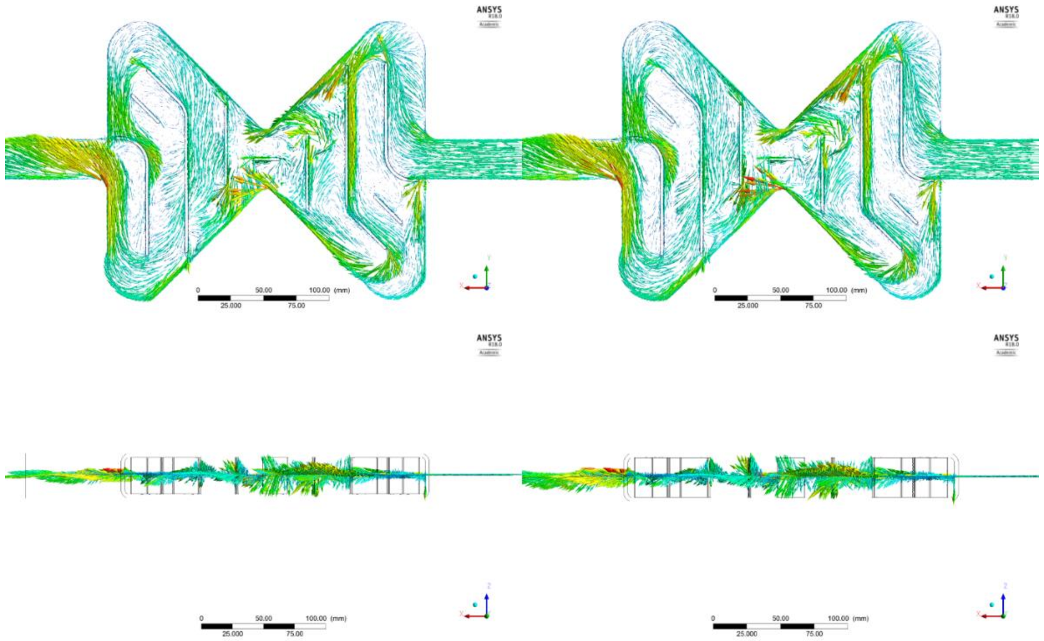

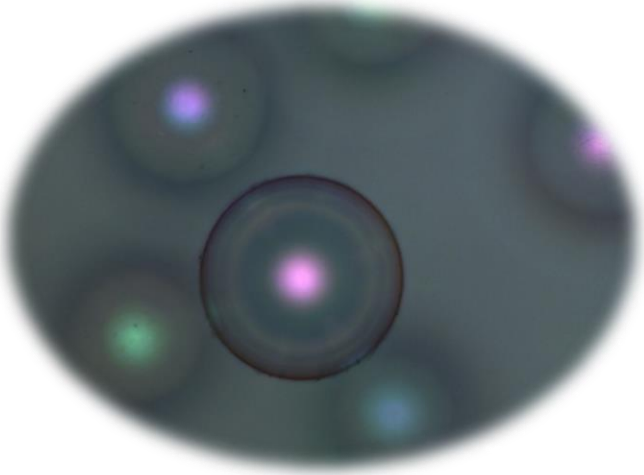

ENGINEERING DESIGN AND TRANSIENT FLUID DYNAMIC SIMULATIONS OF THE SECOND GENERATION OF LOW DIMENSION COLD MODERATOR FOR THE EUROPEAN SPALLATION SOURCE ESS

2019-10-15 I ICANS XXIII, CHATTANOOGA I Y. BEẞLER, G. NATOUR

Mitglied der Helmholtz-Gemeinschaft

EUROPEAN SPALLATION SOURCE

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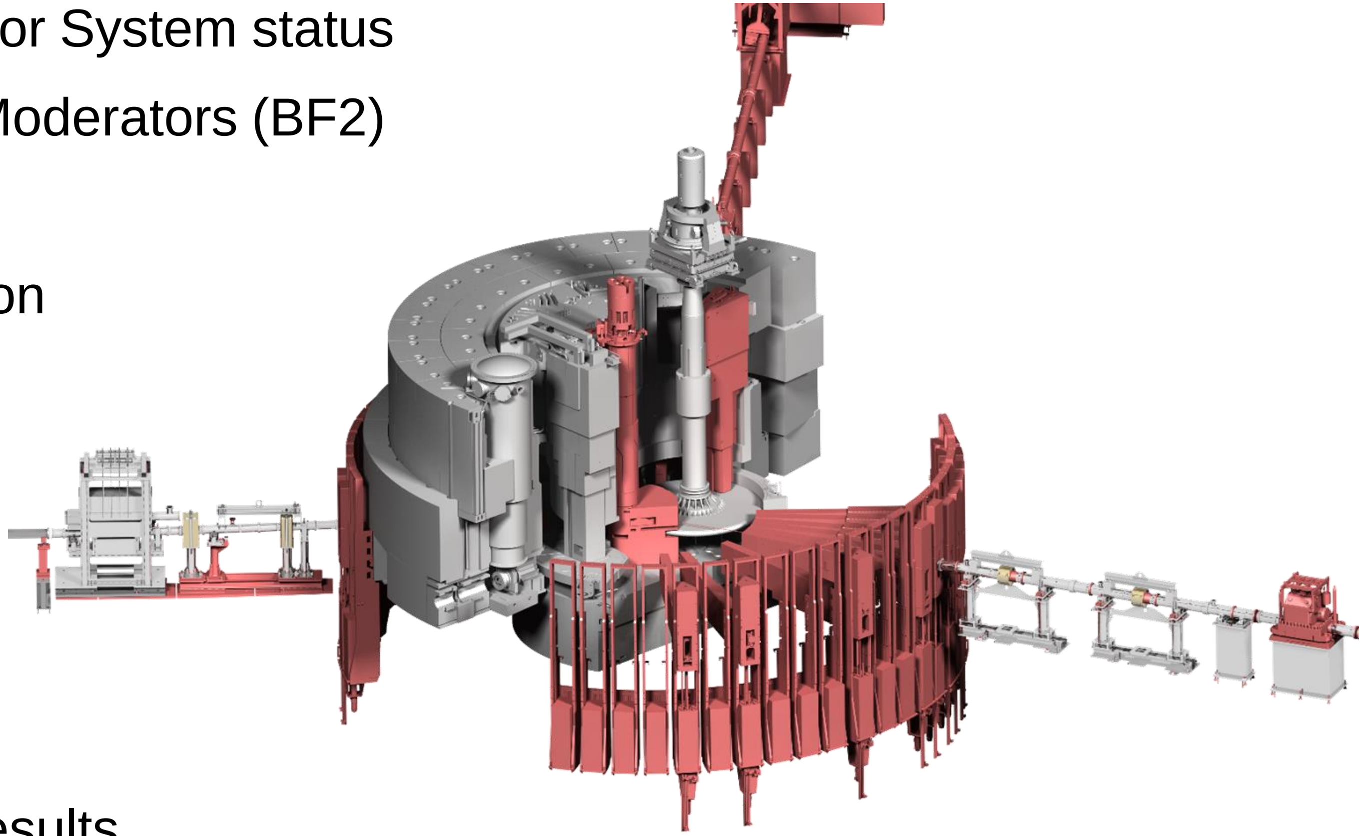
OUTLINE

1. ESS Moderator & Reflector System status
2. First generation of ESS Moderators (BF2)
3. BF1 vs. BF2
4. Design criteria and solution
5. Heat deposition
6. Material properties
7. Start conditions of CFX
8. Uncertainties
9. Simulation results
10. Validation of simulation results
11. Outlook



Red: Jülich deliverables

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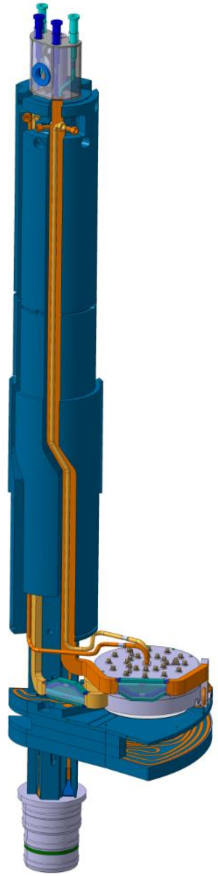
ESS MODERATOR & REFLECTOR SYSTEM

PROJECT OVERVIEW

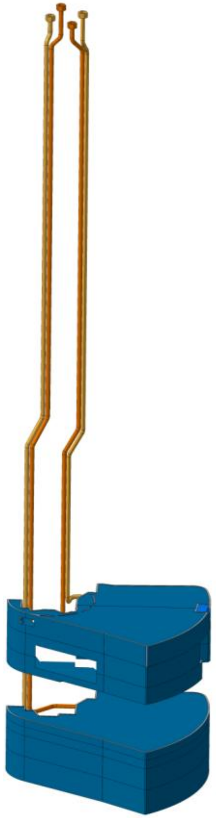
Moderator &
Reflector Unit

+



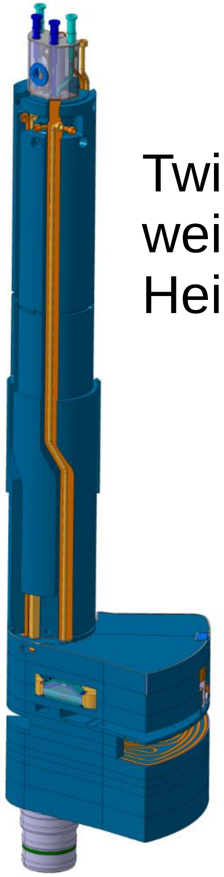
Shaft & mounting
Socket & MRP

+



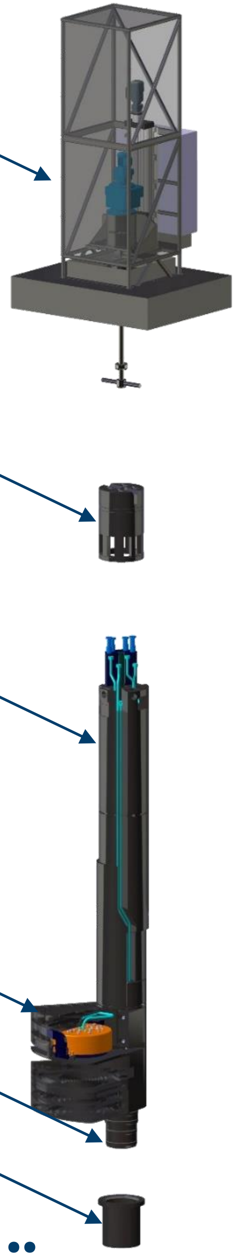
Frames (shielding)

=



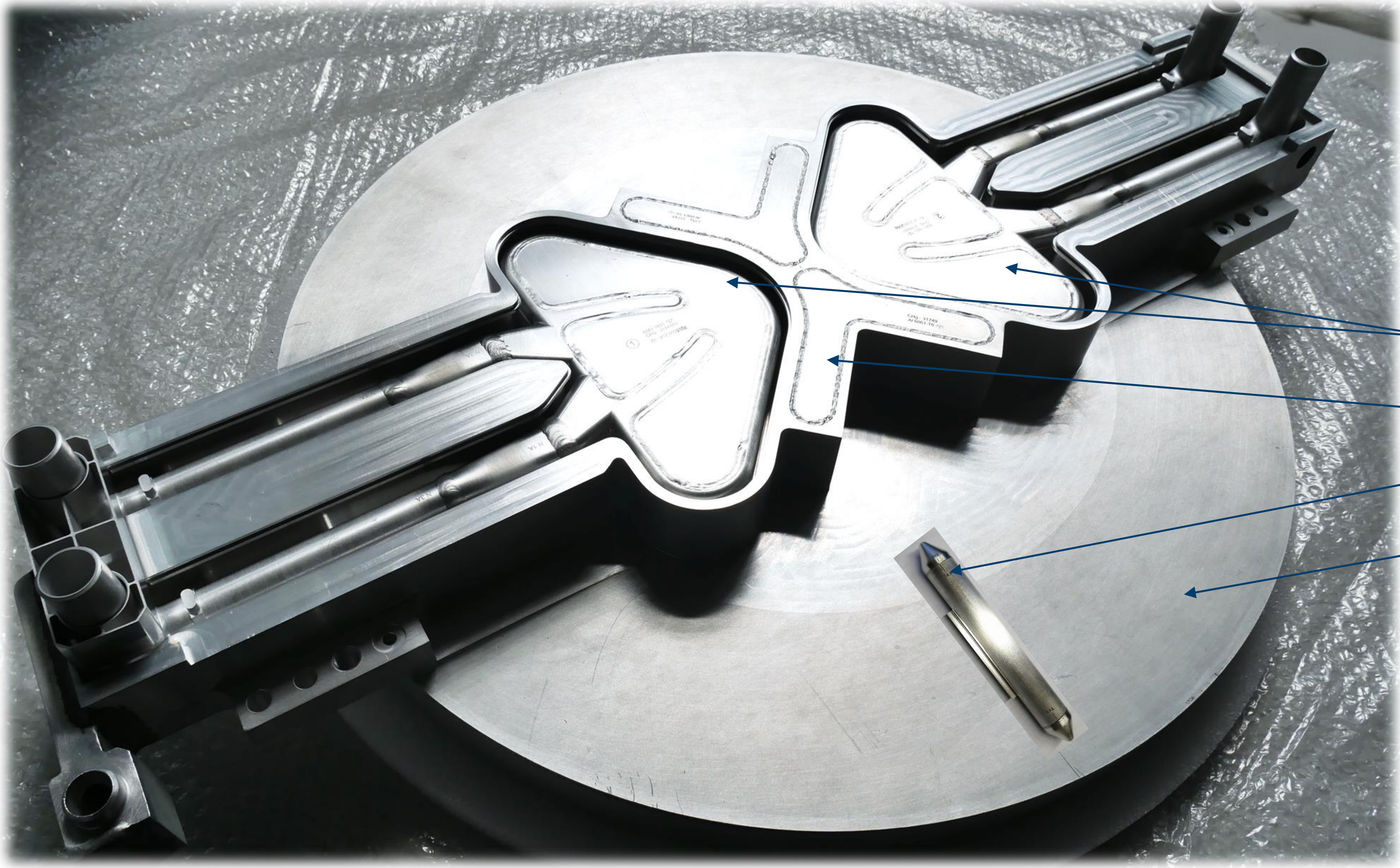
Final twister
assembly

Twister
weight: 13 t
Height: 6,5 m



FIRST GENERATION OF ESS MODERATORS (BF2)

