CERN TE Technology Department

iter

Status of activities

Agreement No. 16 ITER Current Leads

T. Spina, A. Ballarino

January - June 2016

OUTLINE:

- ❑ MAIN TASKS ACHIEVED DURING 6 MONTHS (JANUARY 2016 – JUNE 2016)
- ❑ OTHER ACTIVITIES
- ❑ PLAN FOR THE FUTURE
- ❑ DOCUMENTATION

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- **TASK 1: Completion of the data analysis of measurements of 68 kA HTS leads performed in Hefei in July 2015 (run2).**

- **TASK 2: Analysis of results from the measurements of the 68 kA HTS leads performed in Hefei in January 2016 (run3 – re-test).**

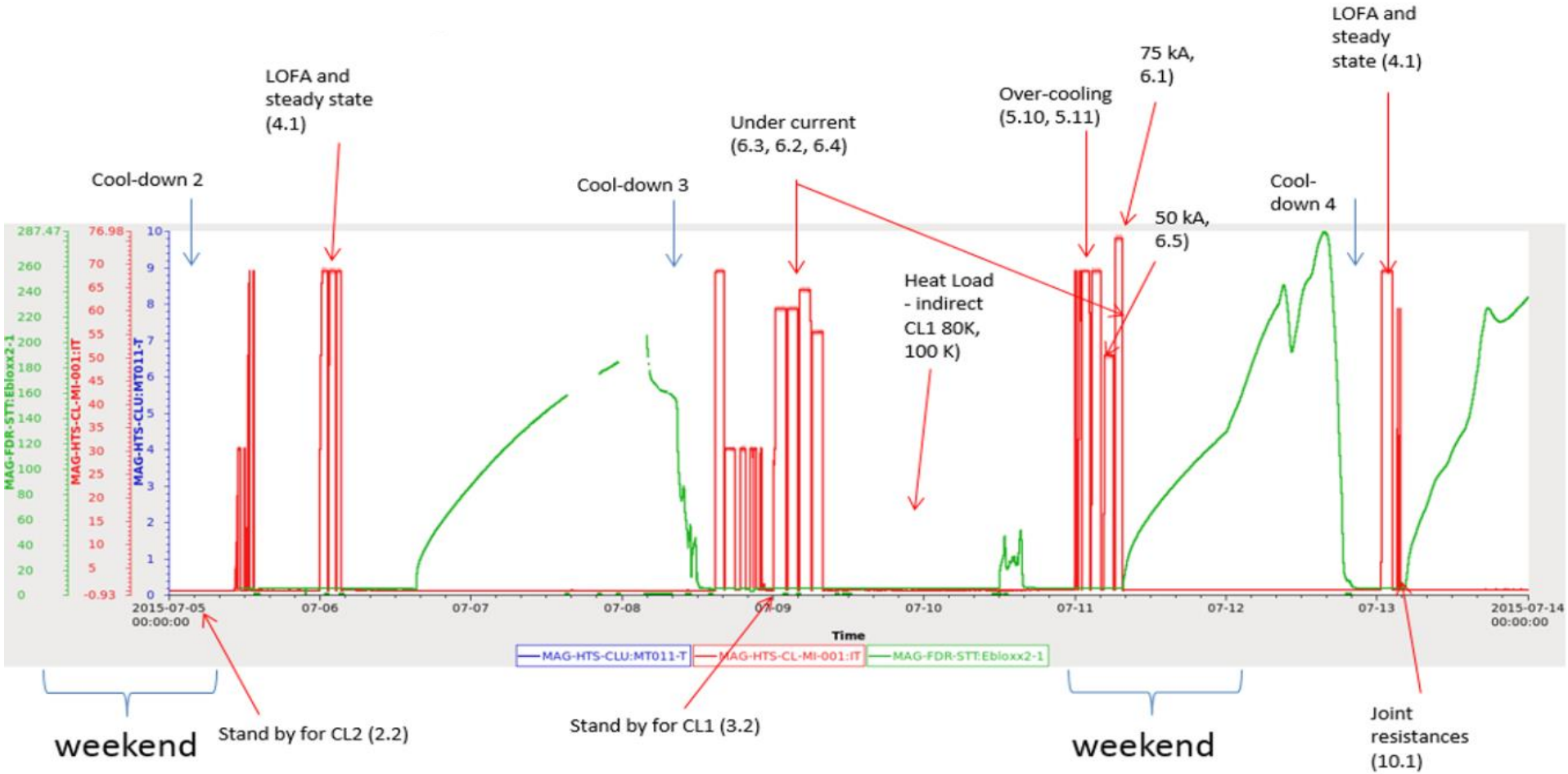
- **TASK 3: New 3D FE thermo-electrical model in transitory regime to simulate LOFA measurements.**

- **TASK 4: Writing up of Internal Notes**

TASK 1

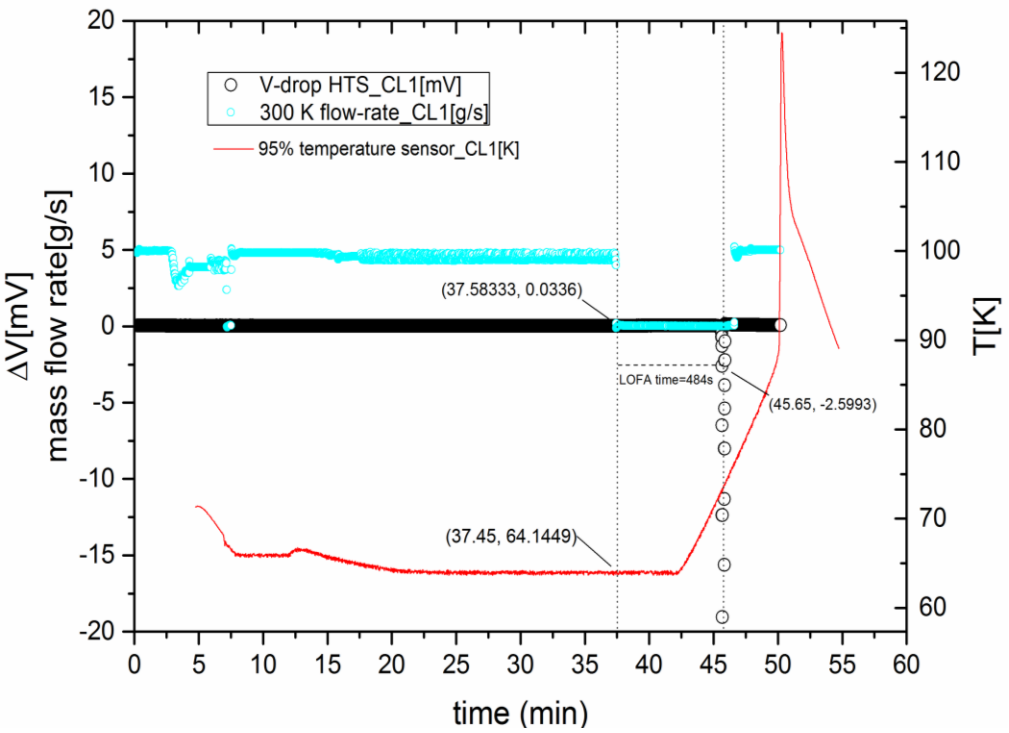
- **Completion of the data analysis of measurements of 68 kA HTS leads performed in Hefei in July 2015 (run2)**. Analysis of steady state and transient regime: DC operation at nominal current, DC operation at currents lower or higher than the nominal, LOFA, sub-cooling and over-cooling of resistive heat exchanger. Comparison between experimental data and 3D FE thermo-hydraulic and electrical model developed during the previous years. Analysis documented in EDMS Nr. 1563784, "Analysis of the measurements performed on TF prototype current leads tested in Hefei in July 2015".

Test summary measurements in Hefei (July 2015, run2)

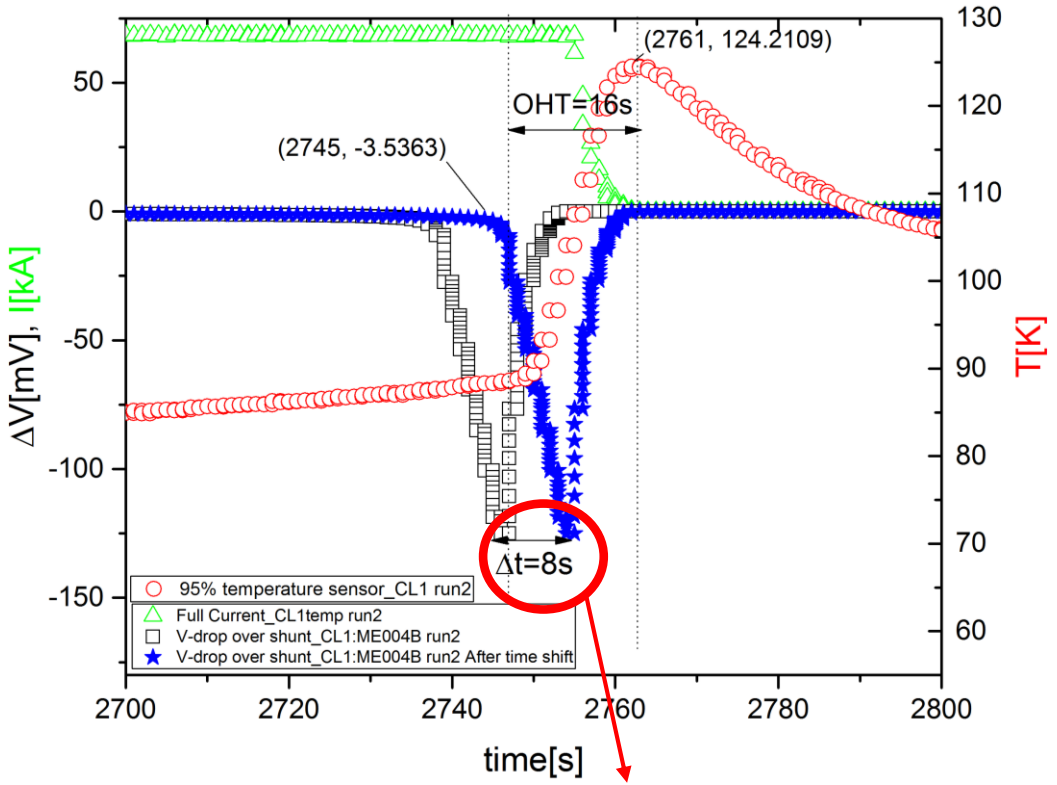


LOFA (Loss Of Flux Accident): Case 4.1

Minimum LOFA time= time interval from the time when the mass flow goes to zero to the end when the voltage across the HTS reaches ~ 3mV.



Minimum OHT time= time interval from start of quench detection at ~3mV to the time the hot spot has reached 200K. N.B. In these measurements the hot spot temperature (MT007) is always <200K!



N.B. time shift of 8s due to the two acquisition systems: QDS for V and CODAC for T and I

√

Parameter	ITER Requirement	CL1	CL2
		EXPERIMENTAL RESULTS	
Minimum LOFA time (s)	400	484	447

√

Parameter	ITER Requirement	CL1	CL2
		EXPERIMENTAL RESULTS	
Minimum overheating time (s)*	15	16	10

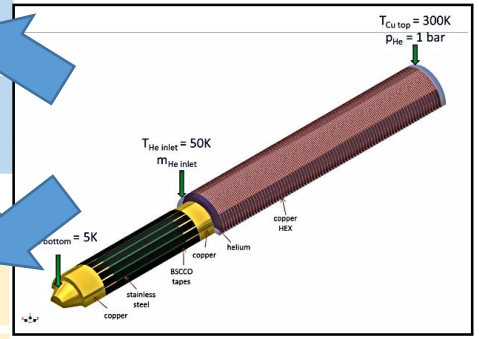
STEADY STATE (Case 4.1)

√

	IO Specification	CL1 (CERN) Experimental	CL2 (CERN) Experimental	3D model
Mass flow rate in HEX (g/s)	<4.8	4.65	4.65	4.5

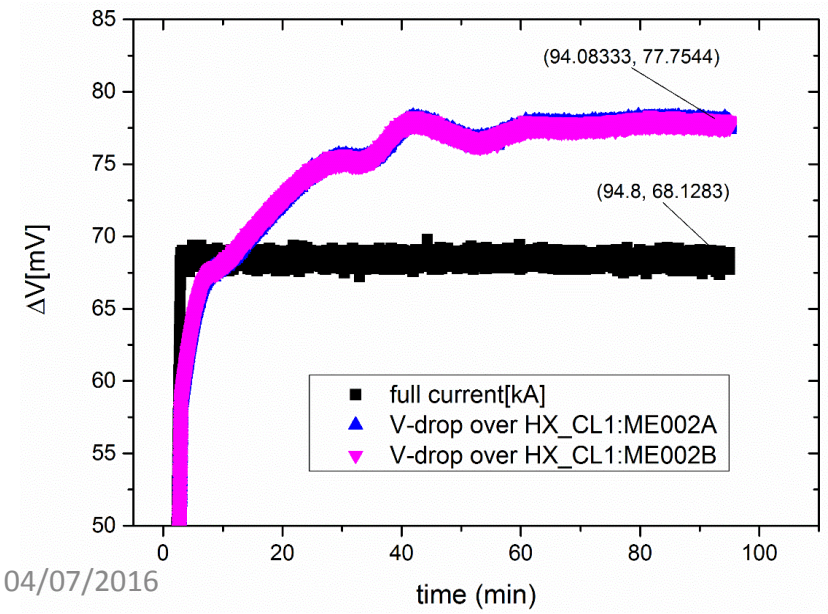
√

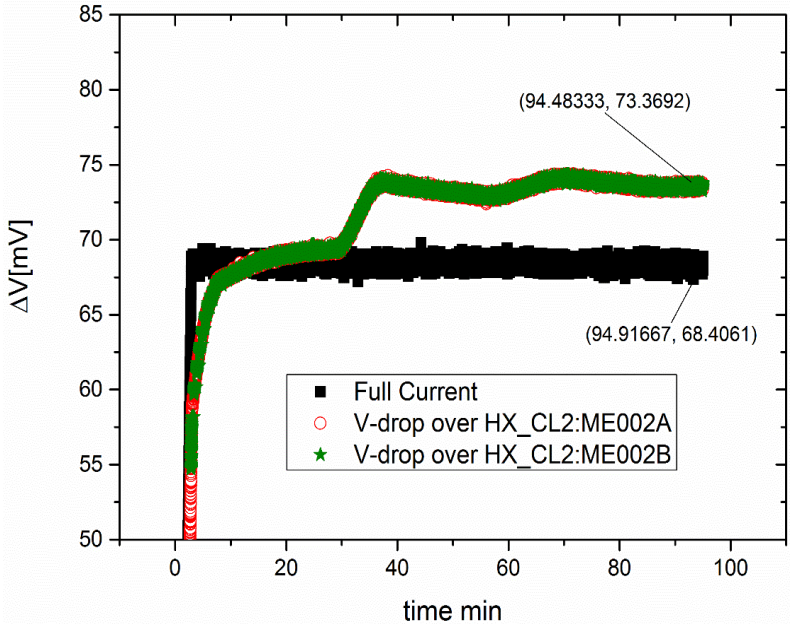
	IO Specification	CL1 (CERN) Experimental	CL2 (CERN) Experimental	3D model
Max pressure drop in 50K circuit in HEX [MPa]	<0.2	0.11	0.12	0.12



Comparison with 3D FE thermo-hydraulic and electrical model developed during the previous years!

