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Production Summary for Extended Barrel Module Fabrication at Argonne for the ATLAS Tile Calorimeter

High Energy Physics Division

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by

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Introduction

The Tile Calorimeter is one of the main hadronic calorimeters to be used in the ATLAS experiment at CERN [1,2]. It is a steel/scintillator sampling calorimeter which is built by stacking 64 segments in azimuth and 3 separate cylinders to provide a total structure whose length is approximately 12m and whose diameter is a little over 8.4m. It has a total weight of about 2630 metric tons. Important features of this calorimeter are:

- A minimum gap (1.5mm) between modules in azimuth
- Pockets in the structure to hold the scintillator tiles
- Recessed channels at the edges of the module into which the readout fibers will sit
- Holes in the structure through which a radioactive source will pass

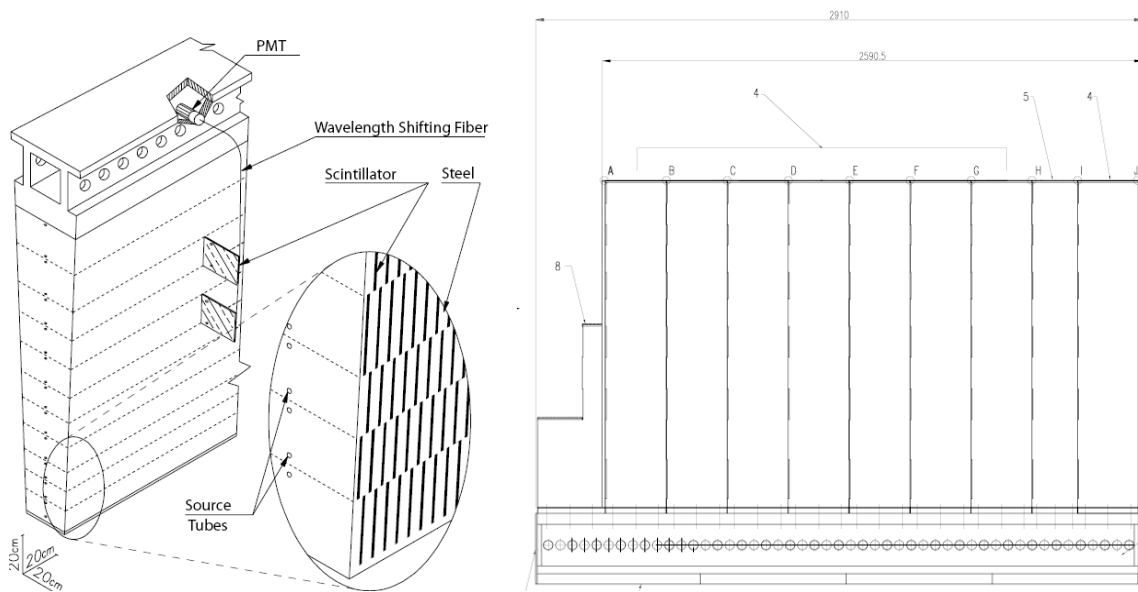


Figure 1, cartoon showing the absorber and readout structure of a tile calorimeter module (left); the layout of a standard module which comprises a structural support (girder) and 10 absorber segments termed submodules (right). The shaped submodule, at the left of the layout, is the ITC.

The mechanical structure for one of the 3 calorimeter sections, the Extended Barrel (EBA) was constructed at Argonne. A schematic of the calorimeter sampling structure and the layout of one of the 64 segments, termed a module, are shown in figure 1. Each module comprises mechanically of a precision machined, structural girder to which 10 submodules are bolted. One of these submodules, the ITC, has a customized shape to accommodate services for other detector elements. Each submodule weighs 850Kg and the assembled mechanical structure of the module weighs approximately 9000Kg (a fully instrumented Extended Barrel modules weighs ~9600Kg). A crucial issue for the tile calorimeter assembly is the minimization of the un-instrumented gap between modules when they are stacked on top of each other during final assembly. The design goal was originally 1mm gap which was eventually relaxed to 1.5mm following a careful evaluation of all tolerances in the construction and assembly process as shown in figure 2 [3].

