DESY Summer Student 2009

METROLOGY AND STUDY OF THE ALFA DETECTOR

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Summary

Introduction

During my work in the DESY-Summer Student Program 2009 I worked on the ALFA Detector, which which is a kind of detector of the ATLAS experiment at the LHC at CERN. One of the four main LHC experiments is ATLAS[1], that includes three detector systems in the forward and very – forward region (called LUCID, ZDC and ALFA). The main purpose of these forward detectors is the precise determination of the luminosity (an important value that characterize the performance of an accelerator), that imposes stringent conditions on the spatial resolution of the detector.
For these reasons metrology measurements of the forward detector are needed. As we will see in the next pages, both the ALFA Main Detector (MD) and the ALFA Overlap Detector (OD) consist of multiple optical fibers glued to a support. The basic idea, in fact, is that charged particles passing through an active material (the optical fiber) will cause light to be emitted.

1.1 Metrology of the ALFA Main Detector

In the laboratory's I measured 20 optical fiber plates for the ALFA Main Detector. To do this, suitable optical instruments are available in the FEC Laboratory (Building 2) at DESY. The results of my measurements gave some information, like the gap's pitch between two following fibers; the knowledge of this kind of parameters is very important for the ALFA tracking system, because it allows to know the exact position where the particles passed.

1.2 Study of the ALFA Overlap Detector

Besides the laboratory's experience I also worked on a study of the ALFA Overlap Detector. The metrology data of the OD plates has already been processed by the ALFA group (they used the so-called ALFACOOR program), but not yet cross – checked by a second – fit method. So, the purpose of my work was to analyze both the raw data and the ALFACOOR results and then compare my fit results with the ALFACOOR ones.

In the next pages I'll do firstly a short description of the ALFA Detector inside the ATLAS experiment and, after that, I'll show my laboratory and results of the MD and the analysis of the OD.

[1] The others are Alice, LHCb and CMS.

ALFA @ ATLAS

The final completion of the Large Hadron Collider (LHC) at CERN will represents a new energy frontier for the proton – proton collider. If we consider, for example, its Luminosity ($10^{34} cm^{-2} s^{-1}$) and its center – of – mass energy ($14TeV$), we can see that today LHC is the most powerful machine. With these high energies and with high collision – rates, the LHC will search for new interactions at very short distances and new particles beyond the Standard Model.
In the next pages I will describe the ALFA (Absolute Luminosity For ATLAS) detector inside the ATLAS experiment (mainly the Main and Overlap detector). As we will see, ALFA will measure the elastic scattering at small angles to determine the absolute luminosity in the Coulomb region.

2.1 ATLAS Detector

One of the experiment at LHC is called ATLAS and it is situated at the Interaction Point 1 (IP1). This detector can be divided in 4 parts: the inner detector (measure of the momentum and tracks of charged particles), the calorimeters (to identify photons and electrons), the muon spectrometer (to measure their tracks) and the magnet system. The Figure 1 shows the ATLAS location in the LHC.

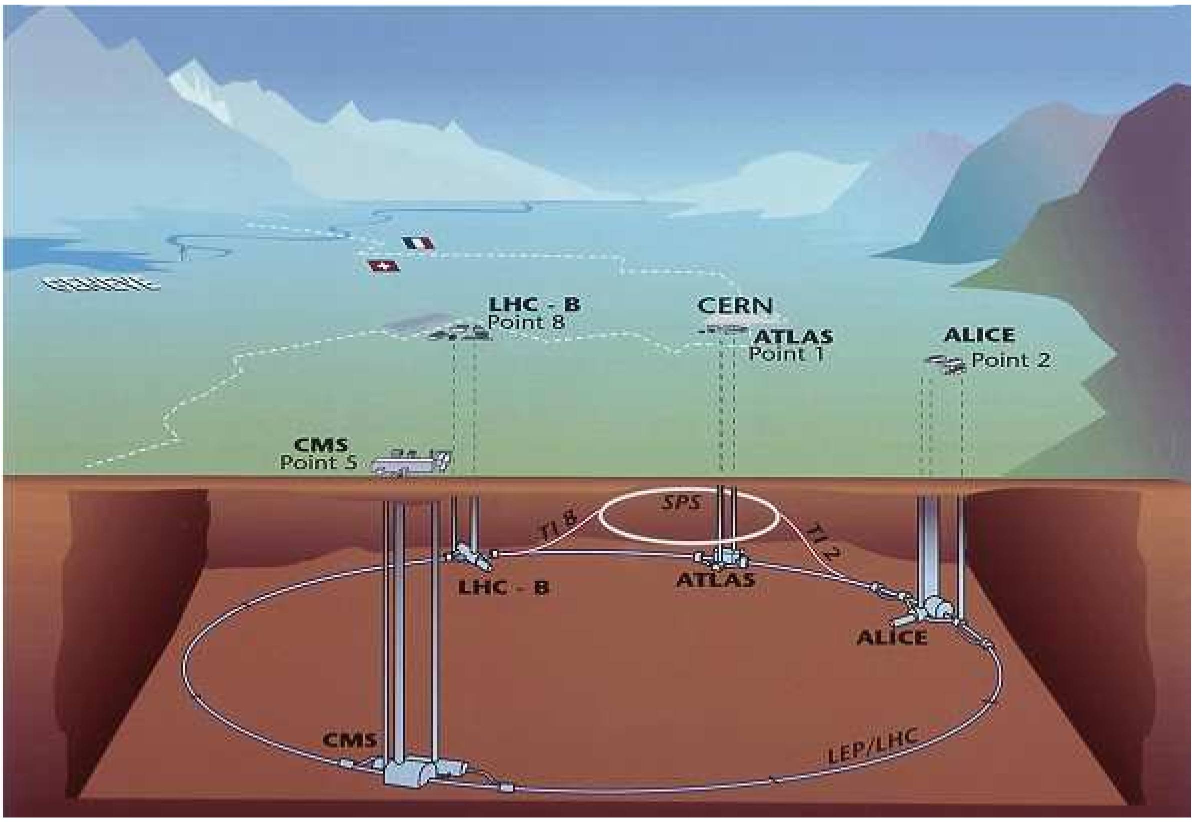

Figure 1: The four LHC experiments.

2.2 Why ALFA?

Any search for new particles or interactions depends largely on the accurate knowledge of the accelerator parameters and conditions, like the luminosity (rate of collisions). ATLAS has its own system for luminosity measurement, that consists of three forward detector (LUCID, ZDC and ALFA[2], as written before). Figure 2 shows the schematically collocation of these detectors inside ATLAS.

