Status of ATF2 Beam Tuning

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2013/07/08

ATF2 Topical Meeting

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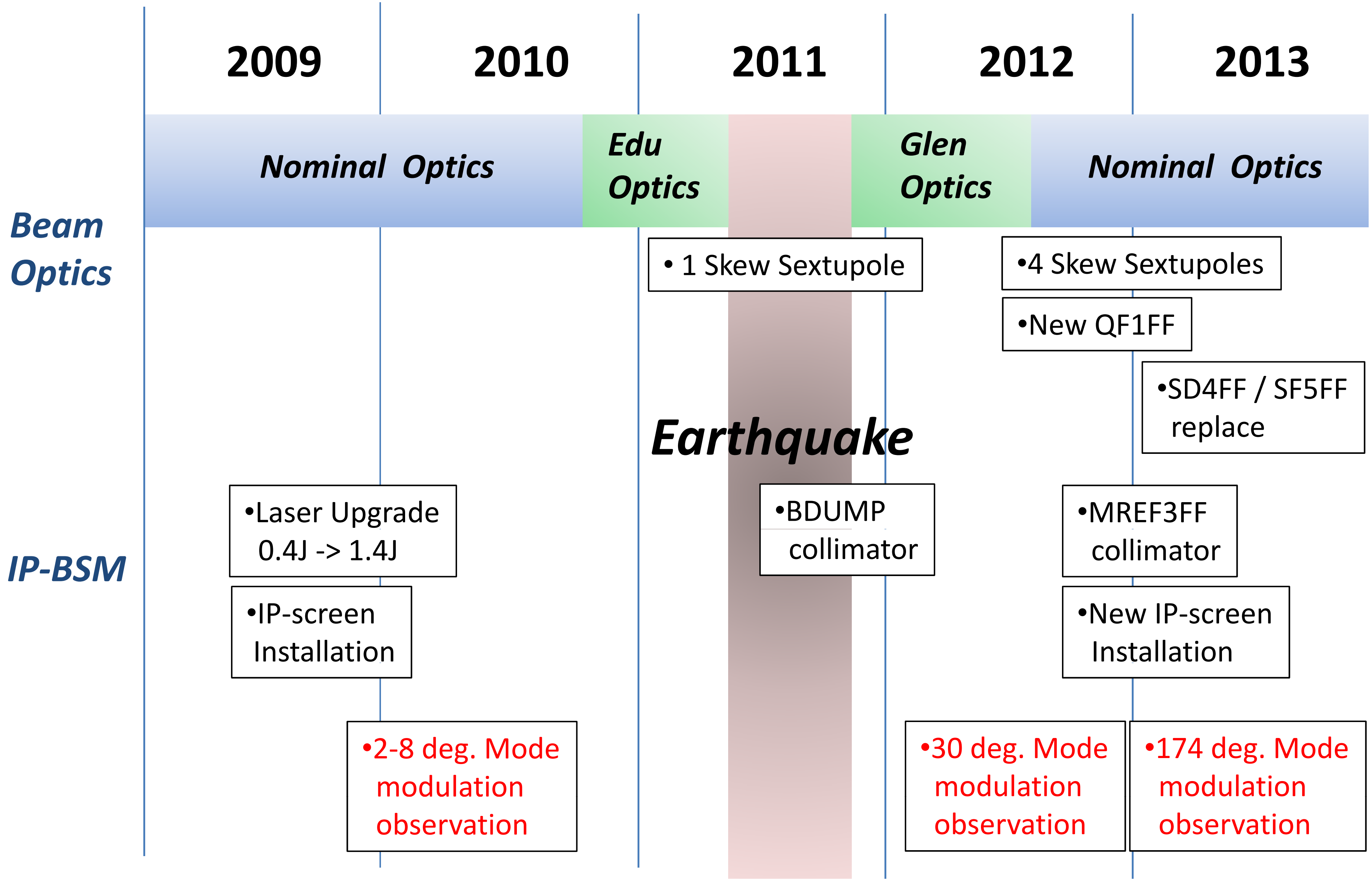
Recent Status of ATF2 Beam Tuning (From December 2012)

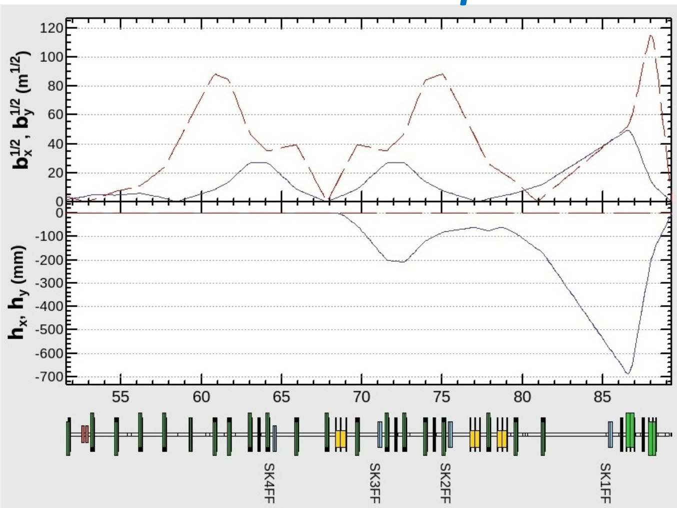
Beam Optics for ATF2 Beamline

History of ATF2 beam tuning

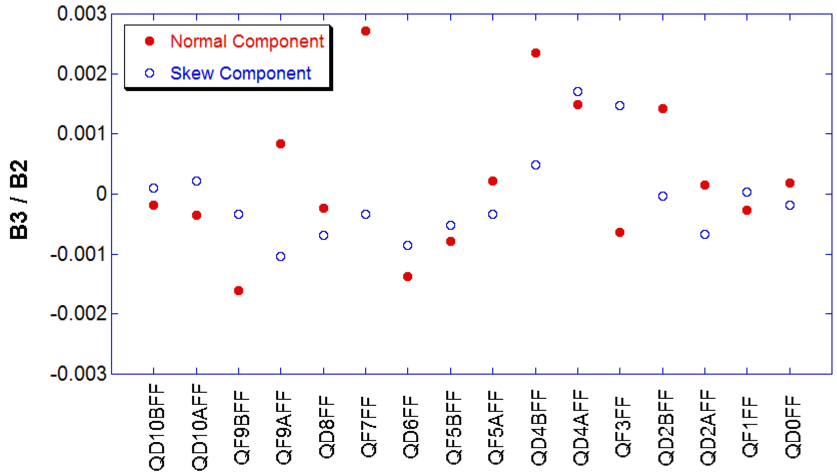


Special Final Focus Optics
to be cancelled the multipole errors

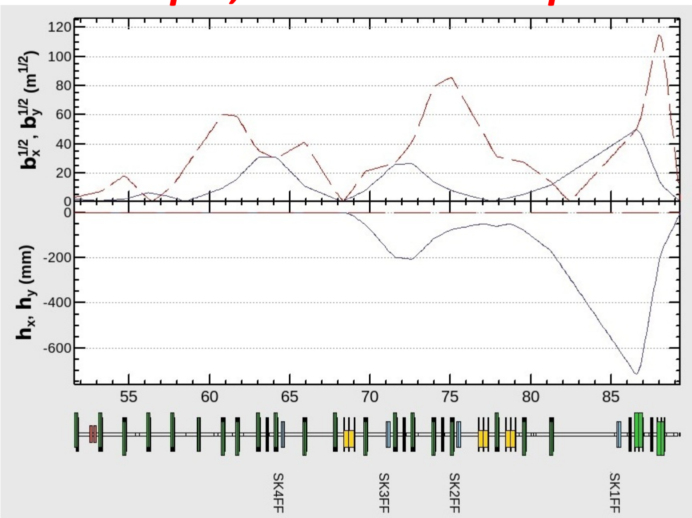
Nominal2.5x1 Optics



Sextupole Field Errors for the quadrupoles in ATF2 beam line



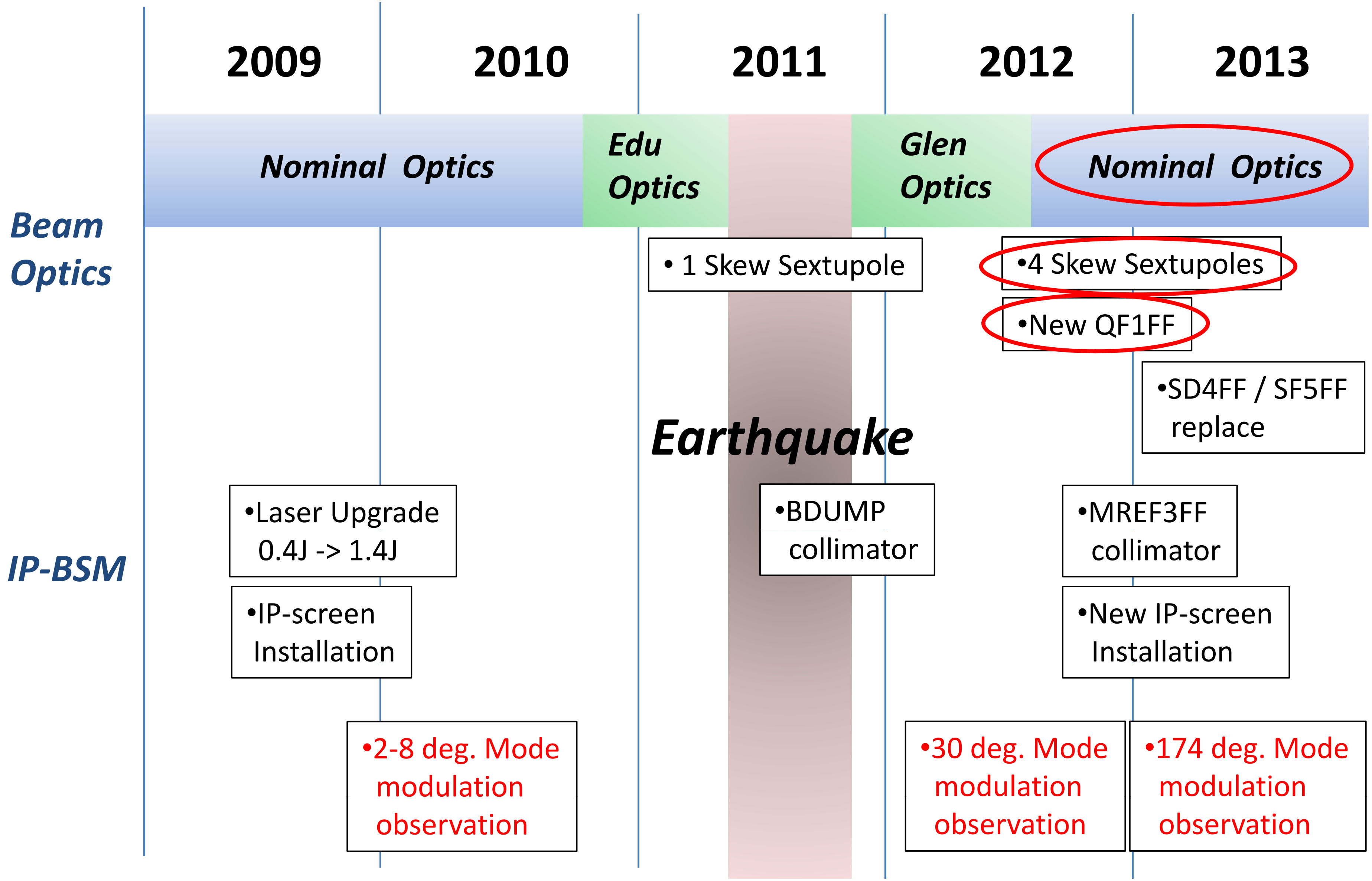
Example; Glen's 2.5x1 Optics



From 2010 Dec. to 2012 June

We used some special FF optics to be cancelled the multipole field errors in ATF2 final focus beam line.

History of ATF2 beam tuning

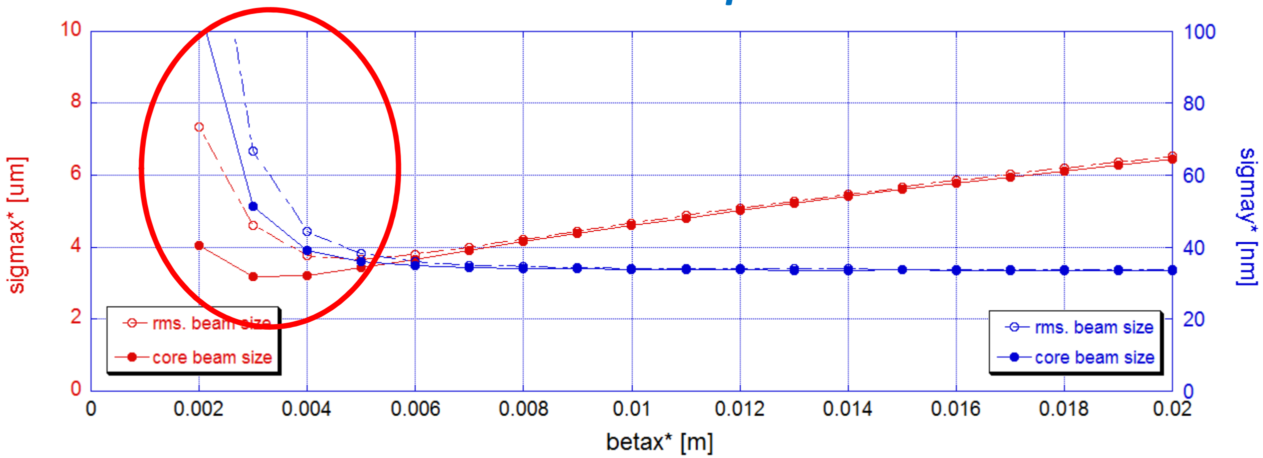


Now, we use the nominal FF optics

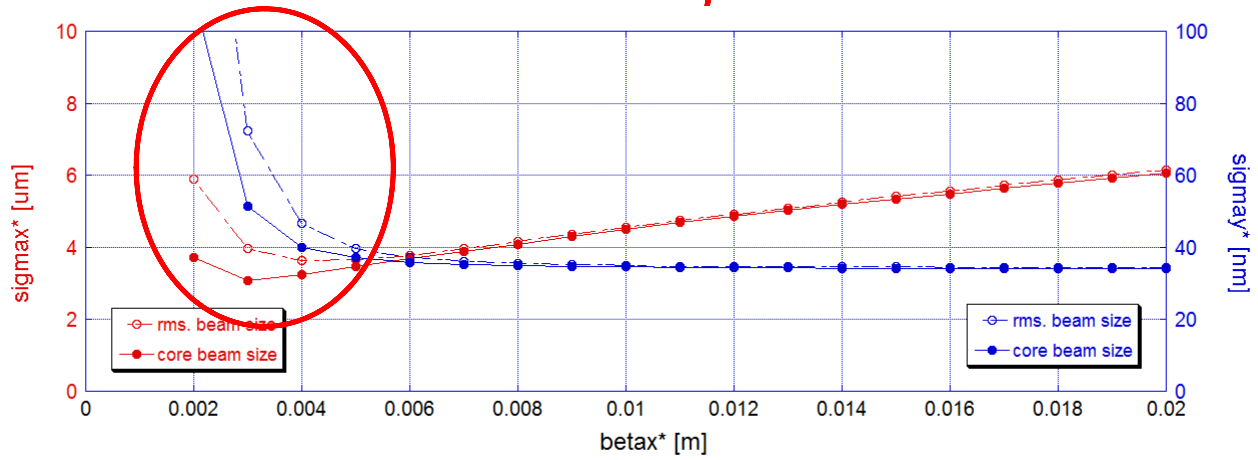
No significant difference after correction with 4 skew sextupoles.

We switched back to Nominal Optics in October 2012.

Nominal Optics



Glen's Optics

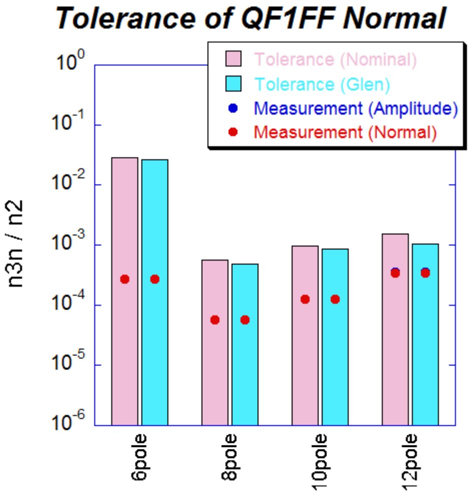


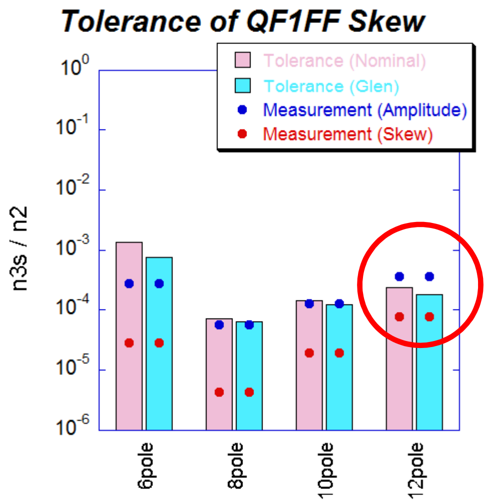
emitx = 2nm
emity = 12pm
betay = 0.1mm*

after Y24 Y46 Y22 Y26 Y66 Y44 correction

betax's are changed by changing matchng quads.*

QF1FF Magnet Replacement in November 2012





Red ; Nominal 2.5x1

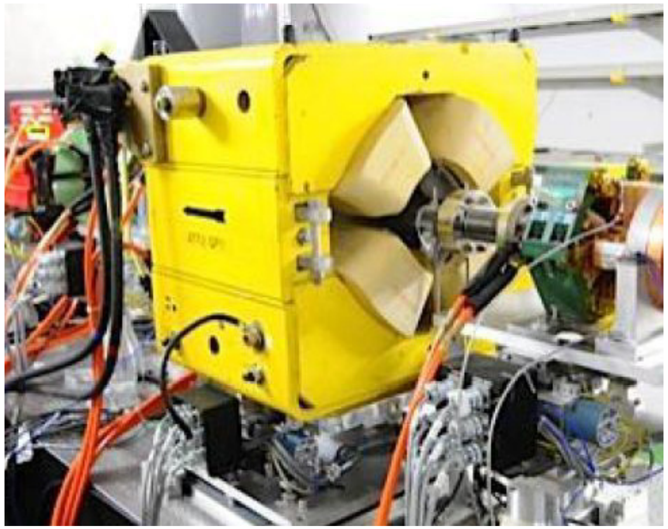
Blue; Glen's 2.5x1

emitx = 2nm

emity = 12pm

with 4 skew sextupole correction

12pole of QF1FF was limited to reduce betax more.*



Therefore, we replaced QF1FF to the quadrupole magnet used in PEP-II.

