Shintake Monitor in ATF2
: Present Status

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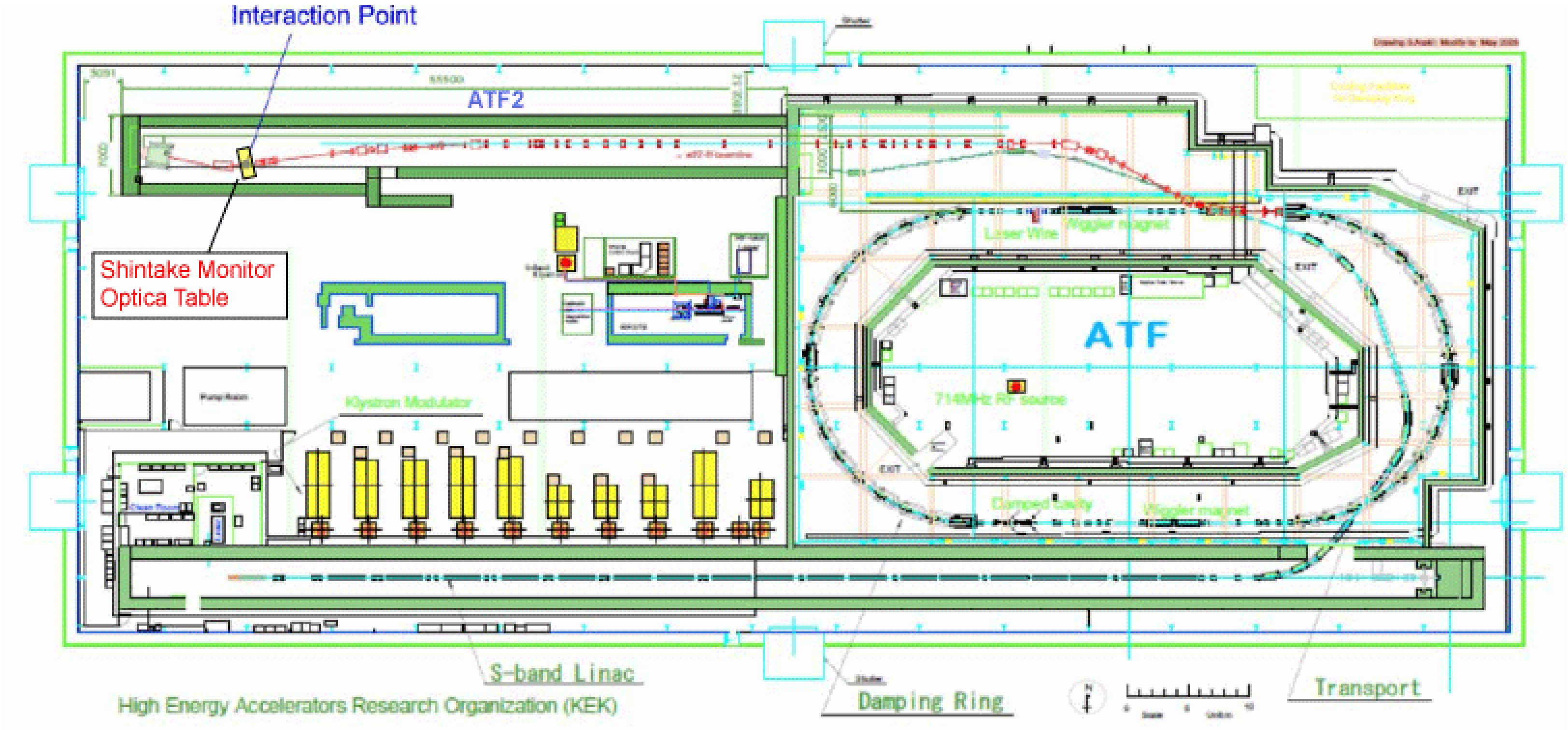
ATF/ATF2

ATF

- accelerate electron beam to 1.3 GeV
- normalized $\gamma\varepsilon_y = 2.8 \times 10^{-8}$ m･rad achieved in the Damping Ring



Layout of ATF/ATF2

Goals of ATF2

- focus the vertical beam size to 37 nm
- stabilize the vertical beam position in 2 nm resolution

Principle of Laser Interference Beam Size Monitor (Shintake Monitor)

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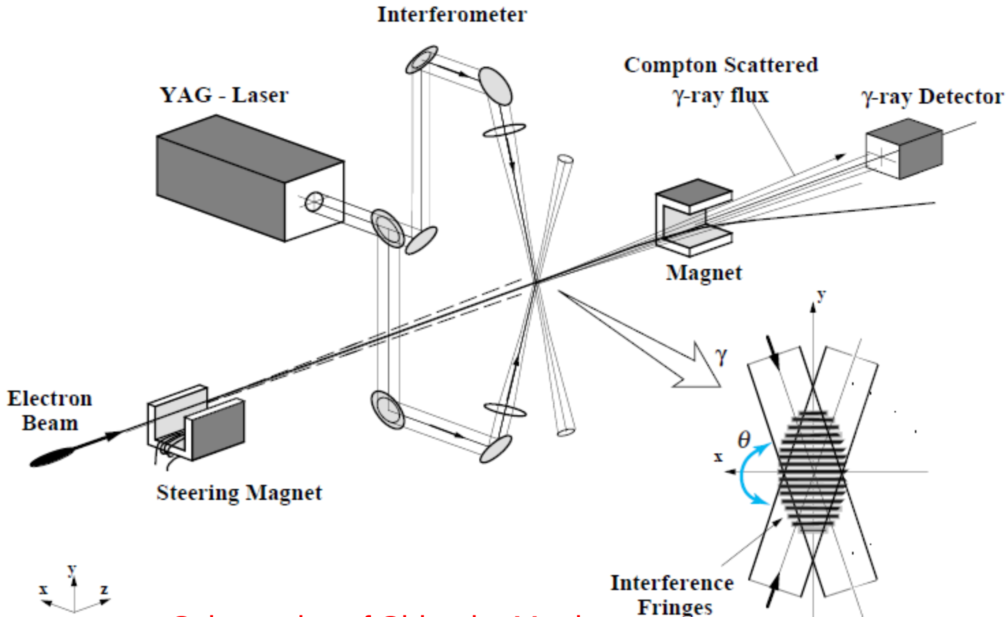
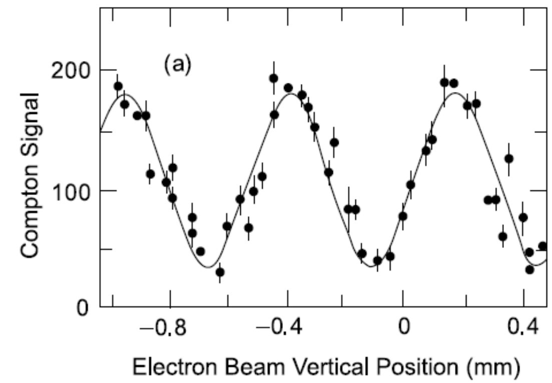
Shintake Monitor



Schematics of Shintake Monitor



Measured signal in FFTB at SLAC
T. Shintake *et al*., 1992
σy~65 nm beam size was measured

