CLIC and ILC Final Focus System: optimization and limitations

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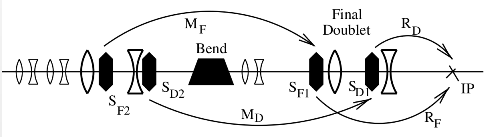
Outline

Why Final Focus Systems?

Idea of FFS

- The Final Focus System has the aim to focalize the beams to the nanometer scale and to correct the aberrations that appear due to strong nonlinear fields contained in the line.
- There are two main schemes: the traditional scheme, with two dedicated sections for chromatic correction in both planes and the local correction scheme, where the chromaticity is corrected very close to the point where it is generated.



Issues

- Chromatic correction at different orders. (Couplings, long sextupole effect, ...).
- Synchrotron radiation in bending magnets.
- Magnetic field and apertures.
- Beam induced backgrounds. Flat beams ensure low beamstrahlung photons level.

CLIC and ILC parameters

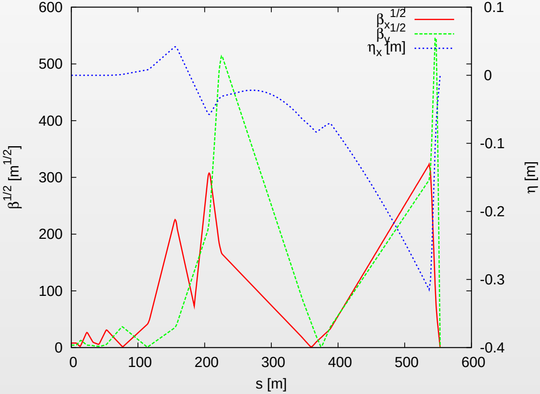
Parameter	**Units**	CLIC500[2]	ILC500[3]
Beam energy E_0	GeV	250	250
Bunches per beam n_b		354	1314
$e^{\pm}$ per bunch N	10^9	6.8	20
Repetition rate f_{rep}	Hz	50	5
Hor. emittance ϵ_x^N	μm	2.4	10.0
Vert. emittance ϵ_y^N	nm	25	35
Hor. beta β_x	mm	8.0	11.0
Vert. beta β_y	mm	0.1	0.48
Hor. beam size σ_x^*	nm	200	474
Vert. beam size σ_y^*	nm	2.26	6.0
Bunch length σ_z	μm	72	300
Energy spread δ_E	%	1.0	0.125
Luminosity $\mathcal{L}_T$	$10^{34} \cdot \mathrm{cm}^{-2}\mathrm{s}^{-1}$	2.3	1.47

[2] CLIC Conceptual Design Report, 2012
[3] ILC Technical Design Report, 2012

CLIC 500 GeV FFS

CLIC 500 GeV FFS CDR

The lattice with CDR parameters fulfills the luminosity requirements but with no margin of error.



Placet+GuineaPig

$$\beta_x^* = 8\text{mm}$$
$$\beta_y^* = 0.1\text{mm}$$
$$\sigma_x^* = 210.4\text{ nm}$$
$$\sigma_y^* = 2.51\text{ nm}$$
$$\mathcal{L}_T = 2.31\text{ s}^{-1}\text{cm}^{-2}$$
$$\mathcal{L}_{1\%} = 1.40\text{ s}^{-1}\text{cm}^{-2}$$
$$\Upsilon = 0.61$$

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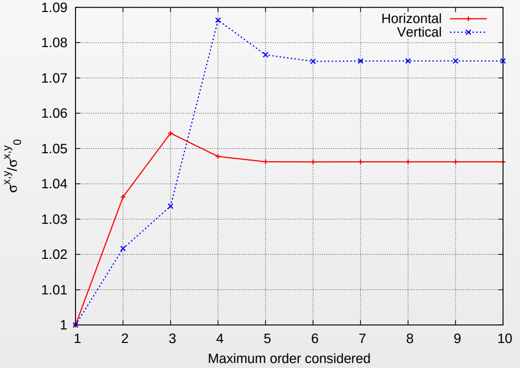

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$$\Upsilon = 0.61 \rightarrow n_\gamma = 1.32$$

Beyond Standard Parameters?

