Present ILC FF optics

2021/09/29

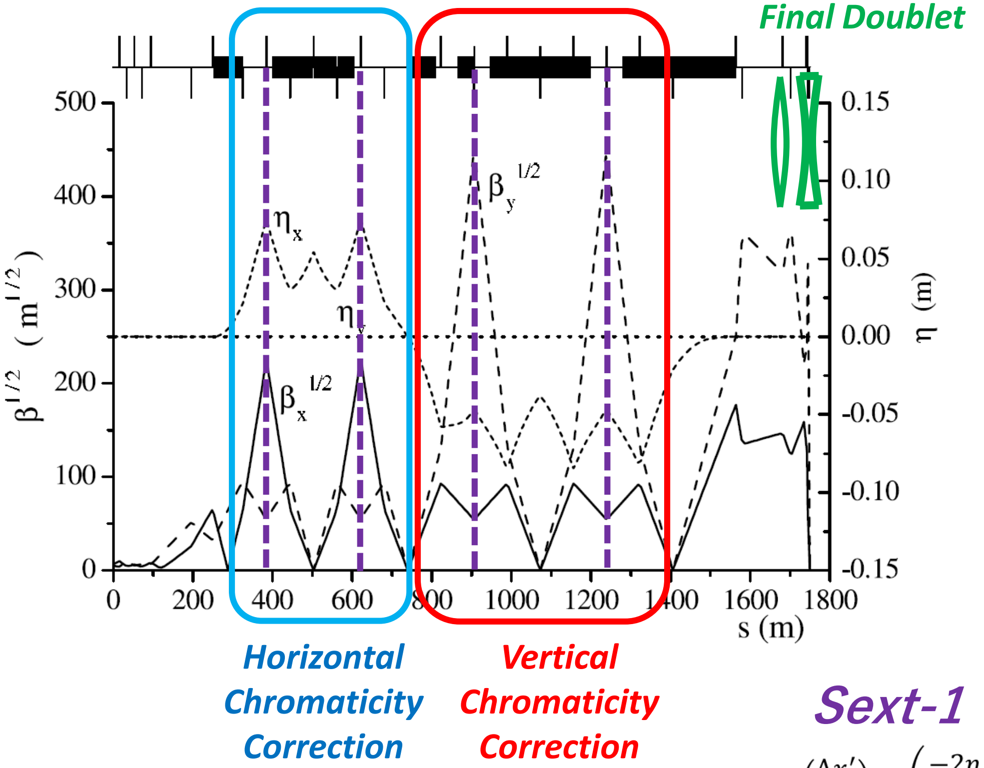
Toshiyuki OKUGI, KEK

IDT WG2 DR/BDS/DUMP group meeting

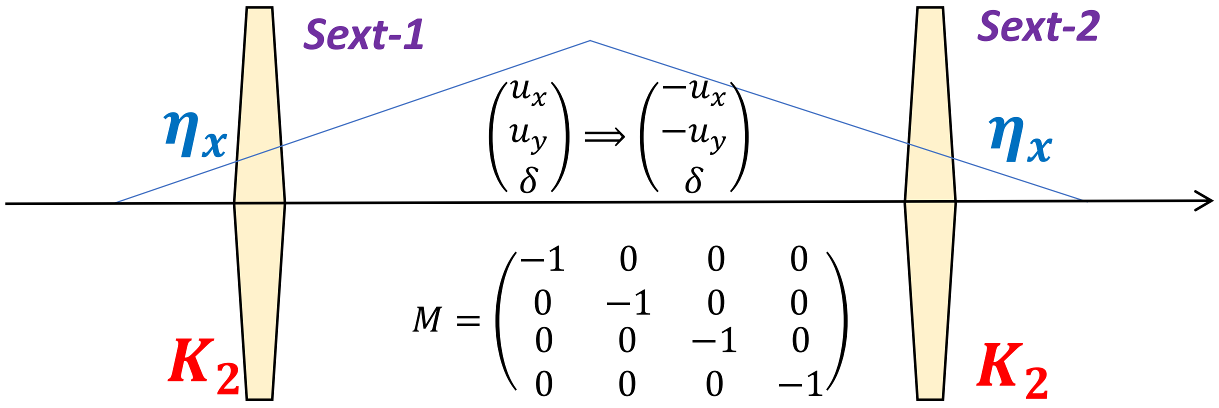
Basic ILC FFS optics design

Global Chromaticity Correction System

Linear collider FFS optics in 1990's



2 sextupoles are put to the following condition.



$$\begin{pmatrix} u_x \\ u_y \\ \delta \end{pmatrix} \Rightarrow \begin{pmatrix} -u_x \\ -u_y \\ \delta \end{pmatrix}$$

$$M = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

Sext-1

$$\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = \begin{pmatrix} -2\eta_x K_2 \sqrt{\beta_x}\, u_x \delta \\ +2\eta_x K_2 \sqrt{\beta_y}\, u_y \delta \end{pmatrix} + K_2 \begin{pmatrix} \beta_y u_y^2 - \beta_x u_x^2 - \eta_x^2 \delta^2 \\ 2\sqrt{\beta_x \beta_y}\, u_x u_y \end{pmatrix} \Rightarrow \begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = -\begin{pmatrix} -2\eta_x K_2 \sqrt{\beta_x}\, u_x \delta \\ +2\eta_x K_2 \sqrt{\beta_y}\, u_y \delta \end{pmatrix} - K_2 \begin{pmatrix} \beta_y u_y^2 - \beta_x u_x^2 - \eta_x^2 \delta^2 \\ 2\sqrt{\beta_x \beta_y}\, u_x u_y \end{pmatrix}$$

$$+$$

Sext-2

$$\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = -\begin{pmatrix} -2\eta_x K_2 \sqrt{\beta_x}\, u_x \delta \\ +2\eta_x K_2 \sqrt{\beta_y}\, u_y \delta \end{pmatrix} + K_2 \begin{pmatrix} \beta_y u_y^2 - \beta_x u_x^2 - \eta_x^2 \delta^2 \\ 2\sqrt{\beta_x \beta_y}\, u_x u_y \end{pmatrix}$$

$$\Downarrow$$

Total

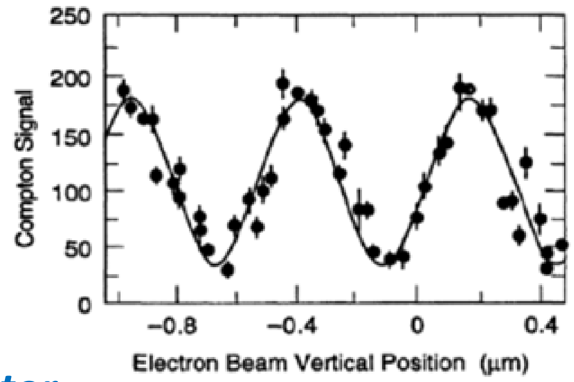
$$\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = \underbrace{\begin{pmatrix} +4\eta_x K_2 \sqrt{\beta_x}\, u_x \delta \\ -4\eta_x K_2 \sqrt{\beta}\, u_y \delta \end{pmatrix}}_{\text{Chromaticity}}$$

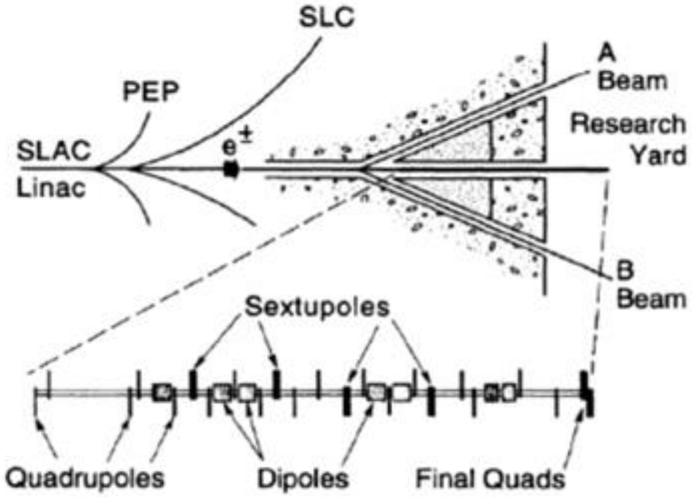
Only chromaticities are generated as total system.

Final Focus Test Beam (FFTB)

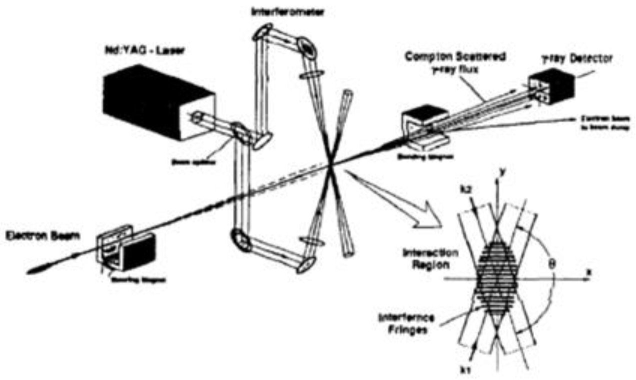
*FFTB is built in SLC research yard (SLAC) for the LC final focus test with **global chromticity correction system** in 1990’s.*

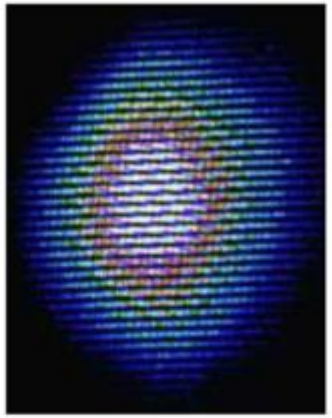
	IP beam size
Design	45 nm
Achieved	70 nm





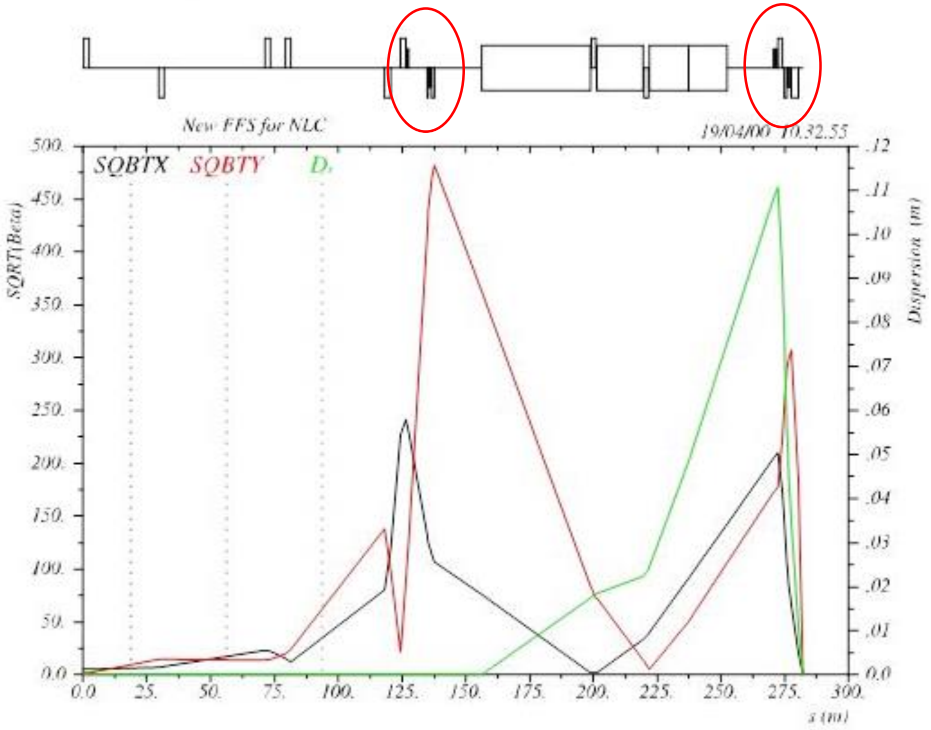
Shintake Monitor

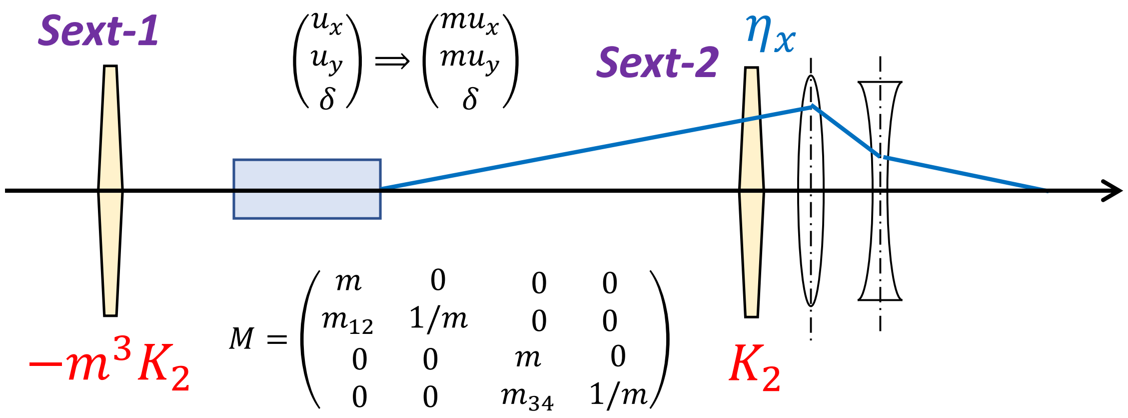




Local Chromaticity Correction System

P. Raimondi and A. Seryi, PRL Vol. 86 3779 (2001)





Sext-1 $\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = -m^3 K_2 \begin{pmatrix} \beta_y u_y^2 - \beta_x u_x^2 \\ 2\sqrt{\beta_x \beta_y}\, u_x u_y \end{pmatrix} \Rightarrow \begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = -m^2 K_2 \begin{pmatrix} \beta_y u_y^2 - \beta_x u_x^2 \\ 2\sqrt{\beta_x \beta_y}\, u_x u_y \end{pmatrix}$

+

Sext-2 $\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = \begin{pmatrix} -2m\,\eta_x K_2 \sqrt{\beta_x}\, u_x \delta \\ +2m\,\eta_x K_2 \sqrt{\beta}\;\; u_y \delta \end{pmatrix} + m^2 K_2 \begin{pmatrix} \beta_y u_y^2 - \beta_x u_x^2 - \eta_x^2 \delta^2 / m^2 \\ 2\sqrt{\beta_x \beta_y}\, u_x u_y \end{pmatrix}$

$\Downarrow$

Total $\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = \underbrace{\begin{pmatrix} -2m\,\eta_x K_2 \sqrt{\beta_x}\, u_x \delta \\ +2m\,\eta_x K_2 \sqrt{\beta_y}\, u_y \delta \end{pmatrix}}_{\text{Chromaticity}} + \underbrace{\begin{pmatrix} -K_2 \eta_x^2 \delta^2 \\ 0 \end{pmatrix}}_{\text{2nd order dispersion}}$

Chromaticity **2nd order dispersion**

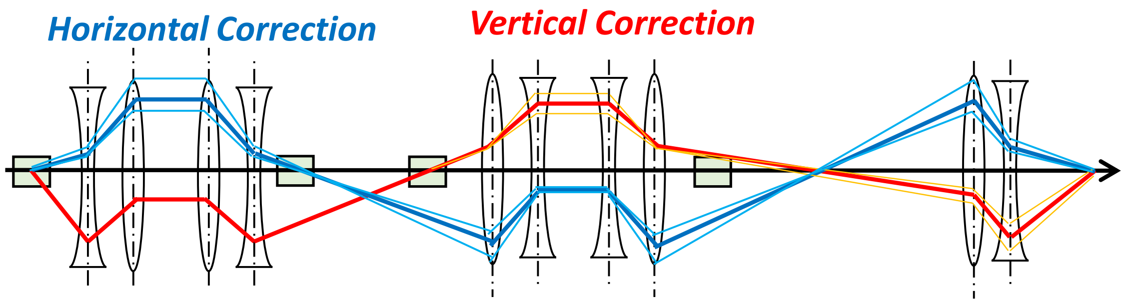
Geonetrical aberration was cancelled.

	X chromaticity	Y chrotaticity	2nd order dispersion
Linear Optics	○	○	○
X chromaticity corr.	○	△ (small)	○
Y chromaticity corr.	△ (small)	○	○

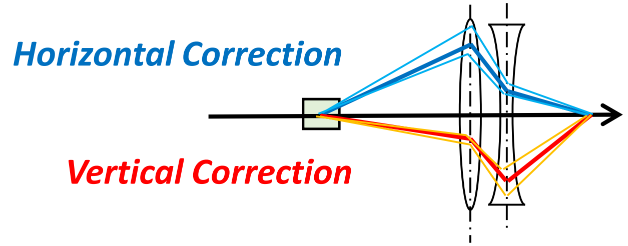
When chroticity correction knobs (sextupoles) are changed.
=> 2nd order dispersion is changed. (linear optics and sextupoles are coupled.)
=> Liniear optics must be changed.

