TUPP32

DEVELOPMENT OF NOVEL NON-DESTRUCTIVE 2D AND 3D BEAM MONITORING DETECTORS AT THE BERN MEDICAL CYCLOTRON*

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ABSTRACT

The Laboratory for High Energy Physics (LHEP) at the University of Bern is developing novel beam monitoring detectors for the 18 MeV medical cyclotron in operation at the Bern University Hospital (Inselspital). A 2D non-destructive beam monitor - named π^2 - was developed, based on a thin aluminum foil coated with P47 scintillating material and a camera. It measures the transverse position, shape, and intensity of the beams for several applications, as radiation hardness or radioisotope production studies. This detector allows the processing of data in real time and a reconstruction of the transverse phase space. Based on the π^2, a first prototype of a 3D beam monitoring detector - named π^3 - was conceived, constructed, and tested. It is based on the same scintillating foil mounted on a movable support with a miniaturized camera. The π^3 detector allows for the study of the beam evolution along a beam line, even inside a magnet, and the reconstruction of the beam envelope. In this paper, we report about the design, construction and beam tests performed with these two detectors. Further developments will be also presented and discussed.

INTRODUCTION

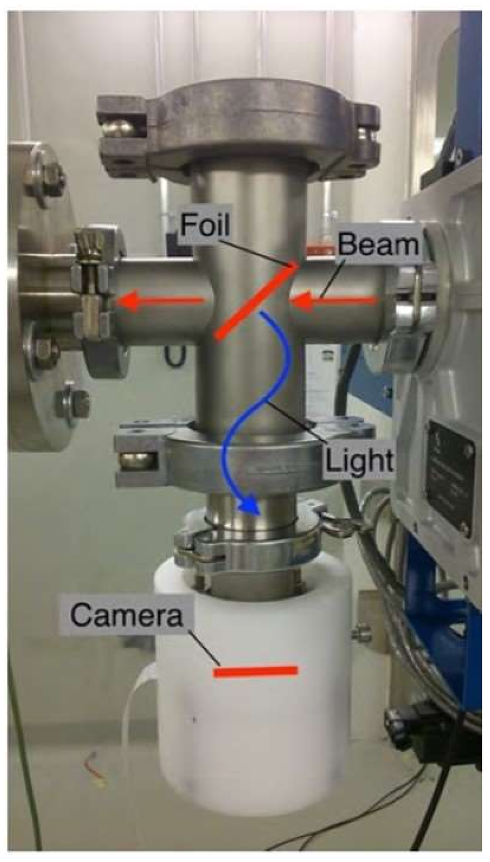
For some medical cyclotron applications, like the irradiation of small and expensive solid targets [1], non-destructive beam monitors are essential.

At the Bern medical cyclotron, three different beam monitors have been developed by the LHEP: (1) the UniBEaM [2], which is used to measure the beam transverse profile by means of a moving scintillating fiber; (2) Tthe π^2 detector, based on a fixed scintillating foil and a camera, which allows to measure the beam spot in 2D; and (3) the π^3, which is the first prototype of an evolution of the π^2 detector, where both the scintillating foil and the camera are mounted in a moving support to allow assessing the beam evolution along the beam path.

Beam tests of the π^2 and π^3 beam monitors were performed using the 6 m long BTL [3] and the 18 MeV proton beam delivered by the Bern medical cyclotron.

THE π^2 BEAM MONITOR

The π^2 detector consists of a phosphor screen and a camera to control the beam, for beam currents in the range between pA and several µA. The scintillating screen has a tilt angle of 45° with respect to the beam path. It has a diameter of 20 mm, and consists of a 0.8 µm aluminium foil coated with a 1 µm layer of P47. It can be moved away from the beam path thanks to a remotely controlled pneumatic system [4].

