THE MICRO-COOLED LIGHT SUPPORT OF THE PIXEL MODULES FOR THE SUPERB EXPERIMENT

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Introduction

In HEP experiments the use of pixel detectors requires that high power density in the sensitive area should be carried away by efficient thermal systems, eventually integrated in the light mechanical support structures. In many cases the dimensions and position of the sensors are such that miniaturization of mechanical support and cooling are strongly necessary, together with very low material budget. Micro-channel cooling technology is featured by high efficient thermal exchange and it can profit by miniaturization technique applied on composite material (CFRP).

Advantages of the MICROCHANNELS technology:

- due to the high surface/volume ratio, heat exchange through liquid forced convection takes place efficiently;
- contiguity between the fluid and the circuit dissipating power reduces thermal resistances;
- micro-channel dimensions allows uniform distribution of the passive material on the sensor.

The key concept

In a thermal convective exchange the h film coefficient is:

Nu = Nusselt number

k = Conductive heat transfer coefficient of the liquid

D_h = Hydraulic Diameter of the cooling channel

$$h = \frac{Nu \cdot k}{D_h} \qquad (1)$$

$$Q = h\,S\,(T_w - T_f) \qquad (2)$$

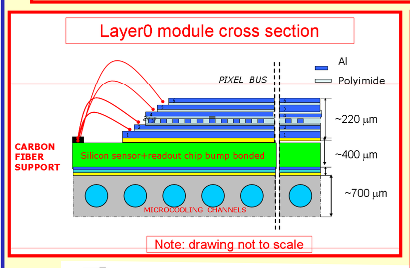
From formulas (1) and (2), for a Laminar flow fully developed, (Nu=constant), to maximize the thermal exchange Q → to maximize h → to minimize the hydraulic diameter : all these considerations brings to the **micro-channel technology**.

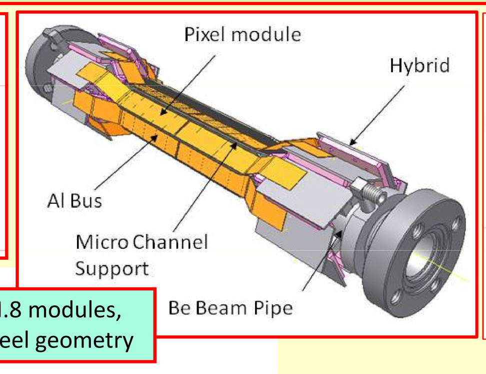
D_h minimization → high pressure drop → (needed a compromise between pressure drops and film coefficient value).

Super-B Silicon Vertex Tracker

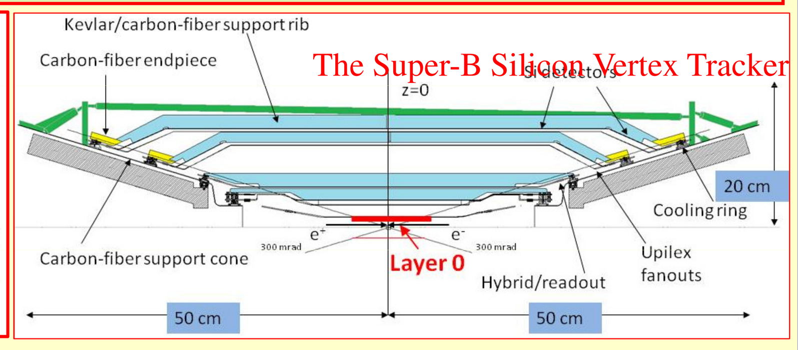
The micro-channel mechanical support is designed to match the specifications for the planned pixel upgrade of the most internal layer (L0) of the Silicon Vertex Tracker of the Super-B experiment :

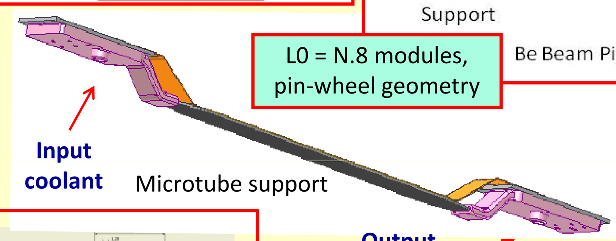
- To evacuate the heat dissipated by the electronics (specific power up to 2 W/cm²) and operating temperature of the sensors below 50°C
- Material budget of the pixel support structure and cooling(w/o cables/sensors) below 0.30% X_0.