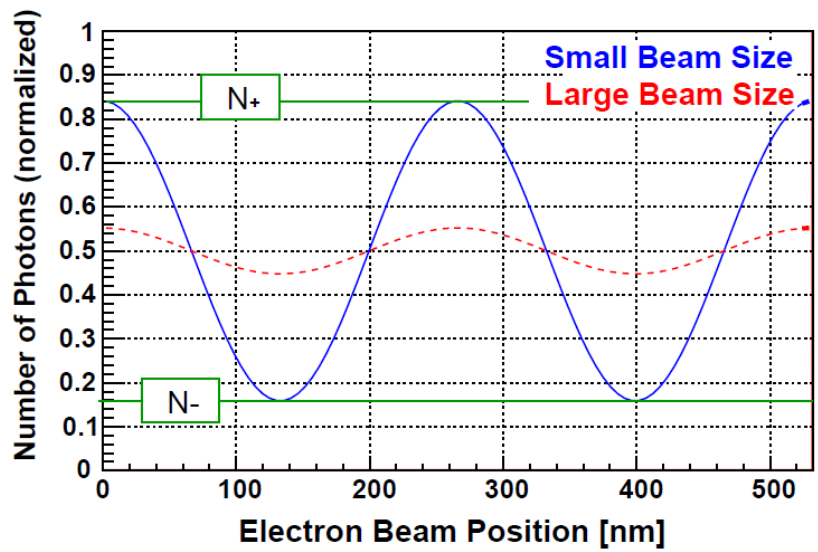
Modulation depth

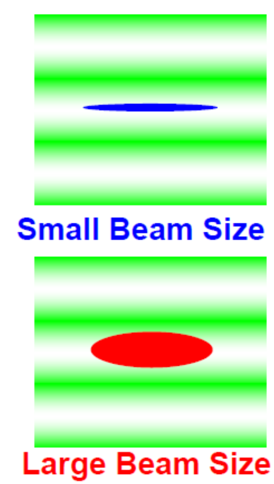
$$M \equiv \left| \frac{N_+ - N_-}{N_+ + N_-} \right| = \frac{\text{Amplitude}}{\text{Average}}$$

Beam Size

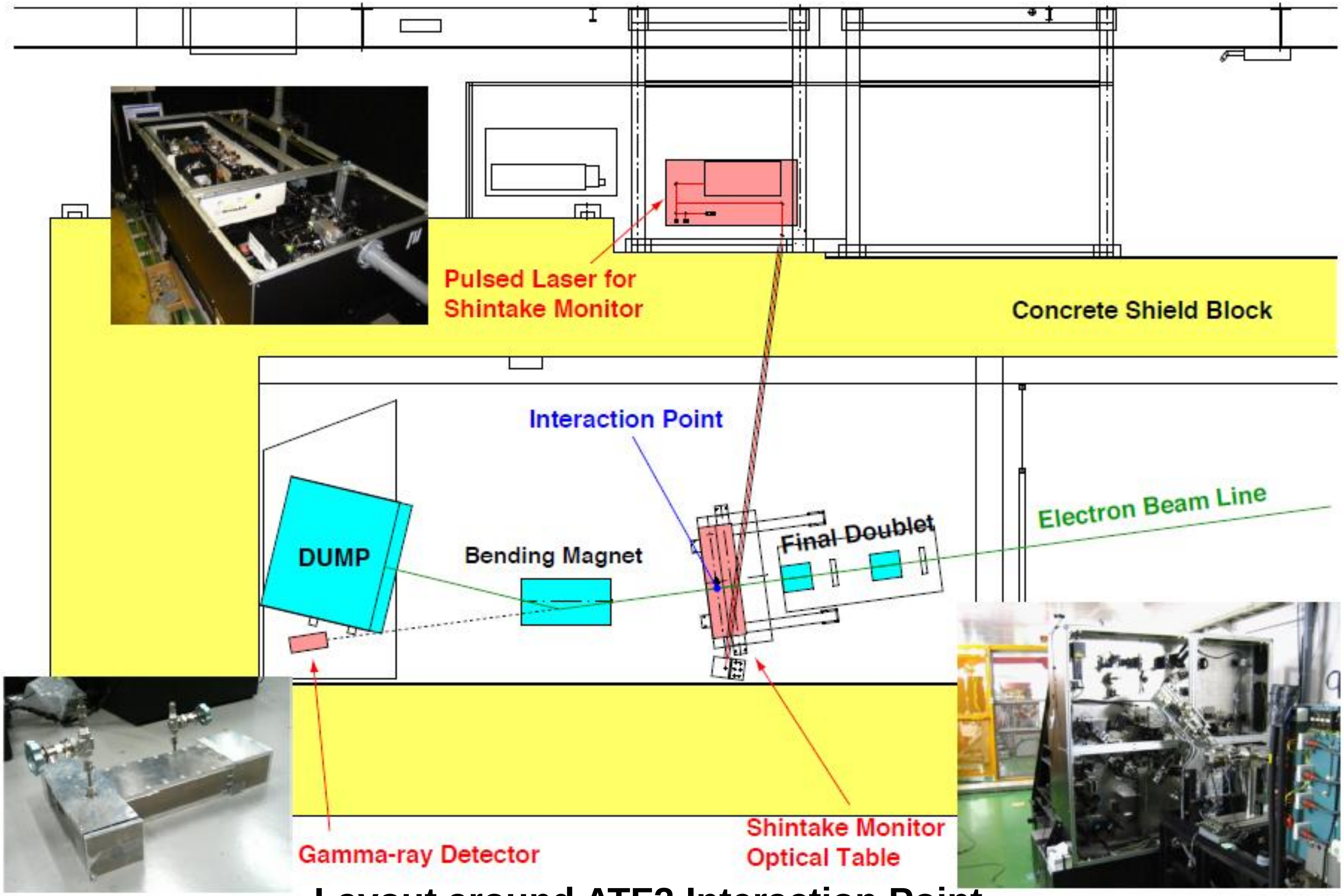
$$\sigma_y = \frac{d}{2\pi} \sqrt{2 \log \left(\frac{|\cos\theta|}{M} \right)}$$

