ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB282

DEVELOPMENT OF A MULTI-CAMERA SYSTEM FOR NON-INVASIVE INTENSE ION BEAM INVESTIGATIONS

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Abstract

The continued popularity of miniaturized cameras integrated into smartphones is leading to further research for more advanced CMOS camera sensors. This made CMOS technology even superior to scientific CCD cameras. Due to the lower power consumption and high flexibility, a multi-camera system can be developed more effectively. At the Institute of Applied Physics at Goethe University Frankfurt (IAP) a prototype of a beam induced rest gas fluorescence monitor (BIF) was developed and tested successfully. The BIF consists of x and y single board cameras integrated into the vacuum chamber. A multi-camera system was installed in the LEBT area of the FRANZ project at the IAP within the first diagnostic chamber. This system consists of six cameras. With this equipment it is possible to investigate the beam along a 484 mm path in x and y direction. The developments on the reconstruction and image processing methods are in progress.

INTRODUCTION

Developments on the Frankfurt Neutron Source at the Stern-Gerlach-Zentrum FRANZ are ongoing [1]. A new Cold Reflex Discharge Ion Source (CHORDIS) provided by GSI Darmstadt was delivered and successfully installed [2]. In addition to this ongoing work, investigations are being conducted on new detectors for beam position and profile measurement. Beam induced fluorescent monitors (BIF) were placed after the first Solenoid within the first diagnostics chamber to test and verify the performance of the new CHORDIS ion source. BIF-Monitors are standard detectors at accelerator facilities. For beam diagnostics in ultra-high vacuum, scientific cameras are commonly used to determine the beam position and profile. Due to the working gas of the ion source, this is a high vacuum region of about 1×10^{-5} mbar. The challenge was to investigate the beam along a 484 mm long path, with the goal of reconstructing the beam position, profile and, within certain limits, emittance without a beam interrupting detector. For this purpose, six single-board cameras including six single-board computers were installed in the vacuum chamber.

EXPERIMENTAL SET UP

FRANZ Beamline Set up

Six of these cameras are integrated into the first diagnostic chamber (D1) in FRANZ LEBT section. The CHORDIS is attached directly to the first solenoid (Sol1). The Sol1 is then attached to D1 which is pumped by one 1 900 l s^{-1} turbomolecular pump. The base residual gas pressure is approx. 8×10^{-8} mbar; at ion source operation it is increased to about approx. 1×10^{-5} mbar. For a short time during camera operation, argon buffer gas is inserted up to a residual gas pressure of 1×10^{-4} mbar. On the D1 there is a movable high power Faraday Cup (FC) with secondary electron suppression for beam power up levels to 24 kW. This FC is used for beam current measurements and as a beam dump. Figure 1 shows the D1 with the cameras in green.

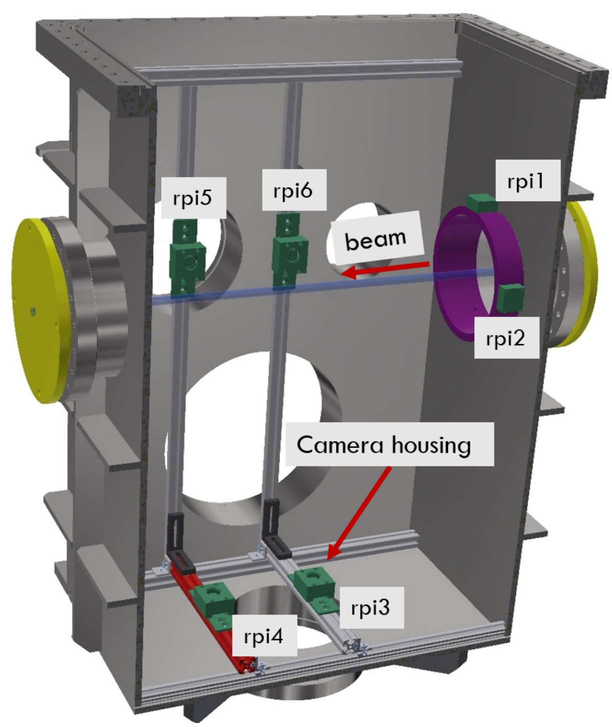

Figure 1: The image shows the first diagnostic chamber after the first solenoid in the FRANZ LEBT section. Six cameras are mounted along the beamline for continuous beam position determination.

