CLIC DR design using variable bends and high-field wigglers

S. Papadopoulou[1,2], F. Antoniou[1], Y. Papaphilippou[1]

[1]CERN, [2]University of Crete

CLIC Workshop 2018

Outline

- **Optimization of the arc TME cell**
  - **-Longitudinally variable bends**
  - **-Parametrization with the drift space lengths and with the phase advances**

- **Optimization of the wiggler FODO cell**
  - **-A high field wiggler**

- **Design parameters of the main CLIC DRs**

- **Magnet design based on the characteristics of the variable bends for the CLIC DR dipoles**
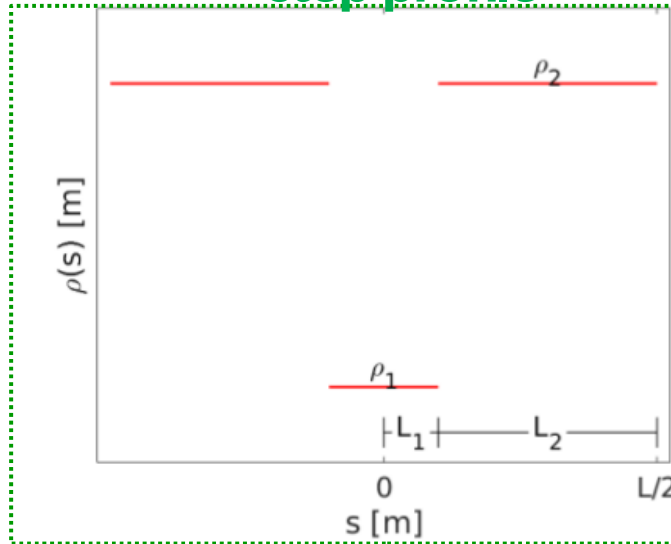
Longitudinally variable bends

The longitudinal variable bends can give lower emittances than a uniform dipole of the same bending angle [1].

$$\epsilon_x = \frac{C_q \gamma^2}{J_x} \frac{\left\langle \frac{\mathcal{H}_x}{|\rho_x|^3} \right\rangle}{\left\langle \frac{1}{\rho_x^2} \right\rangle}$$

Dispersion invariant, determined by the Twiss parameters and the dispersion function

Bending radius

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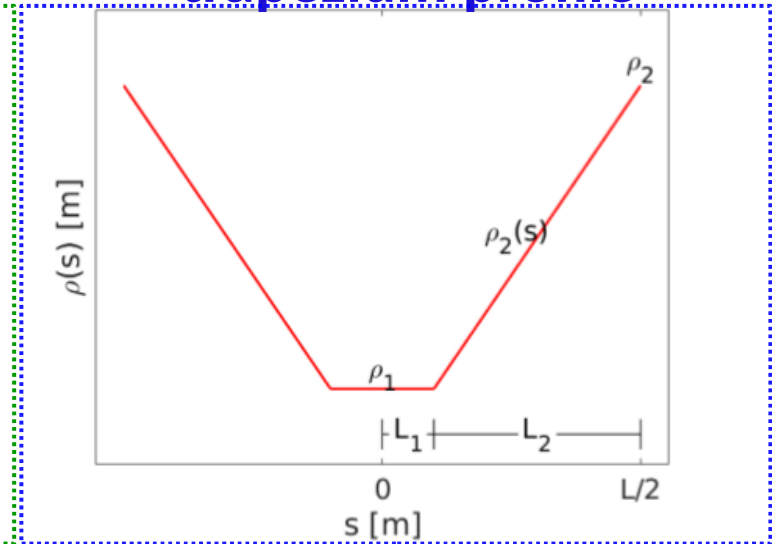
Dispersion invariant, determined by the Twiss parameters and the dispersion function

Bending radius

step profile
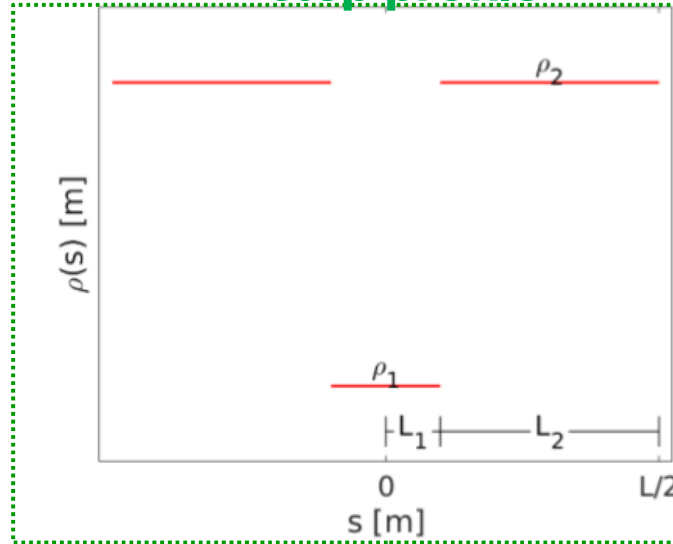

trapezium profile

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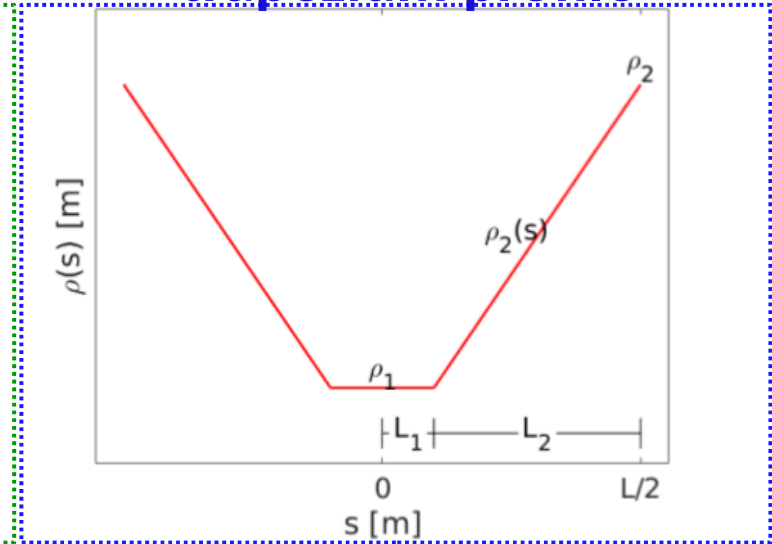
► *Dispersion invariant*, determined by the Twiss parameters and the dispersion function

