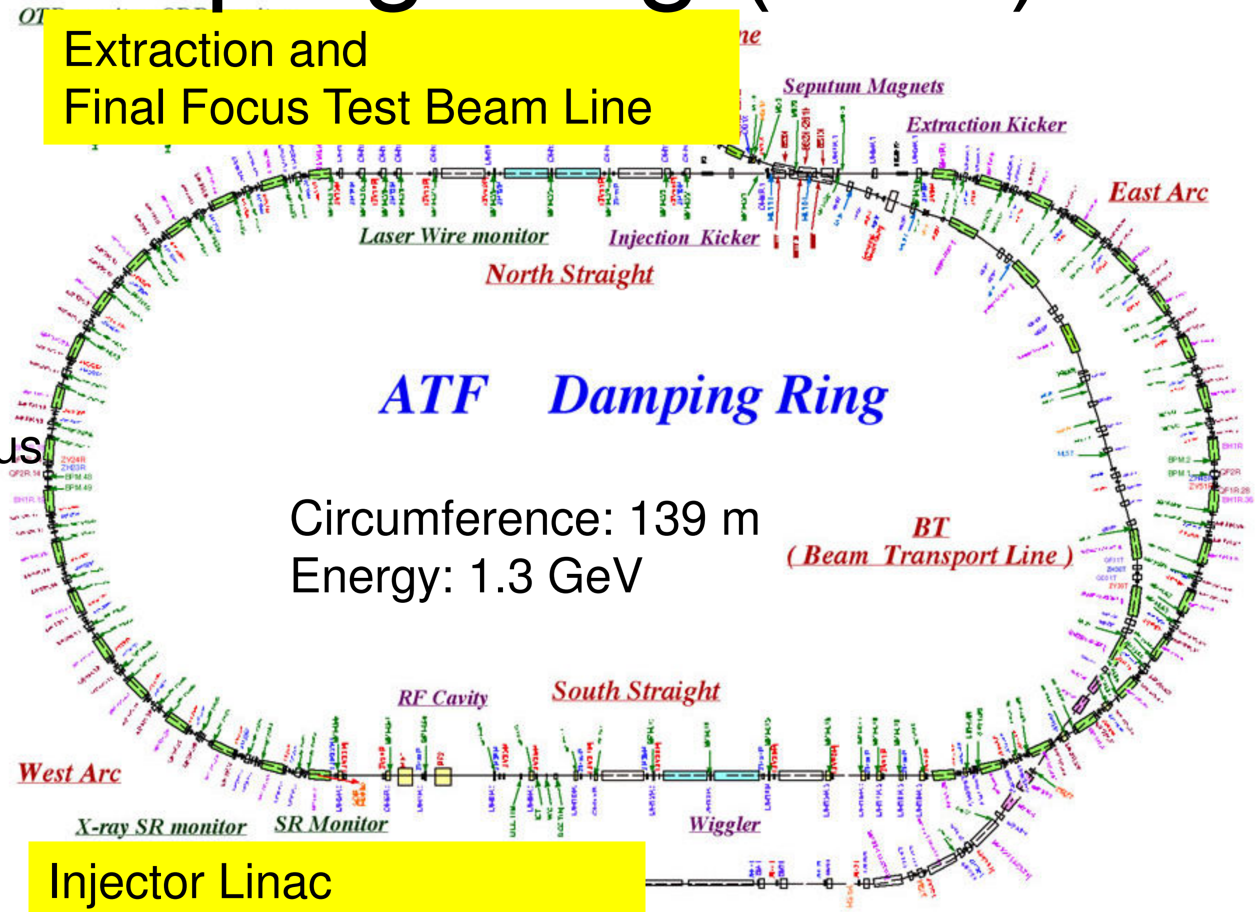
Status of ATF Damping Ring low vertical emittance studies

2009.10.

K. Kubo

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.



Required or target of low vertical emittance

Original design:	**12 pm**
Assumption in ATF2 design:	**12 pm**
ILC damping ring design:	**2 pm**

Low Emittance Tuning

Three consecutive corrections

- COD correction
- Vertical COD-dispersion correction
- Coupling correction

Monitor:

BPM (Beam Position Monitors) (total 96)

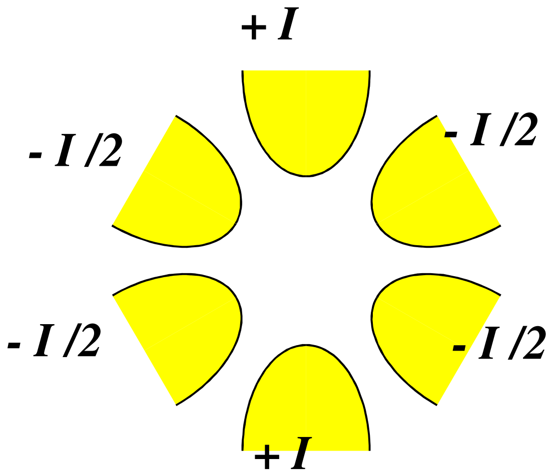
Corrector:

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

Low Emittance Tuning

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

$$\sum_{\mathrm{BPM}} x^2 \quad \text{and} \quad \sum_{\mathrm{BPM}} y^2 ,$$

:*x(y)*: horizontal (vertical) BPM reading.

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

$$\sum_{\mathrm{BPM}} y^2 + r^2 \sum_{\mathrm{BPM}} \eta_y^2$$

ηy: measured vertical dispersion.

r : weight factor = 0.05

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

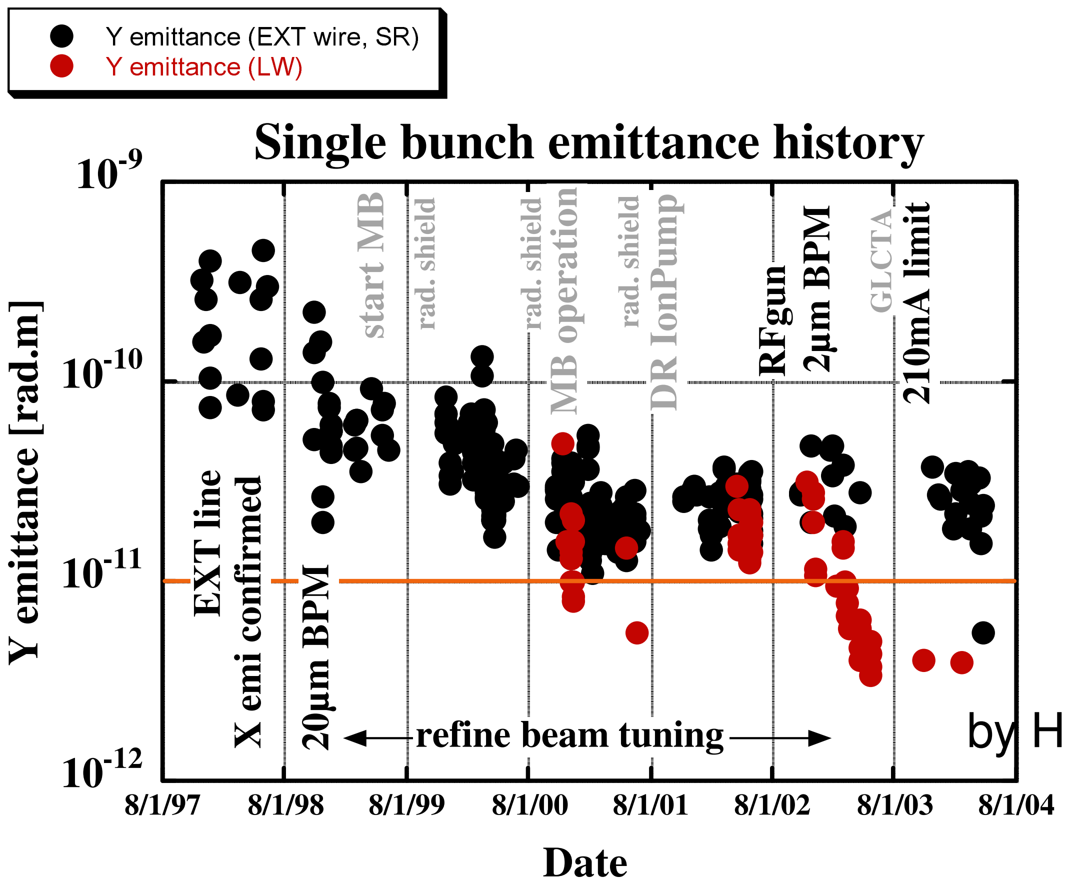
$$C_{xy} \equiv \sqrt{\sum_{\mathrm{H-steers}} \left(\sum_{\mathrm{BPM}} \Delta y^2 \Big/ \sum_{\mathrm{BPM}} \Delta x^2 \right) \Big/ N_{\mathrm{steer}}}$$

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

Two horizontal steering magnets were used (*N*steer=2). About (n+1/2)p phase advance between the two.

