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Study on heat transfer between the High-Luminosity LHC beam screens and the He II-cooled beam tube

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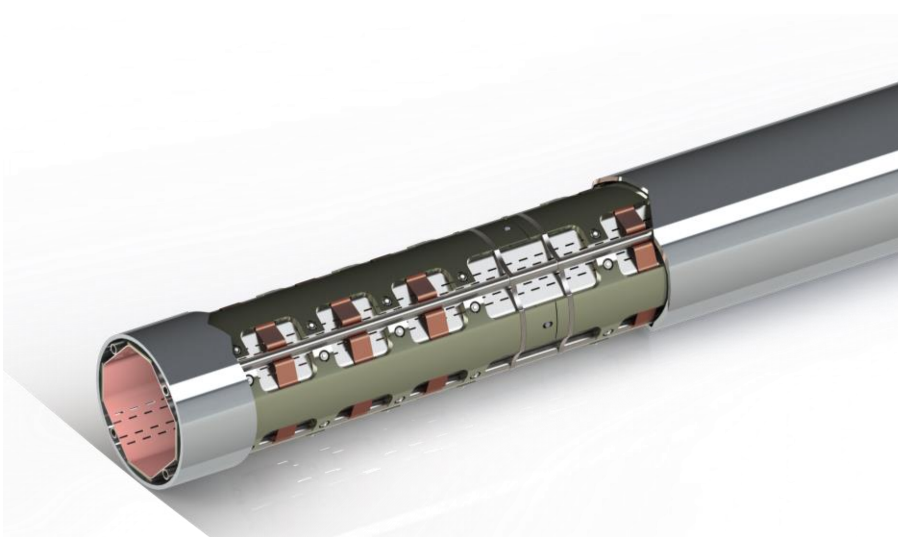
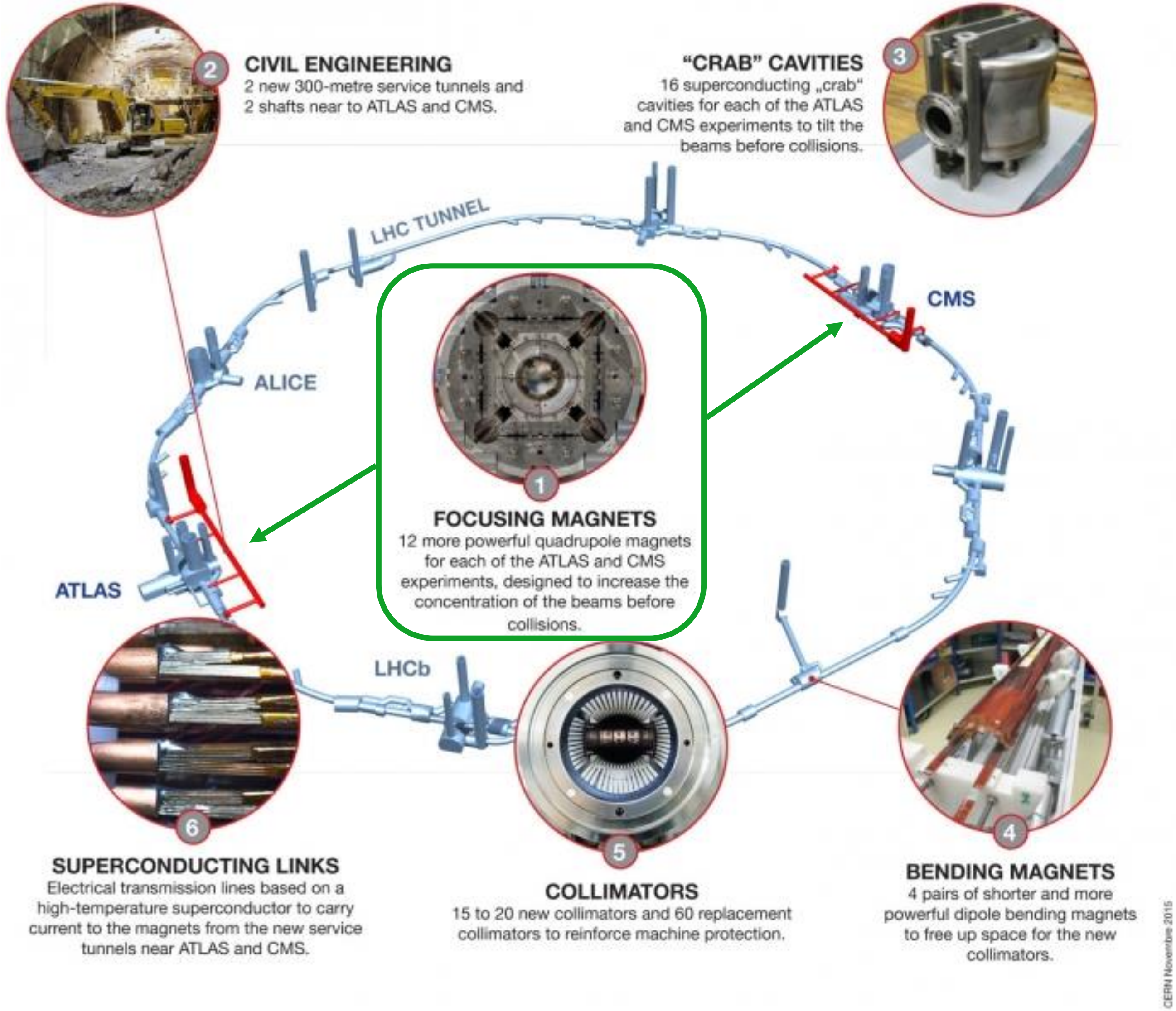
Outline

- Introduction to the HL-LHC beam screen
- Overview of requirements
- Thermal validation test stand: emulating HL-LHC conditions
- Summary of first measurement run
- Results & discussion
- Conclusions and outlook

