a 1D hydraulic model of manifolds

The 0D models for manifolds cannot compute correctly the coolant distribution among the BMs → define a 1D model of the manifolds:

- Two separate models for IM and OM
- Connections to the BM models through fluid ports
- Possibility to implement thermal coupling (not focus here)
- Modular approach: sub-model for BSS portions referring to each BMs, further split in "derivation objects" (IMD/OMD)



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Rationale of the 1D model development and validation

1D Model developed exploiting CFD analyses (see [A. Bertinetti et al., *Fus Eng Des* 2018]):

1. Perform CFD analyses on the BSS outboard equatorial region to:
   - Dimension a sub-size mock-up
   - Derive constitutive relations
2. Develop a 1D model able to reproduce the coolant and pressure distribution in the BSS equatorial region:
   - Use correlations derived from the mock-up analysis
   - Compare the results (in dimensionless form) against CFD on full-size BSS
3. Extend the model to entire BSS and compare against CFD
4. Calibrate and verify the model through experiments on the mock-up

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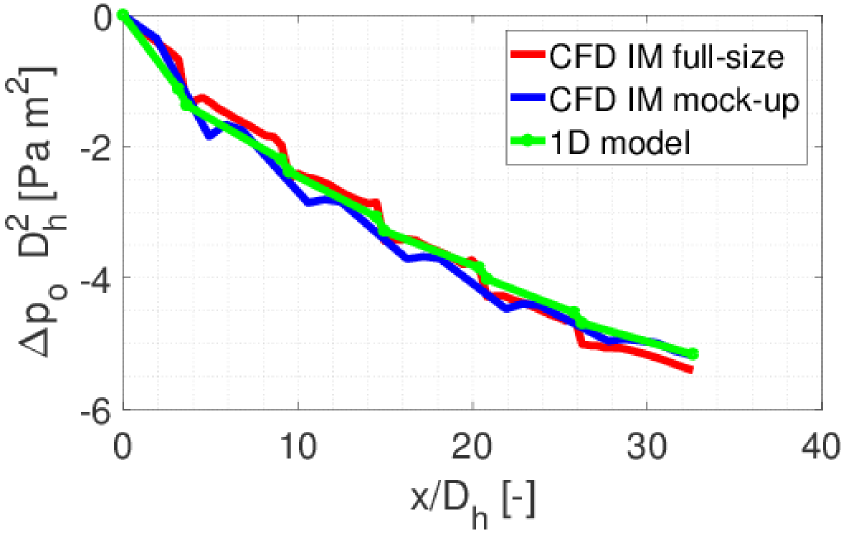
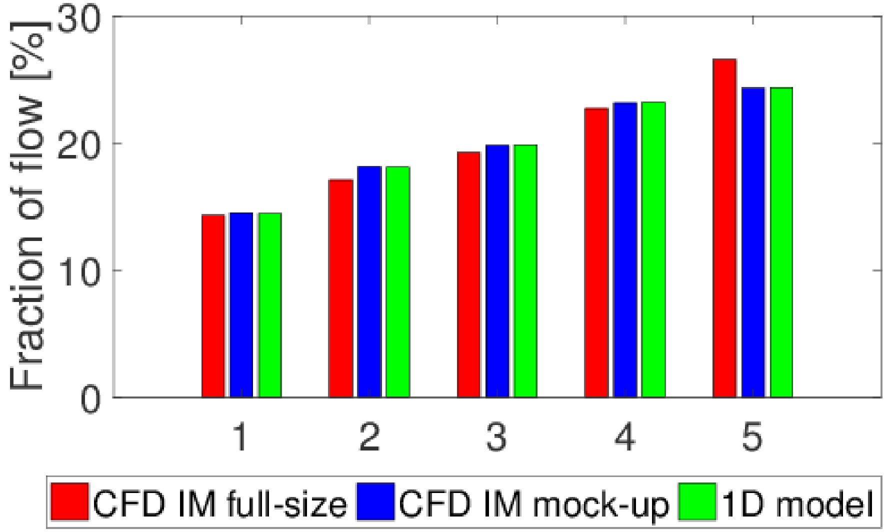
Steps 1 and 2: 1D hydraulic model development