Ref. "Thermo-hydraulic and electrical model of the 68kA HTS ITER current lead", M. Sitko, A. Ballarino, B. Bordini, EDMS Nr. 1396106, June 2014.

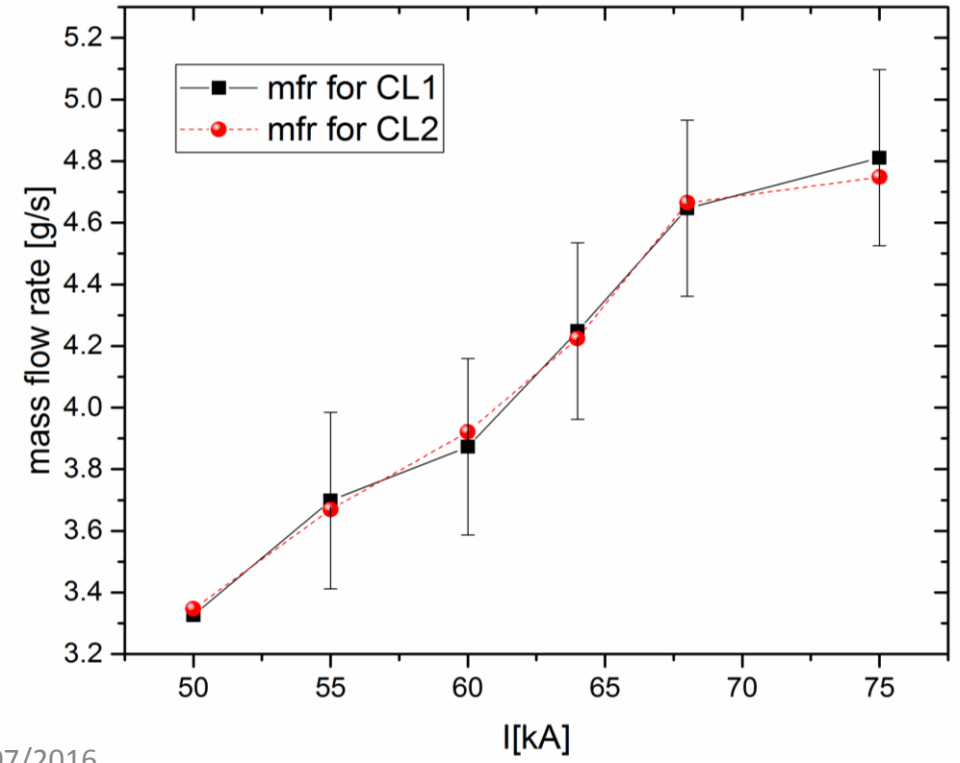


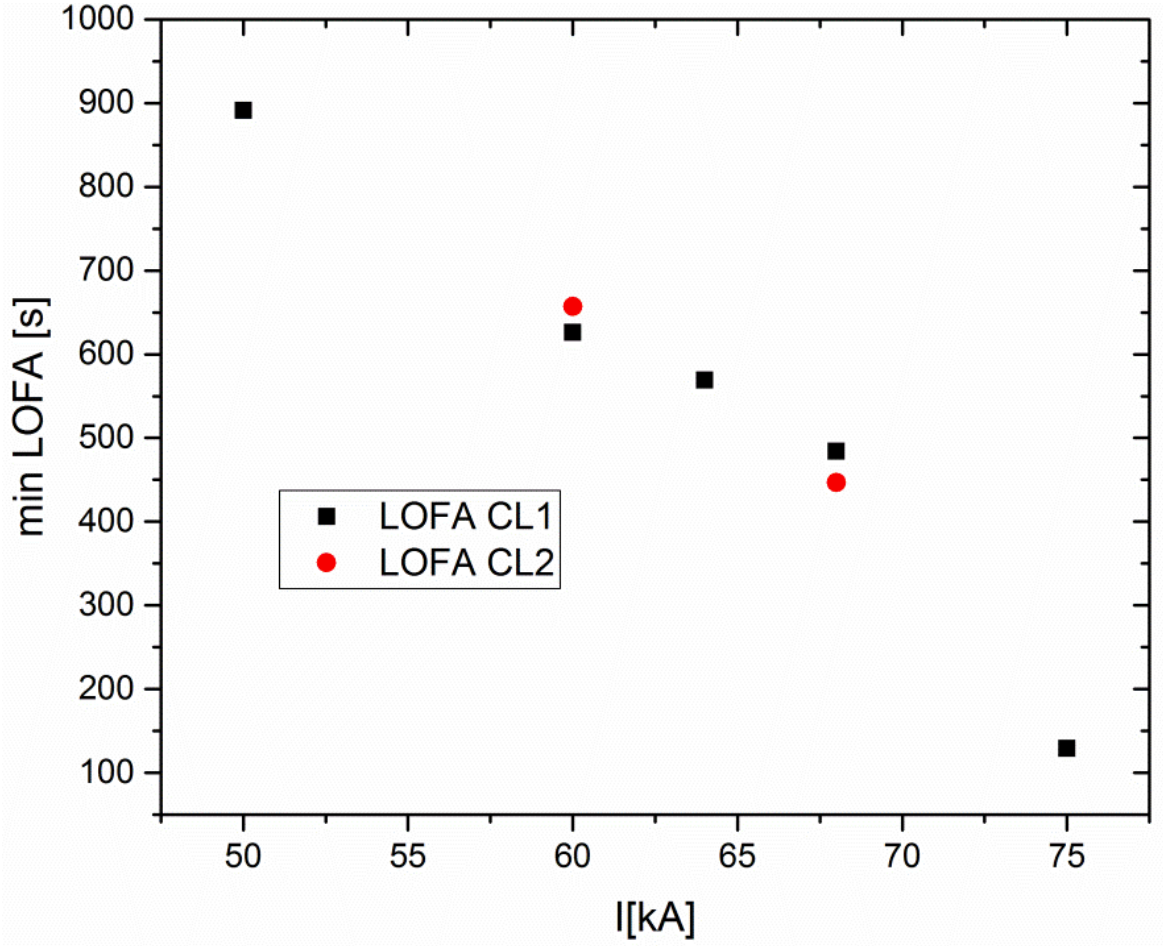


See later on for the comparison with the 3D FE model in stationary regime.

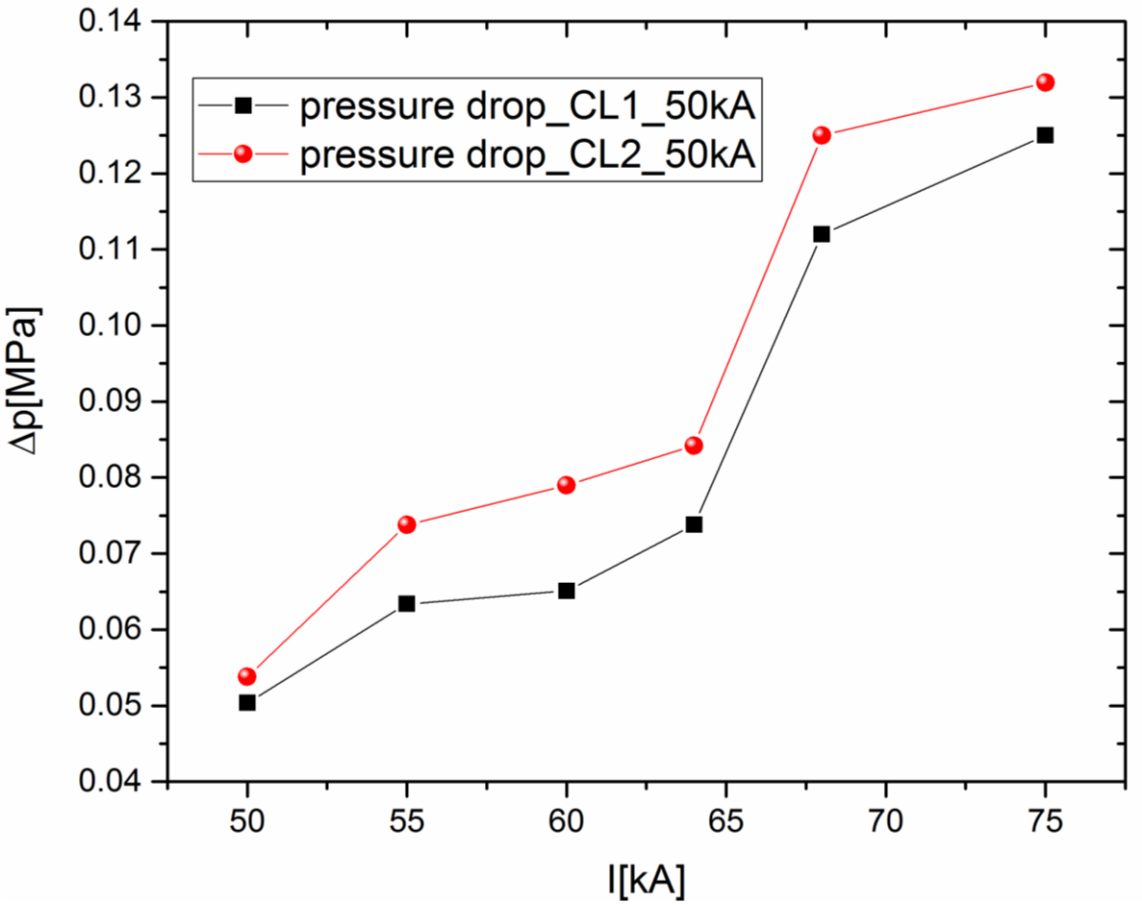
UNDER/OVER CURRENT: mass flow rate and minimum LOFA time

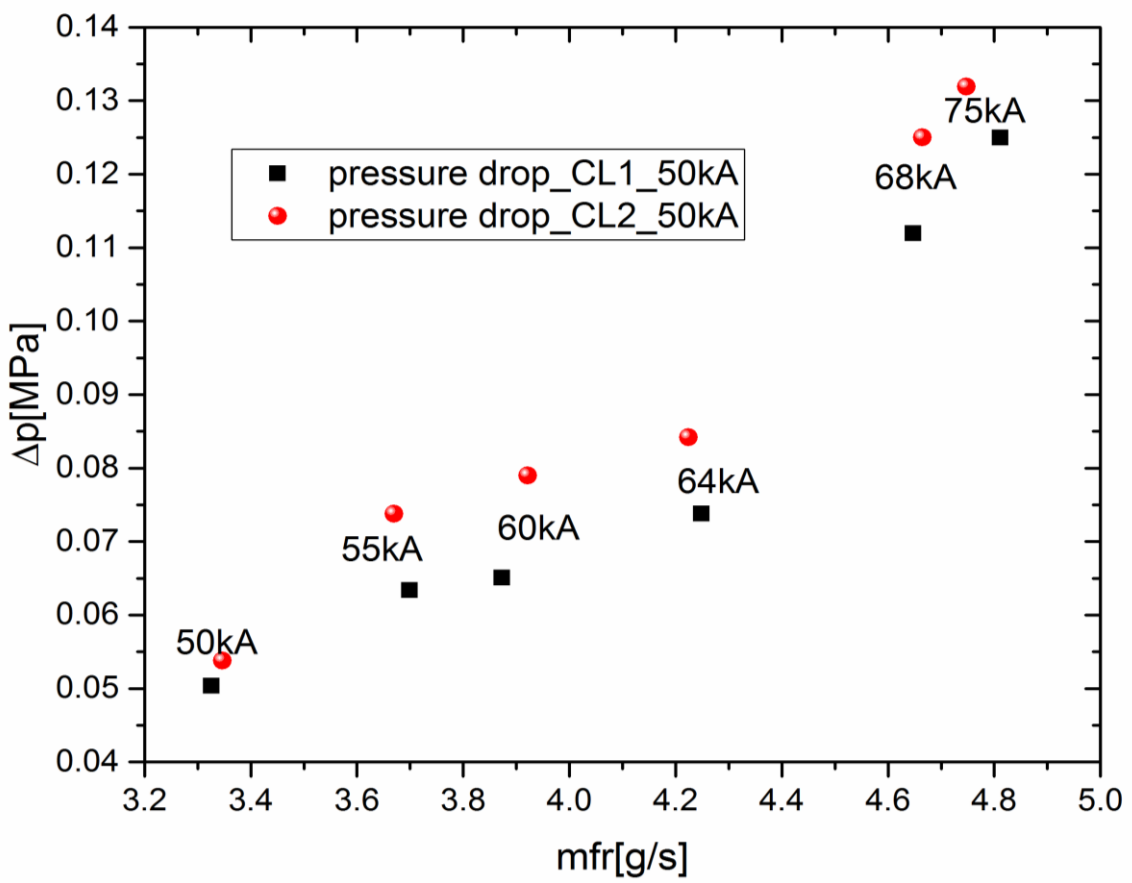
CASE	CURRENT [kA]	DATE	
6.1	75	11.07.2015	Over current
6.2	64	09.07.2015	Under current
6.3	60	09.07.2015	Under current
6.4	55	09.07.2015	Under current
6.5	50	11.07.2015	Under current





