Rijksuniversiteit Groningen

Bachelor Project

Physics

The Analysis of Slit Collimator Alignment for Proton Beam Experiments

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Contents

List of Abbreviations

BIM Beam Ionisation Monitor

FWHM Full Width at Half Maximum

KVI-CART KVI-Center for Advanced Radiation Technology

MU   Monitor Units

Abstract

In narrow field proton dosimetry, a symmetrical and predictable dose profile is desired. In achieving this symmetry, using a LANEX/CCD camera and a paddle detector setup, a slit collimator was aligned with the direction of a 150 MeV proton beam. With the LANEX/CCD camera setup, a light image was measured of the proton field provided by the slit for various orientations of the slit collimator. Using the paddle detector the total number of protons passing through the slit collimator was measured. To assess the alignment a method was developed in Matlab using the FWHM of the dose profile as a function of the angle as a symmetry criterion. Gaussian's were fitted through the middle of these images and the FWHM was determined. A local minimum, at an angle of $0.10^o \pm 0.5^o$, in the FWHM, was found in the LANEX/CCD setup. In the paddle detector setup a maximum in the number of protons passing through the slit collimator, at an angle of $0.1022^o \pm 0.0145^o$, was found. Two studies were done at KVI-CART in 2001[1] and 2019[2] in which different LANEX/CCD setups were used. From the results of our study, the influence of the LANEX/CCD setup on the results of these two studies could be ruled out.

1 Introduction

In multiple disciplines, narrow field proton radiation is used. For example, radio-surgery,[3] macular degeneration[4] and sensor calibration. In narrow field irradiation, a recurring problem is high uncertainty in the dosimetry. The measured signal $M(x)$ of the experiments is a convolution of the lateral dose-response, $K(x)$, and the undisturbed dose distribution $D(x)$. By knowing the lateral dose-response and the measured signal of the beam, the received dose in a patient or device can be determined by deconvolution. Because of the small spot sizes of pencil beams, the internal structure of the detector becomes more important. This internal structure leads to a perturbation of the dose response of the dose detector and can be described by the lateral response function. To determine the lateral response functions of detectors the dose-profile needs to be known. The goal of this study is to develop a Matlab program to align a slit collimator to create a symmetrical and predictable dose-profile. For the alignment, a slit has to be parallel and in the middle of the beam, also called the isocentre. As the angle of the slit deviates from the isocentre an increase in the Full Width at Half Maximum (FWHM) was expected. The data used for the Matlab development is from an earlier experiment done at the Kern Versneller Instituut (KVI-CART), later referred as 'main data set'.[2] To determine the influence of the detection method, LANEX scintillation screen and the camera, used in the main data set, an experiment was conducted. This experiment took place at the KVI-CART in Groningen. A 2 by 50 mm slit collimator was used to provide the narrow dose profile desired. The 150 MeV protons were obtained from the cyclotron. Images were taken from two different scintillator screens and two cameras were used. In both cases, the FWHM was determined as a function of the angle of the slit collimator. The influence of the different LANEX screens and cameras was deduced from the measured FWHM of the dose profiles obtained in the situation with the aligned slit collimator. In this report, the methodology is given followed by the results of the experiment. Lastly, a discussion and conclusion are given.

2   Methods

For the alignment of the slit collimator the isocentre of the beam needed to be found and a method of the slit collimator alignment developed. Using Matlab and the main data set, a method of finding the isocentre and the alignment is described in this section. A short description will be given on the acquirement of the main data set. Thereafter the experimental setup followed by the experimental approach is discussed.

2.1   Matlab code and main data set

How the main data set is acquired and the method of the alignment of the slit collimator is covered in this section. The main data set was acquired in an experiment at KVI in 2019.[2] One of the goals of this experiment was to recreate the results from an experiment conducted at KVI in 2001.[1] The setup used in this experiment is comparable to the setup described in section 1. The experimental approach, however, is different. In the 2001 and 2019 experiment, the old camera/LANEX fine and the new camera/LANEX regular, was used, respectively. In this study the influence of the results of these configurations were tested by using both LANEX screens and cameras. In the experiments the angle of the slit collimator, that sits on a horizontal translational and rotational stage, was altered. These rotational data points from the 2019 experiment were used in this study for the development of the Matlab code. In developing the method for the alignment of the slit, Matlab version R2017b 9.3 was used[1]. For the horizontal alignment of the slit, the 50 mm circular field collimator, that was placed in front of the slit collimator, was used. Assuming that this collimator was positioned at the isocentre of the beam, the middle the of the field collimator was determined. For the rotational alignment, the FWHM was used as a indication of the deviation of the isocentre of the slit relative to the beam. The FWHM is a indication of the spread of a Gaussian curve and is defined as FWHM $= 2\sqrt{2\ln 2}\sigma$ were σ is the standard deviation. In the following subsections the details of the code are covered. The initialization, importing of the data and finally the analysis[2].

2.1.1   Initialization

In the analysis of the data, multiple functions were defined. These functions have multiple parameters that can be changed. To pass these parameters to the functions, conventionally global variables are used. But these global variables are not recommended as they can interfere with internal variables of Matlab itself. Therefore

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[1]It is recommended to use the same version of Matlab when running the code
[2]In appendix A quick start manual is included

structures were used instead of global variables. Structures can contain multiple variables at once. This is convenient because then only one variable needs to be passed to the function to access all parameters. These parameters were stored in the structure called 'this'. To access the parameters in the structure dot notation is used. For example, if we want to access the parameter 'filter_dimension' in the structure 'this', one would write 'this.filter_dimension'. In this structure seven parameters can be changed by the user for optimal results from the analysis. In table 1 the description of all the parameters can be found.

