中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Study of alternative ILC final focus optical configurations

Dou Wang (IHEP), Yiwei Wang (IHEP), Philip Bambade (LAL), Jie Gao (IHEP)

International Workshop on Future Linear Colliders 2014 (LCWS14)

Vinca Institute of Nuclear Sciences, Belgrade, Serbia. *6- 10 October 2014*

Idea

— Reduced bunch length enables:

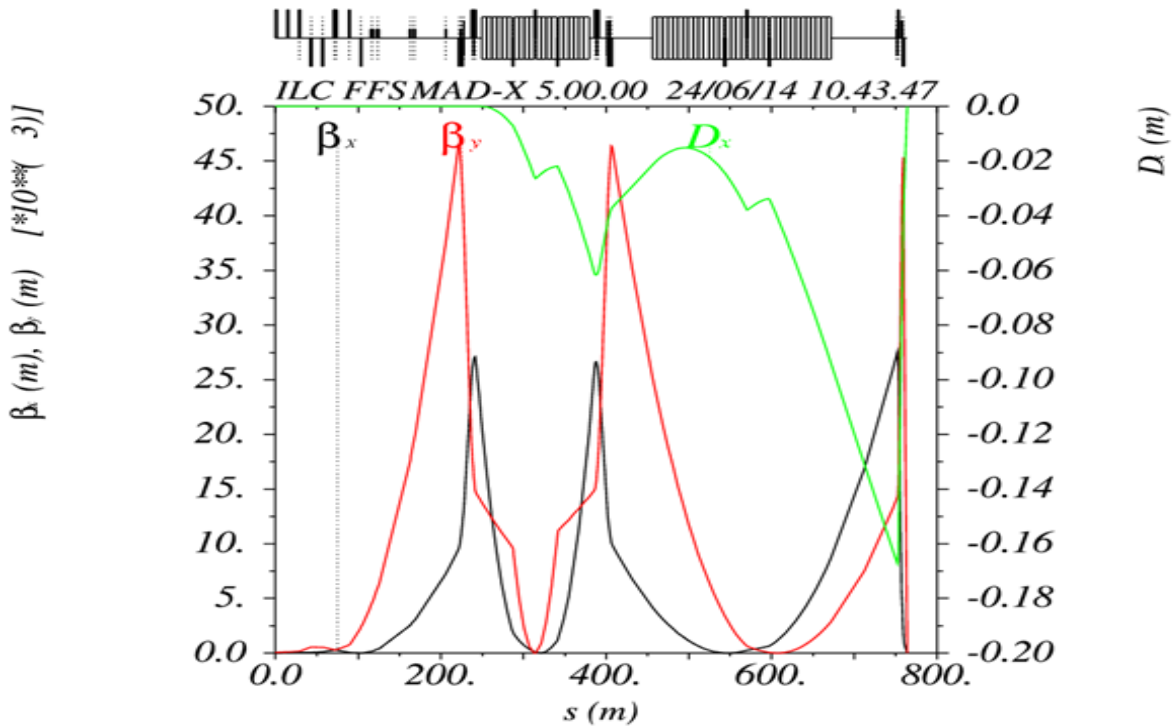
1) less beamstrahlung with the same luminosity,
2) or higher luminosity with equal amount beamstrahlung.

— The approach is to use flatter beams

— using exactly the same magnets as ILC nominal design, only refitting them, but requiring a short bunch length (150 or 200 microns), which is the price to pay...

ILC FFS nominal design

- L*=3.5m
- Total length: 760m
- βx*/βy*=15mm/0.4mm
- local chromaticity correction scheme was adopted
- The chromaticity of IR was corrected to third order by five sextupoles (SD0,SF1,SD4,SF5,SF6)



Luminosity for linear collider

Yokoya and Chen theory:

$$L_0 = \frac{f_{rep} N_b N_e^2}{4\pi\sigma_x^* \sigma_y^*} H_D$$

H_D -- *luminosity enhance factor*

$$D_{x,y} = \frac{2N_e r_e}{\gamma} \frac{\sigma_z}{\sigma_{x,y}(\sigma_x + \sigma_y)}$$

