Shintake monitor in ATF2: status, performance and prospects

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Maybe this is my last talk about the Shintake monitor…

Taikan Suehara, TILC08(GDE+ACFA)@Sendai, 2008/03/05

Topics

1. Overview
2. Optical Table and Support Frame
3. Beam Test of Gamma Detector
4. Performance Estimation & Extension to the ILC
5. Summary

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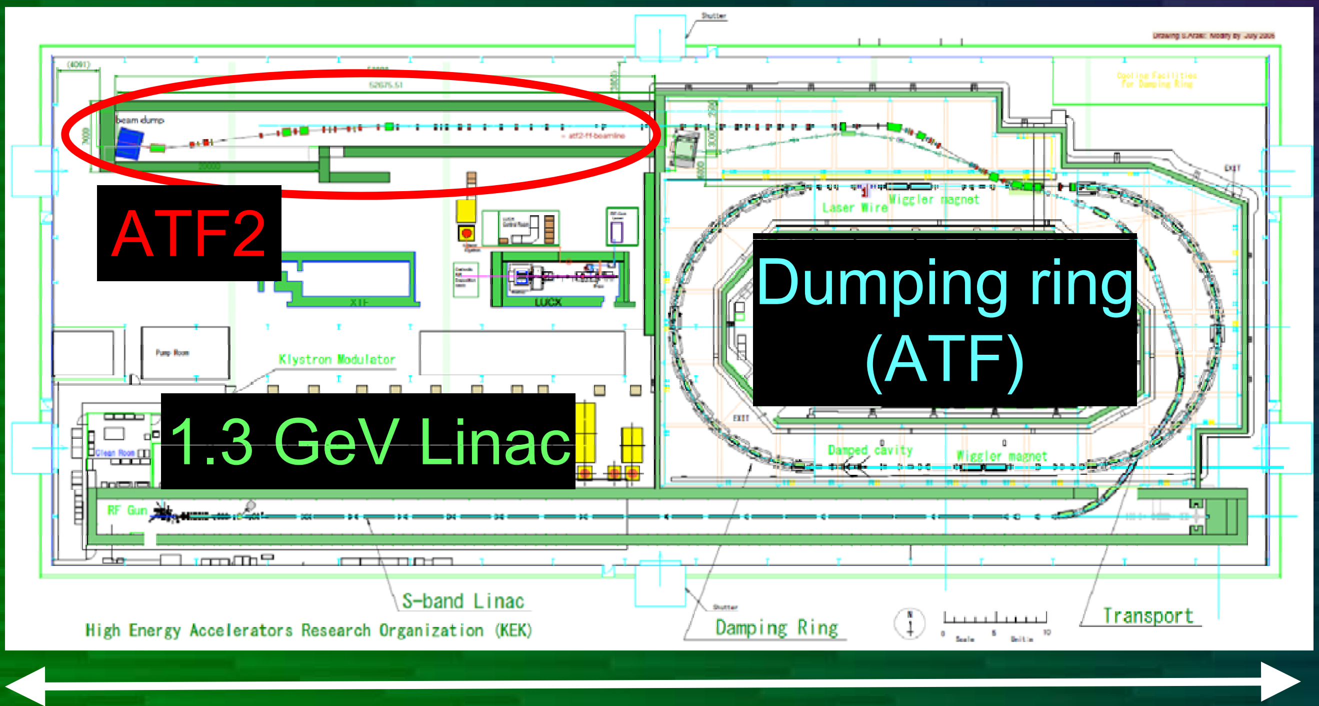
Accelerator Test Facility 2 (ATF2)

- ATF2: a final focus test facility for the ILC (2008/End-)
  - ATF2 goals:
    - 37 nm beam size ←Shintake monitor (IP beam size monitor)
    - 2 nm position stabilization ←IP-BPM (beam position monitor)



ATF2 focuses an ultra low emittance electron beam produced in ATF to achieve 37 nm beam size

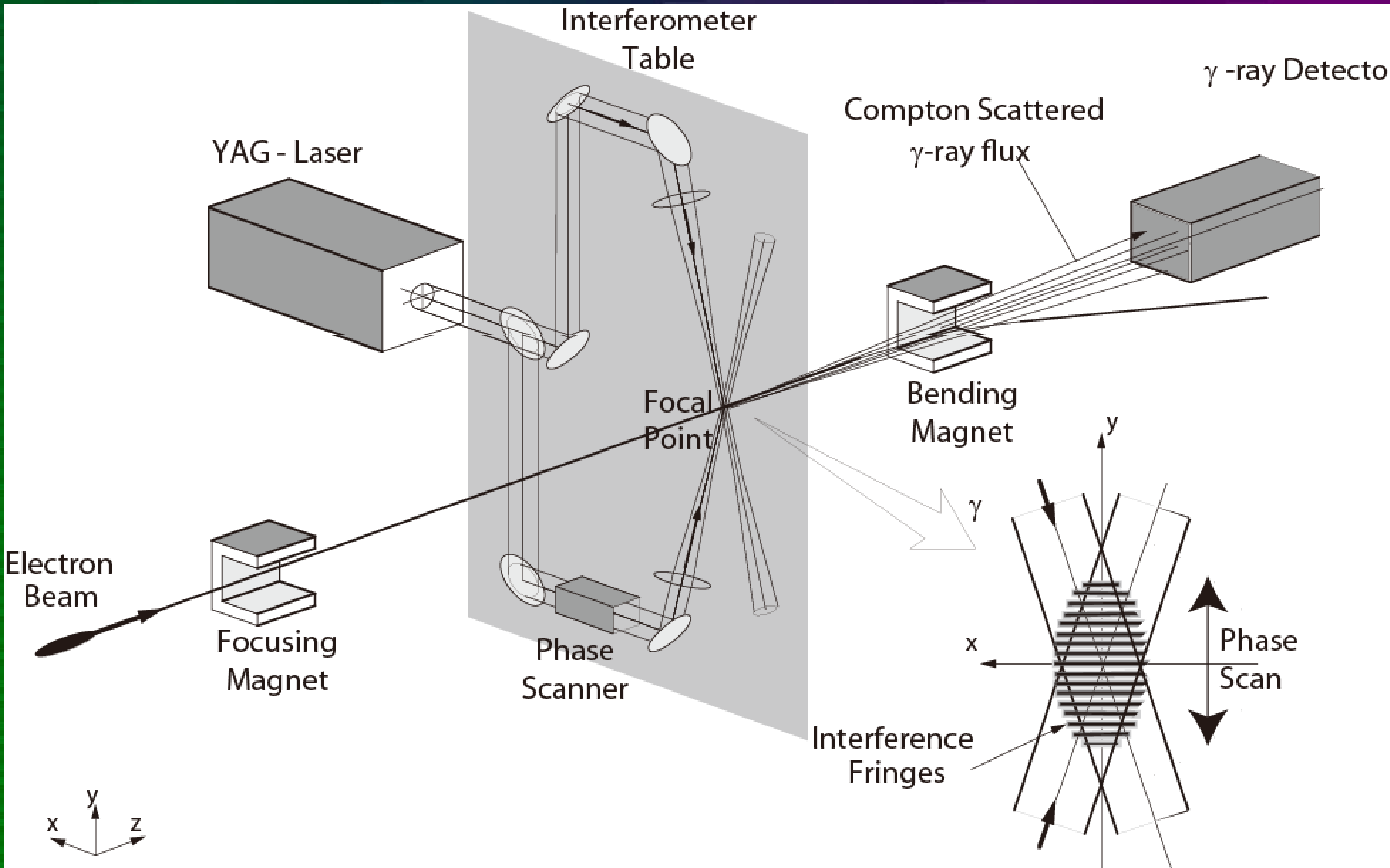
Goals of the Shintake Monitor

Shintake monitor is the most proven beam size monitor for nanometer beams.