► *Bending radius*

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

Longitudinally variable bends

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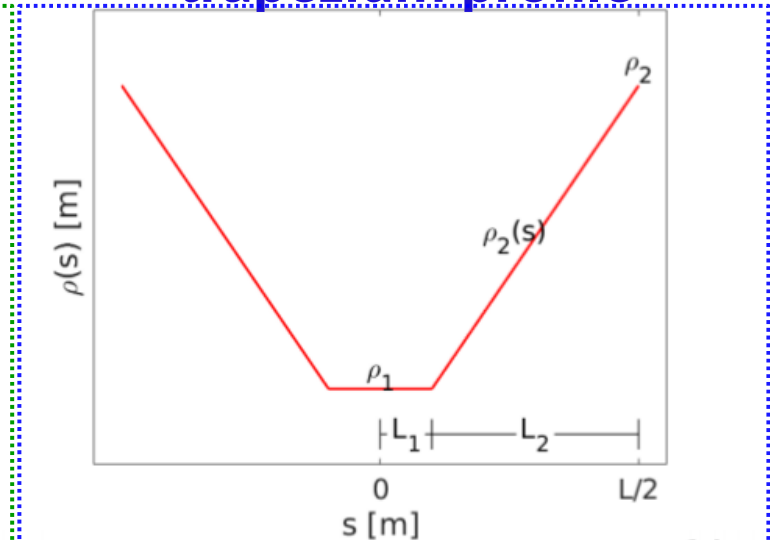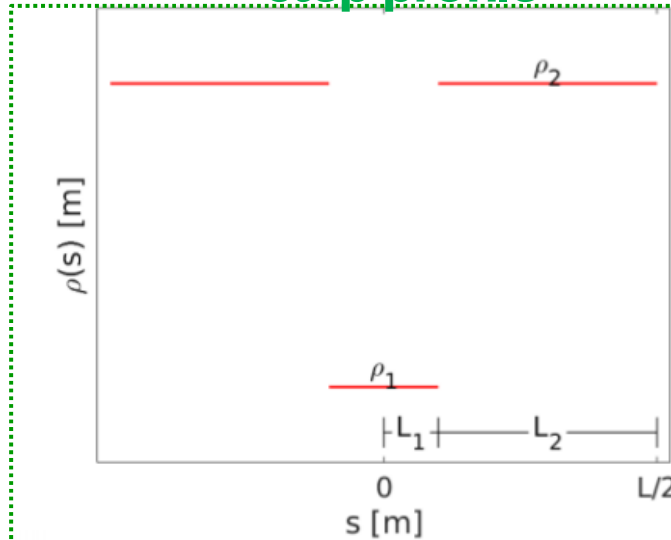
$$\epsilon_x = \frac{C_q \gamma^2}{J_x} \frac{\left\langle \frac{\mathcal{H}_x}{|\rho_x|^3} \right\rangle}{\left\langle \frac{1}{\rho_x^2} \right\rangle}$$

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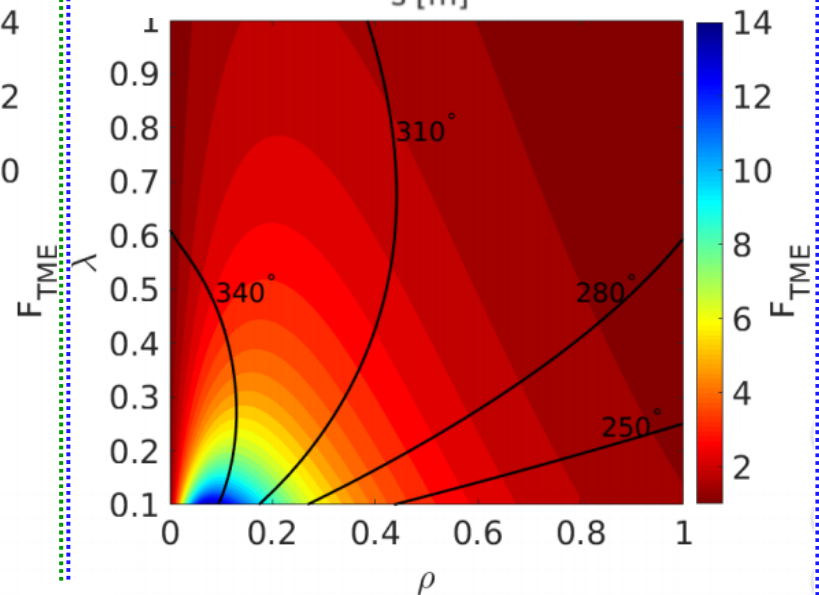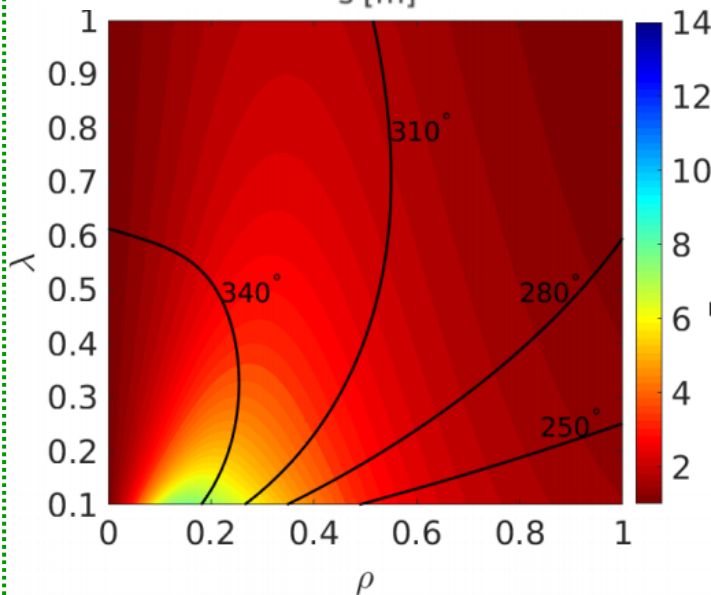$$\rho = \frac{\rho_1}{\rho_2}$$

