Longer L* optics for ILC

2021/03/16

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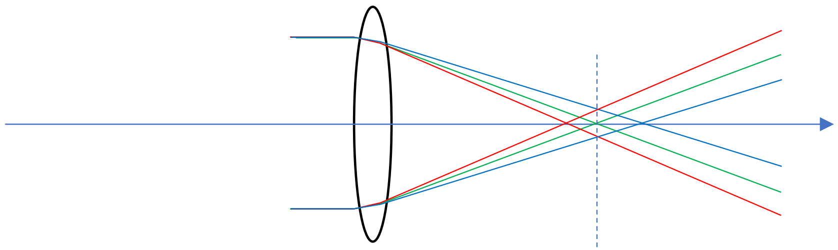
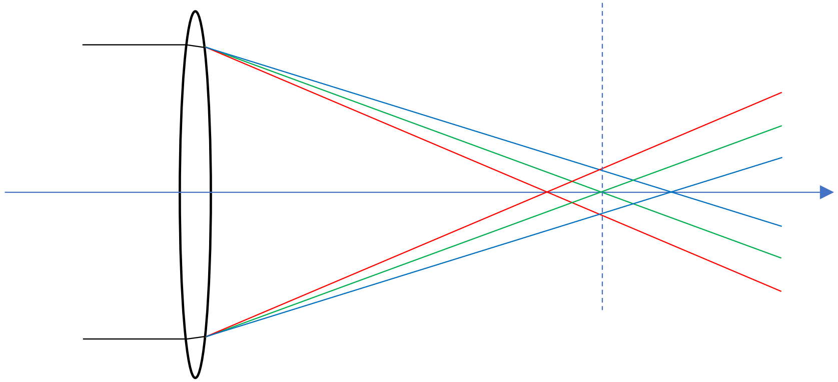
LCWS2021

Long L* and Chromaticity



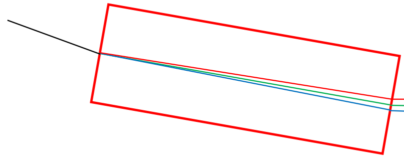
In order to squeeze the beam to the same size at the focus, it is necessary to squeeze the beam at the same divergence angle.

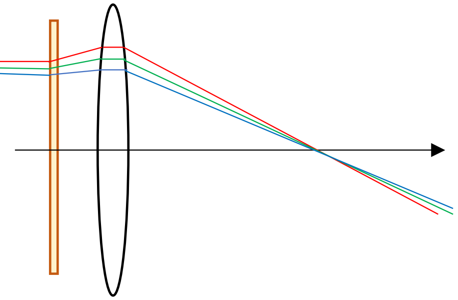
- ➢ The beam size at the final focus magnet becomes larger.
- ➢ The chromatic aberration at the focal point becomes larger.



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

Chromaticity correction



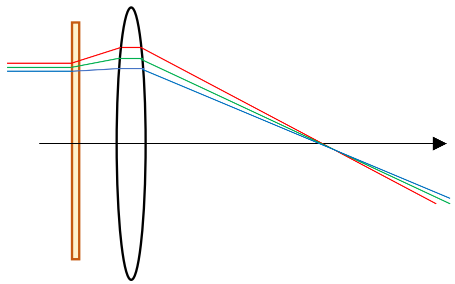


The difference in particle trajectory is created by the difference in energy.

- ➢ 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.

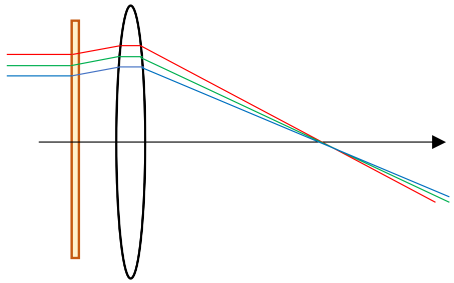
This is especially effective in "the low energy region", because the beam size passing through the magnet is large.

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.

Is it better to take the bending angle of the dipole magnet infinitely large?

- The higher-order aberration derived energy spread becomes stronger.
- The larger the emittance dilution due to synchrotron radiation become larger for the high energy beam.

There is an optimum value of bending angle for each beam energy.