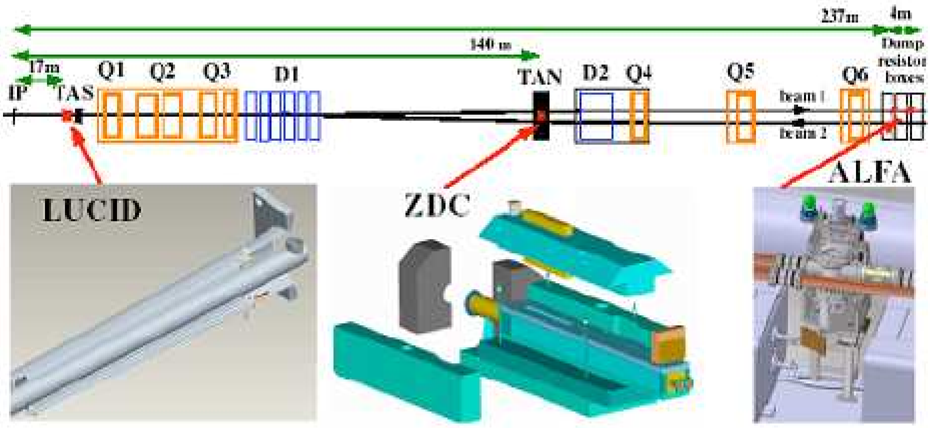

Figure 2: Placement of the forward detectors along the beam – line with the ATLAS detector.

2.2.1 Luminosity Measurements

With a center – of – mass energy of $14TeV$, the colliding beams in the LHC will be able to produce all kinds of particles and interactions. Nevertheless, their production cross – section σ needs to be high enough to be able to study them. The quantity that measures the ability of the particle accelerator to produce the required number of useful events is called luminosity L:

$$\frac{dR}{dt} = L \cdot \sigma\,, \tag{1}$$

where dR/dt is the number of events per second. Then, a precise knowledge of the luminosity will be crucial for all LHC experiments and there are several experimental methods for its measurement.

- Machine Parameters: the luminosity is given in terms of the LHC machine parameters as

$$L = f\,\frac{N_1 N_2}{A_{eff}}\,, \tag{2}$$

  where f is the bunch – crossing – rate, N_i is the number of particles per bunch and A_{eff} is the effective transverse area. During the startup phase of LHC operations, the resulting error from this method on luminosity will be around $\Delta L / L \approx 0.25$

[2] They are located, respectively, at $\pm 17m$, $\pm 140m$ and $\pm 240m$ from the IP1.

- Muon pair production: another method to determine the luminosity experimentally uses the measurement of the rate of well – known cross sections using the equation

$$R = L \cdot \sigma, \qquad (3)$$

where R is the rate of events. While in e^+e^- collider the scattering $e^+e^- \to e^+e^-$ or Bhabha processes are used for precise cross – section determinations, unfortunately for hadron colliders there is no such equivalent process. So we need to use electromagnetic process like the $pp \to pp + \mu^+\mu^-$, but these processes cannot be used as monitors for low luminosity. Moreover, this method will give an estimated precision on L of $\approx 2\%$.
- TOTEM[3] Method: this method apply the optical theorem and can be used to achieve a precision luminosity of approximately $1-2\%$.
- Coulomb Scattering: if smaller angles can be reached, it is possible to measure the pp Coulomb scattering; this implies measuring in the Coulomb region, where the interference between the nuclear and Coulomb scattering amplitudes is maximum[4].

2.3 The ALFA Detector

As stated before, the LHC beam parameters can be used to determine the luminosity with a precision of $\approx 25\%$. For precision measurements this will not be sufficient. One way to reach a much higher precision is to measure the pp scattering; for this measurement it's inevitable to approach the beam in the millimeter – range, so we need forward and very – forward detectors installed in the LHC tunnel. As a solution, the ALFA forward – detector was installed $240m$ away from the ATLAS interaction – point (IP).

ALFA consists of a set of four detector stations (the so called "Roman Pot Units"), two on each side of the IP. The stations on each side are separated by $4m$; a schematic view is shown in Figure 3.

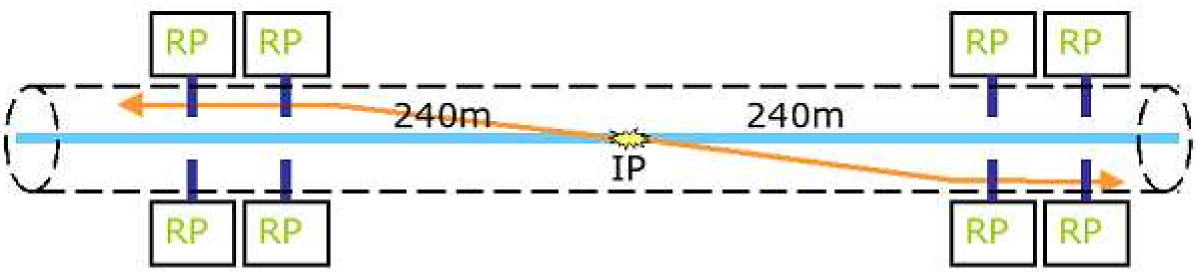

Figure 3: Schematic view of an elastic scattering event at the ATLAS IP detected by the ALFA Roman Pots.

[3] TOTal Elastic and diffractive cross section Measurement.

[4] $6\times10^{-4}GeV^2$ of transferred momentum with the LHC parameters.

2.4 Roman Pots

To not disturb the LHC beam or even destroy the detector itself while operating so close to the beam, a precise mechanics of the detector is necessary. This is achieved by the use of the so-called *Roman Pot*, that consists of a movable part which house the electronics and the tracker components. Due to the radiation hardness, the Roman Pots can be retracted (for example during high luminosity runs) while in other conditions they are moved in to working position. The Roman Pot operating principle is illustrated in Figure 4.

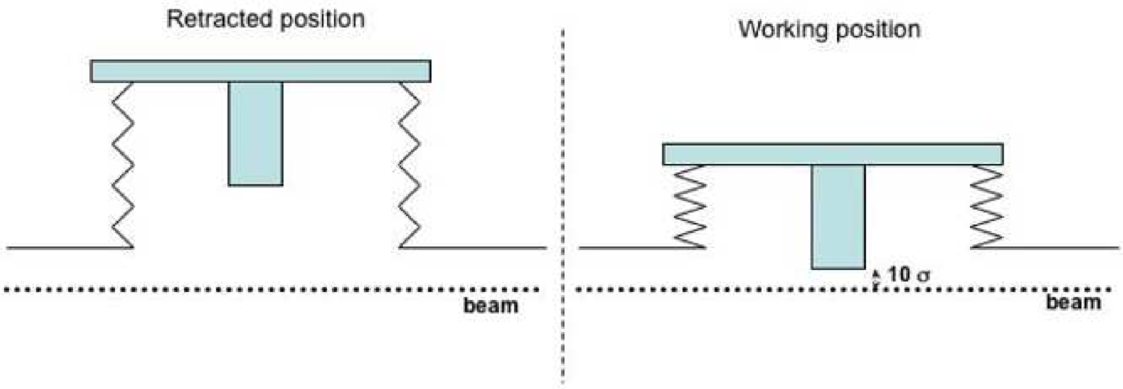

Figure 4: Roman Pot; on the left the Pot is in retracted position, placed out of the beam. On the right the Pot is in working position, approaching the beam.

