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DEVELOPMENT OF A BEAM HALO MONITOR*

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Abstract

Our innovative approach is to design the Beam Halo Monitor, where beam induced synchrotron radiation will be used to monitor the beam Halo. This involves an original scheme of light collection using a coronograph for measuring beam halo.

INTRODUCTION

Intense electron beams pose a challenge for beam profile measurements. Solid-based beam intercepting instrumentation produces unallowable levels of radiation at these high powers. An alternative is to use a zero-or-low mass device such as a synchrotron radiation light. Challenges are to produce repeatable, pulse-by-pulse measurements of beam sizes and positions. Typical beam sizes are ~1 µm to 2 mm rms, and the required pulse-to-pulse precision is ~1 µm in position and size. Beam profile determination at high intensity electron accelerators implies the use of non-destructive methods. The basic physics and recent technical realizations of important non-intercepting profile diagnostics are summarized in Ref. [1,2,3].

Advanced beam diagnostics are essential for a high-performance accelerator beam production and for reliable accelerator operation. It is important to have noninvasive diagnostics which can be used continuously with intense beams of accelerated particles. Noninvasive determination of accelerated particle distributions including beam halo is the most difficult task of providing bunch diagnostics.

Muons, Inc. proposes to develop a novel beam induced synchrotron radiation beam halo bonitor with pulse-to-pulse precision of better than ~1 µm in position and size that will operate over a wide range of electron beam intensities including those needed for beams of future facilities. First we discuss the operation and limitations of synchrotron radiation beam halo monitors.

TECHNICAL DESCRIPTION OF SYNCHROTRON RADIATION BEAM HALO MONITOR

- Beam profile and beam halo measurements are important for accelerator optimization and in general for accelerator experiments. The beam profile monitoring for electron beams is usually based on synchrotron radiation.

Particle density distributions in the beam of a cyclic accelerator are important in all three degrees of freedom x, y, s (x, y are the transverse coordinates, s is the longitudinal coordinate). The typical RMS size is $\sigma x,y,s$. The transverse profiles may be separated into two parts: the central part (within the limits of 5-6σ) and the halo (outside of 6σ). The central part is the body of the beam that determines characteristics such as collider luminosity or brightness of synchrotron radiation. The beam lifetime and detector backgrounds have a direct connection to the distribution in the halo; hence we need reliable information on particle distributions of the halo as well as of the body of beam. On-line measurements of halo distributions are used to tune the accelerator. Nowadays, two methods are widely applied for this purpose: a scraping collimator and a wire scanner. Both methods involve interacting with the beam, changing its properties and even destruction. Moreover, these techniques take a long time and combine poorly with other measurements and experiments on the machine. The advantage of both diagnostics is a wide dynamic range (up to 10^6).

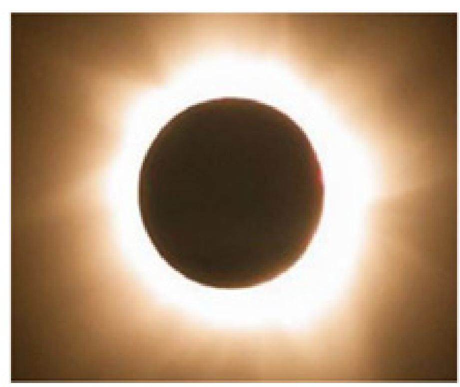

Figure 1: Coronagraph for sun corona observation.

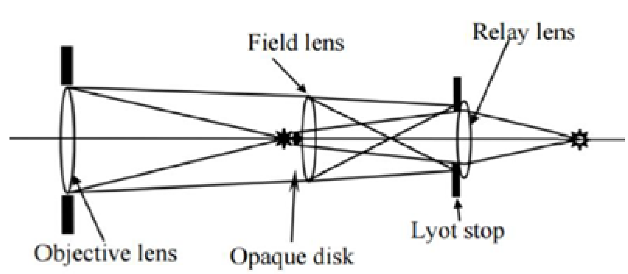

Figure 2: Schematic of classical coronagraph of Bernard Lyot.

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The development of a non-destructive, non-disruptive method that enables on-line measurement of the beam distribution outside 5σ is very relevant. Here we propose an optical coronagraph (used for sun corona observation as shown in Fig. 1) for this purpose. A schematic of classical Lyot coronagraph is shown in Fig. 2. The schematic of a coronagraph for beam halo observation is shown in Fig. 3.