Table 1: The parameters used and their description, their description will become more clear in the following section

Parameter	Description
remove_background	When true removes background from the slit and the collimator images
use_colli_filter	When true use the 2d median filter over the collimator images
use_slit_filter	When true use the 2d median filter over the slit images
filter_dimension	Set 2d filter dimension in form: [x,y]
edge_procent	To isolate the slits from the noise a percentage of the maximum is used, value from 0 to 1
alignment_index	In the conversion from pixels to centimeters a scan is made at the location given in form: [x,y]
deviation_hor_scan	Sets the deviation of the horizontal scan for the two additional Gaussian fits

2.1.2   Importing the data

In the analysis four categories, were one category is optional, of images are necessary. These four categories consisted of a background, a collimator image, the slit image and the optional alignment image. The images are shown in figures 1-4.
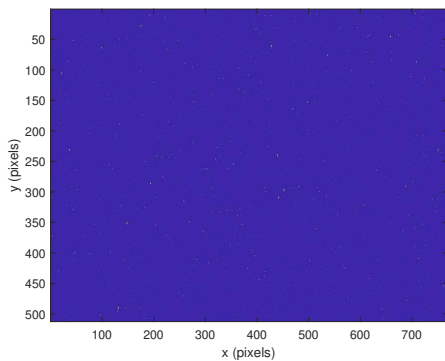

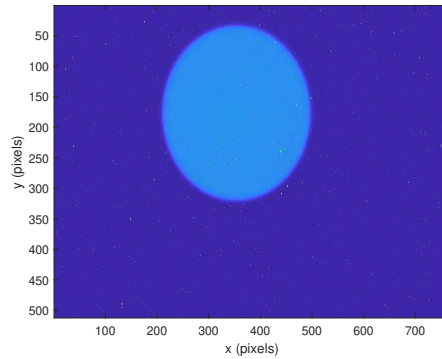**Figure 1:** The background image including the background noise.

Figure 2: The unfiltered collimator image. From the scaling of the x and y axis the collimator does not look round, but in reality it is.
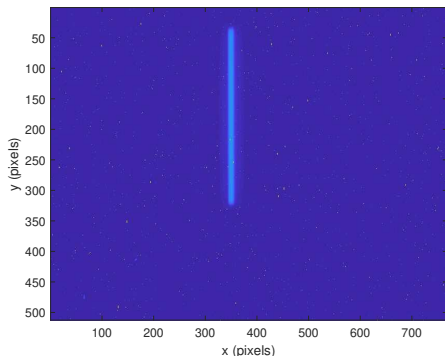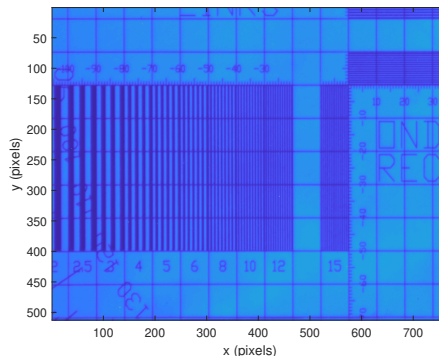
Figure 3: The unfiltered slit image.

Figure 4: The optional alignment image.

The background is a image of the 'background noise' present in all images except the alignment image. This image is therefore taken with the proton beam turned off and is shown in figure 1. In figure 2 an image of the unfiltered collimator is shown, the slit collimator is not present in the setup as this image is taken. When the slit collimator is placed in the setup, images of the slit for different angles can be taken. Multiple images were taken in this category for different angles of the slit, a example of such image is shown in figure 3. Lastly, a alignment image is place at the position of the LANEX screen. This alignment image, shown in figure 4, is not to confuse with the alignment of the slit. This image is taken for the conversion of pixels to centimeters.

For each category a function was written. In these functions the build-in command 'uigetfile' was used. When called, a selection window will pop up. When a file is selected the name and destination of the file are stored, only in the 'load_slits' function multiple files can be selected. Using this information the images are ready to be loaded. The images are intensity arrays of the pixel intensity stored as a 'fit' file. Therefore, the command 'fitsread' was used to import the images, and a matrix the size of the image is created containing the pixel intensity values. These set of operations are called in all of the four image category functions. From here, there are some differences in the functions. As shown in the figures 2 and 3 the background noise is still present. Therefore in these functions the background was pixel-by-pixel subtracted, if the parameter 'remove_background' is true, from all slit images and the collimator image.

2.1.3 The analysis

In finding the isocentre of the slits a two-way method was used. First, the collimator location is used for the horizontal alignment and secondly, the FWHM is used for the rotational alignment. The FWHM was chosen as one would expect that the FWHM would increase as the proton spread would increase as the angle of the slit would

increase. Before these two methods were applied some noise-cancelling was done. As seen in figures 2 and 3 there is some 'salt and pepper' noise in the image.[5] Even after the subtraction of the background some of the noise is present. Therefore a 2d median filter was used. For every pixel in the image, the neighbourhood of a $N \times M$ window, the value of that centre pixel was set to the median of the window. As mentioned in section 2.1.1 this window dimension is set in the variable 'filter_dimension'.
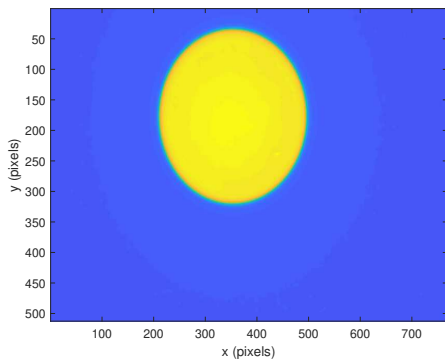

Figure 5: The filtered collimator image with a filter dimension of 7×7
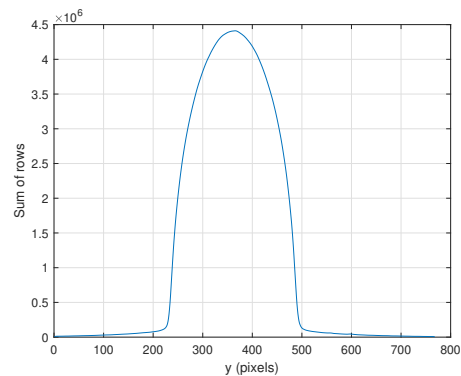

Figure 6: The sum of the rows for finding the y centre of the collimator.

