CLIC DR design using variable bends and high-field wigglers

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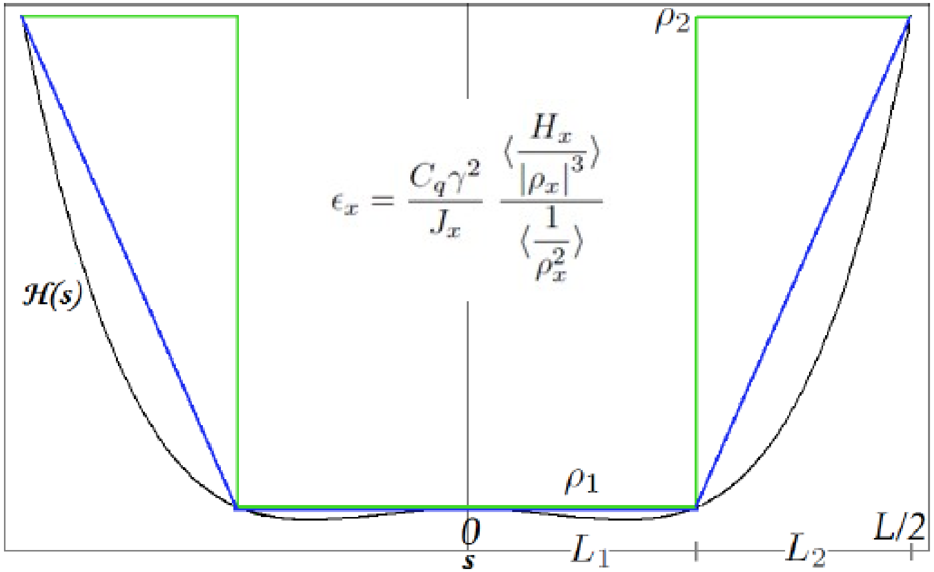
- Design parameters of the main CLIC DRs
- Magnet design based on the characteristics of the variable bends for the CLIC DRs

Longitudinally variable bends[1]



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

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Bending radii ratio

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

Lengths ratio

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

Emittance reduction factor

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

$$F_{TME} > 1$$

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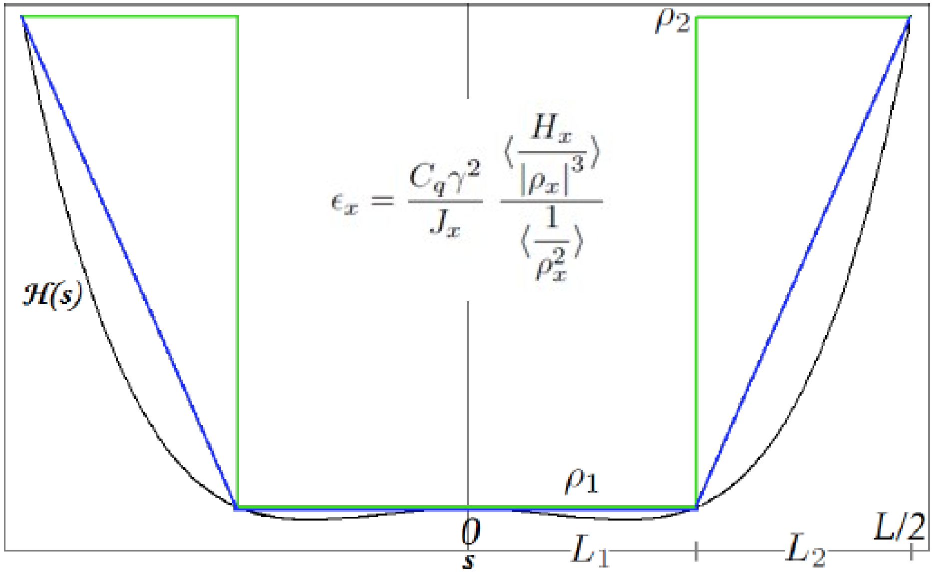

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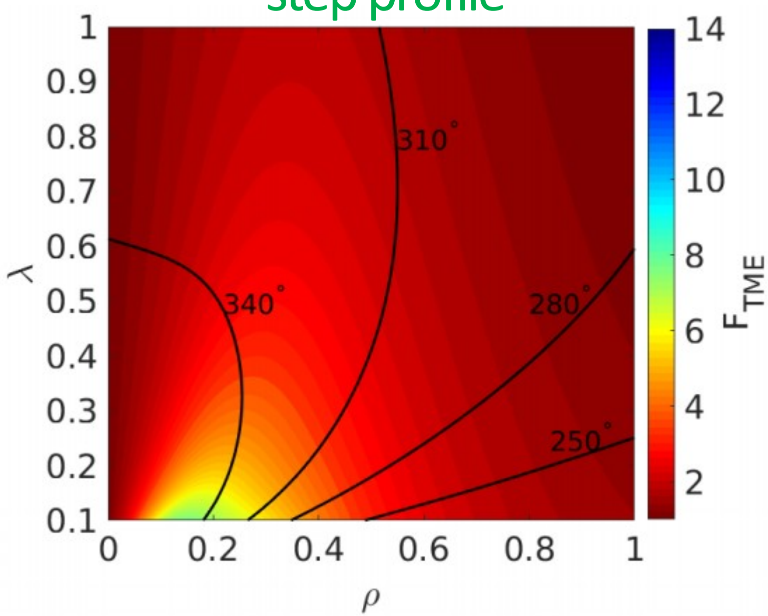
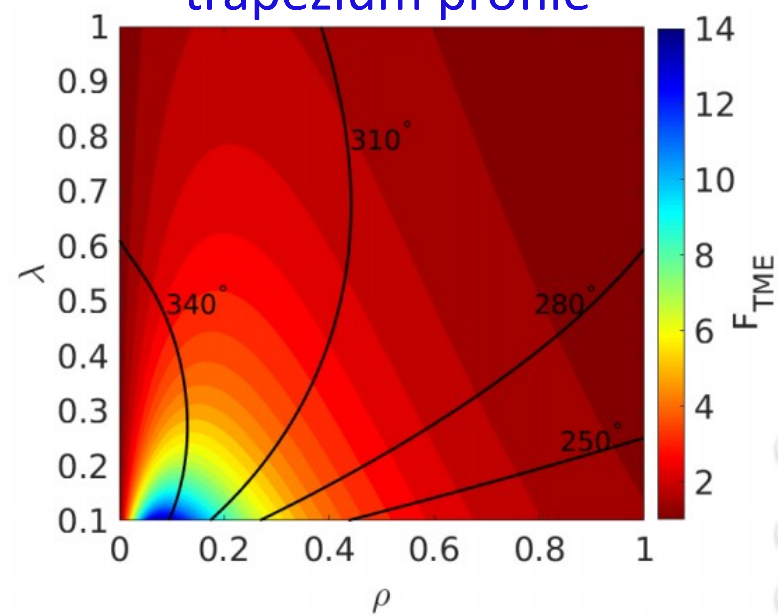
step profile



