LHC Collimation Project CERN

MME Mechanical & Materials Engineering

Experimental and numerical studies of the BPMs embarked in the HL-LHC collimators

Michele Pasquali

A. Bertarelli, C. Boccard, F. Carra, L. Gentini, A. Gerardin, G. Gobbi, J. Guardia

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CERN | EN ENGINEERING DEPARTMENT

Outline

- TCSPM design scenarios
  - 1h BLT / 0.2 BLT case
- Numerical analyses
  - System description
  - Optimized design for heat dissipation
  - Results
- Experimental tests
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  - Results
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TCSPM design scenarios

- TCSPM: low-impedance secondary collimator, jaw in MoGr

- Same as LHC TCS design cases

- Slow losses
  - Nominal operation: 1h BLT
  - Accidental case: 0.2h BLT (10s)

- Direct beam impact (incident)
  - Asynchronous beam dump: 5 full LHC bunches impact
  - Beam injection error: 288 SPS bunches impact

Cases 1 h - 0.2 h BLT

- HL-LHC 7 TeV 25ns (standard)
- N_{tot} = 6.0E+14 → losses on the full collimation system 1.68E11 p/s - 8.34E11 p/s (1h - 0.2h BLT)
- Configuration: 2σ retraction (*TCPs@5.7σ and TCSPMs@ 7.7σ*)
- Most loaded collimator is a skew TCSPM in the position of TCSGA6L1

	Energy deposition on TCSPM ★			
	1 h BLT		0.2 h BLT	
	GeV/p	kW	GeV/p	kW
Tank	86.35	2.03	86.35	10.15
Left Jaw	395	9.30	395	46.5
Right Jaw	398.4	9.38	398.4	46.9
Total		**20.71**		**103.55**

★ Considering a normalization factor of ~0.875, provided by EN-STI (Eleftherios Skordis), due to the losses on other collimators

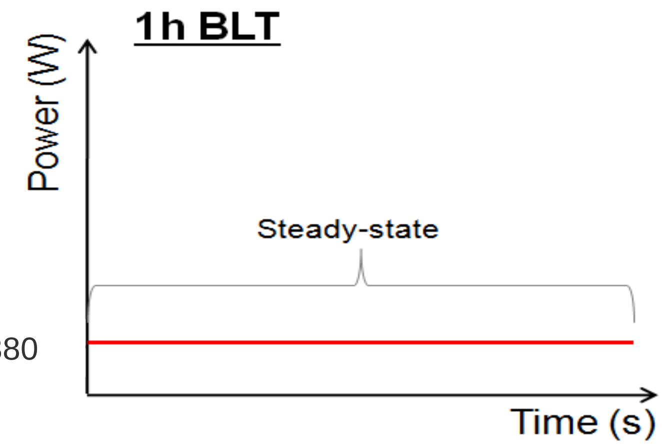


Figure 1: *Power deposition according to the 1h BLT case.*

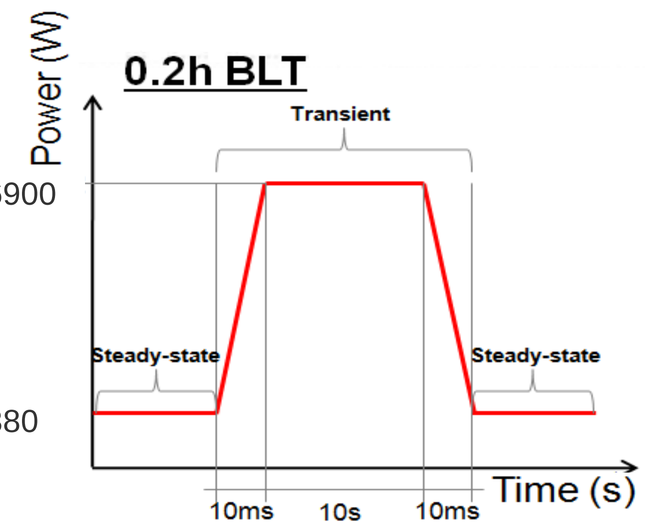


Figure 2: *Power deposition according to the 0.2h BLT case.*

System description

Components	Materials	Power dep. [kW]	
		1 h BLT	0.2 h BLT
Blocks	MoGr 6403 Fc	4	20
Taperings	MoGr 6403 Fc	0.6	3
Clamps	Glidcop Al-15	1.37	6.85
Cooling Pipes	CuNi 90-10	0.35	1.75
Housing	Glidcop Al-15	1.8	9
Counter plate	Glidcop Al-15	0.43	2.15
Stiffener	Glidcop Al-15	0.76	3.8

Parameters	Values
Convective coeff. (v=3 m/s)	13800 W/(m²K)
T initial of water	22°C
ΔT out-in cooling pipes	14°C - 24°C
Conduct. int. 1 - 2,3	83000 - 25000 W/(m²K)
Conduct. 4 (10 cm CuBe cable)	660 W/(m²K)

