Thermal Qualification of the HL-LHC Beam Screens for the Inner Triplets

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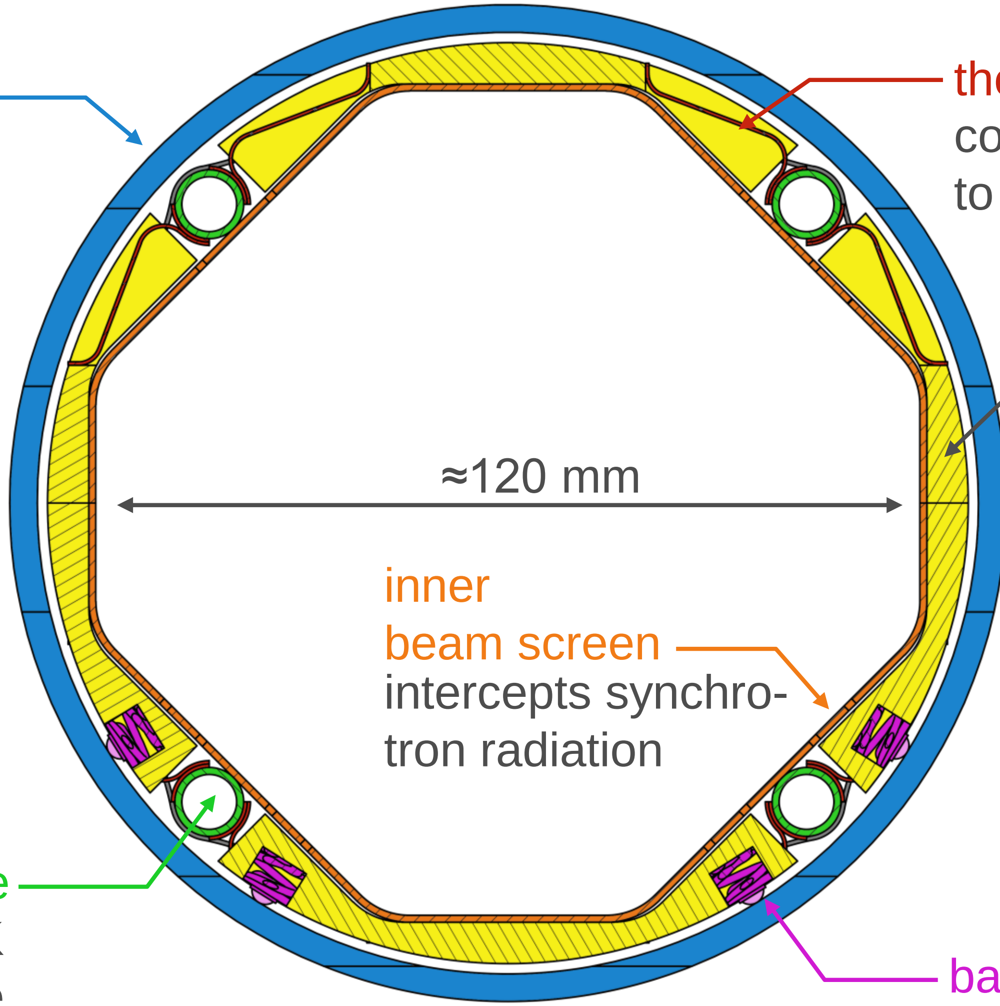
Outline

- Introduction to the HL-LHC beam screen
- Overview of requirements
- Thermal validation test stand: emulating HL-LHC thermodynamic conditions
- Summary of measurement runs
- Results & discussion
  - Run #1
  - Run #2
- Conclusions and outlook

HL-LHC beam screens: overview (D1-type)

