Instrumentation at ATF2 and relevance to CLIC

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CLIC09 workshop, CERN

Introduction of the relevant beam instrumentation devices to CLIC

Beam Position Monitor

- Cavity BPM

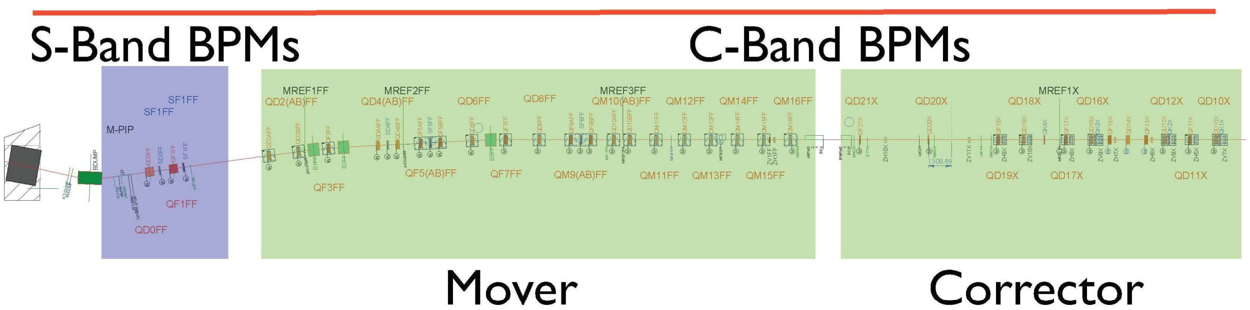
No distractive Beam Profile Monitor

- Laser Wire Beam Profile Monitor

- Laser Interferometer

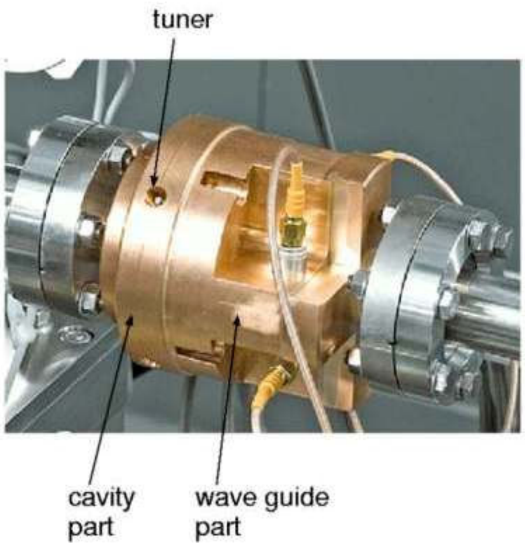
Cavity BPMs in ATF2 Beamline

ATF layout



- 4 (dipole) +1 (ref) S-band
  - Variable attenuation
- 31 (dipole) + 4 (ref) C-band
  - Attenuation : 10 db in all channels (1 removed for tests)
  - 9 corrector calibrated
  - 22 mover calibrated
- 1 MPIP (readout via VME system)

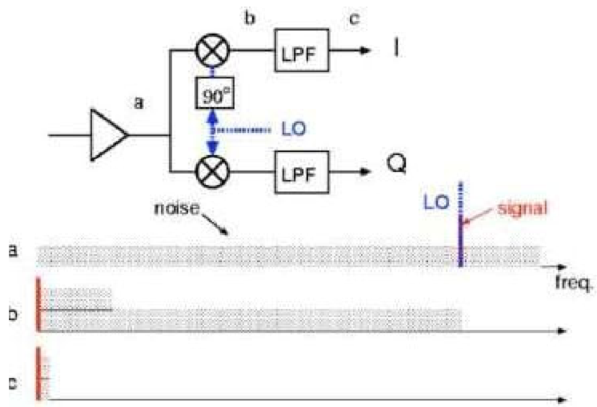
C-band Cavity BPM

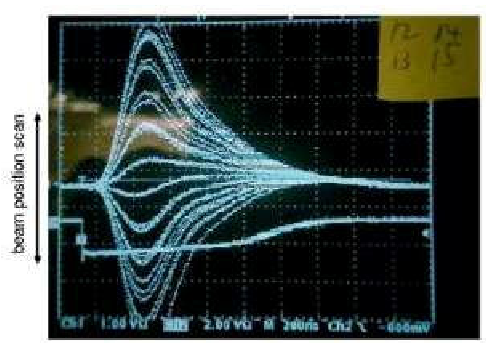


Readout Electronics of Cavity BPM

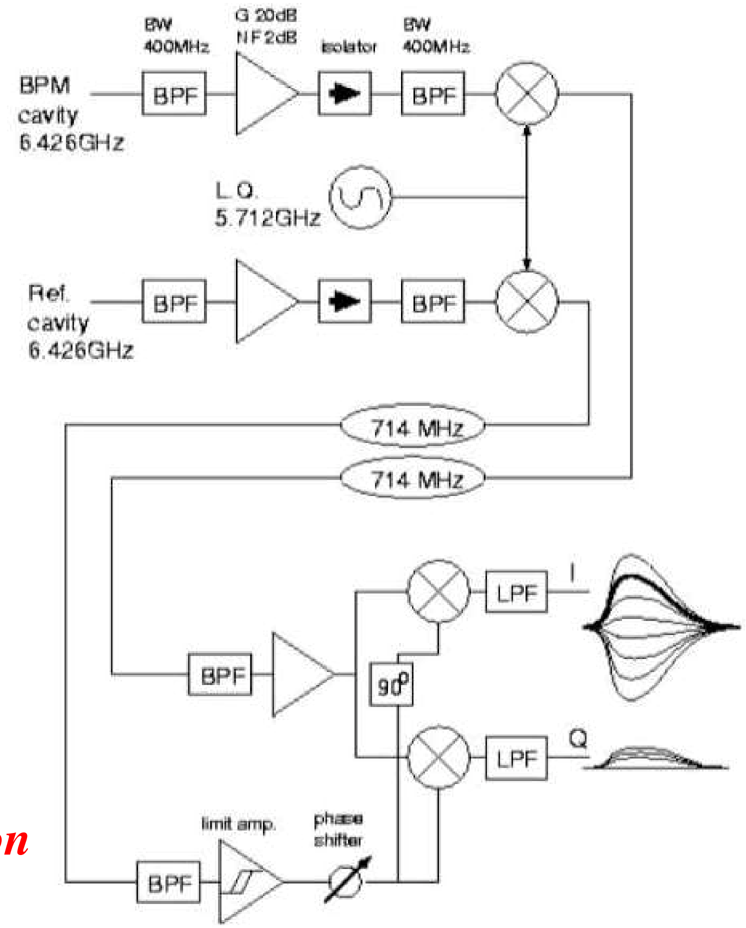
Homodyne Method

-Frequency is directly converted to be DC .
-Converted signal has amplitude information only.