Advantage of local chromaticity correction optics

Global Chromaticity Correction



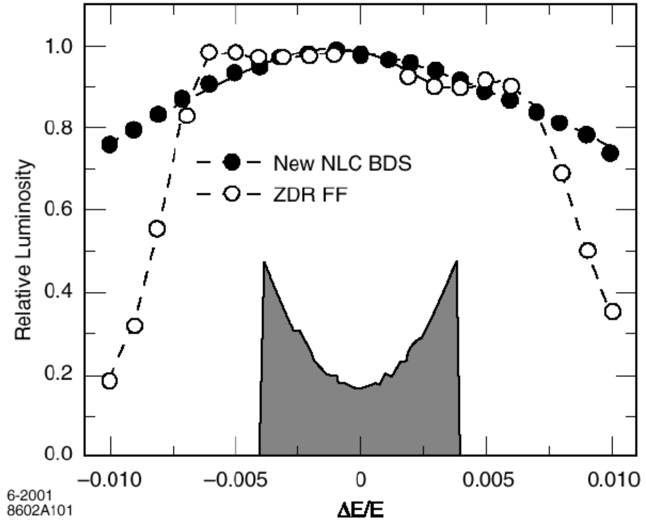
Local Chromaticity Correction



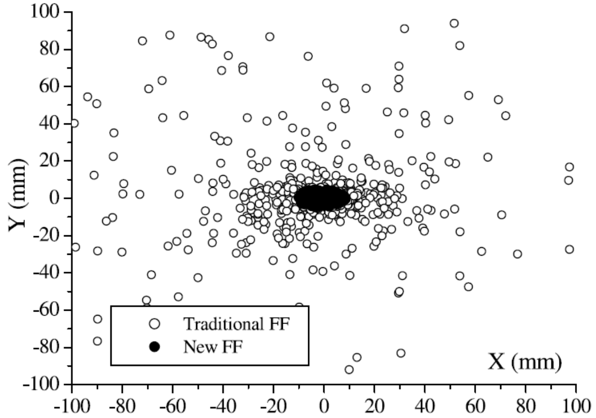
- *The beamline length is shorter than that for the global chromaticity correction system*

- *Orbit distortion through long beamline of off-momentum particle exists for global chromaticity correction beamline.*
  - *Longer L**
  - *Smaller background by the halo particles*
  - *Wider energy bandwidth*

IP Energy Bandwidth



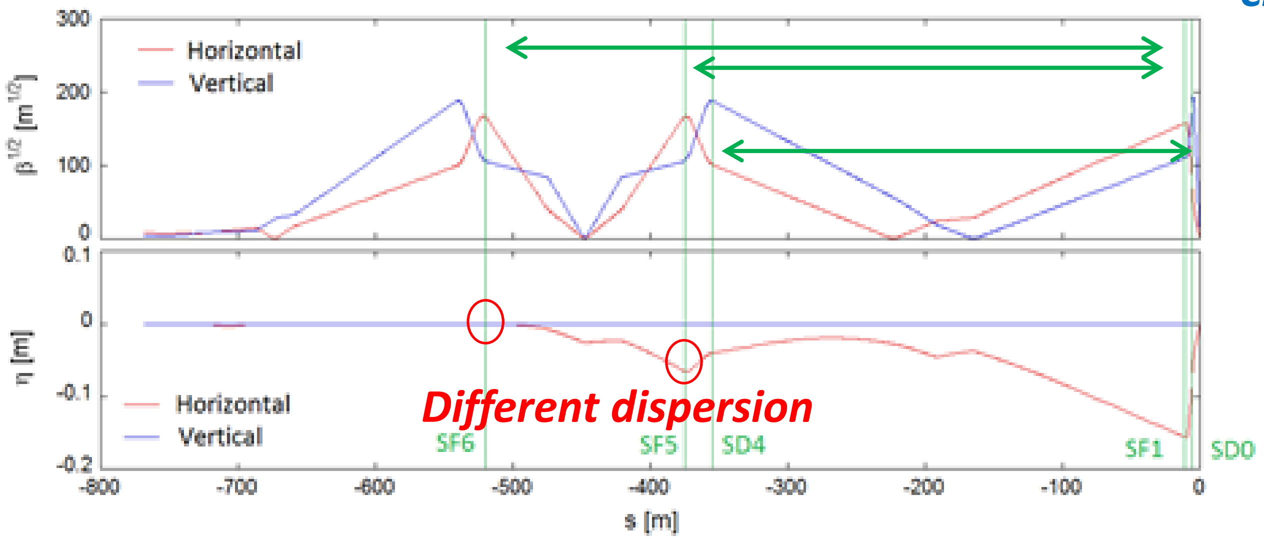
Beam Halo at IP



P. Raimondi and A. Seryi, PRL Vol. 86 3779 (2001)

Present ILC Final Focus Optics

We adopted the modified Local Chromaticity Correction Optics.



3 parameters to be corrected
- *X Chromaticity*
- *Y Chromaticity*
- *2^{nd} order Dispersion*

2 sext. pair for correction
- *SF6, SF5 (combination) and SF1*
- *SD4 and SD0*

We can correct 2^{nd} order aberration
- *only with sextupole magnet.*
- ***without linear optics change.***

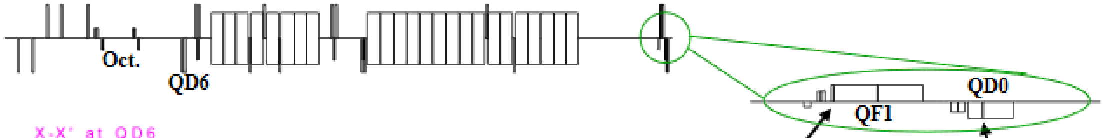
Chromaticities of quad/sext in ILC FF beamline

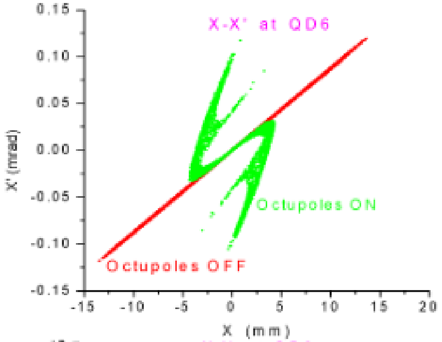
Name	X	Y
QD10B	-131.9	757.6
QD10A	-168.7	673.4
QF9B	437.4	-377.5
SF6	0.0	0.0
QF9A	460.6	-295.4
QD8	-45.0	379.0
QF7B	0.2	-1.2
QF7A	0.2	-1.2
QD6	-45.0	379.0
QF5B	460.9	-295.6
SF5	155.6	-112.9
QF5A	437.6	-377.8
QD4B	-162.6	650.6
SD4	1238.1	-6089.7
QD4A	-126.0	736.6
QD2B	0.0	-3.9
QF3	5.8	-7.5
QD2A	-13.7	0.1
SF1	-9095.3	4954.9
QF1	4830.8	-2934.4
SD0	2497.5	-12835.6
QD0	-1002.9	14564.7
Total	-266.5	-236.9

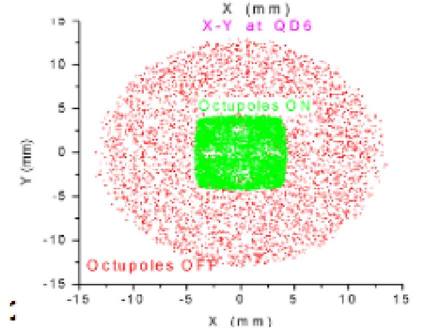
- *The chromaticities are generated not only Final Doublet, but also other quadrupoles.*
- *The chromaticities are corrected by sextupole magnets within the Final Focus Beamline.*
- *The large chromaticities are generated by sextupole near by Final Doublet. (Not perfect local correction)*

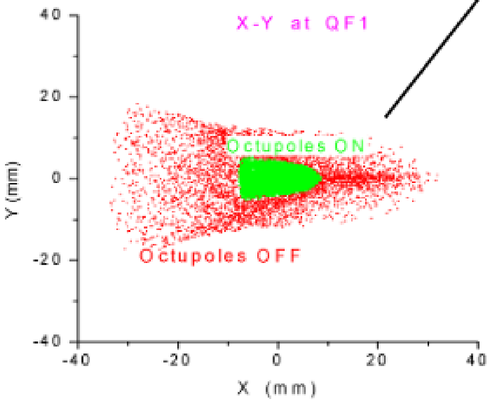
Tail folding in ILC FF

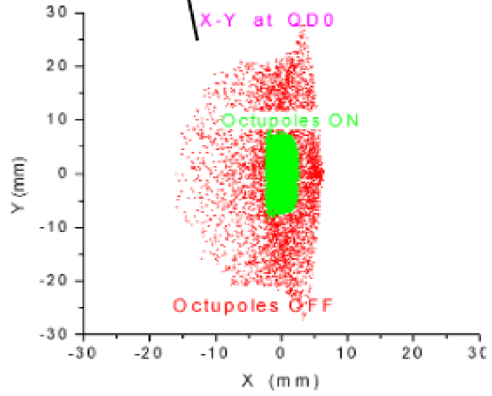
- Two octupole doublets give tail folding by ~ 4 times in terms of beam size in FD
- This can lead to relaxing collimation requirements by ~ a factor of 4











Tail folding by means of two octupole doublets in the ILC final focus
Input beam has (x,x',y,y') = (14µm,1.2mrad,0.63µm,5.2mrad) in IP units (flat distribution, half width) and ±2% energy spread, that corresponds approximately to N_σ=(65,65,230,230) sigmas with respect to the nominal beam

- Two octupoles of different sign separated by drift provide focusing in all directions for parallel beam:

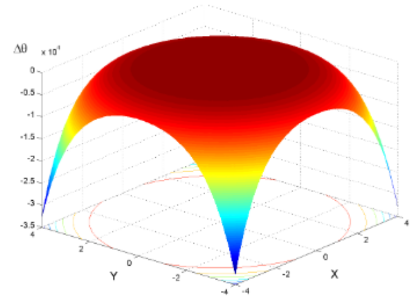
$$\Delta\theta = \alpha r^3 e^{-i3\varphi} - \left(\alpha r^3 e^{i3\varphi}\left(1+\alpha r^2 L e^{-i4\varphi}\right)^3\right)^*$$

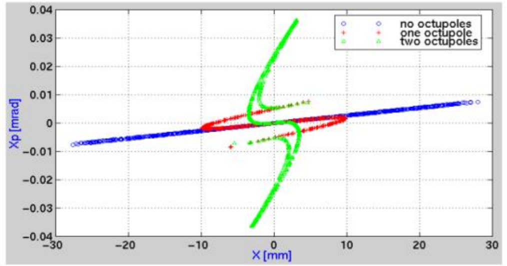
$$x + iy = re^{i\varphi}$$

$$\Delta\theta \approx -3\alpha^2 r^5 e^{i\varphi} - 3\alpha^3 r^7 L^2 e^{i5\varphi}$$

Focusing in all directions

Next nonlinear term focusing – defocusing depends on φ



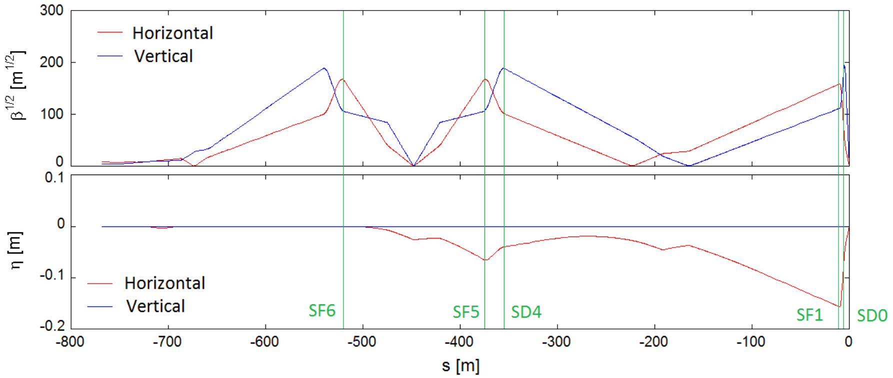


Folding of the horizontal phase space distribution at the entrance of the Final Doublet with one or two octupoles in a "Chebyshev Arrangement".

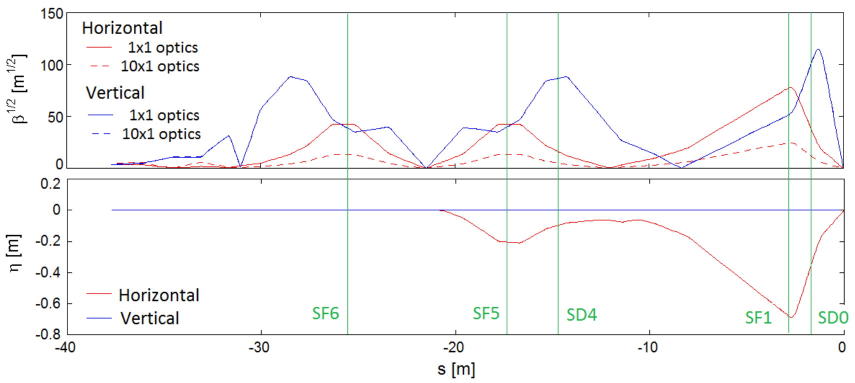
- Octupoles were used only for tail folding in the present ILC FFS design.
- When the octupoles will be used for the IP beam focusing, we should take care of the effect of the collimation depth and the detector background by the halo particles.

Beam Optics of ILC & ATF2

Beam optics of ILC final focus system



Beam optics of ATF2 beamline



- *Same magnet arrangement*
- *Same tuning concept*
- *Comparable magnet tolerances*

ILC final Focus System

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

ATF2 Beam Optics

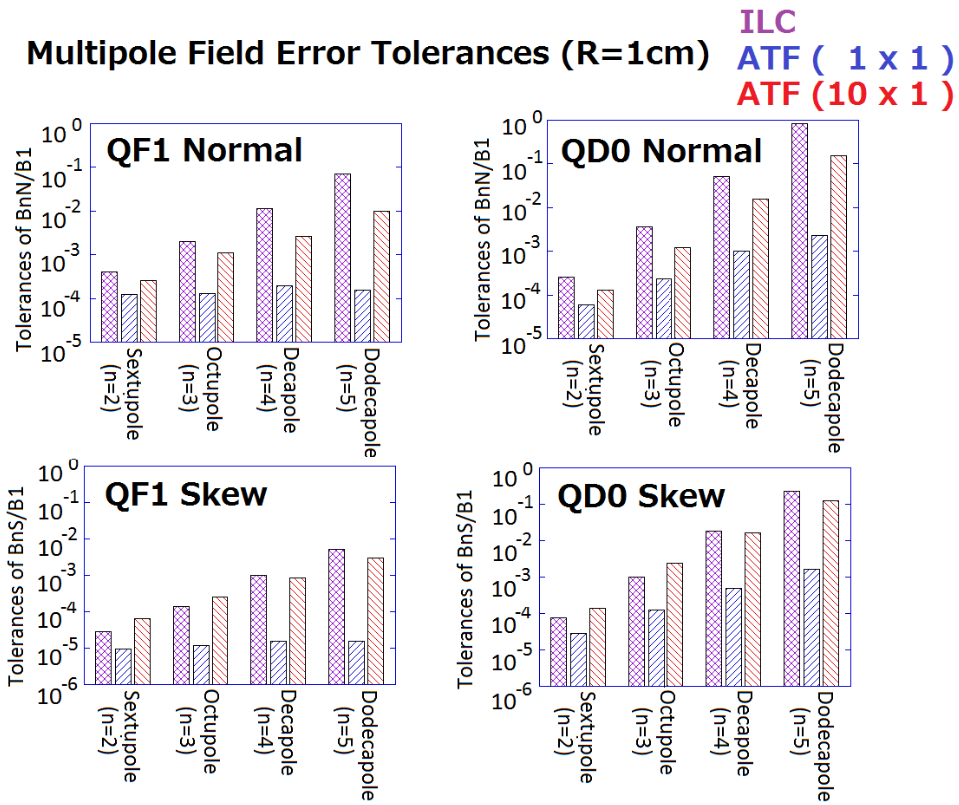
1x1 optics

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 .*

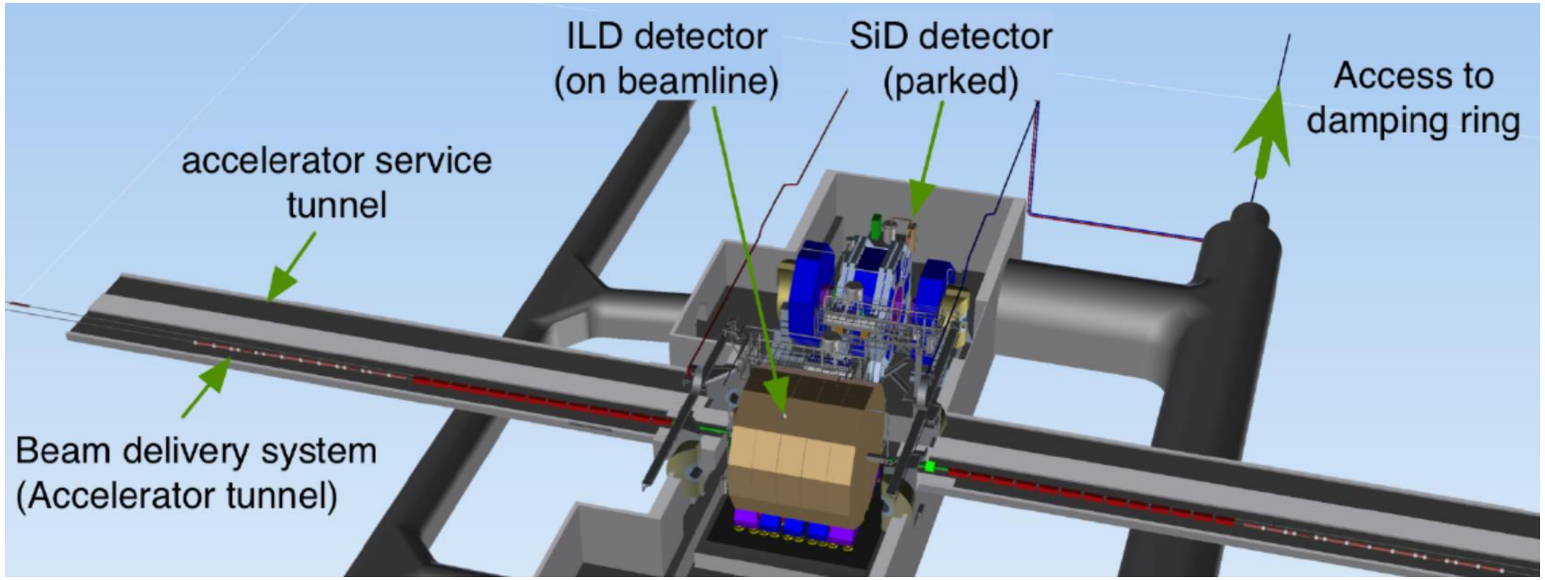
Tolerances of FD multipole field error to IP vertical beam size

