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EURO-LABS

EUROpean Laboratories for Accelerator Based Sciences

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MILESTONE REPORT

MECHANICS OF THE SETUP ADAPTED TO FIT INTO THE EXPERIMENTAL AREA

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Abstract:

An upgrade of the sample scanning system at the high intensity irradiation line of the University of Birmingham MC40 proton cyclotron has been undertaken. This upgrade is intended to allow samples to be irradiated up to up to 10^{17} 1 MeV n_{eq} cm^{-2}, a capability important in the development of new semiconductor detectors for future collider projects. The new system, based on a well validated design used at the Bonn Isochronous Cyclotron, has been successfully procured and assembled. Using a mock beam and irradiation sample constituted by a collimated a laser beam and large area photodiode, the system has been commissioned in the laboratory and confirmed to meet the performance requirements necessary. The system is now ready for the final integration at the irradiation facility to begin later this year.

For more information on EURO-LABS, its partners and contributors please see https://web.infn.it/EURO-LABS/

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TABLE OF CONTENTS

Executive summary

An upgrade of the sample scanning system at the *high intensity irradiation line of the University of Birmingham MC40 proton cyclotron has been undertaken. This upgrade is intended to extend the capability of the facility to irradiate samples to the extreme fluences relevant to the development of semiconductor detectors for future collider projects. The new system, based on a well validated design used at the Bonn Isochronous Cyclotron, has been successfully procured, assembled and commissioned in the laboratory, ready for integration at the irradiation facility to begin later this year.*

1. INTRODUCTION

The high intensity irradiation line at the University of Birmingham MC40 proton cyclotron has provided semiconductor detector irradiations for a wide variety of projects, including the high luminosity upgrades of the LHC experiments. In particular, the facility plays a central role in the QA programme of the ATLAS ITk strip sensor project, delivering regular monthly irradiations for test structures and miniature strip sensors. The typical fluence require by users to date was around a few 10^{15} 1 MeV n_{eq} cm^{-2}. Irradiations to such fluences were comfortably possible with the combination of beam current, sample scanning speed and cooling delivered by the existing infrastructure. In order to reach the higher fluences required to characterise the next generation of semiconductor detectors developed for future High Energy Physics (HEP) collider facilities, the irradiation facility at the MC40 requires an upgrade of its experimental setup.

Samples to be irradiated are installed in an environmental box to control temperature and humidity during irradiation. The box is mounted on an XY-axis scanning system. This setup allows for uniform irradiation of samples of area larger than the beam profile. The current setup allows a maximum scanning speed in the X direction of 4 mm/s. Studies of the temperature profile on the sample during irradiation have shown that at this speed the maximum beam current is limited to 400 nA to avoid heating and thus the annealing of samples during irradiation. For typical prototype sensor areas of a few cm^2, and within a typical irradiation day, this limits the maximum fluence to a few 10^{15} 1 MeV n_{eq} cm^{-2}.

To satisfy the requirements of tests up to 10^{17} 1 MeV n_{eq} cm^{-2} envisaged by the EURO-LABS project, a faster sample scanning system must be implemented. The cyclotron itself can deliver beam currents of 2 mA and the cooling system can reach -50° C, so these are not limiting factors. With a 2 mA current, a fluence of 10^{17} 1 MeV n_{eq} cm^{-2} can be reached within one day of irradiation on a 2 x 2 cm^2 sample with a scanning speed in the X direction of 10 mm/s. Such scanning speed has been achieved by the experimental setups deployed at irradiation facilities at KIT and at the University of Bonn [1]. Colleagues at Bonn have designed their system to be easily implemented at other facilities and we have been in contact at several stages of the project to understand the practicalities of implementing their setup at our facility.

The goal of this service improvement is to upgrade the infrastructure of the University of Birmingham MC40 high intensity irradiation to match the capability achieved in Bonn [1]. The upgrade will include mechanical support for installation at the facility, environmental box, scanning stages, a secondary beam monitor (SEM) for better current monitoring, control electronics for stages and SEM. This report will outline the work that has been performed to meet milestone MS33: "Mechanics of the setup adapted to fit into the experimental area".