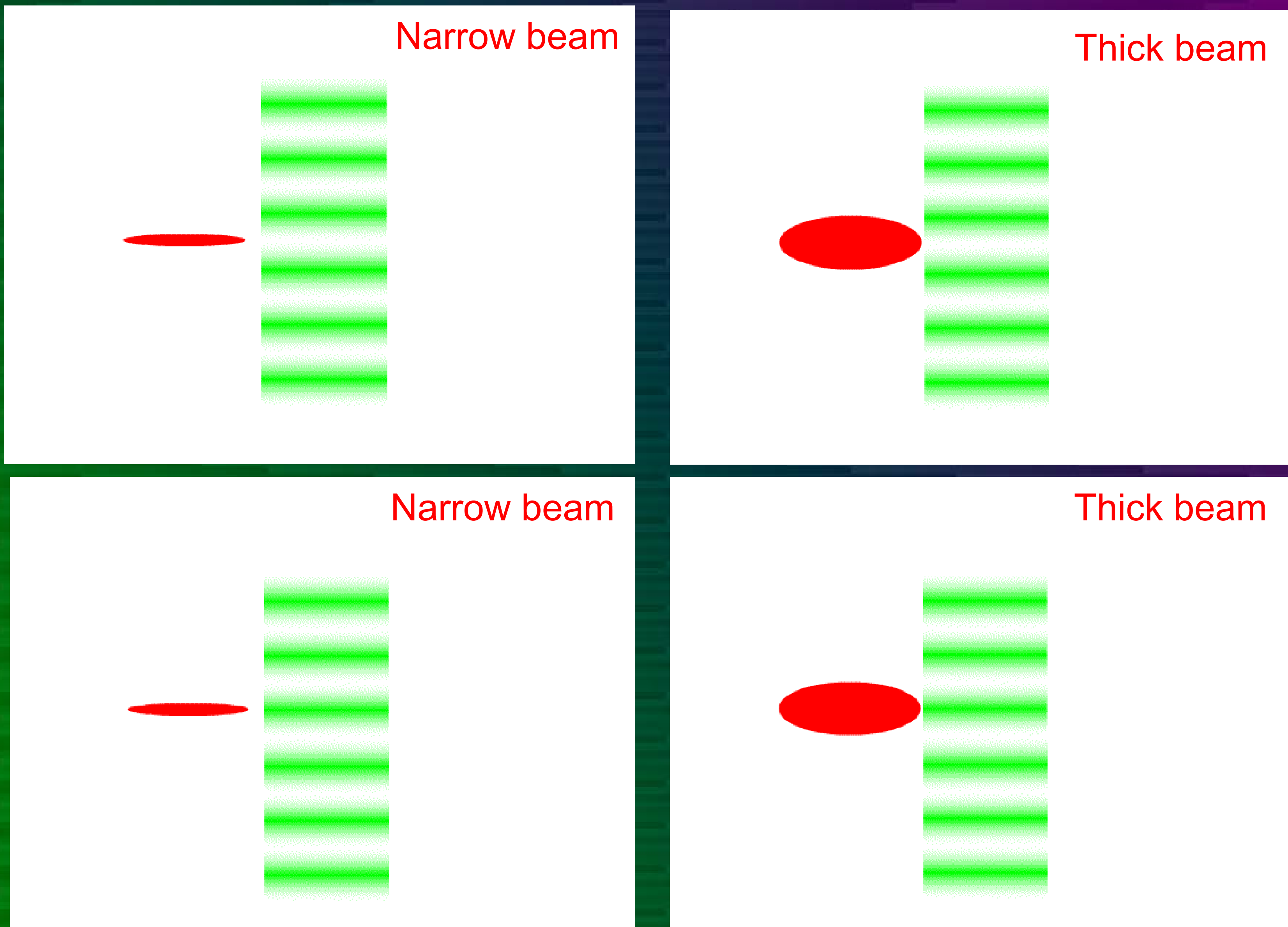
Target performance in ATF2:

- σ_y: 25 nm – 6 μm (Shintake method)
  - < 10% RMS statistical error in 1 minute (90 pulses) meas.
  - < 2 nm systematic error at 37 nm (ATF2 design)
  - Off-axis carbon wire scanner: 1 μm –
- σ_x: 2.8 μm – 100 μm (Laser-wire)
  - < 10% RMS error in 1 minute meas.
  - 3.5 μm (σ) laser spot size at the IP

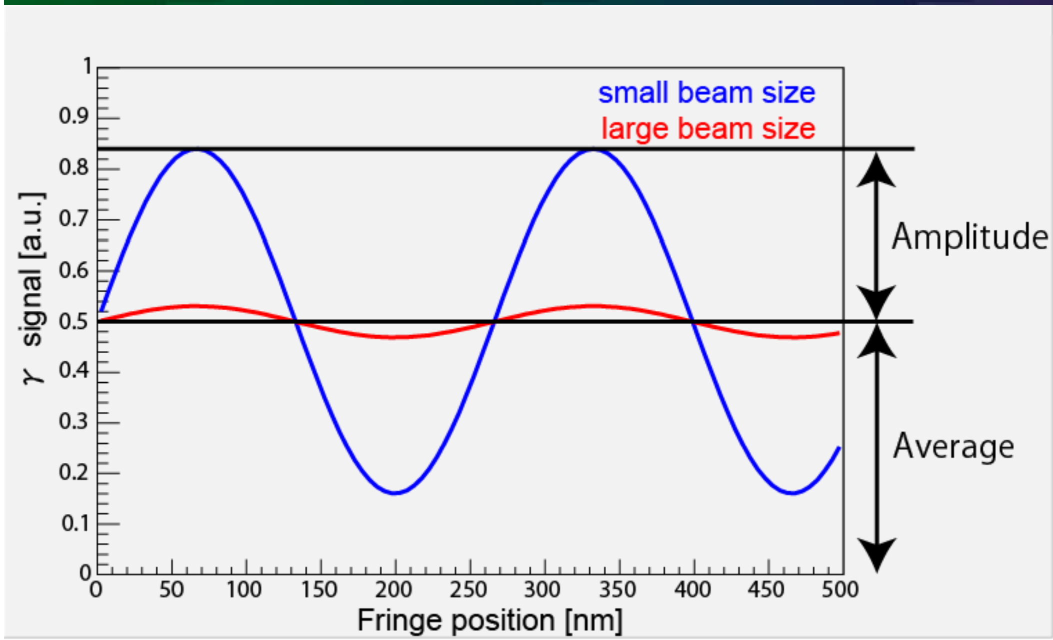
Schematic of Shintake Monitor



Schematic of Shintake Monitor (cont.)

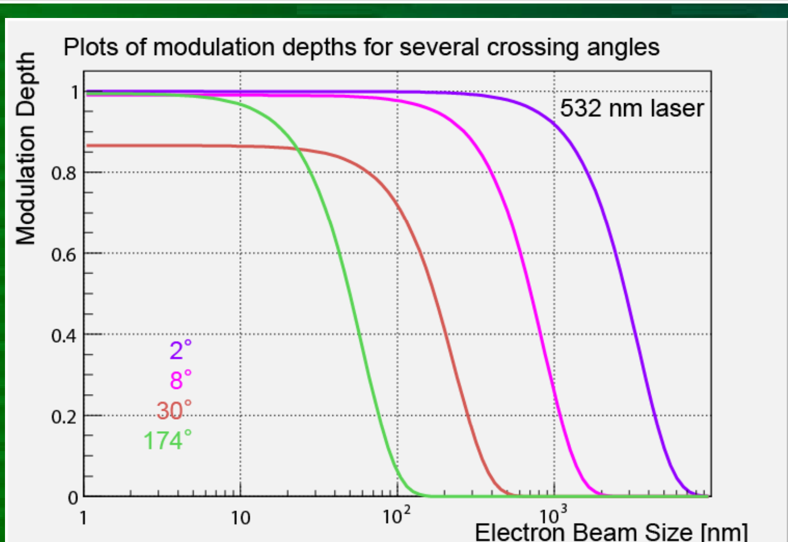


Modulation depth and Crossing angles



$$M = |\cos 2\phi| \exp\left[-2(k_y \sigma_y)^2\right]$$
$$(k_y = k \sin\phi)$$

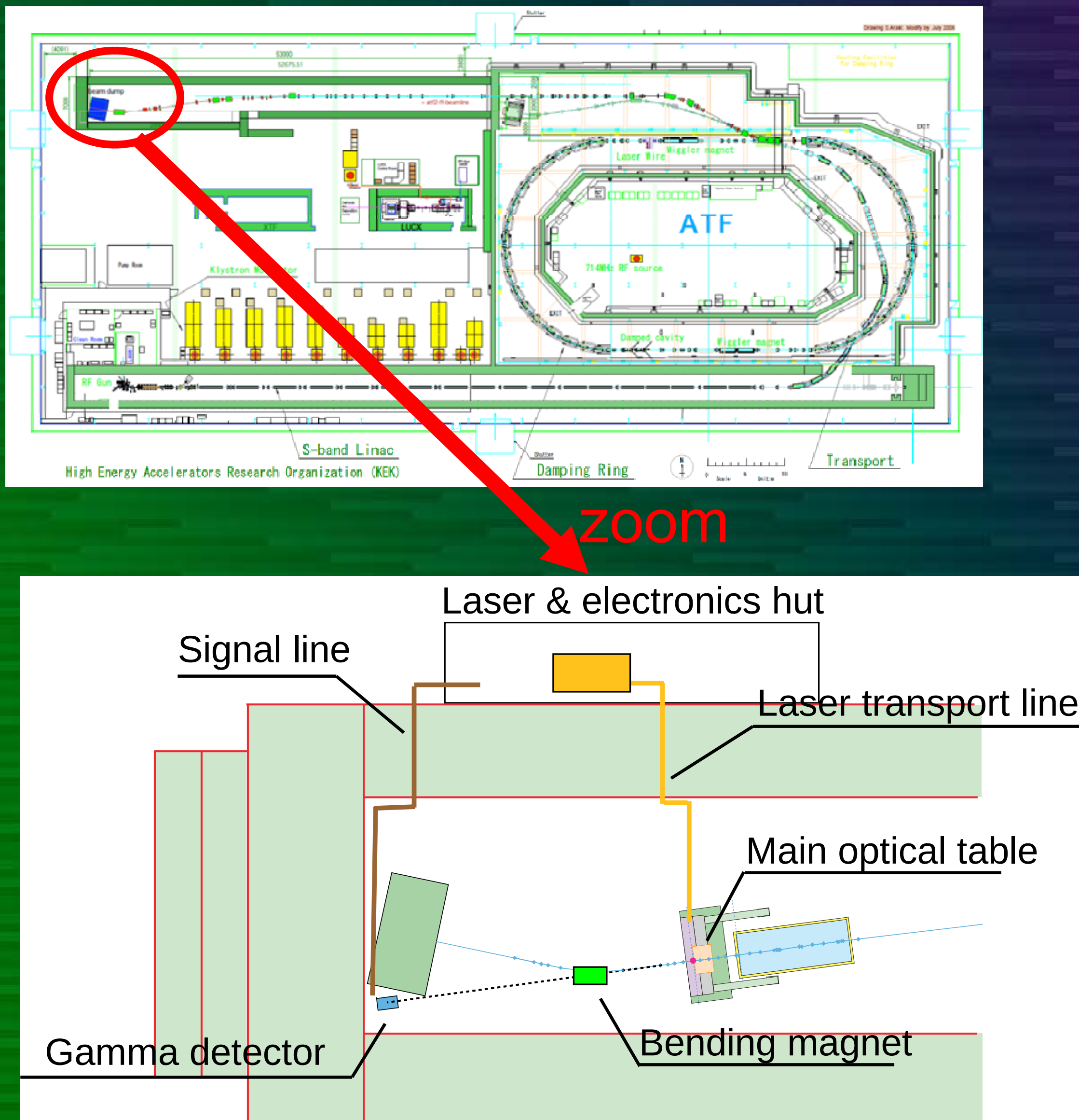
M: modulation depth (amplitude / average)
φ: crossing angle