Old History of low emittance in ATF DR

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.



by H. Hayano

Recent efforts for low emittance

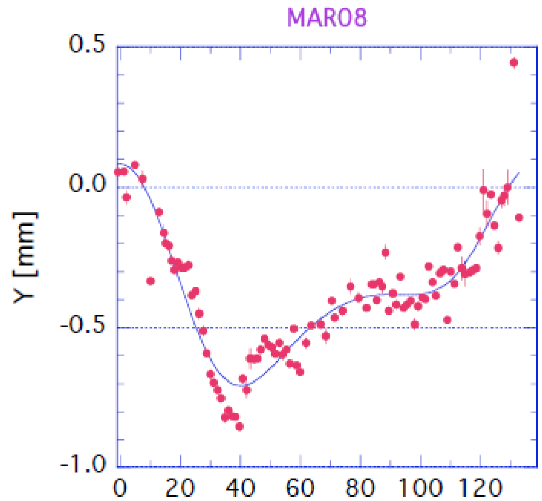
Re-Alignment of magnets

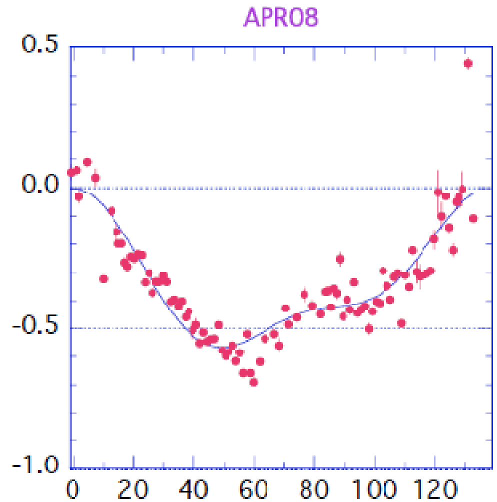
Related to beam measurement

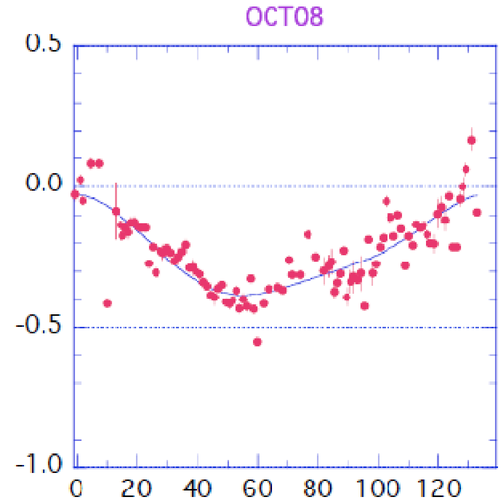
- BBA (Beam Based Alignment) measurement
- Optics matching (Beta-beat correction)
- ORM (Orbit Response Matrix) analysis

Effectiveness of each still needs to be understood.

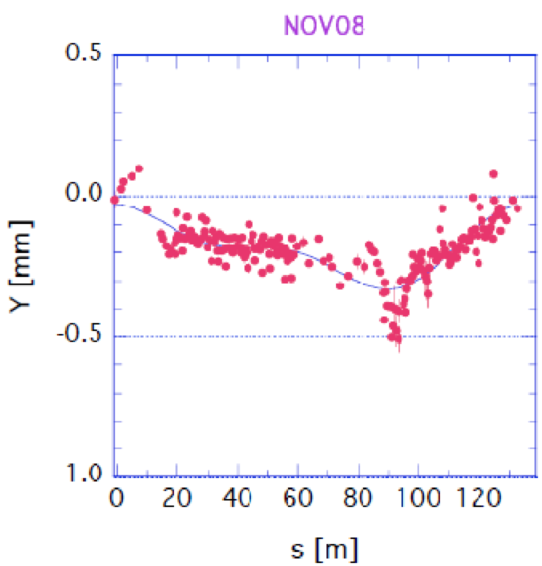
DR Magnet Level Measurement

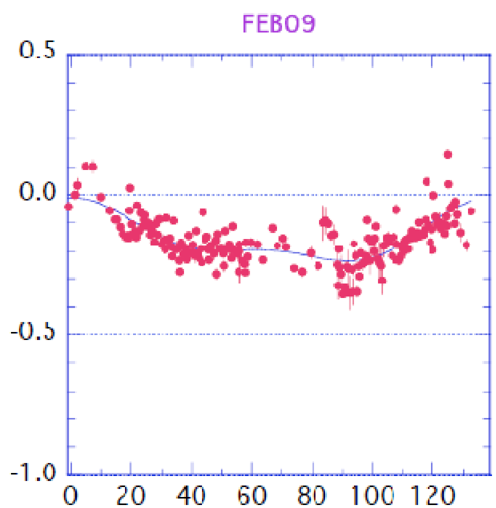






No data for SF, SD and QF1R in the first three measurements.