The camera *rpi1* and *rpi2* on the purple cylinder (Fig. 1) are placed between the FC and the entrance of D1. This makes it possible to observe the beam even during positioning the FC on the beam line. The filament driven CHORDIS ion source can be operated in either AC or DC mode but AC mode is used for beam diagnostic studies. The cathode consists of six tungsten filaments and is located inside the discharge chamber. 18 cobalt samarium permanent magnets around the chamber form a minimum B configuration. The extraction has a single aperture although a multi aperture system is possible. Thus, the parameters to control the ion source are cathode current (up to I_{Fil} = 220 A), anode power

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12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB282

(up to U_{Bog} = 220 V and I_{Bog} = 50 A), extraction voltage (up to U_{ex} = 35 keV), duty cycle and working gas pressure.

Raspberry Pi Camera

A Raspberry Pi camera is used as the BIF monitor. The Raspberry Pi and its camera in particular are attracting more and more attention not only in industry as an IOT device for machine vision projects, but also in science [3]. The camera consists of a 8 MP high resolution SONY IMX219 CMOS image sensor. The sensor size is 5.095 mm × 4.930 mm and has a pixel size of 1.12 µm × 1.12 µm. The sensor is back-illuminated, which makes it more sensitive. It has a fixed focal length (3.04 mm) with a single aperture (F2.0). The sensor sensitivity can be varied between ISO values of 100 to 800 and it is possible to vary the analog gain of the ADC for the blue and red color pixels, i.e. to change the white balance manually. Figure 2 shows a photo of the camera and the Raspberry Pi itself. The very small form factor of the camera (25 × 24 × 9 mm) and the credit card-sized computer are great advantages for integrating this system into the experiment in hard-to-reach areas. The camera was tested in high vacuum up to 1×10^{-7} mbar and in strong magnetic field (up to 0.6 T) [4].

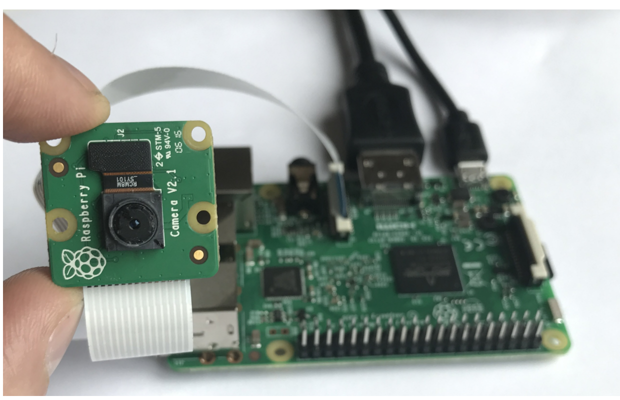

Figure 2: The picture shows the Raspberry Pi Camera v2.1 plugged into the CSI connector of the Raspberry Pi B single board computer via a ribbon cable.

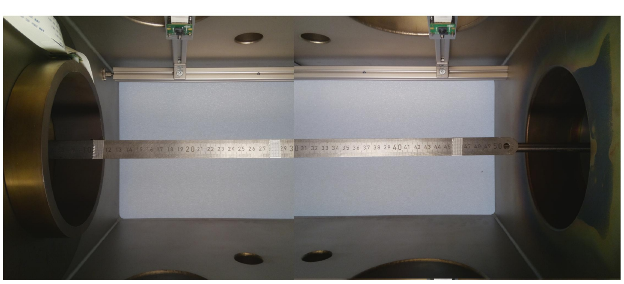

Figure 3: The Images from camera 3 and 4 were merged. The ruler with 0.5 mm spacing was used for scaling.

