ECAL slab Cooling
& Mechanics for End-Cap

CALICE meeting – Manchester

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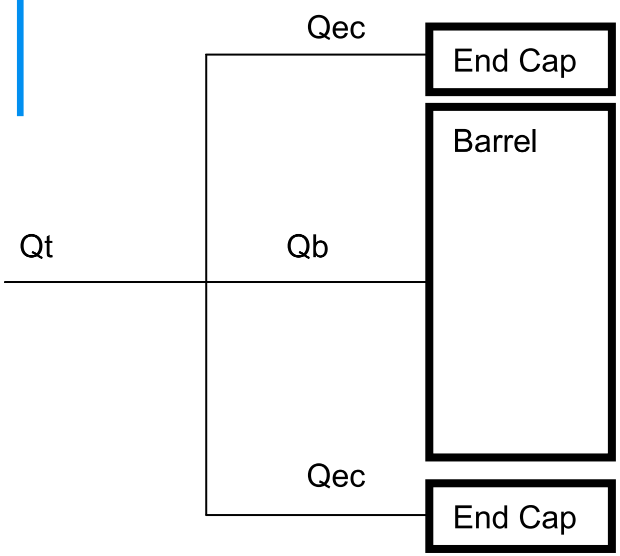
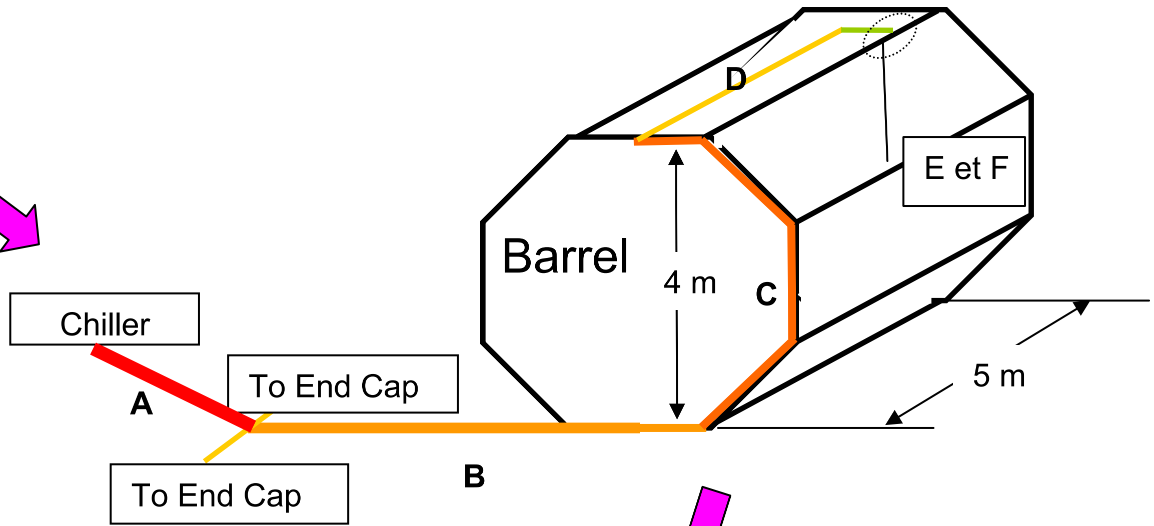
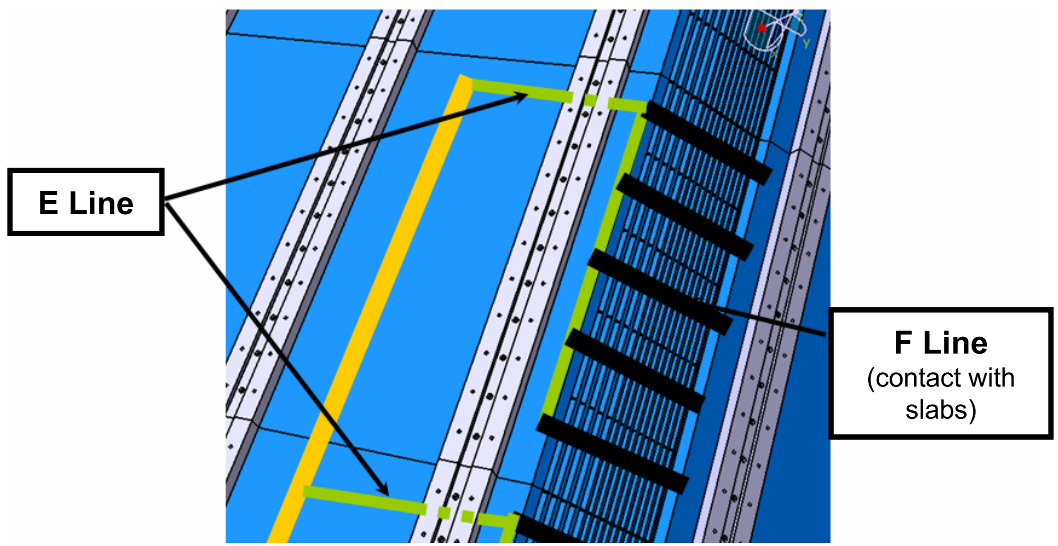
Cooling: global circulation (1)





Taking into account length and diameter for study

Zone	Longueur (m)	Diamètre intérieur (mm)
A	50	45
B	15	35
C	7	25
D	5	15
E	1,5	10
F	0,3	4



Only feeding circuit represented

Cooling: global circulation (2)

Power results :

2 FPGA per SLAB, power: 3 W each, then : 3 x 2 = 6 W
SKIROC : 0.54 W / slab
Barrel :
Global Power : 19484 W
Power per module : 487 W
Power per column : 97.4 W
End Cap :
Power per End Cap : 5060 W
Average power per module : 420 W (390+390+480)/3
Average power moyenne per column : 97 W

Global Power : 30 000 W

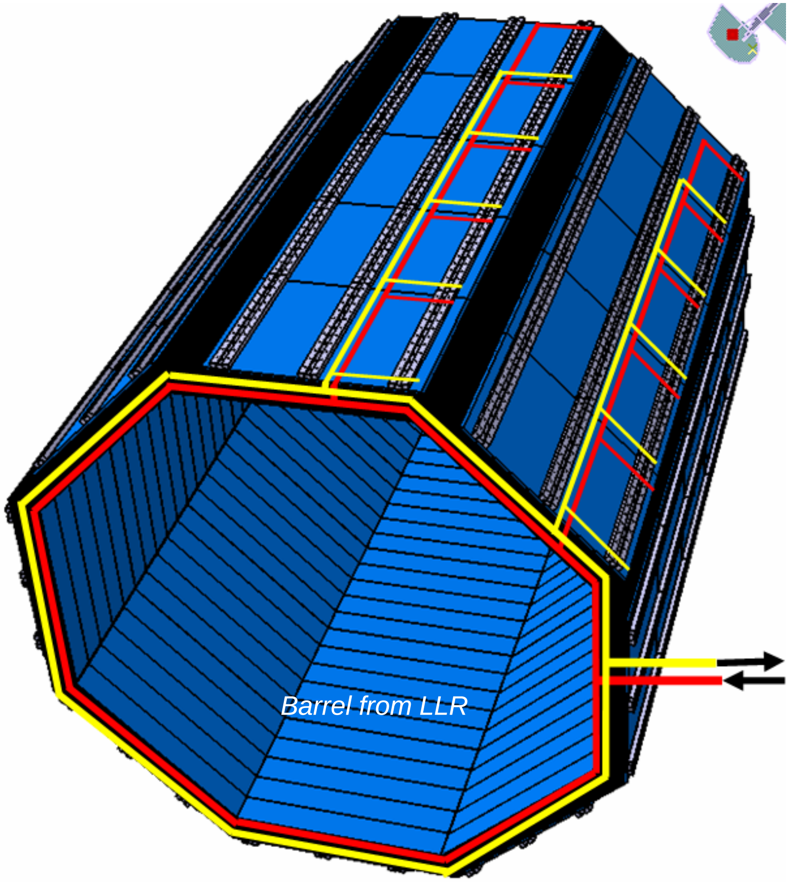
Rough estimate on fluid circulation:

Global flow rate : 150 l/min

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

Fluid speed < 2 m/s

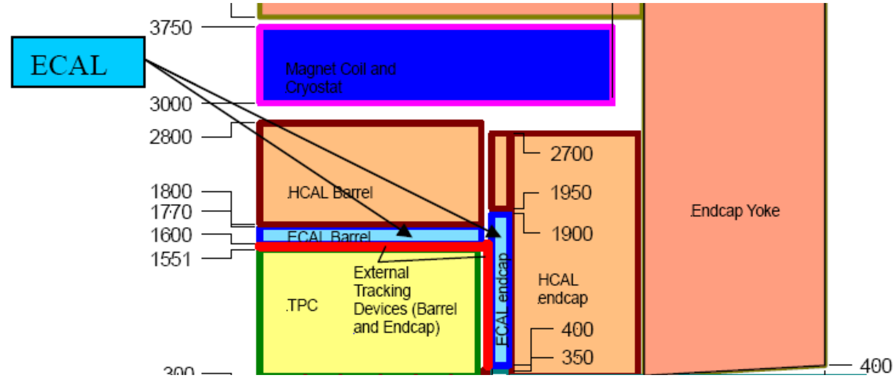
Maximal pressure drop : 1.2 bar

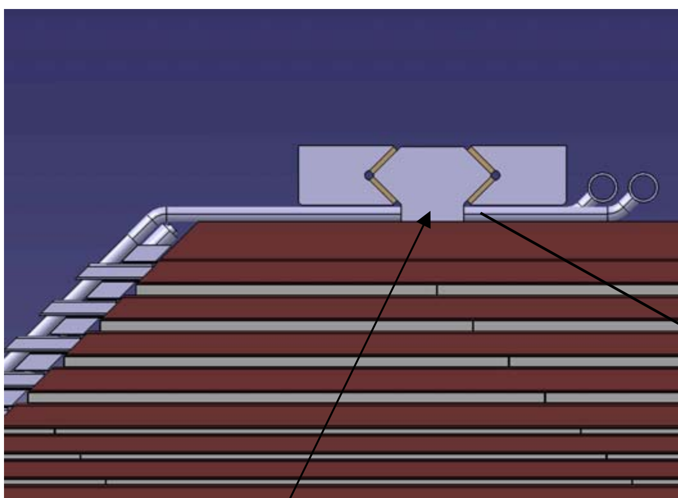


Fluid circulation /mounting

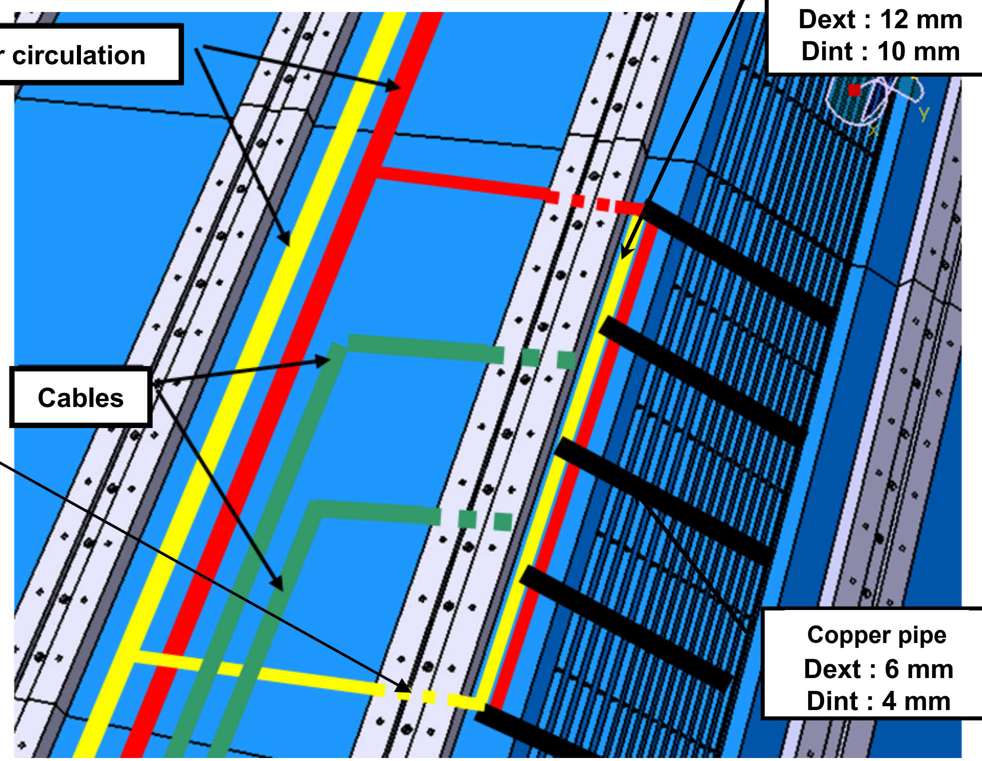
Fluid circulation => passages for pipes toward exterior of detector => free space to find and to adapt:

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



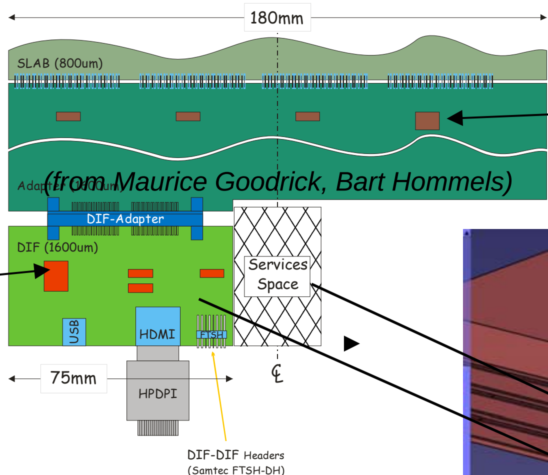


Passage through the rails for both pipes and cables



SLAB COOLING – CONSTRAINTS

Mechanical constraints on ECAL electronics:
Place available , heat sources power & situation

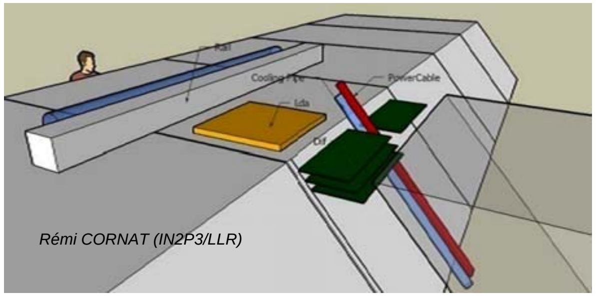


(from Maurice Goodrick, Bart Hommels)

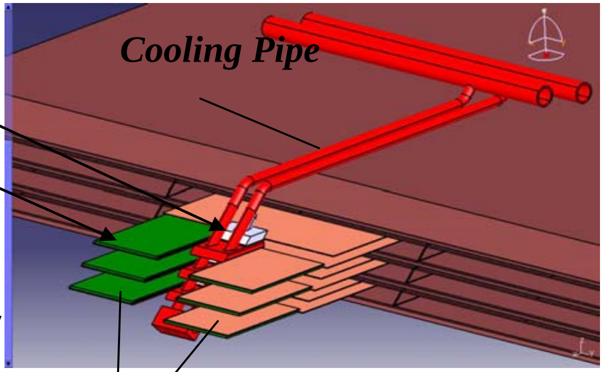
FPGA

Hot points on
interface card ?