cold bore
T = 1.9 K
cooled by He II
pressurised bath /
saturated loop

thermal link
connects the absorber
to the cooling tube

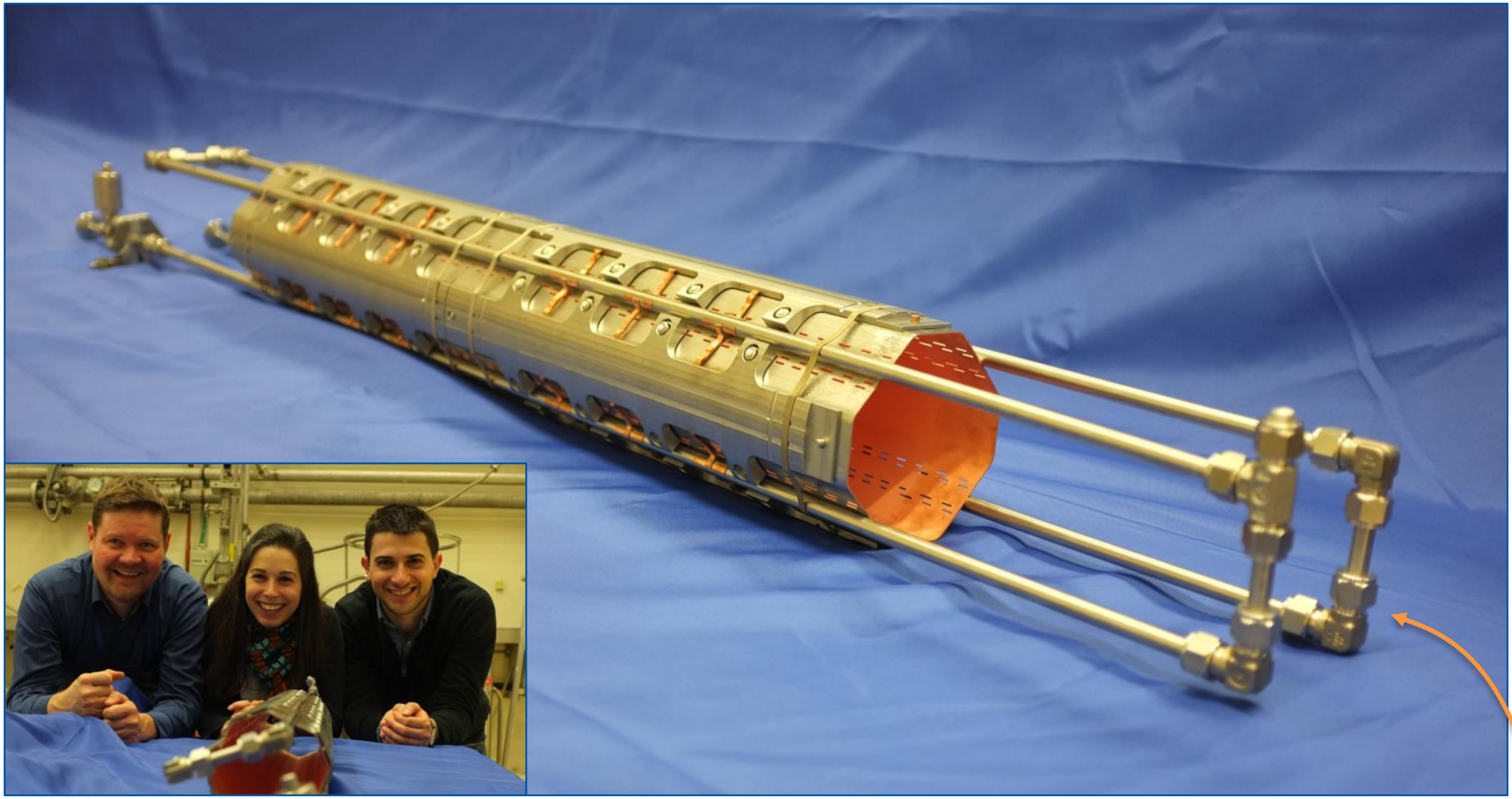


absorber
radiation shield

cooling tube
T = 60 K to 80 K
circulates He
at 20 bar

ball bearings / springs
supporting system

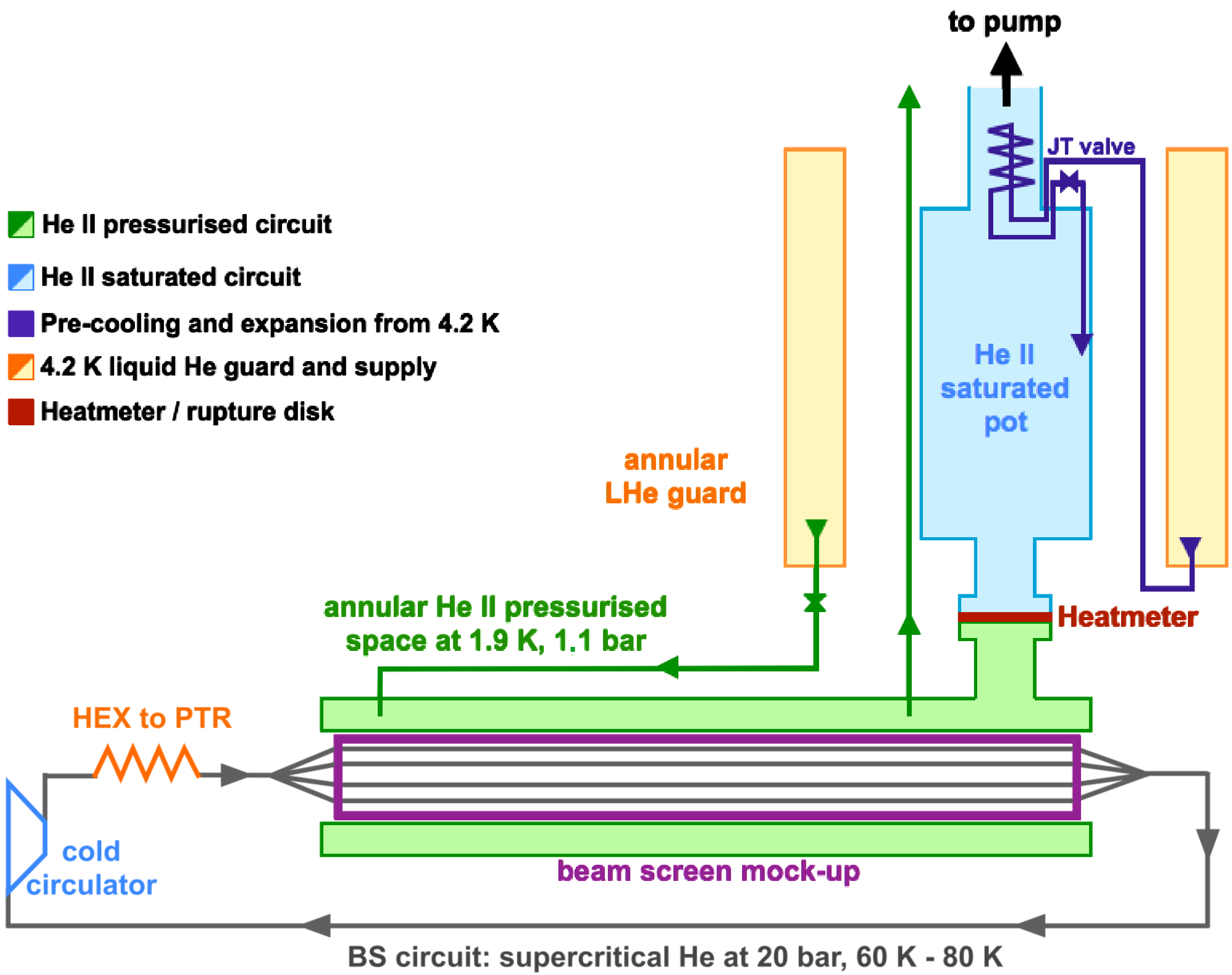
HL-LHC beam screen mock-up (D1-type)



