

Summer Student Project Report

ALICE Experiment: Muon Forward Tracker - MFT

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1 Introduction

1.1 Physics Goals of ALICE

The ALICE experiment in brief deals with the characterisation of a new state of matter called Quark Gluon Plasma (QGP) by colliding heavy lead ions at high energies. Such collisions generate massive amounts of elementary particles which are detected indirectly via identification of the decay products and decay topology.

Protons and neutrons are composed of quarks which are held together by the strong interaction which is mediated by force carrying particles called gluons. It is known that quarks are elementary particles however they were never observed in isolation and quarks as well as gluons always seem to be bound and confined inside non-fundamental particles. This phenomena is known as confinement which is still not yet fully understood. The origin of confinement and generation of mass is still a mystery to the scientific community.

Confinement is predicted at low energies by the theory of quantum chromodynamics (QCD). However at very high temperatures, quarks and gluons should be isolated and no longer confined inside composite particles. They should in fact exist in a new state of matter quark gluon plasma. The temperature required to induce such a state should be around 100,000 times hotter than the sun which was only possible during the very early stages of the universe, a few microseconds from the Big Bang.

When two heavy nuclei move with velocities very close to that of the speed of light and collide, the temperature conditions mentioned in the above paragraph are re-created and gluons as well as quarks are released, thereafter colliding with each other creating a thermally equilibrated environment which is the quark-gluon plasma. This plasma rapidly expands and cools down within a time scale of $10^{-23}s$ after the collision has started. ALICEs main goal is to study the formation and characteristics of the quark-gluon plasma.

1.2 MFT - MUON Forward Tracker

During the Long Shutdown 2 (LS2), an upgrade of the LHC will be made such that the proton-proton and nucleus-nucleus instantaneous luminosity increases to $L_{p-p} = 2 * 10^{34} cm^{-2} s^{-1}$ and $L_{Pb-Pb} = 6 * 10^{27} cm^{-2} s^{-1}$. This will increase the Pb-Pb interaction rate up to 50 kHz. In particular to this project is the inclusion of the MFT which stands for MUON Forward Tracker. Among the particles produced in LHC collisions are resonant states called quarkonia which decay

into muons. A muon is an elementary particle (lepton) which is very similar to an electron but has a much greater mass.

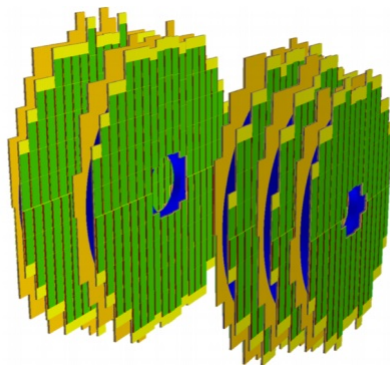


Figure 1.1: Active area of the MFT detector showing sensor and ladder positions

In essence the MFT is a silicon tracking detector which will enhance the vertexing capabilities to the MUON spectrometer. It will be used to measure charged tracks with high spatial resolution just in front of the MUON spectrometer. The MFT will help ALICEs ultimate goal by introducing new measurements which were previously unmeasurable with the MUON spectrometer in isolation. In laymans terms, the momentum of the particle inside the detector system changes and hence with the MFT, the momentum before the detection mechanism may be determined which will help with more reliable measurements.

The MFT project may be summarized into 9 inter-dependent sections. Figure 1.1 shows a 3D model of the active part of the MFT. In order to detect these particles, one would need some sort of '*particle eye*' which in this case would be an active pixel sensor (APS) which is very similar to the ones fabricated for digital imaging. This would then need to be interfaced on some circuit interface (which was the main focus of my summer student project) to which it may easily connect to a DAQ board in order for the acquired data to be read, verified, analysed and processed. More information on the other sections may be acquired from Muon Forward Tracker Technical Design Report. I mainly dealt with work package 2 involving the ladder structure which will be described in the following section in more detail. ¹

¹Taken from [3] MFT Work Packages

2 The FPC and HIC

The sensor chips (shown in Figure 3.2c) are required to be interfaced to a printed circuit board which is no trivial problem given the small dimensions considered. The chips are in fact connected to an FPC which stands for flexible printed circuit board and the combination of the two is referred to as a Hybrid Integrated Circuit or HIC in short. The HIC would then be isolated electrically by encapsulating them using Kapton tape and the resulting structure is referred to as a ladder. In order to improve heat dissipation of the ladders, they are then glued on heat exchanger disks.

