Traditonal Final Focus System for CLIC

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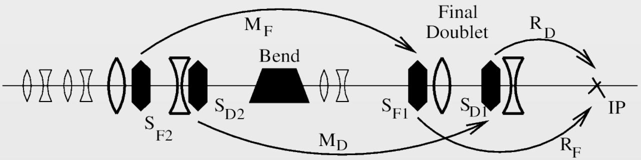
CLIC Final Focus

- 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 a section dedicated to the chromaticity correction,
- In the newer local chromaticity approach the sextupoles are placed within the Final Doublet, allowing a shorter system.

Local Chromaticity Correction Scheme[1]

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



However, recent studies reveal that the current CLIC FFS poses severe challenges when considering realistic imperfections.

[1] Phys.Rev.Lett.**86**, 17, 3779

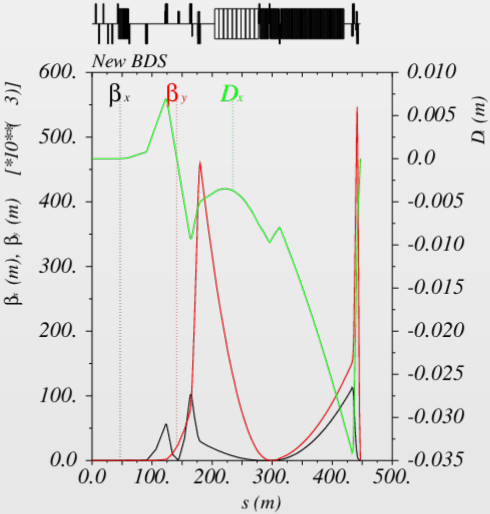
Current CLIC Final Focus System

$$L_{\mathrm{FFS}} = 450\mathrm{m}$$

$$L^* = 3.5\mathrm{m}$$

$$\beta_x^* = 6.9\mathrm{mm}$$

$$\beta_y^* = 68\mu\mathrm{m}$$



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.

Limitations *a priori* and previous studies

- The separate functionality of the lattice makes the system long.
- Relatively large β-functions and high dispersion functions which increase the length of the system and result in tighter tolerances.
- The non-local correction generates high-order aberrations which limit the momentum bandwidth.

but:

- This scheme has been demonstrated in the FFTB at SLAC:

Proposal

- F.Zimmermann proposed a 3km long FFS using the traditional scheme using FFADA.
- We think that such system is too long to be done.
- A proposal of 1.5km is studied in order to compare the performance with the current design.

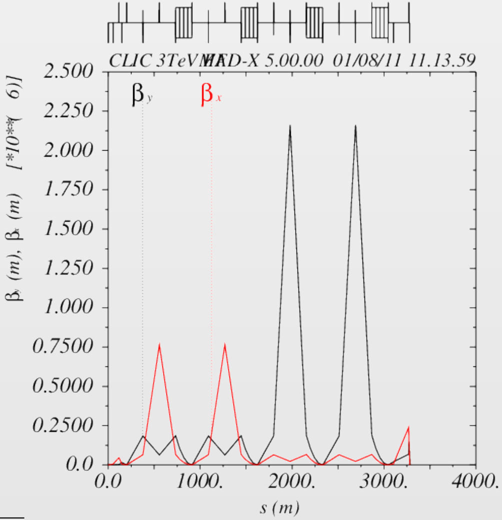
F.Zimmermann proposal scheme, $L_{\mathrm{FFS}} = 3.0\mathrm{km}$[2]

$$L_{\mathrm{FFS}} = 3282\mathrm{m}$$

$$L^* = 2.0\mathrm{m}$$

$$\beta_x^* = 8\mathrm{mm}$$

$$\beta_y^* = 15\mu\mathrm{m}$$



[2] Proceedings EPAC 2000, Viena, Austria

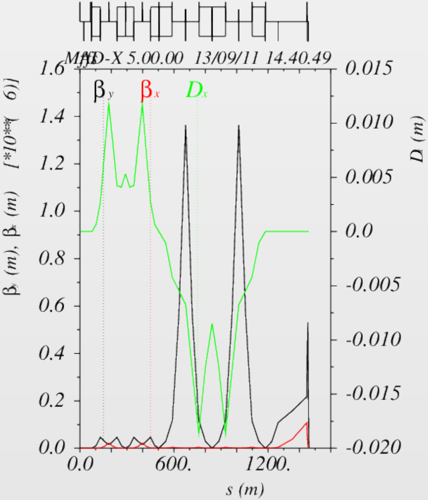
Short proposal scheme, $L_{\text{FFS}} = 1.5\text{km}$

