Small Beam Issues

- Nonlinear field

- Energy bandwidth

Toshiyuki OKUGI, KEK

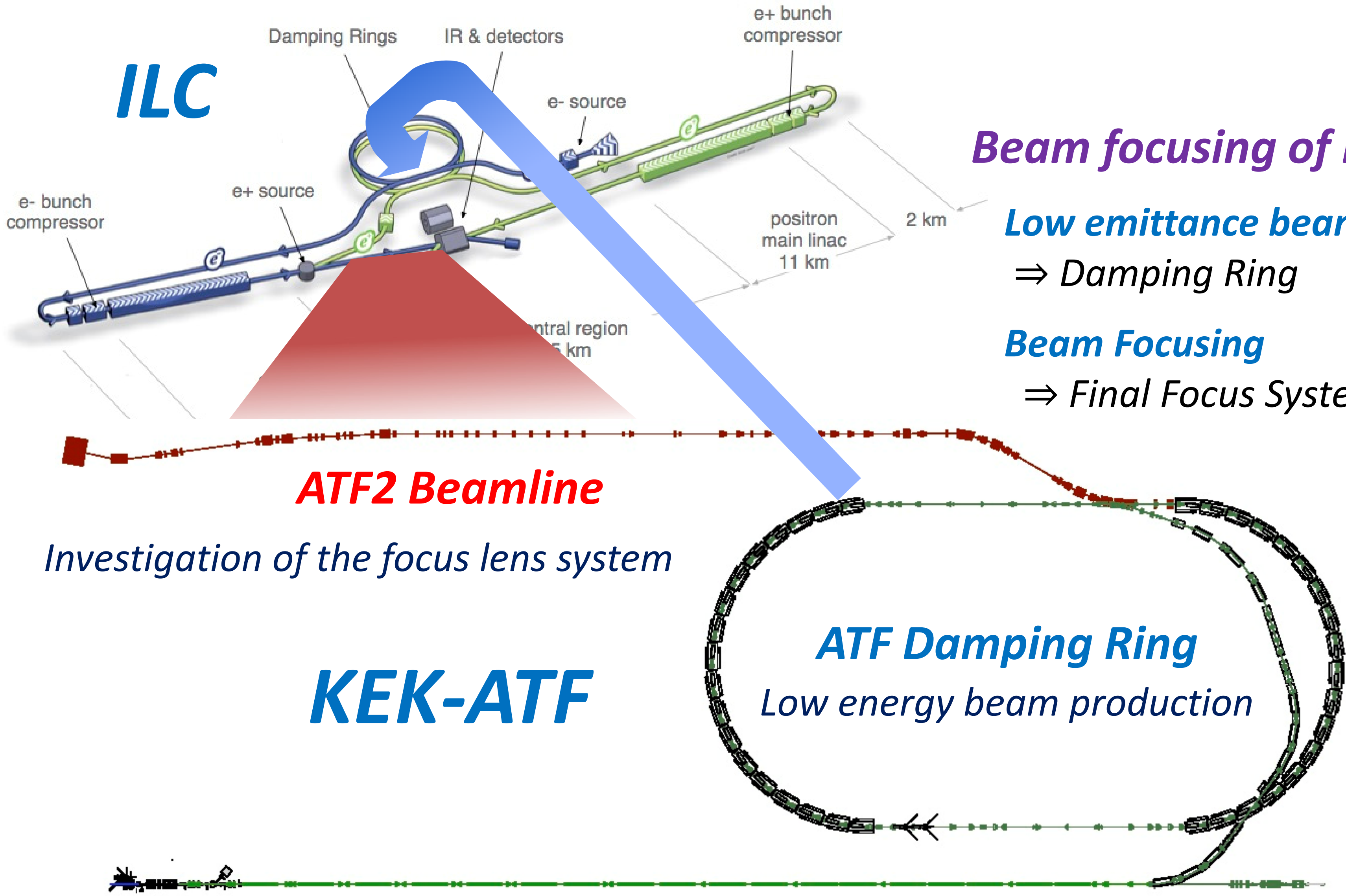
2017/ 03/ 15

The 20th ATF2 project meeting

ATF2 Project

Final focus test with ATF low emittance beam.

ATF2 project was proposed at 1st LCWS (2004 November).