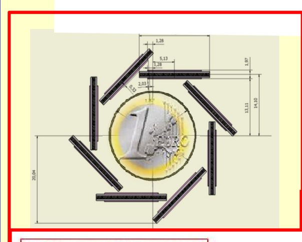




L0 = N.8 modules, pin-wheel geometry

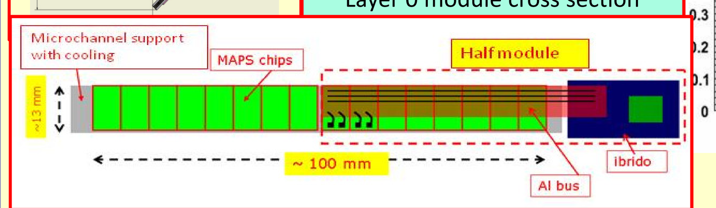




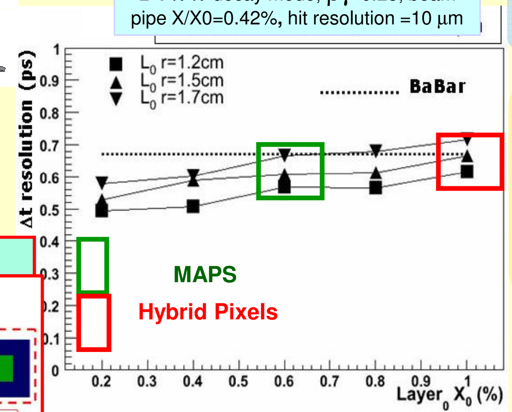


Comparing Layer 0 & beam pipe dimensions

Layer 0 module cross section



B→π π decay mode, βγ=0.28, beam pipe X/X0=0.42%, hit resolution =10 µm



SuperB SVT based on Babar SVT design for R>3cm. BUT:

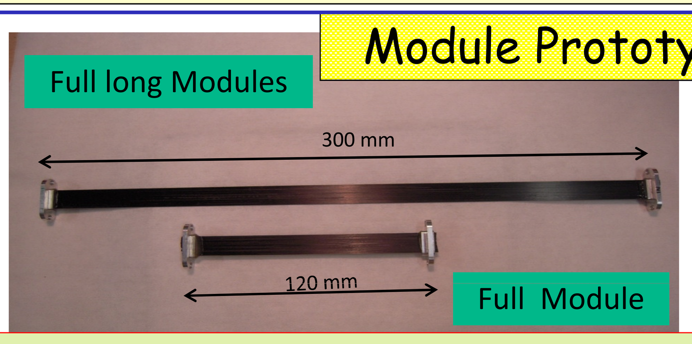
1) reduced beam energy asymmetry (7x4 GeV vs. 9x3.1 GeV) requires an improved vertex resolution (~factor 2)

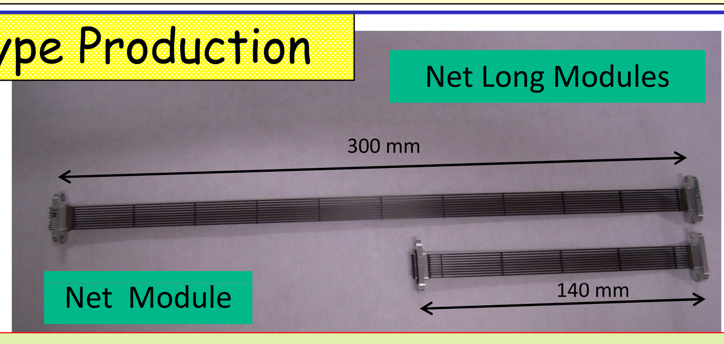
- Layer0 very close to IP (@1.5 cm) with low material budget (<1% X_0) and fine granularity (50 µm pitch)
- Layer0 area 100 cm²

