

FIRST OBSERVATION OF THE LHC BEAM HALO USING A SYNCHROTRON RADIATION CORONAGRAPH

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Abstract

A test coronagraph for the observation of beam halo has been installed in the Synchrotron radiation monitor line LHC B2 in 2015. This coronagraph is commissioned with LHC operation at 450 GeV (injection energy). After some optical testing of the coronagraph with visible Synchrotron radiation in B2, we try to observe artificially-made beam halo. The beam halo of 10^{-3} order of magnitude against the beam core is excited by the kicker of the transverse damper. We have succeeded to observe a diffraction noise free image of beam halo. The effect of beam collimator is also observed. Reduction of beam halo intensity was found nicely proportional to the simultaneously-recorded beam loss.

INTRODUCTION

For high energy or high power accelerators such too much beam in the halo can lead to damage of accelerator components, either due to instantaneous beam loss or through long term irradiation. Beam halo control is essential and is best achieved by tuning the machine to avoid populating the tails of the bunch distribution. The beam diagnostic challenges here lie in developing non-invasive techniques with a high enough dynamic range to resolve a beam halo a factor 10^{-5} lower in intensity than that in the beam core. Synchrotron light sources, FELs and high energy hadron accelerators, such as the LHC, can all use synchrotron light to provide a non-invasive, transverse image of the beam distribution. To be able to measure the beam halo, however, requires an imaging system that eliminates the diffraction fringes created by the intense light from the beam core as it passes through the aperture of the first optical element. These fringes can have an intensity as high as 10^{-2} of the peak intensity and would hide any halo at the 10^{-5} level. To reduce this effect a coronagraph, developed by Lyot [1] in 1936 for solar astronomy, can be used. Such a technique has already been demonstrated by one of authors at the KEK Photon Factory to achieve a 6×10^{-7} ratio for background to peak intensity [2], and is now being actively studied as a possibility for halo diagnostics for the High Luminosity LHC upgrade. In this paper, it is described that construction of coronagraph for LHC, and observation of beam halo using artificial-formed beam halo with beam damper.

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CORONAGRAPH

The optical layout of the coronagraph is illustrated in Fig. 1 [2]. The first lens (objective lens) makes a real image of the object (beam image) on to a blocking mask which makes artificial eclipse. Second lens (field lens) which is located just after the blocking mask makes a real image of the objective lens onto a mask so-called Lyot Stop. The diffraction fringes on focal plane of the objective lens is re-diffracted by field lens aperture and making a diffraction ring onto the focal plane of field lens. The Lyot's genius idea of the coronagraph is to remove this diffraction rings by a mask, so-called Lyot stop in today and relay the hidden image such as Sun corona by a third lens onto final observation plane. The background light on the final observation plane is now mainly come from the leakage of diffraction fringe inside of Lyot stop and the scattering of the input bright light by the objective lens. To applying a very well polished lens as the objective and a good condition of Lyot stop, we can reduce the background light less than 10^{-6} to the peak intensity of blocked main image. With this coronagraph, we can observe a hidden image of beam halo in accelerator surrounding from the bright beam core image.

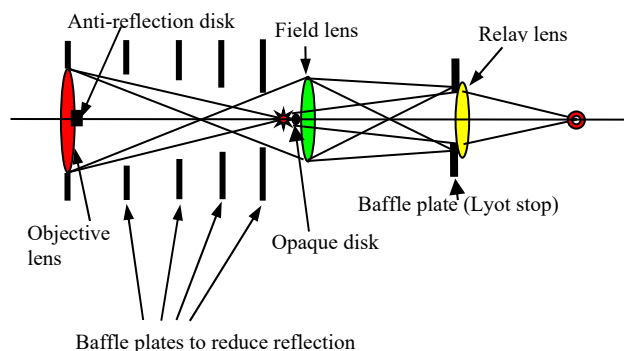


Figure 1: Layout of optical system of the coronagraph.

