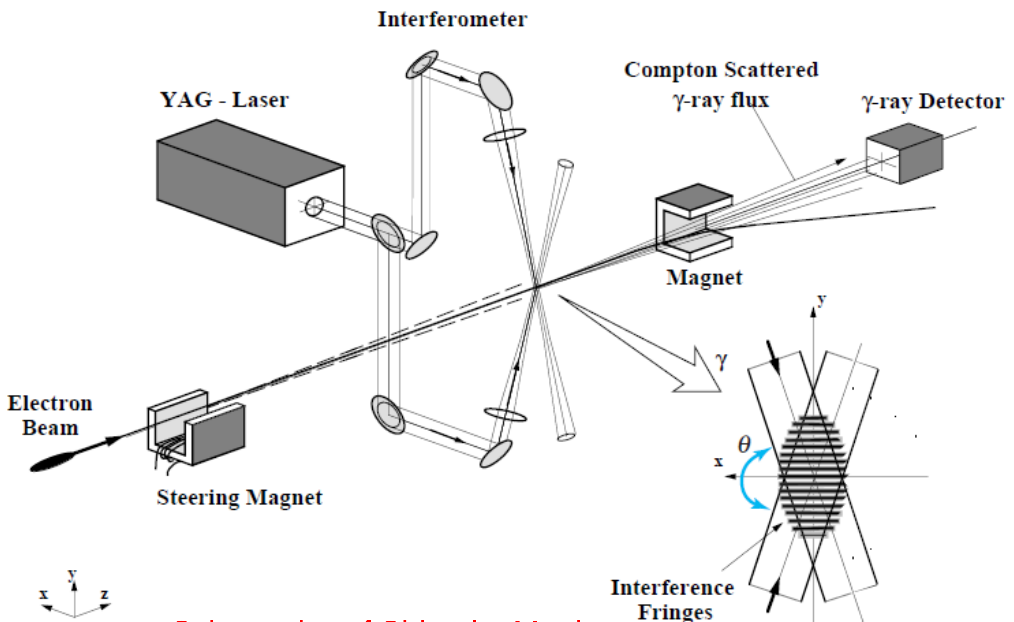
IPBSM status and plan

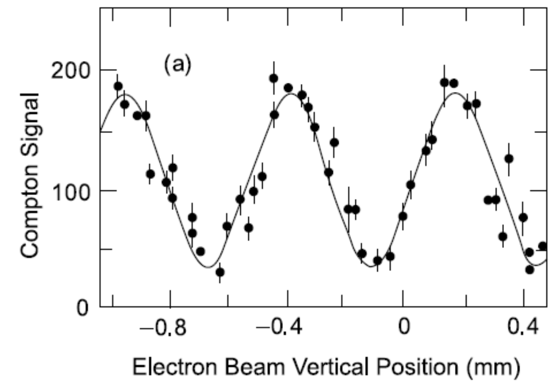
ATF project meeting

M.Oroku

Principle of Laser Interference Beam Size Monitor (Shintake Monitor)



Schematics of Shintake Monitor



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

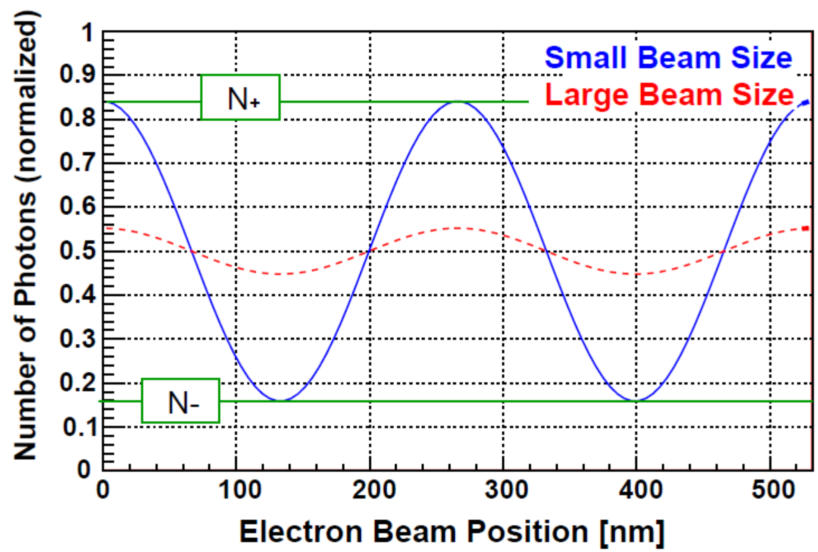
Modulation depth

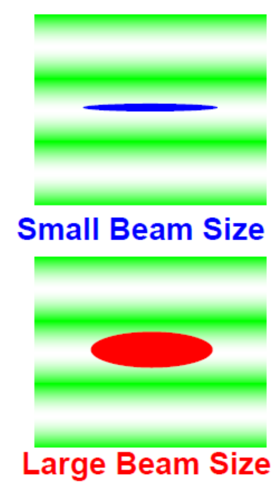
$$M \equiv \left| \frac{N_+ - N_-}{N_+ + N_-} \right| = \frac{\text{Amplitude}}{\text{Average}}$$

Beam Size

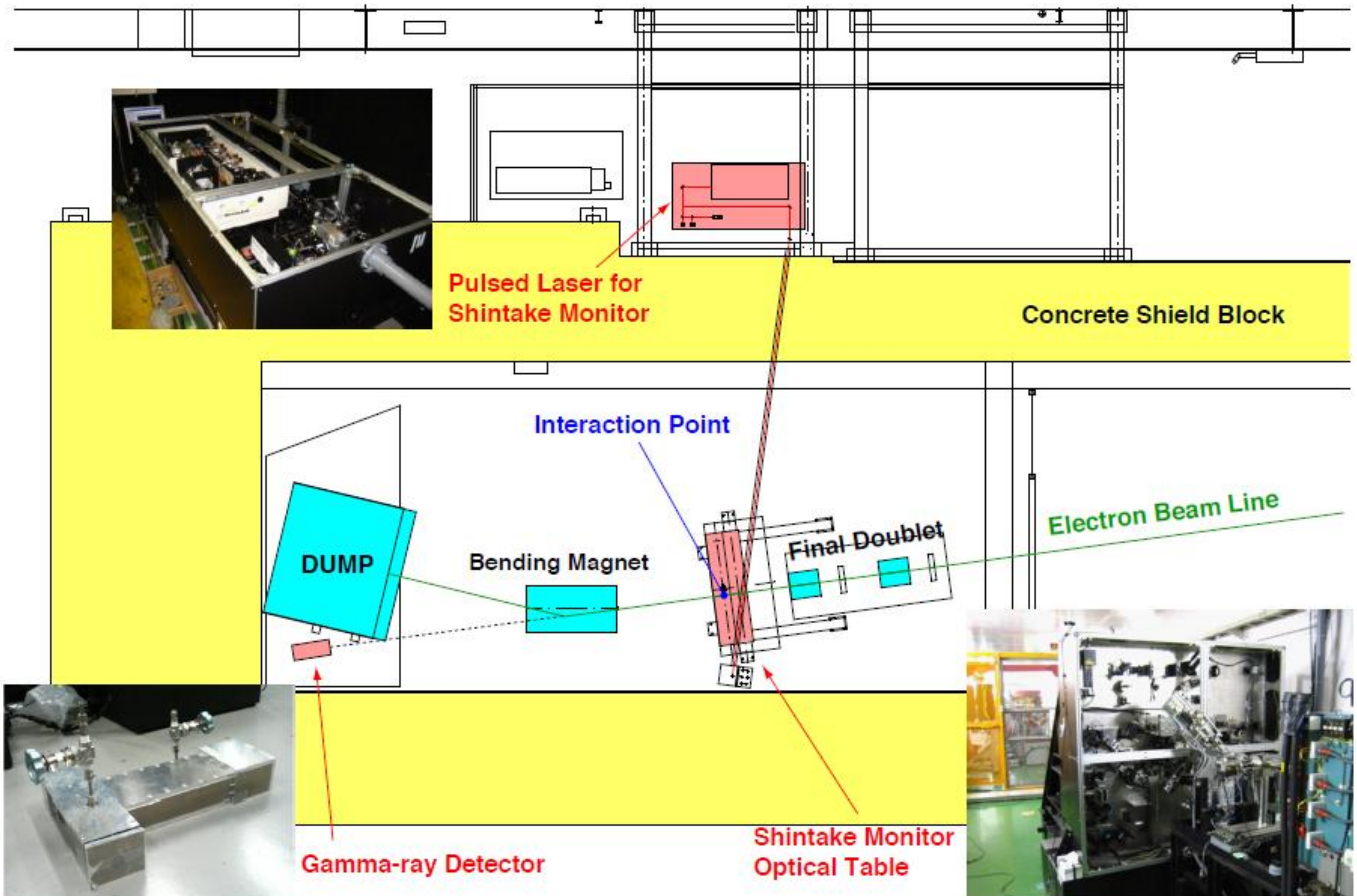
$$\sigma_y = \frac{d}{2\pi}\sqrt{2\log\left(\frac{|\cos\theta|}{M}\right)}$$

