ATLAS

Comparison between the RASNIK analysis programs

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Abstract

The in-plane alignment of the first full-scale BIL MDT chamber prototype ("Calypso") was provided by four RASNIK-CCD systems. Tests have been made to determine the RASNIK resolution in monitoring the relative position of its pieces.

Three programs have been written to analyse the RASNIK images. The results obtained with these three programs on a large sample of images have been compared. The three programs agree to within less than 2 μm.

1. Introduction

The in-plane alignment of the MDTs must be able to monitor the chamber deformations with an accuracy of less than 10 μm. These movements are deduced from the movements of the chamber cross-plates which is measured with RASNIK-CCD systems [1]. This note presents the in-plane alignment system of the first full-scale BIL MDT prototype [2] and its performance.

Three programs were written to process the RASNIK images, each of which was designed to satisfy to different constraints. The first one was written in FORTRAN [3] and uses a fitting procedure to determine the cross-plate movement. The second one was written in PASCAL [4] on Macintosh computers. It uses the steepest ascent algorithm. This program has been rewritten in

C++. The third program was written in C [5] and, like the first one, performs a fit. All three were used to analyse two samples of images - 2780 sharp images and 390 blurred images - in order to compare their performances. The results of the comparison is presented in §3.

2. The in-plane alignment

The in-plane alignment is provided by four RASNIKs (Fig. 1). The two RASNIKs on each side of the chamber, the light rays of which are labeled 1 and 4 on Fig. 1, are parallel to the tubes. The two central RASNIKs (light rays 2 and 3 on Fig. 1) make an angle of ± 55.2 mrad with the tubes.

The RASNIK elements are mounted on supports that are screwed to the cross-plates. The exact position of each pieces on the cross-plate is shown in Fig 2. Each RASNIK instrument consists of a mask, a lens and a CCD camera. The mask is a piece of glass of size 2.5×2.5 cm^2 on which a chessboard is printed. The mask pitch (size of the squares) has been measured to be 120 ± 0.02 µm [6]. The chessboard contains horizontal and vertical coded lines, i.e. lines in which squares are inverted [1]. This mask is backlit by nine infrared lamps arranged in three rows of three lamps. The central lenses are bi-convex lenses with a focal length of 640 mm. The CCD cameras are miniature video cameras. The pixel size is 8.5 µm. The cameras are read by an ISA PC card called a framegrabber. They deliver a continuous signal which is sampled 768 times by the framegrabber and send a synchronization signal at the end of each line. Therefore, the horizontal pixel size is slightly different from the real pixel size. The program that controls the card displays the image on the screen of the PC and allows the displayed image to be saved on the hard disk.

For each measurement, each RASNIK is turned on and a given number of pictures is taken and recorded on the PC hard disk. The cameras have to be turned on for at least five minutes before one begins to take the pictures because the measurement is unstable during that time. A RASNIK measurement consists of recording between 10 and 100 images on disk with each RASNIK. The pictures are then analysed with one of the three programs that are available (see § 3). Each program is able to determine the horizontal and vertical positions of the lens, the tilt of the mask with respect to the optical axis of the RASNIK and the size of the mask squares.

2.1 Adjustment of the RASNIK length

The four lenses that were mounted on "Calypso" were manufactered in Protvino. Their focal length is 640 mm $\pm$ 2 mm. From the positions given in Fig. 3, we can determine that the total length of the RASNIK 2 and 3 is 2563.91 mm, i.e. 3.91 mm bigger than the distance between the two external cross-plates.

RASNIK	Size of the small spacers
1	10 mm
2	7 mm
3	3 mm
4	5 mm

Table 1: Size of the extra small spacers that had to be added between the mask supports and their cross-plates.

The length of each RASNIK line (distance between the external cross-plates) was measured to be 2560 mm for the RASNIKs 1 and 4 and 2564 mm for the RASNIKs 2 and 3. However, the front of the cameras and masks does not correspond to the front of the cross-plates, as shown on Fig. 3. The distance difference between the front surface of the masks and cameras and the surface of the cross-plates had to be taken into account. This led to the addition of an extra spacer between the supports and the cross-plates as shown on Fig. 3 so as to ensure that the distance camera-lens and lens-maks is twice the focal length of the lenses, i.e. 1280 mm. The size of that spacer is 35 mm between the camera supports and their cross-plate and 11 mm between the mask supports and their cross-plate.

This proved to be insufficient as with this set-up, the pictures recorded with all four RASNIK systems were blurred. The position of each mask had to be adjusted a second time using small spacers in order to get sharp pictures. The size of these small spacers is given in Table 1. The biggest difference between the small spacers sizes is 7 mm, i.e. less than 3 ‰ of the total RASNIK length. This lies within the precision of the lenses given by the manufacturer.

2.2   RASNIK resolution

The study of the RASNIK resolution was made using a demo-kit in which elements were fixed on supports that were mounted on a rail. The focal length of the lens used with the demo-kit was 200 mm. The support of the lens contained three micrometric screws that allowed us to move the lens horizontally and vertically perpendicular to the optical axis and along the optical axis. These three directions will be referred to later in the text as x, y and z respectively. The range of the micrometric screws is 15 mm and their precision is ±5 μm (half the distance between two marks on the screw).

A series of tests was made to determine the RASNIK accuracy in reconstructing a movement of the lens in x and y directions. The procedure was the following: a reference position was choosen and five pictures were recorded. Then the lens was moved from -200 μm to +200 μm with respect to that reference position in x or y by steps of 100 μm and five pictures were recorded at each step. Finally the lens was brought back to the reference position and five pictures were recorded. The two measurements in x and y were done one after the other. The NIKHEF program was used to analyse the pictures. The upper plots in Fig. 4 shows the reconstructed positions in x and y versus the position of the lens around the reference position. The lines are the result of a fit made on the seven points. The lower plots in Fig. 4 show the distribution of the residuals with respect to the fitted lines. The r.m.s. for the x direction - 0.9 μm - is slightly better than what we would expect from the micrometric screw precision, which is 1.9 μm.

A similar test was made to determine the RASNIK resolution in the z direction. This was done using another analog system to measure the displacement of the lens in the z-direction. This system was a pressure sensitive gauge with an analog display that had a precision of the order of 1 μm. The procedure was identical as the one described above to test the RASNIK accuracy in measuring displacements in x and y directions, but the steps were of 50 μm: the lens was moved around a reference position from –100 μm to +100 μm by steps of 50 μm. At each step, 25 pictures were recorded. The NIKHEF program was used to analyse these pictures too. The distribution of the reconstructed z position is shown on Fig. 5. The center of gravity of each of the five peaks has been determined by a gaussian fit. The displacements measured with the RASNIK are compared with the one measured using the gauge in Table 2. The r.m.s. of the differences between the

measurement of the gauge and the one of the RASNIK is ~3 µm, which is slightly better than what we expect from the resolution in the z direction from Fig. 9 (14 µm for a RASNIK of 2.56 m, i.e. 4.4 µm for the RASNIK of the demo-kit which was 0.8 m long).