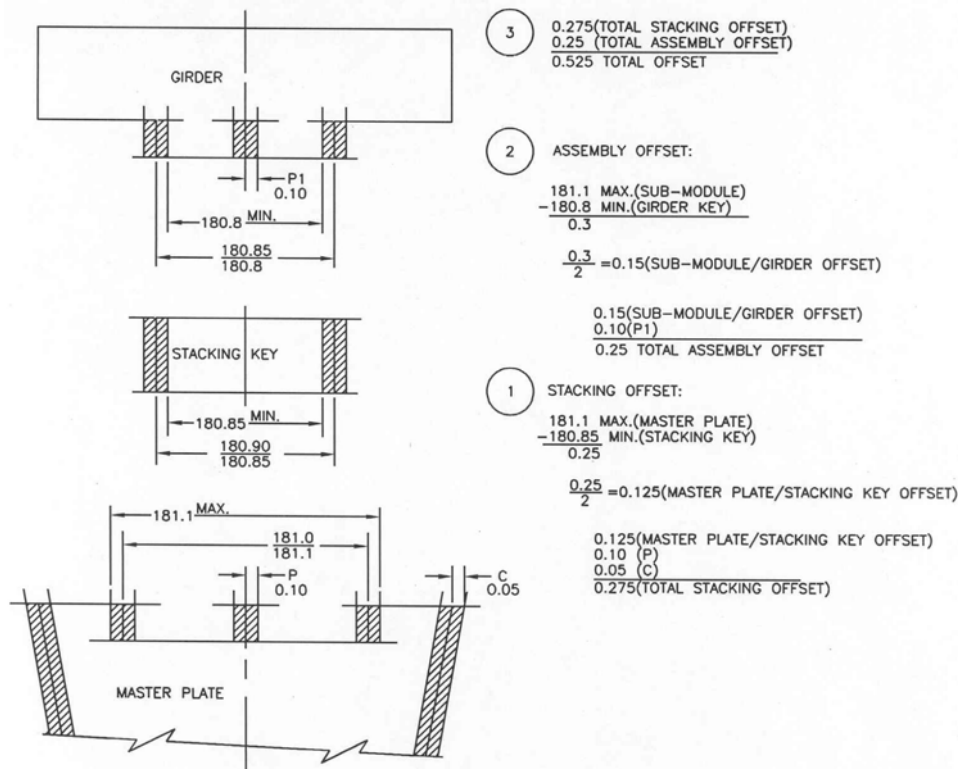


Figure 2, calorimeter design tolerances as established from the fabrication tolerances of all components relevant to the detector (absorber plates, submodule stacking and submodule mounting on the support girder.)

Submodules for this assembly were produced at 4 locations [4] using tooling and procedures which were largely identical [5]. An important issue was the height of each submodule on the stacking fixture on which they were fabricated as this defines the length along the girder for installation, with a design gap between submodules on the girder of 0.3mm. During production we relaxed this tolerance to +0.3, -1.5mm. The height summary for submodules used at Argonne is shown in Appendix I. About 10 submodules fell outside the positive height envelope (due to the raw plate thickness being

out of specification) and we constructed some custom short submodules to allow their use in module assembly. The structural girders were produced commercially following the Quality Control plan agreed to with the Tile Calorimeter collaboration and shipped to Argonne. The crucial tolerances on the girder are the key into which submodules are placed as well as the flatness of the key surface which are used in aligning submodules such that the azimuthal surface lies wholly an envelope of $+0.75\text{mm}$ from nominal [6]. Another important characteristic of the girder are clearance holes through which the wavelength shift fibers pass to couple the light to photomultipliers located inside the girder, as described in [2]. Since these fiber bundles must be located to high precision, rather than position the holes in the steel to this precision, tooling was developed by which the precision pieces are glued into the girder [7]. This is shown in figure 3. More details on the pieces used to accomplish this interface to the readout electronics are discussed in [2].



