Using longitudinally varying fields for lower emittance

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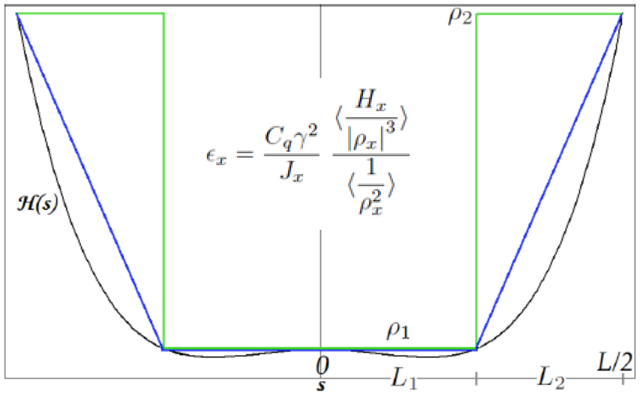
Longitudinally variable bends[1]



$$\rho_{st}(s) = \begin{cases} \rho_1, & 0 < s < L_1 \\ \rho_2, & L_1 < s < L_1 + L_2 \end{cases}$$

$$\rho_{tr}(s) = \begin{cases} \rho_1, & 0 < s < L_1 \\ \rho_1 + \frac{(L_1 - s)(\rho_1 - \rho_2)}{L_2}, & L_1 < s < L_1 + L_2 \end{cases}$$

Bending radii ratio

$$\rho = \frac{\rho_1}{\rho_2}$$

Lengths ratio

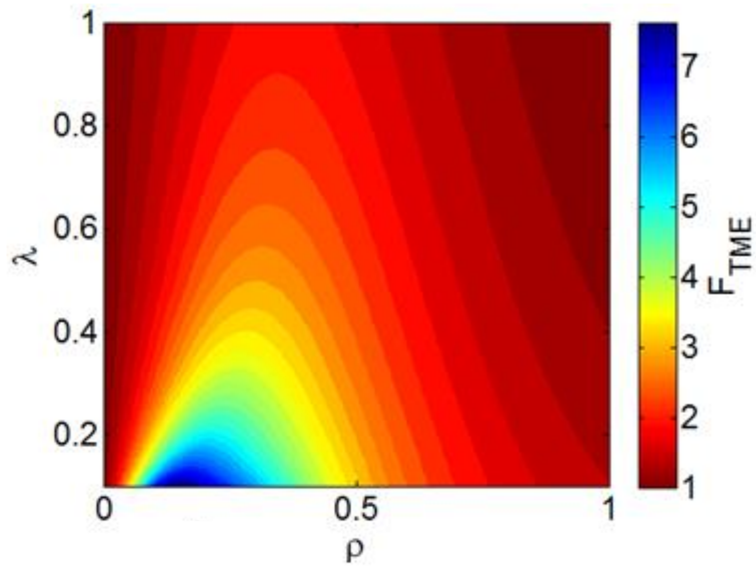
$$\lambda = \frac{L_1}{L_2}$$

Emittance reduction factor

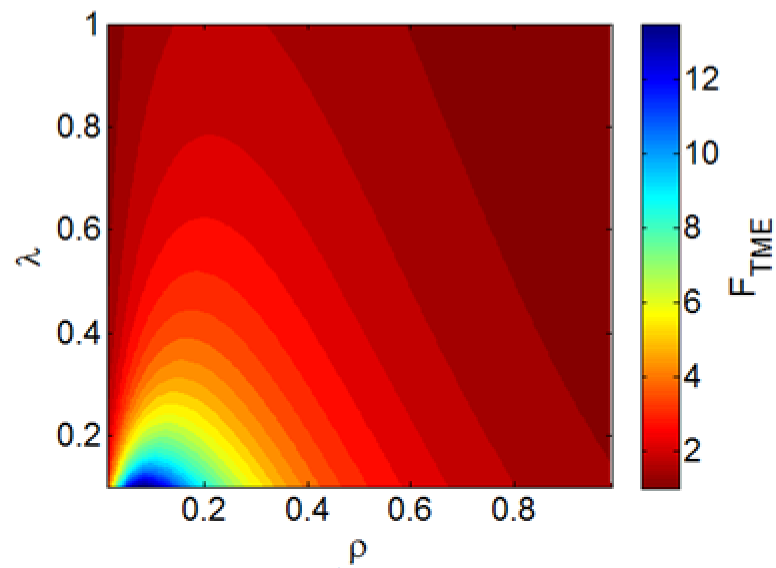
$$F_{TME} = \frac{\epsilon_{TME_{uni}}}{\epsilon_{TME_{var}}}$$

