IPBSM Operation

11th ATF2 Project Meeting

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SLAC National Accelerator Laboratory
Menlo Park, California

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layout

1. Laser wire scan
2. z-scan
3. reducer scan
4. laser phase stability
5. Gamma detector performance
6. run dependence of background
7. Methods on mode switching: 2-8° → 30° →174°

1. laser wire mode

purpose

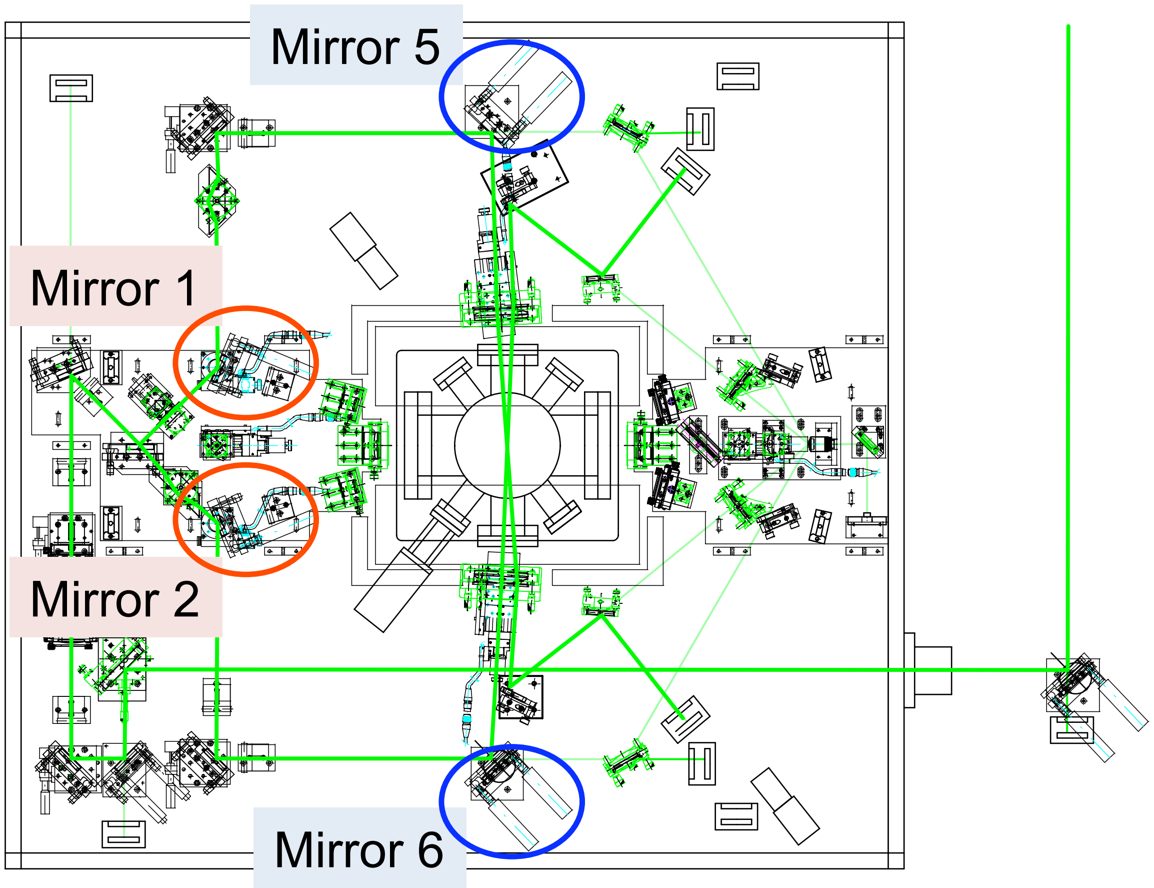
- signal detection
- Laser path alignment
- beam size measurement
- Laser size measurement

