New CLIC FFS design at 380 GeV

CLIC Workshop 2019, CERN

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January 21, 2018

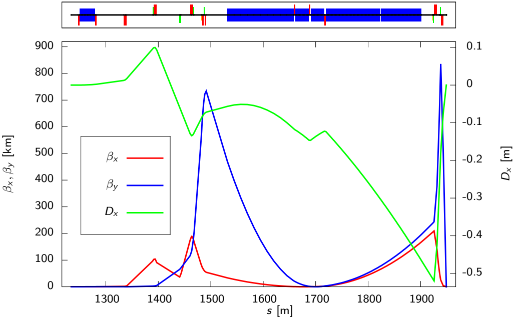
Outline

1. CLIC 380 GeV, reduced β_y^*
   - Beam size matching
   - Luminosity
   - Energy bandwidth
2. Final Doublet optimization
   - FD length reduction
   - Twiss matching
   - Chromaticity optimization
3. Summary and Conclusions

Current FFS design

In the current design of CLIC 380 GeV:

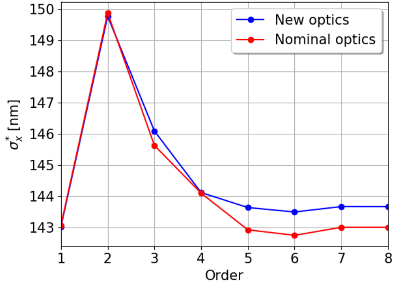
- $L^* = 6$ m is chosen to easy MDI and avoid the need to shield **QD0** (F.Plassard et al, *"CLIC 3 TeV and 380 GeV BDS design with $L^* = 6$ m"*, CLIC workshop 2018).
- IP vertical beta function was reduced from 100 μm to 70 μm.

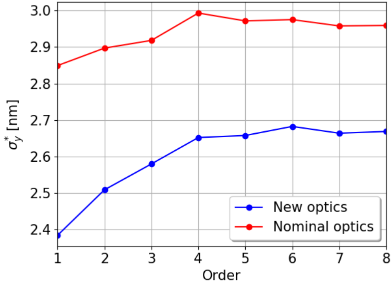


FFS length [m]	770
$\epsilon_{n,x}/\epsilon_{n,y}$ [nm]	950/30
β_x^*/β_y^* [mm]/[μm]	8/70
σ_x^*/σ_y^* [nm]	145/2.9
σ_z [μm]	70
δ_p [%]	0.35
$\mathcal{L}$ [10^{34}cm^{-2}s^{-1}]	1.5
$\mathcal{L}_{1\%}$ [10^{34}cm^{-2}s^{-1}]	0.9

Nonlinear matching

- The beam size at the IP was matched to the linear value as much as possible using MadX-PTC and MAPCLASS.
- The obtained optics is then tested with PLACET.

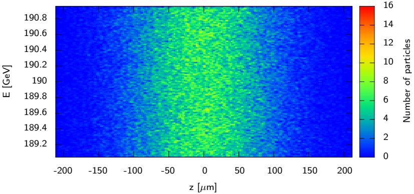




	σ_x^* [nm]	σ_y^* [nm]	Oide effect [nm]
MAPCLASS	143.66	2.67	0.21
Placet without SR	143.27	2.74	
Placet with SR	**145.76**	**2.75**	

Luminosity calculation

- The beam is tracked through the BDS with PLACET up to the IP.
- Beam distribution at the IP is used as an input for Guinea-Pig.



- Transverse Gaussian beam.
- 1% energy flat distribution in longitudinal plane.

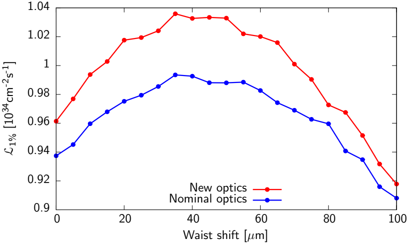
	$\mathcal{L}_{total}$ [10^{34}cm^{-2}s^{-1}]	$\mathcal{L}_{1\%}$ [10^{34}cm^{-2}s^{-1}]
Nominal optics	1.63	0.94
Reduced β_y^*	1.66	0.96

Beam-beam forces greatly affect the final luminosity - the highest luminosity is obtained **off waist**.

