KEK ATF Beam Instrumentation Program

- *Introduction*
- *Beam size monitors*
- *Beam position monitors*
- *Beam feedback*

N. Terunuma, KEK

On the behalf of the ATF International Collaboration

PAC11, NYC, 2011/Mar/30

Challenging goals for ATF/ATF2

An important technical challenge of ILC is the collision of extremely small beams of ***a few nanometers in vertical size.***

ATF/ATF2 will address the development of the techniques for following issues:

- ***achieve the small vertical emittance***
  i.e., ATF-DR 4 pm → 2 pm or less
- ***achieve the design vertical beam size at the IP; 37 nm***
- ***stabilize the the beam position in a few nanometer level at the IP.***

The ATF international collaboration is strongly promoting these activities.

ATF International Collaboration

CERN
DESY
IN2P3
- LAL
- LAPP
- LLR

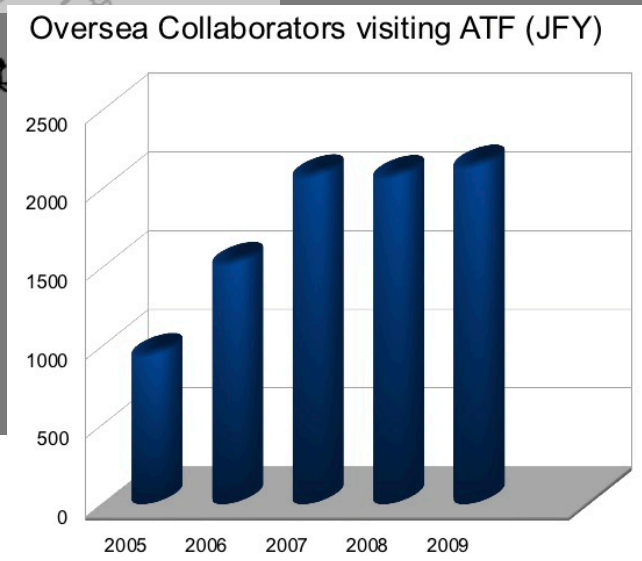
John Adams Inst.
- Oxford Univ.
- Royal Holloway Univ.

Cockcroft Inst.
- STFC, Daresbury
- Univ. of Manchester
- Univ. of Liverpool

University College London
INFN, Frascati
IFIC-CSIC/UV
Tomsk Polytechnic Univ.

KEK
Waseda U.
Nagoya U.
Tokyo U.
Kyoto U.
Tohoku Univ.
Hiroshima U.
IHEP
PAL
KNU
RRCAT

SLAC
LBNL
FNAL
Cornell Univ.
LLNL
BNL
Notre Dome Univ.

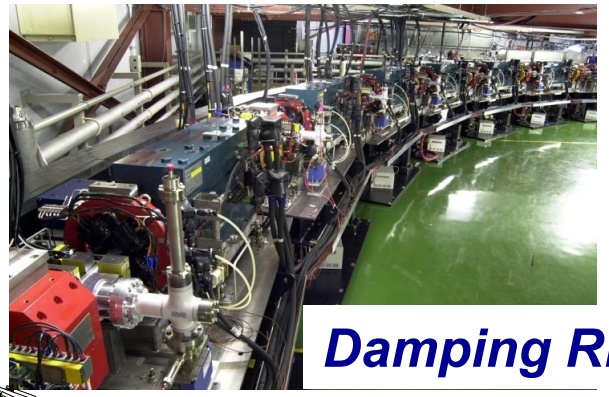


Oversea
25 Institutes,
~70 people,
~2000 people-days
+
KEK and Japanese Universities(6)

KEK Accelerator Test Facility (1.3 GeV)

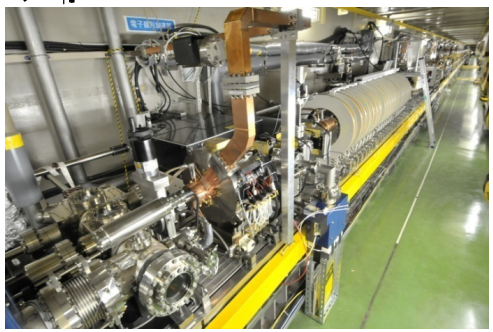
ATF2 beam line (Jan.2009~)

Previous EXT line (~Jun.2008)



Damping Ring

Photo-cathode RF gun (electron source)



S-band Linac

Δf ECS for multi-bunch beam

Instrumentation for ATF2

Beam Size Monitors

1. SR Interferometer
2. X-ray SR monitor
3. CW laser wire
4. Solid (W,C) wire Scanners (meas. for 2um or more)
5. Laser interference fringe monitor (meas. for 20nm~5um)
6. Pulsed Laser wire scanner
7. Optical Transition Radiation monitor

Beam Position Monitors

1. Strip-line BPMs
2. Upgrade of DR BPM readout
3. Cavity BPMs (circular, C-,S-band, resolution 100nm)
4. IP BPM (rectangular, C-band, target resolution 2nm)

Beam Feedback

1. Intra-train fast feedback (FONT)
2. Fast Kicker

Typical beam structure for ATF2

(1) Single bunch operation

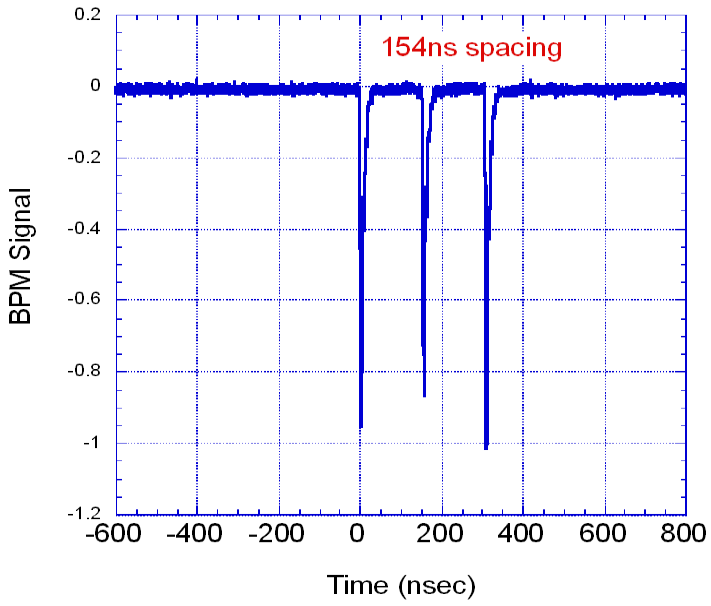
~1x10^{10} e/bunch, 1.56 Hz; (max. 2x10^{10}, 3Hz)

(2) Multi-bunch operation

(Single bunch) x N

(2-1) by a conventional kicker

1~3 bunches, 154 ns spacing



(2-2) by a fast kicker

1~30 bunches, 308 ns spacing

30 bunches extracted from DR (308 ns spacing)