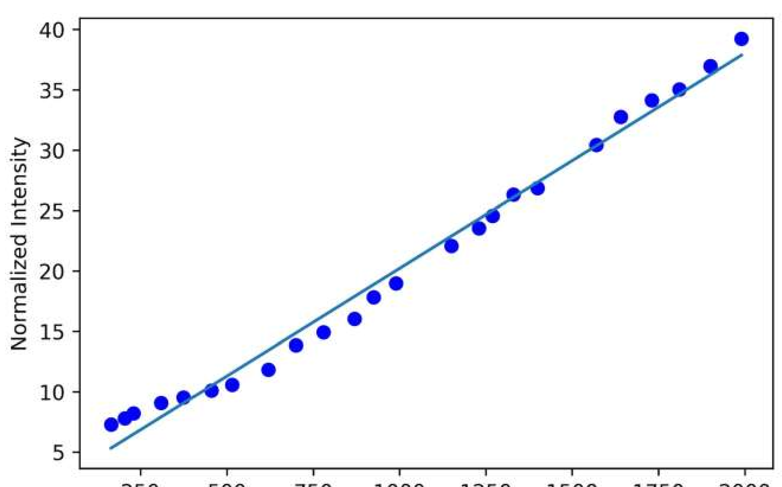


The camera used for this detector is a Raspberry Pi Camera Module V2 [5], which is equipped with a 8 megapixel CMOS sensor [6]. The size of the camera is 4.6 mm (diagonal). The camera can capture images with a resolution of 3280 × 2464 pixels.

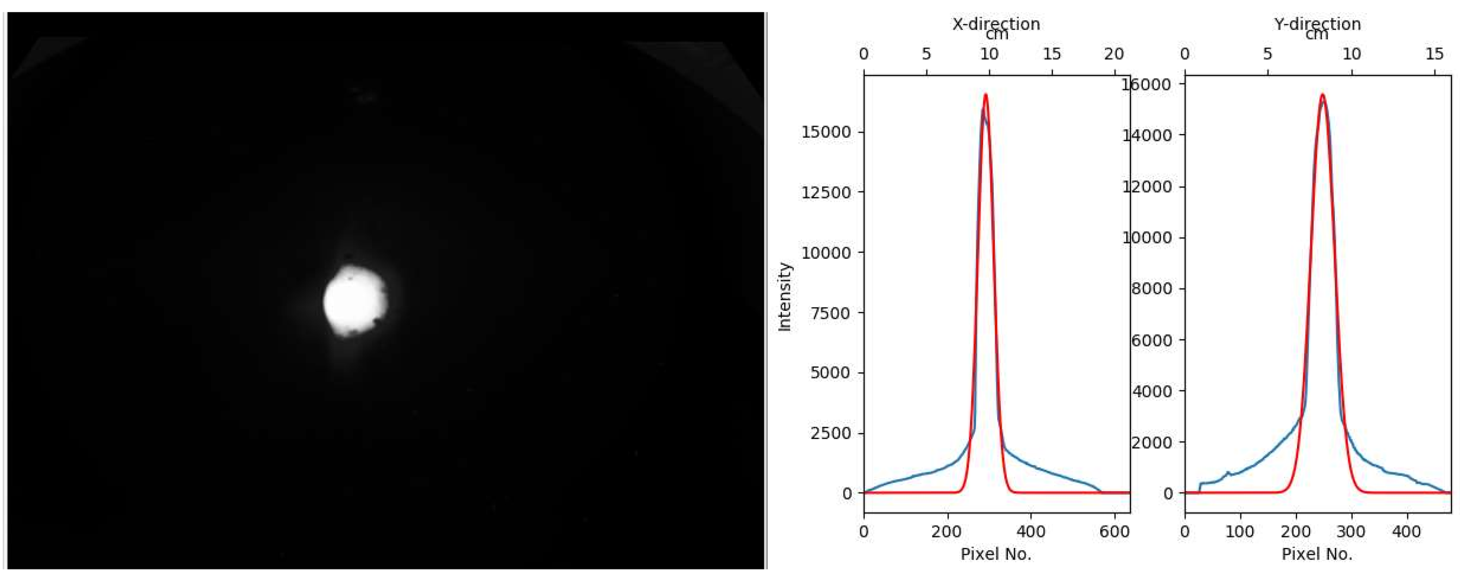
The π^2 hardware is a common design which was already used in some other accelerator facilities [7]. However, the pre-processing and analysis software represents a step forward in the analysis of the images provided by this type of detectors.

The π^2 software

- **Evaluation of beam position, beam size and beam current.** The analysis software allows for the correction of the perspective of the captured image. It also converts pixels to mm. The total intensity of the image is calculated and then normalized to the camera gain and exposure time in order to determine the beam current. The range of beam currents at which a linear response of the π^2 can be expected was found to be from ~ 500 nA to ~ 2µA.