2-8, 30 deg mode

Scan with mirror 1,2

174 deg mode

scan with mirror 5, 6

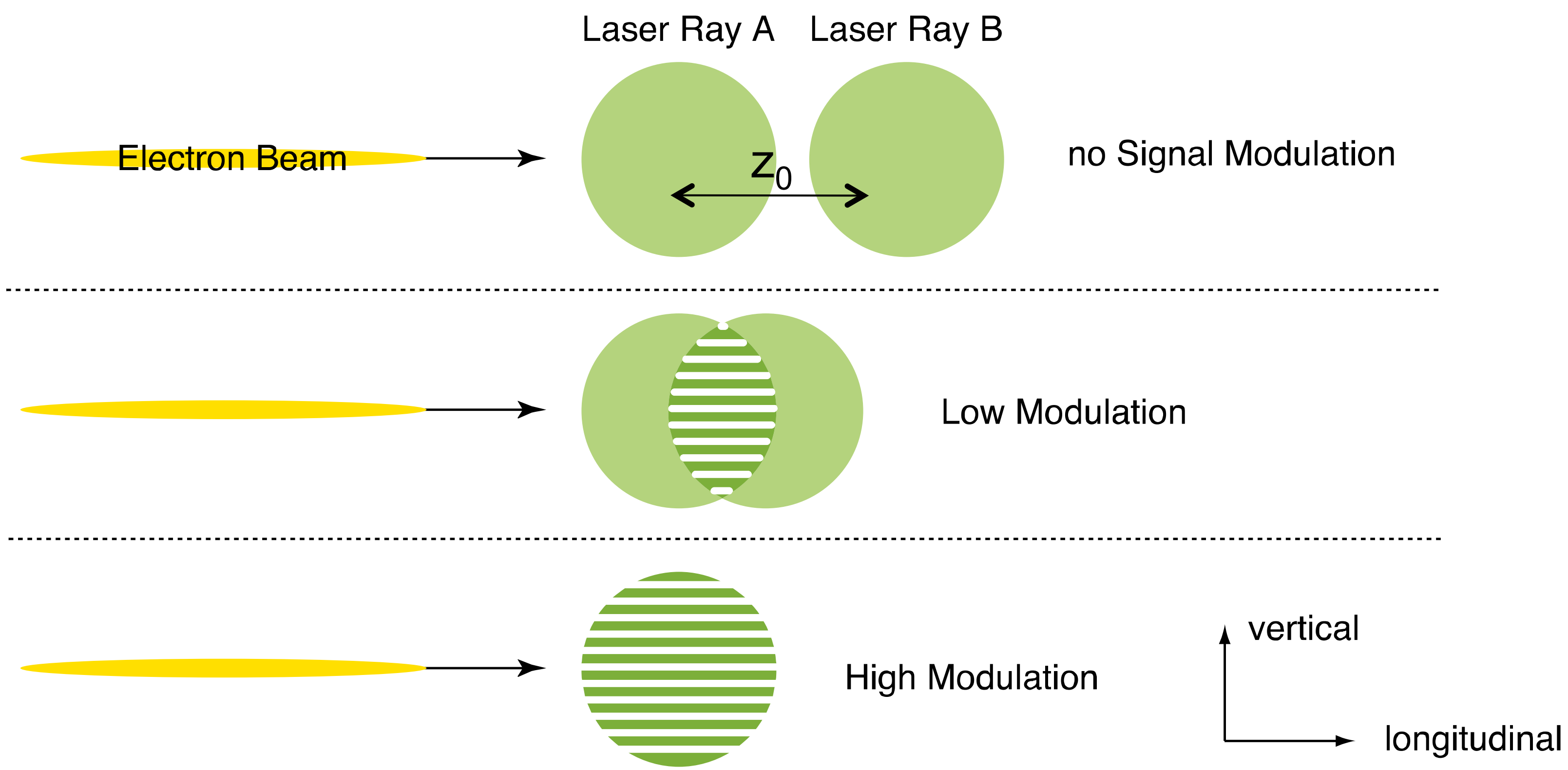


Actuator shift Δa vs. laser shift at IP Δx

$$\Delta x = C\Delta a$$

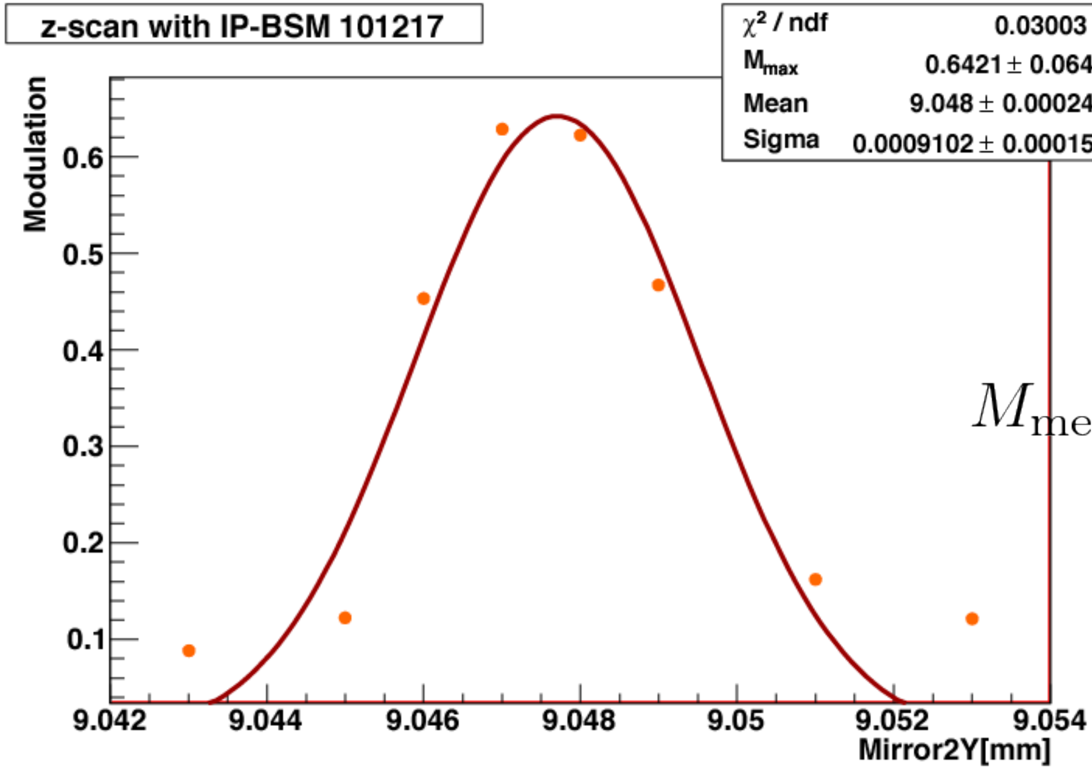
mode	C [μm/ μm]
2 - 8	8.03
30	9.64
174	6.35

2. z-scan



$$M_{\text{meas.}} = \exp\left(-\frac{z_0^2}{8\sigma_{\text{laser}}^2}\right) M_{\text{ideal}}$$

