# Thermal Management (Cooling) Of The CBM Silicon Tracking System

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DPG | Bochum 18

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FAIR Facility for Antiproton and Ion Research in Europe GmbH

# OUTLINE

1. Introduction of the CBM Silicon Tracking System
2. Motivation & challenges for thermal management of CBM-STS
3. Optimisation of thermal interfaces
4. Optimisation of cooling plates
5. Feedthrough test setup
6. Conclusion and outlook

# CBM SILICON TRACKING SYSTEM

- CBM aims to explore regions of high-baryonic densities of QCD phase diagram
- Requires detection of rare probes

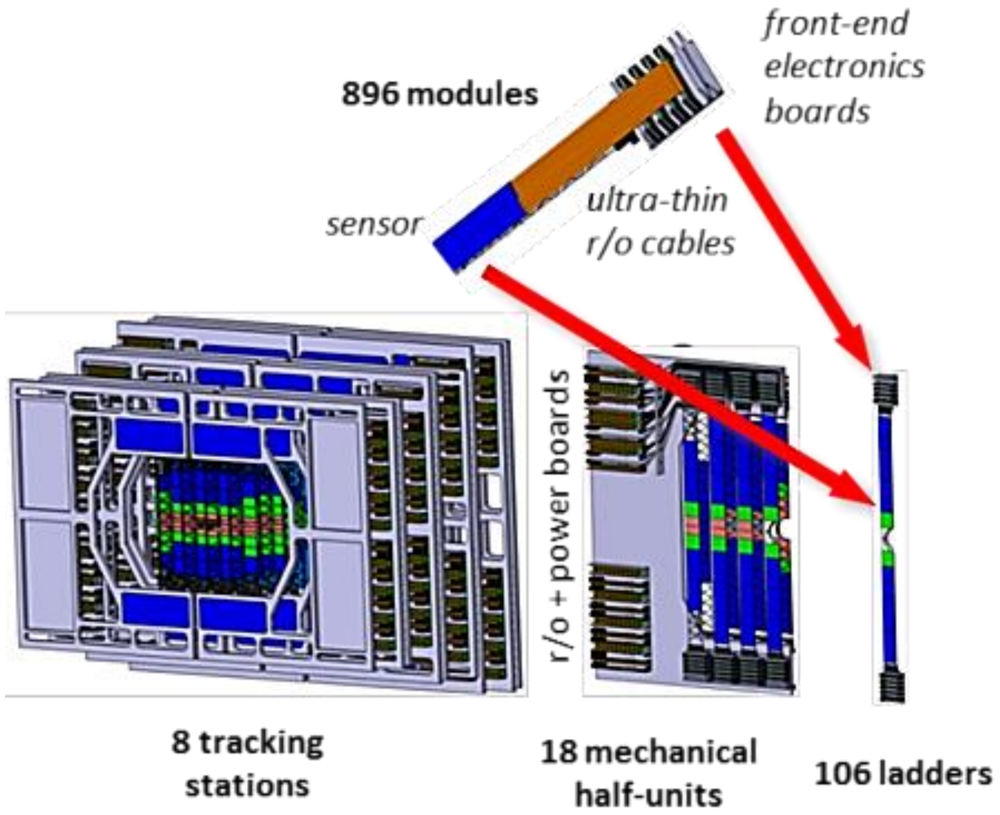
STS Group Report
HK 61.1, 14:00, E. Lavrik

→ $10^5 - 10^7$ collisions/sec (Au-Au)

→ Momentum Resolution $\Delta p/p \approx 1\text{-}2\%$

→ High track reconstruction efficiency with pile-up free track point determination

↓



- Silicon Tracking Station → Key to CBM Physics
- 8 Tracking Stations :- 896 double-sided micro-strip sensors
- Low Material Budget :- 0.3% - 1% $X_0$ per station
- Radiation tolerance: ≤ $10^{14}$ $n_{eq}$ $cm^{-2}$ (1 MeV equivalent)
- ~ 1.8 million read-out channels
- ~ 16000 r/o ASICs "STS-XYTER"

**40kW Power Dissipation!!!**

# MOTIVATION & CHALLENGES FOR STS COOLING

- Adverse effects of high-radiation
  - → Leakage current increases with fluence & temperature

    $\Delta I = \alpha \cdot \Phi_{eq} \cdot (A \cdot d)$  $I_L(T) \propto T^2 exp(-1/T)$
  - → Reduces signal-to-noise ratio (STS req.: S/N > 10)

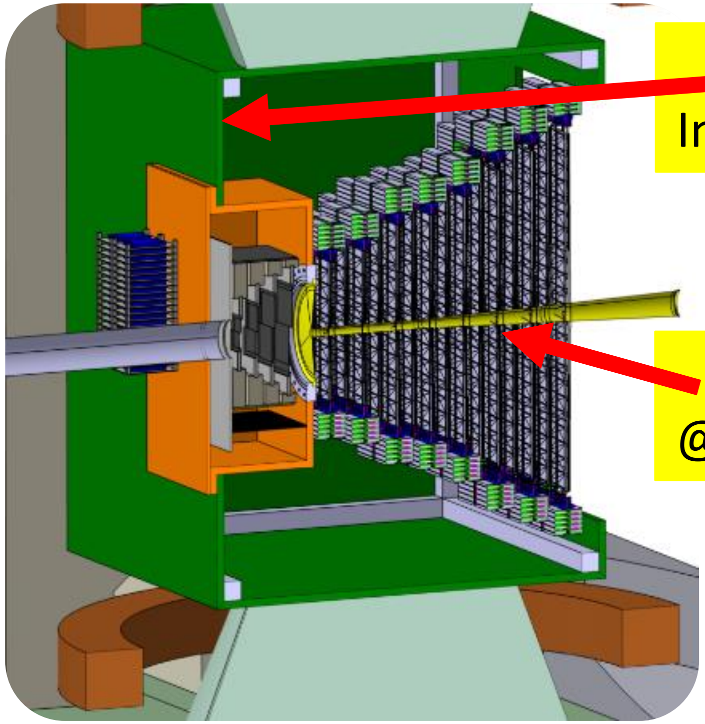
    $\text{Shot Noise} \propto \sqrt{I_L}$
  - → Thermal Runaway
  - → Reverse annealing of depletion voltage

STS Sensor Radiation Damage
HK 61.5, 15:15, E. Friske

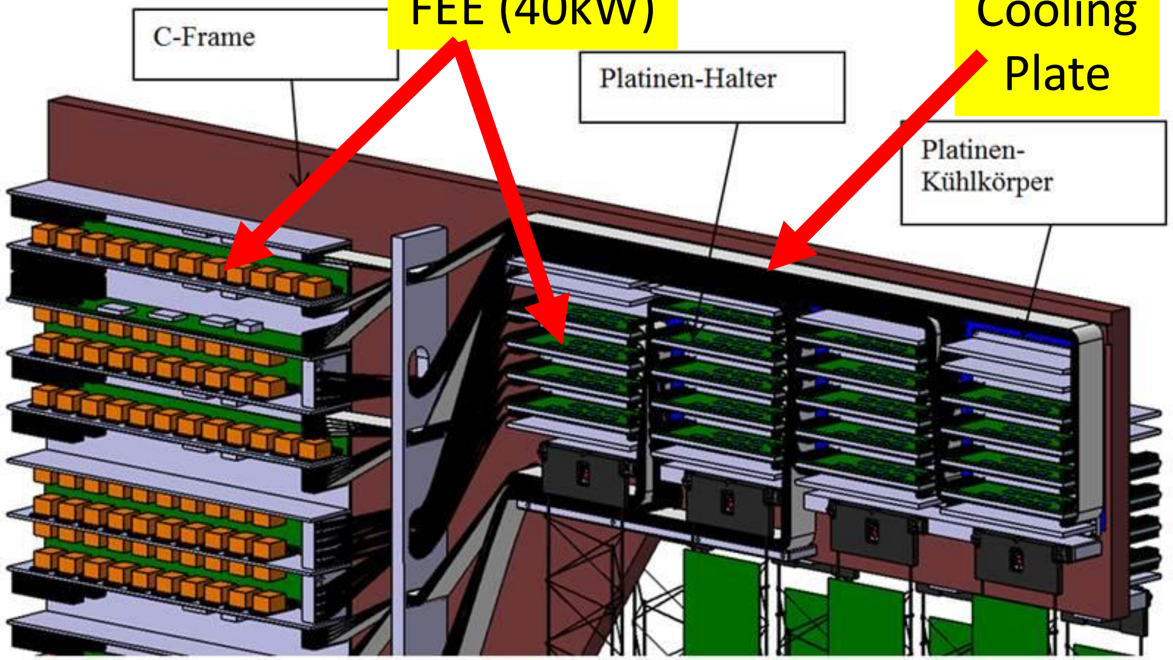
- Sensor cooling could control these adverse effects

**STS sensor temp. -10°C to -5°C at all times**

# MOTIVATION & CHALLENGES FOR STS COOLING


Thermal Insulation Box

<-5°C @sensors



FEE (40kW)

Cooling Plate

No cooling pipes inside detector acceptance

- Cooling of sensors (~ 1mW/cm$^2$) → forced convection ($N_2$ cooling) + thermal enclosure
- Cooling of front-end electronics (~ 40kW) → bi-phase $CO_2$ cooling

