Magnet quench tests of the shielded HL-LHC beam screen

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With contributions and materials from:

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WP3 Meeting

TE-VSC-DLM

16 - 01 - 2019

Outline

- Magnet quench test
- Physics of the problem
- Instrumentation
- Results and comparison with simulations
- Conclusions and next steps

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Test plan

Start date of the test in SM18: 10th October 2018

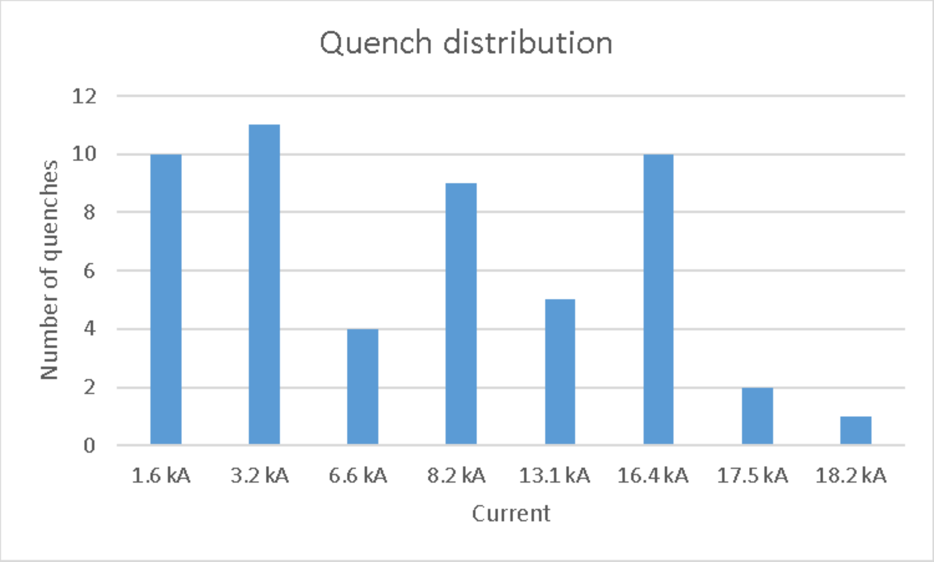
End date of the test in SM18: 18th October 2018

EDMS: 2024740

Time required at cold

- HV, transfer function at 80 K ½ day
- HV, transfer function at 1.9 K ½ day
- Beam screen & training verification 2-3 days
- Protection studies 3-4 days
- HV, transfer function at 1.9 K ½ day
- Other tests? ?

- Total ~8 days



54 quenches

(CLIQ, quench heater, training, extraction, high quench integral, ramp rate)

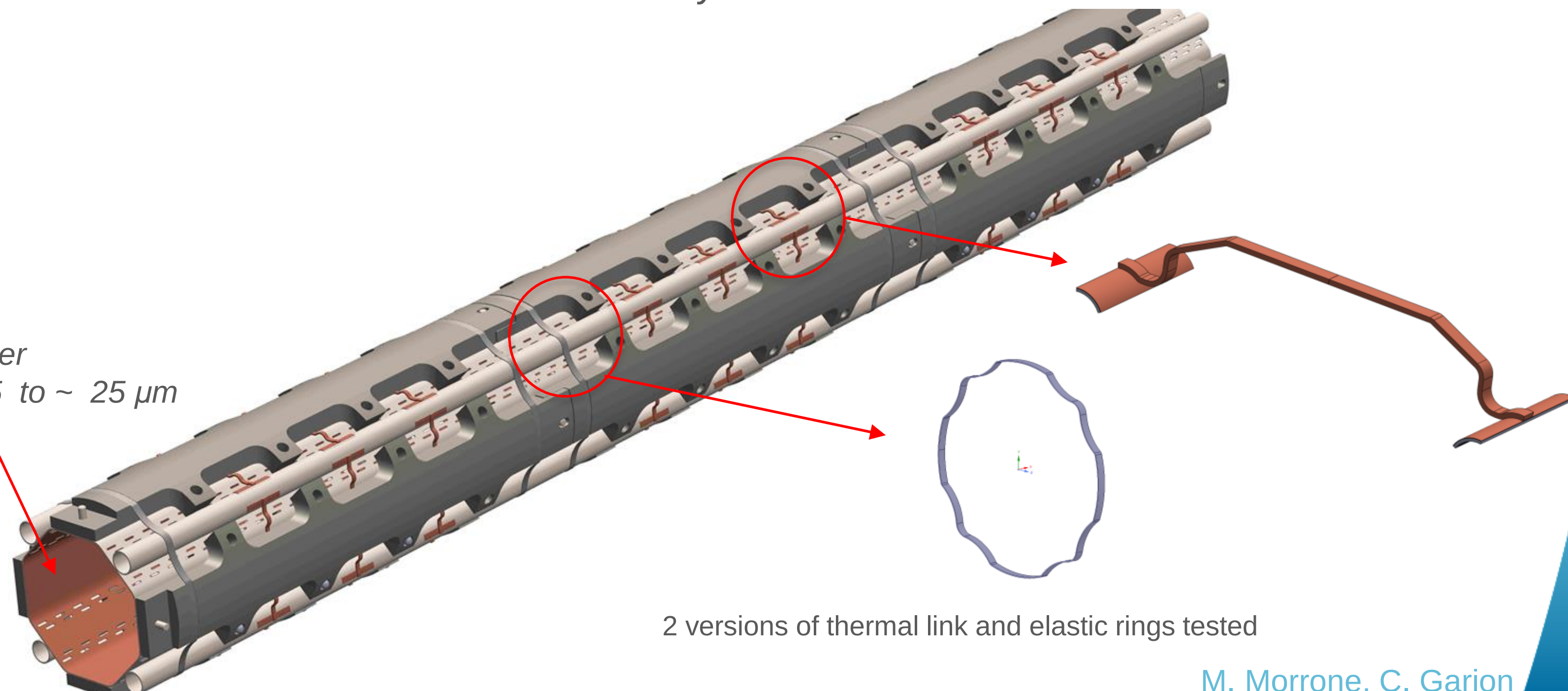
Aim of the test

- Training verification of the MQXFS4b at 1.9 K.
- Flux jump effect on the current studies, both during other tests' ramps and during dedicated exponential cycles;
- Magnet protection studies, including CLIQ discharges in different configurations, QH delay and performance and QH-only discharges;
- **Effect of CLIQ on the beam screen** studied with over 20 runs dedicated to that measurement;
- **Measurement of the magnetic field** during CLIQ and quench heater discharge by means of dedicated pickup coils in the beam screen;

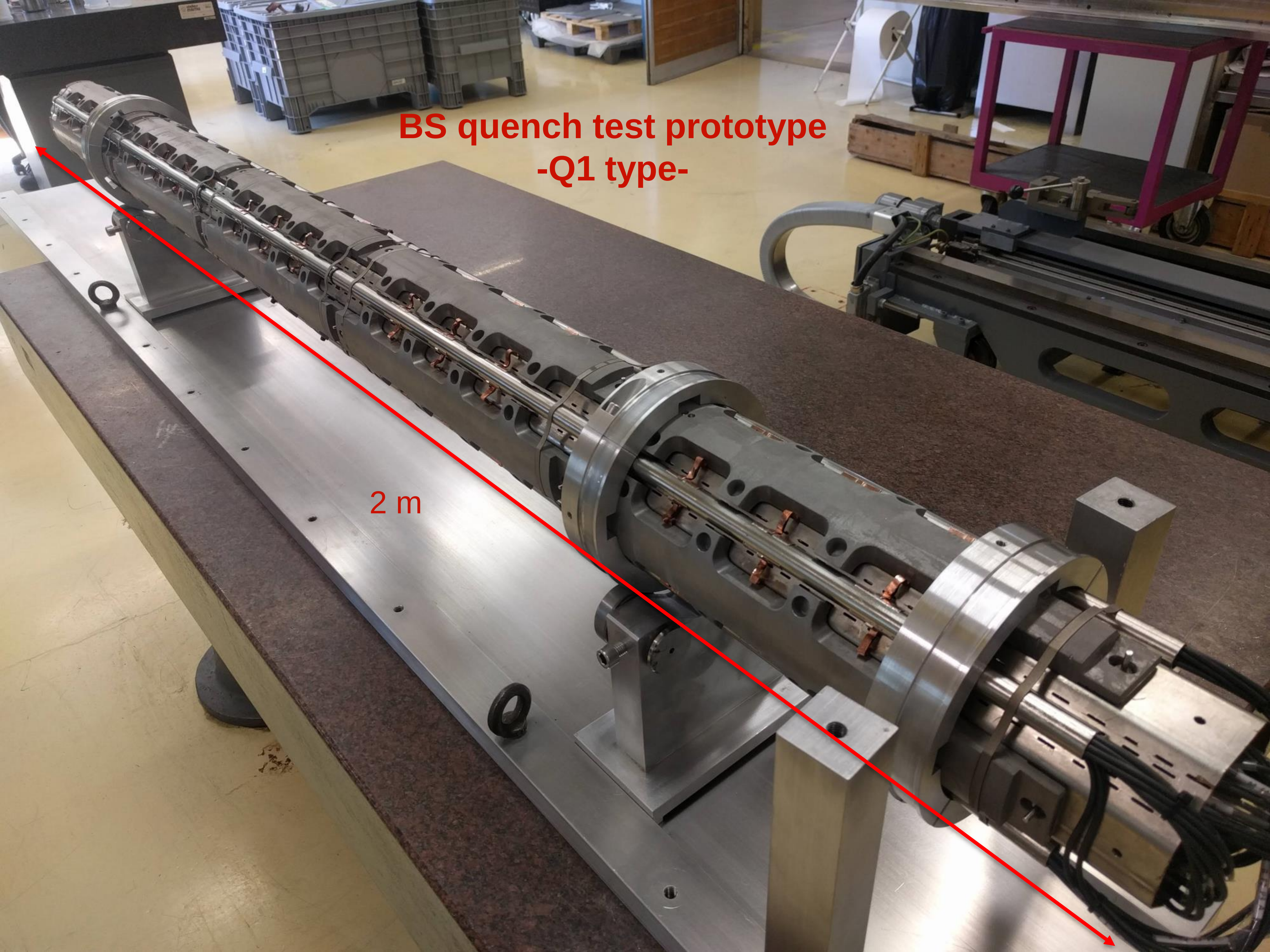
Test conditions

- Q1 beam screen version compatible with the CLIQ discharge (pins and W block geometry modified);
- Beam screen immersed in the 1.9 K helium bath;
- Temperature: 1.9 K (significant change of the electrical resistivity of Cu due to temperature and magneto-resistivity → reduced thickness of Cu inner layer for the prototype, from 75 µm to 25 µm);
- Magnetic field decay representative of the HL-LHC conditions, including the CLIQ system;
- Vertical position of the beam screen within the cryostat.

Inner copper layer reduced from 75 to ~ 25 µm



2 versions of thermal link and elastic rings tested


BS quench test prototype
-Q1 type-
2 m

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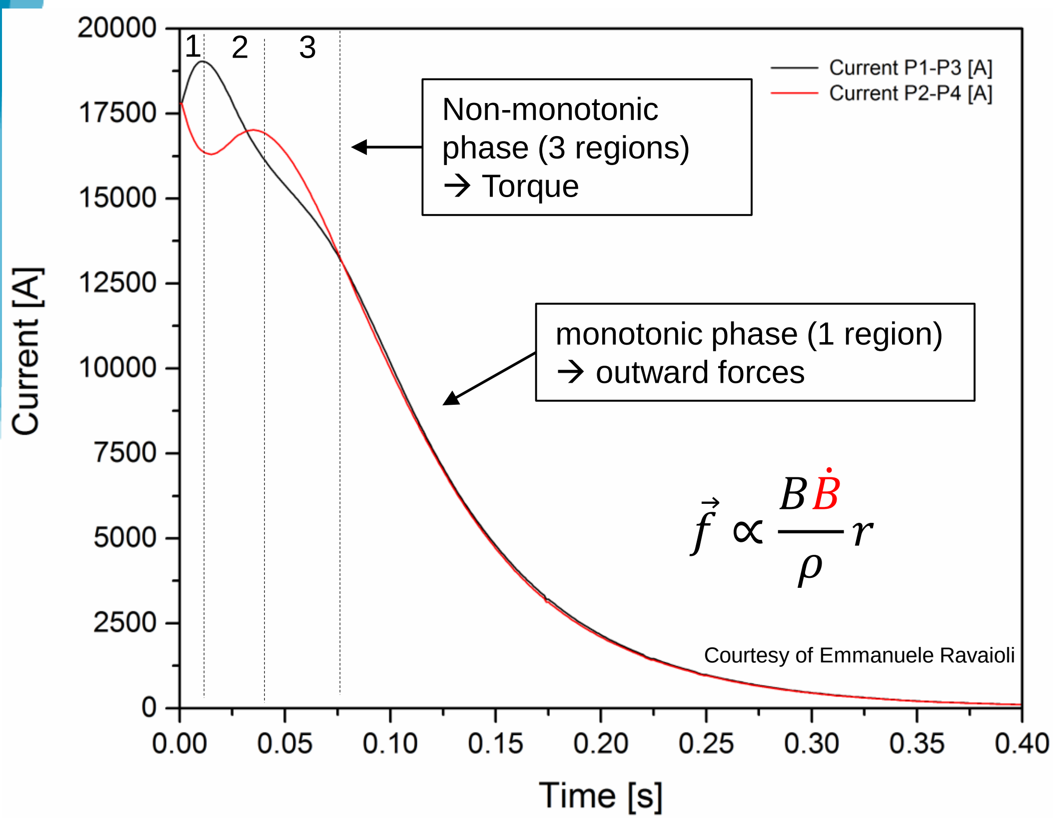
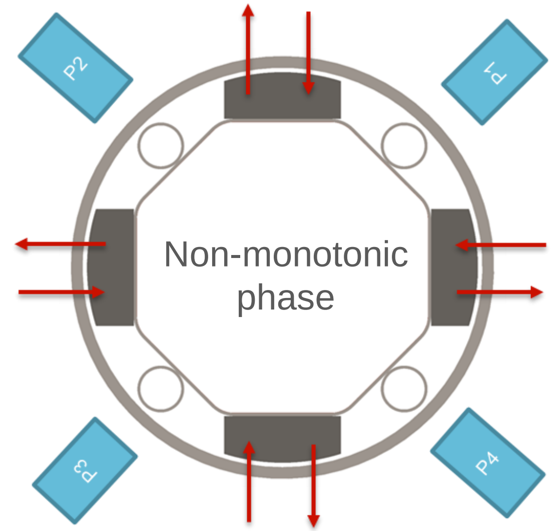
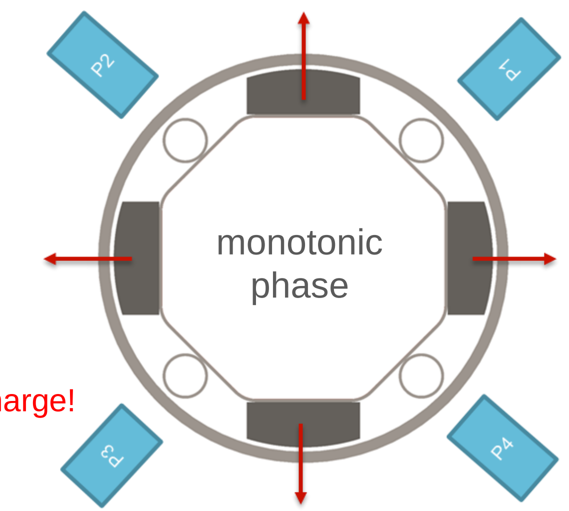
Physics of the problem



