ILC Final Focus Beamline Optimization

Introduction

Beam Optics Design of ILC Final Focus System

Tolerance Evaluation for ILC Final Focus System

*Optics Performances for various QF1 and QD0 L**
(Information of CR2)

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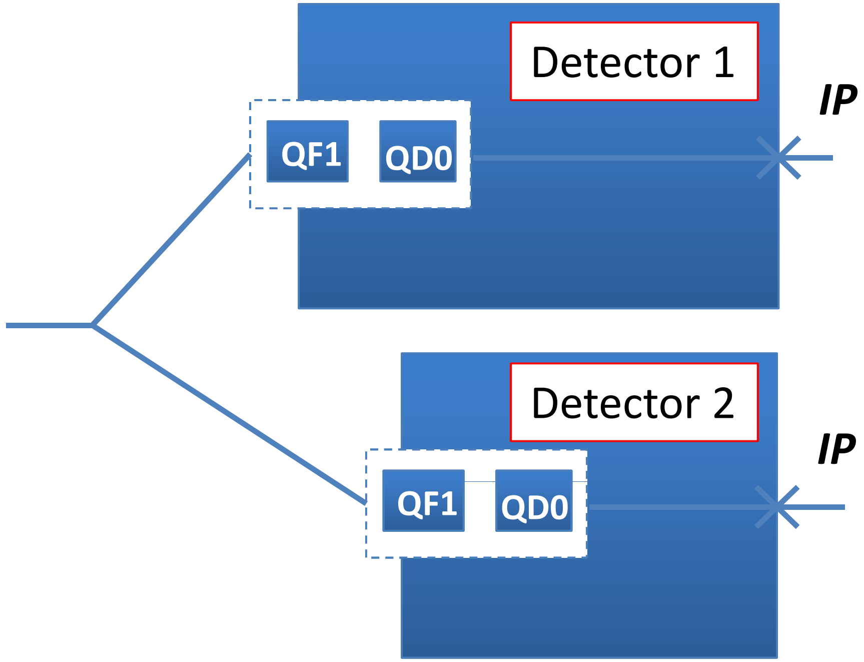
2015/04/21
ALCW2015, KEK, JAPAN

Introduction

FD magnet configuration for push-pull optics

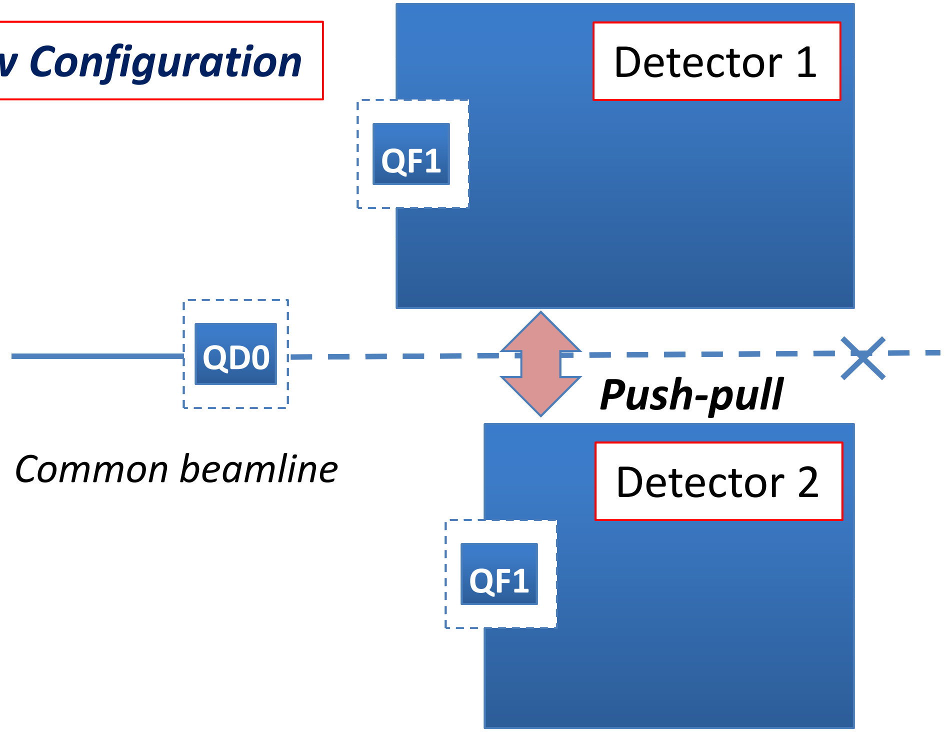
After the RDR was completed (2006),
the push-pull scheme will be adopted for the ILC baseline design.

Old Configuration



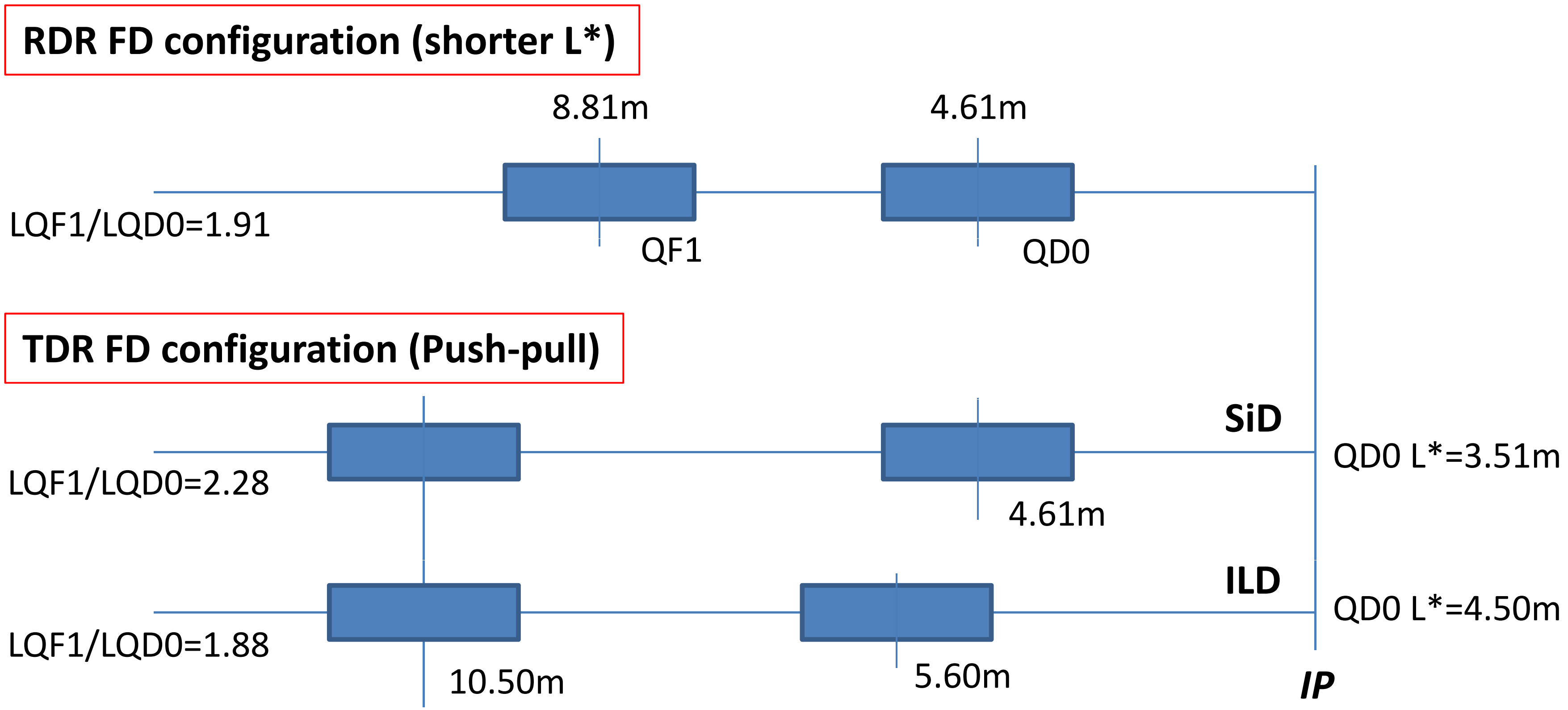
Two different final focus beamline
was prepared for two detectors.

New Configuration



1. *Same beamline up to QF1 will be used for 2 detectors.*
2. *Each detector has different* ***QD0 L****.
3. *The cryomodule of final doublet is divided*
   - *the cryomodule for QD0 belongs to detector.*
   - *the cryomodule for QF1 belongs to accelerator ,*
     and uses for two detectors commonly.

Final Doublet (FD) configuration



Two ***(QD0 L*)*** *should be allowed for same upstream beamline*

(QF1 L*) *will be longer than RDR configuration*

ILC Push-Pull Optics

Presented by T.Okugi at AWLC2014

Push-Pull optics were prepared by A. Seryi in 2006 ,

but the optics was not tuned for beam size and bandwidth etc.

- location of QF1 unchanged when L changed.*

(D1B adjusted according to L)*

I roughly optimize the IP beam size

by changing the strengths of

- QD4, QF3, QD2B, QD2A, QF1 and QD0

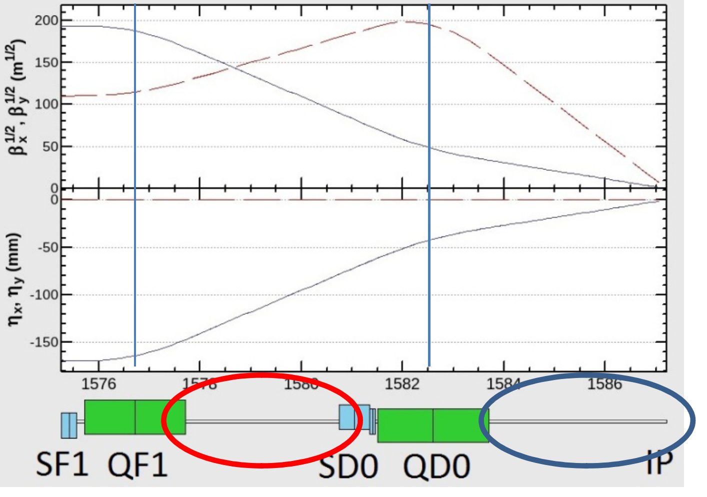
- SF6, SF5, SD4, SF1 and SD0

I also matched the optics to TDR IP parameter

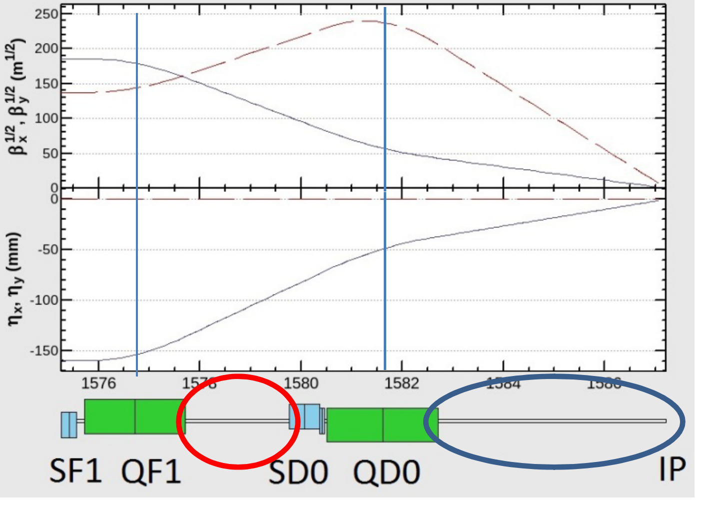
Simulated beam size at E=250GeV

optics	L*=3.51m (351LD0_304D1B)		L*=4.50m (450LD0_205D1B)	
	horizontal	vertical	horizontal	vertical
design	0.47um	5.90um	0.47um	5.90um
original	2.17um	8.52nm	0.76um	5.95nm
optimize	0.49um	6.18nm	0.49um	5.99nm

351LD0_304D1B



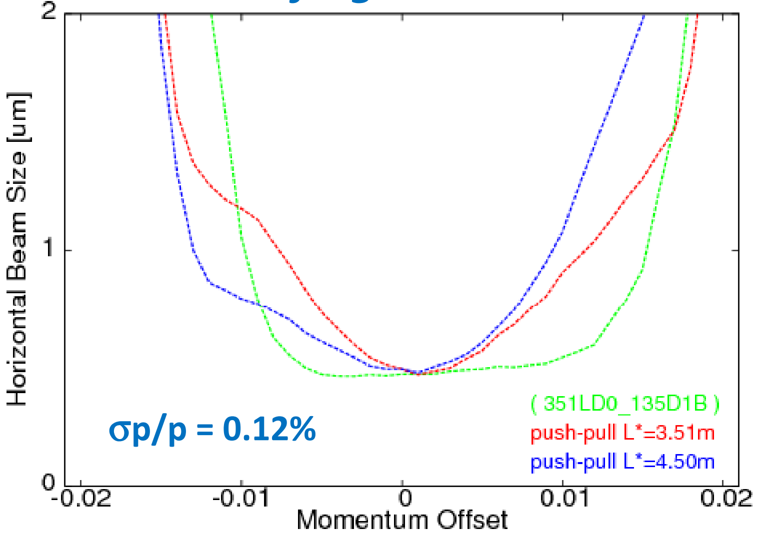
450LD0_205D1B



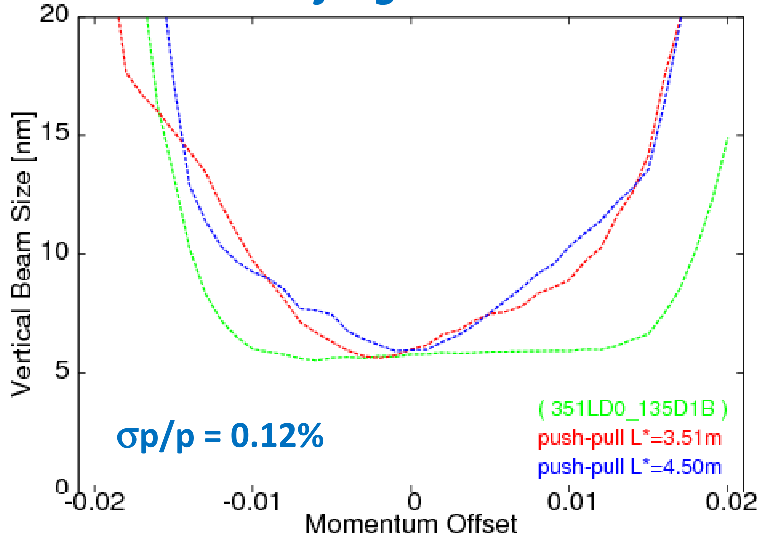
Performances of Push-Pull Optics

Presented by T.Okugi at AWLC2014

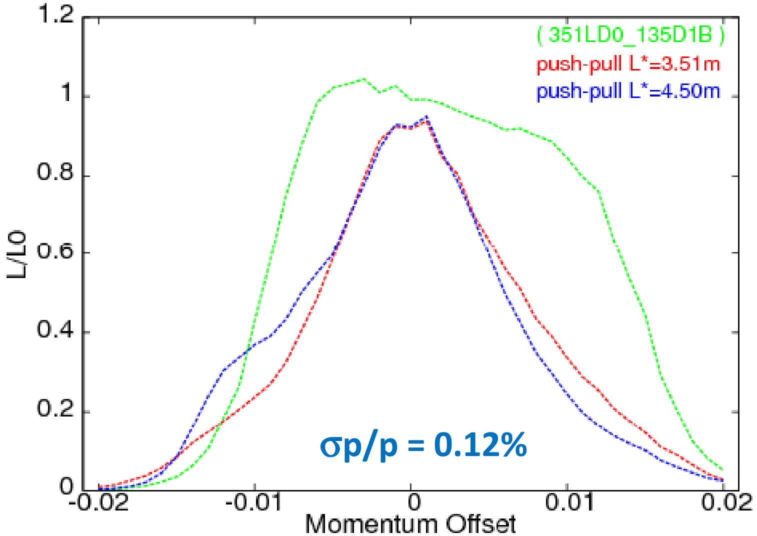
Bandwidth of sigmaX at E=250GeV



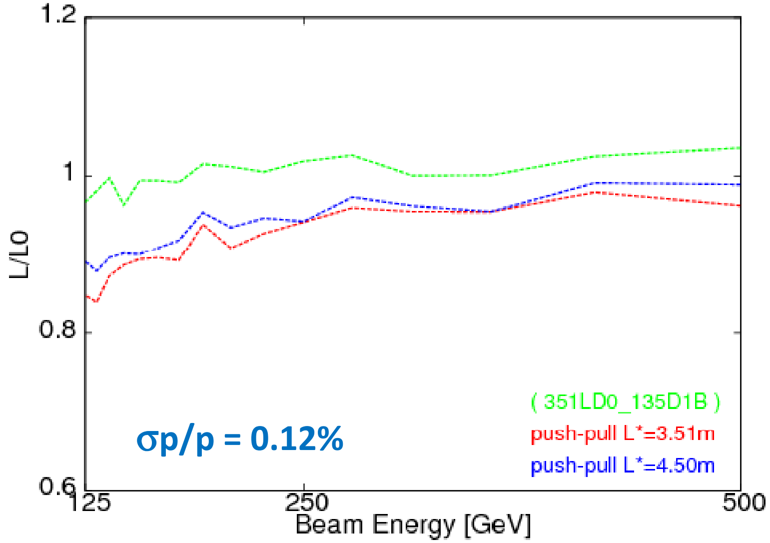
Bandwidth of sigmaY at E=250GeV



Luminosity Bandwidth at E=250GeV



Energy Dependence of Luminosity



The performances were worse than original ILC optics.

