Status of Shintake-monitor Optics (focused on phase stabilization)

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On behalf of ATF2 Shintake-monitor group

Topics

1. Overview
2. Status & Issues
   1. Laser fringe phase stabilization
   2. Others
3. Requests
   1. Beam collimation
   2. Hall layout
   3. Laser
4. Plan & Summary

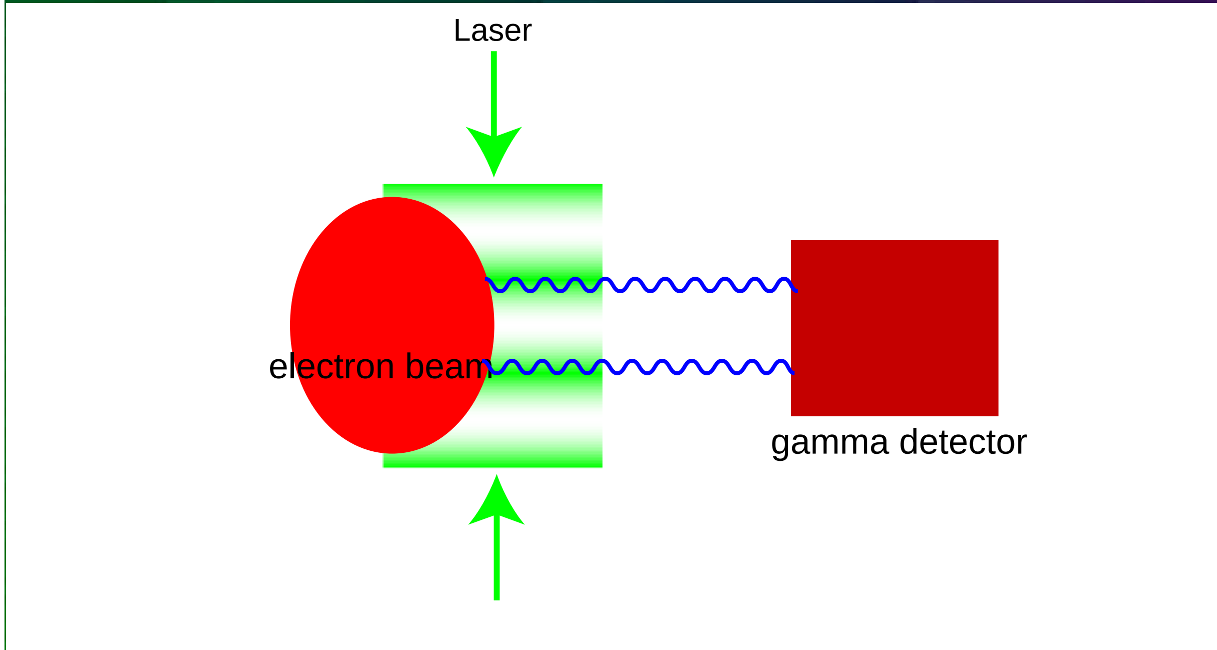
Overview

Shintake-monitor principle

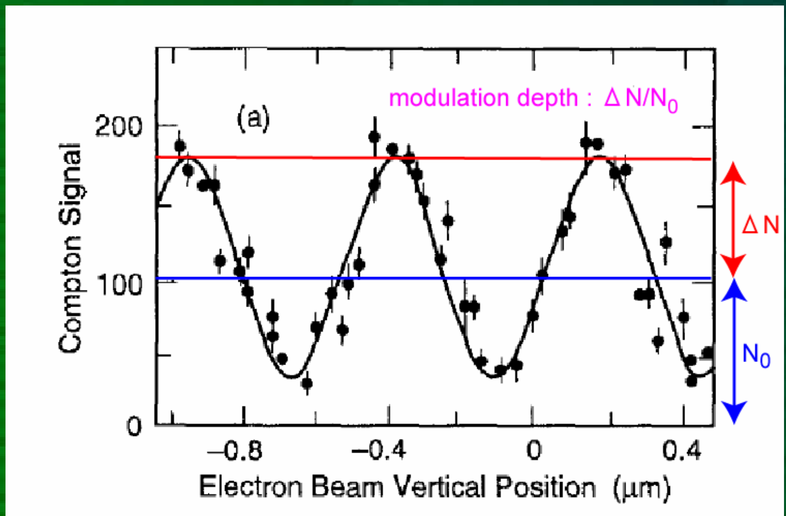
Table layout

Comparison between FFTB & ATF2

Shintake-monitor Principle

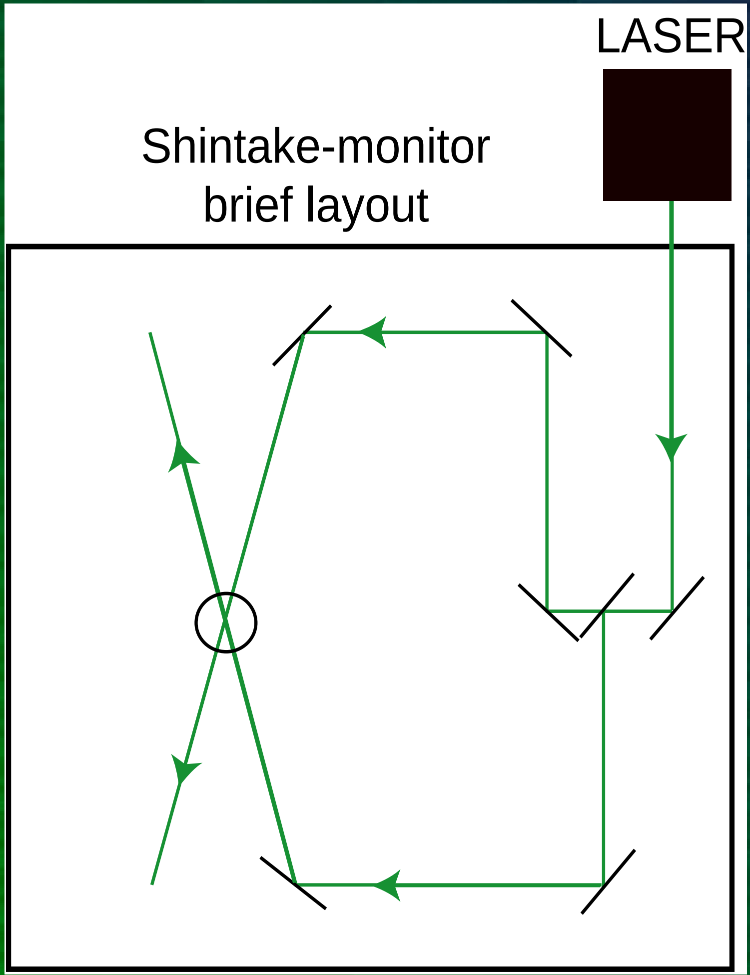


- Electron beam is scattered with laser photons at IP and emits gamma-rays.
- If electron beam is well focused, number of gamma-rays is largely modulated by the phase of the fringe.
- If not well focused, number of gamma is not so largely modulated.



- Practically, we measure the modulation of gamma-ray signal monitored downstream IP.
- The “modulation depth” can easily be converted to beam size.
- The left figure is FFTB result. It corresponds to 70nm beam size.

Table Layout



Laser beam is split and go across the IP from opposite direction.
Size is 1.5m x 1.5m.

Picture of Shintake-monitor
Front optical table is for laser optics tuning.
We are using low power cw. test laser now.

