DEVELOPMENT OF SHINTAKE BEAM SIZE MONITOR FOR ATF2

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Abstract

In this paper, we describe a system design and current status of Shintake beam size monitor. Shintake monitor is a laser-based beam diagnostics tool, which provides a non-invasive measurement of transverse beam sizes. The interaction target probing the electron beam is interference fringes build up by the two coherent lasers that have narrow bandwidth and long coherent length. A scale of the target structure corresponds to approximately one fourth of the laser wave length, and the smallest measurable size reaches down to several tens of nanometers. The monitor we described here is installed at the virtual interaction point of the ATF2 beam line, which is built to confirm the proposed final focus system for Future Linear Colliders. We adopt second harmonics of Nd:YAG laser of 532 nm wavelength, and phase stabilization feedback system to allow to measure the designed beam size of about 37 nm. To widen a measurable range up to about 5 microns (wire scanner's range), we also prepare three crossing modes that change an effective wavelength for the fringes. The monitor is used to measure a focus size during the tuning process. The system is based on the Shintake monitor for FFTB.

INTRODUCTION

ATF2 facility [1] was constructed as a scaled-down version of ILC design, to prove the feasibility of a final focusing scheme based on a local chromaticity collection. Main issues of the project are focusing the beam to nanometer scale (37 nm in design) in vertical and providing nanometer level stability, using the low emittance beam ($\gamma\varepsilon_y \sim 3 \times 10^{-8}$ m·rad) extracted from the ATF damping ring. To measure such a small beam, Shintake monitor[2] has been developed for ATF2 beam.[3]

The commissioning of ATF2 started in a beginning of 2009[4] with an optics option of a large beta function, i.e.100 times larger than the nominal value. From the beam operations in 2010, we implemented 10 times large optics to study and evaluate the operational performance. On the beam operation, we found that a main difficulty for beam size measurement was low signal to noise ratio. To overcome that challenge, we improved the hardware in the system. We also carried out an optimal operation study of the Shintake monitor in parallel with the electron beam line commissioning. In this paper, we describe apparatus, hardware improvements, optimal operation procedures and an example of the size measurement of sub-micron beam currently supplied to the focusing point (virtual interaction point, IP).

APPARATUS

The Sintake beam size monitor consists of laser system, optics system and a gamma-ray detector. Figure 1 shows a schematic overview of the Shintake beam size monitor. The interaction target probing the election beam is interference fringes induced by the two lasers, which have a periodic structure, whose scale is determined by a projected wave number to a vertical plane. Scattered photons from the target via inverse-Compton process are detected on the γ-ray detector located downstream. The amount of the Compton photons depends on where the electron hit on the target, and by analyzing the dependence, one can calculate a beam size of the electron beam. Currently, a maximum signal variation come from the target structure, called a modulation depth, M, is used for the dependence evaluation. Using the modulation depth, a beam size, σ_e, is calculated as

$$\sigma_e = \frac{\lambda}{4\pi \sin(\theta/2)} \sqrt{2\ln(\frac{|\cos\theta|}{M})} \ ,$$

where λ is a laser wavelength and θ is a crossing angle of the two lasers.

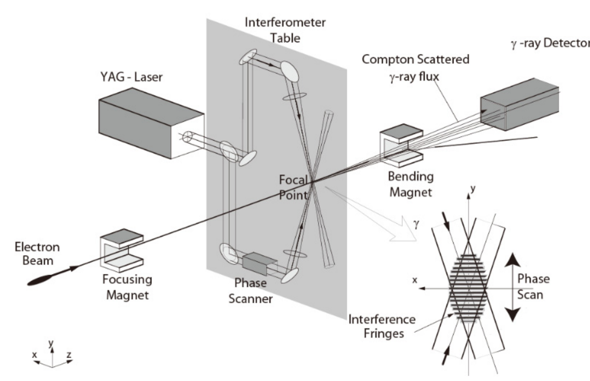

Figure 1: Schematic overview of the Shintake beam size monitor [2].

A frequency-doubled Q-switched Nd:YAG laser of 532 nm wavelength [1] are used to induced the laser fringe target for the ATF2 Shintake monitor. The system is operated with an injection seeder [2] to have narrow line width, less than 0.003 cm^{-1}, for required temporal coherency.