$$F_{TME} > 1$$

Step profile



Trapezium profile



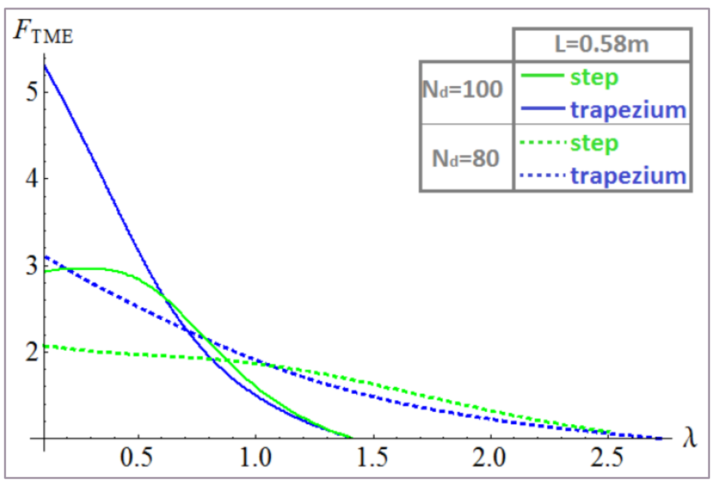
The parameterization of the emittance reduction factor F_{TME} with the bending radii ratio ρ and the lengths ratio λ, always for λ>0.1.

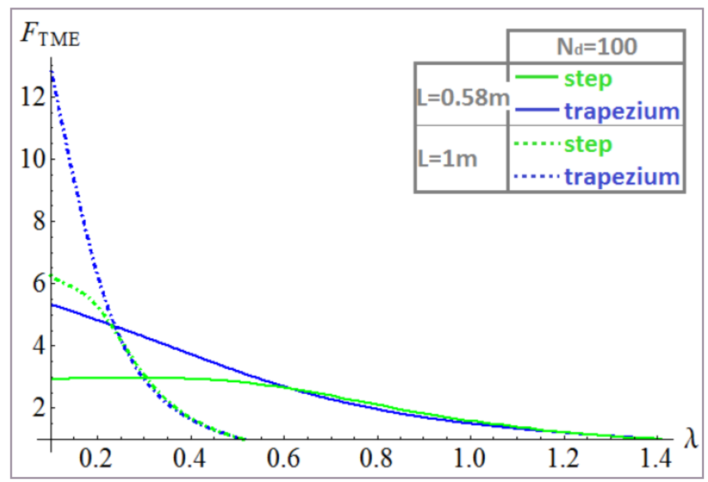
Fixing the dipole's characteristics (bending angle, length and minimum bending radius)

step → $\theta = \dfrac{L(\lambda+\rho)}{\rho_1(1+\lambda)}$

trapezium → $\theta = \dfrac{L(\lambda(-1+\rho)+\rho\log\rho)}{\rho_1\ (-1+\rho)(1+\lambda)}$

→ $\lambda(\rho)$ or $\rho(\lambda)$ → ($F_{TME}(\rho,\lambda)$) → $F_{TME}(\rho)$ or $F_{TME}(\lambda)$

