CLIC Final Focus Systems and Tuning

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29th January 2013

Outline

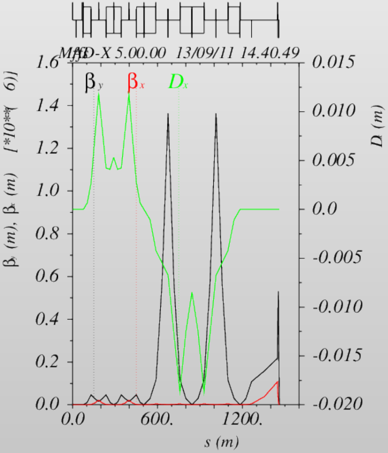
1. CLIC Final Focus System
2. Final Focus Schemes
   - Traditional Correction Scheme
   - Local Chromaticity Correction Scheme
   - CLIC $\sqrt{s} = 3$ TeV FFS
   - CLIC $\sqrt{s} = 500$ GeV FFS
3. Final Focus Tuning
   - Tuning algorithm
   - Tuning CLIC $\sqrt{s} = 3$ TeV
   - Tuning CLIC $\sqrt{s} = 500$ GeV
4. Conclusions

CLIC Final Focus

- The generation of the nanometer IP spot size requires strong focusing.
- The main task of the Final Focus System (FFS) is to focus the beam to such small sizes.
- The chromatic aberrations of the beam transport in the FFS region need to be canceled with sextupoles and higher order multipoles.
- There exist two distinct approaches for the design of Final Focus Systems.
  - The traditional design contains two sections dedicated to the chromaticity correction,
  - The newer local chromaticity approach proposed by P.Raimondi and A.Seryi where the sextupoles are placed within the Final Doublet, allowing a shorter system.

Traditional Chromaticity Correction Schemes

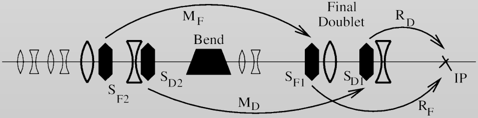
- The chromaticity is compensated in dedicated chromatic correction sections (CCX and CCY).
- Sextupoles in high dispersion and high betas regions.
- The geometric aberrations generated by the sextupoles are canceled using a $-I$ transformation between them.
- It is a relatively simple system for design and analysis.

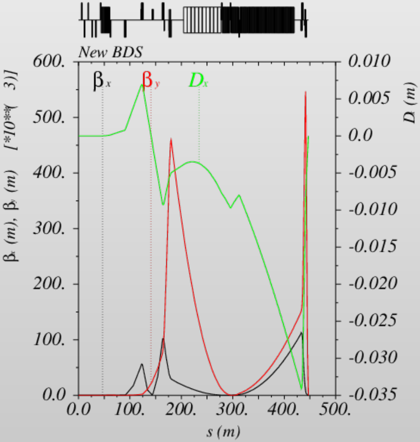


FFTB (SLAC) reached a 70 nm vertical beam size using this scheme in 1995.

Local Chromaticity Correction Scheme

Current CLIC FFS is based in the local chromaticity correction, initially regarded as a way to reduce the cost of the tunnel construction.





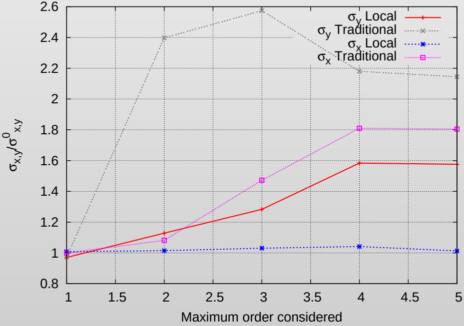
ATF2 (KEK) December 2012 run reached a 70 nm vertical beam size using this scheme using low current beam.

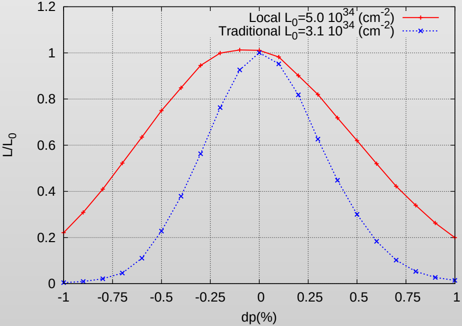
CLIC $\sqrt{s} = 3$ TeV Traditional vs Local

