A more competitive Traditional Final Focus System for CLIC at 3 TeV

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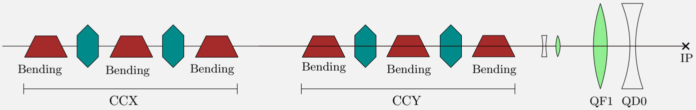
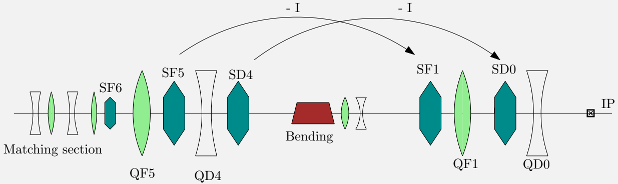
Review of the Final Focus Systems

- The Final Focus System (FFS) provides the demagnification needed to reach nanemeter spot sizes and corrects aberrations generated by such strong quadrupoles.
- Traditionally, in linear colliders, there has been two main approaches to correct chromaticity.

Traditional FFS



Local FFS



CLIC parameters

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

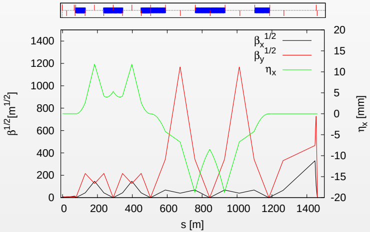
New Traditional FFS

After considering why the old traditional scheme delivered so low luminosity, we observed that perhaps was because of a very long QD0.

Old Final Doublet

Magnet	L_{QD0} [m]	K_{QD0} [m^{-2}]	Ap.rad 30σ [mm]
QD0	7.83	-0.04	1.8
QF1	2.76	0.06	4.4

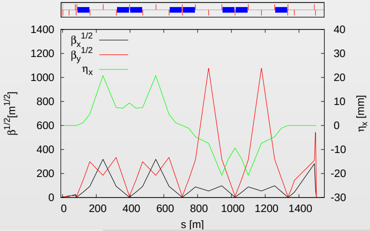
Clearly there were something wrong with this doublet.



New Final Doublet

Magnet	L_{QD0} [m]	K_{QD0} [m^{-2}]	Ap.rad 30σ [mm]
QD0	2.67	-0.12	1.3
QF1	0.88	-0.14	3.9

We clone the local chromatic correction scheme FD.



Comparison with local correction scheme

The reduction of the QD0 length must be translated into a reduction on the chromaticity.

Taylor 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:

$$\sigma_y^* \approx \sigma_{y,0}^* \sqrt{1+\xi_y^2\sigma_\delta^2} \quad \Rightarrow \quad \sigma_{y,0}^* = \sqrt{\epsilon_y \beta_y^*}$$

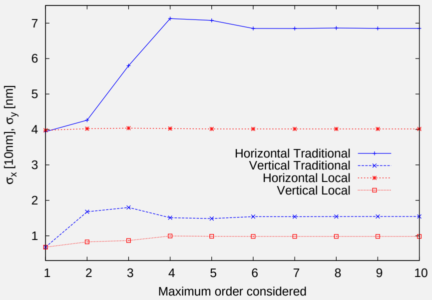
Scheme	Energy [GeV]	L_{FFS} [m]	ξ_y	$\sigma_y^*/\sigma_{y,0}^*$
Local	3000	450	23005	229.7
Old Traditional	3000	1500	39482	398.0
New Traditional	3000	1500	32242	327.1

- The reduction of the chromaticity of the FD allows to relax the strength of the sextupoles, reducing also geometric aberrations.
- Still more chromatic than the local scheme.

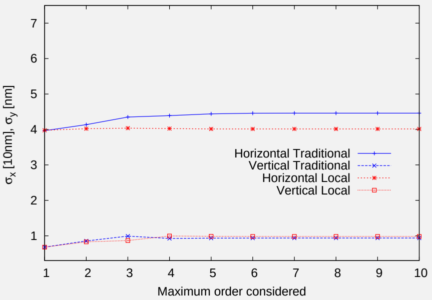
Order by order beam size

After sextupole optimization, the effects of chromatic aberrations are reduced.

Old traditional



New traditional



The improvement is clear and the final beam sizes for the new Traditional scheme are comparable to the ones of the Local scheme.

$$\text{Local: } \sigma_x^*(10) = 40.15\,\text{nm}, \sigma_y^*(10) = 0.98\,\text{nm}$$
$$\text{New traditional: } \sigma_x^*(10) = 44.61\,\text{nm}, \sigma_y^*(10) = 0.94\,\text{nm}$$

Luminosity

- In the end, the performance of the FFS and the accelerator is given by the luminosity it delivers.
- Luminosity is calculated with GuineaPig after a beam tracking in Placet including SR effects.