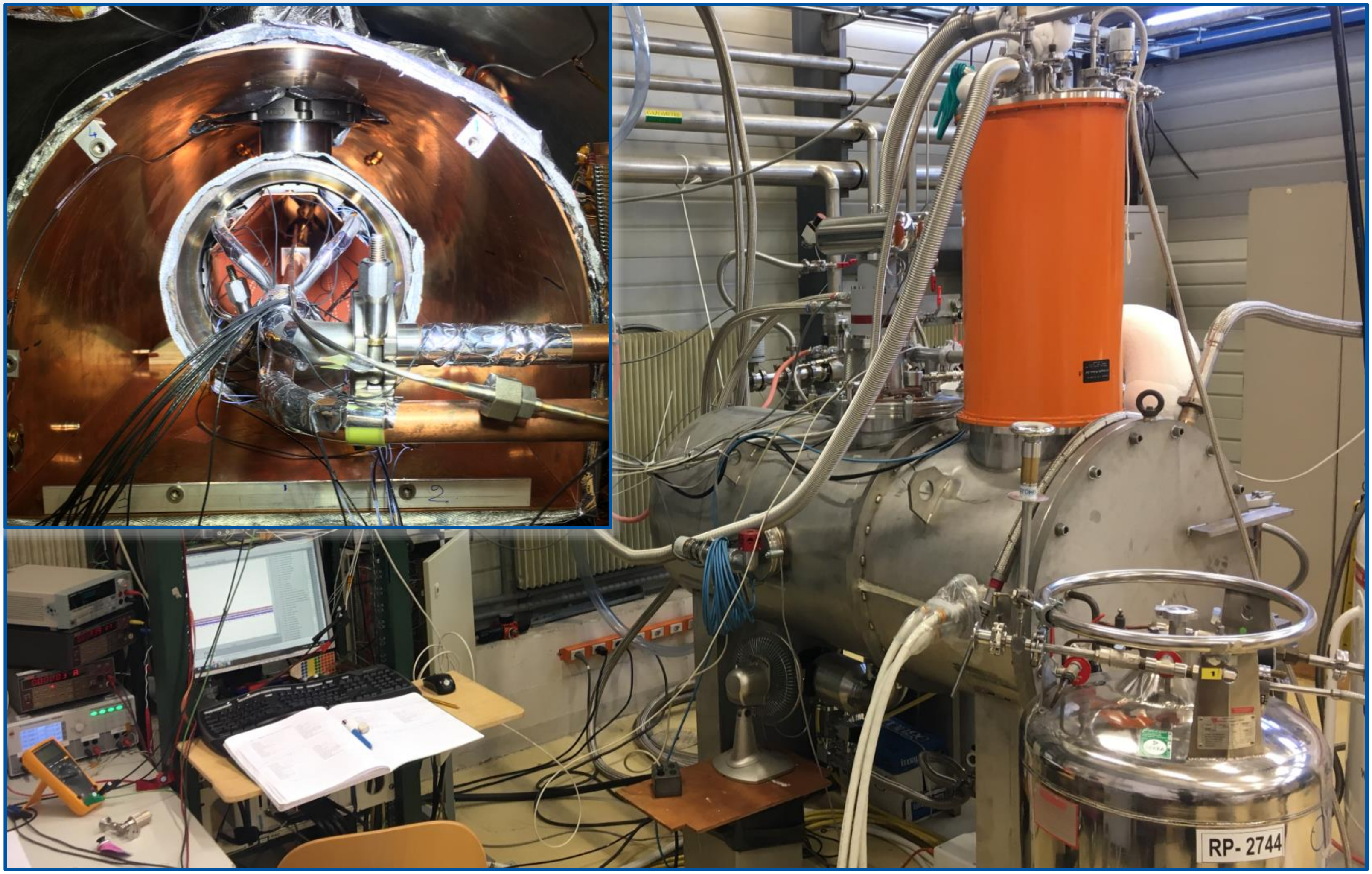
0.8 m full-scale prototype

(cooling tubes connected in series for initial pressure tests)

Piping & Instrumentation Diagram



HL-LHC beam screen test stand at the Cryolab



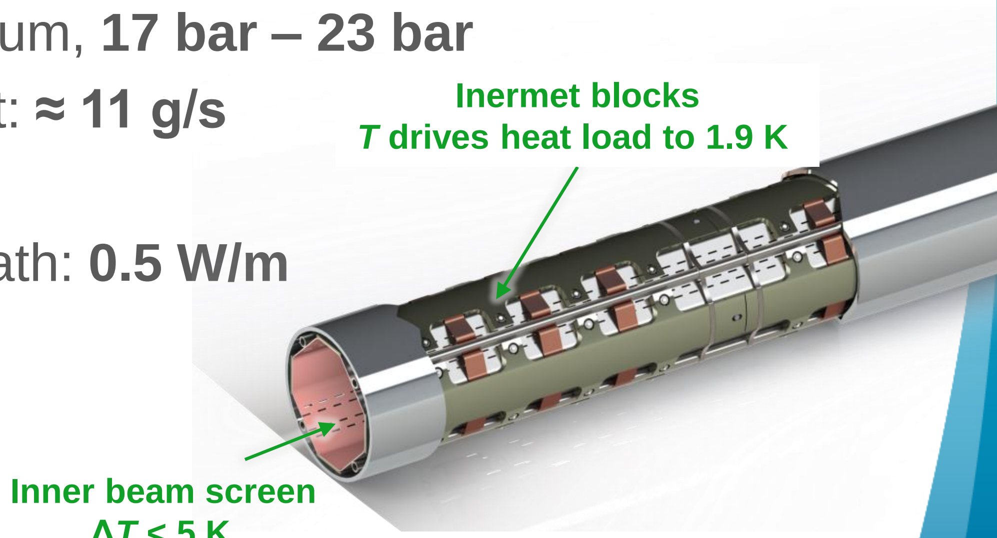
Requirements and first measurement run

- Operating *T* of beam screen (inner surface): **60 K to 80 K**
- Maximum allowed *ΔT* 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, **17 bar – 23 bar**
- Mass flow rate of helium circuit: **≈ 11 g/s**

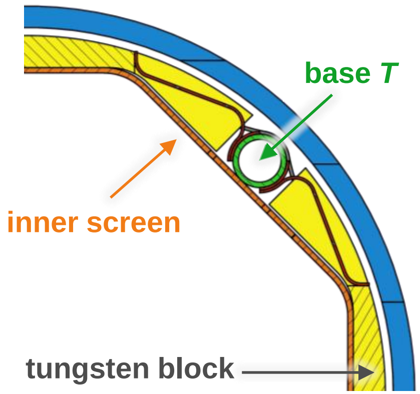
- Maximum heat load to 1.9 K bath: **0.5 W/m**