UNDER/OVER CURRENT: pressure drops in 50K GHe circuit in HEX



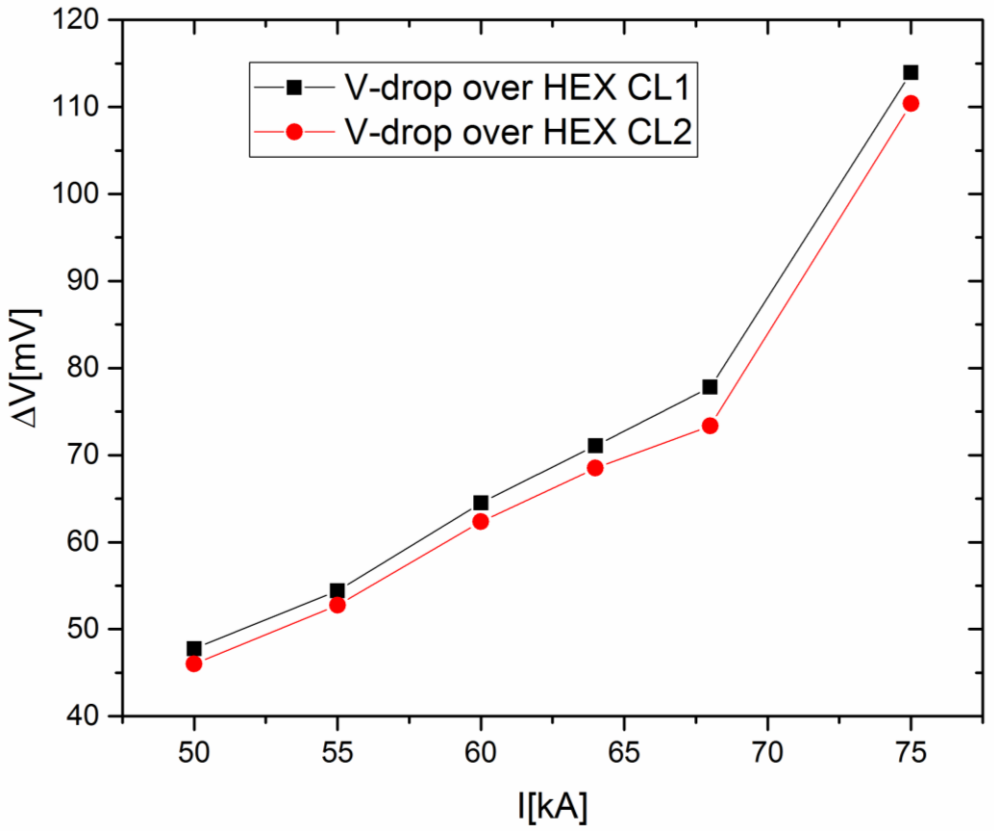


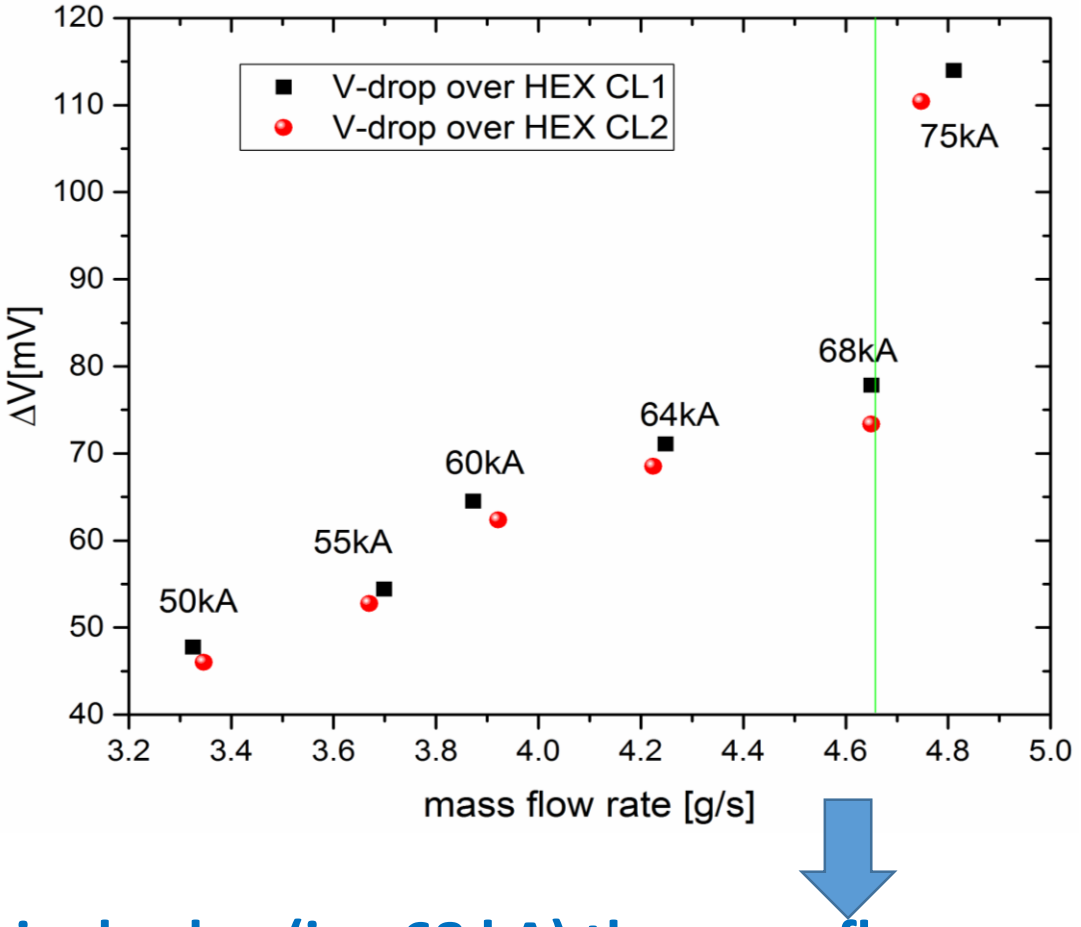
√ As expected, the pressure drop is higher for higher currents, i.e. higher flows!

UNDER/OVER CURRENT: voltage drops over HEX

N.B. The values of the voltage drops and of the mass flow rates are taken at the same time for each case

See later on for the comparison with the 3D FE model in stationary regime.





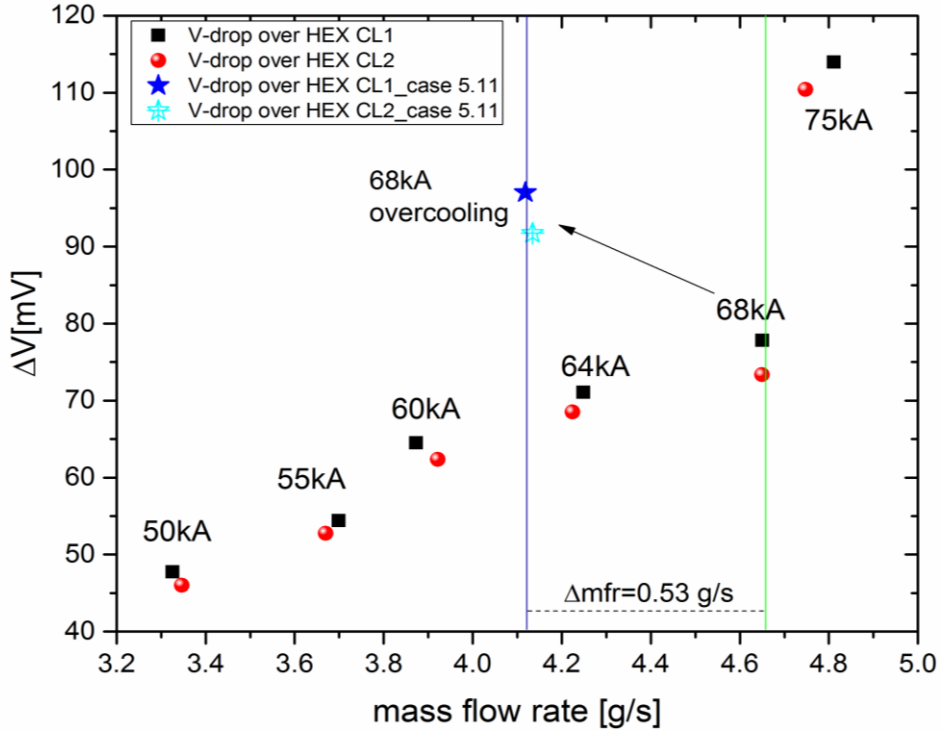
√ **As expected, for currents below the nominal value (i.e. 68 kA) the mass flow rate is lower than 4.65 g\s.**

STAND BY (Cases 2.2-3.2)

The pressure drops in HEX in stand by mode are about **two times lower** than for the steady state; also the mass flow rate is lower than the nominal value, i.e. **1.22 instead than 4.65 g/s**. Some instabilities during the CL1 measurements have been found.

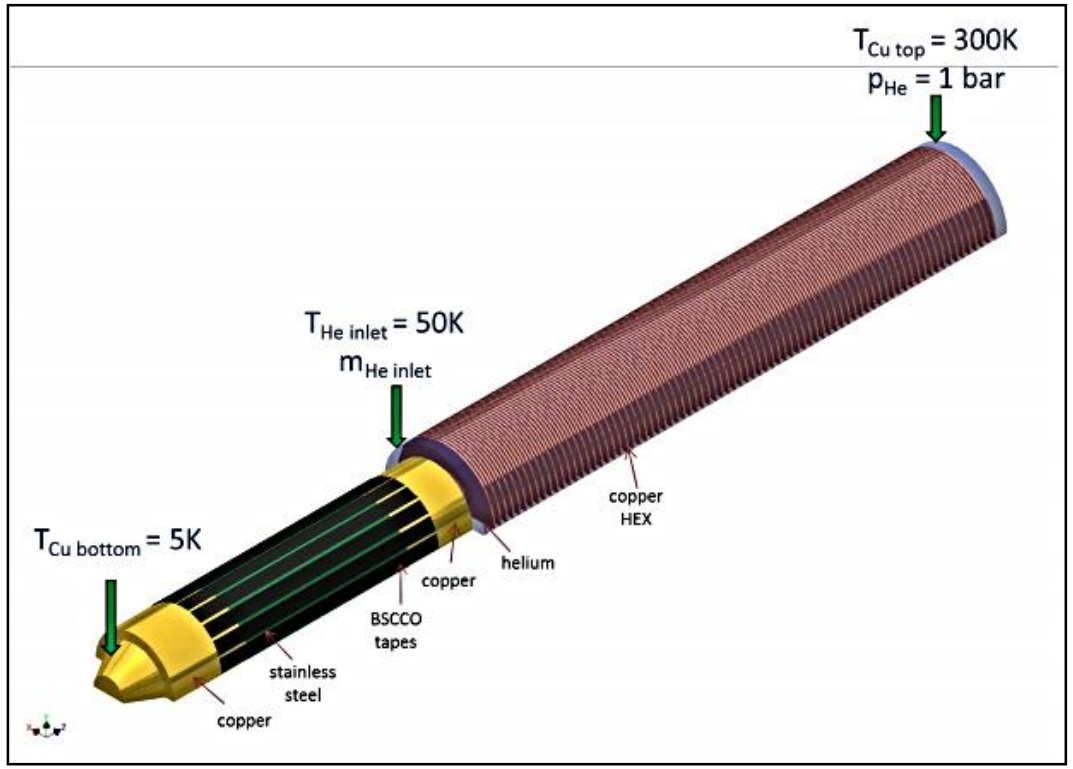
OVER COOLING (Cases 5.10-5.11)

The voltage drop over HEX for case 5.11 (45 K HEX inlet temperaure) are higher at lower mass flow rate than in the steady state regime (50 K HEX inlet temperature).