Fig. 6 shows the distribution of the reconstructed x and y positions, square width and rotation angle of the mask around the z axis for 100 pictures taken in the same conditions for one of the four RASNIK systems that were mounted on "Calypso". The pictures were analysed with the C++ version of the Brandeis program. We can see that the RASNIK resolution for the x and y position determination is less than 1 µm.

Displacement measured with:		
RASNIK [µm]	Gauge [µm]	Difference [µm]
52.7	47.5	+5.2
50.5	53.0	−2.5
45.7	44.5	+1.2
45.9	47.0	−1.1

Table 2: Comparison of the displacement of the lens in the z-direction measured with the RASNIK with the one measured with an analog gauge.

2.3 The RASNIK stability

From measurements made with the RASNIK systems mounted on the BIL MDT prototype "Calypso", it was noted that the reconstructed value for the x and y position could vary with time. This is shown on Fig. 7 for two of the RASNIKs. We clearly see that the reconstructed position increases or decreases with time (upper plots on Fig. 7), changes by a step of ~2 µm during the data taking (lower left plot on Fig. 7, after the sudden change of the reconstructed value[†]) or changes by a few µm for a short period of time of about 1 minute (double peak structure seen on the lower right plot of Fig. 7). These effects are still not understood. The first explanation was that the RASNIK systems had to be warmed for 5 to 10 minutes before recording the pictures in order to allow for the stabilization of the temperature of the CCD camera and the mask. This pre-warming stage decreased the rate of appearance of such a drift of the reconstructed values, but did not make it disappear.

3. Comparison between the analysis programs

There are three analysis programs avalaible to process the RASNIK pictures. The first one is a FORTRAN program written by Frank Linde of NIKHEF [3]. This program searches for the horizontal and vertical transition lines between white and black squares and performs a fit to determine the x, y and z position of the lens, and the three rotation angles α_x, α_y and α_z of the mask around the three axis.

The second program has been written by Kevan Hashemi of the Brandeis University [4] and translated in C++ by Pierre Oberson. It is based on the steepest ascent algorithm and optimizes with

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[†] The sudden change of the reconstructed value by ~6 µm shown in Fig. 9 indicates that after ~300 s of pciture recording, there is some unknown effect taking place that is responsible for the jump. In this case, the ~30 first measurements should be rejected for the analysis as the conditions are still unstable.

an iterative procedure the parameters of a chessboard until it matches the actual image. At each iteration, the parameters are modified by a small value that we call the "step size". The parameters are the x and y coordinates of the chessboard origin, the chessboard square sizes in x and y directions and the chessboard rotation around the z axis. The optimization is done in four stages. In the first stage, the optimization is done on only a small portion of the picture in order to get a first "rough" value of the parameters. In the second stage, the optimization area is increased and the step is smaller. In the third stage, the optimization is done on the border of the picture so as to have the biggest possible lever arm to determine the rotation of the mask around the z axis. In the fourth stage, the optimization surface does not change but the step size is very small. At each iteration, a quality factor is computed that compares the chessboard defined by the five parameters with the picture. At each stage, the algorithm has converged once the σ of the five last values of the quality factor has become lower than a given value, or, in other words, once the small variations of the parameters does not change the match between the computed chessboard and the picture. Once the algorithm has converged in the last stage, it is possible to make up to 100 iterations and keep the successive results so as to have a better estimate of the value of the parameters. The reconstructed parameters are the x and y positions of the mask, the rotation angle around the z axis and the size of the mask squares in both x and y directions. Fig. 8 shows the distribution of the reconstructed values for these parameters for 100 analysis of one file.

The second program has been written in C by Stefan Schael from MPI. This program is extensively described in [5]. It provides a measurement of the x and y positions, the rotation angle around the z axis and the magnification, i.e. the ratio between the reconstructed size of the mask squares and their original size.

These three programs have been used to analyze a sample of 2780 sharp pictures and 390 blurred pictures recorded with the four RASNIK systems that have been mounted on "Calypso" [1]. They were compared in terms of processing speed, reconstruction resolution and ability to analyze blurred images. The programs will be referred to later in the text as the NIKHEF, the MPI and the Brandeis program.

3.1 Processing speed

All the pictures have been analysed on a cluster of 16 IBM workstations running the UNIX AIX operating system. The analysis was done in batch mode and each batch job was allocated one of the computer of the cluster and no other job could be run on that computer.

Program	Total time for 3170 images	Time per image		Fraction of CPU time
		Real time	CPU time	
Brandeis	29542.s	9.3 s	8.7 s	92.9 %
NIKHEF	53699 s	16.9 s	9.7 s	57.2 %
MPI	56356 s	17.8 s	17.4 s	97.7 %

Table 3: Total time taken for the processing of 3170 images, mean real and CPU time needed for the processing of one image and fraction of the CPU time used by each RASNIK analysis program.

Table 3 shows in column 2 the tota l time needed for the processing of 3170 pictures with each of the three programs, in column 3 and 4 the mean real time and CPU time (the fraction of the total time during which the processor is effectively running the analysis program) needed to analyze one picture and in column 5 the ratio between the CPU and the real time. The C++ version of the Brandeis program is the fastest of the three, it is almost twice as fast as the other two programs.

3.2 Reconstruction resolution

Among the sample of images that have been analyzed with the three programs, there is a group of 400 images - 100 images for each RASNIK system - that have been recorded at CERN when the chamber was hung horizontally by its support bars. The distribution of the reconstructed x and y positions, the z position (NIKHEF), the magnification (MPI) or the square width and the rotation angle around the z axis are shown for each program on Fig. 9 (NIKHEF), 10 (MPI) and 6 (Brandeis). From these plots, one can see that the resolution of the NIKHEF and MPI programs is twice as good as that of the Brandeis program for determining the x and y positions of the mask - ~0.35 μm versus ~0.65 μm - and ca. 25 times better for determining the rotation angle of the mask around the z axis - ~0.25 mrad versus ~0.01 mrad. This difference can be explained by the fact that the resolution of the Brandeis program is the convolution of the width of the distributions obtained when making many analysis of the same file (Fig. 8) and the one due to the analysis of 100 images recorded in the same conditions. For example, for the reconstruction of the x and y positions of the mask, the first width is of the order of 0.5 μm and the second one is ~0.35 μm. Added in quadrature, this gives a total resolution of ca. 0.61 μm, which is in good agreement with the observed one - ~0.65 μm, see Fig. 6. However, the resolution obtained with all three programs lies within the required precision for the in-plane alignment.