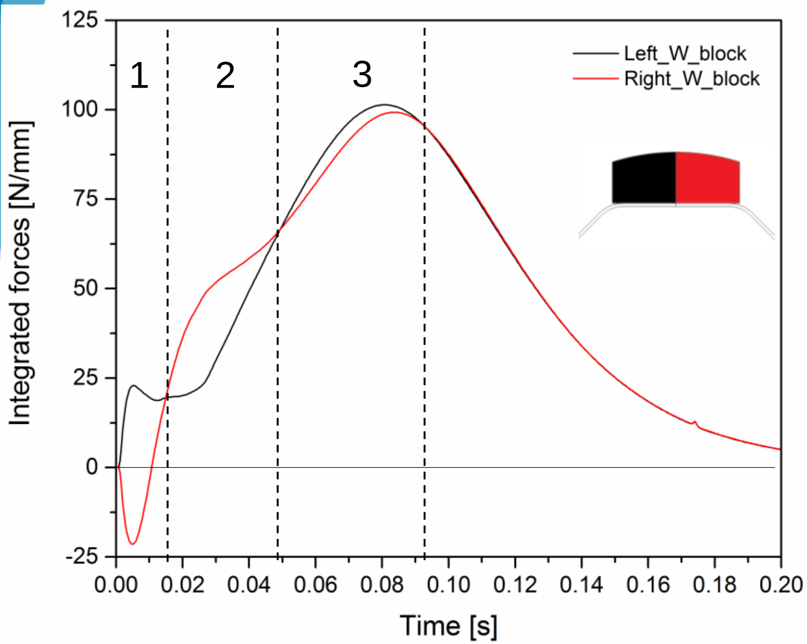




$\dot{B}B$ ($\dot{B}$ has a change of sign) is not monotonic in the first phase of the CLIQ discharge! Therefore, opposite forces are expected in the same component.

Numerical results at 17.8 kA

Integrated forces induced in the W block



Region 1: Most critical!!

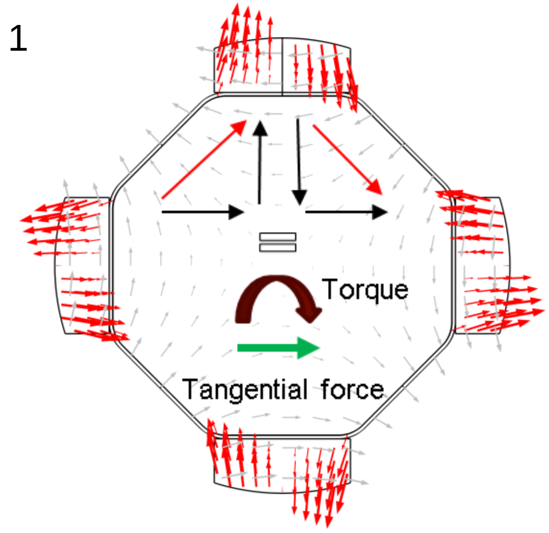
component	Q1	
	Torque [N m/W block]	Tangential force [N/W block]
Cold bore	253	3400
Heat absorber	280	4200
Octagonal pipe	81.5	1600

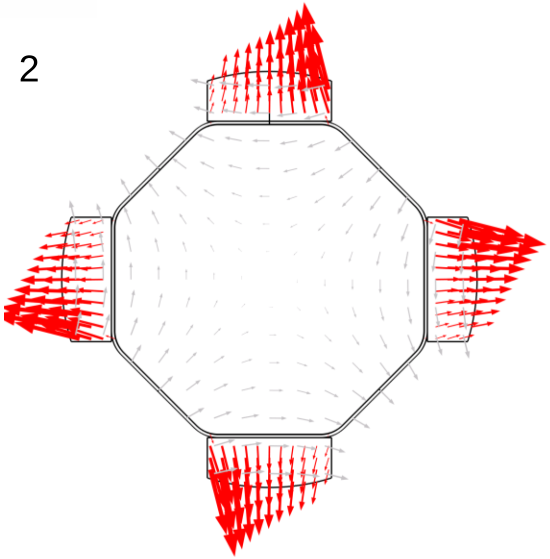
Region 2: Less severe than phase 1

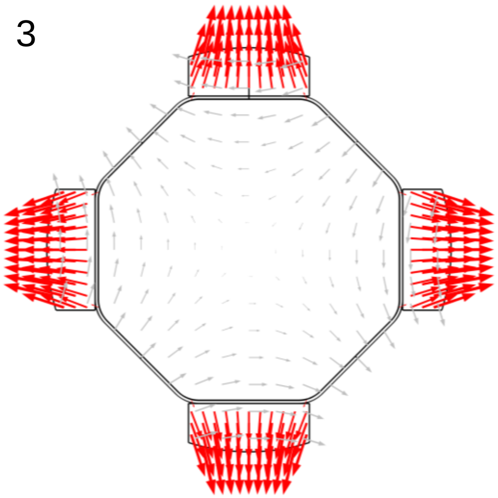
Region 3: Less severe than without CLIQ

E.g. Fy for the tungsten block:

$Q1_{NO\ CLIQ}$ ~233.5 [N/mm] > $Q1_{CLIQ}$ ~200.5 [N/mm]





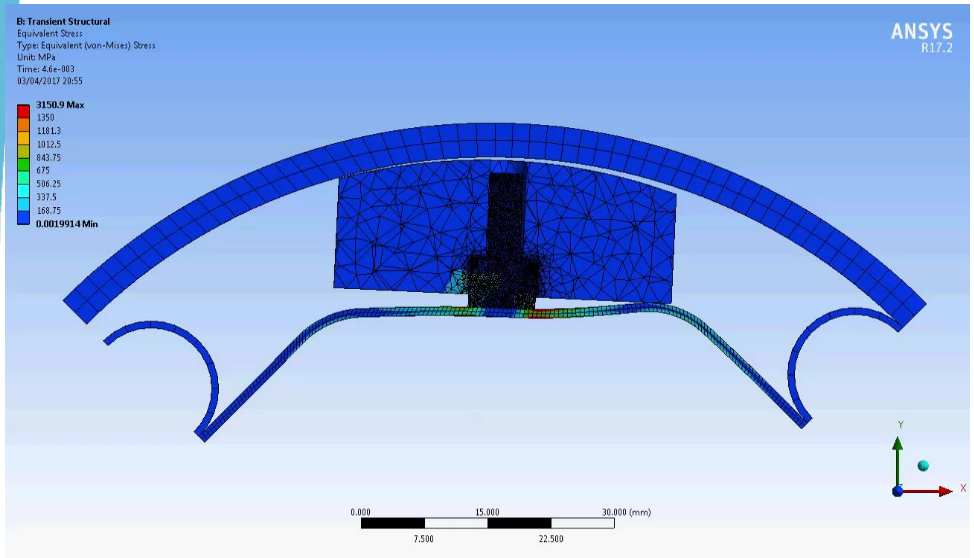


Assumption of the numerical model

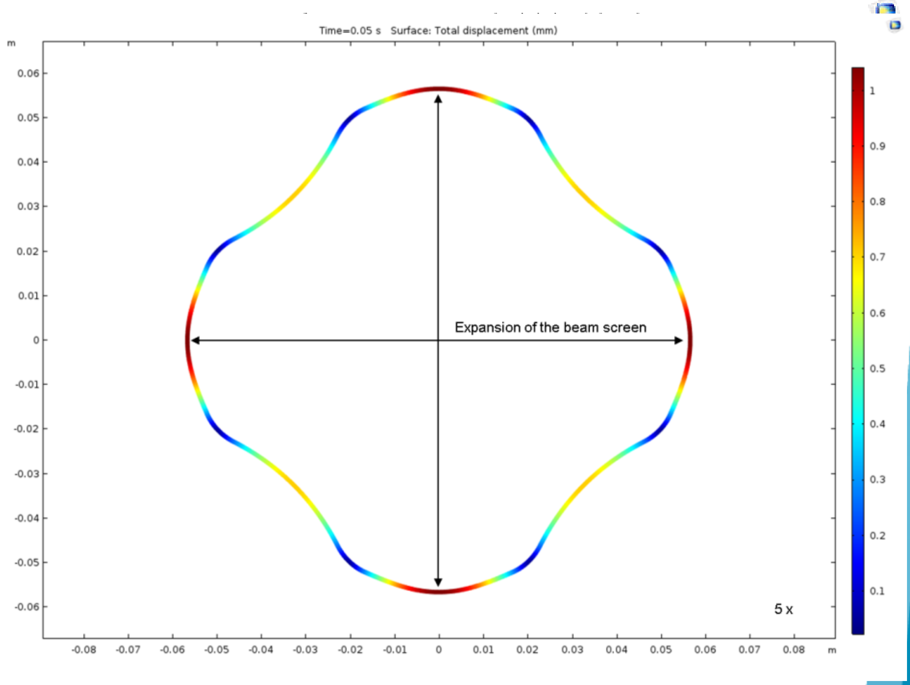
- No magnet coil modelled;
- The electro-dynamic of the magnet is not considered (No IFCC, ISCC);
- Magneto-resistivity of copper considered;
- Heat load affecting the electrical properties considered;
- Measured magnetic field assigned as input for the comparison of the experimental results with the simulations in this presentation.

Animations

First phase



Second phase *



* For visual purposes only as the W blocks are not welded.

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Instrumentation

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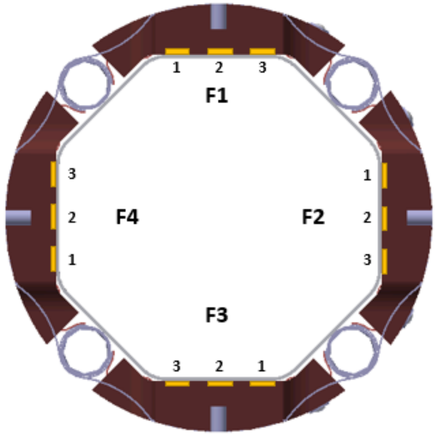
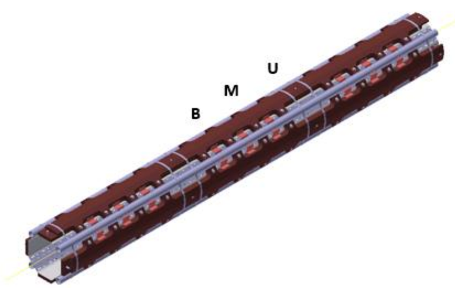
1762736

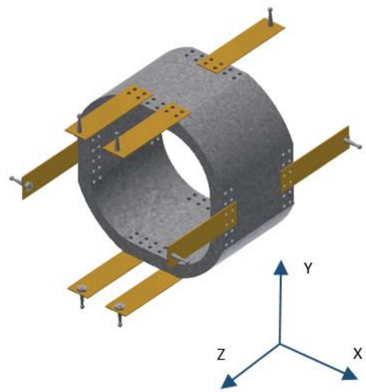
<u>42 Strain gauges </u>*distributed in 3 sections along 4 diametrally opposed faces of the beams screen in axial and transversal directions*

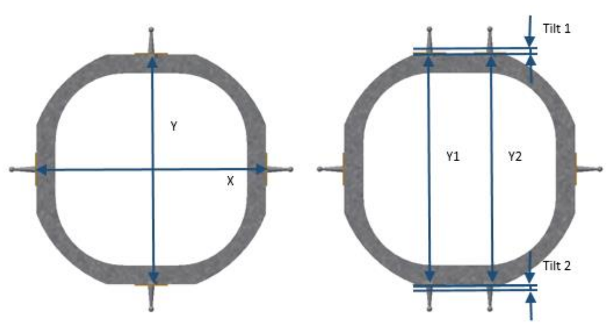




<u>3 custom made displacement measuring heads </u>inside the beam screen to measure:

- *Beam screen expansion*
- *W block tilt*
- *Magnetic field*





expansion tilt

<u>4 lines of fibers </u>installed in 4 diametrally opposed generatrixes of the cold bore: 12 biaxial strain measurement points

Strain gauges

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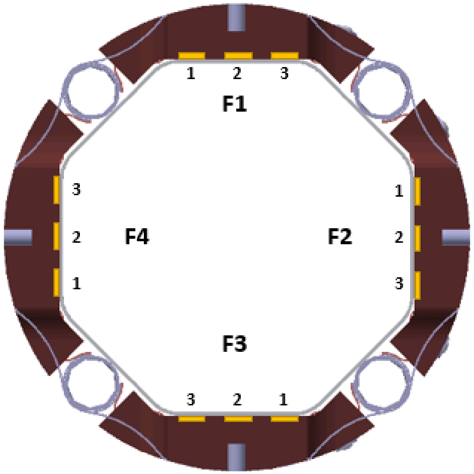
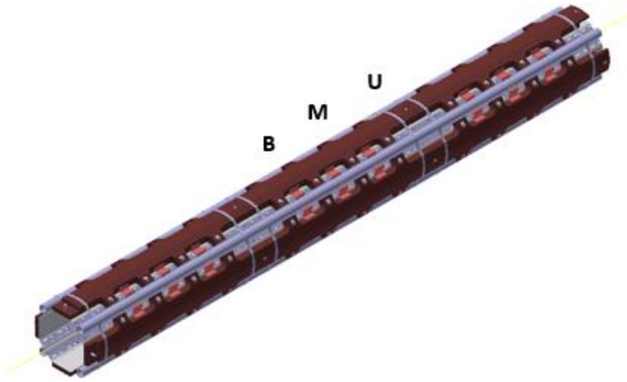
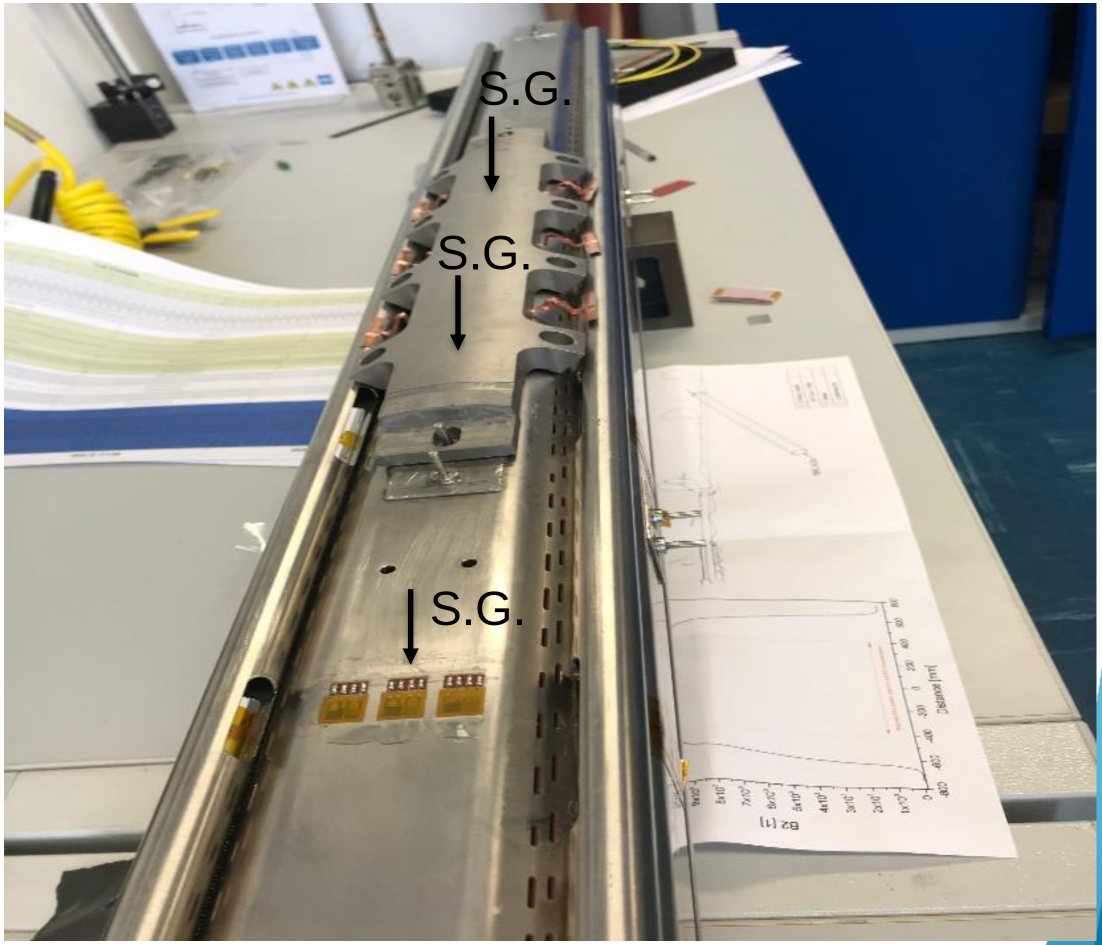
42 Strain gauges distributed in 3 sections along 4 diametrally opposed faces of the beam screen in axial and transversal directions.







