Low energy CLIC Final Focus alternatives

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

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

February 27, 2013

Outline

Final Focus Basics

Idea of FFS

- The Final Focus System has the aim to focalize the beams to the nanometer scale and to correct the aberrations that appear due to strong nonlinear fields contained in the line.
- There are two main schemes: the traditional scheme, with two dedicated sections for chromatic correction in both planes and the local correction scheme, where the chromaticity is corrected very close to the point where it is generated.

Issues

- Chromatic correction at different orders. (Couplings, long sextupole effect, ...).
- Synchrotron radiation in bending magnets.
- Magnetic field and apertures.
- Beam induced backgrounds. Flat beams ensure low beamstrahlung photons level.

CLIC parameters

Parameter	**Units**	CLIC500	CLIC375
Beam energy E_0	GeV	250	187.5
Bunches per beam n_b		354	354
Electrons per bunch N	10^9	6.8	6.8
Repetition rate f_{rep}	Hz	50	50
Horizontal emittance ϵ_x^N	nm	2400	2400
Vertical emittance ϵ_y^N	nm	25	25
Horizontal beta β_x	mm	8	8
Vertical beta β_y	mm	0.13	0.13
Horizontal beam size σ_x^*	nm	200	229
Vertical beam size σ_y^*	nm	2.6	3.0
Bunch length σ_z	μm	72	72
Energy spread δ	%	1	1
Luminosity	$10^{34} \cdot \mathrm{s}^{-1}\mathrm{cm}^2$	2.3	1.6

Different scenarios

Two main schemes

- Dedicated correction scheme.
- Local correction scheme.

More alternatives

- Double CCY correction in dedicated scheme.
- Skew correction scheme for vertical plane.
- Correction mainly in the vertical plane.
- Oide odd dispersion scheme.

Local correction scheme 500 GeV

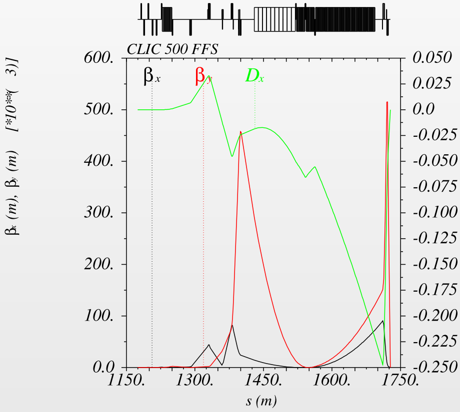
This is the scheme mostly considered in all the general simulations at 500 GeV.

Mapclass

$$\beta_x^* = 9.3\text{mm}$$
$$\beta_y^* = 0.06\text{mm}$$
$$\sigma_x^* = 222\text{nm}$$
$$\sigma_y^* = 2.49\text{nm}$$

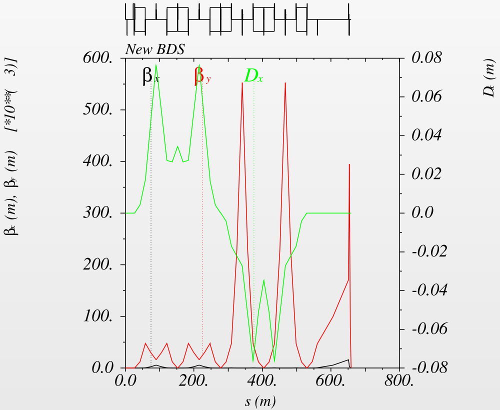
Placet+GuineaPig

$$\sigma_x^* = 224\text{nm}$$
$$\sigma_y^* = 2.48\text{nm}$$
$$\mathcal{L}_T = 1.14\mu\text{b}^{-1}/\text{BX}$$
$$\mathcal{L}_{1\%} = 0.65\mu\text{b}^{-1}/\text{BX}$$



Traditional scheme 500 GeV

Based on the parameters for the local scheme. Already presented in many talks.



Mapclass

$$\beta_x^* = 9.0\text{mm}$$

$$\beta_y^* = 0.057\text{mm}$$

$$\sigma_x^* = 231\text{nm}$$

$$\sigma_y^* = 2.07\text{nm}$$

Placet+GuineaPig

$$\sigma_x^* = 247\text{nm}$$

$$\sigma_y^* = 3.42\text{nm}$$

$$\mathcal{L}_T = 1.01\mu\text{b}^{-1}/\text{BX}$$

$$\mathcal{L}_{1\%} = 0.58\mu\text{b}^{-1}/\text{BX}$$

Local correction scheme 375 GeV

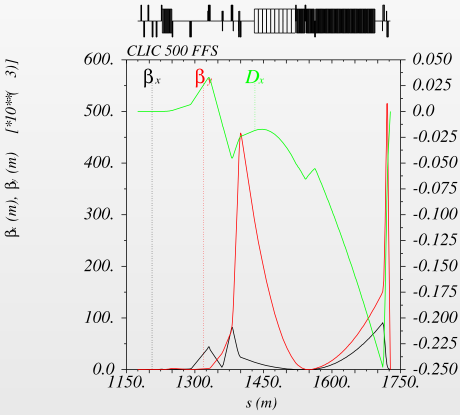
Based on the same lattice (Local scheme) for the 500 GeV case.