DESIGN SOLUTION & STATUS OF MANUFACTURING



Cold Moderators

Thermal Moderator

Irradiation module

Pre Moderator

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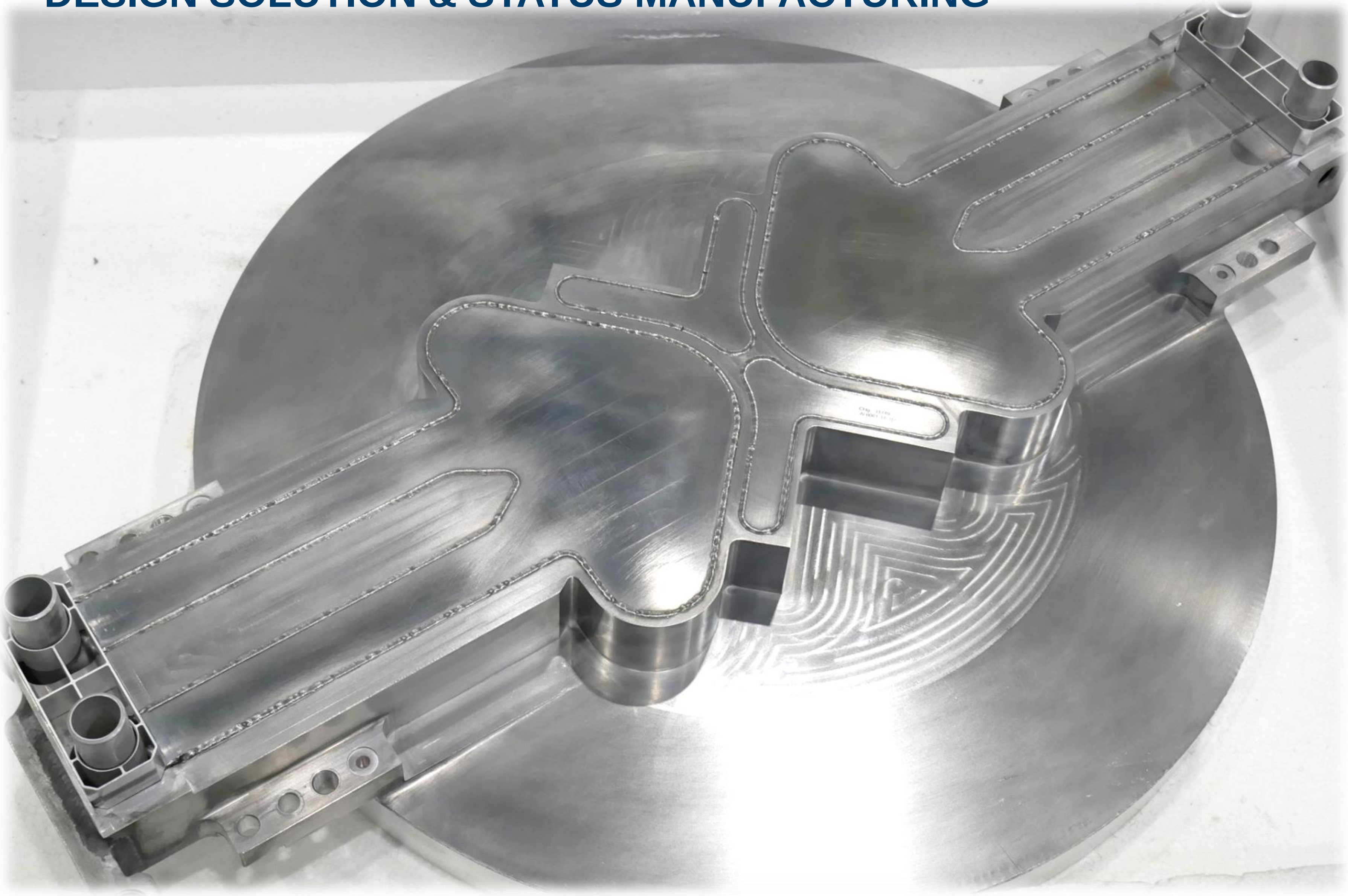
FIRST GENERATION OF ESS MODERATORS (BF2)

DESIGN SOLUTION & STATUS MANUFACTURING



✓Final assembly

✓NDT's

✓ Ready for delivery!

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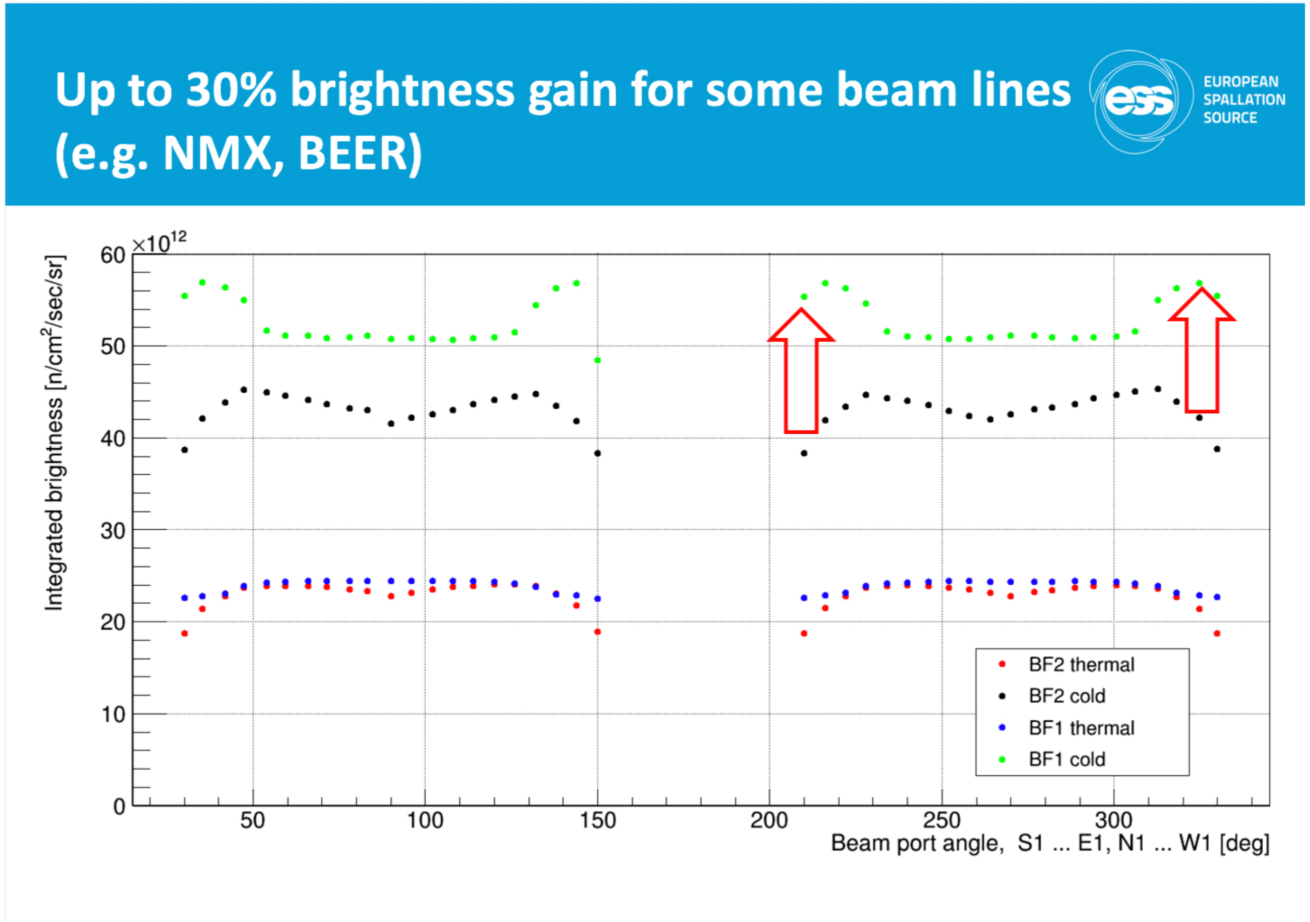
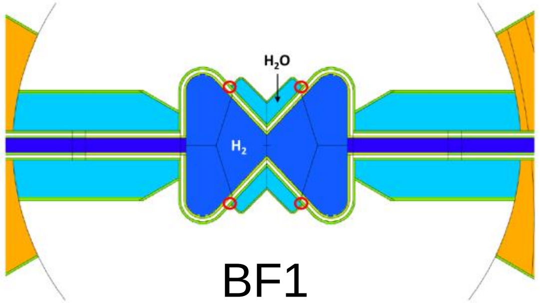
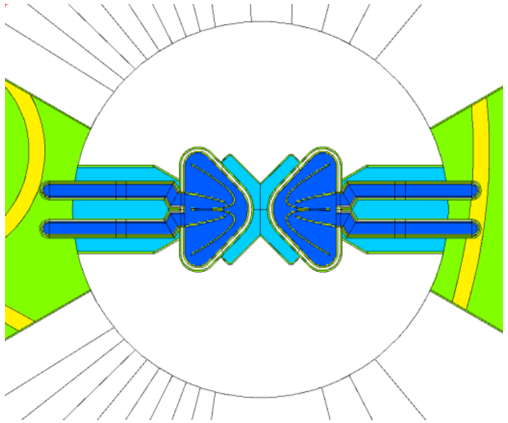
BF1 MODERATOR VS. BF2 MODERATOR, [1]

WHY NEW DESIGN BEFORE THE OLD ONE IS IN USE?





