Laboratoire Leprince Ringuet
Ecole polytechnique - Palaiseau

# – ECAL W/Si –

## *Physics Prototype*

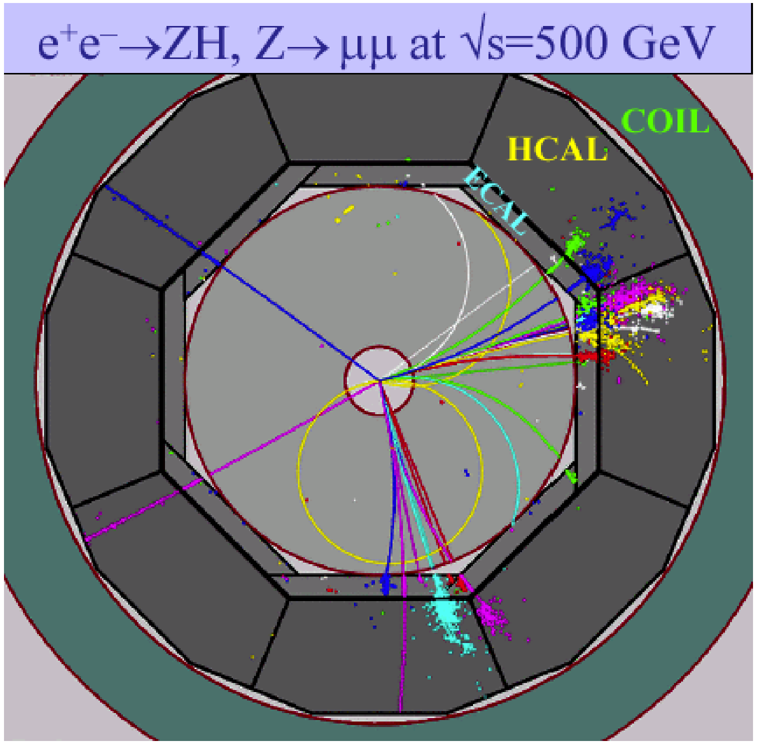
*(CAlorimeter for the LInear Collider Experiment)*

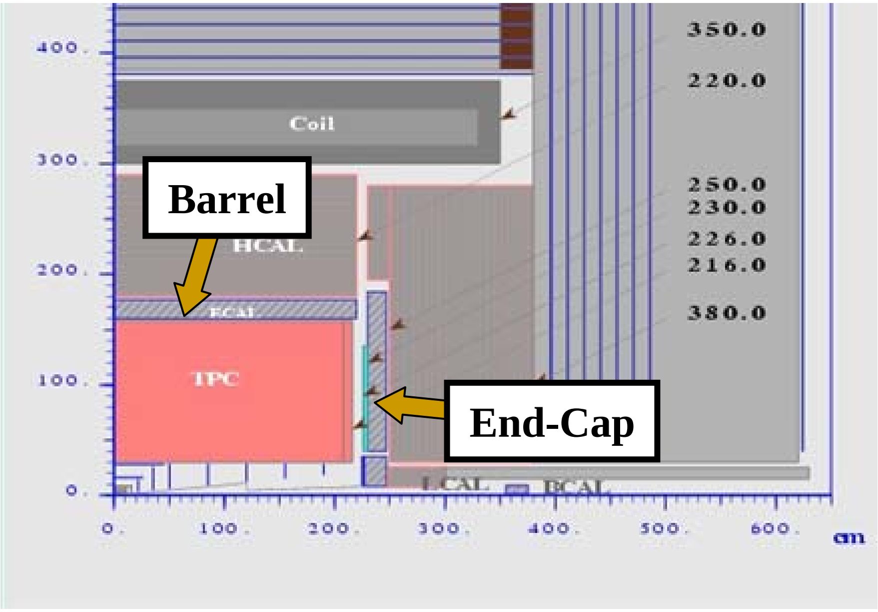
*Marc Anduze* – 18/06/2009

# Introduction

- The CALICE Collaboration is a research and Design group (53 institutes – 16 countries) working to develop new, high performance detectors for high energy $e^+e^-$ experiment (ILC)
- Design of 2 adapted calorimeters (ECAL & HCAL) for a PFA approach :

Every individual particle in the final state is reconstructed

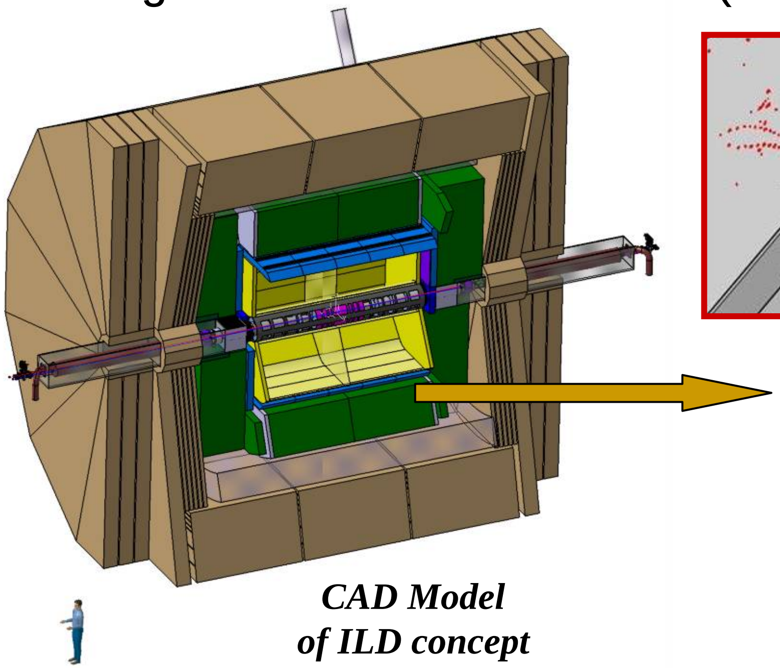


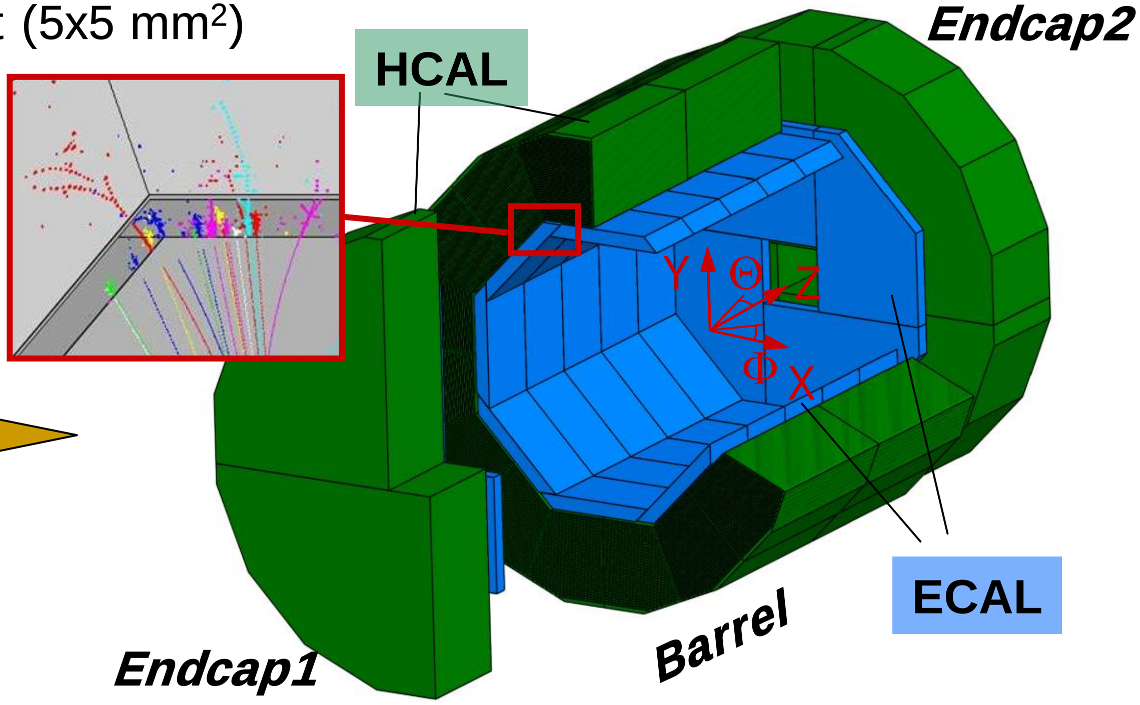

High granularity (tracking)
and compact ECAL
High Hermeticity of detectors

# ILD - Calorimeter concept

- The calorimeter of ILD is divided in depth in an electromagnetic section (**ECAL**), and a hadronic section (**HCAL**)
- The two parts are installed inside the coil to minimize the inactive material in front of the calorimeters. To follow the symmetry imposed by the beams and the coil, the electromagnetic calorimeter is divided into a cylindrical barrel and two end-caps.
- The ECAL barrel consists of 40 identical trapezoidal modules of tungsten absorber plates (80 t) interleaved with layers of Silicon detectors with very fine segmentation of the readout (5x5 mm$^2$)

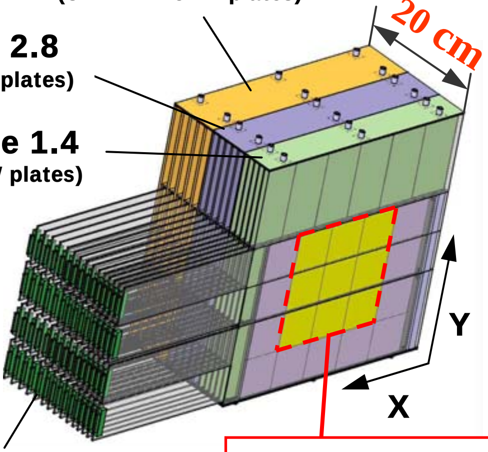


*CAD Model of ILD concept*

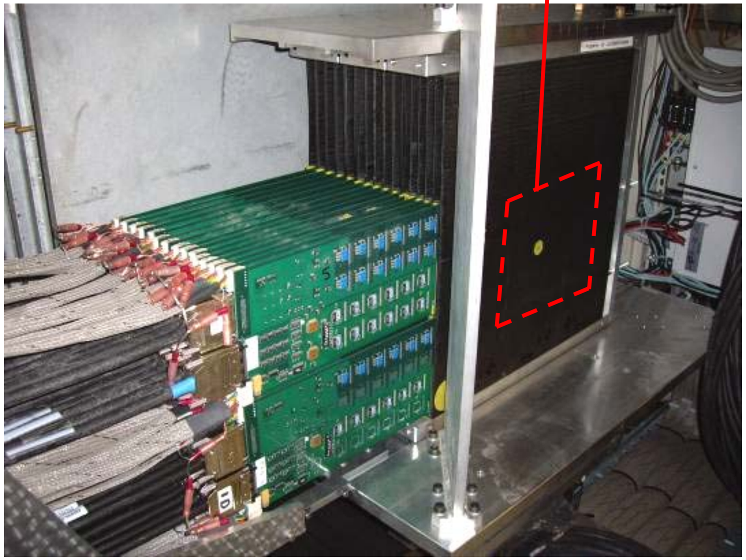


# *Physics Prototype (2002-2005)*

- Multilayer calorimeter as compact as possible (small Molière radius)
- Sampling of W in depth according to the need of energy resolution : 24 $X_0$
- Half of the tungsten plates is incorporated into a supporting alveolar composite structure (carbon) to avoid machining step and reduce dead zone
- Half of W plates supports (H-shaped structure) 30 detection units, called detector slab, which are then slid inside each cell

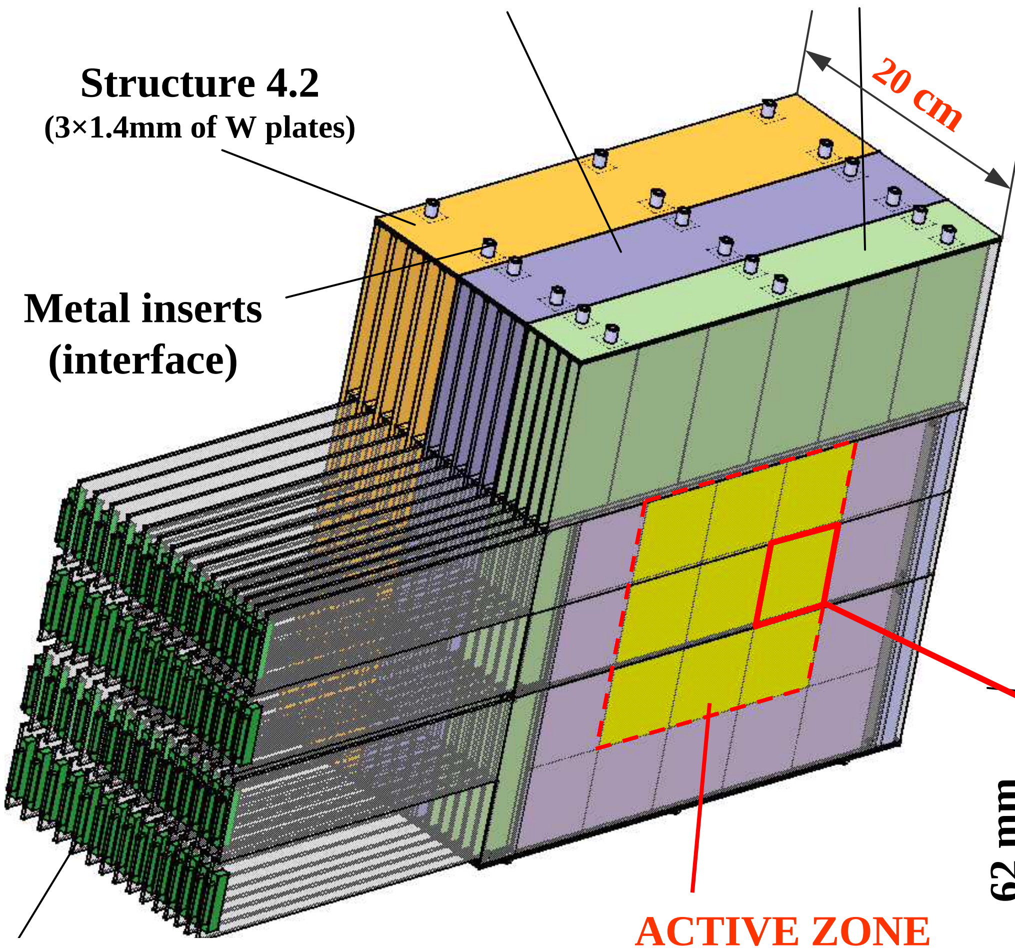



*Active zone*
*~10000 pixels in 0.01 $m^3$*



- **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**
  **(pixel size :10×10 $mm^2$)**
- **Weight : ~ 200 Kg**

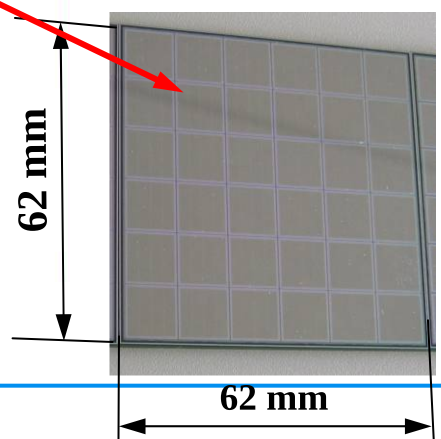
# *Physics Prototype (2002-2005)*




<u>Multi-layer (30) W-Si Prototype :</u>

- 3 independent C-W alveolar structures according to the thickness of tungsten plates
- 30 detector slabs which are slid into central and bottom cells of each structure
- Active zone : 3×3 silicon wafers (180×180 mm²)

➡ **9720 pixels**




**270 Wafers**

**6×6 pads (10×10 mm²)**

**150 MSU (Russie)**

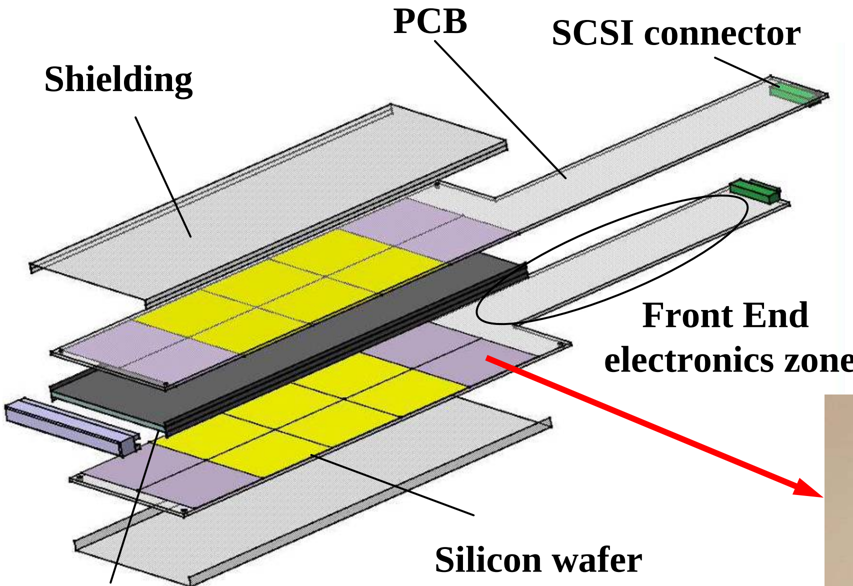
**150 IOP (R. Tchèque)**

# Detector Slab

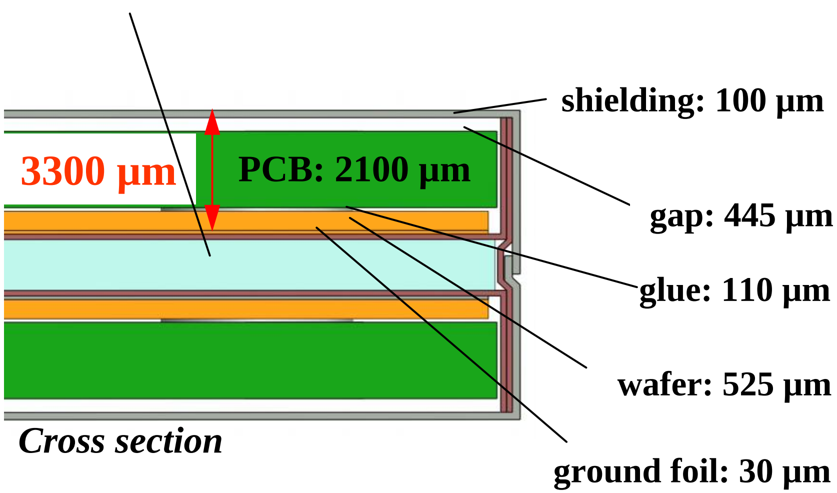
Detector Slab :

