Telescope Design

BDS Meeting
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The Goal

Minimize the beam size at the IP to recover the luminosity L of a circular accelerator, and limiting the energy loss due to radiation (beamstrahlung) δ_{BS}.

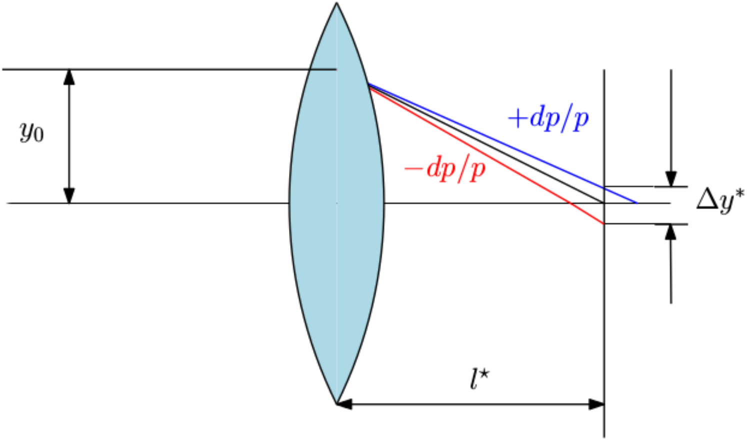
$$L \propto \frac{f_{rep} n_b^2}{\sigma_x \sigma_y} \qquad \delta_{BS} \propto \frac{n_b^2 E}{(\sigma_x + \sigma_y)^2}$$

Parameter	Symbol	LHC	ILC	CLIC 500 GeV	CLIC 3 TeV
Energy/z (TeV)	E	7	0.250	0.250	1.500
Bunch population	n_b	1.15×10^{11}	2×10^{10}	6.8×10^9	3.72×10^9
Repetition rate [Hz]	f_{rep}	11.1×10^3	5	50	50
H/V. IP beam size [nm]	σ_x/σ_y	16.6×10^3	474/5.9	202/2.3	40/1
E loss (Beamstrahlung) [$\Delta E/E$]	δ_{BS}	-???	0.07	0.07	0.28
Luminosity	L	10^{34}	1.57×10^{34}	2.3×10^{34}	5.9×10^{34}

Possible solution : flat beam ($\sigma_x \gg \sigma_y$)

The problem

Chromaticity



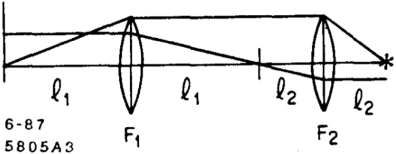
The path length changes as a function of the energy.
This generates an increase of the beam size.

Figure from CERN-THESIS-2014-230.6

Why a telescope ?

Demagnify the beam with minimal chromaticity generation

$x_i = \sum_{j=1}^{6} R_{ij} x_j + \sum_{j,k=1}^{6} T_{ijk} x_j x_k + \cdots \qquad x_i \in x, x', y, y', \tau, \delta$



$$R = \begin{pmatrix} M_x & 0 & 0 & 0 \\ 0 & 1/M_x & 0 & 0 \\ 0 & 0 & M_y & 0 \\ 0 & 0 & 0 & 1/M_y \end{pmatrix}$$

A Conceptual Design of Final Focus Systems for Linear Colliders

...$R_{12}(0) = 0$, $T_{116} = 0$...

$$\beta(\delta)\beta_0 = R_{11}^2 \beta_0^2 + \mathbf{2[0]\boldsymbol{\delta}} + [2R_{11} U_{1166} \beta_0^2 + T_{126}^2]\delta^2 + \cdots$$

So for telescopic systems ... the derivative with respect to δ vanishes...

... the total chromatic distortion in the triplet system is approximately twice that found in the singlet system !

The problem

A Conceptual Design of Final Focus Systems for Linear Colliders

. . .

The principal problem in designing Final Focusing Systems (FFS) for linear colliders is the elimination or minimization of the chromatic distortions introduced by the final lens system nearest to the interaction point (I.P.).

. . .

There are several possible approaches ...