Investigation of the focus lens system

Beam focusing of ILC

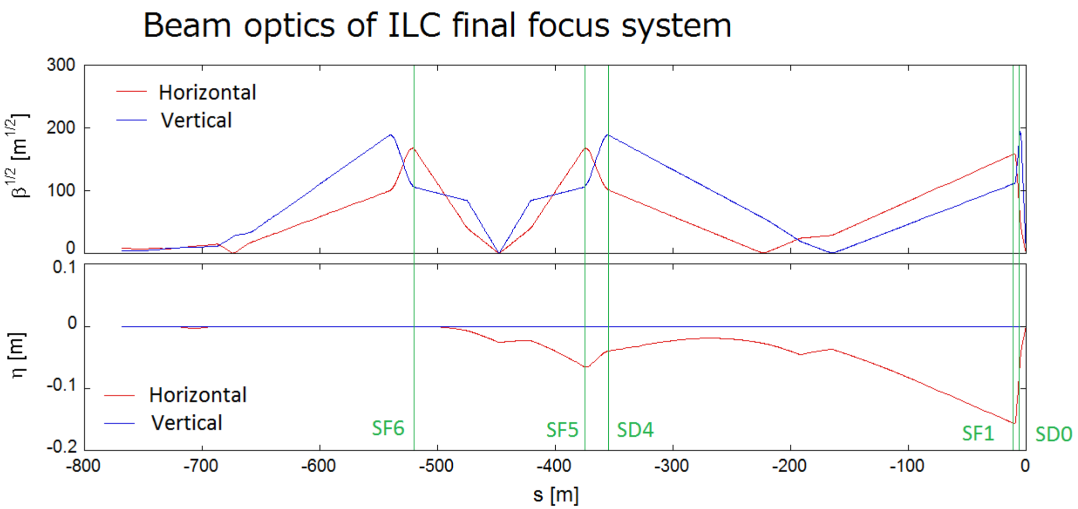
Low emittance beam

⇒ *Damping Ring*

Beam Focusing

⇒ *Final Focus System*

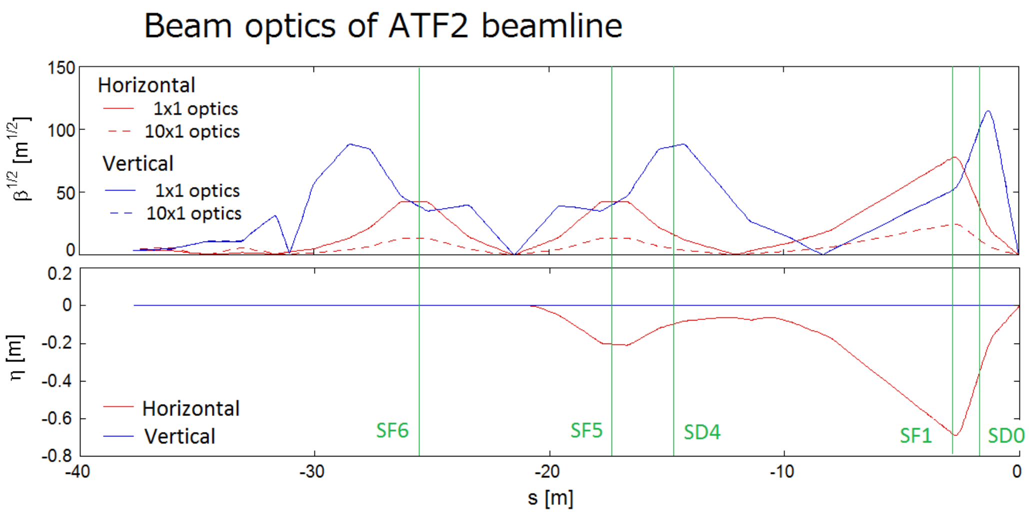
Beam Optics of ILC & ATF2



ILC final Focus System

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

- Same magnet arrangement



ATF2 Beam Optics

1x1 optics

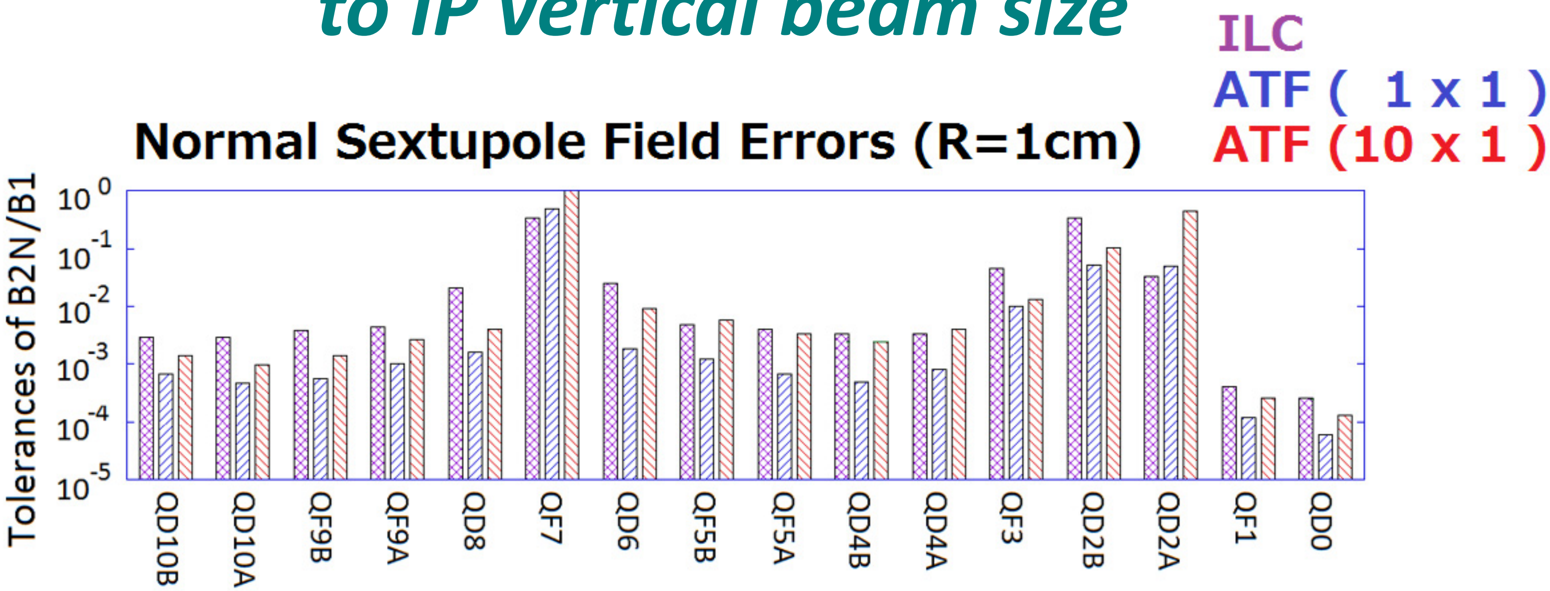
X&Y chromaticities are comparable to ILC FF.

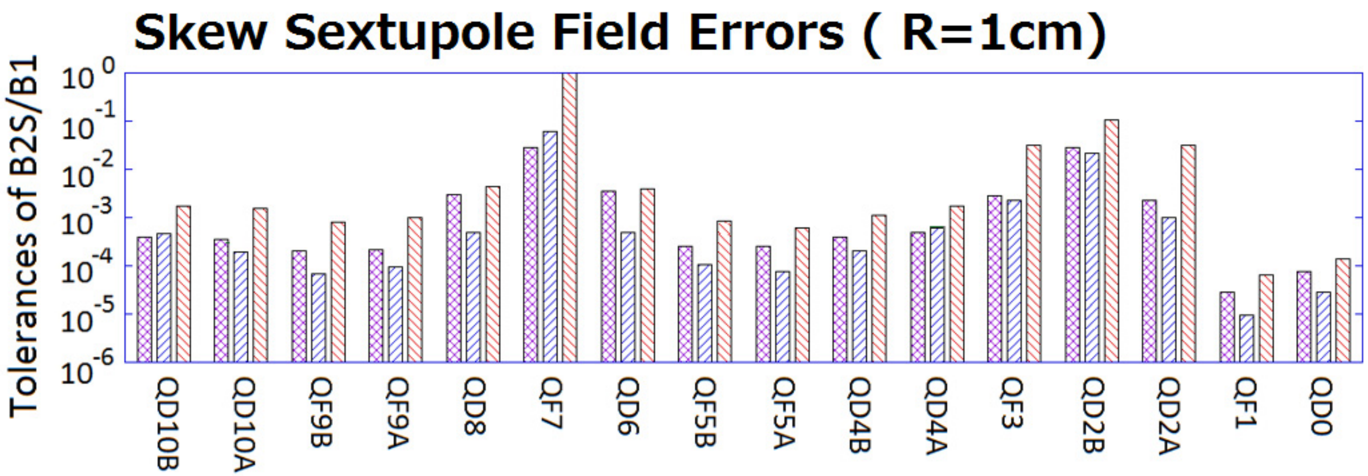
10x1 optics

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

Same concept of beamline design to ILC !

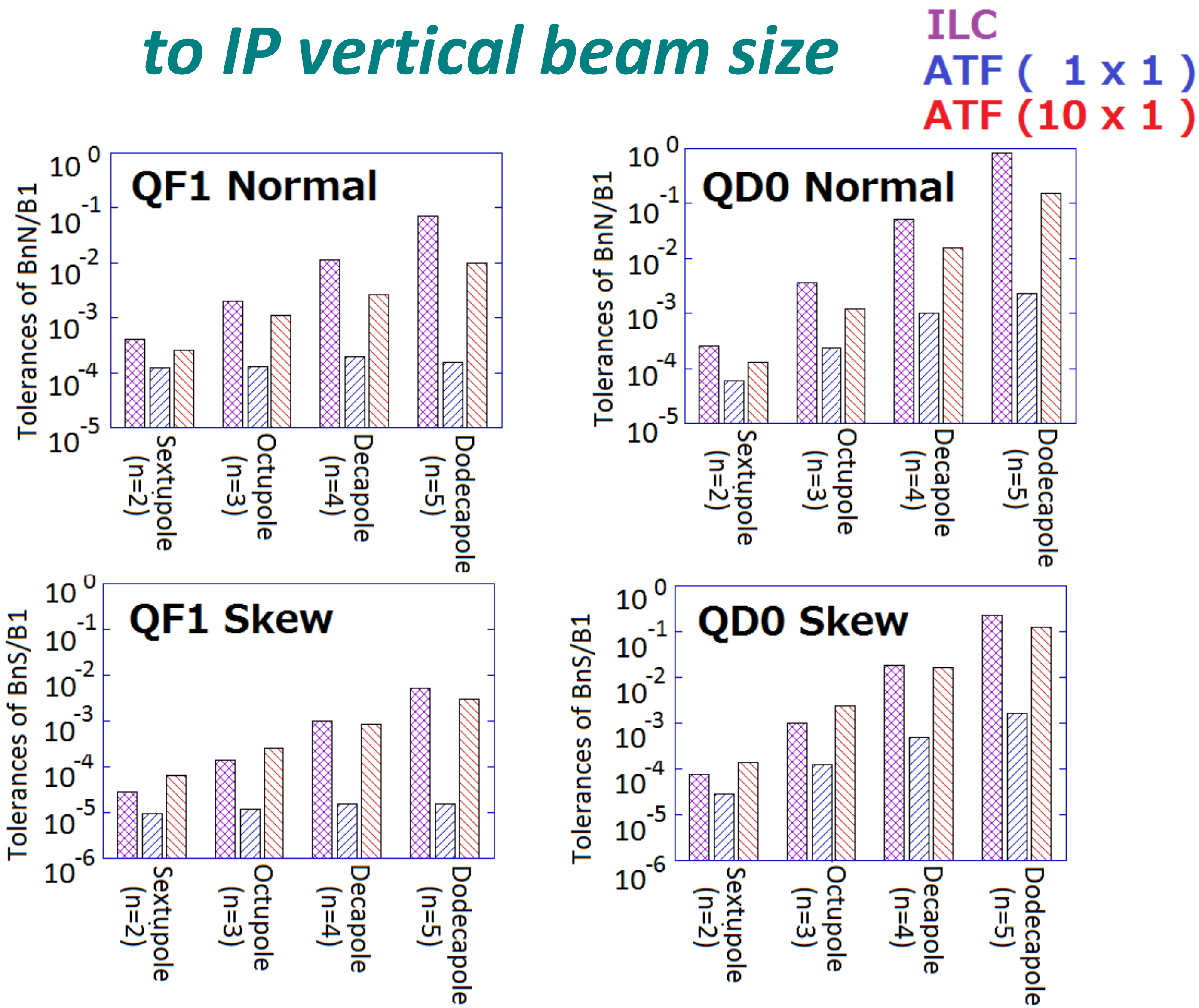
Tolerances of sextupole field error to IP vertical beam size





The tolerances of sextupole errors for ATF2 10x1 optics is comparable to ILC.

Tolerances of FD multipole field error to IP vertical beam size



The tolerances of FD multipole errors for ATF2 10x1 optics is comparable to ILC.

Small IP beam size tuning of ATF2

2^{nd} order optics correction at ILC & ATF2

	Horizontal beam size		Vertical beam size	
	Geometrical Aberration	Chromaticity	Geometrical Aberration	Chromaticity
Normal Sextupole	T122	T126	T324	T346
	T144	T166 2^{nd} order Dispersion		
Skew Sextupole	T124	T146	T322 T366	T326 T344

Ignored (T144, T124, T146)

Sextupole magnets are used for chromaticity correction.
But, the sextupoles generate other 2^{nd} order aberrations.

We use 5 sextupoles to correct 5 aberrations.

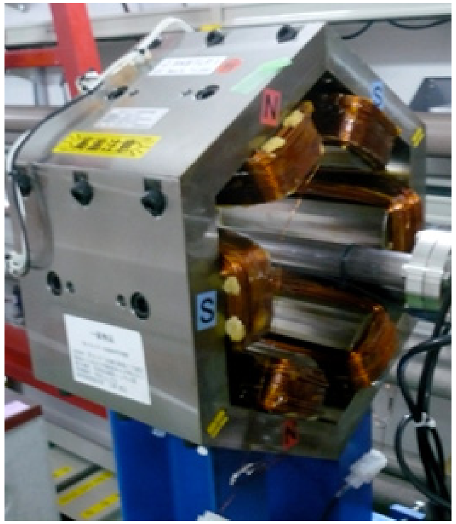
The aberrations are generated by the multipole errors of quad.