- 1 H-shaped structure including W plate
- 2 PCB with 6 wafers glued
- 1 Aluminium shielding (0,1 mm)

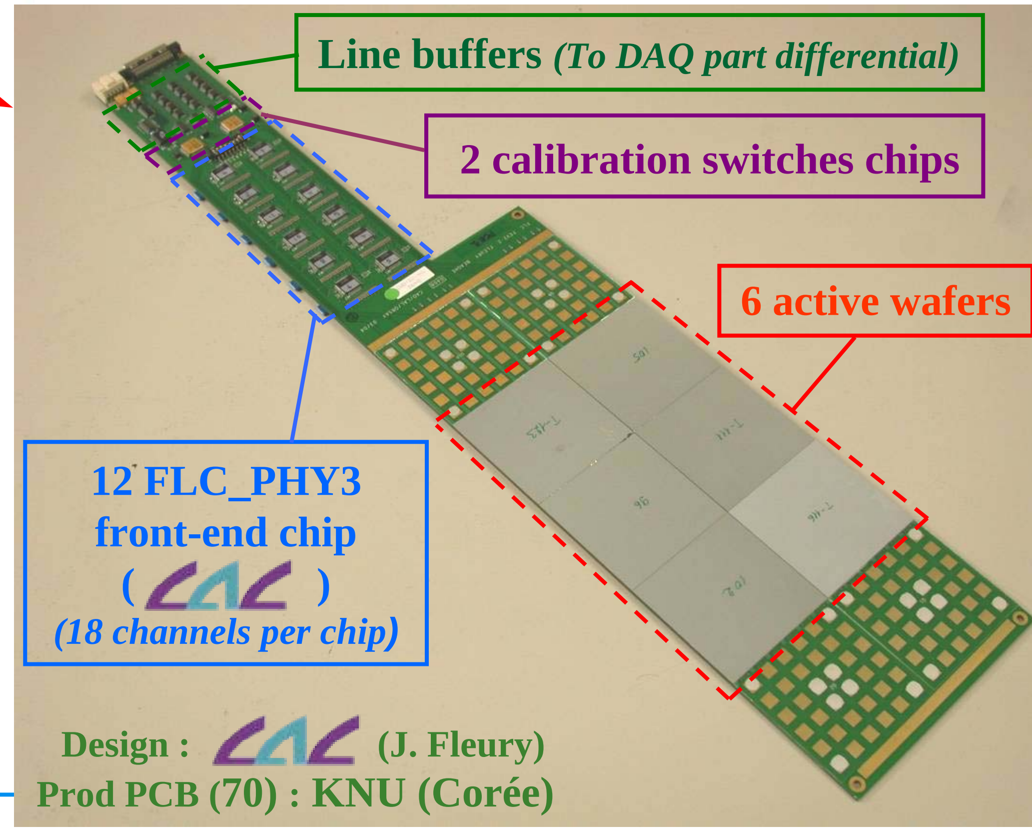
(ground + Electromagnetic noises protection)




(Cfi / W) structure *type H*




*Cross section*



# Composite Structures

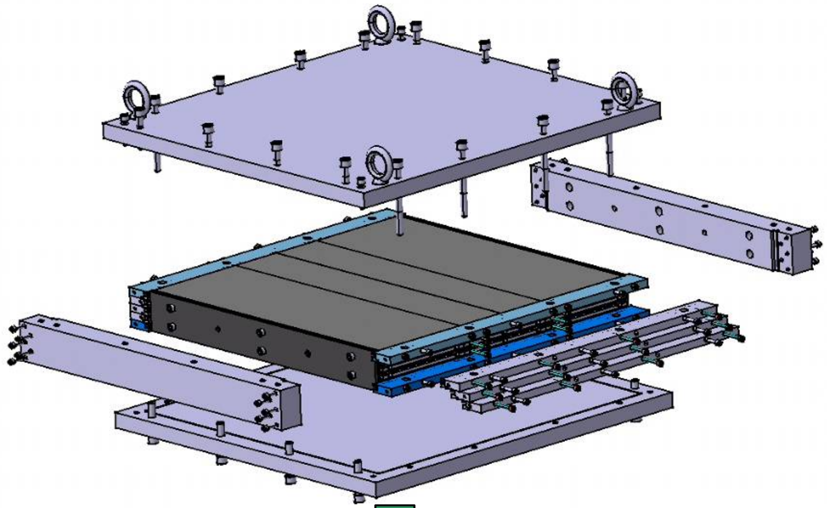
- Study and fabrication of each alveolar structures with its associated moulds

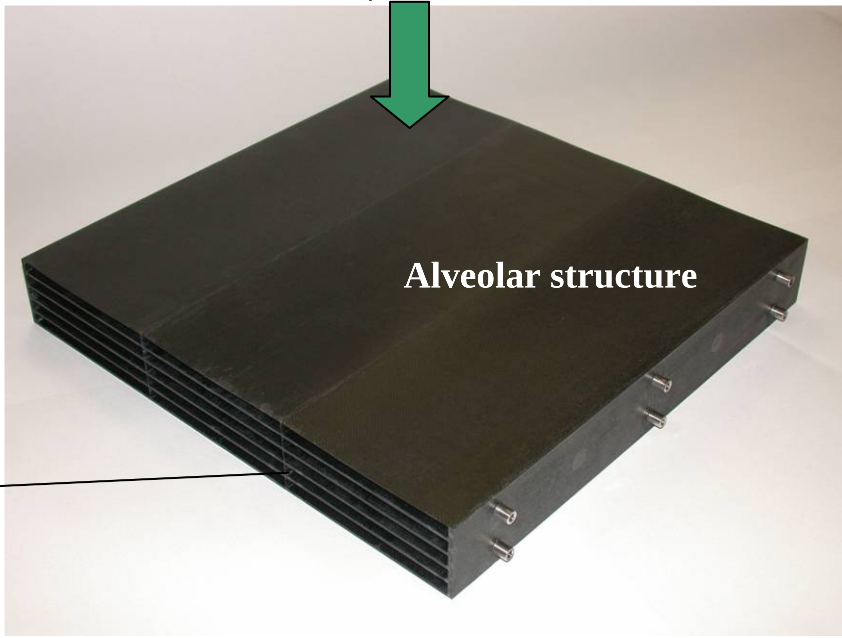
  - alveolar composite structures : **3 / 3**

- Study and fabrication of 30 H-shaped structures

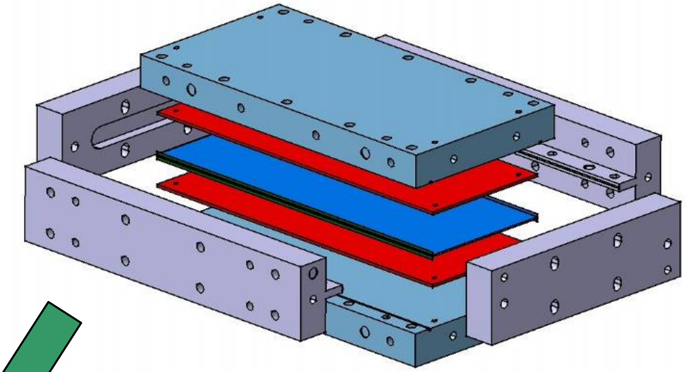
  - H with W = 1.4 mm : **10 / 10**
  - H with W = 2.8 mm : **10 / 10**
  - H with W = 4.2 mm : **10 / 10**

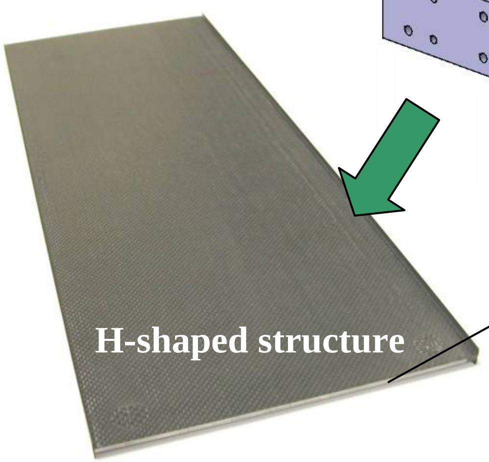
*Alveolar structure mould :*






*Structure H mould :*

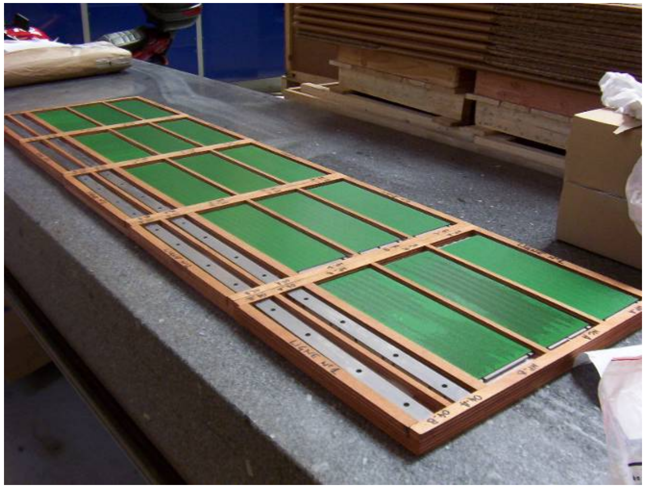




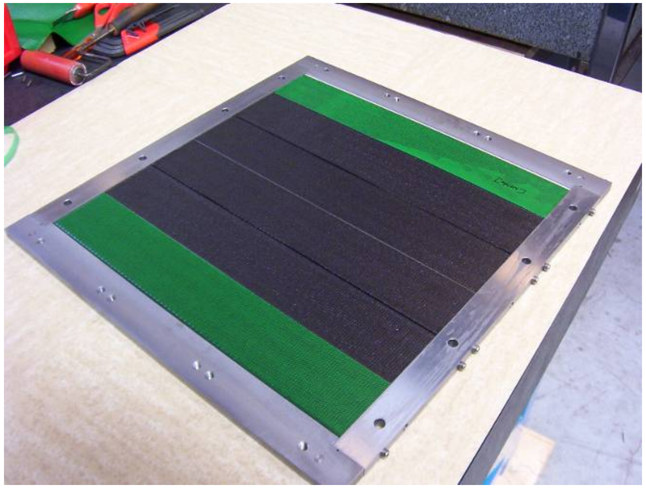

**Tungsten plates**

# Alveolar Structures (1/2)

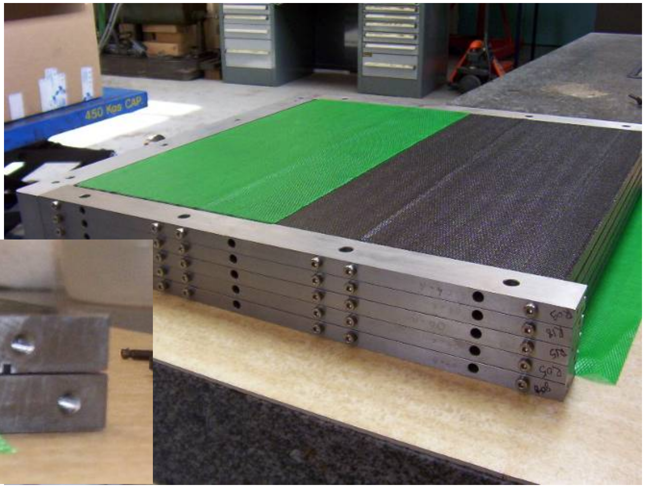
1 – Wrapping of cores

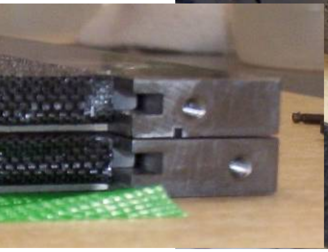


2 – Assembly per layer (+ compacting)

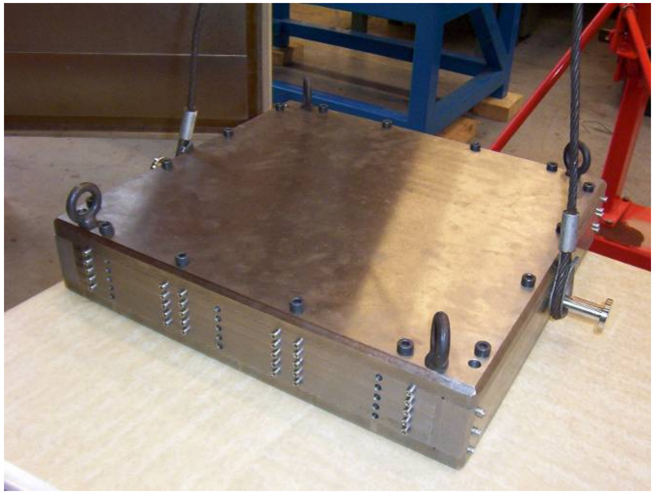


3 – General Assembly (with W layers)



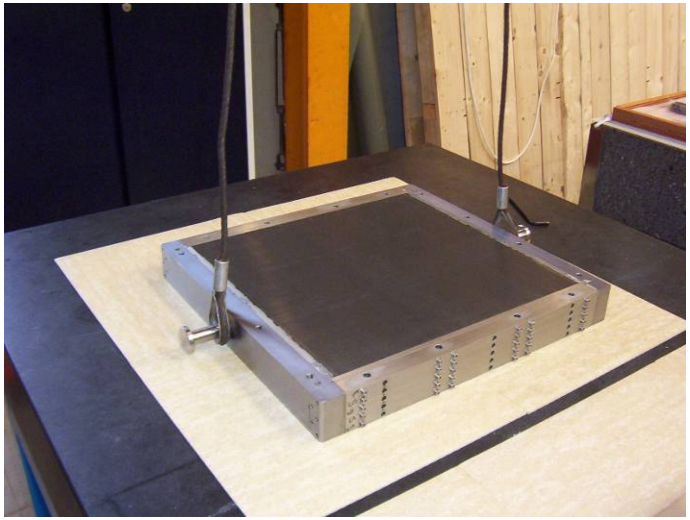


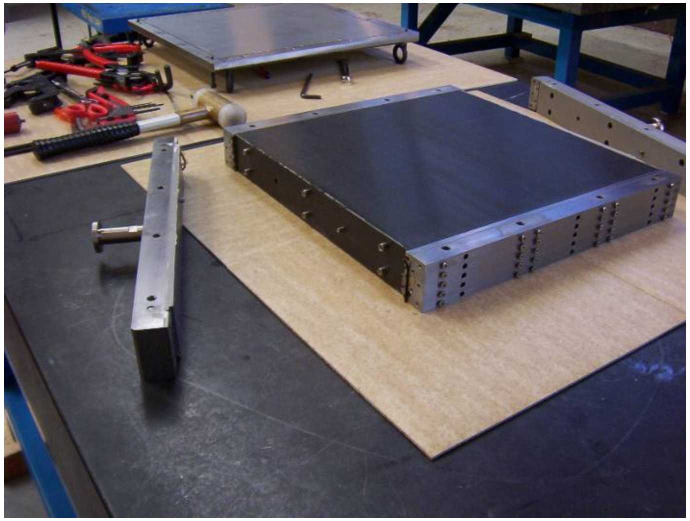
4 – Closed mould

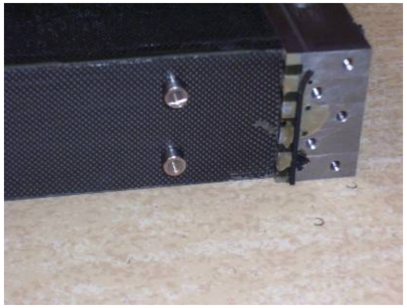


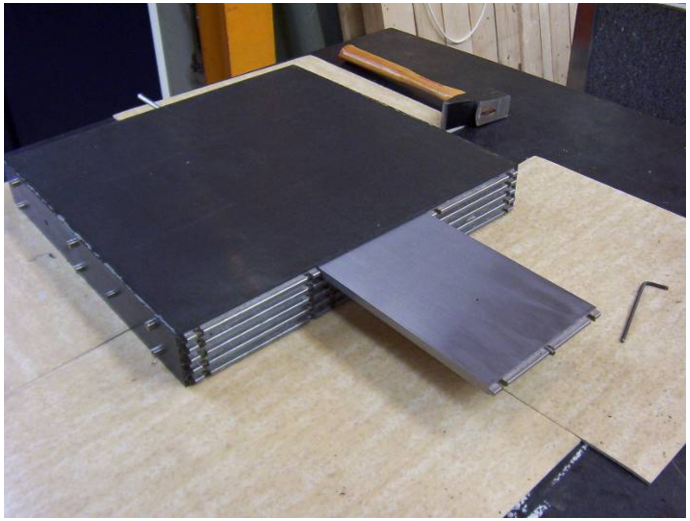
# *Alveolar Structures (2/2)*

**5 –** Curing (2 h @120 °C) and dismounting steps :

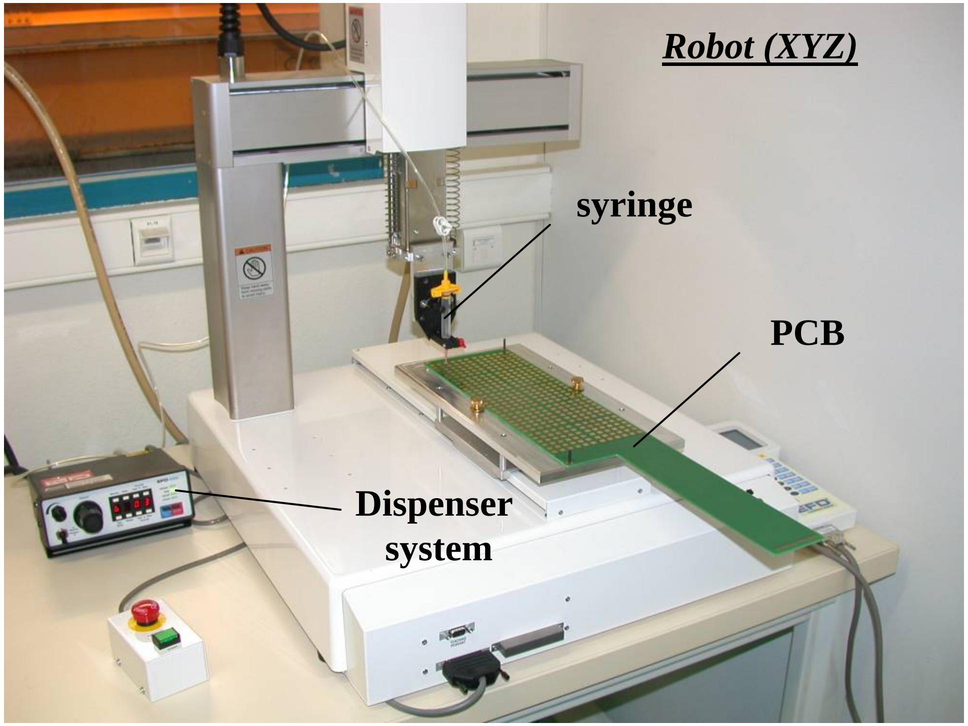






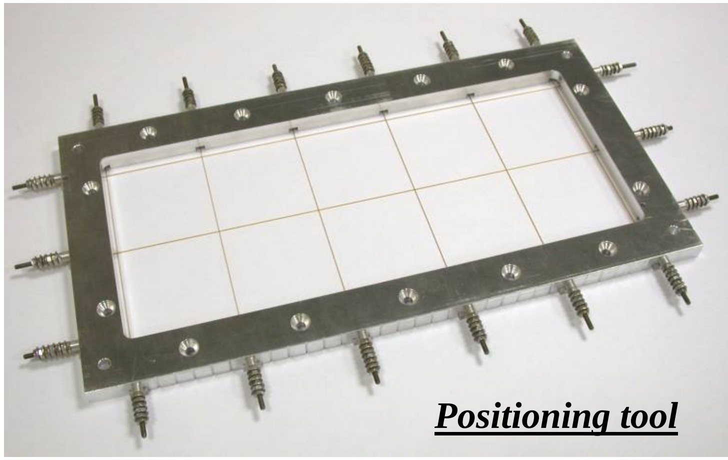


# PCB – Gluing wafers (1/2)




- 216 dots of conductive glue (EPO-TEK) are deposited on PCB pads with an automatic pneumatic dispenser system (PCB with electronics)