3. Sextupoles can be introduced into the optical design to cancel the principal second-order chromatic aberrations ...

4. Alternatively one might choose to 'live with' the small residual second-order chromatic aberrations

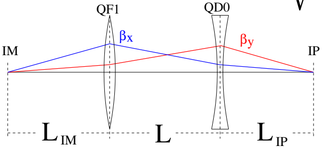
. . .

Karl L. Brown (SLAC-PUB-4159)

Chromaticity minimization

$$\xi_x = \frac{1}{\beta_x^*}\left(\cancelto{0}{T_{116}^2\beta_{x0}} + T_{126}^2\frac{1}{\beta_{x0}}\right) \qquad \xi_y = \frac{1}{\beta_y^*}\left(\cancelto{0}{T_{336}^2\beta_{y0}} + T_{346}^2\frac{1}{\beta_{y0}}\right)$$

Chromaticity increases the beam size : $\sigma = \sigma^*\sqrt{1+\xi^2\sigma_\delta^2}$



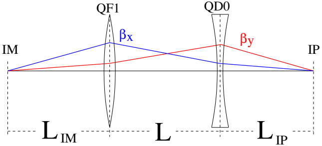
$$\xi_{\substack{x\\y}} = \mp\frac{1}{4\pi}\int \beta_{\substack{x\\y}} k dl = \mp\frac{1}{4\pi}\left(\beta_{\substack{x\\y}1}k_1 l_1 - \beta_{\substack{x\\y}0}k_0 l_0\right) = \frac{1}{4\pi}\frac{L_{IP}}{\beta^*_{\substack{x\\y}}}\Xi_{\substack{x\\y}}(r, r_{im})$$

with

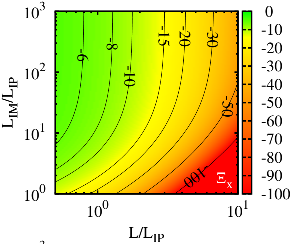
$$\Xi_{\substack{x\\y}}(r, r_{im}) = \mp\sqrt{\frac{1}{rr_{im}}+\frac{1}{r}+\frac{1}{r_{im}}}\sqrt{\frac{1+r/r_{im}}{1+r}}\left[\left(1+r\pm\sqrt{\frac{r}{r_{im}}+r+\frac{r^2}{r_{im}}}\sqrt{\frac{1+r}{1+r/r_{im}}}\right)^2 - \left(\frac{1+r}{1+r/r_{im}}\right)\right] \quad (1)$$

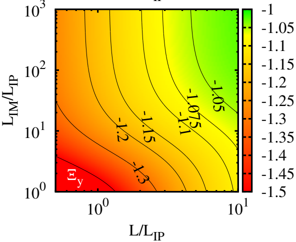
$r = L/L_{IP}, r_{im} = L_{IM}/L_{IP}$

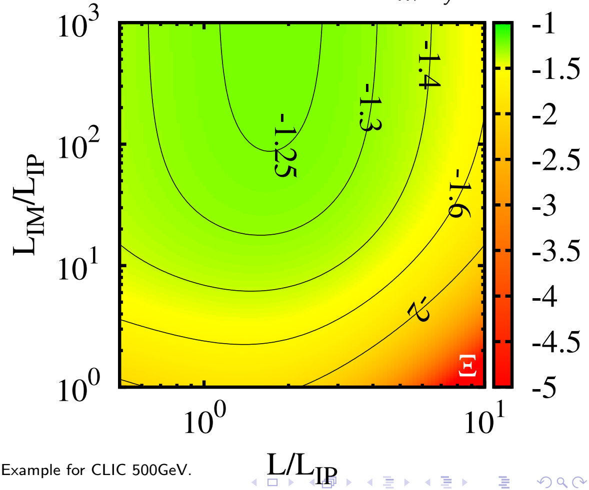
Chromaticity minimization (cont.)



