ATLAS Pixel Module Assembly in Dortmund

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Abstract—**The ATLAS Pixel detector is the innermost substructure of the multi-purpose LHC experiment ATLAS at CERN and part of the tracking system. The Pixel vertex system will consist of 1744 hybrid pixel modules, about 280 of them have been assembled at the University of Dortmund.**
This work provides a detailed description of the ATLAS Pixel module assembly procedure executed at the University of Dortmund. Effort had been put into the developement of a laboratory and testing environment to fulfill all technical demands of a serial production of fully efficent pixel modules.

I. Introduction

The ATLAS detector and its silicon based vertex-system (Fig. 2) are scheduled to be operational in 2007. The barrel part of the innermost system, the pixel detector, consists of the 3 cylindrical layers with the radial positions at 50.5mm, 88.5mm and 122.5mm. These layers are made of identical support and cooling structures (so called staves) inclined with an azimuthal angle of 20 degrees. There are 22, 38 and 52 staves in each of these layers, respectively. Each stave unit contains 13 pixel modules. The forward regions are covered by three disks on each side of the barrel part. One disk is made of 8 sectors, with 6 modules in each sector. Disk modules are identical to the barrel modules, except the electrical connection (to module soldered cable vs. additional flexible circuit board with connector).

Due to the proximity of the pixel detector functional units to the interaction point, their components, adhesives and support structures will have to withstand high fluences of charged and neutral particles. Furthermore a high track density as well as a bunch crossing rate of 40MHz require fast readout electronics and the smallest possible segmentation.

Based on the assembly procedures and toolings of the ATLAS Pixel group of the University of Bonn, a module production chain has been set up and necessary tools and procedures developed regarding our special assembly production course needs. To clarify the difficulties and achievements a module assembly lab has to deal with and to provide we give a brief introduction to the components of a pixel module in section II.

The first and important step during module assembly is the visual inspection of incomming components. Specified annotations on this can be found in section III.

The following sections describe the assembly and tooling of the module parts as constituted in Fig. 1 as well as the difficulties had to be solved. We dwell on several facts one has to take into account regarding the wirebonding. As an outlook in section X we outline our experiences during the past 3 years for future projects.

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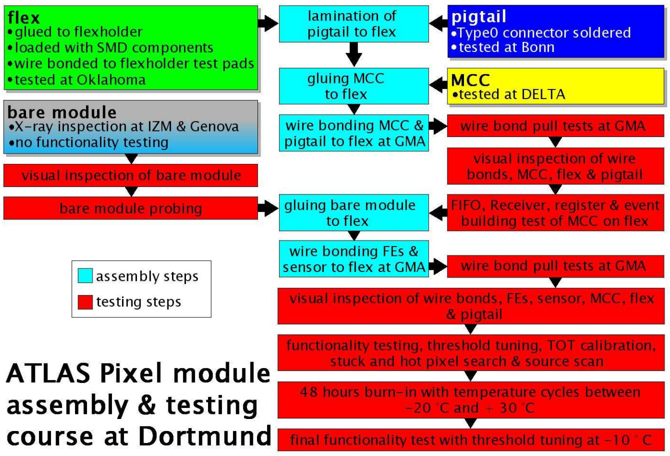

Fig. 1. Course of module assembly and testing in Dortmund [2].

II. Components of an ATLAS Pixel Hybrid Module

Figure 3 shows an ATLAS Pixel module, containing several highly specialised components of a thickness of only a few hundred micrometers. The Flex consists of a printed capton circuit foil of specific high voltage-, radiation- and temperature resistance (Dyconex) with a thickness of 100μm and the rectangular measurements of approximately a sensor tile (Fig. 3). It contains the bondpads for all wirebonds, the front end data- and voltage lines, a special resistance for the temperature monitoring of the module (NTC) and other Surface Mount Devices (SMD). The University of Oklahoma accomplished qualifying electrical tests

