Lab 1: Knife-Edge Scraper for Beam Profile and Halo Measurement

1.1 Aims and Objectives

This experiment aims to demonstrate the principle of a particle beam scraper for fast measurement of transverse beam parameters, by making an analogous transverse profile measurements of a laser beam with a knife-edge scanner. The measurement of a transverse beam profile is important for several methods to determine the emittance, namely the three-screen method, the quadrupole scan, and the pepperpot technique, which are explored further in the other laboratory experiments. The knife-edge scanner is also useful for beam halo measurement. The main objectives are:

- To set up the optics equipment to measure the transverse beam profile of a laser beam.
- To autonomously translate a knife-edge across a laser beam and record the transmitted intensity at a photodiode.
- To analyze the data by filtering, then differentiating the photodiode signal to generate the measured beam profile and determine the laser beam width via a Gaussian fit.
- To appreciate the dynamic range necessary to measure beam halo distributions, through measurements of the Fraunhofer diffraction pattern from a single slit.

1.2 Beam Profile Measurement Theory

Scanning a knife-edge across a particle beam allows the transverse beam profile to be measured from the differential of the transmitted intensity. See for example: J. A. Arnaud et al, *Technique for Fast Measurement of Gaussian Laser Beam Parameters*.

1.2.1 Beam Halo

The core profile of a particle beam may be measured using for example, a wire scanner that records the current resulting from secondary emission due to impacting particles. In addition, however, a particle beam normally has a halo distribution, which arises from various processes including: beam gas elastic and inelastic scattering, incoherent and coherent synchrotron radiation, scattering off thermal photons, intrabeam and Touschek scattering and ion or electron-cloud effects; beam optics, and collective effects. In synchrotrons, the beam halo is an important background source for the experimental detectors, and is also critical for radiation sensitive components in the accelerator. Beam losses at the level of $< 0.1\%$ lost particles per bunch can be harmful, therefore we require a beam monitor capable of measuring the transverse beam halo better than this. The required dynamic range is therefore of the order of 10^5 or better. To achieve this dynamic range, a combination of wirescanners and knife-edge scrapers is sometimes necessary to capture profile data from the intense core and the halo distributions respectively.

1.3 Experimental Setup

The equipment is in the dark room in section-C (far corner) of the RHUL Tolansky teaching laboratory.

Warning: the He-Ne laser in this experiment is a class IIIa laser. Avoid direct eye exposure to laser radiation. Do not stare into the beam and remove any reflective jewellery before operating the laser.

A HeNe $\lambda = 632.8\,\text{nm}$ laser is aligned on an optical rail such that light passes through a series of focusing lenses to converge on distant photodiode, as shown in Fig 1.1.

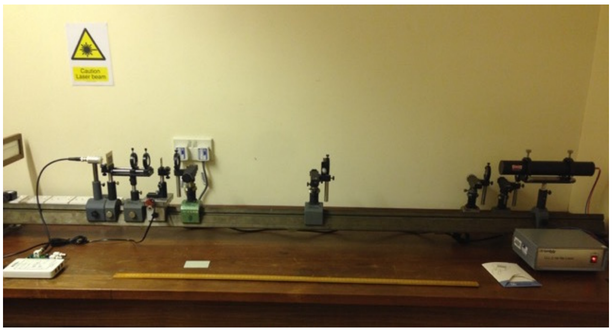


Figure 1.1: Overview of setup for knife-edge laser beam scraper

The photodiode signal is recorded via an National Instruments MyDAQ data acquisition card, as in Fig 1.2, connected to a laptop computer. The laptop also controls a New Focus pico-motor, that drives a knife-edge on a translation stage transversely across the laser beam. The laptop has LabView control software to automate the scan, that can be accessed from the desktop.

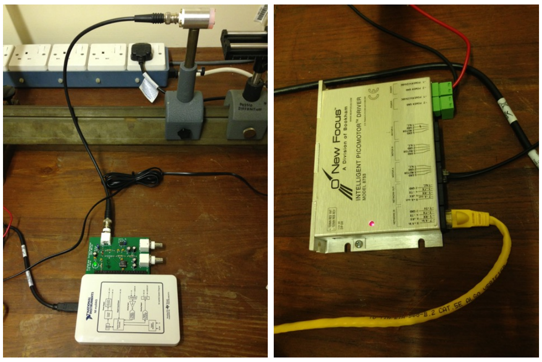


Figure 1.2: NI MyDAQ data acquisition card to record photodiode voltage and New Focus Pico Motor Controller connected via ethernet cable/USB adapter to laptop.