BF1

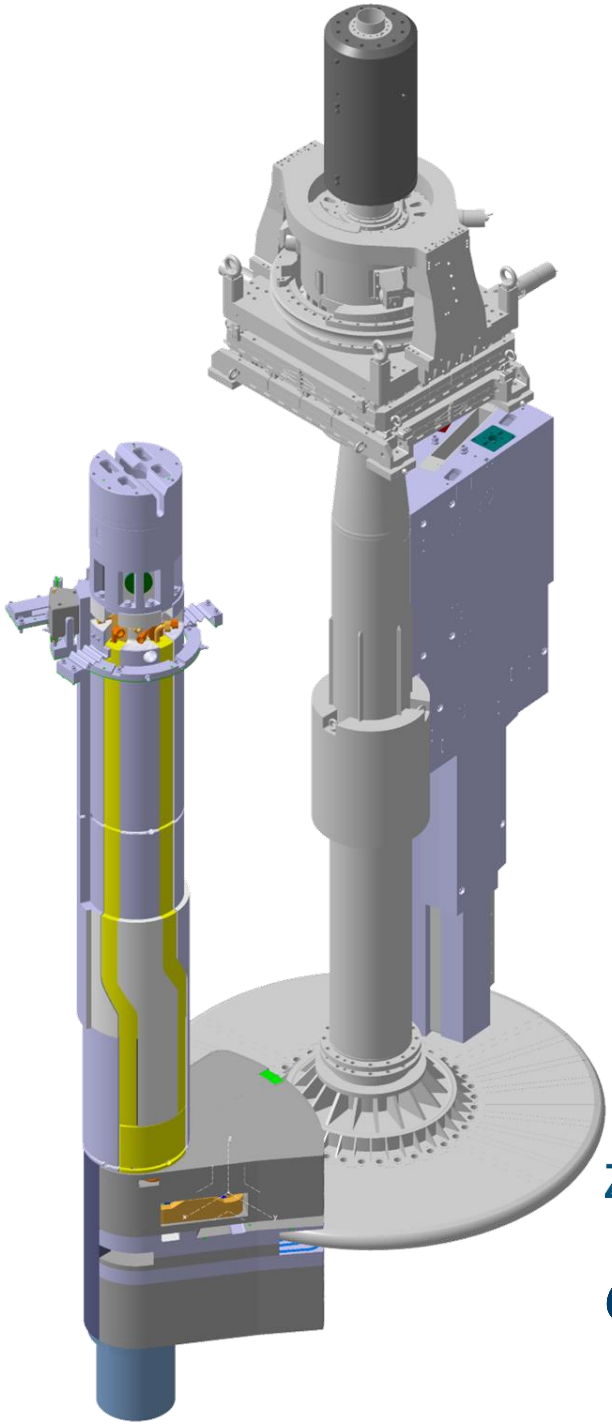


BF2

BF1 MODERATOR STUDY

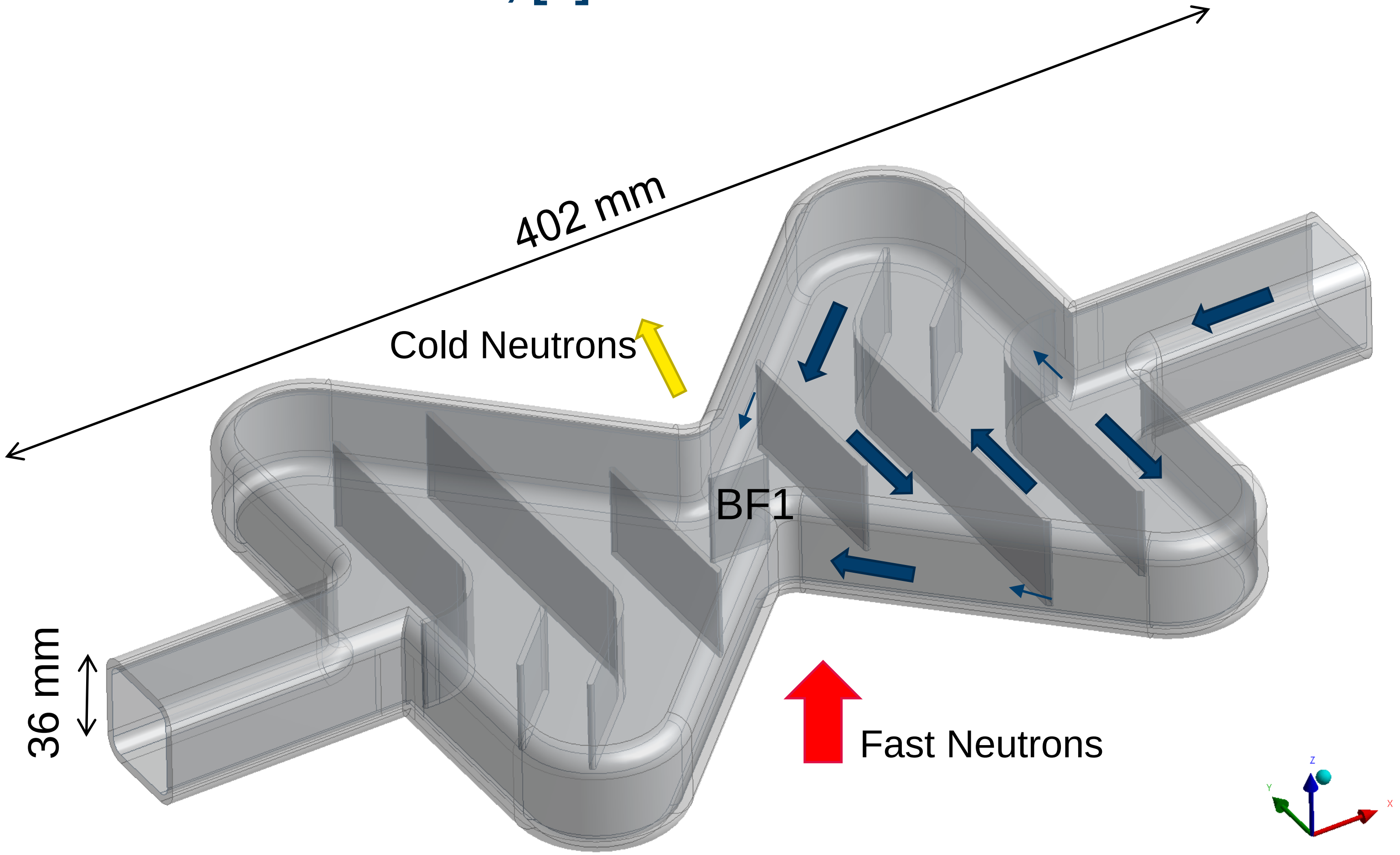
DESIGN CRITERIA

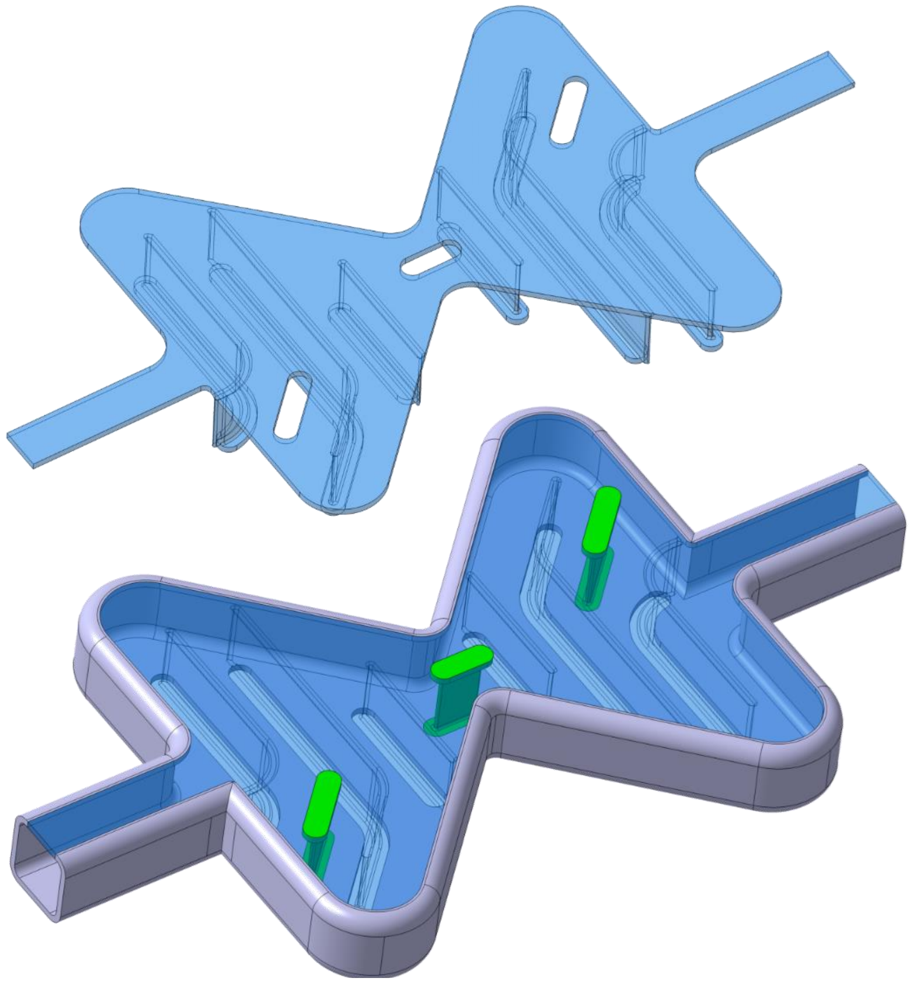
- Minimal structure material content (neutronic)
- Material, location and time-dependent neutronic heat
- Pressure $p_m \approx 10$ bar ($p_d = 17$ bar)
- Temperature $T_m \approx 18{,}5$ K ($dT \leq 3$ K)
- >99,5% para hydrogen
- Consideration of irradiation
- Compressibility of LH_2
- <u>Avoid (local) boiling</u>
- RCC-MRx calculation
- Manufacturability
- Weldability
- …….



BF1 MODERATOR

DESIGN SOLUTION, [2]





Manufacturing concept

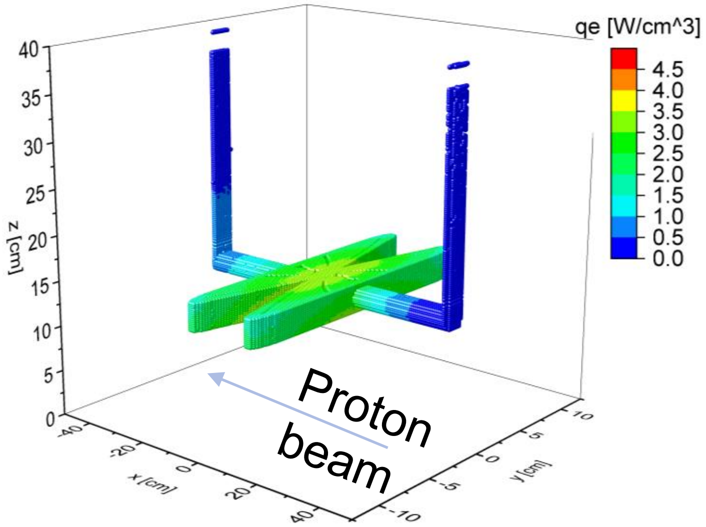
Second generation of ESS cold Moderators…..

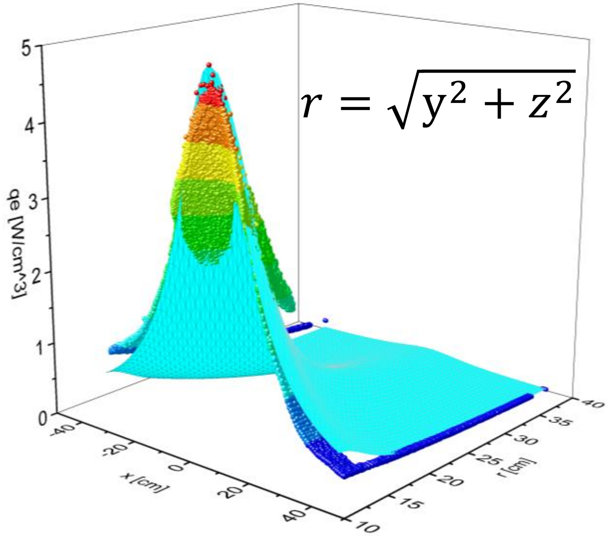
≈1l para LH_2 volume
Dimensions: 250 x 200 x 36
Structural material Al6061-T6

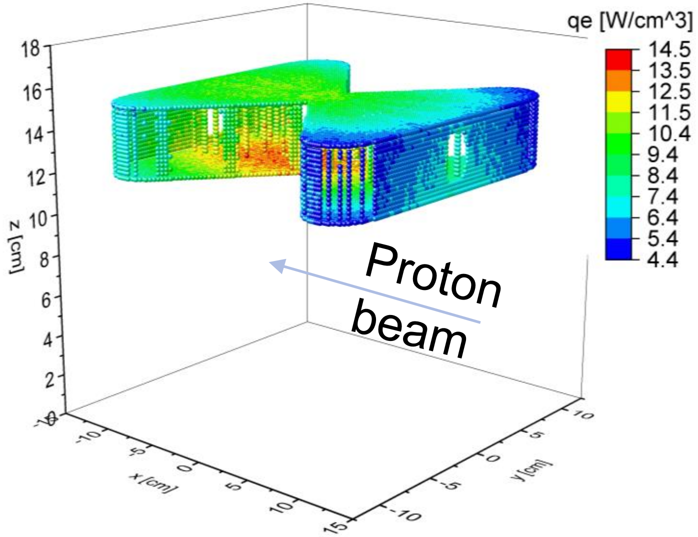
BF1 MODERATOR

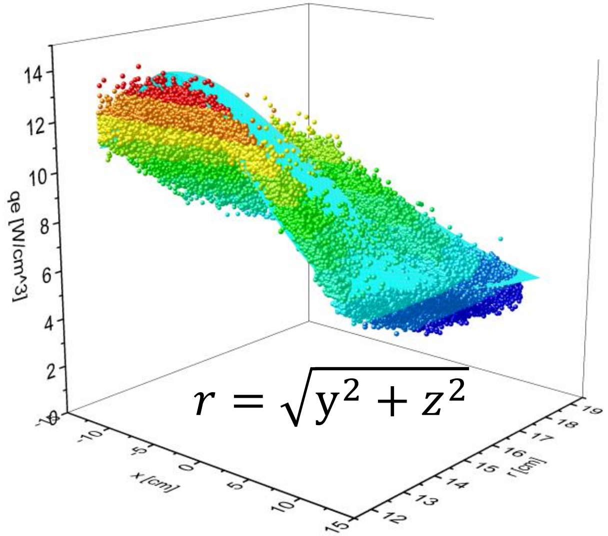
HEAT DEPOSITION =F(MATERIAL,X,Y,Z), [2]

$$q_{VAl}(x,r) = q_{VAlmin} + \frac{q_{VAlmax} - q_{VAlmin}}{\left(1+\left[\frac{x-x_C}{w_{Alx}}\right]^2\right)\cdot\left(1+\left[\frac{r-r_C}{w_{Alr}}\right]^2\right)}$$

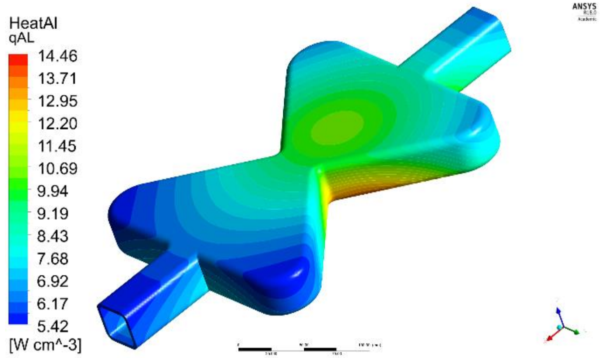








$$q_{VLH2}(x,r) = q_{VLH2min} + \frac{q_{VLH2max} - q_{VLH2min}}{\left(1+\left[\frac{x-x_C}{w_{LH2x}}\right]^2\right)\cdot\left(1+\left[\frac{r-r_C}{w_{LH2r}}\right]^2\right)}$$