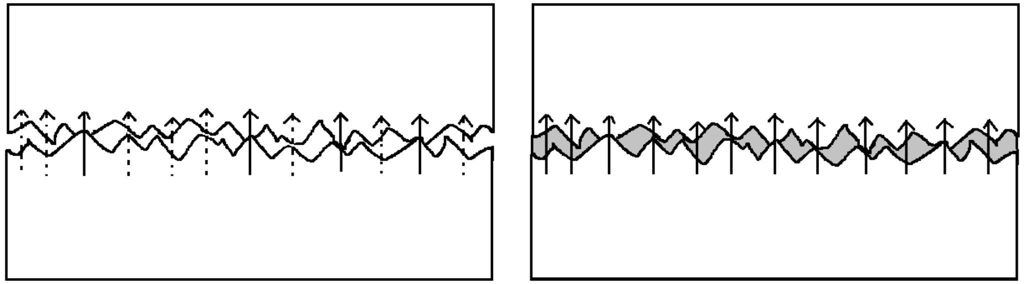
# OPTIMISATION OF THERMAL INTERFACES

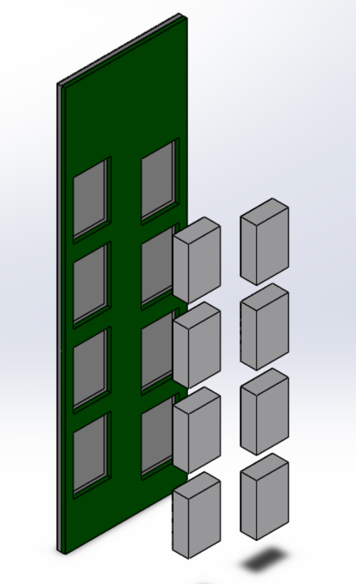
- Thermal Interface Materials (TIMs)

→ increases area of contact at microscopic scale

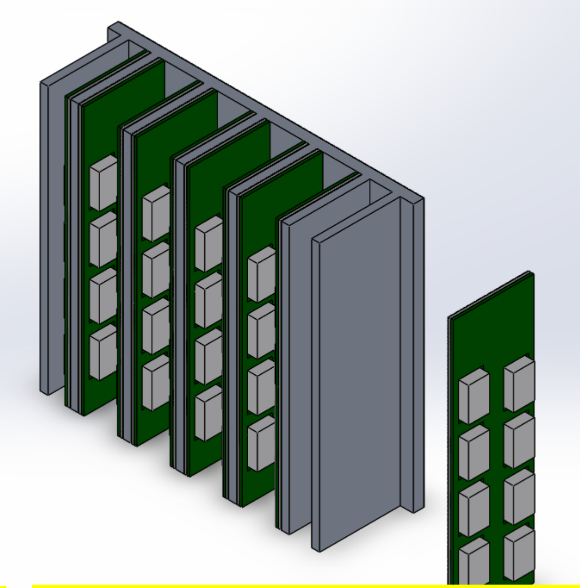
→ increase overall thermal conductivity

($k_{air} = 0.026$ W/(m·K) )

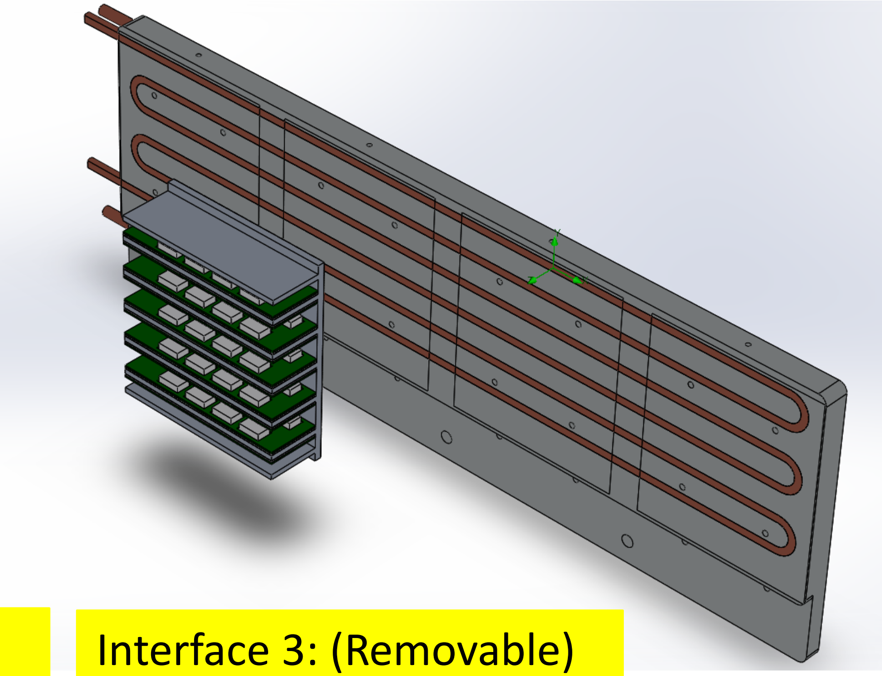




Interface 1: (Fixed)
Aluminium Nitride – ASIC (Resistors)



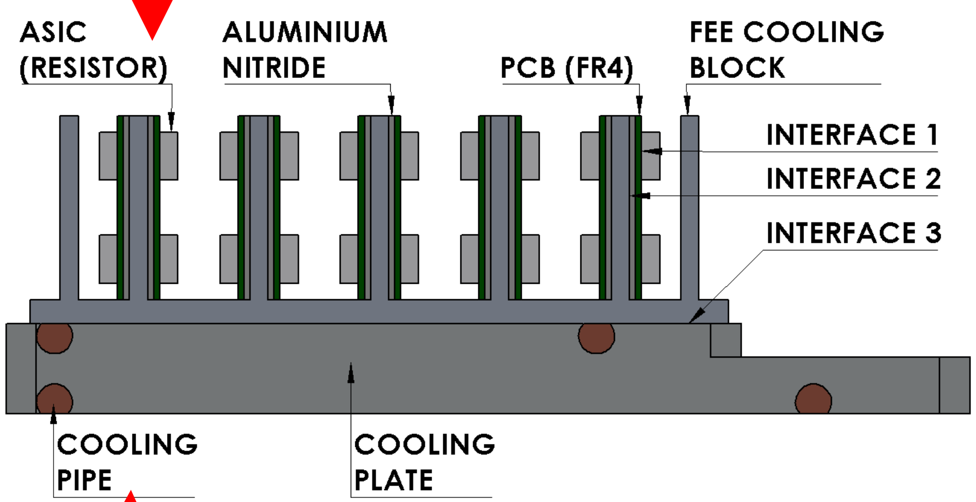
Interface 2: (Removable)
Aluminium Nitride – Aluminium Fin



Interface 3: (Removable)
FEE box – Cooling Plate

# OPTIMISATION OF THERMAL INTERFACES

Power Dissipated: 160W



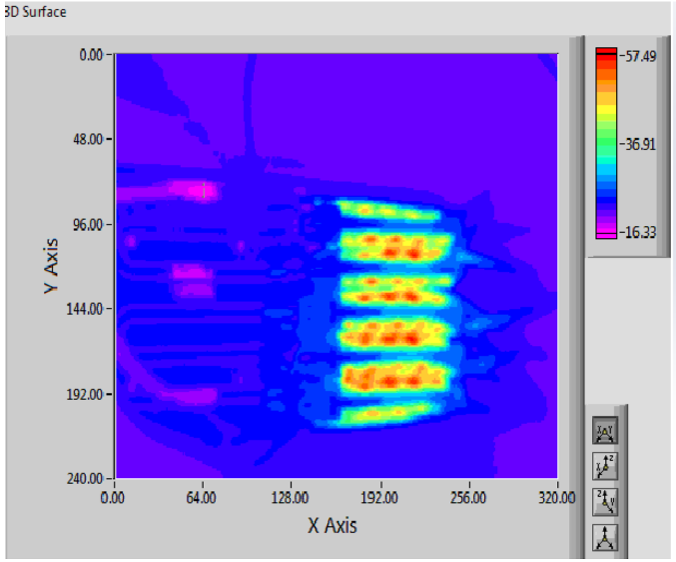
$H_2O$ inlet: 15°C @ 40lt/hr

HTC: 750 W/m²K
Air Convection: 10 W/m²K
Radiation included

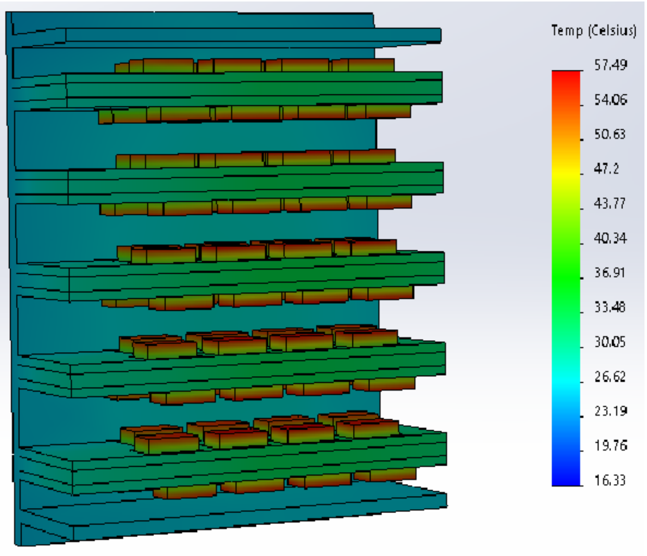
Thermal Interface Material Properties

| Interface# | TIM | k<br>W/m·K | d<br>μm | $R_\Theta$ (d/k)<br>$m^2$·K/W |
|---|---|---|---|---|
| 1 | WLK 10 (Thermal Glue) | 0.836 | 100 | 1.2 x $10^{-4}$ |
| 2-3 | KP97 (Thermal Grease) | 5.0 | 30 | 6.0 x $10^{-6}$ |
| | QGF-G03 (Graphite Foil) | 16.0 | 125 | 7.8 x $10^{-6}$ |

Exp. – IR Camera + PT100



FEA – Solidworks Thermal Sim.