Discussion at AWLC2014

(1st Priority Work)

We must establish a baseline optics of ILC final focus system at first, because we don't have a good Push-Pull ILC FFS optics yet.

*In order to determine the length of BDS as soon as possible, we will continue to optimize the Push-Pull optics with 2 different L*s (3.51m/4.50m).*

Then, we will compare its performances to the fixed L optics (L*=3.51m and L*=4.50m).*

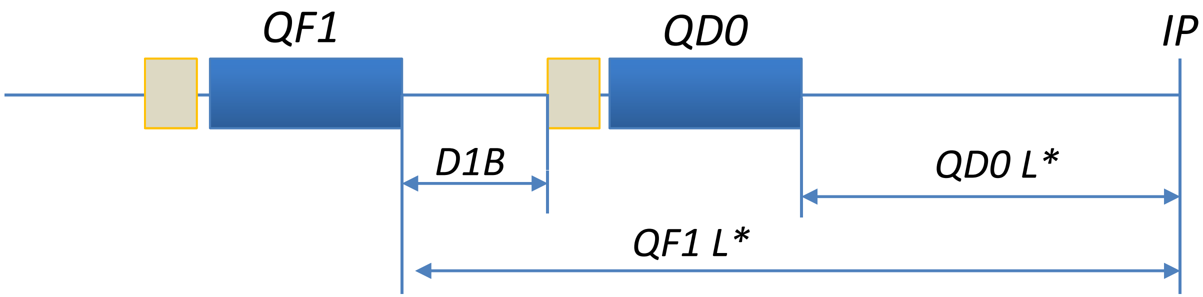
We should also evaluate the tuning difficulty of switching from one detector to another detector with different L.*

From above information, we should fix the ILC baseline FF optics, by communicating with MDI, CFS, detector groups and so on.

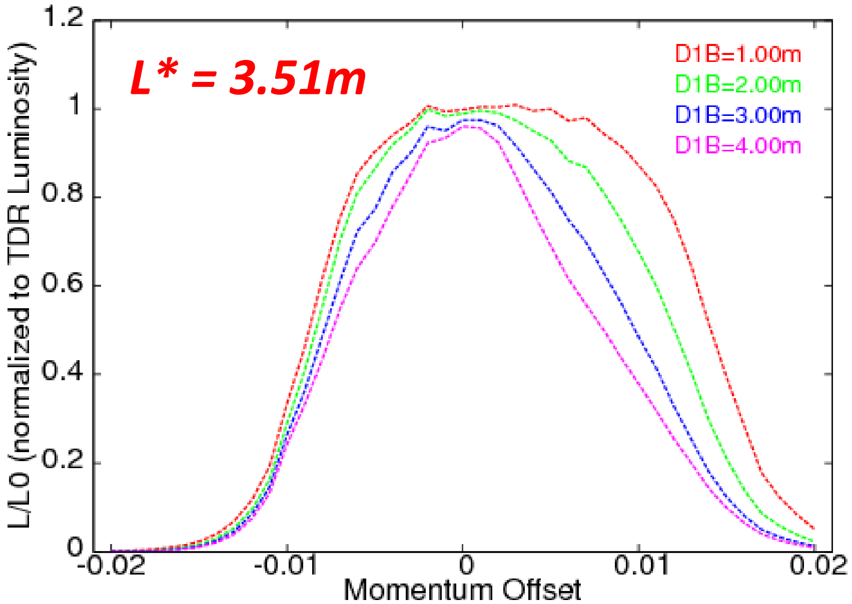
We have a BDS topical meeting at 9/4/2014
a MDI/CFS meeting at 9/5-6/2014
at Ichinoseki to discuss the baseline optics.

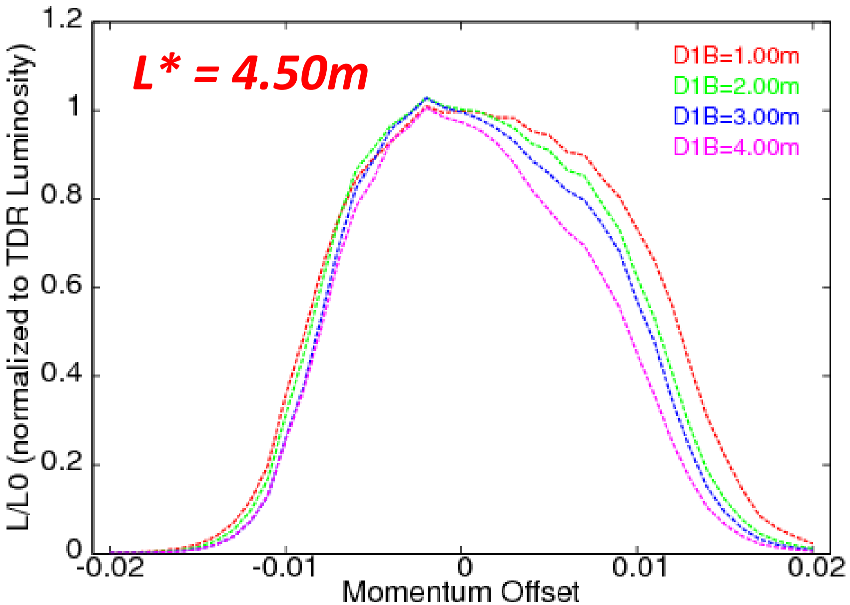
Presentation at the topical meeting 1

Presented at BDS topical meeting at 2014/09/04 by T.Okugi



Bandwidths for optimized optics (not only strength of quad, but also quad location)





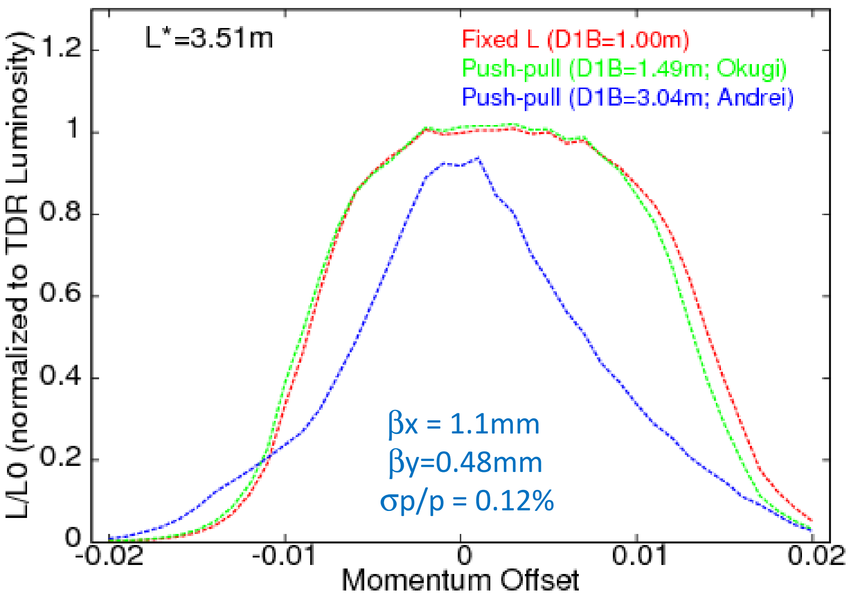
When QF1 move to be close to QD0 by keeping same (QD0 L), the performance of final focus can be improved.*

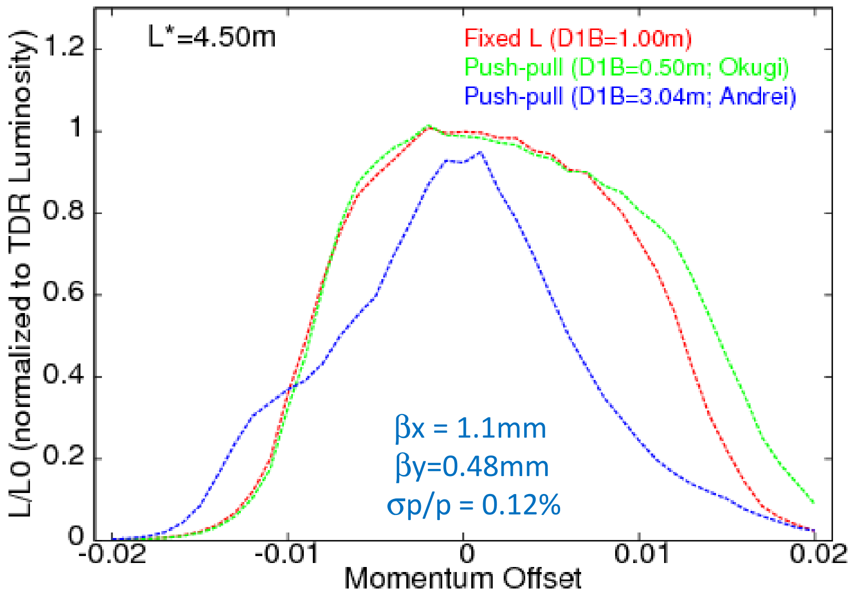
Not only (QD0 L), but also (QF1 L*) is important.*

Presentation at the topical meeting 2

Presented at BDS topical meeting at 2014/09/04 by T.Okugi

*Performance for push-pull optics with shorter QF1 L**





We can make a push-pull optics with comparable performance to the fixed L optics*

by optimizing the geometries of magnets for shorter (QF1 L) .*

(QF1 L) is very important parameter.*

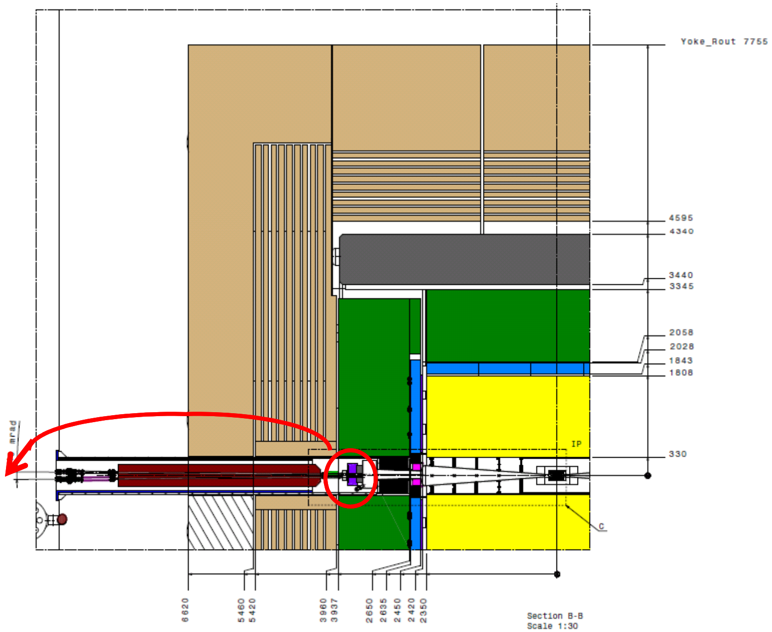
Presentation from Detector Group

at MDI/CFS meeting at 2014/09/05 in Ichinoseki

ILD L Issue*

presented by Karsten Buesser

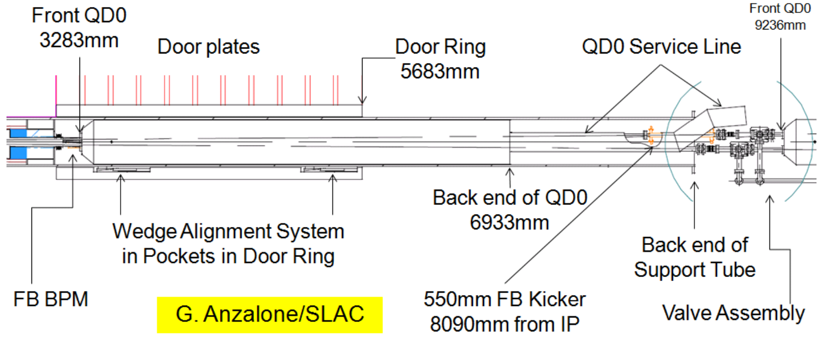
ILD Dimensions



If the ion pump and valve will be removed,
the QD0 L can be shorten to 4.4m -> 4.1m for ILD.*

SiD L Issue*

presented by Tom Markiewicz



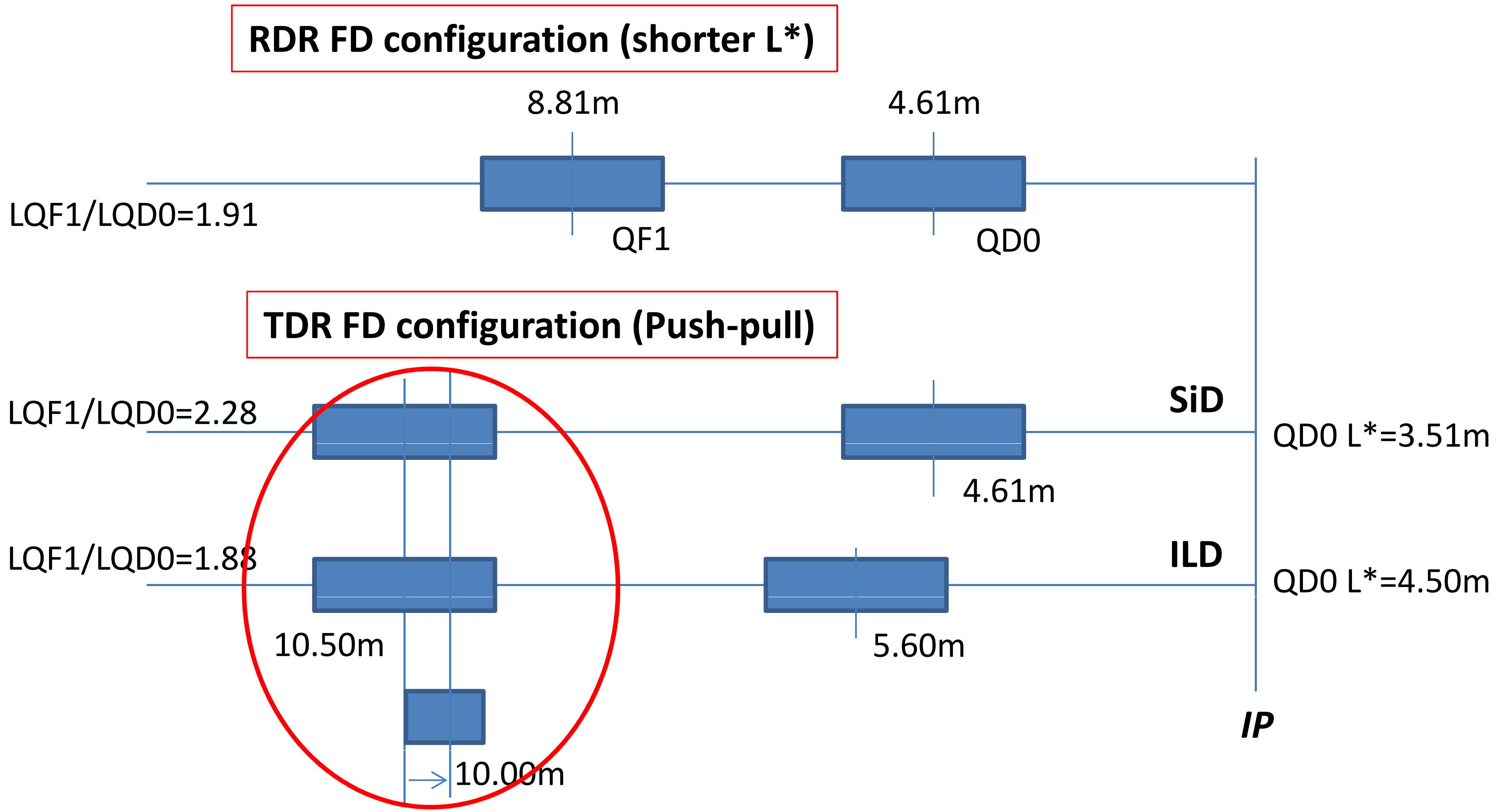
SiD can accommodate a QD0 L between 2.6-4.5m.*

- *Ion pump*
- *Vacuum port*
- *FB kicker*

must put in between SD0 and QF1 .

It is difficult to shorten (QF1 L) from present design so much.*
We must optimize FD magnet configuration with longer (QF1 L) than RDR design.*

Discussion at MDI/CFS meeting



Brett Parker suggested at MDI/CFS meeting that

"We can make the QF1 center close to IP by shortening QF1 length, even for same (QF1 L)."*

Change Request for the L Issue*

The change request was submitted at 2014/9/9 after the MDI/CFS meeting.