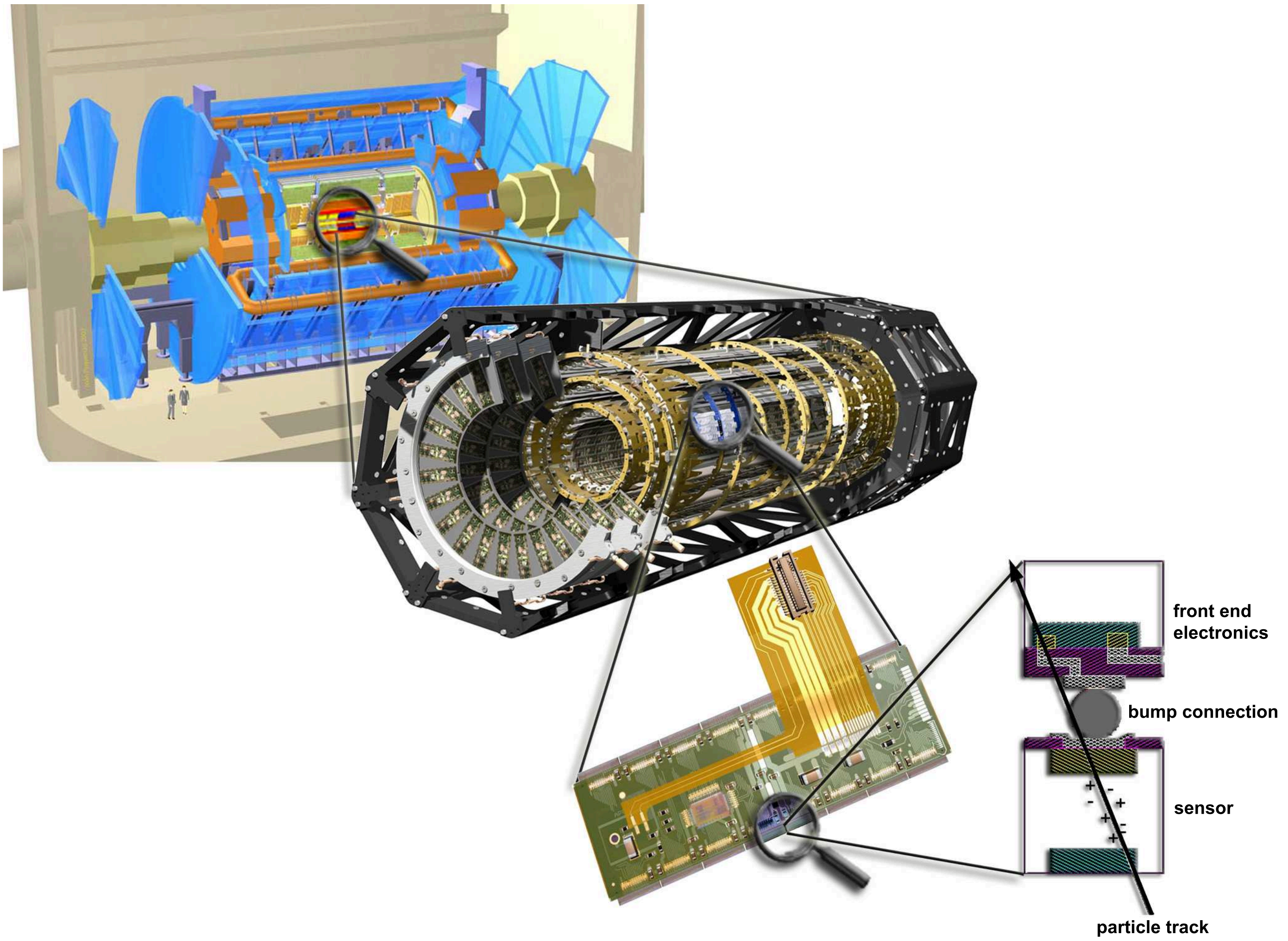

Fig. 2. Overview of the ATLAS detector, focussing on the innermost substructure, the pixel detector with its 1744 modules × 46080 readout channels, and cross-sectional view of a sensor and Front End electronics pixel cell.

(opens, shorts, HV isolation) and mounted the Flex on a PCB Flex frame (Flexholder) with a gold layer underneath the Flex for further electrical tests and assembly steps.

The Pigtail provides a barrel module Type0-connector (disk modules have permanent Type0-cables instead of a Pigtail) as well as lines for communication, electrical power supplies and sensor bias voltage. The connector is soldered to the Pigtail and tested at the University of Bonn.

The module control chip (MCC) performs the tasks of the module event building, controlls the 16 Front End chips and is responsible for data transfers out of the module. It measures $6.84 \times 5.14\text{mm}^2$ and is tested by a commercial chip tester in Denmark.[1]

