CALICE Si/W ECAL

Reminder on SiW Ecal endcaps and cooling system

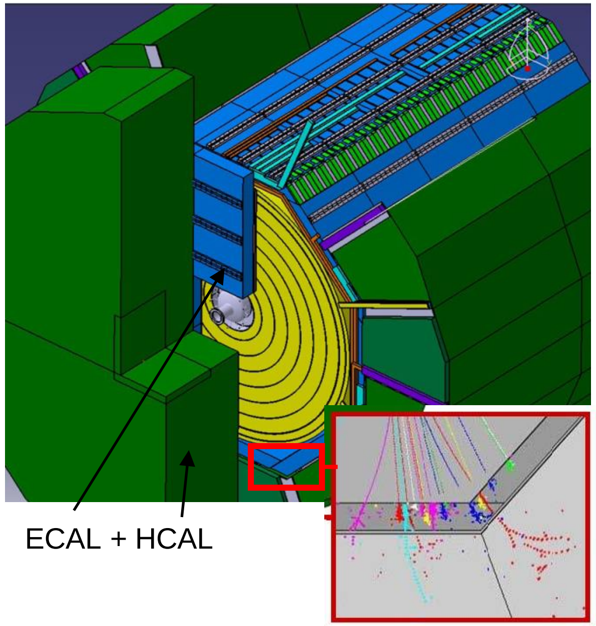
1. Design of the EM end-caps
2. Fastening system on HCAL
2. Electronics and cooling system (end-caps + barrel)
4. Cooling system Integration - AIDA2020
5. Integration of EM End-caps in ILD

Denis Grondin , Julien Giraud

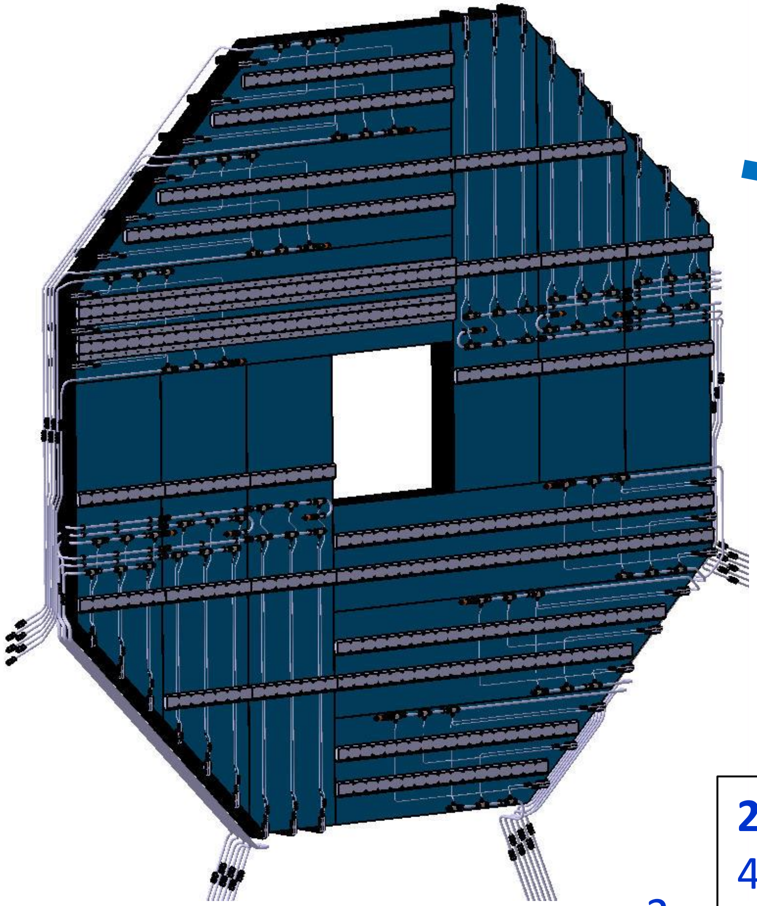
CALICE Collaboration Meeting Everywhere – March 24th, 2021

I.1 – Design of the SiW ECAL End Caps

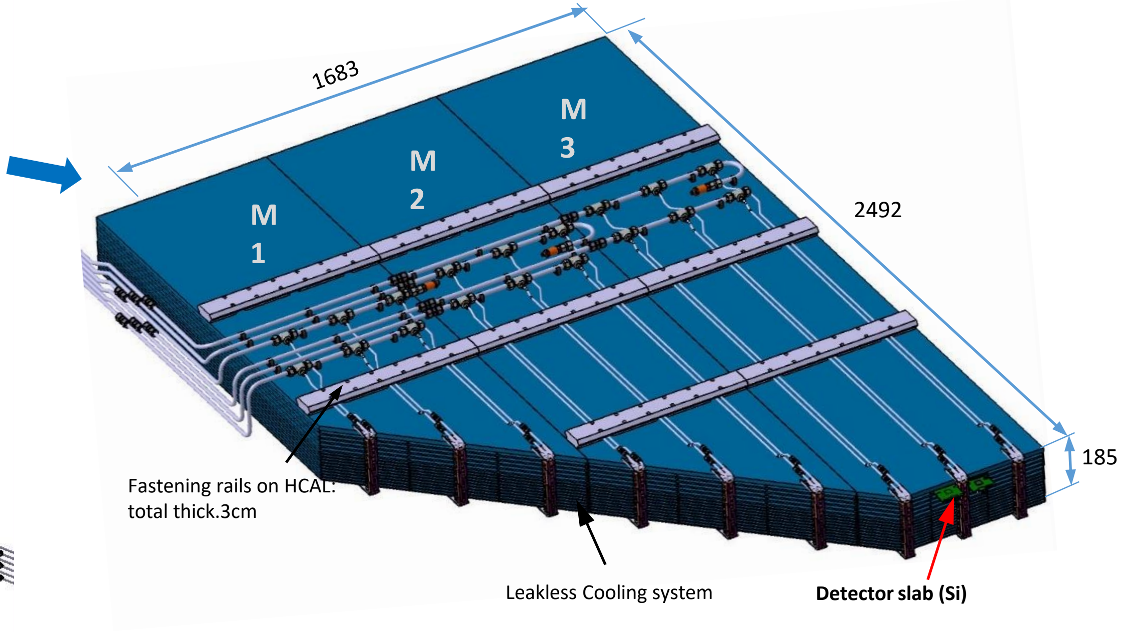
End-Caps: 25,5 t - modular alveolar structure - composite W / Carbone HR
Each End-Cap is divided in 4 quarters composed of 3 modules each
There are 3 alveoli rows per module, each containing 15 alveoli to host Ecal layers



ECAL End-Cap is fastened on HCAL End-Cap inner face with rails



Baseline ECAL End-cap D=4188
Rear face fully equipped with rails and cooling pipes



1 quadrant of 3 modules (~6,5 t)

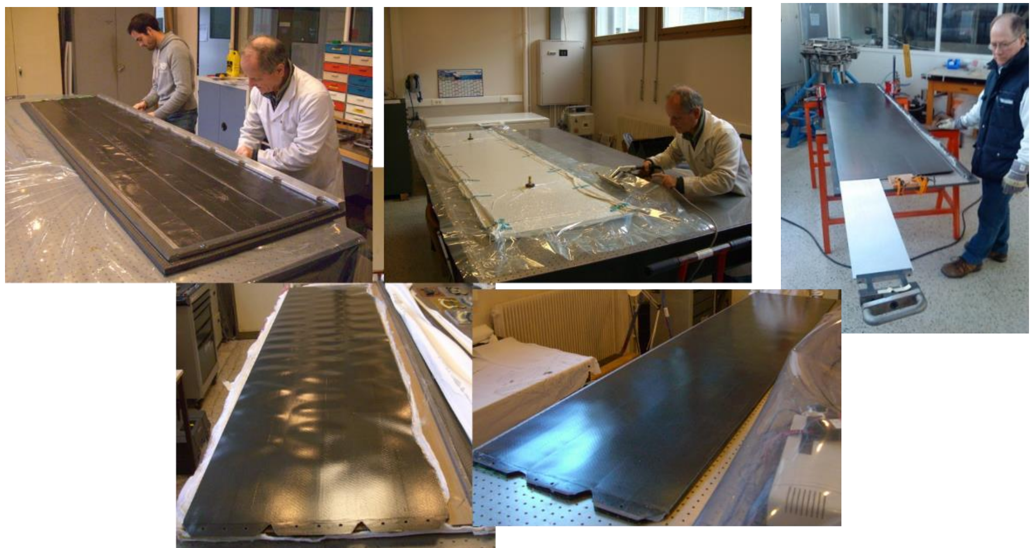
2 x

25,5 t / EC
4 quadrants of 3 modules
12 modules
540 alveoli

	Weight(kg)
Baseline ECAL End-cap D=4188	25208 +rails+services
1 Quadrant	6302
Module 1	1585
Module 2	2164
Module 3	2553

I.2 – Si/W ECAL End Caps : Alveolar structures

CFRP (Carbone HR) components produced with several composite technologies

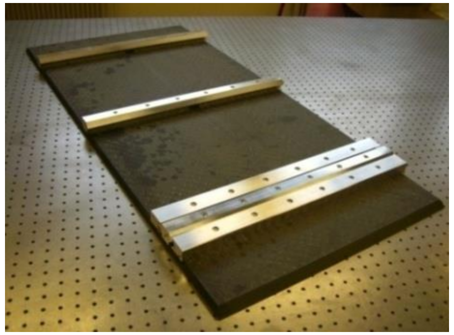


CFRP structures: longest layer of one End-Cap module

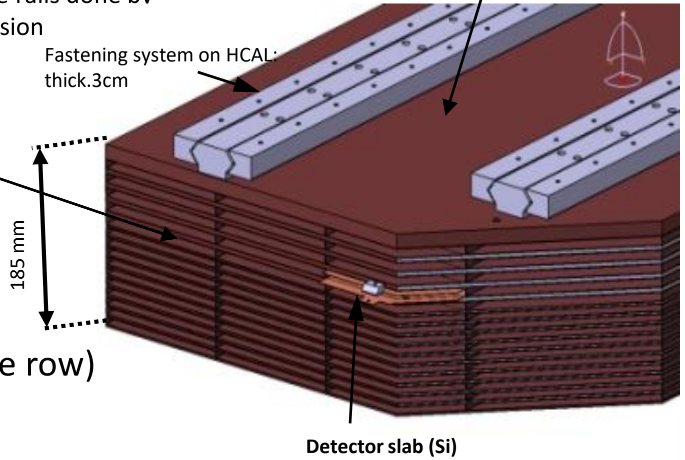
Moulding of one layer / 3 alveoli
L = 2.490 m wall thick. = 0.5mm

Thick Carbon HR plate Th. 13 mm , with inserts and composite rails done bv thermocompression

Thick plates / fastening



End-Cap thick composite plate 13mm+ metallic inserts for single or double row rails



Same concept / EUDET module for barrel (LLR)
bag molding & autoclave
but different shapes and length of alveoli

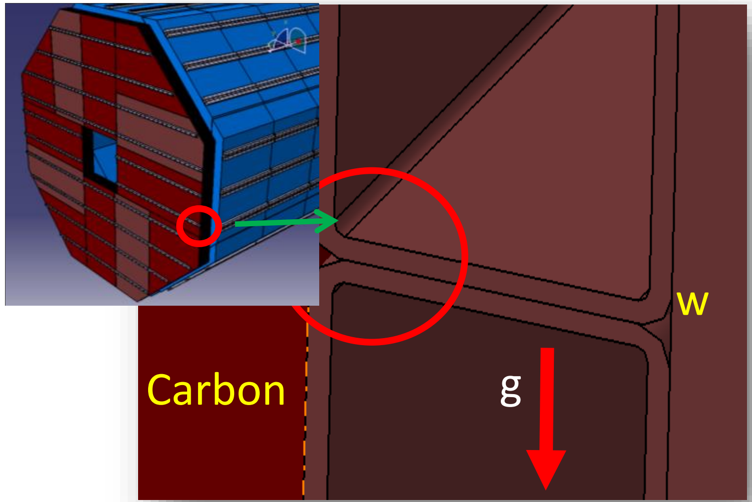
Construction of full size CFRP (Carbone HR) mechanical structures