d: fringe pitch θ: crossing angle



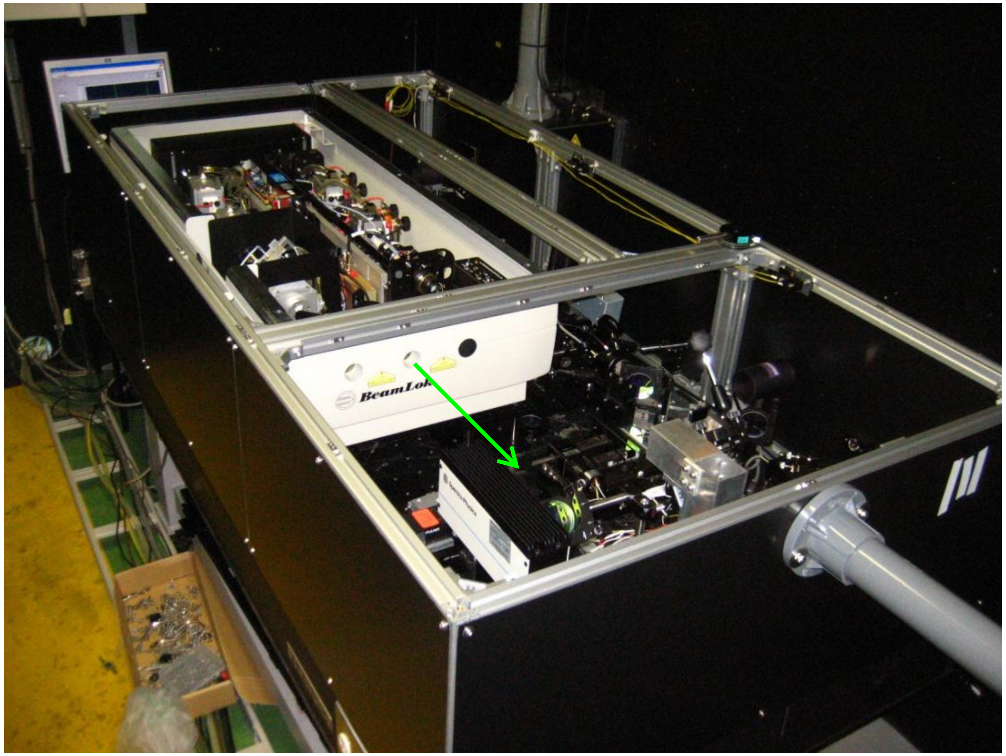


Components of Shintake Monitor



Layout around ATF2 Interaction Point

Laser System



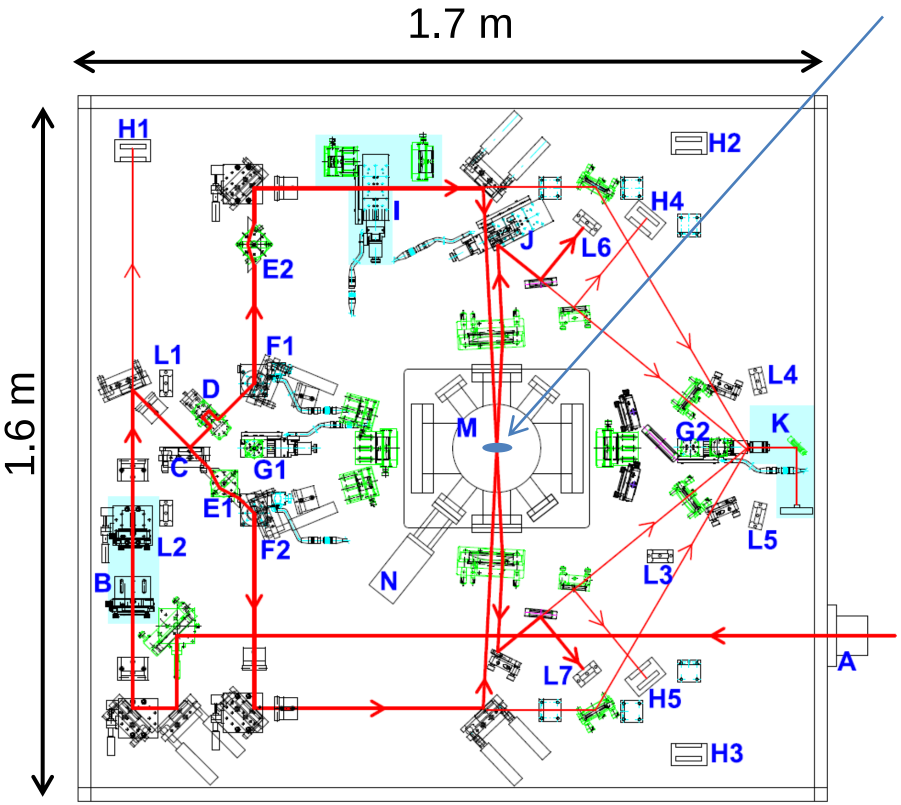
Q-switched Nd:YAG Laser
(wave length:1064 nm)
PRO350 (SpectraPhysics)