CORONAGRAPH FOR LHC

A newly constructed coronagraph is set on B2 BRST beamline optical table [3]. A specially polished lens having a very low scattering noise is necessary for the first objective lens. We used the objective lens of coronagraph which is used in the Photon Factory, KEK. A re-diffraction system and relay system are newly designed and constructed for LHC coronagraph. The optical configuration is shown in Fig.2. The coronagraph is bent after field lens, because length is too long. Since the coronagraph is set at 29m downstream from the source point, the

transverse magnification of first objective lens is 0.075. This magnification is about 3.6 times smaller than magnification in PF, we added a magnification lens in the relay system. Layout of the coronagraph on B2 optical table is indicated in Fig.3 [4].

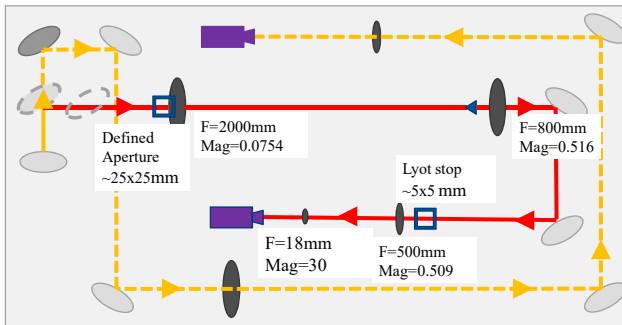


Figure 2: Optical configuration of coronagraph on B2 Optical table.

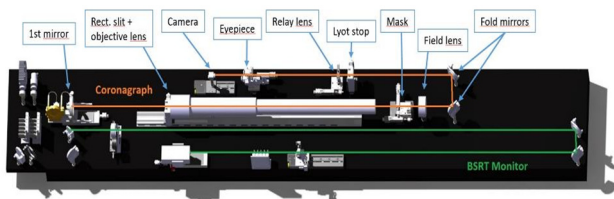


Figure 3: Layout of coronagraph on B2 optical table.

EXPECTED BACKGROUND LEVEL AT FINAL FOCAL PLANE OF RELEY SYSTEM

The leakage of diffraction fringe inside of Lyot stop is transfer to relay system and it produced a diffraction background. This diffraction background is depending on size of blocking mask and Lyot stop condition. We estimated diffraction background level at final focal plane of relay system. A result of simulation for diffraction background using Optical configuration as shown in Fig. 2 is indicated in Fig. 4. From this result, 3.7×10^{-4} contrast is expected for the LHC coronagraph.

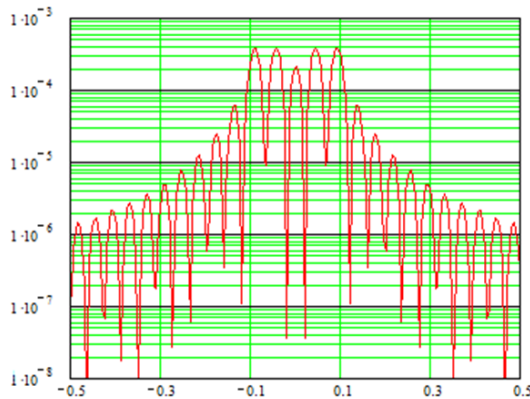


Figure 4: A result of simulation for diffraction background on focal plane of relay system. Horizontal axis is position on the focal plane, and vertical axis is contrast to peak intensity of the beam core image.

FORMATION OF ARTIFICIAL BEAM HALO

LHC doesn't have strong beam halo which is expected in HL LHC by long range beam-beam interaction. Therefore, we applied beam damper for 450 GeV proton beam for blow up one of the beam train. We store three beam trains, each has 12 bunches in the LHC. The beam damper excited horizontal beam blow up for first beam train, and vertical beam blow up for second beam train. Figure 5 shows result of simulation for beam blow up. Original beam has normalized emittance of $1.8 \mu\text{m}$ (a), horizontal blow up to $8 \mu\text{m}$ (b), and vertical blow up to $10 \mu\text{m}$ are shown individually.