A pair of 2 Pots, one from the top and one from the bottom, form a *Roman Pot Unit*. Each top and bottom Pot in a Roman Pot Unit can be moved separately. As the nominal position will be in the millimeter – range from the LHC – beam, the tracking detector components have to be inside the LHC beam – pipe.

2.5 ALFA scintillating fiber detector

A scintillating fiber detector makes use of the fact that charged particles passing through the active material will cause light to be emitted. The scintillated light is then routed through the fibers to the read – out electronics, where PMTs (Photo Multiplier Tubes) convert it into an electrical signal.
The scintillating fibers used for the ALFA detector have a square cross – section of $0.5mm \times 0.5mm$ and are arranged in a so-called U-V or stereo geometry, shown in Figure 5. We have 64 fibers on each side (U and V) glued on to a ceramic substrate which is connected to the titanium base – plate. The fibers are routed to the photo – detectors in group of 64 where the scintillating light is read out by Multi Anode Photo Multiplier Tubes (MAPMTs).

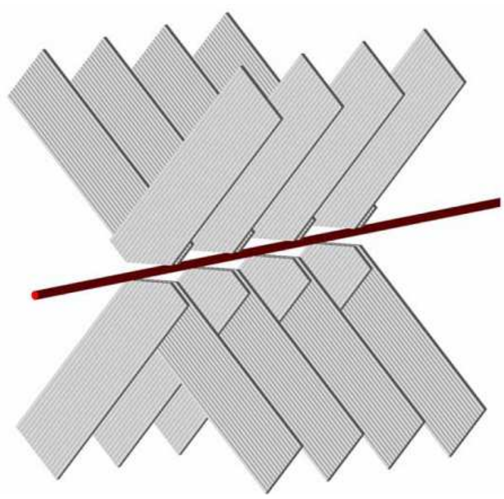

Figure 5: Principle of a scintillating fiber detector using the U-V geometry. The fibers – beam distance is 1.5mm.

2.6 ALFA Overlap Detector

As the exact position of the LHC beam spot at the location of the ALFA Roman Pots may vary from fill to fill, it's necessary to position the ALFA detectors accordingly. It's therefore necessary to know the vertical distance between the two ALFA half detectors with a precision of about $10\mu m$ This vertical distance can be determined with so-called Overlap Detector (ODs) which measure only the vertical coordinate. They are illustrated in Figure 6.

Figure 6: ALFA Overlap Detector. There are 30 fibers on each side of the plate.

Two ODs are mounted below the detector planes (upper Pot) in a test beam setup and two above (lower Pot). They consist of scintillating fibers just as the Main Detector.

Metrology of the Main Detector

For detector plates without any gaps between the fibers, a precise track reconstruction of the traversing particles is easy to do. However, the glueing of the fibers is done through adhesive capillarity of the glue; the glue rises up the fibers (due to the capillarity effect) so there is a gap between two adjacent fibers. The exact fiber's position on the detector's plate thus is not known.
To compensate these imperfections a precise fiber detector metrology is needed.

3.1 Equipment

The FEC laboratory at DESY is equipped with several metrology instruments which were used for the measurement. A picture of these devices is given in Figure 7.

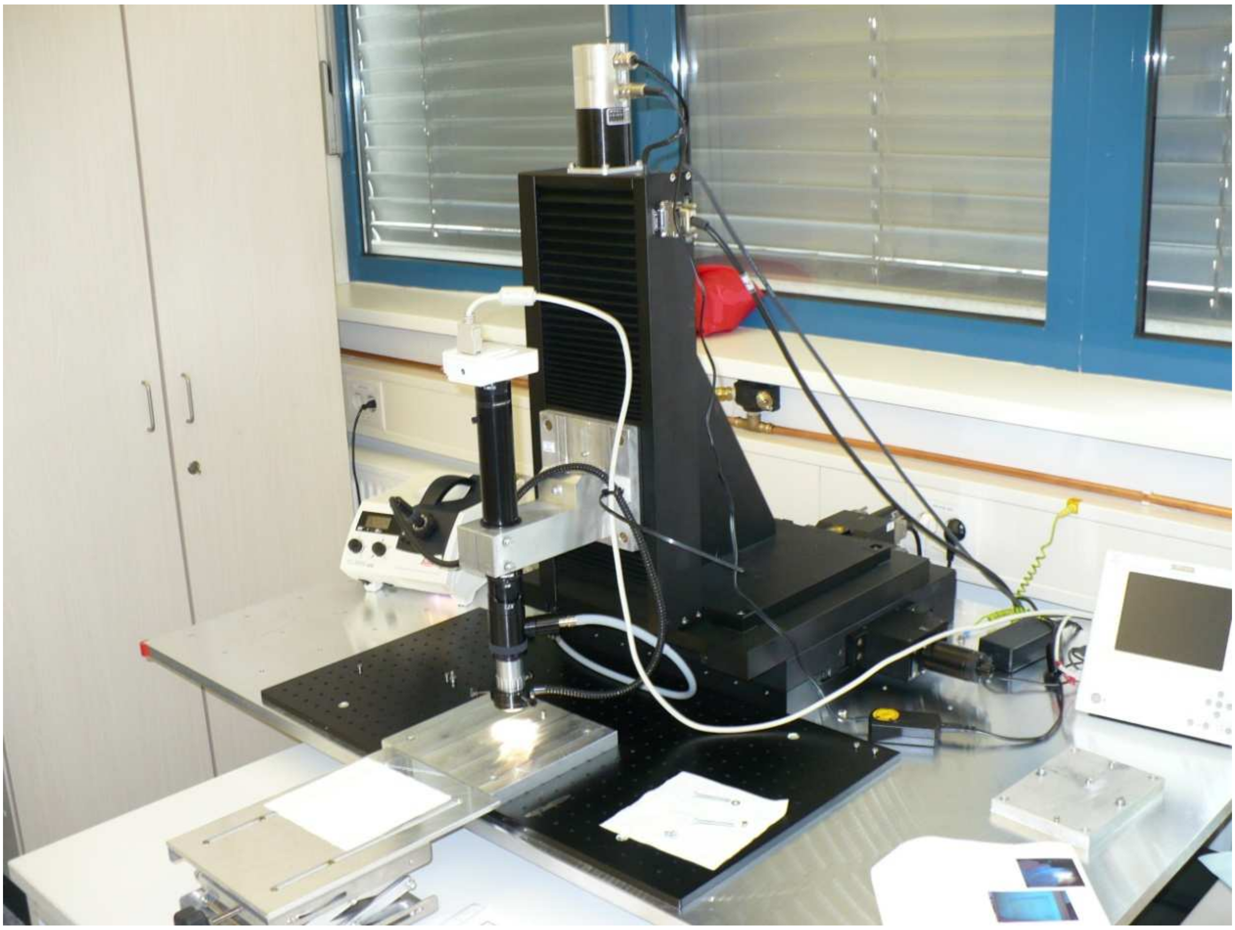

Figure 7: The FEC Laboratory's devices for the plates metrology.

