Illumination System for the MICE Tracker Station Assembly QA

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This document describes the preparation of the optical system used to illuminate the scintillating-fibre planes to be used in the MICE Tracker [1]. This illumination test during the tracker station assembly is a part of the quality assurance (QA) scheme [2].

1 Optical System Overview

QA of the tracker station assemblies involves successively exciting the fibres in a doublet layer, and confirming that the resulting fluorescence signal proceeds across the output in the corresponding sequence. We describe here the optical system, which transforms the output from a violet (405 nm) LED into a line focus in order to excite only a small set of fibres. This optical system is then mounted on to a linear stage [2] so that it can traverse the entire fibre plane, fig. 1.1. The fluorescence from the fibres is monitored with a camera attached to a second stage: the locus of the excitation across the output can then confirm correct bundling or connectorisation of the fibres.

LEDs, such as those used here, are extended, rather than point, sources which also have some internal structure (due to the die shape and presence of bond wires). This makes it very difficult to achieve a fine, homogeneous image. The optical design uses a two-stage approach (see figure 1.2): first, cylindrical optics are used to focus the round beam from the LED into to a long, thin shape. A mechanical slit is placed here to select an evenly illuminated region, providing it with well-defined edges. The second stage is a set of relay optics that projects an image of the slit aperture on to the target. In principle these could be designed to further shrink or expand the final image; however we re-used a matched pair of lenses at about the nominal 1:1 transfer. A useful consequence of using relay optics rather than a simple slit close to the fibre plane is that wear or accidental damage to the fibres are avoided when the illumination system is being scanned across.

