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FFS Lattice optimization for Synchrotron Radiation effects

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Beamsize

We are interested in the beamsize at the IP.

Horizontal plane

$$\sigma^2 = \sigma_0^2 + \sigma_e^2 + \sigma_{rad}^2$$

$$\sigma^2 = \sigma_0^2 + \sigma_e^2 + \overbrace{\sigma_{bends}^2}$$

Vertical plane

$$\sigma^2 = \sigma_0^2 + \sigma_e^2 + \sigma_{rad}^2$$

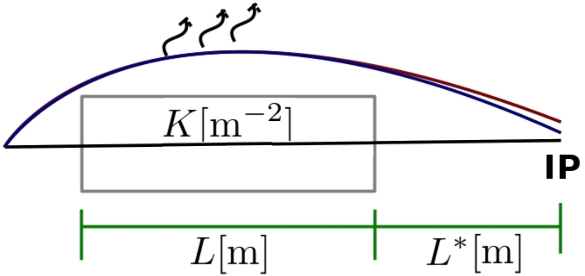
$$\sigma^2 = \sigma_0^2 + \sigma_e^2 + \overbrace{\sigma_{oide}^2}$$

$\sigma_0 \equiv$ zeroth order approx.

$\sigma_e \equiv$ result from aberrations

$\sigma_{rad} \equiv$ interaction with magnets

Introduction



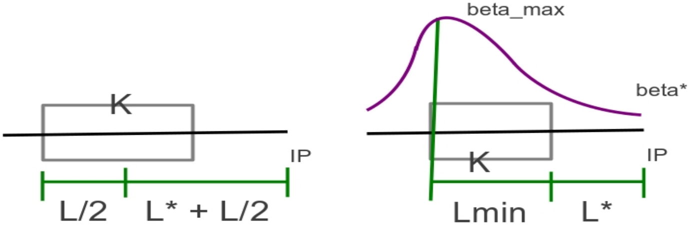
$$\sigma^2_{oide} = \frac{110}{3\sqrt{6\pi}} r_e \lambda_e \gamma^5 F(\sqrt{K}L, \sqrt{K}L^*) \left(\frac{\epsilon_y}{\beta^*_y}\right)^{5/2}$$

$$F(\sqrt{K}L, \sqrt{K}L^*) = \int_0^{\sqrt{K}L} |\sin\phi + \sqrt{K}L^* \cos\phi|^3 \left[\int_0^{\phi} (\sin\phi' + \sqrt{K}L^* \cos\phi')^2 d\phi'\right]^2 d\phi$$

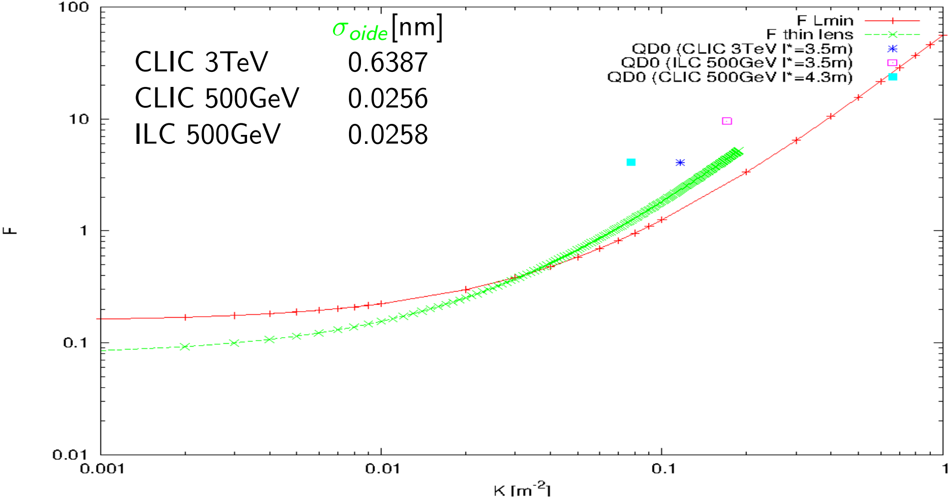
Equation derived by [1].

Two approaches

For a given L^*, what is the gradient K that minimizes $F(\sqrt{K}L, \sqrt{K}L^*)$?



