Shintake Monitor in ATF2：Performance Evaluation

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Outline

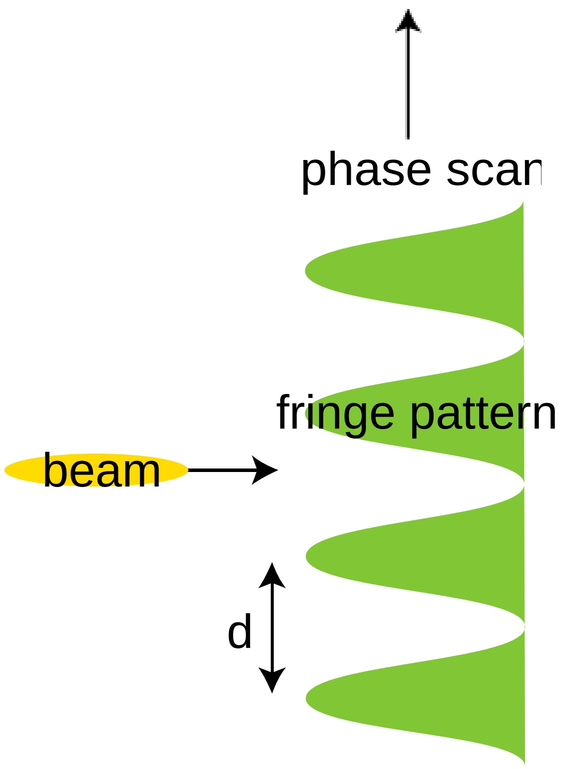
Nov. 2009: success in measuring signal modulation

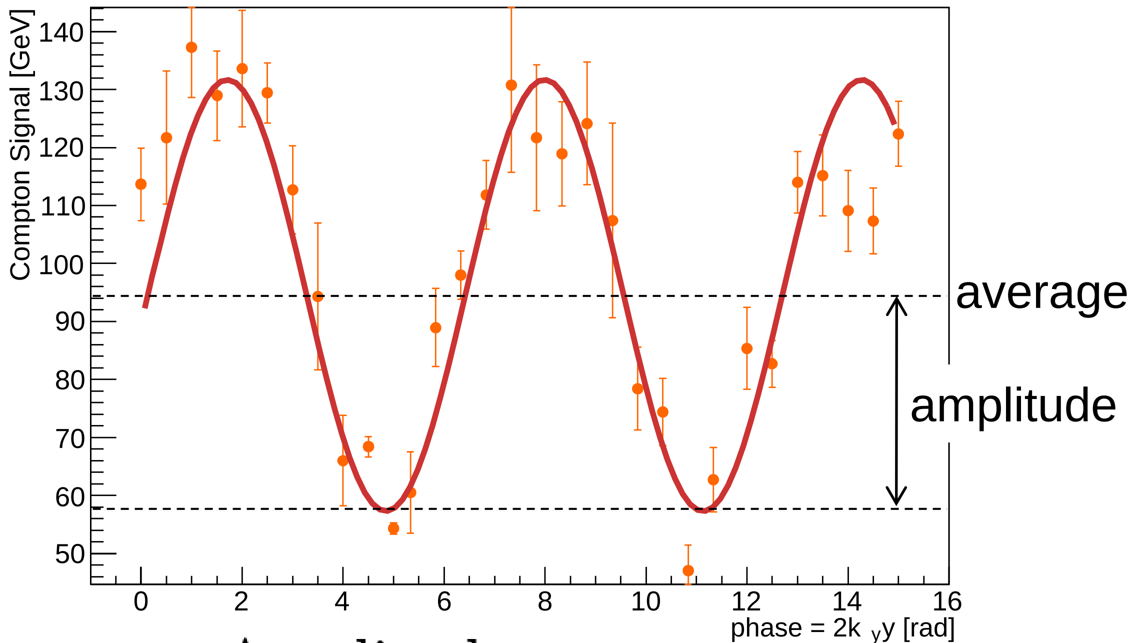
through several beam tests...

Systematic error estimation

Evaluation of the Shintake monitor performance towards 37nm beam size measurement

Principle of the Shintake Monitor





$$M \equiv \frac{\text{Amplitude}}{\text{Average}} \; : \; \text{modulation depth}$$