Beam Size Monitors

Laser Interference Fringe Monitor
Multi-OTR monitor
Pulsed Laser Wire

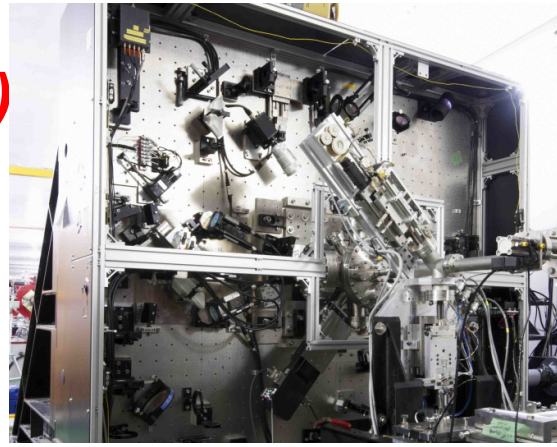
Nanometer Beam Size Monitor

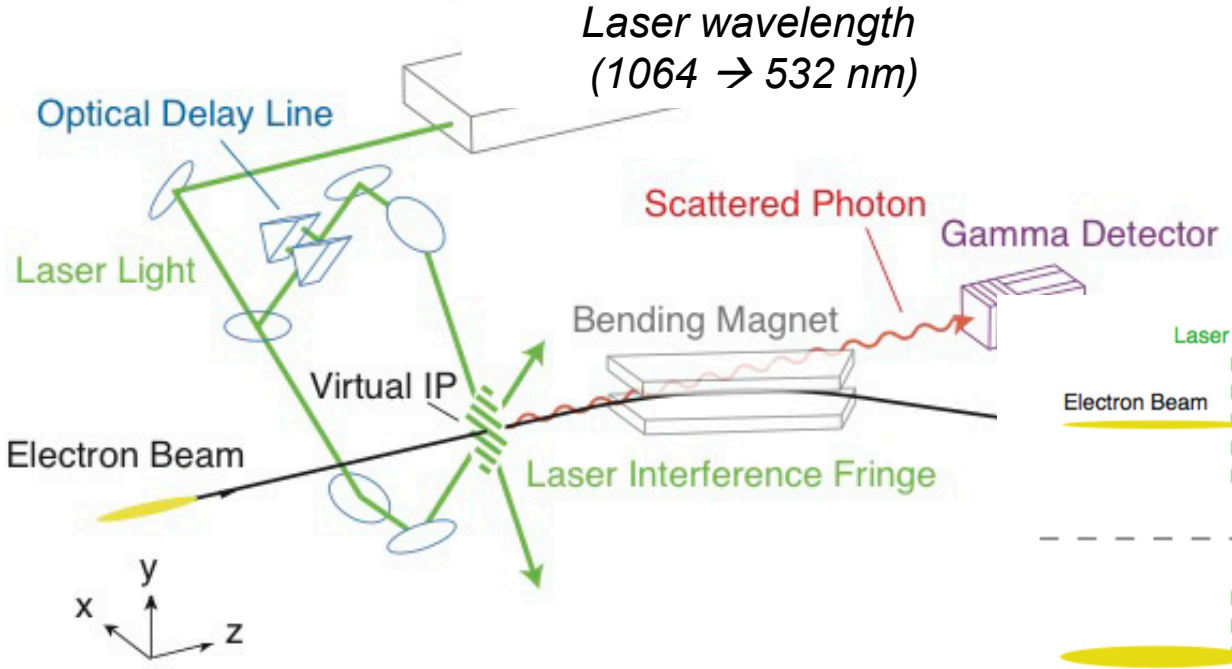
Univ. Tokyo / KEK

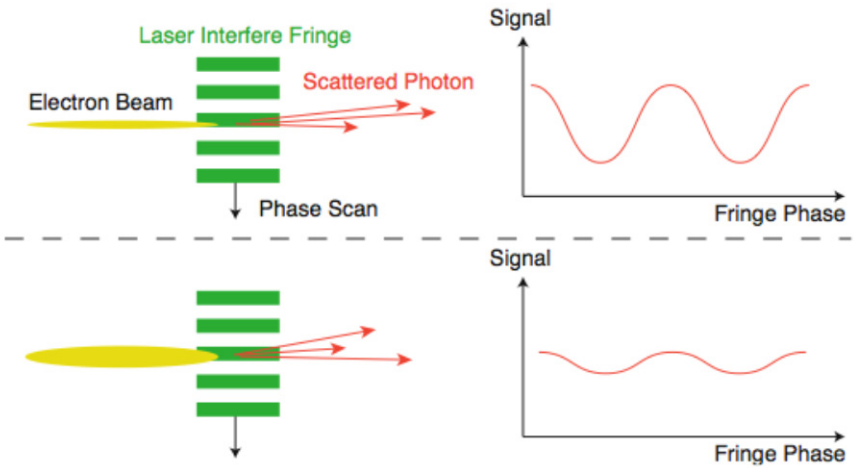
Beam Size Measurements at ATF2-IP

- Solid (W,C) wire Scanners (meas. for 2um or more)
- Laser interference fringe monitor (meas. for 20nm~6um)

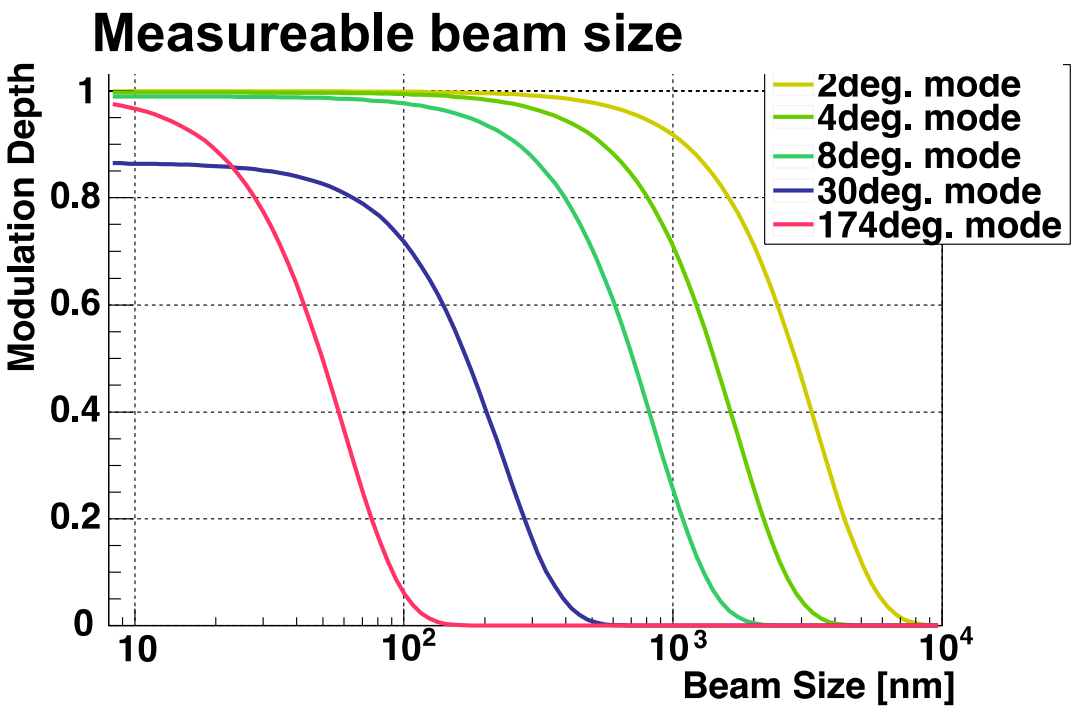
FFTB ~70nm(measured) -> ATF2 37nm(goal)



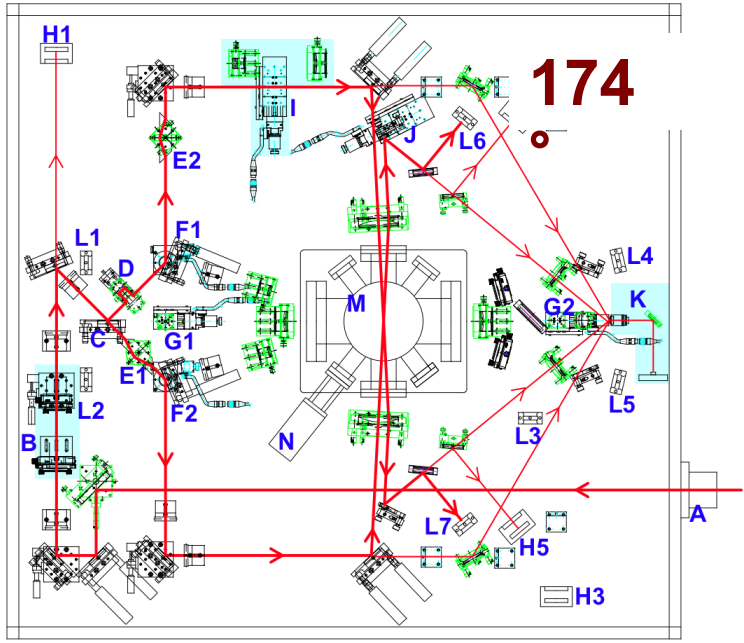


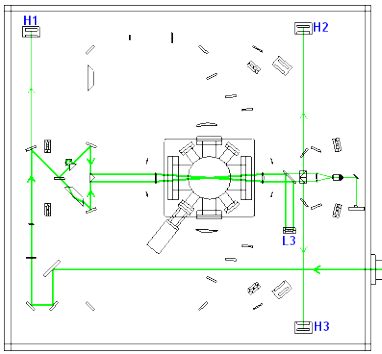


Laser Interference Fringe Monitor for ATF2

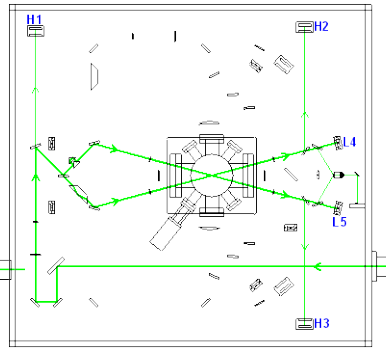


	174°	30°	8° ⟷	2°
Fringe pitch	266 nm	1.03μm	3.81μm	15.2μm
Minimum	**25 nm**	100 nm	360 nm	-
Maximum	**100 nm**	360 nm	-	6 μm



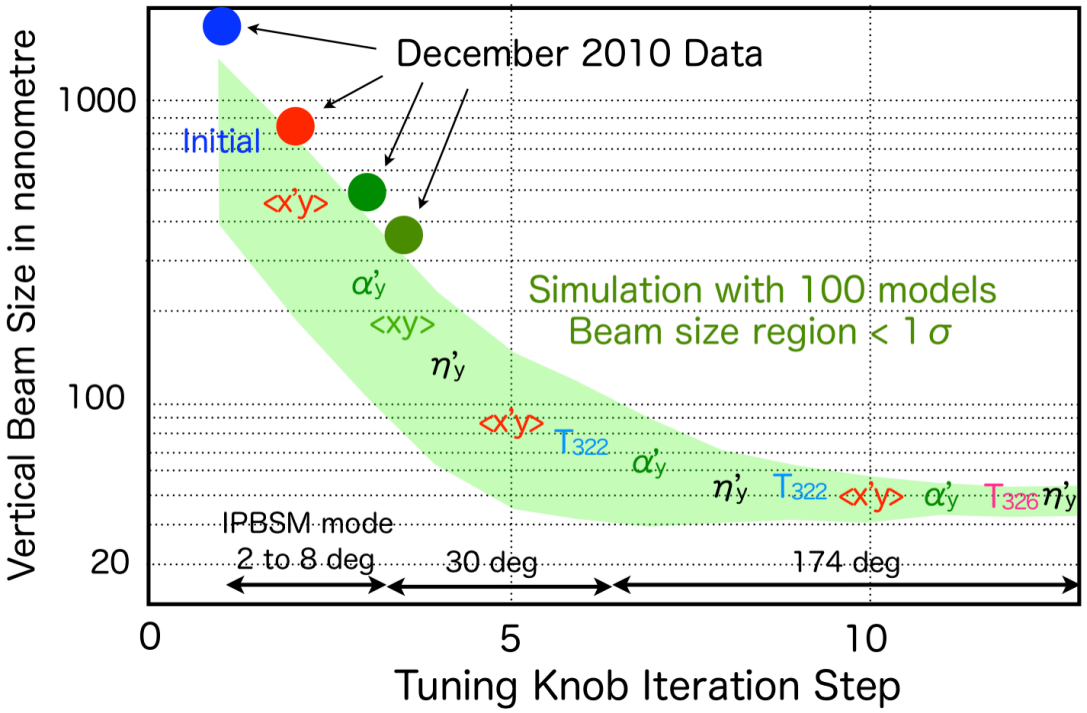


2~8°



30°

Measurement of the vertical beam size at ATF2



We are going to 30 deg mode for the measurement smaller than 300 nm.