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

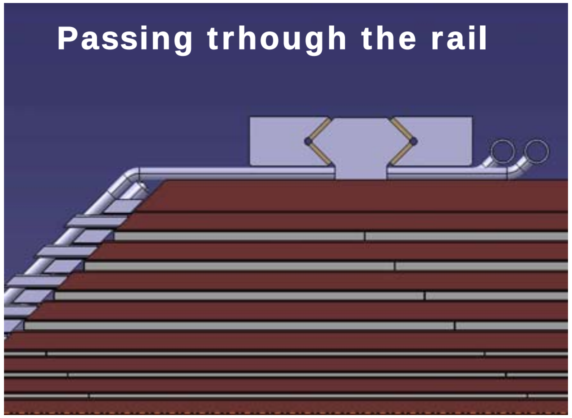


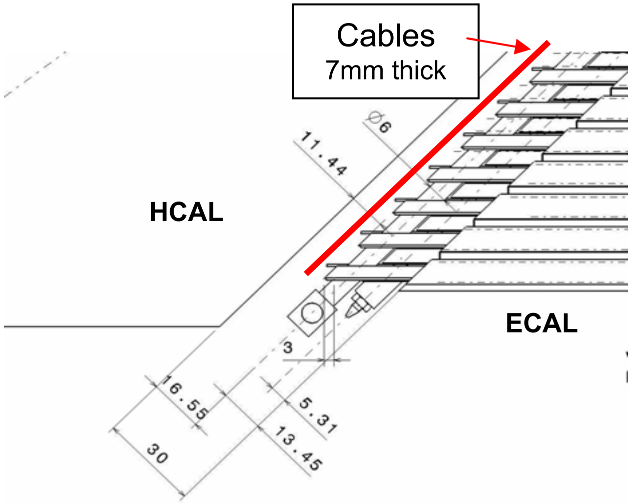
Place for cabling : DAQ + HV + GND
Service space between cooling and HCAL >1cm



DIF

Demonstrator: cooling and copper drain extremities

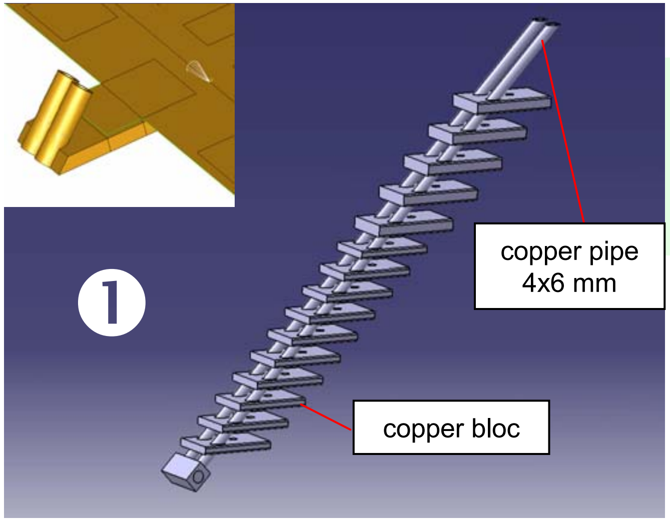




Space for HV and GND

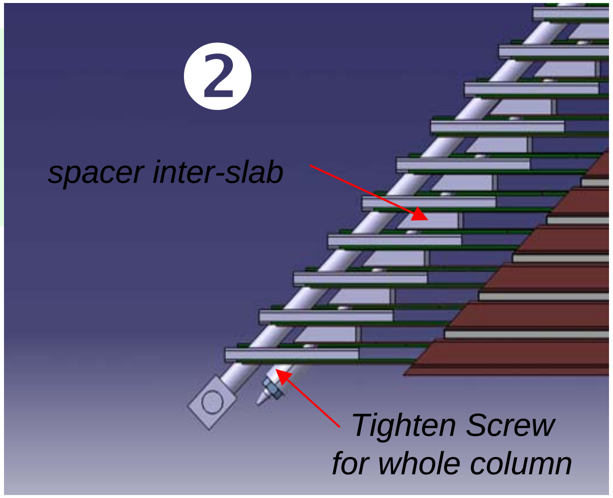
External cooling design

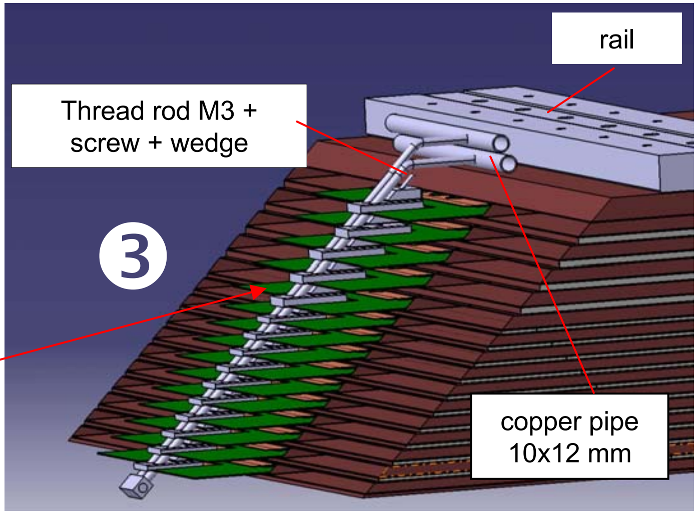
Design : each cooling system ❶ is inserted and screwed to each column of slab with a thread rod and spacers (❷) and connected to the cooling network in a second step ❸.



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

Network of contact areas / connector fixed on the 2 layers



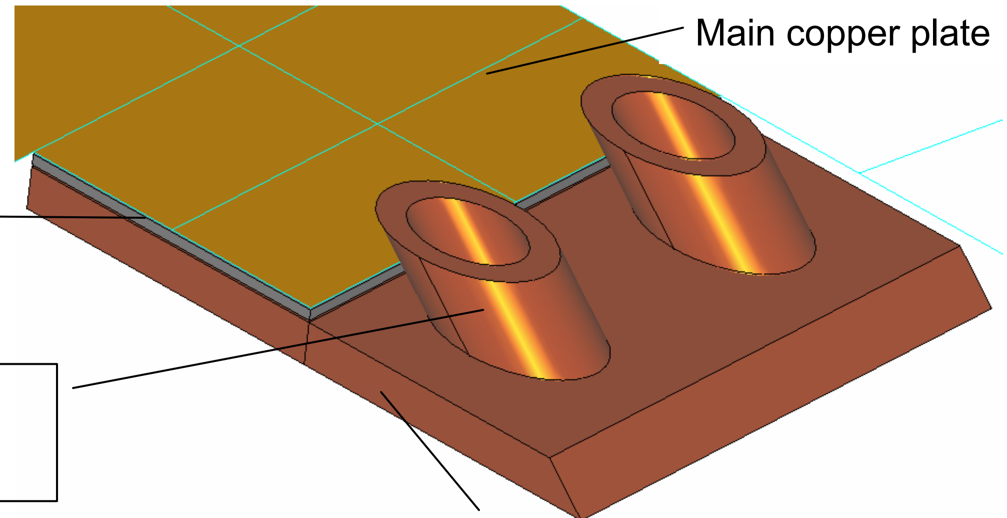


End of PCB (DIF)

Both to be tested on : EUDET and demonstrator

SLAB COOLING - EUDET

Boundary condition:



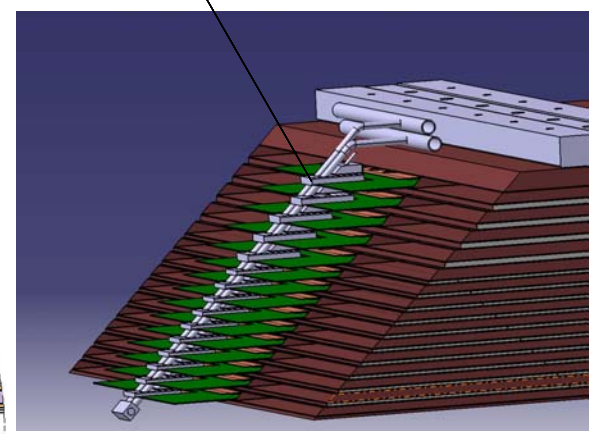
Thermal foam : **λ = 3 w/mK**

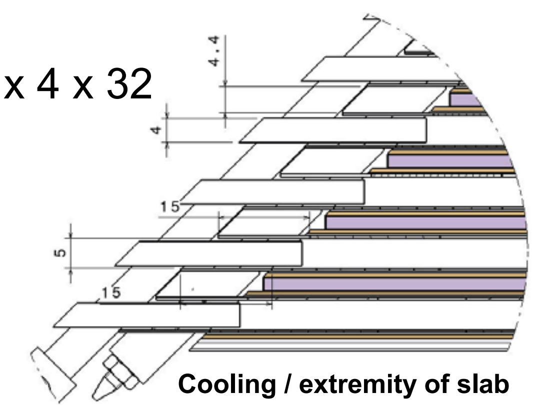
Convective flux into pipe with fluid at 20°c (h = 3445 W/m².K)