We use 4 skew sextupoles to correct 4 vertical aberrations.

T. Okugi et al., Physical Review Special Topics - Accelerators and Beams ***17****(2014) 023501.*

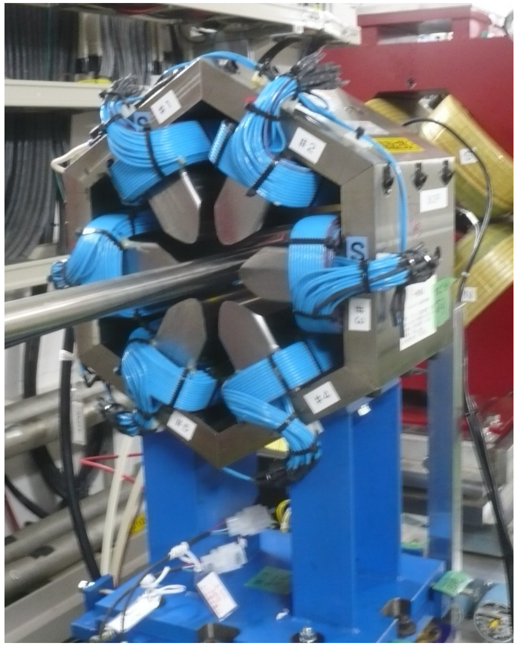
Skew sextupole magnets for 2nd order correction

Borrowed from KEKB



Modified in 2016 January

160mmϕ ⇒ 60mmϕ

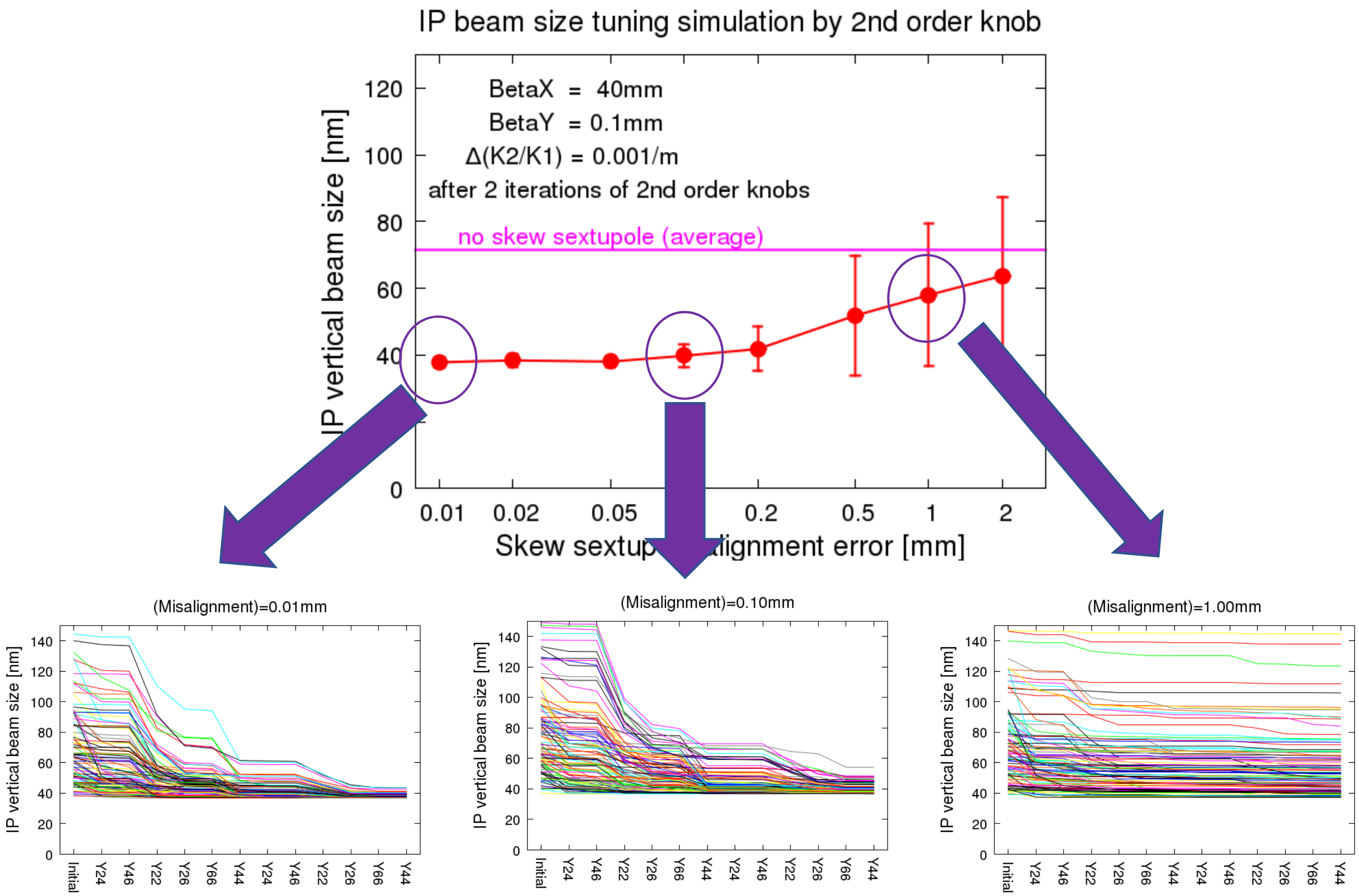


Too weak for knob optimization

Enough strength for knob optimization

Initial alignment for skew sextupole magnets

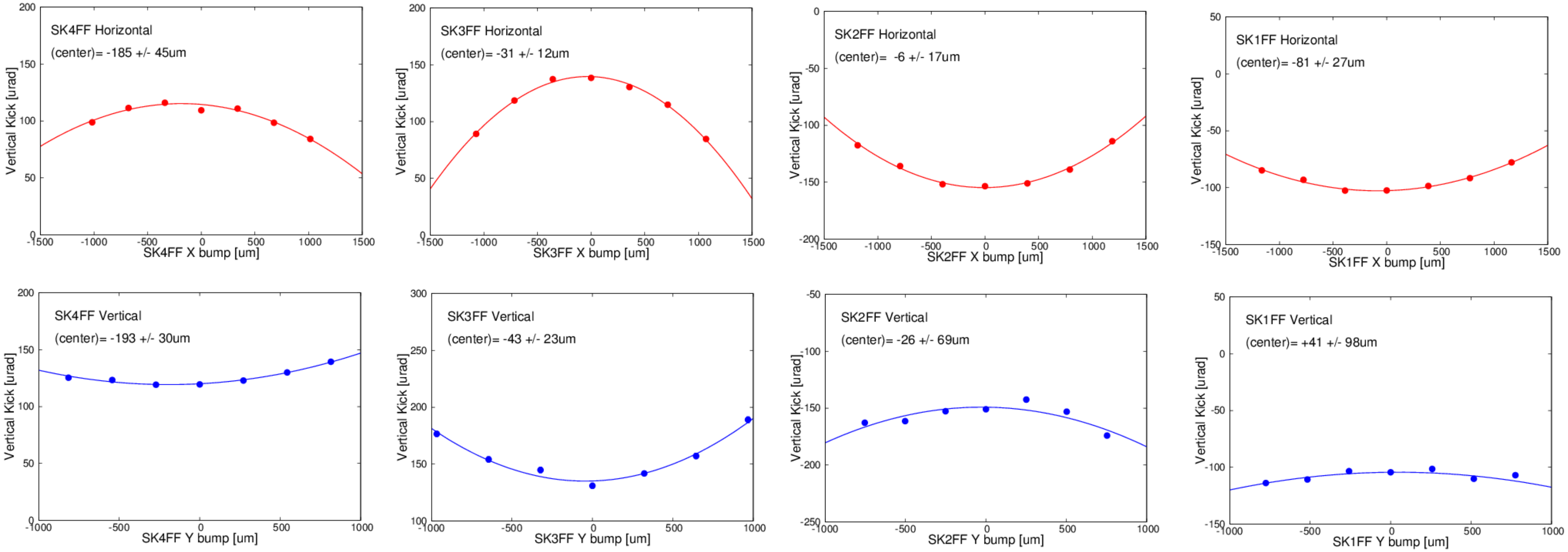
Beam tuning simulation to evaluate the requirement of initial alignment of skew sextupoles.



In order to apply the 2nd order knob effectively,
we must align the magnets within 100um.

Beam based alignment of skew sextupoles

Since the magnets don't have movers,
we did the mechanical position alignment of FF skew magnet
by using the offset information of beam measurement.



	SK4FF		SK3FF		SK2FF		SK1FF	
	X [um]	Y [um]	X [um]	Y [um]	X [um]	Y [um]	X [um]	Y [um]
2016/01/28	+527	+69	-94	-762	-12	-138	-137	+282
2016/02/03	-185	-193	-31	-43	-6	-26	-81	+41

Good training for ILC FF bam size tuning.