Comparison between FFTB and ATF2

	FFTB	ATF2 (plan)
Target	Test of monitor itself Obtain beam size	Tool for tuning High resolution
Period	1992 - 1997	2008-
Beam size @ IP	70 nm (meas.)	35 nm (plan)
Rep. rate	30 Hz	1.5 – 3 Hz
Laser wavelength	1064 nm	532 nm
Beam size resolution	Not specified (“less than” 70nm)	< 2nm
Measurement time	1 hour?? (iteration because of bad resolution)	1 minute (no iteration)

Status & Issues

Required laser fringe phase stability

Fringe phase monitor method & location

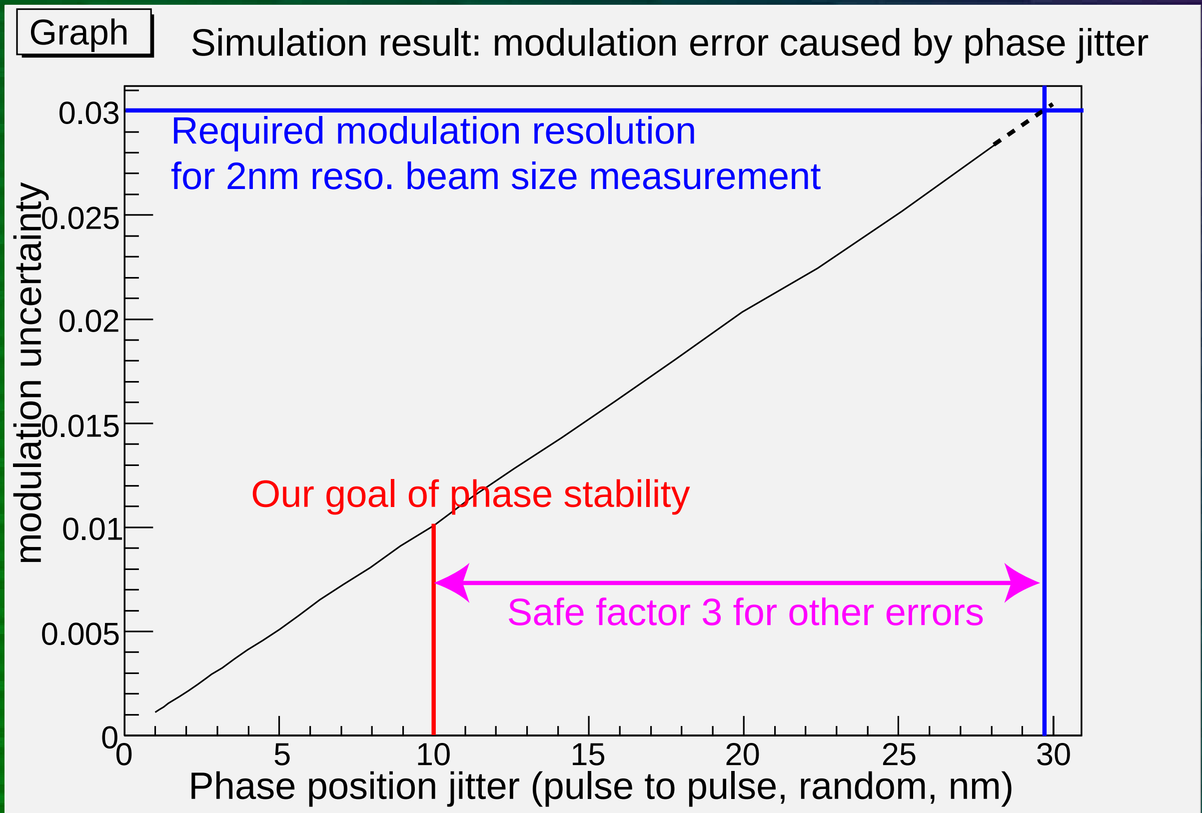
Phase scanning system

Phase stabilization test

Other status

Required Fringe Stability

2nm beam size (required resolution) corresponds to 3% modulation (around 35nm). We need 3% modulation resolution.



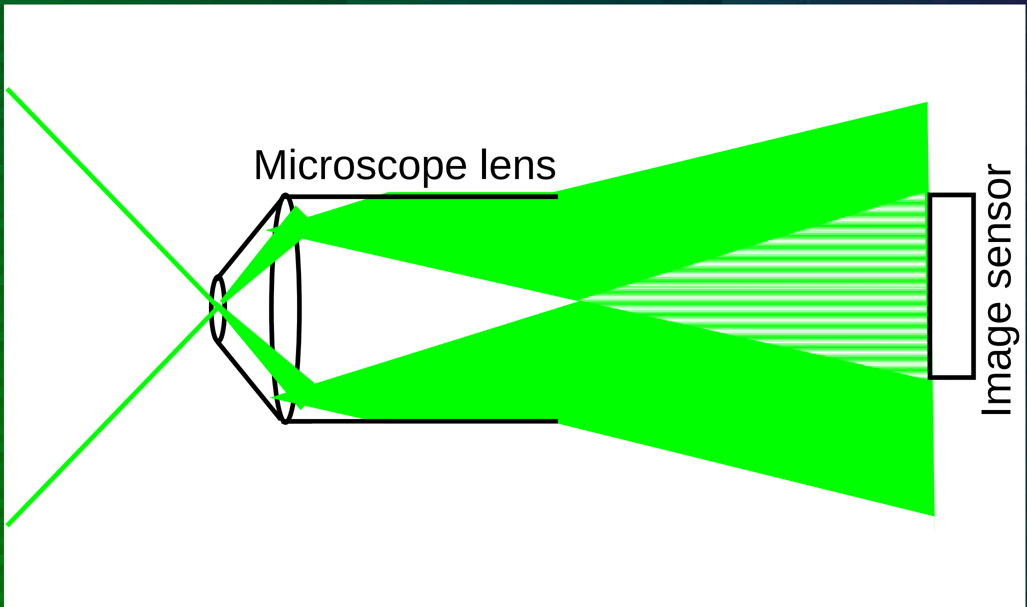
- modulation uncertainty is proportional to phase jitter.
- About 30nm stability corresponds to 3% (goal) modulation uncertainty.
- But we should consider another errors. We keep safe factor 3.

As a result,

We should develop a 10nm level fringe phase stabilization system.

