TUPP10

Development of a Beam Halo Monitor Using Visible Synchrotron Radiation

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ABSTRACT

A Beam Halo Monitor (BHM) has been developed at Diamond Light Source (DLS). It is an optical system that uses visible synchrotron radiation (SR) to image the beam halo. In this paper, the design of the monitor is presented, including the introduction of a Lyot stop system to reduce diffraction effects. The BHM was used to take images of a source point of visible SR from a dipole at DLS. These images were analysed to investigate the beam halo and determine the limitations of the monitor. These results will help inform the design of the visible light extraction system and any future BHMs for Diamond-II.

Motivation

- Diamond Light Source is an electron synchrotron.
- Most electrons reside in the beam core. However, due to gas and Touschek scattering, some are offset from the core and form a beam halo [1].
- In the case of synchrotron light sources, the beam core determines characteristic parameters such as brightness for beamlines. Therefore a significant beam halo is undesirable. This becomes all the more important upon considering planned synchrotron upgrades, such as Diamond-II, with a higher rate of Touschek scattering.
- DLS has x-ray pinhole cameras that image the beam core, as shown in Fig. 1. We cannot see the beam halo with these – it has about 10^{-5} the intensity of the beam core and the pin hole cameras don't have a high enough dynamic range to see that.

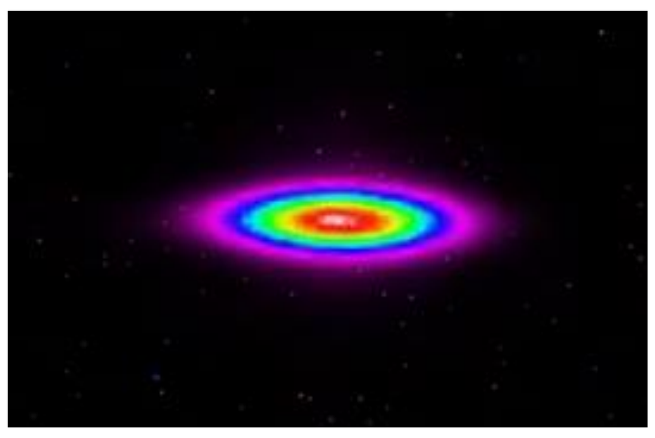

Figure 1: False colour image of the beam core from the x-ray pinhole cameras at 301.7 mA beam current, cropped to area of interest.

