Error Tolerance and Optics Correction

Y. Ohnishi

Five Big Issues (FBI)

1. Injection and Touschek background
   H. Nakayama et al.
2. SR from QC1/QC2
   H. Nakayama et al.
3. Collimator
   Y. Suetsugu et al.
4. Machine error and optics correction
   Y. Ohnishi et al.
5. Beam-Beam interaction (inc. continuous injection, iBump FB)
   N. Iida, Y. Funakoshi et al.

Five Big Issues (FBI)

1. Injection and Touschek background
2. SR from QC1/QC2
3. Collimator
4. **Machine error and optics correction**
5. Beam-Beam interaction (inc. continuous injection, iBump FB)

Five Big Issues (FBI)

4. Machine error and optics correction

- 4-1 Measurement of x-y coupling
- 4-2 Measurement of dispersions
- 4-3 Measurement of betatron phase-advance
- 4-4 Optics correction scheme

4 Introduction

1. Optics measurement based on closed orbit distortion(COD) can be used at low beam-current and non-collision condition. No fundamental difficulty is found at KEKB except for a time-dependent of orbit fluctuation.

2. Alternatively, it is possible to measure optics at high-beam current by using a single-pass BPM when small betatron oscillation is induced by an exciter. If the measurement of a non-collision bunch among many bunches is possible, the optics measurement is feasible during a collision condition. Rotation error of exciter along the beam-axis does not affect x-y coupling measurement at the first order(advantage over the COD-based measurement).

3. The COD-based measurement will be used as well as single-pass BPMs, especially beginning of the commissioning or until single-pass BPMs are ready.

4 Introduction

4. Besides the optics correction, stability of the optics during correction to correction is necessary. The optics correction had been performed once every two weeks at KEKB.

5. Error tolerance without optics corrections is indicative for the requirement of short-term stability at least.

    - drifting field strength of magnets, magnet misalignment, closed-orbit-distortions, and so on.

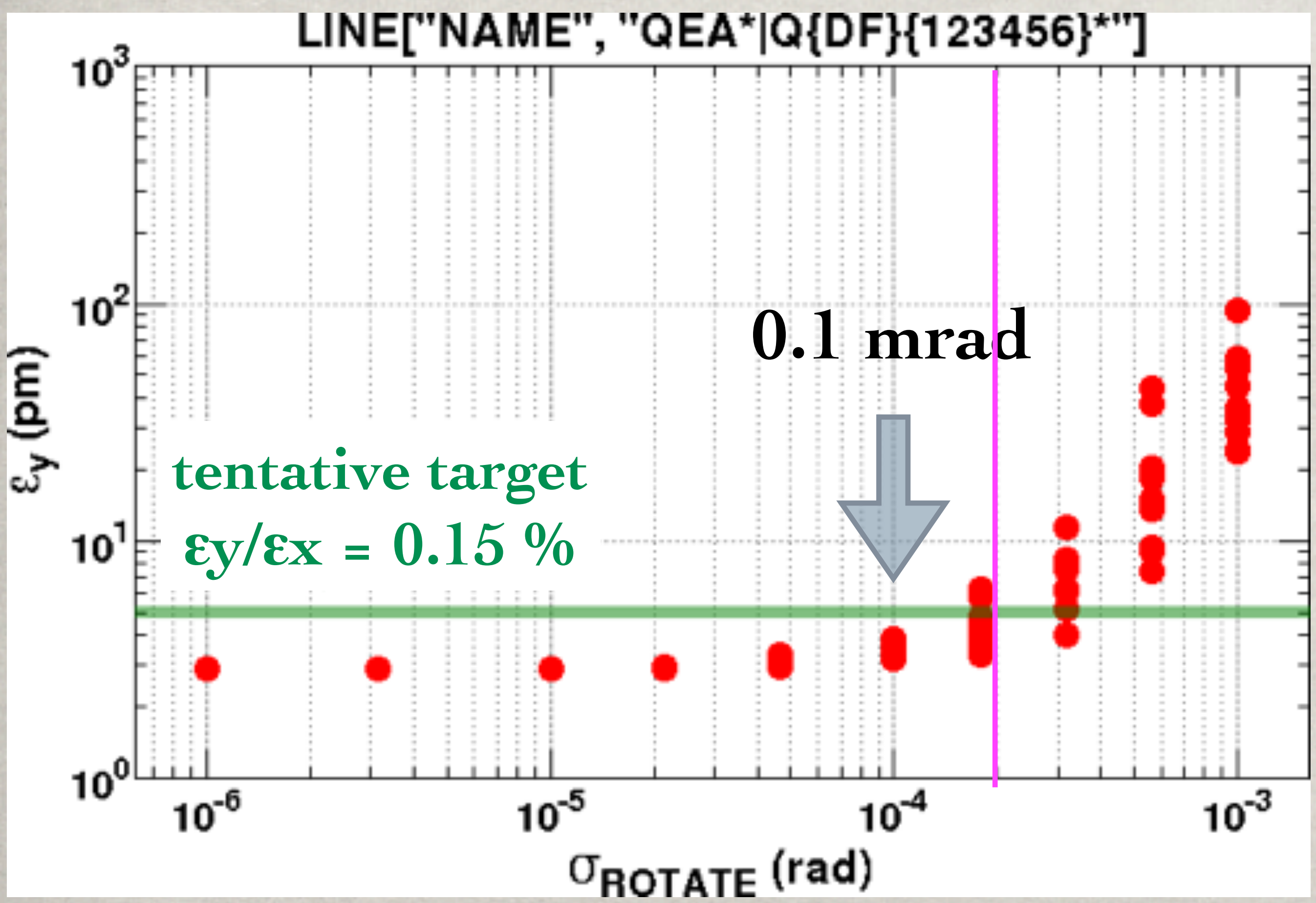
6. The coupling parameter is one of the most important parameters in the nano-beam scheme.

4 Error Tolerance (1)

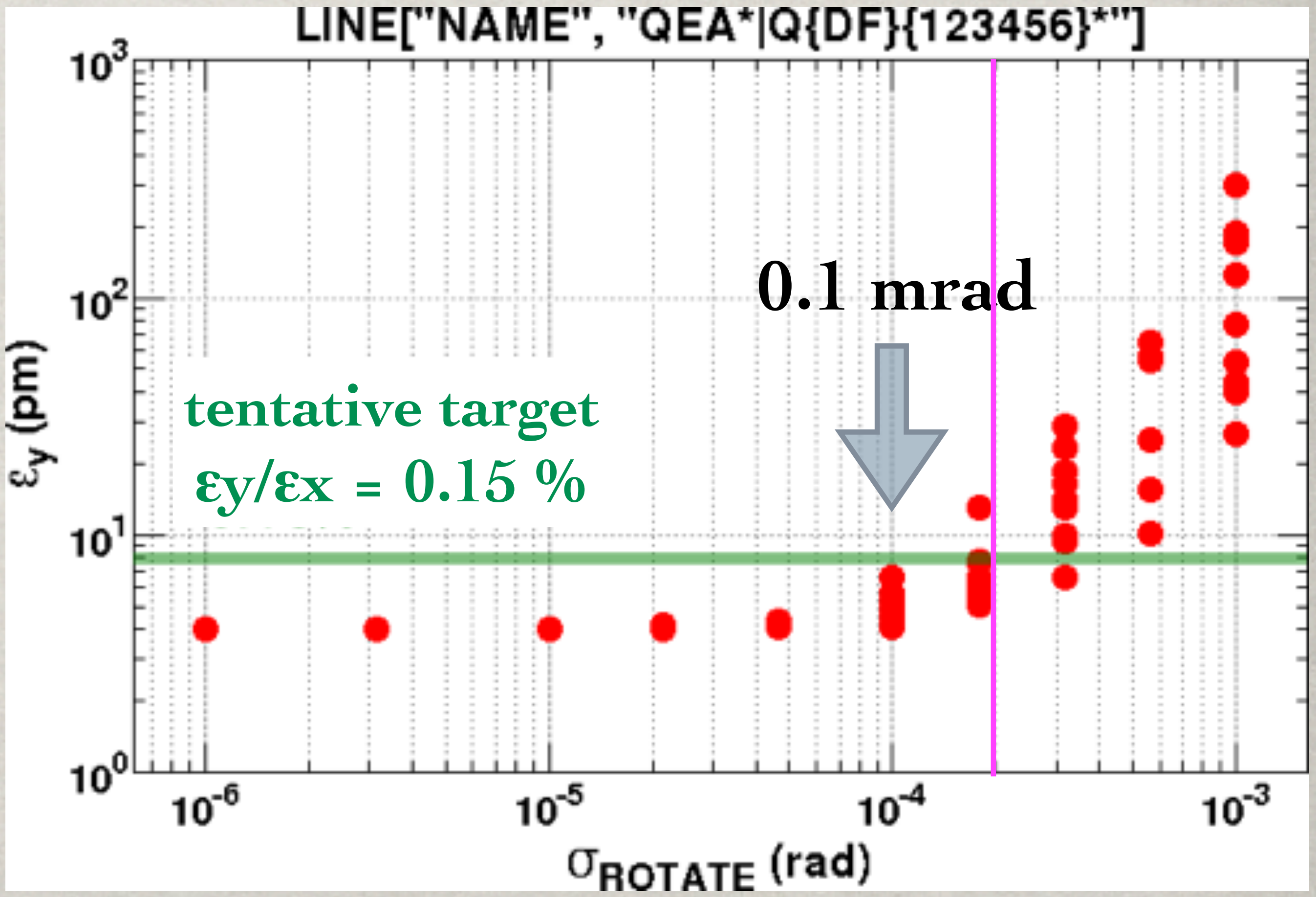
A. Morita

1. Rotation error of normal quadrupoles
2. Orbit offset of sextupoles

LER
normal quads.

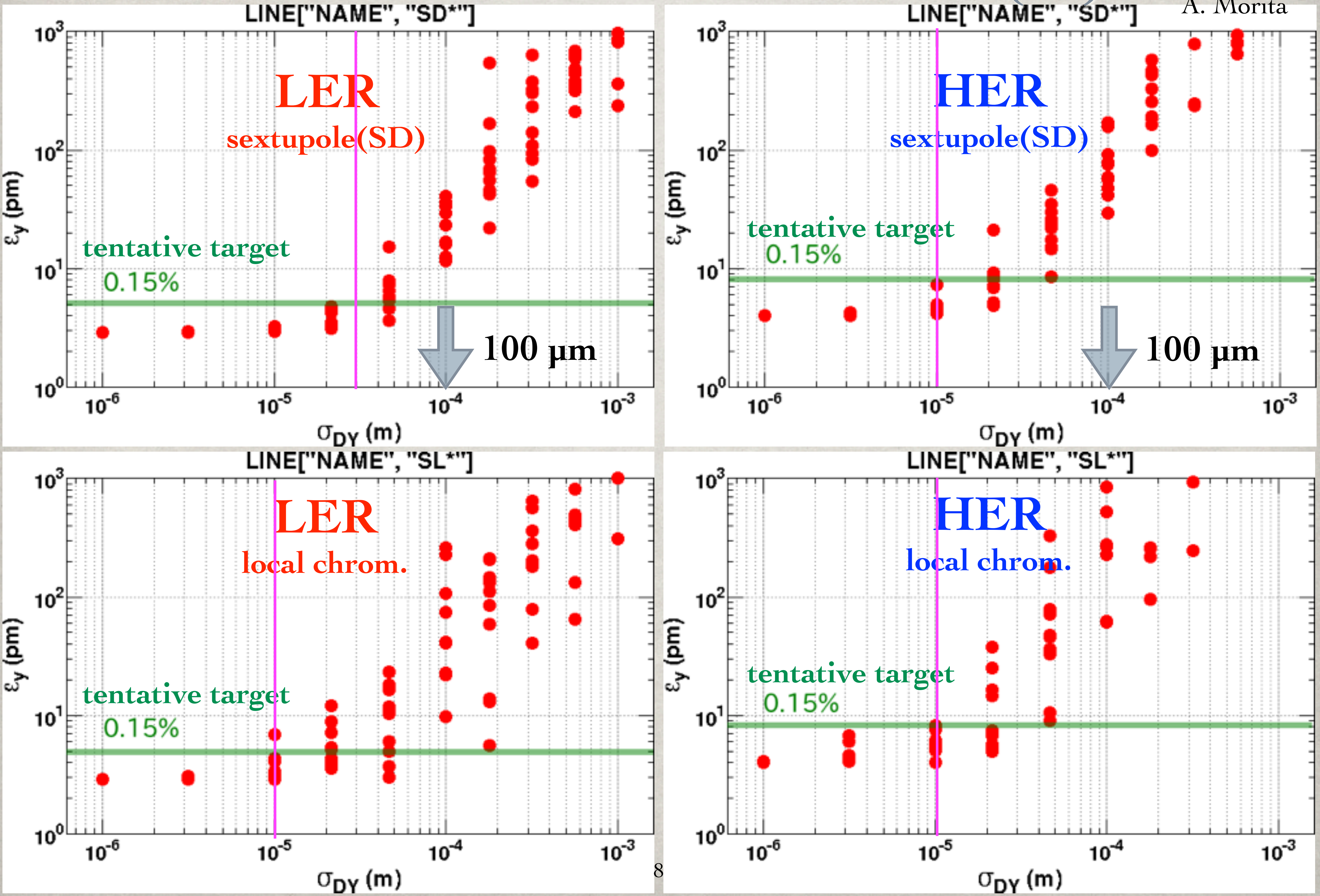


HER
normal quads.



4 Error Tolerance (2)

A. Morita



4 Acceptable Error Tolerance

Stability limit without optics corrections

	s.d.	LER	HER
Rotation error of normal quadrupoles	$\sigma_{\Delta\theta}$	0.2 mrad	0.2 mrad
Misalignment of normal sextupoles	$\sigma_{\Delta y}$	30 μm	10 μm
Misalignment of local chromaticity sextupoles	$\sigma_{\Delta y}$	10 μm	10 μm

4-1 Measurement of x-y Coupling

4-1 Measurement of x-y coupling

- The canonical momenta normalized by a design momentum are defined by:

$$p_x = (1+\delta)x' - \frac{B_z}{2B\rho_0}y \qquad p_y = (1+\delta)y' + \frac{B_z}{2B\rho_0}x \qquad \delta = \frac{\Delta p}{p_0}$$

- The canonical variables can be expressed as:

$$\begin{pmatrix} u \\ p_u \\ v \\ p_v \end{pmatrix} = \begin{pmatrix} \mu & 0 & -r_4 & r_2 \\ 0 & \mu & r_3 & -r_1 \\ r_1 & r_2 & \mu & 0 \\ r_3 & r_4 & 0 & \mu \end{pmatrix} \left\{ \begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix} - \begin{pmatrix} \eta_x \\ \eta_{px} \\ \eta_y \\ \eta_{py} \end{pmatrix} \delta \right\}$$

$$\mu^2 + (r_1 r_4 - r_2 r_3) = 1$$

decoupled coordinate

physical coordinate

4-1 Measurement of x-y coupling

- In the case of H-mode($v=0$, $p_v=0$):

$$
\begin{aligned}
x &= \mu u \\
p_x &= \mu p_u \\
y &= -r_1 u - r_2 p_u + \sum a_m \cos\theta_m \\
p_y &= -r_3 u - r_4 p_u + \sum b_n \cos\phi_m
\end{aligned}
$$

Vertical betatron oscillation due to rotation error of exciter along the beam-axis or x-y coupling is insensitive to the measurement.

$$< xy > = -\mu(r_1 < u^2 > + r_2 < up_u >) = -\frac{1}{\mu}(r_1 < x^2 > + r_2 < xp_x >)$$

$$< p_x y > = -\mu(r_1 < up_u > + r_2 < p_u^2 >) = -\frac{1}{\mu}(r_1 < xp_x > + r_2 < p_x^2 >)$$

$$< xp_y > = -\mu(r_3 < u^2 > + r_4 < up_u >) = -\frac{1}{\mu}(r_3 < x^2 > + r_3 < xp_x >)$$

$$< p_x p_y > = -\mu(r_3 < up_u > + r_4 < p_u^2 >) = -\frac{1}{\mu}(r_4 < xp_x > + r_4 < p_x^2 >)$$

$$\begin{pmatrix} < xy > \\ < p_x y > \end{pmatrix} = -\frac{1}{\mu}\Sigma \begin{pmatrix} r_1 \\ r_2 \end{pmatrix}$$

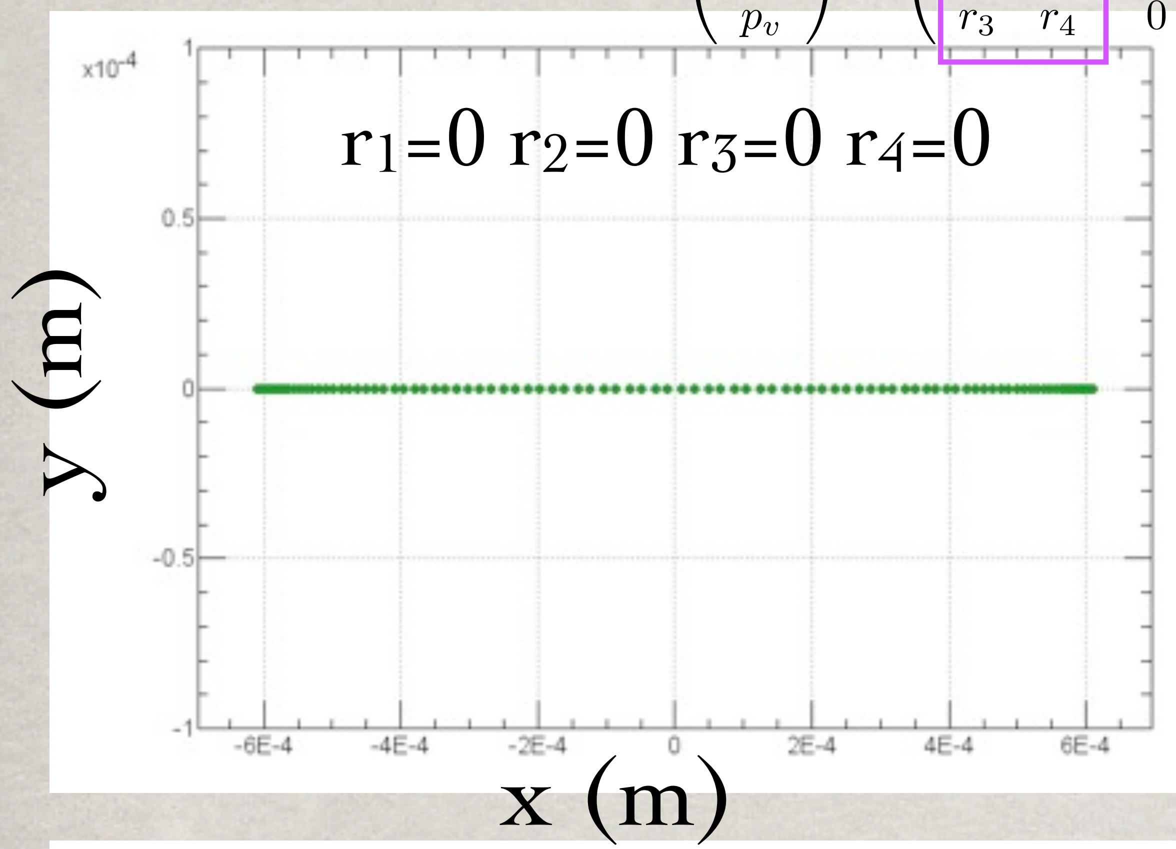
$$\begin{pmatrix} < xp_y > \\ < p_x p_y > \end{pmatrix} = -\frac{1}{\mu}\Sigma \begin{pmatrix} r_3 \\ r_4 \end{pmatrix}$$

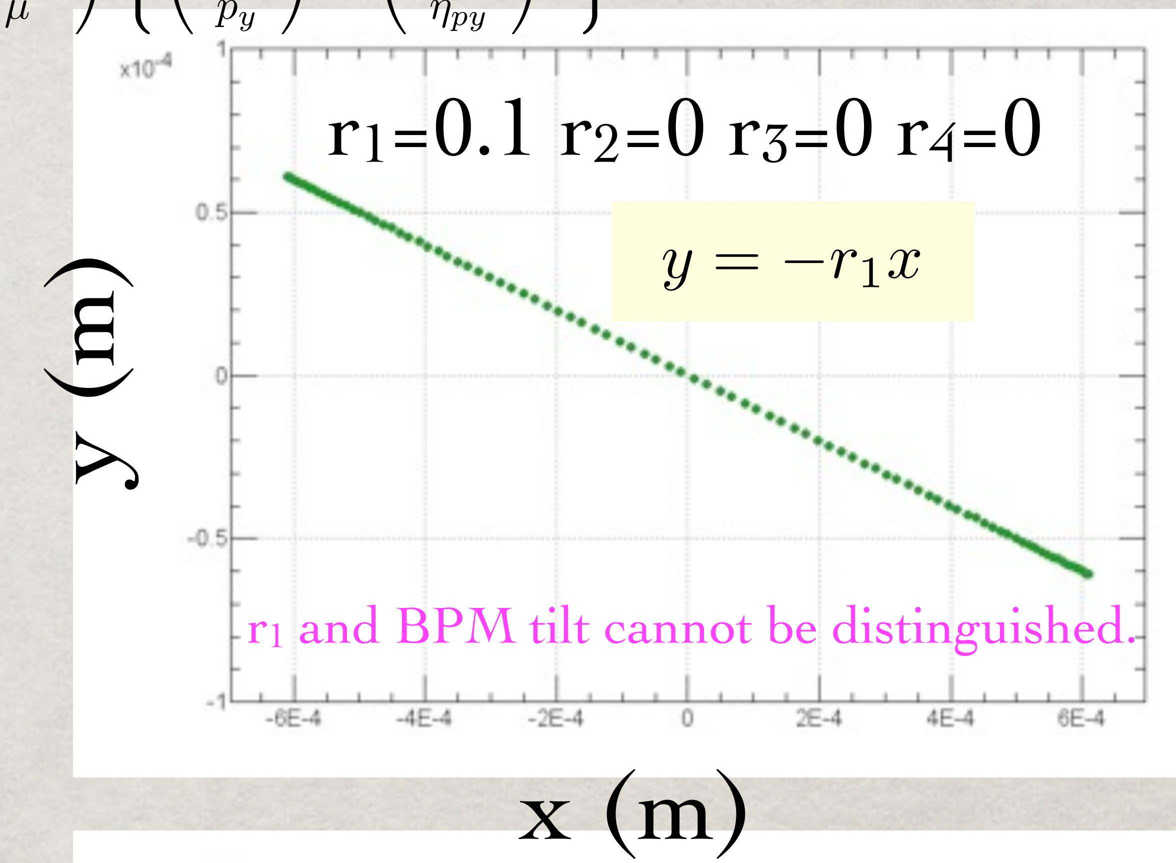
where $\Sigma = \begin{pmatrix} < x^2 > & < xp_x > \\ < xp_x > & < p_x^2 > \end{pmatrix}$

