Comparison of Traditional and Local Chromaticity correction schemes for CLIC Final Focus System

Hector Garcia Morales[1,2]
Rogelio Tomas Garcia[2], Andrea Latina[2]

[1]Universitat Politècnica de Catalunya, Barcelona
[2]CERN, Geneve

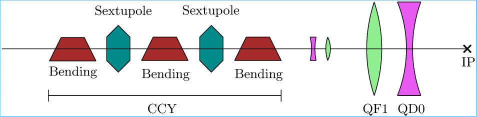
14th November 2013

Outline

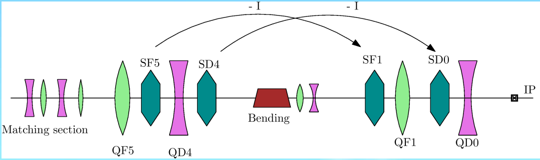
- Motivation
- Final Focus Optimization
- Synchrotron radiation
- Luminosity performance
- Tuning
- Conclusions

Motivation

- The Final Focus System provides the demagnification needed to reach nanemeter spot sizes and corrects aberrations generated by such strong quadrupoles.
- Traditionally, there has been two main approaches to correct chromaticity.
  - Dedicated chromatic correction scheme.



  - Local chromatic correction scheme.



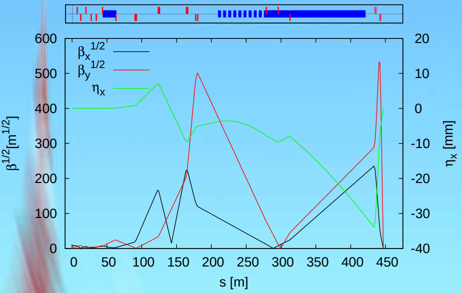
- The comparison in performance was done for the NLC and now is done for CLIC.

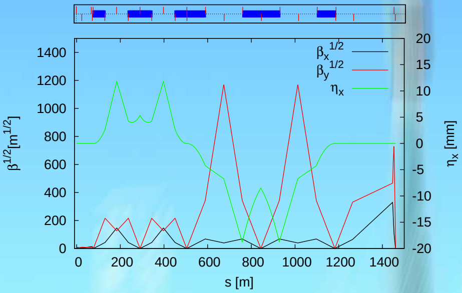
Parameters table

Parameter [Units]	3 TeV	500 GeV
Center of mass energy E_{CM}, [GeV]	3000	500
Repetition rate f_{rep}, [Hz]	50	50
Bunch population N_e [10^9]	3.72	6.8
Number of bunches n_b	312	354
Bunch separation Δt_b, [ns]	0.5	0.5
Accelerating gradient G, [MV/m]	100	80
Bunch length σ_z, [μm]	44	72
IP beam size σ_x^*/σ_y^*, [nm]	40/1	200/2.26
Beta function (IP) β_x^*/β_y^*, [mm]	10/0.07	8/0.1
Norm. emittance (IP) ϵ_x/ϵ_y, [nm]	660/20	2400/25
Energy spread σ_δ, [%]	1.0	1.0
Luminosity $\mathcal{L}_{\mathrm{T}}$ [$10^{34}\mathrm{cm}^{-2}s^{-1}$]	5.9	2.3
Power consumption P_{wall}, [MW]	589	272
Site length, [km]	48.3	13.0

Linear optics 3 TeV $L^* = 3.5$ m

The lattice for the local correction scheme was taken from the repository without applying major changes. The traditional correction scheme was generated by FFADA.

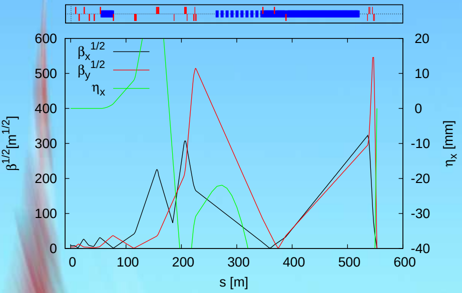


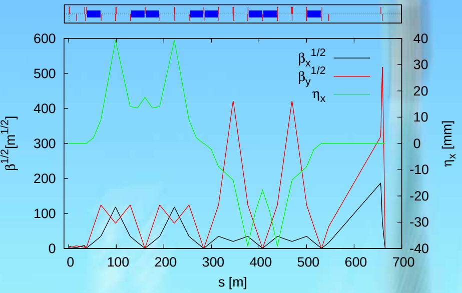


Both schemes are optimized in order to obtain the same $\beta^*_{x,y}$ at the IP.

Linear optics 500 GeV $L^* = 4.3$ m

The lattice for the local correction scheme was taken from the repository rematching the β^* values of the CDR values. The traditional correction scheme was generated by FFADA with the same β^*.





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Nonlinear optimization 3 TeV

The correcion of the nonlinearities is performance by MAPCLASS and PTC.