2. DESIGN OF SAMPLE SCANNING SYSTEM

The design of the system is described in detail in Ref. [1], though a brief description of the system is provided in this report. The system is composed of two independently controlled linear stages, mounted orthogonally, which together allow the position of a sample platform to be precisely controlled in the XY plane normal to the beam axis. The environmentally controlled sample box is then mounted on the sample platform, allowing precise scanning of the beam over the samples during irradiation. The stages are themselves mounted on a portable optical table, allowing for a fast and convenient transition from the qualification of the system in the laboratory to the final integration of the system in the beam area (which can also be reversed for maintenance, if necessary).

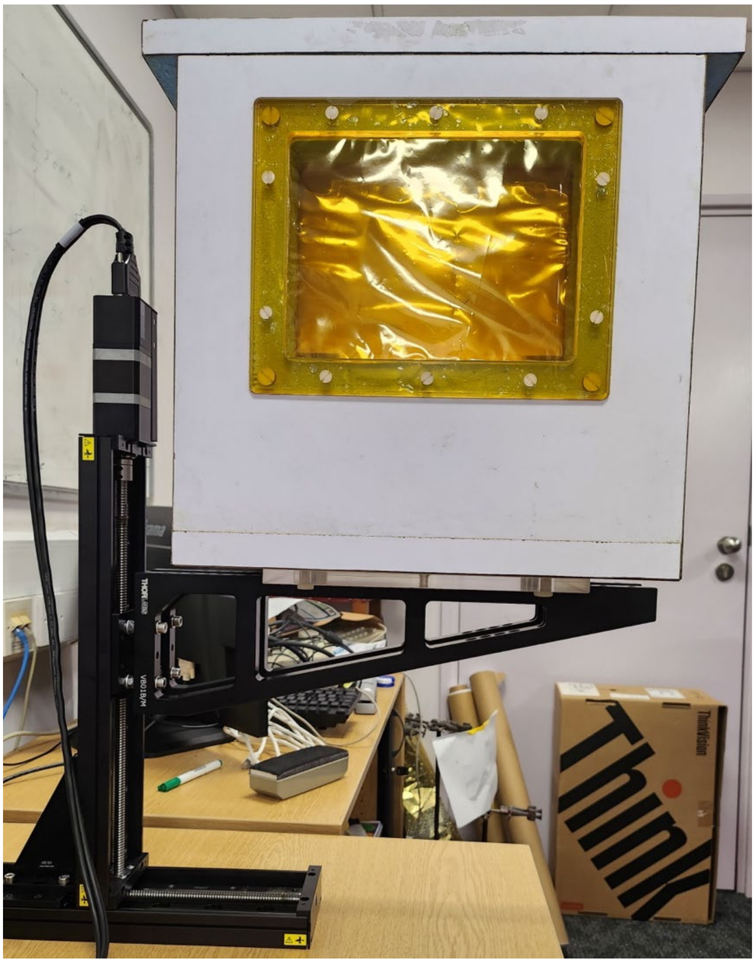


Figure 1 - The two motorised linear stages, with the sample box attached, during laboratory testing.

The system uses two Zaber Motion LRQ300HL motorized linear stages with integrated position encoders, as shown in Figure 1. The stages have a maximum travel distance of 300 mm, maximum speed of 110 mm / s and an absolute position accuracy of 55 µm. Each stage is capable of being simultaneously controlled by means of a dedicated power and control interface box, which itself can be controlled from a PC through a USB connection. A suite of control scripts, written in Python, have been developed to control the movement of the two stages and move the sample in the beamline with the desired scanning pattern. The software is deployed on a dedicated control PC, which is portable and can be deployed both on a lab bench for commissioning or in the cyclotron control room for irradiation operations. The complete system is shown in Figure 2.