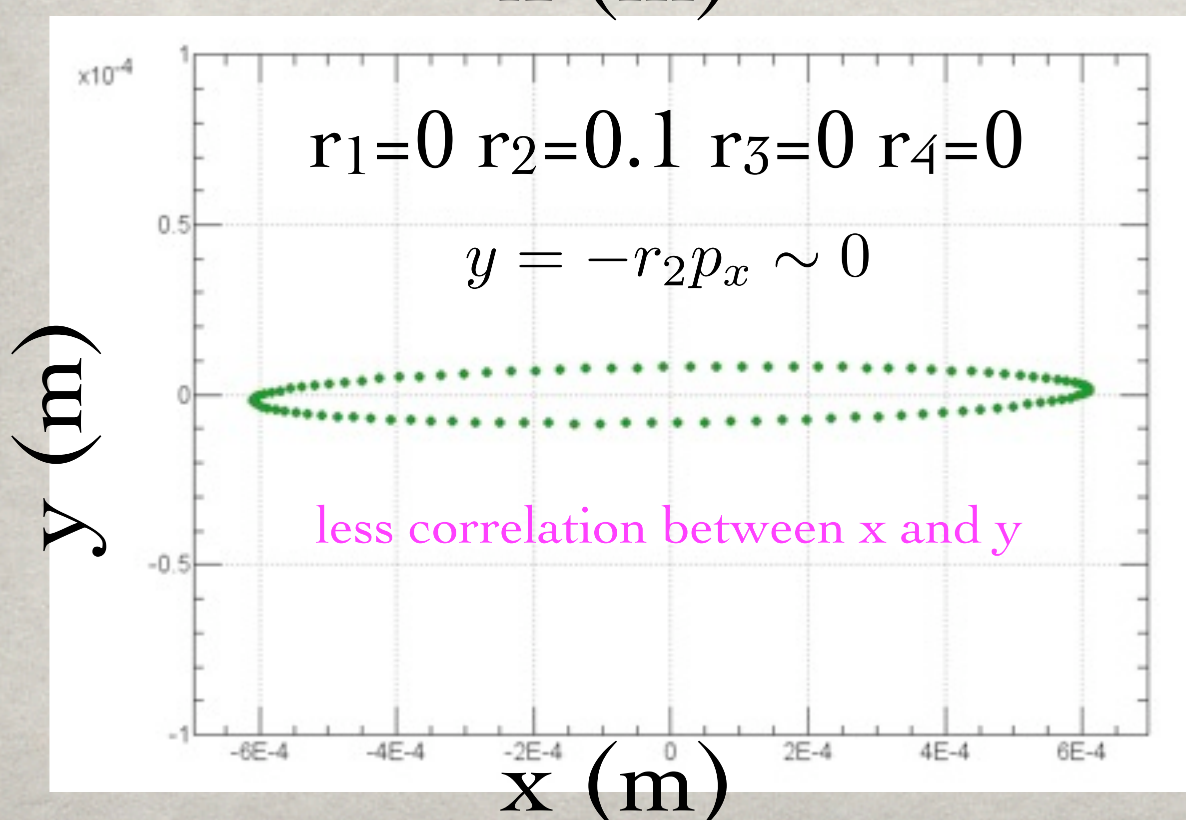
Correlation matrix method

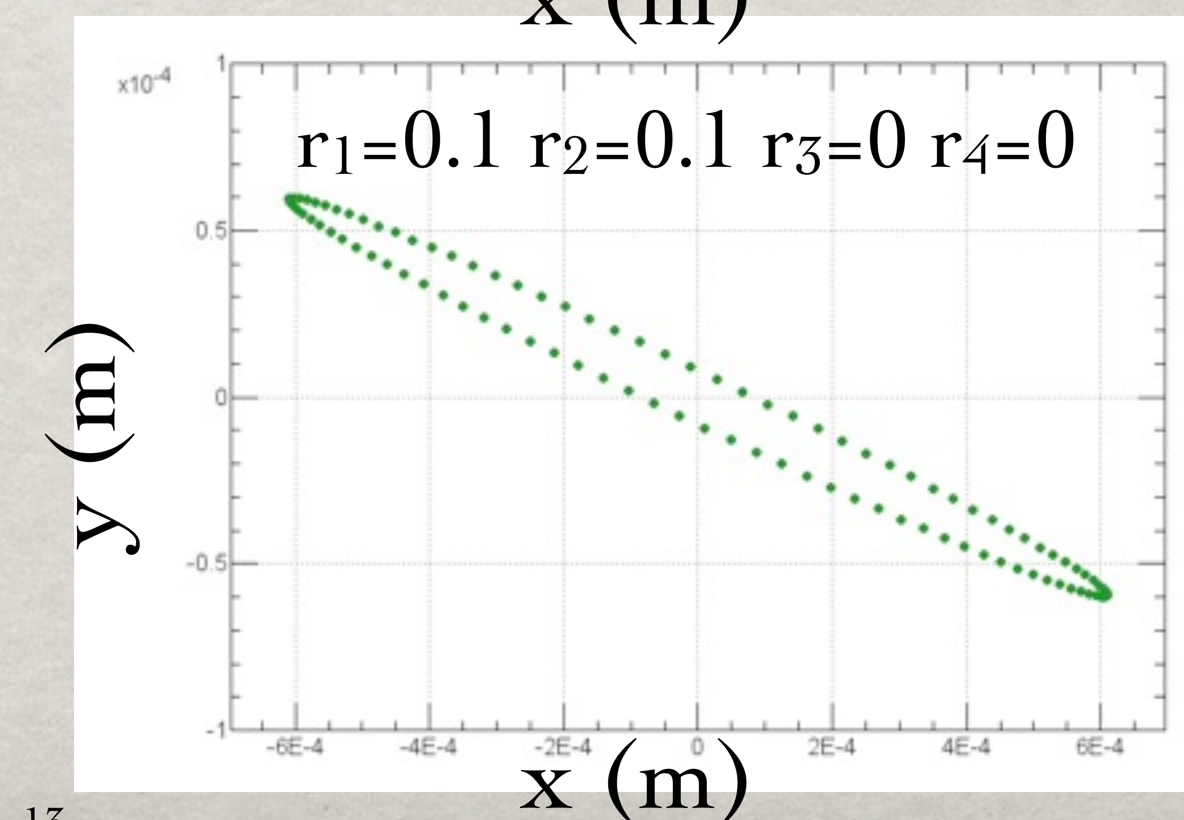
4-1 X-Y Coupling: Single-pass BPM

$$\begin{pmatrix} u \\ p_u \\ v \\ p_v \end{pmatrix} = \begin{pmatrix} \mu & 0 & -r_4 & r_2 \\ 0 & \mu & r_3 & -r_1 \\ r_1 & r_2 & \mu & 0 \\ r_3 & r_4 & 0 & \mu \end{pmatrix} \left\{ \begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix} - \begin{pmatrix} \eta_x \\ \eta_{px} \\ \eta_y \\ \eta_{py} \end{pmatrix} \delta \right\}$$









4-1 Measurement of x-y coupling

- In the case of H-mode($v=0$, $p_v=0$):

$$
\begin{aligned}
x &= \mu u \\
p_x &= \mu p_u \\
y &= -r_1 u - r_2 p_u \\
p_y &= -r_3 u - r_4 p_u
\end{aligned}
$$

- The x-y coupling parameters are derived as:

$$
\begin{pmatrix} r_1 \\ r_2 \end{pmatrix} = -\mu \Sigma^{-1} \begin{pmatrix} < xy > \\ < p_x y > \end{pmatrix}
$$

$$
\begin{pmatrix} r_3 \\ r_4 \end{pmatrix} = -\mu \Sigma^{-1} \begin{pmatrix} < x p_y > \\ < p_x p_y > \end{pmatrix}
$$

$$
\beta_u = \frac{< x^2 >}{\sqrt{\det \Sigma}}
$$

$$
\alpha_u = -\frac{< x p_x >}{\sqrt{\det \Sigma}}
$$

$$
\Sigma = \begin{pmatrix} < x^2 > & < x p_x > \\ < x p_x > & < p_x^2 > \end{pmatrix}
$$

Ref. Phys. Rev. SP-AB, 12, 091002 (2009)
K. Ohmi et al., Proc. of IPAC'10

4-1 Measurement of x-y coupling

- In the case of V-mode($u=0$, $p_u=0$):

$$y = \mu v$$
$$p_y = \mu p_v$$
$$x = r_4 v - r_2 p_v$$
$$p_x = -r_3 v + r_1 p_v$$

- The x-y coupling parameters are derived as:

$$\begin{pmatrix} r_4 \\ -r_2 \end{pmatrix} = \mu \Sigma^{-1} \begin{pmatrix} < yx > \\ < p_y x > \end{pmatrix}$$
$$\begin{pmatrix} -r_3 \\ r_1 \end{pmatrix} = \mu \Sigma^{-1} \begin{pmatrix} < y p_x > \\ < p_y p_x > \end{pmatrix}$$

$$\beta_v = \frac{< y^2 >}{\sqrt{\det \Sigma}}$$
$$\alpha_v = -\frac{< y p_y >}{\sqrt{\det \Sigma}}$$

$$\Sigma = \begin{pmatrix} < y^2 > & < y p_y > \\ < y p_y > & < p_y^2 > \end{pmatrix}$$

Ref. Phys. Rev. SP-AB, 12, 091002 (2009)
K. Ohmi et al., Proc. of IPAC'10

4-1 Measurement of x-y coupling

- p_x and p_y is calculated by using two BPMs:

$$p_{x1} = \frac{x_2}{\sqrt{\beta_{x1}\beta_{x2}}\sin\psi_{x,21}} - \left(\frac{\alpha_{x1}}{\beta_{x1}} + \frac{\cos\psi_{x,21}}{\beta_{x1}\sin\psi_{x,21}}\right)x_1$$

$$p_{y1} = \frac{y_2}{\sqrt{\beta_{y1}\beta_{y2}}\sin\psi_{y,21}} - \left(\frac{\alpha_{y1}}{\beta_{y1}} + \frac{\cos\psi_{y,21}}{\beta_{y1}\sin\psi_{y,21}}\right)y_1$$

- Here, assumed that transfer matrix between location 1 and 2 to calculate p_x and p_y. Design values of phase advance and Twiss parameters are used.

- Alternatively, in the general form:

$$\vec{x}_2 = M\vec{x}_1 \qquad M = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \qquad \vec{x} = (x, p_x, y, p_y)$$

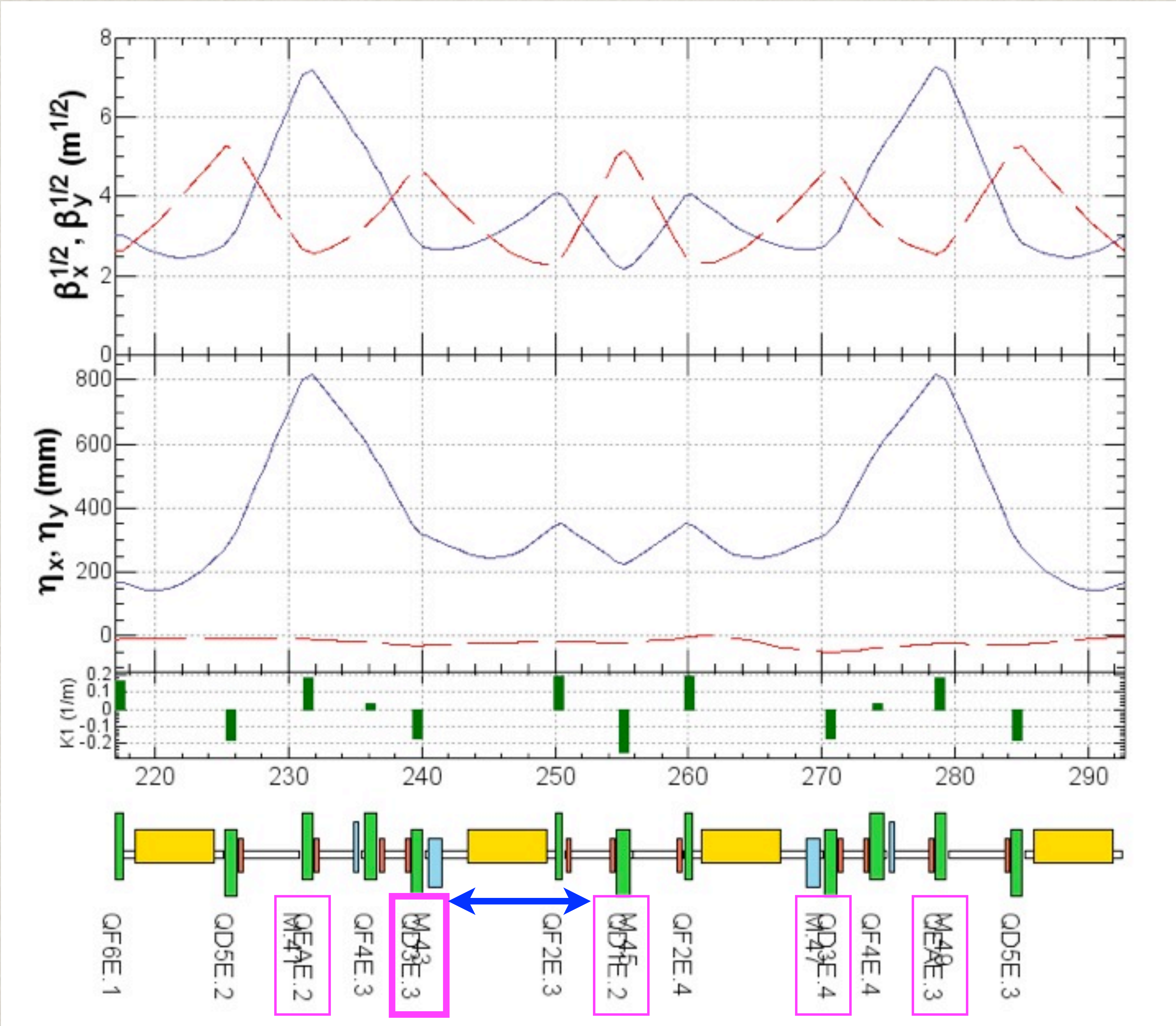
$$\begin{pmatrix} p_x \\ p_y \end{pmatrix} = \begin{pmatrix} m_{12} & m_{14} \\ m_{32} & m_{34} \end{pmatrix}^{-1} \left\{ \begin{pmatrix} x_2 \\ y_2 \end{pmatrix} - \begin{pmatrix} m_{11} & m_{13} \\ m_{31} & m_{33} \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \end{pmatrix} \right\}$$

4-1 Measurement of x-y coupling

Tracking simulation: HER lattice

- Single particle / Free oscillation
- No radiation damping
- Synchrotron oscillation
- 2000 turns
- Excite oscillation/ H-mode
- Assumed that μ=1, then solve iterative procedure. (not found $\mu^2<0$ in this simulation)
- Number of BPMs is 160 for the measurement in a ring.
- Coupling source: vertical displacement of sextupoles and rotation of quadrupoles: $\sigma_{\Delta y}$ = 100 μm for sxtupoles, $\sigma_{\Delta\theta}$ = 0.1 mrad for quadrupoles

4-1 Monitors (HER Arc Cell)



4-1 Measurement of x-y coupling

x-y coupling due to machine error

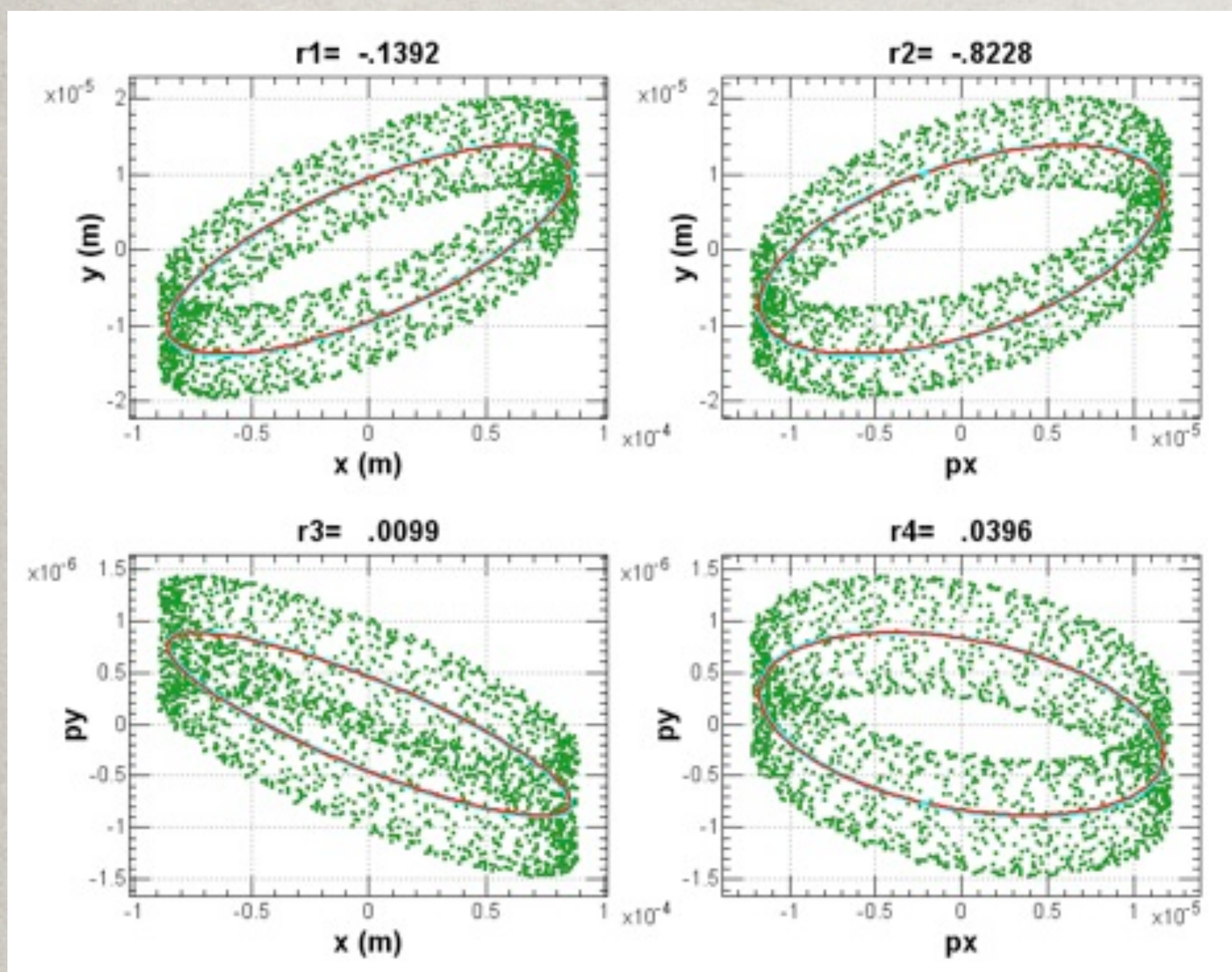
r_1=-0.1392, r_2=-0.8139, r_3=0.0097, r_4=0.0383 @ QD3E.3

