Data analysis and study of the performance of the EUDET beam telescope for the 2009 ALFA test beam

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Abstract

The ALFA experiment is designed to provide the absolute luminosity of LHC at the ATLAS interaction point. In order to characterize the detector several test beams have been performed. During these tests the information concerning the track was provided by the EUDET detector, a pixel telescope designed for test beam operations. The aim of this work is to compare two different clustering algorithms of the EUDET reconstruction software. Furthermore, a study on residuals and χ^2 distributions of some data samples has been performed and finally an alignment procedure using the SVD ROOT method has been studied.

Introduction

ALFA

ALFA (Absolute Luminosity For ATLAS) is one of the forward detectors of the ATLAS (A Toroidal LHC Apparatus) experiment. The purpose of ALFA is to measure the absolute luminosity of LHC (Large Hadron Collider) at the ATLAS interaction point. To reach this purpose ALFA will measure the ratio of elastic scattered protons in the Coulomb-nuclear interference region and then, using a fitting procedure, give an estimation of the absolute luminosity with a precision of $\sim 3\%$ [1]. Reaching the Coulomb interference region is a challenging task. Therefore ALFA has to be sensitive to particles scattered at very small angles. The design chosen for the detector provides four roman pot stations placed 240 m away from the ATLAS interaction point (IP), two stations on each side. This configuration allows the detector to perform measurements very close to the beam axis and thus the revelation of Coulomb scattered protons. The sensitive part of ALFA is formed by planes of scintillating fibers in an U-V (or stereo) configuration read by multianode photomultipliers (one fiber for each channel).

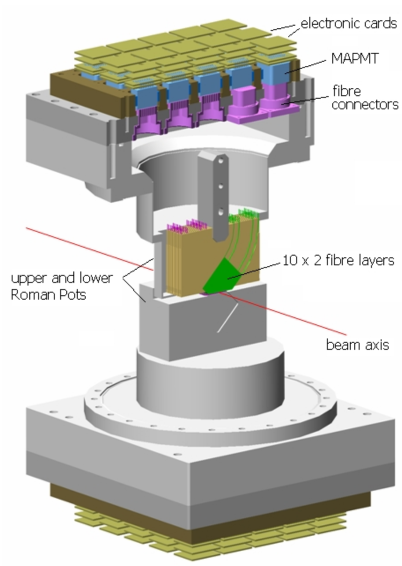

Figure 1: The ALFA detector layout.

Each roman pot station contains two sensitive parts, each made of ten fibers plans that, as shown in figure 1, approach the LHC beam in the vertical direction. The signals coming from each sensitive part are processed by an electronic motherboard so henceforth I will refer to the sensitive parts calling them motherboards (MB). Making use of a particular beam optics configuration, it is possible to relate the measured hit position on ALFA to the scattering angle of the particles. Some dedicate runs with a luminosity from 10^{27} to $10^{28} cm^{-2}s^{-1}$ will be used in order to satisfy the ALFA beam requests. During these runs LUCID (LUminosity measurement using Cherenkov Integrating Detector), a detector able to measure the luminosity variations at the ATLAS IP in the full luminosity regime, will be calibrated and thus will be able to provide the absolute luminosity value even in the physics runs. To reach the desired precision in the luminosity measurement it is fundamental to determine the hit position on ALFA with an accuracy of $\sim 30\mu m$. To find out the real precision of ALFA many test beams have been performed. In these tests an accurate knowledge of the path of the particles is fundamental, which is the aim of the EUDET beam telescope.

EUDET

EUDET is an integrated infrastructure initiative that has the aim to provide infrastructure for detector research and develop (R&D). For this purpose a beam telescope has been built. Such a device can determine the path of the particles during test beams. The precision of the telescope should be better than the one of the device under test (DUT). The EUDET pixel telescope is composed of six pixel detectors planes,three before the DUT and three after. A schematic view of the detector and its DAQ system is given in figure 2.