Parameter	Units	Traditional	Local
Beam energy	GeV	1500	1500
Last drift L^*	m	3.5	3.5
L_{FFS}	m	1460	450
Beta function β_x/β_y	mm	6.9/0.068	6.9/0.068
Linear beam size σ_x^0/σ_y^0	nm	40/0.7	40/0.7
Nonlinear beam size σ_x^5/σ_y^5	nm	70/1.56	40.52/1.10
Total Luminosity L	$10^{34}\mathrm{cm}^{-2}$	3.11	5.06
Peak Luminosity $L_{1\%}$	$10^{34}\mathrm{cm}^{-2}$	1.25	1.71
Placet w/o synch σ_x/σ_y	nm	69.8/1.39	40.4/1.11
Placet w synch σ_x/σ_y	nm	71.6/3.22	48.5/2.69

Table: Parameters of the CLIC Final Focus $\sqrt{s} = 3$ TeV at the IP

CLIC $\sqrt{s} = 3$ TeV Luminosity bandwidth





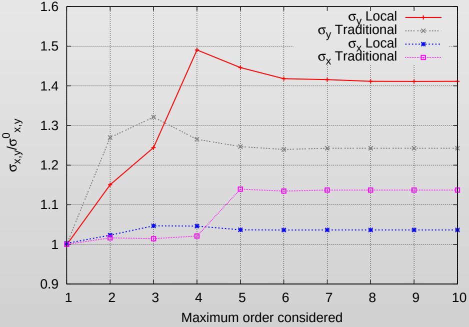
- Traditional scheme correction limited by the length of the system.
- Local correction scheme presents more luminosity and wider luminosity bandwidth.

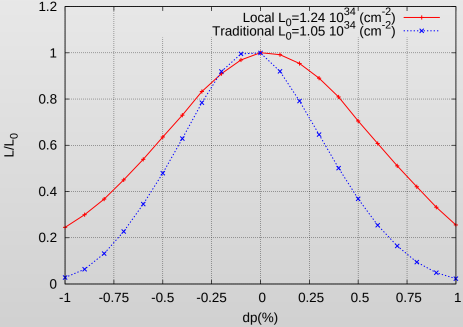
CLIC $\sqrt{s} = 500$ TeV Traditional vs Local

Parameter	Units	Traditional	Local
Beam energy	GeV	250	250
Last drift L^*	m	4.3	4.3
L_{FFS}	m	658.5	553
Beta function β_x/β_y	mm	9.25/0.057	9.32/0.059
Linear beam size σ_x^0/σ_y^0	nm	213.0/1.71	214.5/1.72
Nonlinear beam size σ_x^5/σ_y^5	nm	242.6/2.13	221.9/2.49
Total Luminosity L	10^{34}cm^{-2}	1.07	1.27
Peak Luminosity $L_{1\%}$	10^{34}cm^{-2}	0.65	0.77
Placet w/o synch σ_x/σ_y	nm	245.9/4.16	223.5/2.54
Placet w synch σ_x/σ_y	nm	246.9/3.43	223.5/2.49

Table: Parameters of the CLIC Final Focus $\sqrt{s} = 500$GeV at the IP

CLIC $\sqrt{s} = 500$ GeV Luminosity bandwidth





- Traditional scheme correction does not present length constraints.
- Vertical beam size correction in local scheme is constrained by the 3 TeV lattice.
- Local correction scheme presents, also in the low energy case, more luminosity and wider luminosity bandwidth.

Tuning the FFS

Static misalignments and unwanted beam position monitor offsets induce emittance dilution that can reduce the performance of a linear collider.

- CLIC Traditional and Local FFS
- $\sqrt{s} = 3$TeV, $\sqrt{s} = 500$GeV,
- Integrated simulations: BBA+Tuning Knobs
- PLACET for tracking and Guinea-Pig for Luminosity calculations
- Initial random misalignment: $\sigma = 10\mu$m RMS (x, y) for all elements
- BPM resolution: 10nm
- Corrector Block: BPM+Quadrupole+Corrector

Although extensive experience on Final Focus alignment has been gained at SLC and FFTB the tiny beamsize at the IP of CLIC require the development of new more sofisticated algorithms.