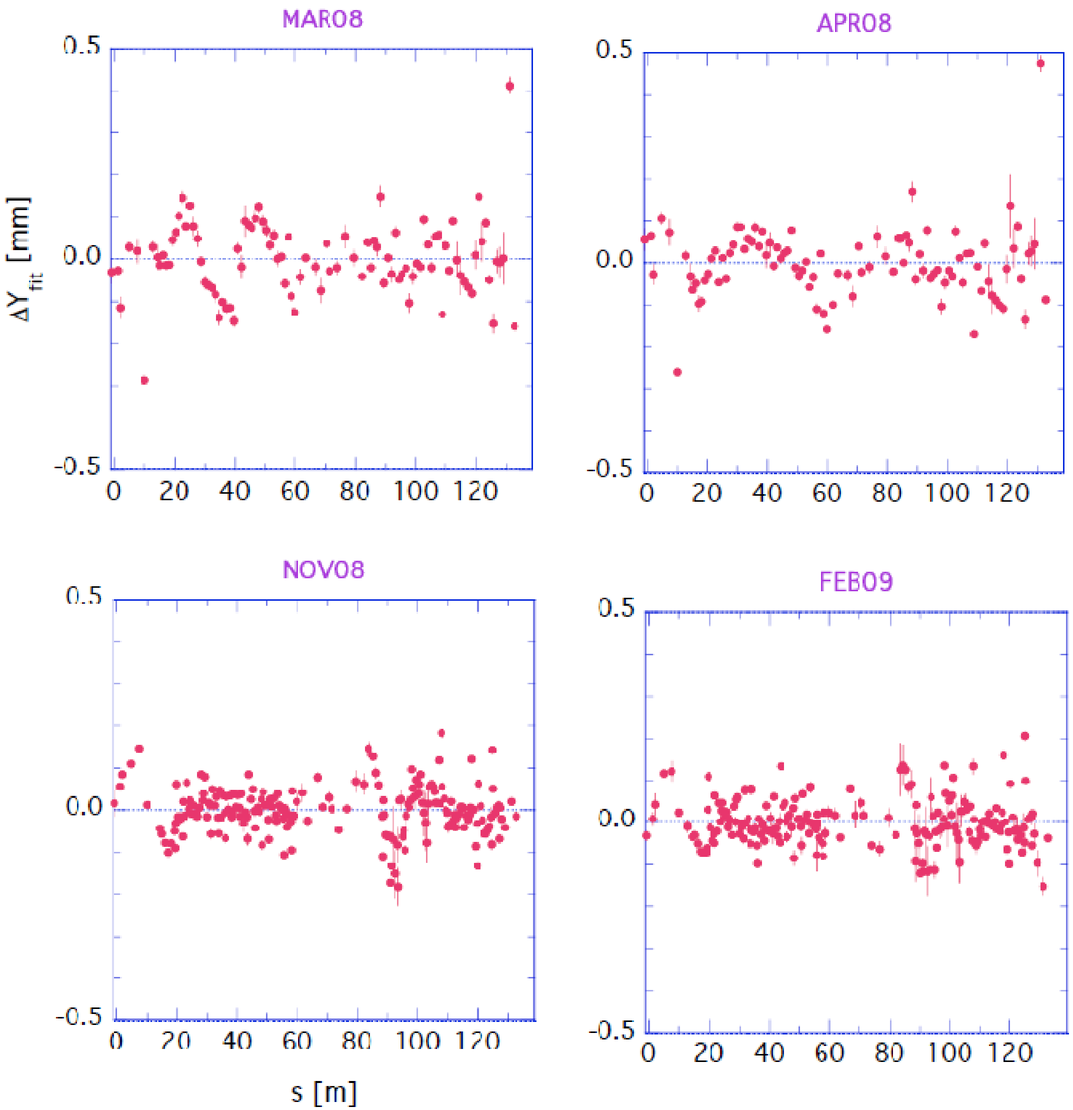


Smooth curves from fitting

$$\sum_{n=0}^{3} C_n \cos(2\pi n s / L + \phi_n)$$

M. Takano

Deviation from smooth curve



Improved?

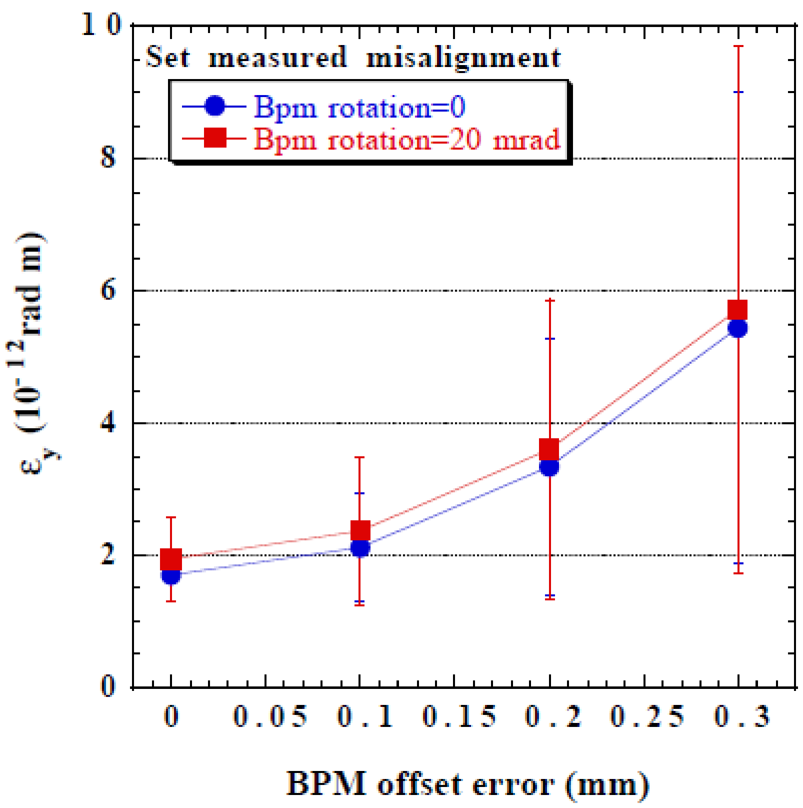
RMS(DY) [mm]
MAR08: 0.086
APR08: 0.084
OCT08: 0.076
NOV08: 0.057
FEB09: 0.056

M. Takano

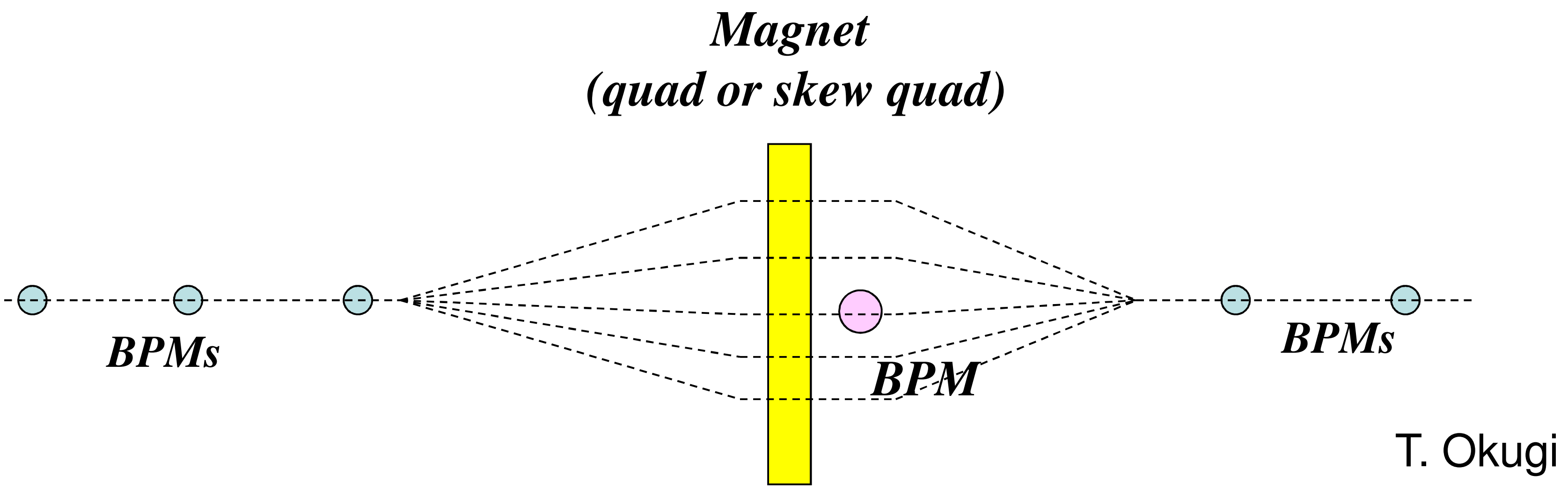
Beam Based Alignment

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: Vertical, Skew Quads: Horizontal
4. Estimate the minimum orbit difference point.

