

# ***L\* issues for ILC Final Focus Beamline***

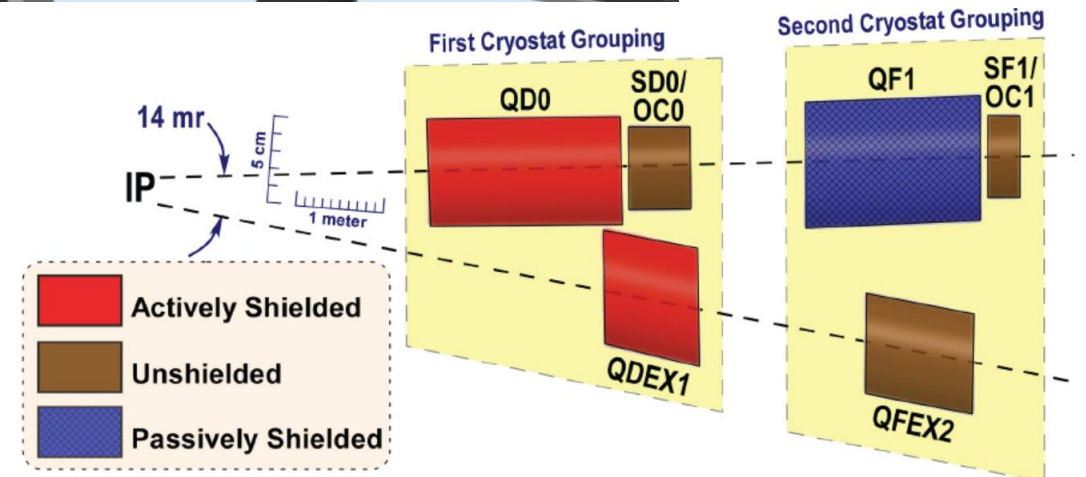
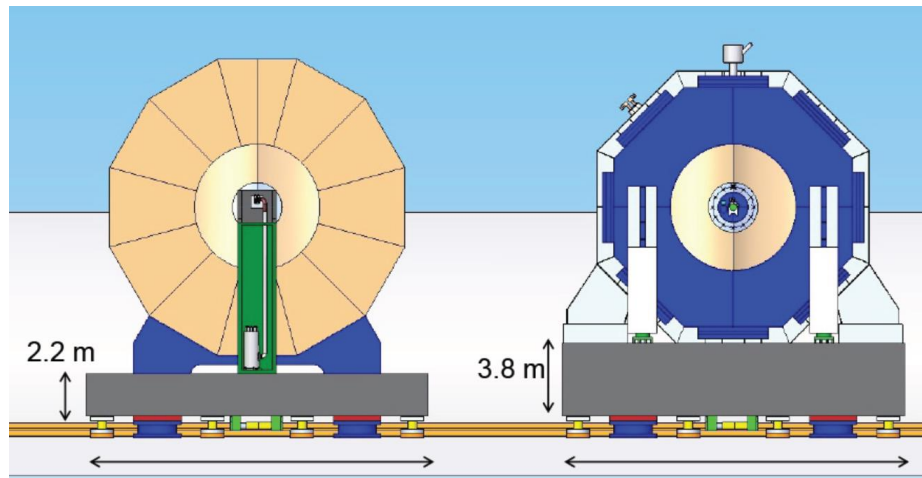
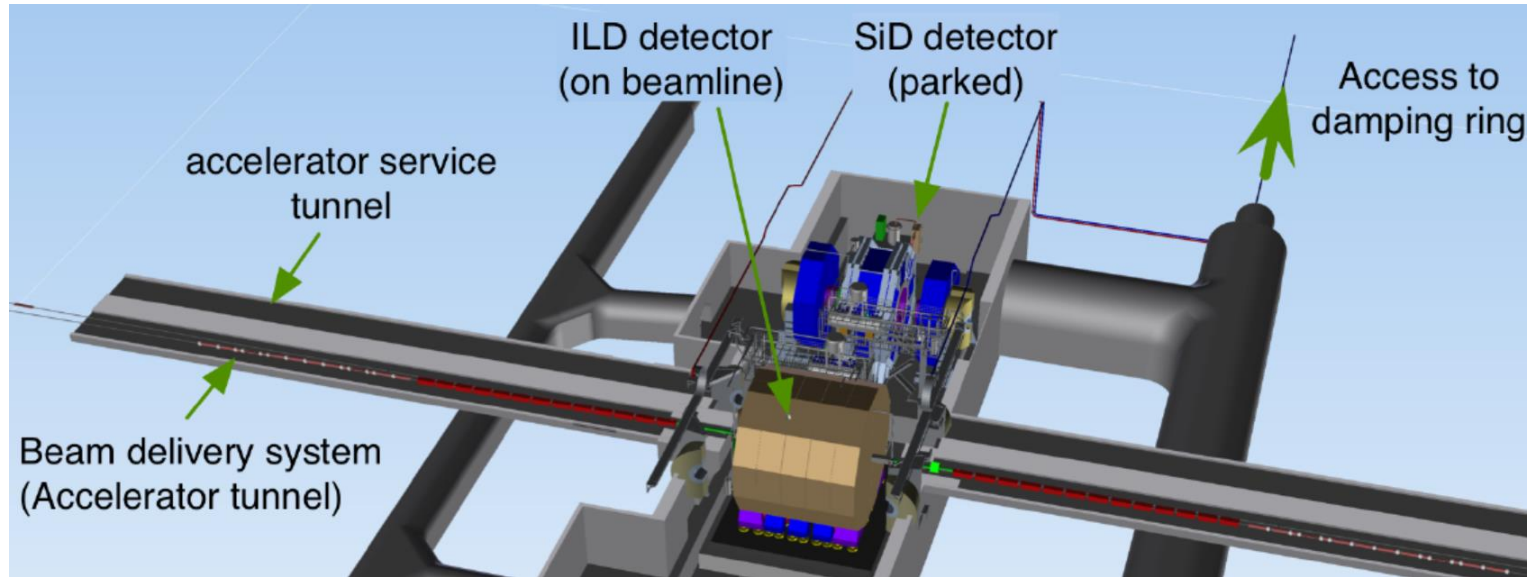
2021/10/14

Toshiyuki OKUGI, KEK  
IDT WG3 MDI meeting

***L\* of present ILC optics***

# 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**

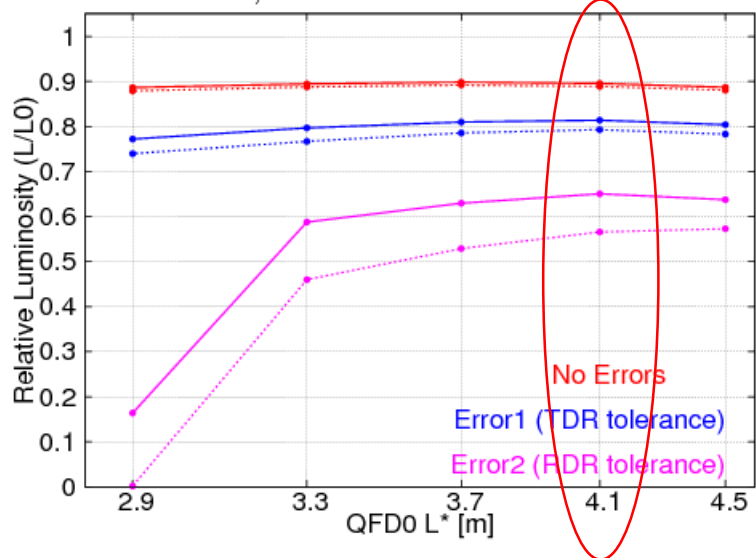
- Better for shorter QF1 L\*
- Determined by the volume of detector hall

## Effect of (QF1 L\*) to Luminosity

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

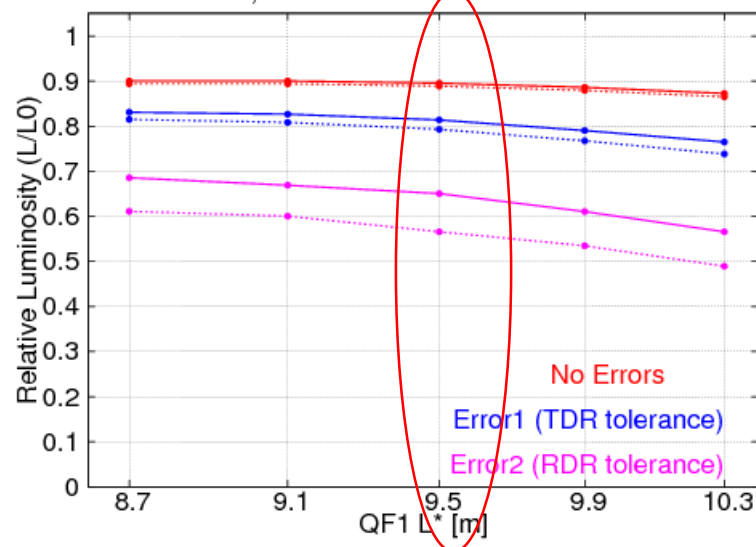
## Results of m Tuning Simulation

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

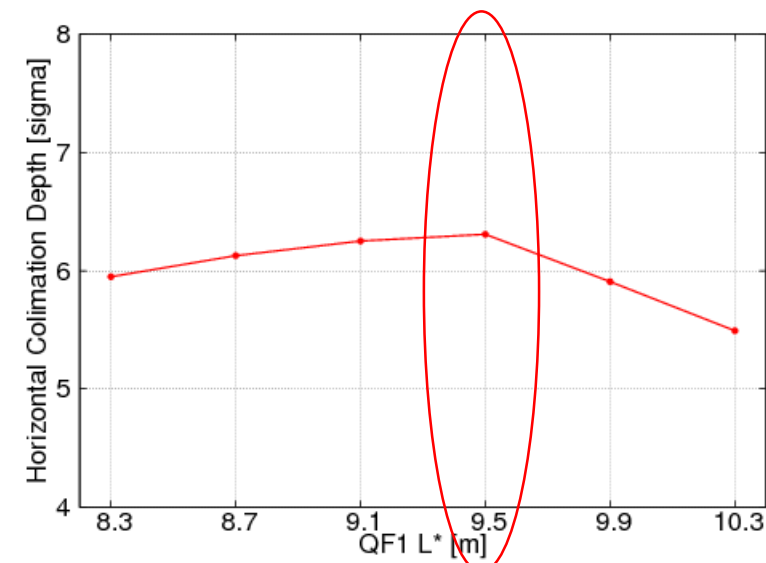


## Results of m Tuning Simulation

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



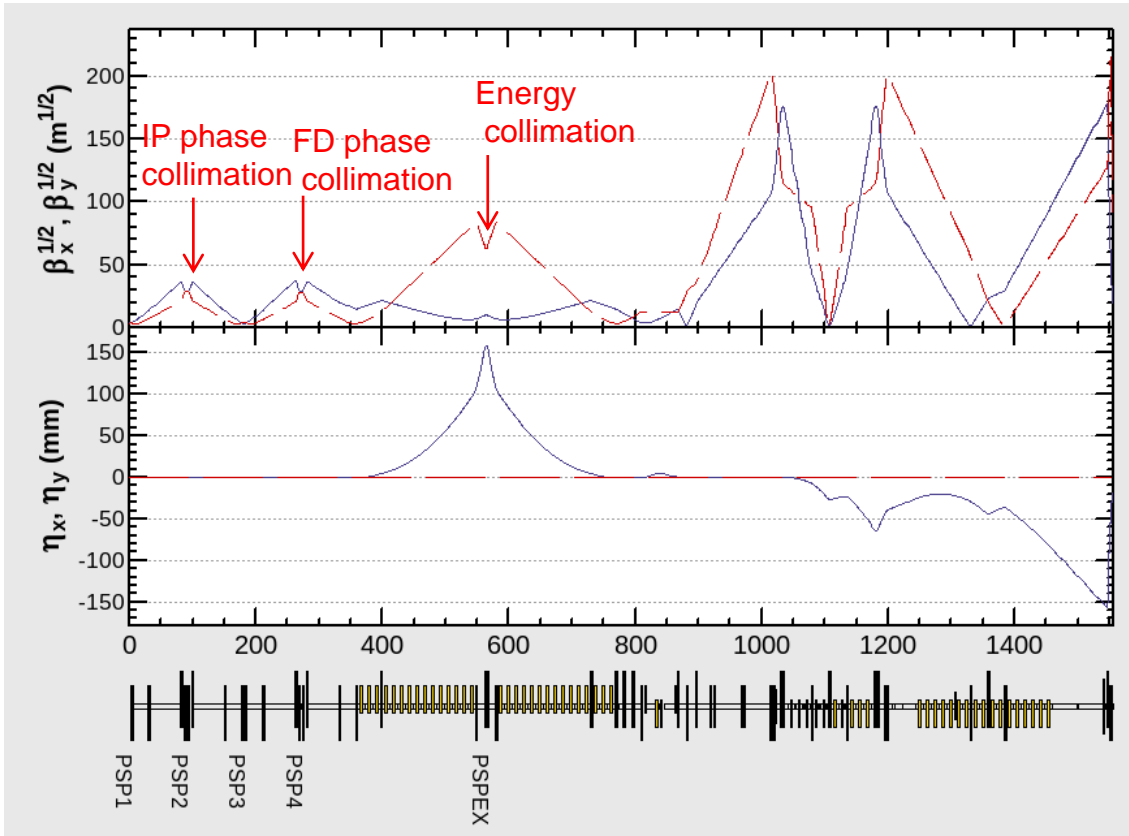
## Horizontal collimation depth



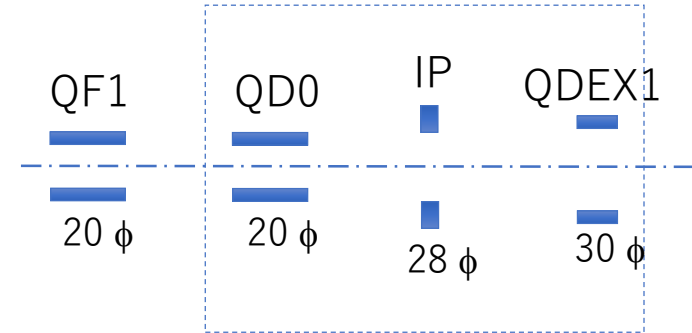
# Consideration of collimation depth

## 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

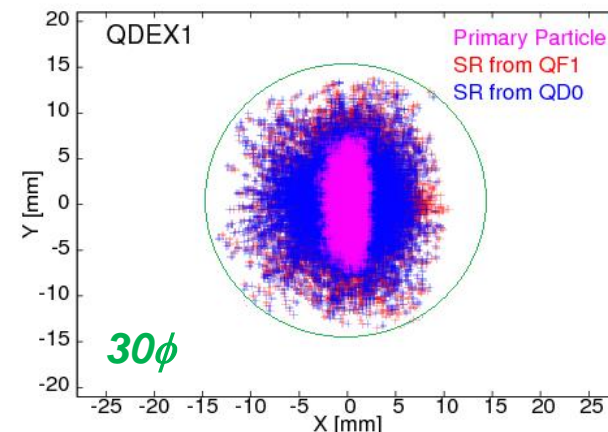


**Source for background**

- 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.