As seen in figure 5 the 'salt and pepper' noise is removed. The filter was also applied on all the slits. In finding the centre location the shape of the field collimator was taken as an advantage. When the image is projected onto the x and y axis a maximum would appear. This projecting was done using the sum of the rows for the y axis and the sum of the columns for the x axis. As one can see in figure 6 the centre is found by finding the index of the maximum. This was done for the x and y axis to get the x and y value for the middle of the collimator.
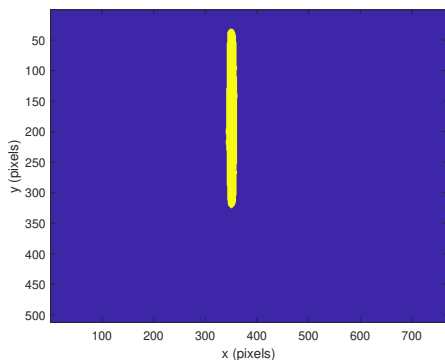

Figure 7: All values above 0.3*maximum value are in yellow

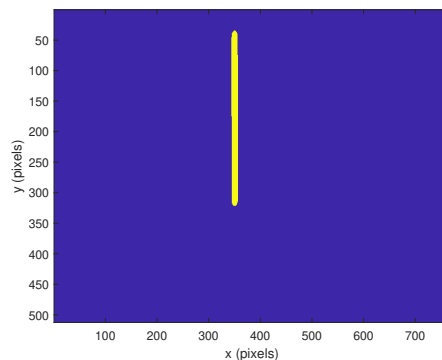**Figure 8:** All values above 0.5* maximum value are in yellow

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This projecting method could not be used for the slits as the horizontal profile did not had enough contrast. Therefore the slit edges would be found first and the middle would be derived from that. In finding the edges of the slit, the slit needed to be isolated first from any noise that could be present in the image. For this isolation a new parameter, 'edge_procent', was introduced. This parameter was multiplied by the maximum value in the image. All the pixel values in the image that were greater and smaller were set to 1 and 0, respectively. In figures 7 and 8 these logical images for different value of 'edge_procent' are shown. It is obvious that the edges of the slit are more clear in figure 8. For the optimal results a small experiment was done to find the best combination parameters. In the experiment of 2001 a 3×3 2d median filter was used.[1] From literature, a 7×7 filter was used without loss of resolution.[6] The best results were achieved with the edge_procent set to a value of 0.5 and the filter dimension set to 7×7.

When the slits were converted to logical images, vertical and horizontal scans were made over the x and y axis, respectively. While these scans were made, the scans were checked when a value was equal to one in the scan. Then the index of the first value and the index of last were appended in different arrays. In figure 9 maximum of the indices of the vertical scans are plotted. By taking the maximum of this array the index of the top edge of the slit is found. This process was repeated for the horizontal axis.
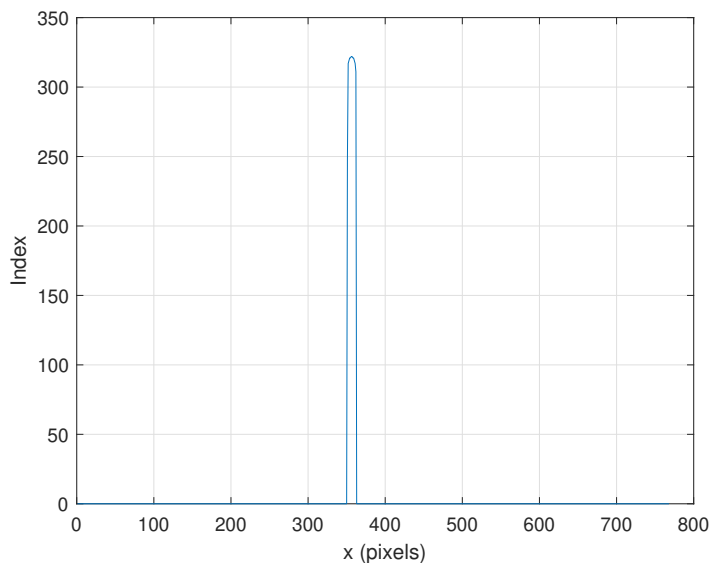

Figure 9: The maximum of the indices of the verticals scans.

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Until now the pixel size is unknown. Using the alignment image, the pixel size was determined. This was done by making a horizontal and vertical scan at the locations given in the parameter 'alignment_index'. The mean and the standard deviation of these scans were then calculated. A threshold was introduced equal to the mean minus the standard deviation. All values of the array above this threshold were set to 1 and all the values below this threshold were set to 0, see figure 10.
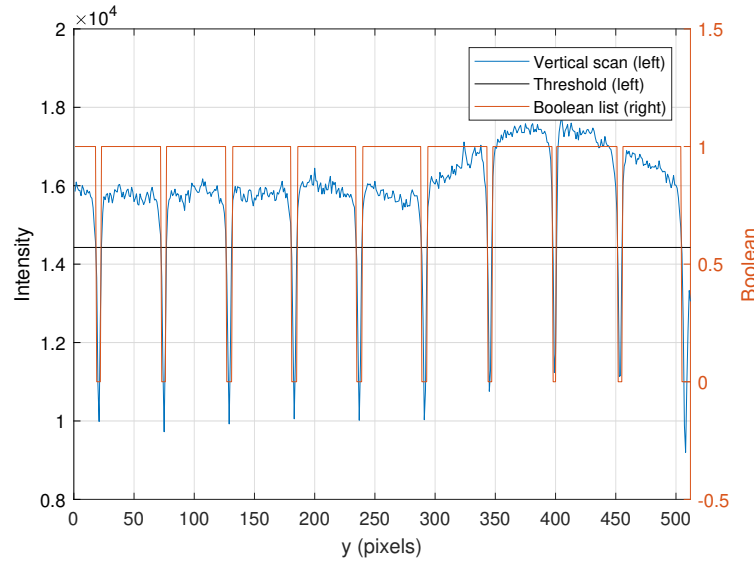

Figure 10: The vertical scan, at the x value of 500, of the alignment image including the threshold.

Now the maximum distance of the blocks were derived. When there is a other feature in the image this would cause the boolean blocks to be smaller and therefore the maximum distance was chosen. As one block would be equal to 53 pixels, the pixel width is equal to 0.188 mm, this applies to the new camera as used in the 2019 experiments.

As the goal is to compare the FWHM against the angle, the angles of the slit needed to be extracted from the image names. Because the file names of the images are all in the same format, Angle_Position', the rotational and positional data did not have to be hard coded, but could be extracted from the file name itself.

