Mechanical R&D for CALICE ELECTROMAGNETIC CALORIMETER

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This paper presents mechanical R&D for the CALICE Silicon-tungsten electromagnetic calorimeter. After the physics ECAL prototype tested in 2006 (DESY-CERN) and before the design of different "module 0" (barrel and end-cap), a technological prototype, called EUDET module, is under study and design in order to have "full scale" technological solutions which could be used for the final detector (moulding process, thermal cooling, inlet/outlet, integration tools...). These solutions will take into account of the industrial point of view.

1 Electromagnetic Si-W Calorimeter design

The electromagnetic calorimeter has been optimized for the reconstruction of photons and electrons and for separating them properly from debris coming from charged hadron interactions in the device. The range of energies for photons and electrons suggests a thickness close to 24 radiation lengths for the ECAL. The following sampling is then under consideration: 20 layers of 0.6 X_0 thick tungsten absorbers (2.1 mm) and another 9 layers of tungsten 1.2 X_0 thick (4.2 mm). The detector design with a solenoid outside the calorimeter imposes an overall cylindrical symmetry. The global design has been developed with an attempt to simplify the device as much as possible, by reducing the number of different module and different technologies used.

1.1 The barrel geometry

One of the requirements for the calorimeter is to ensure the best possible hermeticity. To minimize the number of cracks in the barrel, a design with large modules is preferred, with boundaries not pointing to the vertex. As shown in Figure 1 the perfect ϕ symmetry of the coil has been approximated by an eight-fold symmetry and the modules are installed in such a way that the cracks are at very large angle with respect to the radial direction (trapezoidal shape). This octagonal shape seems to optimize the barrel modules size and their mechanical properties without diverging too far from a circle. One eighth of the barrel calorimeter is called a stave. At the back of a stave, between the ECAL and the HCAL, some space is left which is used to house different services like cooling

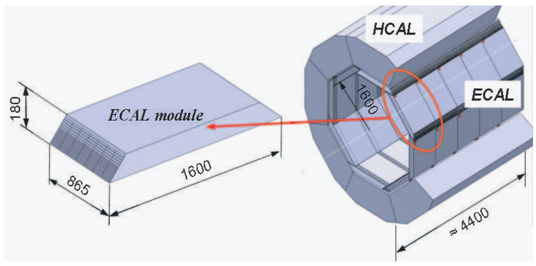

Figure 1: Struture of modules of the ECAL barrel General design of the calorimeter system

or electrical power and signal distribution. Along the beam axis, a stave is subdivided into five modules.

1.2 The end-cap geometry

The ECAL end-caps (Figure 2) could be constructed from very similar modules but with different shapes. To ensure that the depth of the calorimeter remains sufficient, the octagonal shape of the end-cap at the outer radius (1900 mm) follows the barrel part (1770 mm). Each end-cap consists of twelve modules (4x3 types), and can be split vertically into two halves for opening. With this design, no crack is pointing to the origin.

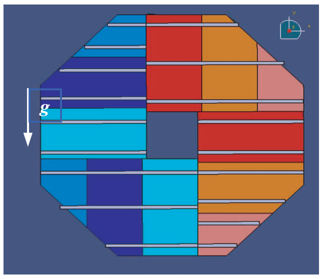

Figure 2: End-cap design for ECAL

2 The mechanical R&D

2.1 The alveolar structure

The design and construction of a module presents an interesting technological challenge. A design has been adopted where half of the tungsten layers are part of a solid mechanical structure, by embedding them into a light composite structure made of carbon fiber reinforced with epoxy. In between these plates and the carbon fiber partitions, free spaces are left into which detector elements, called "detector slabs", are inserted. This design has been validated on the physics prototype.