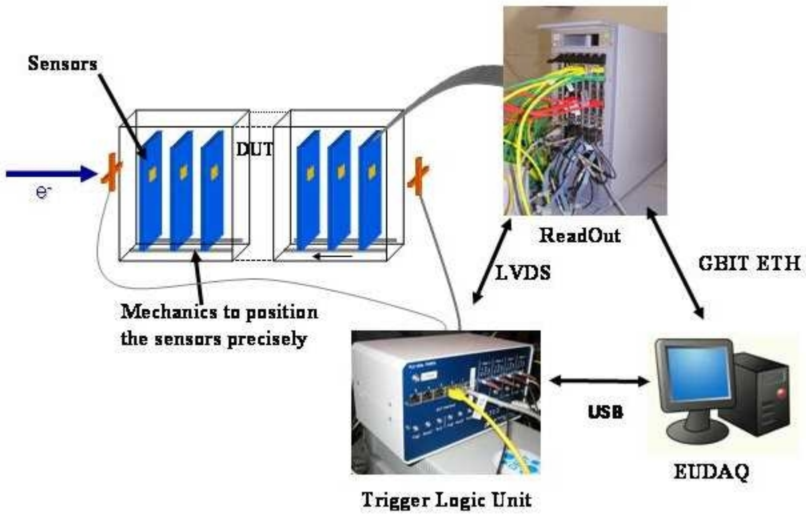

Figure 2: Schematic view of the EUDET telescope and its DAQ system. It's possible to distinguish the detector planes and the trigger scintillators.

The pixel layers are monolithic active pixel sensors (MAPS) with a pixel pitch of $18.4\mu m$. The MAPS technology permits to integrate the readout and signal processing electronics on the same substrate as the sensor [2].

The telescope trigger is provided by the coincidence of four scintillators that ensure that the particles have traveled throughout the whole telescope. The resolution of the telescope is $\sim 4.5\mu m$, much smaller than the ALFA resolution. The telescope provides a digital output, with the possibility to operate both in transparent mode and in zero suppressed mode (ZS) [3]. When operating in transparent mode the signal of every pixel is recorded, which generates a big amount of data because also the information about the pixels that have a signal below threshold is recorded; this mode is mainly being used for debugging and characterization of the telescope itself. The ZS is the mode used during the routine data taking. When operating in ZS mode the DAQ system only record the address of the pixels hit, saving memory space and recording time. An important feature of the telescope is the possibility to integrate the DAQ systems of the telescope and the DUT. This can be made in two different manners: integration at trigger level or a full integration of the DAQ softwares [4]. Figure 3 shows the DAQ integration at the trigger level. In both cases the hardware parts of the DAQ systems of telescope and DUT are separated.

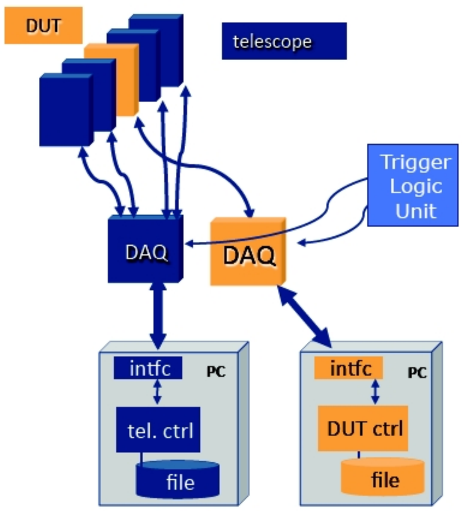

Figure 3: Outline of the DAQ integration at the trigger level between telescope and DUT.

Test beam setup

The test beam took place between October and November 2009 in the Prevessin site of CERN. The beam was made up of 120 GeV pions produced by colliding a proton beam from SPS on a target. As a complete roman pot station was used during the test beam, it couldn't be placed between the telescope planes but downstream them.

