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The TT Production

1 Introduction

The Trigger Tracker (TT) station of the LHCb experiment is a tracking detector located downstream of the RICH1 and in front of the dipole magnet. The station provides transverse momentum information of large impact parameter tracks that serves as input for the Level-1 trigger. The station consists of four planes of wide pitch silicon microstrip sensors and covers an area of about 7 m^2.

The design, construction and installation of the TT detector is the responsibility of the U Zurich.

2 Assembly rooms

We plan to have different assembly locations for the TT detector station and the TT silicon modules. Adequate sites for the TT module production are in the assembly rooms either at the ETH or the U Zurich. The TT detector box plus support beams will be constructed at the large assembly hall of the workshop at U Zurich. The module installation into the TT station will happen at CERN in the LHCb cavern.

2.1 ETH Zurich

The assembly room at the ETH is a 50 m^2 large, well equipped clean room that is readily available and fits our purposes. The floorplan is shown in the left part of figure 1 while the right part shows a photograph of the room.

Filtered air flows at a rate of approximately 10'000 m^3/h in the room and provides a clean room class of 10'000, which is fully satisfactory for our tasks. The following equipment exists already at the assembly room: A stereo inspection microscope Leica GZ6 and a coordinate measurement machine Mitutoyo KN 815. The Delvotec 6300 automatic wedge bonder and a pull tester for wire bonds are presently at the CERN Prevessin site and will not be available for us.

In order to complete the equipment at the ETH, dry storage boxes for sensors and ladder assemblies as well as personal clothing have to be purchased. We estimate a cost of about CHF 10k.

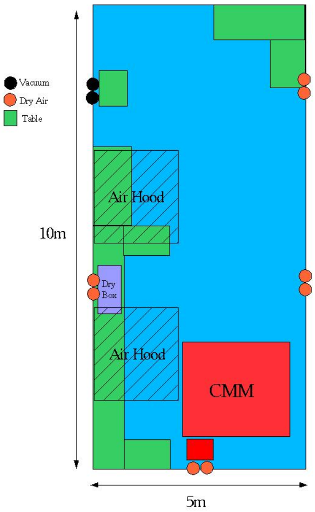

Figure 1: Left: The floorplan of the ETH assembly room. The location of the bonding machine will be close to the vacuum connection. Right: Photograph of the ETH assembly room.

2.2 University of Zurich

The detector lab room of the Physics Institute in the H floor has a manual probe station Karl Suess enclosed in a dark box and equipped with a Keithley 487 source measure unit and a LCR meter HP 4286. An automatic probe station Electroglas 1034X and a manual Delvotec bonding machine are also existing. In addition there is an infrared laser setup with a stepper motor and readout electronics for ladder tests with Beetle hybrids.

The assembly room of the U Zurich houses a small clean room enclosure with an inspection microscope on a movable x-y table. Finally, there is a multi-sensor metrology machine Mahr OMS600 available, with a measurement volume of 600 x 650 x 300 mm^3. The metrology machine is able to measure optically, by touch probe and by laser and will be used for module survey tasks and other component qualification.

If we do the module production in the assembly room, we propose to take out the visual inspection microscope and install a bonding machine in the small clean room enclosure. The available table in the enclosure will be used for module glueing. The burn-in teststand, which will be constructed until October 2004 should also be located in this assembly room. Dry storage boxes will be purchased: one large unit for sensor storage and another wider unit for half-module storage.

The assembly of the TT box and construction of the station will happen in the large assembly room of the workshop at the U Zurich right next to the module assembly room.