In the final analysis the FWHM of the slit is determined. To be sure that the slit was aligned in the rotational z axis three fits were made. In figure 11 the three scans are shown. These scans are determined by the middle of the slit and the parameter $\pm$ 'deviation_hor_scan'.
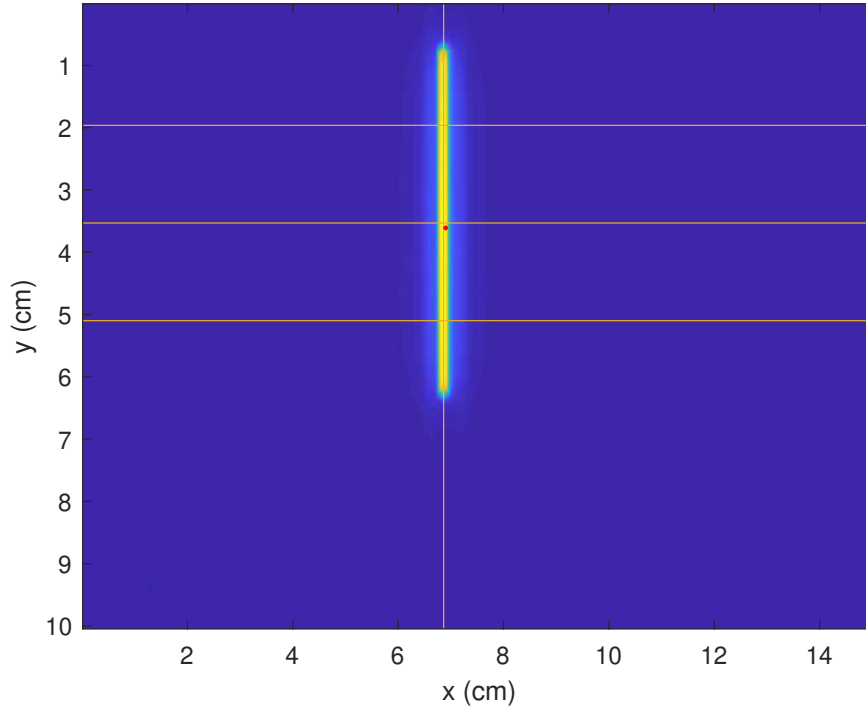
Figure 11: The three horizontal fits. The red dot corresponds to the middle position of the field collimator.

2.2   Experimental setup

In the experimental setup, a 150 MeV proton beam was used from the KVI cyclotron. The proton beam was directed at a 1.44 mm homogeneous lead scatter foil. This creates a Gaussian proton scatter pattern after the foil by the Coulomb interactions between the protons of the beam with the lead atoms..[7] To approximate a flat field the 50 mm field collimator was placed at approximately 3 m from the scatter foil. The slit collimator was placed directly after the field collimator on a translational and rotational stage. The dimensions of the slit were 100 mm by 2 mm in length and width, respectively. After the protons exited the slit collimator they hit the LANEX scintillation screen at 16 cm behind the slit collimator. In the LANEX screen, protons deposit part of their energy which is converted in to scintillation photons. These photons were reflected of a 45° degrees off axis mirror and then registered by a CCD camera. In figure 12 the experimental setup is shown. In the experiment, two different LANEX screens and two different CCD cameras were used. This was done to examine the effect of the different LANEX screens and the cameras on the results. After the experiment with the LANEX screens and the cameras were done, a paddle was used. The paddle is a plastic scintillator that converts the light created by the scintillation, to a voltage pulse by a photomultiplier. Every pulse

represents one proton passing through the paddle detector. Therefore the number of the protons passing through the paddle is measured for a certain amount of time compared to the protons that pass through the BIM (Beam Ionisation Monitor). For each rotation a equal number of Monitor Units (MU) are given and the number of protons is measured.
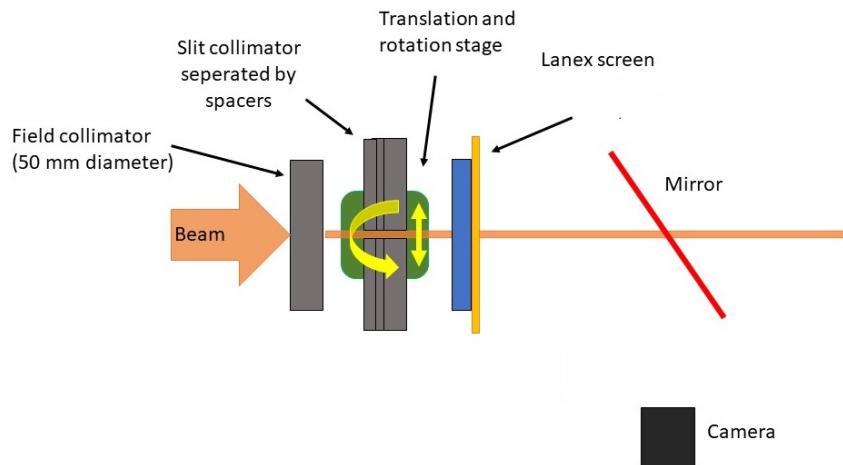

Figure 12: A schematic of the experimental setup

2.3   Experimental Method

After the experimental setup was build and working the experiment was ready for operation. The experiment was done in four steps, see table 2. Before every step an image was taken while the beam was off for a background image. Thereafter a image was taken of the field collimator without the slit in place. Then the slit was set in position and the alignment could begin. First, a rough alignment was done using lasers. An image was taken and loaded into the Matlab code to see the horizontal alignment of the slit relative to the field collimator. When the slit was centered the experiment could begin. In step 1 of the experiment the angle was changed from -1° to $+1^o$ in steps of 0.1^o. Four additional images were taken with the angle $\pm 1^o$ to $\pm 2^o$ in steps of 0.5^o. In steps 2, 3 and 4, three images were taken with the angles from -0.1^o to 0.1^o in steps of 0.1^o.

Table 2: The equipment used in steps of the experiment

	Fine LANEX	Regular LANEX
New Camera	Step 1	Step 2
Old Camera	Step 4	Step 3

After the experiments with the LANEX screens and cameras were done, the paddle was installed at the position of the LANEX screen. Using a Labview program, 5 measurements of 3 seconds of exposure were done for the same angles as in step 1 of the experiment. In appendix B the experimental notes can be found.

3   Results

In this section the results of the experiment and the Monte Carlo simulations are presented and compared. The simulation results are from a Monte Carlo simulation with the same geometry as in the experiments.[8] As the experiment consisted of two separate parts, the alignment and the LANEX and camera influence, these two parts are given separately in the following sections.