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**
=> 2 W for test

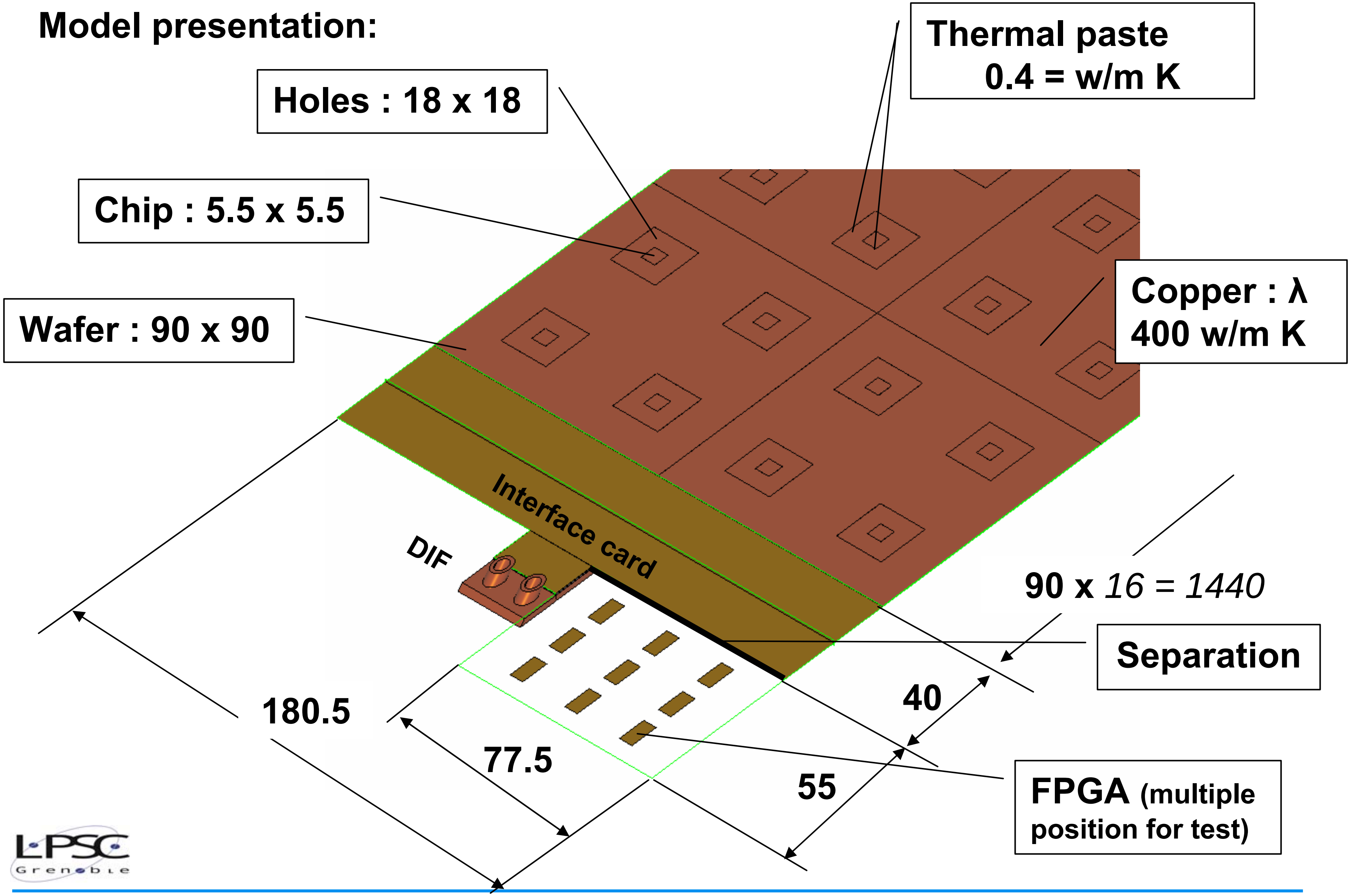




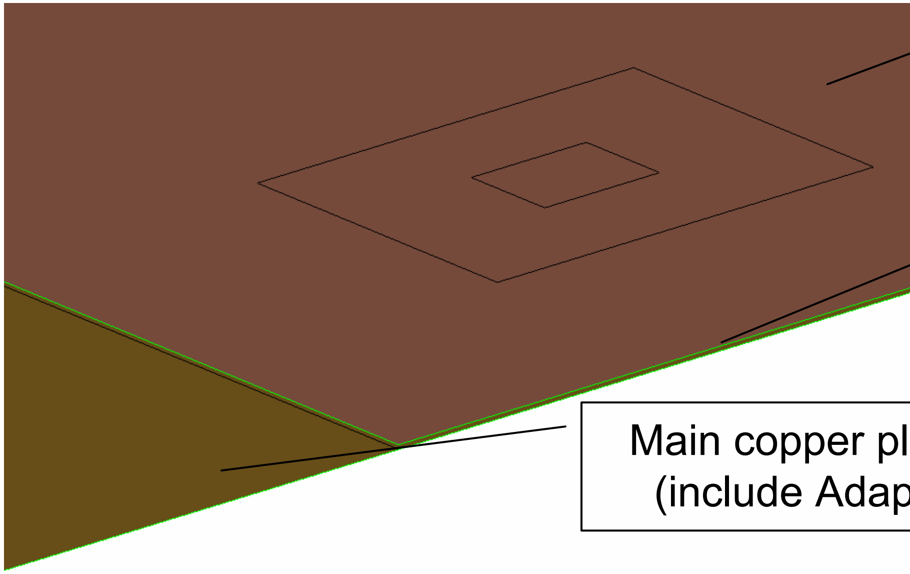
Cooling / extremity of slab

SLAB COOLING - EUDET

Model presentation:



SLAB COOLING - EUDET



Upper copper plate : Ep = 0.1 mm

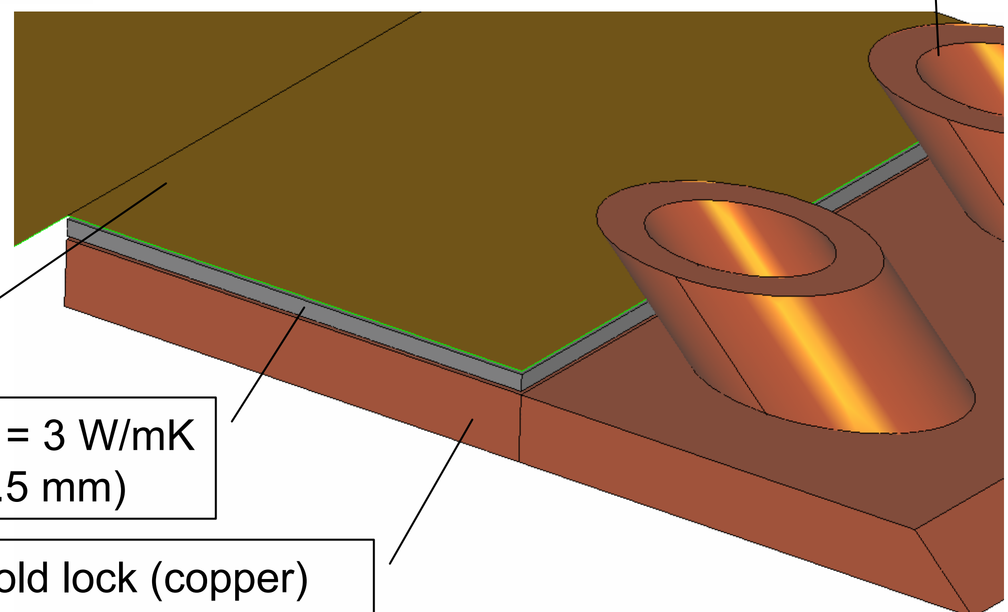
Full thermal contact between Upper and main copper plate

Main copper plate : Ep = 0.3 mm (include Adapter and DIF card

Fluid circulation pipe

Note : The thermal finite element model (shell element) is favorable near the ship power input.

The error estimation is 1°c.