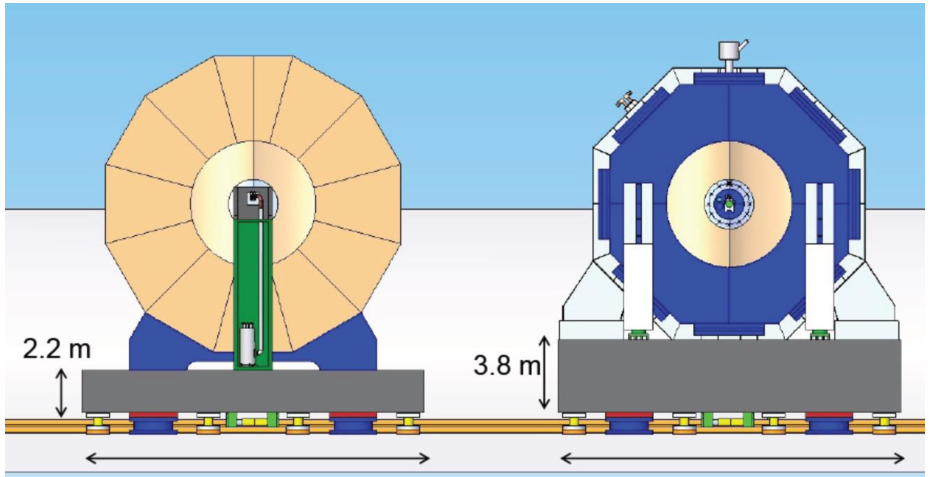


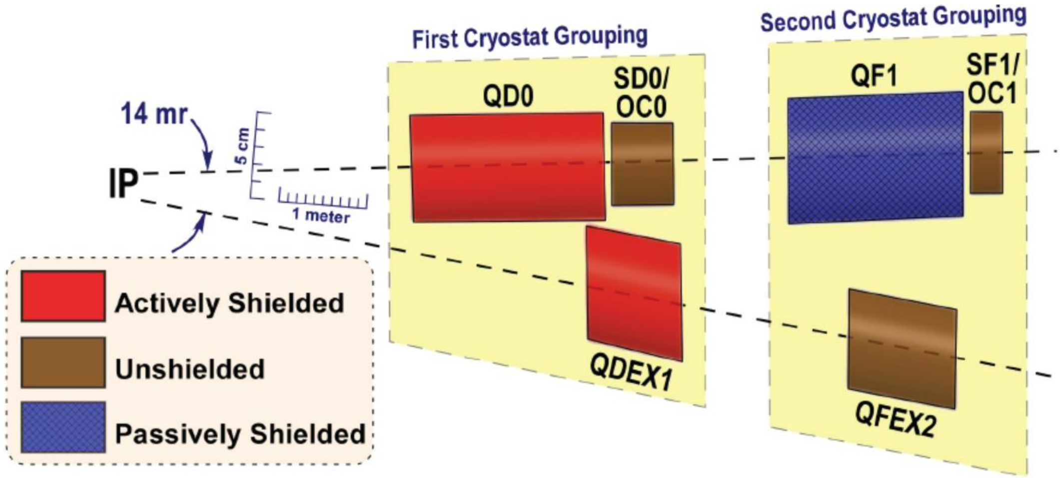
L of the present ILC FFS*

Push-pull scheme of the ILC detectors

- QF1 package is common for both detectors, and located in the accelerator tunnel.
- QD0 package is independent for each detector.
- L* (3.5m and 4.5m) for each detector is different, and the beam optics are not optimized for the L*s in the TDR.







Present ILC L*

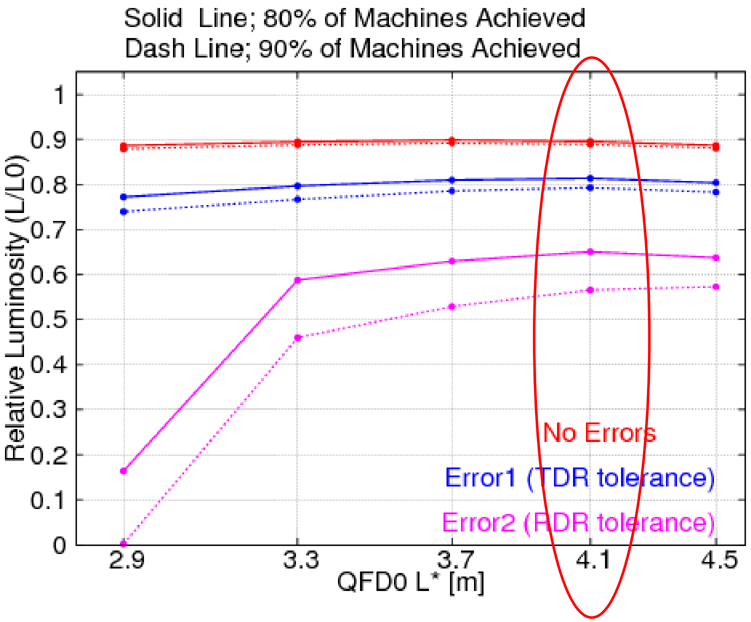
*Optimum QD0/QF1 L*s were discussed in 2014-2015,*
*and the present L*s were fixed by taking account of the luminosity and collimation depth.*

SiD and ILD use same L optics.*
Since QF1 magnet is common, the optimum of QD0 L is also same.*

Effect of (QD0 L*) to Luminosity

ECM = 250GeV
beta (x/y) = 13mm / 0.41mm*
(QD0 L) = variable*
(QF1 L) = **9.5m***

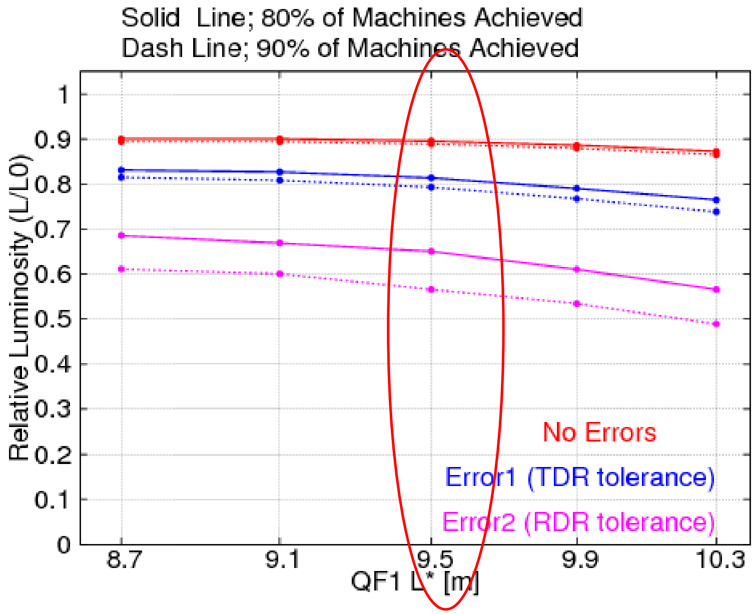
Results of m Tuning Simulation



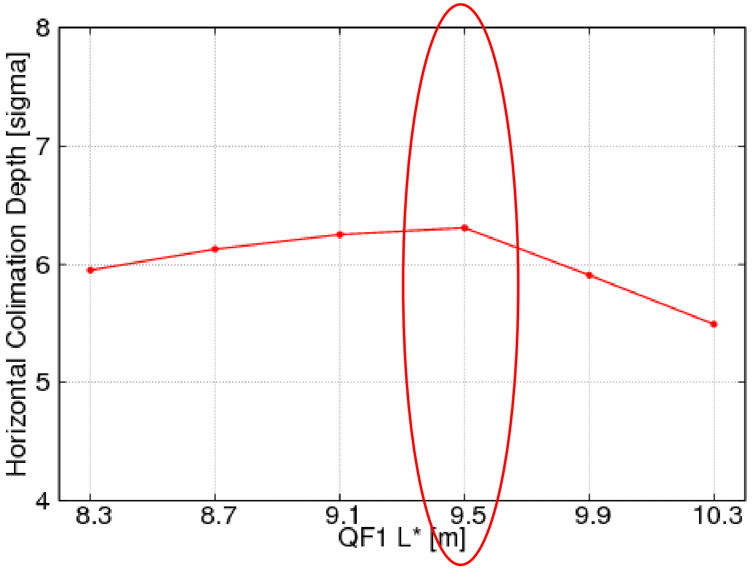
Effect of (QF1 L*) to Luminosity

ECM = 250GeV
beta (x/y) = 13mm / 0.41mm*
(QD0 L) = **4.1m***
(QF1 L) = variable*

Results of m Tuning Simulation



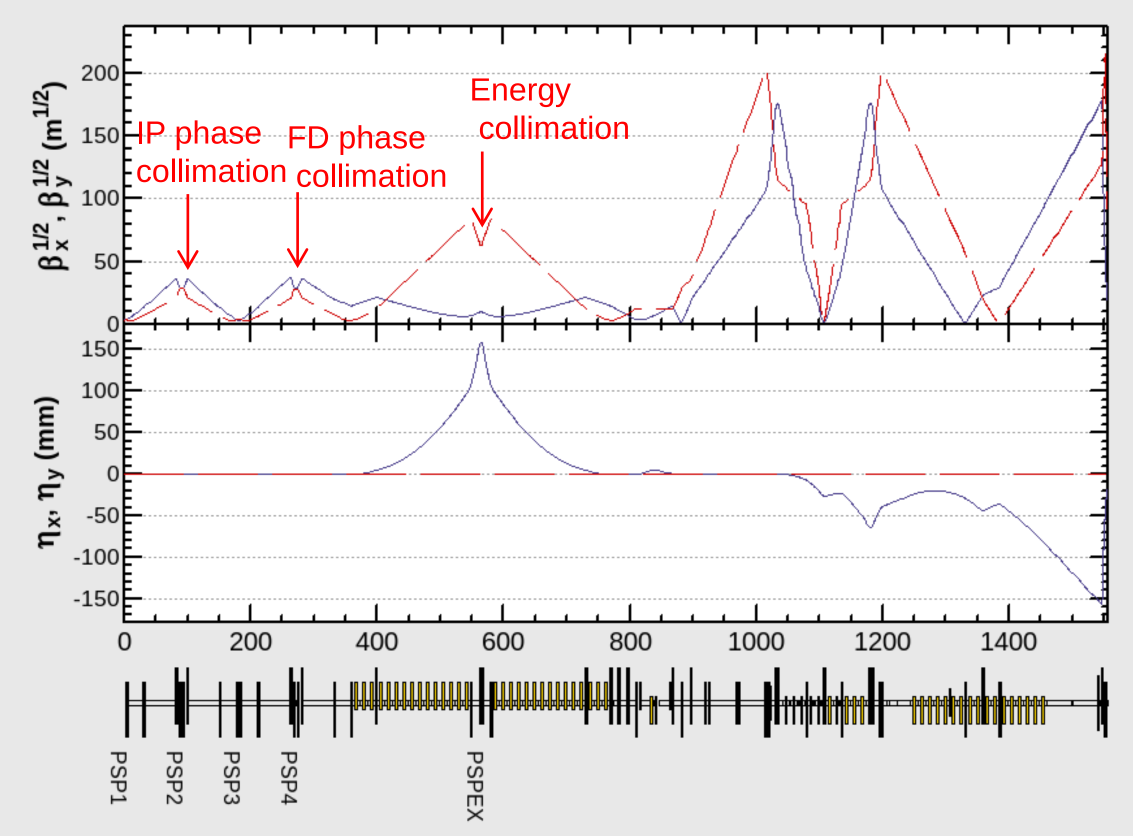
Horizontal collimation depth



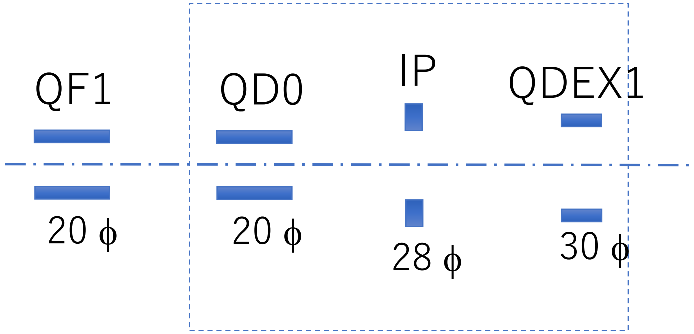
Consideration of collimation depth

Arrangement of the Collimators

Beta Function at SP2/SP4 = (X; 1000m / Y; 1000m)
Phase Advance (SP2/SP4) = (X; 0.5 pi / Y; 1.5 pi)
Phase Advance (SP4/ IP) = (X; 5.5 pi / Y; 4.5 pi)
EtaX at SPEX = 0.158m



Detector apertures

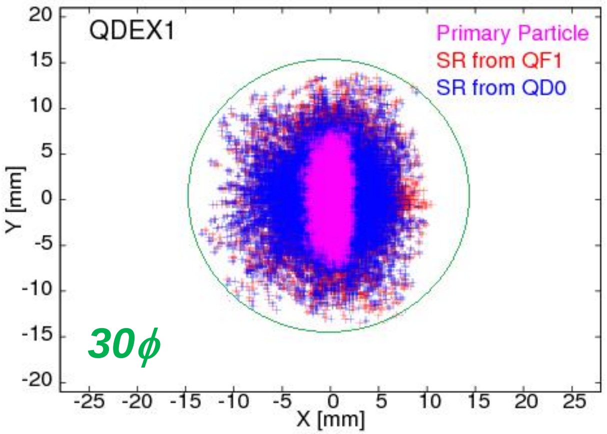


Source for background

1) Halo particles
2) **SR form halo particles**

When the L* of QD0 is increased, the L* of QDEX1 in the extraction line must also be increased.

Since the collimation depth is limited mainly by the fact that SR from the Final Doublet hits QDEX1, the collimation depth becomes more severe when L* is increased.



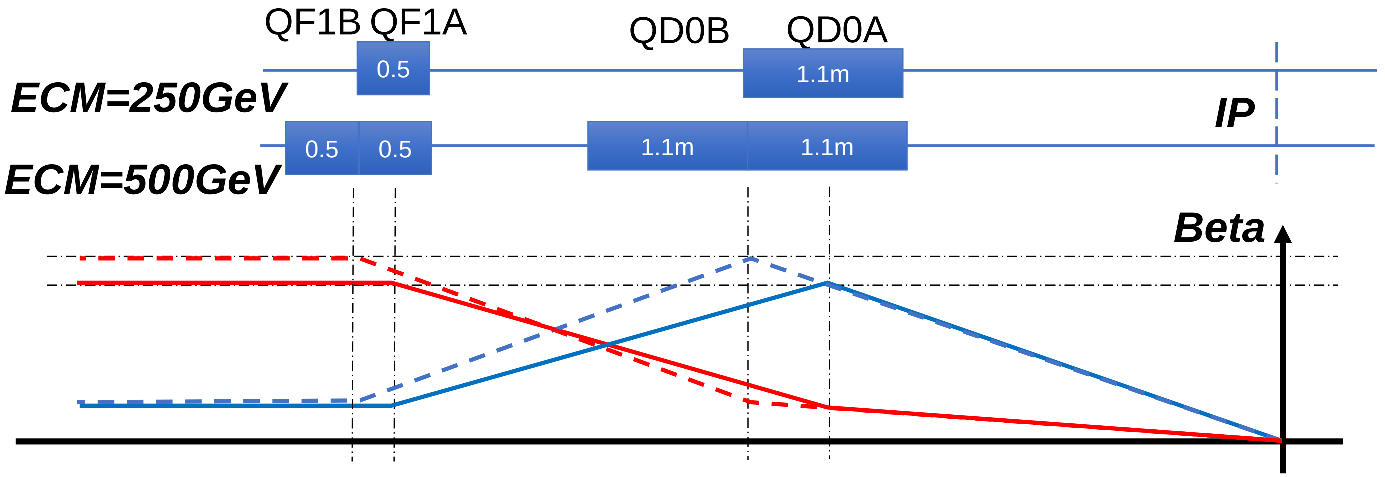
SP2/SP4 X ; 0.86mm
SP2/SP4 Y ; 0.98mm
SPEX X ; 1.60mm
(Dp/p = 1%)

Application to low energy (E_{CM}=250GeV)

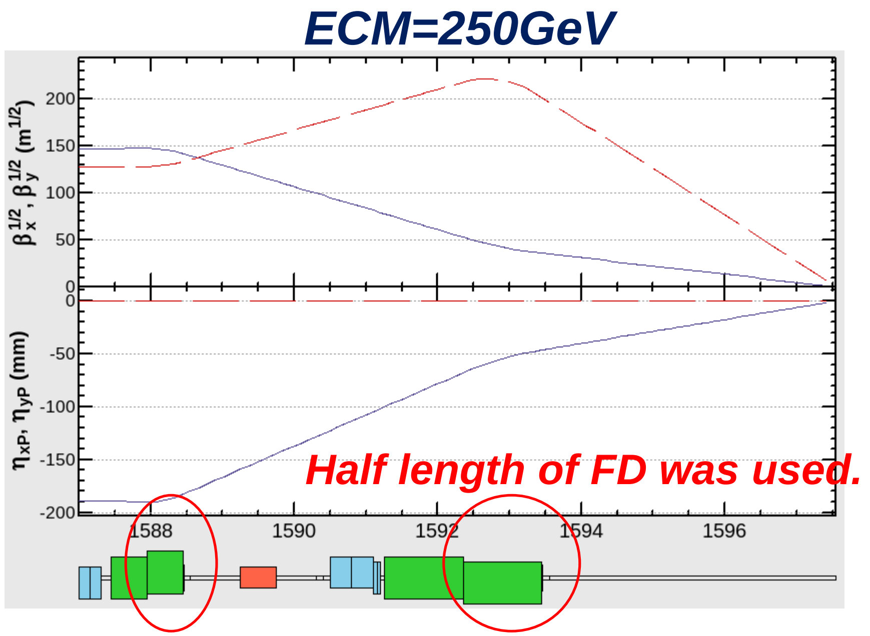
The field strength for ECM=250GeV is a half to ECM=500GeV.