The Method of Phase Detection

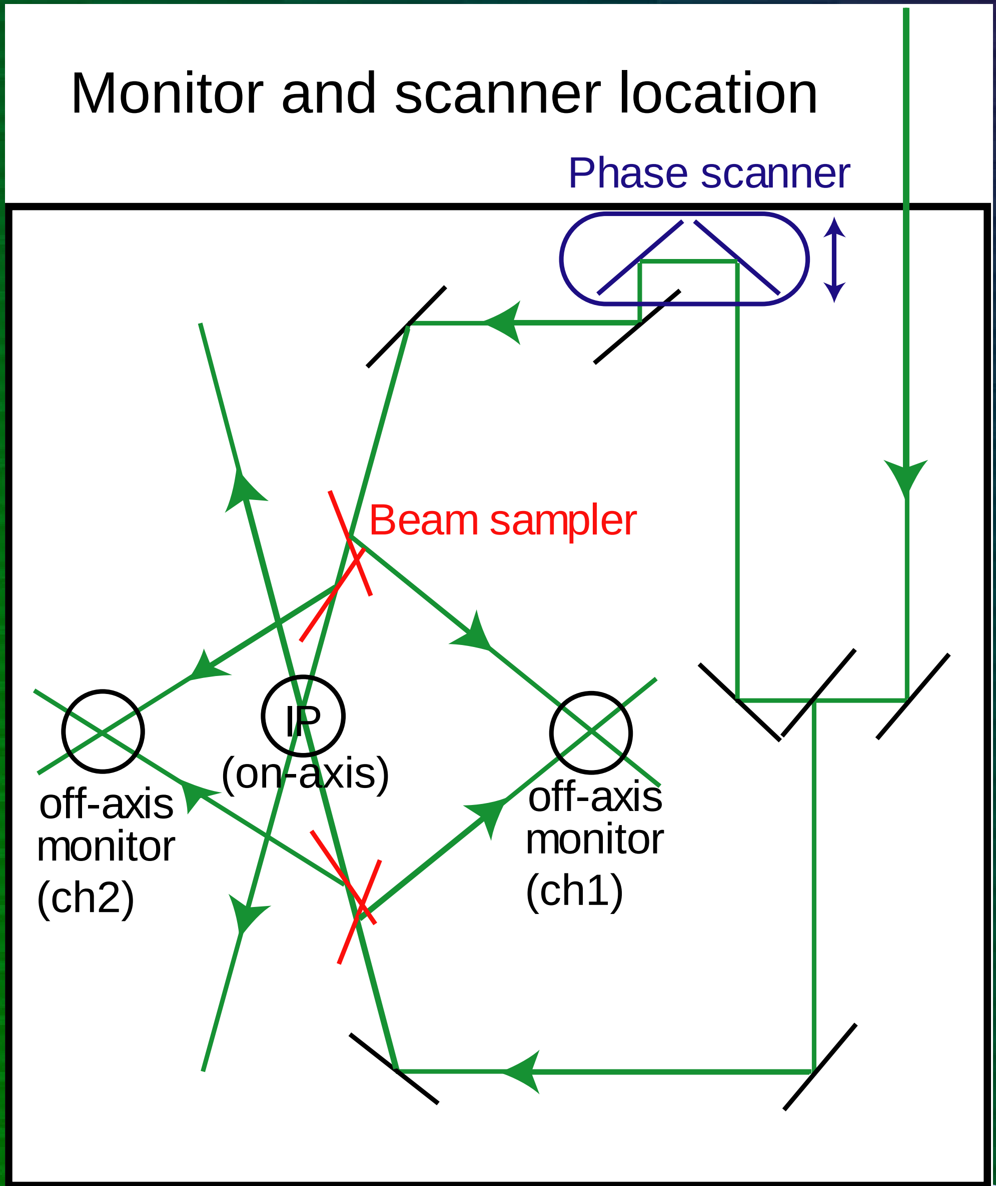
Fringe magnification by a lens with a linear image sensor



- The laser beams pass through the microscope lens to be magnified, and create fringe pattern. (lens works like a double slit)
- The phase of the fringe corresponds to relative phase of 2 laser beams.

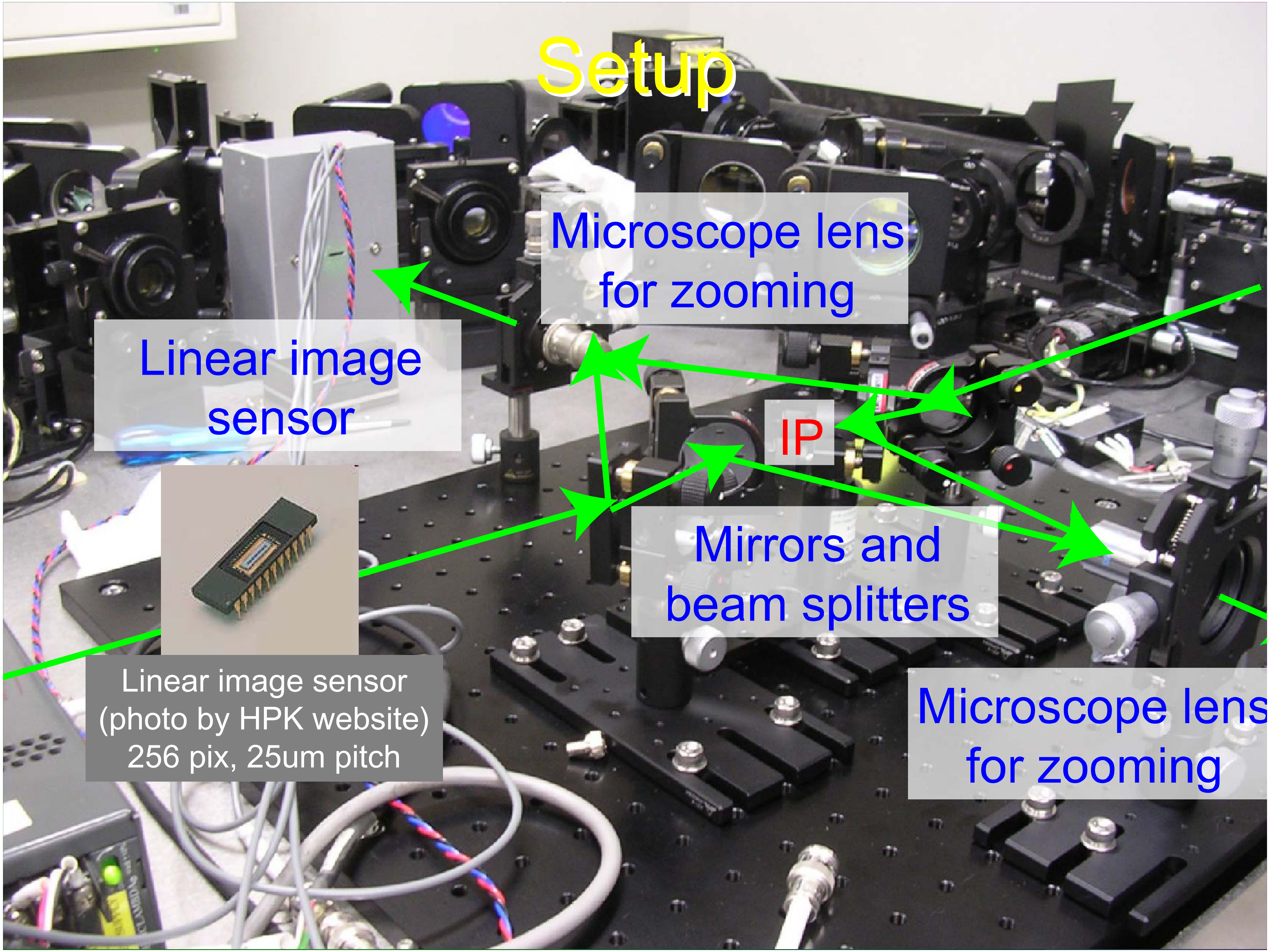
- We obtain the phase by Fourier transform method. Resolution of phase calculation estimated to be < 0.1 rad. (i.e. about 5nm)

