REIMS - Riemann Explicit Implicit Magnet Simulator, new tool for calculating superconductor performance

Jacek Kosek[1], Damien Furfaro[2]

Andrey Ovcharov[1], Tyge Schioler[1]

[1] – ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St. Paul Lez Durance Cedex, France

[2] – DAES SA, Av. Des Grandes-Communes 8, 1213 Petit-Lancy, Switzerland

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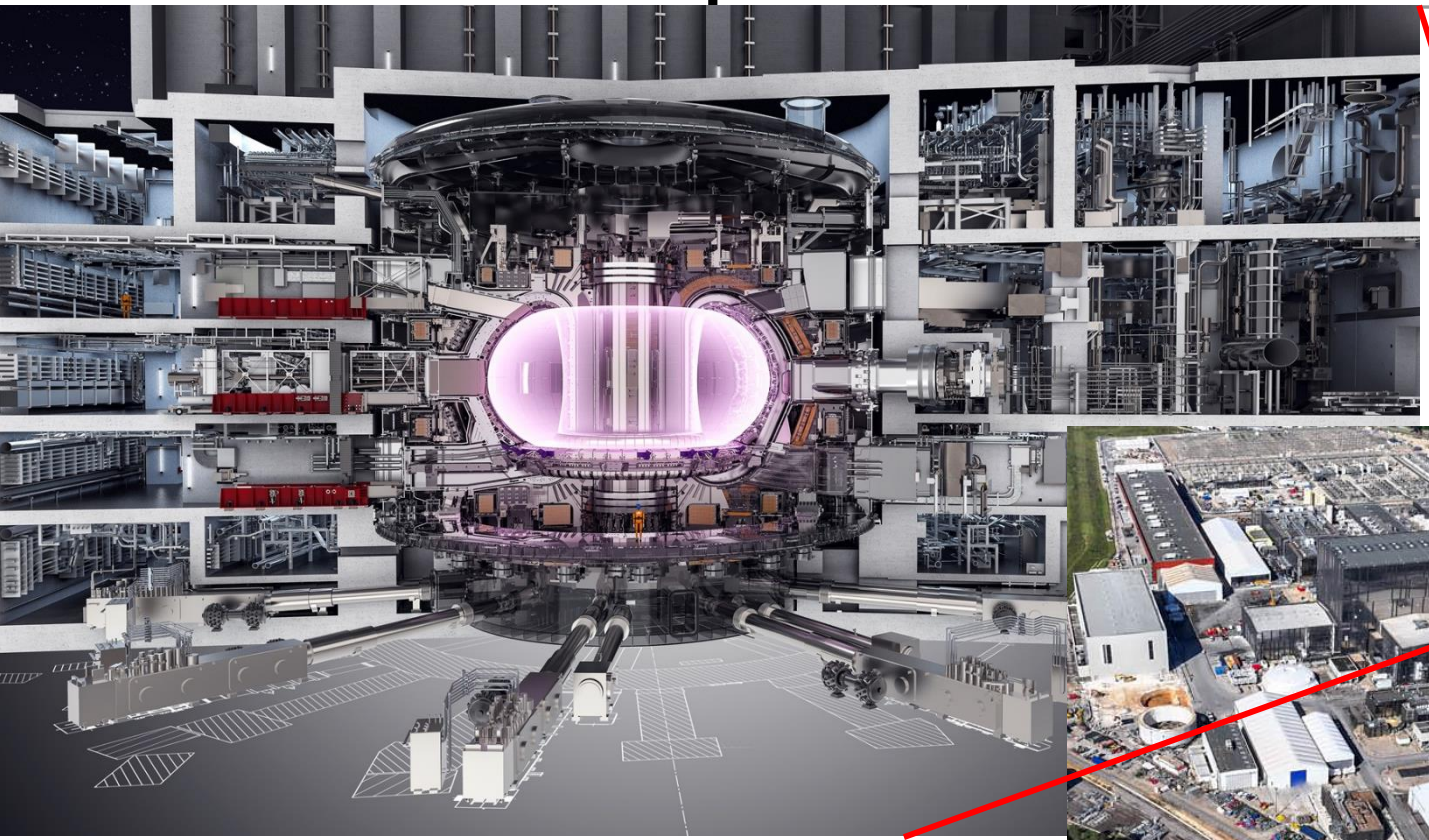
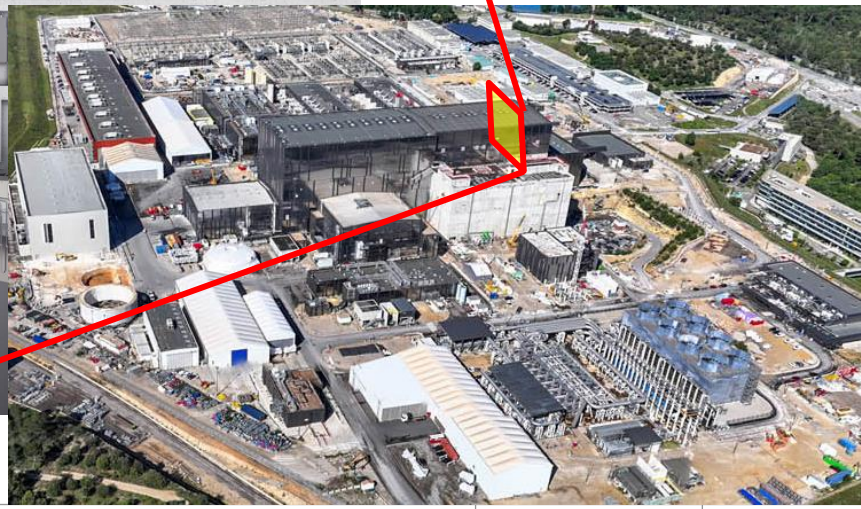
REIMS as part of ITER Plant Simulator