Effect of Nonlinear Component in ATF2 Beamline

We need extremely good quality quadrupoles for ATF2 1x1 optics.

Therefore, we are now operating the ATF2 by 10x1 optics.

		ILC	ATF2(1x1)	ATF2(10x1)
Linear	αy	1	1.37	1.37
Linear	ηy	1	0.04	0.04
Linear	<x y>	1	1.01	3.19
Linear	<x’y>	1	0.79	0.25
2nd order	Y46	1	1.14	1.14
2nd order	Y24	1	6.43	2.03
2nd order	Y22	1	3.72	0.37
2nd order	Y26	1	0.66	0.21
2nd order	Y66	1	0.12	0.12
2nd order	Y44	1	11.12	11.12
3rd (horizontal)		1	17.41	0.55
4th (horizontal)		1	81.62	0.82
5th (horizontal)		1	382.53	1.21

Chromatic aberration (Y46)

Generate by Sextupole (Y24)

Allowed component of quadrupoles (5th (horizontal))

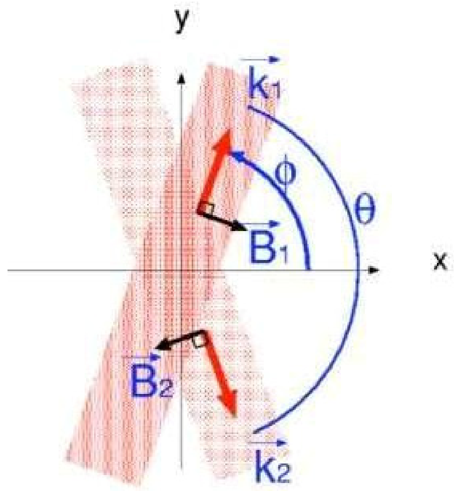
IP Beam Size Monitor in ATF2

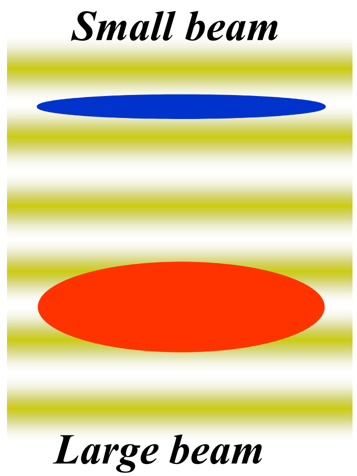
IP Beam Size Monitor (Shintake Monitor)

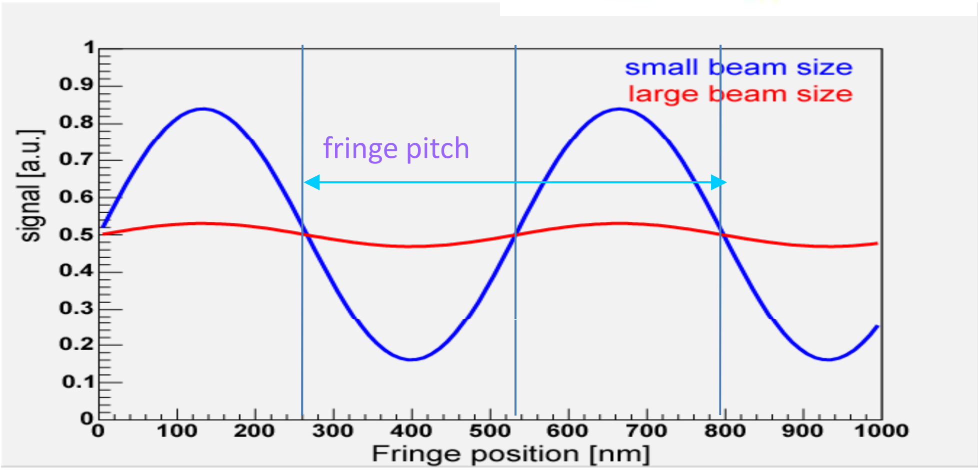
Laser is split into 2 paths.

The both laser paths are collided at IP.

The interference pattern is generated at IP.



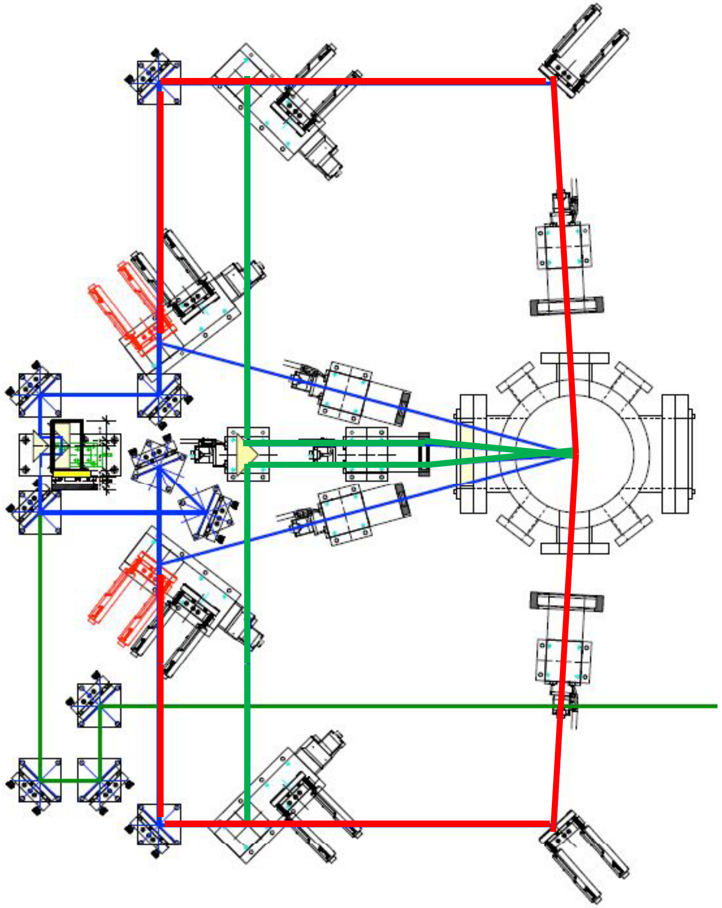




Modulation

$$M = \frac{N_{max} - N_{min}}{N_{max} + N_{min}}$$

IP-BSM for ATF2



Laser wave length was changed.

FFTB ; Nd:YAG fundamental mode (1064nm)

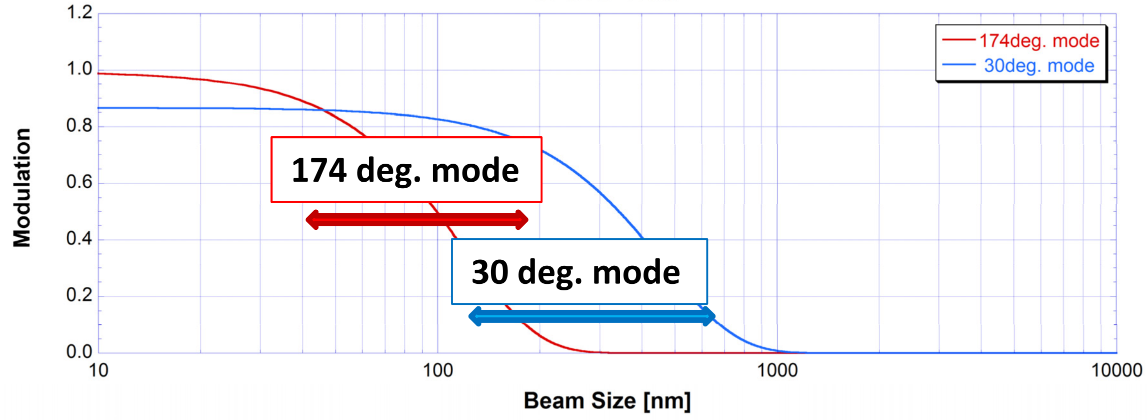
ATF2 ; Nd:YAG harmonic doubler (532nm)

Add the collision mode

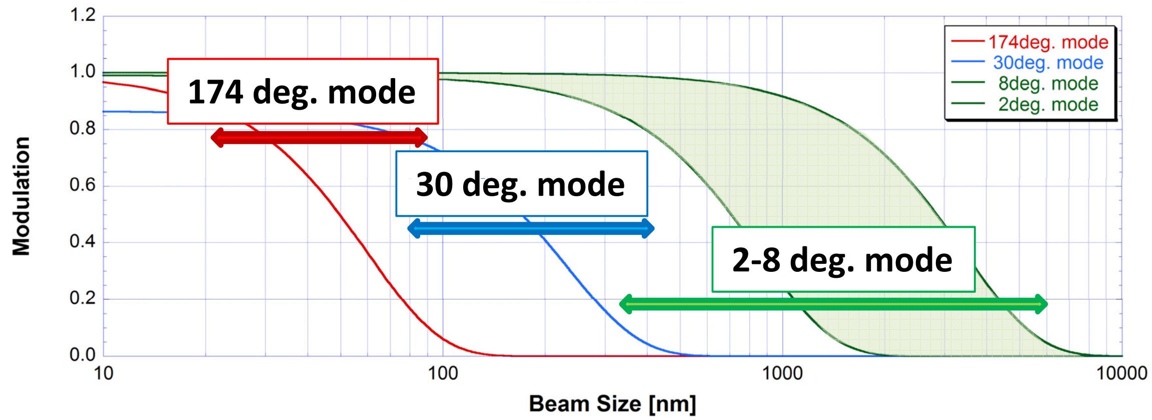
FFTB	**ATF2**
174deg mode	174deg mode
30 deg mode	30 deg mode
	2-8deg mode

Dynamic Range of IP-BSM

FFTB IP-BSM (40 – 600 nm)



ATF2 IP-BSM (20 – 6μm)

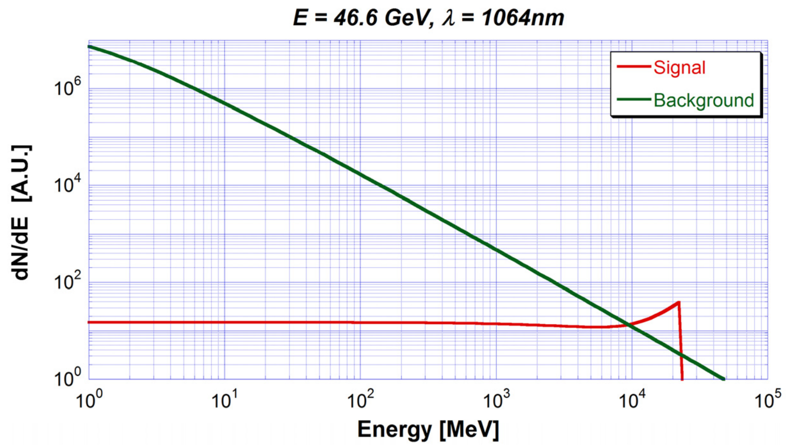


S/N ratio of IP-BSM

FFTB

46.6GeV

λ = 1064nm



Maximum Compton Energy

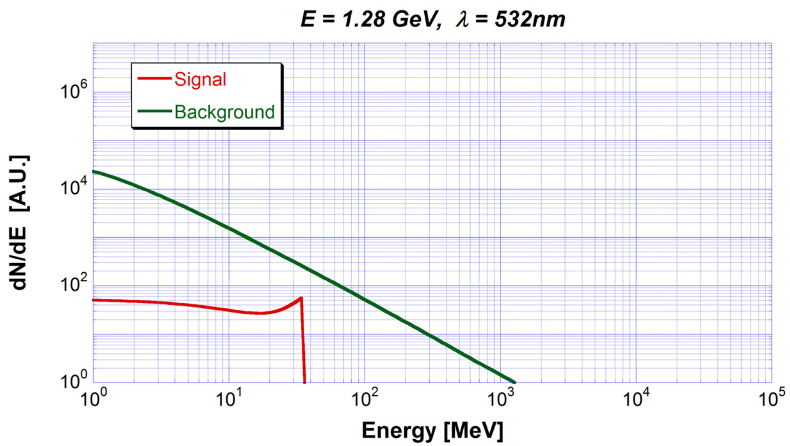
$$E_{max} = 2\gamma^2 E_l$$

Low energy background is larger than high energy BG.

ATF2

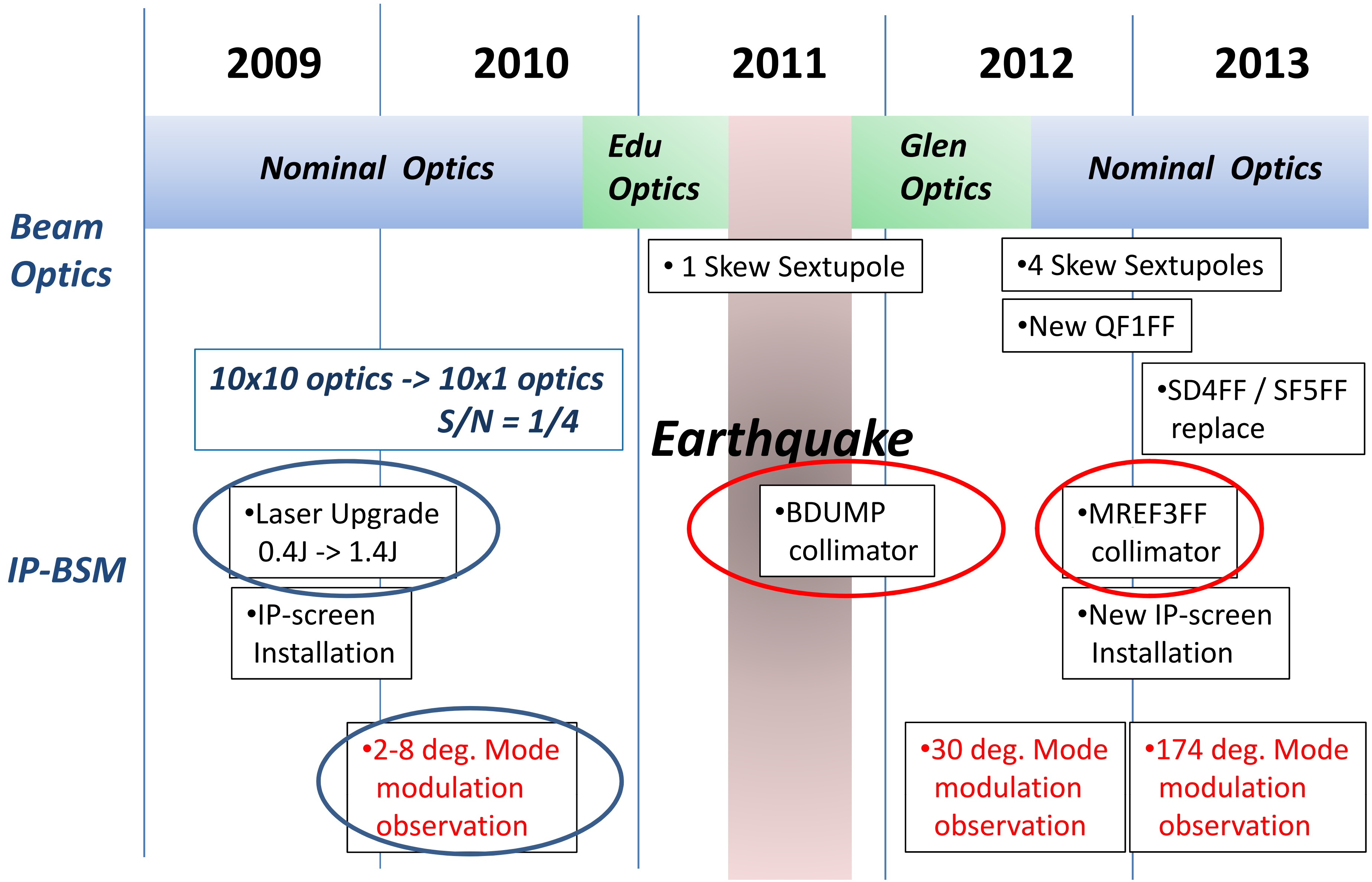
1.28 GeV

λ = 532nm

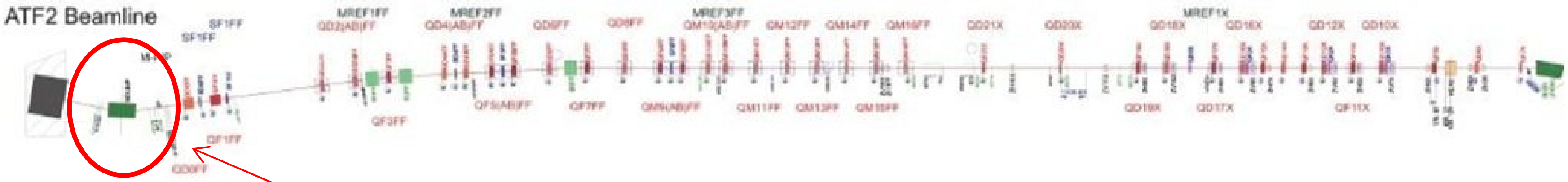


It is difficult to distinguish Compton signal and Background for the small beam energy in ATF.