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)

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

$$\theta_{trapezium} = \frac{L(\lambda(-1 + \rho) + \rho \ln \rho)}{\rho_1(-1 + \rho)(1 + \lambda)}$$

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

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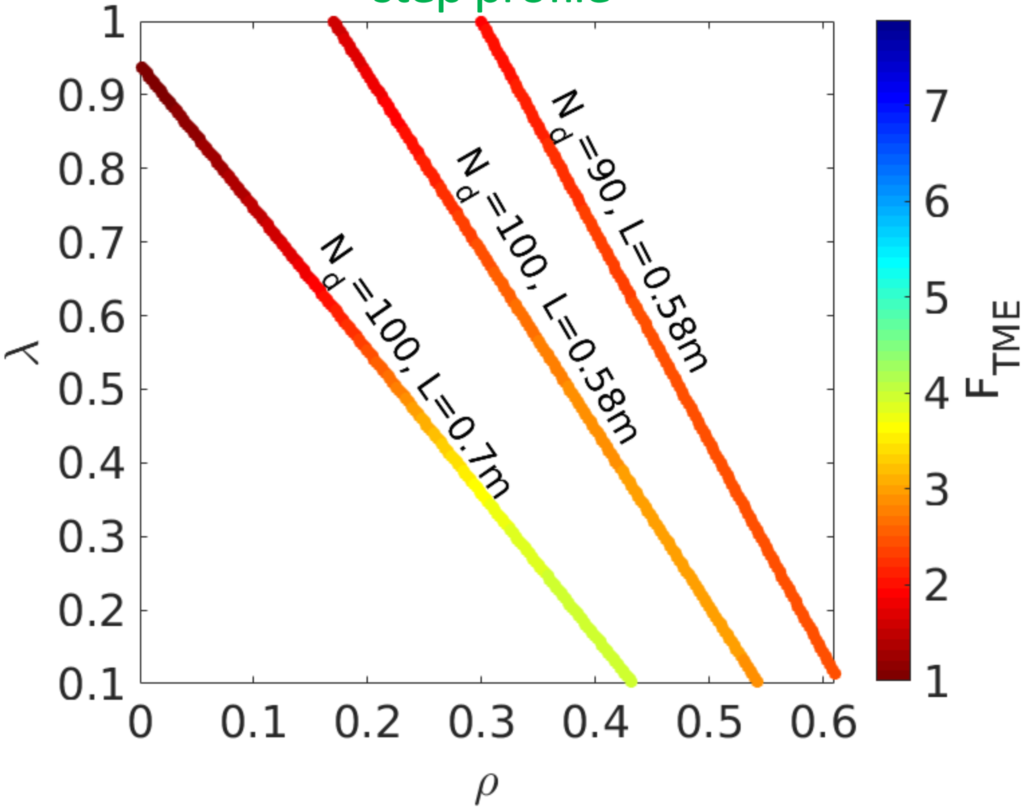
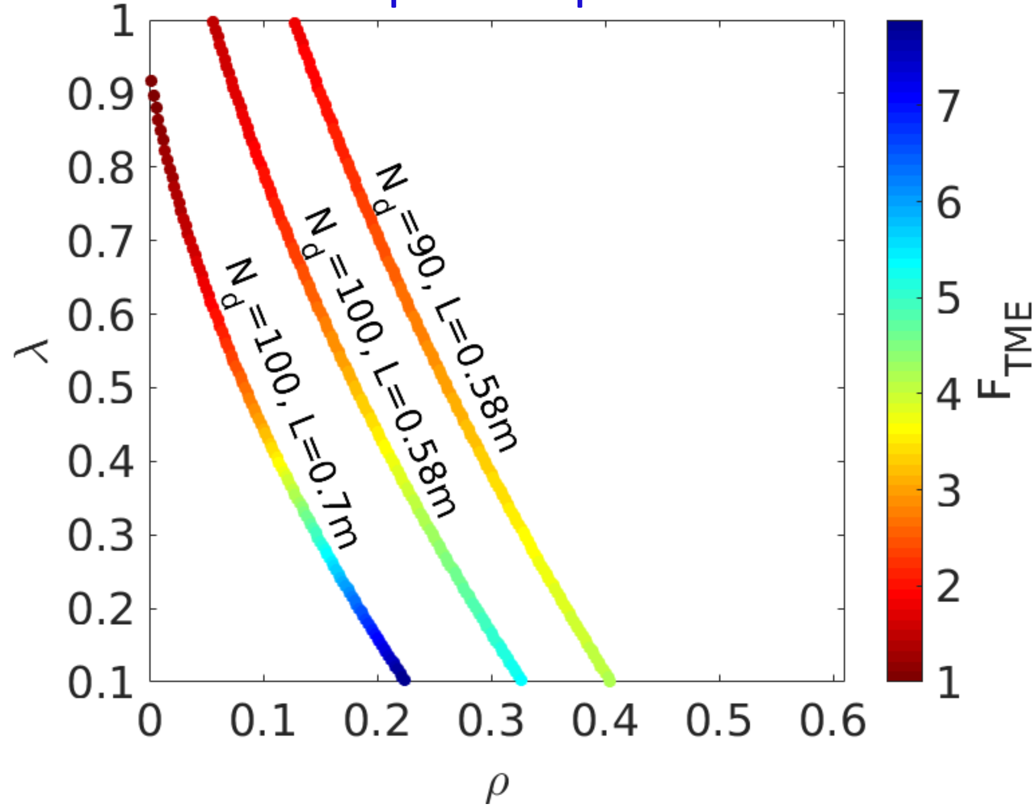
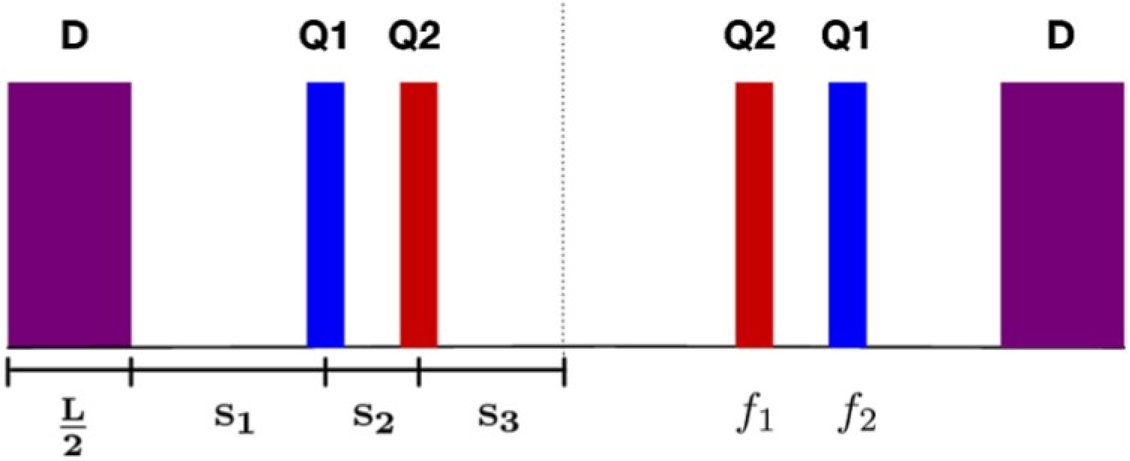