The roman pot station gave the possibility to operate the ALFA detector at different pressure conditions. Besides it was possible to move ALFA in order to expose different parts of the detector to the beam. A scan all over the surface of the two MB has been performed. The trigger condition was given by the coincidence of the four EUDET scintillators and the two ALFA scintillators. The DAQ systems were integrated at the trigger level by the EUDET trigger logic unit. With this setup condition there are, at a fixed pressure, three possible data taking configurations:

- Beam on the upper motherboard
- Beam on the lower motherboard
- Beam on both motherboards at the same time

During the test beam some problems with the last telescope plane had been found, thus no data from this plane are available for data analysis. The aims of the test beam were: measure the detector efficiency and hit reconstruction precision of the ALFA detector and finally to give a description of the behavior of ALFA at different pressure conditions.

Subject of this work

The aim of this work is to compare the performance of two different clustering algorithms of the EUDET reconstruction software in order to find out which one is better to use in the test beam scheduled in the end of summer 2010. The motivation for this comparison is the slowness of the clustering algorithm currently used, which does not allow quick data quality tests during the test beam data taking. Thus, the main characteristics evaluated are the speed of the software and the quality of the reconstructed tracks. The speed of the algorithms is provided by the EUDET software and for the quality of the reconstructed tracks a comparison between the residuals obtained using the two clustering algorithms has been performed. A study of the χ^2 distribution of the tracks reconstructed by EUDET has allowed an estimate of the telescope resolution.

1 EUTelescope software

EUTelescope is the reconstruction software of the EUDET telescope. EUTelescope is composed of a set of MARLIN processors. MARLIN (Modular Analysis & Reconstruction for the LINear collider) is a modular application framework written for the ILC (International Linear Collider) project [5]. The EUTelescope is organized in steps which are run separately: a brief description of each one will be given in this paragraph. In log file of each step, a resume of some characteristic parameters like execution time for each event, number of clusters or tracks found and so on are given after the execution. A scheme of the reconstruction chain is shown in figure 4.

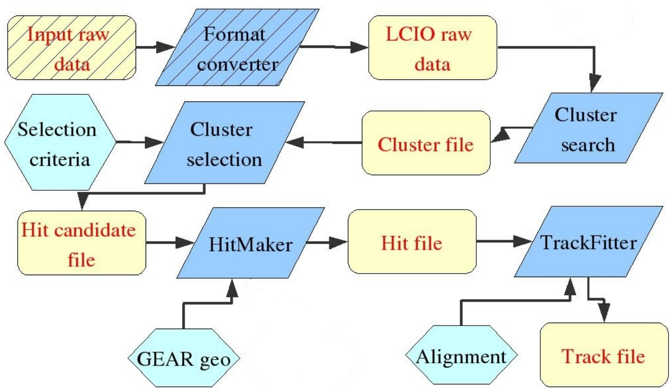

Figure 4: Scheme of the reconstruction chain for the EUDET pixel telescope.

1.1 Converter

The converter is the first part of EUTelescope that acts on the data, it converts the raw data in the .lcio format in order to permit the other parts of the reconstruction software to work.

1.2 Clustering

The clustering procedure is used to define groups of pixels, placed one next to each other, whose signals are over some threshold. This is necessary because the passage of a charged particle can produce signal in more than one pixel. Thus in order to find the point where the particle struck the detector it is necessary first to find out which pixels belong to the same hit. The EUTelescope software provides two different clustering algorithms: digital fixed frame (DF) and sparse cluster 2 (Sp2).

The digital fixed frame algorithm superimposes a rectangular shape frame whose dimensions are defined by the user at the sensor matrix. The algorithm first examines the pixels that have the bigger number of neighbors with signal (the seed). Once the seed is identified, a frame is centered on it and pixels with signal are added to the cluster. Once the cluster is formed, the pixels belonging to it are flagged and the process starts again with the next seed.

The sparsified clustering method is based only on the distance between pixels that have signal. The algorithm starts from the first pixel with signal in the matrix and adds to the cluster all the pixels that are enough close to the cluster border.

1.3 Filtering

During this process it is possible to apply some condition in order to modify the clusters found in the previous step. Here it is possible to define criteria to erase clusters or to merge confining clusters that probably were generated by the same hit.