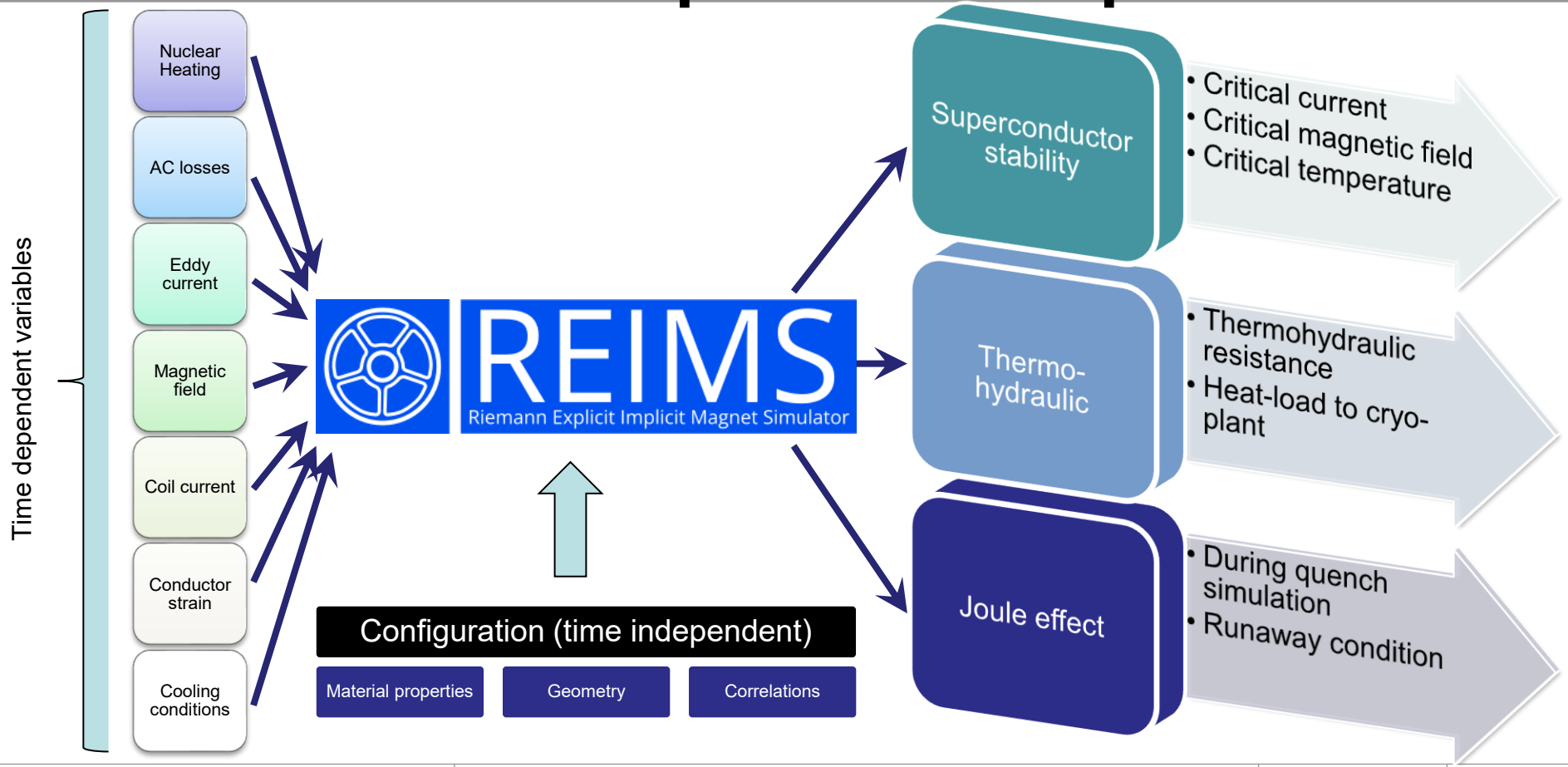




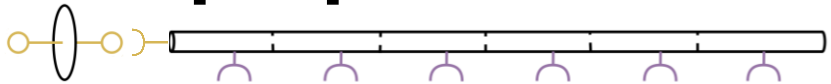
Multi-physics

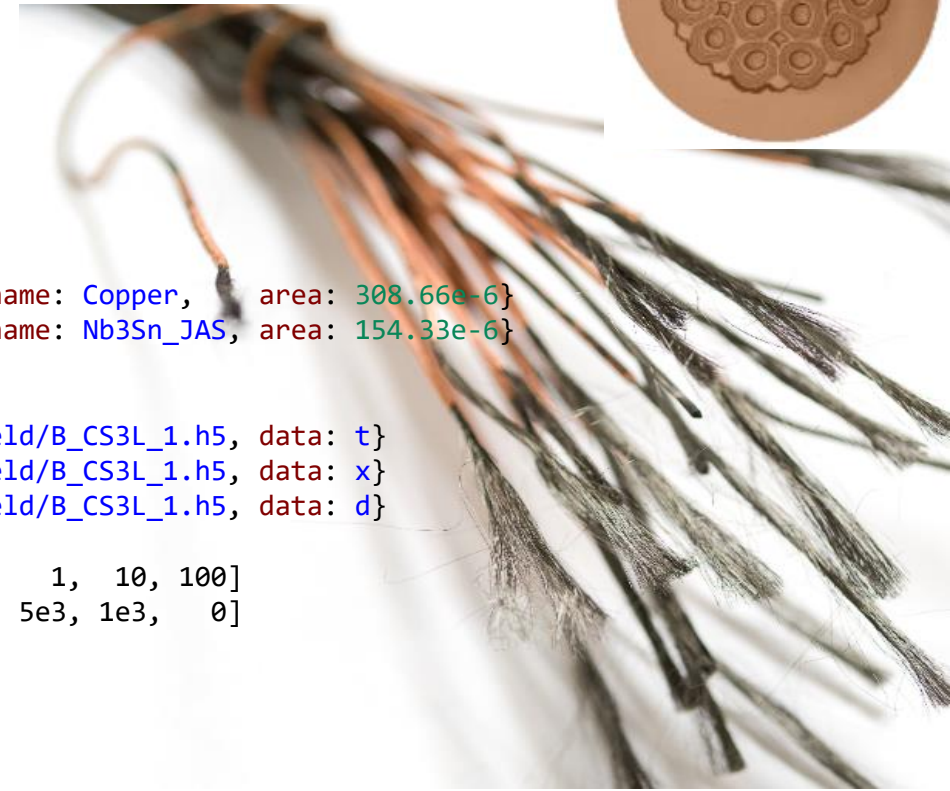
- Thermo-hydraulic calculations
  - Direct helium state calculation (modified Benedict Webb Rubin)
  - Easy to override correlation functions
- Heat transfer calculation
  - Fluid 1D (+some parallel channel exchange)
  - Solid 0D, 1D, 2D
- Superconductor calculations
  - Nb3Sn, NbTi