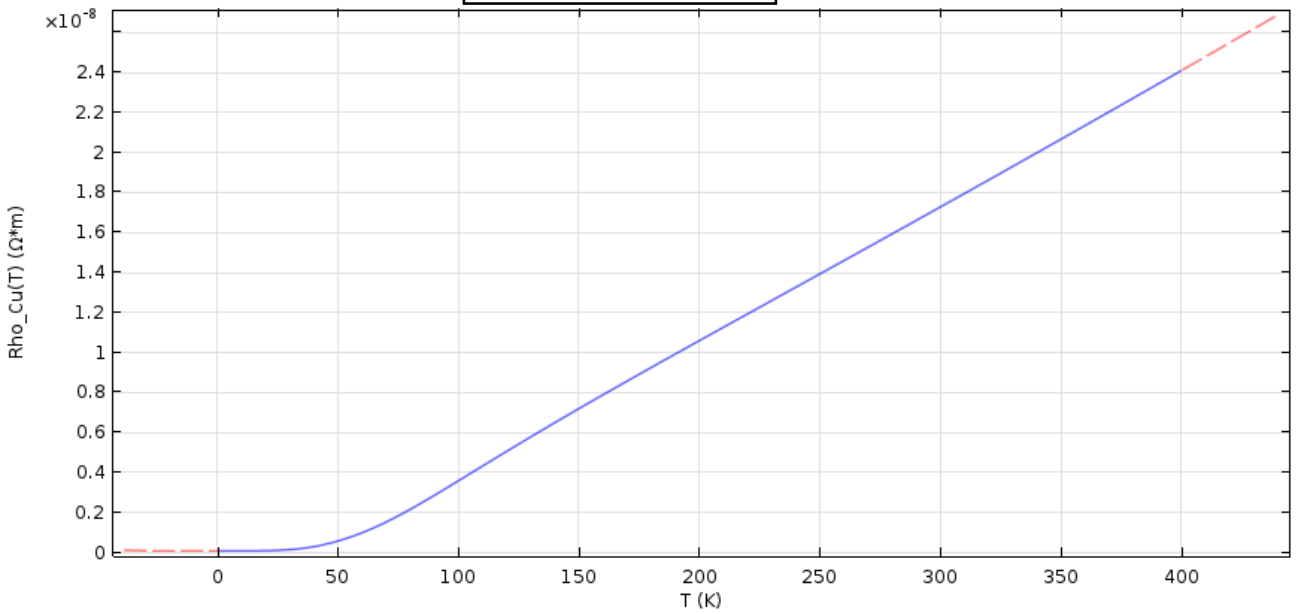


3D FE thermo-hydraulic model in stationary regime

Initial values, boundary conditions and materials



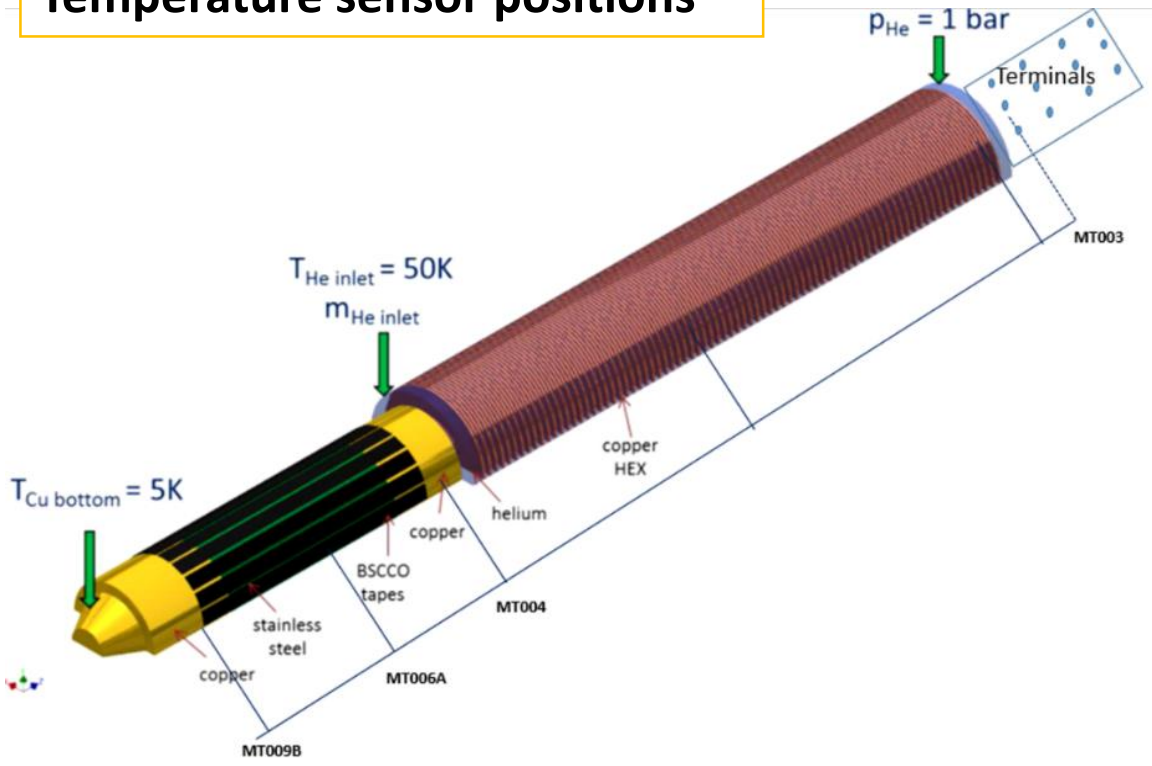
Cu resistivity:



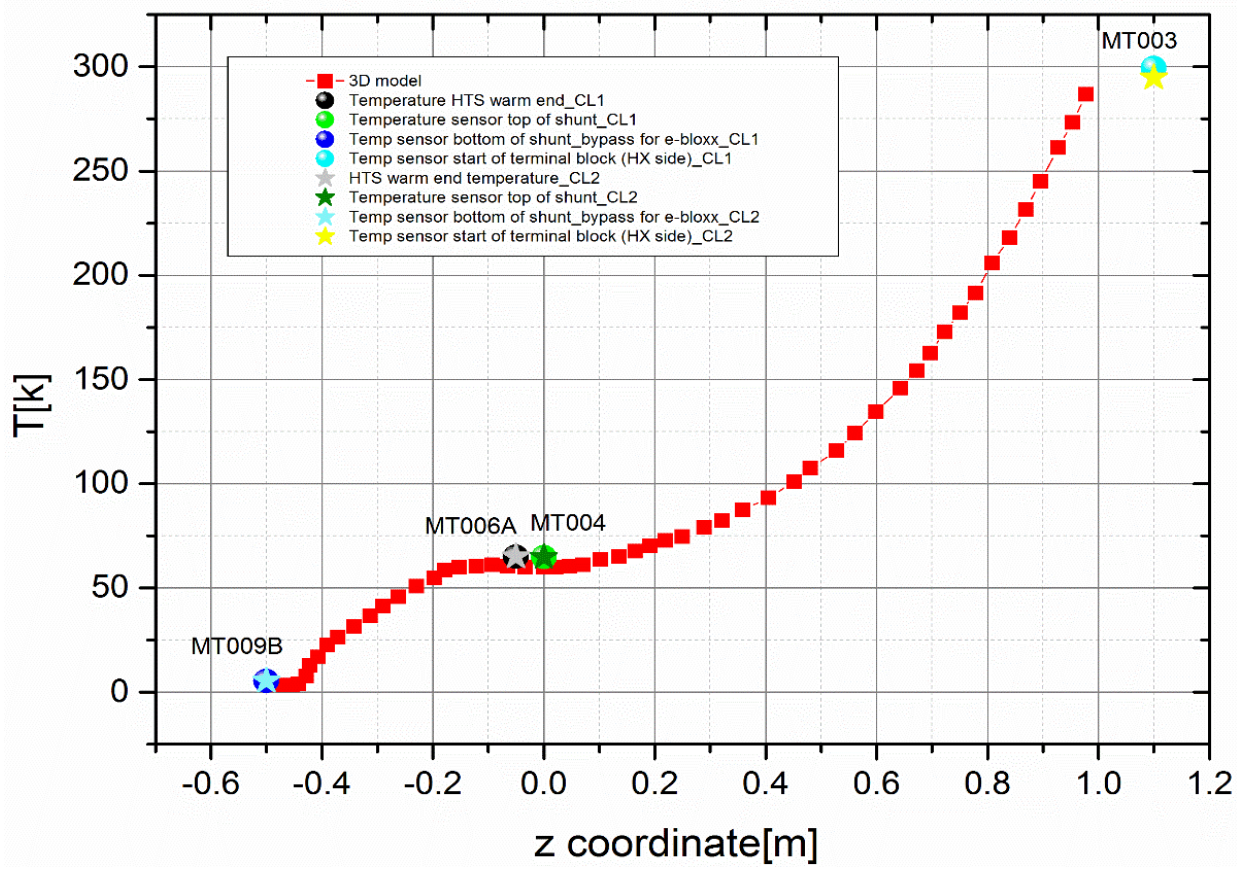
Ref. Internal note "Thermo-hydraulic and electrical model of the 68kA HTS ITER current lead", M. Sitko, A. Ballarino, B. Bordini, EDMS Nr. 1396106, June 2014.

TEMPERATURE PROFILE IN STEADY STATE CONDITION (68 kA; 4.5 g/s)

Temperature sensor positions



Check of the temperature sensors with the simulated temperature profile. √

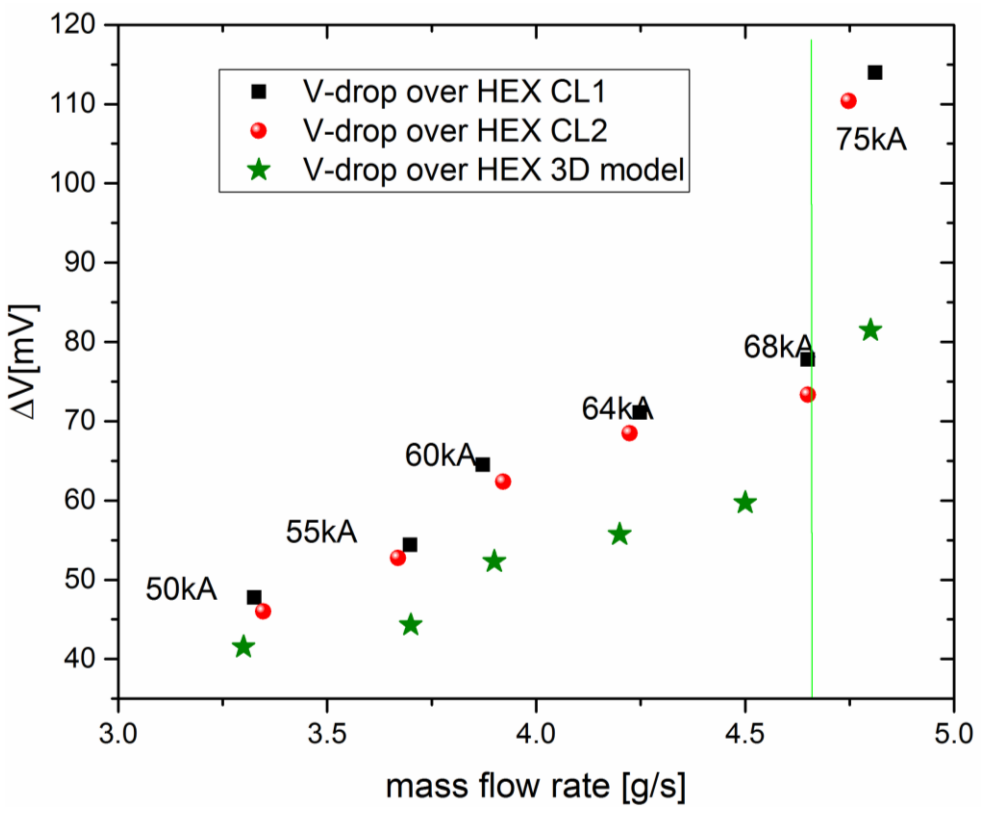


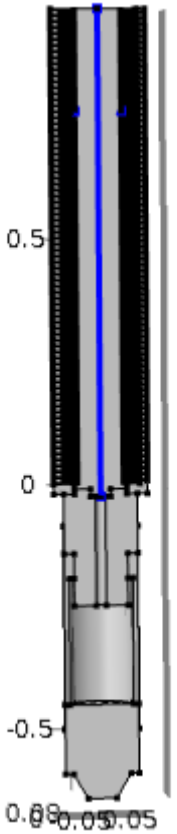
Internal Note "*Analysis of the measurements performed on TF prototype current leads tested in Hefei in July 2015*", T. Spina and A. Ballarino, EDMS Nr. 1563784, May 2016.

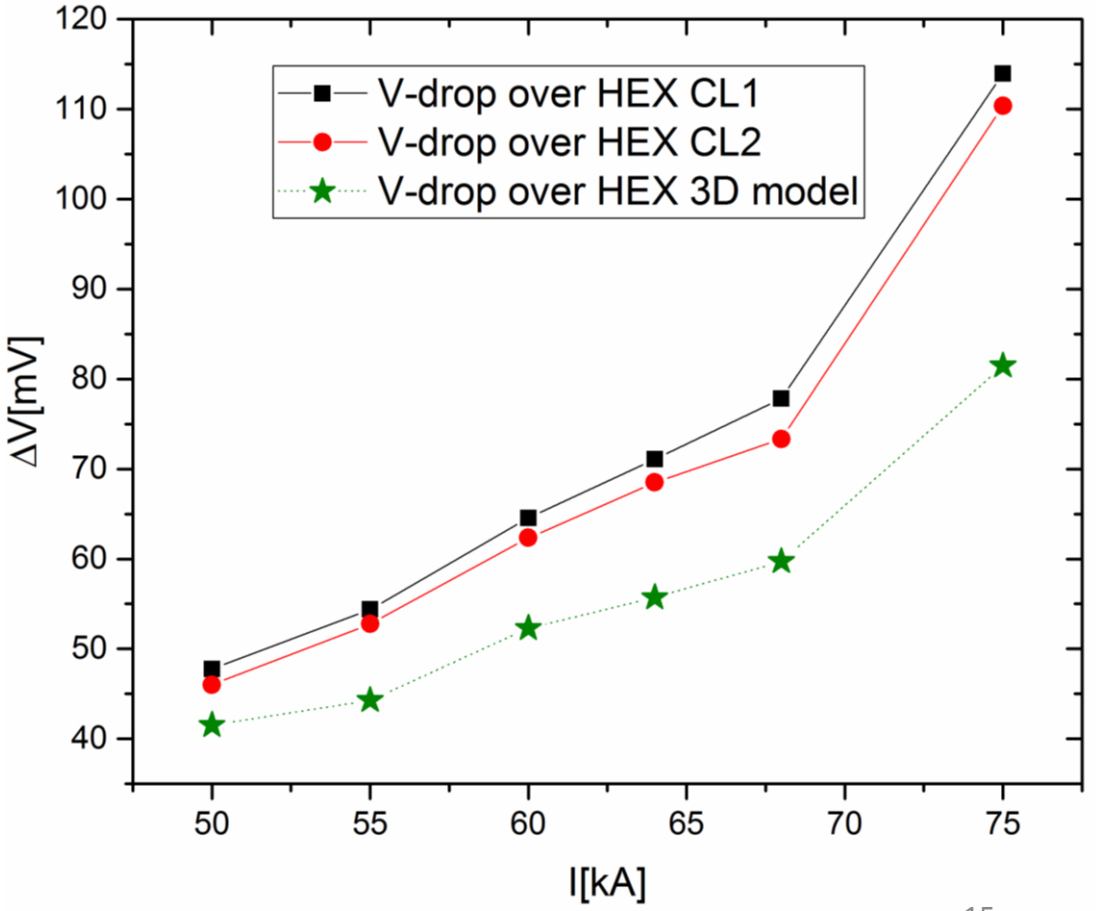
VOLTAGE DROPS IN UNDER/OVER CURRENT CONDITIONS (CASES 6.1, 6.2, 6.3, 6.4, 6.5)