An ATLAS Pixel sensor tile has an n^+-type implant in n-type substrate, a feature that enables it to be operated partially depleted after type inversion. Each sensor tile of a thickness of $250\mu\text{m}$ covers a sensitive area of $16.4\text{mm} \times 60.8\,\text{mm}$, containing 328×144 pixel cells by the majority of size $50\mu\text{m} \times 400\mu\text{m}$. 16 Front End chips (FEs) per module, providing the readout electronics, are connected via bump bond flip chip technology to the pixel implants of a sensor tile by IZM[2] in Germany and AMS[3] in Italy. The pixelated silicon sensor tile connected to the 16 Front End chips form the so-called Bare module. The size of the gap between the chips and the pixelated side of the sensor depends upon the vendor and is less than $20\mu\text{m}$, determined by the bump height. In turn this could lead to damages to the electronics as a consequence of flying sparks within the gap. Therefore, the active area on th n-side is surrounded by an n^+-implant, that is grounded externally. Each Front End chip is

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[1] Danish Electronics, Light & Accoustics, Hørsholm, Denmark

[2] Fraunhofer Institut für Zuverlässigkeit und Mikrointegration, Berlin

[3] Alenia Marconi Systems, Rome

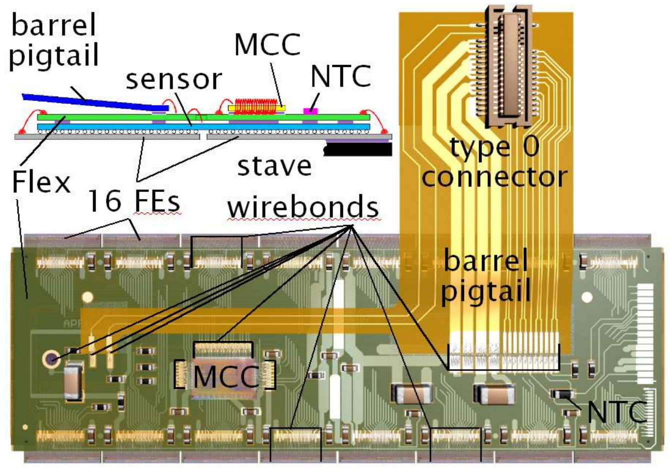

Fig. 3. Detailed view of a single pixel module and its components [2].

connected to the Flex-MCC (Flex capton foil with mounted Pigtail connector and module control chip, but without sensor unit) via 30 wirebonds.

III. Visual inspection of incoming parts

Upon receipt of the module components each part has to pass a visual inspection to exclude parts with obvious mechanical damage or manufacturing errors. The Flex is received loaded with SMD components and glued at both ends to a Flexholder PCB which guarantees stable positioning of the Flex on the vacuum tools during assembly. It has to be checked for missing SMD parts, mechanical damages on the surface, probably responsible for later shorts and small fissures within the cutting zones. Pigtails sometimes show partially lift offs at connector feet due to very small amount of solder. Nevertheless it is proposed to apply as little solder as possible to prevent particle interaction in this area of the detector. The lift offs lead to partial electrical failures. This has also to be checked when the MCC shows certain dysfunctions in the electrical test after wirebonding.

Before gluing the MCC to the Flex it can only be checked for obvious mechanical damages in Dortmund, qualifying electrical test can be performed after wirebonding, prequalifying tests have been done in Denmark.

To guarantee the operativeness of Bare modules beside the visual inspection under a 40-times stereo microscope, Dortmund built a Bare module probe station and a shock resistant laminar flow box for automated Bare module testing. A special needle card with 48 contacts enables us to successively automatical probing of 8 Front Ends.

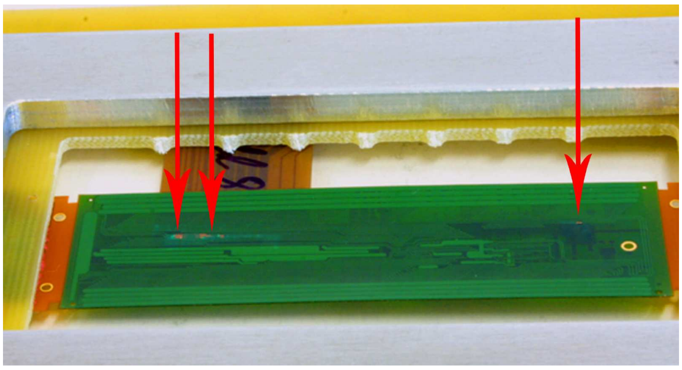

Fig. 4. The picture clarifies the importance of visual inspections. Submitting the capton Flex to another careful examination before Bare module assembly reveals to serious damage on the backside of the Flex, due to missing teflon protecion during Pigtail assembly. This Flex turns to be unserviceable on account of the danger of shorts between Flex and sensor.