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

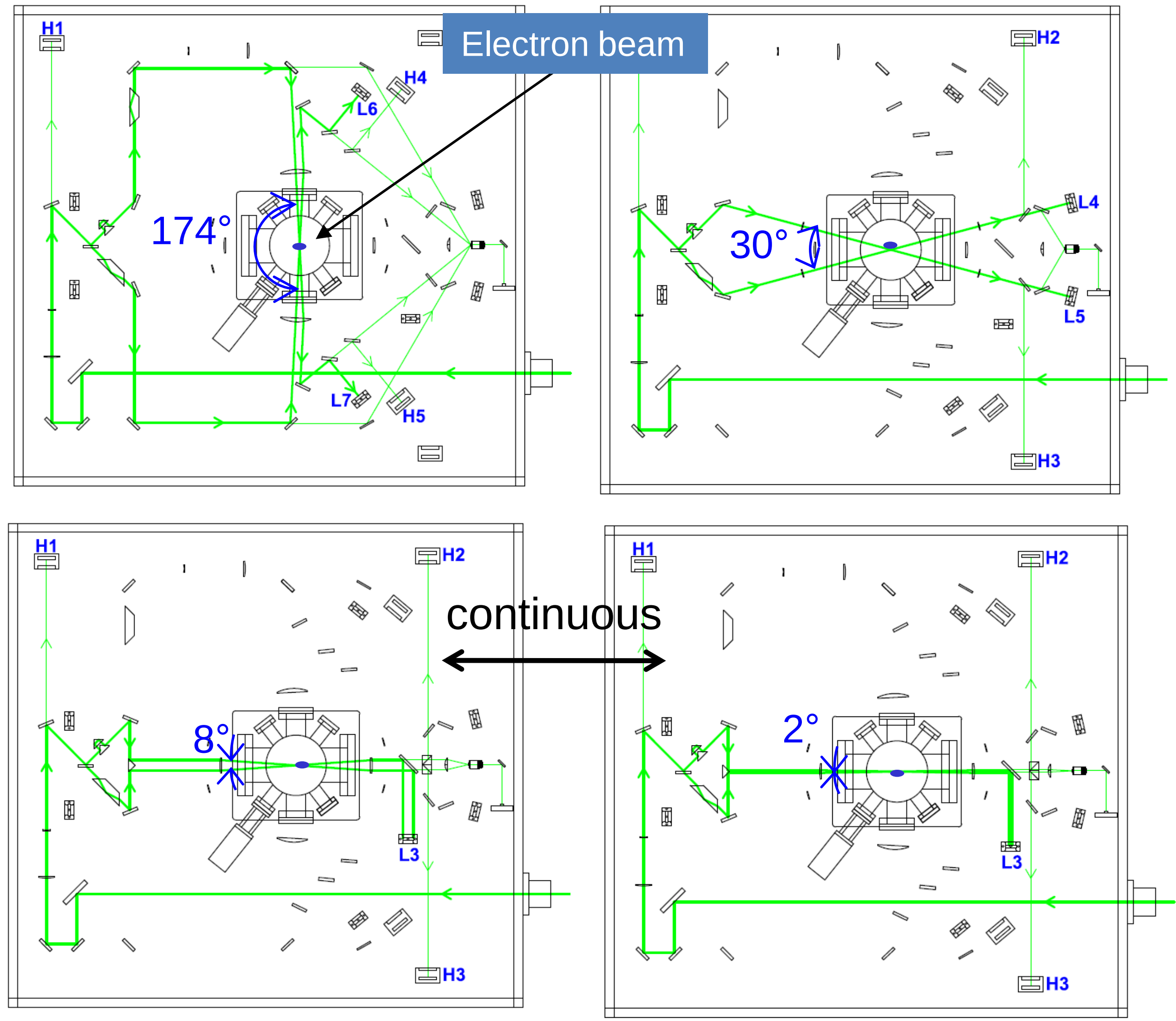
Switch of Laser Crossing Angle

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

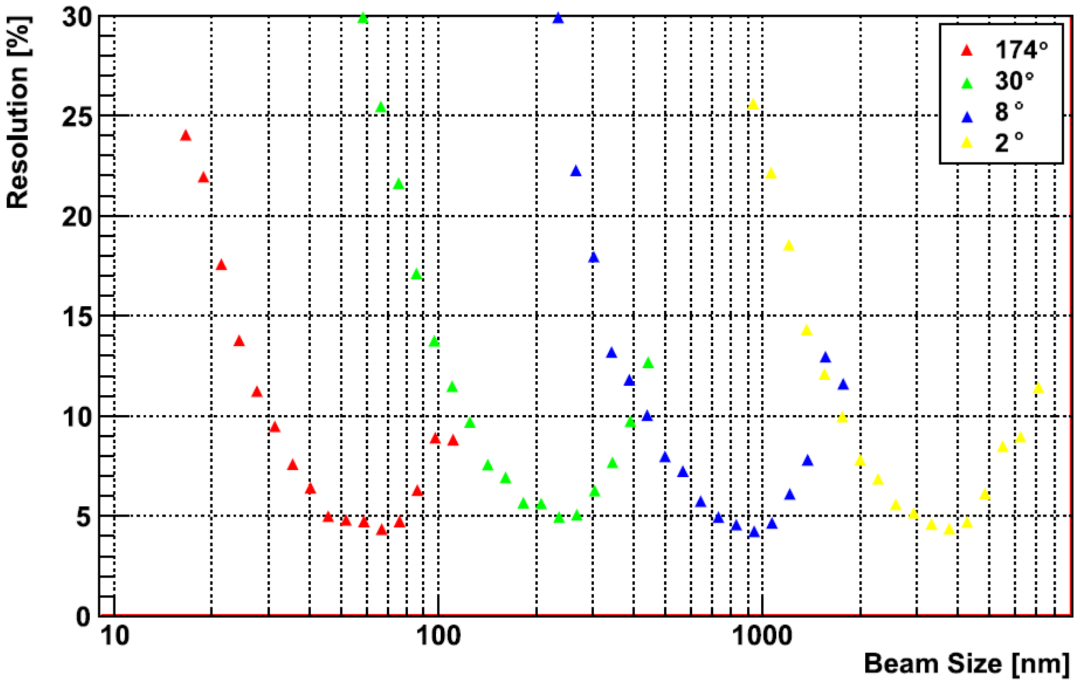
By changing the laser crossing angle, the measurable beam size range can be enlarged.

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

θ : crossing angle



Expected Beam Size Resolution



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.

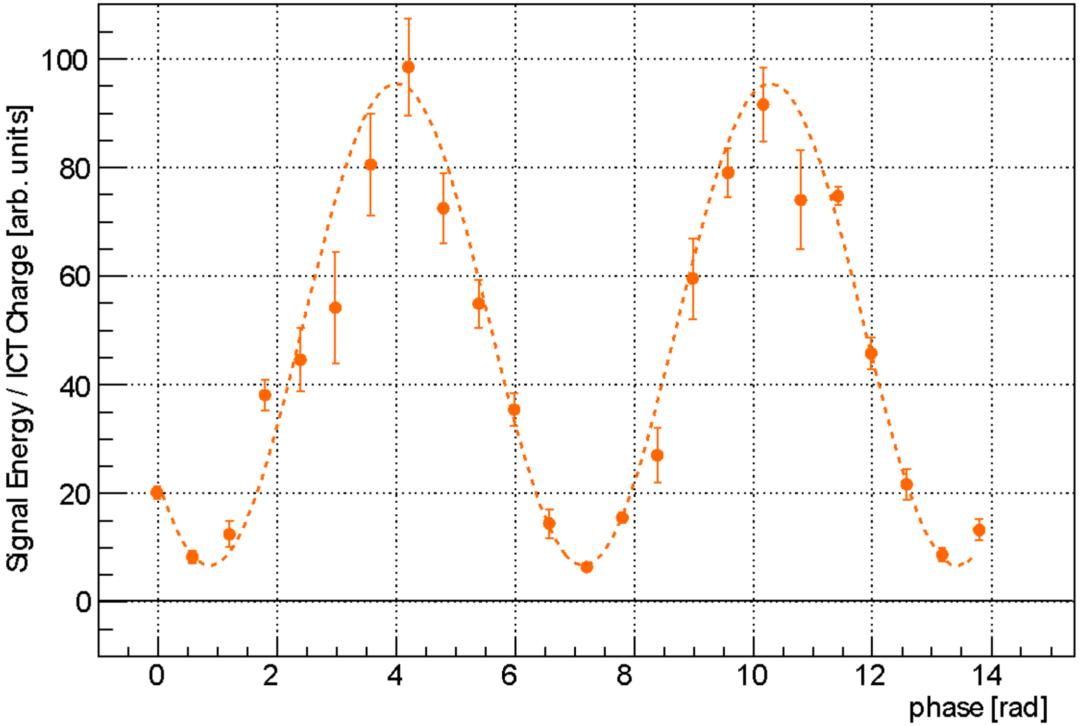
◆ Expected resolution (statistical error) is evaluated by simulation considering the probable error sources

◇ 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

Result of continuous run



Beam condition

- β_x^* ~ 4 cm (setting)
- β_y^*~ 1 mm (setting)

•BG 6.5GeV
•S/N 30

Measurement condition

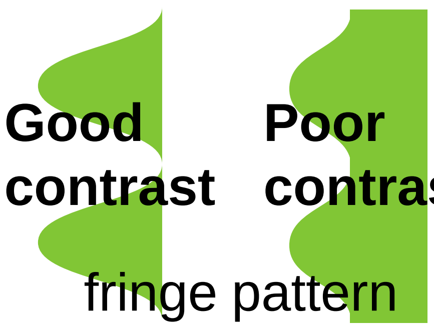
- Crossing angle ~ 7.96 deg
  = fringe pitch ~3.83 μm