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[1] PRO-350 Spectra Physics
[2] model 6350 Spectra Physics

The monitor is designed to have three measurement modes by changing the crossing angle between the overlapping lasers, which are sensitive to beam size of 5000-350 nm (2-8 deg. mode), 100-350 nm (30 deg. mode), and 20-100 nm (174 deg. mode). Table 1 shows a specification of the laser system. The optical system is installed on a vertical

Table 1: Laser Specifications

Wavelength	532 nm
Pulse Duration (FWHM)	8 nsec
Timing Jitter (RMS)	$\leq$ 1 nsec
Repetition frequency	6.25 Hz
Pulse Energy	1400 mJ/Pulse
Pointing Stability	$\leq$ 50 μrad
Line width	$\leq$ 0.003 cm^{-1}

table (1.7 m height × 1.6 m wide) with a rigid mount support [5] at the IP. The figure 2 shows optics design of the 174 deg. mode. Optical delay line mounted on a piezoelectric stage is implemented on the light path of one laser to change phase of the fringes. It is used with a fringe monitor located downstream for phase stabilization. Dove prisms reverse laser images to avoid a degradation of the fringe contrast due to the laser pointing jitter. Linearly polarized laser beams are focused on the IP with lenses of 250 mm focal distance. An alignment target at the IP is an alumina fluorescent screen of 100 μm thickness (screen monitor). A

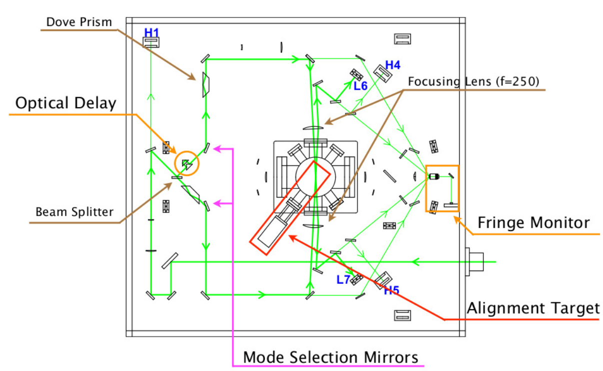

Figure 2: Optics design of the 174 deg. mode.

γ-ray detector locate 6 m after IP, beside the dump. It consists of four front layers of 1 cm thickness and a rear block of 29 cm thickness made of CsI(Tl) scintillator, 16 Bialkali PMTs of 8 mm in diameter, and a gain monitor with fiber injecting reference light. We adapted such a multilayered detector to separate signal from the high energy background by analyzing the longitudinal shower profile. The evaluation scheme improve a signal resolution, comparing to a normal calorimetric operation (i.e. not using shower profile). The figure 3 shows measured signal resolution as a function of a signal intensity, for using or not using the shower profiles. It works powerfully specially when the signal to noise ratio is less than one.

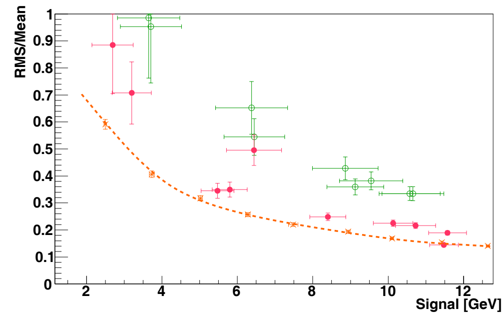

Figure 3: Signal resolution for using (filled circle) and for not using the shower profiles (open circle). Background level is 20 GeV through this measurement. Crosses and dashed line shows a simulated resolution that we do not take into account the beam and the laser position jitter.

IMPROVEMENT OF THE SIGNAL TO NOSE RATIO

At the beginning of the commissioning with the beam optics of the large beta function, background level was around 20 GeV as a total energy deposit on the γ-ray detector. It corresponds to amount of our signal intensity. It is found that the dominant sources of the background γ-rays are around the final doublet section and the last bending magnet, where the beam size become 1 mm level in design. In order to suppress the background level, we changed a vacuum chamber at the bending magnet to one with larger aperture, 26 mm in vertical and 54 mm in horizontal, and installed a additional lead brick collimator of 20 cm thickness and 20 mm in diameter just after the bending magnet. Fine survey and re-alignment of the magnets had been done within 0.1 mm measurement error. Due to those improvements, the background level is suppressed to be less than 5 GeV. In addition, laser system was updated to a double-oscillator-rods and double-amplifiers system, resulting pulse energy improvement from 400 to 1400 mJ/Pulse. Signal intensity increases by approximately 3.5 times, about 65 GeV in this case. The background level increases to be around 50 GeV when we implement the beam optics of the 10 times large case in 2010, however this condition is still acceptable for beam size measurement.