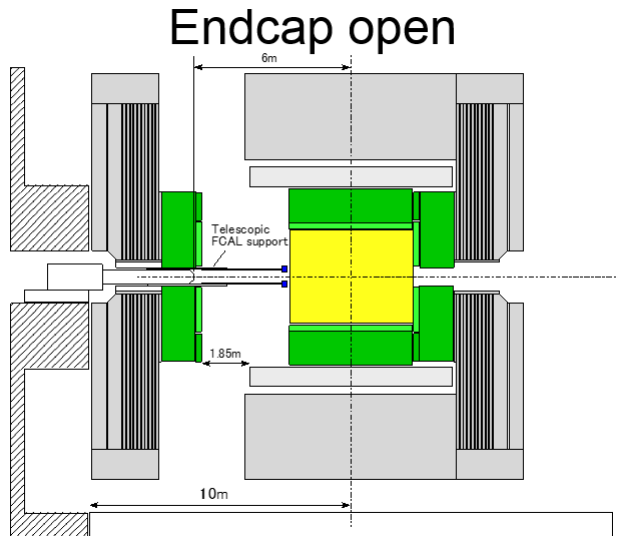
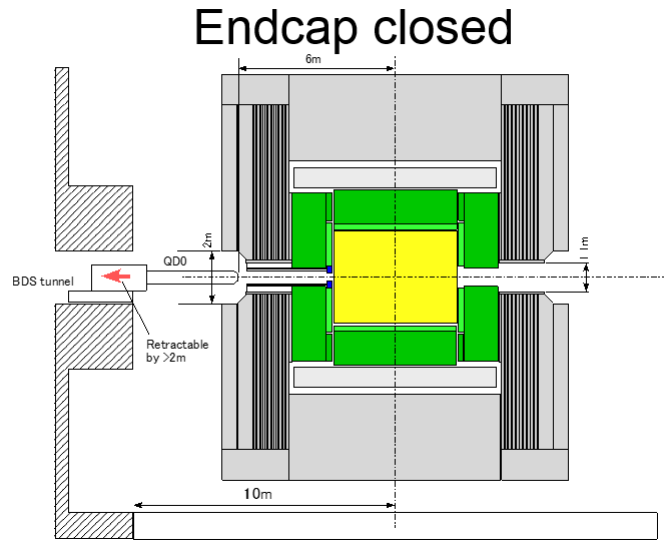


SP2/SP4 X ; 0.86mm  
 SP2/SP4 Y ; 0.98mm  
 SPEX X ; 1.60mm  
 (  $Dp/p = 1\%$  )

# 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  $L^*=6\text{m}$
  - 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:  $\sim 0.5\text{mm}$
    - Support from BDS tunnel: few tens of  $\mu\text{m}$  (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  $Z\sim 6\text{m}$  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.

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

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

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

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

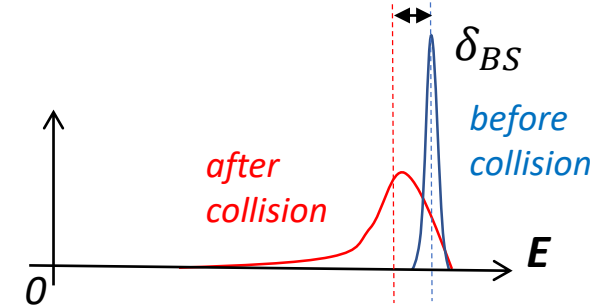
$$L = \frac{f n_b N}{4\pi r_e^{3/2}} \sqrt{\frac{\delta_{BS}}{\gamma \varepsilon_y}}$$

In order to increased the luminosity,

- 1) Make small vertical emittance
- 2) Make beamstrahlung parameter large.  
 $\Rightarrow$  make the balance of the luminosity and energy spread for collision beam.

**Beam energy reduction by beamstrahlung**

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



For ILC 250GeV, the  $\delta_{BS} = 1.8 \%$  ( $Dy = 35$ )  
 For ILC 500GeV, the  $\delta_{BS} = 4.5 \%$  ( $Dy = 25$ )

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

## ***Large $L^*$ optics for ILC***

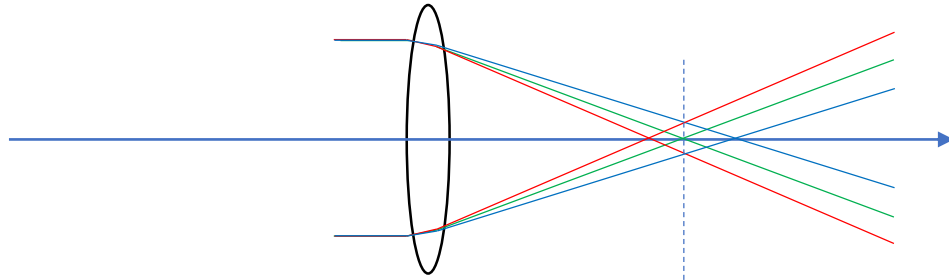
*Toshiyuki OKUGI, KEK*

*2014/ 5/ 15*

*AWLC2014, Fermilab*

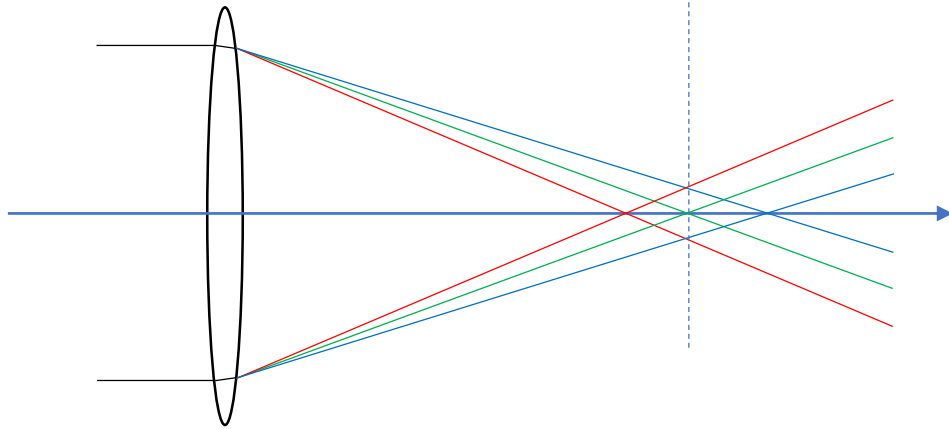


# Long $L^*$ and Chromaticity



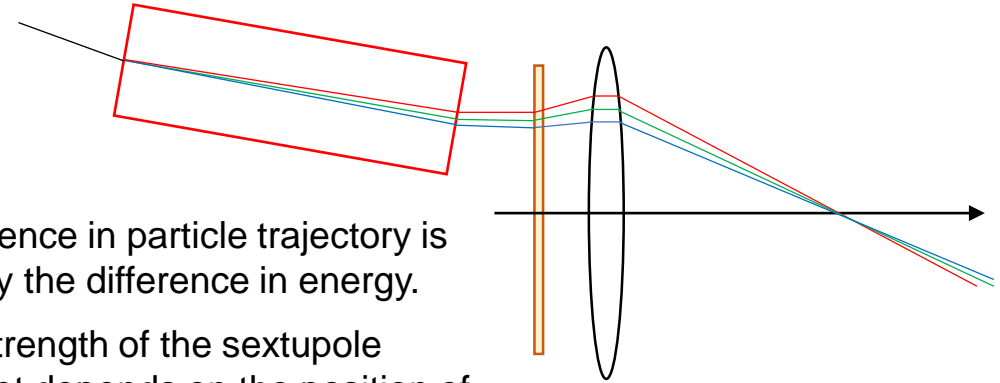
In order to squeeze the beam to the same size at the focus, it is necessary to squeeze the beam at the same divergence angle.

- 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

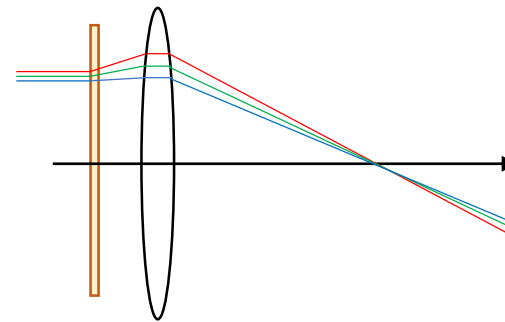


The difference in particle trajectory is created by the difference in energy.

- 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.

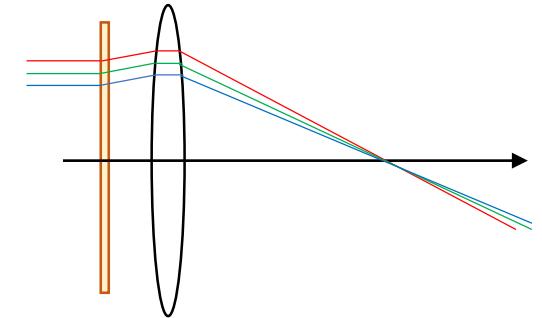
This is especially effective in “the low energy region”, because the beam size passing through the magnet is large.

**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**

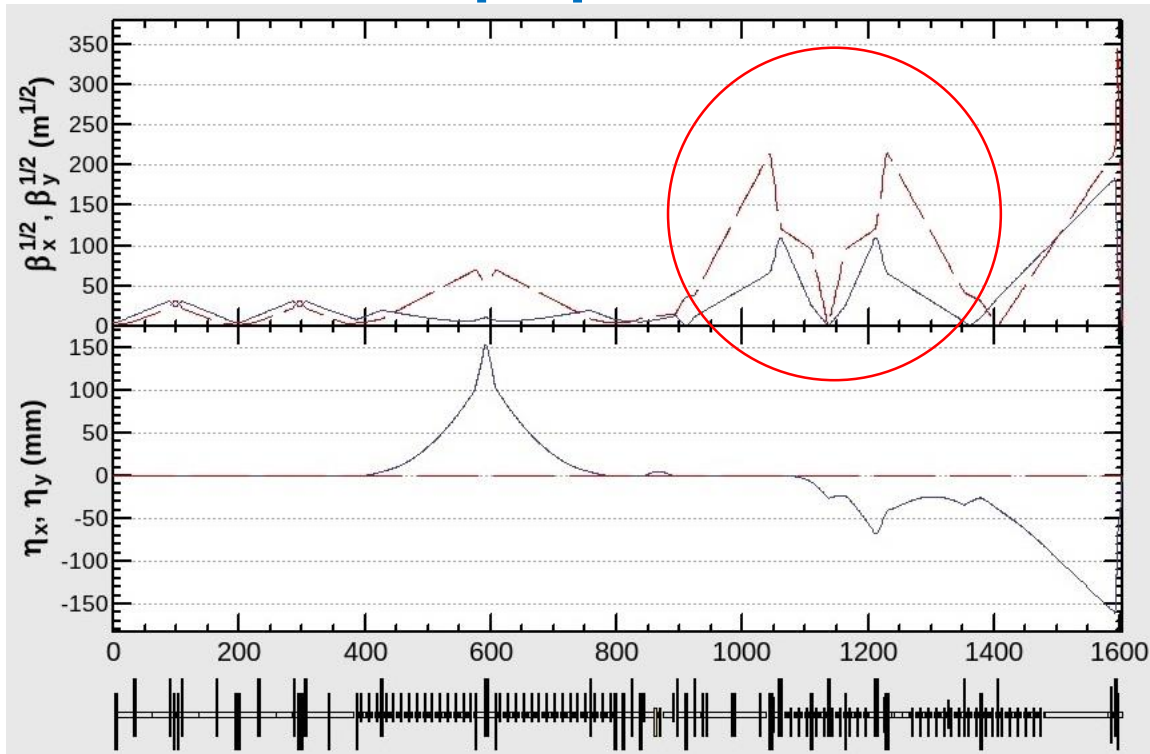


- Enough to use weak sextupoles
- Spatial aberrations are small.