In a clean – room several microscope setups are provided. The one I used consists of a Nikon DS-5M Digital Camera ($2560\times1920\, pixels$, 5 megapixels); the camera is aligned with:

- Navitar 12X Zoom
- Mitutoyo M Plan Apo 10X object lens
- 2X C – Mount Adapter
- Light Source
- 3 – axis positioning table (x–y–z table), driven by a step motor, with a precision of $2-3\mu m$

3.2 Plate's geometry

There are three holes on each plate, used to precisely align the plates behind each other in the Roman Pot. The uppermost hole is a circular precision hole with $6mm$ of diameter. It serves as the origin of the coordinate system for the detector and therefore also during the measurement. The lowermost hole is a $6mm$ wide precision long hole and it is used to define the direction of the y – axis of the coordinate system. Between these two holes there is another one[5]. A detailed scheme of the holes is drawn in Figure 8.

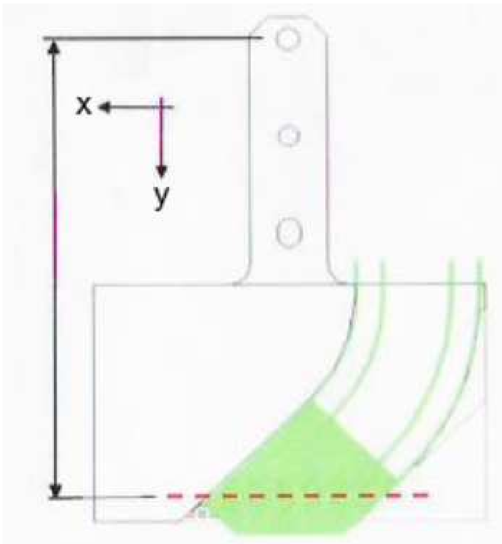

Figure 8: Schematic view of the detector plate and its coordinate system.

3.3 Automated measurements

The manual measurement of the plates takes about two hours per side. In ALFA we have 4 Roman Pot Units with 2 Roman Pots each + 2 spare Roman Pots, which makes a total 100 detector plates with 128 fibers each + 60 overlap detector plates with 60 fibers each. It's clear that we need to make the measurement process more automatic.

[5] This isn't a precision hole and is used only for fixation.

For this reason, the x-y-z table is connected to a PCI – card interface and can be controlled by LabView, a graphical programming environment provided by National Instruments. In order to measure the plates, we have to run two LabView programs. The first is needed to find the center of the lower hole, so we can identify the system coordinate origin. A picture of this procedure is shown in Figure 9. After this, we can start with the real measurement with the second software.

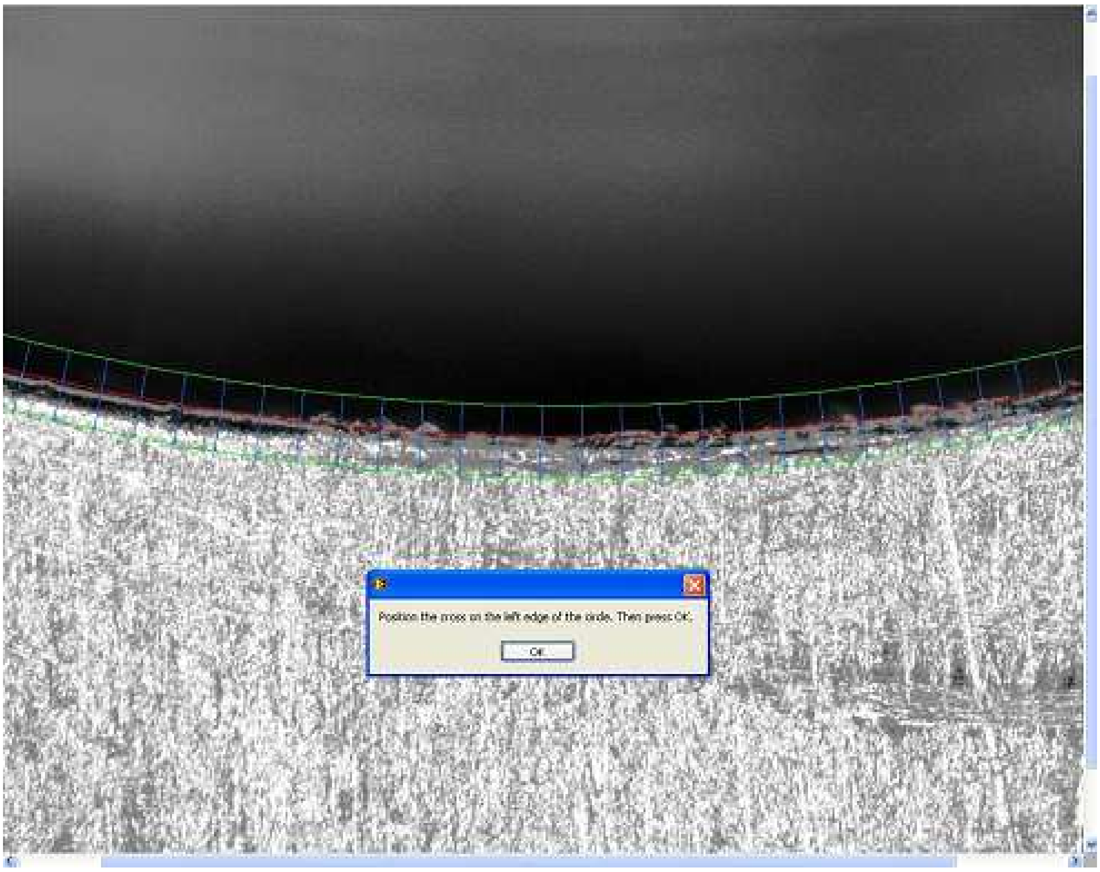

Figure 9: A picture of the lower edge of the circular hole. The colored line means that LabView found correctly the edge.

3.4 Measurement of fiber gaps

To determine the fiber gaps we measured 5 different lines across the fibers, as shown in Figure 10. Line A and B measure all 64 gaps, while line C measures gap 1 to 27 and line D and E measures gap 24 to 64. By this way, each gap is measured in 3 different positions, which allows to make a solid linear fit for each fiber.

In Figure 11 we can see the automated LabView program working; it detects automatically the gap between two fibers. If the program cannot determine the correct gap (or if it does a mistake in the detection), the user can check it manually. At the end the program saves all the gap's pictures and also the measurement's results (these last in an Excel document).