d: fringe pitch θ: crossing angle



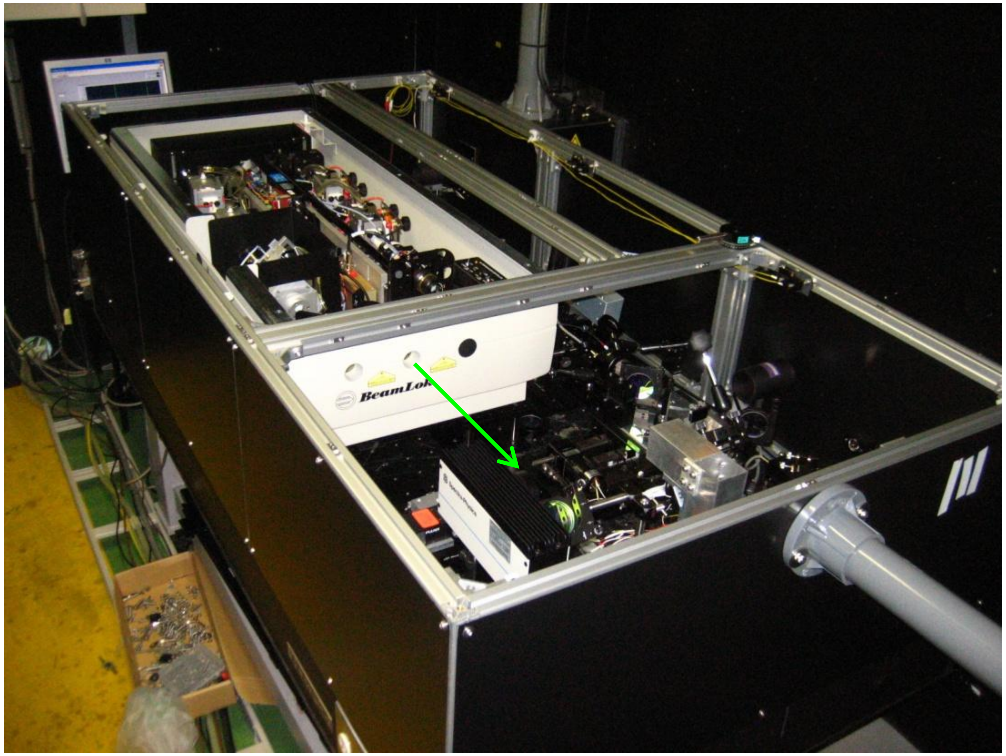


Components of Shintake Monitor



Layout around ATF2 Interaction Point

Laser System



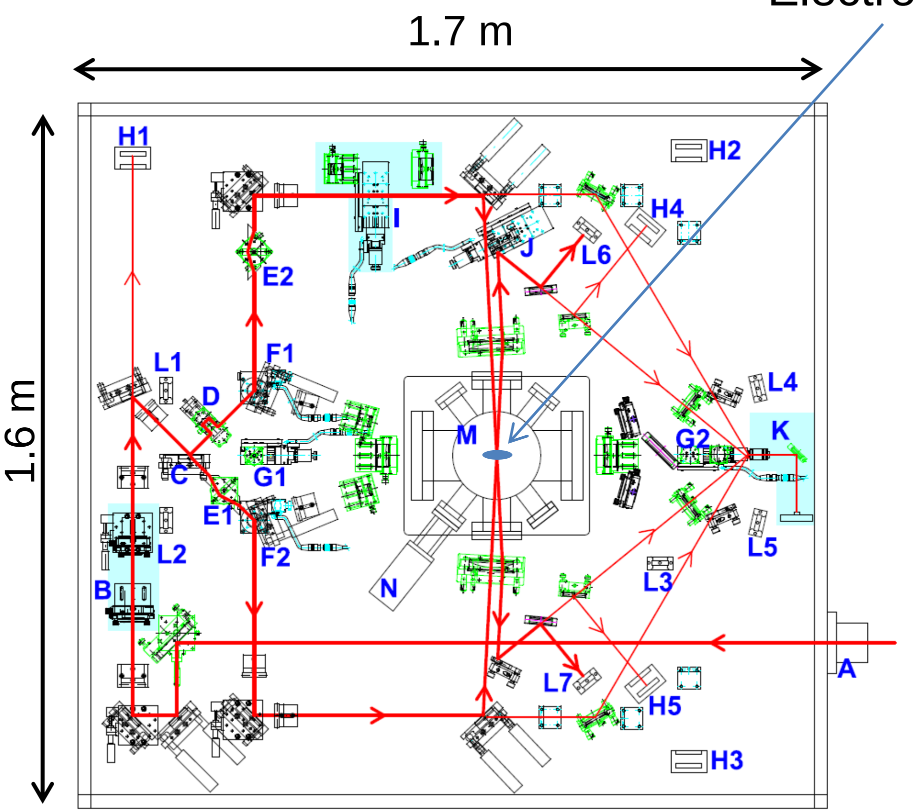
Q-switched Nd:YAG Laser
(wave length:1064 nm)
PRO350 (SpectraPhysics)

Specifications	Value
Wave length (second harmonics)	532 nm
Line width	< 0.003 cm^{-1}
Repetition rate	6.25 Hz
Pulse width	8 ns (FWHM)
Timing jitter	< 1 ns (RMS)
Pulse energy	1.4 J/pulse

- To make smaller interference fringe, small wave length is needed.
  second harmonics 532nm
- High power laser is needed to raise S/N ratio.
  1.4J/pulse

Vertical Optical Table

Electron Beam



Laser path diagram (174 deg crossing angle)

Picture of the vertical optical table installed at ATF2 beam line

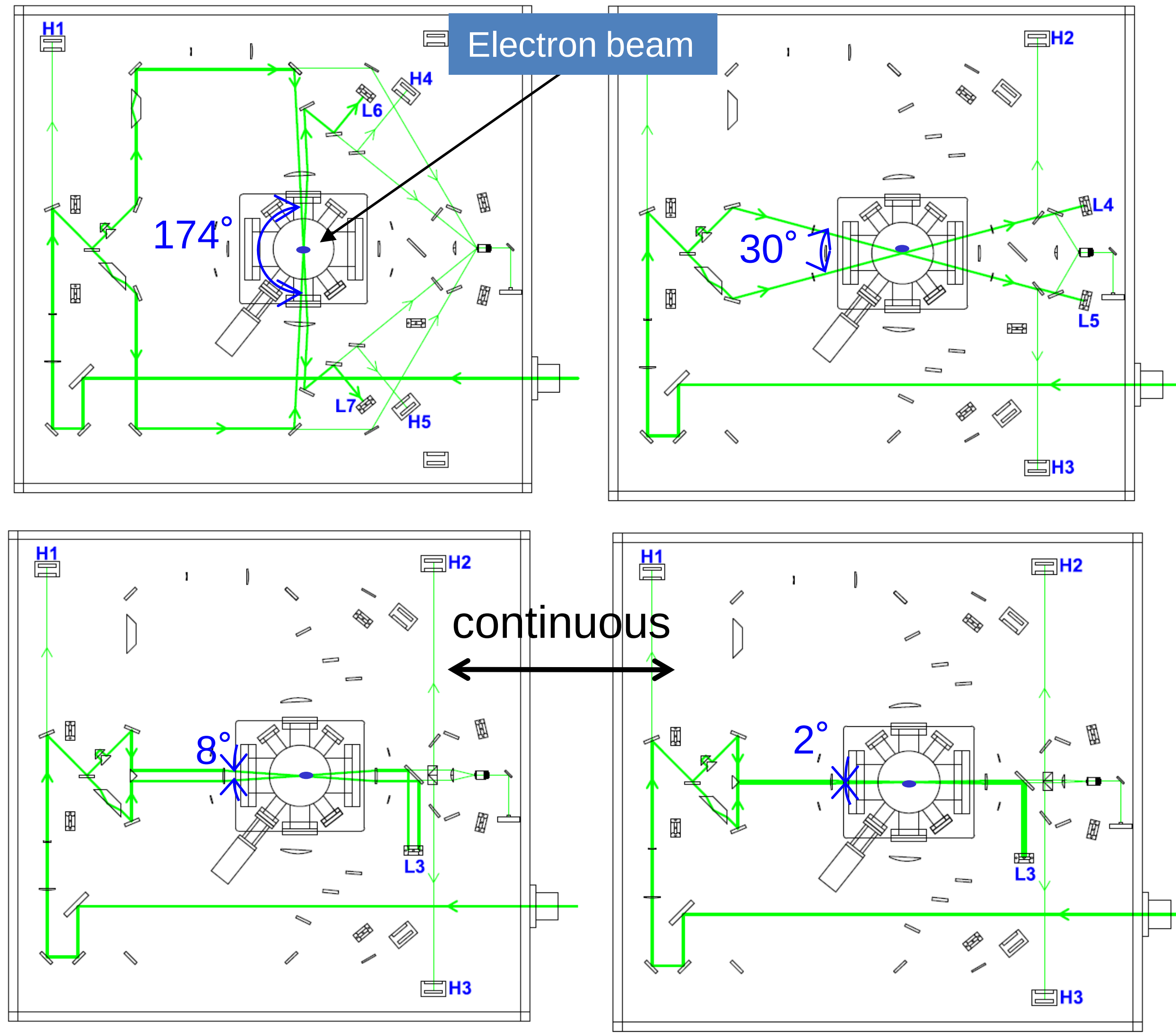
Switch of Laser Crossing Angle

Issue of the Shintake Monitor
⇒ measurable beam size range is limited (7 – 40 % of fringe pitch), if the fringe pitch is fixed.