3.1   The Alignment

Before the influence of the LANEX screens and the cameras could be examined, the slit needed to be aligned. This was done using the step 1 setup given in section 2.3. As mentioned in section 2, the horizontal alignment was achieved by aligning the slit collimator to the middle of the field collimator. This was done using the red dot that is shown in figure 11. When the best horizontal position was found, the angle of the slit collimator was altered. In figure 13 the horizontal scan through the middles are shown for different angles.
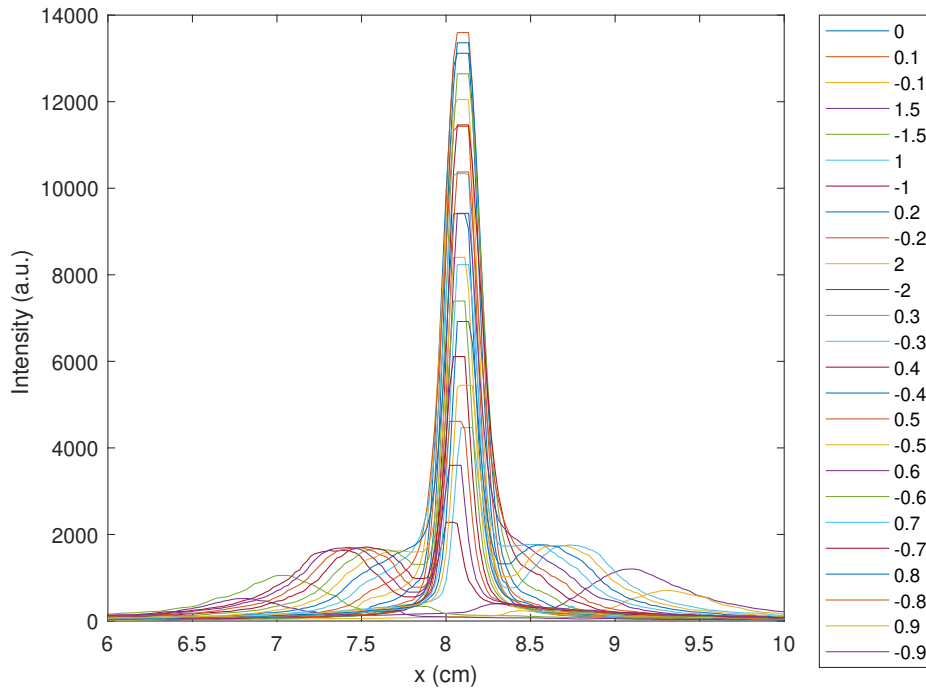

Figure 13: The horizontal profiles trough the middle of the slits at different angles. Note that only the positive angles are shown for clarity.

As one can see the highest maximum is at a angle of 0.1^o. Also can be seen that, as

the angle increases, a second maximum is created and the primary maximum goes down. This second maximum looks like it is created at a angle of 0.7^o. At the high angles, 1.5^o and 2°, the primary maximum is lower than the secondary maximum. In determining the FWHM's, Gaussian's were fitted to the scans. These Gaussian fits are shown in figure 14.
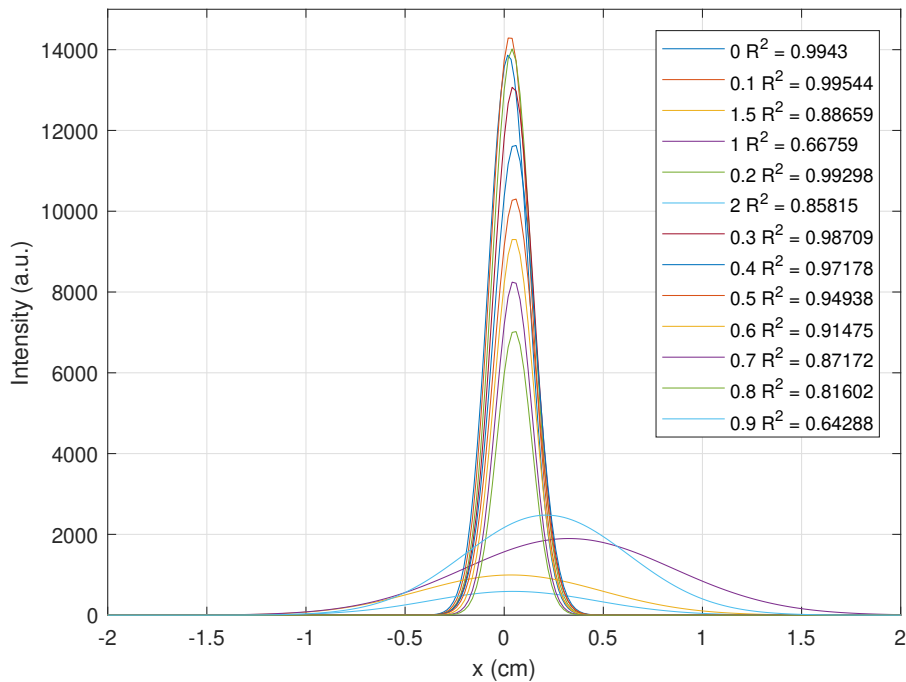

Figure 14: The corresponding fits of the horizontal profiles through the middle of the slits at different angles and their R^2 values are given in the legend. Only the positive angles are given.

Just as in figure 13 the highest maximum is at the angle 0.1 and the Gaussian fits best to the data based on the R^2 value. As the second maximum is developing at a angle of 0.7 the R^2 value drops below 0.9. This makes sense as the second maximum is causing the profiles to look less and less like a Gaussian. Also the width of the Gaussian's increase as the the angle increases. This width is indicated by the FWHM of the curves.

In figure 15 the mean of the three Gaussian's fitted, as seen in figure 11, against the angle of the slit collimator. Also the FWHM of the simulated profiles are presented in the figure.

In the figure the highest value of the FWHM is at $\pm 2^o$. But looking at the error bars the standard deviation of the FWHM of the three Gaussian's are also the highest. This can mean that the slit is not homogeneous in the y-axis. The minimum of the FWHM is hard to see in this figure, therefore in figure 16 a zoomed in version is given on the small angles.