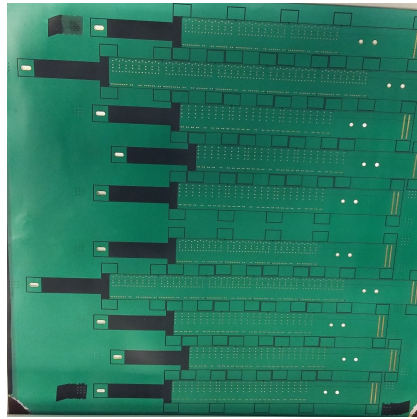


Figure 2.1: Production of Flexible Printed Circuits

It is important to note that the circuit board is flexible in nature in order to accommodate the actual mounting process given the detector surface is not flat. There are also numerous interconnection techniques which will be used to interconnect the FPC to the sensors and hence to produce the HIC.

There are 3 main interconnection techniques which are widely used in this procedure these being laser soldering, conductive gluing and wire-bonding. Laser soldering was discarded since the accuracy of the solder joints thickness and covered area was not in compliance with the technical requirements, however tests are still made to assess the performance for future implementations of other projects. The wire-bonding technique is still being performed, however the via size of the FPC had to be increased, since the current technologies bound the wire to the pad and track at an angle. The smaller the pad size, the more the target angle will approach 90 which up to now is not a realizable production technique. Wire-bonding will ultimately

be the final interconnection technique used in the MFT project. The main reason is that it has been tried and tested before and hence the performance and economical gamble is reduced. The other technique which will be used as a backup in order to test the chips is the conductive glue technique which is currently being performed (some assemblies are being tested in Saclay at the time of this writing). Performance-wise it is inferior to the other techniques since the conductive glue connection has some resistance attributed to it and this will affect signal integrity in a negative manner.

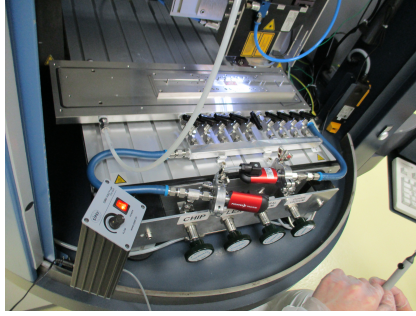
3 Conductive Glue Technique



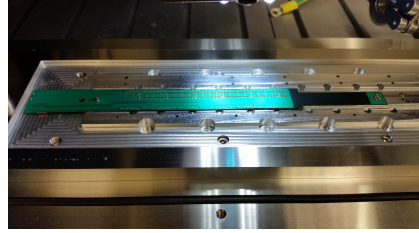
Figure 3.1: Mechanical Structure which holds the FPC

My main task in the summer studentship was to solder the image sensor chip to the flexible printed circuit board (FPC). As explained before this is not a simple task where one just places the glue and connect the two pieces together. This is mainly due to the small dimensions considered. Firstly the FPC is inserted into a machine which has a microscope in-built. The positions of the pads on the flex are recorded on the computer software which comes with the machine (available at the Department Silicon Facility or DSF in short). This is a required calibration every time the glueing is to be performed. The FPC is held in place by using aluminium pins (which were made especially for this assembly). The position of the first pad and last pad of the FPC are used for calibration. The first pad for every chip is identified by a black marking to the left of it and it was made sure that the position recorded was at the center of the pad.