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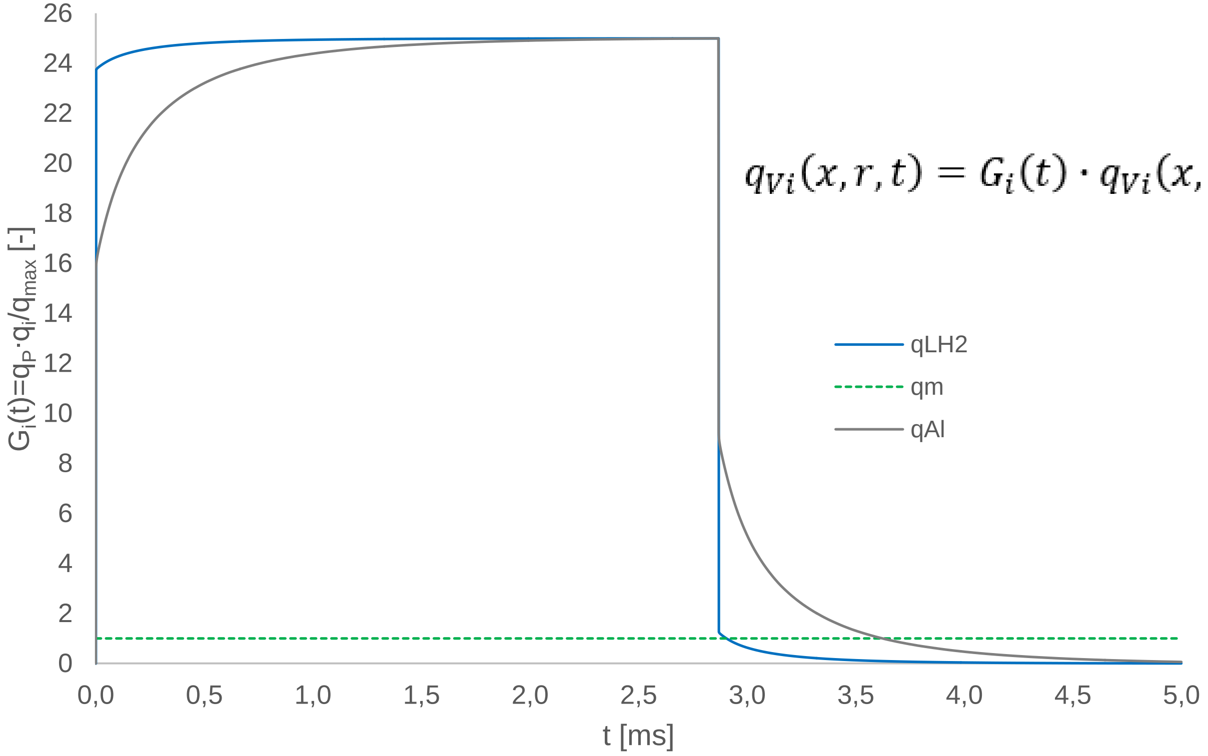
BF1 MODERATOR

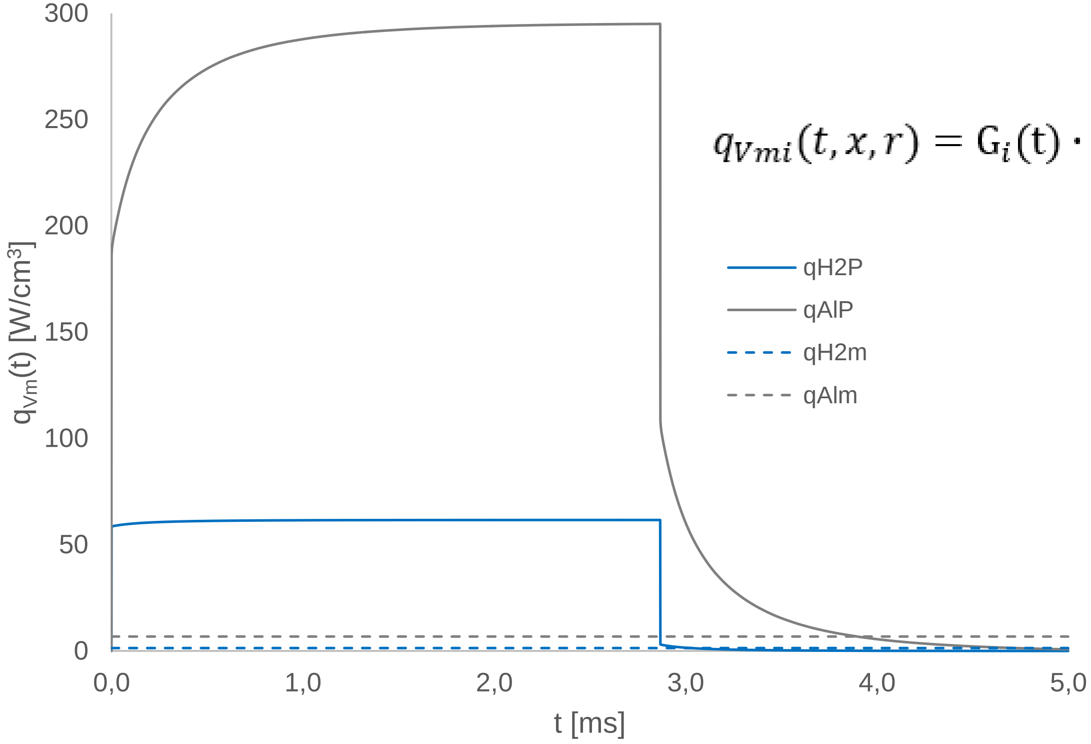
HEAT DEPOSITION =F(MATERIAL,X,Y,Z,T), [2]

Weighting factor for the time-dependent heat



$$q_{Vi}(x,r,t) = G_i(t) \cdot q_{Vi}(x,r)$$

Average volumetric heat in the pulse



$$q_{Vmi}(t,x,r) = G_i(t) \cdot \frac{\sum q_{Vi}}{N}$$

$$q_P = \frac{1\ s}{f_{Puls} \cdot t_{Puls}} \cdot q_m = 24{,}975 \cdot q_m$$

BF1 MODERATOR

START CONDITIONS OF CFX, [2]

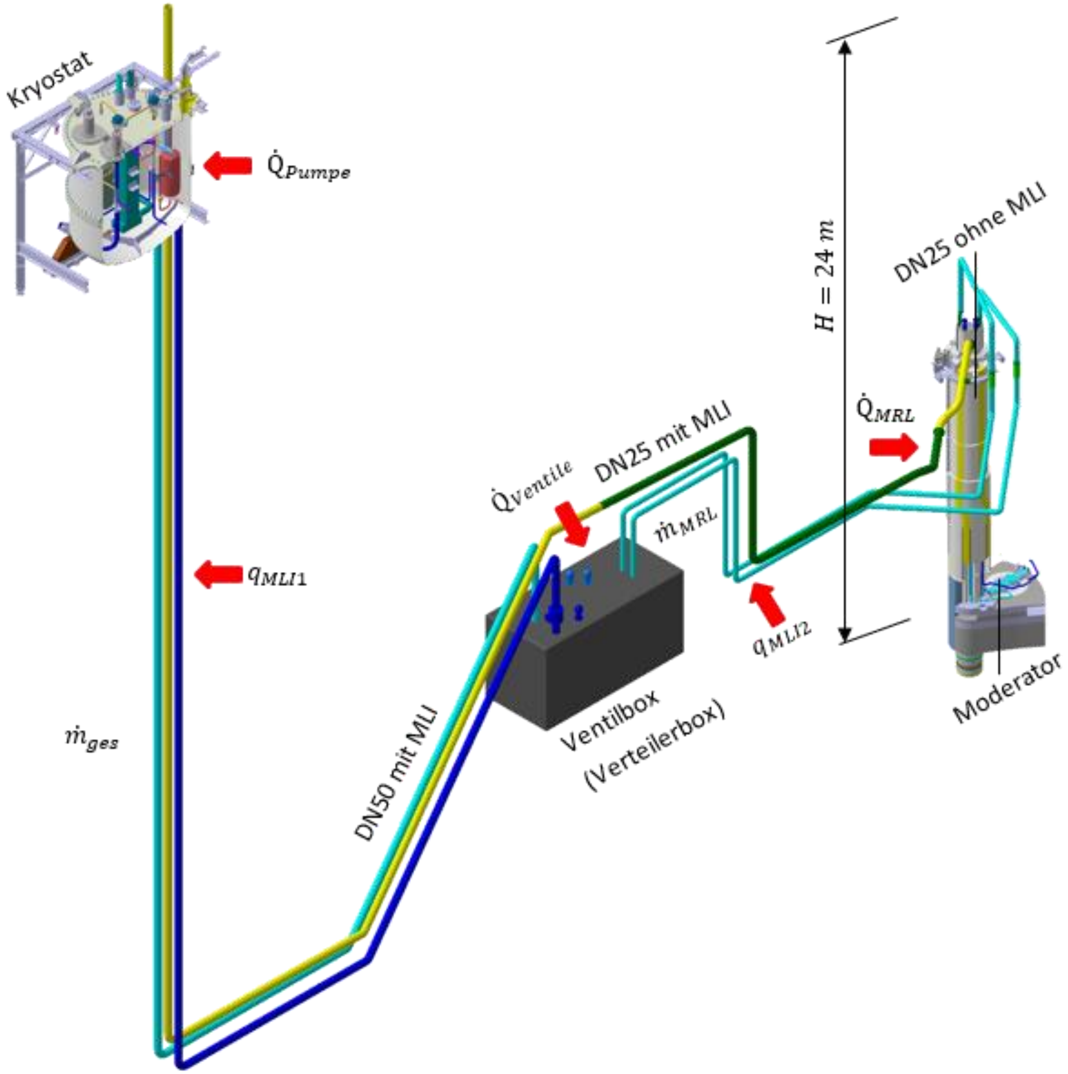
$$\dot{Q}_{Total} = \sum q_{VAli}(x,r) \cdot V_{Ali} + \sum q_{VLH2i}(x,r) \cdot V_{LH2i} = 7{,}1\, kW (\Delta T \leq 3\, K)$$

$$\rightarrow \dot{m} = \frac{\dot{Q}_{Total}}{c_{pm}(T,p) \cdot \Delta T} \approx \boldsymbol{400\ g/s}$$

$$\rightarrow T_{inMo} = T_{minKL} + \frac{\dot{Q}_{Pump} + q_{MLI} \cdot (L_{MLI1} + L_{MLI2}) + \dot{Q}_{Ventile}}{c_{pm}(T,p) \cdot \dot{m}_{ges}}$$

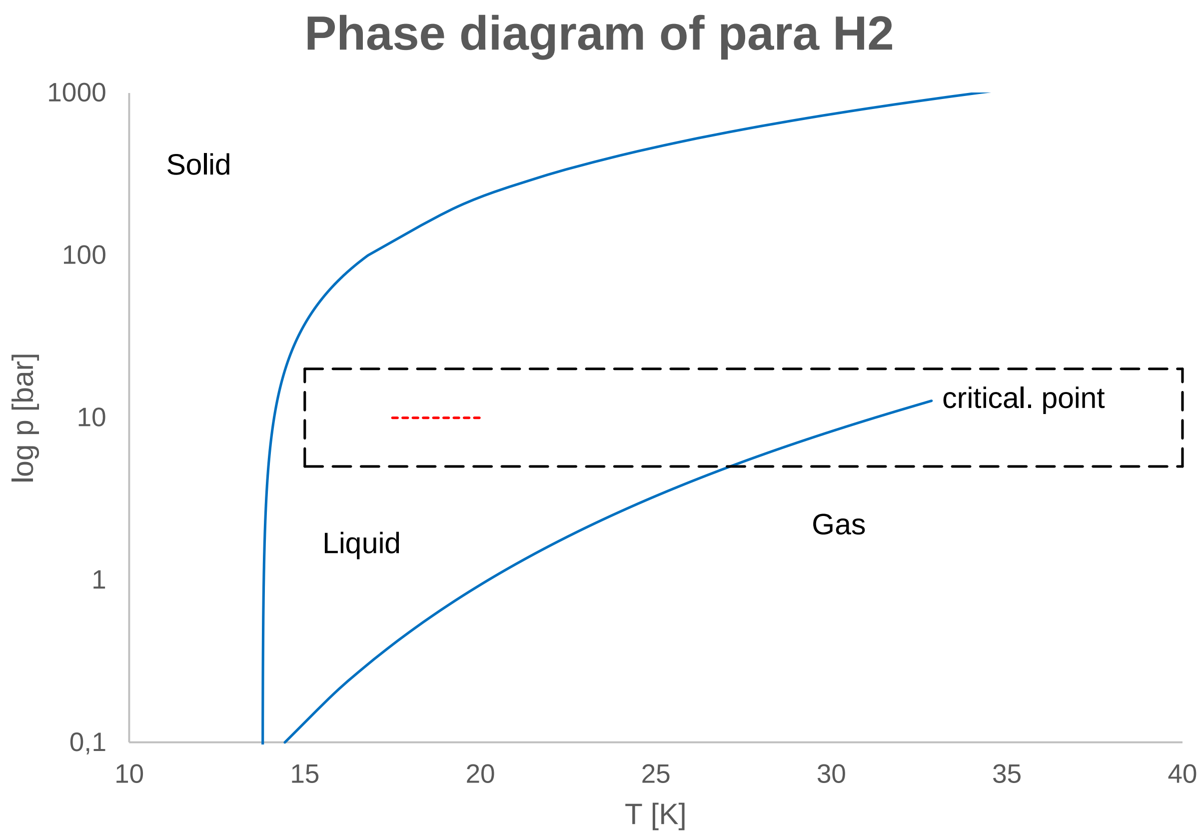
$$+ \frac{\dot{Q}_{MRL}}{c_{pm}(T,p) \cdot \dot{m}_{MRL}} \leq \boldsymbol{17.4\ K}$$

