Cooling system for ECAL

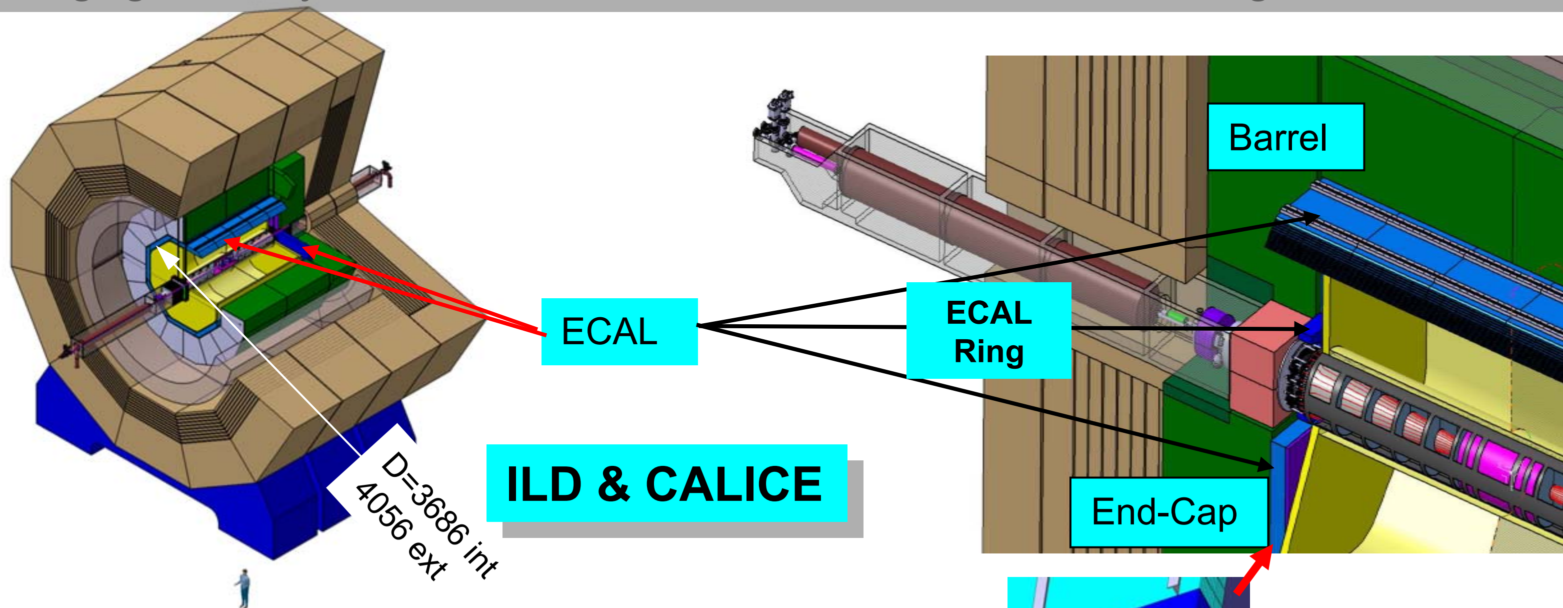
First Results from Thermal Tests with the demonstrator

CALICE Meeting 2009 @ DAEGU

Denis Grondin / Julien Giraud – February 18 & 19th

Si-W ECAL – Current baseline

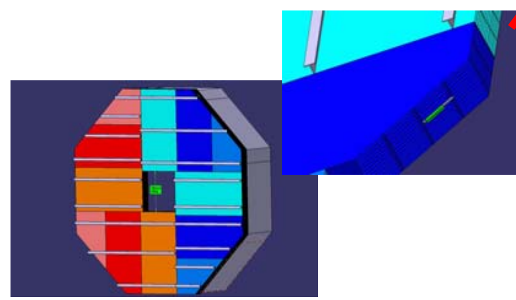
Cooling: geometry & mechanical constraints on the Electromagnetic Calorimeter

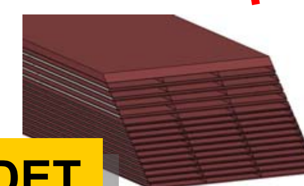


ILD & CALICE

Goal of studies & tests:

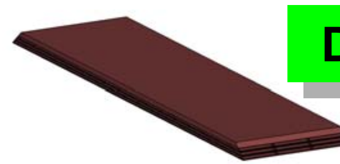
- Validation and sizing of best technological solutions for cooling wich could be used for the final detector,
  - numerical simulations & prototypes
  - industrialization aspect of process,
  - finest cost estimation of one module.





EUDET

SiW Ecal CALICE Prototype



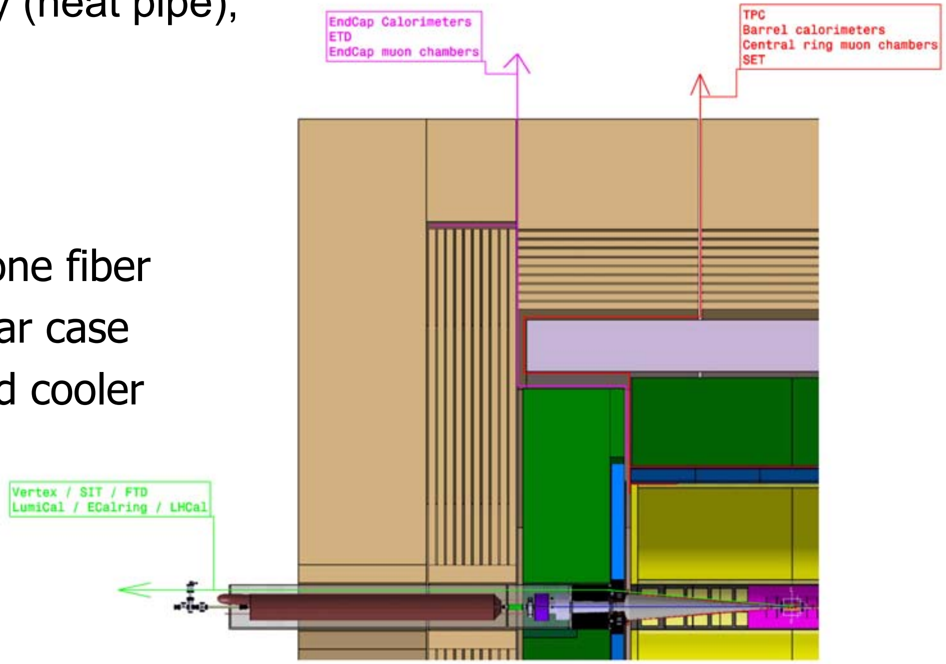
Demonstrator

ECAL COOLING – CONSTRAINTS

Main Design Constraints for the cooling system:

- Cooling temperature maintained at ~ 20°C on the connexion SLAB / Cooler,
- Reduced volume,
- Quick & easy connection, according mounting procedure for modules,
- Service: fluid circulation &/or anti-gravity (heat pipe),
- Security & maintenance free.

- Barrel : 40 identical trapezoidal modules
- End-Cap : 12 modules (3 types)
- ECAL module : alveolar structure - carbone fiber
- Detection elements (slab) in each alveolar case
- Heat shield = interface between slab and cooler

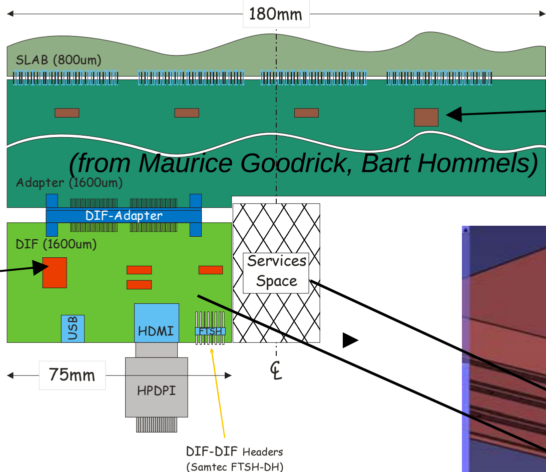


Cooling Technology:

- Convective exchange with ambiant as the cold source : not efficient
- Convective exchange with cold air : not enough space and pb/air pipe insulation
- Cooling system with gaz cycling (Freon…): extra cost and
- Water cooling: satisfying due to T° control request – cost (full circuit or with heat pipes)

SLAB COOLING – CONSTRAINTS

Mechanical constraints on ECAL electronics:
Available space, heat sources power & location



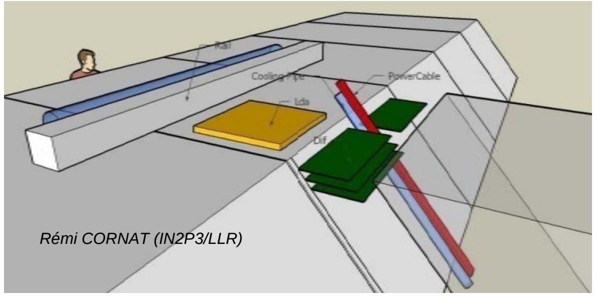
Hot points on interface card : new !

Up to 1W ?

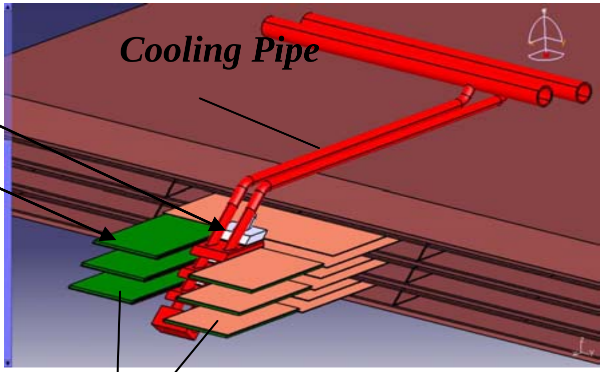
FPGA

Up to 2W ?

