# *Studies of ATF2 Final Focus Beamline related the ATF2 Goal 1*

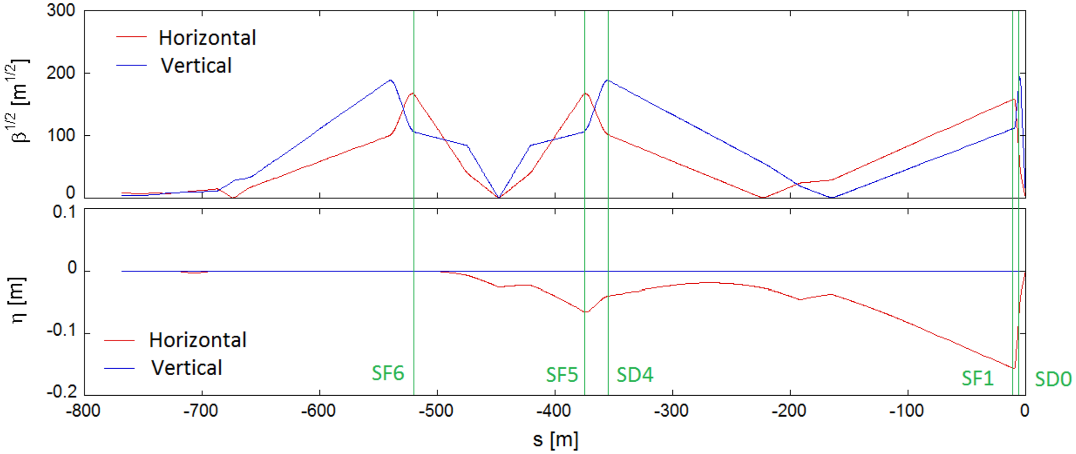
*Toshiyuki OKUGI, KEK*

*2014/ 2/ 12*

*ATF2 project meeting, KEK*

# Beam Optics

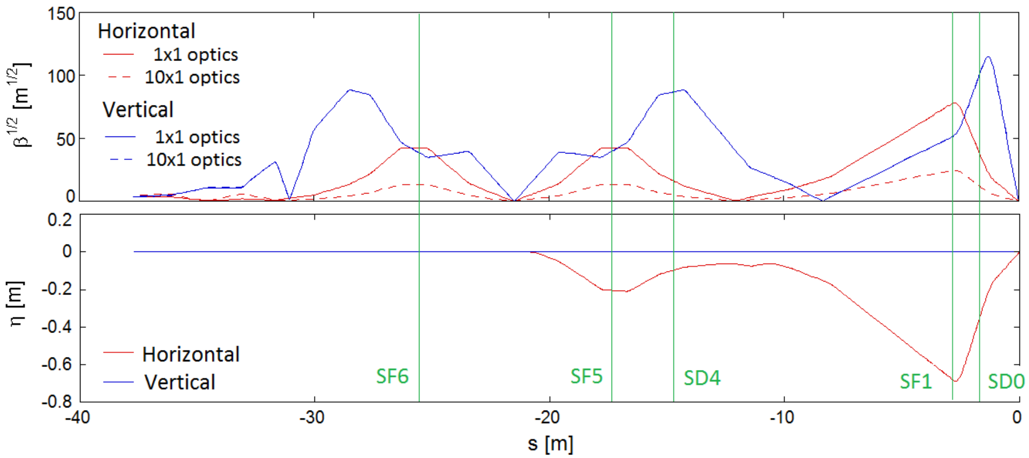
## Beam Optics for ILC final Focus System




- ILC final focus systemand ATF2 beamline are both based on the Local Chromaticity Correction.

- Same magnet arrangement

## Beam Optics for ATF2 beamline




## ATF2 Beam Optics

**1x1 optics**

*X&Y chromaticities are comparable to ILC FF.*

**10x1 optics**

*Since betax* is 10 times larger than 1x1 optics, X chromaticity is one order smaller than ILC .*

***ATF2 is now operating with 10x1 optics.***

# Rough Evaluation of Nonlinear Component in ATF2 Beamline

*When we assumed the beam size at quadrupoles as* $\sigma_{x,y} \propto L^* \sqrt{\frac{\varepsilon_{x,y}}{\beta^*_{x,y}}}$ ,

*the effect of multipole field to IP beam size can be roughly scaled as*

$$Y_{24} \propto L^{*2} \sqrt{\frac{\varepsilon_x \varepsilon_y}{\beta^*_x \beta^*_y}} \Big/ \sqrt{\varepsilon_y \beta^*_y} = L^{*2} \varepsilon_y \sqrt{\frac{\varepsilon_x}{\beta^*_x}} \qquad (5th\ order\ aberration) \propto L^{*5} \frac{\varepsilon_x^2}{\beta_x^{*2}} \sqrt{\frac{\varepsilon_x}{\beta^*_x}} \Big/ \sqrt{\varepsilon_y \beta^*_y} = L^{*5} \frac{\varepsilon_x^2}{\beta_x^{*2}} \sqrt{\frac{\varepsilon_x \varepsilon_y \beta^*_y}{\beta^*_x}}$$

*etc.*

| | | ILC | ATF2(1x1) | ATF2(10x1) |
|---|---|---|---|---|
| 2nd order | Y46 | 1 | 0.91 | 0.91 |
| | Y24 | 1 | 6.50 | 2.05 |
| | Y22 | 1 | 3.76 | 0.38 |
| | Y26 | 1 | 0.52 | 0.16 |
| | Y66 | 1 | 0.07 | 0.07 |
| | Y44 | 1 | 11.14 | 11.14 |
| 3rd (horizontal) | | 1 | 17.80 | 0.56 |
| 4th (horizontal) | | 1 | 84.33 | 0.84 |
| 5th (horizontal) | | 1 | 399.55 | 1.26 |

*Chromatic aberration*

*Generate by Sextupole*

*Allowed component of quadrupoles*

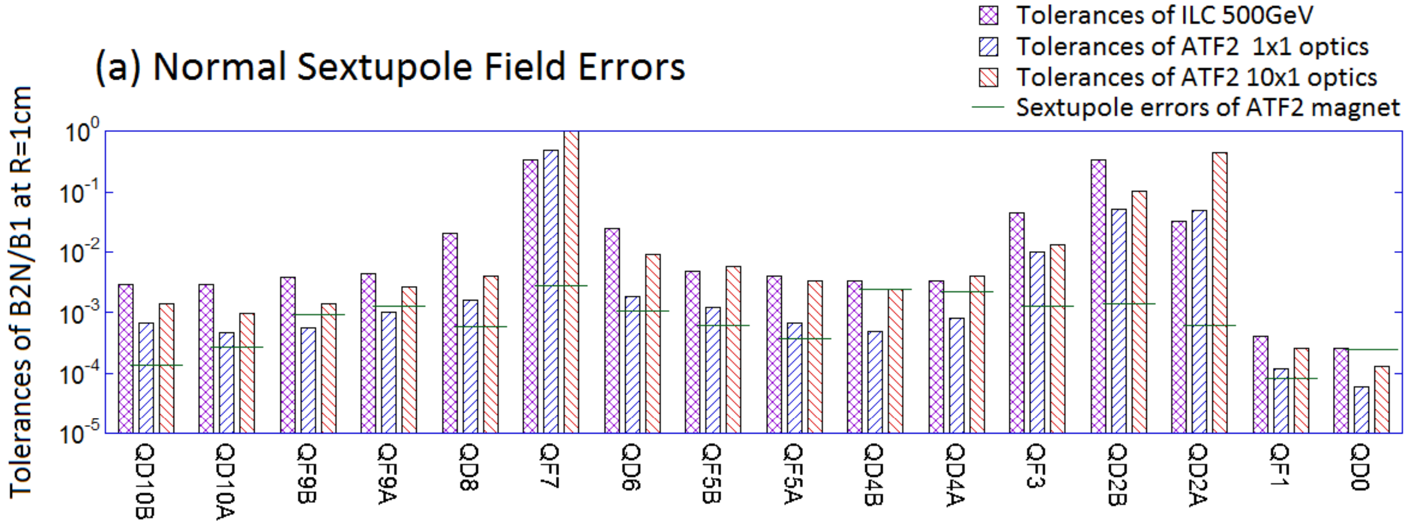
*The effect of ILC higher order multipole field is comparable to ATF2 10x1 optics.*