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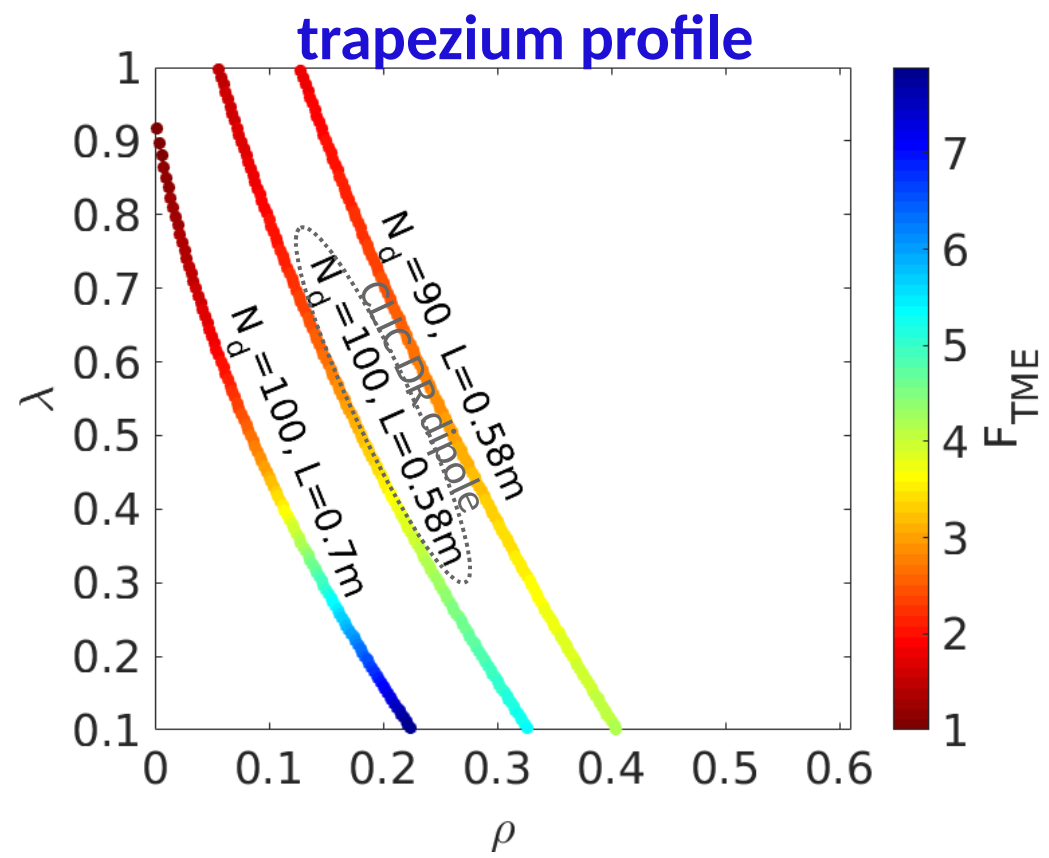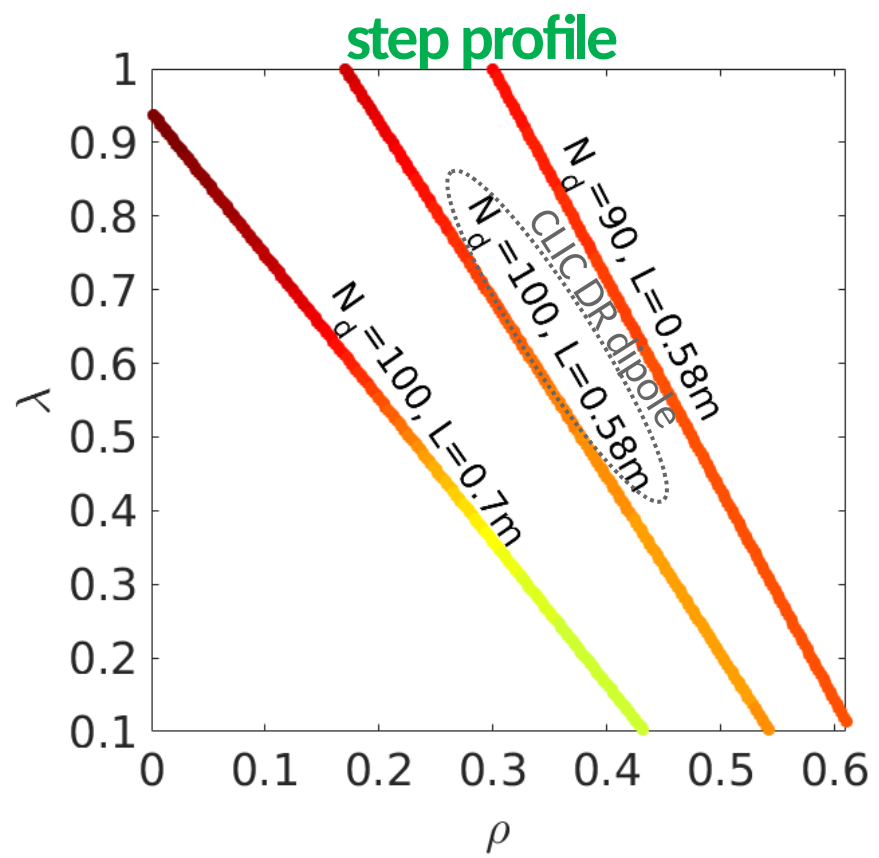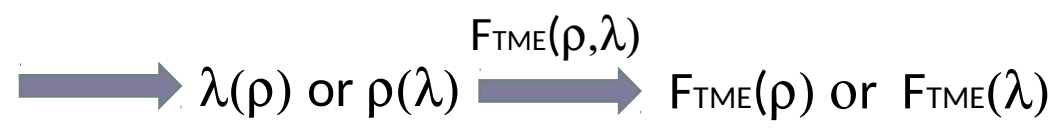$$F_{TME} = \frac{\epsilon_{TME_{uni}}}{\epsilon_{TME_{var}}}$$

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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, for $\lambda > 0.1$.
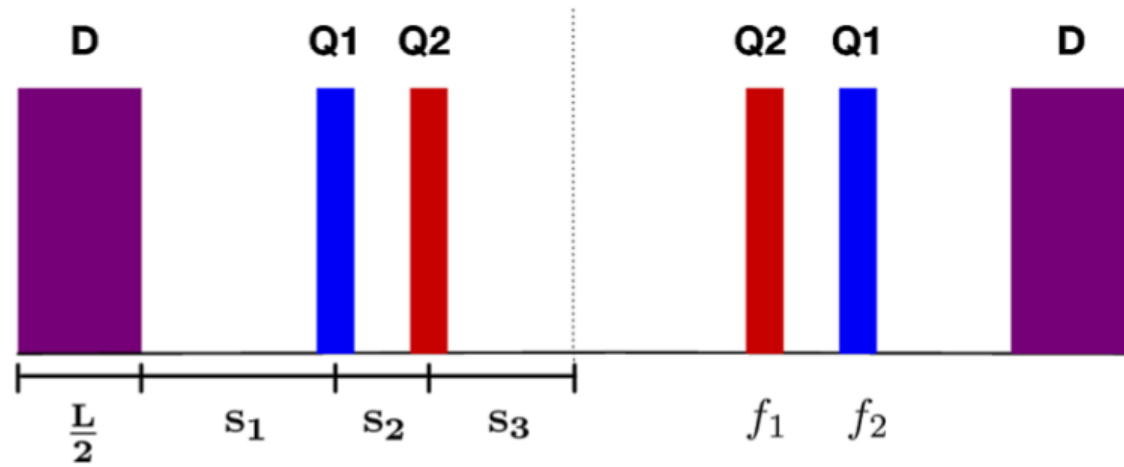
Fixing the dipole's characteristics (bending angle, length and minimum bending radius)

