Beam Tuning of ATF2 Beamline

Toshiyuki OKUGI, KEK

2012 / 10 / 25

LCWS2012, UTA, TX, USA.

Contents

ATF2 Beam Line

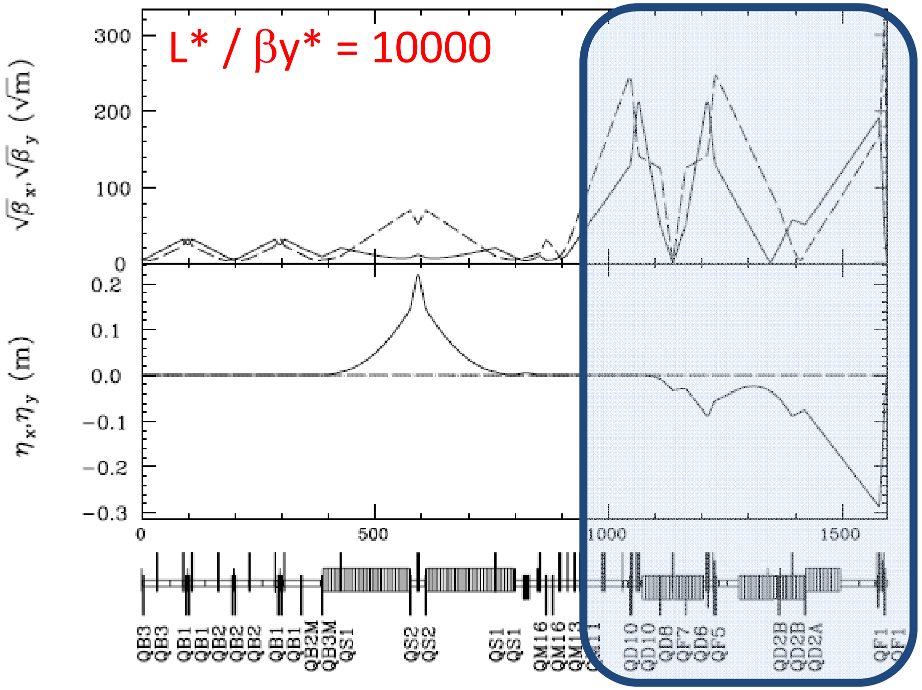
ATF2 beamline was constructed at the extraction line of ATF damping ring for ILC FF R&D.

E = 1.3GeV, $\gamma\varepsilon_x$ = 5e-6m, $\gamma\varepsilon_y$ = 3e-8m

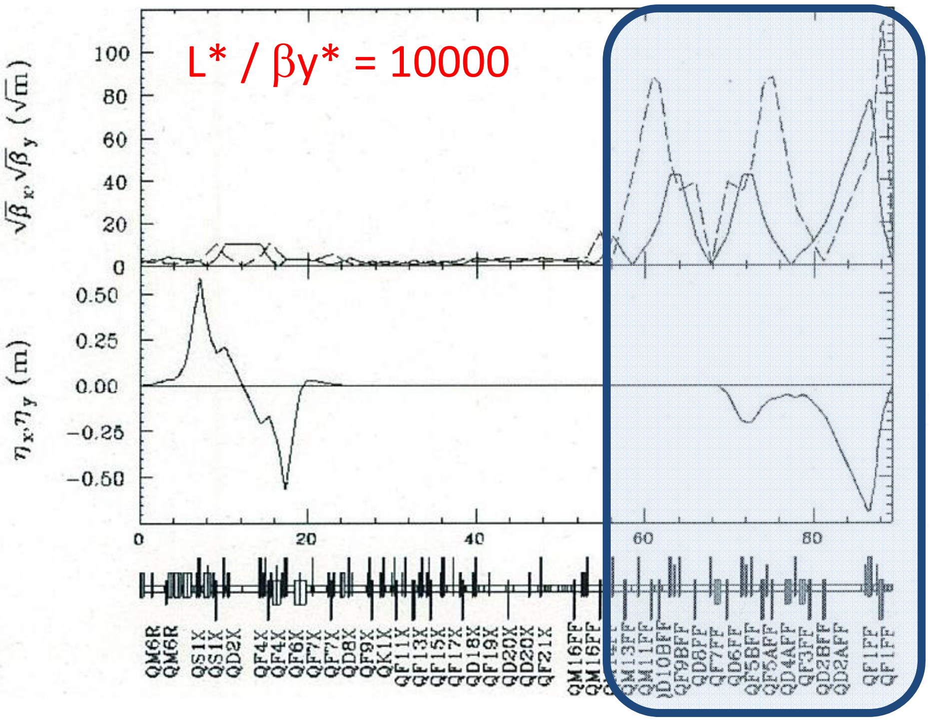
ILC Final Focus System and ATF2 are same magnet arrangements.

The Strength of the chromaticity for ATF2 are designed to the same order of that of ILC.

Final Focus Beam Line for ILC-BDS



Final Focus Beam Line of ATF2



Linear Optics Tuning of ATF2 Beamline

Linear knobs are calculated by changing the positions of FF sexts.

ΔX for FFsext -> change the alphaX, alphaY, etaX, etaX'

- *ΔX for SF6FF, SF5FF, SD4FF, SF1FF, SD0FF are orthogonal to make AX, AY, EX, EPX knobs .*
- *One other free parameter is adjusted to make a large dynamic range of knobs.*

ΔY for FFsext -> change the etaY, etaY', <x'y>

- *ΔY for SF6FF, SF5FF, SD4FF, SF1FF, SD0FF are orthogonal to make EY, EPY, Coup2 knobs .*
- *Two other free parameters are adjusted to make a large dynamic range of knobs.*

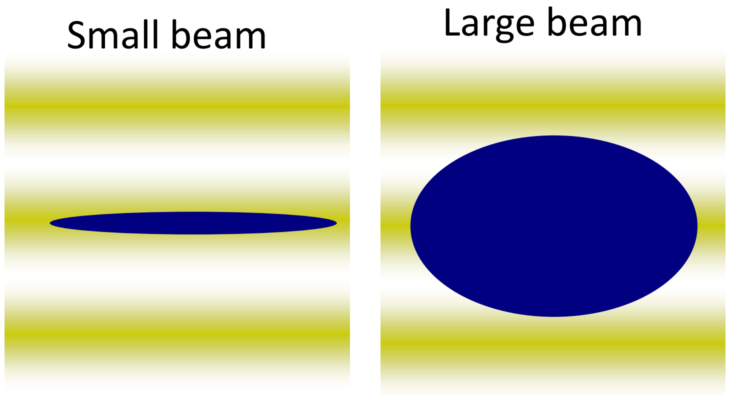
$$\sigma^2 = \sigma_0^2 + (C_\alpha^2 Ay^2 + C_\eta^2 Ey^2 + C_c^2 Coup2^2)$$

C_α ; Effect of beam waist position (depends on vertical divergence)

C_η ; Effect of vertical dispersion (depends on momentum spread; basically constant)

Cc ; Effect of coupling (<x'y>) (depends on horizontal divergence)

Beam Size Evaluation with IP-BSM



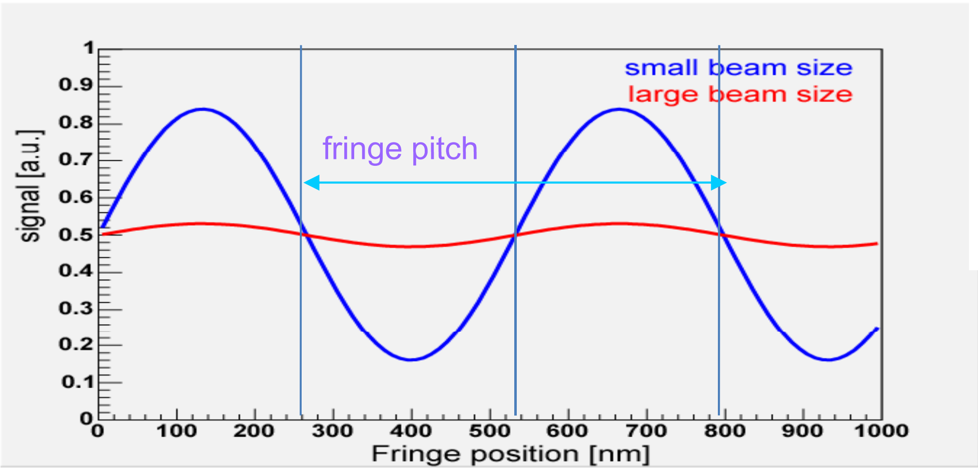
Emitted Photon is evaluated
by the convolution of beam distribution.

$$N_\gamma \propto \int_{-\infty}^{\infty} \exp\left[-\frac{(y-y_0)^2}{2\sigma_y^2}\right](1+\cos\theta\cos 2k_y y)dy$$
$$= N_0[1+\cos(2k_y y_0)\cos\theta]\exp[-2(k_y\sigma_y)^2]$$

$$N_\pm = N_0[1 \pm \cos\theta \exp[-2(k_y\sigma_y)^2]]$$

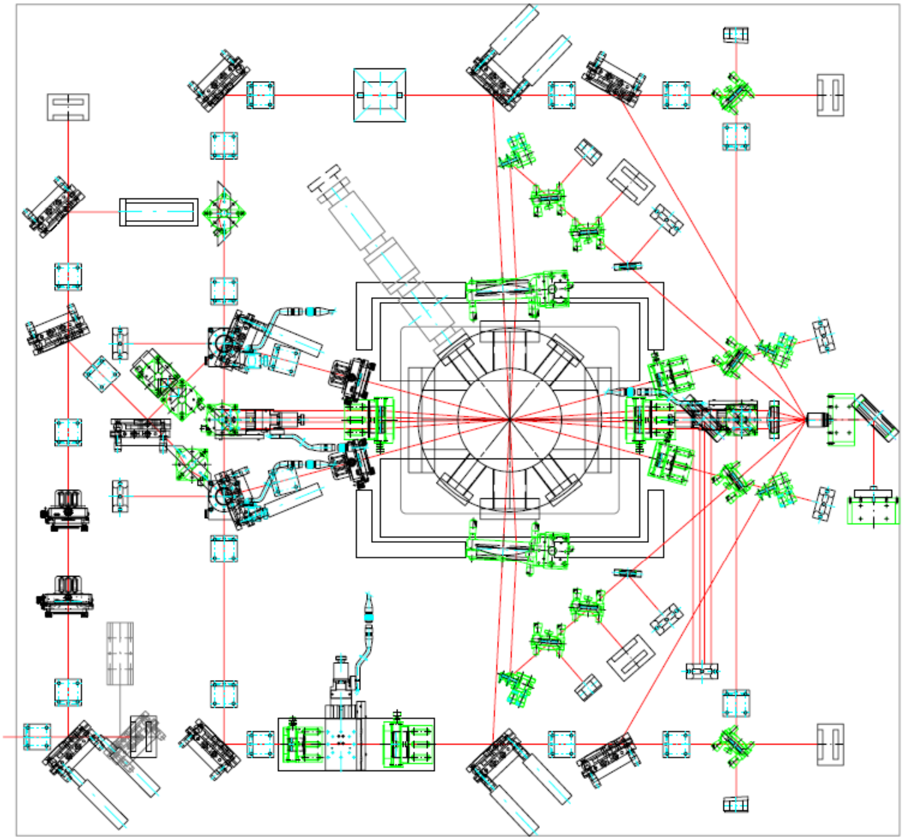
Amount of interference

$$M \equiv \frac{N_+ - N_-}{N_+ + N_-}$$
$$= |\cos\theta| \exp[-2(k_y\sigma_y)^2]$$
$$= |\cos\theta| \exp[-2(\frac{\pi\sigma_y}{d})^2]$$



$$\sigma_y = \frac{d}{2\pi}\sqrt{2\ln\left(\frac{|\cos\theta|}{M}\right)}$$

IP-BSM for ATF2



We have 3 collision angle mode

2-8 degree mode (continuous)

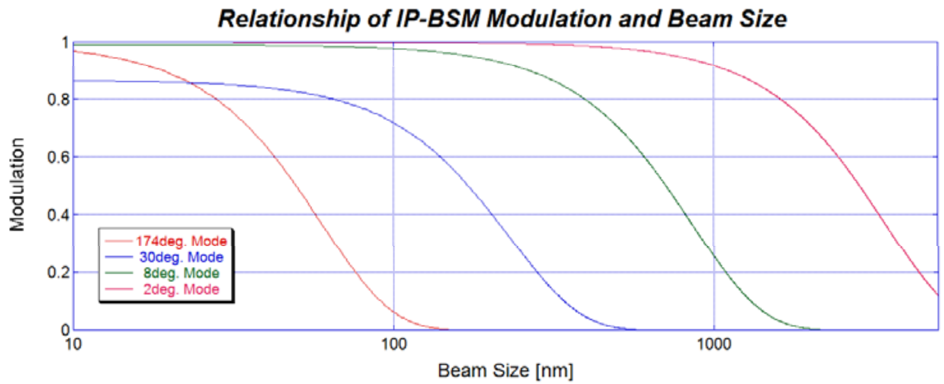
sensitive to 300-6000nm beam size

30 degree mode

sensitive to 90-300nm beam size

174 degree mode

sensitive to 25-90nm beam size



Beam Size Tuning with Linear Knob

Measured Modulation by IP-BSM

$$M = C \cos\theta \exp\left[-2\left(k_y \sigma\right)^2\right]$$

C ; Modulation Reduction Factor (IP-BSM related)