1.4 Hitmaker

This step defines the hits on each detector plane. The criteria to find the hit position is that it must coincide with the "most central" pixel in the cluster. The parameters that are used to find out which pixel is the most central are: the number of pixels bordering and the distance from the cluster border. The hitmaker can work both with filtered and non-filtered cluster files.

1.5 Alignment

The aim of this process is to provide a fine alignment between the telescope planes. This procedure uses events that have signal on all the planes of the detector. Using a quick track fitter, points belonging to the same real track are identified. A software called Millepede II performs the internal alignment using these selected points. The information provided by the alignment procedure are used by the fitter.

1.6 Fitting

The fitting procedure finally provides the tracks using the files from the hitmaker and the alignment steps. The track model used is a broken line that considers the multiple scattering that can arise when the particles pass trough the telescope sensors or the DUT [6]. The tracks are created propagating the particles from a layer to the next one following the track model. Points can be excluded from track reconstruction in order to obtain a better χ^2. The user can control this rejection setting the penalties which are added to χ^2 in case one or more points are removed from the track. A lower penalty can bring to a loss of information because points are easily excluded. On the other hand with higher penalties points with large residual or even background can be included in the tracks. Setting these penalty values a bias is introduced for the points used in the track reconstruction.

2 Comparison

In this section some features of the tracks reconstructed using the two clustering algorithms are measured and compared. The aim is to characterize the algorithms and to find out which are the most suitable applications for them.

2.1 Consistency

The first step in the comparison is checking that the tracks reconstructed using the two different clustering algorithm are the same. Figure 5 shows the difference along x and y of the hits in plane 2 of EUDET belonging to the same tracks reconstructed using the DF and Sp2 algorithms. Figure 6 shows the same for the plane 3.

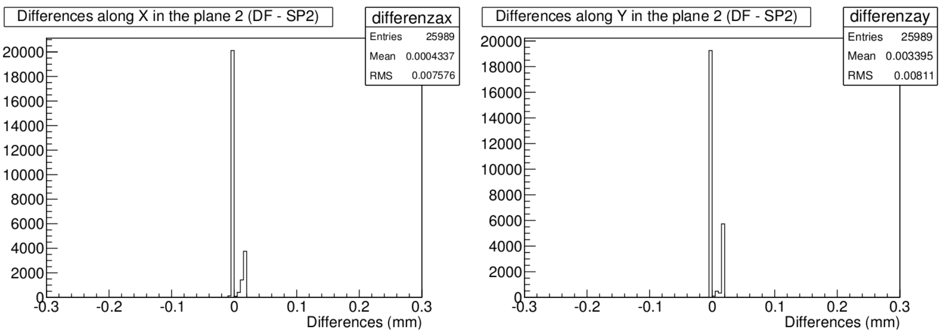

Figure 5: Difference in the tracks hits in the plane 2 of EUDET.

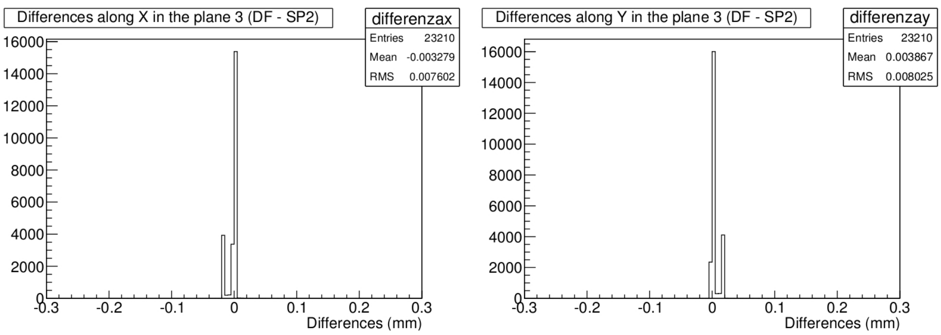

Figure 6: Difference in the tracks hints in the plane 3 of EUDET.

The little peak that appears in each plot can arise from differences in the alignment step for the two collections of tracks and it matches the pixel structure. Changing the clustering algorithm the positions of the hits slightly change and with them the alignment parameters. The tracks reconstructed with different algorithms are very similar.