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

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

$$\longrightarrow \quad \lambda(\rho) \text{ or } \rho(\lambda) \quad \xrightarrow{\; F_{TME}(\rho,\lambda) \;} \quad F_{TME}(\rho) \text{ or } F_{TME}(\lambda)$$

step profile

trapezium profile

$N_d = 90$, L=0.58m
$N_d = 100$, L=0.58m
CLIC DR dipole
$N_d = 100$, L=0.7m

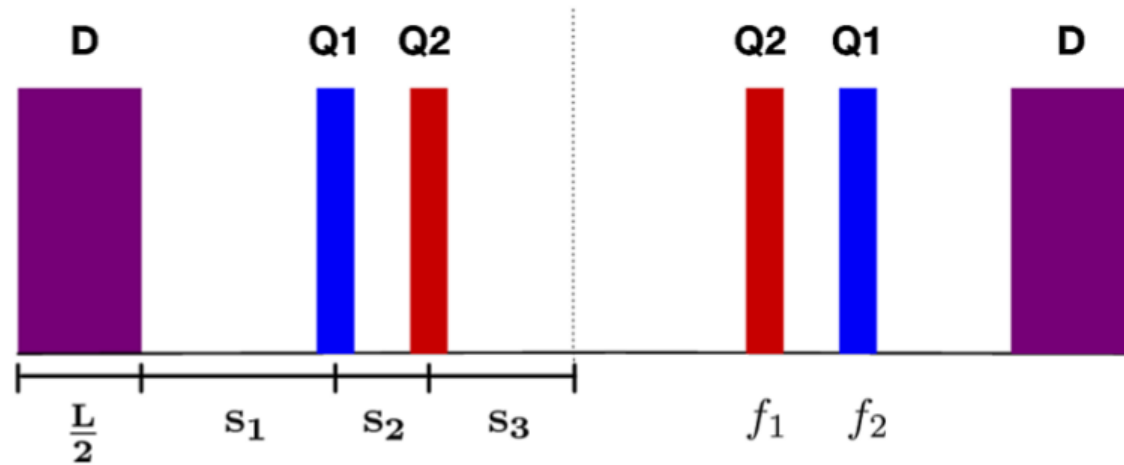$$\downarrow L, N_d \quad \longrightarrow \quad \downarrow F_{TME}$$

Optimization of the arc TME cell

Fix the dipoles' characteristics in order to get a large F_{TME}

Optimization of the arc TME cell

		D		Q1 Q2			Q2 Q1		D

$\frac{L}{2}$ s_1 s_2 s_3 f_1 f_2

Fix the dipoles' characteristics in order to get a large F_{TME}

Find the lengths of the elements and of the drifts that result in a compact cell
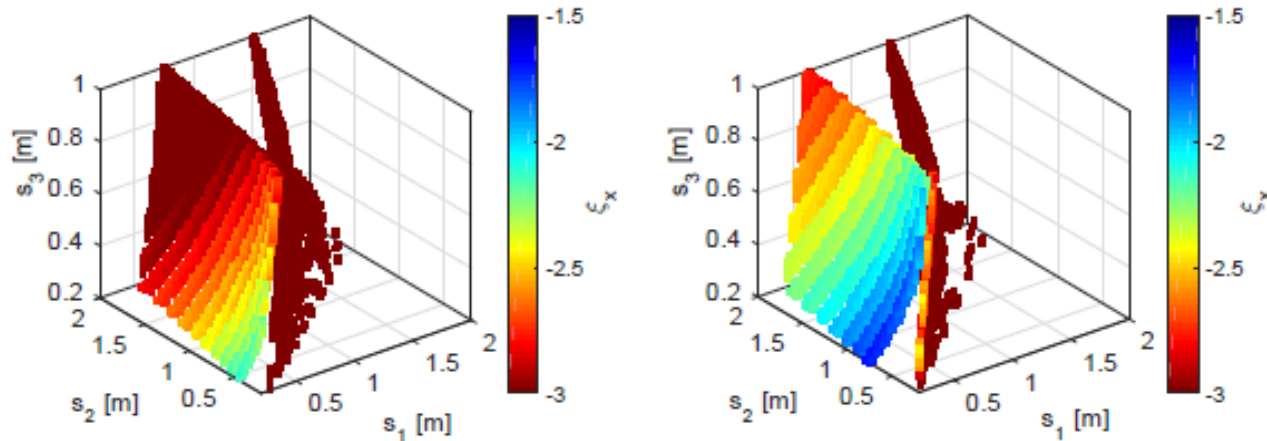
The horizontal chromaticity ξ_x is parameterized with the drift lengths s_1, s_2, s_3 for the TME, for the step (left) and the trapezium (right) profile
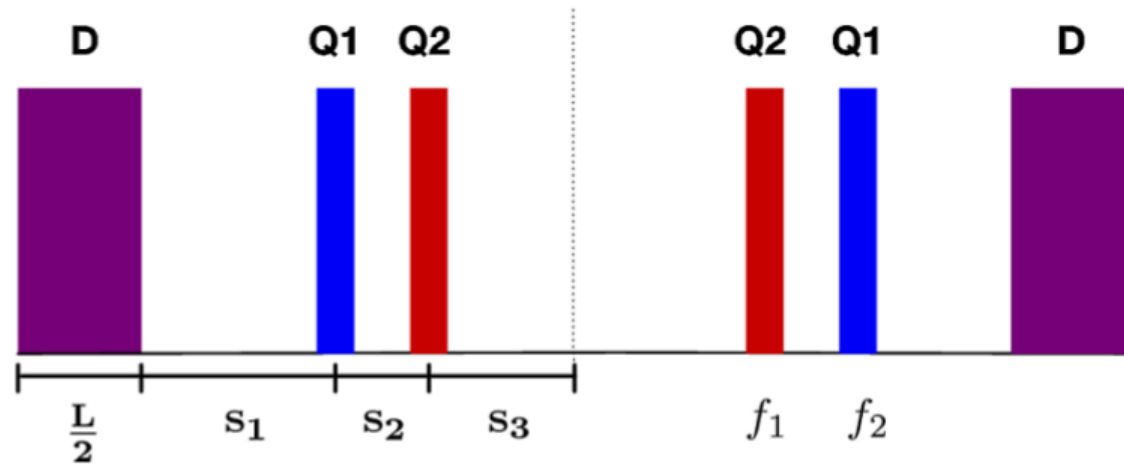
Optimization of the arc TME cell

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Find the lengths of the elements and of the drifts that result in a compact cell

Find the optimal phase advances that give the required emittance, chromaticities, quadrupole strengths

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.

