Quality Assurance for Track Reconstruction in the ALFA detector of the ATLAS experiment

DESY Summer Student Programme, 2014

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31th of August 2014

Abstract

In this paper, several quality assurance macros for the ALFA track reconstruction algorithm are presented and analysed. The acquired plots can be used to judge the quality of the track reconstruction. The results are compared with those from the previous version of the algorithm, in order to gauge the extent of improvement between the two versions. Analysis is performed for Run #191373, for the entire sample, as well as cut samples.

Akademia Górniczo-Hutnicza
im. Stanisława Staszica w Krakowie

Contents

For my brother, my captain, my king.

1 Introduction to the ALFA experiment

1.1 The ALFA subdetector

The following two subsections have been taken from [1].
ATLAS is a multi-purpose detector designed to study elementary processes in proton-proton interactions at the TeV energy scale. The main aim of one of its subdetectors - the ALFA detector (Absolute Luminosity For ATLAS) is to measure the total cross section for elastic scattering in pp collisions. Two tracking stations are placed on each side of the central ATLAS detector at distances of $238m$ and $241m$ from the interaction point:

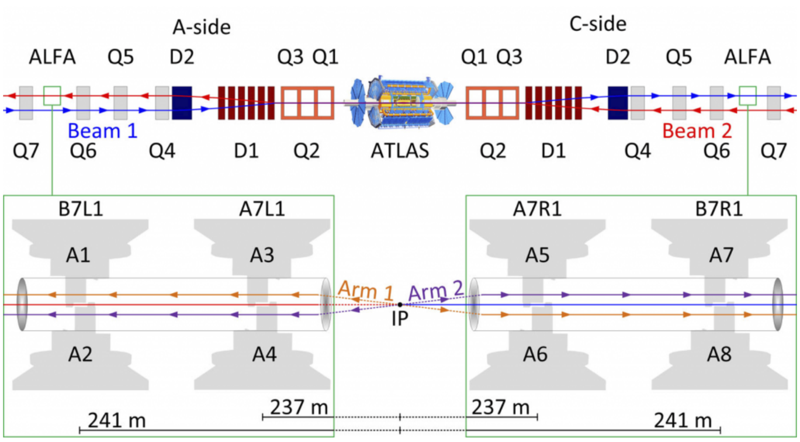


Figure 1: A sketch showing the positions of the ALFA tracking stations (not to scale) - from [1]

1 shows the names of each station. Each station is comprised of two detectors - "Roman Pots" (denoted 'lower' and 'upper'). The eight pots allow to detect elastic scattering events in two "arms": arm 1 - pots A1, A3, A6, A8; and arm 2 - pots A2, A4, A5, A7.

2 shows the construction of a single station. Notice the two main detectors (MDs) - elastically scattered protons are detected there. The two dedicated overlap detectors (ODs) measure the distance between upper and lower MDs, They are needed for the precise determination of the proton scattering angle but not used in the track reconstruction. Each MD consists of 2 times 10 layers of 64 square scintillating fibers each, with $0.5mm$ side length attached to titanium plates.

The fibers in the front and back sides of each titanium plate are orthogonally arranged at angles of $\pm 45°$ with respect to the y-axis. The projections perpendicular to the fiber axes define the u and v coordinates which are used in track reconstruction.

Each MD consists of 2 times 10 layers of 64 square scintillating fibers each, with $0.5mm$ side length glued on titanium plates. The fibers on the front and back sides of each titanium plate are arranged at angles of $\pm 45°$ with respect to the y-axis. The projection perpendicular to the fiber axes define the u and v coordinates which are used in track reconstruction. The individual fiber layers are staggered by multiples of 1/10 of the fiber size to improve the position resolution[1].

[1]This description comes from the experiment documentation. As we can see later, the layers are not staggered as regularly as shown.

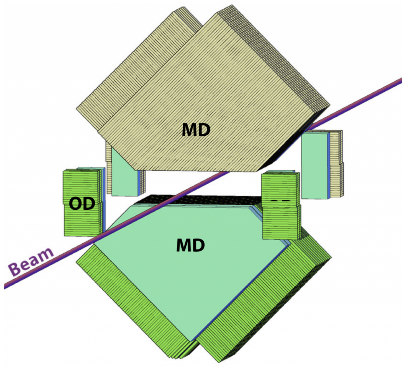


Figure 2: One station with two MDs and two ODs with highlighted beam - from [1]

1.2 The Track Reconstruction Algorithm

The local tracks in the MDs are reconstructed from the hit pattern of traversing protons in the scintillating fiber layers. The reconstruction assumes that the proton pass through the fiber detector perpendicularly. The first step of the reconstruction is to determine the u and v coordinates from the two sets of ten layers which have the same orientation. The best estimate of the track positions is given by the overlap region of the fiducial areas of all the fibers. As illustrated in **Fig. 3.**, the staggering of the fibers narrows the overlap region and thereby improves the resolution. The center of the overlap region gives the u and v coordinate, while the width determines the resolution. Pairs of u and v coordinates are transformed to spatial positions in the beam coordinate system.