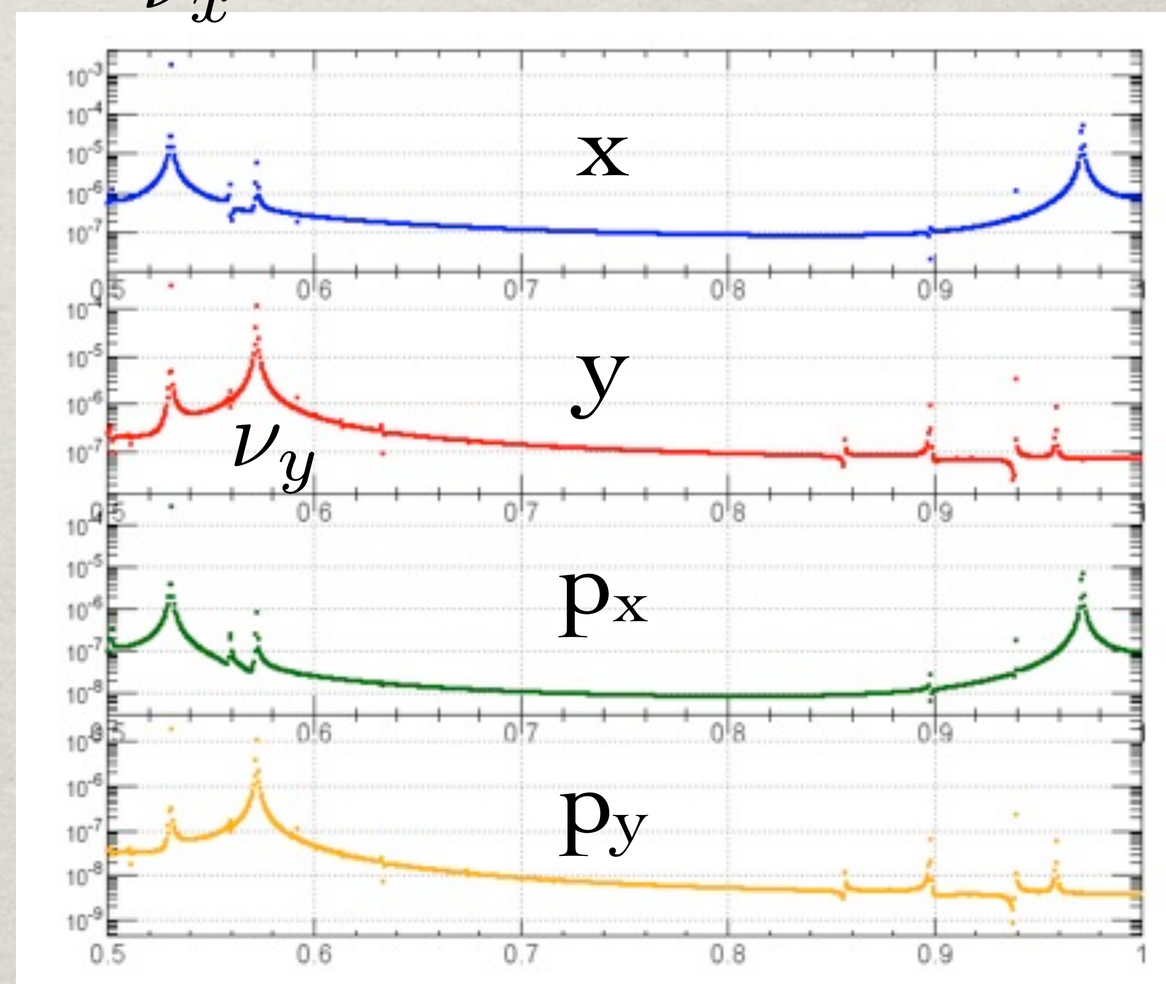
2000 turns

$2J_x = 1\text{x}10^{-9}$ m

green dot: raw data
red: correlation method

FFT



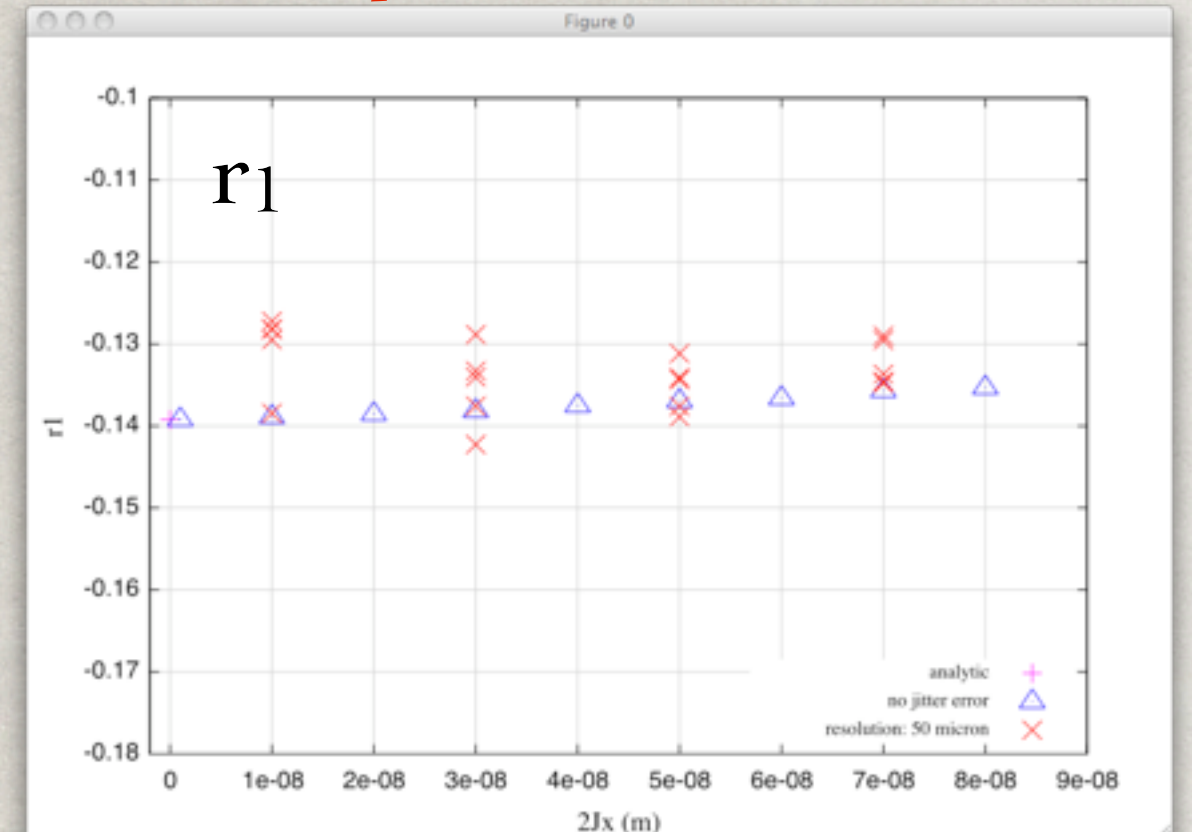


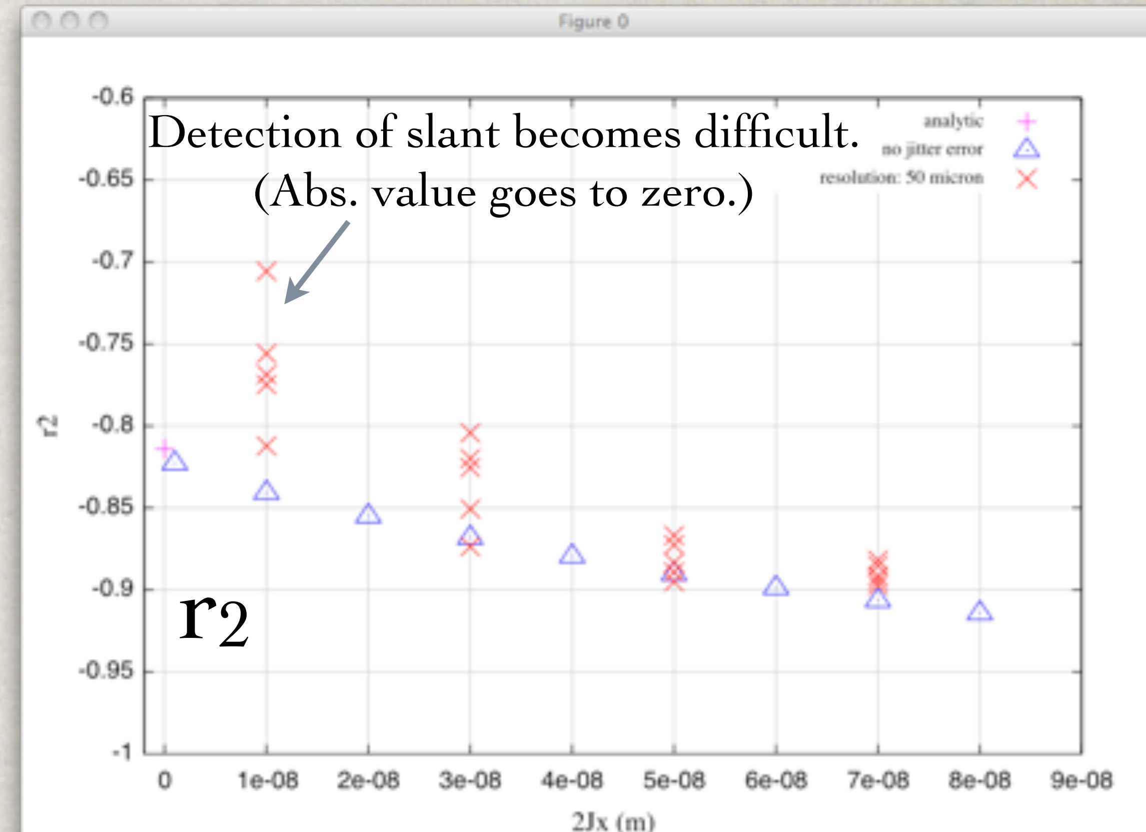
QD3E.3

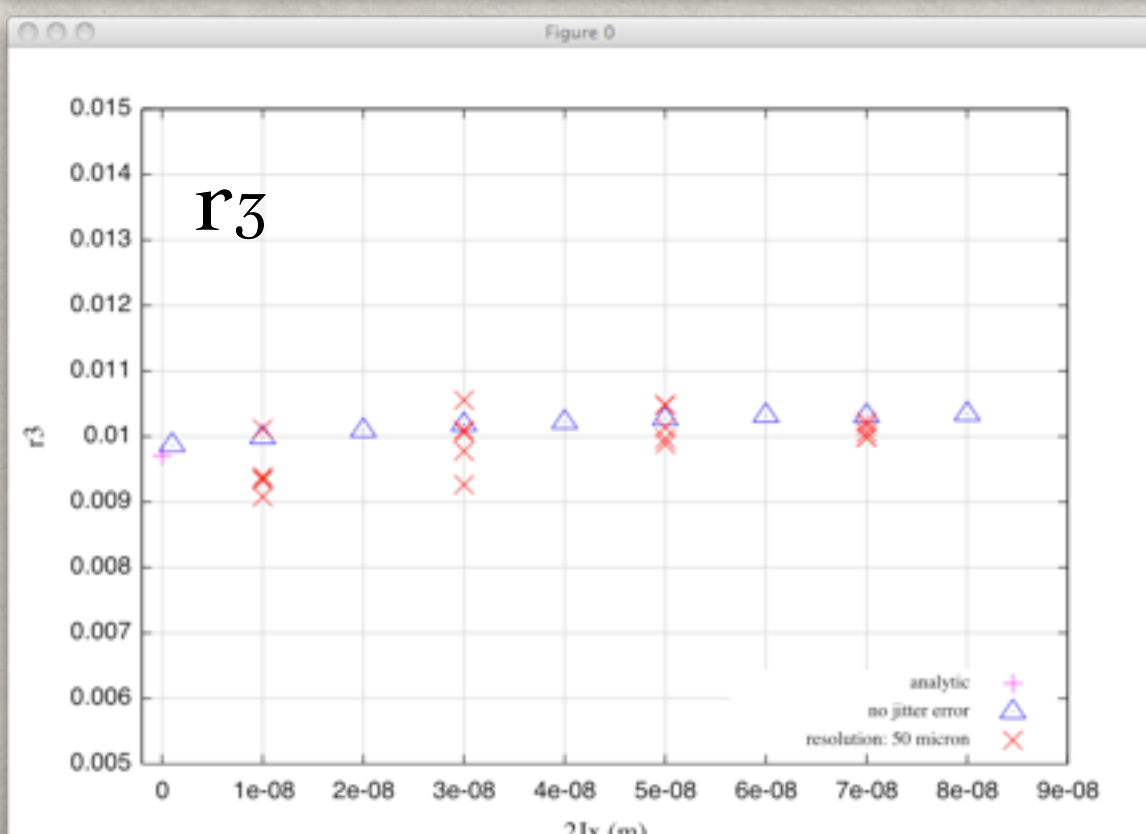
The slant of ellipse corresponds to xy-coupling.

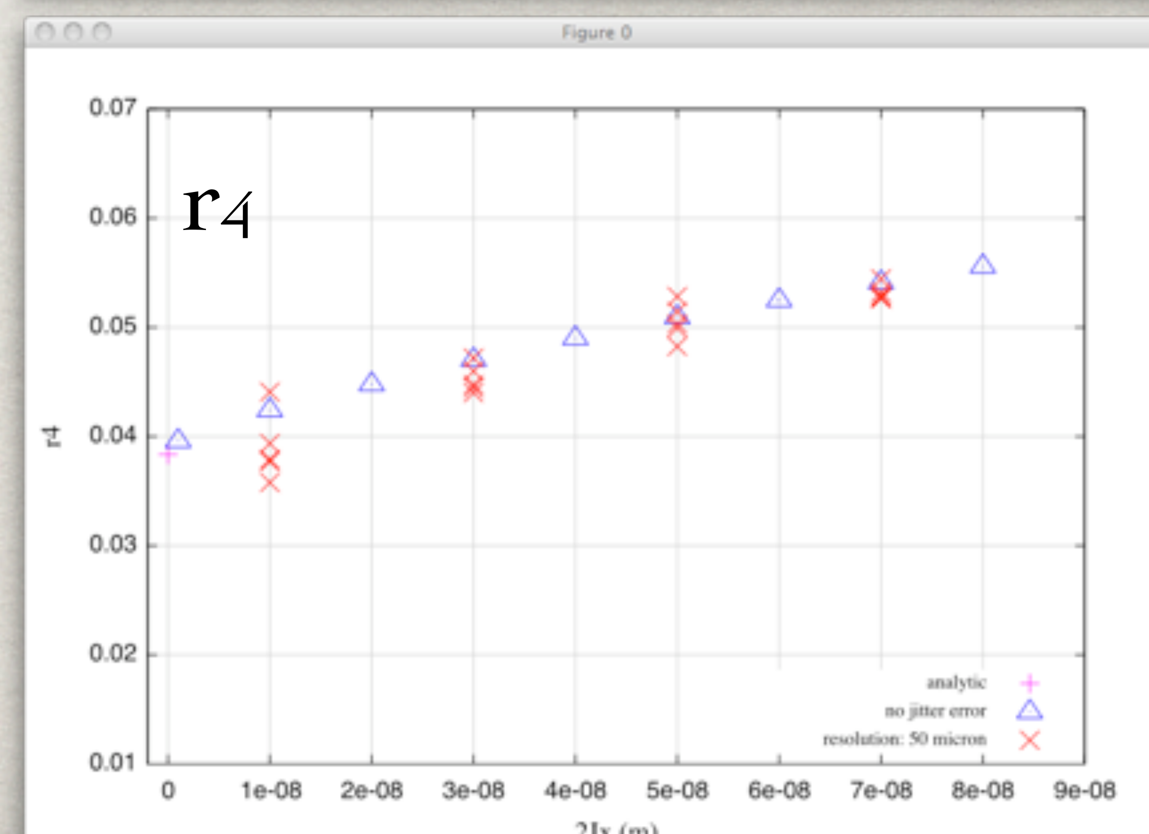
4-1 Amplitude Dependence (monitor:QD3E.3)

×: 50 μm BPM resolution(jitter error) different random seeds









4-1 Method at CESR

- Definition: one-turn transfer matrix (4x4), T:
  - CESR:

$$T = V^{-1}UV = \begin{pmatrix} \gamma I & C \\ -C^{+} & \gamma I \end{pmatrix} \begin{pmatrix} A & 0 \\ 0 & B \end{pmatrix} \begin{pmatrix} \gamma I & -C \\ C^{+} & \gamma I \end{pmatrix}$$

  - KEKB

$$T = V^{-1}UV = \begin{pmatrix} \mu I & -SR^{T}S \\ -R & \mu I \end{pmatrix} \begin{pmatrix} A & 0 \\ 0 & B \end{pmatrix} \begin{pmatrix} \mu I & SR^{T}S \\ R & \mu I \end{pmatrix}$$

$$I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \qquad S = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \qquad R = \begin{pmatrix} r_1 & r_2 \\ r_3 & r_4 \end{pmatrix}$$

$$A = I\cos\psi_u + J_u \sin\psi_u \qquad B = I\cos\psi_v + J_v \sin\psi_v$$

$$J_{u,v} = \begin{pmatrix} \alpha_{u,v} & \beta_{u,v} \\ -\gamma_{u,v} & -\alpha_{u,v} \end{pmatrix}$$

$$\boxed{\begin{pmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{pmatrix} = \begin{pmatrix} r_4 & -r_2 \\ -r_3 & r_1 \end{pmatrix} \qquad \gamma = \mu}$$

4-1 Method at CESR

- In the case of H-mode excitation, we observe x and y position at a BPM:

D. C. Sagan, D. L. Rubin et al.
Ref. CBN 96-20
Proc. of PAC2003, p.2267

$$\vec{w}_0 = V\vec{x}_0 = (u_0, 0, 0, 0)^T$$

$$\vec{x}(n) = (V^{-1}UV)^n\vec{x}_0 = V^{-1}U^nV\vec{x}_0 = V^{-1}U^n\vec{w}_0$$

$$x(n) = \hat{x}\cos(n\psi_u - \delta_1)$$

$$y(n) = \hat{y}\cos(n\psi_u - \delta_2) \qquad \text{where}$$

$$\hat{x} =| \mu u_0 | \sqrt{1+\alpha_u^2} \qquad (1)$$

$$\hat{y} =| u_0 | \sqrt{r_1^2 + (r_1\alpha_u - r_2\gamma_u)^2} \qquad (2)$$

$$\tan\Delta\phi_u \equiv \tan(\delta_1 - \delta_2) = \frac{r_2/r_1}{\beta_u - (r_2/r_1)\alpha_u} \qquad (3)$$

From Eq. (1)~(3):

$$r_1 = -\mu\left(\frac{\hat{y}}{\hat{x}}\right)_u (\cos\Delta\phi_u + \alpha_u \sin\Delta\phi_u)$$

$$r_2 = -\mu\left(\frac{\hat{y}}{\hat{x}}\right)_u \beta_u \sin\Delta\phi_u$$

- r_2 and r_4 can be obtained by a similar way of V-mode.

4-1 Method at CESR

- Alternative explanation for the case of H-mode excitation,

$$< x^2 > = \mu^2 < u^2 >= \mu^2 J_u \beta_u \tag{1}$$

$$< xy > = \mu(-r_1 < u^2 > -r_2 < up_u >) = -\mu J_u \beta_u \left(r_1 - \frac{\alpha_u}{\beta_u} r_2 \right) \tag{2}$$

$$< y^2 > = r_1 < u^2 > +2r_1 r_2 < up_u > +r_2^2 < p_u^2 >= \frac{< x^2 >}{\mu^2} \left\{ \mu^2 \frac{< xy >^2}{< x^2 >^2} + \frac{r_2^2}{\beta_u} \right\} \tag{3}$$

From Eq. (1)~(3):

$$\boxed{\begin{aligned} r_1 &= \frac{\alpha_u}{\beta_u} r_2 - \mu \frac{< xy >}{< x^2 >} \\ r_2 &= \mu \beta_u \sqrt{\frac{< x^2 >< y^2 > - < xy >^2}{< x^2 >^2}} \end{aligned}} = \boxed{\begin{aligned} r_1 &= -\mu \left(\frac{\hat{y}}{\hat{x}} \right)_u (\cos \Delta\phi_u + \alpha_u \sin \Delta\phi_u) \\ r_2 &= -\mu \left(\frac{\hat{y}}{\hat{x}} \right)_u \beta_u \sin \Delta\phi_u \end{aligned}}$$

- r_3 can not be measured by this method, p_x and p_y are necessary.

- Both CESR method and correlation matrix method are applicable in the SuperKEKB lattice except for r_3.