Trim winding of sextupole magnets

Beam Based Alignment - results

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

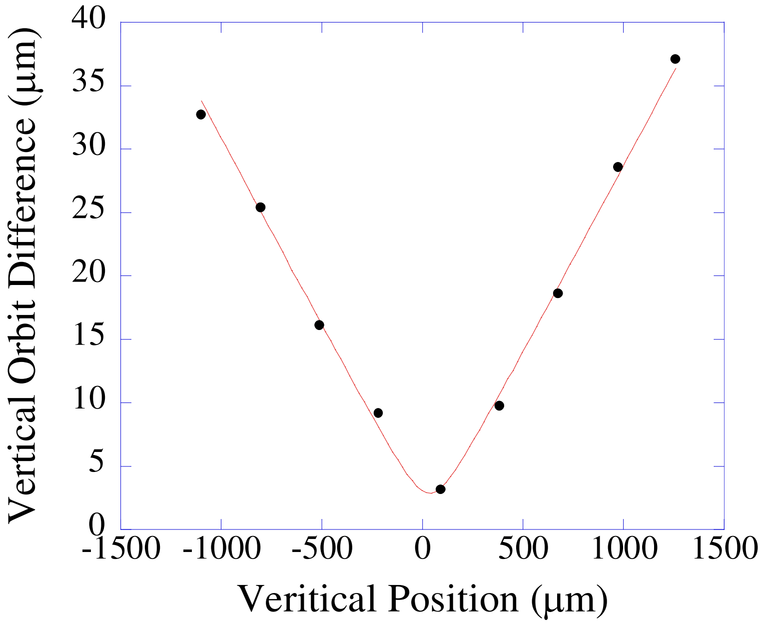
Fitted as

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

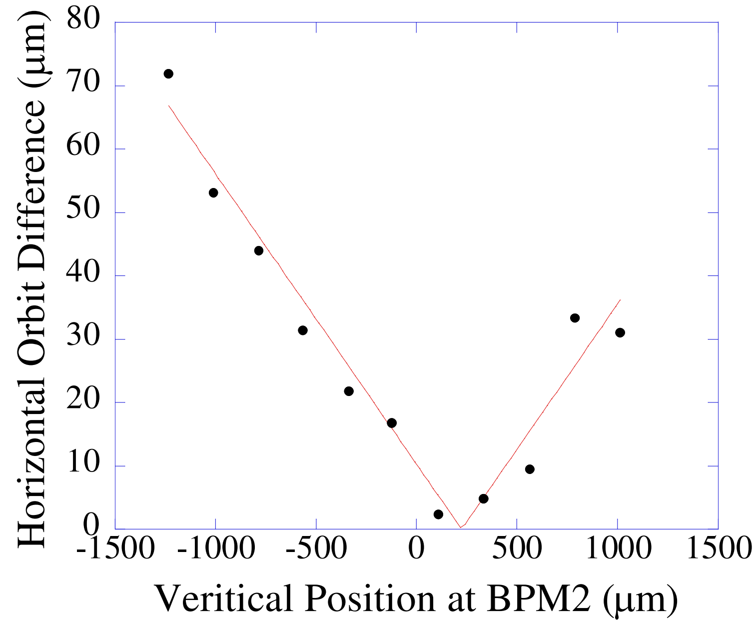
a : BPM - Magnet offset

Examples

Bump at Quad



Bump at Skew Quad (Sextupole)



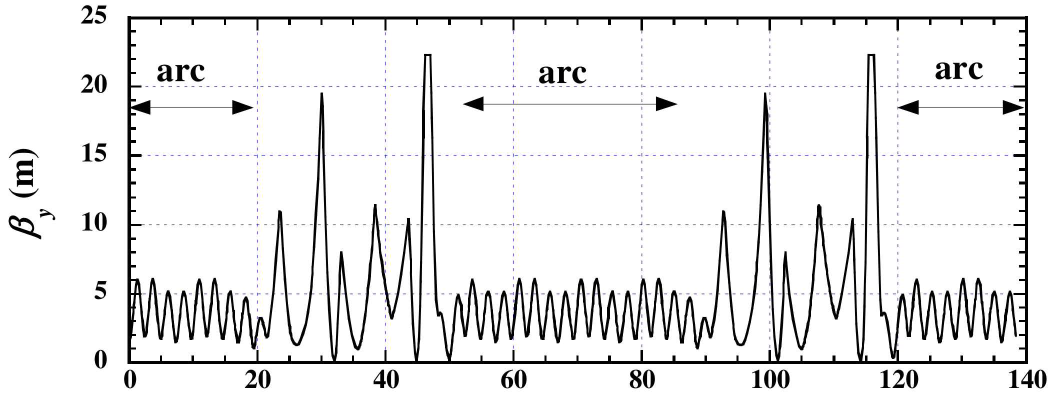
Typical error of offset: ~ 30 μm for Quad
~ 80 μm for Skew Quad

T. Okugi

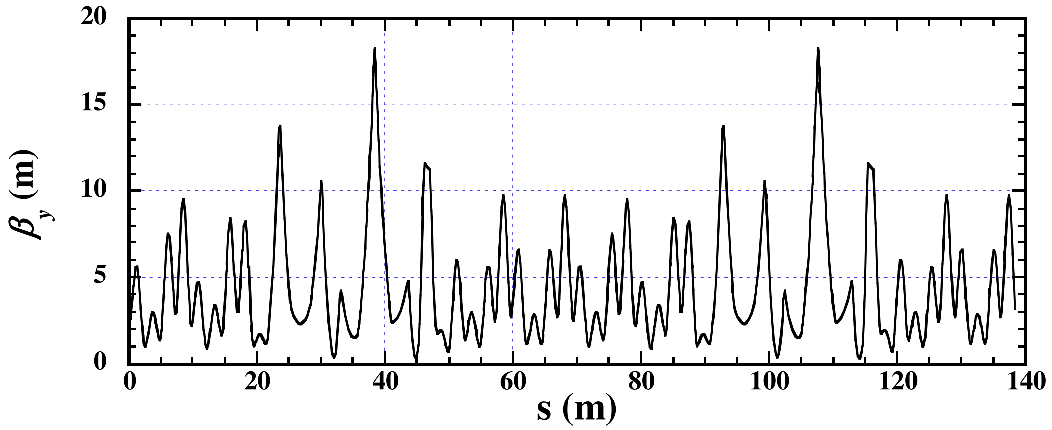
Optics matching (Beta-beat Correction)

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 can increase emittance sensitivity to errors.

Optics matching (Beta-beat Correction)

- Start from setting a “design” optics. (2008 fall)
- Measure beta-function at every quadrupole magnet
  - Beta-beat was observed.

Correction based fully on the model

  - We tried three (?) times. **Results were different from the calculations.**
  - Our model was not good enough for this methods. (?)

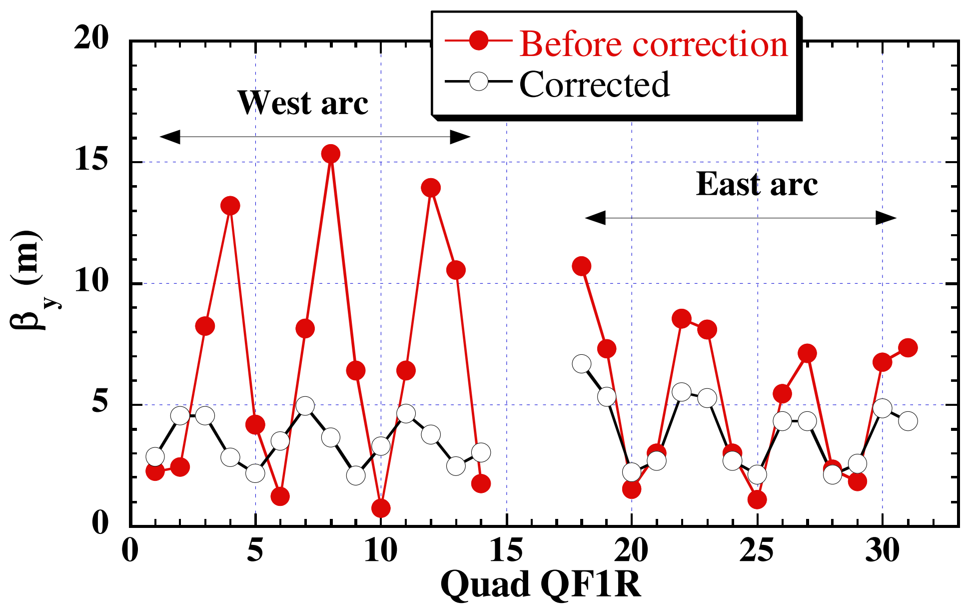
Partially rely on model, partially empirical method

Concentrate on vertical beta-function at QF1Rs (vertical beta-beat in arc sections)

  - Look for quadrupole magnets whose change would partly correct the beta-beat at QF1Rs from optics model.
  - **Some improvement**

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. (Example)



Not completely satisfactory. Need more study for better modeling.
But condition was improved.