Figure 3, gluing the plastic inserts into the girder. The end of the pneumatic tool which allows high precision to be achieved is visible at the end of the

Module Construction

65 modules for use in the tile calorimeter extended barrel EBA were mechanically constructed at Argonne. The basic concept used at Argonne for mounting and aligning submodules on the girder is shown in figure 4. The elements of this concept comprise:

- A level rigid assembly base to which the module is bolted during construction
- An optical transit
- A long plumb-line, aligned to targets at either end of the building and to the transit
- Targets for use in centering the girder on the assembly base
- Targets for use at the submodule inner radius to align it on center with the girder center line
- A precision level to use in leveling the girder on the assembly base

- A precision square to set each submodule vertical to the key in the girder
We estimated the basic alignment precision at 0.05mm such that all envelope non-uniformity is determined by fabrication tolerances.

The concept used at Argonne provides an external reference frame based on the building targets, plumb-line and transit. Our colleagues in Dubna used a somewhat different approach as their task was to assemble barrel modules with a length of almost 6m [8]. A similar approach to that at Dubna was used to build the second external barrel modules as it was convenient.

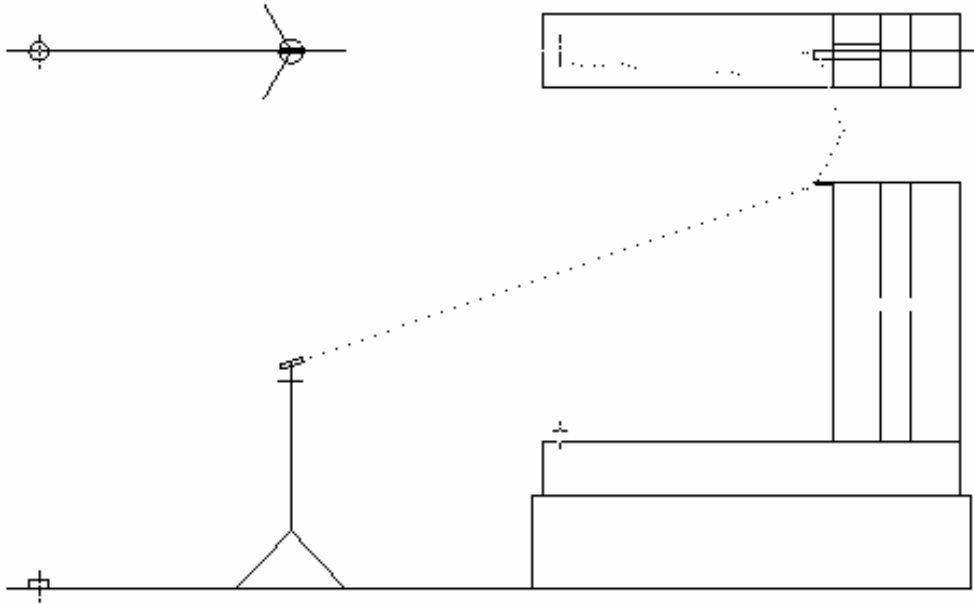


Figure 4 – external reference system based on targets on walls of building and transit.

Figure 5 shows the precision square (approximately 1.2m long) used to set submodules vertically on the girder (it was fabricated in Argonne Central Shops) as well as the task of bolting submodules to the girder (noting here that washers are placed around the bolts to insure that the loading is as designed.) Figure 6 shows the transit in use with a target shown at the inner radius of the submodule being mounted. The top of the 4m plumb-line is not visible. This tooling allowed a module to be fully assembled in about 4 hours and as is shown below was highly accurate.