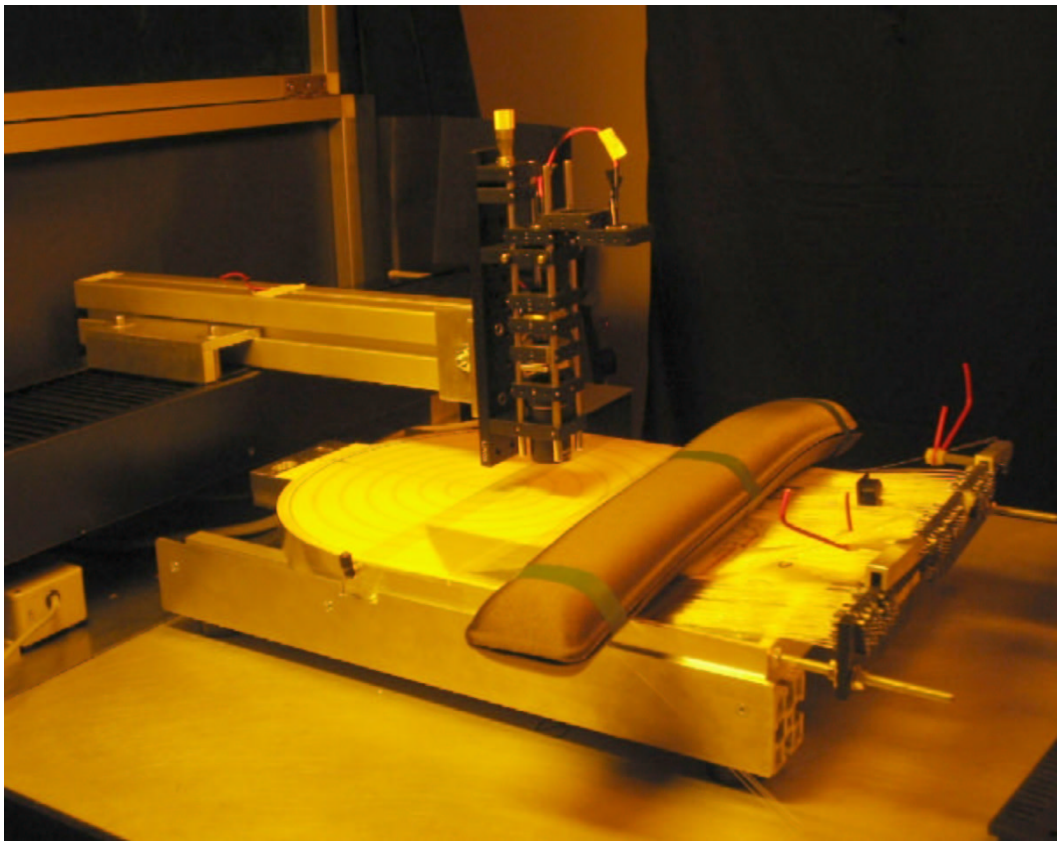


Figure 1.1: An overview of the station assembly QA setup. The optical system is attached to a linear stage and held over the plane of scintillating fibres to illuminate the channels in sequence. The fibre plane is laid on top of a vacuum chuck, which is fixed in place by a guiding rail. The bundled fibre ends are held up in order at the right hand side to be captured by a CCD camera that sits outside this photograph. The extra LED mounted in front of the optical system provides un-focused beam for general illumination. Full details of the complete apparatus are given in [2].

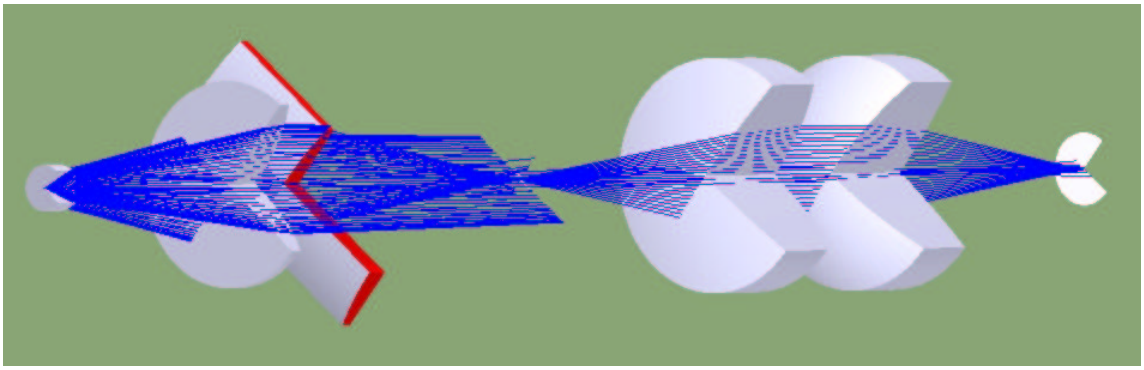


Figure 1.2: The diagram shows how the circular beam of light (represented here by horizontal and vertical ray fans from the LED) is focused in only one plane by the cylindrical (red-shaded) lens to produce a line focus cropped by the slit (tiny white bar at centre), which is then projected on to the fibre plane (far right) by the matched-pair lenses (right). This diagram was generated from a model of the optical system in the Zemax optical design package [3].

2 Optical System Design

The optical system used for the station assembly QA is composed of:

a) violet LED, illumination half-angle of 15°, driven at 20 mA (λ = 405 nm)
b) 40 mm focal length spherical lens to collimate the beam
c) 40 mm focal length cylindrical lens to focus the beam in one plane
d) adjustable slit to vary the beam width
e) matched-pair lenses to project the image of the slit

The opto-mechanics are based on the “Microbench” system from Linos Photonics. This consists of 40 mm × 40 mm square mounting plates with circular apertures into which can be fitted optical components (fig. 2.2) held coaxially by a square array of precision rods in the corners. A complete assembly of plates and rods is here referred to as a "cage". The mounting plates can either be slid along the rods, or fixed to them by small locking screws. The overall configuration is illustrated in figure 2.1 with key specifications noted. Details of the optical elements can be found in Appendix A.

The slit holder is latchable, such that the holder rotates around the rod through the hole on the top left corner of the mount (Fig. 2.2*c*) when the left two rods are removed, and swings out of the cage. This allows an easy access to the slit blades for the width adjustment while the rest of the optics remains unaffected. The vertical (*z*) position of the slit is ensured during this operation by a pair of positioning rings firmly fixed onto the axis rod above and below the slit mount.