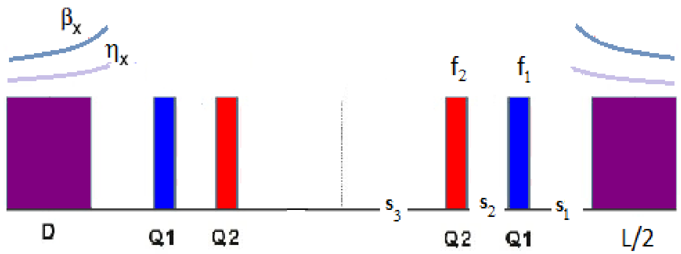




↓N_d → ↓F_{TME} ↓L → ↓F_{TME}

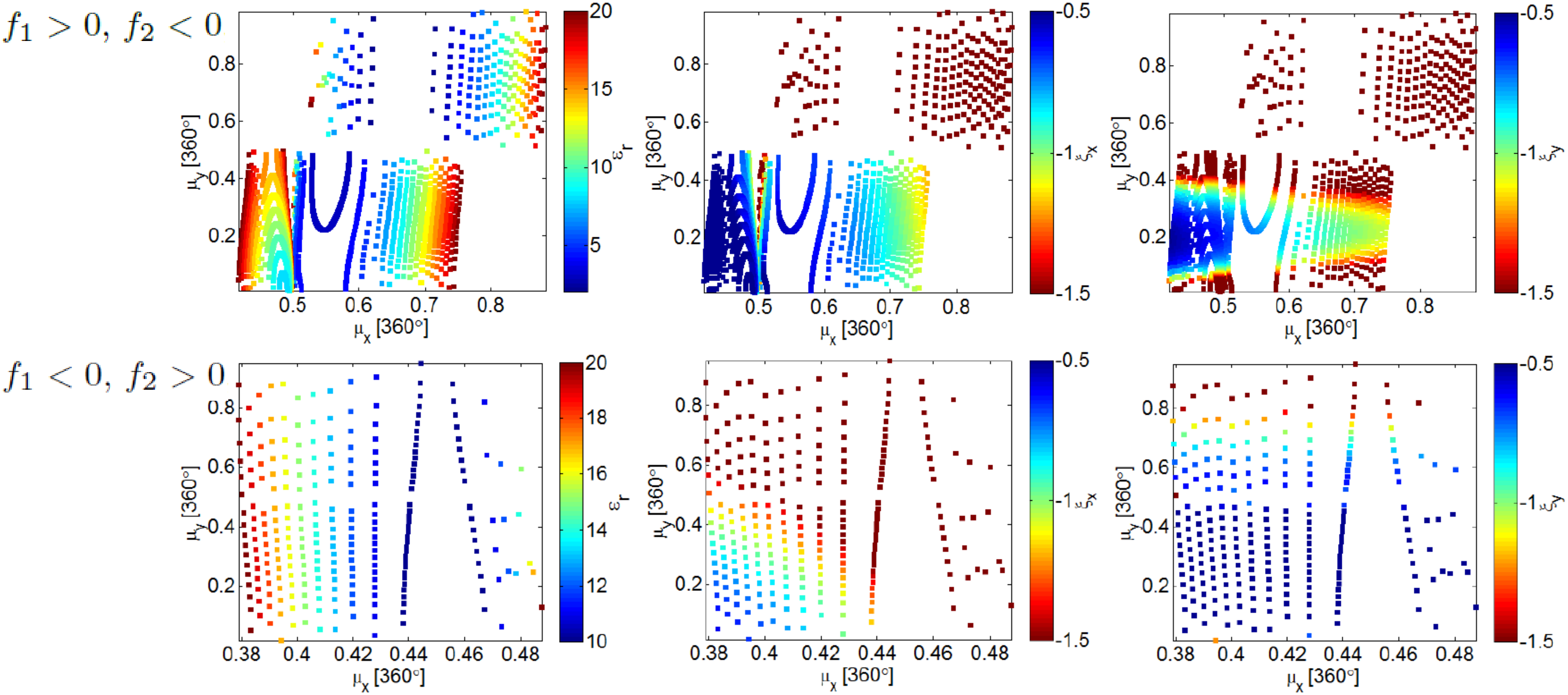
Example: For 100 dipoles having a length of 0.58m the absolute TME is 22pm for the uniform profile and just 4pm for the trapezium profile.

Optimization of the arc TME cell



Aiming to reduce the DR's circumference, it is necessary to find the optimal phase advances for which:

- $\gamma\epsilon_x$ <500nm, ϵ_l <6 keVm
- adequate dynamic aperture (low chromaticities)
- quadrupole strengths<100 T/m
- compact cell



$$\frac{\epsilon_{var}}{\epsilon_{uni}} = \frac{\epsilon_{r_{var}}\epsilon_{TME_{var}}}{\epsilon_{r_{uni}}\epsilon_{TME_{uni}}} = \frac{\epsilon_{r_{var}}}{\epsilon_{r_{uni}}}\frac{1}{F_{TME}}$$

$$\frac{\epsilon_{r_{var}}}{\epsilon_{r_{uni}}} < F_{TME}$$

Summary Table

Fixing the dipoles' characteristics:
bending radii ratio ρ and lengths ratio λ, dipole's length L and bending angle θ or else the total number of dipoles N_d

As long as the required output parameters are reserved, using the variable bends makes it possible to reduce the existing arcs' cells (N_d=100).

The optimal solutions are found to be N_d=96 for the step and N_d=90 for the trapezium profile.