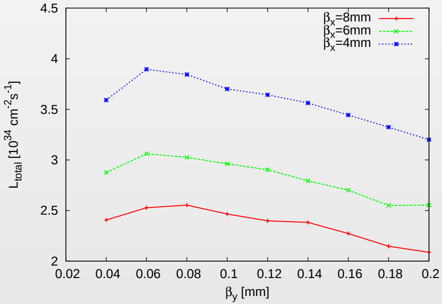
As in any optimization problem one question arises: Can we push the limits of β_x^* and β_y^* and make them even smaller?

Reducing β_y^* and β_x^* in CLIC 500 GeV FFS

Let's start using ideal distributions at the IP...

β_y^*

The nominal value for β_y^* is 0.1 mm. We scan a wide range of β_y^* to find the optimal value that maximizes both $\mathcal{L}_{1\%}$ and $\mathcal{L}_T$.



β_x^*

The nominal value for β_x^* is 8 mm. Reducing β_x^* we can increase the total luminosity while keeping the ration $\mathcal{L}_{1\%}/\mathcal{L}_T$ in a reasonable value.

- Is there any natural limit on $\min(\beta_x^*)$ in the system design?
- What is the minimum value for $\mathcal{L}_{1\%}/\mathcal{L}_T$ we can consider?

Luminosity and Beamstrahlung

$$\mathcal{L} = \frac{N^2 f_{rep} n_b}{4\pi\sigma_x^*\sigma_y^*} H_D, \quad \Upsilon = \frac{N^2 e\gamma}{\sigma_z(\sigma_x^* + \sigma_y^*)}$$

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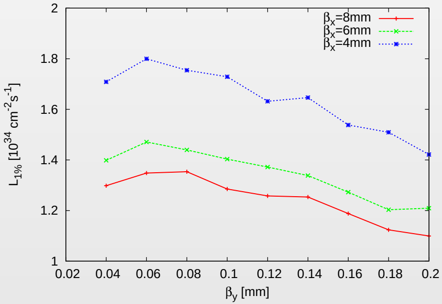

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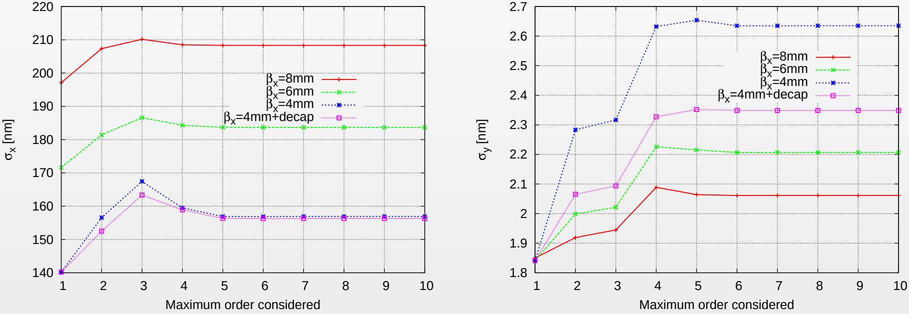
Reducing β_x^*

One expects that some aberrations due to the β_x^* reduction will dilute the beam size in both planes due to uncorrected aberrations. Can we deal with them?



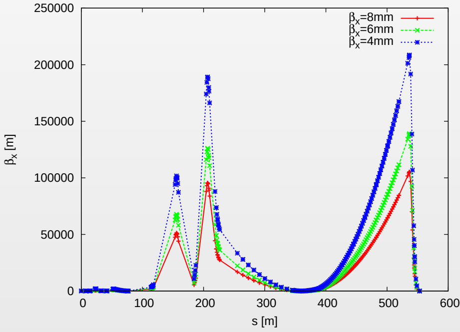
When we reduce β_x^*, we see that σ_x^* does not suffer from severe degradation due to aberrations. This is not the case for σ_y^* where we see that making β_x^* half of its nominal value sends the vertical aberrations to a 44% of the linear vertical beam size.