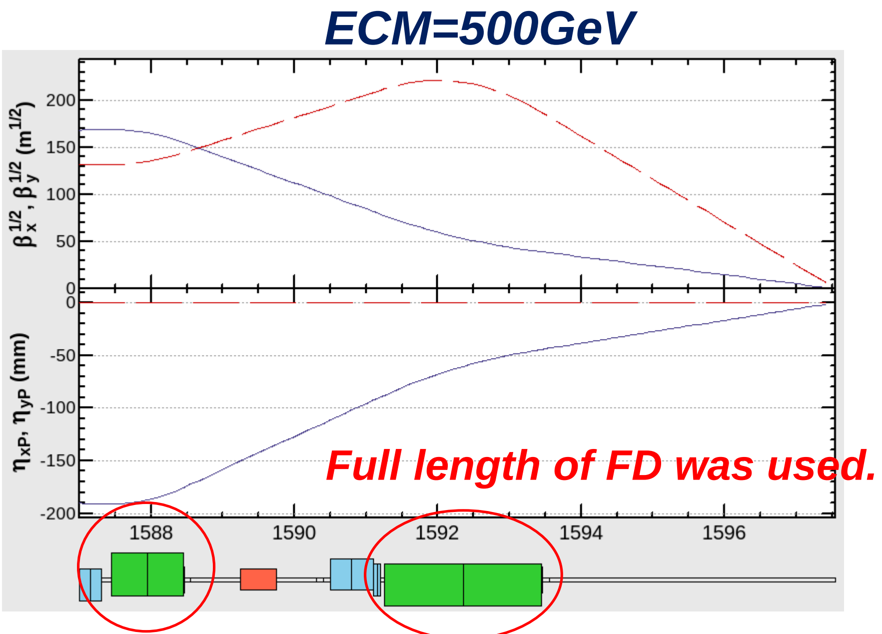
When we only use a half of FD magnets,
the beta functions at FD magnets are decreased.

Therefore, the collimation depth can be increased.



The geometry optimizes the more difficult low-energy optics
and allows the higher-energy optics to deviate slightly from the optimum value.

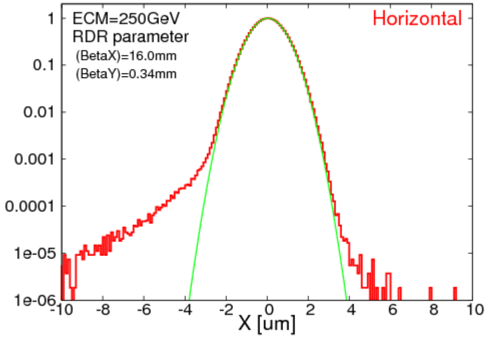




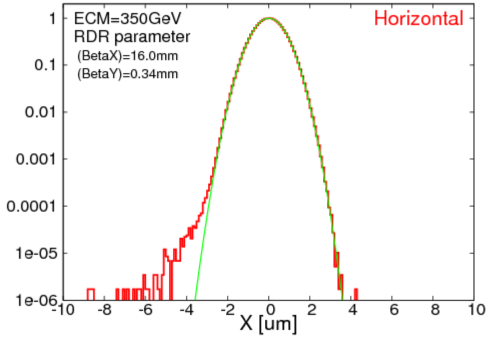
IP beam profile

Horizontal Profile

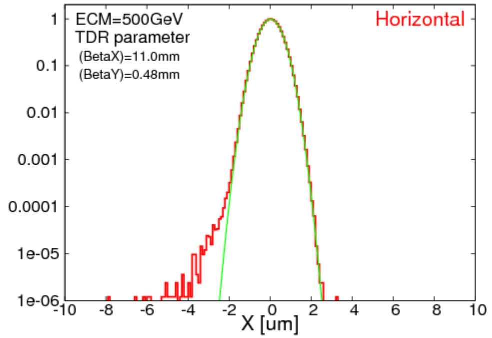
ECM=250GeV



ECM=350GeV

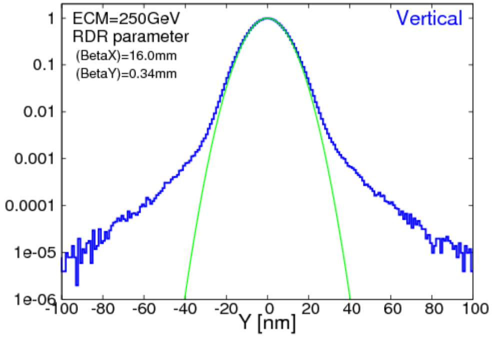


ECM=500GeV

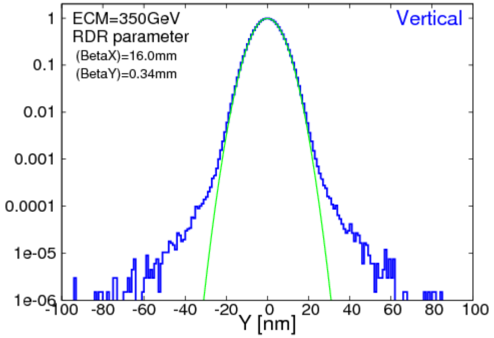


Vertical Profile

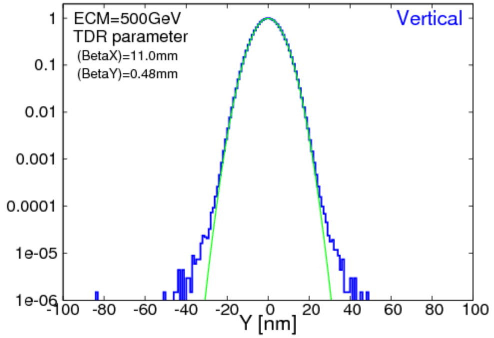
ECM=250GeV



ECM=350GeV



ECM=500GeV



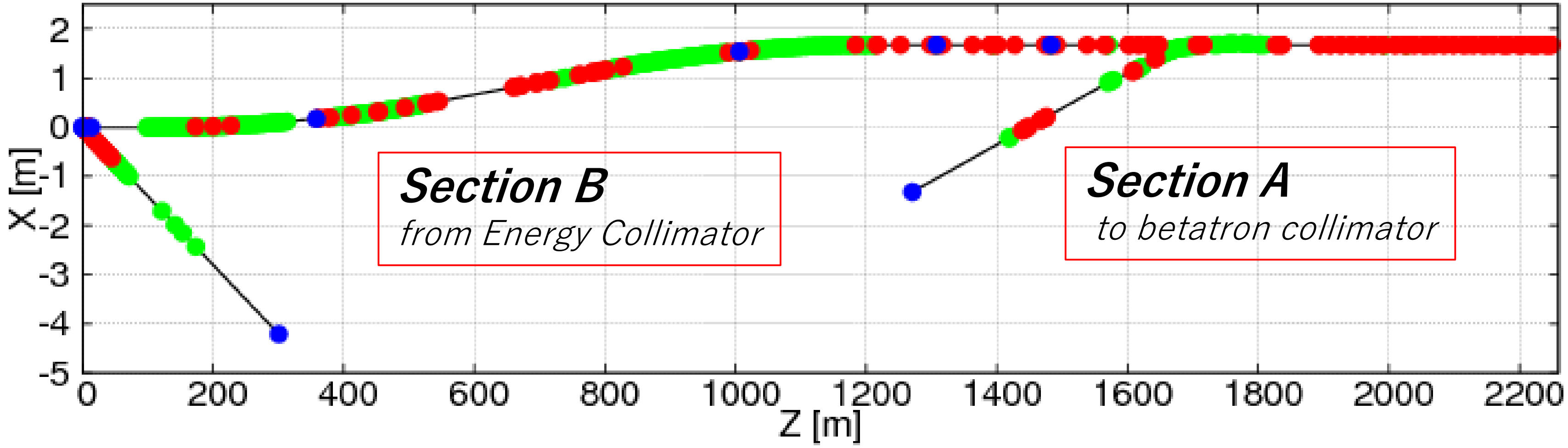
Simulation Results for ECM<500GeV optics (no SR)

ECM	Horizontal		Vertical		Relative Luminosity
	design beam size	simulation (core)	design beam size	simulation (core)	
250GeV	0.729um	0.755um	7.66nm	7.81nm	94.7%
350GeV	0.683um	0.690um	5.89nm	5.97nm	97.8%
500GeV	0.474um	0.482um	5.86nm	5.89nm	97.8%

Application to high energy (E_{CM}=1TeV)

The beam optics is designed to be expandable to ECM=1TeV in the same tunnel.

Beam optics up to 500 GeV can be used with electromagnets to support beam optics up to 1 TeV.



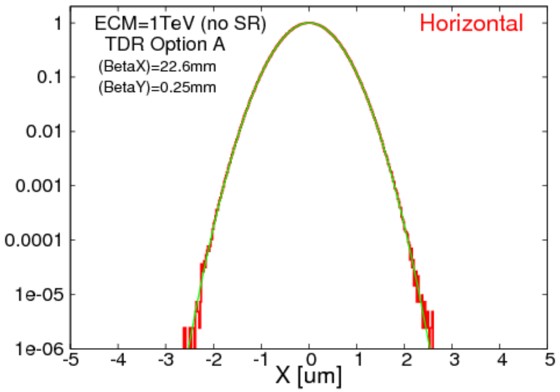
The number of components both for ECM=500GeV and ECM=1TeV

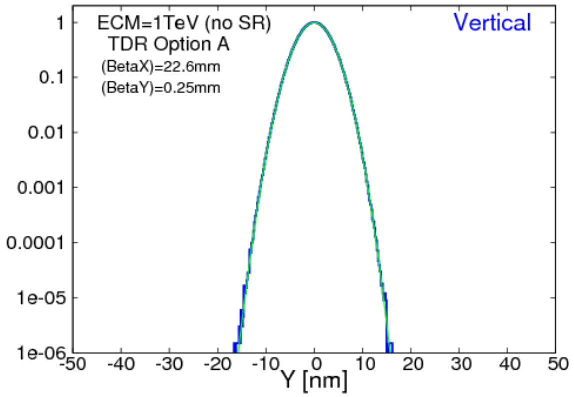
(not include the dumpline)

	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

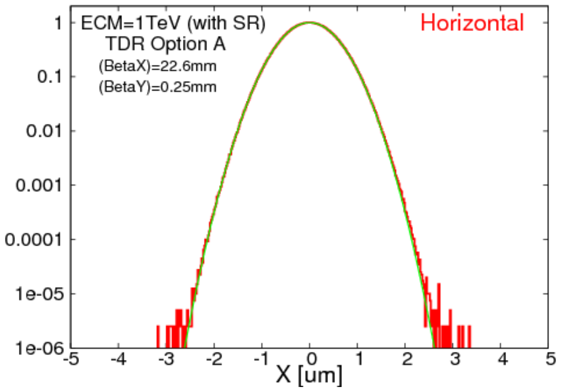
Simulation Results for ECM=1TeV optics

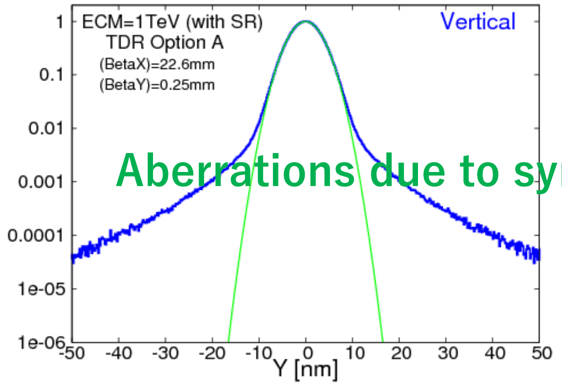
<< no SR >>





<< with SR >>





Aberrations due to synchrotron radiation

	Horizontal			Vertical			Relative Luminosity
	design	rms	core	design	rms	core	
no SR	0.481um	0.481um	0.481um	2.99nm	2.99nm	2.99nm	99.8%
with SR		0.499um	0.498um		3.71nm	3.15nm	91.7%

Luminosity of more than 90% can be achieved for ECM=1TeV, even with the effect of synchrotron radiation on the beamline.

Longer L*

2021/03/16

The longer L issue was discussed in* ***LCWS2021.***

IDT WG3 MDI group meeting

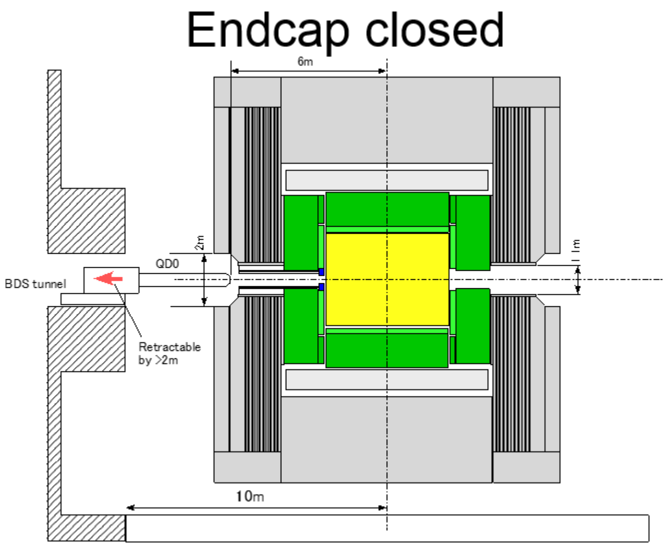
MDI-Physics – Meeting calendar and topics

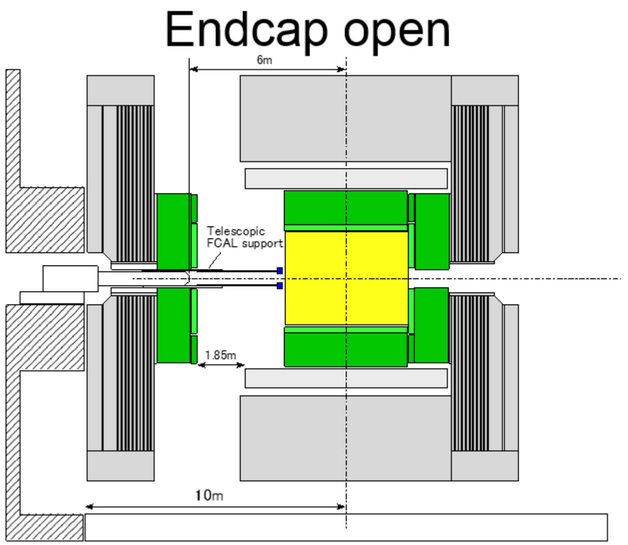
- 16/9/21 – Layout of MDI region
  - Dimensions used in simulation and comparison with current accelerator design
  - Magnet design (Detector magnets and Final Doublet)
  - Closer look at BPMs
  - Do we know all sources of backgrounds?
  - ...
- 30/9/21 – Software for and precision of/for background studies
  - Reminder on Guinea Pig, CAIN, FLUKA
  - Lessons from SuperKEKB (Comparison with CAIN)
  - What theoretical precision is needed?
  - Settings for background simulations and practical handling of background files
  - ...
- 16/10/21 – L*
  - Detailed review of advantages disadvantages for the detectors (including cost)
  - Pros and cons from machine side (including cost)
  - ...

L* issue will be discussed at WG3 MDI group mtg.