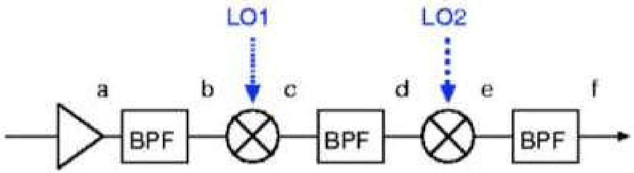


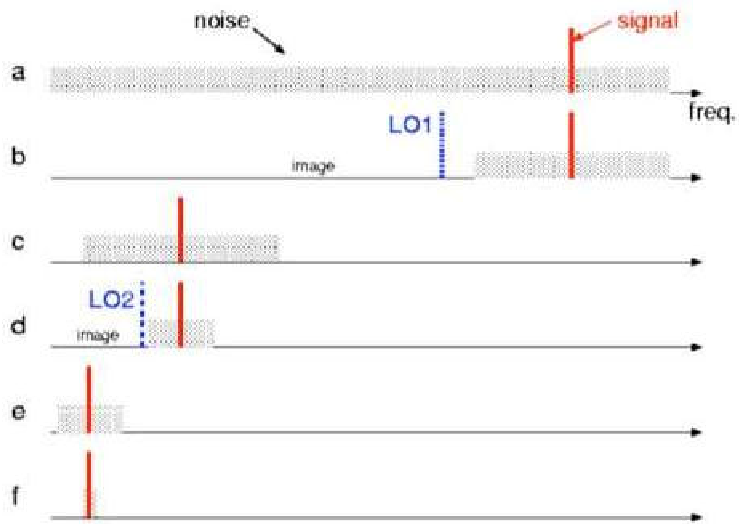
Position information
is converted to
the amplitude information

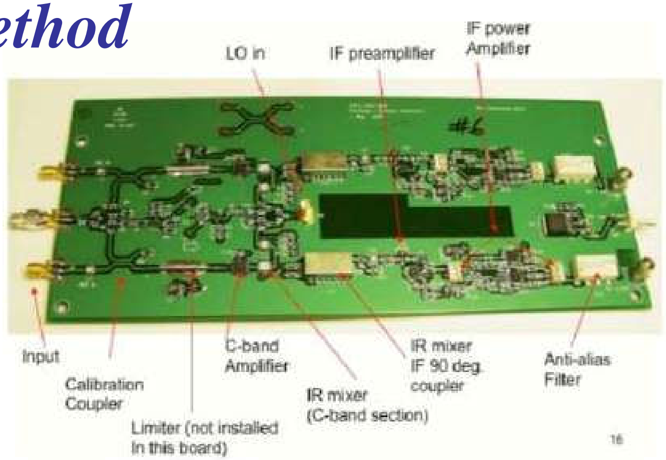


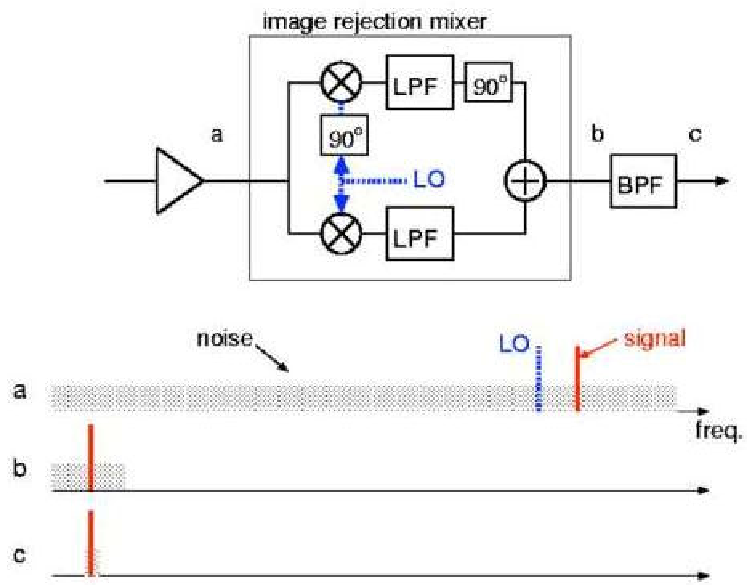
Readout Electronics of Cavity BPM

Heterodyne Method





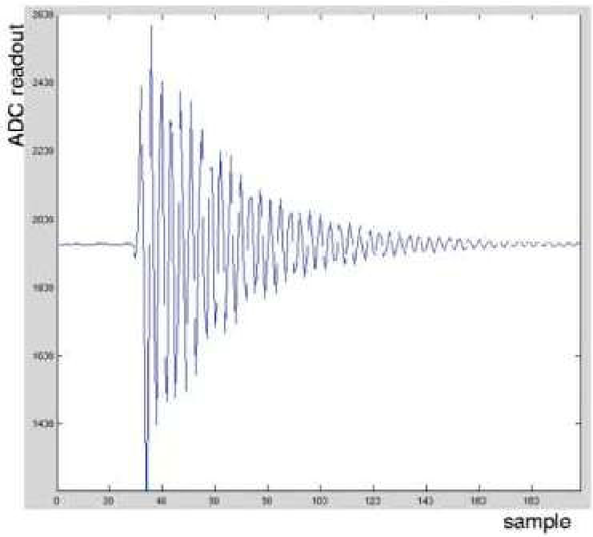




-Frequency is converted to lower frequency .
-Converted signal has
phase and amplitude information.

Readout Electronics of Cavity BPM

Heterodyne Method (continued)



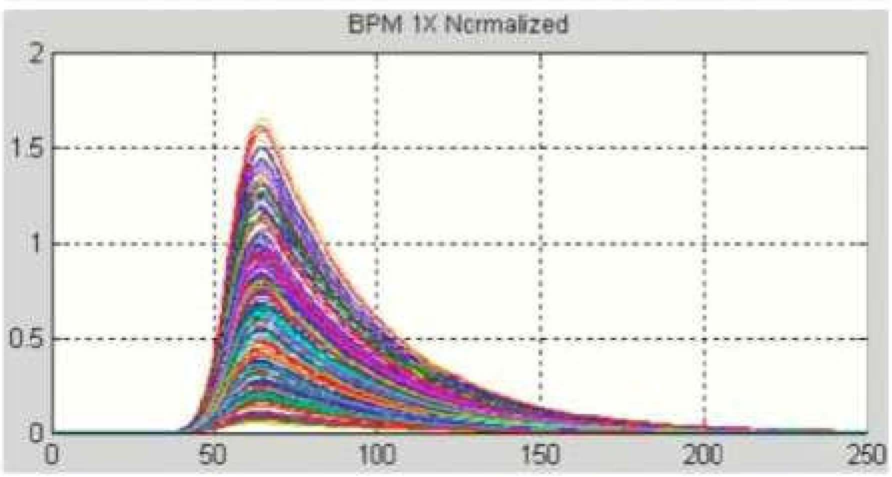
$$V = V_0 + Ae^{-\Gamma(t-t_0)} \sin(\omega(t-t_0)+\phi)$$

$$I_Y = \frac{A_Y}{A_{Ref}} \sin(\phi_Y - \phi_{Ref})$$

$$Q_Y = \frac{A_Y}{A_{Ref}} \cos(\phi_Y - \phi_{Ref})$$

Position information is converted to the amplitude information by the readout software.

Down converted signal is fitted by readout software.