H. Fukuma, K. Ohmi

4-1 Method at CESR

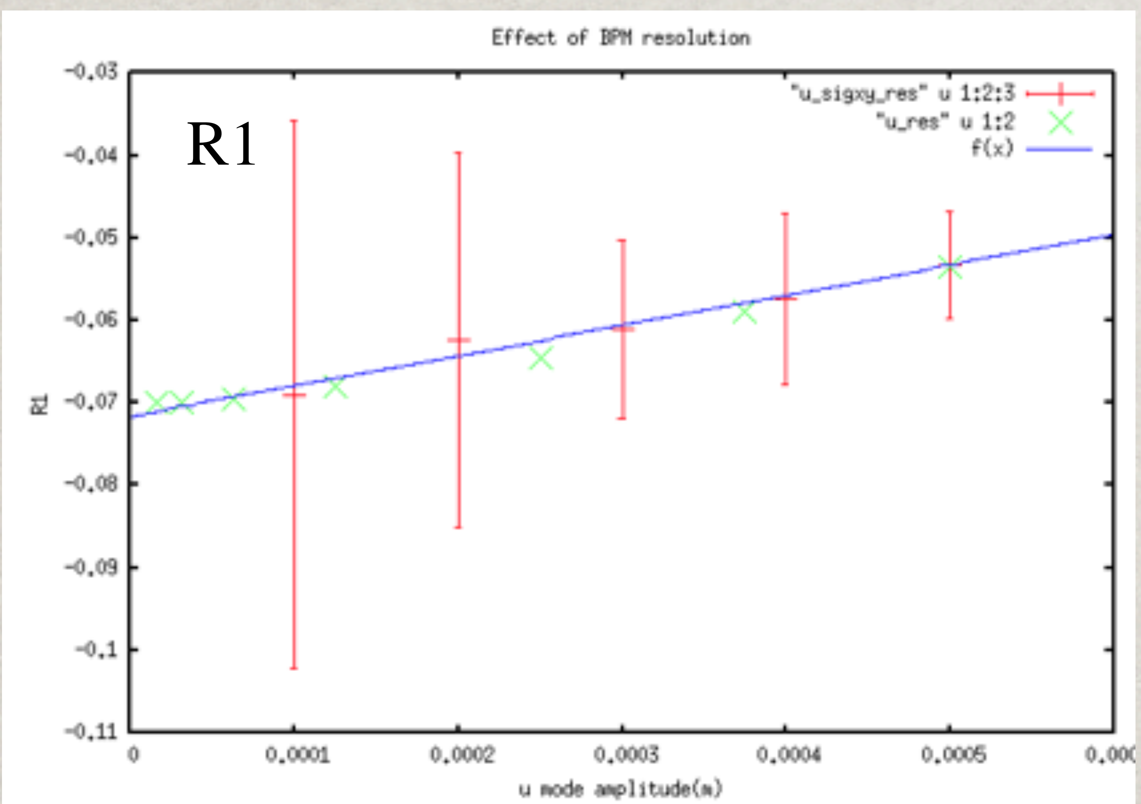
Effect of BPM resolution

H. Fukuma

Put BPM error $\sigma_x=\sigma_y=0.0001$m

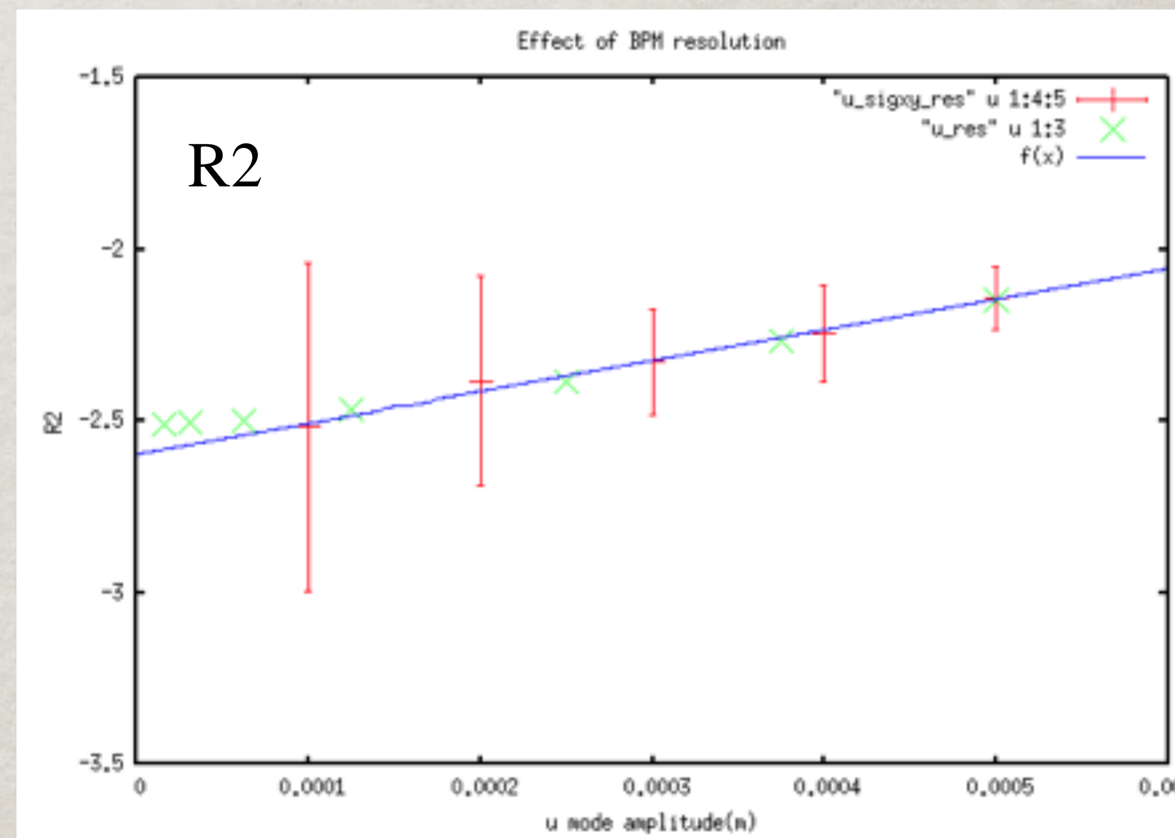
100 trials at each point. Error bar shows rms.

Extrapolate the result to 0 amplitude (blue line).



u_0 amplitude (m)

R1=-0.0718±0.0200

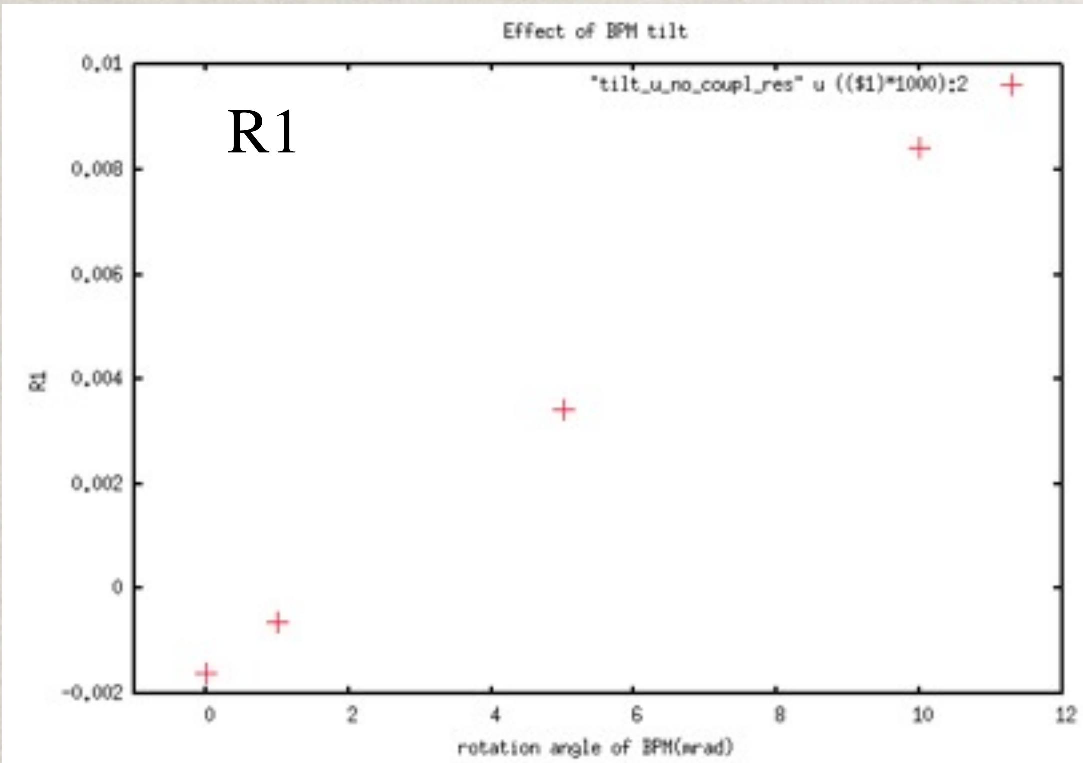


u_0 amplitude (m)

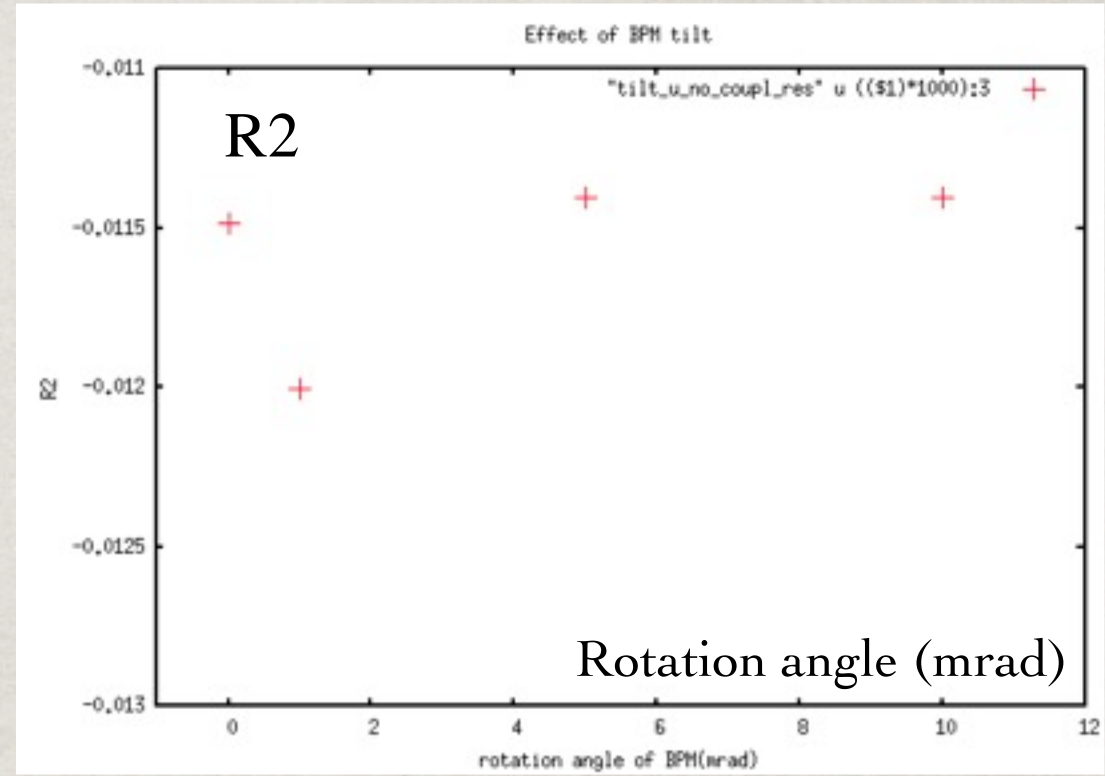
R2=-2.596±0.280

4-1 Method at CESR

Excite H-mode **Effect of BPM rotation error** H. Fukuma

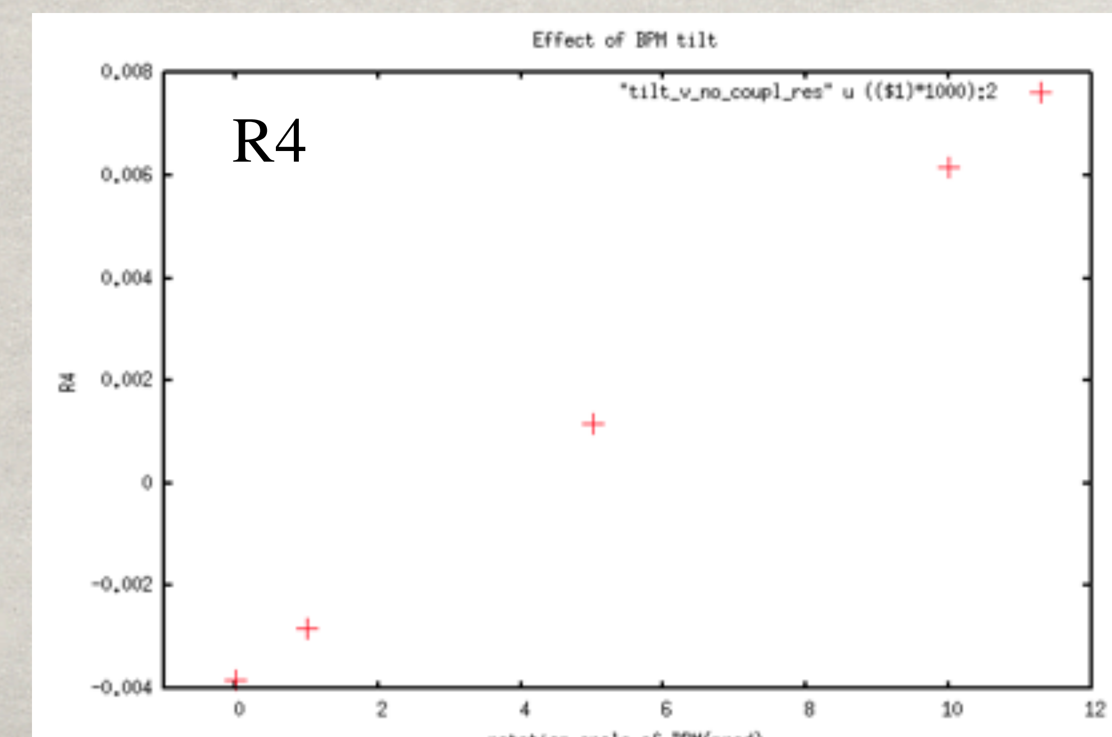


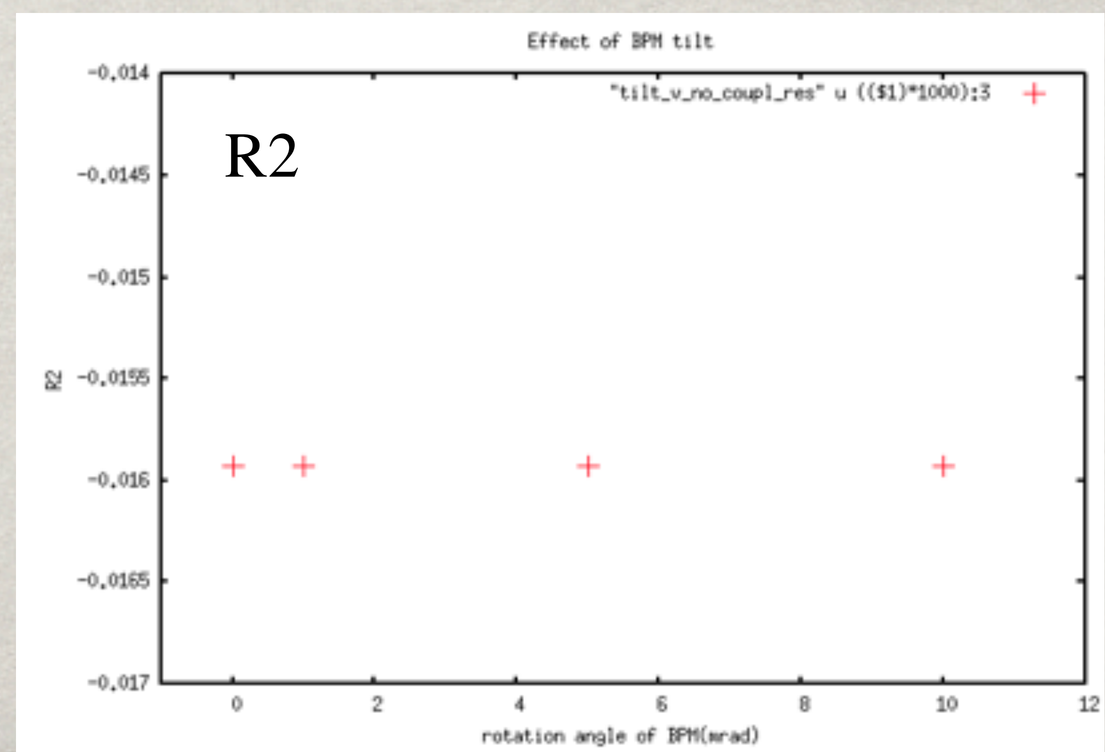
Rotation angle (mrad)



Rotation angle (mrad)

Excite v mode





4-2 Measurement of Dispersions

4-2 Dispersion Measurement

- Dispersion

$$\vec{u} = (u, p_u, v, p_v)$$ decoupled coordinate

$$\vec{u} + \vec{\eta}_u \delta = R\vec{x}$$

$$\vec{x} = (x, p_x, y, p_y)$$ physical coordinate

$$\vec{\eta}_u = R\vec{\eta}_x$$

$$\vec{\eta}_u = (\eta_u, \eta_{pu}, \eta_v, \eta_{pv})$$ decoupled dispersion

$$\vec{\eta}_x = (\eta_x, \eta_{px}, \eta_y, \eta_{py})$$ physical dispersion

$$\vec{u} + R\vec{\eta}_x \delta_1 = R\vec{x}_1$$

$$\vec{u} + R\vec{\eta}_x \delta_2 = R\vec{x}_2$$

R is a x-y coupling matrix

$$\vec{\eta}_x = \frac{\vec{x}_2 - \vec{x}_1}{\delta_2 - \delta_1}$$

A measured dispersion is a physical dispersion

COD based measurement uses a change of RF frequency

$$\delta = -\frac{1}{\left(\alpha_c - \frac{1}{\gamma^2}\right)} \frac{\Delta f}{f_0}$$

In the case of single-pass BPMs with RF kick,
η_{px} and η_{py} can be estimated by using two locations

4-4 Optics Correction

x-y coupling and Vertical Dispersion

4-4 Optics Correction

Corrector:

1. Vertical offset of sextupoles generates both x-y coupling and vertical dispersion(contamination of horizontal dispersion via x-y coupling).
2. Skew quadrupole windings of sextupoles(equivalent to sextupole offset, need to evaluate higher order multipole field).

Primary method:

x-y coupling and vertical dispersion are corrected simultaneously.

$$\Delta r_{n,i} = \sum_{j=1}^{\#sext} M_{ij}^{(n)} \Delta SK_{1j} \qquad n = 1, 2, 3, 4$$

$$\Delta \eta_{y,i} = \sum_{j=1}^{\#sext} N_{ij} \Delta SK_{1j}$$

M_{ij} and N_{ij} is a response matrix calculated by using a design lattice

SK_1 is a strength of skew quadrupole field

Partial correction:

1. x-y coupling correction(r_1-r_4) only
2. one of x-y coupling parameter, r_2 and vertical dispersion

   r_2 is insensitive to BPM rotation along the beam axis.

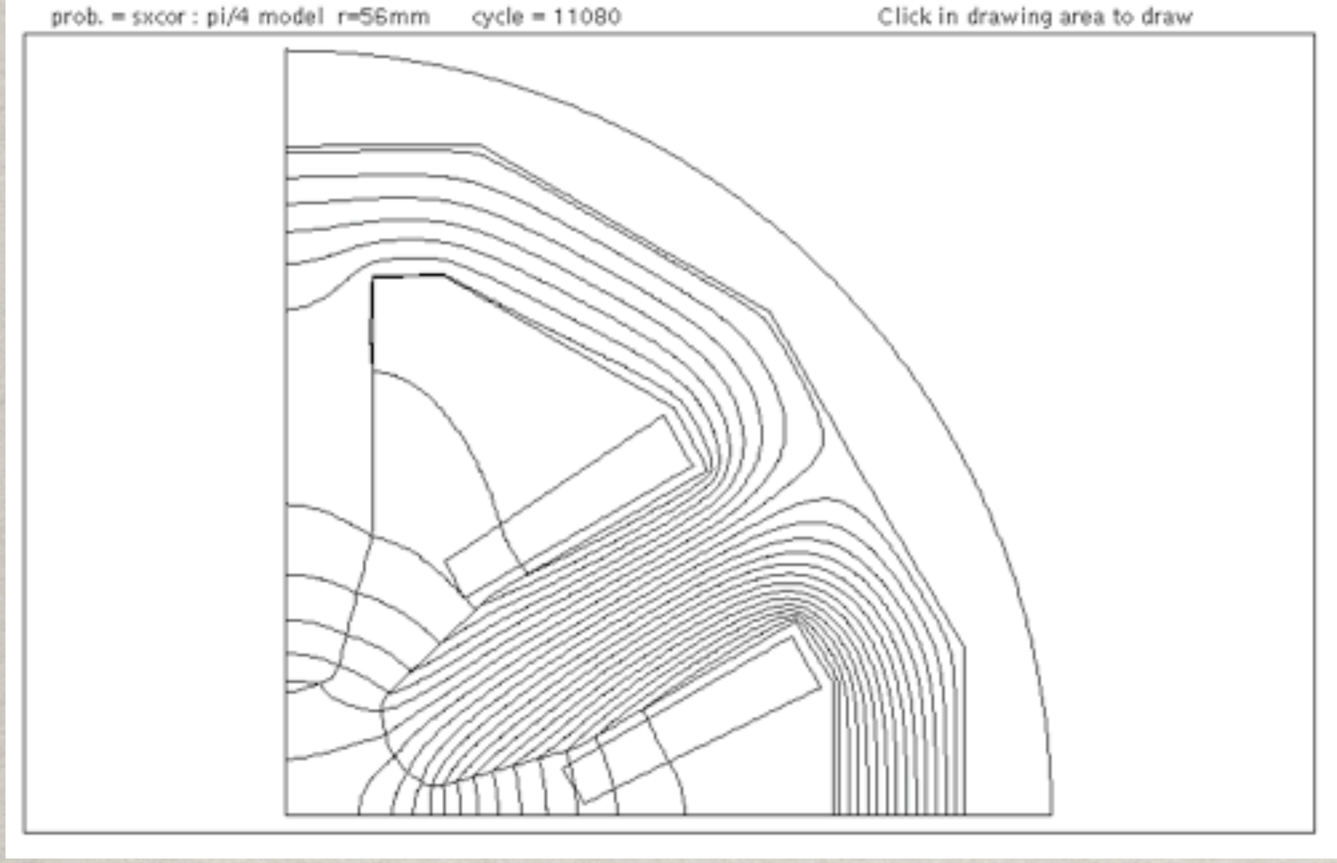
4-4 Optics Correction

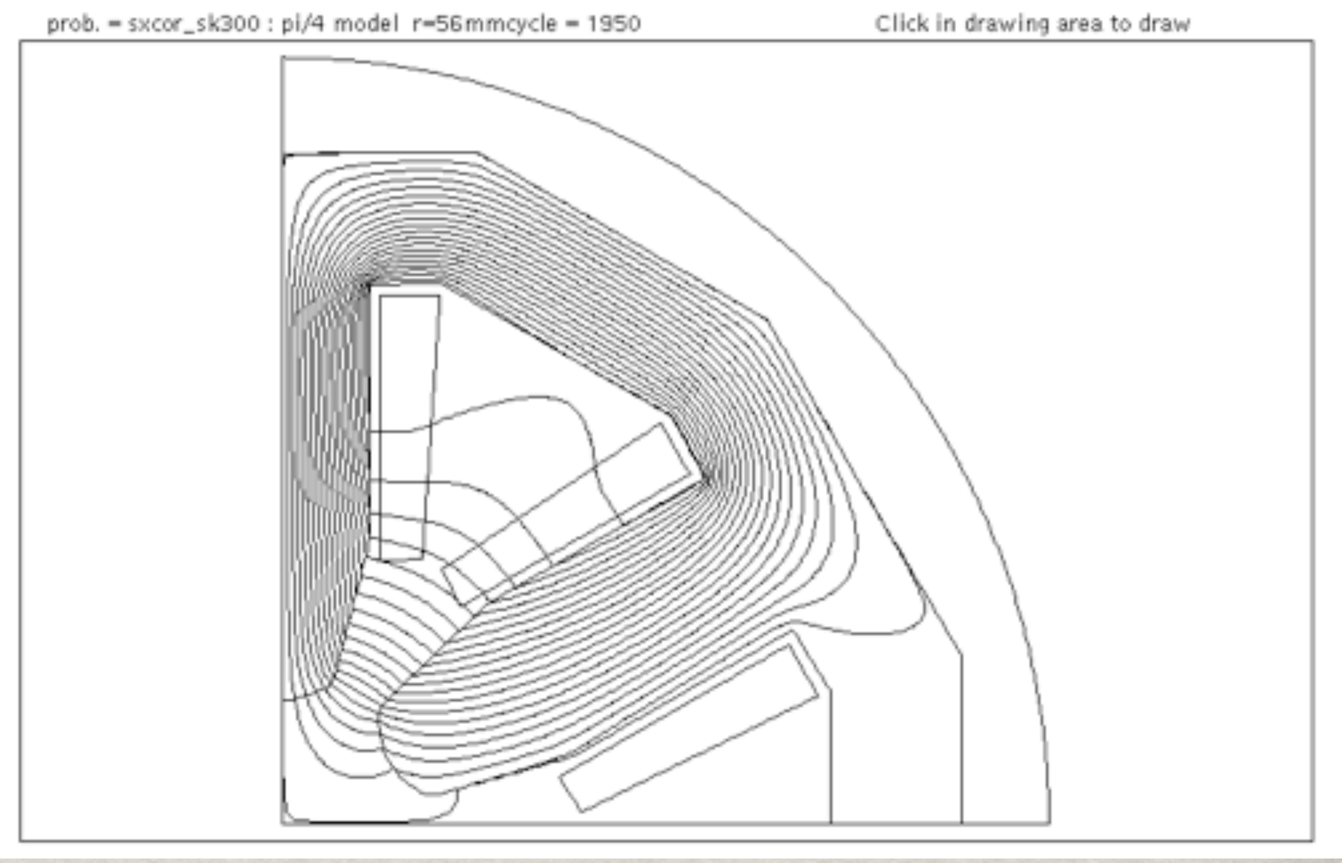
K. Egawa

Q or skew-Q field excited by sextupole correction coils

Q configuration

skew-Q configuration





4-4 Machine Error

* measurement at KEKB

Assumption in this simulation

misalignment	σ_y (μm)	tilt (mrad)
Sextupoles (SD/SF)	100	0
Quadrupoles (normal magnet)	0	0.1 *
BPM	0	1, 10