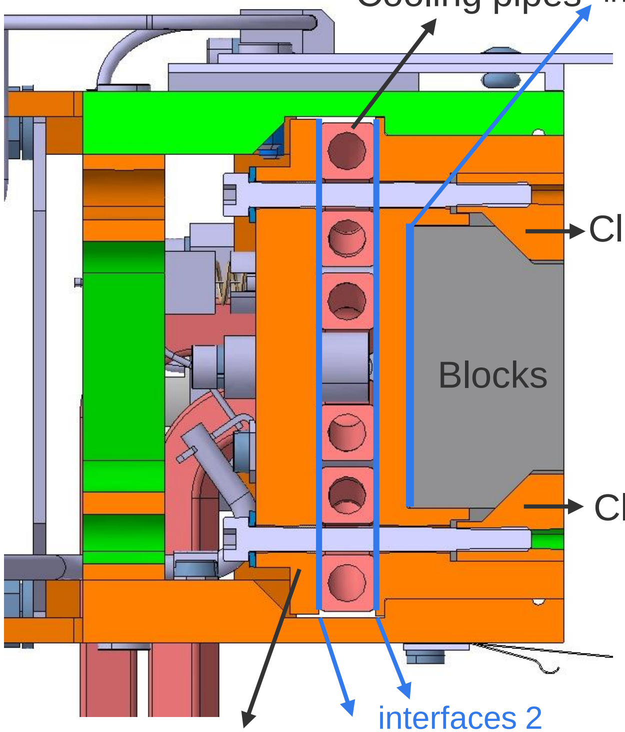


Figure 3: *Cross section of the TCSPM jaw.*

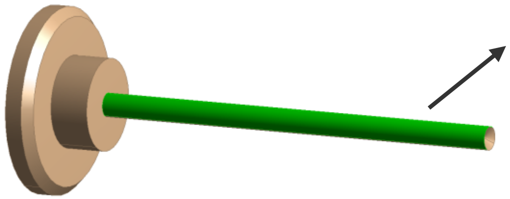


Figure 4: *BPM electrode and pin.*

Optimized design for BPMs' heat dissipation

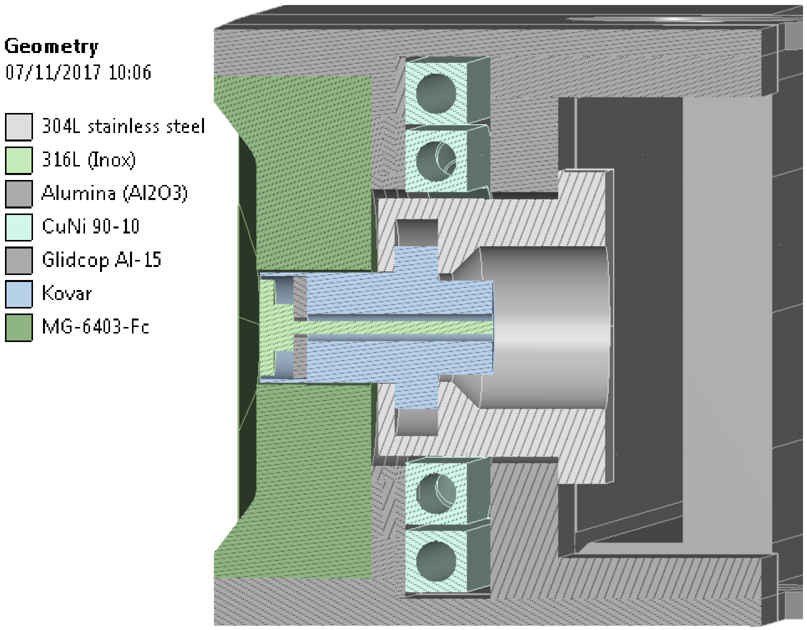


Figure 5: *Old design for BPMs cooling of TCSPM collimators.*

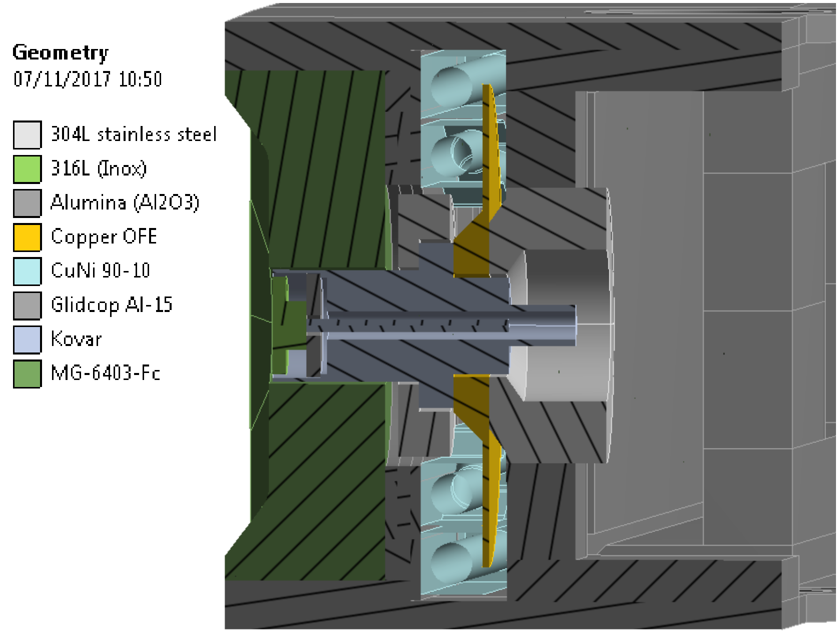
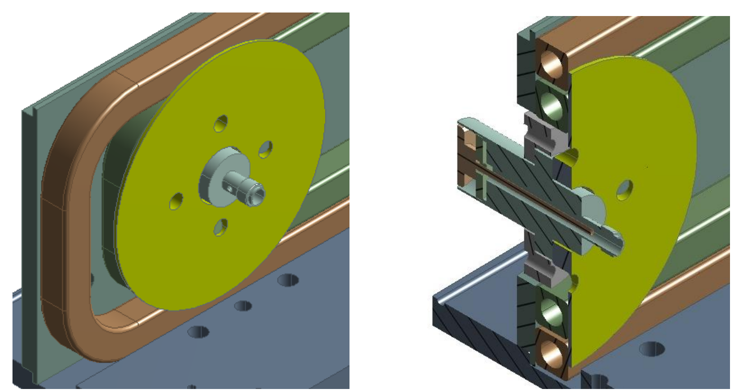


Figure 6: *New design for BPMs cooling of TCSPM collimators.*

- A 1mm-thick OFE copper-made disk has been inserted all around the BPMs to improve its thermalization;
- A direct contact between the cooling pipes and the BPM case is therefore provided.



