ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPORI01

A MULTI-CAMERA SYSTEM FOR TOMOGRAPHIC BEAM DIAGNOSTICS

A. Ateş*, G. Blank, H. Hähnel and U. Ratzinger
Institute of Applied Physics, Goethe University, Frankfurt, Germany

Abstract

A prototype of a beam-induced residual gas fluorescence monitor (BIF) has been developed and successfully tested at the Institute of Applied Physics (IAP) at the Goethe University Frankfurt. This BIF is based on ten single-board cameras inserted into the vacuum and directed onto the beam axis. The overall goal is to study the beam with tomography algorithms at a low energy beam transport section. Recently, we tested the detector with a 60 keV, 33 mA hydrogen beam at 20 Hz and 1 ms puls length. In this paper we present the ongoing investigations on image processing and application of the algebraic reconstruction technique (ART).

INTRODUCTION

Beam-induced fluorescence (BIF) monitors are standard detectors at accelerator facilities [1]. For ultrahigh vacuum beam diagnostics, scientific cameras are commonly used in combination with MCP photon amplifiers to determine the beam position and profile. New BIF monitors have been successfully tested at the low-energy beamline of the Frankfurt Neutron Source at the Stern Gerlach Center [2]. These developments lead to new ways to study the beam. One idea is to view the beam from multiple angles. This allows the use of tomography algorithms to reconstruct the intensity distribution of the transverse beam profile. Beam tomography has previously been studied using a camera and a rotating vacuum chamber to rotate the camera and obtain any number of views. Another approach is to view the beam through viewing windows.

Our goal is to maximize the number of viewing angles and develop a fast tomographic detector with minimal size to be as flexible as possible. Our approach is to use non-scientific single-board cameras with single-board computers and integrate the system into the vacuum. Figure 1 shows a photo of the cameras mounted on the holder. It is designed to fit into a vacuum chamber with a diameter of 200 mm and a length of 300 mm.

The detector is built for low energy beam transport sections in high vacuum regions of about 10^{-7} mbar. To amplify the emitted light, a buffer gas can be introduced during image acquisition. We introduced argon gas and tested the cameras at a residual gas pressure of up to 1×10^{-4} mbar. Figure 2 shows the position of the tomography detector. This position is of particular interest since the RFQ will be placed at this location.

There were several challenges to overcome in developing such a detector. One challenge was to have all the cameras work in parallel and transmit all the data from the vacuum. Another challenge was to align all cameras so that the center

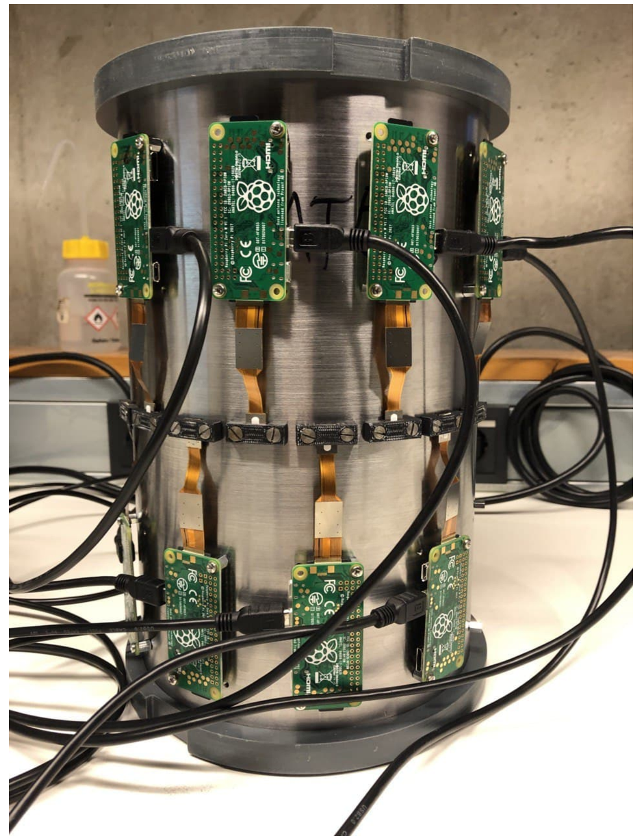

Figure 1: The picture shows a photo of the tomography detector with the Raspberry Pi Zero and its camera modules attached to a stainless steel pipe.

of their field of view matched. For more information about calibration and alignment, see [3].