- 1D manifolds model needs in input friction factor, localized Δp coefficients and mass flow repartition coefficients
- Calibration based on mass flow repartition and average pressure at selected locations from CFD results on the mock-up geometry, and benchmarked against CFD results on the full-size BSS outboard equatorial region





→ The 1D model can be validated from the mock-up test

[A. Bertinetti et al., 2018]

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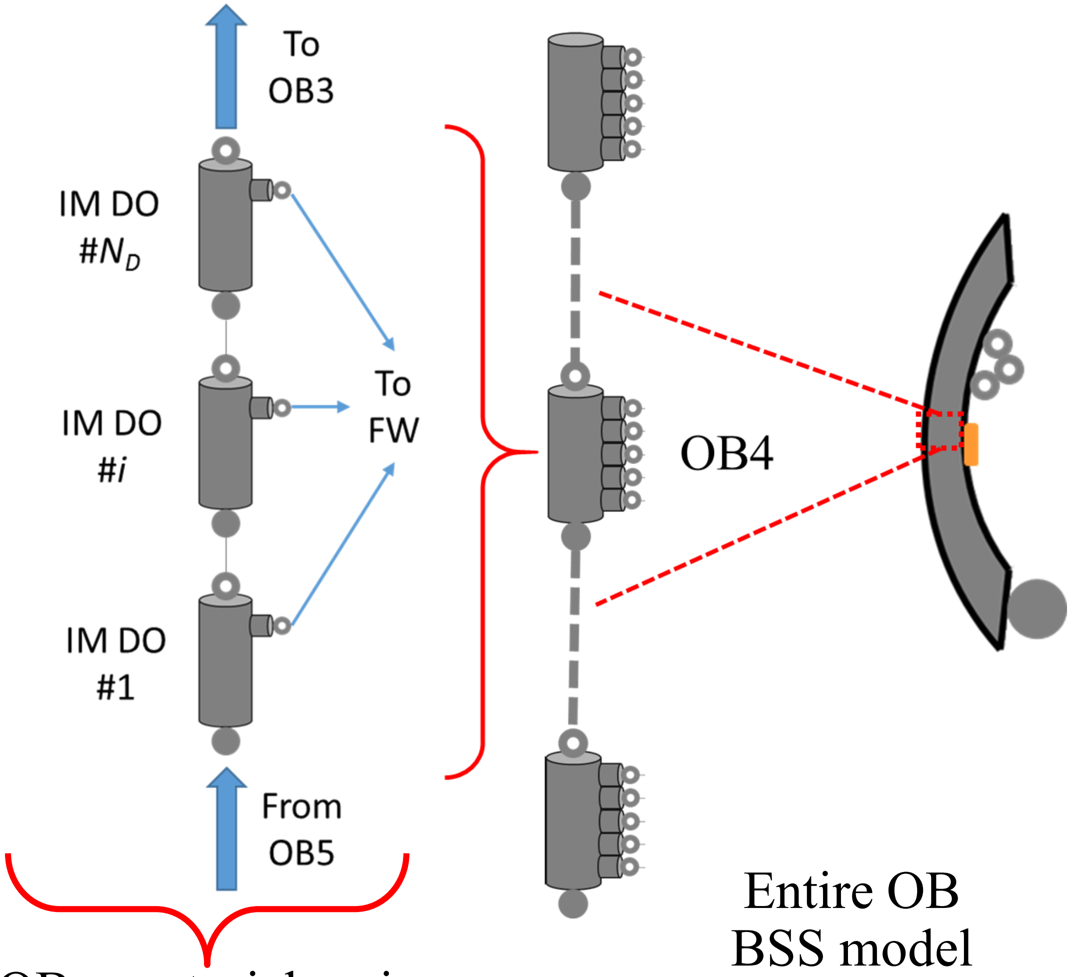
Step 3: model extension to entire BSS (I)