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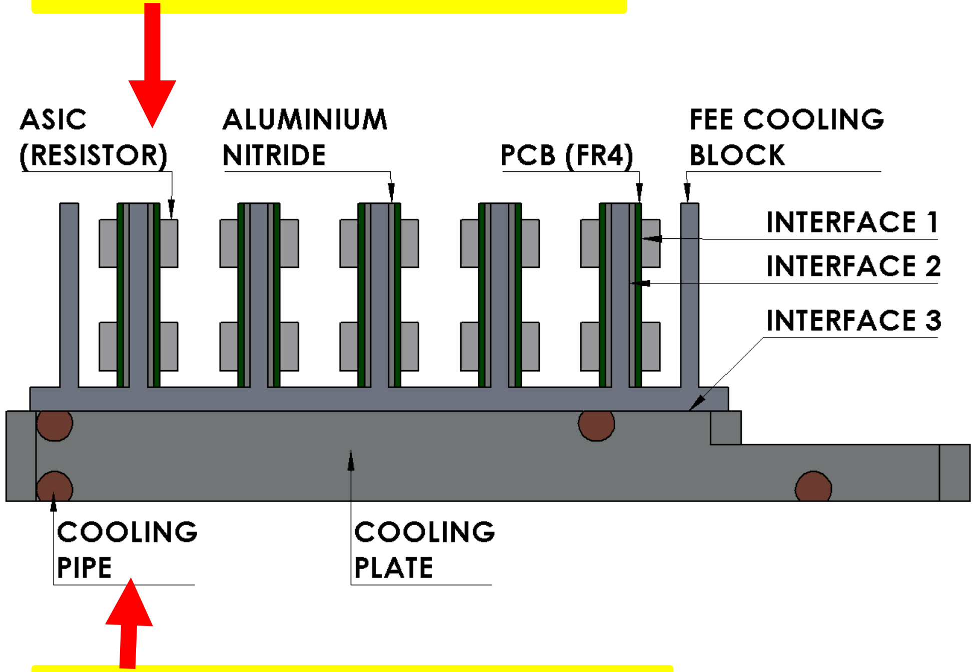


$H_2O$ inlet: 15°C @ 40lt/hr

HTC: 750 W/m²K
Air Convection: 10 W/m²K
Radiation included

$T = 15°C,\ \dot{Q} = 160W,\ \dot{m} = 11.1\ g/s$

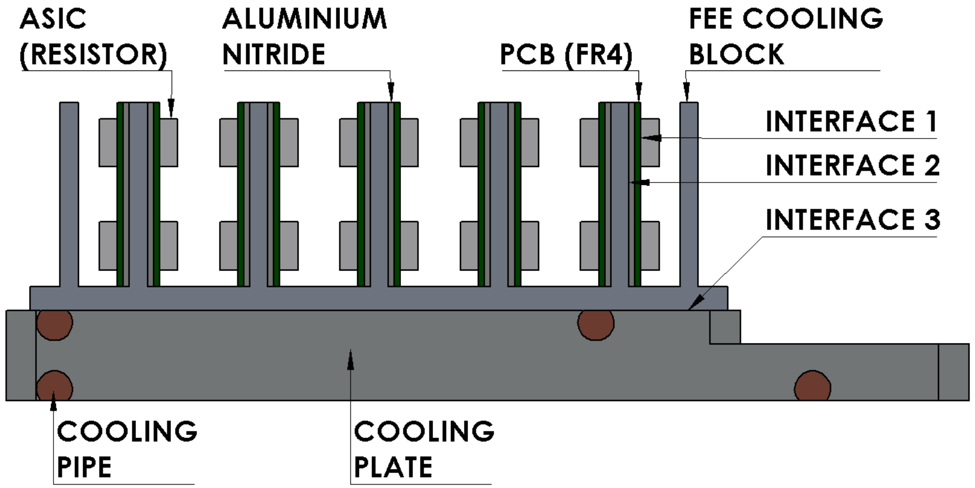
| Interface #1 | Interface #2 | Interface #3 | Max. Fin Temp. (°C) | |
|---|---|---|---|---|
| | | | Exp. | FEA |
| Glue | Grease | Grease | 29.7 | 32.0 |
| | | Foil | 29.6 | 32.0 |
| | Foil | Grease | 33.7 | 32.1 |
| | | Foil | 33.9 | 32.1 |

Key take-aways :

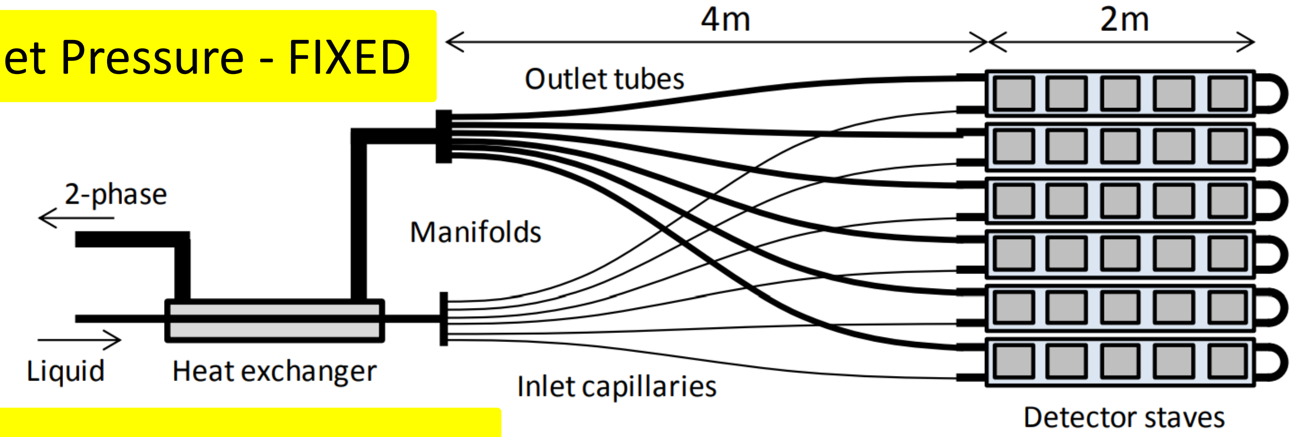
- A more viscous TIM (grease) has a better thermal performance than a relatively rigid TIM (graphite foil, thermal pad)
- Flattening the interfaces (~ 10µm) improves the results substantially
- Good agreement (± 10%) between experiments & simulations

# OPTIMISATION OF COOLING PLATE

- Bi-Phase $CO_2$ cooling for STS-FEE (~ 40kW)
- $CO_2$ heat transfer co-efficient depends on: → cooling plate's tube (diameter & length) (√)
  → mass flow of the coolant (√)
  → targeted amount of heat removal (√)
- STS cooling plate's boundary conditions for this study: → Coolant temp. $T_{CO2}$ = -40°C
  Targeted heat removal = 1300W (~ 8 FEBs)

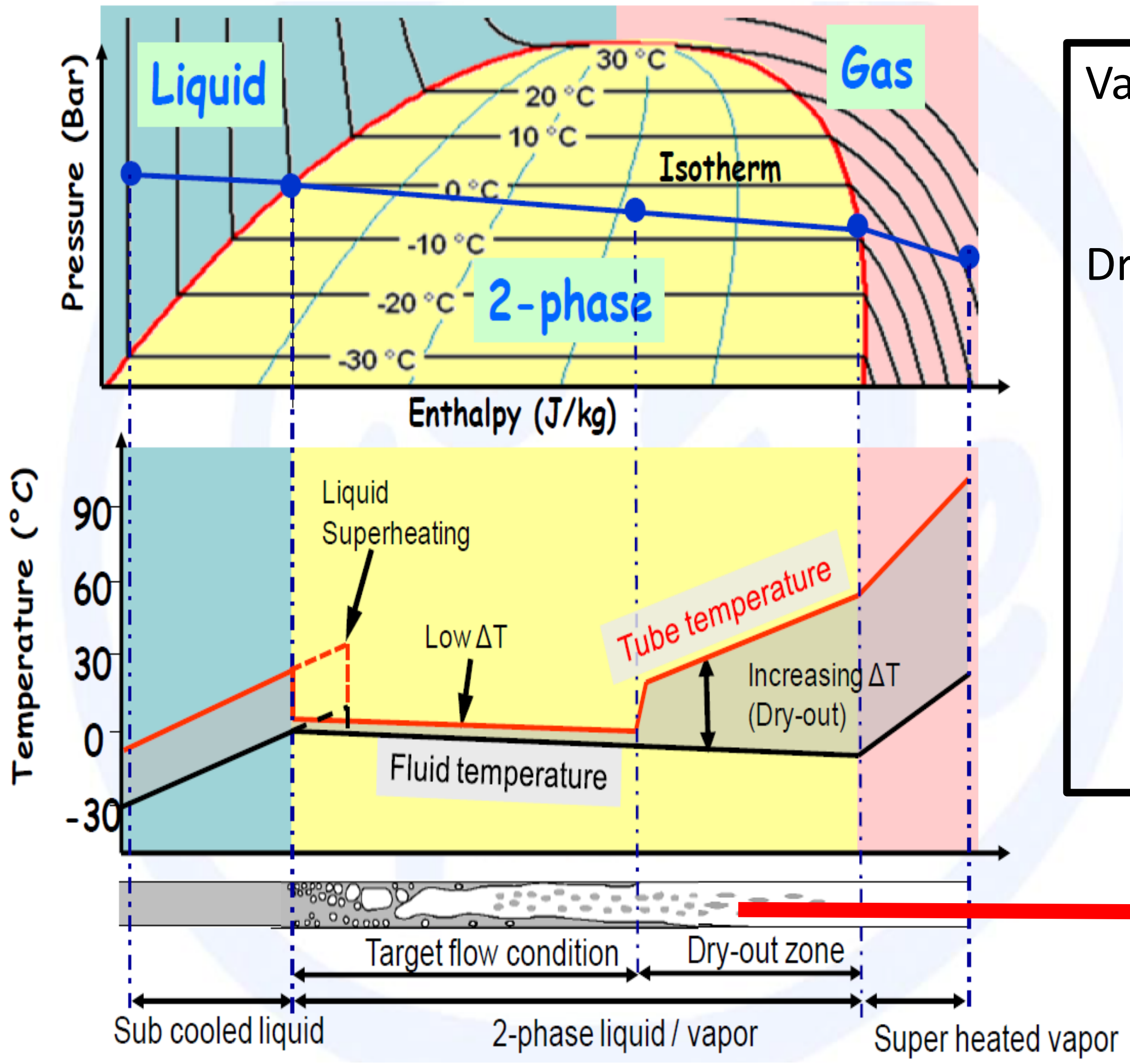


Outlet Pressure - FIXED



Inlet Temperature - FIXED

# OPTIMISATION OF COOLING PLATE



Vapor Quality: $\chi = \frac{\dot{m}_{vapor}}{\dot{m}_{total}}$ (= 0: saturated liq.) (= 1: saturated vap.)