HARDWARE SET UP

Raspberry Pi Zero and its Camera

The cameras you see in Fig. 1 are single-board cameras with so-called Raspberry Pi Zero single-board computers. The Raspberry Pi Zero is the one with the smallest dimensions among the Raspberry Pi computer models. The computer and especially its camera are gaining more and more attention not only in the Maker scene, but also in the scientific community [4]. Due to its compact dimensions and low power consumption of about 15 mW, they are predestined for projects like drones, robots or any mobile devices. The camera consists of a 5 MP high resolution Omnivision OV5647 CMOS image sensor. The sensor size is 3.76 mm × 2.74 mm and has a pixel size of 1.4 μm × 1.4 μm. It has a focal length (3.6 mm) with a single aperture (F2.9). The sensor sensitivity can be varied between ISO values from 100 to 800, and it is possible to vary the analogue gain of the ADC for the blue and red color pixels, i.e. to change the white balance

* ates@iap.uni-frankfurt.de

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPORI01

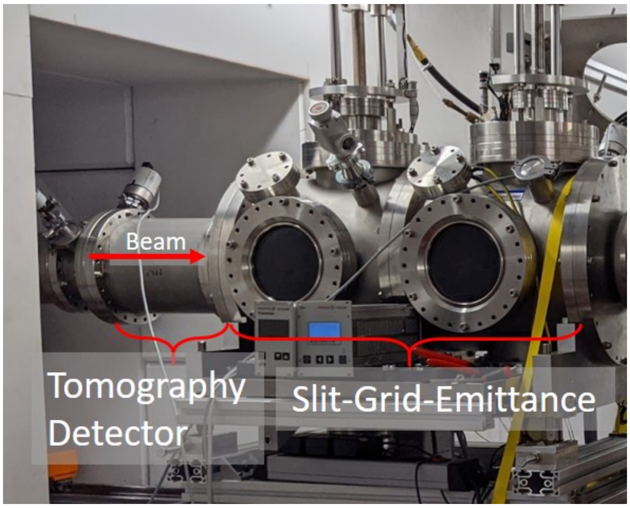

Figure 2: The tomography detector is located in the vacuum chamber behind the last solenoid of the LEBT section. Immediately after the detector is a slit grid emittance detector and a beam dump.

manually. The camera has been tested in high vacuum up to 1×10^{-7} mbar and in strong magnetic field (up to 0.6 T) [5].

Powering and Communication with the Cameras

A wireless connection was used to control the cameras. A Raspberry Pi with an external WIFI antenna was installed as an access point. All ten cameras connect wirelessly as devices to the access point. The controller sends the command to capture the image, and the devices send the image back to the controller. At this point, initial image processing can be performed before all images are sent to the main laboratory computer for further processing and application of tomographic reconstruction algorithms. The main controller is not located inside the vacuum, only the external antenna. Therefore, only two pins for the power supply and five pins for the USB port were needed to control the tomography detector. For beam operation, an electromagnetically compatible circuit (EMC) is required to transmit the data from the vacuum and to protect the devices from flashovers.