$D_{x,y}$ -- *disruption factor due to beam-beam pinch effect*

$$H_{D_{x,y}} = 1 + D_{x,y}^{1/4} \frac{D_{x,y}^3}{D_{x,y}^3 + 1} [\ln(\sqrt{D_{x,y}} + 1) + 2\ln(0.8 \frac{\beta_{x,y}}{\sigma_z})]$$

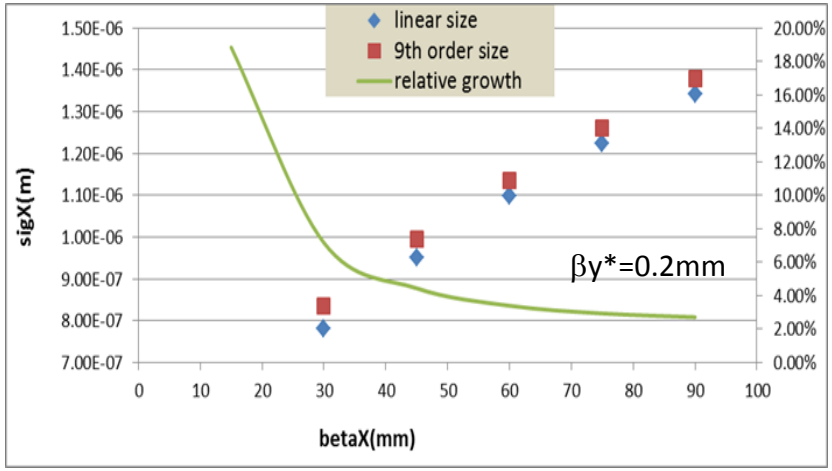
$$H_D = \sqrt{H_{D_x}} H_{D_y}^{(1+2(\frac{\sigma_x}{\sigma_y})^3)/6(\frac{\sigma_x}{\sigma_y})^3}$$

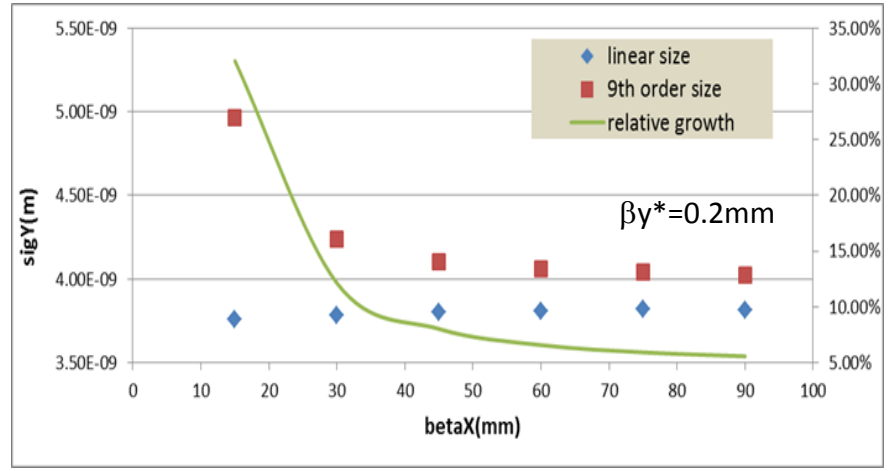
($H_D \approx H_{D_y}^{1/3}$ for flat beam)

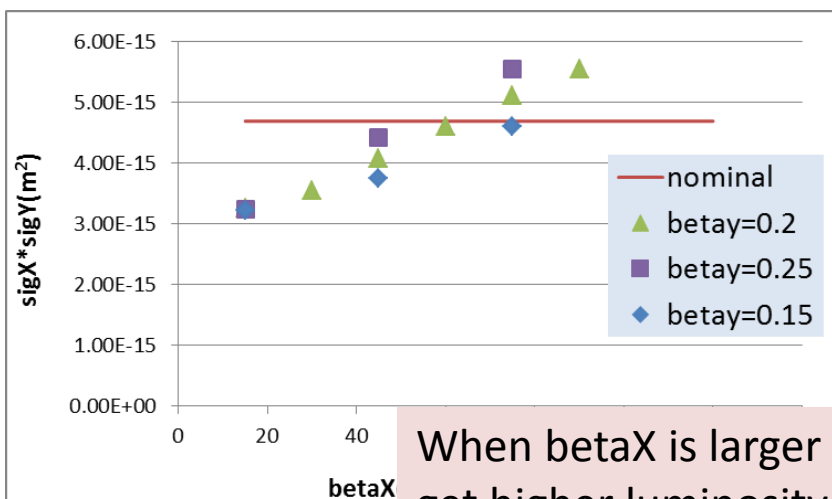
- These formulae are valid when the hour glass effect is small ($A_y = \frac{\sigma_z}{\beta_y^*} < 1$).
- Beam-beam interaction simulation by Guineapig++ is a better way to give more realistic estimates of the luminosity.

