New design of CLIC Damping Rings

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The aim

Current design of the main CLIC DRs, E=2.86 GeV

Parameters, Symbol [Unit]	uniform
Circumference, C [m]	427.5
Norm. horiz. emittance , $\gamma\varepsilon_x$ [nm-rad] *	681

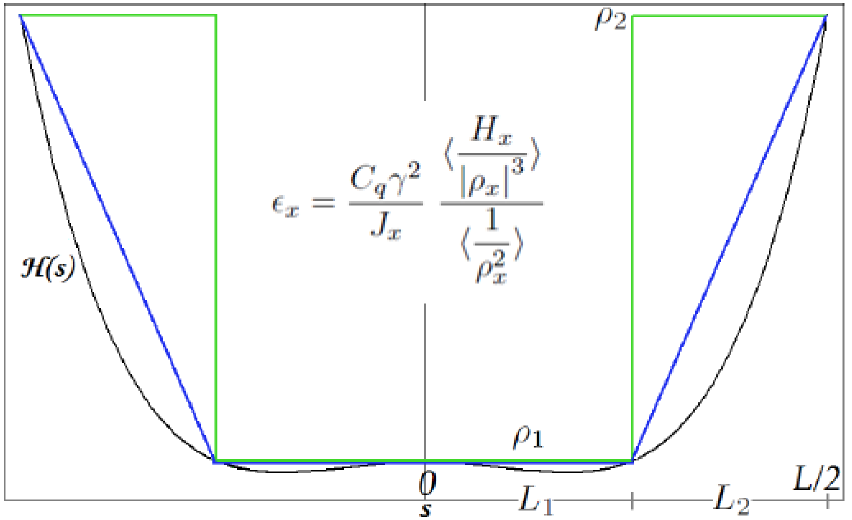
Reduce the number of arc TME cells->longitudinally variable bends

Reduce the number of wigglers->higher wiggler field

500nm required output emittance

*The emittance is calculated using the Bjorken-Mtingwa formalism through MADX.
Using the Piwinski form., the original design (with the uniform dipoles) reaches the target horizontal emittance.

Longitudinally variable bends[1]



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

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

Bending radii ratio

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

Lengths ratio

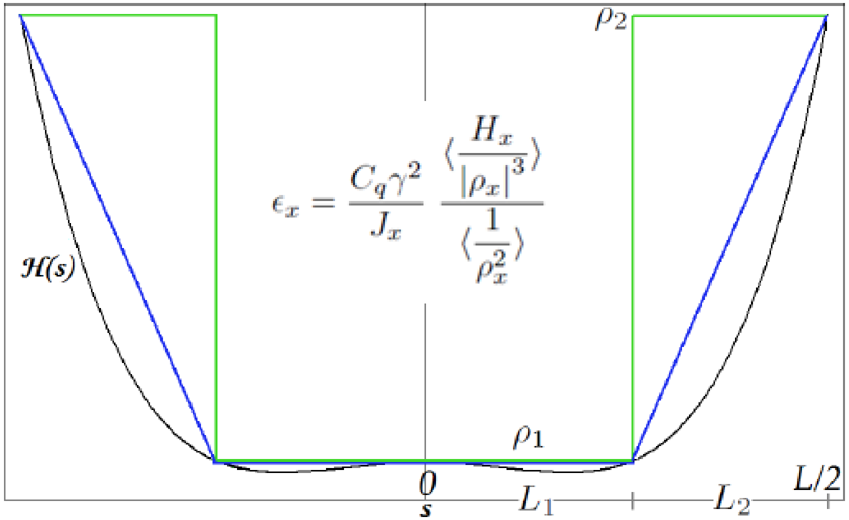
$$\lambda = \frac{L_1}{L_2}$$

Emittance reduction factor

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

$$F_{TME} > 1$$

Longitudinally variable bends[1]



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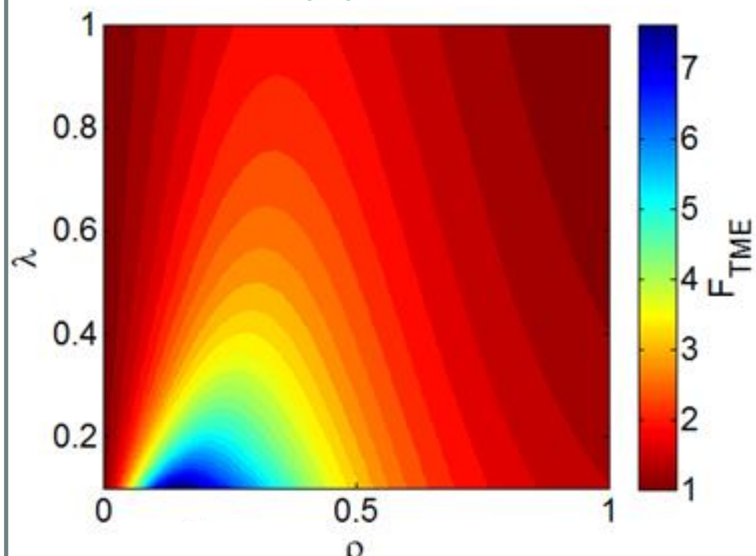
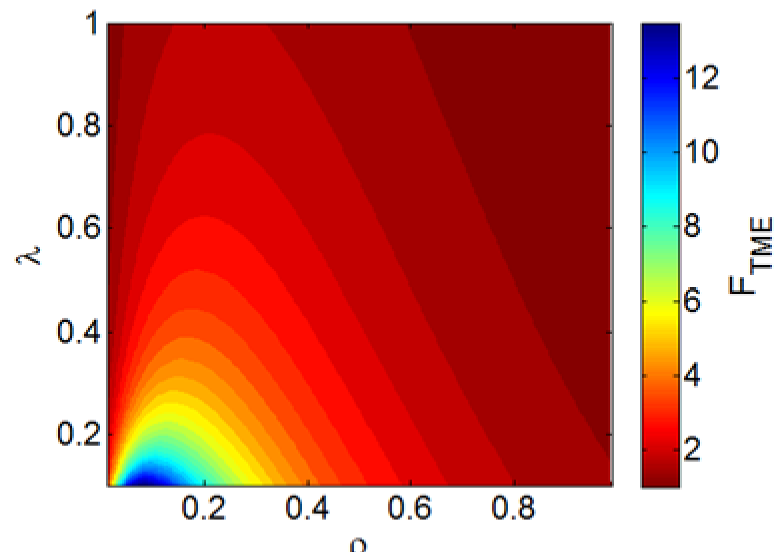
Step profile