Mapclass

$$\beta_x^* = 9.3\text{mm}$$
$$\beta_y^* = 0.06\text{mm}$$
$$\sigma_x^* = 257\text{nm}$$
$$\sigma_y^* = 3.44\text{nm}$$

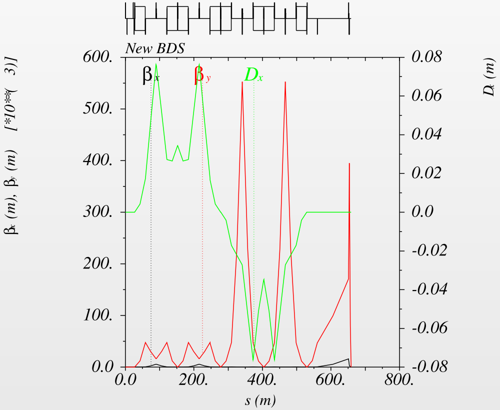
Placet+GuineaPig

$$\sigma_x^* = 256\text{nm}$$
$$\sigma_y^* = 3.34\text{nm}$$
$$\mathcal{L}_T = 0.83\mu\text{b}^{-1}/\text{BX}$$
$$\mathcal{L}_{1\%} = 0.34\mu\text{b}^{-1}/\text{BX}$$



Traditional scheme 375 GeV

Based on the same lattice (Traditional scheme) for the 500 GeV case.



Mapclass

$$\beta_x^* = 9.0\text{mm}$$

$$\beta_y^* = 0.057\text{mm}$$

$$\sigma_x^* = 276\text{nm}$$

$$\sigma_y^* = 2.50\text{nm}$$

Placet+GuineaPig

$$\sigma_x^* = 293\text{nm}$$

$$\sigma_y^* = 3.33\text{nm}$$

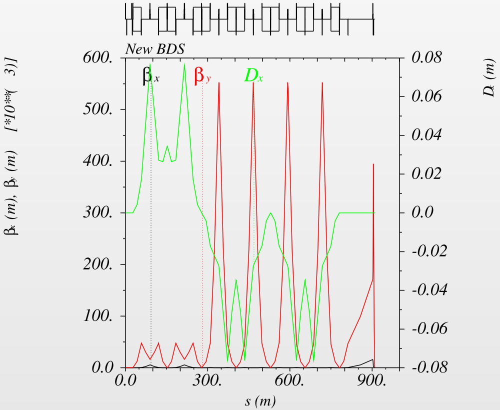
$$\mathcal{L}_T = 0.82\mu\text{b}^{-1}/\text{BX}$$

$$\mathcal{L}_{1\%} = 0.34\mu\text{b}^{-1}/\text{BX}$$

New approaches

Traditional scheme with double CCY (500 GeV)

Two vertical chromatic correction allows weaker sextupoles to reduce the geometric aberration introduced by themselves in the form of an octupolar field.
Problems: Length increase, double synchrotron radiation emission, one $-\mathcal{I}$ more to be unbroken...



Mapclass

$$\beta_x^* = 9.0\text{mm}$$

$$\beta_y^* = 0.057\text{mm}$$

$$\sigma_x^* = 227\text{nm}$$

$$\sigma_y^* = 2.60\text{nm}$$

Placet+GuineaPig

$$\sigma_x^* = 230\text{nm}$$

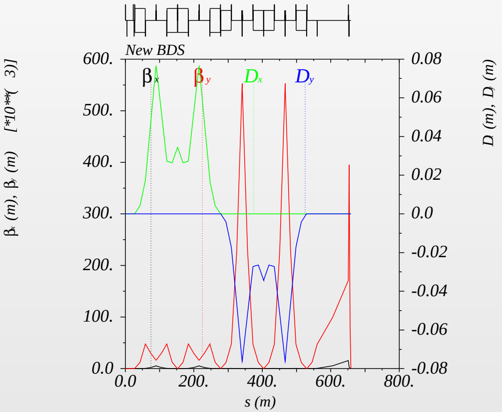
$$\sigma_y^* = 3.76\text{nm}$$

$$\mathcal{L}_T = 0.93\mu\text{b}^{-1}/\text{BX}$$

$$\mathcal{L}_{1\%} = 0.53\mu\text{b}^{-1}/\text{BX}$$

Skew correction scheme

The idea is to introduce vertical dispersion and tilt the sextupoles placed in the vertical correction section. In that way we can decouple the correction in both planes.
Problem = Synchrotron radiation.