REIMS – inputs and outputs



REIMS – how to prepare model





Gmsh

YAML

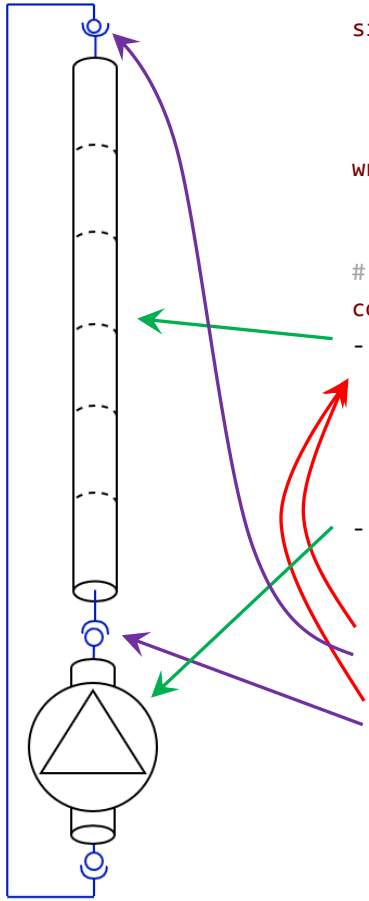
REIMS
Riemann Explicit Implicit Magnet Simulator

HDF

ParaView

```yaml
- type: strand
  id: strand_3L_P1
  nodes: 193
  length: 147.66
  initial: {t: 4.3}
  stabilizer:     {name: Copper,    area: 308.66e-6}
  superconductor: {name: Nb3Sn_JAS, area: 154.33e-6}
  channel_link: yes
  field:
    time:  {h5: Bfield/B_CS3L_1.h5, data: t}
    x:     {h5: Bfield/B_CS3L_1.h5, data: x}
    value: {h5: Bfield/B_CS3L_1.h5, data: d}
  current:
    time:  [0,  0.1,   1,  10, 100]
    value: [0, 10e3, 5e3, 1e3,   0]
  field_gradient: 0
  flux:           0
```

Example of fluid loop

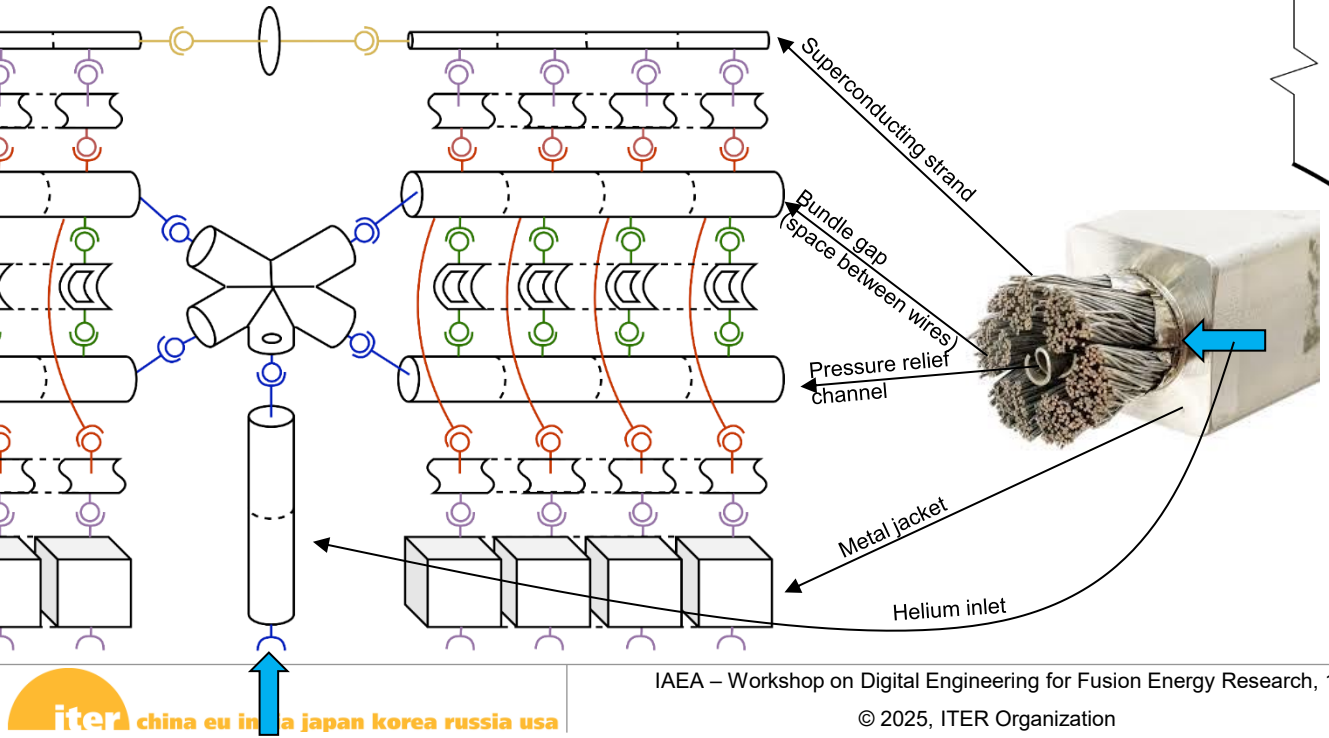


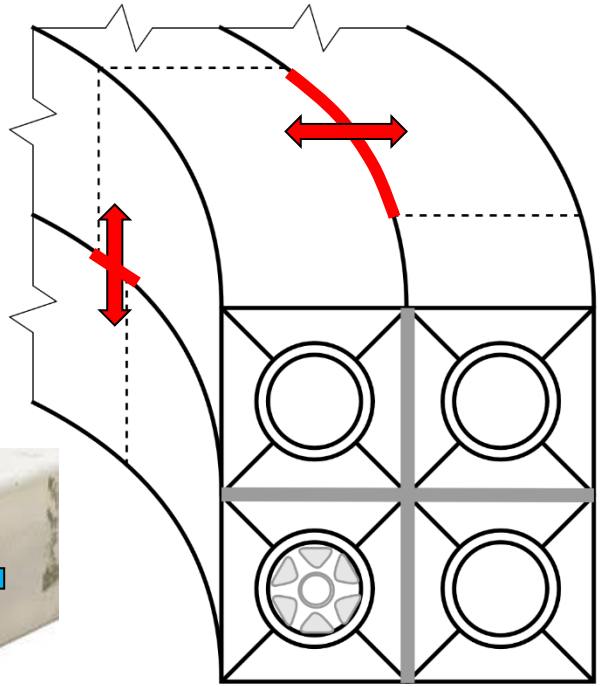
```yaml
simulation:
  simulation_end: 100     # Simulate 100s
  R_correction: no            # Wave front correction near supercritical point

write_results:
  file: reims_output.h5   # Write results to file: reims_output.h5

# Main model description is a list of components and their connections
components:                   # One "state" component and one "link" component
- type: channel     # Type of the component in this case channel
  id: pipe          # Name of the component must be unique
  nodes: [0.1, 0.2, 0.3, 0.4, 0.3, 0.2, 0.1] # Total length: 1.6m (7 nodes)
  diameter: 12e-3   # Channel diameter 12mm
  initial: {p: 4e4, t: 4.5} # initial conditions P = 4bar and T = 4.5K
- type: pump        # Type of the component in this case pump
  m0: 1e-3          # Mass flow rate: 1 g/s
  link:             # 2 links: link 1 - pump inlet, link 2 - pump outlet
  - id: pipe        # inlet of the pump connected to outlet of the 'pipe'
    node: out       # 2 - outlet pipe
  - id: pipe        # outlet of the pump connected to inlet of the 'pipe'
    node: in        # 1 - inlet pipe
```