ATF2 beam tuning procedures of IP beam size

FF sextupoles turned OFF

- *Orbit tuning*
- *QF1FF strength optimization (Carbon wire; Horizontal beam size)*
- *QD0FF strength optimization (Carbon wire; Vertical beam size)*
- *QD0FF rotation optimization (Carbon wire; Coupling)*
- *FF normal and sextupole BBA (Magnetic center)*

FF sextupoles turned ON

Carbon Wire
- *AY knob*
- *EY knob*
- *Coup2 knob*

→

IP-BSM 8degree
- *AY knob*
- *EY knob*
- *Coup2 knob*

→

IP-BSM 30degree
- *AY knob*
- *EY knob*
- *Coup2 knob*
- *Y24 knob*
- *Y46 knob*

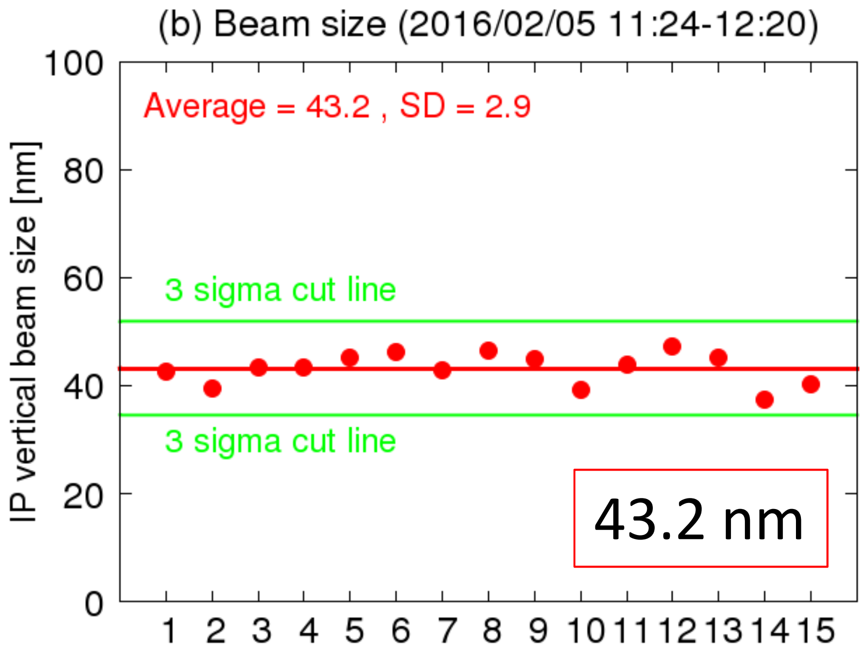
→

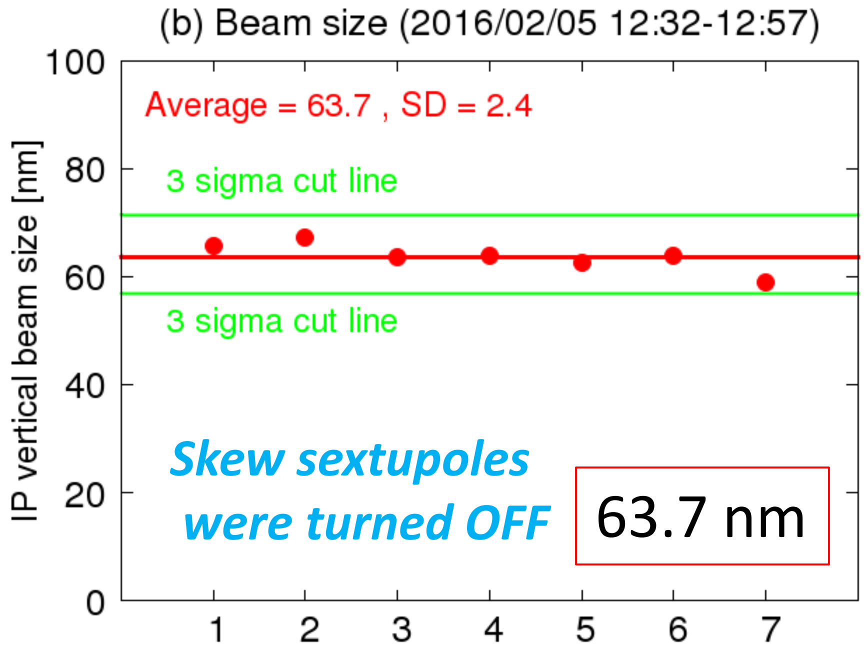
IP-BSM 174 degree
- *AY knob*
- *EY knob*
- *Coup2 knob*
- *Y24 knob*
- *Y46 knob*
- *Y22 knob*
- *Y26 knob*
- *Y66 knob*
- *Y44 knob*

The ATF2 tuning procedure is same to ILC final focus beam line.

Beam size tuning results on 2016/02/05

Presented at LINAC2016 by T. Okugi.





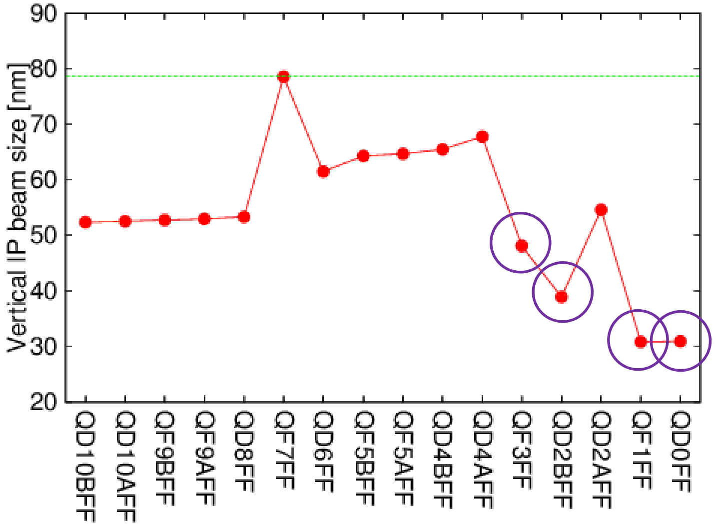
- *The correction with skew sextupoles worked well (same scheme of ILC).*
- *IP beam sizes were evaluated by assuming the perfect laser fringe contrast.*

Normal Sextupole Magnet Setting

Beam size was minimized in simulation for the normal sextupole settings by applying the normal sextupole errors for 1-by-1 quadrupole.

Normal sextupole settings	IP vertical beam size at model
Design setting w/o sextupole errors in quads	35.2nm
Magnet settings after nonlinear knobs	**78.7nm**

Minimum IP vertical beam size after beam size minimization



Candidates of error sources

(K2N/K1) at R=1cm

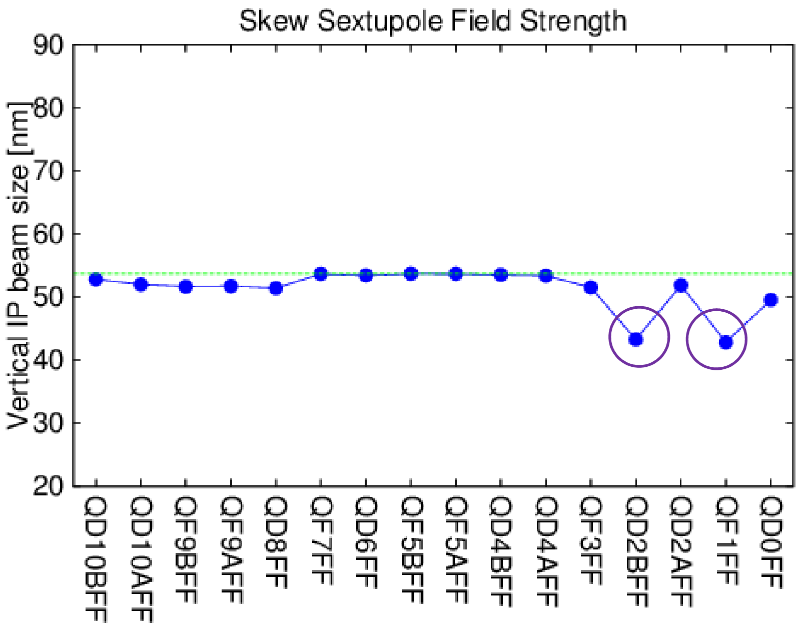
QF3FF	- 0.17756
QD2BFF	+0.97074
QF1FF	- 0.00232
QD0FF	+0.00117

Skew Sextupole Magnet Setting

Normal sextupole settings	IP vertical beam size at model
Design setting w/o sextupole errors in quads	35.2nm
Magnet settings after nonlinear knobs	**53.7nm**

Beam size was minimized in the simulation for the skew sextupole settings by applying the skew sextupole errors for 1-by-1 quadrupole.