Crossing angles	Fringe pitch	Observable beam size
174°	266nm	25 - 100nm
30°	1.0μm	100 - 400nm
8°	3.8μm	0.4 - 1.5μm
2°	15.2μm	1.5 - 6.0μm

2, 8, 30, and 174 degrees are chosen to observe 25 to 6000 nm

Layout and Components



Components:

- Laser
  - 532 nm wavelength
  - 40 MW, 8 ns FWHM
  - Single mode (90 MHz line width)
  - 10 Hz max.
- Laser transport line
  - About 15 m
- Optical table
  - 1.6 by 1.7 m
  - Independent support frame
- Gamma detector
  - CsI(Tl) multi layers
  - Gamma collimators
- Electronics

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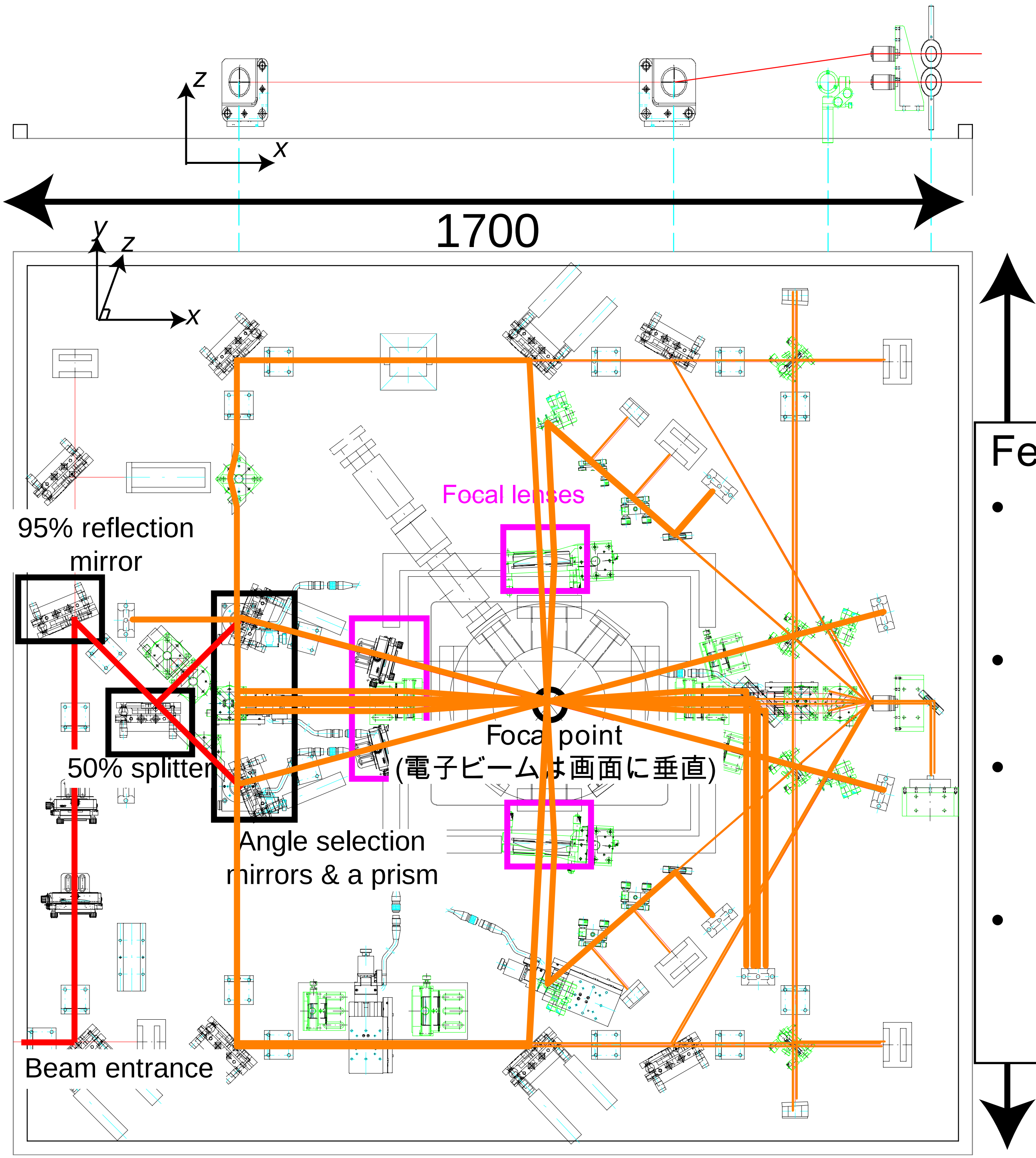
Layout of optical table

174° mode

30° mode

8° mode



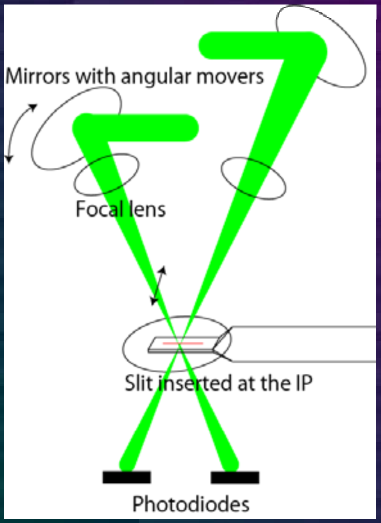
Features:

- Switchable crossing angles
  - Rotation mirrors
- Alignment equipments
  - Slit and Beam scan
- Laser position stabilization / correction
  - 6 PSDs
- Phase stabilization
  - Image sensors with objective lenses

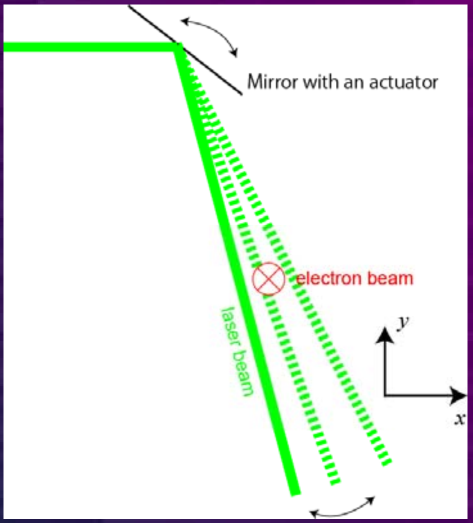
Laser alignment & position stabilization

Alignment:

- Z: for perfect overlap of two laser beams
  - 1.7 μm accuracy achievable
- XY: for minimum power jitter by laser fluctuation
  - 0.6 μm accuracy achievable



Slit scan (Z)



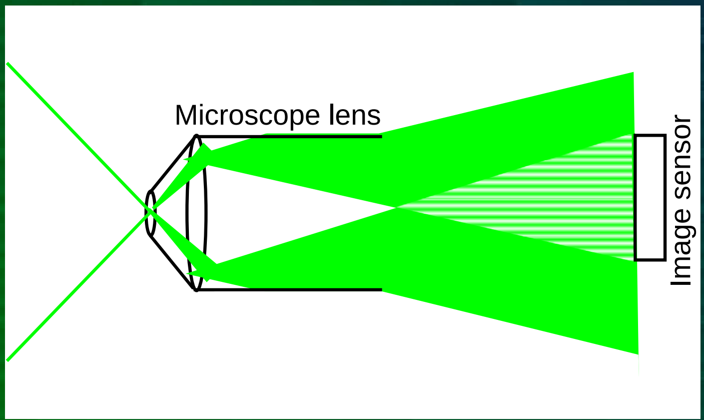
Beam scan (XY)

Laser position jitter/drift:

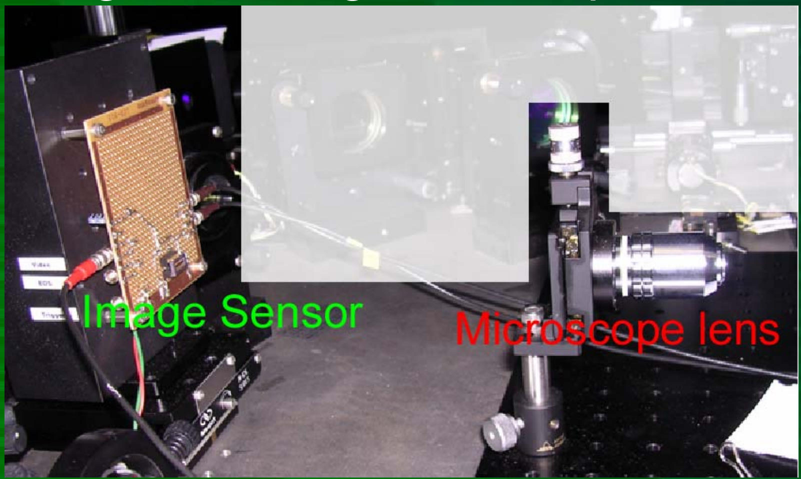
- Stabilization by an active feedback using laser position sensor (PSD)s and mirror movers (for slow drift)
- Correction of a pulse-to-pulse power jitter caused by laser angular jitter
  - Performance is estimated by Monte-Carlo simulation

Phase stabilization

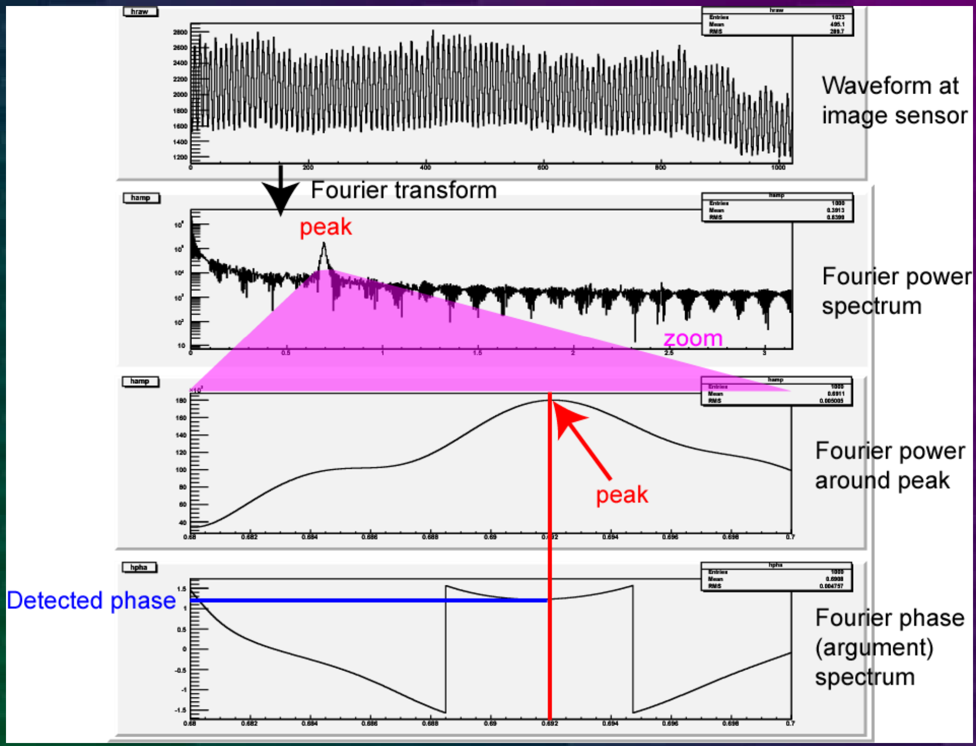
10 nm stability is required → active stabilization



Schematic of the phase monitor: Magnified fringes are captured.

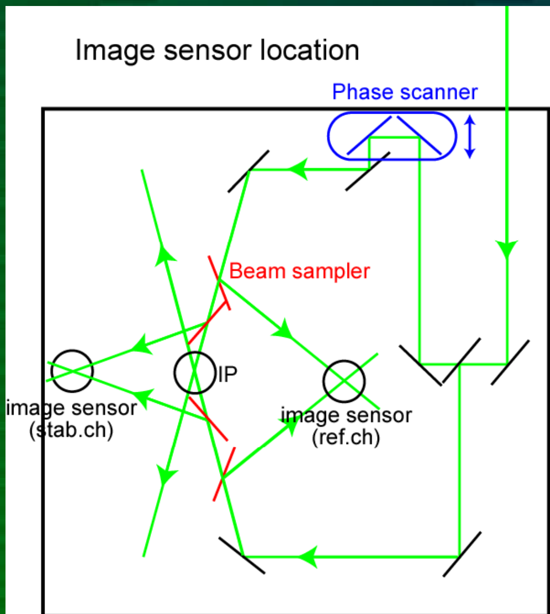


Setup of the phase monitor

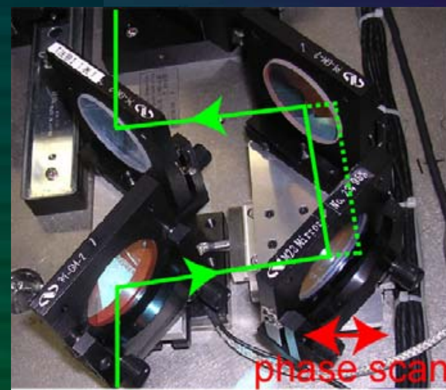


1. Phase acquisition
   Image sensors w/ lenses, Fourier transf.
2. Phase control
   A delay line with a piezo stage (0.2 nm resolution). 10 Hz feedback.

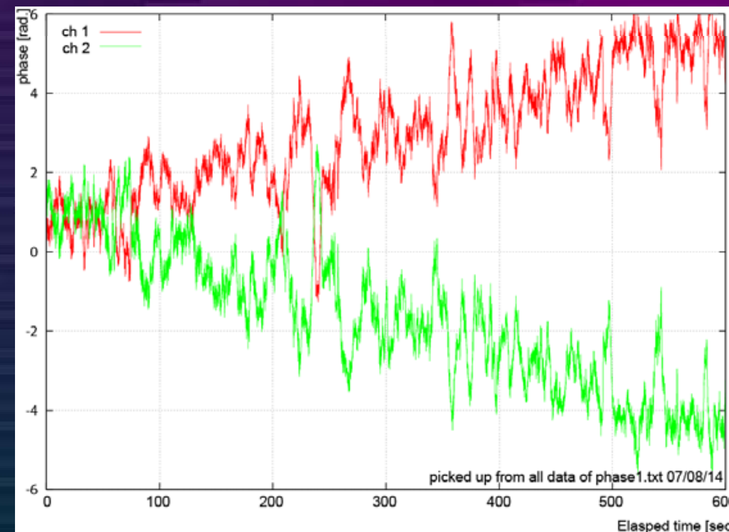
Phase stabilization(2)



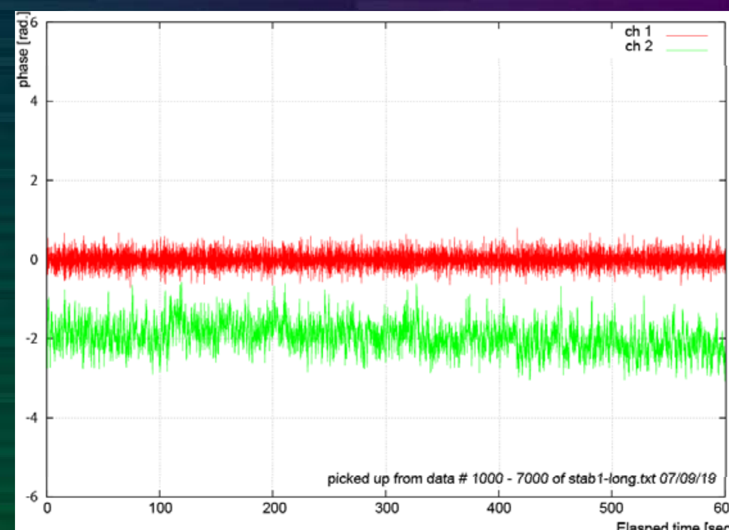
Geometry of the stabilization test



Phase control



Phase without stabilization (10 min.)