The change management board is made the change request panel in order to judge the request #2 (chair ; N.Terunuma, KEK)

Change Request No 2: Common L*<= 4m

CHANGE REQUEST NO. ILC-CR-0002	EDMS No: **D*01082495**	Created: **02-09-2014** Last modified: **09-09-2014**

BASELINE OPTICS TO PROVIDE FOR A SINGLE FFS L* (QD0 EXIT – IP DISTANCE) OPTICS CONFIGURATION

The final focus system (FFS) and beam dump extraction system (EXT) baseline design is to provide a standard optics with fixed L* (yet to be determined, but provisionally assumed to be ≤4m). This optics solution is to be common to both detectors.

- Submitted by Glen White (BDS WG leader) in September 2014
- Change Management Board has formed a Change Review Panel for this request:
  - T. Markiewicz (SiD), N. Terunuma, N. Walker, G. White, KB (MDI, ILD)
  - CRP has agreed to come to a suggestion at the time scale of the next ILC workshop (April 2015, Tokyo)

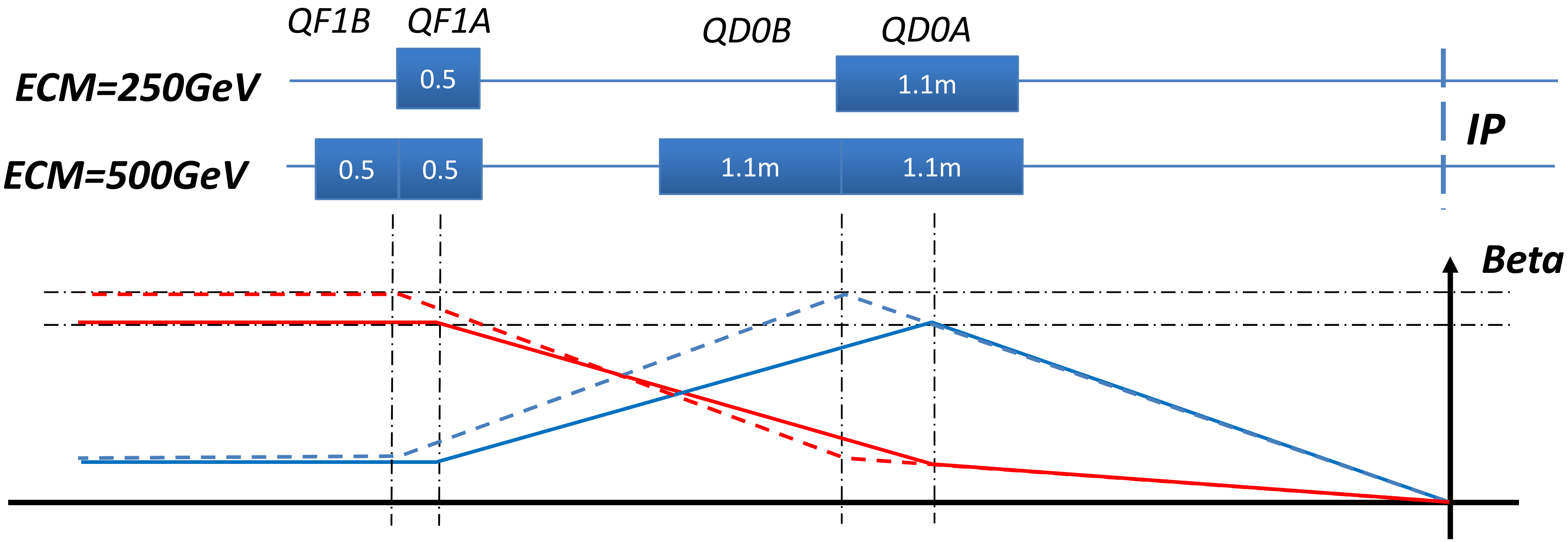
presented by Karsten Buesser at LCWS2014

Low Energy Operation (E_{CM}=250GeV)

The field strength for ECM=250GeV is a half to ECM=500GeV.

When we only use a half of FD magnets,
the beta functions at FD magnets are decreased.

Therefore, the collimation depth can be increased.



This idea was proposed in TDR, but there were no beam optics by LCWS2014.

Beam Optics Design
of
ILC Final Focus System

Procedure of optics optimization

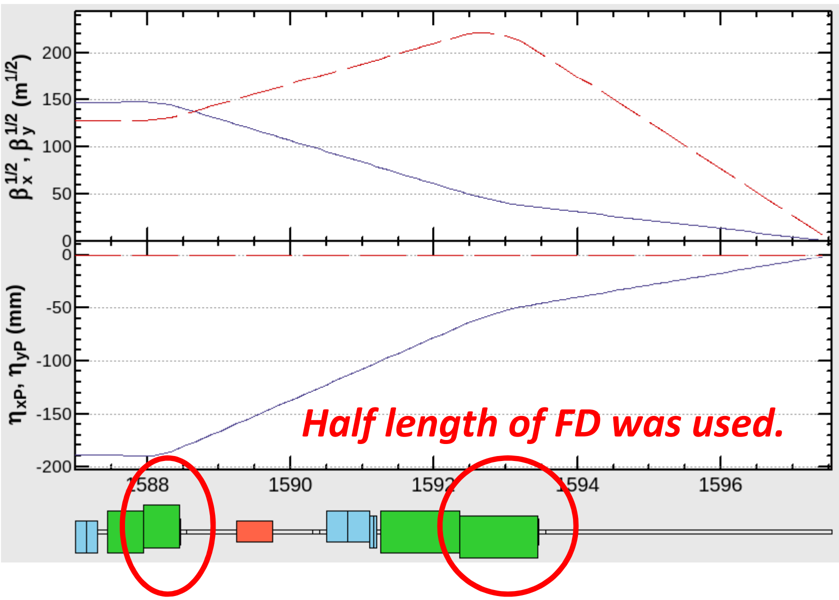
The half length of QF1 (1m long) magnet was used (suggestion by Brett Parker).

Since the optics for ECM=250GeV was used ***half of FD magnets (0.5m QF1 and 1.1m QD0),***
the magnet arrangement for ECM=250GeV was different to others,
and the nonlinear effects of the beam optics for ECM=250GeV is stronger than others.

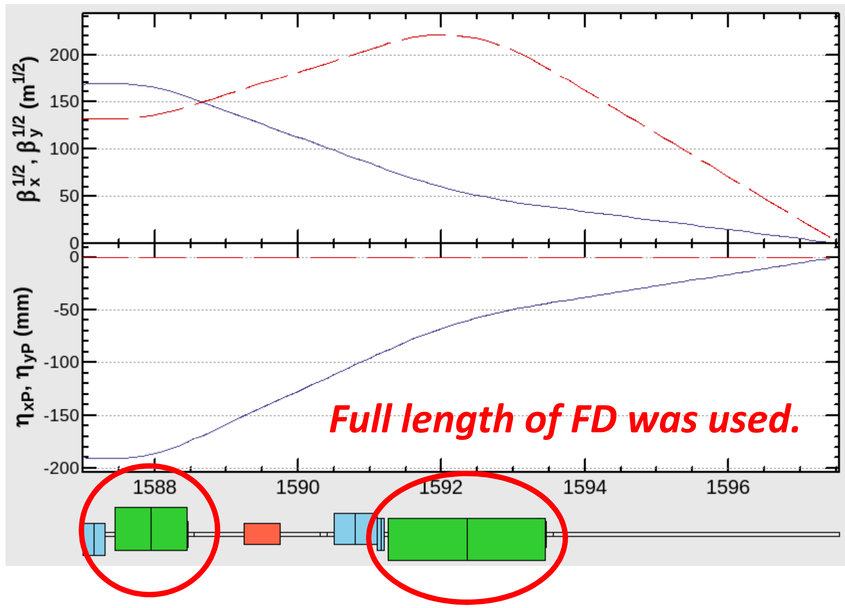
Therefore, I optimized ***the magnet arrangement for ECM=250GeV first****.*

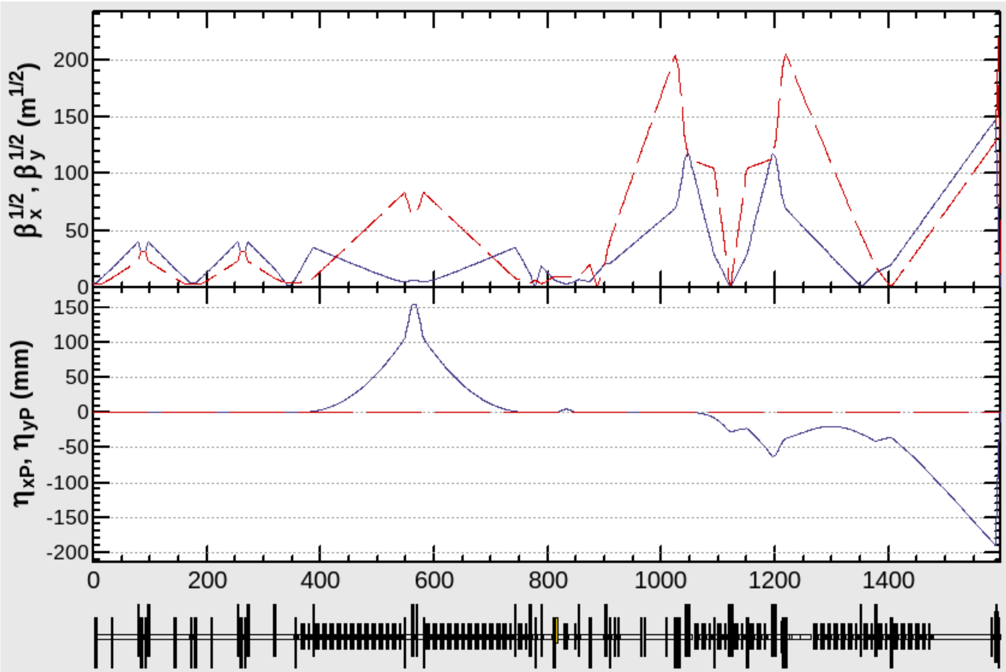
Then, ECM=500GeV optics was designed
with constraint of the arranged magnet to ECM=250GeV*.*

ECM=250GeV



ECM=500GeV

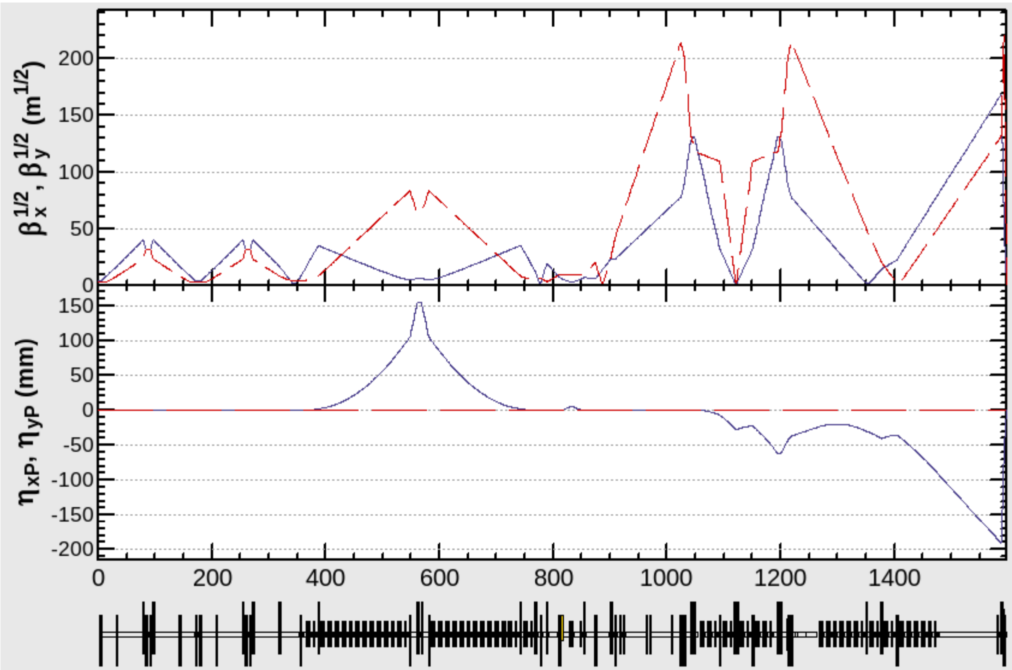




Beam Optics for ***ECM=250GeV***
The half length of FD magnets were used.

betaX* = 13 mm
betaY* = 0.41mm

The ***magnet arrangement and strengths***
(balances of beta and dispersion at sextupoles)
was optimized for this condition.



Beam Optics for ***ECM=500GeV***
The full length of FD magnets were used.

betaX* = 11 mm
betaY* = 0.48mm

The magnet arrangement
was same to ECM=250GeV.

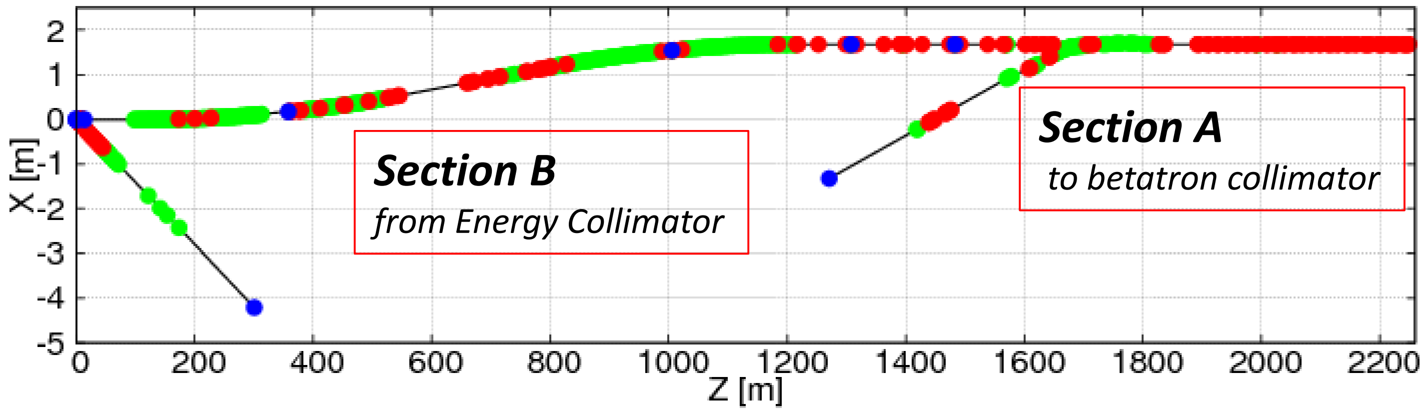
The ***strengths*** *were changed to optimize.*

BDS optics for ECM=1TeV operation

ECM= 500GeV optics can be increased the beam energy up to 300GeV (ECM=600GeV)

The beam optics can be increased to ECM=1TeV by using same geometory.

- The most of magnets for ECM=500GeV can reuse to 1TeV optics.
- Some new magnets should be installed to extend to ECM=1TeV.