Measuring probe

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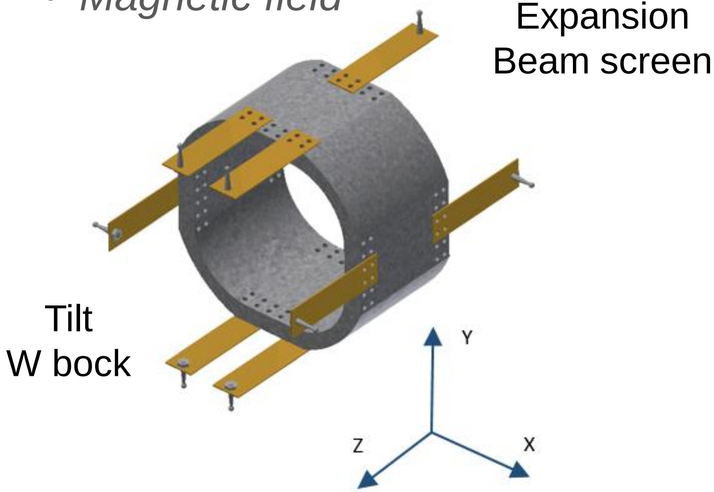
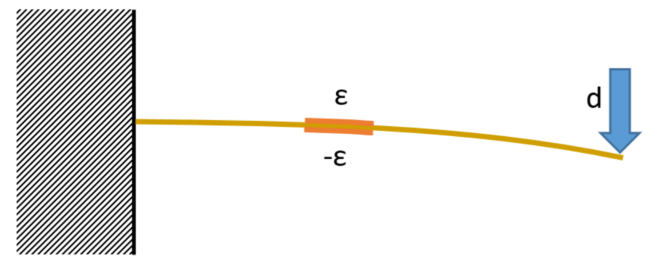
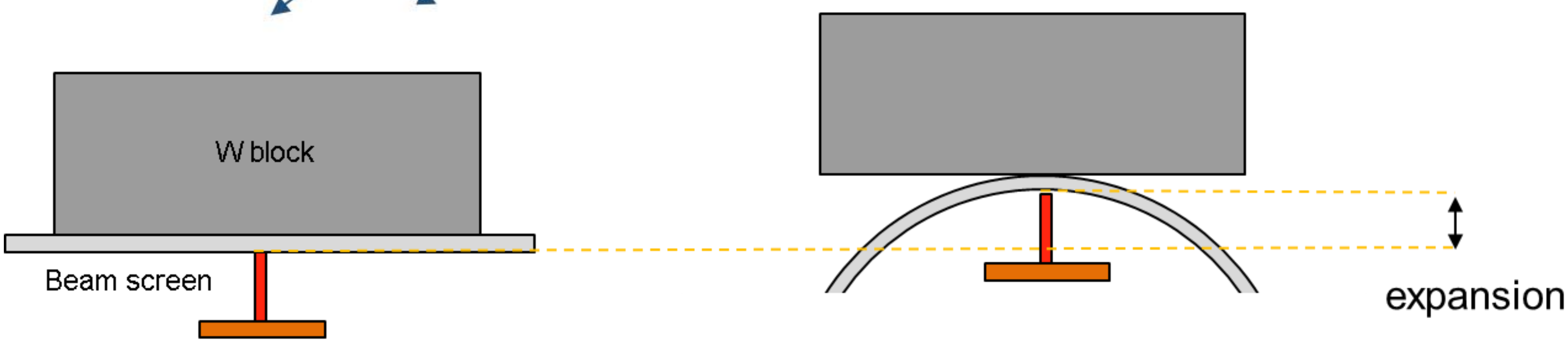
3 custom made displacement measuring heads inside the beam screen to measure:

- *Beam screen expansion*
- *W block tilt*
- *Magnetic field*







UNDEFORMED CONFIGURATION DEFORMED CONFIGURATION

Measuring probe

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3 custom made displacement measuring heads inside the beam screen to measure:

- *Beam screen expansion*
- *W block tilt*
- *Magnetic field*

Before the quench test

After the quench test

Cold bore fibers

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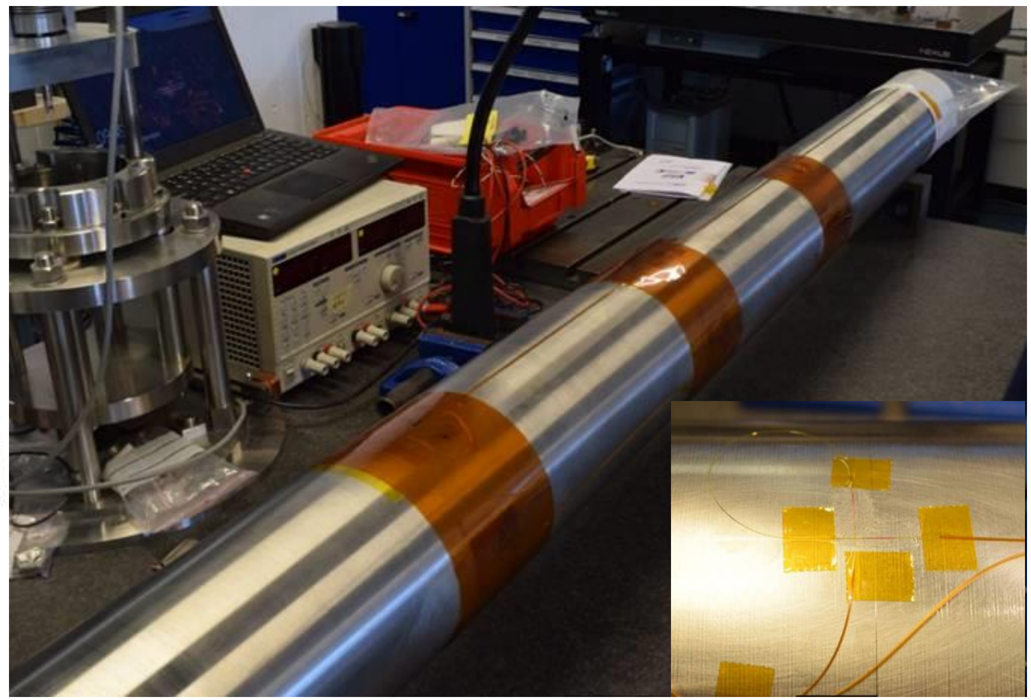
<u>4 lines of fibers</u> installed in 4 diametrally opposed generatrixes of the cold bore: 12 biaxial strain measurement points.



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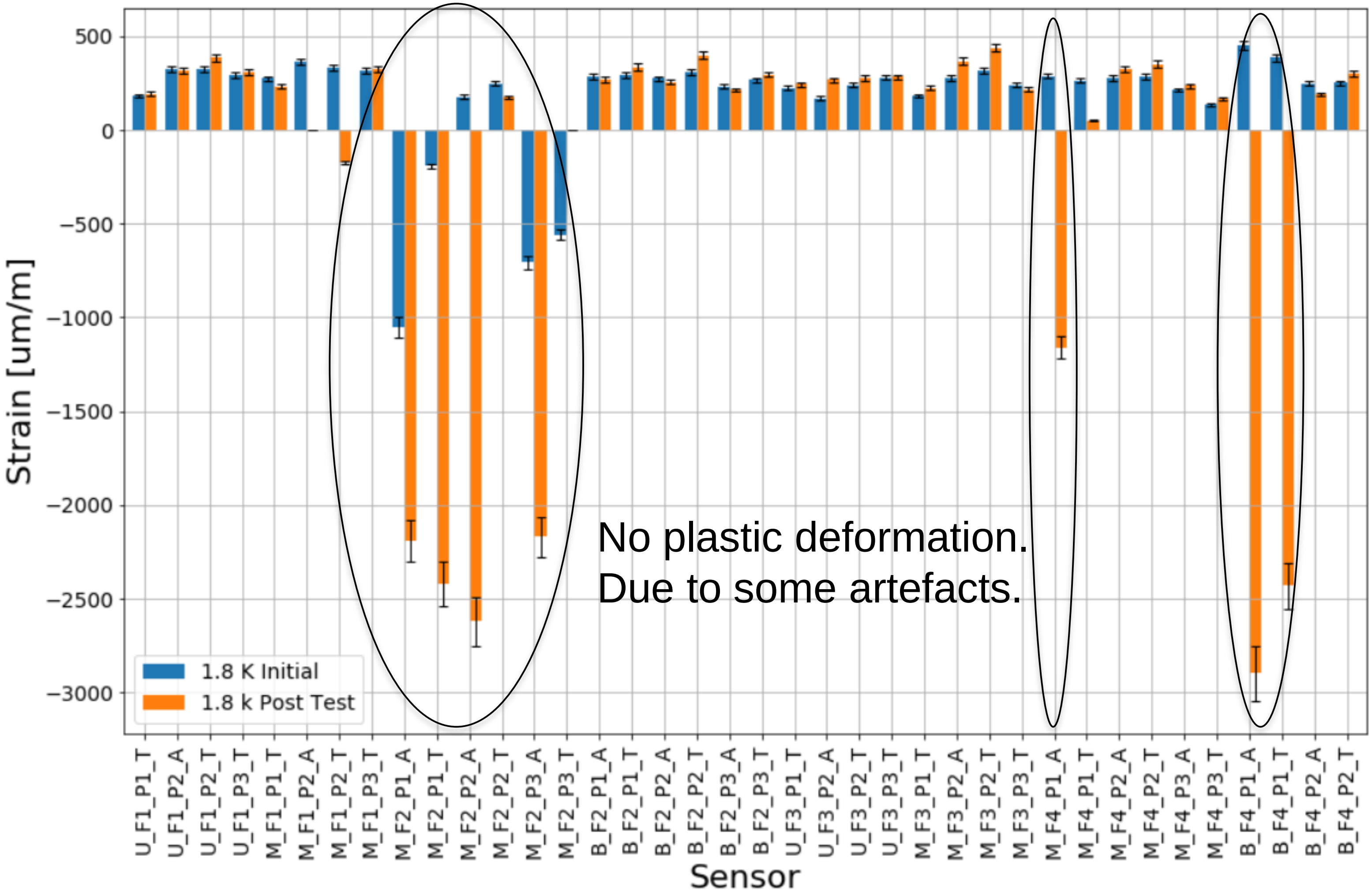
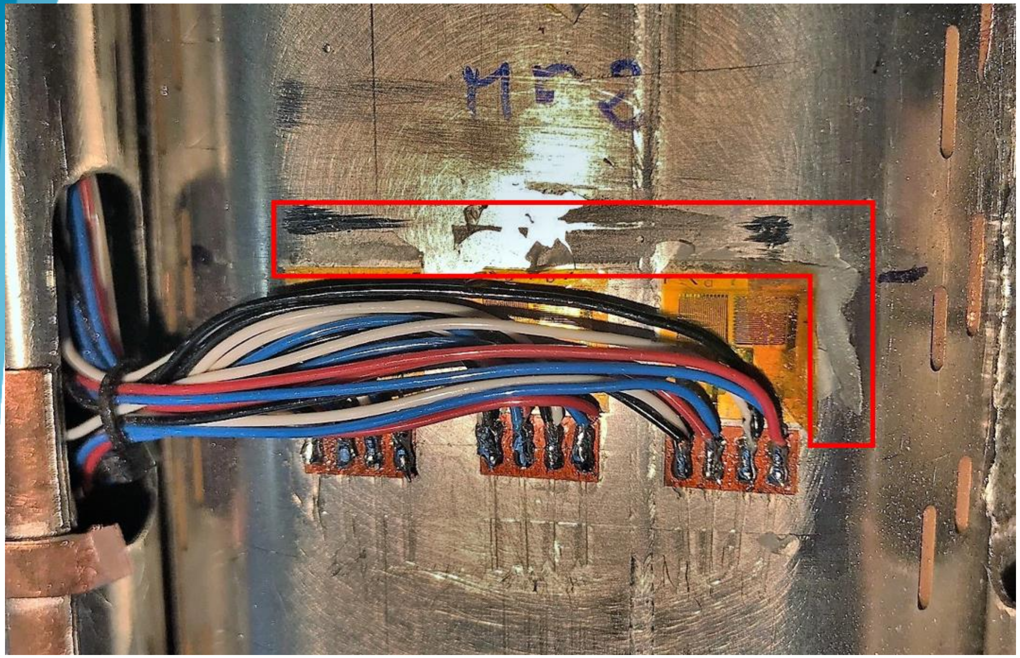
General overview of all the strain gauges