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

Large L* optics for ILC

Toshiyuki OKUGI, KEK

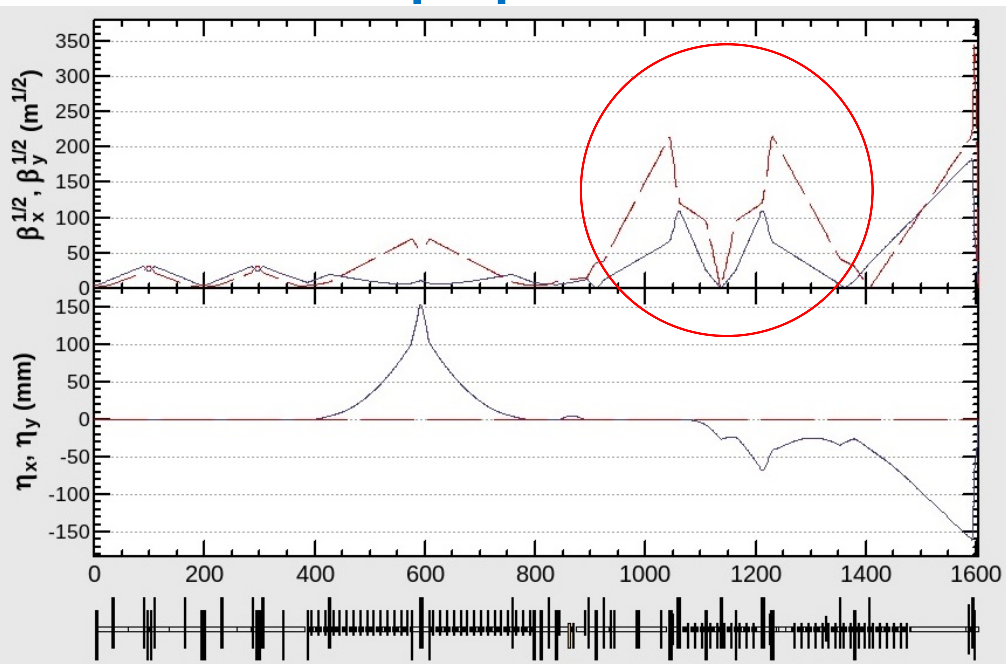
2014/ 5/ 15

AWLC2014, Fermilab

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

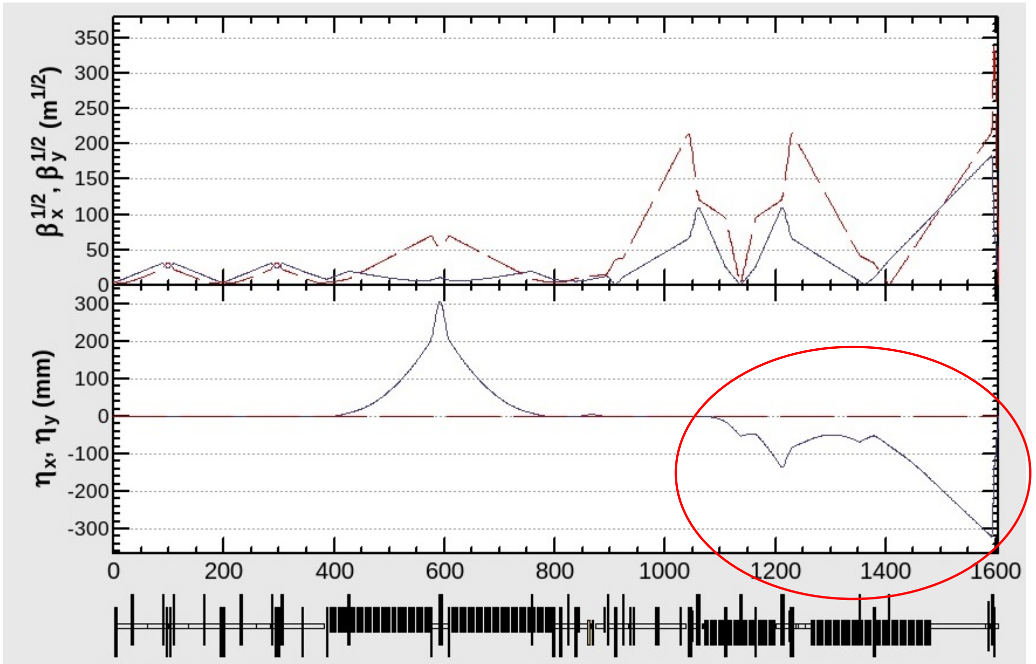
Since the (2nd order and higher) geometrical aberration for large L* optics was large the large L* optics is more difficult than the small L* optics, even if we set same chromaticity.

1st step optimization



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

2nd step optimization

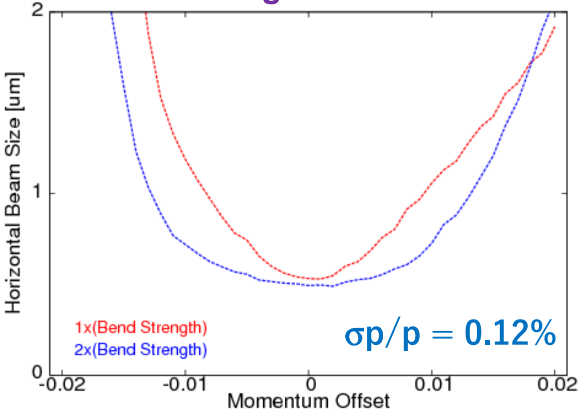


The strength of dipole magnet was increased to twice to increase the dispersion and reduce the strength of sextupoles.

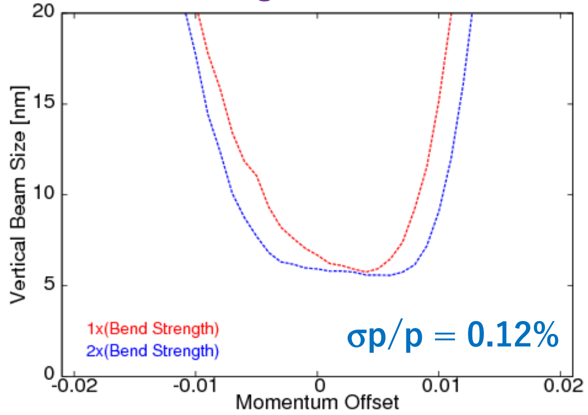
Performances for the optics with strong bending magnet

Optics was matched to ILC TDR parameters.