Chromaticity Cor.

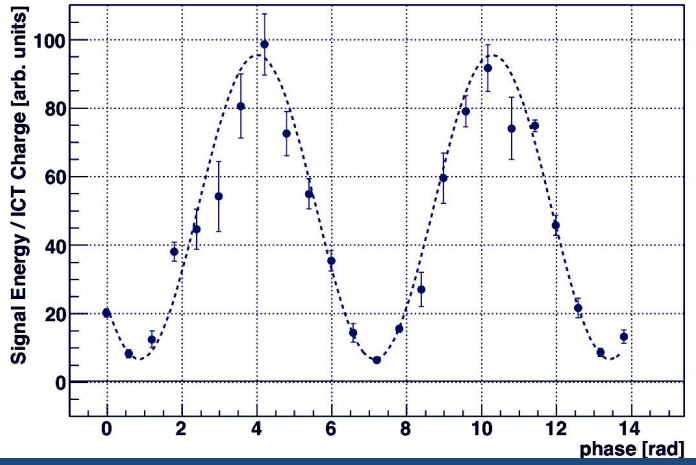
→ 37nm

Example:

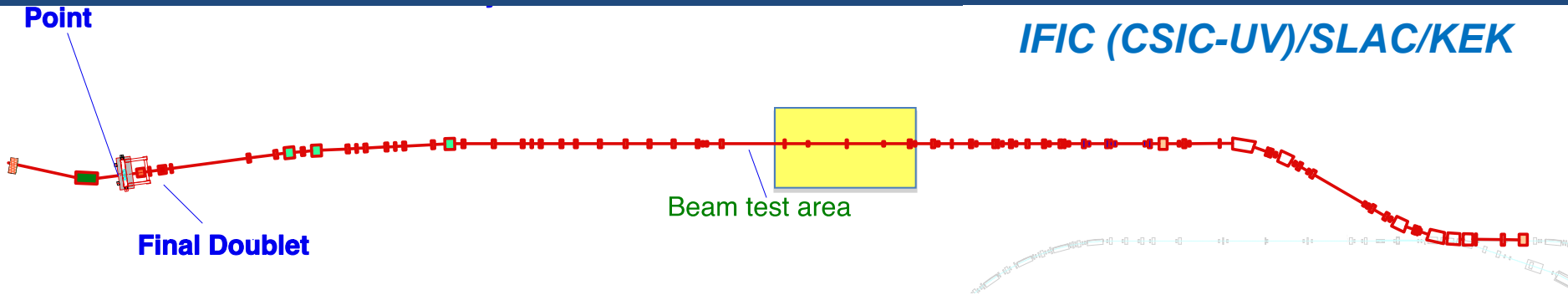
A beam size measured (2010/May/20)

Modulation Depth = 0.87 @ 8.0 deg. mode

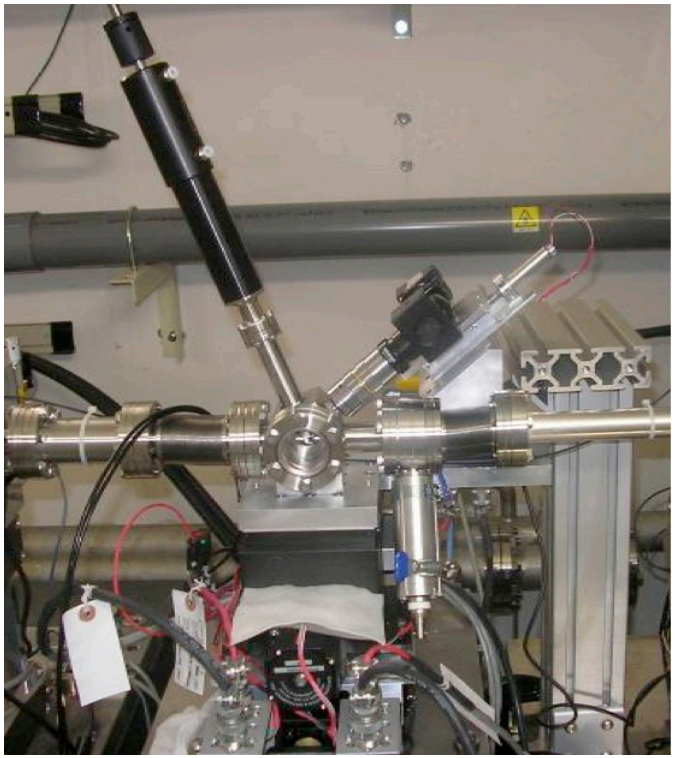
σ_y = 310 +- 30 (stat.) +0-70 (syst.) nm



Multi-OTR Monitor at ATF2



IFIC (CSIC-UV)/SLAC/KEK



OTR (Optical Transition Radiation) monitor developed at ATF demonstrated the ability to measure a 5.5 μm beam size in one pulse.

Multiple OTR monitors for the ATF2

- ***Realize the fast emittance measurement***
- ***Four OTR monitors with the Wire Scanners***
- *Improved resolution of about 2 μm*
- *Aluminum or Aluminized Mylar target*
- *Installed in summer 2010*

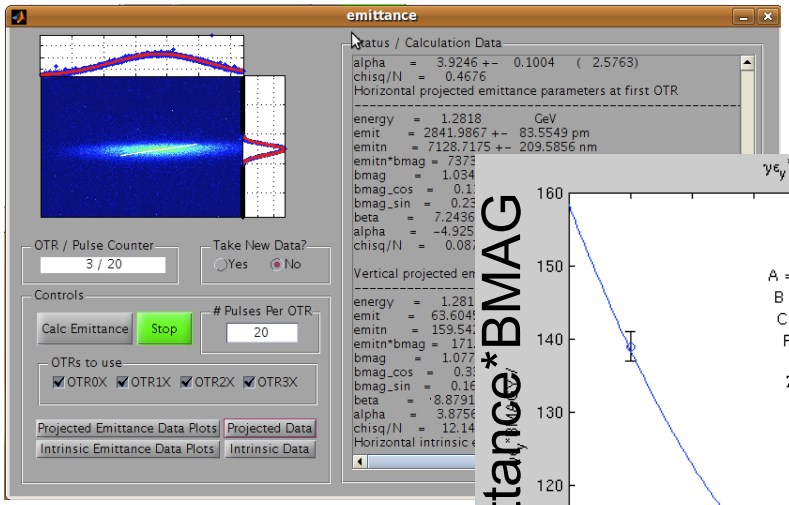
OTR Monitors at ATF2

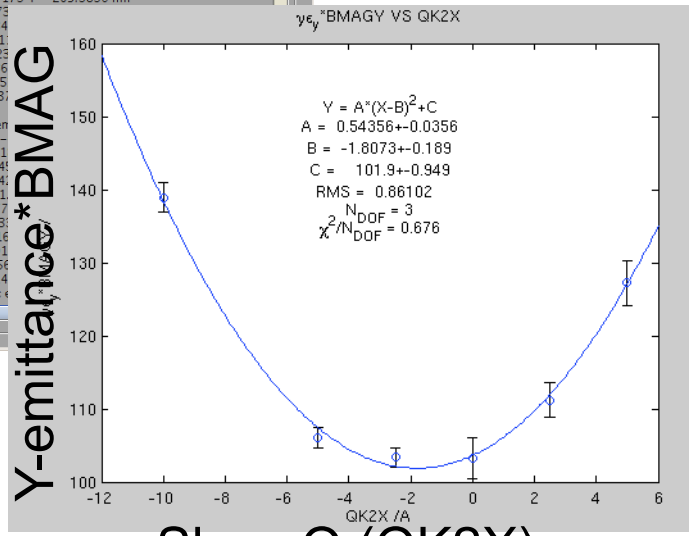
One shot beam size Measurement

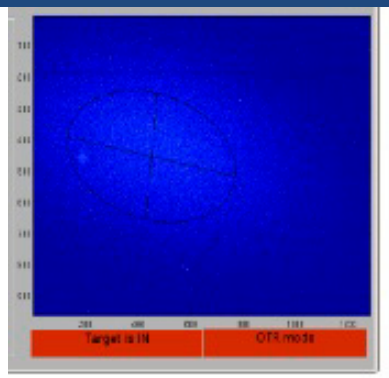
- Fast emittance measurement
- Fast coupling correction

For example: coupling correction

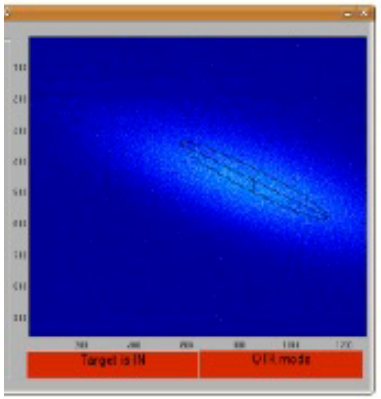
- Wire scanner needs 0.5~1 hours
- Multi-OTR need a few minutes.