2) bkg levels depend steeply on radius

- Layer0 needs to be fast and rad hard (>20x5 MHz/cm², >3x5 MRad/yr)

Module Prototype Production



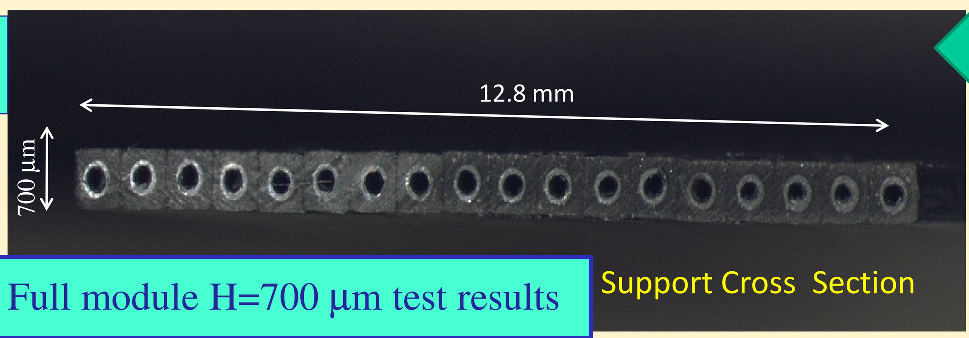


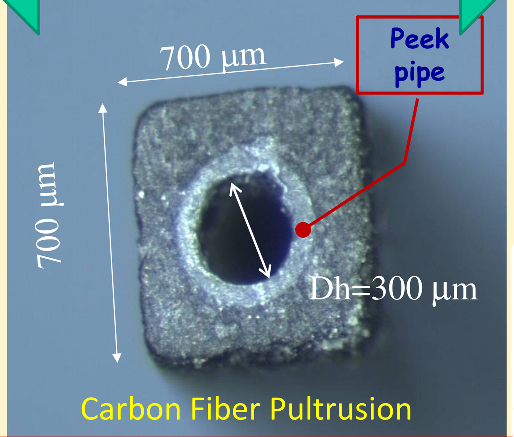
Several module support prototypes with different geometries have been realized in composite materials. Experimental tests have been performed at the TFD test-bench (INFN-Pisa lab).

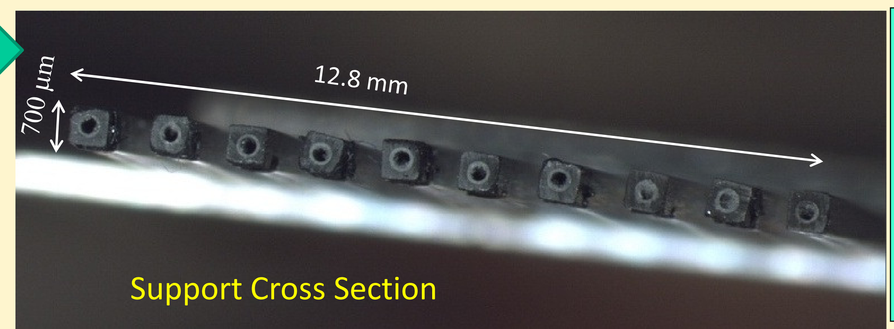
Full micro-channel module

Total radiation length: 0.28 %X_0

Tests performed on full/Net module samples (length = 120 mm) with water-glycol coolant @ 10°C and Δ p =3.6 atm.