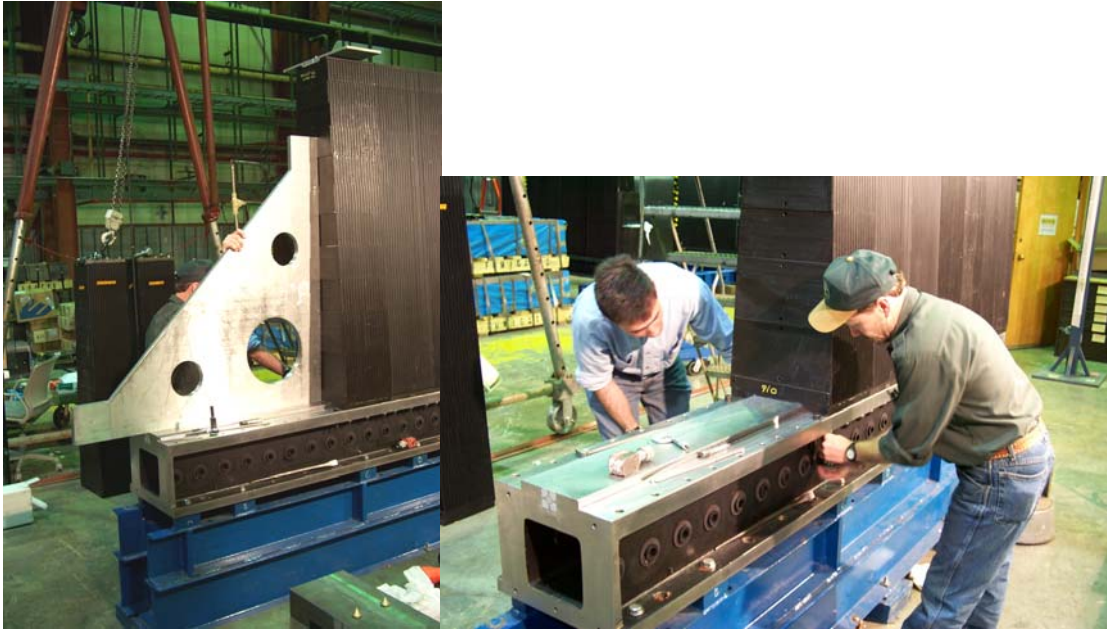


Figure 5, setting submodules vertically on the structural girder (left); bolting submodules to the girder (right)



Figure 6, the optical transit in use aligning a submodule on the support girder.

Special Modules

Of the 65 modules mechanically assembled at Argonne for the EBA section of the tile calorimeter, 10 (plus 10 mirror images) were special in some way (Appendix II.) In addition to the standard ITC, 8 had an ITC whose shape is shown in figure 7 (top), 2 as shown in figure 7 (middle), and 10 simply have a cut inner end plate (bottom).

