CLIC 500 GeV β_x^* reduction

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Motivation

- Flat beams are required to avoid big beamstrahlung photon emission.
- Therefore we set $\sigma_x^* >> \sigma_y^*$. This is achieved normally using $\beta_x^* >> \beta_y^*$.
- But running at low energies (500 GeV), the impact of such radiation is lower.

- Idea: Reduce β_x^* until the limit imposed by physics requirements.

Why?

- It implies a luminosity gain.
- Keeping the same luminosity, reduction of the bunch charge and, probably, a cost reduction.
- Some luminosity recovery if lower energies are considered.

Why not?

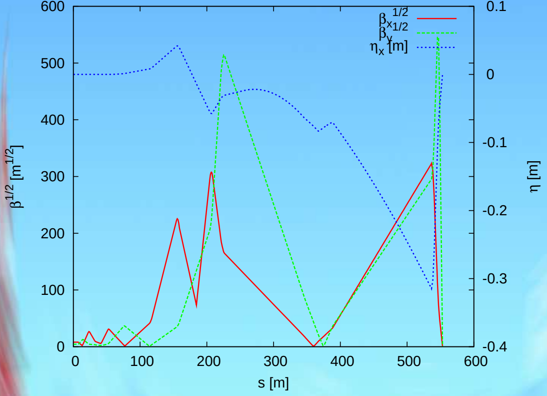
- It reduces the $\mathcal{L}_{1\%}/\mathcal{L}_T$ ratio, because ...
- ... it increases the beam induced background due to beamstrahlung. Experiments affected.

CLIC 500 GeV CDR parameters

Parameter	**Units**	CLIC500
Beam energy E_0	GeV	250
Bunches per beam n_b		354
$e^{\pm}$ per bunch N	10^9	6.8
Repetition rate f_{rep}	Hz	50
Hor. emittance ϵ_x^N	nm	2400
Vert. emittance ϵ_y^N	nm	25
Hor. beta β_x	mm	8.0
Vert. beta β_y	mm	0.1
Hor. beam size σ_x^*	nm	200
Vert. beam size σ_y^*	nm	2.26
Bunch length σ_z	μm	72
Energy spread δ_E	%	1.0
Luminosity $\mathcal{L}_T$	$10^{34} \cdot \mathrm{cm}^{-2}\mathrm{s}^{-1}$	2.3
Peak Luminosity $\mathcal{L}_{1\%}$	$10^{34} \cdot \mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.4

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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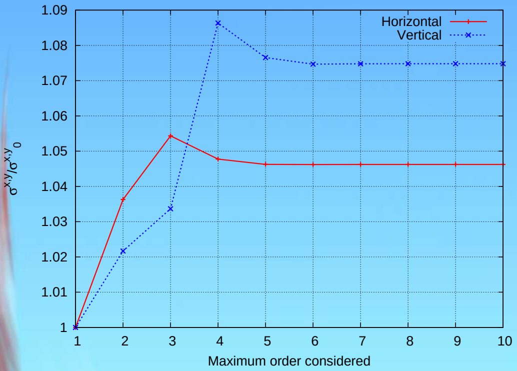

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$$\Upsilon = 0.61 \rightarrow n_\gamma = 1.32$$

Beyond Standard Parameters?

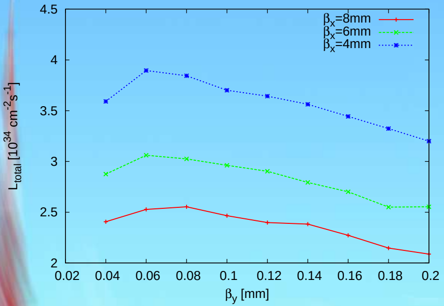
As in any optimization problem one question arises: Can we push the limits of β_x^* and β_y^* and make them even smaller?

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

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

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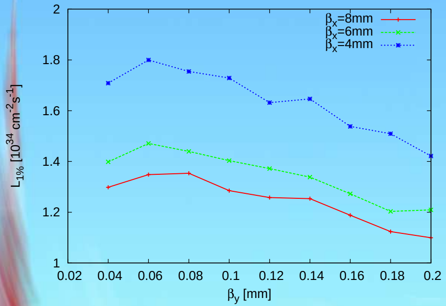

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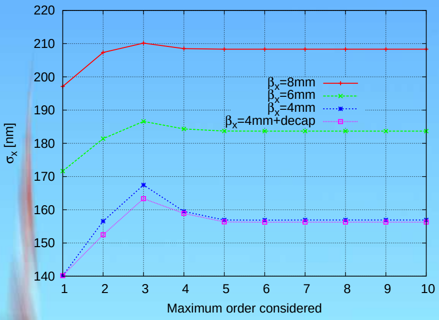
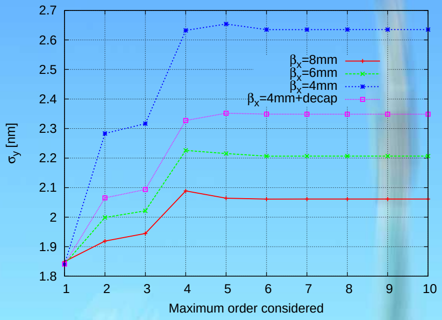
Reducing β_x^*

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.