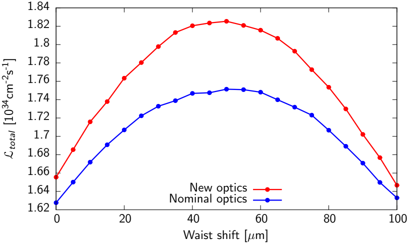
Luminosity - Waist location scan

- Due to the **pinch effect** the beams are focused upstream of the IP.
- The waist location is scanned for larger luminosity

Peak luminosity



Total luminosity

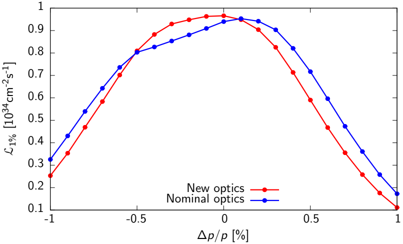


	$\mathcal{L}_{total}$ [10^{34}cm^{-2}s^{-1}]	$\mathcal{L}_{1\%}$ [10^{34}cm^{-2}s^{-1}]
Nominal optics at optimal waist	1.75	0.99
Reduced β_y^* at optimal waist	**1.83** (+4.5%)	**1.03** (+4%)

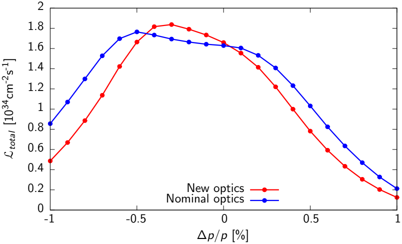
Energy bandwidth

- Energy bandwidth describes how the luminosity changes when the beam has an energy offset.
- The beam energy offset was iterated in the range $\frac{\Delta p}{p} \in [-1\%, 1\%]$.
- Obtained bandwidth is smaller for the new optics - **should be improved, to reach the previous level at least**.

Peak luminosity



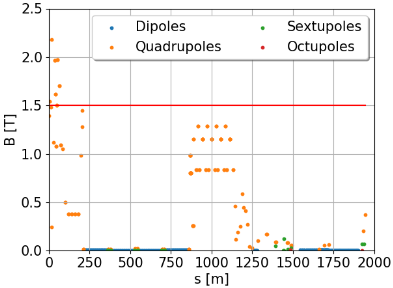
Total luminosity



Pole tip field

Following the apertures calculated for the current design, the results of the pole tip field calculations showed that **QF1** and **QD0** are relatively weak.

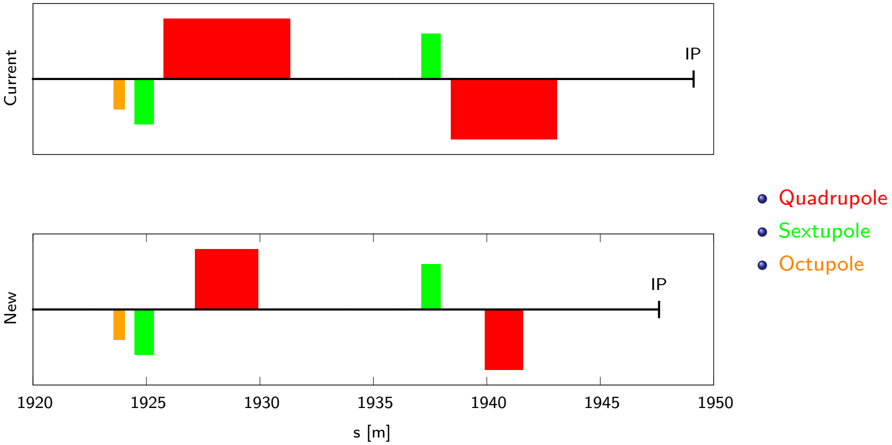
Pole tip field along the BDS



Length of **QF1** and **QD0** can be optimized:

1. Shortening the magnets and increasing magnetic strength
2. Shifting the IP to retrieve $L^* = 6$ m.
3. Twiss matching
4. Adjusting the horizontal chromaticity to retrieve local correction scheme conditions

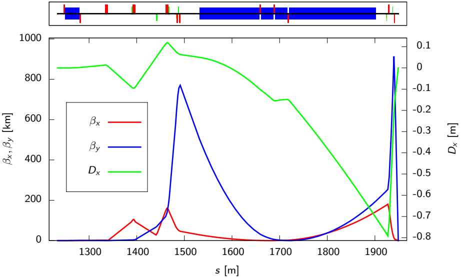
FD optimization



Each magnet is shortened by 3 m. IP is moved towards the FFS to have $L^* = 6$ m. **QF1** may be shifted to balance the chromaticities. Sextupoles are to be moved later (the closer to the quads the better).

Twiss matching

The MadX matching could not converge for the final IP position, so it was done in steps. Each step it was moved by 10 cm, reaching $L^* = 6$ m at the end.



10 cm shift

Twiss matching

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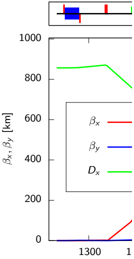

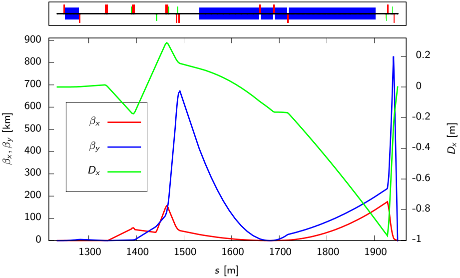

10 cm shift 50 cm shift

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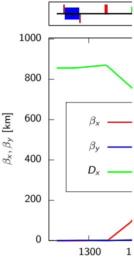
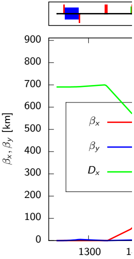
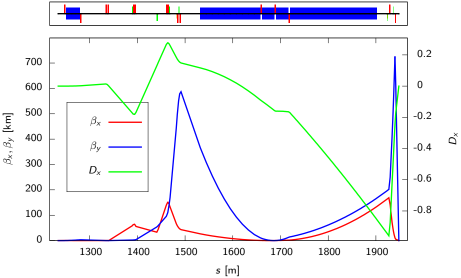


10 cm shift



50 cm shift



100 cm shift

Twiss matching

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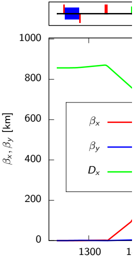
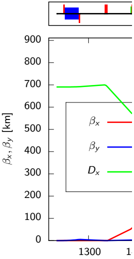
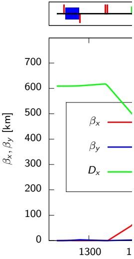


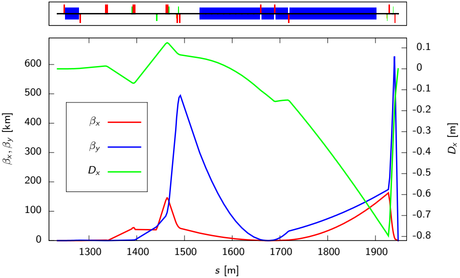
10 cm shift



50 cm shift



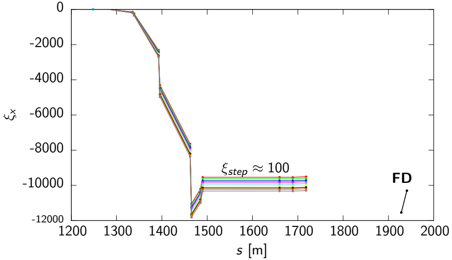
100 cm shift



Final location

Chromaticity optimization

The approach that I used was to fix **QF1** position and try to change the upstream chromaticity by matching it to the desired value with MadX.