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

$$\theta = \frac{L(\lambda+\rho)}{\rho_1(1+\lambda)}$$

trapezium

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

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

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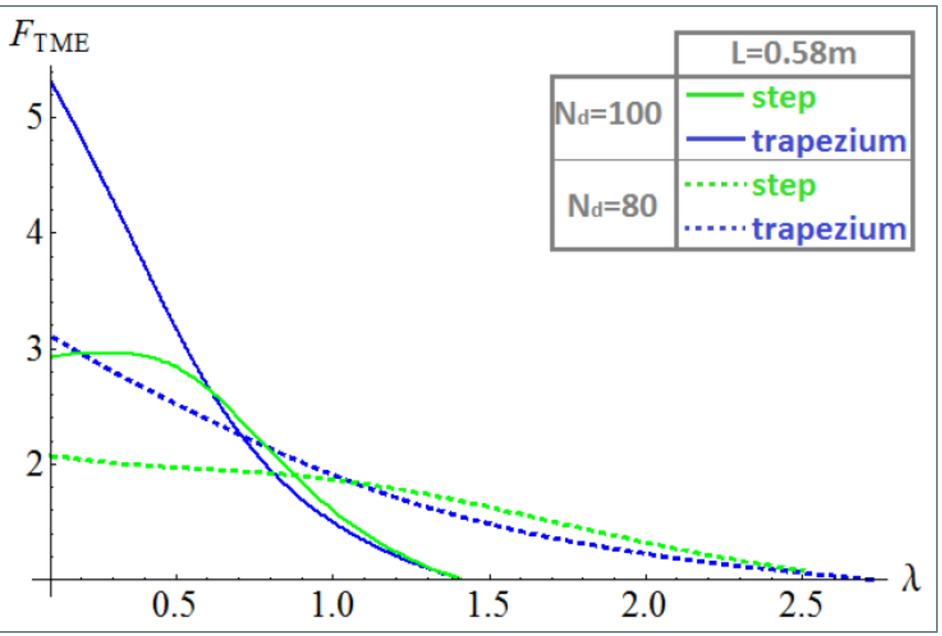
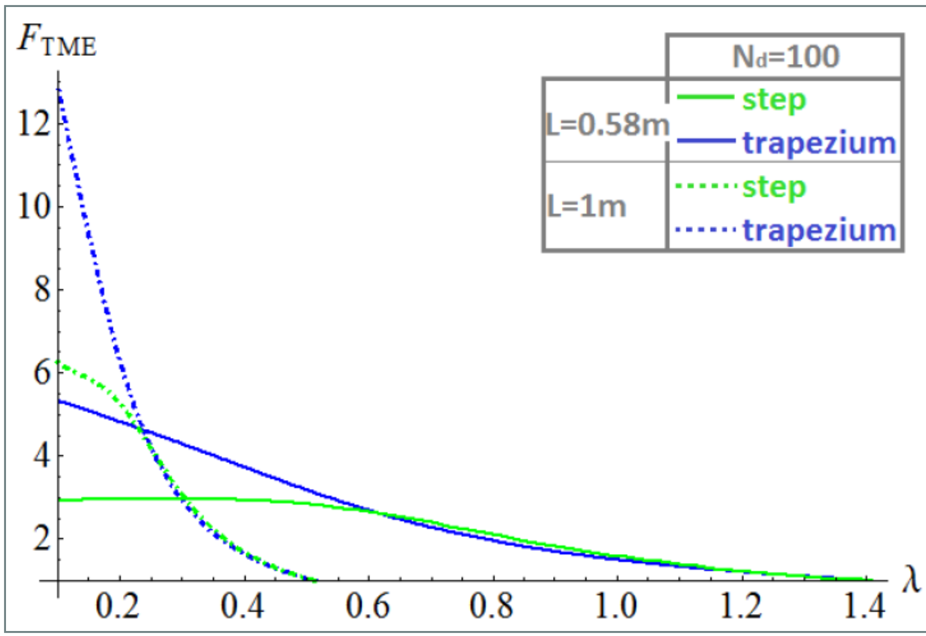
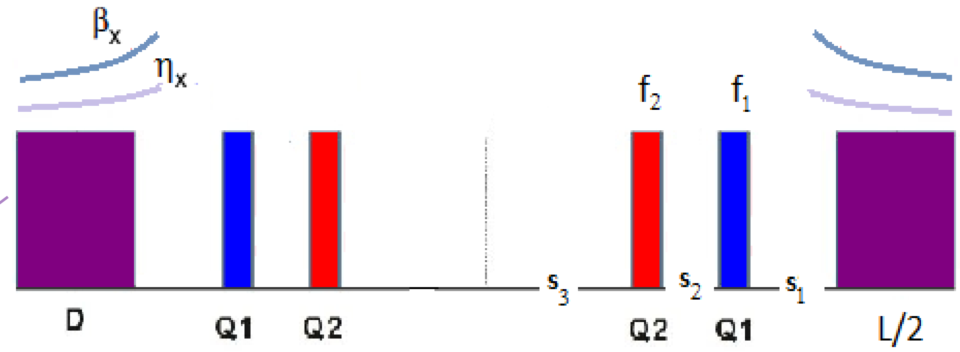