trapezium profile



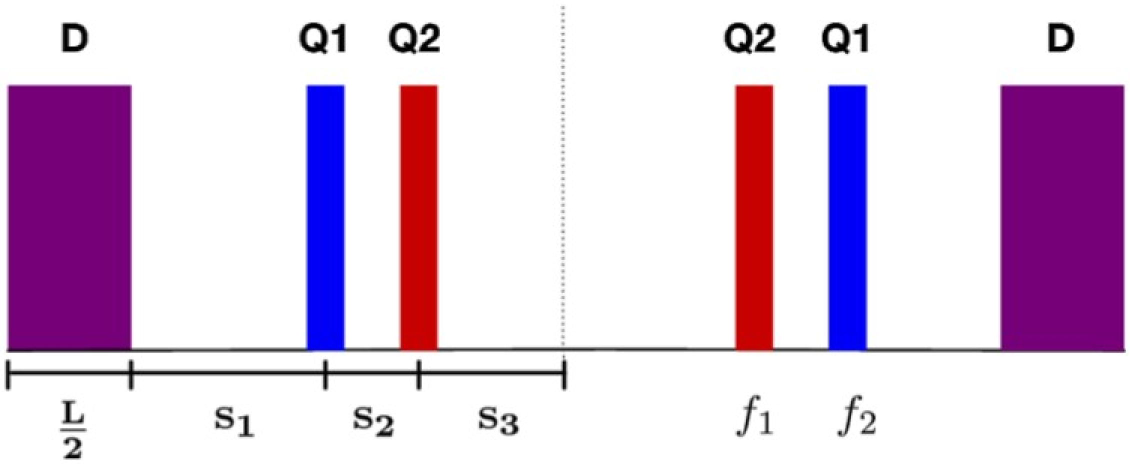
$\downarrow L, N_d$ → $\downarrow F_{TME}$