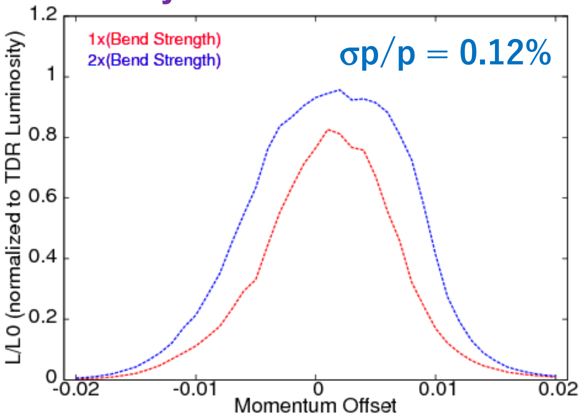
Bandwidth of sigmaX for E=250GeV



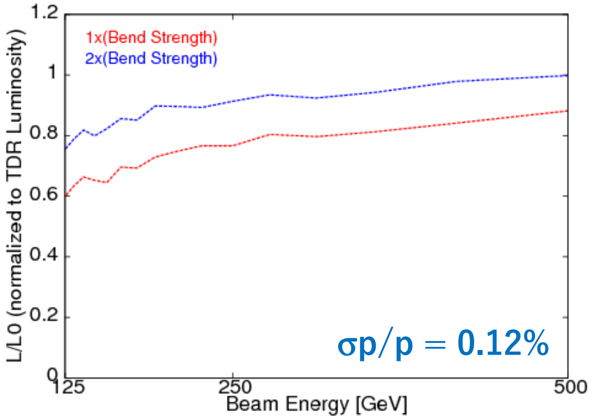
Bandwidth of sigmaY for E=250GeV



Luminosity Bandwidth for E=250GeV



Energy Dependence of Luminosity



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

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.