By changing the laser crossing angle, the measurable beam size range can be enlarged.

fringe pitch $d = \dfrac{\lambda}{\sin\frac{\theta}{2}}$

θ: crossing angle



Expected Beam Size Resolution

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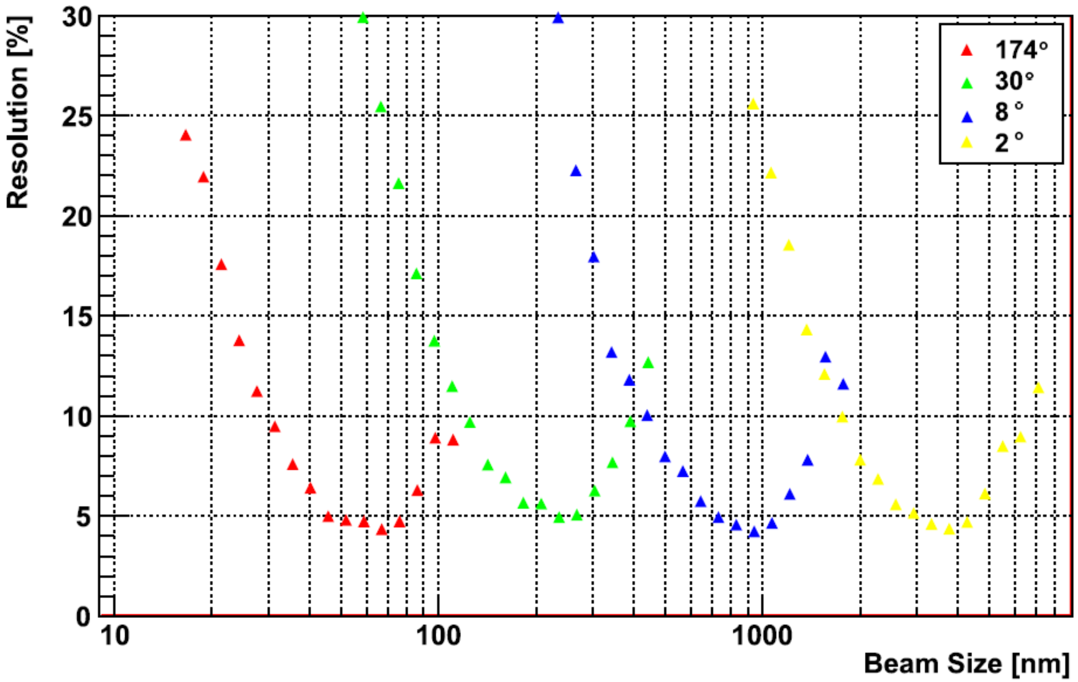
Shintake Monitor



Simulation condition

- Statistical error of the Compton scattered photons (including background subtraction): 10%
- Electron beam position jitter: 30 % of beam size
- Jitter of interference fringe phase: 400 mrad
- Jitter of laser pulse energy: 6.8%
- 1 measurement time : 1 min.

◆ Expected resolution (statistical error) is evaluated by simulation considering the probable error sources

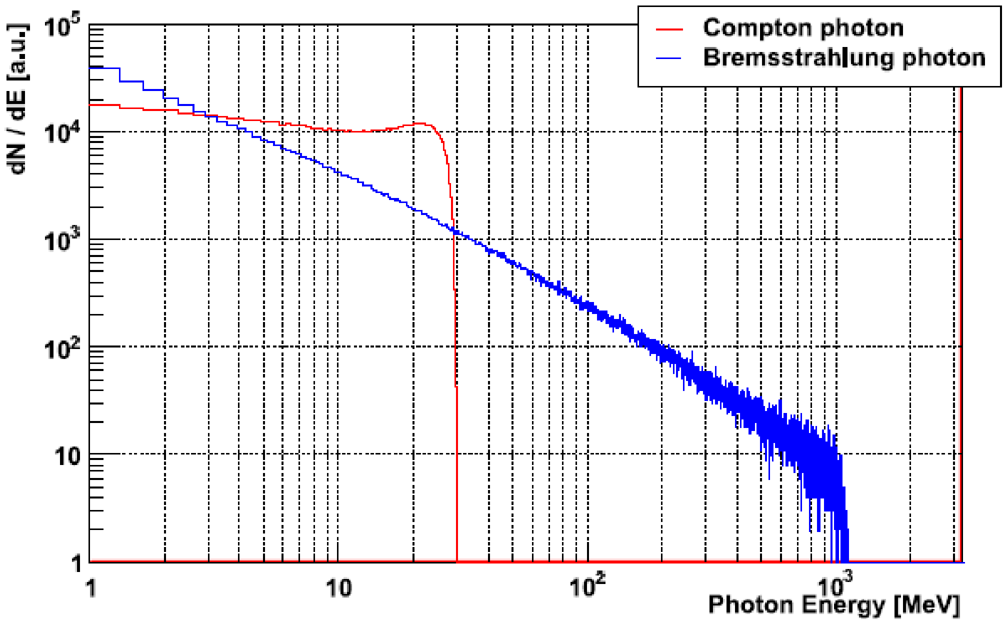
◇ in 25 nm ～ 6 μm range : less than 12 %

◆ Systematic error also need to be evaluated.

	174°	30°	8°	2°
Fringe pitch	266 nm	1.03μm	3.81μm	15.2μm
Minimum	25 nm	100 nm	360 nm	-
Maximum	100 nm	360 nm	-	6 μm

Detection of Compton Scattered Photons

- Difficulty at ATF
  - Background photons have higher energy than the signal photons (Compton scattered photons).



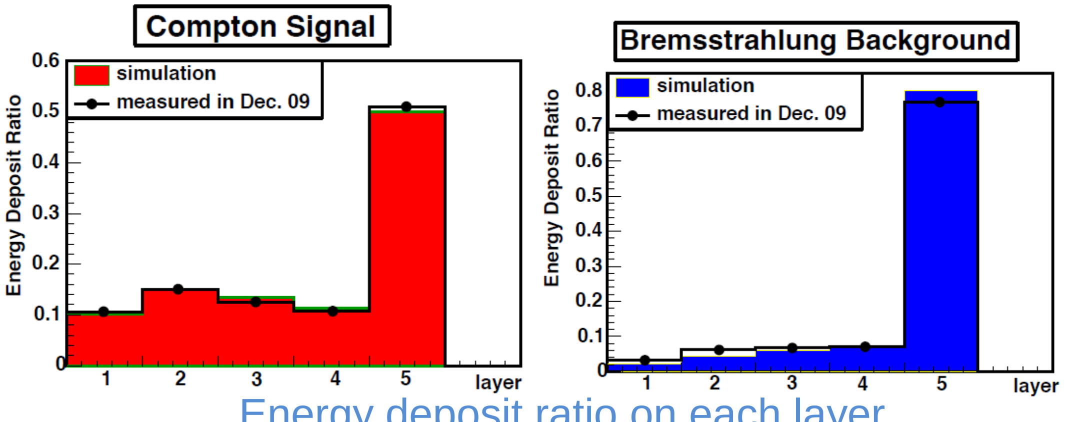
Simulated Gamma-ray Energy Spectrum

◆Signal
- ◇Compton scattered photons
- ◇Compton edge at 30 MeV
  1.3 GeV electron vs.
  532nm (2.3 eV) photons