Results: temperature field (1h BLT)

- Previous BPM design - 316LN electrode
- Enhanced BPM design - 316LN electrode

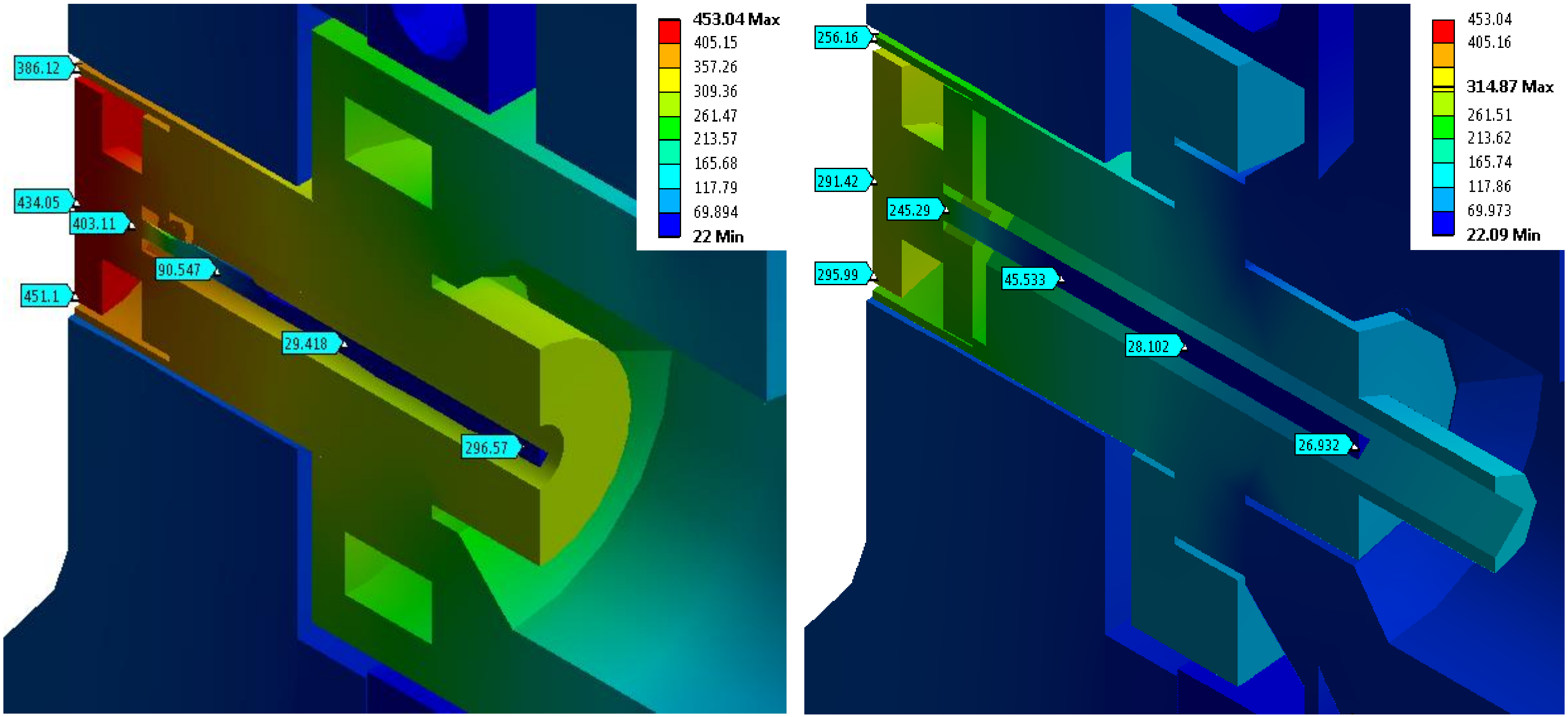


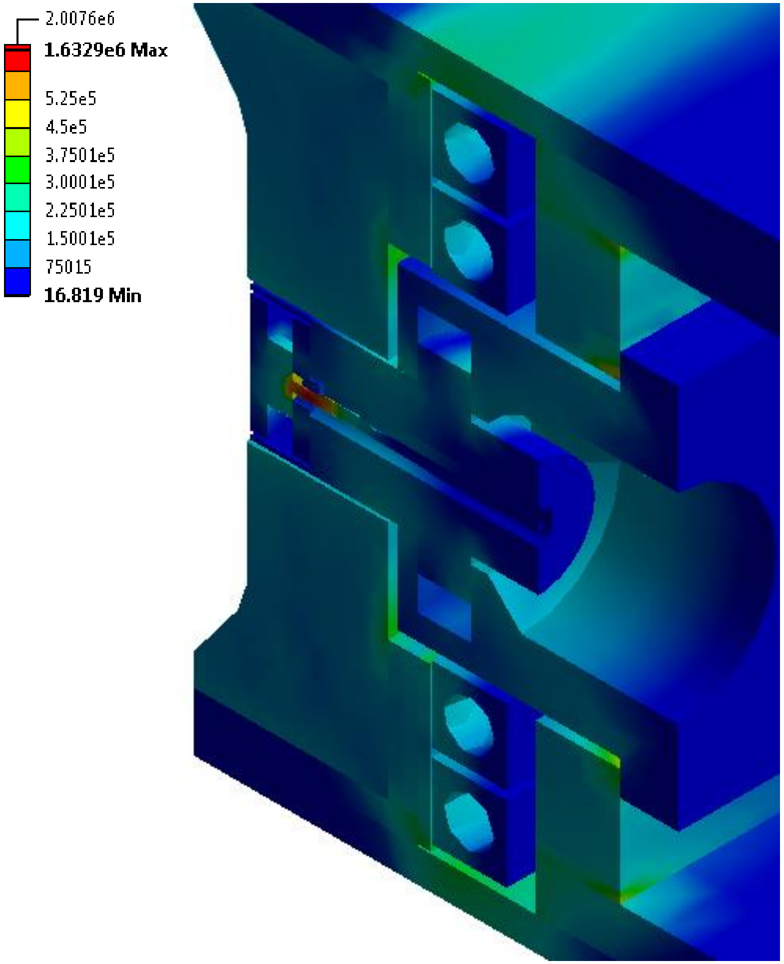
Figure 7: *Temperature field on a cross-section of the TCSPM collimator with previous (left) and enhanced (right) design..*