If each knob is not coupled,

$$M = C \cos\theta \exp\left[-2\left(k_y \sigma_0\right)^2\right]$$ Constant for linear knob tuninig

$$\exp\left[-2\left(k_y C_\alpha Ay\right)^2\right]$$ Effect of Ay knob

$$\exp\left[-2\left(k_y C_\eta Ey\right)^2\right]$$ Effect of Ey knob

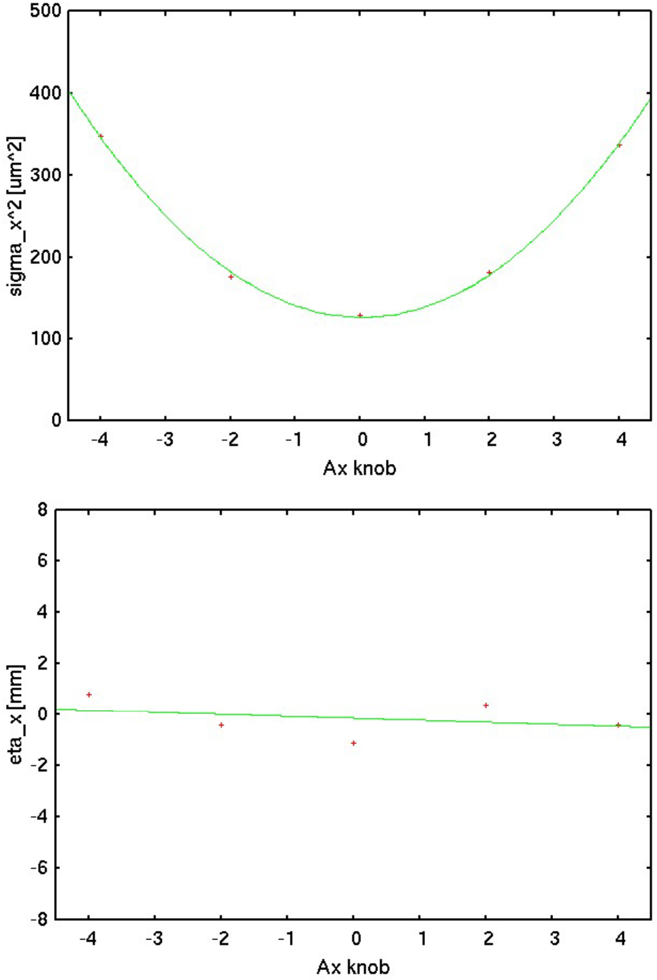
$$\exp\left[-2\left(k \; Cc \; Coup2\right)^2\right]$$ Effect of Coup2 knob

We can optimize each knob independently.

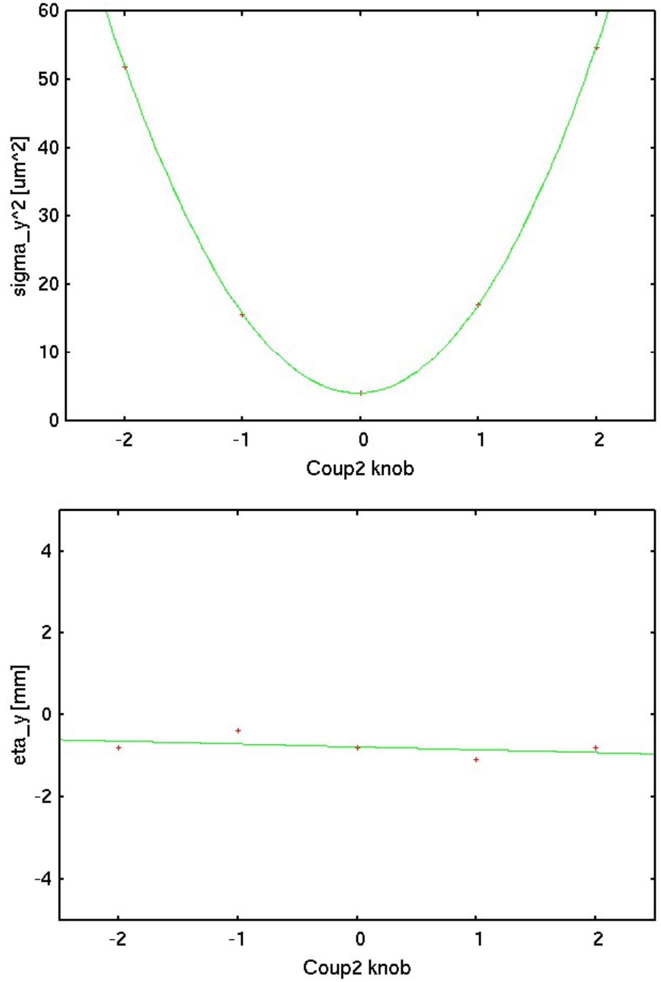
Linear Knob Independency

Measured by carbon wire scanner

Alpha X knob (horizontal movers)



Coup2 knob (vertivcal movers)

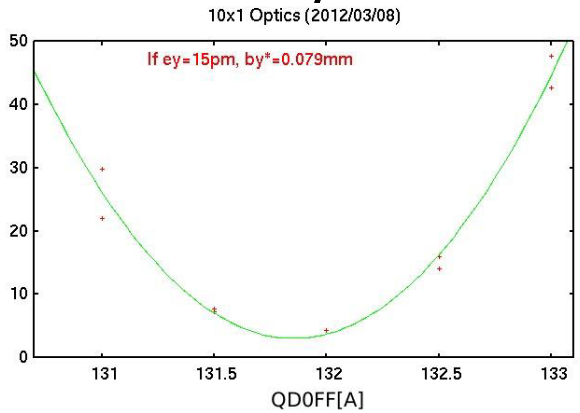


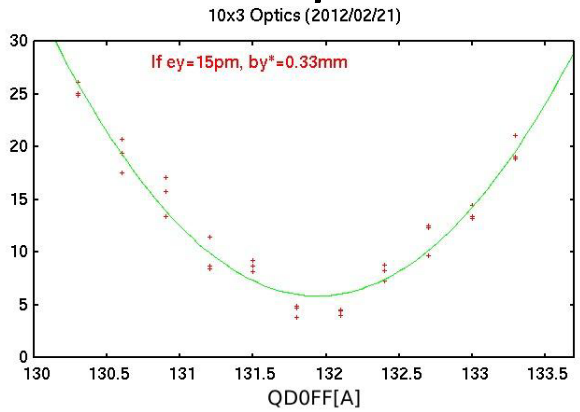
The knobs are not coupled to the dispersions.