3 The TT module components - Part flow and quality assurance QA

3.1 Sensors

The total amount of sensors for the TT project is 1030 sensors including 15% spares. They will be mainly delivered from Hamamatsu Photonics, Japan. About 100 sensors used for the preseries production have been ordered from ST Microelectronics in Catania, Italy through the CERN CMS distribution center. All used sensors are CMS OB2 type sensors. The production order at Hamamatsu is expected to be launched latest in October 2004. The preproduction batch containing 100 sensors from CMS should be available in April/May 2004. The details of the sensor design & specifications can be found on http://home.cern.ch/ angarano/sensors.main.html. The first 100 sensors will be shipped from ST to the CMS central distribution center at CERN and then to U Zurich. For the main production at Hamamatsu we anticipate the first sensor delivery already in November 2004 and the final delivery by end of March 2005.

In addition, 580 sensors from Hamamatsu Photonics are ordered just recently for the stations T1-T3 located after the dipole magnet. The first 10% of the sensors are expected to arrive in September 2004. Another 20% will be shipped by February 2005. All sensors will be delivered latest by August 2005.

Upon arrival, the probing information from the vendor is checked for completeness and the sensors are registered into a database. Moreover, we plan to do the following quality assurance measurements:

- visual inspection
- metrological measurement of the sensors
- I-V and C-V curves
- strip tests on a 10% sample
- long term HV test on a 10% sample

The visual inspection and the metrological measurements will take place in the assembly hall. The sensor characterization of the TT preproduction series of about 100 sensors will happen in May 2004. A test stand consisting of a multiplexer, a picoammeter and a HV unit has to be setup to investigate the long term bias behaviour of several sensors simultaneously. It is not yet clear who designs this sensor-box. We

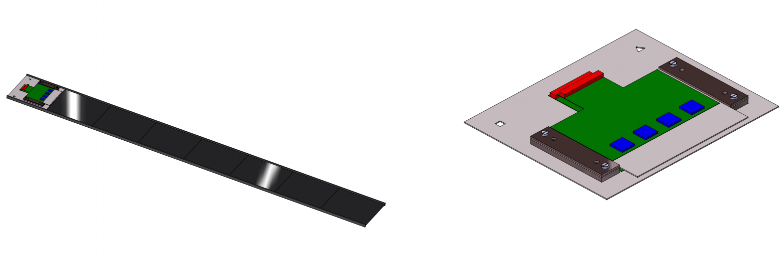

Figure 2: Left: An isometric view of a half module. Right: The TT hybrid with the lower and upper plates, beetle chips and connectors.

presently train 4 students to carry out the sensor probing on the manual and automatic probe station and 3 students for the visual inspection and metrology tasks.

The sensors will be stored in dry boxes in the assembly hall and a depletion voltage grouping is done, in order to match the depletion voltages of the sensors on a ladder.

3.2 Carbon fiber rails

The TT module design requires two carbon fiber composite rails for mechanical support, which are glued sideways to the sensors. In the present design the cross section of the rails is 2 x 5.5 mm. We will use a pitch based carbon fiber with high flexural modulus. The Mitsubishi K13A10 carbon fiber is a good candidate. We have already ordered a laminated 1 mm thick 400 x 800 mm large prepreg sheet from Mitsubishi chemicals consisting of 5 fiber plies in orientation 0-0-90-0-0. The milling of the fiber prepreg is done at the workshop of U Zurich. There will be special cut-outs in the rails for the HV bonds. The milled carbon fiber sheets are then shipped to Cookson Coating service in order to coat the inside grooves with about 25 μm Parylene C, a special dielectric substrate with high breakdown. This coating is necessary to insulate the fibers from the HV at the sensor edges. After coating, the sheets are then machined to the final rails.

The order for the full carbon fiber sheets should go out in May 2004.

3.3 Cooling Balconies

The cooling balconies for the hybrid will be made out of Haba Aluminium and are machined in the workshop of the U Zurich. No special quality assurance measures are foreseen. Some of the balconies however should be measured on the Mahr metrology machine to verify the precision of the holes.