- Power on BPM = 67.03 W
- T_{max} = 453 ºC (on the electrode)

- Power on BPM = 67.03 W
- T_{max} = 315 ºC (on the electrode)

Results: total heat flux (1h BLT)

- Previous BPM design - 316LN electrode



- Enhanced BPM design - 316LN electrode

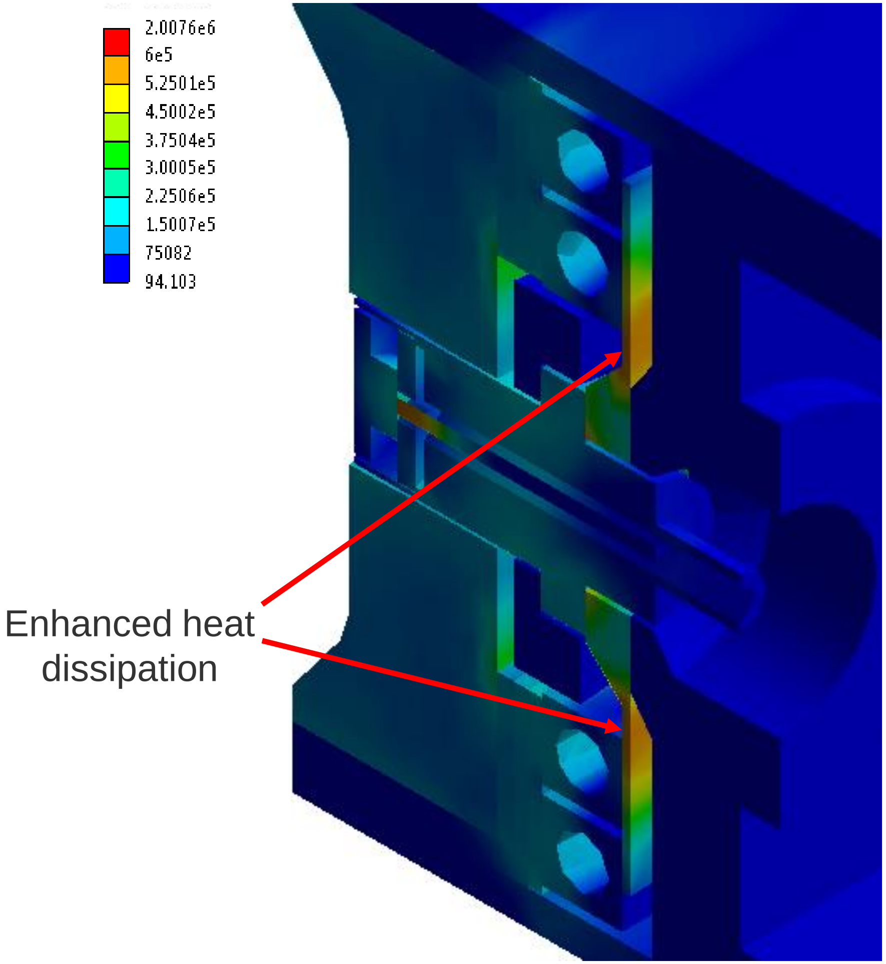
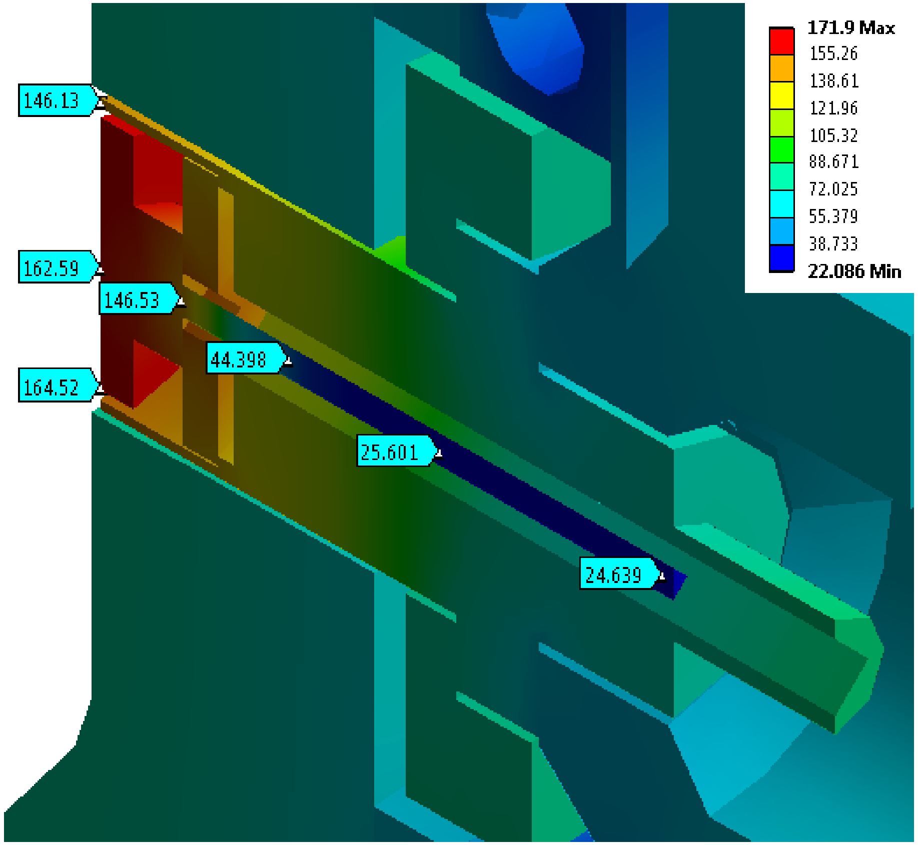
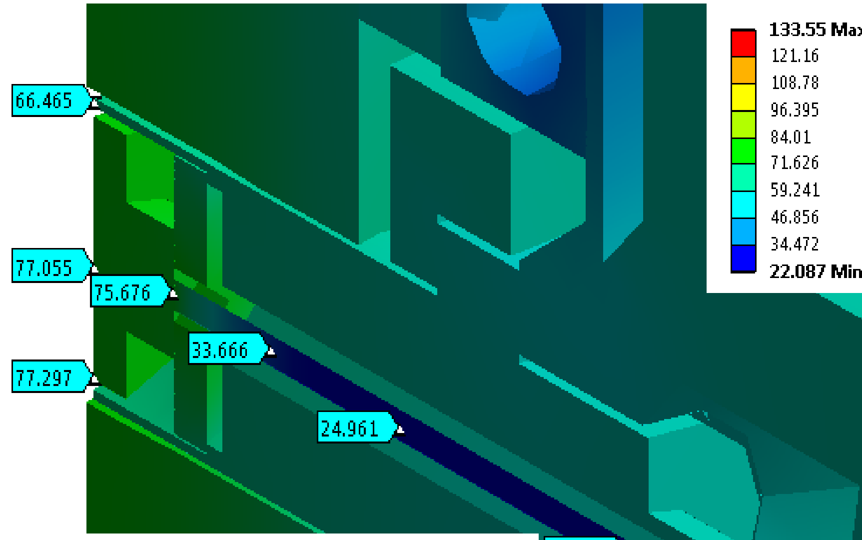