The New Focus pico motor can be incremented in precise 30 nm steps. To minimize the time required for a scan, the laser beam is focused to a tight laser waist, just after which the knife-edge is scanned, as in Fig. 1.3

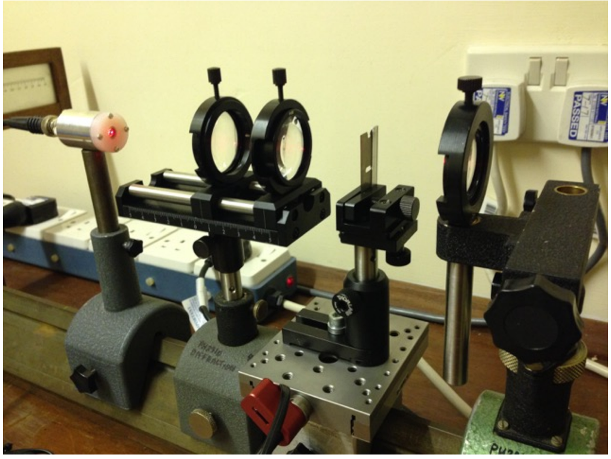


Figure 1.3: Knife-edge between focusing lenses, with the photodiode illuminated by a HeNe laser.

1.4 Measurements

1.4.1 *Knife-edge Scans*

After familiarizing yourself with the equipment, turn on the laser and observe the beam shape using the white-screen as in Fig 1.4 to image the laser beam spot at various locations through the setup, noting the focal lengths of the lenses used. The light should pass through all lens apertures to avoid clipping of the beam profile.

When the knife-edge is positioned half-way through the laser-beam, the pattern on the card appears as in Fig 1.4. You may notice there is a distortion of the geometric shadow on the card as the knife-edge passes through the laser-beam - why is this? Is this effect expected at a particle accelerator? Under what circumstances does this effect not matter for this experiment?

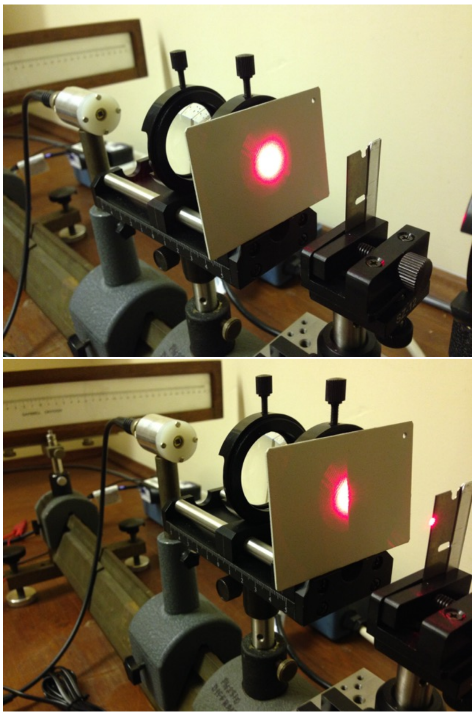


Figure 1.4: Beam imaged on white screen, without and with knife-edge in beam

The active area of the photodiode is small, therefore the light transmitted beyond the knife-edge must be refocused to be collected entirely by the photodiode, as in Fig 1.5.

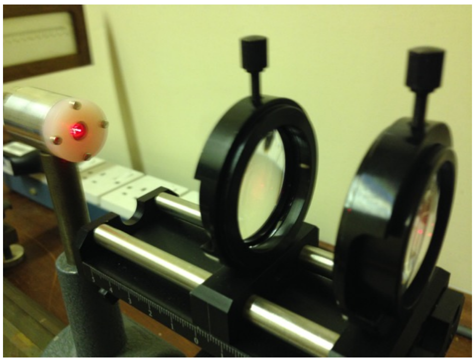
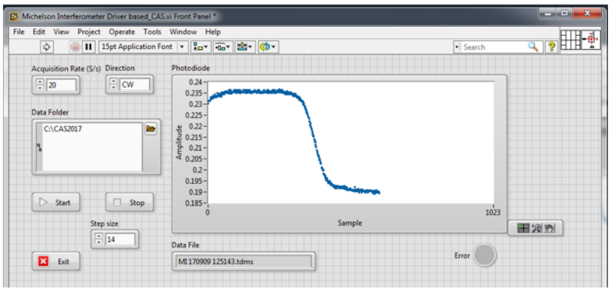