2.2 Residuals

The residuals distributions are useful to compare the precision provided by the two algorithms. The plots shown in this subsection are obtained using the plane 2 of EUDET as DUT. A linear fit has been performed using the hits on the other four planes. The contribution of multiple scattering is negligible because of the high beam energy. The residuals have been calculated as the difference of the measured hit position on the plane and the calculated one through the fit.

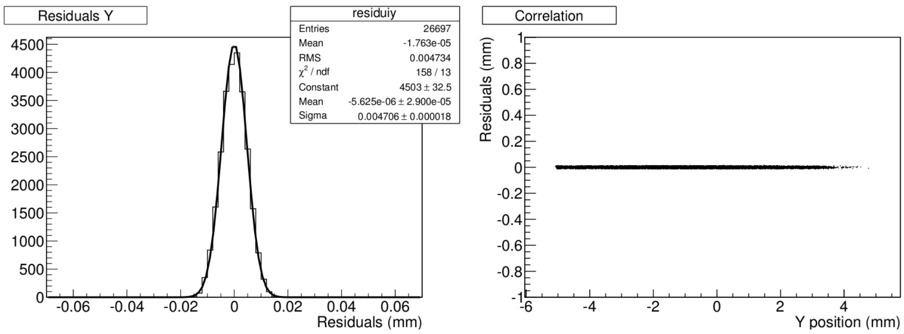

Figure 7: Residuals distribution and correlation between residuals and measured positions obtained in the plane 2 along y using DF algorithm.

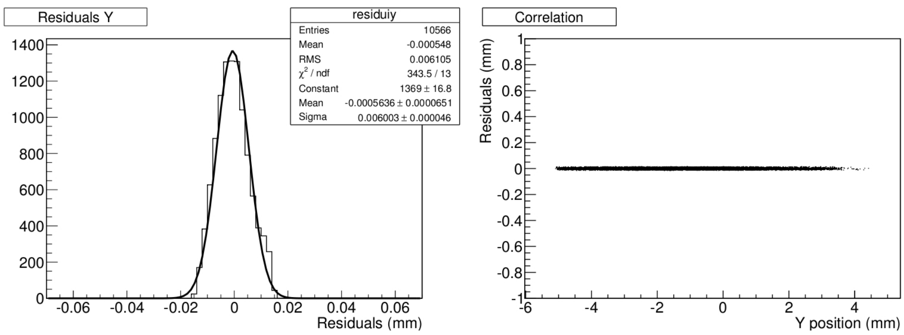

Figure 8: Residuals distribution and correlation between residuals and measured positions obtained in the plane 2 along y using Sp2 algorithm.

From figures 7 and 8 we can see that in both cases the distribution of the residuals is centered in 0 and there is no correlation between residuals and position on the sensor. The values of the sigma of the distribution shows that the DF provides more precise tracks than the Sp2.

2.3 Estimate of EUDET precision using χ^2 distribution

Using the reduced χ^2 distribution it is possible to give an estimation of the effective resolution of the detector. We expect the reduced χ^2 distribution to present a mean value of 1, but more often we obtain other values. Considering the formulas

$$\chi^2 = \sum_{i=0}^{n} \frac{(meas_i - pred_i)^2}{\sigma_{EU}^2} \qquad < \frac{\chi^2}{ndf} >= M \tag{1}$$

where $meas_i$ is the measured position of the i-th hit, $pred_i$ is the predicted position of the i-th hit and σ_{EU} is the intrinsic resolution of EUDET. The biased EUDET resolution σ'_{EU} can then be defined by scaling the intrinsic one in order to have the mean of the distribution equal to 1.

$$\frac{1}{M} < \frac{\chi^2}{ndf} >= 1 \qquad \sigma'_{EU} = \sqrt{M} \cdot \sigma_{EU} \tag{2}$$

Figures 9 and 10 show the distributions of the reduced χ^2 obtained performing a linear fit on the hits belonging to tracks samples reconstructed using the two algorithms. The plots refer to tracks that present four and five hits. In these distributions we used $\sigma_{EU} = 4.5\mu m$, the resulting effective resolutions obtained for these samples are shown in table 1. It is important to remark that the biased resolution is the resolution that we have on the hits of the reconstructed tracks and it is different from the intrinsic resolution of the detector that arise only from geometrical and mechanical features of the sensors.