z-scan result



~ 10 min per scan

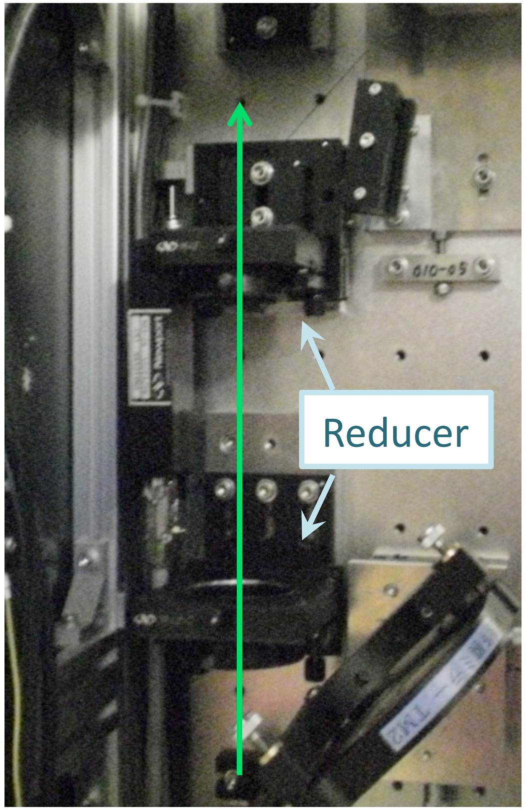
Fitting function

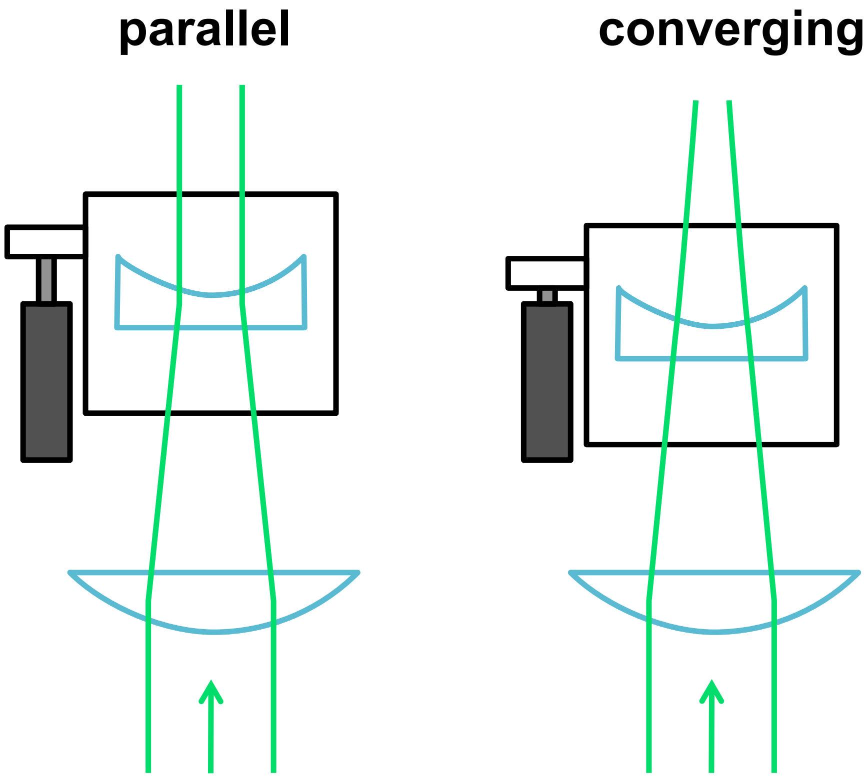
$$M_{\text{meas.}} = \exp\left(-\frac{z_0^2}{8\sigma_{\text{laser}}^2}\right) M_{\text{ideal}}$$

- Re-conducted scan in Dec run with same crossing angle, for confirmation
- ***Only need to scan once if laser position is stable***

3. Reducer Scan

Adjust laser divergence angle





Enter convergence lens:
divergence angle change → **Laser size at IP change**

reproducibility?? Depend on laser condition
Reproducible during cont. run, but **need re-scanning after mode switching**
because focusing lens differs between modes

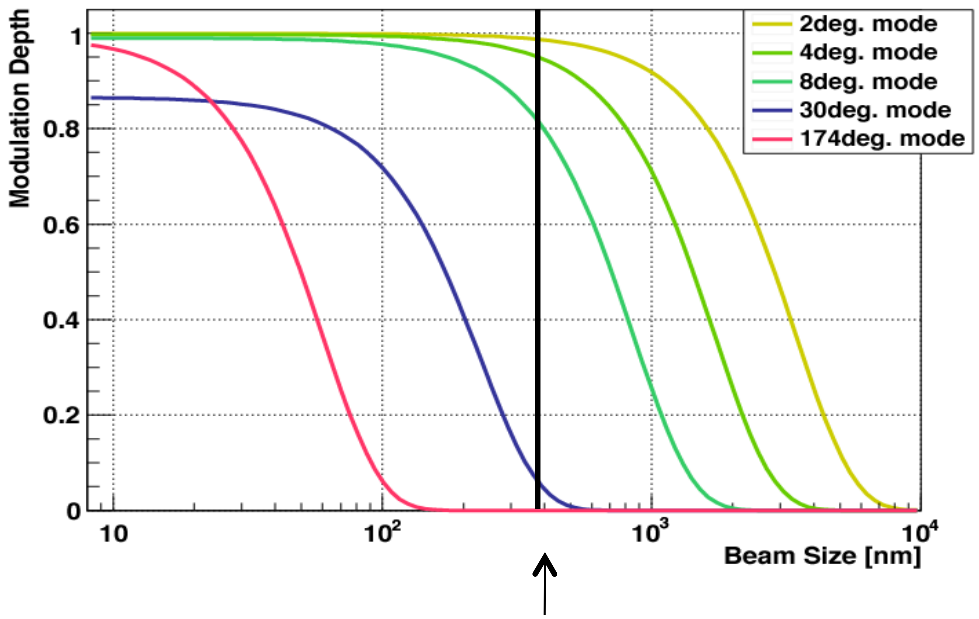
4. Phase stability of interference fringe

- **Jitter < 330 mrad** for 1 minute measurement
  - confirmed during contrast measurement (May, 2010)