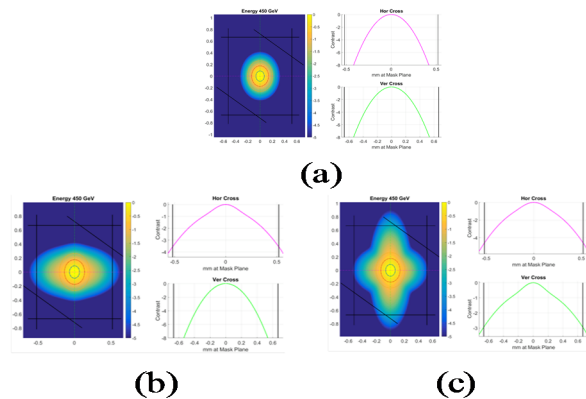


Figure 5: Result of simulation for beam blow up by beam damper. (a) original beam profile $1.8 \mu\text{m}$, (b) horizontal blow up to $8 \mu\text{m}$, (c) vertical blow up to $10 \mu\text{m}$.

BEAM HALO OBSERVATION WITH CORONAGRAPH

The beam halo is observed with coronagraph at 450 GeV for horizontal beam blow up to $5 \mu\text{m}$, $6 \mu\text{m}$, $7 \mu\text{m}$, $8 \mu\text{m}$. Result of two images taken by coronagraph for original beam profile (no excitation of blow up) and blow up to $8 \mu\text{m}$ are shown in Fig. 6. In Fig.6, central black circle is image of block mask. Beam halo is observed surrounding of this mask.

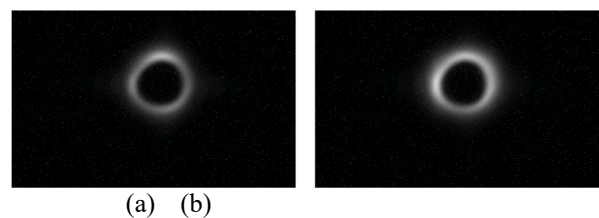


Figure 6: Result of two images taken by coronagraph for horizontal, (a) original beam profile (no excitation of blow up) and (b) blow up to $8 \mu\text{m}$.

To see Fig. 6, two images has not clear difference, so we plot subtraction between blow up ones and original one. Figure 7 shows results of subtraction images for horizontal beam blow up to $5 \mu\text{m}$, $6 \mu\text{m}$, $7 \mu\text{m}$, $8 \mu\text{m}$. To

see Fig. 7, we can see clear change of beam halo for each blow up conditions.

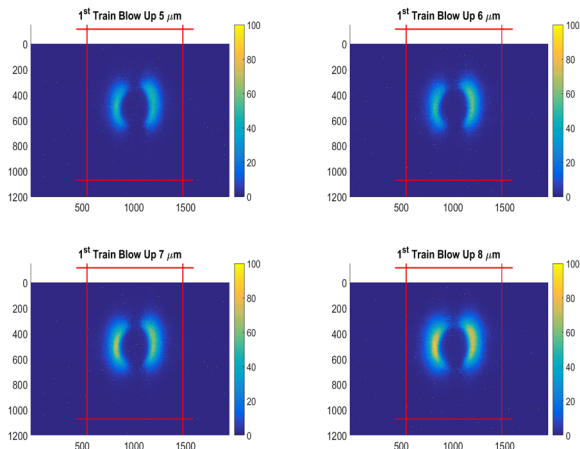


Figure 7: Results of subtraction images for horizontal beam blow up to 5 μm , 6 μm , 7 μm , 8 μm .

For the vertical, beam blow up to 10 μm is observed. Result of two images for original beam profile (no excitation of blow up) and blow up to 10 μm are shown in Fig. 8. Different from horizontal, a clear change is observed in vertical.

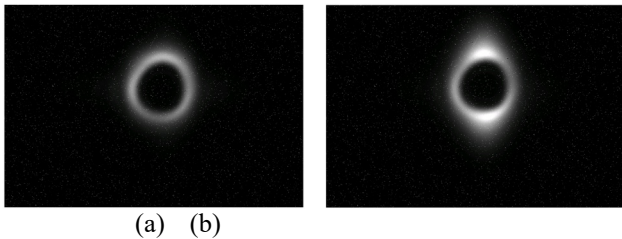


Figure 8: Result of two images taken by coronagraph for vertical, (a) original beam profile (no excitation of blow up) and (b) blow up to 10 μm .