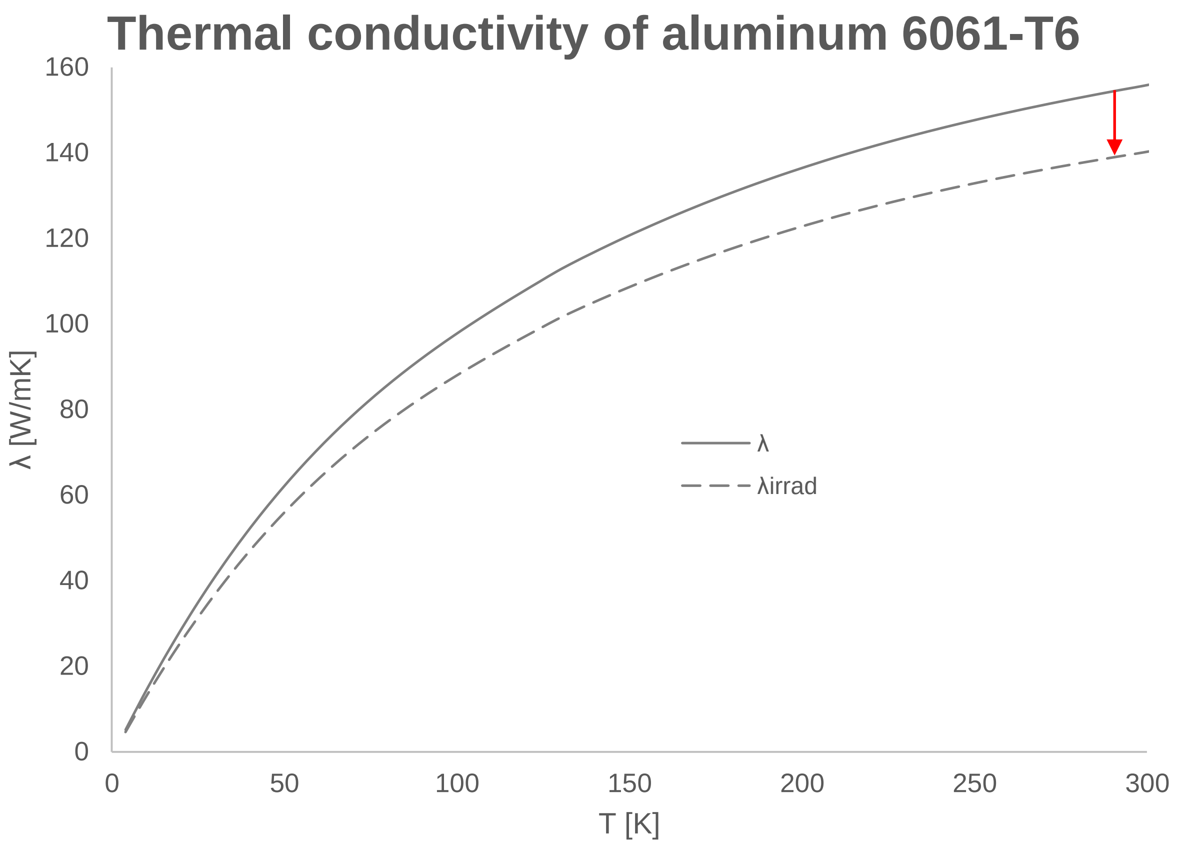
$$p_{ausM} = p_{ausP2} + \rho_m(T,p) \cdot g \cdot H - \Delta p_M - \Delta p_{VL} \leq \boldsymbol{10.4\ bar}$$



BF1 MODERATOR

MATERIAL PROPERTIES, [2]





BF1 MODERATOR

UNCERTAINTIES OF HEAT DEPOSITION, [2]

1. Static error of the MCNPX simulation <1% (AVE)
2. MCNPX model error ±15%
3. Error of the approximation function

	$\sum \dot{Q}_{MCNPX\_i}$ [W]	$\sum q_{VFit\_i} \cdot V_i$ [W]	Δ [%]
Al	2343,031	2379,518	-1,56
LH2	2788,063	2846,508	-2,05

4. Up-normal proton beam parameter

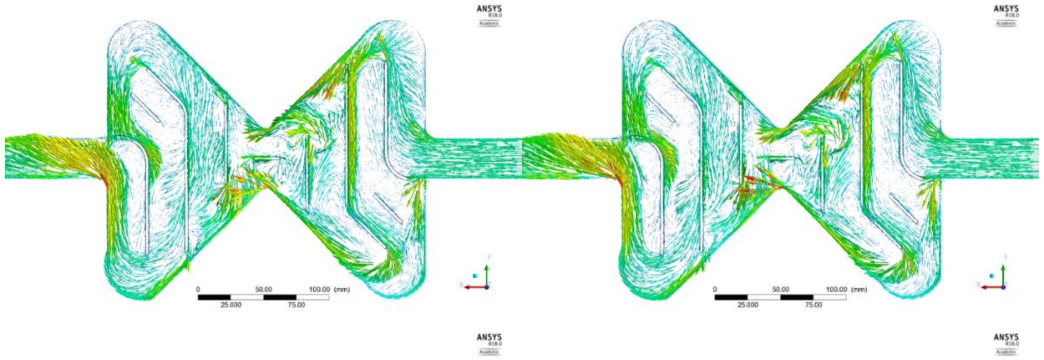
$P_{f1} = 5\ MW + 0{,}2\ MW$, (+4%)

$z_P = \pm 3\ mm$ (+5,6%)

$\rightarrow P_{f2} = 1{,}056 \cdot P_{f1} = 5\ MW + 0{,}49\ MW$

$P_{fm} = P_m \cdot (1 + 0{,}15 - 0{,}01805 + 0{,}138) = 1{,}26995 \cdot P_m$

$\rightarrow \boldsymbol{P_{fm}(max) = 6,35\ \mathrm{MW}}$



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BF1 MODERATOR

ADDITIONAL UNCERTAINTIES, [2]

1. Mass flow →control valves! ($\sum e_i \approx$ ±1%)

2. Outlet pressure →control of PCB and pressure sensor! ($\sum e_i \approx$ ±3,5%)

3. Inlet Temperature →control of HX and temperature sensor ($\sum e_i \approx$ ±2,5%)

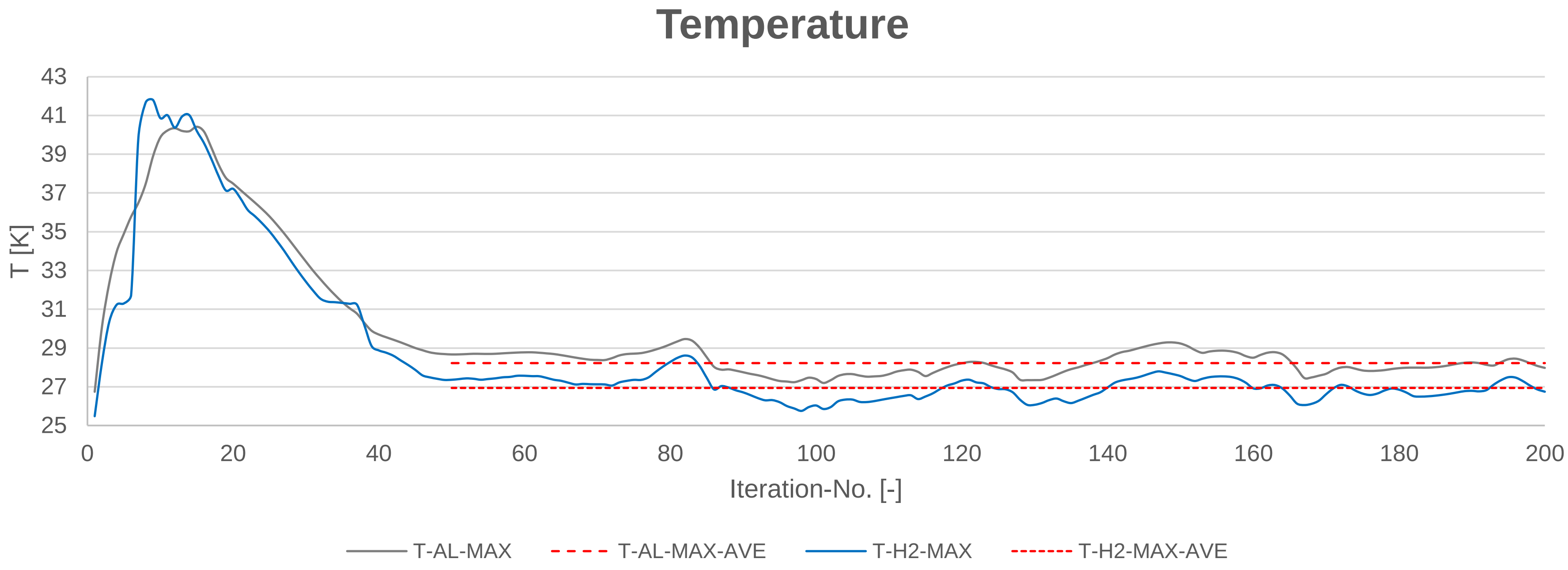
4. Manufacturing Tolerance →using for CFX the max wall thickness!

5. Material properties → comparison with other libraries ($\sum e_i \approx$ ±1%)

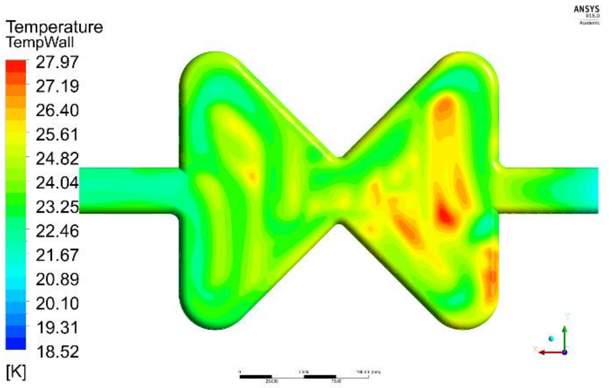
6. **CFX???** **→experiment (PIV)**

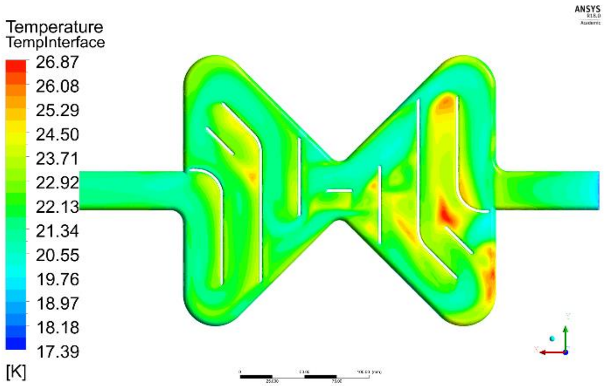
BF1 MODERATOR

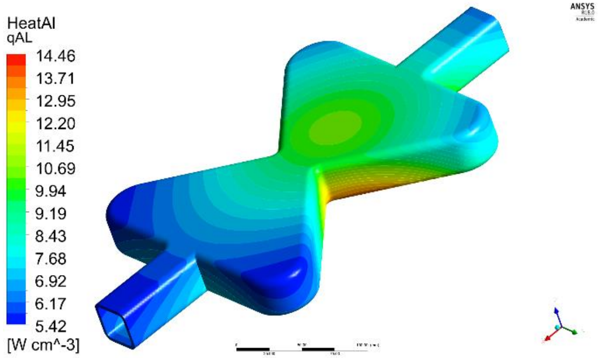
SS RESULTS (TEMPERATURE), [2]



Heat averaged over time!
(results used as start condition for pulsed simulation)

