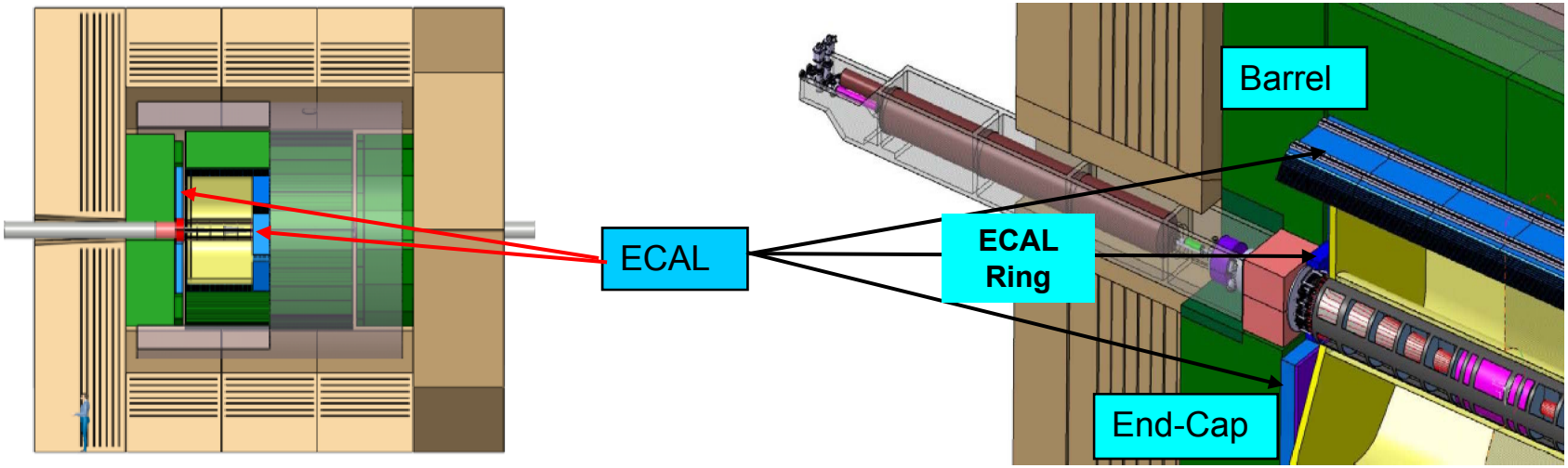
Mechanics studies at IN2P3

SOCLE 2008 @ LAPP

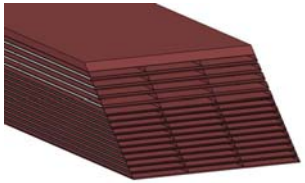
Denis Grondin / Marc Anduze – December 8 & 9th

Si-W ECAL: from ILD to R&D

- Mechanical activities within IN2P3 on the ILD Electromagnetic Calorimeter

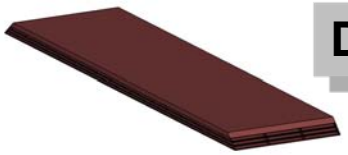


ILD & CALICE *(20..)*

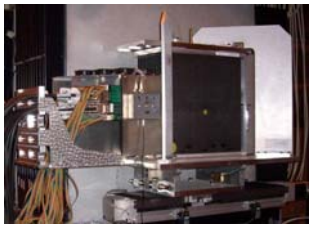


EUDET *(2009)*

What we call “EUDET Module” is in fact the next SiW Ecal CALICE Prototype

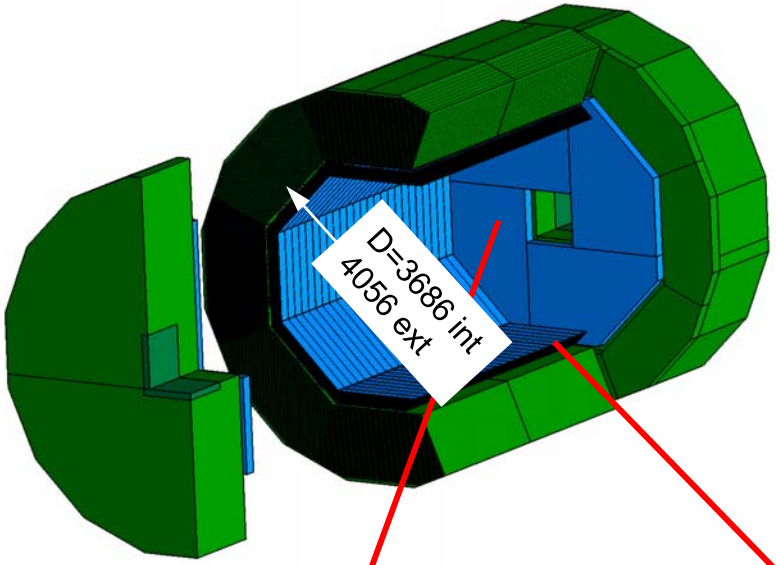


Demonstrator *(2008-09)*



Physical prototype *(2006)*

ECAL – Current baseline



W/Si calorimeter (24 X_0 with 29 W layers)

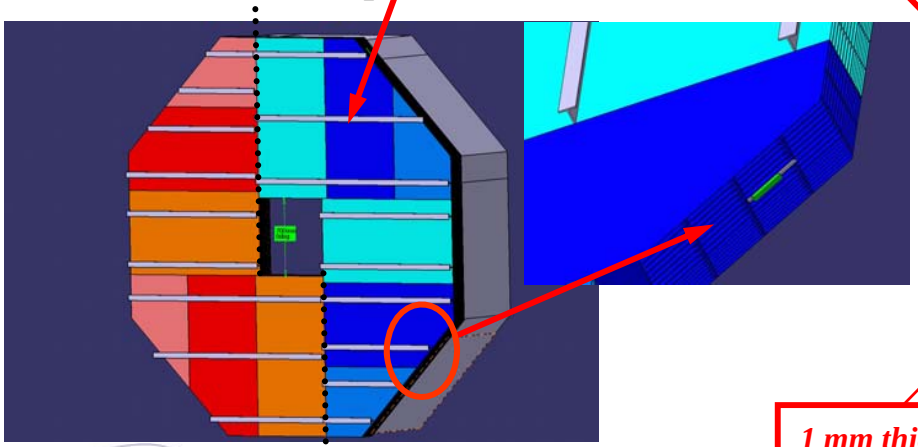
Weight full ECAL: ~ 112 T (80 barrel+32 End-Cap)

- Barrel : 40 identical trapezoidal modules
- End-Cap : constituted of 12 modules (3 types)
- ECAL module : alveolar structure - carbone fibers compound including half of W plates (fixed on HCAL End-Cap with rails)

  ⇨ compactness and minimization of dead zones
- Detection elements (detector slab) in each alveolar case (Si+W), FE chips integrated, pad size : 5×5 mm^2

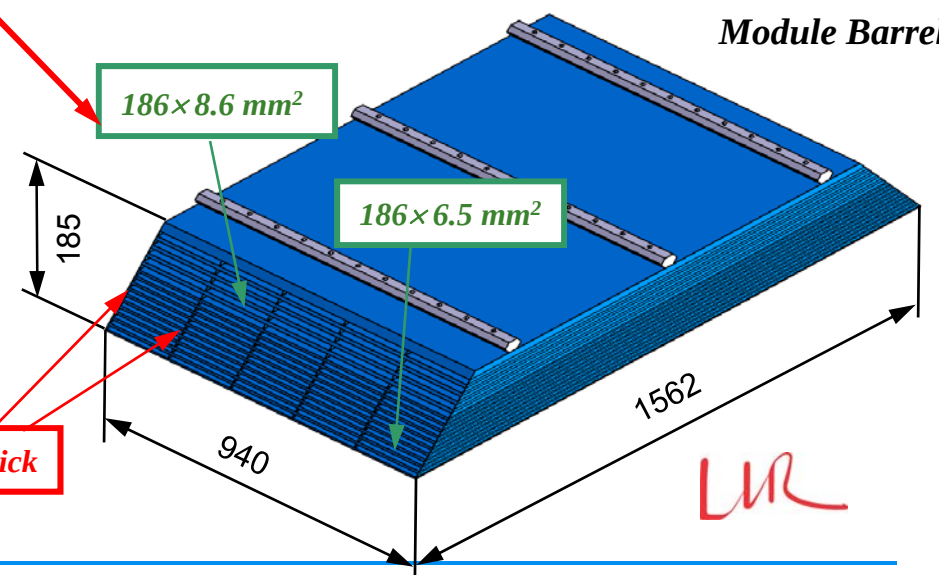
Weight / module : ~ 2 T

Multi-module End-Cap



Opening plan for full End-Cap

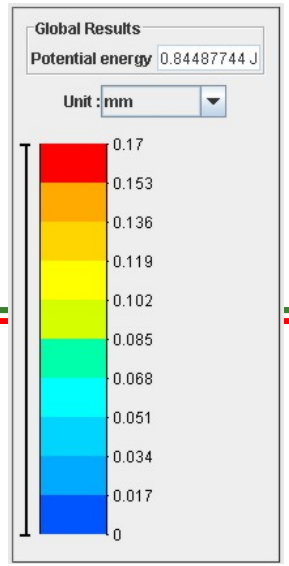
Module Barrel

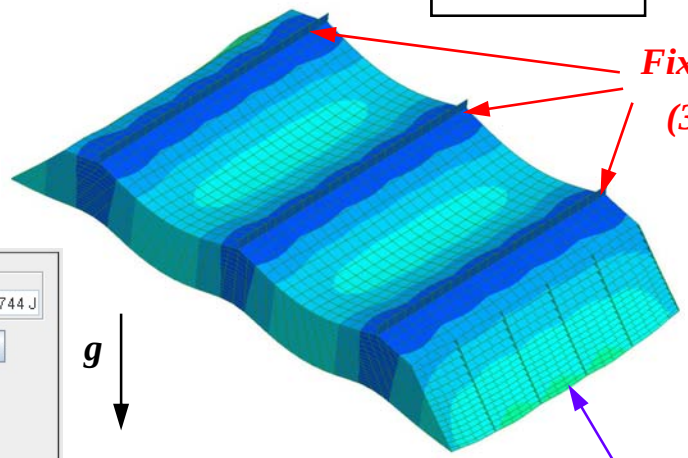


ECAL – 8 vs 12 staves / HCAL

8 staves design

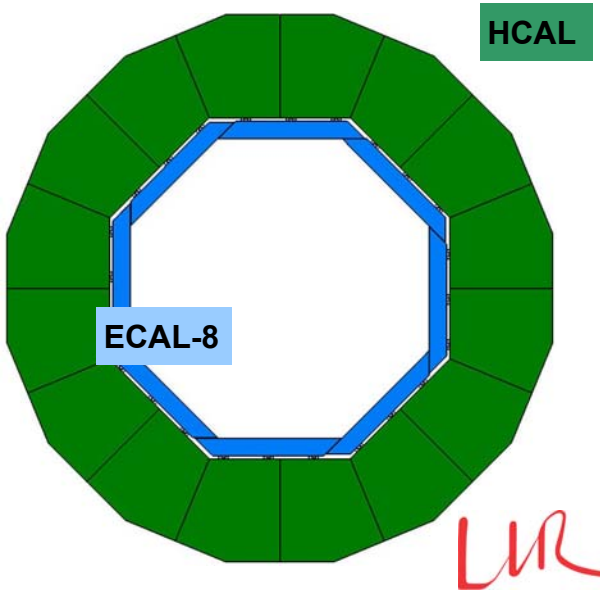
ECAL-8-3



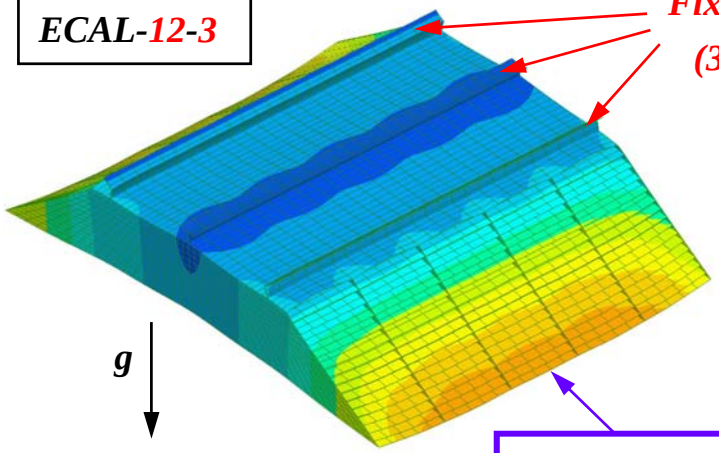


Fixing lines (3 rails)