Theoretical Resolution Limit of ATF Cavity BPM

Thermal Noise

$$p_{TN} \approx kTf_{BW}$$

$$V_{TN} \approx \sqrt{4kTZf_{BW}}$$

For the bandwidth of 3MHz

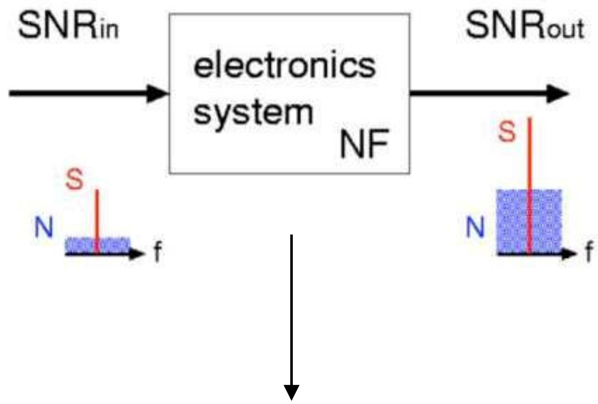
$$p_{TN}[dBm] = -174 + 10\log f_{BW} = -109\text{dBm}$$

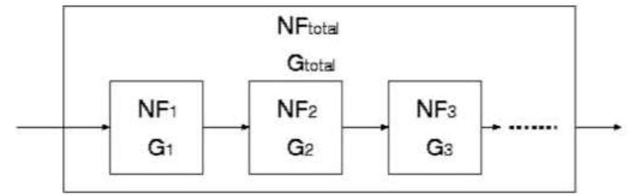
This value corresponds to 4nm resolution for the signal of 1e10 electron beam

But, the noise is amplified by the amplifier in the readout circuit to 12nm resolution .

Almost same both for Homodyne and Heterodyne electronics

$$NF = \frac{SNR_{in}}{SNR_{out}}$$





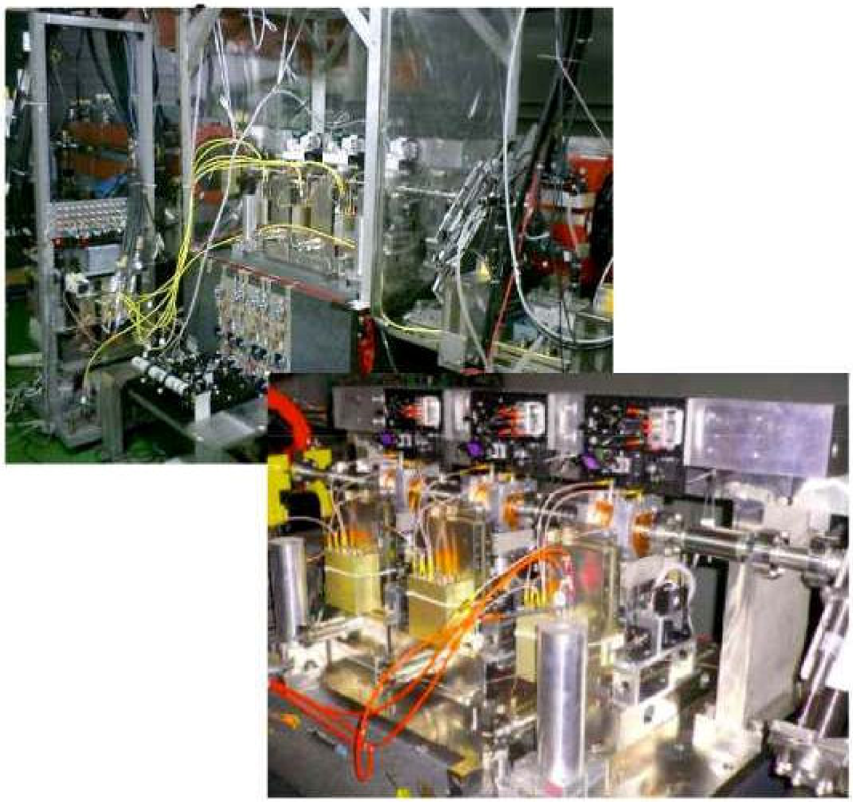
$$NF_{total} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \cdots$$

the main noise source is the first amplifier.

Resolution Measurement in old ATF extraction Line

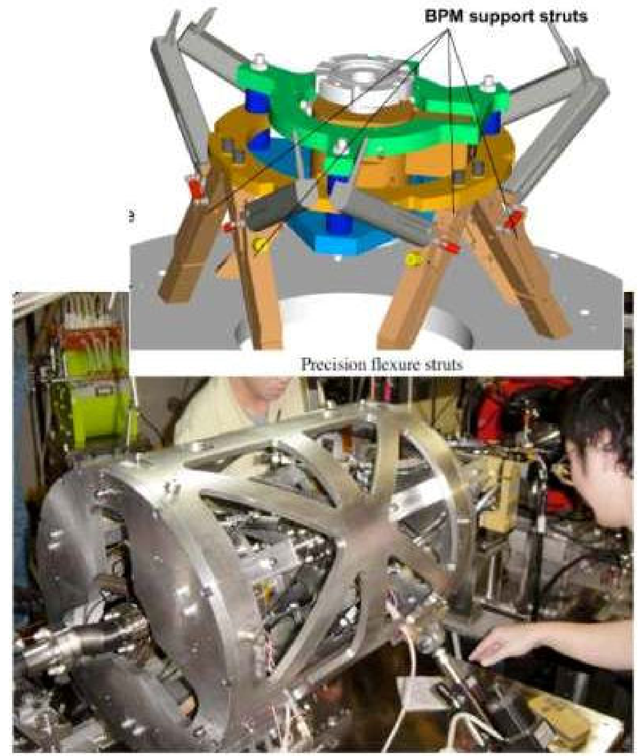
We must stabilized the relative position of BPMs within nm level .

Setup of KEK cavity BPM



-make BPM position stable
by position feedback.
-with Homodyne type electronics

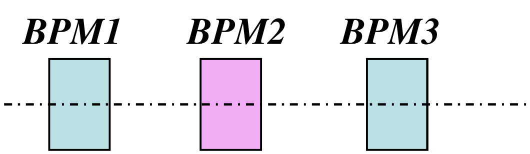
Setup of SLAC cavity BPM

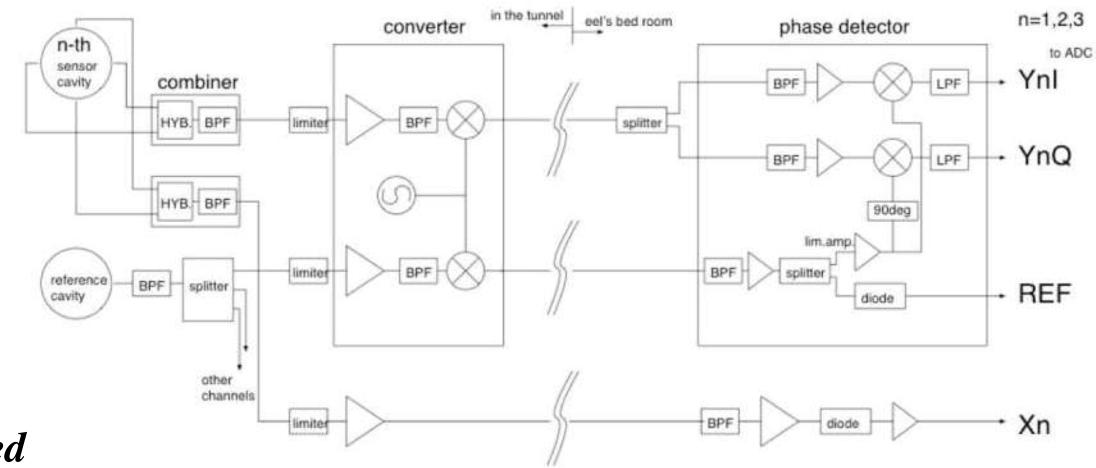


-make BPM position stable
by using mechanical stable stage
-with Heterodyne type electronics

Achieved Resolution in old ATF extraction Line

Example : Homodyne type electronics.