IV. Attachment of the connector “Pigtail”

After the visual inspection the Flexholder is screwed on an aluminium vacuum chuck which allows to fix the Flex and hold it down. Teflon slides between the rear side of the Flex and the Flexholder avoid adhesion to the Flexholder card and mechanical damages on the back side of the Flex (Fig. 4). To guarantee the alignment of the Flex on all production chucks the Flexholder contains two alignment holes and all chucks have two alignment pins. The Pigtail is aligned under a microscope and fixed with help of two teflon-covered aluminium punches attached to a special bridge, which is screwed on the chuck. The correct orientation is given by the position of the corresponding bondpads on the Flex surface. Partial coverage by Pigtail is negligible. The fixtures are located above the HV pads and the LV pads of the Pigtail. Two pieces of heat curing AF42 film (3M[4]) are put and aligned between the Pigtail and the Flex underneath the bondpads with toothpicks or surgical forceps. After one hour of heat curing in an oven at $(174 \pm 2)^\circ$C the Pigtail is glued with mechanical pressure to the Flex. Using vacuum mounting plates and silicon tubes offer the possibility to fix the components also during cure-process and prevent them from slipping. A mechanical load test had been established which provides to turn over Flex and pull down the Pigtail with a force of 2N tensile load. The test has to ensure, that the splices will withstand the mechnani-

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[4] 3M corp., Maplewood, MN, USA (www.3m.com)

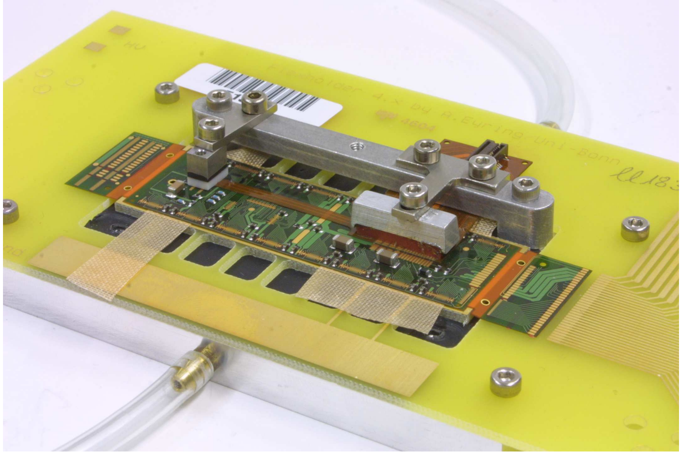

Fig. 5. Setup for the manual attachment of the connector.

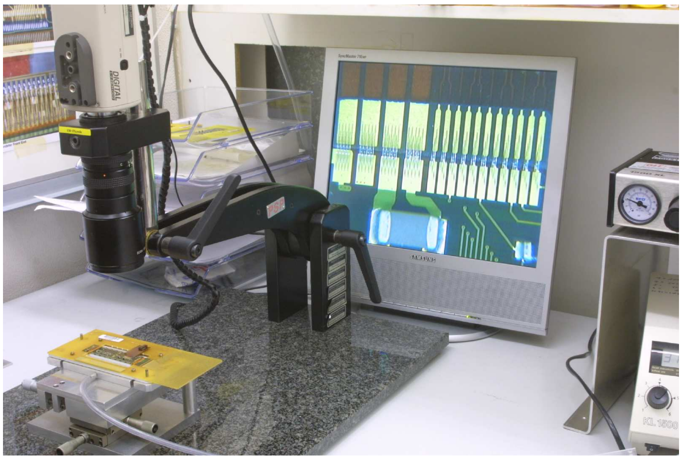

Fig. 6. Exact optical alignment of the Pigtail bond pads.

cal stresses and strains of the integration and operation phase of ATLAS.

V. FITTING AND GLUING OF THE MODULE CONTROL CHIP (MCC)

The MCC is mounted to the Flex on the same vacuum chuck, using the 2-component adhesive SE4445. Same amounts of thermoconducting glue part A (white) and part B (grey) are to be mixed carefully on scales with less than 10% difference of abundance and applied in 5 thin dots in the MCC-field between the three ranks of corresponding bond pads on the capton Flex. It has to be taken into consideration that too thick coatings of SE4445 cause bonding problems, MCC allignment difficulties or bad thermal coupling. Positioning the MCC demands permanent control with a stereo microscope with graticule, because the MCC easily tends to float or distort its position between the bond pads.