$$L_{\text{FFS}} = 1460.61\text{m}$$

$$L^* = 3.5\text{m}$$

$$\beta_x^* = 6.9\text{mm}$$

$$\beta_y^* = 68\mu\text{m}$$



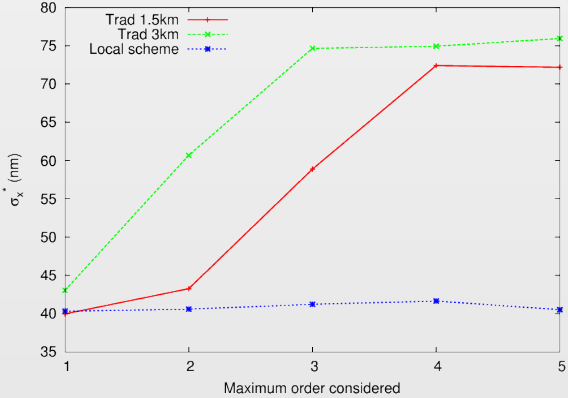
Nonlinear terms correction

MAPCLASS

- Allows us to obtain the beam size order by order.
- We can correct the aberrations minimizing the beam size at any order.

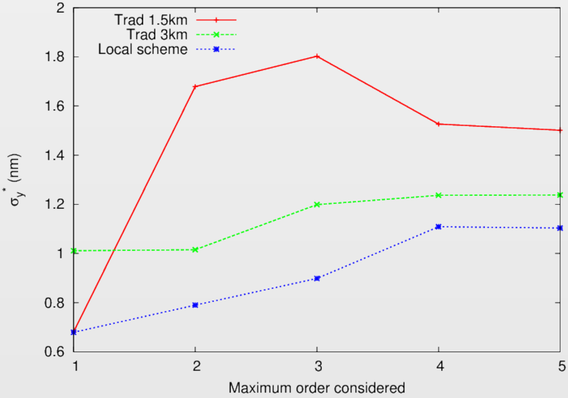
		Trad. 1.5km	Trad 3.0km	Local scheme
Mapclass (rms)	σ_x	45.96	43.06	40.37
$dp = 0.00$	σ_y	1.10	1.01	0.937
Mapclass (rms)	σ_x	69.78	75.94	40.52
$dp = 0.01$	σ_y	1.56	1.24	1.10

Horizontal beam size



- Local scheme does not present horizontal aberrations.
- Dispersion in Traditional scheme generates important aberrations.

Vertical beam size



- Local scheme is still the best one.
- In the traditional scheme more important aberrations.

Tolerances

- Tolerances are another critical point when you shorten the length of the FFS.

- Steering
- Dispersion
- Normal quadrupole
- Sextupole Alignment

Tolerance Budget

$$(\sigma_0^2 + (\Delta\sigma)^2)^{1/2} \leq 1.02\sigma_0$$

$$\Delta\sigma \leq \frac{1}{5}\sigma_0$$

Steering tolerances

- Permit beam centroid motion at the IP to be one standard deviation of the horizontal and vertical distributions.

$$\Delta x^* \approx \sigma_x^*$$

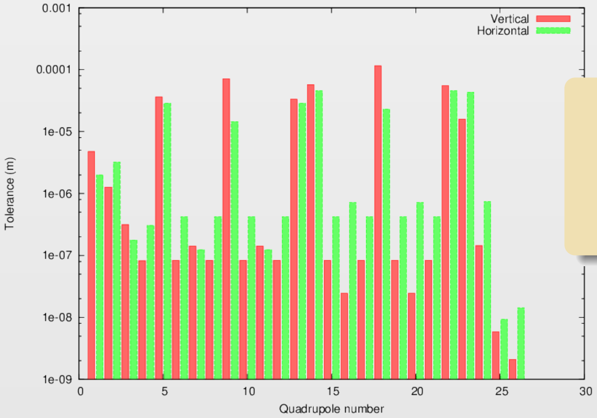
$$\Delta y^* \approx \sigma_y^*$$

Quadrupole Hamiltonian and Kick

$$H_q = \frac{1}{2} k_q((x + d_x)^2 - y^2) \Rightarrow H_{\rm st} = k_q d_x x$$

$$[H_{\rm st}, x'] = k_q d_x \Rightarrow d_x \leq \frac{1}{k_q} \sqrt{\frac{\epsilon_x}{\beta_{x_q}}}$$

$$[H_{\rm st}, y'] = k_q d_y \Rightarrow d_y \leq \frac{1}{k_q} \sqrt{\frac{\epsilon_y}{\beta_{y_q}}}$$



- The most restrictive tolerances are in the FD.
- Stability of about 1nm is required.