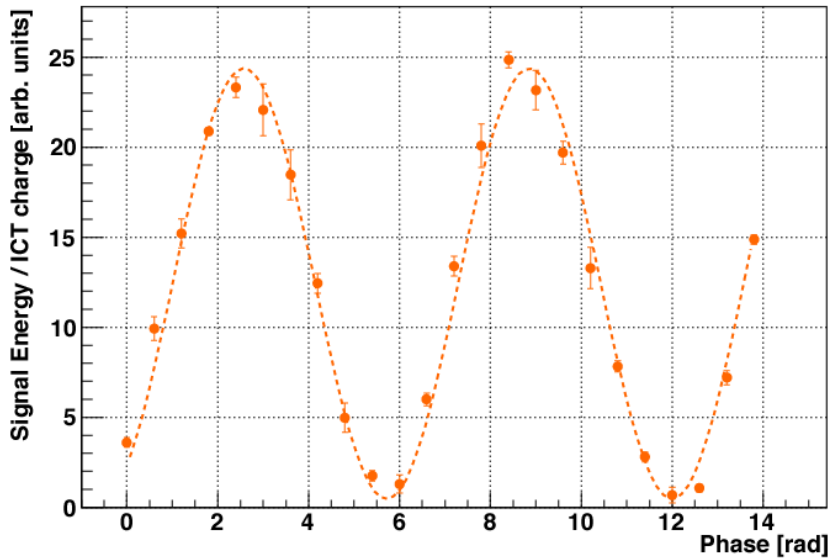
Contrast measurement

Large interference fringe pitch, small beam size M nearly 1

Contrast ~ offset from ideal modulation



$$\sigma_y < 380\,\mathrm{nm}$$



Measured contrast at **2.29 deg**

$$\frac{M_{\mathrm{meas.}}}{M_{\mathrm{ideal}}} = 0.98 \begin{matrix} +0.01 \\ -0.03 \end{matrix}$$

Phase jitter estimation

Bias factors affecting contrast measurement

- Power imbalance
- laser path misalignment
- spatial/ temporal coherence
- interference fringe tilt
- Beam position jitter
- **interference fringe phase jitter**

Determine **upper limit** assuming phase jitter to be the only bias factor

modulation depth degradation due to phase jitter

$$\frac{M_{\mathrm{meas.}}}{M_{\mathrm{ideal}}} = \exp\left(-\frac{\sigma^2_{\mathrm{phase}}}{2}\right)$$

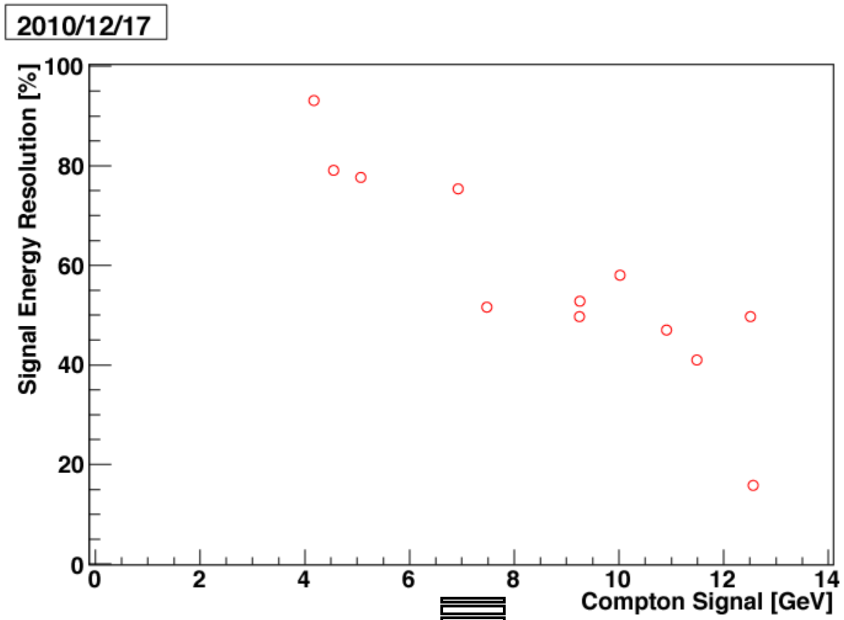
Combine with measured contrast to **derive upper limit of σ_{phase}**

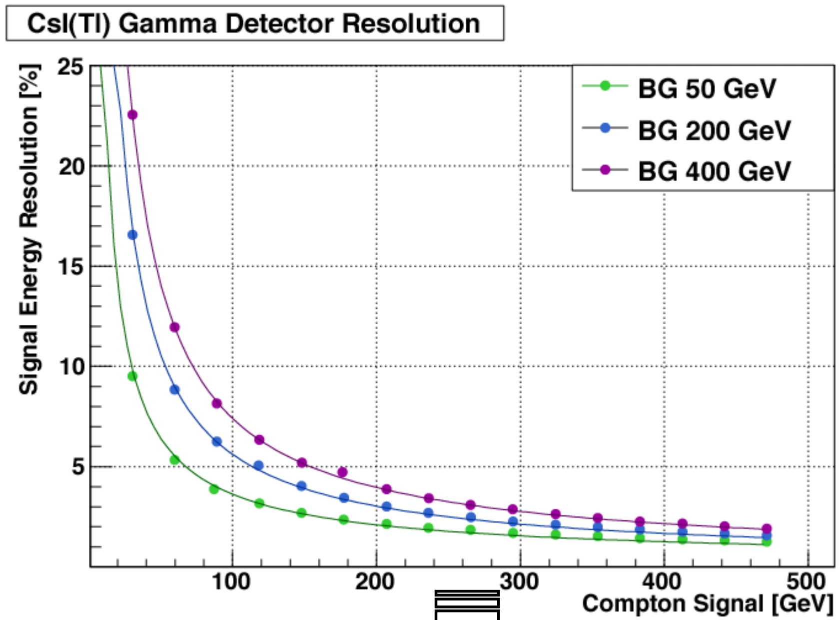
6. Gamma detector
signal・BG separability

Signal fluctuation during Dec run

Simulation under different BG setting

BG: 100 GeV





Signal is too small !