A local minimum is seen. This local minimum is located at the angle 0.1^o. But from the figure the uncertainty is obtained and equal to $\pm 0.5^o$. As the angle deviates from the local minimum the standard deviation increases and is at maximum when the FWHM is at a secondary maximum.
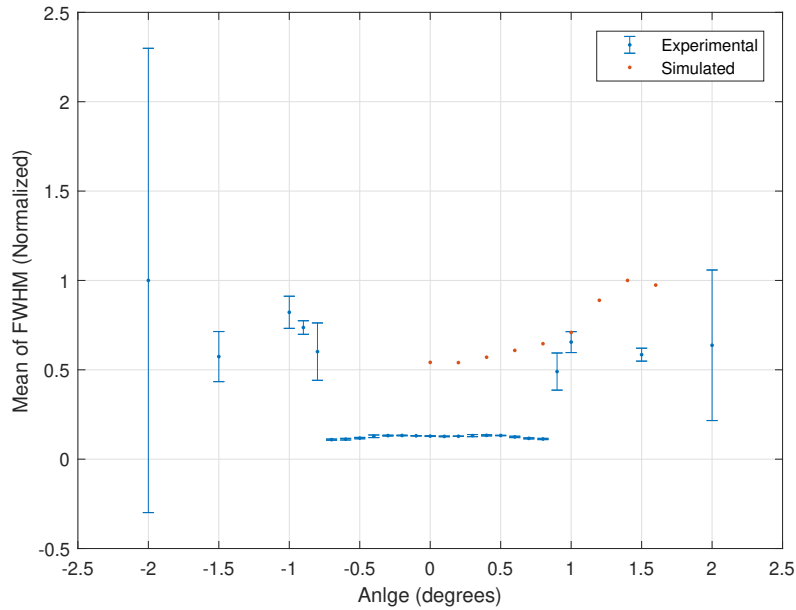

Figure 15: From the three fits, the mean of the FWHM of the fits were taken against the angle for the same translational location. The error bars are $\pm 3\times$ the standard deviation of the three FWHM's. The simulated results are from the Monte Carlo simulation[8]
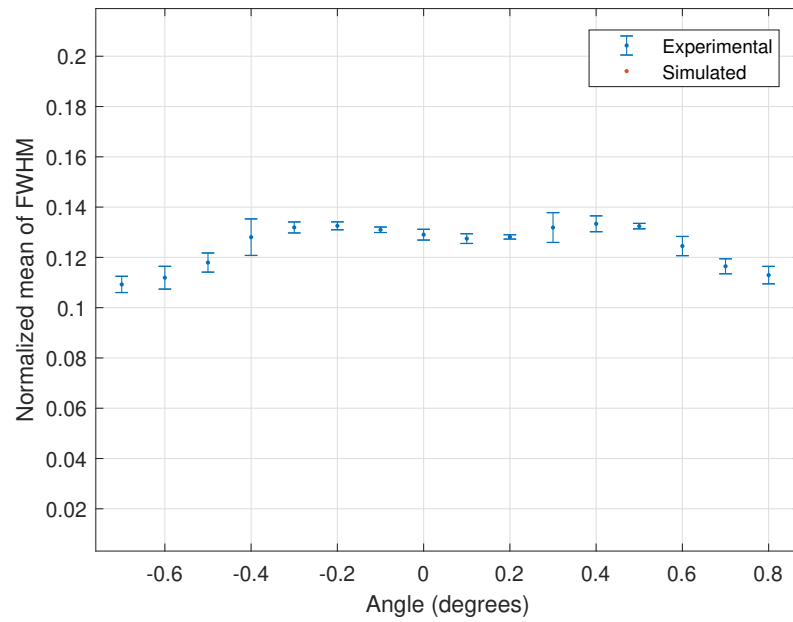
Figure 16: The zoomed in version of figure 15 for the small angles.
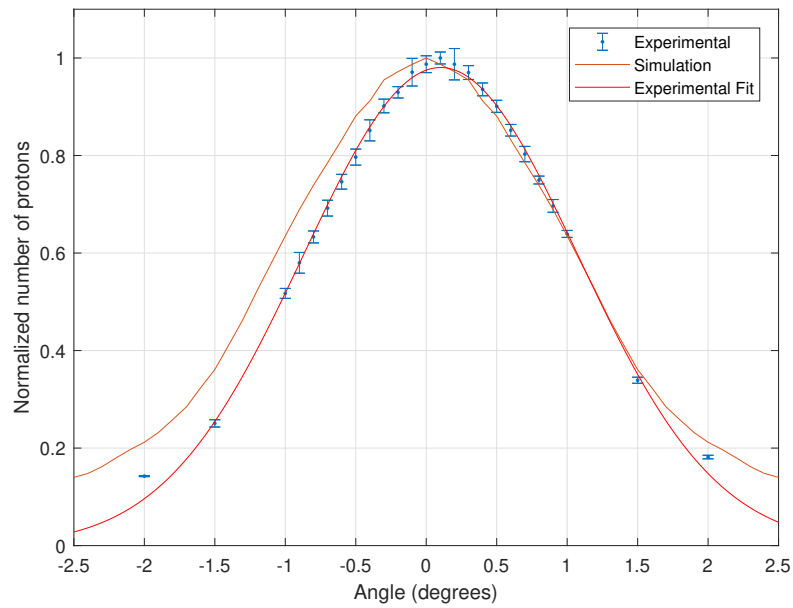

Figure 17: The experimental and simulated values of the paddle, the error bars are $\pm 3\times$ the standard deviation.

For the paddle alignment analysis the results are given in figure 17. Where the mean of the number of protons of five, 3 second measurements are given and normalized. The experimental maximum is found at 0.1^o. As the middle of the slit collimator is already known in the simulation, the maximum is at 0°. Furthermore the shape of the simulation look is a good approximation of the experimental values. In the figure a Gaussian is fitted to the experimental data. The maximum of this Gaussian is at an angle of 0.1022^o with an uncertainty of $\pm0.0145^o$.