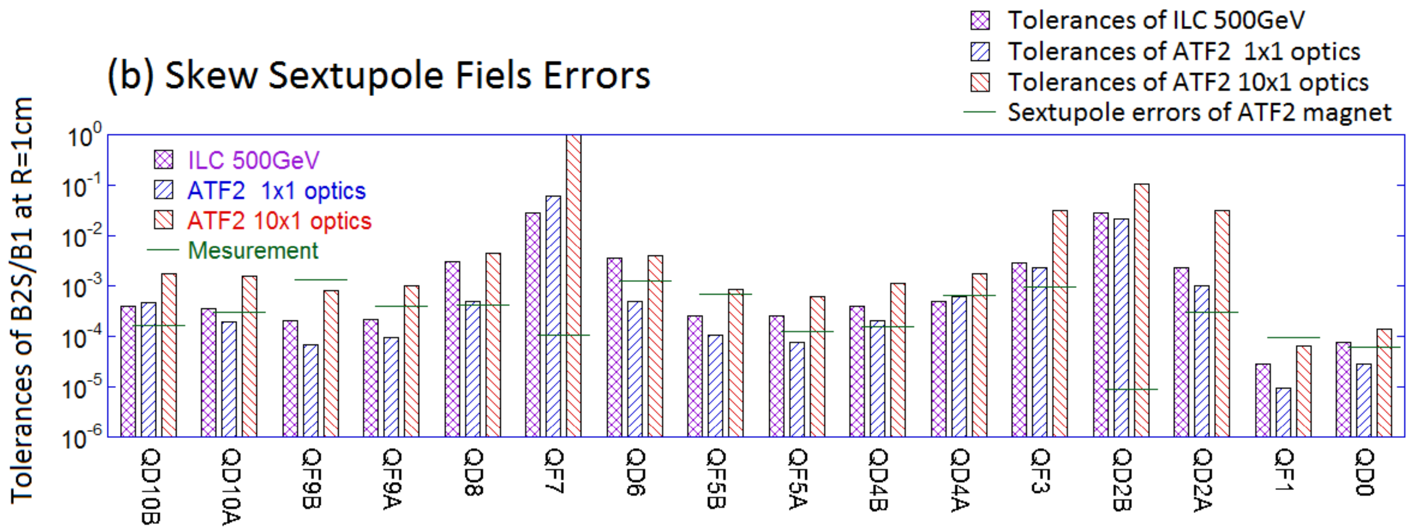
# *Comparison the multipole Errors of ILC and ATF2*

***Purple ; ILC TDR***
***Blue ; ATF2 1x1 optics***
***Red ; ATF2 10x1 optics***

## *1. Tolerance of the Sextupole Field Errors*

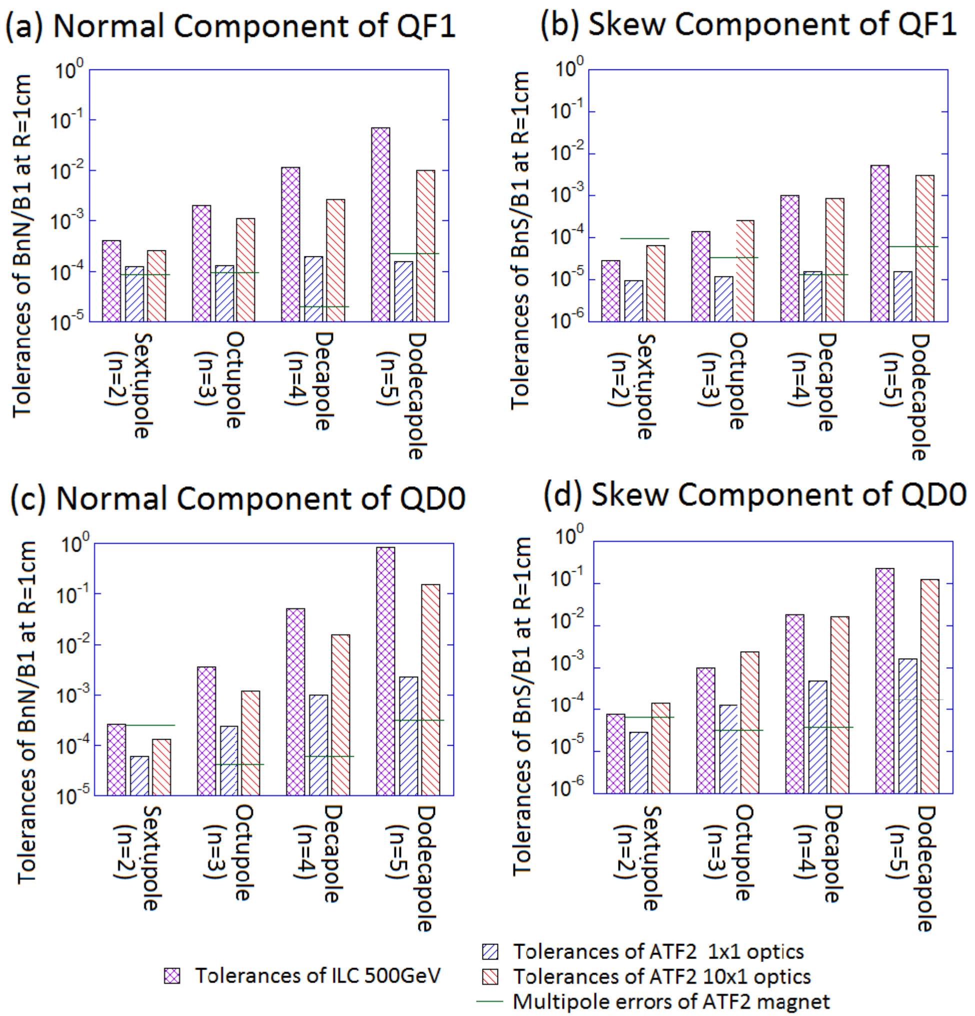
*after 2nd order optics correction*




*The tolerance are comparable to ATF2 10x1 optics and ILC final focus system.*

# 2. Tolerance of the Multipole Field Errors of Final Doublet




***Purple*** ***; ILC TDR***
***Blue*** ***; ATF2 1x1 optics***
***Red*** ***; ATF2 10x1 optics***

*The tolerance are comparable to ATF2 10x1 optics and ILC final focus system.*

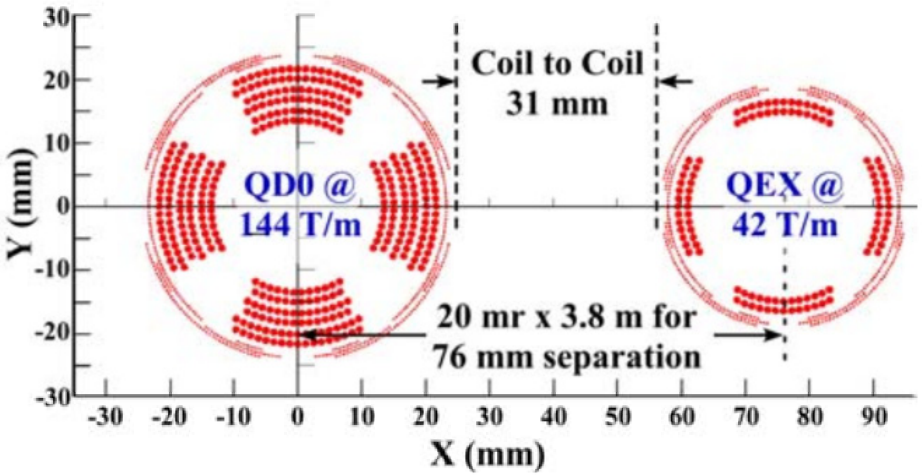
*Since the difference of the bore diameter for ATF2 QF1 and ILC QF1, the fabrication of the ILC QF1 is much difficult to ATF2 QF1.*