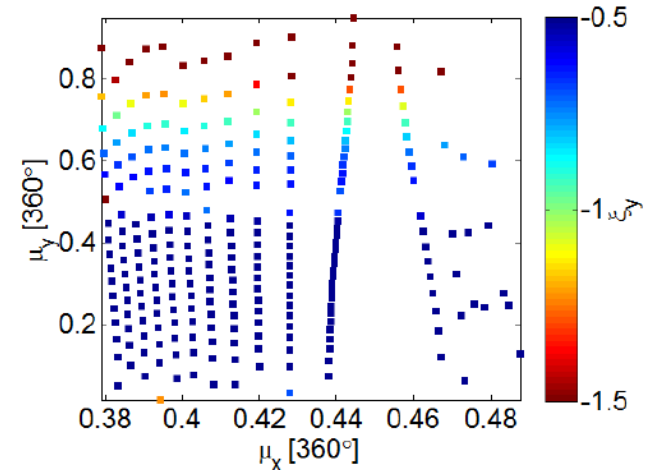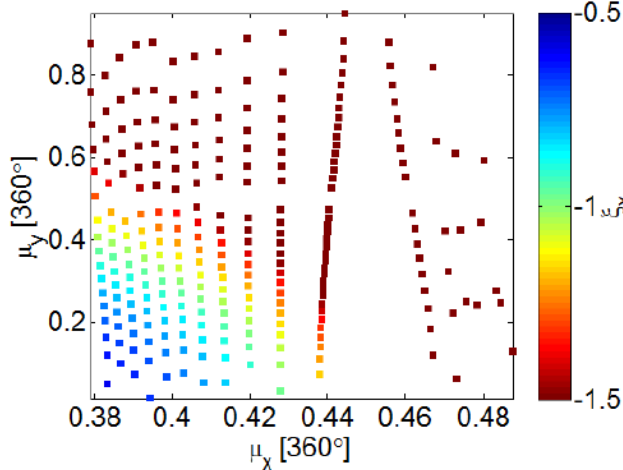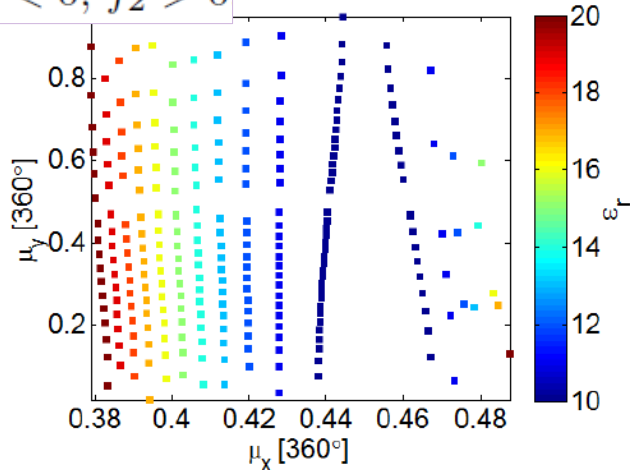# Optimization of the arc TME cell

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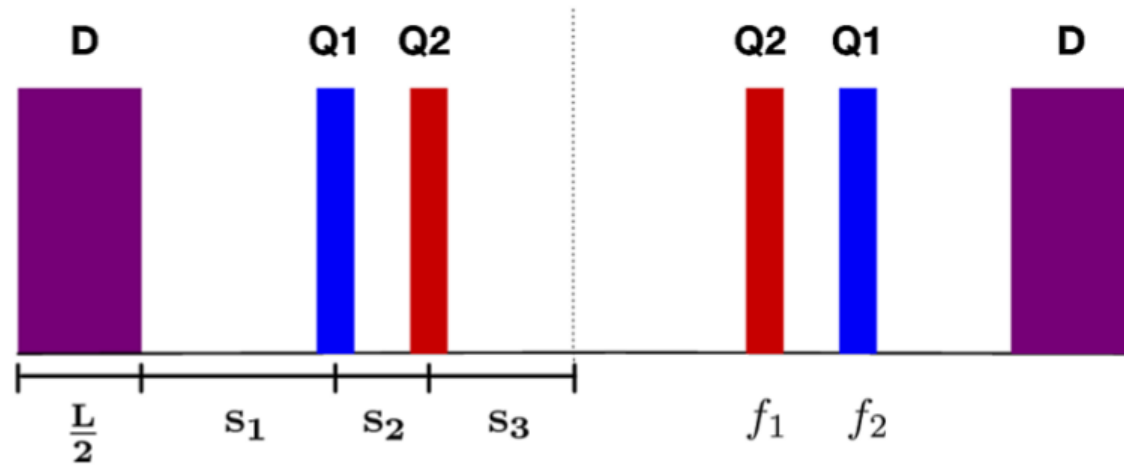Find the lengths of the elements and of the drifts that result in a compact cell

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

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

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

Optimization of the arc TME cell

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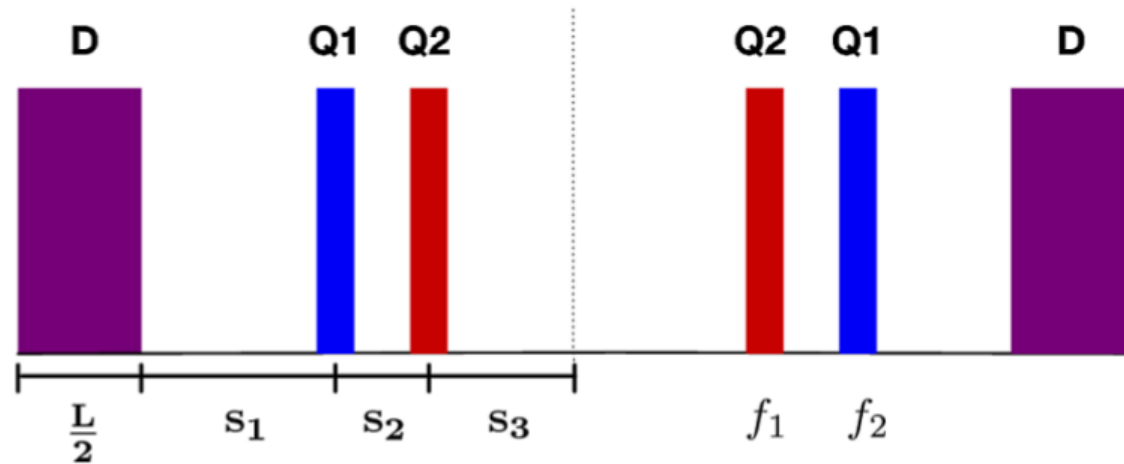Find the lengths of the elements and of the drifts that result in a compact cell

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

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.

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
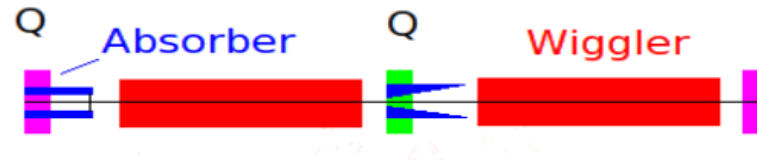
Results obtained after the optimization of the arc TME cell.

+

When increasing the wigglers' peak field B_w up to a certain point, the emittance and the IBS effect are lowered [2].

+

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 [3].

→

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

Optimization of the wiggler FODO cell

Q   Absorber   Q   Wiggler

Results obtained after the optimization of the arc TME cell.