Dry-out zone: Tube's inner surface is no longer in contact with liquid coolant

↓

Much lower Heat Transfer Co-eff

↓

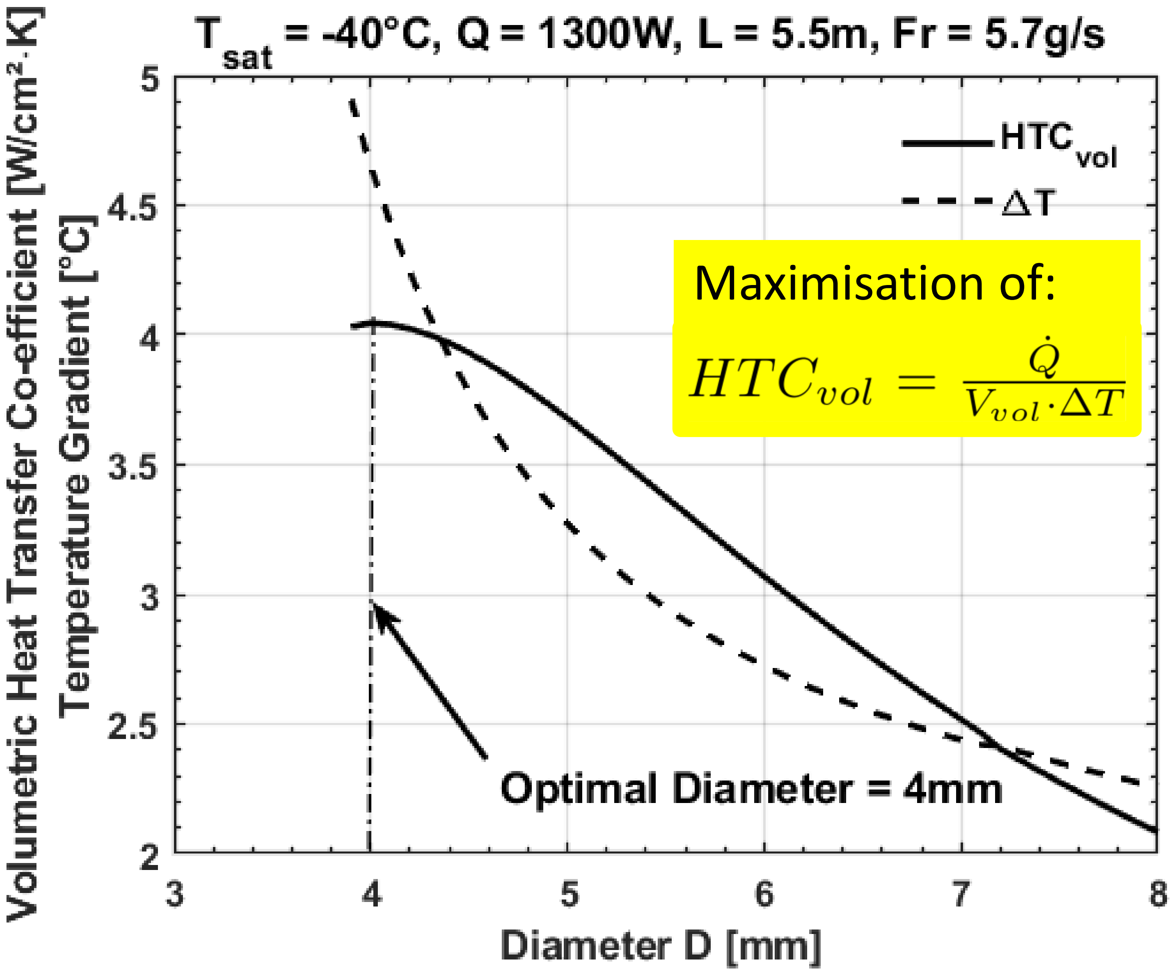
Higher tube wall temperature

↓

Higher ΔT (Local temp. diff. between fluid and tube wall in tube)

Outlet vapor quality **SHOULD NOT** reach dry-out!
Solution: Higher mass flows

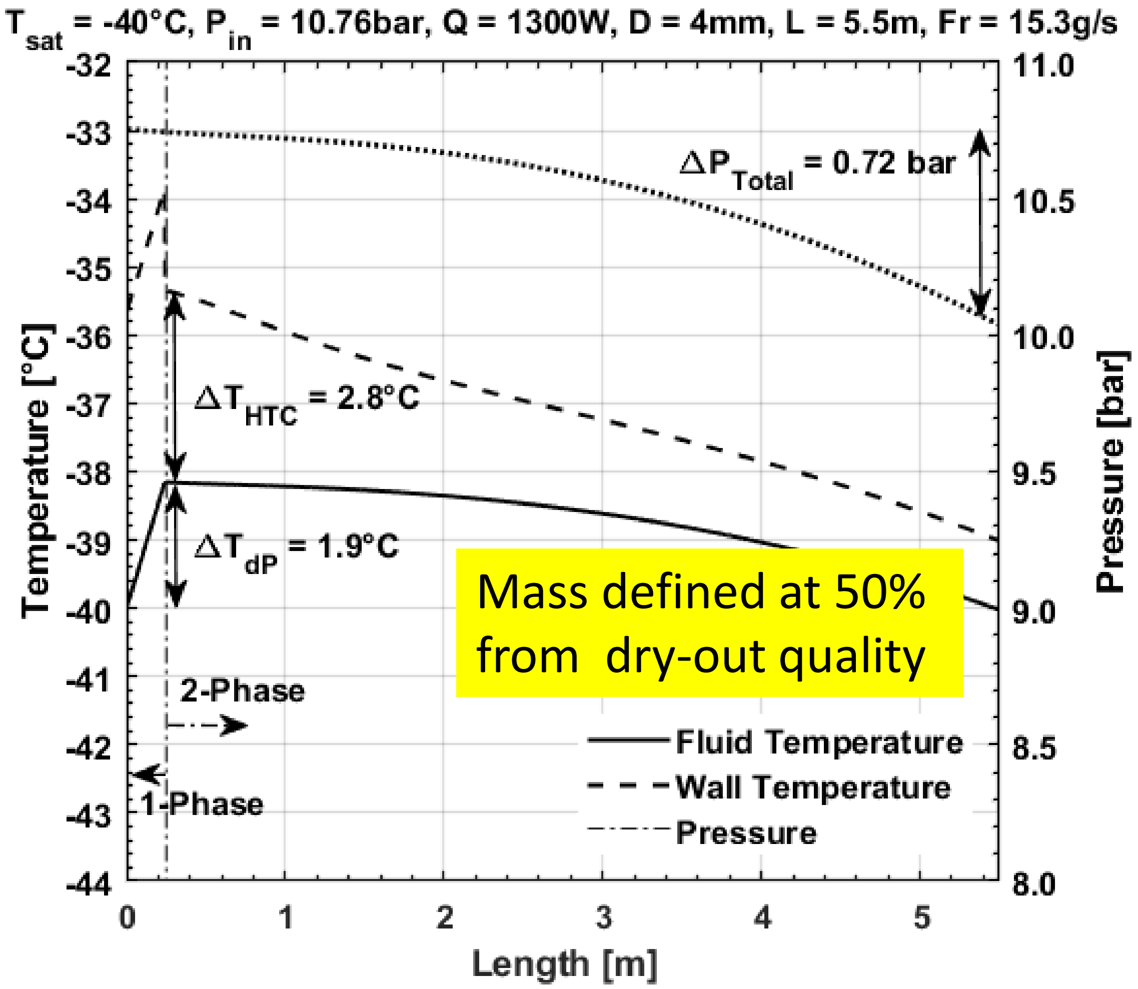
# OPTIMISATION OF COOLING PLATE



Maximisation of:

$$HTC_{vol} = \frac{\dot{Q}}{V_{vol}\cdot\Delta T}$$

Bi-Phase $CO_2$ Pressure/Temp. Distribution v/s Tube Length



Mass defined at 50% from dry-out quality

# OPTIMISATION OF COOLING PLATE

Operational Parameters look-up table
(Diameters w.r.t. Swagelok VCR connections)

$T = -40°C, \dot{Q} = 1300W$

| D (mm) | L (m) | $\dot{m}$ (g/s) | | |
|---|---|---|---|---|
| | | At dry-out | 25% from dry-out | 50% from dry-out |
| 4.00 | 5.50 | 5.70 | 8.30 | 15.30 |
| 4.57 | 8.50 | 5.10 | 7.20 | 12.10 |
| 6.00 | 19.50 | 4.60 | 6.30 | 9.80 |
| | | ΔT (°C) | | |
| | | At dry-out | 25% from dry-out | 50% from dry-out |
| | | 4.53 | 4.59 | 4.69 |
| | | 3.67 | 3.72 | 3.79 |
| | | 2.46 | 2.44 | 2.47 |