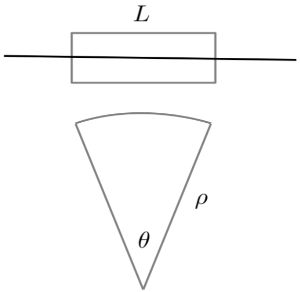
	β_y^*[mm]	L^* [m]	L [m]
CLIC 3TeV	0.09	3.5	2.73
CLIC 500GeV	0.40	4.3	3.35
ILC 500GeV	0.48	3.5	2.20


σ_{oide}[nm]
CLIC 3TeV 0.6387
CLIC 500GeV 0.0256
ILC 500GeV 0.0258
F Lmin
F thin lens
QD0 (CLIC 3TeV l*=3.5m)
QD0 (ILC 500GeV l*=3.5m)
QD0 (CLIC 500GeV l*=4.3m)
F
100
10
1
0.1
0.01
0.001
0.01
0.1
1
K [m^{-2}]

Conclusions

- Longer quadrupoles for the final doublet with lower gradient could reduce the Oide effect.
- There will always be a contribution to the beam size due to Oide effect.
- Importance of this effect is increased when targeting the higher energies (CLIC 3TeV).

$$\sigma^2_{bends} = C_2 \beta^* \int E^5 \left(\frac{1}{\rho^3}\right) H(s) \cos^2 \Phi(s) ds$$



$$H(s) = \frac{1}{\beta}\left[\eta^2 + \left(\beta\eta' - \frac{1}{2}\beta'\eta\right)^2\right]$$

$$\alpha(s) = \arctan\left(\frac{\beta'}{2} - \frac{\beta\eta'}{\eta}\right)$$

$$\Phi(s) = \phi(IP) - \phi(s) + \alpha(s)$$
$$= \Delta\phi(s, IP) + \alpha(s)$$

$$C_2 = 4.13 \times 10^{-11} [\mathrm{m}^2 (\mathrm{GeV})^{-5}]$$

$$E \equiv \text{Beam energy}$$

$$\beta^* \equiv \beta \text{ at the IP}$$

Equation derived by [2].

Is it possible to cancel this term? (Optimization)

Suppose there is a dipole that contributes to beamsize according to

$$\sigma^2_{bends} = C_2 \beta^* \int E^5 \left(\frac{1}{\rho^3} \right) H(s) \cos^2 \Phi(s) ds$$

It might be possible to cancel all term by making

$$\cos \Phi(s) = 0, \forall s$$

then,

$$\Phi(s) = \phi(IP) - \phi(s) + \alpha(s) = (2n+1)\frac{\pi}{2}, \qquad n \in Z$$

Using,

$$\alpha(s) = \arctan\left(\frac{\beta'}{2} - \frac{\beta\eta'}{\eta}\right), \qquad \tan(a \pm b) = \frac{\tan a \pm \tan b}{1 \mp \tan a \tan b}$$

The dispersion function η that makes $\Phi(s) = (2n+1)\pi/2, \forall s$ is:

$$\eta(s) = \eta_0 \left(\frac{\beta(s)}{\beta_0}\right)^{\frac{1}{2}} \frac{\sin(\phi(IP) - \phi(s))}{\sin(\phi(IP) - \phi_0)}$$

It is a **betatron oscillation**. It is not possible to produce such function because the dipole adds dispersion.
Therefore, the only possibility is to minimize the effect.

Before optimizing...

Rewriting the equation

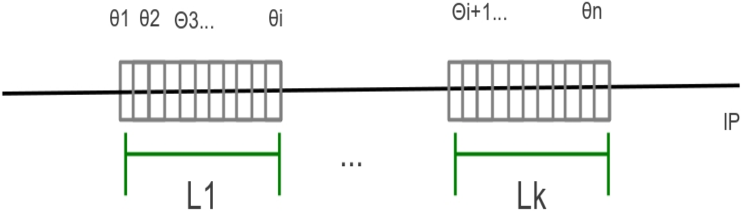
$$\sigma^2_{bends} = C_2\beta^* \int E^5 \left(\frac{1}{\rho^3}\right) H(s)\cos^2\Phi(s) ds$$

$$\sigma^2_{bends} = C_2\beta^* E^5 \int \left(\frac{1}{\rho^3\beta}\right) [\eta\underbrace{\cos\Delta\phi(s,IP)} + (\alpha\eta + \beta\eta')\underbrace{\sin\Delta\phi(s,IP)}]^2 ds$$

when β is large, $\Delta\phi(s, IP) \simeq$ constant. Then, values above brackets define weights during the optimization.
If β is small, then, all term squared in brackets should be minimized ($\eta \rightarrow 0$).