# Final Focus Magnet

*Since the bore diameters of ATF2 final doublet are much larger than ILC,*
*the fabrications of ILC final doublet are much difficult to ATF2 final doublet.*

*The FD magnets were investigated*

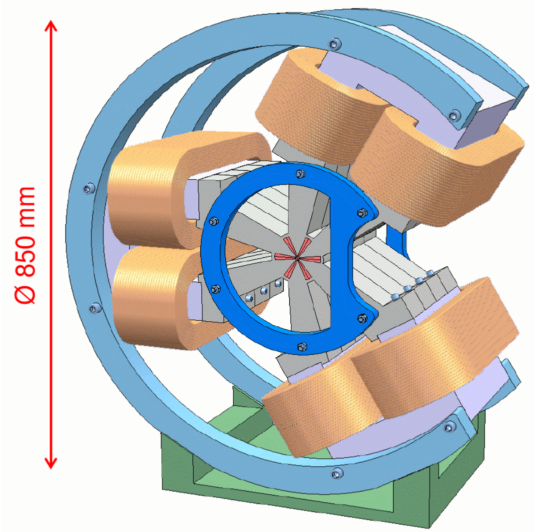
*Superconducting Magnet (BNL)*




*Compact(ϕ50mm)*

*No so stable ( < 50nm )*

*Hybrid Magnet (CERN for CLIC)*

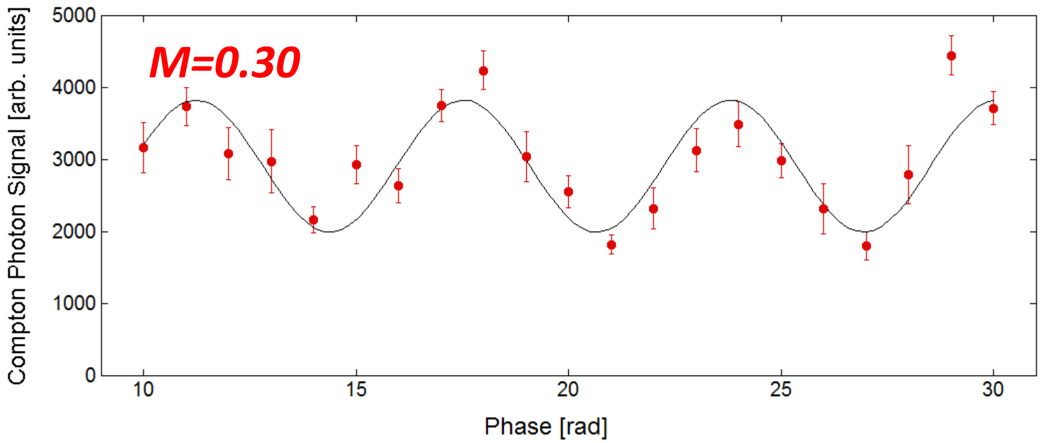



*Not so small (ϕ850mm)*

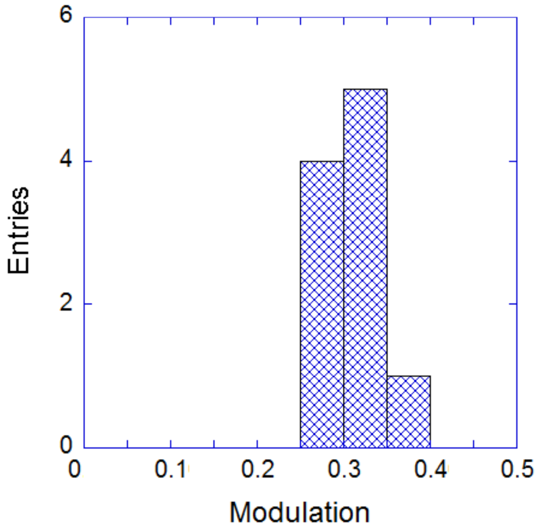
*Small Vibration ( <1nm )*

# IP beam size are measured with IP-BSM (Shintake Monitor)

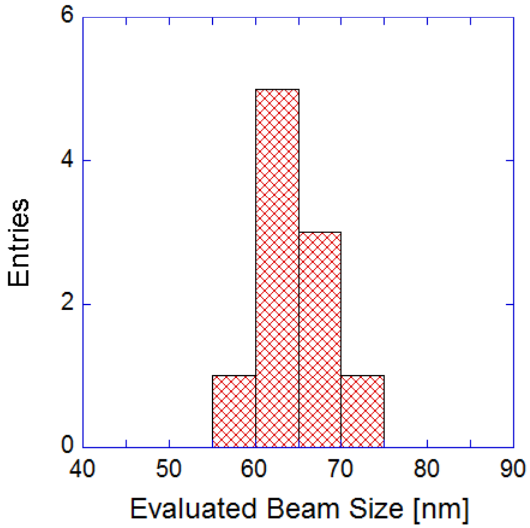
*Example of the typical measured modulation by IP-BSM.*




*Modulation depths of measurement on 03/08/2013*




*Evaluated IP beam size of measurement on 03/08/2013*




*by assuming to be C=1.0*
*( No systematics for IP-BSM)*

*No beam jitter subtraction*

# *Present status of ATF2 vertical beam focusing*

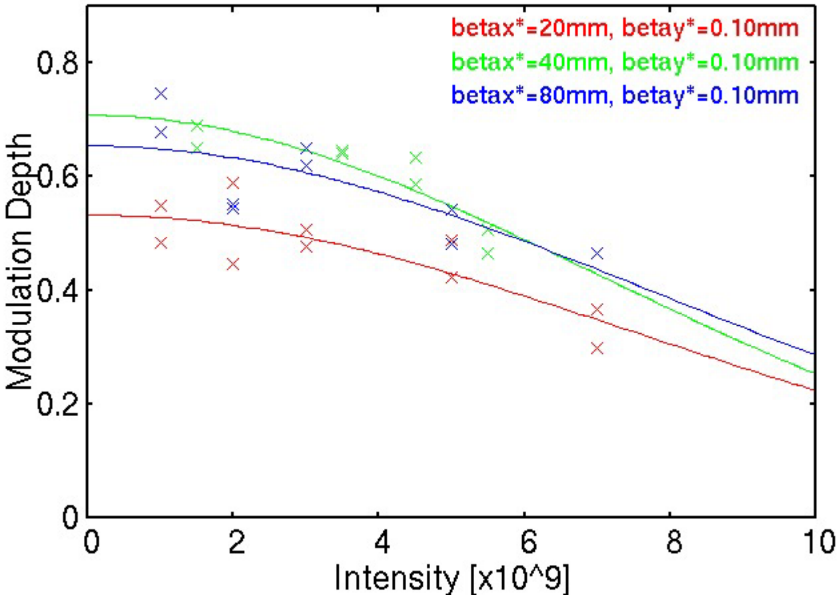
| | ILC - 500GeV | | ATF2 | | |
|---|---|---|---|---|---|
| | RDR | TDR | 10 × 1 optics | | 1 × 1 optics |
| | Design | Design | Design | Achieved | Design |
| Beam Energy | 250 GeV | | 1.28 GeV | | |
| L* | 3.50m | | 1.00 m | | |
| εx[nm] × εy[pm] | 0.02 × 0.07 | | 2.0 × 12 | | |
| σp/p | 0.12% | 0.12% | 0.10% | 0.06% | 0.10 % |
| βx*[mm] × βy*[mm] | 21 × 0.40 | 11 × 0.48 | 40 × 0.10 | | 4 × 0.10 |
| σy* [nm] | 5.3 | 5.9 | 37 | < 65 | 37 |
| L*/βy* | 8750 | 7292 | 10000 | | 10000 |
| L*/βy* × σp/p | 10.5 | 8.75 | 10.0 | 6.0 | 10.0 |