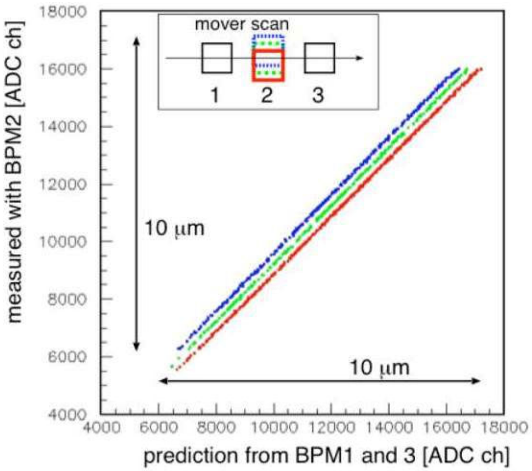
The position resolution is evaluated by comparing the Y2 signal and the Y2 value evaluated from BPM1 and BPM2 information.

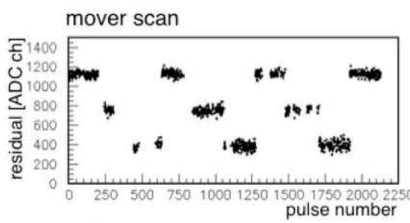
$$
\begin{aligned}
Y2I \;=\;& a_0 + a_{Y1I} \times Y1I + a_{Y3I} \times Y3I + a_{REF} \times REF \\
& + a_{X1} \times X1 + a_{X3} \times X3 + a_{Y1Q} \times Y1Q + a_{Y3Q} \times Y3Q \\
& + a_{Y1I^2} \times Y1I^2 + a_{Y3I^2} \times Y3I^2
\end{aligned}
$$

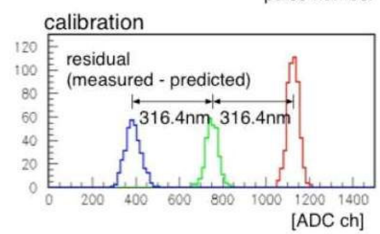
Δ = Y2I – Y2I (Y1I,Y1Q,X1,Y3I,Y3Q,X3)

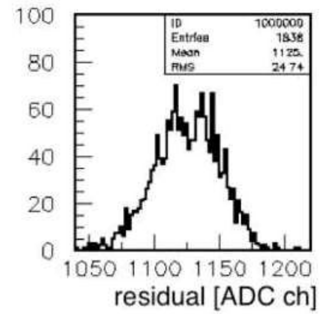
Achieved Resolution in old ATF extraction Line

Continued …









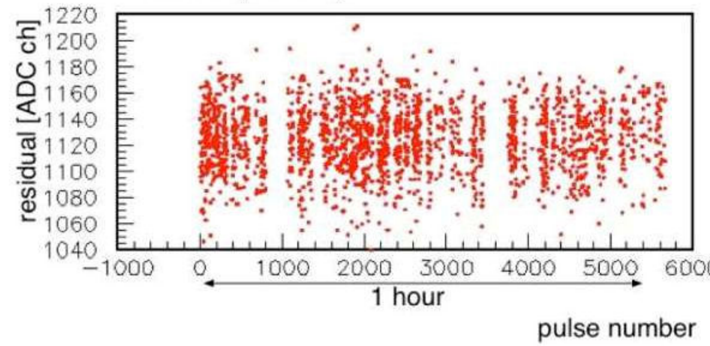
RMS of the residual

= 21.2 nm

resolution of the BPM

$= \sqrt{2/3}$ x RMS

= 17.3 nm



Calibration was done
by changing the BPM2 position.

-The 17.3nm resolution is achieved with Homodyne type electronics

-Almost same result of 15-20nm is achieved with Heterodyne Method.

(Theoretical Limit is 12nm.)

Present BPM resolution in ATF2 beamkine

Method

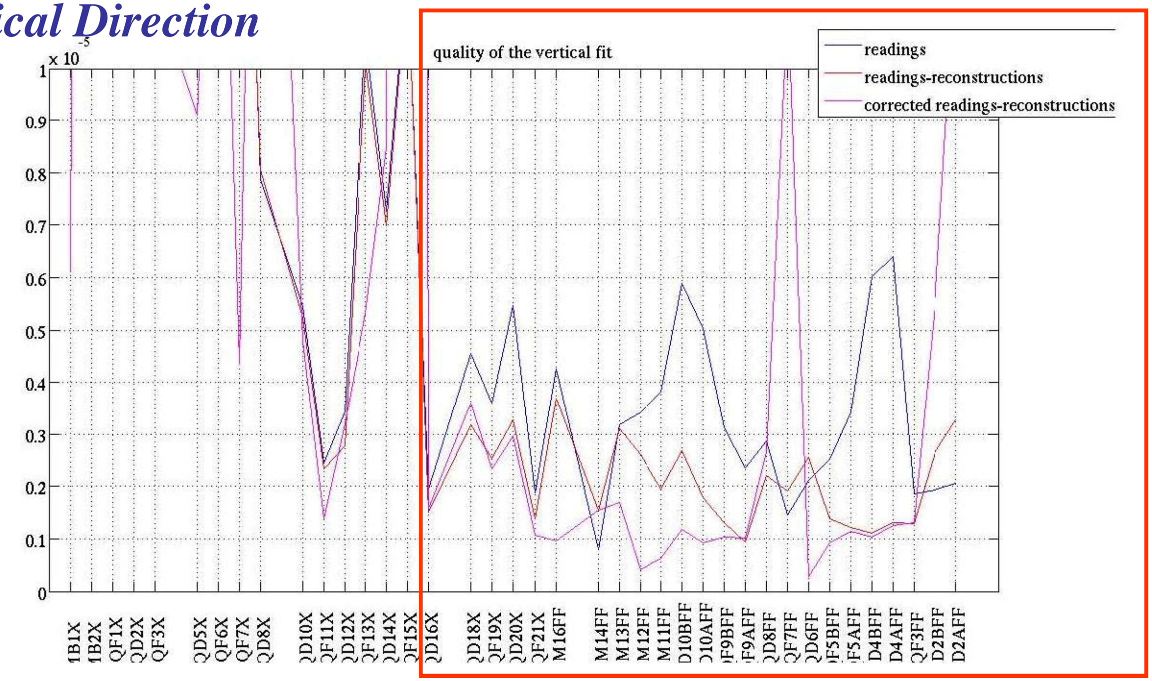
- Compute the influence of the variation of parameters on BPM readings for the current lattice.
- Minimize (least-square) the difference between the variation of trajectory predicted and the measured one, varying these parameters.
- Parameters used : $x(IEX)$, $x'(IEX)$, $y(IEX)$, $y'(IEX)$, $\frac{\Delta E}{E}(IEX)$, $x'(KEX2)$ and $y'(KEX2)$
- That means solve for each reading:

$$\begin{pmatrix} R_{1,1}(1) & R_{1,2}(1) & R_{1,3}(1) & R_{1,4}(1) & R_{1,6}(1)\dots \\ R_{1,1}(2) & R_{1,2}(2) & R_{1,3}(2) & R_{1,4}(2) & R_{1,6}(2)\dots \\ & & \vdots & & \\ R_{3,1}(1) & R_{3,2}(1) & R_{3,3}(1) & R_{3,4}(1) & R_{3,6}(1)\dots \\ & & \vdots & & \end{pmatrix} \times \begin{pmatrix} x(IEX) \\ x'(IEX) \\ y(IEX) \\ y'(IEX) \\ \frac{\Delta E}{E}(IEX) \\ x'(KEX2) \\ y'(KEX2) \end{pmatrix} = \begin{pmatrix} x(1) \\ x(2) \\ \vdots \\ y(1) \\ \vdots \end{pmatrix}$$

where $R_{1,1}(IEX \rightarrow BPM_1)$ appears as $R_{1,1}(1)$

Readout Position Fluctuation after Reduction of Orbit Fluctuation

Vertical Direction



Cavity BPMs on mover

Residual position fluctuations were 0.5-1.5 μm

- *with attenuator in order to expand dynamic range .*
  (dynamic range : a couple mm)
- *resolutions were not limited by thermal noise,*
  but the setting with large dynamic range in ATF2 beamline.