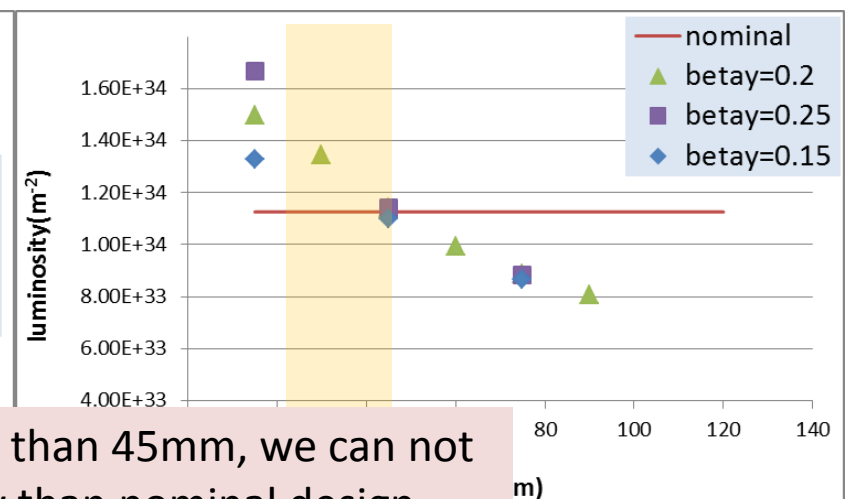
Chromaticity correction using 5 sextupoles

- minimize the product of $\sigma x^* \times \sigma y^*$ with fixed βy^* and σz (σz=150 μm)
- Quick beam-beam simulations with RMS beam size.
- The energy spread for both beam is 0.0006.









When betaX is larger than 45mm, we can not get higher luminosity than nominal design.

Alternative optical parameters for ILC FFS with five sextupoles

	ILC nominal	ILC-low BS	ILC-high Lum
E/beam (GeV)	250	250	250
Ne ($\times 10^{10}$)	2	2	2
σ_z (um)	300	150	150
$\beta^*_{x/y}$ (mm)	15/0.4	45/0.2	20/0.2
Ay	0.75	0.75	0.75
$\sigma^*_{x/y}$ by MAPCLASS (nm)	594/7.89	994/4.10	750/4.6
$\sigma^*_x \times \sigma^*_y$ (nm^2)	4687	4075	3450
Luminosity from guineapig++ ($\times 10^{34}$ m^{-2})	1.126	1.143	1.40
Beamstrahlung energy spread from guineapig++ (%)	2.8	1.8	2.8

We can get higher luminosity while keeping similar beamstrahlung level as nominal design when βx^* is smaller than 45 mm, or we can get same luminosity as nominal design with much weaker beamstrahlung effect if we just choose 45 mm βx^*.