Minimum IP vertical beam size after beam size minimization



Candidates of error sources

(K2S/K1) at R=1cm

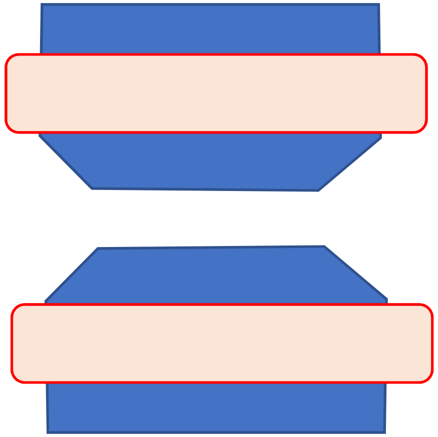
QD2BFF - 0.27321

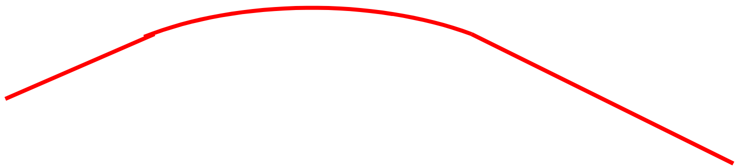
QF1FF - 0.00030

The QF1FF magnet was PEP-II reused magnet

Actual Magnet

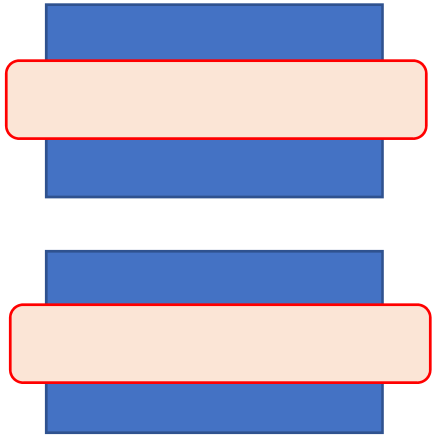
Magnetic field is measured only with long-coil.
(integrated magnetic field)





ATF2 optics model

Hard-edge with typical fringe field
from long-coil measurement.



Beta function at ATF2 FD
is changing along the magnet.

We should evaluate the aberration
with local field variation in the magnet.

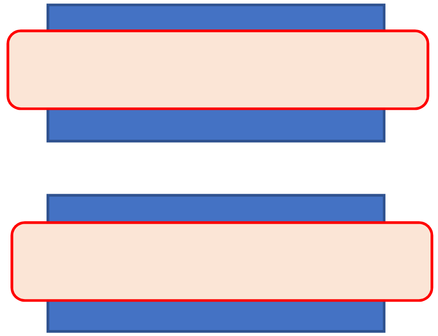
The CAD data of the magnet was prepared by G. White and sent to CERN.
The slice magnet model is helpful to understand the multipole error.

Higher order optics correction for small betaY study

The IP vertical beam size at ATF2 low beta optics is sensitive to the fringe field of final doublet.

The fringe field may be corrected by using octupole magnets.

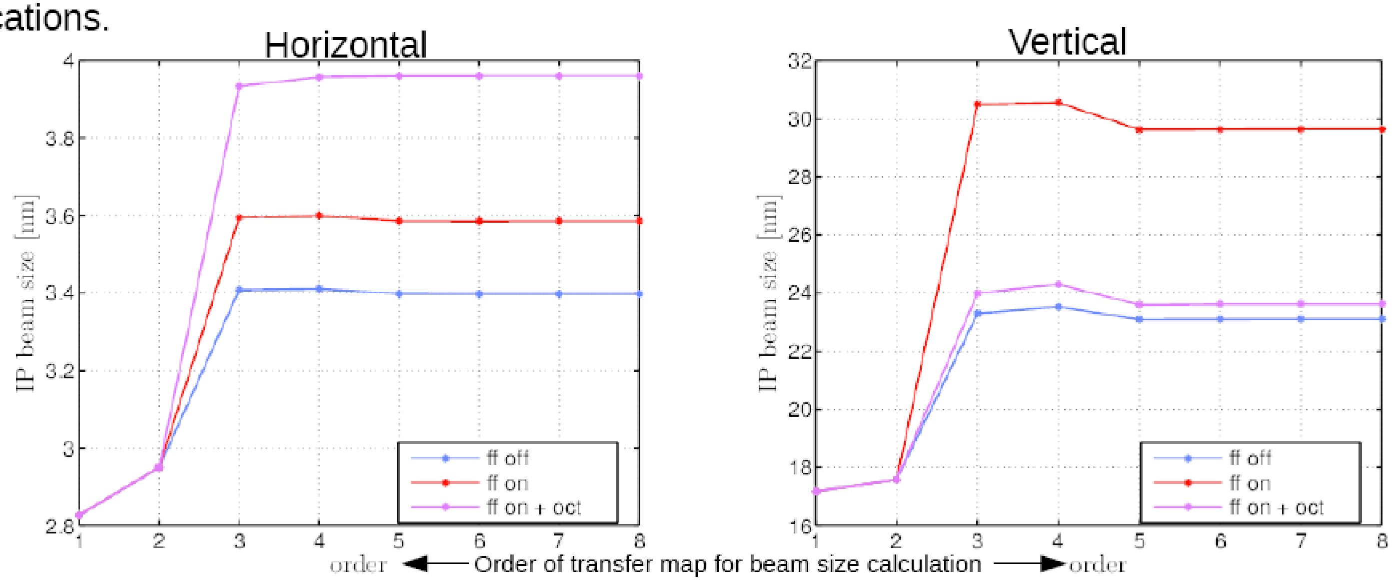
But, the fringe field of QF1FF is not correct for present ATF2 deck, which use the hard-edge model with long-coil measurement by SLAC.



Octupole magnets for ATF2

FD fringe fields effect cancellation

FD fringe fields are responsible for the IP beam size growth. Both multipolar components and fringe fields can be mitigated with the use of the octupole magnets installed in proposed locations.



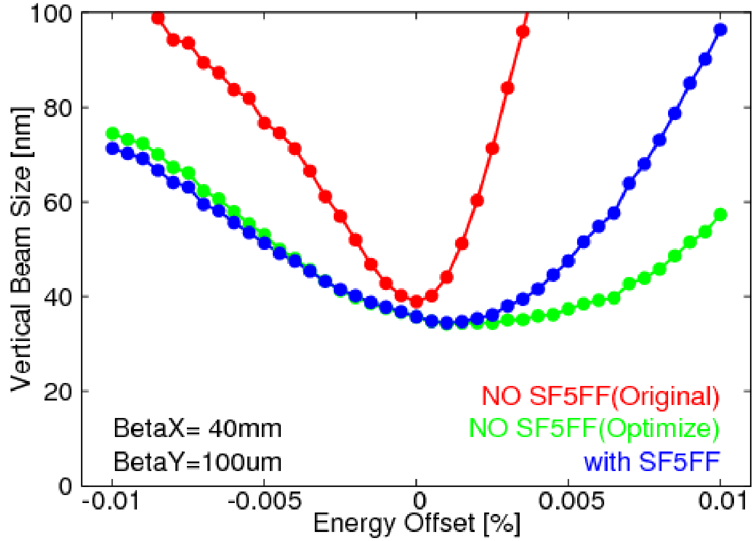
presented by M. Patecki et al., 2015 CLIC workshop

Energy bandwidth Measurement

The simulation was already presented at ATF2 project meeting at LAPP (2015/02/24)

Energy bandwidth for ATF2 10x1 optics

Momentum Offset



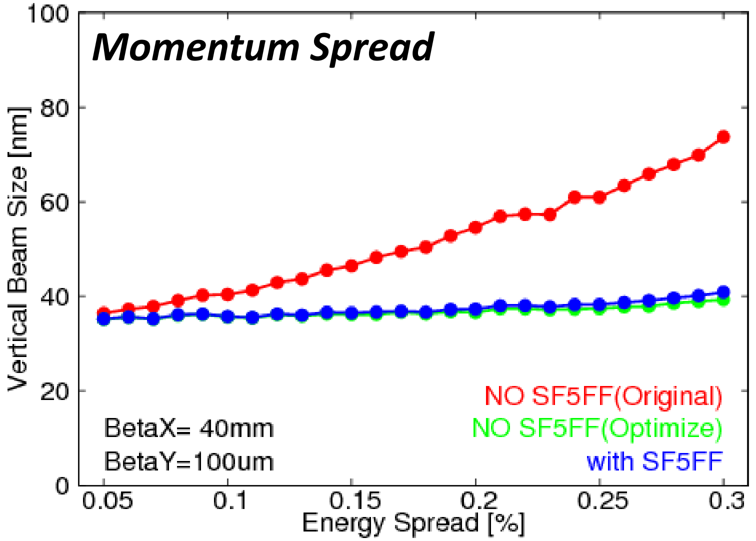
All magnets errors were OFF.

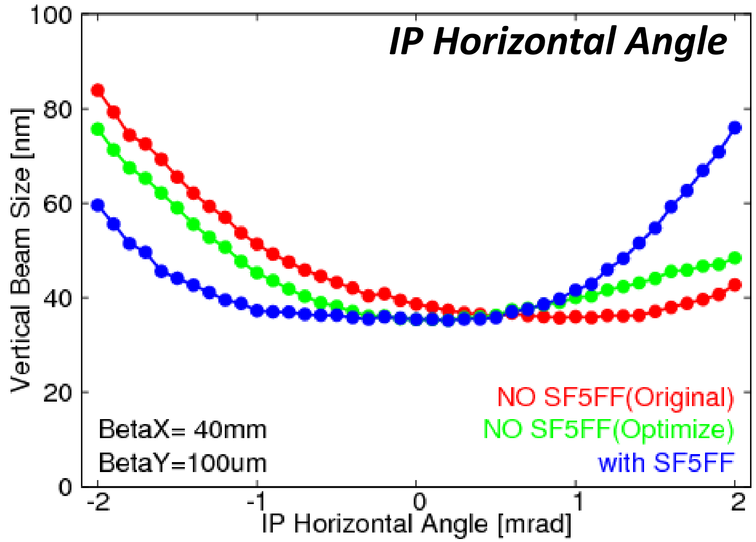
No SF5FF (Present sextupole setting)

No SF5FF (Optimized to make large bandwidth)

with SF5FF (Optimized to make large bandwidth)

Emittances ($\varepsilon_x/\varepsilon_y$)	2nm /12pm
Beta Functions (β_x^*/β_y^*)	40mm / 0.100mm
Momentum Spread (σ_p/p)	0.08%





The bandwidth for present sextupole setting was very narrow.