Main copper plate

Thermal foam λ = 3 W/mK (thickness 0.5 mm)

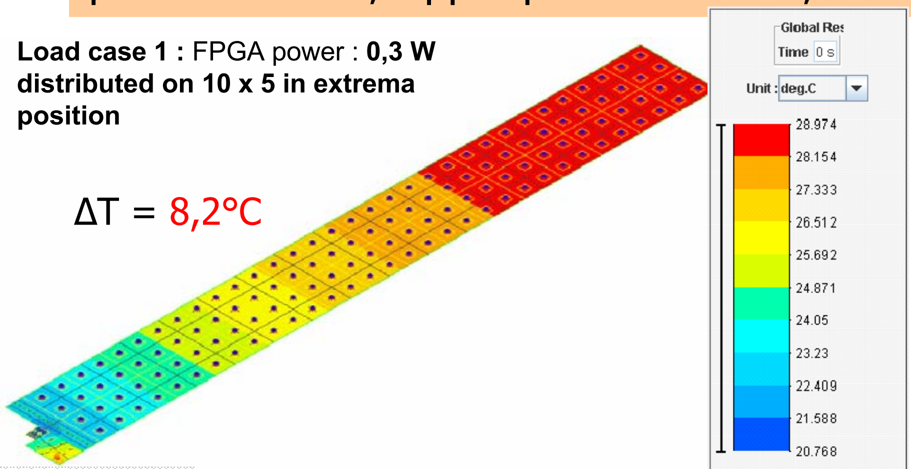
Cold lock (copper)

Thermal analysis of slab

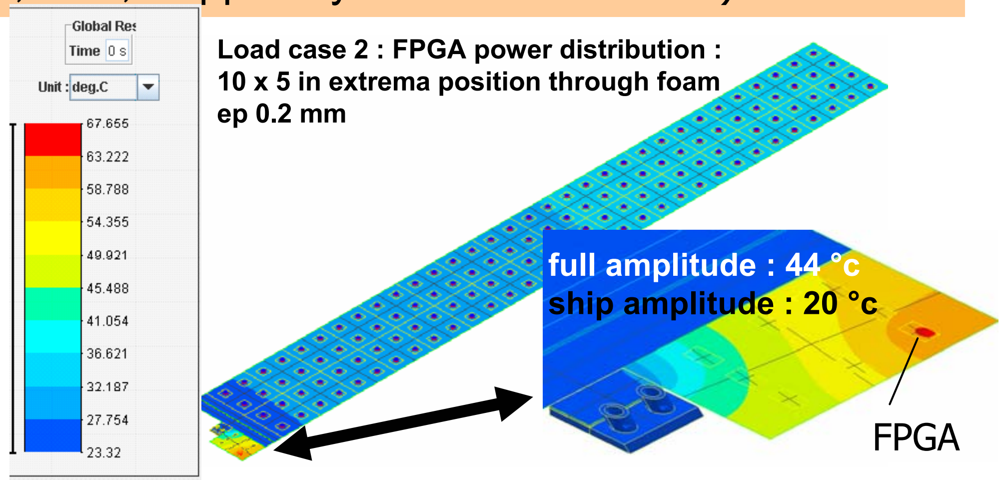
Simulation of heat conduction just by the heat copper shield : Influence of the FPGA dissipation (DIF) on current design of cooling system (Limit Condition of 20°C, with Main plate : 0.3 mm; Upper plate : 0.1 mm; L = 1,55 m; Copper layer : λ = 400 W/m/K)

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

ΔT = 8,2°C

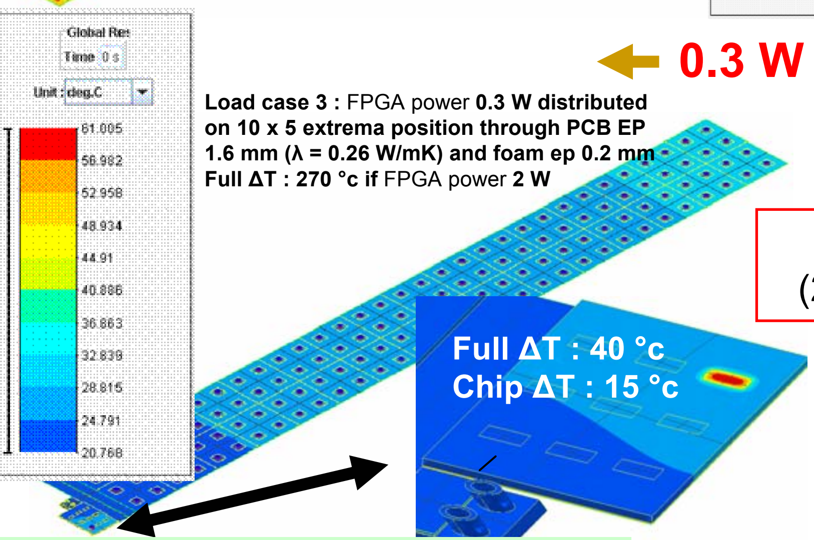


Load case 2 : FPGA power distribution : 10 x 5 in extrema position through foam ep 0.2 mm



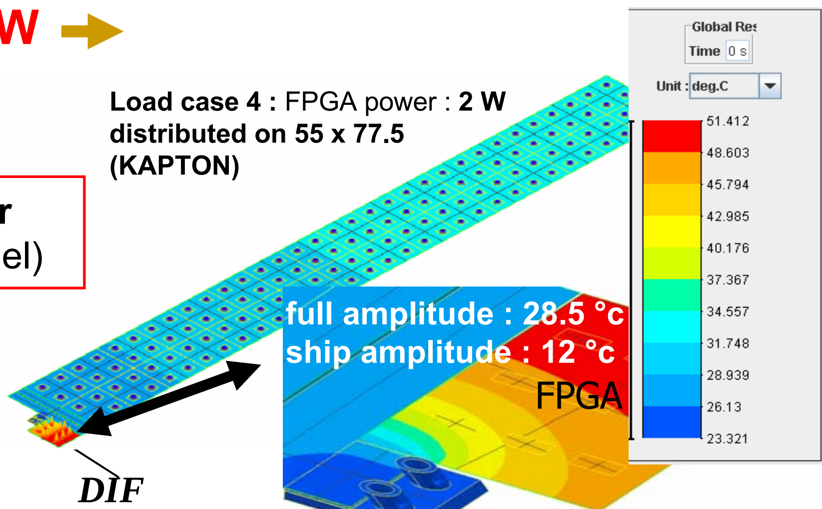
0.3 W < FPGA < 2 W

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**



Φ= 0,27 W/layer
(25 μW per channel)

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

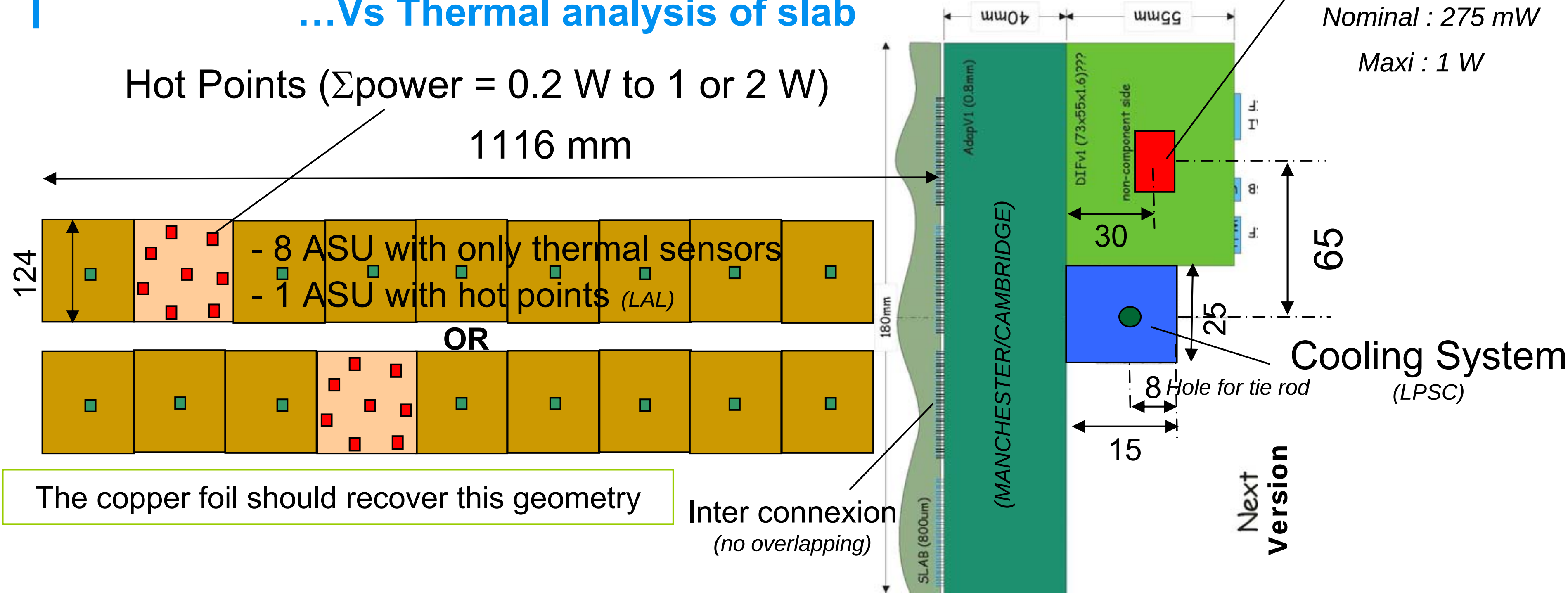


…better cooling if direct contact with FPGA !