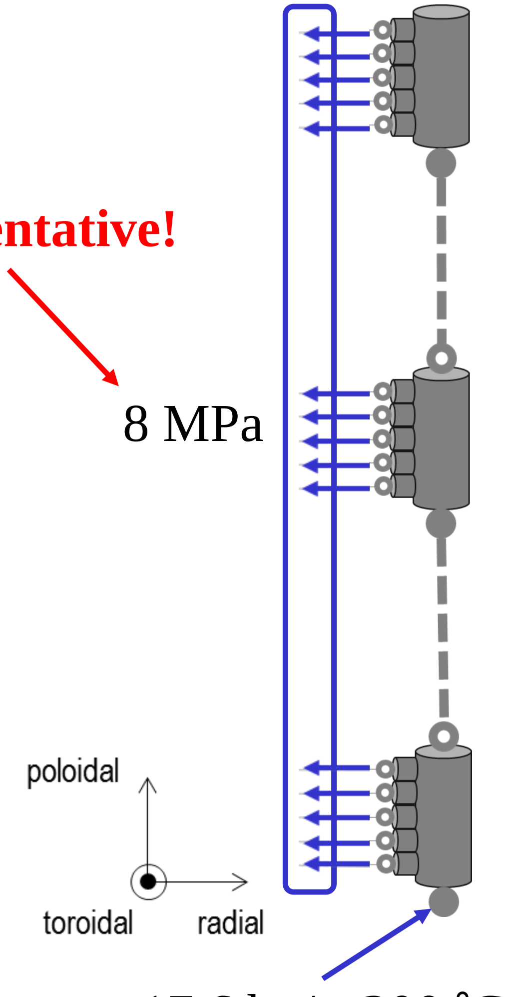


- Full BSS model is obtained connecting in series different instances of single-BM BSS model
- Friction factors obtained through correlations

Step 3: model extension to entire BSS (II)

1D MODEL

BC not representative!



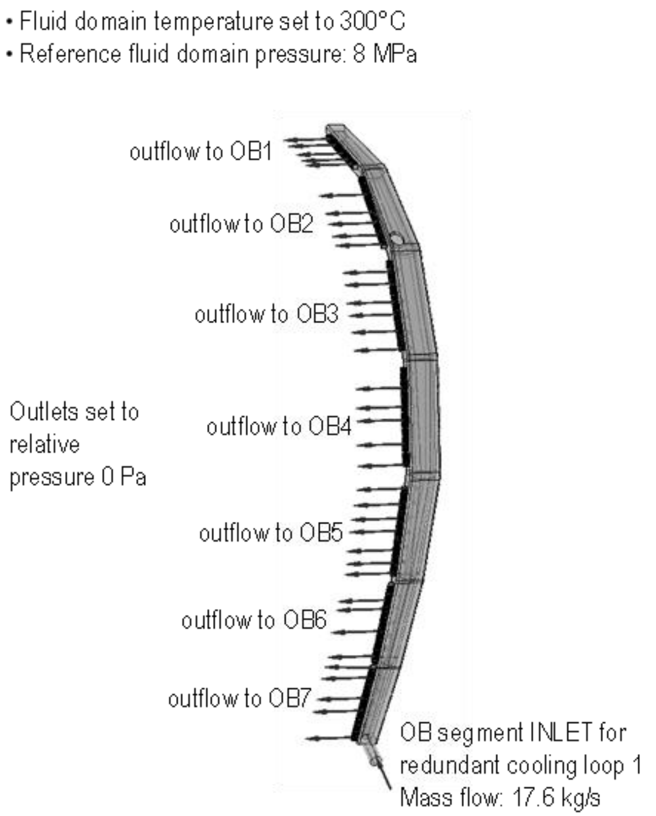
Excellent agreement is found when comparing the 1D model of the full "stand-alone" BSS to CFD