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

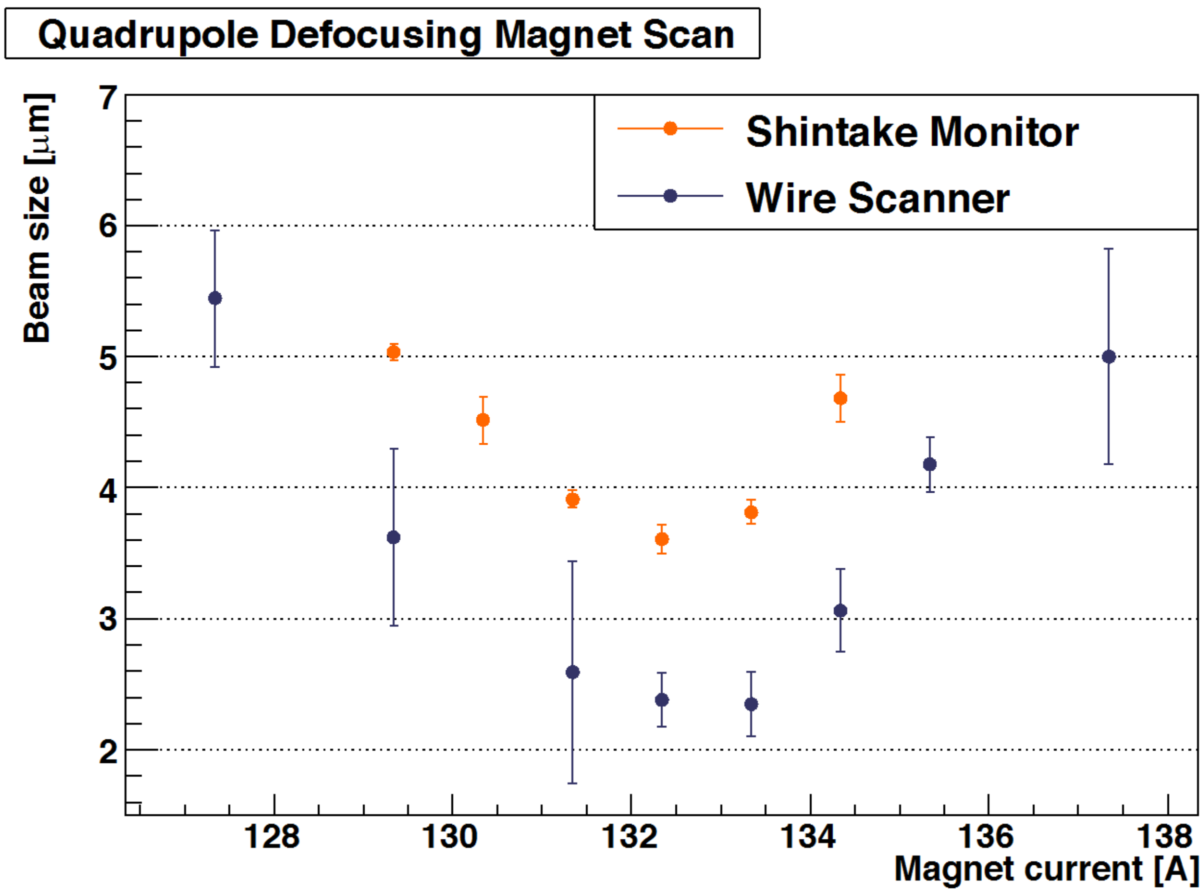
$$\sigma_y = \frac{d}{2\pi}\sqrt{2\ln\frac{|\cos\theta|}{M}}$$

σ_y : vertical beam size

θ : laser light crossing angle

Comparison with the Wire Scanner Measurement

Comparison of the beam size measurement with a φ10μm wire scanner (WS)



The Shintake monitor measurement is always larger than that by WS

⟹

The existence of systematic error

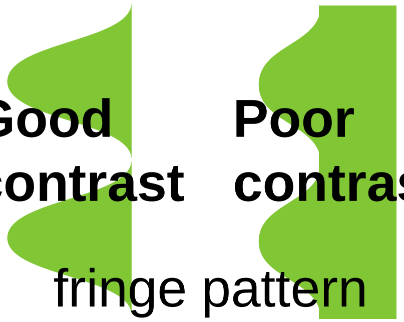
Sources of Systematic Error

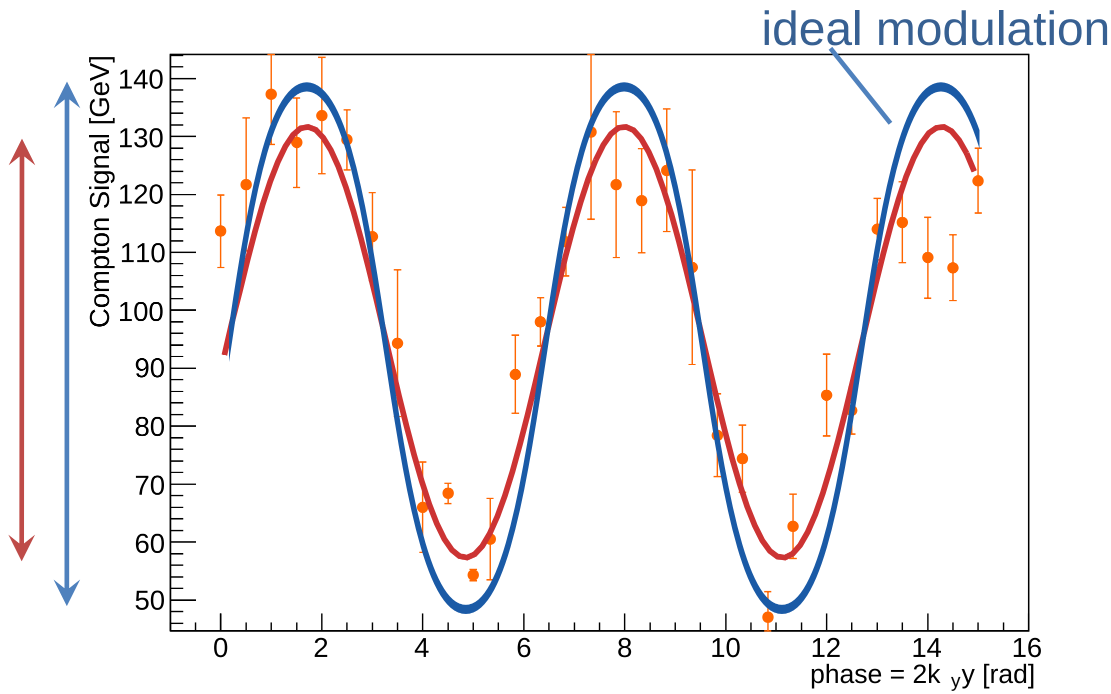
a error source:

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

Corrections due to deterioration of the contrast in 2deg.-crossing mode: $C_\alpha C_\beta \ldots$

Source	by 2009	future
Laser Polarization	96.1 ± 2.1%	99.7 ± 0.1%
Laser Alignment Accuracy	> 97.5%	----
Phase Jitter	92.3 ± 2.0%	95.0 ± 1.2%
Laser Temporal Coherence	> 99.7%	----
$\prod_i C_i$	> 86.3 ± 2.7%	> 92.1 ± 1.2%