The method of an ”assembled structure” has been chosen. Each alveolar layer is done independently, cut to the right length (with 45°) and assembled with tungsten plates in a second curing step. This principle will limit risks losing tungsten plates compared to an ”one block” solution where all the structure is made in one step. After curing, the place holders (core) for the detector slabs are removed, leaving empty spaces called alveoli. This principle reduces also the cost of the industrial process: simpler moulds (one for barrel + 10 for end-caps) and the final piece is obtained in 2 simple polymerization processes, avoiding curing problems like thermal inertia, weight of metal mould, or the control of curing parameters. This method allows the possibility to integrate optical fiber with Bragg grating for Tests-Simulations Dialogue to. The first samples will be used to study mechanical behavior (destroying tests, dimensional controls...). The mechanical strength of "glued" structures has to be validated for these multi-curing steps to obtain the final structure (weight 650kg for the EUDET module, up to 2T for the End-cap modules).

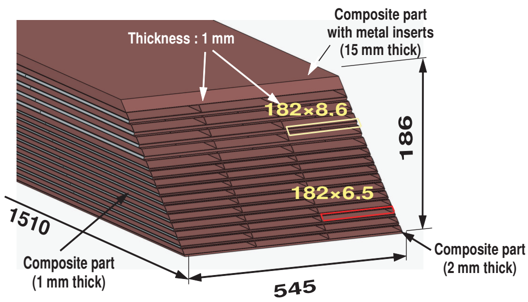

Figure 3: Alveolar structure design of the EUDET module

2.2 The detector slab

A slab (see Figure 4) has a tungsten plate core wrapped with an "H" structure made of carbon fibres. The silicon layers are attached on each side of the "H". Each silicon matrix is glued on a thin short PCB layer where the front end electronics is embedded. The silicon diodes are made of square pads of 5x5 mm2, the thickness of this-one is currently about 300 μm. A detector slab consists also of several "unit" PCBs, allowing more flexibility for different length of slabs. Indeed the length of each long slab will be obtained by the variation of the length of one "end" PCB.

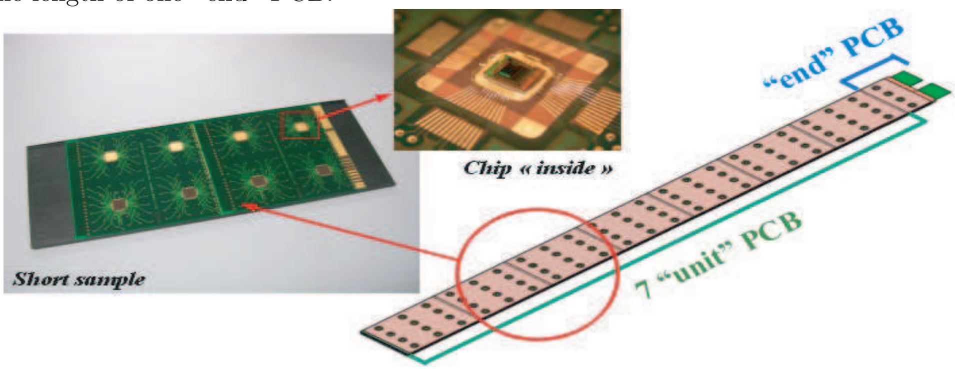

Figure 4: Detector slab to be inserted into the ECAL structure . Principle

2.3 Cooling system and power dissipation

Power dissipation is the key issue for this electronics. Indeed, the front-end electronics is located inside the calorimeter and has to have a very low consumption. The first slab thermal analysis is encouraging: assuming that the chip power is 25 μW per channel (power dissipation for the overall electronic chain including the digitization), a simulation of heat conduction just by the heat shield (copper), added along the slab direction, leads to an estimation of the temperature gradient along the slab of around 7°C. This simulation is probably pessimistic since only copper is used and not the other material of the slab (PCB, tungsten, carbon fibers...). Therefore, passive cooling inside the slab could be sufficient for the full scale ECAL. Then, the main cooling system could be at the end of each slab. For