TOMOGRAPHIC RECONSTRUCTION

The development of tomographic reconstruction algorithms, especially in accelerator facilities, is a current scientific topic [6]. Time and resource efficient software has been developed in different laboratories. Here we use the python-based software toolbox Tomopy [7]. Most of the commonly used tomographic reconstruction algorithms such as Algebraic Reconstruction Tomography (ART) or Filtered Back Projection (FBP) are implemented here. Unlike the usual detectors with an X-ray source rotating over the object and creating as many profiles as necessary, here we have limited viewing angles. The ART algorithm was developed for iterative reconstruction of objects examined at a particular viewing angle [8]. In contrast, the filtered back projection is better suited for unlimited viewing angles. For this reason, the ART algorithm was used to evaluate detector calibration for an initial test.

EXPERIMENTAL RESULTS

The proof of the detector concept was tested on a hydrogen beam with 60 keV, 33 mA at 20 Hz and 1 ms pulse length. There is no momentum filter at the beamline, so all three types of hydrogen beams (p, H_2^+, H_3^+) were transported. Figure 3 shows a false-color profile of the beam recorded by camera 8.

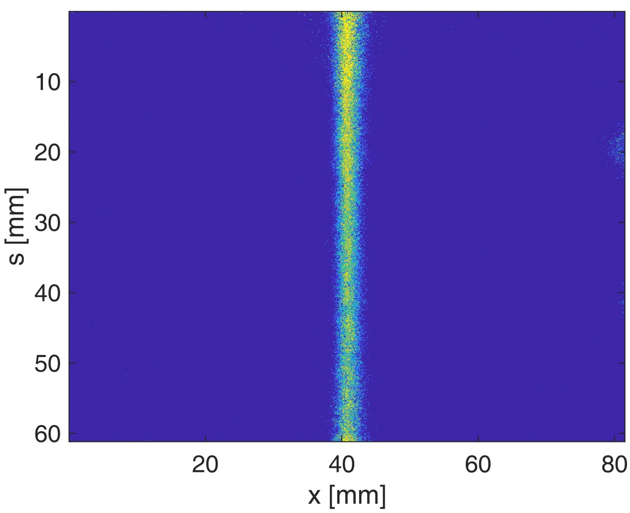

Figure 3: False color image of the beam profile.

After performing the tomopy algorithm, the reconstructed section of the beam is obtained, as shown in Fig. 4. Here one can see that the beam is not radially symmetric. This asymmetry is due to the limited number of profiles. After fitting the image with a Gaussian function, the beam center is obtained at 41.7 mm in the x-direction and 41.4 mm in the y-direction and a beam diameter of 3.6 mm.

An advantage of the tomography detector is the possibility to examine an asymmetric beam or even two beams. Since the hydrogen beam consists of three species, a magnetic steerer was used to shift the beam. The three species are then shifted depending on their momentum. Figure 5 shows such a situation, where two of the three species are shifted against each other and transported in parallel.

This can also be seen in the reconstructed slice. While the study of two parallel beams from the x and y directions would be difficult, the position and diameter could be studied in a tomographic system. Figure 6 shows the reconstructed intensity distribution. And Fig. 7 after fitting the intensity distribution with two Gaussian functions.

CONCLUSION

In this paper, a tomographic BIF detector for ion beam investigations is presented. This BIF is based on ten single-board cameras on a tube concentric to the beam axis and held by the outer vacuum tube. After securing the data transmission by an EMC circuit and camera calibration for real scaling, the detector was ready for the first beam test.