3.2   LANEX and Camera comparison

In the LANEX and camera analysis the best alignment was used at 0.1^o. Now the steps from section 2.3 could be compared. In figure 18 the horizontal scans of the four steps are shown. What stands out is that the values overlay each other and the shape is the same as the LANEX is altered. Gaussian's were fitted to these scans and are shown in figure 19. The mean of the FWHM's of these Gaussian's is 0.2447 with a standard deviation of 0.0051.
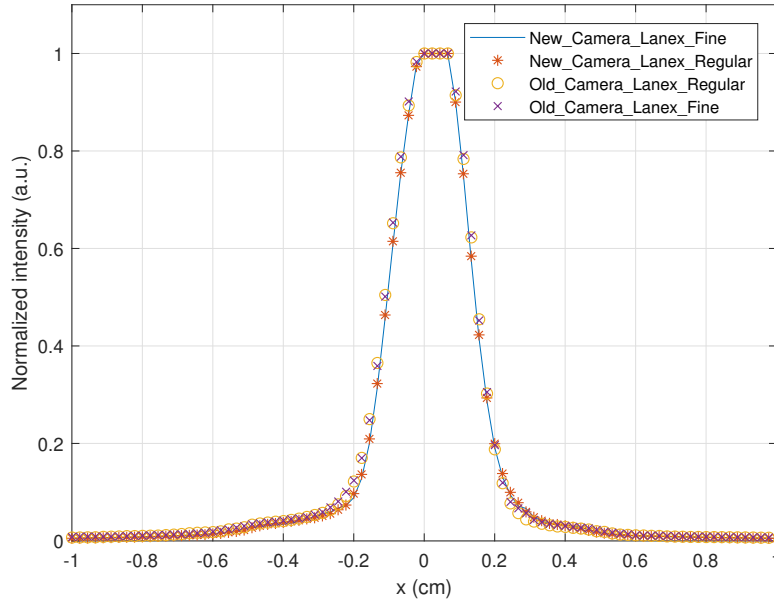

Figure 18: The normalized intensity comparison of the LANEX screens and the camera's. The middle of the slits are all centred at
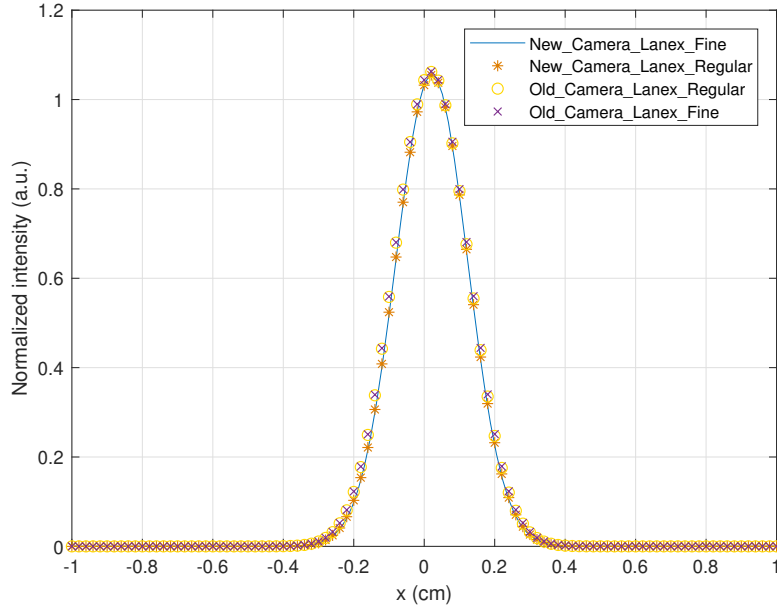
Figure 19: The normalized intensity comparison of the LANEX screens and the camera's

4   Discussion

This study was intended to develop a method using Matlab for the alignment of the slit collimator in proton beam experiments. The main goal was to create a narrow, schematic and predictable dose profile used in radio-surgery,[3] macular degeneration[4] and sensor calibration.

To achieve this dose profile the FWHM was used of a Gaussian fit to the horizontal scan through the middle of the slits images. This method seems to be effective as a local minimum was found. As the angle of the slit increases, more Coulomb scattering takes place with the walls of the slit collimator. This creates a second offset Gaussian relative to the primary Gaussian.[7] Next to the local minimum two maxima are found. At these maxima the standard deviation looks to have a maximum too. Therefore the slit profile loses it's homogeneity in the vertical direction.

In determining the influence of the LANEX screens and the cameras used in the 2001[1] and 2019[2] experiments. The horizontal profiles through the middle of the slit collimator were compared. As seen in section 3.2 the profiles overlap each other and the shape is the same. Therefore the influence of the camera and the LANEX screens could be neglected in the alignment of the slit collimator.

As the method using the FWHM works in the alignment of the slit collimator, the paddle method worked too. As the paddle detector had a maximum and the LANEX/CCD method had a local minimum, the paddle method would be preferred

as a maximum is simpler to determine. The downside of the paddle method is that a spatial resolution dimension is lost, from 2D to 1D, as the paddle only counts the protons that hit it. Also the horizontal alignment would be difficult as the 2D profile is unknown and thus there is no distance indication.

5 Conclusion

In the alignment of the slit collimator using the FWHM the hypotheses was that the FWHM maximum would increase as the angle of the slit collimator would increase. From the result one would state that this is true. A minimum was found at the best aligned angle. However this minimum is a local one, as the angle increases and passes a maximum a lower minimum was found. In future analysis the standard deviation could be included in the method, as this would increase as the angle increases.

In the LANEX and camera comparison a neglected influence was expected in the alignment of the slit. From the comparison experiments it is concluded that this is true. The same dose profile was acquired with the different LANEX screens and cameras.

In further research the paddle detector would be a good alternative for the alignment of the slit collimator. But as stated earlier the horizontal alignment and a spatial resolution dimension would be lost. In fitting the data, a linear combination of Gaussian's could be more accurate as the second Gaussian, created by the Coulomb scattering, would appear in the fitted data.

References

[1] P. van Luijk, A. A. van 't Veld, H. D. Zelle, and J. M. Schippers, "Collimator scatter and 2d dosimetry in small proton beams", *Physics in Medicine and Biology*, vol. 46, no. 3, pp. 653–670, Jan. 2001. DOI: 10.1088/0031-9155/46/3/303. [Online]. Available: https://doi.org/10.1088/0031-9155/46/3/303.

[2] J. Kretschmer, "Improving patient dosimetry under non-reference conditions for proton beams", Carl von Ossietzky Universität Oldenburg, Oldenburg, Tech. Rep., Oct. 2019.