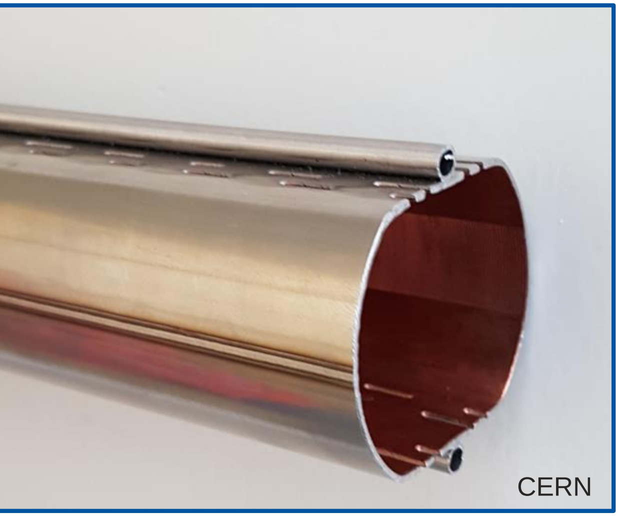


High-Luminosity upgrade of the LHC



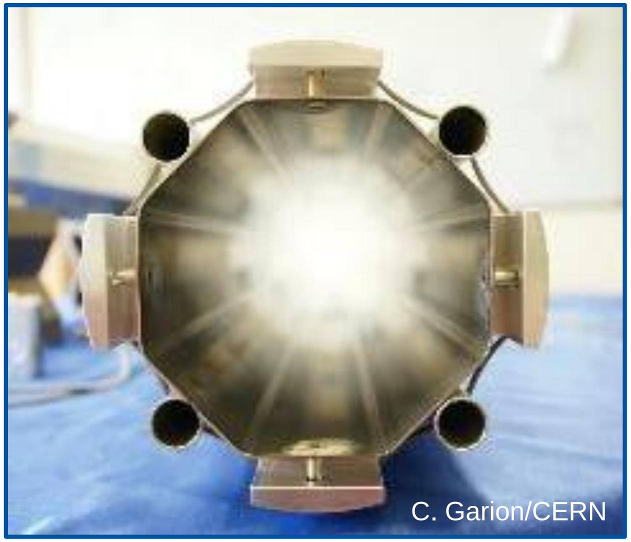
Source: CERN

Motivation: from the LHC to the HL-LHC



LHC beam screen

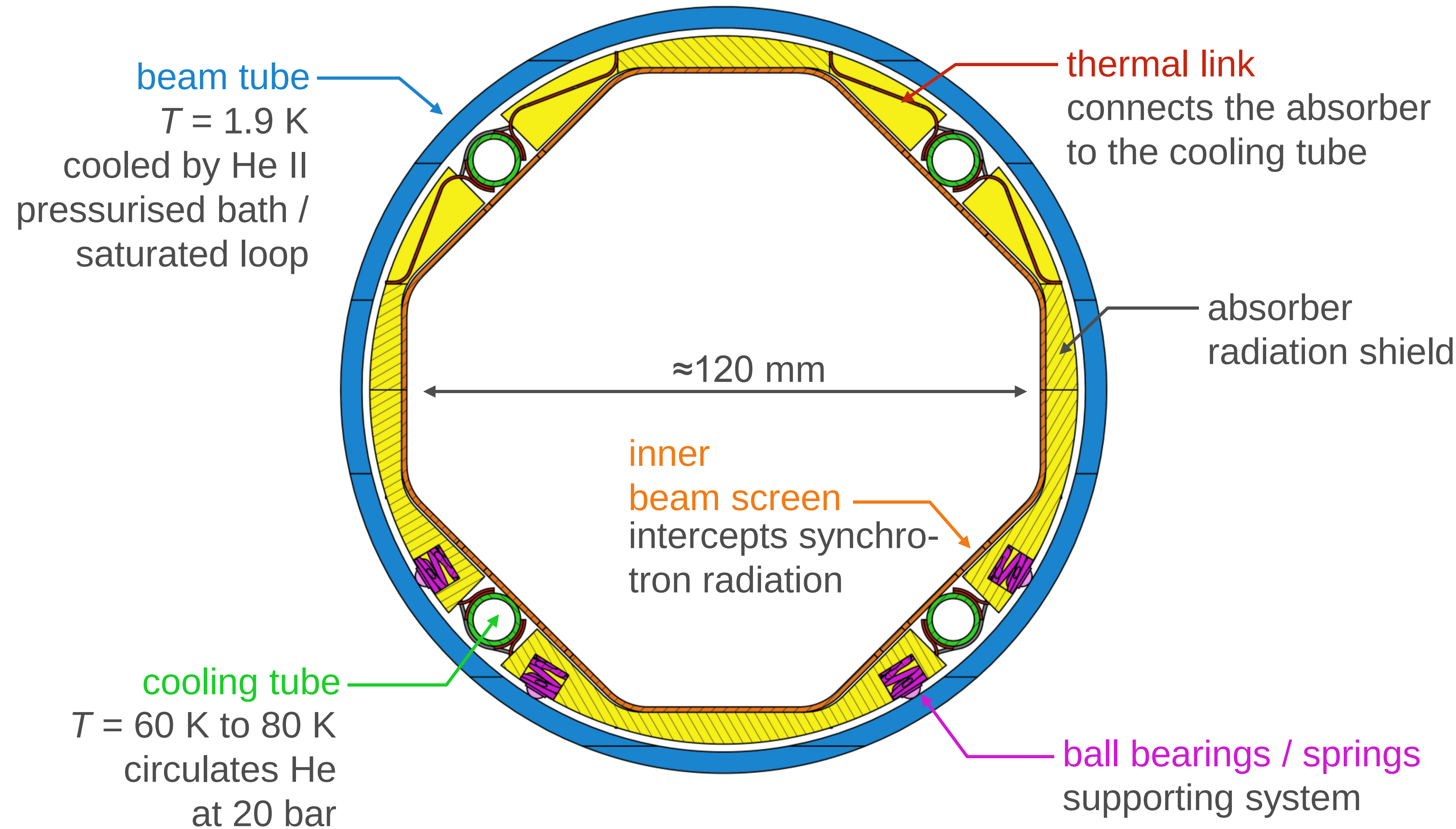
- 4 K – 20 K operating *T*
- Low mass flow (1 g/s)
- He gas at 3 bar
- No absorber (just screen)