Optimization of the arc TME cell



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



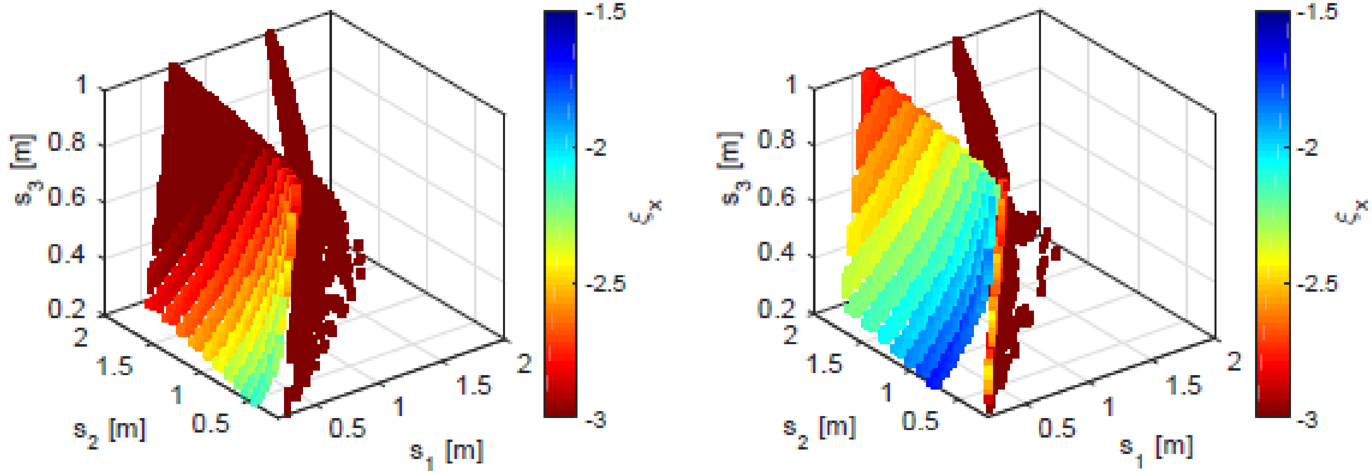
Fixing the dipoles' characteristics (bending radii ratio ρ and lengths ratio λ, dipole's length L and bending angle θ or else the total number of dipoles N_d) in order to get a large F_{TME}

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

- the lengths of the elements and of the drifts 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

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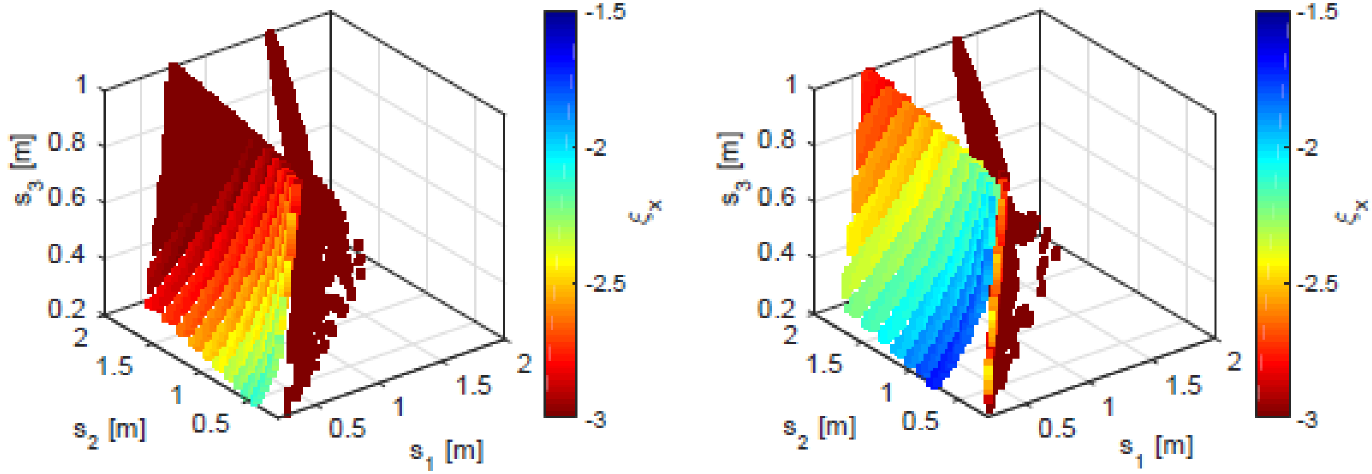

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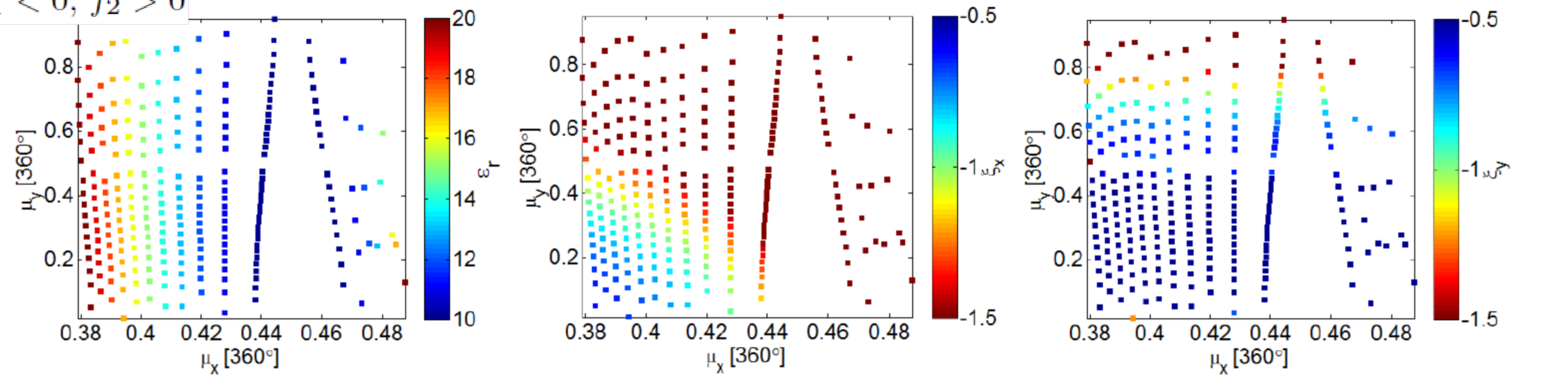
Parametrization with the phase advances

$f_1 < 0,\ f_2 > 0$



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

$$\frac{\epsilon_{var}}{\epsilon_{uni}} < 1$$

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

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

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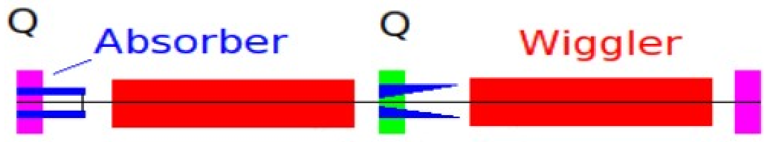
For optimized variable bends characteristics, lower emittances than the ones of the current design are reached. This gives us the flexibility to reduce the existing TME cells of the arcs, till the point we get the required output parameters.