- Natural chromaticity of a magnet is calculated as:

$$\xi_x = k1L * \beta_x$$

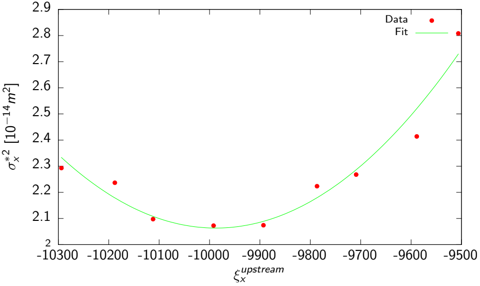
- The expected dependence of the beam size is:

$$\sigma_y^* \sqrt{1 + \xi_y^2 \delta^2}$$

- **QF1** position was fixed.
- The Twiss parameters and upstream chromaticity were matched at the same time

Chromaticity optimization

- The 2nd order beam size was matched to the linear value.
- The smallest beam size calculated was **143.9 nm** (target value is 143 nm).
- From the fit, minimum is of around **143.6 nm**.



Next step would be to shift QF1 closer to the IP to reduce the chromaticity and apply the same method.

Summary and Conclusion

Summary

1. Vertical IP beta function was reduced to 70 μm. The optics was matched to mitigate the nonlinear contributions to the beam size.
2. New optics design was examined for luminosity and energy bandwidth. Luminosity is $\sim 4\%$ larger in the new design.
3. **QF1** and **QD0** were shortened by 3 m. The twiss parameters and 2^{nd} order beam size were matched.

Conclusions

- Another position of **QF1**, which gives smaller chromaticity, should be examined and matched.
- New optics should optimized in terms of energy bandwidth.

Thank you very much for your attention!

Back up slides

Pole tip field in the magnets

Pole tip field for the magnets in the BDS is:

$$B_{dipole} = \frac{1}{\rho}(B\rho) = \frac{1}{\rho}\frac{p}{e},$$

$$B_{quadrupole} = 3.333p[GeV/c]k_1 pA,$$

$$B_{sextupole} = 3.333p[GeV/c]k_2\frac{A^2}{2},$$

$$B_{octupole} = 3.333p[GeV/c]k_3\frac{A^3}{6},$$

where k_1, k_2 and k_3 are the quadrupole, sextupole and octupole strengths respectively.

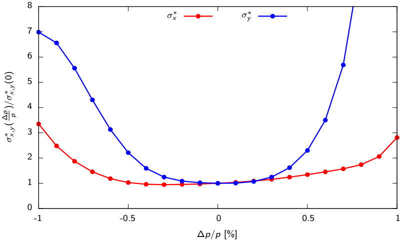
Energy bandwidth

- Geometrical luminosity depends on the beam size:

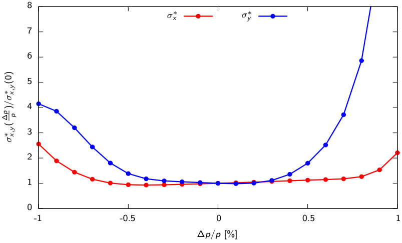
$$\mathcal{L}_0 = \frac{N^2 f N_b}{4\pi\sigma_x^*\sigma_y^*}.$$

- IP beam size dependence on the momentum offset is analyzed.