Looking at the aberration content

Looking at the map of the system from the matching section to the IP we observe a term that increases linearly as we reduce β_x^*. This is the $X_{y,20101} \sim (y|x^2 y\delta)$.

$X_{y,20101}$

- It is some fifth order aberrations coming from the interaction of some sextupole chromaticity and the geometrical part of a different sextupole.
- It is mostly corrected when we introduce a pair of decapoles close to the doublets.
- The aberration is mainly generated in the QF5 area (second doublet area),



CLIC $\sqrt{s} = 500$ GeV optimization

We take $\beta_y^* = 0.065$ mm as the optimal value and we scan β_x^*.

β_x^* [mm]	σ_x^* [nm]	σ_y^* [nm]	$\mathcal{L}_T$ [10^{34}cm^{-2}s^{-1}]	$\mathcal{L}_{1\%}$	$\mathcal{L}_{1\%}/\mathcal{L}_T$	n_γ
[4] 8	210.1	2.51	2.31	1.40	0.61	1.32
8	213.3	2.20	2.34	1.45	0.62	1.30
6	189.2	2.36	2.70	1.56	0.58	1.47
4	163.6	2.84	3.12	1.61	0.52	1.74
4+decap	162.8	2.56	3.20	1.65	0.52	1.74

We observe an important luminosity gain in absolute terms but as long as we reduce β_x^* the ratio between peak and total luminosity decreases mainly due to the photon emission.

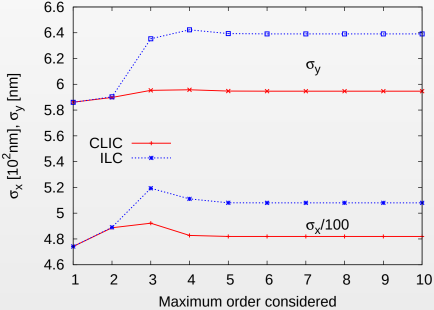
- What is the minimum β_x we can reach? 8mm, 4mm, 2mm?
- What is the minimum luminosity ratio required for physics experiments?

[4] CDR lattice with $\beta_y^* = 0.1$ mm

CLIC FFS as ILC FFS

CLIC 500 GeV FFS-based as ILC FFS

We consider the option to use CLIC 500 GeV FFS lattice with ILC parameters at the IP for ILC beam.



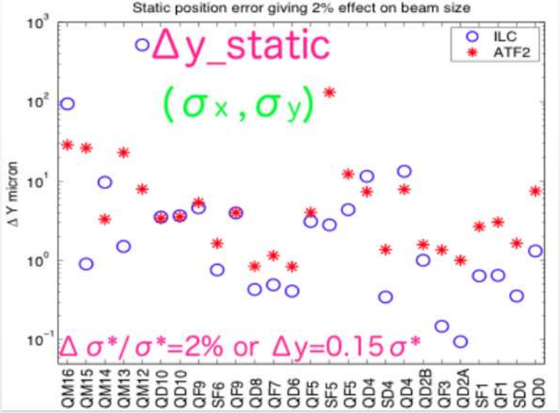
Placet+GuineaPig

Parameter	ILC	CLIC-based
Length [m]	735	553
β^*_x/β^*_y [mm]	11/0.48	11/0.48
σ_x^{core} [nm]	499.3	483.7
σ_y^{core} [nm]	6.03	5.89
$\mathcal{L}_T$ [10^{34} cm^{-2}s^{-1}]	1.39	1.47
$\mathcal{L}_{1\%}$ [10^{34} cm^{-2}s^{-1}]	0.86	0.89

CLIC-based FFS lattice presents a similar performance in terms of beam sizes and luminosity at the IP. For a realistic implementation we should consider some other details. This shows we may move to a common concept.

Tolerances (Quadrupole static alignment)

Tolerances are calculated for a 2% beam size increase.



* Courtesy of T.Tauchi.