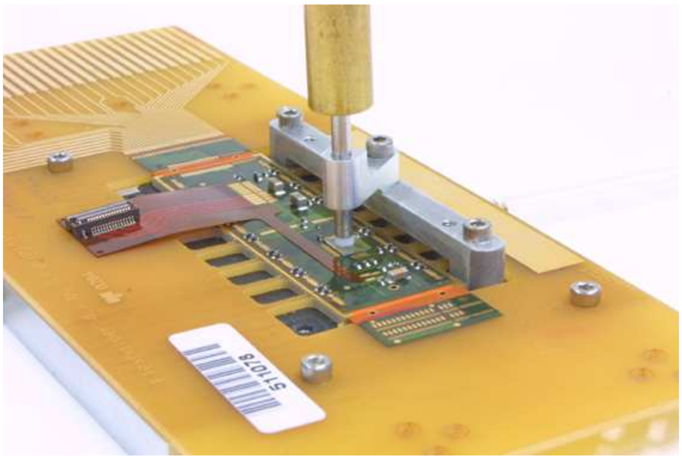

Fig. 7. Setup for the MCC-attachment.

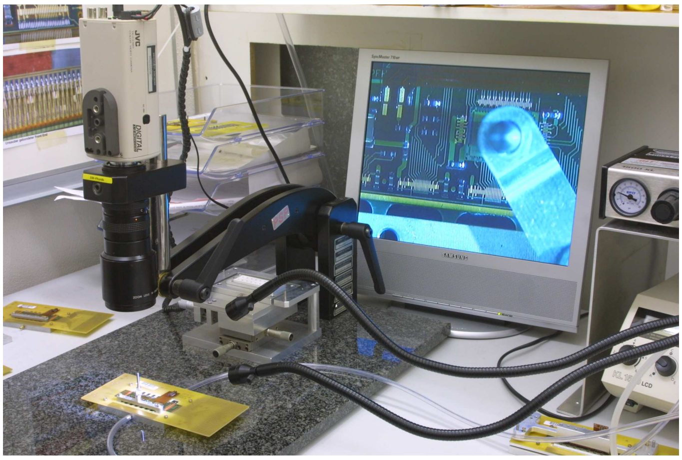

Fig. 8. Optical allignment of bond pad pairs.

A teflon pin with an 19g asymmetrically drilled brass-cylinder for all-around-position-controlling weights the MCC down while curing of SE4445 at $(60 \pm 2)°$C for one hour in the oven.

VI. FIRST WIREBONDING

Wirebonding provides the electrical connections between the readout-, detector- and control components. We split the wirebonding into two major jobs, because this enables us to do an intermediate electrical testing of the Pigtail connections and the MCC functionality. It has been successfully tested to replace a non working MCC of a module, while subsequent removal of a deficient Flex-MCCs probably causes the loss of the entire module due to irreparable mechanical damage to the Bare module. Dortmund assignes the GMA[5] to do the wirebonding and required pulltest. 25μm wires are used with redundant bonding

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[5] Gesellschaft für Mikroassemblierung, Duisburg, Germany

on all pads. Small inaccurancies between component- and Flex bondpads can be balanced by the bond machines.

Before the MCC-bonding the middle section of the Flexholder underneath the Flex is removed, which guarantees best possible adhesion of the Flex on the bond machiche by installing a vacuum tool developed in Dortmund to keep the Flex in its position. The backside of the Flex-MCC is visually inspected to ensure that it has not been damaged by the extreme conditions of the Pigtail assembly. During cutting of the middle section of the Flexholder, the Flex-MCC should be protected against glas fibre dust.

A visual inspection of the assembled modules is necessary after receiving them from the wirebonding vendors to detect wirebond errors, shipment damages and not removed test bonds.

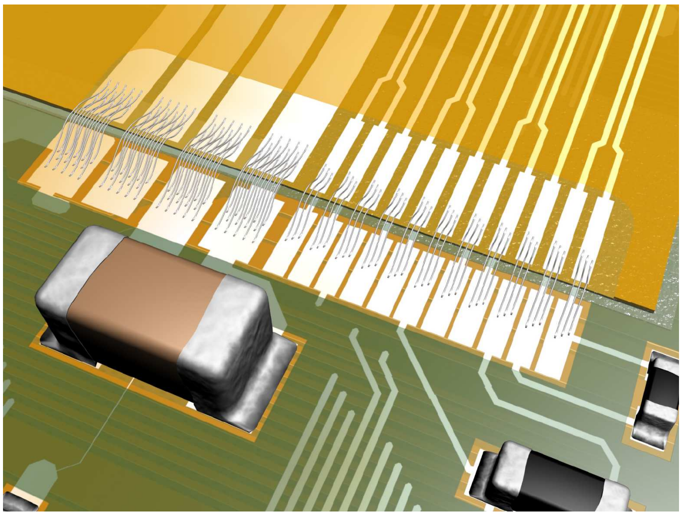

Fig. 9. Detailed draft of the main Pigtail wirebonds.

