

Update on Optics Modeling for the ATF Damping Ring at KEK

*Studies for
low vertical emittance*

2009.05.08.

K. Kubo, S. Kuroda, T. Okugi (KEK)

M.D. Woodley (SLAC),

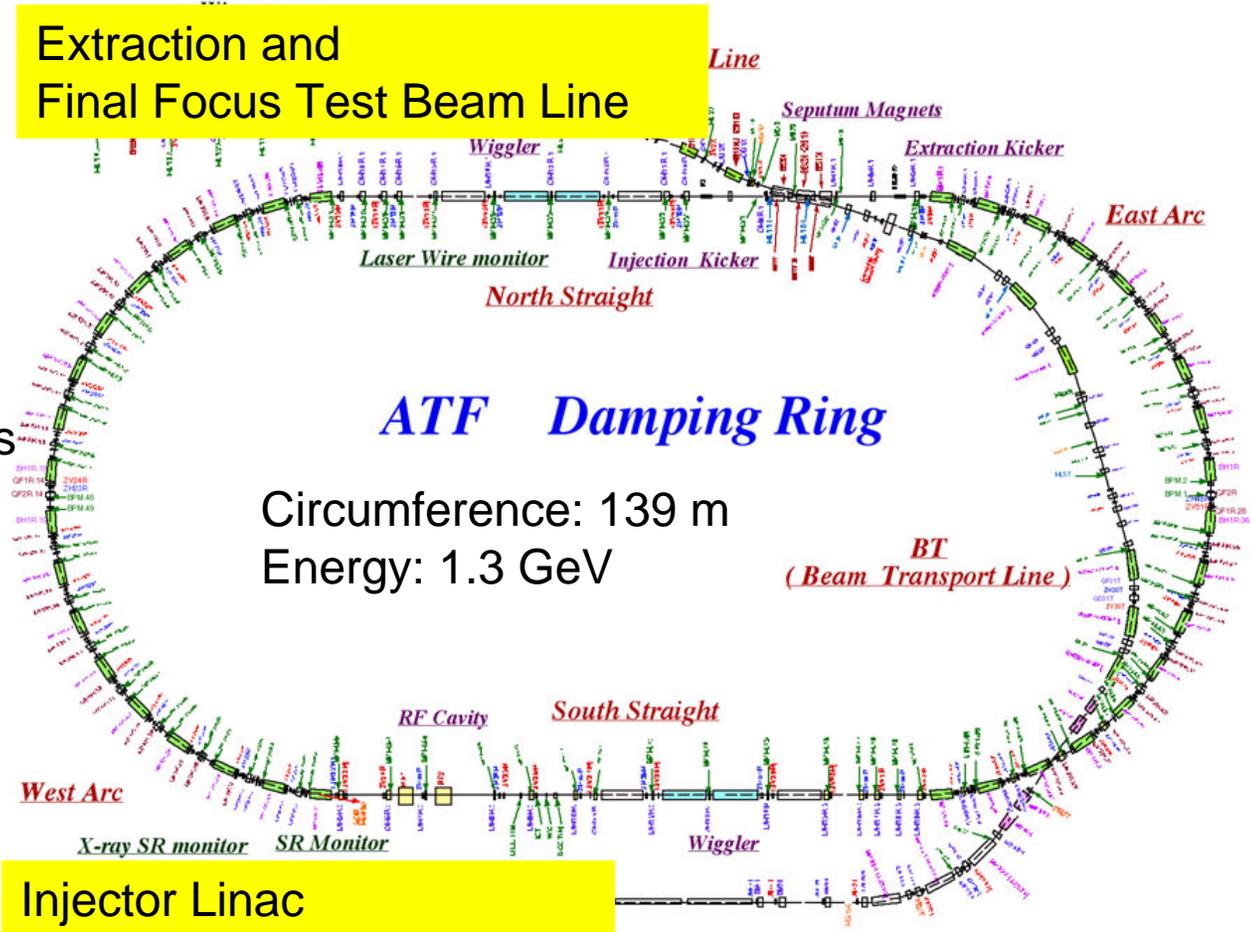
A. Wolski, K. Panagiotidis (U. Liverpool and
the Cockcroft Institute)

ATF Damping Ring (KEK)

Test Facility for LC

- Test of Low emittance beam tuning
- Deliver low emittance beam, e.g. for final focus test (ATF2)
- R & D of instrumentations, etc.

Extraction and Final Focus Test Beam Line



ATF Damping Ring

Circumference: 139 m
Energy: 1.3 GeV

Required or target of low vertical emittance

For ATF2(Final Focus test): 12 pm

ILC damping ring design: 2 pm

Low Emittance Tuning

Three consecutive corrections

- COD correction
- Vertical COD-dispersion correction
 - minimize dispersion and orbit simultaneously with weights
- Coupling correction
 - minimize vertical orbit change by horizontal steerings

Monitor:

BPM (Beam Position Monitors) (total 96)