DIF is part of last ASU of the SLAB
Minimum Space free for cooling

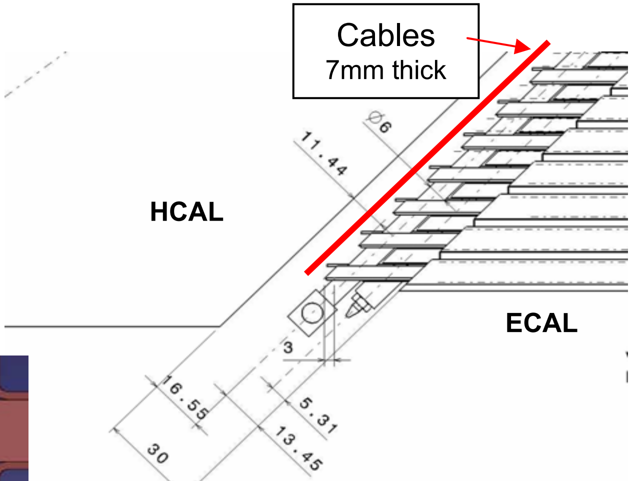


Place for cabling : DAQ + HV + GND
Service space between cooling and HCAL >1cm

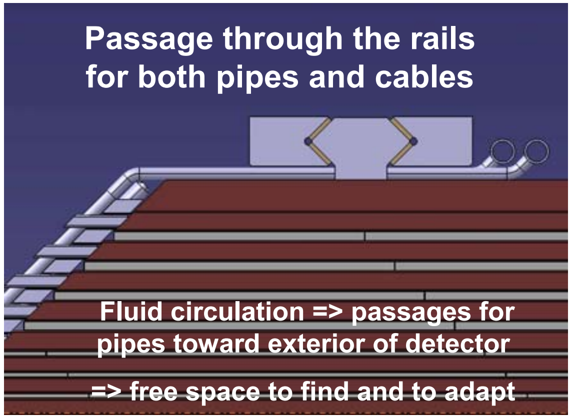


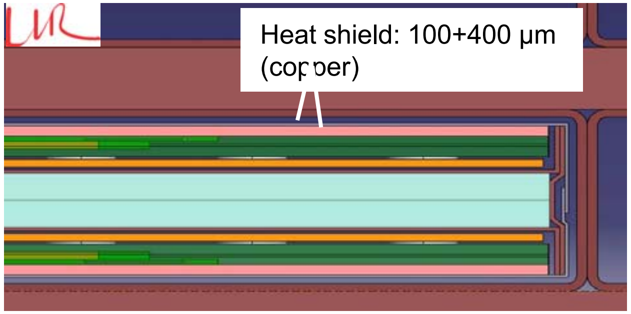
DIF

Demonstrator: cooling and copper drain extremities



Space for HV and GND



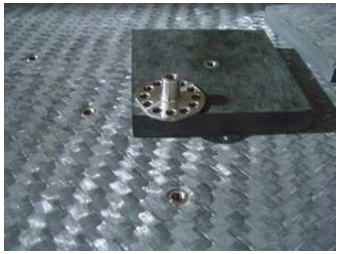


Fastening & cooling system

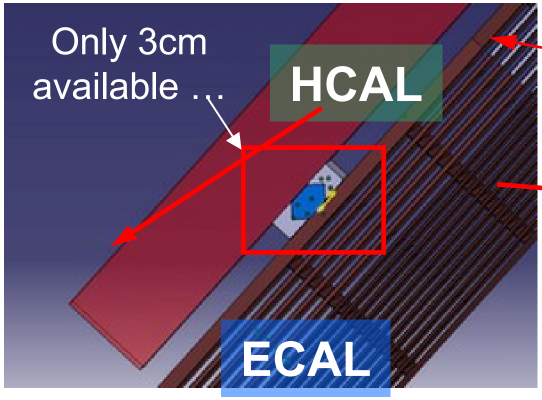
Design

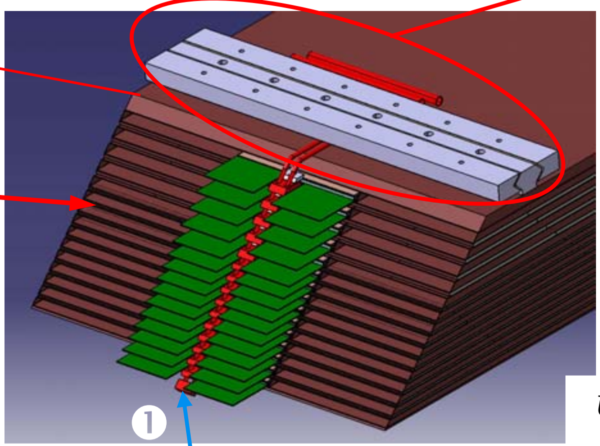
connection of the system : each cooling system ❶ is inserted and screwed to each column of slab with a thread rod and spacers ❷ and connected to the cooling network in a second step ❸.

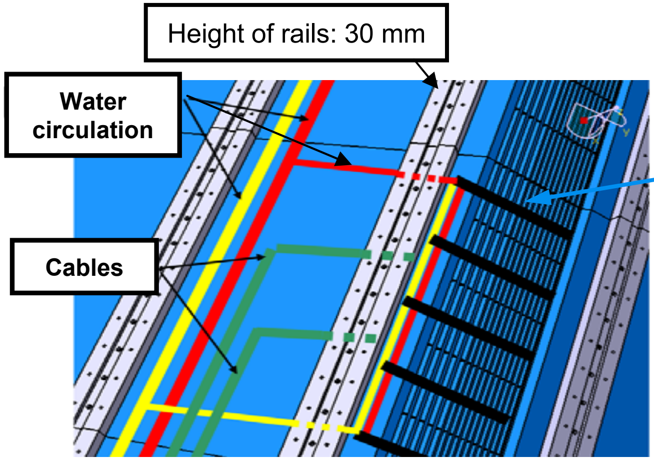
15mm thick plate with it's rails; ready to be assembled with alveoli layers



Uniform dispatch of 18 inserts on the 15mm thick plate

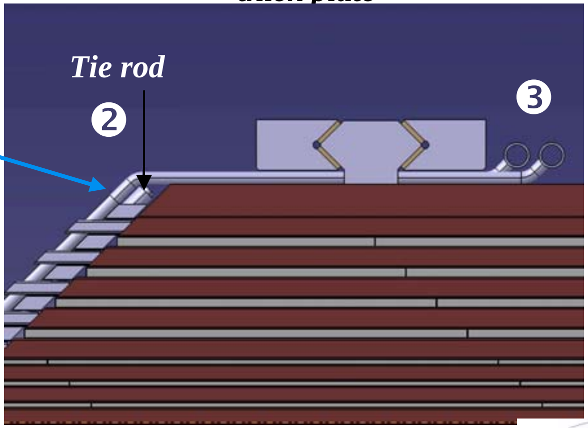






A column (cooling pipe), (25 mm wide minimum) to ensure quick thermal system's connection

Cold copper bloc inserted between 2 copper plates of each slab



Cooling: global circulation

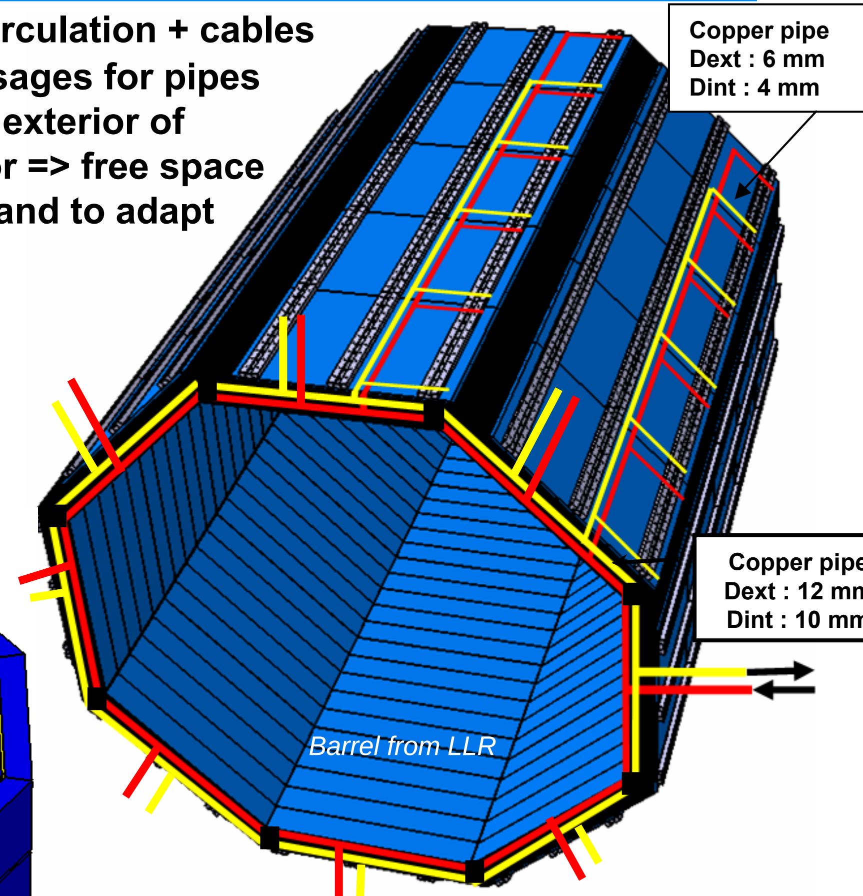
Power results :

2 FPGA per SLAB, power: 3 W each, then : 3 x 2 = 6 W
SKIROC : 0.54 W / slab → 0.3 W soit : 2 x 0.3 = **0.6 W**
Barrel :

Global Power : 19484 W → 3029 W
Power per module : 487 W → 75.7 W
Power per column : 97.4 W → 15.1 W
End Cap :
Power per End Cap : 5060 W → 768 W
Average power per module : 420 W (390+390+480)/3 → 64 W
Average power per column : 97 W → 15 W

Global Power : 30 000 W → 4565 W !

Fluid circulation + cables => passages for pipes toward exterior of detector => free space to find and to adapt



Rough estimate on fluid circulation:

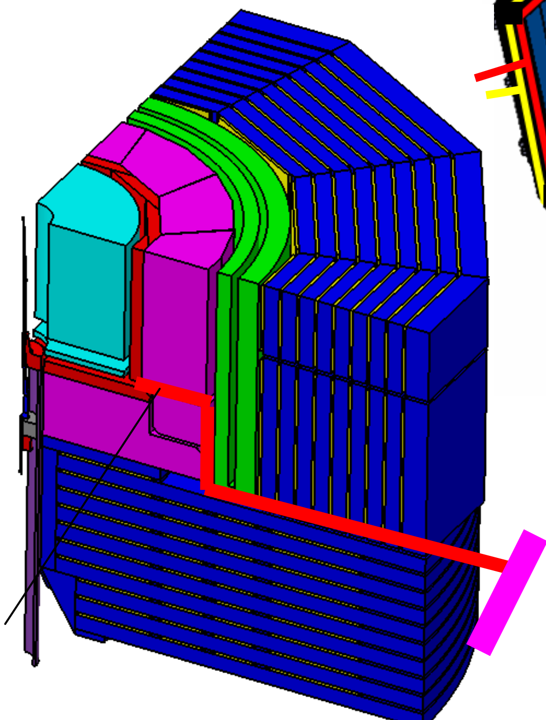
Global flow rate : 150 l/min

Variation of fluid temperature : in-out => 3°c

Fluid speed < 2 m/s

Maximal pressure drop : 1.2 bar

1 feedind line for each group of 5 modules



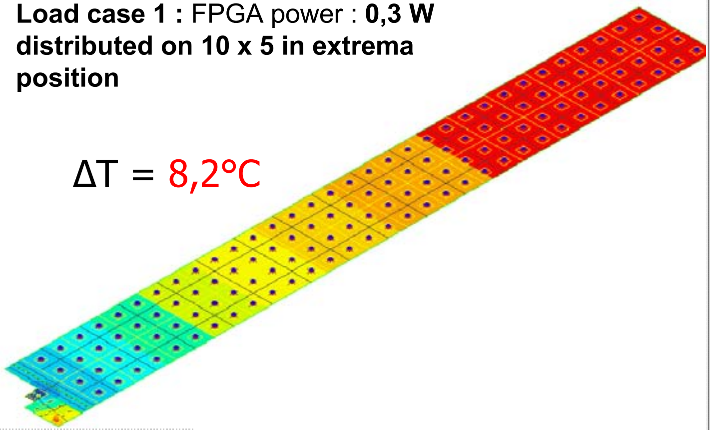
- **Passage for pipes and cables under rails (machining on composite surface)**
- **Connection of pipes according mounting procedure for modules**