- 25/11/21 – Beam calorimeters, beam pipe and vertex detectors
  - Beam pipe: Considerations for different radii
  - Tolerances, time cuts to reduce background
  - Fast feedback by Beam calorimeters, interplay with machine

Discussion of the longer L* in WG3 MDI group





Possible benefit of longer L for detectors*

by Y. Sugimoto @IDT-WG3-MDI-Phys kickoff meeting

- QD0 can be supported from the BDS tunnel
  - We can get rid of QD0 pillar if L*=6m
  - QD0 may have to be retractable like QSC of SuperKEKB
  - Much more stable than the support from the pillar on the platform
  - Much better position repeatability after push-pull
    - Pillar on the platform: ~0.5mm
    - Support from BDS tunnel: few tens of um (SuperKEKB)
  - Much faster machine tuning after push-pull
  - Only one pair of QD0 is necessary (2 pairs for ILD and SiD are necessary for TDR design)
- ILD needs some modification
  - Cut the End-cap iron to make access to flanges at Z~6m possible, and/or remote vacuum connection (RVC) like SuperKEKB
  - FCAL support has to be re-considered (telescopic support?)
  - **No need for split endcap**
- BeamCAL can be placed far from IP
  - Weaker magnetic field at BCAL (and QD0 front surface) causes less back-scattering of pair background
  - No need for AntiDID (?)
  - Less cost, less construction period, and less risk

Comment; L* and luminosity

- *L* is not directly related to **the design luminosity** in linear colliders.*
- *However, it may effectively lead to a decrease the integrated luminosity for ILC through various tolerances and the associated beam tuning etc.*

Luminosity $L = f n_b \dfrac{N^2}{4\pi \sigma_x^* \sigma_y^*}$

In order to increased the luminosity,

1) *Make small vertical emittance*
2) *Make beamstrahlung parameter large.*
   ⇒ make the balance of the luminosity and energy spread for collision beam.

*The vertical beta function is roughly optimized to the bunch length to minimize the **hour-glass effect** as*

$$\sigma_y^{*2} = \beta_y^* \varepsilon_y \qquad \beta_y^* \approx \sigma_z$$

*The horizontal beam size was defined with **beamstrahlung parameter***

$$\sigma_x^{*2} \approx \frac{r_e^3 N^2 \gamma}{\sigma_z \delta_{BS}}$$

Then, the luminosity can be expressed as

$$L = \frac{f n_b N}{4\pi r_e^{3/2}} \sqrt{\frac{\delta_{BS}}{\gamma \varepsilon_y}}$$

Beam energy reduction by beamstrahlung

$$\delta_{BS} \equiv -\frac{\Delta E_\gamma}{E} \cong \frac{0.836\,\gamma N^2 r_e^3}{\sigma_z\left(\sigma_x^* + \sigma_y^*\right)^2} \frac{1}{(1 + 1.31\langle\Upsilon\rangle^{2/3})^2} \approx \frac{\gamma N^2 r_e^3}{\sigma_z\left(\sigma_x^* + \sigma_y^*\right)^2}$$

For ILC 500GeV, the $\delta_{BS} = 4.5\ \%$

Some issues for large L optics*

- In order to change the L*, it is necessary to change not only the arrangement of the magnets near the IP but also the entire FFS optics including the beamline length.

- When increasing L*, the acceptable range of the optimum bending angle for the beam energy becomes smaller, which may limit the future energy extendability (see later).

- We should reevaluate the effect of the collimation depth and detector background (may be worse than present optics).

- We may reevaluate the beam extraction line optics.

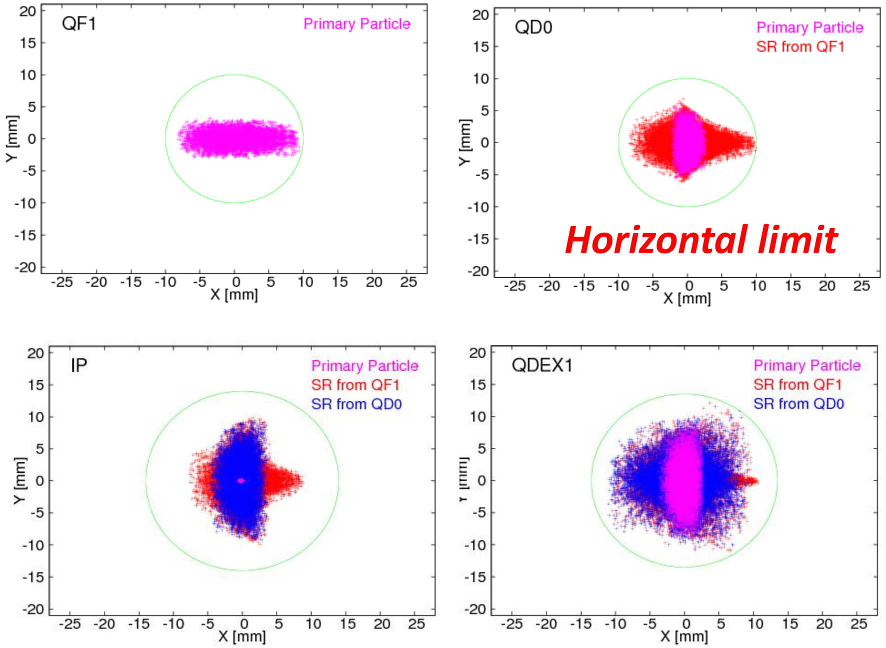
- However, since the accelerator is a tool for conducting physics experiments, I believe that it is necessary to change the L* if it is required by the consensus of physics.

I have heard that there is no consensus on the physics side that L* should be changed at this time, so the accelerator side is not about to start considering it, and this presentation is nothing more than information sharing.

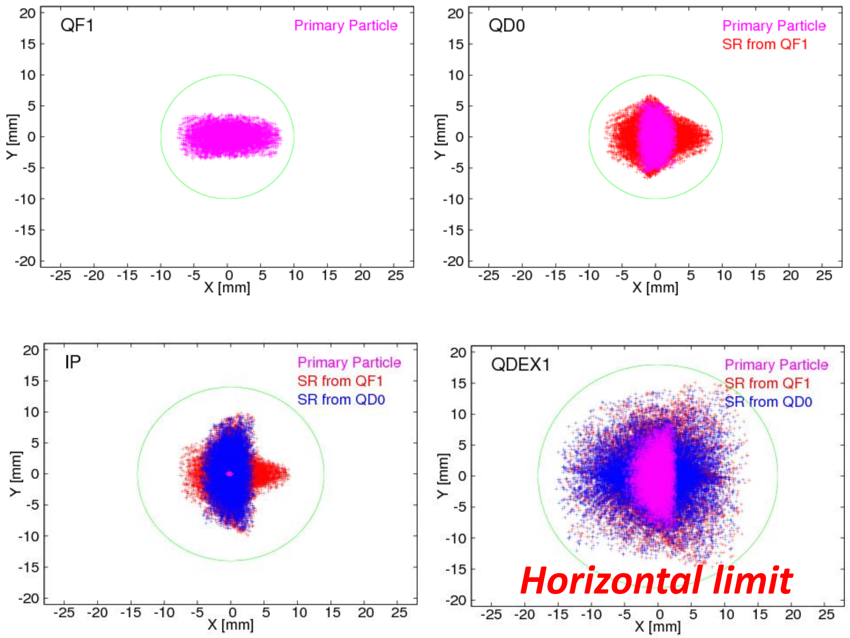
Synchrotron radiation around IP area

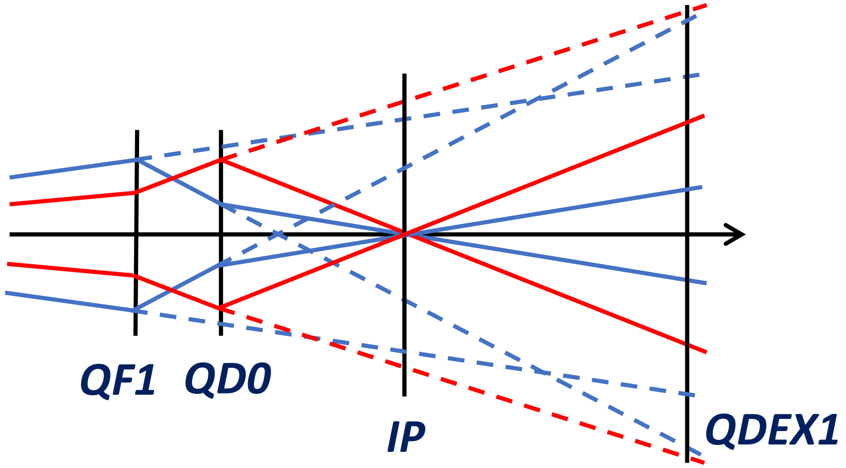
When L is increased, the effect of SR from the Final doublet on the SC magnet in the extraction line becomes larger and the collimation depth is reduced.*

Shorter QD0 L*



Longer QD0 L*

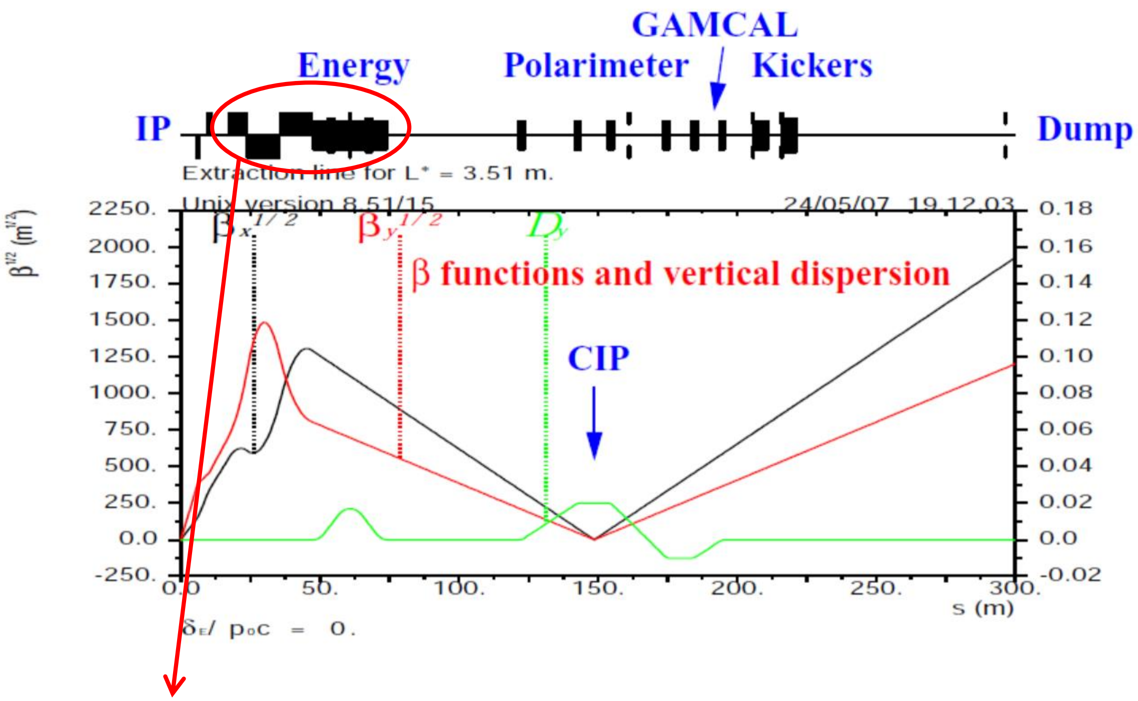




The situation of QDEX1 limit will be changed by the parameters

- *the location of QDEX1.*
- *the aperture of QDEX1.*
- *the vertical aperture of collimator.*

ILC beam extraction line



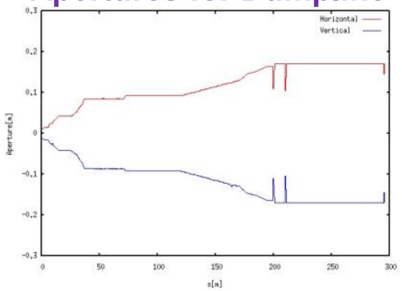
Quadrupole magnets in extraction line

Y. Nosochkov et al., LCWS/ILC 2007

First two quadrupoles : SC magnets in FD package
Other quadrupoles : Large aperture NC magnets

Name	Qty	B′	L	R
QDEX1 (SC)	1	89.41	1.150	17
QFEX2A (SC)	1	33.67	1.100	30
QFEX2 (B,C,D)	3	11.27	1.904	44
QDEX3 (A,B,C)	3	11.37	2.083	44
QDEX3D	1	9.81	2.083	51
QDEX3E	1	8.20	2.083	61
QFEX4A	1	7.04	1.955	71
QFEX4 (B,C,D,E)	4	5.88	1.955	85

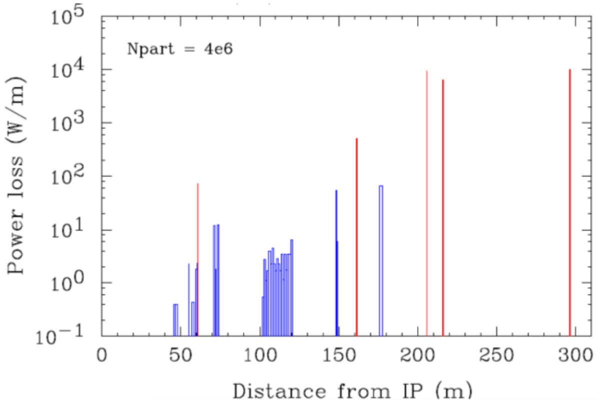
Apertures for Dumpline



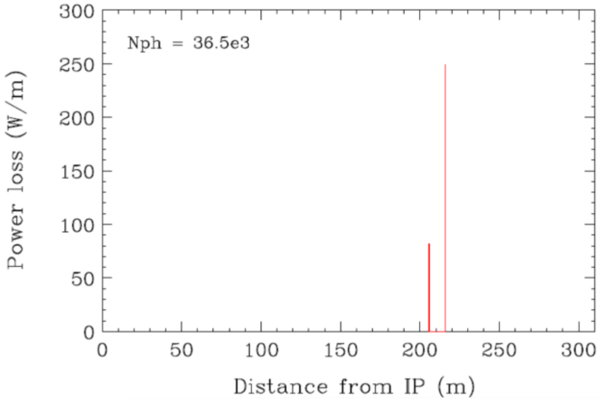
Power loss at extraction line (beam-beam effect)

E. Marin and Y. Nosochkov et al., LCWS 2013

Disrupted charged particles



Beamstrahlung photons



- The ILC extraction line uses large-diameter quadrupole magnets (maximum bore diameter 170 mm) to transport the beam with large beam spread by the beam-beam effect to the dump with minimal loss.
- When the L* of QD0 is lengthened, the L* of the extraction quadrupole magnet QDEX1 is also lengthened, and the diameter of the quadrupole magnet in the entire extraction line may be increased more.
- Therefore, the design of the entire extraction line needs to be redesigned.

I have considered the ILC final focus optics with long L* in the past.

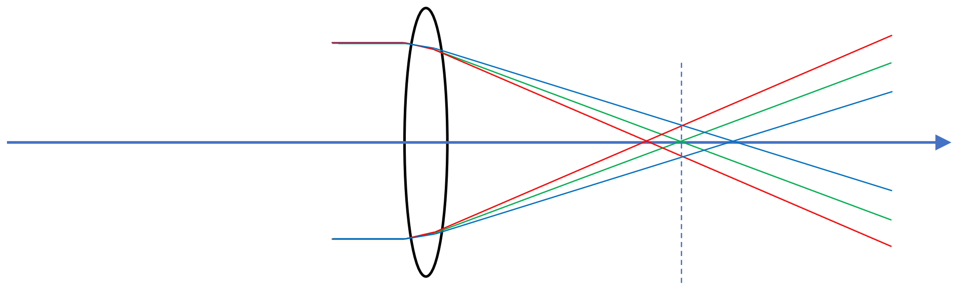
Large L optics for ILC*

Toshiyuki OKUGI, KEK

2014/ 5/ 15

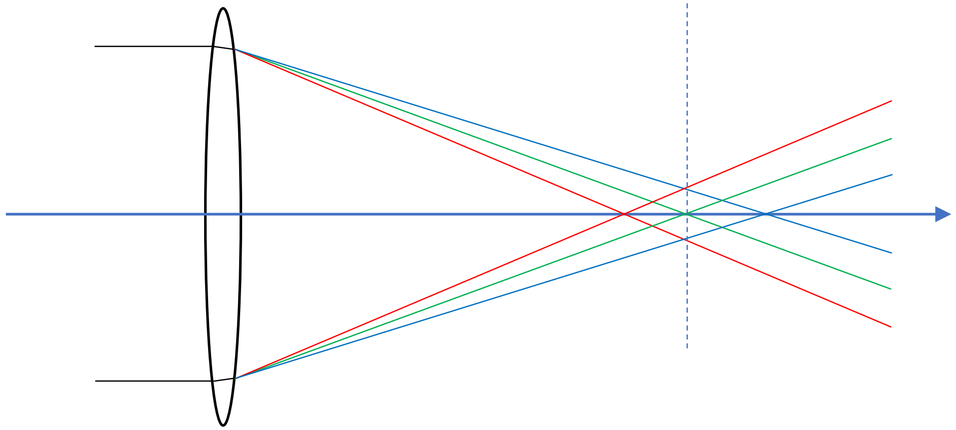
AWLC2014, Fermilab

Long L and Chromaticity*



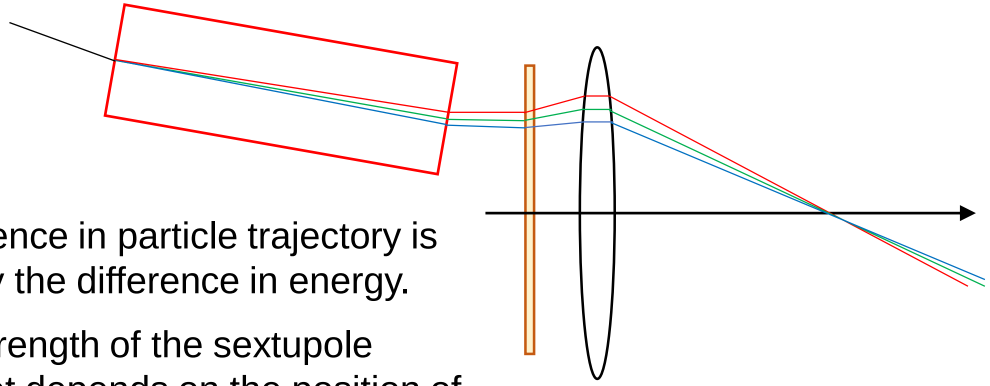
In order to squeeze the beam to the same size at the focus, it is necessary to squeeze the beam at the same divergence angle.