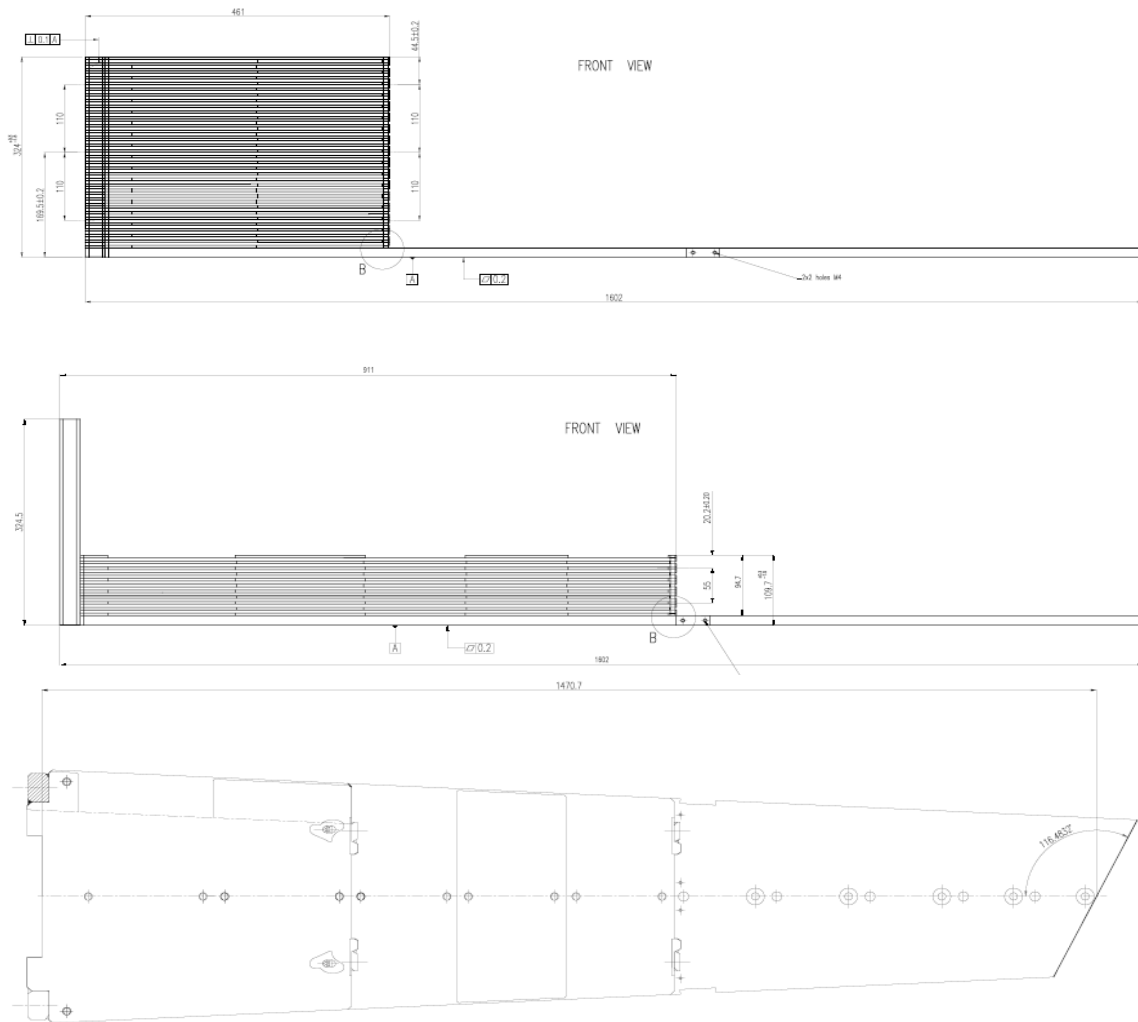


Figure 7, three of the different types of special ITCs.

Module Quality Control

As the key element of the mechanical structure, a detailed assembly protocol was followed for each module. An example of this protocol is shown in Appendix II This included 100% inspection of the welding of the inner radius plate using dye penetrant inspection, as in the initial design this plate transferred the inner radius bearing load.

Perhaps the most labor-intensive part of module construction was dimensional control as part of quality control process, and in particular measurement of the module azimuthal envelope. Here again we used simple tooling – a 6 foot precision straight edge to establish general non-uniformity of the module surface relative to the most outward pair of master plates. This was generally a four person operation with two people holding the straight edge, one person using feeler gauges to measure the gaps between the straight edge and the master plates and one person writing down results. Measurements were made in three rows: just above the girder, at the mid-point of the module surface, and just below the inner radius. The results are shown in figure 8, where we see that no where does the maximum envelope non-uniformity exceed our design specification of 0.75mm