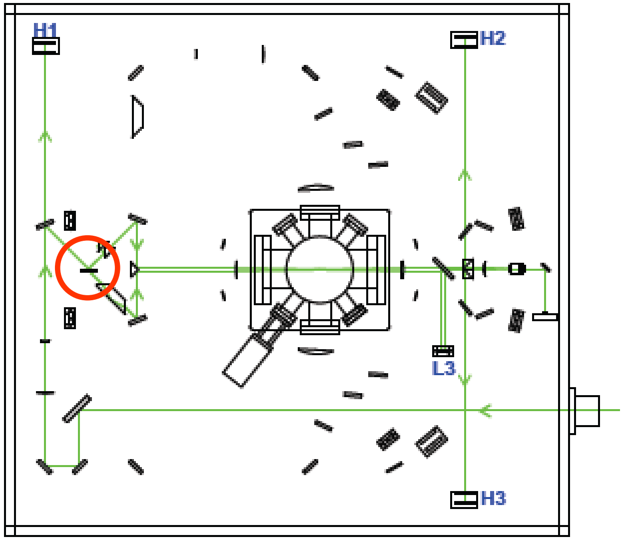
$$M_{meas} = C_\alpha C_\beta \cdots M_{ideal}$$

these improvements will be discussed in the next slides

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.

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



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

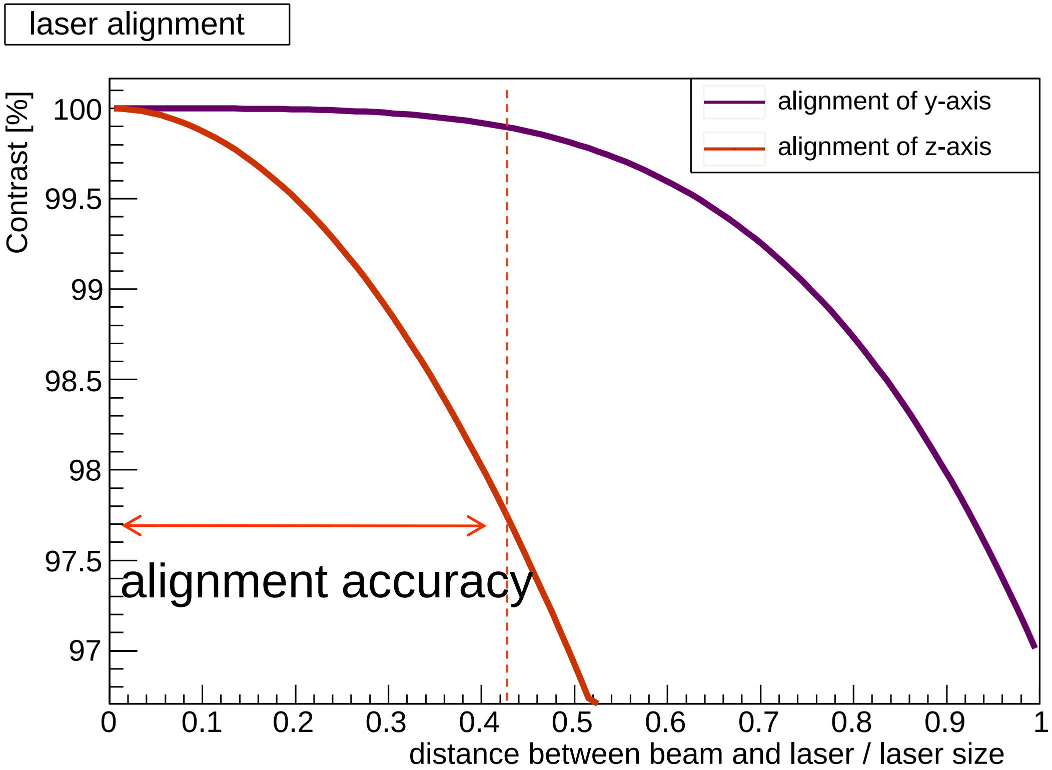
$$C_{\text{pol}} = 96.3 \pm 2.1\%$$

after polarization adjustment with half wave plate

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

Laser Alignment Accuracy

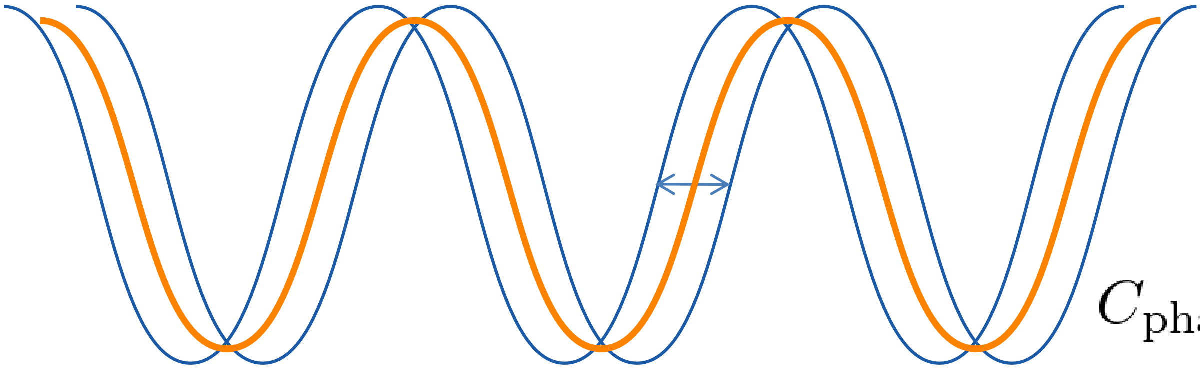
It is important for a good contrast to align the laser pathway with beam position.