When we use SF5FF, the acceptance of horizontal IP angle makes wide for X66 correction.

Procedures of IP beam tuning simulation

Energy spread of the beam assumed to be 0.08%.

1. Put the following errors in Magnets as follows.

	Quadrupole	**Sextupole**
Quadrupole error	0.001	N.A.
Sextpole error	0.001 at R=1cm	0.001
Rotation Error	0.1mrad	0.1mrad
BBA offset	N.A.	50um

2. Tune the beam by the following steps

Carbon Wire
QF1FF strength (H)
QD0FF strength (V)
QD0FF rotation (V)
Sextupole ON
AX knob (H)
EX knob (H)
AY knob (V)
EY knob (V)
Coup2 knob (V)

→ $M_{008} > 0.30$

IP-BSM 8degree
AY knob (V)
EY knob (V)
Coup2 knob (V)

→ $M_{030} > 0.30$

IP-BSM 30degree
Y24 knob (V)
Y46 knob (V)
AY knob (V)
EY knob (V)
Coup2 knob (V)

→ $M_{174} > 0.15$

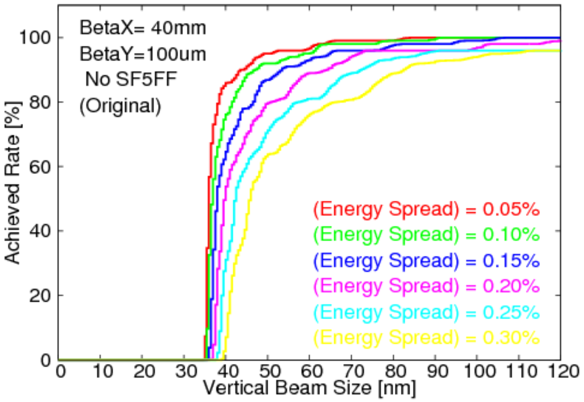
IP-BSM 174 degree
Y24 knob (V)
Y46 knob (V)
AY knob (V)
EY knob (V)
Coup2 knob (V)
Y22 knob (V)
Y26 knob (V)
Y66 knob (V)
Y44 knob (V)
AY knob (V)
EY knob (V)
Coup2 knob (V)

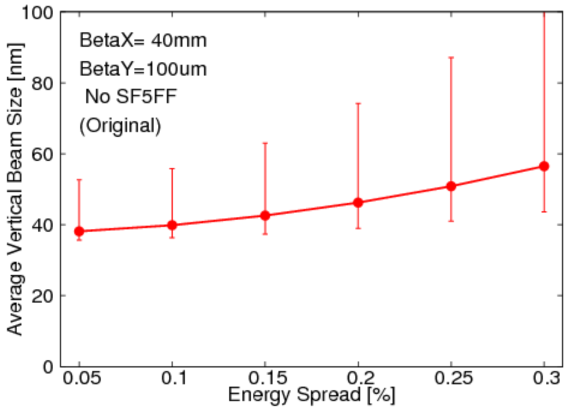
3 times

*3. Simulate the IP beam size for **various momentum spread**.*

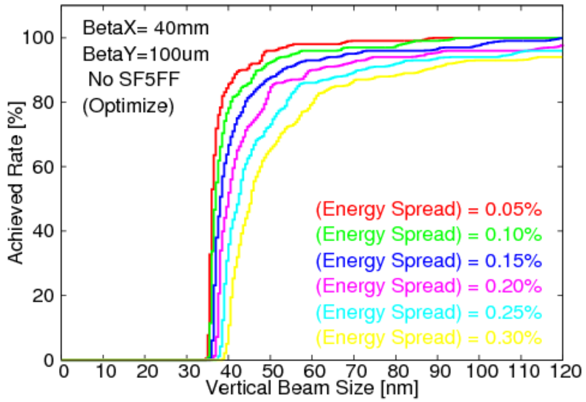
Results of beam tuning simulation for ATF2 10x1 optics

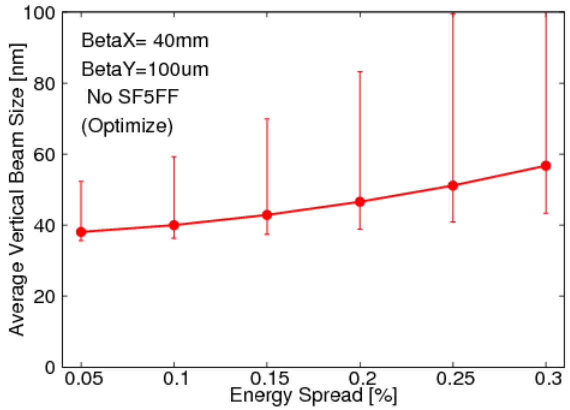
No SF5FF
(Present sextupole setting)



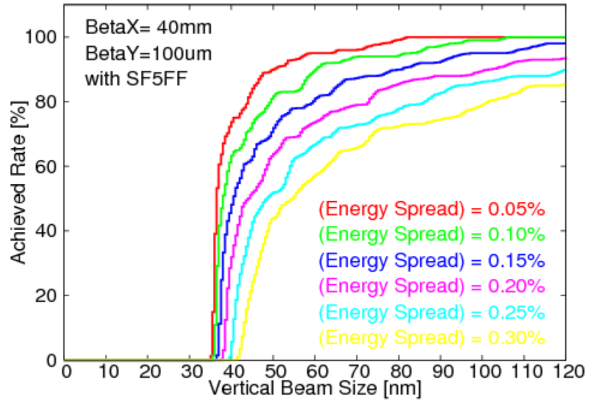


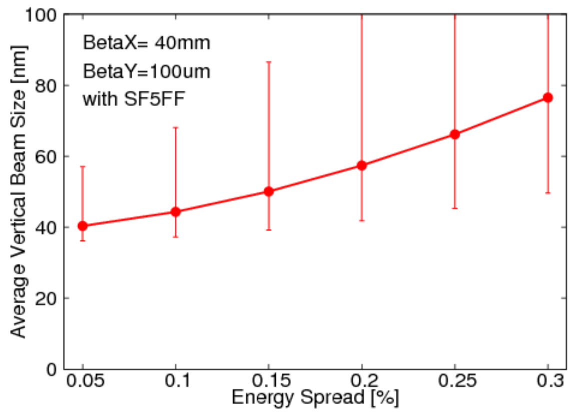
No SF5FF
(Optimize to large bandwidth)





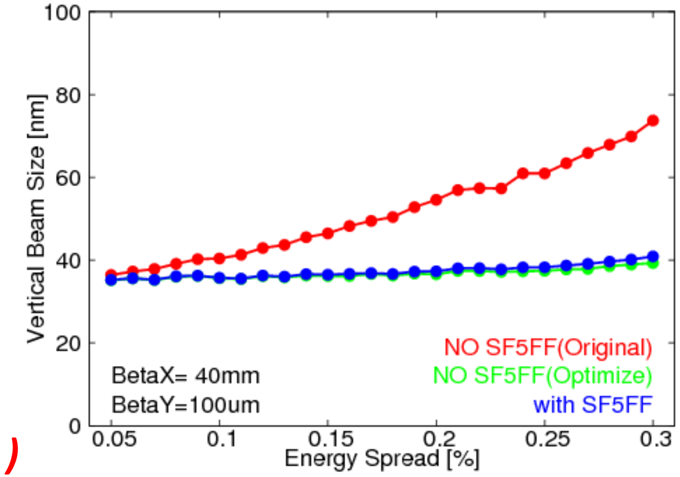
with SF5FF
(Optimize to large bandwidth)



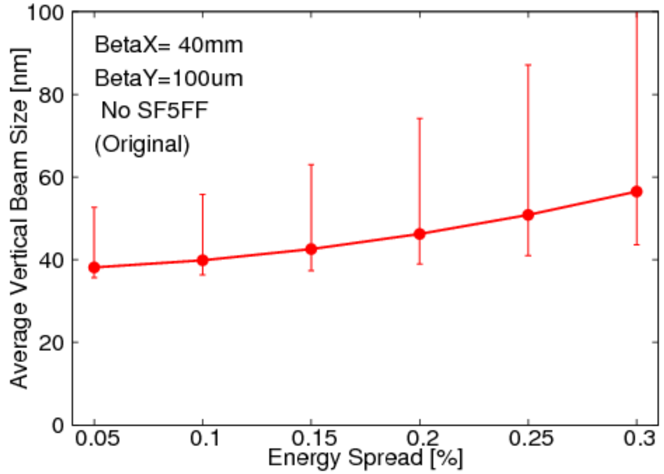


Momentum spread dependence for "NO" SF5FF

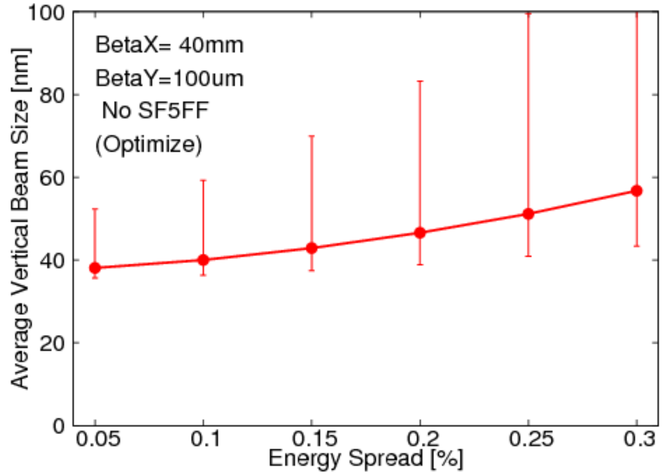
Model calculation, when no multipole errors