Dispersion

- Dispersion arises from an offset of the beam in quadrupoles and is a consequence of the chromaticity of the quadrupole.

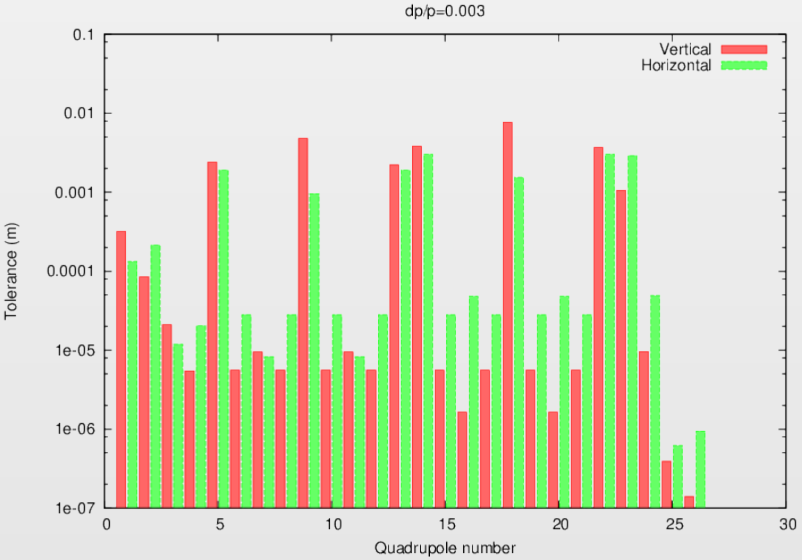
Quadrupole Hamiltonian including chromatic effects

$$H_q = \frac{1}{2}\frac{k_q}{1+\delta}(x^2+y^2) = \frac{1}{2}k_q(\ldots - x^2\delta + y^2\delta + \ldots)$$

In presence of a displacement:

$$H_q = \frac{1}{2}k_q(\ldots - x^2\delta - 2d_x x\delta + \ldots) \Rightarrow H_d = k_q d_x x\delta$$

$$d_x \leq \frac{1}{5k_q\delta_{\mathrm{rms}}}\sqrt{\frac{\epsilon_x}{\beta_x}}$$


dp/p=0.003
Vertical
Horizontal
Tolerance (m)
0.1
0.01
0.001
0.0001
1e-05
1e-06
1e-07
0
5
10
15
20
25
30
Quadrupole number

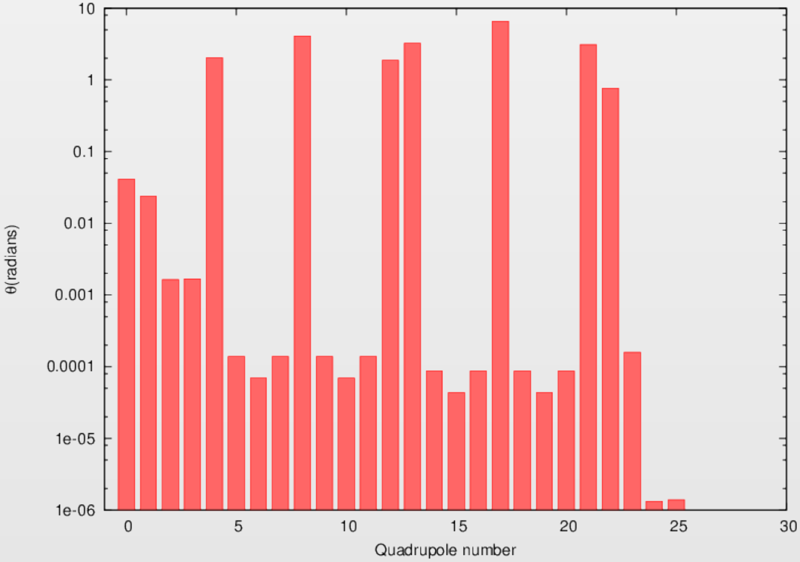
Skew tolerances

- The roll, rotation around the longitudinal axis of a quadrupole by an angle θ introduces a skew-quadrupole component of strength $k_{\mathrm{sq}} = k_q \sin 2\theta$ which couples the horizontal and vertical planes.