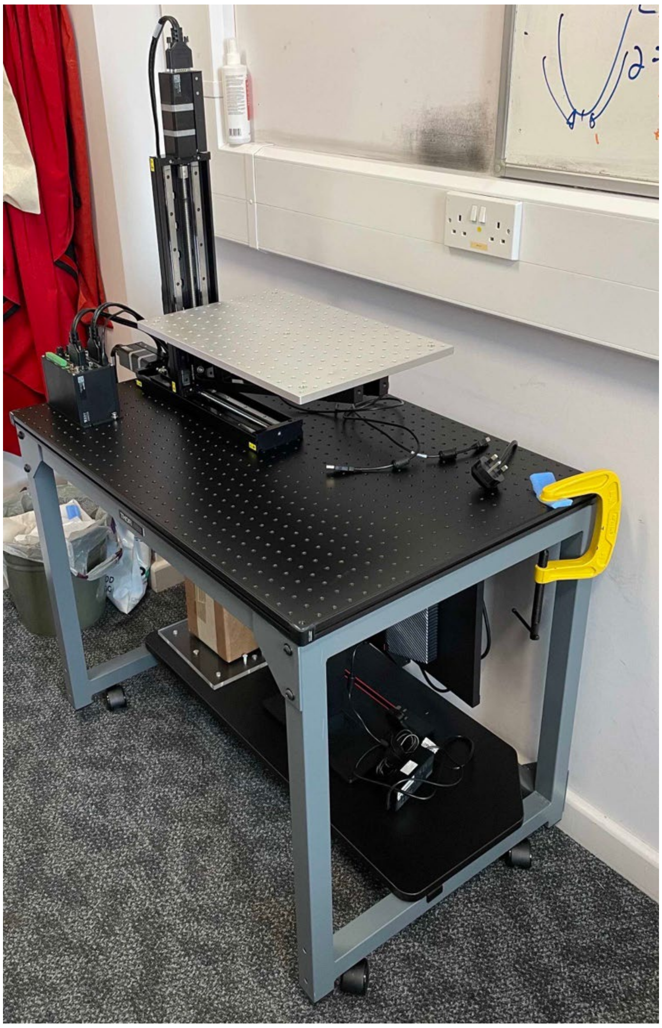


Figure 2 - The fully assembled sample scanning system. The two linear stages and sample platform are clearly visible, mounted on a portable optical table. The sample box is not present, but is easily removable from the aluminium sample platform. The control PC is also visible on the lower shelf, stored in the position ready for laboratory commissioning operations.

3. LABORATORY COMMISSIONING

Initial studies to characterize the performance of the system were undertaken in the laboratory. This phase of commissioning was performed using a laser to mimic the proton beam, together with a large area photodiode placed on the sample panel within the sample box to mimic a sample for irradiation. In order to better match the physical parameters of the proton beam at the University of Birmingham MC40 cyclotron, a low power laser beam is first directed upon a system of diverging lenses and collimators, in order to form a roughly uniform beam of light with a square profile of varying dimensions (values from 1x1 cm^2 to 10 x 10 cm^2 were studied), as shown in Figure 3.