$$\Xi = \frac{\Xi_x}{\beta_x^*/\beta_y^*} + \Xi_y$$



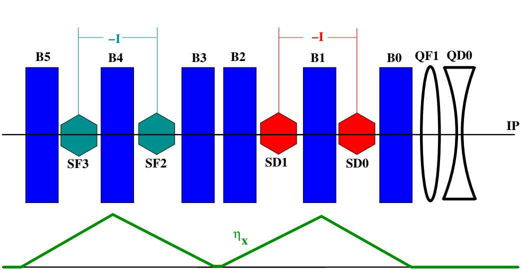




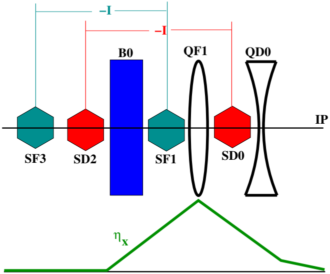
Chromaticity of a doublet in units of L_{IP}/β_y^*. Example for CLIC 500GeV.

Chromaticity correction

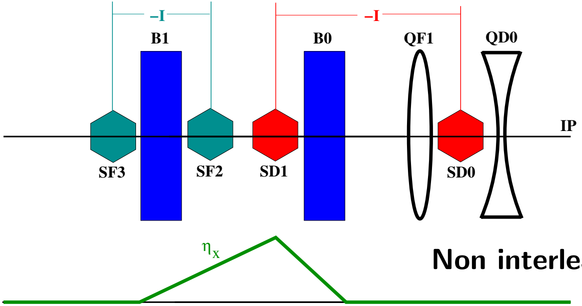
Local, Non-local and Non-interleaved correction



Non-local



Local

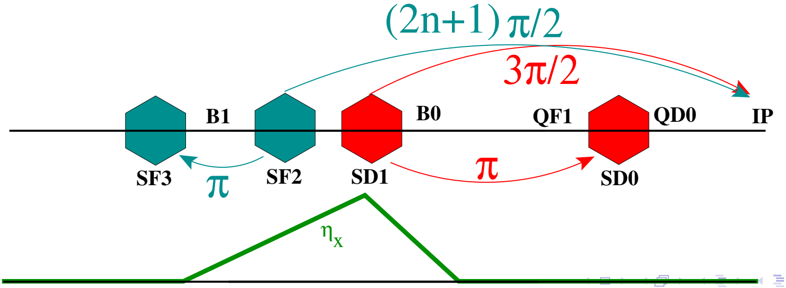


Non interleaved

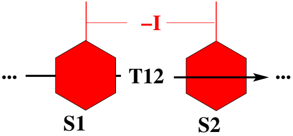
Second order terms reduction

Quadrupoles generate chromaticity ($k_1\delta x, k_1\delta y$) and in dispersive regions also generate second order dispersion ($k_1\eta_x\delta^2$).
One of the paired sextupoles is in a horizontal dispersive region ($\eta_x \neq 0$).
This will correct second order dispersion ($\eta_x^2\delta^2$), twice the h. chromaticity ($\eta_x\delta x_1$) and the total v. chromaticity ($\eta_x\delta y$).
The sextupoles in non-dispersive regions ($\eta_x = 0$) will correct the geometrical components from sextupoles (x^2, y^2, xy).

$$x_2' = \frac{k_2}{2}(x_1 + \eta_x\delta)^2 - y_1^2 = \frac{k_2}{2}(x_1^2 + 2x_1\eta_x\delta + \eta_x^2\delta^2 - y_1^2)$$
$$y_2' = k_2(x_1 + \eta_x\delta)y = k_2(x_1y_1 + \eta_x\delta y_1)$$



geometrical terms



$$T_{12} = \begin{pmatrix} t_{11} & t_{12} & 0 & 0 \\ t_{21} & t_{22} & 0 & 0 \\ 0 & 0 & t_{33} & t_{34} \\ 0 & 0 & t_{43} & t_{44} \end{pmatrix}$$ Ideally the phase advance is π. $$\rightarrow \begin{pmatrix} M_x & 0 & 0 & 0 \\ t_{21} & 1/M_x & 0 & 0 \\ 0 & 0 & M_y & 0 \\ 0 & 0 & t_{43} & 1/M_y \end{pmatrix}$$

$\Delta\phi$ represents the phase advance error.