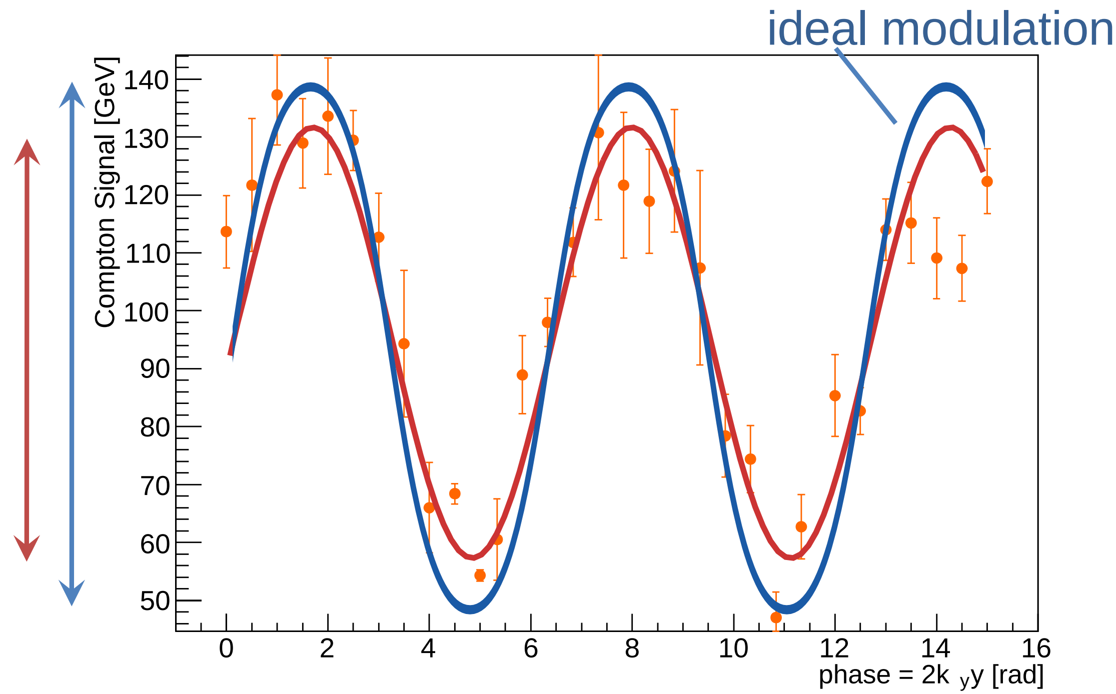
Modulation ~ 0.85

$$\sigma_y = 313 \pm 31 \ (\mathrm{stat.}) \ {}^{+0}_{-40} (\mathrm{sys.}) \ \mathrm{nm}$$

Sources of Systematic Error

a error source:
deterioration of the contrast of the laser interference fringe pattern
↓
decrease in modulation depth





$$\text{Compton Signal} \propto 1 + M \cos 2k_y y$$

$$M_{meas} = C_\alpha C_\beta \cdots M_{ideal}$$

other error sources: e^- beam position jitter
e^- beam size jitter
Tilt of the laser fringe pattern with respect to the e^- beam

List of Error Sources

Oroku@The Univ. of Tokyo

Shintake Monitor

Source	$M_{meas.}$ / M_{ideal} for ~300nm	$M_{meas.}$ / M_{ideal} for 37nm
Laser power imbalance	99.7%	99.7%
Laser alignment accuracy	> 98.1%	> 98.1%
Laser temporal coherence	> 99.7%	> 99.7%
Phase jitter	> 99.5%	99.5 %*
Laser spherical wavefront	~ 100%	> 99.4%**
Beam size growth in the fringe pattern	~ 100%	99.9%***
Π Factor	> 97%	96%

* Beam position monitor is needed.
** Laser focal point alignment is needed.
*** Beam optics study at upper and lower IP is needed.

Towards the 37nm Beam Size Measurement

In future 37nm beam size measurement, following error sources cannot be neglected.

Laser Spherical Wavefront
Alignment of laser focal point is needed.
e^- Beam Size Growth within the Fringe Pattern
We can estimate that influence from measurement of upper stream beam parameters and beam optical design.
e^- Beam Position Jitter
IP-BPM will enables us to correct beam position jitter in 8.7nm resolution. (assuming 30 nm beam jitter)

With evaluation of all error sources (include statistical errors), we evaluate the Shintake monitor performance towards 37nm beam size measurement.

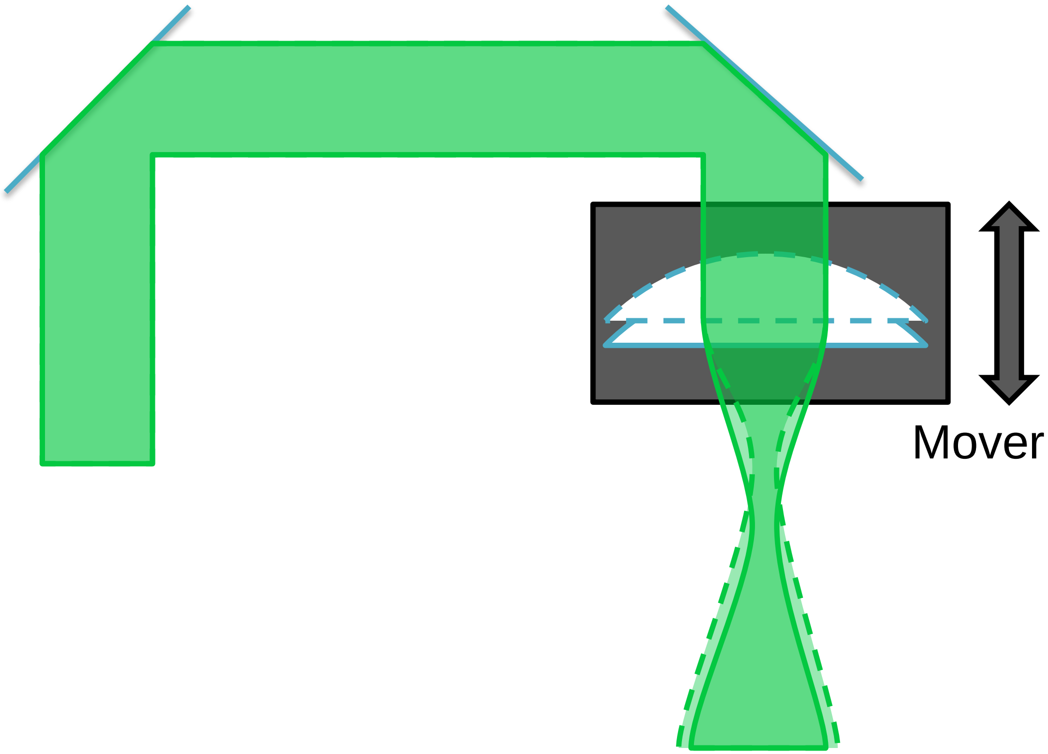
$$\sigma_y = 37 \pm 4\,(\mathrm{stat.})\,{}^{+0}_{-2}\,(\mathrm{sys.})\ \mathrm{nm}$$

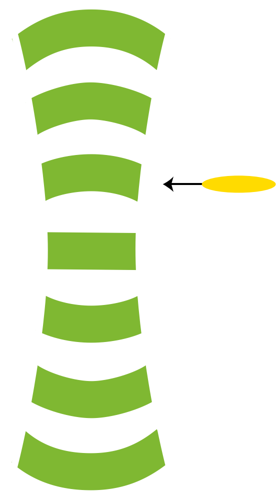
in 1 min. fringe scan

Next Plan

- Focal point scan
- Phase Monitor
- Laser position stabilization with PSDs
- (Carbon wire scanner install)
- IPBPM install (need to discuss?)

focal point scan(174deg)