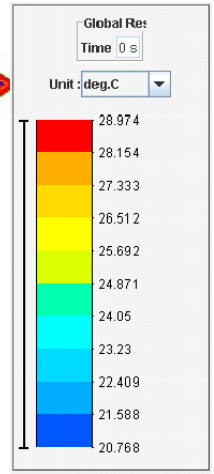
Thermal analysis of slab

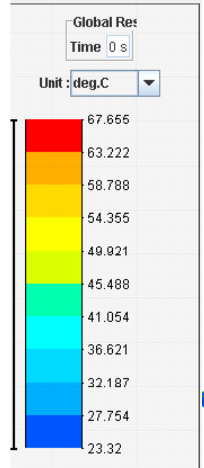
Simulation of heat conduction just by the heat copper shield : Influence of FPGA dissipation (DIF) on current design of cooling system -Limit Condition of 20°C, 100µm housing + 300 µm Cu. The copper drain is adapted / DIF card to be in contact with FPGA on DIF (« hot » Kapton for demonstrator)

Load case 1 : FPGA power : **0,3 W distributed on 10 x 5 in extrema position**

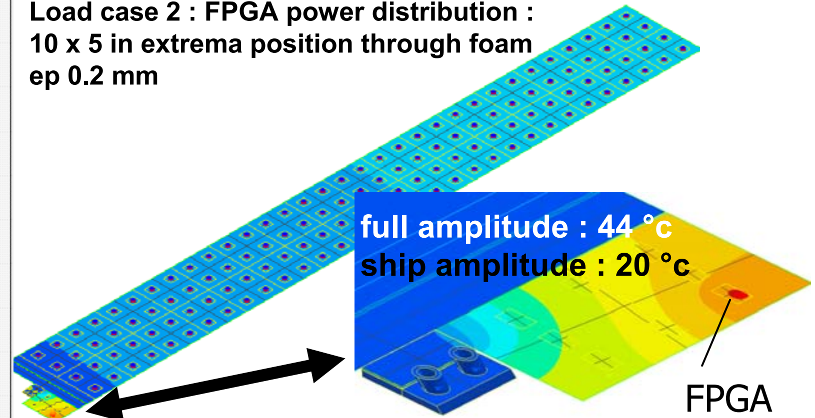
ΔT = 8,2°C





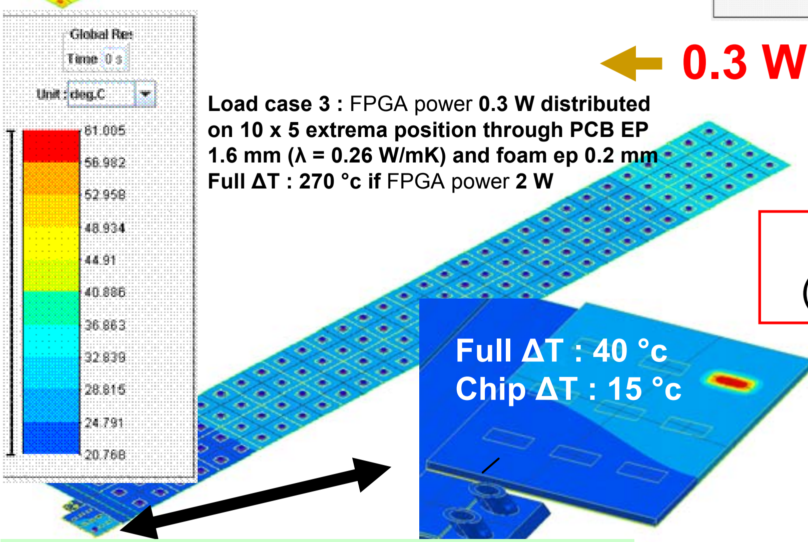


Load case 2 : FPGA power distribution : 10 x 5 in extrema position through foam ep 0.2 mm



0.3 W < FPGA < 2 W

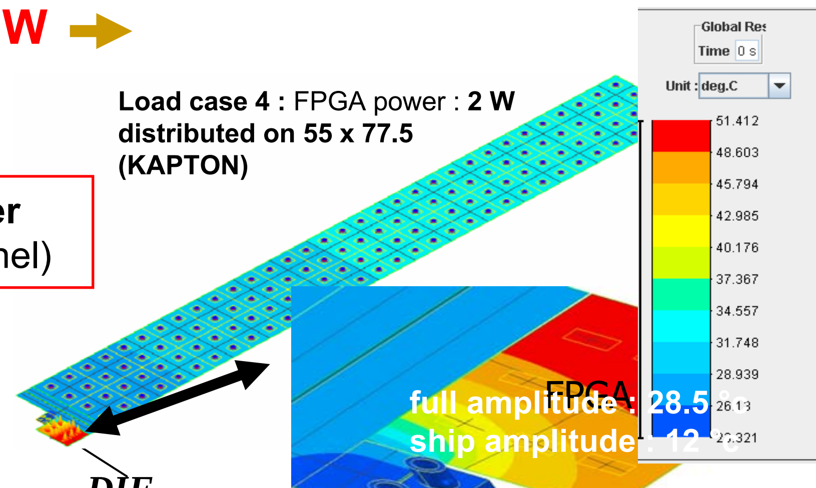
Load case 3 : FPGA power **0.3 W distributed on 10 x 5 extrema position through PCB EP 1.6 mm (λ = 0.26 W/mK) and foam ep 0.2 mm**
Full ΔT : 270 °c if FPGA power **2 W**



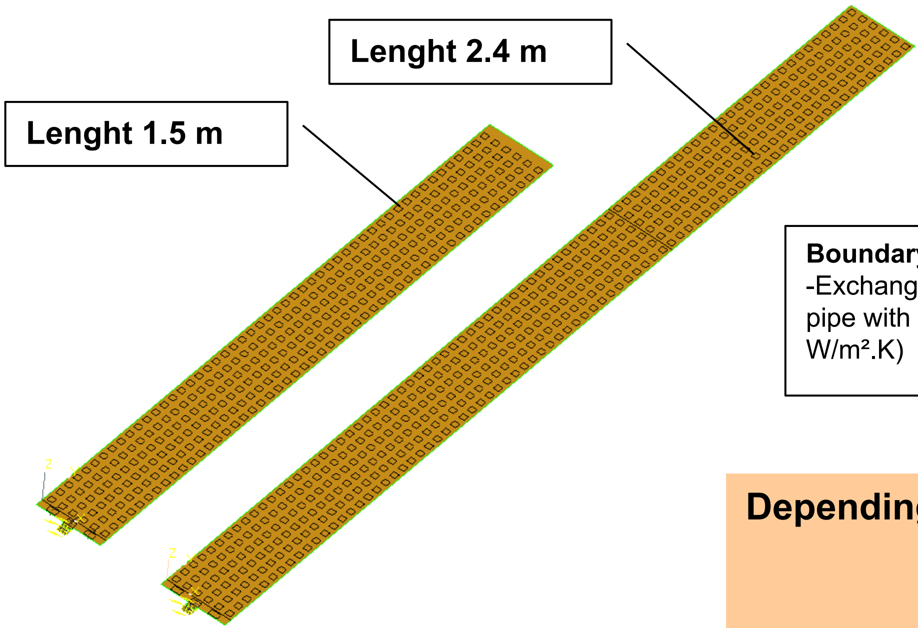
…better cooling if direct contact with FPGA !

Φ= 0,27 W/layer
(25 µW per channel)

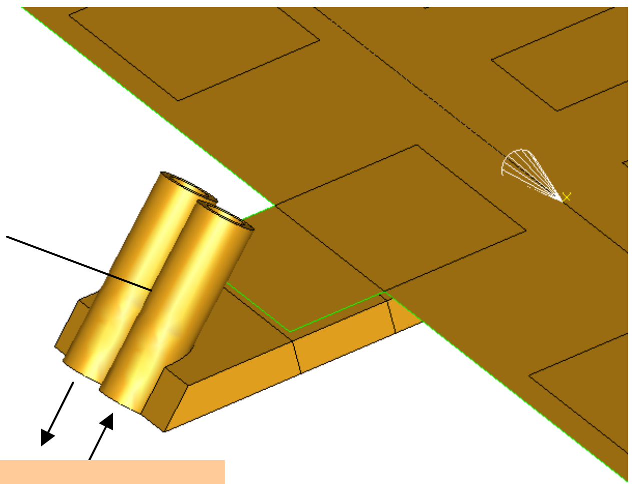
Load case 4 : FPGA power : **2 W distributed on 55 x 77.5 (KAPTON)**



Cooling system: End-cap constraints



Boundary contition:
-Exchange coefficient in the pipe with fluid at 20°c (h = 3445 W/m².K)



Depending on:

- **length of slab**
- ***type of cooling system***

load : 1/2 SLAB	
FPGA power (one side of the SLAB)	0,3 W
SKIROC SLAB 1,5 m	0,27 W
SKIROC SLAB 2,4 m	0,42 W

copper thickness : 0.4 mm, FPGA power : 0.3 W

	SLAB : 1,5 m						SLAB : 2,4 m						
FPGA	with			without			with			without			
Temperature (°c)	Tmin	Tmax	Difference	Tmin	Tmax	Difference	Tmin	Tmax	Difference	Tmin	Tmax	Difference	Comments
Exhange coefficient inside pipe and fluid temperature of 20°c	20,2	29,1	**8,9**	20,1	28,1	**7,9**	20,3	40,0	**19,7**	20,2	38,8	**18,6**	Uniform copper thickness : 0,4 mm

load : 1/2 SLAB	
FPGA power (one side of the SLAB)	3 W

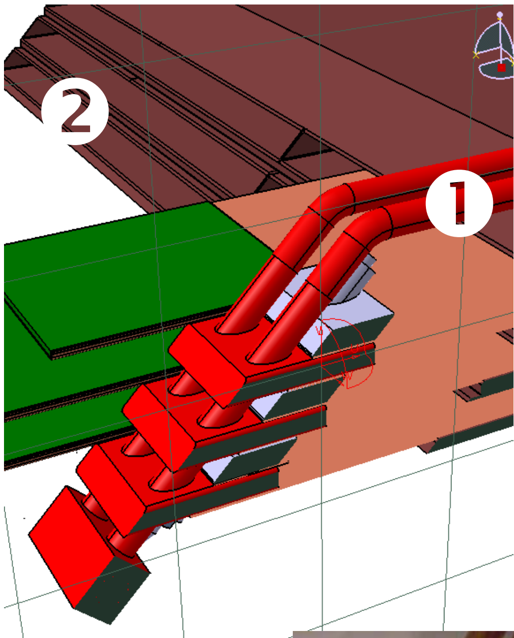
copper thickness : 0.4 mm, FPGA power : 3 W