Location of Monitors and a Scanner



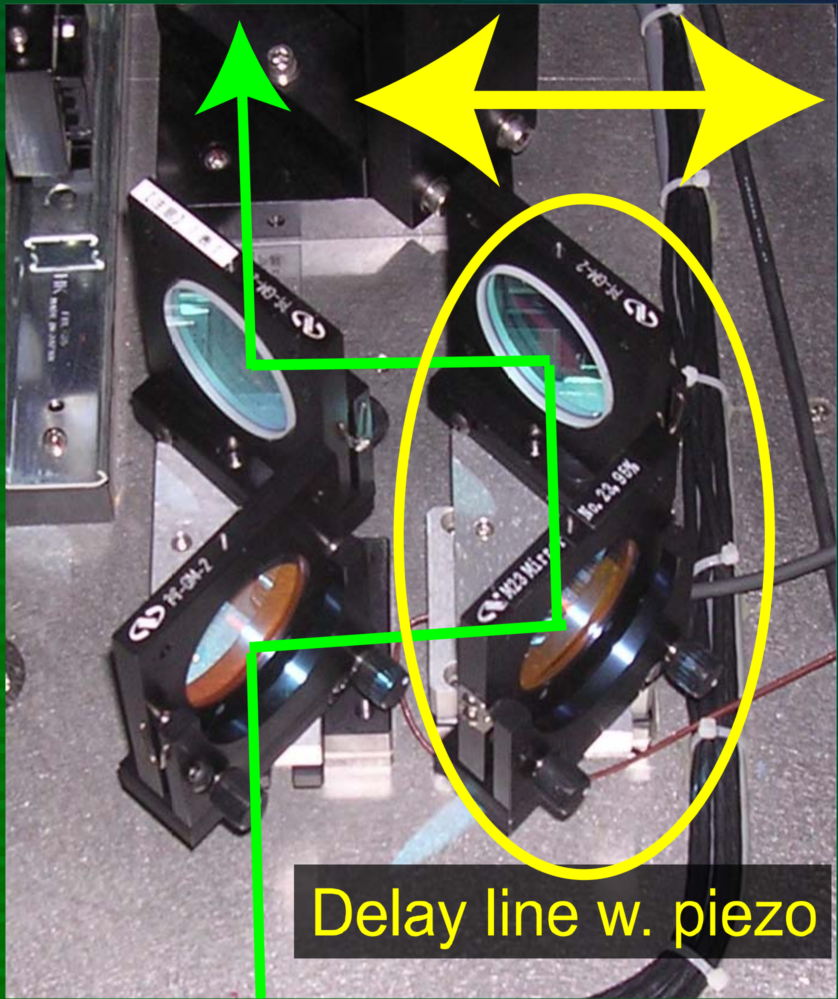
- We cannot place the phase monitor on IP. We place it "off-axis" position.
- To cancel out difference of the phase between IP and monitor position, we place the same monitor on the opposite position (ch2)
- We place a phase scanner (delay line with piezo mover) on one side. We need no beam steering for scanning fringe phase.

Setup



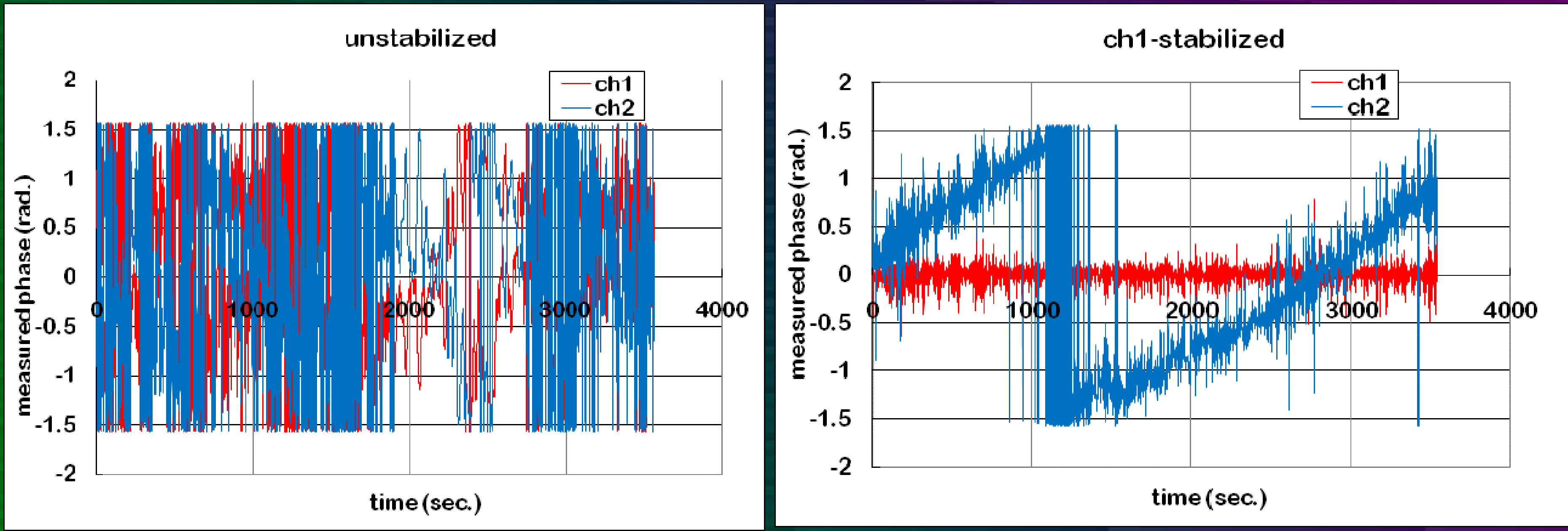
Microscope lens for zooming
Linear image sensor
IP
Mirrors and beam splitters
Linear image sensor (photo by HPK website) 256 pix, 25um pitch
Microscope lens for zooming

Fringe Phase Scanning System



- Optical delay line used for phase stabilization and scan
- Resolution of piezo stage is 1nm, corresponds to 2nm phase resolution.
- We implemented a test stabilization system using the image sensor and this scanner.

Phase Stabilization Test Result



- Stabilization effect is clearly observed.
- σ = 0.076 rad. (3.2nm) for ch1 (stabilized channel)
- σ = 0.178 rad. (7.5nm) for ch2
  (not stabilized channel, except long-time drift)
- Almost achieved 10nm stability in spite of very bad condition
  (no cover, lenses with rods). We can improve.

Issues of phase stabilization

- Resolution of image sensor is low (25 μm pix.). We are improving it by new 5 μm pix. sensor.
- Sensor characteristics of pulsed light are unknown (but the maker said it may be OK.) We need to test that by a pulsed laser.
- We need to know what causes the phase drift. (may be thermal, but not tested yet)
- Stabilization algorithm can be optimized.

Other Topics

- Laser beam position at IP must be stabilized
  for good fringe contrast.
  FFTB version had 2 PSD sensors and mirror movers for stabilization system.
  We are implementing a new system (using existing PSD).
- Power of split laser beam should be equal.
  We plan to correct it by a Pockels cell.
  (Normal variable ND filter cannot be used for high power.)
  The Pockels cell can be also an alternative for phase scanning device (without polarizer).
- We need some tests by pulsed laser (low & high power).
  We found timing jitter of laser is 1ns (σ) in specification.
  It must be also corrected. We will use TDC.