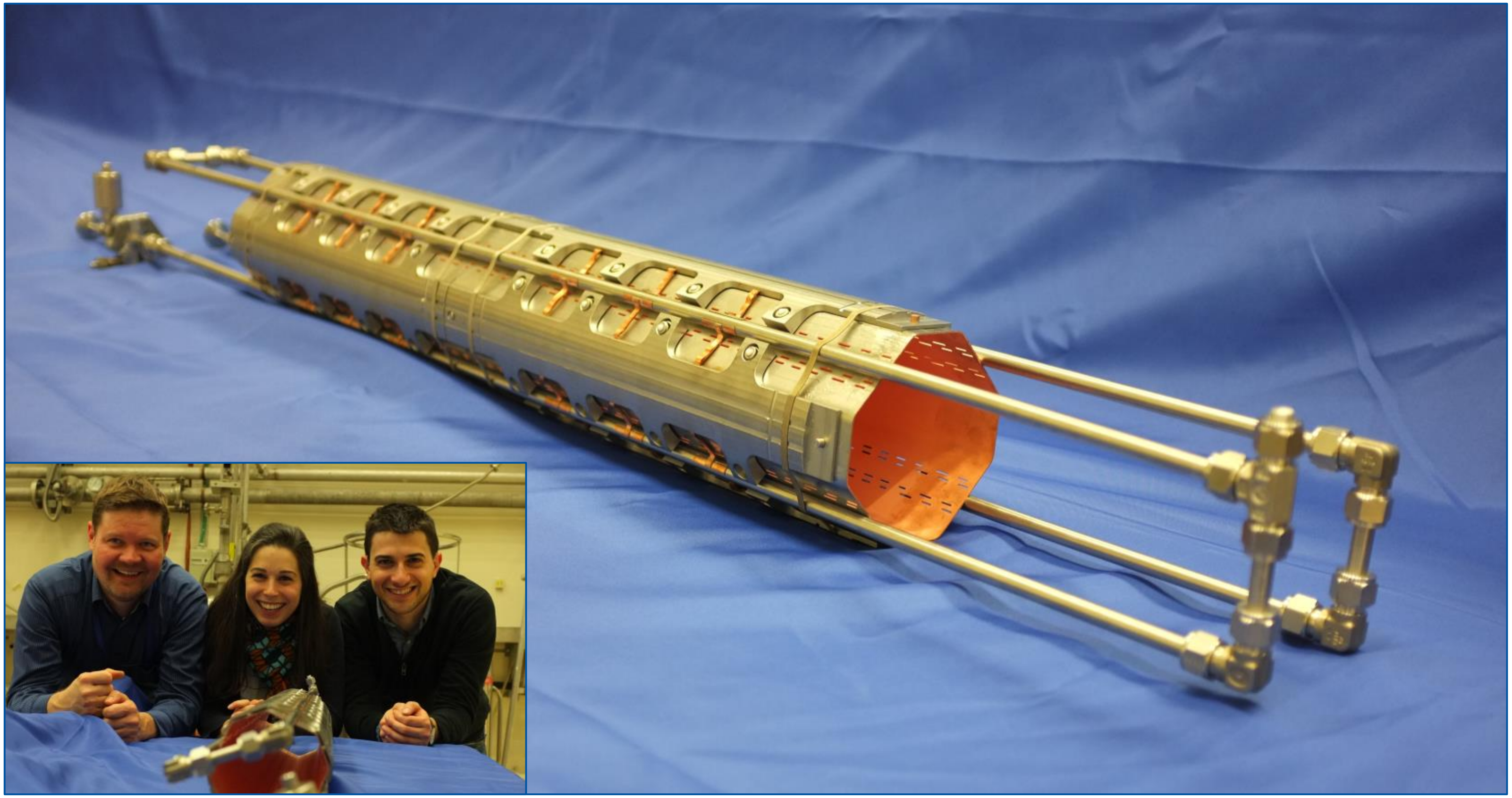
HL-LHC beam screen

- 60 K – 80 K operating *T*
- High mass flow (10 g/s)
- Supercritical He at 20 bar
- Tungsten-based absorber