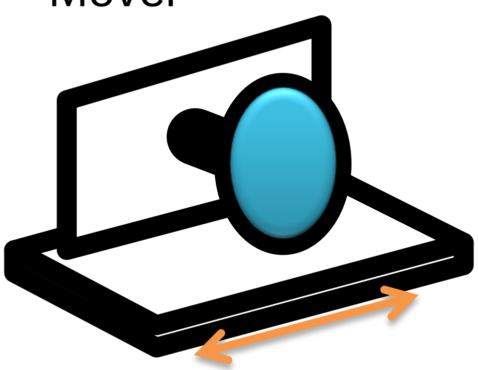


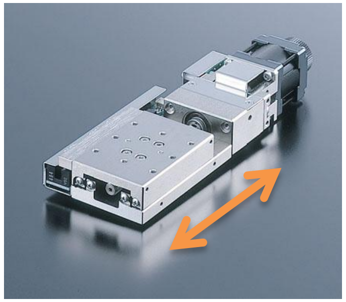


Offset of beam position to the focal point of laser

Systematic error from spherical wavefront of laser

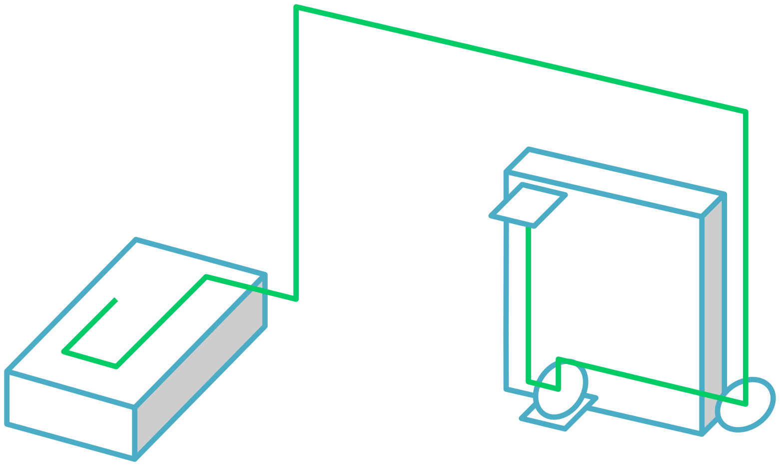
Mover





Stroke: 30mm
Resolution 0.1μm

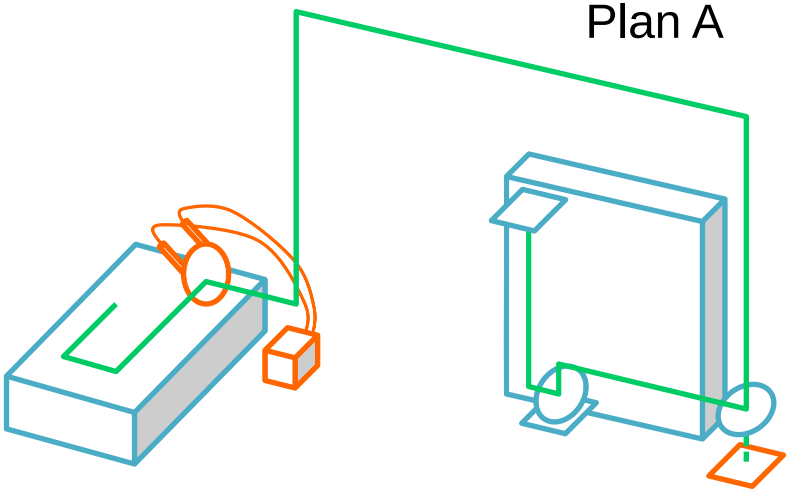
Laser position stabilization with PSDs (1)



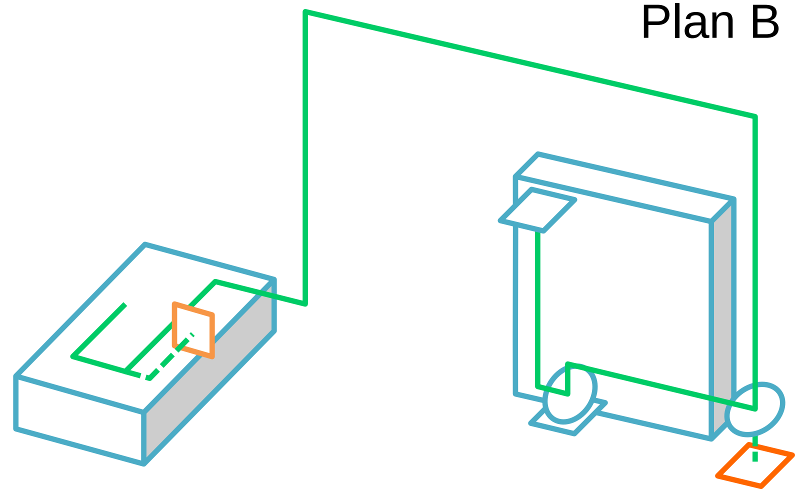
To monitor the drift of laser position:

Put PSD at the end of long transport line
↓
Better stabilization

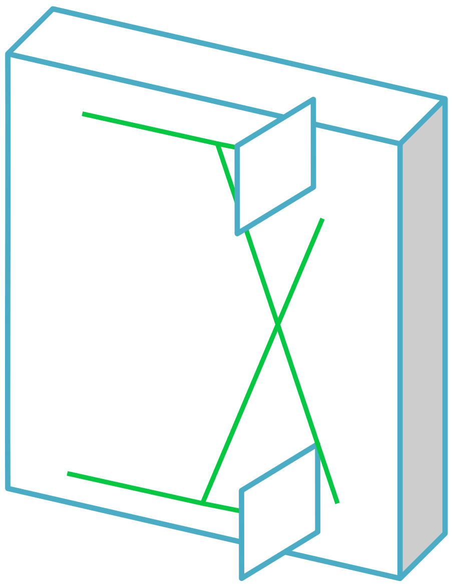
Plan A

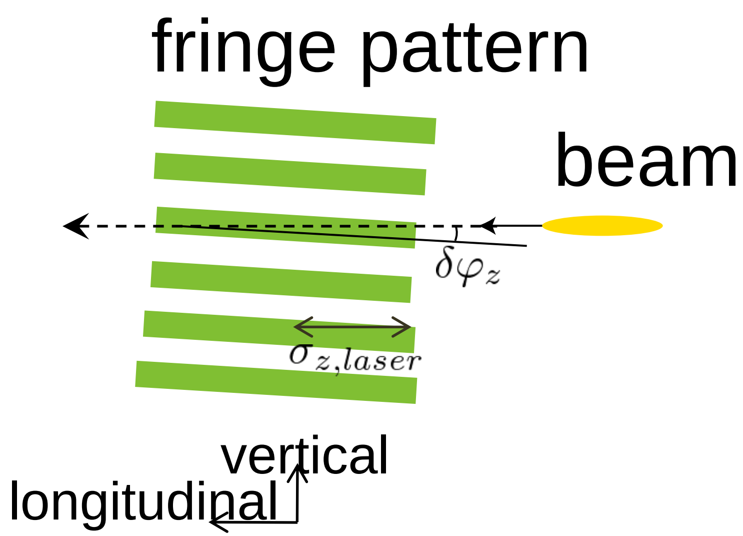


Plan B



Laser position stabilization with PSDs (2)