3D FE model in stationary regime - The current and the mass flow rate are fixed to the experimental values while the voltage drops are derived along the axis over the HEX as:

$$\Delta V_{HEX} = \int_0^L \rho(T(z)) * J \, dz$$





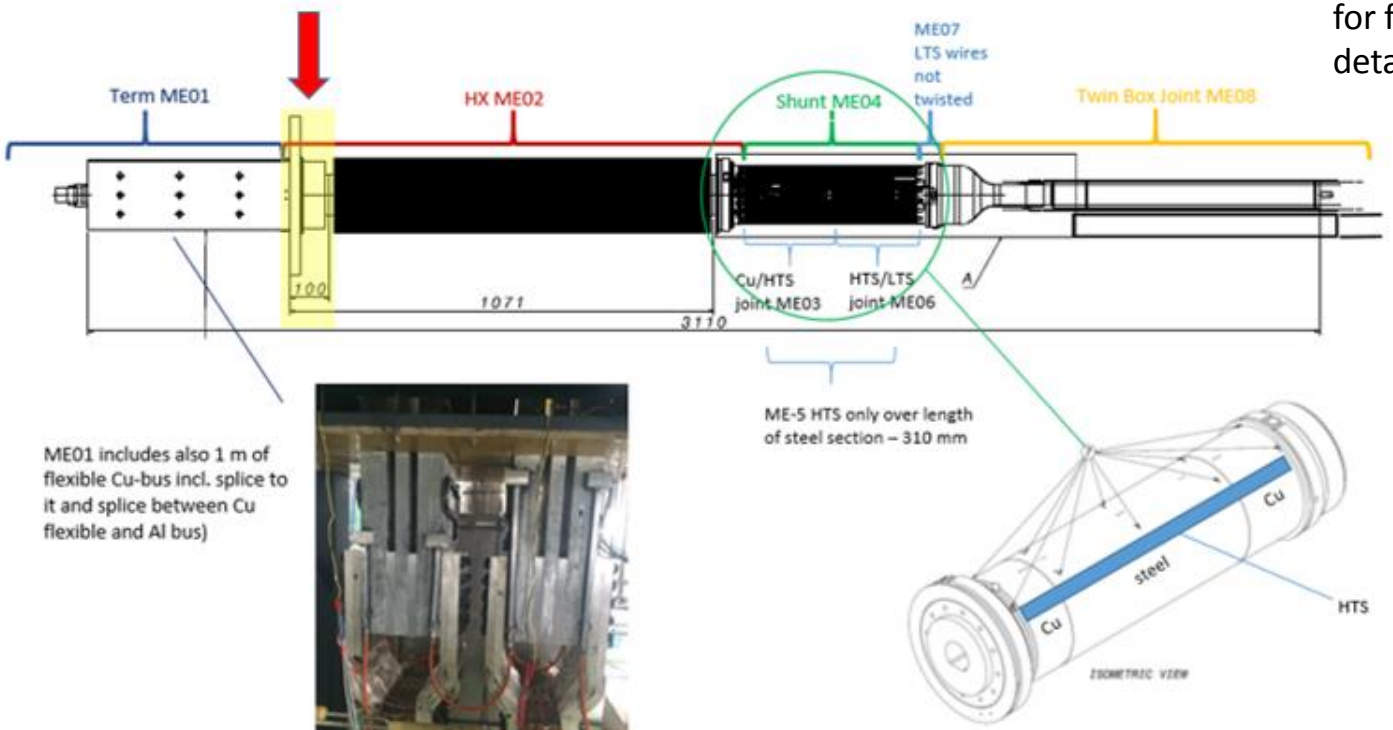


3D FE model including the electrical terminal

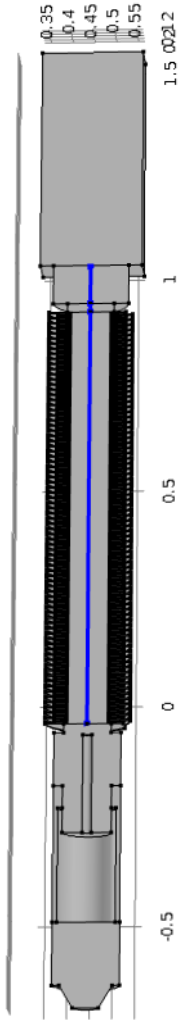
The discrepancy between experimental (ME02 voltage tap) and simulated value (about 20%) is due to the fact that in the "old" 3D model the electrical terminal is not take into account.

New 3D model!

See later on for further details!



Voltage taps position (Courtesy of P. Bauer)



The Voltage drop over the bottom part of the terminal for 68kA is: **18.871mV**

$\Delta V_{HEX\ simulated}$ = (59.717 + 18.871)mV
= 78.588 mV

$\Delta V_{HEX\ exp.\ CL1}$ = 77.811 mV

$\Delta V_{HEX\ simulated} = \Delta V_{HEX\ exp.} \pm 1\%$

√ **Perfect agreement between experimental and simulated results!**

JOINT RESISTANCES (Cases 10.1)

Parameter [nΩ]	ITER requirement	CL1		CL2	
		ASIPP	CERN	ASIPP	CERN
$R_{65K\ Cu\text{-}HTS}$ **ME003**	10	5.14	5.02 before 5.03 after	5.25	5.11before 5.12 after
$R_{HTS\text{-}LTS}$ **ME006**	1	0.14	0.13	0.44	0.3754
$R_{TWIN\ BOX\ (LTS\text{-}LTS)}$ **ME008**	2	0.37	0.44	0.26	0.414
$R_{FLEXIBLE\text{-}Cu\ TERMINAL}$ **ME001**	100	170	1217.75 before 1220.49 after	170	1155.47

- Good agreement for the resistances $R_{65K\ Cu\text{-}HTS}$ (ME003), $R_{HTS\text{-}LTS}$ (ME006) and $R_{TWIN\ BOX\ (LTS\text{-}LTS)}$ (ME008); √
- Some issues have been found for the terminal to flexible contact resistance (ME001). X

We are adding the dissipation due to contact resistance in the electrical terminal in the 3D model: see later on "Plan for future activities"

TASK 2

- **Analysis of results from the measurements of the 68 kA HTS leads performed in Hefei in January 2016 (run3 – re-test).** Analysis of the results during the LOFA test: temperature profile and voltage drops over the heat exchanger. Comparison with the results obtained in run2.

Temperature sensors during LOFA tests

See later on for the comparison with the new 3D FE model in transitory regime.

X

run	MT04 for CL1	MT04 for CL2
2	99.25 K	96.45 K
3	101.45 K	99.15 K

X

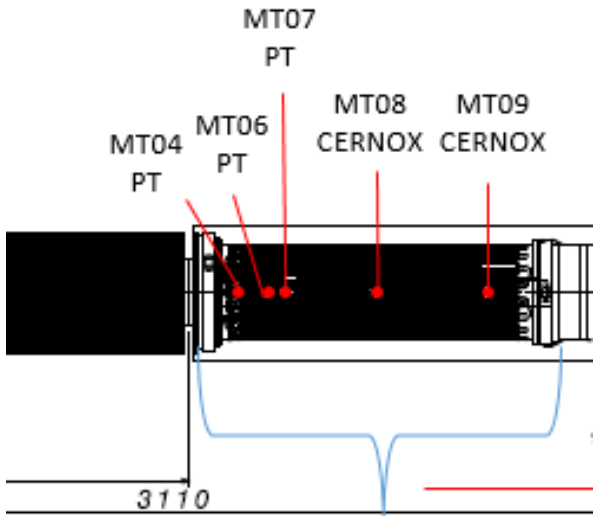
run	MT06 for CL1	MT06 for CL2
2	99.05 K	95.35 K
3	100.95 K	98.35 K

√

run	MT09 for CL1	MT09 for CL2
2	18.5 K	10.7-12 K
3	6.4 K	6.2 K

X

run	MT07 for CL1	MT07 for CL2
2	86.8K quench 124.5K max	89.4K quench 104.3K max
3	73.7K quench 111.9K max	68.8K quench 90.54K max



Weekly meeting of 23.03.2016 for further details

Temperature sensors during LOFA tests

√

run	MT02 for CL1	MT02 for CL2
2	298-304 K	302-304 K
3	276-286 K	275-283 K

√

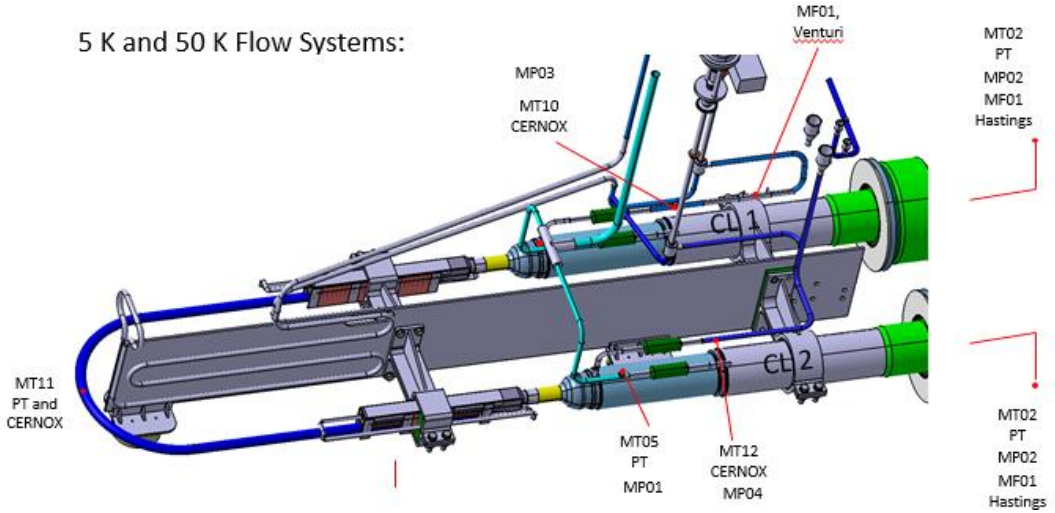
run	MT05 for CL1	MT05 for CL2
2	48-54 K	50-55 K
3	48-56 K	50-60K

√

run	MT010 for CL1	MT010 for CL2
2	4.8-5.4 K	4.8-5.4 K
3	6.4-6.6 K	6.5 K

√

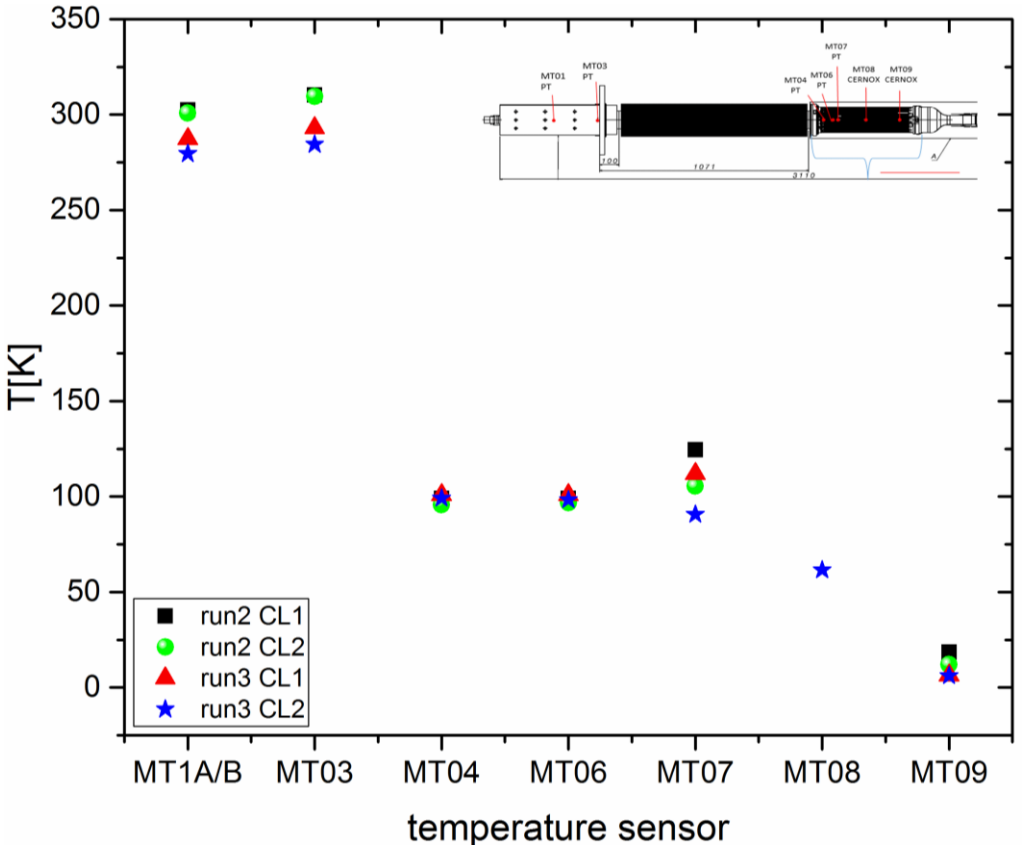
run	MT012 for CL1	MT012 for CL2
2	4.8-5 K	4.7-5 K
3	5.8-6.2 K	6.5-6.8 K



Weekly meeting of 23.03.2016 for further details

Summary of Temperature sensors during LOFA tests: run2 vs. run3

See later on for the comparison with the new 3D FE model in transitory regime.