Modelling example

CICC – cable in conduit conductor

Model of helium inlet inside panckake:

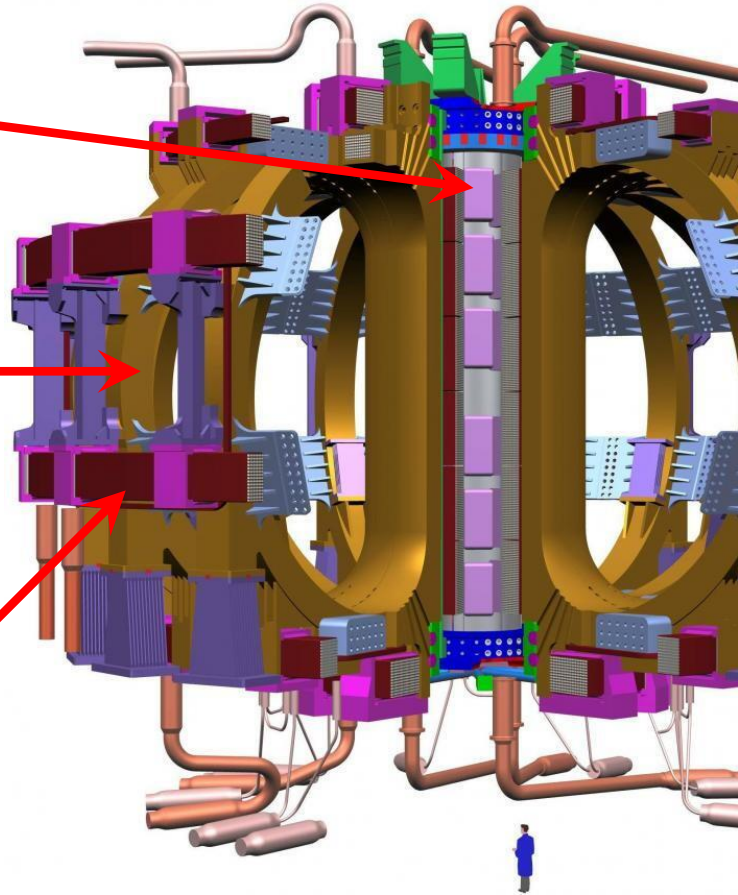




Heat transfer between turns and pancakes

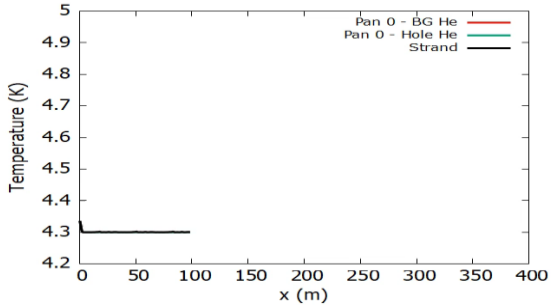
REIMS in ITER

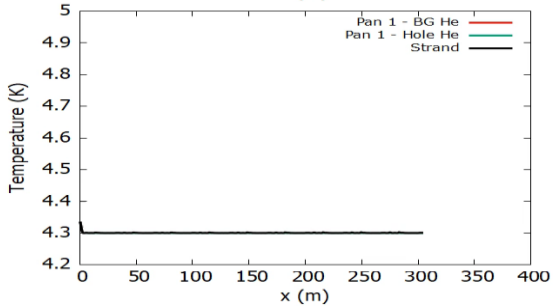
- Central Solenoid (CS)
  - Normal operation (margin estimation)
  - Cooldown analyses
- Toroidal Field Coil (TF) and Magnet Structures (STR)
  - Normal operation (margin estimation)
  - Cooldown analyses
  - Quench analysis – ongoing validation
- Poloidal Field (PF) and Correction Coils (CC)
  - Normal operation (margin estimation)

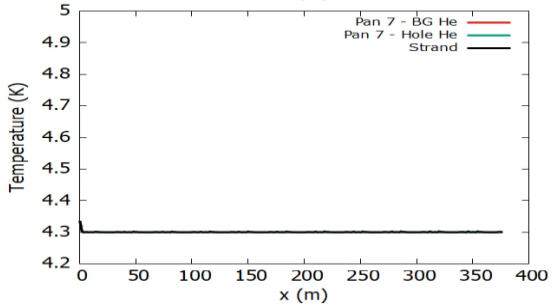


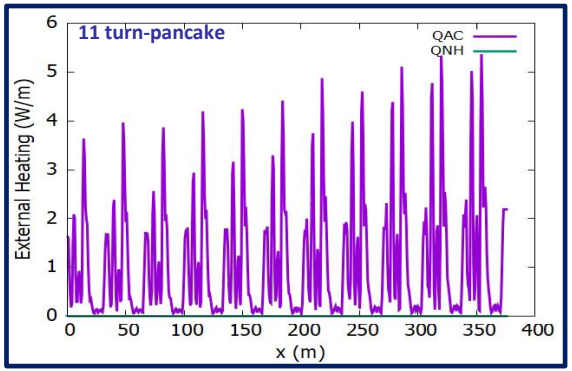
Application of a Short Plasma Pulse Scenario Along the Pancakes