The entire optical system is attached to the end of an aluminium arm, which extends from a linear stage perpendicular to its travel direction (fig. 1.1). Two empty holders are additionally inserted below the spherical lens and the matched pair mounts respectively to provide fixing to the supporting plate attached to the arm, with some flexibility of sliding the entire optical system vertically to obtain an optimum beam spot on the scintillating fibre.

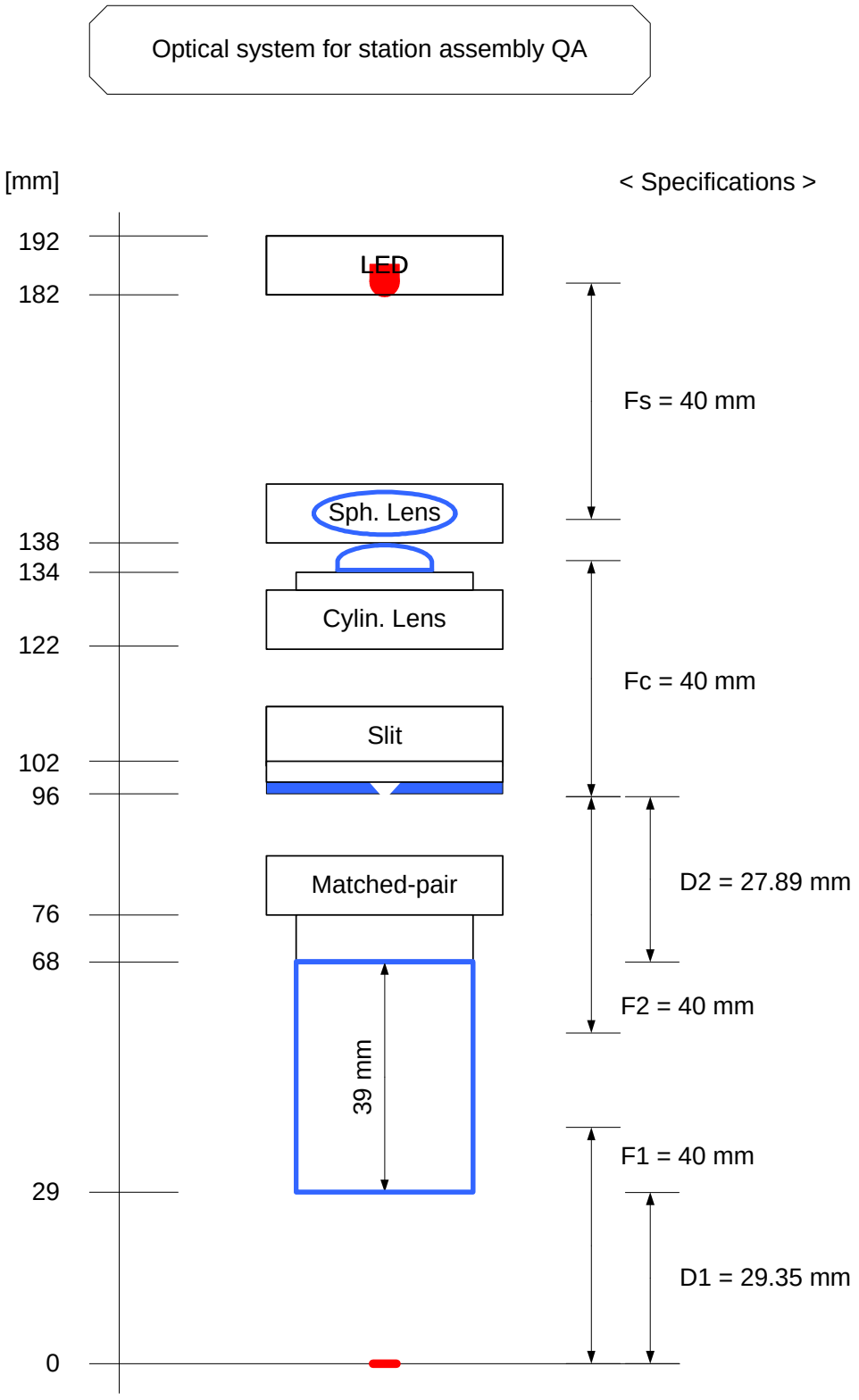


Figure 2.1: An illustration of the configuration of the optical system used for the station assembly QA. The *z* position of each element to the nearest mm is labelled on the left, and the nominal focal lengths of the lenses are noted on the right.

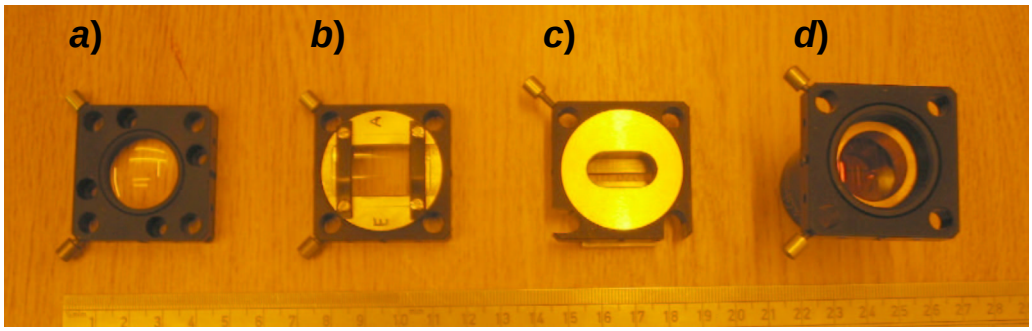
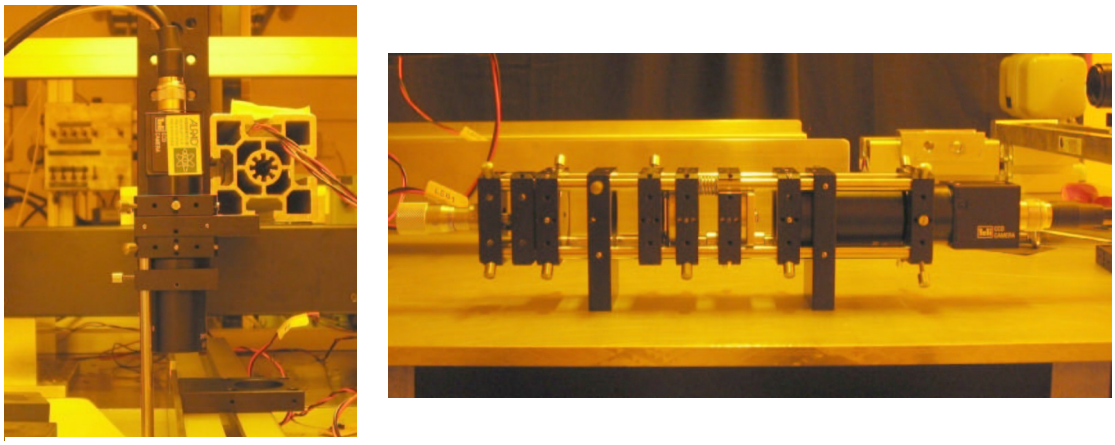


Figure 2.2: *a*) the spherical lens, *b*) the cylindrical lens, *c*) the adjustable slit and *d*) the matched pair lenses, placed in the corresponding holders and subsequently in the square mounting plates. The two screws on each of the holders indicate the position of the two rods (towards the cage mounting plate shown in Fig.1.1) to which the plates remain continuously tightened once the component spacing has been determined.



a) *b*)

Figure 3.1: The setups for the optimisation of the optical system. *a*) The CCD camera orientation was aligned in situ, with respect to the vacuum chuck rail. *b*) The spacing between the optical components held in the cage was adjusted with a spring-loaded micro-positioning mechanism. This particular configuration varies the spacing between the cylindrical lens and the slit.