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

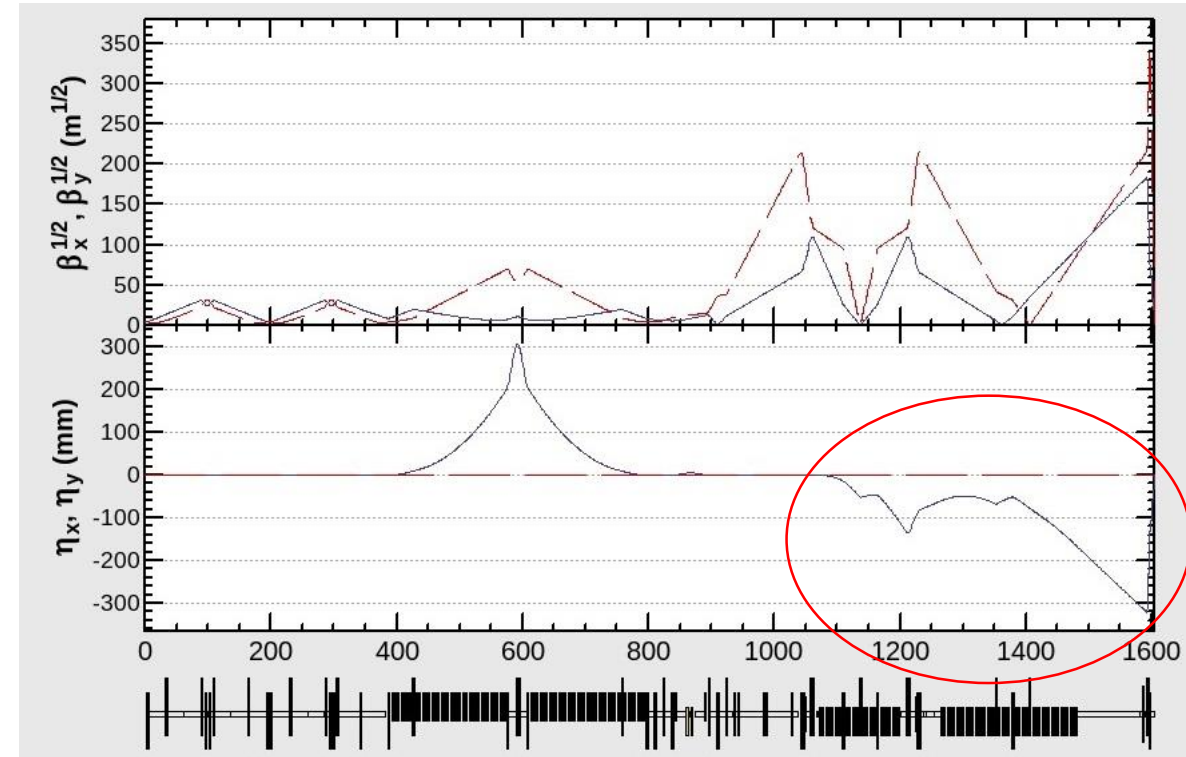
Since the (2<sup>nd</sup> order and higher) geometrical aberration for large  $L^*$  optics was large the large  $L^*$  optics is more difficult than the small  $L^*$  optics, even if we set same chromaticity.

## 1<sup>st</sup> 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).

## 2<sup>nd</sup> step optimization

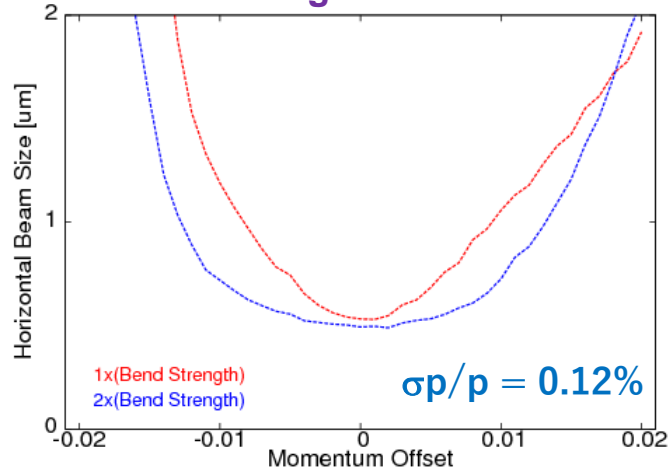


The strength of dipole magnet was increased to twice to increase the dispersion and reduce the strength of sextupoles.

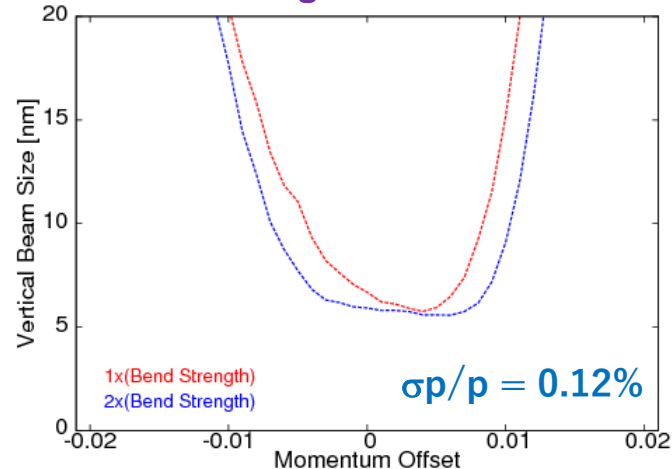
# Performances for the optics with strong bending magnet

Optics was matched to ILC TDR parameters.

Bandwidth of sigmaX for E=250GeV



Bandwidth of sigmaY for E=250GeV

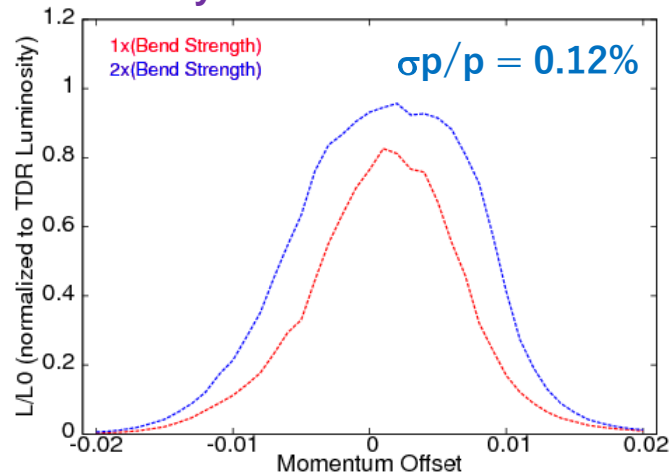


## Effect of SR

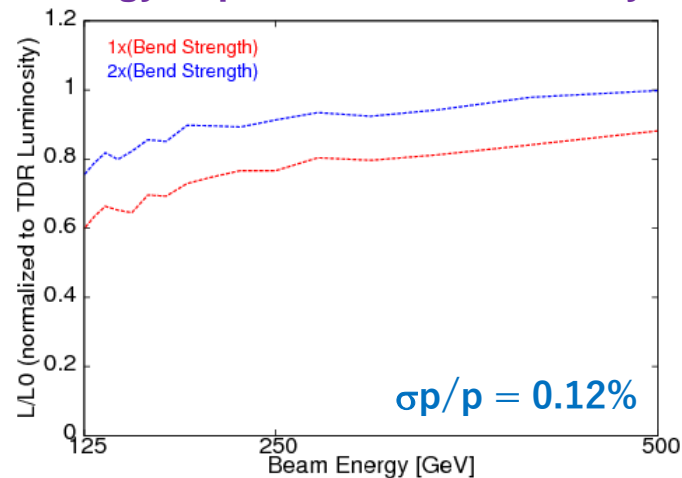
Even at ECM=500 GeV, some effects of synchrotron radiation are appeared.

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

Luminosity Bandwidth for E=250GeV



Energy Dependence of Luminosity



At AWLC2014, this proposal was rejected.

The reasons are

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

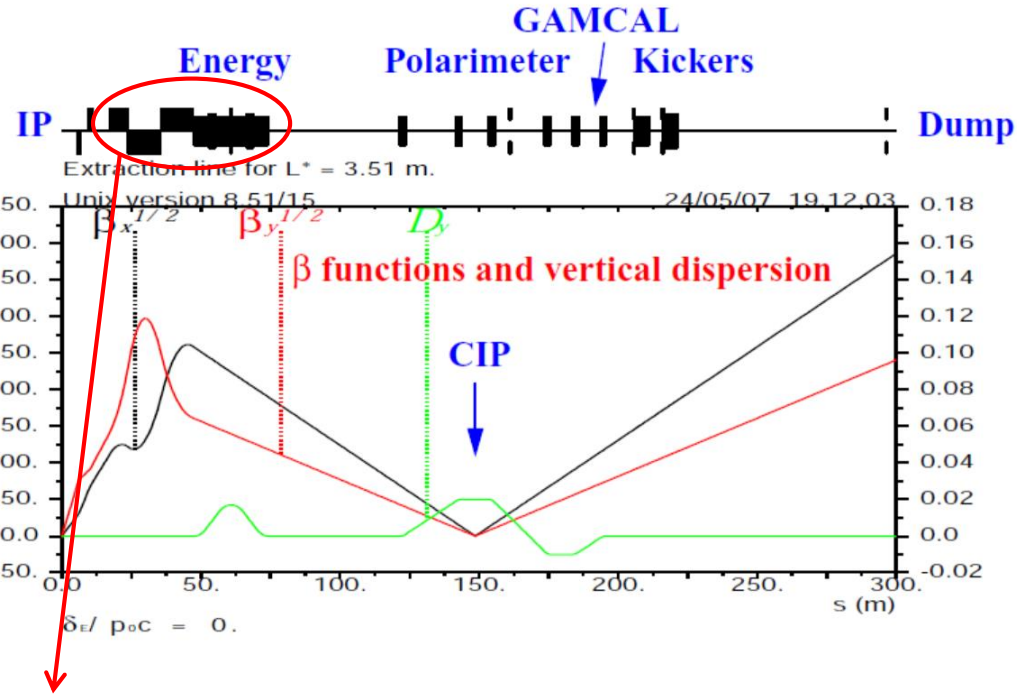
etc.

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

# 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.*
  - *Beam line length*
  - *Extraction line*
  - *Final doublet design*
  - *crab cavity*
  - *anti-DID (?) etc.*
- *When increasing  $L^*$ , the acceptable range of the optimum bending angle for the beam energy becomes smaller, which may limit the **future energy extendability**.*
- *We should reevaluate the effect of the collimation depth, **detector background and aperture of inner detector** (may be worse than present optics).*
- ***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, just an information sharing between accelerator and detector groups.***
- *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.*

# ILC beam extraction line



## Quadrupole magnets in extraction line

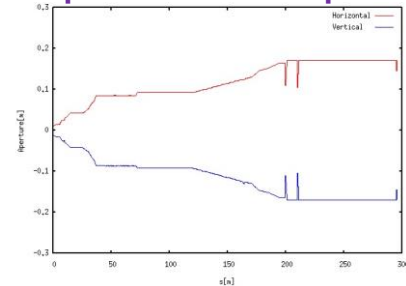
Y. Nosochkov et al., LCWS/ILC 2007

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

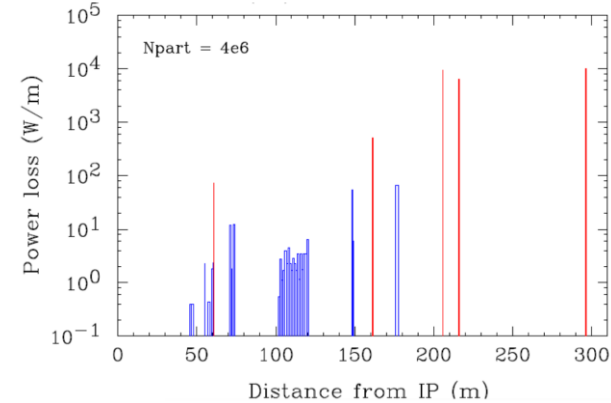
## Apertures for Dumpline



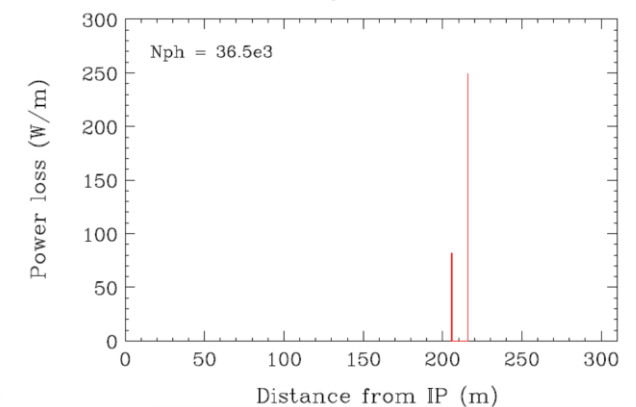
## Power loss at extraction line (beam-beam effect)