e_{max} = 0.07 mm

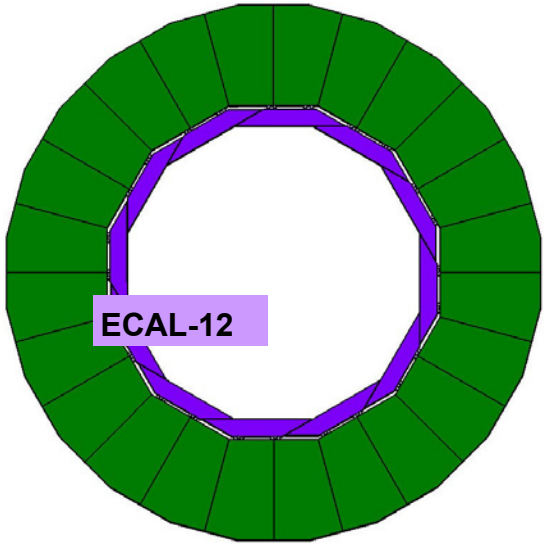


ECAL-12-3



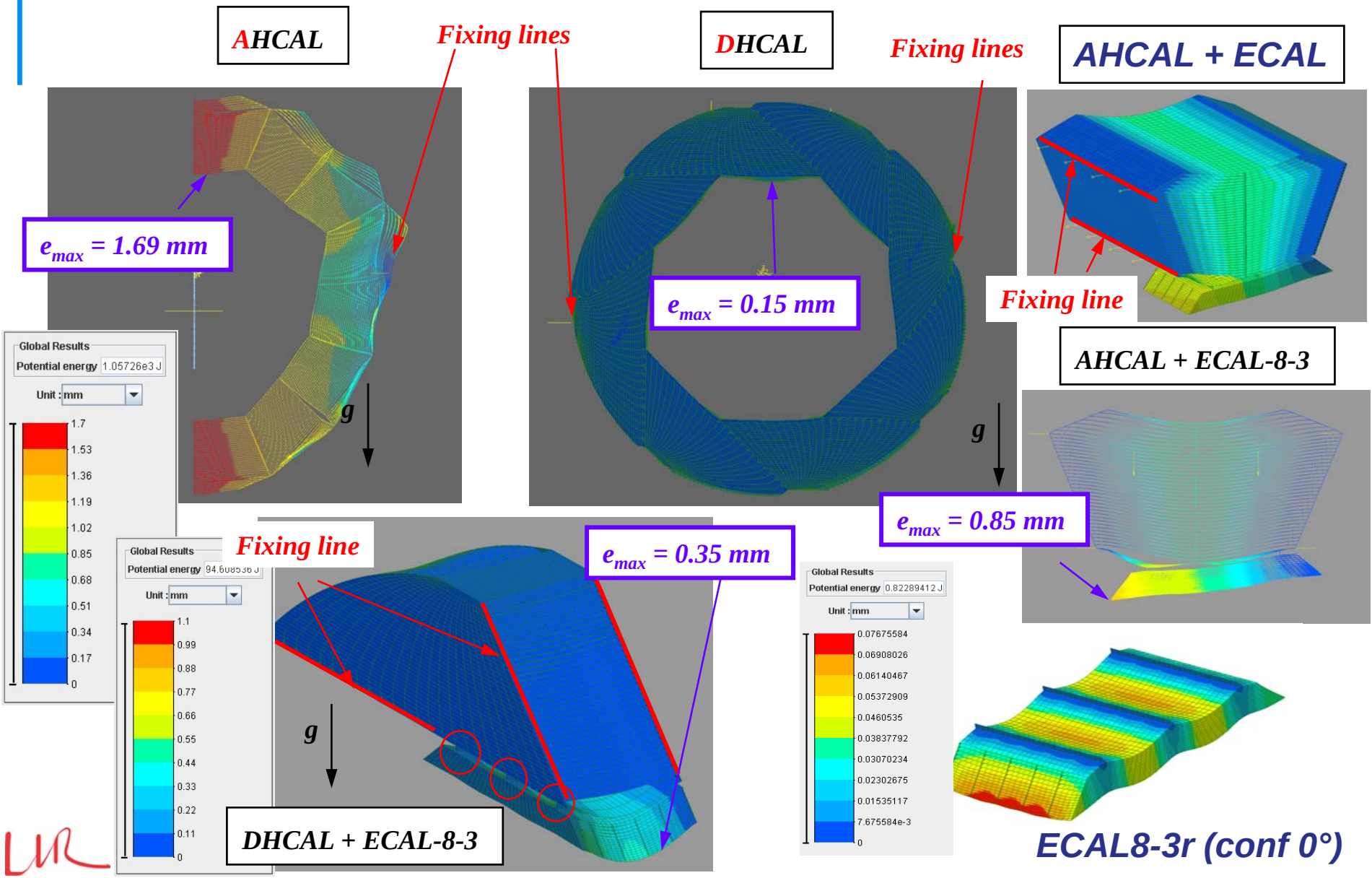
Fixing lines (3 rails)

e_{max} = 0.15 mm



12 staves design

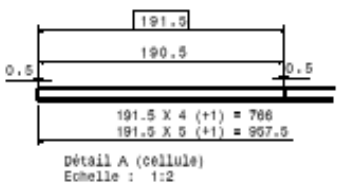
AHCAL vs DHCAL structures



ECAL - End-Caps design

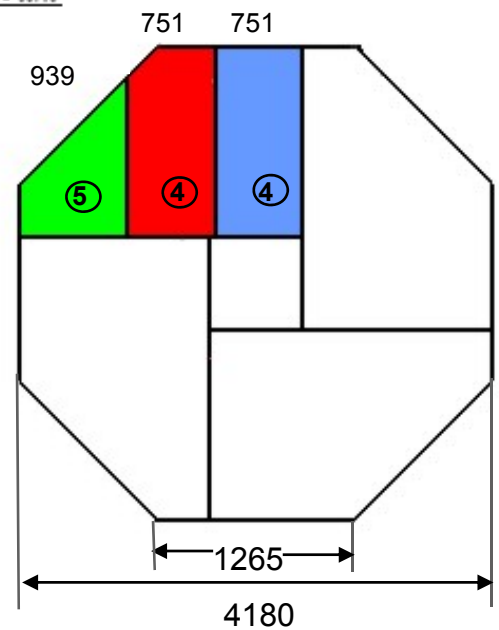
- The same principle than barrel with an alveolar composite/tungsten structure, with different shapes and different sizes (width, end of slabs)
- 12 modules-3 distinct types (~780 cells & detectors slab)

Design: *1*



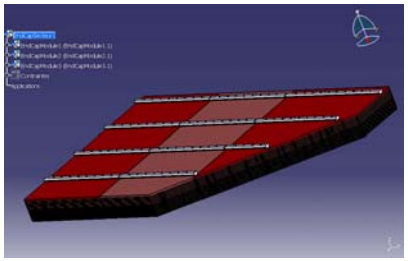
R1=2090

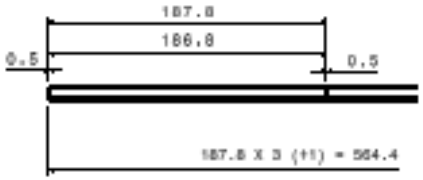
R_{barrel}=2028

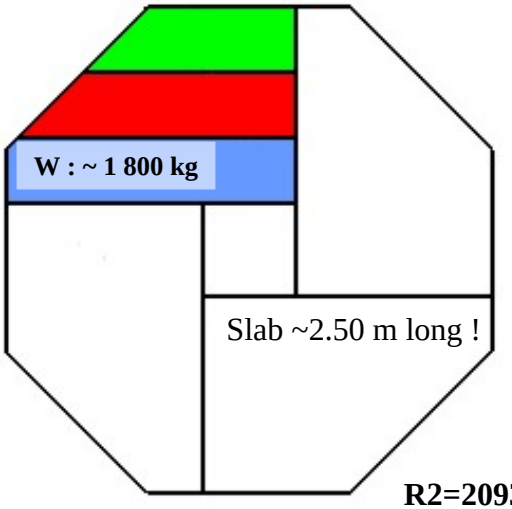


Design: *2*

- 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





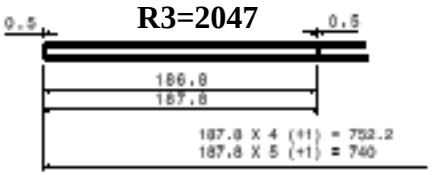


R2=2093

Difficulties:

- Thermal (2.50m instead of 1.50m for longuest):
  T° dangerously rising in back-end of slabs
- Mechanical: >2.50m long thin alveoli maybe not feasible,
- Fastening system on HCAL /weight of module >3T ?
- Different shapes of long slabs: cost increasing

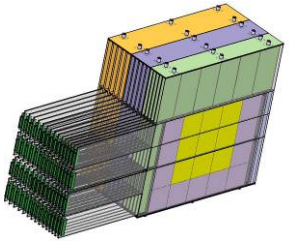
Design: *3*



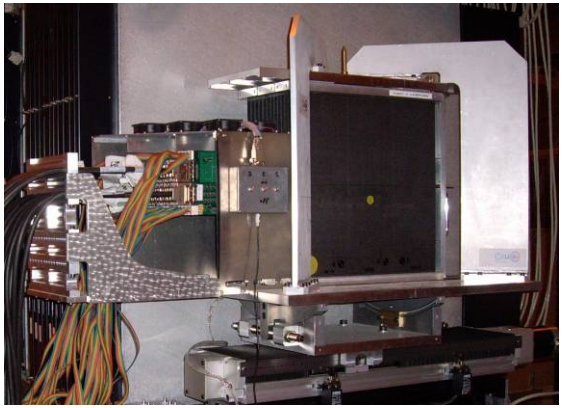
R3=2047

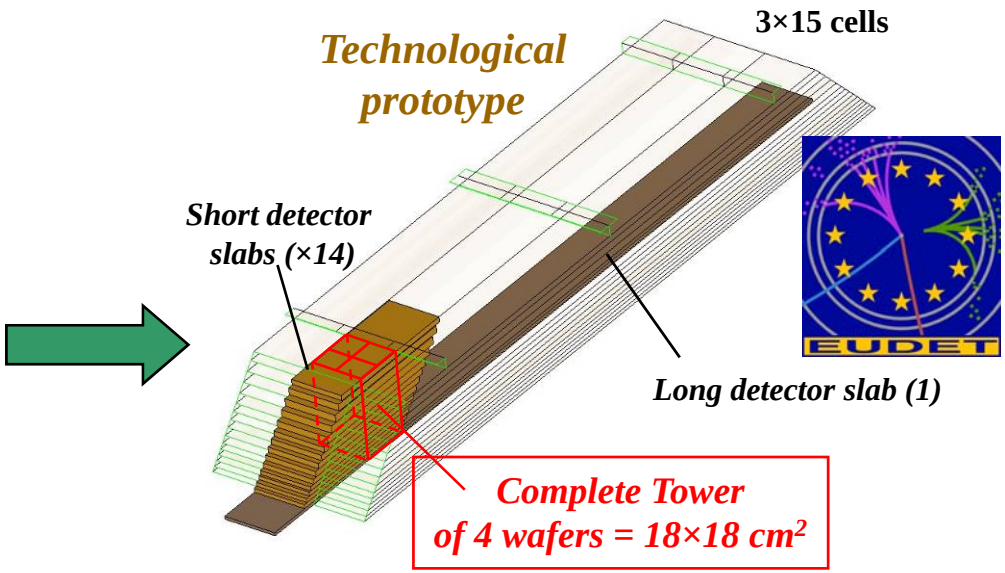
Technological prototype : EUDET module

- Logical continuation to the physics prototype study which validated the main concepts : alveolar structure , slabs, gluing of wafers, integration
- Techno. Proto : study and validation of most of technological solutions wich could be used for the final detector (moulding process, cooling system, sizes of structures,…)
- Taking into account industrialization aspect of process
- Finest cost estimation of one module