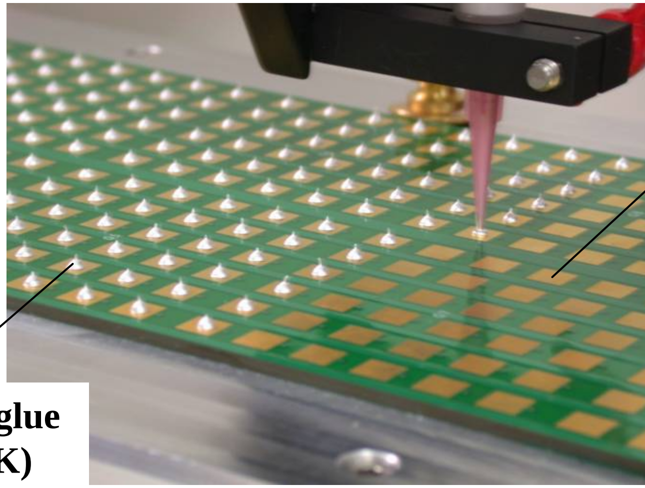
  - X-Y-Z Robot :
    - cutting stroke : 400×400×150 mm
    - precision : ± 0,01 mm
  - Disperser system EFD 2000XL
    - time : 0,2-0,5 s
    - pressure : 0,2-0,4 bar




- A positioning tooling (grid), obtained by Tungsten wires of 0.1 mm in diameter allow a good position of each wafer on PCB with a gap of 0.1 mm during the polymerisation of the glue (12h @40°C)

# *PCB – Gluing wafers (2/2)*

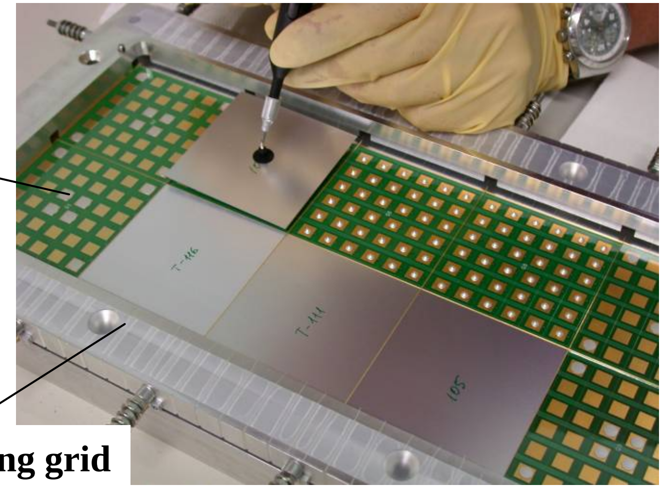
**1 –** dots of are deposited on PCB pads



**Conductive glue (EPO-TEK)**

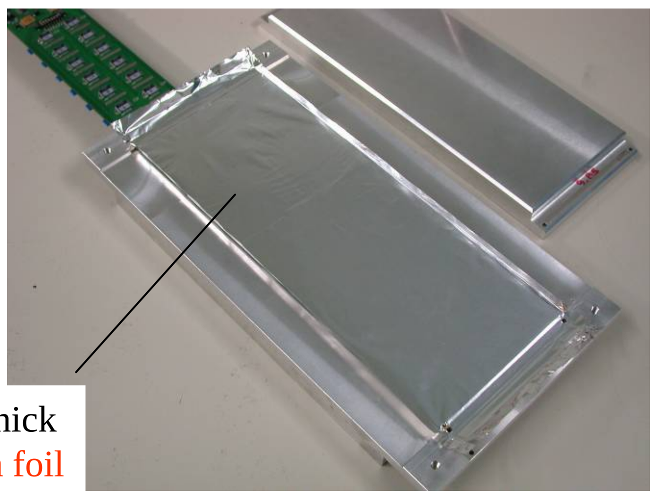
**PCB**

**2 –** Each wafer is placed on PCB manually



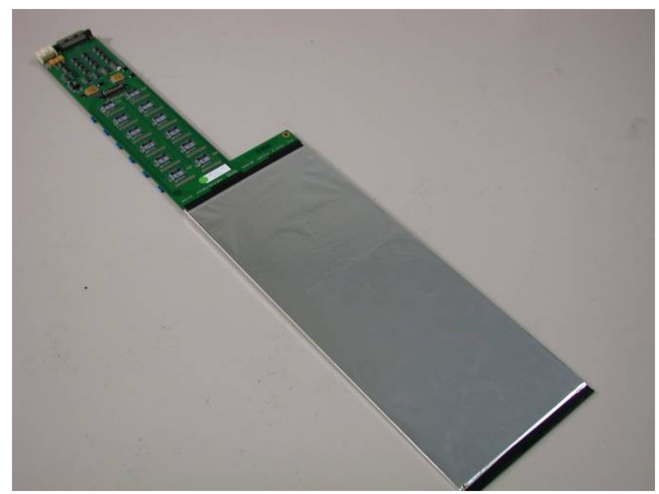
**Positioning grid**

**3 –** An aluminium foil is used to connect all wafers to the ground of the PCB

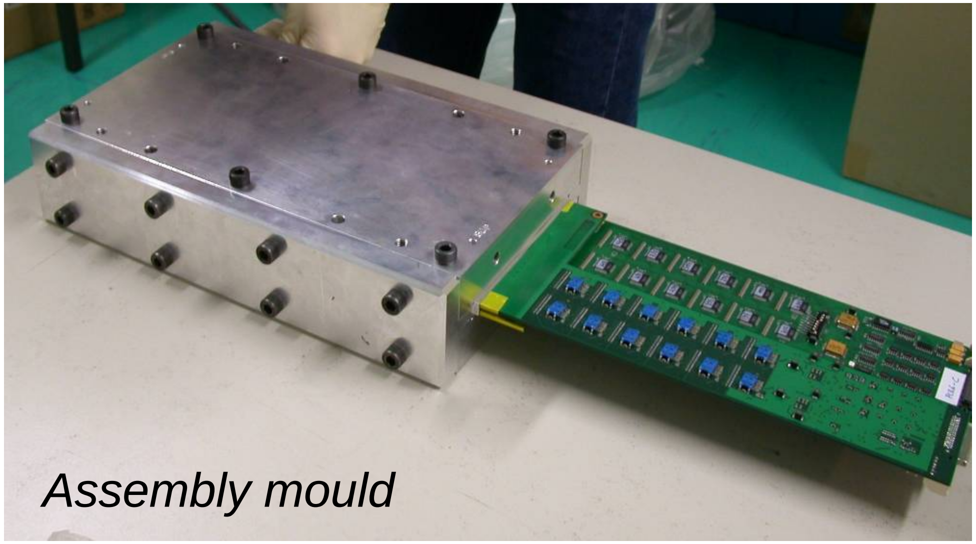


0.03 mm thick aluminium foil

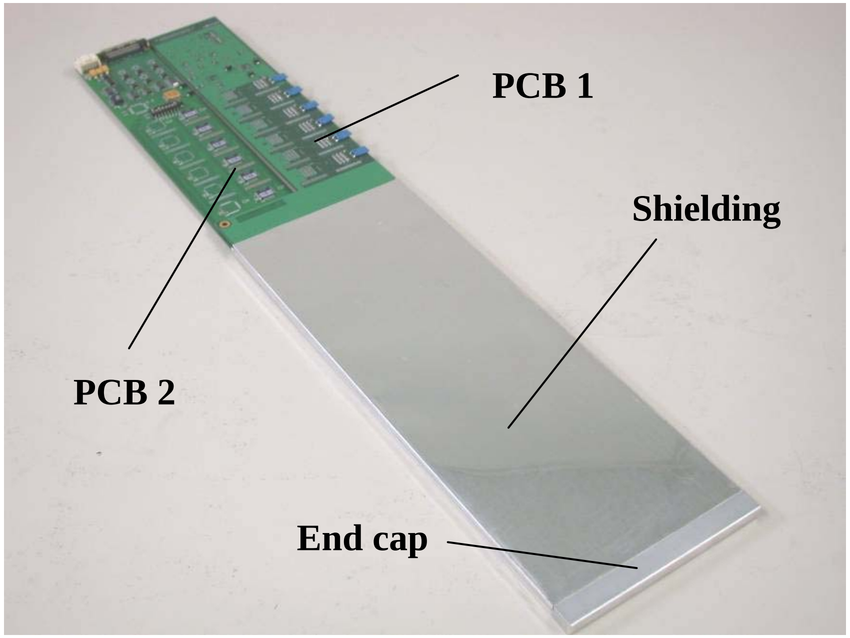
**4 –** 2 days to obtain a finished PCB



# Final Assembly - SLAB




Detector Slab




- Specific tooling for pre-forming the aluminium shielding
- Assembly mould for the final slab
- Polymérisation : 12h@40°C

# *Physics Prototype – Testbeams*

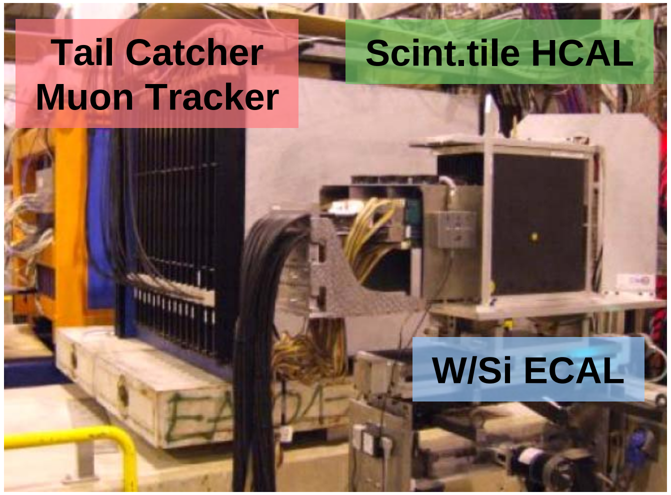
- Since 2005 several rounds of testbeams conducted at DESY, CERN, FNAL for development studies, technical runs and physics

**@ DESY, 2005-2006**


**ECAL (W/Si) alone**

technical & physics run with electrons @ 1-6 GeV

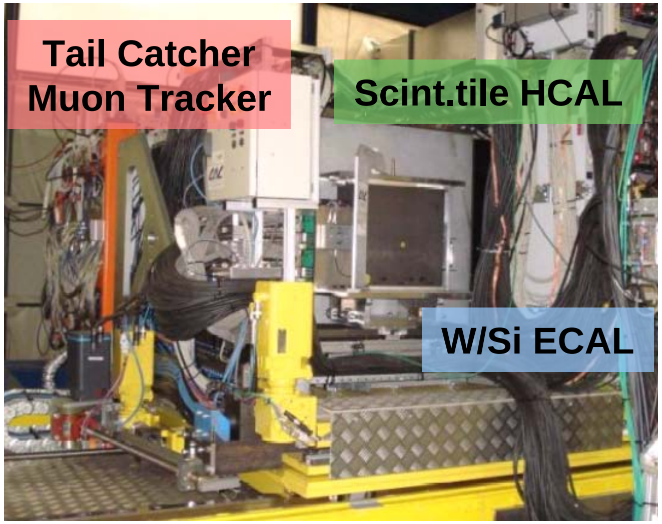
**@ CERN, 2006-2007**




**ECAL + AHCAL + TCMT combined**

**ECAL** testbeam with electrons @ higher energy
**AHCAL** technical & physics run with electrons/pions

**@ FNAL, 2008**

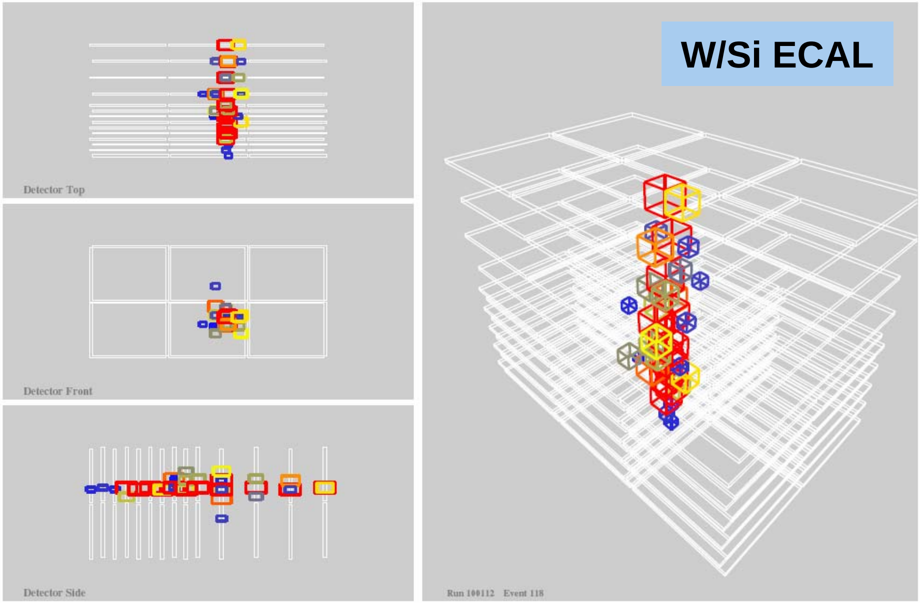



**ECAL + AHCAL + TCMT combined**

**ECAL** testbeam with electrons @ higher energy
**AHCAL** technical & physics run with electrons/pions

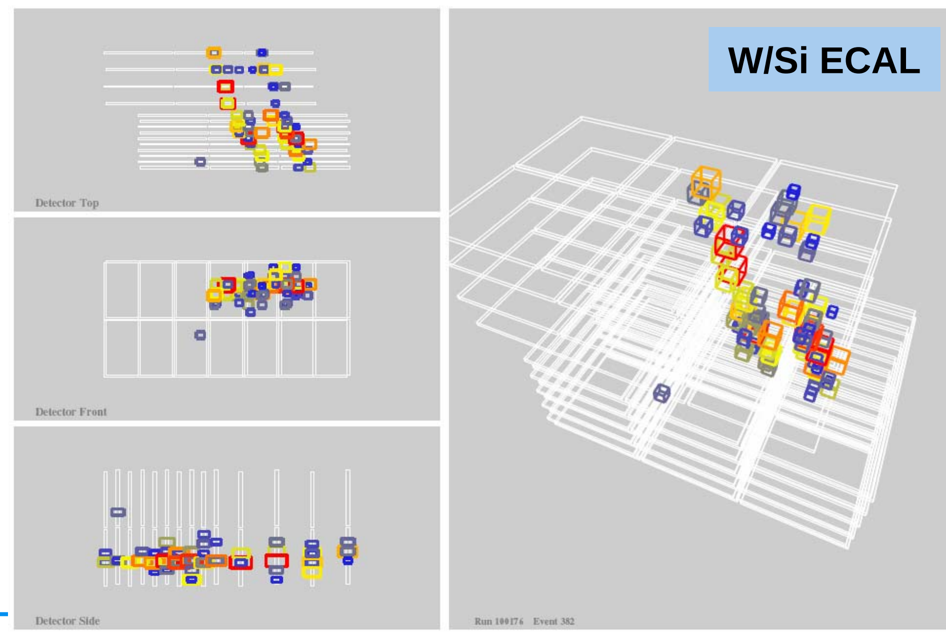
# Example : excellent shower separation

**@ DESY, 2005**



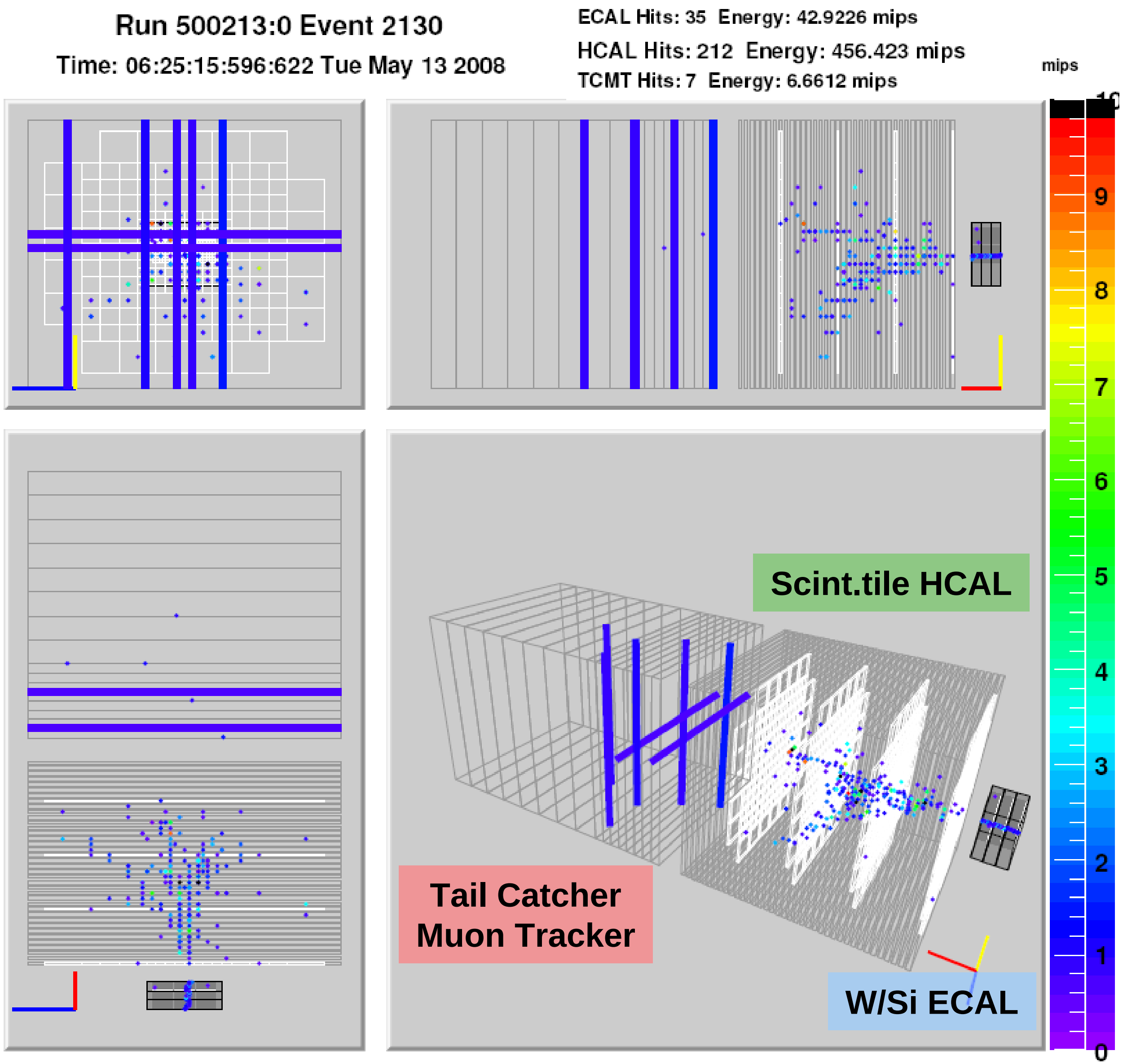

Electron shower @ 3 GeV
(configuration 0°)