The in-plane alignment is designed to measure a displacement of the central cross-plate. So it is relevant to compare the ability of the three analysis programs to reconstruct this displacement. We have done the analysis of a sample of 2780 images recorded with the four RASNIK systems mounted on "Calypso" in June 1996 and October 1996. The number of images taken with each RASNIK varied between 10 and 100. For each of these measurements, we determine the mean of the distribution for each reconstructed parameter.

On Fig. 11, we show the distribution of the difference of the mean value reconstructed by two of the analysis programs for the x and y positions. The two upper (lower) plots show the difference between the results obtained with the NIKHEF (MPI) program and the Brandeis program when making ten analysis of each file for the x and y displacements. Again, the width of the difference distributions of ~0.9 μm shows that all three programs are equivalent.

3.3 Analysis of blurred images

We said in § 2.1 that the RASNIK length had to be adjusted in order to get sharp images. The procedure was the following: the size of the additional small spacer that was added between the spacer and the mask support was increased from 1 to ca. 16 mm (depending on the RASNIK) by step of 1 mm until the image displayed on the screen of the PC used for the acquisition was sharp. At that time - July 1996 - the only analysis program avalaible for processing the images was the NIKHEF program and it was not able to analyse blurred images. So the criteria for choosing the correct small spacer thickness was to record images that could be analysed with the NIKHEF

program. Since then, this program has been improved and now it is able to analyse the blurred images it could not process a few months earlier.

The MPI and Brandeis programs have always been able to analyse blurred images. We have compared the ability of the three programs to analyse blurred images on a sample of 390 pictures. The biggest z-range covered by these images is 9 mm.

Fig. 13 shows the same comparison between the results obtained with the three programs as the one shown in Fig. 11. Again, the two upper and lower plots show that, though the width of the difference distributions is greater for blurred images - ~1.4 μm - all three programs are equivalent.

4. Conclusions

The RASNIK system is well designed for the in-plane alignment. Its precision in determining a displacement of the central cross-plate of a MDT is less than 1 μm. It is possible that the length of each RASNIK system has to be adjusted in order to get sharp images, but we believe this is unnecessary as all the analysis programs avalaible are able to process blurred images.

A comparison between the analysis programs of Brandeis, NIKHEF and MPI shows that:
1. the C++ version of the Brandeis program is the fastest of the three;
2. all three programs are equivalent for determining the displacement of the central cross-plate;
3. all three programs are able to analyse blurred images and are equivalent too in this case.

Acknowledgements

References

[1] C. H. Daly, G. De Zorzi, P. Oberson, Mechanical and thermal tests on the BIL MDT chamber prototype "Calypso", ATLAS Internal Note MUON-NO-144, March 1996.

[2] A. Biscossa et al., The First Full-Scale Prototype of a BIL MDT Chamber for the ATLAS Muon Spectrometer, ATLAS Internal Note MUON-NO-136, January 1996.

[3] H. L. Groenstege, The coding of the mask for CCD_Rasnik, NIKHEF ETR_94-10, 1994.

[4] K. S. .Hashemi, J. Bensinger, RASNIK Image Processing with a Steepest Ascent Algorithm, ATLAS Internal Note MUON-NO-92, September 1995.

[5] S. Schael, RASMI - A Program to Analyze RASNIK Images, ATLAS Internal Note MUON-NO-172, May 1997.
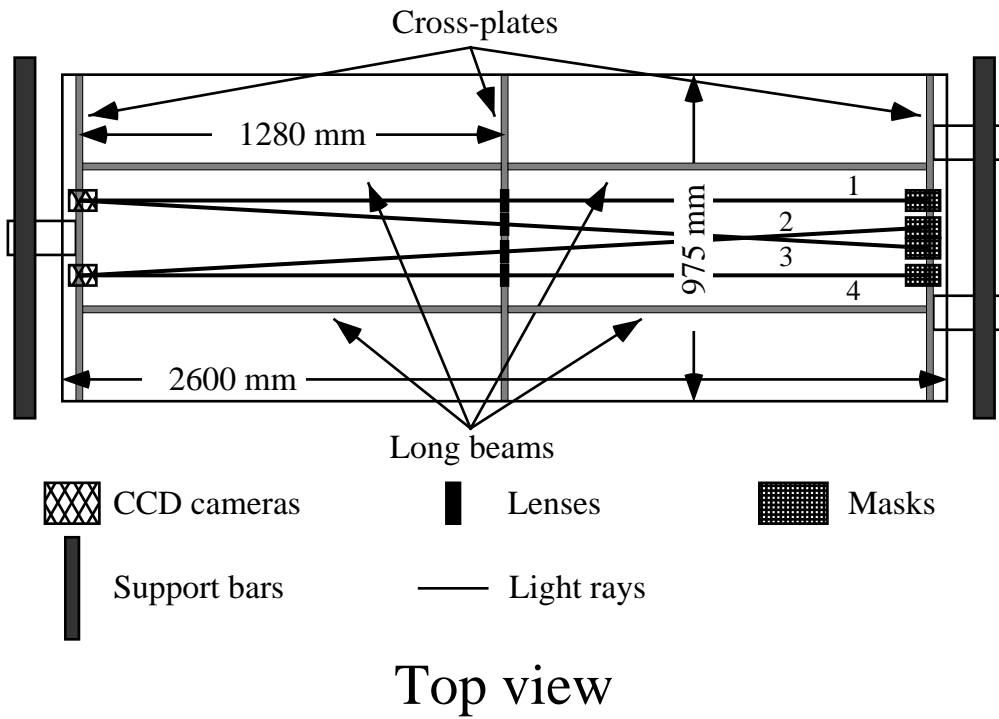
[6] H. Van de Graaf, private communication.