- **GUI for a real-time view of the 2D beam spot and real-time measurement** of the beam position, beam size and beam current, by means of a 1D Gaussian fit of the beam projections.



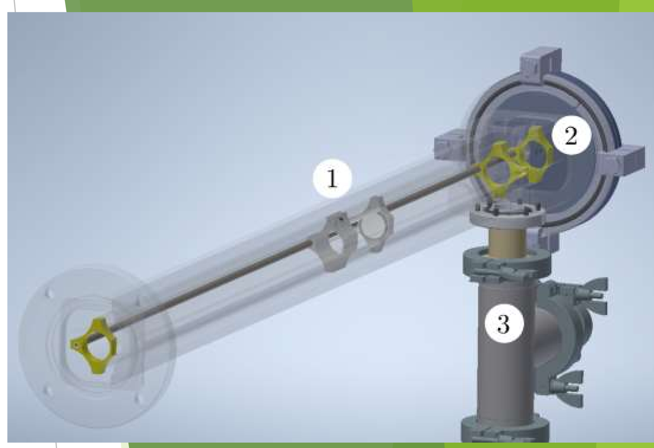
- **Tuning of the BTL magnet currents with the π^2.** In order to ease the tuning of the BTL optics, a ML library of Python (scikit-learn) has been used to train a multi-output linear regression model providing the optics configuration required for a given beam width.

- **Phase space reconstruction.** A software to reconstruct the transverse phase space by using several projections at different angles (tomography) is presently being developed.

THE π^3 BEAM MONITOR

The π^3 beam monitor is based on a scintillating foil mounted on a moving support together with a camera, which allows to reconstruct the beam distribution along the beam path, providing either an online video or a graphical reconstruction of the beam envelope. At the Bern medical cyclotron, the π^3 first prototype has been used to characterize the beam inside the MBL [8]. The MBL consists of a movable ensemble of one quadrupole doublet and two embedded steering magnets, mounted on a beamline of ~ 1 m long. This compact instrument will be used to irradiate solid targets and produce non-standard radioisotopes for medical and nuclear physics.

For the π^3 detector, the scintillating foil is placed in one of the edges of the movable support (1), and the camera in the other one. The camera is a KKMoon 5 mm 2 m Mini Digital USB Endoscope Inspection Camera, with a diameter of 5 mm. The resolution of this camera is 640 × 480 pixels and it can record videos at 8 FPS. A stepper motor (2) is used move the support along the MBL by means of an endless screw. A pulley system is used to pull the cable of the camera when it moves backwards along the MBL (3).