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

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,

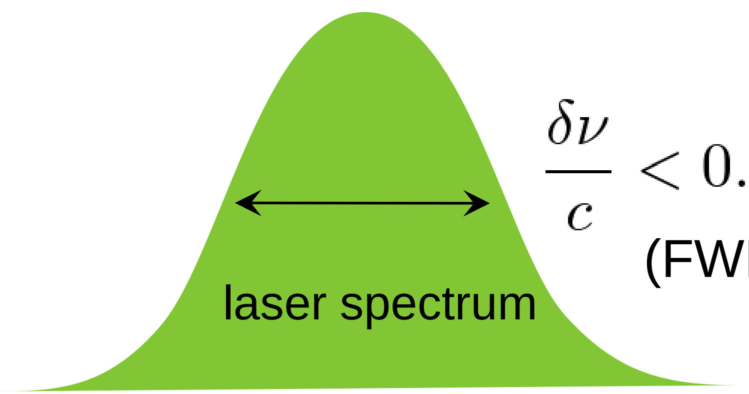
$$\Delta phase = 398 \pm 54\text{mrad} \rightarrow 320 \pm 41\text{mrad}$$

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

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.

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



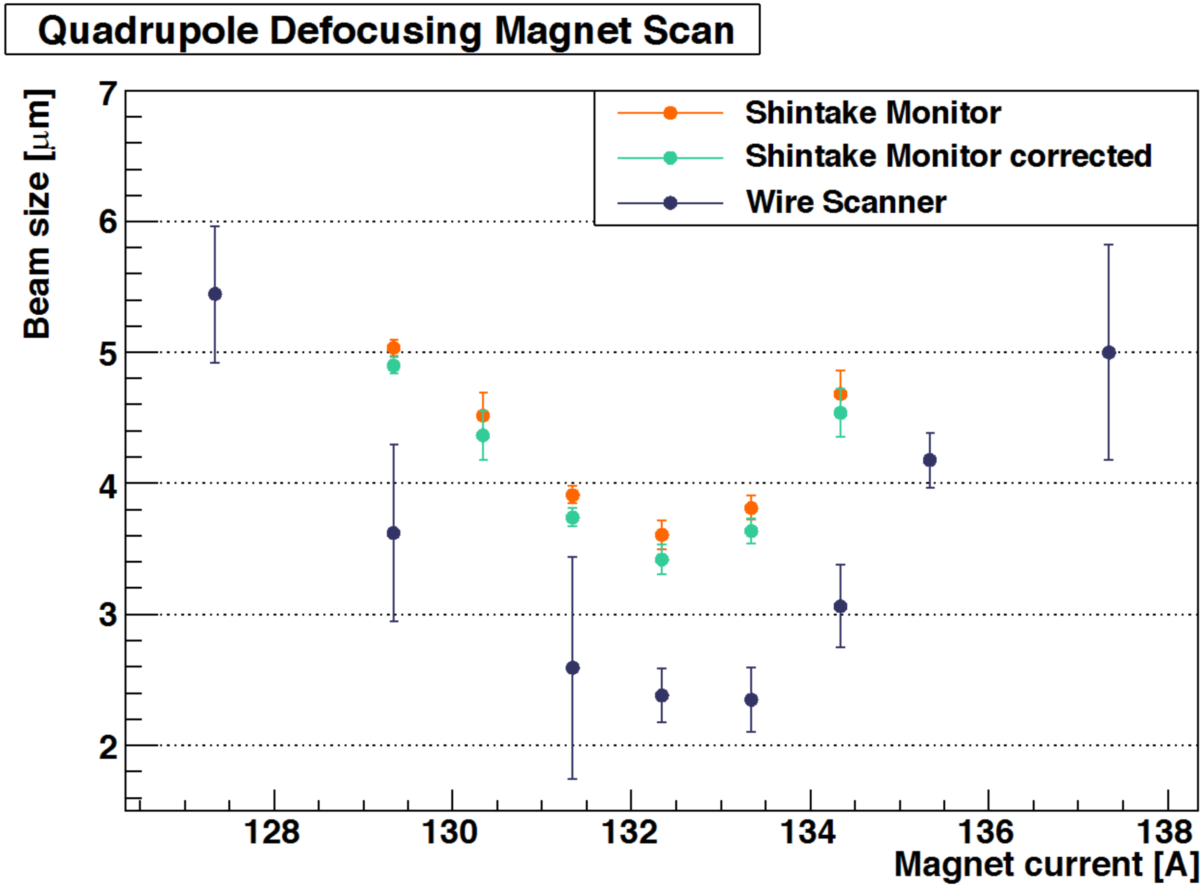
$$\frac{\delta\nu}{c} < 0.003\mathrm{cm}^{-1}$$

(FWHM)

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

Contrast Correction

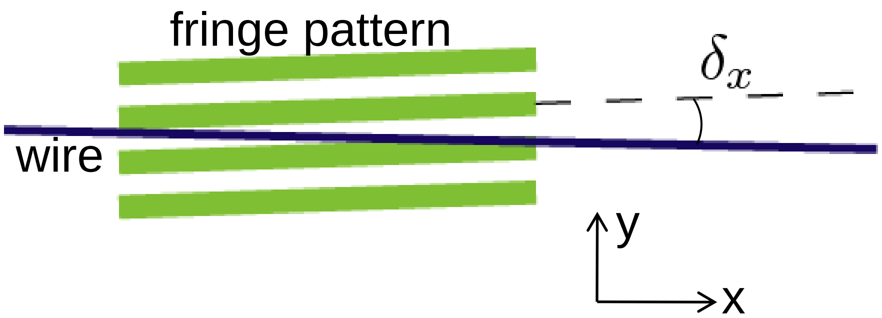
Comparison with the WS measurement after Contrast correction



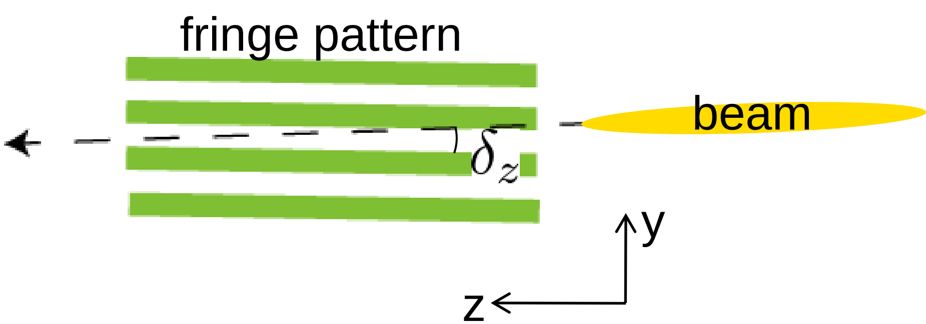
After the above corrections the measured beam size is slightly decreased, but systematic shift still remains.