Map:

$$z_f = \sum_{jklmn} X_{z,jklmn} x_0^j p_{x0}^k y_0^l p_{y0}^m \delta_0^n$$

Chromaticity:

$$\xi_y^2 = \frac{1}{12\beta_y^*}\left(X_{y,00101}^2 \beta_{y0} + X_{y,00011}^2 \frac{1}{\beta_{y0}}\right)$$

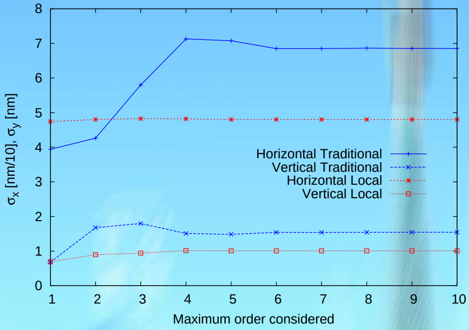
Beam size dilution:

$$\sigma_y^* \approx \sigma_{y,0}^* \sqrt{1 + \xi_y^2 \sigma_\delta^2}$$

where

$$\sigma_{y,0}^* = \sqrt{\epsilon_y \beta_y}$$

Scheme	ξ_y	$\sigma_y^*/\sigma_{y,0}^*$
Local 3 TeV	23005	229.7
Traditional 3TeV	39842	398.0
Local 500 GeV	19231	197.8
Traditional 500 GeV	22186	227.9



Nonlinear optimization 500 GeV

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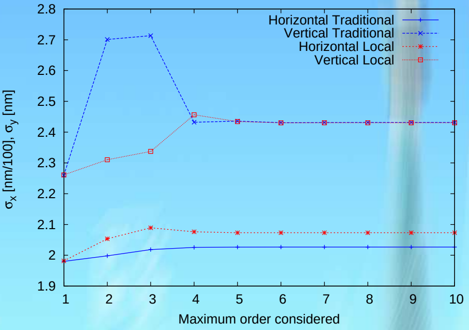


Synchrotron radiation effects

Synchrotron radiation in the bending sections (required to create the needed dispersion for chromaticity correction) is one of the major issues that creates beam size dilution at the IP.

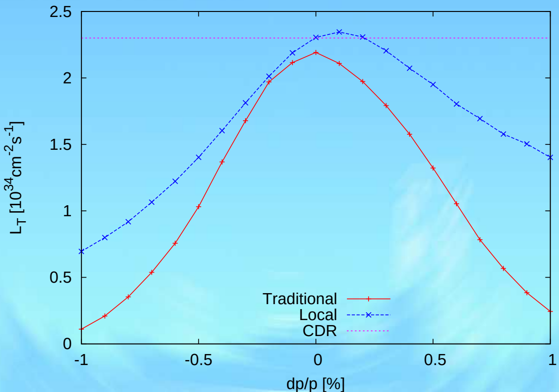
Scheme	$E_{\rm cm}$[GeV]	σ_x/σ_{x0} (Bend)	σ_y/σ_{y0} (Quad)
Local	3000	1.2	202
Traditional	3000	0.2	259
Local	500	1.1	2.0
Traditional	500	0.5	139

- Bending magnet strength must be optimized to provide enough dispersion for the nonlinear compensation but low enough to keep synchrotron radiation effects low.
- The vertical beam size is strongly affected by the radiation in the last quadrupoles but this effect is not reflected in luminosity since the impact is mostly present in the tails of the beam (i.e. increasing the rms beam size) but the core of the beam remains practically the same.

Luminosity performance

Table: Total and peak luminosity computed using GuineaPig for local and traditional systems at high an low energies.

Scheme	Energy [GeV]	$\mathcal{L}_{\mathrm{T}}[\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	$\mathcal{L}_{1\%}[\mathrm{cm}^{-2}\mathrm{s}^{-1}]$
Local	3000	7.6	2.4
Traditional	3000	5.3	1.9
Local	500	2.3	1.4
Traditional	500	2.2	1.3



Tuning simulation

When we consider realistic imperfections, the machine performance decreases rapidly and luminosity drops dramatically.

Tuning set up

- Initial misalignment: 10 μm RMS (x, y) for all elements.
- BPM resolution: 10 nm.
- Dipole correctors: BPM+Quad+Corrector.
- Placet for tracking and GuineaPig for luminosity measurement.
- Four lattices: Traditional and local for 3 TeV and 500 GeV.