$$t_{11}t_{22} = 1 - (\alpha_{x2} - \alpha_{x1})\Delta\phi_x$$
$$t_{33}t_{44} = 1 - (\alpha_{y2} - \alpha_{y1})\Delta\phi_y$$
$$t_{12} = \sqrt{\beta_{x1}\beta_{x2}}\Delta\phi_x$$
$$t_{34} = \sqrt{\beta_{y1}\beta_{y2}}\Delta\phi_y$$
and
$$0 = \beta_{y2}/\beta_{y1} - \beta_{x2}/\beta_{x1}$$

$\alpha\Delta\phi \ll 1$
$M > 1, \beta\Delta\phi < 1$
$M_x - M_y \ll 1$, it will set a limit to the cancellation of geometrical terms in both planes at the same time, when matching the sextupoles.

CLIC 3TeV Non-local (trad)

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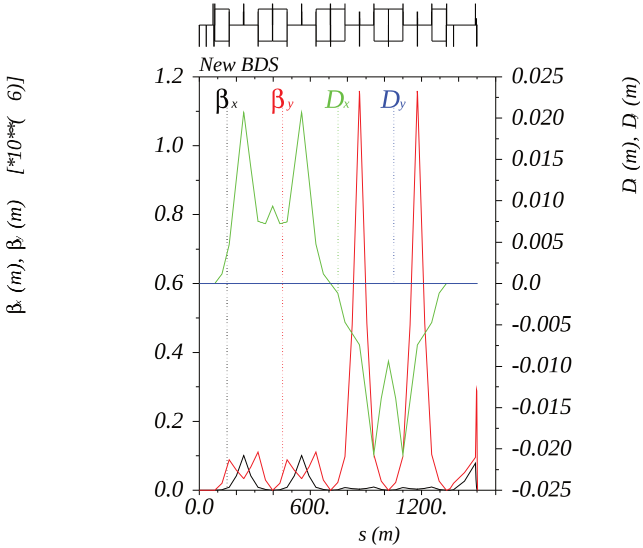

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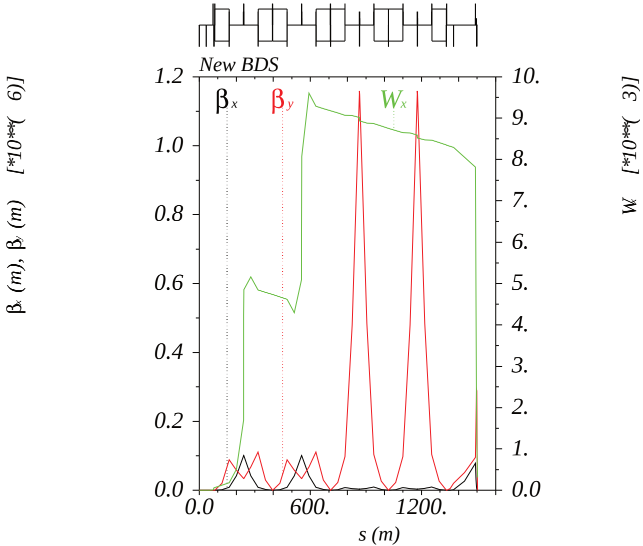
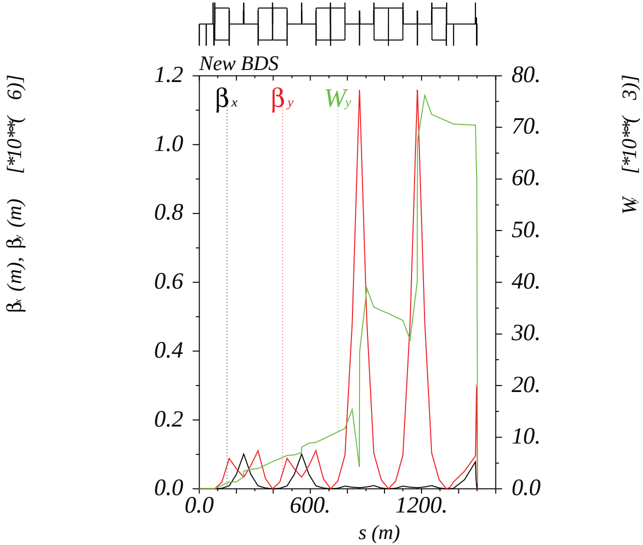
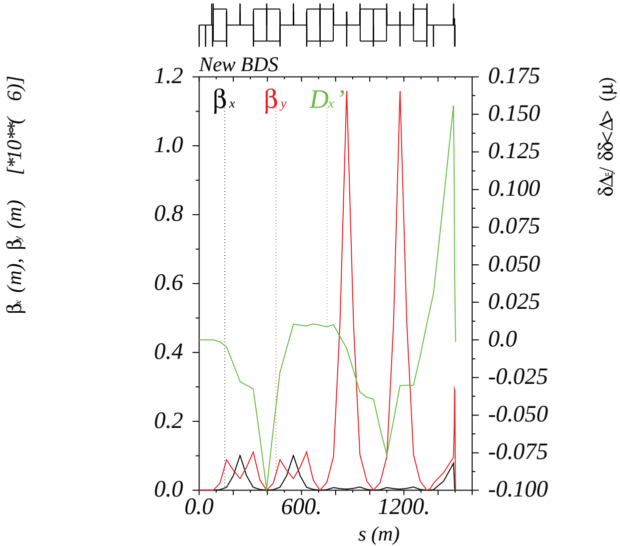