Data Analyzed by Y. Renier

Long-term Stability of the BPM Calibration

QM16FF calibration stability

Date	x iqrot	x scale	y iqrot	y scale
12/05	1.49596	-1862.4	1.948483	-2327.8
13/05	none		2.061953	-1437.2
20/05 (1)	1.07617	-3529.8	1.47416	-2938.3
20/05 (2)	1.08835	-2381.5	1.488422	-2921.9
22/05	1.04746	-2584.1	1.396824	-1134.6
26/05 (1)	1.14398	-966.1	1.529592	-1134.6
26/05 (2)	1.13968	-969.3	none	none
29/05	1.06244	-1155.0	1.445270	-1400.5
18/06	1.080320	-3176.7	1.422404	-3762.3

Jump consistent with Swinson changing reference

- Carefully checked QM16FF
  - After 13/05 I-Q rotation looks stable < 0.1 rad implies cos(0.1) scale stability from RF phases < 1%

Summary of Cavity BPMs in ATF2 Beamline

Thermal noises of the cavity BPMs are corresponds to 4nm resolution for the signal of 1e10 electron beam.

But, we expect that the noises are amplified by the amplifier in the readout circuit up to 12nm resolution.

The < 20nm resolution is achieved in ATF line with Homodyne and Heterodyne type electronics for very narrow dynamic range (10μm for the resolution test).

We use the cavity BPMs with the resolution of around 1μm in order to expand the dynamic range large.

Introduction of the relevant beam instrumentation devices to CLIC

Beam Position Monitor

- Cavity BPM

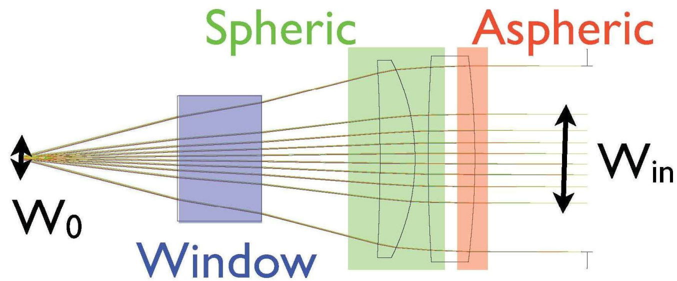
No distractive Beam Profile Monitor

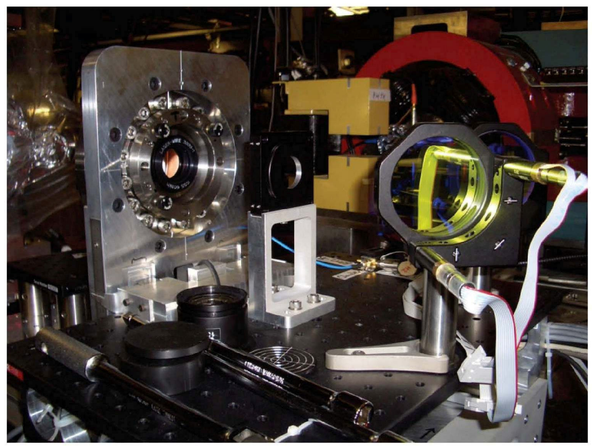
- Laser Wire Beam Profile Monitor

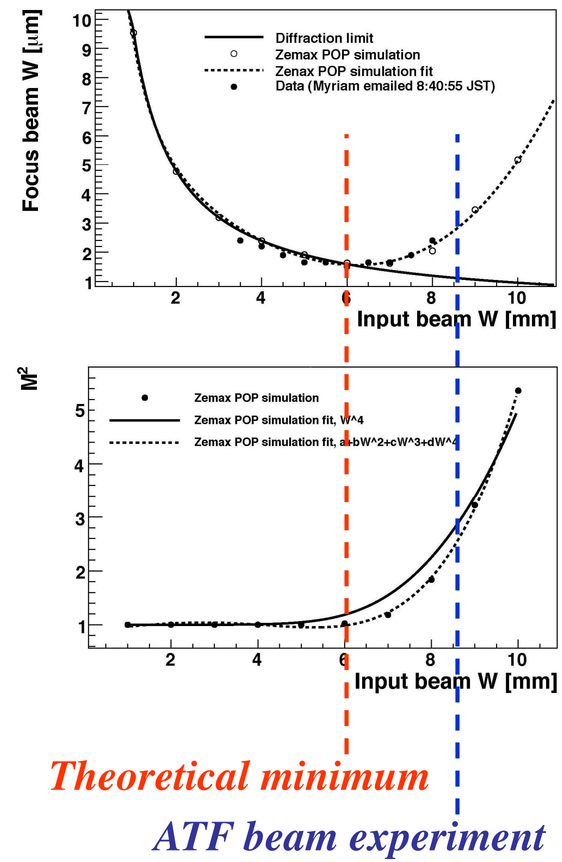
- Laser Interferometer

Theoretical Resolution Limit for ATF Laser Wire

- F/2 lens
  - 3 Elements (aspheric, spheric, window)
  - Parameters
    - Focal length 56.4mm
  - Lab measurements indicate excellent performance
  - Analysis of lens performance data/ simulation ongoing





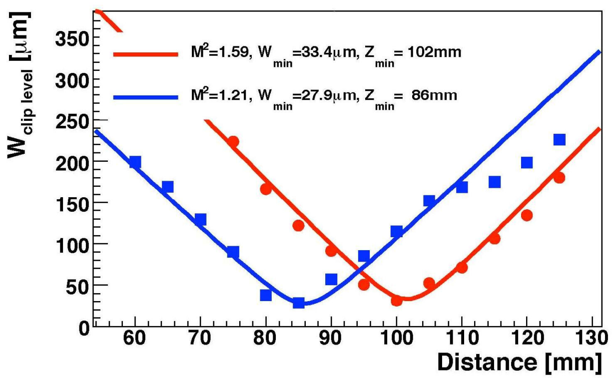


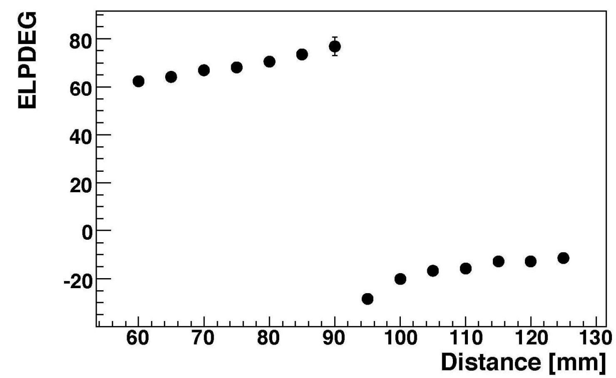
***Theoretical resolution limit* is 2.2 μm (2sigma) for w_{in}= 6mm (2sigma).**

Laser waist was expected to be 3.0 μm (2sigma) for ATF beam experiment.

Performance of Pulsed Laser for ATF Laser Wire

- Laser is significantly astigmatic (simple or general...)
  - Propagation different in two orthogonal planes
  - Measured just before IP but after 5 degree wedged splitter
  - ELPDEG is measure of laser ellipse orientation





-M2 are 1.5 and 1.2 for two orthogonal planes.