2 separated electron showers @ 3 GeV
(configuration 30°)




Analyse de G. Gaycken

# Example : Combined tests




## $\pi^-$ 15 GeV

ECAL threshold = 0.5 mip
HCAL threshold = 0.5 mip
TCMT threshold = 0.7 mip

**@ FNAL, 2008**

Laboratoire Leprince Ringuet
Ecole polytechnique - Palaiseau

# – ECAL W/Si –

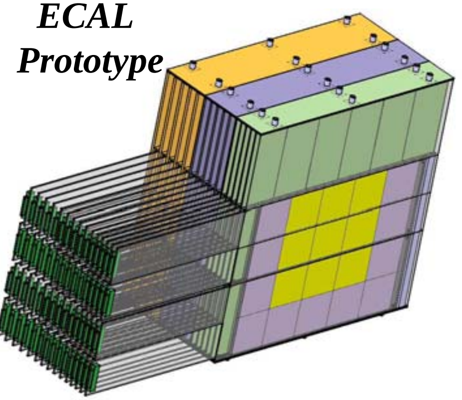
## Technical prototype

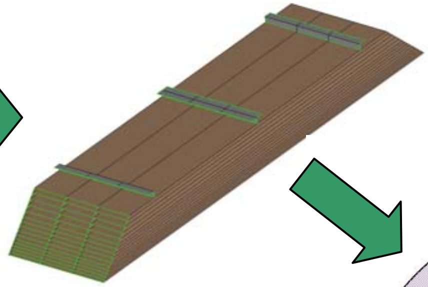
*Marc Anduze* – 22/06/2009

# EUDET : why this prototype ?

- Next step after the physics prototype and before the module 0
- To study “full scale” technological solutions which will be used for the final detector (moulding process, thermal cooling, inlet/outlet, integration tools …)
- To take account of the industrial point of view
- To estimate the cost of the future Si/W ECAL

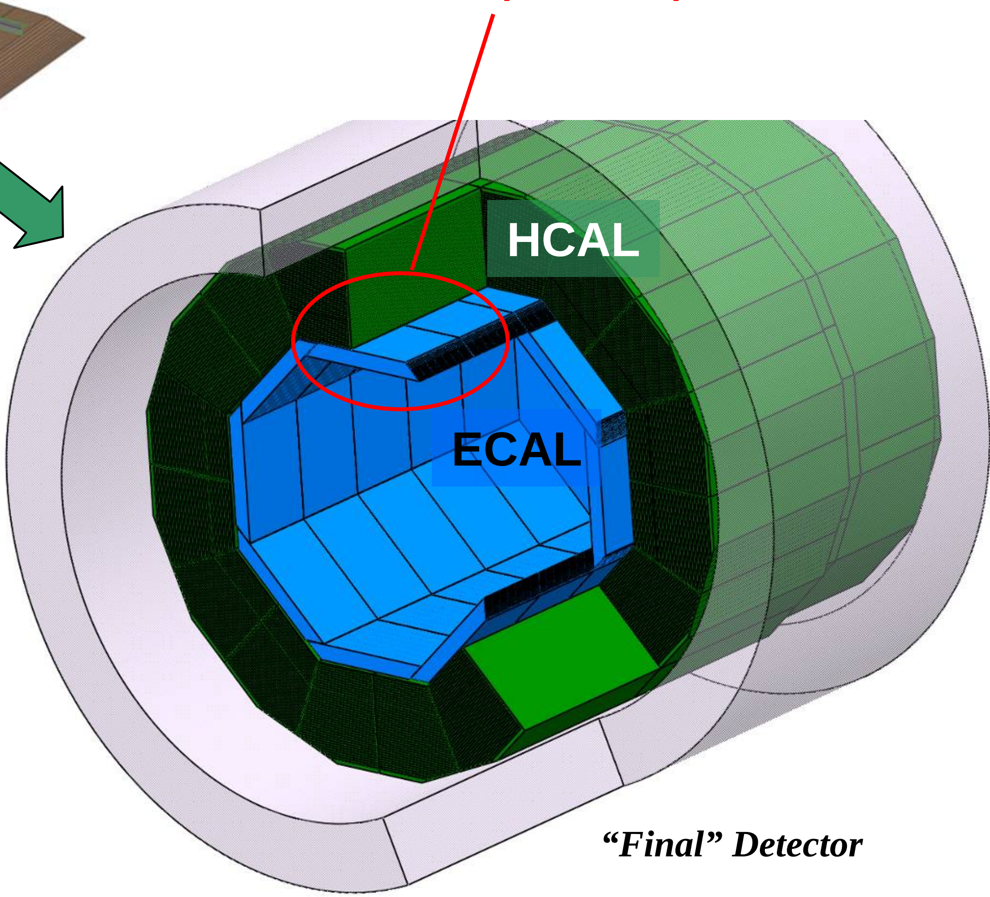
*ECAL Prototype*





*Tech. prototype*

**1st ECAL Module (module 0)**




*“Final” Detector*

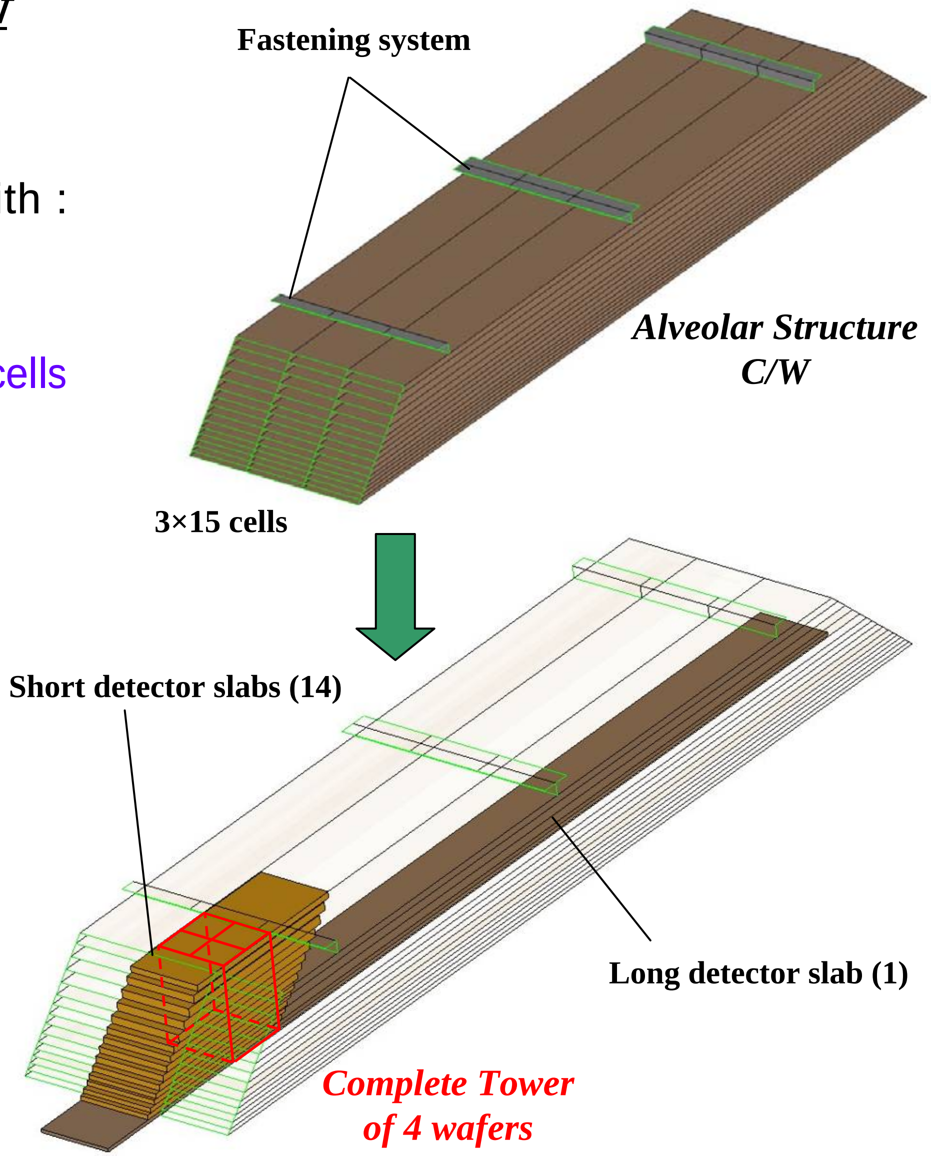
The groups working on the EUDET ECAL:

# Global Presentation

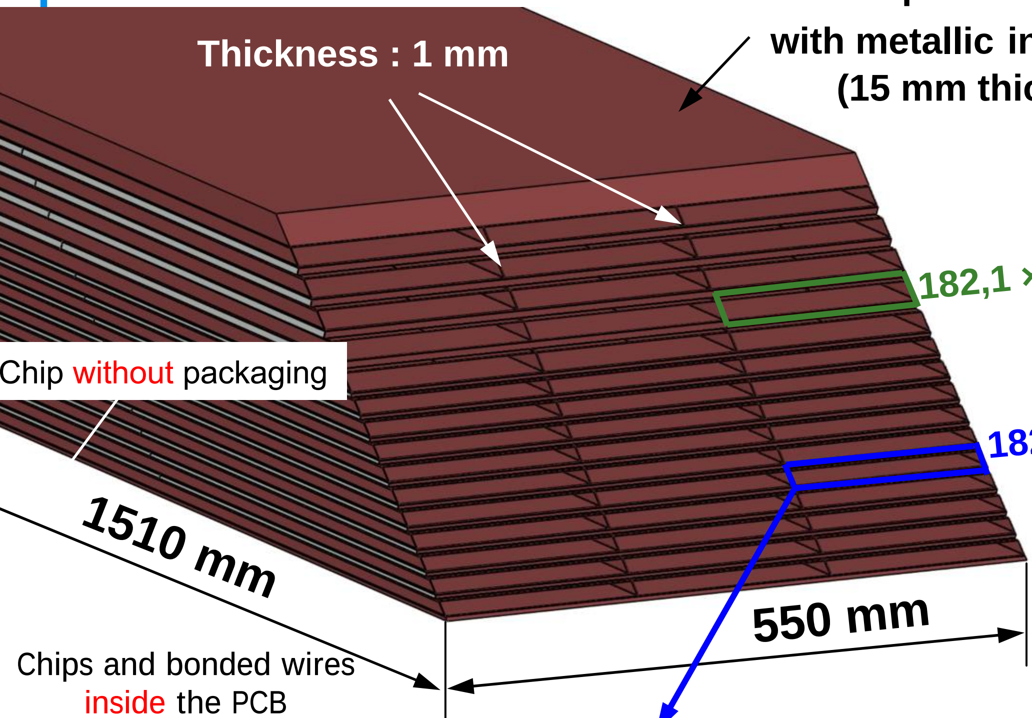
*Concept : to be the most representative of the final detector module :*

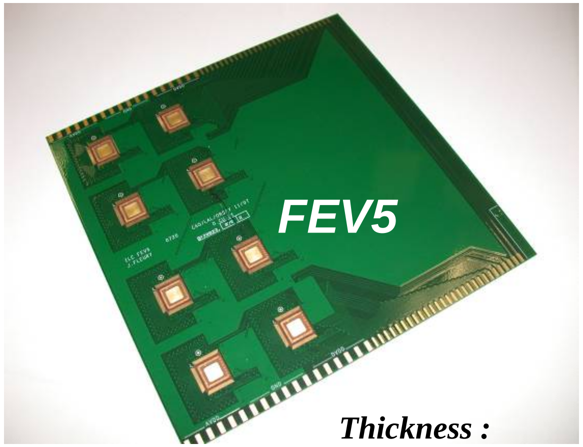
- An alveolar composite/tungsten structure with :
  - same W sampling :
    20×2.1 mm and 9×4.2 mm thick
  - 3 columns of cells to have representative cells in the middle of the structure (with thin composite sheets )
    width : 124 mm ➡ **182 mm**
  - Identical global dimensions (1.5m long) and shape (trapezoidal)
  - fastening system ECAL/HCAL (include in the design of composite structure)

- 15 Detector slabs with FE chips integrated
  - 1 long and complete slab ? (L=1.3m)
  - 14 short slabs to obtain a complete tower of detection (typ. L=40 cm)
  - design of compact outlet (support system)

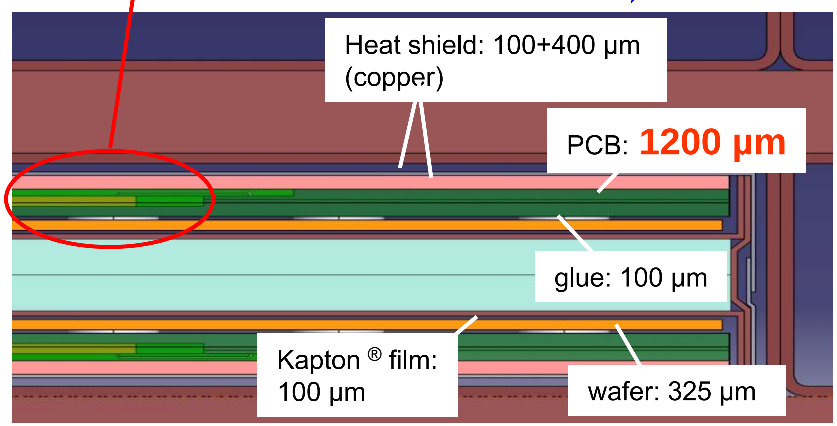


# EUDET - Current design (final)



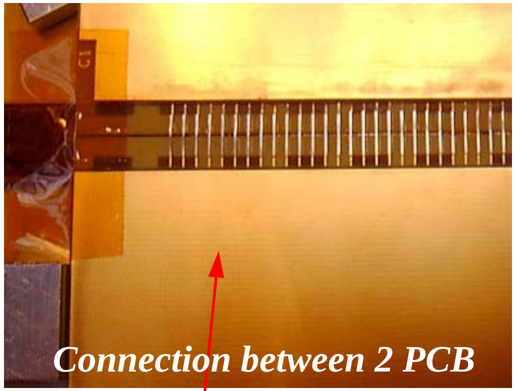

*Thickness :*
*FEV5-1 : 1.17mm (+-0.04)*
*FEV5-2 : 1.19mm (+-0.04)*
*FEV5-3 : 1.20mm (+-0.02)*



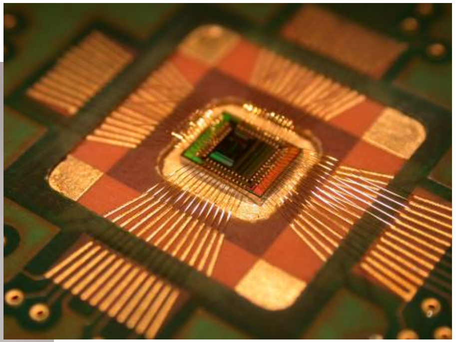

- ⇨ Clearance (slab integration) : 500 µm
- ⇨ Heat shield : **400 µm ?** → Thermal demonstrator
- ⇨ PCB : **1200 µm ?** → design possibilities
- ⇨ Thickness of glue : 100 µm
- ⇨ Thickness of wafer : 325 µm
- ⇨ Kapton® film HV : **100 µm ?** → tests
- ⇨ Thickness of W : 2100/4200 µm (± 80 µm)

# Detector slab - principle

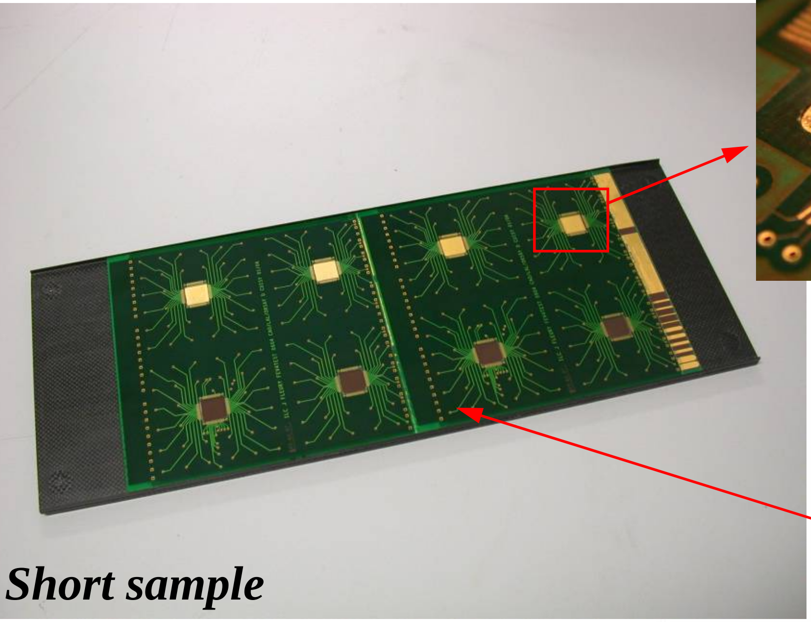
- <u>Long slab is made by several short PCBs :</u>
  - Design of one interconnection (glue ?)
  - Development easier : study, integration and tests of short PCB (with chips and wafers) before assembly
  - The length of each long slab will be obtained by the size of one "end PCB" (tools)