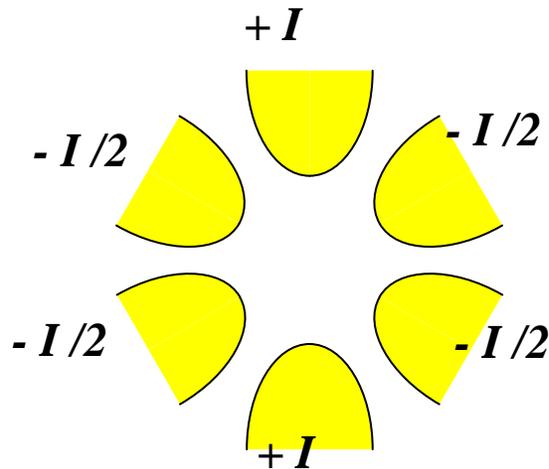
Corrector:

Steering magnets (47 horizontal and 51 vertical)

Skew Qauds (trim coils of sextupole magnets, total 68)

Skew correctors - trim coils of sextupole magnets

The trim windings of all 68 sextupole magnets have been arranged to produce skew quadrupole fields, used as correctors.



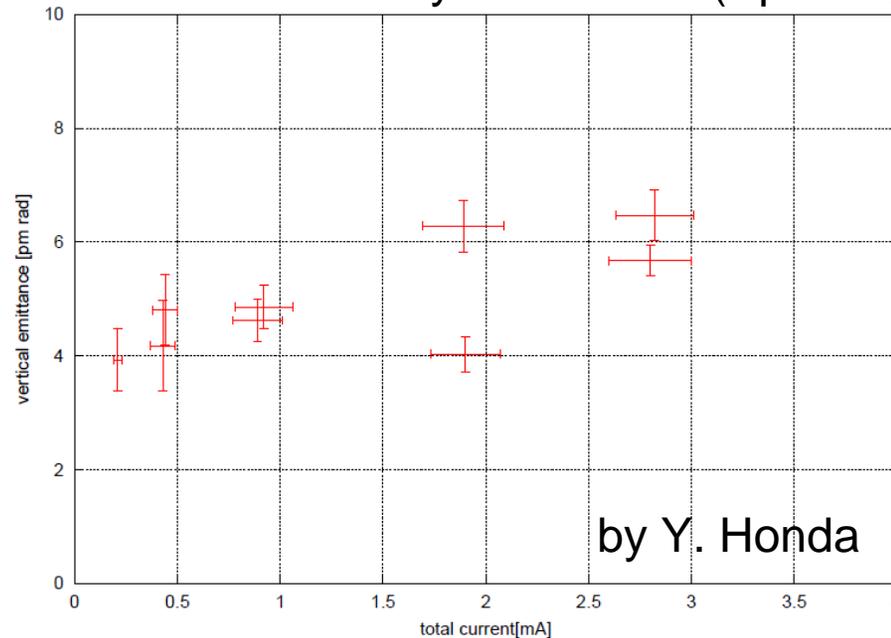
Currents of the top and the bottom poles are the same.
Currents of other poles are one half.

(Suggested by T. Raubenheimer)

Skew Quad Field by Sextupole Magnet

History of low emittance in ATF DR

Vertical emittance measured by Laser Wire (April 16, 2003)



By 2004, we confirmed very low emittance beam, around 4 pm.
Since then, pursuit of low emittance had not been a major study item.
The emittance deteriorated.
Over the past year, renewed efforts have been made for low emittance.

Recent efforts for low emittance related to beam measurement

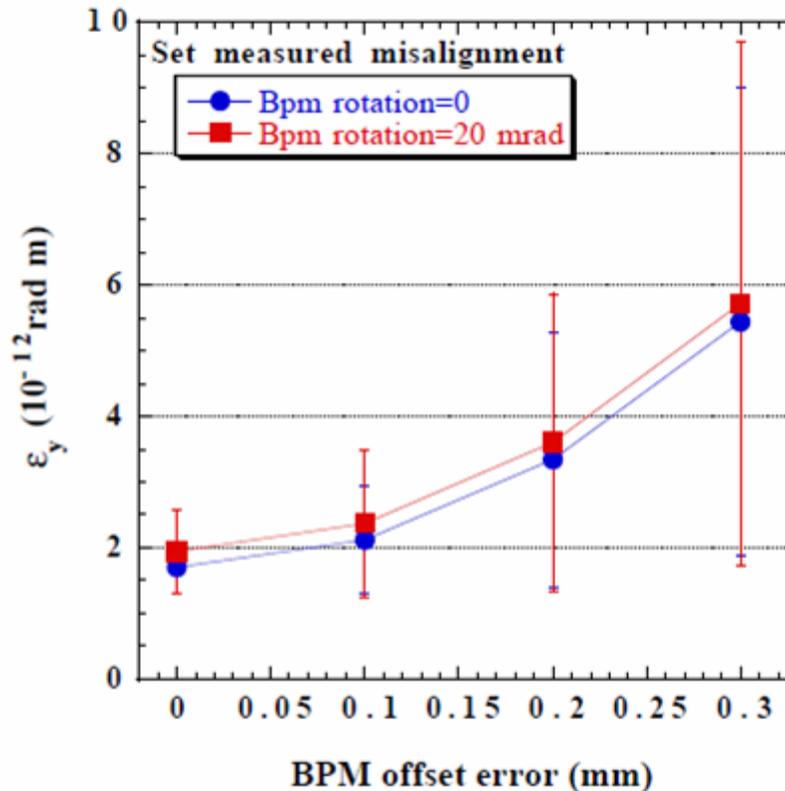
- BBA (Beam Based Alignment) measurement
- Optics matching (Beta-beat correction)
- ORM (Orbit Response Matrix) analysis

Effectiveness of each individual technique
still needs to be understood.