Top view

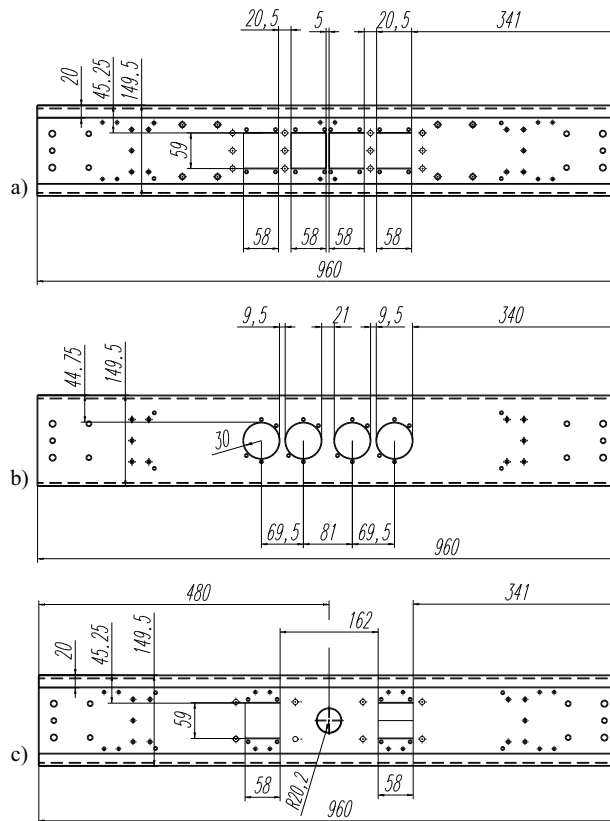*Figure 1: Set-up of the four RASNIK systems used for the in-plane alignment.*

Figure 2: Layout of the BIL MDT prototype cross-plates. The positions of the RASNIK pieces are shown.
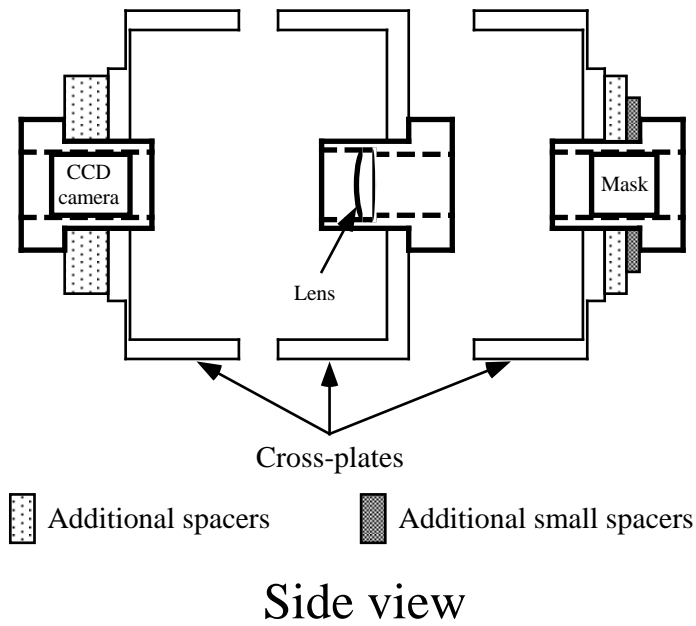
Side view

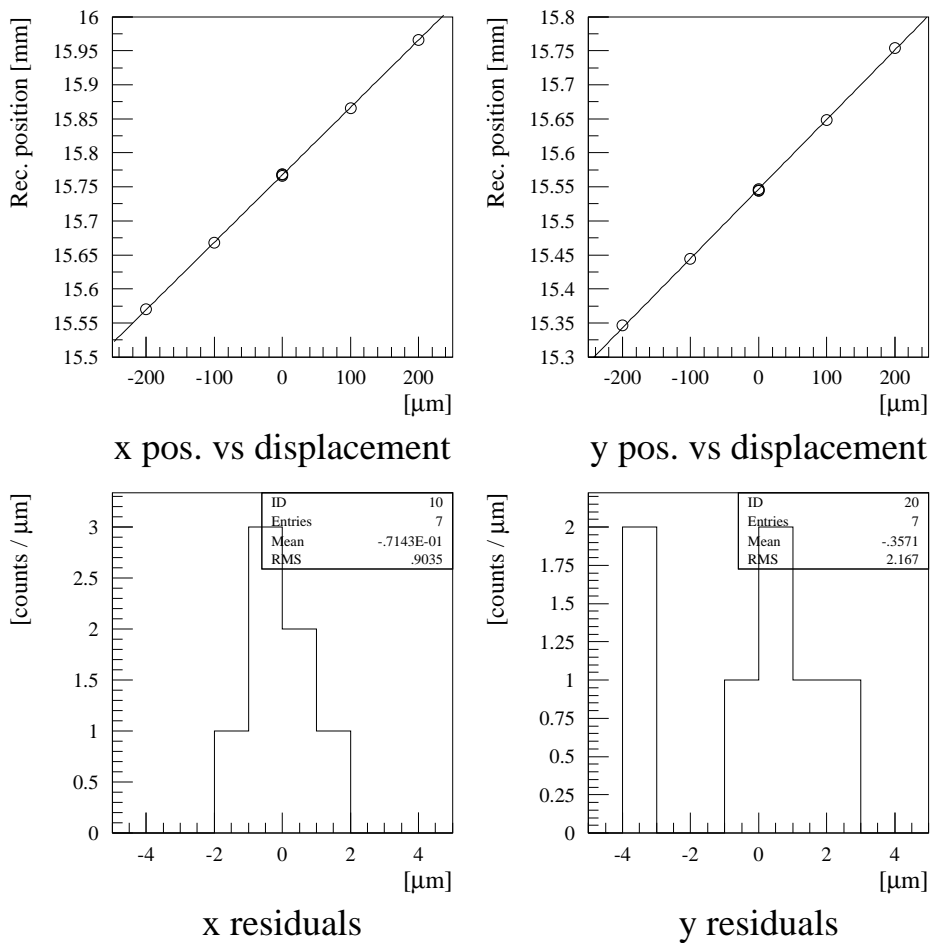*Figure 3: Cross-plates with the RASNIK supports mounted on them.*

Figure 4: Upper plots show the reconstructed position in x and y directions (perpendicular to the optical axis) versus the lens displacement when the lens is moved by steps of 100 μm. The lower plots show the distribution of the residuals fo both the x and y directions.
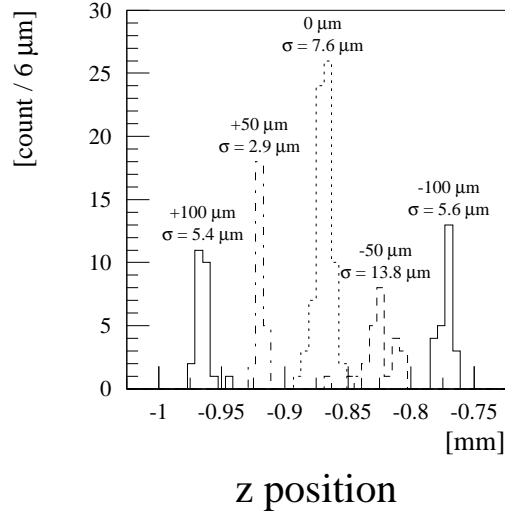
z position