BPM resolution

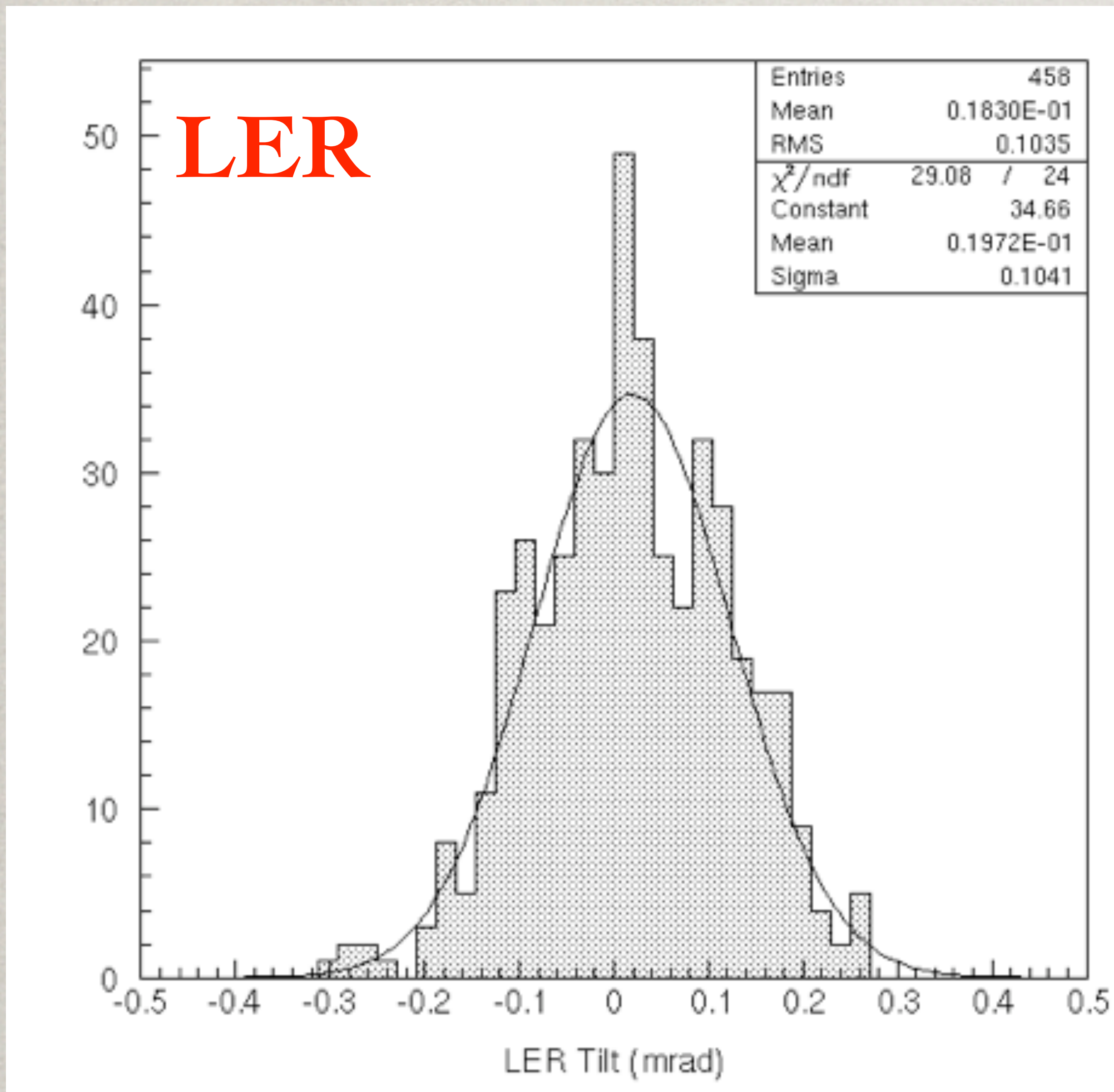
No gradient error of magnets

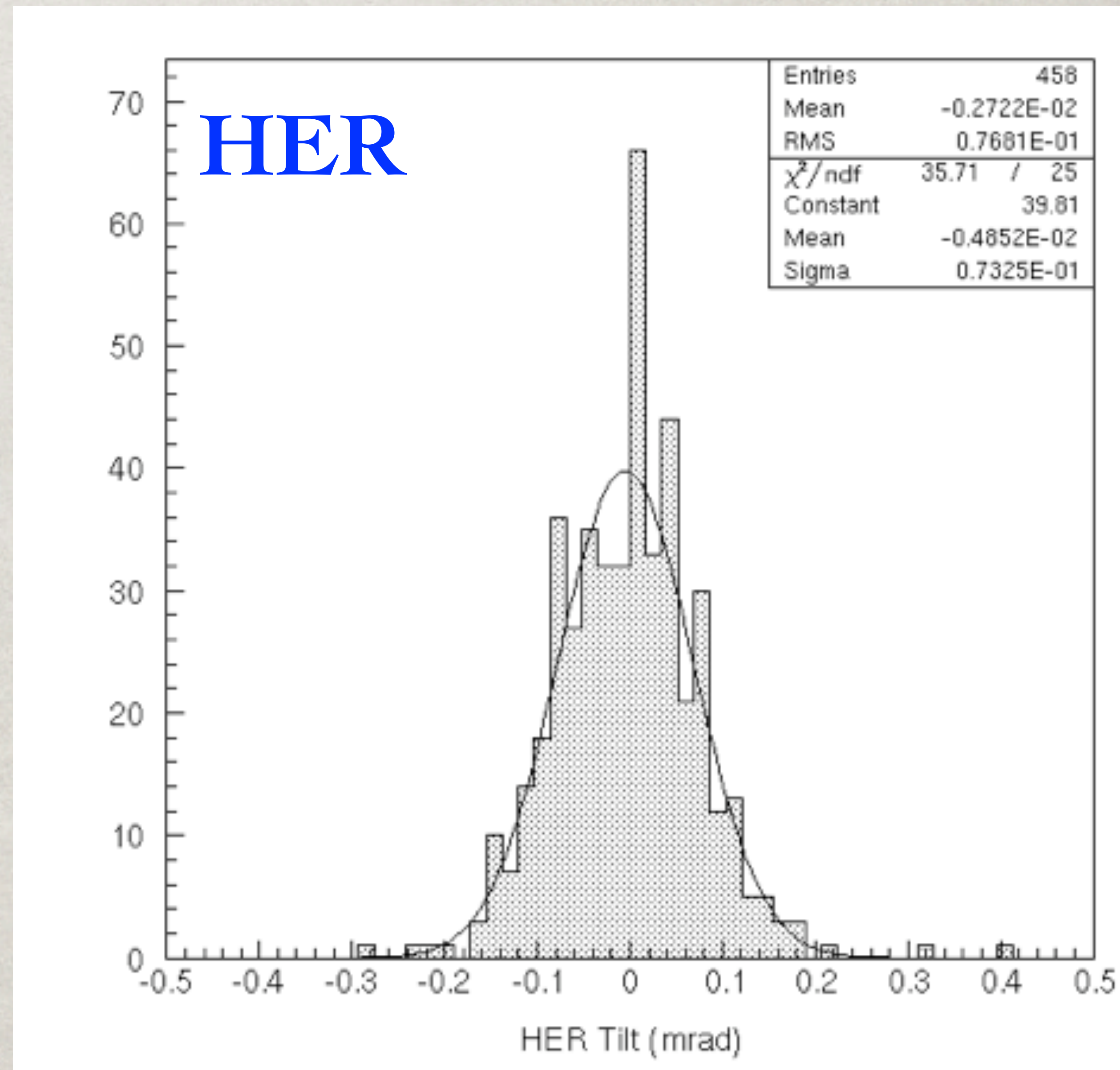
position resolution due to jitter error	$\sigma_{x,y}$ (μm)
BPM (single-pass mode)	50, 75, 100
BPM (average mode)	2, 5

4-4 Tilt Angle of Quadrupoles

M. Masuzawa et al.

Measurement of tilt angle along the beam axis at KEKB





σ_θ = 0.07~0.1 mrad for quadrupoles

4-4 Before Correction

No BPM error

#BPMs = 160

r_1

r_2 (m)

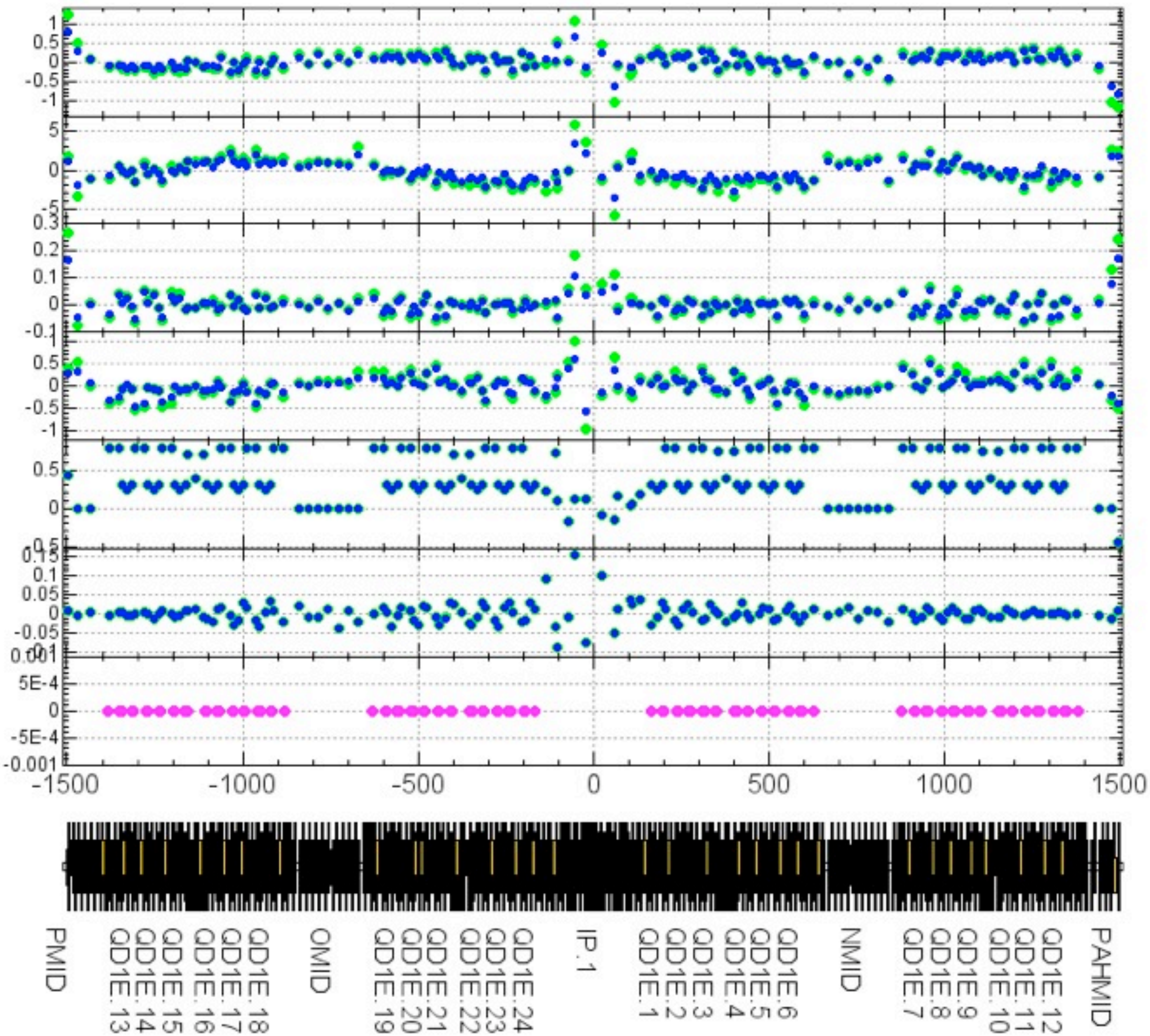
r_3 (1/m)

r_4

η_x (m)

η_y (m)

SK_1 (1/m)



4-4 After Correction

No BPM error

#BPMs = 160

r1

r2 (m)

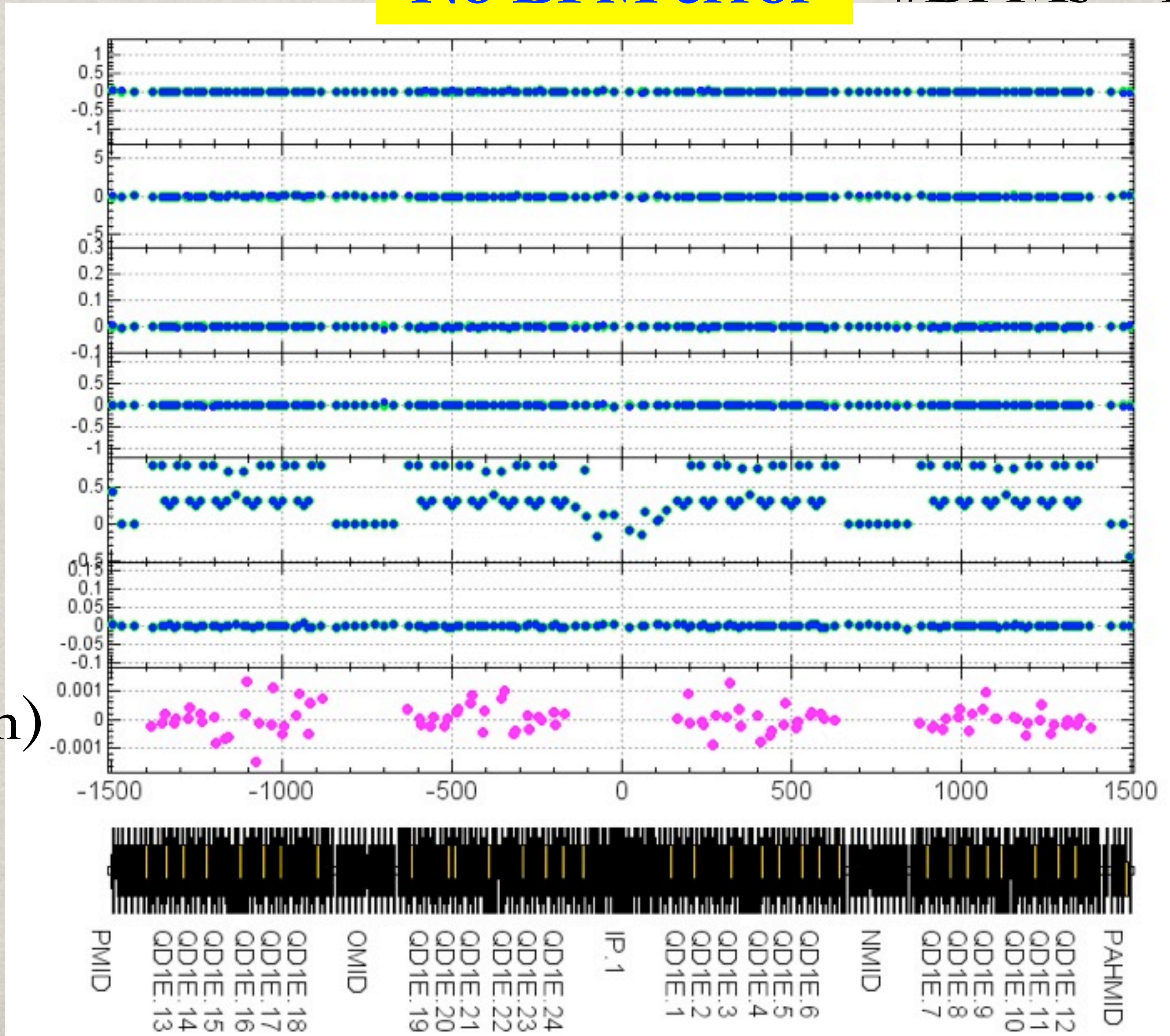
r3 (1/m)

r4

η_x (m)

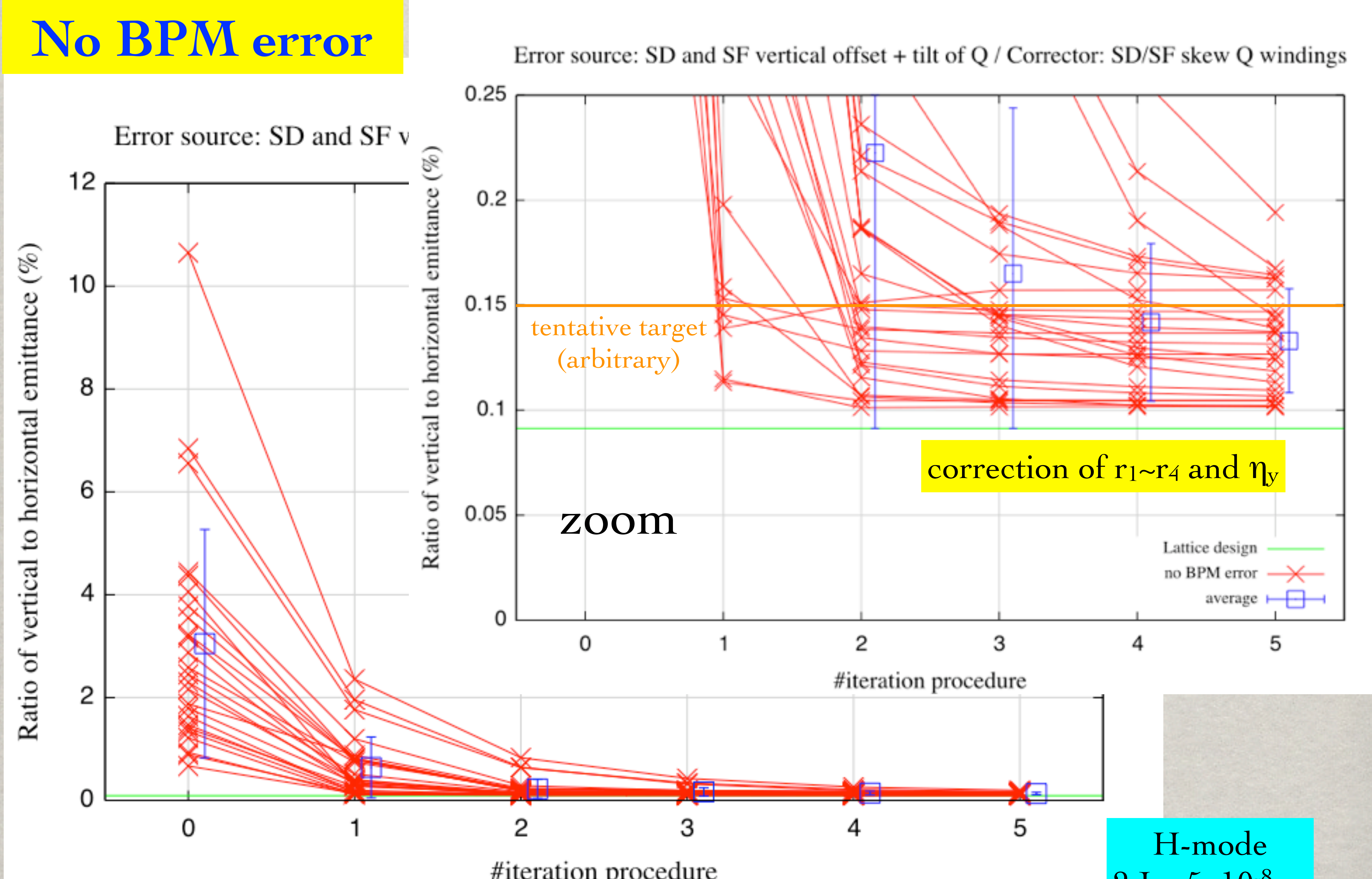
η_y (m)