HL-LHC beam screens: overview

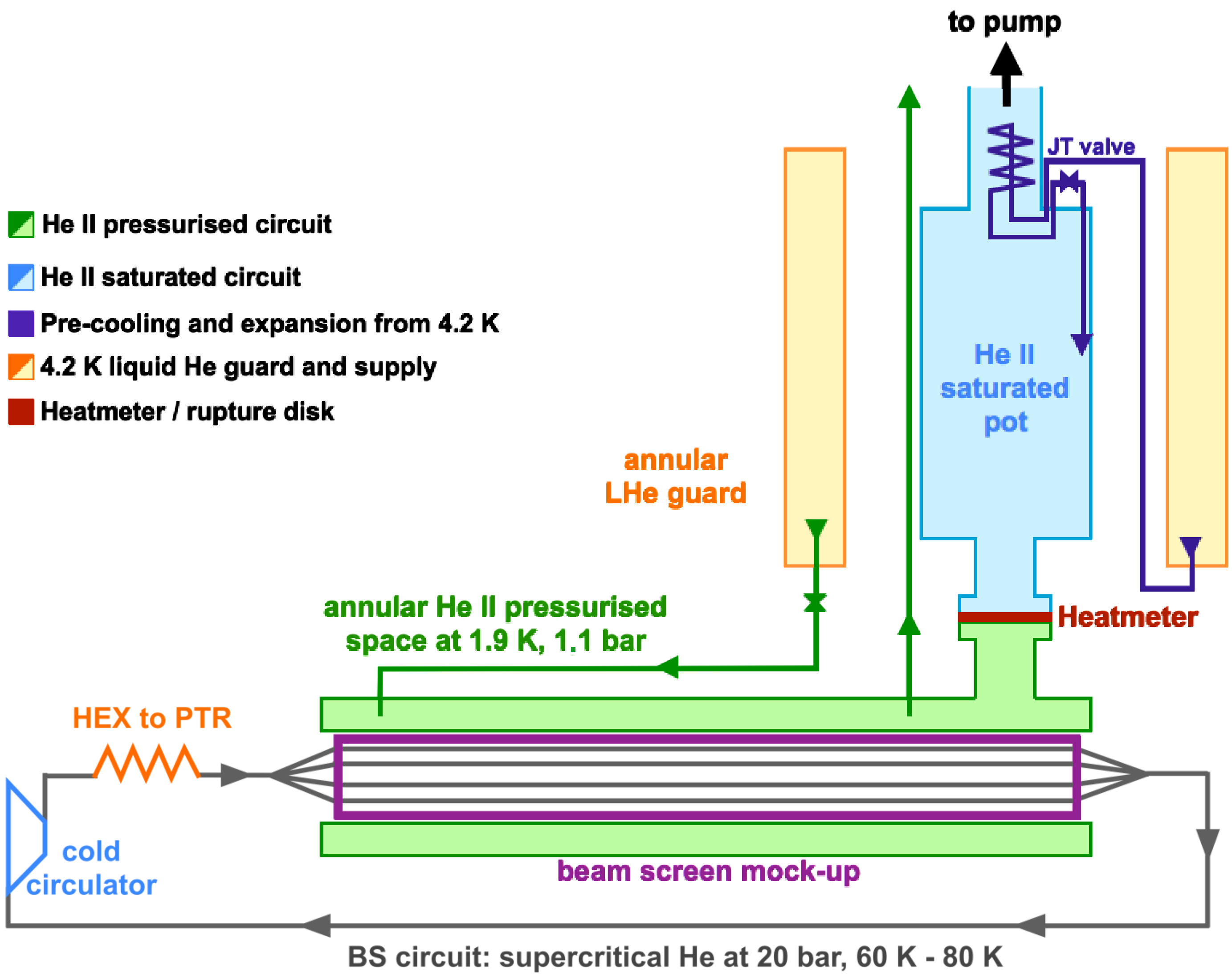


HL-LHC Beam Screen mock-up (D1) after pressure test



0.8 m full-scale prototype

Piping & Instrumentation Diagram



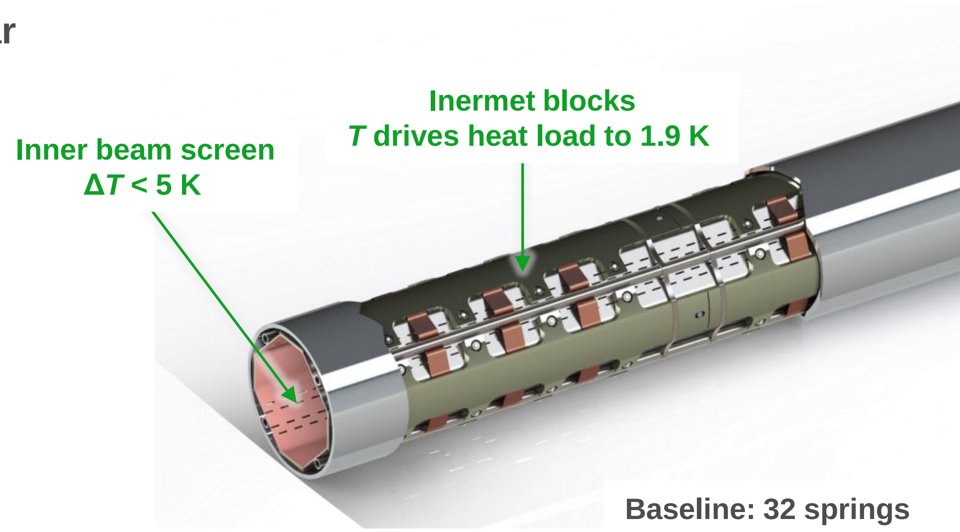
Requirements and first measurement run

- Operating *T* of beam screen (inner surface): **60 K to 80 K**
- Maximum allowed Δ*T* over 60 m: **15 K (5 K in radial direction)**
- Operating *T* of the helium flow: **55 K to 75 K**

- Nominal heat load on the tungsten blocks: **15 W/m**

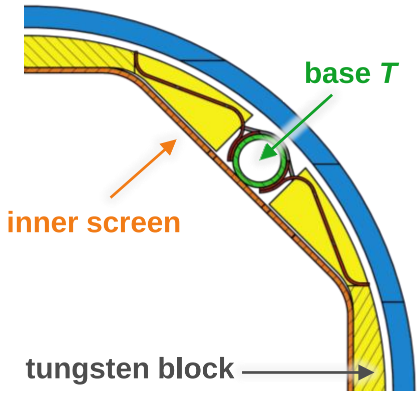
- Working fluid: supercritical helium, **20 bar – 23 bar**
- Mass flow rate of helium circuit: **≈ 11 g/s**

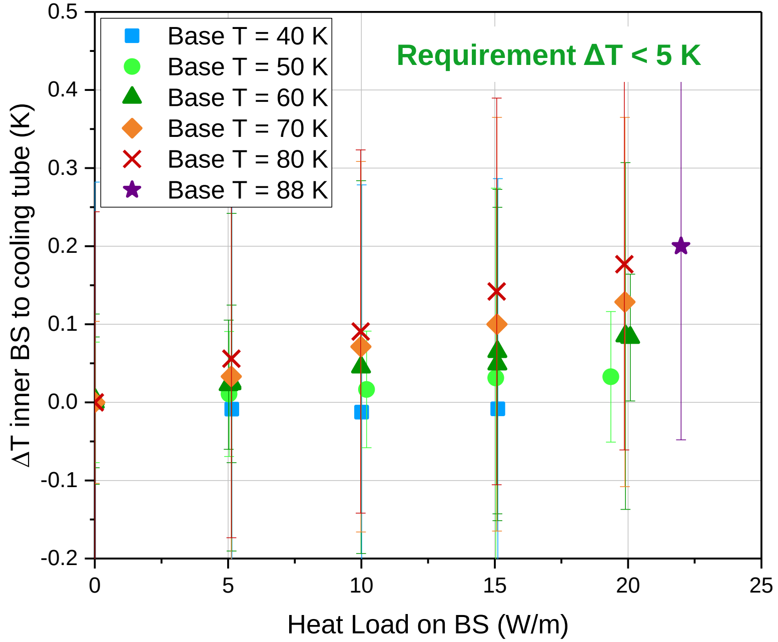
- Maximum heat load to 1.9 K bath: **0.5 W/m**