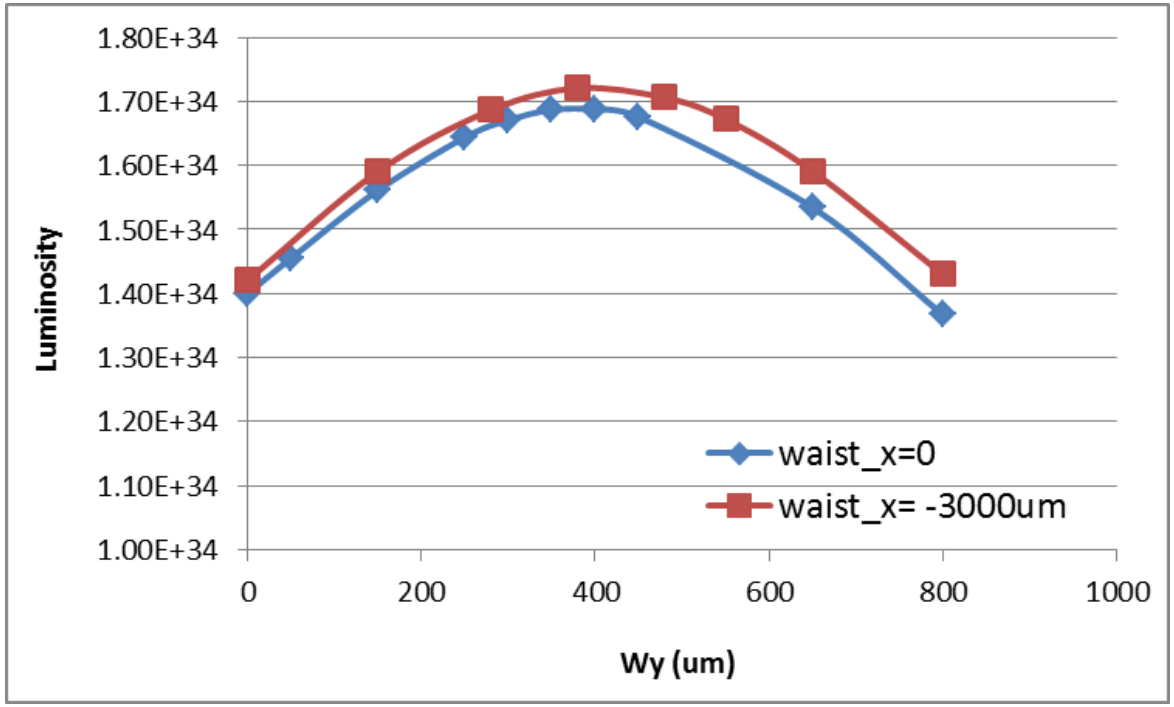
Summary of sextupoles strength

- alternative design with full 5 sextupoles (σz=150 μm)

	nominal	alternative					
		βy*=0.15mm		βy*=0.2mm		βy*=0.25mm	
βx/βy [mm]	15/0.4	15/0.15	45/0.15	15/0.2	45/0.2	15/0.25	45/0.25
SF6 [T/m^2]	1.668	-1.326	-0.748	-1.273	-0.806	-1.365	-0.845
SF5 [T/m^2]	-0.341	-2.480	-1.937	-2.361	-1.933	-2.556	-2.117
SD4 [T/m^2]	3.101	3.088	3.013	3.044	2.988	3.115	3.076
SF1 [T/m^2]	-4.959	-2.092	-2.376	-1.924	-2.212	-2.182	-2.545
SD0 [T/m^2]	7.324	7.419	7.282	7.334	7.242	7.471	7.393

Vertical waist scan

- We can increase the luminosity by seperating the focusing points of two beam because the beam-beam effects give a strong focusing force just like an additional quadrupole.
  —beam-beam simulations with **real beam distribution** at IP
  —ILC nominal design was used