First Stage

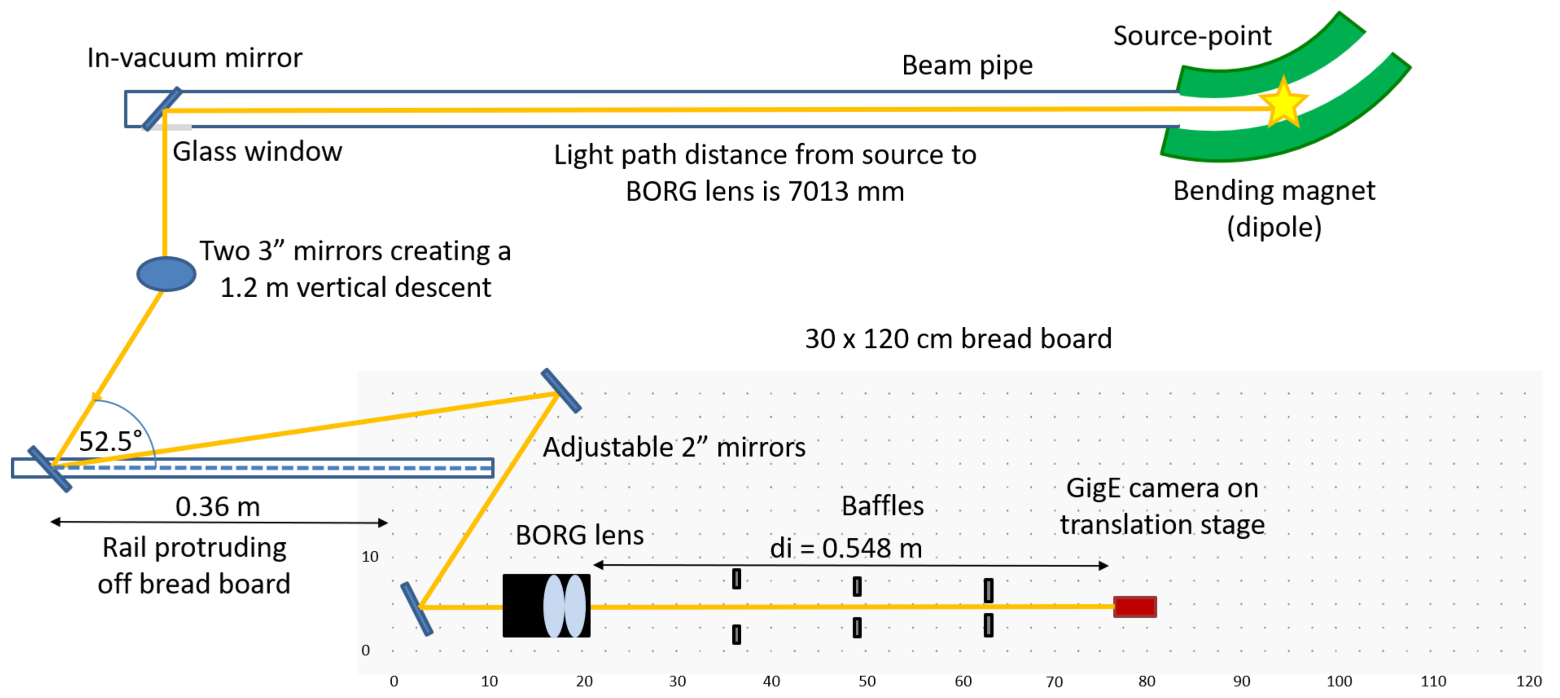

Figure 2: Schematic showing the set up of the beam halo monitor first stage in the accelerator ring, not to scale.

- A simple system using a single high quality lens to focus an image onto the camera with a CMOS sensor was built. It was tested and characterised in the lab using a 1951 USAF target, then installed in the accelerator ring next to the visible light extraction. This is shown schematically in Fig. 2.
- Images were taken of the source point, which is a direct representation of the electron beam.
- A significant diffraction pattern was observed in these images, as shown in Fig. 3. The cross shape of the pattern suggests a rectangular aperture, of which the in-vacuum mirror (IVM) is the only one in the system, shown in Fig. 4.
- We concluded the diffraction pattern was caused by the IVM and, since this mirror cannot be altered, explored ways to mitigate this diffraction.

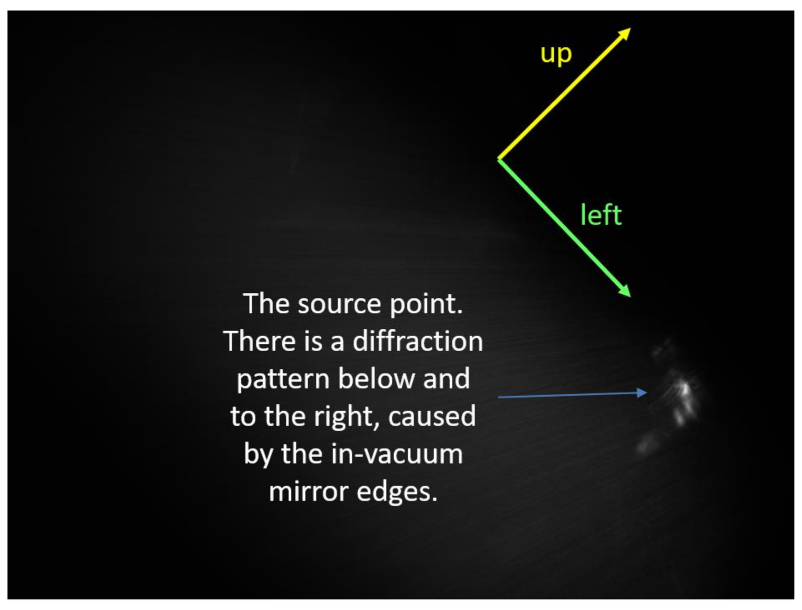

Figure 3: Image of the source point taken using the first stage of the beam halo monitor. The mirrors skew and flip the image, hence the labelled directions.