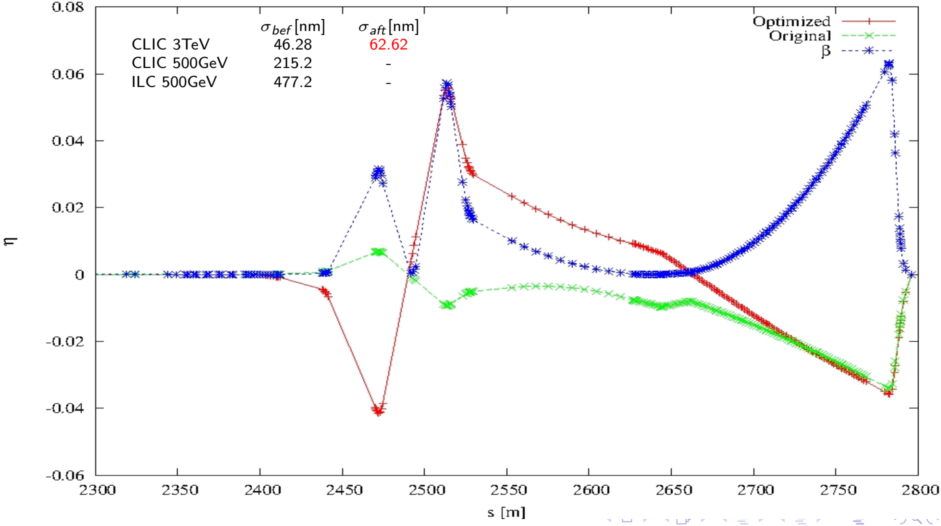
Optimization

The total longitud is fixed.



Total angle distribution will be changed to minimize σ_{bends}, under the following constraints:

- $\eta_x(IP) = 0$
- $\eta'_x(IP) =$constant value

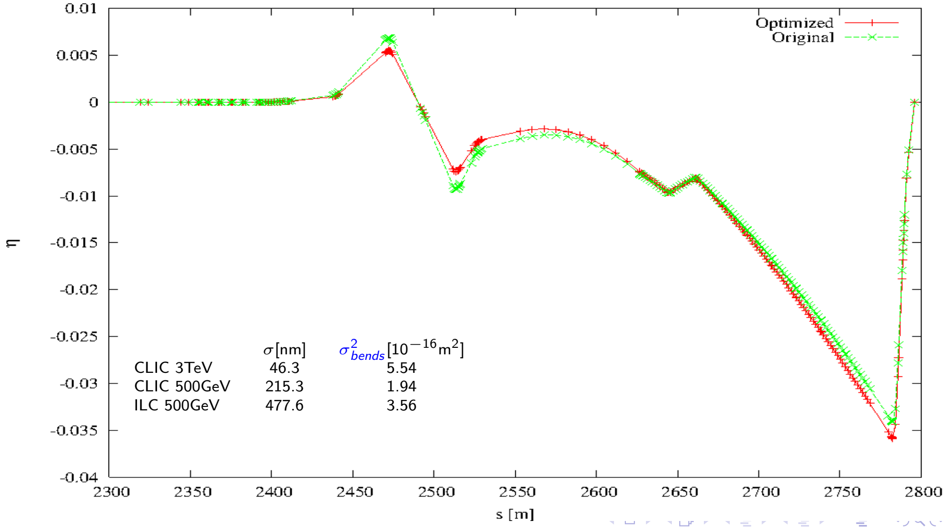

σ_bef [nm] σ_aft [nm]
CLIC 3TeV 46.28 62.62
CLIC 500GeV 215.2 -
ILC 500GeV 477.2 -
Optimized
Original
β
η
s [m]
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
2300
2350
2400
2450
2500
2550
2600
2650
2700
2750
2800

However, beamsize is composed by

$$\sigma^2 = \sigma_0^2 + \sigma_g^2 + \sigma_\delta^2 + \sigma_{bends}^2$$

and, dispersion is used in the lattice to correct geometrical (σ_g) and chromatic (σ_δ) aberrations (see [3]).
It is required to include sextupoles in the optimization.

Results and conclusions



	σ[nm]	σ^2_{bends} [10^{-16} m^2]
CLIC 3TeV	46.3	5.54
CLIC 500GeV	215.3	1.94
ILC 500GeV	477.6	3.56

Conclusions

- Lattice optimization for radiation is restricted by the required corrections of aberration.
- Any region with large betas could be used to place bending magnets with minimum effect on radiation.
- Next optimizations will include more parameters.

References

- Oide, Katsunobu. Synchrotron-Radiation Limit on the Focusing of Electron Beams. Phys. Rev. Lett. 61 – Issue 15, Oct, 1988. Pages 1713 – 1715.
- Sands, Matthew. Emittance growth from radiation fluctuations. SLAC/AP – 47. December, 1985.
- Renier, Ives. Implementation and validation of the linear collider final focus prototype : ATF2 at KEK (Japan). Doctoral Thesis, LAL10-91. June 2010.

Additional slide

Dispersion function

$$\begin{pmatrix} \eta(s) \\ \eta'(s) \\ 1 \end{pmatrix} = \begin{pmatrix} C(s) & S(s) & D \\ C'(s) & S'(s) & D' \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \eta_0 \\ \eta'_0 \\ 1 \end{pmatrix}$$