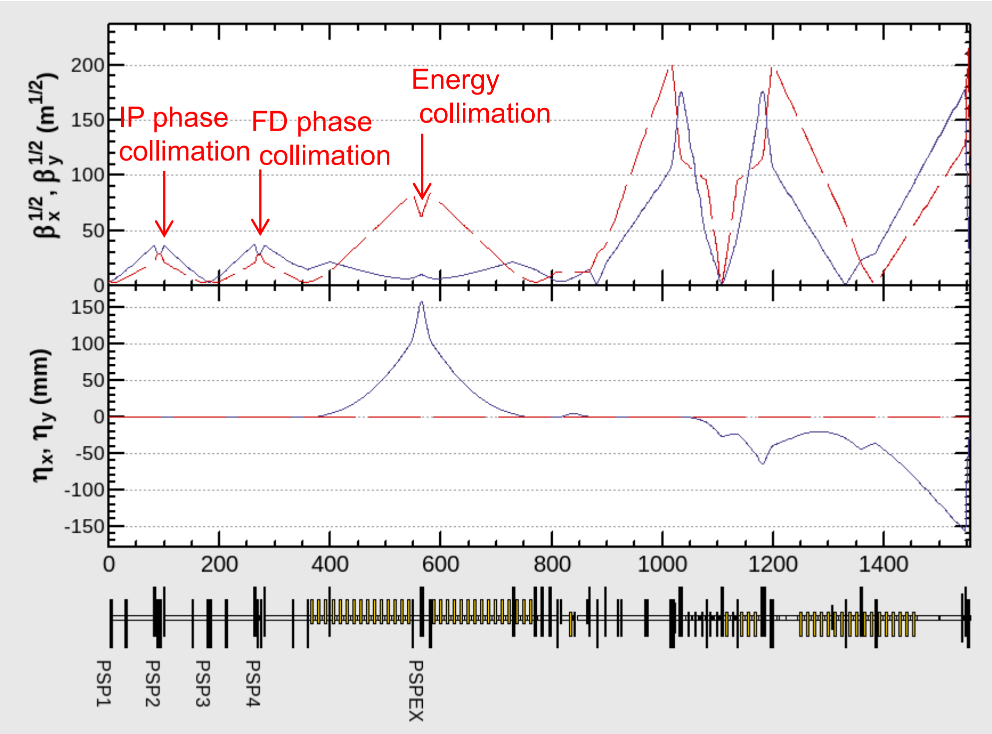
The reasons are

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

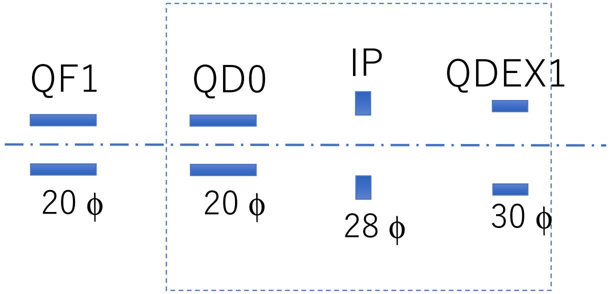
Consideration of collimation depth

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

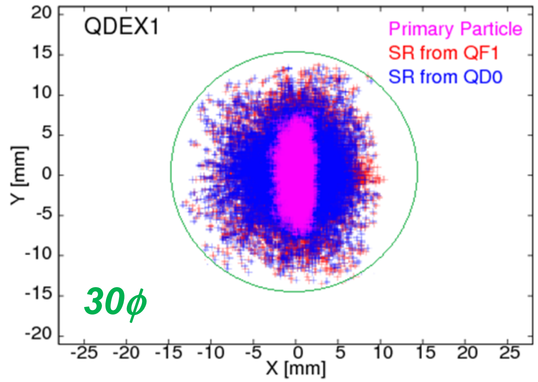


Source for background

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

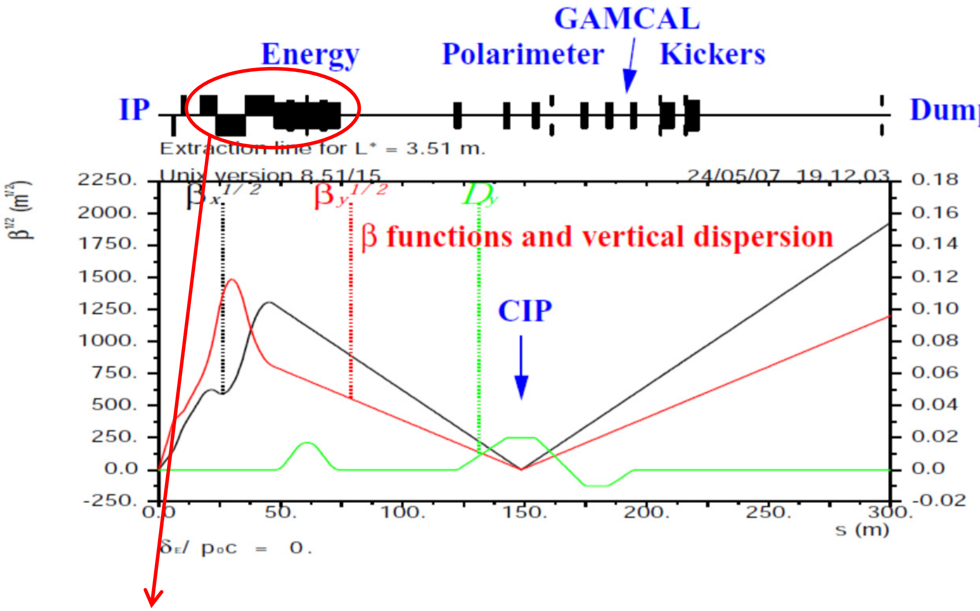
When the L* of QD0 is increased, the L* of QDEX1 in the extraction line must also be increased.

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%)

ILC beam extraction line



Quadrupole magnets in extraction line

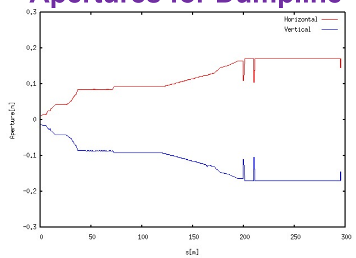
Y. Nosochkov et al., LCWS/ILC 2007

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

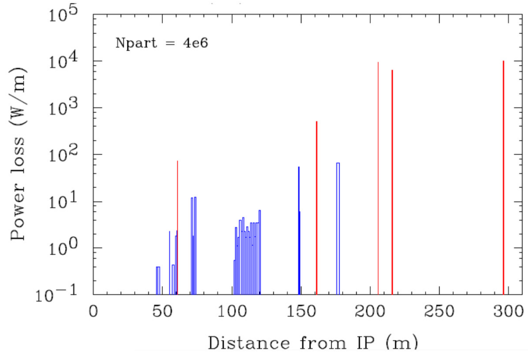
Apertures for Dumpline



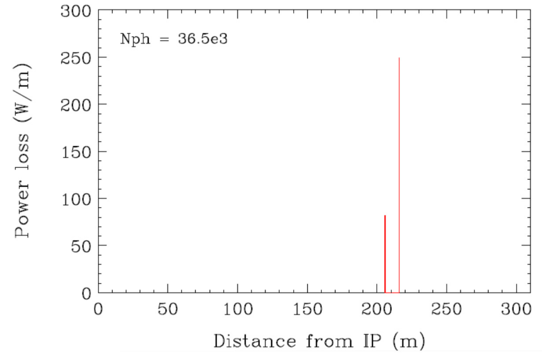
Power loss at extraction line (beam-beam effect)

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 should be increased more.
- Therefore, the design of the entire extraction line needs to be redesigned.