3.4 Hybrids

The hybrid consists of two kapton flex circuits each loaded with four Beetle chips and passive electronic components as well as two 80-pin dual row connectors for the jumper cable. The kapton flex circuits are laminated on a substrate. The lower substrate is made out of Aluminium nitride (AlN) and has an integrated pitch adapter to route traces from a pitch of 183 μm as given on the sensor side to the pitch of the Beetle input pads. We will use AlN as a ceramic material for the lower base material, since it has a high thermal conductivity and a relatively low coefficient of thermal expansion (CTE) which is also matched to that of silicon. The CTE is important here, since the lower base plate is part of the ladder and defines through alignment holes the relative position to the cooling balconies.

The top plate is mounted on two copper cooling blocks which are soldered to the lower base plate. This top plate is made out of a 1 mm thick copper sheet having an extra ceramic pitchadapter made out of Al203. All copper pieces will be produced in the machine shop at U Zurich.

The lower AlN substrate and the extra pitchadapter of the top plate are produced by the company TFT-Siegert (D). We will do a visual inspection at U Zurich on these parts.

The Kapton prints are fabricated by the company Optiprint (CH) under the supervision of the MPI Heidelberg. The lower and upper pitchadapter as well as the copper carrier piece will be sent from Zurich to Optiprint who is laminating the kapton prints on the carrier pieces by using adhesive films. The two laminated hybrids will then be sent to the company Hasec (D) who is doing the stuffing and bonding. Hasec makes the component mounting as well as the chip attachment onto the hybrid. They will further bond the beetle chips to the pitchadapters and all other chip to hybrid bonds. The loaded hybrids will go to the MPI for electrical testing. Hybrids that pass their electrical test are shipped to Zurich for the module production.

3.5 Interconnect cable and jumper cable

The interconnect cable is a 40 cm long Kapton based cable with copper backplane produced by Dyconex, Switzerland. The interconnect cable routes the silicon signals from the inner 3-sensor ladder of a half module to a pitchadapter on the upper level of the hybrid, which is located at the module's end. The interconnect cable fans in the traces from a 183 μm pitch to 112 μm pitch and provides also HV and GND to the silicon sensors. The interconnect cable has a passivated copper mesh backplane. At both cable ends the cable will be glued conductively onto metallic pads on the upper pitchadapter and onto a pad of a 0.5 mm thick FR-4 piece glued onto the sensor.

The delivered interconnect cables will be visually inspected on the pad regions at both ends at U Zurich. The pad inspection is sufficient to catch open traces on the

Table 1: Part count for the TT stations.

	TTa-1	TTa-2	TTb-1	TTb-2	total	total & spare
ganging vertical	4-3-3-4	4-3-3-4	4-3-3-4	4-3-3-4		
around beampipe	4-2-1-1-2-4	4-2-1-1-2-4	4-2-1-1-2-4	4-2-1-1-2-4		
sensors vertical/full column	14	14	14	14		
layout horizontal	7-1-7	7-1-7	8-1-8	8-1-8		
sensors horizontal/row	15	15	17	17		
sensors/plane:	210	210	238	238	896	1030
half modules:	30	30	34	34	128	147
full modules:	14	14	16	16	60	
interconnects:	36	36	40	40	152	175
hybrid base plate:	30	30	34	34	128	147
hybrid top plate:	36	36	40	40	152	175
top pitchadapter:	36	36	40	40	152	175
Kapton prints:	66	66	74	74	280	322
jumper cable:	66	66	74	74	280	322
copper blocks:	72	72	80	80	304	
balconies:	30	30	34	34	128	147
carbon rail profiled:	60	60	68	68	256	294
carbon rail unprofiled:	60	60	68	68	256	294
carbon rail, junction piece:	28	28	32	32	120	138

cable, since traces which are interrupted are not continously gold-plated and their pads look therefore different. On some of the cables the trace capacitance and trace width will be measured.

The 25 cm long jumper cable is part of the TT box housing and will be permanently installed in the insulation walls during box assembly. The jumper cable plugs into the TT hybrid connectors and routes the signals further to service cables running all the way to the service box. The design of this cable is presently in work.