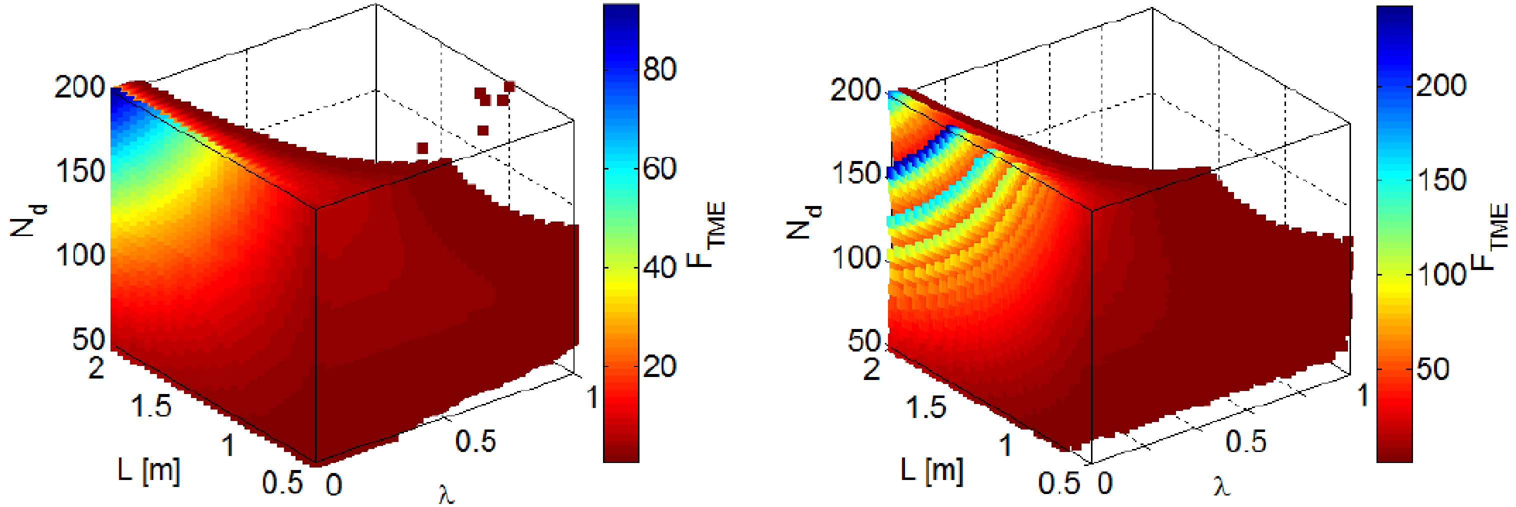
CLIC DRs	Uniform	Trapezium	
Number of dipoles	100	100	90
Horiz. emit (no IBS) [pm]	56	44	64

Design parameters for the CLIC DRs for the original and the improved designs, for the 2 GHz.