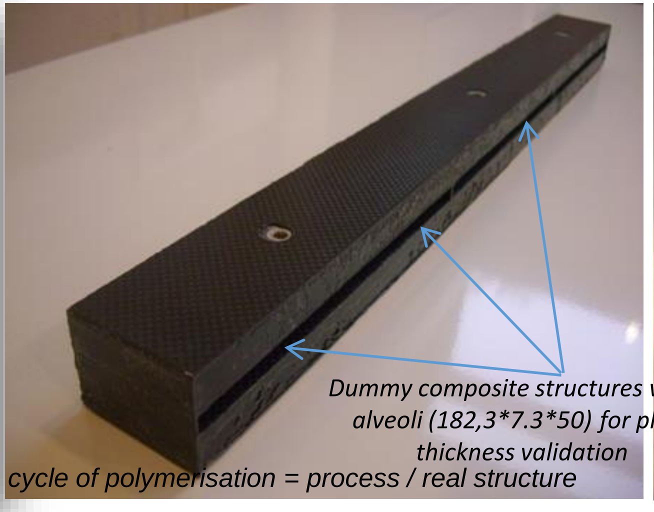
- Up to 2,5m alveoli
- Interface to other detectors i.e. HCAL in ILD
- Moulding of 1 layer of 3 alveoli - 2,5m End-Cap
- Design of specific tools / long wrapping
- Validation of technolocal solutions (bending of thick plates /rails double row)
- Industrialisation aspect of process / long alveoli layers

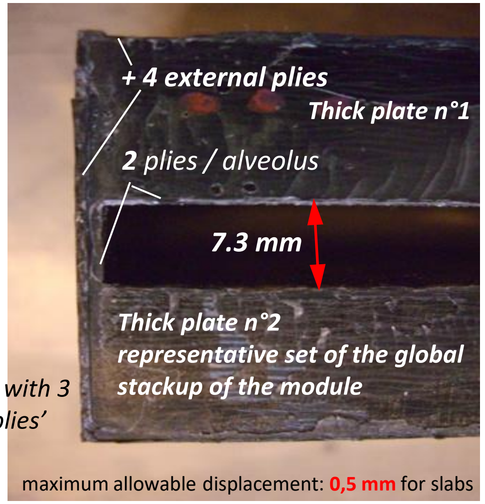
Pioneering work by CALICE France for compact calorimeters

I.3- Composite structure: shearing tests and optimization

Goal: Adapt FEA parameters to simulate the whole structure





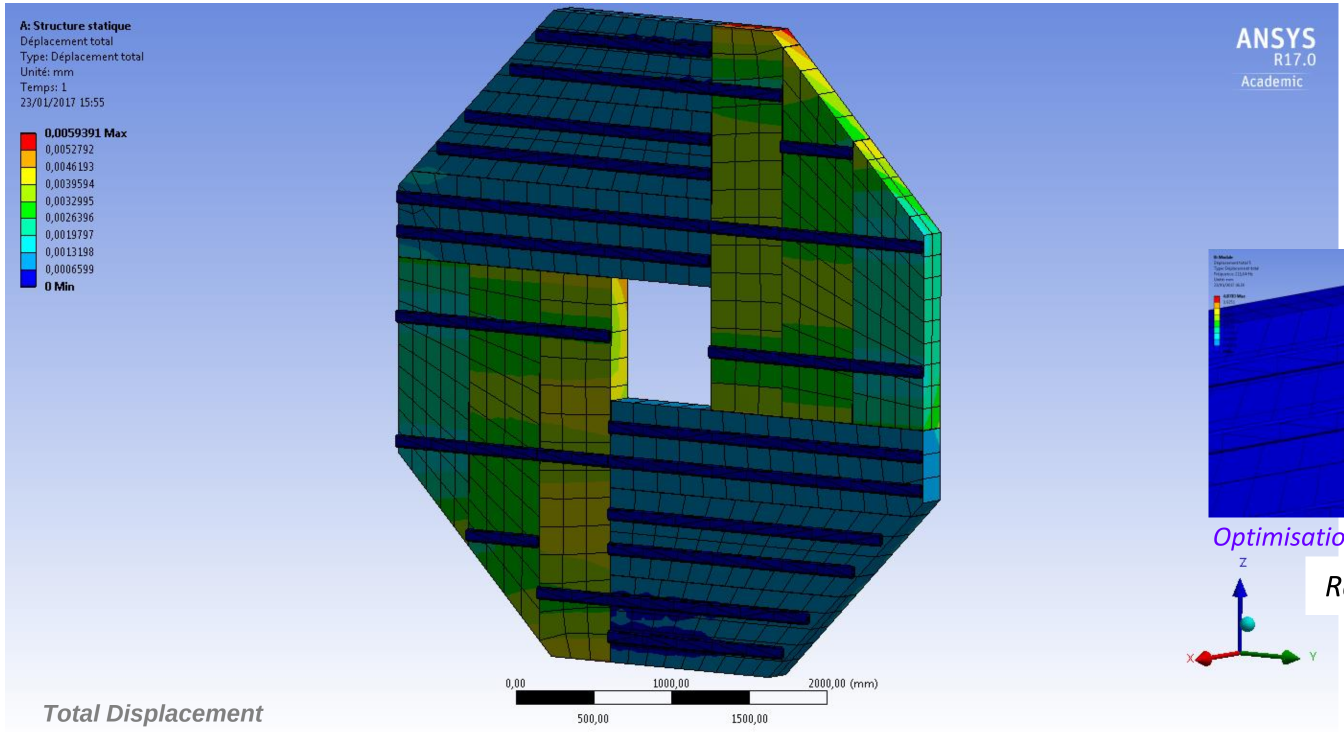


Charge & discharge cycles: hysteresis in specimens' behaviour which evolves towards a progressive decrease in the force / displacement with the gradual breakdown of the resin before destruction of the composite

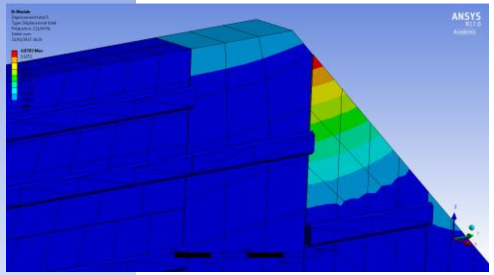
- Correlation of tests with FEA simulations
- Optimization of composite wrapping / long structure
- Shearing tests on demonstrators
- Ensure repeatability of process & characteristics

Problem of bending stress of alveoli skins: influence / evolution of thickness of outer plies

I.4- Composite structure and seism



Total Displacement

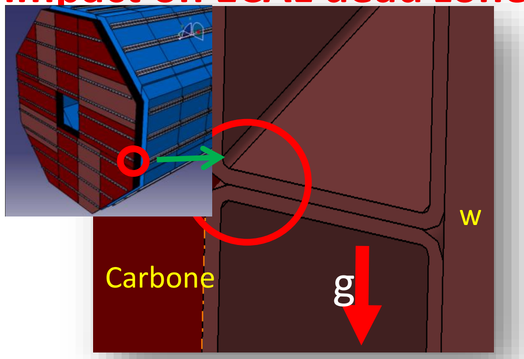


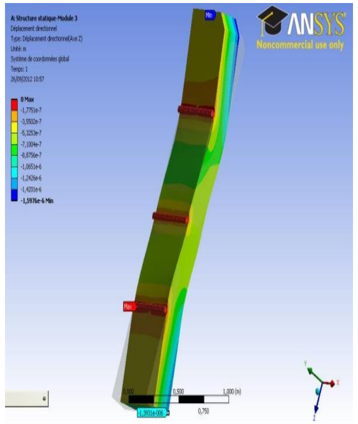
Optimisation on going / rails localisation/ on going

Rails fixed

Mode	Fréquence [Hz]
1,	203,56
2,	204,24
3,	206,17
4,	208,13
5,	211,64
6,	212,02

Impact on ECAL dead zone





Composite simulation
Optimisation of rail localisation
and module' displacements

Problem of bending stress of alveoli skins:
influence / evolution of thickness of outer plies

Safety coefficient Degradation / repeated stress for each module
- Static: Sufficient / to the stress induced by weight of modules
- **not sufficient** / seism (s =3.2 for Japan?)
  / risks during integration and transport

-> increase nb of ext. plies... **Impact on ECAL dead zone=0,5mm= 1 extra external ply on modules**

LPSC GRENOBLE | MODANE

I.5- Geometry: electronics interactions

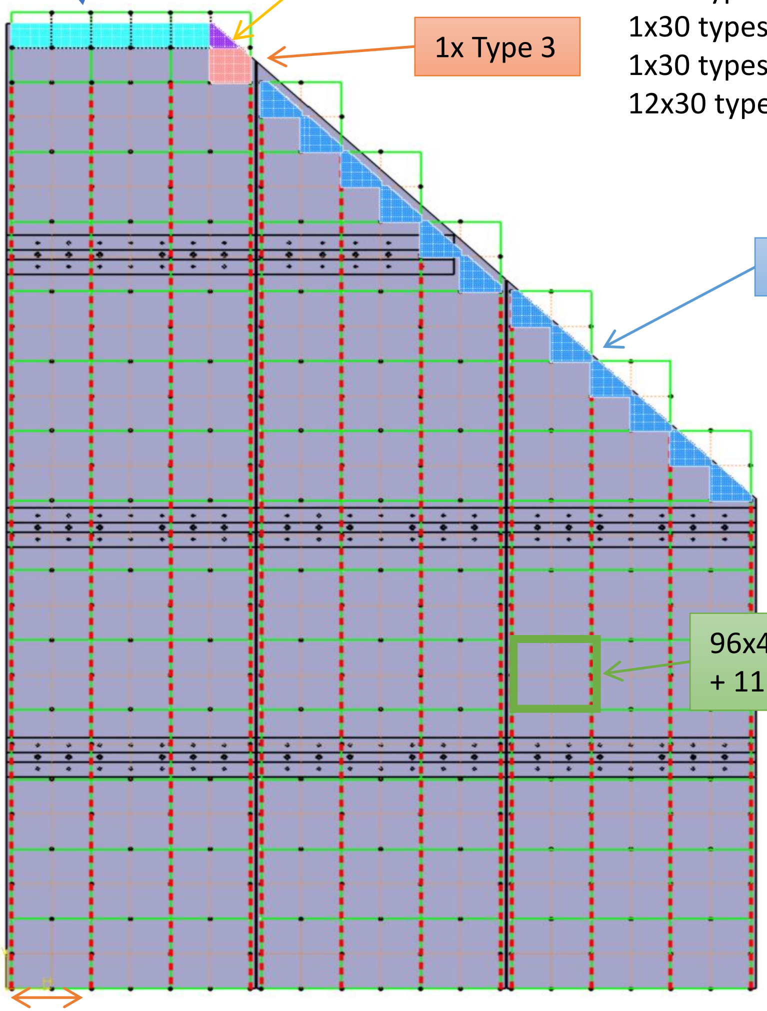
Model with Rext ≈ 2050
Wafer: 90 x 90 mm with gap of 0,1

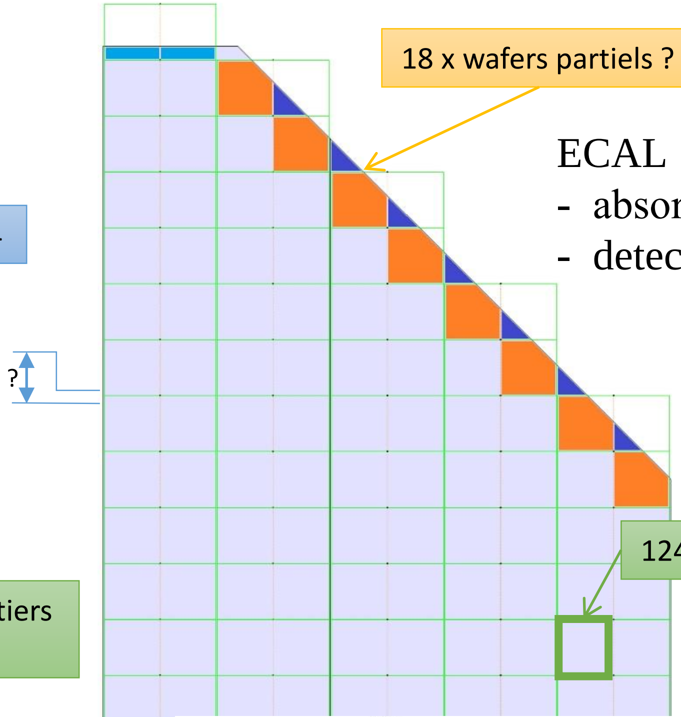
2015

Model with Rext ≈ 2126
Wafer: 130,6 x 130,6 mm with gap of 0,1

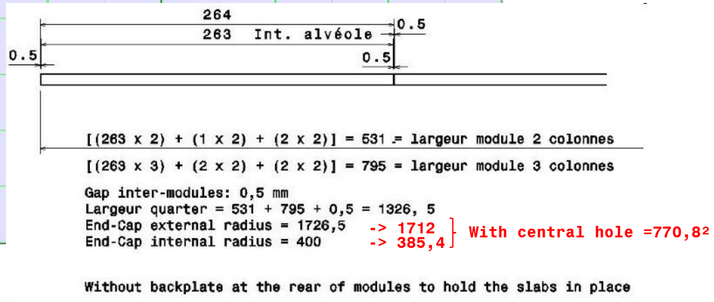
3 types de wafers différents
Pour ¼ End Cap:
- 5x30 types 1
- 1x30 types 2
- 1x30 types 3
- 12x30 types 4

Size of End-Cap Slab's front End ?