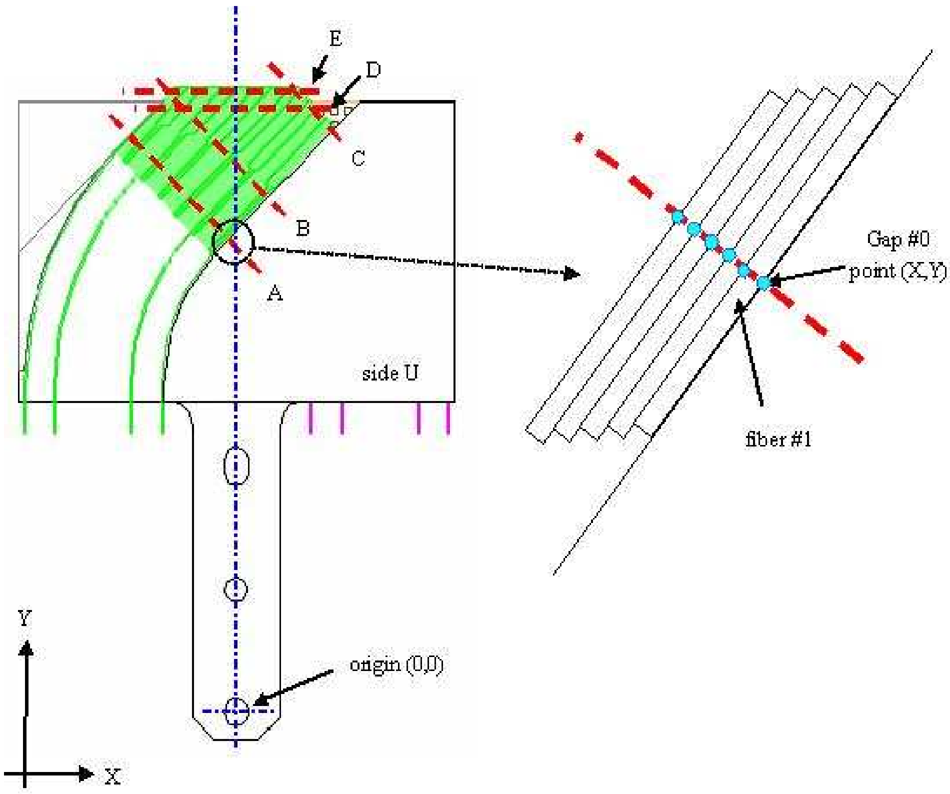

Figure 10: Measurement scheme with 5 lines of measurement (A,B,C,D).

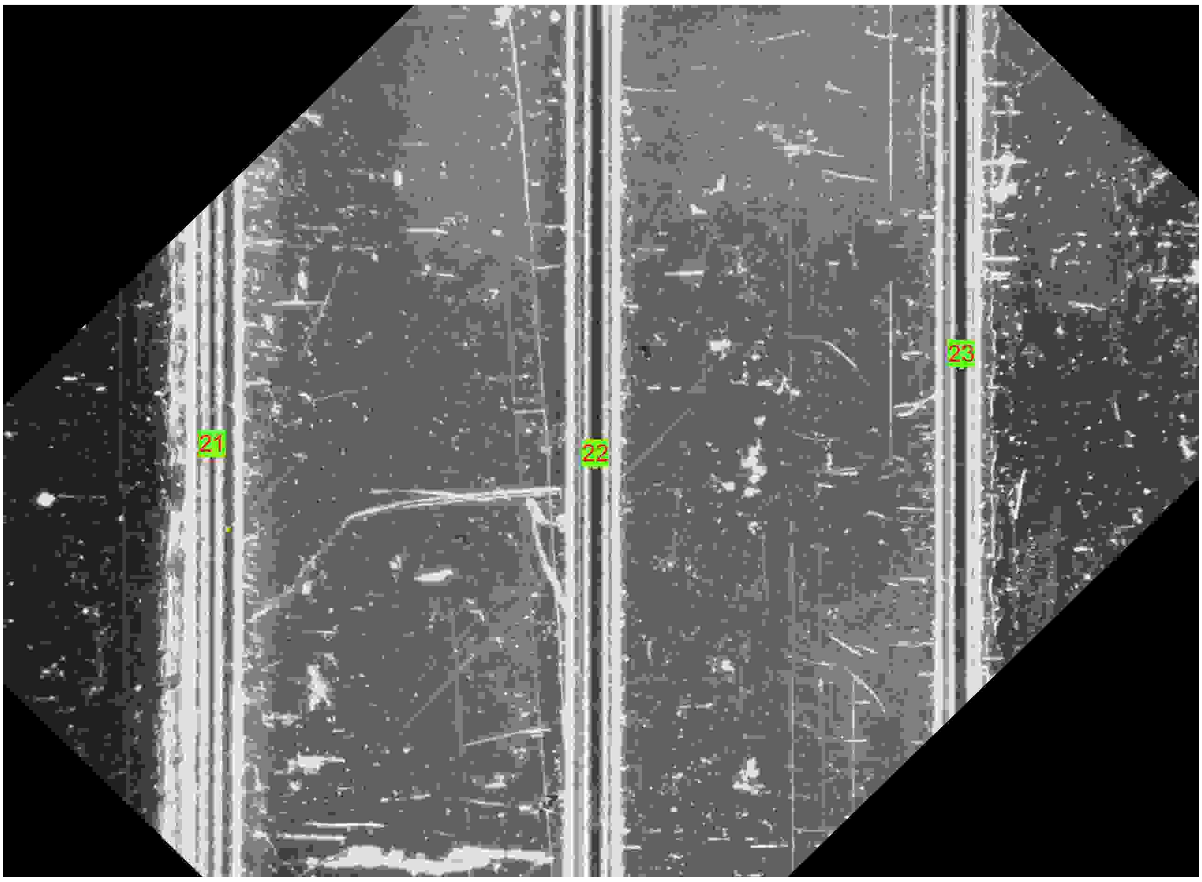

Figure 11: The automated gap's detection done by the LabView Measurement Program.

3.5 Measurement Results

As said before, the raw data are saved in the Excel file. Here there are some calculations made by Excel's macro and, at the end, we can obtain:

- Fiber Pitch: a graph represents the behavior of the fiber gaps. The expected value is $0.5mm$.
- Fiber Position Offset: a graph represents the offsets of the gap-positions in x-direction from nominal. So from the metal edge the macro calculates the positions of the gaps as if they had zero size, and then shows the difference to the real gap positions.
- Angles: between the fibers and the coordinate system there is an expected angle of 45°.