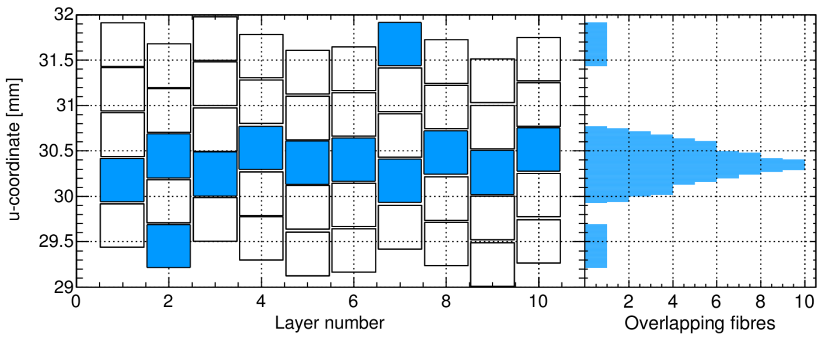


Figure 3: Sample hit pattern of a proton trajectory and histogram with overlap - from [1]

To exclude problematic events (such as events with hadronic showers or with a high noise level), a few cuts are made to the data. Fiber layers with more than ten hits are discarded, and at least three layers are required to have between one and three hit fibers. Finally, the u and v coordinates must be formed from at least three overlapping hit fibers.

1.3 Cuts for the selection of elastic events

To exclude problematic events (such as events with hadronic showers or a high noise level), some cuts are applied to the events. Fiber layers with more than ten hits are discarded, and at least three layers are required to have at least one but not more than three hit fibers. Finally, the u and v coordinates must be formed from at least three overlapping hit fibers.

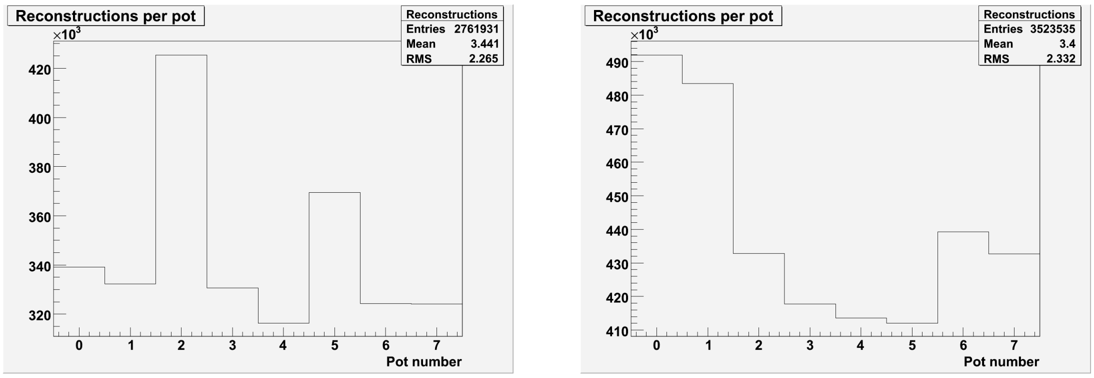
There are also cuts used to retrieve the interesting elastic events by placing appropriate restrictions on the positions of hits in the detectors belonging to each of the arms. For further details, see [3].

2 Quality Assurance Macros

The following macros were written with the intent of providing a standard by which other runs may be judged. They also serve as a way of checking whether the results obtained by the track reconstruction algorithm are sensible. Additionally, a couple of them can shed some light on the differences between the older and current versions of the algorithm.

2.1 Tracks reconstructed per pot

The histograms show the amount of reconstructed tracks in each of the eight Roman Pots.