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPORI01

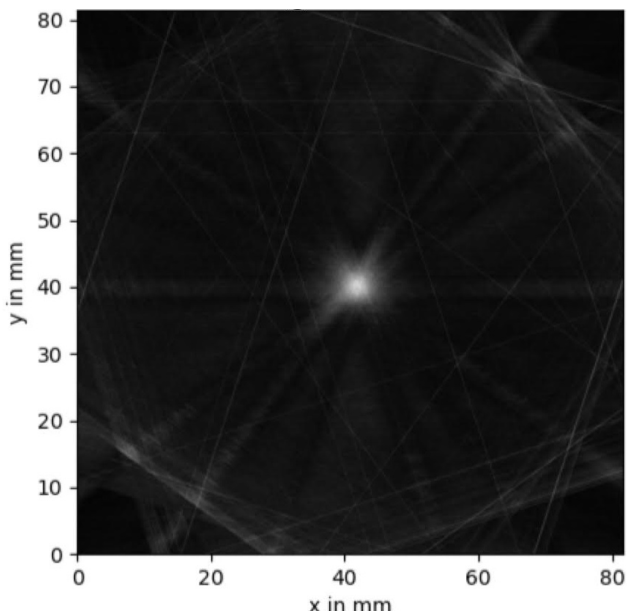

Figure 4: A tomographic slice of the beam profile. The asymmetry of the intensity distribution follows from the limited number of profiles [9].

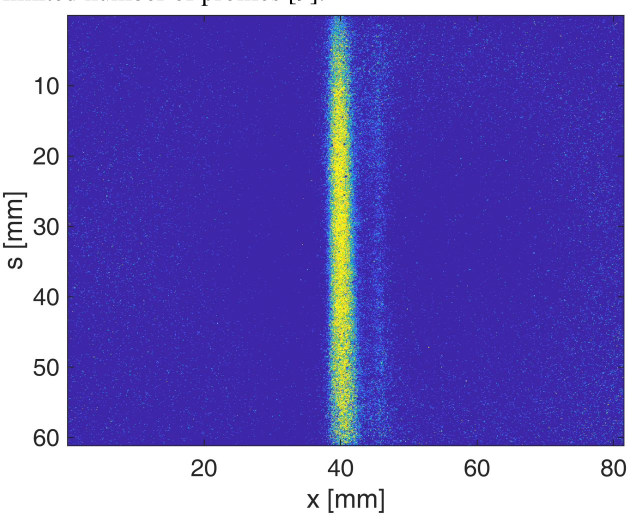

Figure 5: Two species of the hydrogen beam are shifted dependent on their momentum by a magnetic dipol steerer.

A hydrogen beam with its three species (p, H_2^+, H_3^+) was successfully investigated with the detector. The tomographic reconstruction algorithm ART could be applied to the data set using the Tomopy software. The intensity distribution of the reconstructed beam shows asymmetric artifacts. The reason for the artifacts is the limited number of profiles. Despite these difficulties, it was possible to investigate a two-beam scenario where two types of the hydrogen beam could be shifted against each other.

Studies are currently underway to improve image pre-processing and the choice of the right tomography algorithm. The tomography software even provides options to remove the characteristic stripes that lead to an asymmetric intensity distribution. This feature and different ways to filter the images to improve the reconstruction process are current topics of this project.

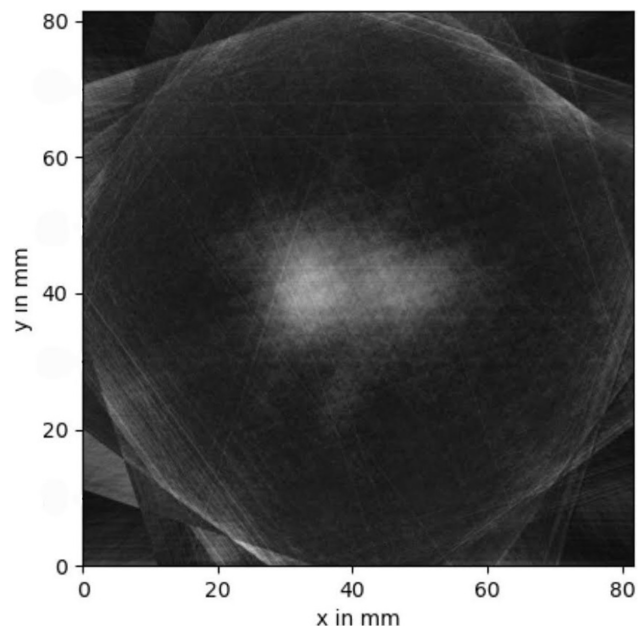

Figure 6: Tomographic reconstrucion of the two beam scenario [9].