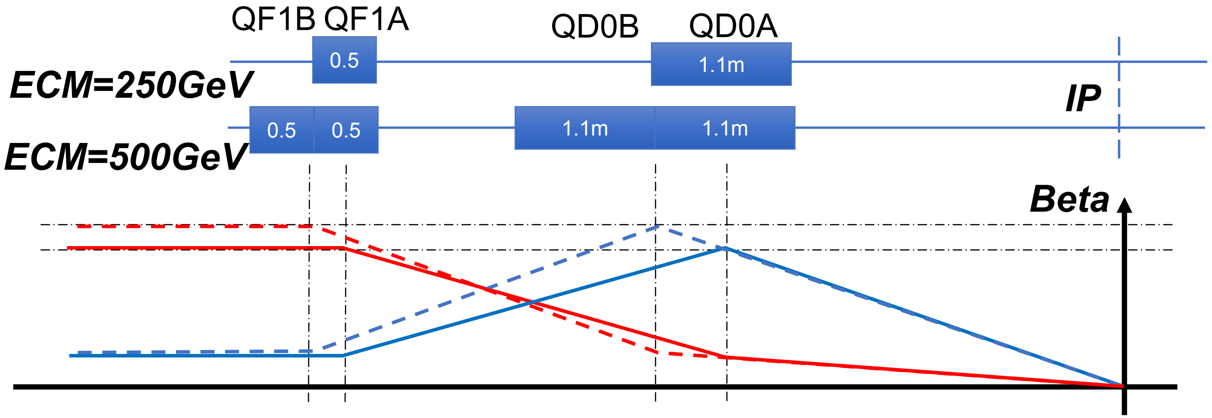
Present ILC Final Focus Optics

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

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

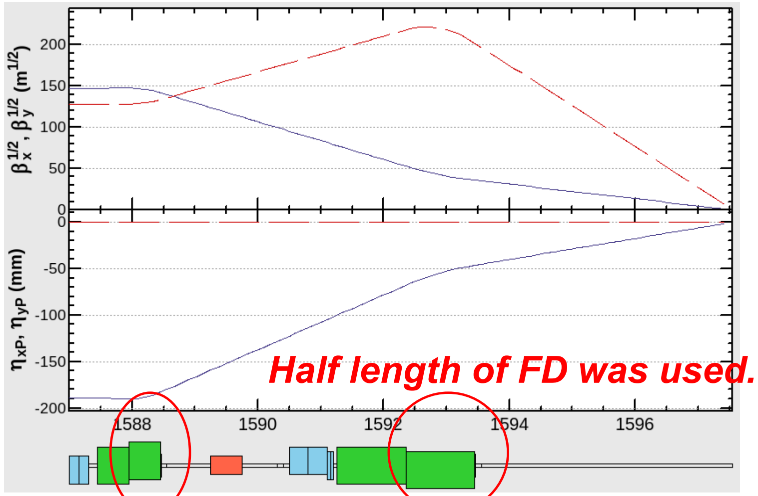
When we only use a half of FD magnets,
 the beta functions at FD magnets are decreased.

Therefore, the collimation depth can be increased.

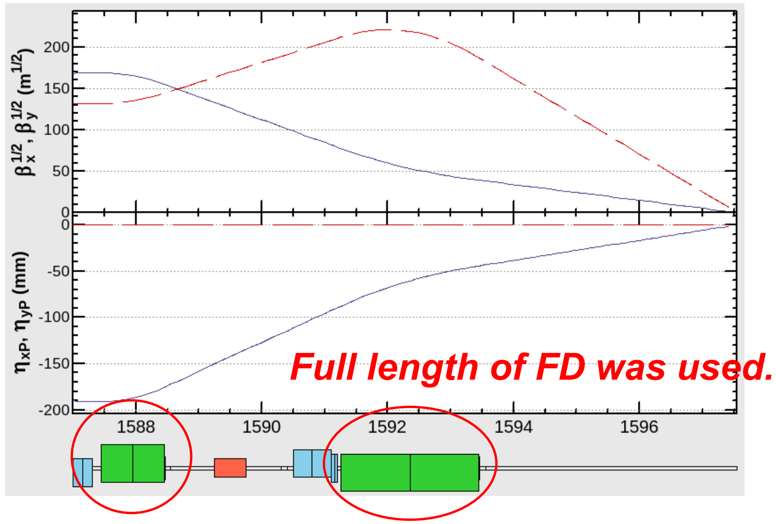


The geometry optimizes the more difficult low-energy optics
 and allows the higher-energy optics to deviate slightly from the optimum value.