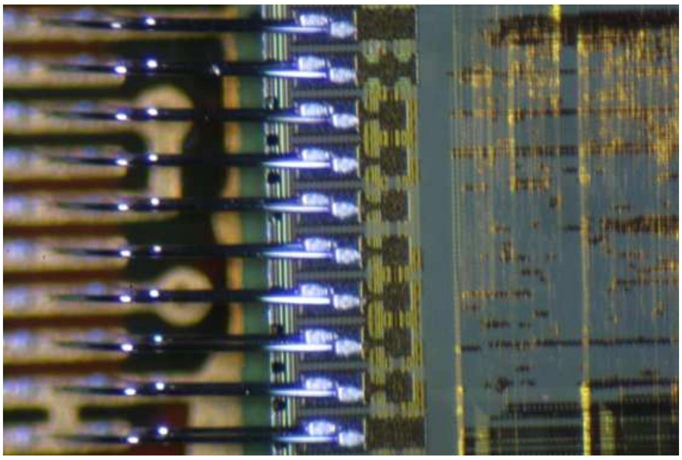

Fig. 10. MCC wirebond pairs.

VII. Fitting and gluing of the sensor unit (Bare module)

The most critical assembly step, due to costs and limited availability of bare modules, is the gluing of the Flex-MCC to the Bare module, since handling or assembly errors can lead to the loss of the entire module as well as adjusting the adhesive assembly or the removal of a non working Flex-MCC. The Flex-MCCs and Bare modules are to be qualified to guarantee, that only efficient working components are used in this assembly step. X-ray images for several Bare modules had been made at IZM and INFN Genova to detect merged and disconnected bumps, as well as a visual inspection after shipment to ensure, that the Bare module has not been damaged during transport. Bare module probing ensures the operativeness of the Bare module before it is glued to the Flex-MCC.

The qualified Bare module is placed, FE-side down, on a perforated rubber plate on an aluminium vacuum chuck. Two alignment dowels in the Bare module chuck and two corresponding alignment holes in the Flexholder frame allow to place the Flex-MCC in a fixed position above the Bare module. A corresponding system of three micrometer screws precisely allow to move or twist the Bare module in two dimensions. The Flexholder of a qualified Flex-MCC is screwed on an aluminium frame containing 5 levelling screws for controlled kneeling of the Flex onto the sensor surface. The Bare module is aligned by four alignment marks on the sensor and four corresponding alignment holes in the Flex. Minimum requirements are the visibility of at least three of the alignments marks to allow a precise position measurement of the sensor after the module has been attached to the stave.

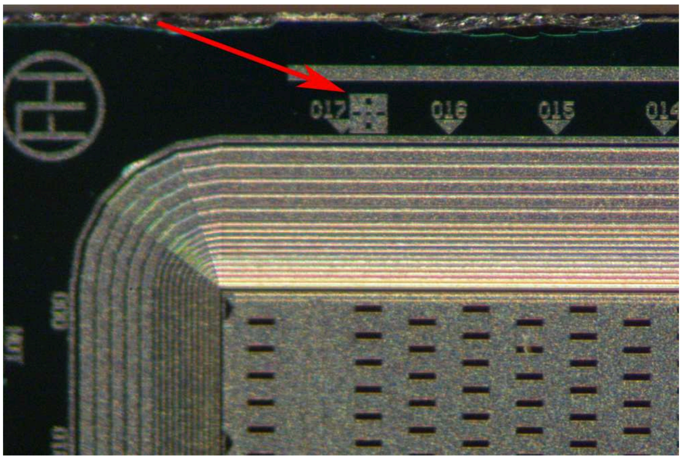

Fig. 11. One of four sensor alignment marks.

Fig. 12. Setup for Bare module align- and attachment.

To glue the Bare module to the Flex-MCC, two different types of adhesives are used, solid stripes of adhesive tape ARclad 8026[5] and liquid Dow Corning 3140 RTV MIL-A-46146. For exact alignment two 3mm $\times$ 5.8cm width and 10μm thick ARclad 8026 adhesive tape stripes are carefully placed on a second vacuum chuck to be applied when their top cover foil is removed. Underneath the Front End bond pads they ensure that the bond pads do not yield during wirebonding. The Flex is glued as flat as possible to the Bare module. Our experiences indicated a better handling and adhesion of ARclad 8026, when it is pressed on very carefully by additional use of toothpics.