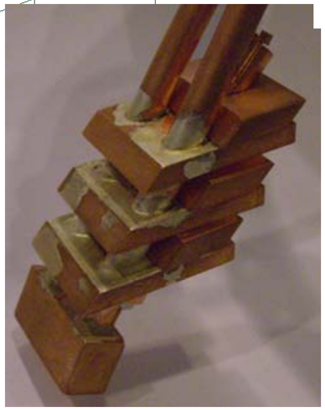
	SLAB : 1,5 m						SLAB : 2,4 m						
FPGA	with			without			with			without			
Temperature (°c)	Tmin	Tmax	Difference	Tmin	Tmax	Difference	Tmin	Tmax	Difference	Tmin	Tmax	Difference	Comments
Exhange coefficient inside pipe and fluid temperature of 20°c	21,4	42,8	**21,4**	20,1	28,1	**7,9**	21,5	50,2	**28,7**	20,2	38,8	**18,6**	Uniform copper thickness : 0,4 mm

SLAB COOLING - solutions

Cold plate : 3 Solutions

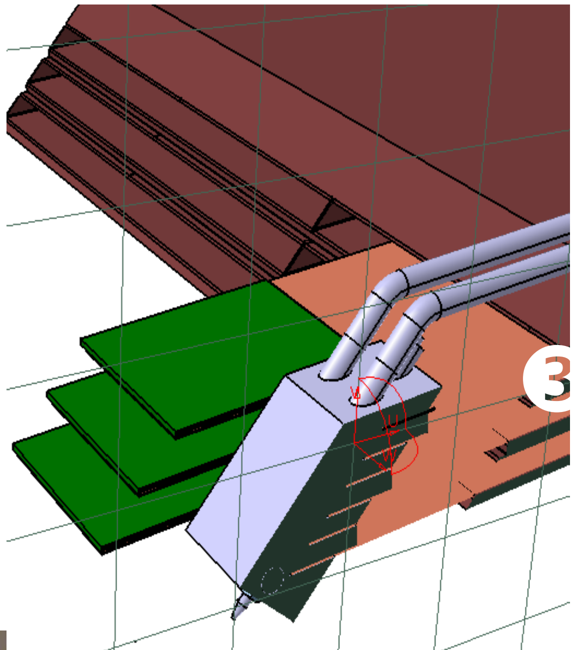
❶ Assembled solution





Water circulating into copper pipe (Internal diameter : 4 mm)

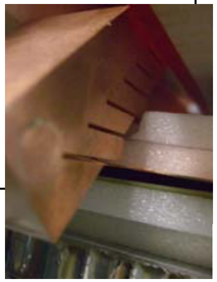
❷ Machining solution



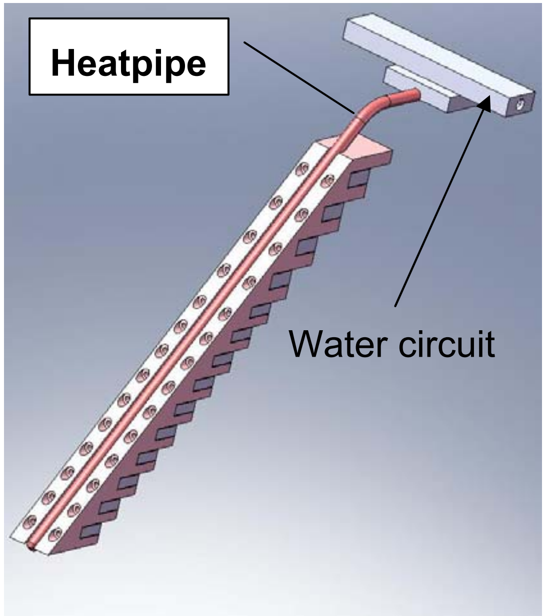
-1 block with water circulating into copper pipe

-(Internal dia.: 4 mm)

- Easier to build



❸ Heatpipe



Main advantage :

Connection between Heat pipe and water circuit => contact, far from front-end.

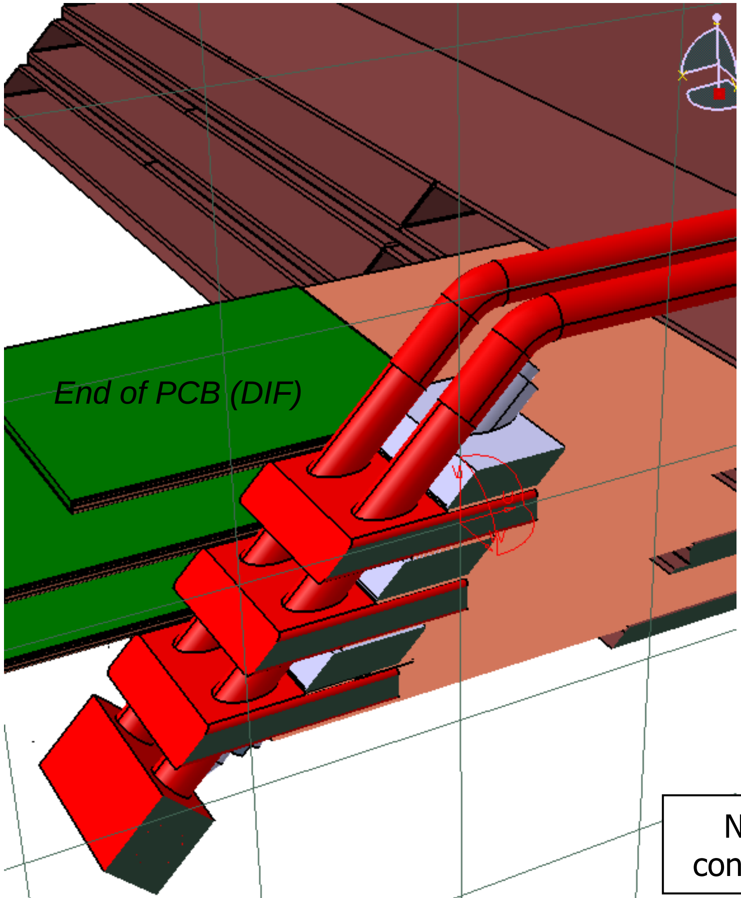
Easy to assemble and reduces leak risk

~ Same geometry

SLAB COOLING - DEMONSTRATOR

Cold plate : 3 Solutions

Solution 1

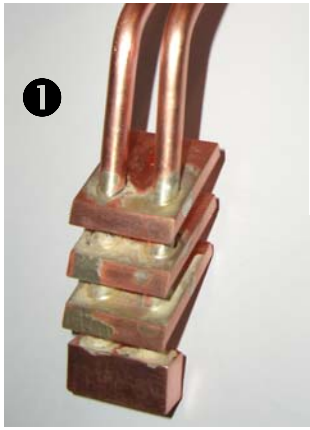


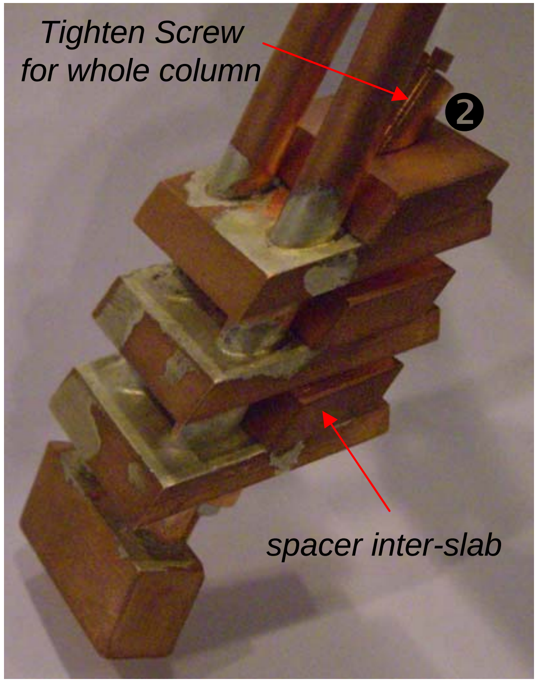
-Assembled solution

-Water circulating into copper pipe (Internal diameter : 4 mm)

- Lot of welded pieces=> tricky assembly

- Good performances





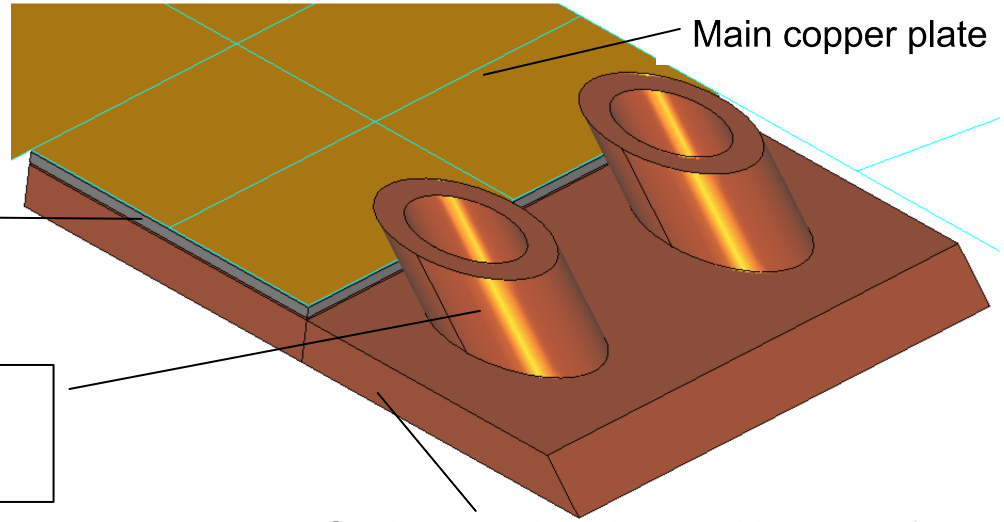
Network of contact areas / connector fixed on the 2 layers

Design : each cooling system ❶ is inserted and screwed to each column of slab with a thread rod and spacers (❷) and connected to the cooling network in a second step.