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 $\sigma_x \sim 50\mu\mathrm{m}$, the Shintake monitor and the WS has comparable measurement result.

Towards the Ultimate 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.

$$\Delta M = {}^{0.01}_{-0.01}\,(\mathrm{sys.}) \pm 0.05\,(\mathrm{stat.})$$

$$\Delta \sigma_y = {}^{+0.7}_{-0.4}\,(\mathrm{sys.}) \pm 3.2\,(\mathrm{stat.})\ \mathrm{nm}$$

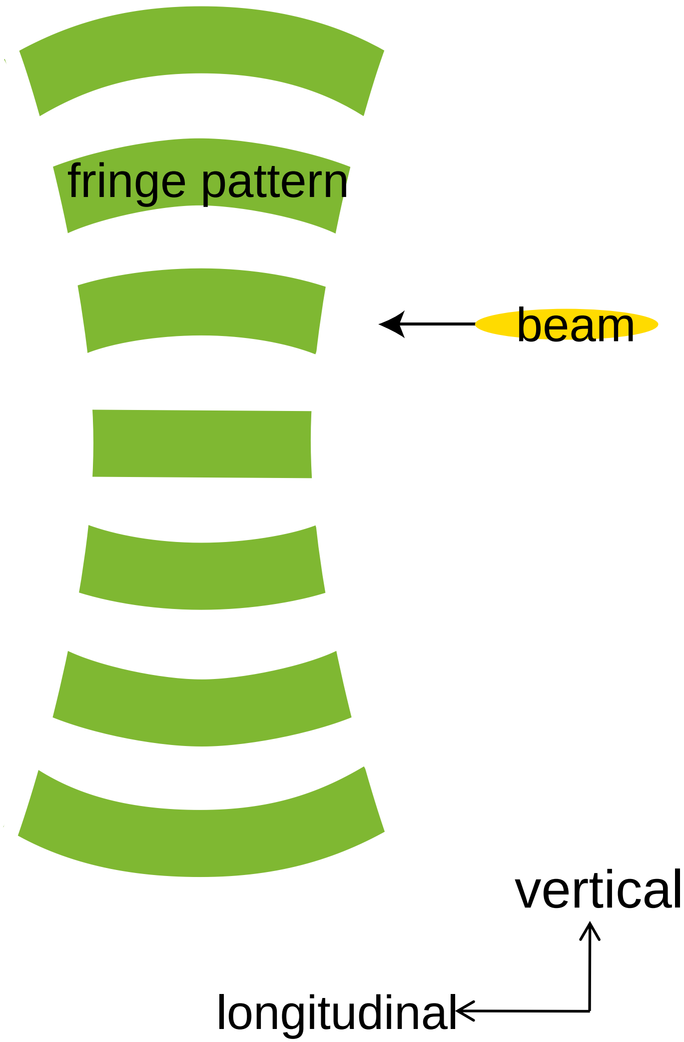
in 1 min. fringe scan

Summary

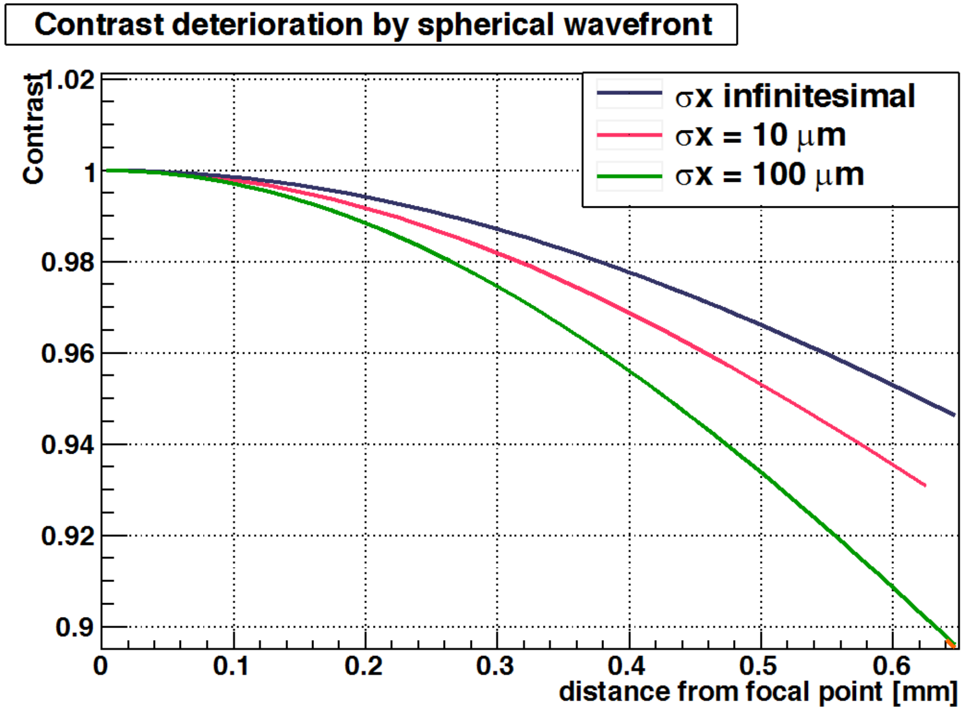
- We have been studying systematic error sources of beam size measurement by the Shintake monitor.
- Now, relative angle between the WS and the Shintake monitor is expected to be the most dominant error source. This error is canceled when beam and the fringe pattern axes are aligned.
- Because of our efforts to reduce systematic errors, systematic error in the beam size measurement would be as small as 3% in the future 37nm beam.
- On the other hand, statistical error would be about 10% in 1 min. fringe scan.