Dow Corning 1204 RTV Prime Coat guarantees a quick and reliable curing of Dow Corning 3140, which is applied in small dots on the backside of the Flex-MCC around the HV hole, underneath the Pigtail wirebond pad rows, the MCC and the NTC. It shows a good thermal conductivity as well as a long-term resistance against moisture and atmospheric contaminants especially where a solvent-free product is needed. The conducting paths on the backside of the Flex, as well as the translucent capton foil provide a good orientation, finding the exact positions for the adhesives. The HV hole and Pigtail wirebond pad glue dots stabilize the module regions for wirebonding whereas the MCC and NTC glue dots guarantee a good thermal contact of these components to the Bare module, cooled in operation. A special aluminium bridge with a sattle adapter and a clamp is used to press down the adhesive film stripes and each region with glue dots to the Bare module and to have access to the FE 1 and 2 by lifting the Pigtail, as well.

Dow Corning 3145 glue dots can optionally be applied with an automatic dispenser between the inter Front End gaps of the Bare module and the Flex to increase the module stability. The curing of all adhesives takes 24 hours at room temperature.

VIII. Wirebonding of Front End pads and High Voltage lines

After adhesive curing on its vacuum tool the Front End- and high voltage wirebonds can be mounted to the pixel module. The wirebonds between the Flex and the Front Ends and between the sensor HV window and the Flex are also done by GMA, as well as the wirebond pull test. The Front End wires are the only non redundant single wires on a pixel module.

Another visual inspection of the assembled module under the microscope is necessary after receiving it from the wirebonding vendor to detect wirebond errors, supplementary lift offs and other possible shipment damages.

IX. Wire bond encapsulation

If a module passes all initial operativeness tests, the Front End and Pigtail wirebonds are potted with UV curing Dymax-E-v3.1 at their feet under the microscope. Handling the dispenser canula demands particular attention to avoid damage to the fragile wires. The potting prevents wirebond damages by resonances of the wirebonds in the ATLAS magnetic field.

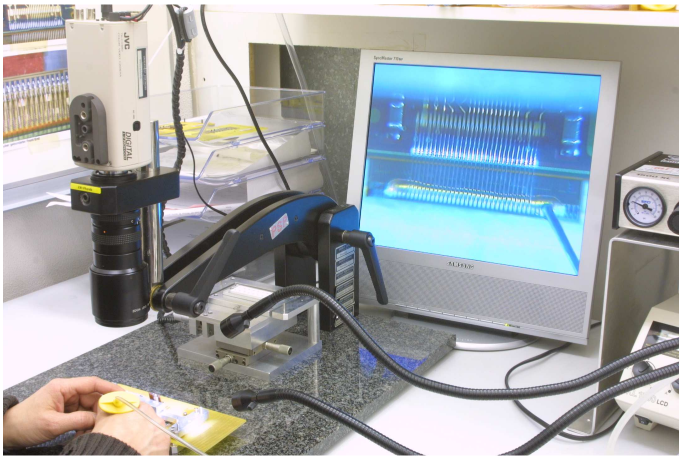

Fig. 13. Setup for wirebond encapsulation.

X. Conclusions and outlook

The past thirty months led us through a difficult but instrcutive phase from the ATLAS Pixel module

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[5] Adhesive Research Inc., Glen Rock, PA, USA *www.adhesivesresearch.com*

prototype assembling to batch production. During preproduction we built up an assembly lab as well as a test setup and improved several assembly tools in terms of our requirements. The preproduction and initial qualification phases was successfully finished in June 2004 with 10 run capable FE I.1 and I.2 modules. Fig. 14 shows the chronological course of our production module output. Until June 2006 Dortmund has produced 276 FE I.3 modules, including 235 IZM modules and 41 of the bump bond vendor AMS. 254 of them passed all tests successfully, 85 of them with less than 60 ranking points [10] as high quality B-layer modules. It further incloses 169 layer one or two modules and 19 modules with electrical problems we try to solve. The main problems that occured can be categorised as MCC problems, disconnected Pigtail ELCOs that have to be resoldered, lost wirebonds, early IV breakdowns of the sensor and MCC pottings that came off during thermal cycling. Furthermore one should not underestimate the requirements to carefully look into adhesive matters occurring during assembly. Recapitulating, we gain a considerably amount of experience in this highly specialized field of technology as well as the ability to successfully contribute with nearly 260 suitable pixel modules to the collaboration work.