SLAB COOLING - EUDET

Boundary condition:

Main copper plate



Thermal foam : λ = 3 w/mK

Convective flux into pipe with fluid at 20°c (h = 3445 W/m².K)

Cold copper bloc inserted between 2 copper plate of 1 slab

Load (for 1 half slab = 1 side)

Channel heat flux : 25 µW

Number of channel / chip : 64 (Hardroc)

Number of chip / wafer : 4

Number of wafer on ½ SLAB : 32

Total wafer power :

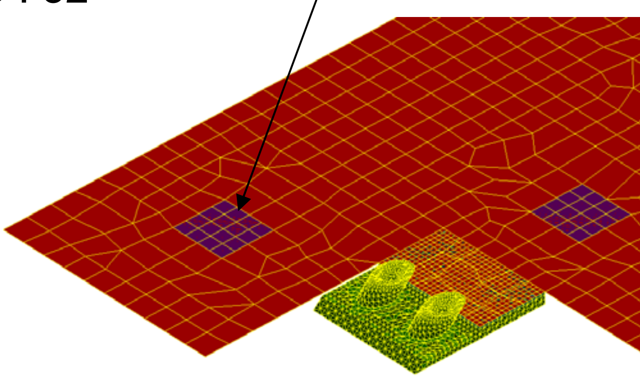
$25 \times 10^{-6} \times 64 \times 4 \times 32$

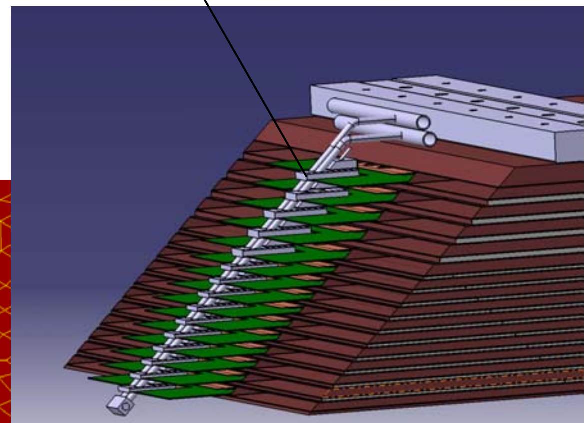
= **0.205 W**

FPGA power : **0.3 W nominal**

=> up to 2 W for test

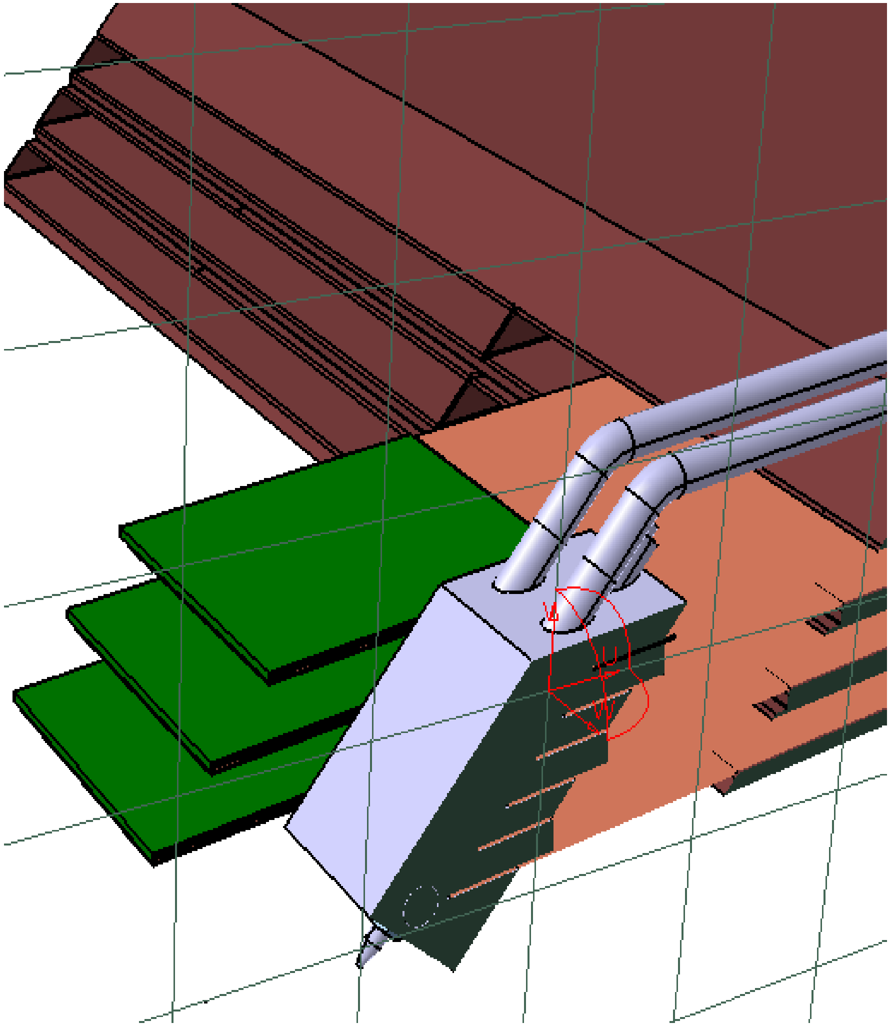
Heat surface and temperature point (FPGA location) 0.2 to 2W…



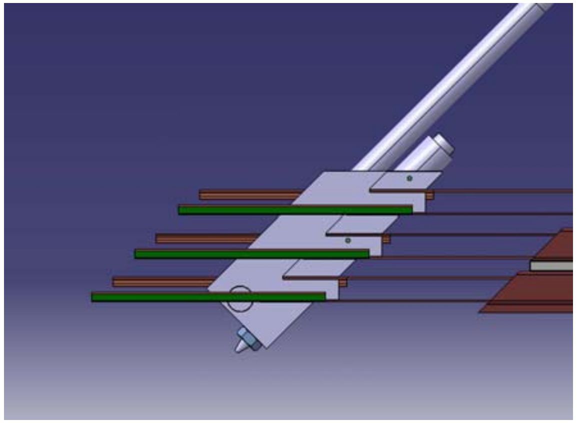


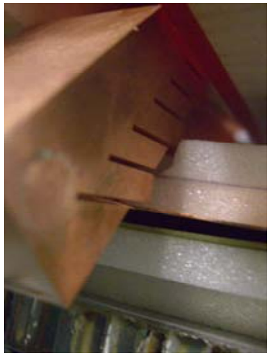
SLAB COOLING - *DEMONSTRATOR*

Cold plate : Solution 2



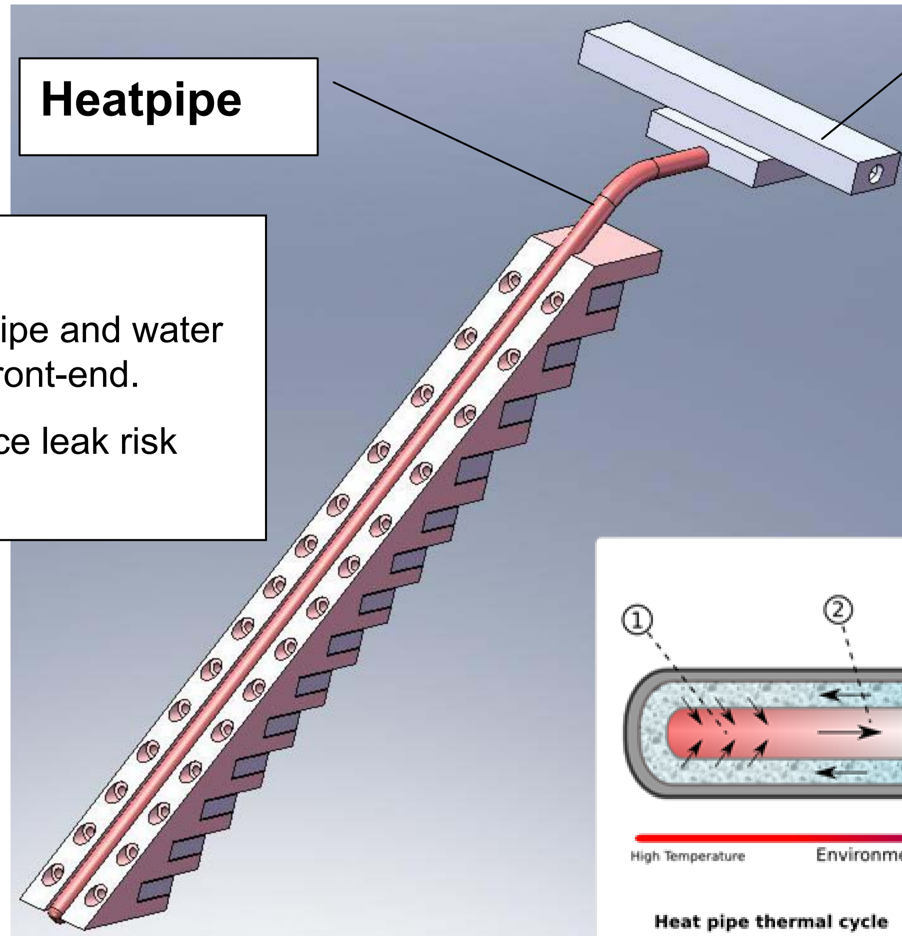
- Machining solution: 1 block
- Water circulating into copper pipe (Internal diameter : 4 mm)
- Easier to build
- Quick thermal system's connection





SLAB COOLING - DEMONSTRATOR & EUDET

Cold plate : Solution 3

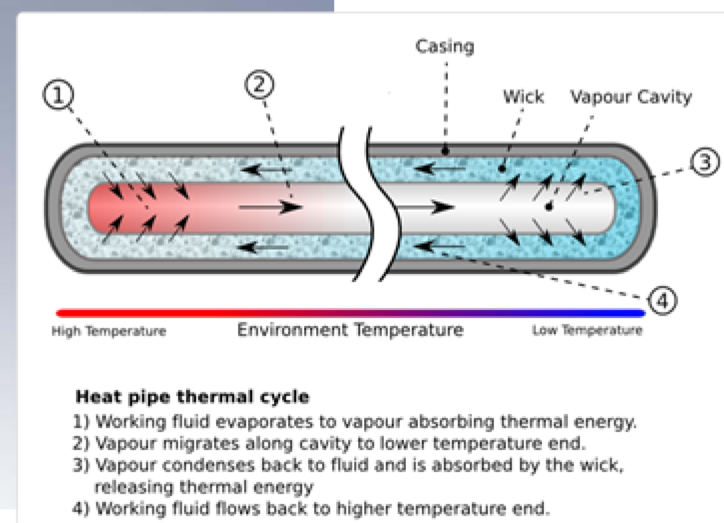


Main advantage :

Connection between Heat pipe and water circuit => contact, far from front-end.