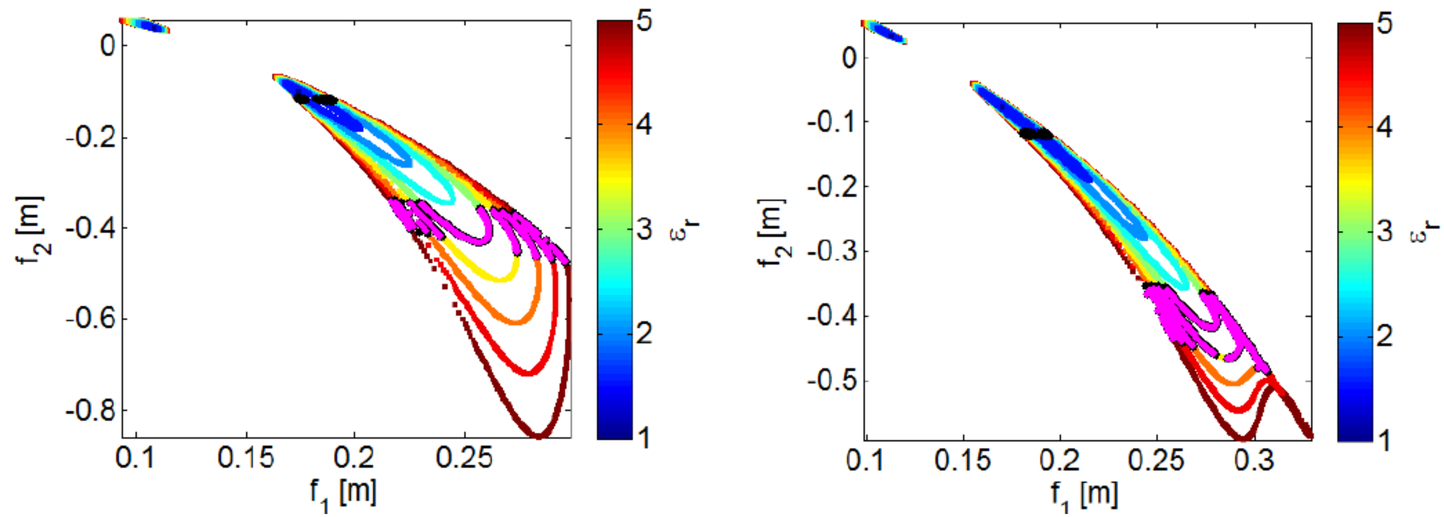
Parameters, Symbol [Unit]	uniform	step	trapezium
Energy, E [GeV]		2.86	
Bunch population, N [10^9]		4.1	
Circumference, C [m]	427.5	374.1	359.4
Basic cell type in the arc/LSS		TME/FODO	
Number of arc cells/wigglers, N_d/N_w	100/52	96/40	90/40
Dipole field (max/min), B_0 [T]	0.97/0.97	1.77/1.01	1.77/0.72
Normalized gradient in dipole [m^{-2}]		-1.1	
Quadrupole gradient strengths k_1, k_2 [T/m]	(-34, 67)	(-33, 65)	(-33, 65)
Phase advance per arc cell [360°] x/y	0.408/0.05	0.426/0.05	0.425/0.05
Horizontal, vertical tune, (Q_x,Q_y)	(48.35, 10.40)	(47.39, 9.45)	(44.15, 9.23)
Horizontal, vertical chromaticity, (ξ_x,ξ_y)	(-113, -82)	(-135,-77)	(-126,-72)
Wiggler peak field, B_w [T]	2.5	3.5	3.5
Wiggler length, L_w [m]		2	
Wiggler period, λ_w [cm]	5.0	5.0	4.9
Damping times, (τ_x, τ_y, τ_l) [ms]	(2.0, 2.0, 1.0)	(1.2, 1.3, 0.6)	(1.2, 1.2, 0.6)
Momentum compaction, α_c [10^{-4}]	1.3	1.3	1.2
Energy loss/turn, U [MeV]	4.0	5.7	5.7
Normalized horizontal emit., $\gamma\epsilon_x$ [nm-rad]*	657	502	500
Normalized vertical emit., $\gamma\epsilon_y$ [nm-rad]	5.0	5.0	4.9
Energy spread (rms), σ_δ [%]	0.11	0.13	0.13
Bunch length (rms), σ_s [mm]	1.8	1.6	1.6
Longitudinal emittance, ϵ_l [keVm]	6.0	6.1	6.0
IBS factors hor./ver./long.	2.1/1.5/1.2	1.4/1.5/1.1	1.4/1.5/1.1
RF Voltage, V_{RF} [MV]	4.2	6.1	6.0
RF Stationary phase [°]	70.4	68.4	70.7
Harmonic number, h	2850	2496	2398

***Both lattices[5] reach the target emittances including IBS, as calculated by the Bjorken-Mtingwa formalism through MADX. Only when using the Piwinski form., the original design[6] (with the uniform dipoles) could reach the target horizontal emittance.**

Thank you!



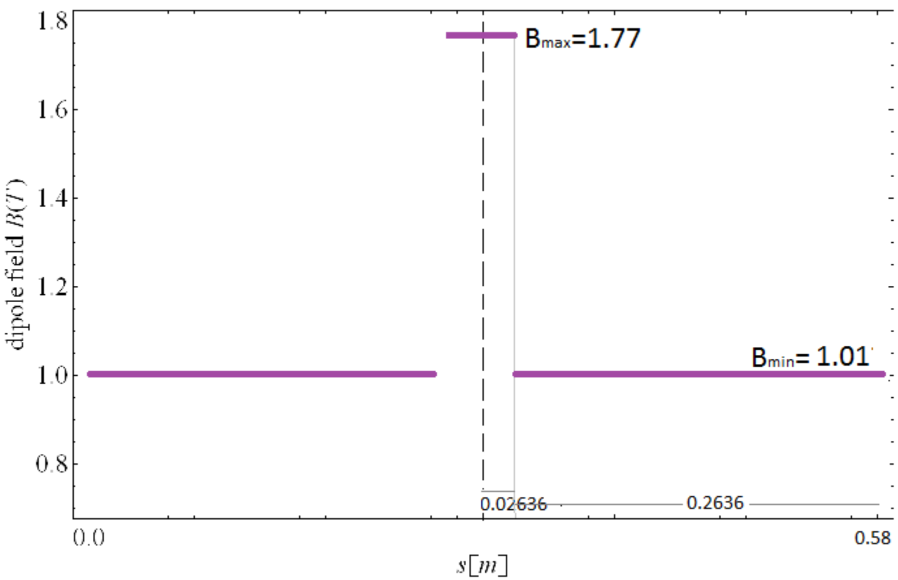
The parameterization of the emittance reduction factor F_{TME} with the lengths ratio λ, the dipole length L and the number of dipoles used N_d for the step (left) and the trapezium (right) profile,