Figure 5: Distribution of the reconstructed z positions (along the optical axis) when the lens is moved from -100 μm to +100 μm by steps of 50 μm.

x position

y position
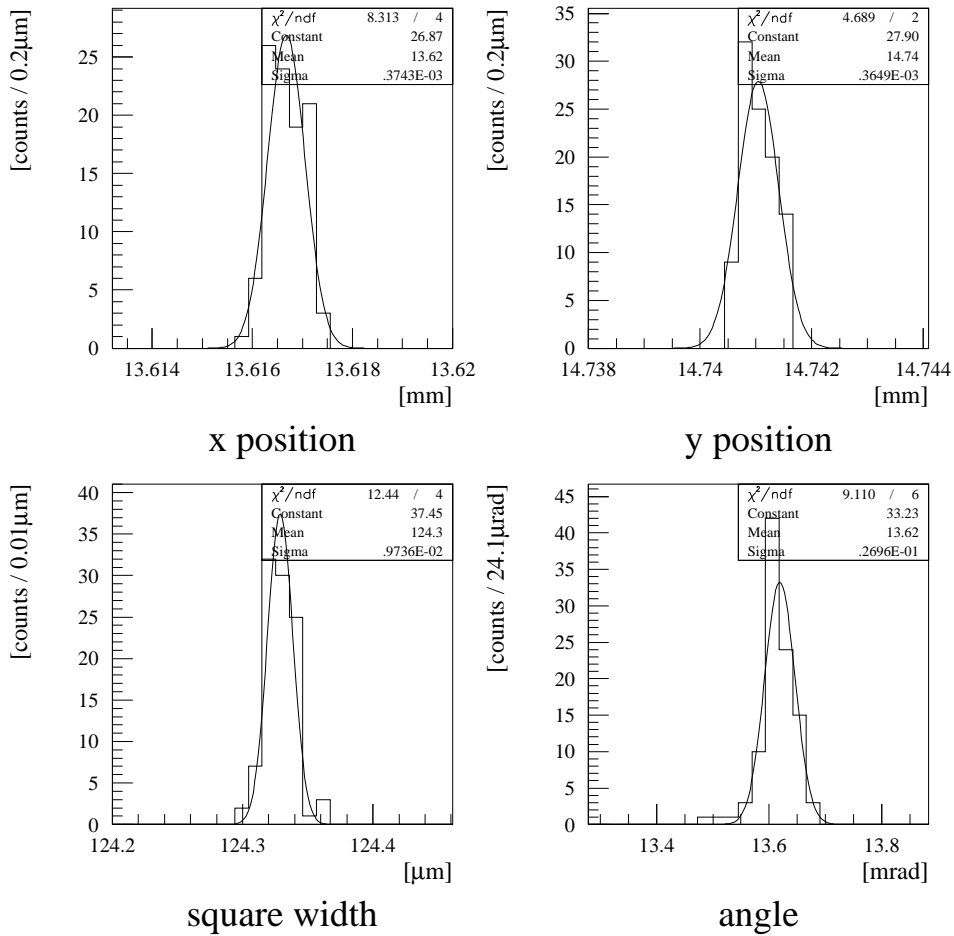
square width

angle

Figure 6: Distribution of the reconstructed x and y positions, the square width and the angle obtained with the Brandeis program. The curves are gaussian fits done on the distributions.

x position

y position

x position
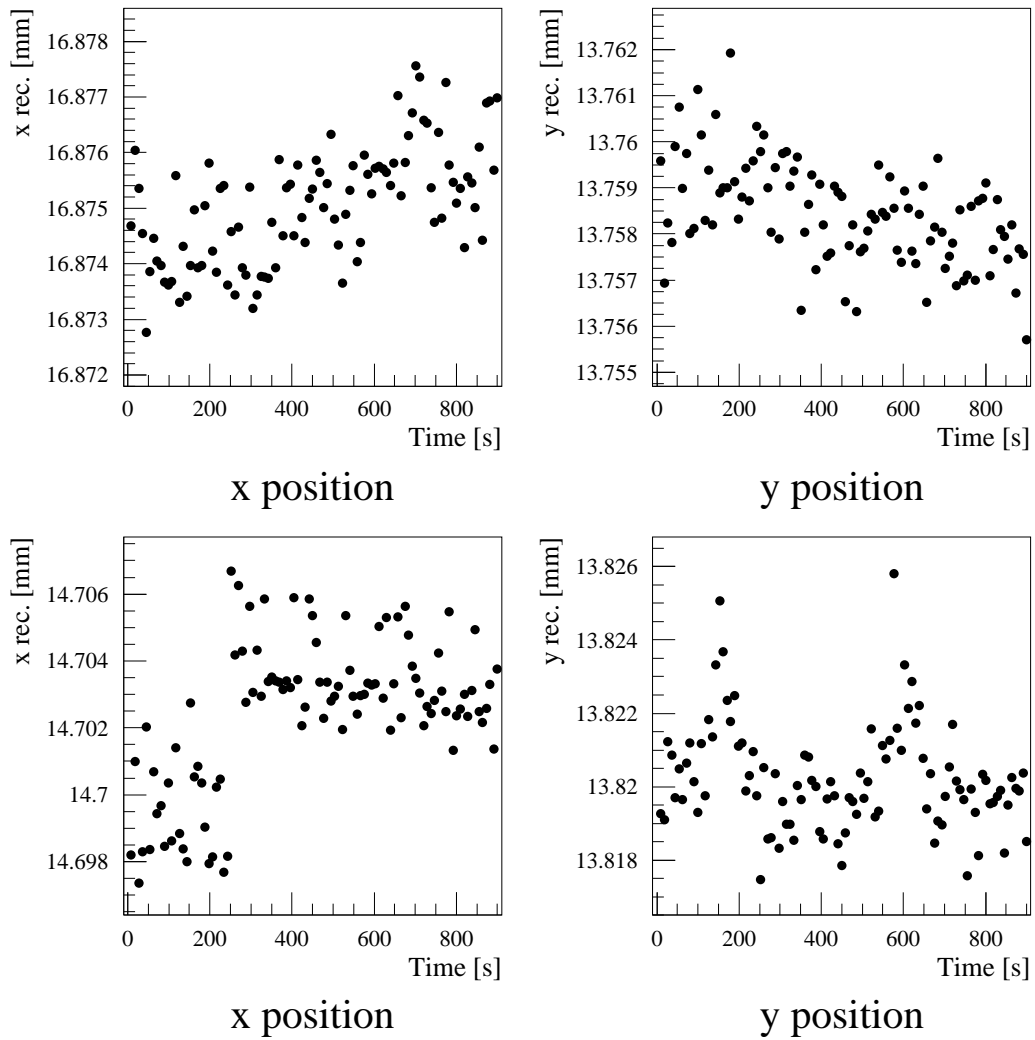
y position

Figure 7: Reconstructed x and y positions as a function of the time of recording of the picture for two RASNIK. We can see the variation of the reconstructed position with time.