$$H_{\mathrm{sq}} = \frac{1}{2} k_q \sin 2\theta (2xy) \approx 2 k_q \theta x y$$

$$x < y \Rightarrow 2 k_q \theta \sigma_x \leq \frac{1}{5} \sigma y'$$

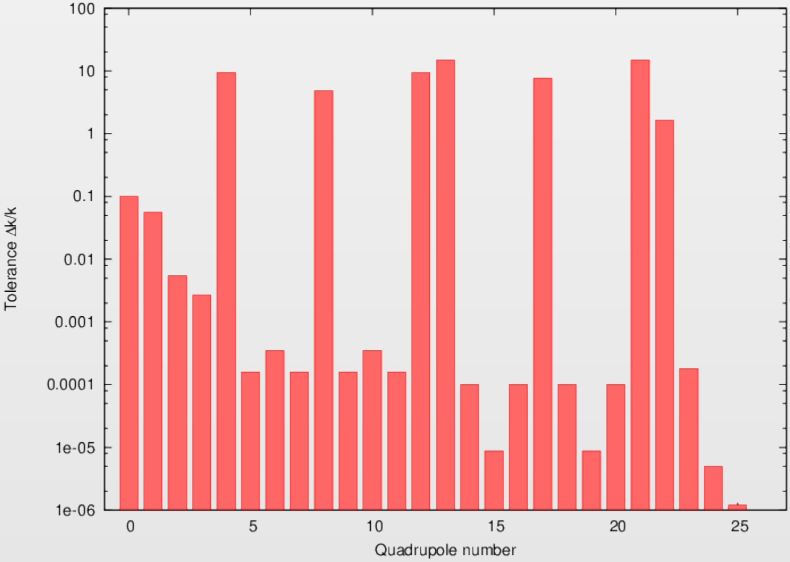
$$\theta \leq \frac{1}{10 k_q \sqrt{\beta_x \beta_y}} \sqrt{\frac{\epsilon_y}{\epsilon_x}}$$


10
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
θ(radians)
0
5
10
15
20
25
30
Quadrupole number

Strength tolerances

- A change in the quadrupole strength will result in a movement of the waist away form the focal point increasing the spot size at the IP.
- The Hamiltonian of the aberration: $H = \frac{1}{2}\Delta k(x^2 - y^2)$

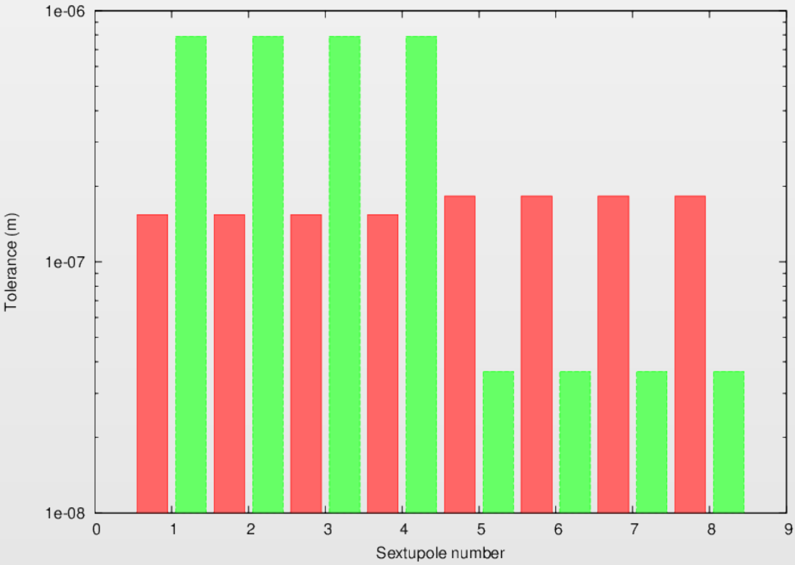
$$\frac{\Delta k}{k} \leq \frac{1}{5k\mathrm{Max}(\beta_X, \beta_y)}$$


100
10
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
Tolerance Δk/k
0
5
10
15
20
25
Quadrupole number