For low energies, it works quite well (LEP3 240 GeV case) but for 500 GeV did not find a acceptable solution. Maybe more time for optimization is needed.

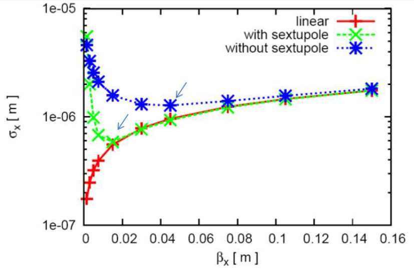
Mainly vertical correction

ILC500 study (P.Bambade Y.Wang scheme)[1]

Y.Wang and P.Bambade proposed to skip horizontal chromatic correction as a way to reduce the number of sextupoles (2 or 3 instead of 5). This would work for small energy spread and large β_x^*.

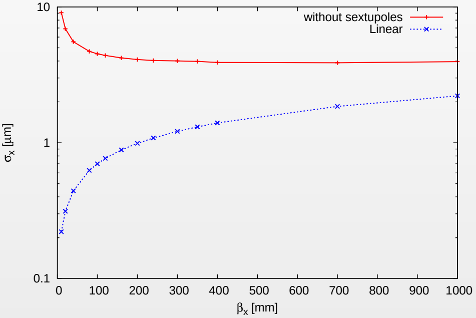
ILC500

- Enlarged β_x^*: 15 $\rightarrow$ 45 mm.
- $\beta_y = 0.08$ mm (0.4 mm nominal).
- $\sigma_x^* = 3\sigma_x^*$ (nominal).
- $\sigma_y^* = 0.4\sigma_y^*$ (nominal).
- Only two sextupoles (SD0 and SD4).



[1] Y.Wang, P.Bambade: CLIC workshop 2013

Mainly vertical correction (P.Bambade Y.Wang scheme)



CLIC500

The minimum horizontal spot size without chromatic correction is $\sigma_x^* > 2000$ nm. This represents a factor ~ 10 with respect to the nominal beam size. Therefore a reduction of about a factor 10 is required in the vertical beam size.

$$\sigma_x^* \sigma_y^* = \sigma_x^*(\text{nominal})\sigma_y^*(\text{nominal})$$

$$\sigma_y^*(\text{nominal}) \approx 2\text{nm} \Rightarrow$$

$$\sigma_y^* \approx 0.2\text{nm}$$ Far below limit!

Odd dispersion scheme

K.Oide idea[1]

By making dispersions of paired sextupoles unequal it becomes possible to reduce chromo-geometric aberrations and increase the momentum bandwidth.

$$\Delta y^* = (-k'y\eta_1\chi)(c_1 l\chi)k'x\sqrt{\beta_y\beta_y^*}+$$
$$+(k'xy)(c_1 l\xi)(k'\eta_2\chi\sqrt{\beta_y\beta_y^*}) - \xi_{y2}\chi\sqrt{\beta_y^*/\beta_y}+$$
$$+(-\xi_{x1}x\chi/\beta_x)(c_2 l\chi)(k'y\sqrt{\beta_y\beta_y^*})$$

- Even dispersion: $\eta_1 = \eta_2$
- Standard odd dispersion: $\eta_1 = 0, \eta_2 = \frac{\xi_y}{\beta_y K_s}$
- Strong odd dispersion: $\eta_1 < 0$ and $\eta_2 > \frac{\xi_y}{\beta_y K_s}$

First glance

Varying η for vertical correction is always difficult because σ_x^* is very sensitive to that. Optimization seems delicate.

[1] K. Oide, Final Focus System with odd-dispersion scheme, KEK-92-58

Lowering β_x^* (375 GeV)

Reducing β_x^* we can gain some total luminosity, but peak luminosity is reduced due to beamstrahlung. It could work for low energies i.e. $\sqrt{s} \sim 375$ GeV.