3.6 Total part count for TT modules

Table 1 shows the total part count for module components of the TT project. We have assumed 15% spare parts. The vertical readout segmentation is normally 4-3-3-4, excerpt for the modules around the beam pipe where the segmentation is 4-2-1-1-2-4.

4 Module assembly and module testing

4.1 Logistics

The full assembly of the TT modules is split into half-module production and mating of two half modules. The half-module production is done at the assembly room of either ETH or University. The production steps involve hybrid preassembly, sensor aligning, sensor glueing and bonding as well as visual inspection of the half module assemblies. The half modules are electrically tested in a burn-in station. After electrical qualification, the half-modules are mated together and then again measured on the metrology machine.

The electrical QA on the half modules after their assembly is performed at the University and described later in this document. After passing the electrical QA tests, the mating of the half-modules to full modules is done. The mated full-modules will finally be measured on a metrology machine.

4.2 Hybrid preassembly

Two electrically separated hybrids, the lower and the upper one have to be assembled. Upon arrival of the hybrid parts from MPI Heidelberg we visually inspect the pieces and bonds. The two copper blocks are glued onto the lower pitchadapter AlN piece. A solder connection from the Kapton ground pads to the ceramic pads is done. The upper Kapton circuit is grounded similarly.

4.3 Half-module Assembly & testing

The seven sensors and the lower pitchadapter base hybrid plate are placed on a vacuum assembly jig and their edges are put up against posts in order to align the pieces in the vertical and horizonal direction. We will maintain a 0.2 mm wide gap between the sensors and a 0.5 mm wide gap between first sensor and hybrid base plate. The sensors are kept in position with vacuum, and the rails are then glued on the assembly using standard Araldit epoxy. The curing time of the epoxy at room temperature is typically about 12h. After curing, the half-module is bonded on the Delvotec machine. The following bonds have to be made: Sensor-sensor and sensor-pitchadapter bonds. After each bonding step we plan to do a visual inspection of the bonds.

In the next fabrication step the top hybrid plate including pitchadapter and interconnect flex cable is mounted on the base plate. The interconnect cable is routed along the half-module using foam spacers and glued on the sensor. After another curing cycle the final cable-sensor bonds on the half module are done. A mechanical survey of the relative sensor position of a half-module completes this assembly task. The exact position of sensor targets on the half-module are recorded with a metrology machine and registered in a database. This measurement task can be performed at U Zurich using the Mahr OMS600. The half-modules are mechanically graded according to this mechanical measurement.

Before mating the half modules together, they are subject to an electrical test. A so-called burn-in station is constructed which allows to test 4 half-modules simultaneously. The burn-in test stand will be designed and assembled by a Physiklaborant from the ETH. It is desirable to have the burn-in stand with infrared laser diodes to shine on the silicon sensors. The burn-in stand should provide collected charge versus bias voltage setting measurement so that the operation voltages for the two independent readout units per half module is determined. The other important aspect of this electrical test will be a long term burn-in test. The 4 half-modules placed in the test stand will be read out for 24h. The burn-in setup has to provide liquid cooling of the readout electronics. In addition the box is thermally insulated and a programmable chiller will allow for controlled temperature cycles. The burn-in data are analyzed and the long term stability and noise is investigated.

An electrical grading completes then the module testing and the information obtained from the burn-in stand are recorded in a database.

4.4 Full-module mating

The half-modules are mated by glueing 1 mm thick rails to both module side. Two half module fixtures will be joined together for this mating process. Half modules are selected as pairs based on the metrology survey of the half-modules. After mating, the region where the two half-modules were joined is surveyed on the Mahr OMS 600.