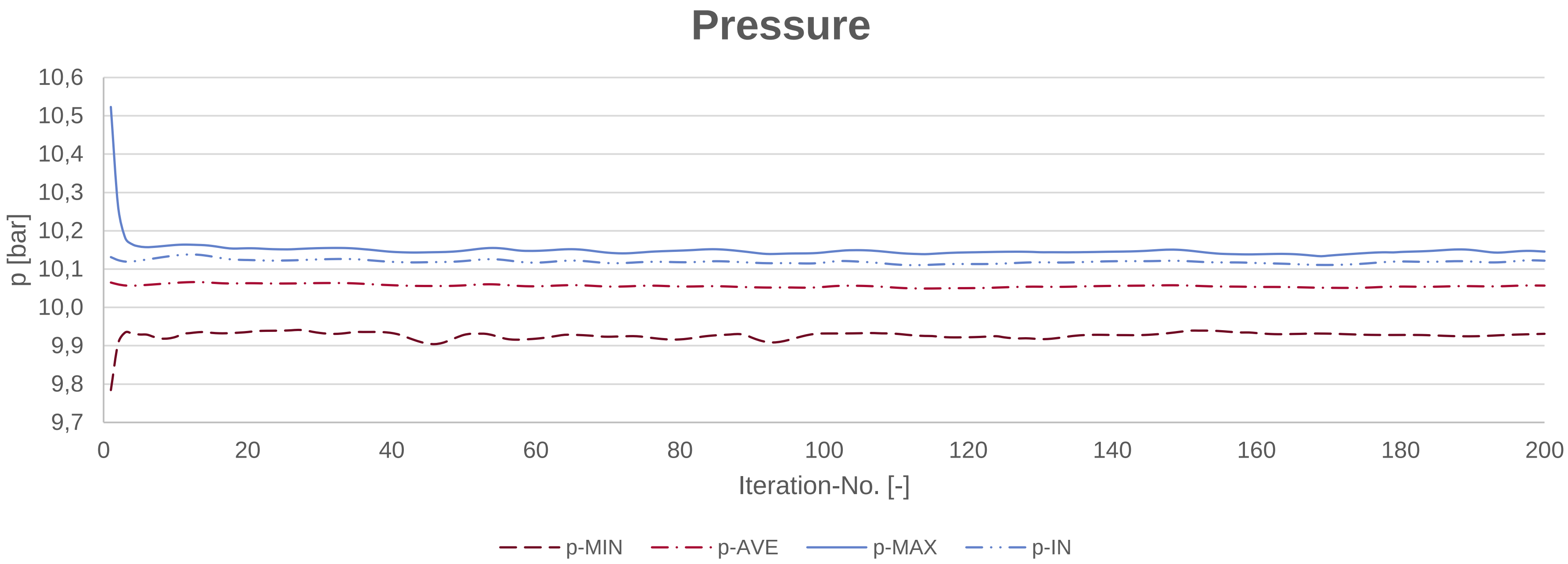




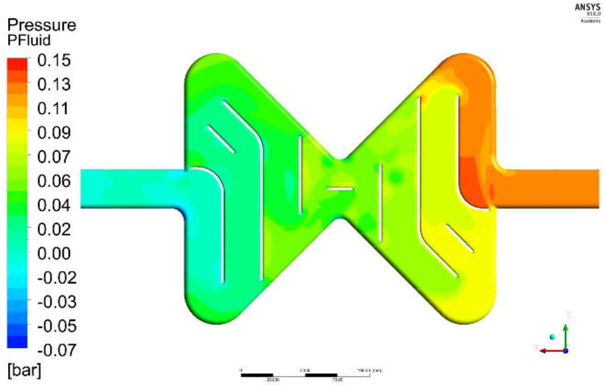


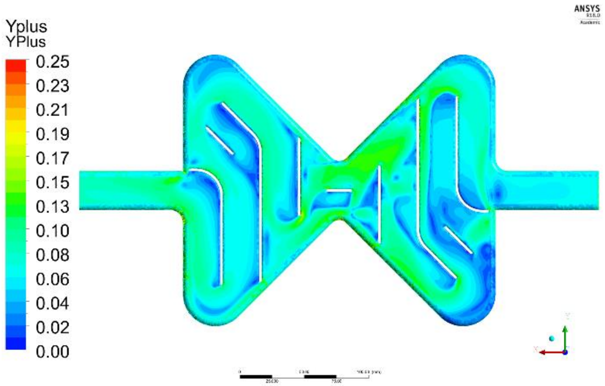
BF1 MODERATOR

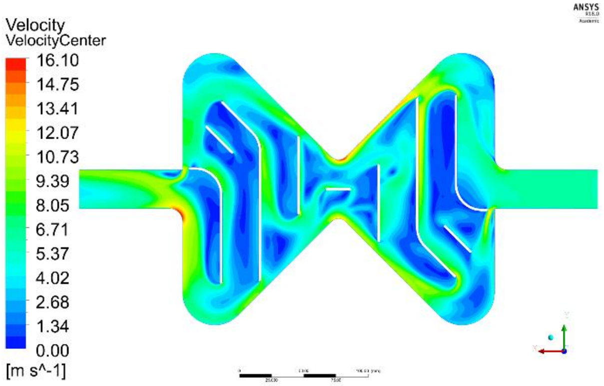
SS PRE RESULTS (PRESSURE), [2]



Heat averaged over time! (results used as start condition for pulsed simulation)

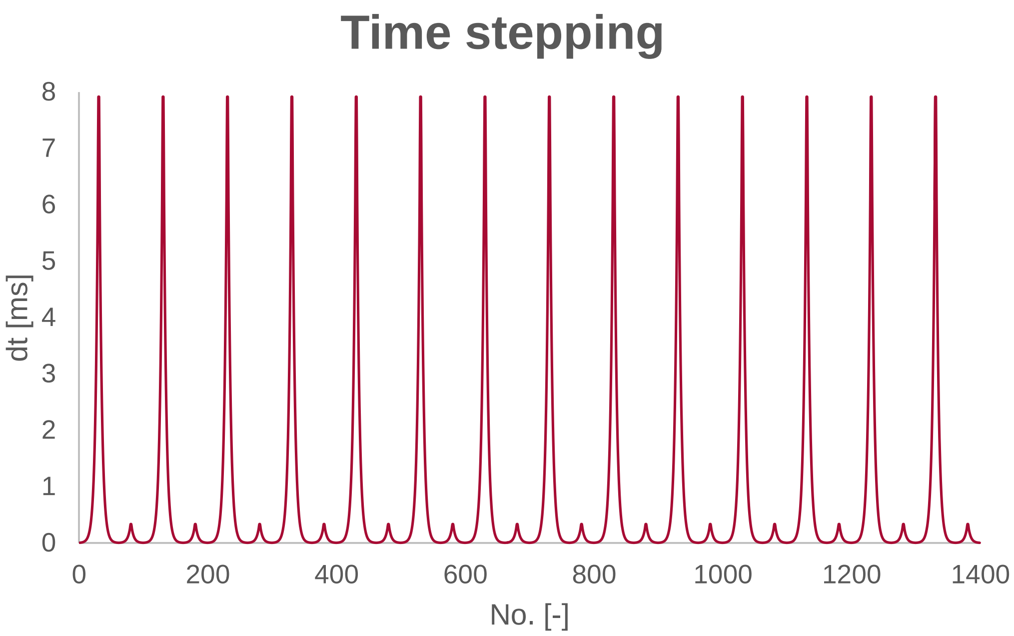


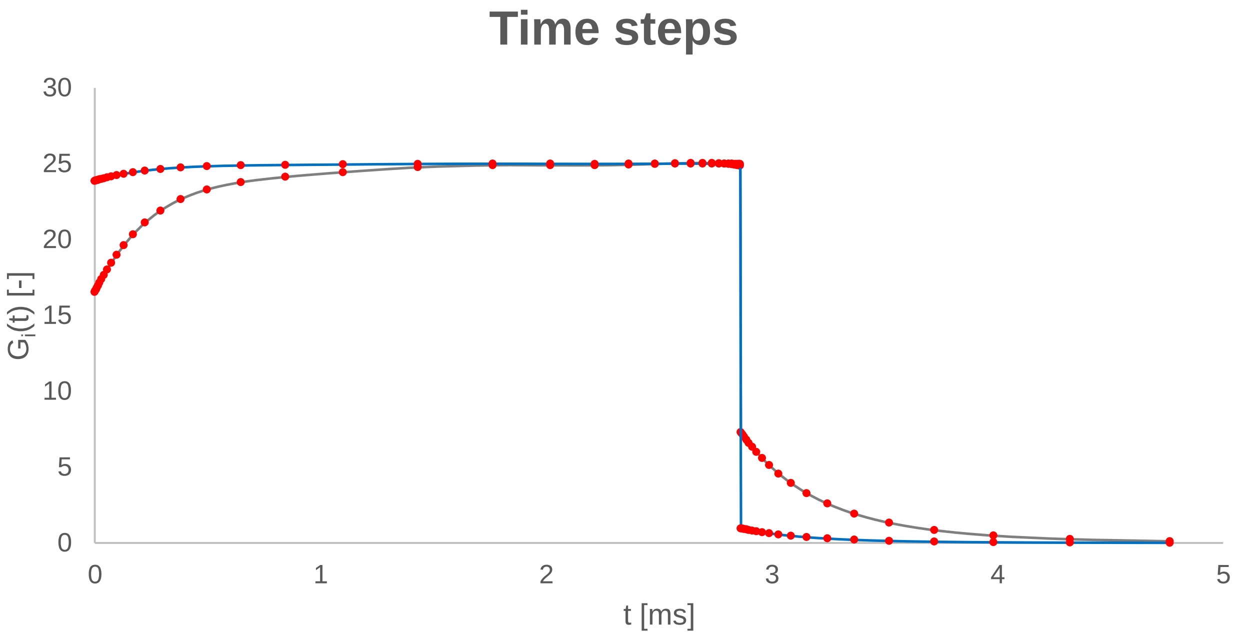




BF1 MODERATOR

TIME DISCRETIZATION (TIME STEPPING), [2]





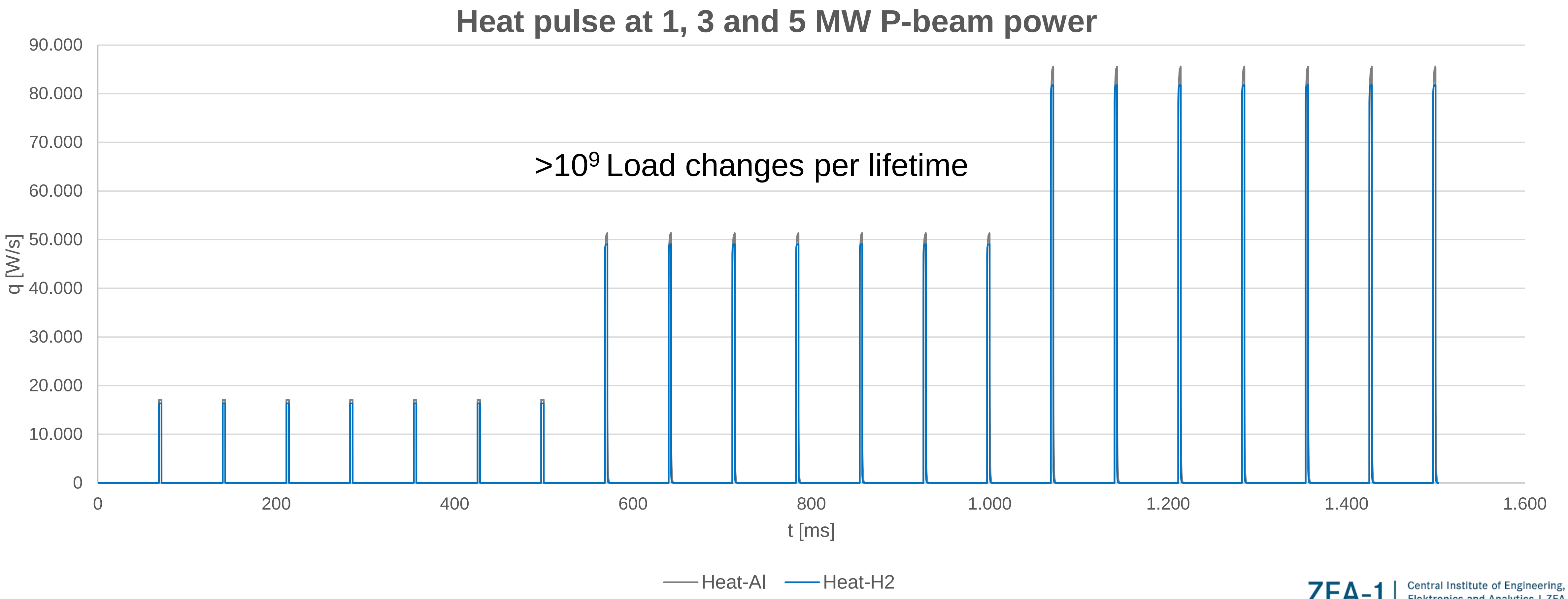
$$G_{i.H2}(t) = \begin{cases} -0.599t^6 + 5.924t^5 - 23.26t^4 + 46.48t^3 - 50.473t^2 + 29.71t + 16.54 \\ 43107t^{-8,256} \end{cases}$$

$$G_{iAl}(t) = \begin{cases} -0{,}102t^6 + 1{,}000t^5 - 3{,}89t^4 + 7{,}656t^3 - 8{,}073t^2 + 4{,}478t + 23{,}87 \\ 22653t^{-9{,}58} \end{cases}$$

$$\Delta t_i = \begin{cases} 1{,}3 \cdot (t_i - t_{i-1}) & \text{für } 0 < t \leq \frac{1}{2} \cdot (t_{Cycle} - t_{Pulse}) \\ 1{,}3^{-1} \cdot (t_i - t_{i-1}) & \text{für } \frac{1}{2} \cdot (t_{Cycle} - t_{Pulse}) < t \leq (t_{Cycle} - t_{Pulse}) \\ 1{,}3 \cdot (t_i - t_{i-1}) & \text{für } (t_{Cycle} - t_{Pulse}) < t \leq \left(t_{Cycle} - \frac{1}{2} \cdot t_{Pulse}\right) \\ 1{,}3^{-1} \cdot (t_i - t_{i-1}) & \text{für } \left(t_{Cycle} - \frac{1}{2} \cdot t_{Pulse}\right) < t \leq t_{Cycle} \end{cases}$$

BF1 MODERATOR

HEAT INTEGRAL VALUES, [2]