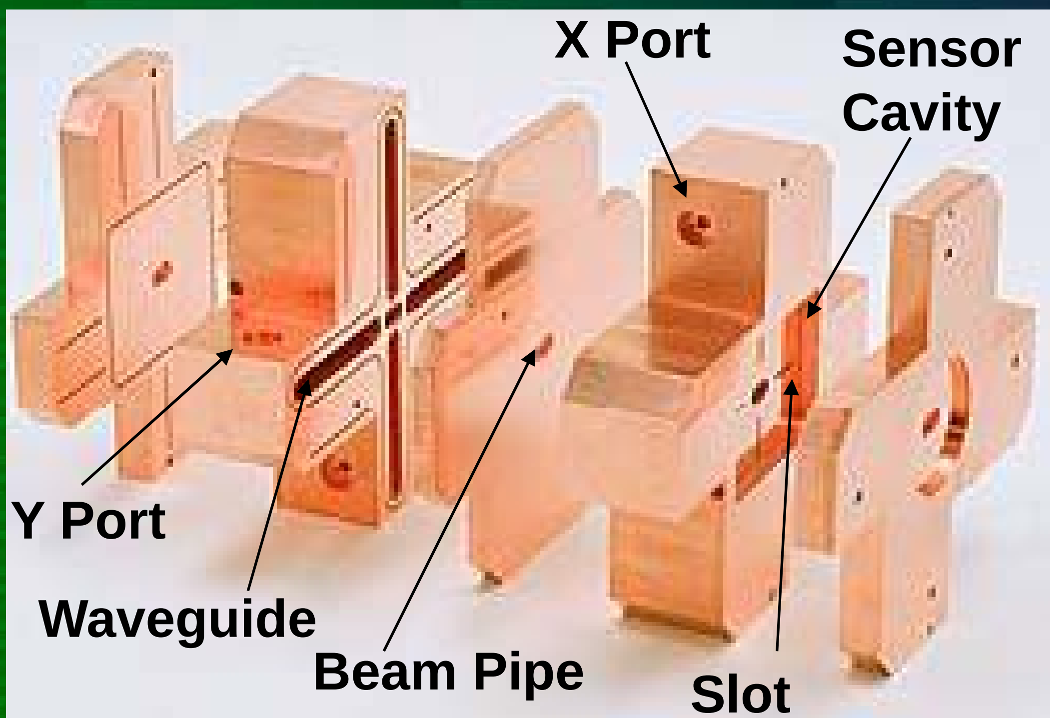


Phase with stabilization (10 min).

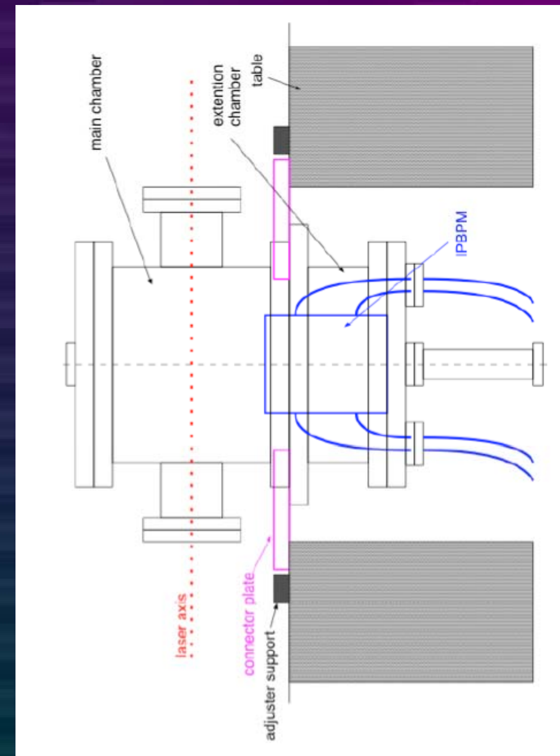
In the test setup,
0.24 rad.(10.1 nm) RMS stability
is achieved in 1 minute window.
(Acceptable stability)

Vacuum chamber with the IP-BPM

Electron beam position jitter
→ phase jitter on modulation plot
↓
IP-BPM (8.7 nm resolution demonstrated) is attached to cancel the jitter

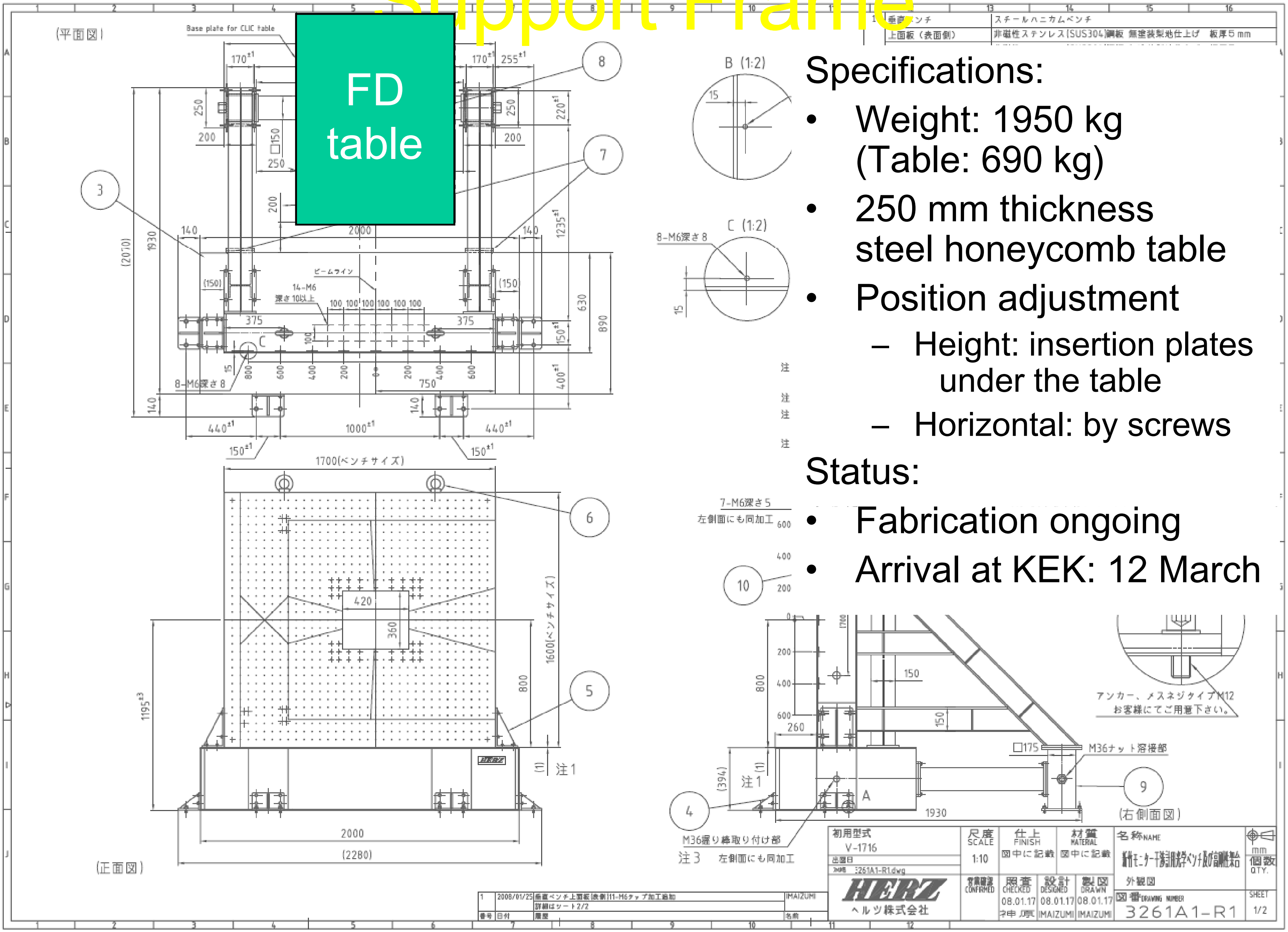


← IP-BPM before assembly



Schematic of the IP-BPM attached to the chamber of the Shintake monitor

Support Frame



Specifications:

- Weight: 1950 kg (Table: 690 kg)
- 250 mm thickness steel honeycomb table
- Position adjustment
  - Height: insertion plates under the table
  - Horizontal: by screws

Status:

- Fabrication ongoing
- Arrival at KEK: 12 March

Status & Summary

- New optical table is designed
  - Basic features have almost been checked
    - Phase monitor / stabilization
    - Laser position monitoring / stabilization / correction
    - IP-BPM
  - Design almost fixed, fabrication ongoing
- Schedule
  - Transportation, installation and initial alignment of the optical system: ~ Jun. 2008
  - Control software and its tests: ~ Aug. 2008
  - ATF2 Beam on: Oct. 2008
  - 37 nm measurement: 2009?