Physical prototype





- 3 structures : 24 X_0 (10×1,4mm + 10×2,8mm + 10×4,2mm)
- sizes : 380×380×200 mm3
- Thickness of slabs : 8.3 mm (W=1,4mm)
- VFE outside detector
- Number of channels : 9720 (10×10 mm²)
- Weight : ~ 200 Kg

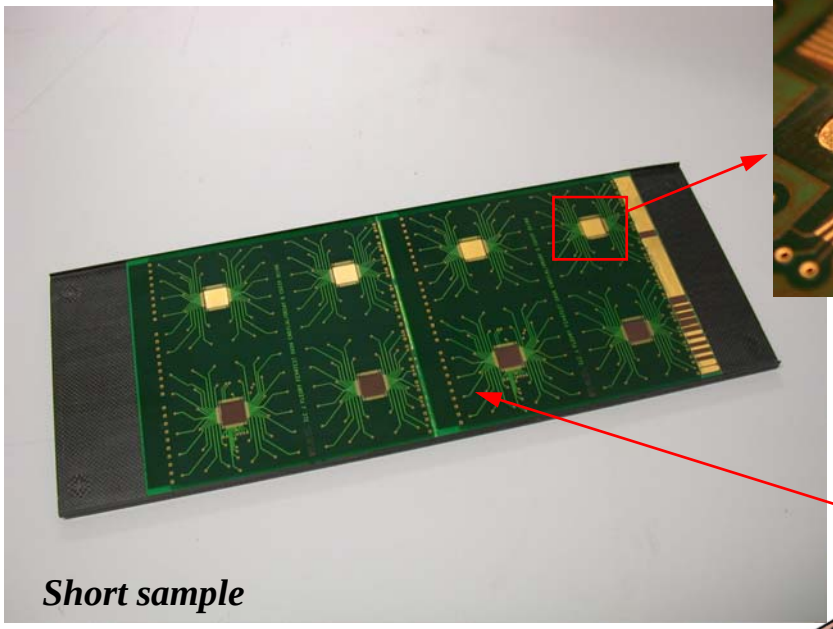
- 1 structure : ~ 23 X_0 (20×2,1mm + 9×4,2mm)
- sizes : 1560×545×186 mm3
- Thickness of slabs : 6.8 mm (W=2,1mm)
- VFE inside detector
- Number of chan. : ~37890 (5.5×5.5 mm²)
- Weight : ~ 700 Kg

Détecteur slab - principe

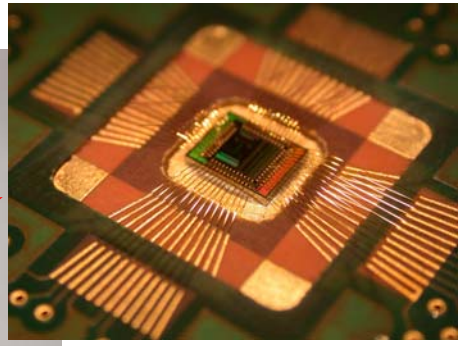
The slab is obtained with several short PCBs:

A.S.U. : Active Sensors Unit

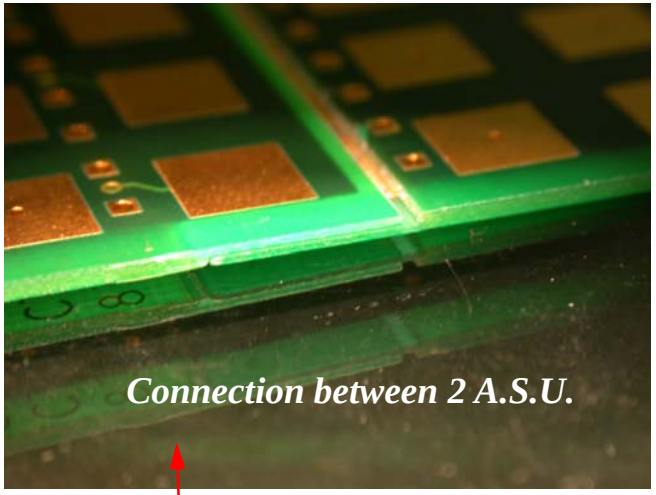
- Conception of interconnexion (gluing ?)
- Development easier : study, tests and integration of A.S.U in parallel of project
- The length of each slab is adjusted with one « end » PCB



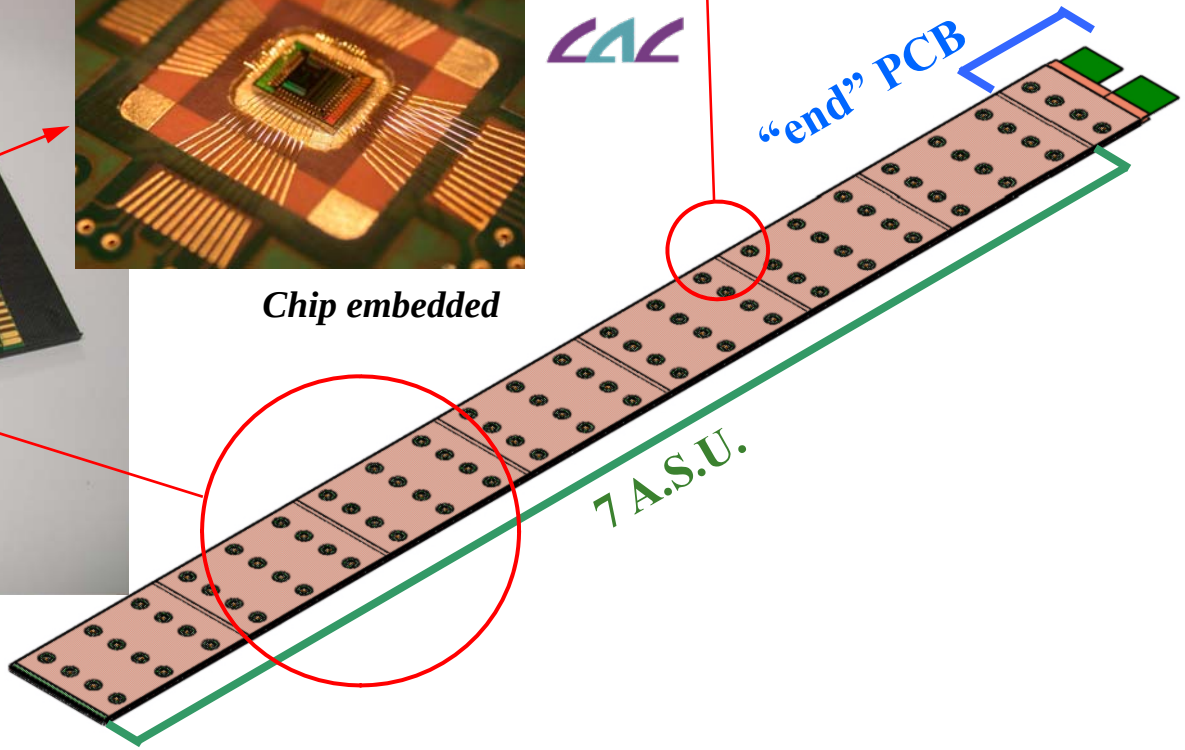
Short sample



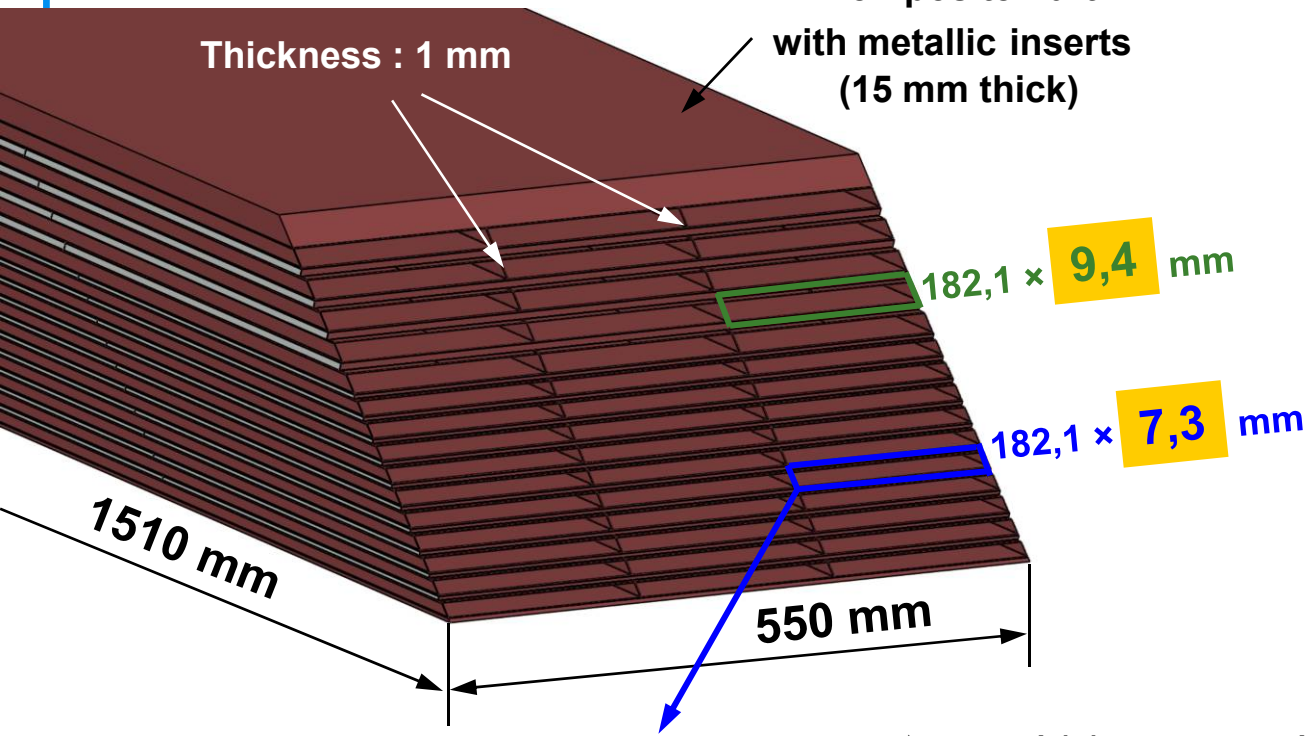
Chip embedded



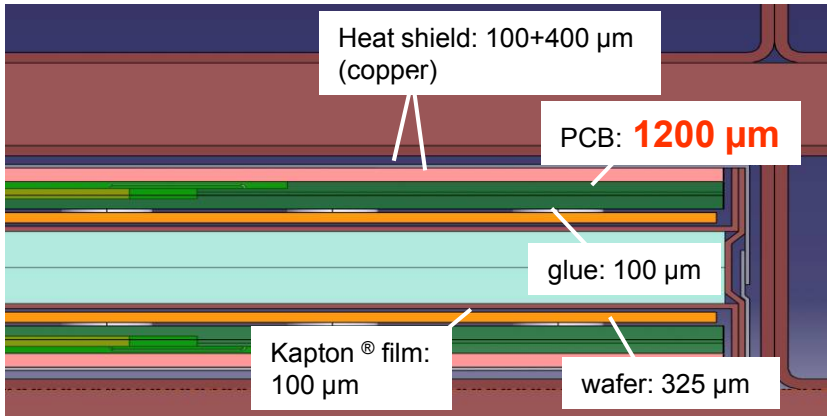
Connection between 2 A.S.U.