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.

Need more studies for understanding how to use information from ORM.

Coupling correction using 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

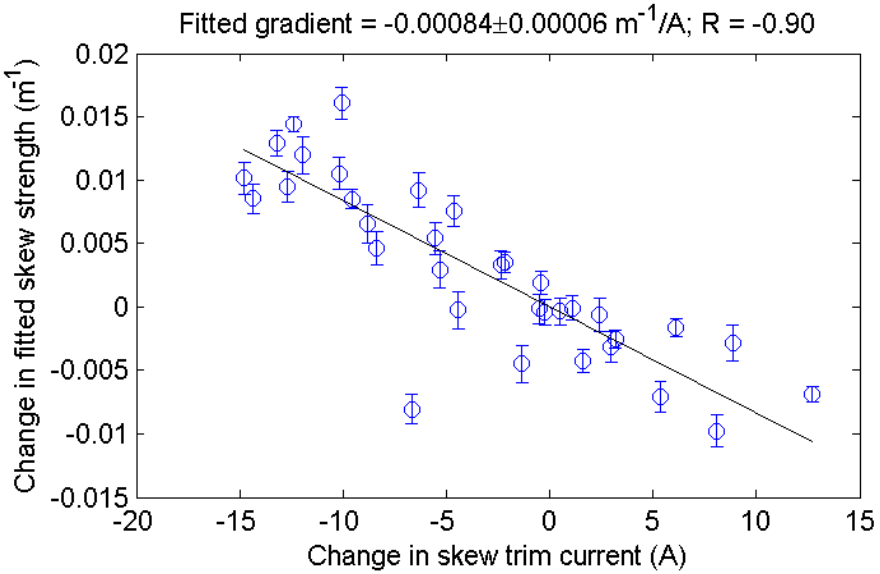
Possible limitations

- 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

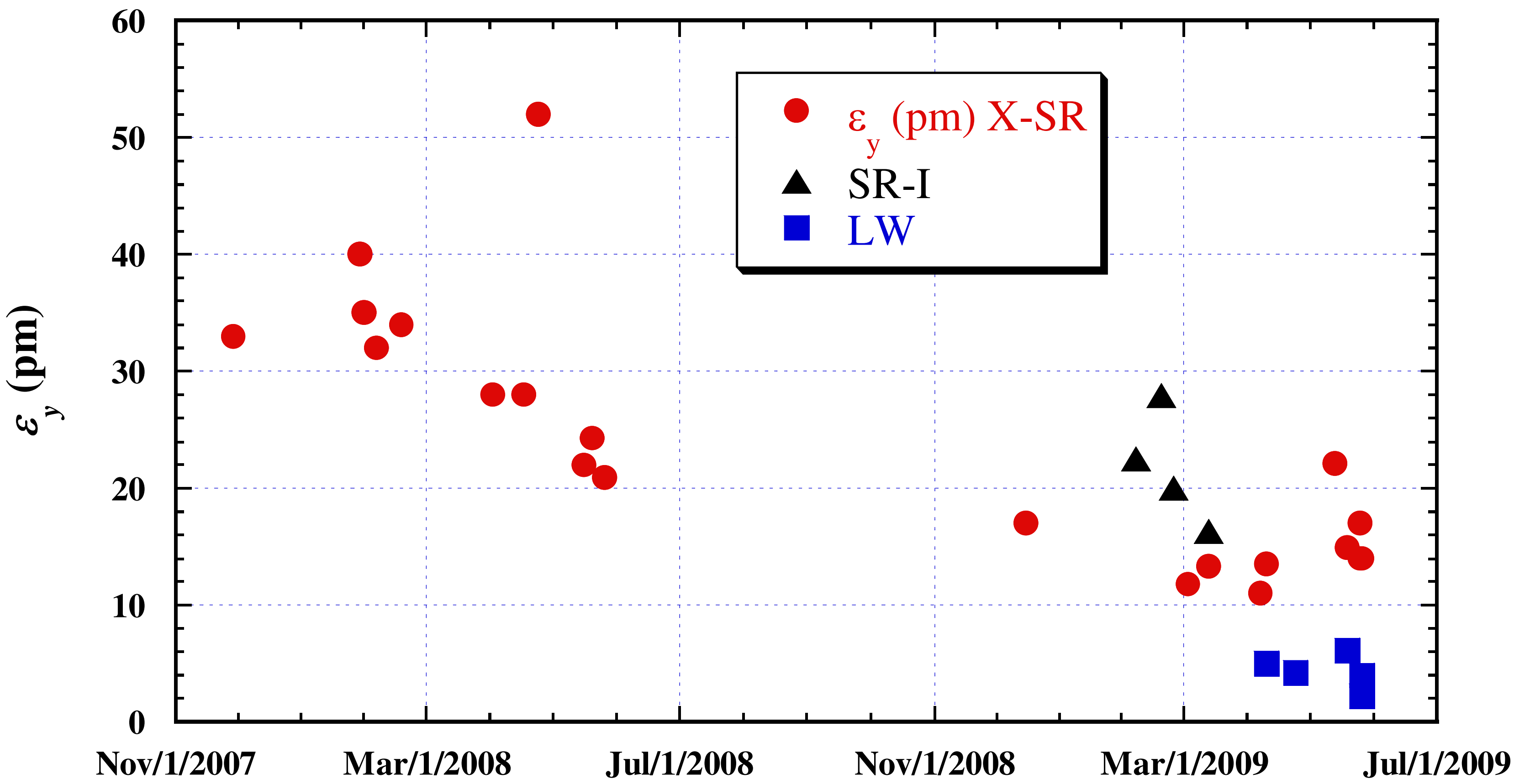
Correlation between

- 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.

Recent history of emittance in ATF DR



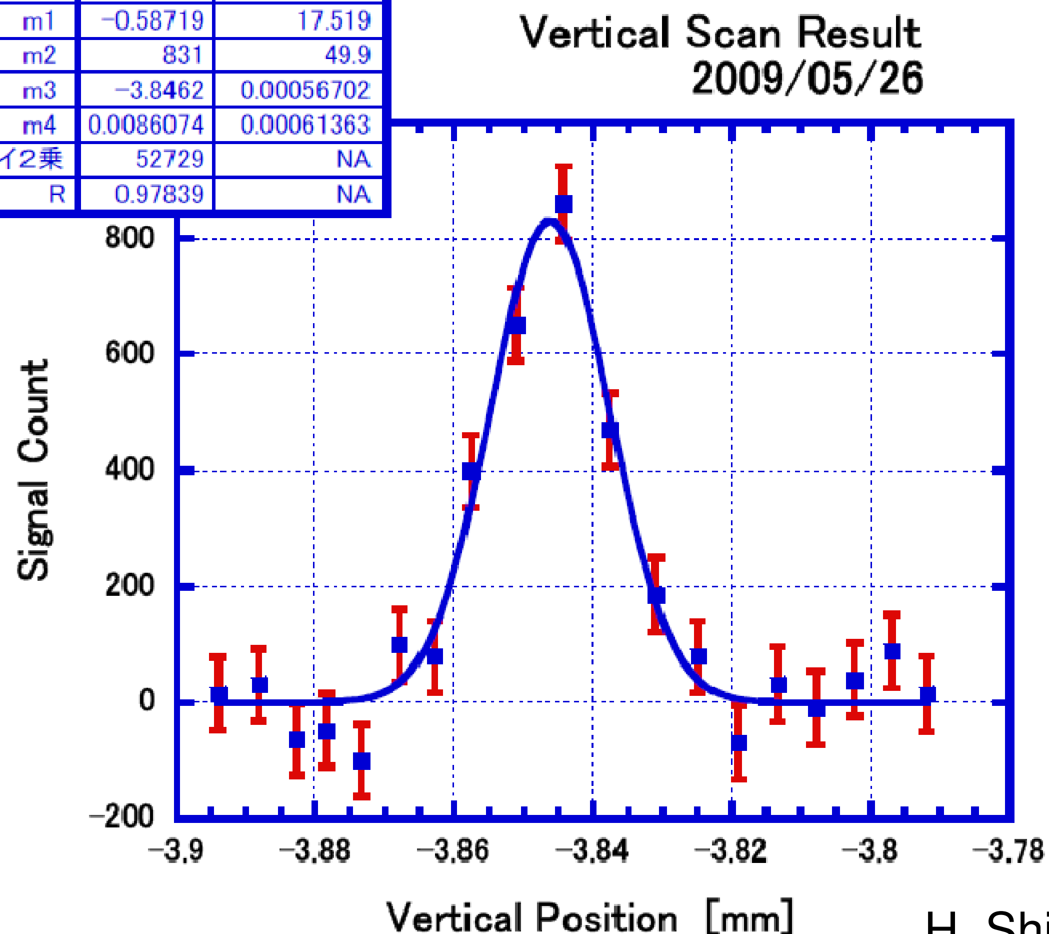
Vertical emittance < 10 pm (from Laser Wire measurement)
Smaller than limits of other monitors?