11
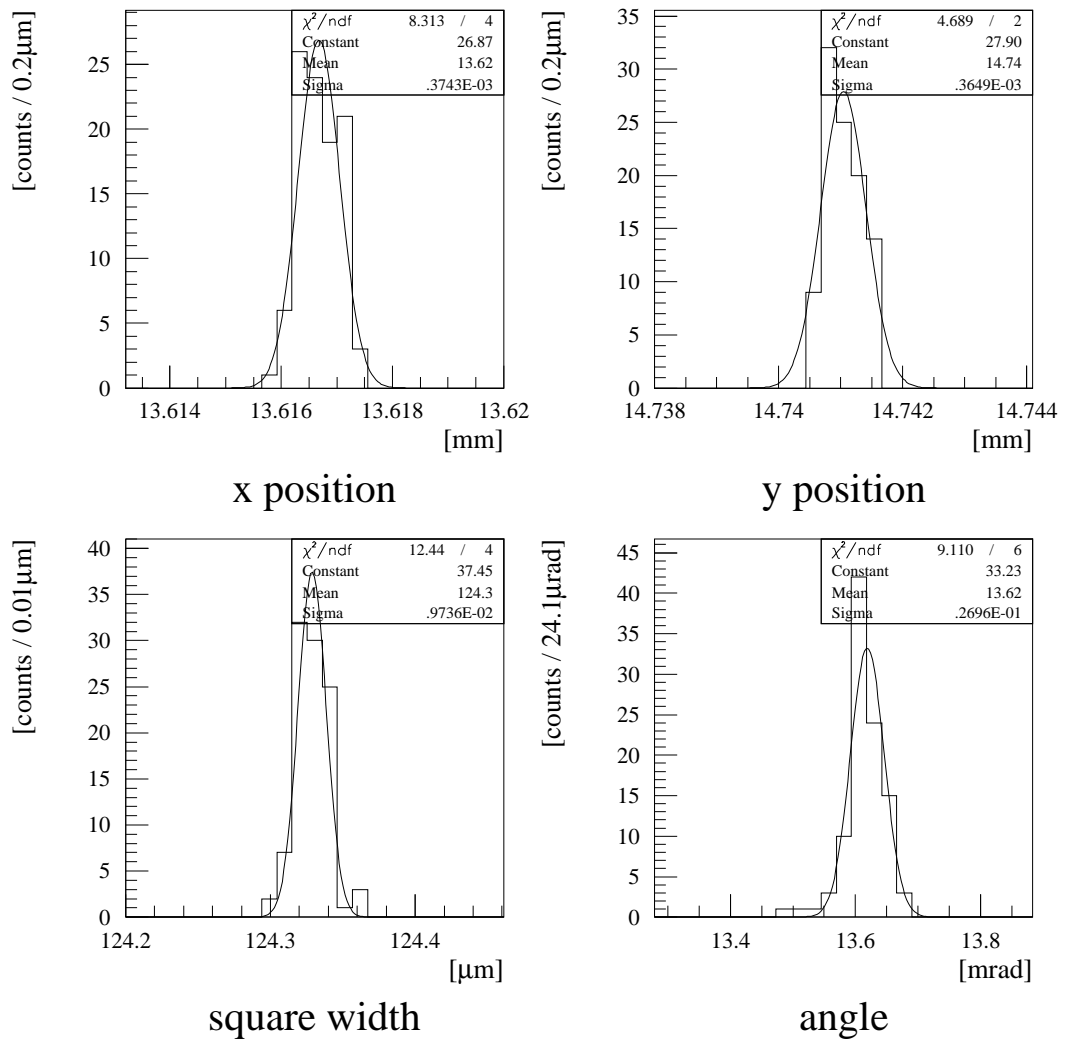
Figure 8: Distribution of the reconstructed x and y positions, the square width and the rotation angle around the z axis for 100 analysis of one file.
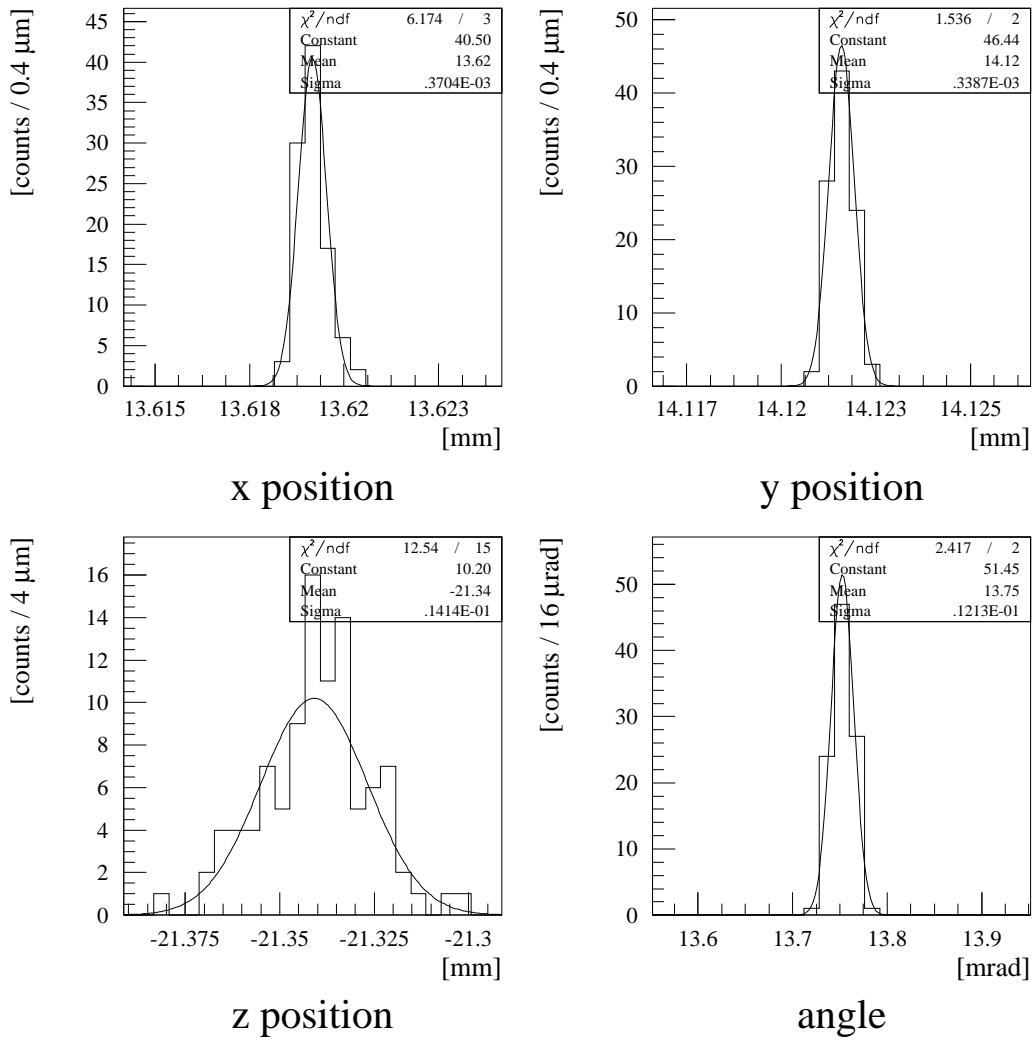
Figure 9: Distribution of the reconstructed x, y and z positions and the angle obtained with the NIKHEF program. The curves are gaussian fits done on the distributions.