Plan to monitor the tilt of laser fringe by 2 PSDs

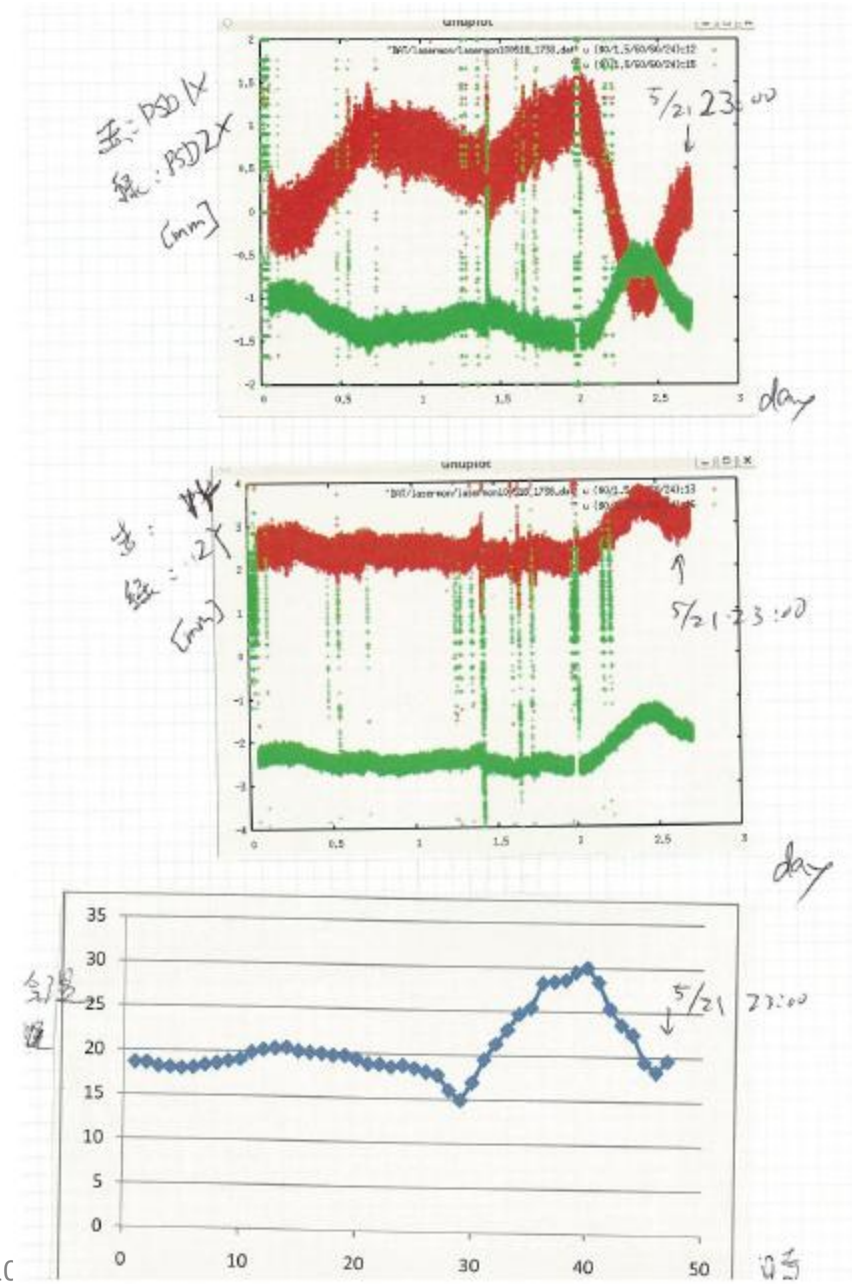
The beam senses fringe pattern projected on transverse- and longitudinal-plane which the beam forms on.

$$\sigma^2_{\mathrm{y,meas.}} = \sigma^2_{\mathrm{y,ideal}} + \delta\varphi_z^2 \sigma^2_{\mathrm{z,laser}}$$

Summary

- Until now, the measurement by 2- 8 deg.mode was done and systematic error sources were studied
- The current status and the upgrade plan was reported

Backup



光路ドリフト

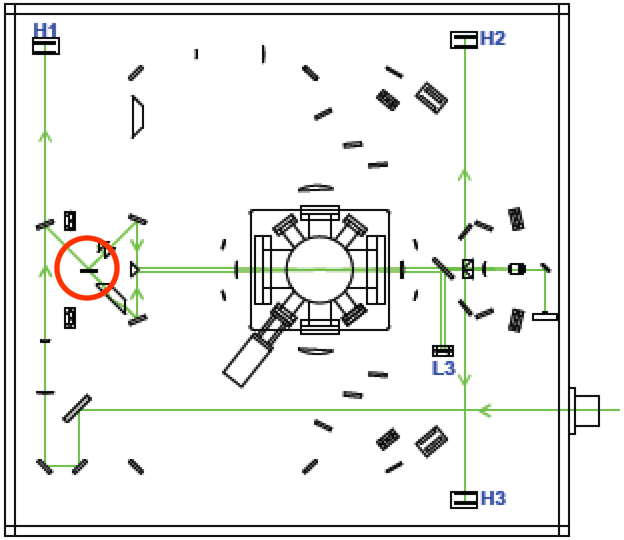
気温とともにlaser positionがドリフト

Laser Polarization

P-polarized reflectance of the beam splitter is not 50%, since the splitter is tuned for S-polarized light.
So the existence of P-polarized light causes power imbalance of the split laser beams and makes the fringe contrast worse.

$$C_{\mathrm{pol}} = \frac{2\left(\sqrt{Ps^{up}Ps^{down}} + \sqrt{Pp^{up}Pp^{down}}\right)}{P}$$

Ps: the intensity of S-polarized light
Pp: the intensity of P-polarized light
P: the whole intensity of laser



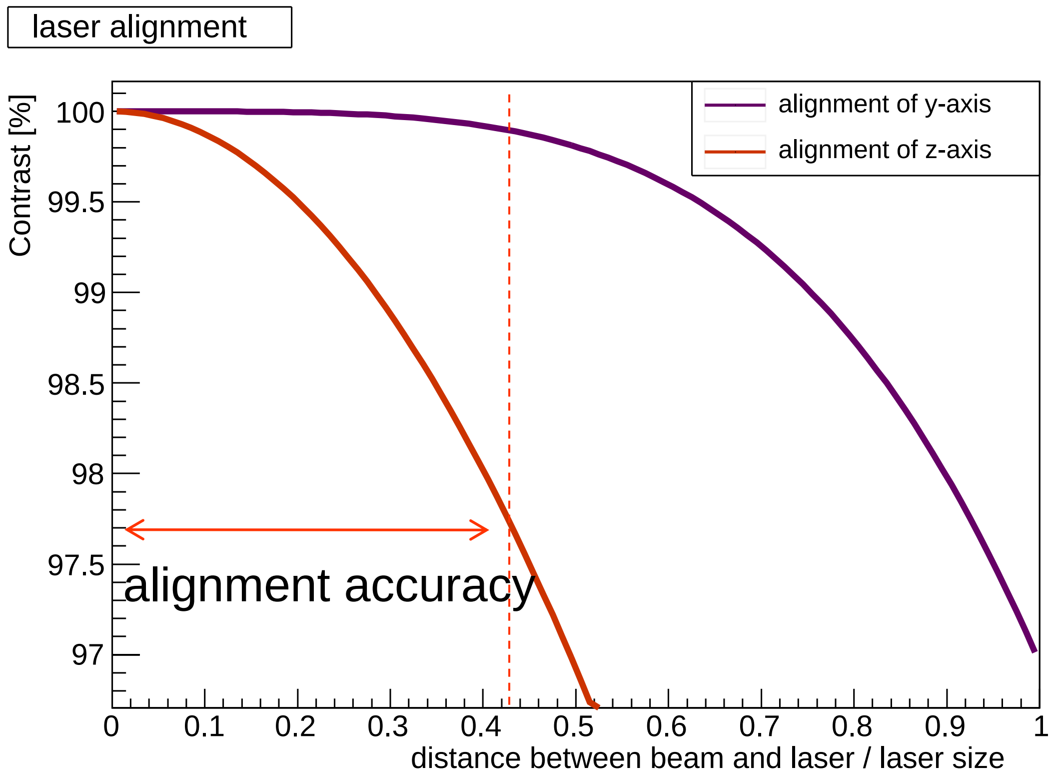
$$C_{\mathrm{pol}} = 96.3 \pm 2.1\%$$

after polarization adjustment with half wave plate

$$C_{\mathrm{pol}} = 99.7 \pm 0.1\%$$

Laser Alignment Accuracy

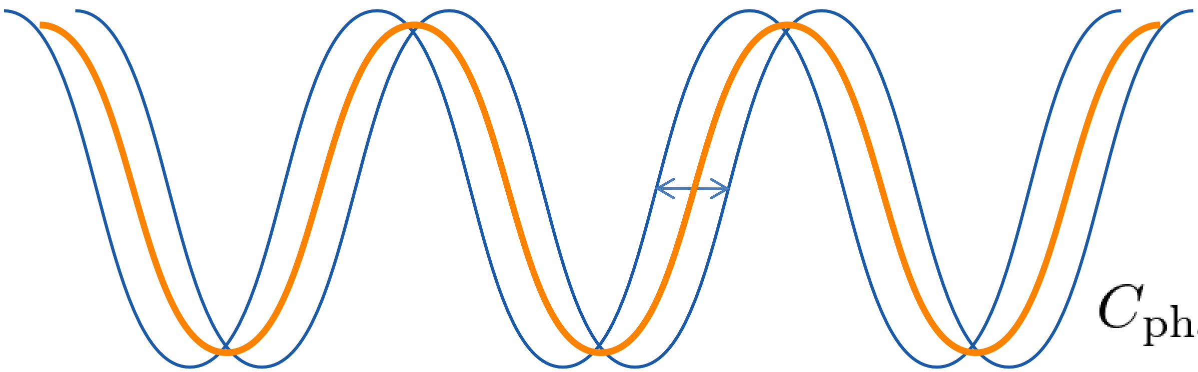
It is important for a good contrast to align the laser pathway with beam position.