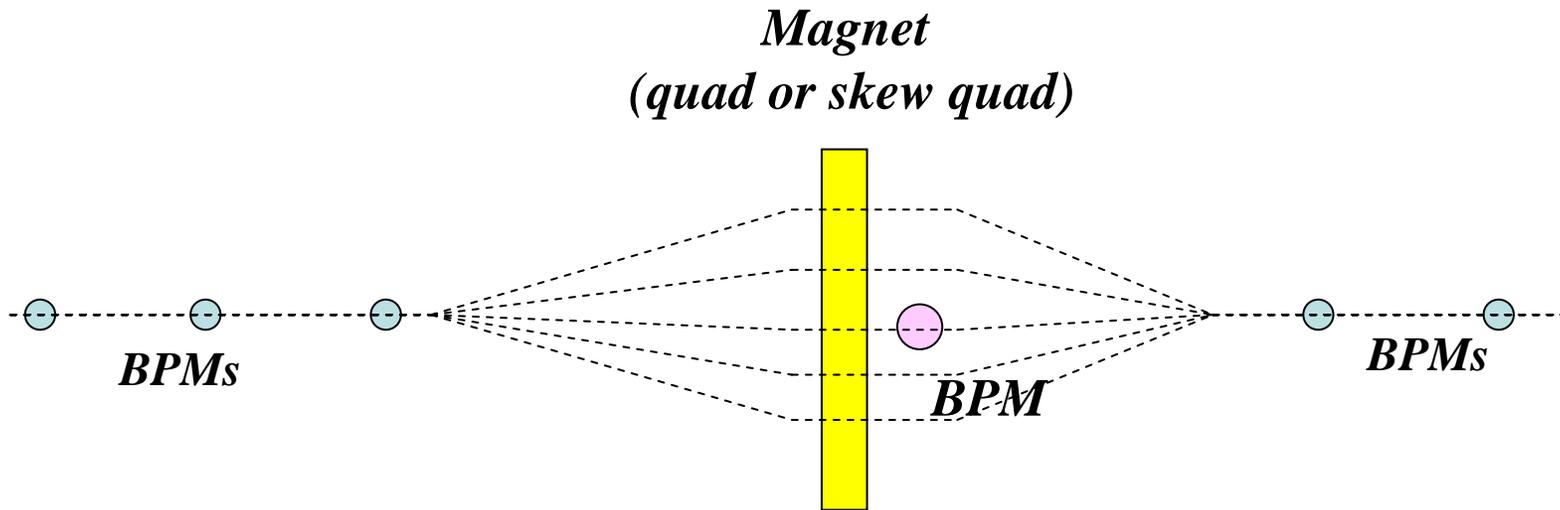
Beam Based Alignment

Simulation of the tuning showed importance of
BPM - magnet center offset error

Emittance
vs. BPM offset error
with respect to the
nearest magnet



Beam Based Alignment - Method



1. Make **vertical** local bump at the Magnet-BPM.
2. Change Magnet strength.
3. Measure the orbit difference for all the BPMs.
Normal Quads: **Horizontal**, Skew Quads: **Vertical**
4. Estimate the minimum orbit difference point.

Trim winding sof sextupole magnets

Beam Based Alignment - results

RMS of beam position change at all (except for noisy) BPMs vs. local bump amplitude.