The number of components both for ECM=500GeV and ECM=1TeV

(not include the dumpline)

	Energy [GeV]	# of BEND	# of QUAD	# of SEXT	# of Steer	# of PS	# of Mover	# of BPM
Section A	500	16	64	0	19	73	70	78
	1000	43	108	0	19	115	108	116
Section B	500	63	33	7	55	46	40	101
	1000	176	41	7	55	56	48	112

Field strength of FD magnets

List of FD magnets for (QF1 L)=9.1m, (QD0 L*)=4.1m*

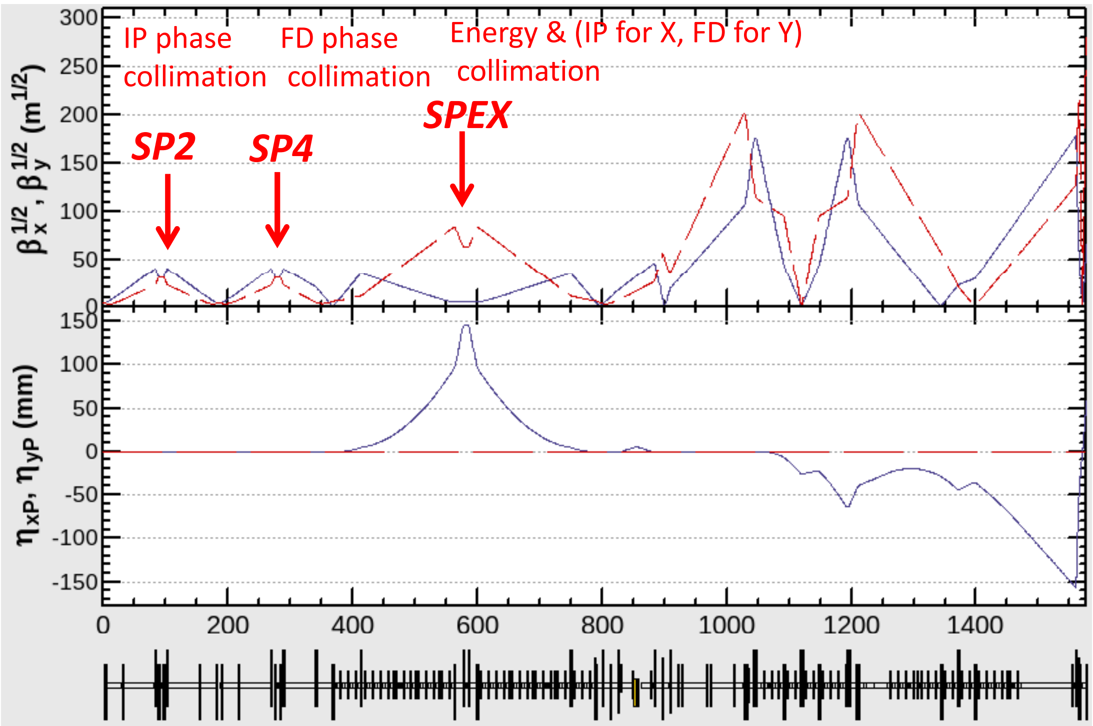
E_{CM} [GeV]	MAGNET	L* [m]	Length [m]	B [(1)] or 2B[(2)]	B at coil [T] (*)
250	QD0	4.10	1.10	124.23	1.739
	SD0	6.45	0.60	2597.3	0.2545
	QF1	9.10	0.50	134.81	1.887
	SF1	10.25	0.30	2774.1	0.2719
500	QD0	4.10	2.20	124.66	1.745
	SD0	6.45	0.60	4310.5	0.4224
	QF1	9.10	1.00	144.40	2.022
	SF1	10.25	0.30	4395.5	0.4308
1000	QD0	4.10	2.20	249.32	3.491
	SD0	6.45	0.60	8563.0	0.8392
	QF1	9.10	1.00	288.79	4.043
	SF1	10.25	0.30	8892.1	0.8714

(*) Evaluated with simple scaling with R=0.014m, actual field will be larger than this simple scaling

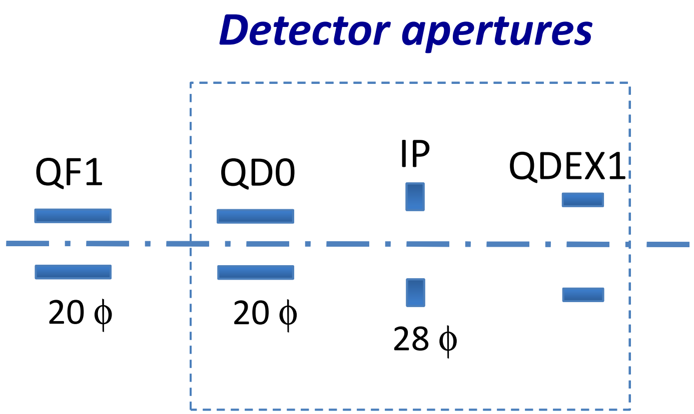
Configuration of the collimators and apertures

Phase advances between collimators to IP were optimized to increase collimation depth.

Beta Function at SP2/SP4 = (X; 1000m / Y; 1000m)
Beta Function at SPEX = (X; 36m / Y; 4000m)
Phase Advance (SP2 / IP) = (X; 7.0 pi / Y; 6.0 pi)
Phase Advance (SP4 / IP) = (X; 6.5 pi / Y; 4.5 pi)
Phase Advance (SPEX / IP) = (X; 5.0 pi / Y; 3.5 pi)
EtaX at SPEX = 0.145m



The aperture is limited by the synchrotron radiation around detector.

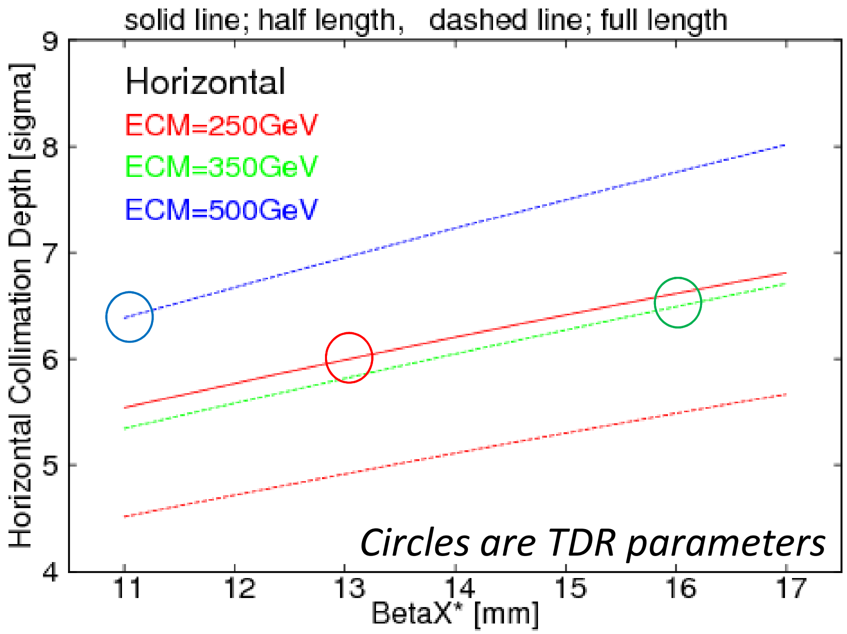


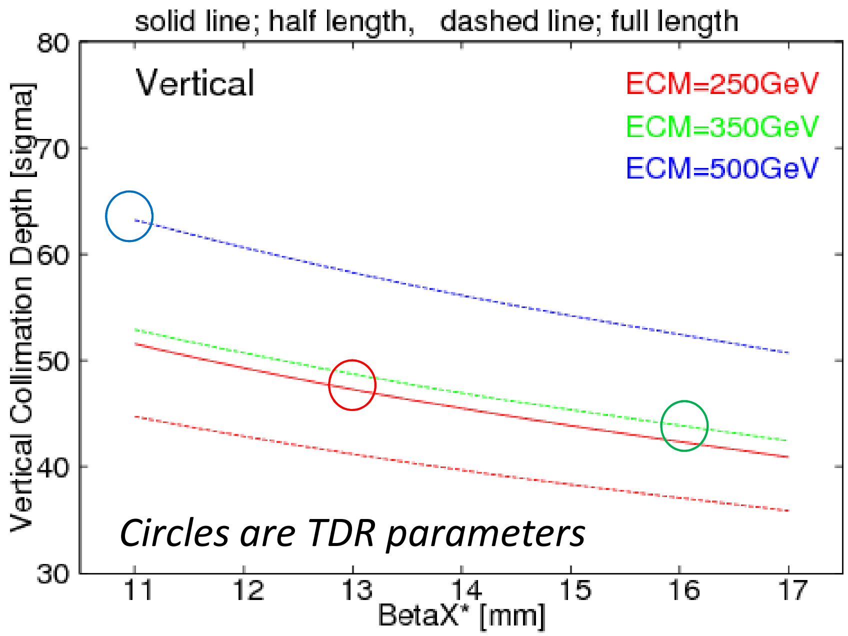
The collimation depth were defined to 70% of aperture limit for safety margin.

The collimation depth for various beam energy

ECM	BetaX*	BetaY*
250GeV	13mm	0.041mm
350GeV	16mm	0.034mm
500GeV	11mm	0.048mm

(QF1 L) = 9.1m*
(QD0 L) = 4.1m*





The collimation depths for ECM=250GeV is comparable to ECM=350GeV and 500GeV, because we can focus the beam only with half of final doublets for ECM=250GeV.

But, the horizontal beam size at FF sextupoles are much larger than ECM=350GeV.

IP beam profile

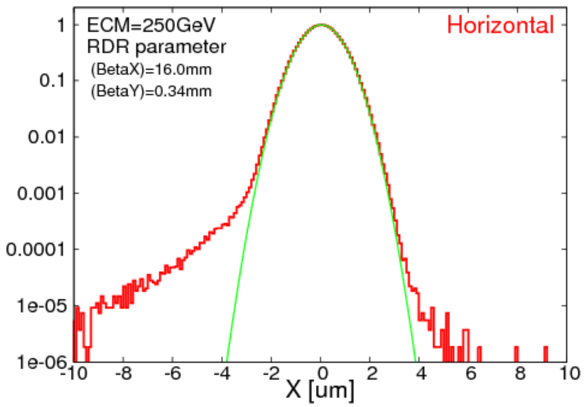
TDR IP Parameters

(QF1 L) = 9.1m*

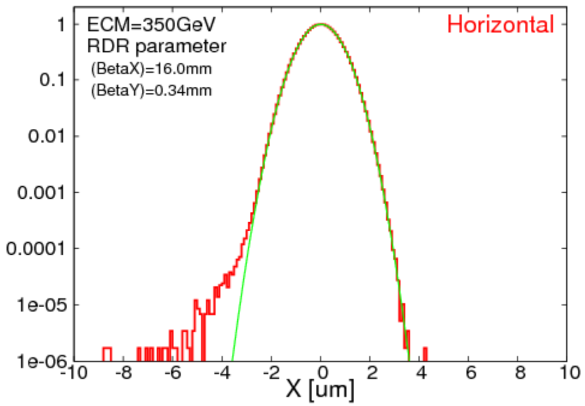
(QD0 L) = 4.1m*

IP Horizontal Profile

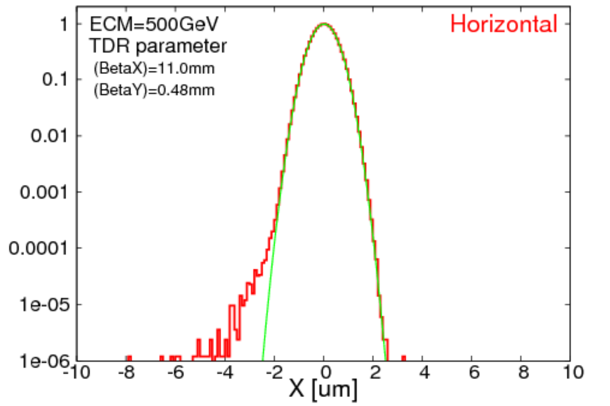
ECM=250GeV



ECM=350GeV

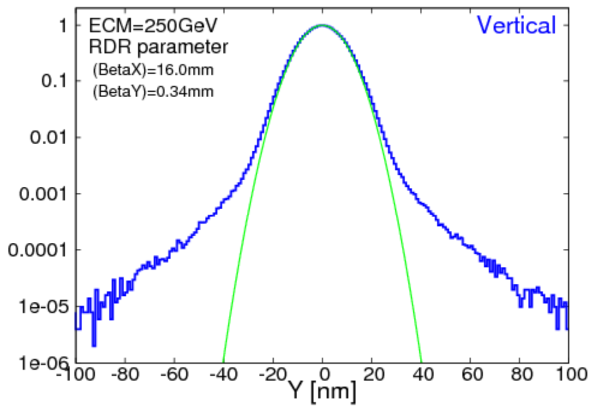


ECM=500GeV

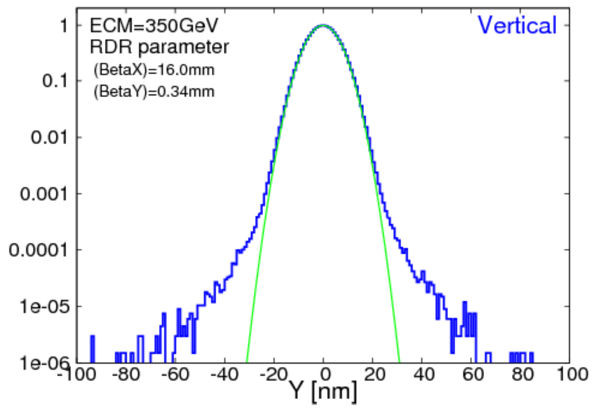


IP Vertical Profile

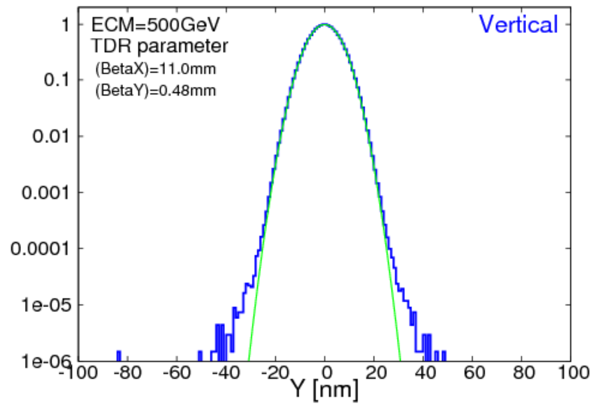
ECM=250GeV



ECM=350GeV



ECM=500GeV



The multipole effect for ECM=250GeV is huge compared to other parameters.

Since the horizontal profile was asymmetric, we could not correct with octupoles.

Summary of the IP beam size of the ILC BDS optics

		ECM=250GeV	ECM=350GeV	ECM=500GeV
Horizontal beam size	**design**	0.729 um	0.684 um	0.474 um
	core	0.749 um	0.685 um	0.478 um
	rms	0.756 um	0.705 um	0.489 um
Vertical beam size	**design**	7.66 nm	5.89 nm	5.86 nm
	core	7.84 nm	5.99 nm	5.90 nm
	rms	8.03 nm	6.08 nm	5.93 nm
Relative Luminosity (L/L0)		95.1 %	98.2 %	98.6%

-The TDR IP parameters was used for each beam energy.

-The beam size simulation was not included the effect of Synchrotron radiation.

-The multipole effects for ECM=250GeV was larger than others, and the final luminosity for ECM=250GeV is also smaller than others.

Tolerance Evaluation
for
ILC Final Focus System

IP Beam size tuning Simulation

Beam size minimization was simulated for the following conditions

Tuning knobs

1) Orbit correction

- *movers for quadrupoles .*
- *dipole correctors for bending magnets.*

2) IP-beam size tuning

- *sextupole position shift for linear optics*
- *skew and normal sextupole strength for 2nd order optics*

(same procedures to ATF2 tuning)

Monitors ; *Luminosity monitor (informations for X and Y are coupled)*

IP beam parameters

Beam Energy	125 GeV
gamma * emit (x/y)	10um / 35pm
momentum spread	0.19%
RDR IP beta function (x/y)	21 mm / 0.40mm
TDR IP beta function (x/y)	13mm / 0.41mm

Since ECM=250GeV is difficult to others, I evaluated the tolerances for ECM=250GeV.

Tolerances evaluation by IP-beam size tuning

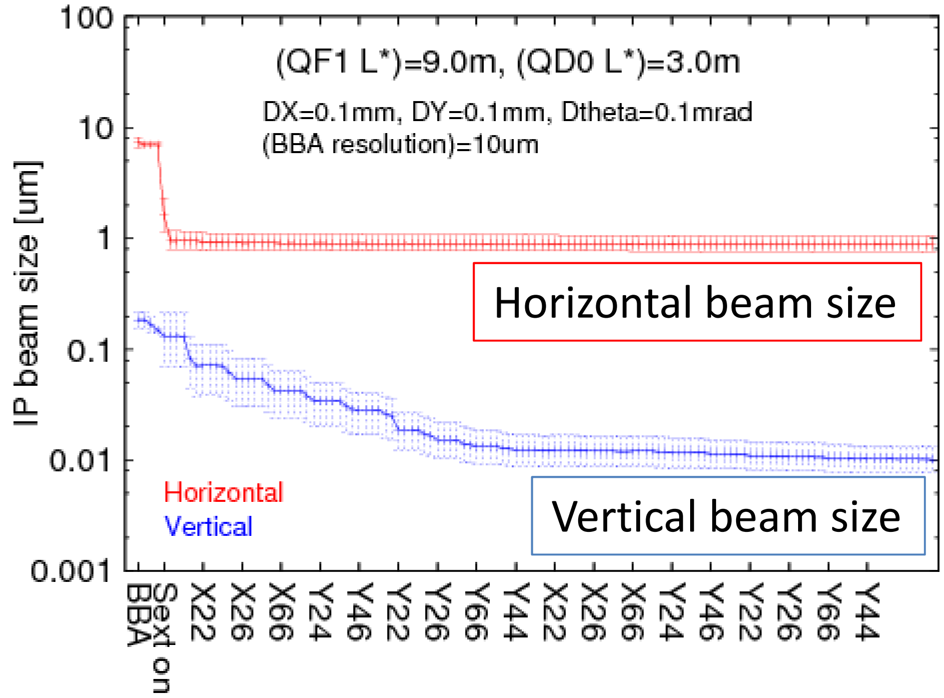
Procedures

1. *Put the errors for single parameter*
2. *Apply the orbit tuning*
3. *Tuned on the sextupole after sextupole BBA*
4. *Apply the linear and 2nd order optics tuning*