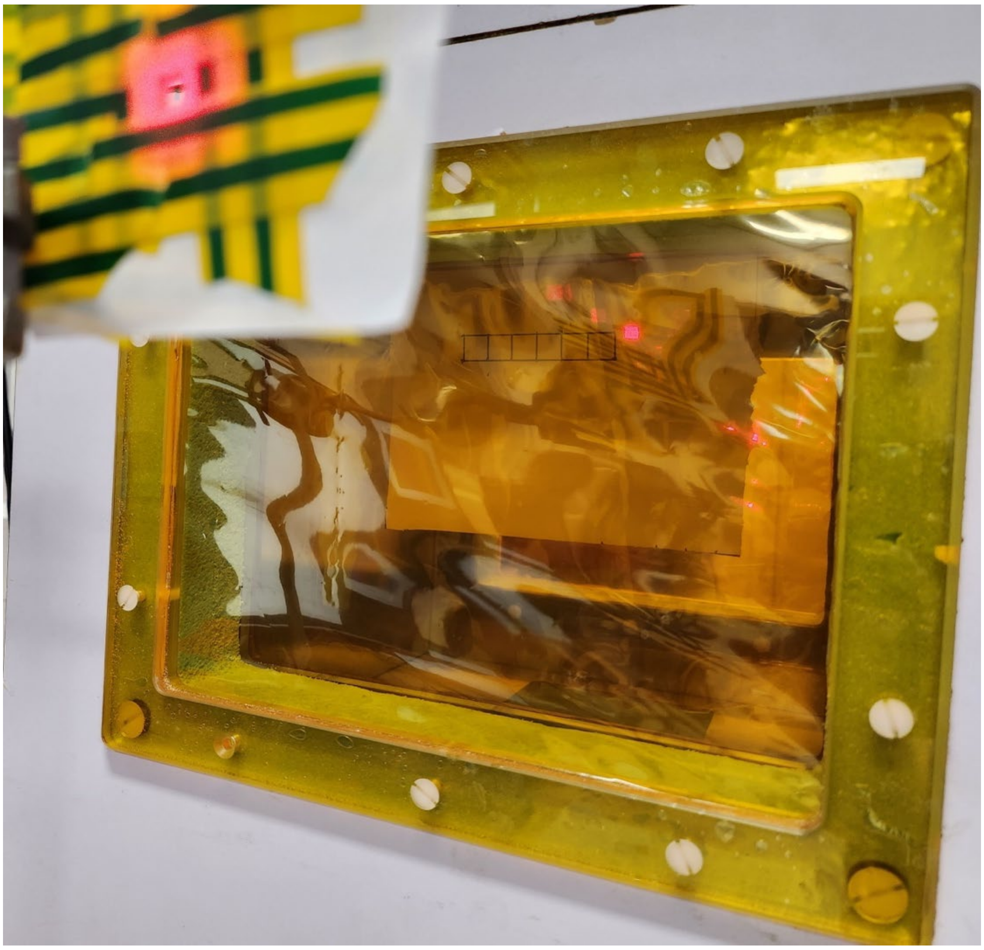
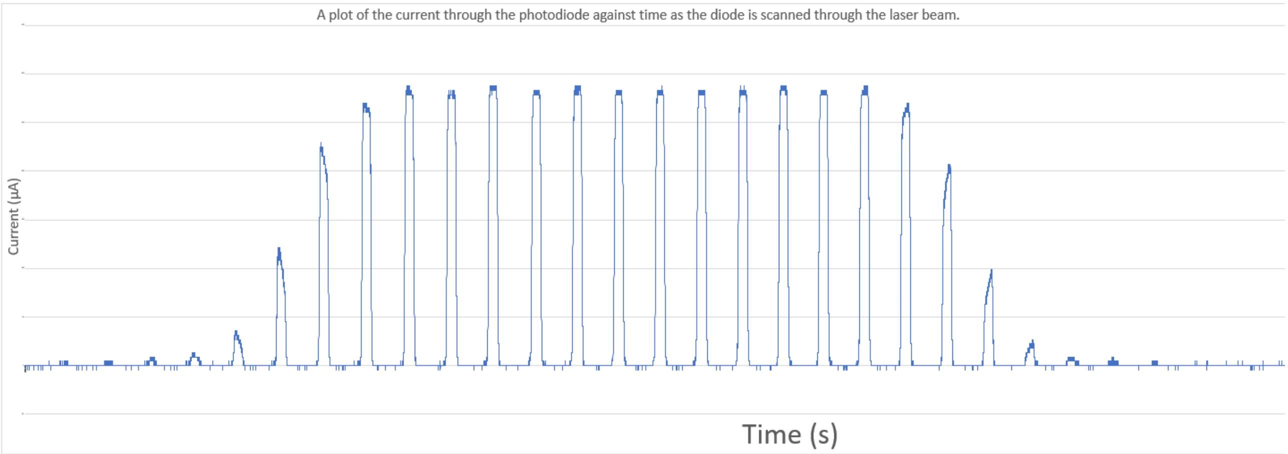


Figure 3 - The collimated laser beam entering the sample box and impinging upon the aluminium sample panel.

To complement the physical laser setup a simulation of the expected laser beam position on the sample plate was developed, for comparison with the experimental data from the photodiode. In this way, the expected position of the beam in the control software can be compared with the actual beam position in the physical system, to validate its accuracy.