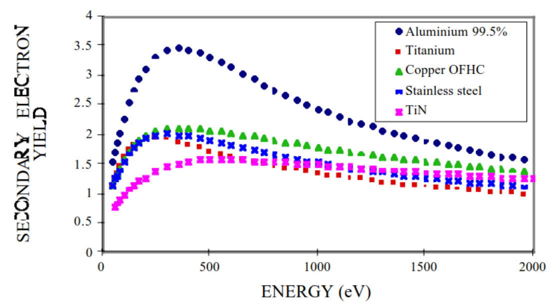
Figure 8: *Total heat flux on a cross-section of the TCSPM collimator with previous (left) and enhanced (right) design..*

Results: temperature field (1h BLT)

- Enhanced BPM design – Ti electrode
- Enhanced BPM design – Al electrode







SEY values out of design limits

Figure 9: *Temperature field on a cross-section of the TCSPM collimator with Ti electrode (left) and Al electrode (right) featuring the new design.*

- Power on BPM = 43.60 W
- T_{max} = 172 ºC (on the electrode)

- Power on BPM = 39.04 W
- T_{max} = 134 ºC (on the electrode T_{max} = 78 ºC)

Results: temperature field (0.2h BLT)

- Previous BPM design - 316LN electrode
- Enhanced BPM design - 316LN electrode

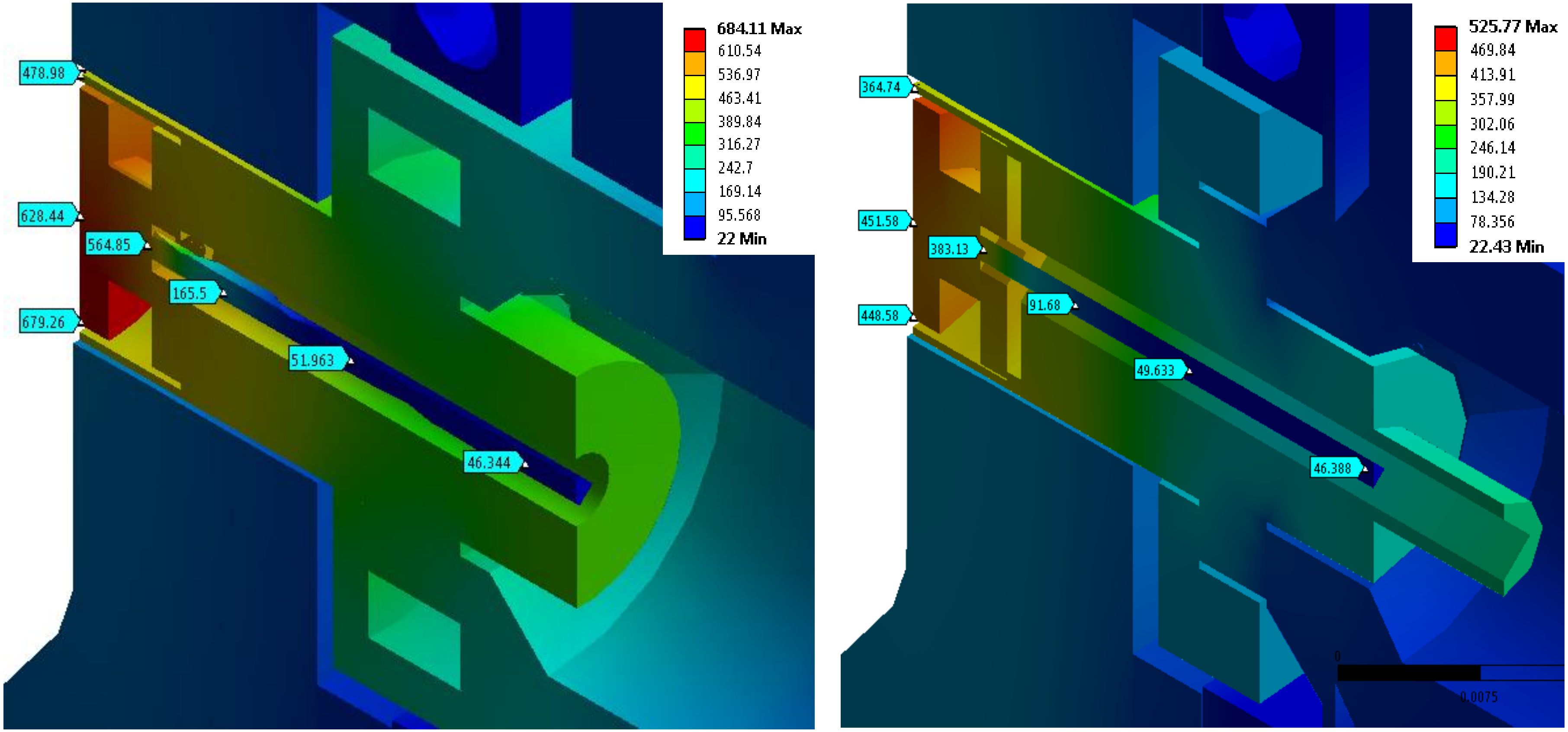
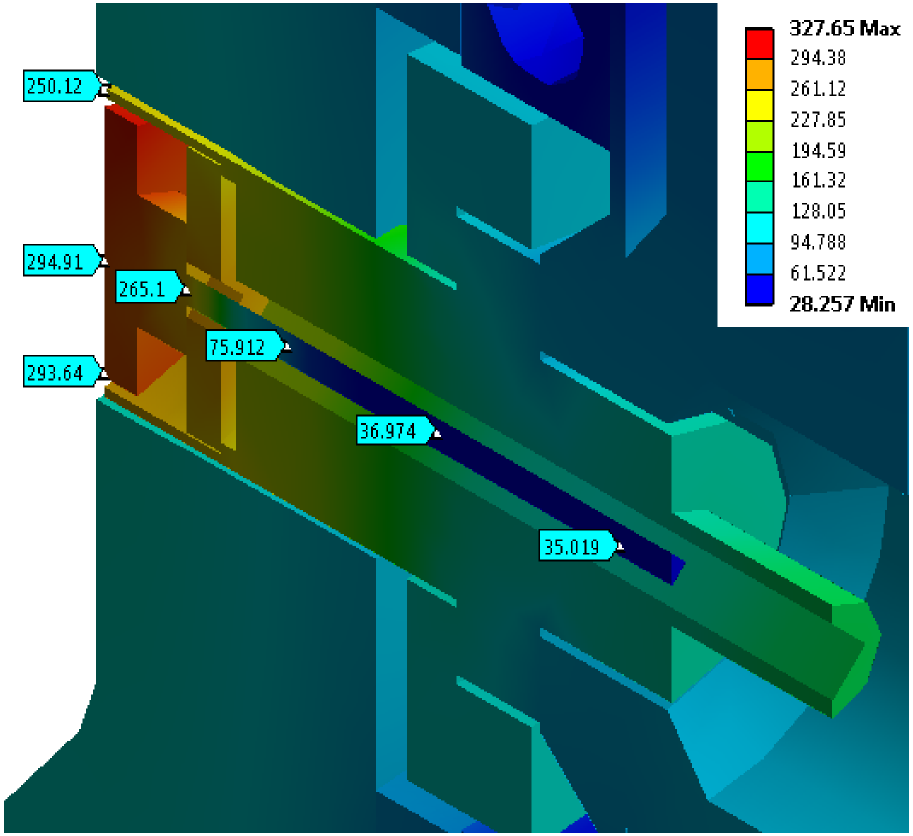