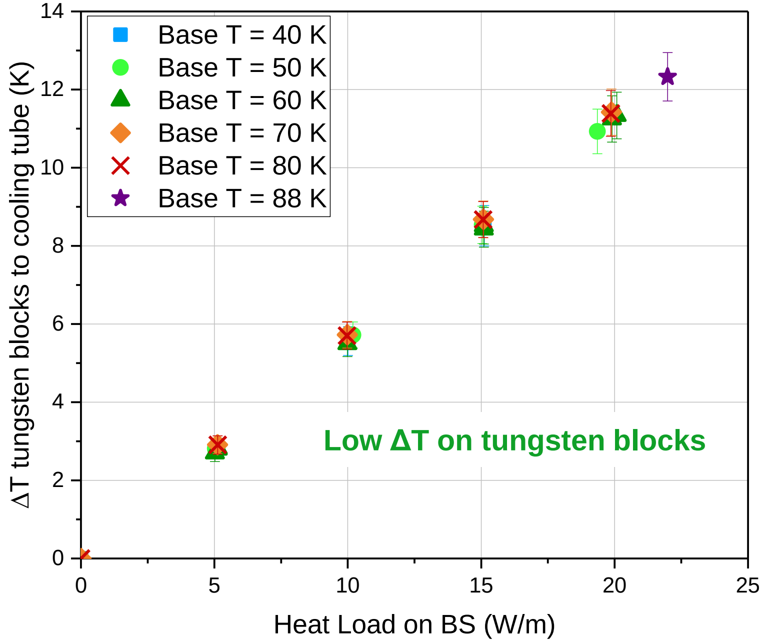


Results: beam screen temperature profile

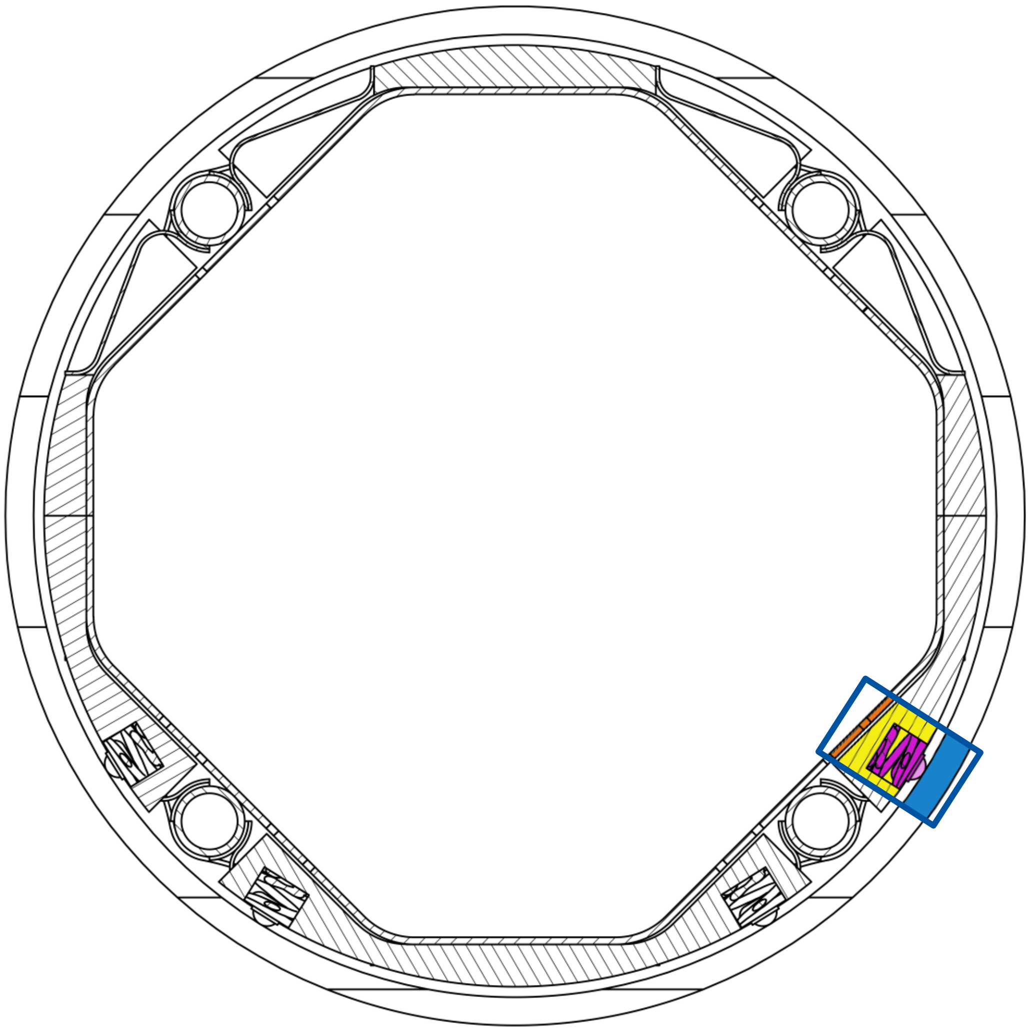
- **Steady-state** measurements
- **Homogeneously distributed heat load** on all four quadrants (0 to 20 W/m)
- Varied base (helium) temperature between **40 K and 80 K**
- Pressurised He II bath (beam tube) **actively controlled at 1.9 K ± 1 mK**



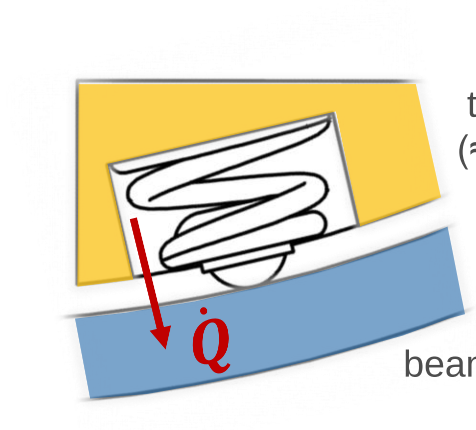




Measuring the heat load to the 1.9 K beam tube

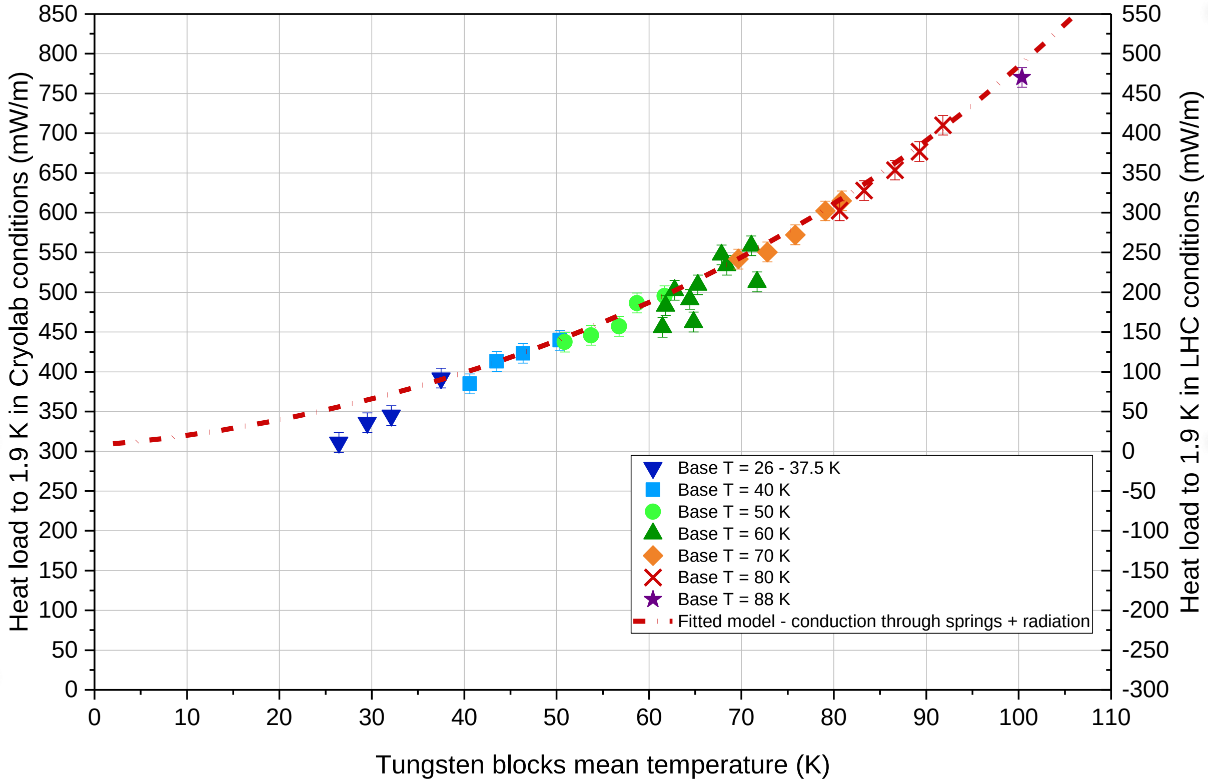


- Heat load transmitted to the 1.9 K bath (beam tube) by **radiation** and **conduction**
- Requirement **< 0.5 W/m**
- **Conduction** through each of the 32 spring + sphere sets
- **Radiation** from the tungsten and beam screen surfaces