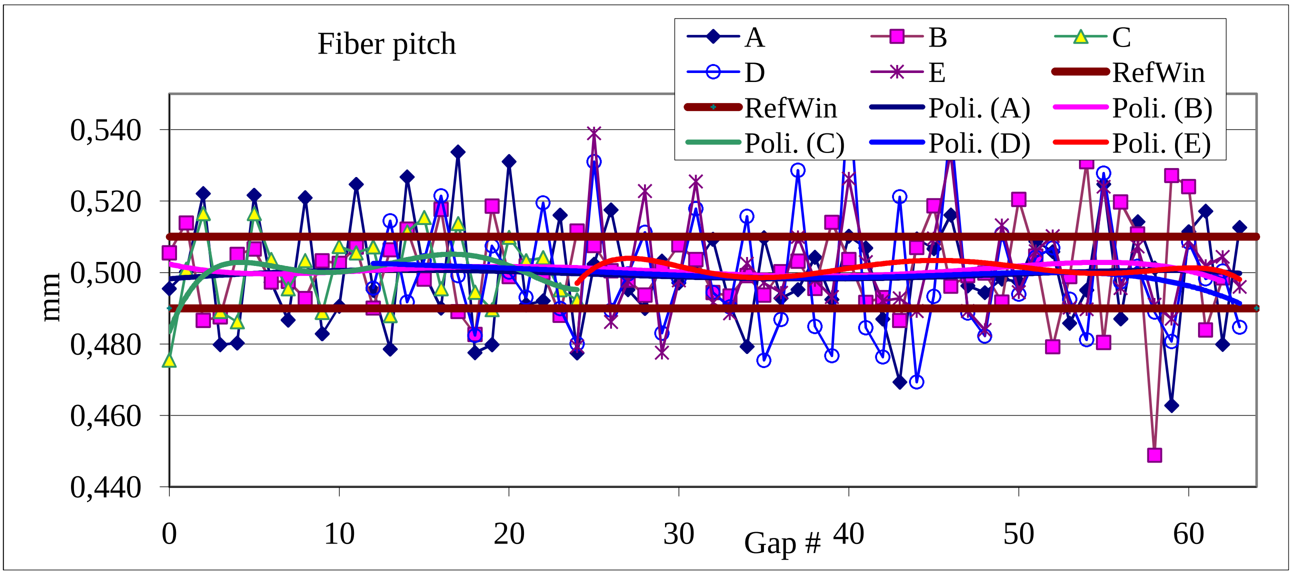

Figure 12: Fiber pitch for the ALFA Main Detector (series A4-2, plate 3, side V).

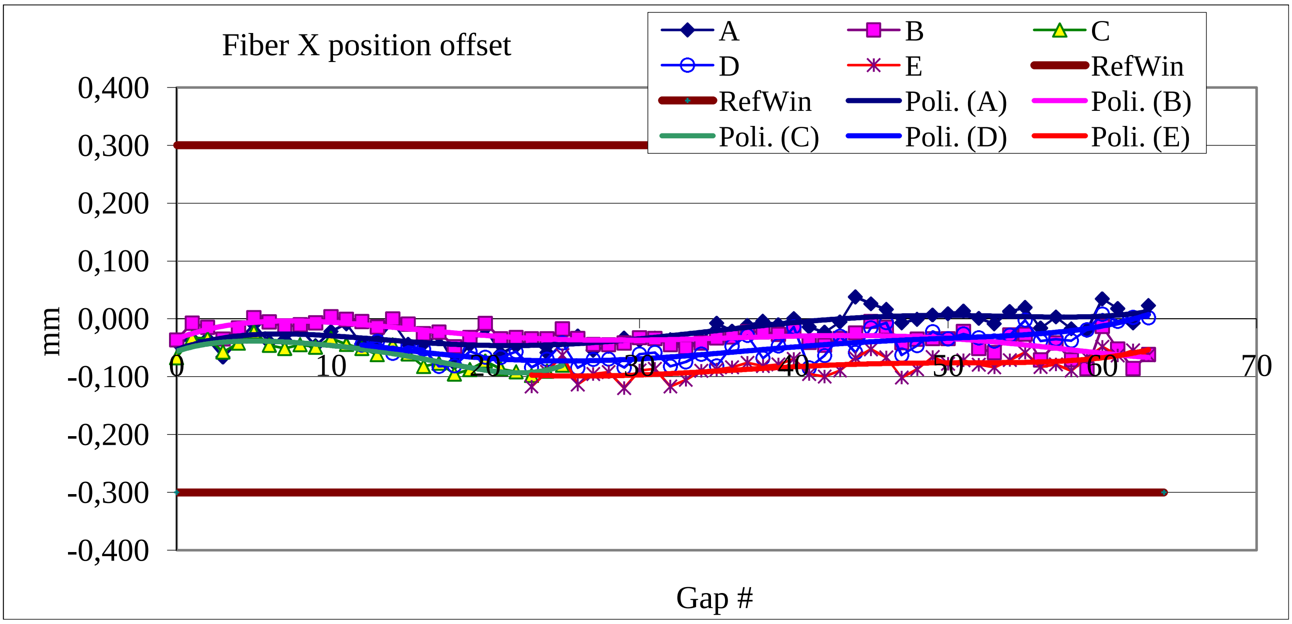

Figure 13: Fiber offset position (series A4-2, plate 3, side V).

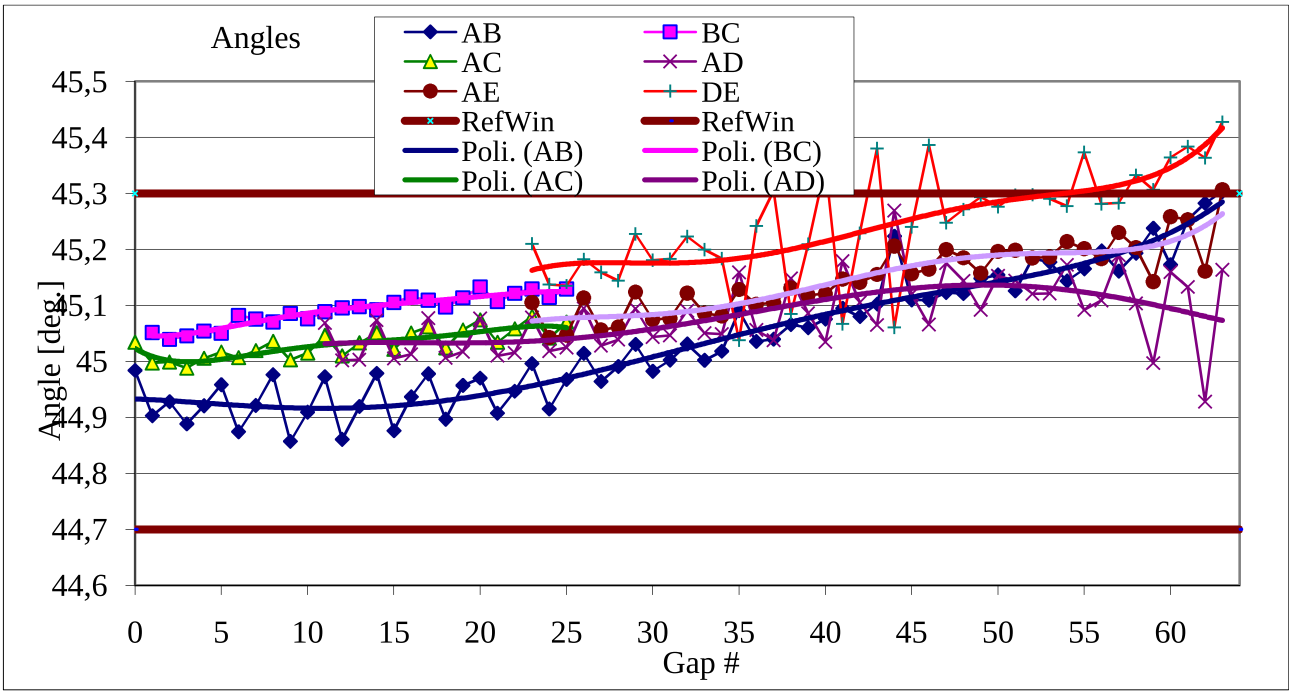

Figure 14: Angle between two lines (series A4-2, plate 3, side V).