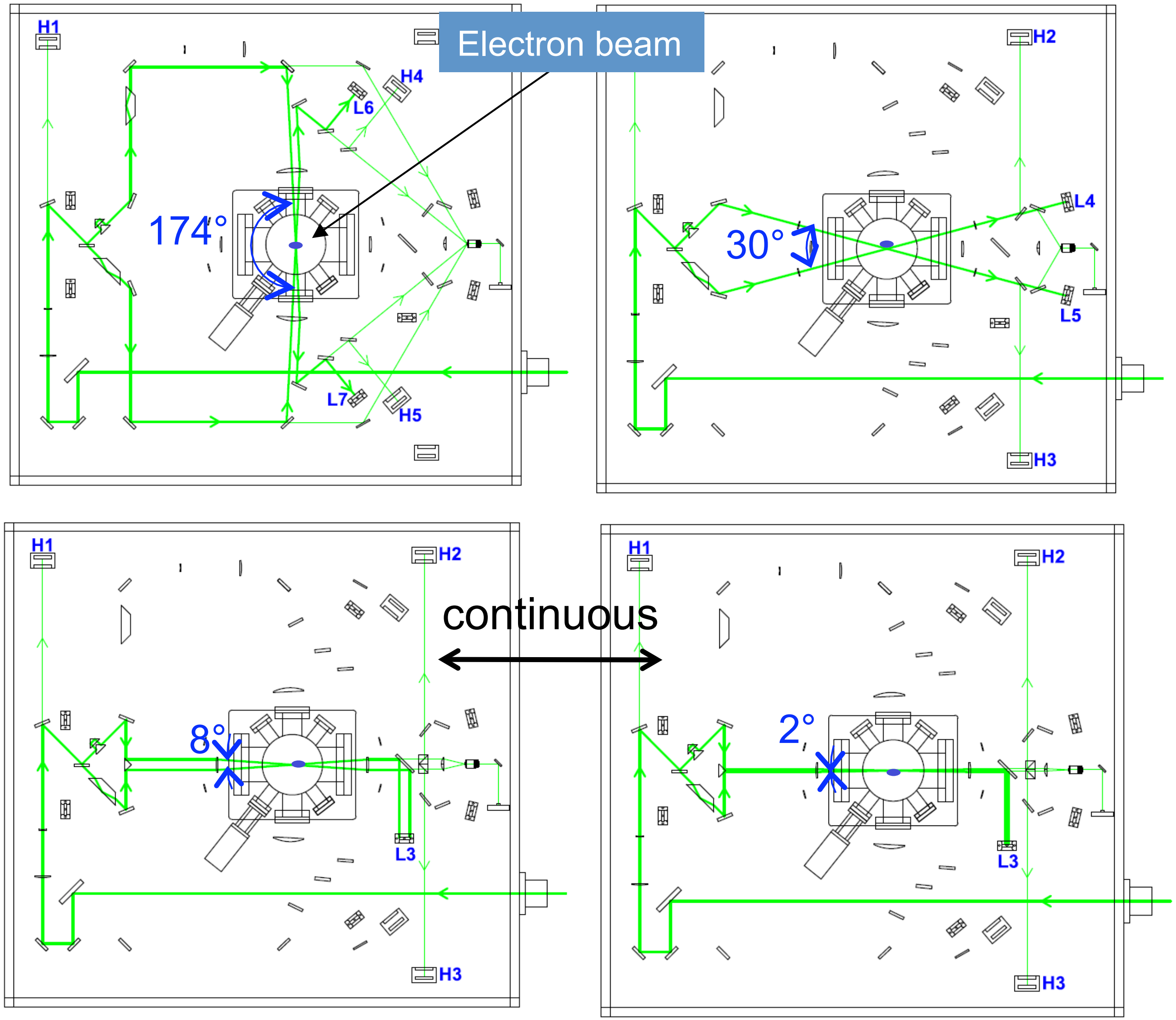
Higher BG tolerable if signal > 50 GeV

BG levels : May and Dec

	Optics	Signal [GeV]	BG [GeV]	Beam Current [10^9 e^-]
May, 2010	**Beta x 10 optics**	**150**	**15**	**~ 4**
Dec, 2010	**nominal**	**15* - 60**	**100**	**~ 3**