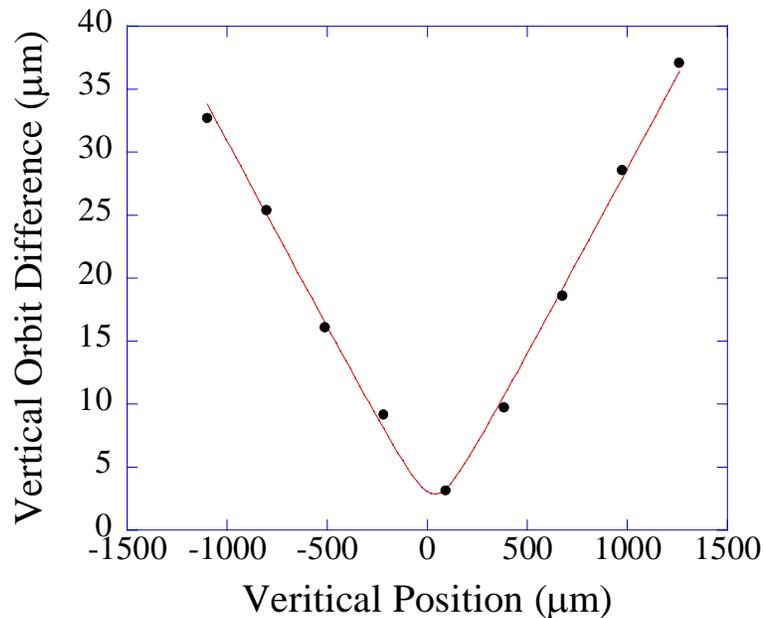
Fitted as

$$\Delta_{RMS} = b\sqrt{c^2 + (y - a)^2}$$

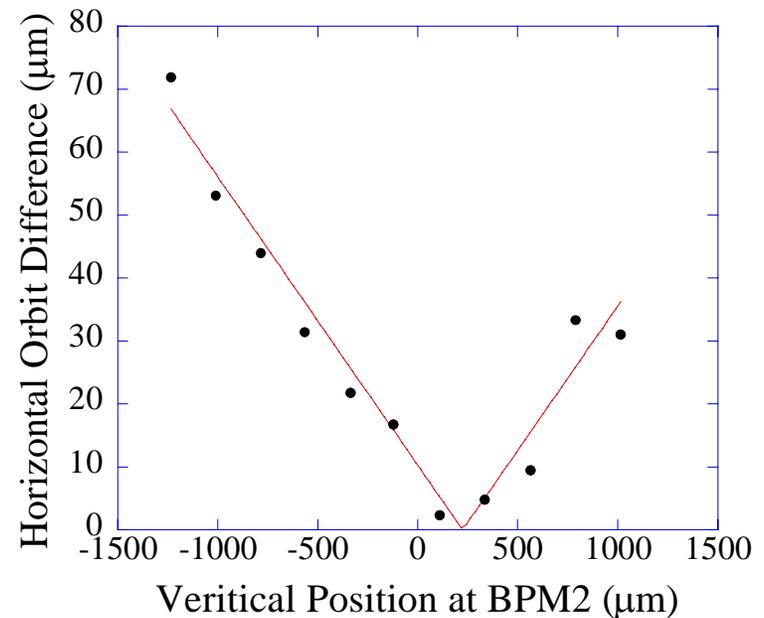
a : BPM - Magnet offset

Examples

Bump at Quad



Bump at Skew Quad (Sextupole)



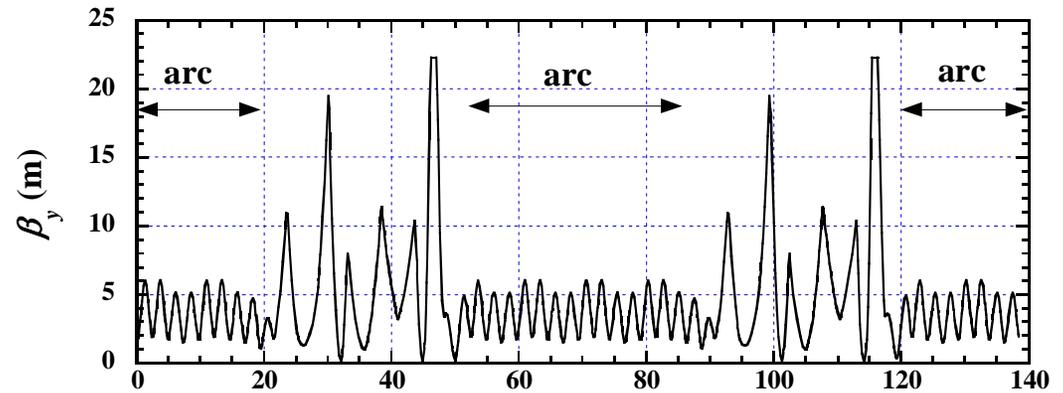
Typical error of offset: ~ 30 μm for Quad

~ 80 μm for Skew Quad

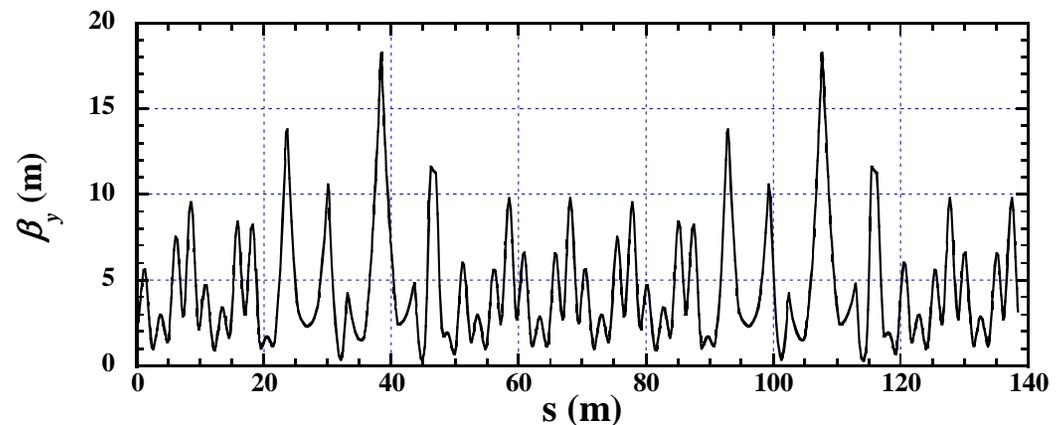
Optics matching (Beta-beat Correction)

Calculated vertical beta functions of two different optics matching conditions.

December 1999, when we observed small vertical emittance (about 5pm).