We observe similar tolerances in all cases for ATF2, ILC and CLIC-based lattices.

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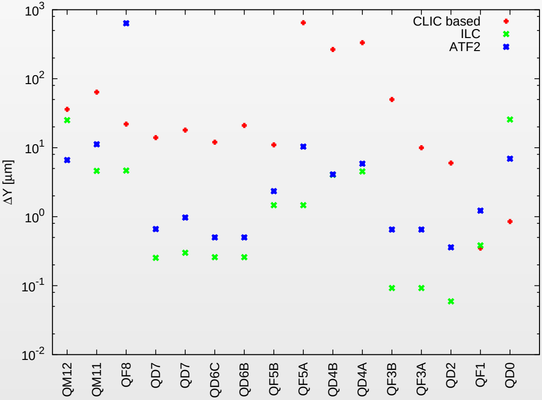

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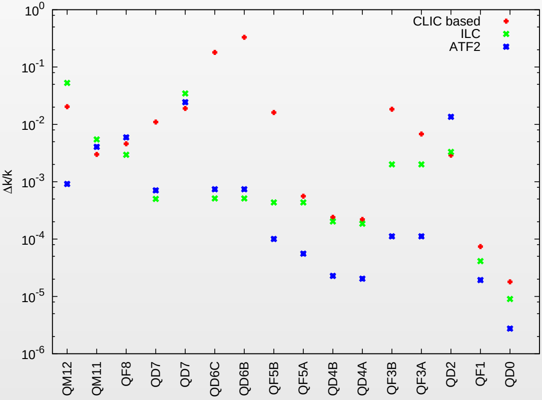

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Tolerances (Quadrupole tilt)

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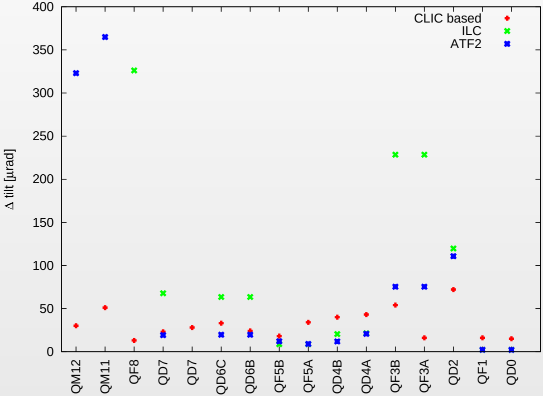
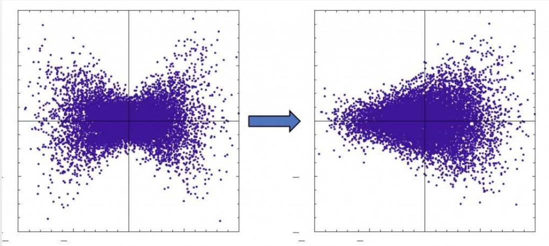


We observe similar tolerances in all cases for ATF2, ILC and CLIC-based lattices.

Traveling focus

Traveling focus motivation

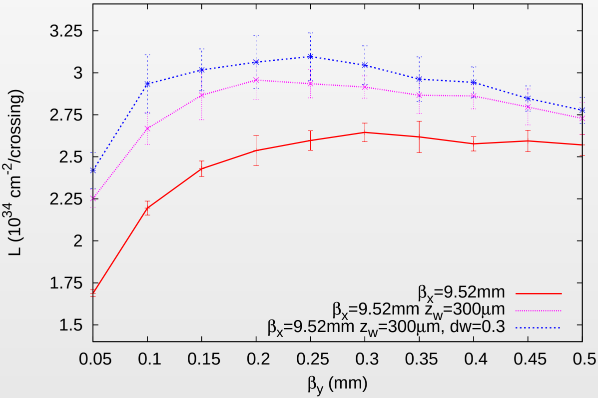
- So far we have considered head on collisions.
- If we consider the crossing angle scheme we have to consider crab cavities.
- Thanks to the crab cavities, we can introduce a controlled $E - z$ correlation in order to control the correct focusing of the head and the tail of the beam. Also called Traveling focus scheme.
- We analyze the case of ILC500 and CLIC500 via ideal distributions and its possible implementation in real lattices.