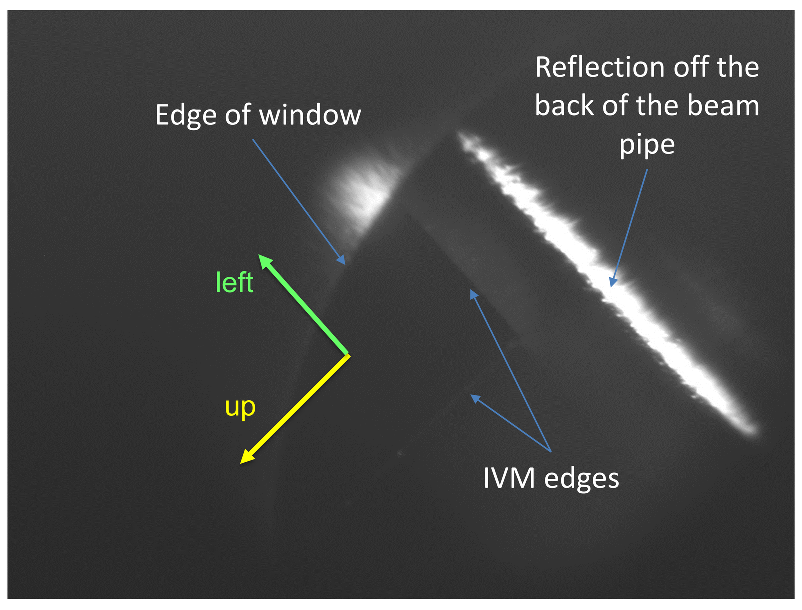

Figure 4: Image of in-vacuum mirror taken using the second stage of the beam halo monitor and by shining a torch through the beam pipe window.

Conclusion and Recommendations

- The in-vacuum mirror causes a significant diffraction pattern that can be reduced, but not completely eliminated by a Lyot stop.
- Therefore it is difficult to obtain significant information on the beam halo using this monitor.
- For an improved beam halo monitor on Diamond-II, an in-vacuum mirror with minimal diffraction, background subtraction via post-processing and/or PSF suppression with a micro mirror array could be considered.

References

[1] A. Piwinski,The Touschek Effect in Strong Focusing StorageRings, DESY 98-179 (1999)
[2] L. C. Chapon et al., Diamond-II Conceptual Design Report, May 2019
[3] T. Mitsuhashi, Beam Halo Observation by Coronagraph. Proceedings of DIPAC 2005, (ITMM03) .

Second Stage with Lyot Stop

- A Lyot stop system uses lenses and an aperture (stop) to reduce diffraction effects by re-imaging the predominant cause of diffraction [3].
- It usually reduces diffraction caused by the first lens aperture, as shown in Fig. 5, but for the beam halo monitor (BHM), the concept was adapted to instead reduce diffraction from the IVM.

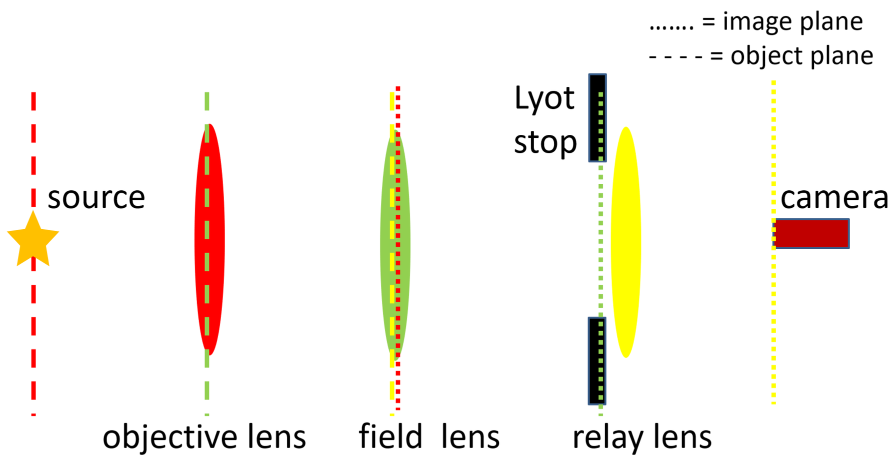

Figure 5: Schematic of a Lyot stop coronagraph used to reduce the diffraction pattern created by the first lens.

- The schematic of the BHM with a Lyot stop included to reduce diffraction effects from the IVM is shown in Fig. 6.