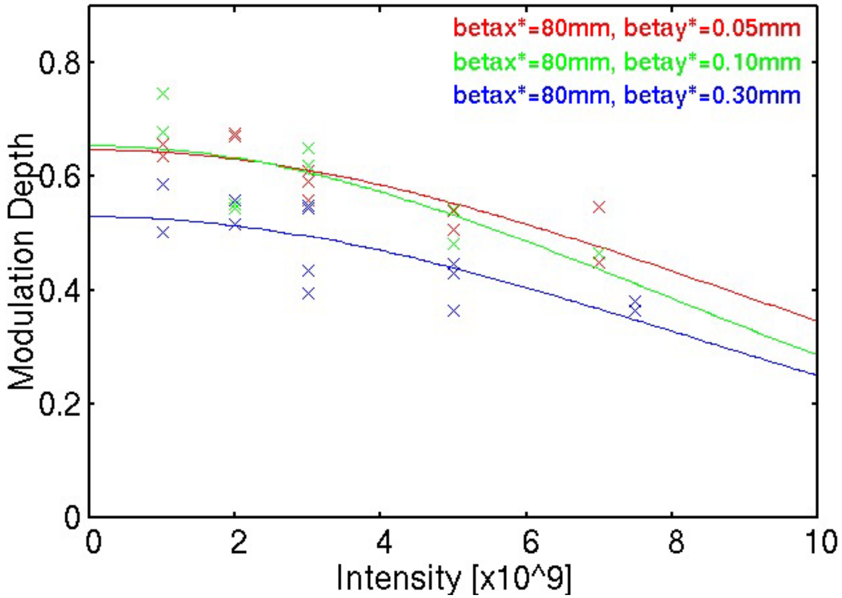
*Strength of chromatic aberration*

- The difficulty of 10x1 optics is comparable to that of ILC.
- ATF2 achieved to focus the beam to less than 65nm by using with the local chromaticity correction scheme

# *Intensity Dependence*

Intensity Dependence measured with IP-BSM 30 degree mode.

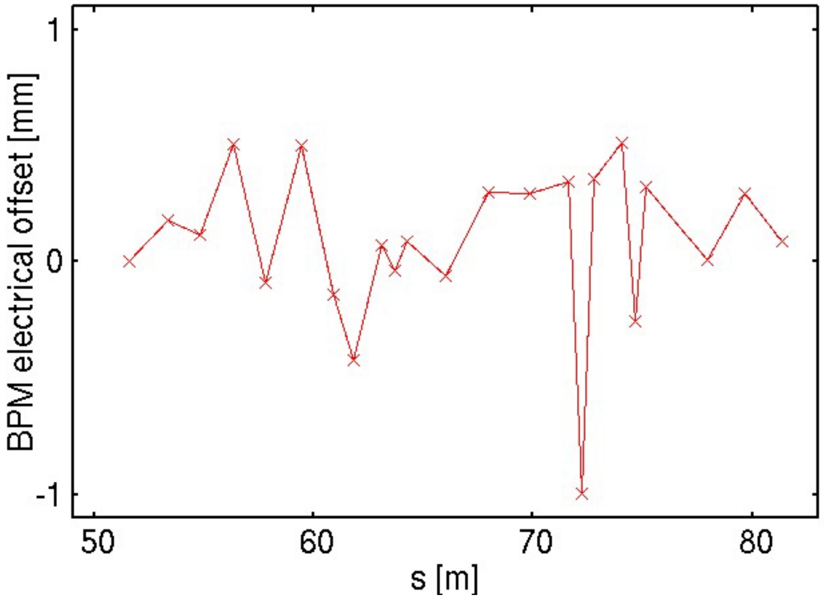


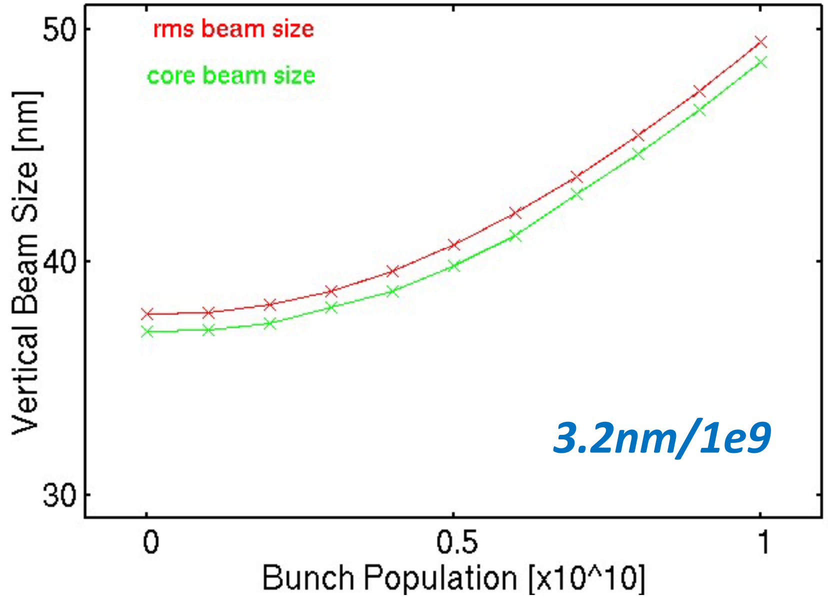

| betax* | betay* | Beam Size Growth |
|---|---|---|
| 20mm | 0.10mm | 21.6nm/1e9 |
| 40mm | 0.10mm | 23.5nm/1e9 |
| 80mm | 0.10mm | 21.0nm/1e9 |
| 80mm | 0.05mm | 18.3nm/1e9 |
| 80mm | 0.30mm | 20.0nm/1e9 |

# *Expected beam size growth from the cavity*

*Beam orbit with respect to electrical center of C-band BPMs*




Expected IP vertical beam size growth For V=-0.16V/pC/mm




| betax* | betay* | Beam Size Growth |
|---|---|---|
| 20mm | 0.10mm | 21.6nm/1e9 |
| 40mm | 0.10mm | 23.5nm/1e9 |
| 80mm | 0.10mm | 21.0nm/1e9 |
| 80mm | 0.05mm | 18.3nm/1e9 |
| 80mm | 0.30mm | 20.0nm/1e9 |