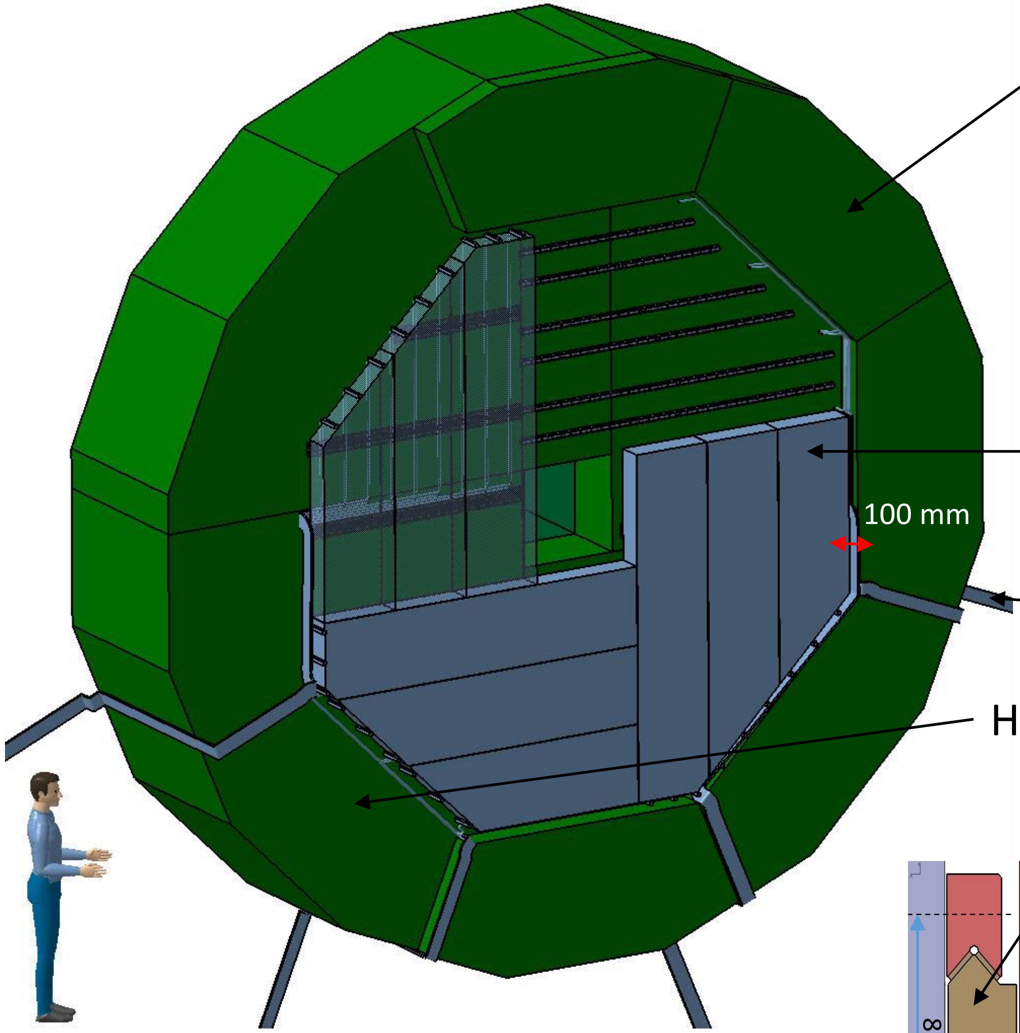


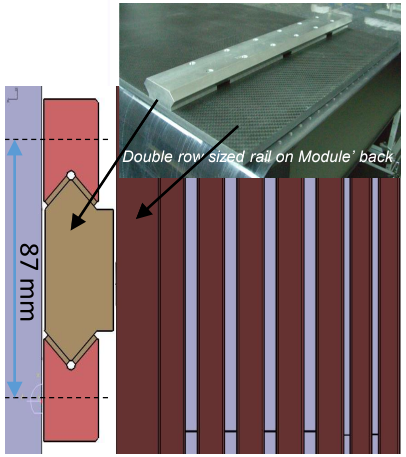


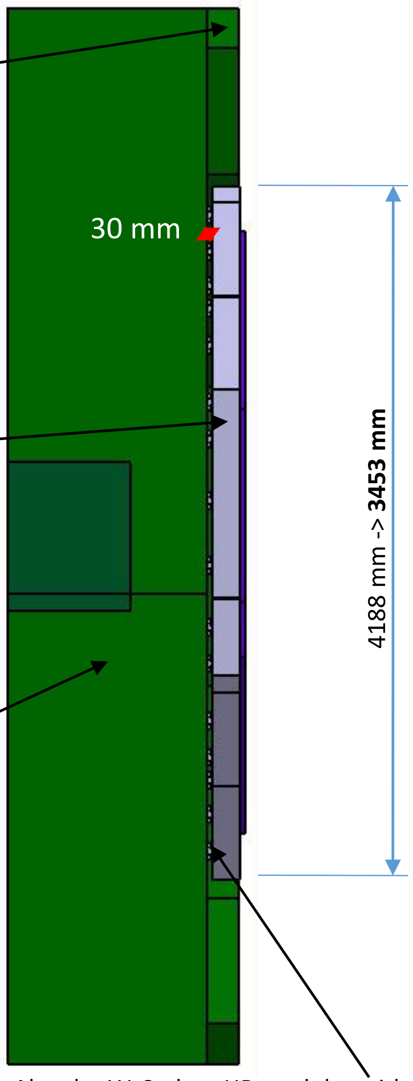
ECAL
- absorbers : W (~80 tons) …
- detector : Si (~300 000 wafers), FE (~1.2 M ASICs), ASU (~ 73000 PBCs) …



II.1 - Fastening system on HCAL



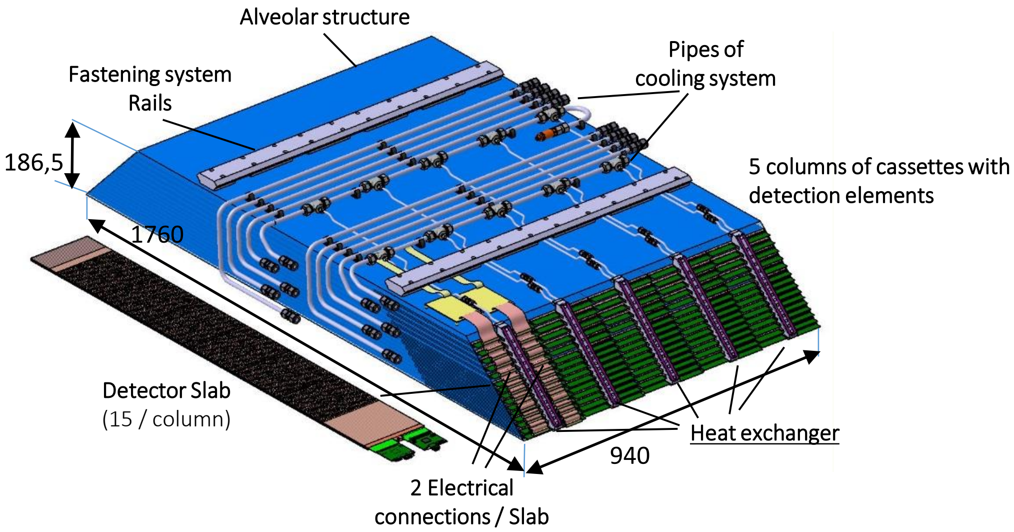


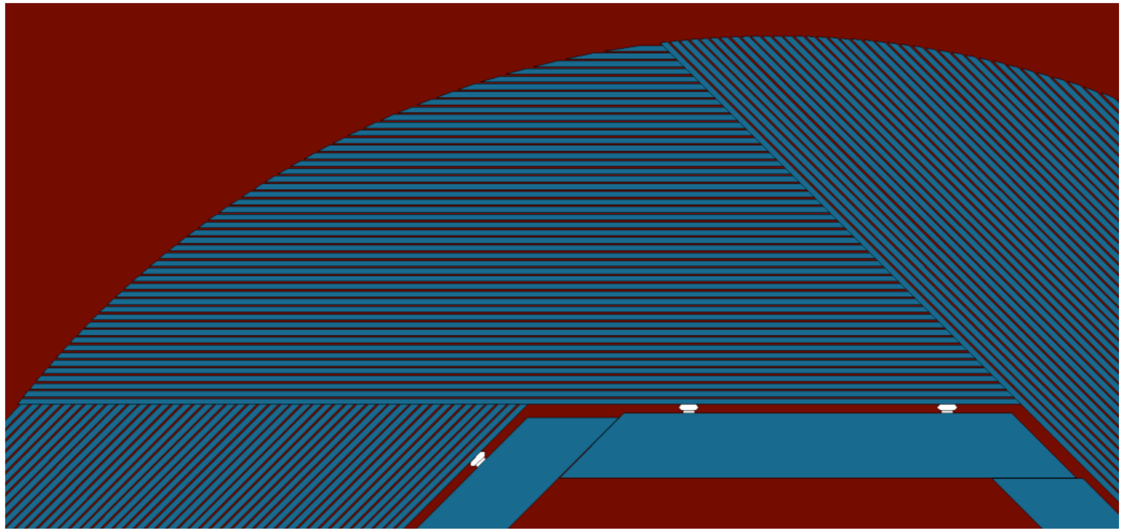


4 quadrants subdivided into 3 modules each
D_{endcap} = 4188 mm
Weight of endcap ~ 25.5 t

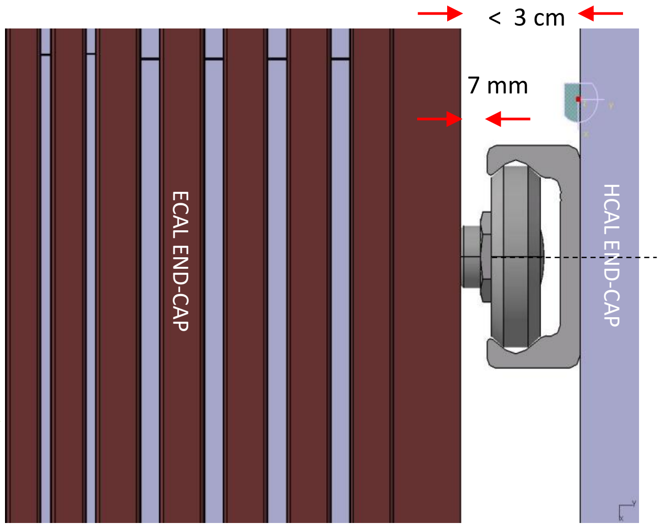
Alveolar W-Carbon HR modules with Rails for Fastening system on HCAL
Tests foreseen in 2017 for definition of interfaces (flatness/precision…)

Guiding and fastening system of modules (ends-caps + barrel)…and <u>free passage for services</u>

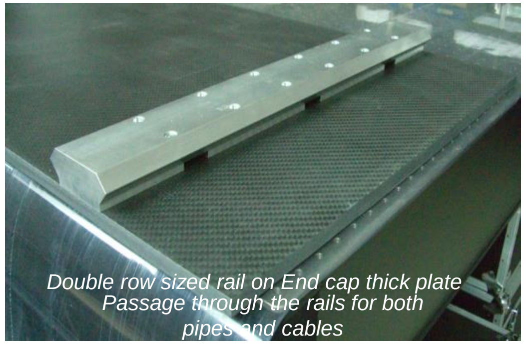


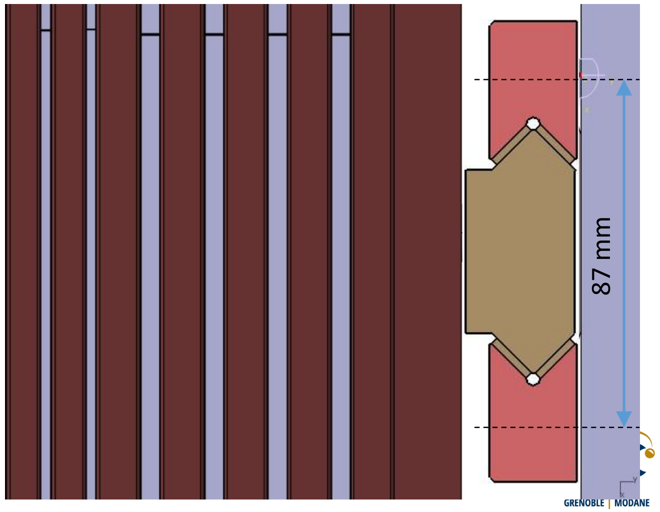


2 / Self-aligning rollers



1 / Specific shaped rails



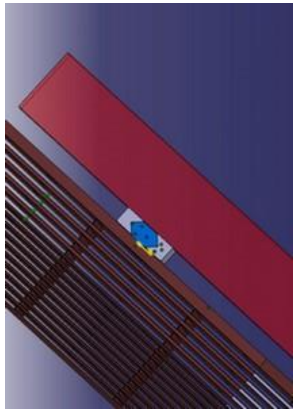


II.3 - FASTENING SYSTEM ON HCAL

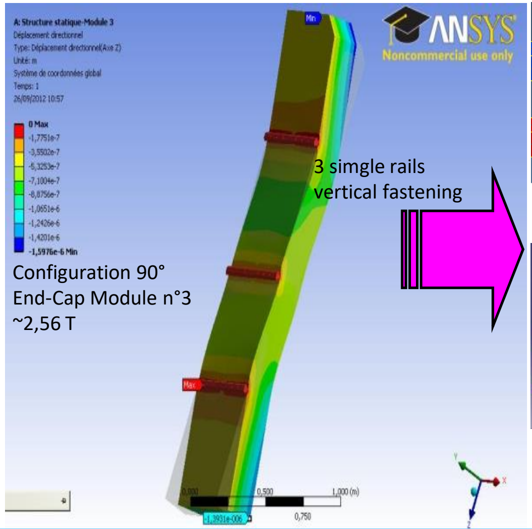
Guiding and fastening system of modules (ends-caps + barrel)