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



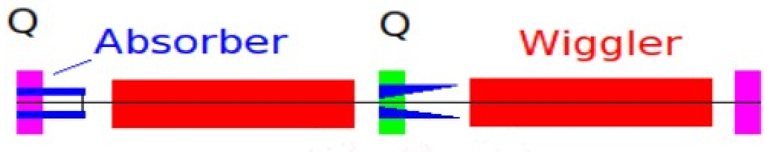
Results obtained after the optimization of the arc TME cell.

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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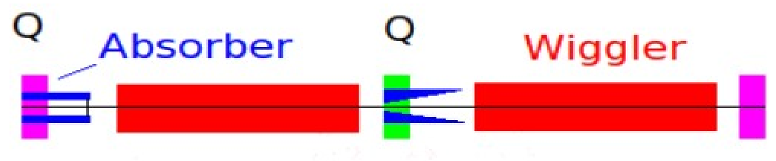

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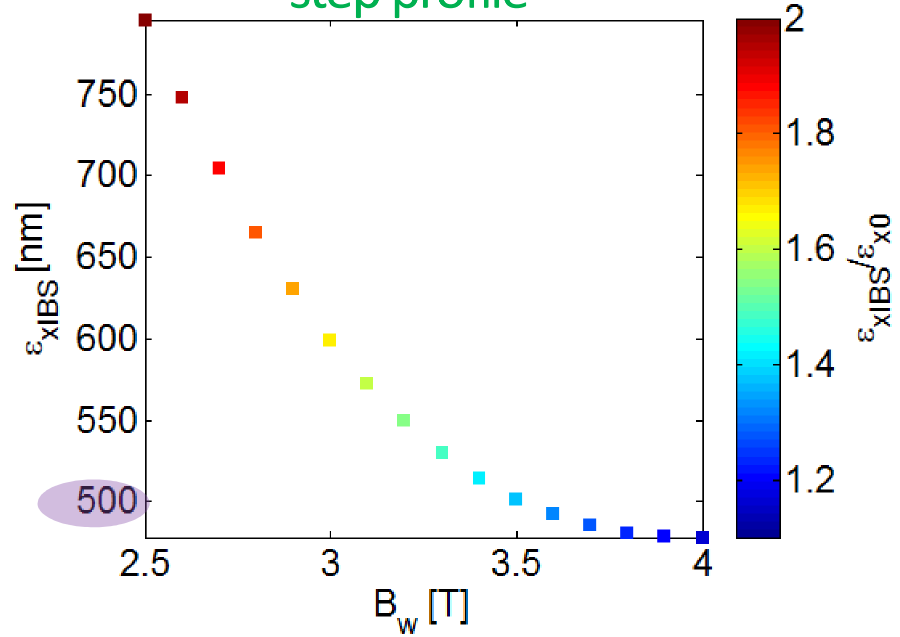
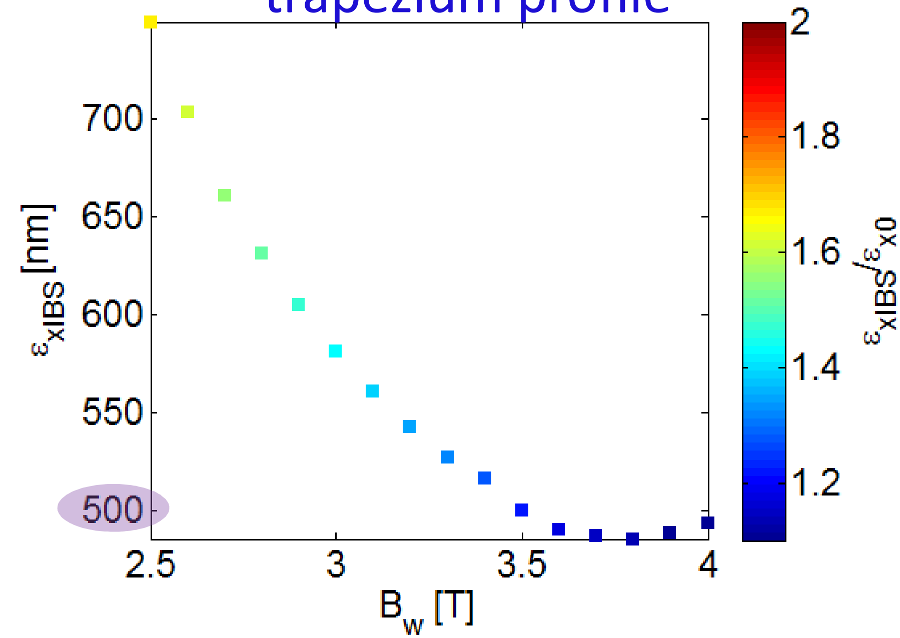




Parametrization of the steady state emittance and the IBS effect with the wiggler's peak field B_w