Example of the beam size minimization by the beam tuning simulation

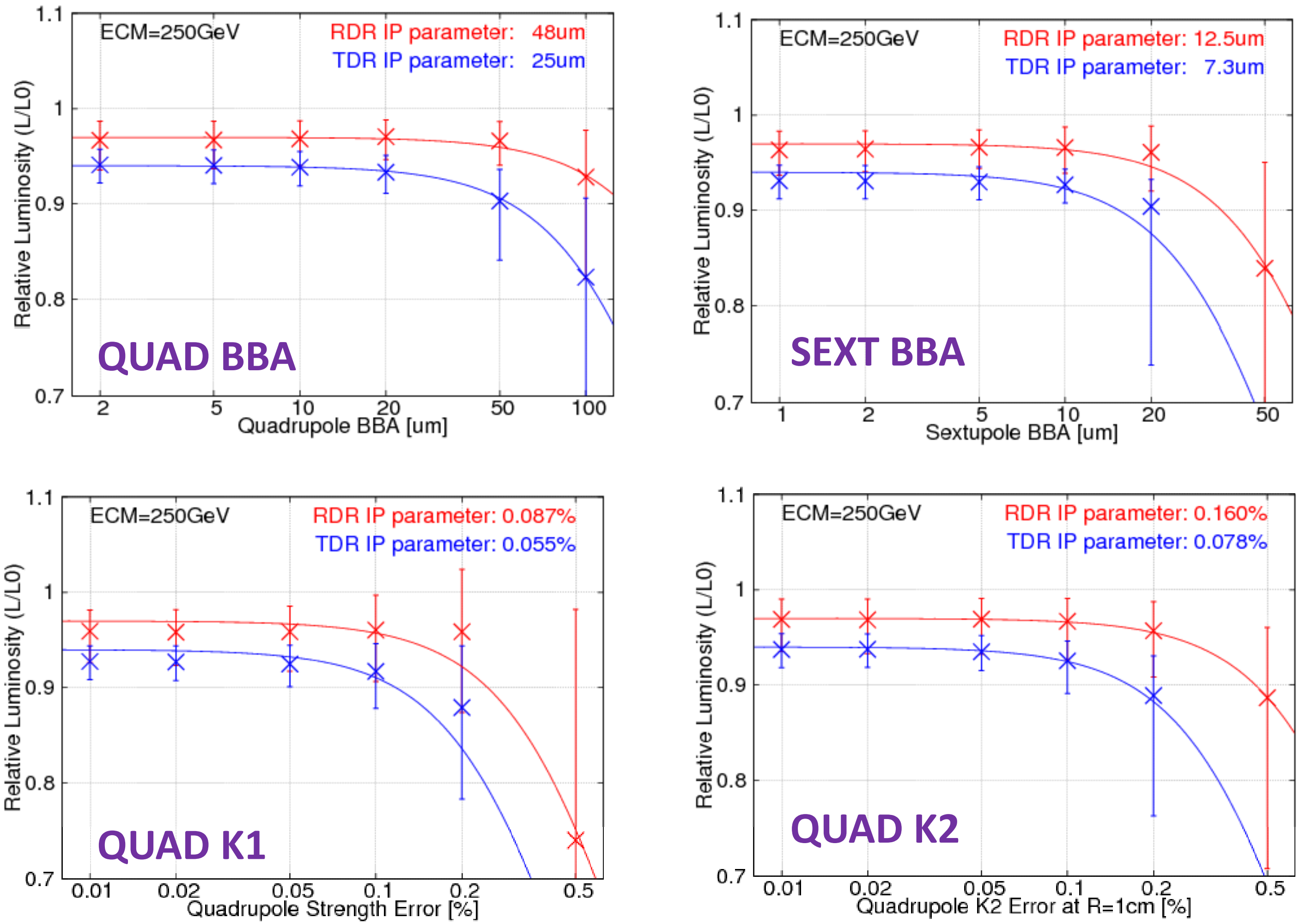
Alignment errors

	Bend	Quad	Sext
ΔK	0.1%	0.1%	0.1%
ΔX	N. A.	0.1mm	0.1mm
ΔY	N. A.	0.1mm	0.1mm
Δθ	0.1mrad	0.1mrad	0.1mrad



Example of tolerance evaluation

The tolerances were defined to
1% luminosity reduction of 100 seed average.



Summary of BDS Alignment Tolerances (ECM=250GeV)

1% average luminosity reduction

Red seems difficult.

Parameters			RDR (BX=21.0mm, BY=0.40mm)	TDR (BX=13mm, BY=0.41mm)
Quadrupole	Initial Alignment	Position	> 200um	> 200um
		Roll	0.20mrad	0.16mrad
	Strength	K1	0.087%	0.055%
		K2 at R=1cm	0.160%	0.078%
	BBA		48um	25um
Sextupole	Initial Alignment	Position	> 200um	> 200um
		Roll	> 1mrad	> 1mrad
	Strength		> 1%	0.60%
	BBA		12.5um	7.3um
Bending Magnet	Initial Alignment	Position	> 200um	> 200um
		Roll	> 1mrad	> 1mrad
	Strength		> 1%	> 1%
	BPM Alignment		103um	73um

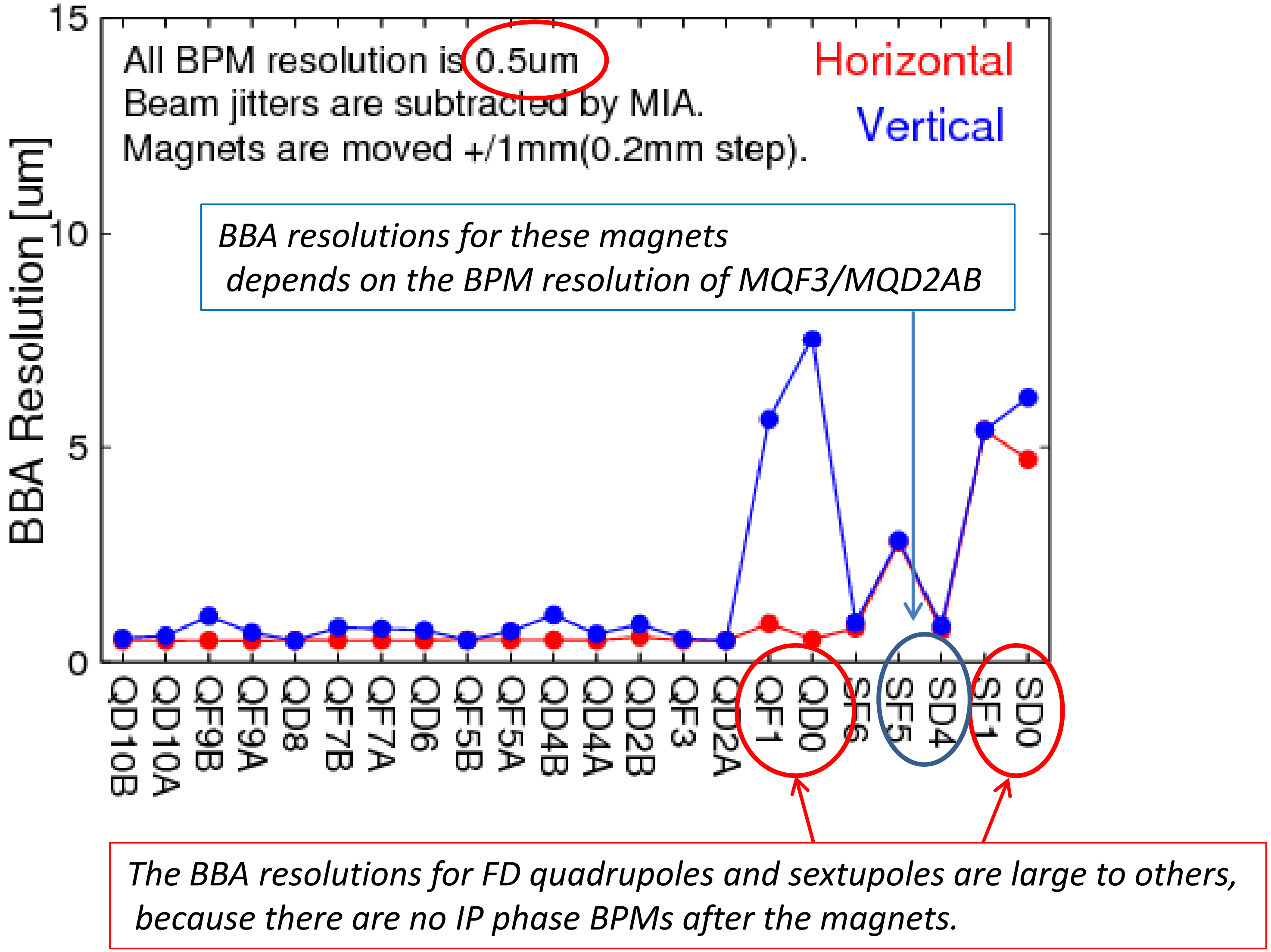
Simulation results said that

- the tolerances for TDR is 1.4times difficult to RDR for the errors related to linear optics .

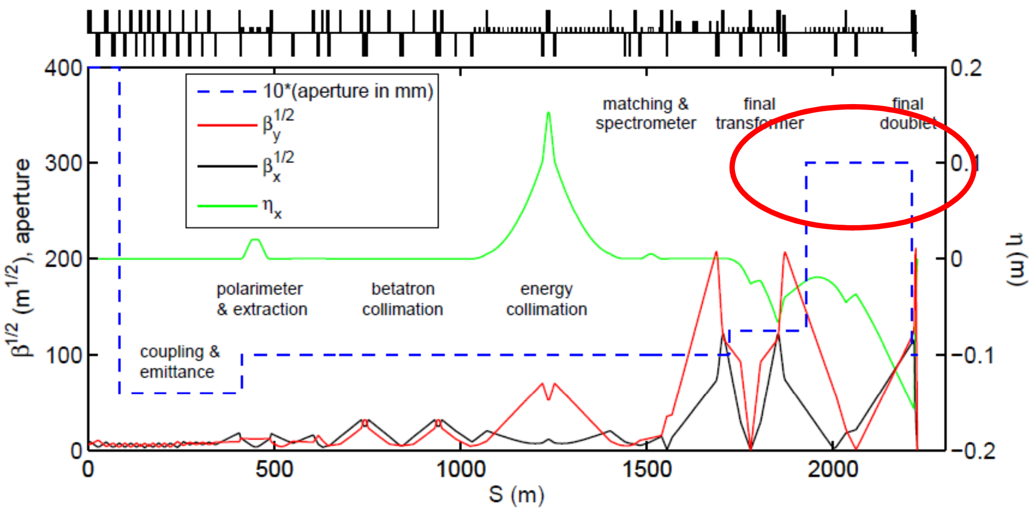
- the tolerances for TDR is 2.0times difficult to RDR for the errors related to 2nd order optics.

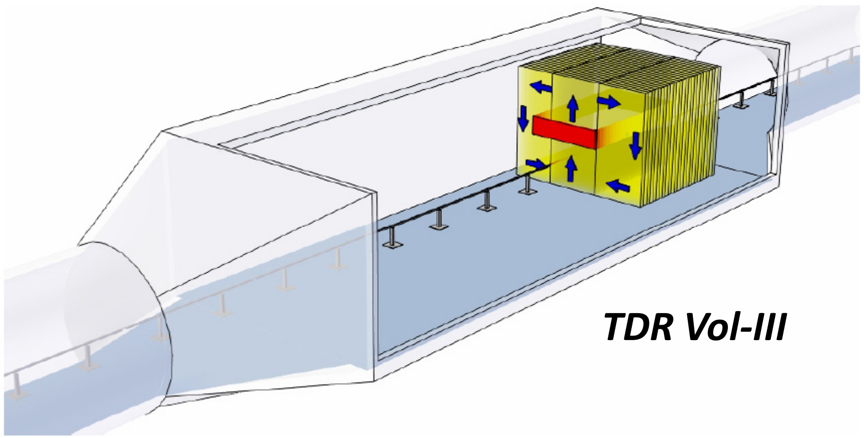
Evaluation of the BBA resolution

(*) The resolutions of C-band cavity BPMs
are typically around 0.2um for normal beam operation .



Muon spoiler and BPM resolution





In TDR, the aperture is designed to be very large after Muon spoiler.

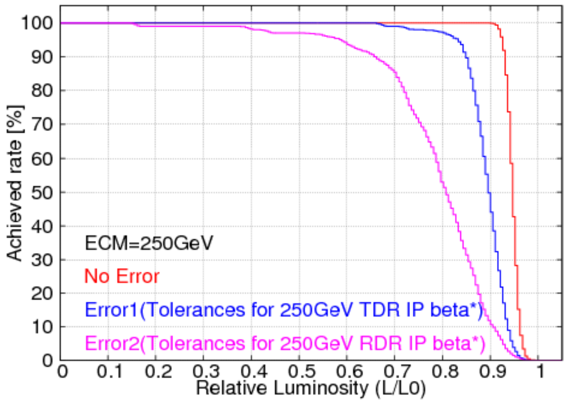
Then, L-band cavity BPM is used at this region.
The resolution is not good.

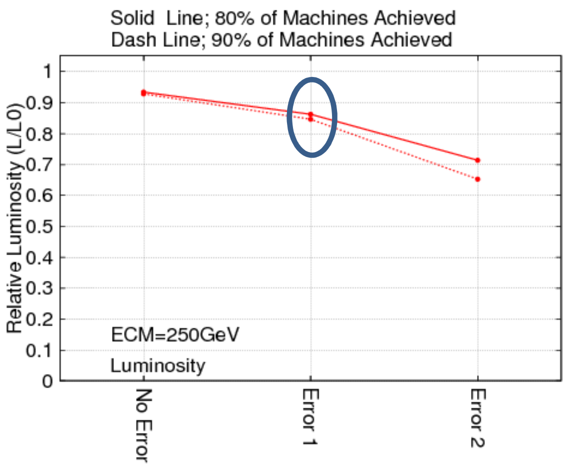
The BBA resolution is also not good.

- Evaluation of background after Muon spoiler
-Minimization of chamber aperture as small as possible
is very important
to get good BBA resolution.
to align the BPMS precisely.

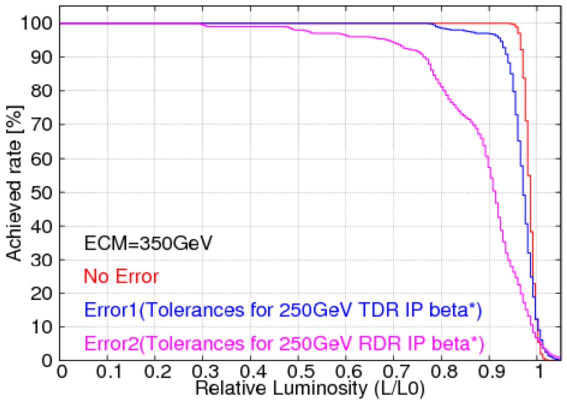
IP tuning simulation by putting total alignment errors

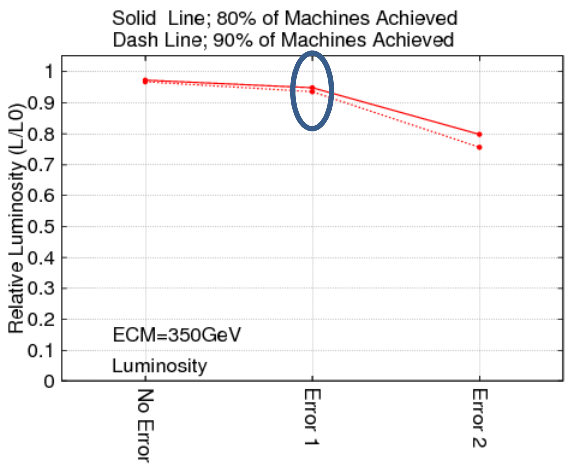
ECM=250GeV
TDR IP parameter



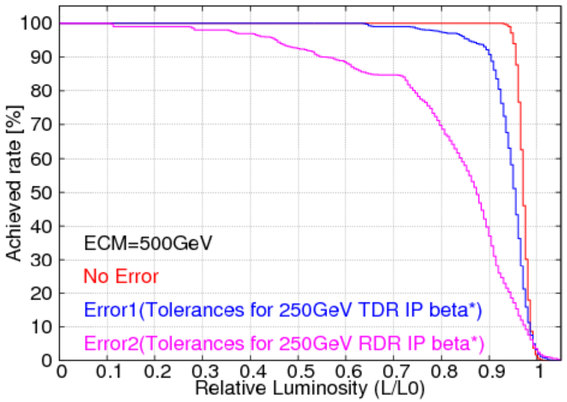


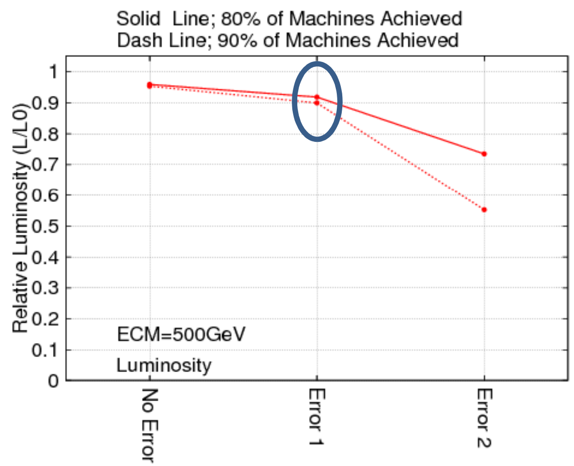
ECM=350GeV
TDR IP parameter





ECM=500GeV
TDR IP parameter





When the alignment error is increased by the factor 1.4/2.0, the achieved luminosity is reduced so much.