(a) Previous version of the algorithm **(b)** Current version of the algorithm

Figure 4: Number of tracks reconstructed per pot

For the current track reconstruction algorithm, the first two pots are the ones with the largest amount of reconstructed tracks, although the variance is relatively small (415 tracks in [pot #5] to 490 in [pot #0]). The older version of the algorithm however, the variance was larger (320 in [#4] and 430 in [#2]), with peaks at [#2] and [#5].

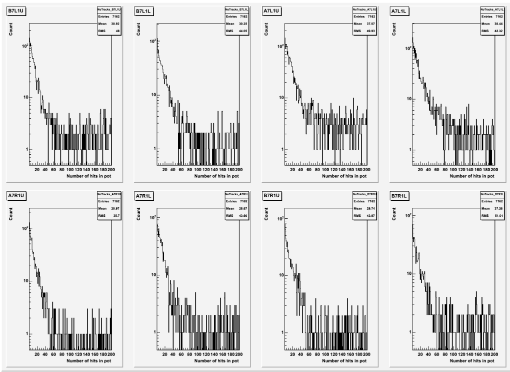
With a good reconstruction, one should expect a tendency for more tracks in the outer pots (0,1,6,7) because of more secondary interactions. Clearly this was a big problem in the earlier version of the algorithm, and has since been improved.

An asymmetry between the upper and lower pots can be seen, in that the lower pots have more background noise.

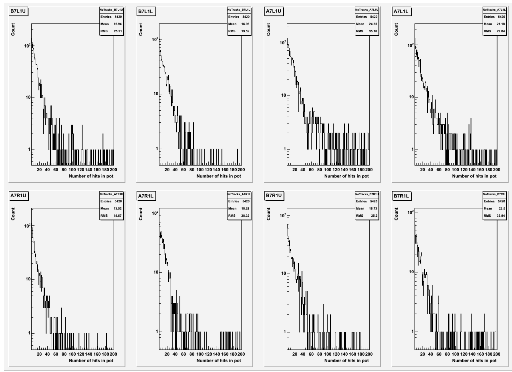
2.2 Hits per pot given number of tracks reconstructed

The histograms show the number of hits registered in each pot, given that there was zero, one, or more than one track reconstructed, respectively.

Events with zero hits are excluded from the plots. The plots use logarithmic scale. Although the maximum possible amount of hits in a pot is 1280 (20x64), the plots only show hits up to a value of 200, for clarity. The entries past that value can be safely regarded as noise.