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

### Disrupted charged particles

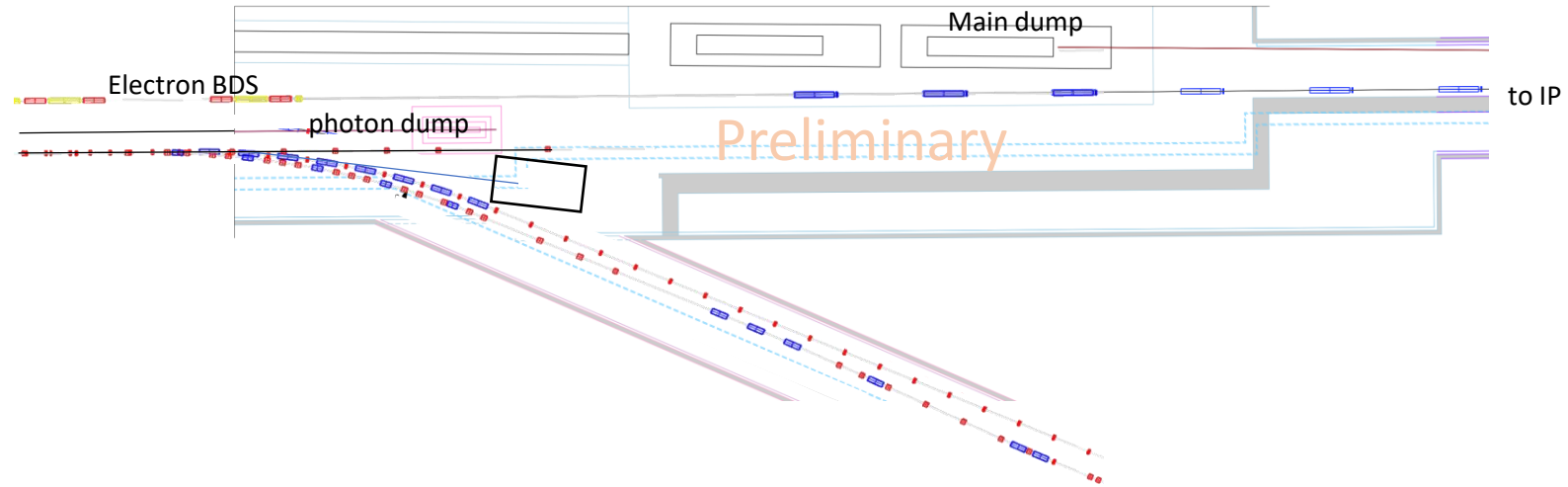


### Beamstrahlung photons



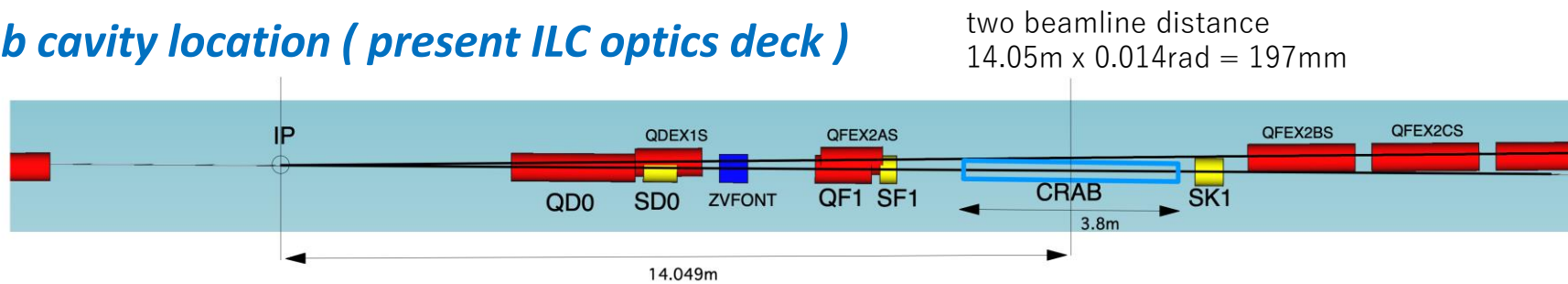
- The ILC extraction line uses large-diameter quadrupole magnets (maximum bore diameter 170 mm) to transport the beam with large beam spread by the beam-beam effect to the dump with minimal loss.
- When the  $L^*$  of QD0 is lengthened, the  $L^*$  of the extraction quadrupole magnet QDEX1 is also lengthened, 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.

# Tunnel layout around beam dump



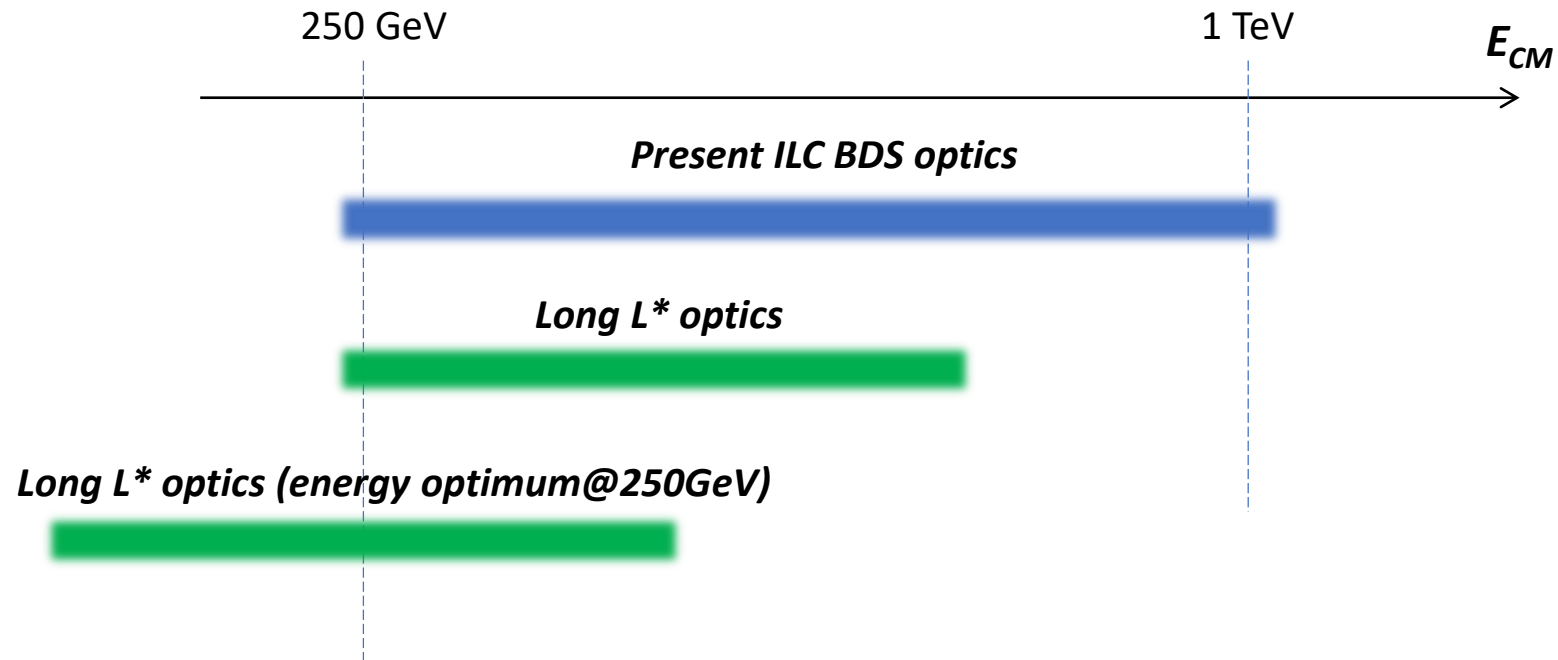
## Crab cavity location

Crab cavity location ( present ILC optics deck )



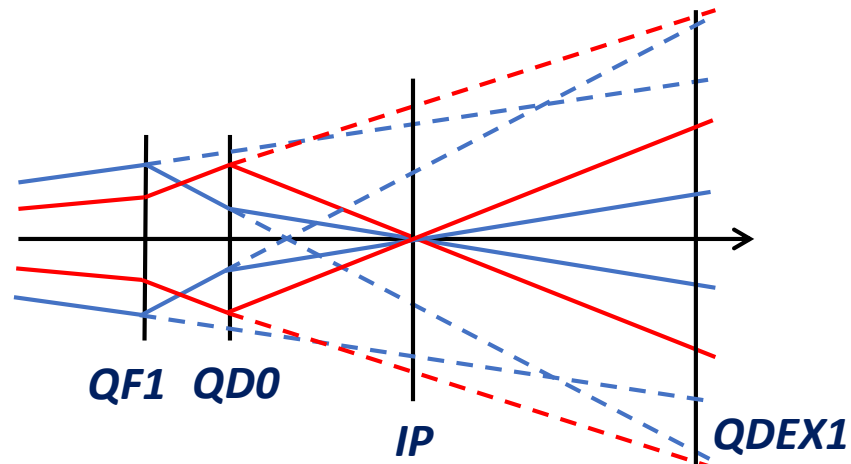
# Energy extendability

- *As  $L^*$  is increased, the energy extendability becomes narrower.*
- *When the optimum energy of the beam optics is set to  $E_{CM}=250$  GeV, the extendibility becomes even narrower (we will not discuss the optimum energy of the beam optics in today's presentation).*



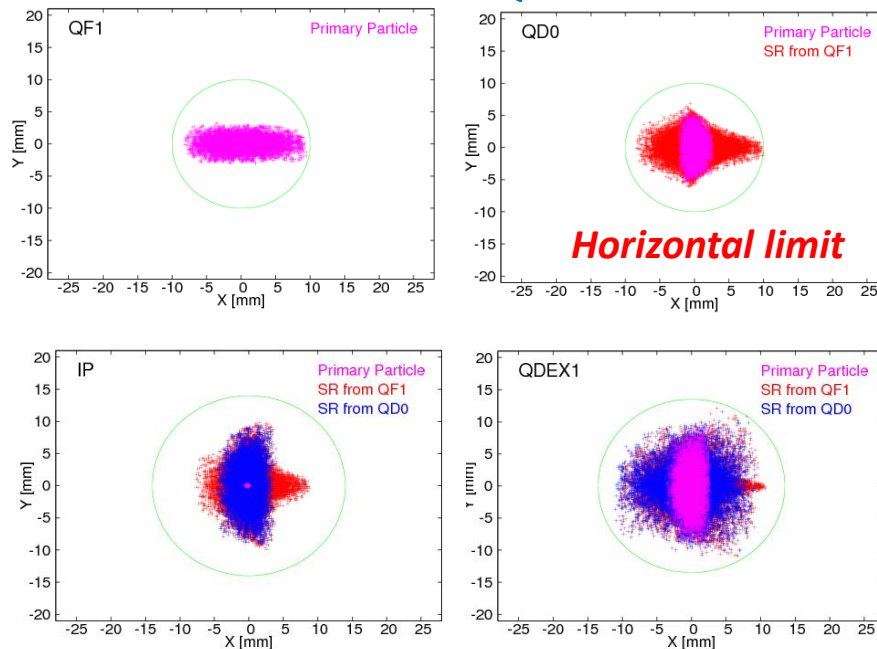


# Synchrotron radiation around IP area

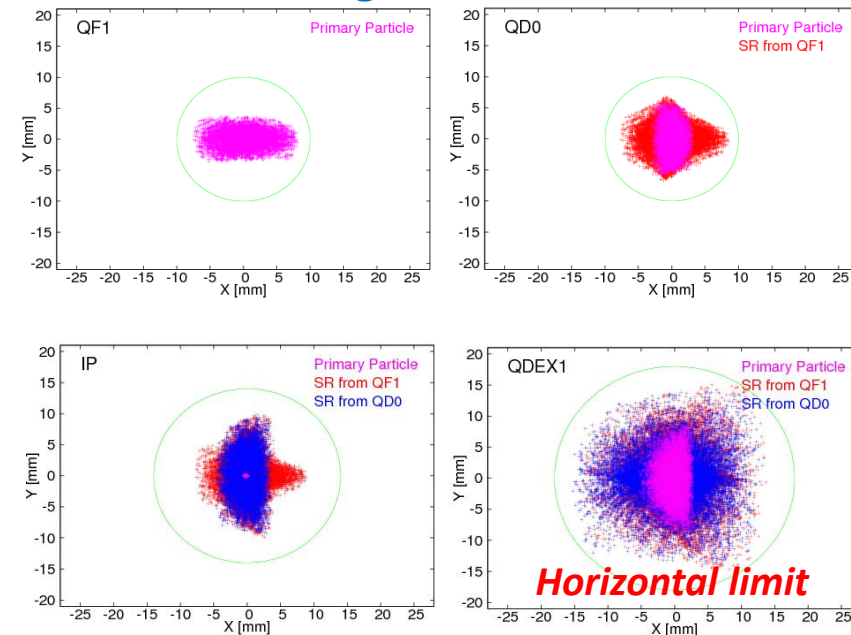


- The aperture of the inner detector with  $R=16\text{mm}$  is not a problem with the current  $L^*$  setting.
- When  $L^*$  is increased, the effect of SR from the Final doublet on the SC magnet in the extraction line becomes larger, *the collimation depth is reduced, and the inner detector aperture should be increased.*

**Shorter QD0  $L^*$**



**Longer QD0  $L^*$**

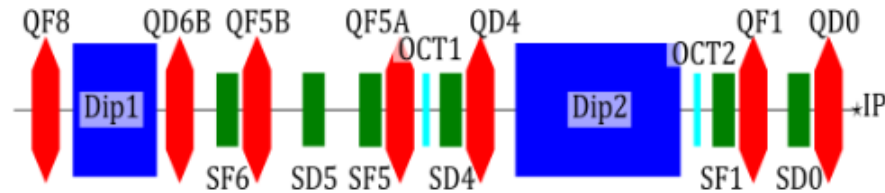




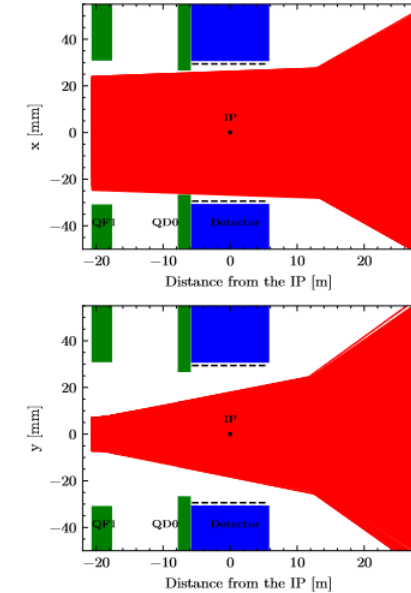
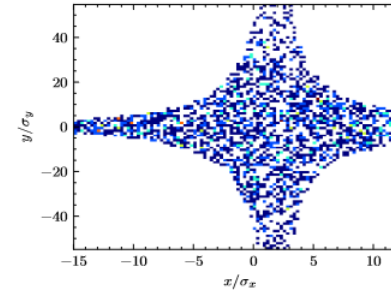
# $L^*=6m$ optics for CLIC 380GeV by A. Pastushenko at ICWS2021