$\downarrow N_d \Rightarrow \downarrow F_{TME}$

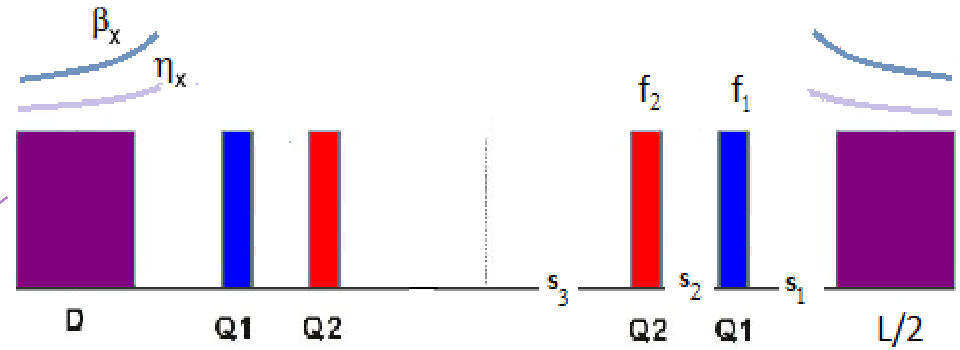
$\downarrow L \Rightarrow \downarrow F_{TME}$

Optimization of the arc TME cell



After 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) in order to get a large F_{TME}

Optimization of the arc TME cell



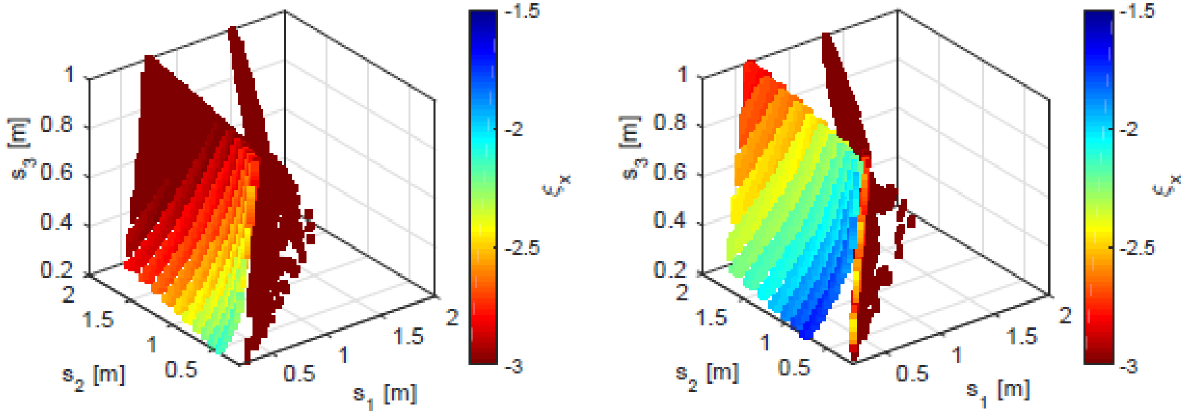
After fixing the dipoles' characteristics (bending radii ratio ρ and lengths ratio λ, dipole's length L and bending angle θ or else the total number of dipoles N_d) in order to get a large F_{TME}

Aiming to reduce the DR's circumference and get the required output parameters, it is necessary to find the:

- the elements' and drifts' lengths that result in a compact cell.
- the optimal phase advances for which:
  - -the horizontal and vertical emittances are $\gamma\varepsilon_x$ <500nm, ε_l <6 keV m
  - -the low chromaticities in both planes guarantee an adequate dynamic aperture
  - -and the quadrupole strengths are k_1,k_2<100 T/m.