1600 Time steps, 20-50 iterations each

128 CPU's, Simulation time ≈70 h

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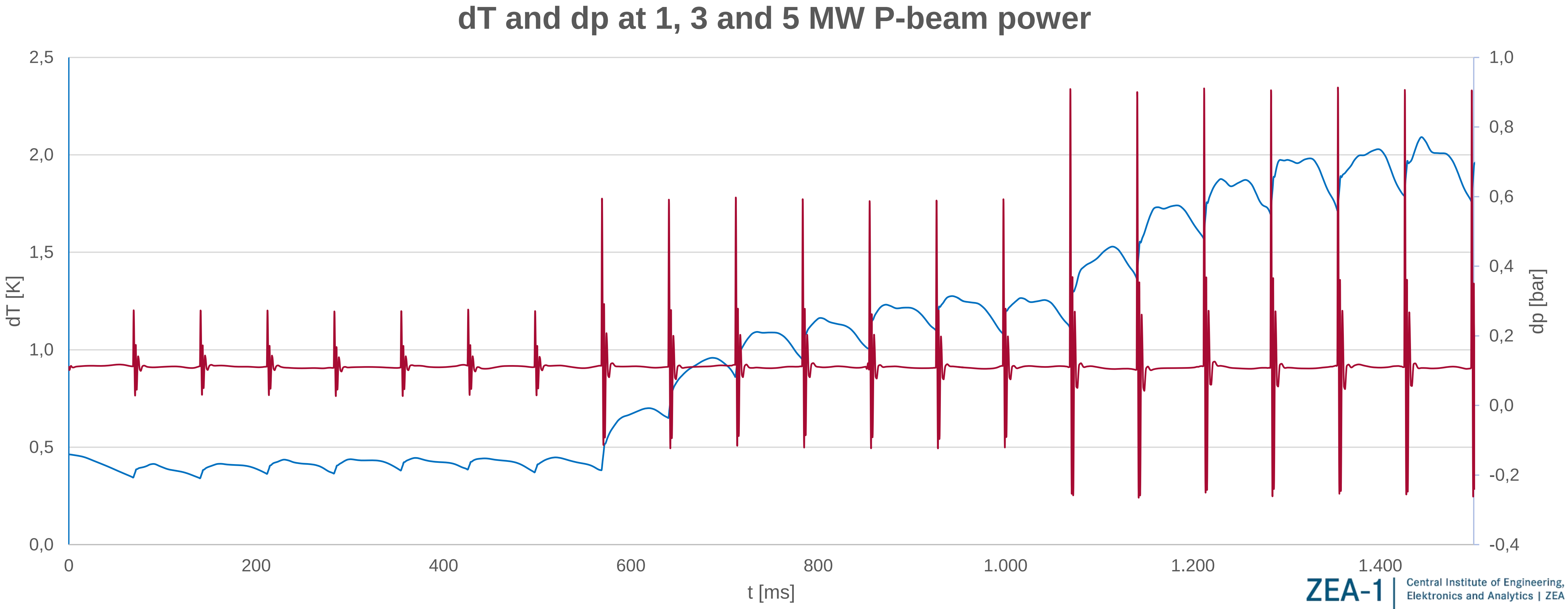
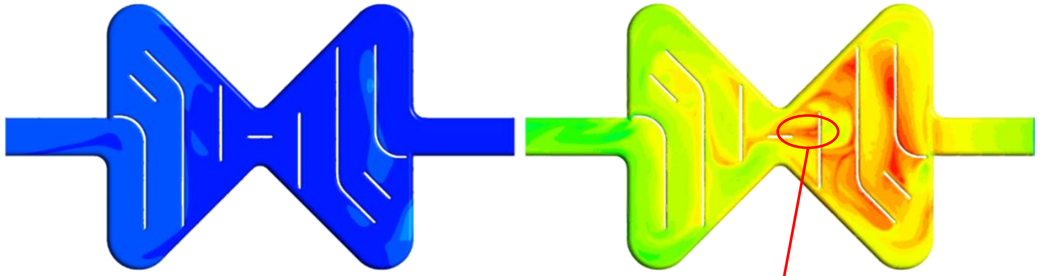
DT, DP, [2]

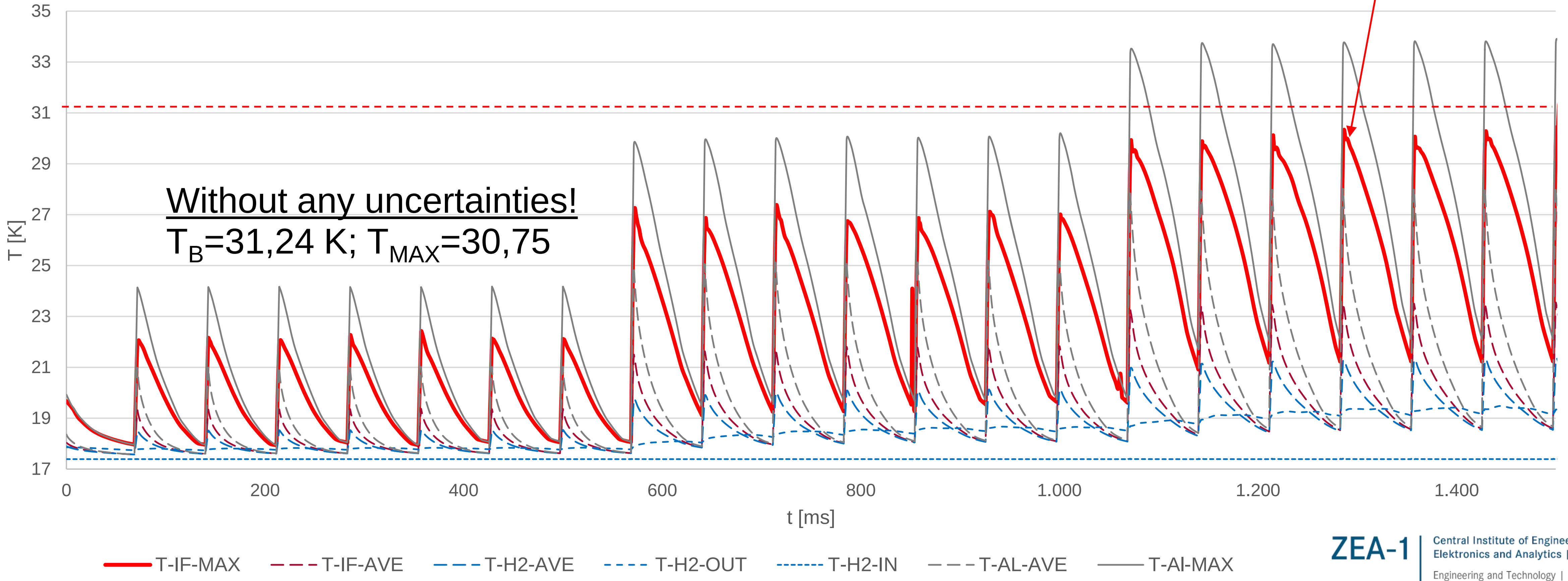


BF1 MODERATOR

TEMPERATURE DISTRIBUTION, [2]



Temperature at 1, 3 and 5 MW P-beam power



Without any uncertainties!

T_B=31,24 K; T_{MAX}=30,75

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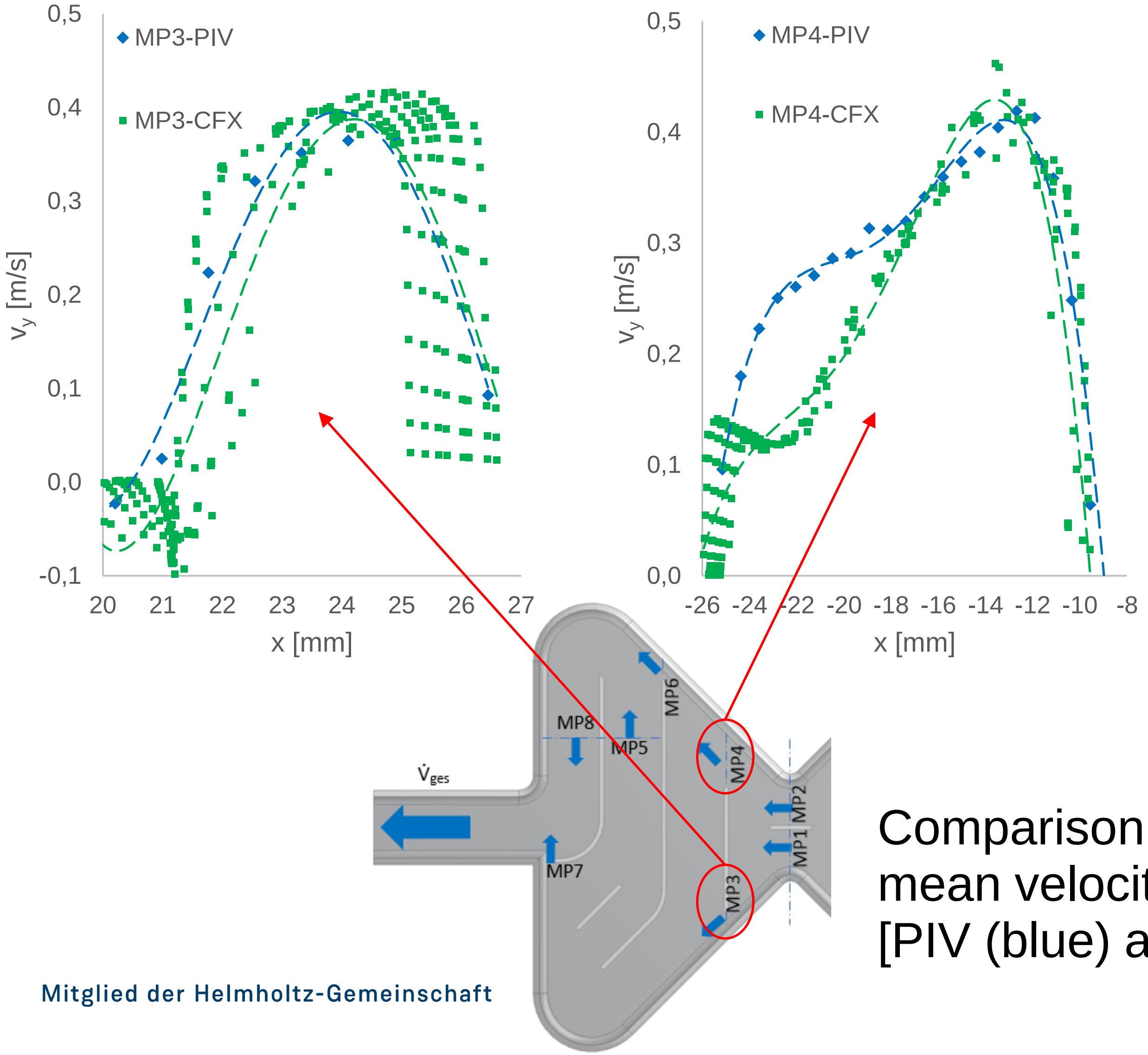
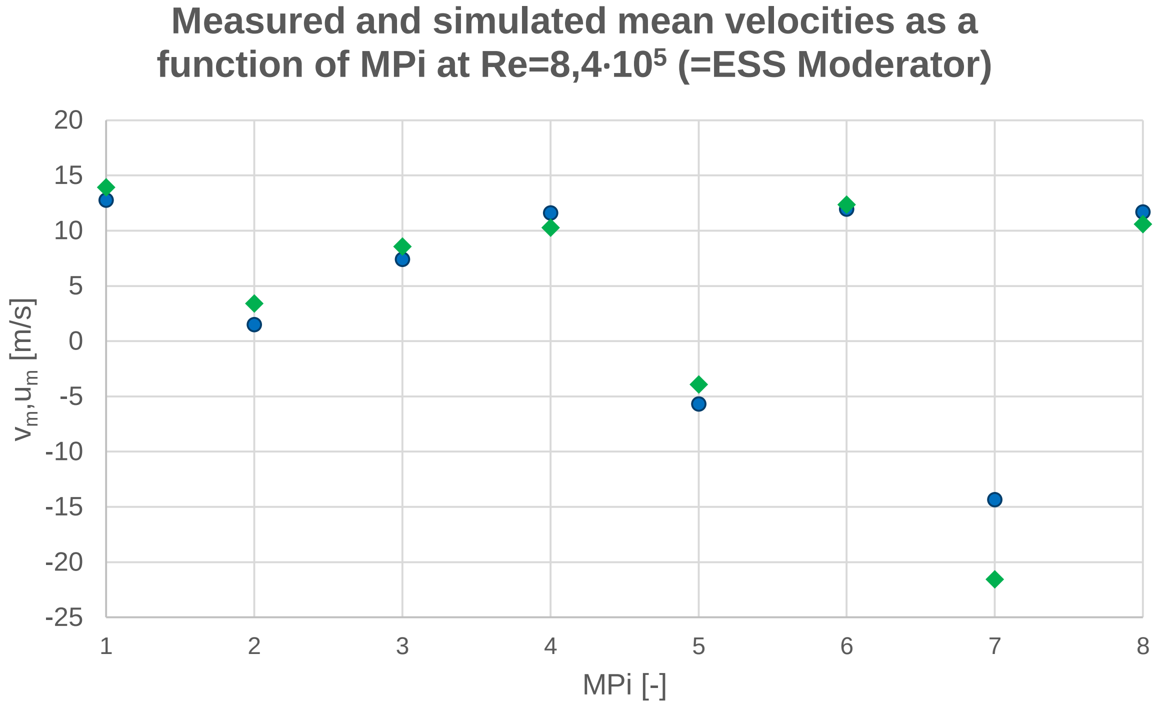
BF1 MODERATOR