May 2008, when we could not achieve low emittance.

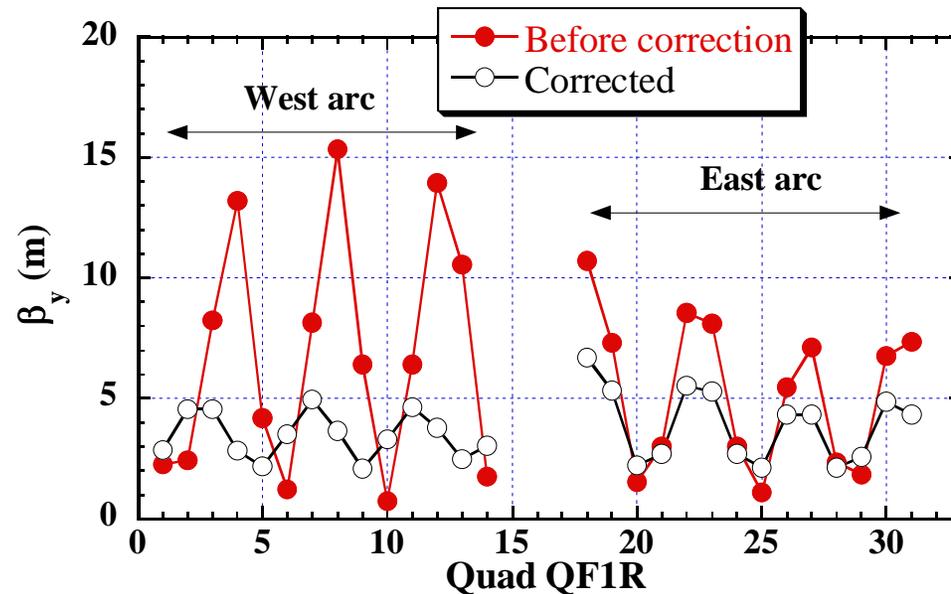


Beta-beat may increase emittance sensitivity to errors.

Optics matching (Beta-beat Correction)

Vertical beta-function at all quadrupole magnet of one family in the arc sections. (Should be flat for matched optics.)

Before and after a beat correction.



**Condition was improved but not completely satisfactory.
Need more study for better modeling.**

ORM Analysis

- Measure changes in the closed orbit with respect to changes in strength of a number of orbit correctors
- Fits a machine model to the data, by adjusting:
 - Quadrupole strengths,
 - BPM gains and couplings,
 - Corrector magnet strengths and tilts.
- Here, we report on coupling corrections using ORM analysis.

ORM Analysis

ORM analysis effectively projects the betatron coupling sources onto the skew quadrupoles

→ Determination of skew quadrupole strengths required to cancel the coupling sources

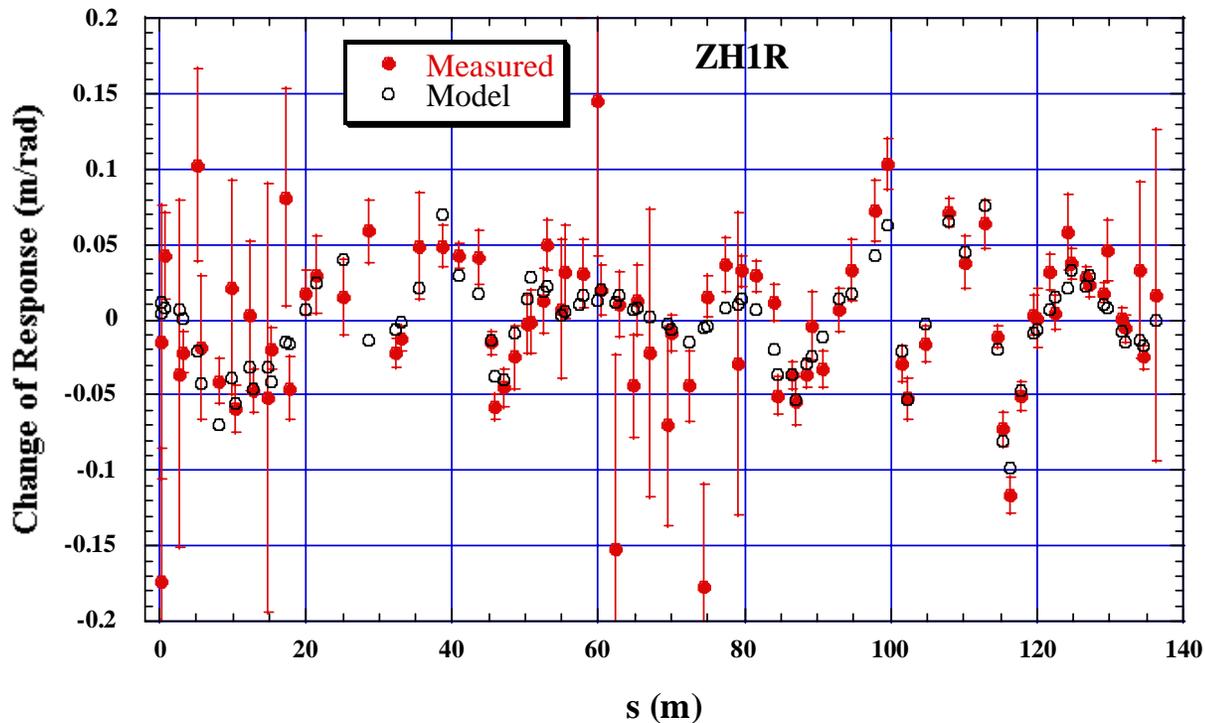
Possible limitations

- Present analysis do not include orbit distortion
 - which can affect predictions of effects of correctors
 - will be tried after BBA and more accurate orbit corrections
- Degeneracy between errors causing apparent coupling