EUDET - Current design (final)



Thickness :
FEV5-1 : 1.17mm (+-0.04)
FEV5-2 : 1.19mm (+-0.04)
FEV5-3 : 1.20mm (+-0.02)

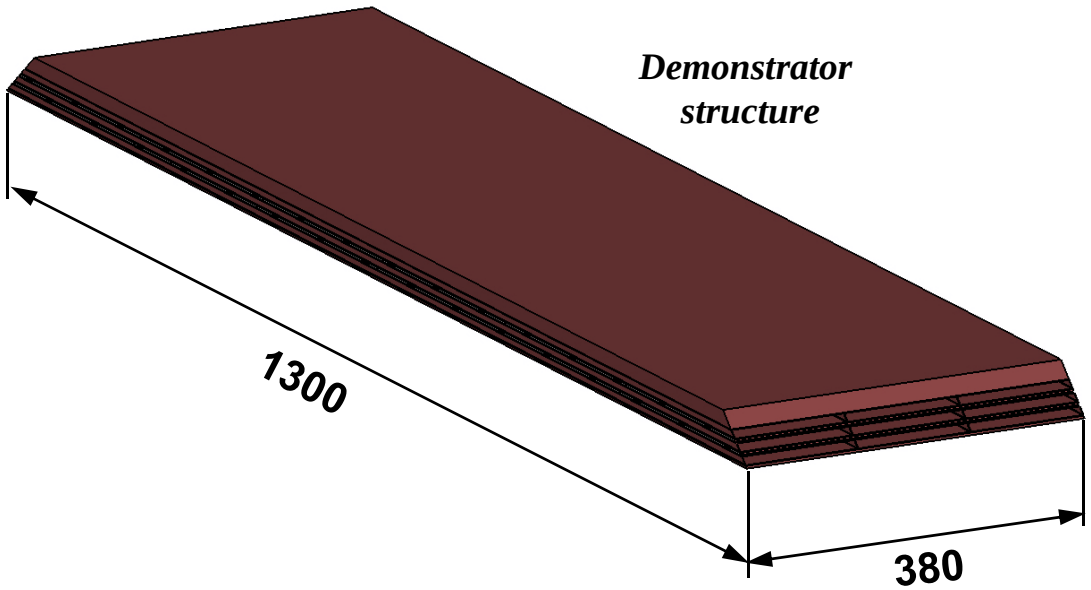


- ⇨ Gaps (slab integration) : 500 µm
- ⇨ Heat shield : **400 µm ?** Validation by the demonstrator
- ⇨ PCB : ~~800~~ µm → **1200 µm**
- ⇨ Thickness of glue : 100 µm
- ⇨ Thickness of wafer : 325 µm
- ⇨ Kapton® film HV : **100 µm ?** → Patrick's talk
- ⇨ Thickness of W : 2100/4200 µm (± 80 µm)

Demonstrator design

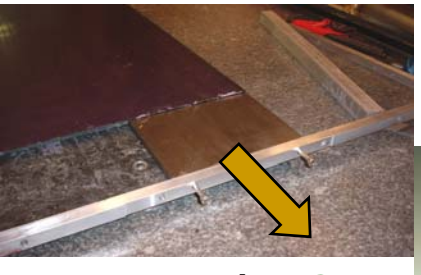
- We plan to build a first small demonstrator to validate all composite process before the EUDET module
- Width is based on physic prototype (124 mm)
- Used for thermal studies and analysis : design of a thermal PCB and cooling system.
- First test of slab integration (gluing, interconnection …)

- 3 alveolar layers + 2 W layers
- 3 columns of cells : representative cells in the middle of the structure
- Thermal studies support
- Width of cells : 126 mm
- Identical global length : 1.3m and shape (trapezoidal)
- Fastening system ECAL/HCAL



Demonstrator – Alveolar structure

Assembled structure : Each alveolar layer ❶ are done independently , cut to the right length and angle (❷) and bonded alternatively with W plates in a second curing step. The assembling is closed by 2 composite plates ❸ of 15 mm and 2 mm thick (from LPSC)



cores extraction: OK

first test of alveolar layer

Cutting tests

top composite plate (15mm)

- ⇨ Global design : ***OK***
- ⇨ 2/3 "Alveolar layer" structure ❶ : ***OK***
- ⇨ Cutting test ❷ : ***OK***
- ⇨ Composite plates (15mm and 2 mm) ❸ : ***OK***

Demonstrator – Assembly mould

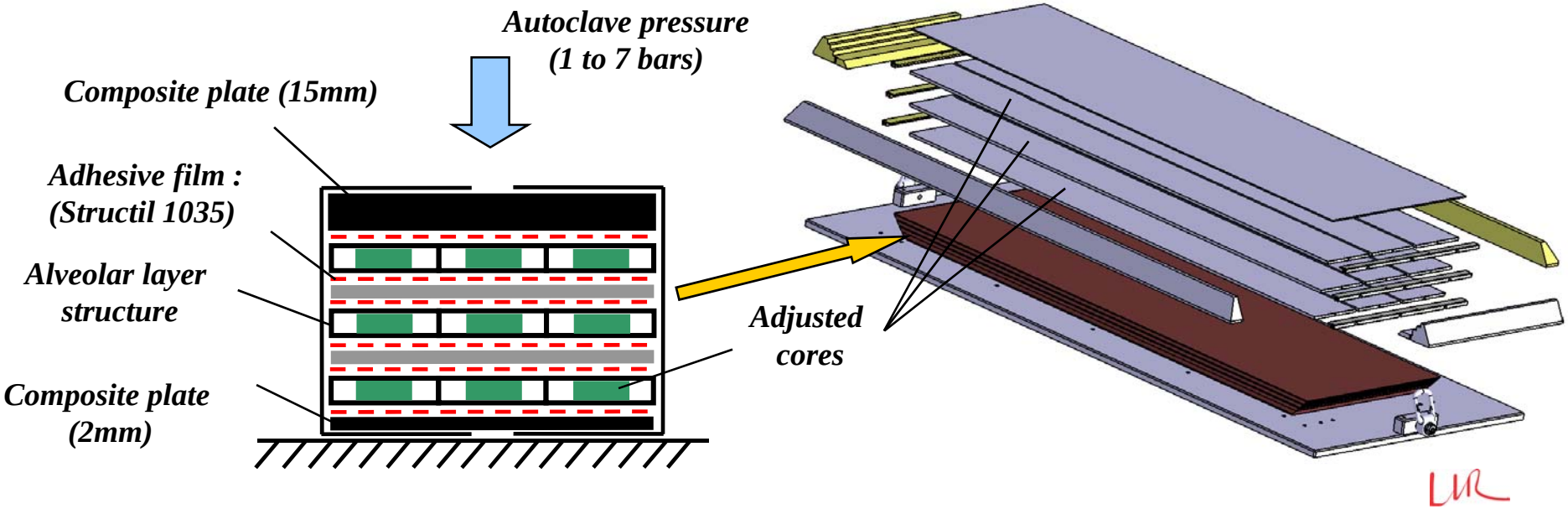
Several issues to be studied and validated yet:

- cores system for the assembly solution : use of adjusted metallic cores (in thickness) keeping each alveoli against W plates to obtain a correct assembly during the curing
- Curing parameters (thermal inertia)
- Reduce costs by changing the kind of carbon fibers
- Tests of deformation measurements by sensors embedded in the structure (optical fibers with bragg grating)

⇨ Design of mould : ***OK***

⇨ Ordered : ***OK***

⇨ W Needs : ***OK***



Mechanical tests

- Destructive tests of inter alveolar walls until breaking of interface in order to evaluate loads and elongations under Tensile and compression loading cases
- 2 kinds of carbon fibers :