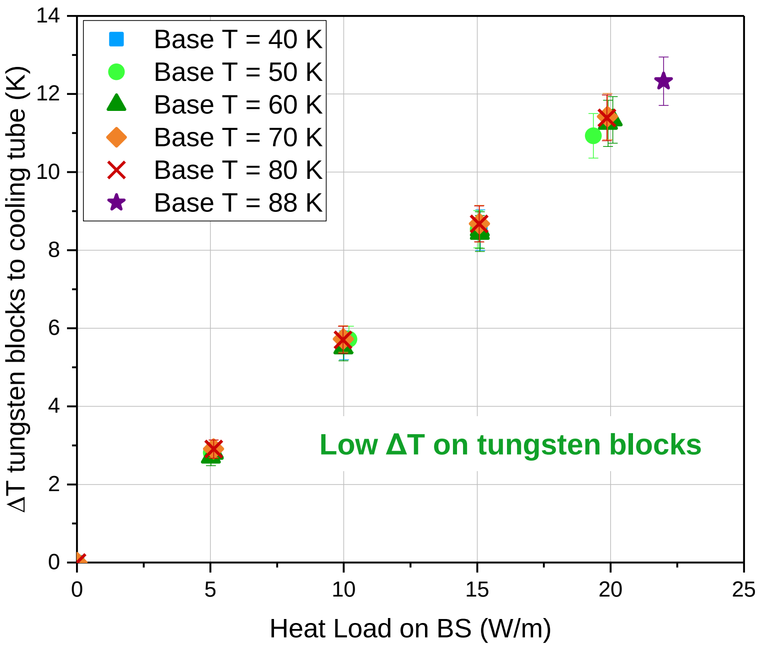


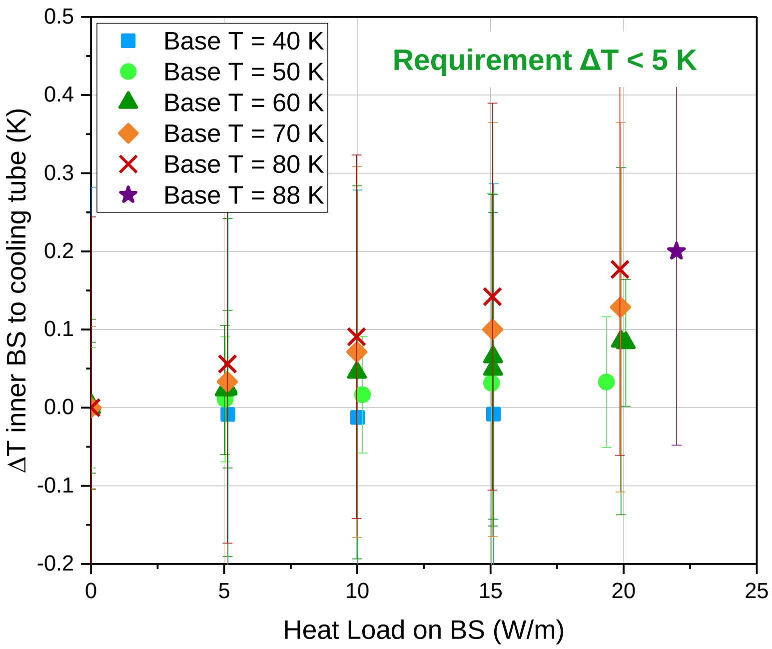
Baseline: 32 springs

Results: beam screen temperature profile

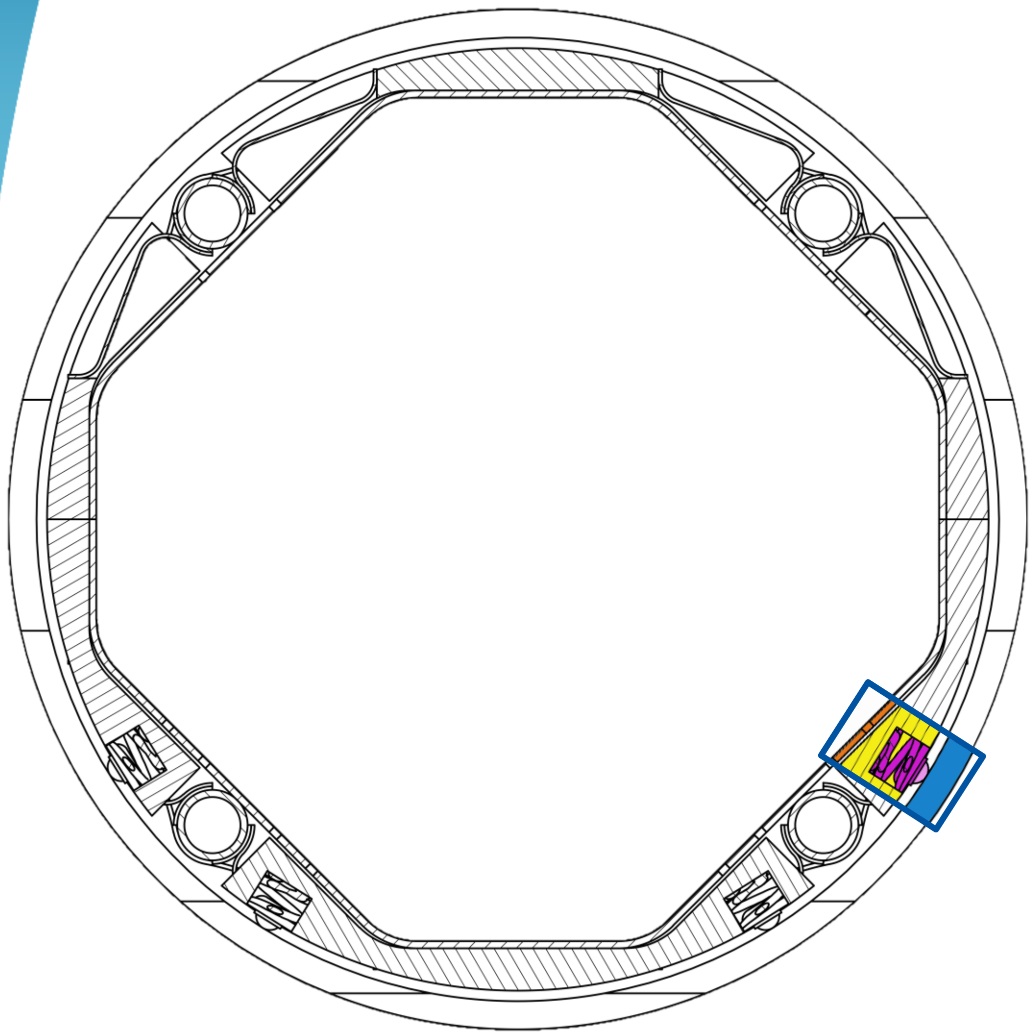
- **Steady-state** measurements
- **Homogeneously distributed heat load** on all 4 quadrants (0 to 20 W/m)
- Varied base (helium) temp. between **40 K and 80 K**
- Pressurised He II bath (cold bore) **actively controlled at 1.9 K ± 1 mK**