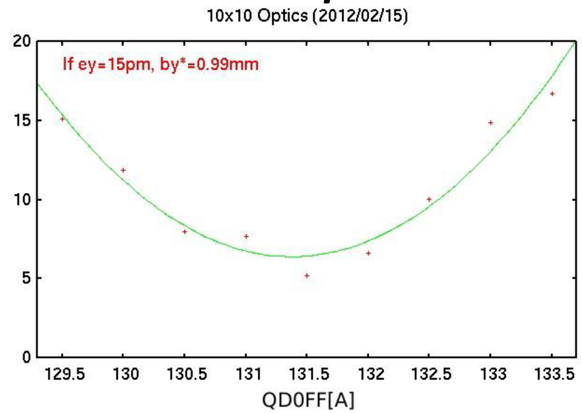
Response of the Ay knob

10x1 optics | 10x3 optics | 10x10 optics

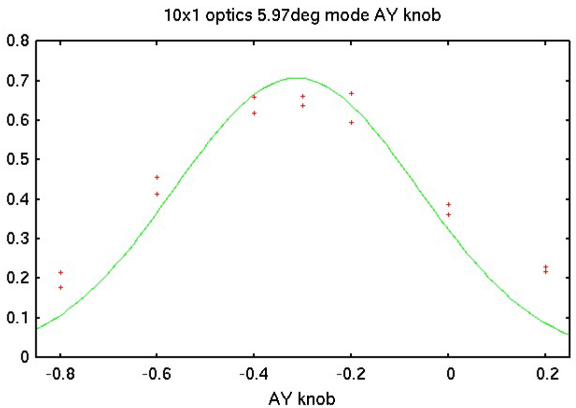
QD0 Scan

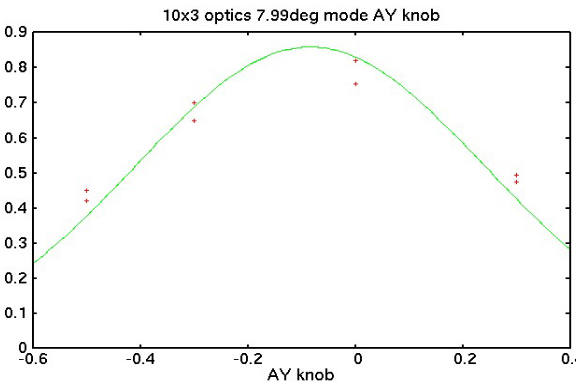


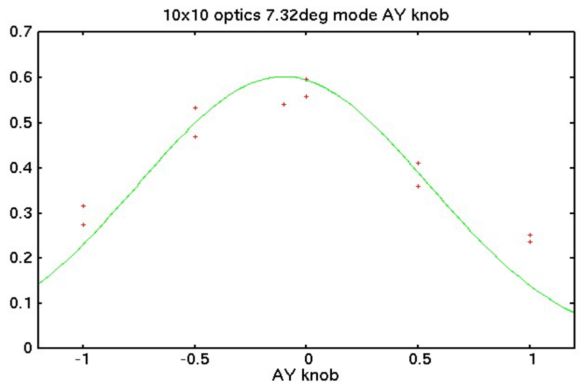




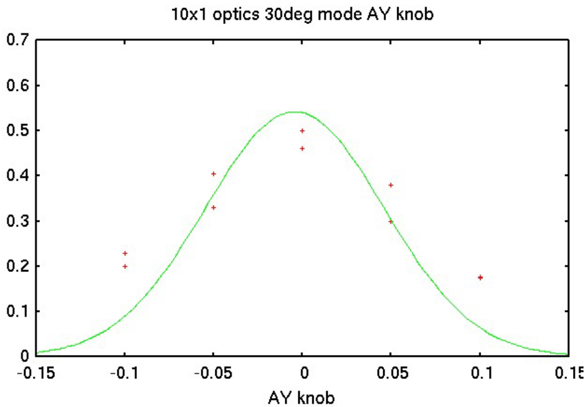
2-8 ° mode

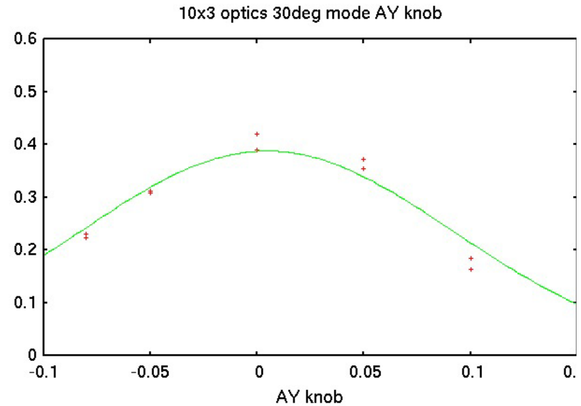


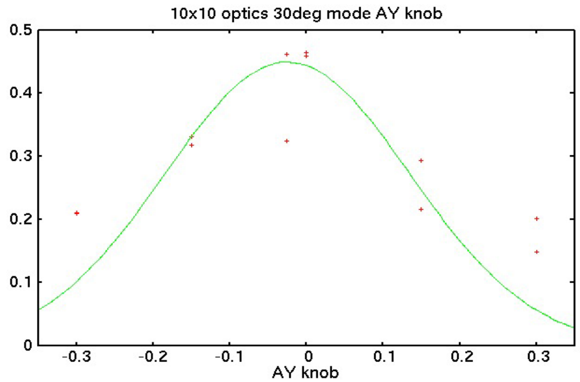




30 ° mode



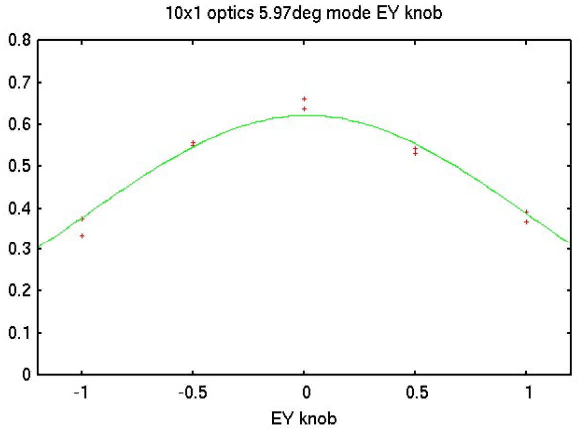


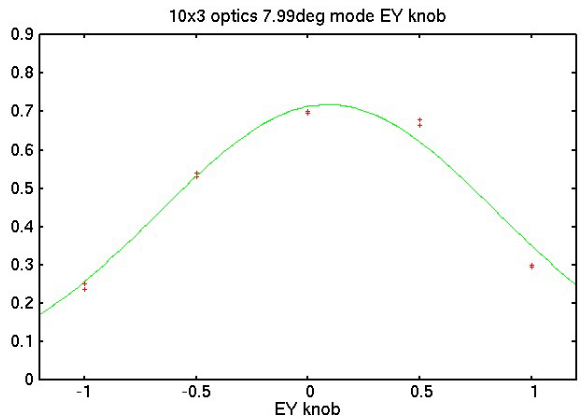


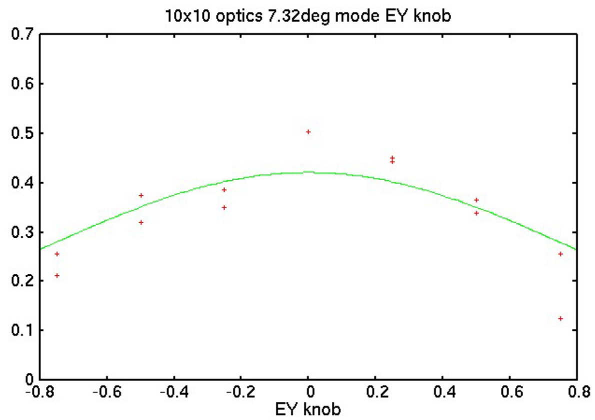
Response of the Ey knob

10x1 optics ***10x3 optics*** ***10x10 optics***

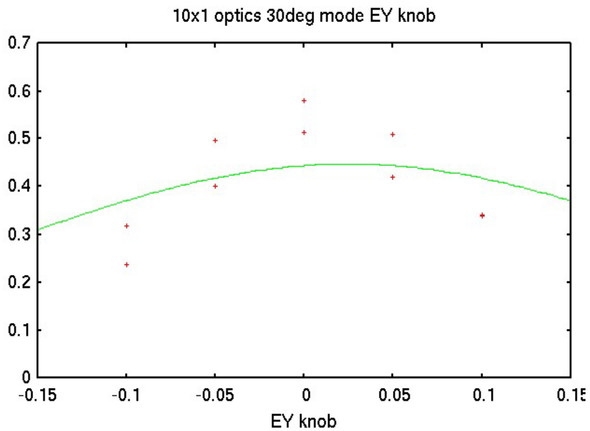
2-8° mode

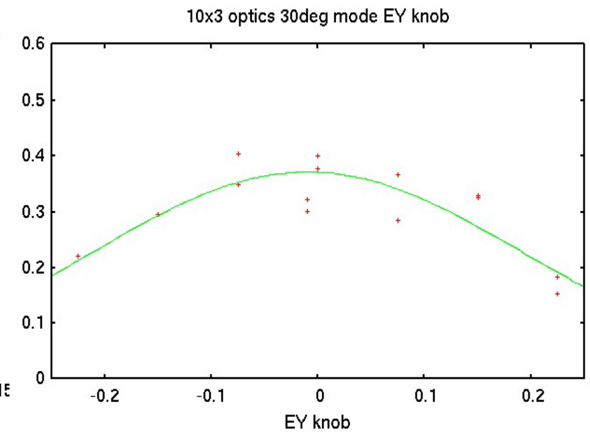


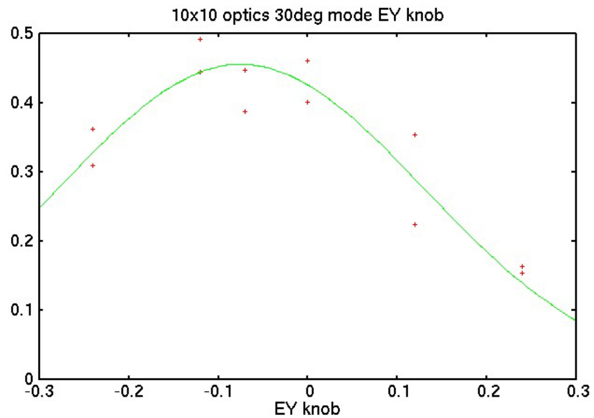




30° mode





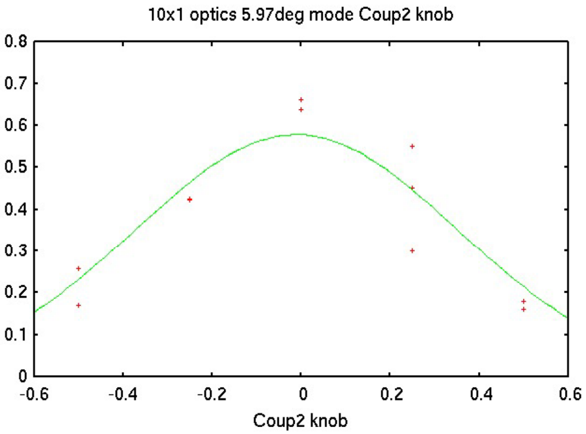


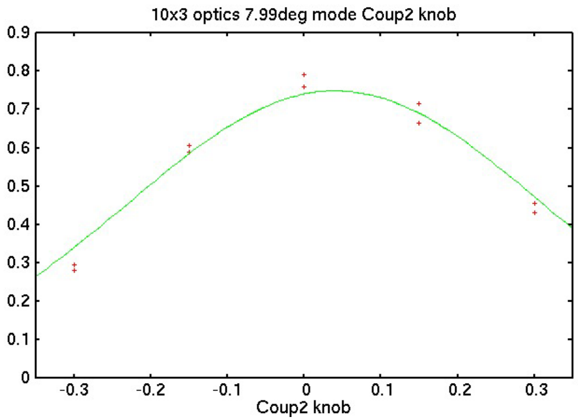
Same sensitivity of Ey knob,
because the momentum spread were same for all optics.

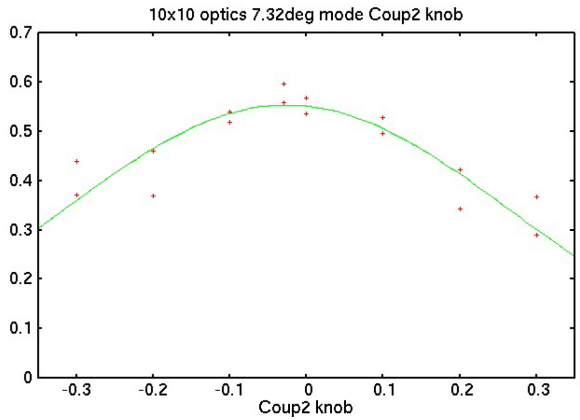
Response of the Coup2 (<x'y>) knob

10x1 optics | **10x3 optics** | **10x10 optics**

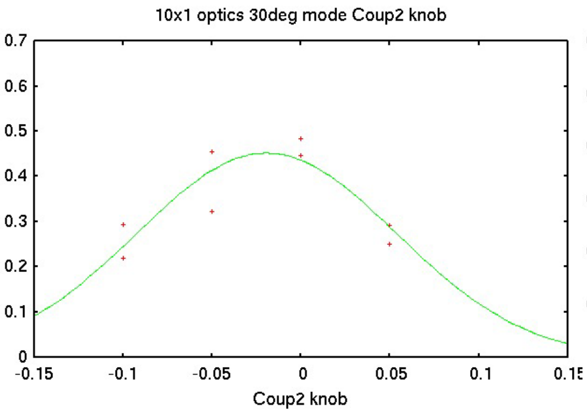
2-8° mode

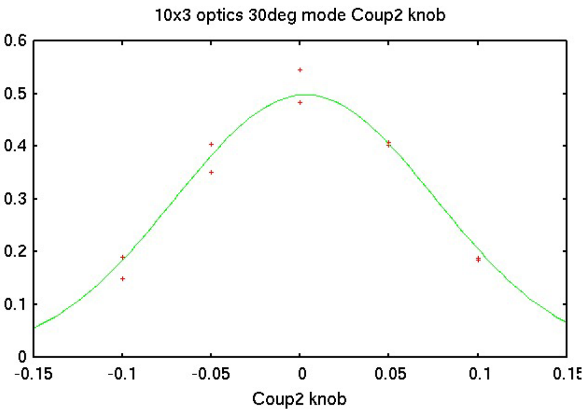


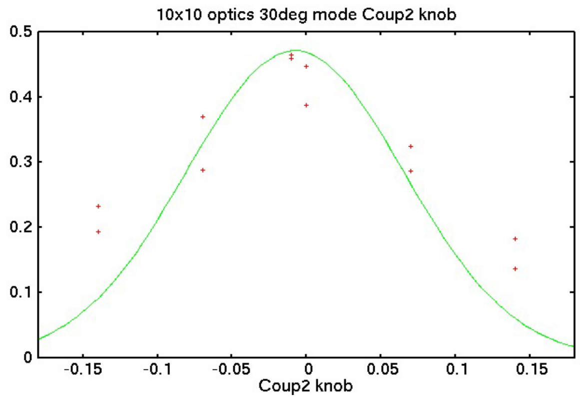




30° mode







Same sensitivity of Coup2 knob,
because betax were same for all optics.*

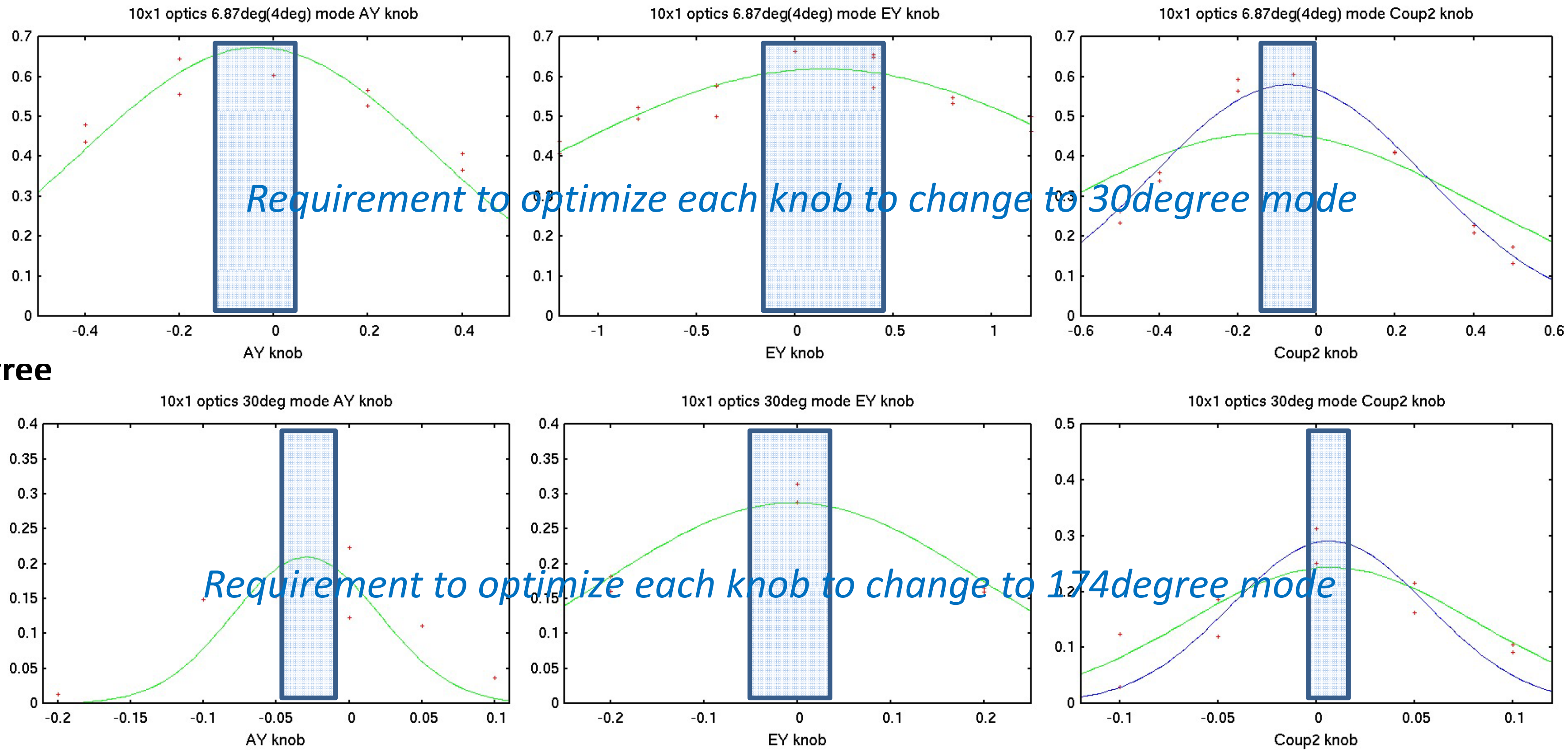
Requirement of the accuracy of knob center search

Modulation reduction factor is not important for IP beam size tuning, but important for the stability of the measurement.