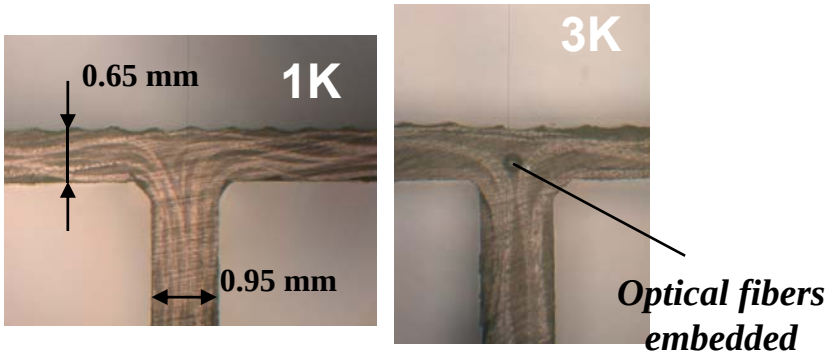
  CC120 (1K) : 0.12 mm thick ; 130€/m2

  CC202 (3K) : 0.25 mm thick ; 65€/m2

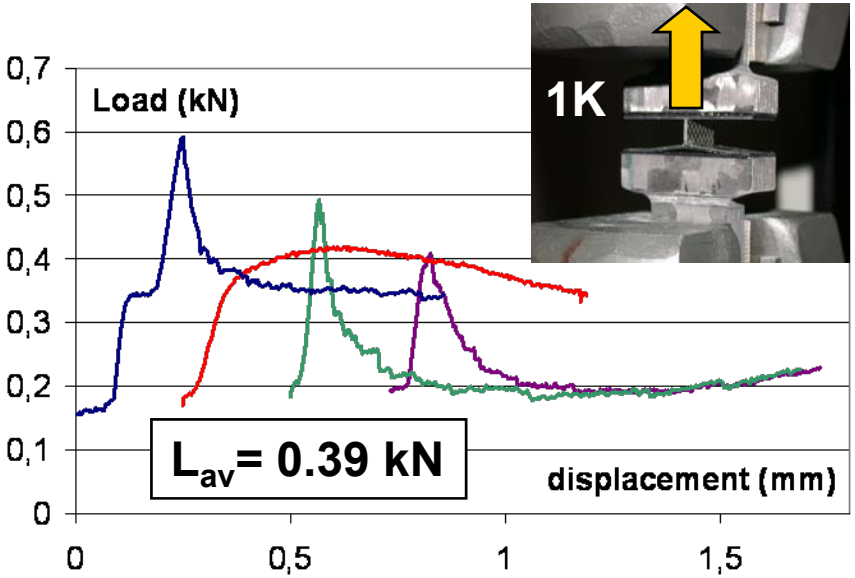
⇨ Destructive tests 1K: ***OK***

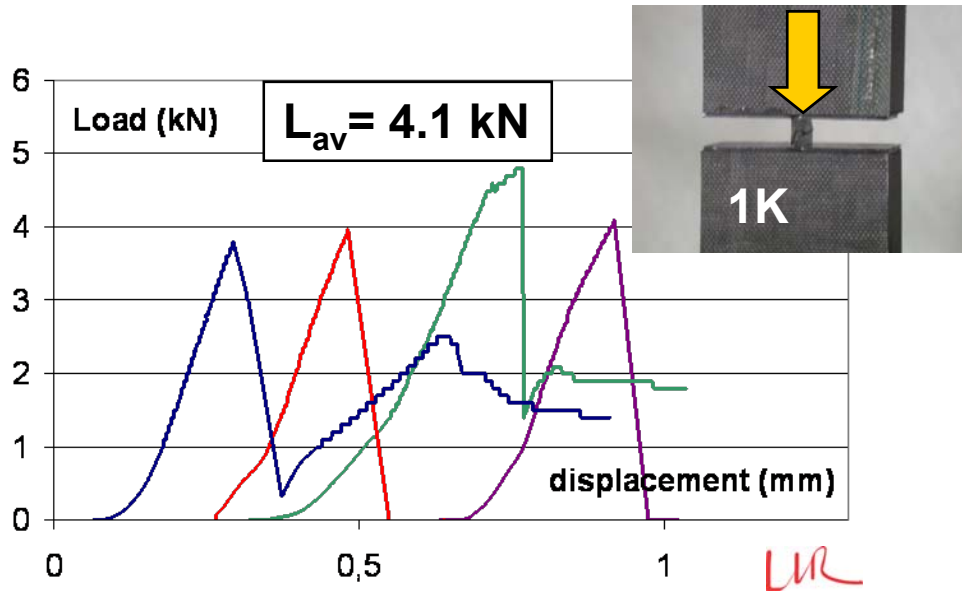
⇨ Destructive tests 3K: ***ongoing***

⇨ Measurements with optical fibers: ***ongoing***



Cross section

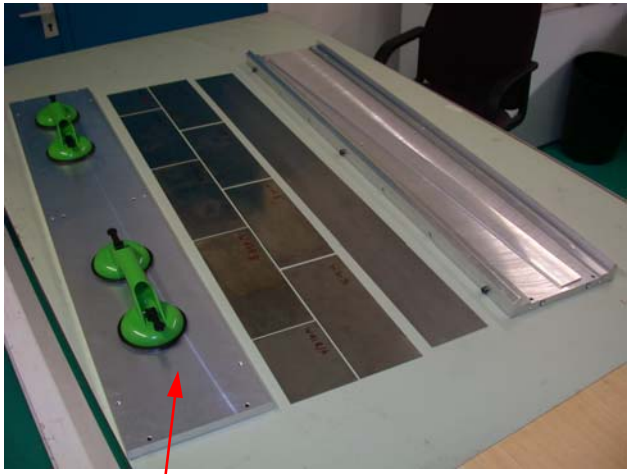




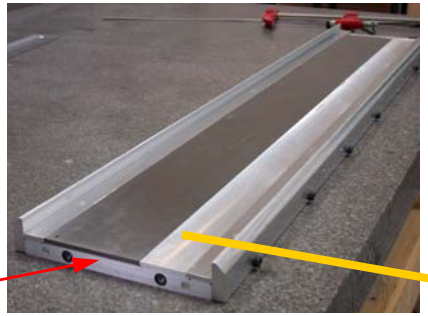
Demonstrator - H structure

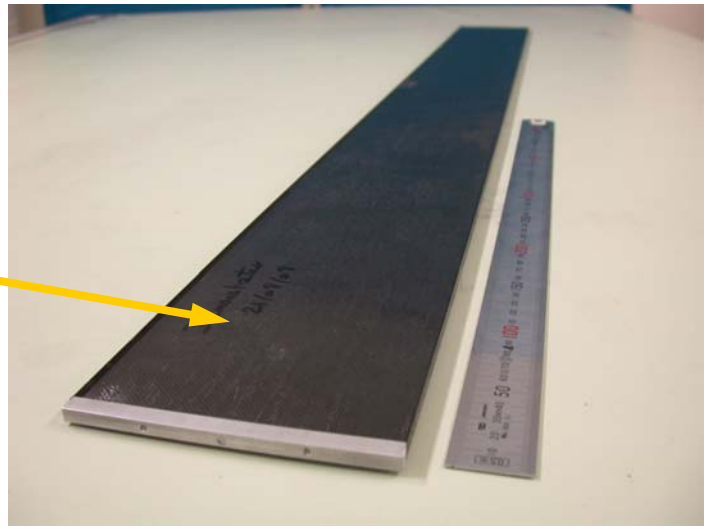
Study of one mould for whole structures:

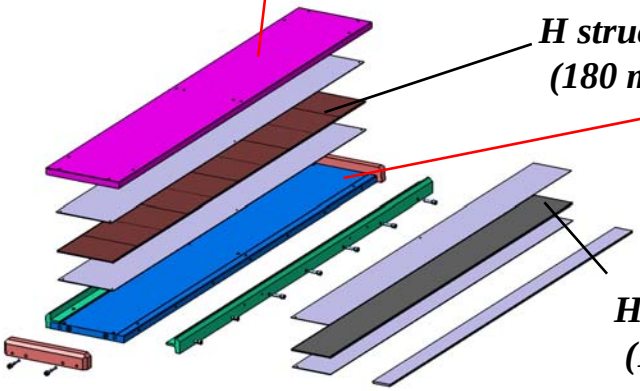
- Same principle than the mould used to do H physical prototype structures but using the autoclave)
- One long mould for both long and short H structures and 2 width (124 and 180 mm)



⇨ Design : *OK*
⇨ Mould machining : *OK*
⇨ H structure for demonstrator : *OK*







Cooling: global circulation

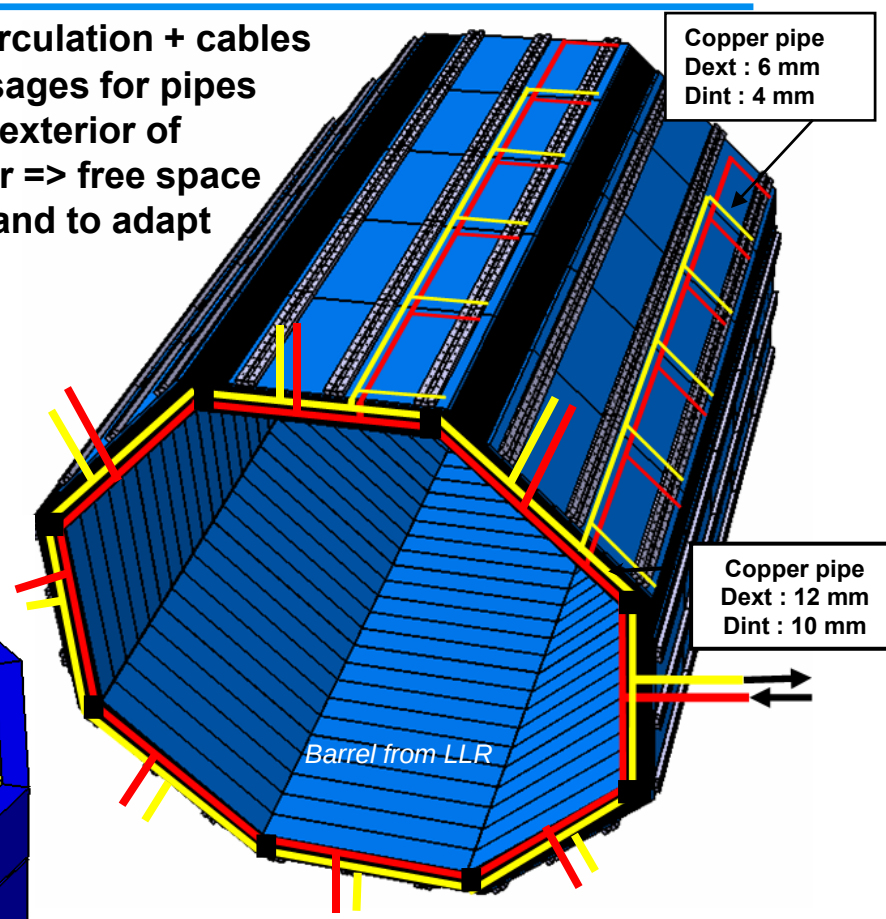
Power results :

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 moyenne 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:

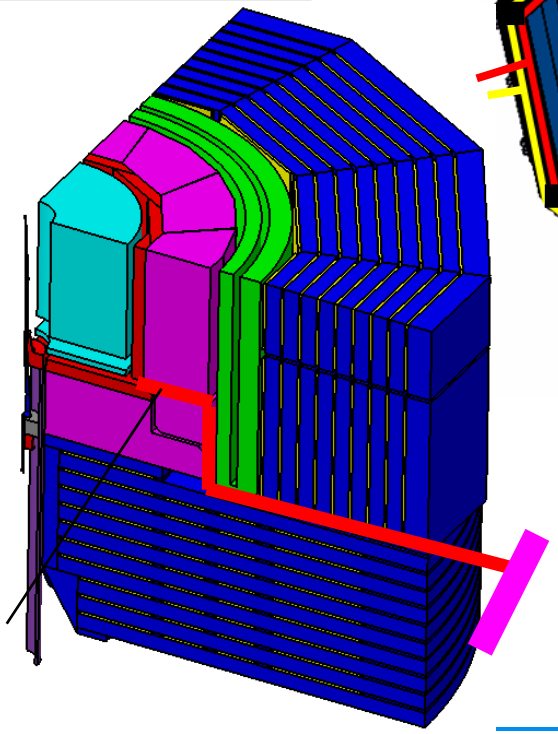
Global flow rate : 150 l/min

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

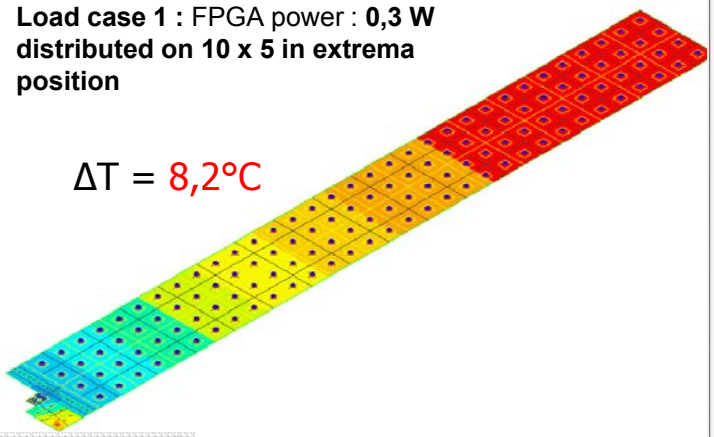
- **Passage for pipes and cables under rails (machining on composite surface)**
- **Connection of pipes according mounting procedure for modules**

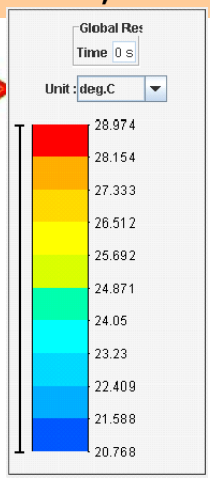
Thermal analysis of slab

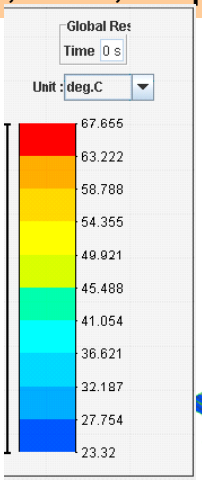
Simulation of heat conduction just by the heat copper shield : Influence of the FPGA dissipation (DIF) on current design of cooling system (Limit Condition of 20°C, with Main plate : 0.3 mm; Upper plate : 0.1 mm; L = 1,55 m; Copper layer : λ = 400 W/m/K)

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

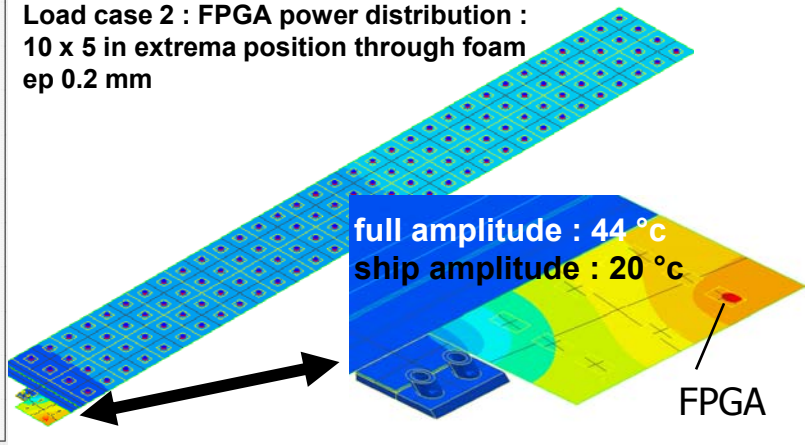
ΔT = 8,2°C



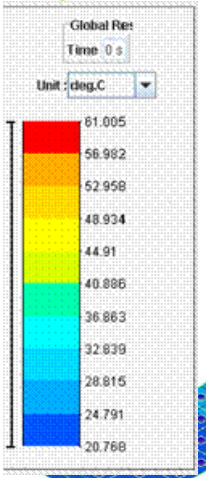




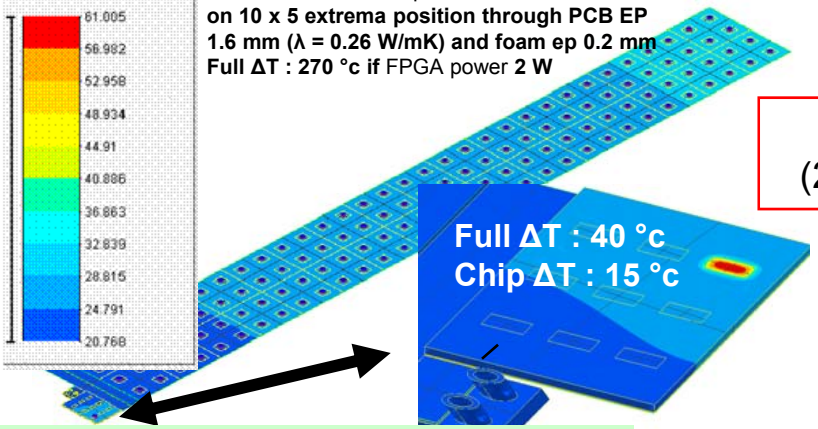
Load case 2 : FPGA power distribution : 10 x 5 in extrema position through foam ep 0.2 mm