ECM=250GeV



ECM=500GeV

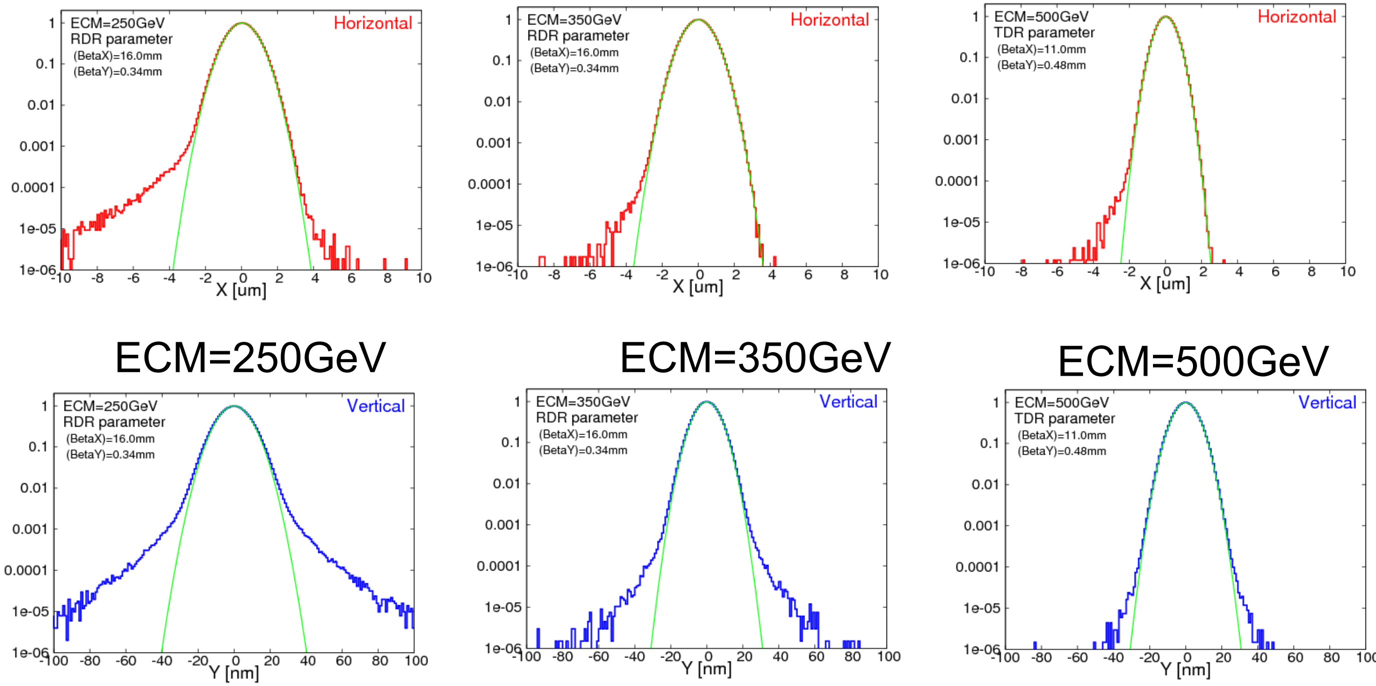


IP beam profile

ECM=250GeV ECM=350GeV ECM=500GeV

Horizontal Profile

Vertical Profile



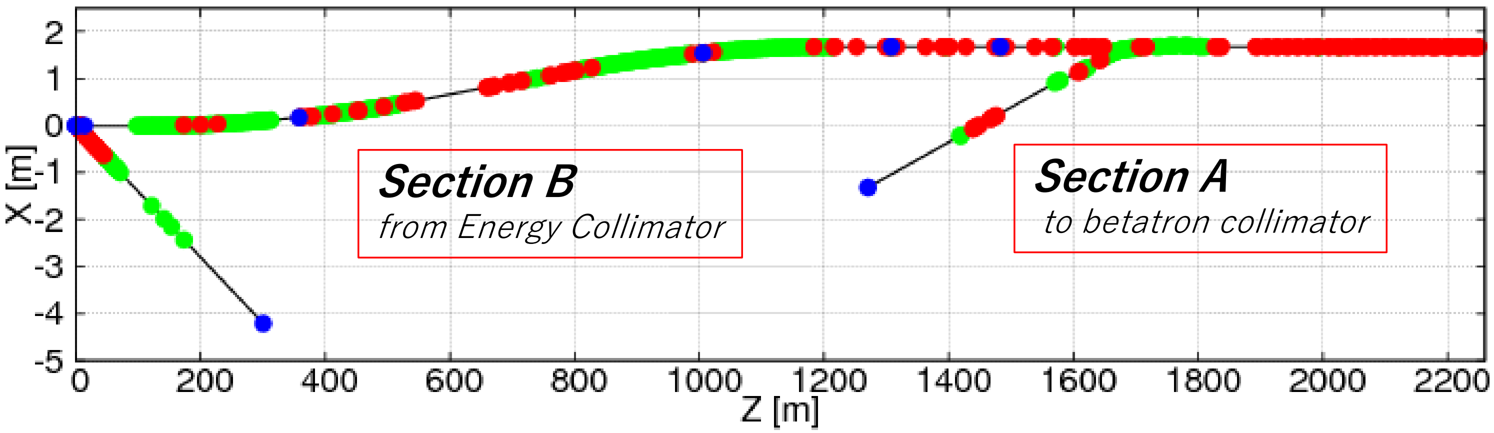
Simulation Results for ECM<500GeV optics (no SR)

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.



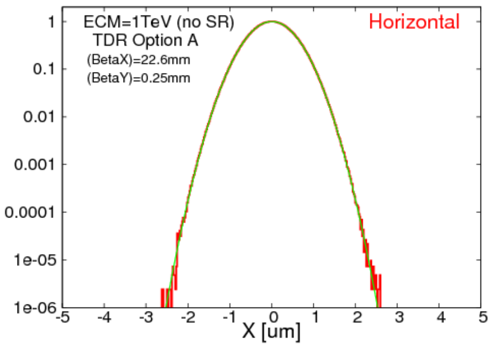
The number of components both for ECM=500GeV and ECM=1TeV

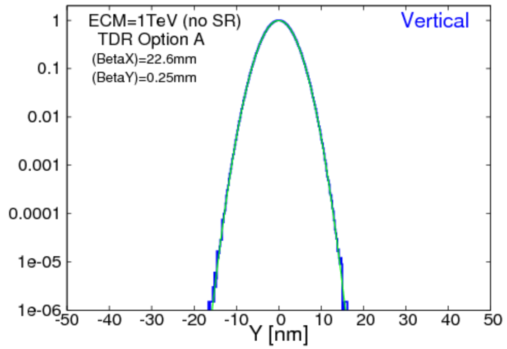
(not include the dumpline)