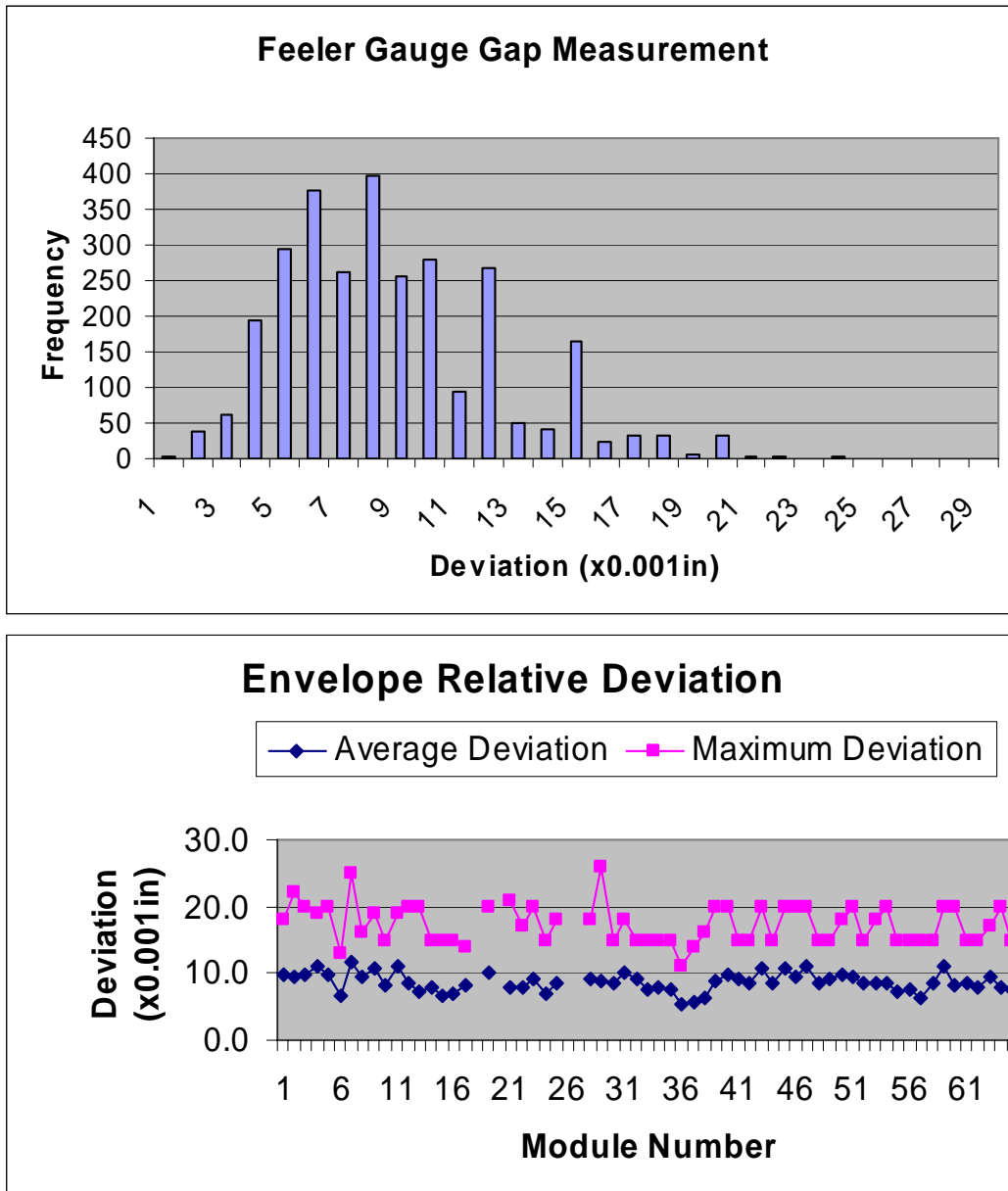


Figure 8, feeler gauge measurements of module azimuthal envelope determined as described in the text. The design specification is that no point should exceed a deviation of 0.75mm (0.029”) – this is clearly met.

Acknowledgements

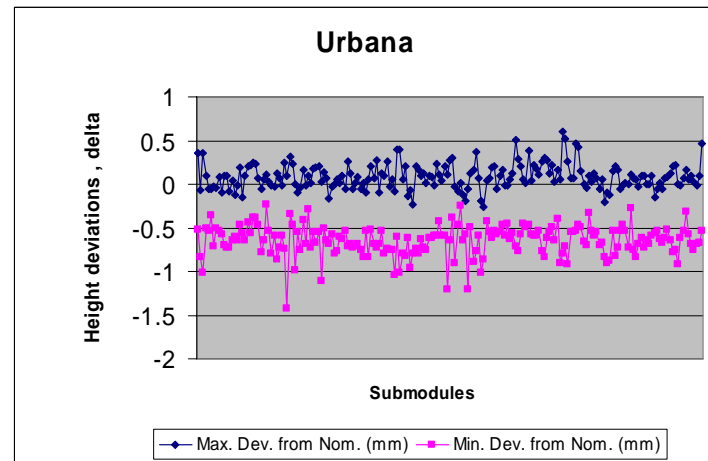
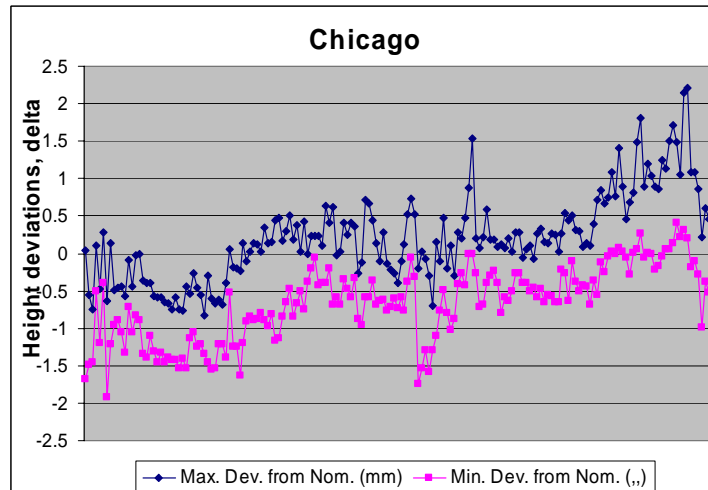
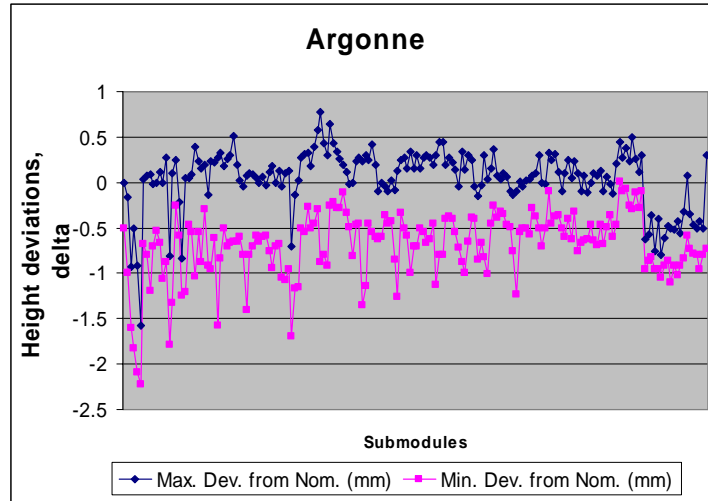
Thanks to Larry Price for providing some of these great photographs (too many of the others have deleted.) The construction of the tile calorimeter was a worldwide collaboration and many, many individuals contributed to its success. Of those, three stand out and we would like to thank Marzio Nessi, Lluís Miralles and Nikolay Topilin for their outstanding technical contributions as well as being fabulous people to work with.