Optimization of the arc TME cell

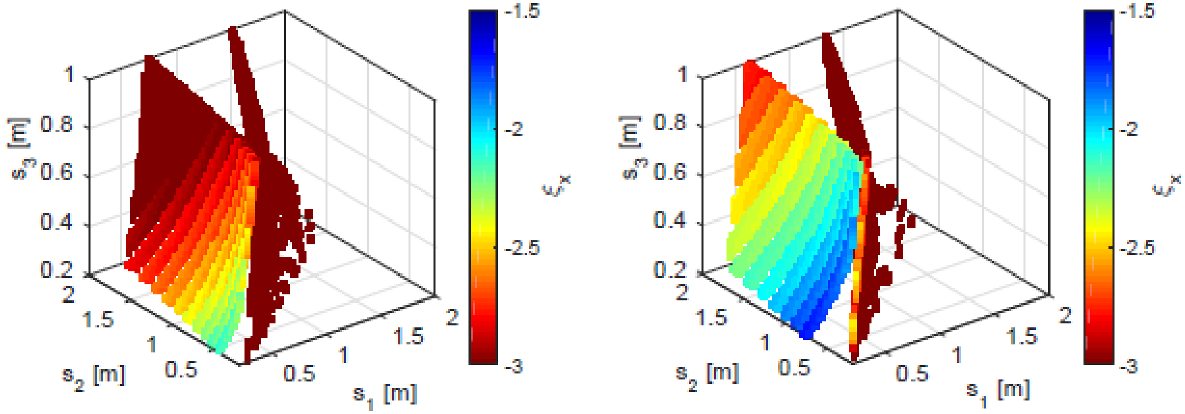
Parametrization with the drift lengths



The horizontal chromaticity ξ_x is parameterized with the drift lengths s_1, s_2, s_3 for the TME, for the step (left) and the trapezium (right) profile

Optimization of the arc TME cell

Parametrization with the drift lengths



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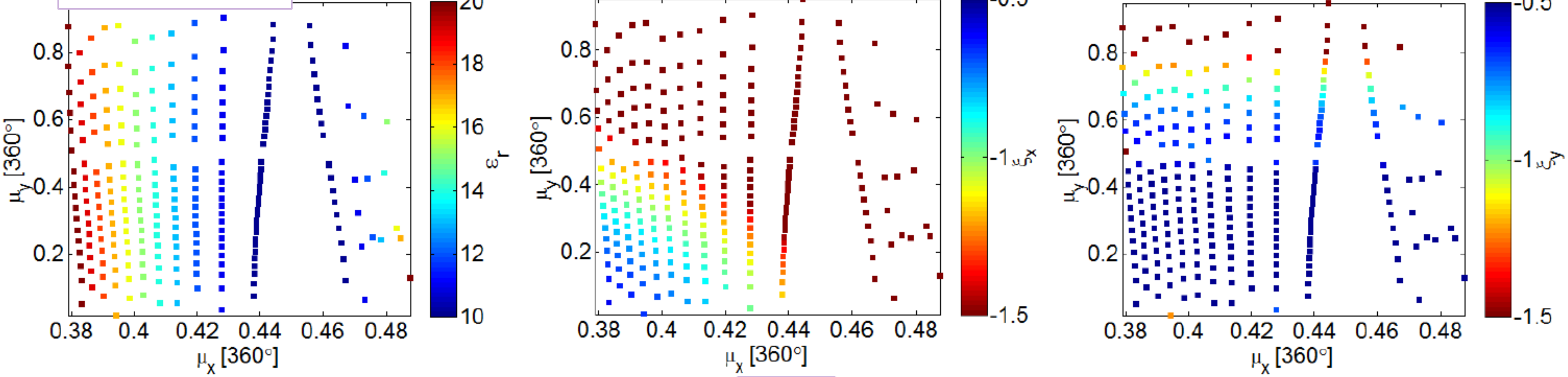
Parametrization with the phase advances

$f_1 < 0,\ f_2 > 0$



The parameterization of the detuning factor ε_r ($\varepsilon_r = \varepsilon_x/\varepsilon_{TME}$) and of the horizontal and vertical chromaticities (ξ_x and ξ_y) with the horizontal and vertical phase advances μ_x and μ_y , only for the trapezium profile.

Optimization of the arc TME cell

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

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When properly using the variable bends, lower emittances than the current design's ones are reached. This gives us the flexibility to reduce the existing arcs' TME cells, till the point we get the required output parameters (because the aim was not a lower emittance than the one that already exists, but a shorter ring).

procedure followed in MADX

removing TME cells
checking the output parameters

Optimization of the arc TME cell

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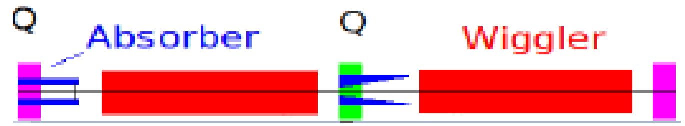
procedure followed in MADX

removing TME cells
checking the output parameters

The optimal solutions are found to be N_d=96 for the step and N_d=90 for the trapezium profile, instead of the existing arc's cell that are N_d=100.

Optimization of the wiggler FODO cell



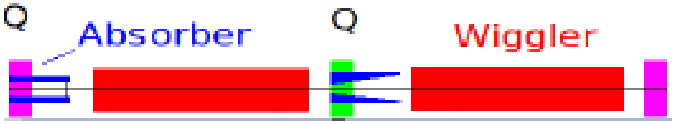
Results obtained after the optimization of the arc TME cell.

When increasing the wigglers' peak field B_w up to a certain point, the emittance and the IBS effect are lowered [3].