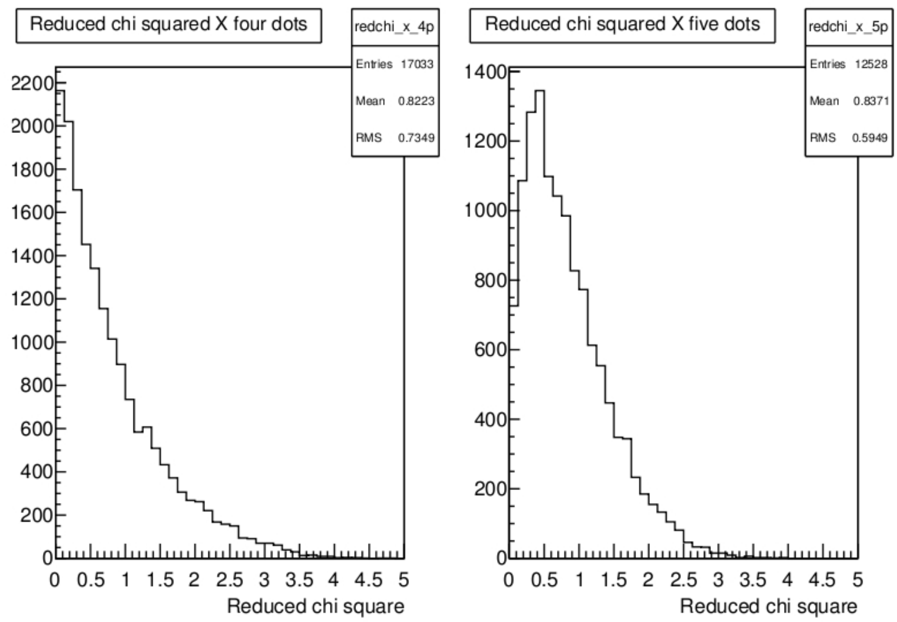

Figure 9: Distributions of the reduced χ^2 obtained from tracks reconstructed using DF algorithm. The distributions are for tracks with four (left) and five (right) hits.

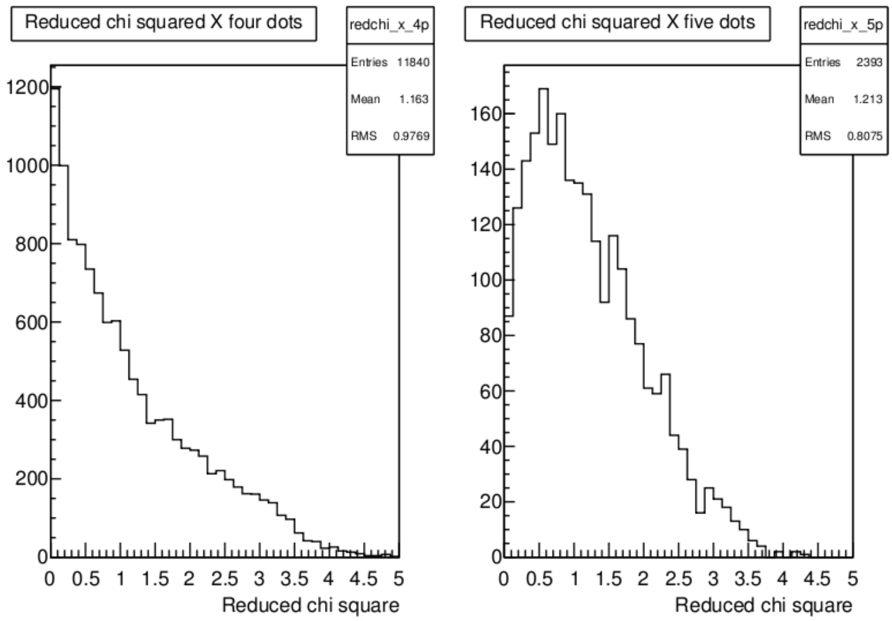

Figure 10: Distributions of the reduced χ^2 obtained from tracks reconstructed using Sp2 algorithm.The distributions are for tracks with four (left) and five (right) hits.