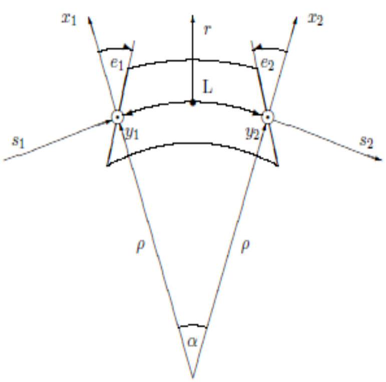


Parameterization of the focal lengths f_1, f_2 with the detuning factor for (a) the step and (b) the trapezium profile. The black and magenta squares respectively indicate stability and feasibility-low chromaticities solutions.

Step profile

CLIC DRs	Step profile
Number of dipoles	96
Dipole length [m]	0.58
Lengths ratio λ (difference between dipole parts with different field)	0.1
Bending radii ratio ρ (difference between min and max filed along the dipole)	0.57
maximum magnetic field [T]	1.77
minimum magnetic field [T]	1.009

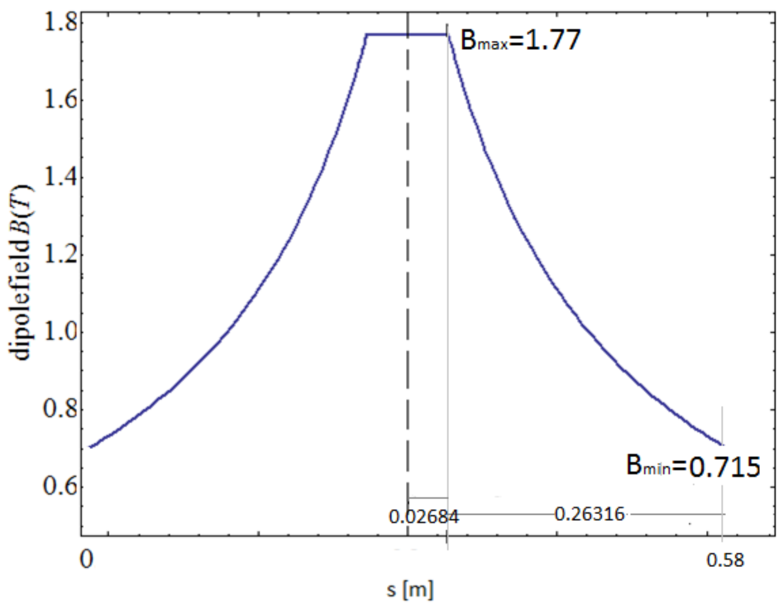


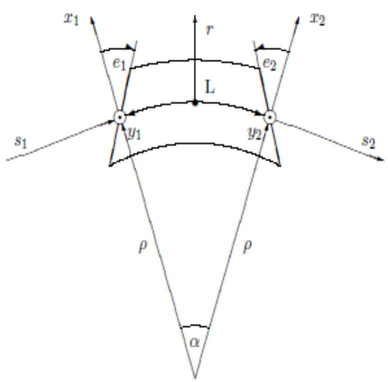


The rotation angle for the entrance (e_1) and the exit (e_2) pole faces is 1.875°

Trapezium profile

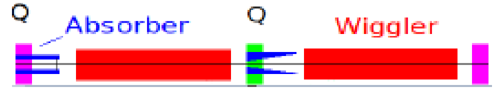
CLIC DRs	Trapezium profile
Number of dipoles	90
Dipole length [m]	0.58
Lengths ratio λ (difference between dipole parts with different field)	0.102
Bending radii ratio ρ (difference between min and max filed along the dipole)	0.404
maximum magnetic field[T]	1.77
minimum magnetic field[T]	0.715





The rotation angle for the entrance (e_1) and the exit (e_2) pole faces is 2°

Optimization of the wiggler FODO cell



Results obtained after the optimization of the arc TME cell.