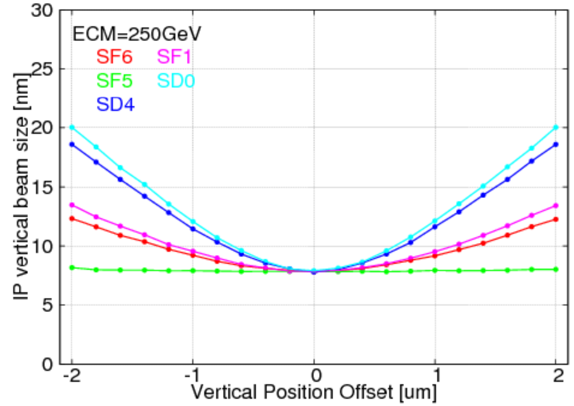
Tolerances for ECM=350GeV, 500GeV are easier than ECM=250GeV.

Requirement of the magnet movers

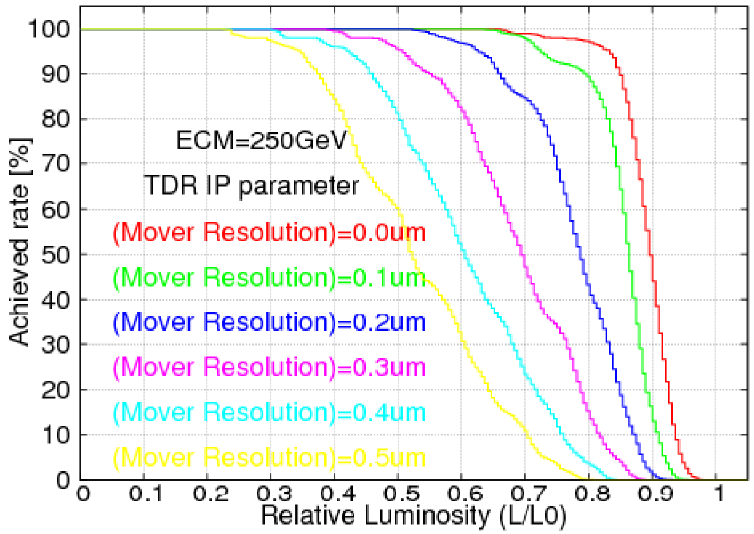
When the position of the sextupoles were moved by sub-micron, IP-beam size was increased so much.

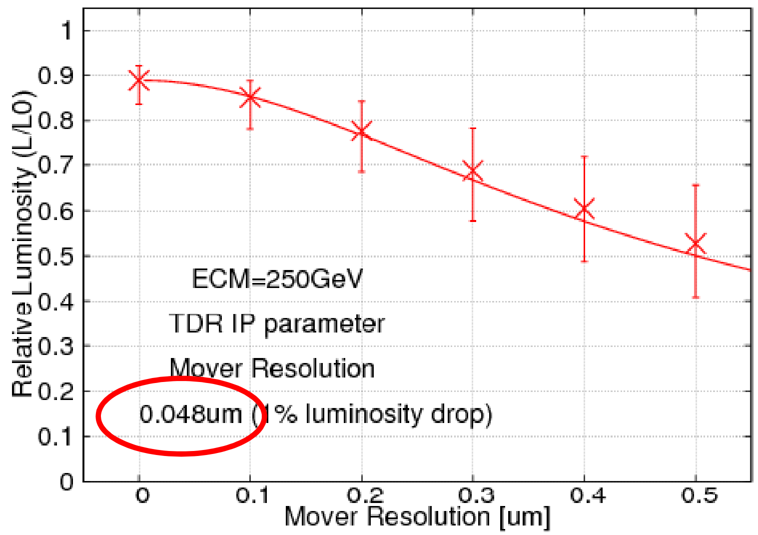
Therefore, the mover tolerances also evaluated by IP tuning simulation.

The tolerance is evaluated for ECM=250GeV, and TDR IP beta functions (betaX/betaY*= 13mm/0.41mm).*



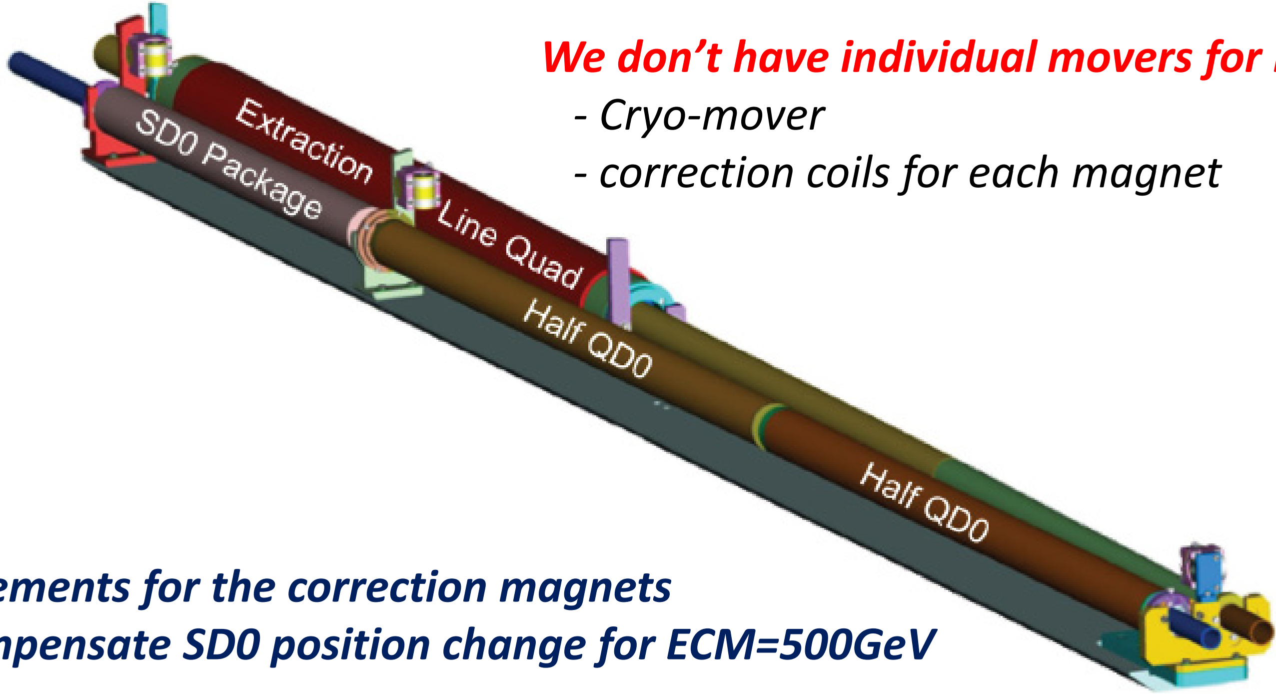
The alignment error is set to the tolerance for 250GeV TDR parameter.





This is one of the difficult requirement of ILC FF.

FD sextupole correction



We don't have individual movers for FD magnets.

- *Cryo-mover*
- *correction coils for each magnet*

Requirements for the correction magnets to compensate SD0 position change for ECM=500GeV

1. By using SD0 normal and skew quadrupole correction coils

+/-1mm dynamic range
0.05um resolution ➡ *GL = +/- 2.6 T*
5e-5 precision to maximum field

2. By using combination of Cryo-mover and QD0 dipole correctors

+/-1mm dynamic range
0.05um resolution ➡ *BL = +/- 0.27 Tm*
6e-5 precision to maximum field
(100nm of IP position offset was correct by intra-train FB)

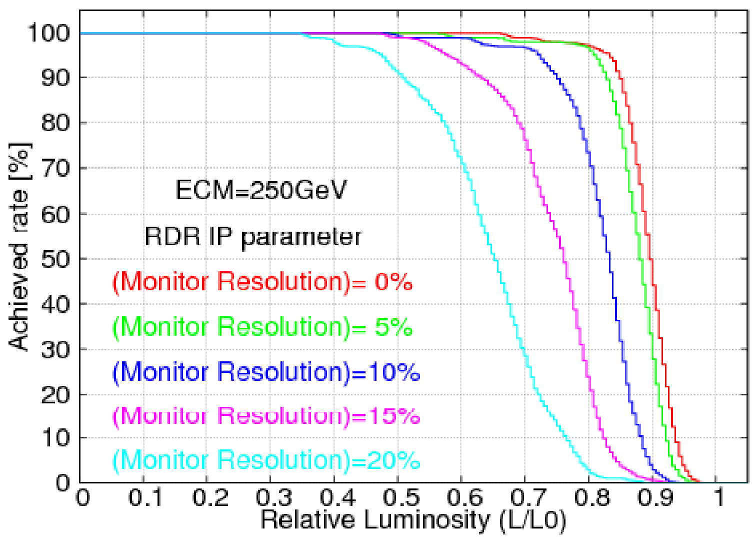
Requirement of Luminosity monitor resolution

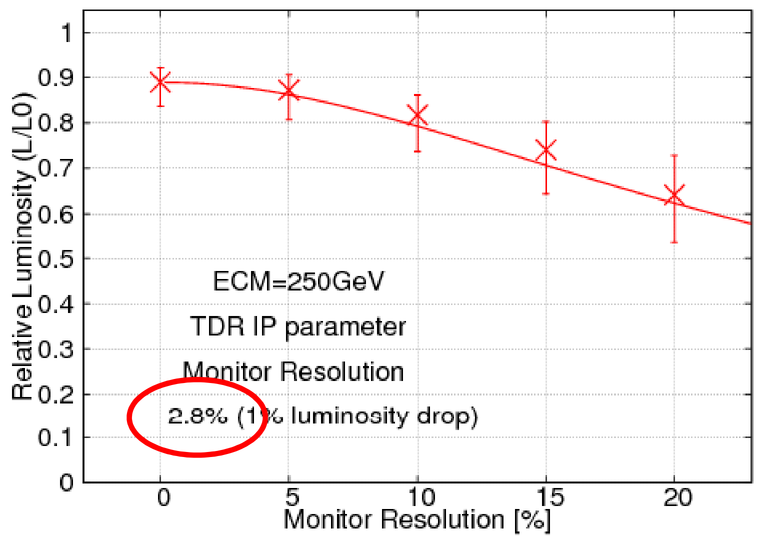
In present MDI-BDS design, the luminosity monitor will be
- Beamstrahlung monitor for large beam
- Incoherent pair monitor for small beam

The resolution requirement for IP beam size tuning also evaluated.

The tolerance is evaluated for ECM=250GeV,
and TDR IP beta functions (betaX/betaY*= 13mm/0.41mm).*

The alignment error is set to the tolerance for 250GeV TDR parameter.





Resolution of luminosity monitor should be less than 3%.

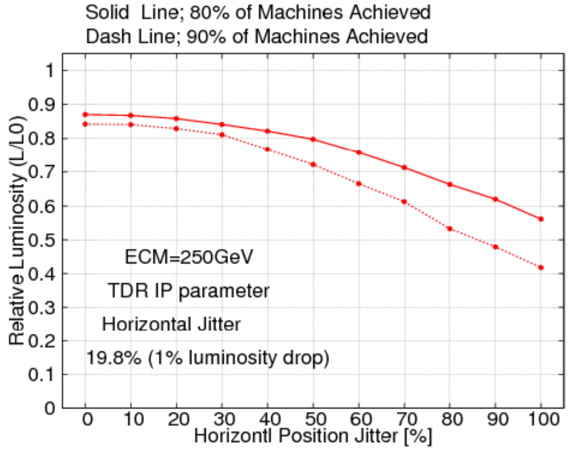
Tolerance of the beam jitter

The tolerance is evaluated for ECM=250GeV, and TDR IP beta functions (betaX/betaY*= 13mm/0.41mm).*

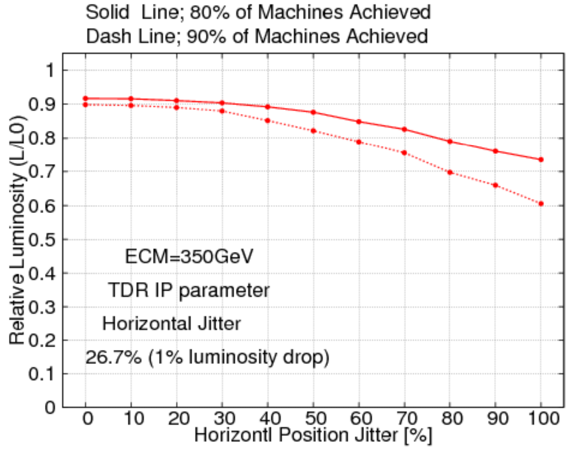
The alignment error is set to the tolerance for 250GeV TDR parameter.