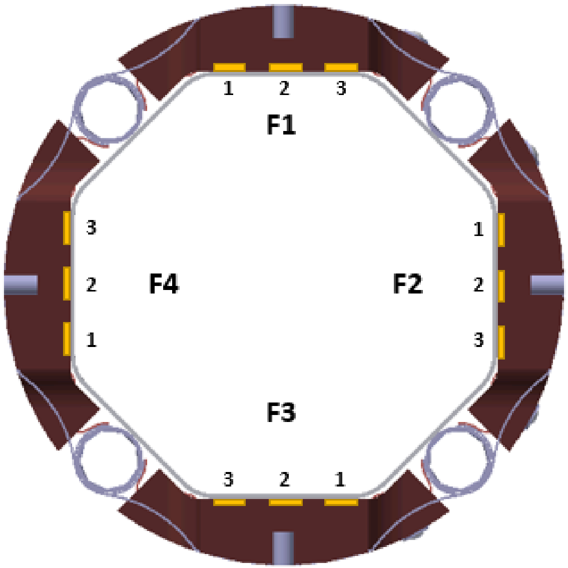


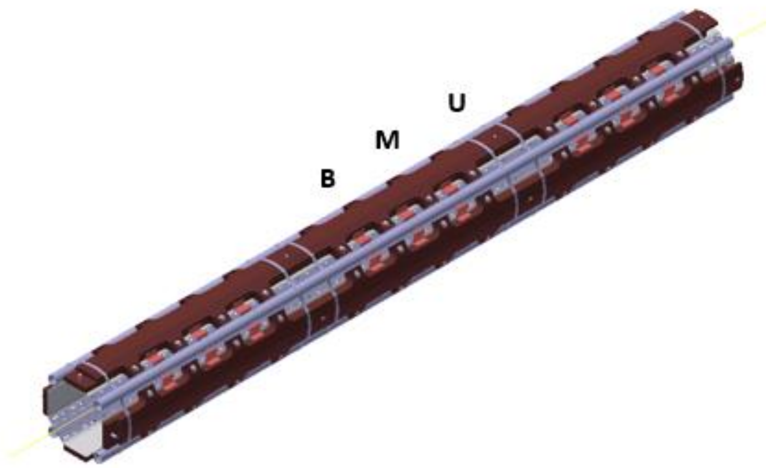
General overview of all the strain gauges



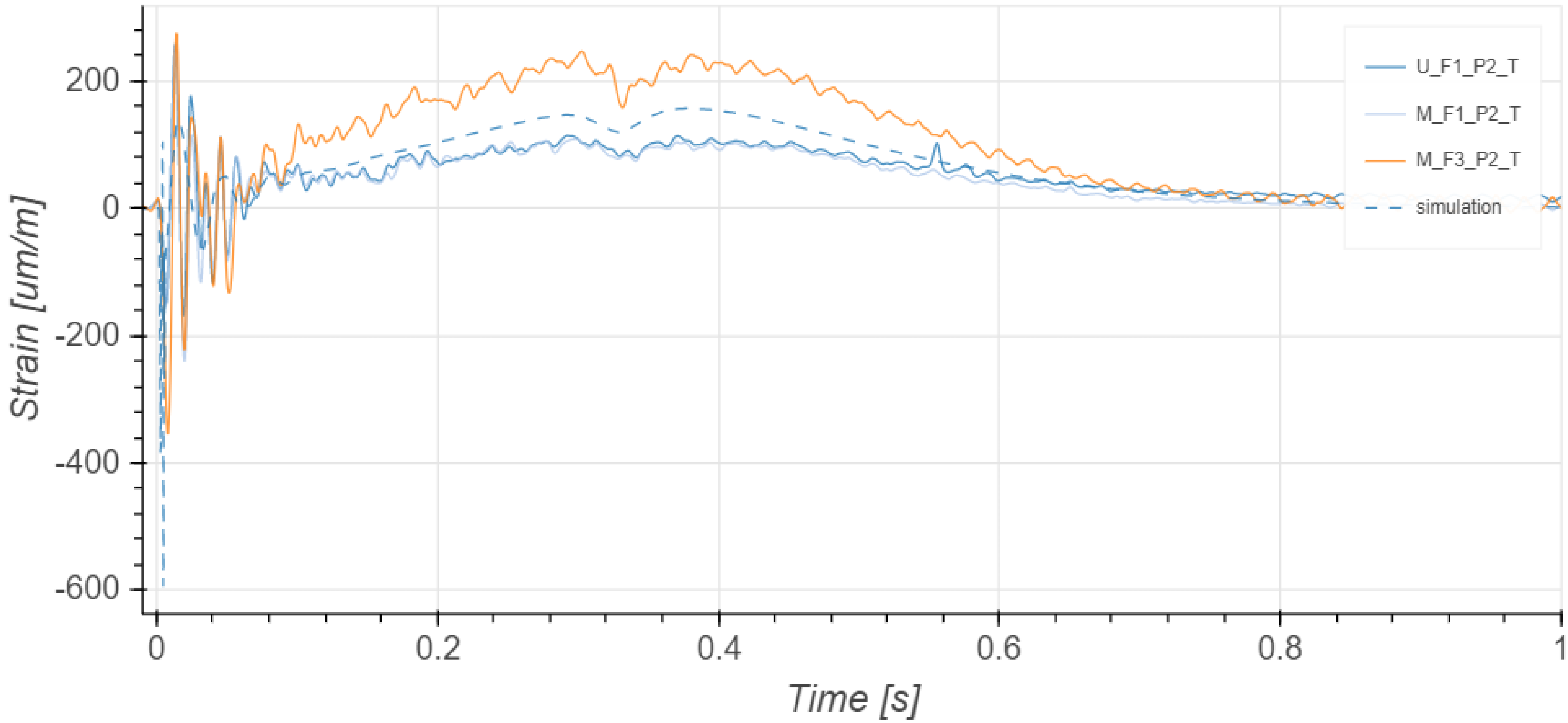
The behaviour observed at the points located at M_F2 can be explained by the extra thickness induced by a slight surplus of the adhesive used for the bonding of the strain gages which entered in contact with the tungsten block. It can be seen in the red frame on the picture above on the left. It is also noticeable that a strain gauge got detached (picture on the right).

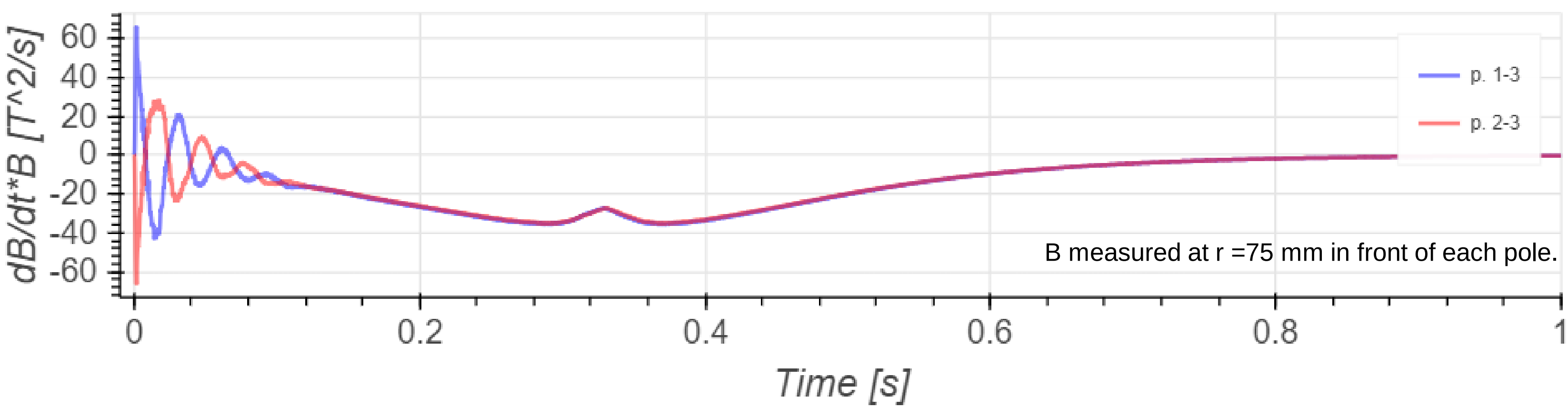
Results at 8.2 kA
(Strain gauges, measuring probe)