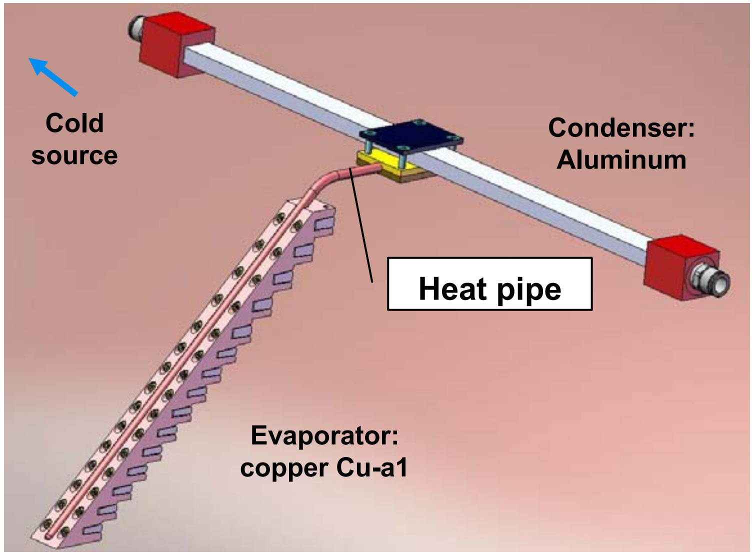
Easy to assemble and reduce leak risk

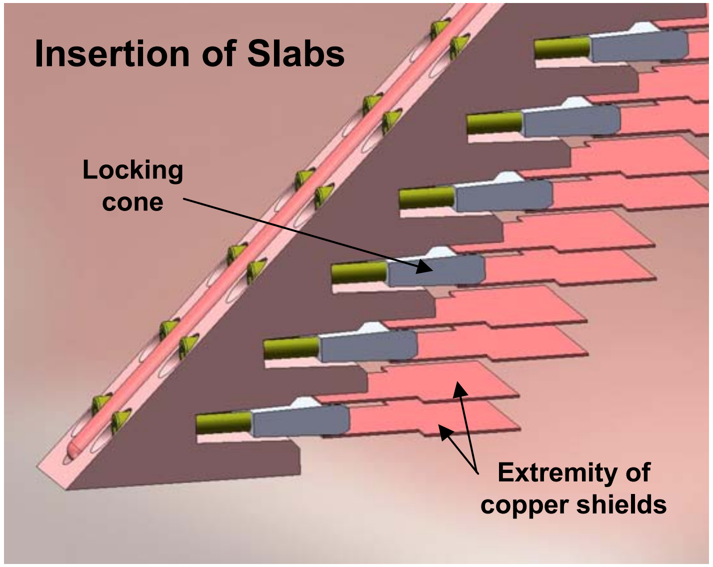
~ Same geometry



Inside a heat pipe, at the hot interface a fluid turns to vapour and the gas naturally flows and condenses on the cold interface. The liquid falls or is moved by capillary action back to the hot interface to evaporate again and repeat the cycle. Anti-gravity work.

Heat pipe technology for CALICE





Presentation of Heat pipe prototype & model

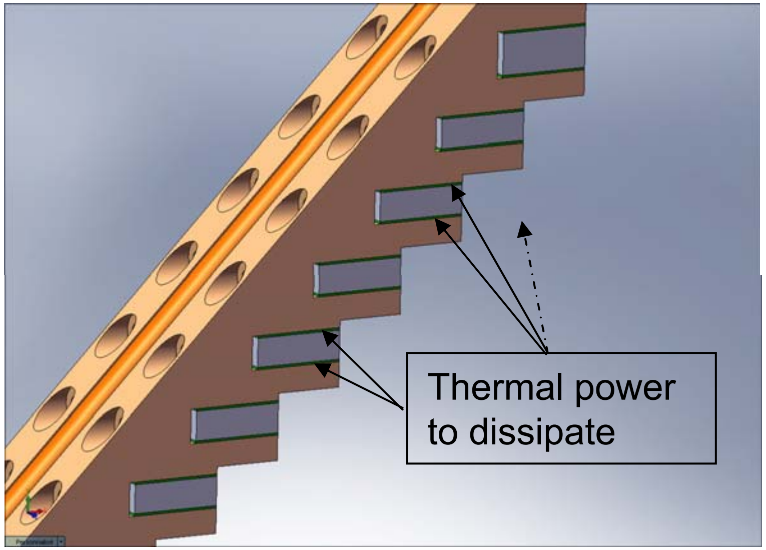
- ***Simulation vs. tests: contact resistances***

We have to know precisely the value of thermal contact resistances in opposition to heat transfer, in order to correlate simulations and the real system.

- In the simulation only the cold plate is used for cooling the system => no extra convection with the ambiant air or conduction with the support is taken into account.

- Conclusion

The cooling power of water gives a cooling solution with little dimensions and a serial feeding network making the connection of these systems easier to the cooling circuit.



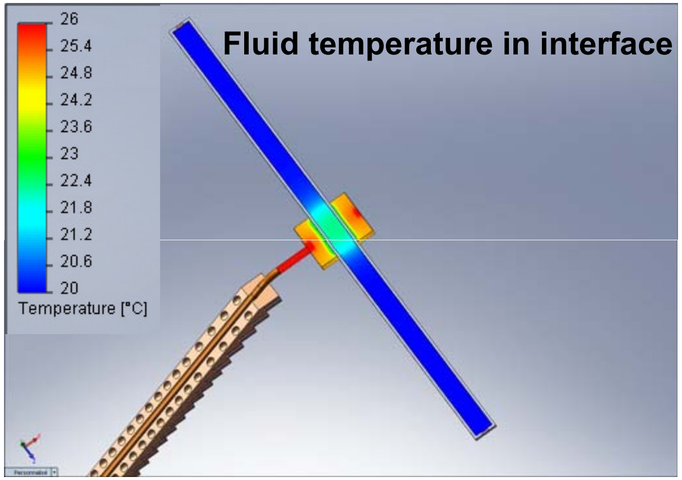
Heat pipe technology - simulation

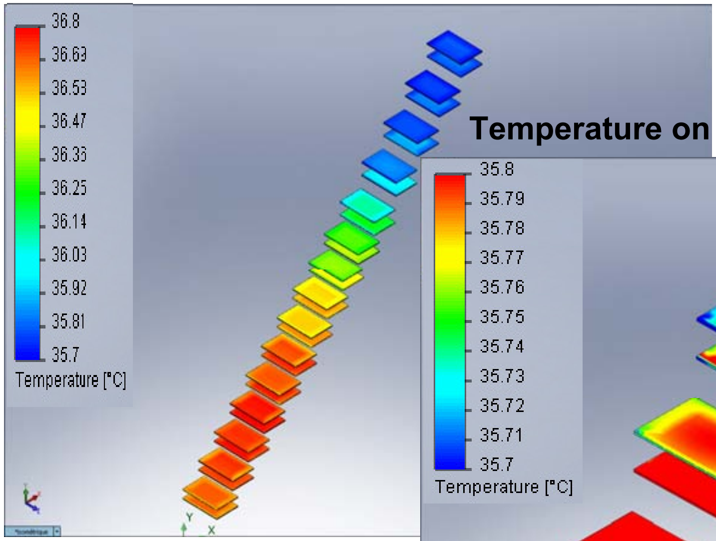
RESULTS *of on going fabrication*

Heat to dissipate and cooling fluid:

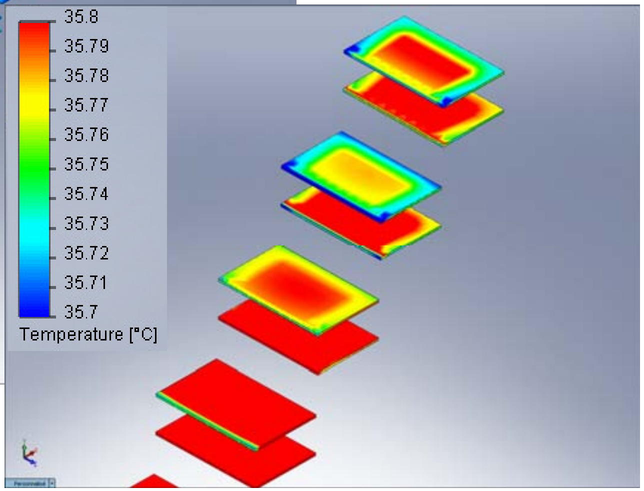
Power: 1,01W / 2 = 0,505W imposed on each of both copper shields extremities (surface 15x25mm)

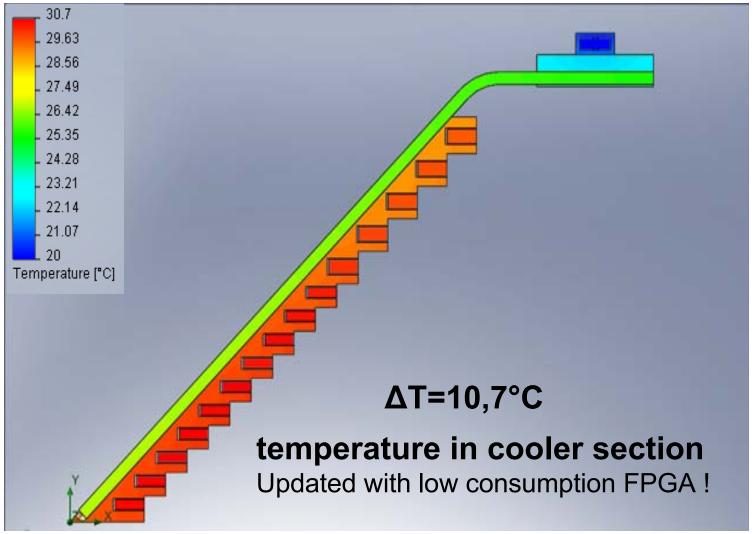
Power needed 15,15W for 1 column, flow 5L/min, average T° of cooling fluid negligible. DT water = 0,04°C.
Fluid T° increasing on the contact shell / condenser. →





Temperature on copper drain surface





CONCLUSION (*today*)

The prototype ensure the Slabs cooling at ± 1,1°C with a ΔT of 10,7°C between surface of Slab detectors and cooling fluid.

And…under standard operating conditions, with a more important flow and a fluid T° at 0°C, cooling of slab detectors at 20 °C will be ensured (contact resistances are now responsible for T° difference between slab and cooling fluid).

SLAB COOLING - Test SLAB

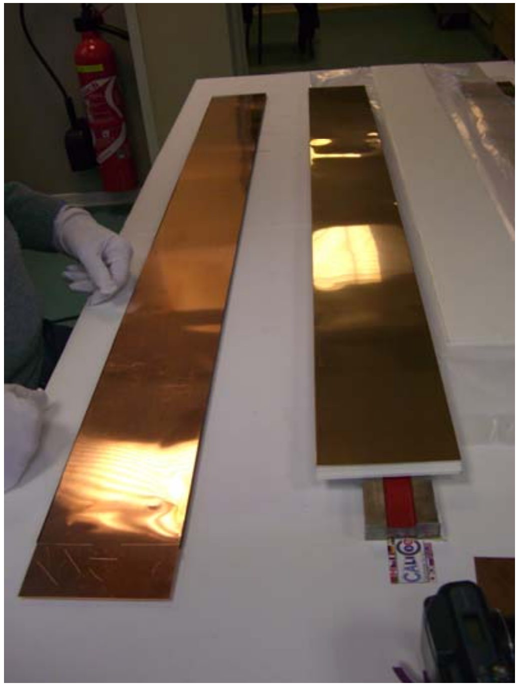
Interface

Barrel : 40 trapezoidal « Module ECAL », then 3000 detectors : «SLAB detectors».

End-Cap: 12 Modules (3 types) », then 1560 detectors : «SLAB detectors».