S. Kuroda and N. Terunuma

Example of DR Laser Wire measurement

s = 8.6 μm (convolution of beam size and laser size)

y = m1+m2*exp(-(m0-m3)^2/2/...		
	値	エラー
m1	-0.58719	17.519
m2	831	49.9
m3	-3.8462	0.00056702
m4	0.0086074	0.00061363
カイ2乗	52729	NA
R	0.97839	NA



H. Shimizu

Summary and Future Plans

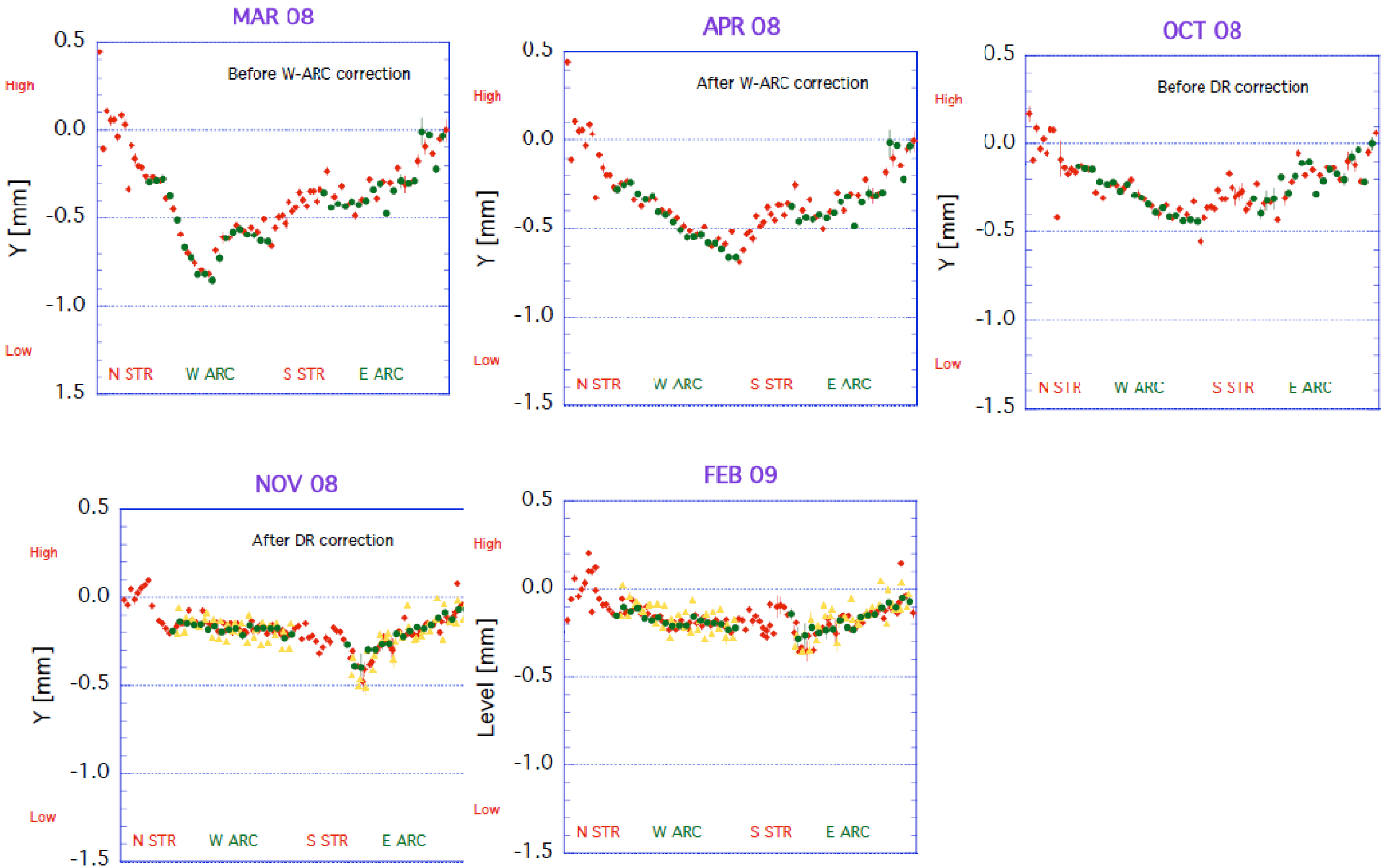
- Low emittance tuning and efforts for improving DR emittance
  - Re-alignment
  - BBA (BPM - Magnet offset measurement)
  - Optics matching (Beta-beat correction)
  - ORM (Orbit Response Matrix) analysis

- The emittance performance has been recovered.
  - **$\varepsilon_y < 10$ pm in April and May 2009. Good enough for FF test.**
  - Effectiveness of each item for this recovery is not clear yet.

- Plans for smaller emittance (2 pm is ILC DR design.),
  - More simulation studies on the tuning procedure
  - Analysis of beam measurement, e.g. ORM.
  - Upgrade of all BPM electronics (20 out of 96 BPMs were already upgraded)
  - Re-alignment of magnets.