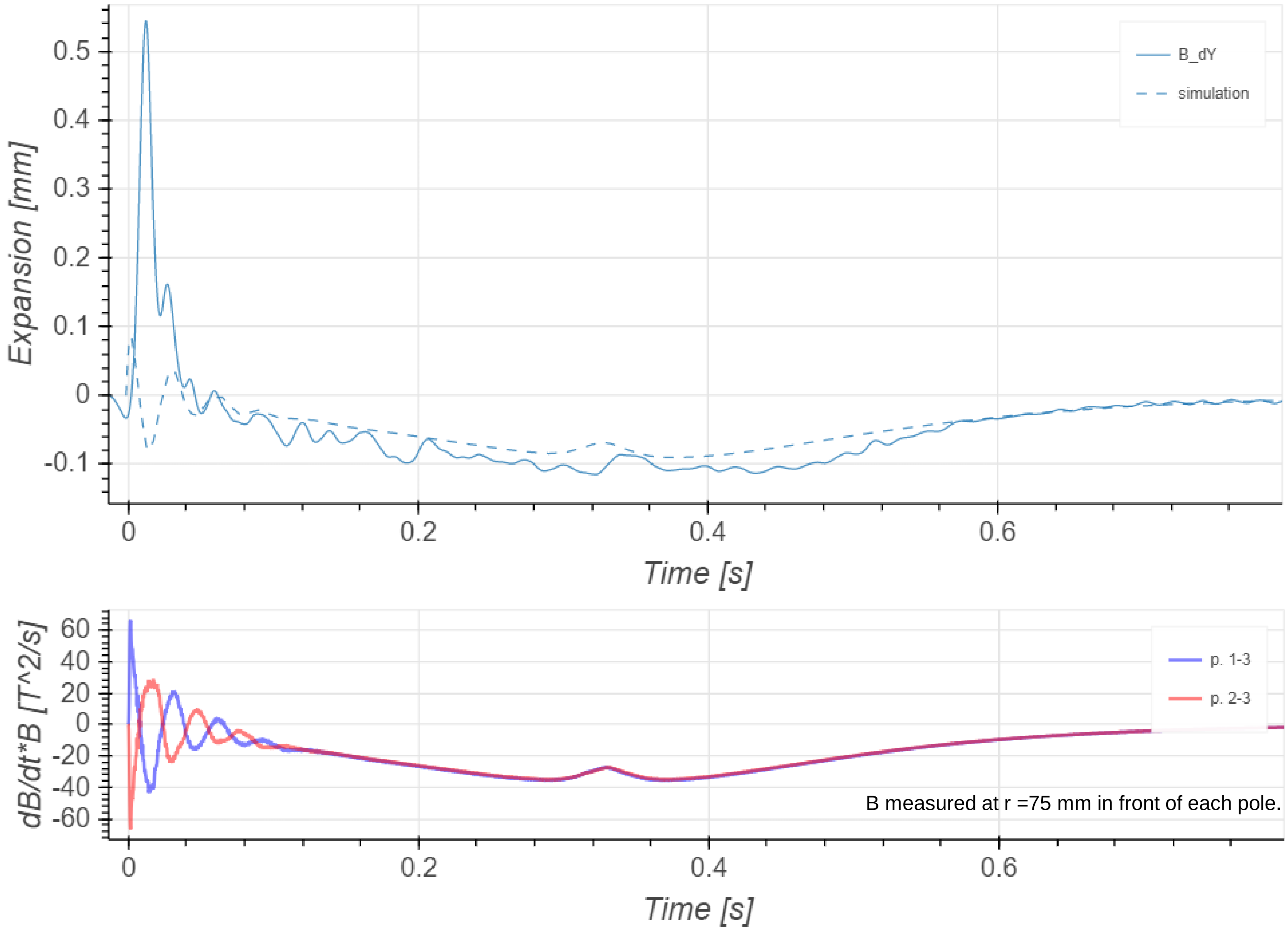


8 kA Face Center (P2) Transversal Strains

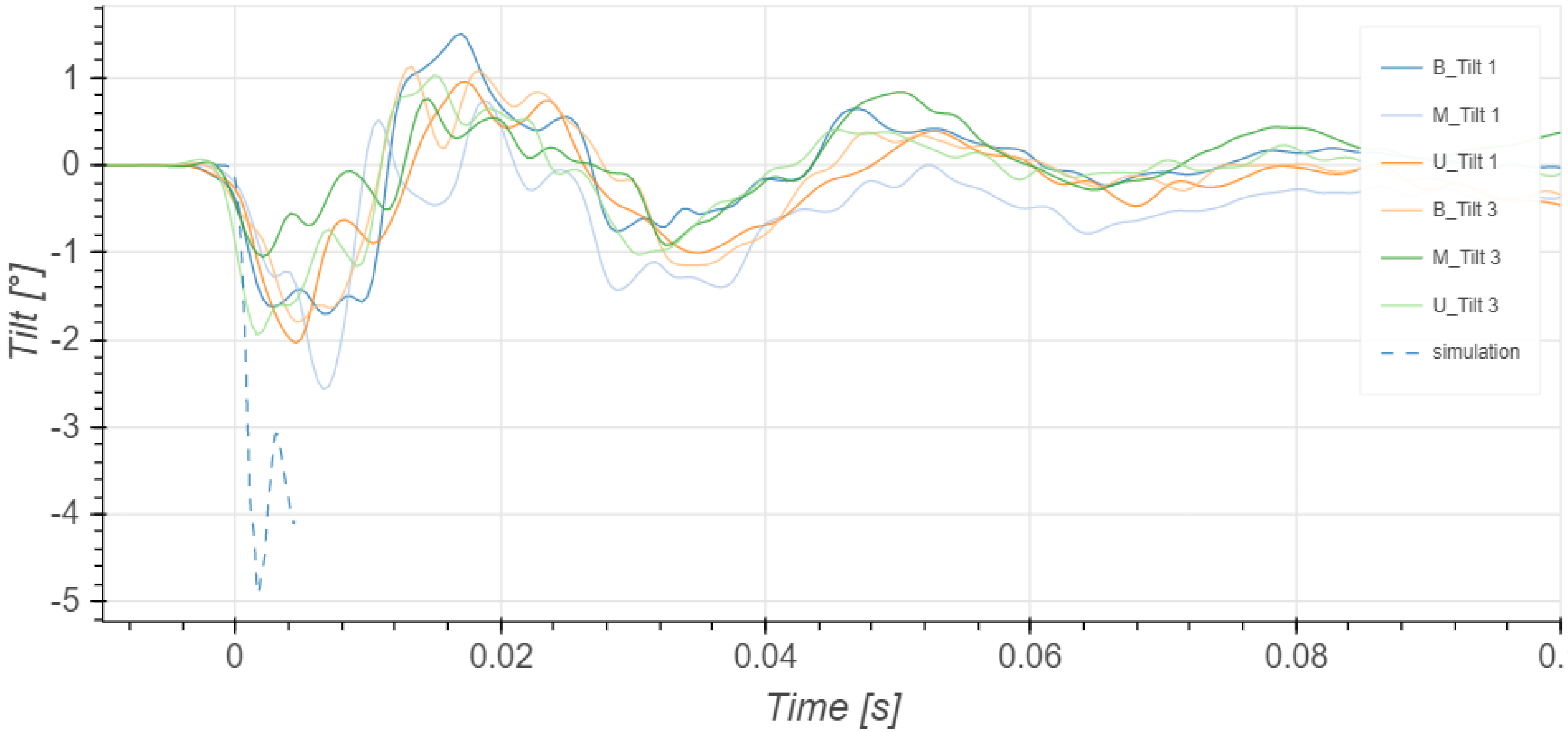


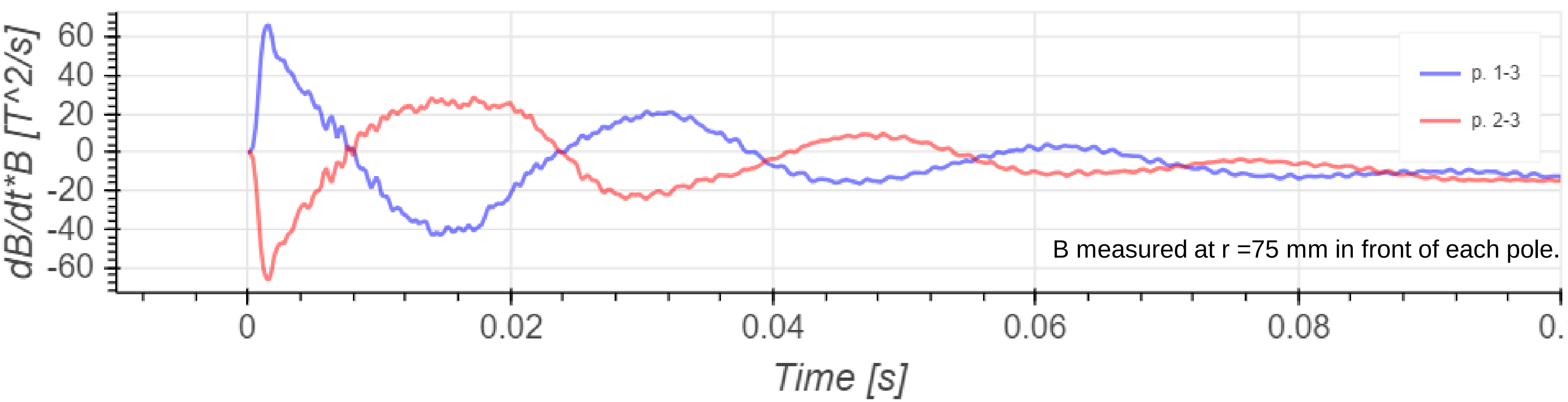


8 kA Beam Screen Expansion

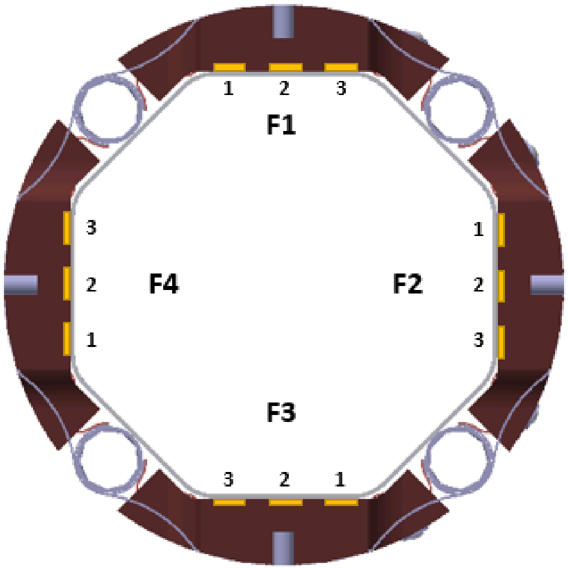


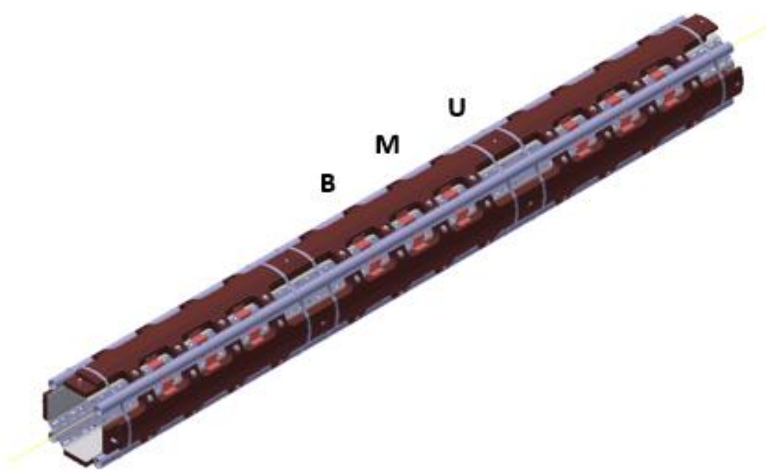
8 kA CLIQ Discharge Induced Tilt



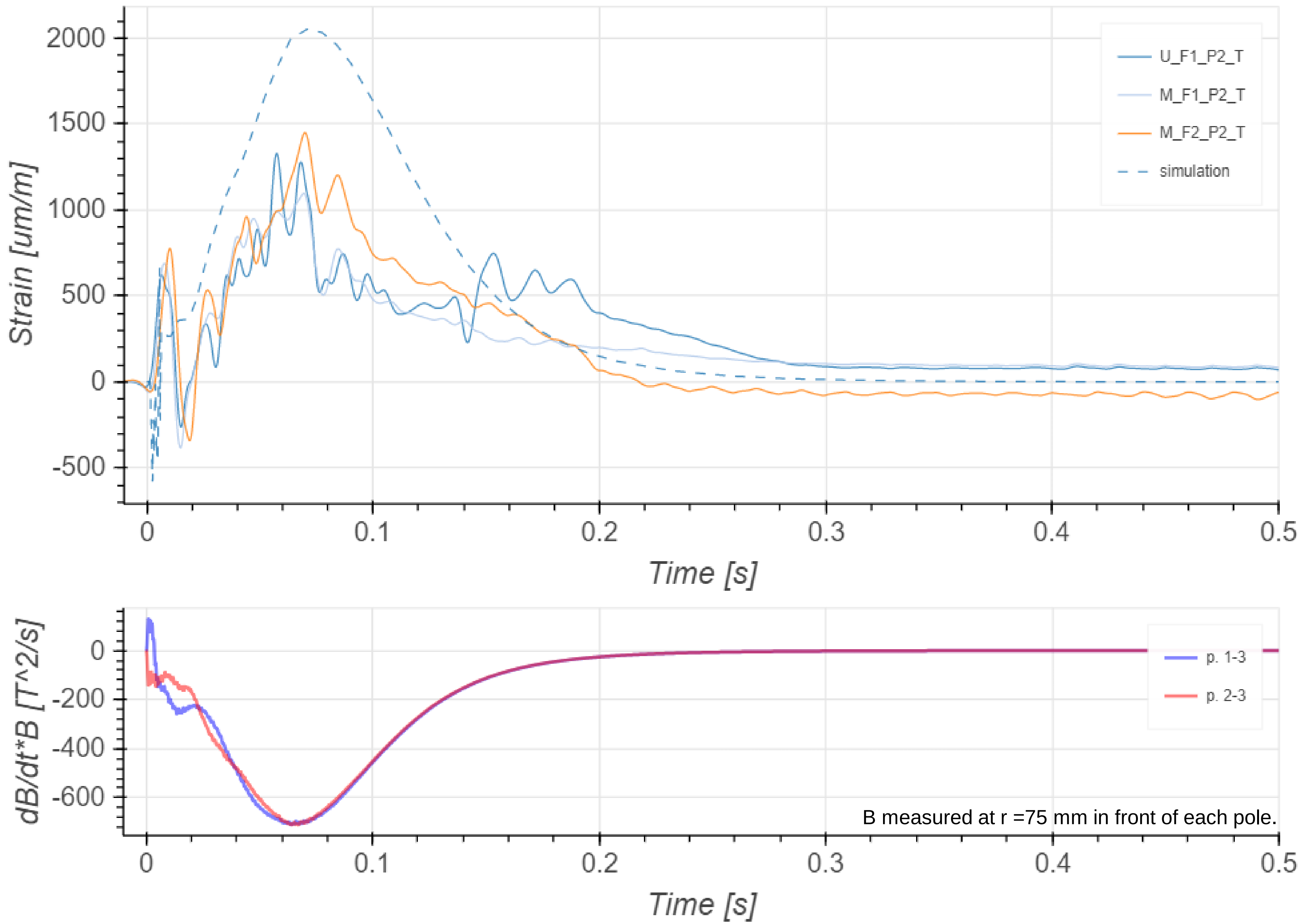


Results at 18.2 kA
(Strain gauges, measuring probe)

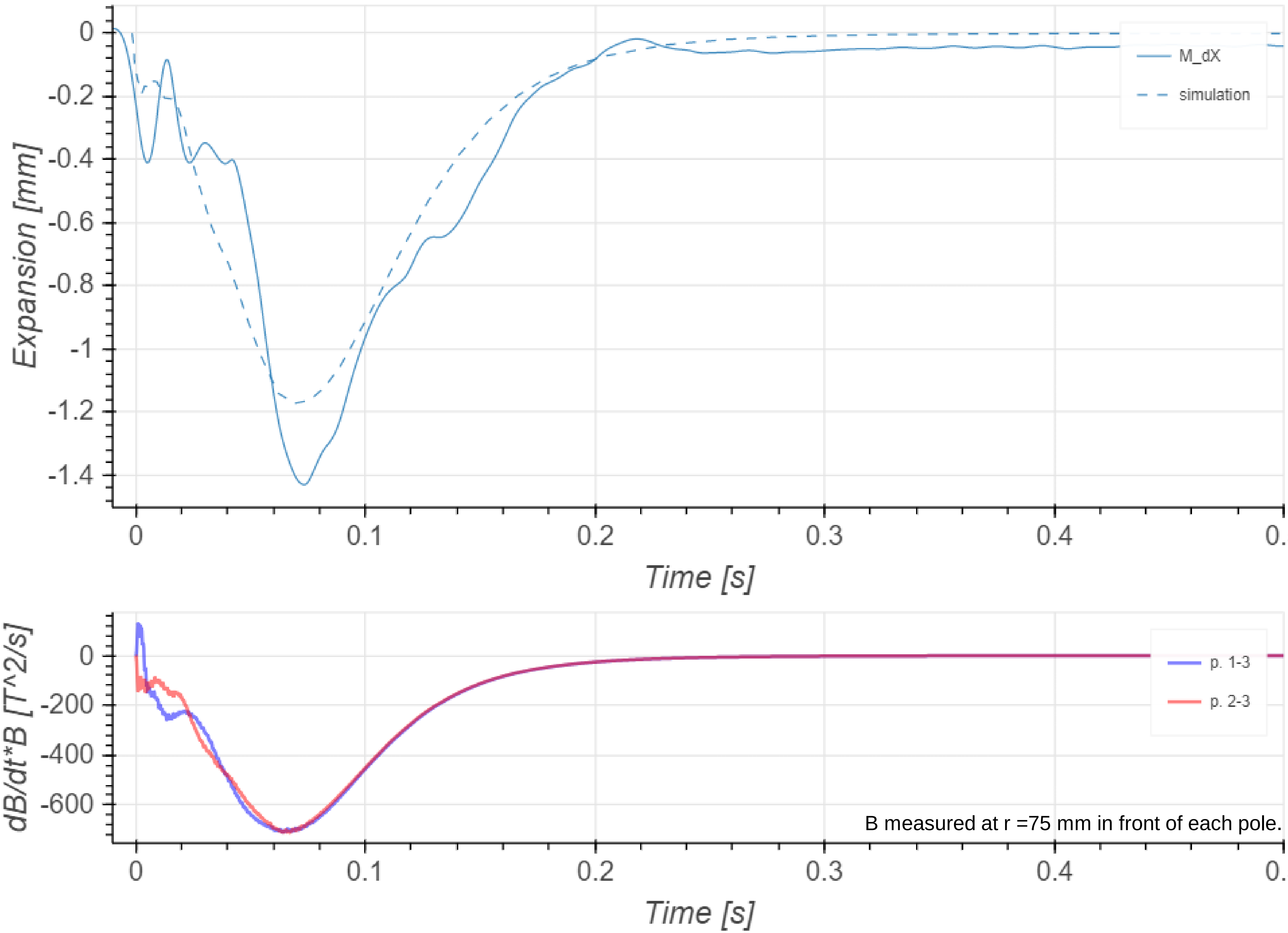




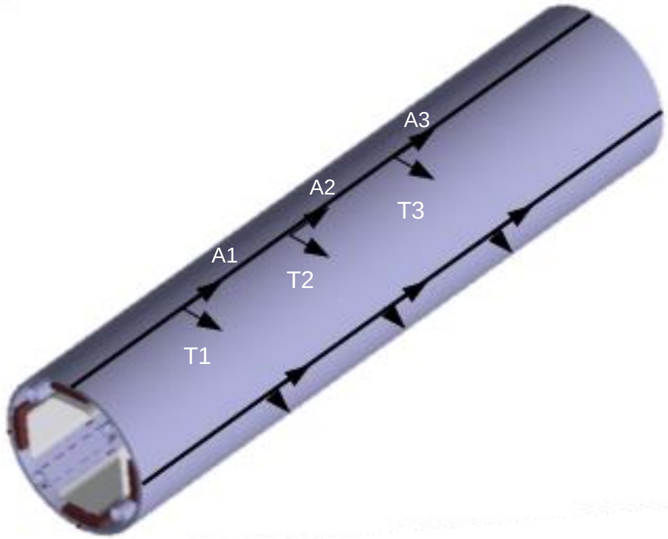
18.2 kA Face Center (P2) Transversal Strains