Horizontal Beam Jitter

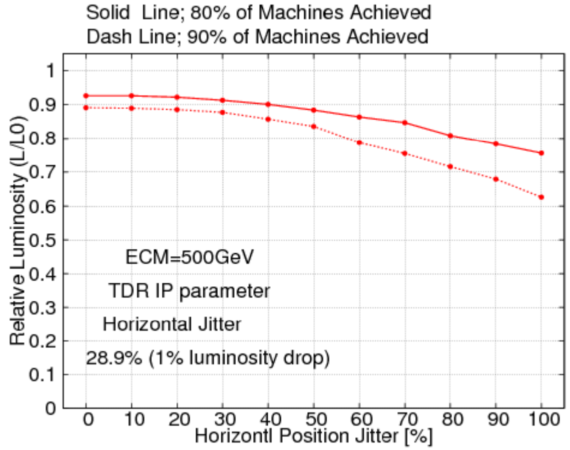
ECM=250GeV



ECM=350GeV

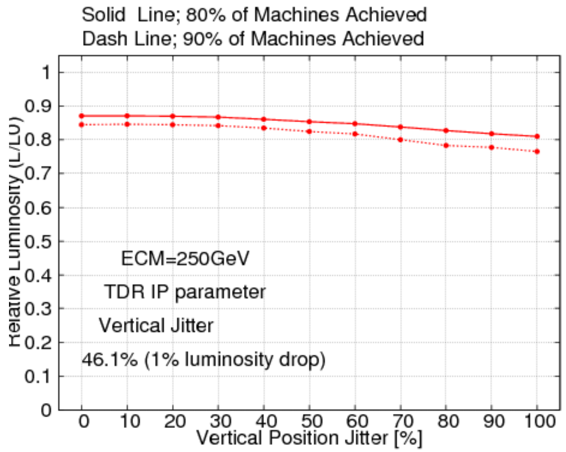


ECM=500GeV

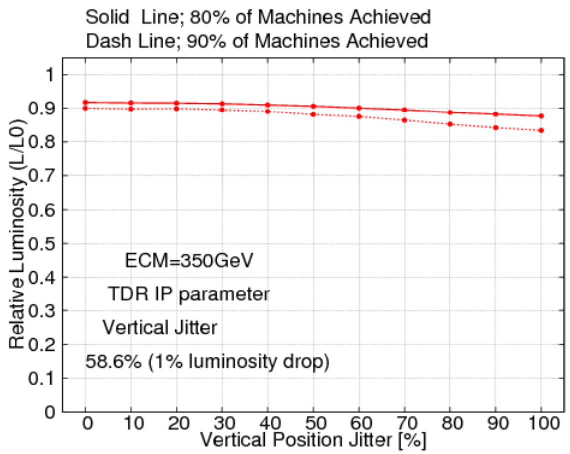


Vertical Beam Jitter

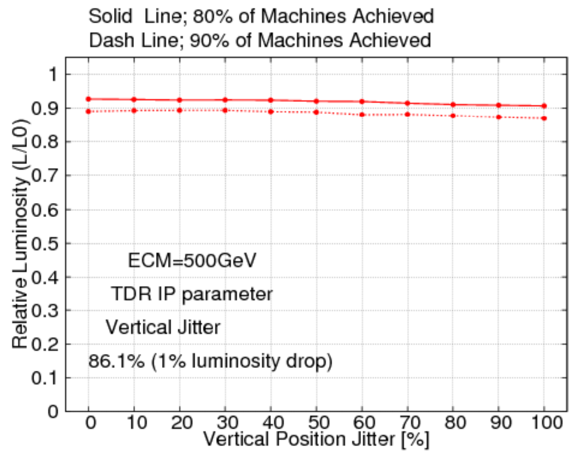
ECM=250GeV



ECM=350GeV



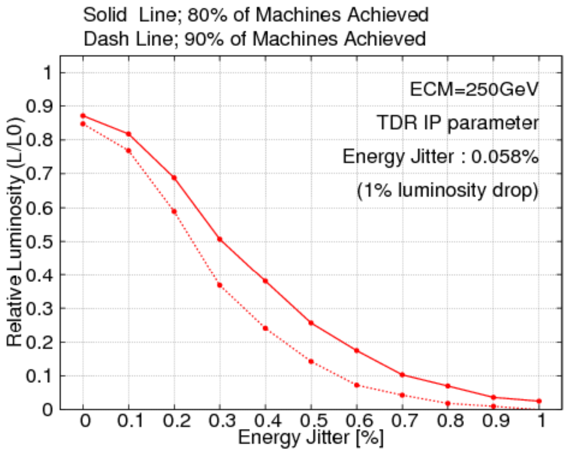
ECM=500GeV



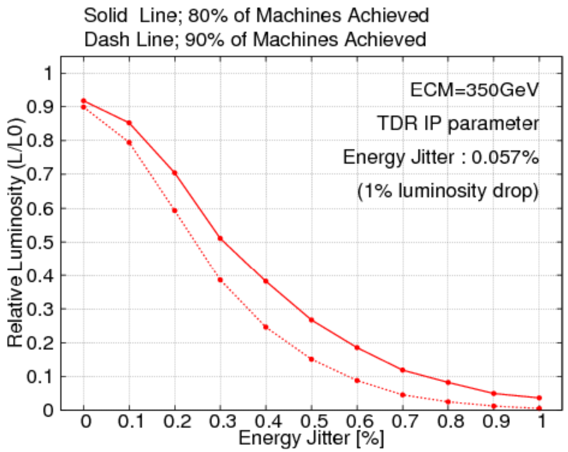
Tolerance of the beam jitter 2

Beam Energy Jitter

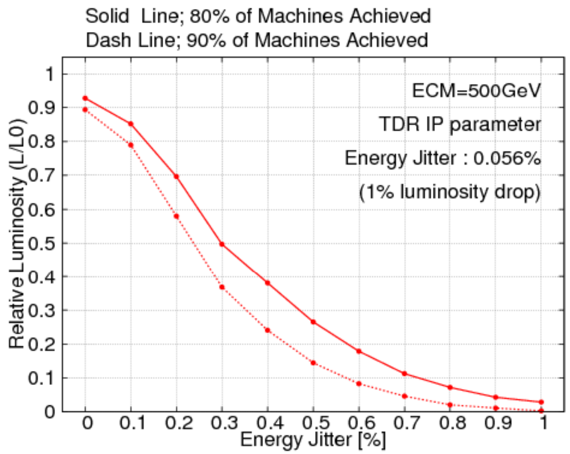
ECM=250GeV



ECM=350GeV



ECM=500GeV



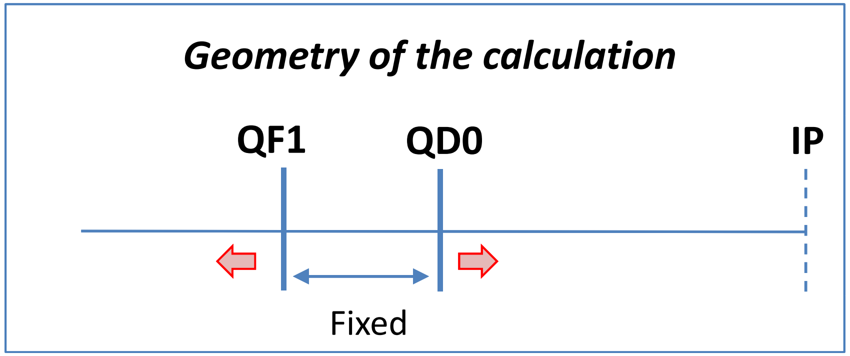
Summary of tolerances for beam jitter

	ECM=250GeV	ECM=350GeV	ECM=500GeV
Horizontal	19.8%	26.7%	28.9%
Vertical	46.1%	58.6%	86.1%
Energy	0.058%	0.057%	0.056%

Requirement of horizontal and vertical jitters for lower energy are tight, but not so tight.
Energy jitter should be 0.06% for all energy range.

Optics Performances for various QF1 and QD0 L (Information of CR2)*

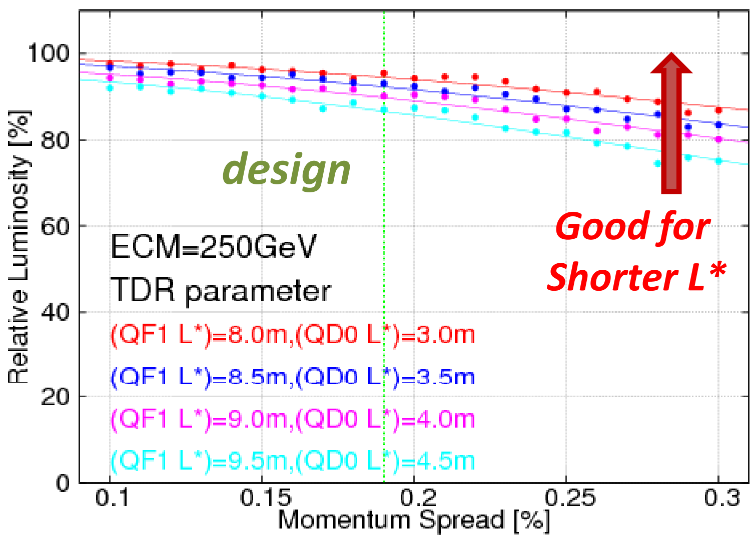
L dependence for same distance between QF1 and QD0*



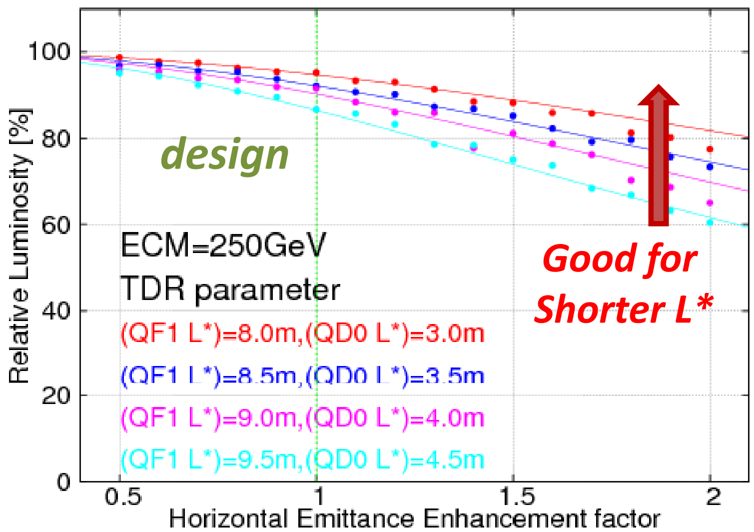
ECM = 250GeV
beta (x/y) = 13mm / 0.41mm*

(QF1 L) - (QD0 L*) = 5.0m*
(QF1 Length) = 1.0m (half length of TDR design)
(QD0 Length) = 2.2m

Momentum Spread

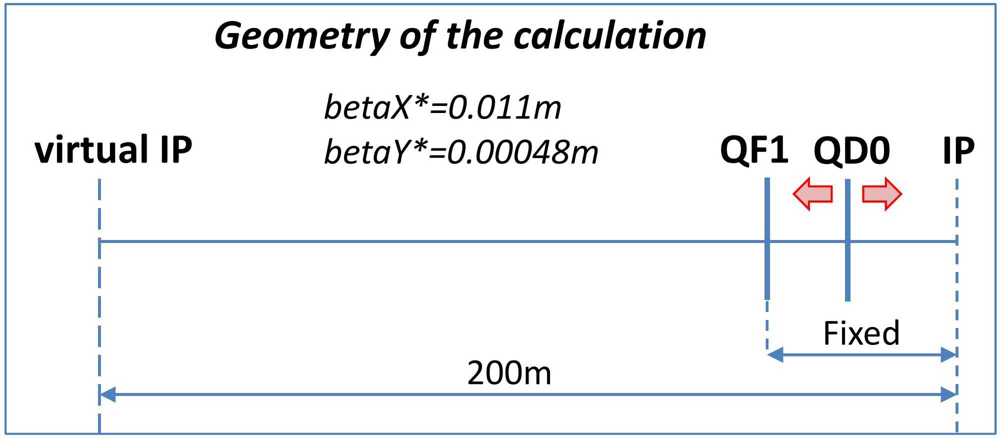


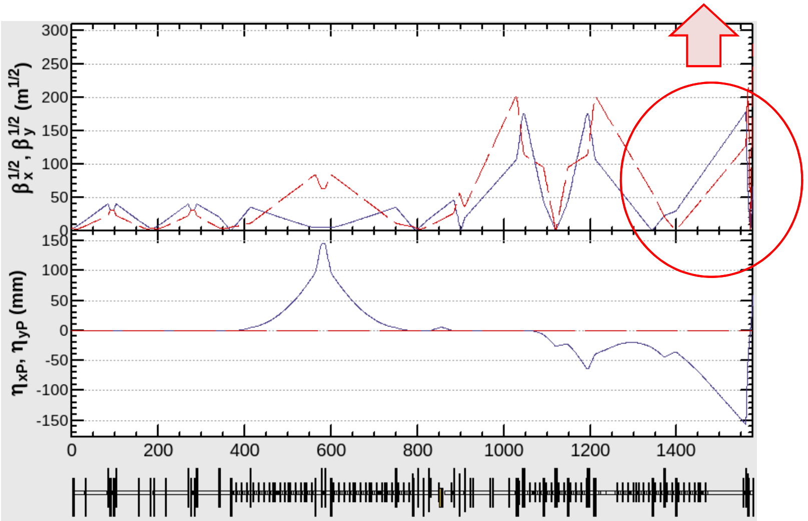
Horizontal Emittance



In generally, the performance of FF beamline is better as small L as possible.*

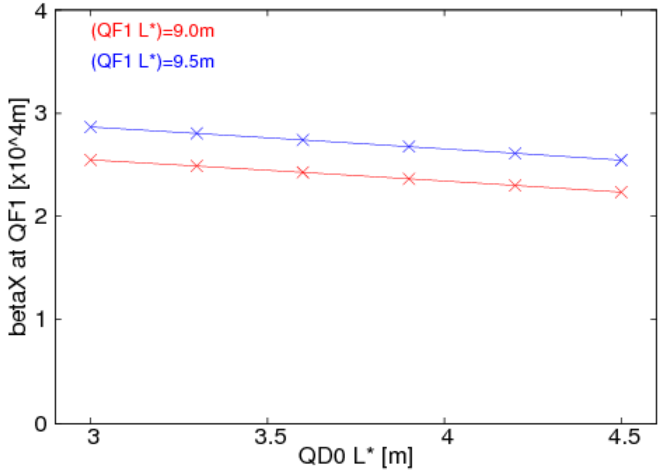
QD0 L* dependence, when QF1 position is fixed





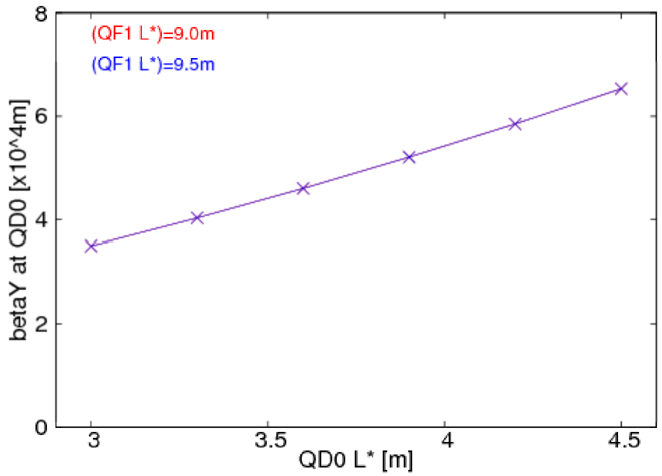
When QD0 is move to be closer to IP,
the horizontal beta function at QF1 is increased.

Horizontal beta function at QF1



Affect to the horizontal collimation depth

Vertical beta function at QD0

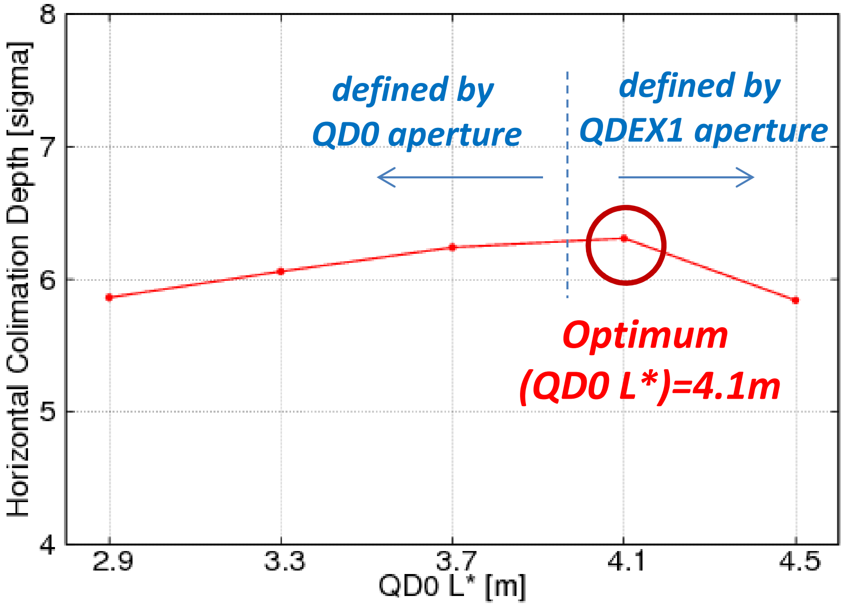


Affect to the vertical collimation depth

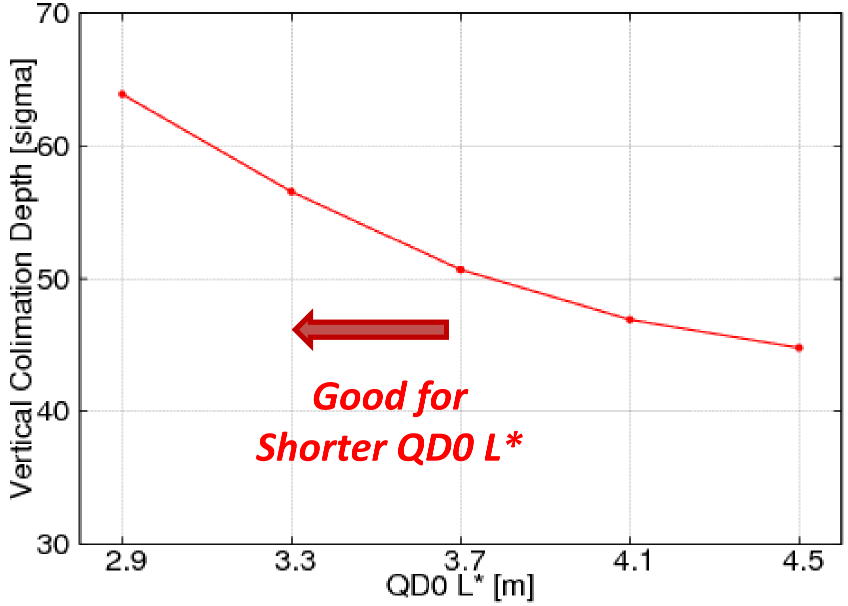
Effect of (QD0 L*) to collimation depth

ECM = 250GeV
beta* (x/y) = 13mm / 0.41mm
(QD0 L*) = variable , (QD0 Length) = 2.2m
(QF1 L*) = 9.5m, (QF1 Length) = 1.0m (half length of TDR design)

Horizontal Collimation Depth



Vertical Collimation Depth



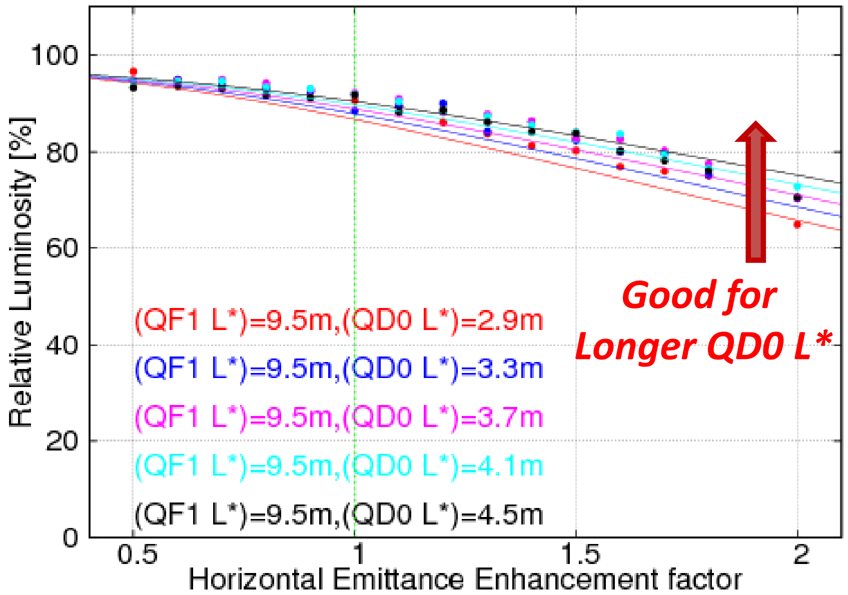
The horizontal collimation depth have small dependence to QD0 L.*
And the optimum QD0 L is 4.1m, when (QF1 L*) = 9.5m .*