Design parameters for the main DRs, E=2.86 GeV , 2GHz

		Nb=4.07e+09		Nb=5.7e+09
Parameters, Symbol [Unit]	uniform	step	trapezium	trapezium
Number of arc cells/wigglers	100/52	96/40	90/40	90/40
Dipole field (max/min), B [T]	0.97/0.97	1.77/1.01	1.77/0.73	1.77/0.73
horiz. /vert. chromaticities ξ_x/ξ_y	-113/-82	-135/-76	-126/-72	-134/-41
Wiggler peak field B_w [T] for length L_w =2m	2.5	3.5	3.5	3.5
Wiggler period, λ_w [cm]	5.0	4.9	4.9	4.9
Mom. compaction, α_c [10^{-4}]	1.3	1.3	1.2	1.2
Energy loss/turn, U [MeV/turn]	4	5.7	5.7	5.8
Energy spread (rms), σ_δ [%]	0.12	0.13	0.13	0.13
Bunch length (rms), σ_s [mm]	1.8	1.6	1.6	1.3
Long. emittance , ε_l [keV m]	5.9	6.1	6.0	5.0
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)	(1.2, 1.2, 0.6)
IBS factors hor./ver./long.	2.2/1.5/1.2	1.4/1.5/1.1	1.4/1.5/1.1	1.4/2.0/1.1
Norm. horizontal emittance (with IBS), $\gamma\varepsilon_x$ [nm]	681	502	500	579
Norm. vertical emittance (with IBS), $\gamma\varepsilon_y$ [nm]	5	5	5	6.7
Circumference, C [m]	427.5	374.1 (-14%)	359.4 (-19%)	359.4 (-19%)

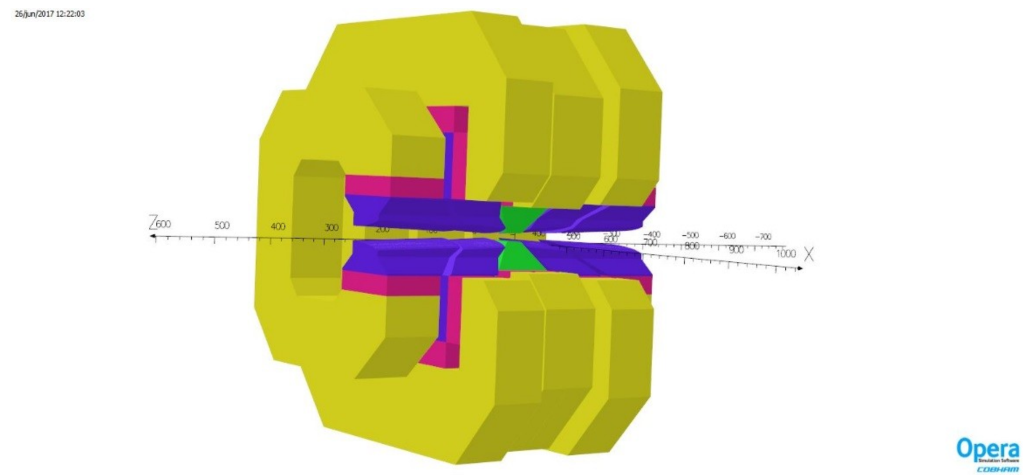
- S. Papadopoulou, F. Antoniou and Y. Papaphilippou, Alternative optics design of the CLIC Damping Rings with variable dipole bends and high-field wigglers, proc. of IPAC’15

-H. Ghasem et al. , “Nonlinear Optimization of CLIC DRS New Design with Variable Bends and High Field Wigglers”, proc. of IPAC'16

Magnet design based on the characteristics of the variable bends for the CLIC DRs

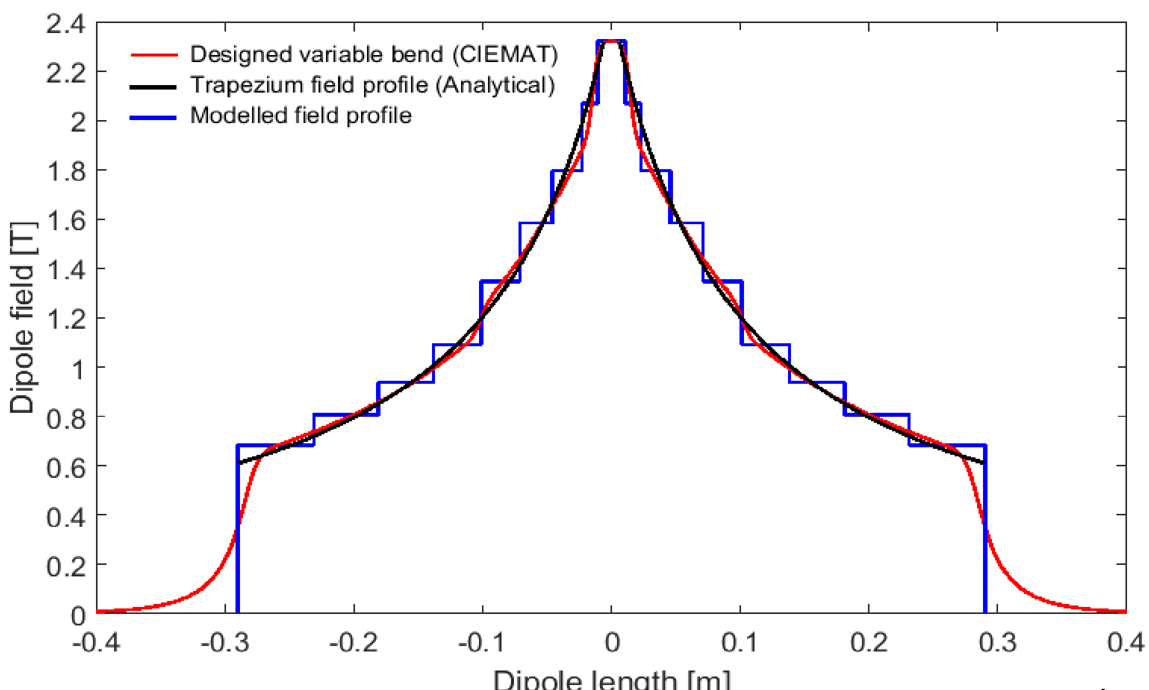
-Based on the trapezium profile, the designed dipole has a total length of 56 cm and bends the beam by 4 degrees.