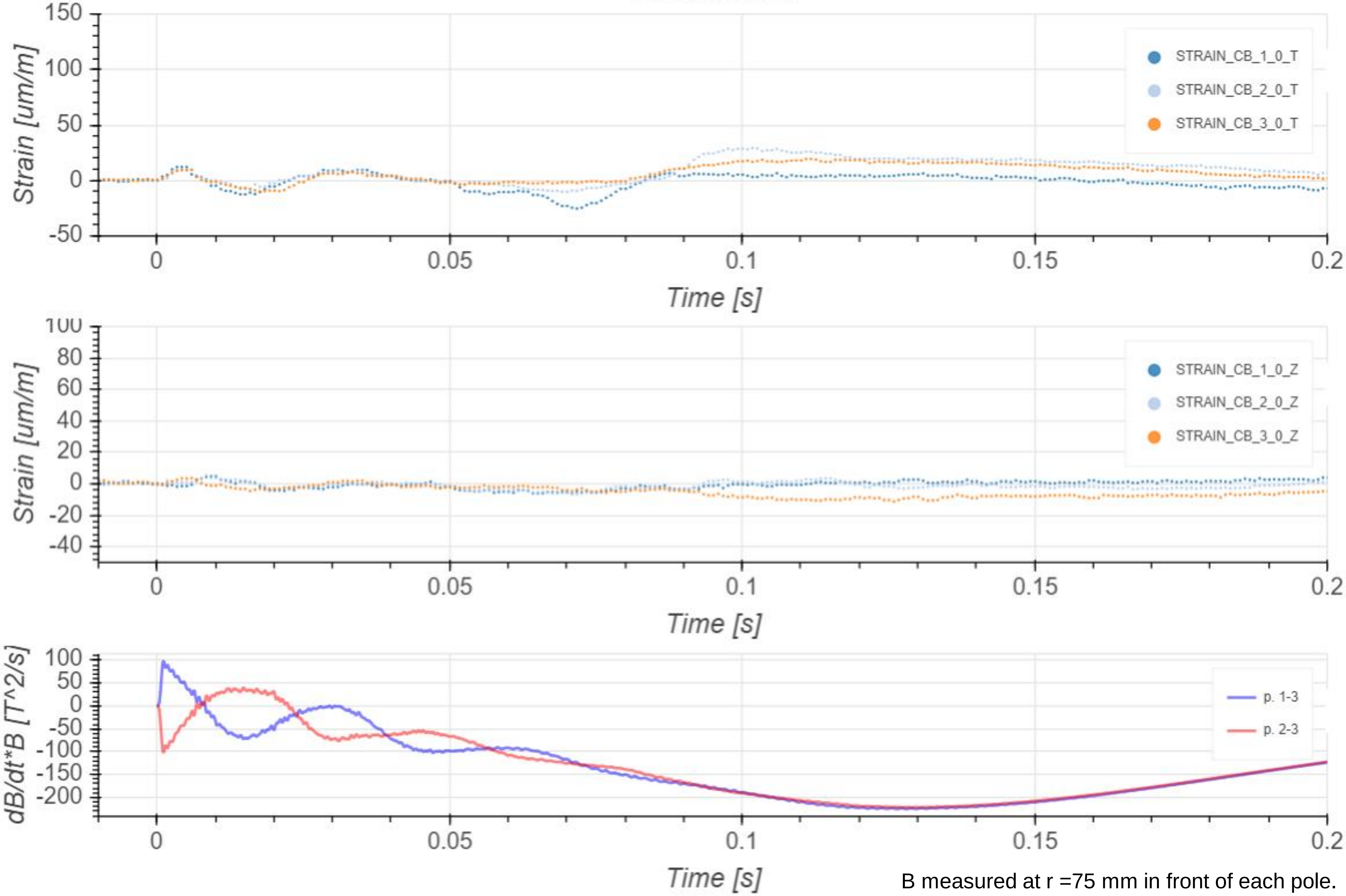
18.2 kA Beam Screen Expansion



Cold bore
(optical fibers)

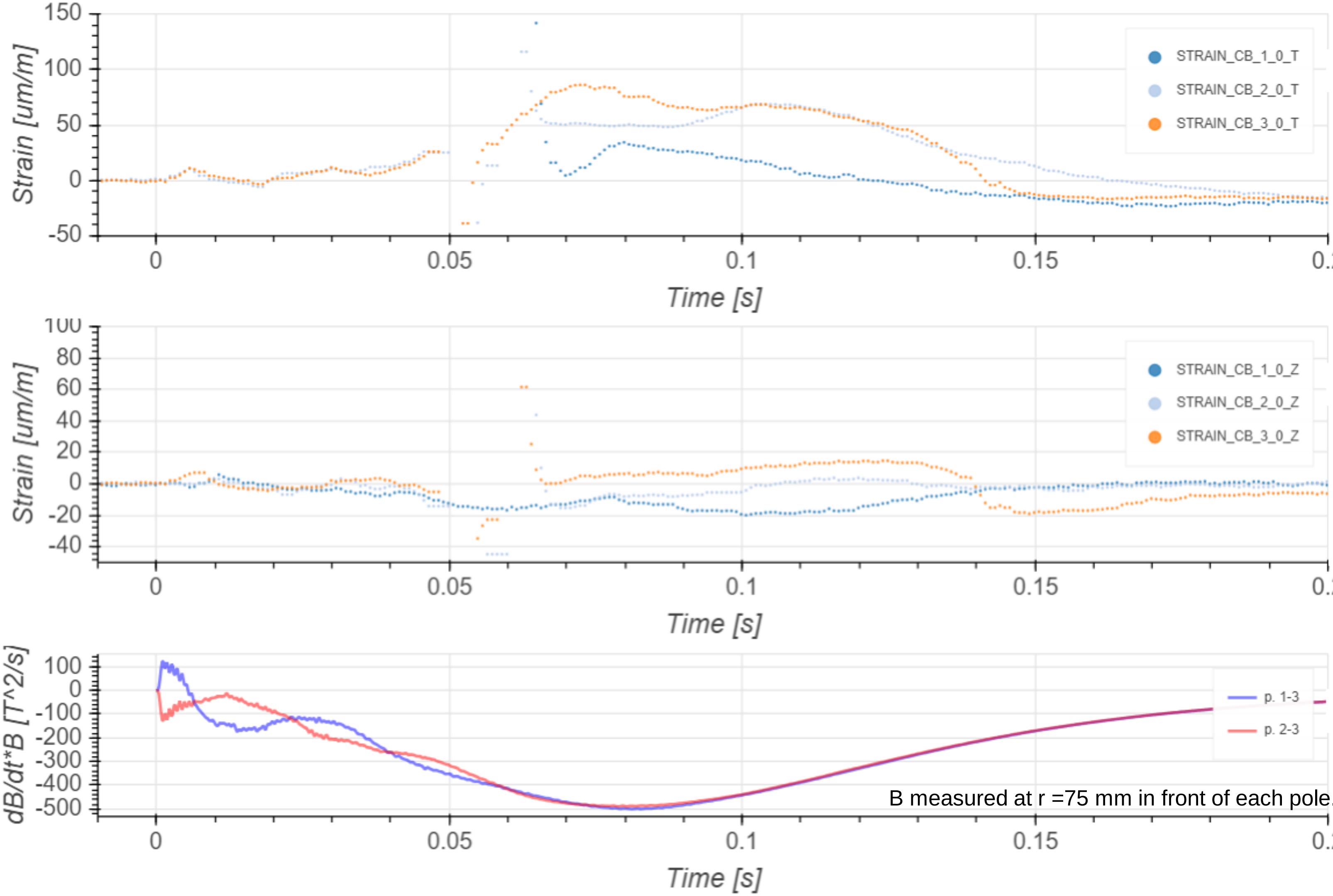


13 kA OFS



B measured at r =75 mm in front of each pole.

16 kA OFS



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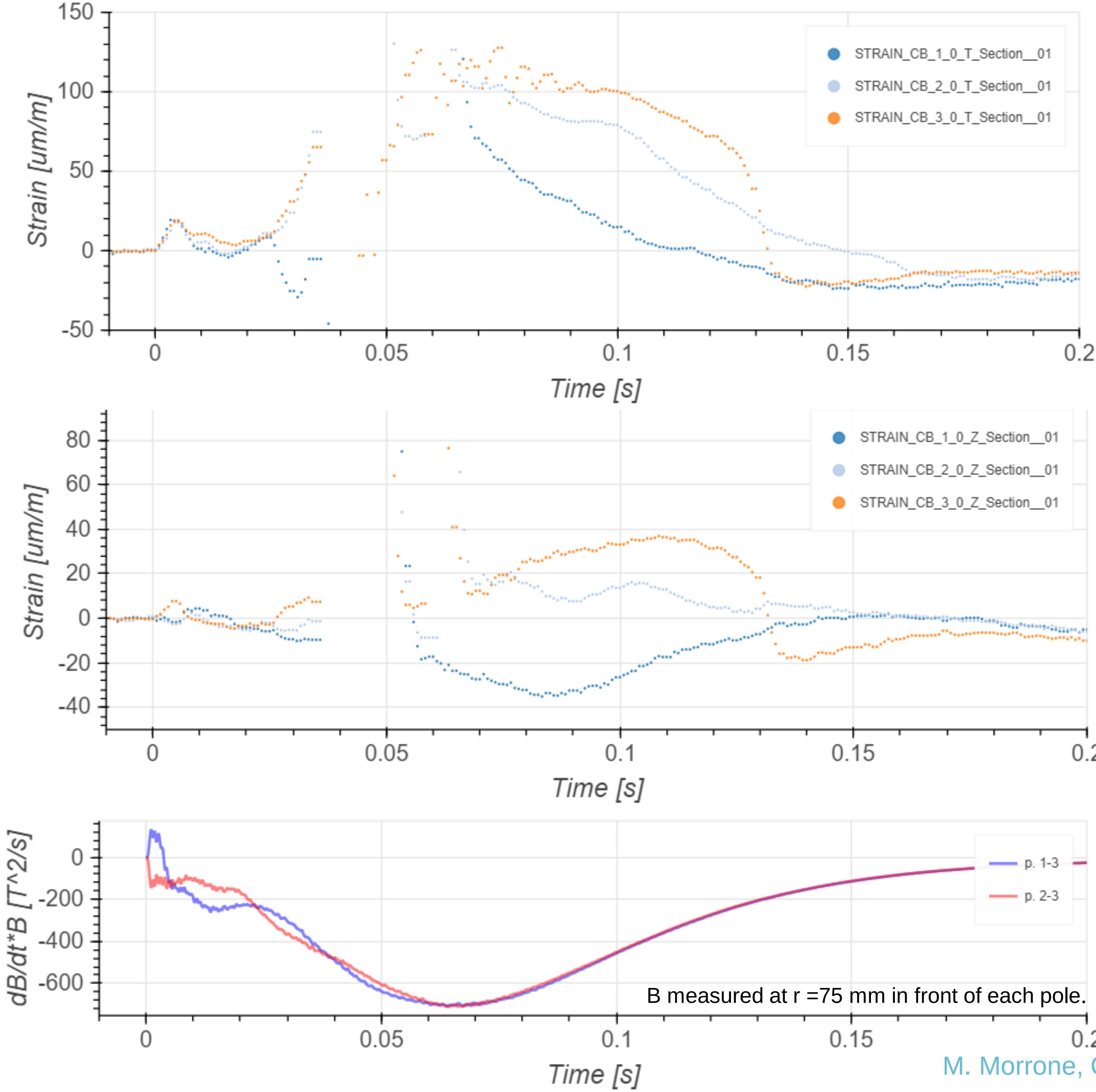
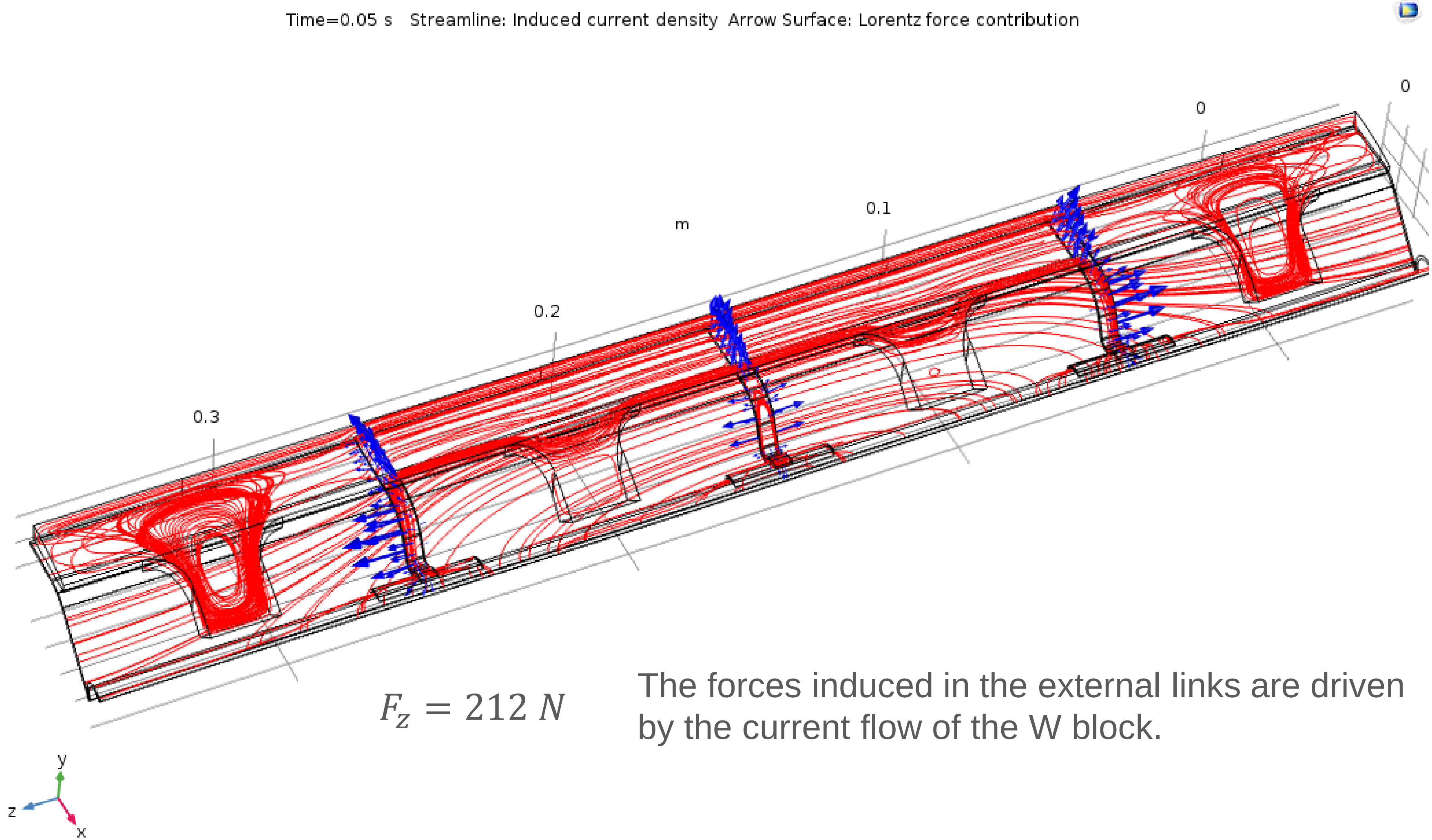
18 kA OFS



Strain [um/m]
Time [s]
STRAIN_CB_1_0_T_Section__01
STRAIN_CB_2_0_T_Section__01
STRAIN_CB_3_0_T_Section__01
STRAIN_CB_1_0_Z_Section__01
STRAIN_CB_2_0_Z_Section__01
STRAIN_CB_3_0_Z_Section__01
dB/dt*B [T^2/s]
p. 1-3
p. 2-3
B measured at r =75 mm in front of each pole.