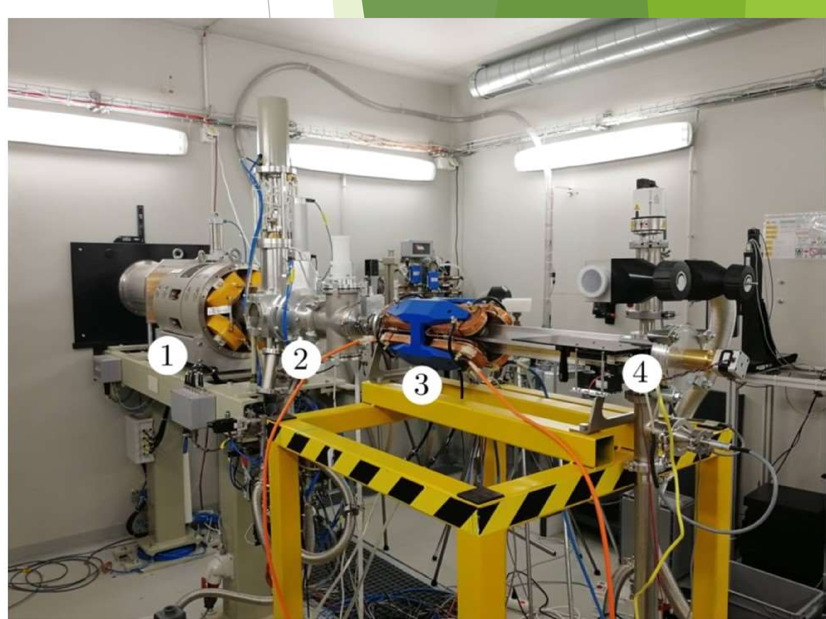


The π^3 software

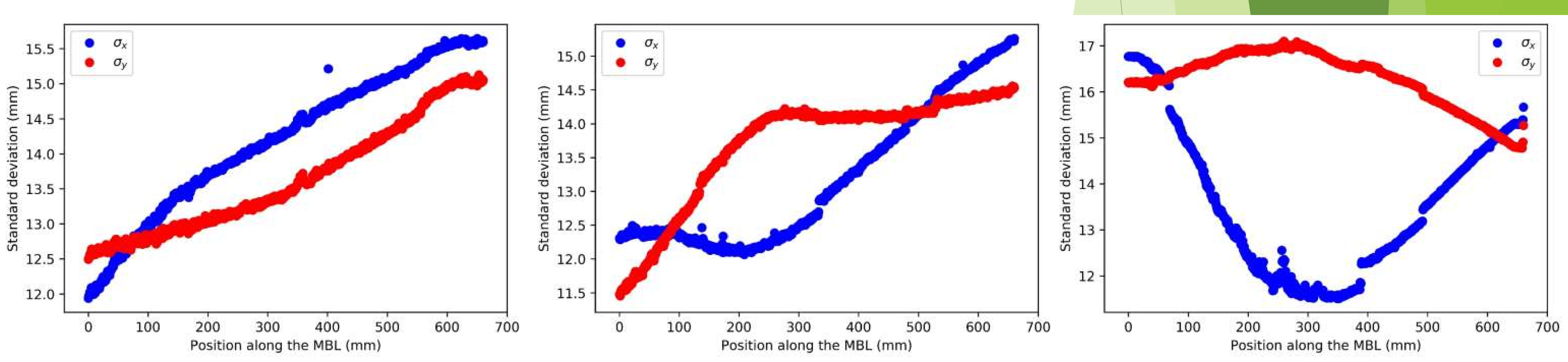
During a measurement, the support is moved for a given distance and the camera view is recorded at the same time. Images can be analysed after pre-processing is applied, including a perspective correction and the application of a circular mask. The goal of the analysis program is to fit a 2D Gaussian distribution to all the individual images to reconstruct the beam shape at each acquired position inside the MBL.

First beam tests

The π^3 prototype was installed in the BTL of the Bern cyclotron. In the figure below, the following parts of the setup are visible: (1) one of the two BTL quadrupole doublets, (2) the π^2 detector, (3) the integrated magnets of the MBL, and (4) the controller and motor of the π^3.



The π^3 beam monitor has been able measure the evolution of the beam width along the MBL, for a length of 660 mm, with several magnet configurations. For the first configuration, the beam was focused by the BTL magnets, whereas the MBL magnets were disabled. The sigma of the beam distribution increases in both planes, as expected in a drift space. In the second case, the beam is focused at the MBL entrance by the BTL magnets and refocused by the MBL magnets. In this case, the sigma inside the MBL shows the effect of the MBL quadrupoles, both with a current of 40 A. The net effect is a focusing in the vertical plane. In the third case, when a flat beam enters the MBL, the MBL magnets are able to slightly reduce the sigma in both planes, when the first quadrupole is disabled and the second one has a current of 75 A.



CONCLUSIONS AND OUTLOOK

Two types of beam monitoring detectors have been developed at the LHEP, both using a scintillating foil and a camera to image the beam cross-section and measure beam position, size and current. The first detector, named π^2, is already used in a daily basis at the BTL of the Bern medical cyclotron. It is used to control the beam in experiments where beam currents from about hundred nA to a few µA are required. A complete Python software and a GUI have been developed for this detector, allowing additional features such as the tuning of the BTL magnet currents on-line and reconstruction of the transverse phase space. The second detector, named π^3, is a first prototype that has been tested with the BTL. The main differences between the π^2 and the π^3 detectors are the movable support of the π^3, which holds together the scintillating foil and the camera, and allowed to study the beam evolution along the MBL, and the location of the camera outside and inside the vacuum chamber, respectively. The results of the first beam tests show that the π^3 monitor can successfully be used to study and understand the effects of the optics of a beam line on an ion beam. Further developments of these two detectors are ongoing.

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