- A maximum field of 2.3 T is reached. The λ and ρ values achieved are 0.04 and 0.29 respectively, corresponding to a F_{TME}=7.



M. A. Domínguez, F. Toral (CIEMAT, Spain)

see “Design of a Dipole with Longitudinally Variable Field using Permanent Magnets for CLIC DRs“



H. Ghasem

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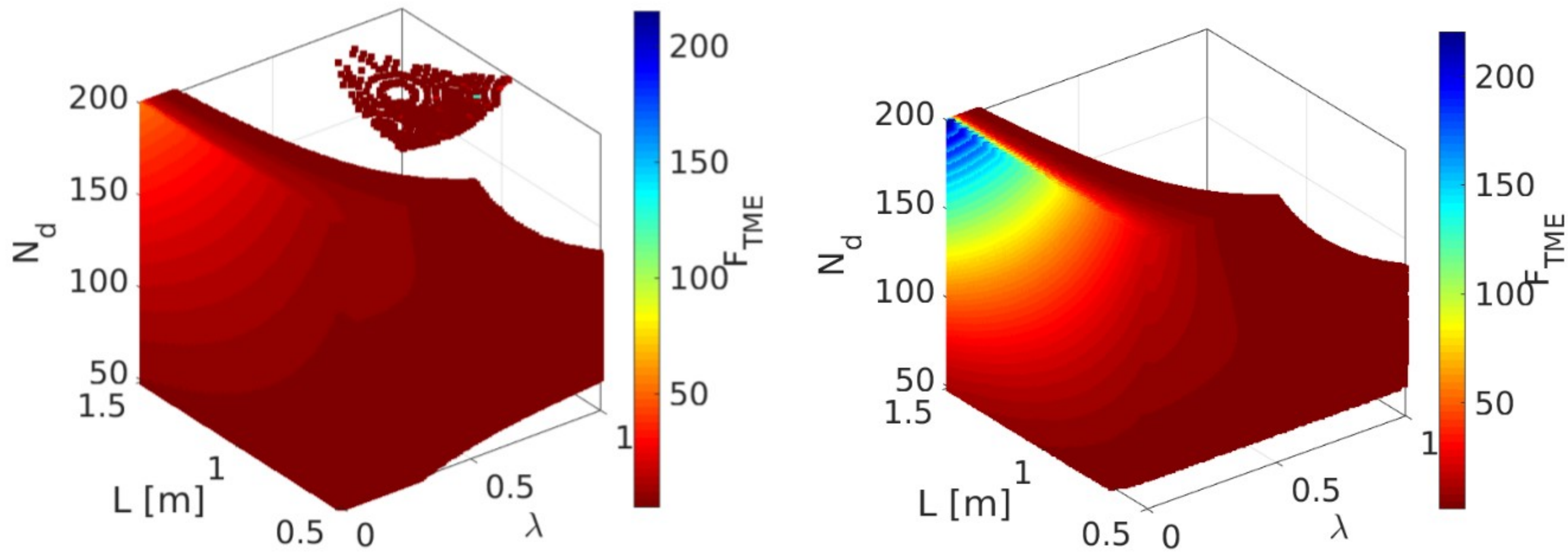
-R. Nagaoka, A.F. Wrulich, Nucl. Instrum. Methods Phys. Res., Sect. A 575, 292 (2007).
-C.-x Wang, PRST-AB 12, 061001 (2009).
-C.-x Wang, Y. Wang, Y. Peng, PRST-AB 14, 034001 (2011).

[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).

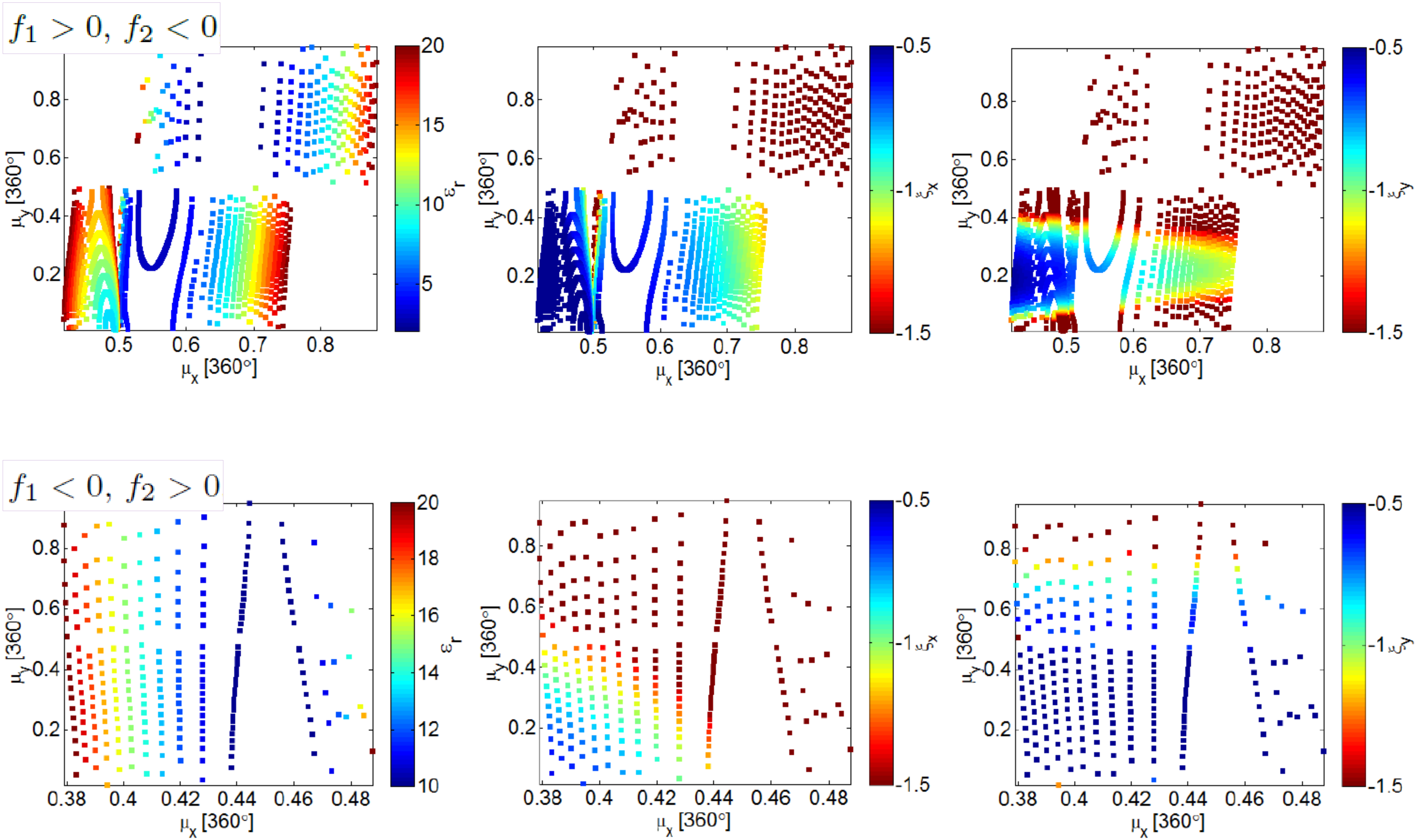
[4] L. Garcia Fajardo, ``Nb3Sn prototype progress'', CLIC Workshop, CERN, Geneva (2015).