No SF5FF
(Present sextupole setting)



No SF5FF
(Optimize to large bandwidth)



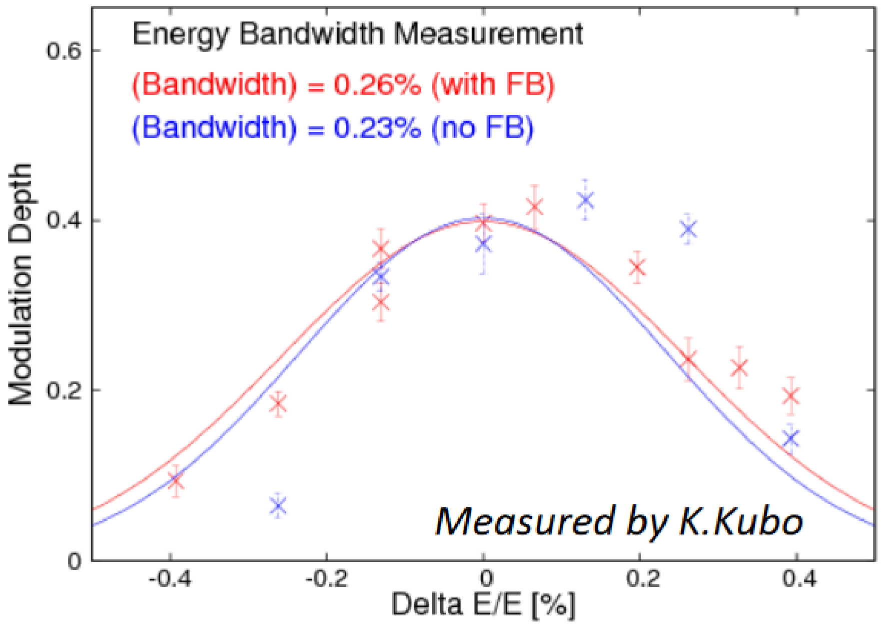
The momentum bandwidth will be increased after IP beam tuning by their small energy spread.

- momentum spread dependence for un-designed setting and optimized optics was almost same.

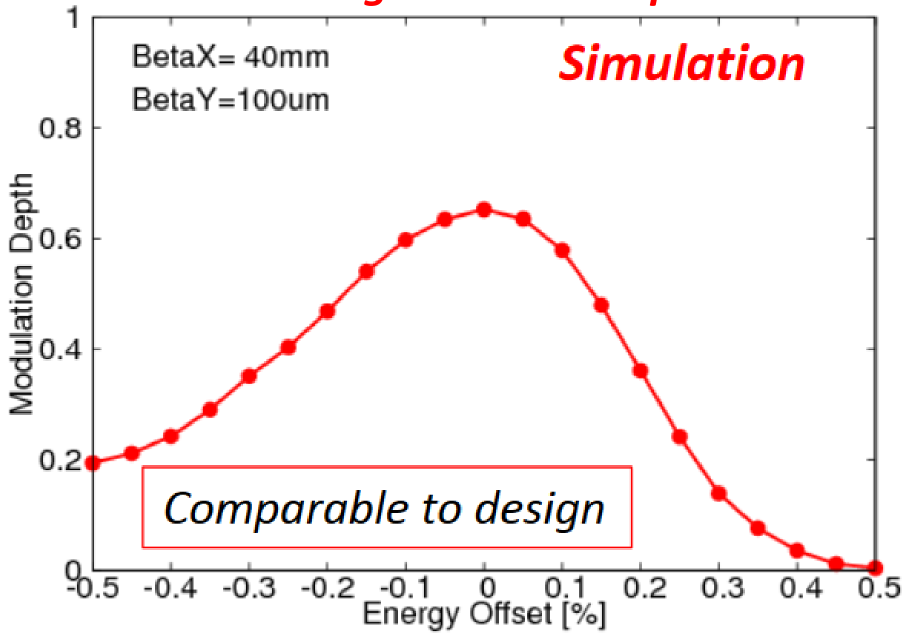
- momentum spread dependence was almost same model to the calculation for un-designed optics.

Comparison with the measurement

Beam size was measured by changing the RF frequency in DR at 2015/05/21.



FF sext. setting are at the experiment



The energy bandwidth after the beam size tuning was optimized not to design, but to be optimized to the energy spread for actual beam.

Beam Tuning Simulation for ATF2 10x0.25 Optics

Energy bandwidth for ATF2 10x0.25 optics

All magnets errors were OFF.

No SF5FF (Matched only with QM magnets)

No SF5FF (Optimized to make large bandwidth)

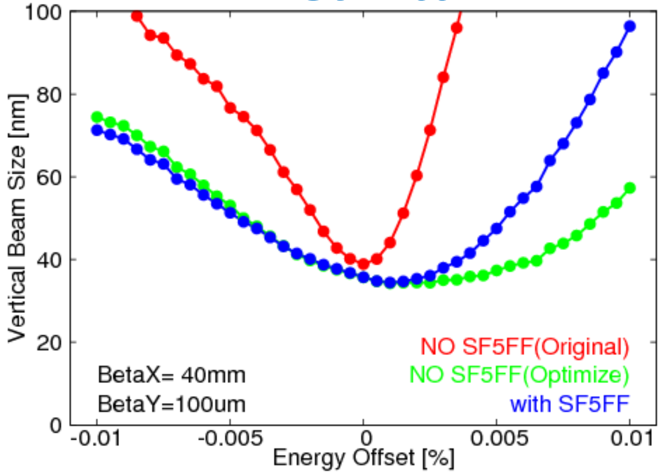
with SF5FF (Optimized to make large bandwidth)

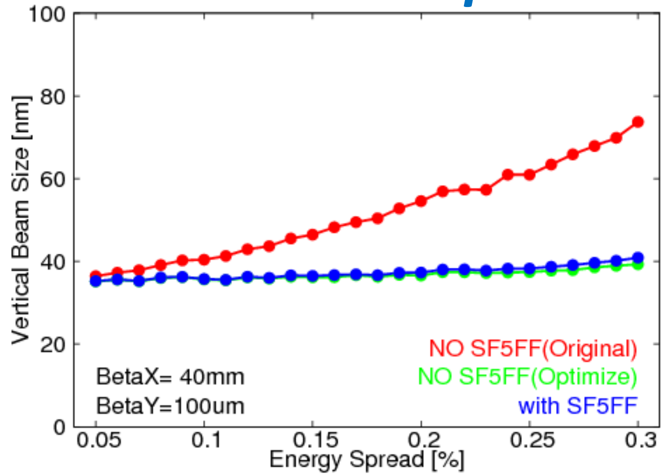
Emittances ($\varepsilon_x/\varepsilon_y$)	2nm /12pm
Beta Functions (β_x^*/β_y^*)	40mm / 0.100mm
Momentum Spread (σ_p/p)	0.08%