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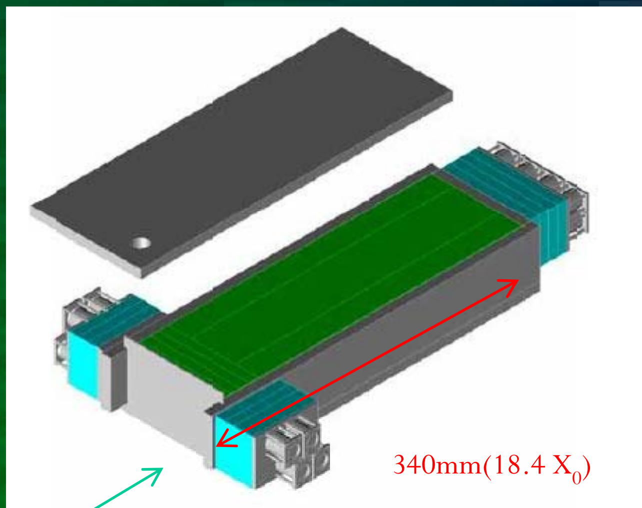
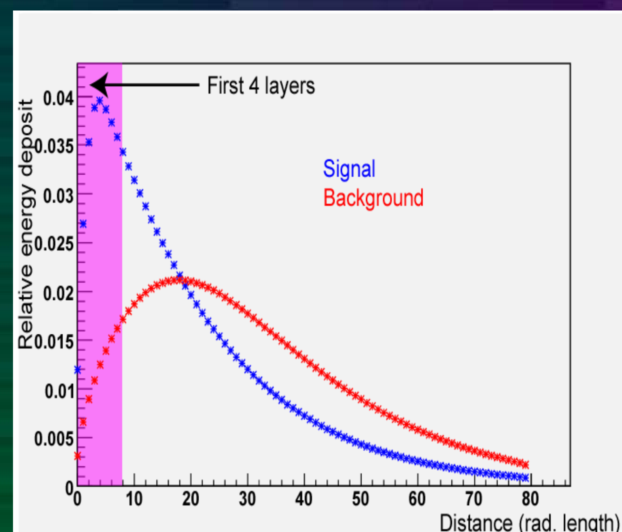
Overview of the detector



CsI(Tl) scintillator
4 front layers (5 mm thick each)
+ 1 bulk layer (290 mm thick)

Brems. background from the beam line should be subtracted.

- On-Off method
  Subtract laser-off data as background
- Shot-by-Shot method
  Using layer information to separate background

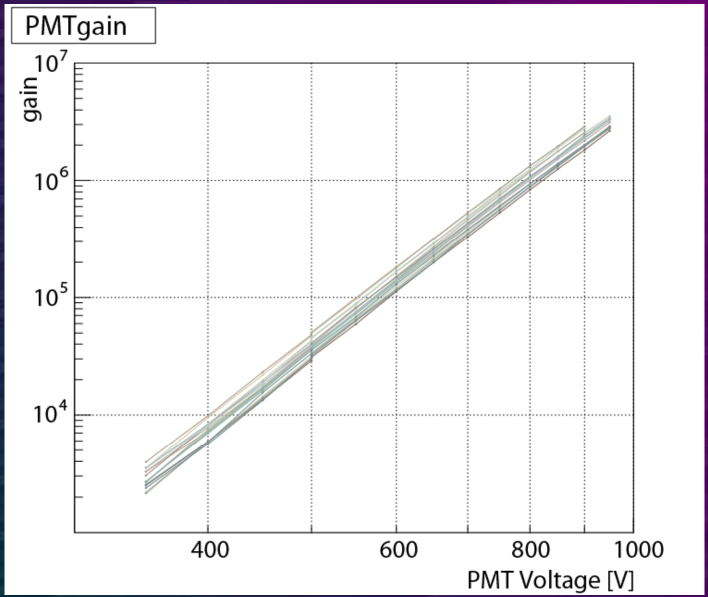


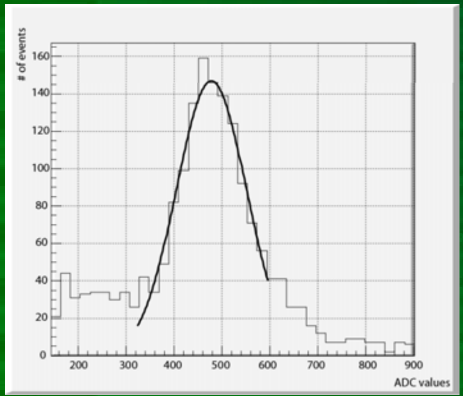
Simulated shower development of signal and background

Calibration

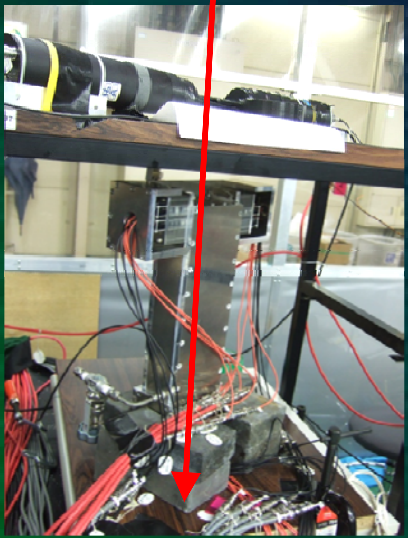
- Calibration using laser photons
  Voltage-gain relation
  - High gain (~900V) for cosmic-ray test
  - Low gain (~300V) for operation
- Calibration by cosmic rays
  - Front 4 layers
  - Bulk layers