Mass flow rate [kg/s]

BM	1D model	CFD
OB1	2.29	2.3
OB2	2.59	2.6
OB3	2.70	2.7
OB4	2.80	2.8
OB5	2.60	2.6
OB6	2.51	2.5
OB7	2.12	2.1

CFD

HCPB Design Report 2015



[F. A. Hernández et al., 2016]

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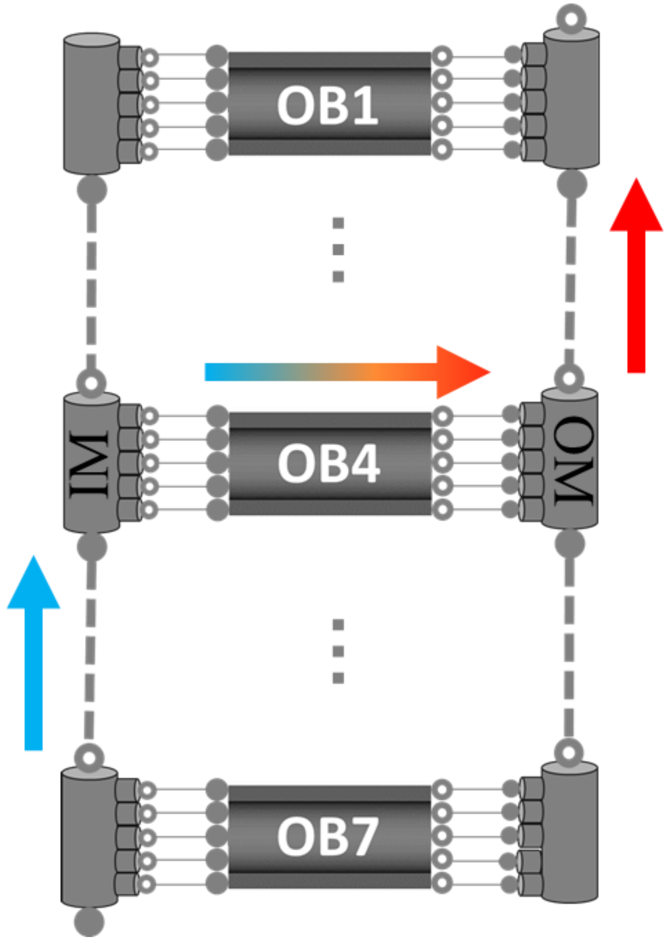
"Advanced" system level model of a blanket segment

- The newly-developed 1D model can be substituted to the old 0D model in GETTHEM, connected to the models of the Blanket Modules
- The full model can be applied to:
  - Design the equivalent loop for the mock-up test
  - Derive a hydraulic characterization of the full BB system
  - Analyse the *actual* coolant distribution among the BMs, with correct BCs