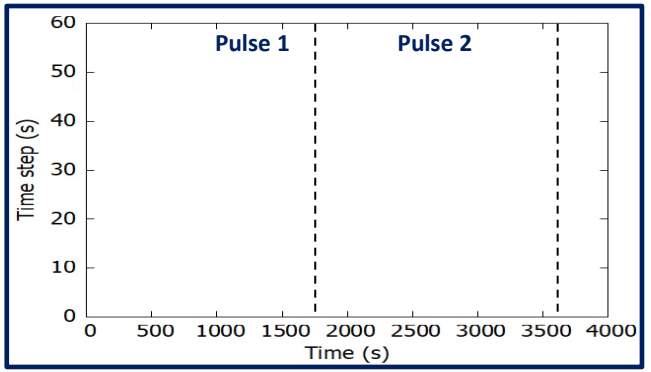
11 turn-pancake 9 turn-pancake 3 turn-pancake



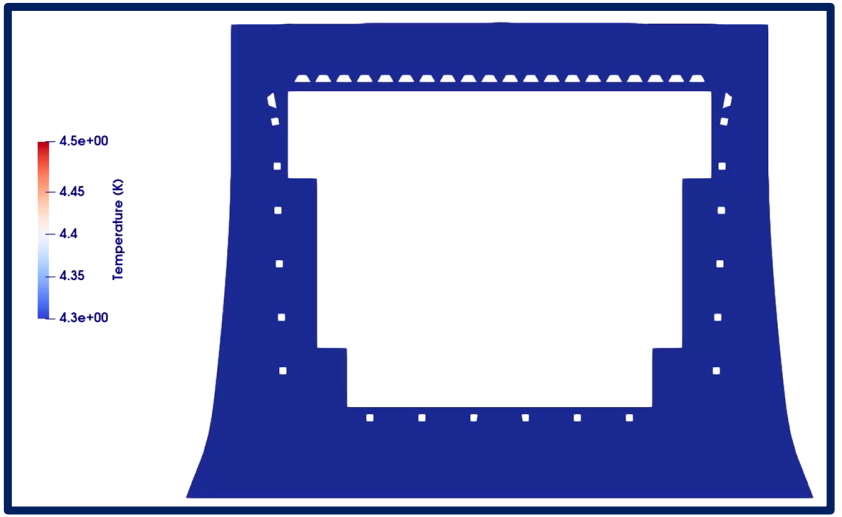






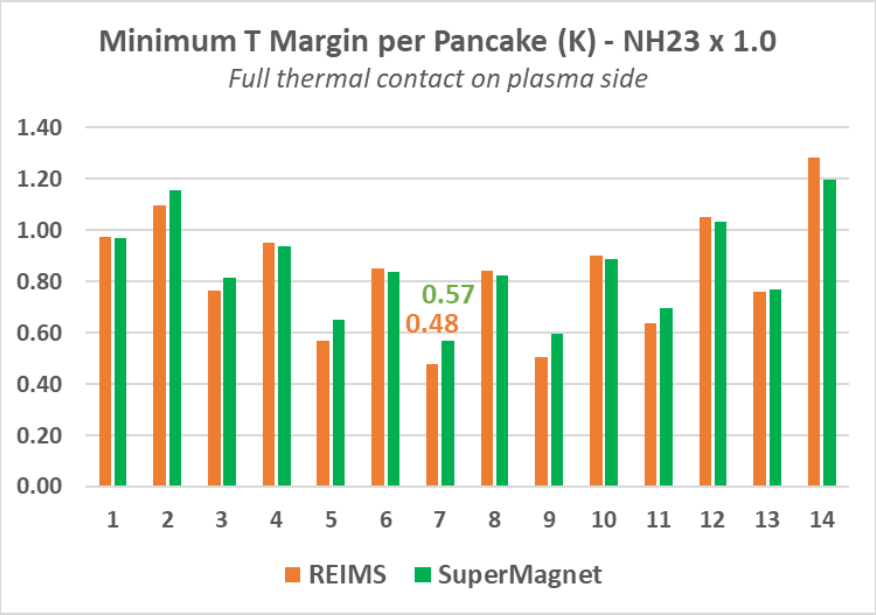


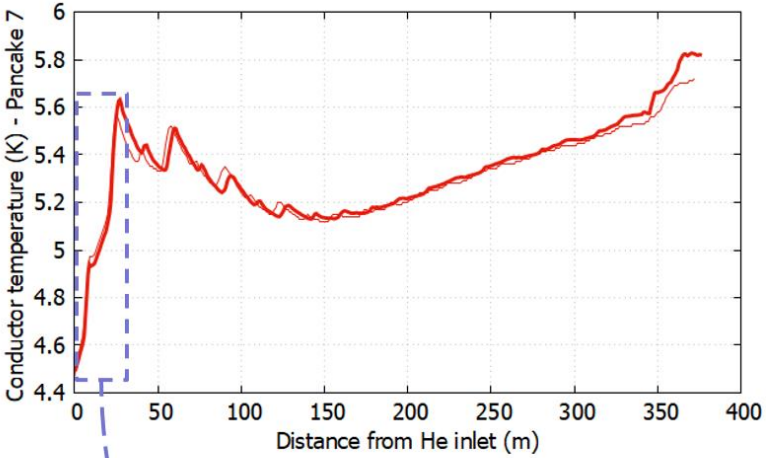
Time : 0 s

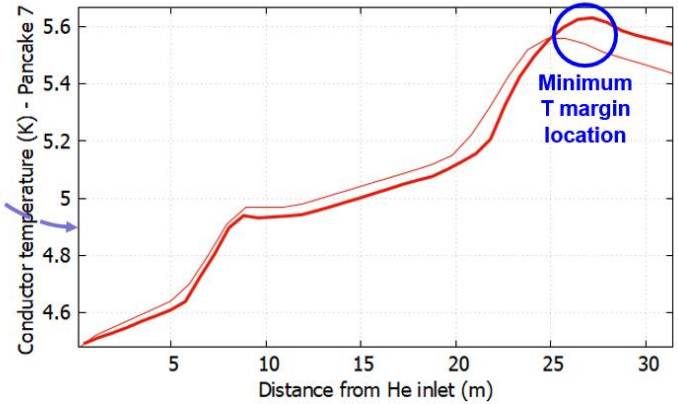


Steel casing external heating absent in this specific study