0.3 W < FPGA < 2 W

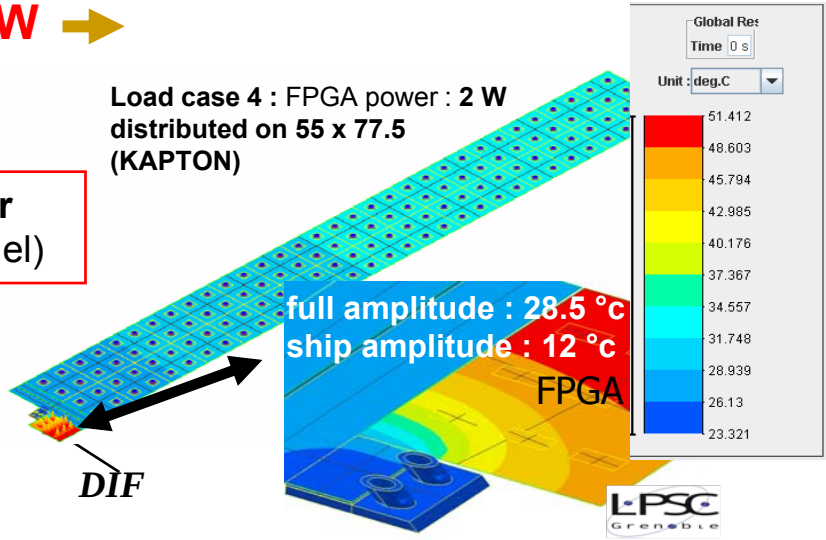


Load case 3 : FPGA power **0.3 W distributed on 10 x 5 extrema position through PCB EP 1.6 mm (λ = 0.26 W/mK) and foam ep 0.2 mm**
Full ΔT : 270 °c if FPGA power **2 W**



Φ= 0,27 W/layer
(25 µW per channel)

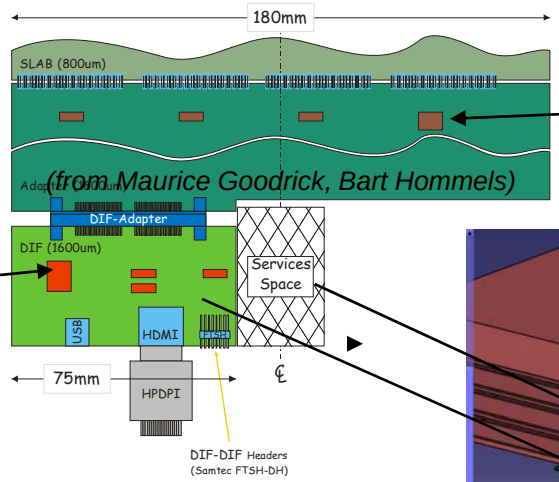
Load case 4 : FPGA power : **2 W distributed on 55 x 77.5 (KAPTON)**



…better cooling if direct contact with FPGA !

SLAB COOLING – CONSTRAINTS

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

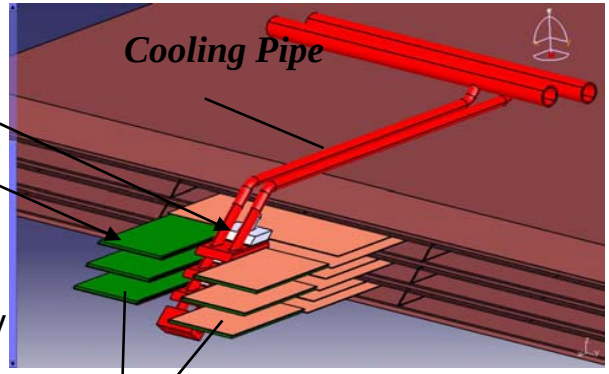


(from Maurice Goodrick, Bart Hommels)

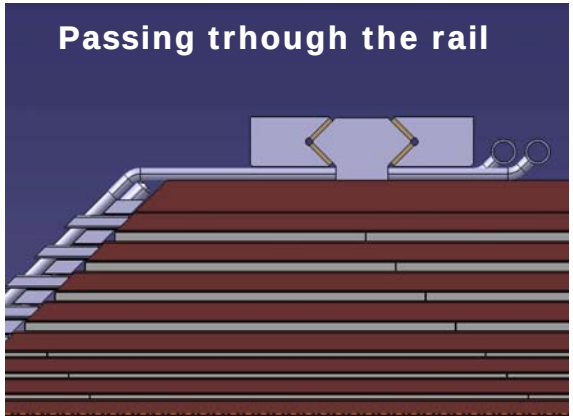
Hot points on interface card ?

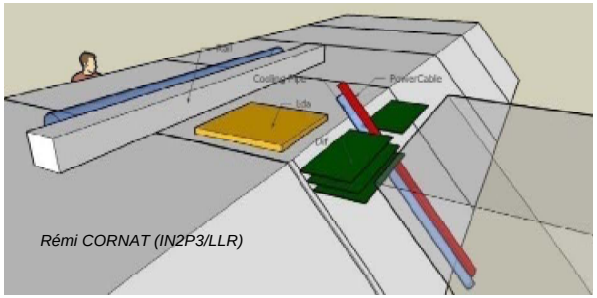
FPGA

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

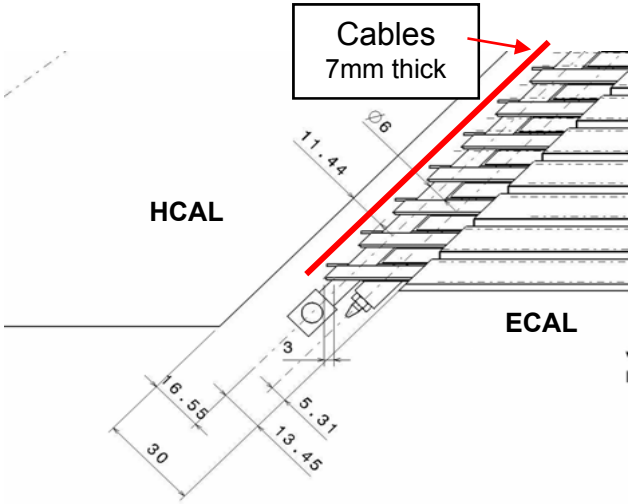


Demonstrator: cooling and copper drain extremities





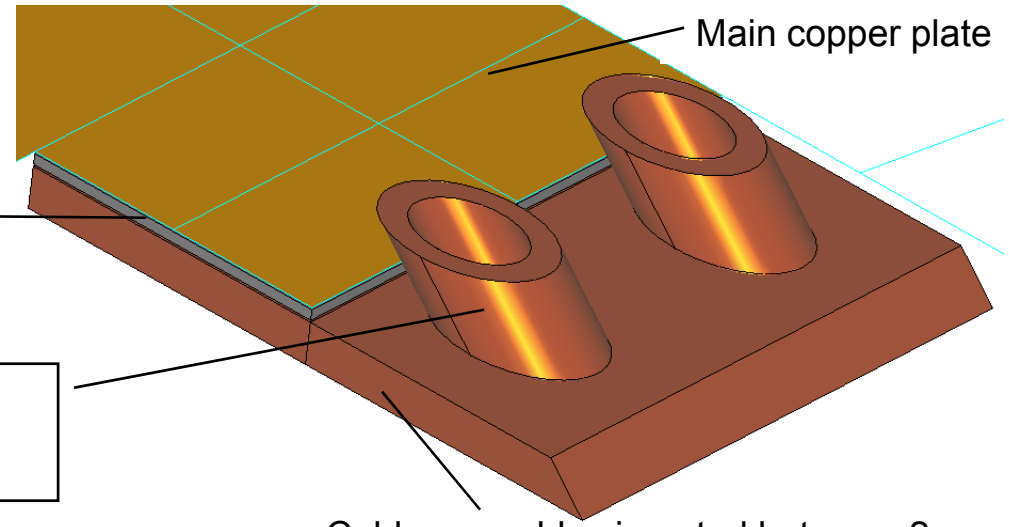
Place for cabling : DAQ + HV + GND
Service space between cooling and HCAL >1cm



Space for HV and GND

SLAB COOLING - EUDET

Boundary condition:

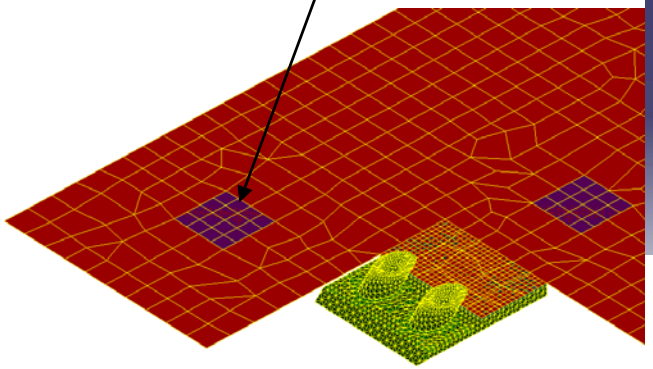


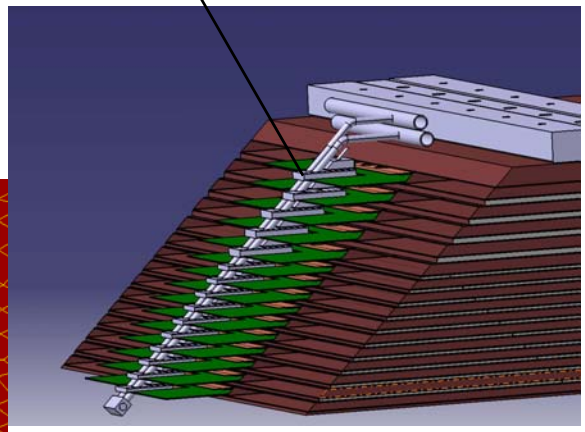
Load (for 1 half slab = 1 side)
Channel heat flux : 25 µW
Number of channel / chip : 64 (Hardroc)
Number of chip / wafer : 4
Number of wafer on ½ SLAB : 32

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…

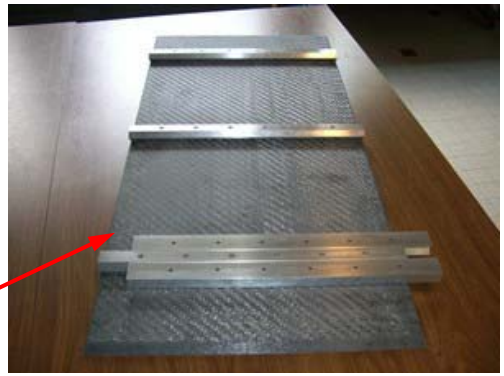




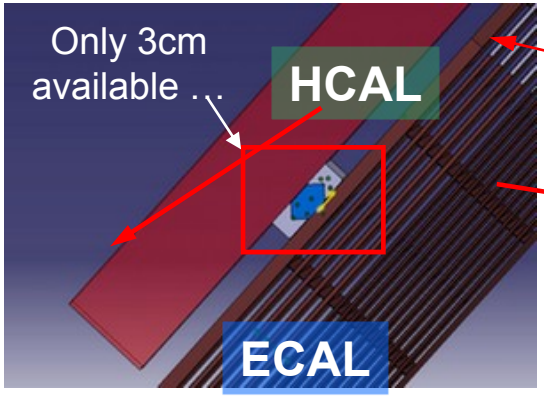
Fastening & cooling system

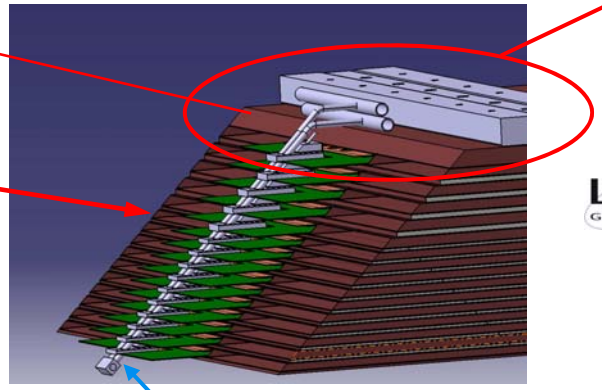
•Choice of fasteners : aluminum rails screwed through the medium of inserts. Non magnetic (B=4T !)