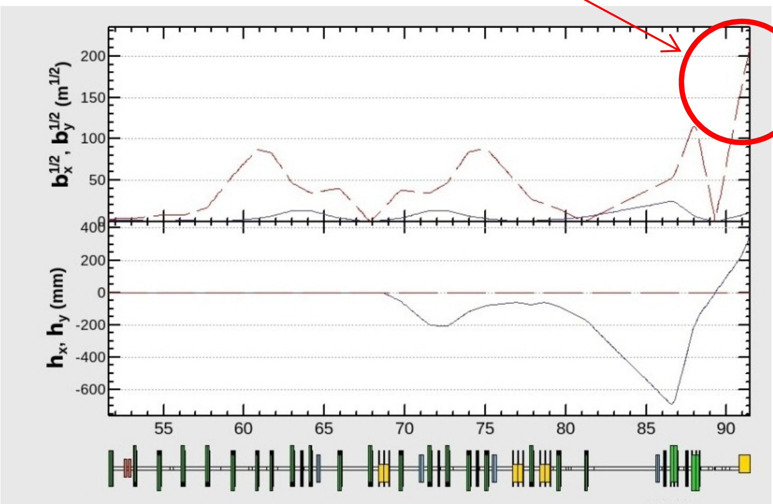
History of ATF2 beam tuning



Collimator at Dump Bend

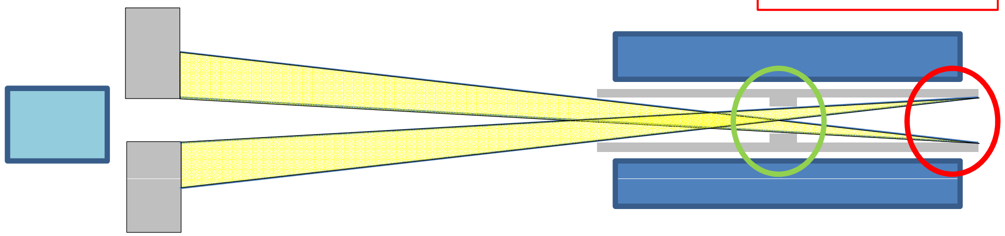


BG source



Since vertical aperture of dump bend was large BG source,

BG source

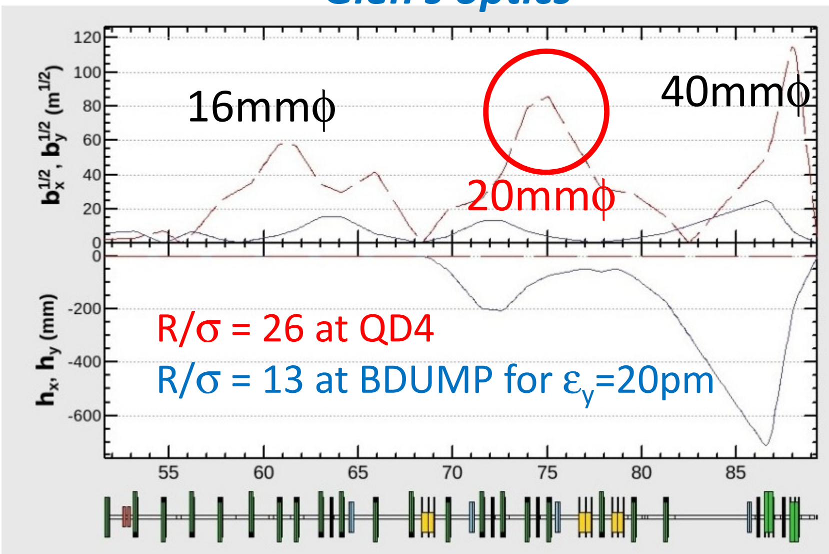


We put the collimator in the bend chamber.

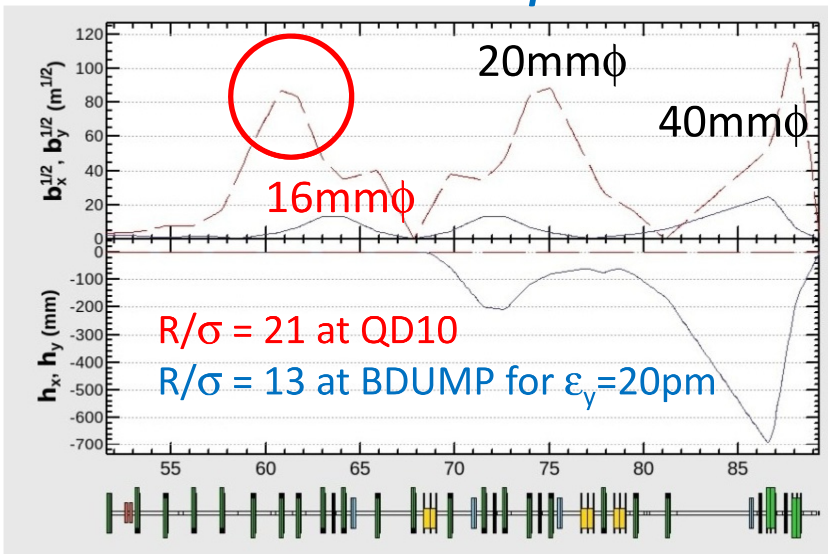
BG level was reduced 1/3 – 1/4.
Then, S/N = 1 for 10x1 optics

Optics dependence of IP-BSM background

Glen's optics



Nominal optics



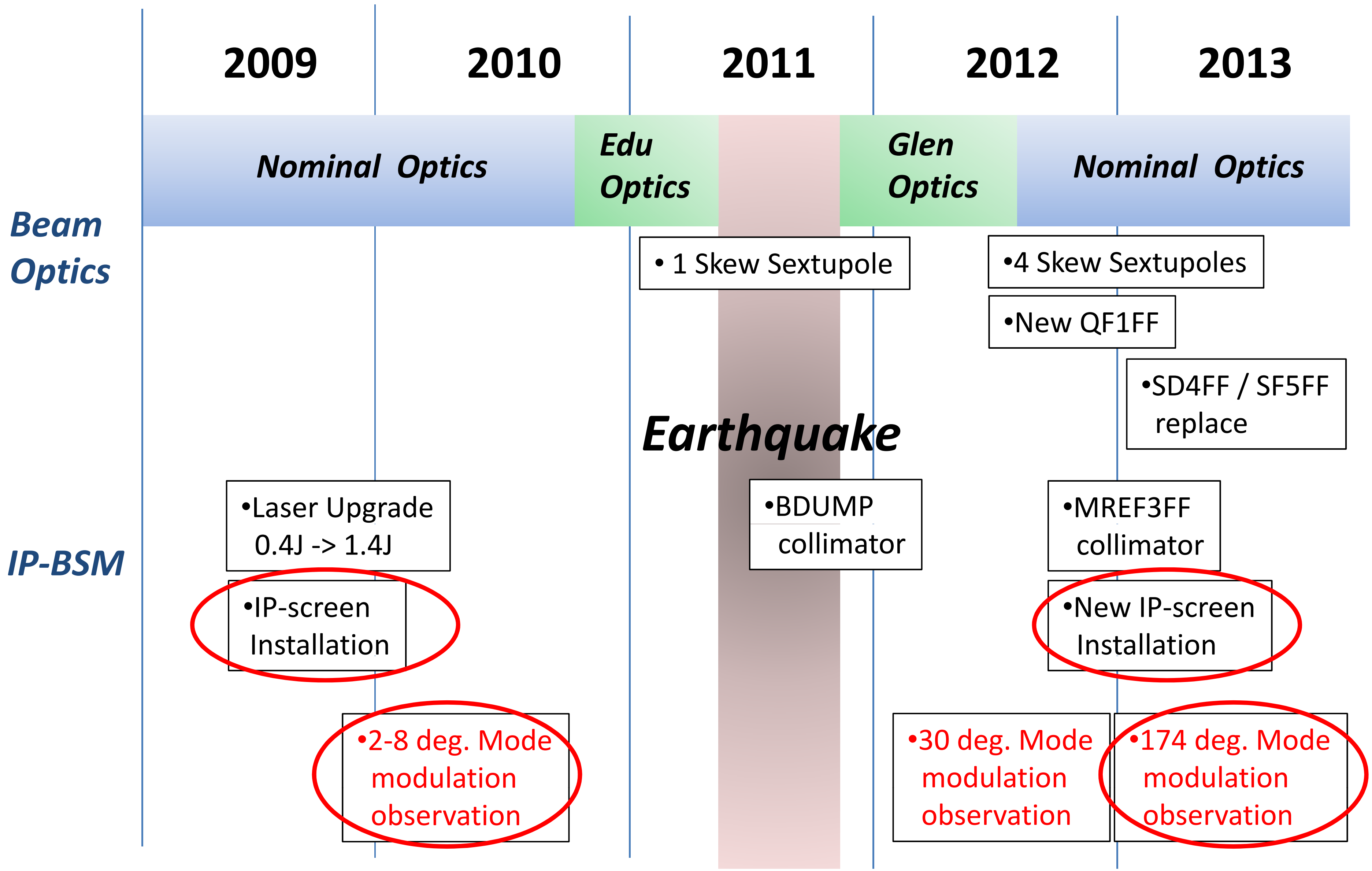
Reference cavity at high beta region affect as a collimator.

Reference cavity was on mover for wake study.

The position of reference cavity is very sensitive to the IP-BSM BG.

The BG level was reduced by factor 2-3 to optimize the position of reference cavity after we switched back to nominal optics (S/N = 2-3).

History of ATF2 beam tuning

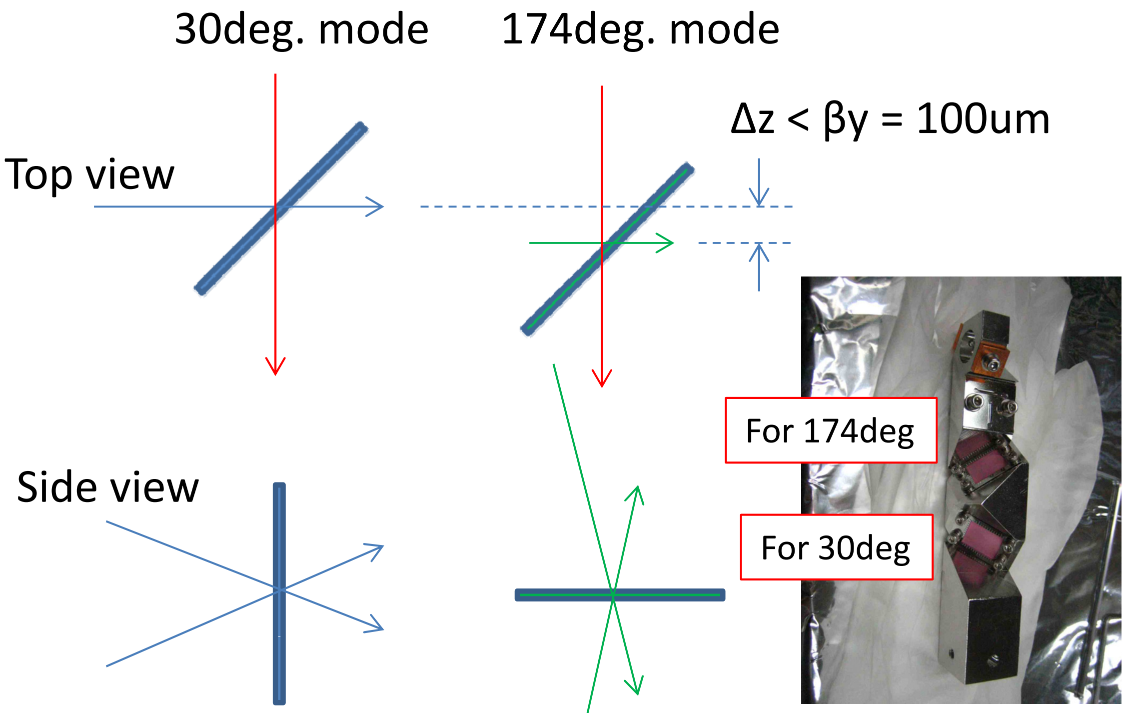


ATF2 IP-BSM Screen monitor

Old Screen System

We have 2 screens.

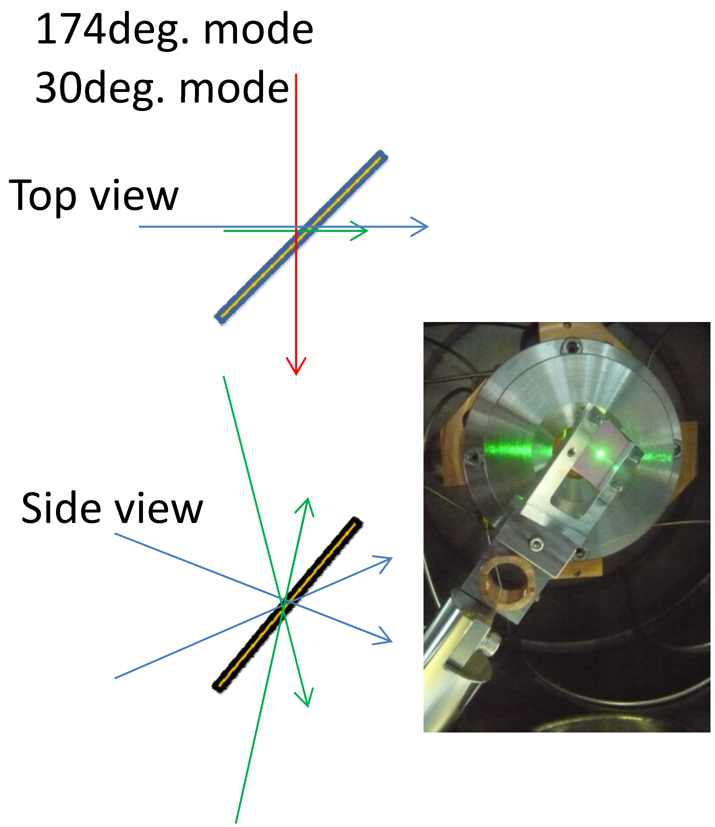
- 1 for 30 deg. mode
- 1 for 174 deg. mode



- easy to confirm to collide electron beam and laser.
- easy to confirm to collide two laser beams.
- difficult to confirm to set same z-position
  for 30deg & 174deg mode.

New Screen System

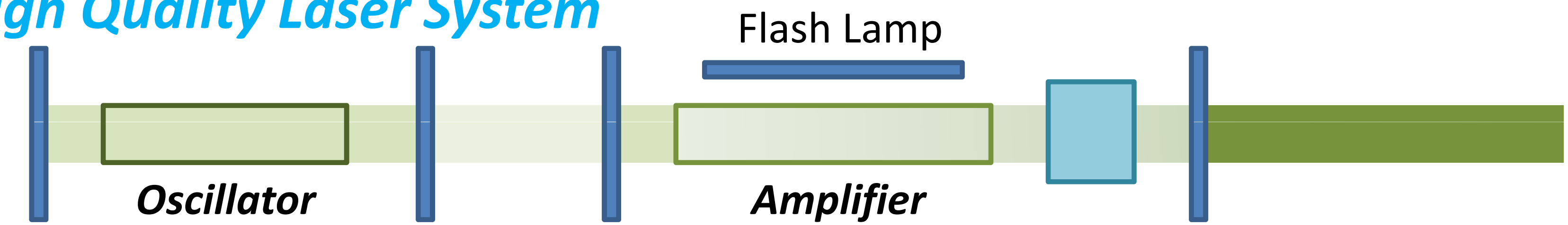
We adjust the laser paths both of 30 deg. and 174 deg. modes with 1 screen.



- easy to confirm to set same z-position
  for 30deg & 174deg mode.

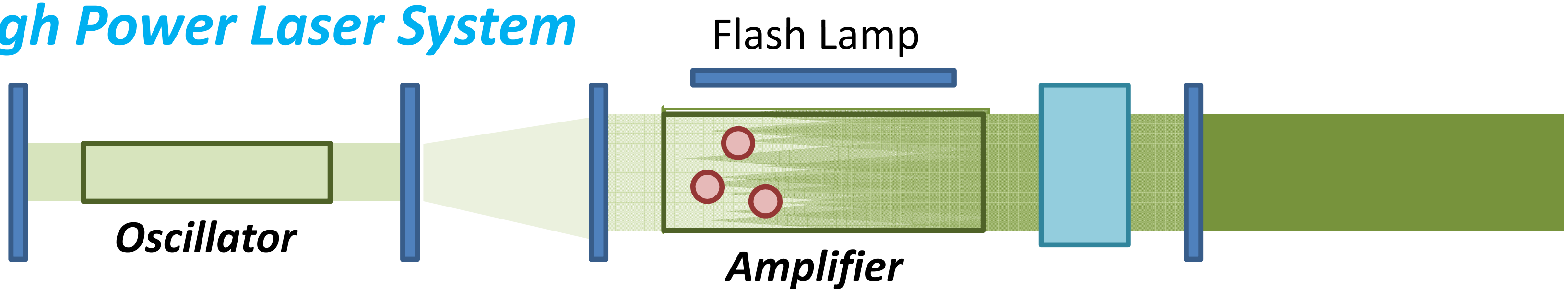
Present Problems of ATF2 IP-BSM laser

High Quality Laser System



- The YAG crystal of oscillator and amplifier are same diameter to keep a good laser profile and spatial coherency of seed laser.