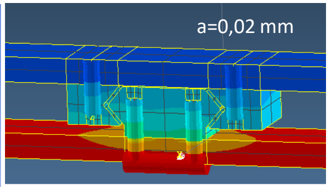
Full Prototype EUDET with opening in rails for the cooling pipes and services' path facing each column

Metallic inserts casted in the thick CFRP plate, holding the rails

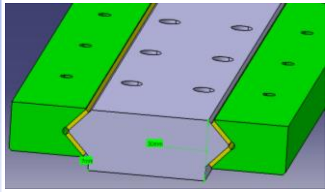


Design 3D of different fastening systems thick. 30 mm & double row





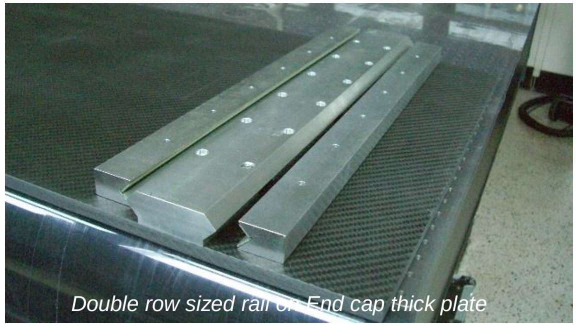
FE simulation to determine the rigidity of rails



Détermination des rails doubles

Développement de nouveaux rails

FE simulation of End Caps : MODULE N°3
2.5 m long / 3 columns / position 0° and 90° / M = 2550 Kg
⇒ but / simulations: Influence of the **position / nbr** of rails
Even with a two double rows rails instead of 3 simgles
, the module' bending is less important



Double row sized rail on End cap thick plate

Carbon HR Rails for EUDET

High pressure mold for Carbon HR Rails

- *Validation* of technological solutions (bending of modules)
- Industrialisation matter for process (carbon rails)
- *Optimization* / simulation of best *localisation* on modules
- Integration of an *heavy handling tool* for modules' tests / rails

III - Electronics and Cooling System

Cooling needs for electronics and constraints

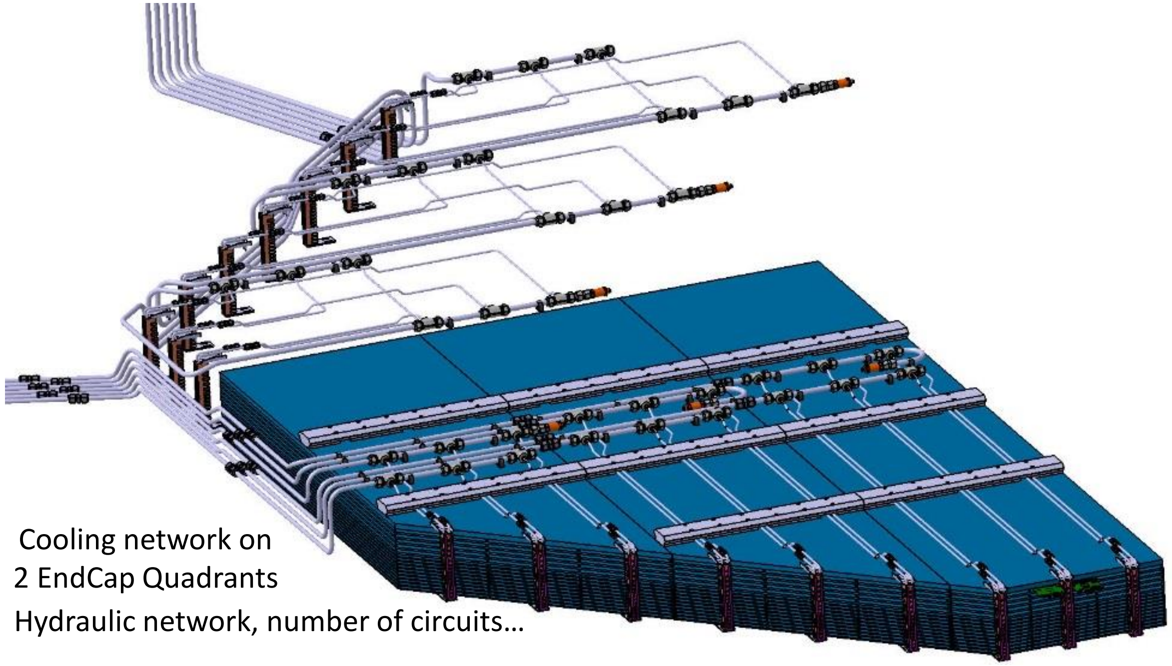
- Mechanical constraints due to electronic design (geometry of DIF card);
- Space available: heat sources location;
- Heat power to dissipate, including (chips + DIF FPGA + interface components);
- Electronic systems and cooling Interfaces at slab's extremity
- Hydraulic network, number of circuits…

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168.

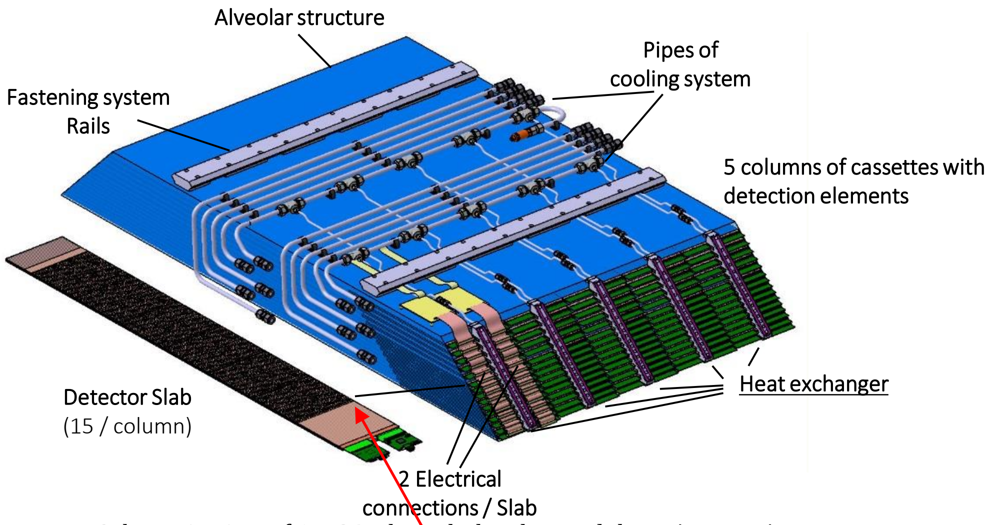
III.1 – Mechanical constraints due to electronic design

ECAL: (CFRP+W structures + Silicon detectors)
The cooling technology is active, using **fluid circulation**

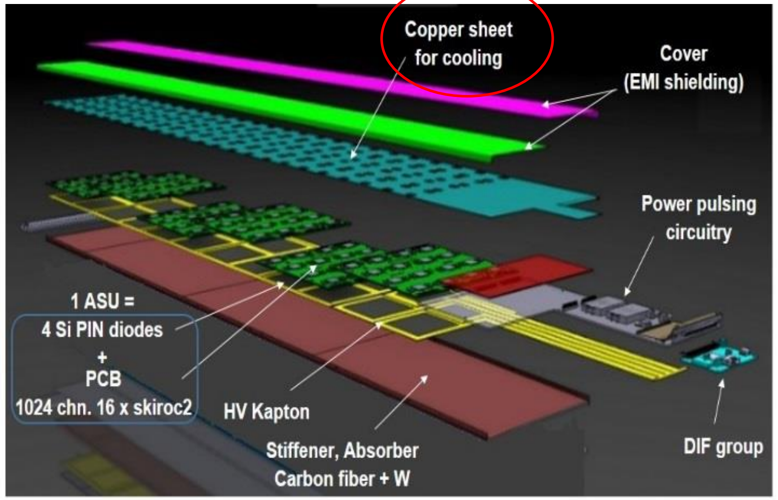
- **Tests and simulation on detector** (EUDET module)
  - Demonstration and performance of the thermal model
- **Integration**
  - Detailed design of cooling pipes scalable to ECAL detector
- **Thermal model**
  - Full Leakless System Design and Analysis



Cooling network on
2 EndCap Quadrants
Hydraulic network, number of circuits…



Schematic view of 1 ECAL barrel alveolar module with its cooling system - 10 to 15 layers of double sided integrated detector elements (SLABs) in a Tunsgten-Carbon Fiber (W-CF) support

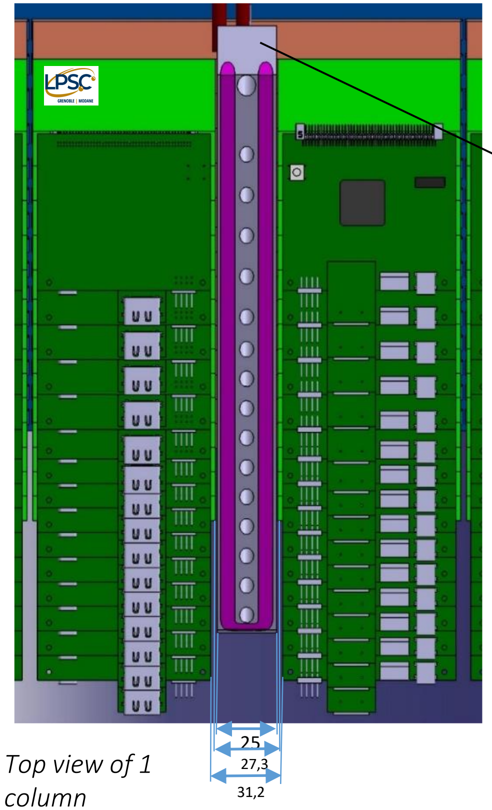


Exploded view of half a long slab with 6 ASU – (An assembly line for long slabs with 8 connected ASU is AIDA-2020 deliverable D14.3)
final goal with power pulsing 1/100 s: ECAL 4.6 Kw

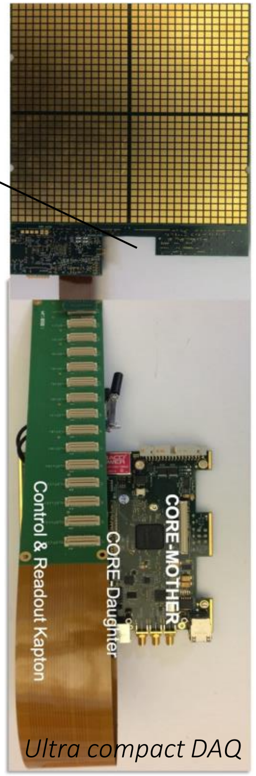
III.2 – Cooling System interface & local heat exchangers

Design of the local heat exchangers: one prototype of the water heat exchanger fitting the dimensions of one column of the EUDET Module has been tested to remove the heat from the front end electronics.
A particular innovative effort is proposed to reduce the dead area whereby the whole column of 15 slabs (30 layers) is connected to the cooling network.