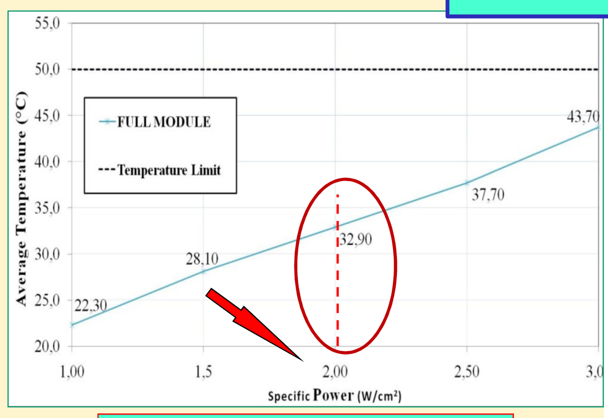


Net micro-channel module

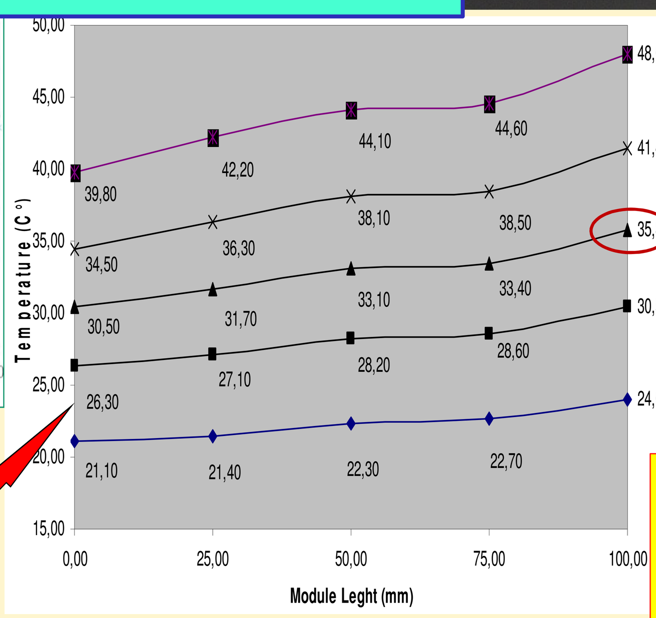
Same dimensions of Full micro-channel but vacancies of tubes in the structure.

Total radiation length 0.15 %X_0

Full module H=700 µm test results



Average module Temperature vs Specific Power



Temperature along the module: ΔT = 5,3 °C at 2W/cm² and Δp =3,6 atm

Single base micro-channel unit

A square CF micro-tube with an internal peek tube 50 µm thick used to avoid moisture on carbon fiber

Module structure obtained with additive method by gluing together single microtube using ARALDITE 2011.The micro-tubes are obtained by a pultrusion process using carbon fiber Toho tenax HTS 40

Net Module H=700 µm test results

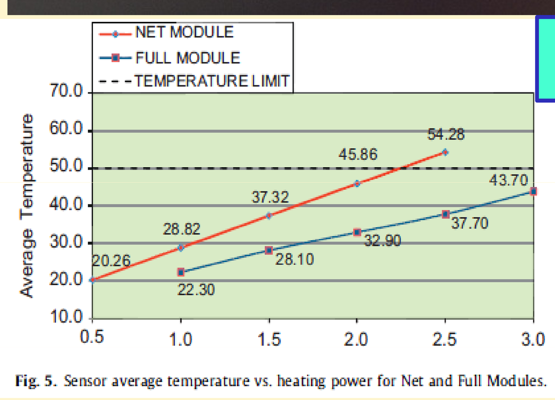
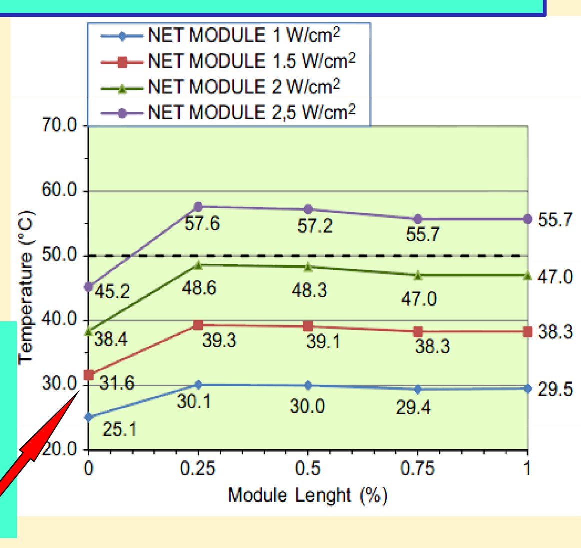
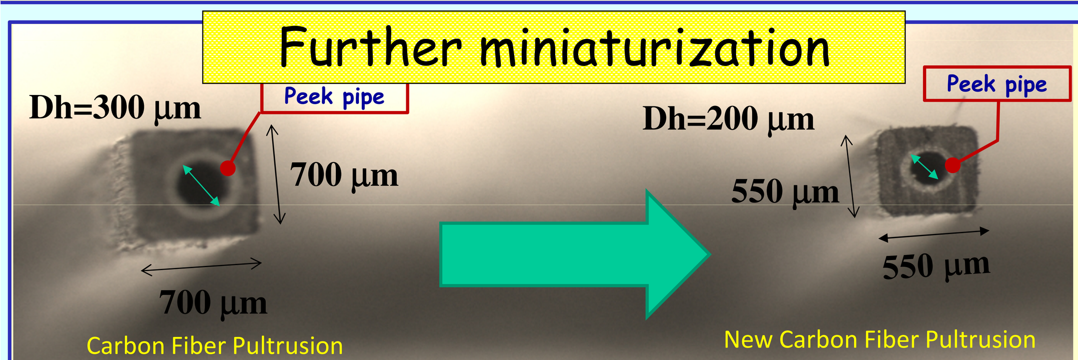