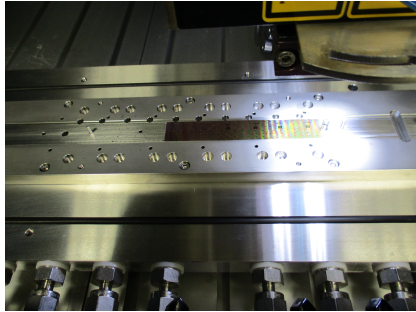
Once calibration is done, the FPC is removed from the machine and mechanical support pins are inserted into the mechanical structure which will hold the sensor chips in place for the gluing procedure. These mechanical support pins are important such that the sensor can be properly placed. The sensor chip is very fragile and hence cannot be handled directly by hand, partly due to dust problems and also due to it breaking easily. Hence it is extracted from its container using a vacuum sucker. It is then placed onto the mechanical structure



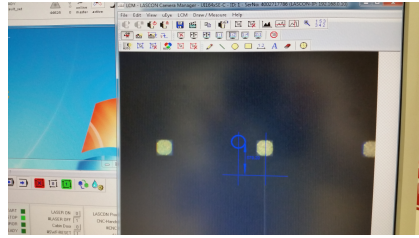
(a) Machine upon which mechanical structure is placed



(b) FPC placed on structure for calibration



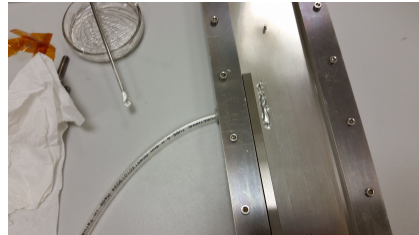
(c) Placing the Sensors after calibration - Support pins on the sides



(d) Adjusting the sensor position to the calibrated flex positions



(e) Removing the support pins



(f) Preparing the glue

Figure 3.2: Conductive Glue Procedure

(where the support pins lie). It is a bit difficult to get the positioning accurate once the sensor is placed and it has to be moved by the vacuum sucker until the pin is on the recorded (in the calibration step) position as shown in Figure 3.2d. Once the desired position is achieved, the vacuum provided in the machine is turned on and the sensor will not move any more. Also one must check that when switching on the vacuum, the sensor does not move up or down and

is still within the desired positions. If this is the case, it must be repositioned. This procedure is then repeated for all the number of sensors the FPC can hold.

After this step, the conductive glue was prepared in a Petri dish. The glue which is Polytec EC 244 is a solvent free, electrically conductive, two component epoxy adhesive. 1g of resin and 0.1g of hardener were mixed well and spread along the FPC which is connected to the mechanical structure as shown in Figure 3.2f. Vacuum is then applied and the conductive glue is forced within the pads. The FPC along with the mechanical structure (with the vacuum still applied) is then placed on the sensors and left inside for around 24 hours. This time period ensures the sensor and FPC are connected together.