Requests

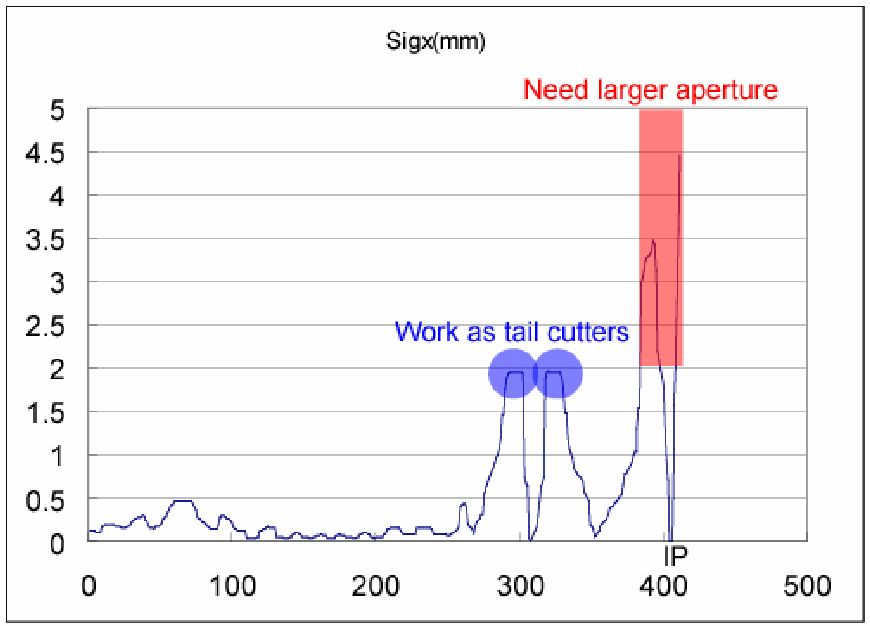
Beam collimation

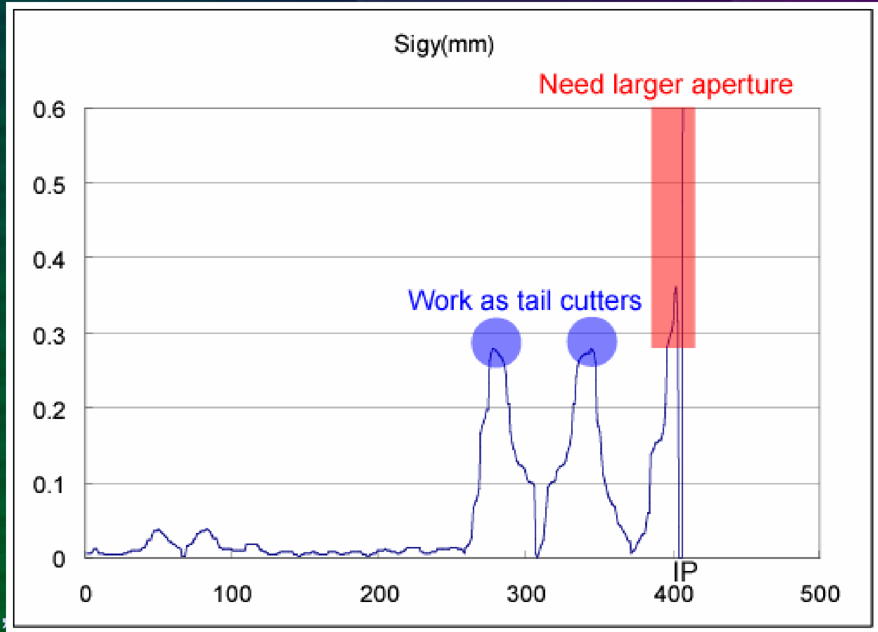
Hall layout

Laser

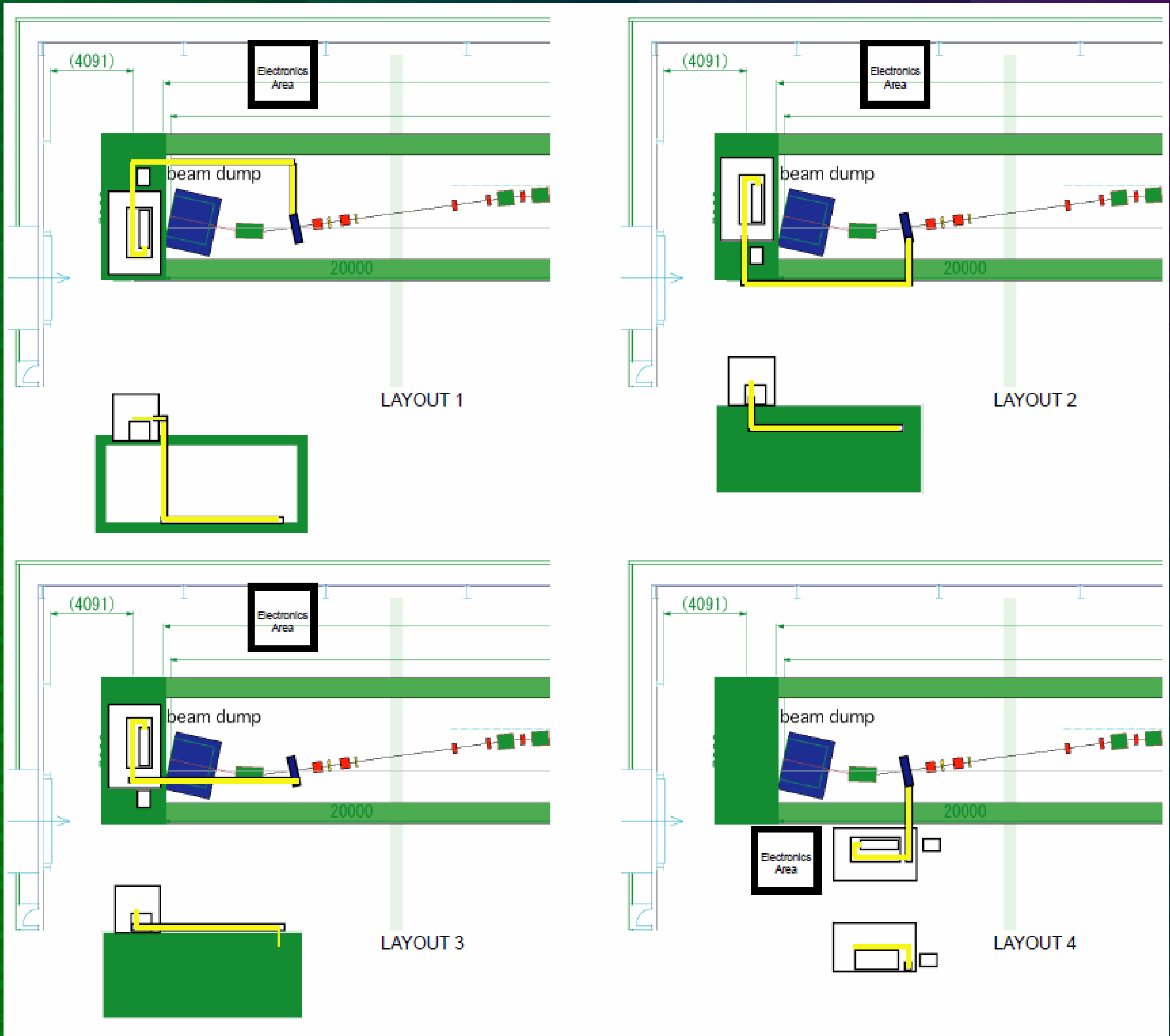
Request for Beam Collimation

- Cut of beam tail is necessary for both X & Y.
- Maximum σ_x before final bend ~ 1.95 mm
  - Aperture of OC1~SD0 must be larger (S-band)
  - Beam size between IP and dump must be also considered.
- Maximum σ_y before final bend ~ 0.27 mm
  - Aperture of LXS.9~QD0 must be larger (S-band)
  - Beam size between IP and dump must be also considered.





Hall layout



- About 3m x 6m space needed for the laser hut.
- On the top of the shield (end of beam line) is acceptable.
- Laser transport line will goes through wall or ground.

Laser

- The power of FFTB laser is not sufficient
  - 320mJ,532nm,10Hz,8nm bunch length
  - Bunch length is too long, > 99% of the beam is “out of the date”. 100ps is enough.
  - Average number of Compton photons is ~1000. may be buried by background.
  - Number of Compton photons is proportional to laser power.
- Laser with more power / shorter bunch is highly desirable.

Summary & Plan

- Laser "phase stabilization" is essential for 2nm beam size resolution.
- Required phase stability is 10nm, which is almost achieved by active stabilization with linear image sensor phase monitor.
- Now we use cw. low power laser. We will perform test with pulsed / high power laser.
- We plan to finish tuning optics before next autumn (detailed schedule will be showed in the schedule session).