Beamstrahlung

$$\langle \Upsilon \rangle = \frac{5}{6} \frac{N r_e^2 \gamma}{\alpha \sigma_z (\sigma_x^* + \sigma_y^*)}$$

$$\frac{\Upsilon^2}{\Upsilon_0^2} = \frac{\gamma^3 \beta_x^0}{\gamma_0^3 \beta_x} \leq 1$$

$$\beta_x \geq 0.42 \beta_x^0 \approx 4.2\text{mm}$$

Luminosity

$$\mathcal{L} \sim \frac{1}{\sigma_x^* \sigma_y^*} \sim \frac{\gamma}{\sqrt{\beta_x^* \beta_y^*}}$$

$$E/E_0 = 375/500 = 0.75$$

Keep constant luminosity (at least):

$$\frac{\mathcal{L}^2}{\mathcal{L}_0^2} = \frac{\gamma_0^2 \beta_x^0 \beta_y^0}{\gamma^2 \beta_x \beta_y} \geq 1$$

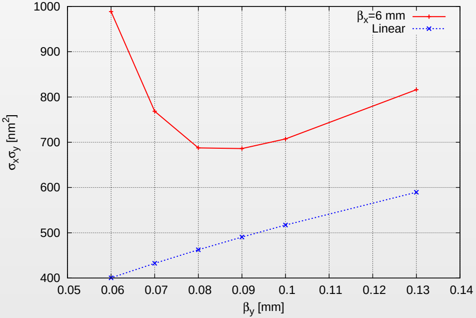
$$\frac{\beta_x^0 \beta_y^0}{\beta_x \beta_y} \gtrsim 1.77, \quad \beta_x : 10\text{mm} \rightarrow 6\text{mm}$$

$\beta_y^0 \approx \beta_y$ to obtain the same luminosity.

But reduce β_y^* is for free in terms of backgrounds!

Low β_x^* (375 GeV)

According to the previous argument and taking the optimal β_y^* we can construct a new system based on the traditional correction scheme.



Mapclass

$$\beta_x^* = 6.0\text{mm}$$

$$\beta_y^* = 0.09\text{mm}$$

$$\sigma_x^* = 208\text{nm}$$

$$\sigma_y^* = 3.30\text{nm}$$

Placet+GuineaPig

$$\sigma_x^*(\text{rms}) = 208\text{nm}$$

$$\sigma_y^*(\text{rms}) = 3.44\text{nm}$$

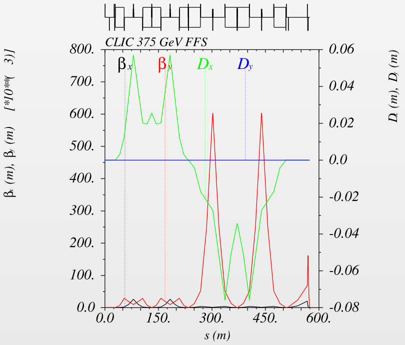
$$\sigma_y^*(\text{core}) = 3.44\text{nm}$$

$$\mathcal{L}_T = 1.13\mu\text{b}^{-1}/\text{BX}$$

$$\mathcal{L}_{1\%} = 0.62\mu\text{b}^{-1}/\text{BX}$$

Low β_x^* (375 GeV)

According to the previous argument and taking the optimal β_y^* we can construct a new system based on the traditional correction scheme.



Mapclass

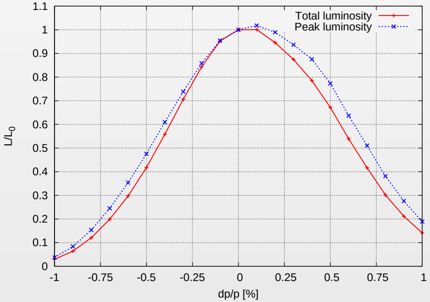
$$\beta_x^* = 6.0\text{mm}$$
$$\beta_y^* = 0.09\text{mm}$$
$$\sigma_x^* = 208\text{nm}$$
$$\sigma_y^* = 3.30\text{nm}$$

Placet+GuineaPig

$$\sigma_x^*(\text{rms}) = 208\text{nm}$$
$$\sigma_y^*(\text{rms}) = 3.44\text{nm}$$
$$\sigma_y^*(\text{core}) = 3.44\text{nm}$$
$$\mathcal{L}_T = 1.13\mu\text{b}^{-1}/\text{BX}$$
$$\mathcal{L}_{1\%} = 0.62\mu\text{b}^{-1}/\text{BX}$$

Low β_x^* (375 GeV)

According to the previous argument and taking the optimal β_y^* we can construct a new system based on the traditional correction scheme.