Ay knob **Ey knob** **Coup2 knob**

2-8 degree mode

30 degree mode



The fluctuation of the modulation measurement was too large to optimize the knob for 30degree mode.

Correction of Normal Sextupole Field Errors

Sextupole field correction knobs by changing the strength of FF sexts.

Sextupole field

$$B_y = \frac{B^{(2)}}{2}\,(x^2 - y^2)$$

$$B_x = B^{(2)}\,x\,y$$

$$\Delta X_{IP} = \frac{R_{12} K_2}{2}\left(\Delta x^2 + 2\eta\Delta x\frac{\Delta p}{p} + \eta^2\frac{\Delta p^2}{p^2} - \Delta y^2\right)$$

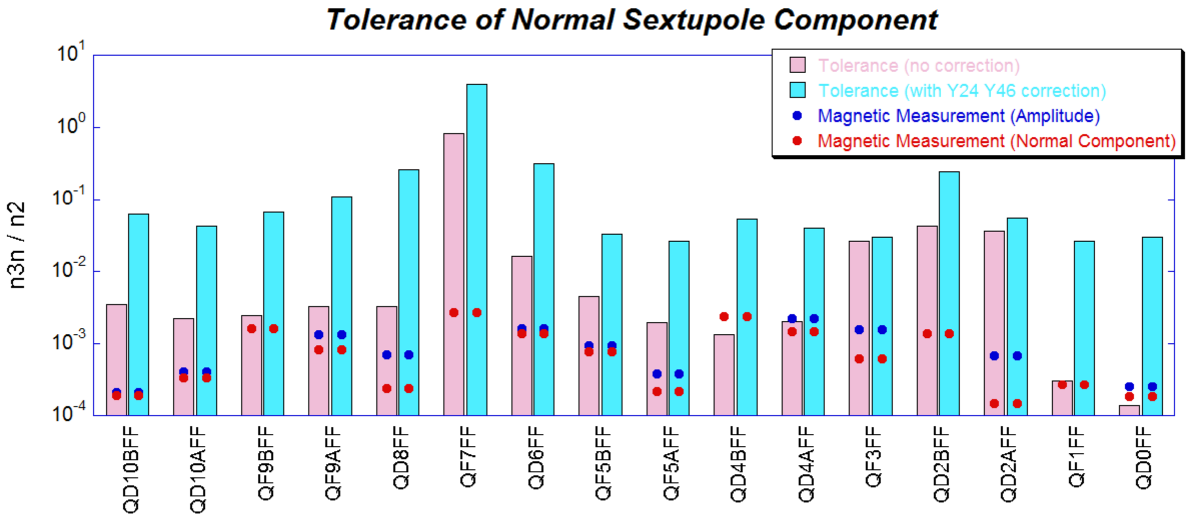
X22 X26 X66 X44

ignore (effect is small)

$$\Delta Y_{IP} = R_{12} K_2\left(\Delta x\,\Delta y + \eta\,\Delta y\frac{\Delta p}{p}\right)$$

Y24 Y46

ΔK2 for SF6FF, SF5FF, SD4FF, SF1FF, SD0FF are orthogonal to make X22, X26, X66, Y24, Y46 knobs



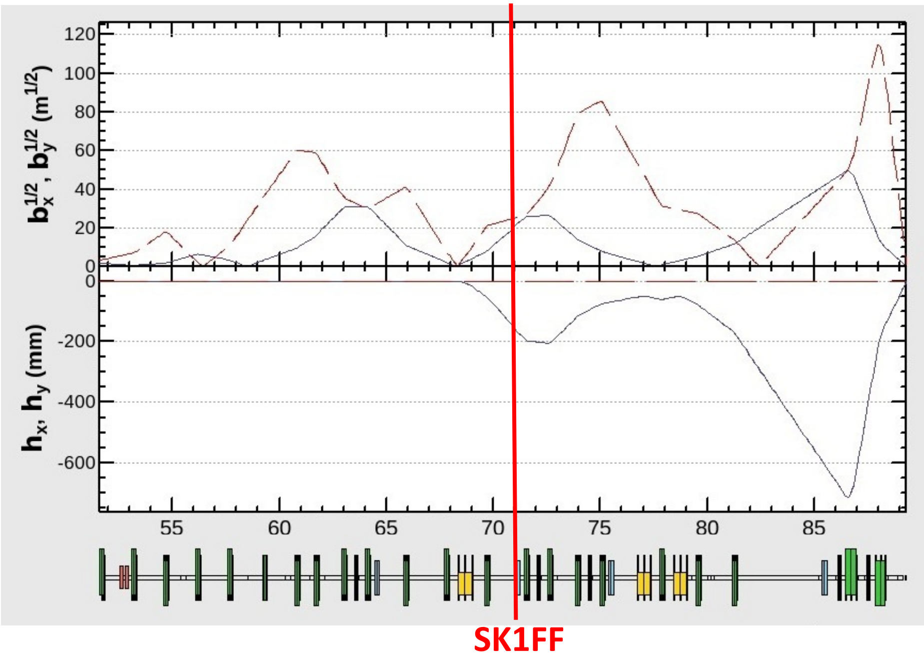
Definition of tolerance

$$\Delta\sigma = 0.05\,\sigma$$

with Glen's 2.5x1 FF optics
betax*= 0.0100m, emitx = 2nm
betay*= 0.0001m, emity = 12pm

Red ; No correction
Blue; with Y24 Y46 correction

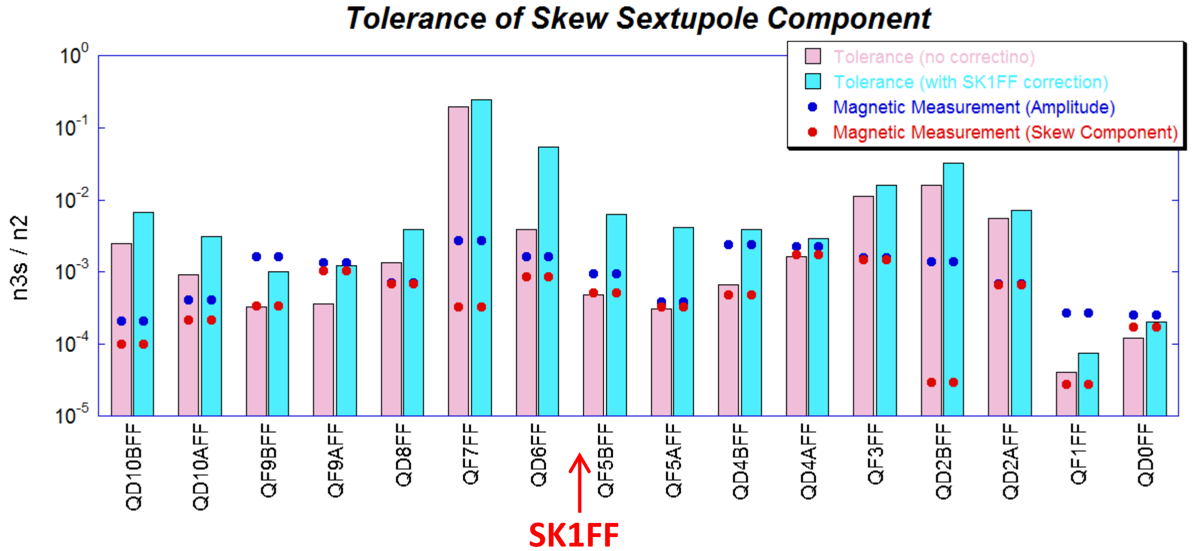
Skew Sextupole Field Correction Knob (until 2012 June)



In order to relax the tolerance of skew sextupole errors, we put the skew sextupole magnet (SK1FF)

(borrowed from KEKB)

Location of the skew sextupole was optimized by E. Marin.



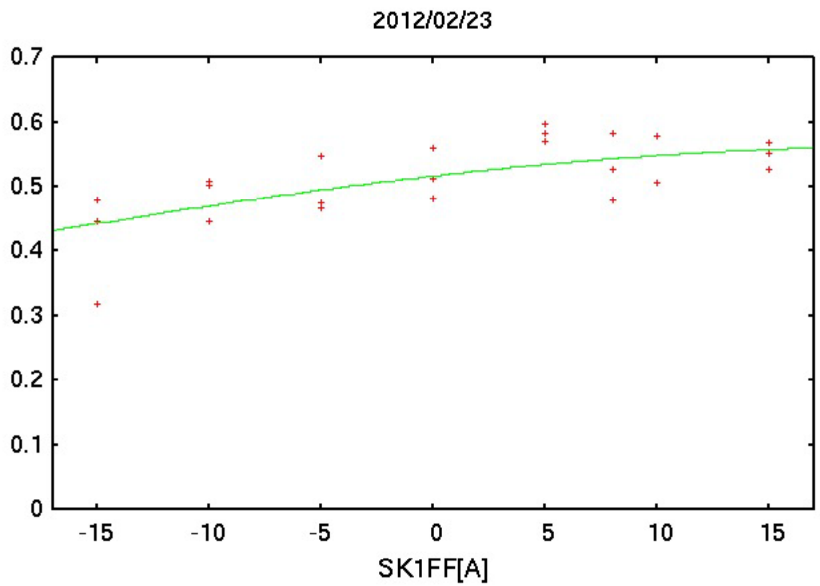
Definition of tolerance

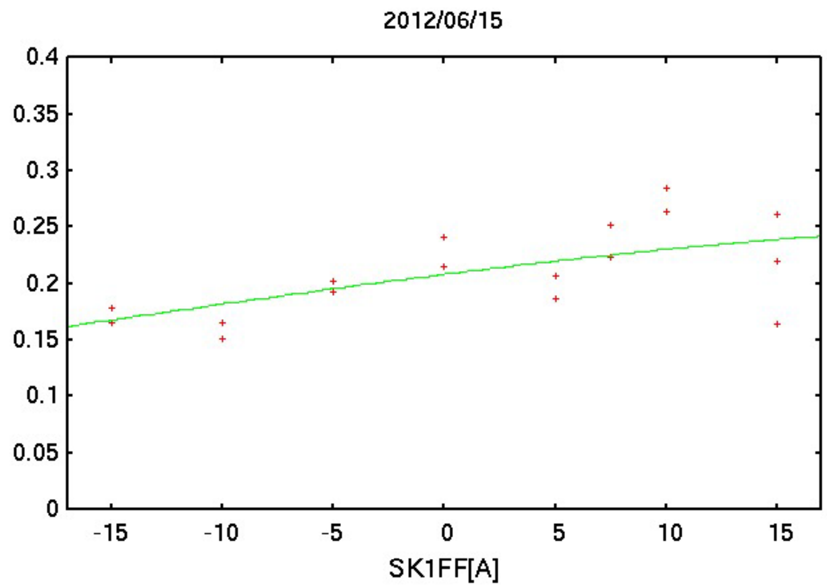
$$\Delta\sigma = 0.05\ \sigma$$

with Glen's 2.5x1 FF optics
betax*= 0.0100m, emitx = 2nm
betay*= 0.0001m, emity = 12pm

Red ; No correction
Blue; with SFD correction

Correction of Skew Sextupole Field in 2012 Spring Run



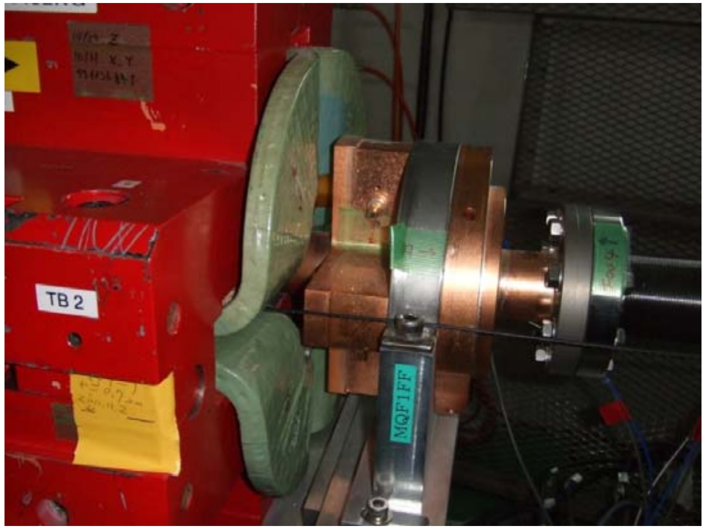


Correction field of skew sextupole component was much larger than expected one.

We measured same response of SK1FF strength scan in Feb. and June 2012.