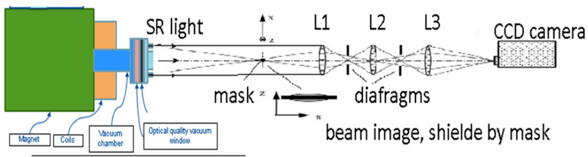

Figure 3: Schematic of the halo diagnostic by coronagraph (beam is in the magnet to the left).

The coronagraph is an astronomical tool for solar corona studies in which the enormous optical power of the solar disk is masked, permitting the much fainter corona to be observed. Here we use a movable mask to hide the beam image within the limits of ±5σ, permitting the much fainter light from the halo to be imaged. The optical system is designed to suppress stray and diffracted light, giving a clear view of the halo projected onto the CCD camera. It consist of 4 lenses and 2 diaphragms with a mask to shield the image of the beam core and a CCD camera. The shielding mask and diaphragms are positioned by remote control.

The coronagraph method was also used in experiments on the CTF3 accelerator (CLIC Test Facility 3, CERN). However, in this case, due to the low energy of the beam (35 MeV), instead of SR, transition radiation from an electron beam passing through a 10 µm aluminum foil was used. A further installation scheme was constructed according to the classical Lyot scheme as shown in Fig. 4 [4].

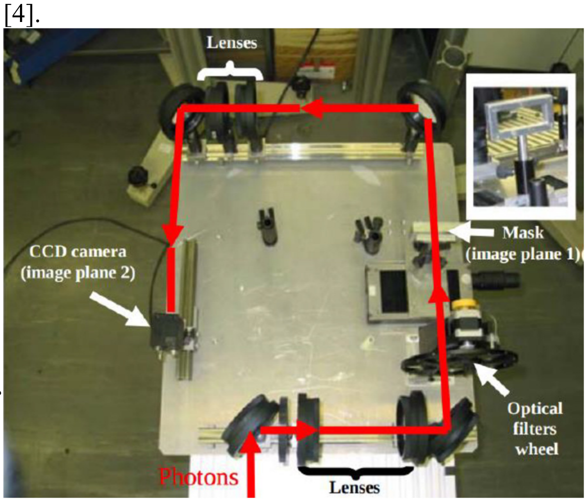

Figure 4: Photograph of optical system of the beam halo registration on CTF3.

An image printed on polyester was used as a shadow mask. This scheme made it possible to achieve attenuation of 3 orders of magnitude, and using information about the attenuation of radiation through a light filter, the

Tests of contrast and examples of beam halo images are shown in Fig. 5.

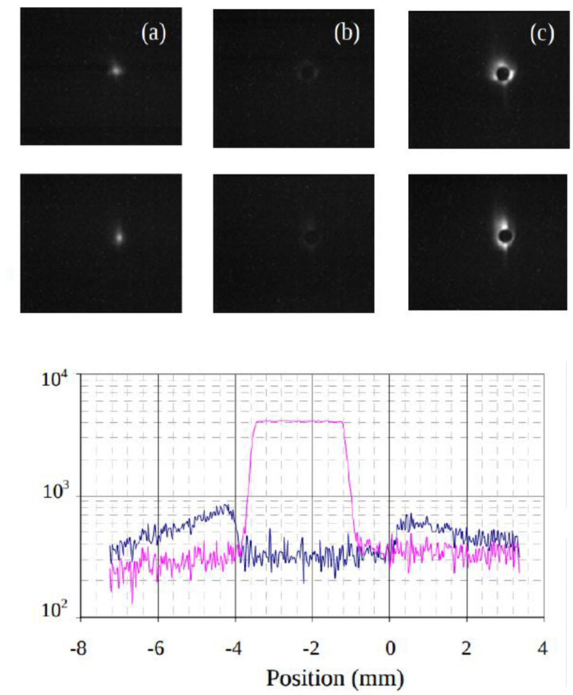

Figure 5: Test of contrast and examples of beam halo images.

IOTA STORAGE RING IN FERMI LAB

Integrable Optics Test Accelerator (IOTA) is a research electron and proton storage ring at Fermilab's Accelerator Science and Technology (FAST) facility. It has a circumference of 40m, and is designed to use either 2.5 MeV protons provided by an RFQ injector, or 150 MeV electrons from FASTlinac. A wide variety of experiments are planned, including a demonstration of optical stochastic cooling as well as techniques for improving proton beam intensity and stability - electron lenses and quasi-integrable optics, the latter using strongly nonlinear magnetic inserts placed in special equal beta function drift regions, as shown on ring schematic in Fig. 6. It has 4 bending magnets and 8 straight sections. Synchrotron radiation for beam halo monitoring can be extracted from the 30° bending magnets.