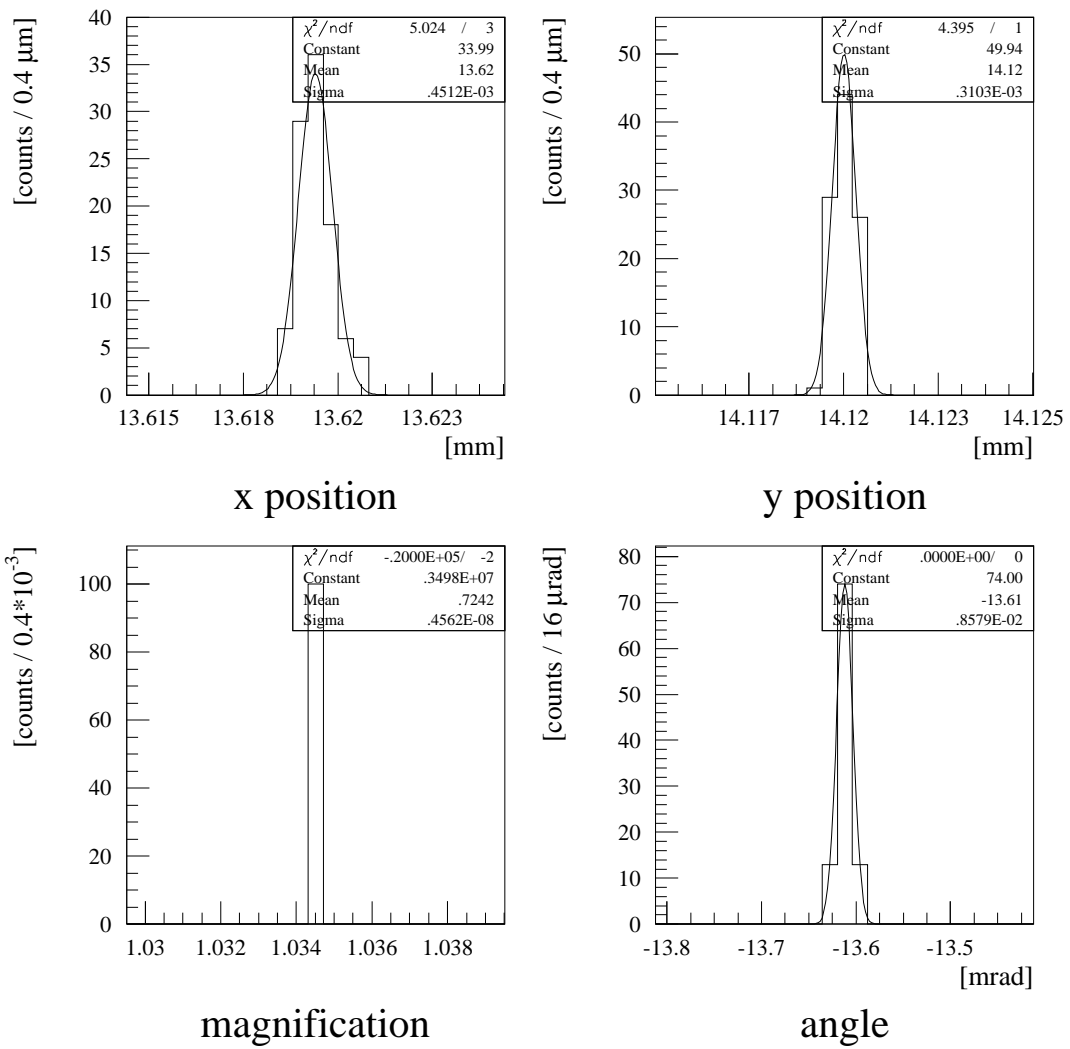
Figure 10: Distribution of the reconstructed x and y positions, the magnification and the angle obtained with the MPI program. The curves are gaussian fits done on the distributions.
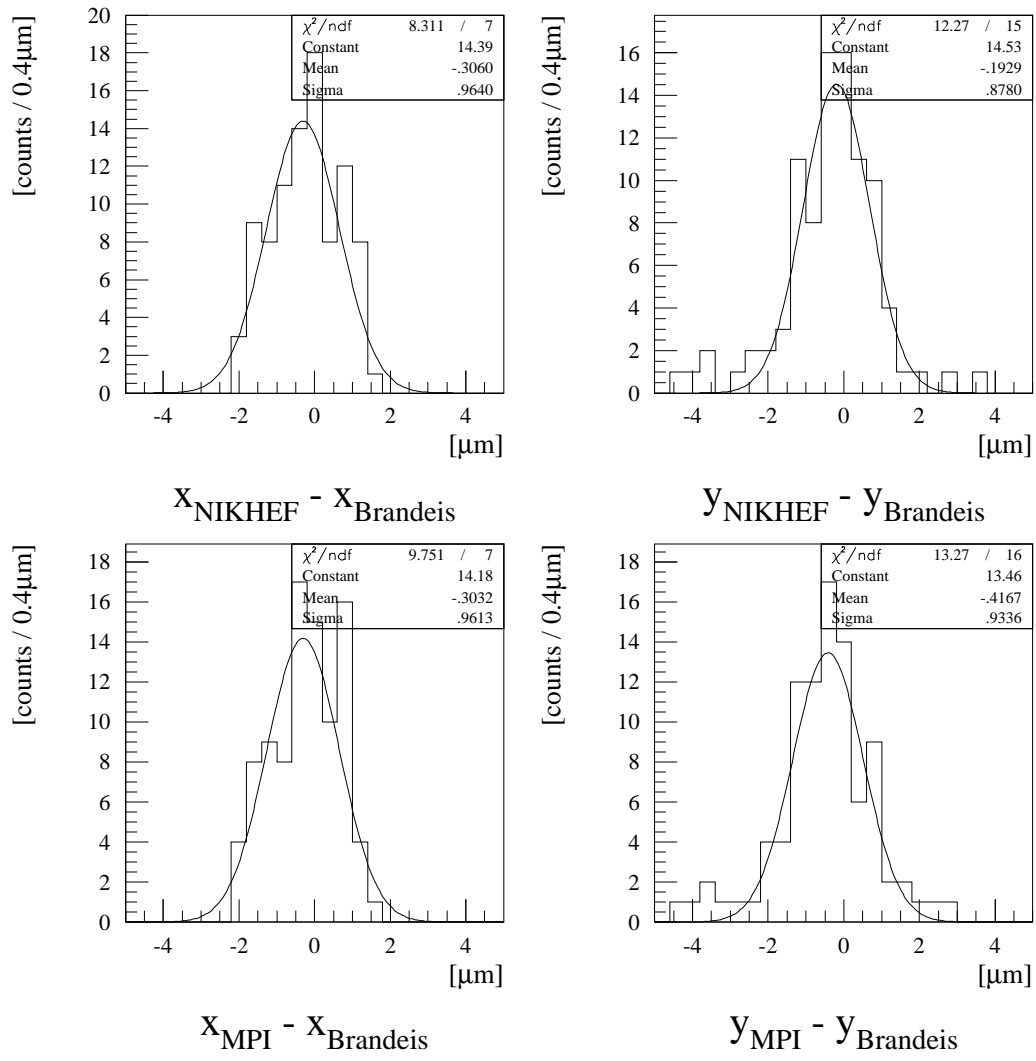