(Minimum SK1FF was around 20A ; design was 2A)

Candidate of the large skew sextupole field error



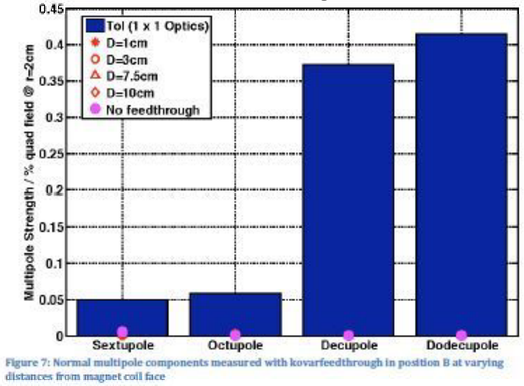
Feed through of S-band BPM (Kovar)

	Magnetic Field
QF1FF	*150-200Gauss*
QD0FF	*300-350Gauss*

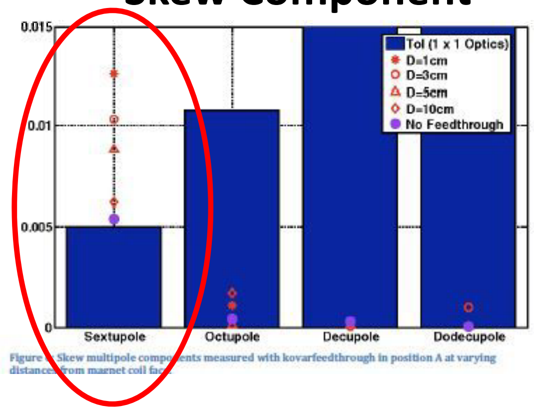
Effect of Kovar Feedthrogh Test in SLAC

Presented by G.White at ATF meeting (2012/10/12)

Normal Component



Skew Component

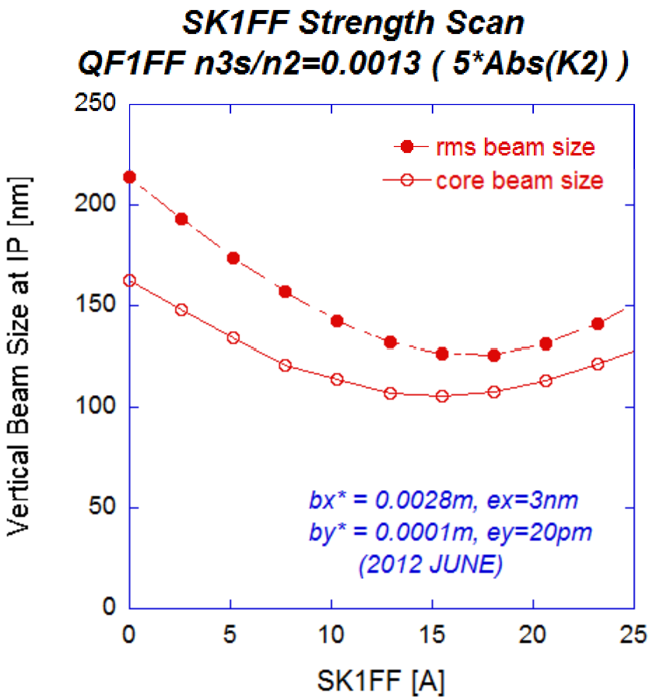


Effect for skew sextupole component was large

We will remove the S-band BPMs in next week (the week from 2012/10/29).

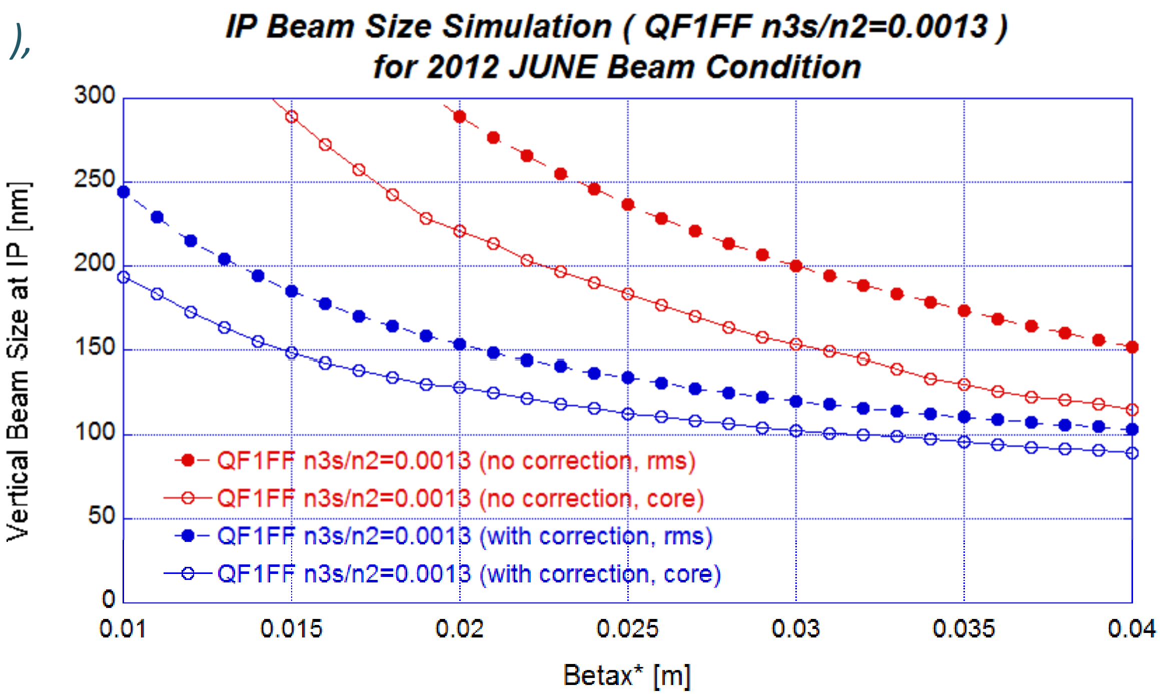
Beam size limit for the beamline with a large skew sextupole error at QF1FF.

When we put n3s/n2=0.0013 (comparable to error of QEA magnets), the simulation is reproduced to the QK1FF correction in beam time.



Emittx = 3nm
Betay = 0.1mm*
Emitty = 20pm

with Y24, Y46 SK1FF knob correction



When there is large skew sextupole error for QF1FF, we could not squeeze the beam size less than 100nm, even if we applied the Y24, Y46, SK1FF correction.

Skew Sextupole Field Correction Knobs (from 2012 October)

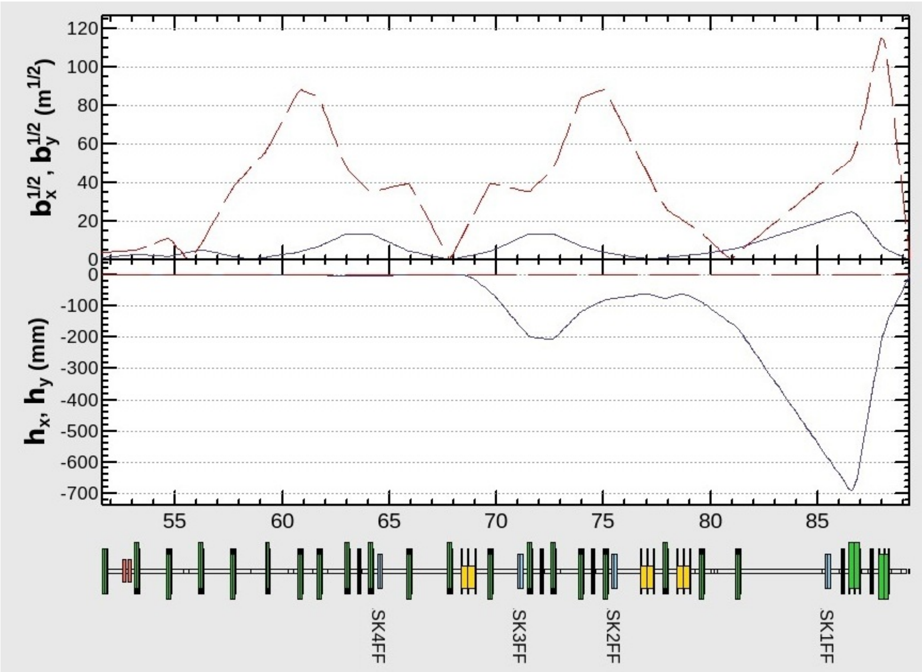
Skew sextupole field

$$B_x = \frac{B_s^{(2)}}{2}(x^2 - y^2)$$

$$\Delta y_{IP} = \frac{R_{34} K_{2S}}{2}\left(\Delta x^2 + 2\eta \Delta x \frac{\Delta p}{p} + \eta^2 \frac{\Delta p^2}{p^2} - \Delta y^2\right)$$

Y_{22} Y_{26} Y_{66} Y_{44}

We will put 4 skew sextupole correctors



SK1FF ; sensitive to Y22, Y26, Y66

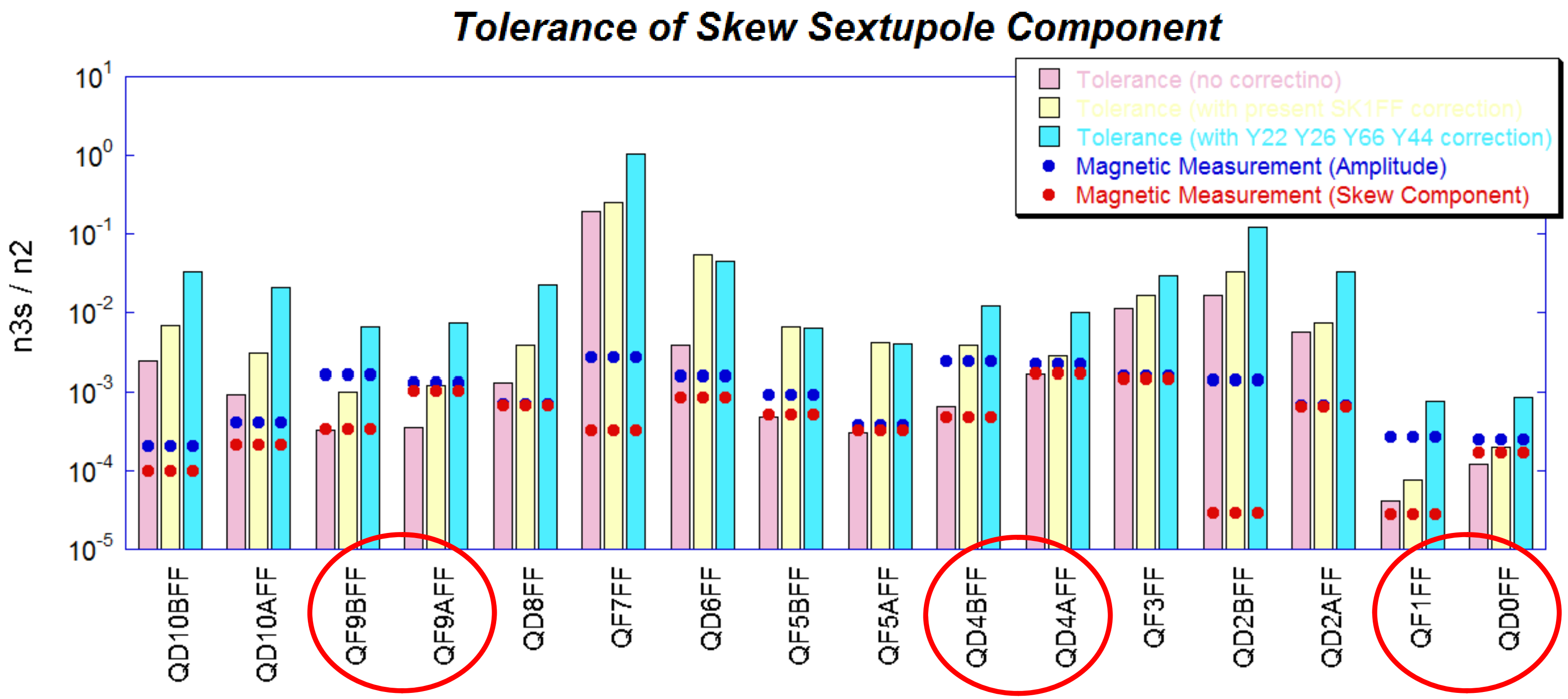
SK2FF ; sensitive to Y44

SK3FF ; sensitive to Y22, Y26, Y66

SK4FF ; sensitive to Y22

Y22, Y26, Y66, Y44 knobs are calculated by the combination of SK1FF, SK2FF, SK3FF, SK4FF.

