Si-W ECAL – Current baseline

**W/Si – ECAL weight:**
~ 112 T (80 barrel + 32 End-Cap)

- No dead zone, compactness
- 40 identical trapezoidal modules

**Module Barrel**
- Poids / module: ~ 2 T

**Multi-module End-Cap**
- 12 modules - 3 distinct types
- Compactness, no dead zone if…

**Module End-Cap n°2**
- 40 identical trapezoidal modules
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, but...

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

**Design: 1**

- R1 = 2090 matches LOI
- Long. 1.5 m

**Design: 2**

- R2 = 2093
- Long. 2.4 m
- W: ~ 1800 kg

**Design: 3**

- R3 = 2047
- Alveoli = barrel’s one
End-Cap structure: long alveoli (2/4)

Today, with the demonstrator and EUDET, the process for composite structure has been validated, with a built layer module width based on 182.1 mm for EUDET, and 1.50 m long.

- End-cap structure: study and validation of most of technological solutions which 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
End-cap – First alveolus & layer (3/4)

- For End-caps (design 2) the goal is now to build 2.50 m long alveoli, and to demonstrate whether or not the main process steps can be adapted.
- Several issues to be studied:
  - use of adjusted long metallic cores (monolithic or multi-parts)
  - After-curing step: demoulding

- the end-cap layer consisted of
- 1 long alveolar layer of 3 cells
  (representative of the end-cap module n°2 layers)
- Width of cells : 186.8 mm
  (Design2-to fit LOI parameters (R~2090))
- Thickness cells : 6.5 mm
- Length : 2.492 m

Design & Technical drawing : OK
Core : OK
Machining: Oct 2009
“Long Alveolus” mould reception : Nov 09
Long alveolus: Dec 2009
Design of End-cap modules (4/4)

… based on mechanical simulations:

*Linear Analysis of “full scale” ECAL modules (End-caps)*

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

⇒ Global EC design updated: *End 09*
⇒ Local simulation (flexion): *Spring 10*
Fastening ECAL/HCAL (1/2)

**Constraints**
- Fastening in a structure “wheel”: bending constraints
- Carbon structure (thick plates and support…)
- Electronics: place for cabling: DAQ + HV + GND
- Cooling pipes integration

**Design** of connection system: each cooling system ① is inserted and screwed to each column of slab with a thread rod and spacers (②) and connected to the cooling network in a second step ③.

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

**Available space HCAL/ECAL**
- **Barrel:** 3cm
- **End-Caps:** 1.5 cm: Insufficient / cooling fastening

15mm thick plate with its rails; ready to be assembled with alveoli layers

A column (cooling pipe), (25 mm wide minimum) to ensure quick thermal system’s connection
Fastening ECAL/HCAL (2/2)

From metallic rails… to… composite structural system…

Mould delivered, ready to mould HexMC & SMC
Carbon rails on a 80T heating press

Solutions to investigate:
- Alternative for fastening and positioning system: isostatic system
- Coupling of modules.
- Handling and positioning tools for modules

composite structural system
• validation of technological solution
• industrialization aspect of process
ECAL Cooling

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

- Barrel : 40 identical trapezoidal modules
- End-Cap : 12 modules (3 types)
  ~ 4600 cells to join

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

Cooling Technology:
- Convective exchange with ambient as the cold source : not efficient
- Convective exchange with cold air : not enough space and pb / air pipe insulation
- Water cooling: satisfying due to T° control request – cost (full circuit or with heat pipes)
- Cooling system with gas cycling (Freon…) or with CO²: extra cost, pressure… on study
- µ fluid-circulation on slab themselves: on study 2010
### ECAL: Global COOLING

**Power results:**

- 2 FPGA per SLAB, power: 3 W each, then: \(3 \times 2 = 6\) W
- SKIROC: 0.54 W / slab \(\rightarrow\) 0.3 W soit: \(2 \times 0.3 = 0.6\) W

**Barrel:**

- Global Power: 19484 W \(\rightarrow\) 3029 W
- Power per module: 487 W \(\rightarrow\) 75.7 W
- Power per column: 97.4 W \(\rightarrow\) 15.1 W

**End Cap:**

- Power per End Cap: 5060 W \(\rightarrow\) 768 W
- Average power per module: 420 W \(\rightarrow\) 64 W
- Average power moyenne per column: 97 W \(\rightarrow\) 15 W

Global Power: 30 000 W \(\rightarrow\) 4565 W !

#### 1 feeding line per column!

**Rough estimate on fluid circulation:**

- Global flow rate: 150 l/min
- Variation of fluid temperature:
  - in-out \(\Rightarrow\) 3°c
- Fluid speed \(<\) 2 m/s
- Maximal pressure drop: 1.2 bar

<table>
<thead>
<tr>
<th>Column Type</th>
<th>Power per Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUDET</td>
<td>100 W/ colonne</td>
</tr>
<tr>
<td>Objectif ILD</td>
<td>15 W/ colonne</td>
</tr>
</tbody>
</table>

Depending on control... one per column, the cost of equipment near detector will be more complex and expensive... but more efficient.
ECAL: Global COOLING

Simplified P&I diagram of cooling plant extrapolated from a CERN's Detector.