Alignment procedure. (A.Latina's 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-Shunting
- Multipole Knobs
- Multipoles ON:
  - DFS

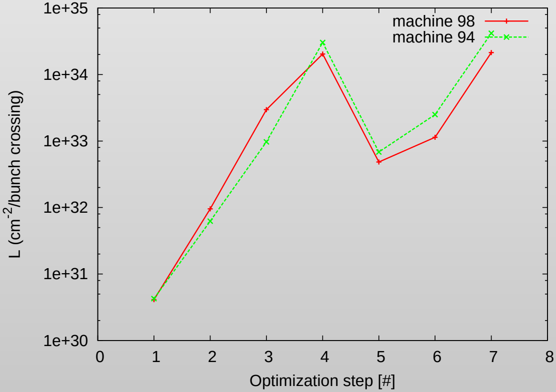
$$\begin{pmatrix} b \\ \omega_1(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} R \\ \omega_2 D \\ \beta I \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$$

  - Multipole Shunting
  - Multipole Knobs

Results 3TeV

We can compare the luminosity gain after each step:

1: 1:1
2: DFS
3: Multipole Shunting
4: Knobs
5: DFS
6: Multipole Shunting
7: Knobs



We see a luminosity reduction after second DFS but a total recovering after second align-multipoles and second Knobs.

Tuning results 3 TeV

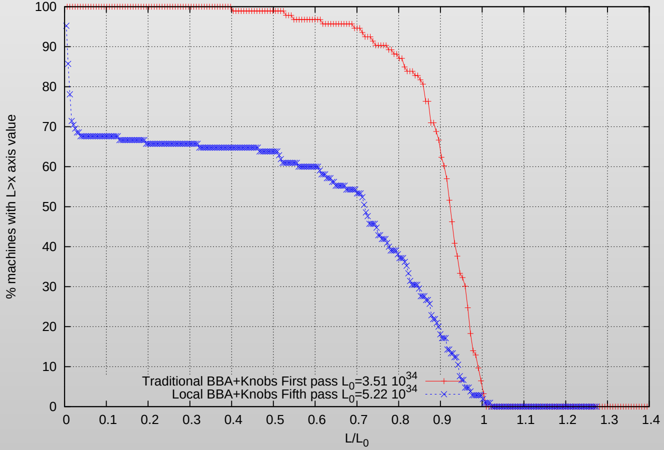


Figure: Tuning results for the Traditional and Local schemes after 110 seeds normalized to their nominal luminosity.

Tuning results 3 TeV

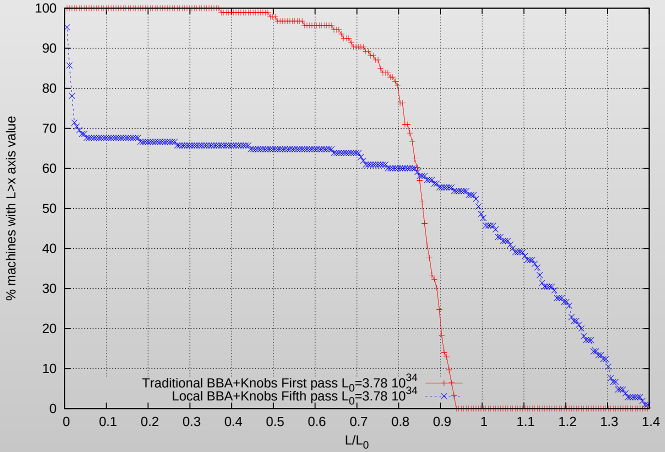
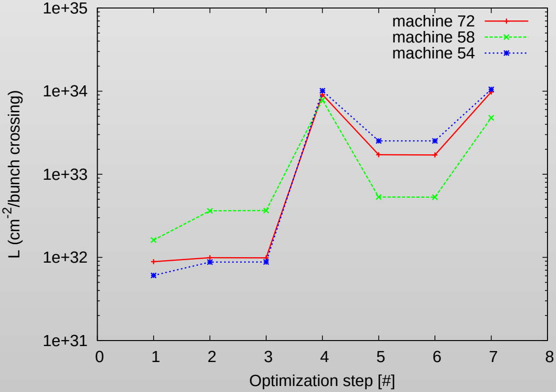


Figure: Tuning results for the Traditional and Local schemes after 110 seeds normalized to $\mathcal{L}_0 = 3.78 \cdot 10^{34}$

Results 500GeV

We can see again the evolution of the luminosity atfer each step:

1: 1:1
2: DFS
3: Multipole Shunting
4: Knobs
5: DFS
6: Multipole Shunting
7: Knobs



We see that non optimal second DFS reduces luminosity gain without net gain in the end. We stop the script after first knobs.