ORM Analysis

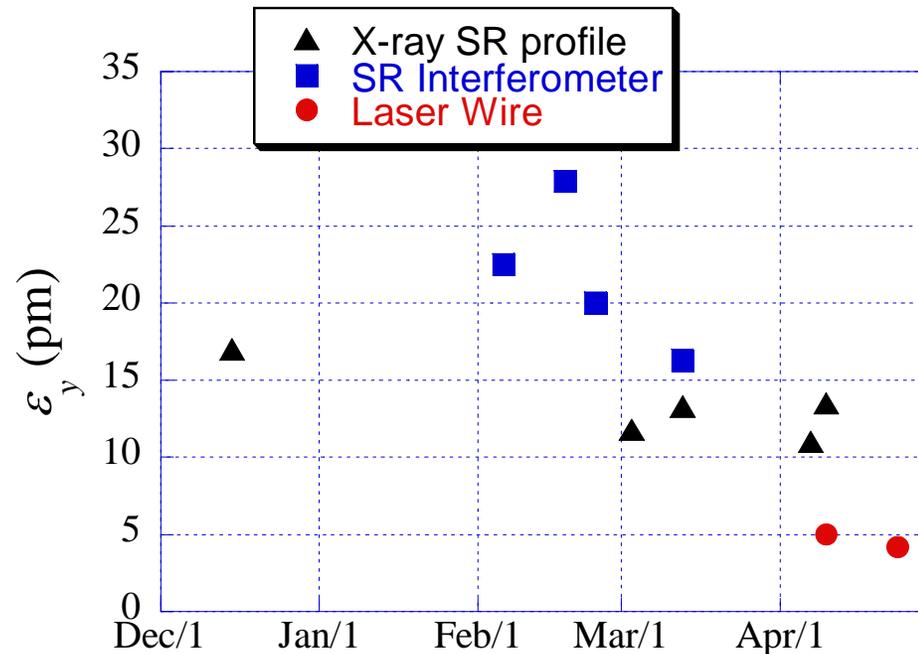
Example of data from coupling correction.
Measurement and prediction from present model.

Change of Response at all BPM to one horizontal steering magnet.



Measured April 10, 2009

Recent History of Low Emittance



(Error from Laser Wire measurement is about 3 pm)

**Recent measurement showed improvement.
Vertical emittance < 10 pm (low intensity)
Good enough for ATF2 (Final Focus Test)**

Summary and Future Plans

- Low emittance tuning and efforts for improving the low emittance performance in the ATF damping ring were reported.
 - BBA (BPM - Magnet offset measurement)
 - Optics matching (Beta-beat correction)
 - ORM (Orbit Response Matrix) analysis
- The emittance performance has been recovered.
 - $\varepsilon_y < 10$ pm in April 2009. (Good enough for ATF2, final focus test)
 - Effectiveness of each technique for this recovery is under investigation.
- Plans for smaller emittance (2 pm is the target),
 - More simulation studies on the tuning procedure
 - Analysis of beam measurement
 - Upgrade of all BPM electronics (20 out of 96 BPMs were already upgraded)
 - Re-alignment of magnets.

Backup Slides

Low Emittance Tuning

- (a) COD correction: **using steering magnets**,
minimize BPM reading

$$\sum_{\text{BPM}} x^2 \quad \text{and} \quad \sum_{\text{BPM}} y^2, \quad :x(y): \text{ horizontal (vertical) BPM reading.}$$

- (b) V-COD-dispersion correction: **using steering magnets**,
minimize dispersion and orbit

$$\sum_{\text{BPM}} y^2 + r^2 \sum_{\text{BPM}} \eta_y^2 \quad \eta_y: \text{ measured vertical dispersion.}$$

r : weight factor = 0.05

- (c) Coupling correction: **using skew quads**,
minimize vertical response to horizontal steering

$$C_{xy} \equiv \sqrt{\sum_{\text{H-steers}} \left(\frac{\sum_{\text{BPM}} \Delta y^2}{\sum_{\text{BPM}} \Delta x^2} \right) / N_{\text{steer}}}$$

$\Delta x(\Delta y)$: horizontal (vertical) position change at BPM due to excitation of a horizontal steering magnet.