Calculations based on:
L. Cheng *et al.*, Int. J. Heat Mass Transfer 51 (2006), p.111 & p.125
B. Verlaat *et al.*, Proceedings of 10th IIR Gustav Lorentzen Conference on Natural Refrigerants (2012), GL-209
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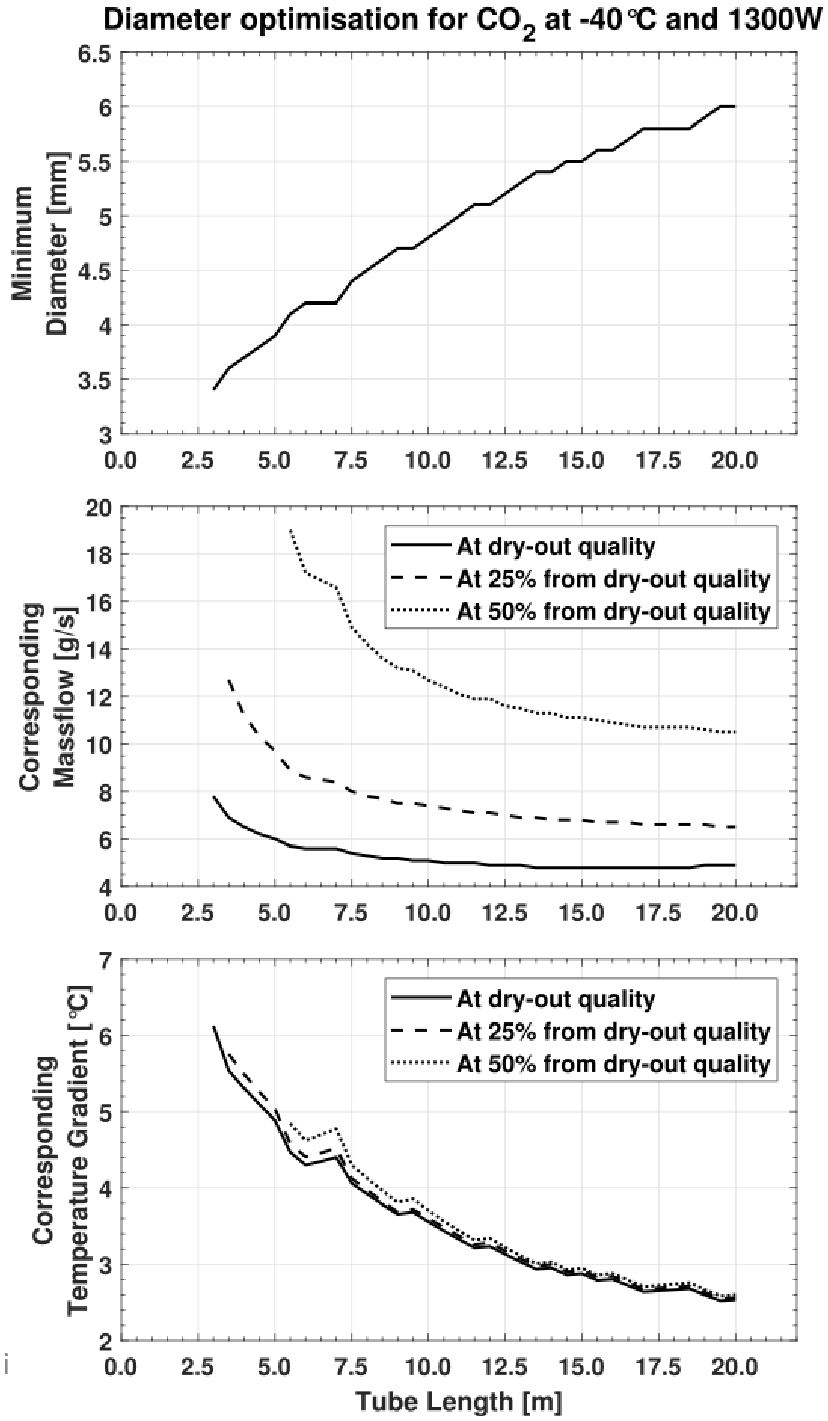

# FEEDTHROUGH INTEGRATION & TESTS

- All services (HV, LV, data transmission, cooling etc) will be routed through STS front panel
- Total available area = 1.5m²
- Easy cabling & de-cabling
- Maintainence of thermal environment inside STS

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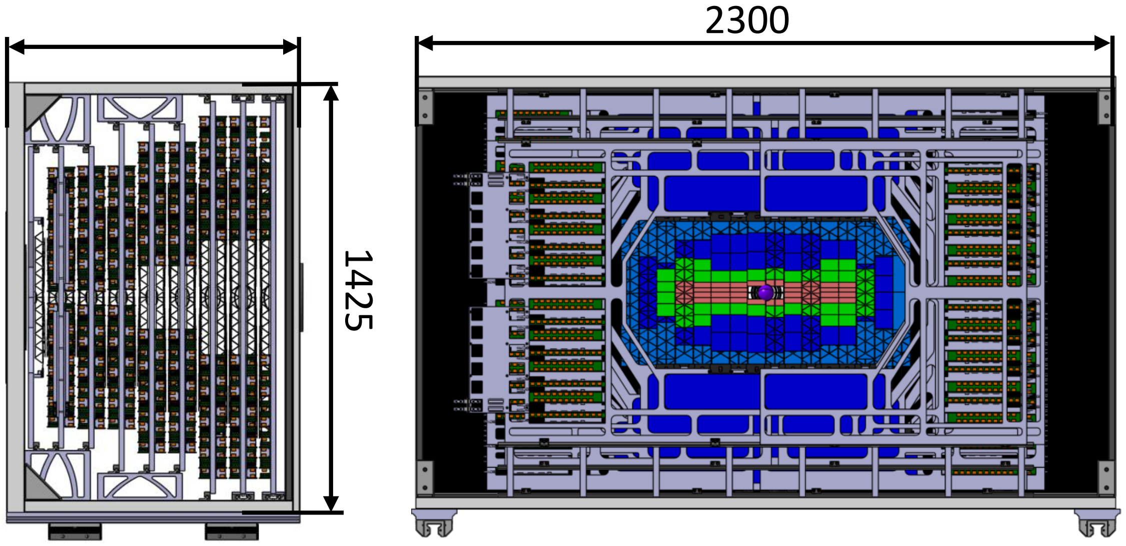
**High-density thermally-insulating feedthroughs!**