High Power Laser System



- The YAG crystal of amplifier is larger than that of oscillator.
- Seed laser is expanded to inject the main laser amplifier in order to avoid to a damage from an extremely high laser density in YAG crystal.
- It makes several source points in YAG crystal -> reduce the spatial coherency.

In order to increase S/N, we use a high power type of laser in ATF2 IP-BSM.

2012 February ; Maximum modulation was almost 80%.

- The good mode lock condition kept only 1 or 2 weeks.
- The optical components (viewports and mirrors) were broken by hot spot of laser.
- We frequently called the laser expert from laser company to tune the laser.

2012 March ; Maximum modulation was reduced to almost 60%.

- We expand the laser diameter in the laser amplifier.
- We exchanged the mode lock circuit.
- We put a half mirror to decrease the laser intensity at viewports.
- The good mode lock condition kept several weeks without the laser expert tuning.
- The optical components did not have sevire damage.

2012 November ; Maximum modulation was increased to 80-90%.

- The laser diameter in the laser amplifier was back to the original diameter.
- The stable mode lock condition kept without the laser expert tuning.

2013 February ; Maximum modulation was decreased to about 70%.

- The flash lamps were changed for their lifetime.
- The laser profile was changed (by thermal lens effect in crystal ??).

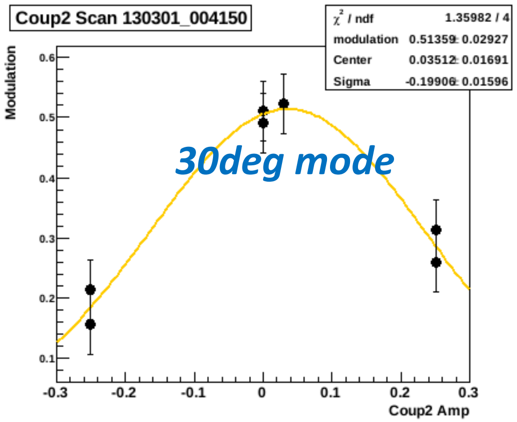
2013 March (next week); Maximum modulation was increased to above 85%.

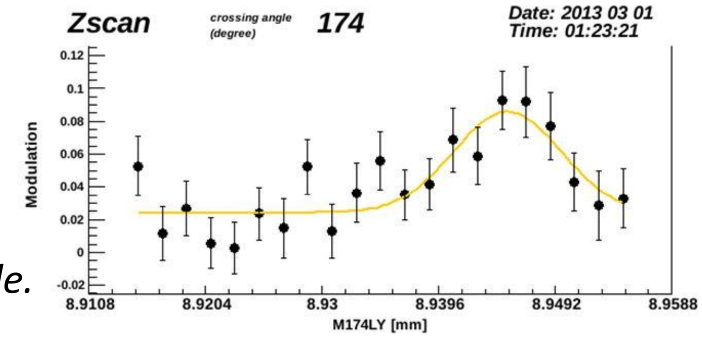
- The laser expert tune the laser profile.

The spatial coherency strongly depends on the laser profile.

The week of 2/25 – 3/01

Require to 174deg mode ; > 73%
Max modulation ; 51%





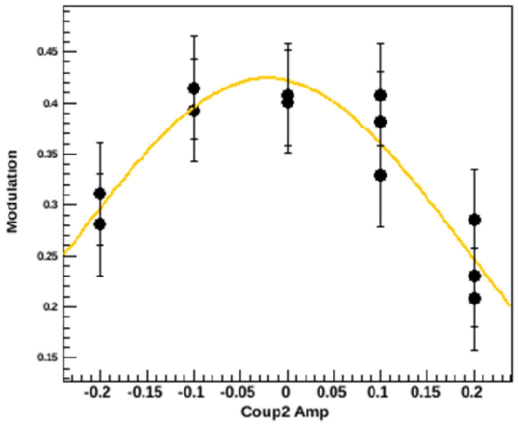
We could find the IP-BSM modulation of 174 deg mode.

We can use the IP-BSM for beam tuning, even if the maximum modulation is small.

But, it is difficult to evaluate the beam size from IP-BSM modulation.

The week of 3/04 – 3/08

30deg mode (3/6)

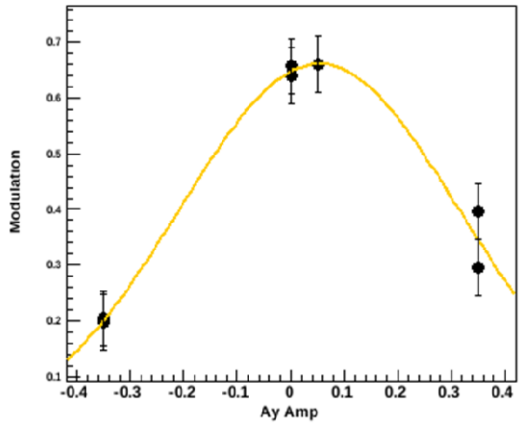


Max modulation ; 42%

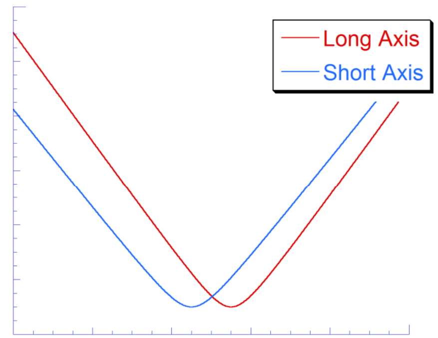
Laser profile tuning by laser expert.

Maximum modulation was increased.

30deg mode (3/7)



Max modulation ; 66%



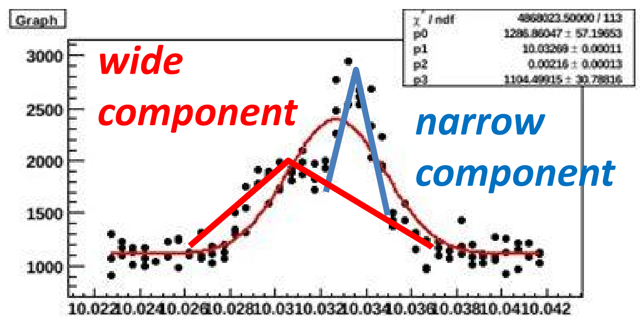
The laser divergences for horizontal and vertical were different.

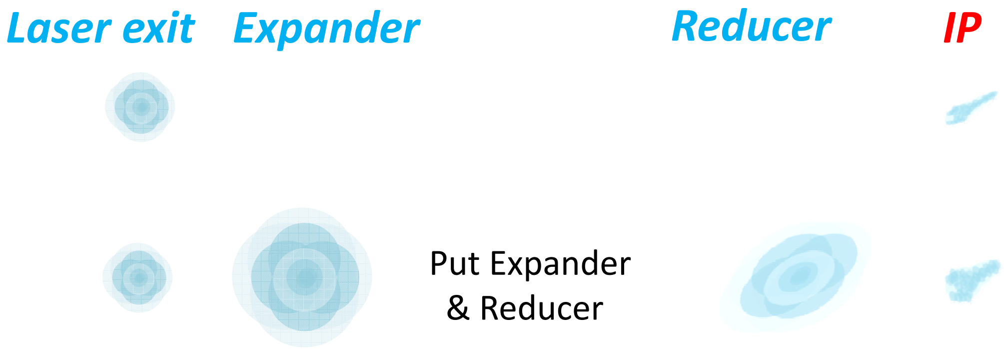
The laser profile of vertical and longitudinal plan was rotated at IP.

Vertical and longitudinal profiles are the projection of these axis.

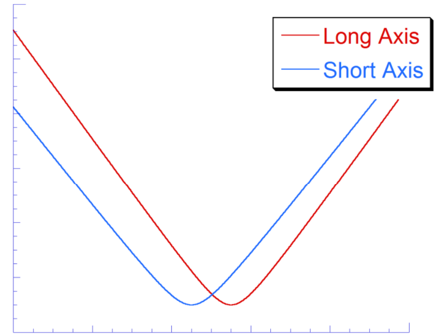
Since the laser focus was checked by measuring the projected beam size to vertical axis, it is difficult to focus to the laser waist.

The laser overlap for upper and lower path was smaller than the expectation from laser wire scan in vertical axis.

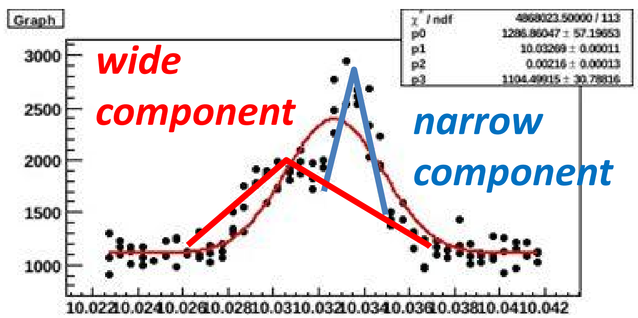


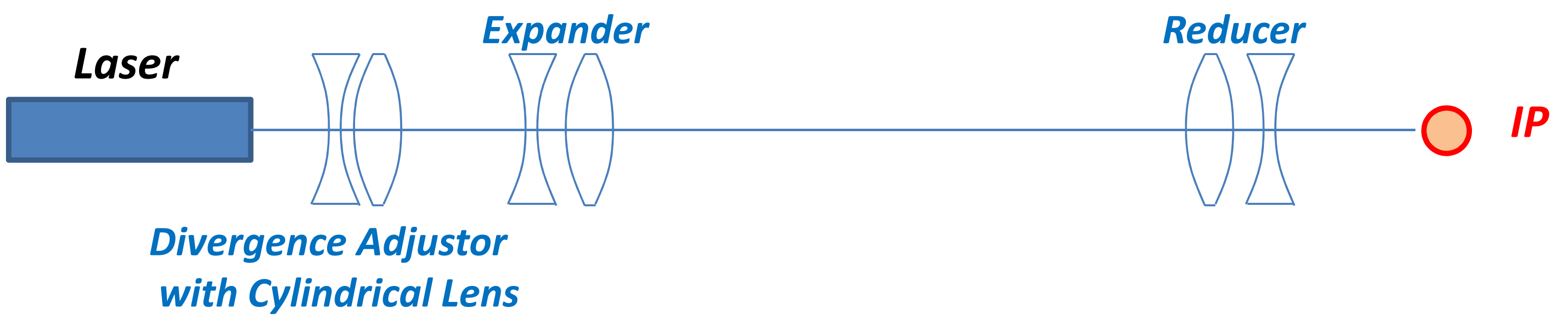


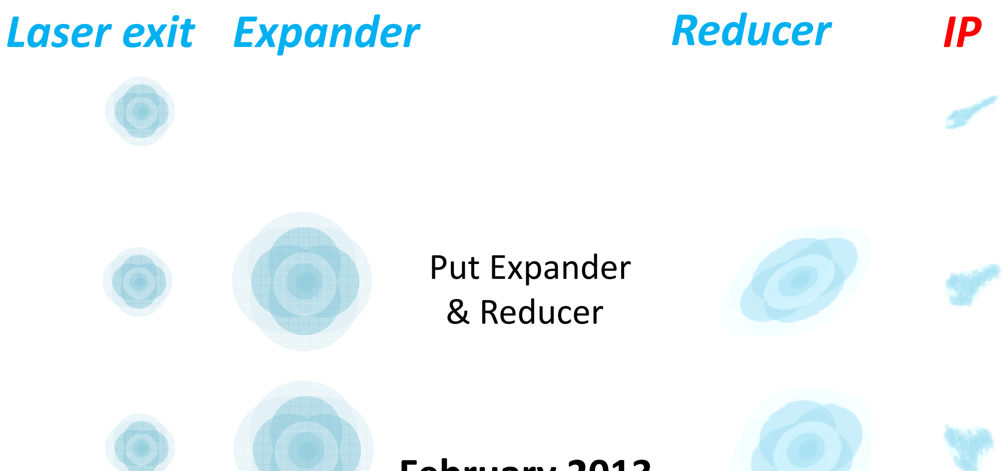
Shorten the effective laser path length



Vertical and longitudinal profiles are the projection of these axis.



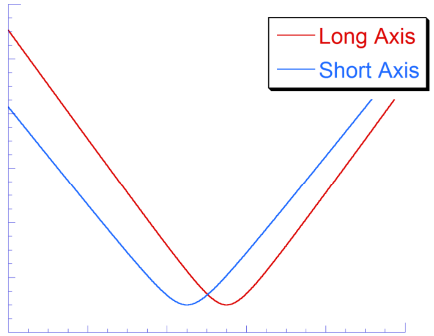




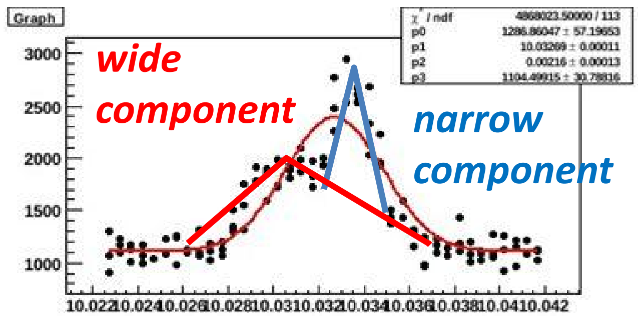
February 2013
Put Cylindrical Lens System

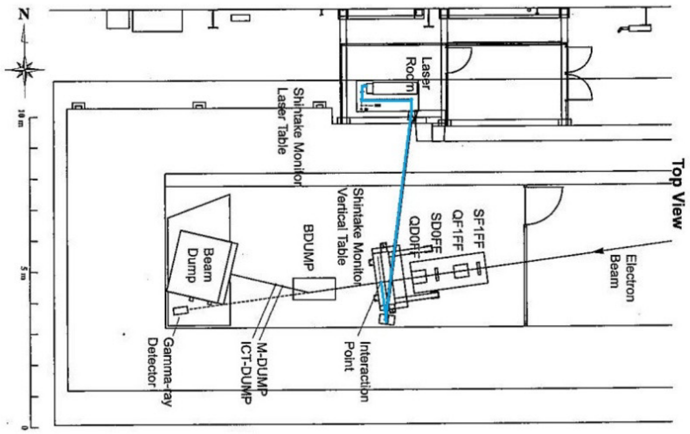
Change the aspect ratio of laser.

The focal points for 2 axis were closed.

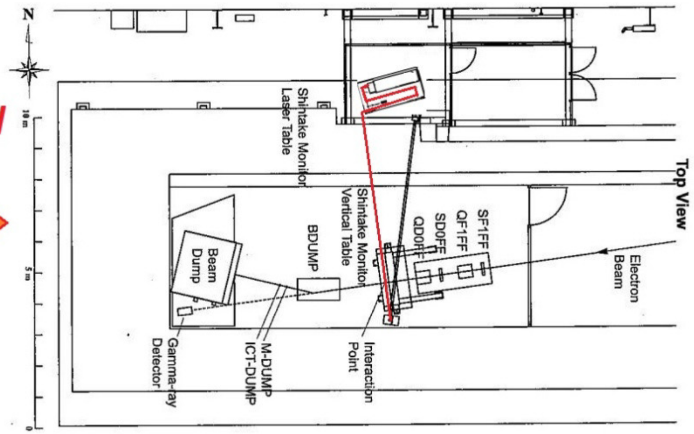


Vertical and longitudinal profiles are the projection of these axis.