Fig. 5. Sensor average temperature vs. heating power for Net and Full Modules.



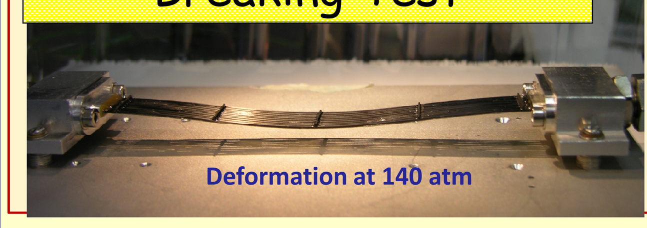
Net Module is able to cool up to about 2-1.5 W/cm² below the max required Temperature (50 °C).This goal can be achieved with a greater safety factor by reducing the inlet coolant temperature.

Further miniaturization



Full Module X = 0.28 % X_0	Full Module X = 0.22 % X_0
Net Module X = 0.15 % X_0	Net Module X = 0.11 % X_0

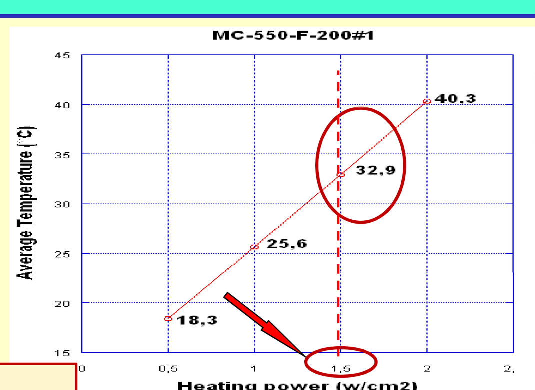
Breaking Test



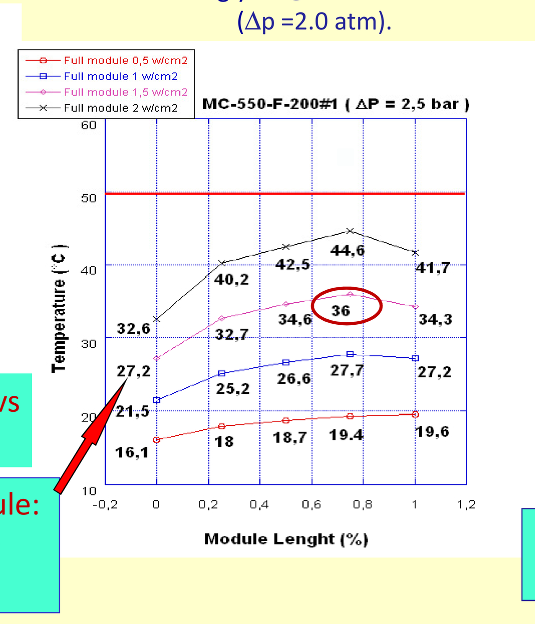
Structural test was realized on Net Module and Full Module prototypes. The test has been performed up to 140 atm . At this pressure the flanges of hydraulic interface were deformed to extrude the seal and produced the failure.