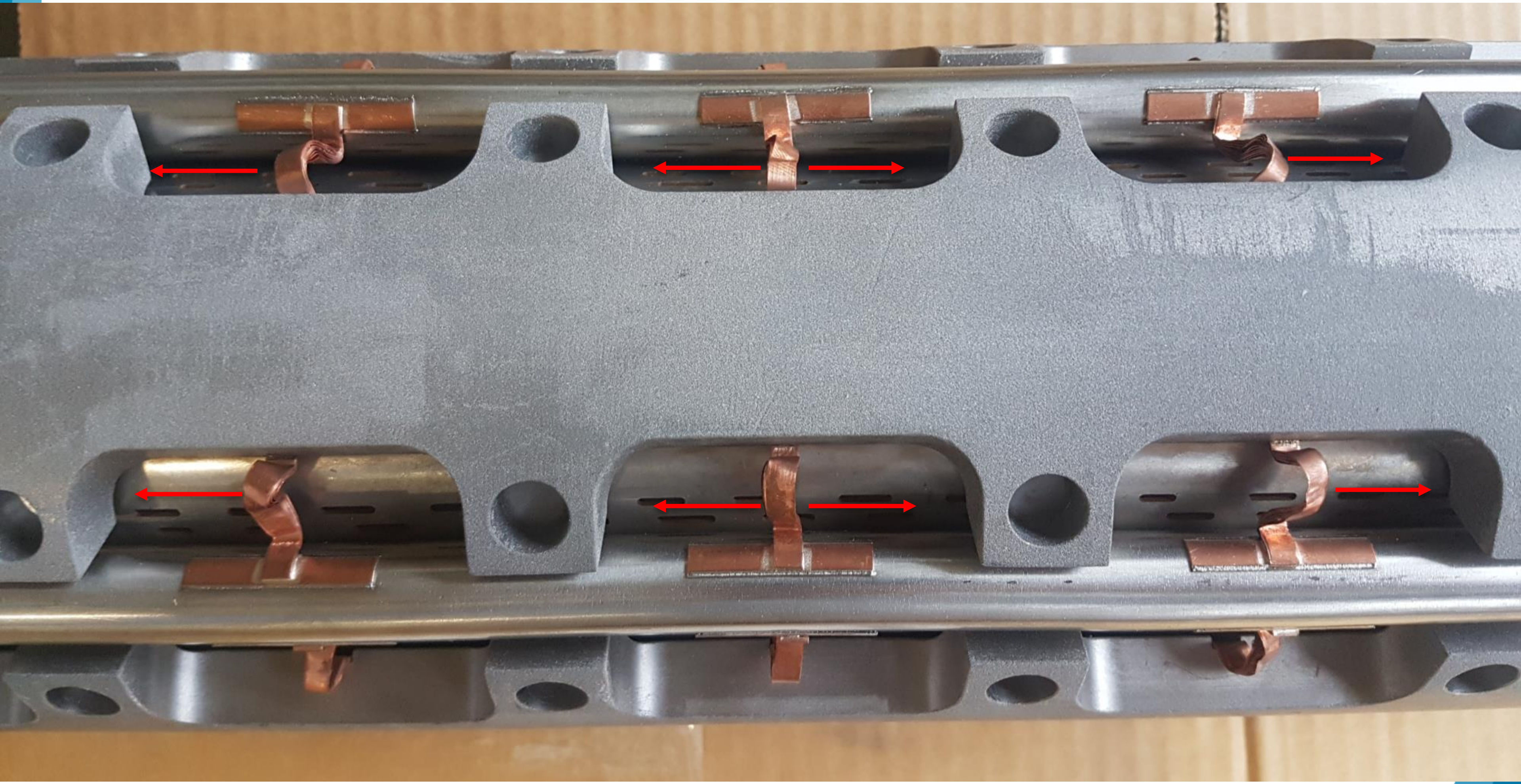
Thermal link (17.8 kA)



$F_z = 212\ N$

The forces induced in the external links are driven by the current flow of the W block.

Thermal link



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Conclusions

- The mechanical integrity of a Q1 beam screen prototype has been demonstrated. The behaviour of the beam screen remains elastic after 54 quenches up to 18.2 kA of current (ultimate current 17.8 kA);

- The thermal links, the elastic rings and the centring pins have been inspected after the quench test and no damage nor unexpected deformation has been observed;

- The beam screen behaves as expected during a quench:
  - The torque induced during the first phase of CLIQ has been observed;
  - The beam screen goes in contact with the cold bore;

- The mechanical response of the beam screen is directly correlated with the magnetic field measurements.

- A good agreement with simulation has been found;

Next steps

- Test of a Q2 type beam screen with the correct material (P506 instead of 316 L) and aC coating:
  - Magnetic field quality measurements;
  - Quench test.

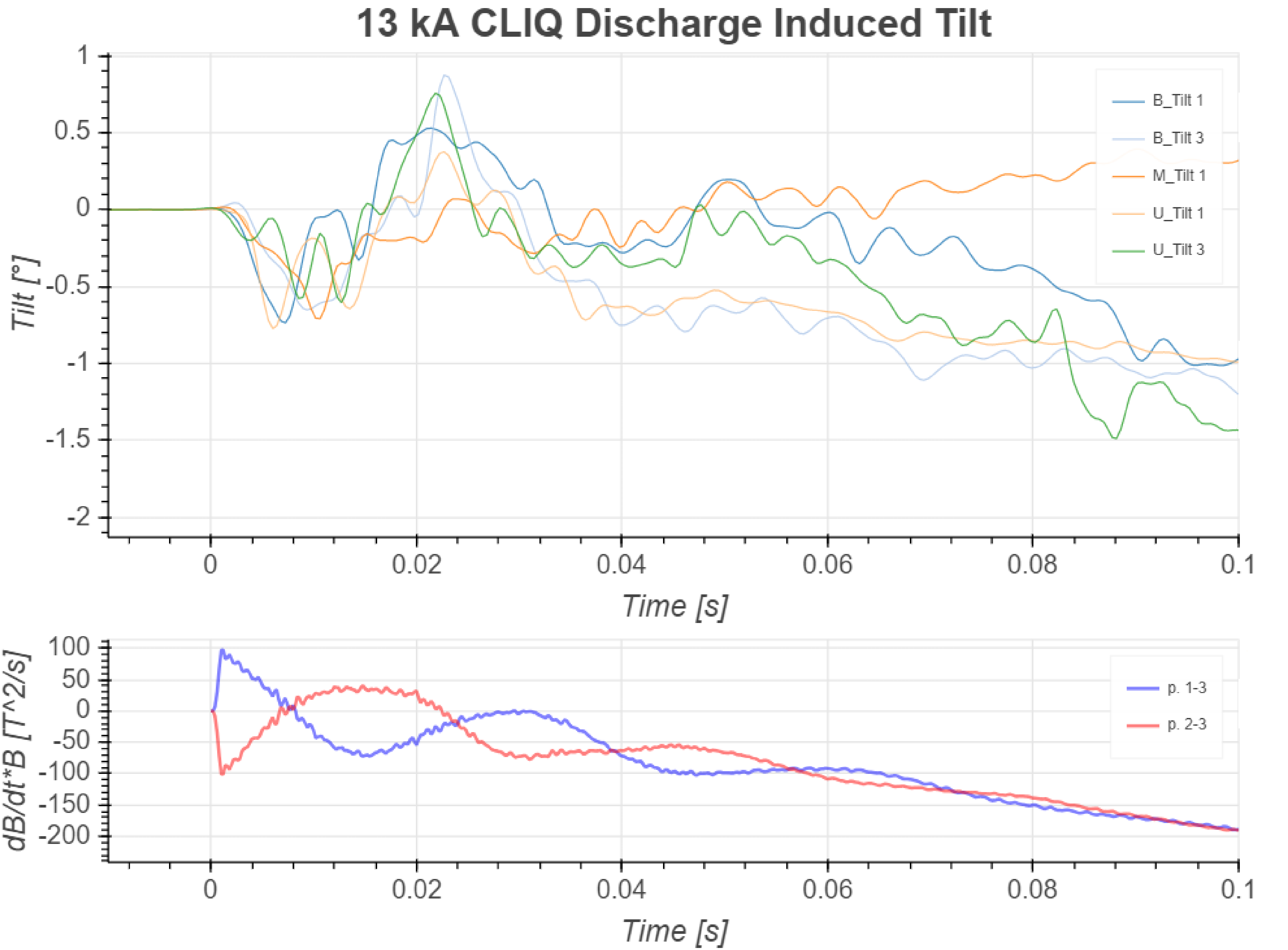
Acknowledgements

A big thanks to the colleagues of WP3, SM18 and EN-MME. In particular:

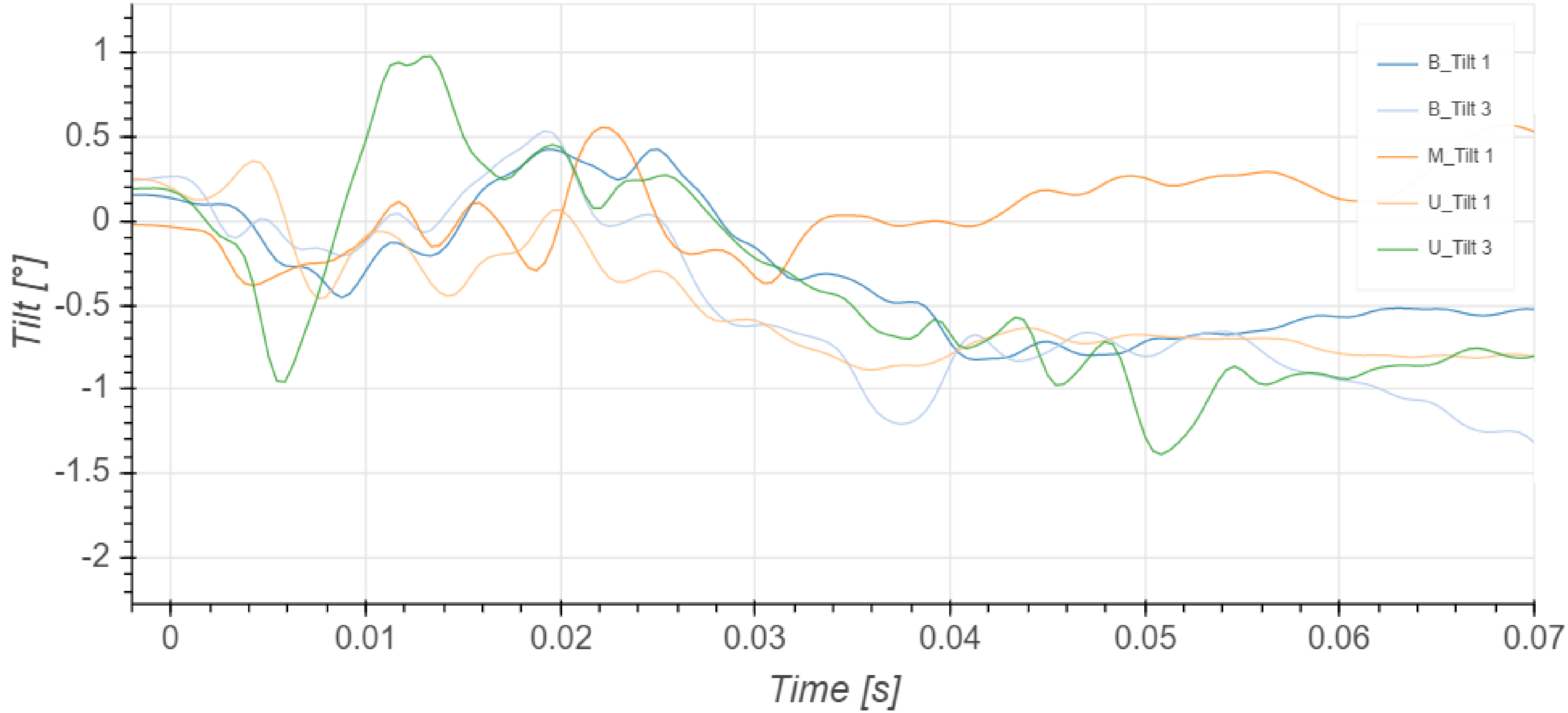
P. Ferracin, E. Todesco, N. Bourcey, S. Izquierdo Bermudez, J.C. Perez, M. Bajko, F. Mangiarotti, J. Feuvrier, O. Sacristan, M. Guinchard, L. Fiscarelli, E. Ravaioli, L. Bortot

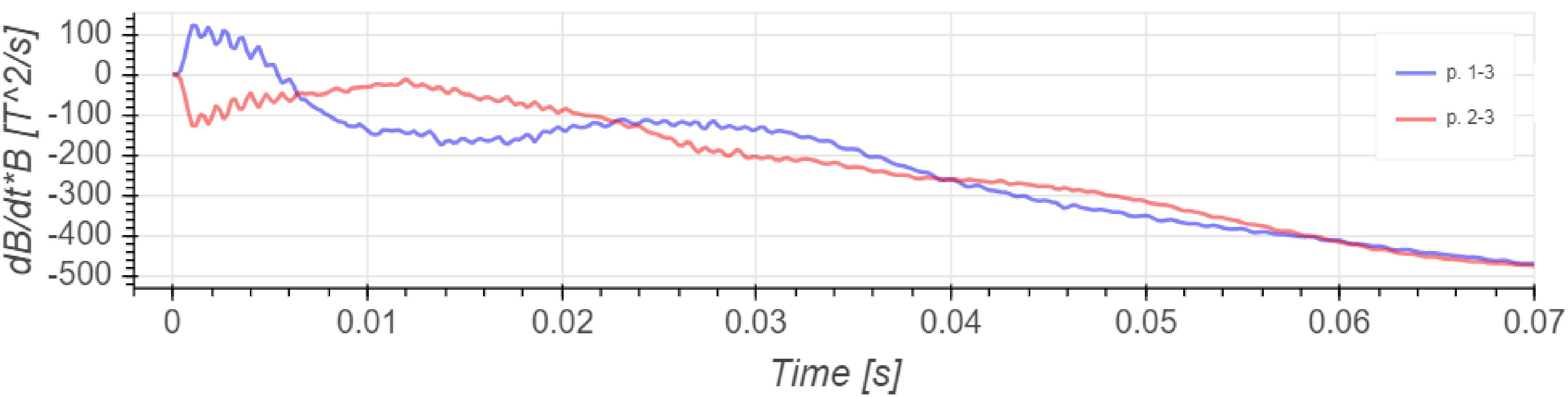
Thank you

Back up slides


13 kA CLIQ Discharge Induced Tilt
Tilt [°]
1
0.5
0
-0.5
-1
-1.5
-2
0
0.02
0.04
0.06
0.08
0.1
Time [s]
B_Tilt 1
B_Tilt 3
M_Tilt 1
U_Tilt 1
U_Tilt 3
dB/dt*B [T^2/s]
100
50
0
-50
-100
-150
-200
0
0.02
0.04
0.06
0.08
0.1
Time [s]
p. 1-3
p. 2-3