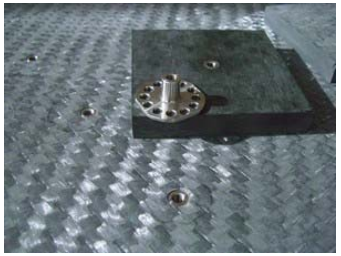
Design of connection system : each cooling system ❶ is inserted and screwed to each column of slab with a thread rod and spacers (❷) and connected to the cooling network in a second step ❸.



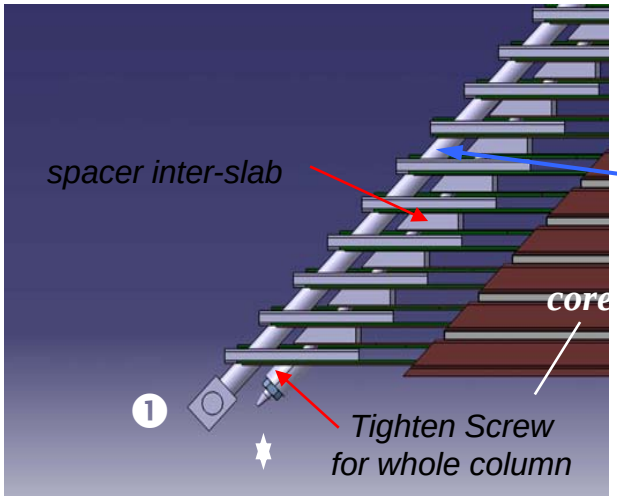
15mm thick plate with it's rails; ready to be assembled with alveoli layers





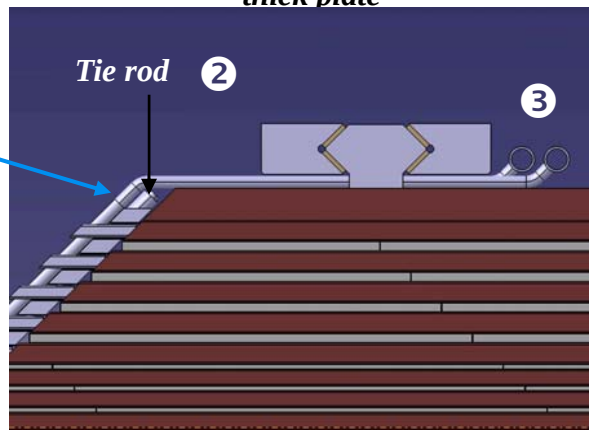


Uniform dispatch of 18 inserts on the 15mm thick plate

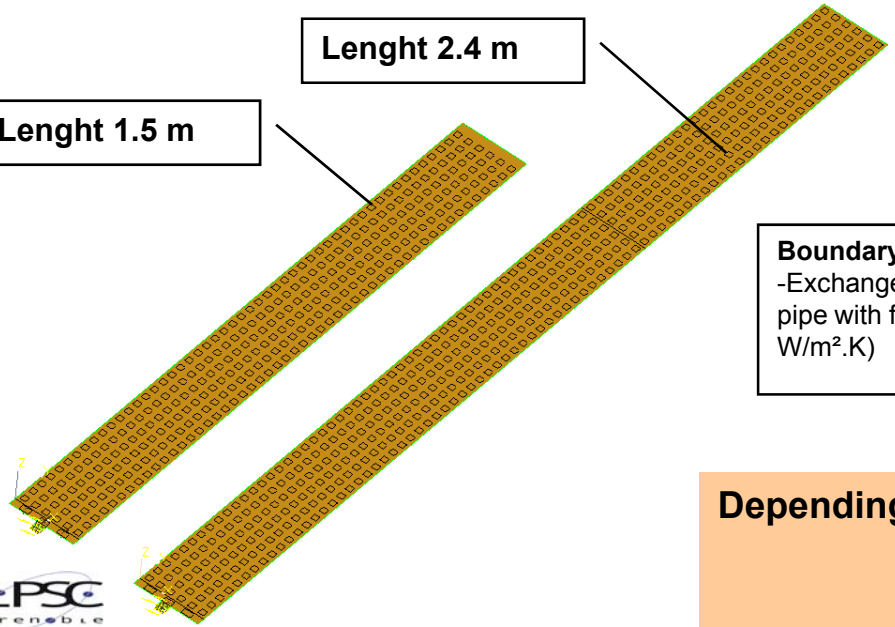


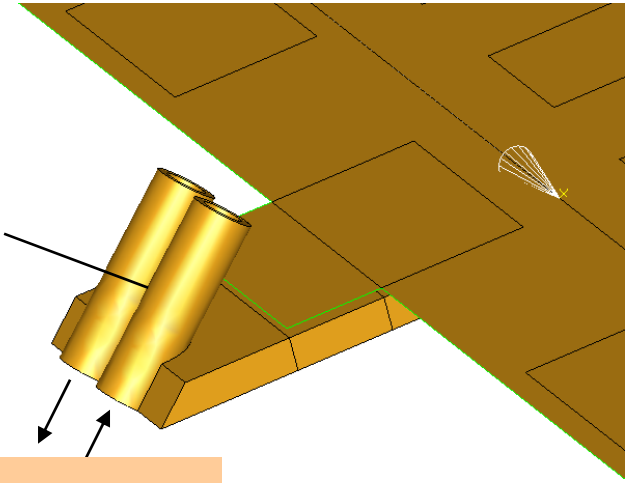
A column (cooling pipe), (25 mm wide minimum) to ensure quick thermal system's connection

Cold copper bloc inserted between 2 copper plates of each slab



Cooling 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

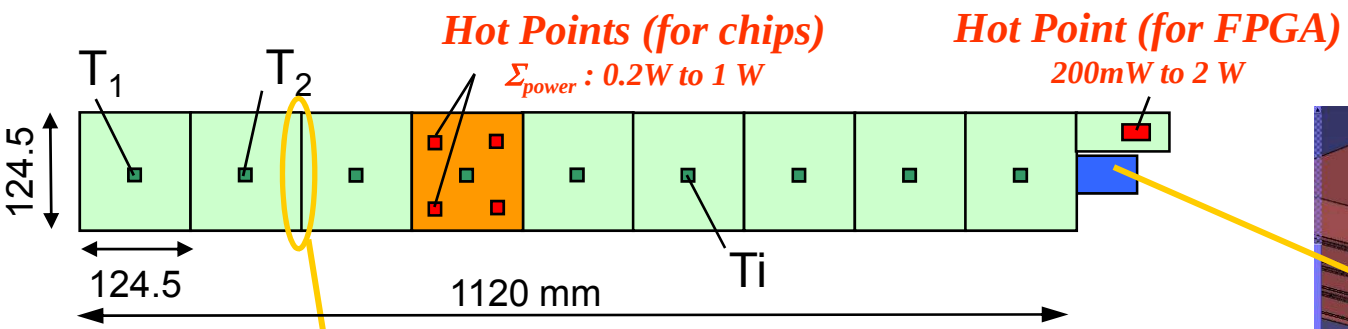
	SLAB : 1,5 m						SLAB : 2,4 m						
FPGA	with			without			with			without			
Temperature (°c)	Tmin	Tmax	Difference	Tmin	Tmax	Difference	Tmin	Tmax	Difference	Tmin	Tmax	Difference	Comments
Exhange coefficient inside pipe and fluid temperature of 20°c	21,4	42,8	**21,4**	20,1	28,1	**7,9**	21,5	50,2	**28,7**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

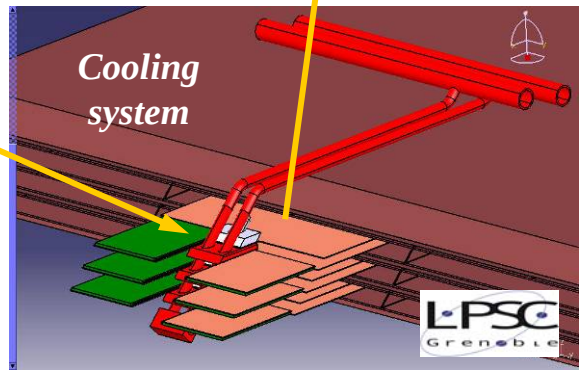
Demonstrator – Thermal studies

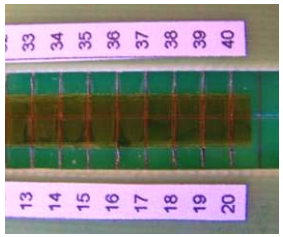
Slab cooling tests (1 Hot ASU + 8 thermal ASU):

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

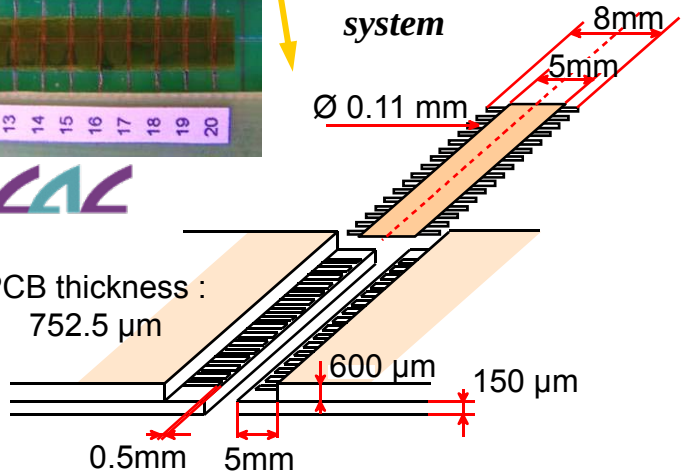
Copper (400 µm)





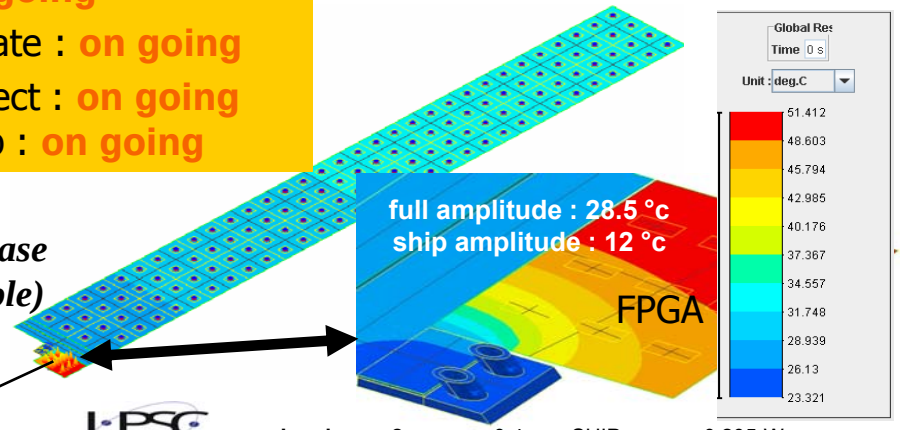


Simple interconnect system



- ⇨ Design : *OK*
- ⇨ Simulations : *OK*
- ⇨ PCB : on going
- ⇨ Copper plate : on going
- ⇨ Interconnect : on going
- ⇨ Exp. setup : on going

Load case (exemple)

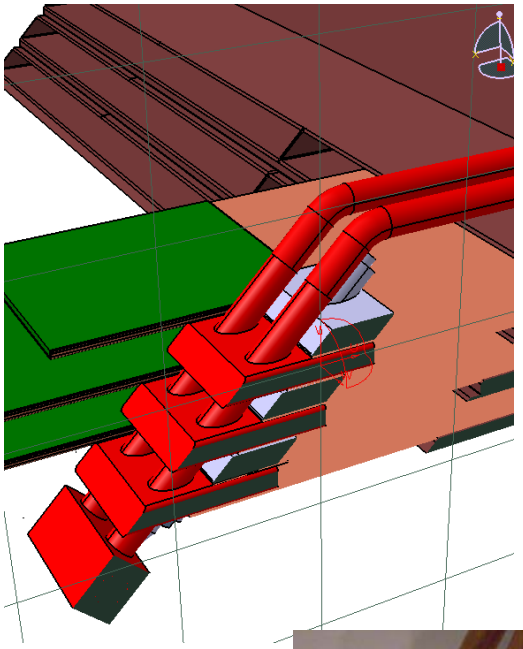


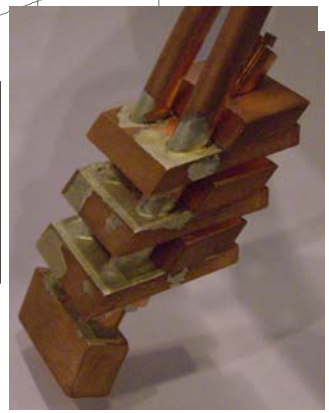
Load case 2 : copper 0,4mm; SHIP power : 0.205 W; FPGA power : **2 W distributed : 55 x 77.5 (KAPTON)**