3 Alignment and Optimisation of the Illumination System

The orientation and axial position of each optical element, whose transverse alignment is ensured by the cage, were adjusted to create an ideal beam to illuminate the fibres. The optimisation was carried out by studying images of the beam spot or of the optical components themselves, captured by a CCD camera. The goal was to control the beam size to suit the QA purposes while achieving sufficiently high intensity, uniform illumination of each fibre/channel.

3.1 Component Orientation

The orientation of the CCD camera was first calibrated with respect to that of the vacuum chuck so that the line illumination could subsequently be aligned to the direction of the scintillating fibre run. The camera was placed in a mounting plate and attached to one side of an optical cage with only the matched pair lenses. The cage was then fixed onto the stage arm, looking down onto one side of the vacuum chuck rail through the lenses (fig. 3.1*a*). The vertical positions of the camera and the matched pair were adjusted manually by sliding the mounts along the rods until the image of the rail was in best focus. The CCD was rotated within the mounting plate until the length of the rail in the image was parallel to the edge of the view of the camera.

The orientations of the slit and the cylindrical lens were adjusted while observing the slit itself (under ambient light) and then the shape of the beam through the lens. For this, the optical cage was detached from the stage and laid horizontally on the table for convenience, and the LED and the relevant optical piece were placed within the same cage. A combination of several ND filters (total density 4.6) was placed in front of the LED to reduce the light intensity to prevent saturation of the camera. The orientation was altered until the most defined line in an image has the same vertical pixel position at each end, achieving a precision of the order of 10 microns over the length of 10 mm.