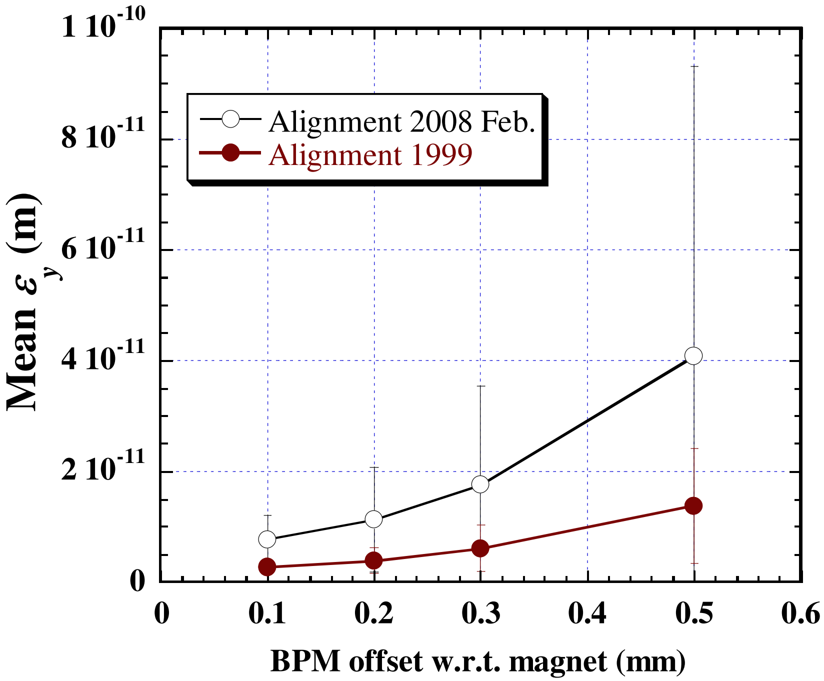
Backup Slides

DR Magnet Level Measurement

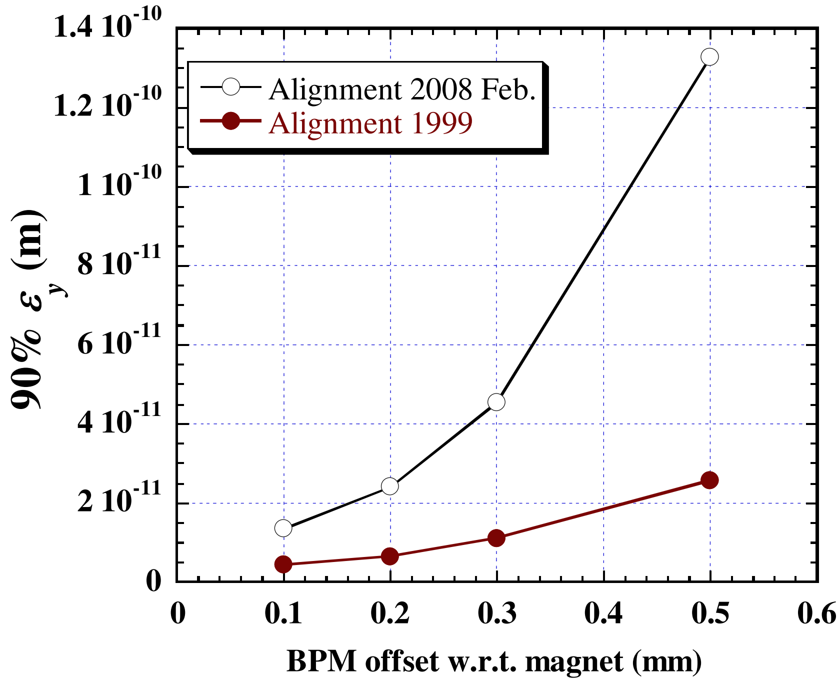


Emittance vs.
BPM offset w.r.t. nearest magnet
with two different magnet misalignment

Average of 100 seeds

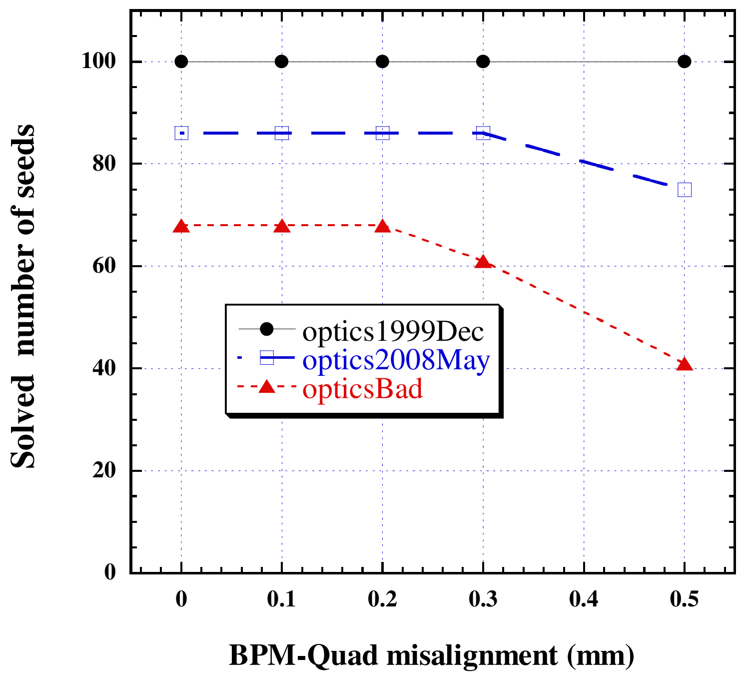


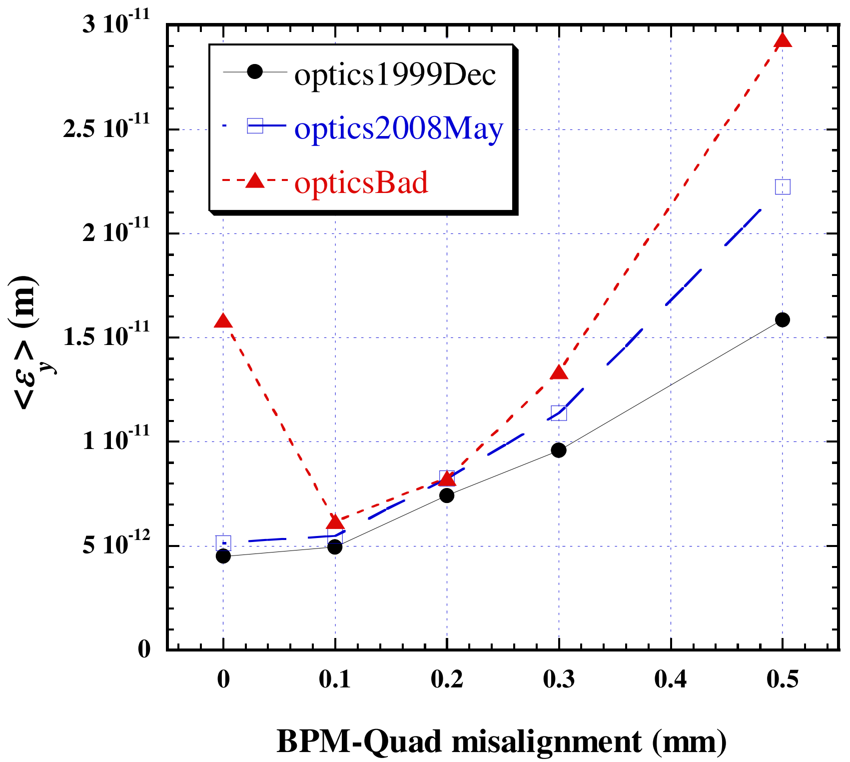
90% CL (90th among 100 seeds)



1999 data and 2008 data used different measurement methods.
Measurement error may be dominant in2008 data.
→ Can not tell change of alignment conditions from these data.

Result of tuning simulation, 3 optics
Number of random seeds giving results
Emittance vs. BPM-Magnet offset error





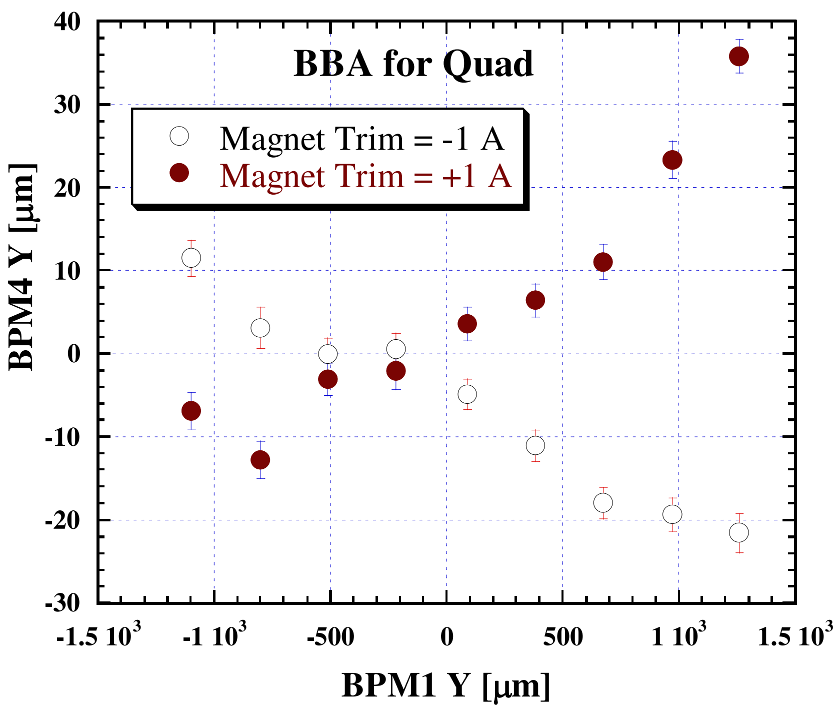
For some random seeds, SAD cannot find closed orbit, betafunctions, etc.
The left figure shows number of seeds out of 100, which give results.
The reason was not well studied and how to treat these results is not clear.