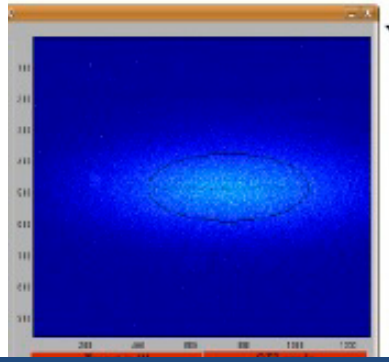




Before Correction



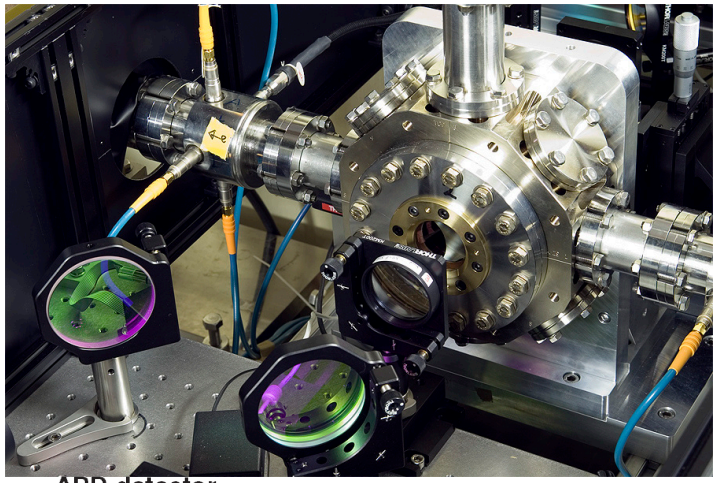
Dispersion Correction

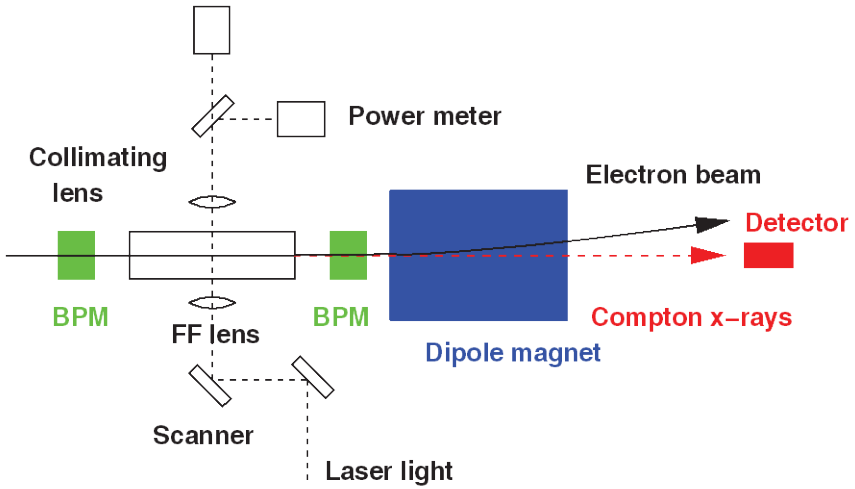


Coupling Correction

Pulsed Laser Wire monitor

JAI(RHUL,Oxford) / KEK





A laser beam is focused with a specially designed f/2 lens system.

Develop a system capable of reliably measuring an electron beam of order one micron in vertical size with a non-destructive method.

ILC design requirement:

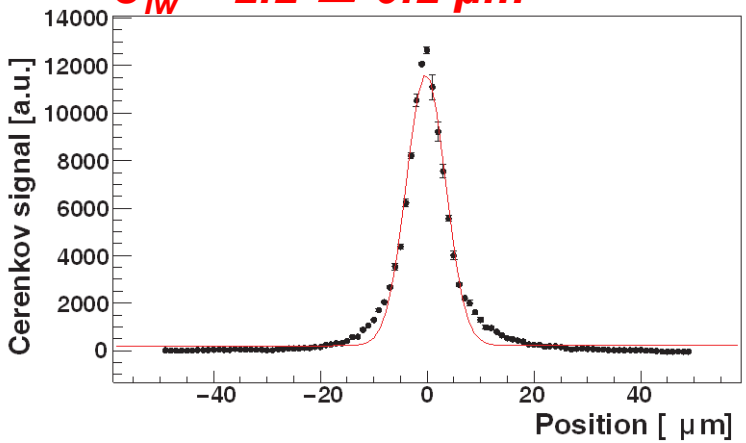
< 1 um laser wire scanner

Results at ATF extraction line

smallest beam size (2008)

$\sigma_y = 3.65 \pm 0.09$ μm (convoluted)

$\sigma_{lw} = 2.2 \pm 0.2$ μm



Upgrade of Laser wire monitor at ATF2

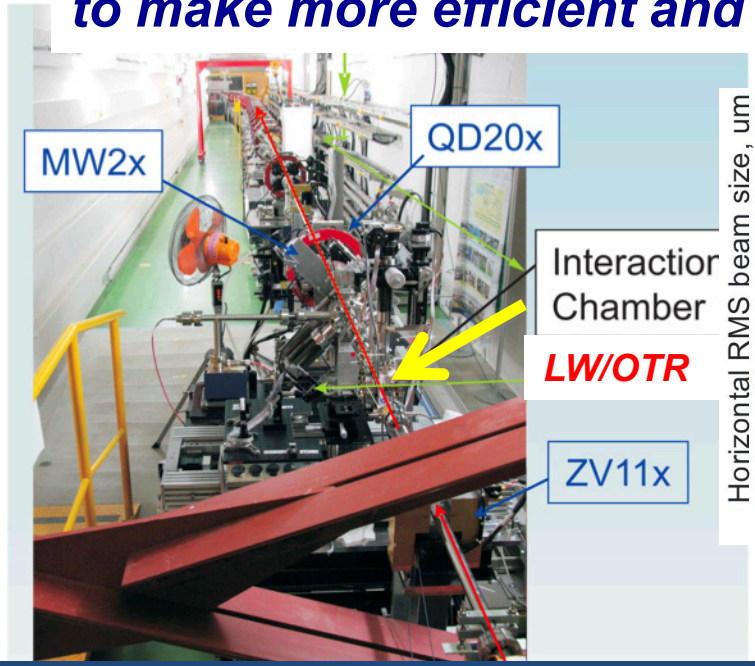
JAI(RHUL,Oxford) / KEK

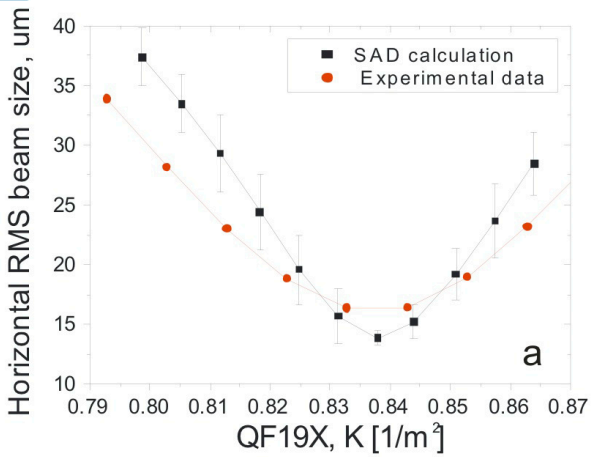
The system has been re-commissioned in the ATF2 after the re-location.

Improvement for ATF2

inclusion of an ***OTR target*** *in the system for* ***collision optimisation*** *and* ***cross calibration****.*

Studies will be continued to find resolution limit on this system and to make more efficient and reliable system by a fibre laser.





Beam size scanning by LW-OTR at ATF2

8.1 +- 0.1 μm

Beam size scanning by LW at ATF2

Beam Position Monitors

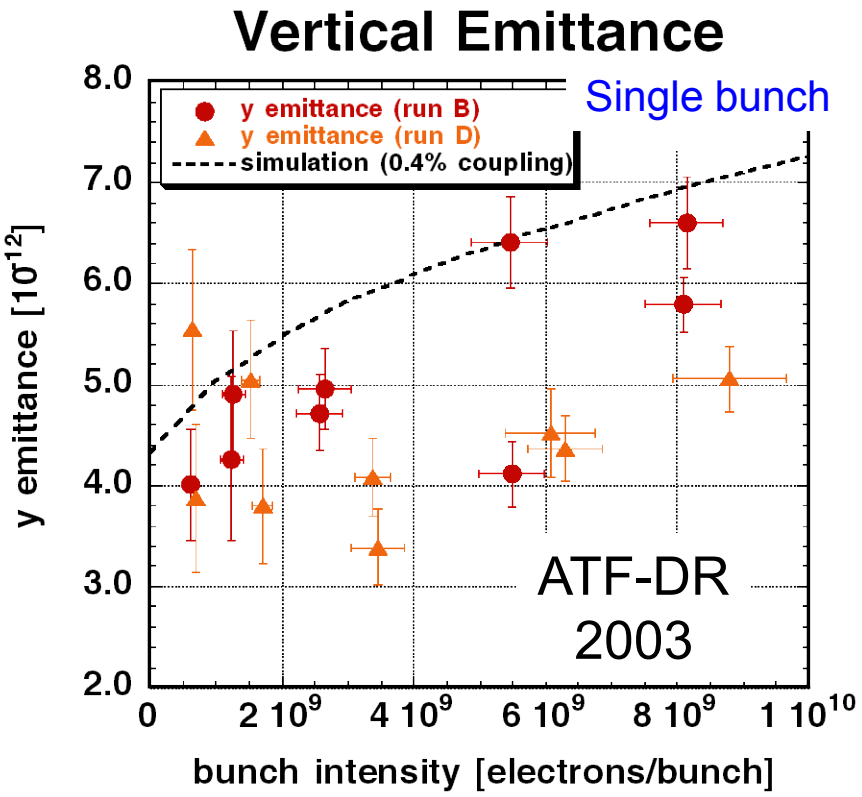
Upgrade of the DR BPM system
Cavity BPMs for ATF2 beamline
Cavity BPM for ATF2 IP

DR BPM Upgrade for < 2 pm emittance

FNAL / SLAC / KEK

ILC requirement:

low emittance beam (ε_y = 2 pm) at 2x10^{10} e-/bunch



A major tool for low emittance corrections:
a high resolution BPM system

- Optimization of the closed-orbit, BBA,…
- Correction of non-linear field effects,…
  i.e. coupling, chromaticity,…

The new readout system for the DR BPMs has been installed in May 2010.
The position resolution is improved less than 1 μm.

More challenge to reach ~1pm will be tried.