Results: heat load to the 1.9 K beam tube

Heat load **from beam screen to 1.9 K bath** vs. tungsten block temperature



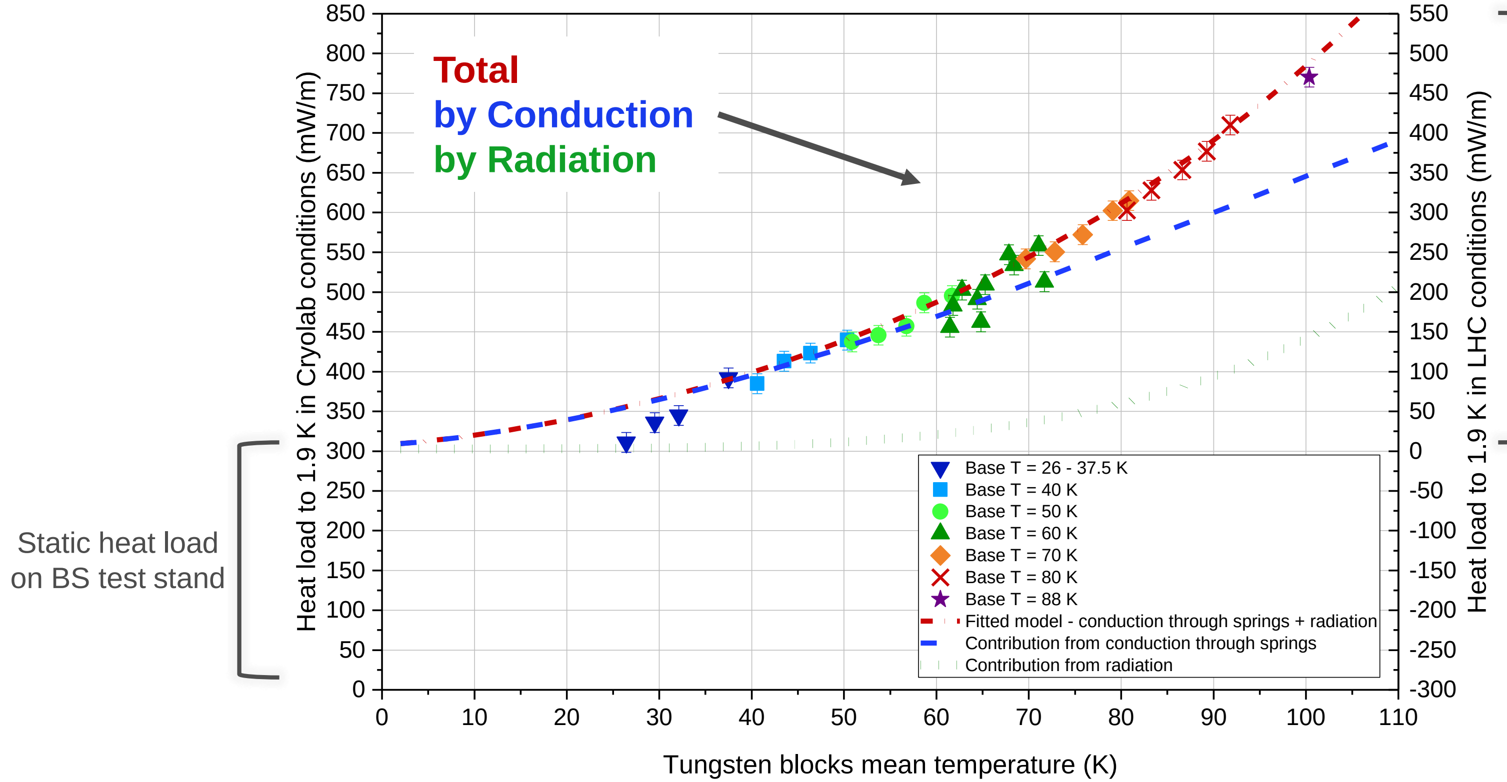
Static heat load on BS test stand

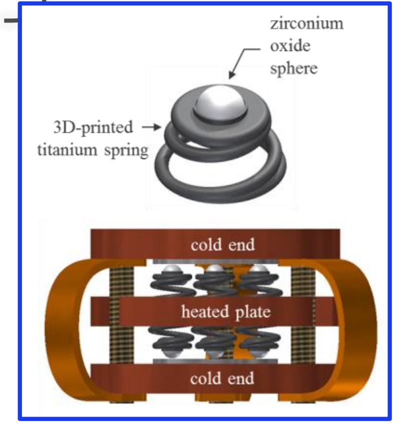
Heat load from beam screen to cold bore in HL-LHC environment

200 mW/m if beam screen is at 60 K, **375 mW/m** if beam screen is at 80 K ⟶ **17 W** over the 60 m