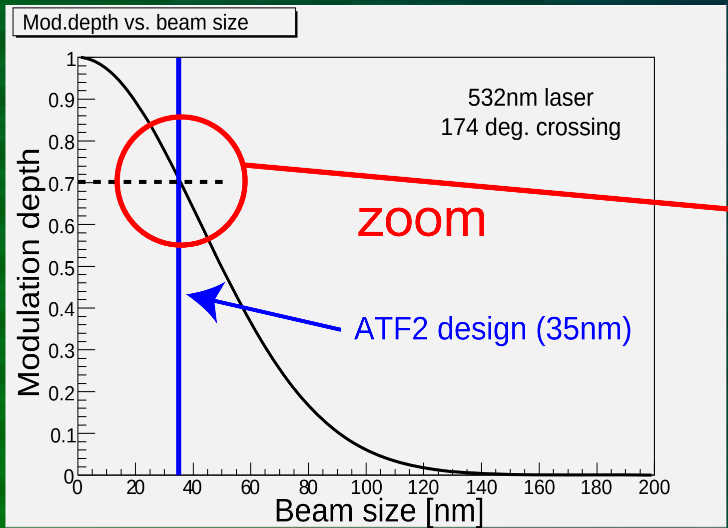
Thank you!!

ATF2 Shintake-monitor group

- Students
  - Taikan SUEHARA (Univ. of Tokyo, D2)
    - Optics (main table, laser table)
    - Overall design,etc.
  - Hakutaro YODA (Univ. of Tokyo, M1)
    - Gamma detector
- Staffs
  - Tatsuya KUME (KEK)
    - Optics support
    - Table support frame
  - Yosuke Honda (KEK)
    - Support (optics etc.)
  - T.Tauchi (KEK), T.Sanuki (Univ. of Tokyo)
    - Advisor (ATF2, overall)

Required Modulation Resolution

GOAL : to measure 35 nm beam size
by < 2nm resolution



Beam size	modulation
33nm	73%
35nm	70%
37nm	67%

2nm beam size corresponds
to 3% modulation (around 35nm).
We need 3% modulation resolution.

Then, how much stability of laser fringe phase
do we need to achieve 3% modulation resolution?
→ We performed a Monte Carlo simulation to obtain that relation.

Modulation Error Estimation

Assumed measuring condition for simulation is:

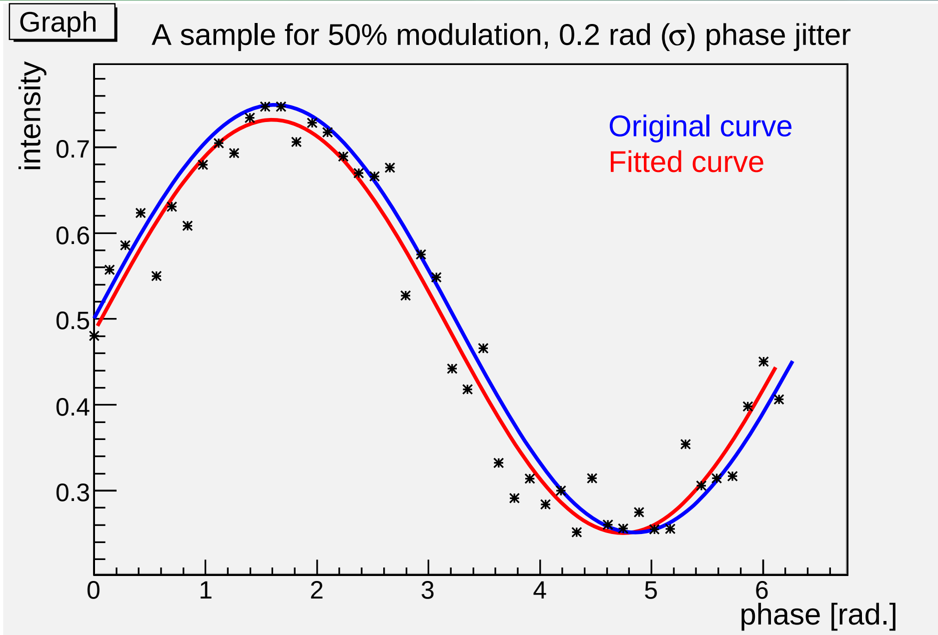
45 points (phases) meas., 1 bunch for each point

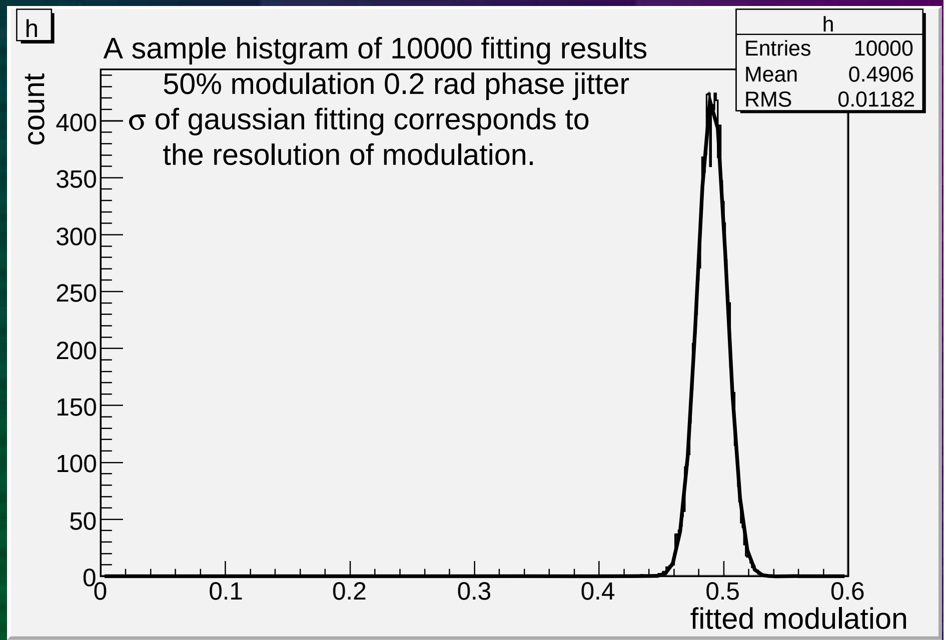
It's determined by desired measuring time (1 minute)

45 points $\times$ 1 bunch + same for background reduction = 90 bunches.

90 bunches / 1.5 Hz (ATF2 operation freq.) ~ 60sec.

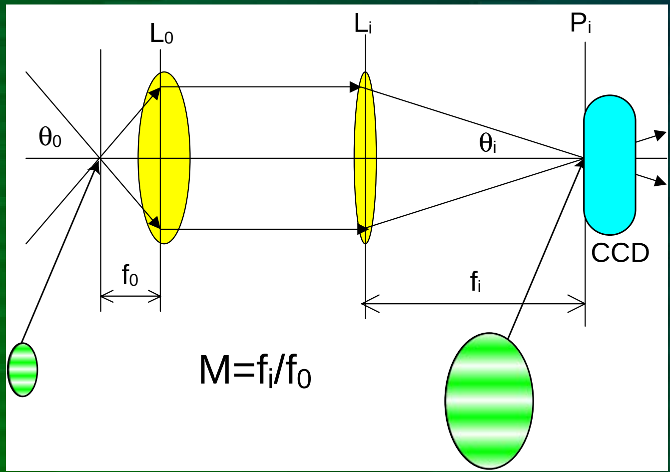
Simulation method is shown below (by example)



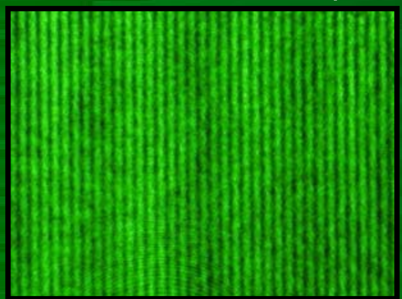


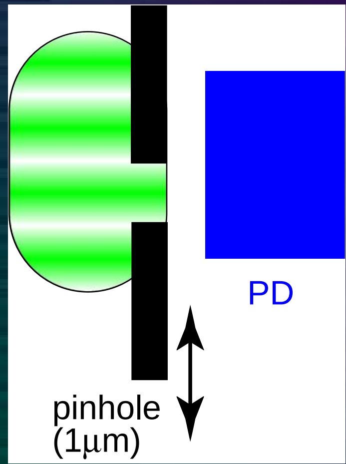
A sample of error simulation caused by phase jitter