Energy Offset

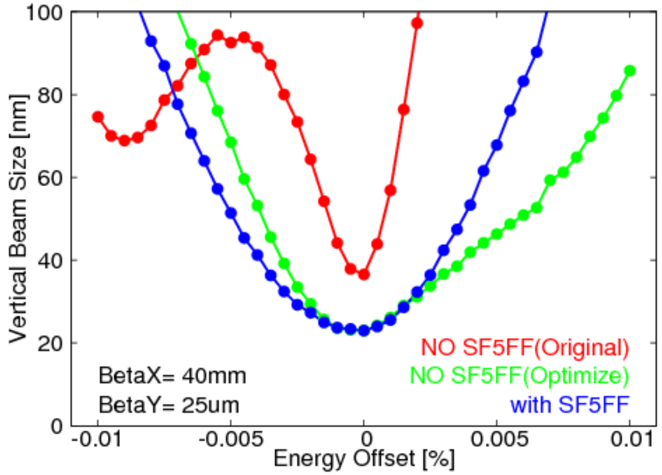
Momentum Spread

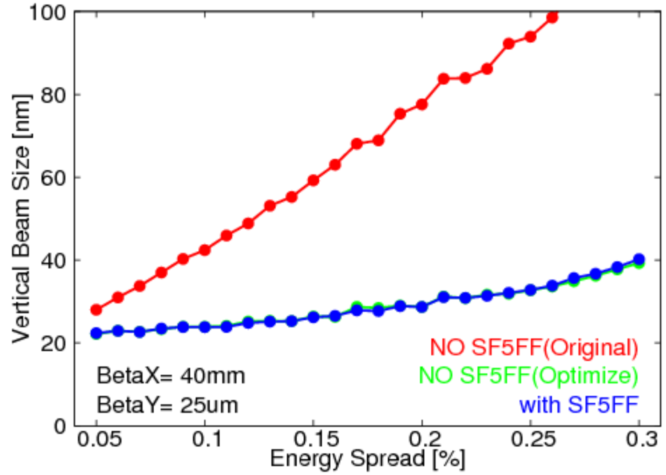
10x1 optics





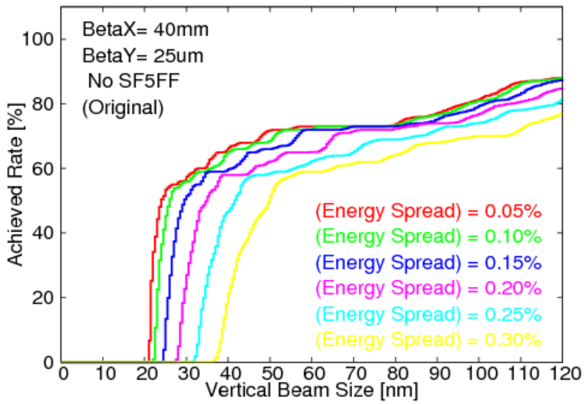
10x0.25 optics

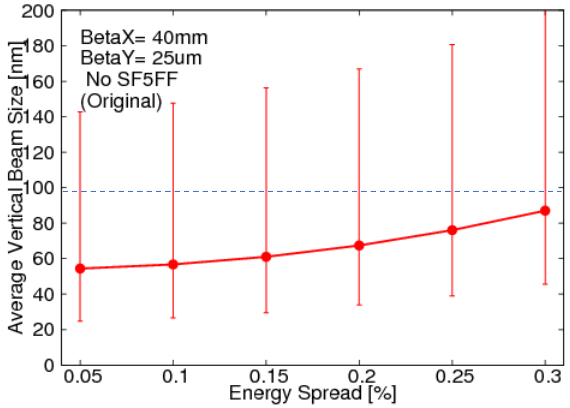




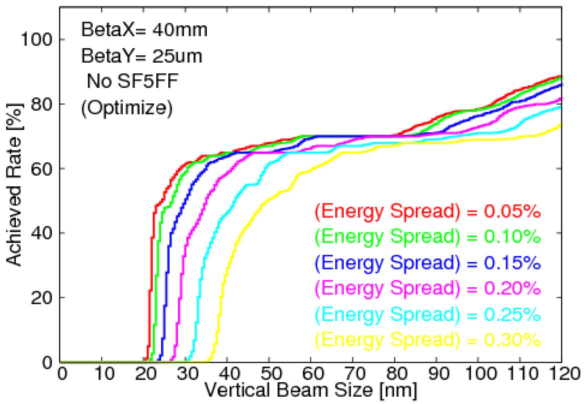
Results of beam tuning simulation for ATF2 10x0.25 optics

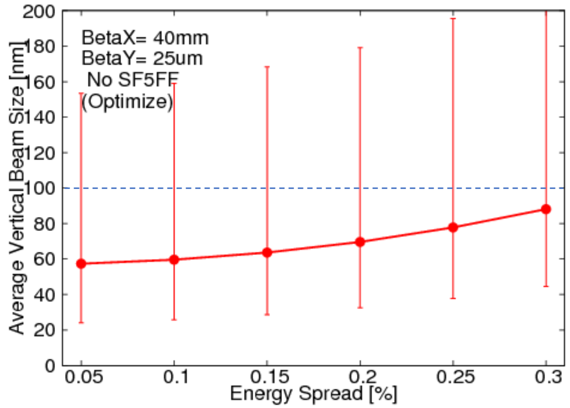
No SF5FF
(Matched only with QM magnets)



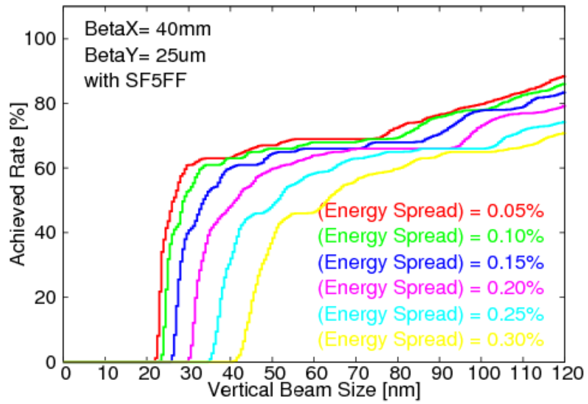


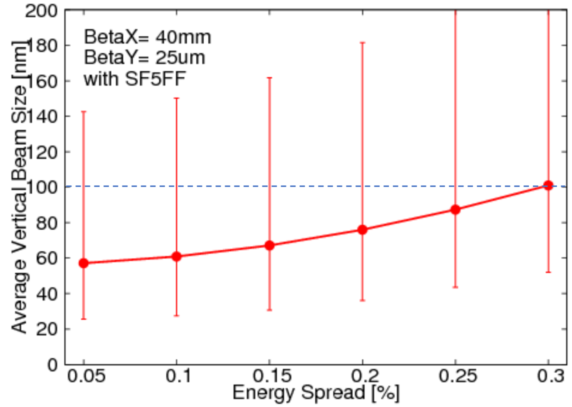
No SF5FF
(Optimize to large bandwidth)





with SF5FF
(Optimize to large bandwidth)



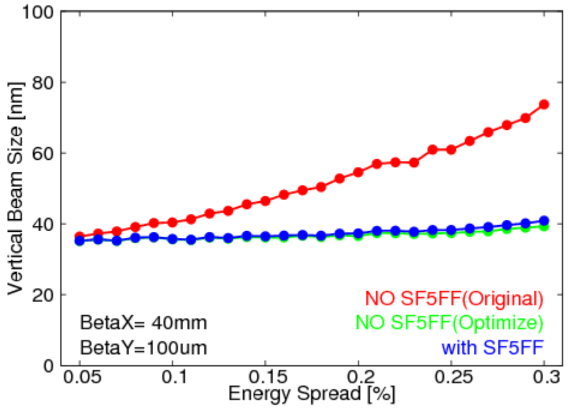


When momentum spread was increased after IP beam tuning with small momentum spread,
- momentum spread dependence are almost same for present and optimized optics without SF5FF.
- momentum spread dependence of optics with SF5FF was larger than that without SF5FF.

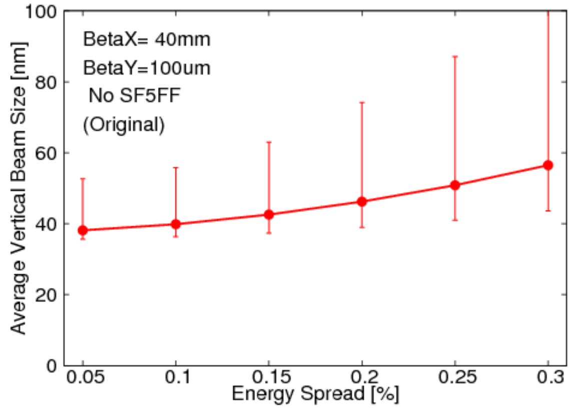
Momentum spread dependence

All of the results shows "NO SF5FF (Original)" as typical example.

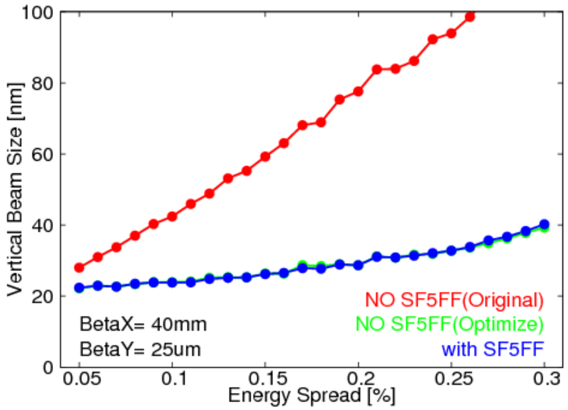
Model calculation
10x1 optics



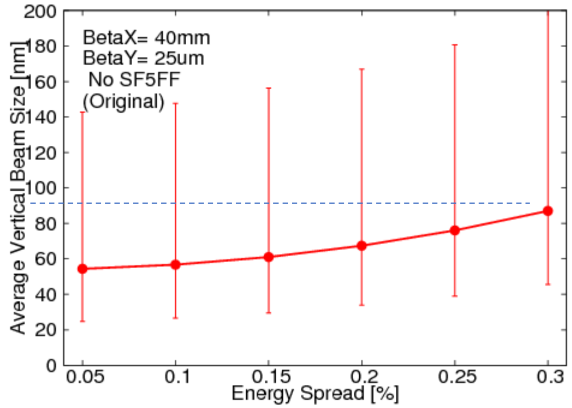
Simulation Result
10x1 optics



10x0.25 optics



10x0.25 optics



When momentum spread was increased after IP beam tuning with small momentum spread,

- momentum spread dependence of 10x0.25 optics was also in between model calculation for present and optimized optics.

Summary of energy bandwidth

When we apply the enough number of the iteration of knob tuning,
the final sextupole setting after the beam size tuning is automatically optimized
for the momentum spread of the beam ($\Delta p/p$=0.06-0.08%).

It suggested both for the simulation and the measurement.

Therefore, it is small impact for the initial sextupole setting.

The momentum bandwidth for 10x0.25 optics
is tighter than those for 10x1 optics.

Therefore, the energy bandwidth for 10x0.25 optics is tighter than that for 10x1 optics.
But, the energy bandwidth will be optimized to the ATF2 energy spread of $\Delta p/p$=0.06-0.08%.
(not reached to the design energy bandwidth.)