Backup

Laser Spherical Wavefront



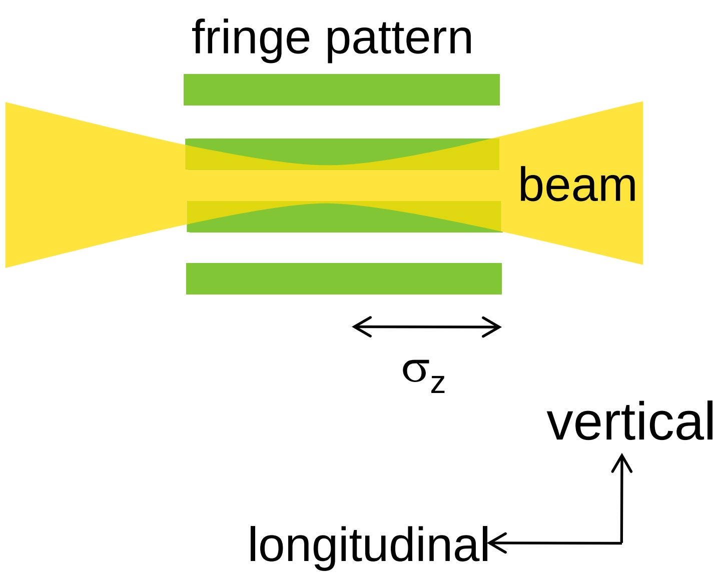
If beam position is away from the laser focal point when beam pass the fringe pattern, beam senses courved fringe due to the laser spherical wavefront.



σx: horizontal beam size

Beam Size Growth in the Fringe Pattern

The smaller beta function becomes, the more beam size grows within the fringe pattern.

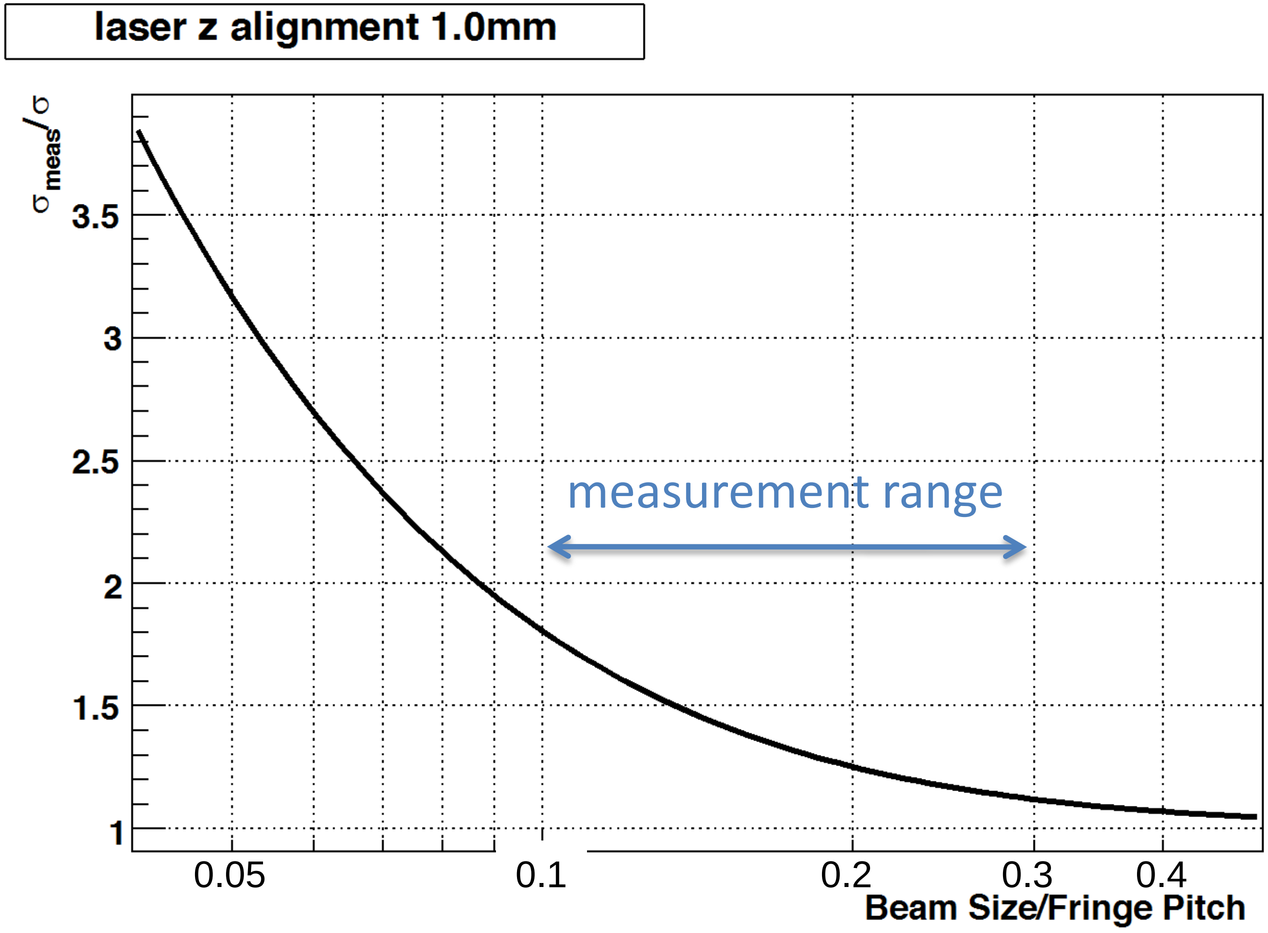


$$C_{\mathrm{beam\,growth}} = \left(1 + 4k_y^2\sigma_z^2\frac{\epsilon}{\beta*}\right)^{-\frac{1}{2}}$$