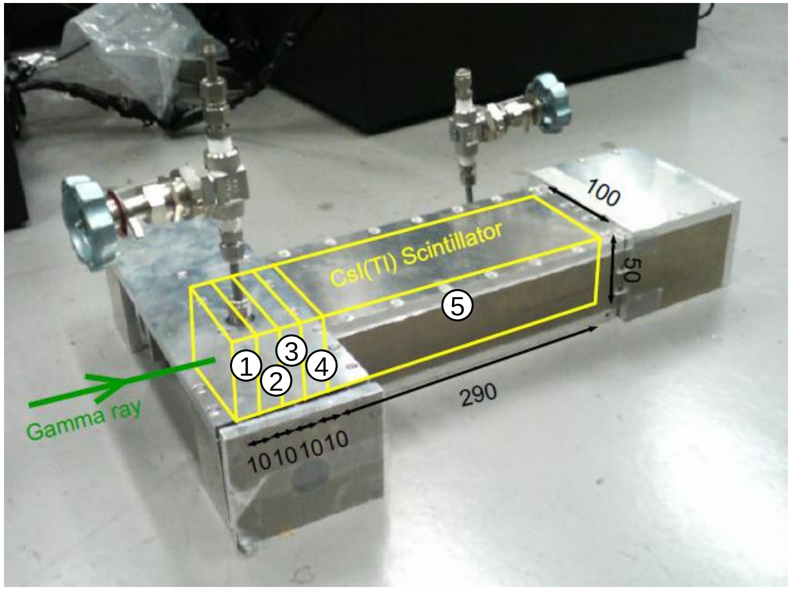
◆Background
- ◇Bremsstrahlung
- ◇Broad spectrum from 1.3 GeV (energy of electron beam)

Gamma-ray Detector

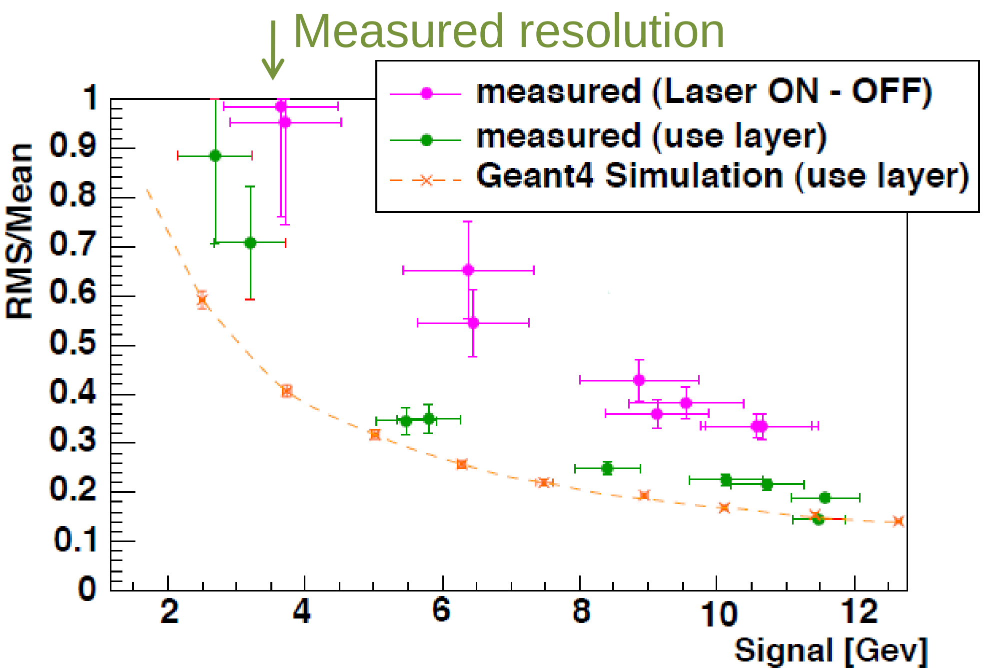
- Use multi-layerd calorimeter
  - CsI(Tl), 4 thin layers + 1 bulk
- Calculate the amount of Compton signal and the background using the difference of energy deposit on each layer.