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]

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

Optimization of the wiggler FODO cell



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+

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+

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N_{FODO}=10 per straight section

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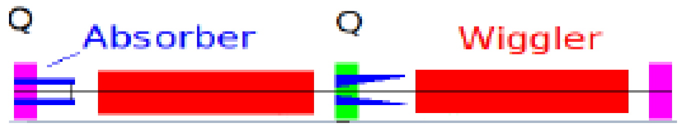

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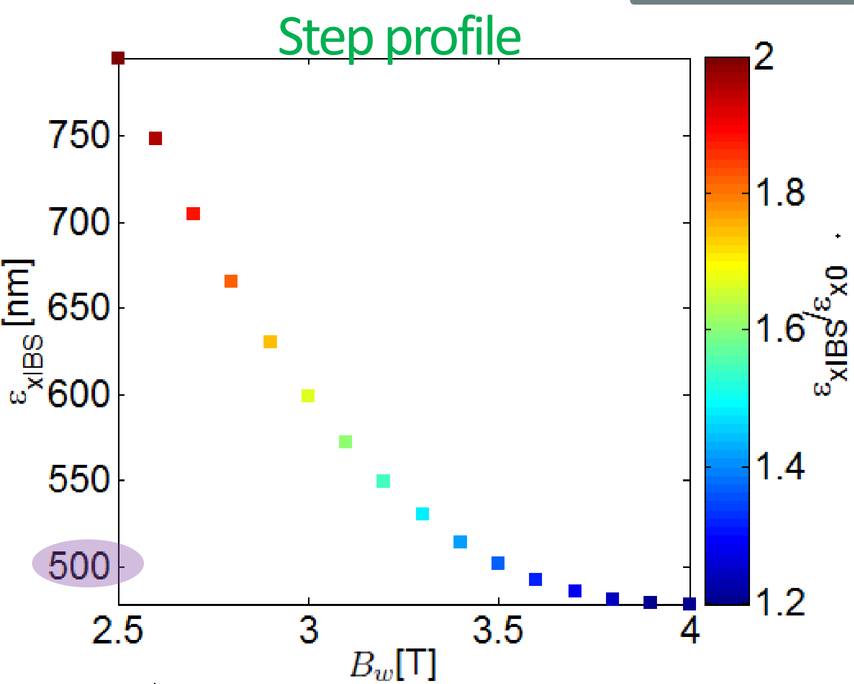

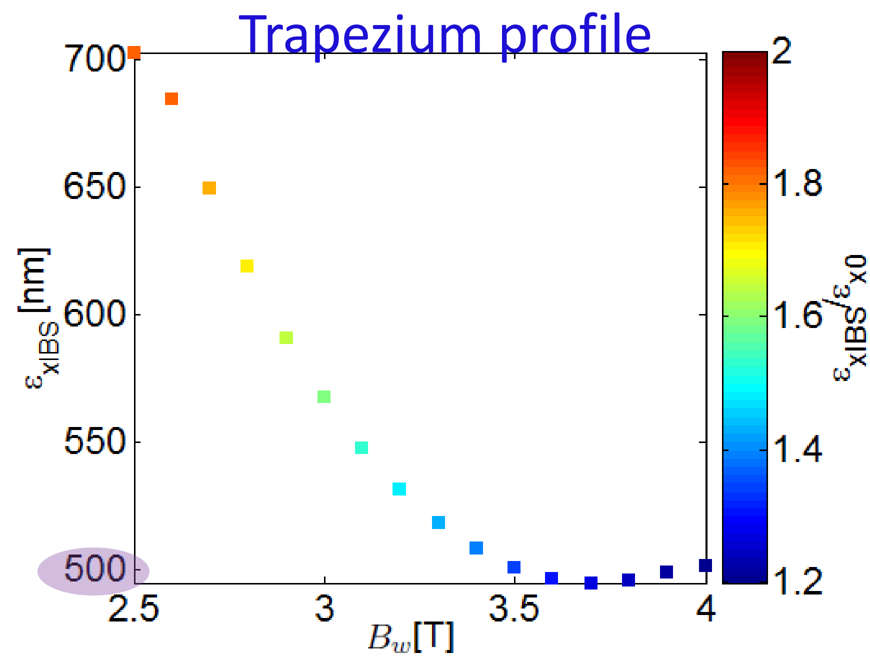

Parametrization of the steady state emittance and the IBS effect with the wiggler's peak field B_w

Design parameters for the main DRs, E=2.86 GeV

Parameters, Symbol [Unit]	uniform	step	trapezium
Number of arc cells/wigglers	100/52	96/40	90/40
Circumference, C [m]	427.5	374.1 (-14.3%)	359.4 (-18.9%)
Dipole field (max/min), B [T]	0.97/0.97	1.77/1.01	1.77/0.72
Horiz./Vert. chromaticities ξ_x/ξ_y	-113/-82	-135/-76	-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	4.9	4.9
Damp. 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)
Mom. compaction, α_c [10^{-4}]	1.3	1.3	1.2
Energy loss/turn, U [MeV]	4	5.7	5.7
Norm. horiz. emittance , $\gamma\varepsilon_x$ [nm-rad] *	681	502	500
Norm. vert. emittance, $\gamma\varepsilon_y$ [nm-rad]	5.0	4.9	4.9
Energy spread (rms), σ_δ [%]	0.12	0.13	0.13
Bunch length (rms), σ_s [mm]	1.8	1.6	1.6
Long. emittance , ε_l [keVm]	5.9	6.1	6.0
IBS factors hor./ver./long.	2.2/1.5/1.2	1.4/1.5/1.1	1.4/1.5/1.1
RF Voltage, V_{RF} [MV]	5.10	7.25	6.97
Stationary phase [^{o}]	51.4	51.3	54.2

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

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).
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-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, Alternative optics design of the CLIC Damping Rings with variable dipole bends and high-field wigglers, proc. of IPAC'15, Richmond, Virginia, USA (2015)
-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).