  Systematic error remains between front and bulk layers

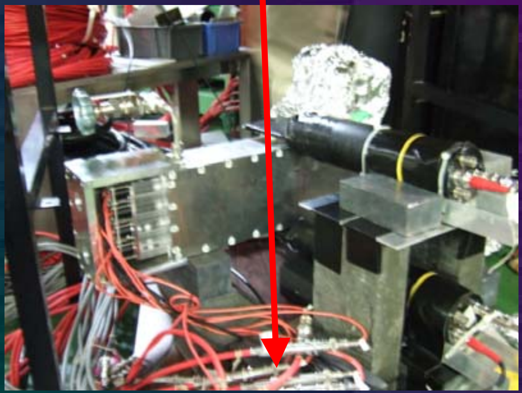




Cosmi. sample



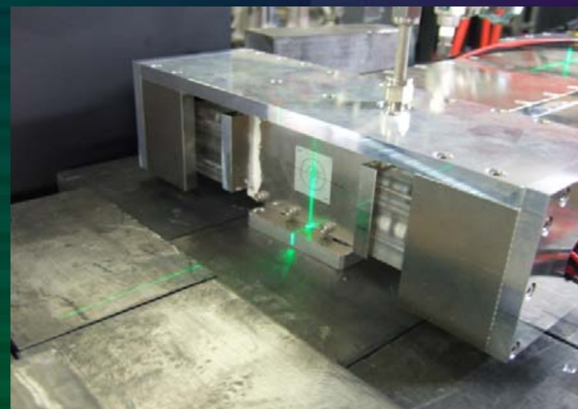
Front layers



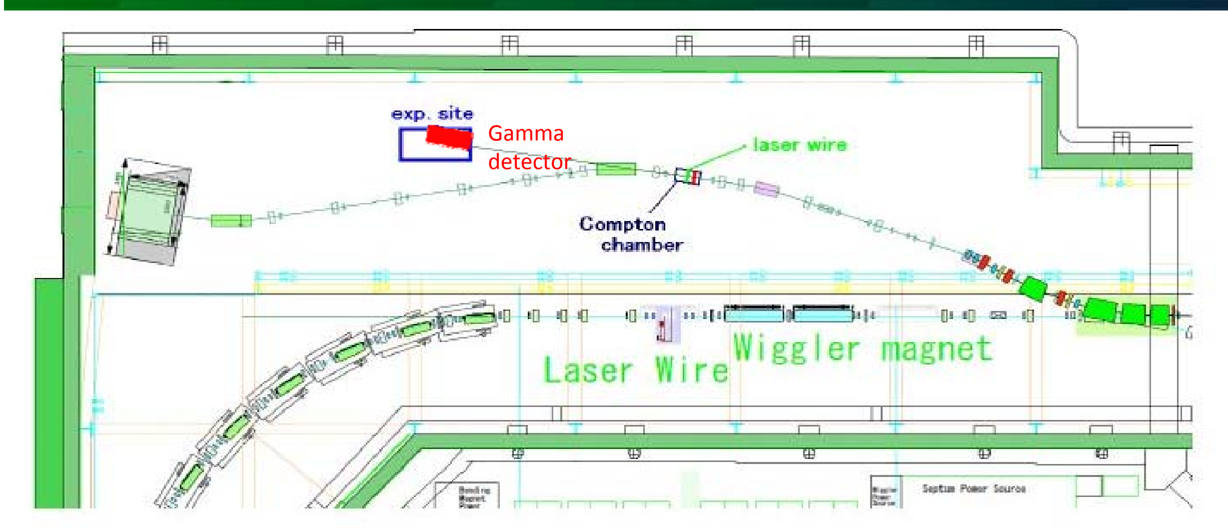
Bulk layers

Setup of beam test

Detector at exp. site



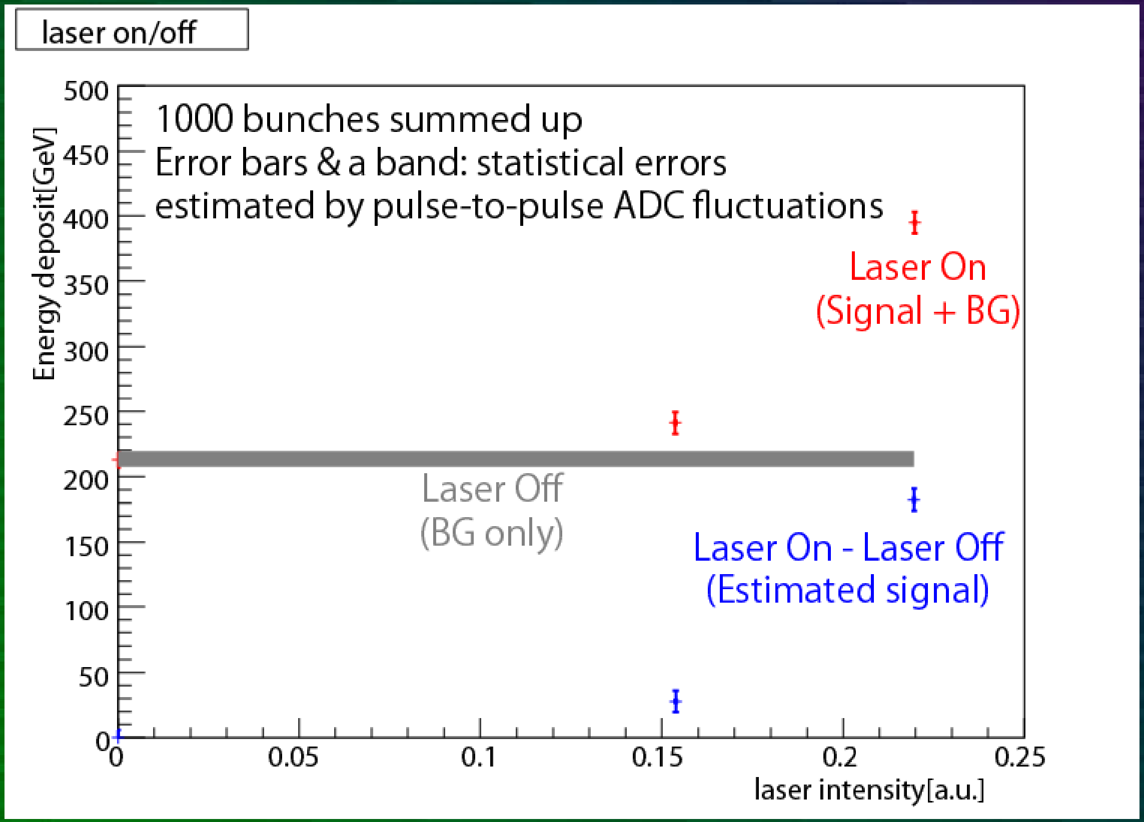
Position alignment using laser



Layout of Beam test setup

- ATF extraction line 2007 Oct. – Dec.
- Wire scanner photons
  - similar energy spectrum to background
  - System check
  - Not used in following analyses
- Laser-wire photons
  - Almost the same energy spectrum to signal photons
  - Statistics is very limited (only 30 minutes acquisition time, O(10000) photons)
- Two subtraction methods are compared using laser-wire data.

On-Off method



Procedures:

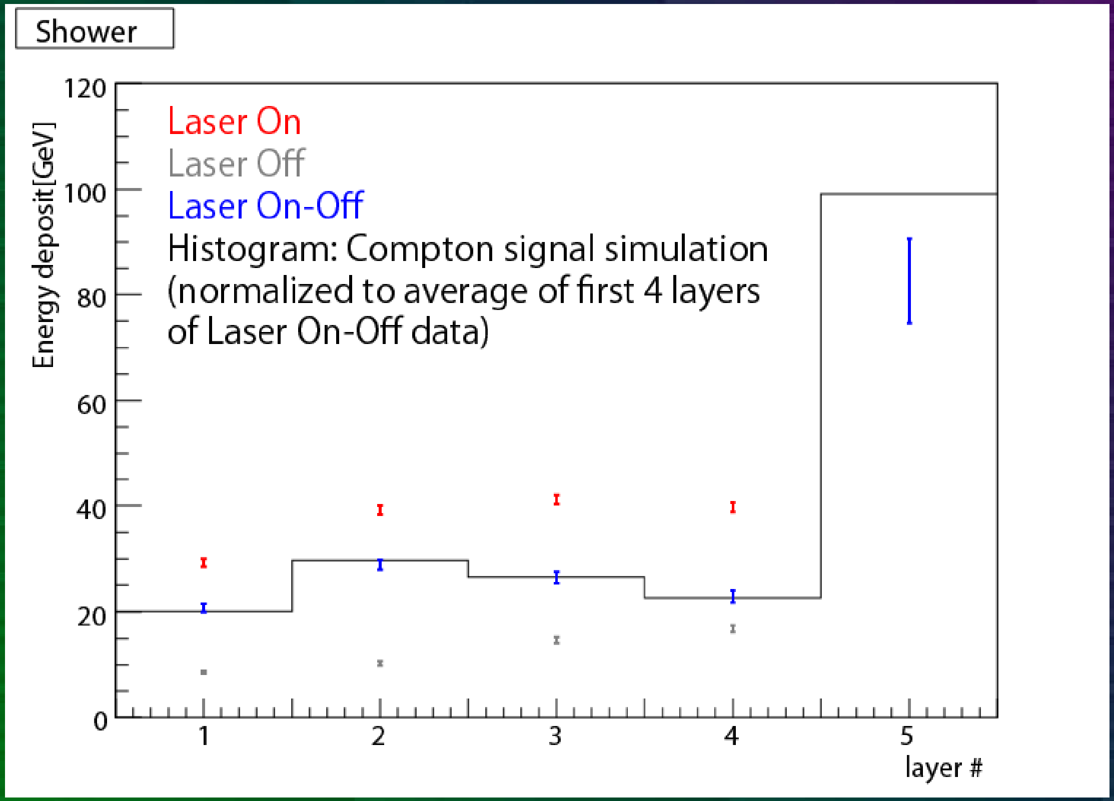
- Acquire 1000 bunches of "laser-off" data.
- Acquire 1000 bunches of "laser-on" data.
- Acquire 1000 bunches of "laser-on" data with lower laser intensity.
- Subtract "laser-off" data from each "laser-on" data set.
  Signals from all layers are summed before subtraction.

Result:

- Apparent excess of "laser-on" data is observed.
- Laser intensity and signal strength are correlated (though not proportional due to unspecified effects).

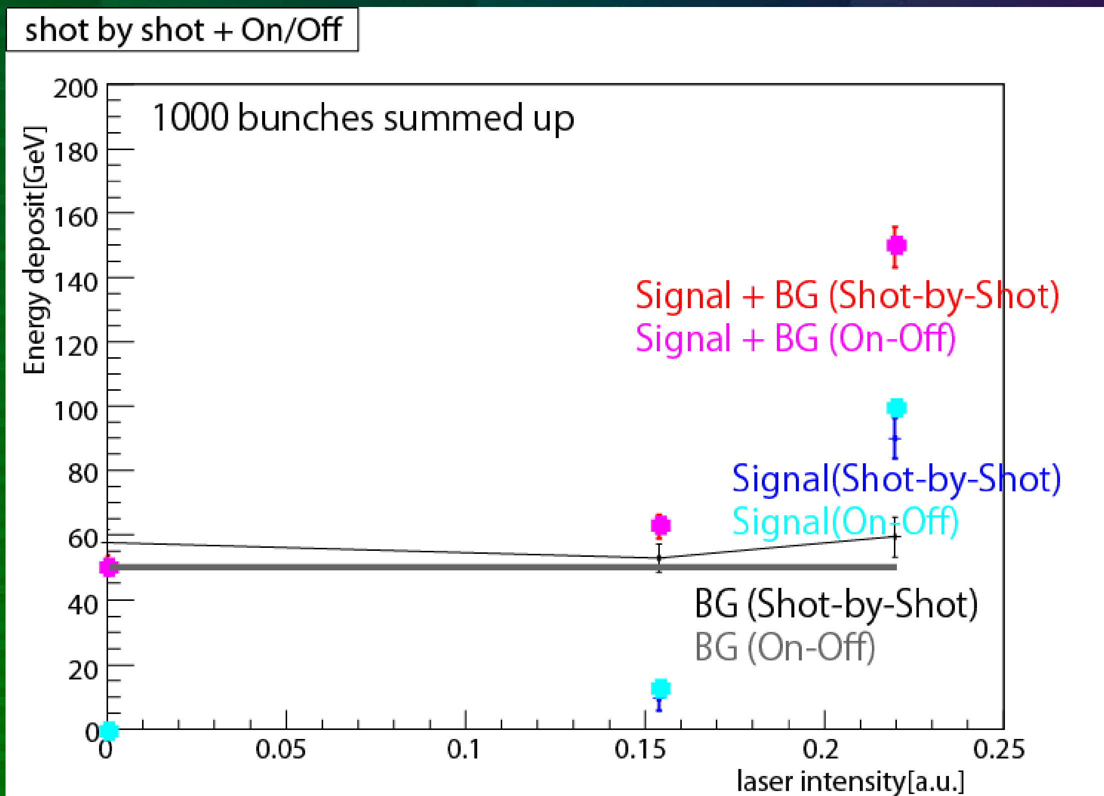
Shower development

For the Shot-by-Shot method, fraction of energy deposit at each layer is compared to Geant4 simulation data.



- Gain of the bulk layer is not matched to the front layers because of the systematic error of the cosmic ray calibration.
- Only front 4 layers are used for the current analysis.

Shot-by-Shot method (4 layers)



Procedures:

1. Acquire 1000 bunches of "laser-on" data.
2. Estimate "signal" and "background" using layer information.

- Pure "signal" and pure "background" energy deposit at each layer is derived from the beam test data.
- The amount of "laser-off" signal is not used. Background amount is

Consistent!