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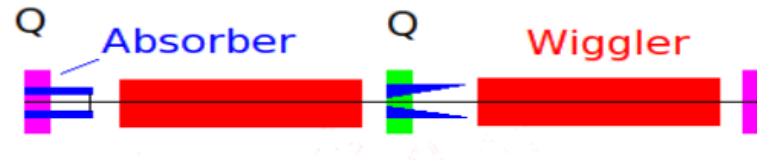
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Optimization of the wiggler FODO cell

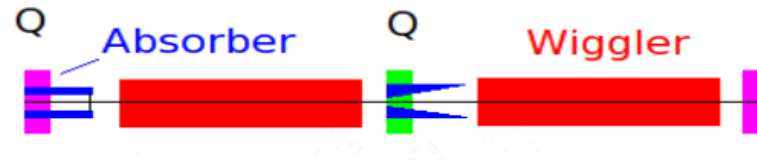|	
Results obtained after the optimization of the arc TME cell.	When increasing the wigglers' peak field B_w up to a certain point, the emittance and the IBS effect are lowered [2].

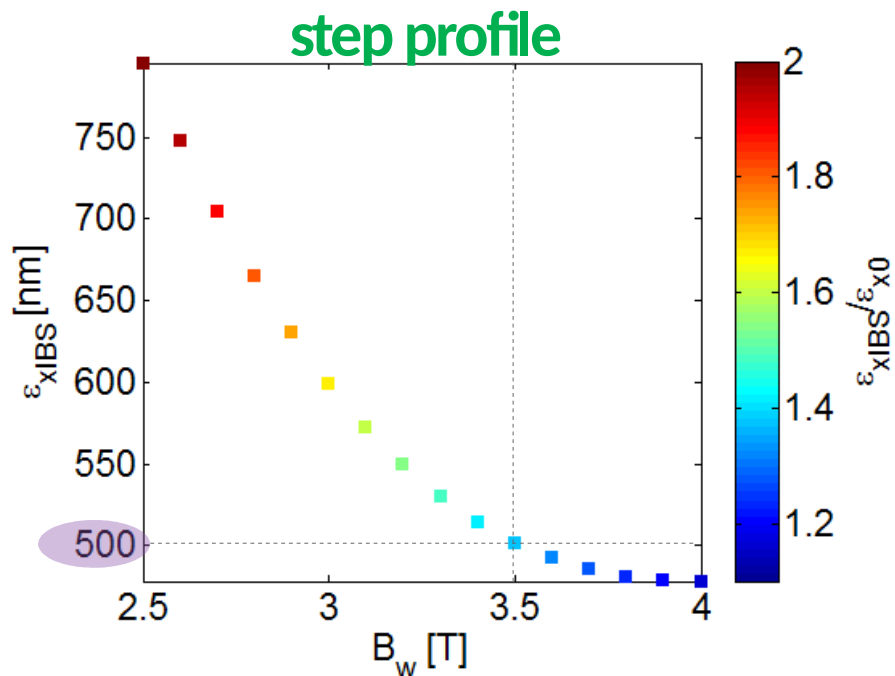Based on the technological restrictions, a new working point for the damp. wiggler is proposed to be at 3.5T (prev. 2.5T), with 49mm period length [3].

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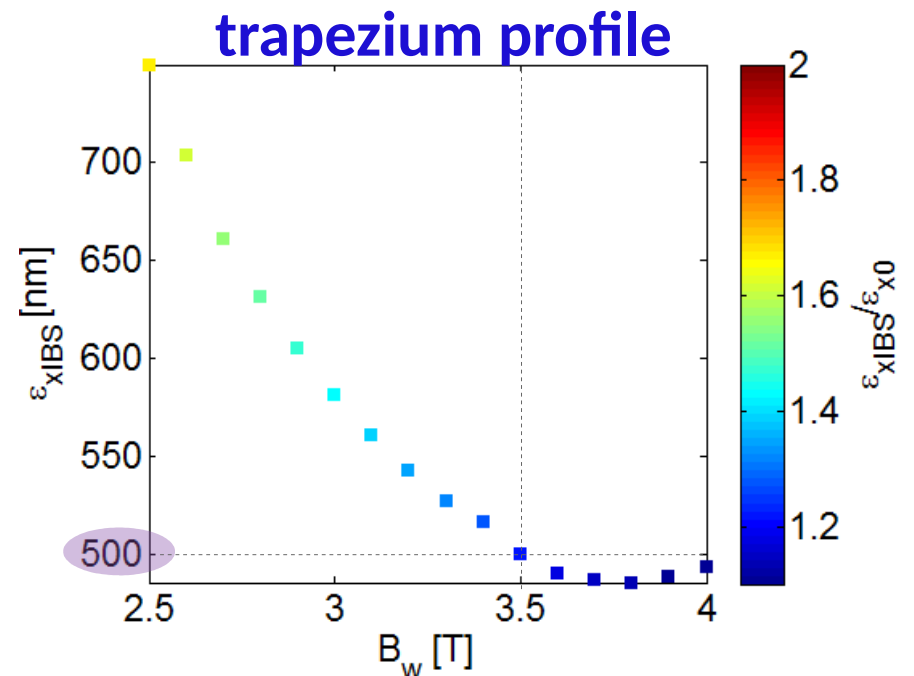
Parametrization of the steady state emittance and the IBS effect with the wiggler's peak field B_w

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

Parameters, Symbol [Unit]	uniform	step	trapezium	trapezium
		Nb=4.07e+09		Nb=5.7e+09
Number of arc TME 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, IPAC'15
-H. Ghasem et al. , Nonlinear Optimization of CLIC DRS New Design with Variable Bends and High Field Wigglers, 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 $F_{TME}=7$.