## Collimation depth

Final Focus System scheme

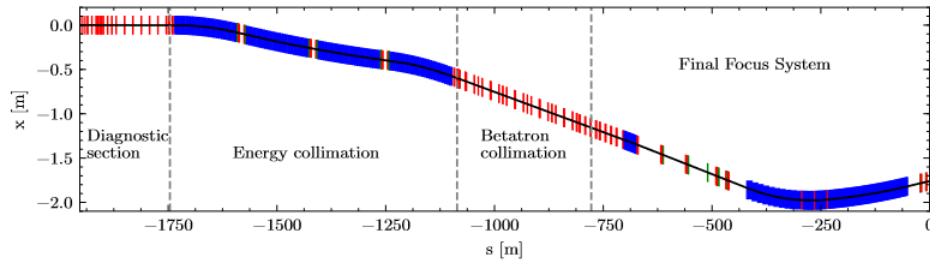


- The collimation depth has to satisfy the condition that neither beam halo nor emitted photons hit the FD or the detector. The beam halo used in the simulations:

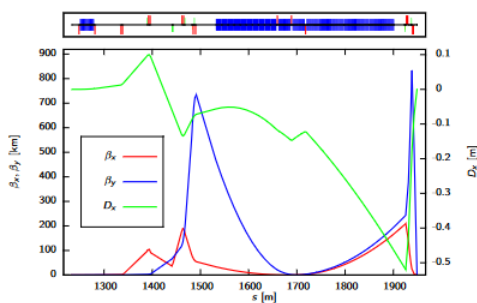


	QF1	QD0
Gradient [T/m]	16.3	73.7
Aperture [mm]	31.2	27.0
Pole tip field [T]	0.51	1.99

## Beam Delivery System of CLIC@380 GeV:



FFS optics<sup>1</sup>:



FFS length [m]	770
$L^*$ [m]	6
$\epsilon_{n,x}/\epsilon_{n,y}$ [nm]	950/30
$\beta_x^*/\beta_y^*$ [mm]/[μm]	8/70
$\sigma_x^*/\sigma_y^*$ [nm]	145/2.9
$\sigma_z$ [μm]	70
$\delta_p$ [%] (Uniform distr.)	1.0
$\mathcal{L}$ [ $10^{34} \text{cm}^{-2} \text{s}^{-1}$ ]	1.66
$\mathcal{L}_{1\%}$ [ $10^{34} \text{cm}^{-2} \text{s}^{-1}$ ]	0.96

- Basically same concept as ILC FFS** (modified local chromaticity correction). The additional sextupoles were put to the original chromaticity correction optics.
- They also use octupoles for IP focusing.
- The effect on the detector background and collimation depth needs to be carefully examined, when using octupole magnets for beam adjustment.
- 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 aperture of the inner detector around the IP is assumed to be wider than ILC.

<sup>1</sup>A. Pastushenko, "Optics calculations for CLIC". Master's thesis.



# 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

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

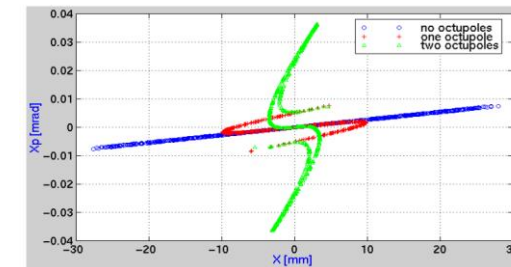
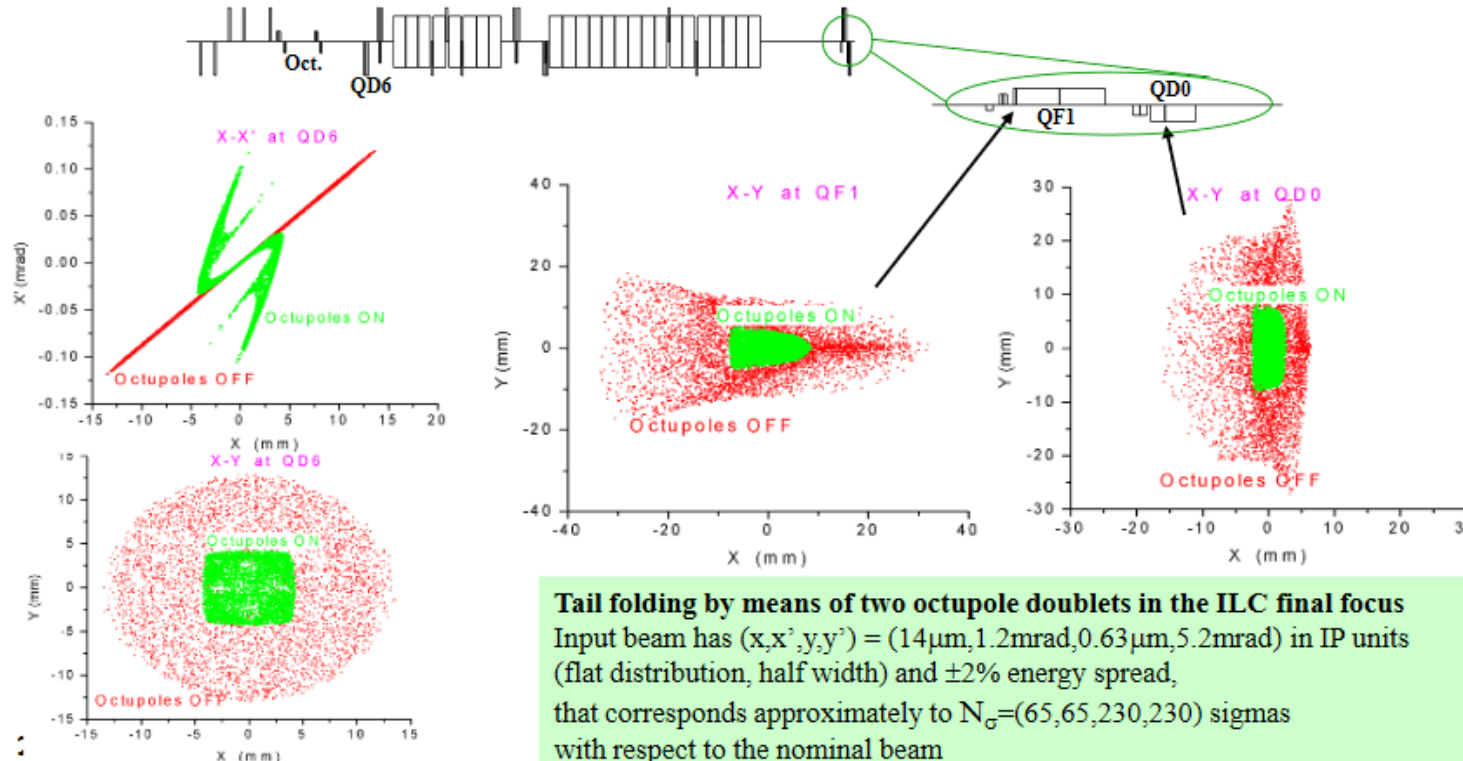
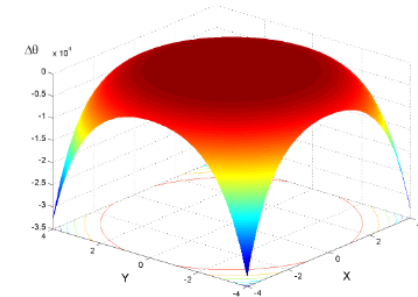
$$\Delta\theta = \alpha r^3 e^{-i3\varphi} - (\alpha r^3 e^{i3\varphi} (1 + \alpha r^2 L e^{-i4\varphi})^3)$$

$$x + iy = r e^{i\varphi}$$

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

Focusing in all directions

Next nonlinear term focusing – defocusing depends on  $\varphi$



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.

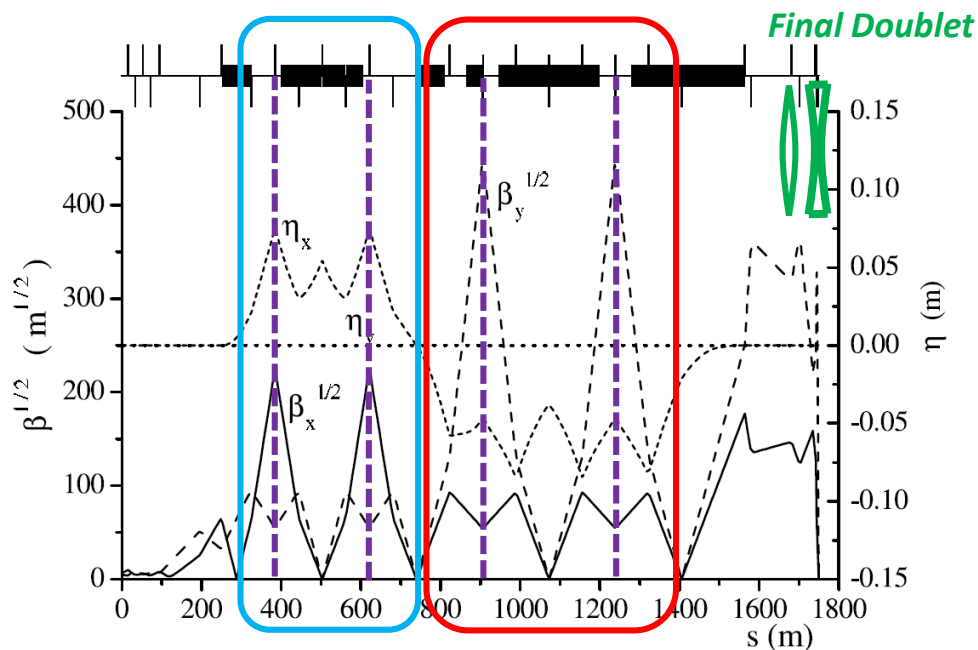
# Comments at IDT WG2 BDS group meeting @09/29/2021

- ***It is doubtful that anti-DID is no longer necessary when  $L^*$  is increased.***
  - *I think it is something that the detector group can show us in simulation.*
- ***There is a need to make  $L^*$  smaller as well as larger.***
  - *This is possible if we can move the QF1 position closer to the current position, but the current position of the QF1 magnet is determined by the size of the detector. However, the position of the QF1 magnet is currently fixed due to the size of the detector. Under these conditions, moving only QD0 closer to IP would not be beneficial.*
- ***We should reconsider not only  $L^*$  but also the crossing angle.***
  - *This is not an issue that can be decided by the BDS group alone (gamma-gamma collider is also involved).*
  - *From the point of view of the CFS, now would be the last opportunity to reconsider.*
- ***Wouldn't it be nice to have a larger group to discuss  $L^*$ , crossing angle, and other accelerator-related issues?***
  - *In the framework of IDT, it will be difficult from the point of view of resources, but it will be necessary at the beginning of the Pre-Lab phase.*

***Backup slide***

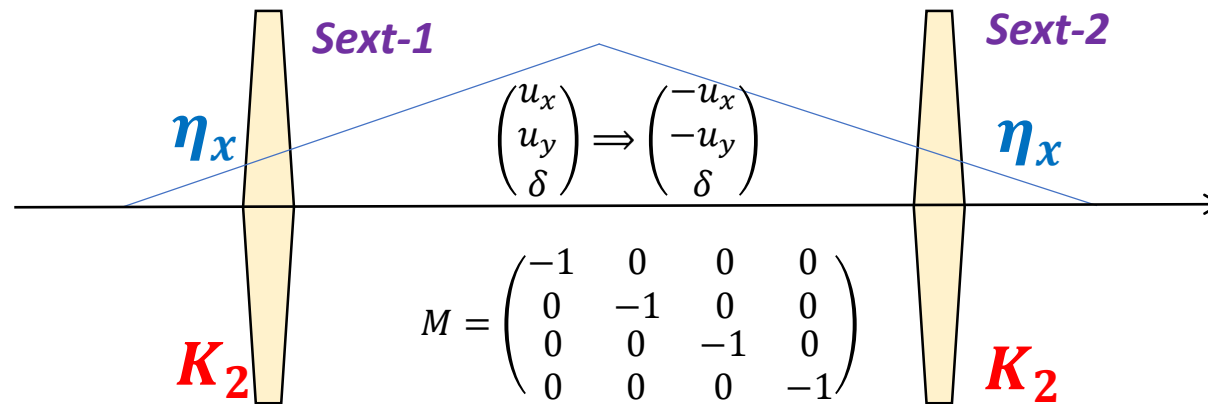
# Global Chromaticity Correction System

Linear collider FFS optics in 1990's



**Horizontal Chromaticity Correction**  
**Vertical Chromaticity Correction**

2 sextupoles are put to the following condition.



**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**

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

↓

**Total**

$$\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = \begin{pmatrix} +4\eta_x K_2 \sqrt{\beta_x} u_x \delta \\ -4\eta_x K_2 \sqrt{\beta_y} u_y \delta \end{pmatrix}$$

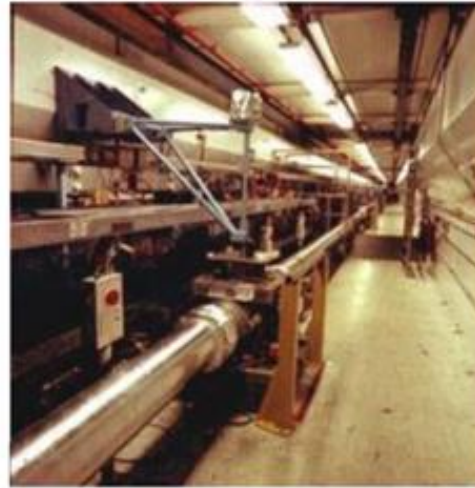
**Chromaticity**

Only chromaticities are generated as total system.