The vertical collimation depth is larger for smaller QD0 L.*

Effect of (QD0 L*) to Luminosity

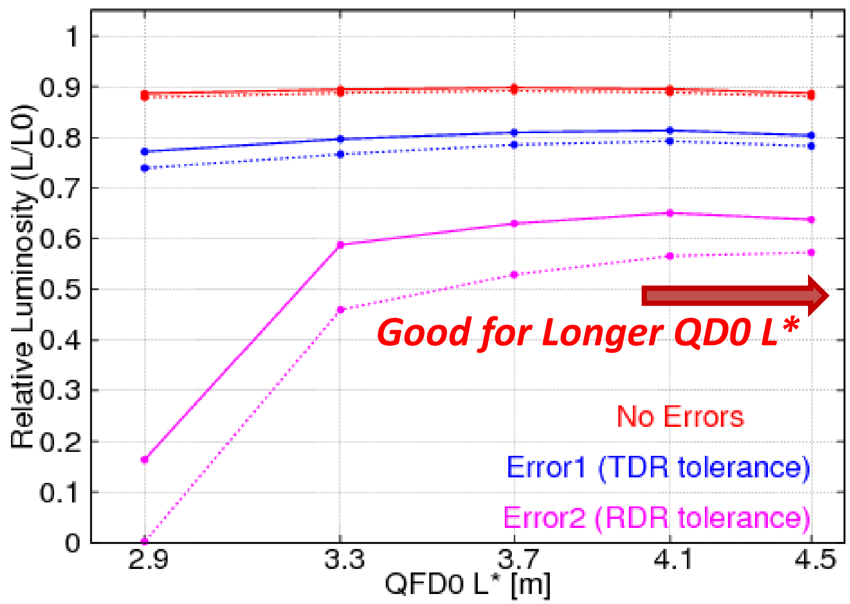
ECM = 250GeV
beta* (x/y) = 13mm / 0.41mm
(QD0 L*) = variable , (QD0 Length) = 2.2m
(QF1 L*) = 9.5m, (QF1 Length) = 1.0m (half length of TDR design)

Horizontal emittance dependence of relative luminosity



Relative Luminosity by Beam Tuning Simulation

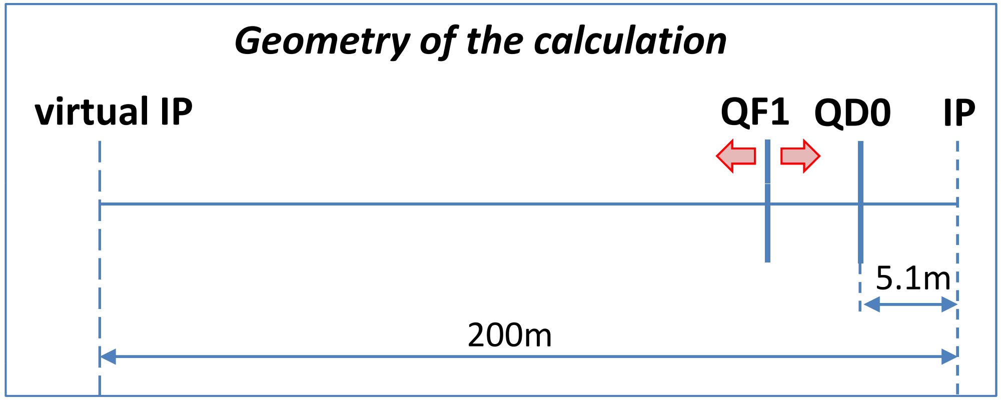
Solid Line; 80% of Machines Achieved
Dash Line; 90% of Machines Achieved

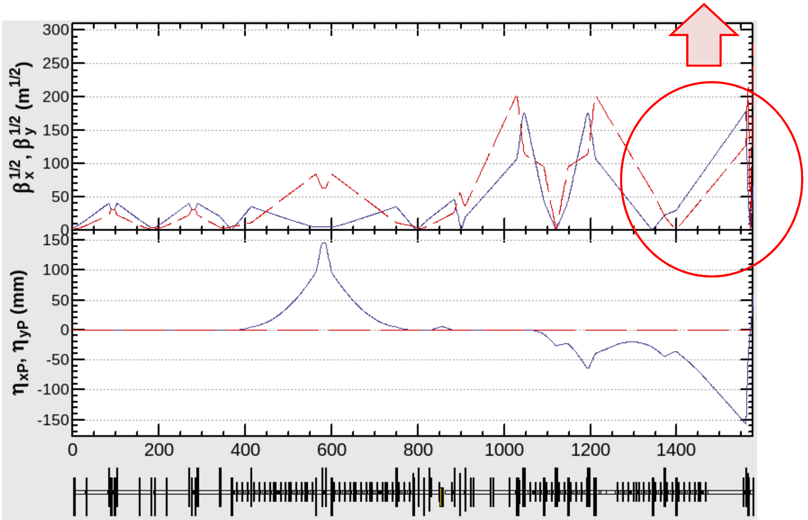


- When the horizontal beam size at FF beamline is increased, the luminosity reduction is small for longer QD0 L*.

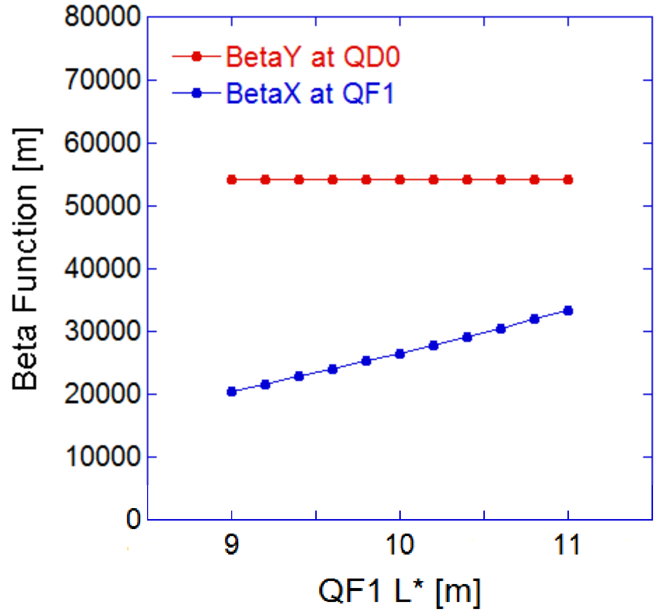
-The IP beam tuning simulation also said the longer QD0 L* is better.

QF1 L dependence, when QD0 position is fixed*





The beta functions at FD was calculated by thin lens approximation.



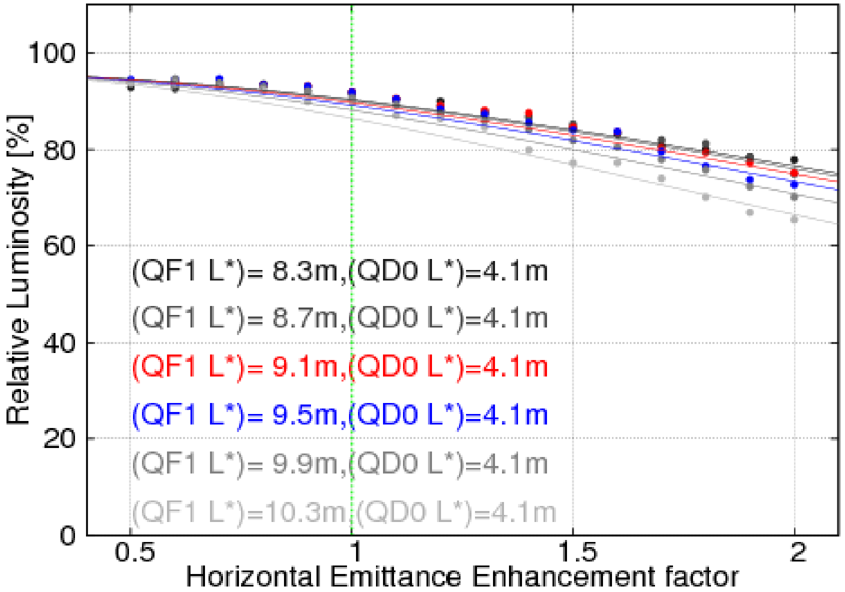
When QF1 is move to be closer to IP, the horizontal beta function at QF1 is decreased, by keeping the vertical beta function at QD0.

Since most of difficulties come from the horizontal beam size at QF1, we must optimize not only QD0 location, but also QF1 location carefully.

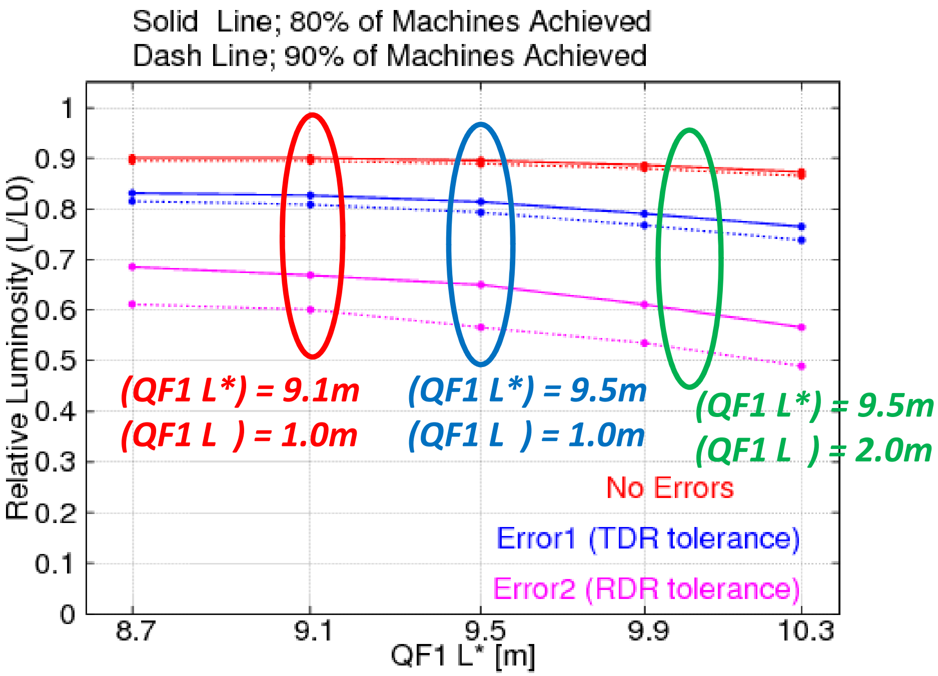
Effect of (QF1 L*) to Luminosity

ECM = 250GeV
beta (x/y) = 13mm / 0.41mm*
(QD0 L) = 4.1m , (QD0 Length) = 2.2m*
(QF1 L) = variable, (QF1 Length) = 1.0m (half length of TDR design)*

Horizontal emittance dependence of relative luminosity



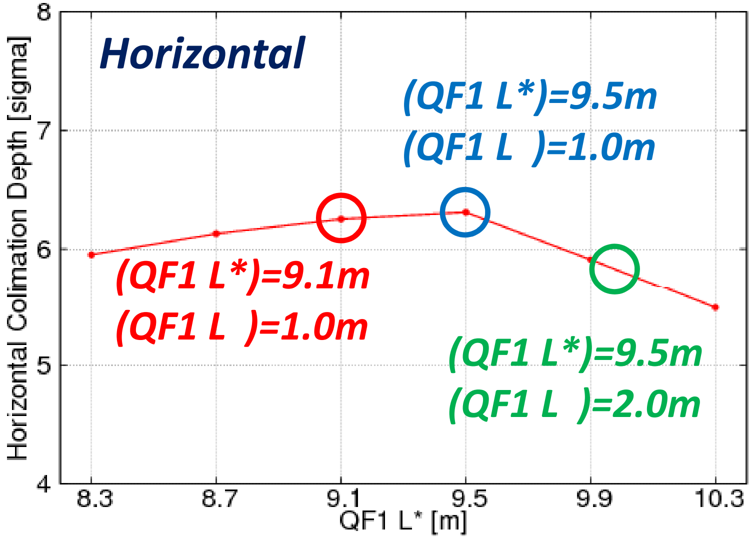
Relative Luminosity by Beam Tuning Simulation

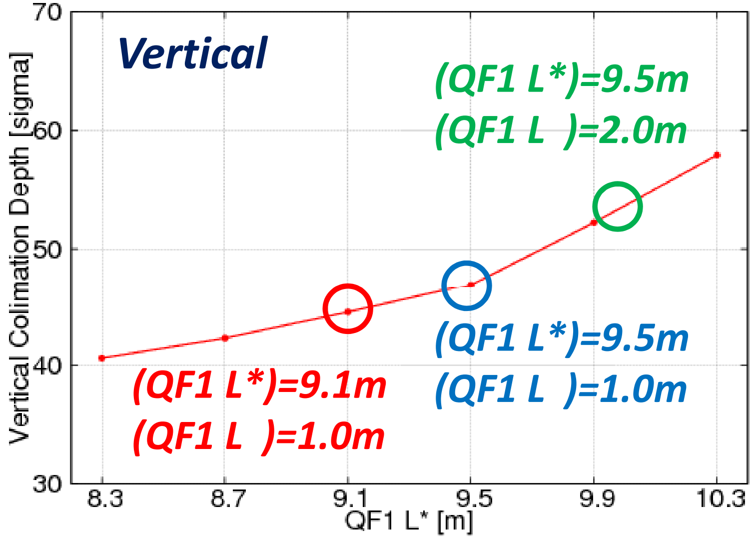


- *When the horizontal beam size at FF beamline is increased, the luminosity reduction is small for shorter QF1 L*.*
- *The IP beam tuning simulation also said the shorter QF1 L* is better.*

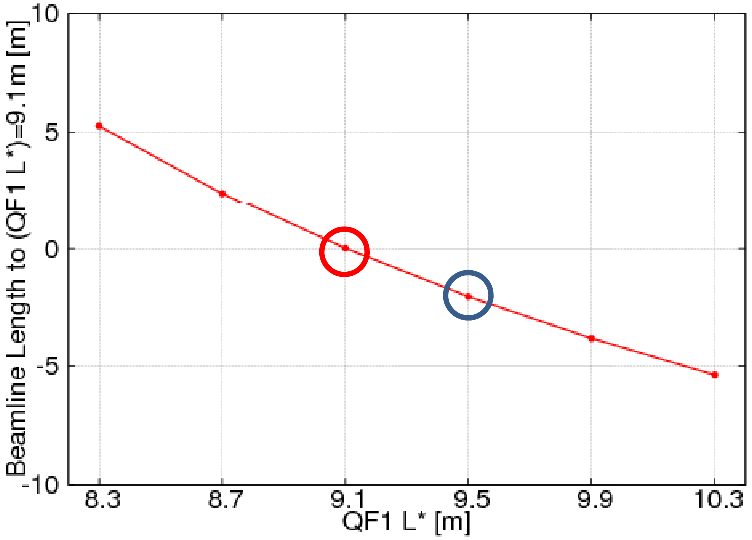
Other Consideration for (QF1 L*)=9.1m and 9.5m

Collimation Depth





FF Beamline Length



The X and Y collimation depths both for (QF1 L)=9.5m are a little bit larger than (QF1 L*)=9.1m.*

When we use the full length of QF1 magnet, the horizontal collimation lengths are smaller.

Optics for (QF1 L)=9.5m is about 2m shorter than (QF1 L*)=9.1m.*

Summary of ILC Final Focus Optics

The common L optics was made for ILD/SiD.*

In ECM=250GeV operation, the half length of final doublet will be used to increase the collimation depth.

We can increase the beam energy to ECM=1TeV by putting the additional magnets in same tunnel layout.

The tolerances for ILC final focus system were evaluated.

- *Field qualities of quadrupole*
- *BBA for sextupoles*
- *BPM alignment for bending magnets*
- *Resolution of sextupole mover*
- *Accuracy of FD correction coils*
- *Resolution of Luminosity monitor*

are difficult (but not impossible ??).

Summary of L issue*

When we change (QF1 L) and (QD0 L*) simultaneously,
the FF performances are better for shorter L*.*

When we change (QD0 L) by keeping (QF1 L*),
the IP beam tuning performance is better for longer (QD0 L*).*

When we change (QF1 L) by keeping (QD0 L*),
the IP beam tuning performance is better for shorter (QF1 L*).*

The shorter QF1 is helpful to improve the performance of FF beamline.

Comparison of (QF1 L)=9.1m and 9.5m with shorter QF1.*

- *The tolerances for horizontal emittance growth and IP beam size tuning are a little bit better for (QF1 L*)=9.1m.*
- *The horizontal and vertical collimation depths are a little bit better for (QF1 L*)=9.5m.*
- *Since the beamline length is different only by 2m for (QF1 L*)=9.1m and 9.5m, we can change the QF1 L* with small modification after the decision.*

(QD0 L*)=4.5m , (QF1 L*)=9.0m