OPERATION PROCEDURES

In order to prepare the fringe interaction target with ideal contrast on the IP, the two lasers are aligned and overlapped at a three-dimensional point. We adopt the Q-switched pulsed laser, therefore timing coincidence between the lasers and the electron bunches is additionally required. Keeping in mind that the signal intensity and the modulation depth are maximum when those alignment and/or coincidence is made ideally, operational procedures after observation of the Compton signal are considered and designed. Procedures are

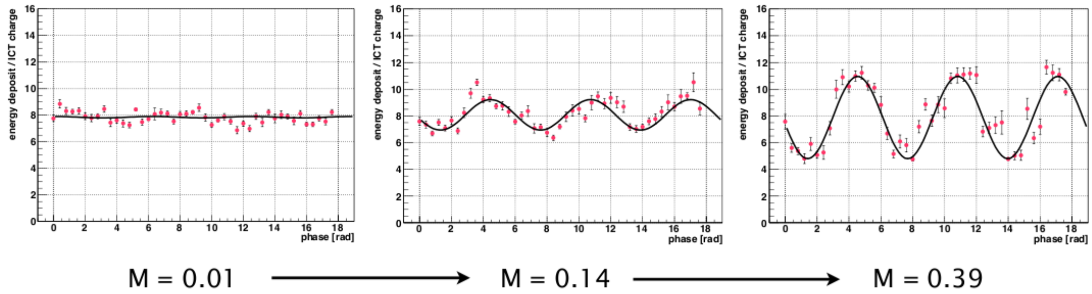

Figure 4: Example of the varying modulation depth by moving one laser along the z-axis. (40 μm move from left to center. 20 μm from center to right in this example.) One can align two lasers in z-axis by finding a maximum modulation.

- *Beam orbit tuning to reduce a background photons*
- *Beam angle adjustment with the γ-ray detector*
  – There is a movable γ-ray collimator of ϕ10 mm in front of a ϕ20 mm immovable collimator. By inserting the screen monitor at the IP, collimated photons along the beam axis are generated. The angle is determined by the peak position of the collimated photons using the movable collimator.
- *First laser alignment with the beam on the screen monitor at the IP*
  – By moving laser spots to a beam position on the screen, they overlap each other within $\pm$ 100 μm difference.
- *Check the timing coincidence on an oscilloscope*
  – Laser pulse duration is 8 nsec in FWHM. Accuracy of several nsec is enough at this procedure.
- *Fine laser alignment in x-y plane by analyzing a signal intensity*
  – Find the maximum signal by scanning lasers one by one in x-y plane.
- *Fine timing adjustment*
  – Find the maximum signal by scanning laser timing.
- *Laser alignment along the z-axis*
  – Signal modulation depth is proportional to an effective fringe contrast through the z-axis, which is evaluated by integration of position depending fringe contrast that the electron beam feels. The effective contrast is maximize when two lasers overlap along the z-axis. The figure 4 shows an example of this procedure. A measured modulation depth increases when an overlap area is increases by moving one laser along the z-axis (left to right in the figure.). The effective contrast is written as

$$M_{eff} \propto \exp(-\frac{\delta z^2}{2(2\sigma_{z,laser})^2}),$$

where δz is a spatial difference between two lasers and $\sigma_{z,laser}$ is a laser spot size in z-direction. From this equation, we can evaluate the laser spot size, which could be a dominant source of the systematic error on the beam size measurement in the current situation. Details are discussed in [6].

Figure 5 is an example of a measured signal modulation ($M = 0.87$, $\theta = 8.0$ deg). Corresponding vertical beam size is 310 $\pm$ 30 (stat.) $^{+0}_{-40}$ (syst.) nm.

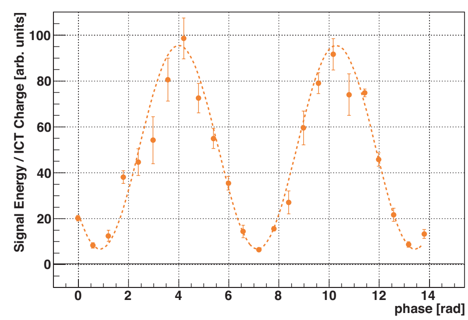

Figure 5: An example of a measured signal modulation.

SUMMARY

Shintake monitor has been developed for ATF2. An optimal operation study has been carried out in parallel with the beam line commissioning. As a result, we succeeded to measure vertical beam size in sub-micron level.

ACKNOWLEDGMENTS

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