	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

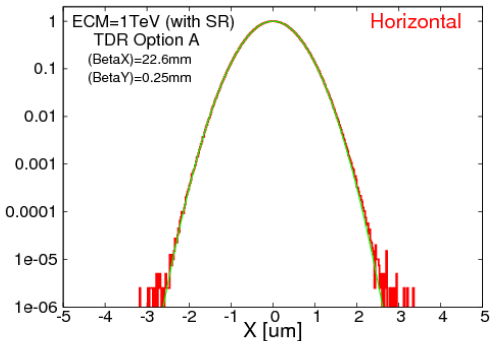
Simulation Results for ECM=1TeV optics

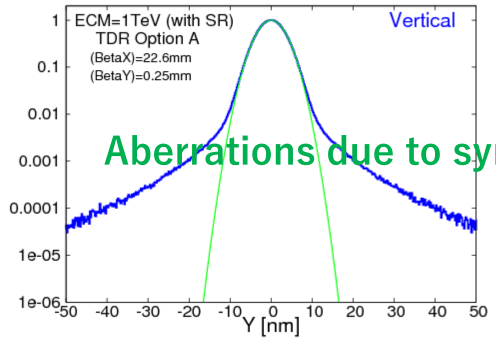
<< no SR >>





<< 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.

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.

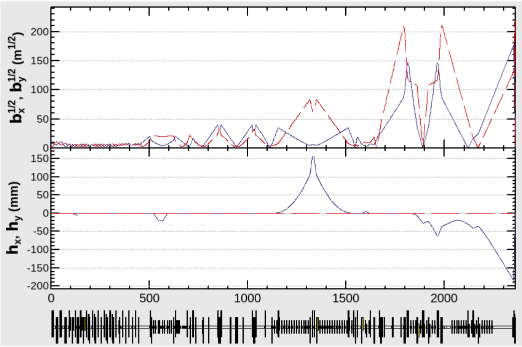
- In order to optimize for each energy, we need to choose optimal bending angle of dipole for each beam energy.
- A layout to optimize for two energies, ECM=250GeV and 1TeV, was proposed in 2017.

Optimization of ILC BDS optics
for wide energy range

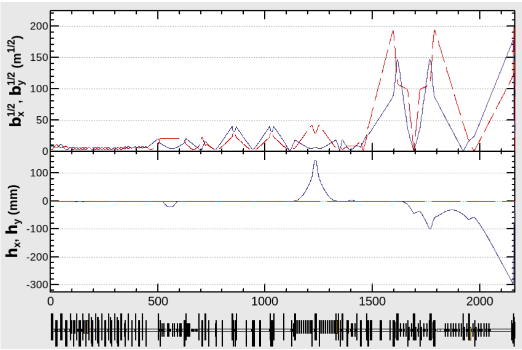
Toshiyuki OKUGI, KEK
2017/ 06/ 26
AWLC2017, SLAC

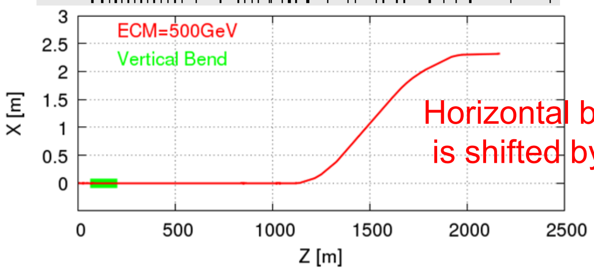
Strong dipole for low energy

Original beam optics



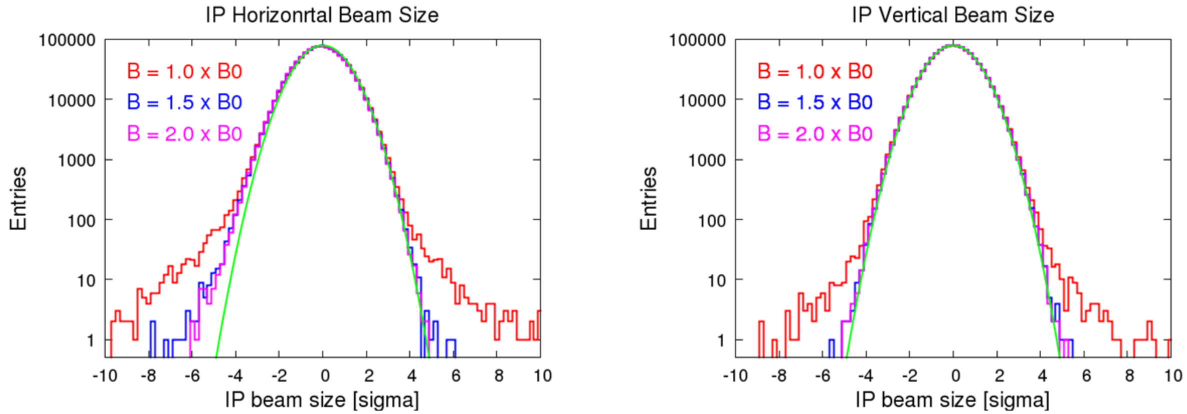
Beam optics with strong bending magnet





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%

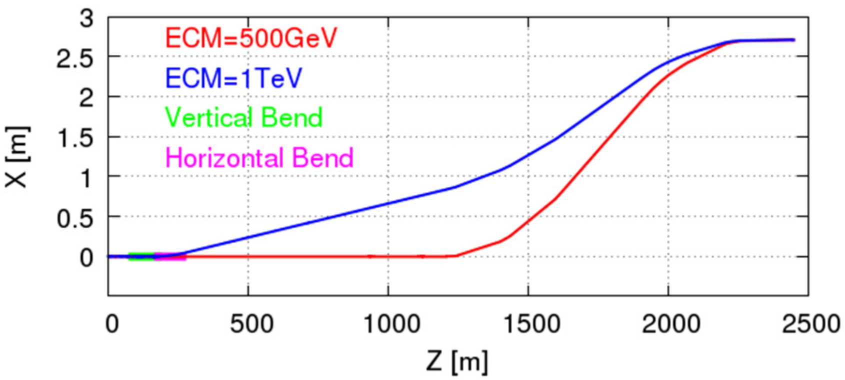
Horizontal Emittance Growth by Synchrotron Radiation

	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).