- Magnet re-alignment, < 30 μm.
  → **εy ~ 1 pm**

DR BPM Upgrade for 2 pm emittance

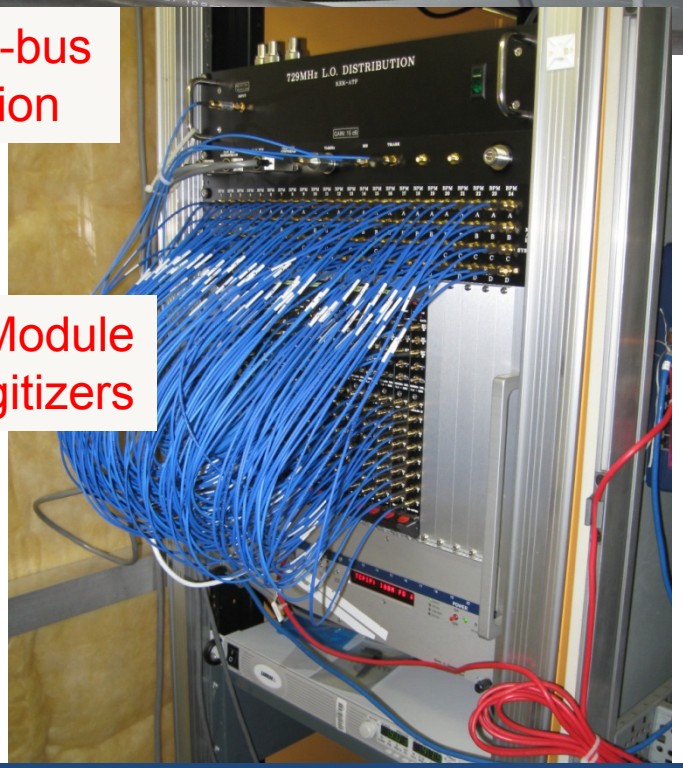
The original read-out system designed for the **single path** position measurement has a 10 μm resolution.

New Downmix & Calibration

Upgraded BPM readout system:

- Utilize analog down-conversion and digital signal processing techniques
- automatic gain-correction

LO & CAN-bus Distribution



New functions for optics analysis

- **Broadband turn-by-turn mode** (< 10 μm resolution)
  - Injection 1,000 turns
  - Extraction 64 turns
- **Narrowband mode with high resolution** (~ 100 nm range)
  - 160 ms, 500,000 turns after injection

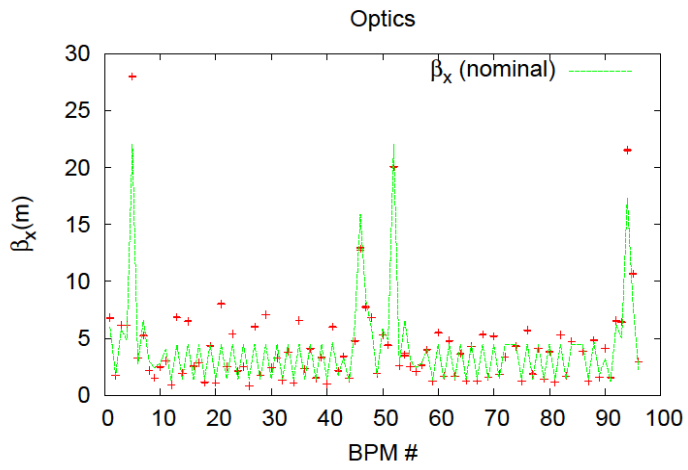
New Timing Module & Custom Digitizers

Further investigation for the system completion is continued.

Example: DR BPM Upgrade Studies

Fermilab

in



011, ATF Damping Ring BPMs

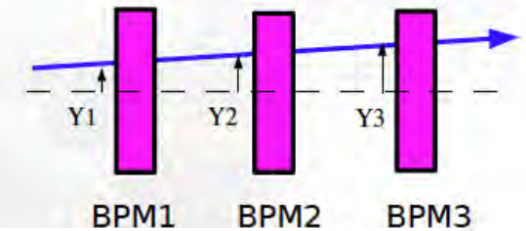
By M. Wendt (FNAL)

Results of Cavity BPM prototypes

KEK / SLAC / LLNL

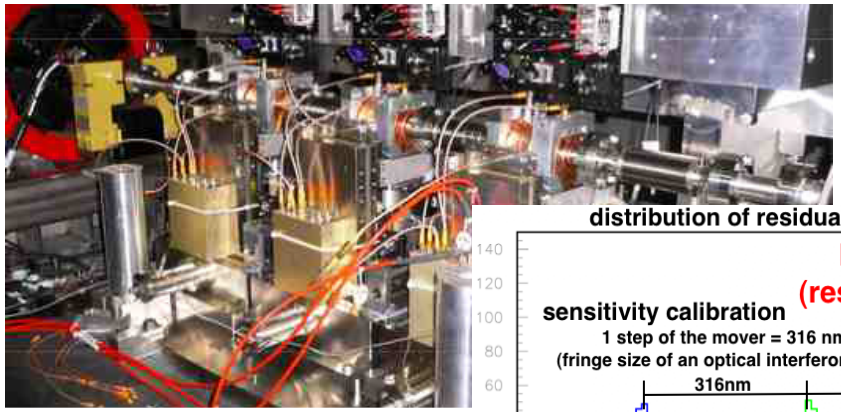
Cavity BPM:

- **strong signal, possible to reach "nm" resolution**
- better mechanical rigidity and reliability of the electric center

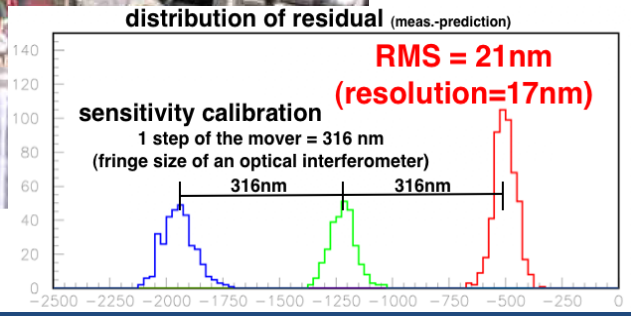


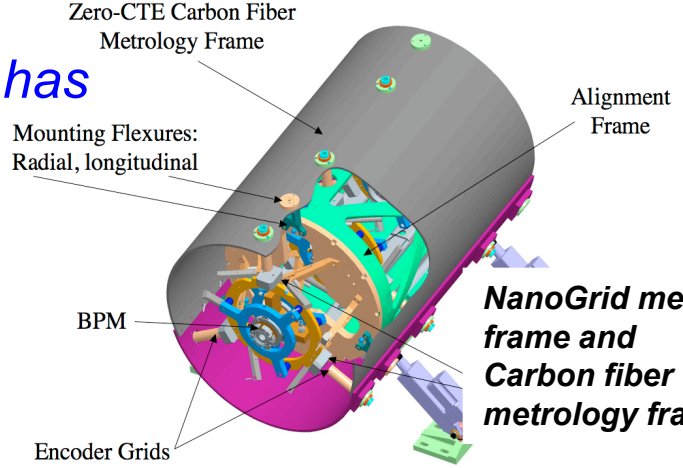
Two R&Ds with the prototype cavity BPMs has been done until 2008 for ATF2.

They have proved position resolutions smaller than 20 nm.

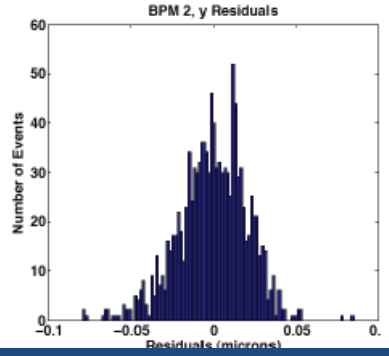


Active stabilization with optical interferometers





NanoGrid metrology frame and Carbon fiber metrology frame



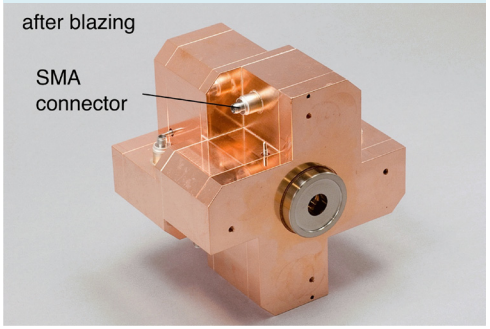
Achieved resolution 15.6 nm @dymamic range ±20μm

ATF2 Cavity BPM system

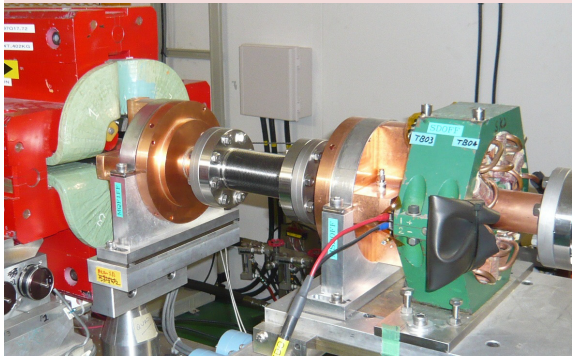
KNU / PAL / KEK / RHUL / SLAC

Beam test area

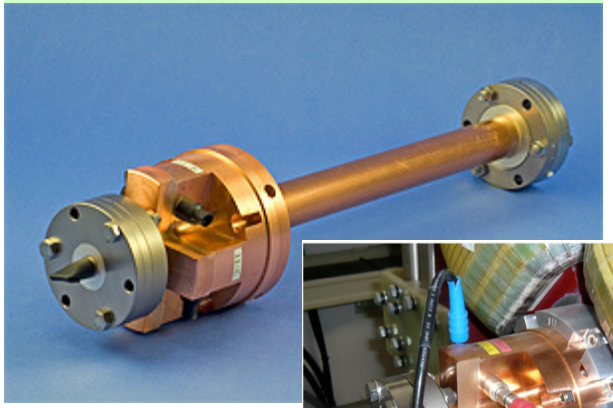
IP BPM system
(BPM + Ref) Cavity
1 unit
Target : 2 nm
Aperture: 6 mm(V)