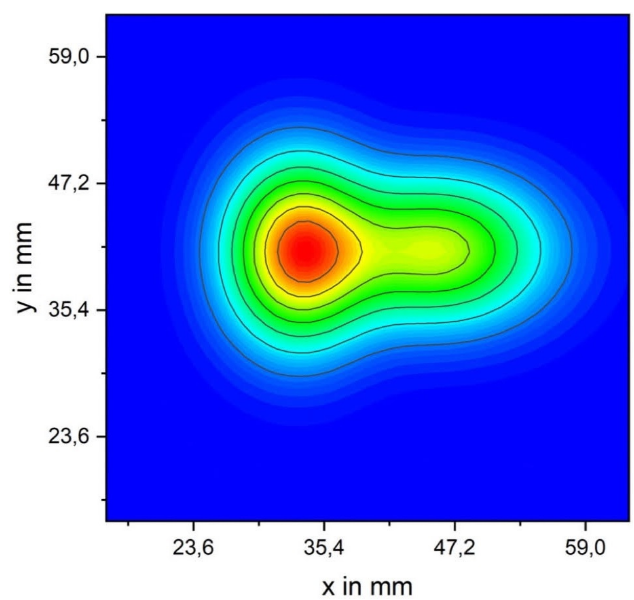

Figure 7: 2D contour plot of the two-beam distribution fitted by two Gaussian functions [9] .

REFERENCES

[1] P. Forck, C. Andre, F. Becker, D. Hoffmann, and H. Iwase, "Profile Measurement by Beam Induced Fluorescence for 60 MeV/u to 750 MeV/u Heavy Ion Beams", in *Proc. EPAC'06*, Edinburgh, UK, Jun. 2006, paper TUPCH010, p 1013.

[2] S. Alzubaidi *et al.*, "The Frankfurt neutron source FRANZ", in *Eur. Phys. J. Plus*, vol. 131, p. 124, 2016. doi:10.1140/epjp/i2016-16124-5

[3] A. Ate, G. Blank, U. Ratzinger, and C. Wagner, "Development of a Multi-Camera System for Tomography in Beam Diagnostics", in *Proc. IBIC'21*, Pohang, Korea, Sep. 2021, paper TUPP07, pp. 201.

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPORI01

[4] M. Pagnutti *et al.*, "Laying the foundation to use Raspberry Pi 3 V2 camera module imagery for scientific and engineering purposes", *J. Electron. Imaging*, vol .26, no. 1, p. 013014, 2017. doi:10.1117/1.JEI.26.1.013014

[5] A. Ates *et al.*, "Non-invasive diagnostics of ion beams in strong toroidal magnetic fields with standard CMOS cameras", *Nucl. Instr. Phys. Res. A*, vol. 877, pp. 69–73, 2018. doi.org/10.1016/j.nima.2017.09.020

[6] D. M. Pelt *et al.*, "Integration of TomoPy and the ASTRA toolbox for advanced processing and reconstruction of tomographic synchrotron data", *J. Synchrotron Radiation*, vol. 23, pp. 842–849, 2016. doi:10.1107S1600577516005658

[7] D. Gürsoy *et al.*, "TomoPy: a framework for the analysis of synchrotron tomographic data", *J. Synchrotron Radiation*, vol. 21, pp. 1188-1193, 2014. doi:10.1107/S1600577514013939

[8] J. S. Fraser, "Beam Tomography or Art in Accelerator Physics", Los Alamos, USA, Los Alamos Scientific Laboratory Report LA-7498-MS, 1978.

[9] G. Blank, "Optische Tomographie mit einem Multikamerasystem für intensive Ionenstrahlen", Bsc thesis, Institute of Applied Physics, Goethe University, Frankfurt a.M, Germany, 2022.