*We have not yet understand the reason of the large intensity dependence.*

# Head-tail position offset

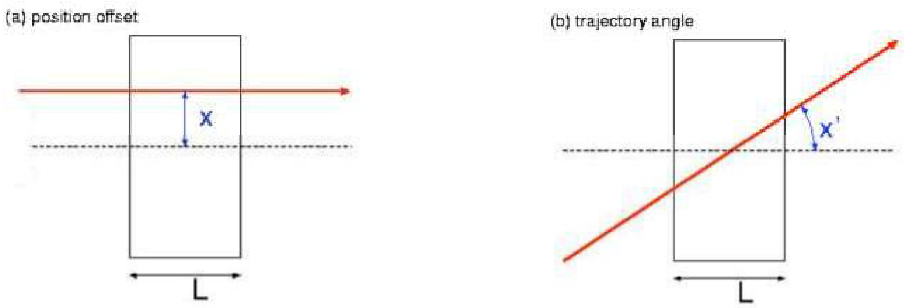
*In the domestic ILC review, T.Shintake pointed out the possibility of head-tail position offset.*

*He also recommended to check the effect by the IP-BPM pickup signal.*

*Therefore, I roughly evaluated the possibility of the head-tail position offset  with IP-BPM.*

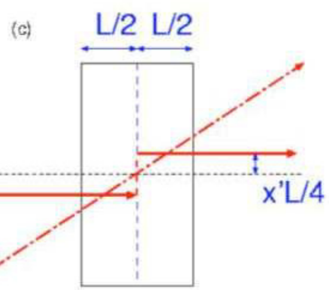
## *Effect of the beam angle to IP-BPM pickup signal.*

*evaluated by Y.Honda*




$$\text{position signal} = Ax\sqrt{L}\,\underline{\underline{\sin(\omega t)}}$$

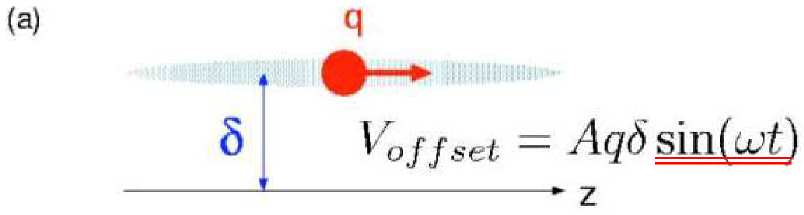
$$\begin{aligned}\text{angle signal} &= Ax'\frac{L}{4}\sqrt{\frac{L}{2}}\sin(\omega(t+L/4c)) \\ &\quad -Ax'\frac{L}{4}\sqrt{\frac{L}{2}}\sin(\omega(t-L/4c)) \\ &= Ax'\frac{L}{2}\sqrt{\frac{L}{2}}\sin\left(\frac{\omega L}{4c}\right)\underline{\underline{\cos(\omega t)}}\end{aligned}$$



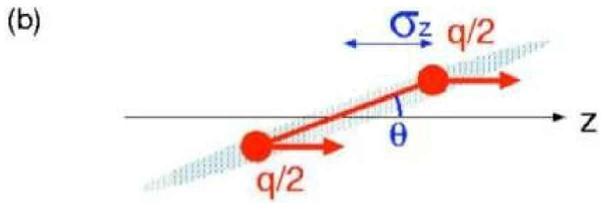

Phase of angle signal is shifted
by 90degrees from position signal

# *Effect of the bunch tilt to IP-BPM pickup signal*

*evaluated by Y.Honda*




$$V_{offset} = Aq\delta \sin(\omega t)$$




$$V_{+} = A\frac{q}{2}\frac{\theta\sigma_z}{2}\sin(\omega(t+\sigma_z/c))$$

$$V_{-} = -A\frac{q}{2}\frac{\theta\sigma_z}{2}\sin(\omega(t-\sigma_z/c))$$

Phase of angle signal is shifted
by 90degrees from that of bunch tilt.

The sensitivity of the bunch tilt
is proportional to $\sigma_z^2$ .

$$\begin{aligned} V_{tilt} &= V_{+} + V_{-} \\ &= \frac{Aq\theta\sigma_z}{2}\sin\left(\frac{\omega\sigma_z}{c}\right)\cos\omega t \\ &\approx \frac{Aq\theta\omega\sigma_z^2}{2c}\cos\omega t \end{aligned}$$

***Comparison of the effect of beam angle jitter and bunch tilt***

$$\frac{V_{tilt}}{V_{angle}} \simeq \frac{4\sqrt{2}\,\sigma_z \Delta y}{y' L^2}$$

$$If\ \ \Delta y = \sigma_y,\ y' = 0.1\,\sigma_{y'}$$

$$\frac{V_{tilt}}{V_{angle}} \simeq \frac{40\sqrt{2}\,\sigma_z \beta_y^*}{L^2} = \frac{40\sqrt{2}\ \times 0.01 \times 0.0001}{(0.006)^2} = 1.57$$

*The 10% of angle jitter and*
*1 sigma of the head-tail position offset*
*are comparable at ATF2 IP.*

# *Horizontal IP beam size issue of ATF2*

## *Horizontal IP Parameters for ILC and ATF2*

| | ILC - 500GeV | | ATF2 | |
|---|---|---|---|---|
| | RDR | TDR | 10x1 optics | 1x1 optics |
| Beam Energy | 250 GeV | | 1.28 GeV | |
| L* | 3.50m | | 1.00 m | |
| σp/p | 0.12% | | 0.10% | |
| εx | 0.02nm | | 2.0nm | |
| βx* | 21mm | 11mm | 40mm | 4mm |
| σx* | 0.65um | 0.47um | 8.9um | 2.8um |
| L*/βx* | 167 | 318 | 25 | 250 |
| L*/βx* × σp/p | 0.20 | 0.38 | 0.025 | 0.25 |

*Strength of chromatic aberration*

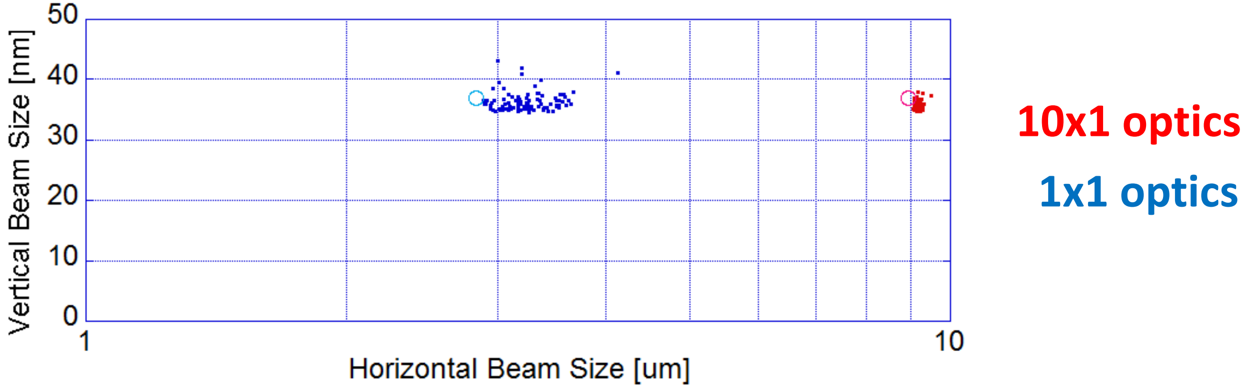
The horizontal chromaticity for ATF2 10x1 optics is much smaller than ILC.