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
[1] 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?

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

Charge scaling

Luminosity:

$$\mathcal{L} = \frac{N^2 f_{\mathrm{rep}} n_b}{4\pi\sigma_x^*\sigma_y^*} H_D = \frac{N}{\sigma_x^*}\frac{\eta P_{\mathrm{wall}}}{4\pi\sigma_y^*} H_D$$

Options

- Bunch population reduction:

$$\beta_x^* \downarrow \Rightarrow N \downarrow \Rightarrow \frac{N}{\sigma_x^*} = \text{const.} \Rightarrow \mathcal{L} = \text{const.}$$

- Luminosity increase:

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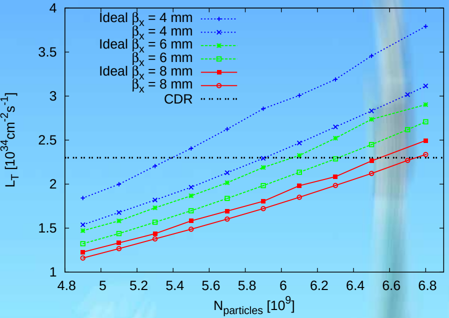

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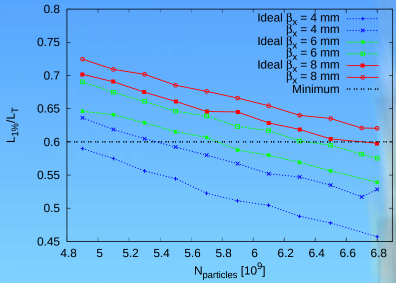
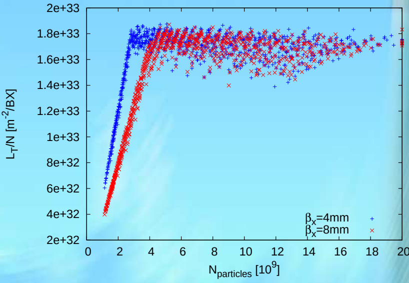
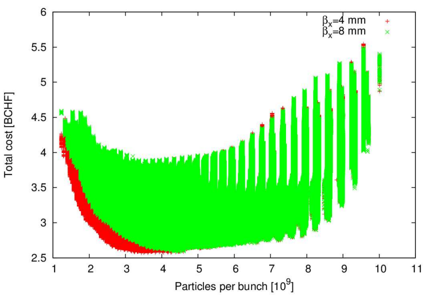
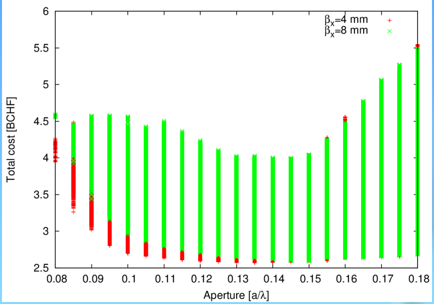




Cost optimization





- Some cost gain is seen for low bunch charges, but it does not imply a big impact.
- Luminosity for this cases would be very small even with lower β_x^*

Running at lower energies (250 GeV and 350 GeV)

To be able to reduce β_x^* a factor 2 is very convienent in case of running at lower energies.

- Due to linac considerations, the number of particles per bunch N is proportional to the energy of the beam E.
- Since luminosity $\mathcal{L}$ is proportional to N^2, from 350 GeV to 250 GeV this implies a luminosity reduction factor of 2.7.
- If we keep the ratio N/σ_x^* constant, the luminosity reduction factor is only 1.7, a 60% less.
- Therefore, the β_x^* reduction can partially mitigate the effect of the energy reduction.

Detail

$$N \sim G \sim E, \qquad \mathcal{L} \sim \frac{N^2}{\sigma_x^* \sigma_y^*}, \qquad \sigma_{x,y}^* \sim \gamma^{-1/2}$$

$$\mathcal{L} \sim N^2 \gamma \sim E^3$$

$$\text{Keep: } N/\sigma_x^* = \text{const.}$$

$$\mathcal{L} \sim \frac{N}{\sigma_x^*} N \gamma^{1/2} \sim E^{3/2}$$

Conclusions and future prospects

Conclusions

- We have designed a lattice with half of the nominal β_x^*.
- It could imply a luminosity gain of $> 30\%$.
- It can be used to reduce bunch charge keeping the same luminosity.
- The reduction of the cost is not very large.
- The β_x^* reduction could be very useful for lower energy options.

Future prospects

- Study the impact of such agressive lattice on the physics.
- Study in detail lower energies: Higgs peak production and top threshold (250 and 350 GeV).