SK1 (1/m)



4-4 Correction Performance

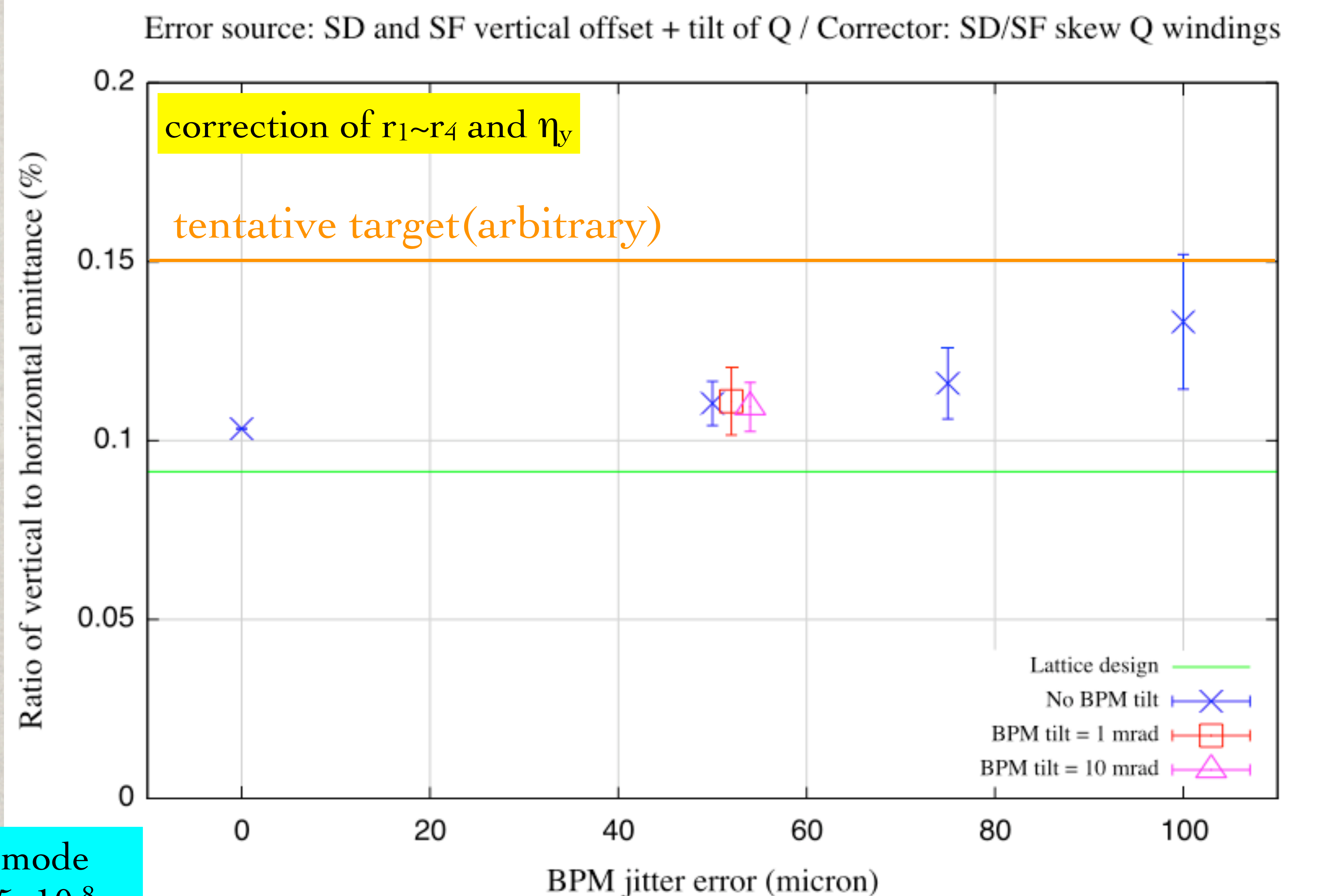
No BPM error



H-mode
$2Jx=5x10^{-8}$ m

4-4 BPM resolution and tilt

#samples = 25 for each point (error bar: standard deviation)
of common SD/SF/Q misalignment after 5 iterative procedures

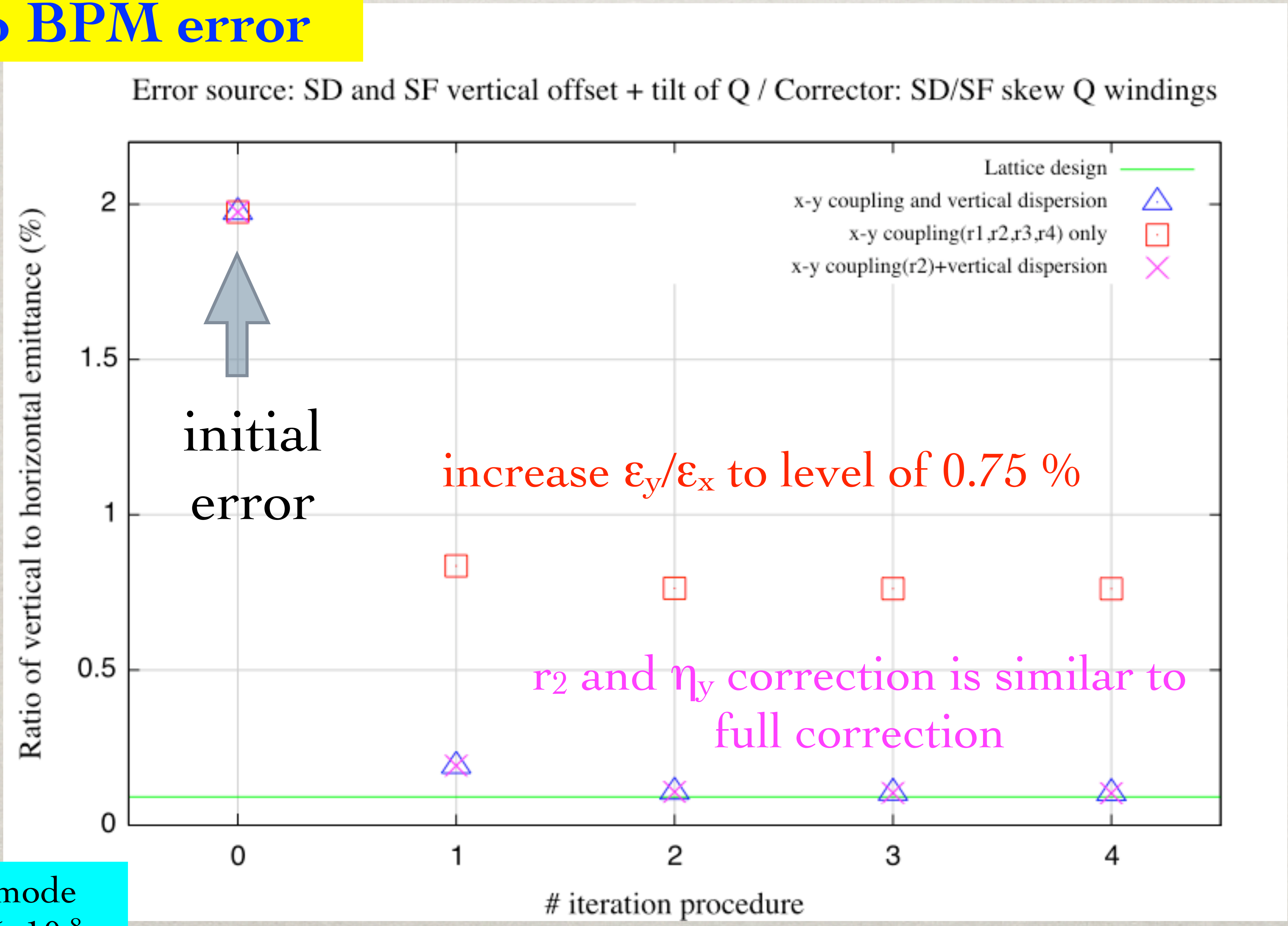


H-mode
$2Jx=5 \times 10^{-8}$ m

4-4 Correction Performance

How is correction of x-y coupling only ?

No BPM error

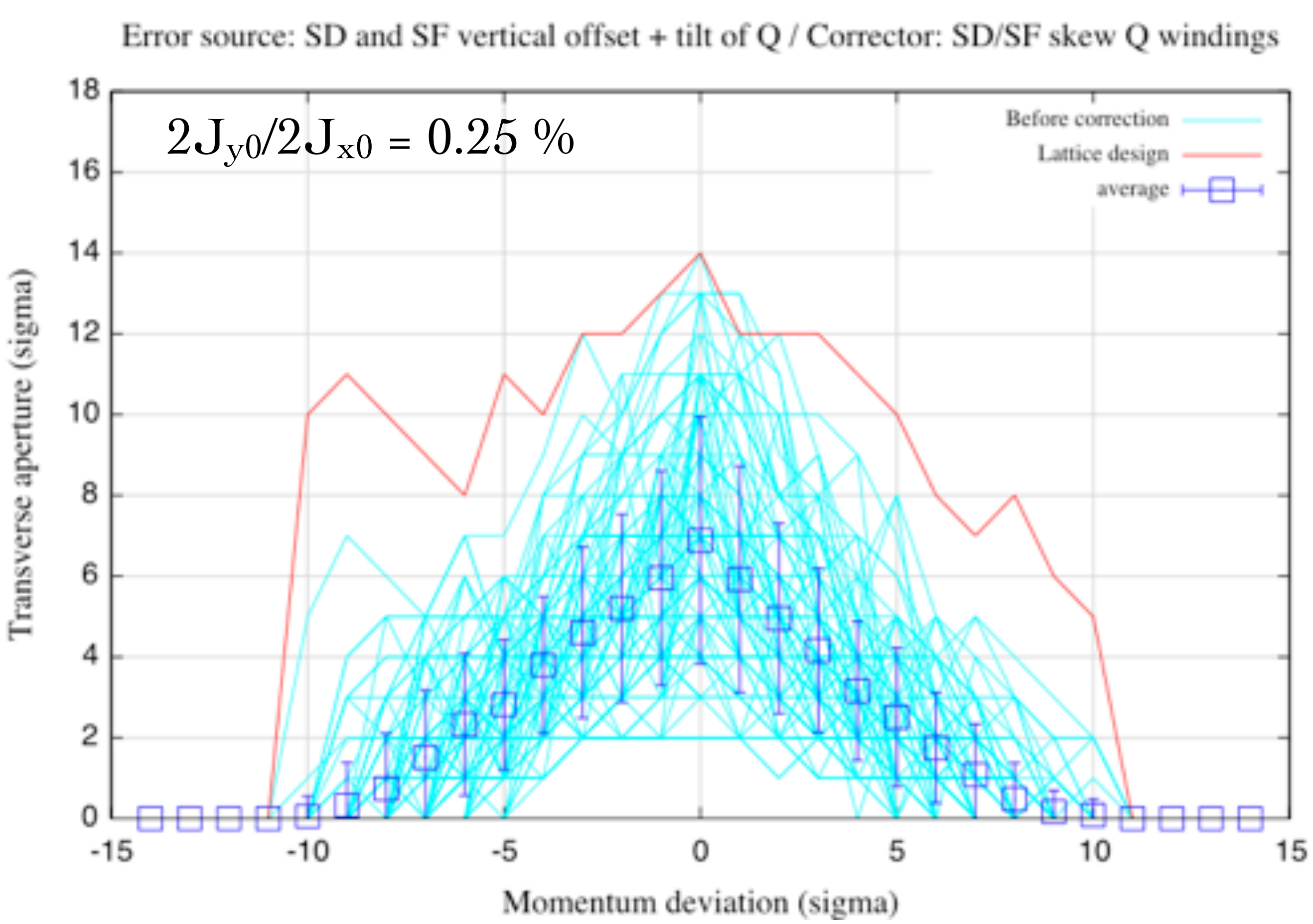


H-mode
$2Jx=5x10^{-8}$ m

4-4 Dynamic Aperture

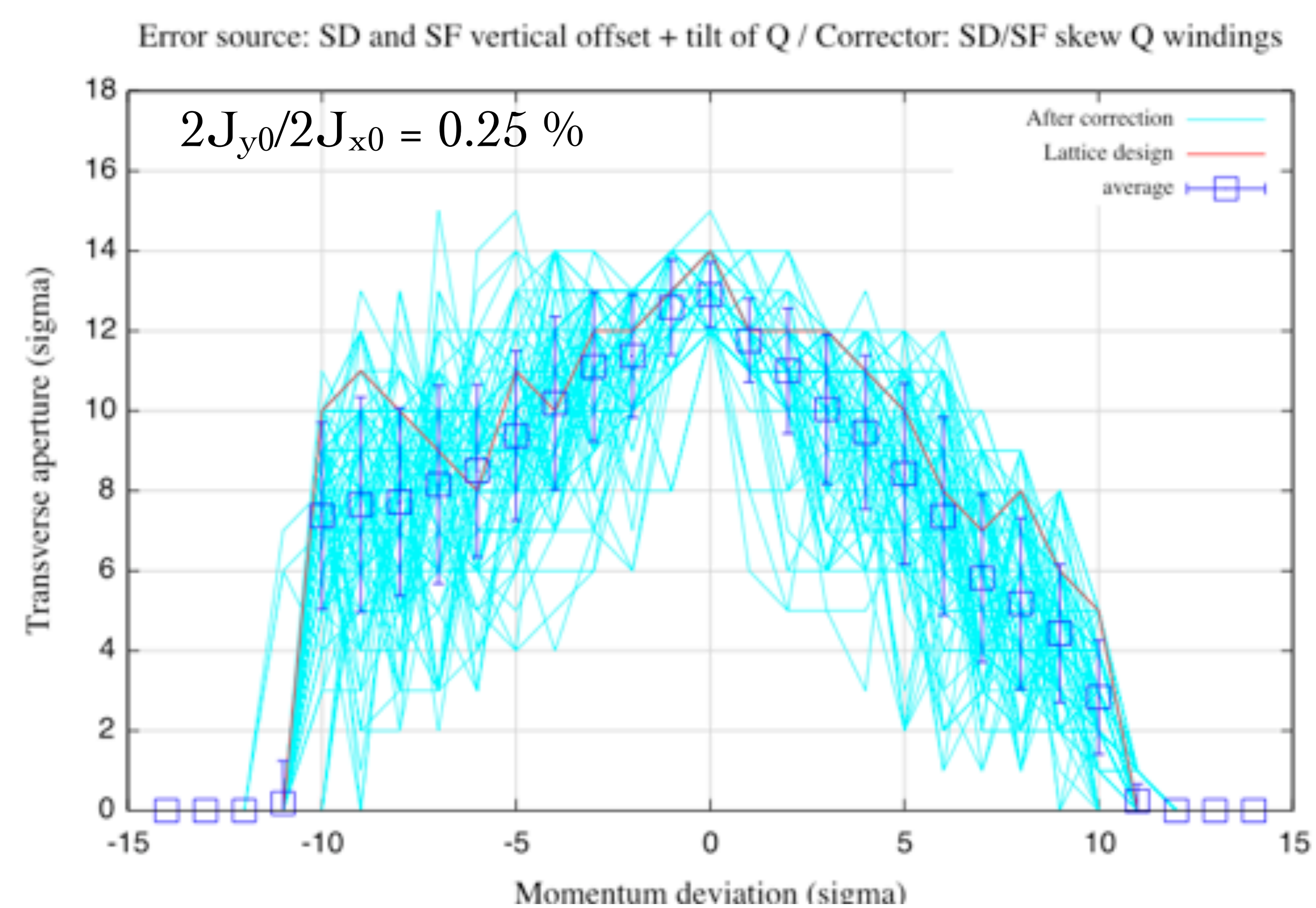
100 samples:
Sextupole $\sigma_{\Delta y}$ = 100 micron / Q tilt $\sigma_{\Delta\theta}$ = 0.1 mrad
BPM jitter error $\sigma_{x,y}$ = 50 micron / BPM tilt $\sigma_{\Delta\theta}$ = 1 mrad

Before correction



δ_0/σ_δ

After correction

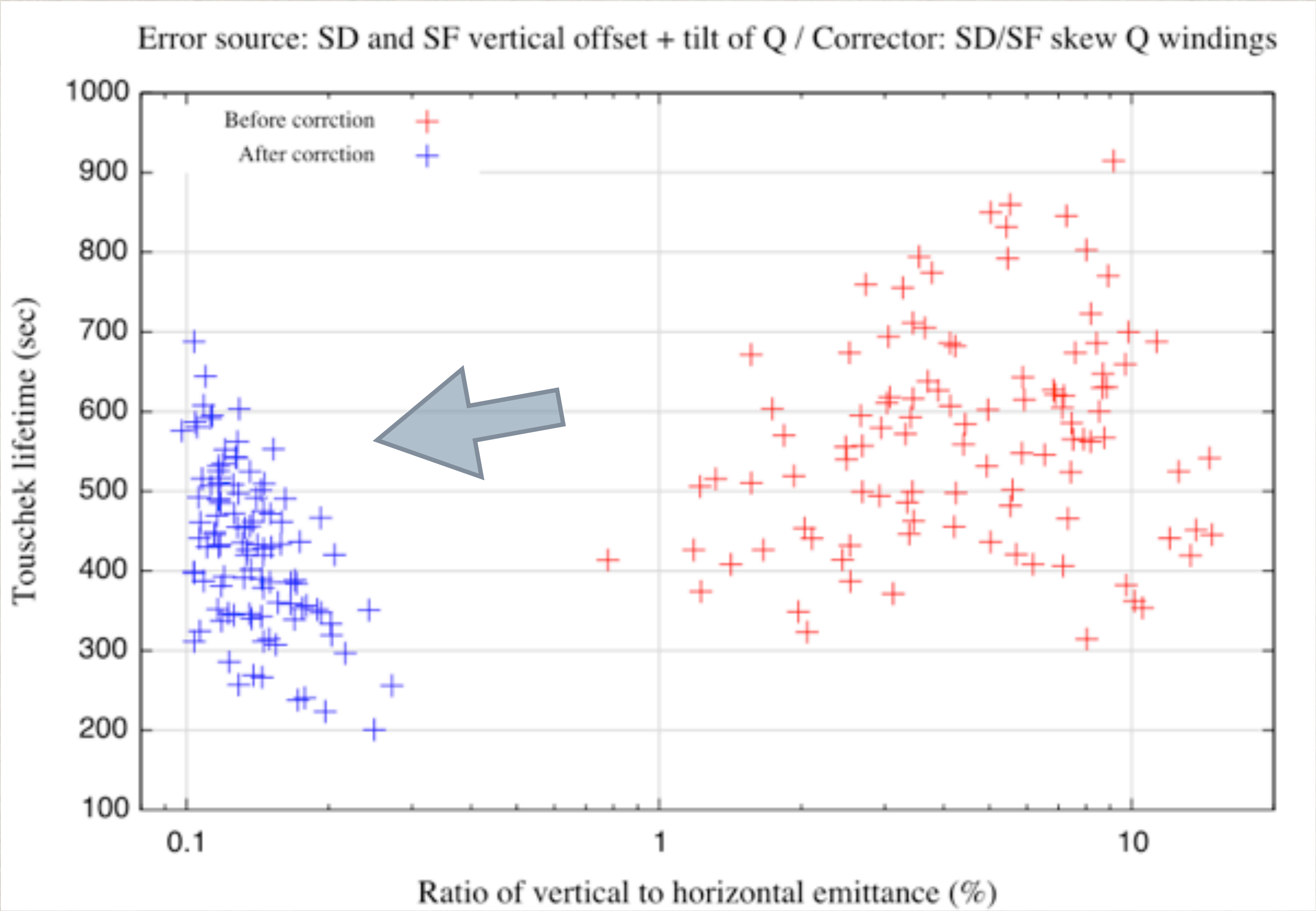


δ_0/σ_δ

Degradation of dynamic aperture is improved by the correction of x-y coupling and vertical dispersion.