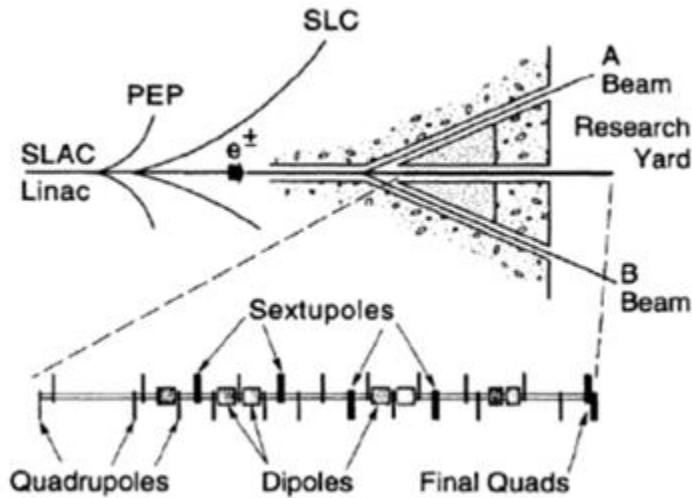
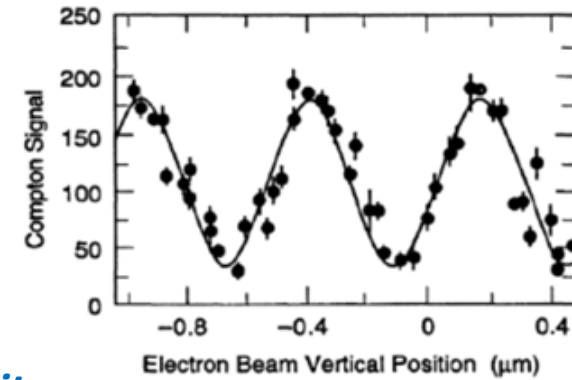


# Final Focus Test Beam (FFTB)

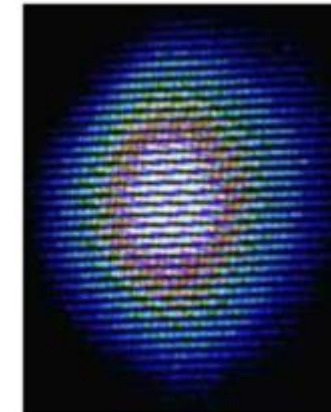
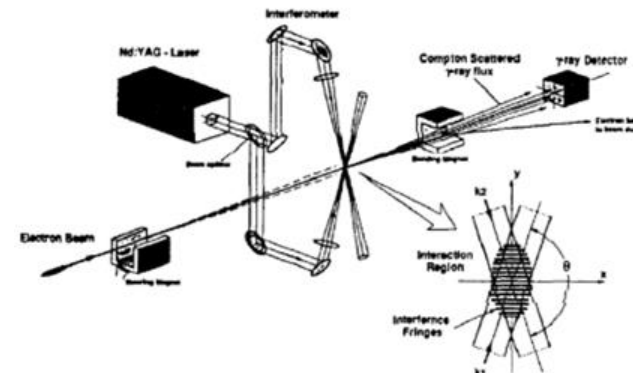
FFTB is built in SLC research yard (SLAC) for the LC final focus test with **global chromaticity correction system** in 1990's.



	<i>IP beam size</i>
<i>Design</i>	45 nm
<i>Achieved</i>	70 nm

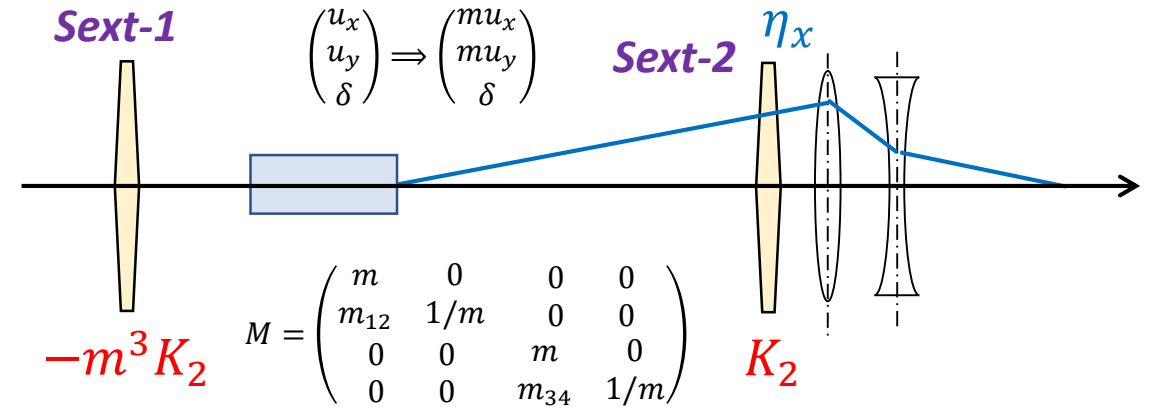
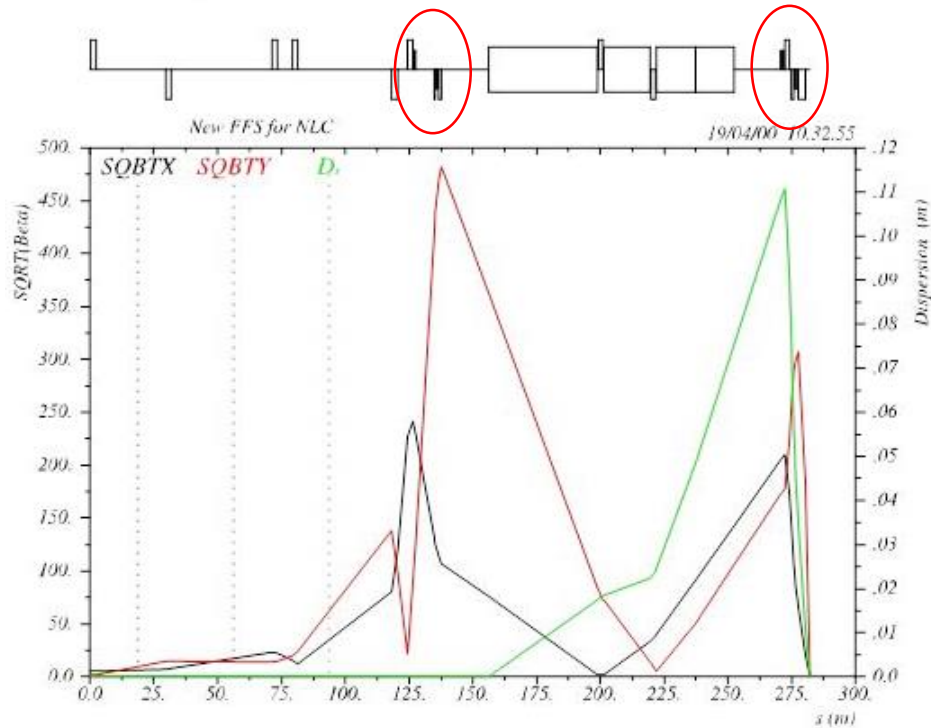


## Shintake Monitor



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

**Total**  $\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix} = \begin{pmatrix} -2m \eta_x K_2 \sqrt{\beta_x} u_x \delta \\ +2m \eta_x K_2 \sqrt{\beta_y} u_y \delta \end{pmatrix} + \begin{pmatrix} -K_2 \eta_x^2 \delta^2 \\ 0 \end{pmatrix}$

**Chromaticity**      **2<sup>nd</sup> order dispersion**

Geometrical aberration was cancelled.

	X chromaticity	Y chromaticity	2 <sup>nd</sup> order dispersion
Linear Optics	○	○	○
X chromaticity corr.	○	△ (small)	○
Y chromaticity corr.	△ (small)	○	○

When chromaticity correction knobs (sextupoles) are changed.

=> 2<sup>nd</sup> order dispersion is changed. (linear optics and sextupoles are coupled.)

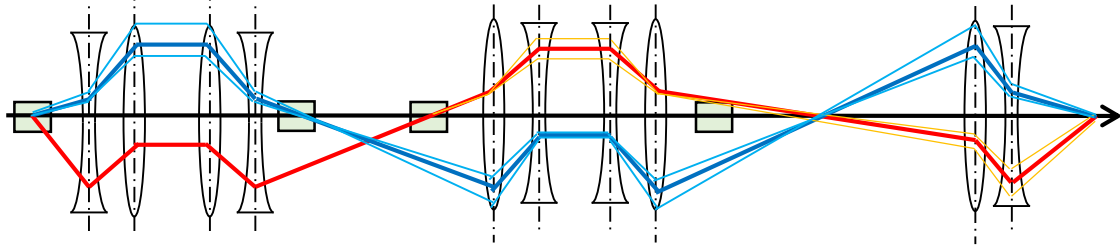
=> Linear optics must be changed.

# Advantage of local chromaticity correction optics

## Global Chromaticity Correction

### Horizontal Correction

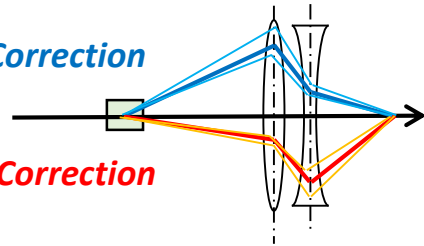
### Vertical Correction



## Local Chromaticity Correction

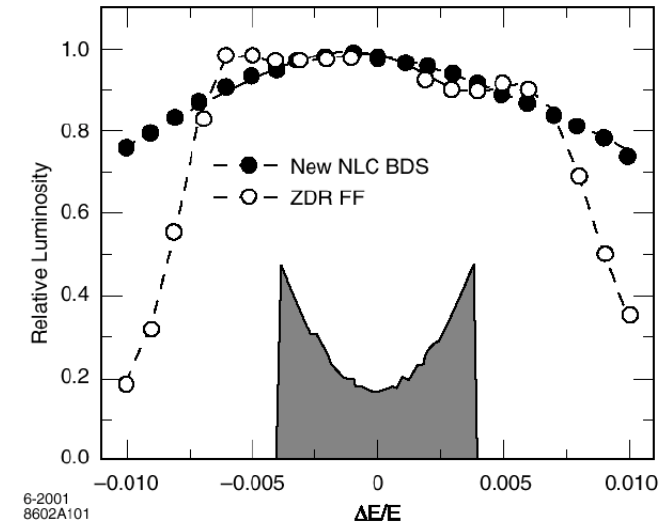
### Horizontal Correction

### Vertical Correction

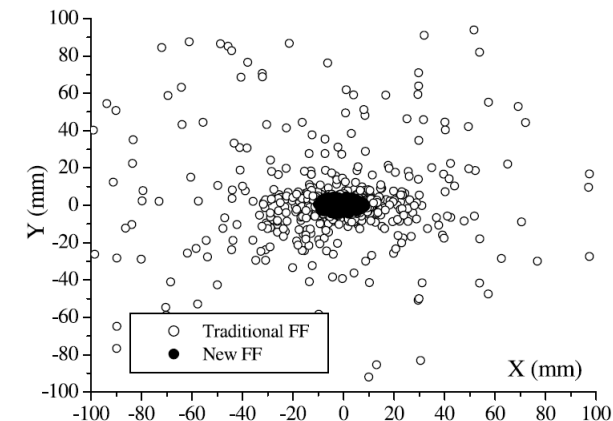


- The beamline length is shorter than that for the global chromaticity correction system
- Orbit distortion through long beamline of off-momentum particle exists for global chromaticity correction beamline.
  - Longer  $L^*$
  - Smaller background by the halo particles
  - Wider energy bandwidth

## IP Energy Bandwidth



## Beam Halo at IP

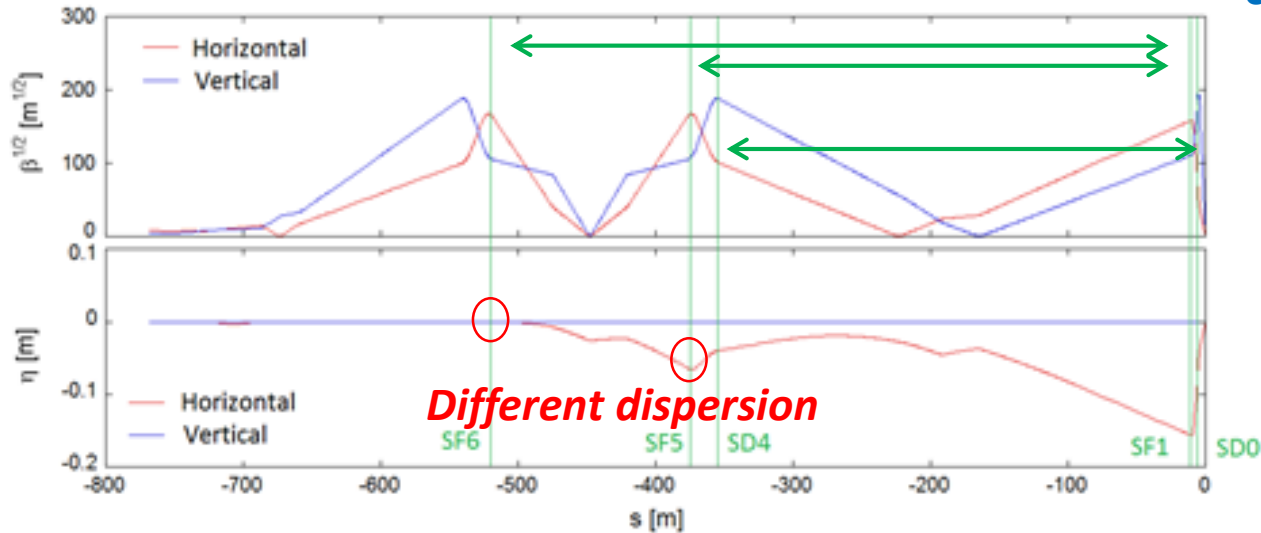


P. Raimondi and A. Seryi, PRL Vol. 86 3779 (2001)



# Present ILC Final Focus Optics

We adopted the *modified* Local Chromaticity Correction Optics.