Figure 11: Difference between the x and y displacement reconstructed by the NIKHEF program (upper plots) and the MPI program (lower plots) and the Brandeis program for sharp images.
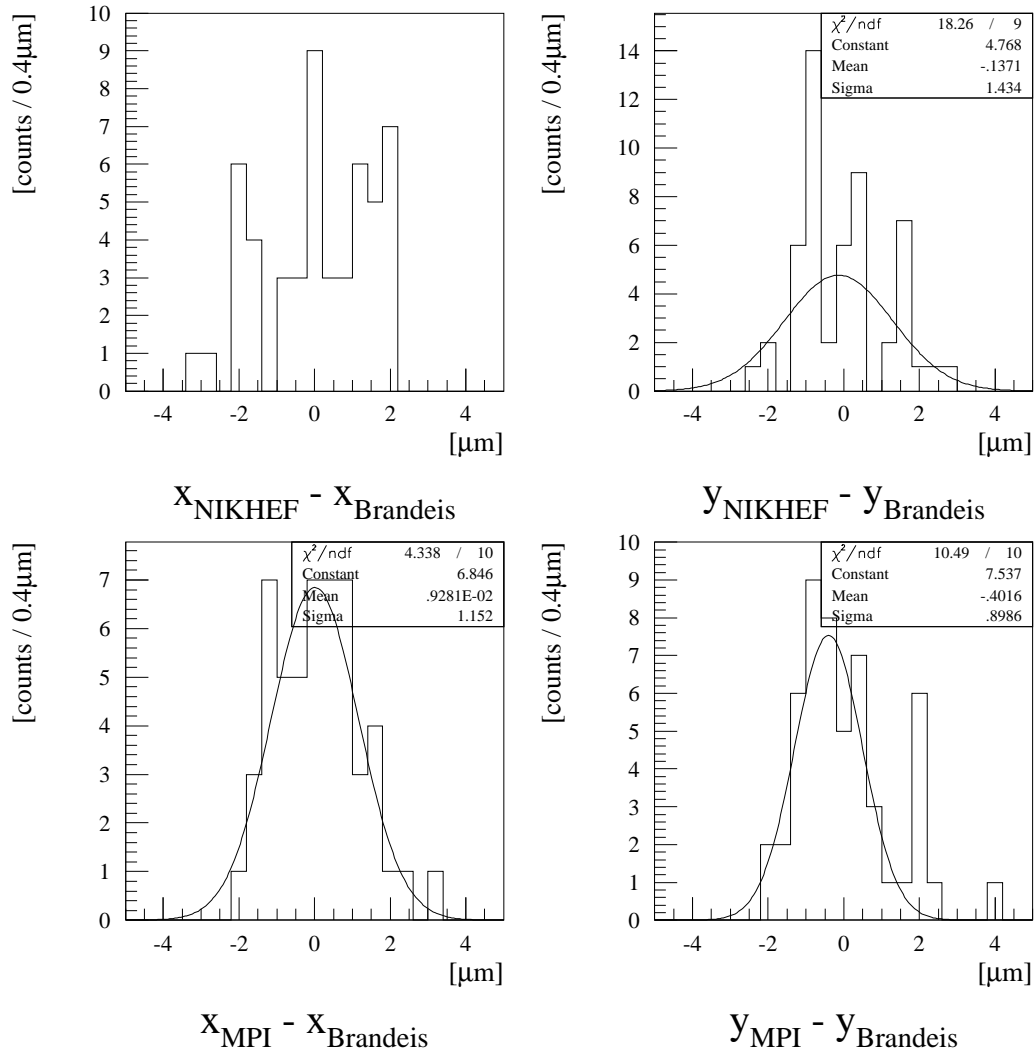
Figure 12: Difference between the x and y displacement reconstructed by the NIKHEF program (upper plots) and the MPI program (lower plots) and the Brandeis program for blurred images.