Results: heat load to the 1.9 K beam tube

Heat load **from beam screen to 1.9 K bath** vs. tungsten block temperature

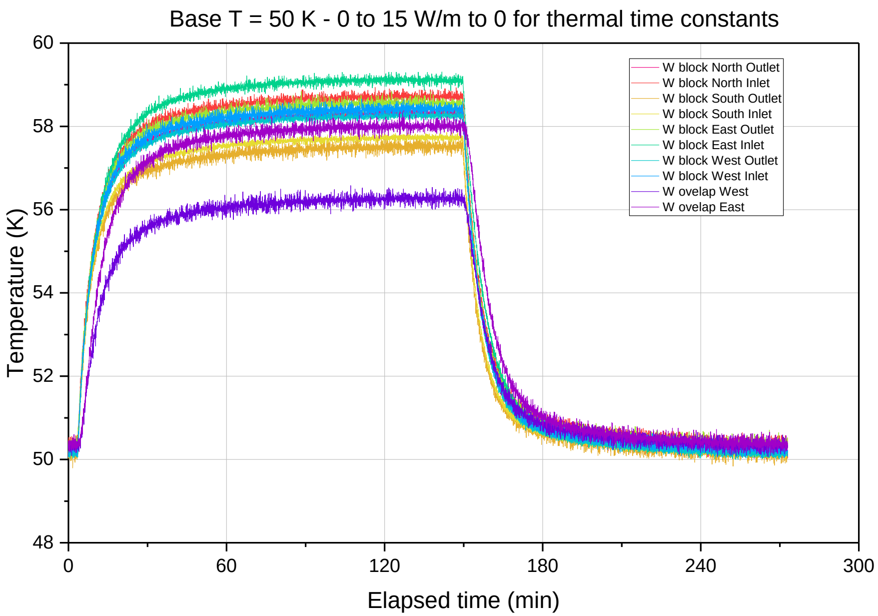


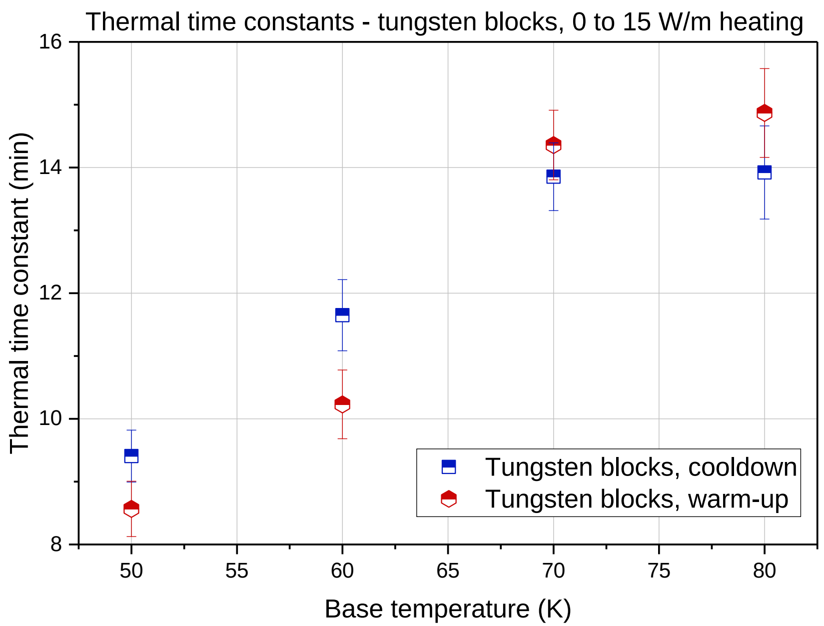


200 mW/m if beam screen is at 60 K, **375 mW/m** if beam screen is at 80 K ⟶ **17 W** tover the 60 m

For operational beam screen (and Inermet block) temperatures, **most of the heat load to the 1.9 K beam tube is transferred via conduction** through the springs (90% at 60 K and 70% at 80 K)

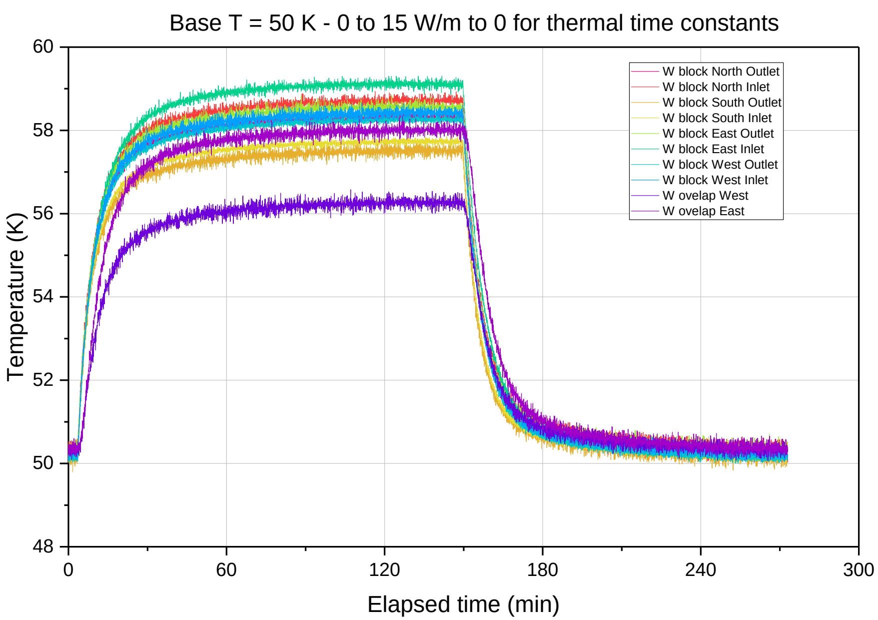
Results: thermal time constants “beam ON → beam OFF”

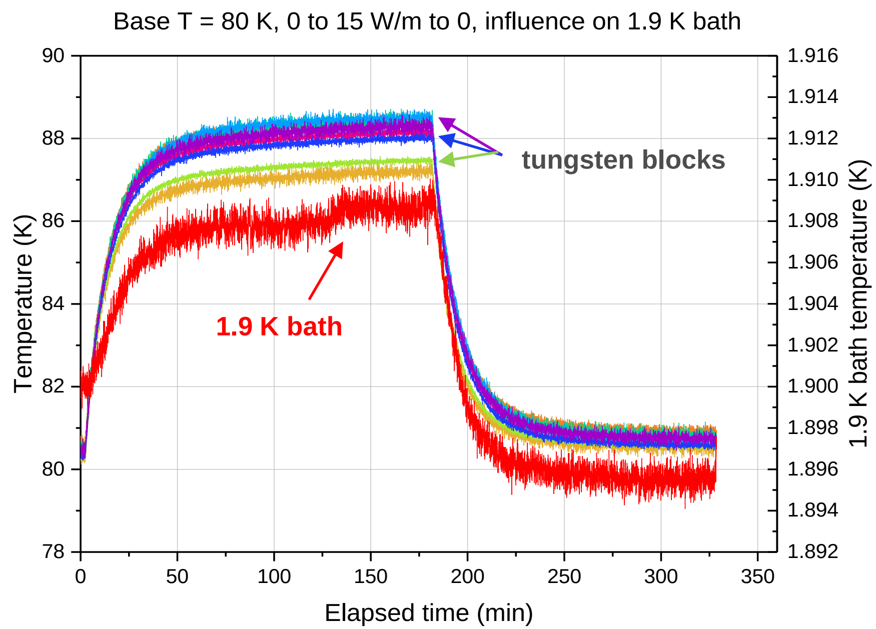




- Time constants of the tungsten blocks rise with rising base temperature
- Steady state in ≈ 5τ:
  - ≈ 43 min at 60 K
  - ≈ 75 min at 80 K (tungsten at 90 K)

Results: thermal time constants “beam ON → beam OFF”