SLAB COOLING

DEMONSTRATOR design for tests…
…Vs Thermal analysis of slab

Hot Point = FPGA power : 200mW to 2 W



Slab cooling tests (1 Hot ASU + 8 thermal ASU):

- Correlation with simulations (transfer coefficients, contacts …)
- Check a thermal dissipation behaviour close to EUDET design
- Validate the cooling system (400 µm copper plate + pipes)

… taking into account thermal analysis of slab…

Cooling setup

- ⇨ Global design : *OK*
- ⇨ Cooling system ❶ : *Oct 08*
- ⇨ Chiller determination ❷ : *OK*
- ⇨ Sensors and aquisition ❸ : *OK*

❷

Chiller

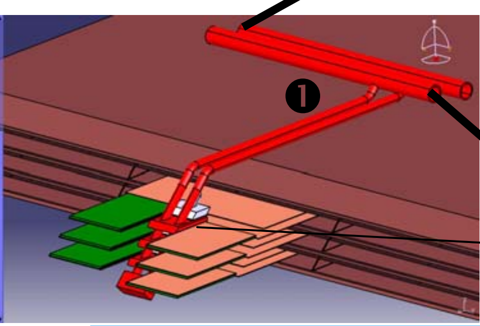
with indication and tuning of flow rate and temperature

Temperature sensor

Acquisition (PC)

❸

Flow rate sensor



❶

Cooling system and copper drain extremities

EUDET and demonstrator Mounting characteristics :

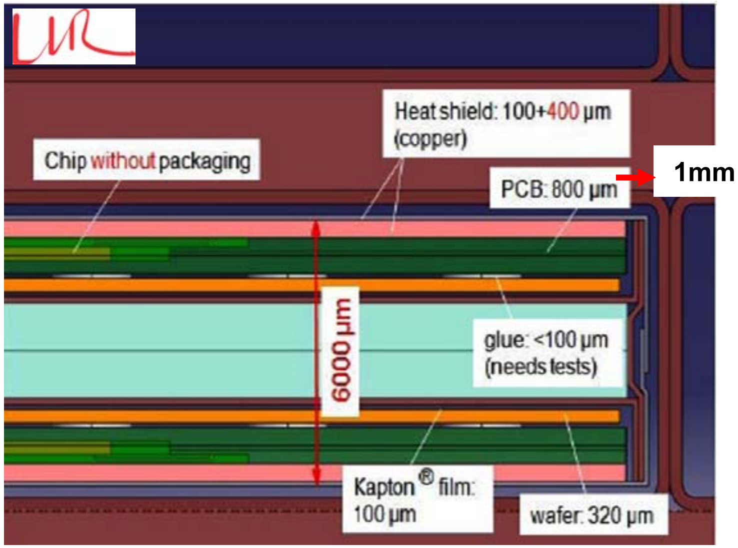
- Flow rate : 0.5 l/min to 1 l/min
 Power to drain off : 100 W (3 layers) to 300 W (EUDET)
- Temperature of fluid control at 20°C ajustable parameters : temperature & flow rate

Design of copper foils

The expected heat shield thickness is 500 µm=100+400 µm:

⇨ Brazing of copper foils (T<300°C) to be validated

Heat shield : 100 (housing Al or CuBe?**)** + 300 or 400 µm Cu = 4 options for copper assembling to test:



- Options 1
  - 100µm housing Cu.. + **400 µm** Cu (without brazing – with holes) / **0.4 mm** considered for simulation. Thermal grease only in holes (1.8x1.8 cm^2 chips***400 µm** thick).
- Options 2
  - 100µm housing Cu.. + **400 µm** Cu + 0.05 (silver brazed) / **0.5 mm** considered for simulation. Thermal grease only in holes (1.8x1.8 cm^2 chips***400 µm** thick).
- Options 3
  - 100µm housing Cu.. + **300 µm** Cu + 0.05 (silver brazed) / **0.4 mm** considered for simulation. Thermal grease only in holes (1.8x1.8 cm^2 chips***300 µm** thick).
- Options 4
  - 100µm housing Cu.. + **400 µm** Cu (whithout brazing) / **0.4 mm** considered for simulation. No holes (1.8x1.8 cm^2), chip no overlapping.

Simulations to be performed on the final option for demonstrator.

Actually done with 100µm housing Al + 300 µm Cu with holes and grease (0.4 mm considered for simulation)

For simulation : the 100µm housing Cu do not cover the ADAPTER et DIF cards.

The copper drain is adapted / DIF card to be in contact with FPGA on DIF (« hot » Kapton for demonstrator)

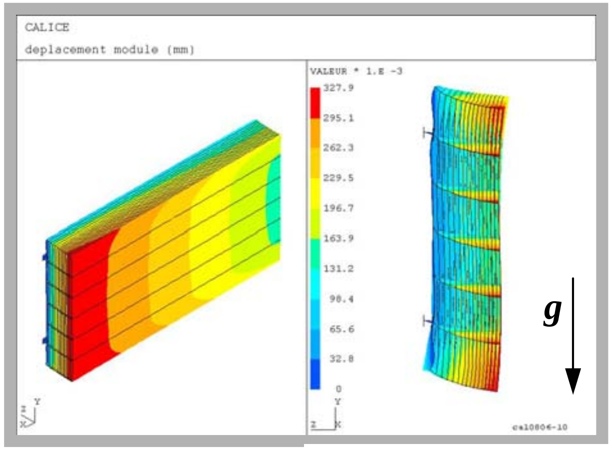
Design of module …

… based on mechanical simulations :

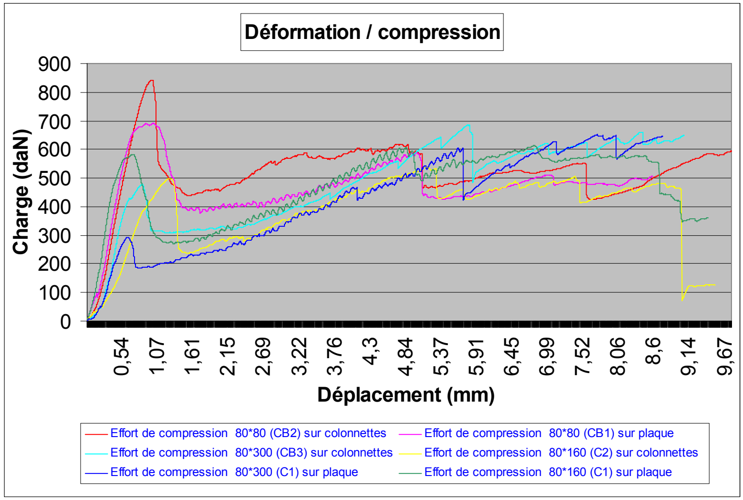
Linear Analysis of "full scale" ECAL modules (barrel and End-caps)

OK

- Global simulations : global displacements and localization of high stress zone for different solutions (dimensions)
- Local simulations : more precise simulations and study of different local parameters to design correctly each part of this structure (thickness of main composite sheets, fastener's behaviour…)
- Check and validate simulation results by destructive tests for each issues