Full module H=550µm test results

Tests performed on Full Module sample (length = 120 mm) with water-glycol @ 10°C as coolant (Δp =2.0 atm).



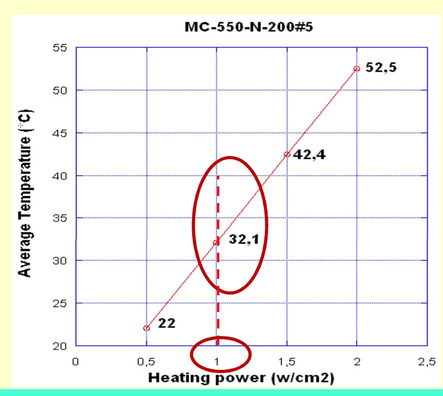
Average module Temperature vs Specific Power



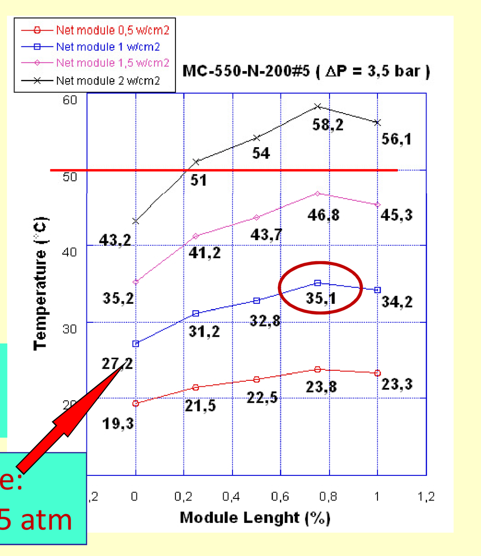
Temperature along the module: ΔT = 7.1 °C at 1.5 W/cm² Δp =2.0 atm

Net Module H=550µm test results

Tests performed on Net Module sample (length = 120 mm) with water-glycol @ 10 °C as coolant (Δp =3.5 atm).



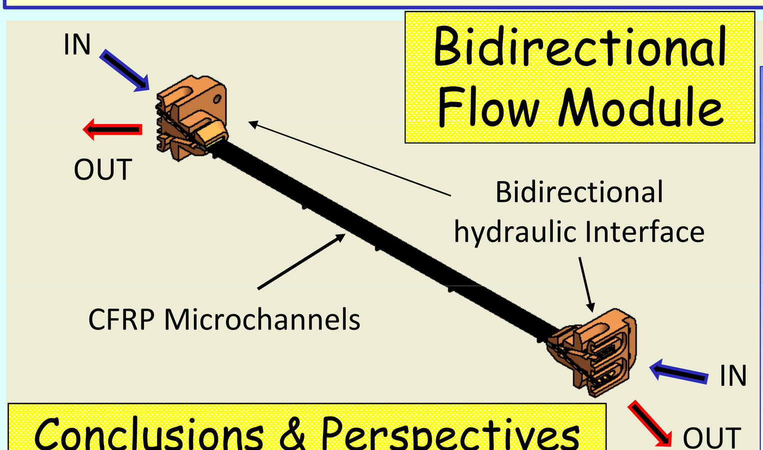
Average module Temperature vs Specific Power