Energy deposit ratio on each layer

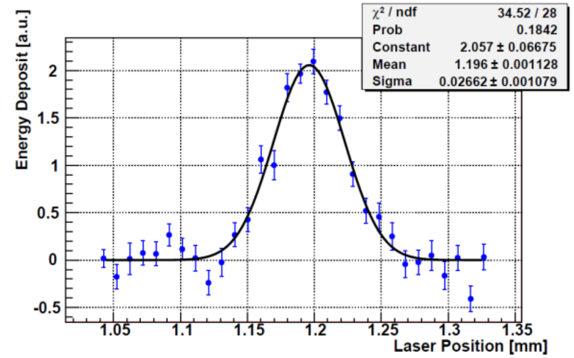


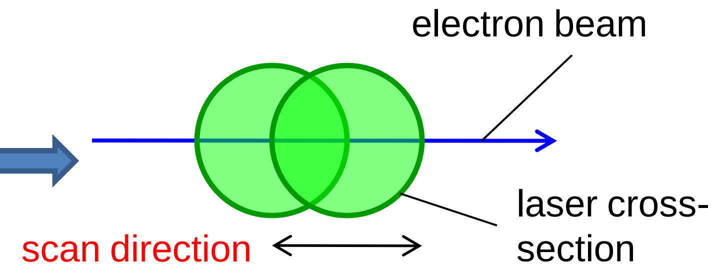
Multi layered gamma-ray detector

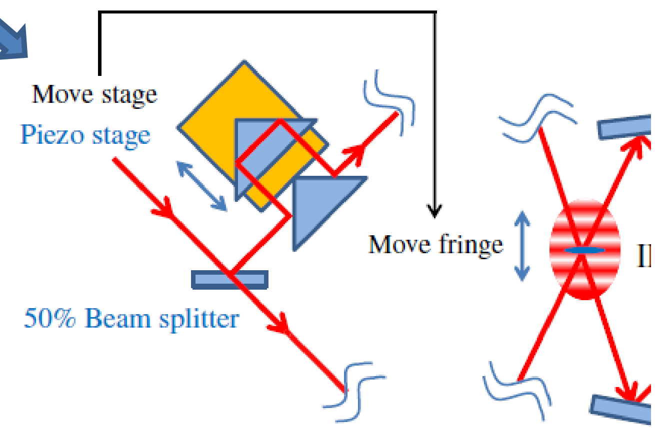


Measurement Procedure

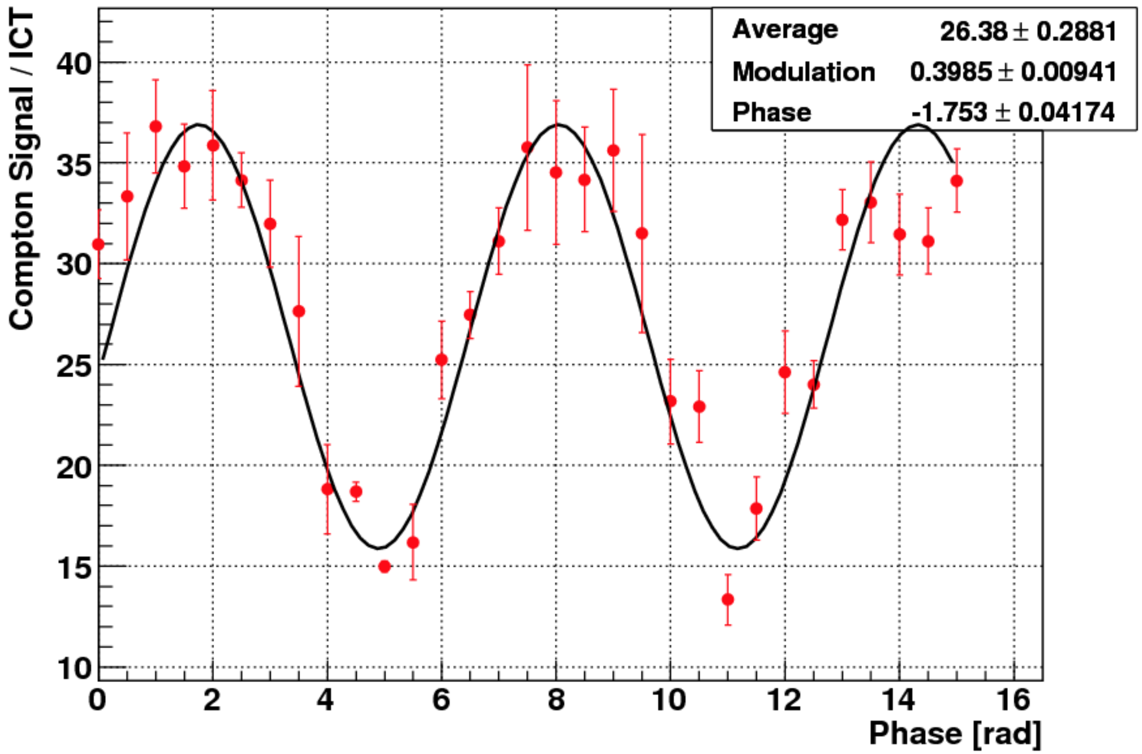
1. Adjust the laser pulse and the electron beam timing
2. Scan the laser beam perpendicular to the electron beam axis
   – Then move two laser beams to the Compton signal peak position
3. Scan one laser beam in the electron beam axis and scan the laser phase
   – search the maximum interfering position
   – The present beam size is obtained from this maximum modulation depth
4. Then repeat the beam tuning and the beam size measurement







Measurement Result



Example of the measurement
(measured on 25 Feb. 2010)

Beam condition
- β_x^* ~ 4 cm (setting)
- β_y^*~ 1 mm (setting)
- σ_x^* ~ 10 μm (measured)

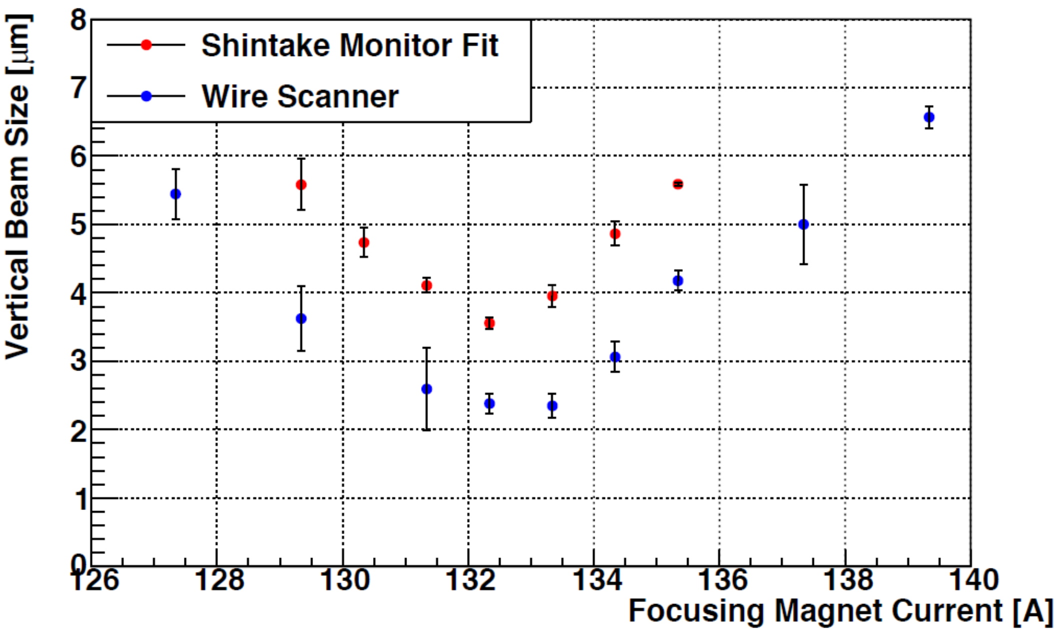
Measurement condition
- Crossing angle ~ 2.75 deg
  = fringe pitch ~11 μm

measured σ_y^* ~ 2.4 μm

Systematic Error

- At the IP, another beam size monitor (wire scanner) is installed
  - 10 um diameter tungsten wire
  - resolution limit is 2.5 μm
- Compared the Shintake monitor and the wire scanner measurement results
  - measurement was done by changing the final focusing magnet current
  - Systematic difference was observed between two measurements

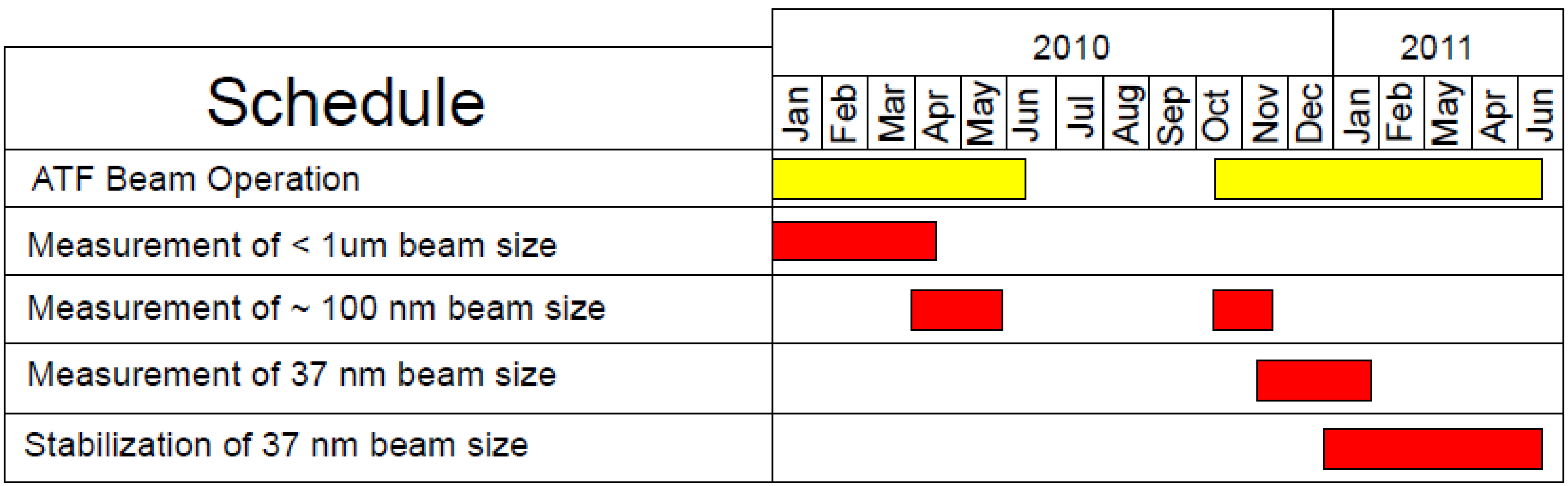
Correction of the systematic errors will be explained in next talk



Summary and Near Future Plan

- Succeeded in the measurement of several μm beam size by using the Shintake Monitor in ATF2
- Laser optics is ready for all measurement ranges.