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When increasing the wigglers' peak field B_w up to a certain point, the emittance and the IBS effect are lowered (see F. Antoniou talk "Lattice Design of Intrabeam Scattering dominated LERs")[3].

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Based on the technological restrictions, a new working point for the damp. wiggler is proposed to be at **3.5T** (prev. 2.5T), with 49mm period length[4]

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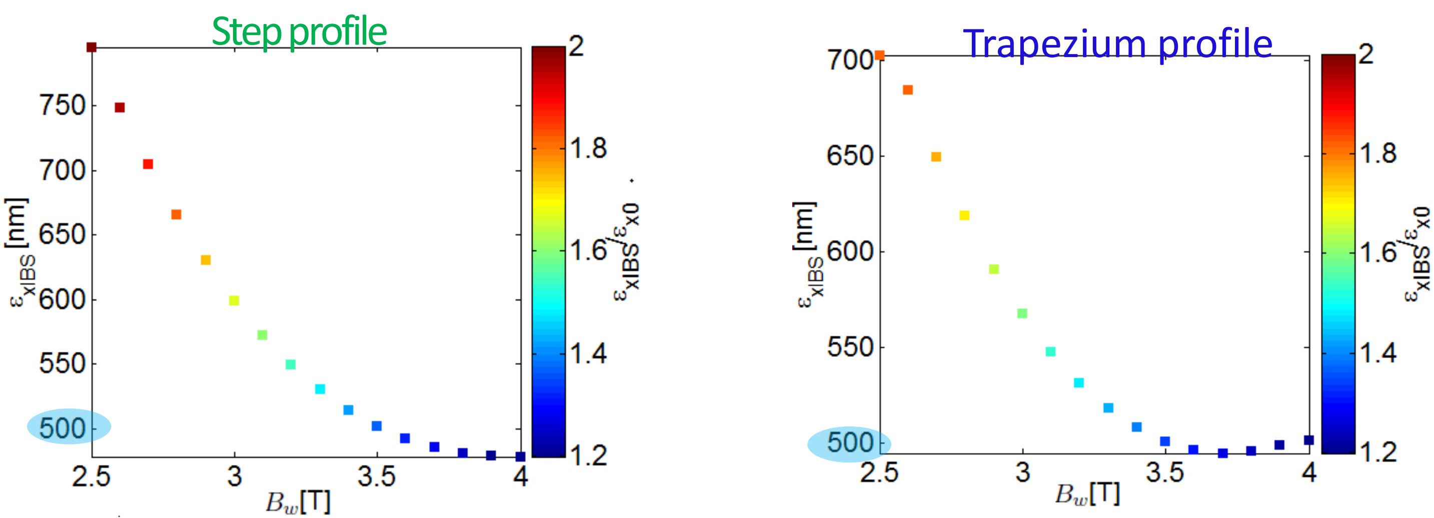
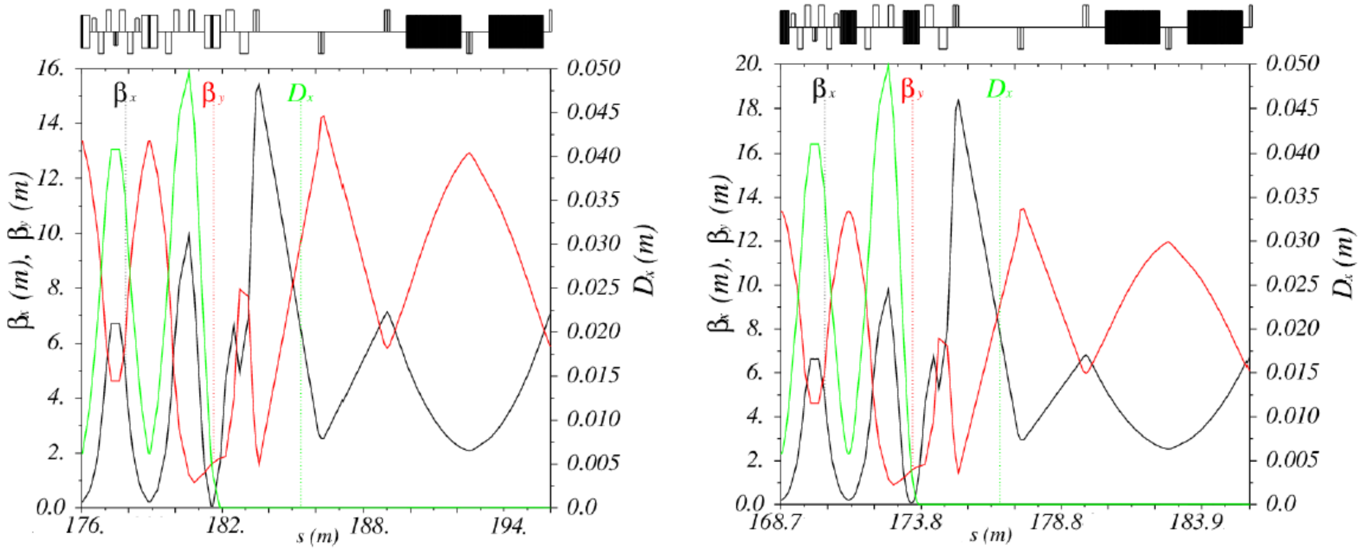
Removing some FODO cells from the existing straight section (N_{FODO}=13 per section) is possible.

