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- The SWELL 1.3 GHz cooling geometry
- Literature, boiling regimes and limits
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- Heat transfer in He II at 1.9 K
- Comparison



# Cooling performance in saturated He I

• Heat transfer at the vertical ring-shaped geometry of the 1.3 GHz cavity (mock-up), semi-forced flow condition



Nb coating



Three views of the 3D CAD design of the quarter part of the 1.3 GHz SWELL cavity, showing the location of the vertical cooling tube with its height of 131 mm.

### Design and literature comparison

1.5 m

0.90 m

0.76 m

0.53 m

0.3 m ld

0.07 m

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• Heat transfer at the vertical ring-shaped geometry of the 1.3 GHz cavity (mock-up), semi-forced flow condition

TT<sub>0</sub>

TT5

TT4

TT3

TT2

TT

(PT)d



#### Literature data for He I cooling loop



Reference data found for heat transfer in a tube. Left) scheme of the measurement arrangement, right) temperatures measured at the heated wall for the following heat flux values in rising order:  $q_1=100 \text{ W/m}^2$ ,  $q_2=502 \text{ W/m}^2$ ,  $q_3=1005 \text{ W/m}^2$  and  $q_4=1605 \text{ W/m}^2$ . Graphs replotted from Benkheira et al.

### **Experimental setup**











### Measurements – step heating function Q

Rising heat load step function response => dT and time constant

2 W heat load

#### 4.34 ● R5 ● R6 ● R7 ● R8 4.32 4.3 Temperature in K 4.28 4.26 4.24 4.22 0.00 100.00 200.00 300.00 400.00 500.00 600.00 Time in s

### 17.5 W heat load



### Results

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Results

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Comparison with the highest data of the current measurement run to the literature esp. Eq. 6 stated in Benkheira. Please pay attention to the different scale of dT on the horizontal axis.

### Results, He I @ 4.2 K bath, long outlet => below or above the bath level

10 W with outer level below exit of the tube



### Results, He I @ 4.2 K bath, long outlet => below or above the bath level

10 W with outer level below exit of the tube

17.5 W with outer level above exit of the tube



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## He I to He II cooling comparison

#### He I @ 4.2 K, 17.5 W heat load

#### He II @ 1.9 K, 17 W heat load



Two-phase cooling in saturated He I conditions is more efficient than He II saturated conditions, due to heat transfer limits at the liquid to Cu interface (Kapitza) and  $\lambda_{Cu}(T)$ 

#### Results, He II @ 1.9 K bath, short outlet => below the He bath level



Captured picture of the outlet of the mock-up copper block with removed exhaust, fully submerged in LHe. Initial blowout of vapor bubbles in He II after 81 s from the start of the applied heat load.

### Results, He II @ 1.9 K bath, short outlet => below the bath level



- Start of the instabilities in He II after 81 s from the start of the applied heat load.
- Exceeding the critical heat flux in the diameter 30 mm tube.
- A=7 cm<sup>2</sup>  $q_{cr}$  = ~ 1 W/cm<sup>2</sup> depending on liquid height, sat. conditions etc.

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# Summary

- The SWELL cavity heat transfer has been tested up to 17.5 W
- Flow by self-sustained convection loop (corresp. to V5 cond. in SM18 at CERN)
- He I condition with min. 35 cm subcooling by static height
  - ➢ dT<sub>max</sub>=0.75 K
  - Stable end temperatures have been observed
  - No thermal run-away effect
- He II condition with 10-20 cm subcooling by static height
  - ➢ dT<sub>max</sub>=1.55 K
  - Stable end temperatures have been observed
  - No thermal run-away effect
  - Instabilities in sat. He II heat transfer => may require press. He II in case of T<4.5 K</p>
- Vertical temperature distribution depends on local boiling phenomena
- Link to movies and pictures: <u>https://edms.cern.ch/document/2732654/1</u>

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### Summary 2 – Cooling options, cryogenics point of view



Cooling options (which I would suggest):

- 2.0 K He II saturated condition is excluded by boiling instabilities
- 2.0 K He II pressurized cooling tubes with heat exchanger (LHC magnet like),
  => need to be tested for the high heat flux of the SWELL quadrants?
- 4.5 K saturated liquid He with thermo-syphon to a two-phase tube (4 times) and using the small inclination angle of the tunnel plus cooling tube inclination, 1 example shown in the above pictures



# Thank you for your attention

### Reference data from literature

• Heat transfer in a free convection cooling loop arrangement, Benkheira et al., Heat transfer characteristics He I (4.2 K) thermosiphon flow, Int. J. of Heat and Mass Transfer 50 (2007), pp. 3534-3544.



Experimental setup of the reference, thermosiphon arrangement.

Graphs replotted from Benkheira, stating the critical heat flux vs. temperature difference for different locations in height in respect to the diameter z/D replotted [1]. The respective values for the SWELL setup are ranging for a hydraulic diameter of the ring-shaped tube up to  $z/D_h=131/20=6.55$ .