- Interface to cooling system for compact Carbon/Fibers structures (25 mm width)
- **CU shielding and thermal drain:** a light, fast connected and performing system with copper drains with long exchange surface, adapted to the DIF card to be in contact with FPGA



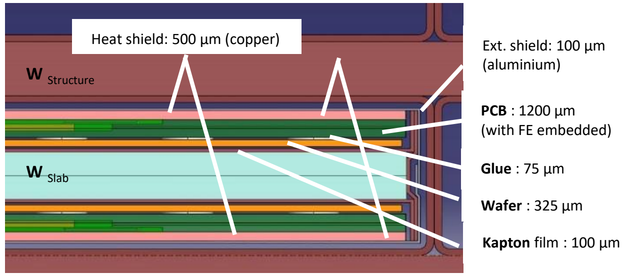
Top view of 1 column



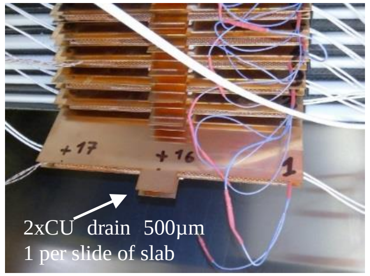
Ultra compact DAQ

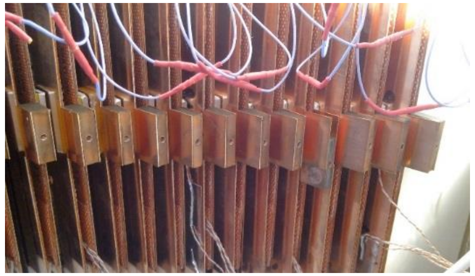
Design & thermal tests of heat exchanger

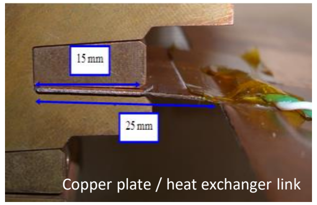
Thermal properties of tungsten and carbon fibre based absorber elements drive the cooling concepts of ultra-granular SiW ECAL. It will feature 10 to 15 layers of double sided integrated detector elements (SLABs) in a Tunsgten-Carbon Fiber (W-CF) support

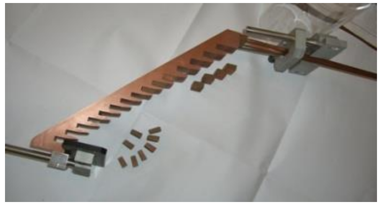
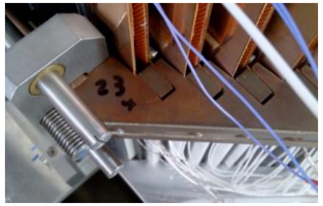


Design of connection of heat exchangers- Schematic view of a slab with 2 copper drains




Copper drain extremities for one column as tested on EUDET module, with copper blocs to screw on heat exchanger





(Left) Design of connection of heat exchangers with one copper drain extremity (Middle) heat exchanger for 15 (x2) connections with Inlet and Outlet pipes on the upper side (Right) localisation of cooling system on one module

The connection of pipes to each slab is done by the way of cold copper blocs, brazed on pipes, inserted between the 2 copper sheets of the slab, in the free space let between the 2 DIF cards.
There is one cooling water exchanger in front of each column.

III.3 – ECAL: Thermal modeling

Thermal modelling

It will feature 10 to 15 layers of double sided integrated detector elements (SLABs) in a Tunsgten-Carbon Fiber (W-CF) support

Cooling needs for electronics and constraints :

1. Maintaining temperature close to ambient
2. Gradient accepted in SLAB detector 20°C (then, 20°C< T < 40°C maximum)
3. Wide surface for exchange / low surfacic power (**4.6 Kw** for the full ECAL detector)
4. Precision of cooling regulation +/- 2.5°C acceptable
5. Service space between cooling and HCAL >1cm for cabling: DAQ + HV + GND
   - Mechanical constraints due to electronic design (geometry of DIF card);
   - Space available: heat sources location;
   - Fastening system for cooling allowing fast connection/disconnection;
   - Heat power to dissipate, including (chips + DIF FPGA + interface components);
   - Hydraulic network, number of circuits;
   - Unfavourable environment (high radiation levels, magnetism, particles jets…) etc.…

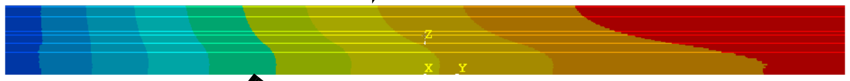
Thermal flux inside a column of 1 module

Power on PCB = 0,205 W (barrel) / 0,356 W (End-cap)
Boundary condition T = 23 °C

Results
Barrel : (1.5m)

Max T < 25,5 °C
ΔT = 2,2°C

End Cap : (2.5m) → 2,1m if R_{Endcap} ≈1726mm



Max T = 29 °C
ΔT = 6°C

Power : 30*0,356 = 10,68 W

Thermal gradient complient in SLAB detectors and modules

General distribution foreseen:
- Water circulation @ sub atmospheric pressure
- Water temperature input: 18°c
- Water temperature output: 23°c
- Maximal power per column: 150 W
- Pipes diameter : 13 mm

- **Leakless cooling system**
  - Cooling front–end
  - Low water speed
  - Low temperature gradient
  - Risk of spray limited

For ½ SLAB from barrel
- Wafers consumption : 0.205 W
- Front SLAB electronic : 0.3 W

IV - Cooling System integration

AIDA2020 - WP14.5

Task 2	Infrastructure to evaluate thermal properties of calorimeter structures

2.1 Cooling system to test thermal modelling of large CF (carbon fiber) structures *(LPSC)*
2.2 Cooling system for low power calorimeter readout electronics *(DESY)*

Mechanical & Thermal tools for Innovative Calorimeters

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168.

GRENOBLE | MODANE

IV.1 -Compact and highly efficient Cooling Systems

Development of a cooling system for low power calorimeter readout electronics

Report on the design of a leakless water cooling system for absorber structures for highly granular calorimeters

AIDA 2020

Grant Agreement No: 654168

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Horizon 2020 Research Infrastructures project AIDA-2020

MILESTONE REPORT

DESIGN OF COOLING SYSTEMS FOR TUNGSTEN / CARBON FIBRE AND FOR HADRON CALORIMETER STRUCTURES

MILESTONE: MS31

Document identifier:	AIDA-2020-MS31
Due date of deliverable:	End of Month 18 (October 2016)
Report release date:	31/10/2016
Work package:	WP14: Infrastructure for advanced calorimeters
Lead beneficiary:	DESY
Document status:	Final

Abstract:

The front-end electronics for both, highly granular silicon-based electromagnetic and scintillator-based hadronic calorimeters require a highly integrated and efficient cooling. Thermal properties of tungsten and carbon fibre based absorber elements drive the cooling concepts of electromagnetic calorimeters. The feasibility of a cooling system has been successfully demonstrated for low power calorimeter readout electronics. Thermal modelling and measurements performed on demonstrators constructed within the EUDET project (www.eudet.org) and distributed between two participating labs, meet the thermal requirements. For the scintillator-based hadronic calorimeter, a cooling system has been designed for use in beam test experiments using the mechanical infrastructure constructed within the EUDET project.

Grant Agreement 654168 PUBLIC 1 / 12

Milestone 31 report has been uploaded on the AIDA-2020 report webpage by the 31/10/16.

- Milestone 31 **/ Thermal model**
  - ➢ **ECAL: SPECIFICATION OF LOCAL COOLING SYSTEM**
    - ✓ Cooling system for large carbon fiber structures
    - ✓ Preliminary thermal considerations
    - ✓ Thermal Analysis of SLAB and modules
    - ✓ Design of Local heat exchangers / CU shielding & thermal drain
    - ✓ Tests and simulation on local detector (EUDET)
    - ✓ Cooling Plant Development : the leakless operation mode
- Deliverables 14.8 / **Large leak-less System, thermal model**
  - ➢ **GLOBAL COOLING SYSTEM MODELLING**
  - ➢ **THE LEAKLESS OPERATION MODE**

    Develop and test a Global cooling True scale leak less loop for ECAL on 3 levels (13m-10m-9m) - demonstration and performance

    Demonstrators and results

AIDA 2020

Grant Agreement No: 654168

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Horizon 2020 Research Infrastructures project AIDA-2020

DELIVERABLE REPORT

LARGE LEAK-LESS SYSTEM, THERMAL MODEL

DELIVERABLE: D14.8

Document identifier:	AIDA-2020-D14.8
Due date of deliverable:	End of Month 36 (April 2018)
Report release date:	18/06/2018
Work package:	WP14: Infrastructure for advanced calorimeters
Lead beneficiary:	DESY
Document status:	Final

Abstract:

This deliverable report describes the successful construction of real size sub-atmospheric water-cooling systems distributed between two participating labs, to test thermal modelling of calorimeter structures produced with AIDA-2020 funding. The on-detector electronics for both, highly granular silicon-based electromagnetic and scintillator-based hadronic calorimeters require a highly integrated and efficient cooling. Thermal properties of tungsten and carbon fibre based absorber elements drive the cooling concepts of electromagnetic calorimeters. A large leak-less cooling loop has been constructed to confront thermal modelling with measurements. For the scintillator-based hadronic calorimeter, a cooling system has been developed for use in beam test experiments using the mechanical infrastructure constructed within the EUDET project (www.eudet.org). Both systems meet the thermal requirements.

Grant Agreement 654168 PUBLIC 1 / 22

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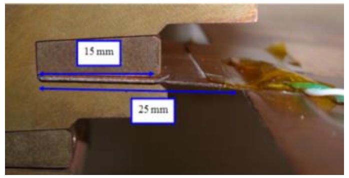
DESY LPSC GRENOBLE | MODANE

IV.2 -Tests and simulation on EUDET Module

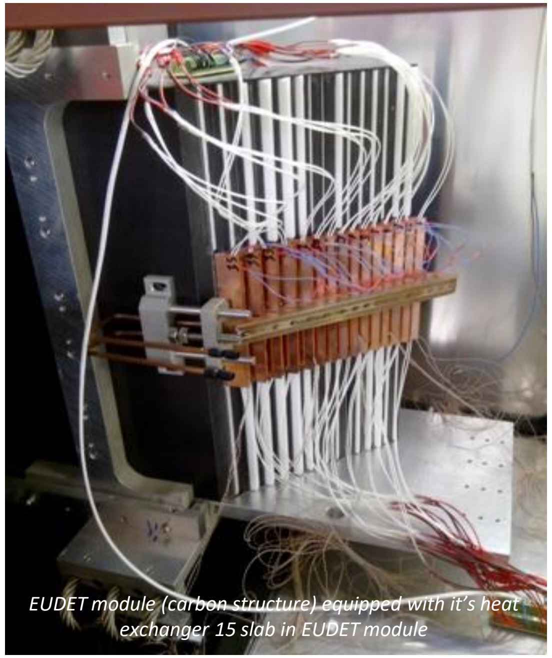
<u>Demonstration and **performance** of Thermal **model**</u>

- Cooling tests: **From detector** to cooling station
- Realistic interface electronics for slabs
  - Dummy ASU with representative power dissipation to simulate and DIF with localisation of hot spots
  - Geometry, power distribution and representative materials + Cooling effect
- Local Heat exchanger with 15 connections
- Full module equipped / conductive materials



Adaptation of Water heat exchanger Connection on slab

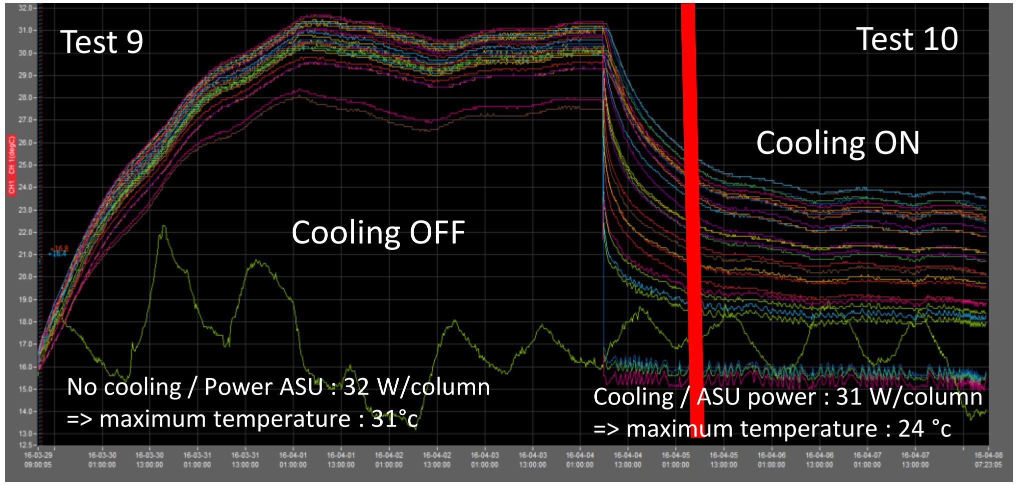

Dummy slab detector under construction for thermal tests on EUDET 15 slabs for 1 column


EUDET module (carbon structure) equipped with it's heat exchanger 15 slab in EUDET module

- **First tests results in line with simulations**

Requirements for 15W nominal
- Gradient accepted in detector elements: 20°c
- 20°c < T < 40°c