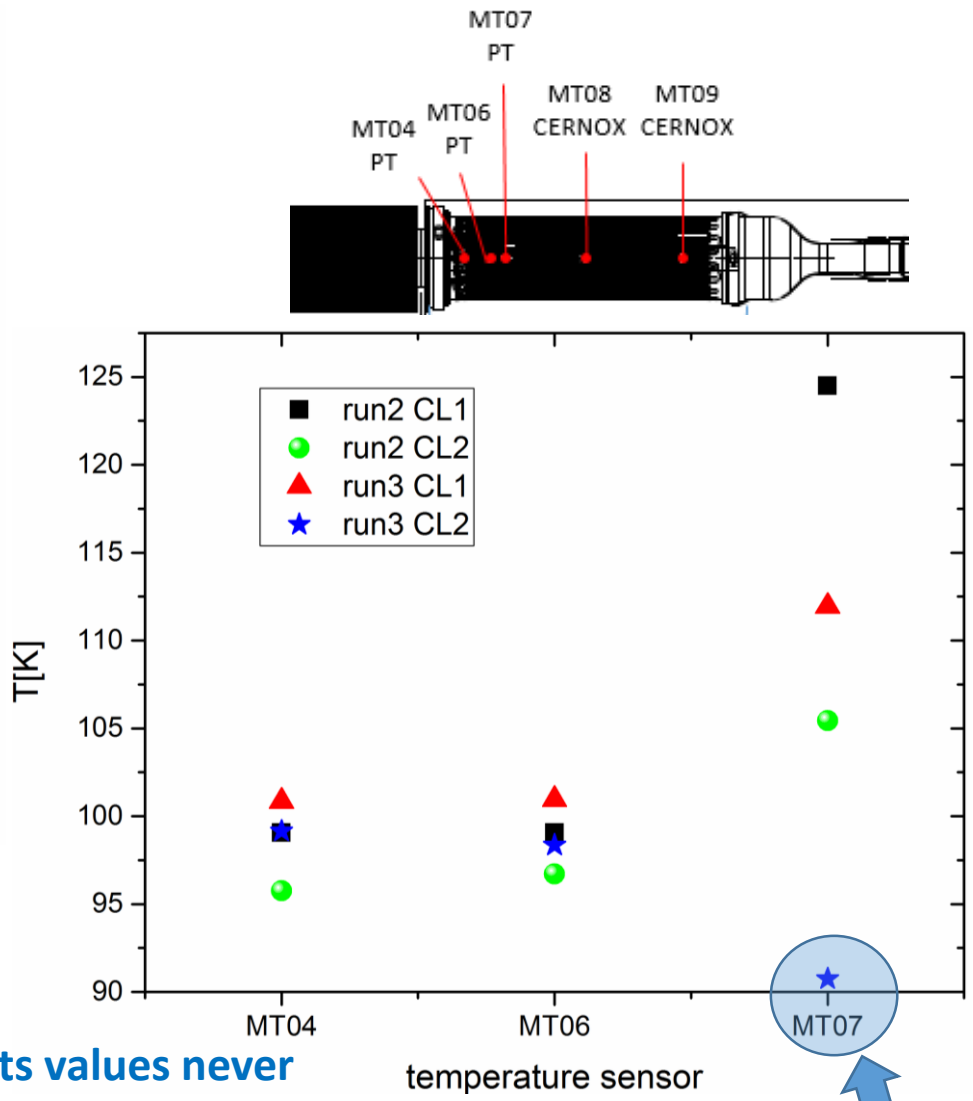


Remember:

The MT07 corresponds to:

➔ run2: 95%

➔ run3: 80%



This value is too low!

Conclusion:

the sensor MT07 is the closest sensor to the quench point although its values never reached the expected one (200K).

The highest temperature value detected by MT07 sensor is 124.5K for run2 in CL1.

Summary LOFA

Minimum LOFA time= time interval from the time when the mass flow goes to zero to the end when the voltage across the HTS reaches ~ 3mV

run	Min LOFA for CL1 [s]	Min LOFA for CL2 [s]	ITER requirement [s]
2	484	447	400
3	505	468	

√

TASK 3

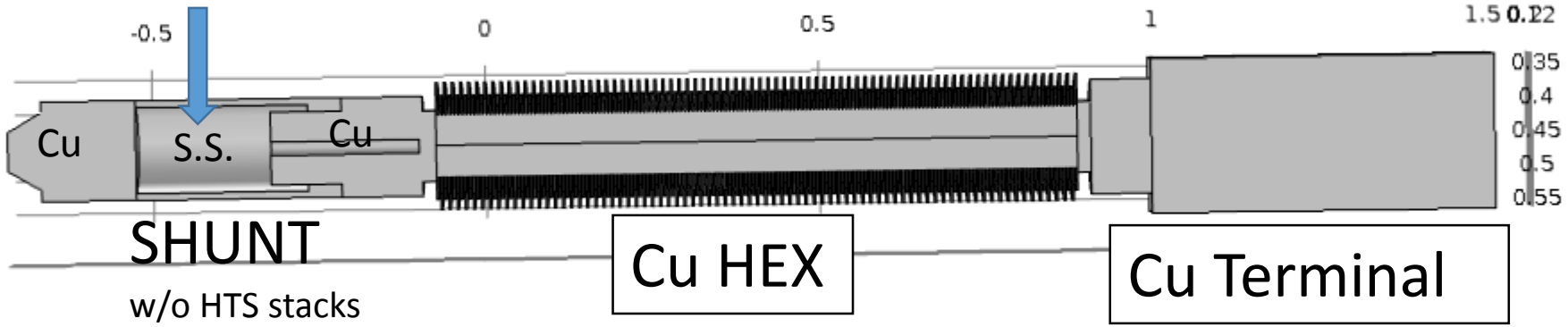
- **New 3D FE thermo-electrical model in transitory regime to simulate LOFA measurements.** The room temperature electrical terminal was added to the previous geometry. 3D solution in steady state was used as initial value for the transient model; this model has been developed to check the discrepancy found in temperature measurements during the two tests performed in Hefei (run2 vs. run3).

3D FE model in transitory regime

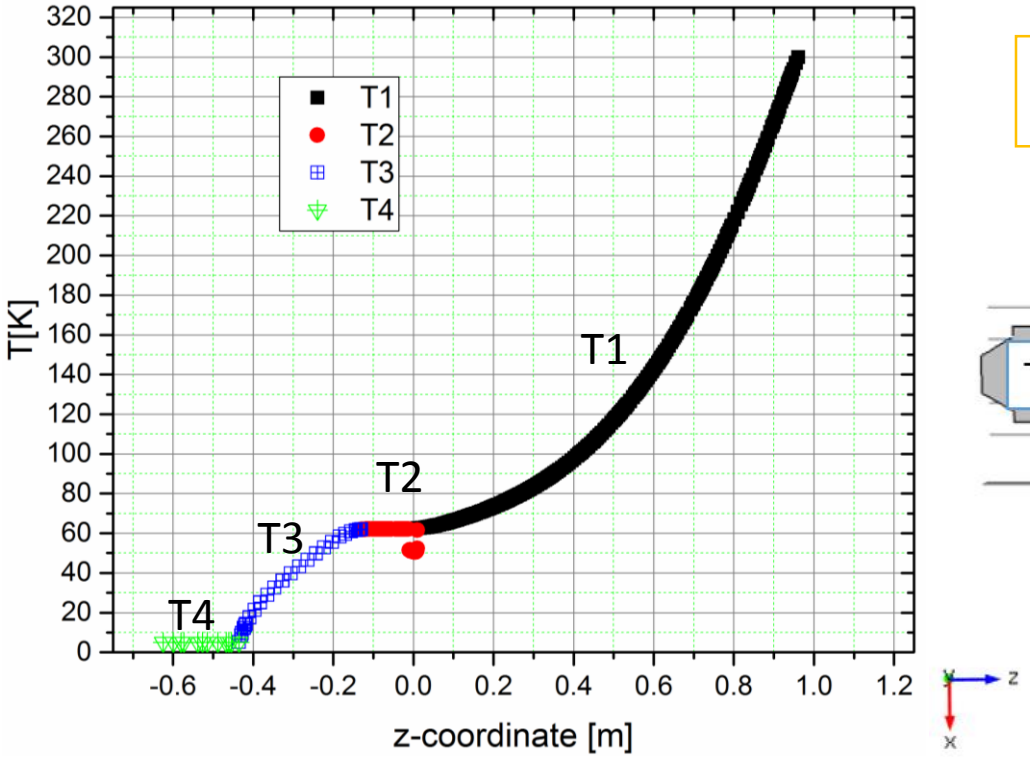
New 3D FE model!

Geometry and materials

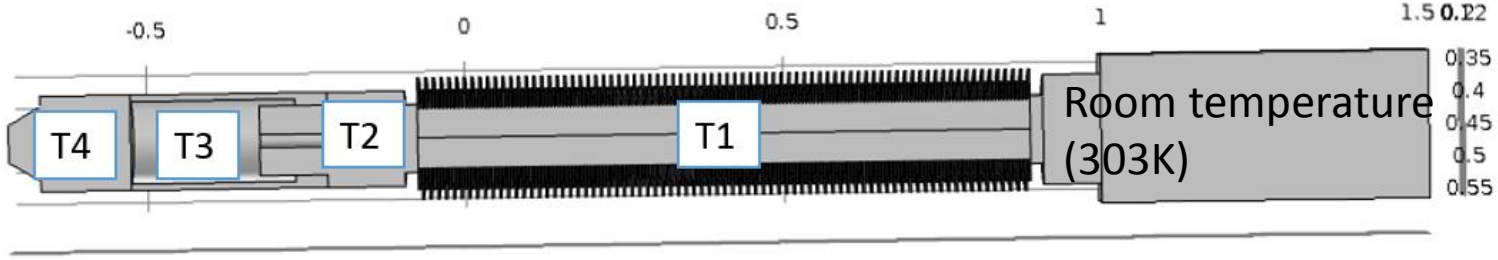
S.S.
UNS S30400, SUS 304



3D FE model in transitory regime



Initial (t=0) temperature profile



Boundary conditions

Temperature bottom of shunt: 5 K
Temperature top HEX: 303 K

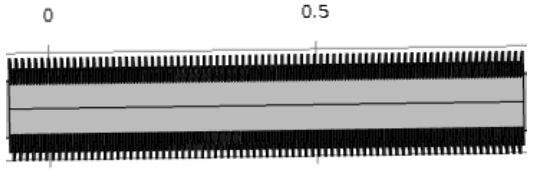
The initial temperature profile has been extracted from the 3D thermo-hydraulic model in steady state condition (68 kA, 4.5g/s).

Ref. "Thermo-hydraulic and electrical model of the 68kA HTS ITER current lead", M. Sitko, A. Ballarino, B. Bordini, EDMS Nr. 1396106, June 2014.

3D FE model in transitory regime

Heat sources

Heat source in HEX



Study 2, Time Dependent

$Q = Q_0$

Sorgente di calore

Sorgente generale

Q_0 Definito dall'utente

Rho_Cu(T)*((x^2+y^2)^0.5<R_Cu)*J^2 W/m^3

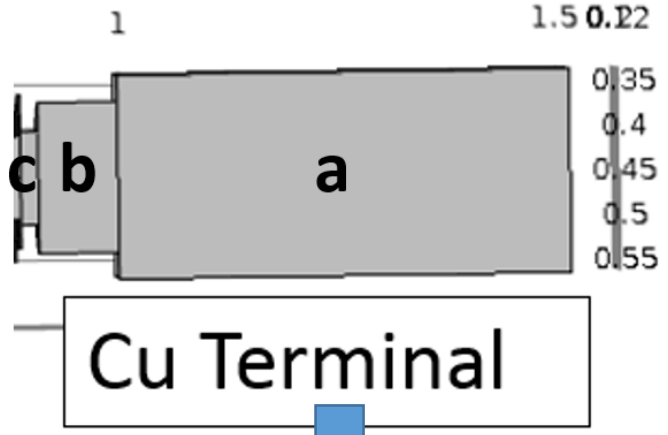
Sorgente lineare

$Q_0 = q_s \cdot T$

Trasferimento di calore complessivo

$Q_0 = \frac{P_0}{V}$

Heat source in the terminal

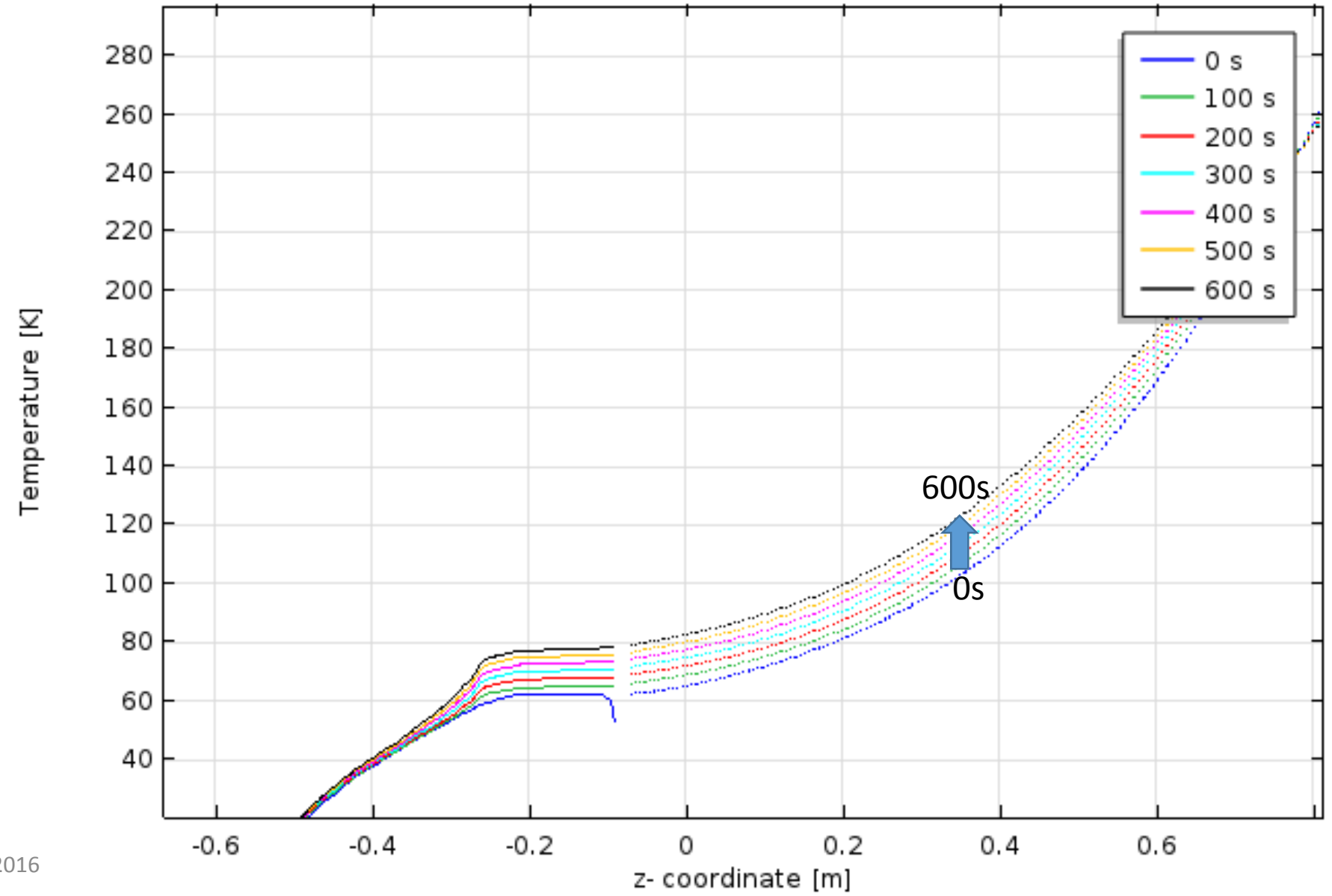


Heat source over terminal a:
Rho_Cu(T)*J_a^2

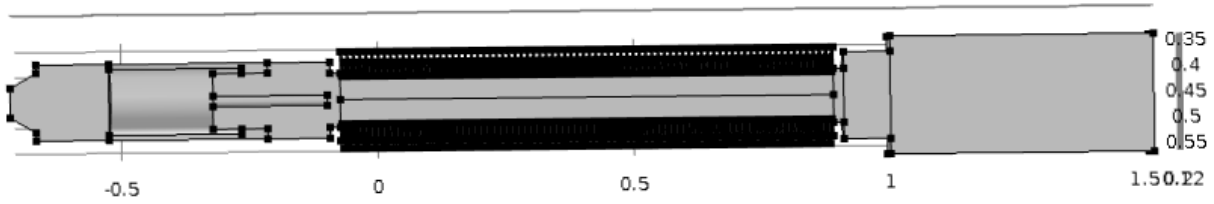
Heat source over terminal b:
Rho_Cu(T)*J_b^2