- Time constants of the tungsten blocks rise with rising base temperature
- Steady state in ≈ 5τ:
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Conclusions & Outlook

- ✓ **Maximum temperature rise on inner BS:** 0.5 K
  - **Factor 10 lower** than max. allowed, nominal conditions
- ✓ **Maximum temperature rise on tungsten blocks:** 9 K (nominal conditions)
  - Independent of base temperature
  - Highly linear with increasing heat loads
- ✓ **Heat load to 1.9 K beam tube:** 200 mW to 375 mW **per meter** (nominal conditions, 60 K to 90 K tungsten blocks temp.)
- ✓ **Thermal time constants Inermet blocks 0-15 W/m:** 9 min to 15 min, temperature-dependent
- ✓ Uneven heat loads **show no instabilities** in the flow

Further reproducibility tests are needed but results thus far
validate the thermal design of the HL-LHC beam screens

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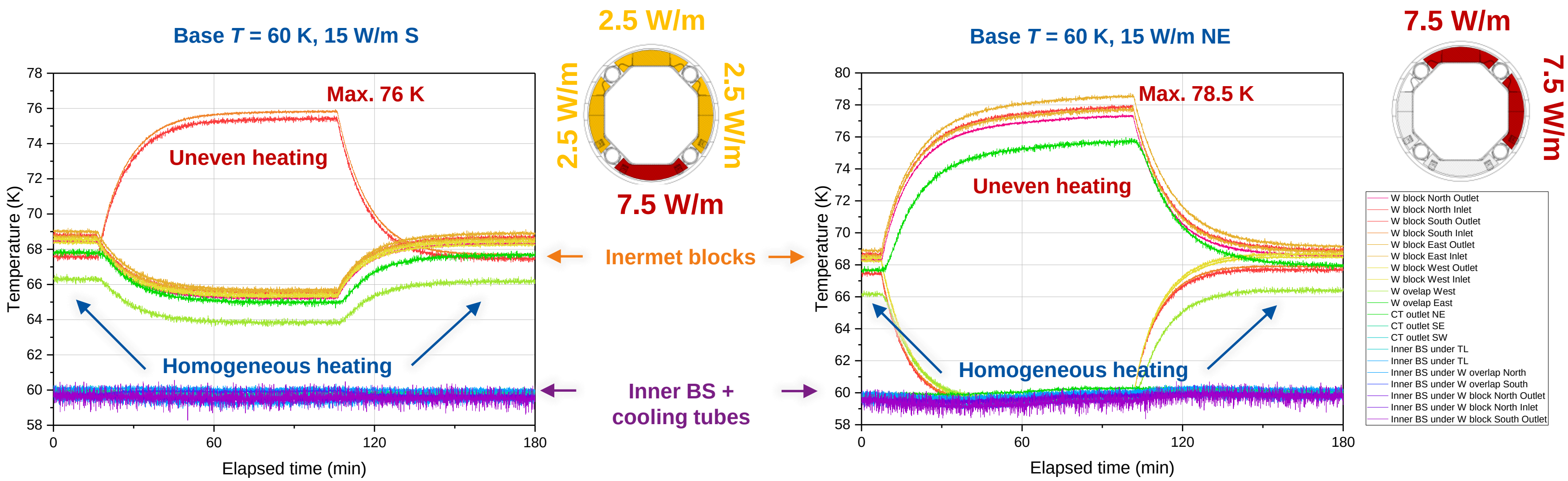
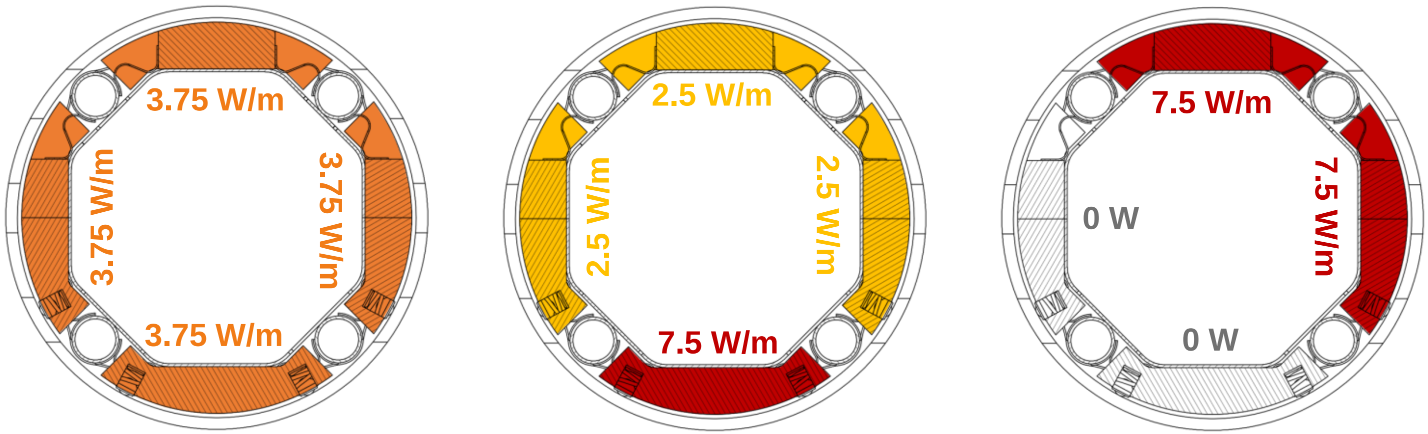
Results: uneven heating on Beam Screen quadrants

- **Nominal overall heat load** on beam screen (15 W/m)
- **Unevenly distributed heat load**
- Base temperature kept **constant**
- **Influence of heat load distribution** on Inermet and beam screen temperatures
- Influence of heat load distribution **on 1.9 K bath**



Results: uneven heating on Beam Screen quadrants



	Nominal heating			Uneven “South”			Uneven “Northeast”		
	60 K	70 K	80 K	60 K	70 K	80 K	60 K	70 K	80 K
Min. Δ*T* to base *T*	7.8 K (S)	7.8 K (S)	7.7 K (S)	5.7 K (W)	5.7 K (N)	5.8 K (N)	0	0	0
Max. Δ*T* to base *T*	9.0 K (E)	8.9 K (E)	8.9 K (E)	15.9 K (S)	15.8 K (S)	15.5 K (S)	18.2 K (E)	18.0 K (E)	18.0 K (E)
Heat load to 1.9 K	189 mW	243 mW	282 mW	198 mW	261 mW	289 mW	180 mW	242 mW	280 mW

Even though heat load on BS is the same, heat load transferred to 1.9 K bath changes → south quadrant dominates heat transfer (2 rows of springs)