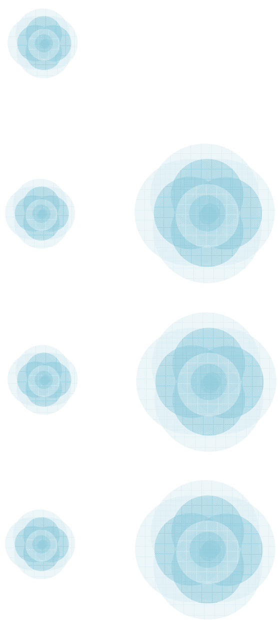




2013 April

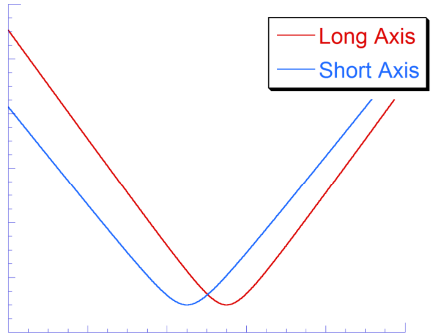


Laser exit **Expander** **Reducer** **IP**

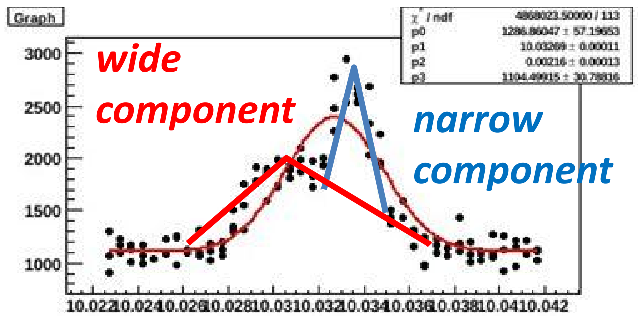


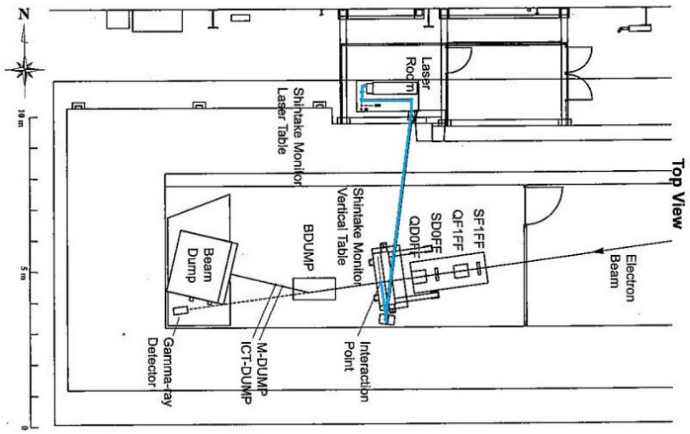
April 2013
Change Laser Transport

Correct the rotation of laser at IP

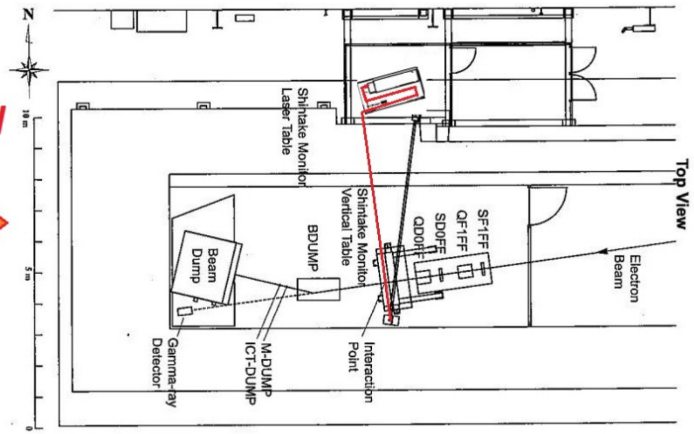


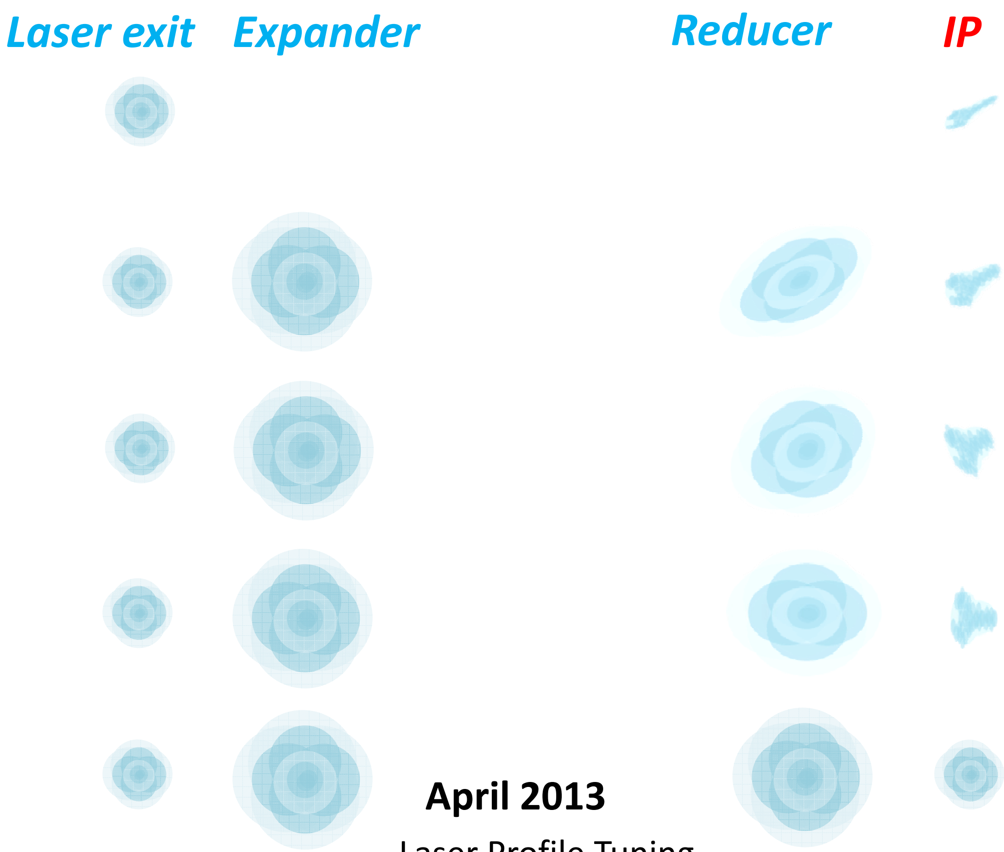
Vertical and longitudinal profiles are the projection of these axis.





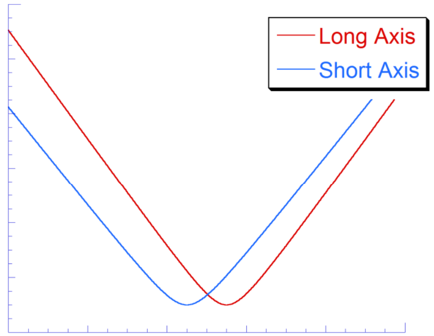
2013 April



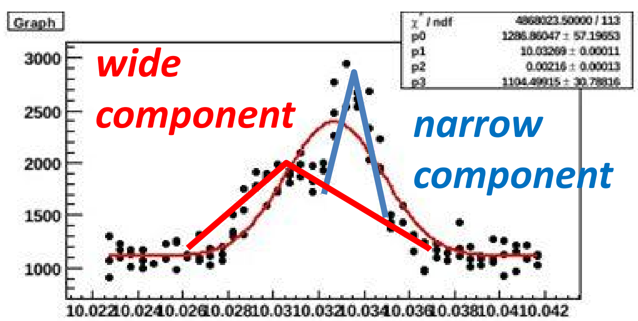


April 2013

Laser Profile Tuning



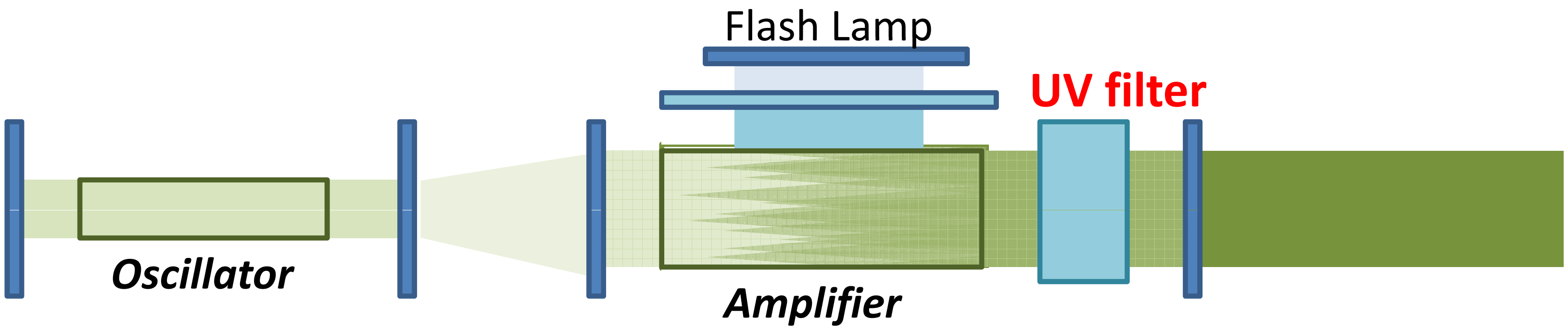
Vertical and longitudinal profiles are the projection of these axis.



Profiling the IP-BSM Laser

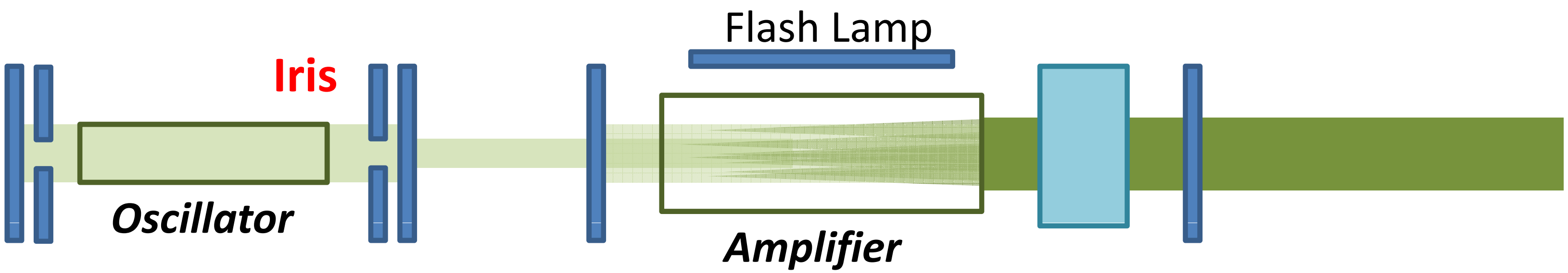
1) Put UV filter in between flash lamp and YAG crystal.

The thermal expansion of YAG crystal was suppressed.



2) Put an iris in laser oscillator.

Laser light in amplifier was centered.



The laser intensity was reduced to be 75%, but the laser profile was improved, but still the laser profile is asymmetric shape.

IP Beam Size Tuning

Linear knob (Linear Optics Correction at IP)

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 Tuning with Linear Knob

Measured Modulation by IP-BSM

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

C ; Modulation Reduction Factor (IP-BSM related)

If each knob is not coupled,

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

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

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

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

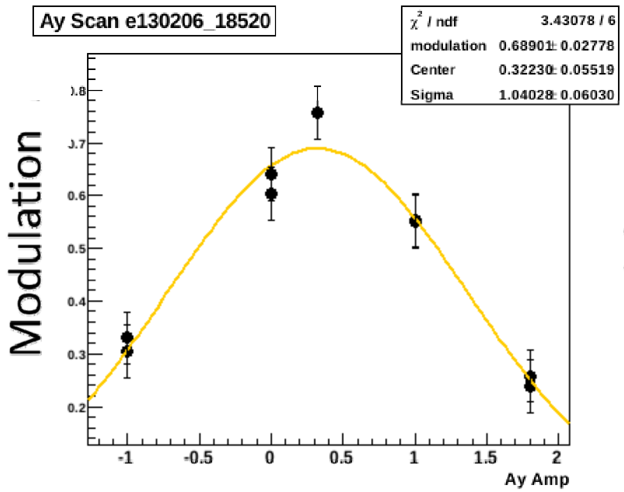
We can optimize each knob independently.

Example of Linear Optics Tuning with IP-BSM

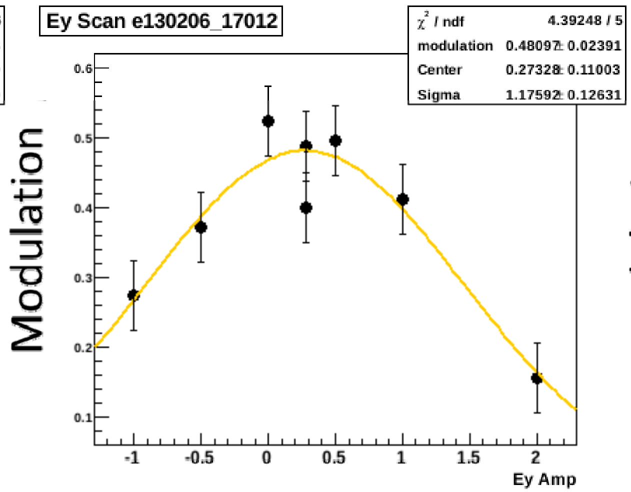
- We can optimize each knob by finding the maximum modulation
- Since it is difficult to find the optimum knob setting
  only by scanning around peak for IP-BSM stability,
  we scan the wide range (typically +/- 1.5σ) for the knob optimization.

Linear Knob Optimization for IP-BSM 30 deg mode

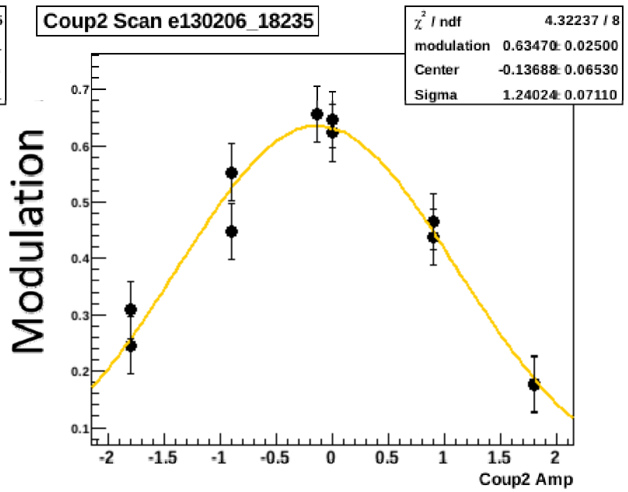
Ay knob (beam waist)



Ey knob (dispersion)



Coup2 knob (<x'y> at IP)



Normal Sextupole Field Correction Knobs

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

Sextupole field

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

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

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

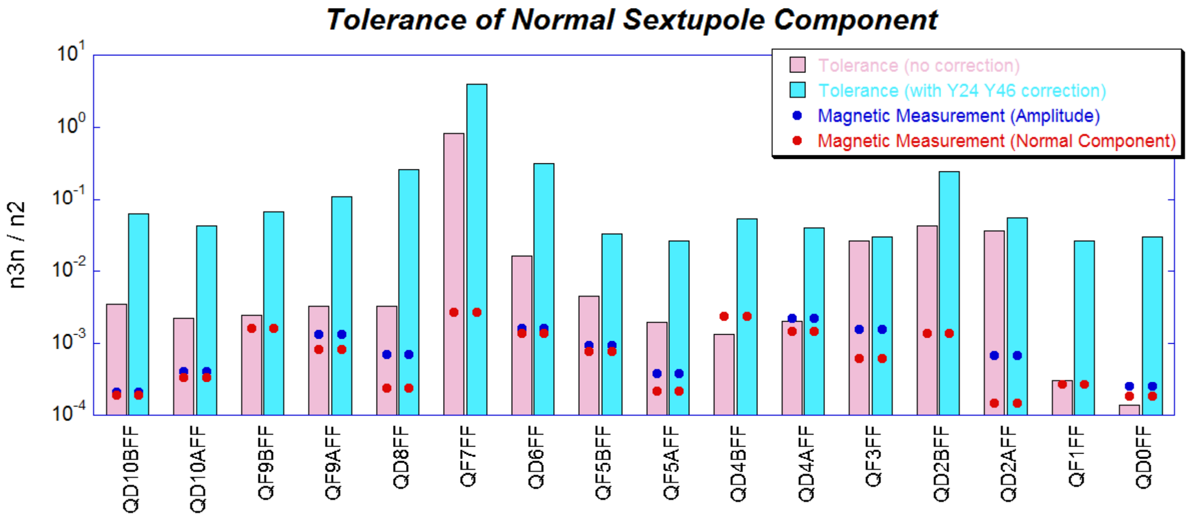
X_{22} X_{26} X_{66} X_{44}

ignore (effect is small)

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

Y_{24} Y_{46}

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

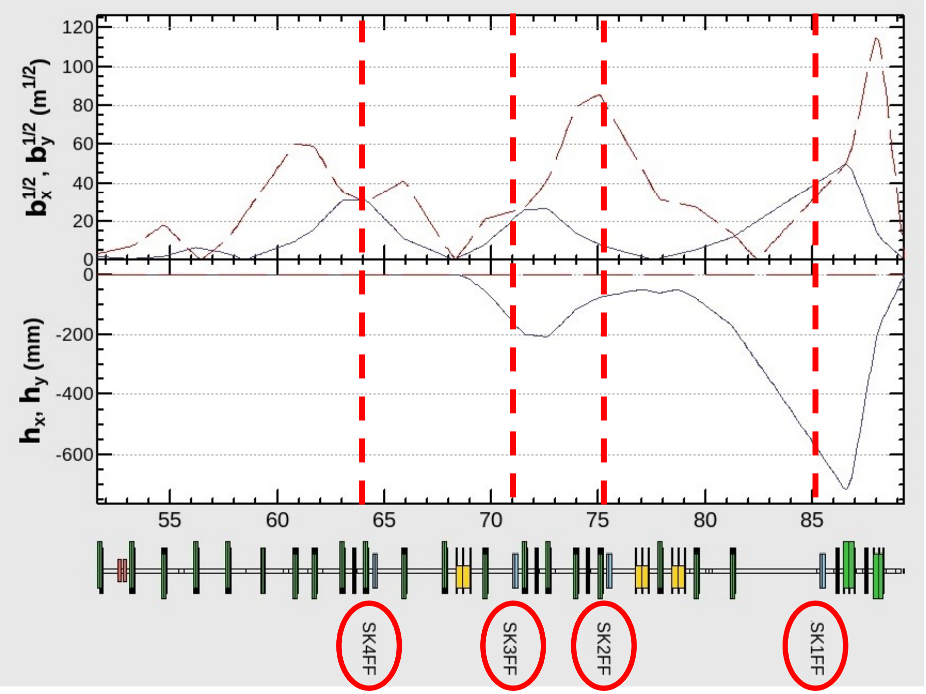
Present Correction Scheme of Skew Sextupole Field (from 2012 Autumn Operation)

Skew sextupole field

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

$$\Delta y_{IP} = \frac{R_{34} K_{2S}}{2}\left(\underbrace{\Delta x^2}_{Y22} + \underbrace{2\eta\Delta x\frac{\Delta p}{p}}_{Y26} + \underbrace{\eta^2\frac{\Delta p^2}{p^2}}_{Y66} - \underbrace{\Delta y^2}_{Y44}\right)$$