Sextupole alignment

- The same coupling effect arises when the beam is vertically offset in a sextupole.
- Skew-quadrupole aberration: $H_s = \frac{k_s d_y}{2} xy$

$$d_y \leq \frac{1}{5k_s\sqrt{\beta_x \beta_y}}\sqrt{\frac{\epsilon_y}{\epsilon_x}}$$


1e-06
1e-07
1e-08
Tolerance (m)
0
1
2
3
4
5
6
7
8
9
Sextupole number

Luminosity

- The ultimate goal of a collider and concretely of the FFS is to obtain the highest luminosity.

$$\mathcal{L} = \frac{N_e^2 N_b f_{\text{rep}}}{4\pi\sigma_y^*\sigma_x^*} H_D$$

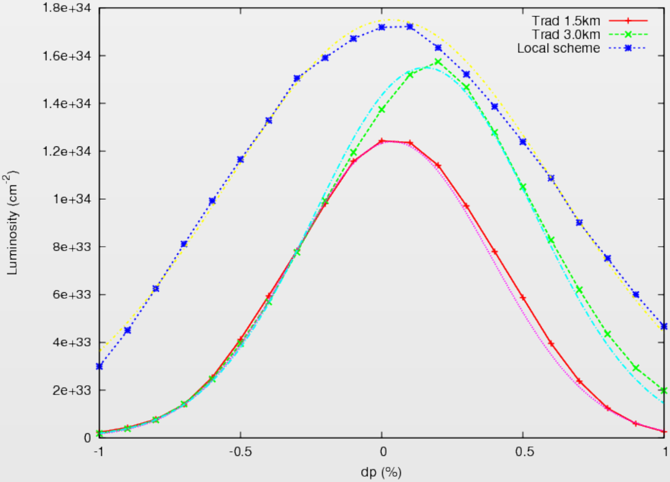
- Luminosity will determine the performance of the FFS and its feasibility.

Luminosity calculations have been done using Guinea-Pig after Placet tracking.

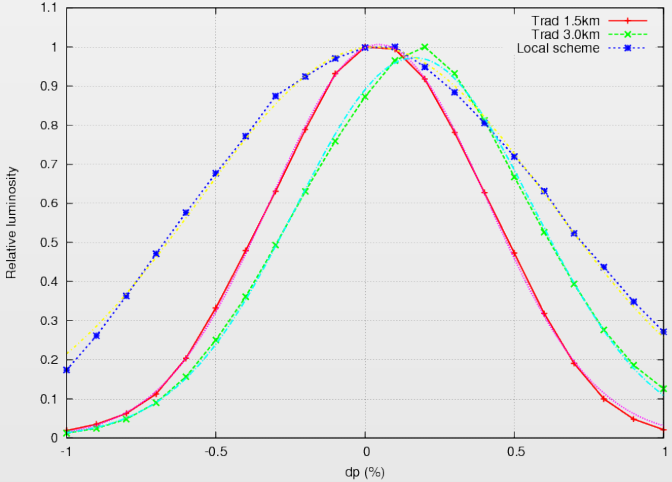
Table: Beam sizes in nm and Luminosity in units 10^{34}cm^{-2} per BC

		Trad. 1.5km	Trad 3.0km	Local schene
Placet (rms)	σ_x	69.80	76.05	40.39
No synchr.	σ_y	1.39	1.24	1.11
Placet (rms)	σ_x	71.62	78.85	48.46
Synchr.	σ_y	3.22	1.47	2.69
No synchr.	$\mathcal{L}_{1\%}^{\text{peak}}$	1.51	1.52	2.24
Synchr.	$\mathcal{L}_{1\%}^{\text{peak}}$	1.25	1.37	1.71

- The vertical beam size increase more than the double due to synchrotron radiation.
- As a consequence of the synchrotron radiation, there is a 17% luminosity loss .



- The peak luminosity in the 1.5km scheme is much lower than the local scheme.



- If we fit a gaussian, the 1σ-widths are $(\sigma_{1.5\mathrm{km}}, \sigma_{3\mathrm{km}}, \sigma_{\mathrm{local}}) = (0.366, 0.398, 0.588)$.

Conclusions

- Clear superiority of the local correction system.
- The length of the system limits the Final Focus performance.
- Synchrotron radiation is unavoidable and the longer the system the lower the synchrotron radiation effect.
- The main limitation comes from high order aberrations.
- Need a dedicated section in order to correct high order aberrations.

Further studies

- Study the tuning of the compact traditional FFS.
- If the performance of the tuning is not much better we should follow another way.
- Study alternatives and possible modifications.