- ➢ The beam size at the final focus magnet becomes larger.
- ➢ The chromatic aberration at the focal point becomes larger.



When the L* is long, the chromatic aberration becomes larger, and a strong chromatic aberration compensation is needed.

Chromaticity correction

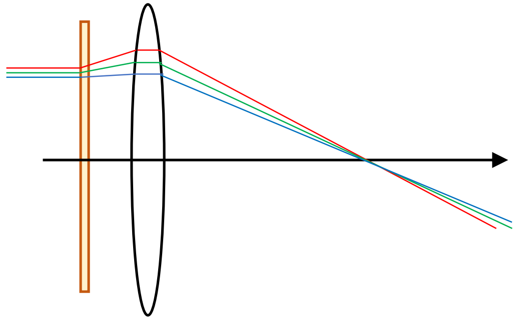


The difference in particle trajectory is created by the difference in energy.

- ➢ The strength of the sextupole magnet depends on the position of the particle passing through it.
- ➢ The angle at which a particle injects a quadrupole magnet depends on its energy.

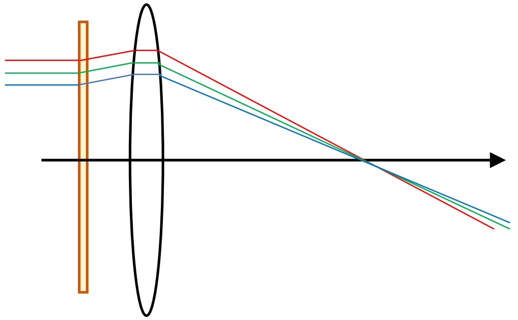
This is especially effective in “the low energy region”, because the beam size passing through the magnet is large.

Small difference in position due to energy in sextupole



- ➢ Requires strong sextupoles
- ➢ Spatial aberration becomes large

Large difference in position due to energy in sextupole

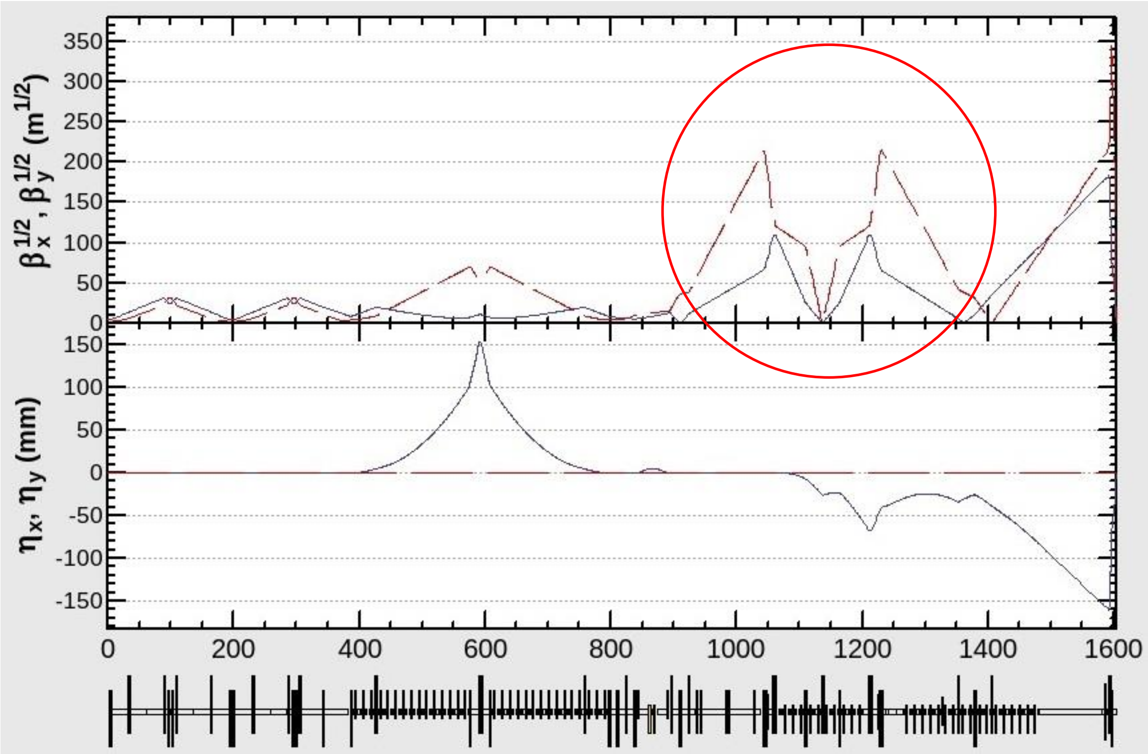


- ➢ Enough to use weak sextupoles
- ➢ Spatial aberrations are small.

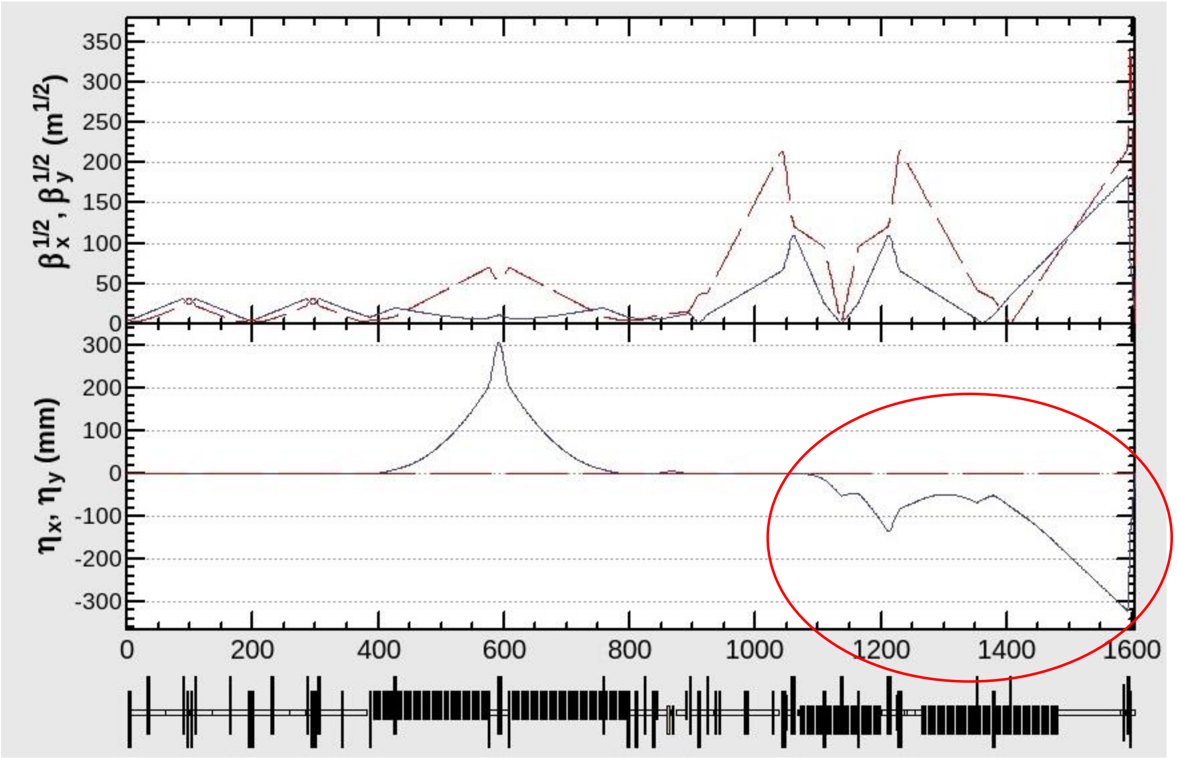
L*=7.0m optics based on ILC RDR optics (ECM=500GeV)

Since the (2nd order and higher) geometrical aberration for large L* optics was large the large L* optics is more difficult than the small L* optics, even if we set same chromaticity.

1st step optimization



2nd step optimization



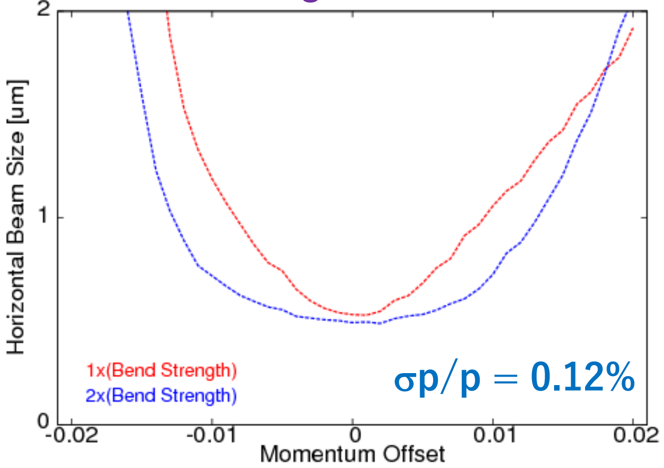
In order to reduce the beam size at SF6, SF5 and SD4, the beta function at the section was reduced (ATF2-like optimization).

The strength of dipole magnet was increased to twice to increase the dispersion and reduce the strength of sextupoles.

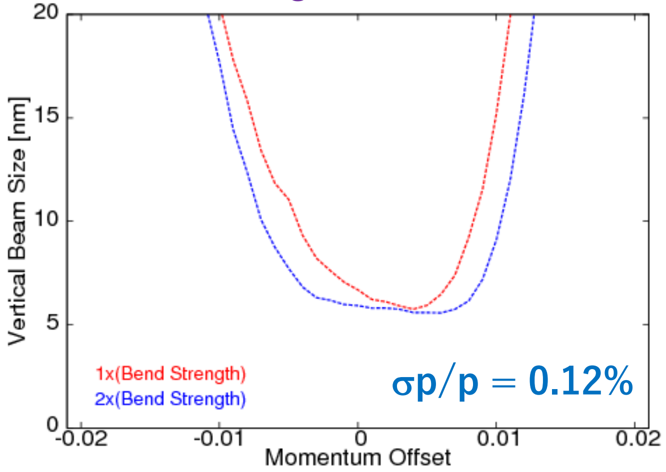
Performances for the optics with strong bending magnet

Optics was matched to ILC TDR parameters.

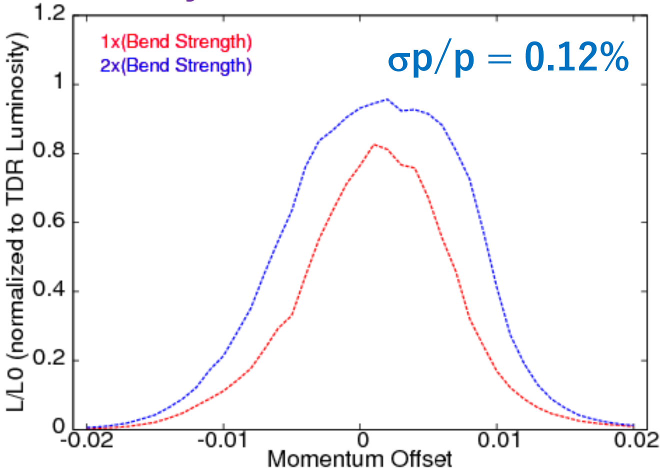
Bandwidth of sigmaX for E=250GeV



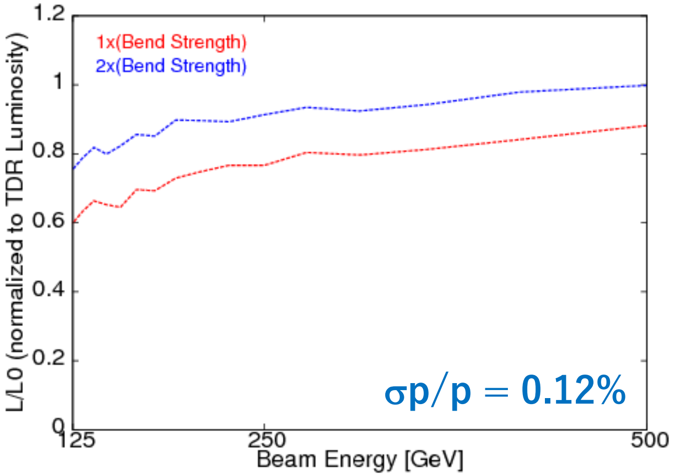
Bandwidth of sigmaY for E=250GeV



Luminosity Bandwidth for E=250GeV



Energy Dependence of Luminosity



Effect of SR

Even at ECM=500 GeV,
some effects of synchrotron radiation are appeared.

IP Beam Size at E=250GeV	sigmaX*	sigmaY*
w/o Synchrotron Radiation	0.50um	5.81nm
with Synchrotron Radiation	0.50um	5.95nm

At AWLC2014, this proposal was rejected.

The reasons are

1) Energy extendability
2) Collimation depth
3) Aperture of the dumpline .

The luminosity was increased to almost 97%, and the bandwidth increased.
But, the luminosity reduction for low energy was still large.

CLIC 380 GeV FFS optimization

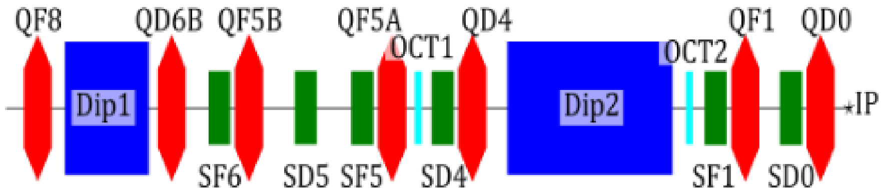
LCWS 2021

Andrii Pastushenko, Rogelio Tomás, Angeles Faus-Golfe

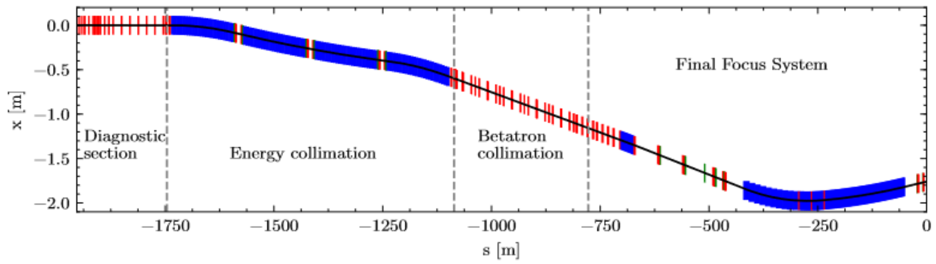
March 15, 2021

L*=6m optics for CLIC 380GeV

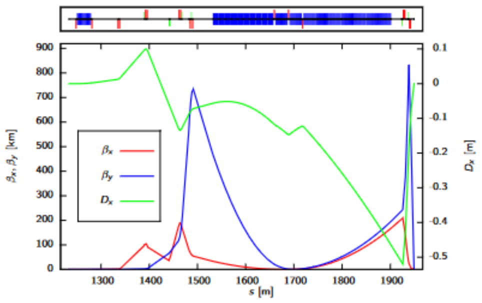
Final Focus System scheme



Beam Delivery System of CLIC@380 GeV:



FFS optics[1]:

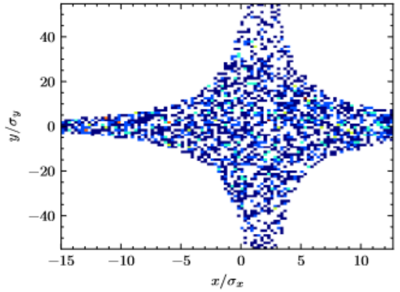


FFS length [m]	770
L^* [m]	6
$\epsilon_{n,x}/\epsilon_{n,y}$ [nm]	950/30
β^*_x/β^*_y [mm]/[μm]	8/70
σ^*_x/σ^*_y [nm]	145/2.9
σ_z [μm]	70
δ_p [%] (Uniform distr.)	1.0
$\mathcal{L}$ [10^{34}cm^{-2}s^{-1}]	1.66
$\mathcal{L}_{1\%}$ [10^{34}cm^{-2}s^{-1}]	0.96

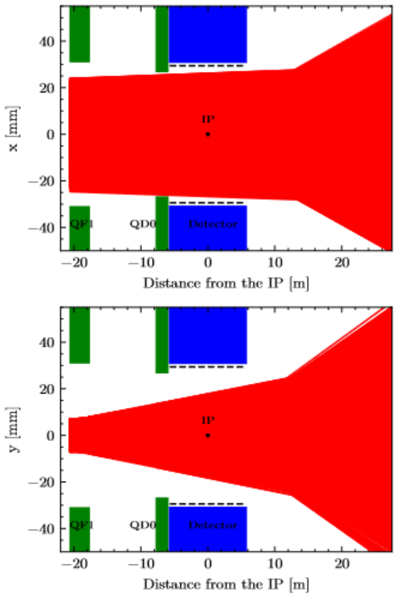
[1] A. Pastushenko, "Optics calculations for CLIC". Master's thesis.