$$C_{\mathrm{alignment}} > 97.5\%$$

Phase Jitter

Phase jitter of the laser light smears the fringe pattern, and decreases modulation depth.
Phase jitter is caused by optical device vibrations.



$$C_{\text{phase}} = \exp\left(-\frac{\Delta phase^2}{2}\right)$$

The Shintake monitor has a phase monitor and a light path length feedback system with piezoelectric device.
Using the feedback system,

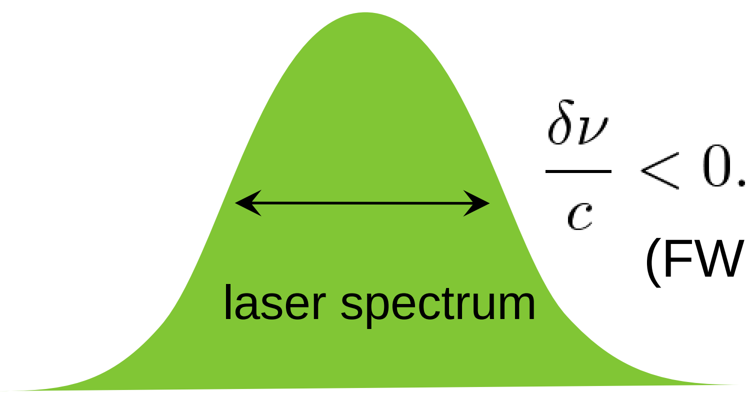
$$\Delta phase = 398 \pm 54\text{mrad} \rightarrow 320 \pm 41\text{mrad}$$

$$C_{\text{phase}} = 92.3 \pm 2.0\% \rightarrow 95.0 \pm 1.2\%$$

Laser Temporal Coherence

- If the laser temporal coherence is poor and the two laser path lengths are different, the fringe pattern contrast is reduced.
- This is because each frequency component of the laser contributes to interference in different phase under the existence of laser path length difference Δl.

$$C_{\mathrm{t-coherence}} = \exp\left(-\frac{\pi^2}{4\ln 2}\left(\frac{\delta\nu\Delta l}{c}\right)^2 \right)$$



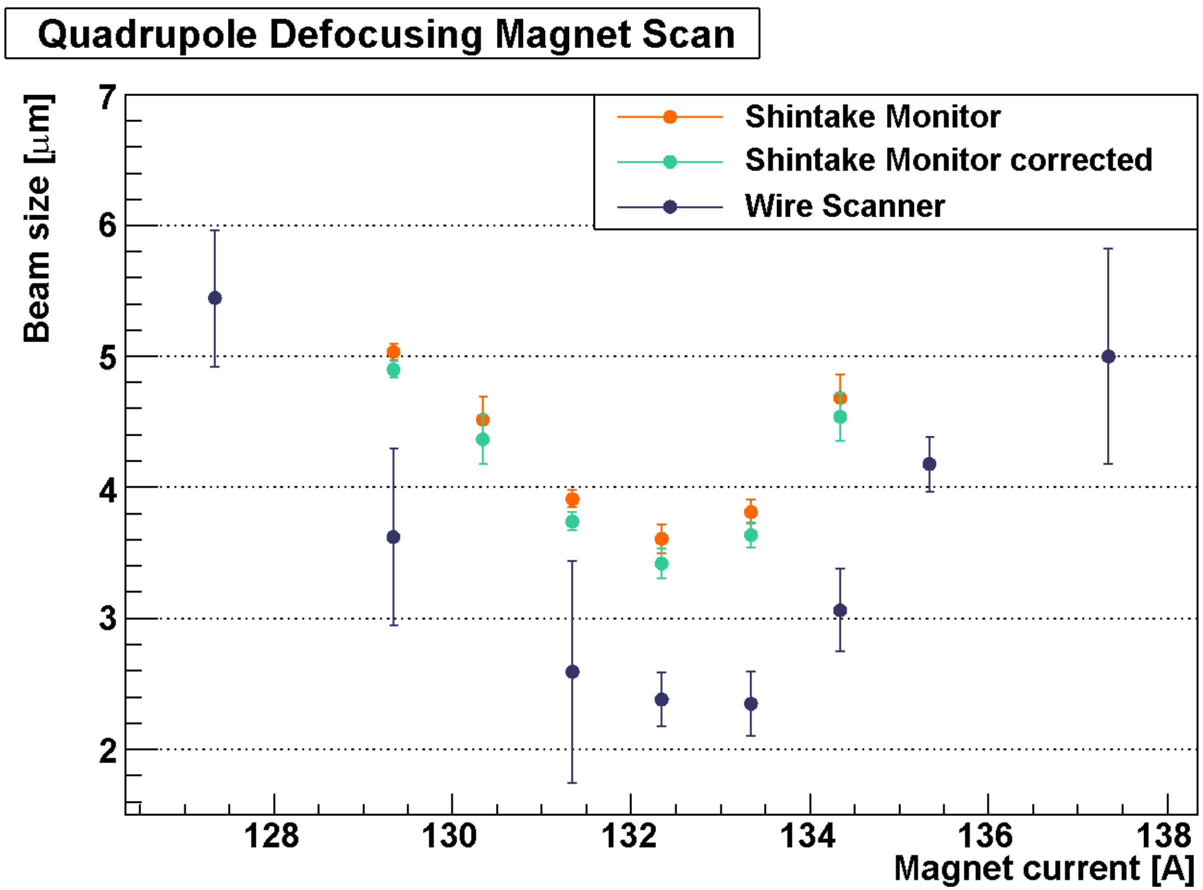
$$\frac{\delta\nu}{c} < 0.003\mathrm{cm}^{-1}$$

(FWHM)

$$C_{\mathrm{t-coherence}} > 99.7\%$$

Contrast Correction

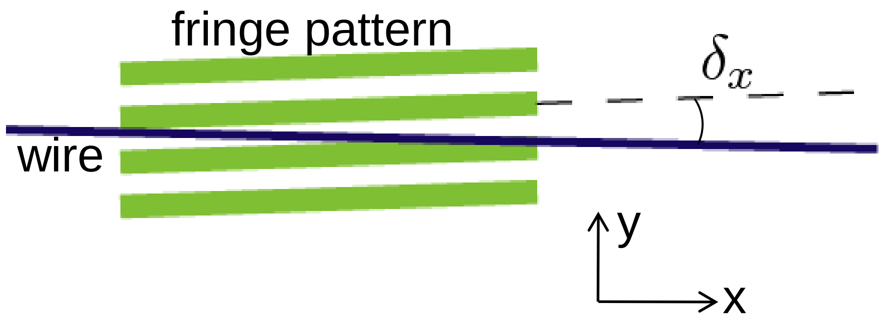
Comparison with the WS measurement after Contrast correction



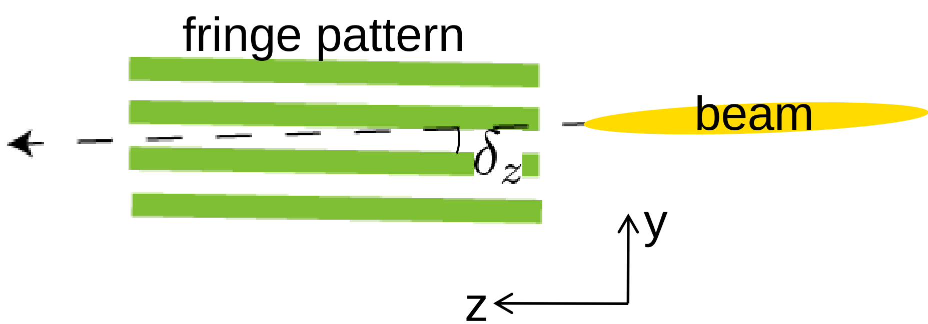
After the above corrections the measured beam size is slightly decreased, but systematic shift still remains.