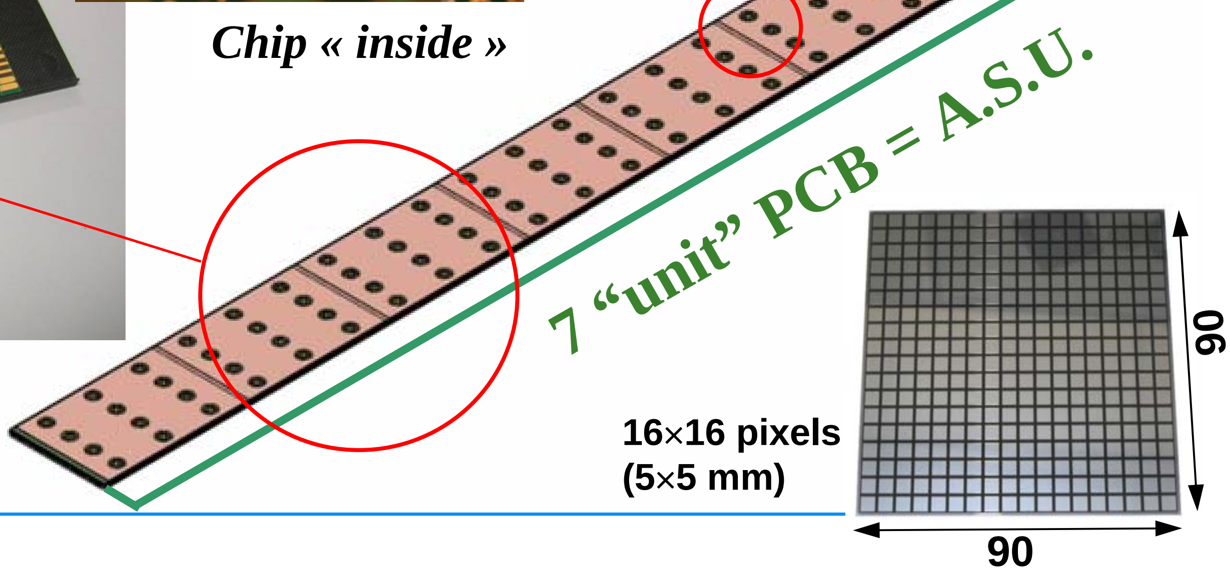
Connection between 2 PCB



Chip « inside »



Short sample



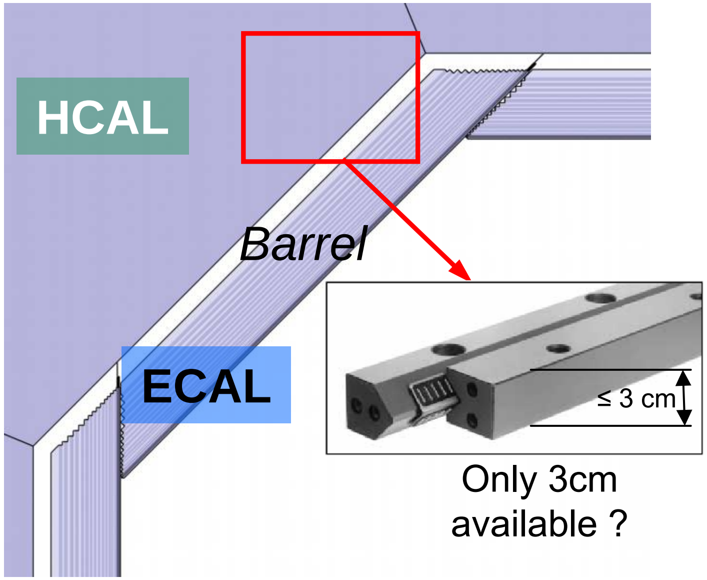

16×16 pixels
(5×5 mm)

# *Design of the module …*

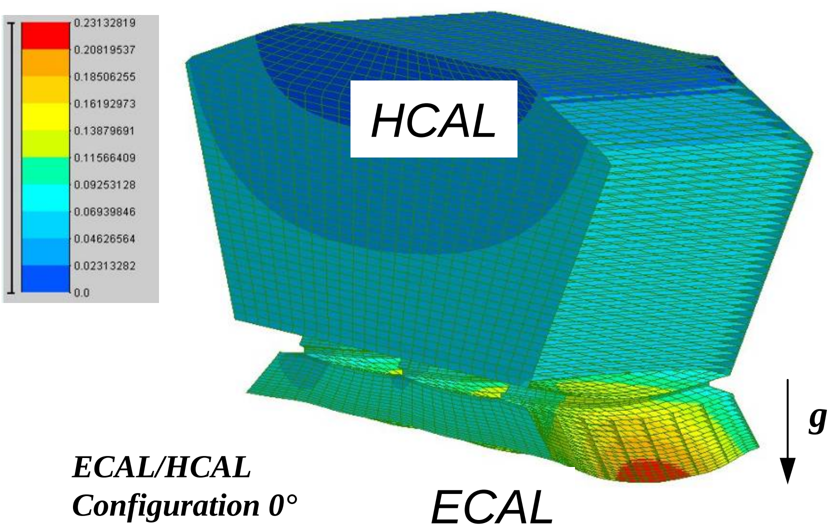
... including ECAL/HCAL interfaces (+ inlet/outlet) :

The fastening and connection system for the module has to be representative of the ECAL/HCAL interfaces.

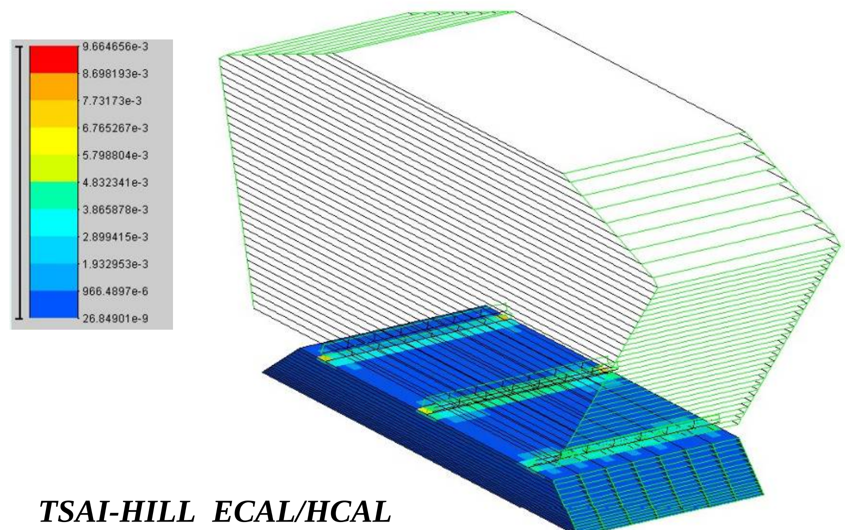
- Choice of fasteners : rails directly glued on composite or metal inserts inside the structure ?
- Mechanical simulations of the ECAL/HCAL interface to take into account of its influence
- Design of connection system (power supply + cooling + outlets)




Only 3cm available ?




*ECAL/HCAL Configuration 0°*



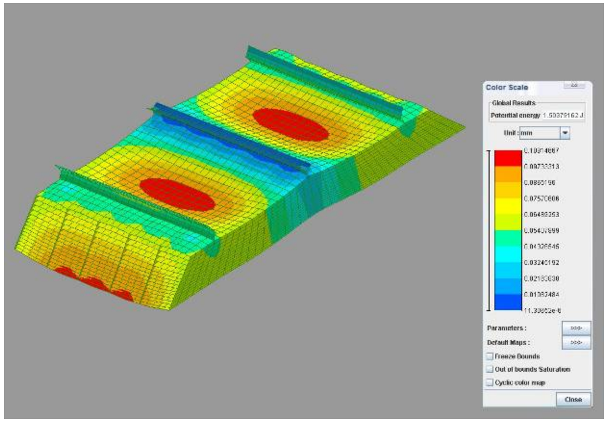

*TSAI-HILL ECAL/HCAL Configuration 0°*

# Design of the module…

Calorimeter for ILC

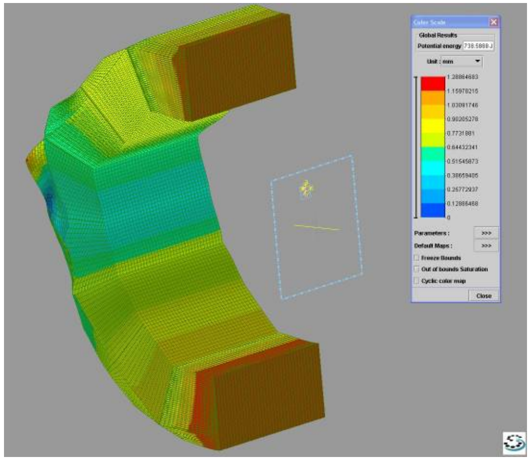
... based on mechanical simulations :

<u>*Linear Analysis of "full scale" ECAL and HCAL modules*</u>



ECAL

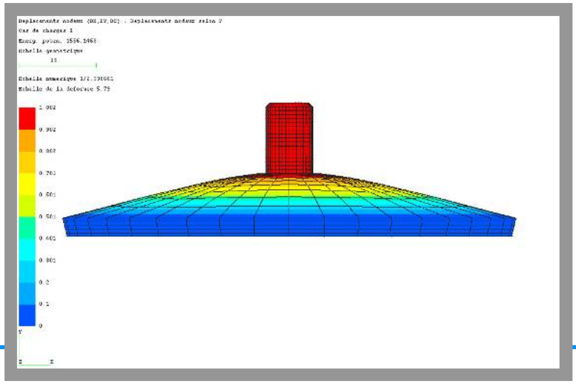
- Global simulations : global displacements and localization of high stress zone for different solutions (dimensions)



HCAL

- Local simulations : more precise simulations and study of different local parameters to design correctly each part of this structure (thickness of main composite sheets, choice of fasteners : metal inserts, rails...)

- Check and validate simulation results by destructive tests for each issues



**behaviour of an insert in composite with tensile loads**

# Design of the module …

… while taking account of Slab Thermal analysis

Thermal sources:

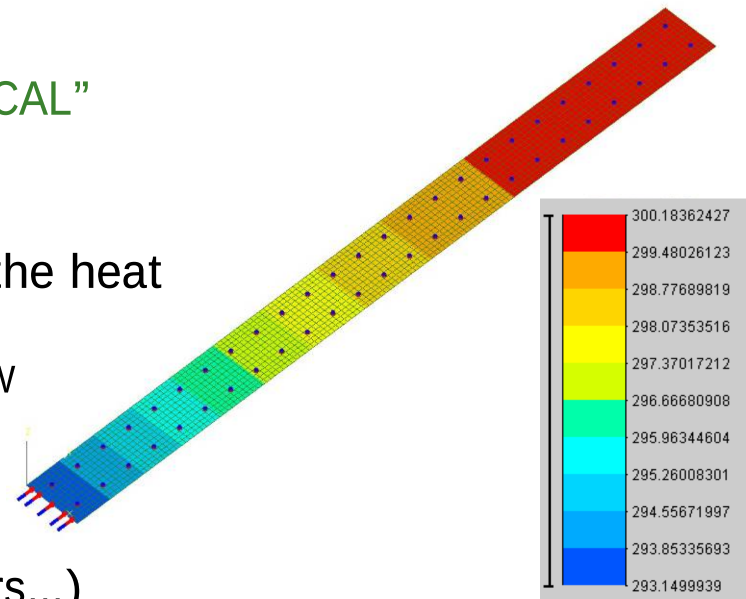
| Pad size | Chan/ wafers | Ch/chip | Chip/wafer | Chip size mm² | Chan/barrel | Chan/ End-cap |
|---|---|---|---|---|---|---|
| 5*5 mm ² | 144 | 72 | 2 | 15x15 | 60.4 M | 21.8 M |

➡ CALICE ECAL: ~ 82.2 M of channels

Assuming that the chip power is 25 µW/channel
total power to dissipate will be : 2055 W

⇨ external cooling OK for the "full scale ECAL"

inside each slab :
necessity of cooling system but active or passive ?
*Ex:* Pessimist simulation of heat conduction just by the heat shield : $\lambda$ = 400 W/m/K (copper) ; S = 124*0,4 mm²
L = 1,55 m ; $\Phi = 50^* \, \Phi_{chip}$ = 0,18 W




We can estimate the temperature difference along the slab layer around 7°C and without contribution of all material from slab (PCB, tungsten, carbon fibers...)

⇨ passive cooling OK :

Thermal conductors (heat shield) can be added in the slab to carry heat more efficiently along the slab direction.

# Demonstrator – Gluing of ASU

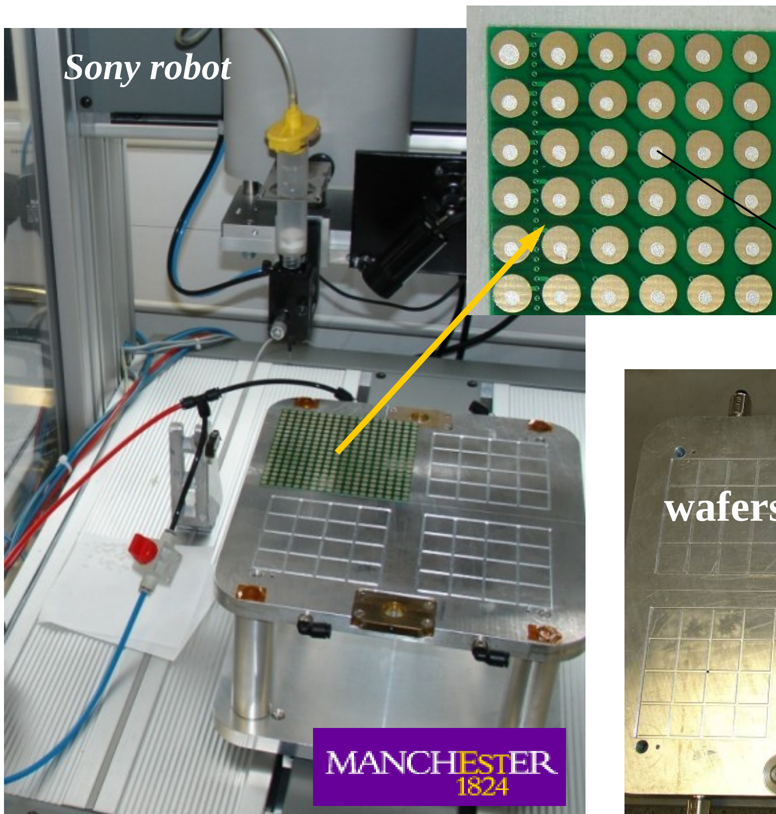
Principle is close to the physics prototype :

- Sony Robot and precision glue dispenser tool (glue: EPO-TEK® 4110)

But more industrial for EUDET module (~40000 dots):

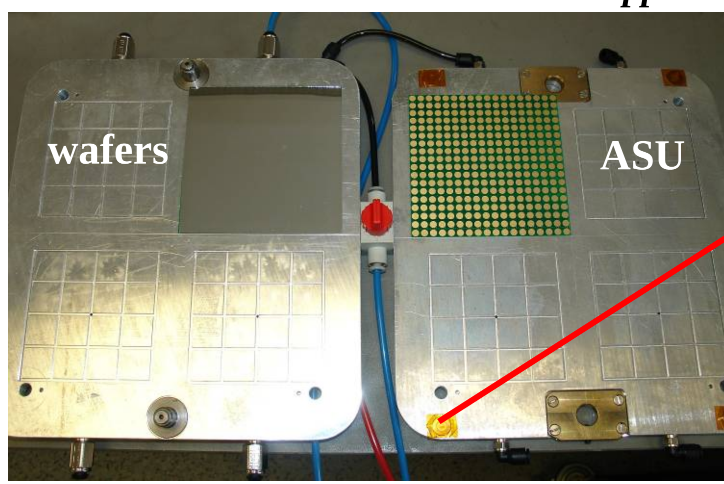
- Vacuum system to hold PCBs and wafers during all operations
- Alignment of wafer and PCB pixels using a viewing system

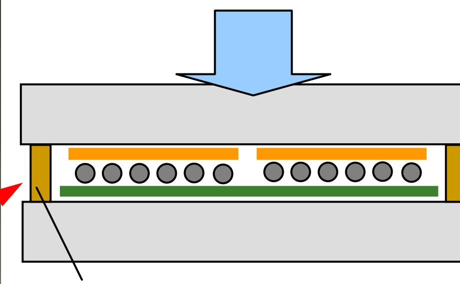
⇨ Robot adaptation and tools : *OK*
⇨ Glue dot parameters : *OK*
⇨ Tests with Cambridge PCBs: **on going**




**Reproducible dots**

***Vacuum supports***



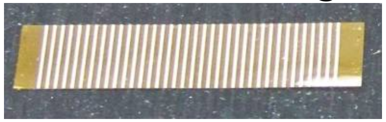



**Calibrated spacers (control gap thickness)**

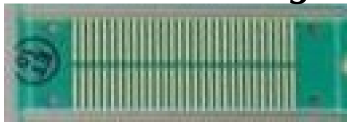
# *Demonstrator – Interconnect system*

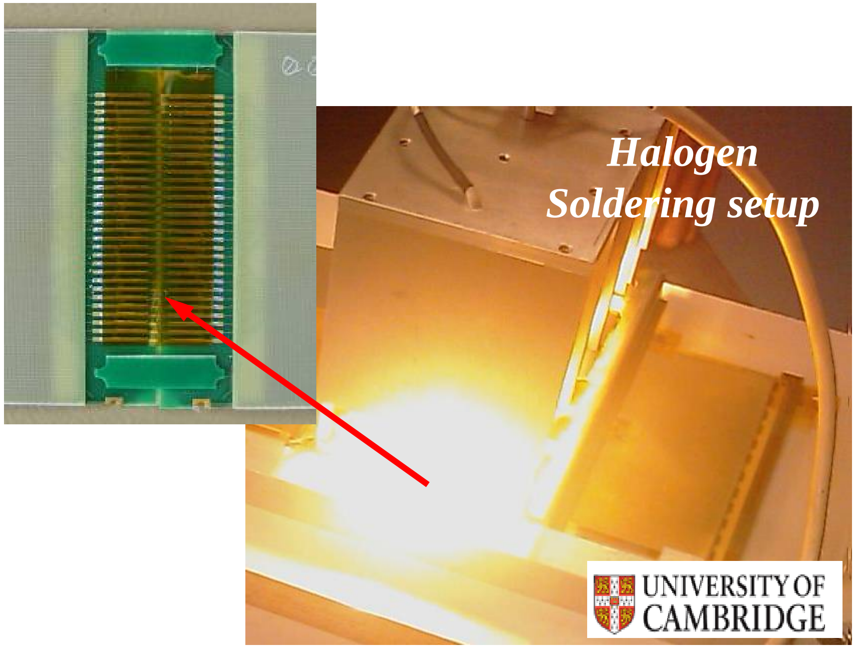
- Use “Bridges” principle to link multiple connections (30-40 each) between all adjacent ASUs (embedded in the thickness)
- Different designs tested: Short Flat Flexible Cable (electrical joint)
  Thin PCB (electrical & mechanical joint)
- Thermal Bonding process investigations :
  - good electrical behaviour (voltage drop, crosstalk)
  - Use Soldering setup with no stress and damage for wafers (temp & pressure parameters)
  - Remove and rework the joint (dismounting aspect)