Figure 1.5: Laser spot focused onto photodiode


Michelson Interferometer Driver based_CAS.vi Front Panel *

Acquisition Rate (S/s): 20

Direction: CW

Data Folder: C:\CAS2017

Step size: 14

Data File: MI 170909 125143.tdms

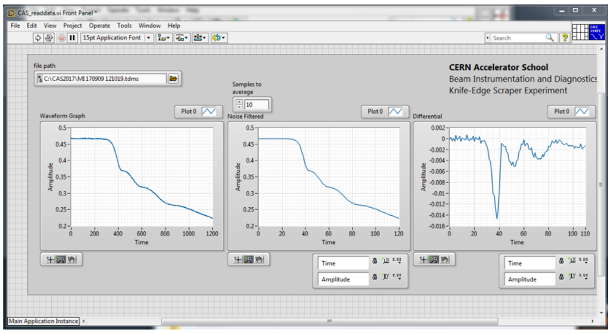
Figure 1.6: LabView software to control the stage and read out the photodiode during a scan of the knife-edge.

Performing a scan:

- Open the LabView software in Fig. 1.6 and use it to record a scan, by running the program, then pressing the start and stop buttons. Select COM3 when prompted.
- The voltage signal at each sampling point is recorded to a timestamped data file in the C:/temp/CAS2024/ folder.
- Check that the scan records the full beam profile as an error function; you may wish to adjust the step size and sampling time for a more rapid scan, within the limits of the driver.

1.4.2 Beam profile extraction

The recorded data file may be analyzed by the CAS_readata.vi LabView software shown in Fig. 1.7. The raw data are filtered by averaging over a certain number of samples, then the signal is differentiated to obtain a plot of the beam profile versus knife-edge position.


CAS_readdata.vi Front Panel *

file path: C:\CAS2017\MI 170909 121019.tdms

Samples to average: 10

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Figure 1.7: Analysis software to read the photodiode data, filter for noise and differentiate to obtain the profile.

1.4.3 Gaussian beam profile

Fit a Gaussian (or otherwise) to the beam profile to extract the width. Compare this with the width of the Gaussian waist you would expect at the focus of the lenses. How would you improve / calibrate the setup?

If there is sufficient time, replace the knife-edge with the adjustable slit and repeat the scan. Can you optimize the slit size to obtain the best beam profile?

1.4.4 Beam Halo measuring a single-slit diffraction pattern

When the first lens in the setup is replaced with an adjustable single slit, a diffraction pattern is produced in the far field with the intensity: $I(x) = \frac{\sin^2(x)}{x^2}$, as in Fig. 1.8. Thus the distribution has a central *"core"* and an interesting side patterns that can be considered as the *"beam halo"*.

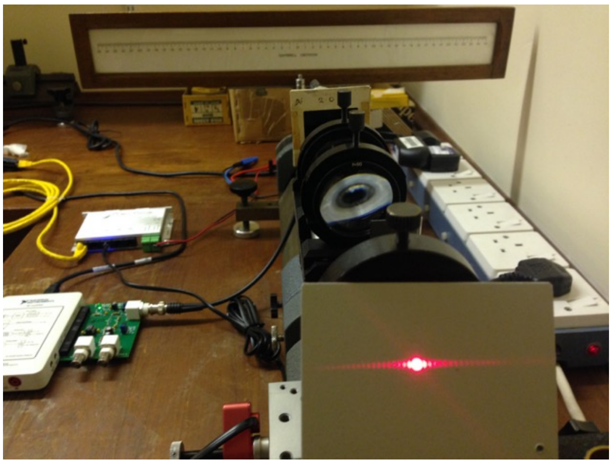

Figure 1.8: Single slit diffraction pattern.

Use the apparatus to obtain beam profiles showing clear features of the core and halo. Consider whether the photodiode will saturate when exposed to the full laser beam. Place different optical filters (ND > 2.0) in front of the photodiode, as in Fig 1.9 to obtain profiles with the necessary dynamic range. How could the setup be modified to obtain both sides of the halo distribution?

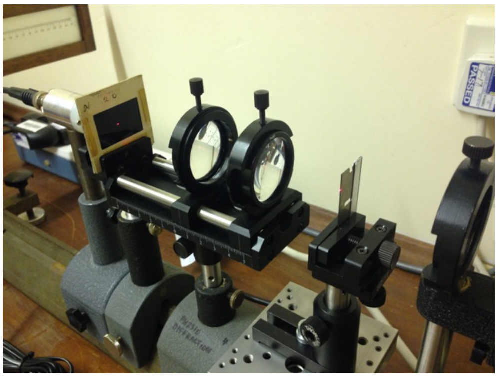

Figure 1.9: Filter inserted in front of photodiode.