# Results of Beam Tuning Simulation

## Errors for the tuning simulation

| | | | |
|---|---|---|---|
| Quadrupole Sextupole | Misalignment | Δ $x$ | 100 µm (Gaussian) |
| | | Δ $y$ | 100 µm (Gaussian) |
| | | Δ $\theta$ | 200 µrad (Gaussian) |
| | Strength Error | Δ $K$ | 0.1% (Gaussian) |
| Bend | Misalignment | Δ $\theta$ | 200 µrad (Gaussian) |
| | Strength Error | Δ $K$ | 0.1% (Gaussian) |
| BBA Accuracy | | | ±100 µm (uniform) |
| IP-BSM Accuracies | 2-8 degree mode | | ±100 nm (uniform) |
| | 30 degree mode | | ±20 nm (uniform) |
| | 174 degree mode | | ±8 nm (uniform) |
| Wire Scanner Accuracy | | | ±800 nm (uniform) |

## Result of IP beam tuning simulation ( core beam size )




*Expected IP horizontal beam size growth for 1x1 optics (20%) was larger than 10x1 optics(3%).*

| | $\beta_x^*$ | $\beta_y^*$ | | $\sigma_x^*$ [μm] | | $\sigma_y^*$ [nm] | |
|---|---|---|---|---|---|---|---|
| | | | | r.m.s. | core | r.m.s. | core |
| Original (1×1 optics) | 4 mm | 0.1 mm | Design | 2.83 ( linear optics ) | | 34.6 ( linear optics ) | |
| | | | Linear | $4.17 \pm 0.32$ | $3.50 \pm 0.26$ | $86.9 \pm 13.2$ | $72.2 \pm 10.1$ |
| | | | Linear+2nd order | $4.07 \pm 0.31$ | $3.43 \pm 0.22$ | $44.3 \pm 2.5$ | $37.9 \pm 1.8$ |
| Present (10×1 optics) | 40 mm | 0.1 mm | Design | 8.94 ( linear optics ) | | 34.6 ( linear optics ) | |
| | | | Linear | $9.24 \pm 0.07$ | $9.16 \pm 0.07$ | $47.1 \pm 2.5$ | $43.5 \pm 1.6$ |
| | | | Linear+2nd order | $9.24 \pm 0.07$ | $9.16 \pm 0.06$ | $36.5 \pm 0.9$ | $36.0 \pm 0.9$ |

*The large tail was expected for 1x1 optics.*

*Since the IP horizontal IP beam size affects to the luminosity for ILC, it is important the IP horizontal beam size tuning, too.*

*The IP horizontal beam size tuning for ATF2 10x1 optics is much easier than ATF2 1x1 optics and ILC.*

By the way,

*We should investigate whether the tail folding octupoles (CERN proposed) help to reduce the beam tail ?*

# *Summary*

*Now, we operate the ATF2 with 10x1 optics at N=1e9.*
*- 10x1 optics ---- reduce the effect of the multipole field error*
*- N = 1e9 ---- strong intensity dependence of IP beam size*

***Study with 10x1 optics***

*The difficulty of the vertical beam size tuning at ILC IP is comparable to ATF2 10x1 optics.*

*0-1. Improvement of IP-BSM stability*
*0-2. IP-BSM should be available to the ATF2 online monitor.*
*1-1. IP beam size tuning with $2^{nd}$ order knob ( IP-BSM should be stable )*
*1-2. Jitter subtraction at IP ( IP-BPM requirement 10-20nm resolution with +/-100um dynamic range)*
*1-3 Study of the head-tail offset at IP*

***Study with 1x1 optics***

*The difficulty of the horizontal beam size tuning at ILC IP is comparable to ATF2 1x1 optics.*
*But, the difficulty of the vertical beam size tuning for ATF2 10x1 optics is much difficult to ILC .*

*Furthermore, the large beam tail s are expected for ATF2 1x1 optics.*

*1. Octupoles will help the tail folding ?? (* E. Marin will be proposed at TB&SGC meeting on 2/13 )

***Study of the intensity dependence***

*High intensity IP tuning is not only important to investigate of the source of the intensity dependence, but also important to improve the resolution of IP-BPM (important to ATF2 phase 2 study).*

*1. Shielding the vacuum pumping port.*
*2. Wakefield free steering* ( Y.Kim and J. Snuverink will be proposed at TB&SGC meeting on 2/13 )

***Shall we discuss the schedule of the Goal-1 study at the discussion session ( 2/13 morning ).***

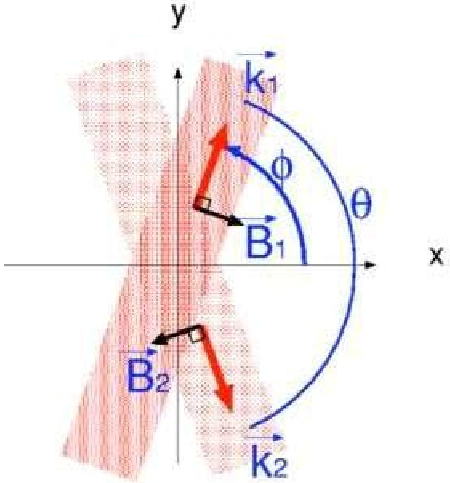
***Backup***

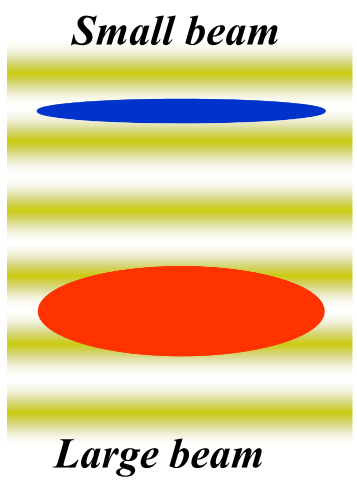
# *IP Beam Size Monitor ( Shintake Monitor )*

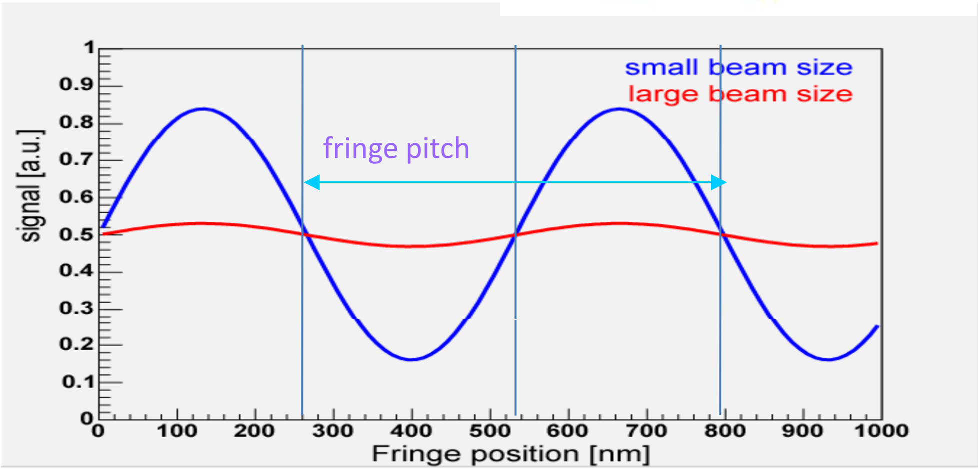
Laser is split into 2 paths.

The both laser paths are collided at IP.

The interference pattern is generated at IP.