For mm/px scaling, a ruler was placed in the center of the beam path with an offset of 5 mm (Fig. 3). The lens has a linear scaling so that the offset can be corrected afterwards. The scaling of both cameras for the horizontal and vertical

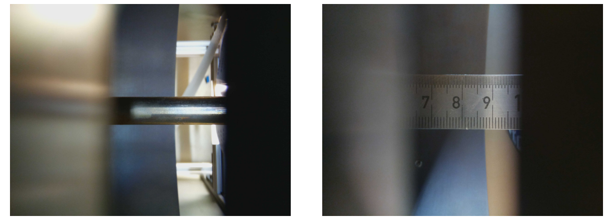

Figure 4: Images from camera 1 (rpi1) and 2 (rpi2).

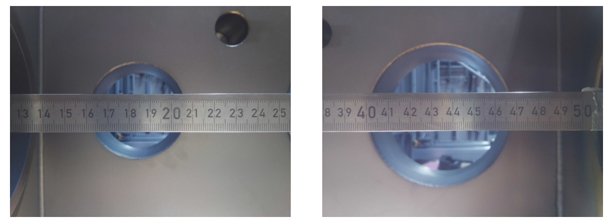

Figure 5: Images from camera 6 (rpi6) and 5 (rpi5).

direction is 0.11 mm/px. In addition, a calibration rod was used to define the beam center and calibrate the alignment of the cameras. The cameras have an offset of approx. 3 px i.e., the calibration rod has an inclination of 0.08° with respect to the beam center path. Figures 4 and 5 show cameras 1, 2, 5, and 6. Cameras 1 and 2 are held at 90° from each other. The fields of view of cameras 5 and 6 have a distance of 124 mm.

EXPERIMENTAL RESULTS

The CHORDIS was operated in AC mode at 10 Hz and a pulse length of 0.5 ms. The beam consists of hydrogen species p, H_2^+ and H_3^+. All species are transported through the LEBT into D1. Figure 6 shows a 35 kev, 45 mA total beam current at a residual gas pressure of 1×10^{-4} mbar argon. The advantage of a multi-camera system is the large field of view. At a solenoid magnetic field of 380 mT, we could see two focal points. A focal point of species H_2^+ seen from camera 3 and another focal point of species H_3^+ seen from camera 4. The focal point of p is outside the field of view for this magnetic field. Due to the previous calibration, both images could be merged and it is possible to view both focal points at the same time (Fig. 6).

This also made it possible to fit the beam envelope from the Tracewin simulation software to the image data. At this stage of the research, there is no suitable algorithm to determine the beam edges within the image. One limit of optical diagnostics is the distinction between image background, beam halo and beam center. For this reason, the adjustment of the Tracewin simulation was done by subjective estimation of the experimenter. In the bottom graph in Fig. 1, an offset between the simulated and experimental data can be seen. Further investigations comparing the simulated data, the optical data, and a third, well-established emittance measurement system such as a slit grid emittance detector will be installed in the near future. To distinguish between the three species, the magnetic field of the solenoid was varied