New optics



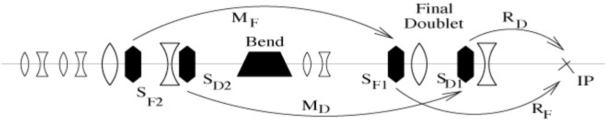
Nominal optics



Chromaticity optimization

Natural chromaticity generated by the FD is:

$$\xi_y \equiv \frac{L_y^C}{\beta_y^*} \approx -\int k_1 \beta_y ds$$



Beam size dilution due to the chromaticity is:

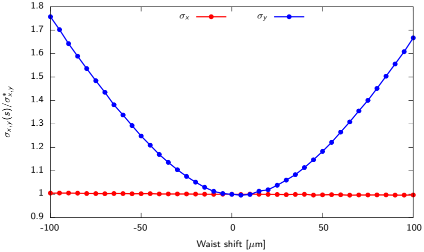
$$\sigma_y^* \sqrt{1 + \xi_y^2 \delta^2}.$$

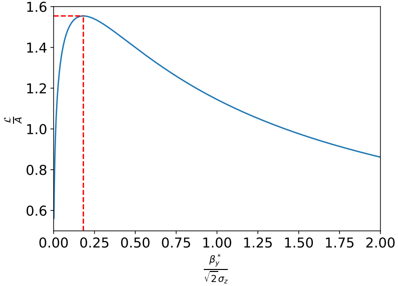
To retrieve the linear beam size, one has to generate the same natural chromaticity upstream of the FD to cancel chromaticity and 2nd order chromatic term.

Hourglass effect

The **Hourglass effect** - the bunch particles interact with each other with different transverse beam size which changes significantly within the bunch.

Hourglass effect for the optics with $\beta_y^* = \sigma_z = 70\ \mu$m.



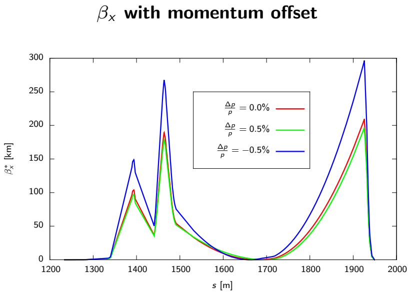


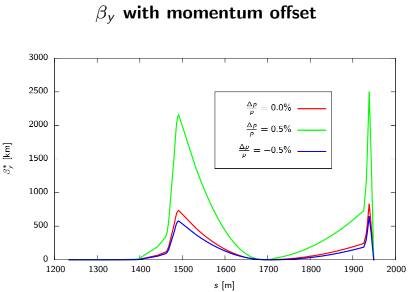
Luminosity reduction due to the Hourglass effect:

$$\mathcal{L} = \mathcal{L}_0 H_D = \mathcal{L}_0 \sqrt{\frac{2}{\pi}} a e^{a^2} K_0(a^2),$$

$a = \frac{\beta_y^*}{\sqrt{2}\sigma_z}$; K_0 is modified Bessel function.

Beta function dependence on momentum offset





Chromaticity optimization

QF1 shifting

Shift [cm]	σ_x^* [nm]	σ_y^* [nm]
-10.0	712.3	25.2
-5.0	455.5	2.76
0.0	436.9	2.72
+5.0	416.5	2.88
+10.0	362.9	2.61
+15.0	629.8	3.29
+17.5	359.3	2.62
+20.0	267.5	2.69
+20.5	219.9	2.54
+21.25	229.5	2.79
+22.5	259.7	2.59
+30.0	491.8	3.39
+40.0	693.3	3.29
+50.0	242.7	3.40
+60.0	213.5	2.64
+70.0	207.7	2.72
+80.0	196.5	2.46
+90.0	433.3	2.52

Chromaticity scan

$\xi_x^{upstream}$	ξ_x^{FD}	σ_x^* [nm]	σ_y^* [nm]
-9506.2	-10296.5	167.6	2.46
-9588.7	-10297.0	155.4	2.48
-9709.0	-10298.4	150.6	2.43
-9786.7	-10299.0	149.1	2.44
-9893.0	-10299.9	144.0	2.41
-9992.0	-10300.9	143.9	2.43
-10112.1	-10302.4	144.8	2.42
-10187.9	-10303.2	149.6	2.48
-10293.9	-10304.1	151.4	2.48