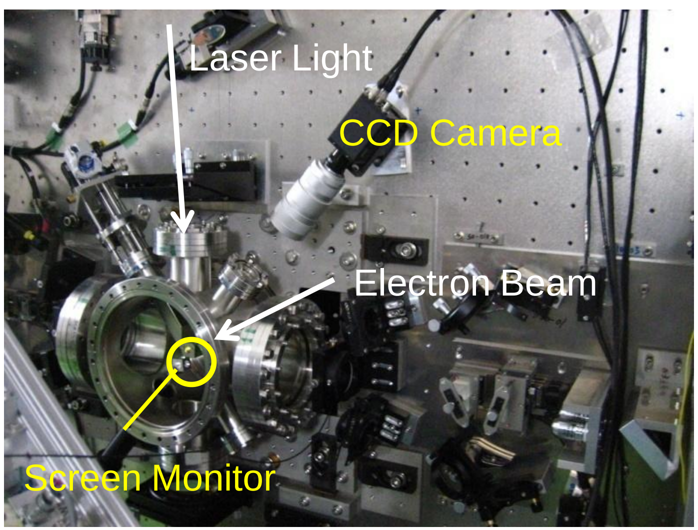
- The current beam time will be continued until June
  - Next beam time will be started in October
- Before the summer shutdown, aim to measure ~ 100 nm beam size



Backup

Adjustment of Laser Position

- To adjust the laser beam position to the electron beam initially, screen monitors are used
- Check the laser beams and the electron beam image on the screen
- Adjustment of several 10 um resolution is possible.



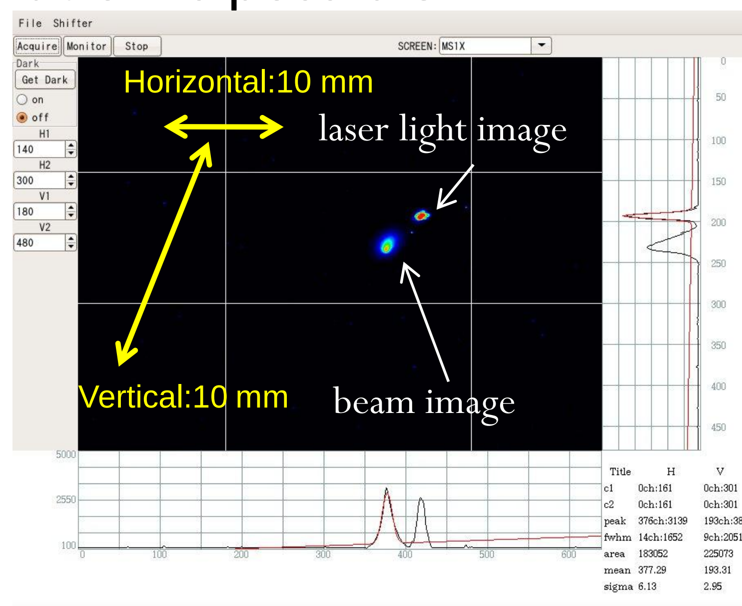
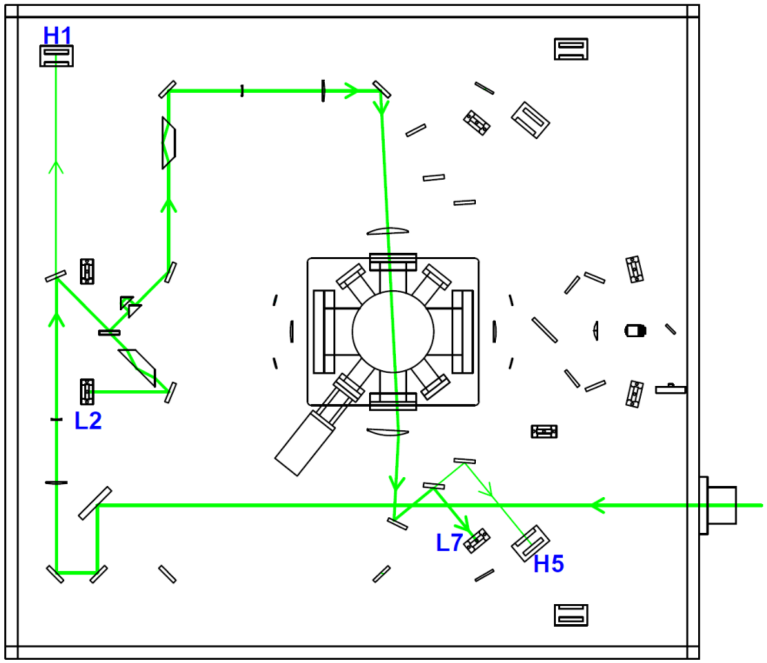


Image of screen monitor

Measurement of Horizontal Beam Size

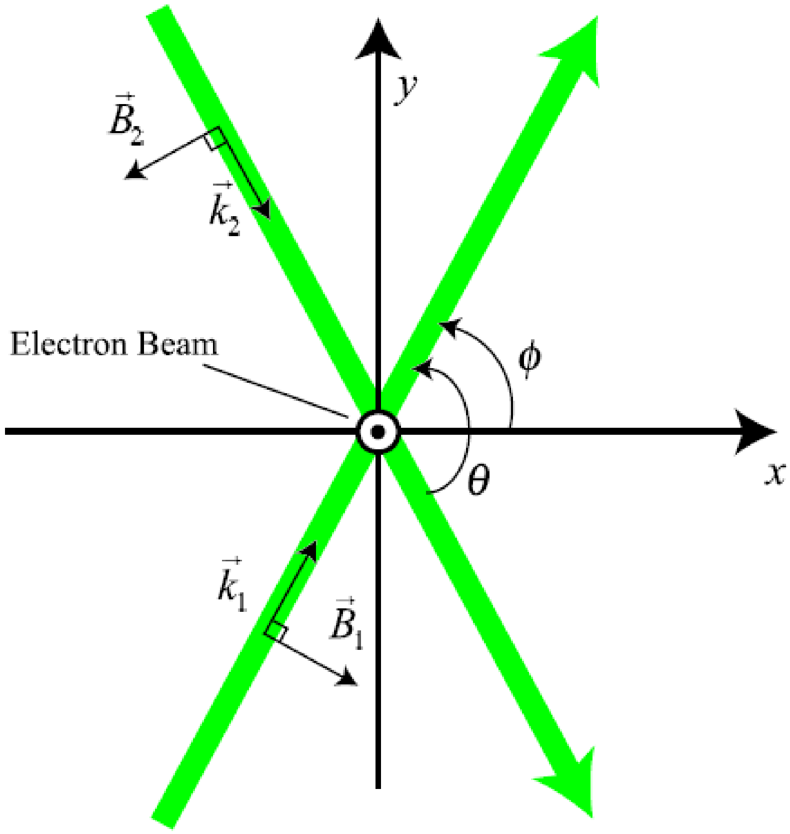
- For the horizontal beam size measurement, 2 types of measurement are possible.
  - Tungsten wire scanner
    - uses 10 um diameter
    - 2.5 um beam size measurement is possible
  - Laser wire
    - Designed laser width at the IP is σx = 5 um
- Designed horizontal beam size at the IP of ATF2