For ~30W tested with cooling
- ➡ T° rising in slab: ~up to 7°C
- ➡ maximum: 24°C



IV.3 - ECAL: Full size leak-less cooling-loop

Demonstration and performance of a large **leak-less cooling-loop** on 3 levels (13m-10m- 9m)

Rough estimate on fluid circulation:

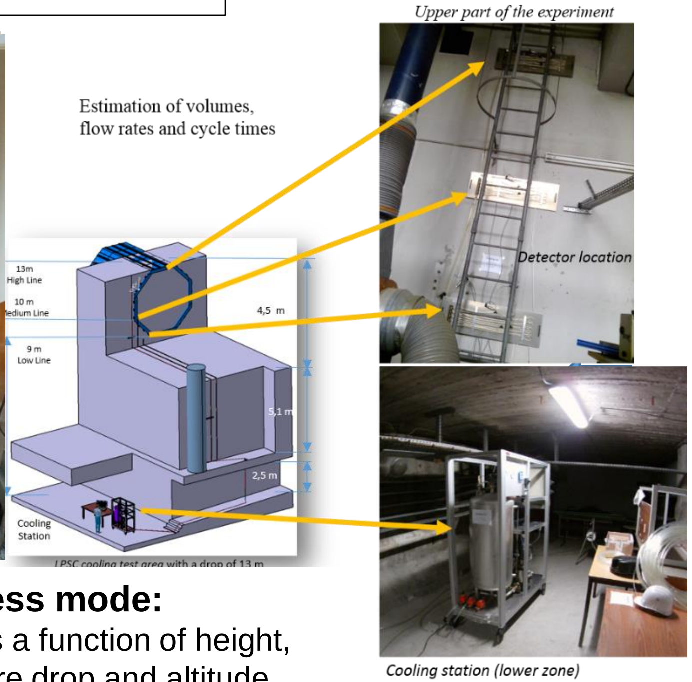
Global flow rate : 150 l/min

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

Fluid speed < 2 m/s

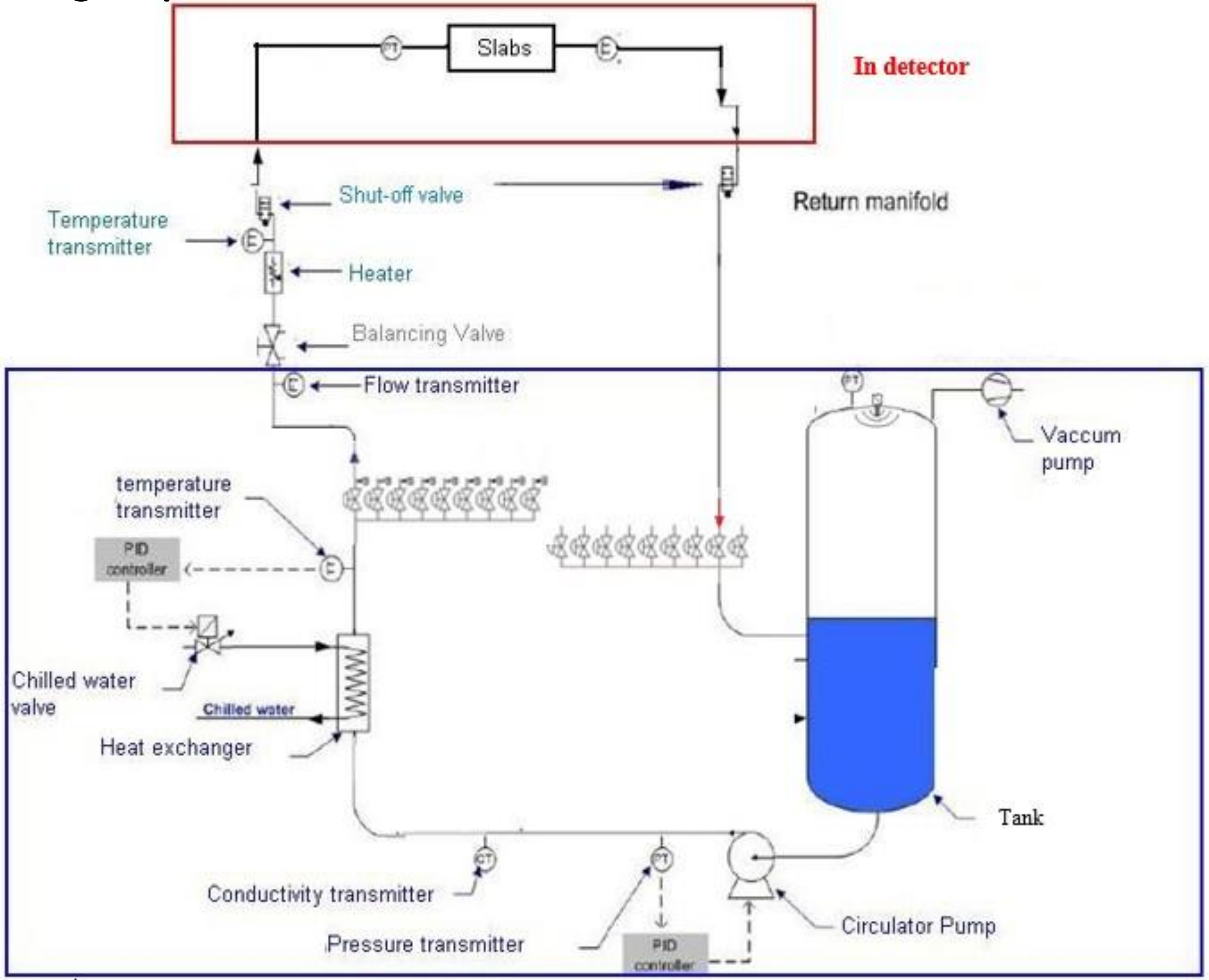
Maximal pressure drop : 1.2 bar

Estimation of volumes, flow rates and cycle times



Principle of the leak less mode:

- Pressure distribution as a function of height, depends on the pressure drop and altitude



Design of one leakless loop for next tests

IV.4 - ECAL: cooling station location

Location of the cooling station

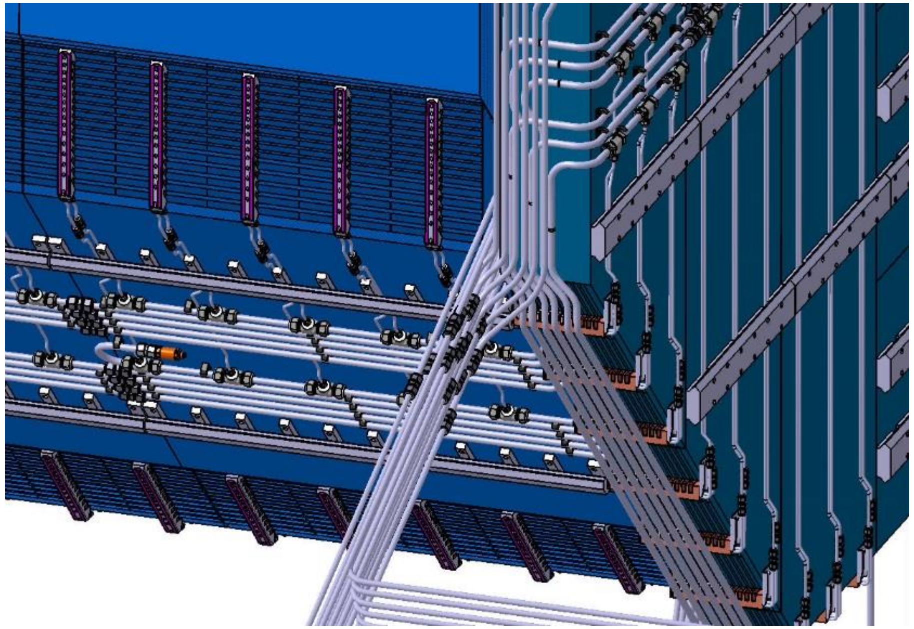
Demonstration and performance of the full size leak-less cooling loop on 3 levels

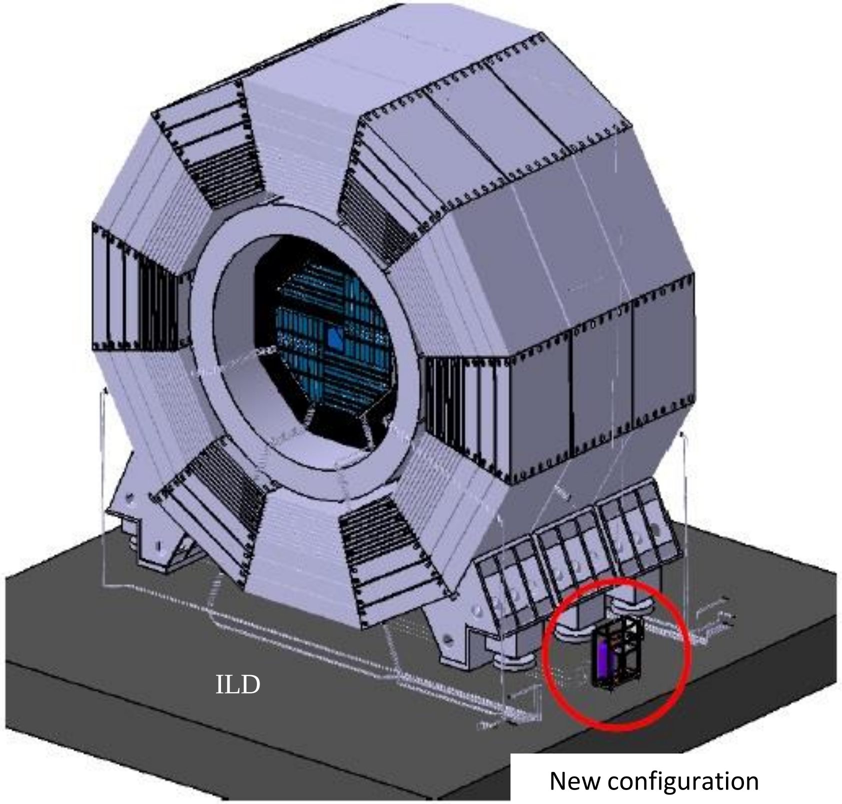
The Leakless-Cooling station can operate on the ILD platform

General path update, passages in the external detectors

(limitation of the congestion and of pressure drops)

- Pipe network definition
- Definition des dimensions of passages in the other detectors
- Cooling stations' location on the Platform
- Connection to Barrel and 2 End Caps





New configuration corresponding to cooling station **on** the ILD platform.

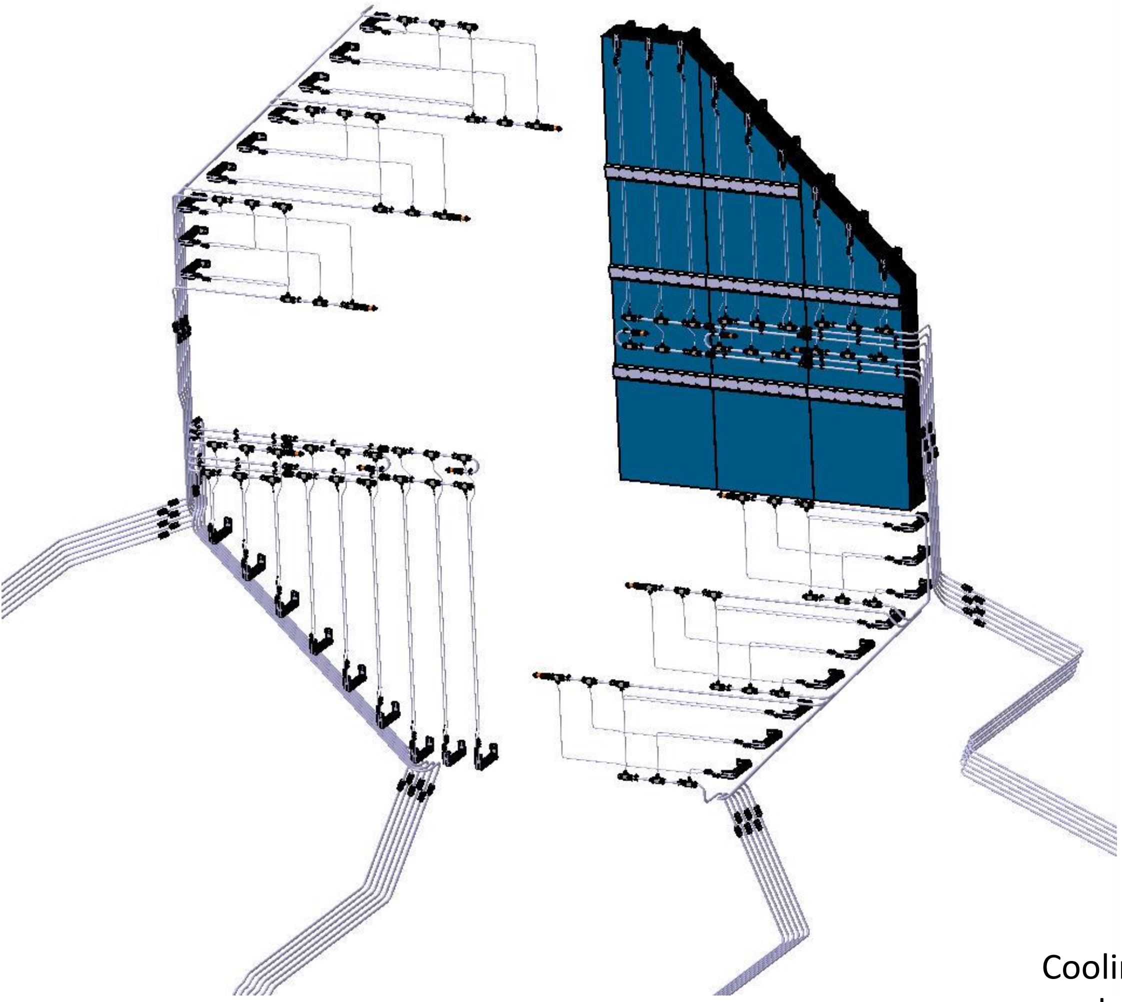
Real dimensions detector / zone of tests