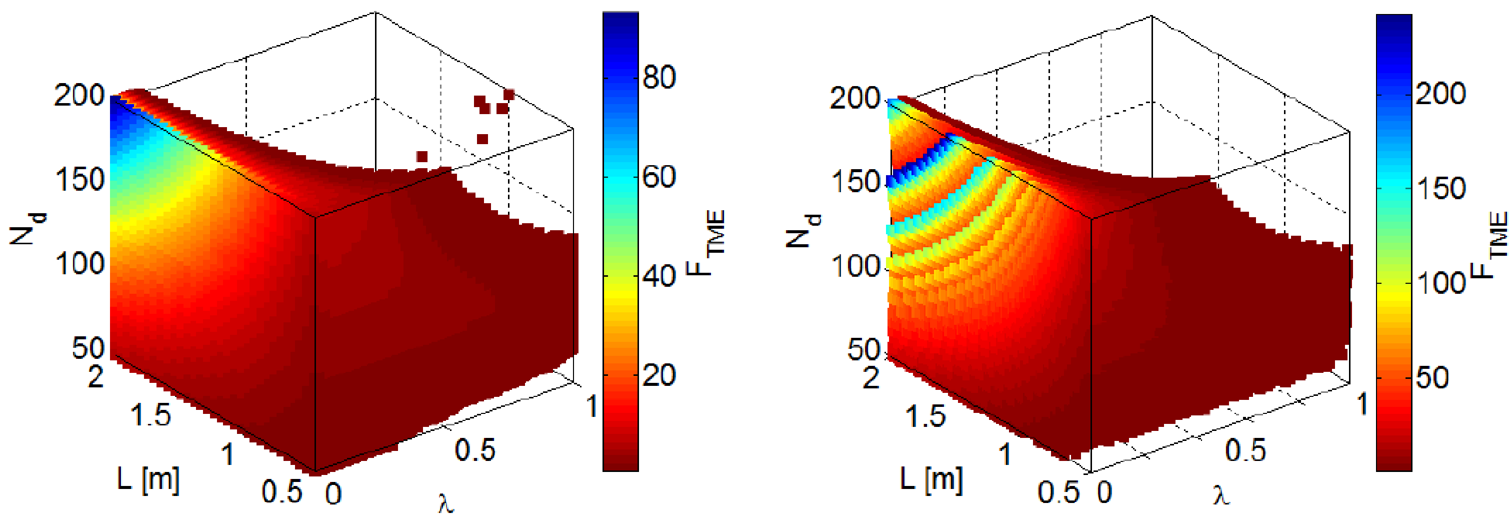
Thank you!

CLIC DRs	Uniform	Trapezium	
Number of dipoles	100	100	90
Horiz. emit (no IBS) [pm]	56	44	64
Horiz. emit (with IBS) [pm]	117	122	90

Identical wigglers at LSS

Higher field wigglers (and shorter LSS)