Algorithm	Effective resolution using 4 hits (μm)	Effective resolution using 5 hits (μm)
DF	4.08	4.12
Sp2	4.85	4.96

Table 1: Values of the effective resolution obtained using DF and Sp2. These values are obtained from figures 9 and 10.

Algorithm	Efficiency
DF	94.1%
Sp2	94.0 %

Table 2: Reconstruction efficiencies using the two algorithms.

2.4 Other features

In this subsection some other features of the algorithms and the reconstructed tracks are shown. The reconstruction efficiency is defined as the ratio of events in which at least one track is reconstructed and the number of total events. The efficiencies are shown in table 2. Using six planes instead of five the efficiency would increase.

The speed ratio of the two clustering algorithms have been calculated using the execution times measured by the reconstruction software.

$$\frac{Speed\ Sp2}{Speed\ DF} = 3.07$$

Another feature is the number of hits used to reconstruct the tracks. These distributions are shown in figures 11 and 12 which have been obtained using the same penalties.

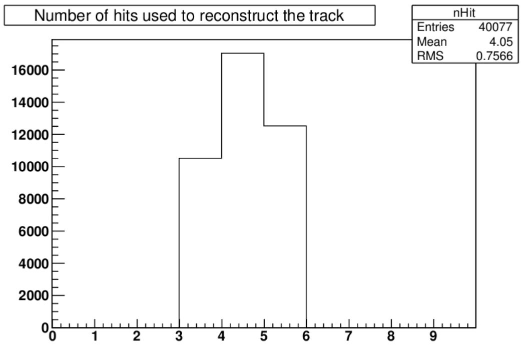

Figure 11: Number of hits used for tracks reconstruction using the DF algorithm.

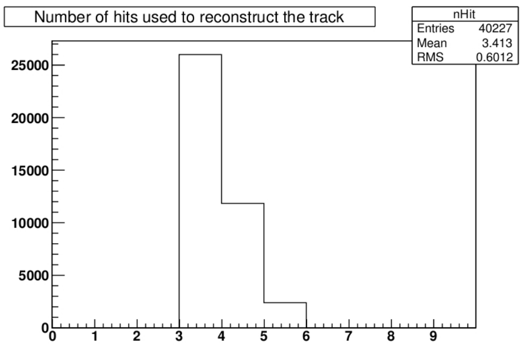

Figure 12: Number of hits used for tracks reconstruction using the Sp2 algorithm.

It is possible to see that tracks reconstructed using the DF algorithm have more hits than the ones reconstructed with the Sp2. In case of the Sp2, hits have larger residuals compared to DF algorithm, so they can be easier rejected.

Comparing in table 3 the number of clusters found in each layer, it is possible to see that the Sp2 algorithm find more clusters than the DF. Since the number of reconstructed tracks is roughly the same, this means that Sp2 generates more fake hits than the DF.

	0	1	2	3	4
DF	82206	110351	163928	143849	145864
Sp2	144157	173566	243518	212444	216296

Table 3: Number of clusters found in each layer using the two algorithms on the same data sample.

3 Alignment using a linear combination

In this section the results achieved using an alternative procedure for the ALFA-EUDET alignment are shown.

3.1 Principles and purpose

The ALFA detector is currently aligned to EUDET considering two translations and a rotation in the plane perpendicular to the beam axis.