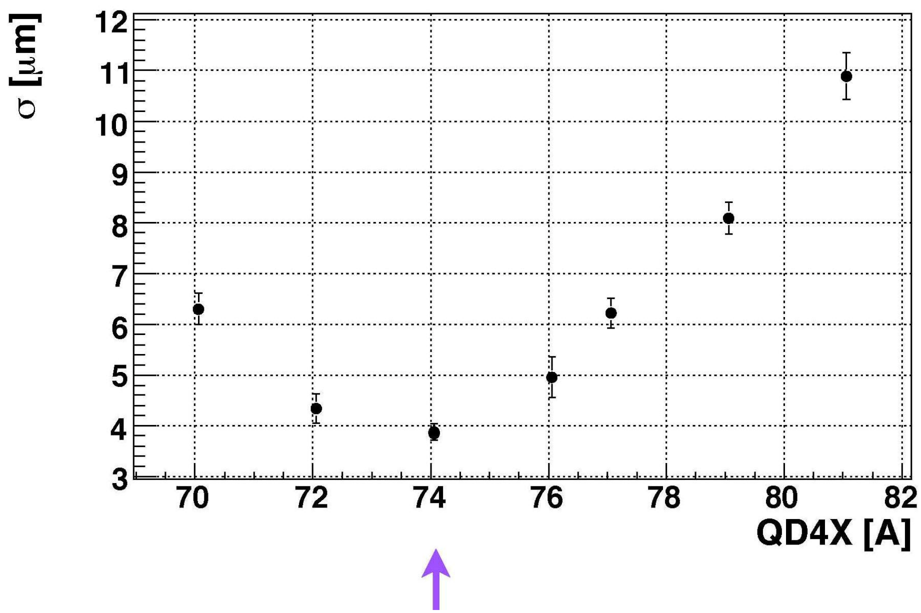
-Focal position was different for both planes.

-Expected laser spot was

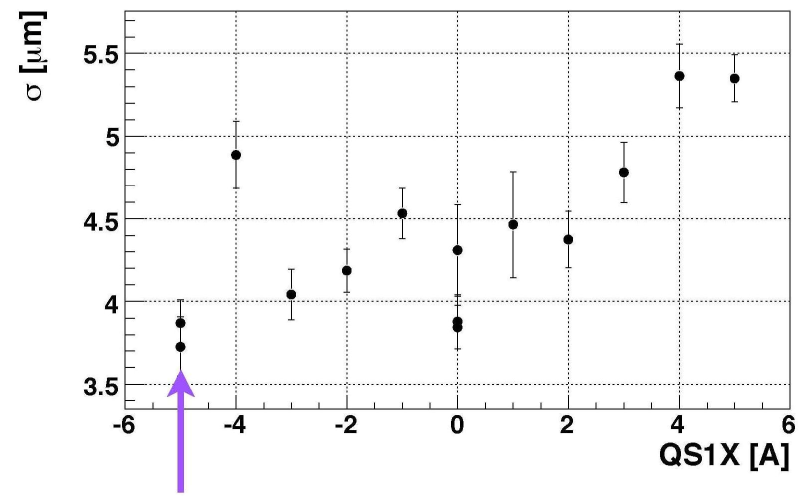
*1.5μm(lens) * 1.5 (M2) * 1.5 (Astigmation)= 3.4μm*

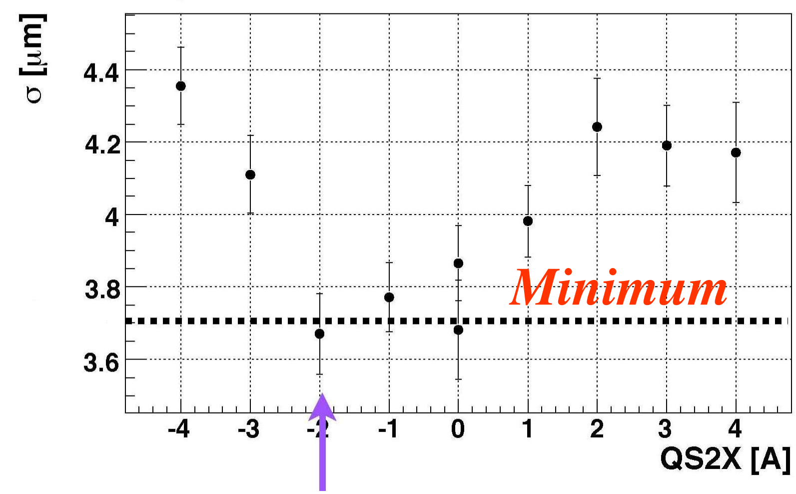
Minimum Beam Size in ATF Laser Wire Experiment

Quadrupole Scan



Skew Quadrupole Scan





3.7 μm electron beam size was measured with ATF laser wire.

Summary of Laser Wire Beam Profile Monitor

Theoretical resolution limit with ideal laser and F/2 lens for the ATF laser wire is expected to be 1μm.

The resolution limit for the condition of ATF laser wire beam experiment is expected to be 3.4μm.

The minimum beam size at ATF laser wire beam experiment was 3.7μm, and almost consistent with the expectation.