Collimation depth

- The collimation depth has to satisfy the condition that neither beam halo nor emitted photons hit the FD or the detector. The beam halo used in the simulations:



	QF1	QD0
Gradient [T/m]	16.3	73.7
Aperture [mm]	31.2	27.0
Pole tip field [T]	0.51	1.99



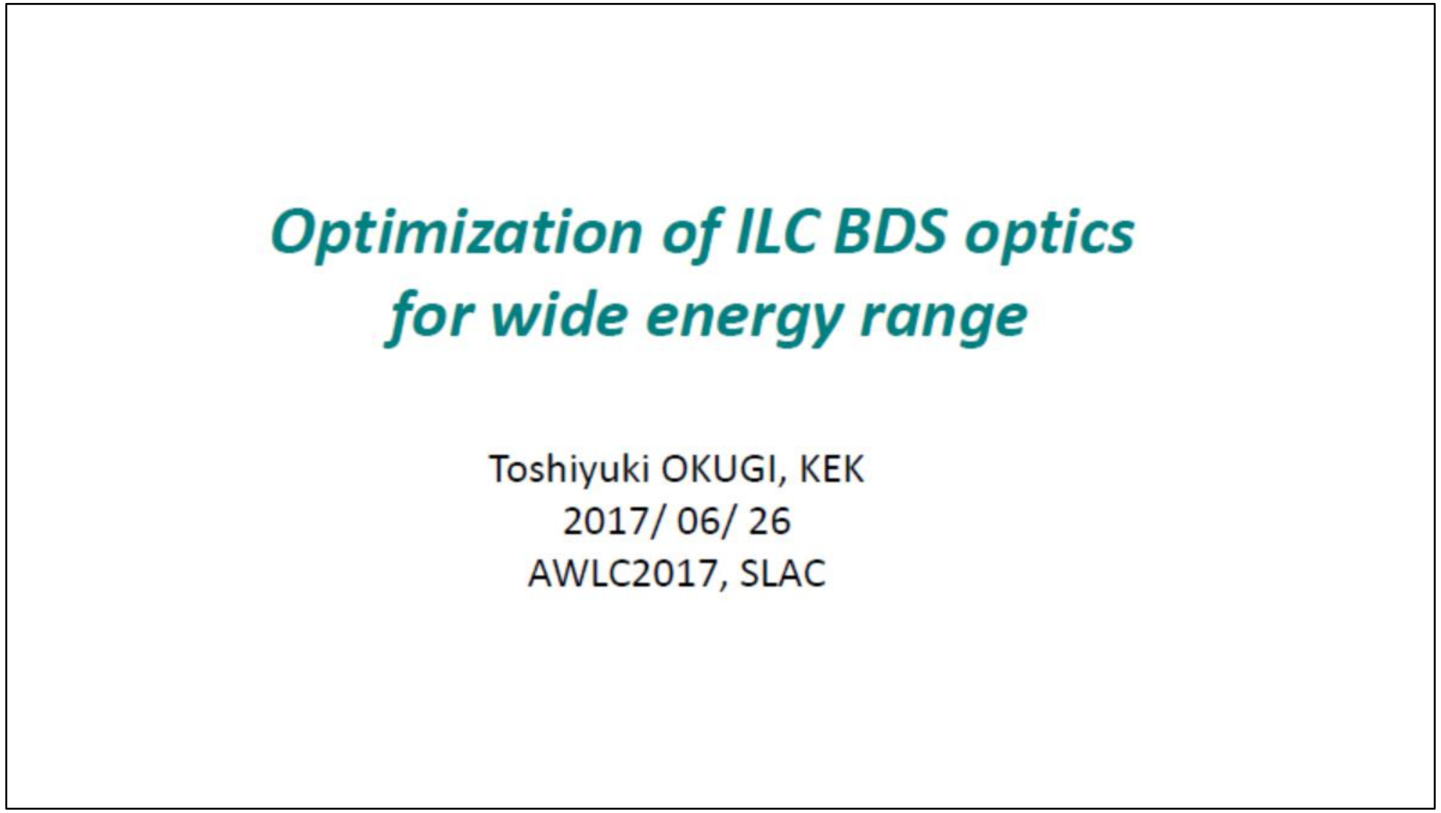
- *The additional sextupoles were put to the original chromaticity correction optics. They also use octupoles for IP focusing.*
- *Since CLIC is designed to have weaker nonlinear effects than ILC, such as smaller horizontal emittance and higher energy, it will be necessary to examine carefully when matching the parameters of ILC.*
- *The effect on the detector background and collimation depth when using octupole magnets for beam adjustment needs to be carefully examined.*
- *The aperture of the inner detector around the IP is assumed to be very wider than ILC.*

Other topics

The current ILC FF optics are designed to support energies of ECM=250GeV-1TeV with the same geometry.

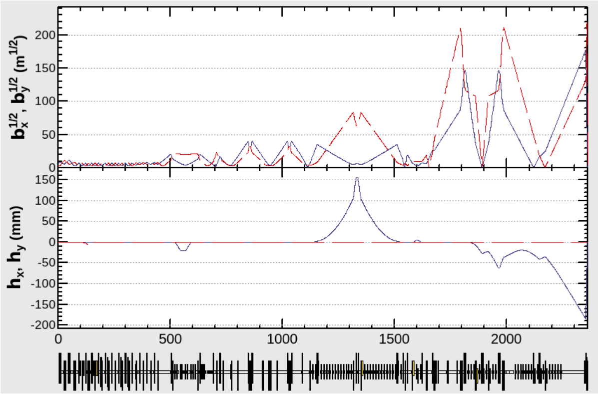
However, the FF optics is not optimized for each energy, because the bending angle of the dipole magnet does not have an optimum angle for each energy.

- In order to optimize for each energy, we need to choose optimal bending angle of dipole for each beam energy.
- A layout to optimize for two energies, ECM=250GeV and 1TeV, was proposed in 2017.

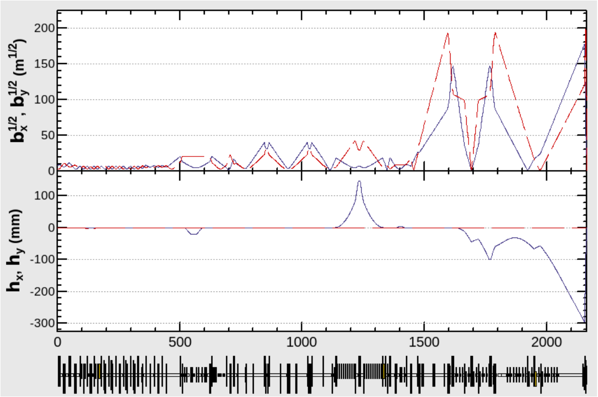


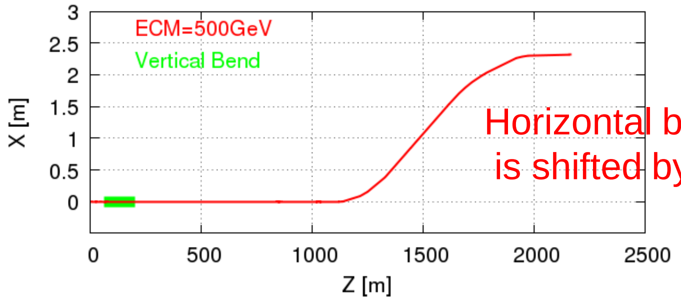
Strong dipole for low energy

Original beam optics



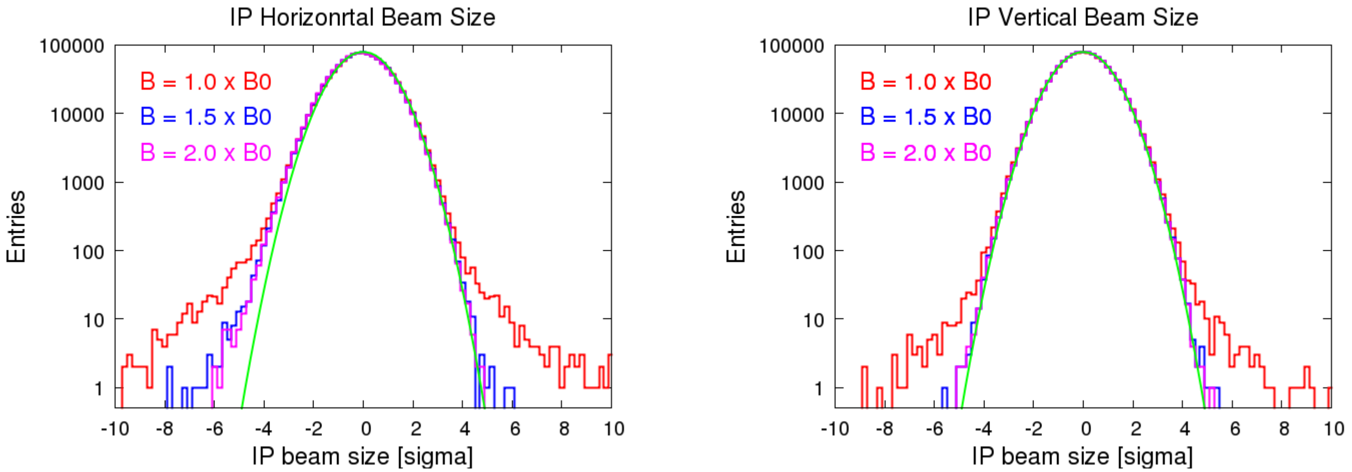
Beam optics with strong bending magnet





Horizontal beamline offset is shifted by 1m at 2xB0.

IP beam profile at ECM=250GeV



Synchrotron radiation for BDS at ECM=500GeV

Momentum Spread Growth by Synchrotron Radiation

	Collimator	FF beamline	Total
B = 1.0 x B0	0.0058%	0.0017%	0.0061%
B = 1.5 x B0	0.0059%	0.0020%	0.0062%
B = 2.0 x B0	0.0060%	0.0024%	0.0064%

Horizontal Emittance Growth by Synchrotron Radiation

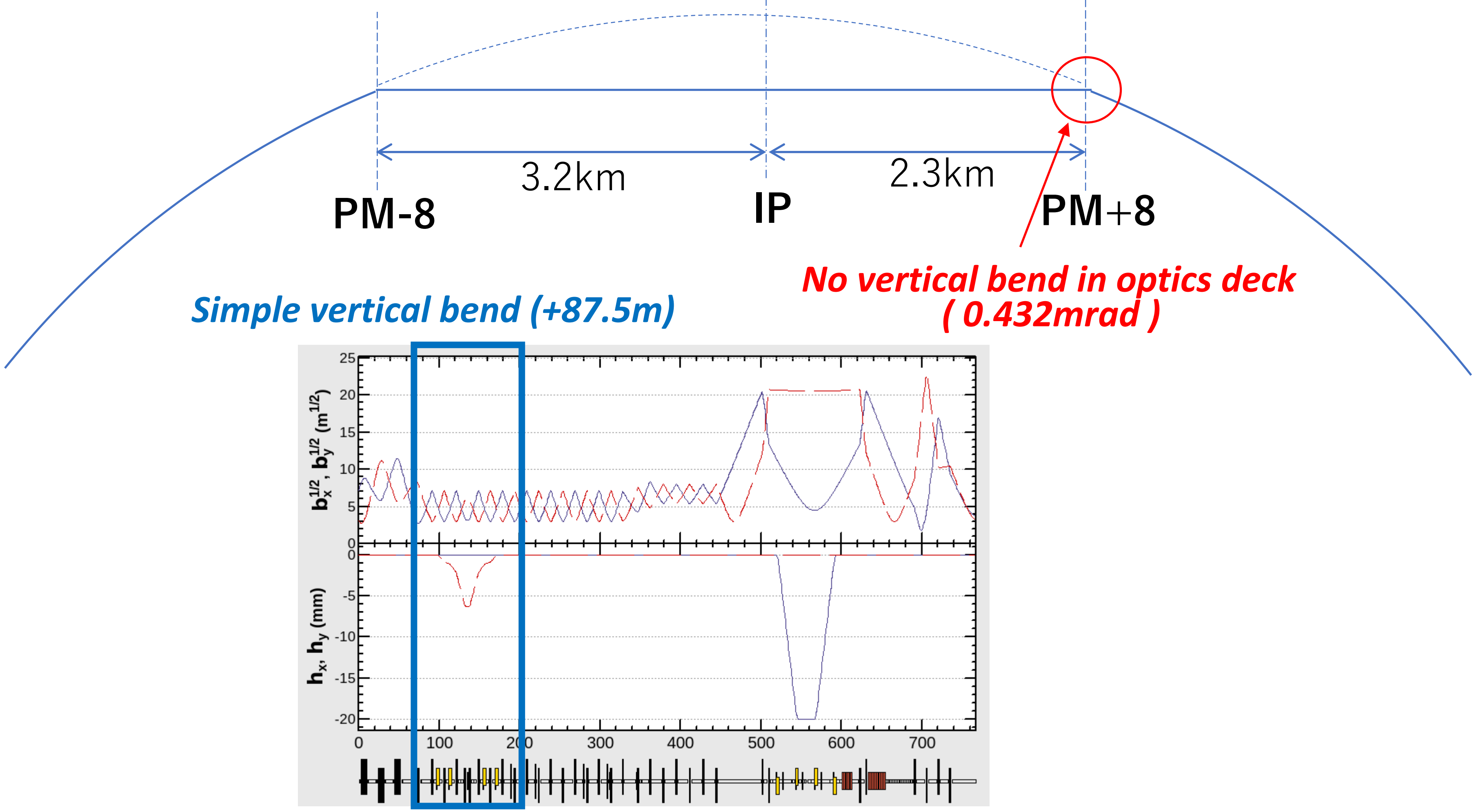
	Collimator	FF beamline	Total
B = 1.0 x B0	0.45%	0.07%	0.52%
B = 1.5 x B0	0.67%	0.49%	1.16%
B = 2.0 x B0	1.49%	2.06%	3.55%

Even at ECM=500 GeV, the effect of SR is not so small (1 TeV is impossible).

Design of vertical bead at entrance of BDS

BDS beamline will be longer, when we put the vertical bend.

BDS tunnel is laser straight.

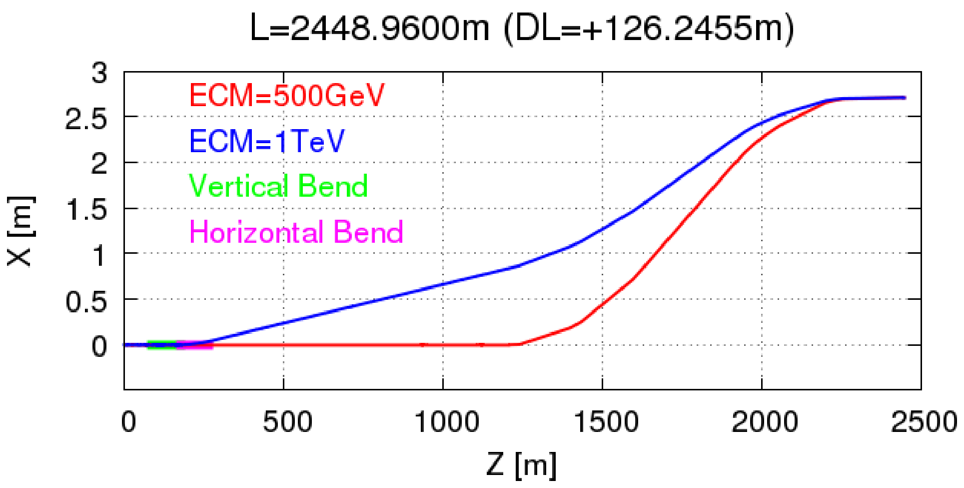


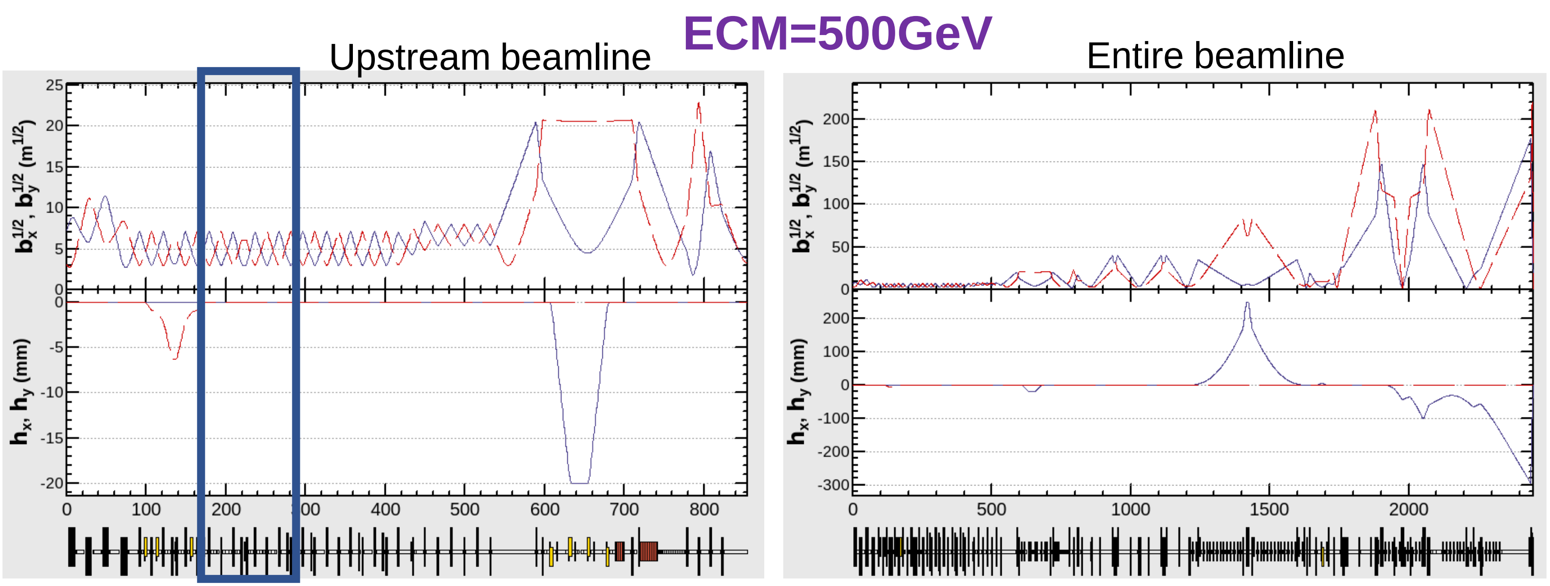
The vertical bending section was designed in between MPS and skew quadrupole section.