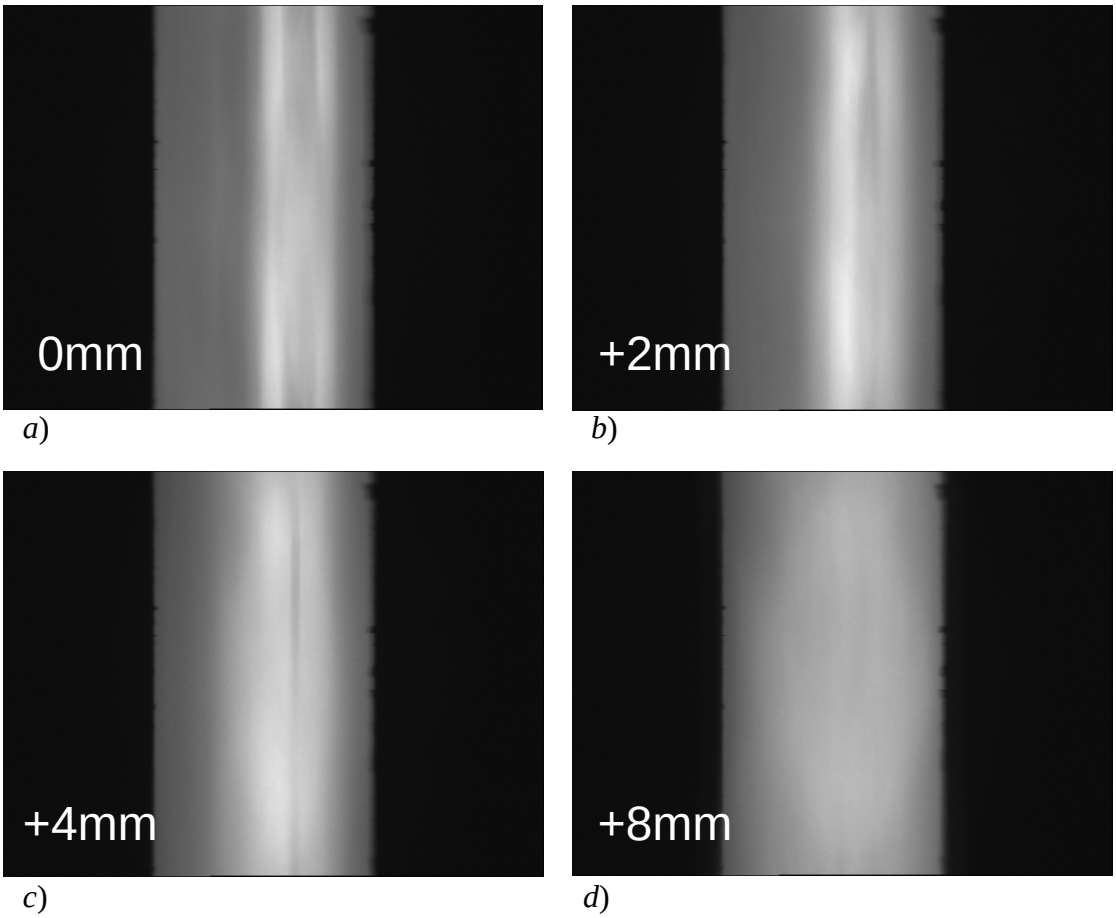
3.2 Component Spacing

For the spacing optimisation, all the optical components were placed back in the mounting cage in the configuration described in section 2. The CCD camera was attached below the matched pair lenses, at a distance approximately equal to the focal length of the bottom lens. The setup for the spacing optimisation is shown in figure 3.1*b*. A micrometer was mounted onto the two nearest rods, against which had been tightened the locking screws of the plates holding all the optical components that should remain stationary. The micrometer shaft was pressed against a dummy mounting plate that was locked to the other rods, to which the component to be moved had also been fastened. A pair of springs was inserted between an adjacent pair of stationary and moving plates to allow backward movement.

First, the spacing between the matched-pair lenses and the slit was adjusted to obtain a clear image of the slit projected onto the CCD camera, while the LED was switched

off. Then the LED was turned on to observe the beam at the slit after the light had travelled through the spherical and the cylindrical lenses. The spacing between these two lenses was kept at minimum, and the LED was approximately one focal distance away from the plane face of the spherical lens.

Figures 3.2*a–d* are the images of the beam for different spacings between the cylindrical lens and the slit, covering a range about the focal distance of the lens. The vertical axis corresponds to the illumination along the length of the scintillating fibres, and the images show the lateral focus provided by the cylindrical lens. The slit was left "open" to observe the structure of the beam over a wide enough range of ~3 mm, equivalent to ~2 channels of 14 fibres on the doublet-structured plane. The images taken with a shorter lens-slit separation show the nature of the beam from an LED, a bright ring with a low intensity region at the centre.



a) *b*)

c) *d*)

Figure 3.2: Images of the focused LED light through a wide slit for an increasing distance between the cylindrical lens and the slit, starting from an arbitrary separation a few millimetres shorter than the focal distance of the lens.

The profile of the beam for eleven different lens-slit spacing is summarised in figure 3.3. The brightness of each pixel extracted from the CCD images (e.g. figs. 3.2*a–d*) was integrated over all vertical pixels and plotted against the horizontal position across the width of the slit. The integrated intensity was normalised to the brightest strip in all the 11 images used. This is equivalent to the relative illumination on a fibre at different position across the doublet plane, where the sizes of a 350 micron fibre and the ~1.5 mm channel are as indicated. The uniformity of the beam over a channel width improves with increasing lens-slit separation, but the illumination of the individual fibres is reduced. In practice, the beam projected on to the fibre plane scatters sideways, exciting fibres beyond the edges of the beam defined by the slit blades. It was concluded that the illumination of one fibre at a time would be more effective for the QA procedure; hence the lens-to-slit distance was chosen as "+3mm", provided that the slit width be kept less than the diameter of a fibre.