→ 4560 detectors «SLAB detectors» to thermalize.

400 µm Copper Shield and electrical copper shielding (100 µm)



Cu shield 100µ clamped on lateral edges of H structure

Inner & outer slab layers, Cu drains 300 or 400µm glued with few glue dots inside lateral edges of H structure

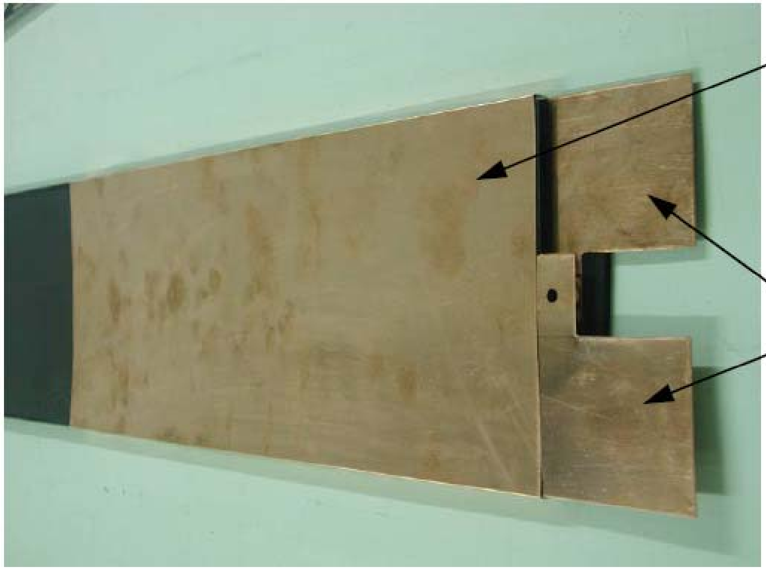
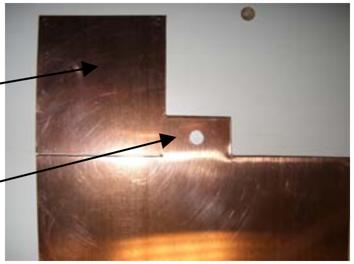


Figure 10.2 - Location of DIF board and cooling bloc at one end of the detector slab



DIF (FPGA) contact

Connection to cooler

Thermal power to dissipate

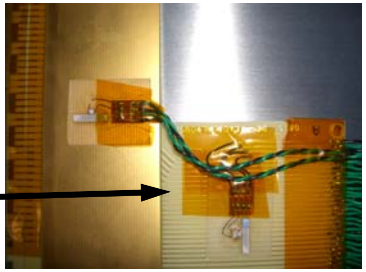
Global Power for Barrel = 3029 W (with FPGA at 0,3W)
Global Power for 2 End-Cap = 1537 W then,
Power to dissipate per Slab for barrel = 1,01 W
Power to dissipate per Slab for End-Cap = 0,99 W (! Average value)
Variation of ambiant temperature regulated from 18°C to 22°C (between top and bottom of detector).

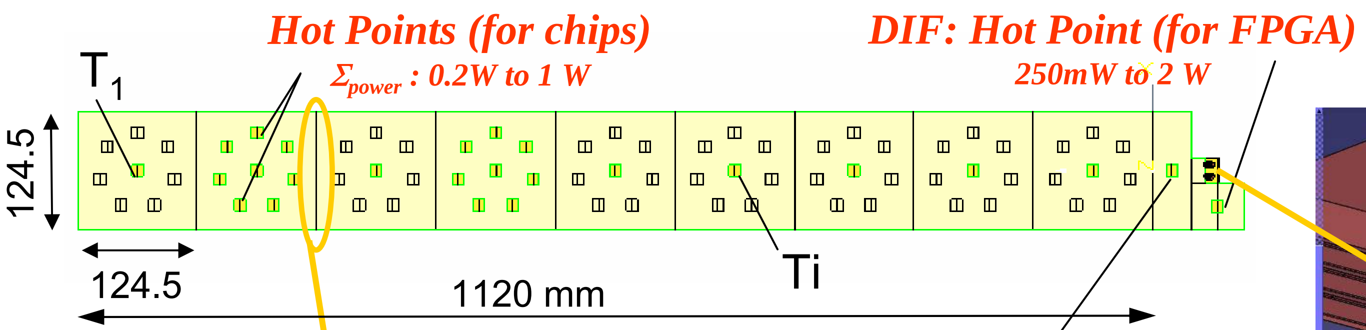
Demonstrator –Test SLAB

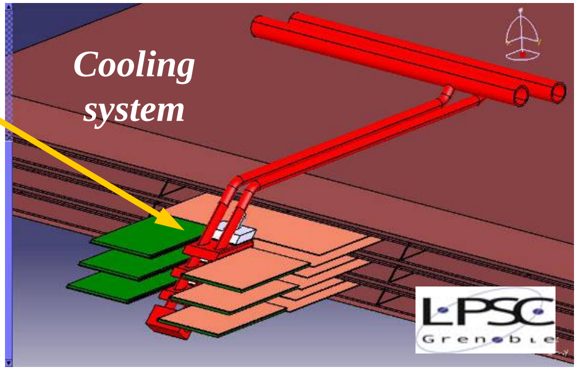
Goal of experimental tests: to make the simulation closest to the reality

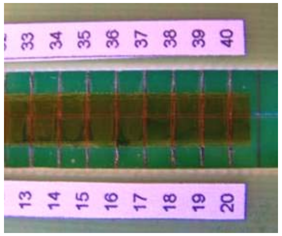
A real thermal test to be compared to numerical simulation,

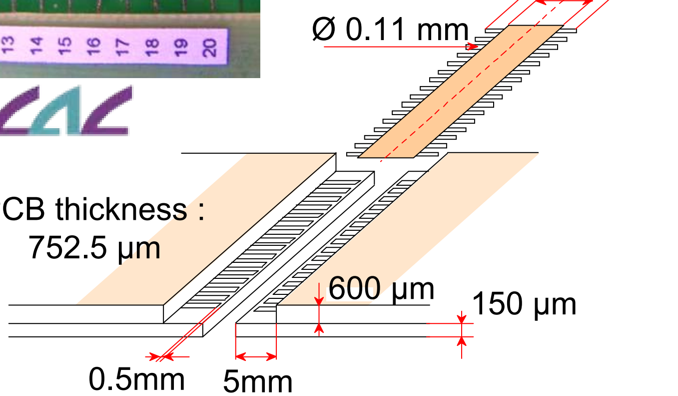
- To reproduce as precisely as possible these tests in simulations (precision on transfer coefficients),
- To verify the behaviour of the cooling system.



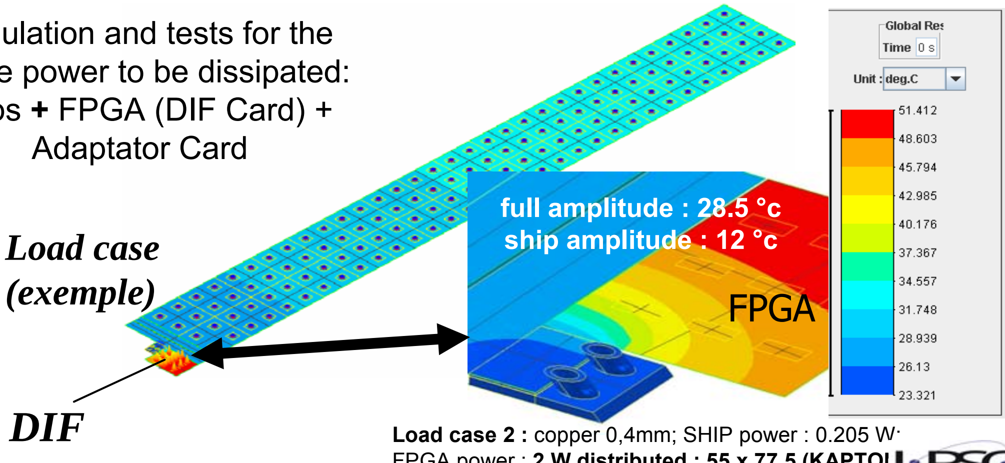






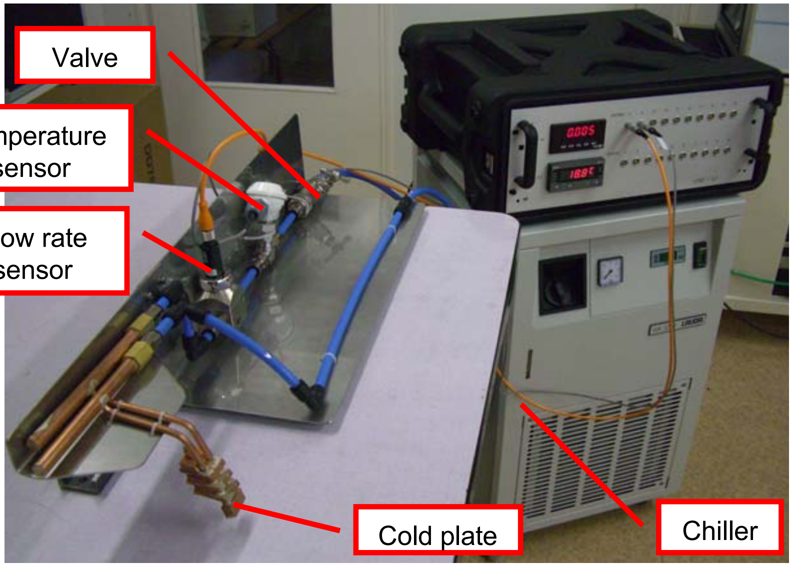


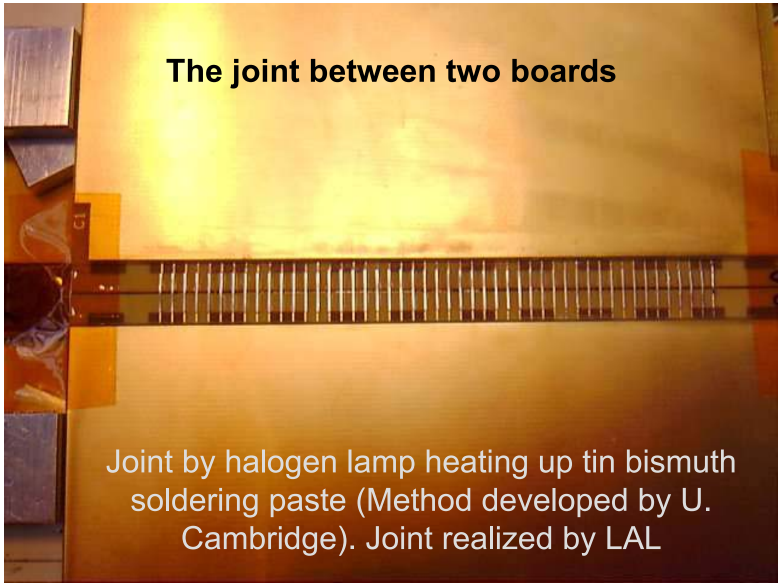
Simulation and tests for the whole power to be dissipated: chips + FPGA (DIF Card) + Adaptator Card