Result:

- Similar spectrum to the On-Off method is obtained.
- Effectiveness of this method is validated.
- Statistical error is bigger in this method (as expected).

Discussion

- Basic ideas of the two methods are validated by the beam test.
- Exact calibration of the bulk layer is very important for both methods
  - Fluctuation of the total energy deposit is much smaller than that of the shower development
  - → more exact calibration method is being investigated.
- Background spectrum varies by experimental conditions
  - Spectrum differs from simulation – effects of secondary particles
  - → spectrum should be checked frequently and we use the obtained spectrum for the Shot-by-Shot method.
- Statistics of the laser-wire data are very short
  - We obtain only Compton photons of O(10) bunches in real operation.

→ Additional beam tests are highly desired after proper calibration is performed.

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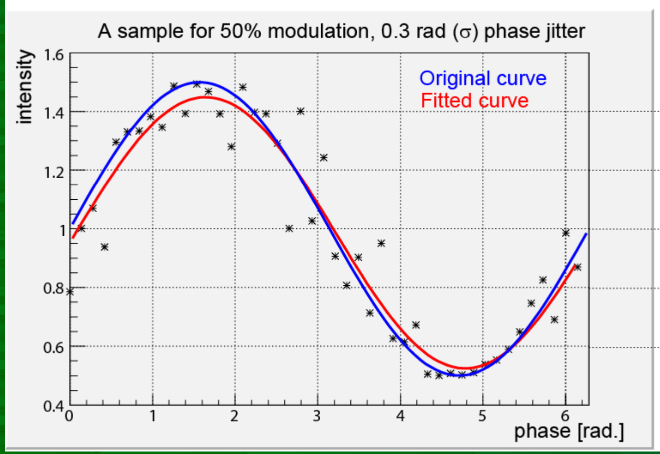
Error factors of the Shintake monitor

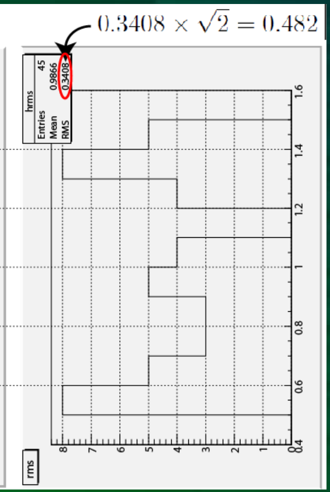
- Statistical fluctuation
  - Power jitter: 4.4% (after correction/stabilization)
    - Electron beam charge, corrected by a current monitor: 1%
    - Laser intensity, corrected by power monitors: 3.8%
    - Laser direction fluctuation, corrected by position monitors: 1.4%
    - etc.
  - Phase jitter: 13.3 nm (after correction/stabilization)
    - Phase stabilization fluctuation: 10.1 nm
    - IP-BPM: 8.7 nm
  - Background fluctuation: 8.3%
    - Statistical fluctuation of estimated number of background photons
- Systematic errors
  - Fringe contrast: measured by < 5% accuracy
  - etc. (<< 5%)

Modulation Acquisition

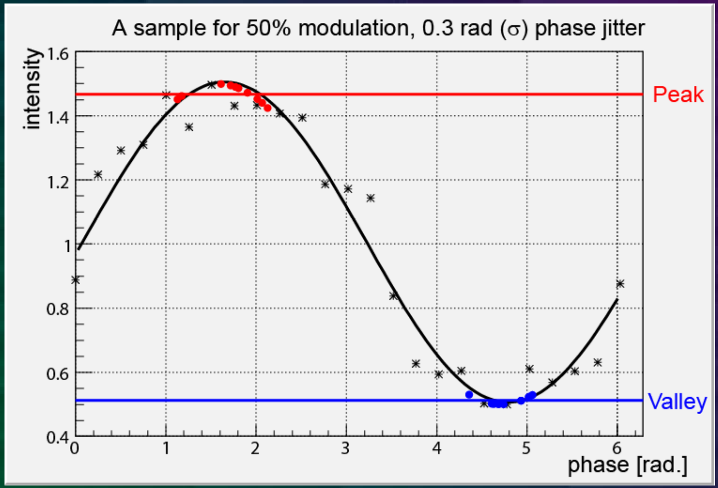
- Fitting Method
  - Phase scan of 45 points (equal interval), fitted by a sine function
- RMS Method
  - Phase scan of 45 points (equal interval), using RMS of the spectrum
- Peak Search Method
  - Phase scan of 25 points to obtain peak/valley positions
  - Average 10 pulses for both peak and valley positions



Fitting Method



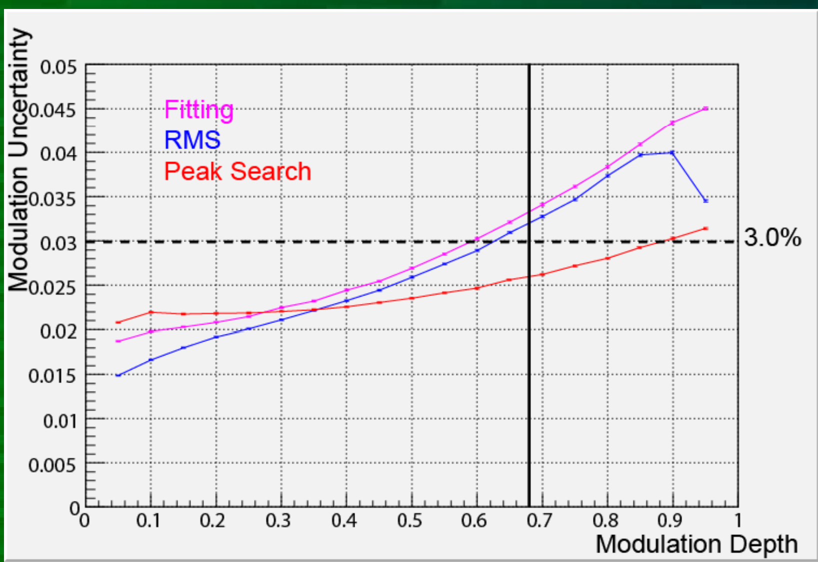
RMS Method



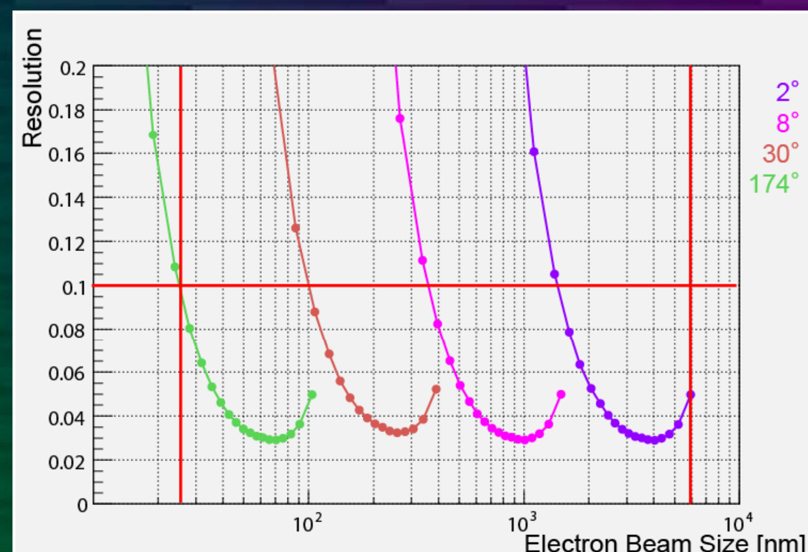
Peak Search Method

Beam size resolution

- RMS method is the best in M < 40%, and peak search method is the best in M ≧ 40%
- < 10% statistical fluctuation can be achieved within 25 – 6000 nm measurement range
- Systematic error (~5%) is not included



Statistical fluctuation of the modulation depth



Resolution of the beam size using peak search & RMS methods

Taikan Suehara, TILC08(GDE+ACFA)@Sendai, 2008/03/05

Shintake Monitor for the ILC

- Modulation depth @ 5.7 nm ILC beam
  - 89.6% with 157 nm F2 laser
  - 92.9% with 193 nm Excimer laser
  - 93.9% with 213 nm YAG 5th laser

  In current error factors (ATF2), 17% resolution at M=90%
- Multi bunch operation
  - Quick accumulation of statistics
    - Improvement of resolution by a factor of 10 at 3940 bunches
  - 1 train measurement – slow drift suppressed
  - Need high-repetition laser
  - Fast phase scan by a Pockels cell
- Systematic error is similar, 5% can be achieved

Shintake monitor for the ILC (2)

- Installation at the Interaction Point in the beam commissioning stage
  - Assure 5.7 nm beam focusing
  - Fast tuning without interaction
  - Must be removed when installing the detectors
    - By push-pull structure??
- Installation to the second IP for a diagnostic monitor
  - > 25 nm beam size measurements are much more realistic using current scheme.

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Summary

- Shintake monitor in ATF2 can measure σ_y from 25 nm to 6 μm within 10% resolution, 5% systematic error in 1 minute period.
- Optical table fabrication is ongoing.
- The beam test demonstrates basic signal/background separation using two methods.
- 5.7 nm measurement is realistic if we use a high-repetition deep-UV laser.

Thank you.