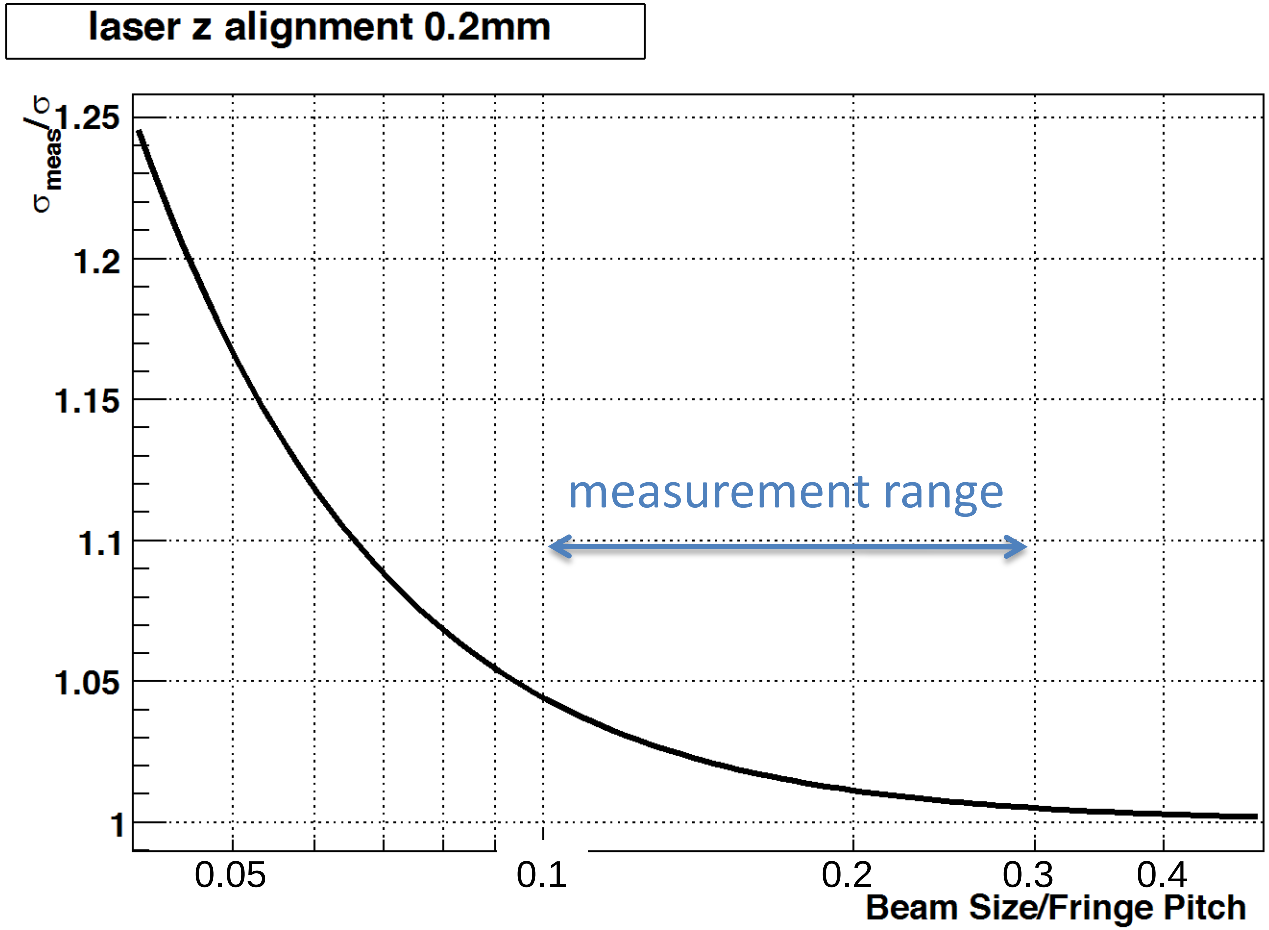
for 37nm beam size measurement

$$C_{\mathrm{beam\,growth}} = 98.5\%$$

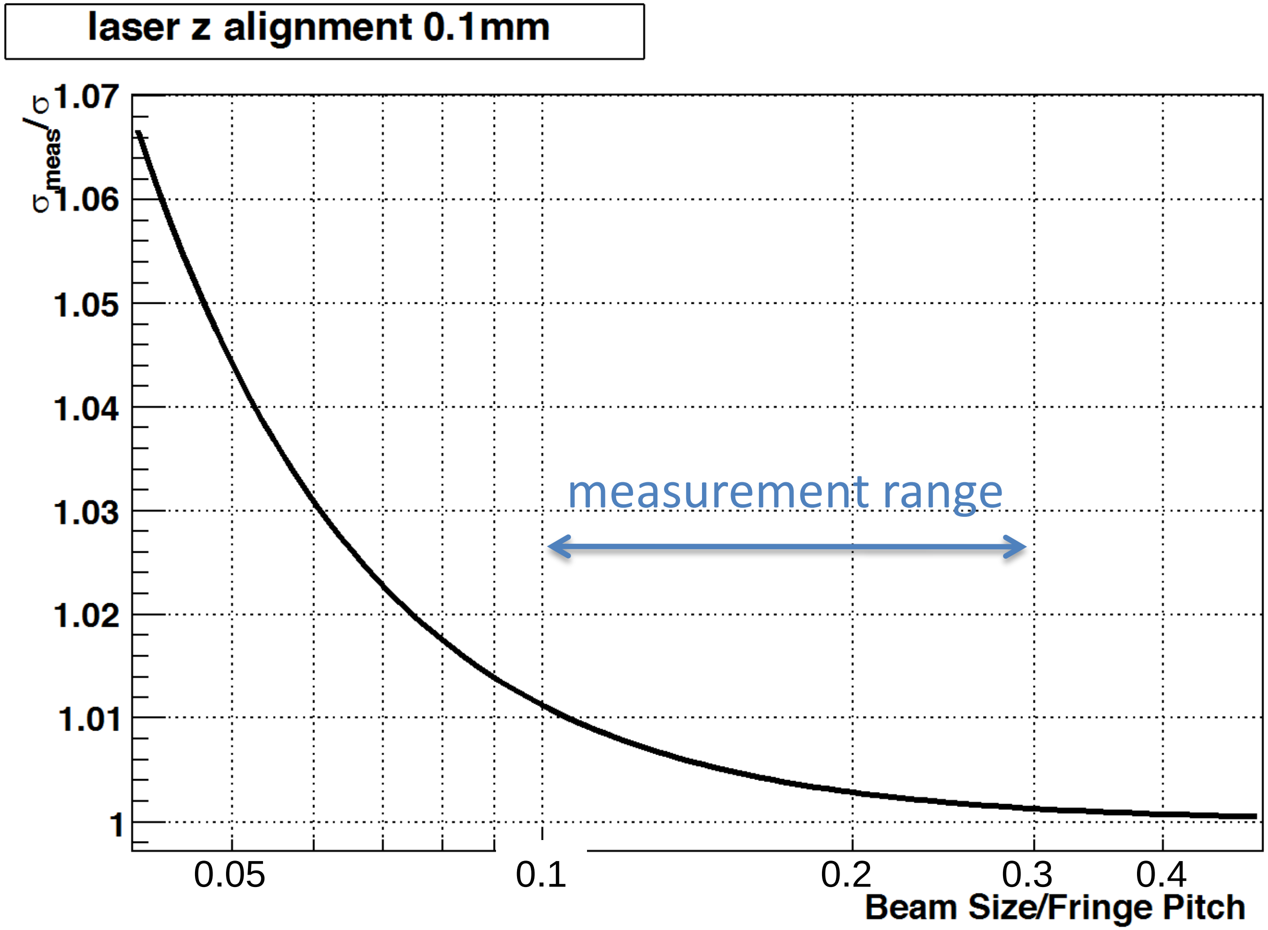
laser z alignment