Profile measurements of electrons for the IOTA ring are provided by imaging the synchrotron radiation emitted from the dipole magnets. The design of the beam pipe dictates that the collected light originates from the entrance of the 30° magnets and from the center of the 60° magnets. The light is transported to a light-tight box positioned on top of the dipole containing a GigE-type CCD camera. The optical trajectory is controlled by a remotely-

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moveable turning mirror and an iris which controls the length of the emission source seen by the camera. Focusing is done via a 400 mm focal length lens resulting in a magnification of 0.837.

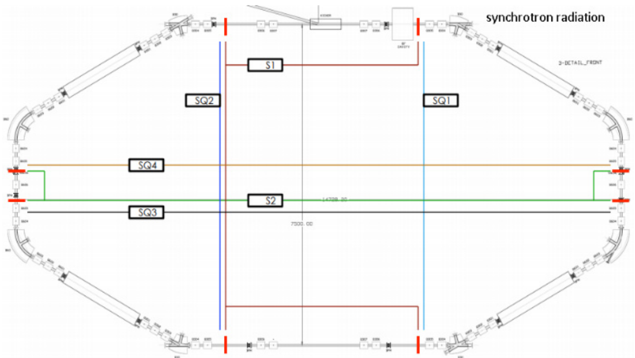

Figure 6: Layout of the IOTA storage ring. One of the potential monitor testing locations is labeled “synchrotron radiation”.

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A possible design of the halo detection system connected to the vacuum chamber and the 30º magnet is shown in Fig. 7.

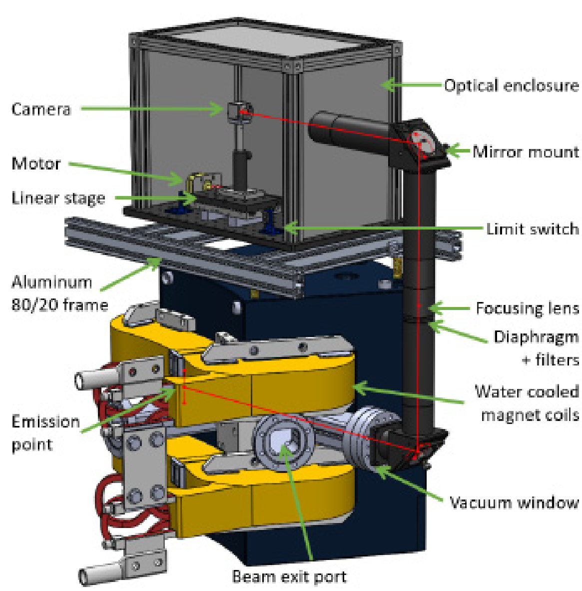

Figure 7: Illustration of the apparatus for extraction of synchrotron radiation from a 30º magnet. Note the vacuum chamber and window and the optical components shown.

The schematic of the apparatus for the extraction of synchrotron radiation from a 30º magnet with coronoraph, and the vacuum chamber, window and the optical components are shown in Fig. 8.

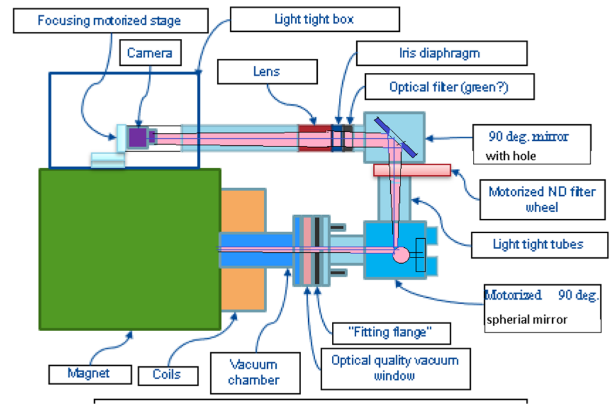

Figure 8: Schematic of the apparatus for extraction of synchrotron radiation from a 30º magnet with coronoraph. Note the vacuum chamber and window and the optical components are shown.

Software that can be used in the analysis include the open source utitilies such as “Ray Optics Simulation”, (https://ricktu288.github.io/ray-optics/), which can be used for simulations of the beam halo monitor optical system. Matlab is also useful.

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