Tuning results 500GeV

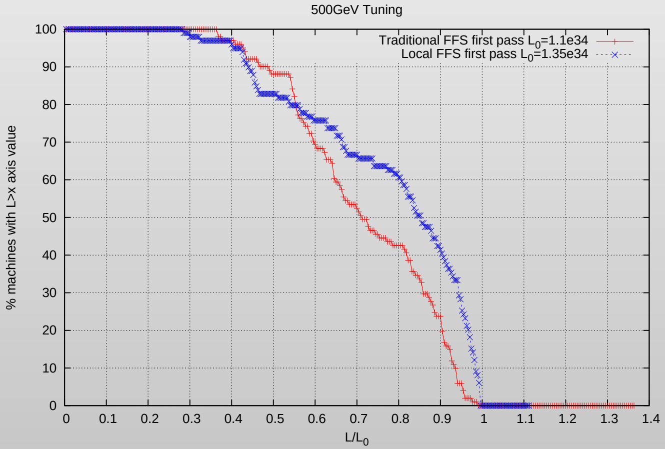


Figure: Tuning results for the Traditional and Local schemes after 110 seeds normalized to their nominal luminosity.

Tuning results 500GeV

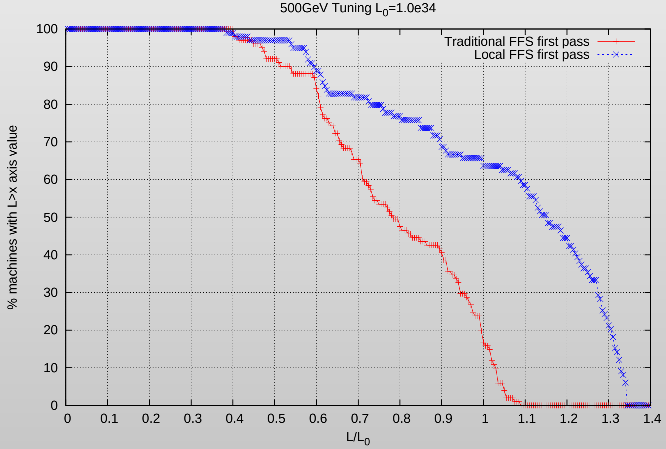


Figure: Tuning results for the Traditional and Local schemes after 110 seeds normalized to $\mathcal{L}_0 = 1.0 \cdot 10^{34}$

Global algorithm optmization

The tuning procedure is tedious given the huge amount of possibilities and combinations we can try. The time consumption is one of the major issues for the algorithm development.

Strategy

Instead of trying to find the optimum final result after doing global modifications in the algorithm, we want to optimize each step individually.

- Introduce and optimize weights everywhere we think they can speed up and make the algorithm more effective.
- Once step is fully optimized, move to the next one.
- After individual optimization, final global optimization.

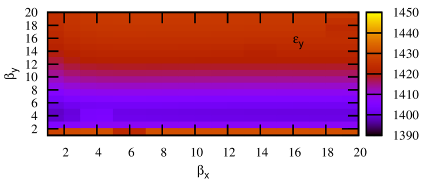
Example: 1 to 1 optimization

- Introduce one weight for each plane (β_x, β_y).

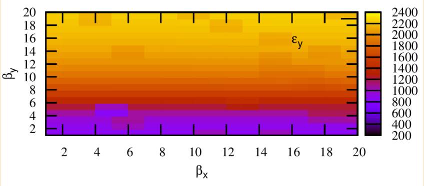
$$\begin{pmatrix} b_x \\ b_y \end{pmatrix} = \begin{pmatrix} R_{xx} & 0 \\ 0 & R_{yy} \\ \beta_x & 0 \\ 0 & \beta_y \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$$

- In this case both values tend to small values of the weight.
- Uncorrelated system. ϵ_y is β_x independent.

Local



Traditional



Conclusions

Results

- We have compared the traditional and local chromaticity correction schemes for both CLIC 3 TeV and CLIC 500 GeV.
- Local chromaticity correction looks better correcting nonlinear effects, luminosity and luminosity bandwidth.
- Tuning turns out to be really complex and sofisticated but convergence after the first pass in all cases seems to be good.

- For $\sqrt{s} = 3$ TeV and $\sqrt{s} = 500$ GeV and after only a first iteration, the alignment of the traditional FFS seems to work better but with lower absolute luminosity.

Further studies

- Introduce a new free parameter β_2 for second DFS and optimize it.
- Second, third and more passes to see the final convergence of the algorithm.
- Optimize main algorithm to find the best combination.