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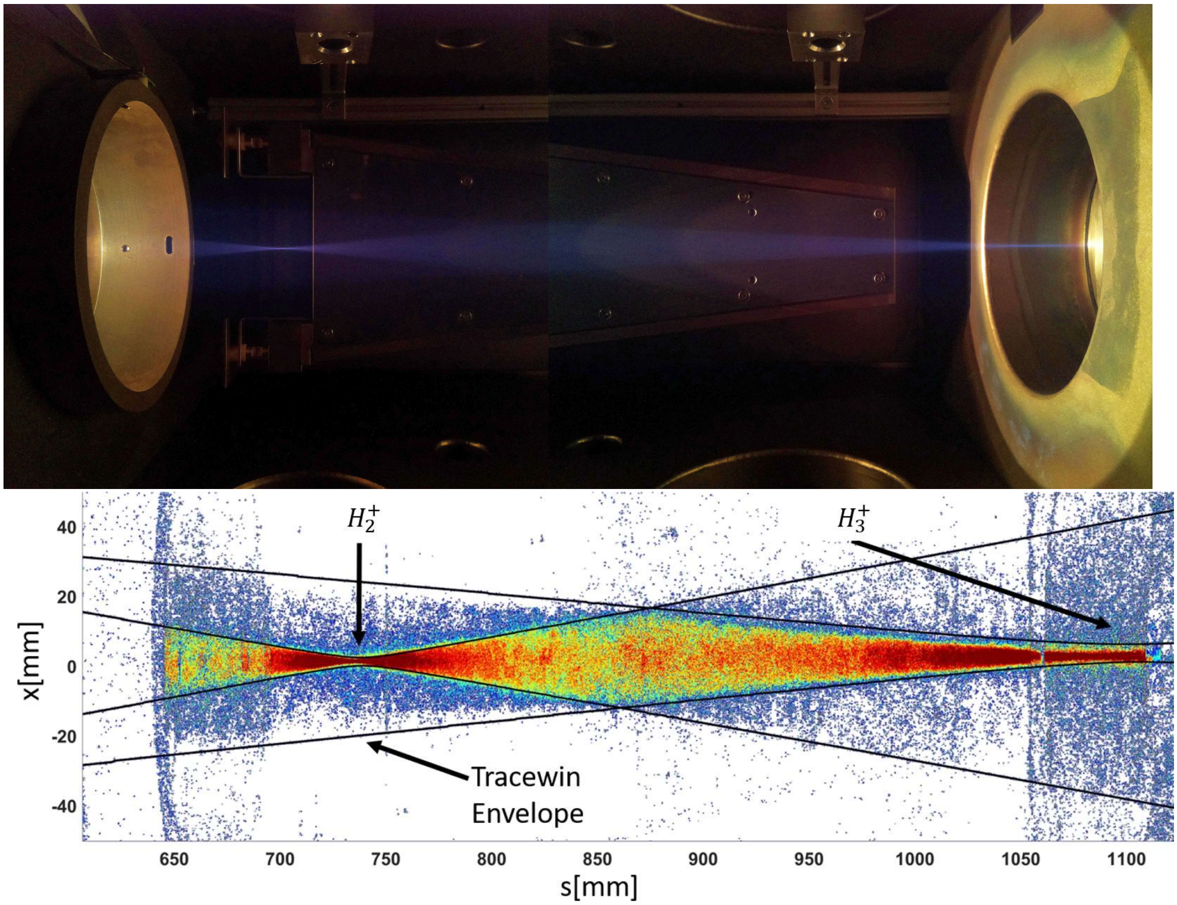

Figure 6: The upper image shows the real image of the two X cameras (rpi3 and 4) stitched together in their original state. The beam goes from left to right. In the background are the y-cameras (rpi5 and 6) and the Faraday Cup. The bottom image shows the processed false color after removing the background and adjusting the scaling. The beam envelopes from the Tracewin simulation (black line) were adjusted to the estimated real ray envelope.

and looked at the three foci of each species at one position. Figure 7 shows that for a magnetic field of the solenoid of 264 mT protons are focused at 160 mm within D1, H_2^+ at 380 mT and H_3^+ at 461 mT. These results could be verified and compared with Tracewin simulations.

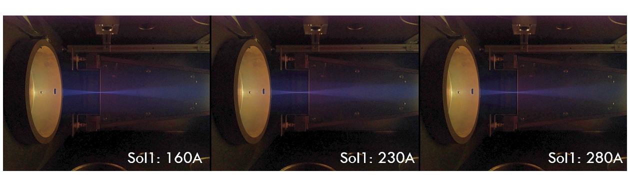

Figure 7: Variation of the magnetic field results in three focal points at one position. From left to right: protons at 264 mT, H_2^+ at 380 mT, H_3^+ at 461 mT.

CONCLUSION

The beam was successfully investigated along a path of 484 mm. The experimental data could be verified by comparison with simulations. For more accurate beam investigations, a beam edge detection algorithm will be developed.

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