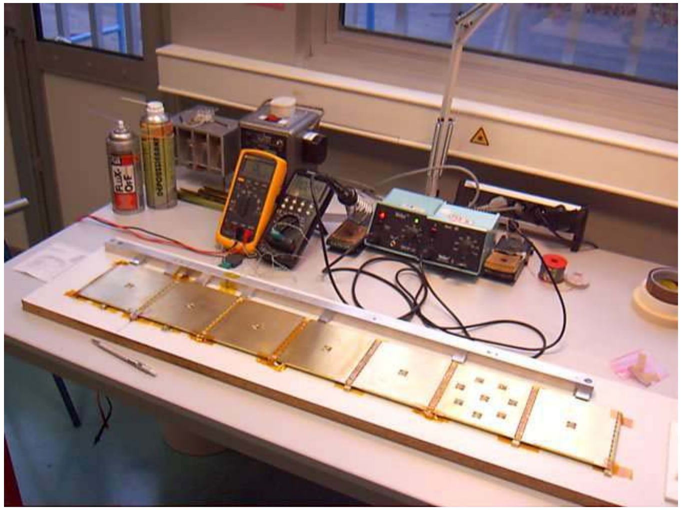
SLAB COOLING - Test SLAB

Cooling system

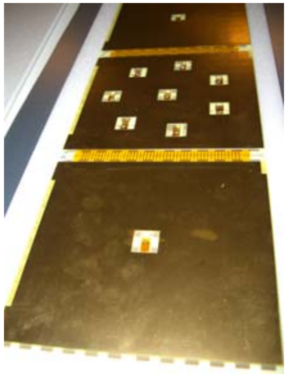




Successful interconnection of ASU



EUDET and demonstrator
Mounting characteristics :
- Flow rate : 0.5 l/min to 1 l/min
 Power to drain off : 100 W (3 layers) to 300 W (EUDET)
- Temperature of fluid control at 20°C
ajustable parameters : temperature & flow rate

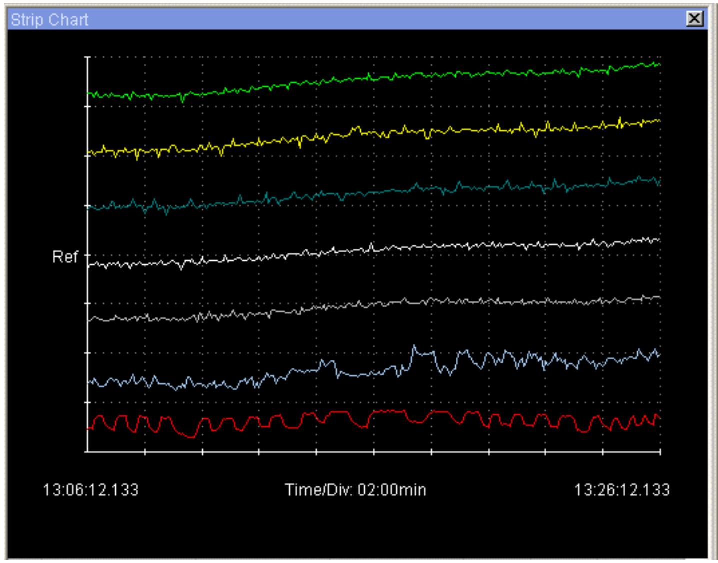


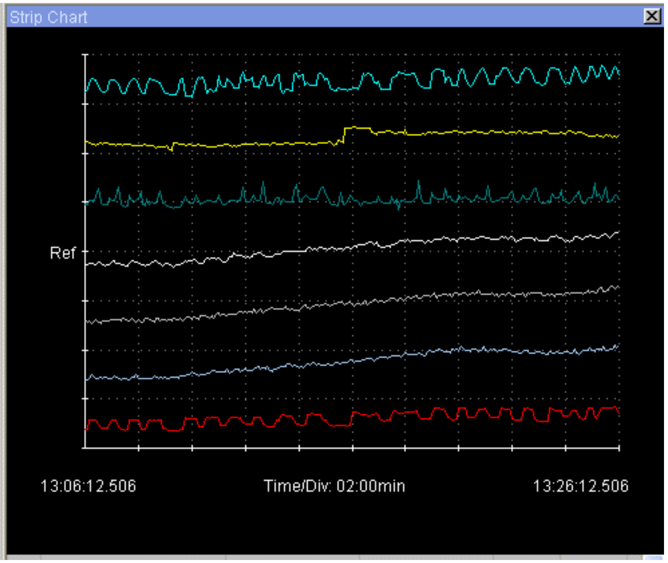
ASU boards assembling

First Results from Thermal Tests/ demonstrator

Cooling System: Test Program on going

YES: ALL IS LINEAR and ΔT < 10 °C !

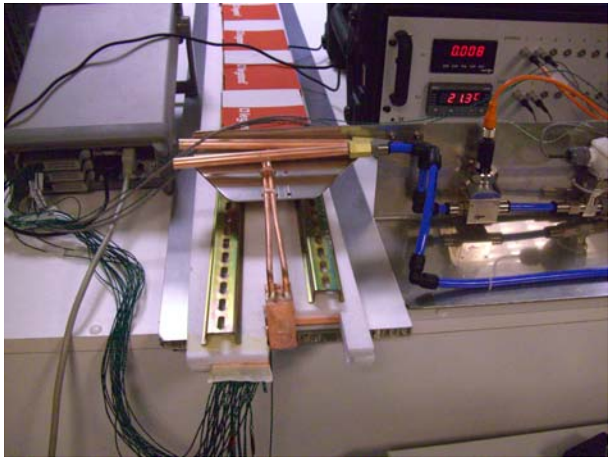




Evolution and correct stabilization of each thermal sensor in response to hot points implementation:

Chips:	**0 to 1 W**
Int.board:	**0 to 1 W**
DIF:	**0 to 2 W**

Extreme test: from Steady state up to cooling failure => temperature curve increasing to determine the maximal acceptable time without cooling (info for Elec…)



- ⇨ Design : *OK*
- ⇨ Simulations : *OK*
- ⇨ Copper plate : *OK*
- ⇨ Interconnect : *OK*
- ⇨ Exp. setup : *OK*
- ⇨ End of first tests: ***Feb 09***

Next tests with EUDET structure

Conclusion : cooling Schedule

Demonstrator

- Slab cooling_tests & the 3 cooling systems — Jan 09
- Correlation (thermal tests) with simulations (transfer coefficients, contacts…) — Feb 09
- Compilation of a second layer (thermal drain + electrical copper shielding) — Mar 09
- Demonstrator (3 layers) assembled - Optimization of cooling simulations — Mar 09
- Validate the cooling system (400 µm copper plate + pipes+thermal contacts) — Jun 09

Goal: **- Test of cooling system: mechanical aspect and performances**
- Optimization of simulation: conductivities, materials, geometries

EUDET

- **Cooling system for EUDET** (copper type) — Feb 09
- Alternative for 15mm thick composite plates, integrating composite rails — Apr 09
- Alternative cooling system with heat pipes — Mar 09
- Eudet structure assembled — Jun 09

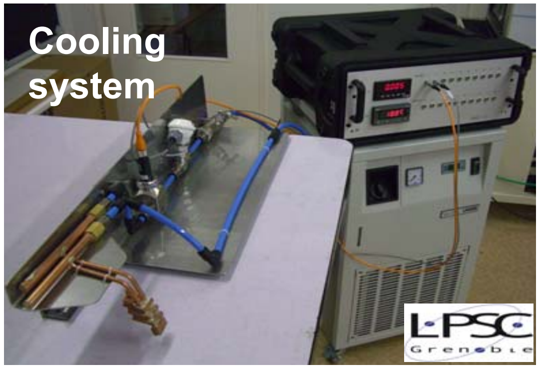
CALICE - ILD

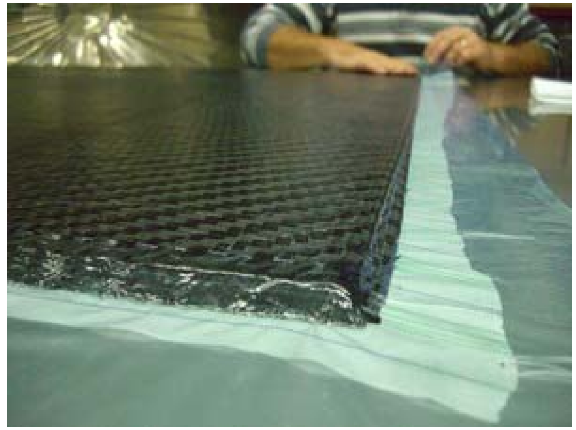
on going

- End-cap **design** & mechanical simulations — Apr 09
- Moulds for a specific **End-cap** module's **layer** (2,50m !) — Summer 09
- Optimization of composite elements — Fall 09
- First Design for the **whole** detector **cooling system** — Fall 09
- **Fastening system** ECAL/HCAL: alternative for thick composite plates and rails …

Thank you for your attention

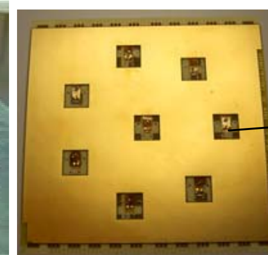
ECAL Mechanical R&D

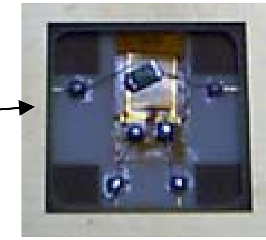




Fabrication and destructive tests of 15mm thick composite plate with inserts

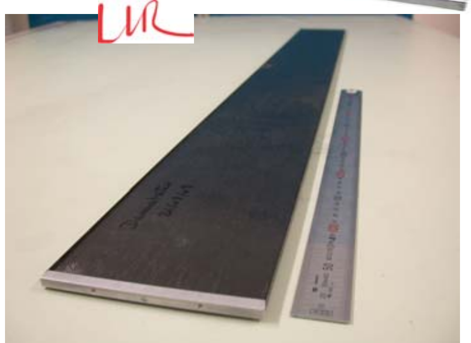
THERMAL PCB…



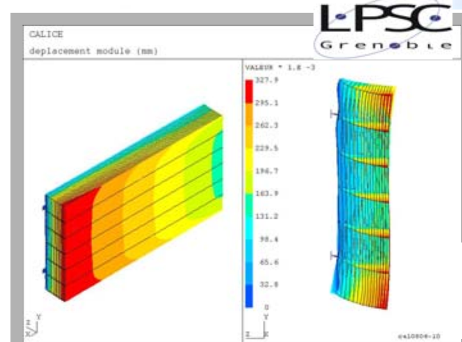


PCB FEV_HEATERS

15mm thick plate with rails



Destructive tests



End-Cap module

Configuration 90°

400µm thick & 180 mm larg copper heat shield