Phase detection method

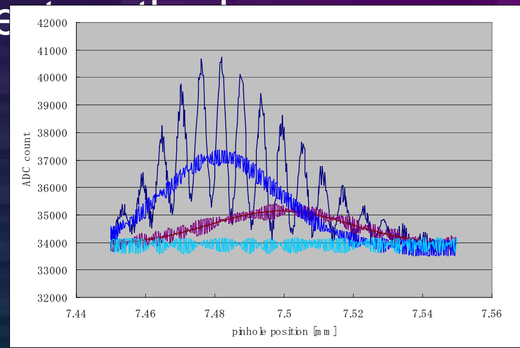


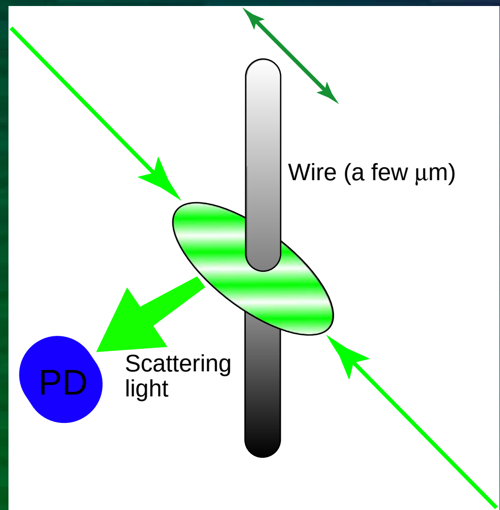
CCD with fringe magnify optics
(using microscope lens)
> 1μm fringe (6°, 30° setup)
single shot (usable for online monitor)
indirect method (need to check responsibility)





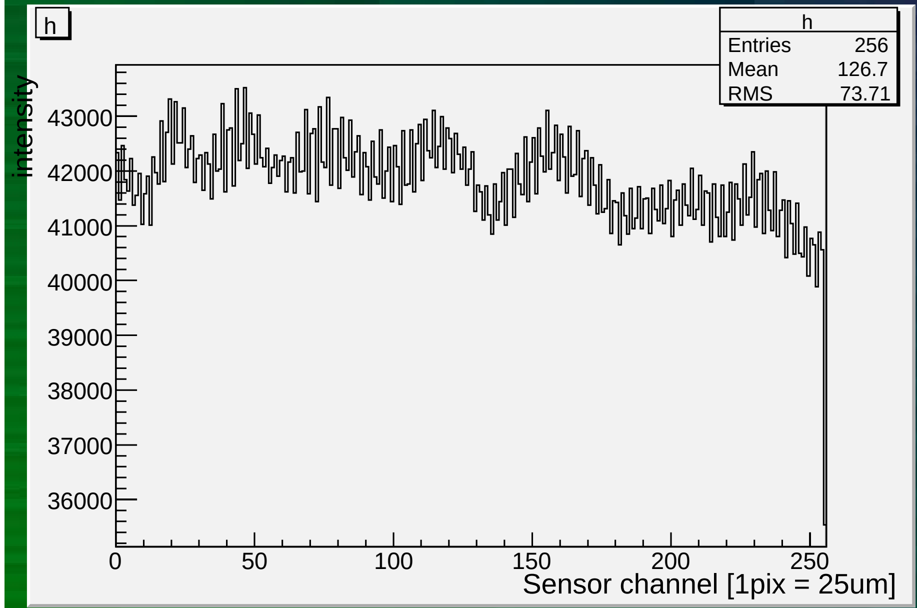
Pinhole scan
> 1μm fringe (6°, 30° setup)
not single shot
simple theory
(good for cross check)
dire



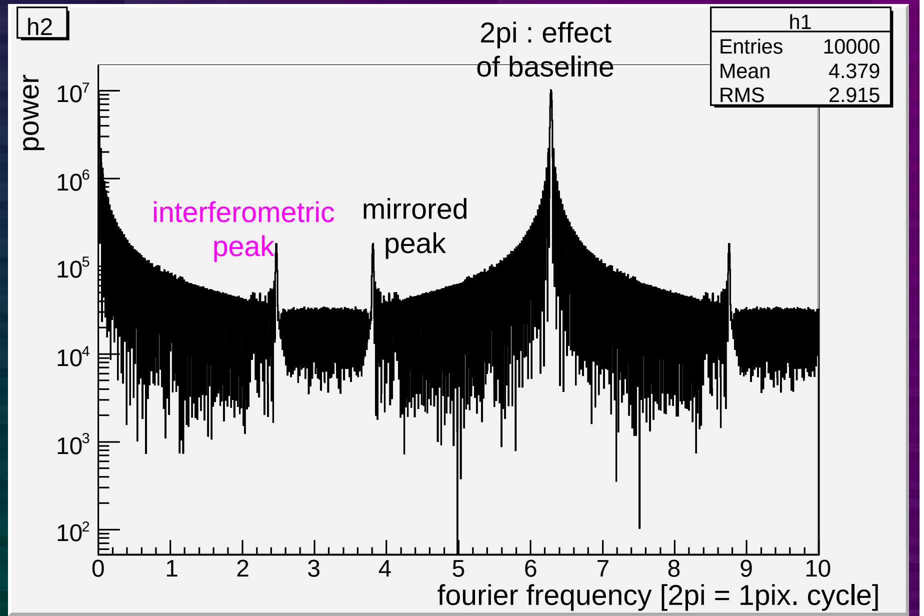


Wire scan
~ 250nm fringe
(all setup)
not single shot
tuning is difficult
direct method

Linear Image Sensor Data



Raw spectrum. Wave of dense pitch

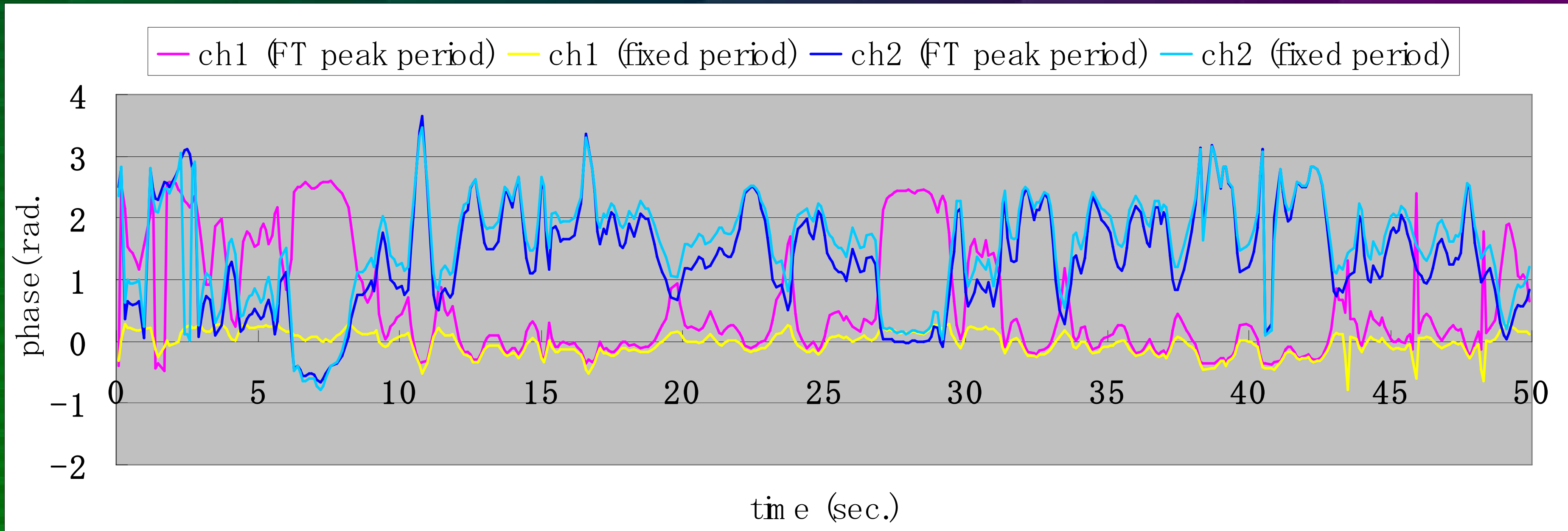


Fourier spectrum. Clear peak near 2.5.