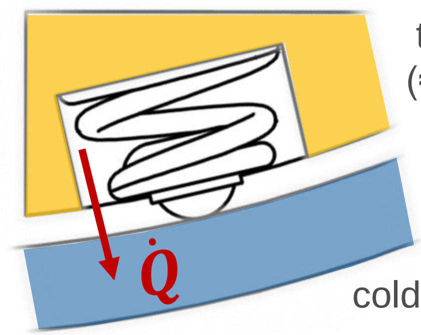




Measuring the heat load to the 1.9 K cold bore

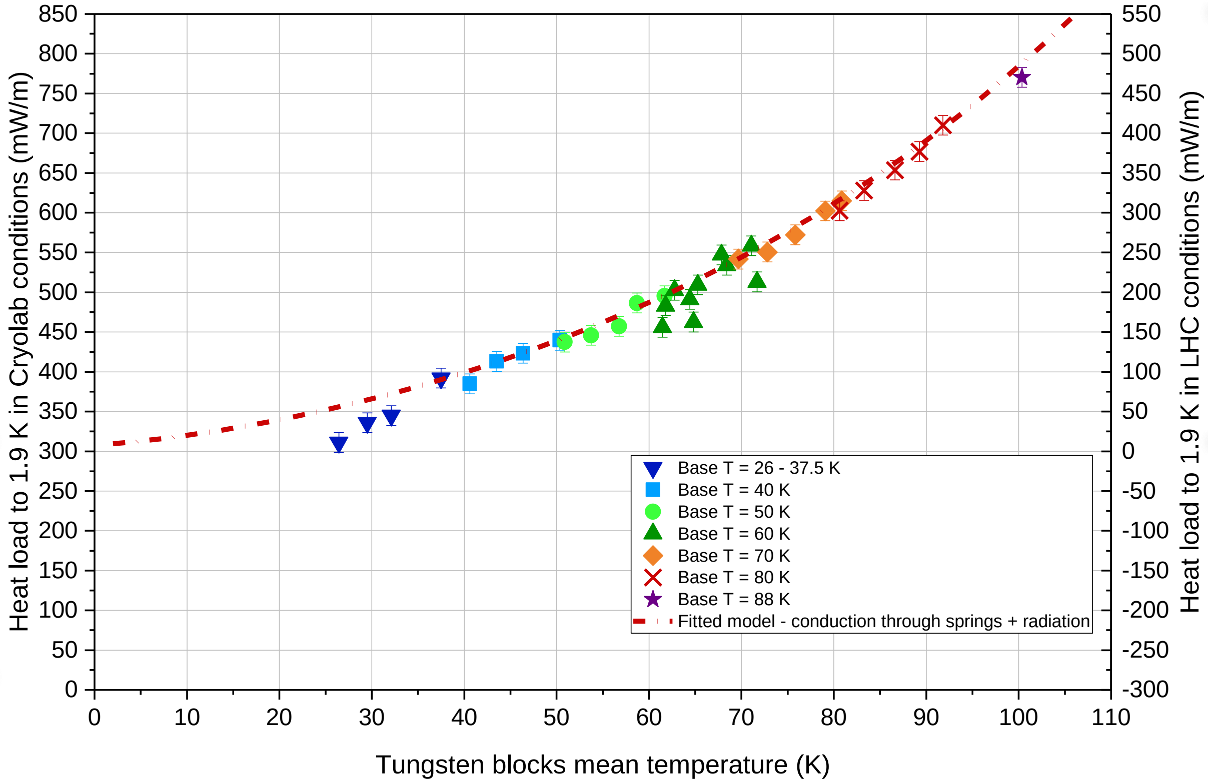


- Heat load transmitted to the 1.9 K bath (cold bore) by **radiation** and **conduction**
- Requirement **< 0.5 W/m**
- **Conduction** through each of the 32 spring + sphere sets
- **Radiation** from the tungsten and beam screen surfaces



Results: heat load to the 1.9 K cold bore

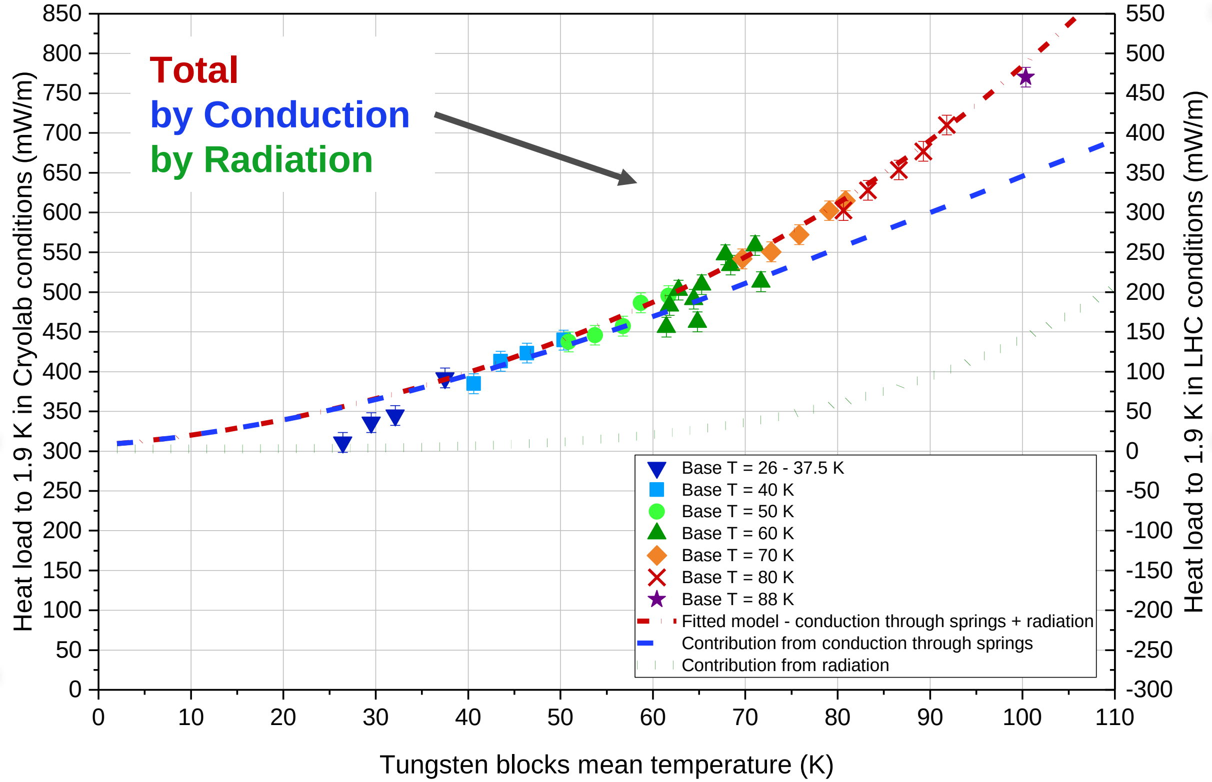
Static heat load on BS test stand



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

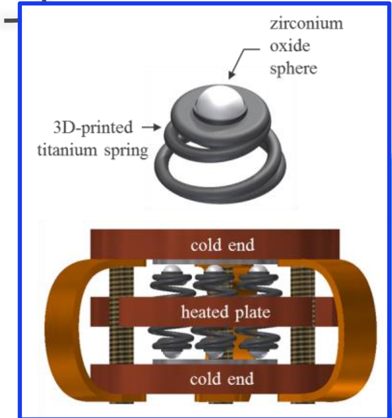
200 mW/m if beam screen is at 60 K, **375 mW/m** if beam screen is at 80 K ⟶ **17 W** over the 60 m

Results: heat load to the 1.9 K cold bore



Static heat load on BS test stand

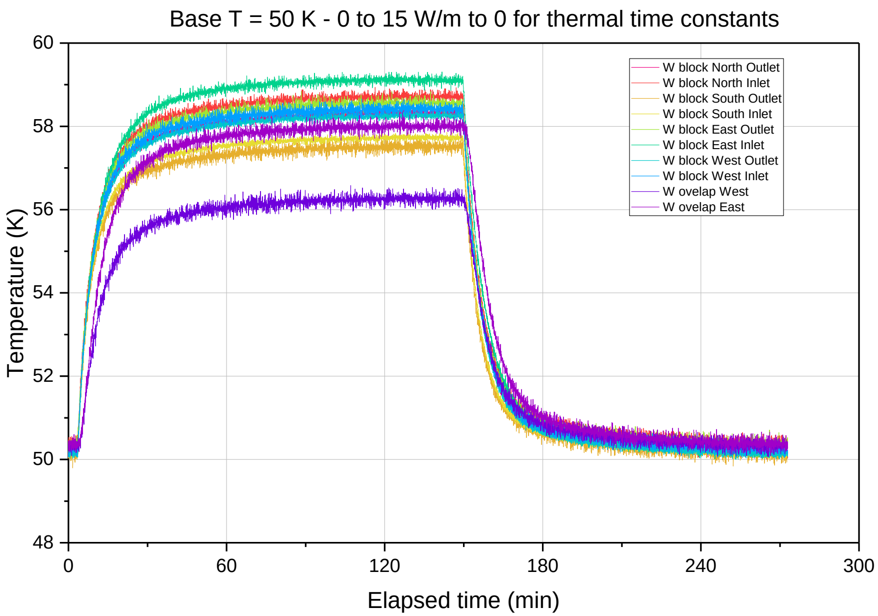
Heat load from beam screen to cold bore in HL-LHC environment