Minimum temperature margin for TF coils





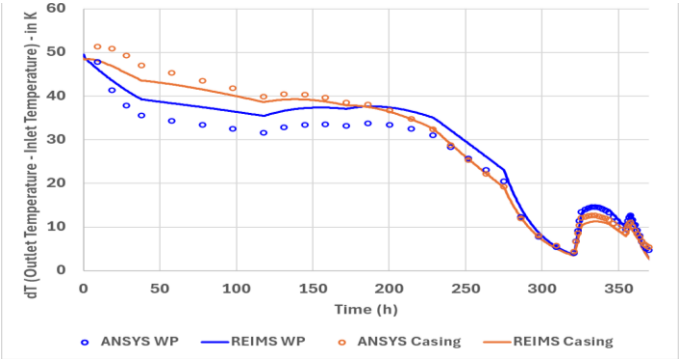


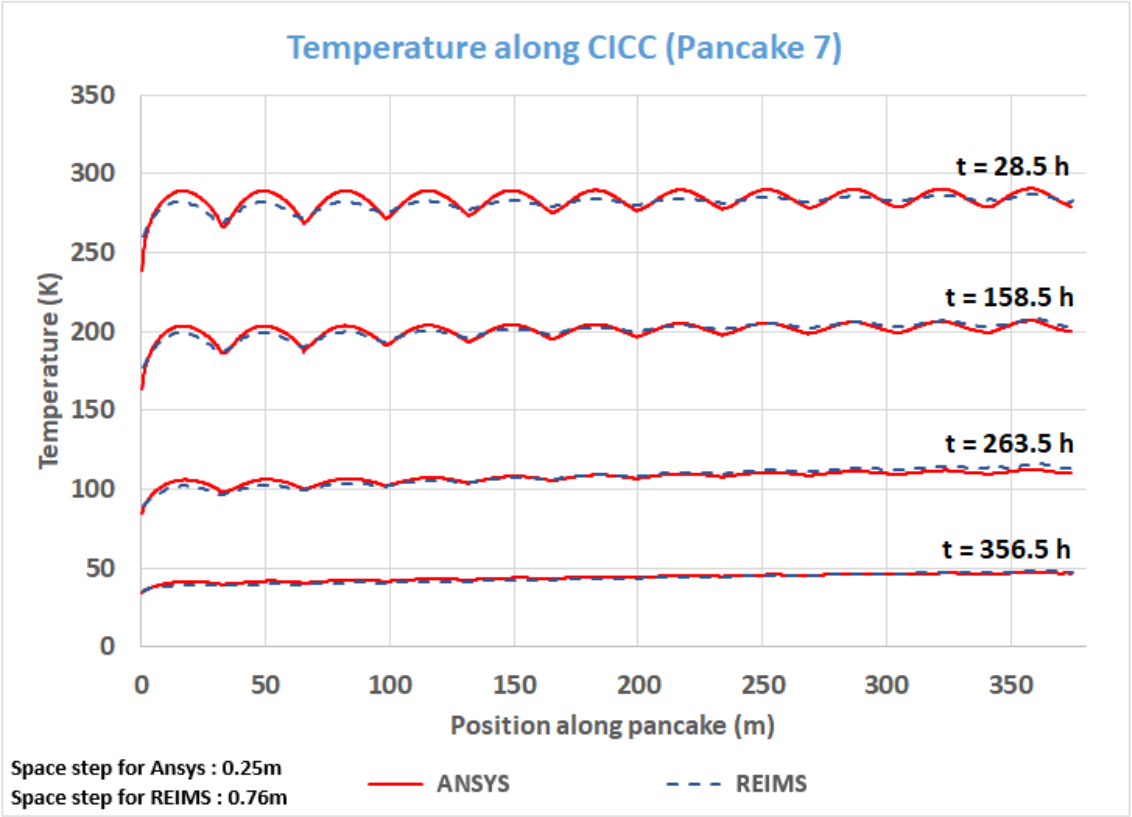
- **2 TF coils** – 4 pulses ⟺ 2 hours of physical time
  18 min (6.5 times faster than real time)
- **1 TF coil** – 4 pulses ⟺ 2 hours of physical time
  11 min (10.5 times faster than real time)