Performance of New Correction Scheme



***Red** ; No correction*

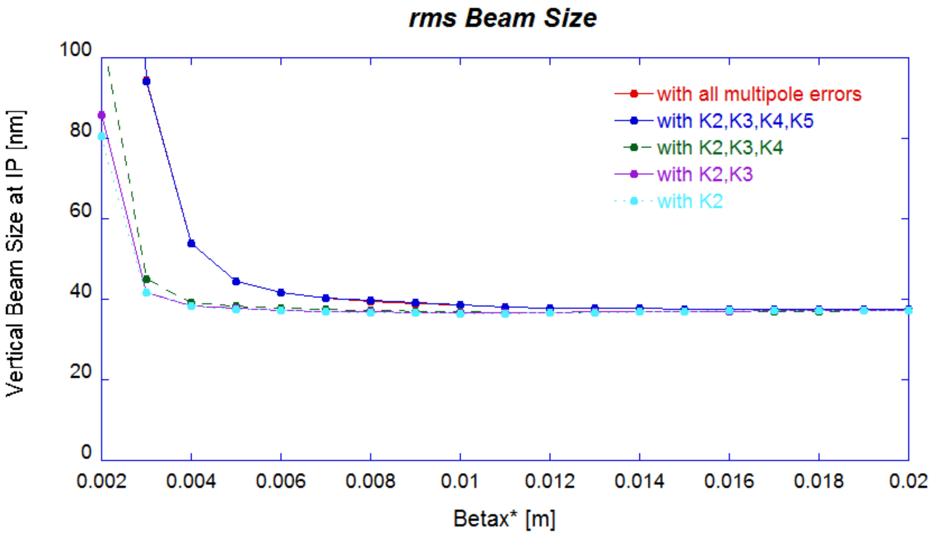
***Yellow** ; with SK1FF correction*

***Blue;** with 4 SKs correction*
(10A maximum)

By using 4 SKs correction,
tolerances for all quadrupoles are increased.

(especially for Final Doublet)

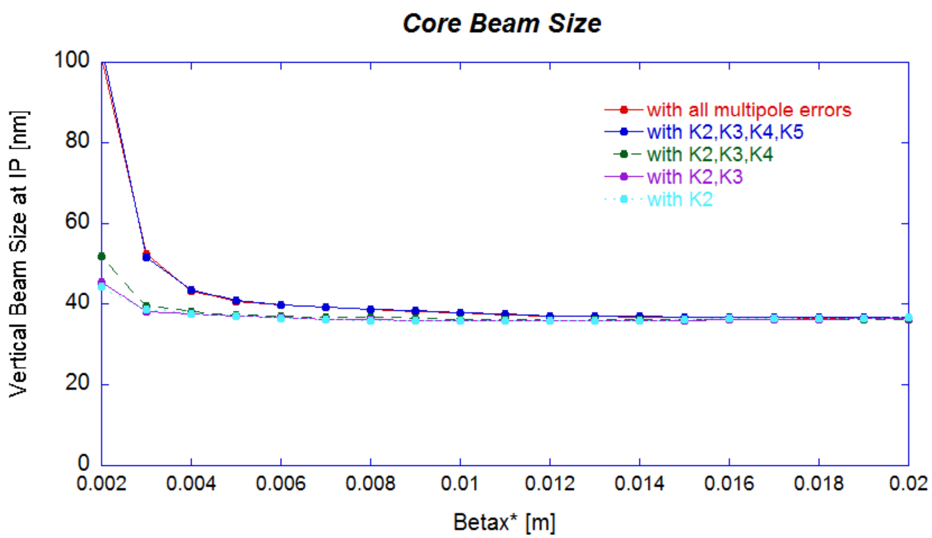
Higher Order Multipole Errors



applied the measured multipole error to quads.

Emittx = 2nm
Betay = 0.1mm*
Emitty = 12pm

after Y24 Y46 Y22 Y26 Y66 Y44 knob correction



The 12pole error (QF1FF) is dominant for the IP vertical beam size growth both for rms and core beam size.

New QF1FF magnet

We will replace the QF1FF to PEP-II quads.

Figure 1: 4Q17 magnet with rotating coil and feedthrough holder setup

Presented by G.White at ATF meeting (2012/10/12)

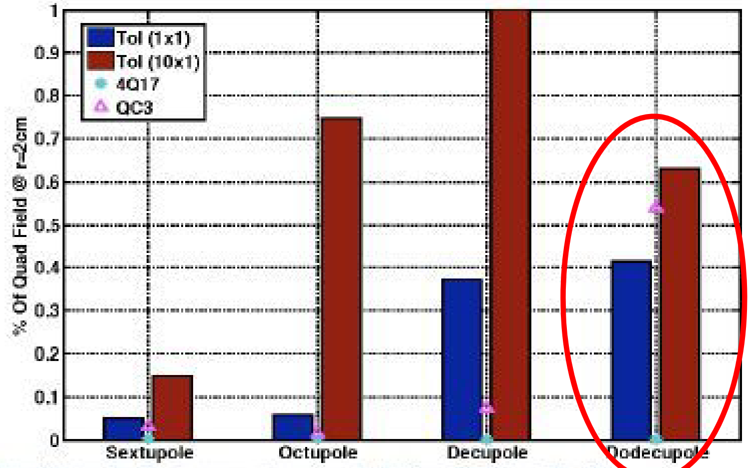


Figure 3: Normal multipole components measured as % of quad field at a radius of 2cm.

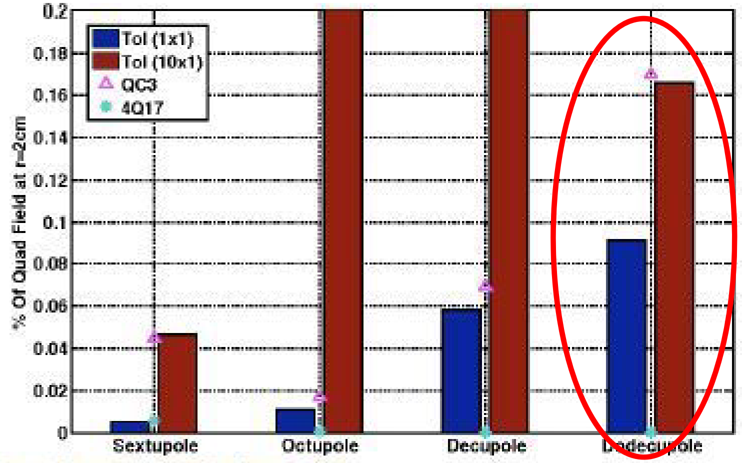
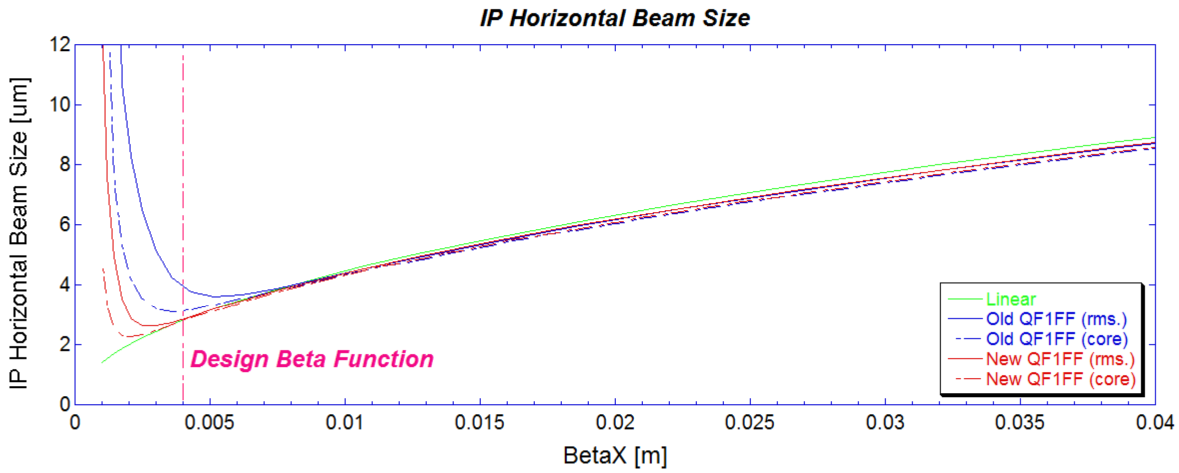


Figure 4: Measured skew multipole components.

We expect the 12pole component will reduced after this magnet replacement.

Expected Beam Size with New QF1FF Magnet

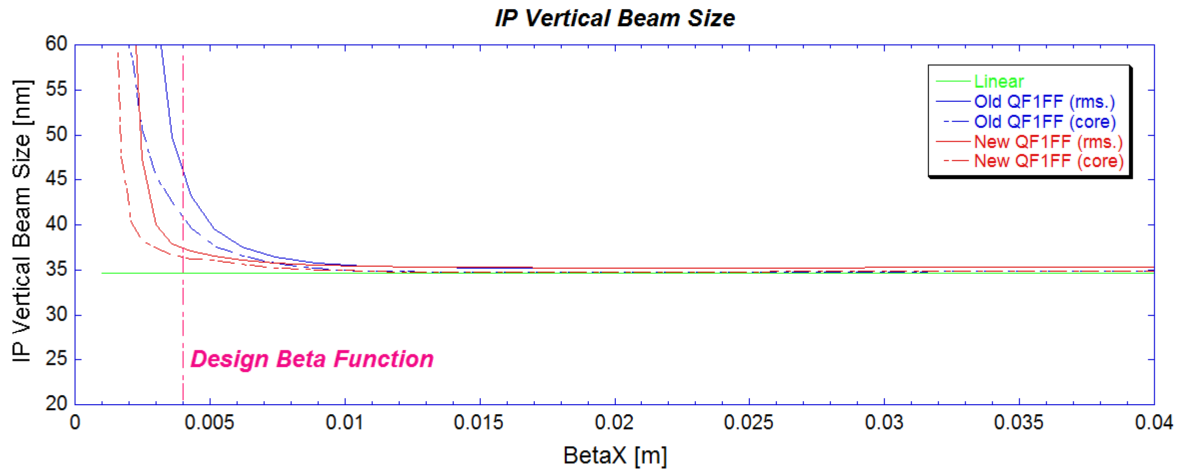
Horizontal



applied the measured multipole error to quads.

Emittx = 2nm
Betay = 0.1mm*
Emitty = 12pm

Vertical



after Y24 Y46 Y22 Y26 Y66 Y44 knob correction

We can squeeze the beam less than 40nm by reducing to new PEP-II QF1FF with small 12pole error.

Beam Tuning Method for ATF2 Beamline

To maximize the modulation of IP-BSM

$$M = C \cos\theta \, \exp\,[-2\,(k_y \sigma)^2]$$

C ; Modulation Reduction Factor (IP-BSM related)

$$\sigma^2 = \beta\varepsilon + (C_\alpha^2 Ax^2 + C_\eta^2 Ey^2 + C_c^2\, Coup2^2) + Ct^2 \langle xy\rangle^2$$

Correct with linear knobs **Correct with QKs**

$$+ (C_{24}^2 Y_{24}^2 + C_{46}^2 Y_{46}^2) + (C_{22}^2 Y_{22}^2 + C_{26}^2 Y_{26}^2 + C_{66}^2 Y_{66}^2 + C_{44}^2 Y_{44}^2) + \sigma_{6pole,res}^2$$

Correct with normal sextupole knobs **Correct with skew sextupole knobs**

$$+ \sigma_{8pole}^2 + \sigma_{10pole}^2 + \sigma_{12pole}^2 + \ldots\ldots$$

-***can not correct with any tuning knobs***
-***But, since the effect strongly depend on the beam size at quads, we can control the effect by changing*** $\sigma_{x'}^*$

If the beam size was reached to the limit, we should increase the betax.*

Summary

ATF2 beamline was constructed at the extraction line of ATF damping ring for ILC FF R&D.

In the ATF2, we measure the beam size with the beam size monitor based on laser interferometer.

In 2012 Spring run

-We performed that linear Knobs were worked very well.

-We found a large skew sextupole errors.
(This is one reason to make the IP beam size large?)