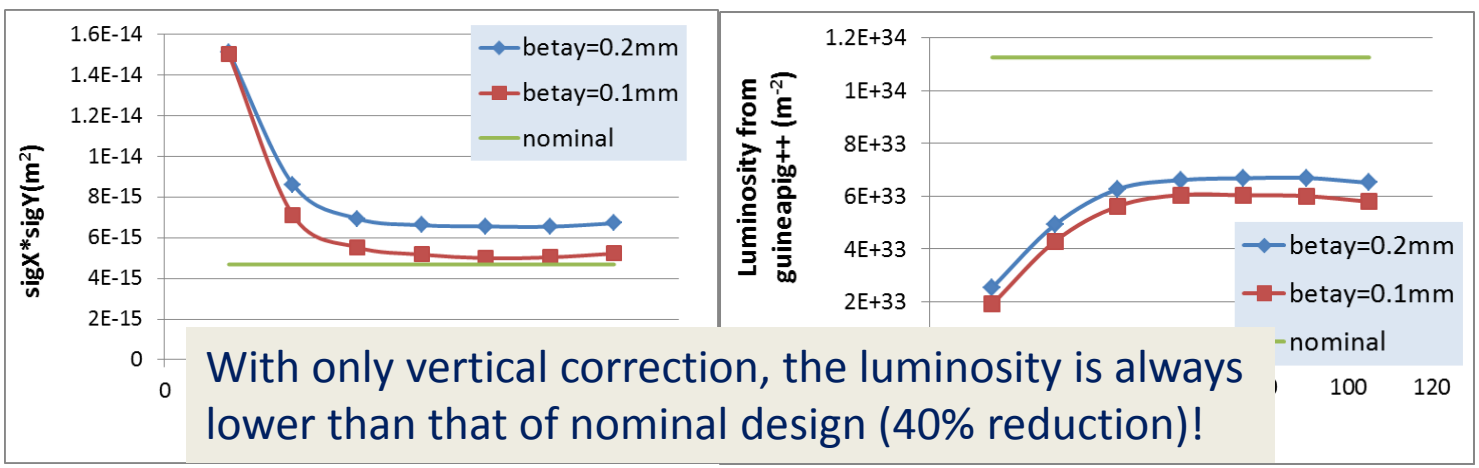
- Real beam distribution give higher luminosity than just use RMS beam size. *(The beam distribution at IP may far deviate from Gaussian shape so that RMS size overestimate the size of beam core.)*
- Highest luminosity is at Wy=380um (~20% growth).
- Horizontal waist shift has little effect to luminosity.

New FFS optics with real beam distribution and coherent waist shift

	ILC nominal (theoretical)	ILC nominal (real)	ILC-low BS (real)	ILC-high Lum (real)
E/beam (GeV)	250	250	250	250
Repetition rate (Hz)	5	5	5	5
Bunch number/pulse	2625	2625	2625	2625
Ne ($\times 10^{10}$)	2	2	2	2
σ_z (um)	300	300	150	150
$\beta^*_{x/y}$ (mm)	15/0.4	15/0.4	45/0.2	20/0.2
Luminosity by single collision ($\times 10^{34}$ m^{-2})	1.8	1.40	1.42	1.82
Luminosity by single collision (inc. vertical waist shift) ($\times 10^{34}$ m^{-2})		1.69	1.72	2.21
Total luminosity (inc. vertical waist shift) ($\times 10^{34}$ $cm^{-2}s^{-1}$)	2.4	2.22	2.25	2.9

ILC luminosity with pure vertical chromaticity correction scheme

- enlarge βx^* and reduce βy^* in order to reduce the horizontal chromaticity and meanwhile keep similar value for $\sigma x^* \times \sigma y^*$.
- this scheme only works for beams with very small energy spread (e.g. 0.06% for e+ at 500 GeV c.m.)
- Reduce σ_z from nominal 300um to **150um** to cure hourglass effect
- Choose two cases for βy^*:
  - βy^*=0.1mm: minimum vertical beam size
  - βy^*=0.2mm: keep same hourglass effect as ILC nominal design ($Ay=\sigma_z/\beta y^*=0.75$)
- Luminosity simulations from guineapig++ (Single collision).
- Quick beam-beam simulations with **RMS beam size** from Mapclass.



With only vertical correction, the luminosity is always lower than that of nominal design (40% reduction)!

➢ The reason of luminosity reduction in spite of both the product of $\sigma x^* \times \sigma y^*$ and the ratio of $\sigma_z/\beta y^*$ being close to the nominal design is that the shorter bunch length by a half gives much smaller disruption parameter $D_{x,y}$ and hence results in less luminosity enhancement H_D from the pinch effect.

partial correction for the horizontal chromaticity

- add a horizontal sextupole to recover the luminosity drop from the pure vertical correction scheme
- SF5 is most effective to realize horizontal chromaticity correction and hence to recover the luminosity
- 0.06% energy spread was used

	ILC nominal	New-1	New-2
Sextupoles used	SD0,SF1,SD4,SF5,SF6	SD0,SD4	SD0,SD4,SF5
E/beam (GeV)	250	250	250
Ne ($\times 10^{10}$)	2	2	2
σ_z (um)	300	150	150
$\beta^*_{x/y}$ (mm)	15/0.4	60/0.2	60/0.2
Ay	0.75	0.75	0.75
$\sigma^*_{x/y}$ by MAPCLASS (nm)	594/7.89	1689 /3.88	1524/3.92
$\sigma^*_x \times \sigma^*_y$	4687	6553	5974
***Luminosity of single collision from guineapig++ ($\times 10^{34}$ m^{-2})**	1.126	0.668	0.741

*For the total luminosity, we need to multiply the bunch number and the repetition frequency.