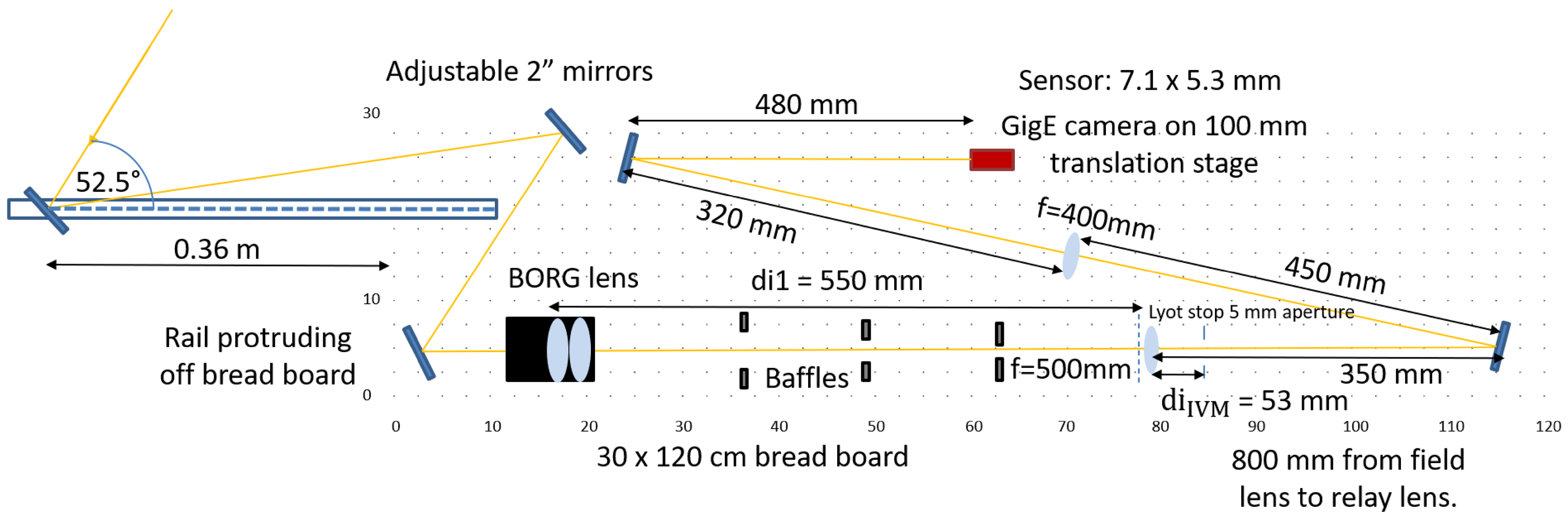

Figure 6: Schematic showing the set up of the beam halo monitor second stage with a Lyot stop system designed to reduce diffraction effects caused by the IVM.

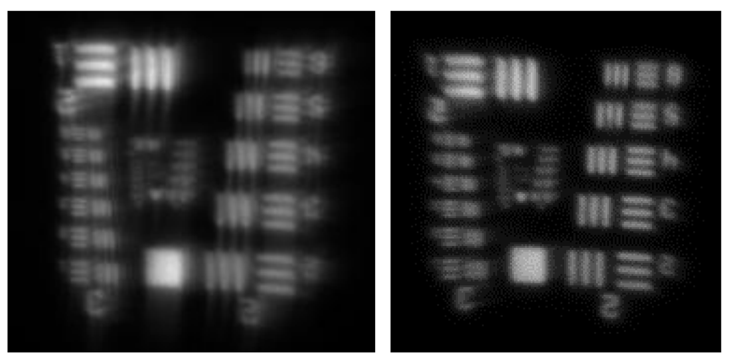

Figure 7: A 1951 USAF imaged through the lab set up with no Lyot stop (left) and with a Lyot stop (right).

- A system similar to the BHM in the accelerator ring was set up in the lab, using a rectangular aperture to replicate the IVM.
- Comparisons of 1951 USAF target images, as in Fig. 7, showed that there was a significant reduction of the diffraction pattern when a Lyot stop system was included, but the image became dimmer.

- The second stage was installed in the accelerator ring and images of the source point were taken.
- As expected, these images showed a significantly reduced diffraction pattern but were dimmer, as seen by comparing Fig. 3 and Fig. 8, which were taken with the same exposure and camera gain.
- However, there was still some diffraction pattern visible.

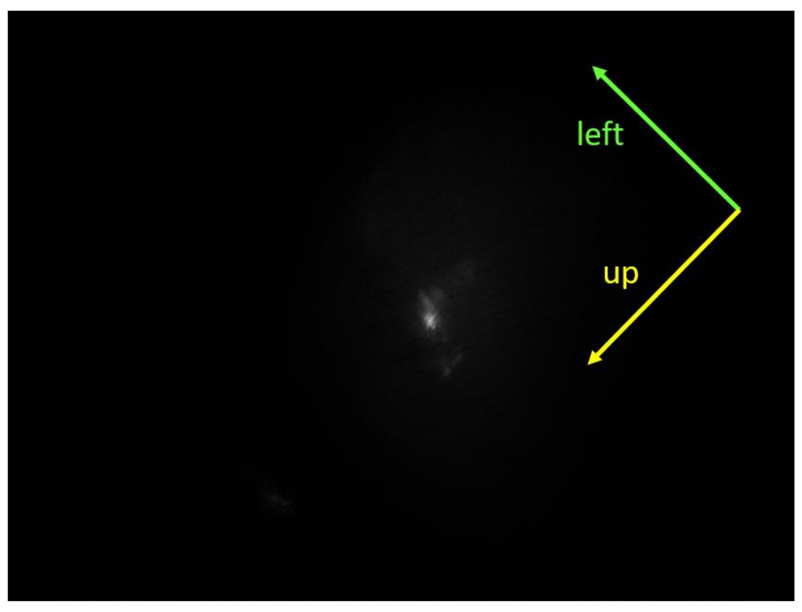

Figure 8: Image of the source point taken using the second stage of the beam halo monitor.