Modulation

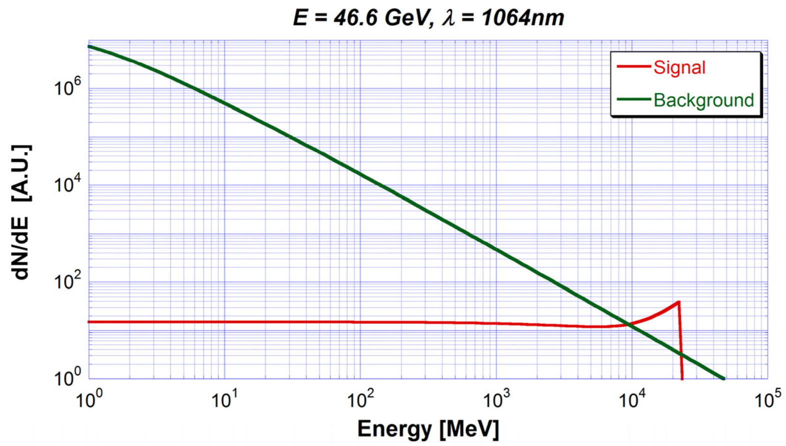
$$M = \frac{N_{max} - N_{min}}{N_{max} + N_{min}}$$

# *S/N ratio of IP-BSM*

***FFTB***

46.6GeV

λ = 1064nm




Maximum Compton Energy

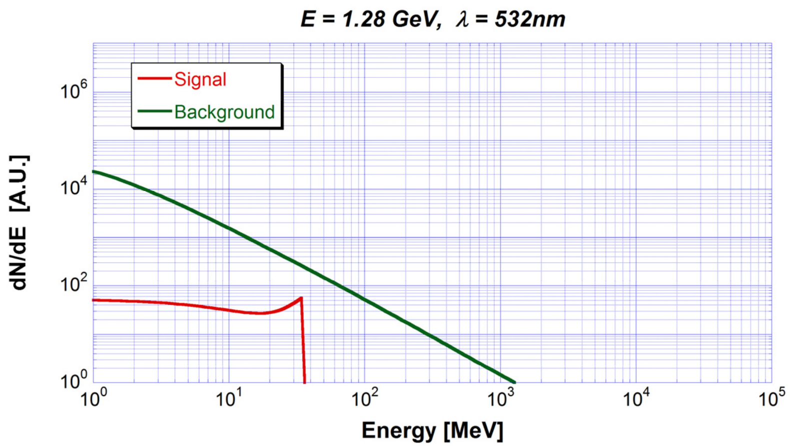
$$E_{max} = 2\gamma^2 E_l$$

Low energy background is larger than high energy BG.

***ATF2***

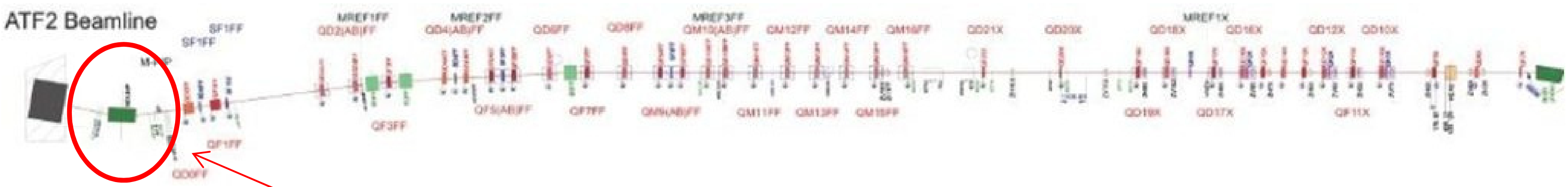
1.28 GeV

λ = 532nm

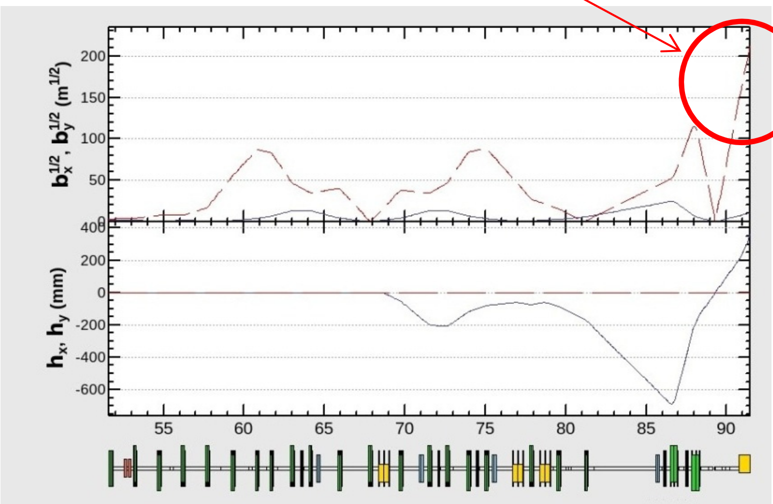



It is difficult to distinguish Compton signal and Background for the small beam energy in ATF.

# *Collimator at Dump Bend*

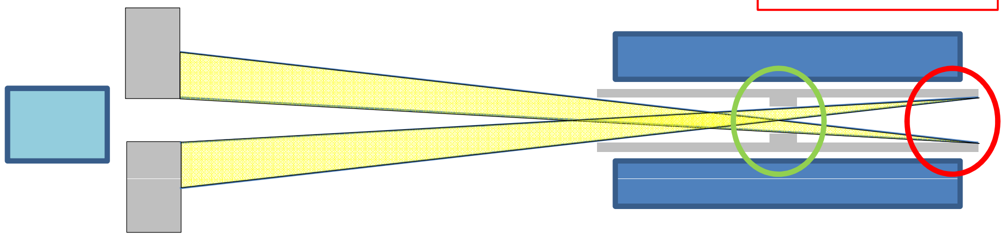



**BG source**




Since vertical aperture of dump bend was large BG source,

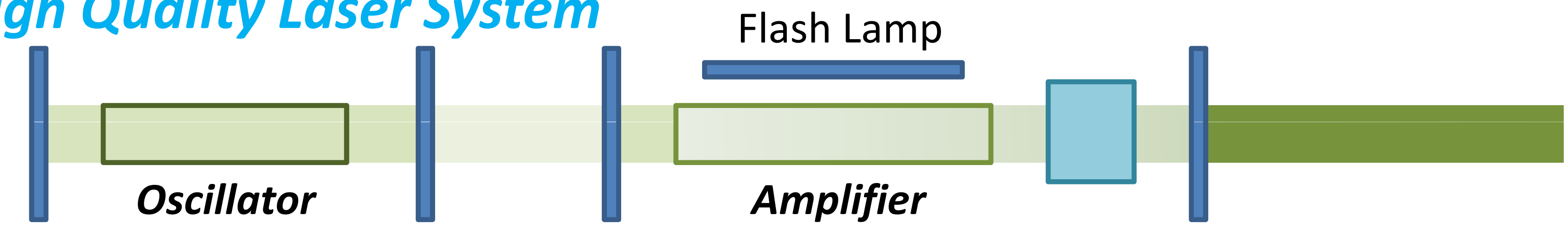
**BG source**



We put the collimator in the bend chamber.

