Impact of the main linac couplers on the beam

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Objectives of this work

1. Study the impact of the baseline main linac couplers on the beam dynamics, TD26_CC

2. Compare the baseline design with an alternative design
   - baseline TD26_CC : “double-feed” coupler
   - alternative TD26_CCSF : “single-feed” coupler

Tools developed:

- Set of programs to extract the multipole coefficients from a 3-dimensional complex field-map
- Introduced rf-multipolar kicks in Placet

Overview of this talk

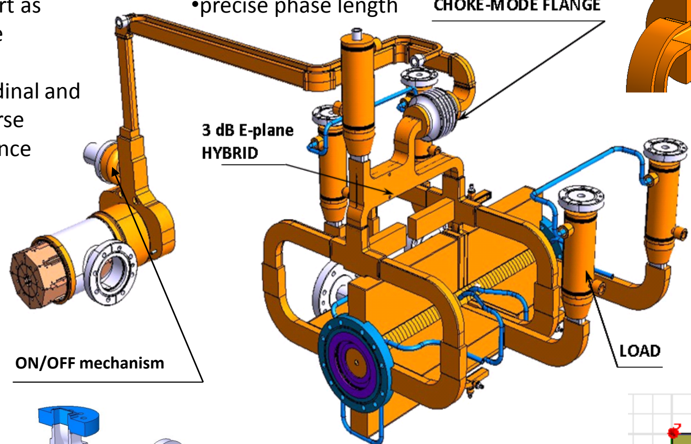
- Introduction
- Multipole expansion of a field map
- RF-Multipoles
- Simulation setup and case studies
- Results
- Conclusions

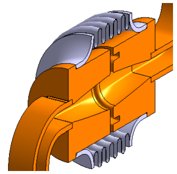
TD26_CC: double-feed compact coupler

(pictures courtesy of W. Wuensch and G. Riddone, CLIC ACE Meeting, Feb 2011)

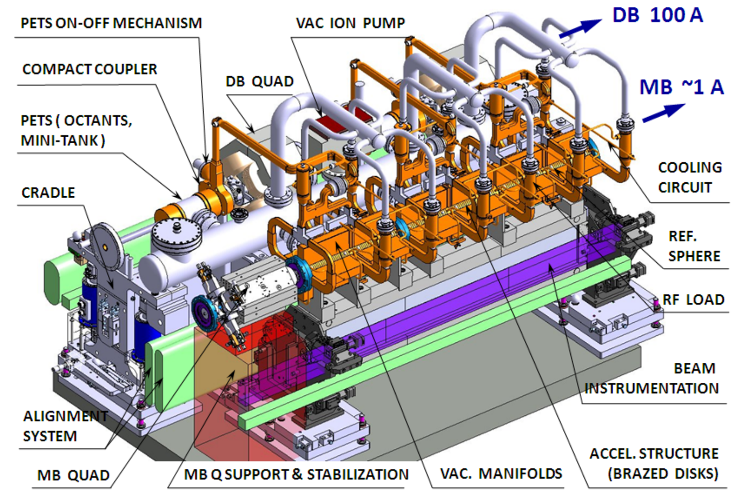
PETS
- high-power
- as short as possible
- low longitudinal and transverse impedance

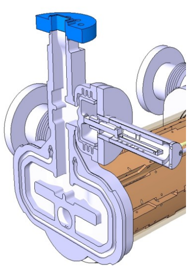
Waveguide network
- high power
- precise phase length