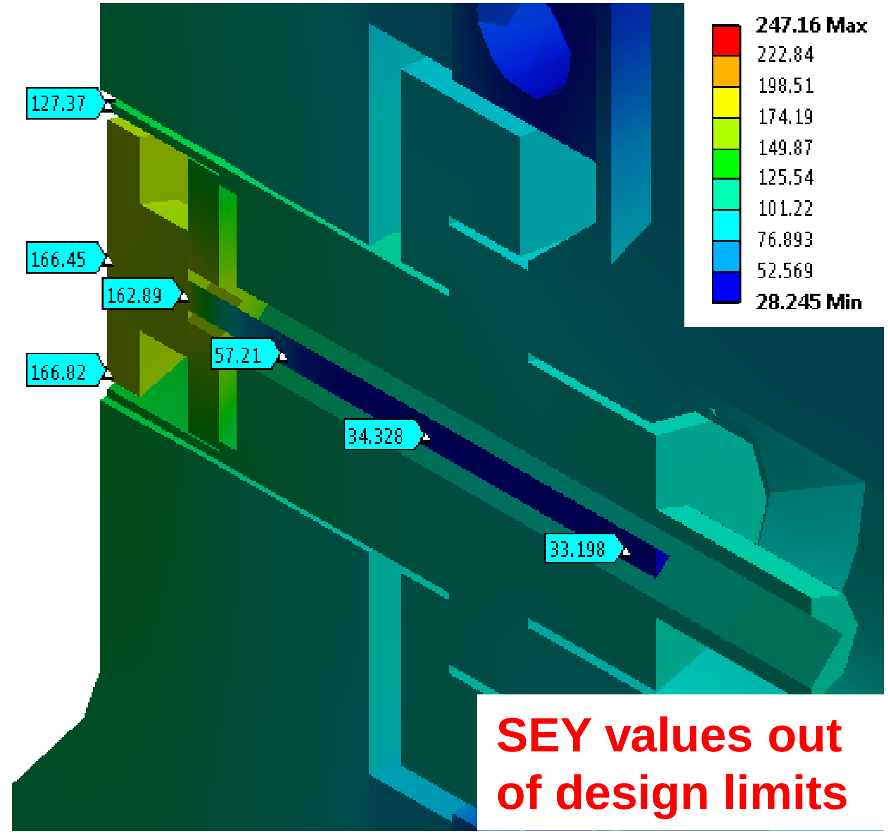
Figure 10: *Temperature field on a cross-section of the TCSPM collimator with previous (left) and enhanced (right) design.*

- Electrode: 316LN (Power on BPM = 335.15 W)
- T_{max} = 685 ºC (on the electrode)
- Electrode: 316LN (Power on BPM = 335.15 W)
- T_{max} = 526 ºC (on the electrode)

Results: temperature field (0.2h BLT)

- Enhanced BPM design – Ti electrode
- Enhanced BPM design – Al electrode





SEY values out of design limits

Figure 11: *Temperature field on a cross-section of the TCSPM collimator with Ti electrode (left) and Al electrode (right) featuring the new design*

- Electrode: Ti (Power on BPM = 203 W)
- T_{max} = 328 ºC (on the electrode)
- Electrode: Al (Power on BPM = 195.2 W)
- T_{max} = 247 ºC (on the electrode T_{max} = 169ºC)

Results: summary of numerical predictions

- Power deposition on downstream TCSPM BPM

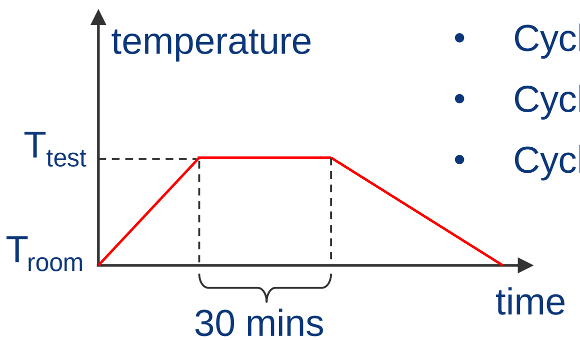
Absorbers	BPM Electrode	Total Deposited Power [W]		Max Power Density [MW/m³]	
		1h BLT	0.2h BLT	1h BLT	0.2h BLT
MG6403Fc	316LN	67.03	335.15	43.9	220
MG6403Fc	Ti	43.60	203	20.1	101
MG6403Fc	Al	39.04	195.2	16.6	83

- Max temperature on downstream TCSPM BPM

Absorbers	BPM Electrode	Enhanced Cooling Design	Max Electrode Temperature [ºC]		
			1h BLT	0.2h BLT	
MG6403Fc	316LN	No	453	684	
MG6403Fc	316LN	Yes	315	526	
MG6403Fc	Ti	Yes	172	328	← Available from supplier
MG6403Fc	Al	Yes	78	169	← SEY out of design limits

Experimental tests on TCSPM/TCSP BPMs

- Test description

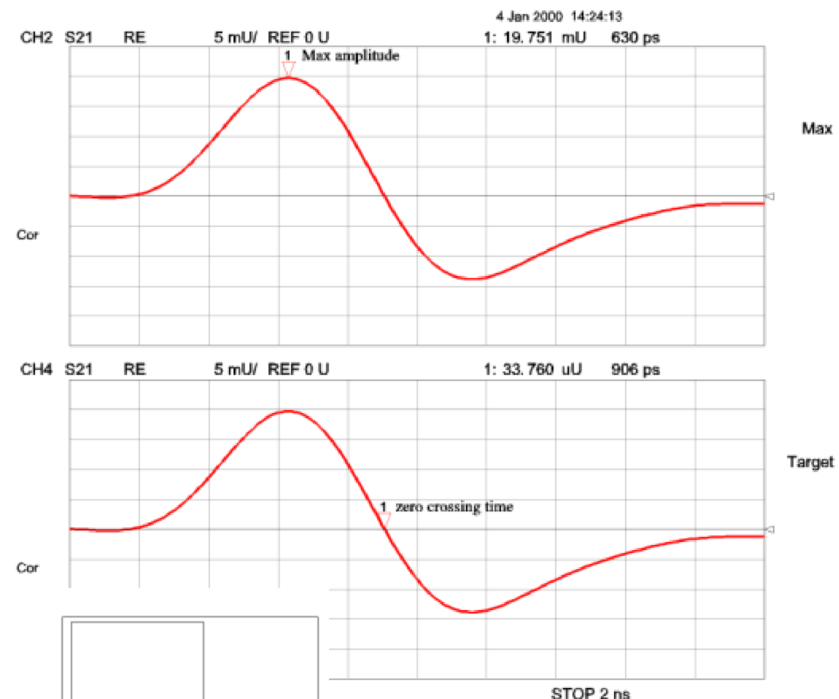


T_{ramp} = 500 ºC/h

- Cycle #1: T_{test} 400 ºC
- Cycle #2: T_{test} 500 ºC
- Cycle #3: T_{test} 600 ºC

- A HP network analyser within a frequency range up to 6 GHz.
- A synthetic 200 ps step is applied at the input of the button feedthrough.
- The pulse travel along the coaxial line and is differentiated by the button capacitance.