PRELIMINARY RESULTS OF PARTICLE IMAGE VELOCIMETRY MEASUREMENT (PIV), [2]

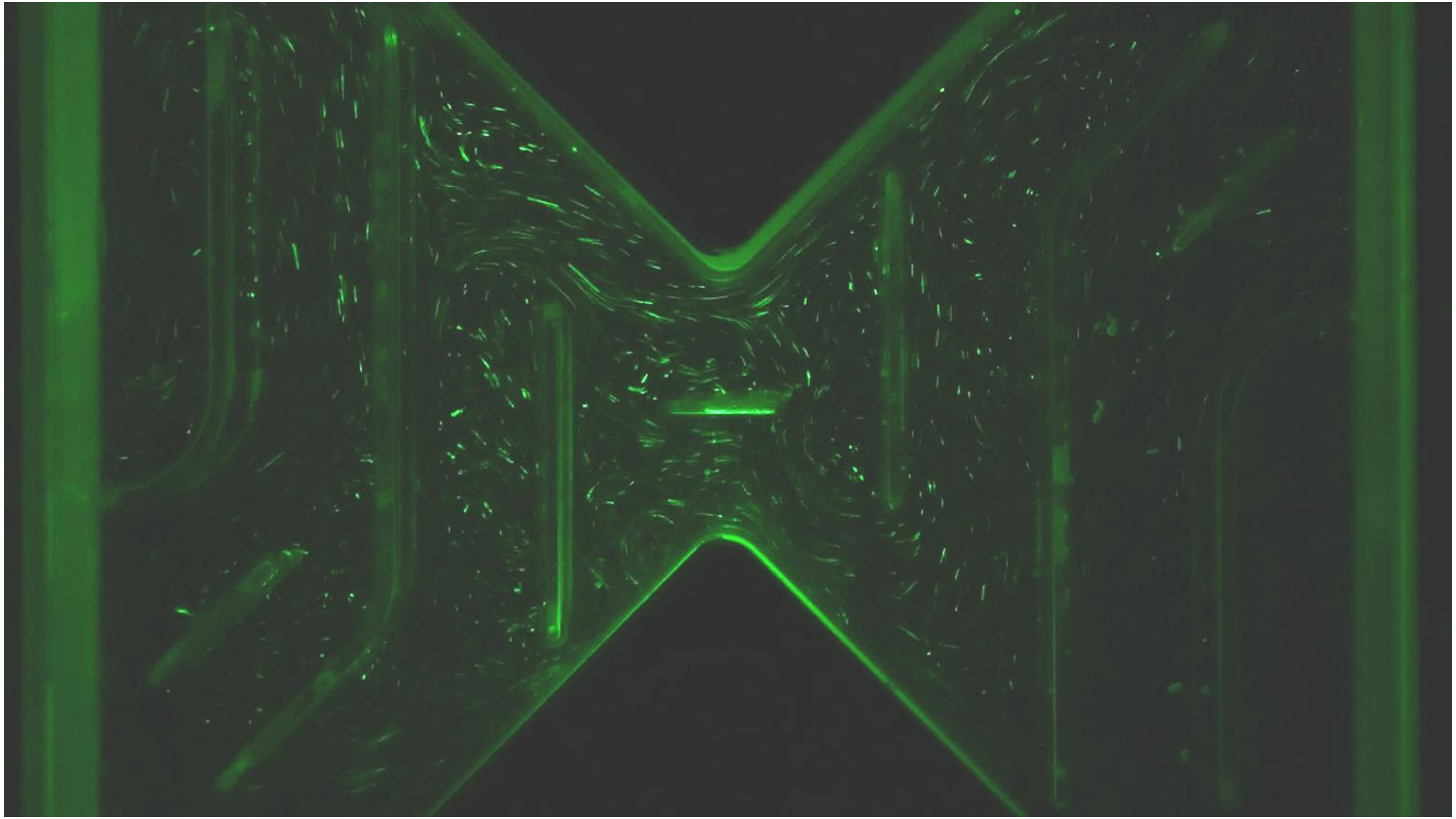




Comparison of the velocity profiles (left) and mean velocities (right) in the measuring Points [PIV (blue) and CFX (green)]

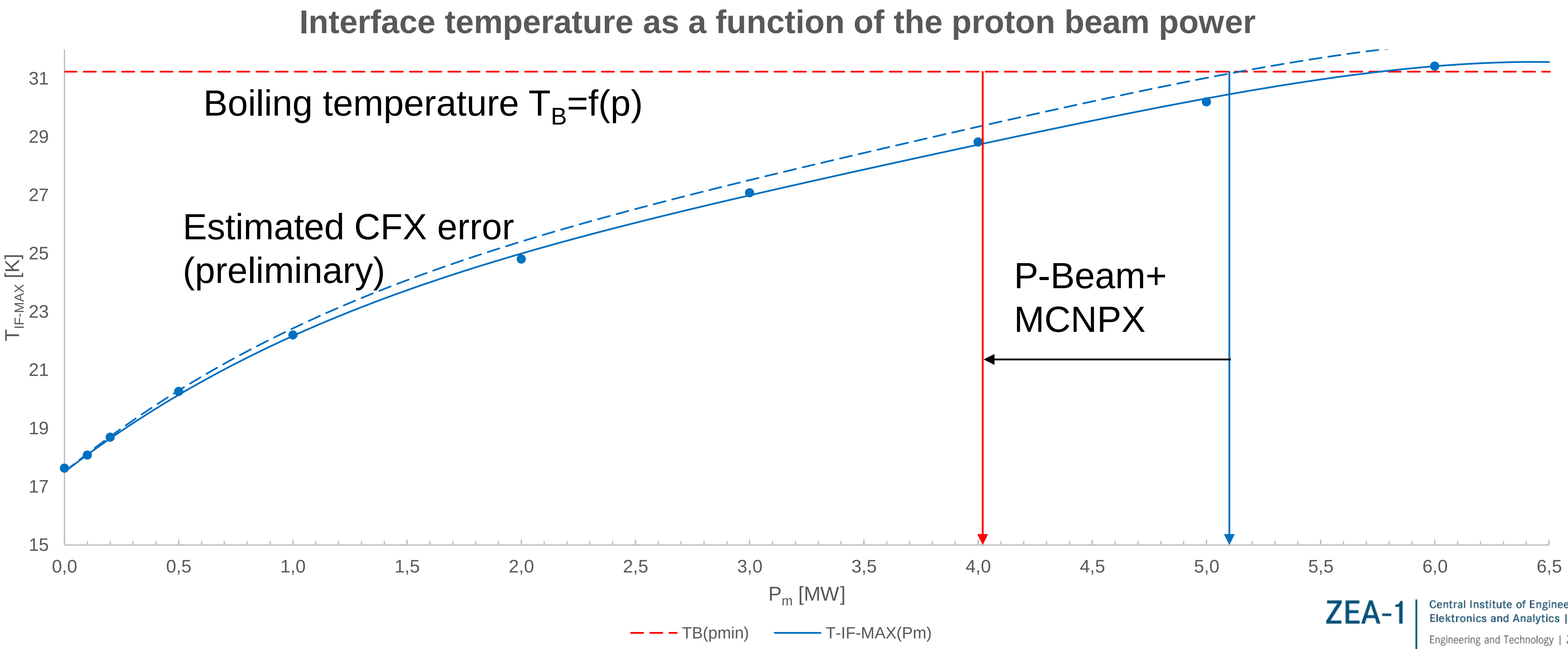
BF1 MODERATOR

PRELIMINARY RESULTS OF PARTICLE IMAGE VELOCIMETRY MEASUREMENT (PIV), [2]

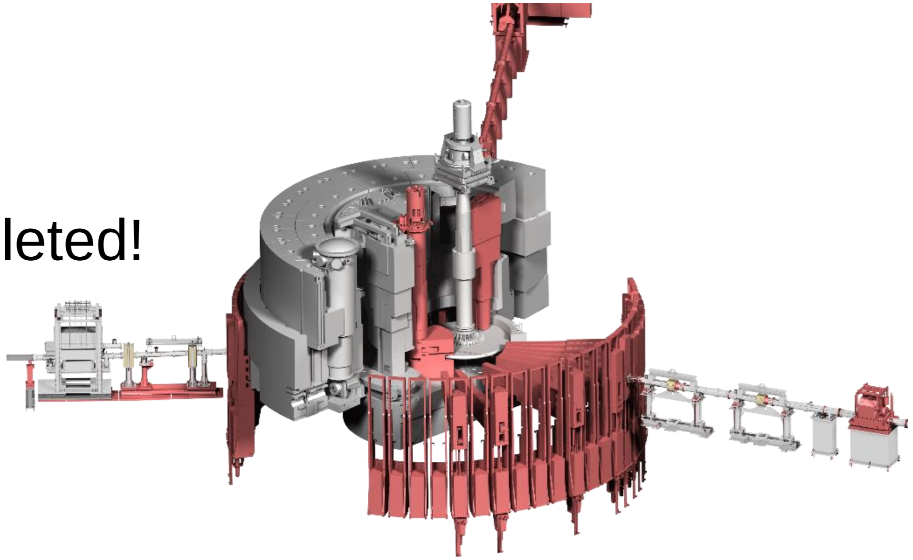


BF1 MODERATOR

MAX “THEORETICAL” BEAM POWER (PRELIMINARY RESULTS), [2]



OUTLOOK



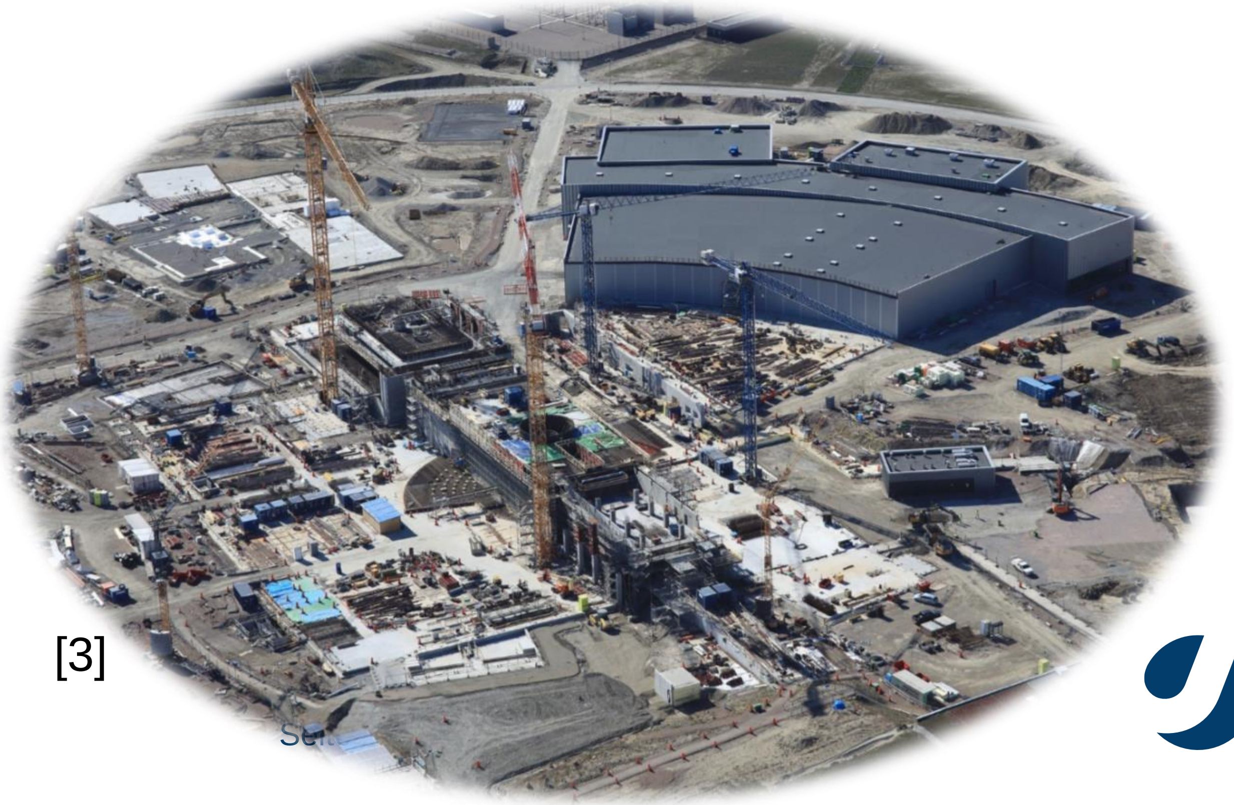
- Design and CFX simulation of BF1 Moderator are completed!
- Comparison with PIV measurement is still in progress
  - Max Proton beam power will be around ≈4MW (based on current requirements)
  - For 5 MW local boiling can occur (possible cavitation needs to be analyzed)
- Prototyping will be completed in January
- PhD thesis will also be published in January

SOURCES

[1] Zanini, L., et al. The neutron moderators for the European Spallation Source. Oxford : 22nd meeting of the International Collaboration on Advanced Neutron Sources (ICANS XXII), 2017

[2] Bessler, Yannick. *Strömungsmechanische Simulation und experimentelle Validierung des kryogenen Wasserstoff Moderators für die Europäische Spallationsneutronenquelle ESS*.
Unpublished PhD, RWTH Aachen.

[3] europeanspallationsource.se



[3]