***FFC bridge***



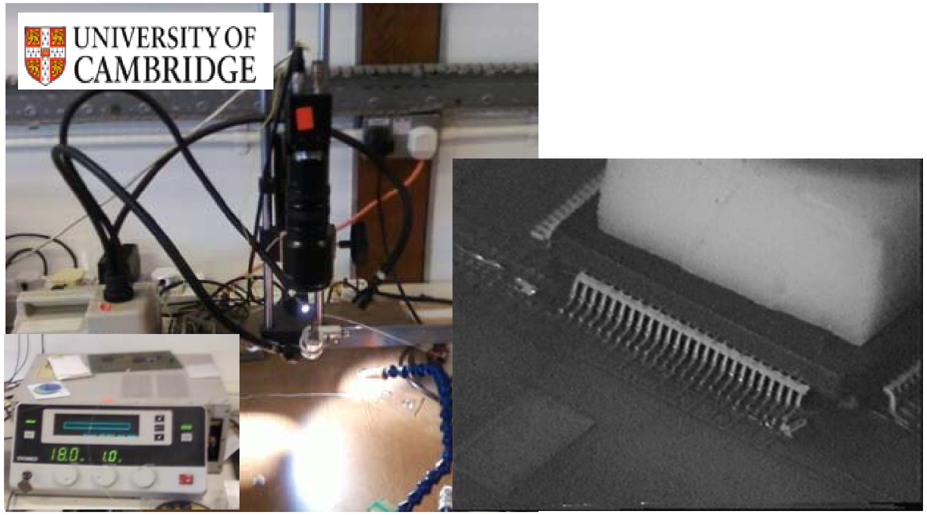
***PCB bridge***






***Halogen Soldering setup***

***Laser soldering setup***



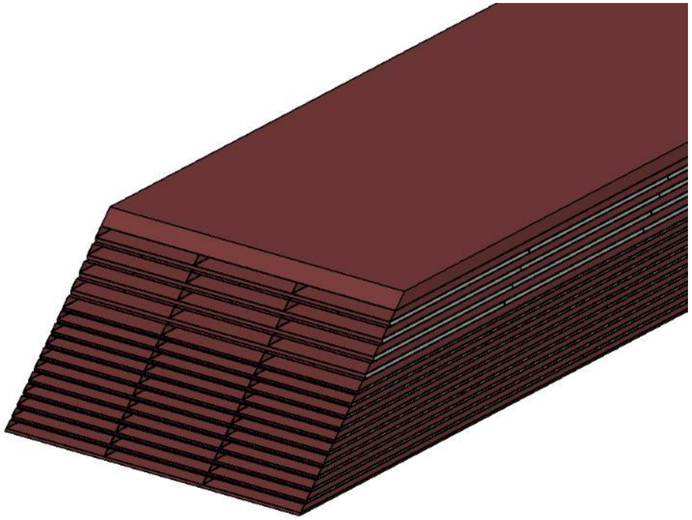
# EUDET - Alveolar structure

Study of different principle (with industrial expertise):

- *Principle #1* : "one block" structure

    One curing step to obtain the final structure

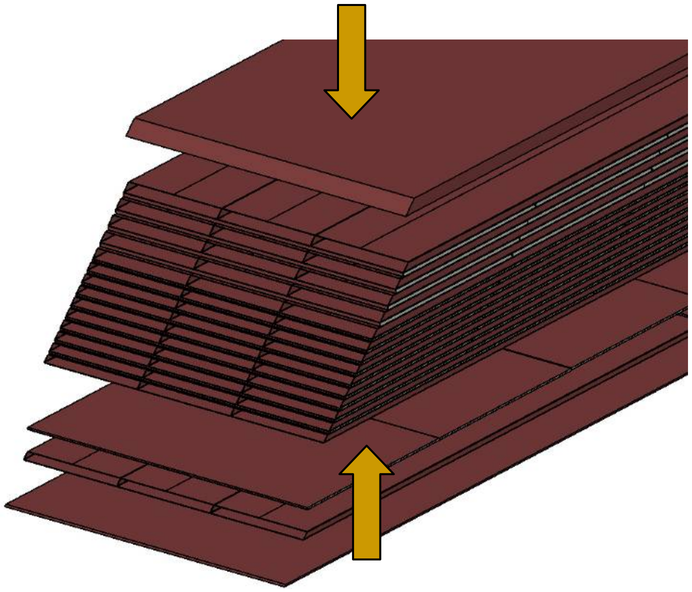
    - Final piece in one step
    - Better mechanical strength
    - Only one but more complex mould (45 cores)
    - Curing problems : thermal inertia, weigh of metal mould, control of curing parameters ...
    - Important risks to fail the structure : what about W plates ?



- *Principle #2* : Assembled structure

    Each alveolar layer are done independently, cut to the right length (with 45°) and assembled with W plates in a second curing step

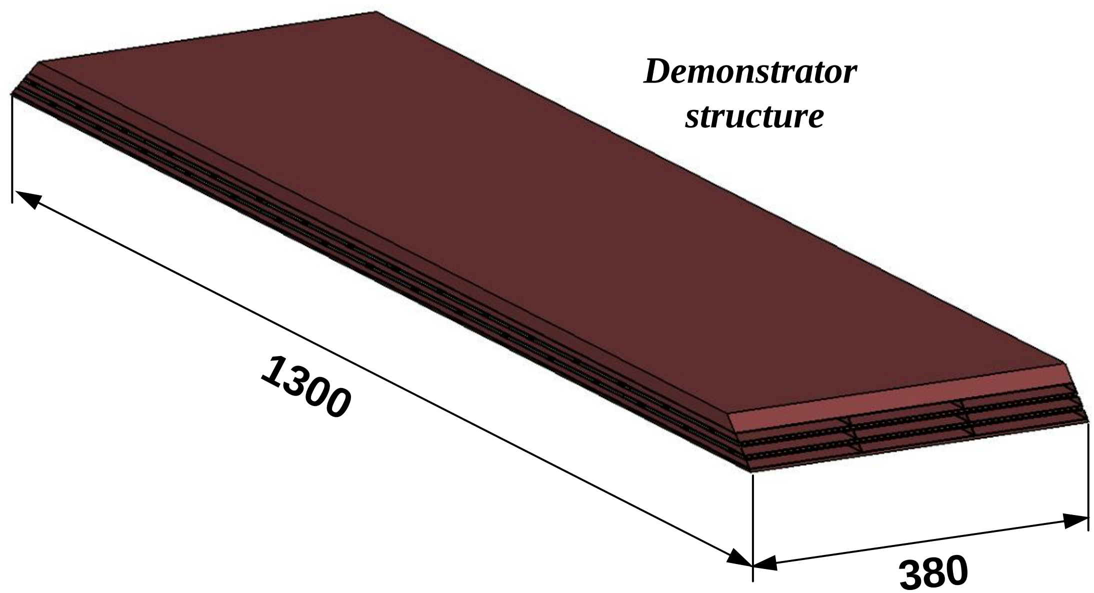
    - Individual inspection and choice
    - Limit risks to lose W plates
    - Reduction of cost (simpler moulds)
    - 2 polymerization process : 2 moulds
    - Mechanical strength of "gluing" structures



# 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 ...)

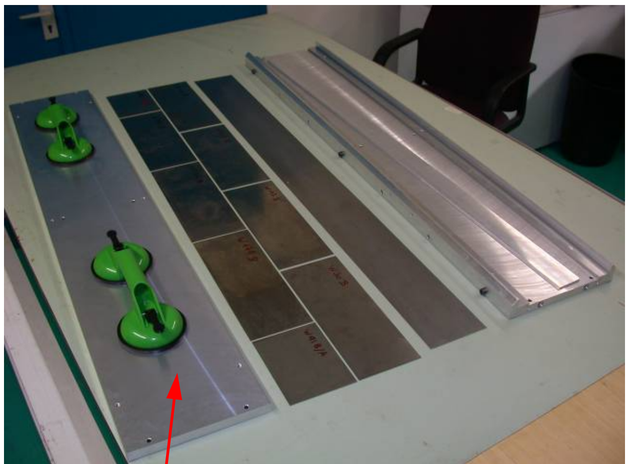
**• 3 alveolar layers + 2 W layers**
**• 3 columns of cells : representative cells in the middle of the structure**
**• Thermal studies support**
**• Width of cells : 126 mm**
**• Identical global length : 1.3m and shape (trapezoidal)**
**• Fastening system ECAL/HCAL**



# Demonstrator – H-shaped structure

Study of one mould for whole structures:

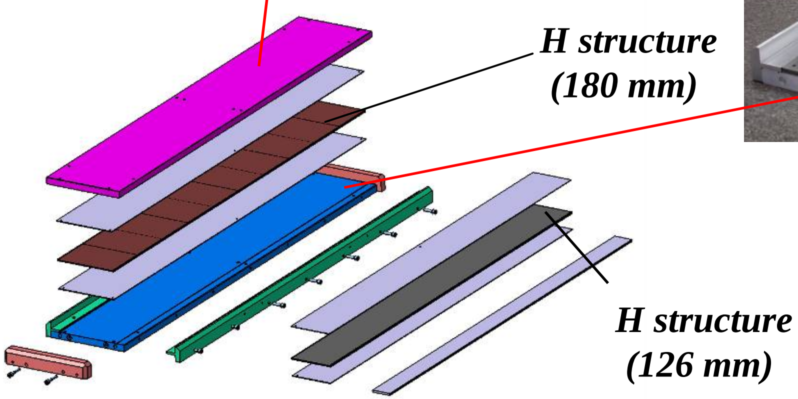
- Same principle than the mould used to do H physical prototype structures but using the autoclave)
- One long mould for both long and short H structures and 2 width (124 and 180 mm)

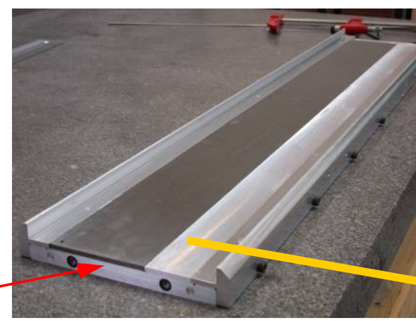


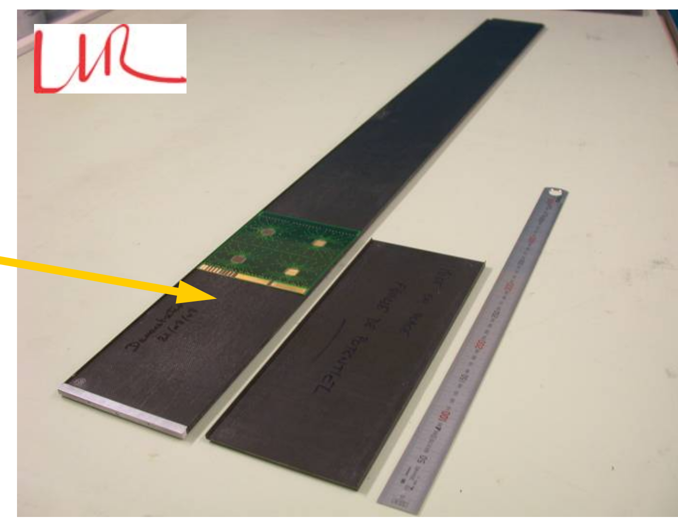
⇨ Design : ***OK***

⇨ machining : ***OK***

⇨ first H-shaped structure (1300×124): ***OK***

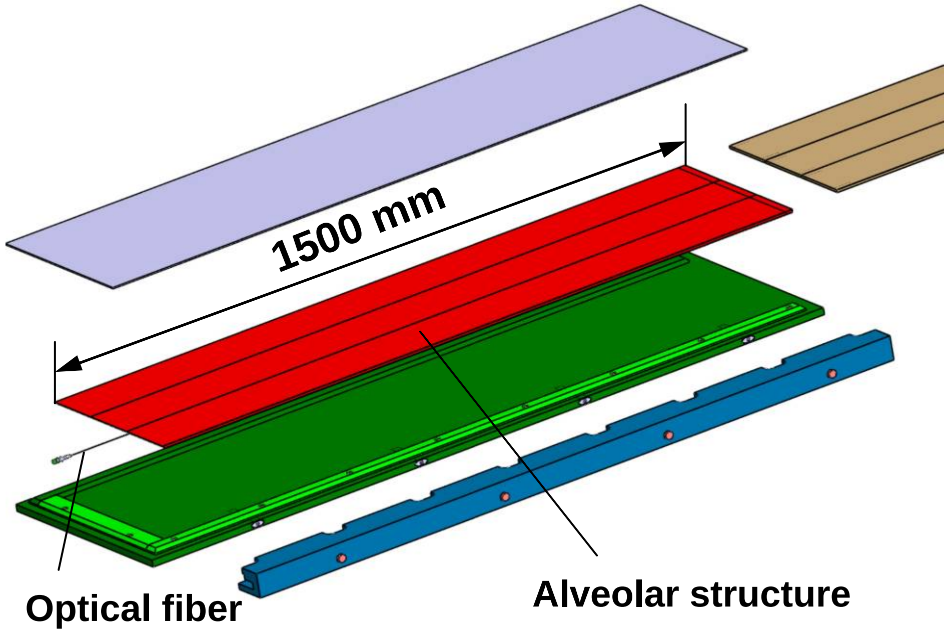


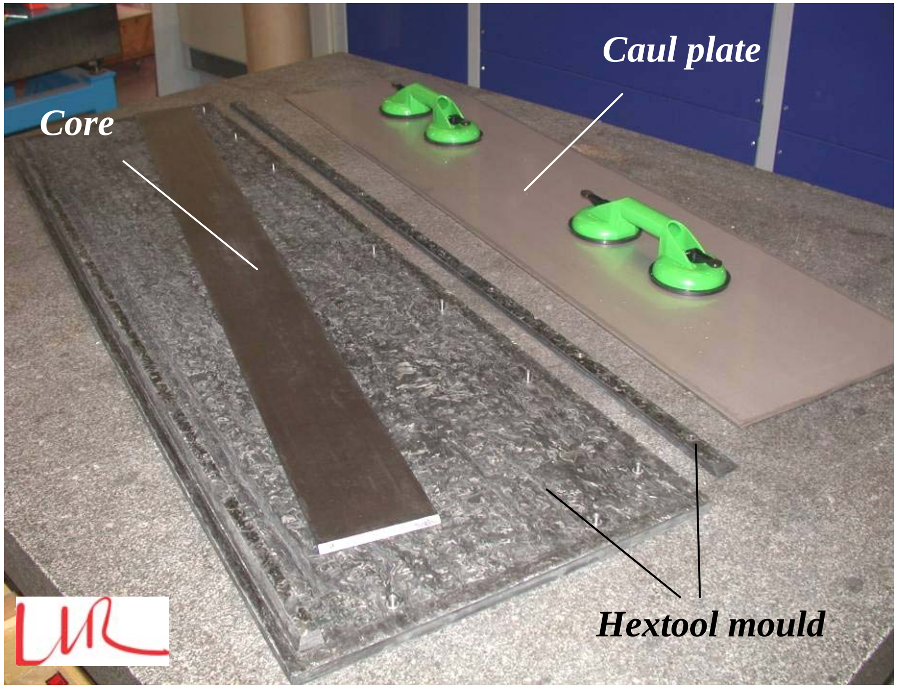





# Demonstrator - Alveolar layer mould

- <u>Study of one first mould based on principle#2 :</u>
  - Design of one mould for all alveolar layers
  - Possibility to integrate optical fiber with Bragg grating for Tests-Simulations Dialogue
  - The length of each layer will be obtained by machining one side (tools)
  - First samples will use to study mechanical behavior (destroy tests, dimensional inspections ...)