26/Jun/2017 12:22:03
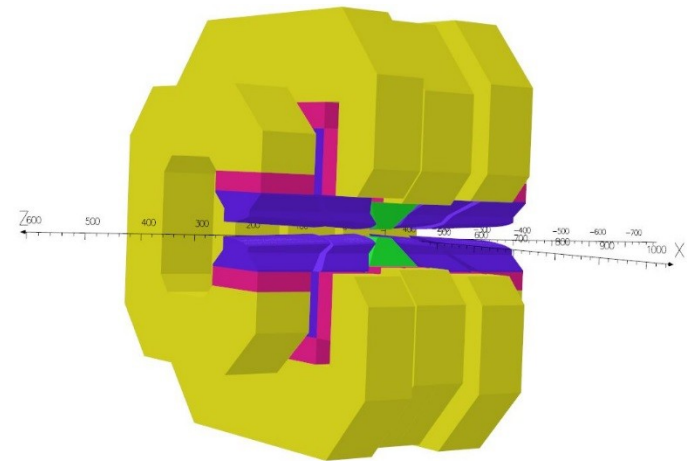
Opera

M. A. Domínguez, F. Toral (CIEMAT, Spain)
see "Design of a Variable bend prototype", CLIC workshop 2018
https://indico.cern.ch/event/656356/contributions/2838073/
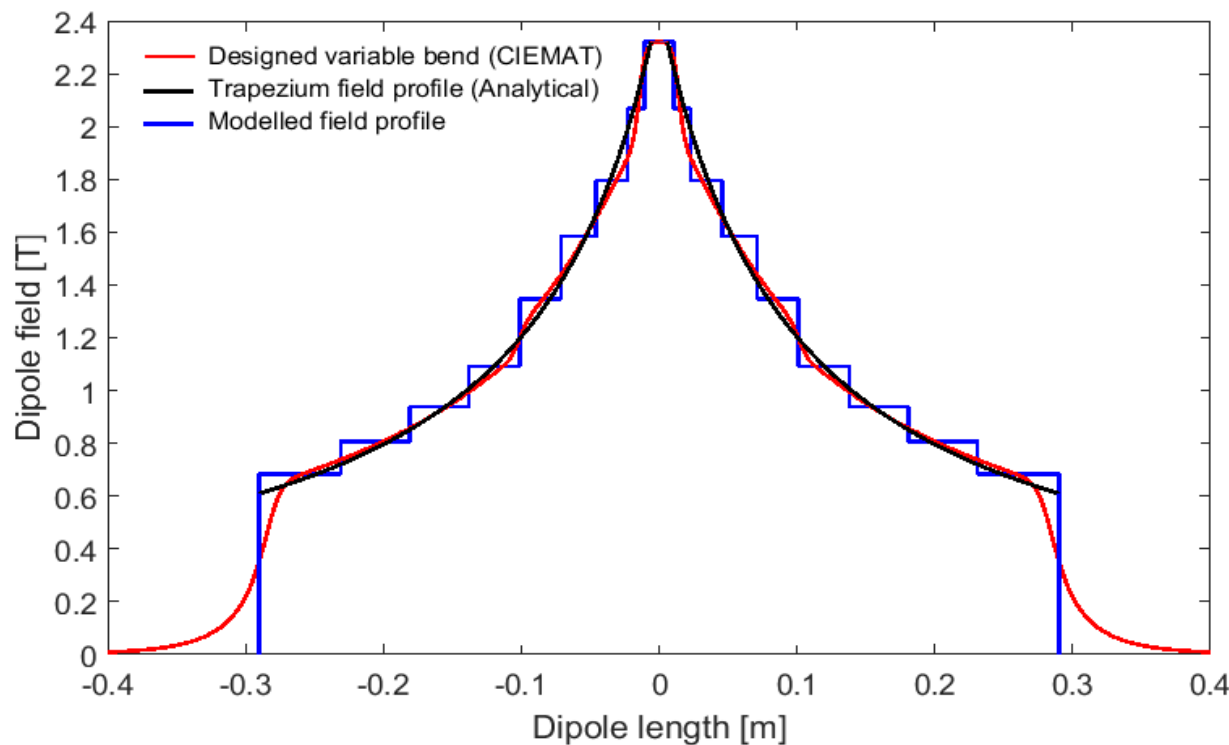

H. Ghasem

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).
        -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

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

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

Thank you!