CLIC 3TeV Non-local (trad)

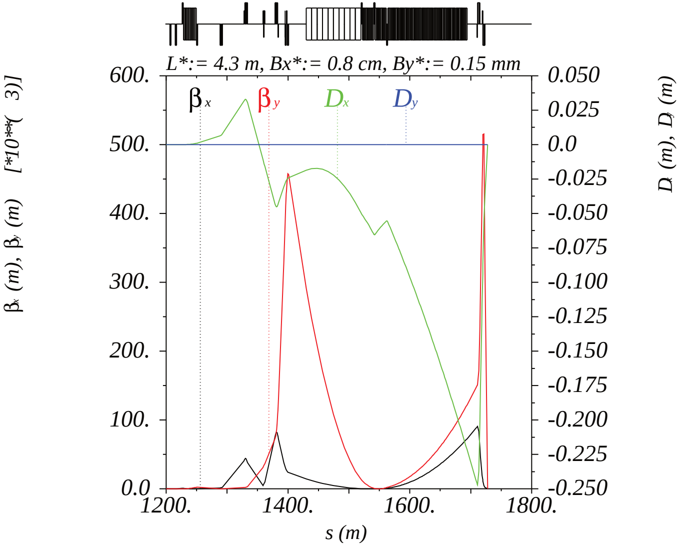


CLIC 3TeV Non-local (trad)



ILC 500 GeV

ILC 500 GeV (Local)



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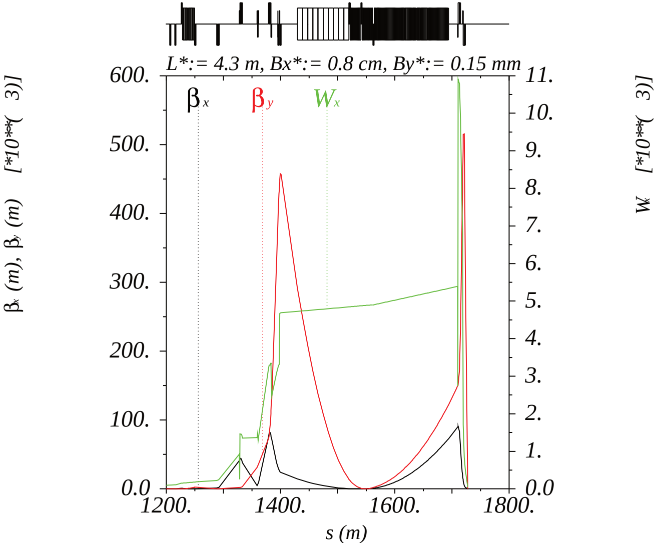