Study of the global cooling system for ECAL to continue:

- Design including safety systems
- Cost estimation (several solutions)

Leakless system:
- Low water speed
- Heat pipe termination
- Temperature and power range adapted

Co2 system:
- High pressure (30 bar)
- Enable very low temperature
- Small pipes

True scale leakless cooling system test
Base line: leakless system with representative systems to control

Leakless cooling system mock-up: 2010
- the right components, sensors…
- process, regulation
- Interface and control
**SLAB COOLING – tests on going**

**Cold plate: 3 Solutions**

1. **Assembled solution**
   - Water circulating into copper pipe (Internal diameter: 4 mm)

2. **Machining solution**
   - 1 block with water circulating into copper pipe
   - (Internal dia.: 4 mm)
   - Easier to build

3. **Heat pipe**
   - Main advantage:
     - Connection between Heat pipe and water circuit => contact, far from front-end.
     - Easy to assemble and reduces leak risk
     - Same geometry

**Diagrams:**
- **Evaporator:** Copper
- **Condenser:** Aluminium
- **Water circuit**
- **Heat pipe**
- **Condenser: Aluminium**
- **Evaporator:** Copper
- **Heat pipe**
- **Water circuit**
- **Cold source**
**Simulation vs. tests: contact resistances**

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

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

**CONCLUSION (today)**

Cooling solution with little dimensions
A serial feeding network (connection easier to cooling circuit)

Slabs’ cooling @ ± 1,1°C with ΔT = 10,7°C slabs’ surface and cooling fluid

**Heat pipe prototype : reception and tests: Sept 2009**
**EUDET: SLAB COOLING**

**Boundary condition:**
4560 detectors «SLAB detectors» to thermalize.

- **Thermal foam**: \( \lambda = 3 \text{ W/mK} \)
- **Convective flux into pipe with fluid at 20°C** (\( h = 3445 \text{ W/m}^2\text{K} \))
- **Heat surface and temperature point (FPGA location)** 0.2 to 2W...
- **Cold copper bloc inserted between 2 copper plate of 1 slab**

**Simulation** of heat conduction just by the heat copper shield: Influence of FPGA dissipation (DIF) on current design of cooling system - Limit Condition of 20°C, 500 µm Cu. Copper drain adapted / DIF card to be in contact with FPGA on DIF.

**Important implication upon cooling dimensions!**
Ø pipe important / system for P<1 atm.

\( \Phi = 0.27 \text{ W/layer} \)
(25 µW per channel)
Cooling: Thermal Tests (1/2)

Goal of experimental tests: (1 Hot ASU + 8 thermal ASU):

- A real thermal test to be compared to numerical simulation
- Simplification of slab’s numerical model
- To determine more precisely the transfer coefficients
- Validation of the cooling system (400 µm copper plate + pipes)
- To verify the thermal dissipation behaviour (EUDET design)

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
See Julien’s talk today « Studies with demonstrator in 2009 »

• Thermal comportement along the slab:

   Conclusion:

   The thermal slab comportment can’t be based to the comportment of the copper plate with conduction only.

   ⇒ We need to take into account the whole structure (W, composite material…)

• Thermal contact resistance characterization:

   Conductivity values with/without thermal paste

On going : global simulation on slab section…
## Conclusion:

### Cooling

- Slab cooling tests in alveolar structure, heat pipe system (EUDET config.)  
  **Oct 09**  
- Cooling system for EUDET (water circulation with better thermal contact)  
  **Fall 09**  
- First Design for the whole detector cooling system  
  **Spring 10**  
- Correlation (thermal tests) with simulations (transfer coefficients, contacts...)  
  **End 09**  
- Alternative cooling system: CO\(^2\), \(\mu\)-circulation fluid, carbon pipes; MCP…  
  **2010**  
- First Design: hydraulic safety, hardened components, cooling supervision…  
  **Sum 10**  
- Design & build a “true scale test loop” : cooling system « Leakless » (<1atm)  
  **2010**

### Fabrication - tests - characterization

- First End-Cap alveolar cell and layer: mould reception  
  **Nov 09**  
- Cooling system: copper with better thermal contact for EUDET (45°)  
  **Dec 09**  
- Characterisation, tests & optimisation: composite elements and rails  
  **Sum 10**

### Conception - Simulation

- End-cap **design** & mechanical simulations  
  **End 09**  
- Moulds for a specific End-cap module’s **cell & layer** (2,50m !)  
  **Dec 09**  
- **Fastening system** ECAL/HCAL: alternatives; modules’ coupling.  
  **Spring 10**  
- Handling and positioning tools for modules  
  **Spring 10**  
- Collaboration to extend with Moroccan RUPHE (Univ.HassanII-Casablanca)  
  **2010**
Thank you for your attention

Mechanical R&D on ECAL

Cooling system & test

15mm thick plate with its rails; ready to be assembled with EUDET’s layers

End-cap design

Water cooling block

THERMAL tests

Destructive tests

Fastening system