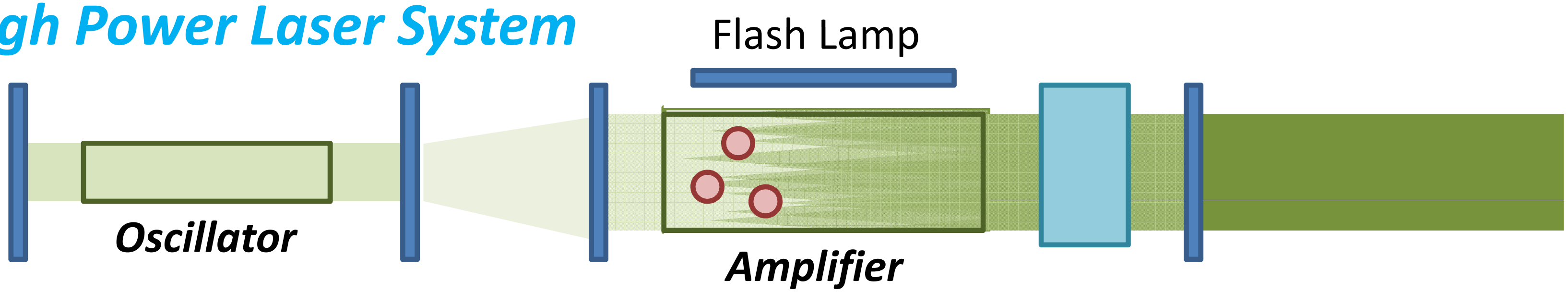
# Present Problems of ATF2 IP-BSM laser

## 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 ?? ).

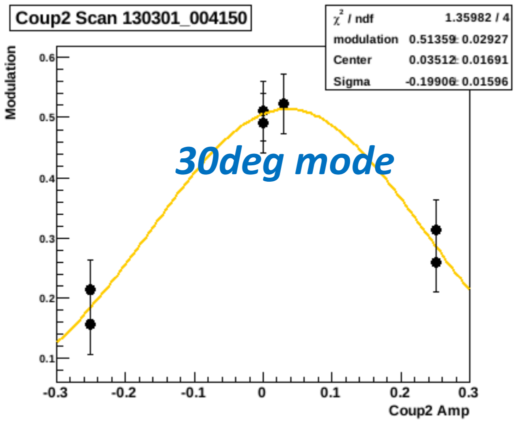
**2013 March (next week);** Maximum modulation was increased to above 85%.

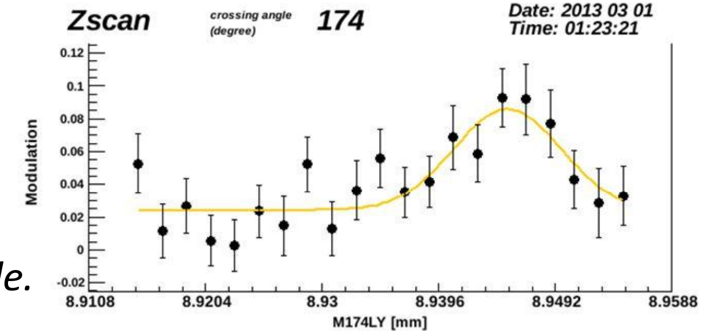
- The laser expert tune the laser profile.

*The spatial coherency strongly depends on the laser profile.*

## *The week of 2/25 – 3/01*

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



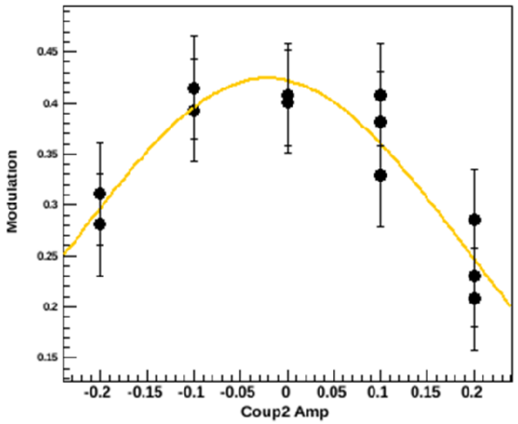

*We could find the IP-BSM modulation of 174 deg mode.*

*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)*

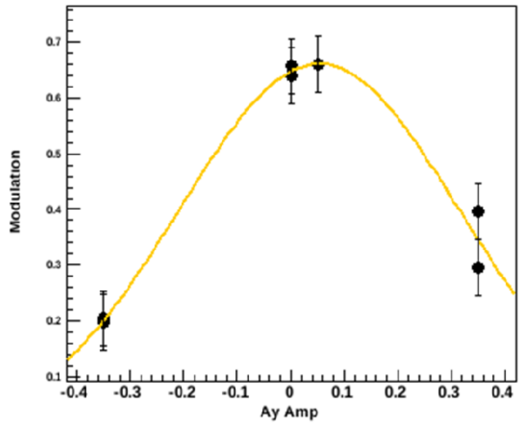



*Max modulation ; 42%*

*Laser profile tuning by laser expert.*

*Maximum modulation was increased.*

*30deg mode (3/7)*

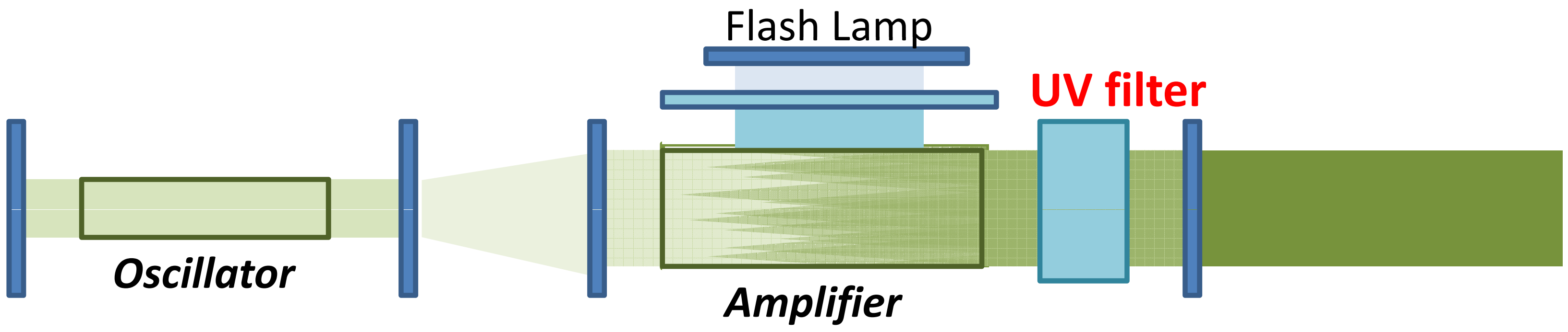



*Max modulation ; 66%*

# Profiling the IP-BSM Laser

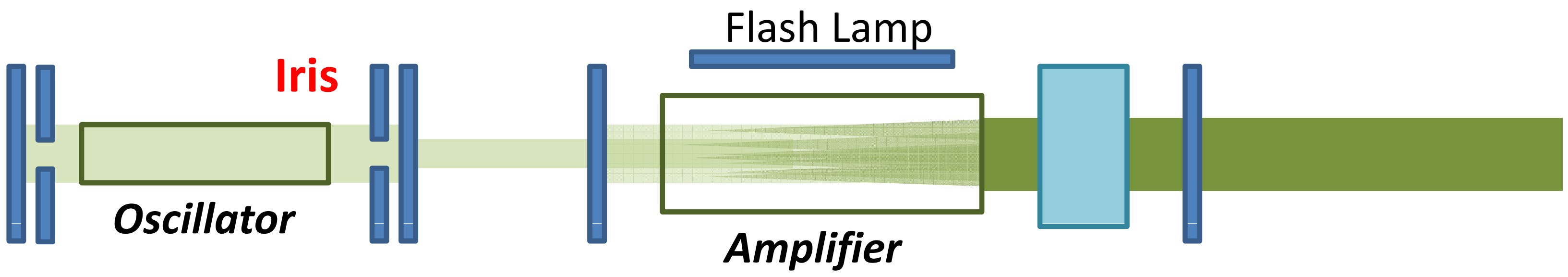
**1) Put UV filter in between flash lamp and YAG crystal.**

*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 so much.*