4-4 Dynamic Aperture

100 samples:
Sextupole $\sigma_{\Delta y}$ = 100 micron / Q tilt $\sigma_{\Delta\theta}$ = 0.1 mrad
BPM jitter error $\sigma_{x,y}$ = 50 micron / BPM tilt $\sigma_{\Delta\theta}$ = 1 mrad

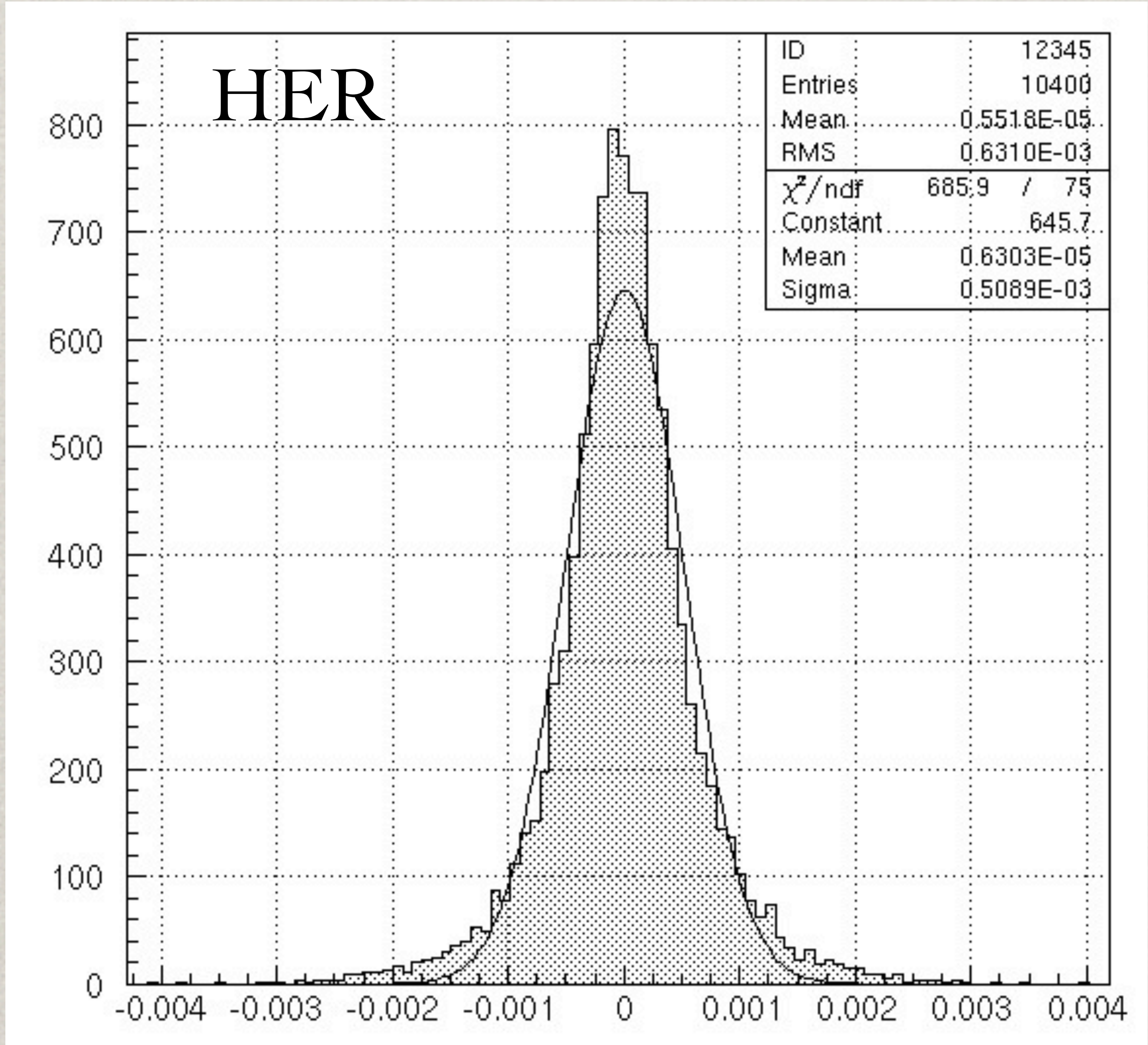


Larger coupling makes longer lifetime even if dynamic aperture is small

Distribution of Touschek lifetime is widely scattered after the correction of x-y coupling and vertical dispersion.

4-4 Required Filed Strength of Skew Quadrupole Windings

Requirement of field strength: $SK_1 = \pm 5 \times 10^{-3}$ m^{-1}



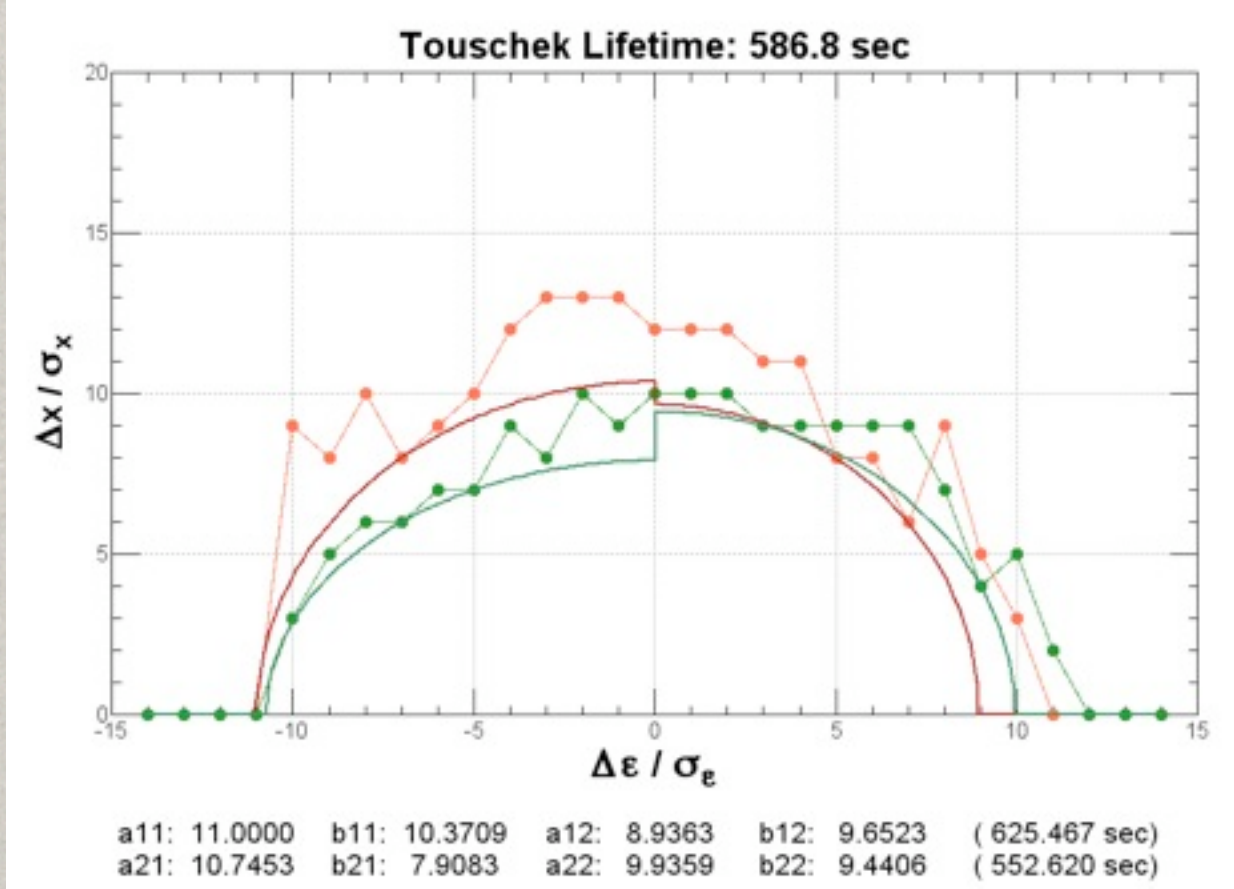
#Entries

SK_1 (m^{-1})

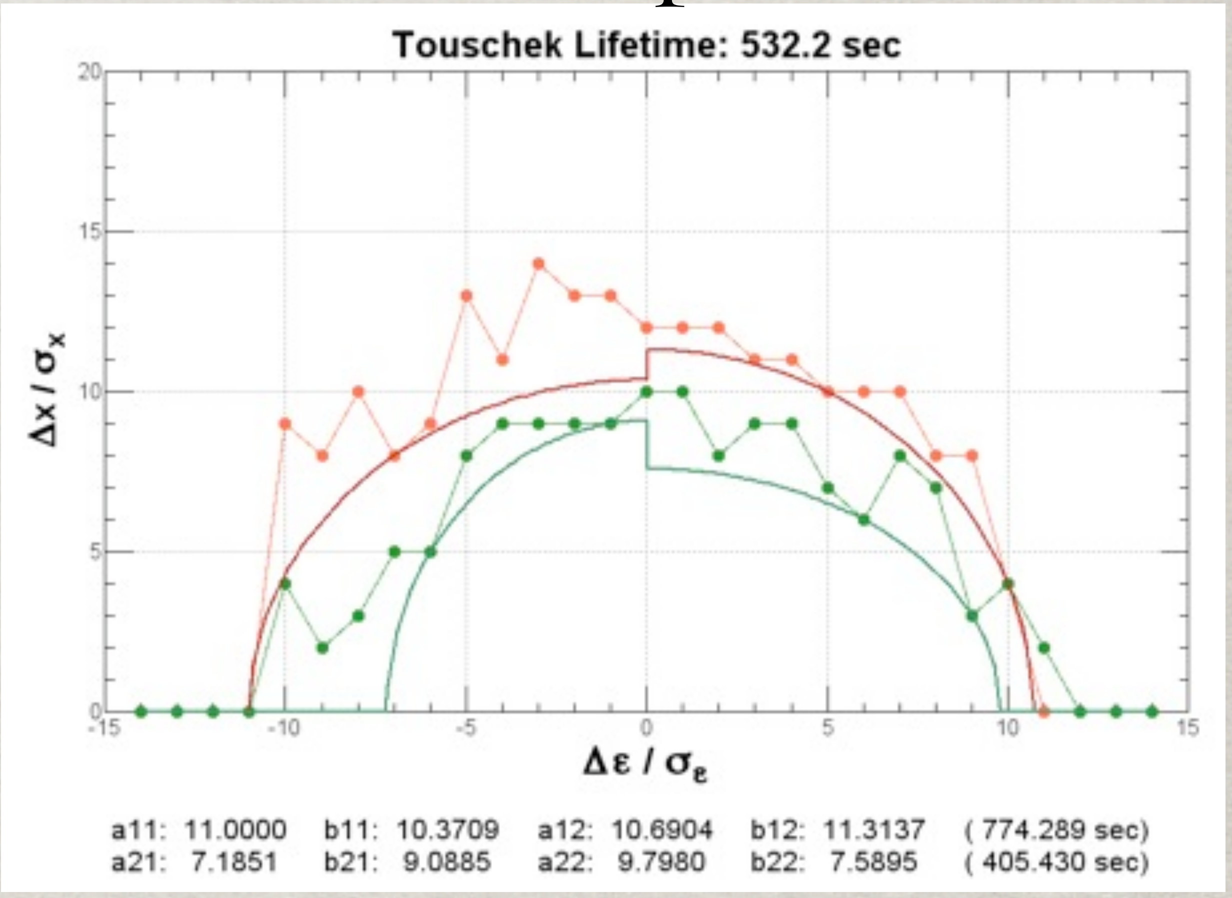
104 samples x 100 sextupoles in HER

4-4 Effect of Skew Octupole from Skew Quadrupole Windings

Skew octuples OFF



Skew octuples ON



Effect is about 10 % for Touschek lifetime.

4 Summary

- Specification for single-pass BPM to achieve target emittance ratio:

	standard deviation	
BPM resolution (jitter error)	50 μm	Better
	75 μm	Good
	100 μm	Acceptable
BPM tilt (misalignment)	1 mrad	Insensitive to the correction for global coupling
	10 mrad	

4 Summary

- x-y coupling and vertical dispersion correction

  1. x-y coupling measurement

     - multi-turn method (H-mode)
     - Position resolution smaller than ~100 micron for single-pass BPMs satisfies the requirement of tentative target of $\varepsilon_y/\varepsilon_x$ = 0.15 %. (with considering margin of 0.25% in HER, 0.27% in LER)

  2. Dispersion measurement

     - RF-frequency method (COD-based) is used tentatively.
     - Position resolution of BPMs (average mode) is assumed to be 2 micron. This resolution is enough.
     - The worse case of 5 micron is acceptable to correct the global x-y coupling and the vertical emittance.

4 Summary

- x-y coupling and vertical dispersion correction

3. Simultaneous correction of x-y coupling and vertical dispersion
   - No fundamental difficulty
4. Performance of x-y coupling correction only
   - Emittance ratio, $\varepsilon_y/\varepsilon_x$ is reduced from 2 % to ~ 0.75 % (typical example).
5. One of x-y coupling parameters, r_2 and vertical dispersion
   - It seems to be similar to all x-y coupling parameters and vertical dispersion(need to check various machine error)
   - Both correlation matrix method and CESR method
   - Advantage:

$$r_1 = \frac{\alpha_u}{\beta_u} r_2 - \mu \frac{< xy >}{< x^2 >}$$

$$r_2 = \mu \beta_u \sqrt{\frac{< x^2 >< y^2 > - < xy >^2}{< x^2 >^2}}$$

a. The r_2 parameter is insensitive to the BPM tilt.

b. No necessary of transfer matrix between two BPMs(β-function is necessary)

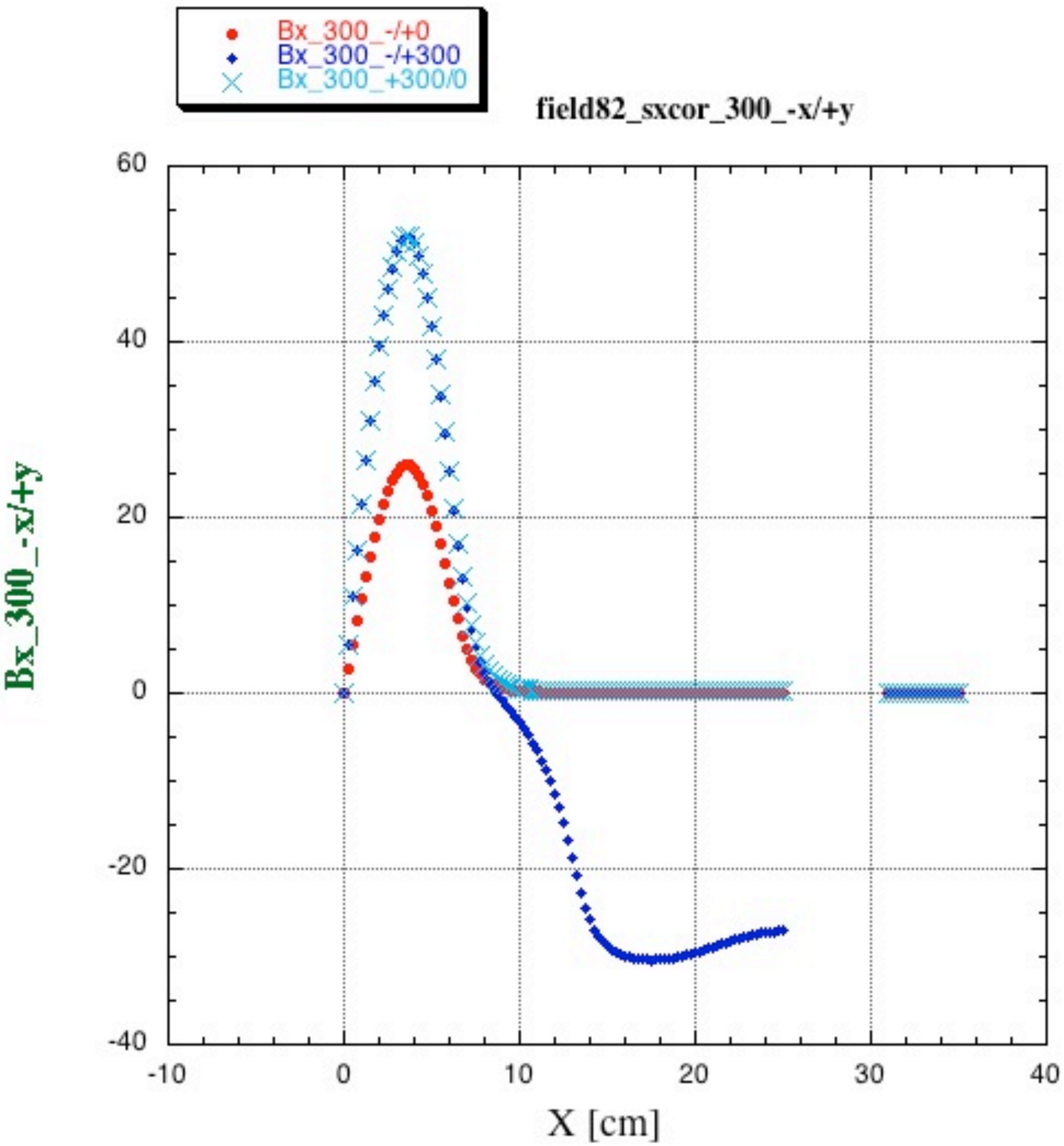
4 Summary

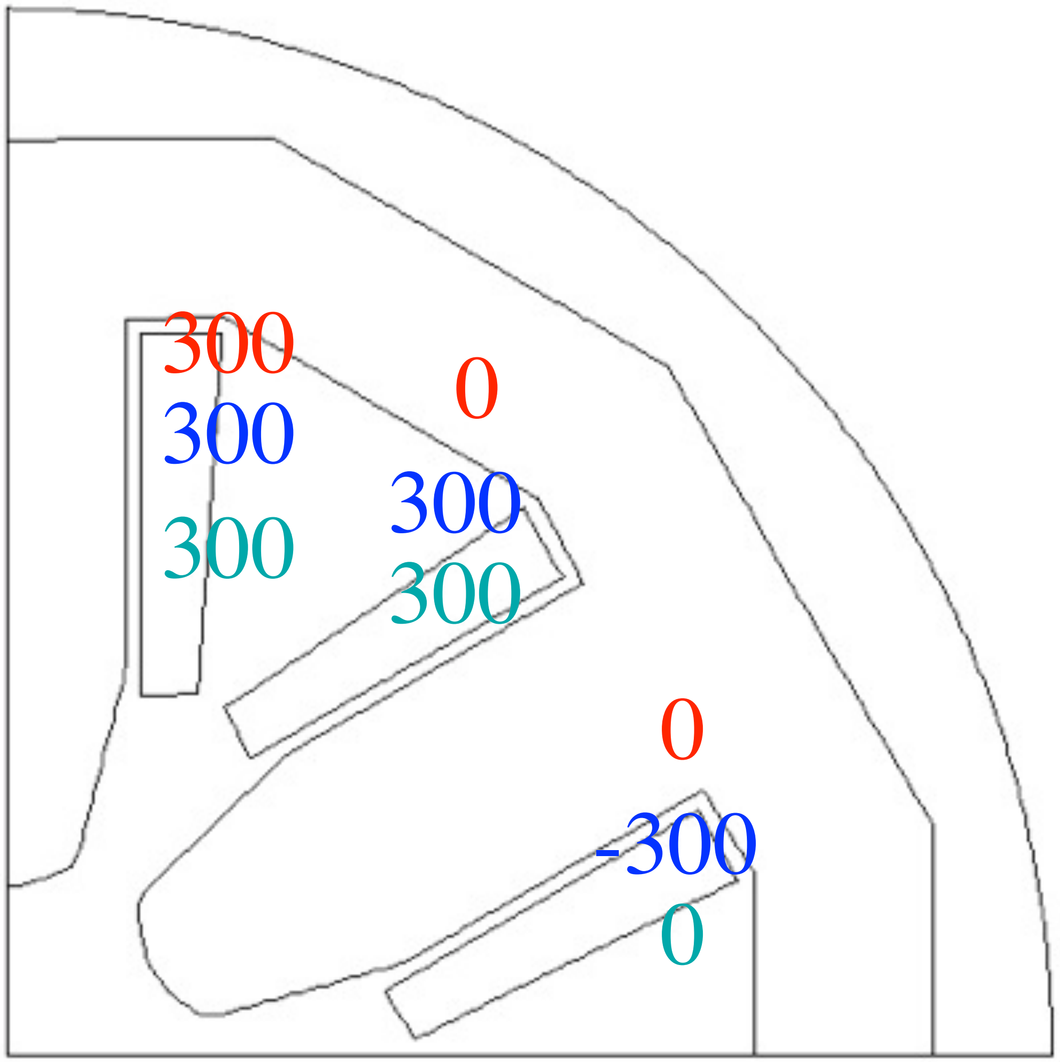
- ☑ Dynamic aperture (Touschek lifetime) after optics corrections
- ☑ Higher-order multipole field due to skew quadrupoles winding of sextupoles

Appendix

skew Q component excited by Sx's correction coils : Bx [x] for different current configurations