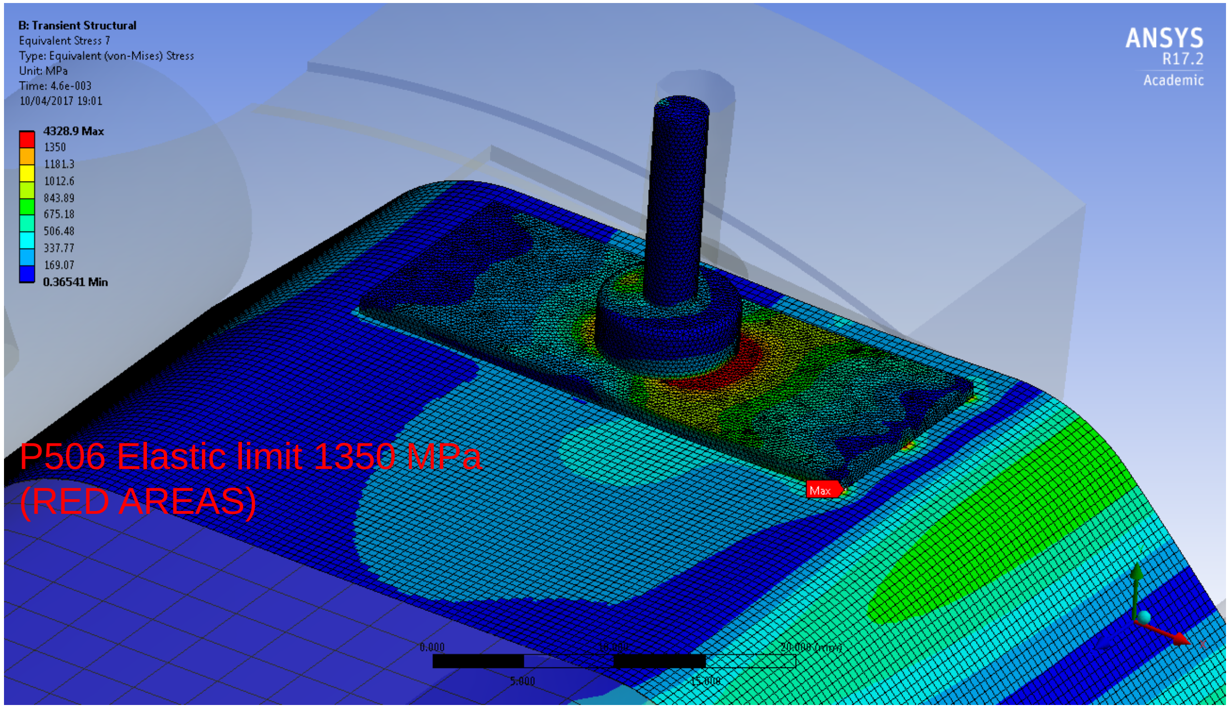
16 kA CLIQ Discharge Induced Tilt





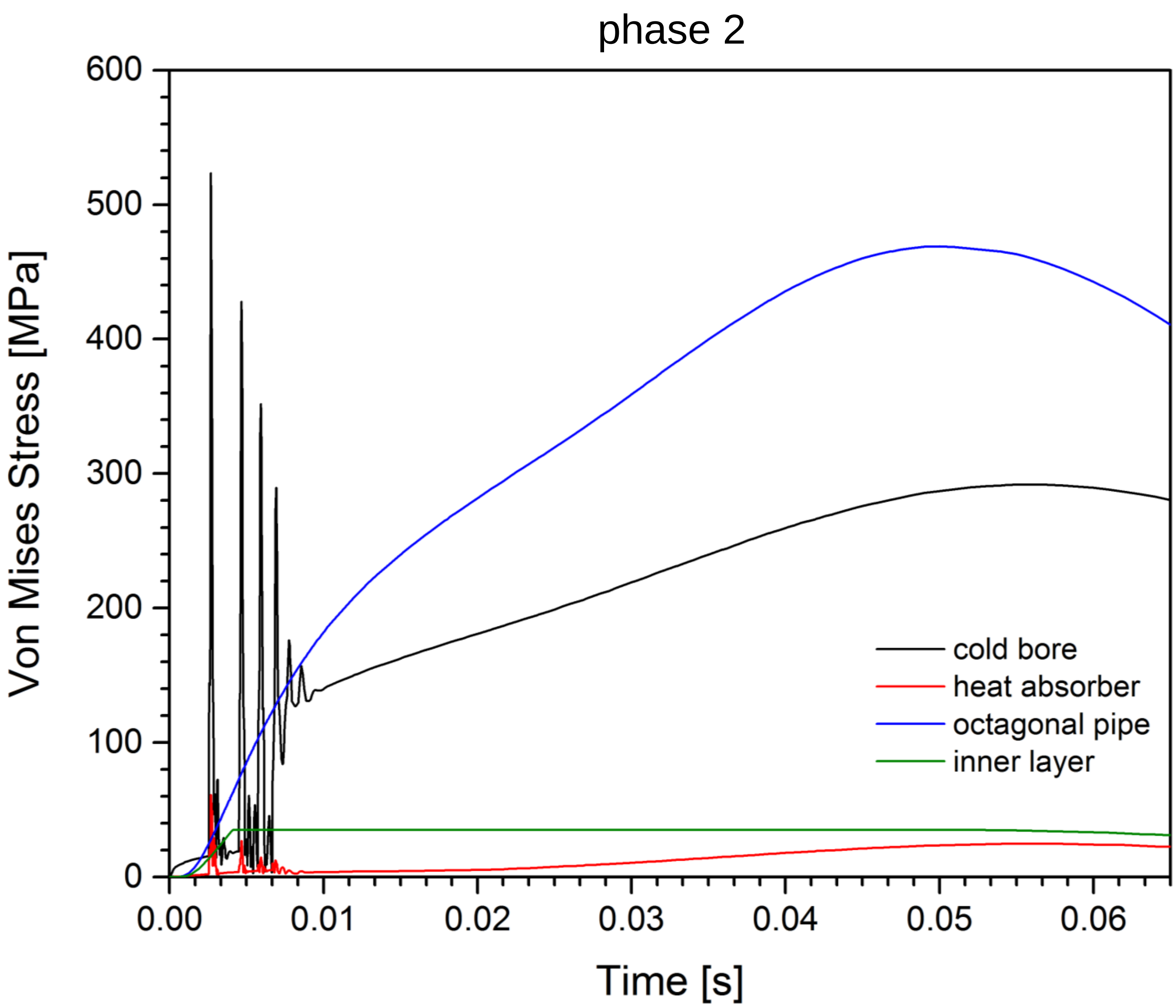
Numerical results: baseline (17.8 kA)

CLIQ phase 1

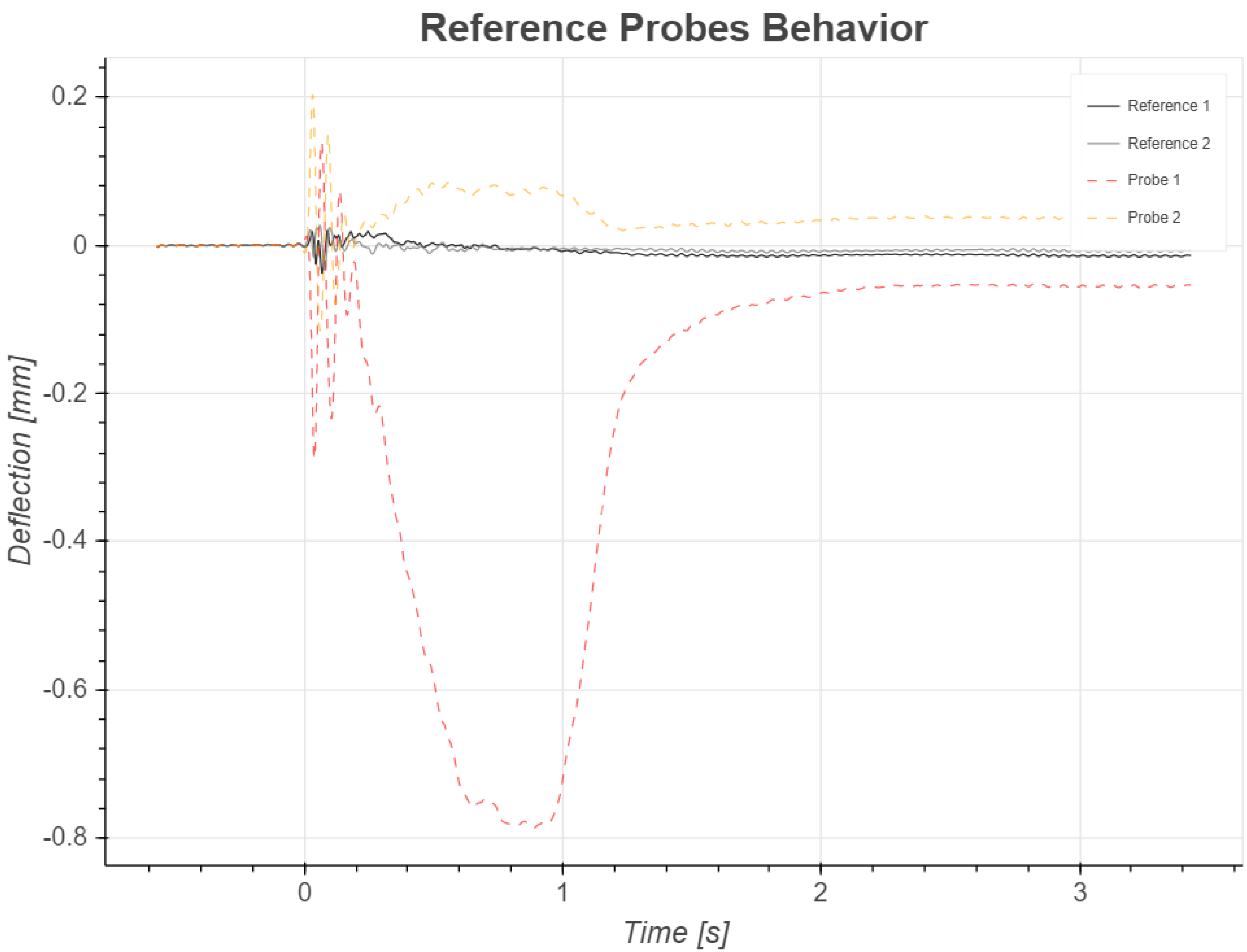


component	material	Elastic limit	Q1		
			$F_{y\ max}$ [N/mm] -per eight-	σ_{max} [MPa]	δ_{max} [mm]
Cold bore	Ss 316 LN	860 MPa (at 4 K)	12.3	624	1.51
Heat absorber	Inermet	1284 (at 77K)	22	> 1284 (loc.)	-
Octagonal pipe+ Cu layer	Ss P506	1350 MPa (at 50 K)	5.3	> 1350 (loc.)	-
Pin	Ss P506	1350 MPa (at 50 K)	-	> 1350 (loc.)	-

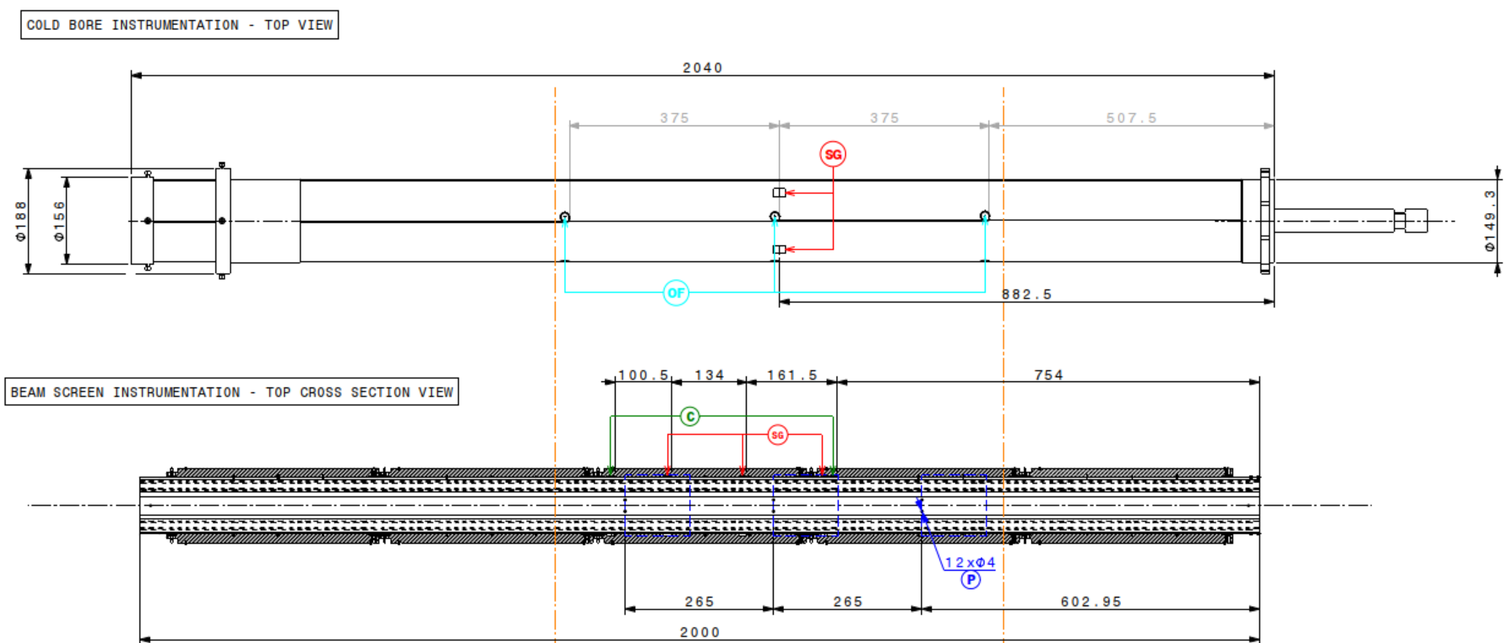
Numerical results: baseline (17.8 kA)

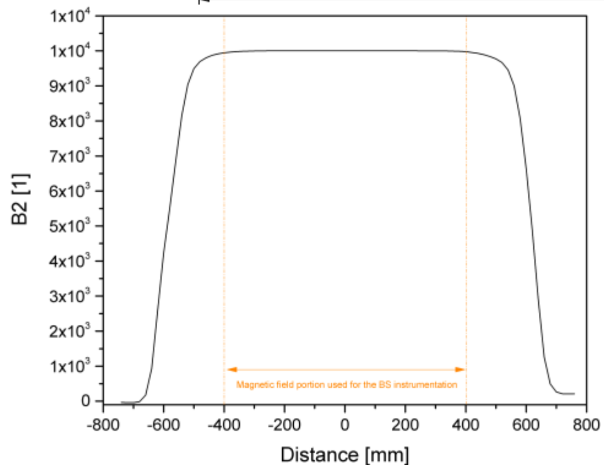


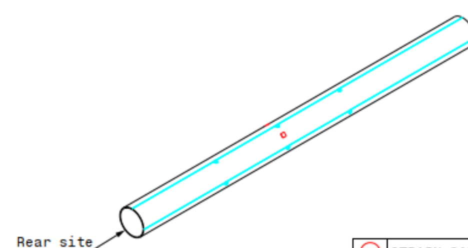
signal of the compensator probe at 8.2 kA



Cold bore and beam screen instrumentation layout







SG	STRAIN GAUGE	-
OF	OPTICAL FIBRE	-
P	PROBE	-
C	COMPENSATOR	-