5 TT Station assembly and installation

After their arrival, the T-shaped aluminium support beams will be joined to form the support structure of the left and right station of the TT. The TT support structure will be constructed in the assembly hall of the University of Zurich. Aluminium (Haba) plates as mounting surfaces for the ladders and the copper cooling plates will be installed. The parallelity of the lower and top mounted aluminium plates will be verified. The insulation walls are prepared and equipped with jumper cables, which will connect to the hybrid receptables on the modules. The insulation walls are mounted onto the box. The TT rails to slide the stations are adjusted and the open/close mechanism of the box carefully verified. Several full modules will be pre-mounted to work out the module installation procedures. The cooling and dry air systems are connected and cooling and purging tests are performed. In particular, the heat attack through the innermost region around the beam pipe is investigated.

The assembled TT box will be transported to CERN. The module installation is done in the cavern. The location of the module installation has to be defined.

6 Schedule and production time estimations

6.1 Overall

The TT preseries production of about 10% of the half modules will start in October 2004. The TT main production will start beginning of 2005 and continues throughout the year. The full TT system is ready for installation in the cavern by May 2006. The global commissioning of the fully equipped TT starts beginning of September 2006.

6.2 Sensors

A preproduction order of 10% for the TT station through CMS for ST OB2 sensors was launched in February 2004. This preproduction batch will be available in April/May 2004 as promised by CMS. The final sensor order at Hamamatsu will be placed latest in fall 2004. It is expected to have all TT sensors delivered and tested latest by spring 2005.

The other sensors (total 580) produced by Hamamatsu for the tracking stations T1-T3, located behind the dipole magnet, are already ordered. The first 10% will arrive in September 2004. Another 20% are expected to be shipped by February 2005. All sensors will be delivered by August 2005.

The time estimates for the visual inspection per individual sensor will be initially about 30 minutes in the preseries phase going down to 20 minutes in the production phase. The time estimate for I-V and C-V is about 30 minutes per sensor. An exact time estimate for the automatic probe station is not yet known. The metrology per sensor takes about 30 minutes. Two groups of students which are already being trained will do the visual and metrology task on the one hand and the sensor probing on the other hand.

6.3 Readout electronics

A production type version of the 4-chip hybrid and the analog cable has to be ready by May 2004 in order to build two full-scale half module prototype latest in June. This production type version includes the final components for ceramics, connectors and components. The hybrids have to be stuffed and bonded by the company Hasec in order to qualify this company for this task. The analog cable and kapton flex production as well as the pitchadapter production should start in July/August 2004. The design for the jumper cable has to be ready by May 2004 and a first prototype to be delivered latest in July 2004. Production of the jumper cables could start in fall 2004.

The pitchadapters and analog cables will be visually inspected. We estimate 20 minutes each for analog cables and both types of pitchadapter.

6.4 Mechanical Parts for half-modules

The Aluminium balconies are being produced already now. The copper pieces for the hybrid should be produced after the testing of the production type hybrid is hopefully complete, i.e. in July 2004. The carbon fiber order should go out in May 2004. We expect the 50 carbon fiber sheets to be delivered by July 2004. After their delivery, the plates have to be milled at the workshop of U Zurich and sent out for coating. The turn-around time for the coating is expected to be 4-6 weeks. A machining of the sheets to rails will then take place in August/September 2004.

In addition we need small Rohacell foam standoffs to route the analog cable over the sensors.

6.5 Module production and testing

A decision on the assembly site has to be made by end of April 2004. This assembly site should then to be ready for us by July 2004. This includes that most of the infrastructure is in place and manpower for the TT production is allocated and defined. Especially a bonding machine needs to be purchased by then.

The pilot production of about 10% of half modules is launched in October 2004 and will last until December 2004. The TT half-module main series production will start in January 2005 and lasts until December 2005. The pilot- or preproduction will use the ST sensors which are then available. The preproduction phase will optimize the production procedures and should exercise the quality control chain.