From 2012 Autumn run

To reduce Sextupole field errors

- *We improved the skew sextupole field correction with 4 skew sextupole corrector*
- *We will remove S-band BPM after some magnetic field test.*

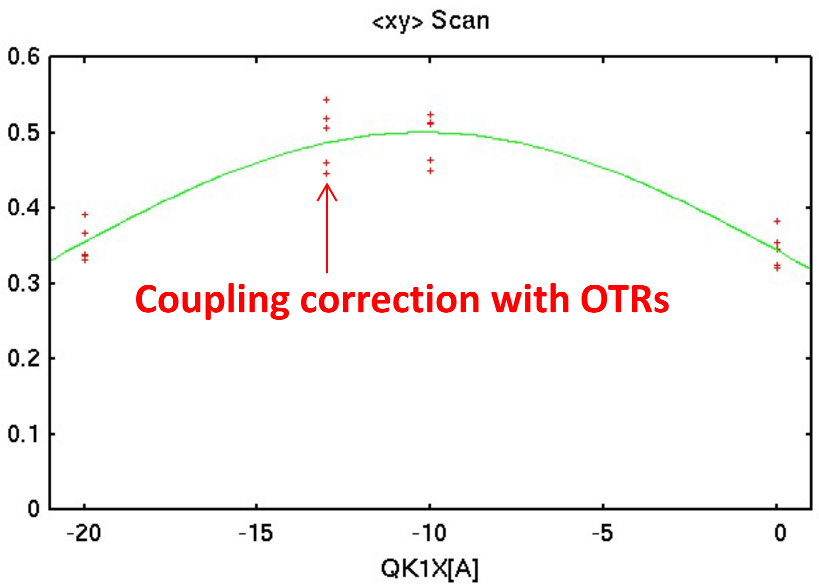
To reduce 12pole field errors

- *We will replace the QF1FF magnet, which has small 12pole field error.*
- *By this replacement, we expected to squeeze the IP vertical beam size for design horizontal beam size at IP.*

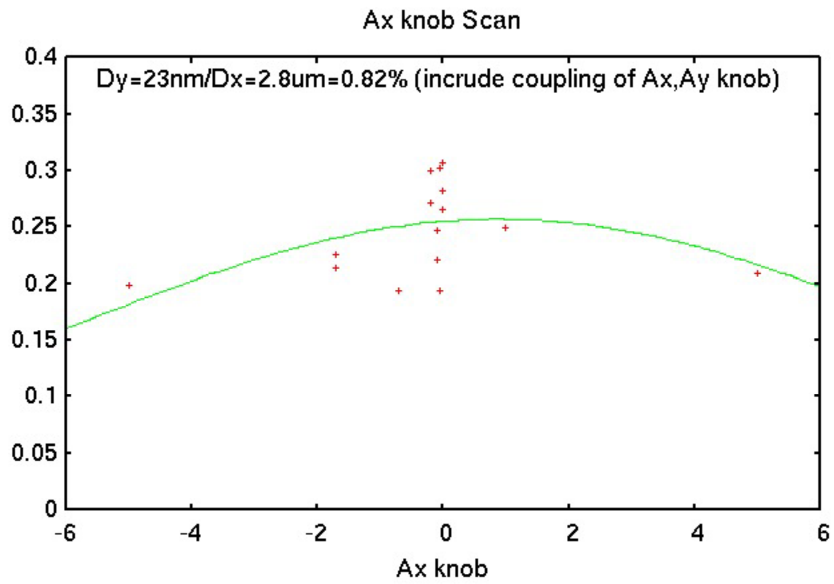
Backup

Effect of beam tilt

2012 February



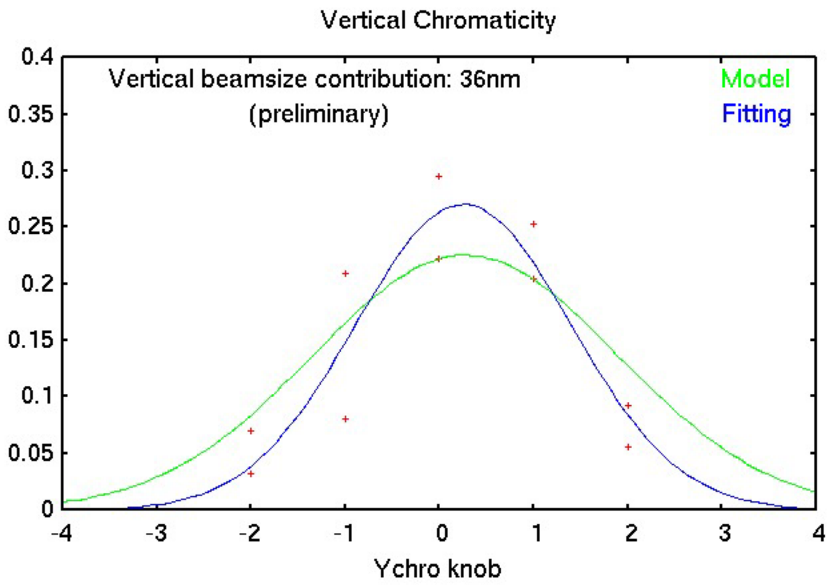
2012 June

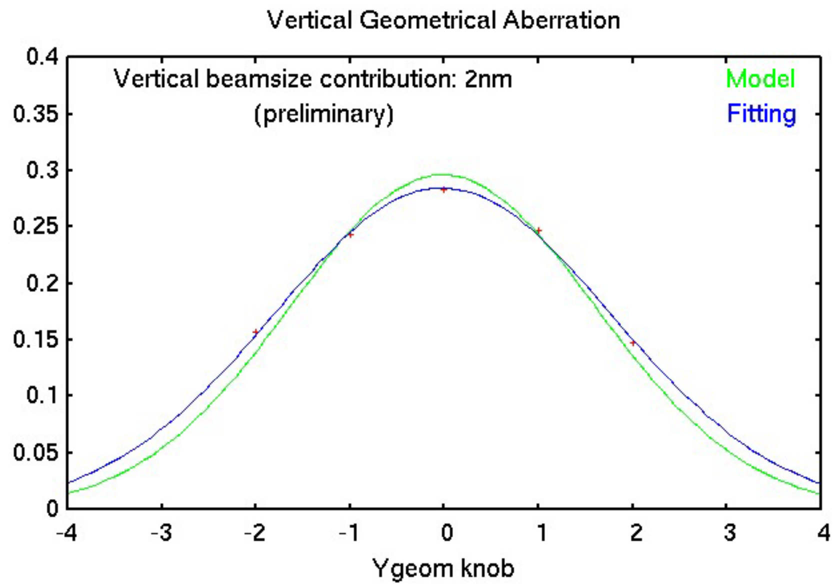


Optimum <xy> was not so far from the coupling correction in EXT.

The beam tilt angle was less than 8.2mrad. (include of the coupling of Ax and Ay for Ax knob)

Test of Sextupole Field Correction Knobs





Model was calculated when the beam passed through the center of sextupole magnet.
(No effect of linear knob, when we changed the strength of sextupole)

The effect of the nonlinear knobs were a few 10nm in June operation.

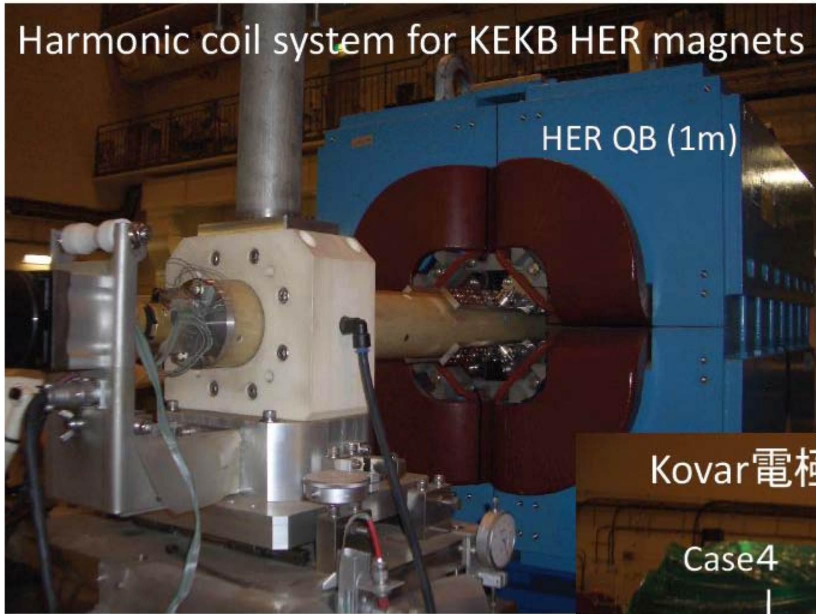
The nonlinear knobs were now on ready for beam size tuning.

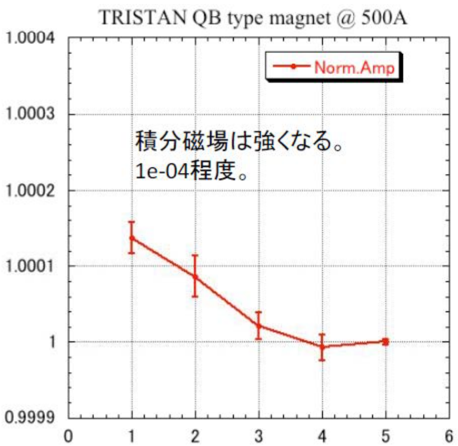
Effect of the Kovar BPM Electrode for KEKB Quadrupole

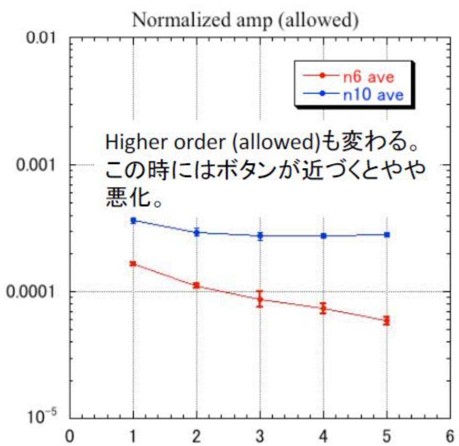
by M.Masuzawa

The kovar electrode affect the quadrupole component.

The kovar electrode affect the 12pole,20pole component.







We will decide whether we will remove S-band BPM after some magnetic field test.

- The effect of the Kovar feed through in SLAC.
- The field measurement around BPM in KEK.
(The instruction will be prepared by SLAC .)

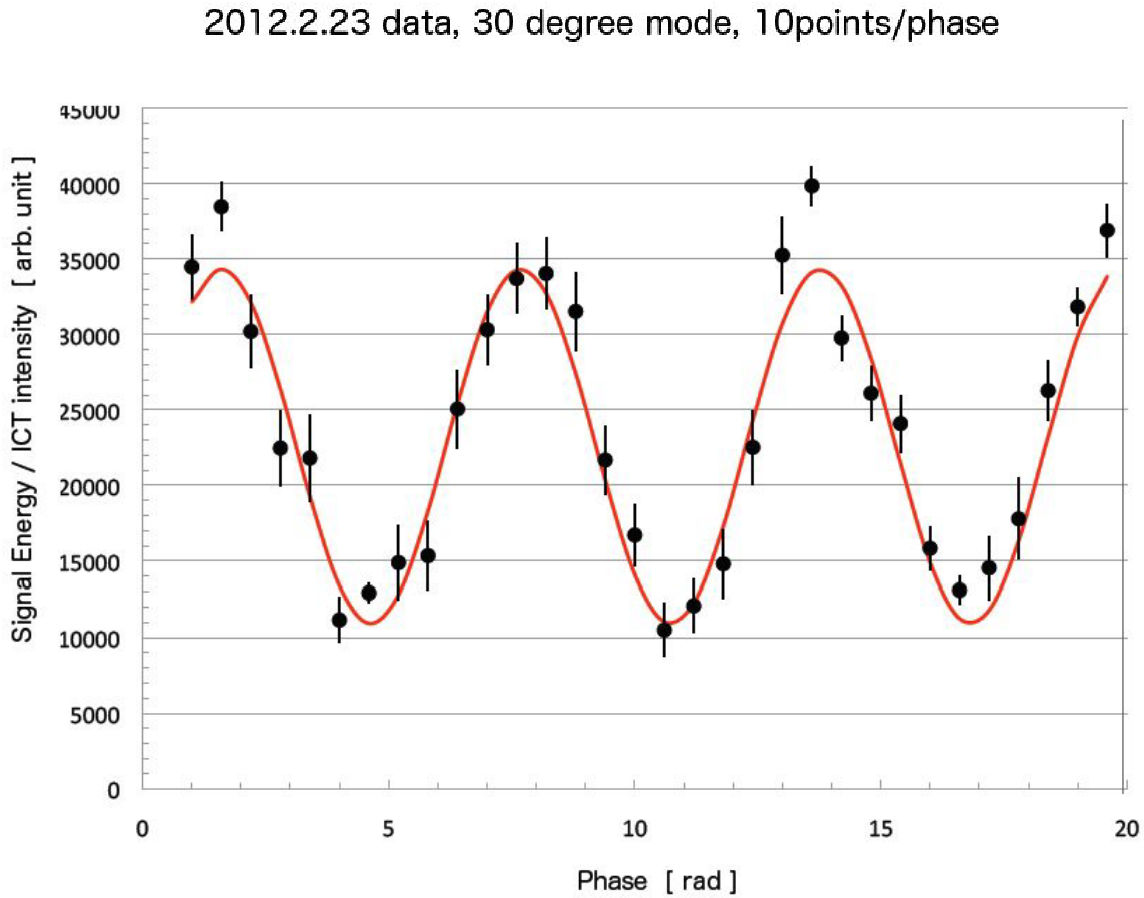
Beam Size Evaluation in 2012 Spring Operation Period

IP-BSM Status in 2012 Spring Operation

Improve the IP-BSM system

The achieved beam size in 2012 spring operation (preliminary)

Observation of the modulation for IP-BSM 30degree mode



We had succeeded to find the modulation of IP-BSM 30 degree mode in Febraury 2012.

The maximum modulation was 55%.

IP-BSM Laser Issues in 2012 Spring Operation

February – early March

Many optical devices were broken by the laser light.

Middle of March

IP laser size was changed to avoid the damage of the optical component

- *change the laser output size by replacing the rear mirror of the laser oscillator.*
- *change the parameters of laser expander and reducer.*

After the change, no damage of the optical component.