I analyzed 20 ALFA Main Detector Plates[6]. The Figures 12, 13 and 14 report the results for the Series A4-2, Plate 3, Side V.

[6] Ten plates for the series A3-2 and other ten for the series A4-2.

Study of the Overlap Detector

The second part of my Summer Student Program consists in the study of the Overlap Detector. The final goal is to analyze the acquired data for the fibers positions inside the ALFA Overlap Detector. As said before, the Overlap Detector consists in plates containing 30 fibers on each side. These data have been already been processed by the ALFA group (using the ALFACOOR software) and my work is finalized to obtain the same results in a different way and then compare them.

4.1 Overlap Detector Metrology

To determine the exact position of the fibers, the y-coordinate of the *gap* between the fibers was measured at three different positions (20, 23 and 25mm from the centre of the system, as shown in Figure 15). Because the 30 fibers, on each side of the plate, are in two group of 15, these three point have been measured on the line A,B,C and D,E,F.

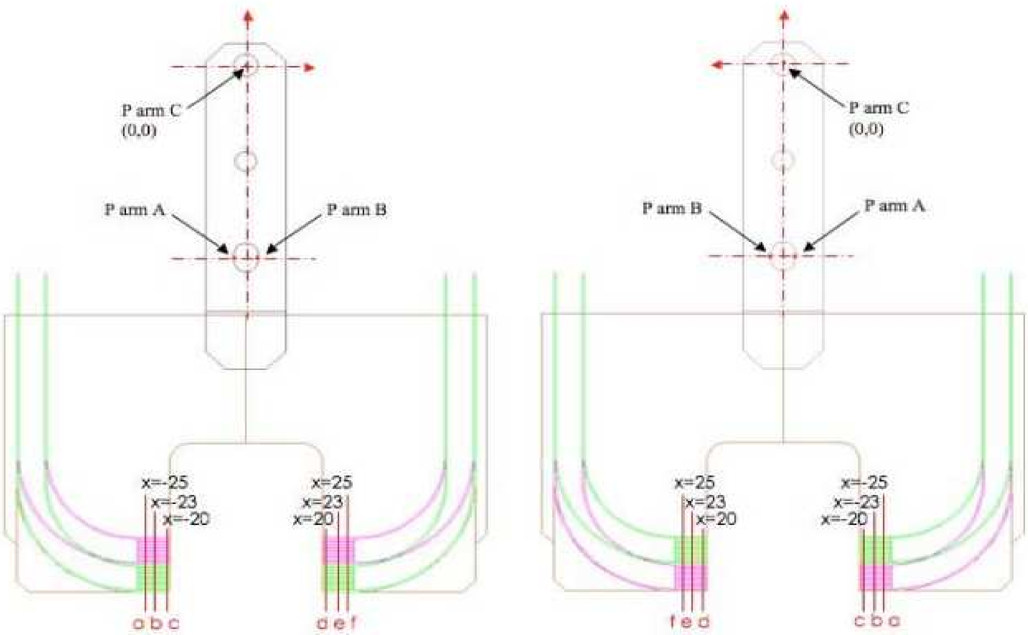

Figure 15: Metrology procedure for the Overlap Detector plates to determine the fibers position.

4.2 Fitting and Plotting gap positions

I analyzed three Overlap Detector Series (OD2, OD3 and OD4, each one with three plates). To do this I created a ROOT program that reads the raw data from the files and then plot the *gap* positions in a graph. The result is shown in the Figure 16.

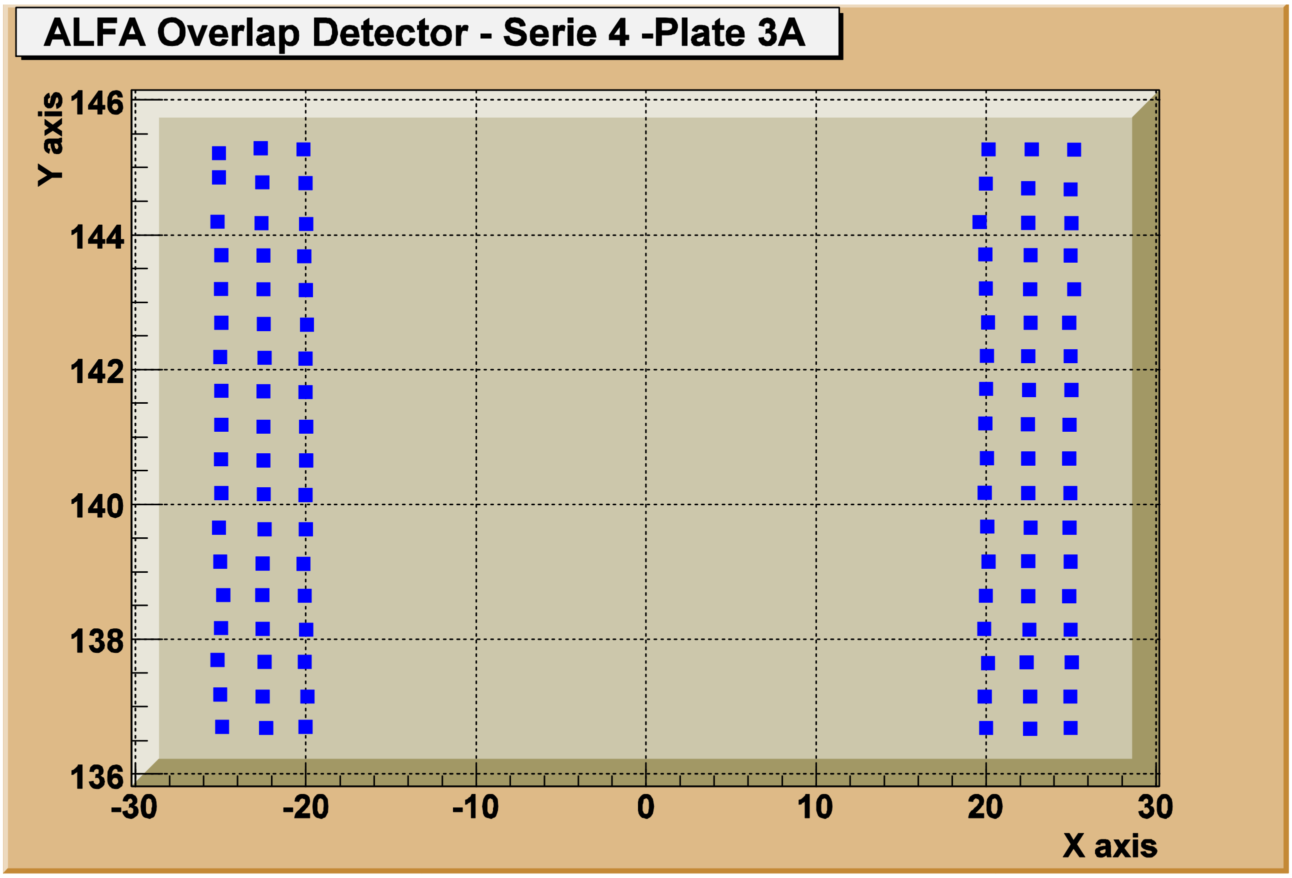

Figure 16: Plot of the gap positions in the ALFA Overlap (Series 4, Plate 3, Side A). The last 2 series of points are dummy points, because they don't represent real gaps.