### 3 parameters to be corrected

- X Chromaticity
- Y Chromaticity
- 2<sup>nd</sup> order Dispersion



### 2 sext. pair for correction

- SF6, SF5 (combination) and SF1
- SD4 and SD0

We can correct 2<sup>nd</sup> 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 )

# Beam Optics of ILC & ATF2

## ILC final Focus System

- ILC final focus system and ATF2 beamline are both based on **the Local Chromaticity Correction**.

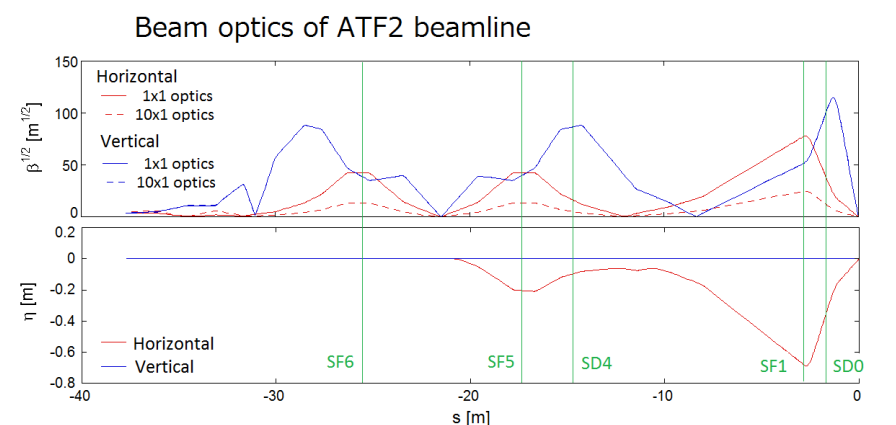
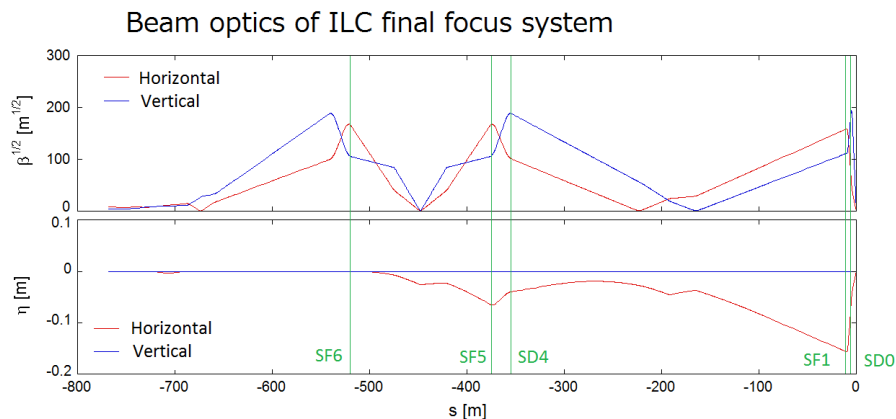
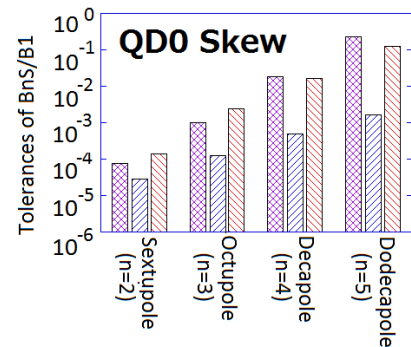
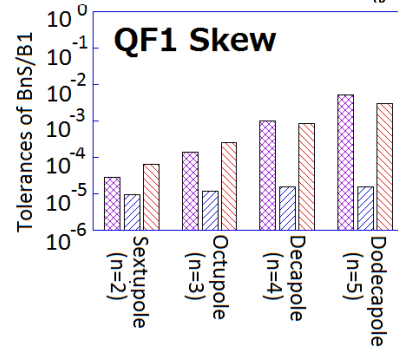
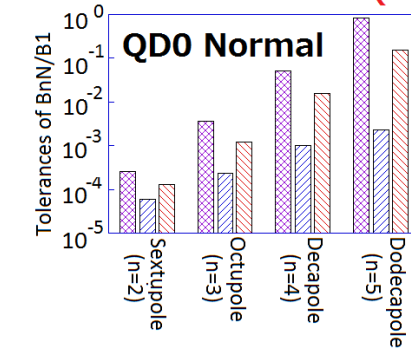
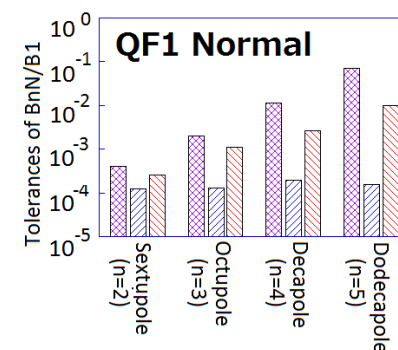
## ATF2 Beam Optics

**1x1 optics**  
X&Y chromaticities are comparable to ILC FF.

**10x1 optics**  
Since  $\beta_{x^*}$  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

Multipole Field Error Tolerances (R=1cm) **ILC**  
**ATF ( 1 x 1 )**  
**ATF ( 10 x 1 )**



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

The current ILC FF optics are designed to support energies of  $ECM=250\text{GeV}-1\text{TeV}$  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.

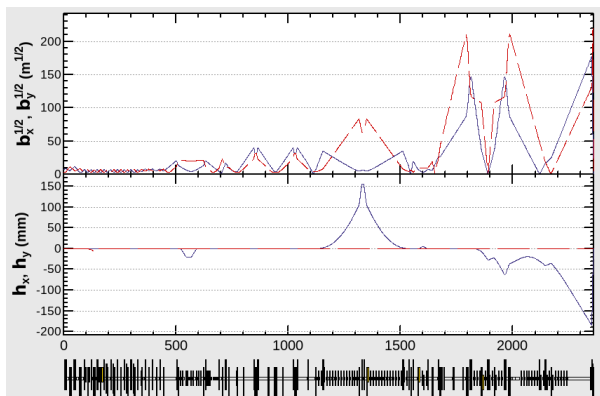
- In order to optimize for each energy, we need to choose optimal bending angle of dipole for each beam energy.
- A layout to optimize for two energies,  $ECM=250\text{GeV}$  and  $1\text{TeV}$ , was proposed in 2017.

***Optimization of ILC BDS optics  
for wide energy range***

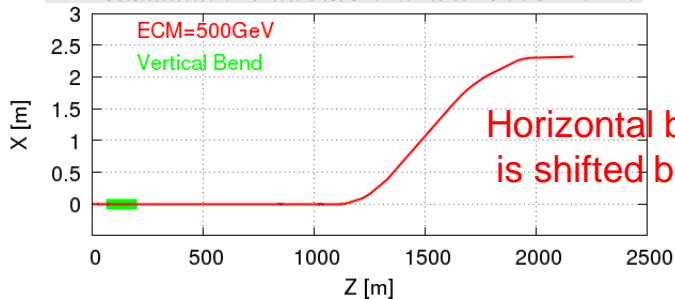
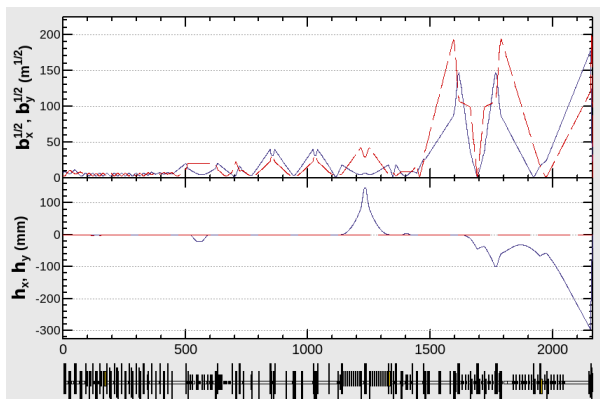
Toshiyuki OKUGI, KEK  
2017/06/26  
AWLC2017, SLAC

# Strong dipole for low energy

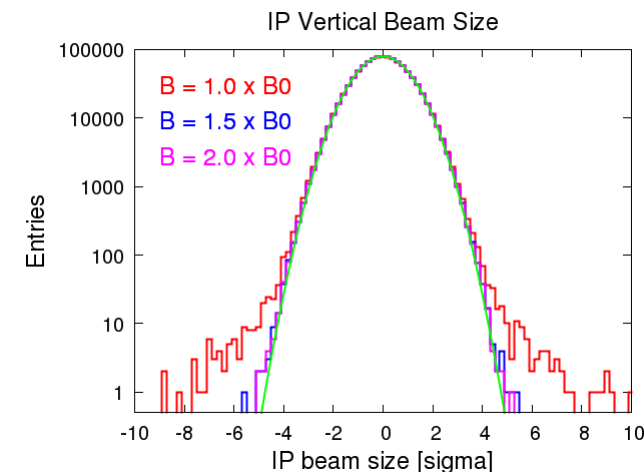
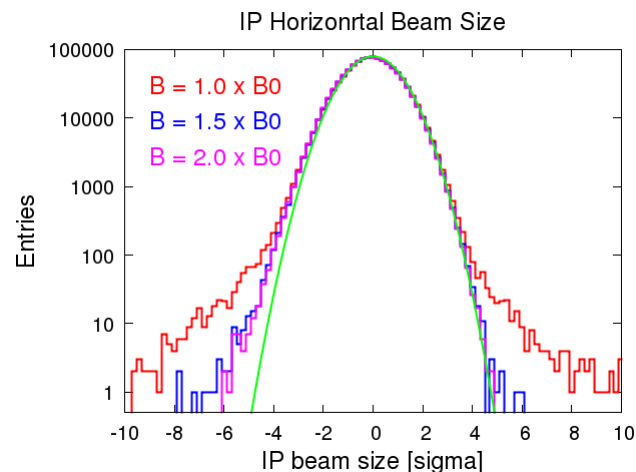
## Original beam optics



## Beam optics with strong bending magnet



## IP beam profile at ECM=250GeV



## Synchrotron radiation for BDS at ECM=500GeV

### Momentum Spread Growth by Synchrotron Radiation

	Collimator	FF beamline	Total
$B = 1.0 \times B_0$	0.0058%	0.0017%	0.0061%
$B = 1.5 \times B_0$	0.0059%	0.0020%	0.0062%
$B = 2.0 \times B_0$	0.0060%	0.0024%	0.0064%

### Horizontal Emittance Growth by Synchrotron Radiation

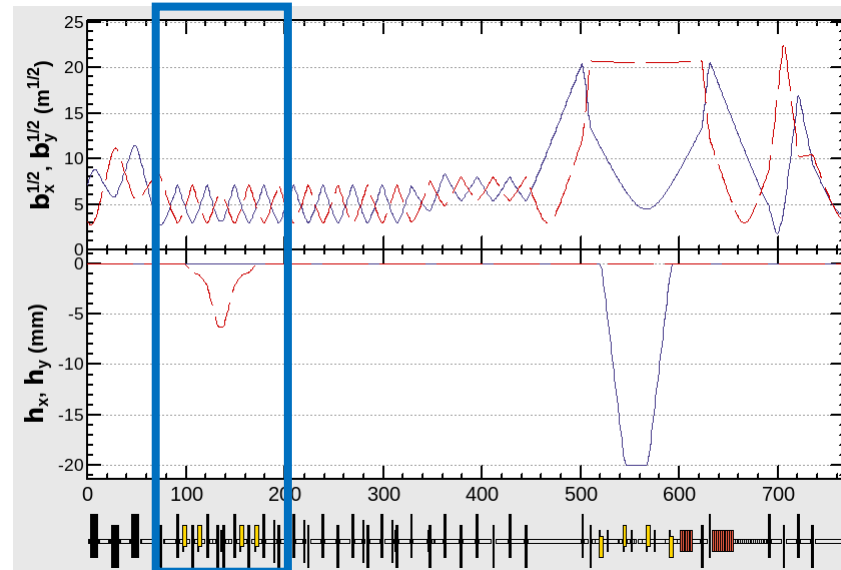
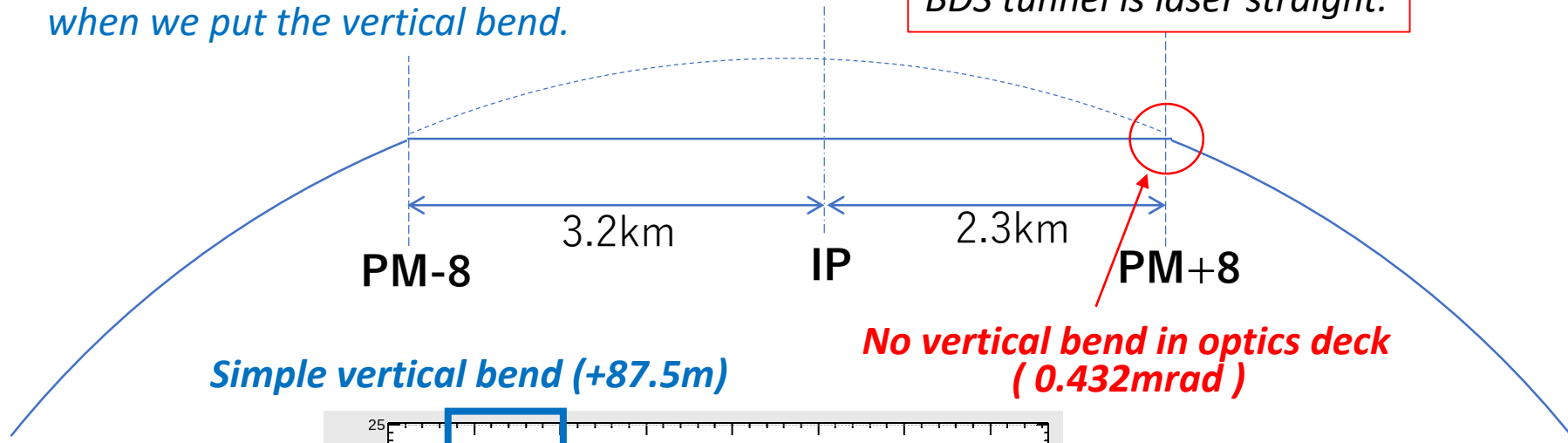
	Collimator	FF beamline	Total
$B = 1.0 \times B_0$	0.45%	0.07%	0.52%
$B = 1.5 \times B_0$	0.67%	0.49%	1.16%
$B = 2.0 \times B_0$	1.49%	2.06%	3.55%