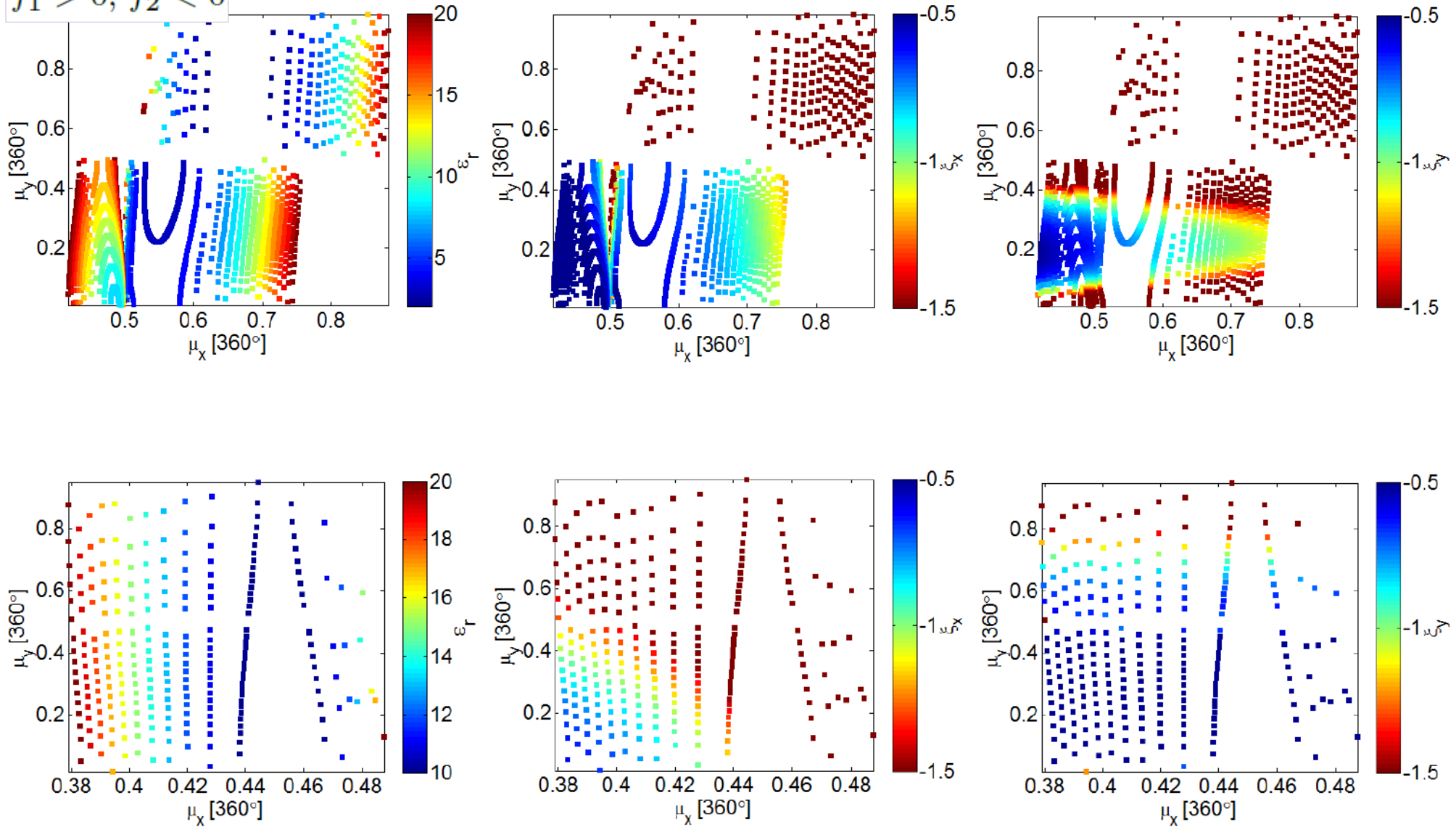# Magnet design based on the characteristics of the variable bends for the CLIC DRs
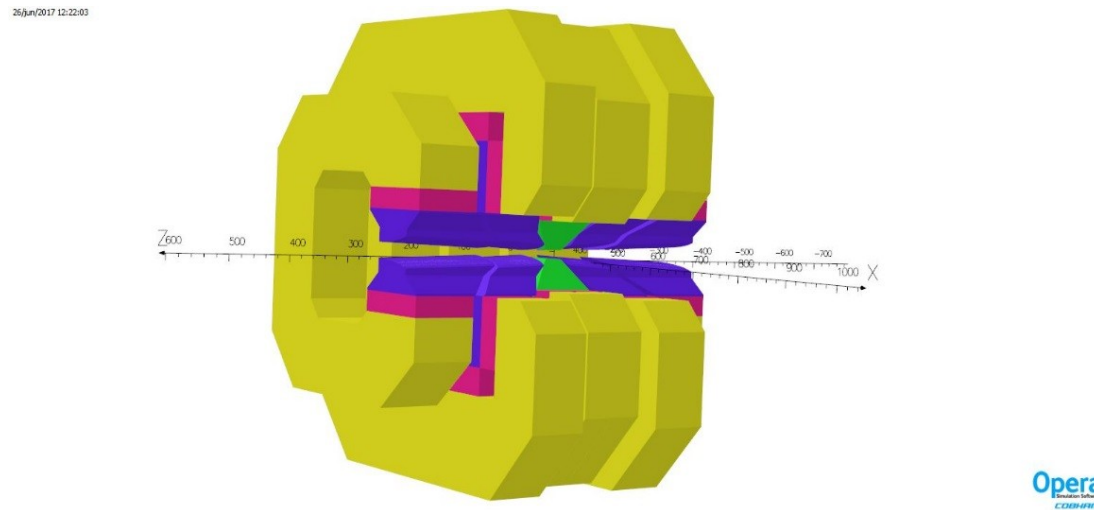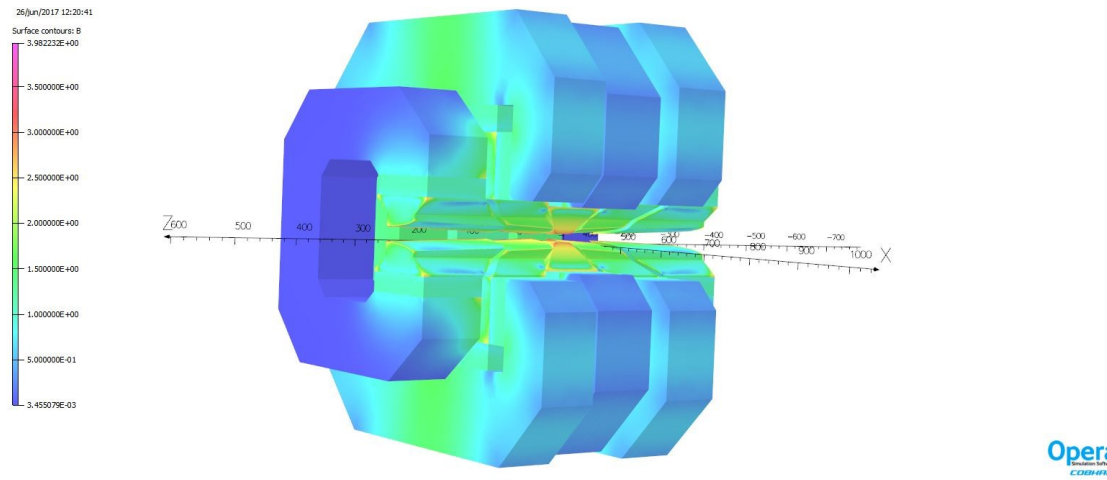
-Armco (pure iron) for the yokes, low and medium field poles
-Iron-cobalt in the high field pole
-SmCo in the low field permanent magnet
-NdFeBo in the medium and high field permanent magnets
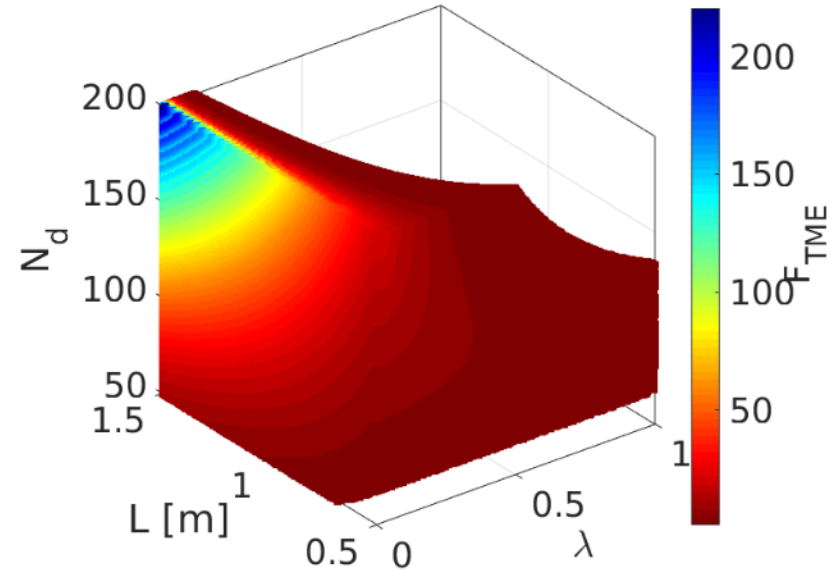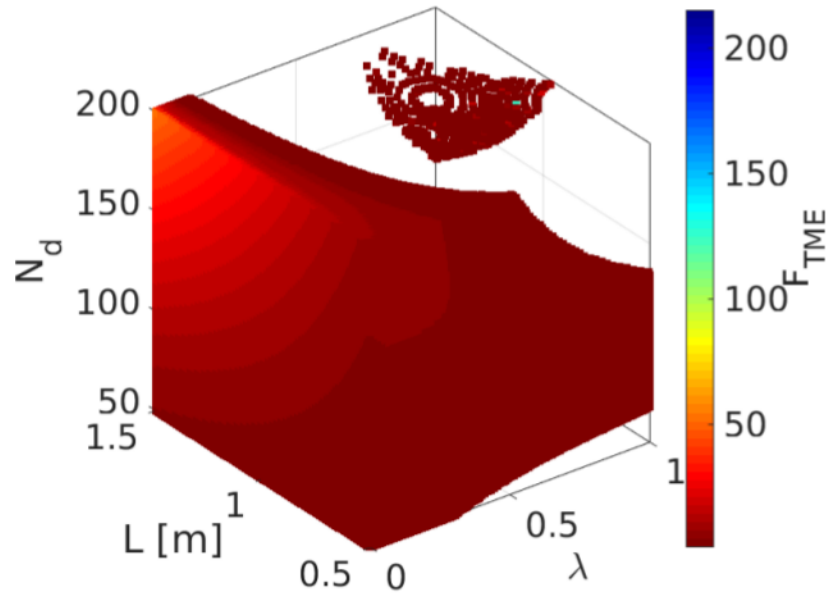
The parameterization of the emittance reduction factor F$_{TME}$ with the lengths ratio λ, the dipole length L and the number of dipoles used N$_d$ for the step (left) and the trapezium (right) profile.

Optimization of the arc TME cell

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.