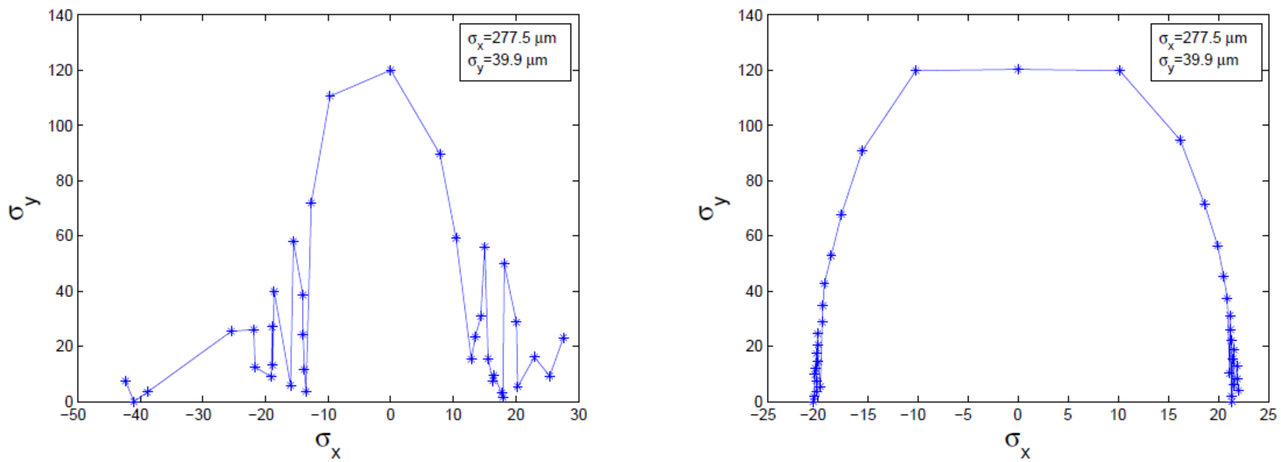
N_{FODO}=10 per straight section



Parametrization of the steady state emittance and the IBS effect with the wiggler's peak field B_w



Optical functions of one TME cell, the dispersion suppressor-beta matching section and one FODO cell when using in the arcs the step (left) and the trapezium (right) profile.



The on momentum dynamic aperture of the DR for the step (right) and the trapezium (left) profile.

References

[1] J. Guo and T. Raubenheimer, proc. of EPAC 2002, Paris (2002).
Y. Papaphilippou, P. Elleaume, PAC 2005, Knoxville (2005).
R. Nagaoka, A.F. Wrulich, Nucl. Instrum. Methods Phys. Res., Sect. A 575, 292 (2007).
C.-x Wang, PRST-AB 12, 061001 (2009).
C.-x Wang, Y. Wang, Y. Peng, PRST-AB 14, 034001 (2011).

[2] Y. Papaphilippou et al., ``Conceptual design of the CLIC damping rings'', TUPPCO86, proc. of IPAC'12, New Orleans, USA (2012).

[3] F. Antoniou, PhD thesis, NTUA, (2013)
D. Schoerling et al, PRST-AB 15, 042401 (2012).

[4] L. Garcia Fajardo, ``Nb3Sn prototype progress'', CLIC Workshop, CERN, Geneva (2015).

[5] S. Papadopoulou, F. Antoniou and Y. Papaphilippou, Emittance reduction with variable bending magnet strengths: Analytical optics considerations, preprint (2015).

[6] F. Antoniou, PhD thesis, NTUA, (2013).