We will start in January/February with 2 TT half-modules/week and expect to be able to ramp up the half-module production to 3 half-modules/week in March and April 2005. Starting with May 2005 we will produce 4 half-modules per week and beginning with September we should prepare ourselves to be able to produce even 5 half-modules per week. Even under conservative assumptions like machine breakdown times or a 2 month summer vacation time, we should be able to produce all half-modules within 2005. The required number of glueing/bonding jigs is initially two, in May 2005 four half-module fixtures/jigs and in September 5 half-module jigs.

The half-modules will be surveyed on the Mahr OMS600. The expected time for a half-module survey is 1 hour. The survey data will be put in the database and the half-module mechanically graded. After the mechanical survey, the half-modules are subject to a burn-in test. The burn-in test will readout four half-modules simultaneously in an insulating box. The burn-in time is between 24h and 36h, so that burn-in can easily keep up with the production pace. The design of the burn-in teststand will start in May 2004. The mechanics of the box is expected to be finished by October 2004. The preparation of the readout electronics of the burn-in stand can not start before July 2004 due to lack of Tell1 boards.

6.6 TT station and part assembly

Most of the material for the TT station like support beam profiles, Aluminium or copper sheets and insulating materials could be ordered until summer 2004. The construction of the TT station is planned to happen in the first half of 2005. The second half of 2005 will be used for dedicated mechanical measurements on the station as well as cooling and gas purging tests of the box.

We should have a first rough prototype version of the special beam pipe piece ready by November 2004. This prototype should be used for a careful testing of the insulation capability of the TT box. Measurements should be performed using Kapton heaters at the wall facing the beampipe.

A first smaller-scale Aluminium cooling plate should be ready by summer 2004. This plate could then be used for the burn-in stand in October. It is also important to measure the pressure drop along the pipes on the plate to verify that we do not have too large pressure drops at our design flow.

A copper cooling plate element should be ready by beginning of February 2005 and will be manufactured by a company.

7 Manpower

For the module production we need as a core team two dedicated technicians full time. The first should start already in September 2004 with bonding training so that we are ready for a pre-series production in October 2004. The second technician will mainly work on module construction like aligning, glueing and mounting tasks and should preferably start in November 2004. It is still unclear from which institute we should hire the technicians. The construction and assembly of the TT station itself is done by the workshop group of the U Zurich.

For sensor or module testing issues like probing, metrology and burn-in etc. we will train a group of students each working 10%, i.e 4 hours per week in the following categories:

- Visual Inspection and metrology: 3 Students

- Sensor Probing: 4 Students
- General laboratory work: so far 1 Student
- Module burn-in tests: 3 Students
- Database: 2 Students

Nr.	Vorgangsname
1	**ST project**
2	Engineering design finished
3	Support and first T1-T3 box installation in IP8
4	Full detector installation IP8
5	Full system ready for global commissioning
6	**Silicon sensors**
7	Sensor specifications
8	Ordering sensors T1-T3
9	T1-T3 preseries production 10%
10	Probe T1-T3 preseries sensors
11	T1-T3 sensor production (full batch)
12	Probe T1-T3 production sensors
13	TT preseries delivery 10% (from CMS)
14	Probe TT preseries
15	Order TT production
16	TT sensor production (full batch)
17	Probe TT production sensors
18	**Ladder prototyping**
19	T1-T3 prototype and test
20	TT prototype hybrid with 4 beetles
21	TT - Assemble full prototype ladder and test
22	**Ladder production and assembly**
23	Beetle engineering run
24	T1-T3 hybrid and pitch adapter production and tests
25	TT hybrid and pitch adapter production and test
26	Kapton cable production and test
27	Component production
28	Prepare assembly sites
29	Preseries production
30	Preseries test
31	Ladder assembly and test
32	**Readout link and service box**
33	Final designs
34	Production and test
35	**Detector stations**
36	Mechanical design
37	Mechanical component production
38	Assembly and test
39	**Infrastructure: HV, LV, cooling**
40	System engineering
41	Ordering, delivery, installation