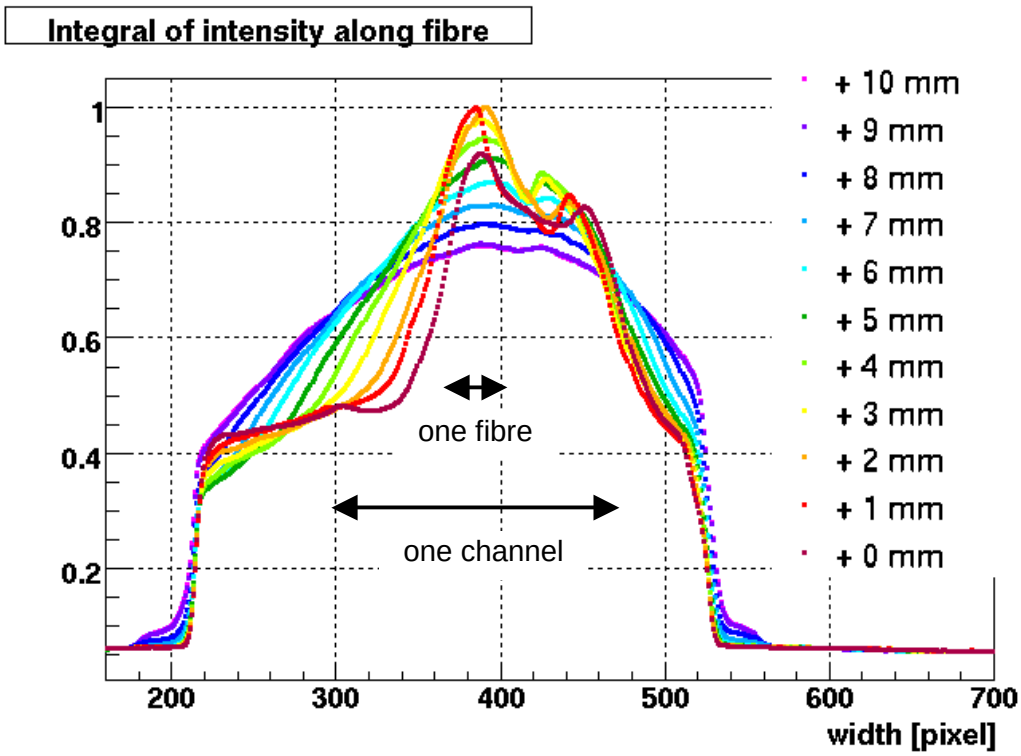


Figure 3.3: The integrated pixel intensity extracted from CCD images (examples shown in Figures 3.2*a–d*) plotted along the width of the slit for different spacing between the cylindrical lens and the slit.

3.3 Slit Width

The slit width was adjusted, first by moving one of the blades to a suitable position by a micrometer placed on the side of the optical cage to push against it while confirming the blade position on the CCD images. The position of the blade was decided depending on the slit width such that the peak of the focused beam intensity would lie at the centre of the slit. The other blade was pushed gently into place by hand with a feeler gauge inserted in between. The smallest gauge of 50 microns was used. A narrow beam was favoured for targeting single fibres within the doublet-structure fibre plane. The top and bottom fibres are spaced at a 427 micron pitch in each layer, which is 77 microns more than the fibre diameter, and the bottom fibres are displaced from the top ones by half the period. Hence a narrow beam that can penetrate through the inter-fibre gap was desired.