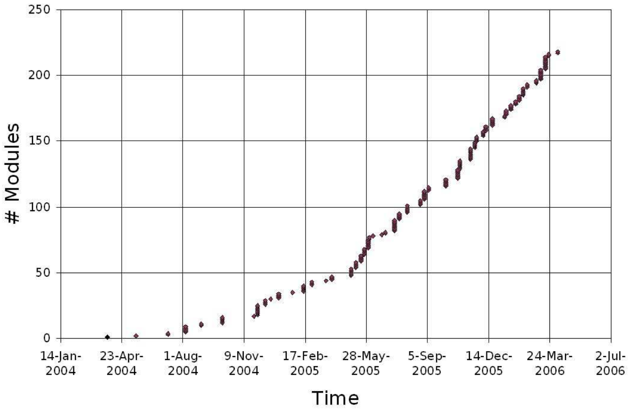

Fig. 14. Course of the integrated module assembly in Dortmund.

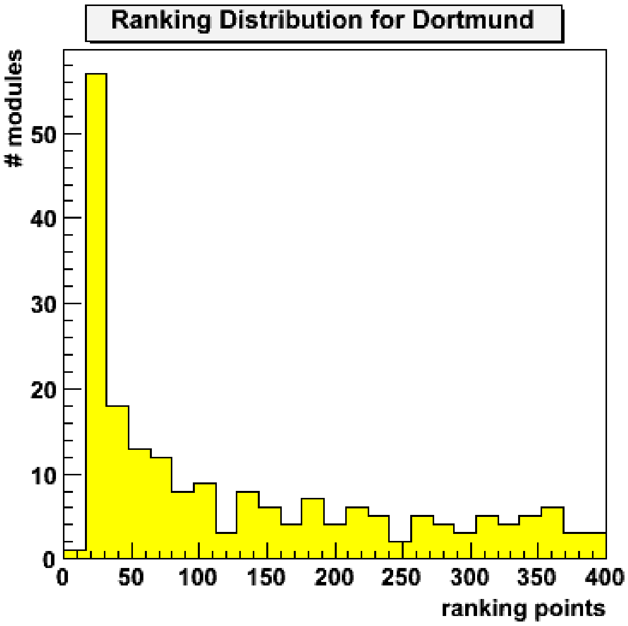

Fig. 15. Ranking Point distribution for Dortmund production modules [13].

XI. Acknowledgments

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References

[1] R. Boyd, G. Darbo, A. Eyring, M. Garcia-Sciveres, C. Gemme, P. Netchaeva, W. Ockenfels, O. Runolfsson, L. Rossi, E. Vigeolais, N. Wermes “ATLAS Pixel Module Assembly”, ATL-IP-AN-0003 (2003)

[2] D. Dobos, “Production accompanying testing of the ATLAS Pixel Module”, Diploma thesis (2004)

[3] M. Maß, “ATLAS Pixel Module - Der Aufbau und deren Test im Labor und im Pionenstrahl”, Dissertation (2005)

[4] R. Boyd et al., “ATLAS Pixel Module Assembly?, ATL-IP-AN-0003 Rev. 3, Geneva, 2003.

[5] “ATLAS Detector And Physics Performance Technical Design Report,Volume 1 ” ATLAS TDR 14,CERN/LHCC 99-14 (1999)

[6] M. Garcia-Sciveres, “Overview of Production Module Assembly, ATLAS Pixel Module Assembly, Production Readiness Review”, Presentation at the ATLAS Pixel Module Assembly meeting, CERN, October 2003

[7] M. Garcia-Sciveres, “ATLAS Pixel Module Assembly Site Qualification Procedure”, ATL-IP-QP-0141 (2003)

[8] M. Garcia-Sciveres, “ATLAS Pixel Assembled Module Specifications”, ATL-IP-ES-0081 (2003)

[9] M. Garcia-Sciveres, D. Giugni “ATLAS Pixel Barrel Module Production and QA Plan”, ATL-IP-QA-0016 (2003)

[10] F. Hügging, J. Grosse-Knetter “Description of data anal-

ysis and implementation of selection criteria for ATLAS Pixel assembled modules", ATL-IP-QP-0145 (2003)

[11] F. Hügging, W. Ockenfels, Ö. Runolfsson "Specifications for assembly procedure and quality control of Pixel modules in Bonn", ATL-IP (2003)

[12] J. Walbersloh (Dortmund), M. Cristinziani (Bonn), I. Ibragimov (Siegen), W. Walkowiak (Siegen)"Status of Module Production in the German Assembly Sites", Presentation at the ATLAS Pixel Week, July 2006

[13] D. Dobos, C. Gößling, R. Klingenberg, M. Maß, G. Troska, J. Walbersloh, J. Weber, "ATLAS Pixel module test and characterization in Dortmund", ATL-IP in preparation (2006)