Mapclass

$$\beta_x^* = 6.0\text{mm}$$

$$\beta_y^* = 0.09\text{mm}$$

$$\sigma_x^* = 208\text{nm}$$

$$\sigma_y^* = 3.30\text{nm}$$

Placet+GuineaPig

$$\sigma_x^*(\text{rms}) = 208\text{nm}$$

$$\sigma_y^*(\text{rms}) = 3.44\text{nm}$$

$$\sigma_y^*(\text{core}) = 3.44\text{nm}$$

$$\mathcal{L}_T = 1.13\mu\text{b}^{-1}/\text{BX}$$

$$\mathcal{L}_{1\%} = 0.62\mu\text{b}^{-1}/\text{BX}$$

Summary table

Scheme	$\sqrt{s}$ [GeV]	σ_x^* [nm]	σ_y^* [nm]	$\mathcal{L}_T[\mu b^{-1}]$	$\mathcal{L}_{1\%}[\mu b^{-1}]$	$\Upsilon_{\max}$	n_γ	$\frac{\delta E}{E}$
Nominal	500	200	2.6	1.5	0.93	-	-	-
Local500	500	224	2.48	1.14	0.65	0.6	1.23	0.059
Trad500	500	247	3.42	1.01	0.58	0.52	1.20	0.056
Local375*	375	256	3.34	0.83	0.34	1.11	0.36	0.041
Trad375*	375	293	3.33	0.82	0.34	1.06	0.36	0.038
2×CCY	500	230	3.76	0.93	0.53	0.54	1.22	0.058
Skew	500	-	-	-	-	-	-	-
Vertical	500	-	-	-	-	-	-	-
Odd disp.	500	-	-	-	-	-	-	-
Low β_x^*	375	210	3.44	1.13	0.62	0.48	1.37	0.056

CLIC Final Focus Scenarios discussion

Good options

- Old schemes for 500 GeV.
- Low β_x^* for 375 GeV.

Discarded options

- Mainly vertical correction.
- Double CCY?
- Skew scheme?

In consideration

- Odd dispersion scheme.

Or maybe none of these, maybe a novel one or a mixture of all of them.

Backup slides

Beam induced background

For physics reconstruction, It is very important to know the distribution of the beam induced backgrounds to remove that signal from the detector or use it to measure the luminosity of the collisions.

Local 500 GeV

$$\Upsilon_{\max} = 0.60$$

$$n_\gamma = 1.23 \text{ per particle}$$

$$\frac{\delta E}{E}_{BS} = 5.9\%$$

$$n_{\text{pairs}} = 69000$$

Low β_x^* 375 GeV

$$\Upsilon_{\max} = 0.48$$

$$n_\gamma = 1.37 \text{ per particle}$$

$$\frac{\delta E}{E}_{BS} = 5.6\%$$

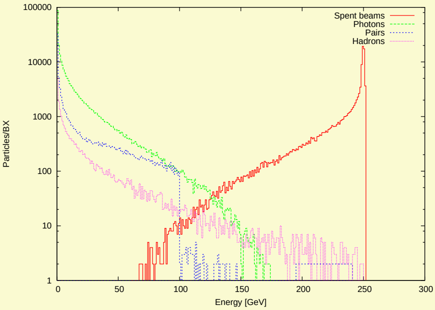
$$n_{\text{pairs}} = 67000$$

We can see no significant difference between both energies since we have adapted the system to be like that.

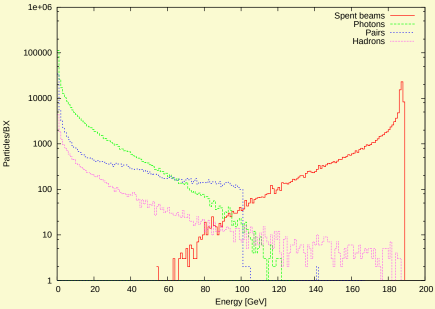
Beam induced background

For phyics reconstruction, It is very important to know the distribution of the beam induced backgrounds to remove that signal from the detector or use it to measure the luminosity of the collisions.

Local 500 GeV



Low β_x^* 375 GeV

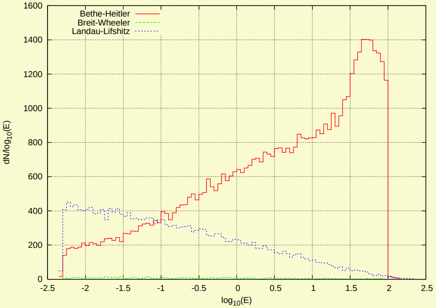


We can see no significant difference between both energies since we have adapted the system to be like that.

e^+e^- pair creation

For instance, the different processes that yield to creation of pairs follow the same distributions for both schemes.

Local 500 GeV



Low β_x^* 375 GeV