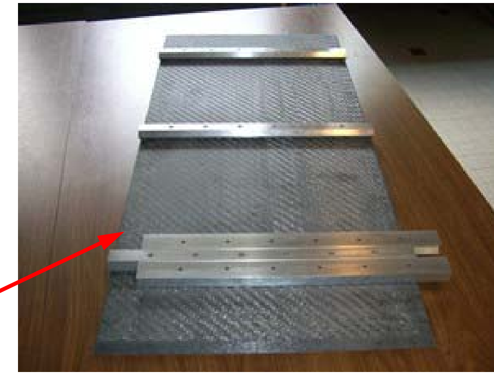
End-Cap module
Configuration 90°



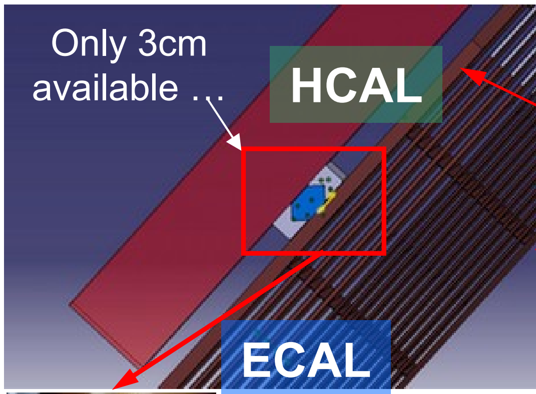
Fastening & cooling system

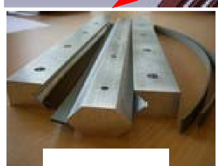
•Choice of fasteners : aluminum rails screwed through the medium of inserts. Non magnetic (B=4T !)

Uniform dispatch of 18 inserts on the 15mm thick plate



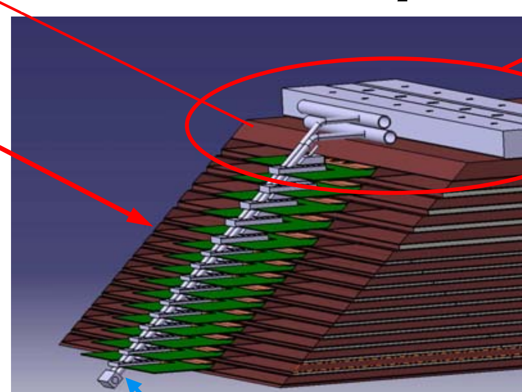
15mm thick plate with it's rails; ready to be assembled with alveoli layers

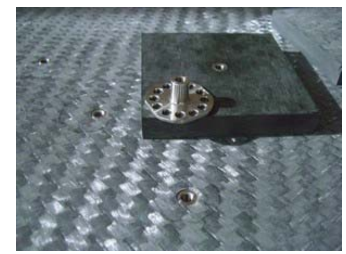




Rail

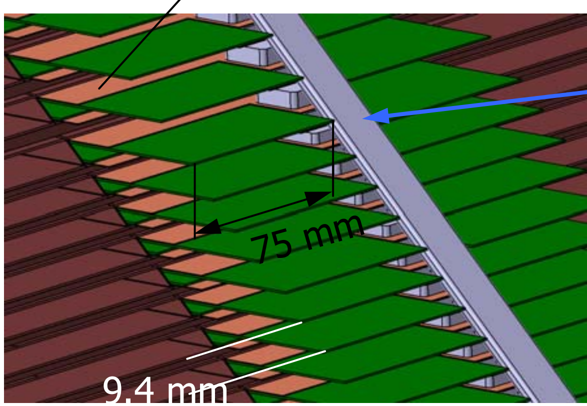
Rails fixed by the way of inserts directly on ECAL modules.





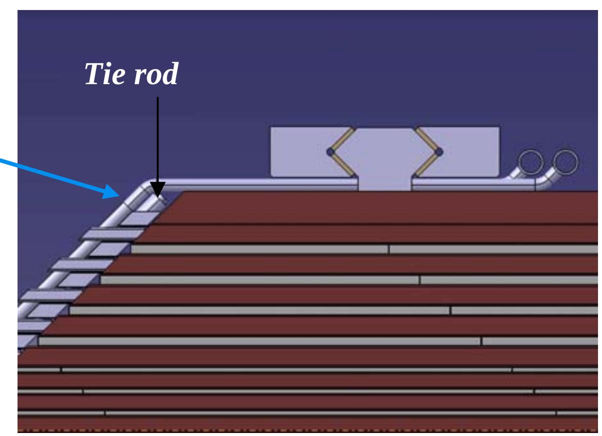
Fastening system (inserts)

Copper plate on the PCB



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

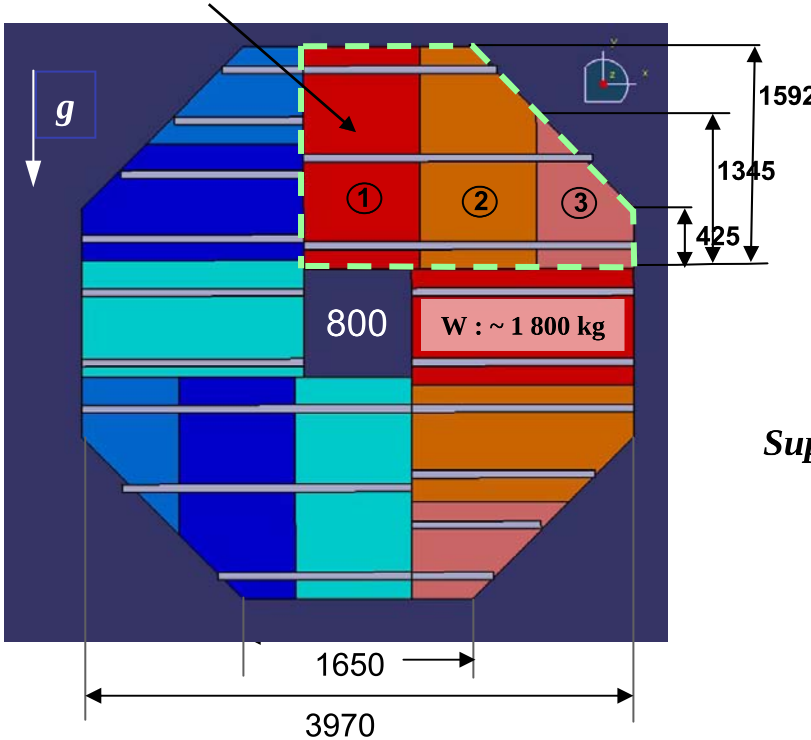


ECAL - End-Caps design (1)

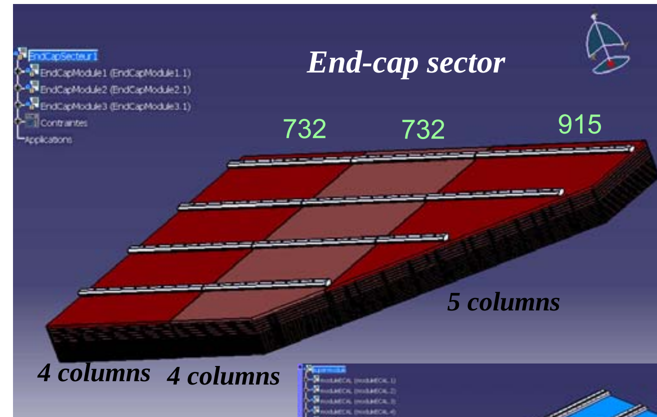
Design: *1*

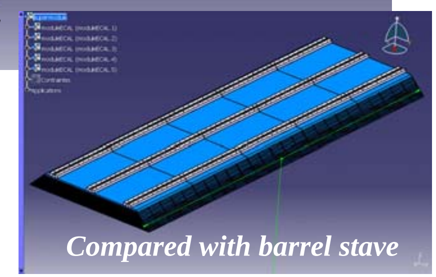
- The same principle than barrel with an alveolar composite/ tungsten structure, with different shapes and different sizes (end of slabs)
- Difficulty: getting shape for W plates
- 12 modules-3 distinct types (780 cells & detectors slab)