DECREASE OF BEAM HALO WITH BEAM SCRAPING

Relation between beam halo against beam scraping is observed. Results for decrease of intensities in horizontal beam halo for the horizontal scraper conditions of 3.7, 3.3 and 2.9 nominal sigma are shown in Fig. 9. Results for same observation for vertical scraper conditions of 4.1, 3.6, 3.0 and 2.6 nominal sigma are shown in Fig. 10. Note these figures are subtraction between reference halo image taken at scraper condition of 5.7 nominal sigma and halo image at each scraper conditions. From these figures, we observed decrease of beam halo intensities by closing the scraper. The correlation plots between beam loss intensity and integrated intensity of halo image are shown in Fig. 11 for horizontal and vertical, individually. From these correlation plots, integrated intensities linearly correlated with beam intensities loss for both horizontal and vertical.

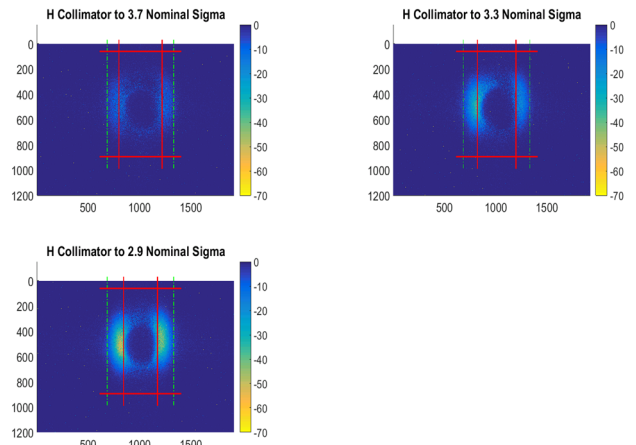


Figure 9: Results for decrease of intensities in horizontal beam halo for the horizontal scraper conditions of 3.7, 3.3 and 2.9 nominal sigma

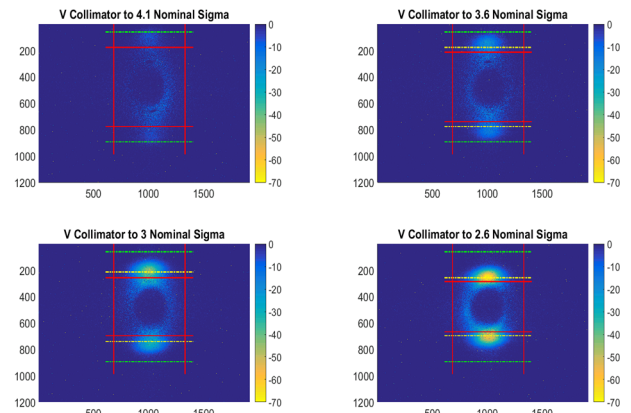


Figure 10: Results for decrease of intensities in vertical beam halo for the vertical scraper conditions of 4.1, 3.6, 3.0 and 2.6 nominal sigma

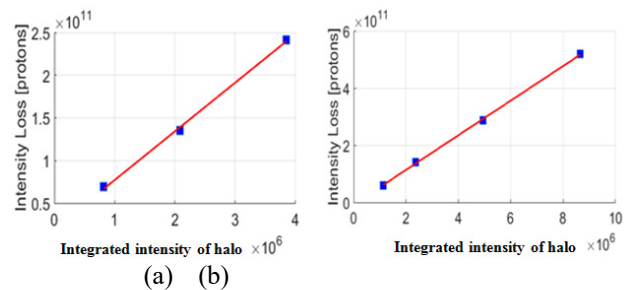


Figure 11: The correlation plots between beam loss intensity and integrated intensity of halo image. (a) horizontal, (b) vertical.

SUMMARY

A Coronagraph constructed with special objective lens from the PF coronagraph is installed at B2 (SR monitor line). Test for Observation started with 450 GeV beam using artificial halo which is formed by beam damper. Decrease of beam halo intensity with beam scraper is observed. Integrated intensities linearly correlated with beam intensities loss.

REFERENCES

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