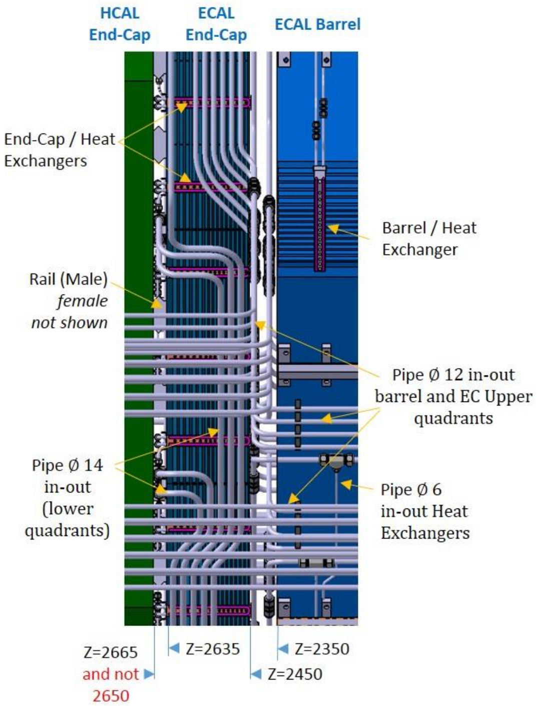
Maximum elevation between ground and ECAL top is 14m, (test zone 13 m).
This configuration is conservative
The test conditions are more binding than real ones

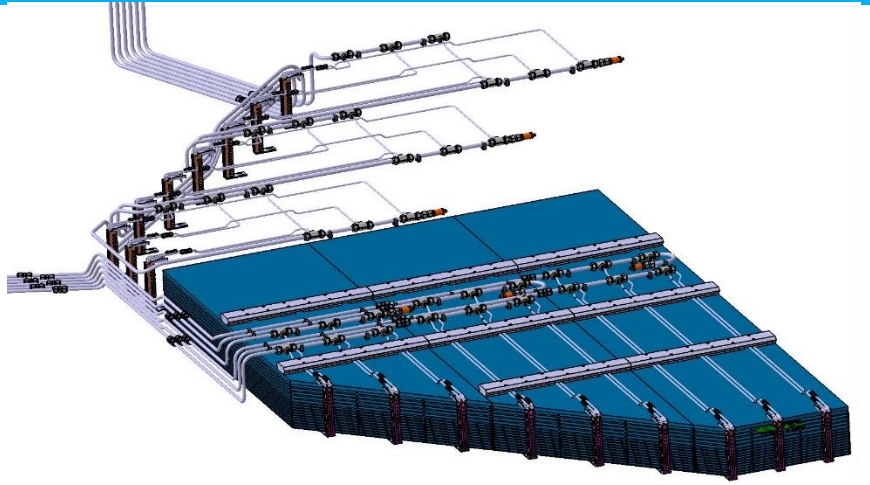
IV.5 - General cooling network

Improvement of the cooling network / END-CAP+Barrel

Hydraulic Network = Control per module







Cooling lines and rails for ECAL End-cap and Barrel

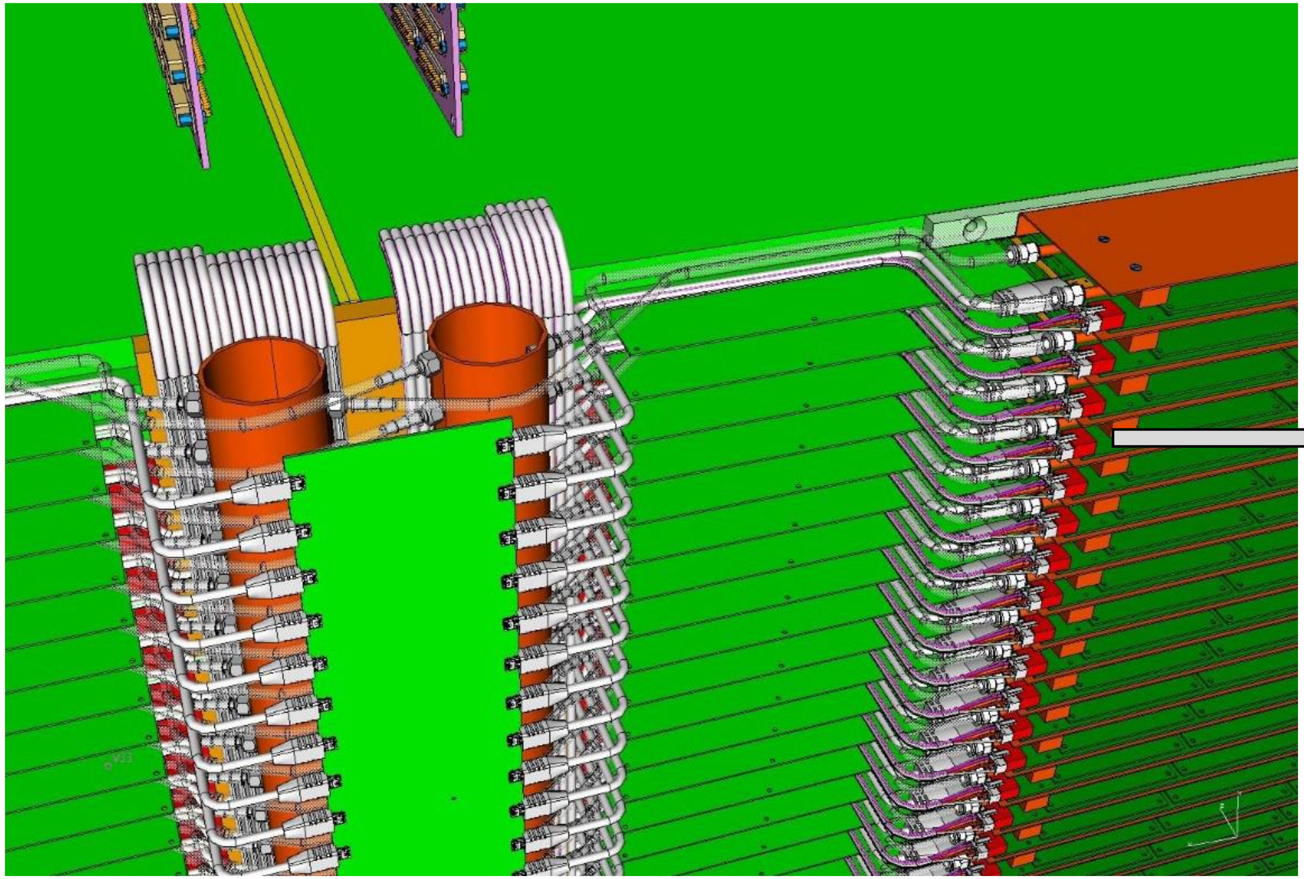
Cooling local Barrel (inlet/outlet via lower part)
-> global network section growing at the interface