Analysis

- Images were taken of the source point at a range of exposures, which were then combined into a HDR image using matlab.
- Cross sections of the source were taken. Looking at these HDR cross sections, as in Fig. 9, we see some evidence of a beam halo distributed around a Gaussian beam core. However, the background and diffraction pattern caused by the IVM make it difficult to distinguish the beam halo from the background.

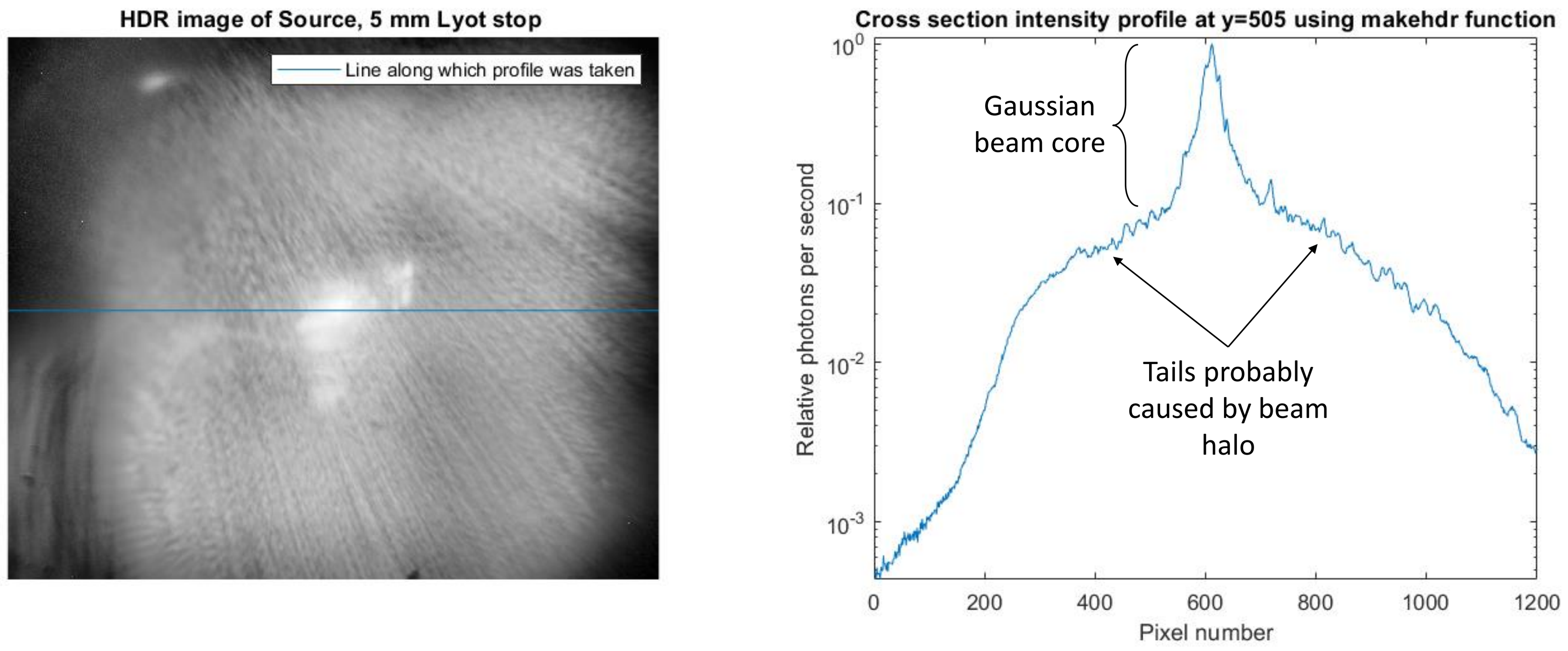

Figure 9: HDR image of the source point area of interest (left) made using matlab 'makehdr' and 'tonemap' functions. The images were rotated and flipped so the orientation appears correct. HDR cross section (right).

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