Scheme	Energy [GeV]	$\mathcal{L}_{\mathrm{T}}$ $[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	$\mathcal{L}_{1\%}$ $[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	$\mathcal{L}_{1\%}/\mathcal{L}_{1\%}^{(\mathrm{w/o\ SR})}$
Local	3000	7.8	2.4	0.79
Old traditional	3000	5.3	1.9	0.76
New traditional	3000	7.5	2.4	0.76

- We observe a big improvement of the Traditional scheme in terms of luminosity.
- Now, Local and Traditional deliver the approximately the same luminosity.

Tuning simulation

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

Tuning set up

- 100 randomly misaligned machines (seeds).
- 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.
- Two lattices: Traditional and local at $\sqrt{s} = 3$ TeV.

Alignment algorithm

- 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

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

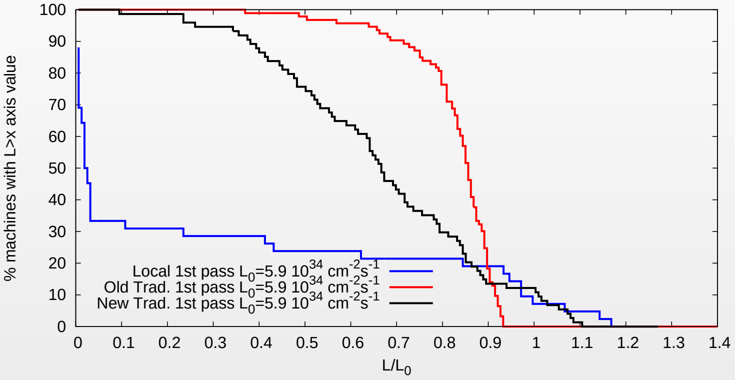
- Multipole Knobs
- Multipoles ON:
  - DFS

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

  - Multipole Knobs

Tuning simulation results

We test the BBA algorithm explained before for different lattices.

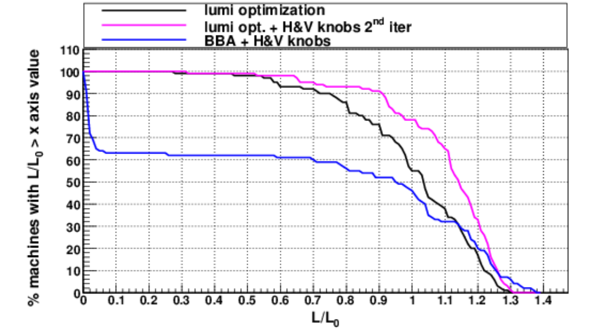


- The tuning of the new lattice seems to be more challenging than the previous one.
- The local scheme seems more difficult to tune than the traditional scheme.
- To complete the tuning, it is clear that something more must be done...

Improving the tuning

- Apply more passes of the BBA+Knobs algorithm.
- Add Simplex optimization on top of the BBA+Knobs.
- This method has been proven to be efficient for higher charges.

Previous Local 3 TeV tuning results



- Results courtesy of B. Dalena.
- Bunch charge $N = 4.0 \cdot 10^9$ (instead of the nominal value $N = 3.72 \cdot 10^9$).
- BBA+Knobs after 5th pass.

Tuning results

- The number of luminosity measurements per pass is ~ 1200.
- We consider that fast luminosity measurement takes approximately 1 second.
- Therefore, the tuning time is about $20 - 30$ minutes per pass.
- In the local scheme, in order to recover the missing luminosity at 3 TeV, a simplex algorithm is applied after BBA+Knobs. The performance is improved but the tuning time increases considerably.
- The traditional scheme needs more iterations of the BBA+Knobs algorithm and also to add also a simplex optimization on top of that.

Conclusions and prospects

- We have designed a FFS based on the Traditional chromatic corrections scheme that performs as good as the Local correction scheme in terms of luminosity.
- Under the same conditions, the Traditional scheme seems to tune easier than the Local scheme.
- But, the tuning simulations reveal that the new improved Traditional scheme is more difficult to tune than the old scheme with lower luminosity.

Near future prospects

- Apply more BBA+knobs iterations to both systems.
- Add Simplex optimization on top of BBA+Knobs.
- Optimization of the IP parameters taking into account tuning perfomance?

We will keep pushing the boulder!

Thank you!

Albert Camus:
*"Il n'y a qu'un problème philosophique vraiment sèrieux : c'est le **tuning**"*

*"There is but one truly serious philosophical problem and that is **tuning**"*