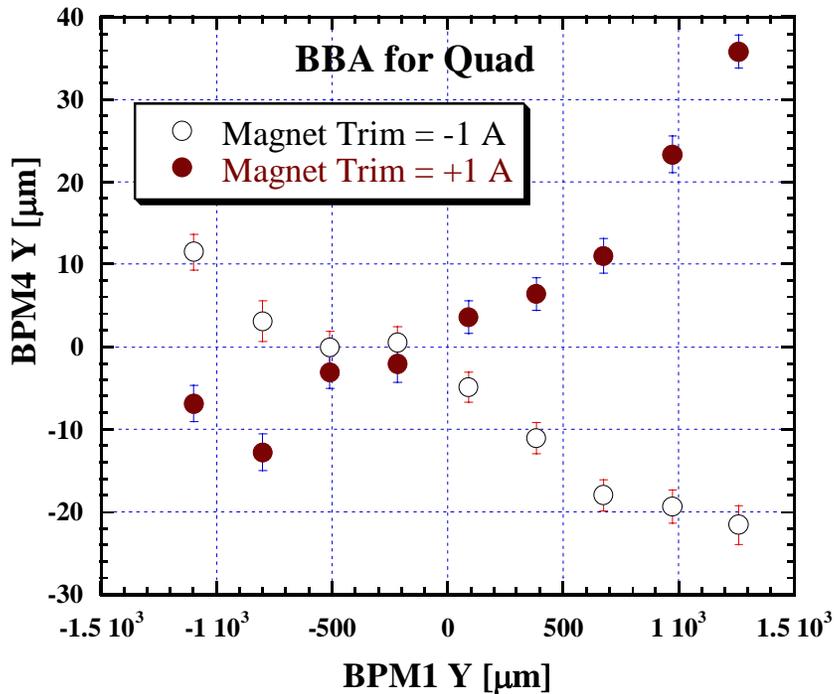
Two horizontal steering magnets were used ($N_{\text{steer}}=2$). About $(n+1/2)\pi$ phase advance between the two.

Beam Based Alignment

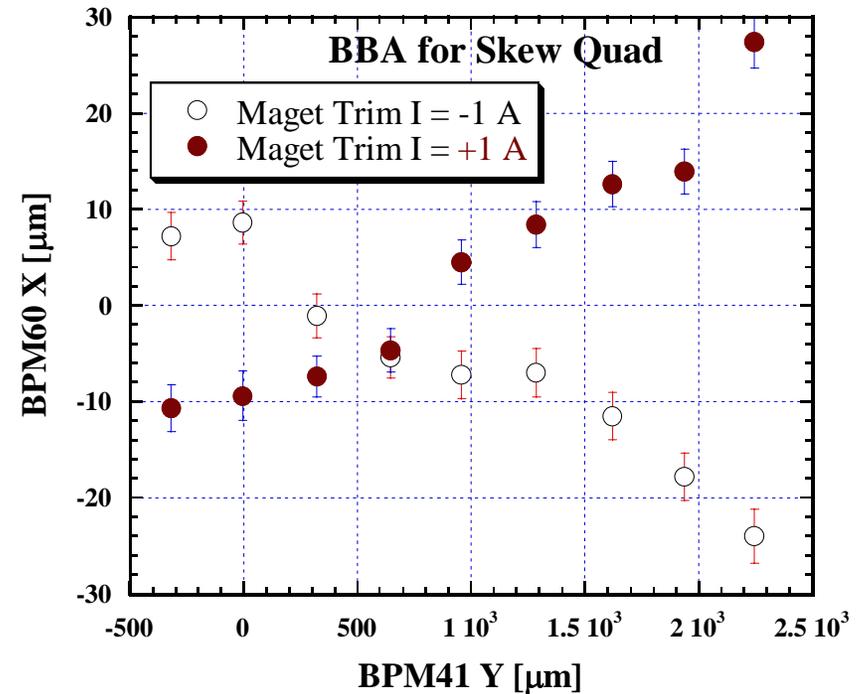
Position at BPM outside local bump vs. amplitude of bump

Examples

Bump at Quad



Bump at Skew Quad



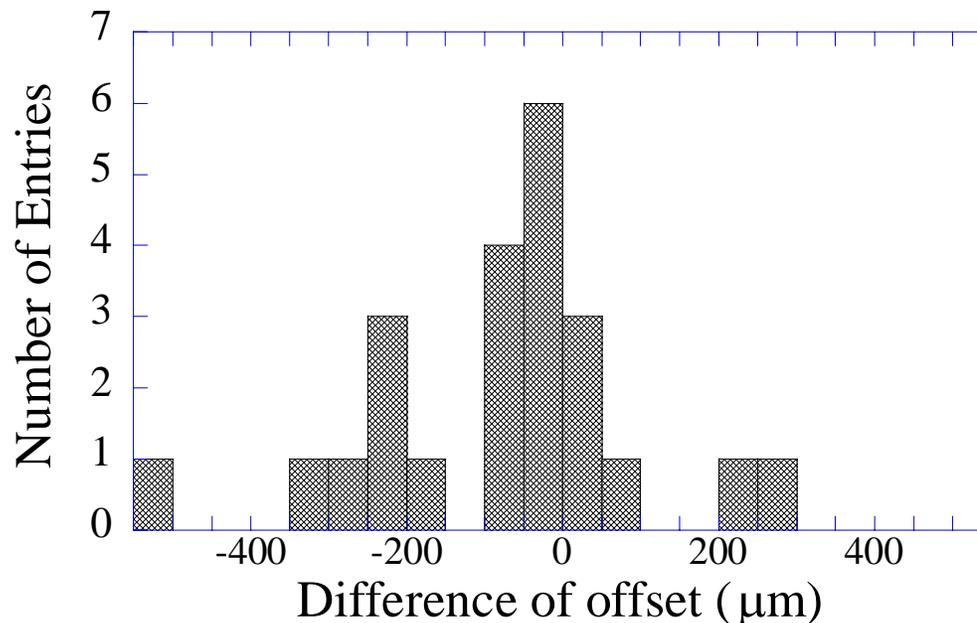
Beam Based Alignment - results2

Long term Stability

Measured in April 2008 and April 2009.