References

- [1] ATLAS Technical Design Report, CERN/LHCC/94-43
- [2] Tile Calorimeter Technical Design Report, CERN/LHC/96-42
- [3] Mechanical tolerances and their effect on the assembly of the ATLAS TileCal hadron calorimeter, N. Hill, E. Petereit, ANL-HEP-TR-94-54
- [4] Submodules were constructed from master raw plates at the Argonne National Laboratory, the University of Chicago, the University of Illinois and the University of Texas at Arlington.
- [5] Production summary for submodule fabrication at Argonne for the ATLAS Tile Calorimeter, ANL-HEP-TR-07-69
- [6] Support Girder Design for the Atlas Hadron Calorimeter, ANL-HEP-TR-94-87. The production drawing can be obtained from the CERN CDD, drawing ATLLEMGB0001
- [7] The so-called girder ring gluing tool was designed by the Clermont-Ferrand group in France.
- [8] ATLAS Hadron Tile Calorimeter: Experience in Prototype Construction and Module Mass Production, Physics of Particles and Nuclei, Vol. 37, No 5, 2006

Appendix I

Submodule Height Distributions



Appendix II Special Submodule List

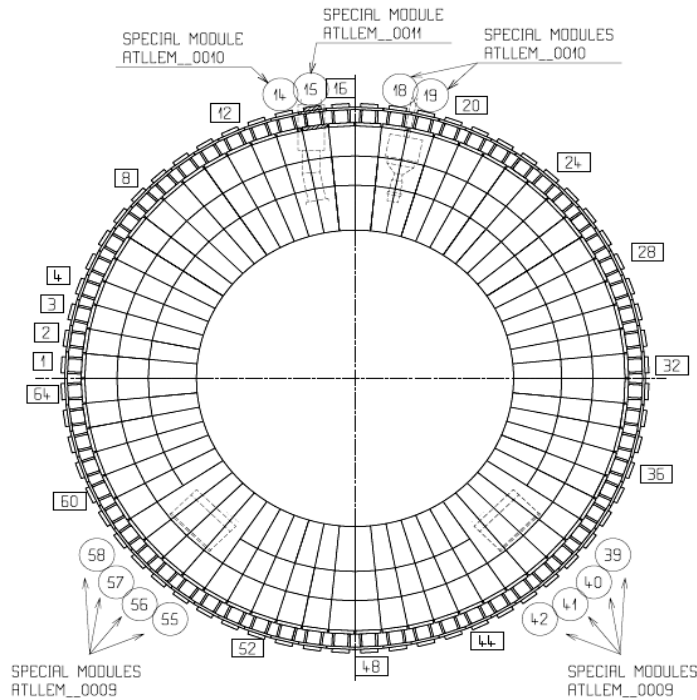
Elements in the table refer to the ATLAS drawing numbers in
CERN CDD