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

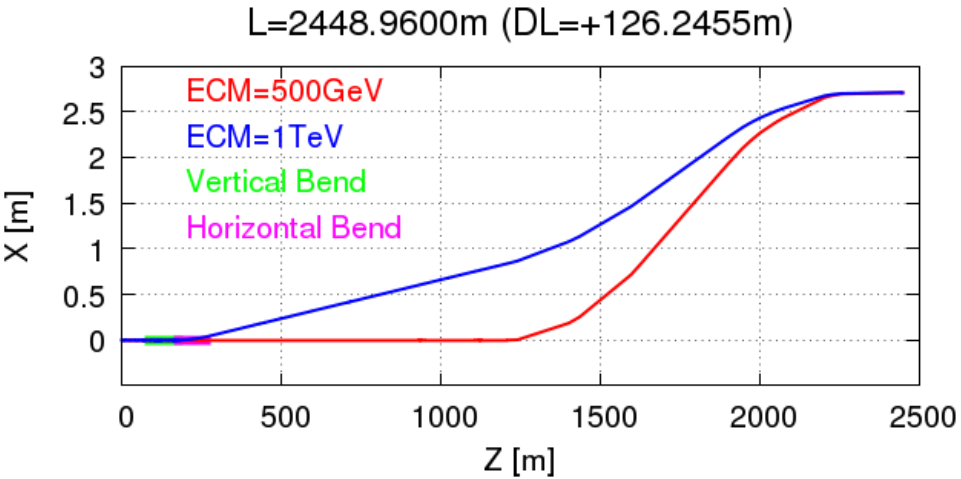
BDS beamline will be longer,  
when we put the vertical bend.

BDS tunnel is laser straight.

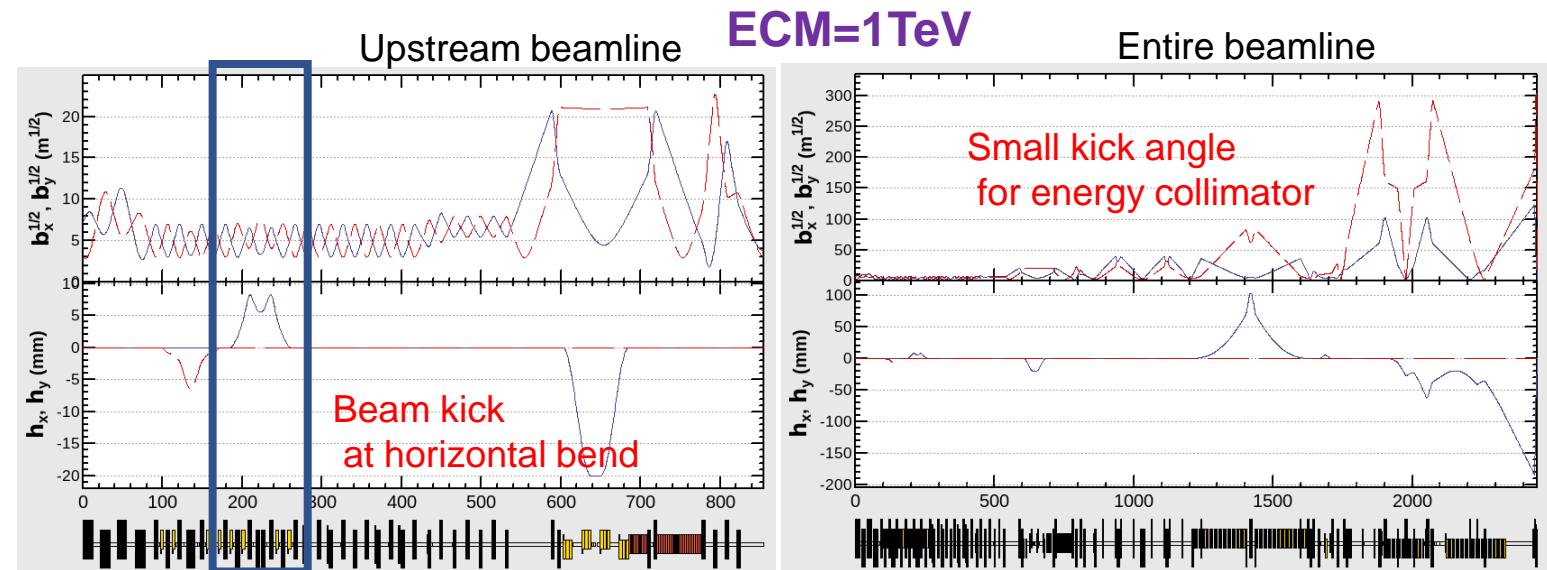
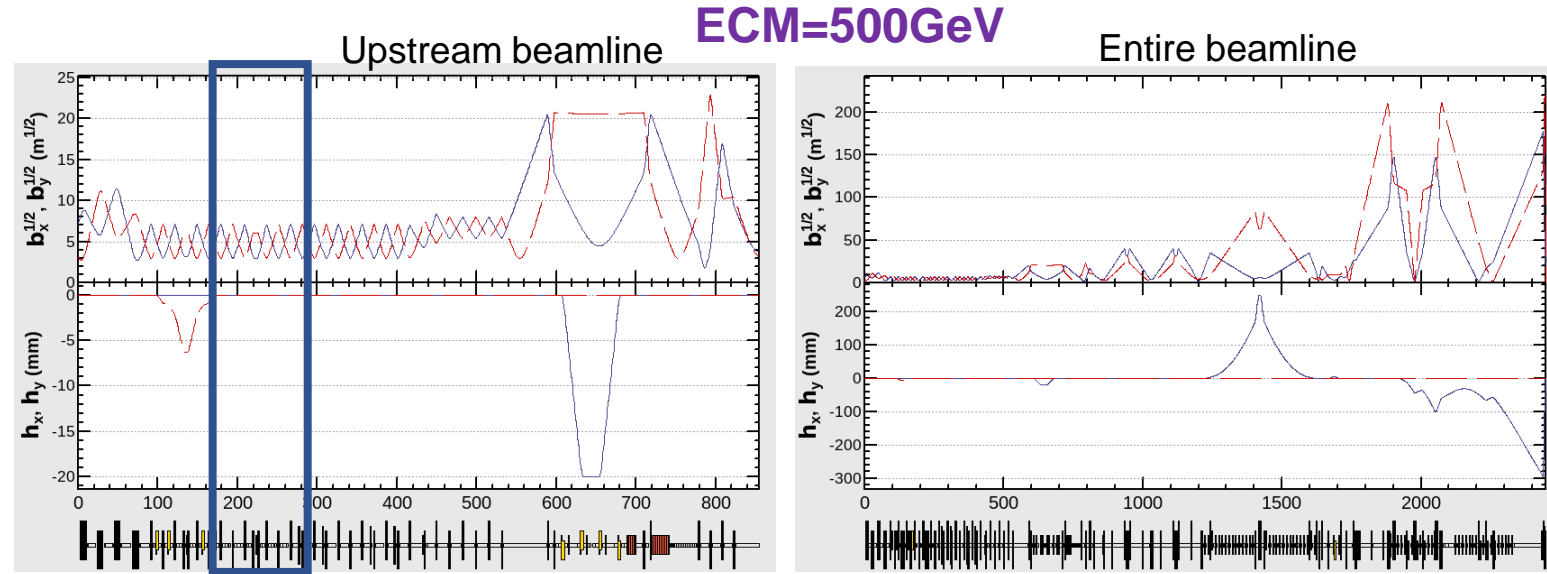


The vertical bending section was designed in between MPS and skew quadrupole section.  
The optics was designed to smoothly connected to FODO cell of skew quadrupole section.  
The vertical emittance growth, generated by the bending system is less than 1%.

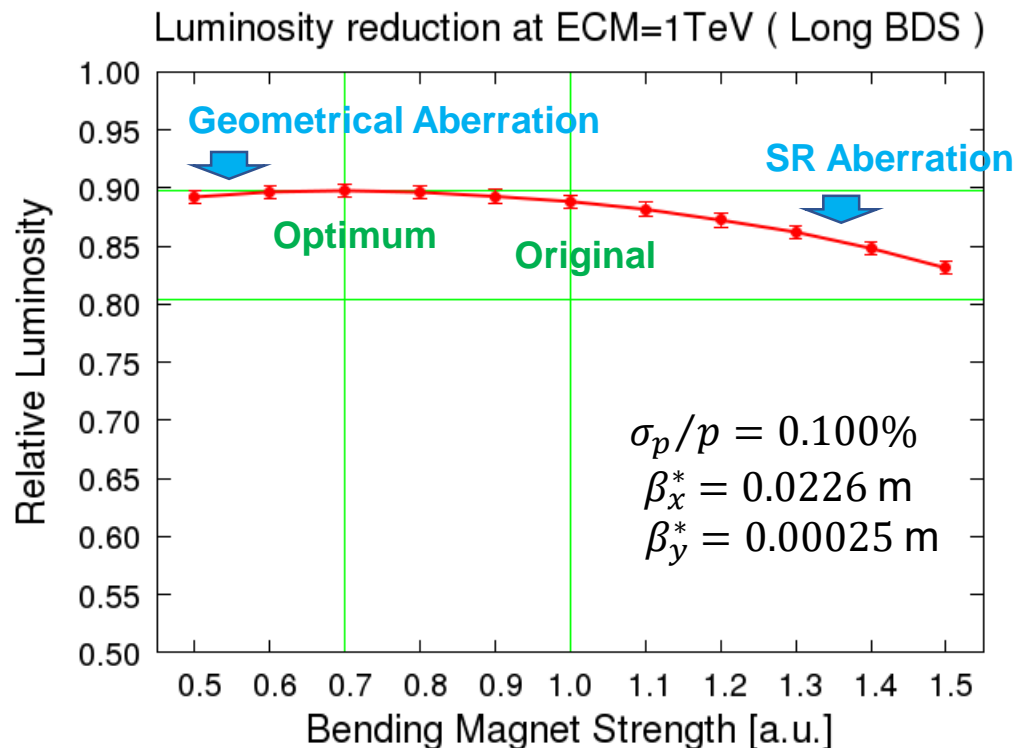
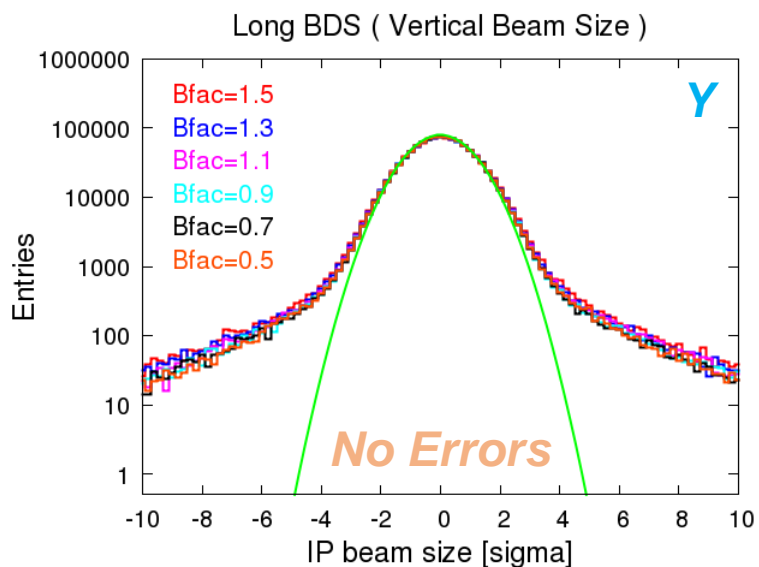
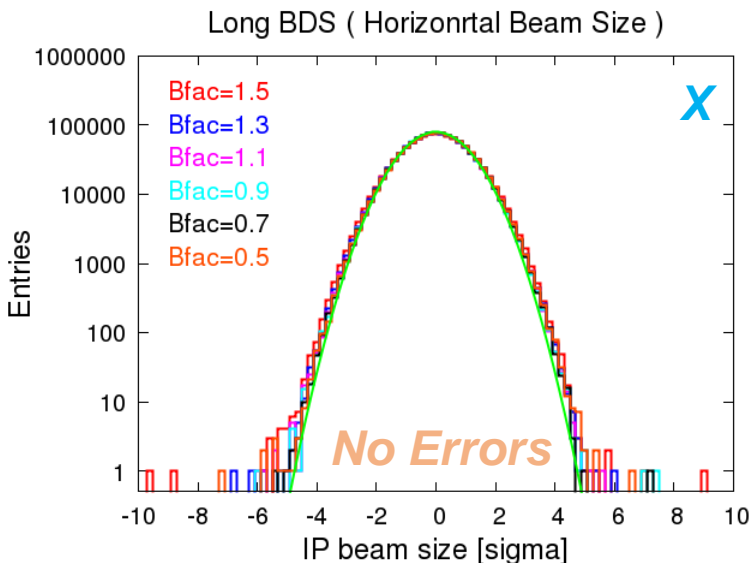
# New beamline layout to allow ECM=250GeV to 1TeV



- 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 )