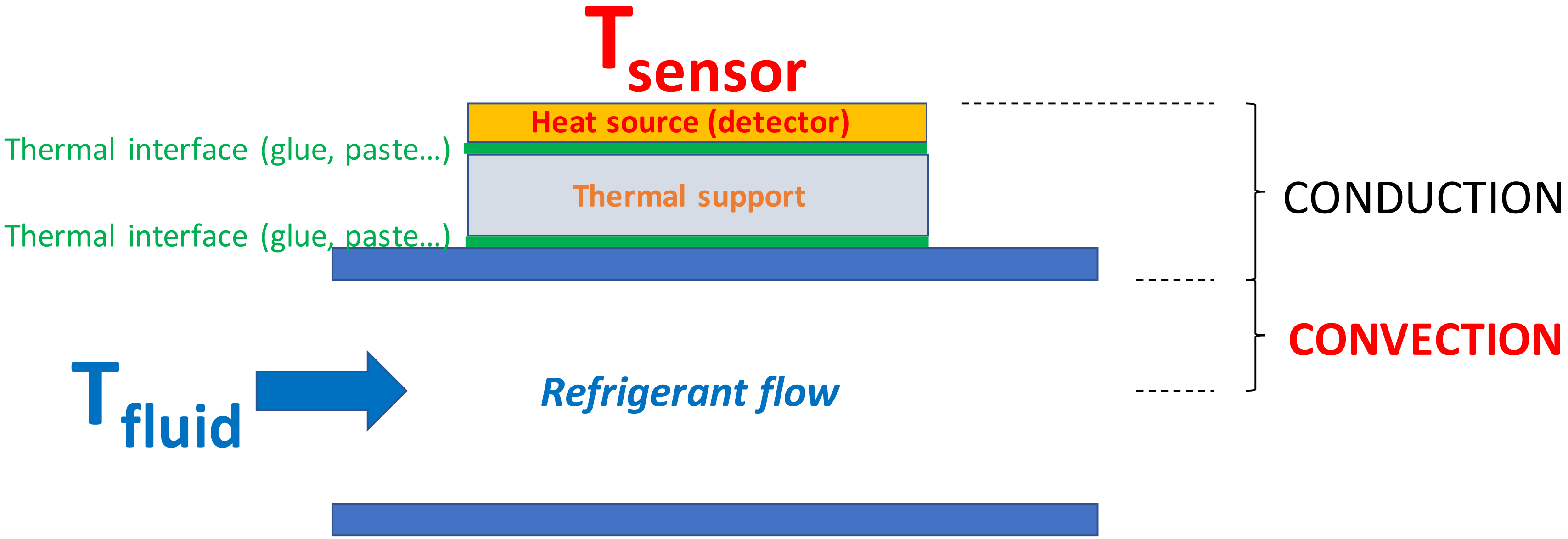
THERMAL MANAGEMENT OF SILICON DETECTORS: ΔT fluid-sensor depends on the full chain of thermal resistances



The thermal resistance can be exactly calculated if the properties and the thickness of all materials are known

Calculating the thermal resistance requires knowing the **convective Heat Transfer Coefficient**

CONVECTIVE HEAT TRANSFER COEFFICENT

Single-phase flow: very reliable correlations available, only requiring Re and Pr ➡ ***Cp, μ, ρ, k***

Boiling flow: Not much is changed from the foundational work of J.C. Chen (1962) ➡

Determining the HTC value requires a large number of parameters and **FULLY EMPIRICAL exponents**, combined into two ADDITIVE factors (i.e. “non-similar” w.r.t. Buckingham theorem)

From 1962 to today, the efforts of the researches have been focused in producing experimental databases and adapt some “Chen-like” correlation to them

The only different approach has been the one tried by the group of J.R. Thome at EPFL, linking the correlations to “flow maps”, i.e. to the specific phenomenology of boiling pattern (for CO_2: L Cheng, G Ribatski and JR Thome, 2008)

A CORRELATION FOR BOILING HEAT TRANSFER
TO SATURATED FLUIDS IN CONVECTIVE FLOW
John C. Chen

ABSTRACT

An additive mechanism of micro- and macro-convective heat transfer was formulated to represent boiling heat transfer with net vapor generation to saturated, non-metallic fluids in convective flow. The final equations are:

$$h_{mic} = 0.00122 \frac{k_L^{0.79} c_{pL}^{0.45} \rho_L^{0.49} \Delta T^{0.24} \Delta P^{0.75} g_c^{0.25}}{\sigma^{0.5} \mu_L^{0.29} \lambda^{0.24} \rho_v^{0.24}} \times S$$

$$h_{mac} = 0.023 \frac{Pr_L^{0.4} Re_L^{0.8} k_L}{D} \times F$$

$$h = h_{mic} + h_{mac}$$

The second equation will be recognized as the Dittus-Boelter equation with the additional factor F. The two functions F and S are defined as

$$F = (Re/Re_L)^{0.8}$$

$$S = (\Delta T_e/\Delta t)^{0.99}$$

where Re is the effective Reynolds number for the two-phase fluid and ΔT_e is the effective superheat for bubble growth. F and S were obtained as functions of the Martinelli parameter and the two-phase Reynolds number, respectively.

HOWEVER ALL TWO-PHASE CORRELATIONS HEAVILY RELY ON THE AVAILABILITY OF RELIABLE EXPERIMENTAL DATA

PRODUCING RELIABLE MEASUREMENTS OF CO_2 BOILING IN SMALL CHANNEL IS UNFORTUNATELY VERY DIFFICULT

ONLY EXISTING Heat transfer and **pressure drop database** available in literature (*trustable & established data*) for CO_2 boiling flows in small channels (ID < 3 mm):

Author(s)	**D_h [mm]**	**G [kg/m²s]**	**T_{sat} [°C]**	**Heat flux [kW/m²]**	**data points**
Choi et al. 2007 [1]	1.5, 3.0	300 ÷ 600	-5	30 ÷ 40	471
Pamitran et al. 2011 [2]	1.5, 3.0	300 ÷ 600	1, 2, 3, 10	20 ÷ 30	2898
Wu et al. 2011 [3]	1.42	300 ÷ 600	-40, -35, -30, -20, -10, 0	7.5 ÷ 29.8	~ 2000
Yun et al. 2005 [4]	1.14, 1.54	200 ÷ 400	5	20	
Ducoulombier et al. 2011 [5]	0.53	200 ÷ 1200	-10, -5, 0	10 ÷ 30	2710

> 8079 data points

↔ **scattered**

↔ limited in **test range**

↔ limited in **test consistency**

TWO PARALLEL APPROACHES

LAPP (short term):

1. focus on a well defined detector configuration (ATLAS ITk Pixel Local Support)
2. produce reliable measurements of $\Delta T_{fluid\text{-}sensor}$ for this configuration
3. precisely calculate the conductive component
4. adapt an existing HTC correlation to fit the experimental data
5. use the modified correlation for parametric performance forecast of that configuration

CERN (medium-long term)

1. focus on as much as possible simple and general configurations
2. produce systematic measurements of $\Delta T_{fluid\text{-}sensor}$ and Δp as a function of varying parameters
3. create the largest possible empirical database to be used as “look-up table”
4. analyze in detail the physics of CO_2 boiling as a function of varying parameters
5. work with world-wide boiling specialists to define new, more reliable, models