Another way to perform the alignment is to express the position of the hits on ALFA as a linear combination of the points measured in the EUDET layers. In general, we can write

$$X_{ALFA} = c + \sum_{i=0}^{4}(a_i x_i + b_i y_i) \qquad Y_{ALFA} = f + \sum_{i=0}^{4}(d_i x_i + e_i y_i) \tag{3}$$

where x_i and y_i are the hit positions on the i-th layer of EUDET, a_i, b_i, d_i and e_i the coefficients of the linear combination and c and f two constants. In this way all the information that we have is used to make the alignment and all the degrees of freedom of the detectors are considered. An interesting feature is that this process does not need information about the distance between the detectors planes. The coefficients are determined using the Single Value Decomposition (SVD) method or the minimization package Minuit.

3.2 Alignment results

In figures 13 and 14 the distributions of the residuals obtained on ALFA using this linear combination with DF and Sp2 are shown. In these plots the sigma of the distributions is large because of the ALFA precision ($> 30\mu m$).

Figure 15 shows the residuals distribution obtained using the currently used alignment procedure with the DF algorithm.

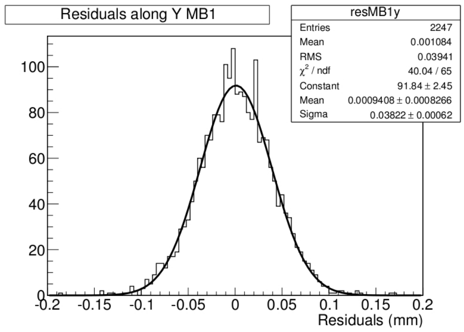

Figure 13: Residuals along y obtained on ALFA using the linear combination method with the DF algorithm.

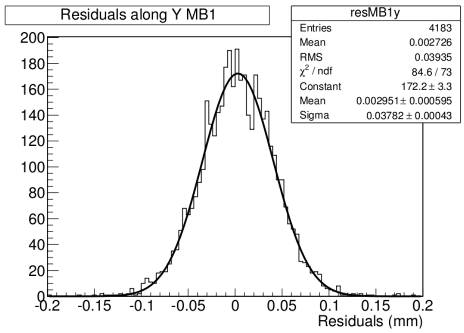

Figure 14: Residuals along y obtained on ALFA using the linear combination method with the Sp2 algorithm.

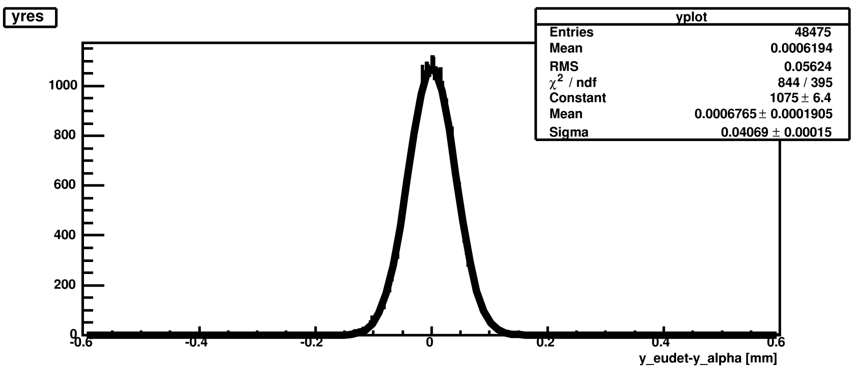

Figure 15: Residuals along y obtained on ALFA using the currently alignment procedure with the DF algorithm.

We have to be careful in doing a direct comparison between the sigma values in the distributions showed because the data sample is biased by different cuts.

Some problems arise with this method when the data comes from runs in which the beam was on both the MB at the same time, but applying some geometrical cuts it is nevertheless possible to obtain acceptable results.

Conclusions

The DF algorithm is slower and more precise than the Sp2. Both the algorithms provide good χ^2 distributions and the Sp2 is about 3 times faster than the DF. In the ongoing test beam, the Sp2 method is used for online control plots during the data taking, while the DF will be used for the offline reconstruction of the tracks after the test beam.

The linear combination method could allow without the knowledge of some input parameter, like distance EUDET-ALFA, a good alignment between EUDET and ALFA detector. For this subject further studies are necessary.

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