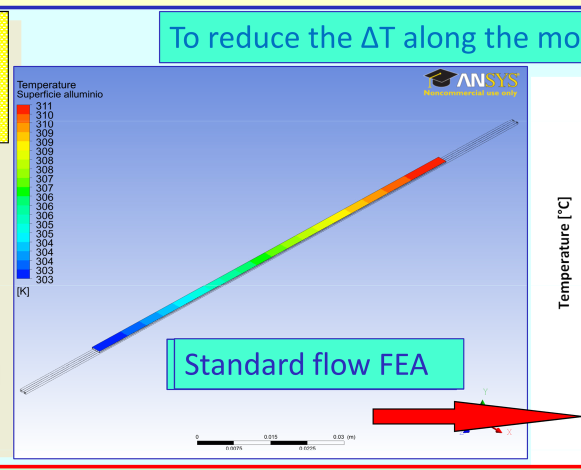


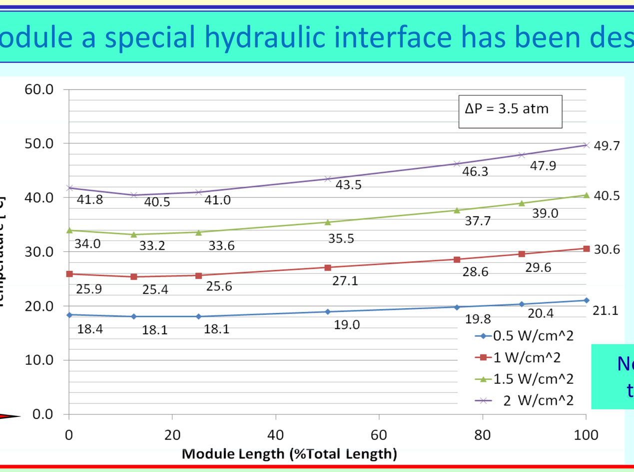
Temperature along the module: ΔT = 7.9 °C at 1.0 W/cm² Δp =3.5 atm

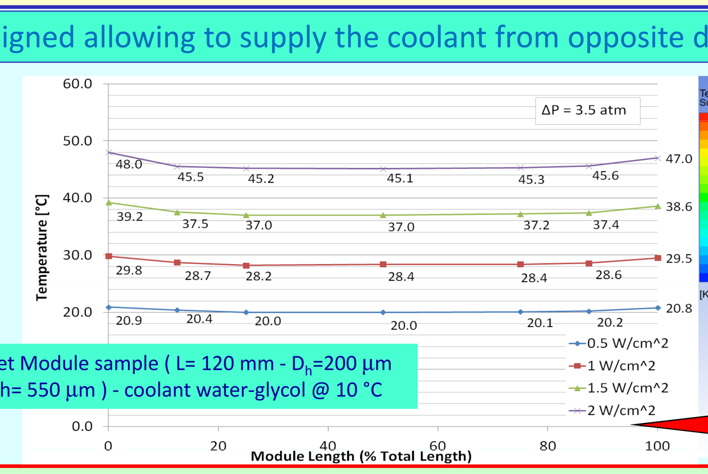
Bidirectional Flow Module

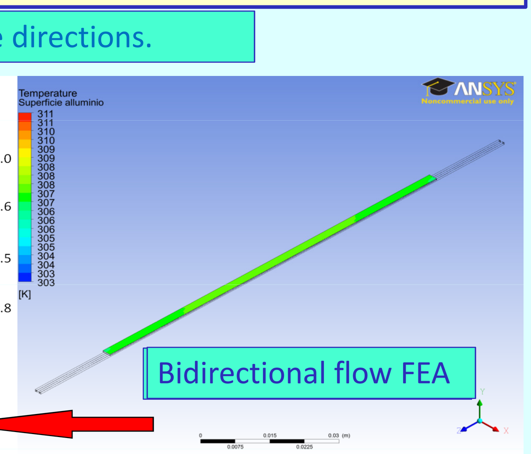
To reduce the ΔT along the module a special hydraulic interface has been designed allowing to supply the coolant from opposite directions.











Conclusions & Perspectives

The micro-channel CFRP prototypes match the Super-B Layer 0 pixel detector requirements on material thickness (X_0). An efficient heat evacuation has been achieved by micro-channel technology through liquid forced convection. The experimental results show that the Net Module is able to cool sensors with a power density up to 1.5 W/cm² with a X_0 value of 0.11 % and keep the sensor below 50 °C, as requested from specs. Moreover, with bidirectional coolant flow, it is possible to reduce the ΔT along the sensor below 2°C . Further optimization currently under development at the TFD Pisa laboratory: in progress the set-up for transition phase CO_2 cooling on CFRP micro-channels .