Quadrant 1,2,3 & 4 are different / cooling extraction

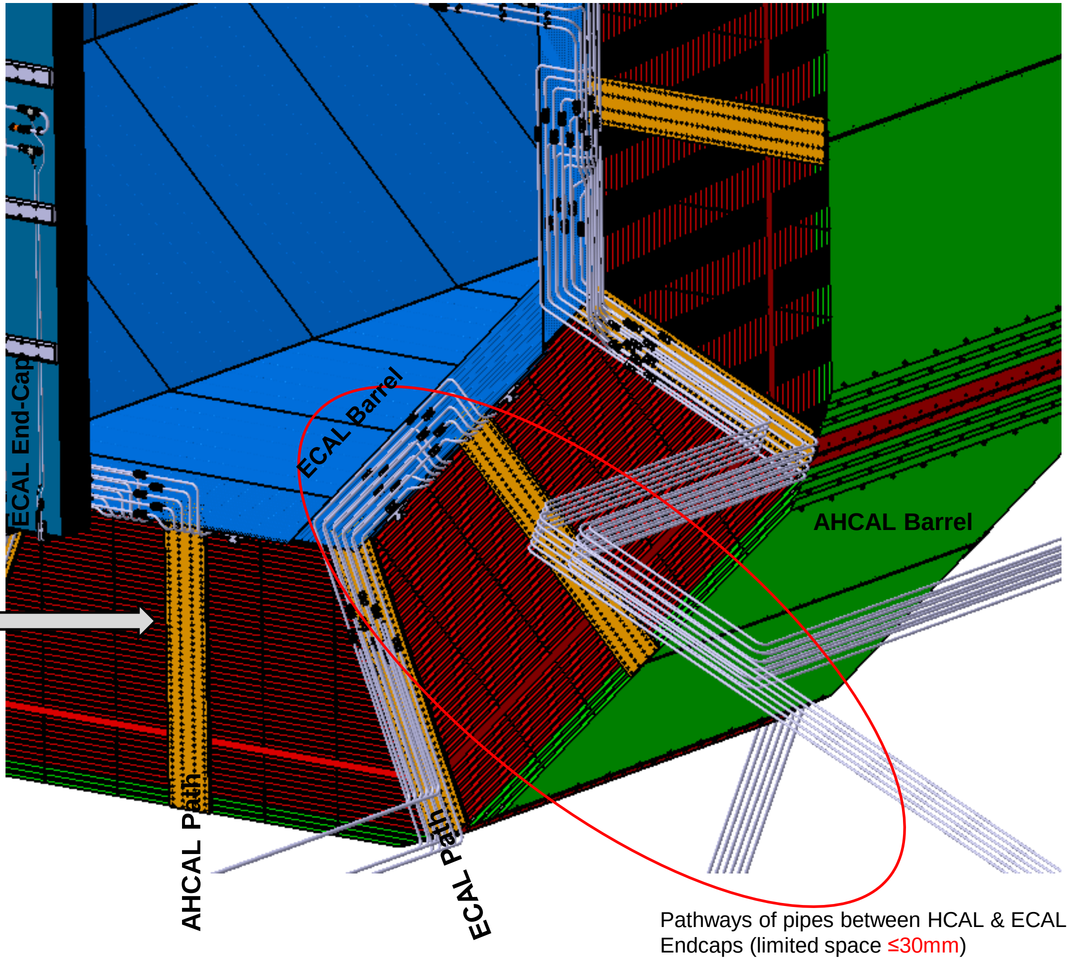
IV.6 - AHCAL/ECAL General cooling path

- Detailed design of the AHCAL and ECAL services

Integration

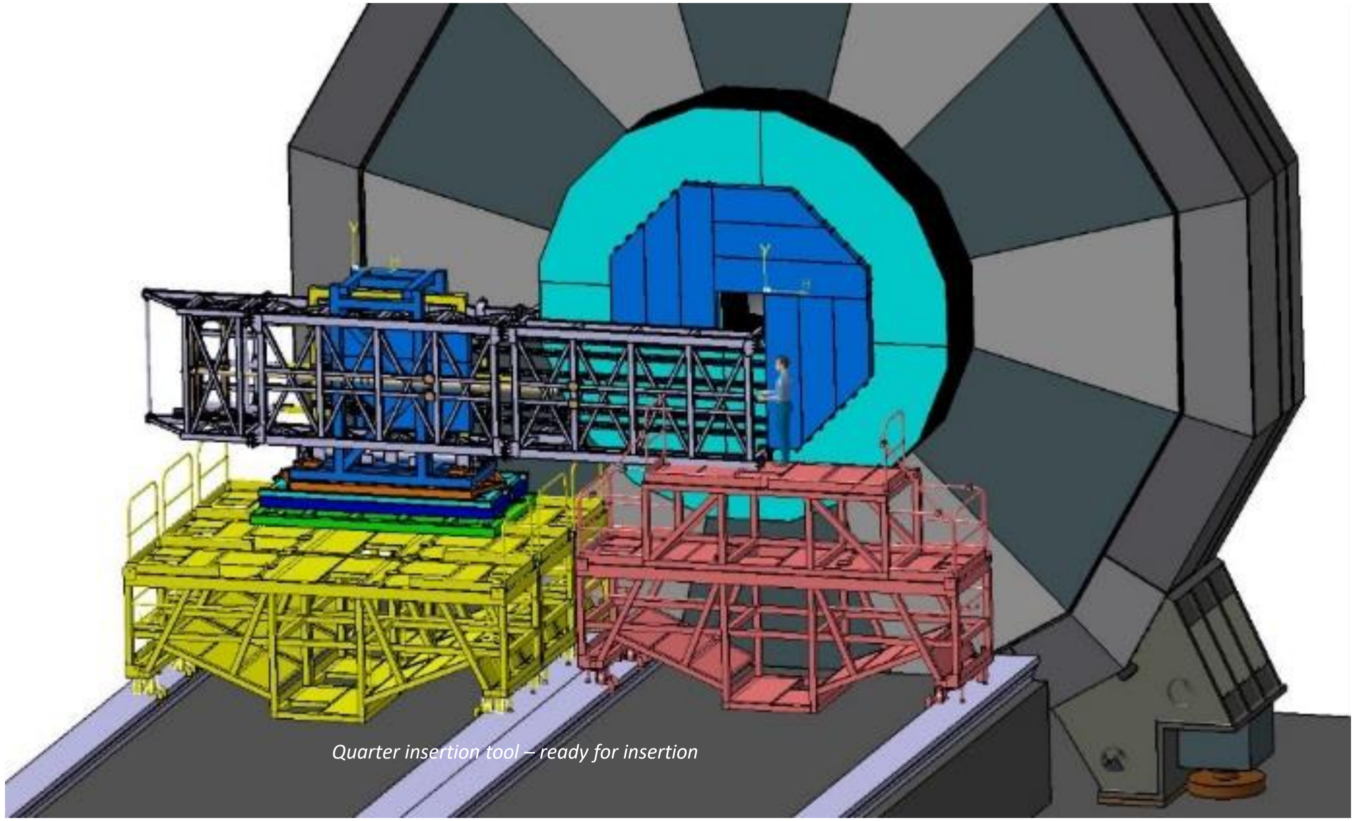


Due to leakless system, the pipes come from the bottom, implying significant congestion



Pathways of pipes between HCAL & ECAL Endcaps (limited space ≤30mm)

V – Integration in ILD

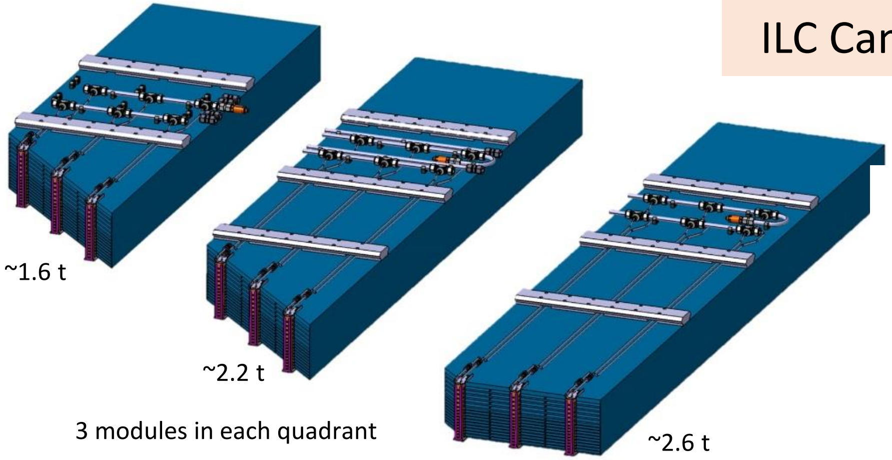


Quarter insertion tool – ready for insertion

V.1 – Handling and integrating tools

1 - Assembly and test of modules and quadrants

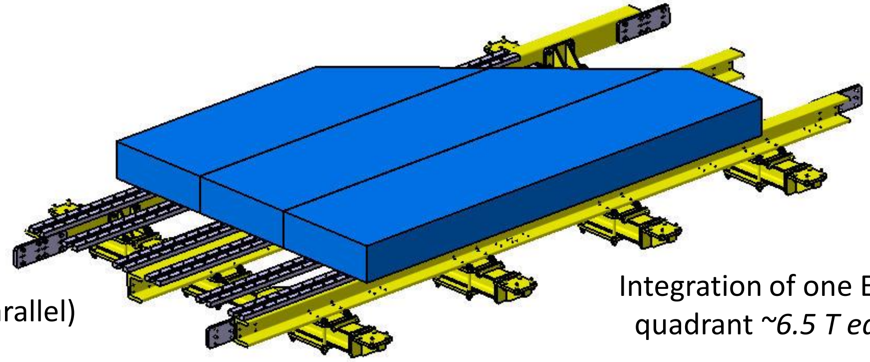
1-1. Modules equipment and test (24)



3 modules in each quadrant

ILC Campus – ECAL Hall

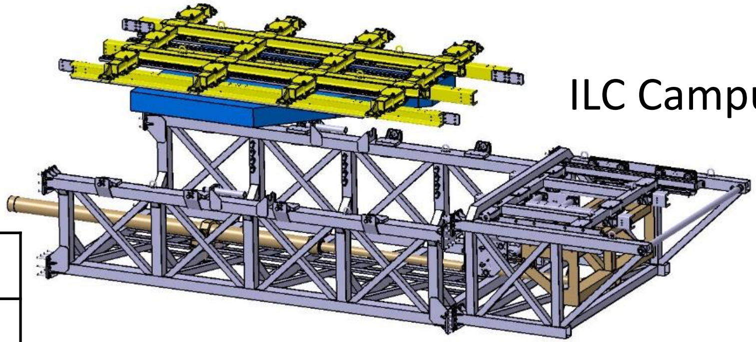
Dimensions
L,H,l: 2.8 x 0.6 x 0.7 m³ -> 2x40 m²
Boxes: ~0.7 m² -> 50 m² with access
Testing space: 50 m²
Assembly area: 180 m²
Weight per module: ~1.6 t to 2.6 t



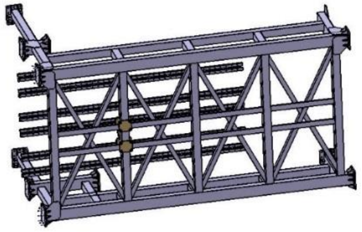
Integration of one ECAL quadrant *~6.5 T each*

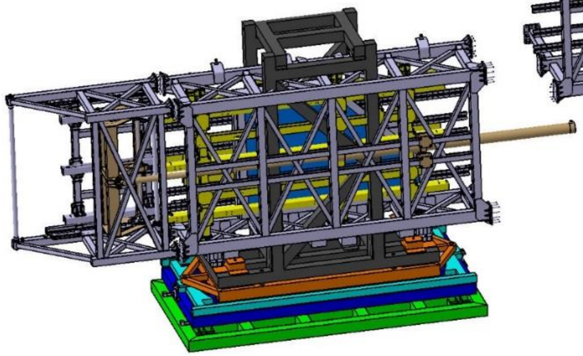
*** Module handling tool**
for rails' tests and module integration 4.2 x 1.2 x 2.1 m

1-2. Quadrants assembly (2x4) on cradles (2 in parallel)



ILC Campus ⟺ Assembly hall





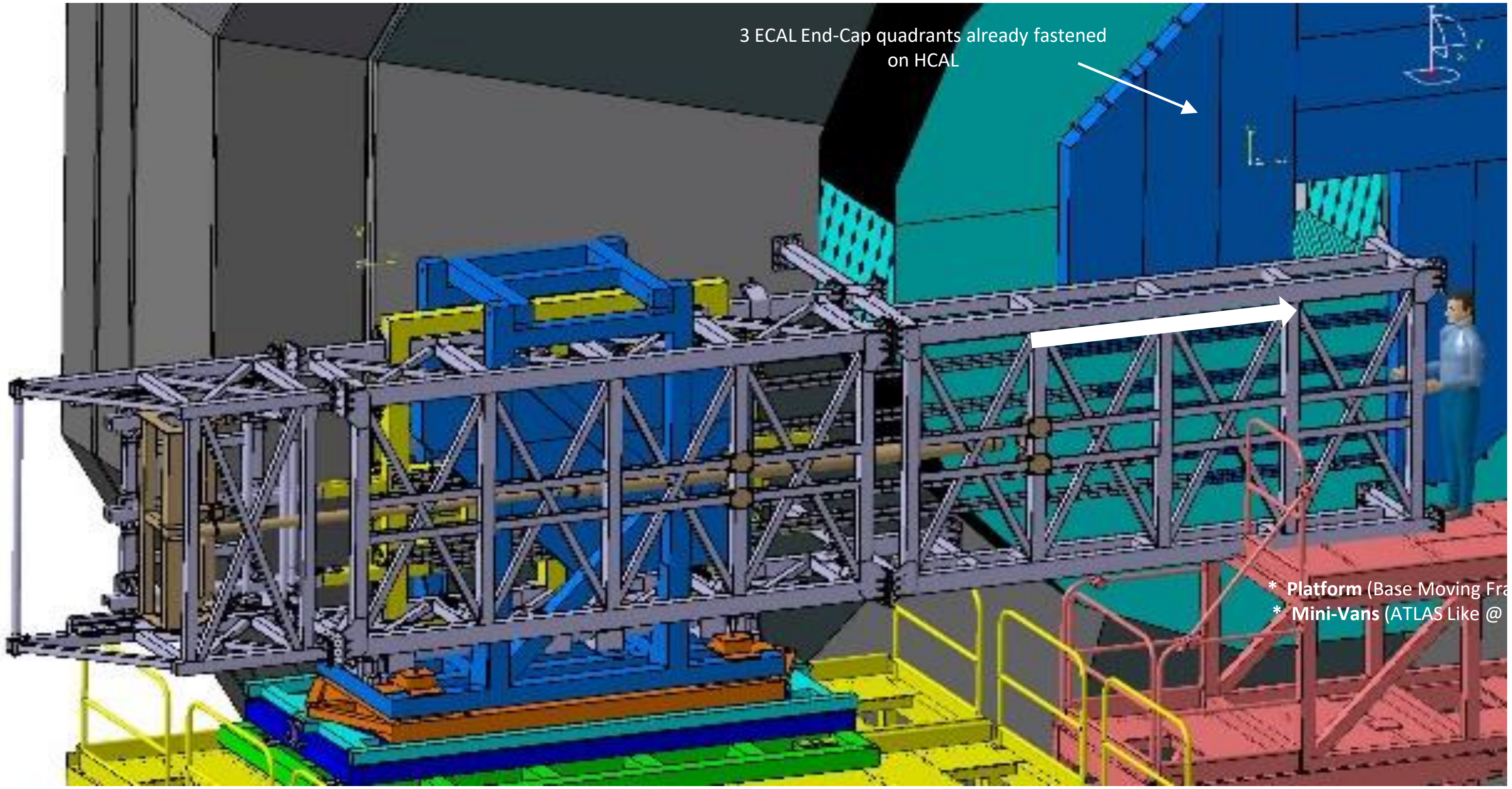
Dimensions
8 quarters (of 3 modules each):
Assembly area: 50m² / quarter
(quarters assembly 2 by 2)
Assembly area: 100m² / total-2 quadrants
Total weight : ~ 6.5 t / quadrant
Testing-Storage area: 100m² / 2 quadrants

V.2 - ECAL End-cap : integration overview (Assembly Hall)

2 - Assembly of quadrants on HCAL End-Cap	Assembly hall

Quadrant Insertion tool (lateral) area: 120 m²
Minimum width = 7 m/beam line for integration
Assembly area: 25 m² / quadrant
Storage area : 1 quarter=> 10 m² / 12 modules=> 50 m²
Insertion on HCAL End-Cap on each side: per full quadrants

* **Quadrant insertion tool**
with orientation tuning, alignment and fastening systems 10.4 x 2.3 x 2.3 m



Sliding, tuning, alignment & fastening *of the last ECAL quadrant on HCAL End-Cap*

Summary and conclusion

Contributions on the SiW Ecal endcaps and cooling system :

1. Design of the EM end-caps (drawings, FE simulations, prototypes, tests)
2. Fastening system on HCAL
3. Electronics and cooling system (end-caps + barrel)
4. Cooling system Integration - AIDA2020
5. Integration of EM End-caps in ILD

2021

- LPSC management activities has <u>stopped</u> in 2019 (then, *no involvement in AIDA Innova)*

Thank you for your attention