Configuration 0°

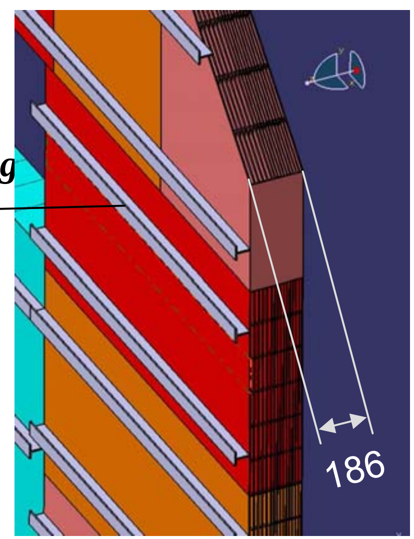


Weight of each End-Cap : ~ 16 T





Supporting rails



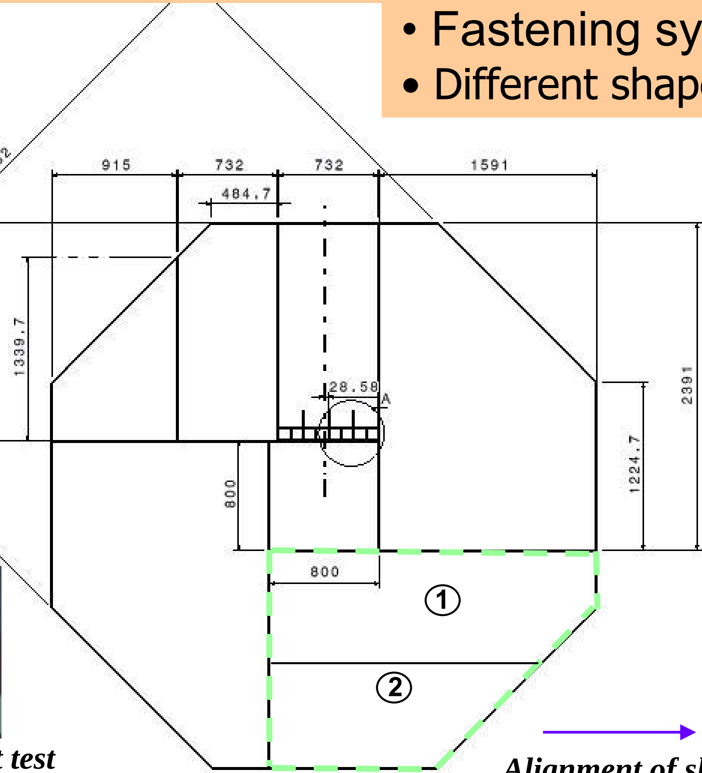
ECAL - End-Caps design (2)

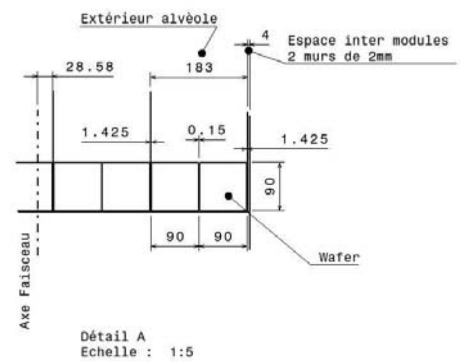
Design: 2

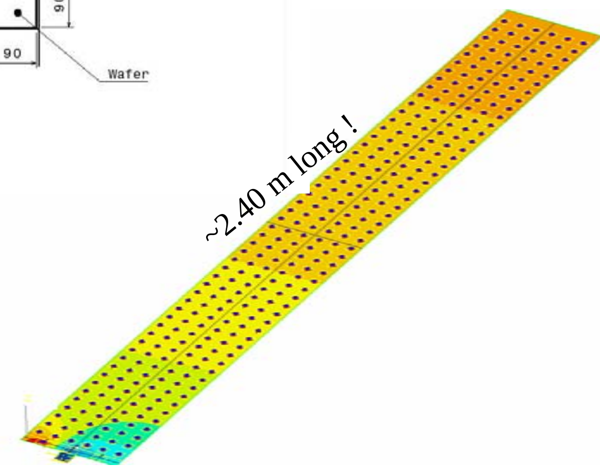
- Due to the possible crack in the geometry of design 1
  the same general shape could be saved with different size and position of modules
- Instead of 12 modules from 3 distinct types: 8 super-modules from 2 distinct types

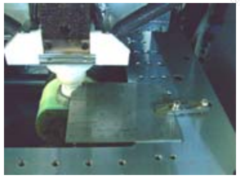
Difficulties:

- Thermal (2.40m instead of 1.50m for longuest): T° dangerously rising in back-end of slabs
- Mechanical: >2.40m long thin alveoli maybe not feasible,
- Fastening system on HCAL /weight of module >3T ?
- Different shapes of long slabs: cost increasing





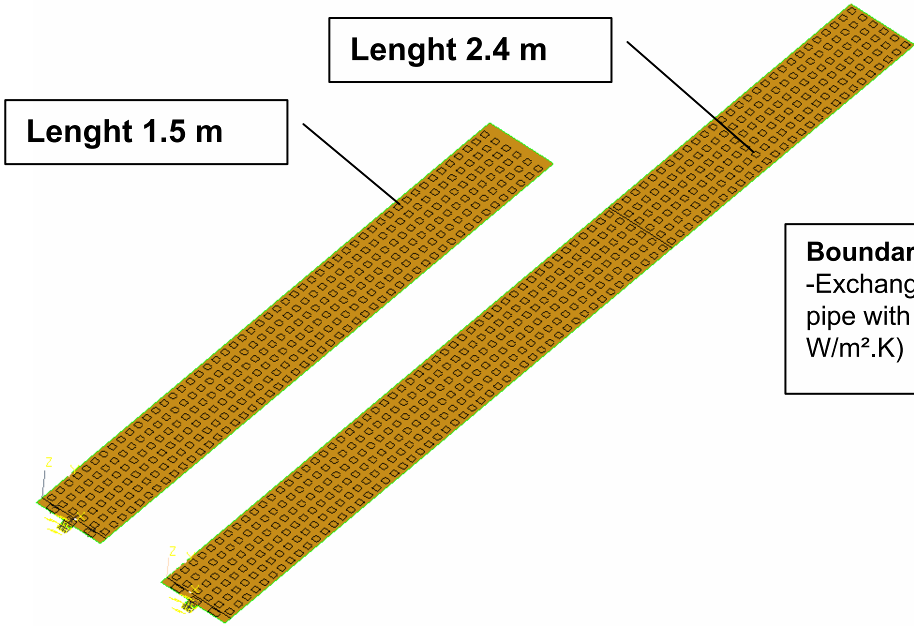




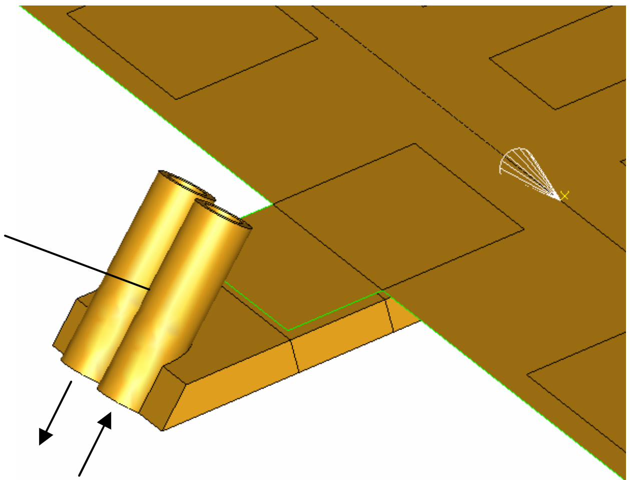
W wire erosion cut test

Alignment of slabs

Cooling system: End-cap constraints



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



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

Schedule

Demonstrator

Slab cooling tests (1 Hot ASU + 8 thermal ASU): with all **Cooling setup** — **Oct 08**

- Correlation with simulations (transfer coefficients, contacts …)
  Check a thermal dissipation behaviour close to EUDET design
  Validate the cooling system (400 µm copper plate + pipes) — **Nov 08**
- **Updated numerical simulations** — **Oct 08**

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

EUDET

- **Cooling system for EUDET** — **Nov 08**
- Alternative for 15mm thick composite plates, with rails integrated — **Dec 08**
- Alternative cooling sytem with heat pipes — **Dec 08**

CALICE

on going

- End-cap **design** & mechanical simulations
- Moulds for a specific End-cap module and **optimization of composite elements**
- Design for the **whole** detector **cooling system**
- Validation of the **fastening system** ECAL/HCAL

…