Introduction of the relevant beam instrumentation devices to CLIC

Beam Position Monitor

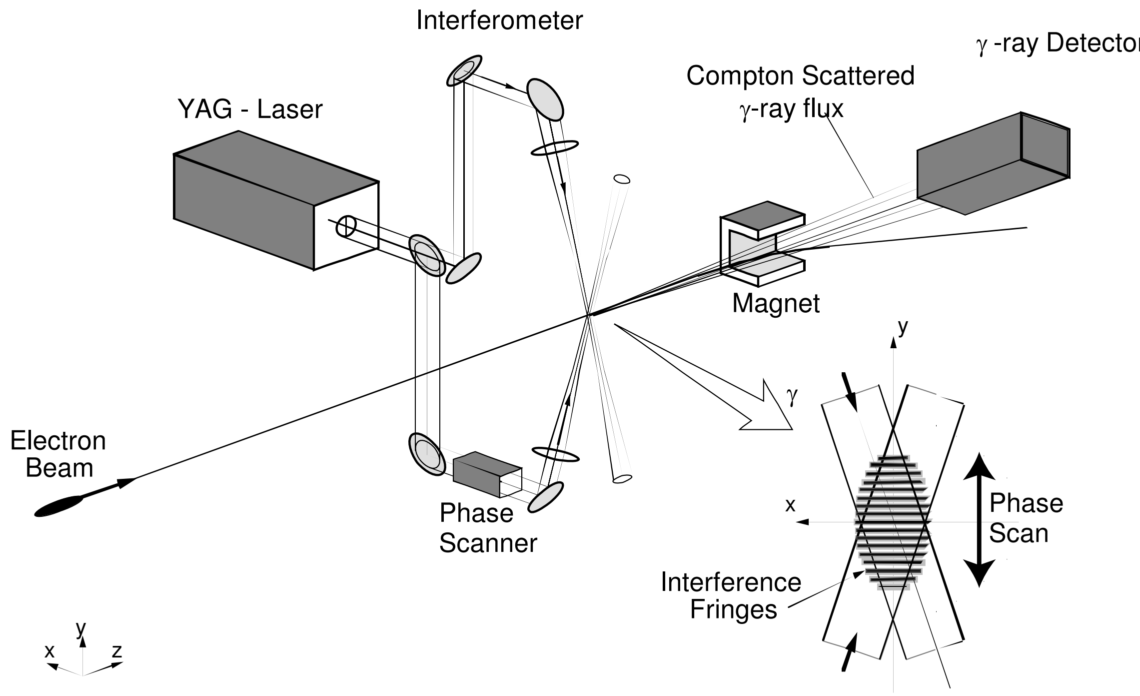
- Cavity BPM

No distractive Beam Profile Monitor

- Laser Wire Beam Profile Monitor

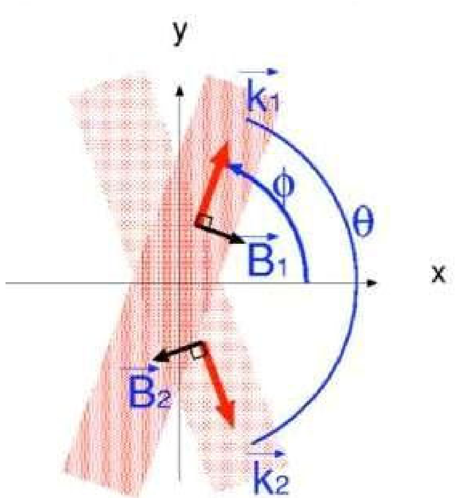
- Laser Interferometer

Concept of Beam Size Measurement with Laser Interferometer

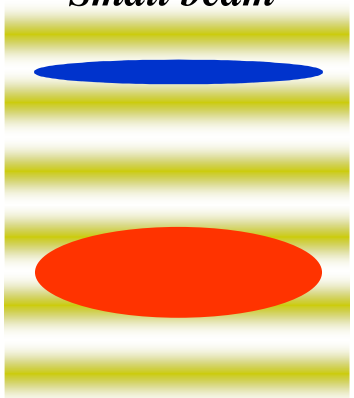


Laser light is divided to laser path and collide at beamline to make a interference pattern .

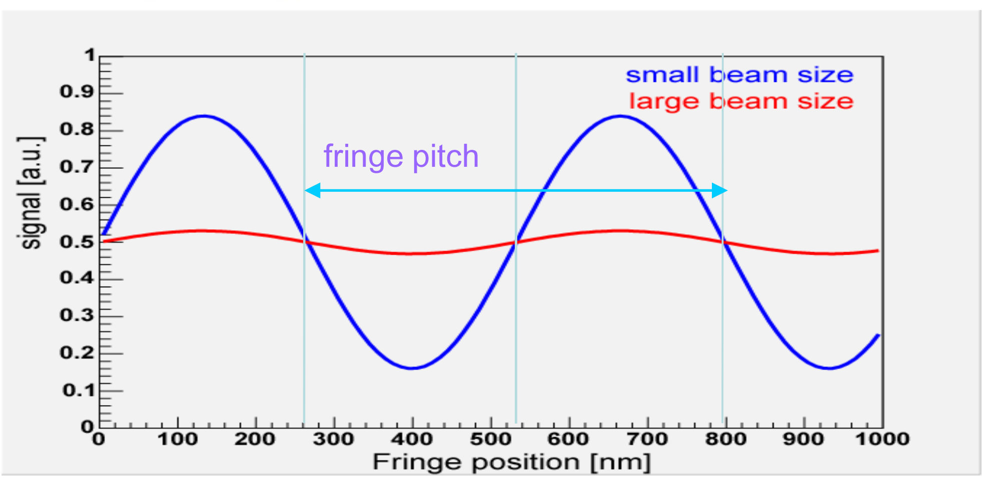
Beam Size Evaluation with Laser Interferometer



Small beam



Large beam



Emitted Photon is evaluated by the convolution of beam distribution.

$$N_\gamma \propto \int_{-\infty}^{\infty} \exp[-\frac{(y-y_0)^2}{2\sigma_y^2}](1+\cos\theta\cos 2k_y y)dy$$
$$= N_0[1+\cos(2k_y y_0)\cos\theta]\exp[-2(k_y\sigma_y)^2]$$

$$N_\pm = N_0[1 \pm \cos\theta \exp[-2(k_y\sigma_y)^2]]$$

Amount of interference

$$M \equiv \frac{N_+ - N_-}{N_+ + N_-}$$
$$= |\cos\theta| \exp[-2(k_y\sigma_y)^2]$$
$$= |\cos\theta| \exp[-2(\frac{\pi\sigma_y}{d})^2]$$

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

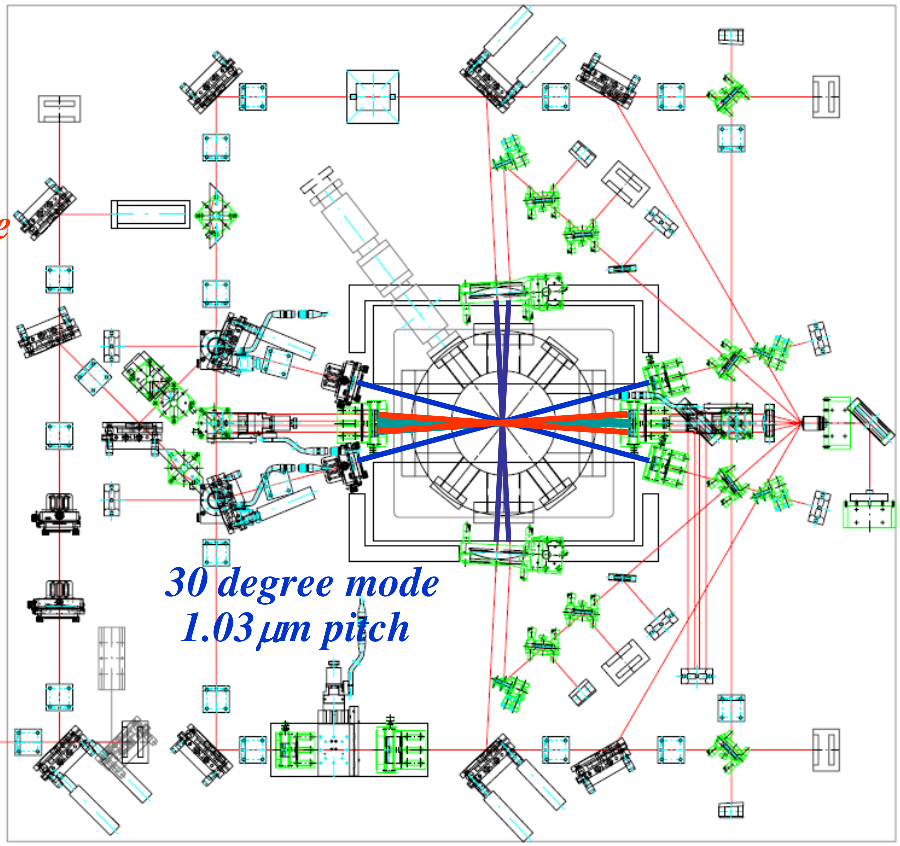
Laser interferometer in ATF2

2&8 degree modes are very small laser tunable range.
-> 4.5 degree mode is prepare instead of 2&8 degree modes.