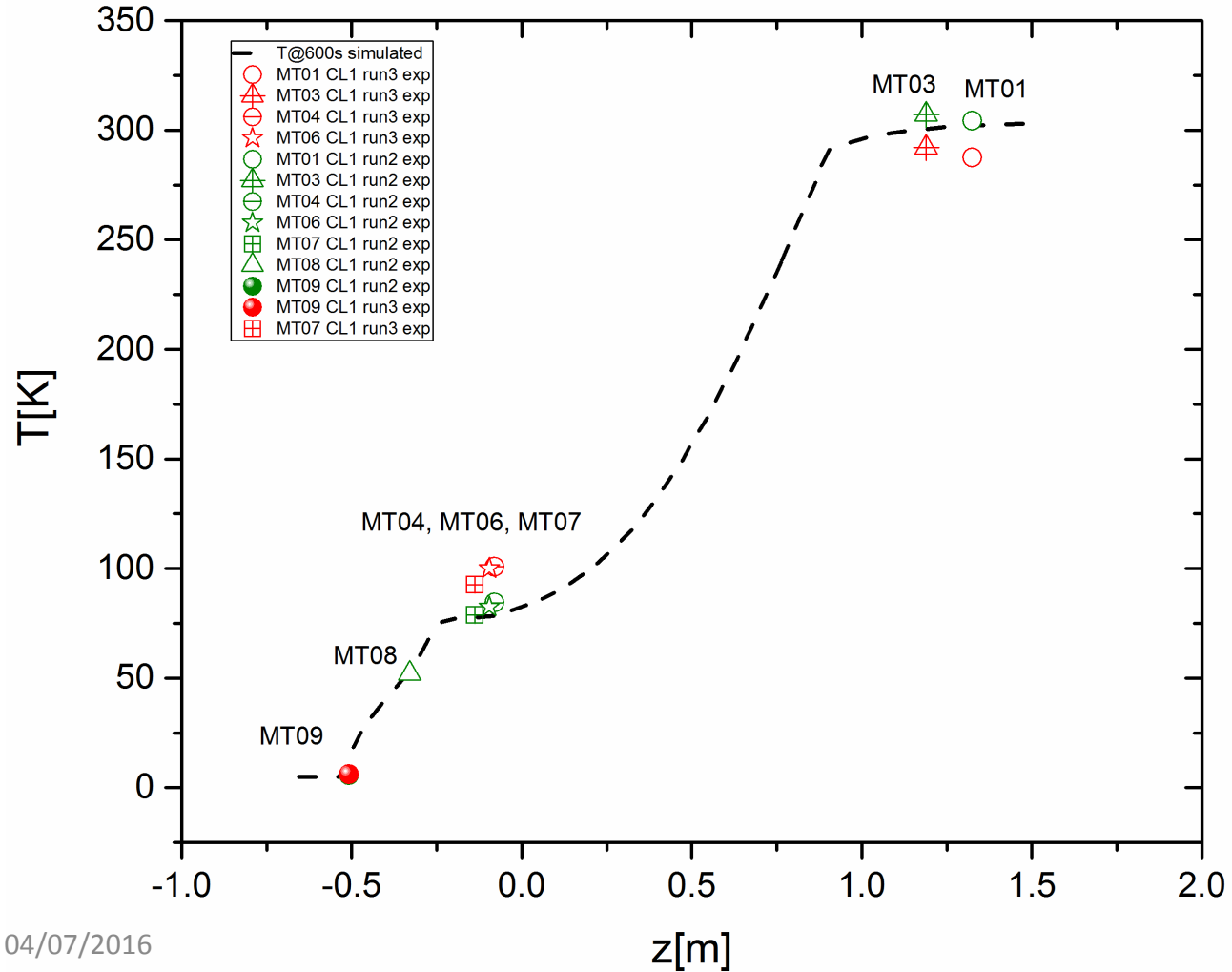
Heat source over terminal c:
Rho_Cu(T)*J_c^2

EVOLUTION OF THE TEMPERATURE PROFILE DURING LOFA

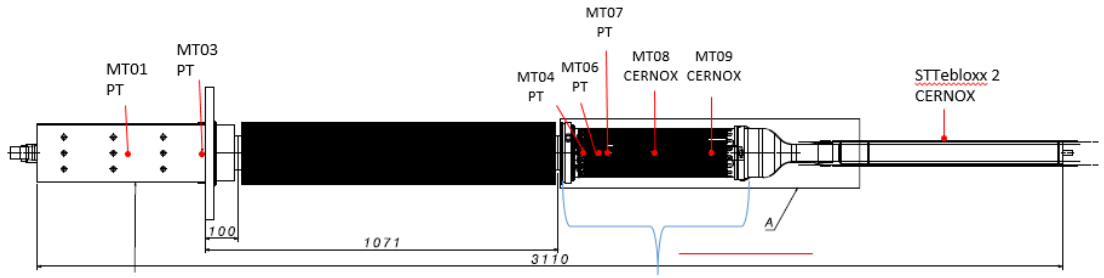


TEMPERATURE SENSOR:EXPERIMENTAL VS. SIMULATED VALUES





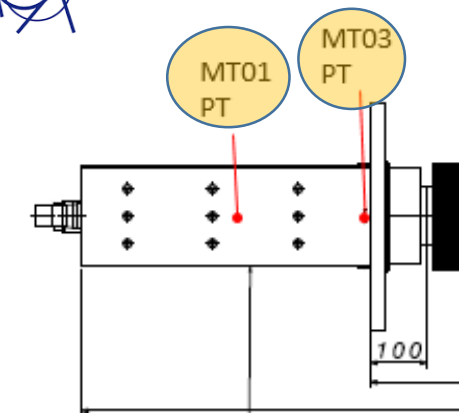
Temperature sensor positions (Courtesy of P. Bauer)



Conclusion:

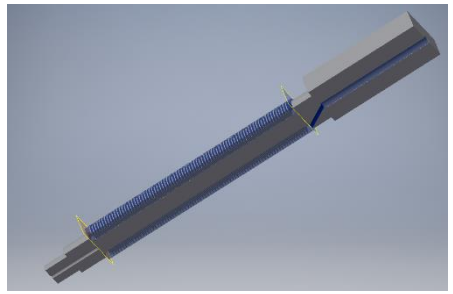
The temperatures acquired during the run2 fit better to the simulated temperature profile than those acquired during the run3.

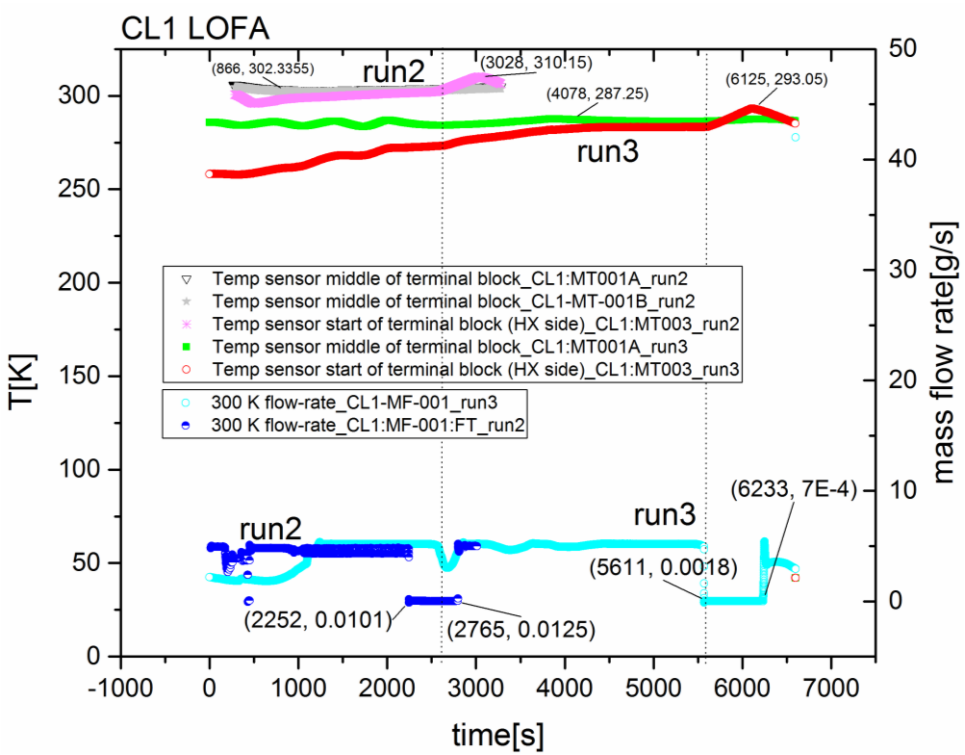
MT01A/B and MT03 temperature sensor during LOFA tests

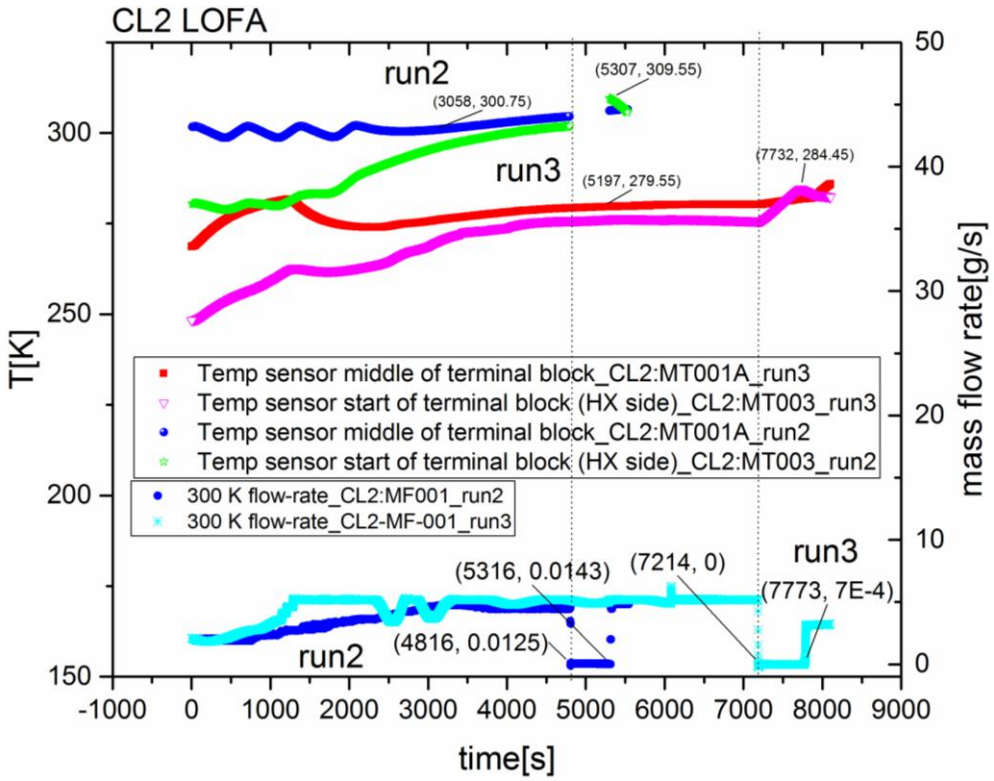


Only the MT03 temperature sensor reveals a temperature increase due to LOFA!

To investigate this behaviour the initial temperature profile has to be added into the electrical terminal!