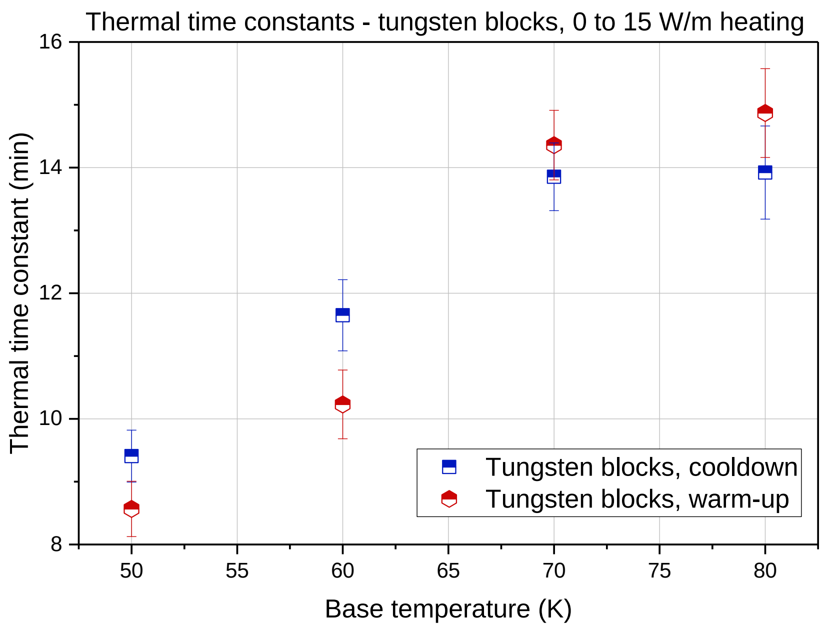


200 mW/m if beam screen is at 60 K, **375 mW/m** if beam screen is at 80 K ⟶ **17 W** tover the 60 m

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

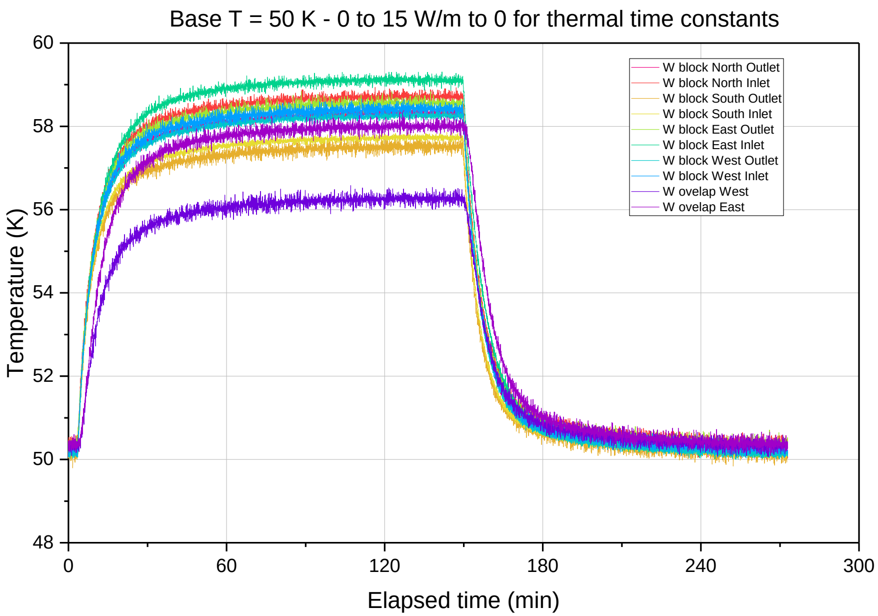
Results: thermal time constants "beam ON → beam OFF"

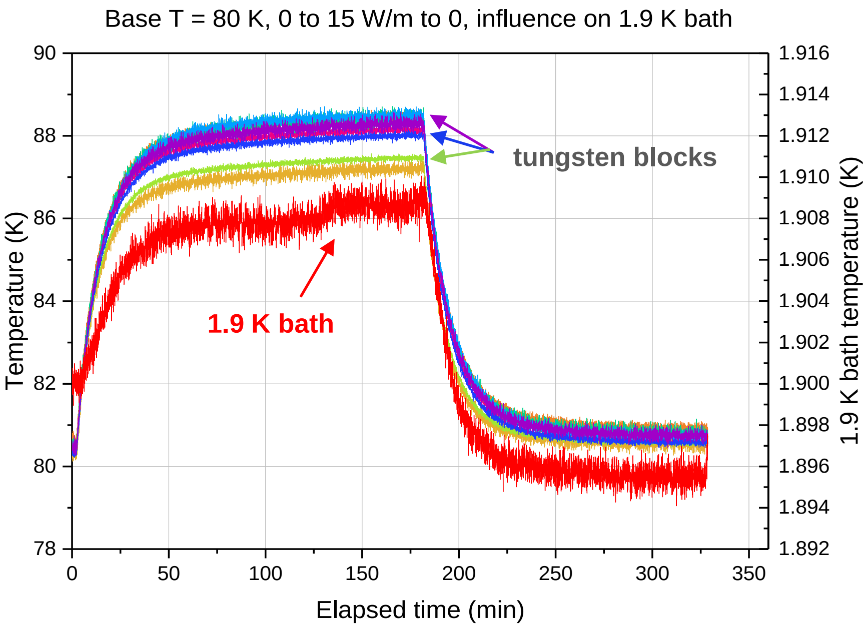




- Time constants of the tungsten blocks rise with rising base temperature
- Steady state in ≈ 5τ:
  - ≈ 43 min at 60 K
  - ≈ 75 min at 80 K (tungsten at 90 K)