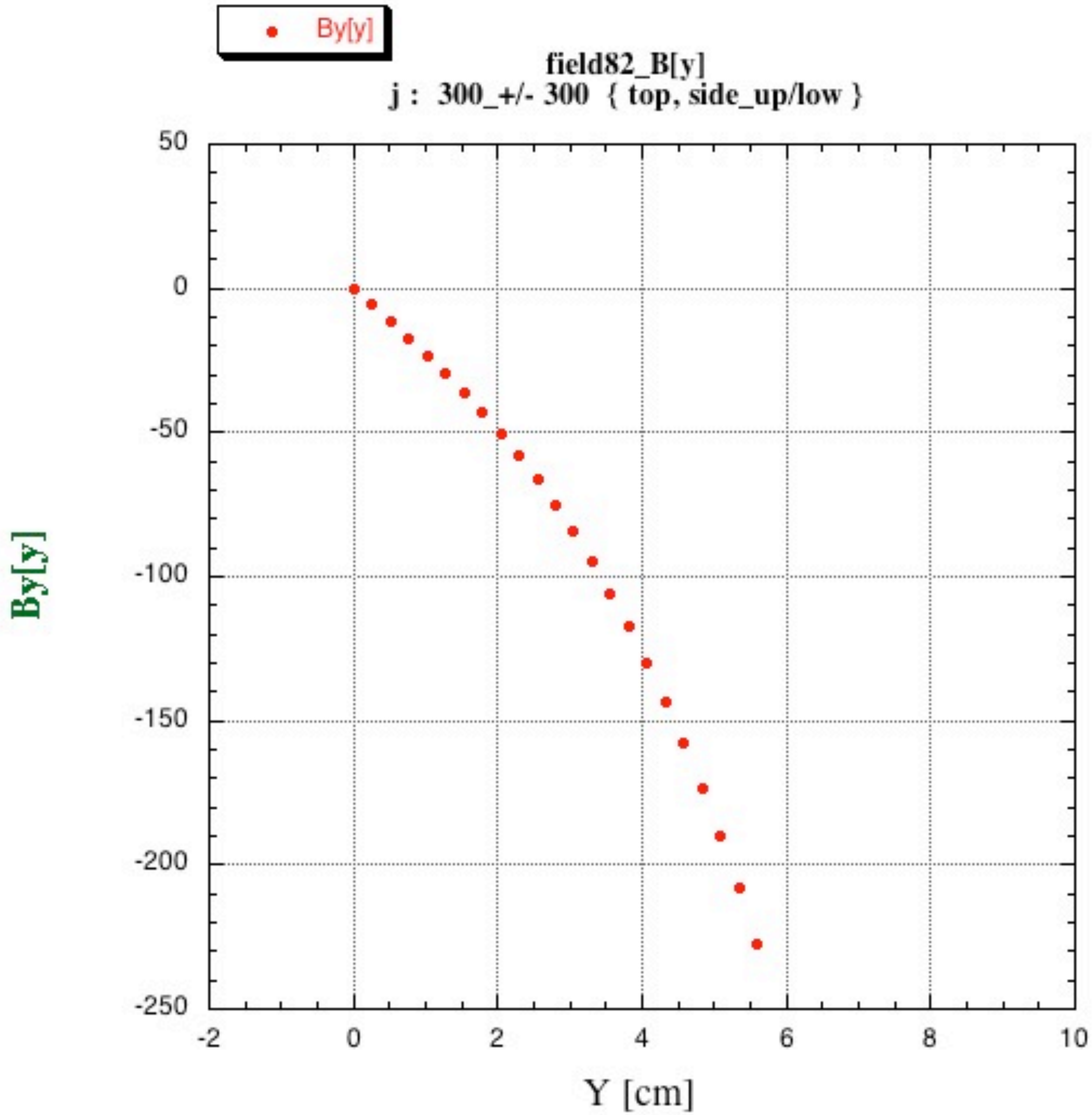
K. Egawa





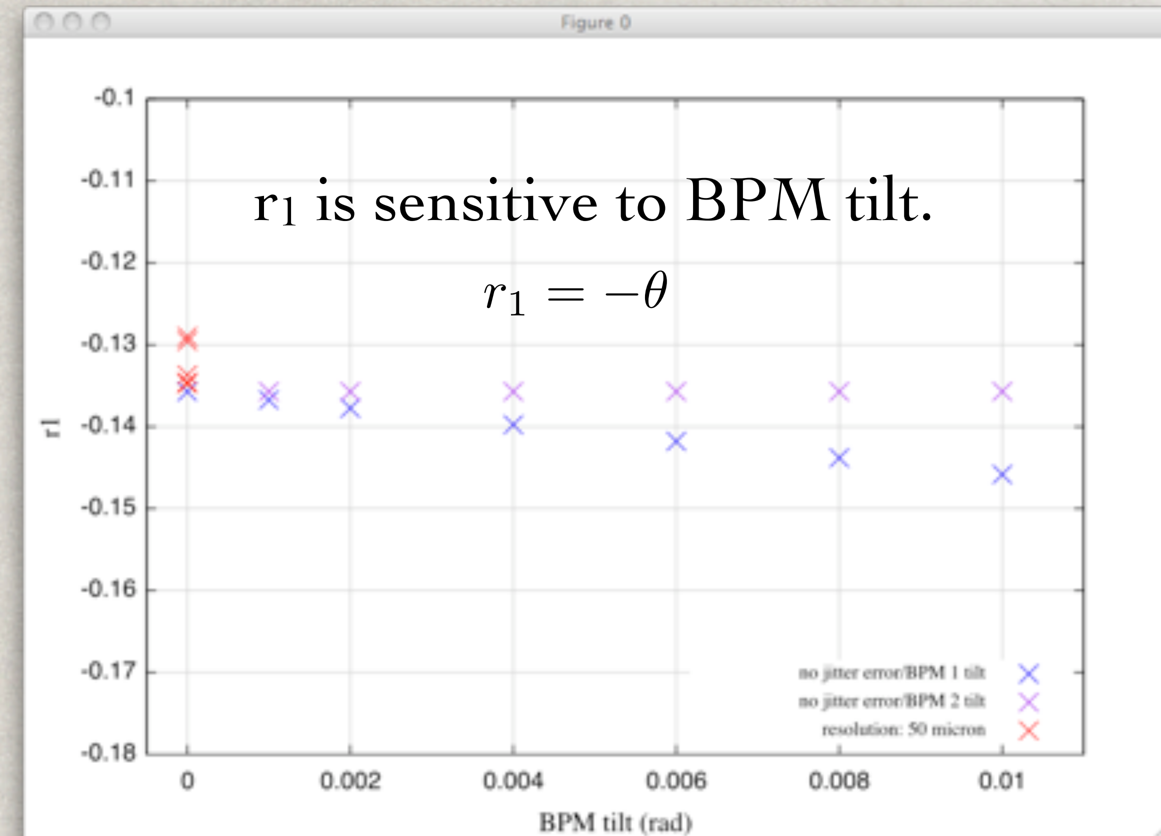
By [y]

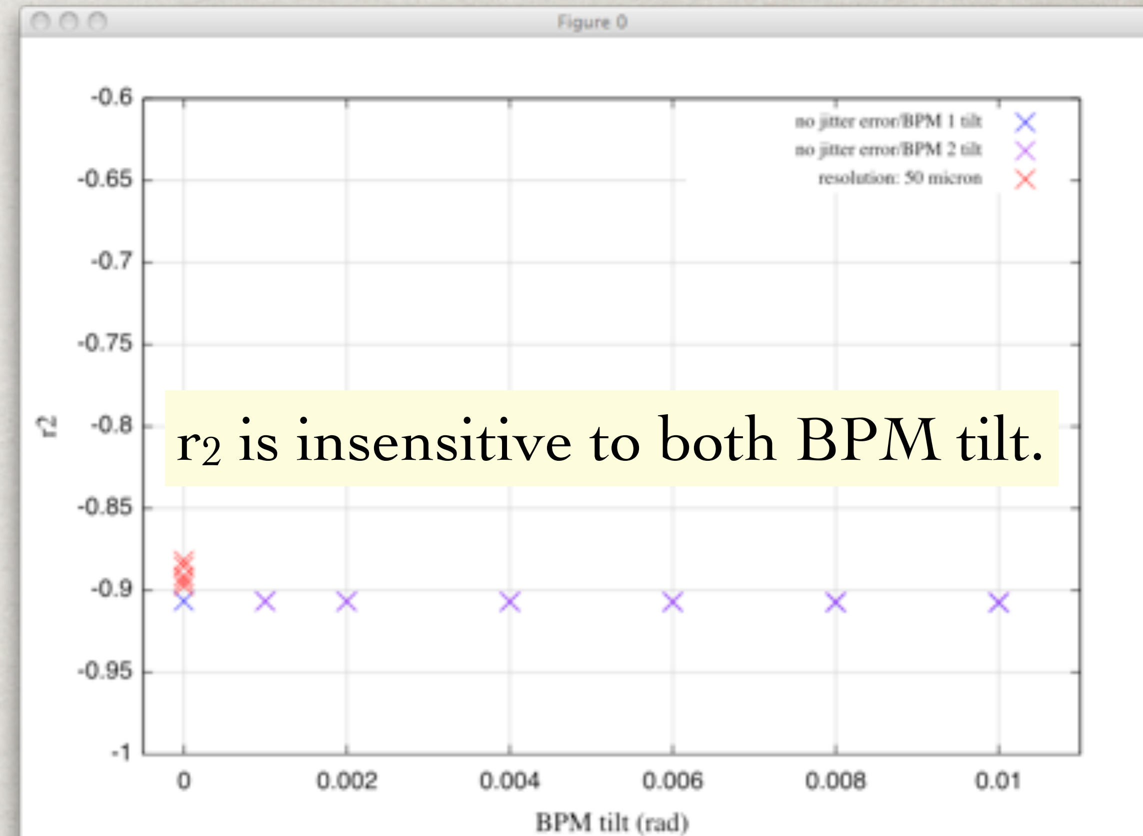
K. Egawa

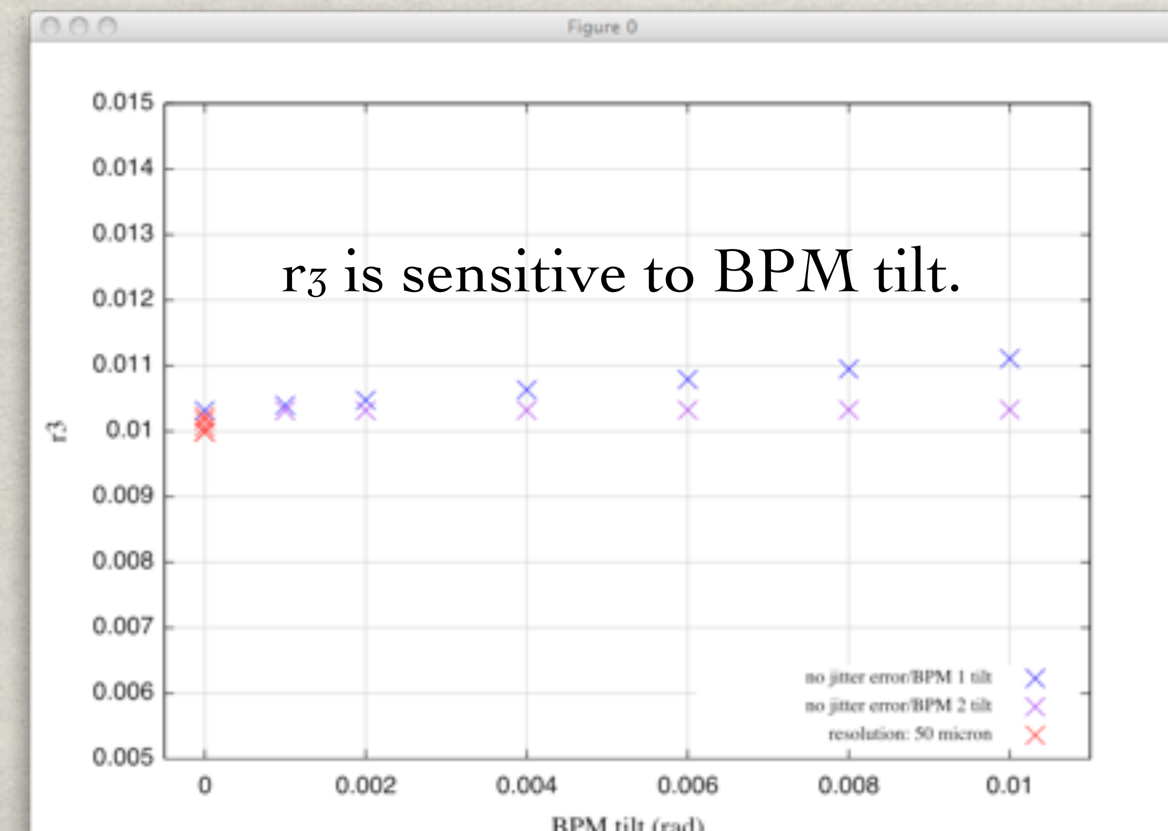


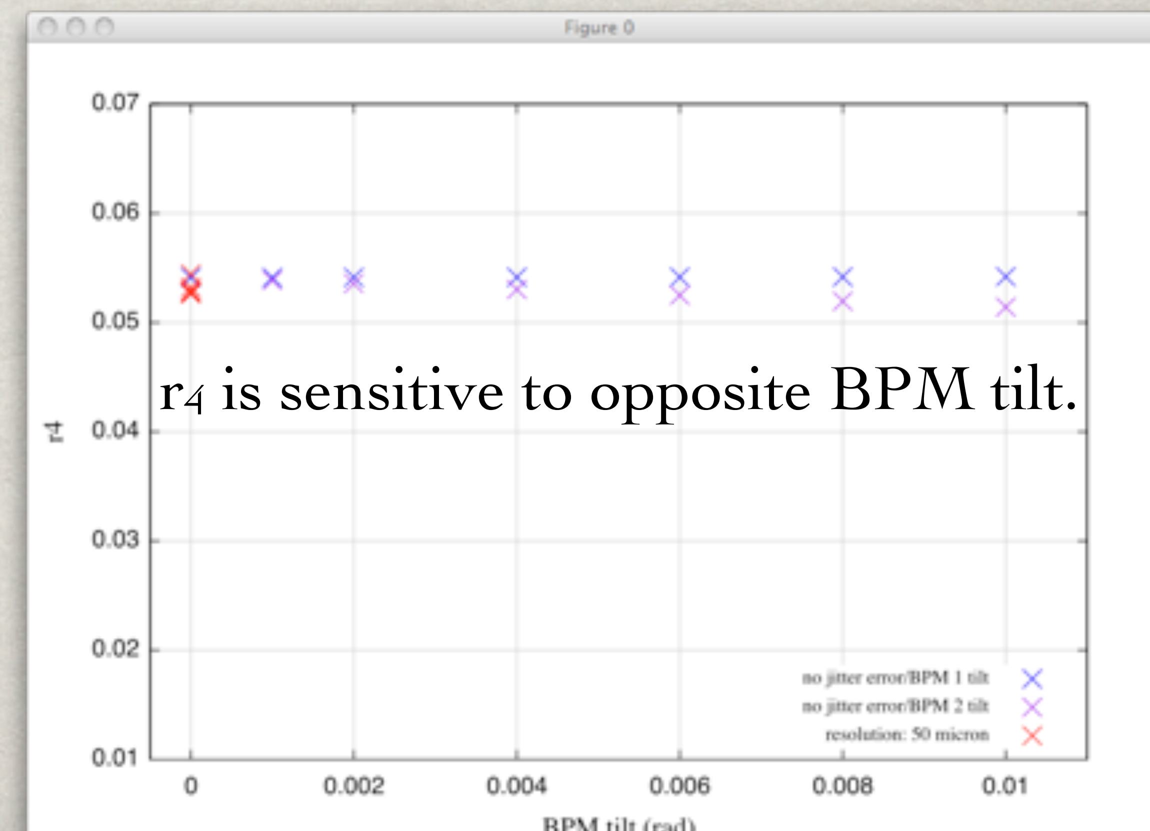
By[y]
field82_B[y]
j : 300_+/- 300 { top, side_up/low }
50
0
-50
-100
-150
-200
-250
-2
0
2
4
6
8
10
By[y]
Y [cm]

4-1 BPM Tilt (monitor:QD3E.3)



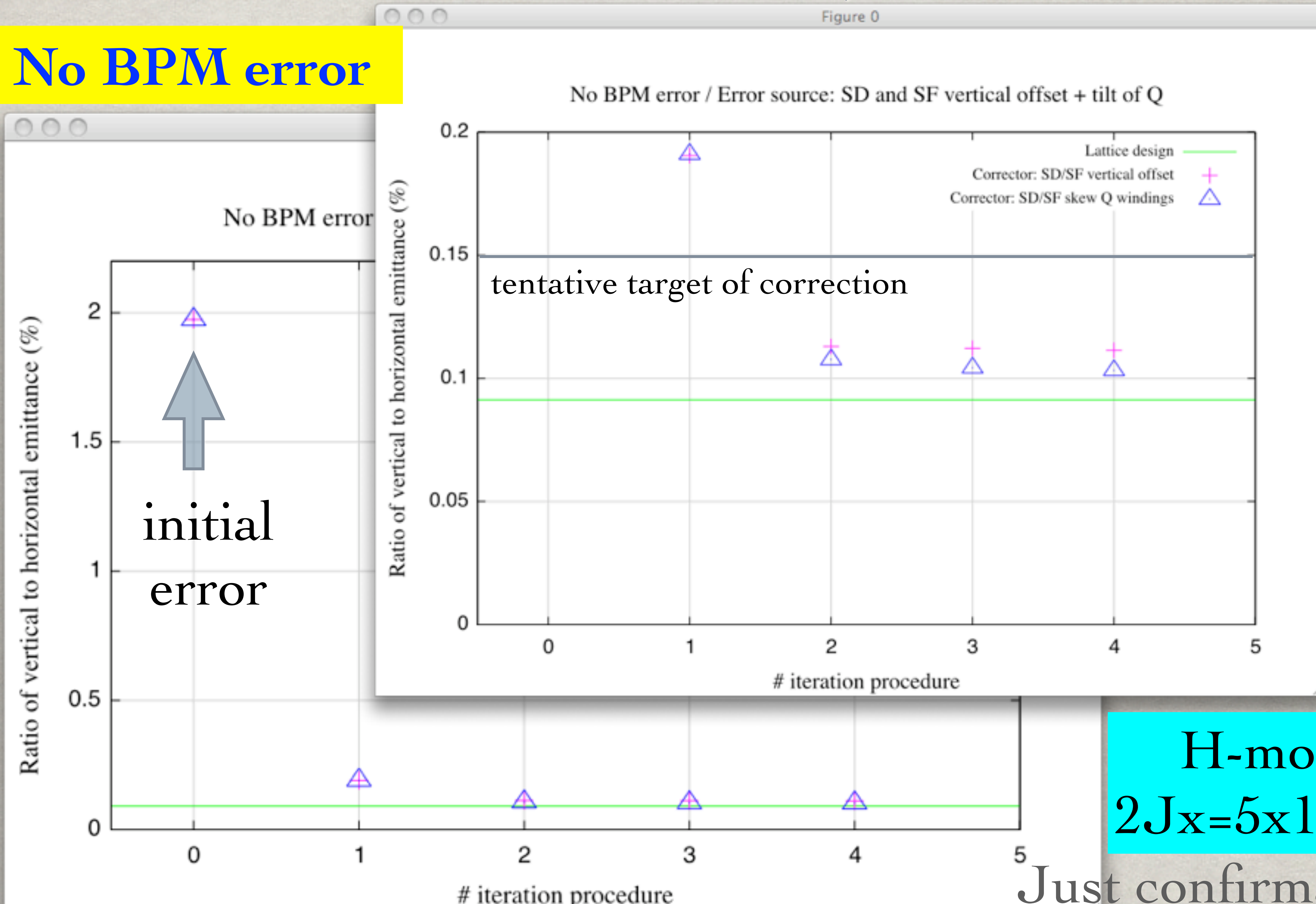






4-4 Correction Performance Offset and Skew Q Element

No BPM error

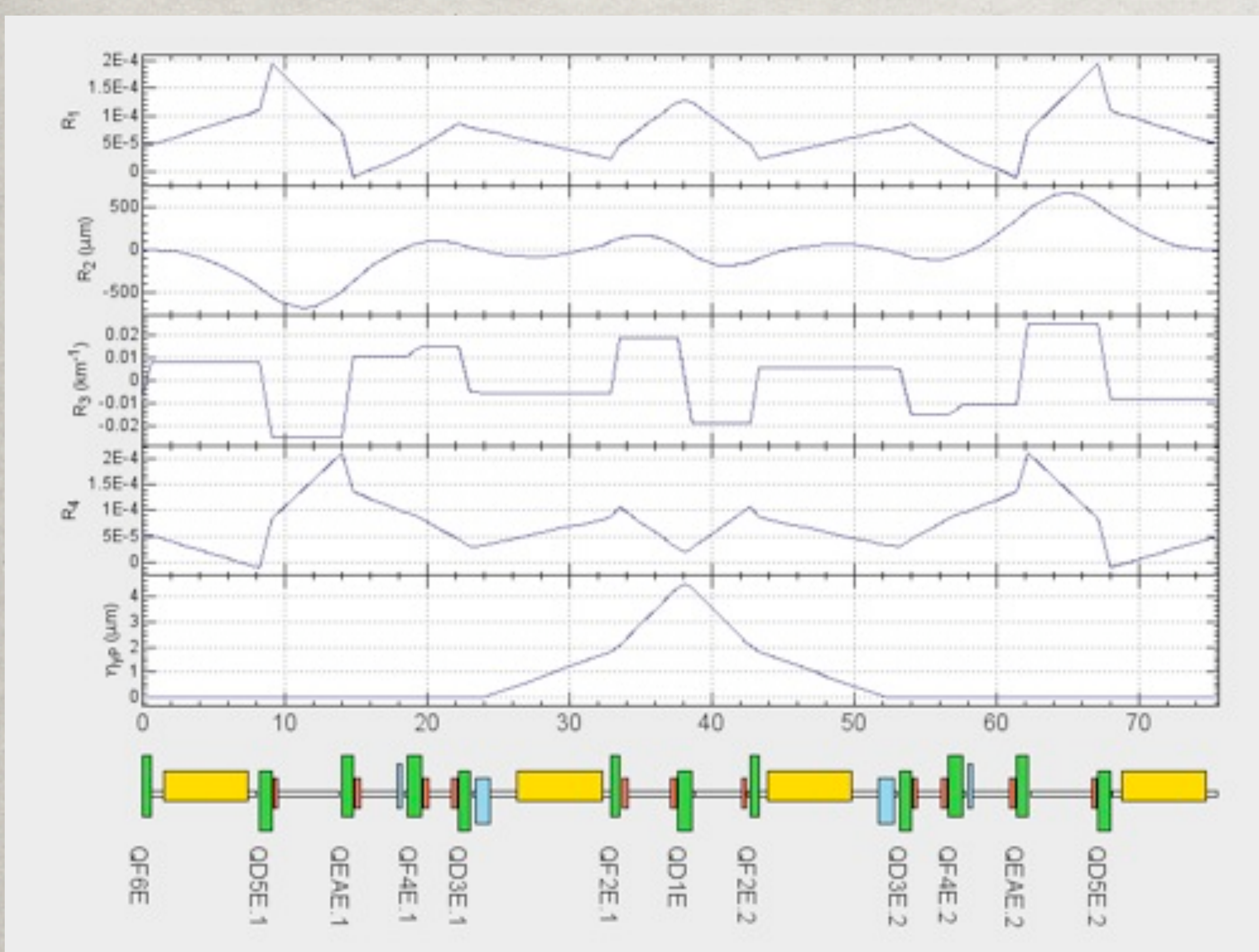


H-mode
$2Jx=5\times10^{-8}$ m

Just confirmation

Sextupole Offset

$\Delta y_{(SD1)}$ = +0.1 mm
$\Delta y_{(SD2)}$ = +0.1 mm



SD1 -I’ SD2

$\Delta y_{(SD1)}$ = +0.1 mm
$\Delta y_{(SD2)}$ = -0.1 mm

SD1 -I’ SD2