TF cool down scenario

No thermal coupling TF WP / TF casing

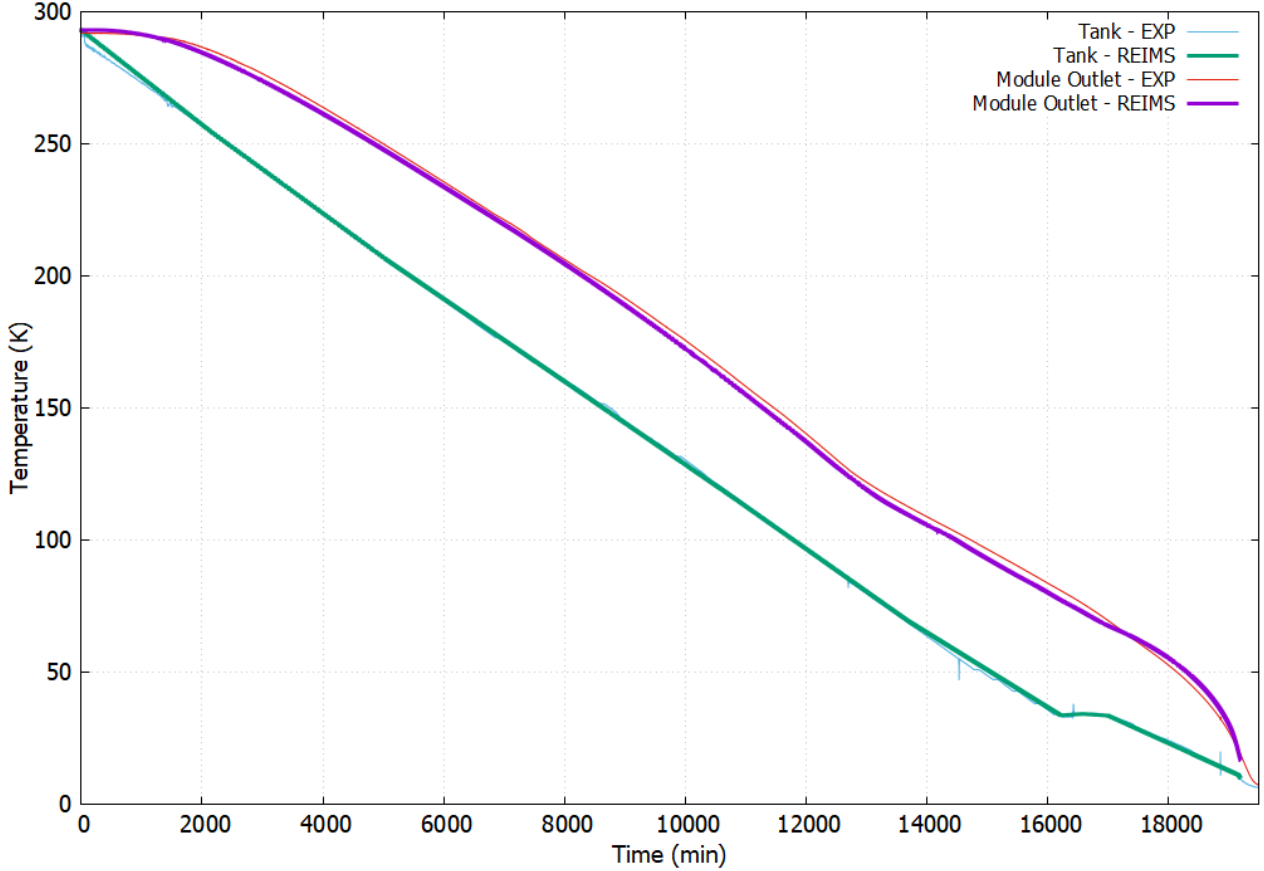
Thermal coupling + Thermal radiation

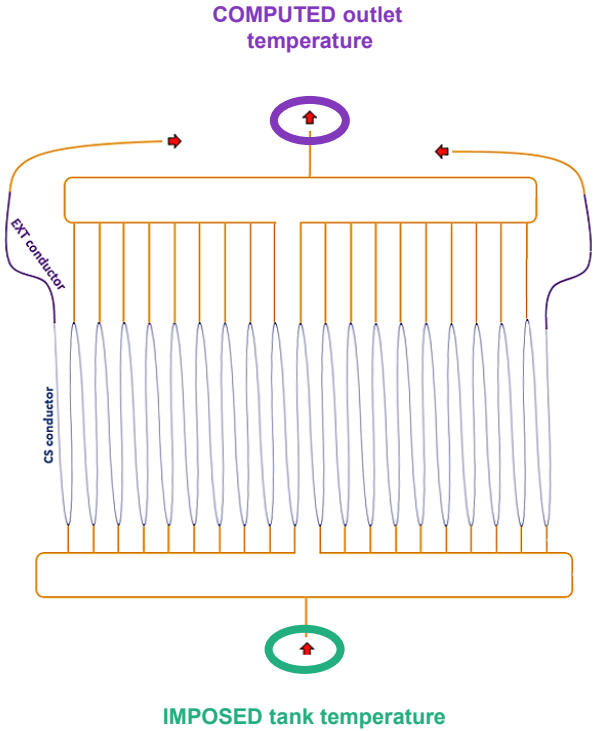




Benchmark involving Ansys with FLUID116 elements and REIMS

CSM1 cool down simulation vs Experimental data





Summary

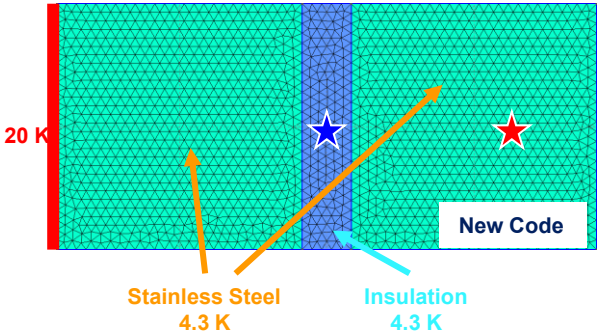
- References
  - **A new fast and robust thermo-hydraulic code for ITER superconducting magnet simulation,** *Damien Furfaro, Jacek Kosek, Andrey Ovcharov, Tyge Schioler, Rossella Rotella, Tim Luce.* Cryogenics Volume 144, December 2024, 103978
  - **Thermal structural analyses during cool down of the ITER toroidal field coil in the magnet cold test bench,** *Valerio Tomarchio, et all*, Fusion Engineering and Design, Volume 216, July 2025, 115017
- Open-source release expected early 2026
- Numeric methods:
  - Riemann with Godunov scheme (implicit and explicit) for compressible fluid
  - Most of derivatives calculated analytically
  - Monolithic simulation – no co-simulation
  - Single sparse linear set of equations solve by MKL Pardiso

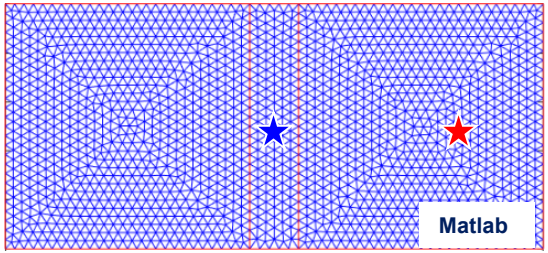
Thank you

Backup

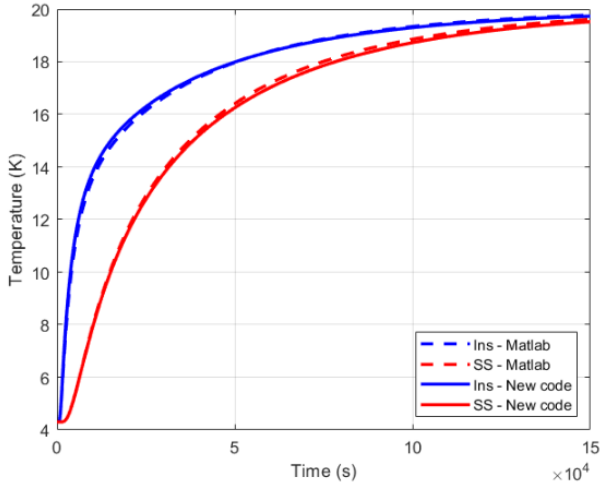
- Verification: heat transfer
- Validation: junction wave propagation
- Example of components