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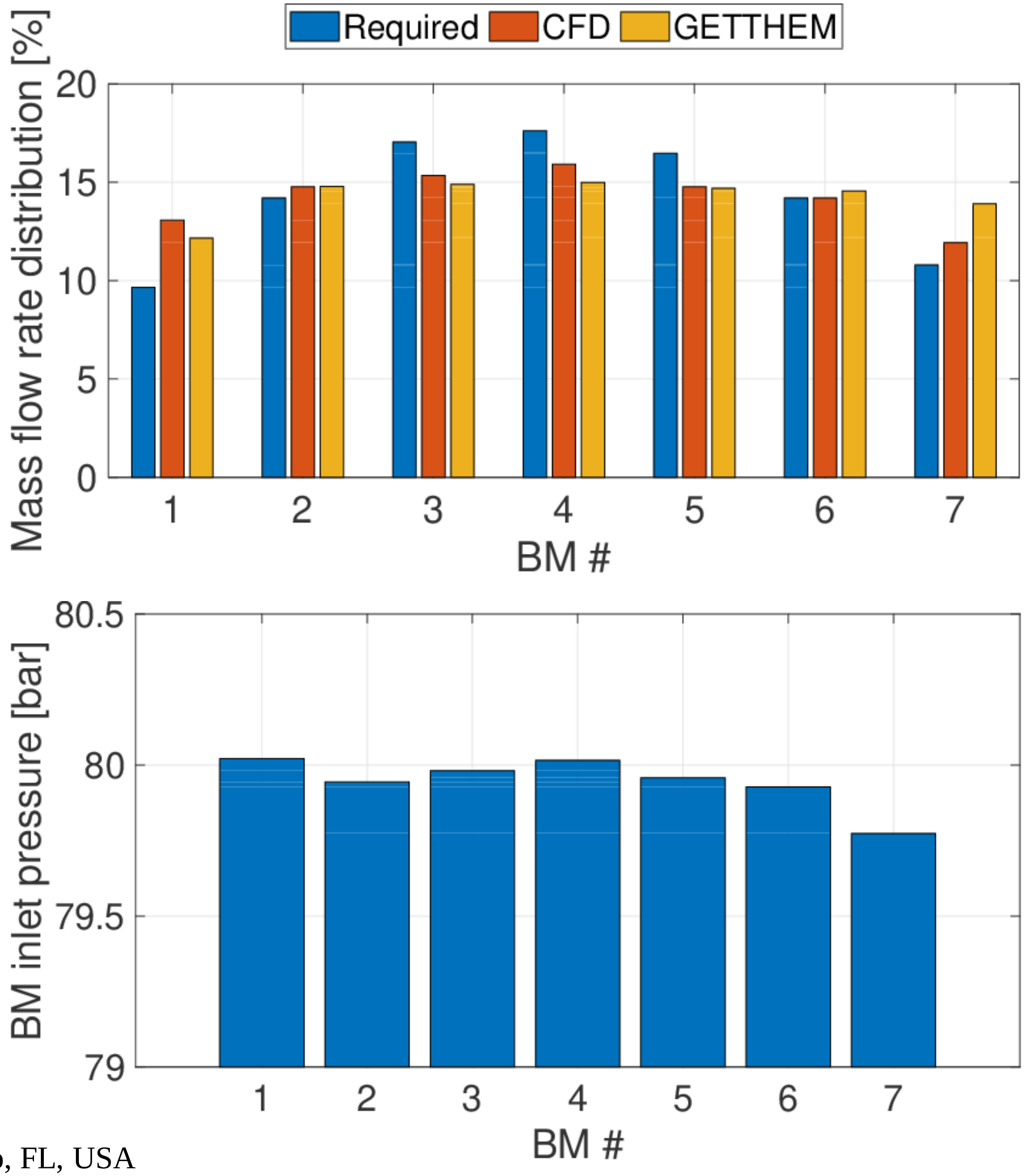
Results

- When connected to the detailed models of the BM, the coolant is redistributed differently from what CFD found
- Both CFD and GETTHEM highlighted the need for orifices and/or design changes, but the use of non-representative BCs in CFD causes an *underestimation* of the maldistribution!
- GETTHEM computes different values of pressure at the inlet/outlet of the BMs, which may be used as BCs for CFD analyses



Conclusions & perspective

- ✓ 1D hydraulic model of the BSS manifolds has been developed in the GETTHEM model and benchmarked
- ✓ When applied to a blanket segment, it allows a more accurate evaluation of the coolant flow distribution, and of the possible need for orifices or design modifications

In perspective:

- → Validation of the 1D model against experiments on the mock-up (to be carried out at HELOKA in KIT)
- → Similar model for Water-Cooled Lithium-Lead BB concept ongoing

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