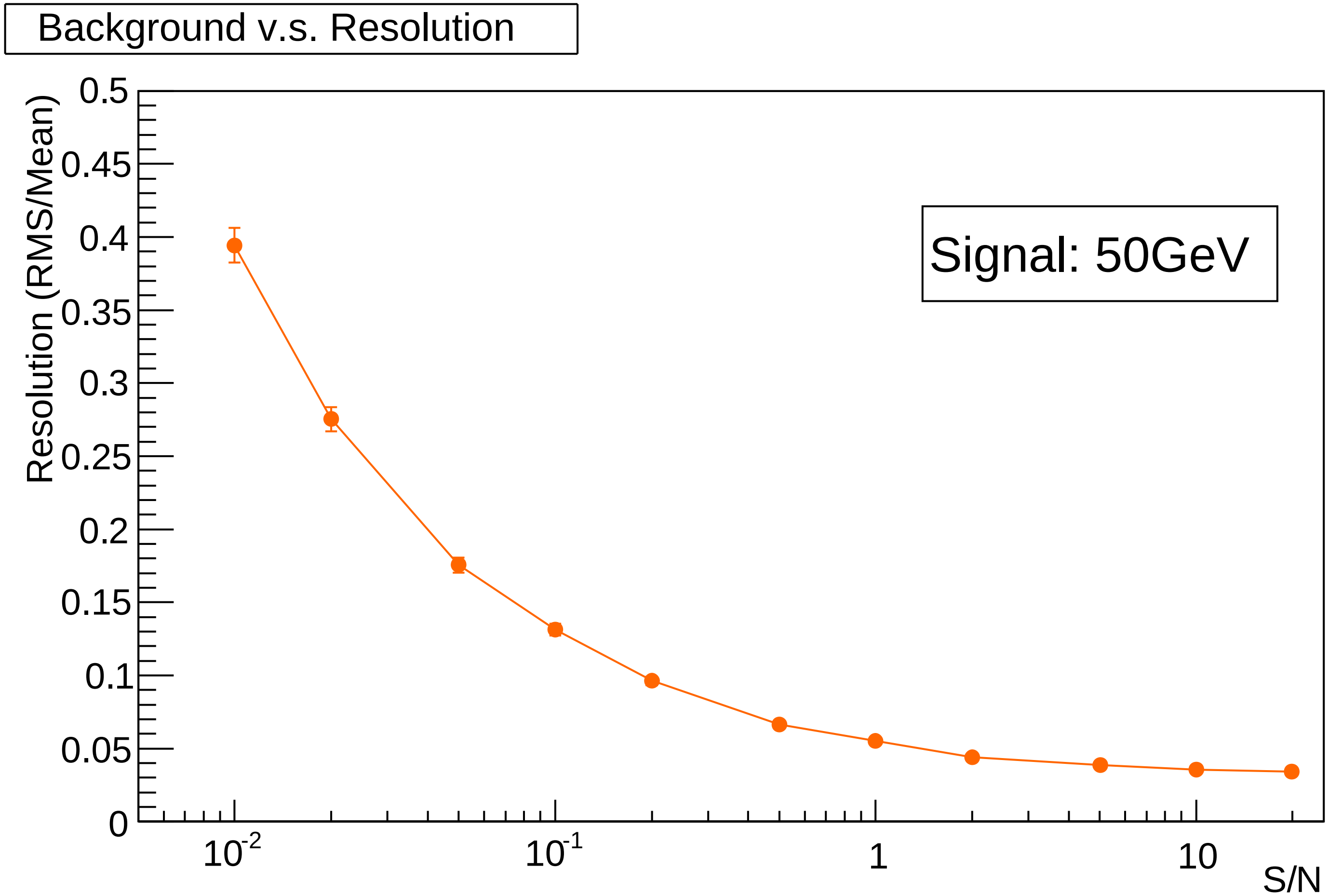
laser z alignment



laser z alignment



Gamma Detector Resolution



Evaluation of resolution of signal and BG separation

- no correction measurement: σ_{meas} = 40.6nm