- Current specification: BPMs buttons should withstand a temperature of T = 300 ºC (steady state)



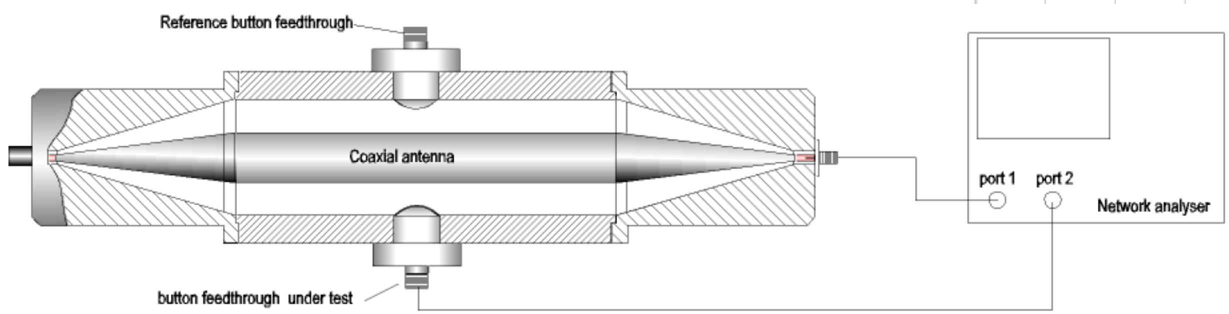
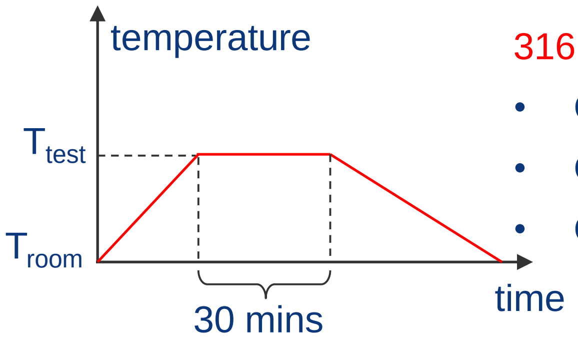


Figure 12: *Above: the measured amplitude of the button' response; left: the network analyzer used to test the BPMs buttons.*

Experimental results on TCSPM/TCSP BPMs

- Thermal cycles on BPMs (T_{ramp} = 500 ºC/h)



316LN Electrodes

- Cycle #1: T_{test} 400 ºC
- Cycle #2: T_{test} 500 ºC
- Cycle #3: T_{test} 600 ºC

Figure 13: *The broken (left) and pin-distorted (right) BPMs.*

Pick-Up Location	Jaw type	Impulse Response Amplitude Normalized to Ref. BPM					Visual inspection				
		Before HRMT23	After HRMT23	After Cycle 1	After Cycle 2	After cycle 3	Before HRMT23	After HRMT23	After Cycle 1	After Cycle 2	After cycle 3
Ref. button		1.000	1.000	1.000	1.000	1.000	Ok	Ok	Ok	Ok	Ok
MoGr Upstream	TCSPM MoGr + MoGr	1.004	0.992	0.991	0.990	0.991	Ok	Ok	Ok	Ok	Ok
MoGr Dnstream		0.984	0.988	0.986	0.987	0.988	Ok	Dot on pin side	Dot on pin side	Dot on pin side	Dot on pin side
CuCD Upstream	TCSPM CuCD + MoGr	0.985	0.991	0.989	0.990	0.992	Ok	Ok	Ok	Ok	Ok
CuCD Dnstream		1.008	1.011	1.010	1.009	1.010	Ok	Ok	Distorted pin	Distorted pin	Distorted pin
CFC Upstream	TCSP CFC+ Glidcop	1.007	1.005	1.005	1.006	1.008	Ok	Ok	Ok	Ok	Ok
CFC Dnstream		0.986	1.125	1.112	1.114	1.125	Ok	Broken*	Broken*	Broken*	Broken*

Conclusions

- Numerical tests

- New design effectively enhance the BPMs heat dissipation (≈ - 140 ^{o}C/-160 ^{o}C for 316LN electrode in 1h/0.2h BLT scenario);
- Sensible additional peak temperatures reduction on BPMs with Ti electrodes in both the 1h BLT (≈ -140 ^{o}C) and the 0.2 h BLT (≈ -200 ^{o}C) scenarios (commercial solution);
- Al electrodes deliver the best performances in terms of temperature peaks (78 ^{o}C and 169 ^{o}C)but, due to high SEY, they may cause the appearance of an electron cloud over the BPMs region possibly affecting the beam.

- Experimental tests

- No electrical change up to 600 ^{o}C;
- Deformation of the pin at 400 ^{o}C on one button. Not affecting the behaviour during operation;
- Results on 316LN electrodes show that Ti-made BPMs would be probably able to withstand the beam loss thermal load up to the 0.2h BLT case;
- Discussion with the supplier to deliver BPMs with Ti electrode by LS2.

Thanks for your attention