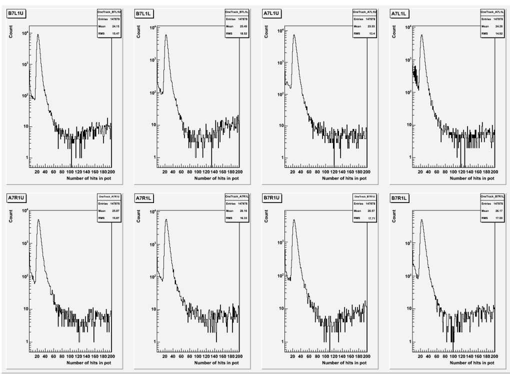


(a) Previous version

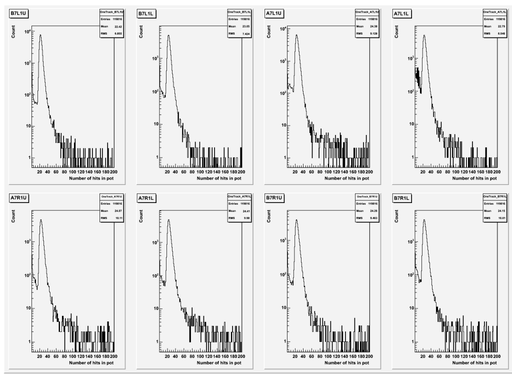


(b) Current version

Figure 5: Hits per pot, no tracks reconstructed



(a) Previous version



(b) Current version

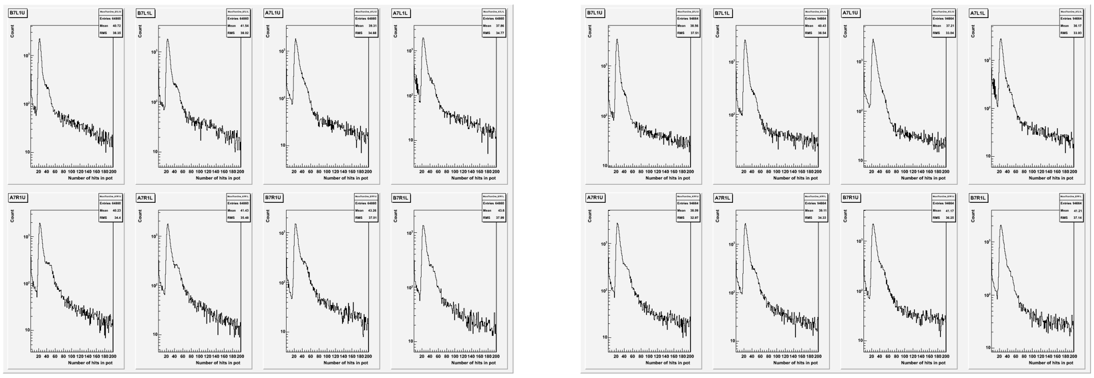
Figure 6: Hits per pot, one track reconstructed

Both versions of the algorithm exhibit very similar behavior: when no tracks are reconstructed, there usually were very few hits in the pot. There are of course some cases with a large amount of hits, but those can be thought of as either background or showers with which the algorithm does not deal well. With the current version of the algorithm, the amount of unreconstructed tracks for large numbers of hits in the pot is lower, indicating that the algorithm does better at reconstructing such events.

The difference between the two versions is again fairly small. There is a very strong peak at approximately 25 hits. This makes sense, ideally one would expect 20 hits, but the background raises this average. Most of the reconstructed tracks have very little background, although as always there is a certain amount of tracks with a strong one.

There is a "curve" (shown on 8), i.e. an increase in count for large amount of hits in outer detectors, which hints to reconstruction of secondaries rather than elastic collisions, which is problematic. The small amount of entries with a large number of hits indicates that the background is relatively small.

The behavior is once again very similar to the previous case, though large amounts of hits in the pot contribute to the number of events with several reconstructed tracks.



(a) Previous version **(b)** Current version

Figure 7: Hits per pot, multiple tracks reconstructed

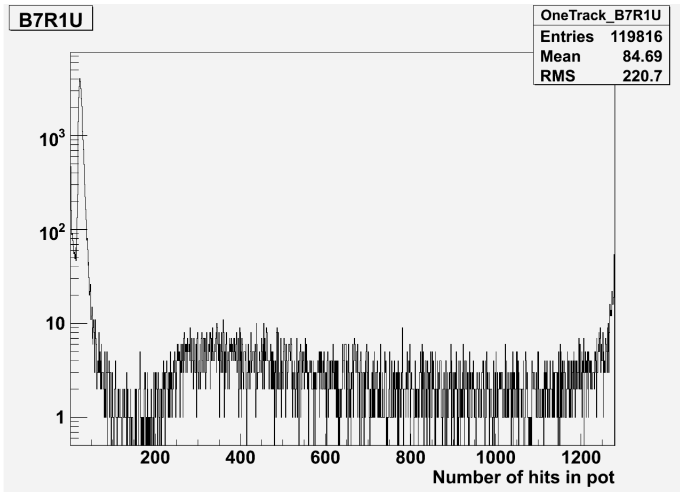


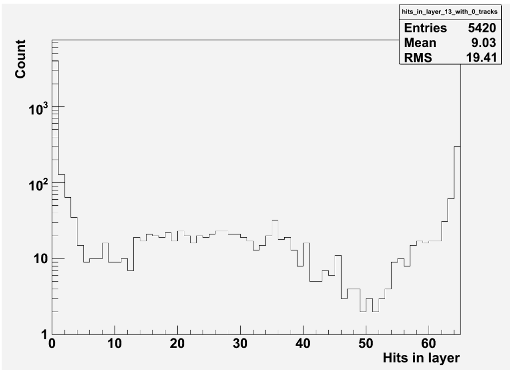
Figure 8: The noise curve, one track, current version

The results seem to be sensible and consistent with one's expectations. The plots confirm that the newer version of the algorithm does better at filtering out unwanted tracks.

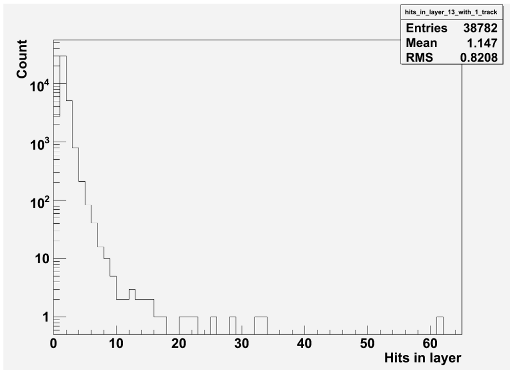
2.3 Hits per layer for a given number of tracks reconstructed

This analysis was performed on two pots: B7L1U (upper) and B7L1L (lower). The plots for each layer are nearly identical, up to statistical fluctuations, therefore for illustration, two layers were chosen: layer #6 in the U plane, and layer #5 in the V plane. The histograms show the number of hits registered in each layer.