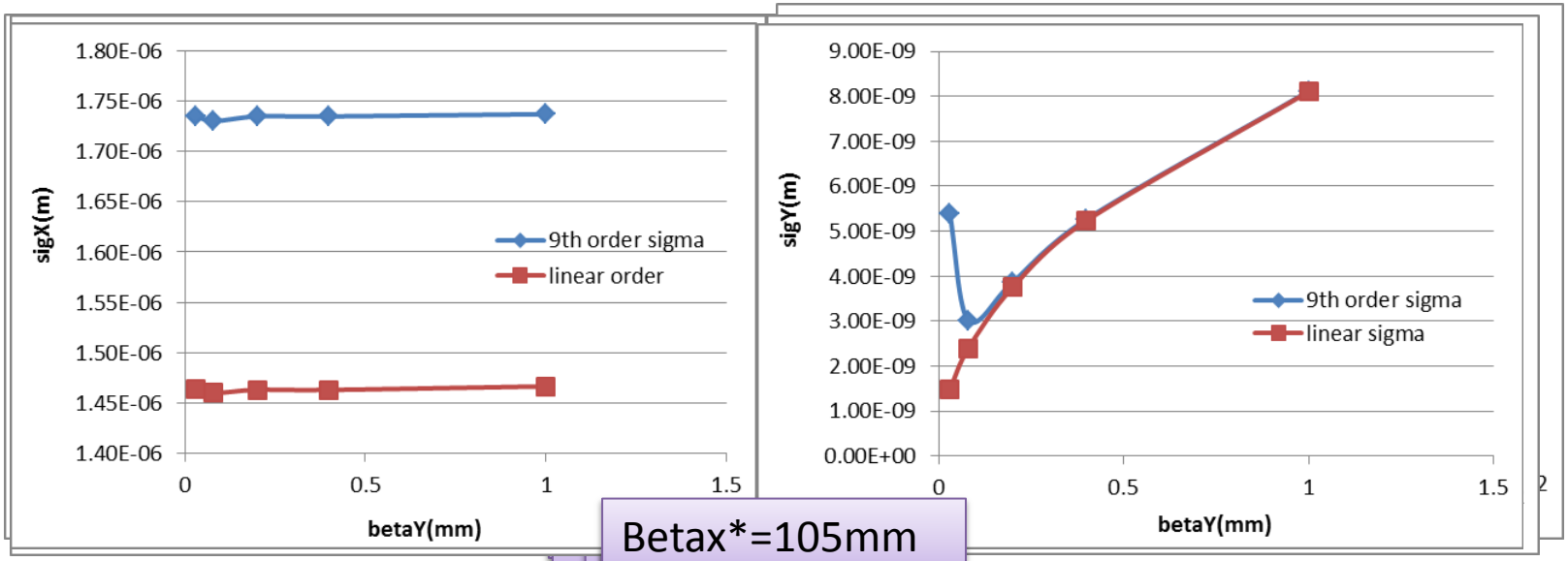
Summary

- We have tried both the simplified chromaticity scheme which is mainly in vertical direction with fewer sextupoles (2 or 3) and the thorough chromaticity scheme with 5 sextupoles.
- With an enlarged $\sigma x^*/\beta x^*$ and a smaller $\sigma y^*/\beta y^*$, we expect less beamstrahlung effect at IP.
- Luminosity for alternative ILC FFS optics were studied through beam-beam simulations by Guineapig++.
- With 5 sextupoles, we can either recover the luminosity with much lower beamstrahlung effect or get a higher luminosity while keeping same beamstrahlung as nominal design. No changes in the present FFS design are needed, only refitting of existing magnets.
- 150um bunch length is needed to reduce the hour glass effect => it seems worthwhile to invest in some additional bunch compression
- Thorough luminosity simulations with real beam distribution and coherent waist shift were done based on the newly proposed ILC FFS design.
- For 2 sextupoles's (SD0, SD4) correction, we get a simple FFS and much less beamstrahlung, at the expense of much lower luminosity (40% drop). The luminosity reduction will be 34% with 3 sextupoles (SD0, SD4, SF5).
- Study will be continued based on ILC TDR parameters and newest FFS optics.