We will put 4 skew sextupole correctors



SK1FF ; sensitive to Y22, Y26, Y66

SK2FF ; sensitive to Y44

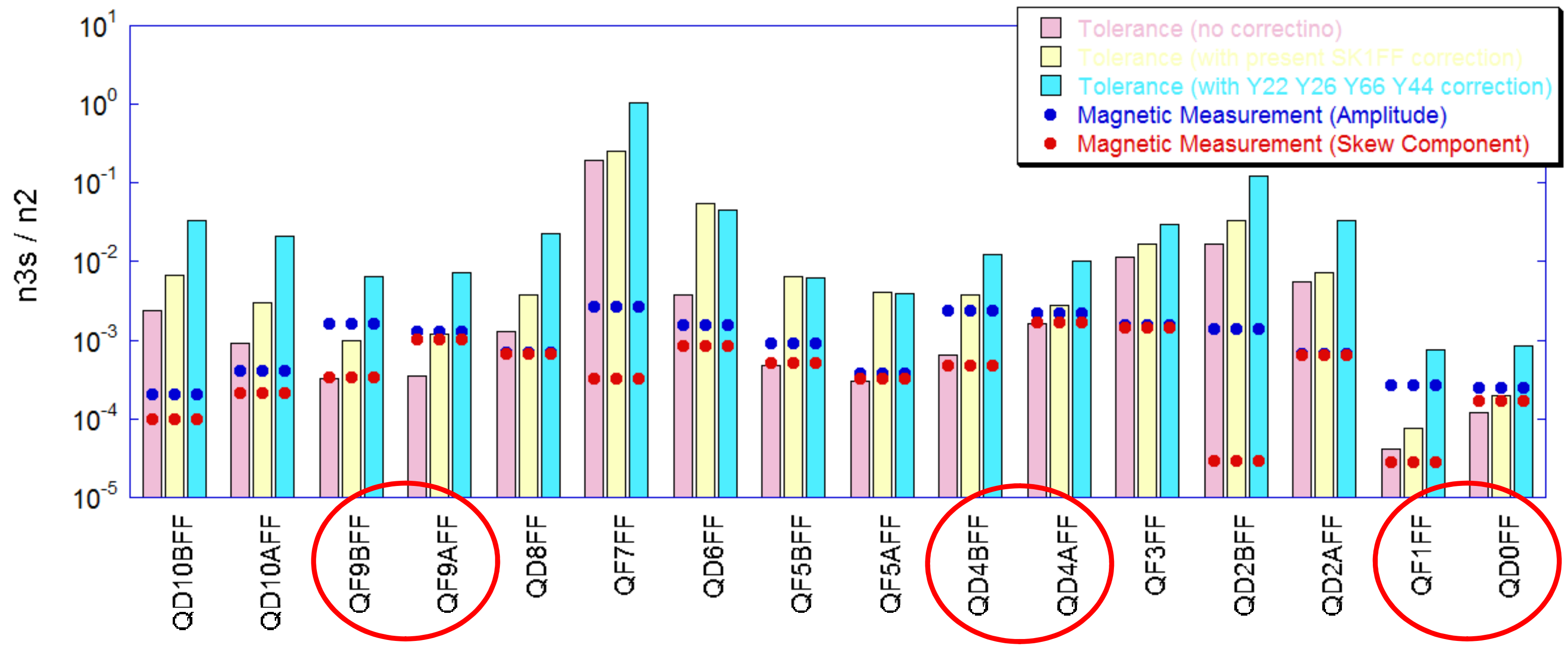
SK3FF ; sensitive to Y22, Y26, Y66

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)

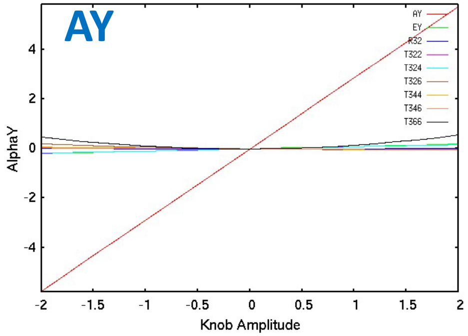


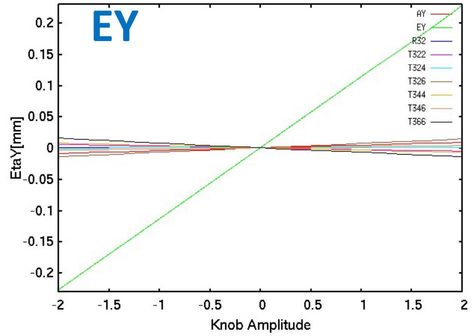
By using 4 SKs correction,

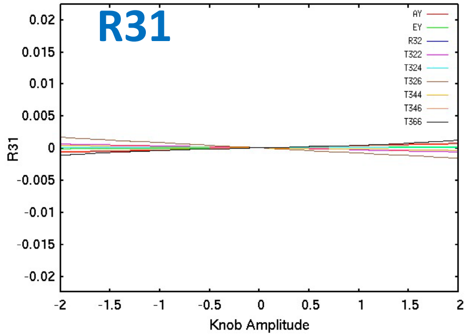
- *Tolerances for all quadrupoles are increased.*
- *We can investigate the error source of skew sextupole field.*

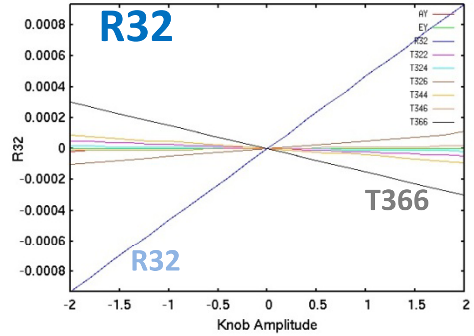
Multiknob Response

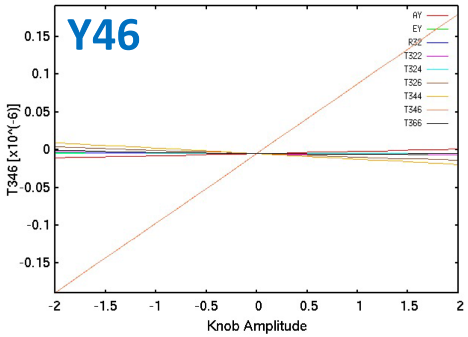
Each knob is normalized to (knob=1 -> $\Delta\sigma y$ = 100nm).
Maximum vertical axis of plots are scaled to $\Delta\sigma y$ = 200nm.

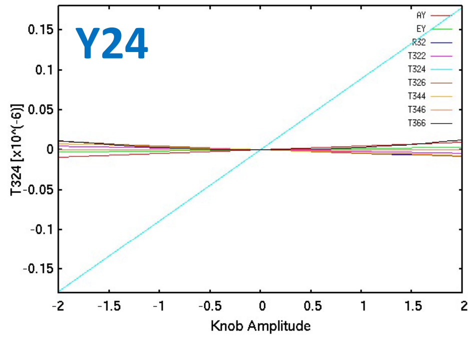




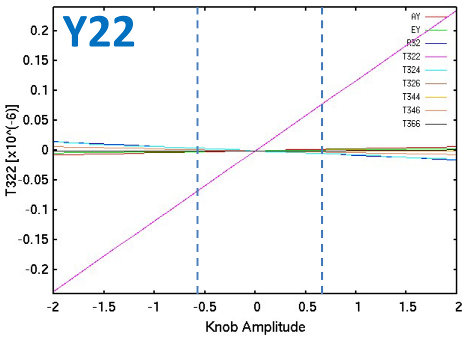


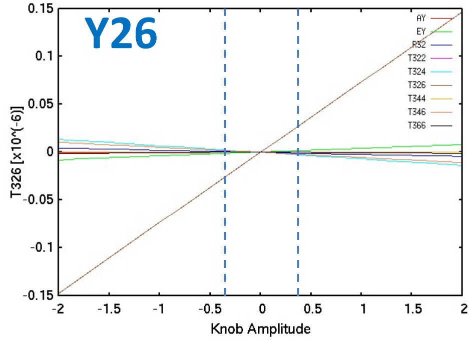


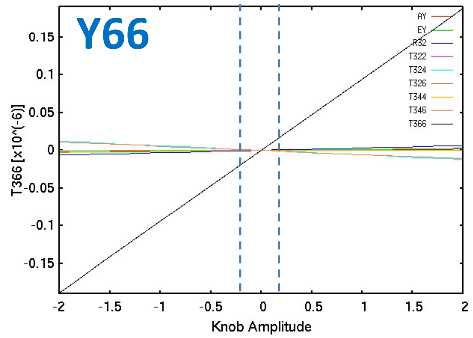


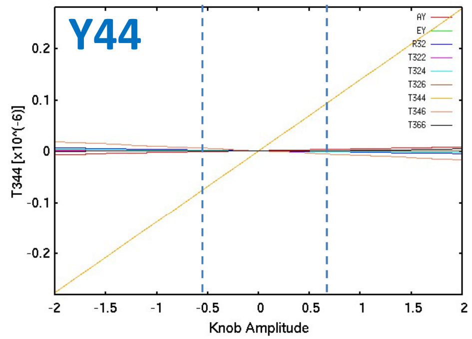


dynamic range of 20A PS









Summary of Beam Tuning Method in ATF2

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

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**

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

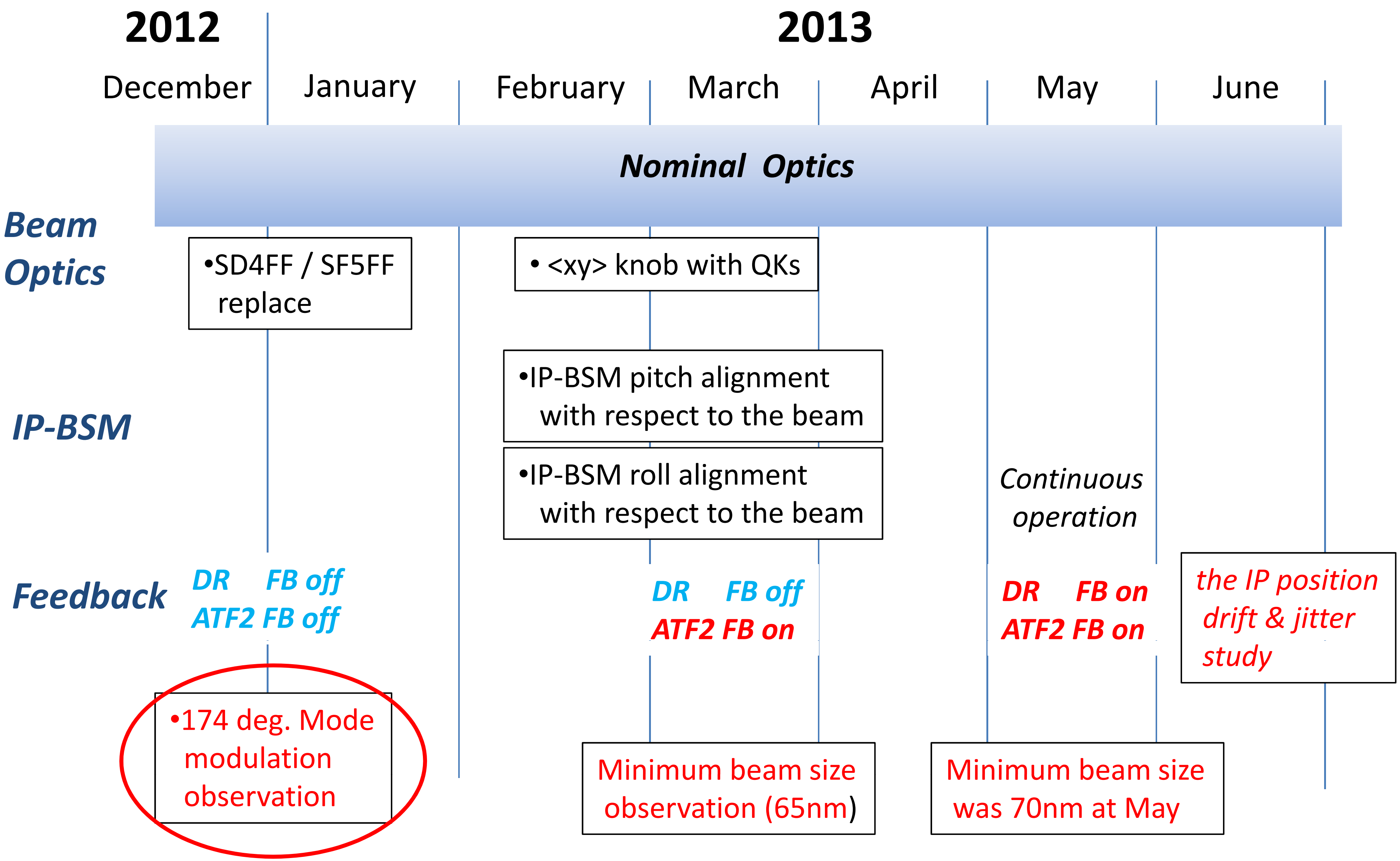
-can not correct with any tuning knobs
-But, since the effect strongly depend on the beam size at quads, we can control the effect by changing $\sigma^*_{x'}$

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

I will submit the paper about the IP beam size tuning method, especially for the skew sextupole correction to "Physical Review ST-AB" in this summer.

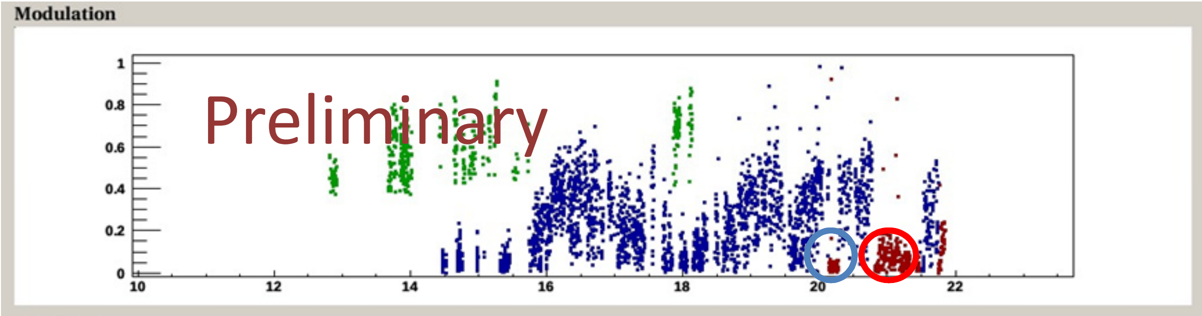
Recent Status of ATF2 Beam Tuning
(From December 2012)

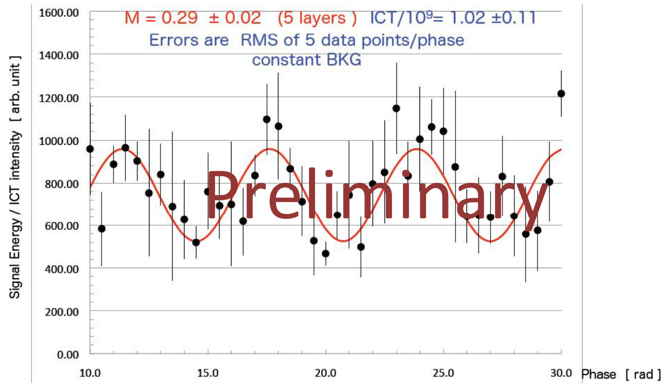
Recent History of ATF2 beam tuning

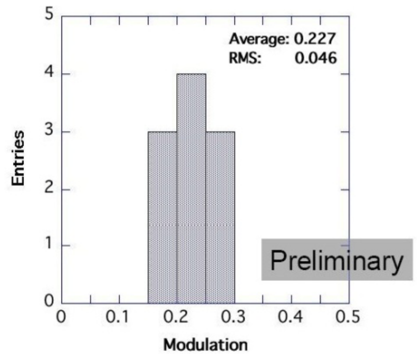


First Observation of modulation of IP-BSM 174deg mode

History of last 2 weeks in 2012 Dec. operation

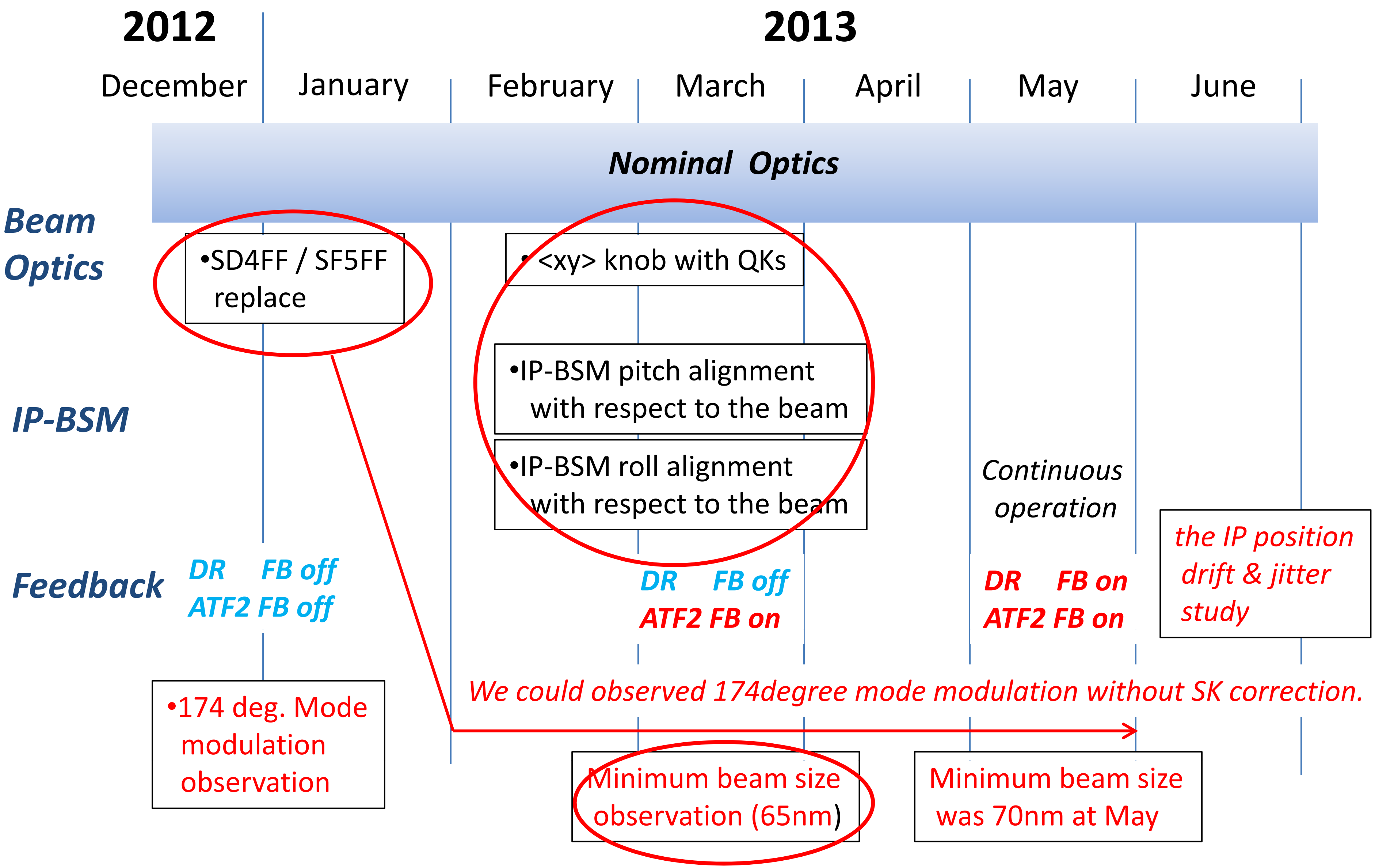






If we assume (modulation reduction factor)=1,
the modulation corresponds to 73nm (upper limit) beam size.