$$\sigma_x^* = 2.8\ \mu m$$



Laser Path for horizontal beam size measurement

Calculation of Beam Size



Change of Compton photon signal

$$N_\gamma(y_0) = \frac{N_0}{2}\left\{1 + \cos 2k_y y_0 \underbrace{\cos\theta \exp\left[-2(k_y\sigma_y)^2\right]}_{M}\right\}$$

y_0 : position of e- beam

$$M \equiv \left|\frac{N_+ - N_-}{N_+ + N_-}\right| = \frac{\text{Amplitude}}{\text{Average}}$$

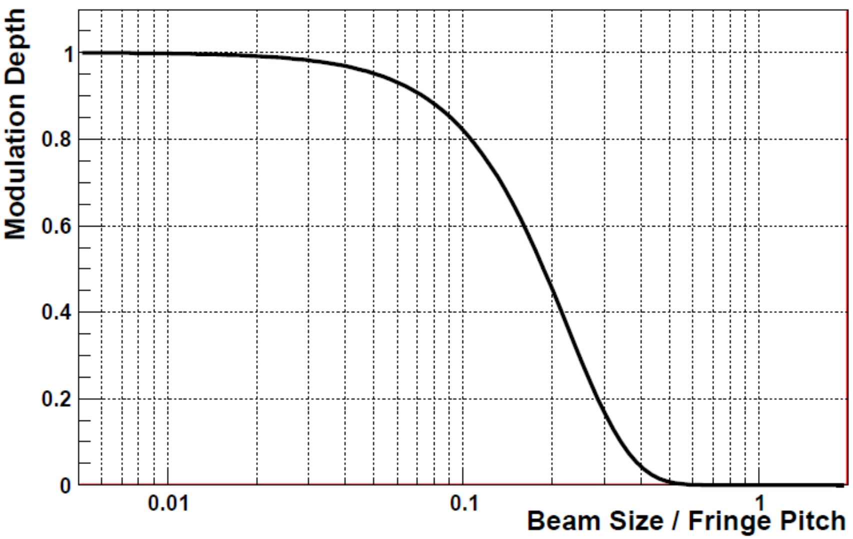
Beam Size

$$\sigma_y = \frac{d}{2\pi}\sqrt{2\log\left(\frac{|\cos\theta|}{M}\right)}$$

Interference fringe pitch

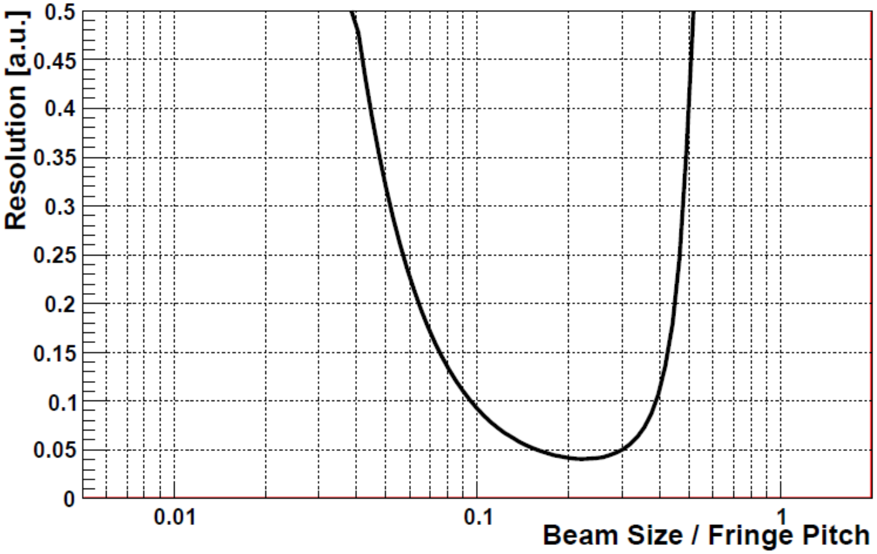
$$d = \frac{\lambda}{2\sin\phi}$$

Estimation of Measurement Resolution



Relationship between the modulation depth:M and beam size

- Beam size large → M ≈ 0
- Beam size small → M ≈ 1
- there exists measurable range according to each fringe pitch



Relationship between the measurement resolution and beam size (assume ΔM=const.)

- The best resolution is obtained at around the 20% of the fringe pitch

Interaction of Electromagnetic Field and Electron

- Electromagnetic field in electron rest frame (with *)
- Electromagnetic field in laboratory frame (wo *)

$$\begin{cases} \mathcal{E}_x^* &= \gamma(\mathcal{E}_x - \beta B_y) \\ \mathcal{E}_y^* &= \gamma(\mathcal{E}_y + \beta B_x) \\ \mathcal{E}_z^* &= \mathcal{E}_z \end{cases},$$

$$\begin{cases} B_x^* &= \gamma(B_x + \beta \mathcal{E}_y) \\ B_y^* &= \gamma(B_y - \beta \mathcal{E}_x) \\ B_z^* &= B_z \end{cases},$$

- γ-factor : 2544 @ 1.3GeV electron

Shintake Monitor for the ILC

- Modulation depth @ 5.7 nm ILC beam
  - 89.6% with 157 nm F2 laser
  - 92.9% with 193 nm Excimer laser
  - 93.9% with 213 nm YAG 5th laser

  In current error factors (ATF2), 17% resolution at M=90%
- Multi bunch operation
  - Quick accumulation of statistics
    - Improvement of resolution by a factor of 10 at 3940 bunches
  - 1 train measurement – slow drift suppressed
  - Need high-repetition laser
  - Fast phase scan by a Pockels cell
- Systematic error is similar, 5% can be achieved

Shintake monitor for the ILC (2)

- Installation at the Interaction Point in the beam commissioning stage
  - Assure 5.7 nm beam focusing
  - Fast tuning without interaction
  - Must be removed when installing the detectors

    By push-pull structure??
- Installation to the second IP for a diagnostic monitor
  - > 25 nm beam size measurements are much more realistic using current scheme.

Experiment at ATF2

- Experiment at ATF2 with 37 nm beam size can be the test for ILC 5.7 nm beam size?
- Vertical beam size is given as follows,

$$\sigma_y = \sqrt{\frac{\beta_y \varepsilon_{n,y}}{\gamma}}$$

  - βy : β-function (determined by the strength of the focusing magnet)
  - $\varepsilon_{n,y}$: normalized vertical emittance (determined by the performance of the damping ring)
  - γ : γ –factor of the accelerated beam
- Therefore, if the same b and emittance will be obtained with the ILC beam, 5.7 nm focusing is possible with the ATF2 beam optics

	ATF2	ILC
beam energy	1.3 GeV	250 GeV
γ for electron	2544	4.89×10^5
1/γ	3.9×10^{-4}	2.0×10^{-6}