SLAB COOLING - DEMONSTRATOR

Cold plate : 3 Solutions

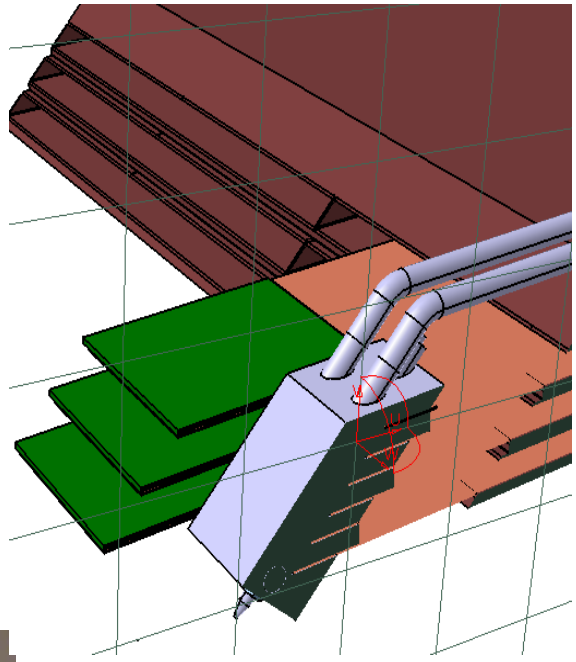
❶ Assembled solution





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

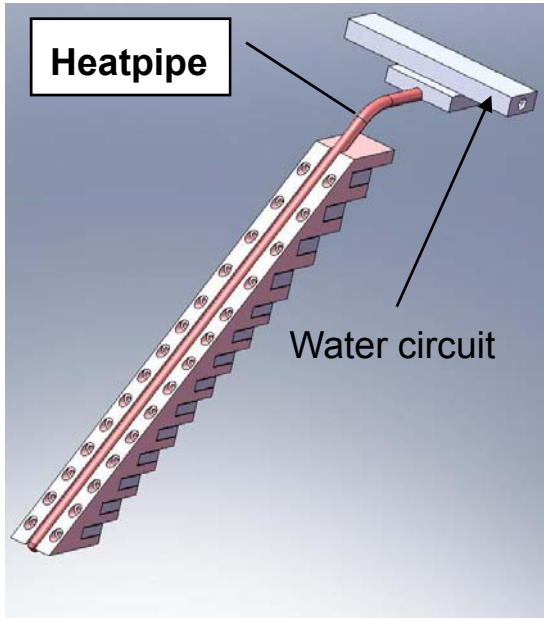
❷ Machining solution



- 1 block with water circulating into copper pipe (Internal diameter : 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

Organisation pour EUDET

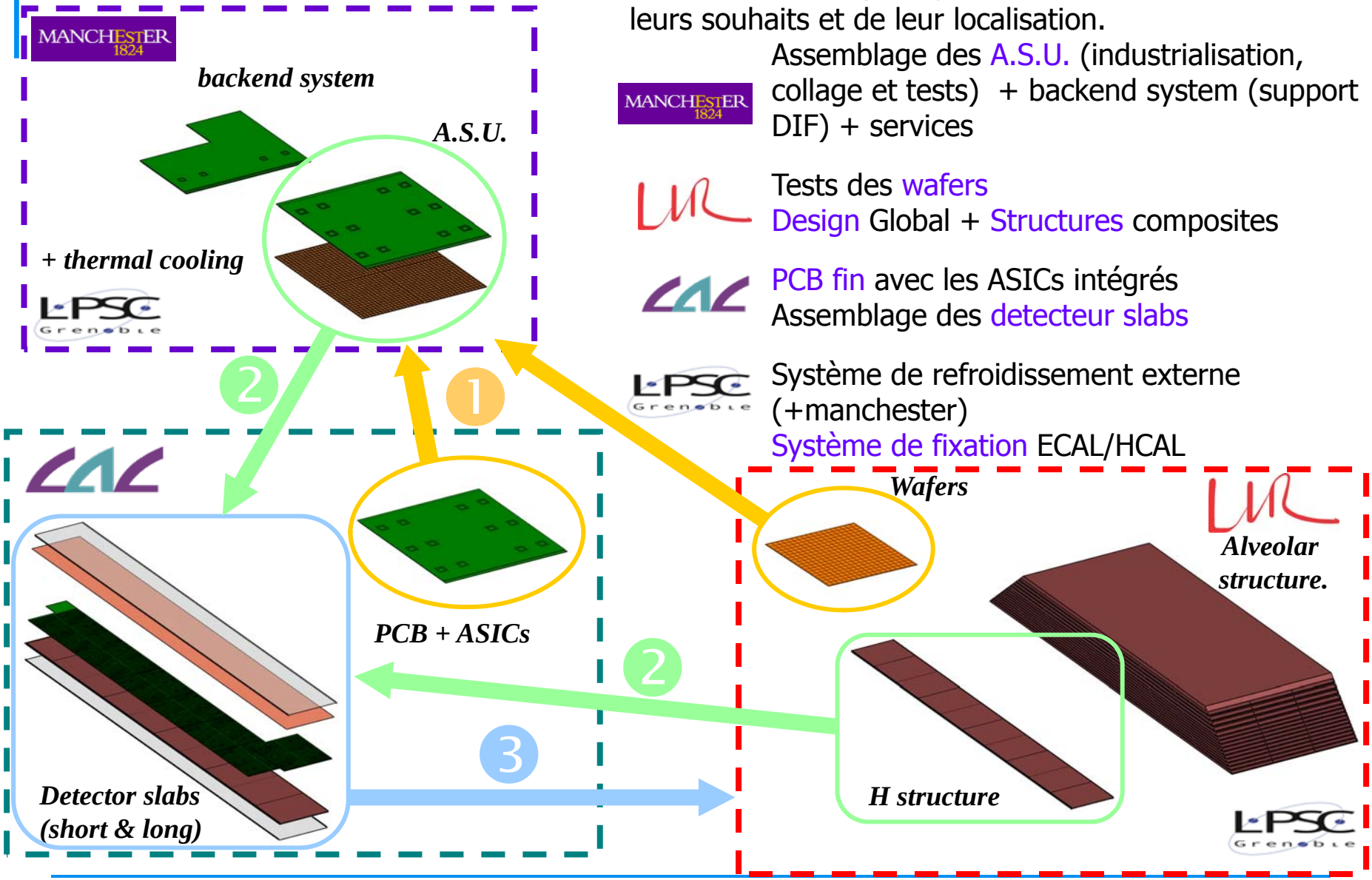
4 Laboratoires partagent les taches en fonction de leurs souhaits et de leur localisation.

Assemblage des A.S.U. (industrialisation, collage et tests) + backend system (support DIF) + services

Tests des wafers
Design Global + Structures composites

PCB fin avec les ASICs intégrés
Assemblage des detecteur slabs

Système de refroidissement externe (+manchester)
Système de fixation ECAL/HCAL



Conclusion : Schedule

Demonstrator

H structure	Aug 08
2/3 "alveolar layer" structures - Reception of the Cooling setup	Nov 08
Carbon fibers choice & destructive tests	Dec 08
Reception of the Assembly mould	Jan 09
Third alveolar layer with sensors embedded (& tests)	Jan 09
Slab cooling_tests & the 3 cooling systems	Jan 09
Demonstrator (3 layers) assembled - Optimization of cooling simulations	Fev 09

EUDET

"Alveolar layer" mould ordered	Nov 08
Cooling system for EUDET & thick composite plates	Dec 08
"Assembly mould" design (with thermal curing studies)	Fev 09
Alveolar layers & H production	Mar 09
Eudet structure assembled	Jun 09

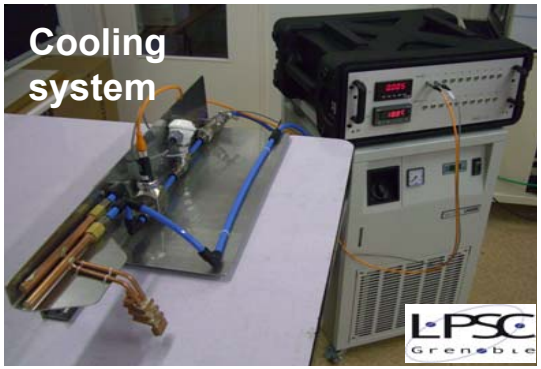
ILD

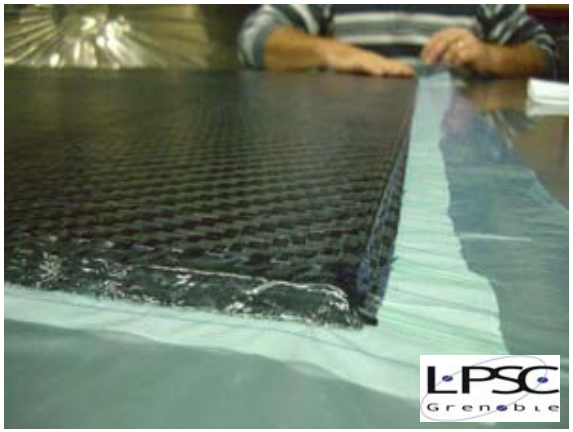
on going

- Barrel + End-cap + ECAL Ring **design** & mechanical simulations
- Moulds for 1 layer of End-cap module n°2 and **optimization of composite elements**
- Design for the **whole** detector **cooling system**
- **Fastening system** ECAL/HCAL: alternative for thick composite plates and rails **...**

Thank you for your attention

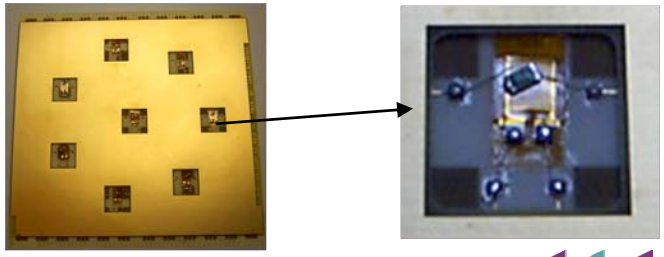
ILD - ECAL Mechanical R&D





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

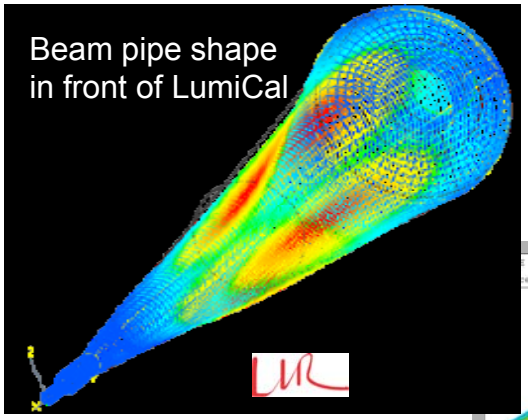
THERMAL PCB…

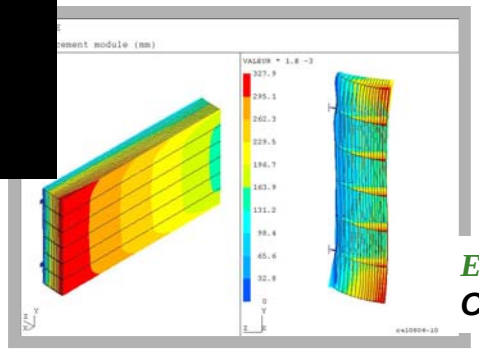


PCB FEV_HEATERS

15mm thick plate with rails

400µm thick & 180 mm larg copper heat shield





End-Cap module
Configuration 90°