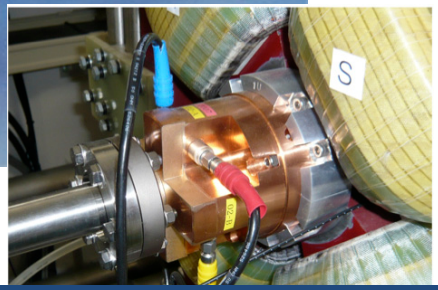


S-band BPM system
BPM cavity: **4 units**
Ref. cavity: **1 unit**
Target : 100 nm
Aperture: ϕ40 mm



C-band BPM system
BPM cavity: **34 units**
Reference cavity: **4 units**
Target resolution: 100 nm
Aperture: ϕ20 mm





Present Status of the ATF2 Cavity BPMs

C-band BPM

20 dB attenuation, most of C-band BPMs to widen the dynamic range

Resolutions:

with 20dB att. ~ 200 nm

w/o 20dB att. ~ 50 nm (well centered beam w/o saturation → 27 nm)

S-band BPM

Resolution ~ 1 μm

- Jitter subtracted calibrations
- Cavity frequency correction
- Amplifiers were not sufficient.

IP-BPMs

- Just installed to assist the small beam size study.
- Not yet well calibrated!

Further investigations are continued.

By S. Boogert (RHUL)

Cavity BPM for the focal point (IP)

KEK / KNU / SLAC / RHUL

Goal resolution: 2 nm

Provide a direct demonstration of beam position stability

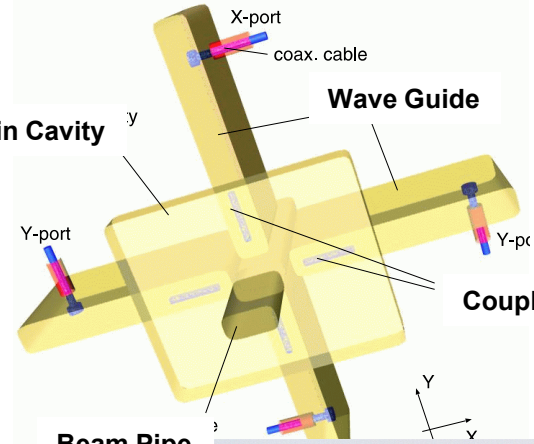
- *tracks the beam trajectory during beam size measurements to correct the effects of position jitter*
- *produces a feedback signal to stabilize the beam orbits of the following bunches.*

Rectangular shape:

isolates two (x,y) dipole mode

Thin cavity:

reduces the sensitivity to trajectory inclination.



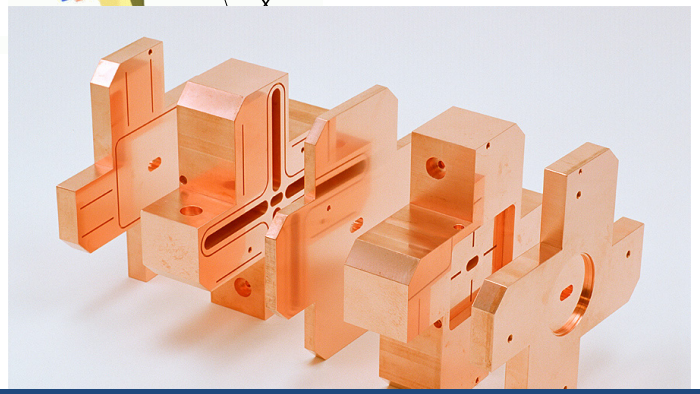
Achieved resolution at ATF

8.72 +-0.28(stat) +-0.35(sys) nm

@ 0.7×10^{10} electrons/bunch,

@ 5 μm dynamic range

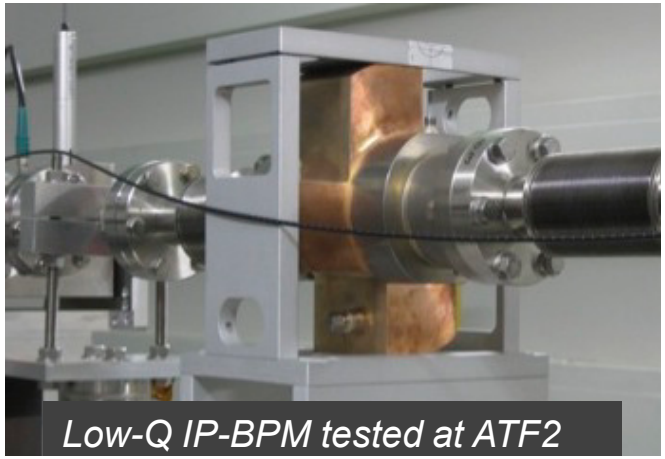
[Y. Inoue et al., Phys. Rev. ST-AB 11, 62801 (2008)]



Low-Q Cavity BPM for multi-bunch beam

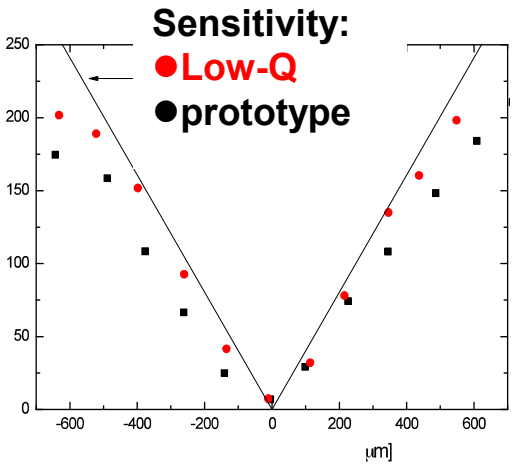
KNU / KEK / RHUL / Oxford

low-Q BPM: to enable the bunch-by-bunch position measurement for the multi-bunch beam with bunch spacing of 154 ns



Low-Q IP-BPM tested at ATF2

Bunch-by-bunch signal separation
for the 3 bunch beam, 154ns spacing



Improvements on the readout electronics have been continued to achieve the 2 nm resolution.

Nanometer stabilisation (IP-BPM + FONT feedback)

Beam Feedback

Intra-train fast feedback (FONT)
Fast kicker
Pulsed Laser Wire

Beam Stabilization at the ATF2-IP

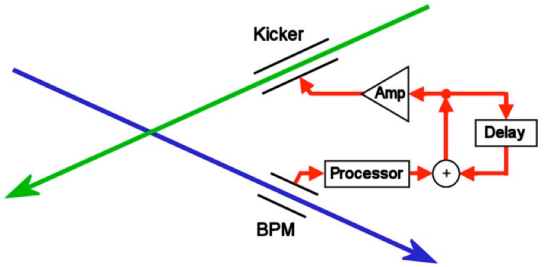
Oxford / KNU / RHUL / KEK

Challenging goals for ATF2

1. *achieving of the 37 nm vertical beam size at IP*
2. ***demonstration of the stabilization of beam in a few nanometer level at the IP.***

FONT (Feedback On Nano-Second Timescales) has been developed

- *as a prototype of a beam-based intra-train feedback system for the interaction point of LCs.*
- *Correct the impact of fast jitter sources such as the vibration of magnets.*



FONT1~FONT3

Analogue feedback system for very short bunch-train LCs.

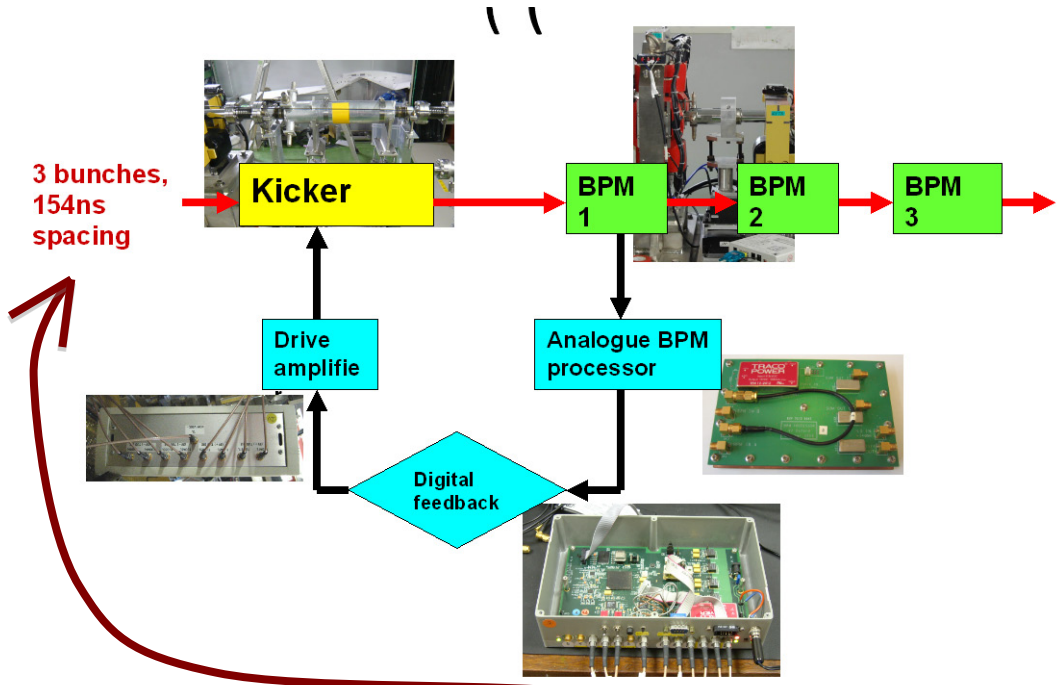
Latency FONT3(ATF) 23 ns.