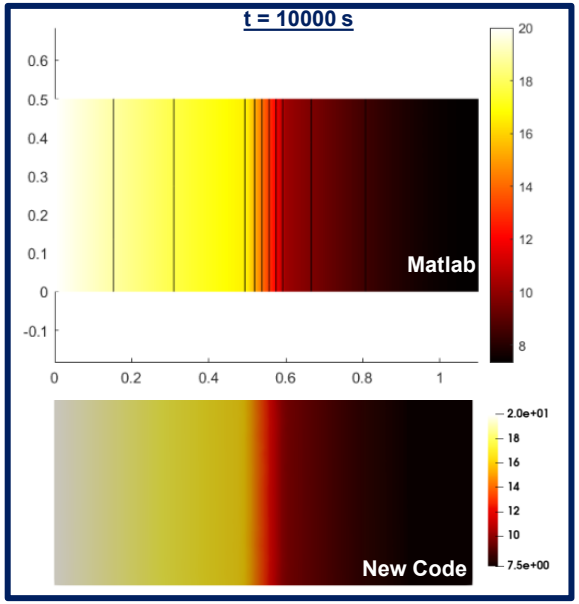
2D Heat Diffusion – Validation



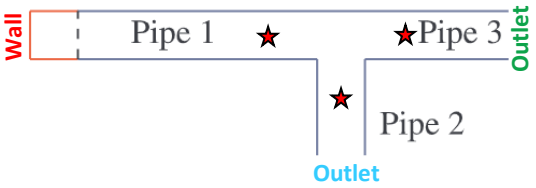


2D equivalent linear mesh



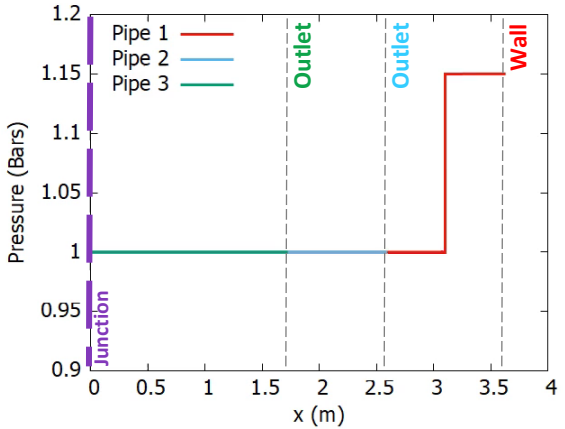


Introduction of a numerical method for junction treatment

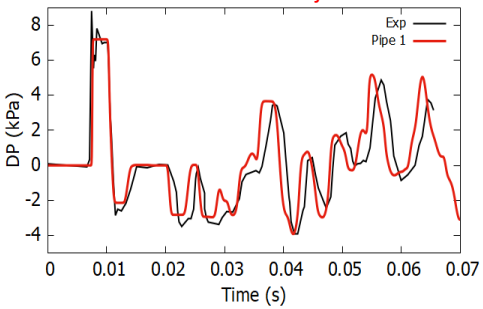


(William-Louis et al., 1998).

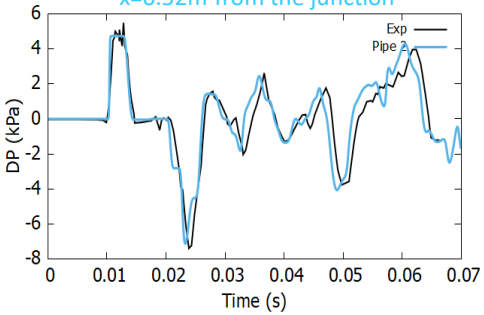
Position		p (bar)	ρ (kg.m^{-3})	u (m.s^{-1})	L (m)	d (m)
Pipe 1	(high-pressure)	1.15	1.4145	0	0.53	0.01
	(low-pressure)	1	1.23	0	3.1	0.01
Pipe 2		1	1.23	0	2.595	0.01
Pipe 3		1	1.23	0	1.725	0.01



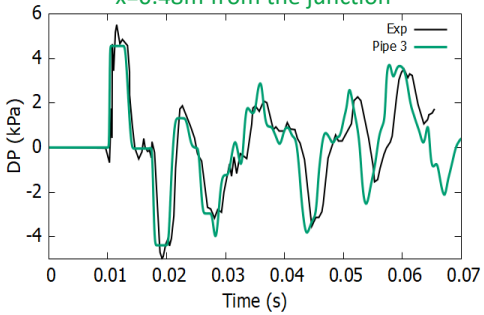
x=0.48m from the junction



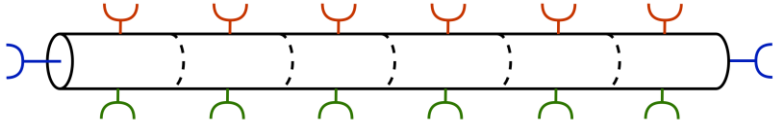
x=0.52m from the junction



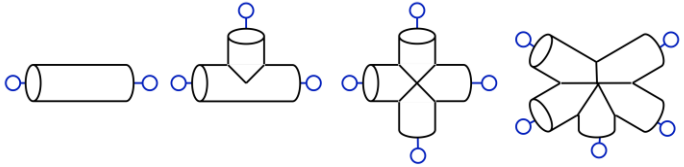
x=0.48m from the junction



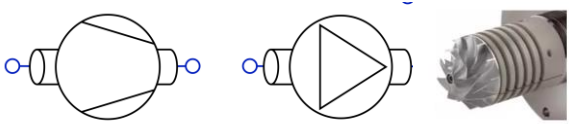
Example of hydraulic components



Helium channel

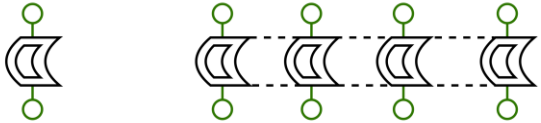


Junction



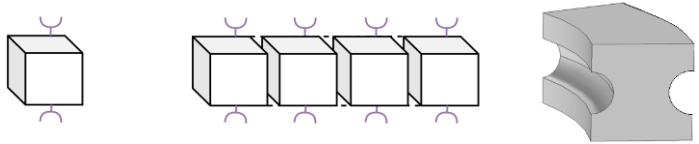
Pump and compressor

Mass flowrate and pressure imposed boundary

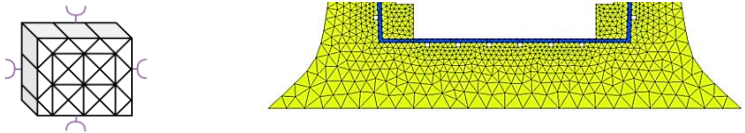


Energy and mass exchange along the channel

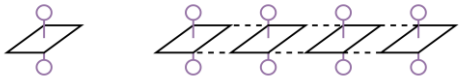
Example of thermal components



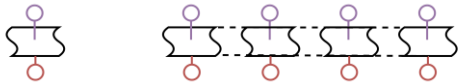
Solid component (metal chunk)



2D mesh (connection require some work)



2 solid connection + optional resistance



Fluid ←→ solid thermal connection