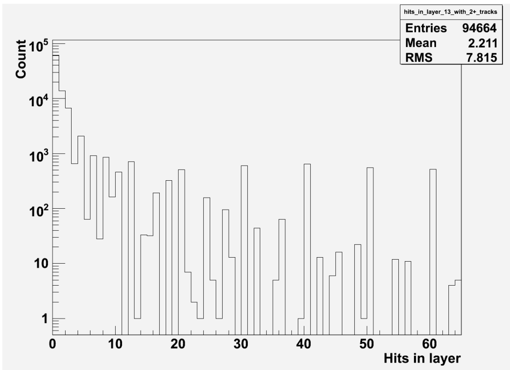
The zero entry dominates of course, as the simplest way of not having a track is not having any hits in the first place. Having all 64 fibers lit up also eliminates the possibility of recovering a sensible track. The (mostly) zero counts in other bins indicate that there were very few cases in which the algorithm didn't manage to reconstruct tracks despite there being several hits. This illustrates the fact that the algorithm is able to potentially reconstruct tracks incorrectly, for instance not taking into account that a several layer wide gap (layers with no hits) most likely means the end of a track. If there are some random



(a) No tracks reconstructed



(b) One track reconstructed



(c) Multiple tracks reconstructed

Figure 9: Hits per layer - lower detector, U plane

hits or more activity in the outer layers of a detector, the algorithm might have incorrectly reconstructed a track.

A clearly visible peak at 1 in each layer makes sense when there is only one track reconstructed. This again indicates a small background.

A peak at zero is puzzling, but a possible explanation of this is that in most cases, having more than one track reconstructed results in the tracks being bad. If this is the case, then it is indicative of some sort of problem in the algorithm.

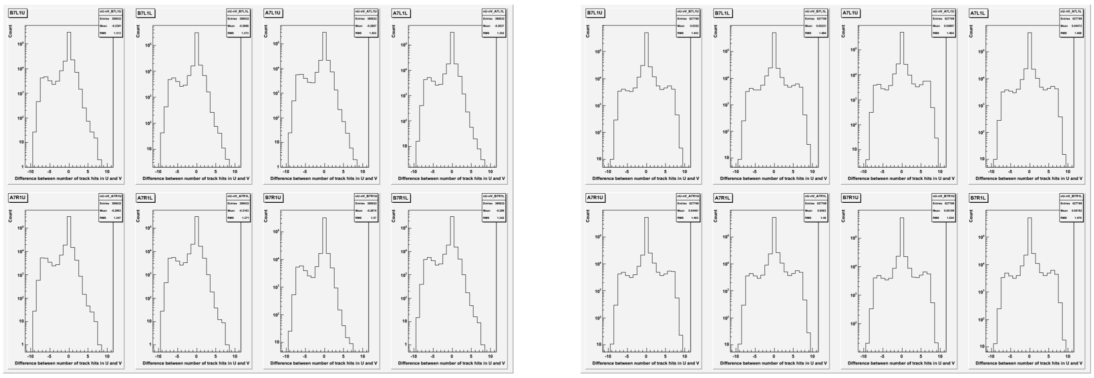
The difference between the upper and lower pots can be observed in the number of entries: there are far more in the upper pot.The extra entries are almost exclusively those with a large amount of hits per layer. This might indicate that the upper pots are subject to more background.

For brevity, only the results from the current version of the algorithm are presented. The behavior of the two versions is similar, however once again the new version generates fewer false tracks (i.e. those due to the background noise).

2.4 UV track difference per pot

This macro measures the asymmetry in the algorithm between the U and V planes by calculating the number of fibers selected for reconstruction from each plane, and subtracting them.

In the previous version of the algorithm, the U plane was incorrectly preferred over V -



(a) Previous version **(b)** Current version

Figure 10: UV track difference per pot

this can be very clearly seen from the plot. This has been since corrected. The asymmetry in the U-V hit distribution is now diminished, which is an important improvement in the track reconstruction algorithm, seeing as neither coordinate should be preferred. Ideally, the distribution should be completely symmetric up to statistical fluctuations.