ILC β_y-scan. Ideal distributions results

Generic head-on beam is mapped in the y-plane to introduce the traveling waist and waist shift parameters $\frac{\partial w}{\partial z}$, z_{waist}.

$$\mathcal{M} : y_0 \to y = y_0 + \frac{\partial w}{\partial z} z_0 y_0' + z_{\text{waist}} y_0'$$



New FFS traveling waist results[5]

- Important: Only one crab cavity needed for implementation.
- Cavity placed upstream QD2 and QF1.

After ideal scan, we try to reproduce the same results with real distributions.

Waist shift z_{shift}

Vary QD0 strength slightly to move the waist:

$$z_{\text{shift}} = -\alpha^* \beta_y^*$$

$$\frac{\Delta K}{K} \sim \frac{z_{\text{shift}}}{\sqrt{\beta^{\text{QD0}} \beta^*}} \sim \mathcal{O}(10^{-5})$$

Traveling waist $\partial w / \partial z$

Choose Crab cavity location:

$$\frac{\partial w}{\partial z} \sim \frac{R_{12}^{\text{CC-sext}}}{R_{12}^{\text{CC-IP}}}$$

Best position: Between last Bend and SF1.

Lattice parameters

$\beta_x = 9.0$mm, $\beta_y = 0.25$mm
Crossing angle: $\theta/2 = 0.010$ mrad
Voltage needed: $V_{CC} = -0.38\,\text{MV}$
QD0 str. shift: $\Delta K/K = 5 \cdot 10^{-6}$

Distribution parameters

$z_w = 300\mu$m
$\partial w / \partial z = 0.35$

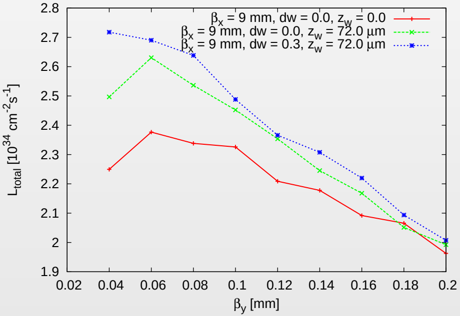
$$\mathcal{L}_T / \mathcal{L}_{ILC} > 20\%$$

[5] [illegible]

Implementing traveling waist in CLIC $\sqrt{s} = 500$ GeV

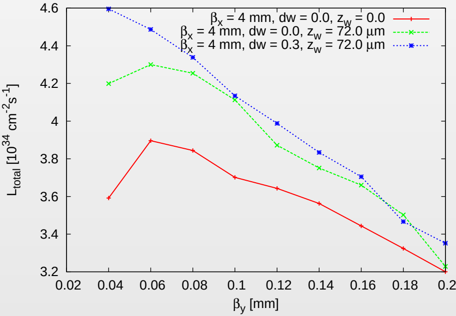
- Following the non negligible effect of the traveling focus on ILC we want to see how far we can go when we consider CLIC500.
- Short CLIC bunches compared to ILC bunches limits the expected luminosity gain.
- We follow the steps carried out in the ILC case.

$\beta_x^* = 9\text{mm}$



$> 12\%$ gain

$\beta_x^* = 4\text{mm}$



$> 15\%$ gain

Conclusions

Towards a common purpose

Conclusions

- CLIC-based FFS could be used for ILC even with nominal parameters.
- ILC β^* can be squeezed with its consequent luminosity gain without any extra challenge.
- Traveling focus gives a maximum gain of 15% from waist shift and a 10% more from traveling focus for ILC and could give a 15% gain for CLIC and really squeezed lattices .

Future prospects

- Explore and understand the limits of the local chromatic correction scheme.
- Traveling focus studies with re-optimized CLIC-based lattice for ILC and CLIC
- Progress in tuning simulations.