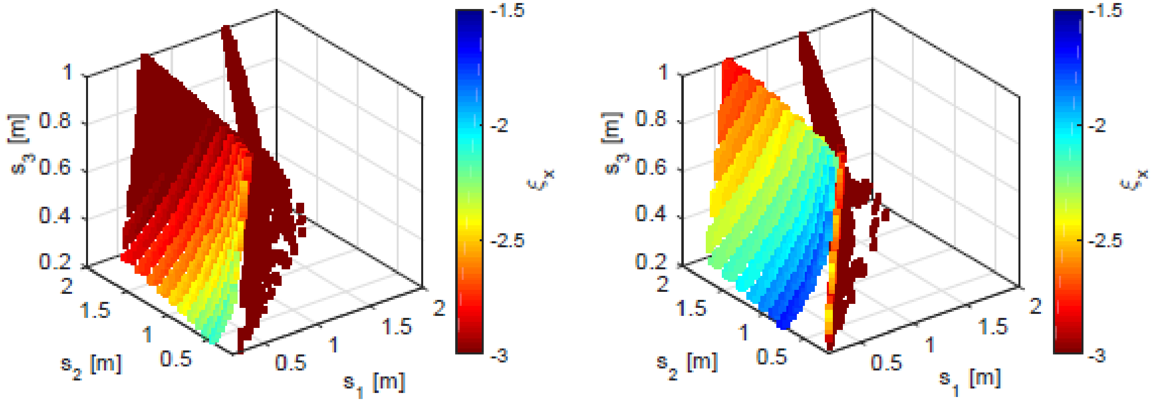
Extremety for λ–>0



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,

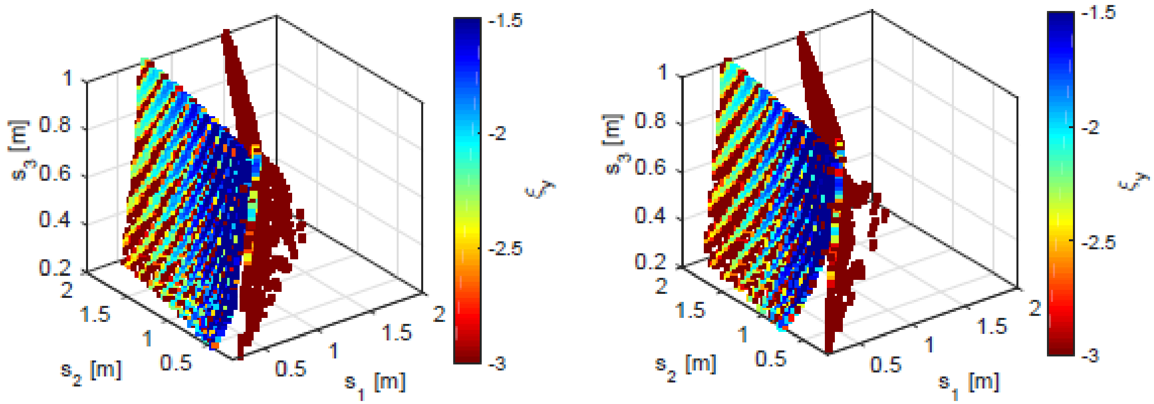
Optimization of the arc TME cell

Parametrization with the drift lengths



(a) (b)

The horizontal chromaticity ξ_x is parametrized with s_1, s_2, s_3 for the TME, for (a) the step and (b) the trapezium profile.

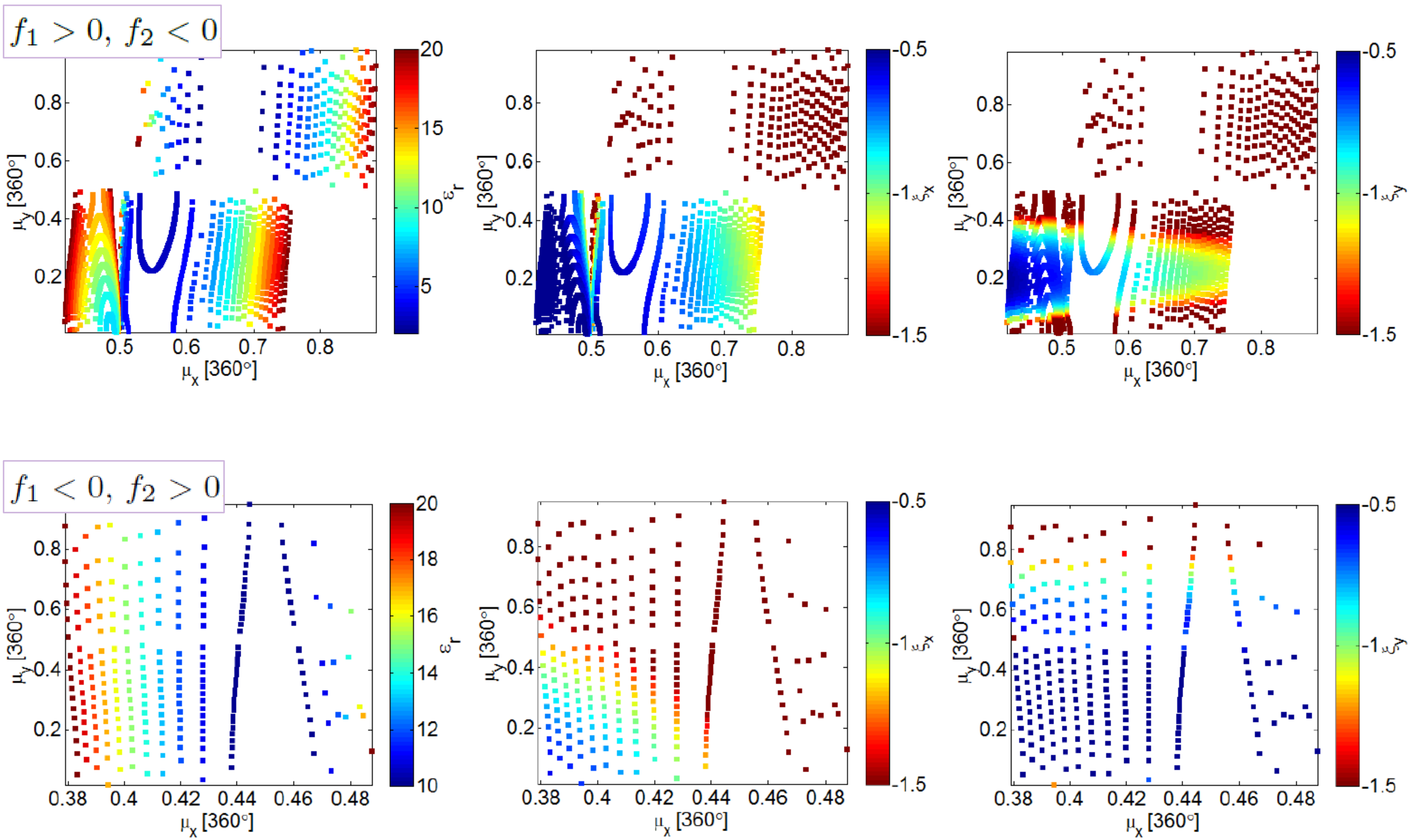


(a) (b)

The vertical chromaticity ξ_y is parametrized with s_1, s_2, s_3 for the TME, for (a) the step and (b) the trapezium profile.

