論文の内容の要旨

論文題目 Study on a Precise Beam Size Monitor Using Laser Interferometer (レーザー干渉を用いた高精度ビームサイズモニターの研究)

氏名　大録　誠広

The goals of our project are development of a nanometer scale beam size monitor and measurement of nanometer scale beam sizes at ATF2. This thesis evaluates the performance of the monitor and reports the result of beam size measurement. The instruments to consist the monitor is also described.

In Chapter 1, the motivation and the location of this study in the context of the plan towards the future ILC are overviewed. In the International Linear Collider project, nanometer scale focusing of the electron/positron beam to obtain high luminosity is a major technical challenge. Focusing strategies will be realized in the test facility for ILC, called the Accelerator Test Facility 2 (ATF2). ATF2 is a realistic scaled down model of the final focus system for ILC. To confirm the 37 nm ATF2 design vertical beam size at the focal point (virtual interaction point), a beam size monitor with novel techniques is required.

In Chapter 2, the measurement scheme and overall design of the beam size monitor is described. We developed a beam size monitor based on the scheme which is originally proposed by T. Shintake. In this scheme laser interfere fringe is used as a probe to scan electron beam bunch. The measurement scheme is shown in Fig.1. In their intersecting region, the electromagnetic fields of the two laser beams form a standing wave (interference fringe). Relativistic (1.28 GeV at ATF2) electrons in a bunch of beam scatter laser photons as inverse Compton γ ray (with energy up to 30MeV). The energy sum of inverse Compton photons is measured by a γ ray detector which is located downstream from the interaction point. The probability of the Compton scattering varies according to the phase of the standing wave where the electrons pass through.

Taking y to be the vertical beam position, the energy of inverse Compton photons, which is measured by the gamma detector shown in Eq.1 expressed as the following:

$$S = S_{ave}(1 + \cos((2k_y y) + \alpha)) \cos\theta \exp(-2(k_y \sigma_y)^2) \tag{1}$$

Here, S_{ave} is the average energy of inverse Compton photons. 2 times of the energy of γ ray scattered from a single laser beam. θ is the crossing angle of the split laser

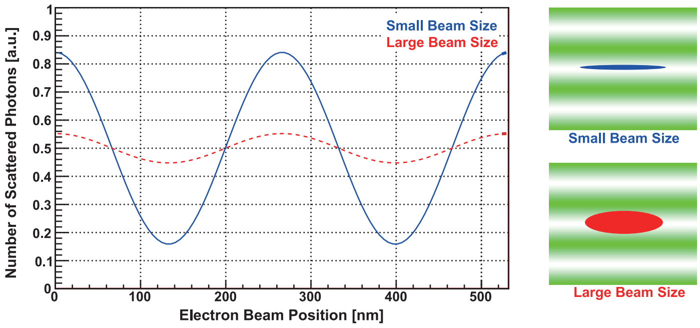

Figure 1: Different modulation for different beam size (from T.Suehara's doctor thesis)

beams. k_y is the vertical component of the wave number $k_y = \frac{2\pi}{\lambda}\sin\frac{\theta}{2}$. α is the phase difference made by the optical delay line. σ_y is the vertical beam size.

Using the maximum and the minimum energy sum of inverse Compton photons S_+ and S_-, modulation depth M of gamma signal is function of beam size σ_y as Eq.2. In Eq.2,

$$M = \frac{S_+ - S_-}{S_+ + S_-} = |\cos\theta| exp(-2(k_y\sigma_y)^2) \tag{2}$$

Therefore beam size can be obtained from modulation depth using calculation formula as shown in Eq.3.

$$\sigma_y = \frac{d}{2\pi}\sqrt{2ln(\frac{|\cos\theta|}{M})} \tag{3}$$

The monitor has been designed to measure a vertical beam size down to 20 nm. Also it is possible to measure wide range of beam size with different crossing angle modes. In order to achieve the wide range measurement range of σ_y(20nm $\sim$ several μm), it is possible to change the crossing angle mode (2-8 degree, 30 degree, 174 degree). It is also possible to use a single laser path as laser wire to measure σ_x.

In Chapter 3, components of the monitor are described. The monitor consists of laser optics and γ detector as shown in Fig2. The laser system is required to have good stablity of timing and power, good coherence, and high intensity pulse. We use a Class IV Nd:YAG seeded Q-switched pulsed laser "Pro-350" made by Spectra-Physics Lasers Inc. to meet these requirements. The wavelength of laser is 532 nm, reduced from original Nd:YAG laser (1064 nm) in order to obtain good resolution for beam size measurement. The power, timing and profile of laser is always monitored. The γ ray detector is made up of multilayer CsI(Tl) scintillators. Background for the detector is mainly due to Bremsstrahlung photons emitted when the beam halo hit the beam pipe. Using the difference of shower development between inverse Compton signal(average energy $\sim$ 15 MeV) and Bremsstrahlung background (average energy $\sim$ 50 MeV) , the detector is designed to optimize the S/N ratio and have tolerance for the fluctuation of background. The performance of each component is evaluated.