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.

Optimization of the arc TME cell



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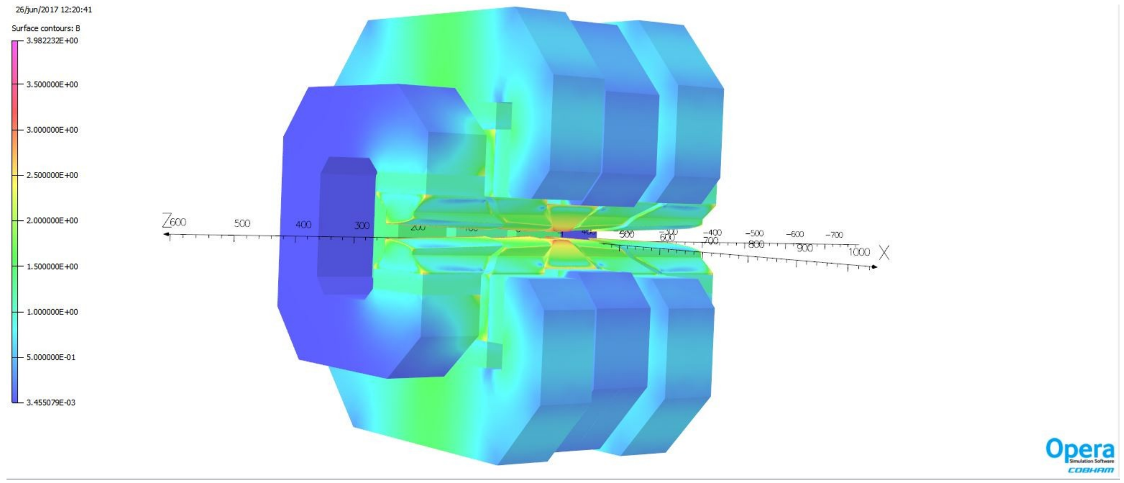
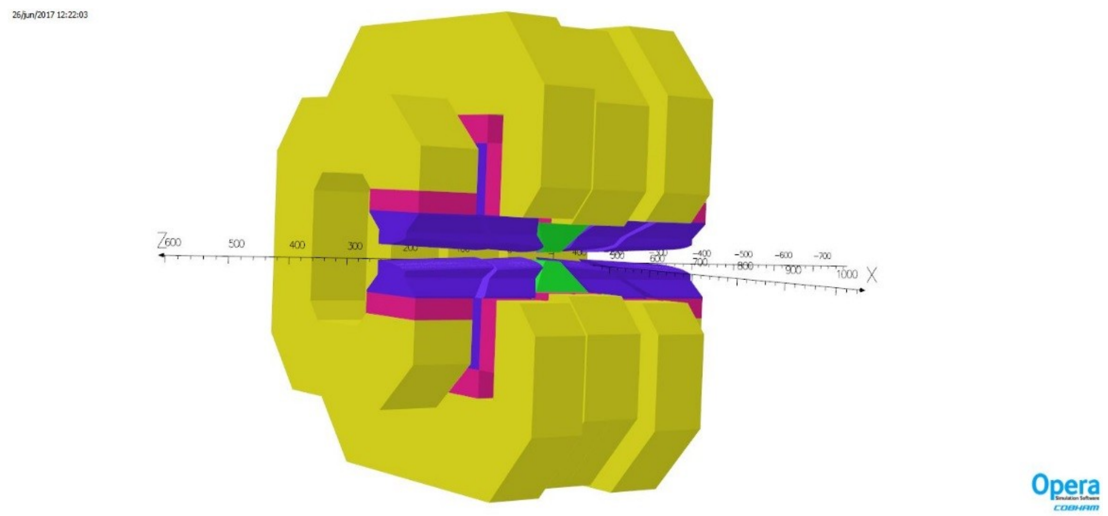
Magnet design based on the characteristics of the variable bends for the CLIC DRs





-Armco (pure iron) for the yokes, low and medium field poles
-Iron-cobalt in the high field pole
-SmCo in the low field permanent magnet
-NdFeBo in the medium and high field permanent magnets