Minimum beam size observation in ATF2 beam tuning



Result of Minimum Beam Size in ATF2

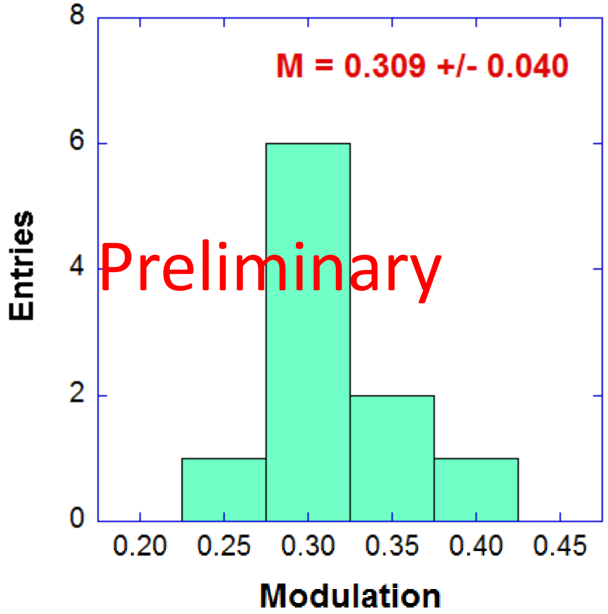
From February 2013, we could observed the modulation of IPBSM 174degree mode every week.

The maximum modulation was measured at March 2013 (03/08 and 03/14).

The beam optics were set to 10x1 optics for both measurement.

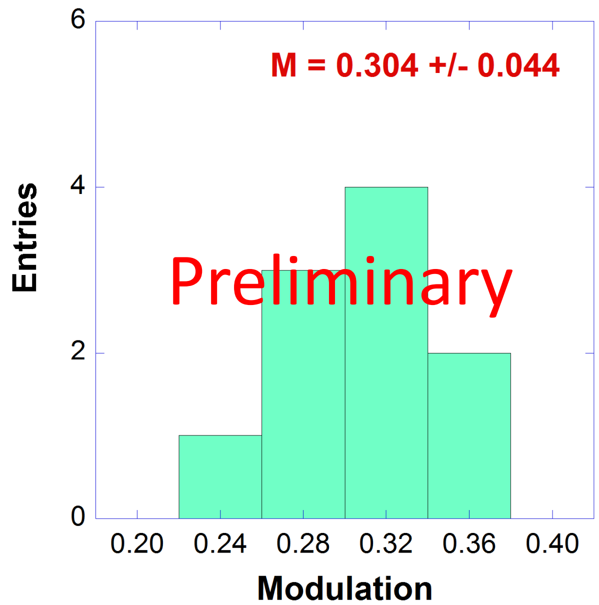
We have never measured the smaller beam size than March 2013.

2013/03 /08



Correct the IPBSM pitch by laser path alignment
Correct the IPBSM roll by QK <xy> knob correction

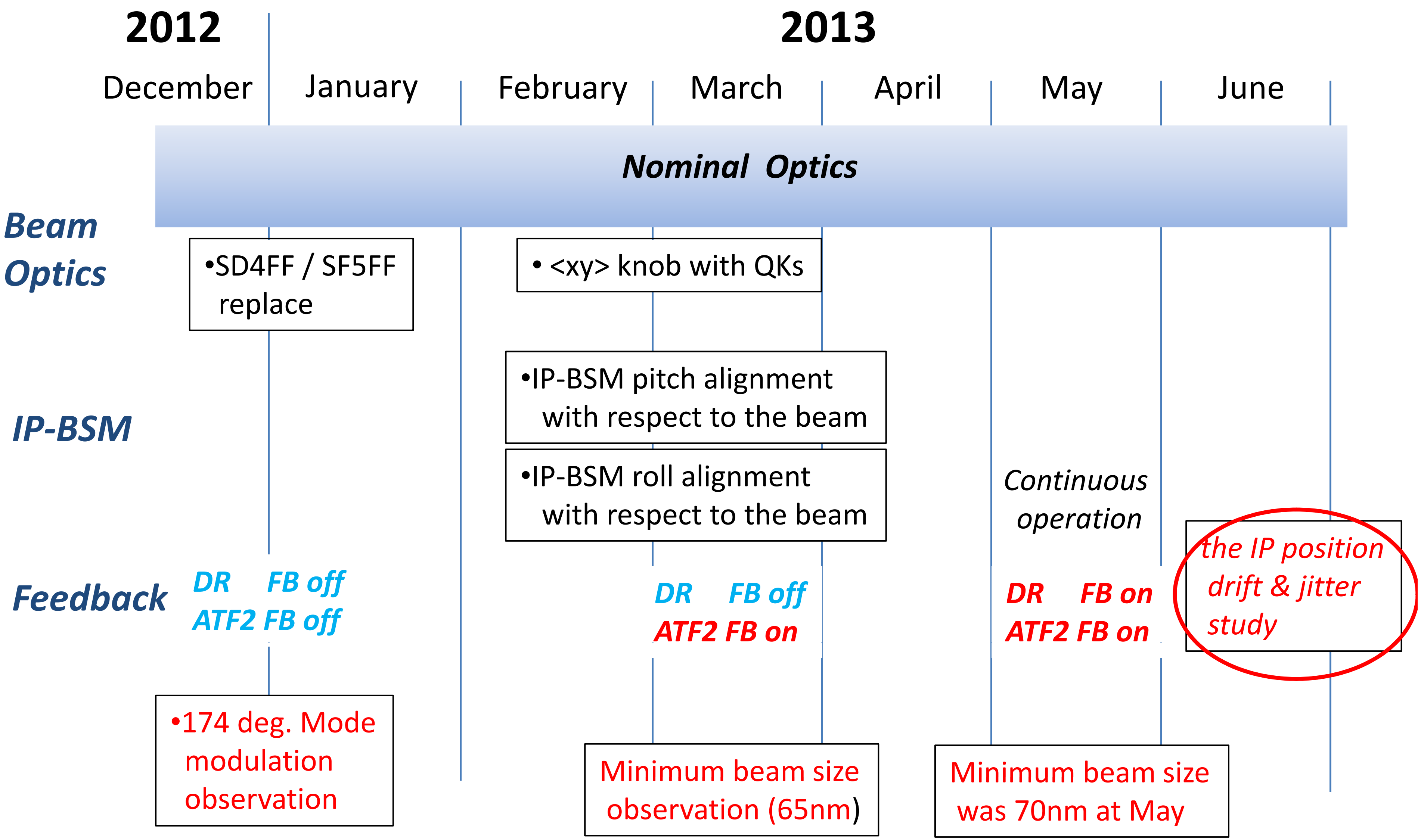
2013/03 /14



Correct the IPBSM pitch by laser path alignment
Correct the IPBSM roll by laser path alignment

If we assume (modulation reduction factor)=1,
the modulation corresponds to 65nm (upper limit) beam size.

Minimum beam size observation in ATF2 beam tuning



Fixed phase data taking of IP-BSM

We took the IPBSM signal by at the same laser phase.

We took 4 conditions of laser shutters of IPBSM laser,

1) *The shutters of both upper and lower paths are closed (Background).*
2) *The shutter of upper path is opened, but lower path is closed (Upper path signal).*
3) *The shutter of lower path is opened, but upper path is closed (Lower path signal).*
4) *) The shutters of both upper and lower paths are opened (Both path signal).*

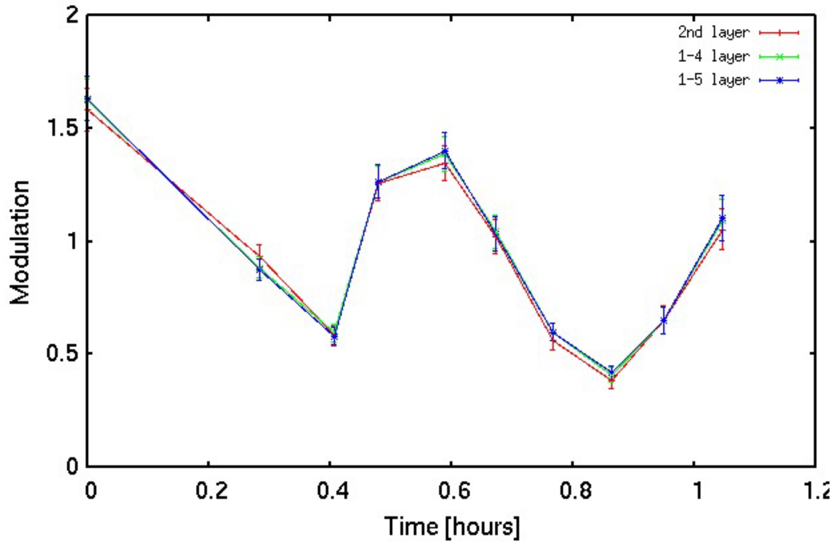
In order to decrease the signal drift in the data set, the data was taken as following sequence,

10 shots of (Background),
10 shots of (Upper path signal)
10 shots of (Lower path signal)
10 shots of (Both path signal)

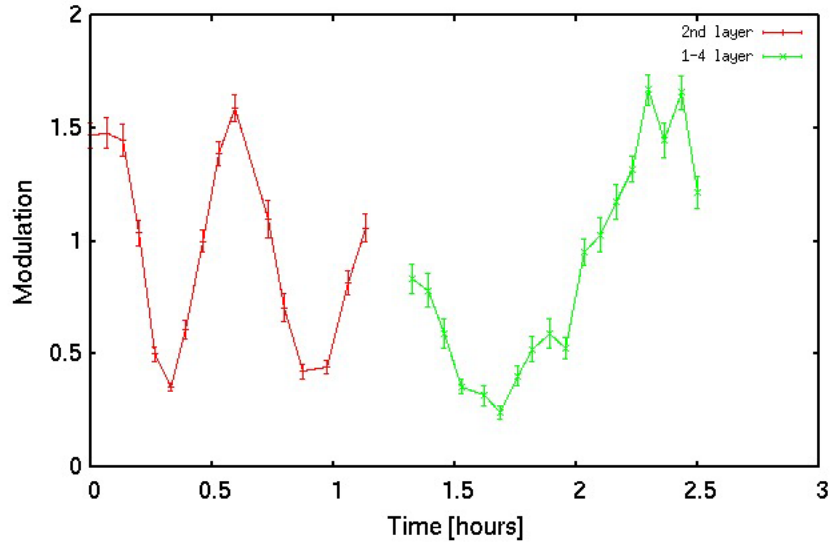
10 shots of (Background),
10 shots of (Upper path signal)
10 shots of (Lower path signal)
10 shots of (Both path signal)
…

IPBSM signal drift evaluated by the fixed phase data taking

Data at 06/06



Data at 06/13



Definition of modulation

$$M = \frac{(Both\ path) - (Background)}{(Upper\ path) + (Lower\ path) - 2 \times (Background)}$$

The signal modulations both for 6/6 and 6/13 were drifted.

The first half data of 6/13 were 30degree mode, and second half data were 7.8degree mode.
We observed the signal drift both for 30degree mode and 7.8degree mode.

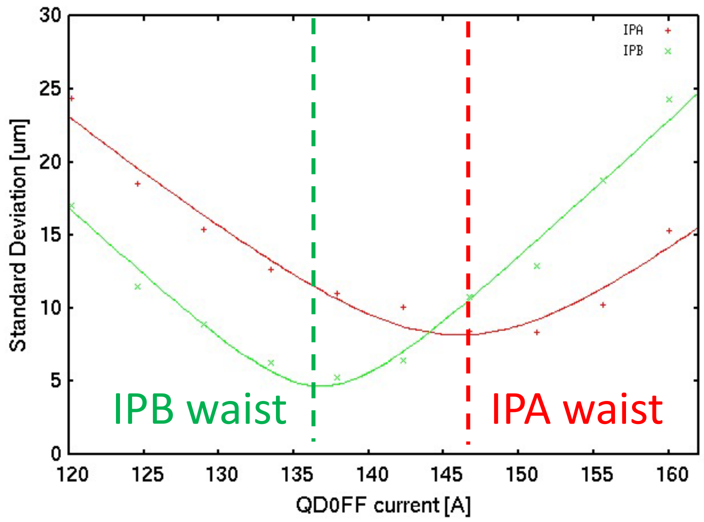
We need to check the IP beam position drift.

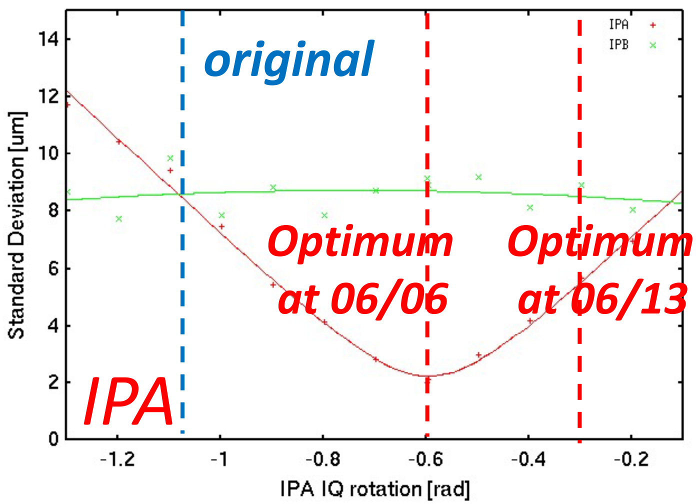
IP-BPM (online SLAC electronics) calibration

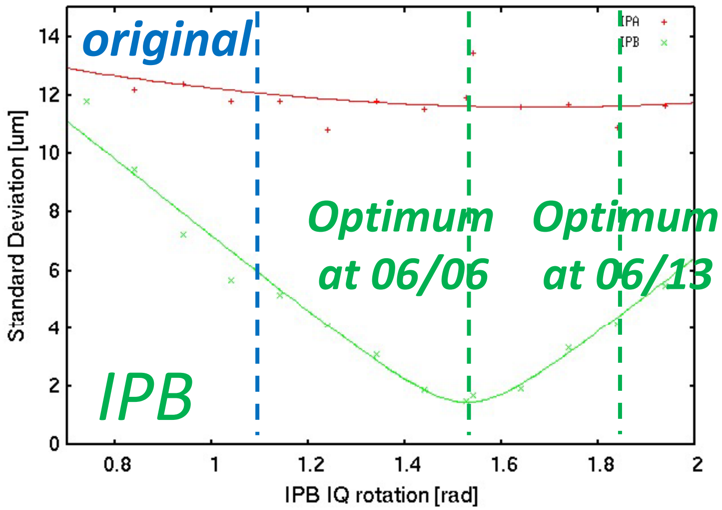
1) Beam waist was set to IPA or IPB to be minimize the position jitter at BPMs.

2) We found the minimum jitter point by changing IQ rotation phase

The readout fluctuation was reduced
IPA ; 8um -> 1.9um ,
IPB ; 5um -> 1.5um ,
IP ; 16.8um -> 4.1um .







We observed the IQ rotation phase was drifted by 0.3 in 1 week.

The position information was coupled to the angle information at no optimum IQ rotation phase.

IP beam position analysis

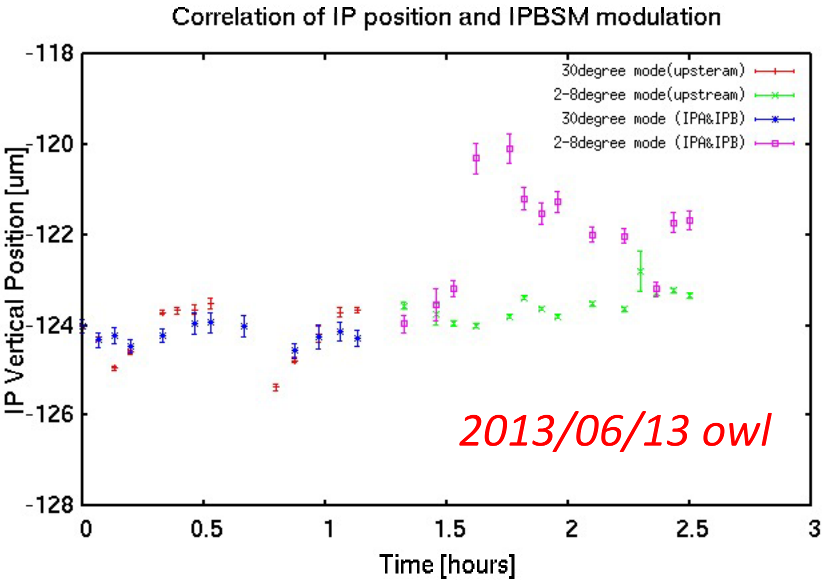
IP position drift was analyzed the following procedure.