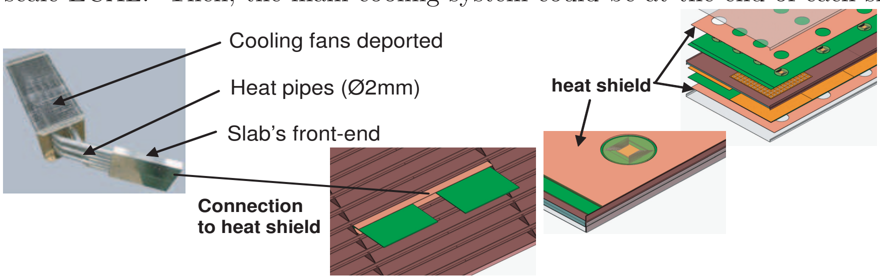

Figure 5: Possible cooling system for ECAL barrel and endcaps

each module, on the front end, cooling pipes connected to each heat shield, could be located in the gap between ECAL and HCAL, with all slab's input/output for the readout and power supply. Total power to dissipate will be approximately 2055 W for about 82,2 M of channels for the whole ECAL. After thermal study, design and tests of heat pipes technology has to be done, testing connection to slab and prototype of full system for 1 slab and 1 layer.

2.4 The interface with the HCAL: mounting and alignment

Alignment and cooling system are both crucial to ensure the needed detector performances from the point of view of good functioning and precisions and heavy withstanding. The ECAL will be fastened to the HCAL stave by stave, through accurate rail systems. The main issue designing this rail system is to reduce as small as possible the gap between ECAL and HCAL to keep the continuity between the 2 calorimeters (typically less than 4 cm). However, this gap has to be sufficient to install all the different services like cooling pipes and fans, electrical power and signal distribution. A fastening system, based on rails which will be fixed by metal inserts, directly inside the composite structure of the ECAL could solve this problem (see Figure 6). But this gap has to be optimized according to mechanical simulations and destructive tests of the ECAL/HCAL interface and the needs of cooling and fluid systems.

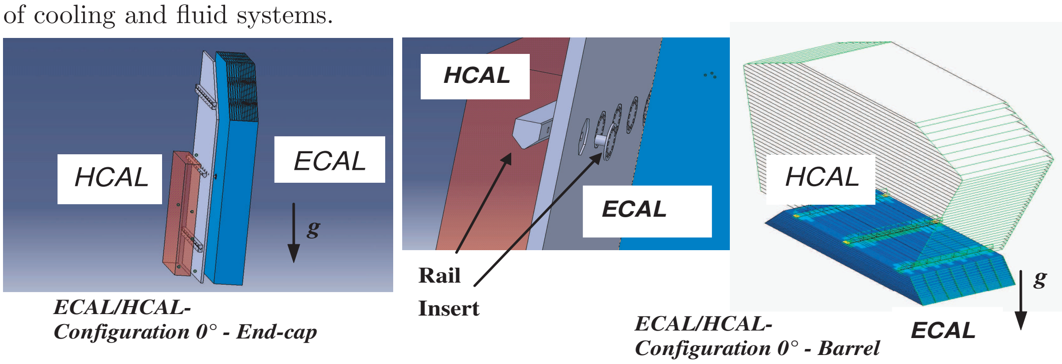

Figure 6: Barrel and endcap ECAL/HCAL interface with its fastening and guiding system.

3 The scope of work

Before the design of one "full scale" modules (barrel and specific module geometry 45°/end-cap) the technological demonstrator, or EUDET module, should allow to solve several technological issues: long composite structures moulding, thermal cooling, ECAL/HCAL interface, tools... In this way, Finite Element models of modules have to be continued to estimate the global behaviour of the ECAL, overall deflection for all configuration ECAL/HCAL, thermal dissipation, and start the optimization of the thickness of composite sheets to reduce the dead zones. In parallel, the mould design and fabrication, with its specific difficulty in long alveoli fabrication will be demonstrated with the EUDET module, using news materials and taking into account the industrial process and constraints. A first prototype of alveolar structure (1500 mm long) should be built mid 2008, allowing a cost estimate of the future Si/W ECAL clearly driven in first by the silicon diodes and the tungsten price.

References

[1] Slides of our presentation in ILCWS07 in Hamburg:
`http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=393&sessionId=108&confId=1296`