Alignment procedure (Andrea's script)

- Multipoles OFF:
  - 1:1 correction

$$\begin{pmatrix} b_x \\ b_y \end{pmatrix} = \begin{pmatrix} R_{xx} & 0 \\ 0 & R_{yy} \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$$

  - DFS

$$\begin{pmatrix} b \\ \omega_1(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} R \\ \omega_1 D \\ \beta I \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$$

- Multipole-Shunting (only 3TeV)
- Multipole Knobs
- Multipoles ON:
  - DFS

$$\begin{pmatrix} b \\ \omega_1(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} R \\ \omega_2 D \\ \beta I \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$$

  - Multipole Shunting (only 3TeV)
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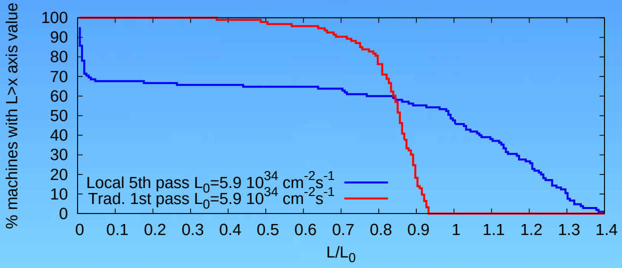
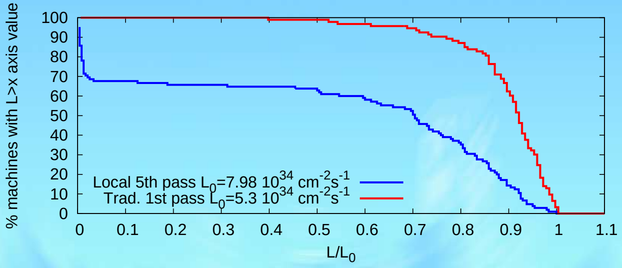
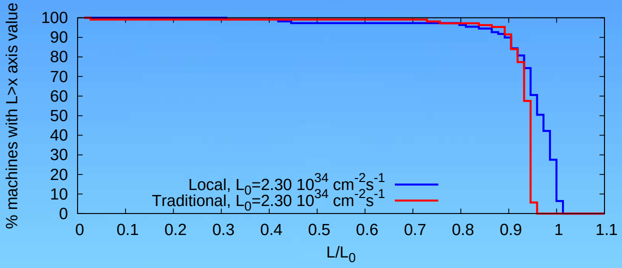
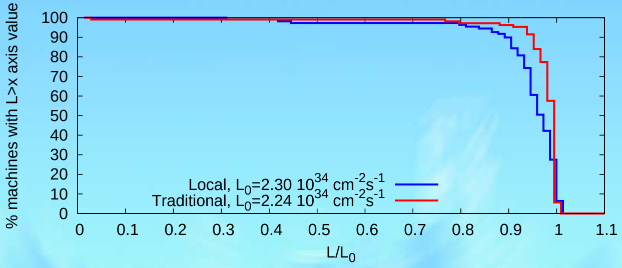
Tuning simulation 3 TeV





Tuning simulation 500 TeV

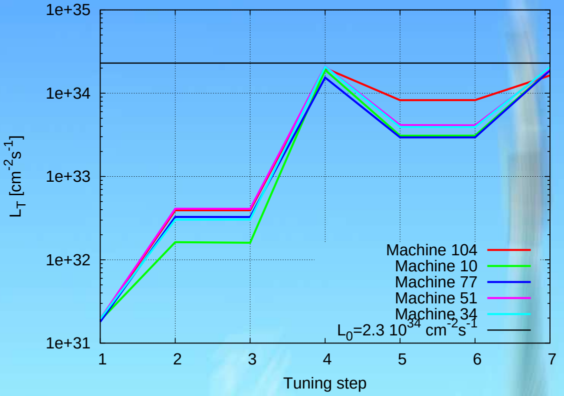




Tuning simulation evolution

Since the tuning is composed by several parts, we can analyze the contribution of each method.

- Initial luminosity: $\sim 10^{29} - 10^{30}\text{cm}^{-2}\text{s}^{-1}$
- Step 1: One to one steering.
- Step 2: DFS
- Step 3: Multipole alignment (not used in 500 GeV)
- Step 4: Sextupole knobs
- Step 5: DFS
- Step 6: Multipole alignment (not used in 500 GeV)
- Step 7: Multipole knobs.



The number of luminosity measurements per iteration is about 1200, that corresponds to a time span of about 20 minutes per iteration if a fast luminosity measurement takes 1 second.

Tuning results

- The number of luminosity measurements per iteration is ~ 1200.
- We consider that fast luminosity measurement takes approximately 1 second.
- Therefore, the tuning time is about $20 - 30$ minutes per iteration.
- Dedicated correction scheme is always faster to tune than the local scheme.
- At 3 TeV, the dedicated correction scheme needs more than 1-2 hours to be tuned.
- In order to recover the missing luminosity at 3 TeV, a simplex algorithm is applied after BBA+Knobs. This reaches a good performance but the number of luminosity measurements increases in one order of magnitude and therefore also the tuning time increases.

Conclusions and future prospects

Conclusions

- We have compared the performance and tuning simulation of two different FFS schemes for CLIC at 3 TeV and 500 GeV center of mass energy.
- If one wants to keep the length of the FFS in a reasonable value the local chromaticity correction scheme always performs better than the dedicated correction scheme.
- The tuneability of the traditional correction scheme is faster and easier, with a notably difference for high energies.

Future prospects

- Add a Simplex blind optimization to the already applied algorithm for the 500 GeV case. (Very soon)