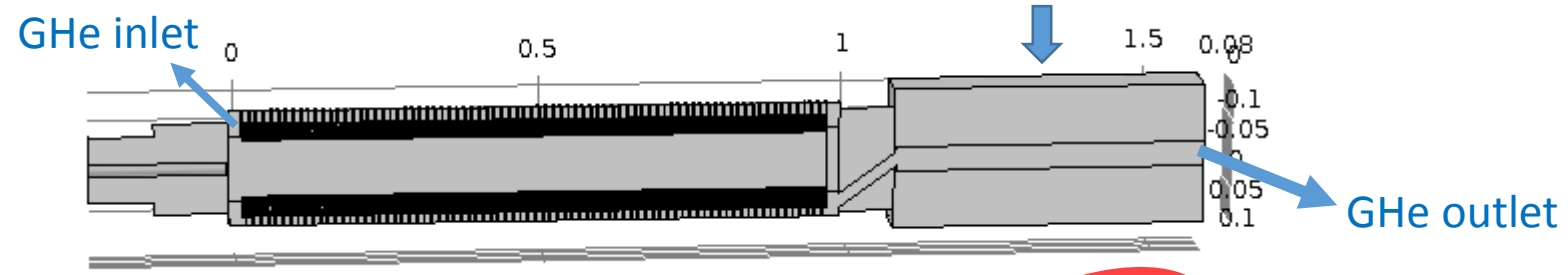
Duration of the LOFA during the measurements: between 500 and 600 s

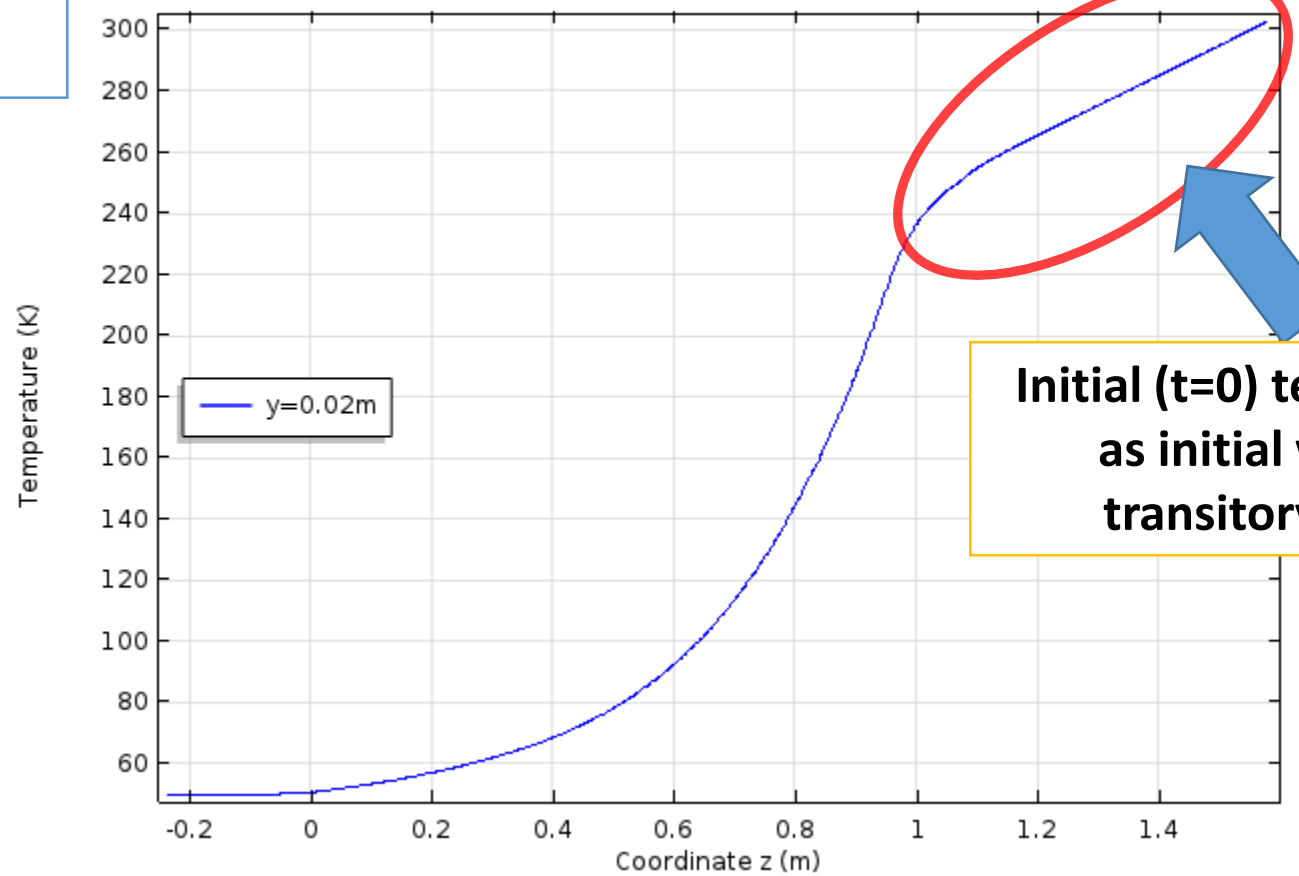
TEMPERATURE PROFILE IN THE ELECTRICAL TERMINAL

In the 3D thermo-hydraulic and electrical FE model in stationary regime the electrical terminal has been added to obtain its temperature profile.

Boundary conditions

Temperature bottom of shunt: 50 K
Temperature top HEX: 303 K
Temperature He outlet: 303 K
Temperature He inlet: 50 K

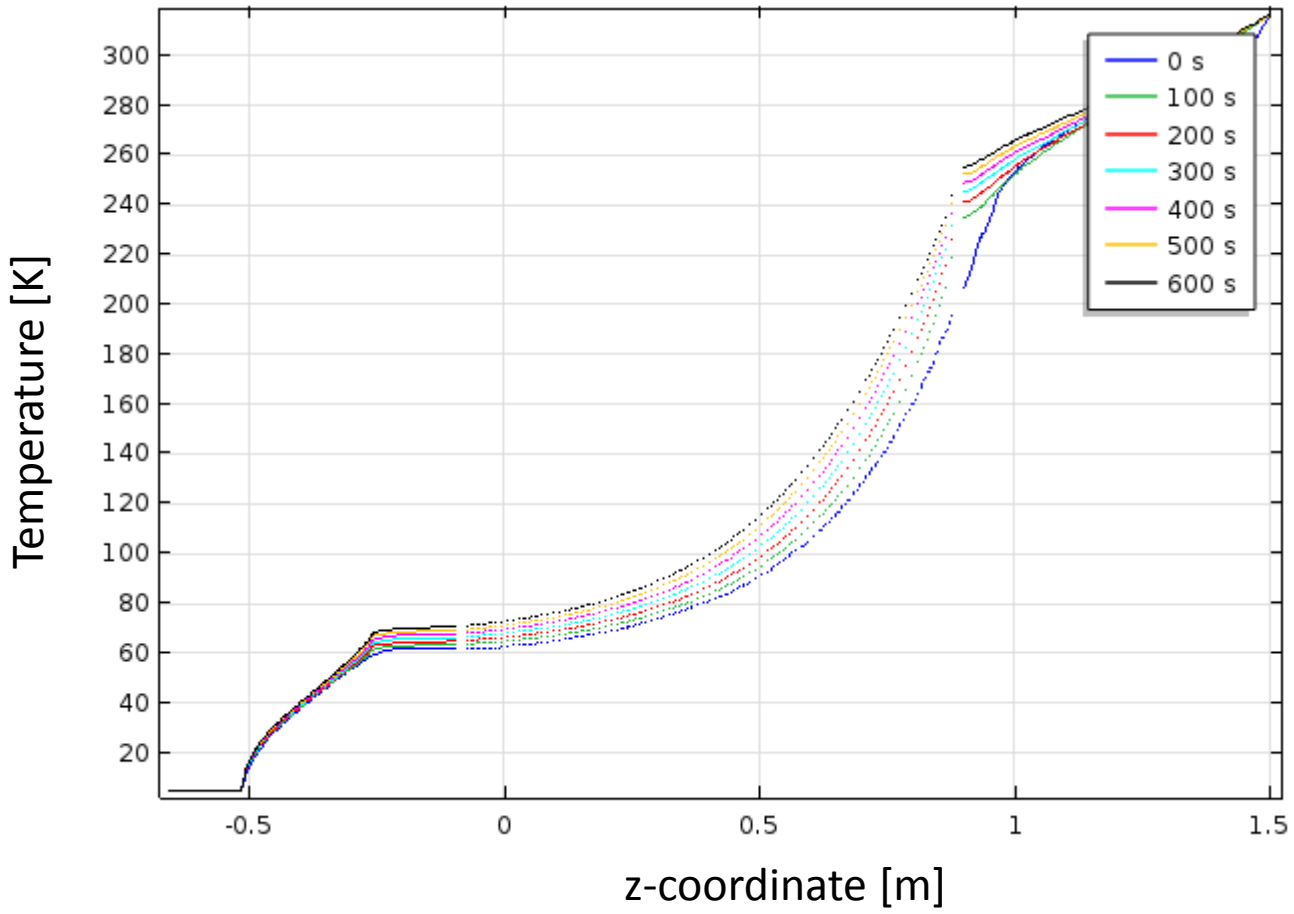




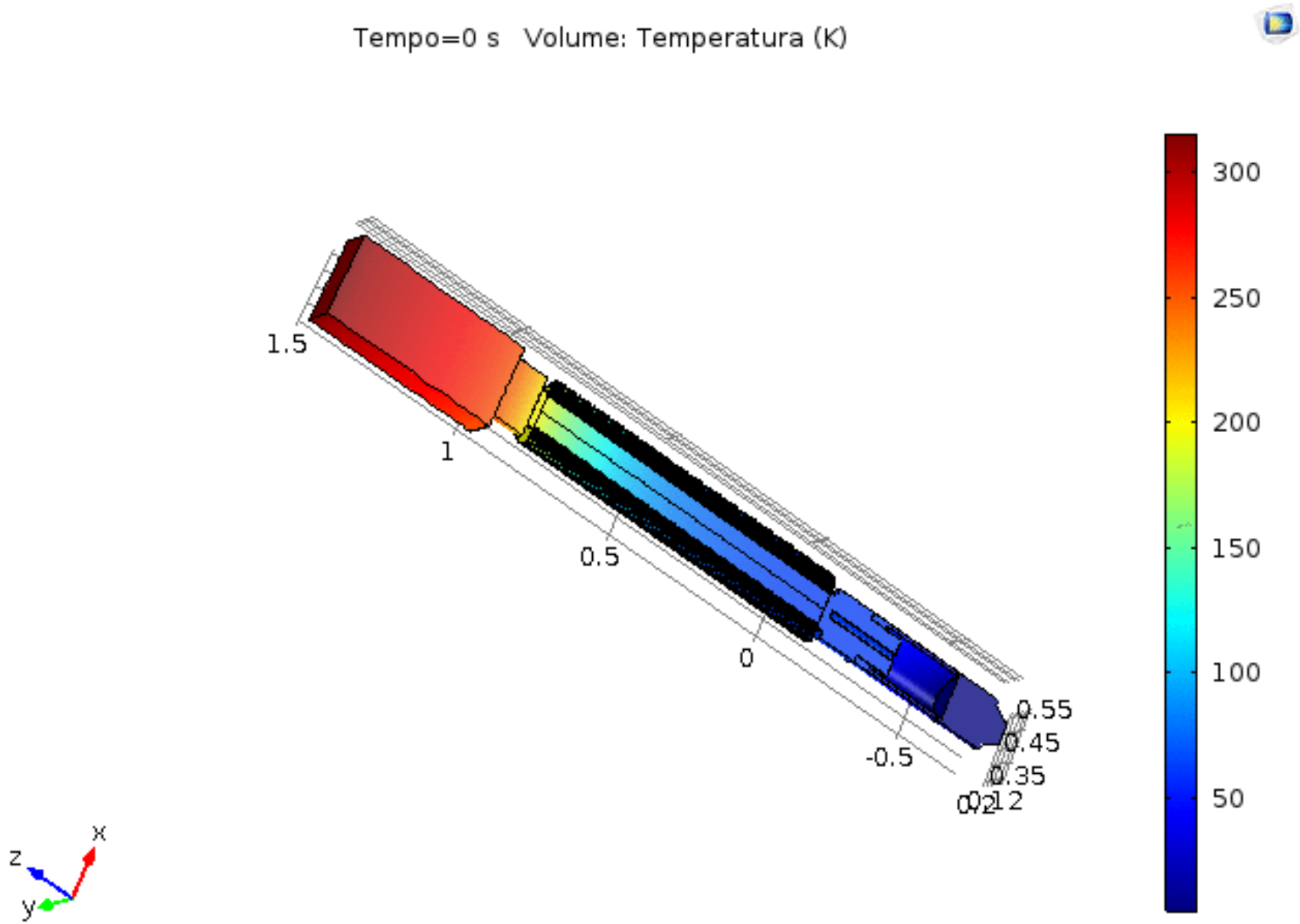
Initial (t=0) temperature profile to add as initial value into the new 3D transitory model (see slide 24)

TEMPERATURE EVOLUTION DURING LOFA

After the introduction of the initial temperature profile (t=0) to the electrical terminal



TEMPERATURE EVOLUTION DURING LOFA: animation



TEMPERATURE SENSOR OVER TERMINAL: EXPERIMENTAL VS. SIMULATED VALUES

- ✓ Results from the new 3D FE model being analyse;
- ✓ **<u>Will be done</u>**: evaluation of the dissipation due to contact resistance in the electrical terminal in the 3D model.

TASK 4

➢ **Writing up of Internal Notes:**

- **EDMS Nr. 1563785**, "A comparison between experimental pressure drop over HEX and 3D FE model for CC mock-up".
- **EDMS Nr. 1563784**, "Analysis of the measurements performed on TF prototype current leads tested in Hefei in July 2015".
- **EDMS Nr. 1572890**, "Summary of FE models developed at CERN for the analysis of the ITER Current leads".

OUTLINE:

- ❑ MAIN TASKS ACHIEVED DURING 6 MONTHS (JANUARY 2016 – JUNE 2016)
- ❑ **OTHER ACTIVITIES**
- ❑ PLANS FOR THE FUTURE
- ❑ DOCUMENTATION

OTHER ACTIVITIES

➢ **Material analysis**: HTS stainless steel shunt (EN-MME-MM):

- **Metallographic inspection**: found dark grey features expected to be inclusion or some type of secondary phases. **EDX/SEM analysis on-going (next Thursday 07.07.2016);**
- Evaluation of **quality of silver coating**. Found no defects and no detachments at the interface coating-substrate.

➢ **Overview of all the models developed at CERN since 2009**, Internal Note EDMS Nr. 1572890, "Summary of FE models developed at CERN for the analysis of the ITER Current leads".

OUTLINE:

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PLAN FOR THE FUTURE

- Introduction of the dissipation due to contact resistance in the terminal to check the issue found over the ME001 sensor (terminal to flexible contact resistance);
- EDX/SEM analysis;
- Fluido-dynamic behaviour over HEX and evaluation of the pressure drops in the electrical terminal;
- Writing up of Internal Note about the 3D model in transitory regime as well as the updated one in stationary regime developed during these 6 months;
- Data analysis of recent tests of 55 kA prototype CLs.

OUTLINE:

- ❑ MAIN TASKS ACHIEVED DURING 6 MONTHS (JANUARY 2016 – JUNE 2016)
- ❑ OTHER ACTIVITIES
- ❑ PLANS FOR THE FUTURE
- ❑ **DOCUMENTATION**

DOCUMENTATION

- **EDMS Nr: 1538422, "Test report of CC (10kA) and TF (68kA) HEX pressure drop measurements", published January 2015.**
- **EDMS Nr. 1572890, "Summary of FE models developed at CERN for the analysis of the ITER Current leads", published January 2016.**
- **EDMS Nr. 1563785 "A comparison between experimental pressure drop over HEX and 3D FE model for CC mock-up", published April 2016.**
- **EDMS Nr. 1563784, "Analysis of the measurements performed on TF prototype current leads tested in Hefei in July 2015", published May 2016.**
- **Presentation weekly meeting 23.03.2016: "LOFA Analysis – run2 (July 2015) and run3 (January 2016)"**

THANK YOU FOR

YOUR ATTENTION!