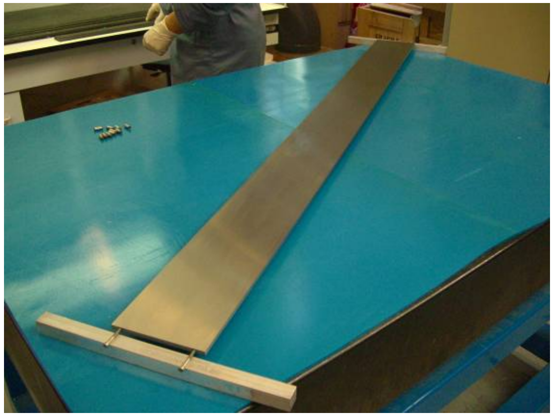


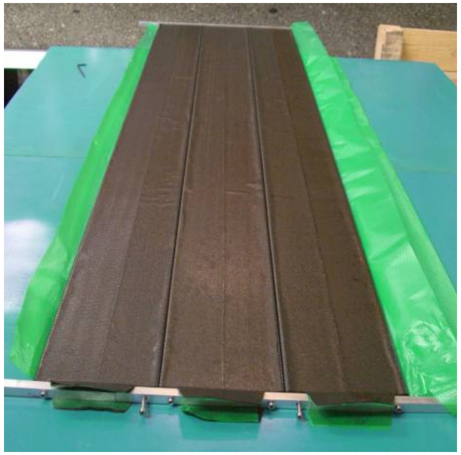
# Demonstrator - First long test (1/2)

Main process steps :

1 - mould release preparation

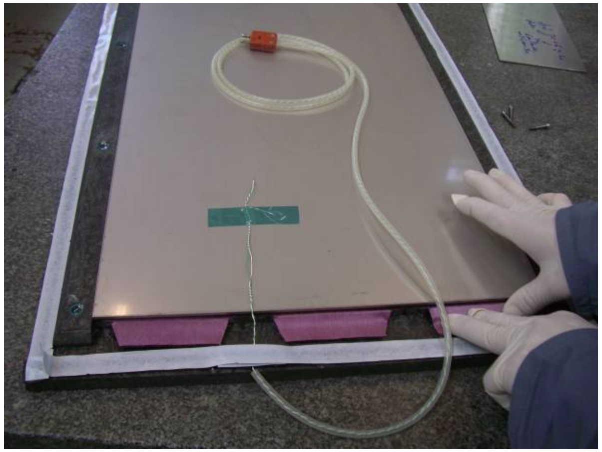


2 - Cores wrapped with prepreg

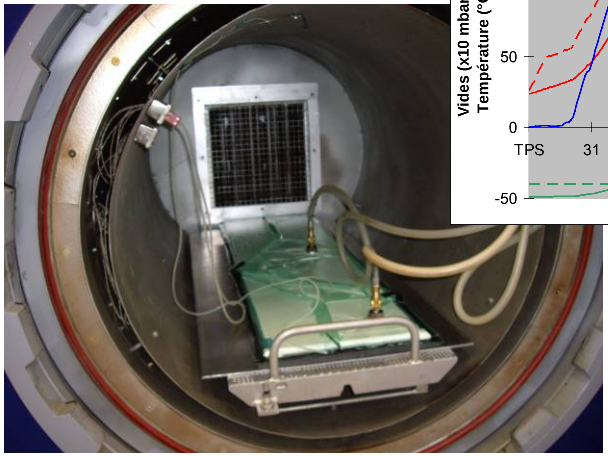


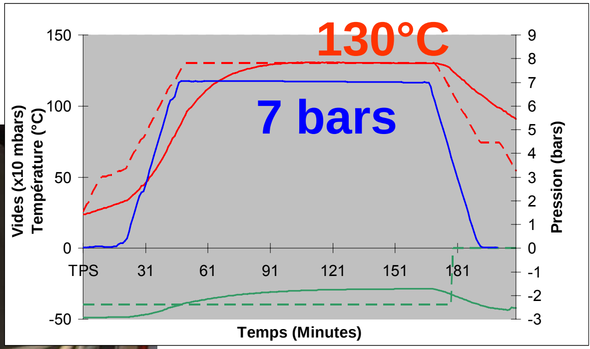
3 – Compression step

4 – Thermal sensor equipment



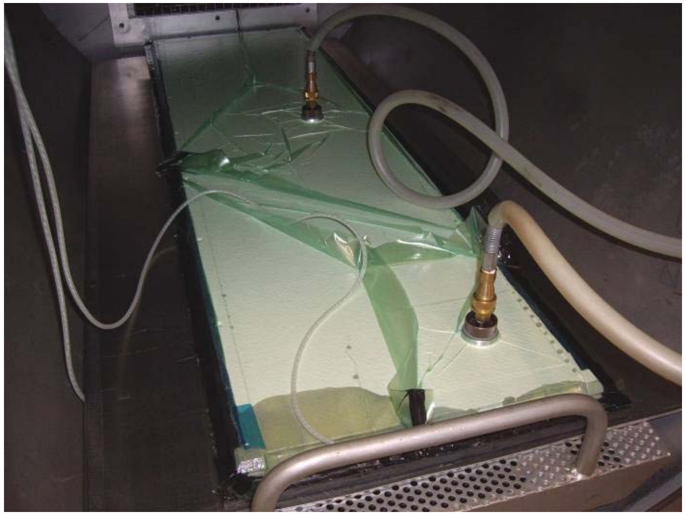
5 – Curing operation (autoclave)



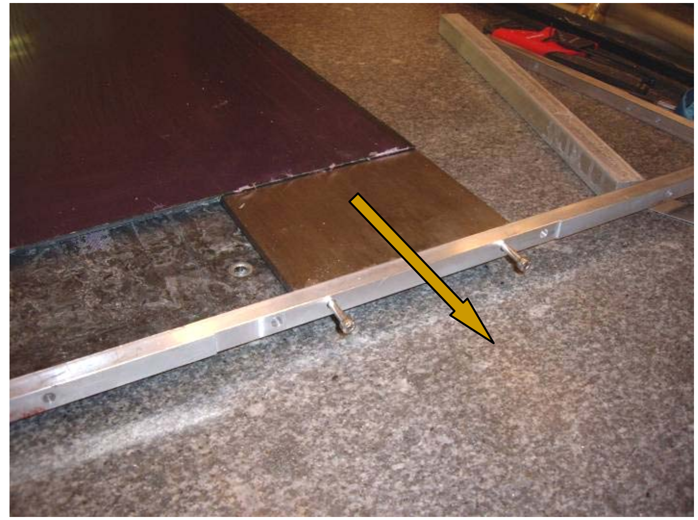


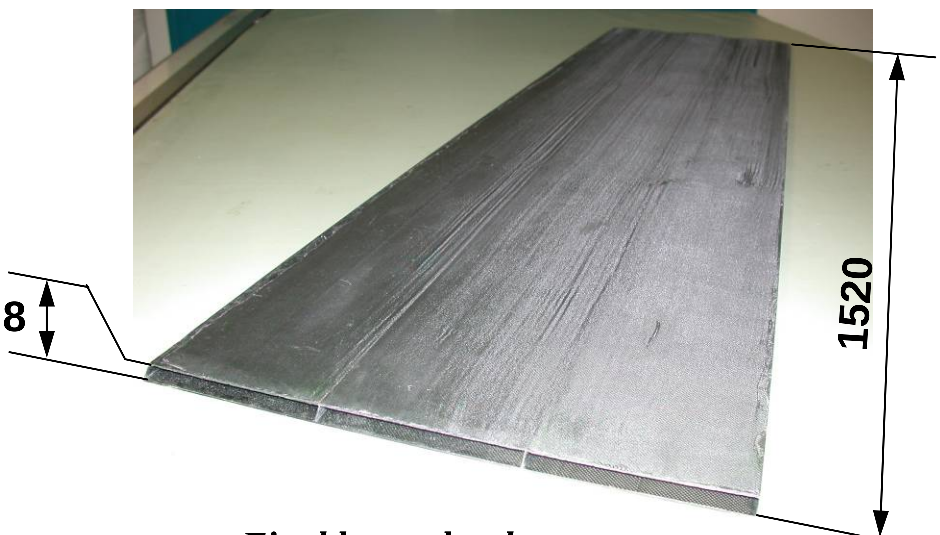
# Demonstrator - First long test (2/2)

**6 –** After curing step

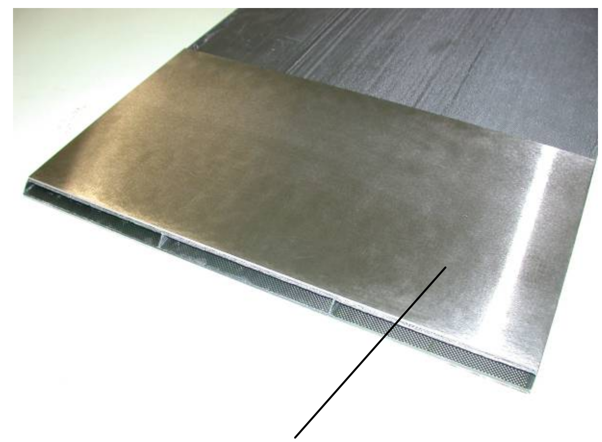


**7 –** Main issue : cores extraction – OK !!!





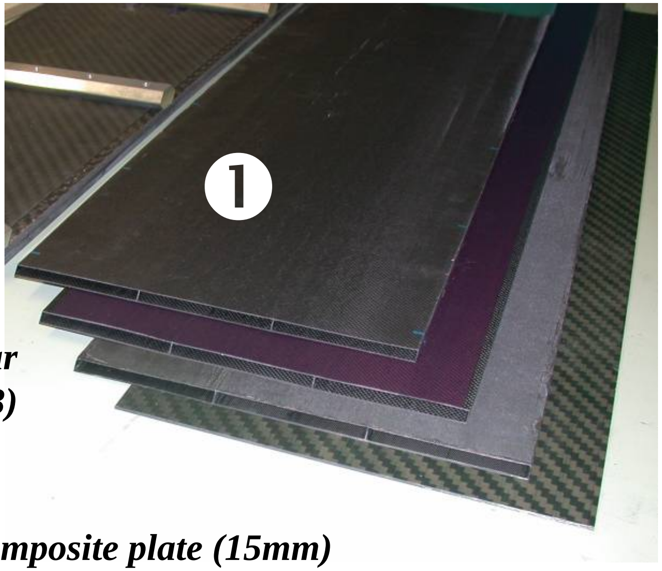

*Final layer alveolar structure*



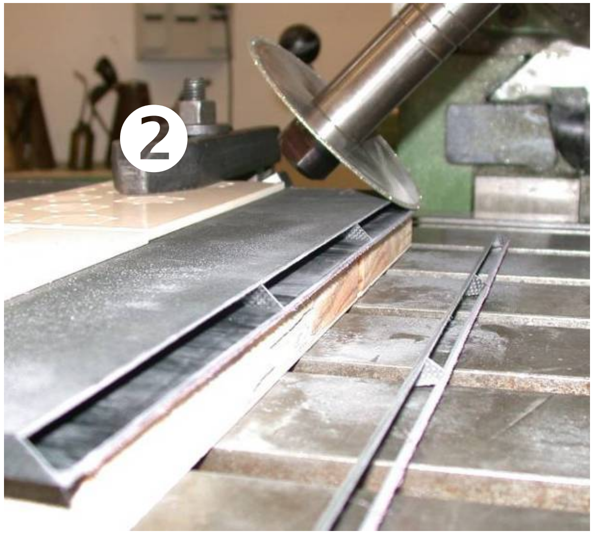
*W plate (2.1 mm thick)*

# 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)




*Alveolar layers (x3)*



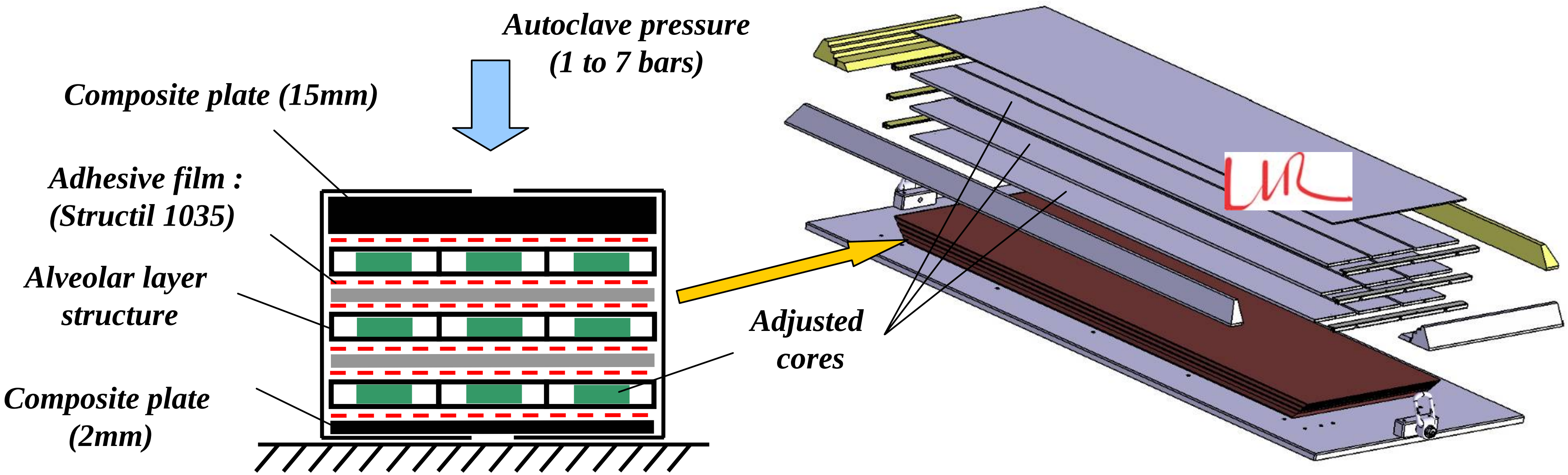

*Cutting tests*

*top composite plate (15mm)*


- ⇨ Global design : *OK*
- ⇨ 3 "Alveolar layer" structure ❶ : *OK*
- ⇨ Cutting test ❷ : *OK*
- ⇨ Composite plates ❸ (LPSC) : *OK*

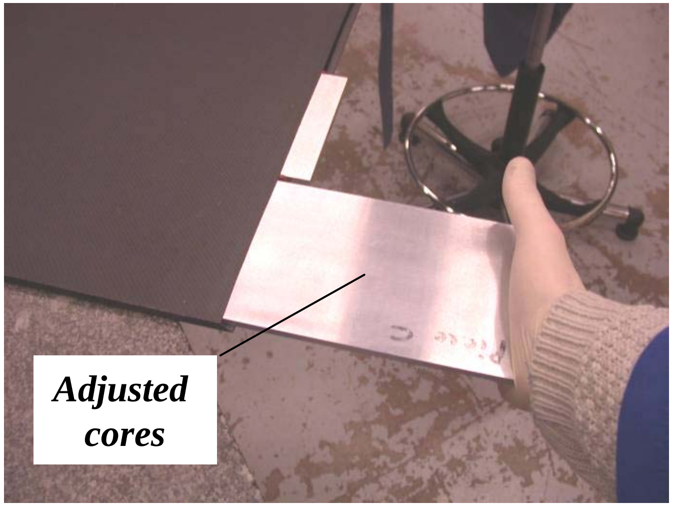
# Demonstrator – Assembly mould

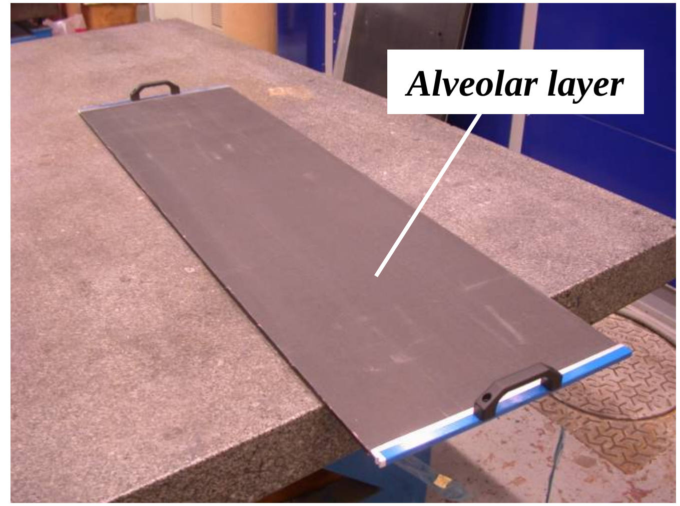
- Cores system for the assembly solution : use of adjusted metallic cores (in thickness) keeping each alveoli against W plates to obtain a correct assembly during the curing
- Curing parameters studies (thermal inertia)
- Reduce costs by changing the kind of carbon fibers
- Tests of deformation measurements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



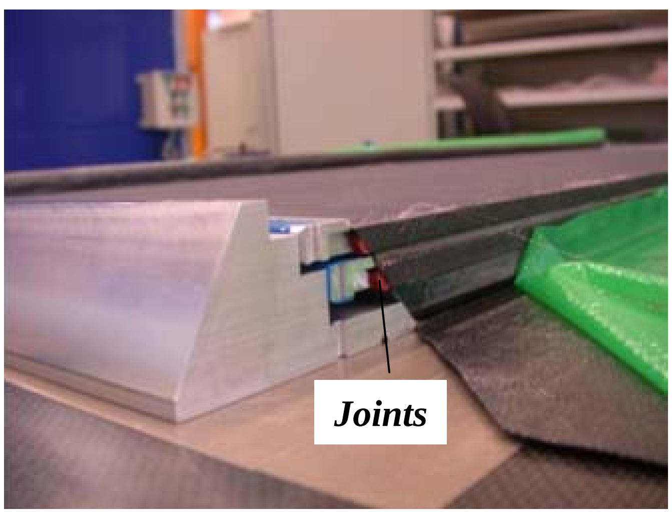
# Demonstrator - Assembly Steps (1/2)