Tilt of the laser fringe pattern with respect to the WS

Horizontal and longitudinal axes defined by the WS and those defined by the fringe pattern might be different.



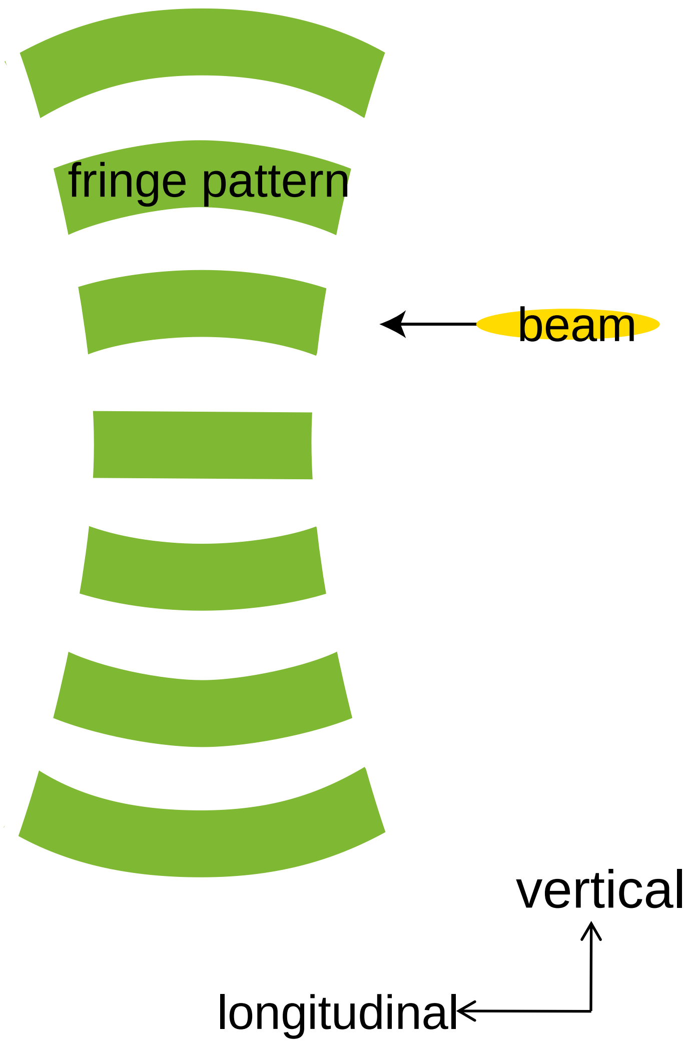
$$\sigma_{meas}^2 = \sigma_y^2 + \sigma_x^2\delta_x^2 + \sigma_{laser}^2\delta_z^2$$



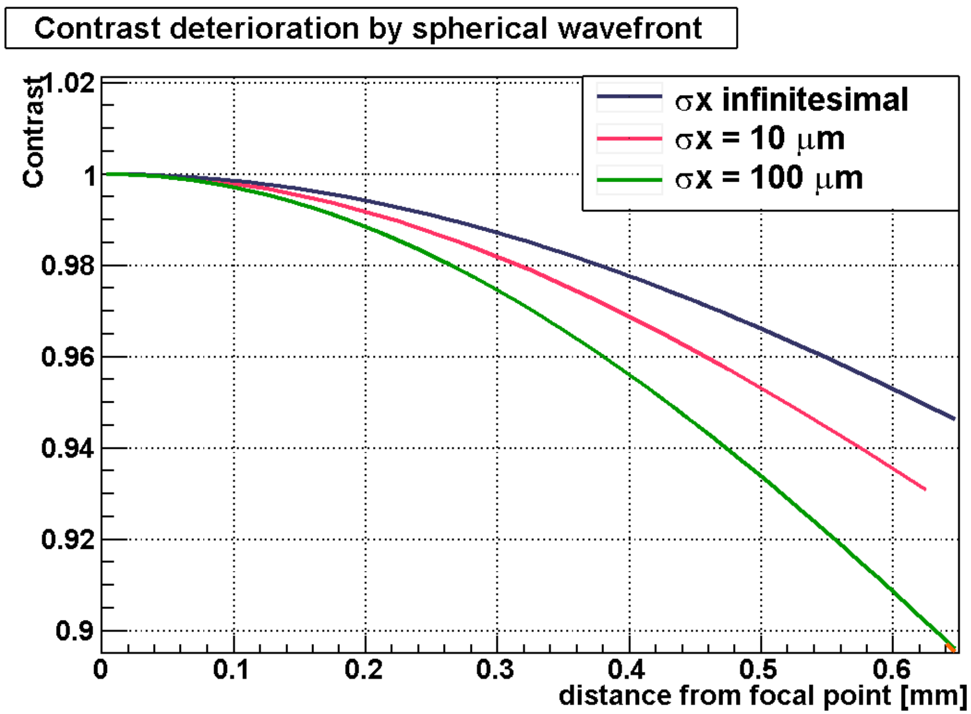
σ_{meas}	measured vertical beam size
σ_y	vertical beam size
σ_x	horizontal beam size
σ_{laser}	laser size

If $\delta_x \sim 2$ degrees and $\sigma_x \sim 50\mu\text{m}$, the Shintake monitor and the WS has comparable measurement result.

Laser Spherical Wavefront

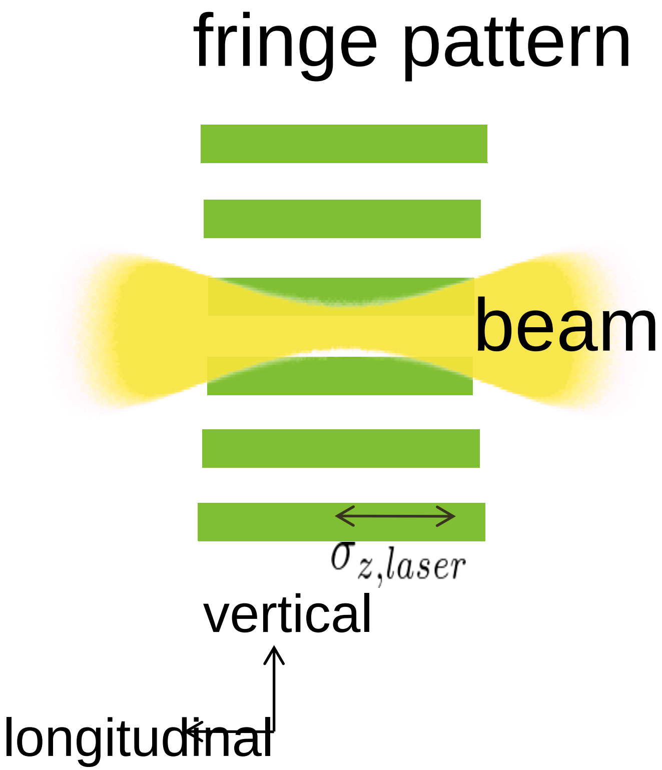


If beam position is away from the laser focal point when beam pass the fringe pattern, beam senses courved fringe due to the laser spherical wavefront.



σx: horizontal beam size

Beam Size Growth in the Fringe



Smaller Beam Size

⇓

Strong Focusing

⇓

Smaller Beta Function at IP

⇓

Beam Size Growth in the Fringe

⇓

Modulation Depth Degradation

⇓

$$M_{\text{meas.}} = \left(1 + 4k_y^2 \sigma_{z,laser}^2 \frac{\epsilon_y}{\beta^*}\right)^{-\frac{1}{2}} M_{\text{ideal}}$$

ϵ_y : vertical emittance

β^* : β function at IP

k_y : vertical component of wavenumber

$\sigma_{z,laser}$: laser spot size in beam dirrection