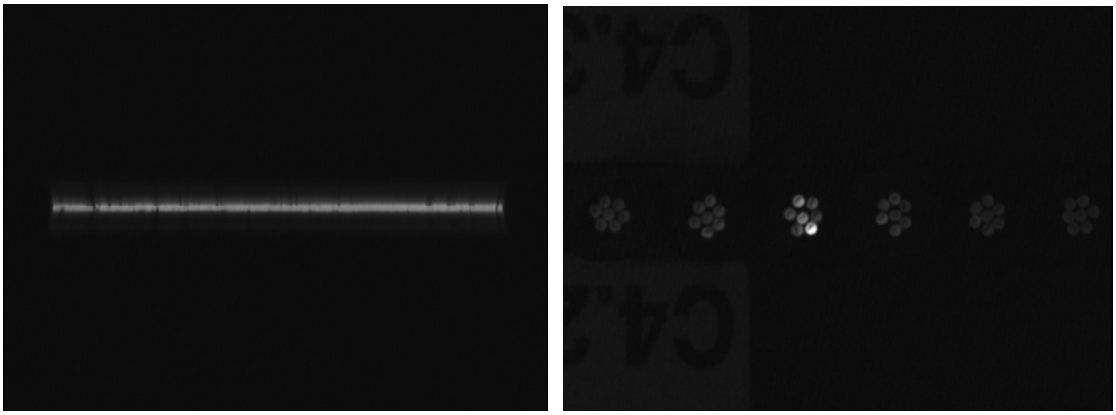
The illumination test for the QA is interleaved with the station assembly which involves manual handling of fibres on a loosely held doublet plane which is not aligned at this stage to the final precision achieved by using a microscope. The slit length was shortened to ~4 mm using pieces of a thick insulating tape to reduce the spread of the illumination due to misalignment.

The image of the slit in its final form of 50 microns × ~4 mm is shown in figure 3.4*a*. (The CCD configuration is exactly the same as for the images in figs. 3.2*a–d*, however, this image is trimmed on the sides and rotated for convenience.)

3.4 Height Above Fibre Plane

With the optical components in place and all the locking screws securely fastened, the entire cage was placed on the stage arm for the final adjustment of its z position. The micrometer was attached to the top of the cage on the two rods nearest to the supporting back plate on the arm (fig. 1.1). By extending the micrometer shaft against an additional holder inserted underneath and fixed to the back plate, the entire optical system was pulled upwards with respect to the rest of the apparatus. For a downward movement, the cage had to be pressed down gently by hand after retracting the micrometer shaft. Starting from the bottom of the matched-pair lenses positioned roughly at a focal distance away from the vacuum chuck that holds the fibre plane, the vertical position was adjusted until a suitable illumination of the fibres was achieved.

Figure 3.4*b* is an example of fibre illumination using the optimised optical system. The 50 micron width slit provided enough light output while keeping the leakage to the neighbouring fibres low. It was proven difficult to illuminate the top and the bottom fibres equally due to the attenuation of the beam in the glue between the fibres, however, the bottom fibres were still distinguishable within the consecutive shots of illumination scan.



a) *b*)

Figure 3.4: *a*) An image of the slit with 50 micron width and ~4 mm length. The dark spots within the slit are mostly the grease from the feeler gauge. *b*) A snap shot of a column of channels containing 7 fibres each. The optical system in its final configuration is illuminating one upper fibre in the plane.

Appendix A: List of Optical Components

Component	Details	Supplier	Product code
LED	wavelength = 405 nm input = 3.7 V, 20 mA output = 12 mW	ETG Inc. http://www.etgtech.com	ETG-5UV405-15
spherical	25 mm dia., 40 mm f.l. plano-convex spherical lens (fused silica)	Linos Photonics http://www.linos.com	063050
cylindrical	15×30 mm, 40 mm f.l. plano-convex cylindrical lens (fused silica)	Linos Photonics http://www.linos.com	318813 (cut in half by optical workshop)
adjustable slit	Homebrew design	Brunel University	
matched achromatic pair	focal lengths f1 = f2 = 40 mm	Thorlabs Ltd. http://www.thorlabs.com	MAP104040-A1
Microbench	Microbench Mechanics Set	Linos Photonics http://www.linos.com	060004

References

1. MICE collaboration, “MICE Technical Reference”, http://www.isis.rl.ac.uk/accelerator/MICE/TR/MICE_Tech_ref.html

2. T. Matsushita: “Scintillating Fibre Tracker Station Assembly” *MICE Note* (in preparation)

3. ZEMAX-EE dated 31st July 2006, ZEMAX Development Corporation, 3001 112th Avenue NE, Suite 202, Bellevue, WA 98004-8017 USA