- We use Fourier transform to obtain phase (at central channel) for high resolution and noise reduction.
- Clear peak can be seen near 2.5 on Fourier spectrum. It corresponds to the wave seen on raw spectrum.
- We use the Fourier phase (i.e. argument of complex Fourier) of the peak for the phase stabilization.

Preliminary Result(1)

Simply measured phase for 50 sec. No stabilization.



FT peak period: the phase of the Fourier peak freq.
Fixed period: the phase of fixed freq. (near the peak).

- Ch1 and Ch2 are almost opposite because they face opposite directions (it's expected behavior).
- This shows correlation of phases at two monitors.

Fringe phase stabilization strategy

Taikan SUEHARA, 3rd ATF2 project meeting @ KEK, 2006/12/18

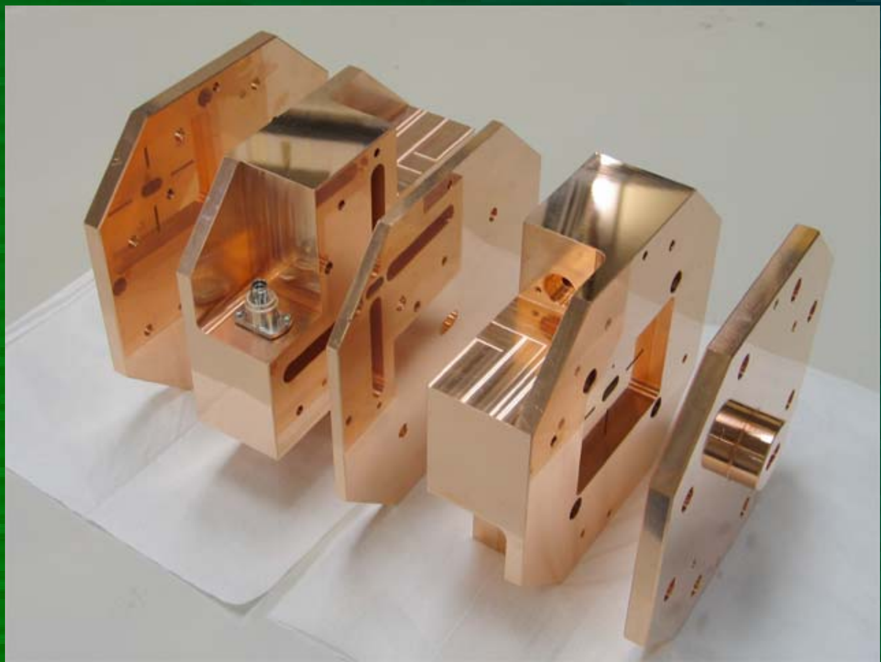
Stabilize to what?

- We have to know the point of origin of stabilization.
- We want to stabilize fringe to beam position
  - We cannot stabilize directly to "beam position".
  - How to obtain beam position? (2 possibilities)
    - IP BPM. The other purpose of ATF2 is to achieve 2nm stabilization of beam position. IP BPM is used to achieve that.
      → We can use the BPM center as the point of origin.
    - Position of the Final Doublet can be translated to beam position
      → Position of the Final Doublet can also be the point of origin.
- We are creating a stabilization system for above 2 points of origin (may be selectable).

First possibility : with IPBPM

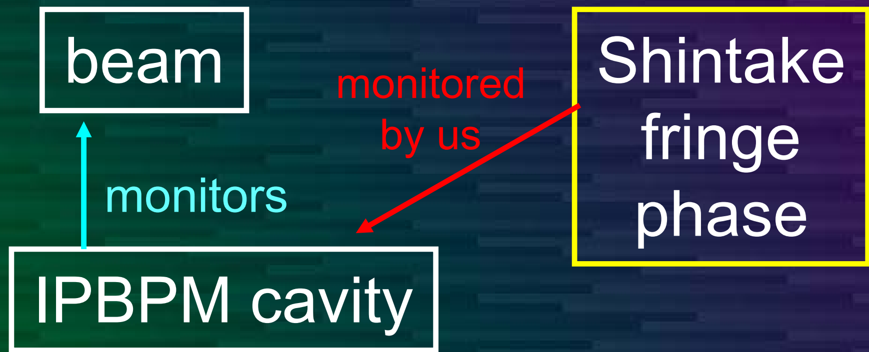
- IPBPM will be able to measure 2 nm BP.

  Dr. Honda and Mr. Nakamura are developing the IPBPM.
- We plan to attach IPBPM within Shintake-monitor.

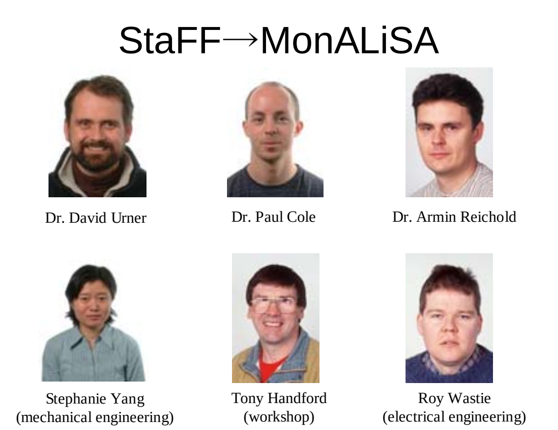


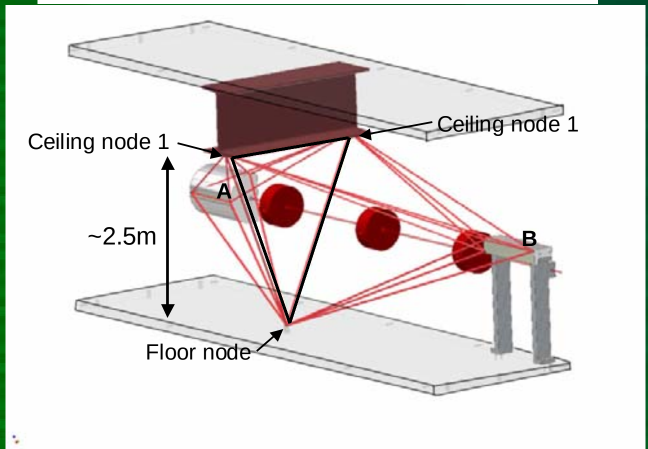
IP BPM prototype by Dr.Honda

- If IPBPM has enough resolution, we can use that (BPM cavity) as the point of origin.



Second possibility : with MonALiSA position monitor





MonALiSA people and their proposed monitor (Urner's talk on ATF2 project meeting, May 2006)

- MonALiSA (former StaFF) uses a laser interferometer to monitor position between some objects.
- Position of Final Doublet is correlated to beam position (by the relation of lens and focus point).
- We can define the point of origin freely in Shintake table (MonALiSA can monitor the point).