* After problem of unfocused laser

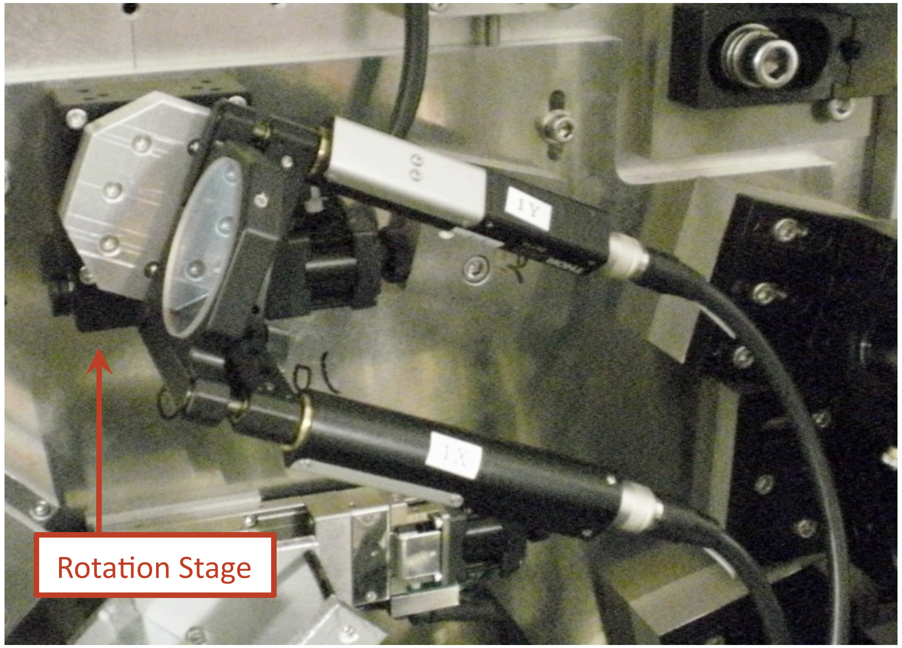
7. Laser crossing angle control



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

θ : crossing angle

Laser crossing angle control

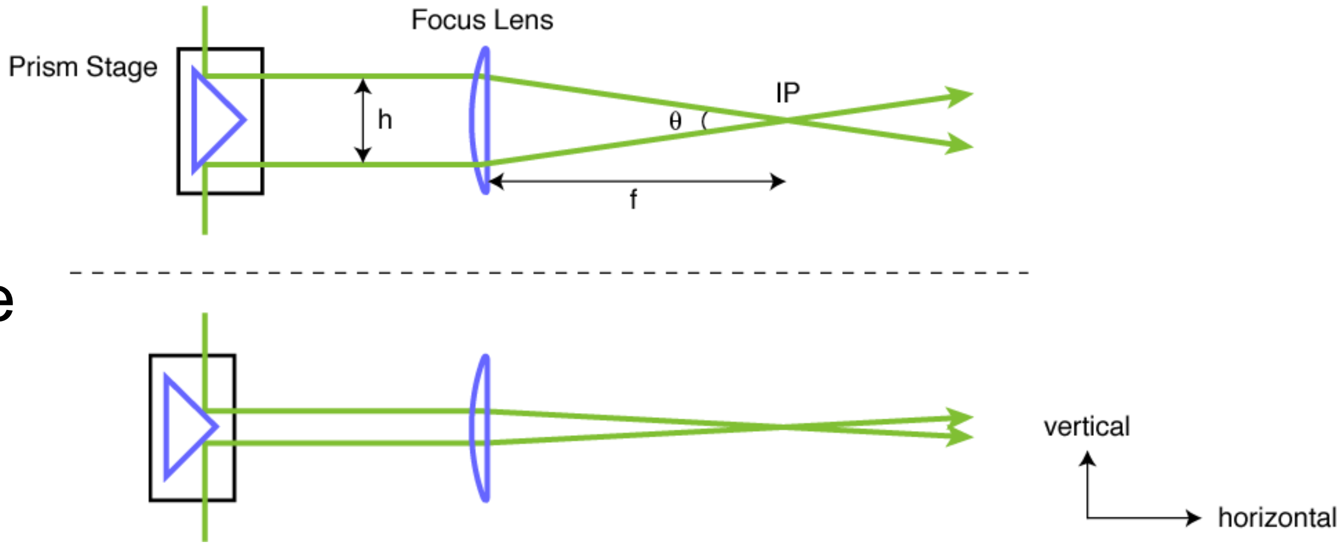


Rotating stage

Switch between
2-8, 30, 174 deg modes

Prism stage

Continuous change
from 2 to 8 deg



Mode switching + re-alignment

After changing modes:

- **transverse plane alignment by laser wire scan**

- switching from 2-8 deg to 30 deg
  - Also need **longitudinal direction scan**

    ➔ **z - scan**
  - transverse alignment alone cannot make ideal laser path
  - laser will not hit screen monitor

  - 30 deg path pass close to lens edge

    → better to adjust inside shield

  remote control possible if align during weekend shut-down

summary

- Must re-align from beginning after mode switching
- If beam position is stable:
  Stable IP-BSM operation expected after alignment for each mode
- Transverse alignment needed if beam position changes
- S/N tolerable if laser is focused at IP

backup

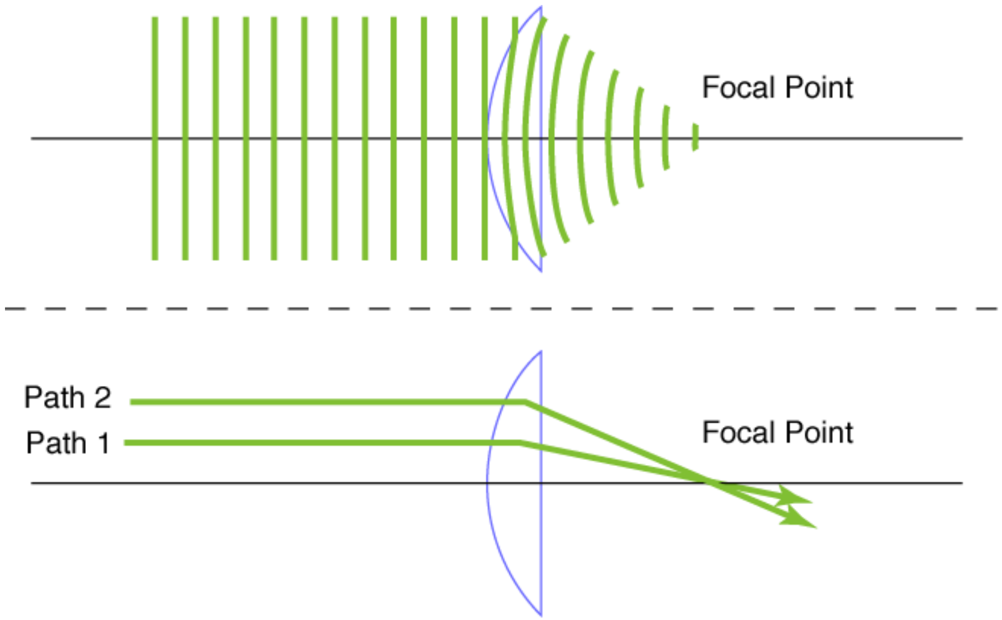
4. Phase stability of Interference fringe

- **Phase monitor not in use**
  - **Phase jitter at IP partially cancelled by lens effects**
  - **unseen with phase monitor**

  - Phase monitor measured **790 mrad** jitter
    much over-evaluated

- **Jitter < 330 mrad**
  confirmed during 2010 May`s contrast measurement

Lens cancel phase jitter



1. Plane wave gather at focal point after entering lens

➢ **optical path length to focal point is equal** from any point on wave plane

2. **Extract path1 and path 2 from plane wave**

➢ assume path 2 is jittering (in position) compared to path 1

➢ **no phase difference** since optical length is same for both paths

Path length difference due to laser position changes before half mirrors are same for both paths → do not contribute to phase jitter