Laser spot size at IP	large	small
Laser size on vertical table	small	large
Damage of optical component	loose	severe
Rayleigh Length	short	long
Laser overlap condition	severe	loose

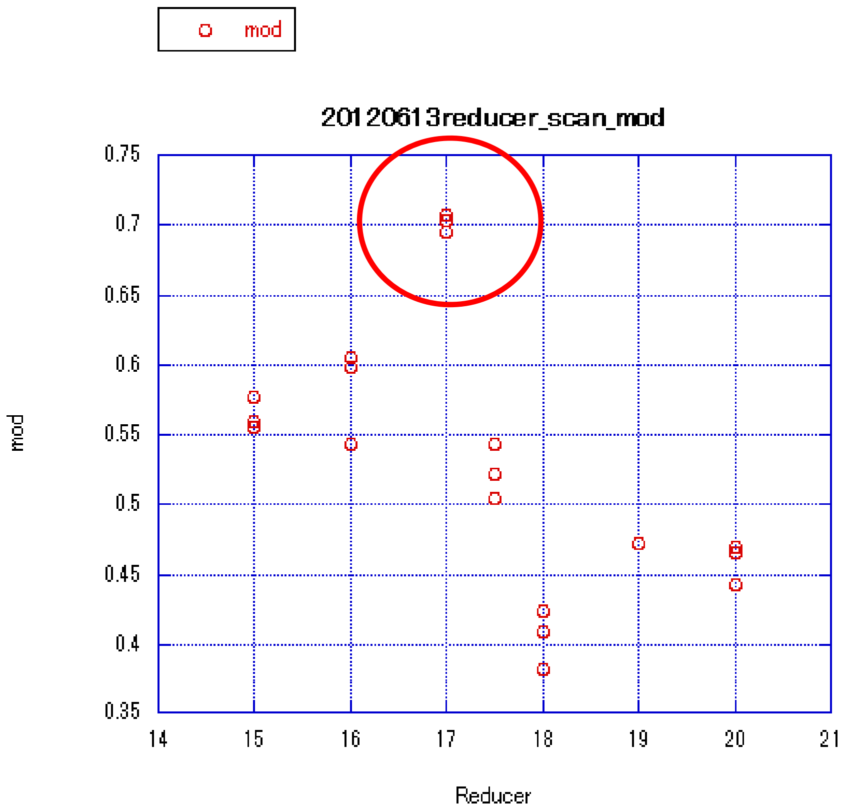
The maximum modulation of IP-BSM in 2-8degree mode

The maximum modulation for 2-8 degree mode was changed from 60-80% to 50% from middle of March.

However, we had measured 3times more than 60% modulations from the middle of March.

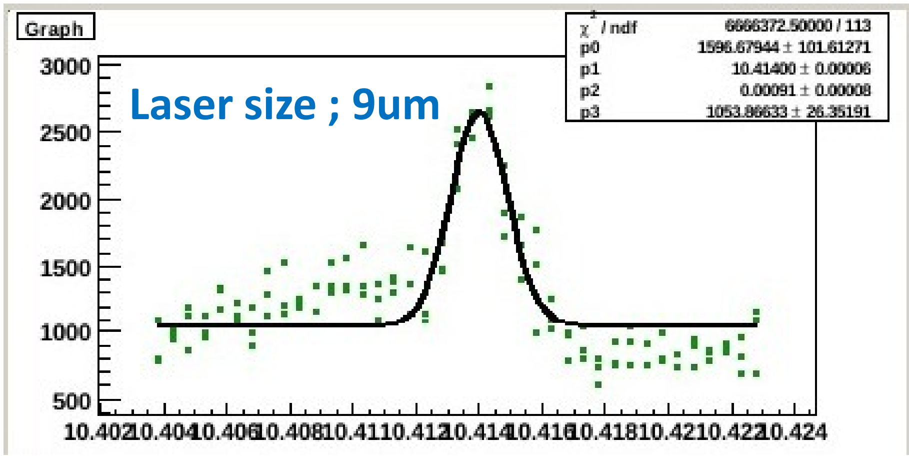
1. *80%(04/26) ; half of the lower path laser light did not go to IP by drift.*
   After the realignment of laser path, the modulation was decreased to less than 60%.
2. *83% (06/06) ; only the laser path of 2-8degree mode was made.*
   After making 30 degree mode (laser path for 2-8 degree mode also changed), the modulation was decreased to less than 60%.
3. *80%(6.3degree mode), 90%(4.0degree mode) 6/13-6/14*

IP-BSM setting in 6/13-6/14

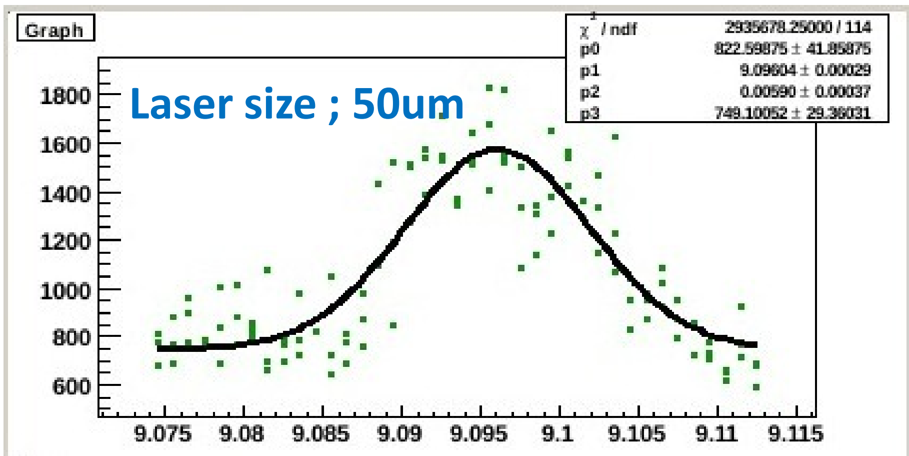


Very narrow optimum setting

Beam profile of upper path



Beam profile of lower path



Very large unbalance of laser profile at this setting.

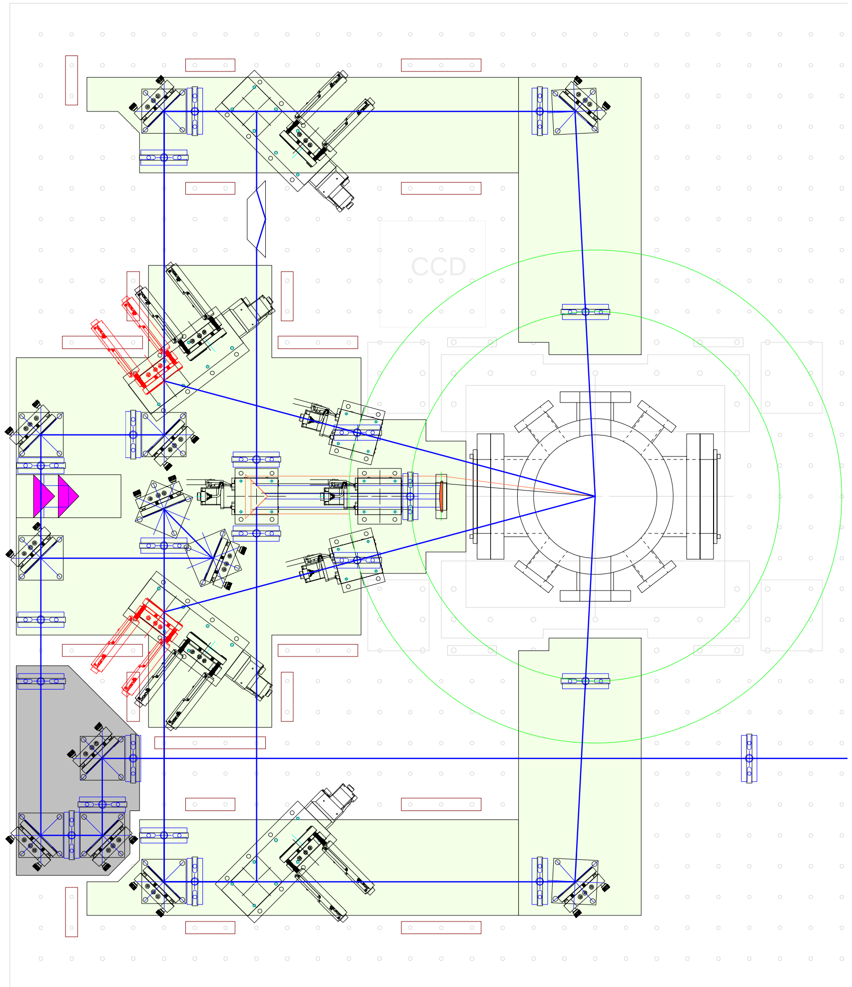
We did not understand how to optimize the setting of IP-BSM

Other problems of IP-BSM

1. *Alignment of optical components on the vertical table are different from the design.*
   - Laser injection angle is different from 2-8degree mode and 30degree mode.
   - When the rotator is rotated, the laser position at the mirror on the rotator is change.
   - Upper path for 174degree mode is not seen in the screen of 2-30degree mode.
   (no reference line to put the optical components)
2. *The focal points for upper path and lower path are different.*
3. *We are not sure whether the collision angle is correct or not.*
   - Laser is not on the center of lens for 30degree mode.
4. *The laser paths for lower angle mode are not kept in higher angle mode measurement.*
5. *Rotator move unexpected direction sometimes.*
6. *The effect of Dove Prism*
   - If the injected laser has divergence, the focal point is shifted.
   - If the injected laser has angle, the image is rotated.
   - The reduction of maximum modulation

New IP-BSM System from 2012 Autumn Operation

by N.Terunuma



All optical component should be aligned with respect to the reference line of base plate
(old system don't have the reference line for the optical component).

Laser collision angle will be controlled by linear stage (old system used the rotator).

- The laser paths for lower angle mode can be kept in higher angle mode measurement.

Path length for upper path and lower path are designed to the same length

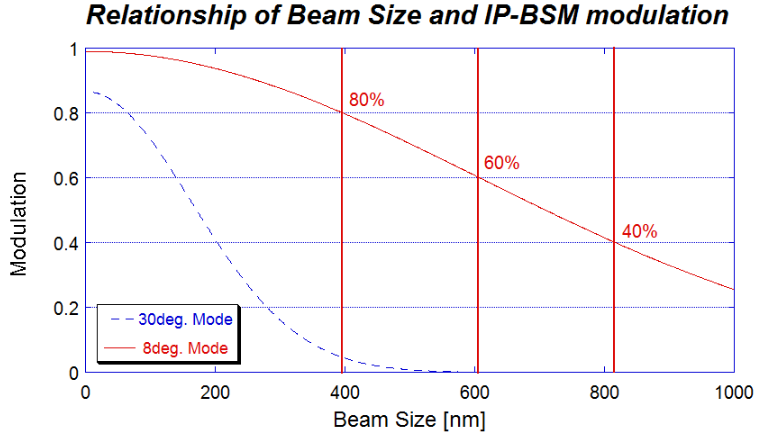
All focal lenses will be on the linear stage.
(old system was used the reducer to change the focal length)

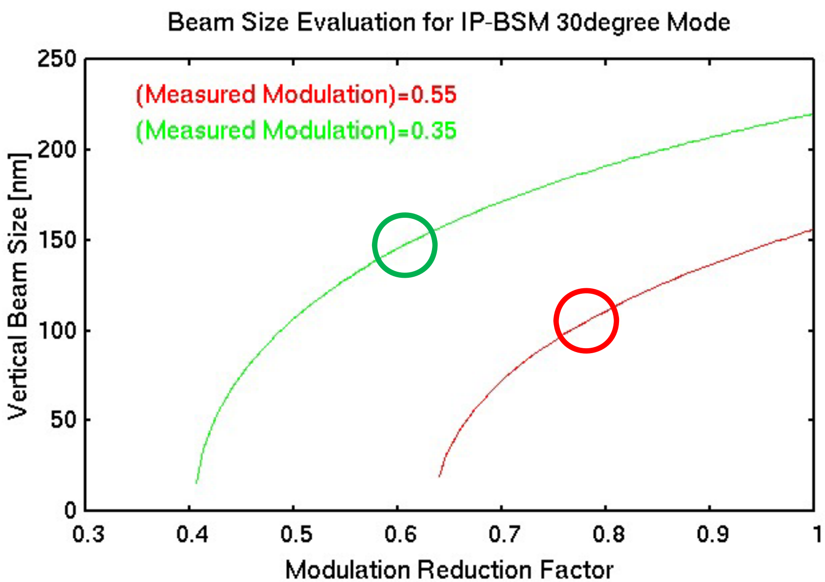
-The focal points for upper path and lower path can be set to same .position.

Dove prism for 30degree mode will be removed.

Achieved beam size in 2012 spring operation (preliminary)

If the modulation reduction factor C is 1,





Maximum modulation of 30degree mode

10x10 optics (the week of 2/13-2/17) ; 0.45
10x 3 optics (the week of 2/20-2/24) ; 0.55
10x 1 optics (the week of 3/05-3/09) ; 0.55
After middle of March ; 0.35

Typical modulation of 2-8degree mode

Before middle of March ; 0.6-0.8
After middle of March ; 0.4-0.6

$$\sigma = \frac{1}{k_y}\sqrt{\frac{1}{2}\ln\frac{C\cos\theta}{M}}$$

C ; Modulation Reduction Factor
(IP-BSM related)

Improvement and evaluation of modulation reduction factor is important to the IP beam size evaluation.

Is the difference of Feb.-March and June from the difference of IP horizontal beam divergence ?