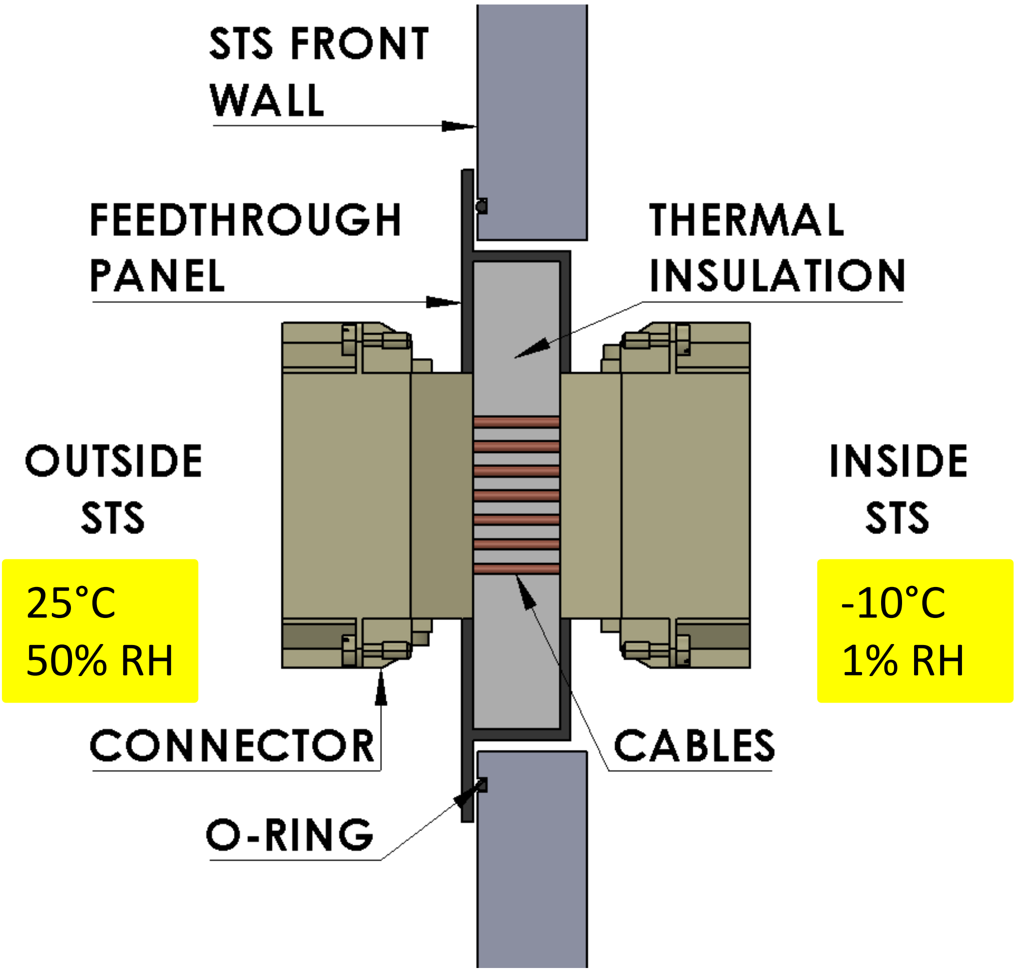


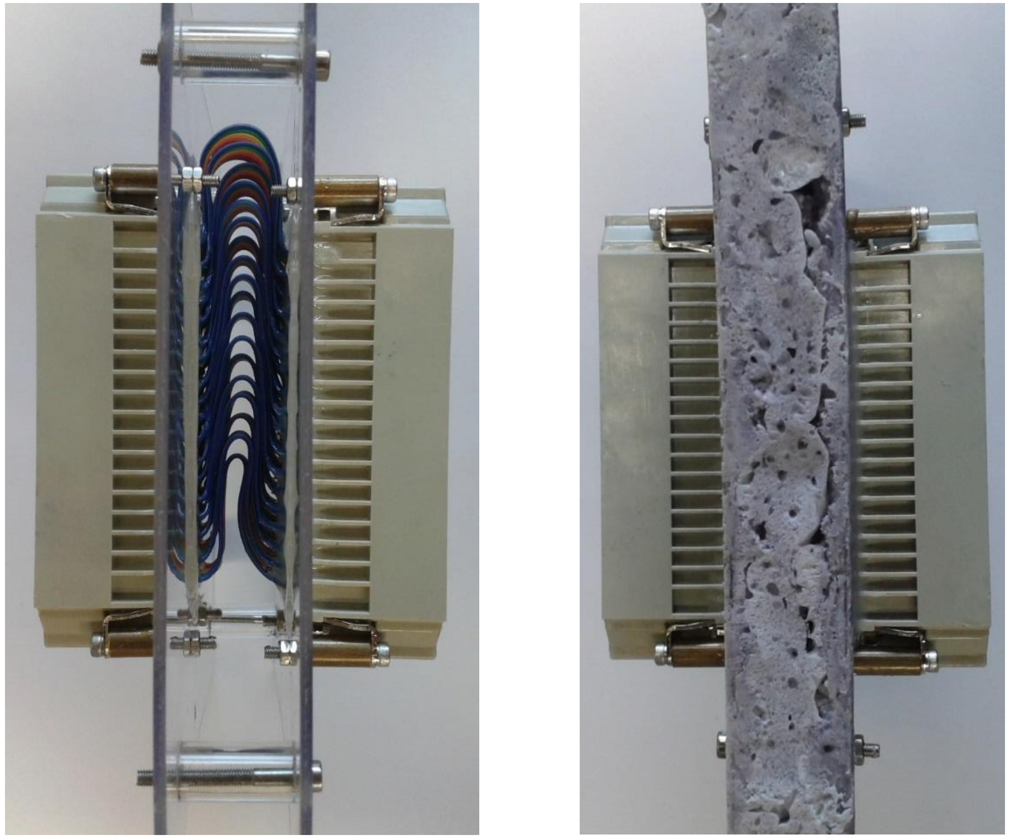
| | # Cables | U/I | Wire (mm$^2$) | Incl. shielding /insulation (mm$^2$) | Total Area (cm$^2$) |
|---|---|---|---|---|---|
| LV (Floating) | 4 × 900 | 12V/1A | 0.25 | 4 | 144 |
| HV | 2 × 900 | ± 250V/5mA | 0.10 | 4 | 72 |
| GBTx | 4 × 150 | 12V/1A | 0.25 | 4 | 24 |
| Opical | 256 | - | - | 4 | 10 |
| Cooling | 80 | - | - | bundled + 6cm insulation | 40 |
| Controls | 200 | - | - | 4 | 8 |

+ Micro Vertex Detector (MVD)
+ Beam Pipe

**Total: 1.5m² (only)**

# FEEDTHROUGH INTEGRATION & TESTS

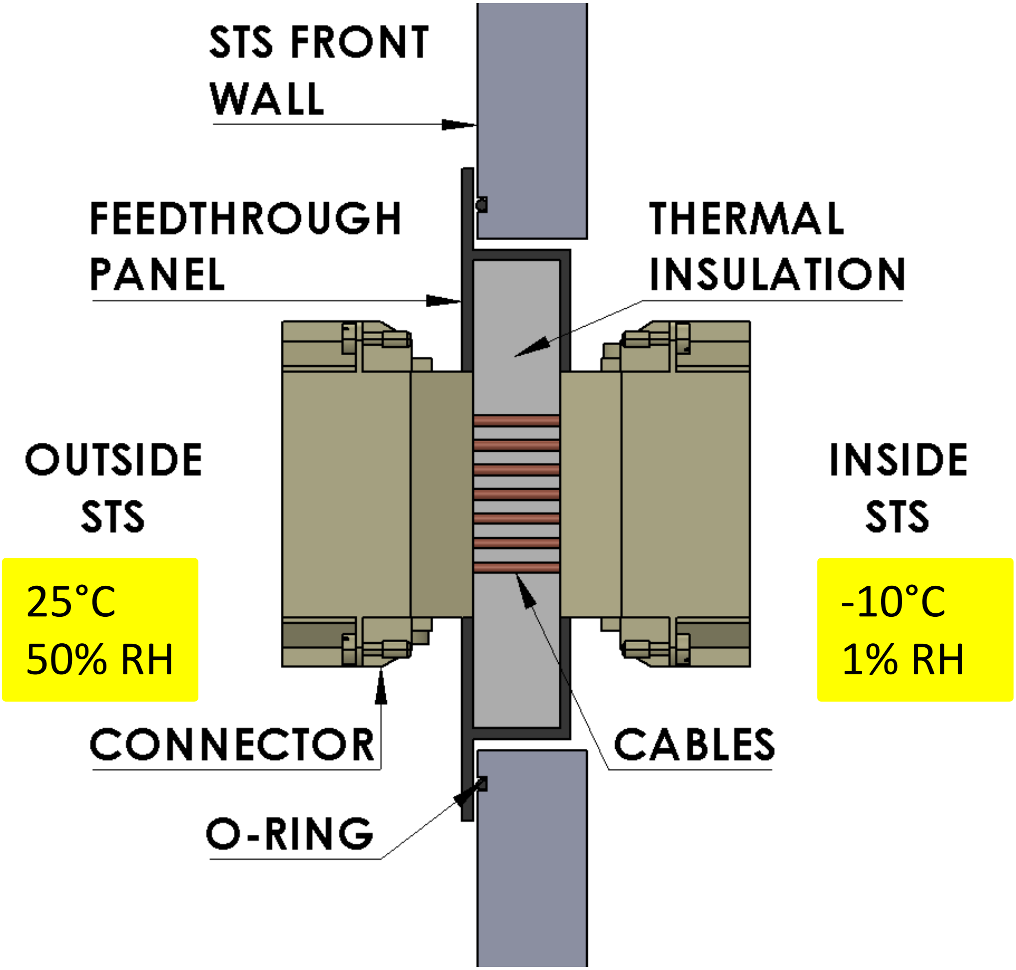




1st Dummy

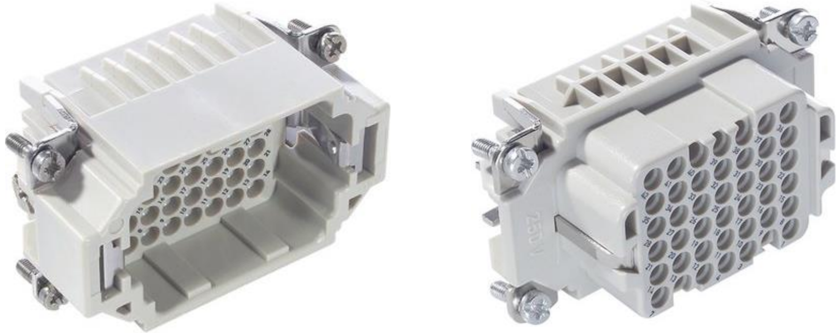
- 108 cables squeezed in 2cm gap!
- Sealed with silicone & filled with PUR foam

# FEEDTHROUGH INTEGRATION & TESTS



Next Steps:

- Panel with 9 x EPIC H-DD 42 connectors will be fabricated (area: 20cm x 20cm, #pins: 378)
- Shielded flat-band cables
- Thermal Insulation
- Similar panels with different connectors & configurations will be thermally tested at Universität Tübingen & electrically tested at GSI-Darmstadt
- Could be tested at mSTS



# SUMMARY AND OUTLOOK

- Challenges of STS Thermal Management:
  - → STS sensors temp. < -5°C
  - → Removal of FEE power (40kW) by bi-phase $CO_2$ cooling
  - → Operation in thermal enclosure
  - → High-density thermally insulating feedthroughs for services
- Progress towards construction of cooling demonstrator:
  - → Thermal interfaces are optimised: Viscous TIM (grease etc.) more efficient
  - → Optimised operational parameters for cooling plates available
  - → Feedthrough dummys are under construction

# SUMMARY AND OUTLOOK

- Sensor cooling: Heat-producing sensor dummies & $N_2$ cooling system
- FEE cooling:
  → Thermal FEA Simulations with different cooling plate designs + electronics
  → Feasibility of cooling plate‘s industrial manufacturing
  → Cooling plant commissioning (TRACI – XL)
- Environment management: Thermal enclosure & feedthroughs
- Integration: Aim towards start of production of parts by Sept 2018

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THANKS A LOT
FOR YOUR
ATTENTION!

# BACKUP
# SLIDES

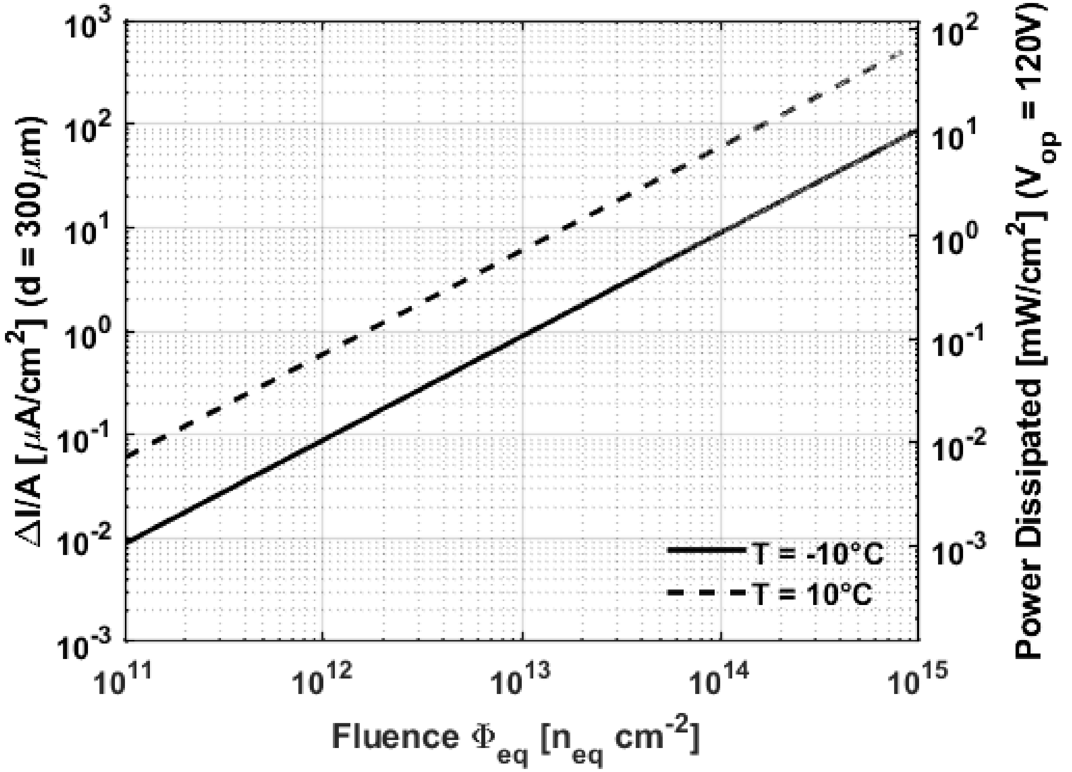
# <u>MOTIVATION</u> & CHALLENGES FOR STS COOLING

- Adverse effects of high-radiation → Leakage current increases with fluence & temperature

$$\Delta I = \alpha \cdot \Phi_{eq} \cdot (A \cdot d) \qquad \frac{I_L(T_2)}{I_L(T_1)} = \left(\frac{T_2}{T_1}\right)^2 \exp\left[-\frac{E_g}{2k}\left(\frac{T_1 - T_2}{T_1 T_2}\right)\right]$$