Difference of estimated vertical BPM- magnet offset between two sets of measurements for 26 main quadrupole magnets.

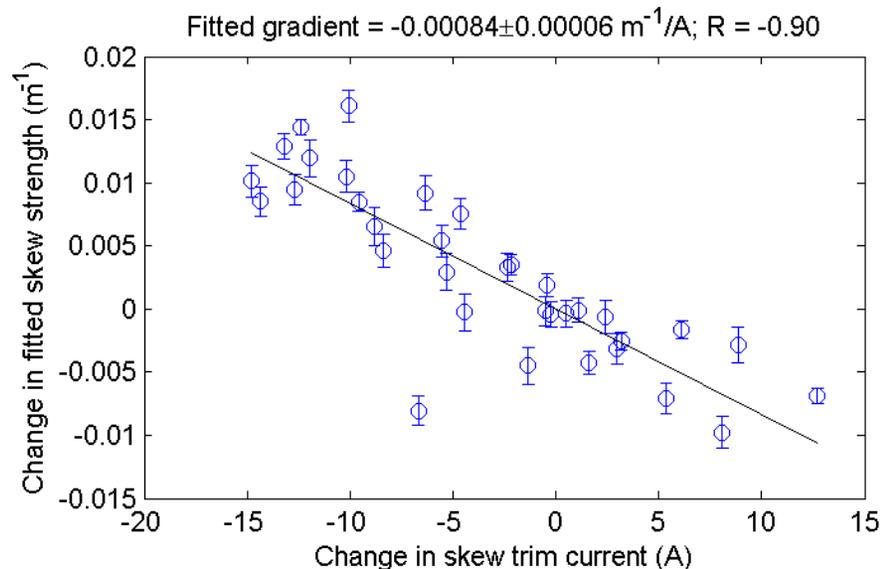
**Significant change in one year for some BPM-magnet pairs.
Probably came from BPM electronics.**



ORM Analysis

Correlation between

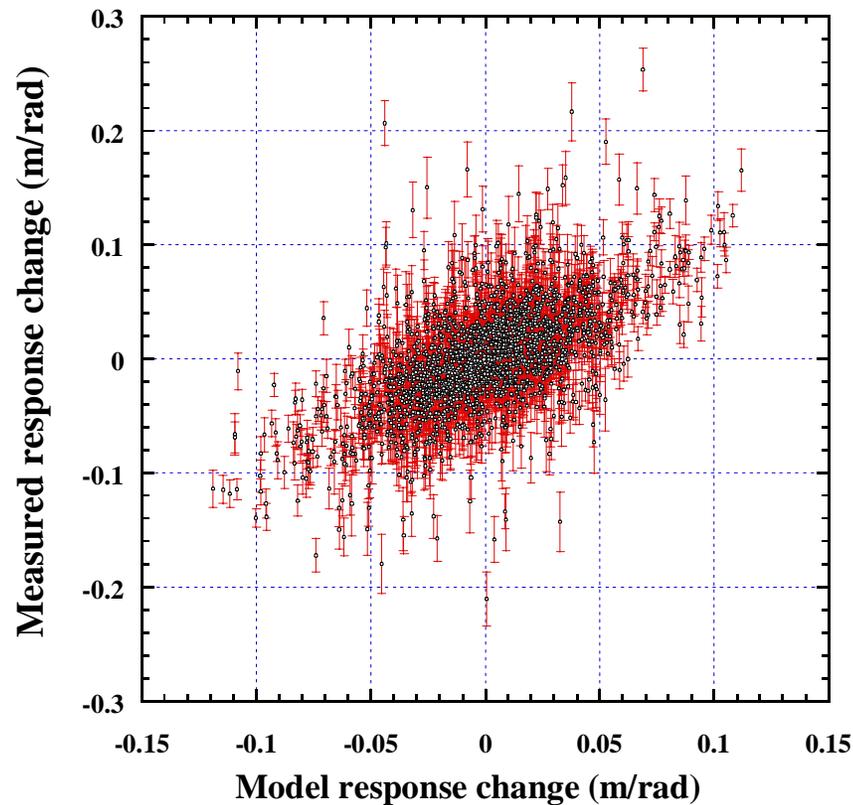
- Changes in skew quadrupole strengths determined from ORM analysis, and
- Known changes in currents applied to correctors



Deviations from the straight line indicate error of present model.

ORM Analysis

Response of all BPMs to all horizontal steering magnets
(But omitted if error < 0.03)



Measured April 10, 2009