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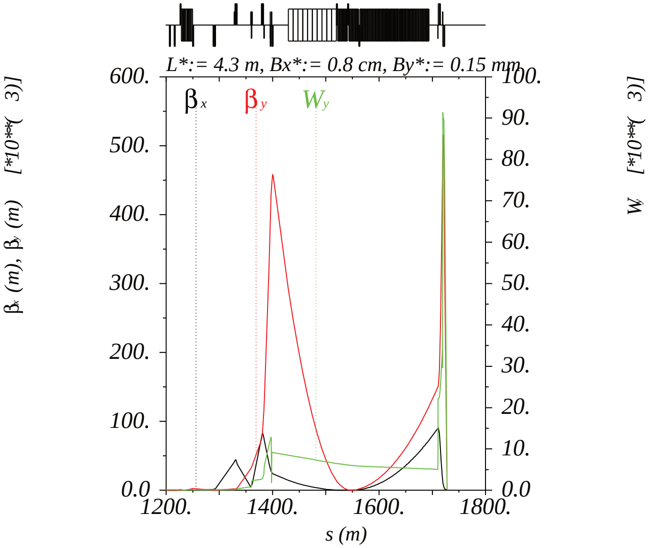

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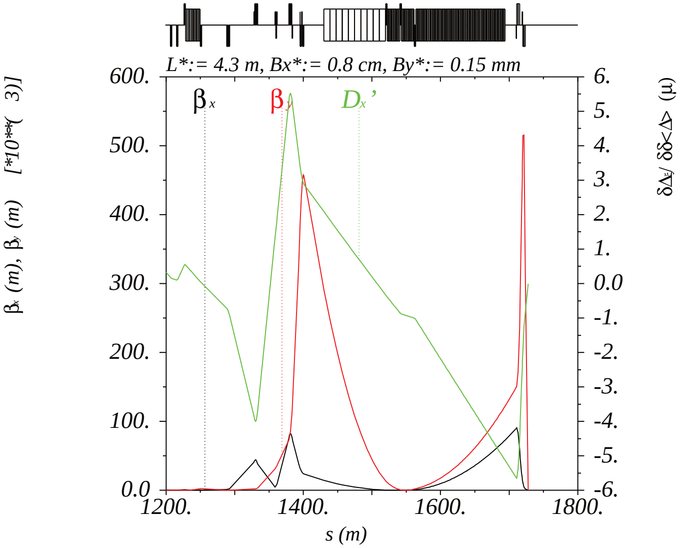
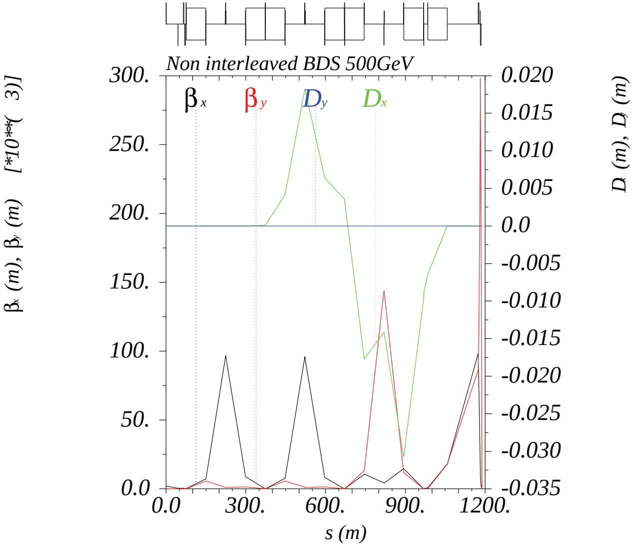