→ Reduces signal-to-noise ratio (STS req.: S/N > 10)

$$\text{Shot Noise} \propto \sqrt{I_L}$$



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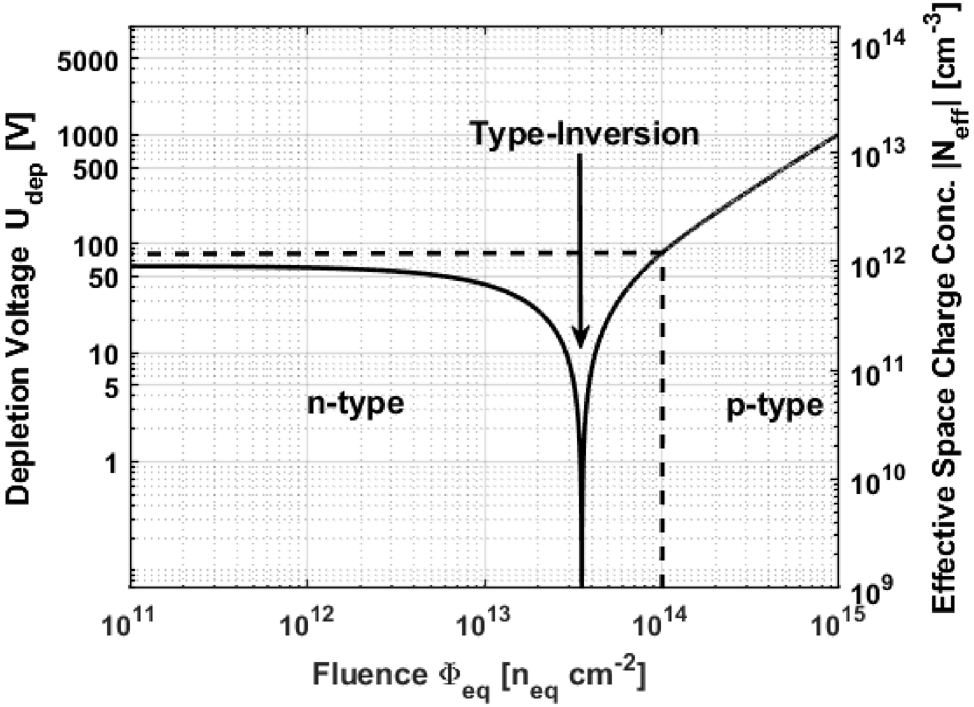
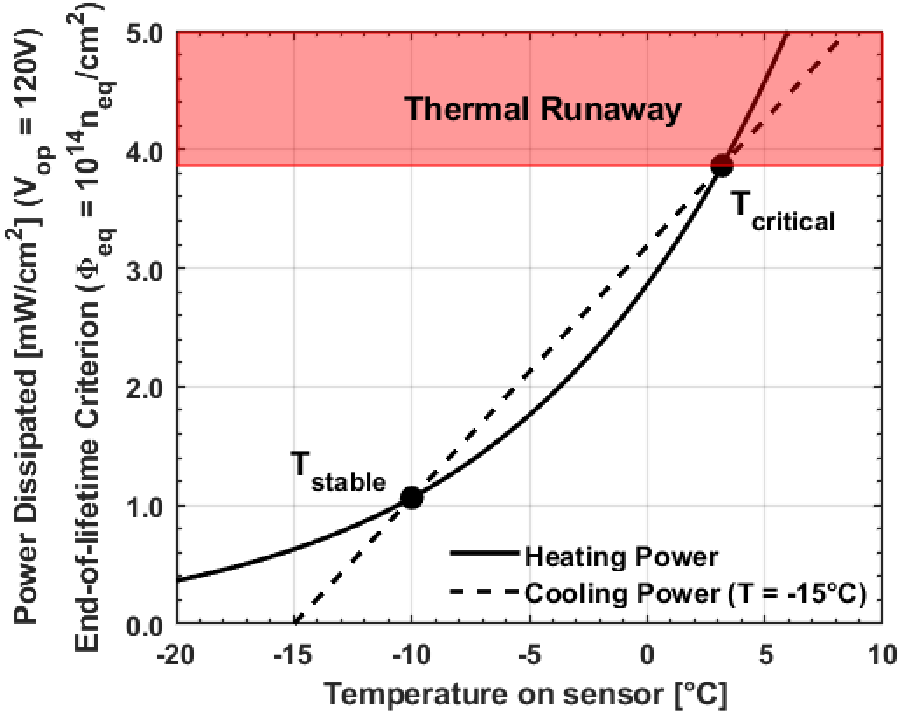
→ Thermal Runaway





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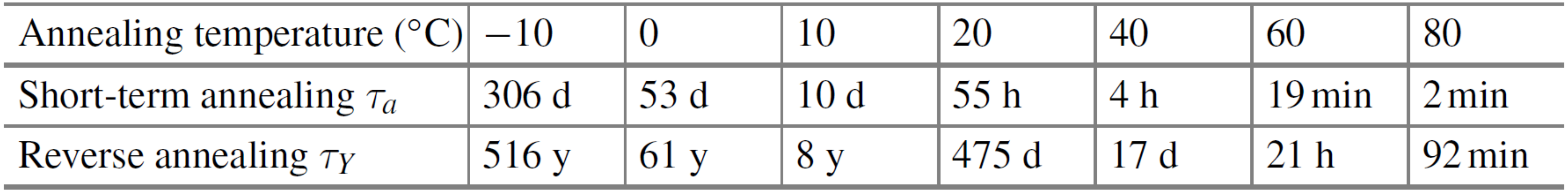

| Annealing temperature (°C) | −10 | 0 | 10 | 20 | 40 | 60 | 80 |
|---|---|---|---|---|---|---|---|
| Short-term annealing $\tau_a$ | 306 d | 53 d | 10 d | 55 h | 4 h | 19 min | 2 min |
| Reverse annealing $\tau_Y$ | 516 y | 61 y | 8 y | 475 d | 17 d | 21 h | 92 min |

F. Hartmann, *Evolution of Silicon Sensor Technology in Particle Physics*, Springer Tracts in Modern Physics 275, DOI 10.1007/978-3-319-64436-3_2

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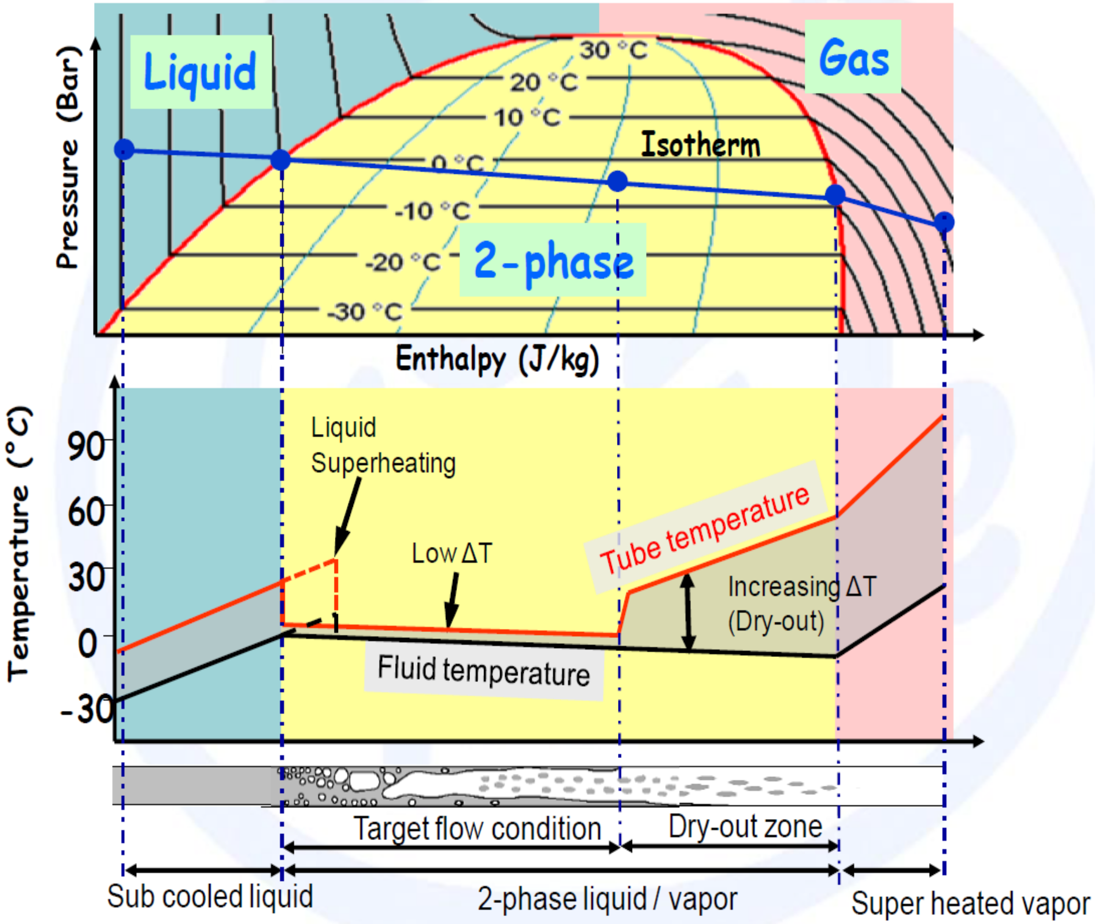
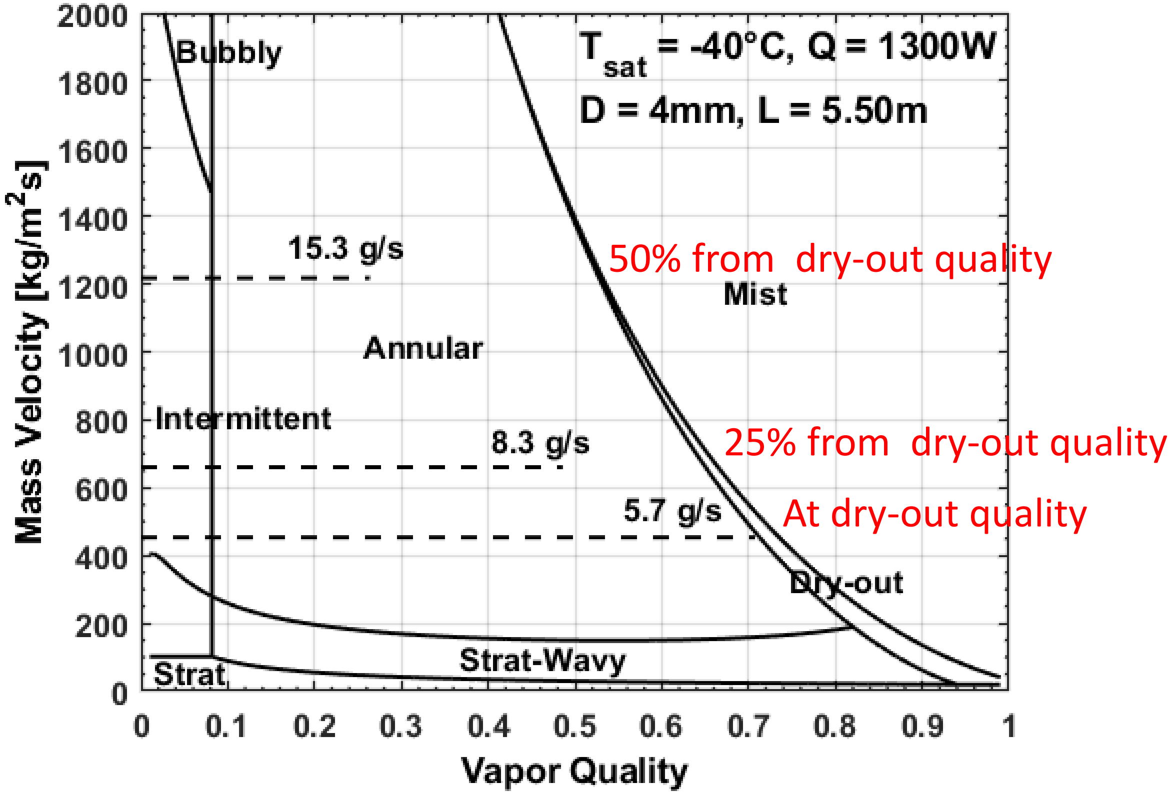