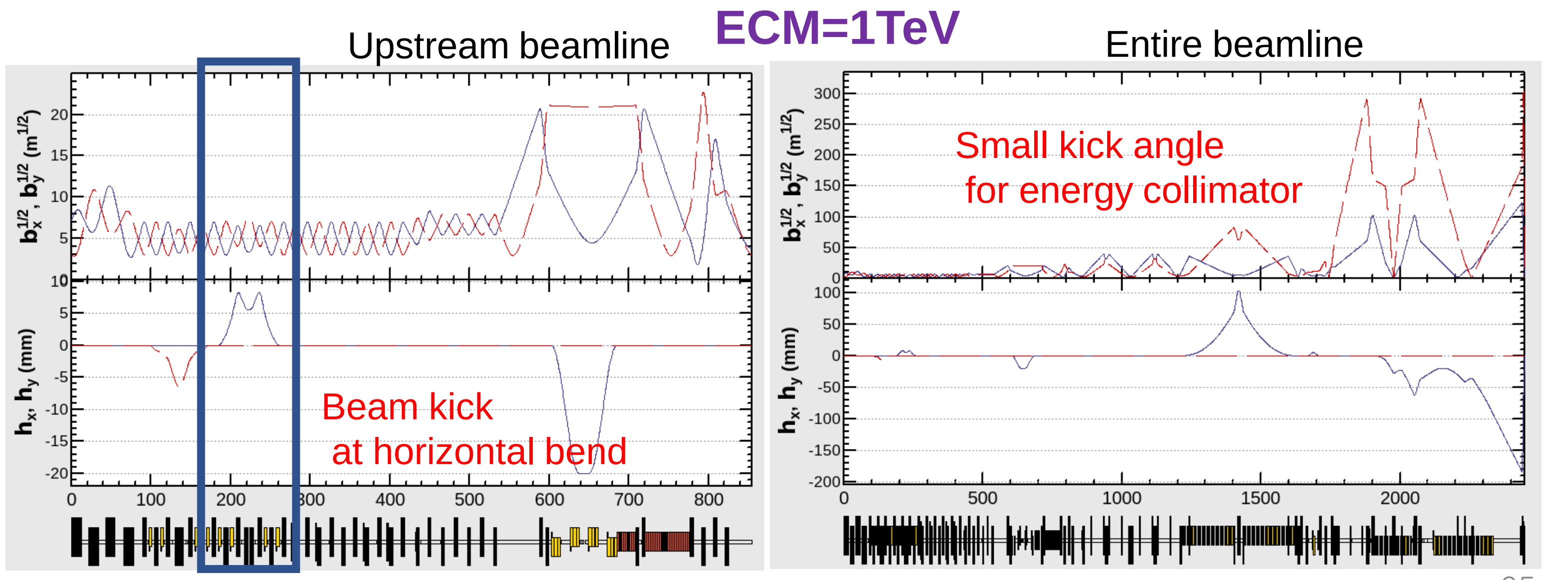
The optics was designed to smoothly connected to FODO cell of skew quadrupole section.

The vertical emittance growth, generated by the bending system is less than 1%.

New beamline layout to allow ECM=250GeV to 1TeV

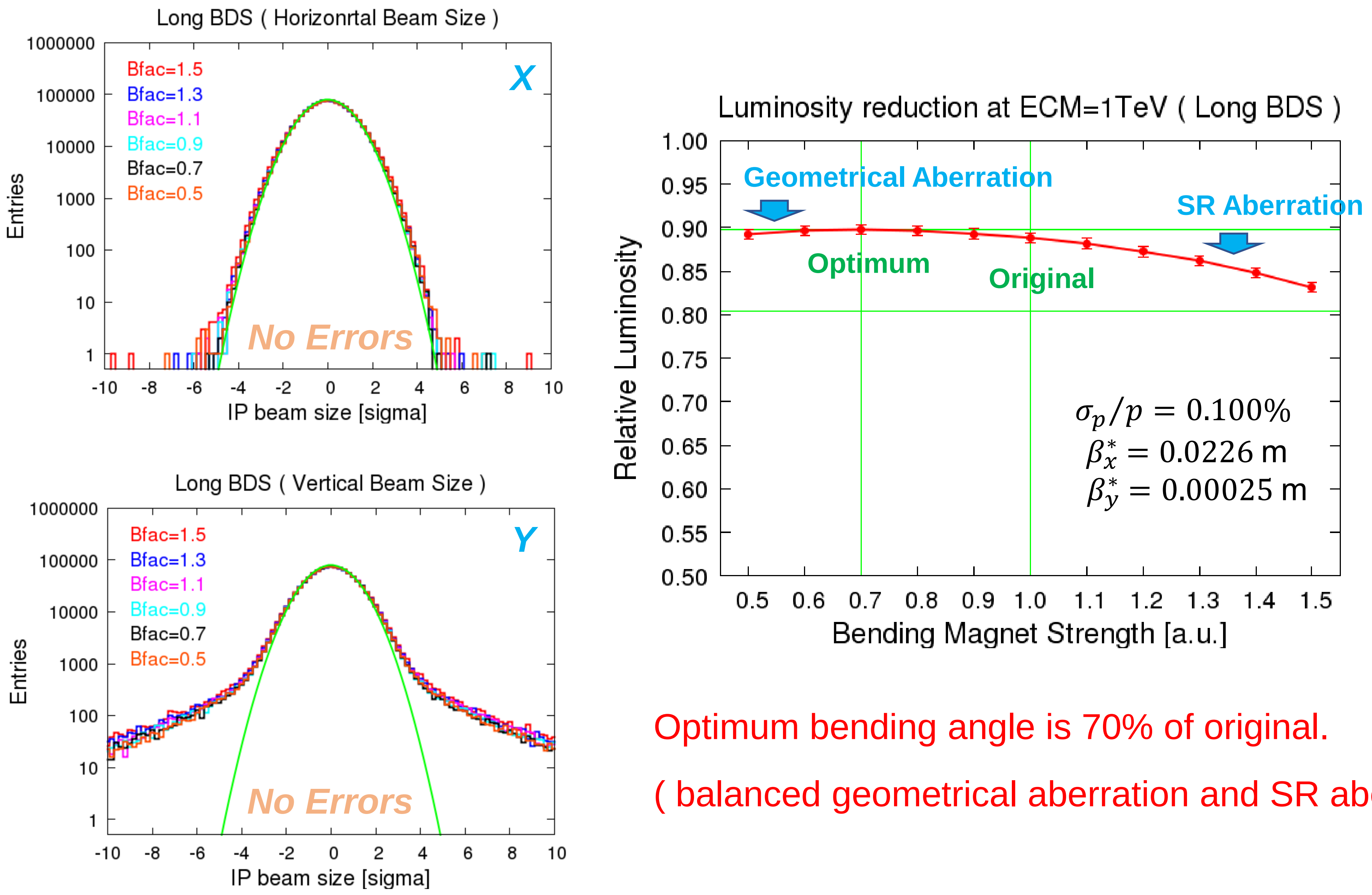






- Add horizontal bend at BDS entrance.
- When we upgrade the energy to ECM=1TeV, we will align the IP position and angle of the two beamlines by adjusting the angle of this horizontal bend and the energy collimator.
- This beam optics improves the performance of ECM=250 GeV, and has the expendability up to ECM=1 TeV.
- This was proposed in 2017, but was rejected because of the slightly longer beamline (cost).

Optimization of bending angle for ECM=1TeV



Optimum bending angle is 70% of original.

(balanced geometrical aberration and SR aberration)

Summary

- The current FF optics of the ILC is designed to cover ECM=250 GeV to 1 TeV with the same geometry. However, they are not optimized for all energies.

- The present QD0/QF1 L* was determined by communicating with SiD and ILC groups in 2014-2015.

- There are L*=6m optics for CLIC 380GeV. But, we have not yet evaluated the optics is fit to the ILC FF optics.

- Long L* optics for ILC was proposed in 2014, but it was rejected for the following reasons.
  1) Energy extendability
  2) Collimation depth .
  3) Aperture of the dumpline

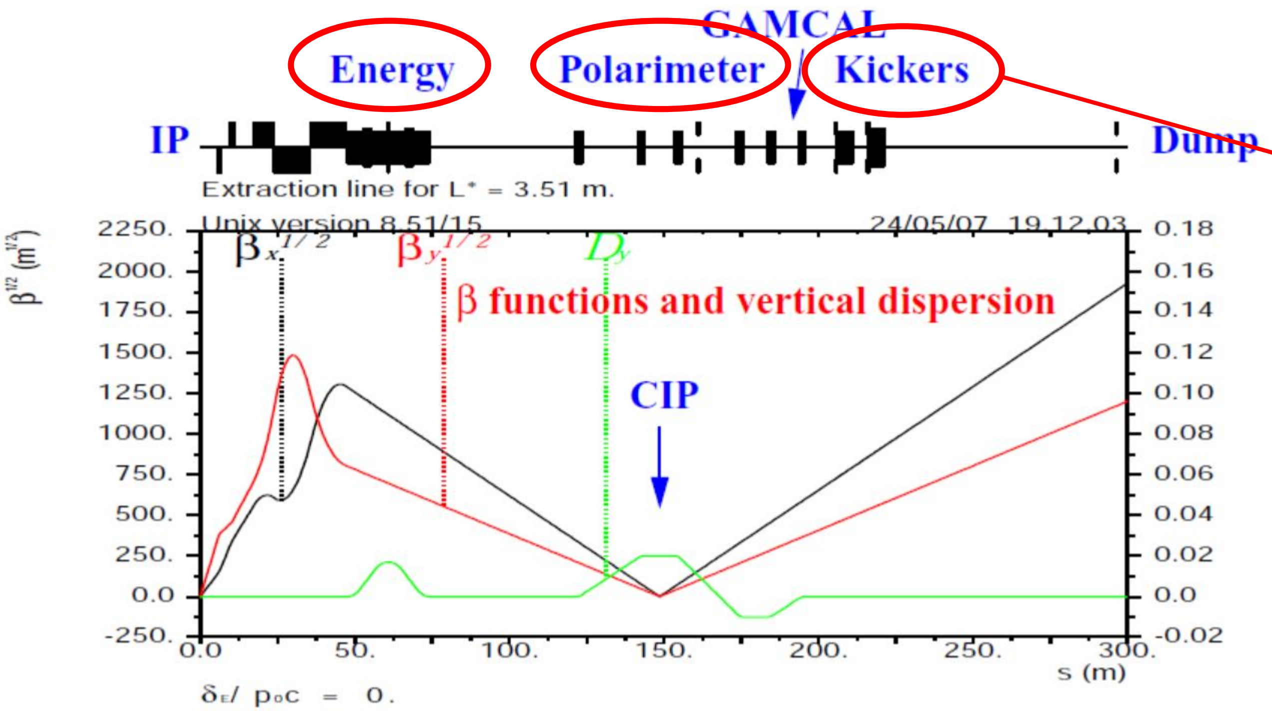
- If we will consider for the adoption, a comprehensive design must be developed to meet these conditions (especially for 2 and 3, which have a significant impact on the entire accelerator system).

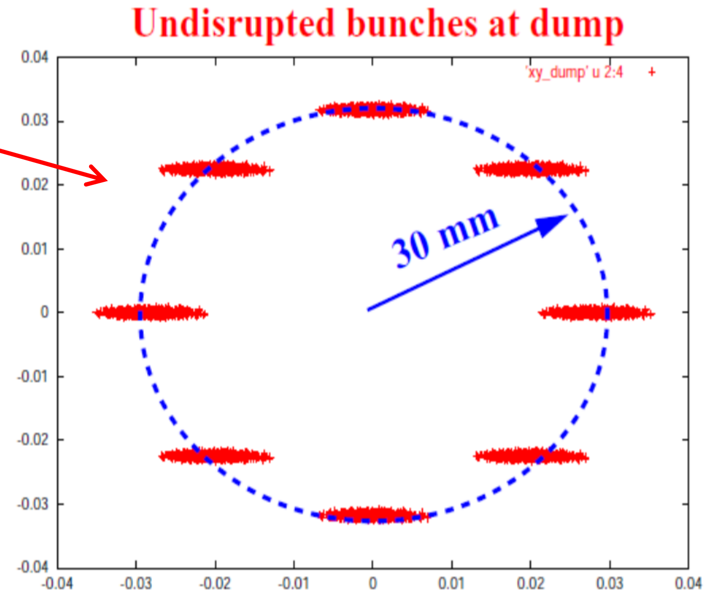
- In order to optimize for each energy, we need to choose optimal bending angle of dipole for each beam energy. A layout to optimize for two energies, ECM=250GeV and 1TeV, was proposed in 2017.

- When we prioritize the optimization of FFS at ECM=250GeV, we should consider it again (just my opinion).

Backup

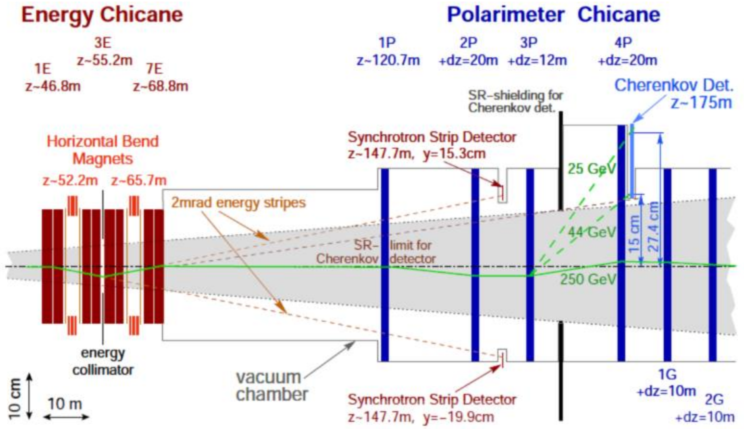
Beam diagnostics for ILC beam extraction line

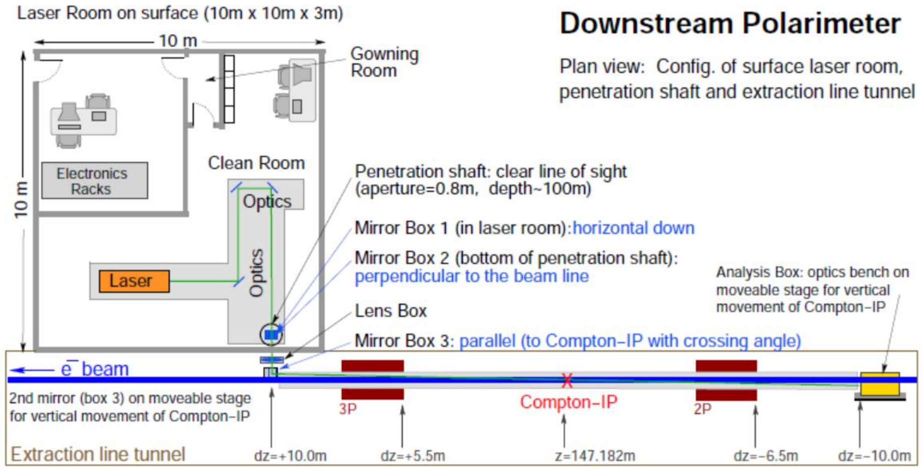


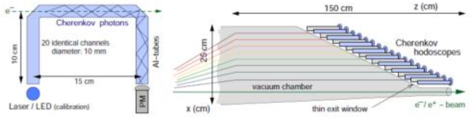


ILC extraction line beam diagnostics

S Boogert *et al* 2009 *JINST* **4** P10015







Cross section of Compton scattering with different beam polarization