Optimization of the arc TME cell

Parametrization with the phase advances



The parameterization of the detuning factor ε_r ($\varepsilon_r = \varepsilon_x/\varepsilon_{TME}$) and of the horizontal and vertical chromaticities ξ_x and ξ_y with the horizontal and vertical phase advances μ_x and μ_y, only for the trapezium profile.

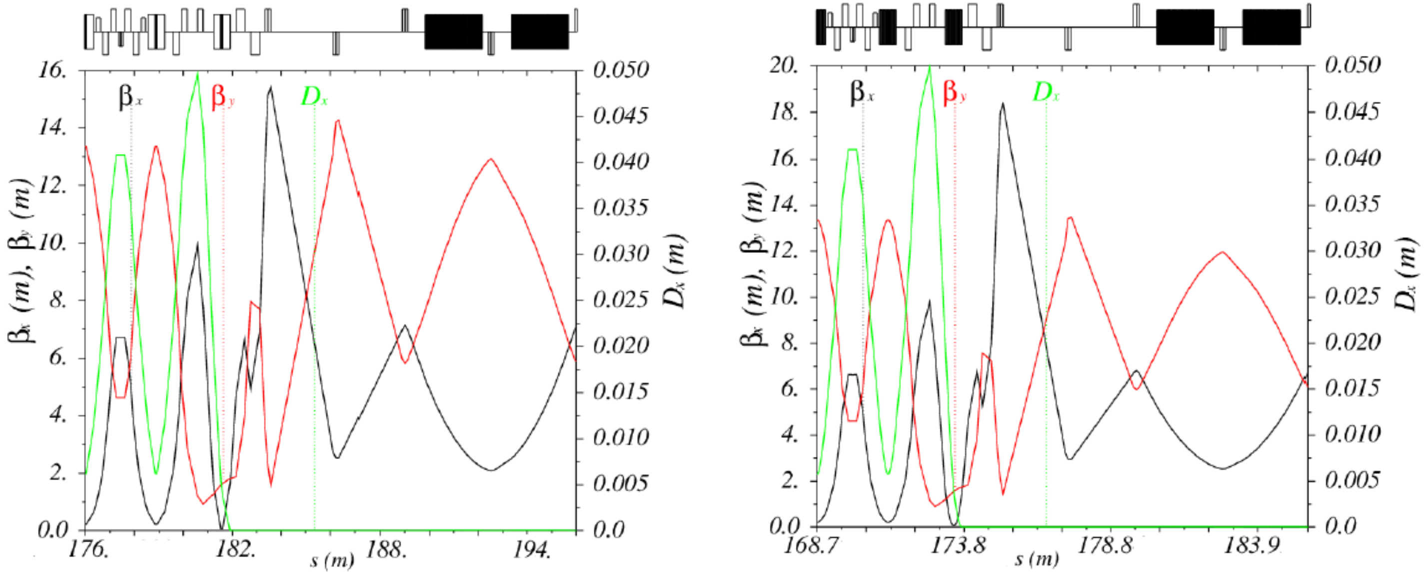
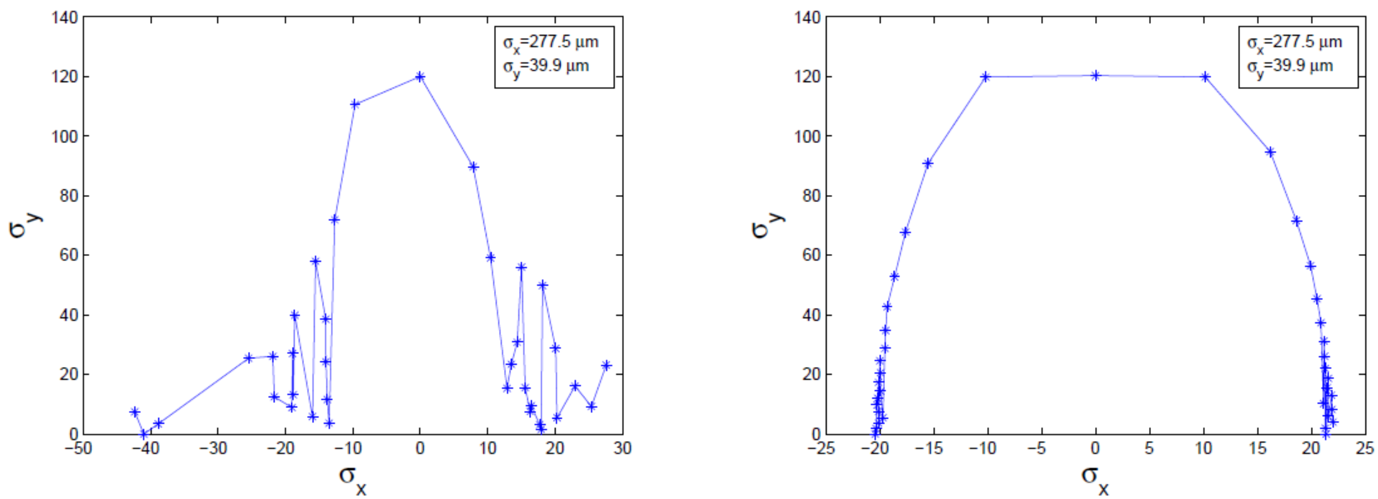


FIG. 23: Optical functions of one TME cell, the dispersion suppressor-beta matching section and one FODO cell when using in the arcs the step (left) and the trapezium (right) profile.



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