Reserved

Pure vertical chromaticity correction with SD0 and SD4

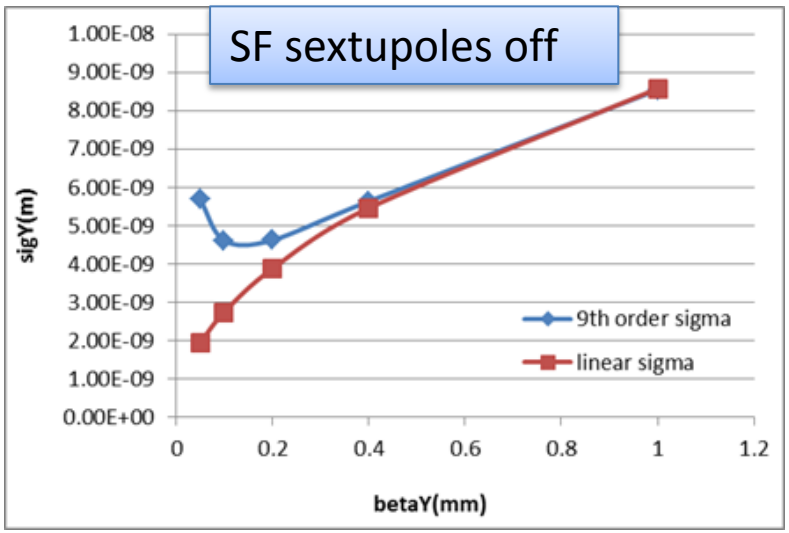
- Rematch the IP beta function to a different value using six matching quadrupoles (QM16 to QM11)
- Use SD0 and SD4 to correct the second order vertical chromatic item T_{342} and T_{346} by the code of Madx
- Beam size at IP was simulated by Mapclass
- The energy spread for both beam which was used is 0.0006.

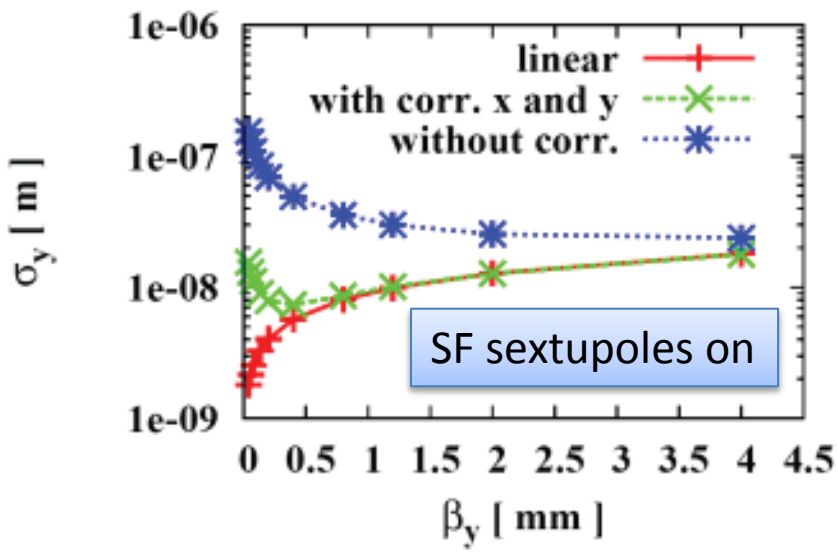


Betax*=105mm

-- There is always a minimum for σy^* around βy^*=0.1mm.
-- The minimum value for σy^* is 3nm when βx^* is at the range [60mm, 90 mm].

Comparison of nominal design and pure vertical correction scheme (βx^*=15 mm)





The vertical beam size is limited in the nominal design. The reason is the higher order coupling terms such as T_{313}, T_{314}, U_{3136}, U_{3246} and so on due to three SF sextupoles.