[3] S. M. Vatnitsky, D. W. Miller, M. F. Moyers, R. P. Levy, R. W. Schulte, J. D. Slater, and J. M. Slater, "Dosimetry techniques for narrow proton beam radiosurgery", *Physics in Medicine and Biology*, vol. 44, no. 11, pp. 2789–2801, Oct. 1999. DOI: 10.1088/0031-9155/44/11/308. [Online]. Available: https://doi.org/10.1088%5C%2F0031-9155%5C%2F44%5C%2F11%5C%2F308.

[4] M. F. Moyers, R. A. Galindo, L. T. Yonemoto, L. Loredo, E. J. Friedrichsen, M. A. Kirby, J. D. Slater, and J. M. Slater, "Treatment of macular degeneration with proton beams", *Med Phys*, vol. 26, no. 5, pp. 777–782, May 1999.

[5] C. Boncelet, "Chapter 7 - image noise models", in *The Essential Guide to Image Processing*, A. Bovik, Ed., Boston: Academic Press, 2009, pp. 143–167, ISBN: 978-0-12-374457-9. DOI: https://doi.org/10.1016/B978-0-12-374457-9.00007-X. [Online]. Available: http://www.sciencedirect.com/science/article/pii/B978012374457900007X.

[6] J. Barkhof, G. Schut, J. B. Flanz, M. Goitein, and J. M. Schippers, "Verification of the alignment of a therapeutic radiation beam relative to its patient positioner", *Medical Physics*, vol. 26, no. 11, pp. 2429–2437, Nov. 1999. DOI: 10.1118/1.598761. [Online]. Available: https://doi.org/10.1118/1.598761.

[7] B. Gottschalk, A. Koehler, R. Schneider, J. Sisterson, and M. Wagner, "Multiple coulomb scattering of 160 mev protons", *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, vol. 74, no. 4, pp. 467–490, 1993, ISSN: 0168-583X. DOI: https://doi.org/10.1016/0168-583X(93)95944-Z. [Online]. Available: http://www.sciencedirect.com/science/article/pii/0168583X9395944Z.

[8] E. van der Graaf, *Monte Carlo Simulations of Slit Collimator Alignment*, Nov. 2020.

A   Matlab Manual

RIJKSUNIVERSITEIT GRONINGEN

MATLAB MANUAL

Matlab Manual for Slit Alignment in CCD\Scintillating Screen Setup for Proton Beam Experiments

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Contents

Quick start

1. Before running the code make sure that the file names of the slits that will be analysed are in the format 'Angle_Position'. Example: 'Deg-02_Pos23.8.fit' so here the angle is -0.2^o and position 23.8 mm.

2. In the initialization the parameters for the analysis can be change to your specifications. A description of all the parameters can be found in subsection 2.1.

3. After the initialization the code can be run. If there is no variable named 'data' in the workspace a selection window is opened to select the collimator fit file. After the collimator is selected a new window is opened asking to select the background. If your want to get the pixel to centimeter ratio a alignment file is asked for opening, this is optional. And finally a window to select the slits. Note: Multiple slits can be selected and opened.

4. Calling the function 'showimage(data)' in the command window will open all necessary images for the alignment. In the images horizontal and vertical lines are drawn. These are the scans used in the analysis of the images. The red point in the images is the middle of the collimator and is therefor useful for the alignment.

5. For further analysis of the images additional information is given in section 2. And more detail are given in the subsections.

1 Introduction

This manual is written for the Matlab code for the analysis of fit files from the proton beam experiment at the KVI in Groningen. Here protons with 150 MeV are projected to a 1.44 mm thick lead scatter foil followed by a 50mm diameter field collimator to create a homogeneous proton field. Thereafter a slit collimator is placed. To get the field as narrow as possible, its important that the slit is perfectly aligned with the field collimator. Slight deviations in the alignment can cause various dose perturbations. For detecting the protons a scintillating screen and CCD camera setup is used. The data from the camera is the used for the alignment or analysis of the experiment.

2 Main File

For an overview of the code, there is a initialization part a loading part and a analysis part. The initialization part is covered in subsection 2.1. The loading part is pretty self explanatory it loads in the fit files. For the analysis part there are eight functions that manipulate the data, these functions are more detailed described in the following subsections.

2.1 Initialization

Because there are multiple functions used in the analysis and alignment, a structure is used to read and write the parameters and data. For the parameter that the user can change is stored in the structure called 'this'. All the image data and the analysis data is stored in the structure called 'data'. This is done to keep everything nice and organized and it is convenient for reading and writing in a external function. In the code the meaning and usage of the parameters are given.

2.2 Loading the files

There are four functions for loading in the necessary files for the analysis and alignment. Loading the collimator, background, alignment and the slits. In all of these functions the names of the files are extracted and stored in the structure 'data'. In the functions 'load_slits' and 'load_colli' the background is subtracted depending on the value of the parameter 'this.remove_background'

2.3   The analysis

For the analysis of the images a median filter is applied. Because the name of the files also contain important information, the name of the files is read and stored. For finding the middle of the slits the edges are detected next, this is also done for the collimator. Thereafter the middle difference of the slits relative to the collimator is found. To get the pixel to centimeter ratio the alignment scan is made and a nested function 'pixel_to_centi' is called. The slit scans are stored and finally a Gaussian is fitted through the horizontal scan of the slits.

B   Experimental notes

94 khz. Dinrit

9-6-2020

slit collimator   2mm
3 cm achter de field collimator
LANEX 16 cm achter behind slit collimator
(1.5mm)   New Camera
    x positie   Angle   LANEX
d   24 mm   0.000.   FINE
    24 mm   +0.5 °
    24 mm   -0.5 °
    24 mm   0.1 °
    24 mm   0.2 °
    24 mm   0.3 °
    24 mm   0.4 °
    24 mm   0.6 °
    24 mm   0.7 °
    24 mm   0.8 °
    24 mm   0.9 °
    24 mm   1.0 °
    24 mm   1.5 °
    24 mm   .2.0
    24 mm   -0.1
    24 mm   -0.2
    24 mm   -0.3
    24 mm   -0.4
    24 mm   -0.6
    24 mm   -0.7
    24 mm   -0.8
    24 mm   -0.9
    24 mm   -1.0
    24 mm   -1.5
    24 mm   -2.0   LANEX

    24 mm   0 °   Regular
    24 mm   +0.1 °
    24 mm   -0.1 °

Old camera
Fine LANEX

Position-x	Angle
24 mm	0
40 seconds exposure	MMC = 3
24 mm	0