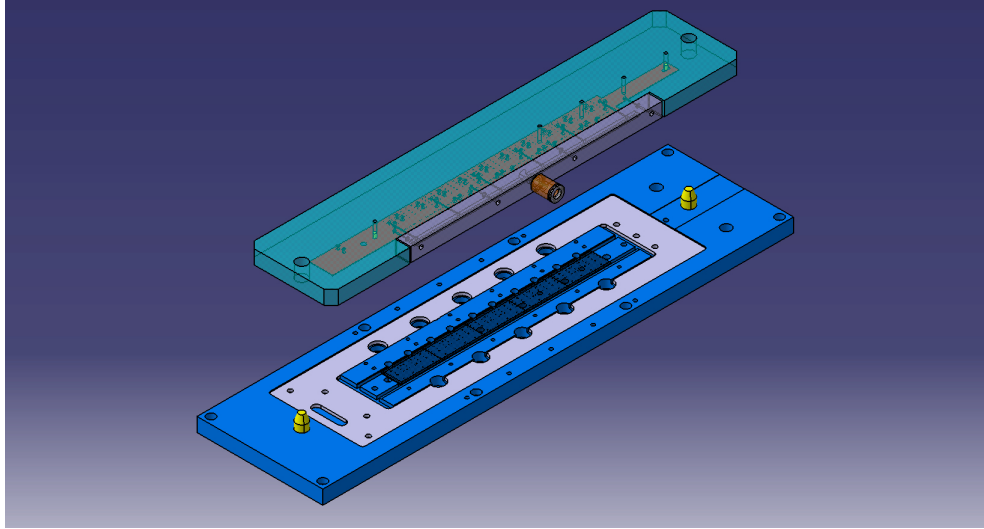


Figure 3.3: Final configuration - FPC with glue placed on sensors for 24 hours

Along every step of the way, the equipment must be cleaned with ethanol or some other alcohol. This ensures that no dust particles inhibit the sensor. The importance of keeping the sensor dust-free is due to the fact that the dust particles may break the sensor given its high fragility.

4 Encapsulation

One HIC configuration was made with dummy sensors and this was done particularly for encapsulation testing. The main reason of encapsulating the sensor is purely for maintenance issues. If for some

reason a sensor is malfunctioning and the HIC must be replaced, there is a risk of damaging the sensor if there is no encapsulation. Hence by enclosing the HIC one may be able to remove it without doing any physical damage to it and thus testing and debugging to solve or find the issue may be performed.

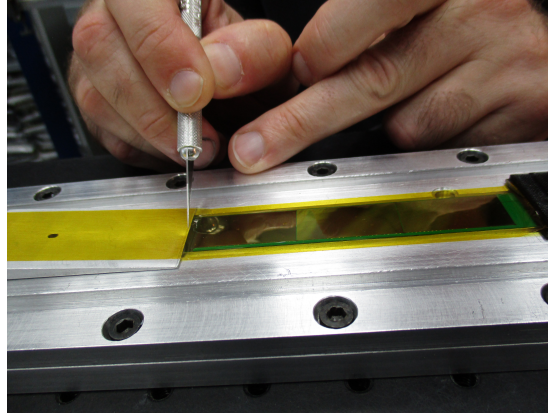


Figure 4.1: Kapton Tape Used for Encapsulation

The material used for encapsulation is Kapton. There are various reasons why this tape is used. It has a wide range of operating temperatures from -269°C - 260°C . It also exhibits excellent electrical properties particularly due to the high electrical insulation it provides which in this application is of utmost importance. Its high dielectric strength is also a great asset. Moreover there are thermal tests being performed by other teams to assess the thermal characteristics of the sensor under this material encapsulation.

5 Perspectives

Personally coming from an electrical engineering undergraduate background, I can say that this studentship helped me gain more insight on the scientific community as a whole. Particular to the assigned project, I further strengthened my belief that one of the most fundamental aspects is to apply the learnt knowledge in universities and not just know it. Moreover I have never been aware of certain problems which occur in these grand-scale projects, for example the interconnection seemed like a trivial task at first glance but then observing the efforts involved to perform this helped me appreciate more these problems and to look at them in a different perspective.

In conclusion, working in such a large collaboration was not possible before. The amount of effort and teamwork towards one common goal was one thing I've never experienced on such a grand scale.

References

- [1] ALICE Technical Design Report *Muon Forward Tracker* May 30, 2015.
- [2] The ALICE Experiment - Looking for Strange Particles *taken from* <http://alice.physicsmasterclasses.org/MasterClassWebpage.html> 2013.
- [3] TWiki ALICE Web Muon Forward Tracker (MFT) *taken from* <https://twiki.cern.ch/twiki/bin/viewauth/ALICE/MuonForwardTracker> June 7, 2016.
- [4] Kapton Tape Home Page *taken from* <https://www.kaptontape.com/> 2016.