As it is, there is a slight bias towards the positive direction of U-V, indicating that U might be preferred.

The shape of the distribution looks highly irregular, it is in particular very wide due to all the fake tracks. However, after introducing cuts, the shape is far more regular, indicating that the amount of fake tracks has significantly decreased.

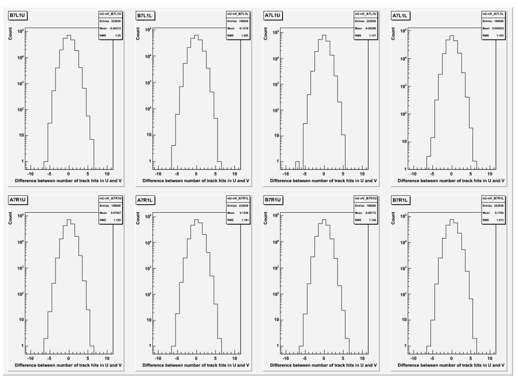
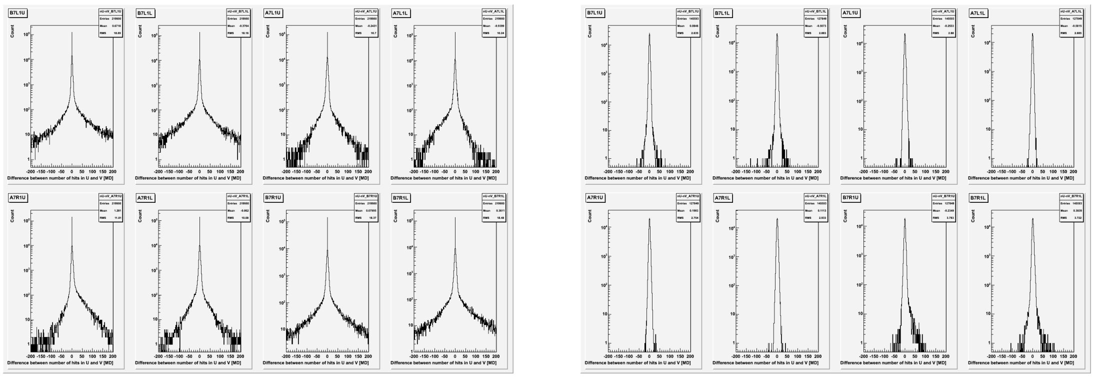


Figure 11: UV track difference, current version after cuts

2.5 UV hit difference per pot

The histogram shows the difference between the total amount of hits in the U and V planes.

There is a very clear, large peak for the 0 entry, as expected. The distribution is notably very wide, and there is significant contamination by events with a lot of hits caused by various background effects (secondary interactions, electronic noise). After introducing the cuts, these events are suppressed, and the distribution becomes fairly narrow.



(a) No cuts **(b)** After cuts

Figure 12: UV difference per pot

3 Summary

The goal of this work was developing quality assurance macros which could be used to control whether the track reconstruction algorithm produces results consistent with theoretical expectations. The resulting plots may now potentially be used for checking the quality of a new run. The current version of the track reconstruction algorithm has been compared with an older one, allowing one to see its deficiencies, most notably with respect to the UV track asymmetry and Tracks reconstructed per pot. Using the various cuts described in the introduction allows one to see how the plots become much more regular when using a nearly purely elastic sample.

Acknowledgments

My work would not be possible without the help of my supervisors: Wolfgang Friebel and Karl-Heinz Hiller. I would like to thank them for their assistance during the Summerstudent Program, and for everything they have taught me. Thanks to them I have familiarized myself with the ALFA experiment and with the track reconstruction algorithm, a vital part of data analysis.

I would also like to thank the administrative staff of the Summerstudent Program, for providing this wonderful opportunity of working and living in Zeuthen, where I was able to develop my skills and interests, as well as meet wonderful people.

Finally I would like to thank Krzysztof Janas for helping me format this document using LaTeXand his assistance with the ROOT environment.

References

[1] Measurement of the total cross section in pp collisions at $\sqrt{s} = 7$ TeV from elastic scattering with the ATLAS detector, The ATLAS Collaboration, CERN, 1211 Geneva 23, Switzerland (July 24, 2014);

[2] W. Friebel and K.H. Hiller, private communication.

[3] Analysis of the Track Reconstruction Algorithm in the ALFA detector of the ATLAS experiment, K. Janas