Bi-Phase $CO_2$ Flow Pattern Map



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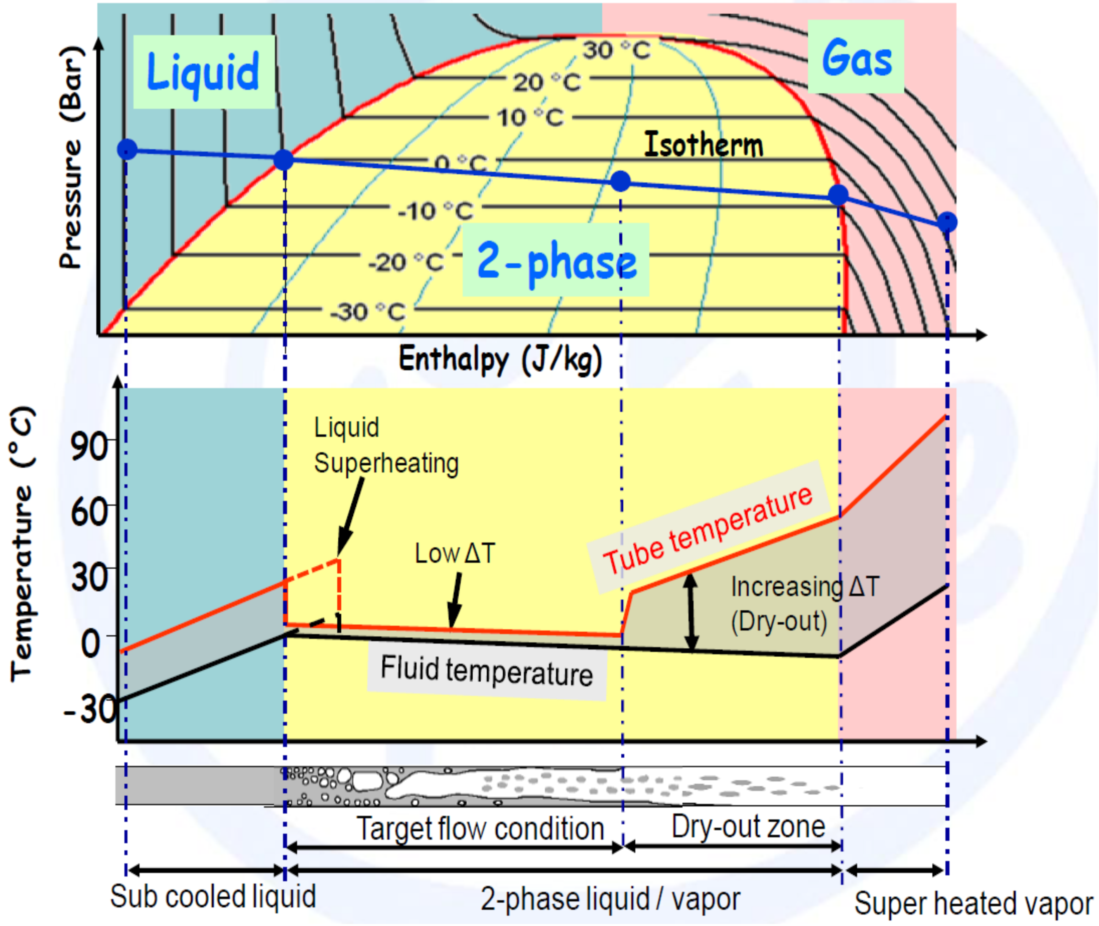
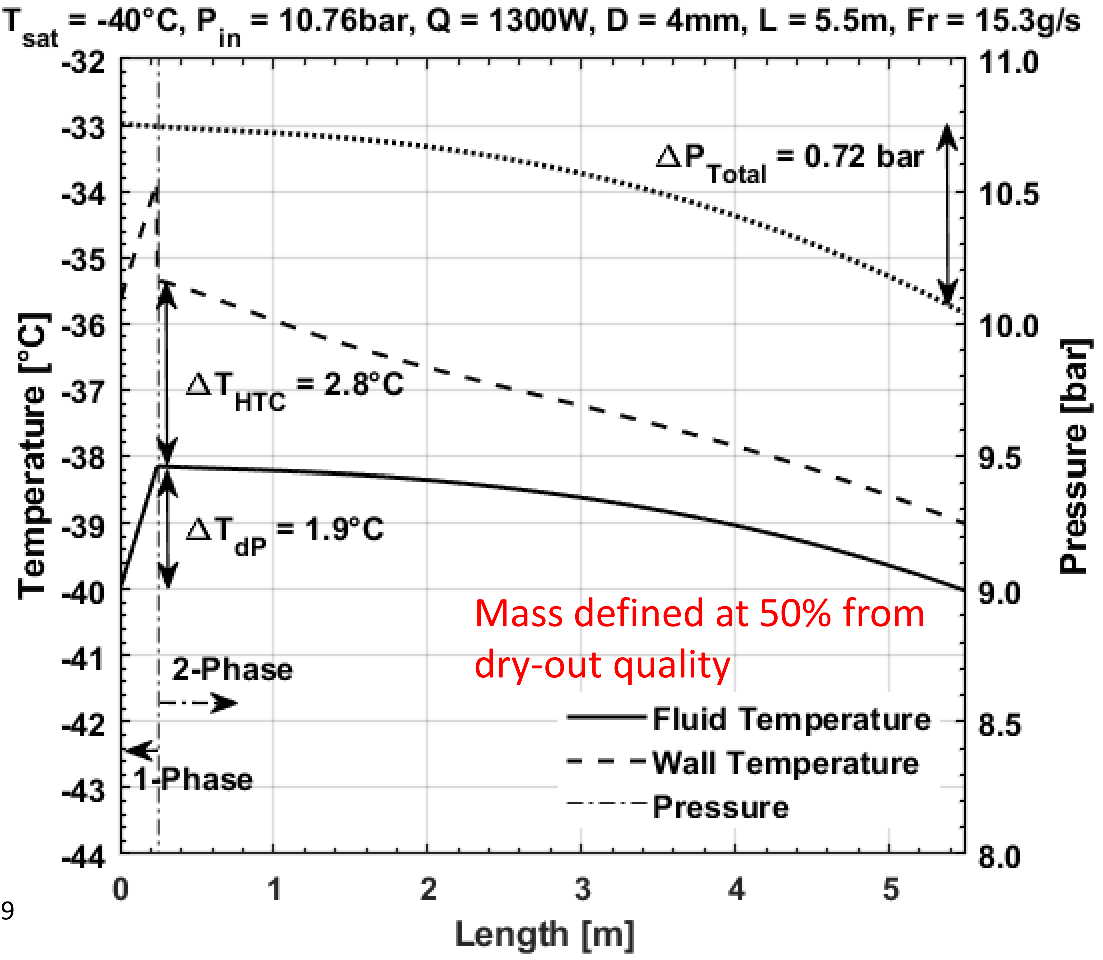


Bi-Phase $CO_2$ Pressure/Temp. Distribution v/s Tube Length


$T_{sat}$ = -40°C, $P_{in}$ = 10.76bar, Q = 1300W, D = 4mm, L = 5.5m, Fr = 15.3g/s

Mass defined at 50% from dry-out quality

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