However path length difference between half mirror and lens does contribute

Contrast measurement

Interference fringe at IP can only be measured with beam

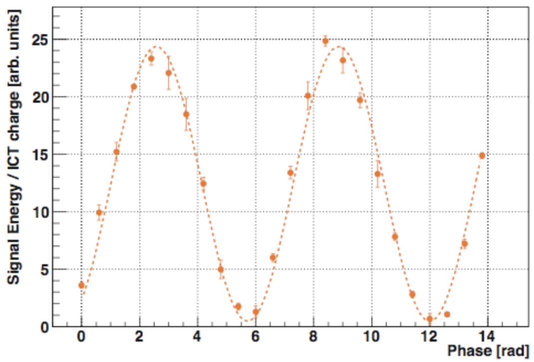
(1) Laser power too strong, cannot use CCD

(2) Fringe felt by beam (rest frame) is different from lab fram

Biggest fringe pitch 2 deg + much smaller beam size

Ideal M |cosθ| = 0.9994

Measured result is less due to modulation degradation factor



The measured M is fringe contrast felt by beam

2010: measured beamsize@8 deg: 380 nm (actually smaller ; there is error for 8 deg also)

Measure contrast at 2.29 deg

Ideal: M > $\exp\left(-2k_y^2\sigma_y^2\right)|\cos\theta| = 0.983$

Actual: $M = 0.96 \pm 0.01$

$$\frac{M_{\text{meas.}}}{M_{\text{ideal}}} = 0.98 \begin{array}{l} +0.01 \\ -0.03 \end{array}$$

Phase monitor

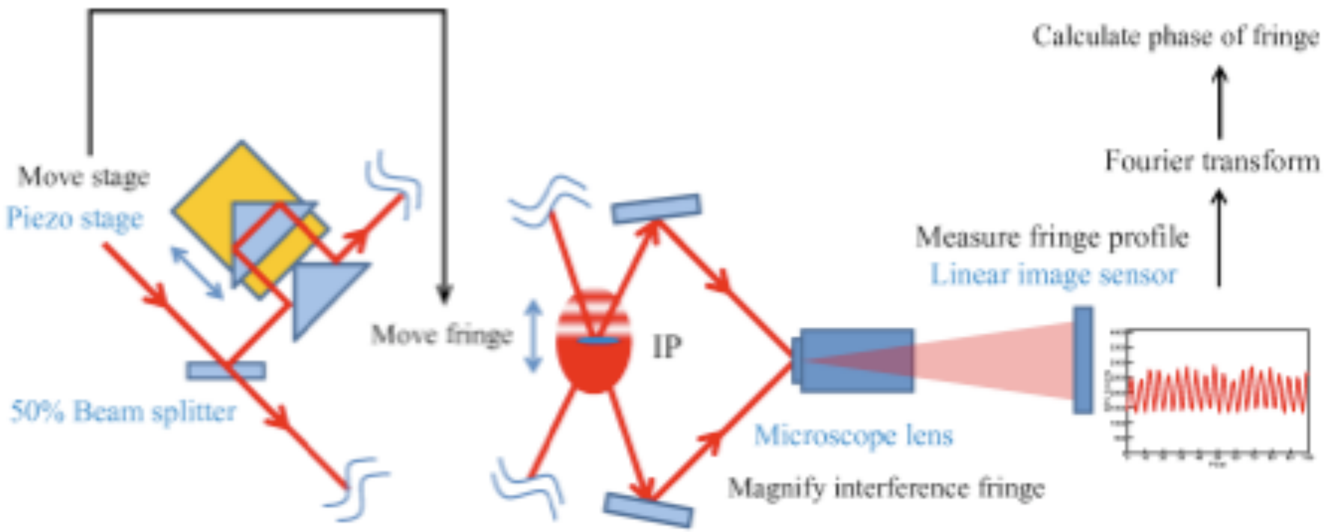
Cut intensity → expand with lens（must be smaller than pixel size d)

→ form laser **interference on 1D CMOS image sensor** (downstream from IP)

→ **Fourier transf. image**

- simultaneous with beam size measurement

- **Correct beam size result with measured phase jitter??**
- Phase jitter contribute to relative laser – beam position jitter and signal fluctuation



Phase monitor over-evaluation

1 min measurement: 790 mrad (400 mrad with old laser)

→ **73% degradation**

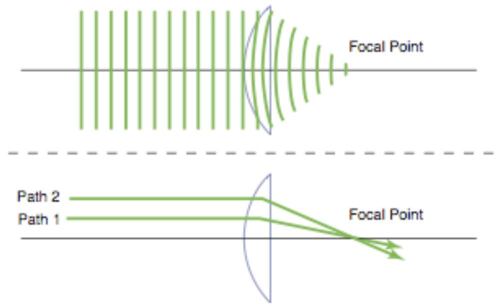
However **modulation degradation factor (from contrast meas.) ~ 98%**

Only 200 (330) mrad even if all degradation only come from phase jitter

<u>**Cancellation effect of lens**</u>

2 paths from same plane wave entering lens

Gather at single focal point → no phase difference

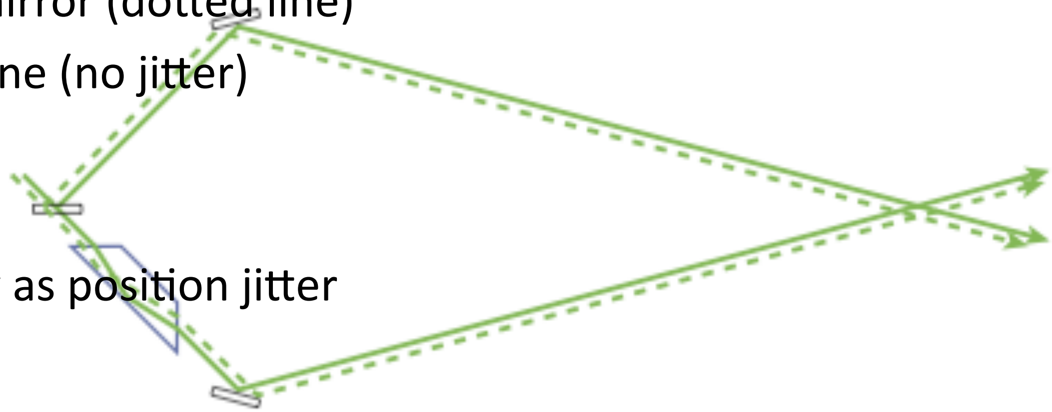


<u>**No lens:**</u>

Assume jitter before entering half mirror (dotted line)

Path 2 has larger phase than solid line (no jitter)

Angle jitter is cancelled in same way as position jitter



Phase monitor: Fourier transf.