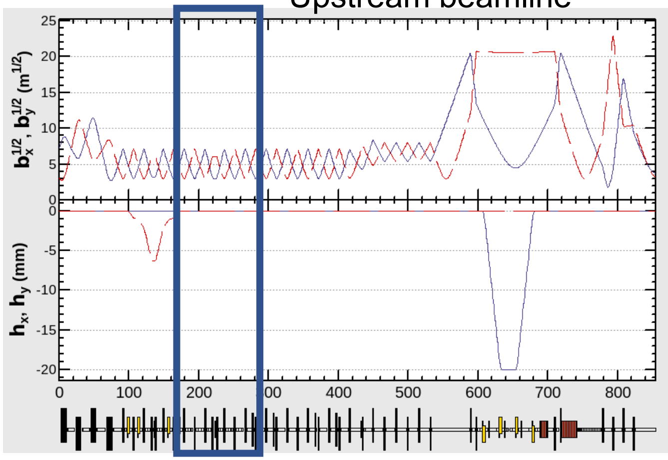
New beamline layout to allow ECM=250GeV to 1TeV

L=2448.9600m (DL=+126.2455m)

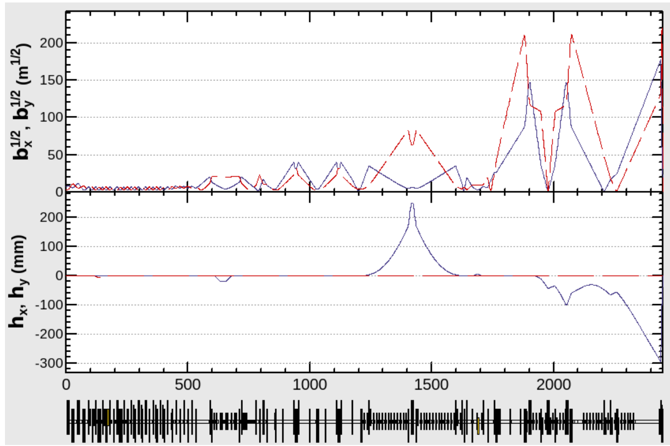


ECM=500GeV

Upstream beamline



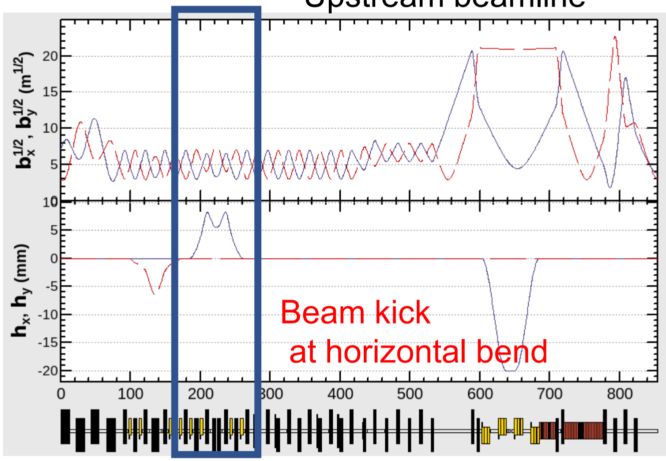
Entire beamline



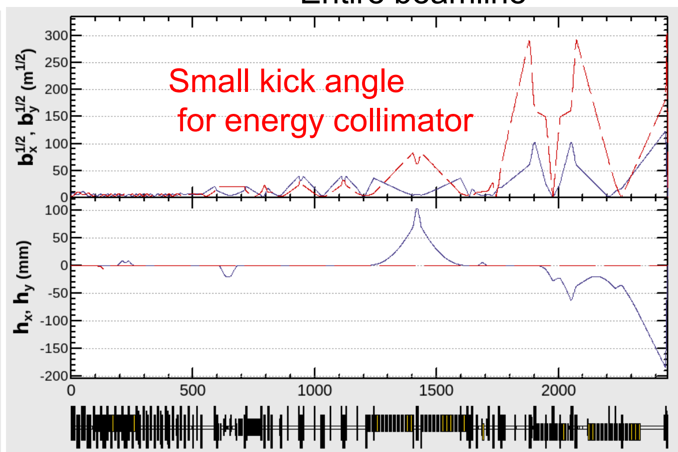
- Add horizontal bend at BDS entrance.
- When we upgrade the energy to ECM=1TeV, we will align the IP position and angle of the two beamlines by adjusting the angle of this horizontal bend and the energy collimator.
- This beam optics improves the performance of ECM=250 GeV, and has the expendability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

ECM=1TeV

Upstream beamline



Entire beamline



Summary

- 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).

- 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.

- 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).