In Chapter 4, the overall performance of the monitor and the measurable range are discussed. There are two types of uncertainties in the experiment, fluctuations on signal energy and the biases on the modulation depth. Candidates of signal fluctuation

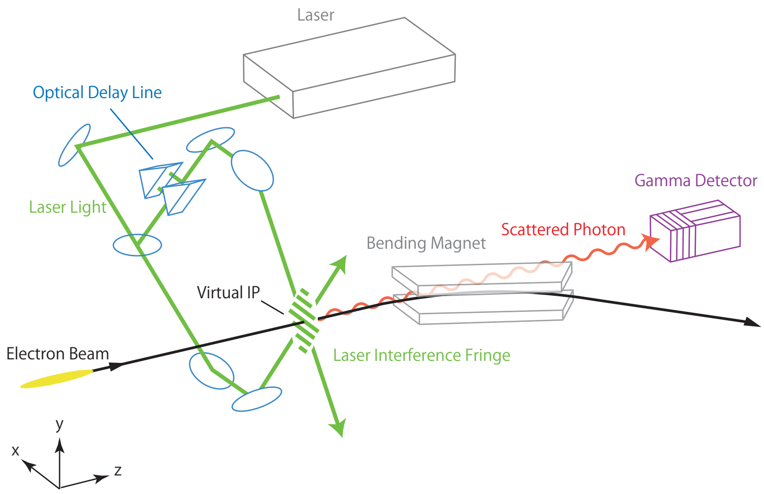

Figure 2: Schematic diagram of shintake-monitor at ATF2 (from Y.Yamaguchi's master thesis)

sources are jitter of laser power, relative timing jitter between laser beam and electron beam, relative position jitter, and background fluctuation. Contribution of each source is evaluated then overall fluctuation of signal energy $\Delta S/S_0$ is estimated. The biases on the modulation depth is represented as factor C. Measured modulation M_{meas} is biased as $M_{meas} = C_{total}M_{ideal}$. Candidates of bias sources are relative position jitter, relative position drift, and axis mismatch between laser fringe and beam. Contribution of each source is evaluated then overall bias C_{total} is estimated for each mode.

In Chapter 5, the results of beam size measurents are reported. Beam tuning issues are also discussed. The measurement with 2-8 degree mode has been performed since 2010. The measurement with 30 degree mode was succeeded to observe during the beamtime at February 2012. The plot of 30 degree mode fringe scan is shown in Fig.3.

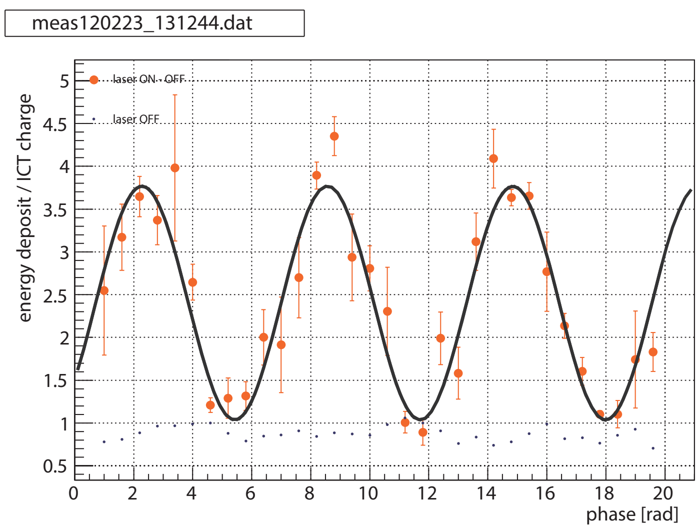

Figure 3: plot of fringe scan with 30 degree mode

After beam size minimization by beam tuning, modulation $M = 0.522 \pm 0.013$ was measured. 10 times measurement histgram of measured modulation with 30 degree mode is shown in Fig.4.

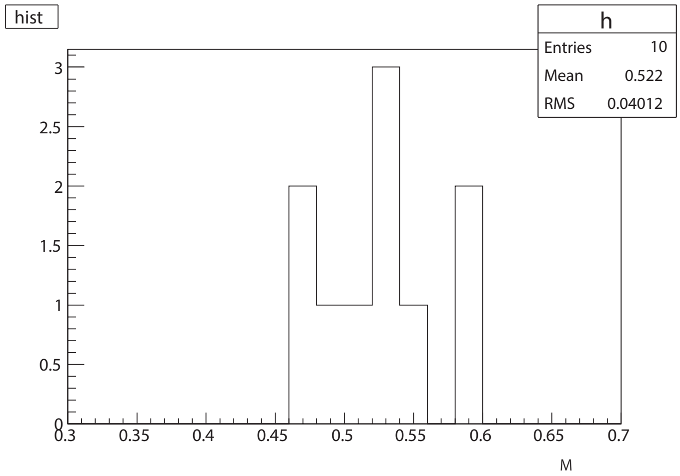

Figure 4: 10 times measurement histgram of measured beam size

Corrected by the bias on the modulation, measured beam size is estimetad to be about 110 nm. In Chapter 6, The study discussed in this thesis is concluded. Conclusion is based on following major points:

- Performance and systematic errors were evaluated
- $2-8$ degree mode and 30 degree mode were succeeded to detect fringe. A 110 nm beam size measurement was performed with 30 degree mode