Dedicated validation software was written to simultaneously control the scanning system and read the photodiode response with an oscilloscope. This allowed for the collection of datasets comprising the expected position of the laser beam and photodiode current, both as a function of time. The system was then programmed to scan the photodiode through the laser beam in the manner which a sample would be irradiated in the MC40 proton beam. The known position of the photodiode on the sample panel, together with a simple absolute calibration of the coordinate system, allows for a direct comparison between the measured and expected (from simulation and control software) beam exposure of the photodiode as a function of time. As shown in Figure 4, a good general agreement between the measured and expect photodiode response was achieved, with the time between the response peaks being in particularly good agreement (some offsets are expected due to the low accuracy of the absolute spatial calibration in this test).



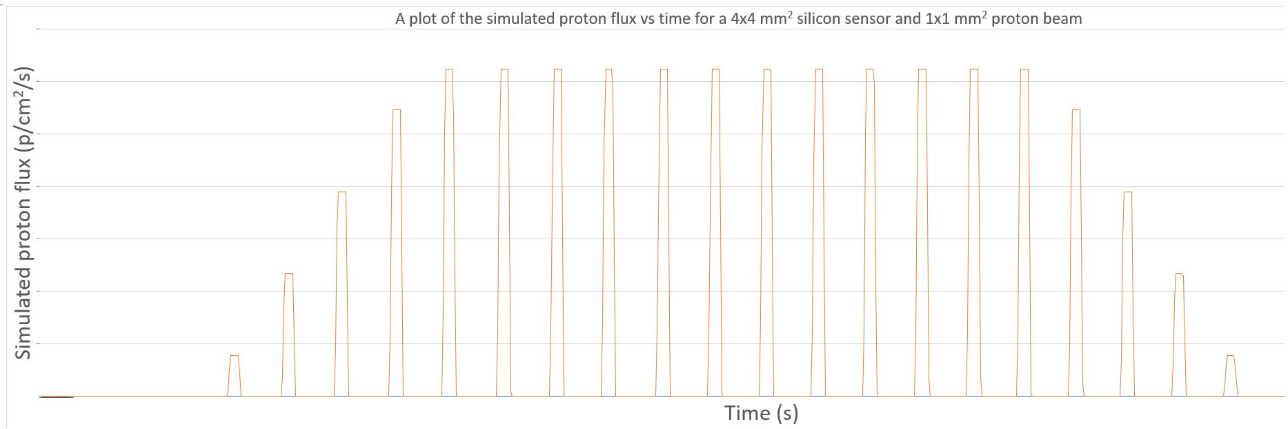


Figure 4 - Comparison of measured (top, blue) and expected (bottom, orange) photodiode response, during a mock irradiation of a photodiode with a collimated laser beam.

Various beam scanning patterns and stage speed combinations were tested, with the stability of the agreement between the expected and observed beam positions being compared throughout. This led to the confirmation that the assembled system was able to perform with high accuracy up to the required scanning speed of 10 mm / s and beyond, without vibrations or other mechanical issues affecting its performance.

4. SUMMARY AND OUTLOOK

The milestone associated with the completion of design, procurement, assembly and laboratory commissioning of the new sample scanning system for proton irradiation beam line at the University of Birmingham MC40 has been successfully met. The system is now ready for integration into the beam hall for commissioning activities with the proton beam to begin. This phase of the commissioning is expected to begin in late 2024, once an appropriate time window to pause routine irradiations for the ATLAS ITk strip sensor QA programme can be identified. Once the new sample scanning system has been fully commissioned at the irradiation facility, expected in early 2025, work will turn towards the final aspect of the upgrade, namely the dedicated secondary beam monitor.

5. REFERENCES

[1] P. Wolf, D. Sauerland, R. Beck and J. Dingfelder (2024), “A beam-driven proton irradiation setup for precision radiation damage tests of silicon detectors”, Nucl. Instrum. Meth. A 1064, 169358

ANNEX: GLOSSARY

Acronym	Definition
LHC	Large Hadron Collider
ATLAS	The ATLAS experiment at the CERN LHC
ITk	The upgrade of the ATLAS inner tracking system for high luminosity operations.