Beam Based Alignment

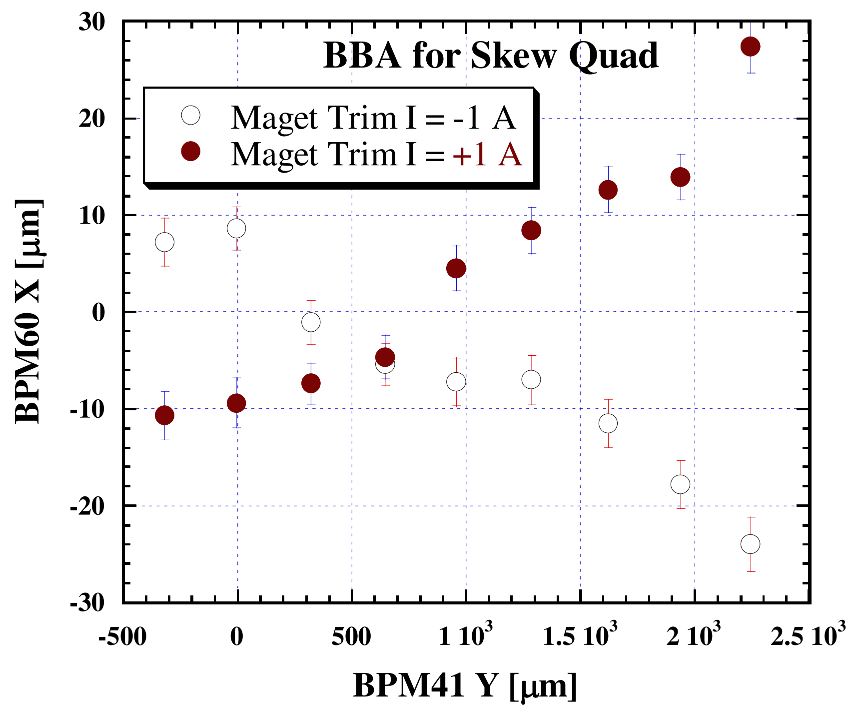
Position at BPM outside local bump vs. amplitude of bump

Examples

Bump at Quad



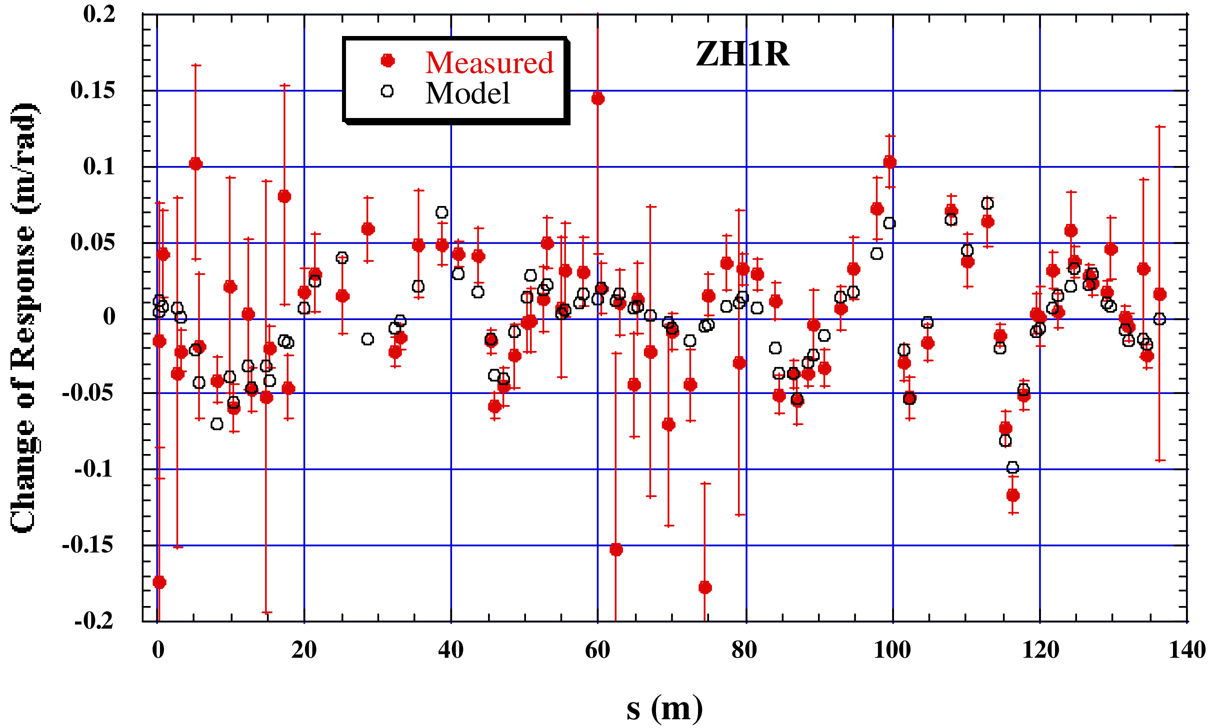
Bump at Skew Quad



Example of data from coupling correction

Changes in vertical orbit response to a horizontal steering.
Measurement and prediction from present model.

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

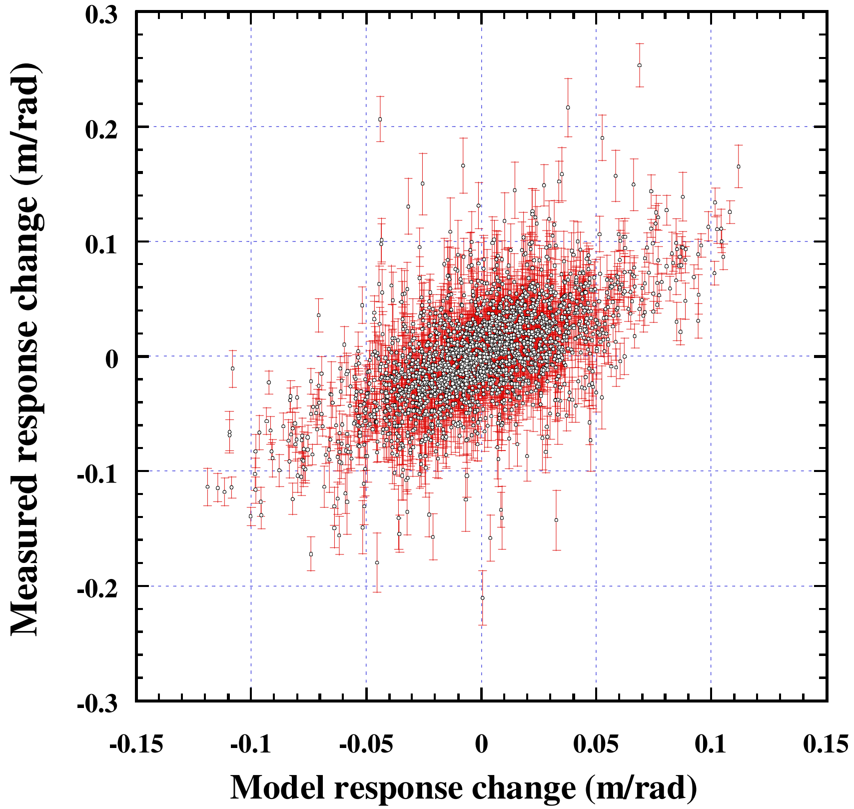


Measured April 10, 2009

ORM Analysis

Response o f all BPMs to all horizontal steering magnets

(But omitted if error<0.03)



Measured April 10, 2009