CLIC 500 GeV Non-interleaved Lattice

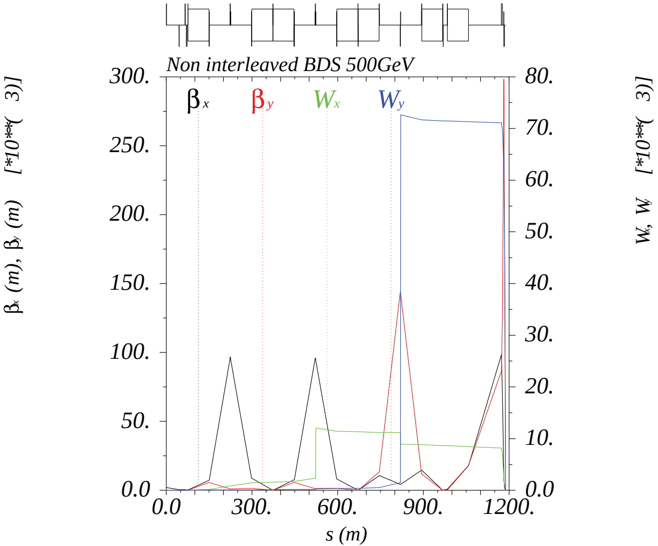
Current 500 GeV Lattice Parameters (from CDR)

Parameter [Units]	Value
Length (linac exit to IP distance/side [m])	1750
Maximum energy/beam [TeV]	0.25
Distance from IP to first quad, L^* [m]	4.3
Crossing angle at the IP [mrad]	18.6
Nominal core beam size at IP, σ^*, x/y [nm]	202/2.3
Nominal beam divergence at IP, θ^*, x/y [μrad]	25/23
Nominal beta-function at IP, β^*, x/y [mm]	8/0.1
Nominal bunch length, σ_z [μm]	72
Nominal disruption parameters, D, x/y	0.1/12
Nominal bunch population, N	6.8×10^9
Beam power in each beam [MW]	4.9
Preferred entrance train to train jitter [σ]	< 0.2
Typical nominal collimation aperture, x/y [σ_x/σ_y]	10/55
Vacuum pressure level, near/far from IP [10^{-9} mbar]	100/10

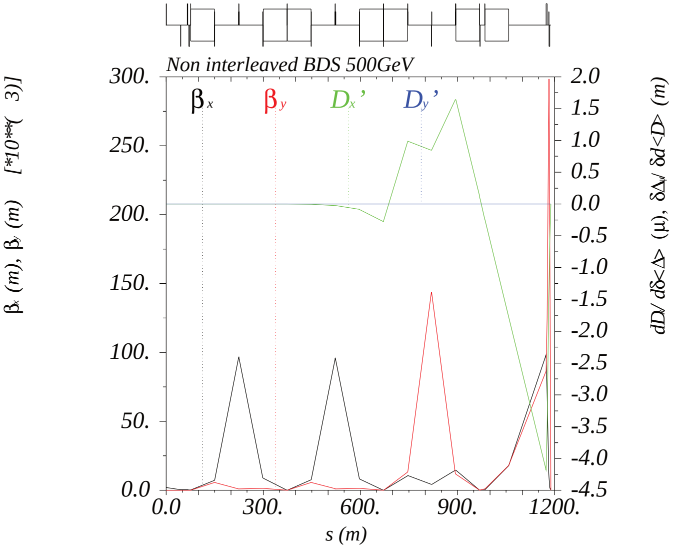
CLIC 500GeV Non-interleaved Lattice



CLIC 500GeV Non-interleaved Lattice



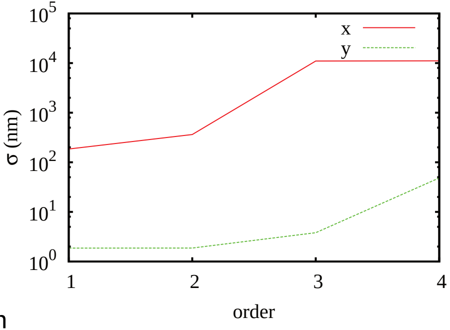
CLIC 500GeV Non-interleaved Lattice



Non-interleaved CLIC 500 GeV (cont.)

The lattice desing gives linear (order=1) beam size of :

$\sigma_x = 1.9$nm, $\sigma_y = 186$nm



$\sigma_{bends} = 0.2$nm

The third order terms U_{1166} and U_{3466} increase the beam size due to second order dispersion at the sextupole inside the Final doublet. Second order dispersion needs to be corrected before the FD (not only at the IP) and must remain zero because of the sextupole, or we should tolerate some dispersion in the FD.