1) We did the calibration of IPA and IPB (phase and amplitude).
The IQ rotation phase of IPBSM was optimum just after the calibration.

2) We make an empirical model to reproduce the IPA&IPB position (model independent analysis) by using the position information of upstream BPMs (MQF16FF to MQD2AFF).

3) We can calculate the IP position by using the evaluated IPA&IPB position from upstream BPMs.

(Example of IP position analysis)



The fluctuations of IP positions by evaluated with IPA&IPB were larger than those with upstream BPMs.

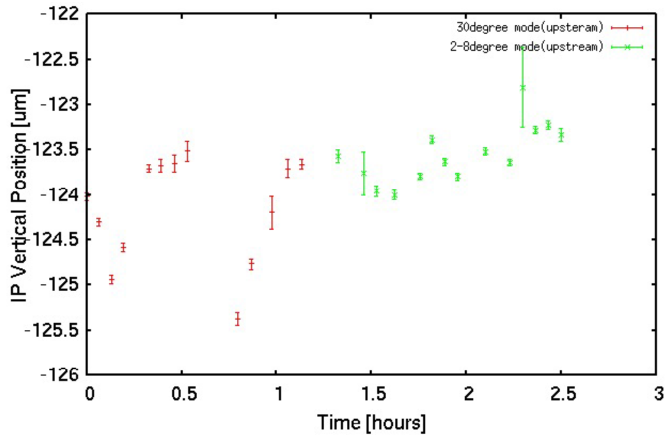
The IP position evaluations by upstream BPMs were good agreement with those with IPA&IPB just after calibration.

The IP position evaluations with IPA&IPB were suddenly jumped. (maybe caused by the jump of IQ rotation phase)

IP position was evaluated only with the BPM information, not used any information of IPBSM.

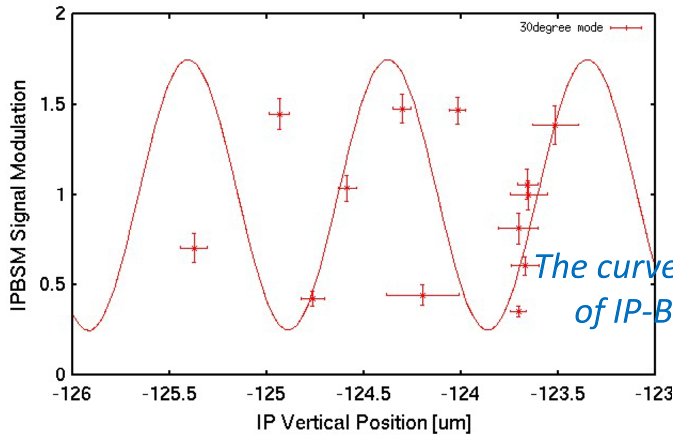
Correlation of the IP beam position and IPBSM signal

IP beam position evaluated upstream BPMs



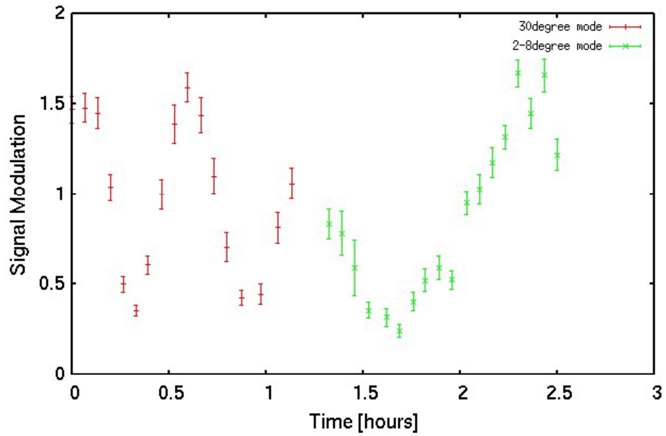
Correlation of IP beam position and IPBSM signal

30 degree mode

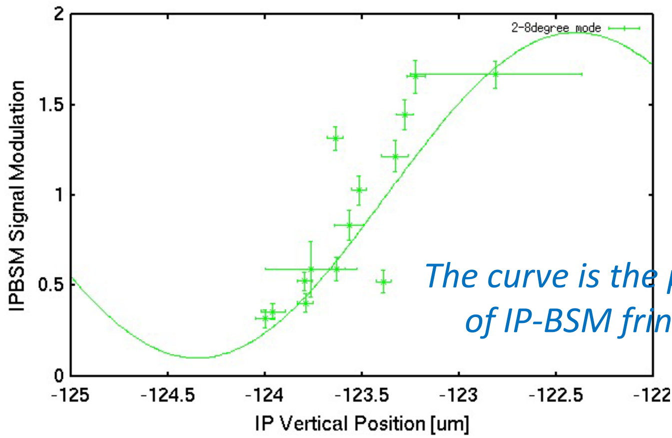


The curve is the pitch of IP-BSM fringe

IPBSM modulation evaluated by phase fix data



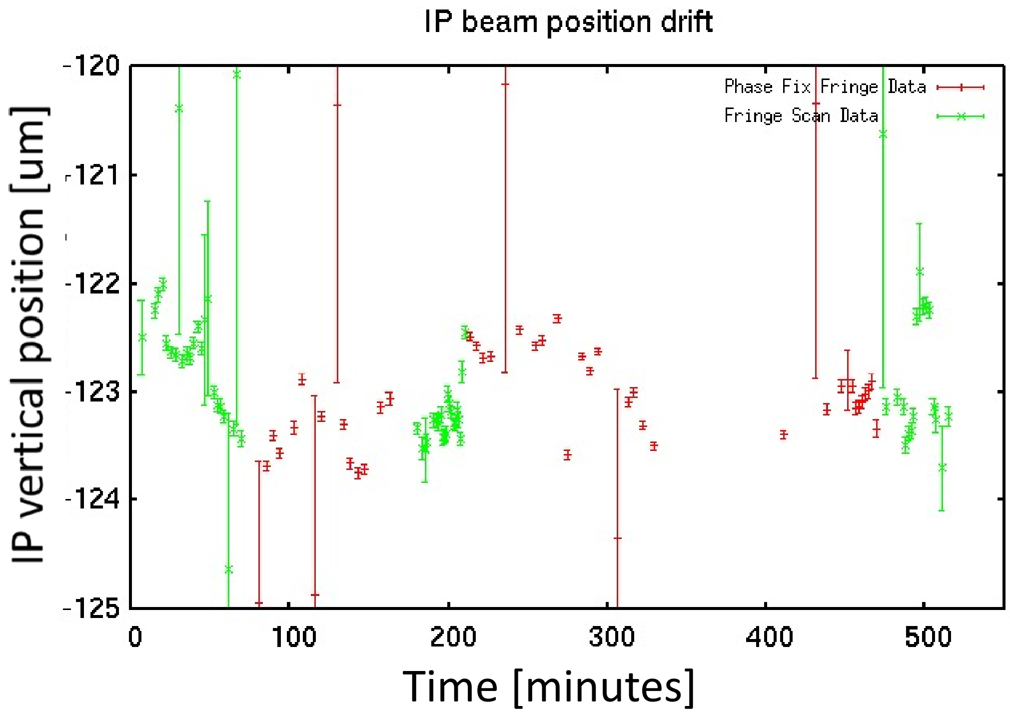
7.8 degree mode



The curve is the pitch of IP-BSM fringe

Long time IP drift data (2013/06/13 swing)

We turned on both DR & ATF orbit feedback



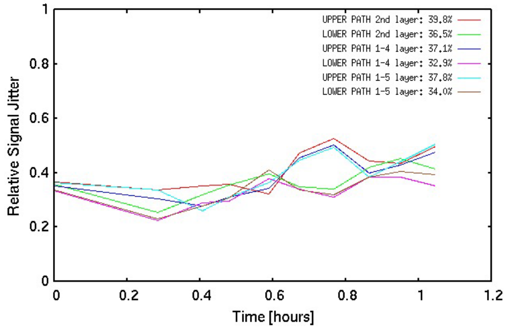
We can observed 2 IP drift component

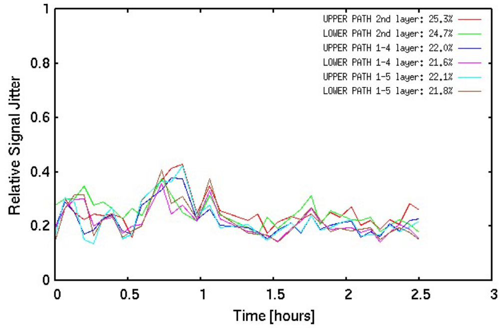
1) the period was 4 hours (slow drift).
2) the period was 30-40minutes (sensitive to IP-BSM 30degree mode)

IPBSM Signal Jitter

Data at 06/06 Data at 06/13

Variation of signal fluctuation for upper & lower paths

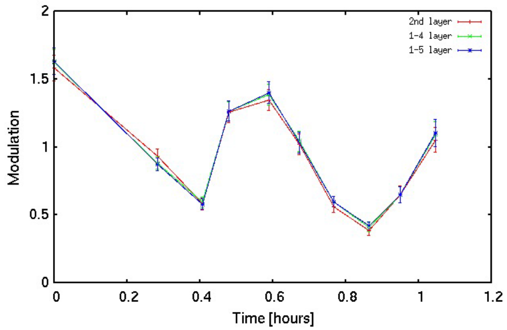


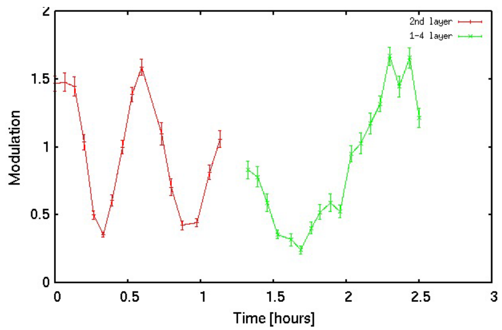


The signal fluctuations for single path were almost constant through the measurement.

The single path signal fluctuations of 6/13 were smaller than those of 6/6.

Variation of signal modulation for both paths

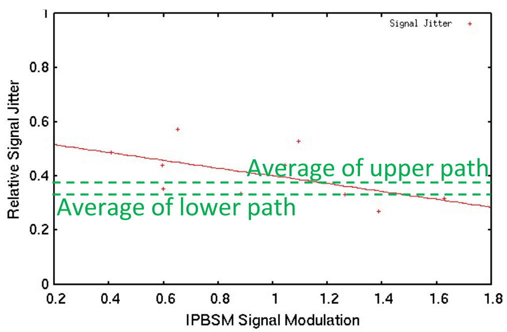


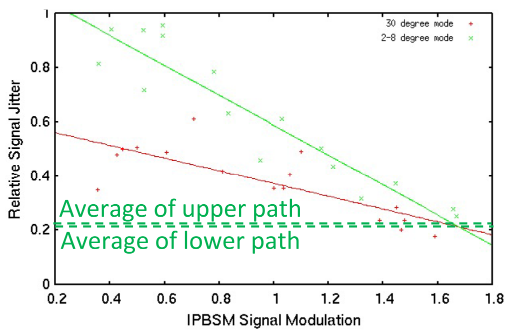


The first half data of 6/13 were 30degree mode, and second half data were 7.8degree mode.

The signal modulations both for 6/6 and 6/13 were drifted.

Correlation between modulation and fluctuation for both paths





The signal fluctuation for both laser paths on 6/13 were almost same to those on 6/6, even if the signal fluctuations for single path were small.

The signal modulations for 7.8 degree mode were larger than those for 30 degree mode.

Candidate for the IPBSM Signal Jitter Sources

The jitter analysis suggest that there are some jitter sources not for the fluctuation of laser beam collision.

The main jitter sources were not the beam position jitter.

If the jitter source was the beam position jitter, the fluctuation for 30 degree mode was smaller than that for 7.8 degree mode.

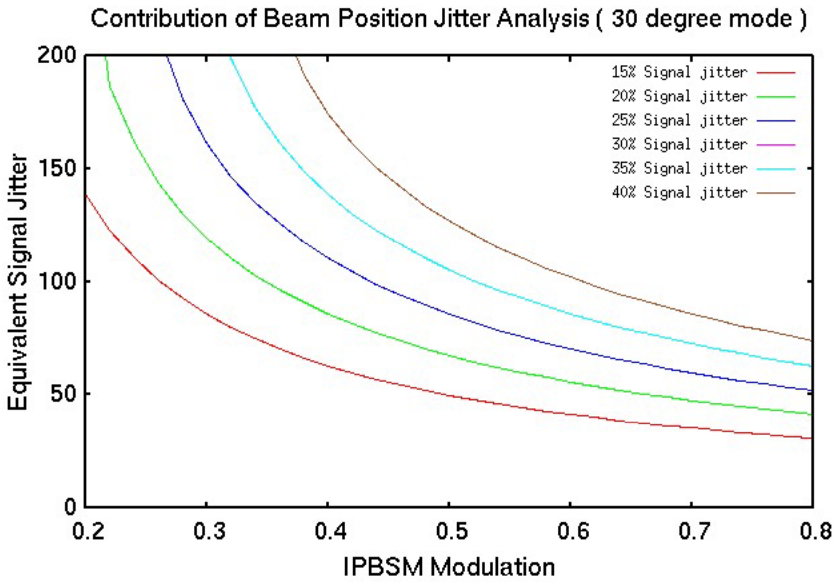
One possibility of the jitter source was "laser position jitter".

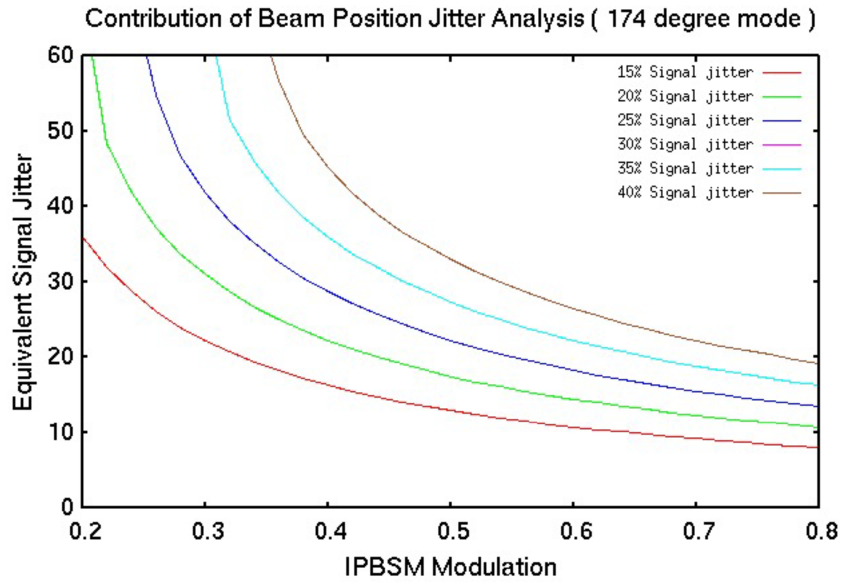
When the laser profile was asymmetric , the range with good contrast of laser fringe was narrow for the lower angle mode. Therefore, there is possibility to make the IPBSM signal for both paths large fluctuation by the laser position jitter. However, it is very difficult to evaluate the amount of jitter quantitatively , because the sensitivity is strongly depends on the laser profile.

When we put the "Dove prism" to one path, the good contrast range make wider for vertical, and the good contrast range make narrower for horizontal than the present setting.

We can check the effect of the laser position jitter by comparing the signal fluctuation with/without Dove prism.

Possibility of the beam position jitter evaluation from the IPBSM signal fluctuation of fringe scan





The equivalent beam position jitter of IPBSM amplitude jitter was evaluated as a function of the IP-BSM modulation.

Since the signal fluctuation was almost 40% at 30 degree mode now, it was difficult to evaluate the beam position jitter smaller than 100nm by the analysis.

It is very important to reduce the IPBSM signal jitter and increase the modulation to evaluate the beam position jitter from the jitter analysis of IPBSM fringe scan.

We could not analyze the contribution of the IP position jitter to the beam size.

Summary

Beam Optics for ATF2 Beamline

We operate the ATF2 by using nominal FF optics from 2012 autumn operation, after we installed 4 skew sextupoles and replaced the QF1FF to be small multipole errors.

We used 10x1 optics at March 2013 (we measured the minimum beam size).

IP Beam Size Monitor in ATF2

The beam tuning status has been improved with IP-BSM improvement.

We still had a problem for laser profile and we should improve the modulation reduction factor.

We are preparing the beam position jitter study with IPBSM fringe data (see. J.Yan presentation) .

Recent Status of ATF2 Beam Tuning (From December 2012)

We succeeded to find the IP-BSM modulation in 2012 December.

We can squeeze the beam within the dynamic range of IP-BSM 174deg mode, after we swapped the SD4FF and SF5FF.

We could correct the IP-BSM fringe pitch and roll, and we could squeeze the beam to less than 65nm.

After that, we, however, could not squeezed the beam to be less than 65nm.

We observed the IP beam position drift, we need to be evaluate the effect.

We have never evaluated the effect of the beam jitter, and it seemed to be difficult with the present data both of BPM and IP-BSM.