## 1 - Alveolar layers preparation

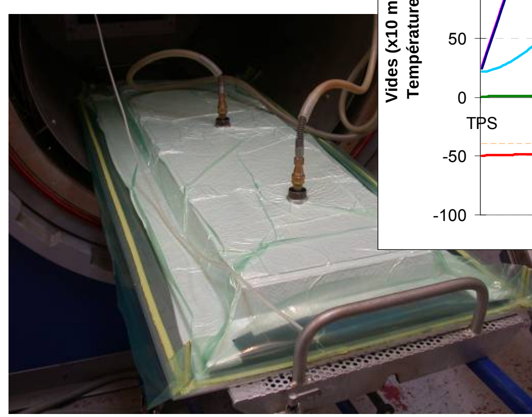


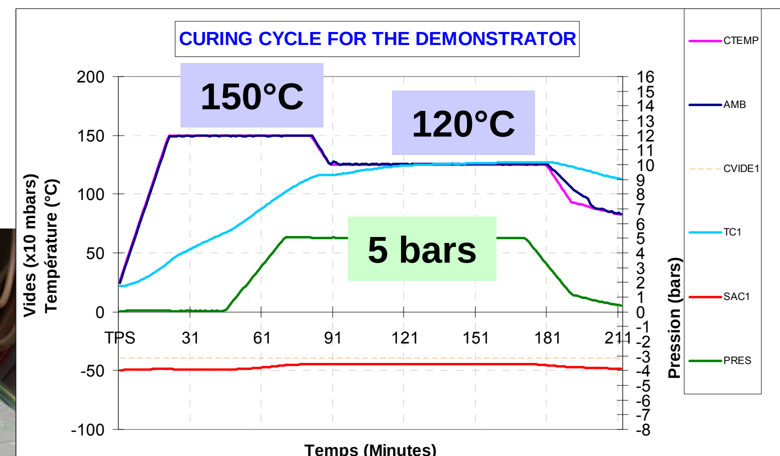




## 2 – Assembly in the mould (3 alveolar layers + 2 W layers)



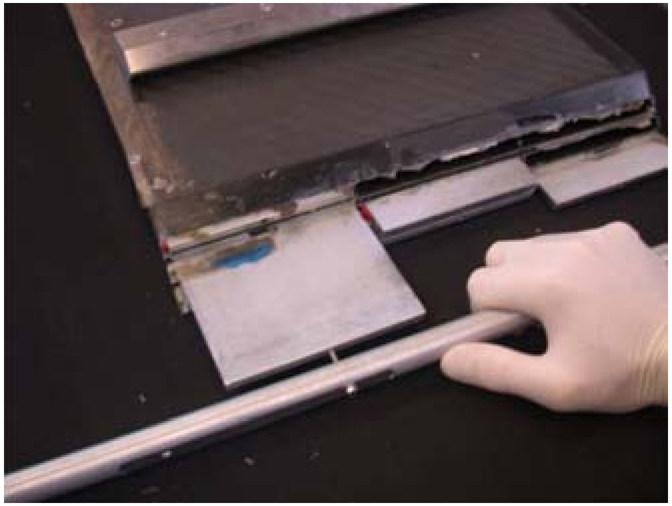

## 3 - Curing

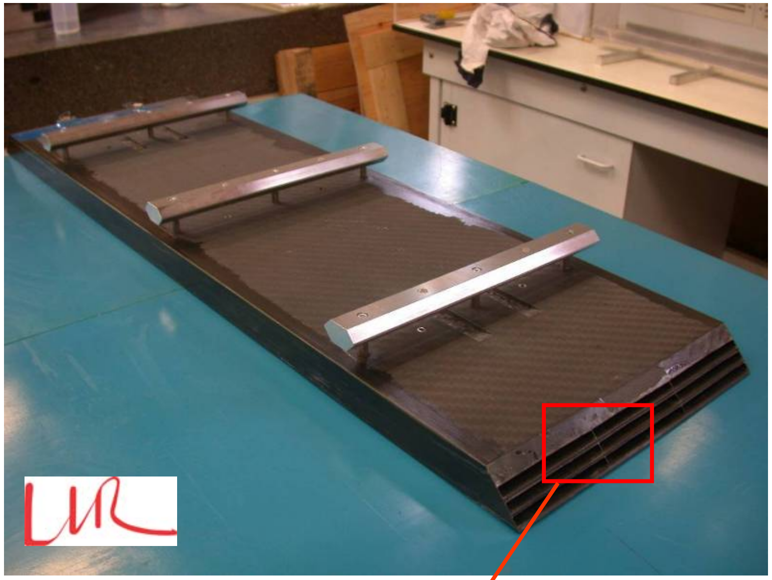


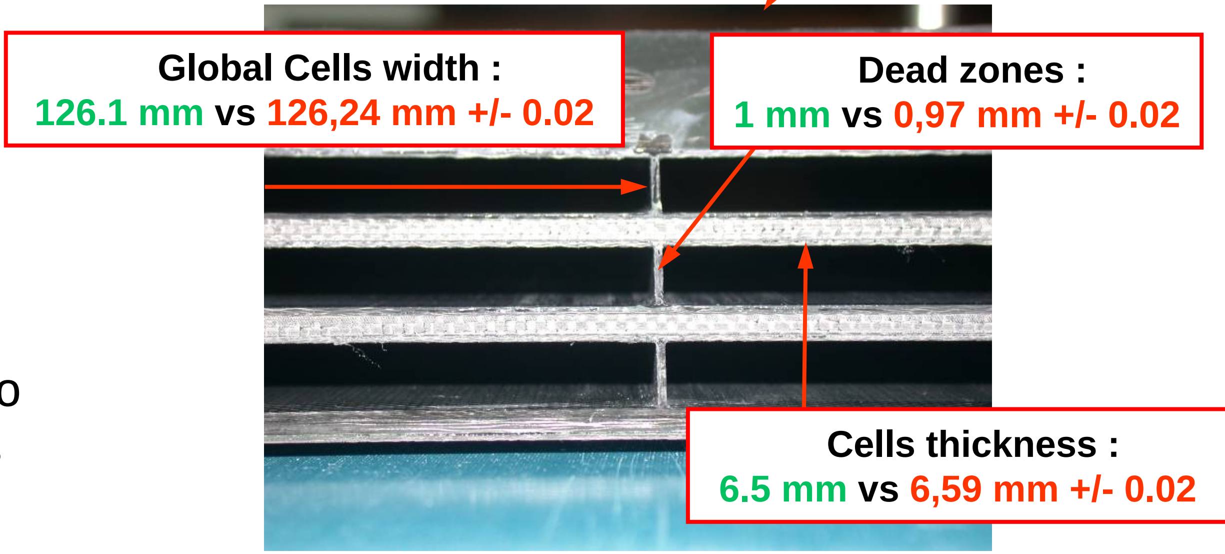


# Demonstrator - Assembly Steps (2/2)

**4 –** dismounting steps





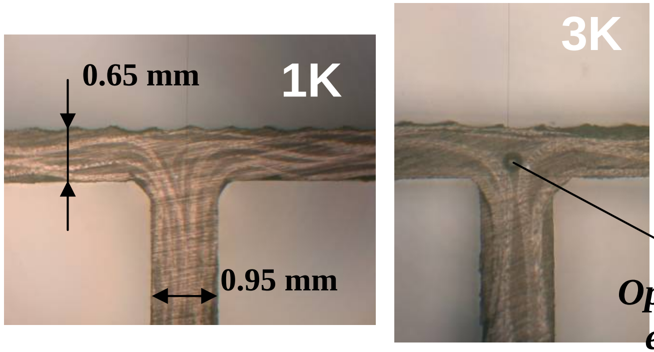



- Good precision (width, dead zone, cells thickness) due to the rectification of cores (global tolerance +/- 0,01mm).
- The initial width and thickness are respected. No problem to insert the slabs

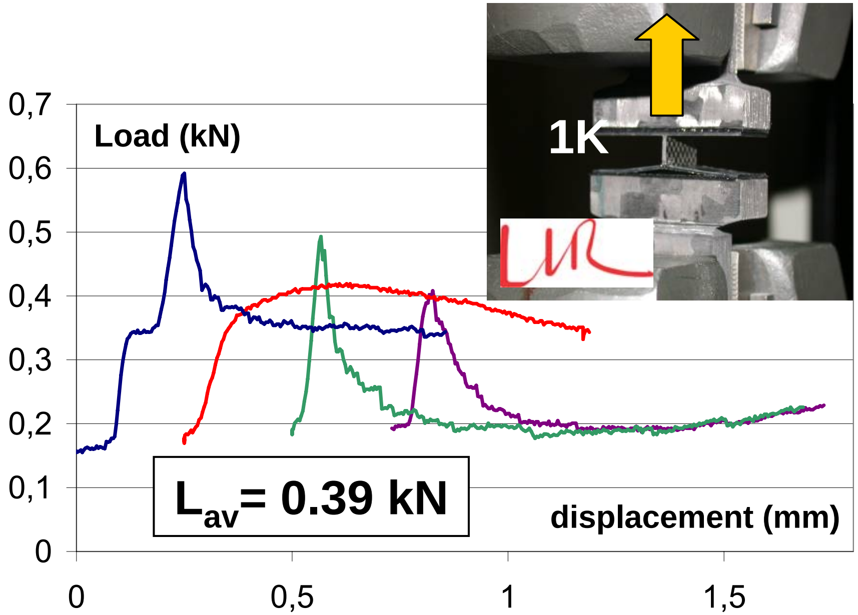
# *Mechanical tests - Destructive*

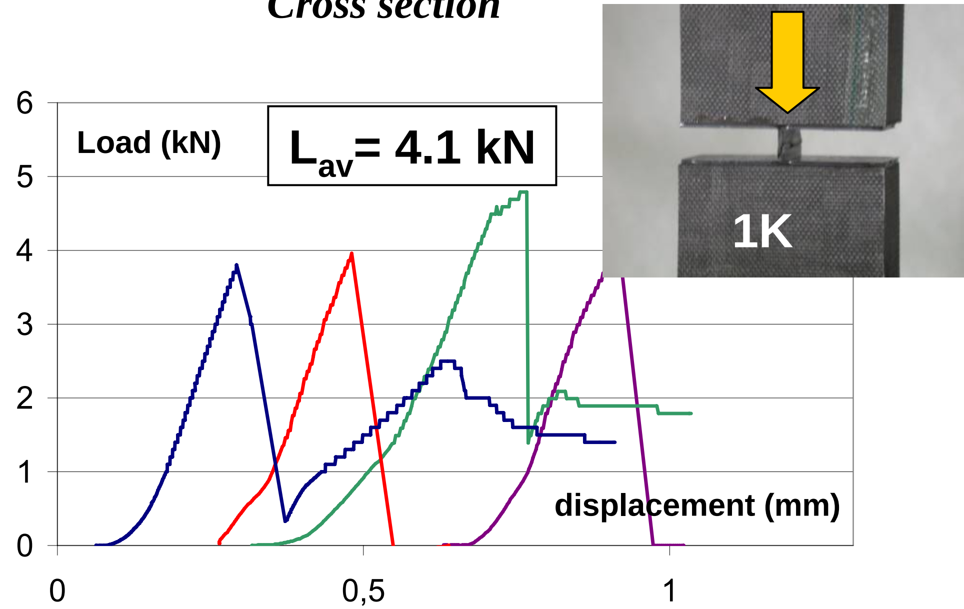
- Destructive tests of inter alveolar walls until breaking of interface in order to evaluate loads and elongations under Tensile and compression loading cases

- 2 kinds of carbon fibers :
  CC120 (1K) : 0.12 mm thick ; 130€/m2
  CC202 (3K) : 0.25 mm thick ; 65€/m2



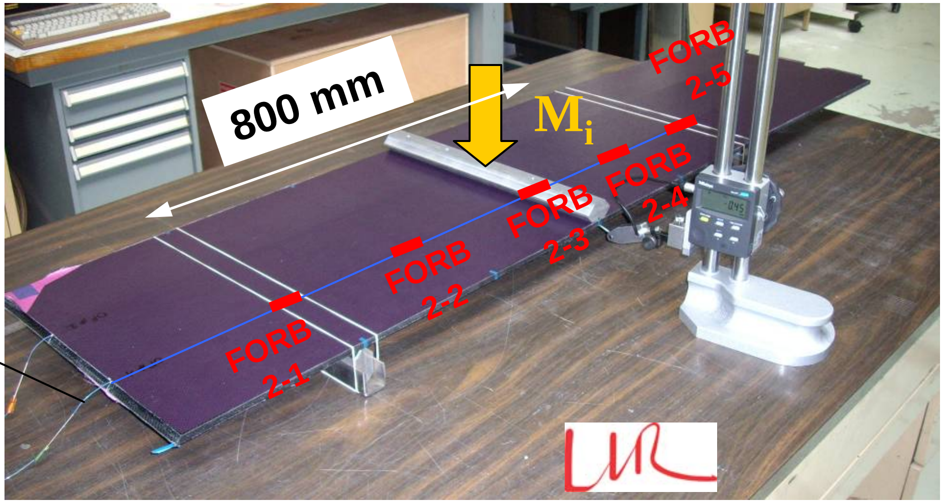

*Cross section*



# *Mechanical tests – bragg grating*

- Non-Destructive tests using optical fibers with 5 bragg gratings along the alveolar structure layer

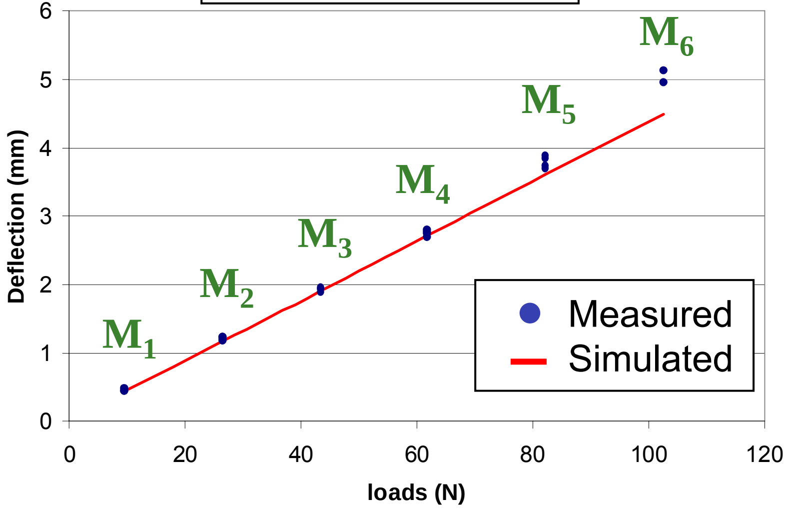



*Optical fibers*

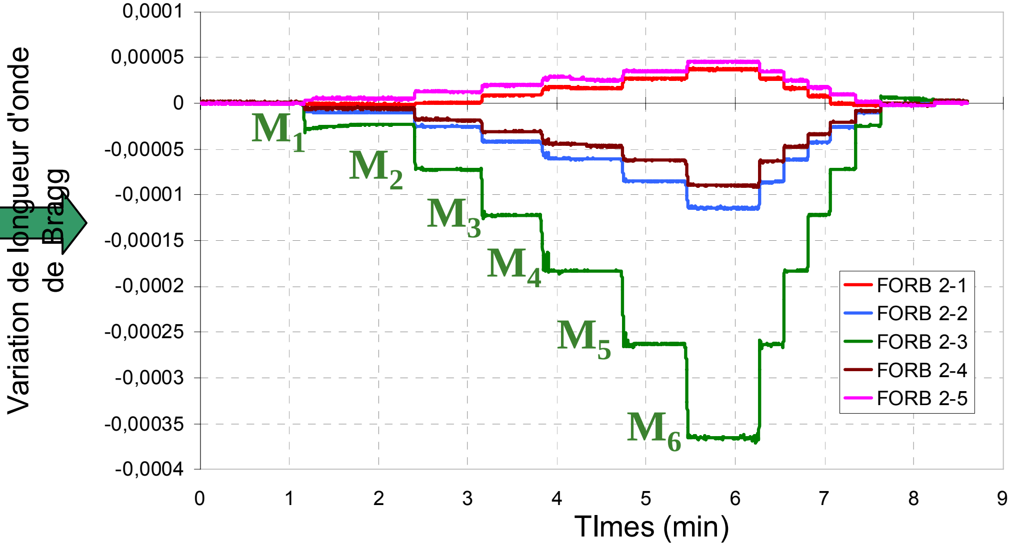
- Bending tests (3 pts):

  6 different cases (Mi) compared with SAMCEF simulations

**Bending behaviour**




**Optical fibers behaviour**

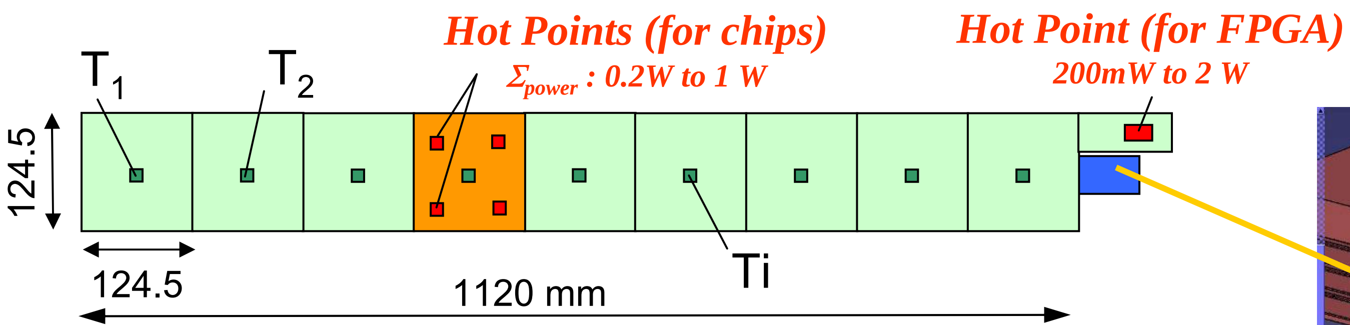


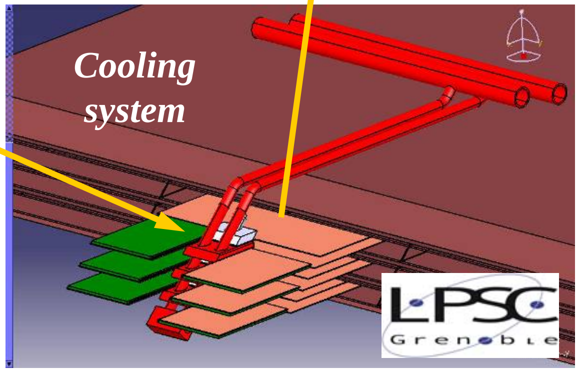
# Thermal tests - Demonstrator

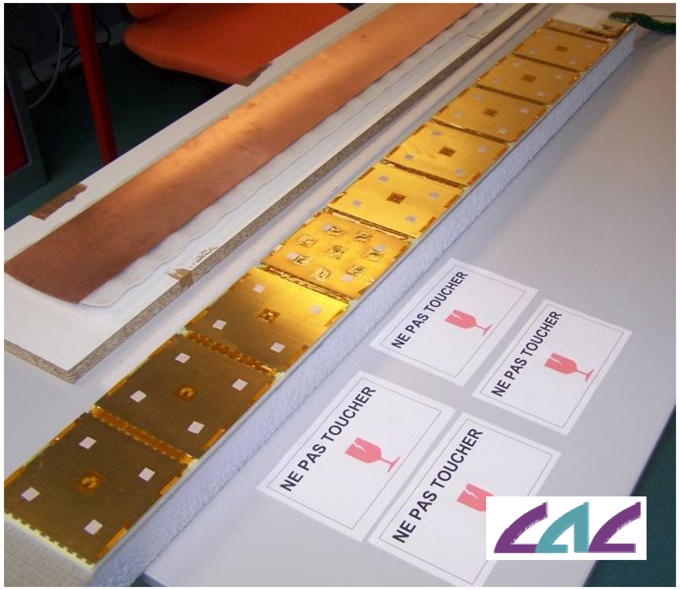
Slab cooling tests (1 Hot ASU + 8 thermal ASU):

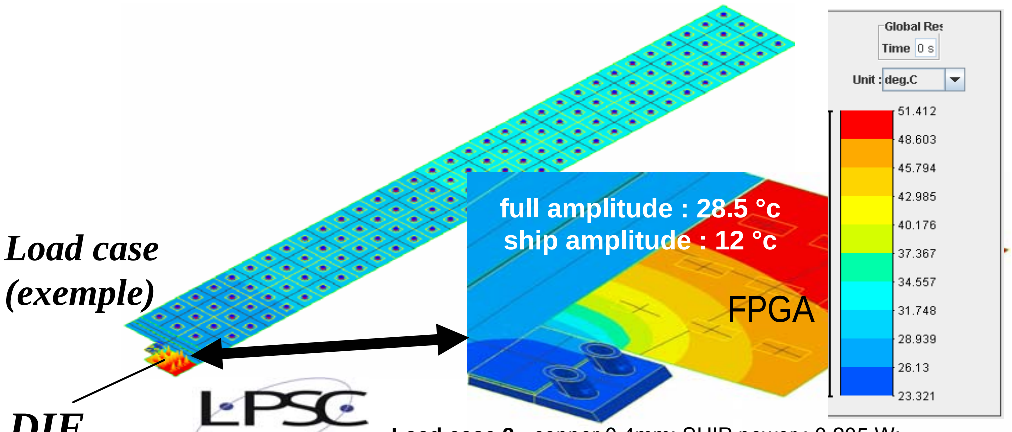
- Correlation with simulations (transfer coefficients, contacts ...)
- Check a thermal dissipation behaviour close to EUDET design
- Validate the cooling system (400 µm copper plate drain + pipes)

Copper (400 µm)




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