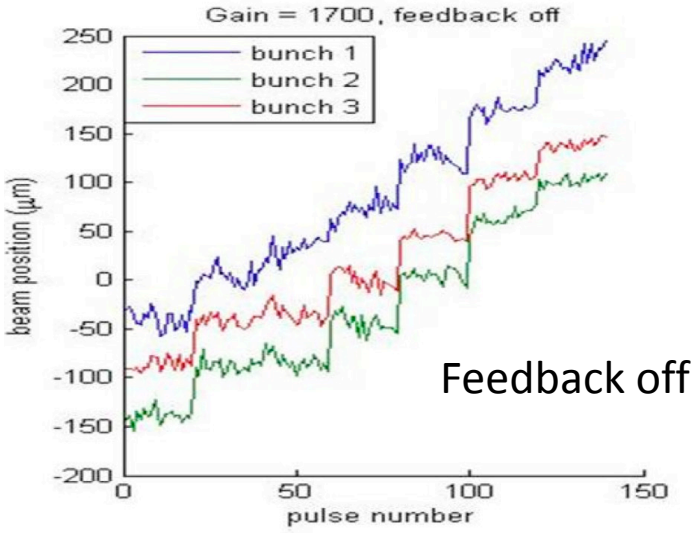
FONT4 & FONT5 (ATF2)

Digital feedback system for long bunch-train ILC.

allow the implementation of more sophisticated algorithms

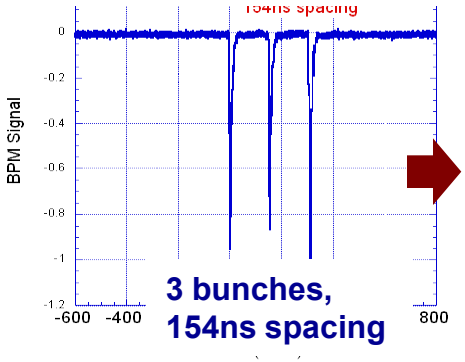
FONT4: first digital intra-train feedback





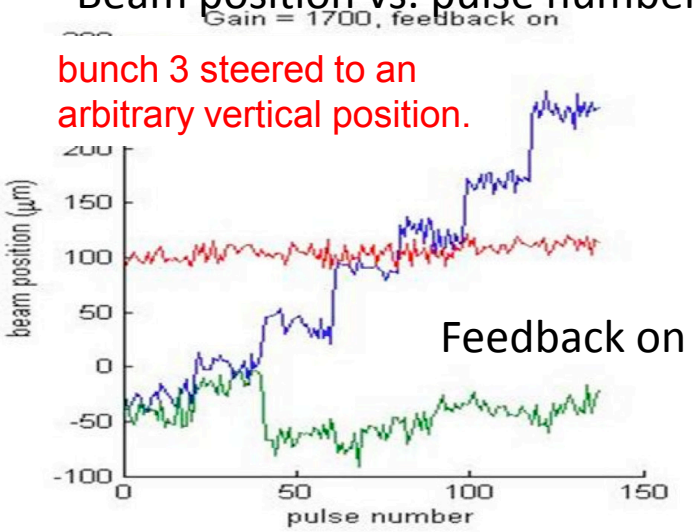
Beam position vs. pulse number

Extracted beam from DR

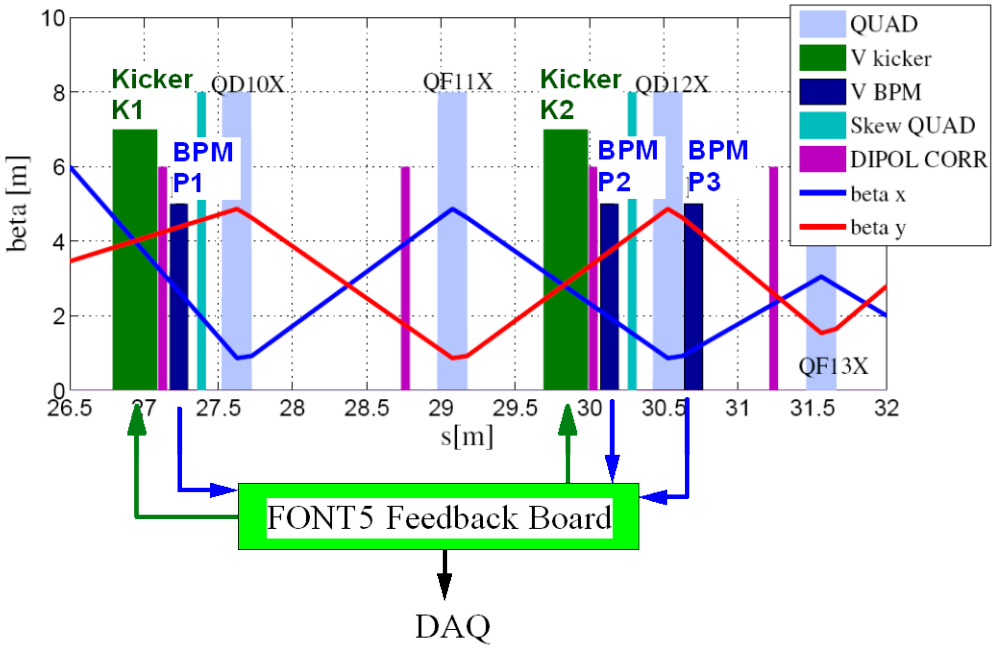


Shift the beam positions by a beam-steering dipole to simulate the possible beam jitter etc.

bunch 3 steered to an arbitrary vertical position.



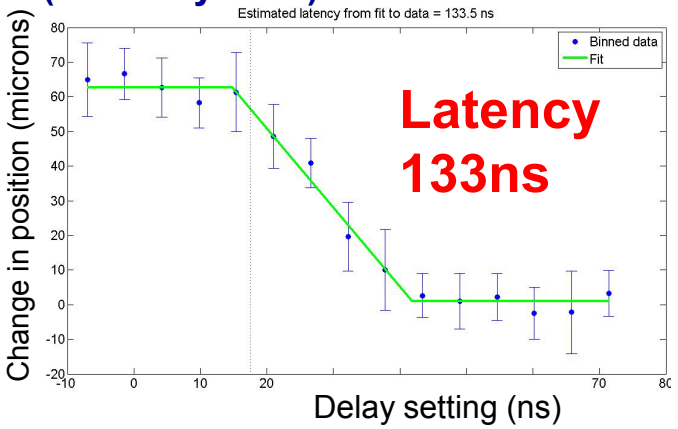
FONT5: intra-train feedback at ATF2



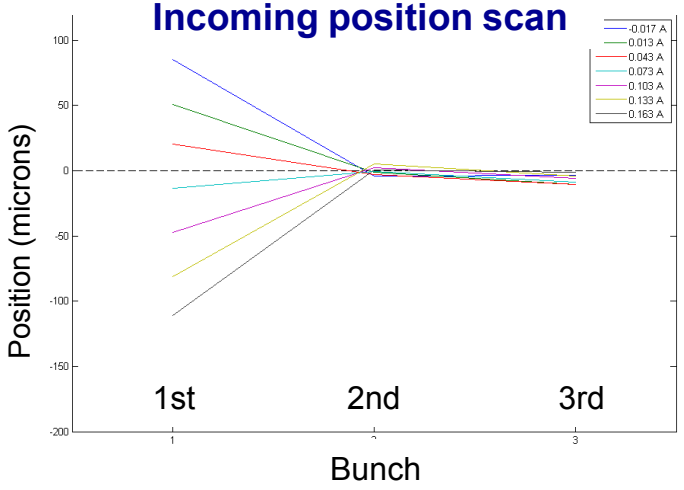
FONT5 system

- flexible configurations
  two kickers and **three BPMs**
- **coupled feedback system of two loops correcting both position and angle jitter in the vertical plane**

FONT5 P2 → K1 FB-loop (February 2010)



Incoming position scan

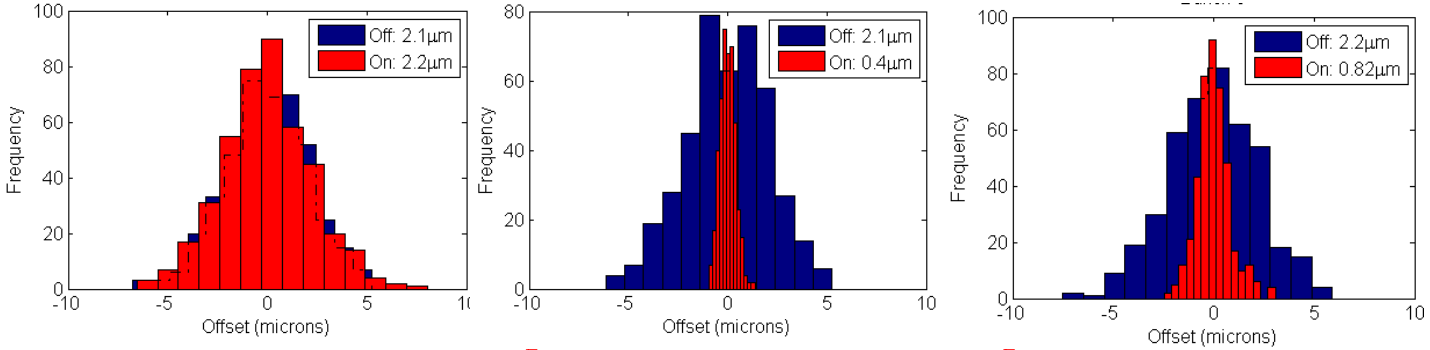


Beam jitter reduction by FONT5

Results of P2 → K1 loop (measured)

(April 16 2010)

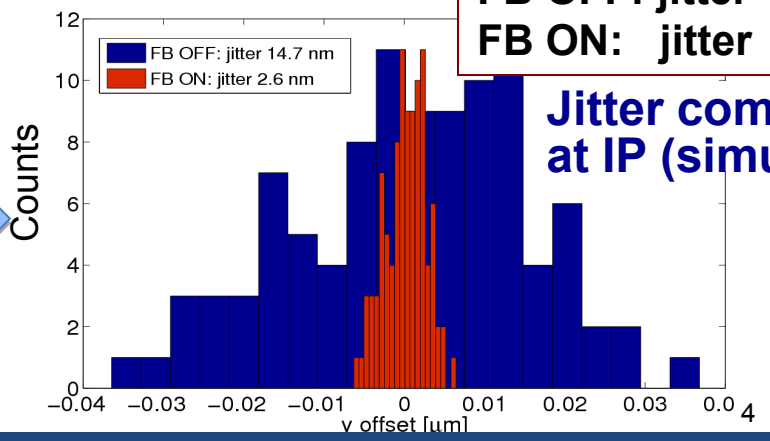
Bunch 1 | Bunch 2 | Bunch 3



2.1 um → 0.4 um → 0.8 um

Assuming perfect lattice, no further imperfections (!)