After plotting, the program makes a linear fit $y = A + Bx$ for the three points of each gap and then finds, in the middle of two adjacent gaps, the straight line that represents the real fiber. A schematic sketch of this is represented in Figure 17. At the end, the software saves the fit results in a text file.

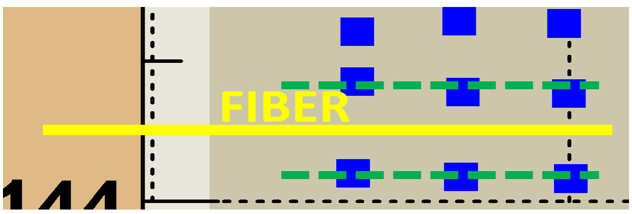

Figure 17: Schematic view of how to calculate the fiber position from the gap's data.

4.3 Comparing fit Results

The second ROOT program that I wrote compare my fit results with the ALFACOOR ones. In particular, I will estimate the difference on the angle between the two fit, because we can say that

$$B = \tan(\theta) \rightarrow \theta = \arctan(B), \tag{4}$$

where B is the angular coefficient of the linear FIT and θ the corresponding angle.

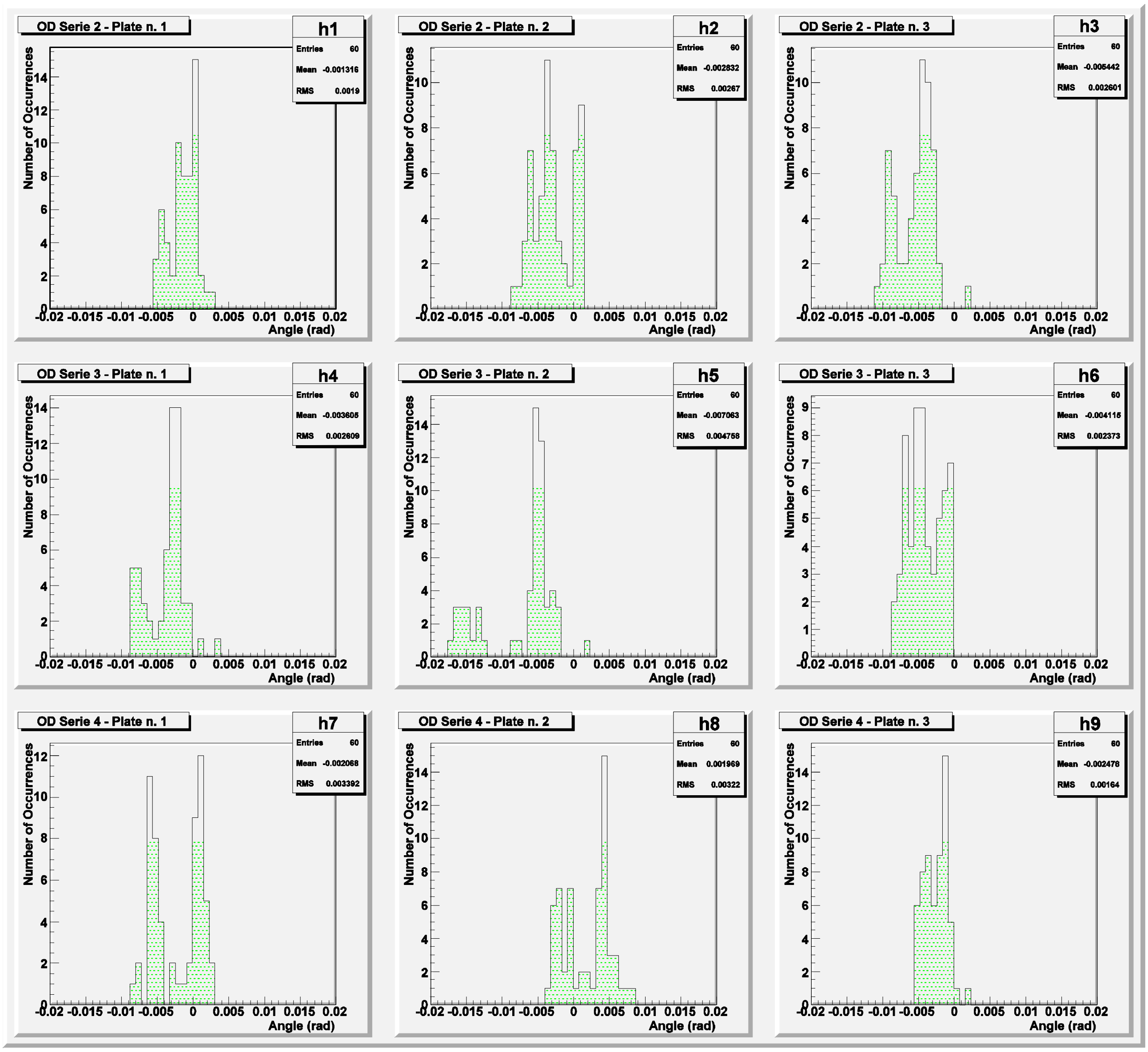

Figure 18: Resulting plots showing the angular difference between my fit and the ALFACOOR fit.

As we can see in Figure 18, there is a general agreement between the two FIT: in fact the angular difference is in the range of $mrad$.

Conclusions

At the end of this Summer Student Program, the work in the ATLAS Group gave me some interesting satisfactions. Firstly I had the possibility to do some laboratory measurements that I never did and that will be important in the LHC experiment. The “practical” results I obtained are:

- Knowledge of some specific instruments for these measurements, available in the FEC Laboratory at DESY.
- Determination of the gaps between the fibers in the ALFA Tracking System.

Secondly, I learned the ROOT Environment Programming, that will be very important for me in my future applications. For my work, I analyzed the ALFA Overlap Detector data with two ROOT programs and the results are:

- General agreement between my resulting fits and these obtained by the first analysis of the ALFA Group.

Acknowledgements

First of all I would to thank all people that have given me the possibility to do this Summer Student. I really appreciated this experience that has been very important for me, because it gave the possibility to do some useful and practical stuff that are typical in the research situations; I already did some kinds of laboratory experiences in my University but this one will be surely the most authentic and interesting.
Then, I would thank Dennis Petschull for helping me (many and many times!) during this time; with him I learned the basic principle of the ROOT Programming and, also, what to do in laboratory for the measurements; thanks also to my supervisor Tobias Haas, that gave me the opportunity to work inside the ALFA Group.

Finally, thanks to my teachers Massimo Ferrario and Mario Mattioli that showed me the occasion to do this Summer Student at DESY.

So, I hope to be there again, in the next years!