- **Cut noise of all frequencies**

xj: jth pixel coordinate

image sensor signal:

$$
\begin{aligned}
S_j =& S_0 + S_1 \cos\left(k_{pm} x_j + \alpha_{pm}\right) \\
=& S_0 + S_1 \cos\left(2\pi \frac{\hat{k}_{pm}}{n_{pixel}} j + \alpha_{pm}\right)
\end{aligned}
$$

Fourier transformed:

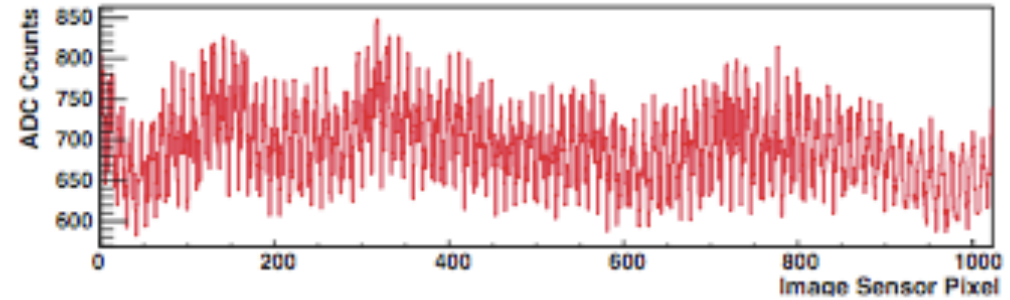
$$
\begin{aligned}
\mathcal{S}_k =& \sum_{j=0}^{n_{pixel}-1} S_j \exp\left(-2\pi i \frac{k}{n_{pixel}} \left(j - \frac{n_{pixel}}{2}\right)\right) \\
=& n S_0 \delta_{k,0} + \frac{n}{2} S_1 \delta_{k,\hat{k}_{pm}} \exp\left(i\pi k + i\alpha_{pm}\right)
\end{aligned}
$$

- **spectrum peak sharply at k_{pm}**
- phase centering technique for stable phase around peak

Phase monitor: Fourier transf.

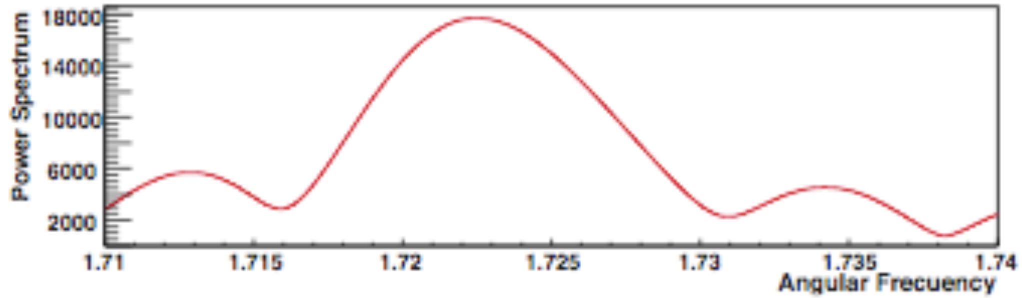
image sensor measurement

$$\begin{aligned} S_j =& S_0 + S_1 \cos\left(k_{pm} x_j + \alpha_{pm}\right) \\ =& S_0 + S_1 \cos\left(2\pi \frac{\hat{k}_{pm}}{n_{pixel}} j + \alpha_{pm}\right) \end{aligned}$$

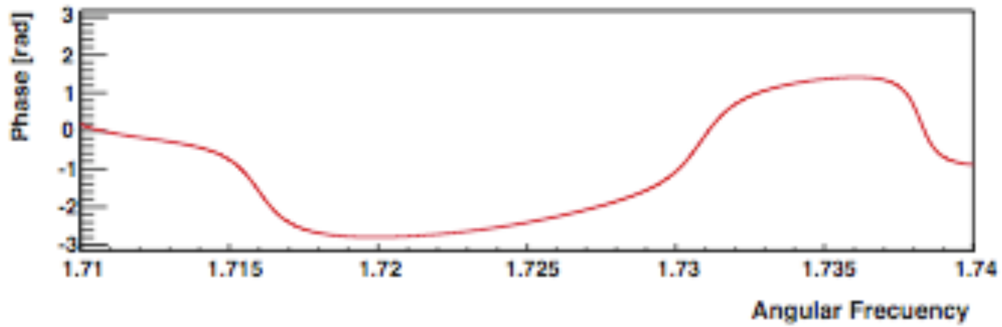


fourier transformed signal

$$\begin{aligned} S_k =& \sum_{j=0}^{n_{pixel}-1} S_j \exp\left(-2\pi i \frac{k}{n_{pixel}}\left(j - \frac{n_{pixel}}{2}\right)\right) \\ =& n S_0 \delta_{k,0} + \frac{n}{2} S_1 \delta_{k,\hat{k}_{pm}} \exp\left(i\pi k + i\alpha_{pm}\right) \end{aligned}$$



calculated phase α



Reducer

Expander → 20 m transport → reducer

Distance between pair of converge and convex lenses

Control expansion/reduction/diverging angle

After reducer Enter Focusing lenses

f = 250 mm for 2-8, 174 ° **f = 300 mm for 30°**

$\boldsymbol{\sigma_{laser} = \lambda f/\pi\sigma_0}$

σ_0 should be 3.5 μs if transported correctly

→ σ_{laser} = 6 μm for 2-8, 174 (measured for 2 deg)

→ σ_{laser} = 7.2μm for 30 deg

- However too small will cause unstable interference fringe

So **design size at 10 μm**