Note: Prefix drawing identifier with ATL

Module #	Girder #	SM #1	SM #2	SM #3	SM #4	SM #5	SM #6	SM #7	SM #8	SM #9	ITC
19	LEMGB001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMI0004
18	LEMGB001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMI0004
14	LEMGB001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMI0004
55	LEMGB0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMI0002
42	LEMGB0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMI0002
35	LEMGB0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0008	LEMS0008	LEMS0008	LEMI0006
36	LEMGB0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0006	LEMS0006	LEMS0010	LEMI0008
62	LEMGB0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0007	LEMS0007	LEMS0007	LEMI0005
61	LEMGB0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0005	LEMS0005	LEMS0009	LEMI0007
60	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0003	LEMS0003	LEMS0011	LEMS0015	LEMI0009
58	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0015	LEMS0015	LEMS0015	LEMI0002
57	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0015	LEMS0015	LEMS0015	LEMI0002
56	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0015	LEMS0015	LEMS0015	LEMI0002
41	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0015	LEMS0015	LEMS0015	LEMI0002
40	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0015	LEMS0015	LEMS0015	LEMI0002
39	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0015	LEMS0015	LEMS0015	LEMI0002
59	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0015	LEMS0015	LEMS0015	LEMI0001
38	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0015	LEMS0015	LEMS0015	LEMI0001
37	LEMGB0003	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMP0001	LEMS0004	LEMS0004	LEMS0012	LEMS0015	LEMI0010
15	LEMGB0002	LEMS0001	LEMP0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMS0001	LEMI0004

Note:

1. ATLLMI0001 is a standard ITC submodule, ATLLEMS0001 is a standard submodule
2. The module # is given in the assembly indexing scheme shown below



Appendix III Sample Module QC Sheet

Module Fabrication Checklist

Module #: ANL#34

Step	Complete?	Task	Date	Tech Initials
1.		Start Module Mechanical QC File.	5/19/01	KLW
2.		Place girder onto assembly base. Align in phi and Z. Place girder QC data into Module Mechanical QC File.	5/14/01	LJK
3.		Align transit with girder centerline. Put down external references and track string.	5/17/01	KLW/LJK
4.		Select and stage submodules next to girder. Inspect submodule IR and OR welds, inspect for paint on weld bars are in keys. Check all threads in the OR weld bars. Make repairs as necessary.	5/16/01	LJK
5.		Collect all submodule QC sheets and put into the Module Mechanical QC file.		
6.		Place submodules onto the girder. Check transit alignment before the first submodule is placed on the girder. Align submodules in phi and Z. Fill out appropriate QC documentation.	5/17/01	KLW/LJK
7.		Check that all bolts are torqued to the required amount.	5/17/01	KLW/LJK
8.		Measure phi alignment with plumb bob and record on QC sheet. Inspect phi using a parallel slid along the side of the module.	5/17/01	AC
9.		Mount endplate onto girder. Check phi alignment of the endplate at the IR key, at girder OR, and along the edge of the submodules. Check endplate Z alignment by measuring the gap between the endplate and the first submodule and by measuring the overall length of the module.	5/17/01	A/L
10.		Weld in front plate.	5/18/01	Robin
11.		Certify the front plate weld.	5/18/01	KRISTI
12.		Check endplate phi alignment, then pin endplate.	5/22/01	F/F
13.		Measure phi alignment with 8ft. long straight edge and record on QC sheets.	6/6/01	CREW
14.		Measure and record module length.	5/17/01	KLW
15.		Inspect all profile grooves and slots. Clean as needed. Touch up paint on submodules as needed.		
16.		Paint endplate and front plate blue. Paint girder edges black.	VERIFIED 6/5/01	IA
17.		Stencil module with its number.	6/5/01	IA



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