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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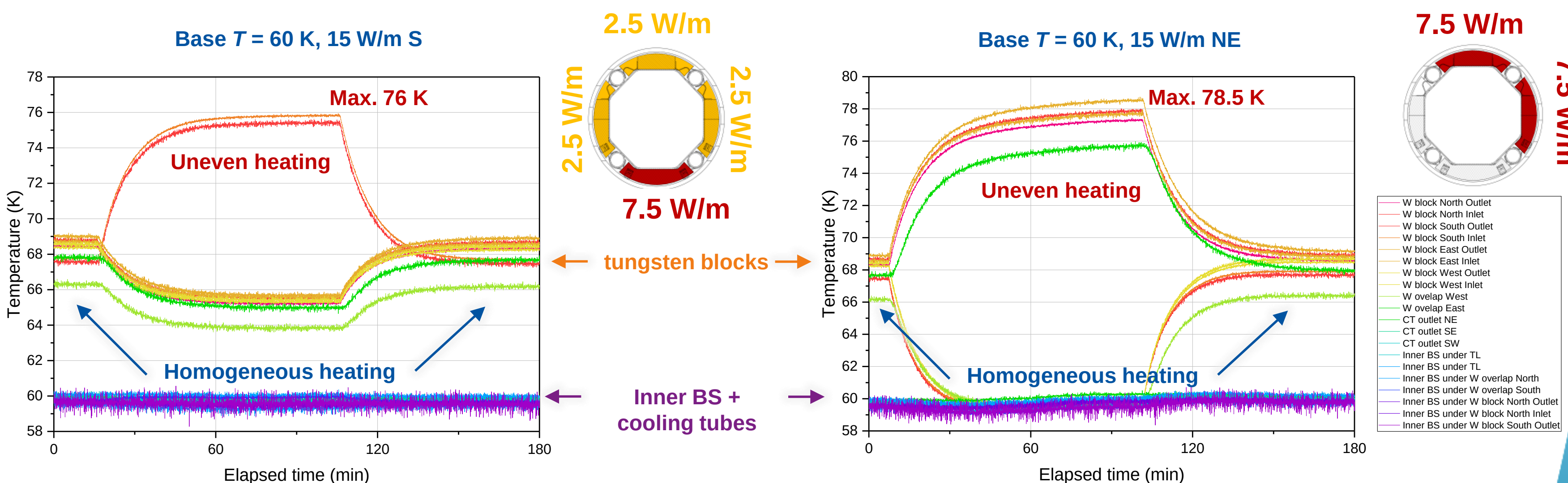
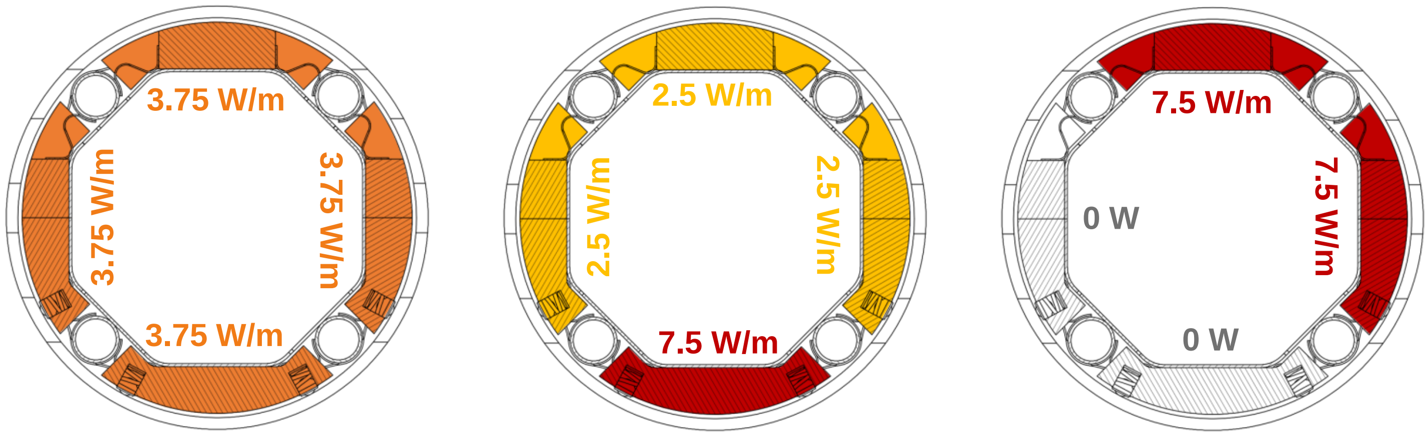
Results: uneven heating on beam screen quadrants

- **Nominal overall heat load** on beam screen (15 W/m)
- **Unevenly distributed heat load**
- Base temperature kept **constant**
- **Influence of heat load distribution** on tungsten 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. ΔT 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. ΔT 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)

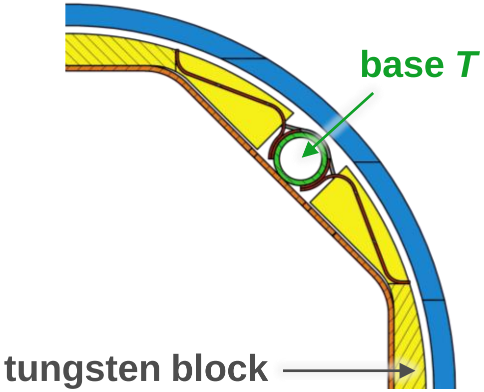
Conclusions for the first run

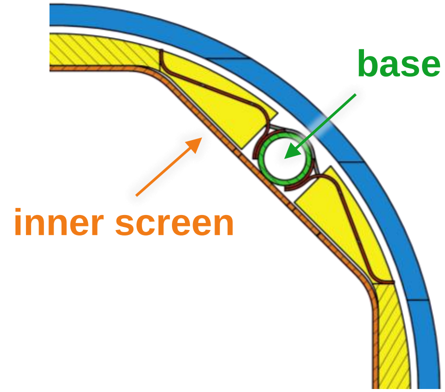
- **Maximum temperature rise on inner BS:** 0.5 K
  - **Factor 10 lower** than max. allowed (nominal conditions)
- **Maximum temperature rise on tungsten blocks:** 9 K (nominal conditions)
  - Independent of base temperature
  - Highly linear with increasing heat loads
- **Heat load to 1.9 K cold bore:**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

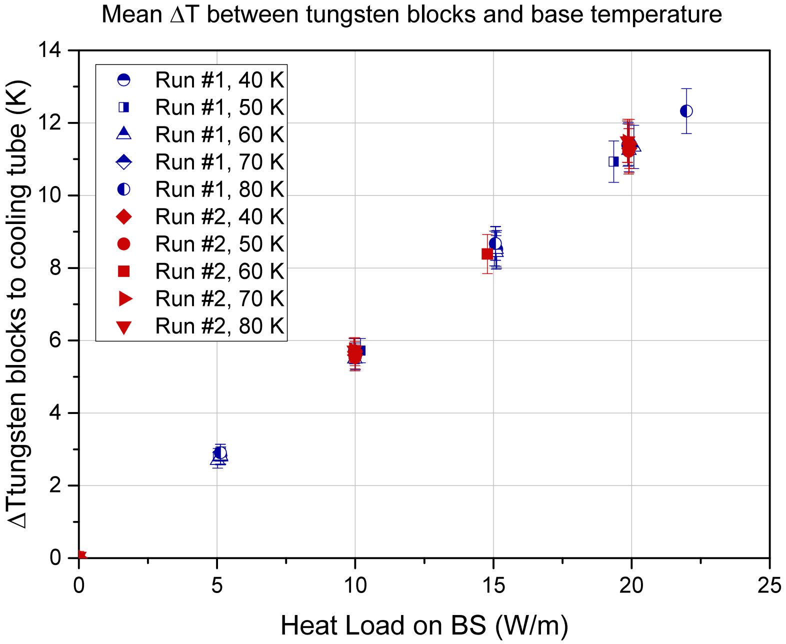
Parameters for the second measurement run