FONT + IP-BPM



FB OFF: jitter 14.7 nm
FB ON: jitter 2.6 nm

Jitter comparison at IP (simulation)

Strip-line kicker for multi-bunch extraction

The Injection/extraction kicker for ILC-DR has a very special role.

- It act as a bunch-by-bunch beam manipulator to compress and decompress the bunch spacing into/from the DR.
- It requires a fast rise/fall time (3 - 9 ns) and a high repetition rate (6 - 2 MHz).

A beam extraction experiment with a prototype strip-line kicker has been carried out at the ATF.

ATF beam extraction by Fast Kicker

ATF2 beamline

Intra-train feedback (FONT)

Wire Scanners

C-band BPM

OTRs

C-band BPM

Pulsed Laser Wire

Fast Kicker

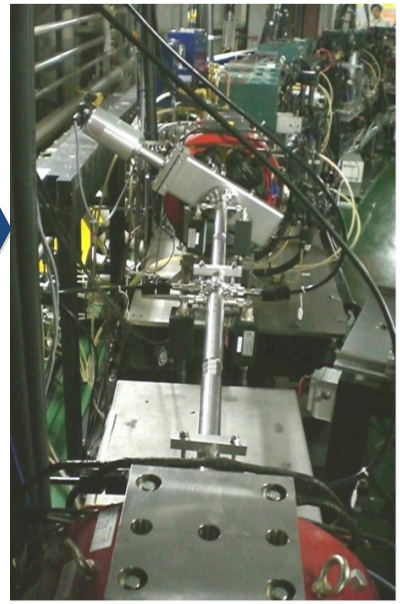
Kicker 3 mrad + bump orbit, aux. septum

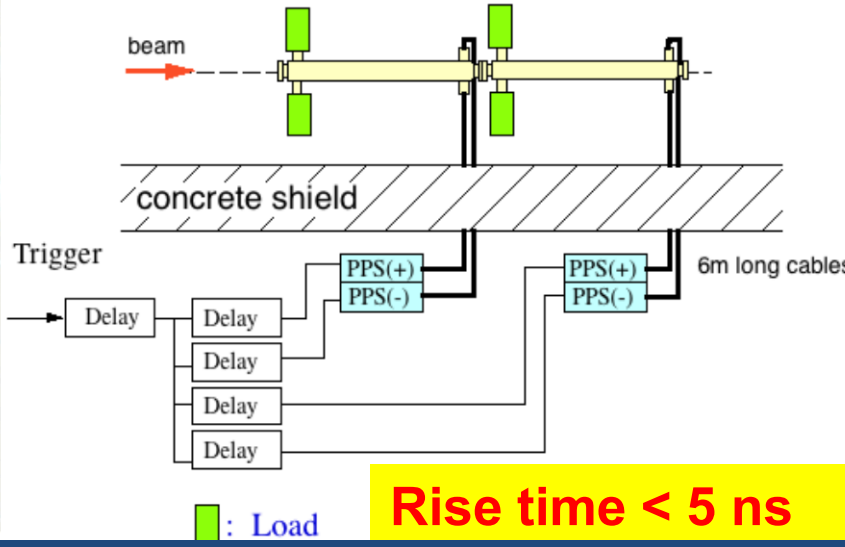
Damping Ring

Two sets of (+10,-10 kV) strip-line kickers

Kicker pulse
10 kV
3 MHz

Rise time
1.5 ns

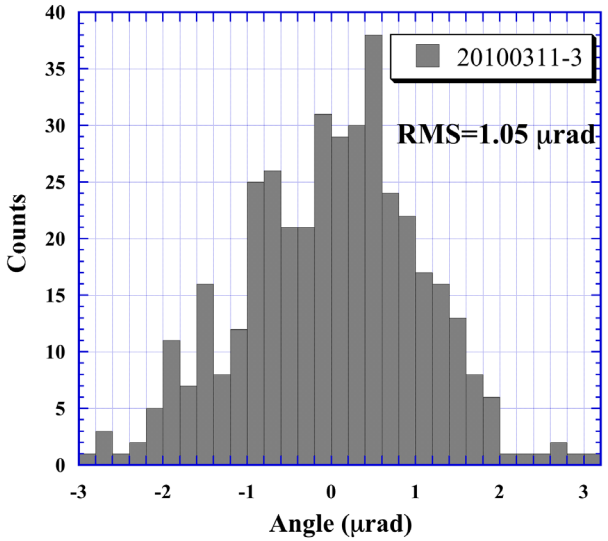




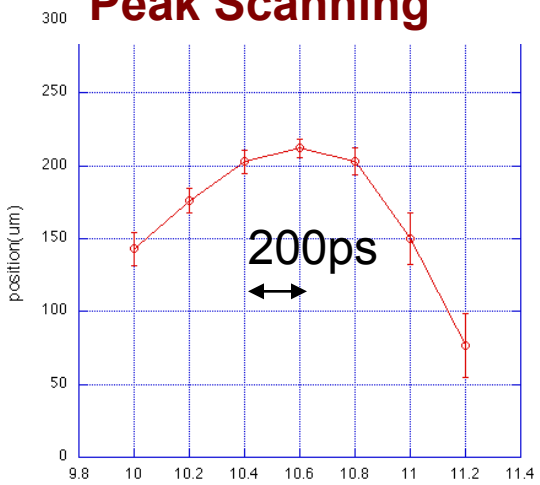
Rise time < 5 ns

Stability of the Fast Kicker

Kick Angle Stability



Peak Scanning



Kick angle stability was evaluated by using the cavity BPMs at ATF2 beamline.

RMS 1.05 μrad/4.6 mrad
= **3.5×10^{-4}**

It still has a jitter due to the timing jitter.

- **Satisfy the ILC requirement**
- **Comparable to that of the double kicker system of ATF;** two conventional Pulse Kickers with phase advance π

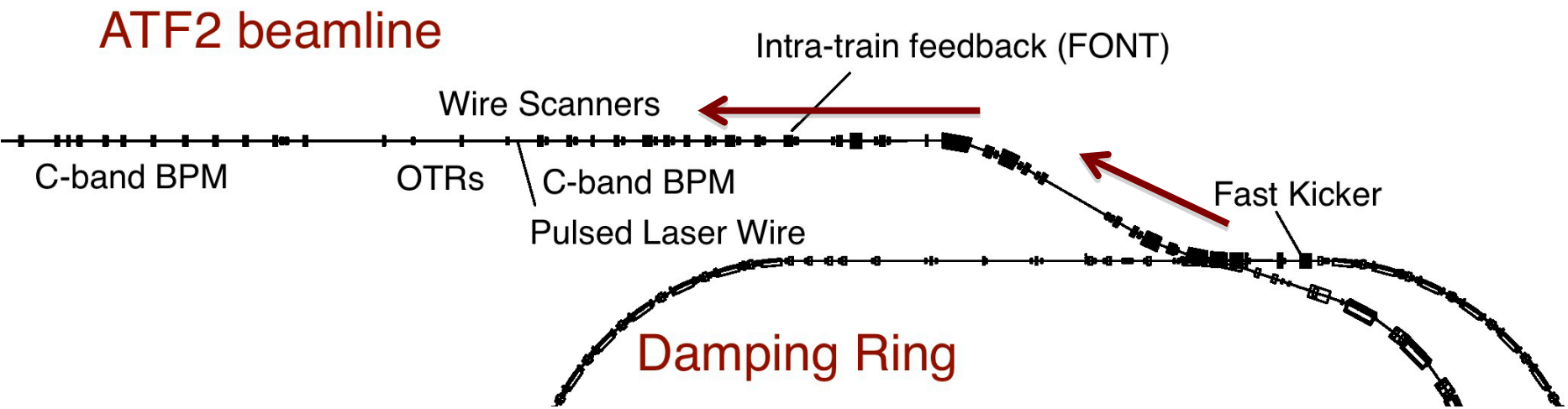
  Stability of the ATF double kicker system

  2.8×10^{-4}

  (Ref) Stability of the single kicker configuration

  9.4×10^{-4}

Demonstration of Multi-bunch Extraction



October 2011

3 trains in DR (10 bunches, 5.6 ns spacing)

30 bunches extracted from DR (308 ns spacing)

By T. Naito

Summary

A variety of beam instruments have been developed in ATF/ATF2.

The readout of the damping ring BPMs are upgraded to realize the 2 pm vertical emittance.
The cavity BPMs with a nanometer level resolution, the beam size monitor based on the laser interference fringe and the fast intra-train feedback system are essential tools to realize the challenging goals of the ATF2. These systems are working well.

ATF/ATF2 requires these complex instruments to operate continuously with minimal intervention to realize.

Thank you for your attention.