4.5 degree mode
9.5 μm pitch

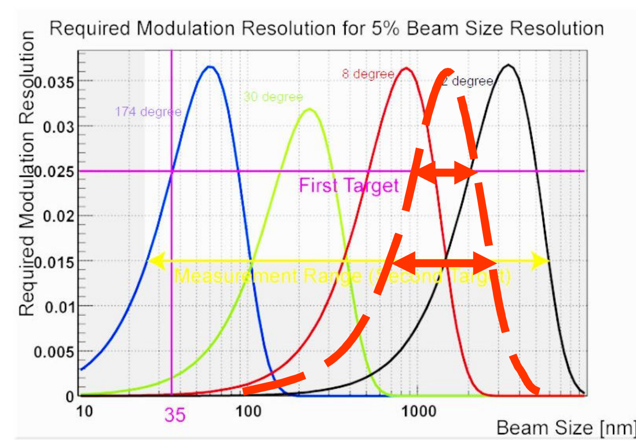
2 degree mode
15 μm pitch

8 degree mode
3.8 μm pitch



174 degree mode
266nm pitch

By changing 4 laser collision angle, dynamic range of Interferometer is 25nm – 6 μm of beam size.



By using 4.5 degree mode, dynamic range of Interferometer is 600nm – 3 μm of beam size.

The first target of Interferometer is measurement of 1-2 μm beam size.

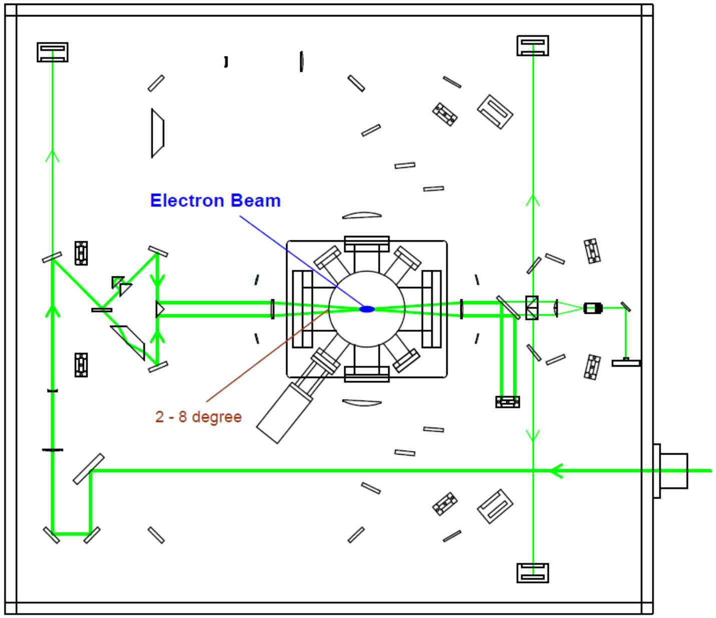
Commissioning Status of Laser Interferometer

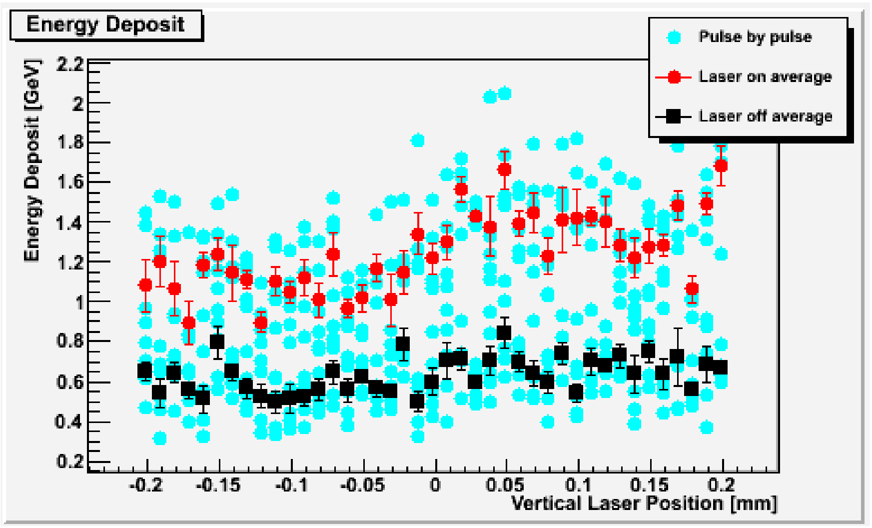
- 4.5 degree crossing angle was used to measure several μm vertical beam size.

- Signal (excess of energy deposit when laser is on) was detected.

- But, since we must focus the laser beam size to be 10μm at IP to get large signal, it is very difficult to collide two laser beams and electron beam at IP. We could not established laser-laser collision and laser-electron collision procedures in the 2009 spring run for poor laser and electron diagnostics.

- In order to measure the beam size with the interferometer, we must focus electron beam to be around 1μm.





Presented by T.Yamanaka, 8th ATF2 project meeting (6 / 9 / 2009)

For 2009 Autumn Beam Commissioning

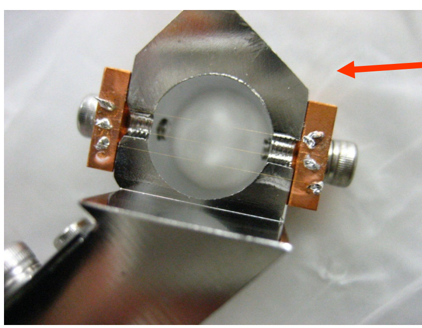
New IP target was installed

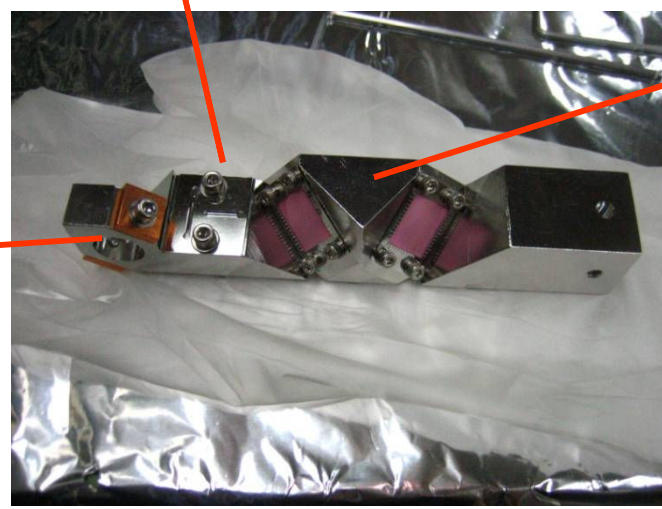
Laser beam size measurement

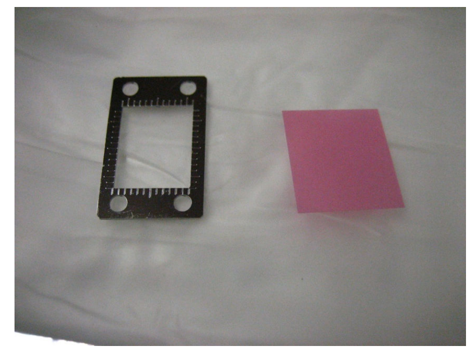
Prepare knife edge target to make 10μm laser spot at IP

Electron beam size measurement

Attach10μm tungsten wire at the tip of the holder to make 1μm beam size at IP







- Laser-laser collision for all laser mode

- Electron-laser collition

Prepare 2 screen monitor

Summary of Laser Wire Beam Profile Monitor

Theoretical dynamic range of ATF laser interferometer is 25nm-6μm with 4 crossing angles.

The ATF laser interferometer is now under commissioning, and we did not yet have clear experimental results for the resolution.

We are now commissioning the laser interferometer with 4.5 degree mode, the requirement of electron beam size is 1-2μm.

Since it is very difficult to collide two laser beams and electron beam at IP, new IP target was installed in 2009 summer shutdown.