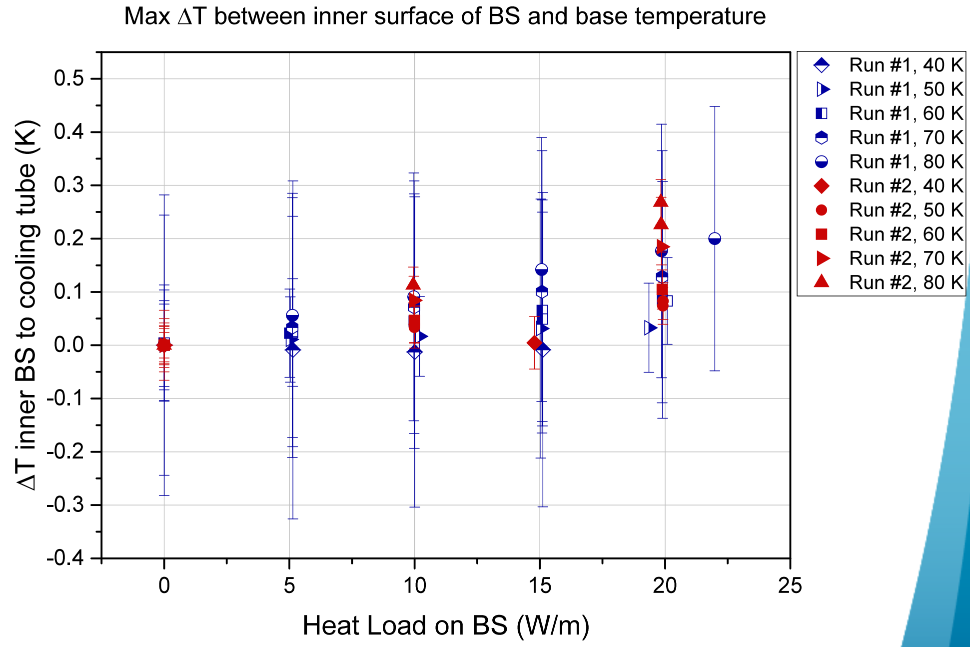
- Identical run to assess **reproducibility** of results
- Base temperature varied from **40 K to 90 K**
- Heat load on beam screen varied from **0 to 20 W/m** (fewer steps)
- **Beam screen circuit pressure** varied from 17 bar to 23 bar

Results: beam screen temperature profile (both runs)

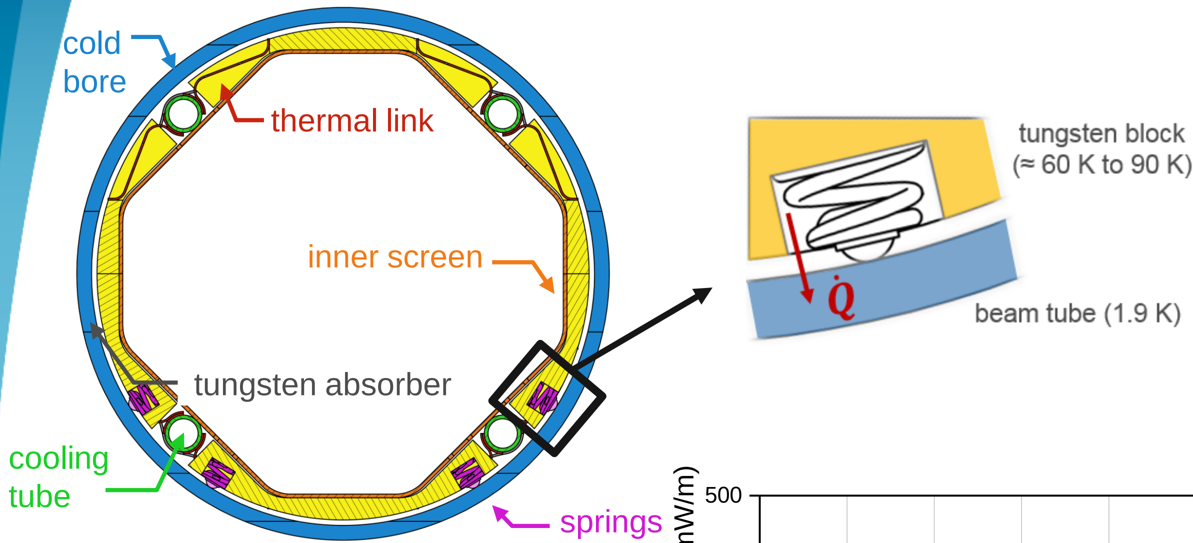




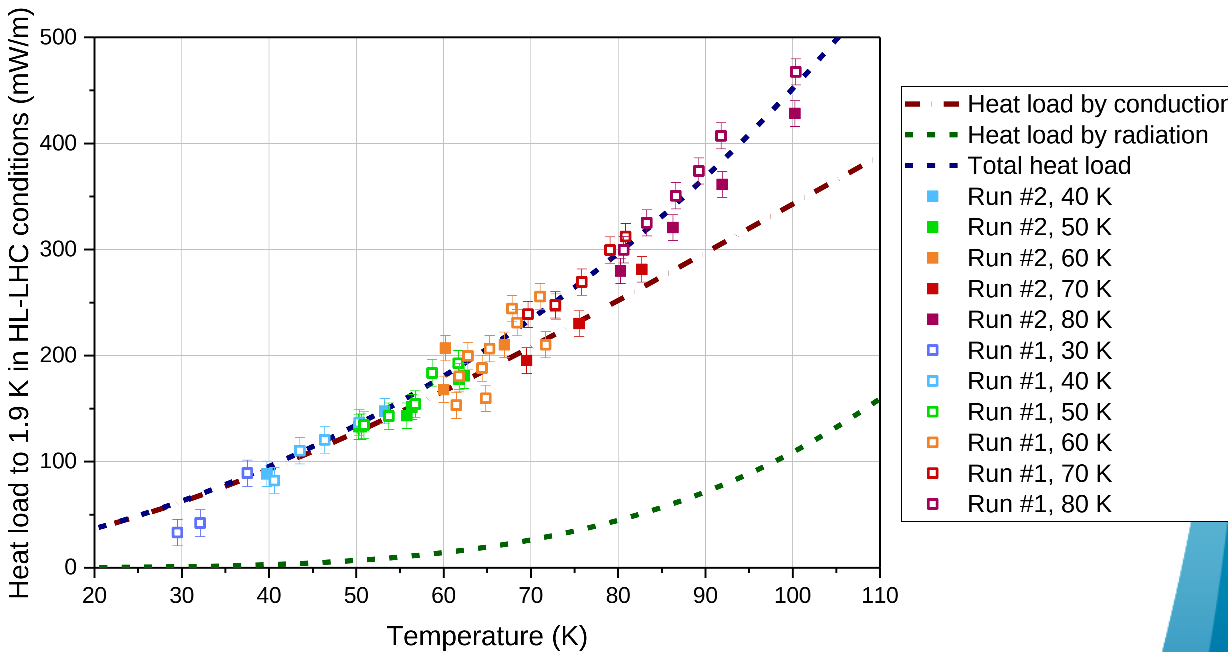




Results: heat load to the 1.9 K cold bore (both runs)



Tungsten block temperature (base T of cooling tubes + ΔT due to heat load of 15 W/m) **drives heat load to 1.9 K**



Fit curve:
Data from measured springs
Radiation with emissivity values of 0.10 and 75% of total beam screen area

Conclusions & Outlook

New measurement run will focus on analysing what happens to the overall 1.9 K heat load **if the beam screen touches the cold bore**

(motivated by the tolerances between beam screen and cold bore)

Experimental results validate the thermal design of the HL-LHC beam screens

Thank you for your attention!