Choke mode flange
- independent alignment of main and drive beam

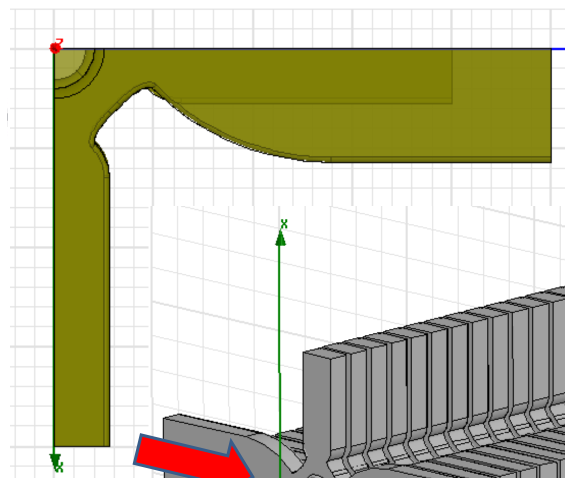


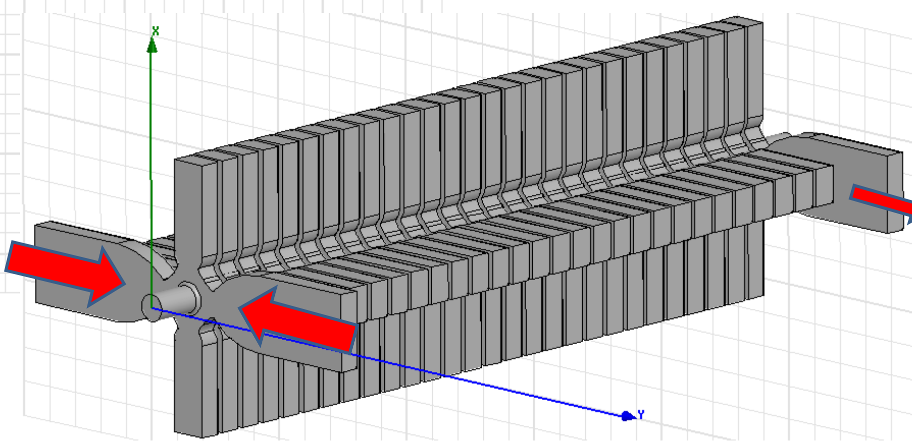


On/ramp/off
- necessary (?) to react to breakdown and/or failure

Accelerating structure
- high-gradient
- as long as possible
- micron precision
- transverse wakefield suppression

Will be used for CLIC module prototype and for a structure prototype for high power testing with damped compact coupler (TD26_vg1.8_R05_CC)





Introduction

- Baseline main linac cavities, TD26, foresee double-feed compact couplers (TD26_CC)

- An alternative design exists, implementing single-feed couplers (TD26_CCSF)

- Each carries pros and cons:
  - complexity, cost, impact on the beam-dynamics, …

➢ Couplers, as they break the cylindrical symmetry of the beam pipe, give (undesired) transverse RF-kicks to the beam

➢ By design:
  - ➢ TD26_CC introduces quadrupolar and octupolar fields
  - ➢ TD26_CCSF introduces, also, a dipole and a sextupole component

Extracting the Multipolar Components

Given a 3d field map, $E_{xyz}(x,y,z)$:

- the field is sliced along the z axis : $E_{xyz,i}(x,y)=E_{xyz}(x,y,z_i)$
- the multipolar components are calculated over each slice : $E_{xyz,i}(x,y)$

The multipole expansion can be carried out either in the *xy* plane, or along the *z* axis:

(1) Using E_x and E_y	(2) Using E_z
$E_y + iE_x = \sum_{n=1}^{N} C_n \,(x+iy)^{n-1}$	$E_z = \sum_{n=0}^{N} D_n \,(x+iy)^{n}$

The coefficients can be computed through a disk integral within the aperture, or along a circle

$$C_n = \frac{1}{A_{\Omega}} \iint_{\Omega} \left[\frac{B_r(r,\varphi)}{r^n e^{in\varphi}}\, r \right] \mathrm{d}\Omega$$

Whether (1) or (2) are considered, the transverse kick on the particles can be computed:

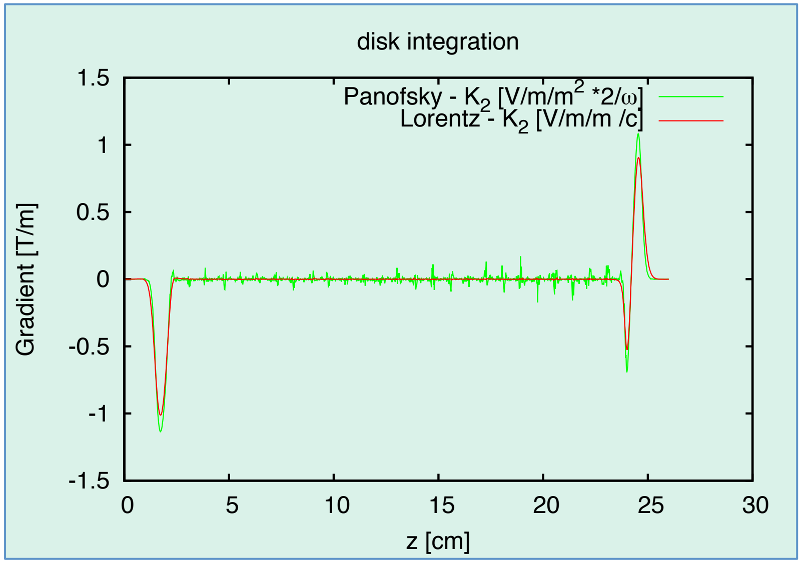
(1) applying the Lorentz force

(2) using the Panofsky-Wenzel theorem

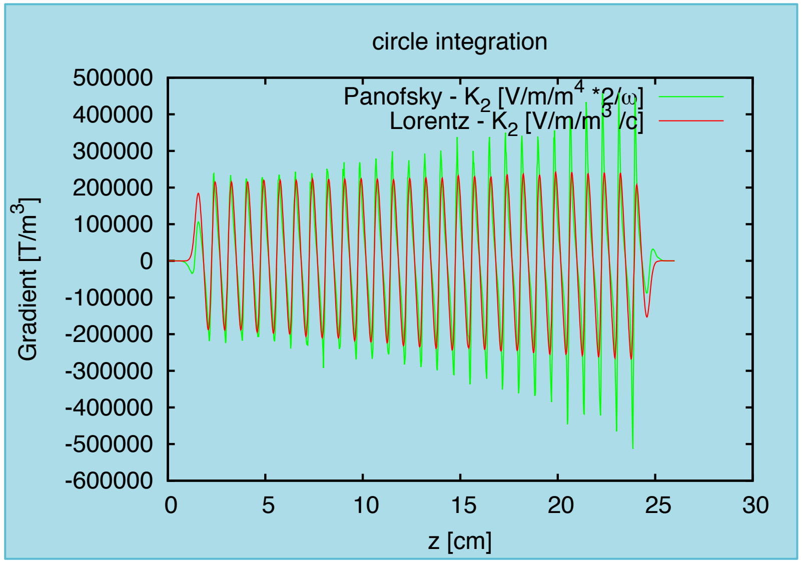
Qadrupole and Octupole Components in TD26_CC

The multipole coefficients have been converted in the equivalent magnetic gradients

Quadrupole



Octupole



The integrated strengths have been calculated (and applied) in:

- 2 locations: Input Coupler, Output Coupler for the *quadrupole* component
- 1 location: Average (middle of the cavity) for the *octupole* component

Rf-Multipolar Expansion

- Given the symmetries of the problem, the RF-field can be expanded in multipoles
- As it's a phasor, i.e. a "rotating field" : its components depend on the longitudinal position of the particles within the accelerating structure
- A rotating multipolar field can be represented using a modified multipole: an **rf-multipole**, where the coefficients are the real part (cosine) of the *phasor* associated with the standard multipolar coefficient.
- Multipole expansion of a (magnetic) field

$$B_y + iB_x = \sum_{n=1}^{N} \left(B_n(r_0) + i\, A_n(r_0)\right) \cdot \frac{z^{n-1}}{r_0^{n-1}}$$

- Dependence of the coefficients on *z* and on the RF parameters

$$C_n(z) = B_n(z) + i\, A_n(z),$$

$$B_n(z) = B_n \cos\left(k_{\mathrm{RF}} z + \vartheta_n\right)$$

$$A_n(z) = A_n \cos\left(k_{\mathrm{RF}} z + \varphi_n\right)$$

$k_{\mathrm{RF}} = \frac{\omega_{\mathrm{RF}}}{c} = \frac{2\pi}{\lambda_{\mathrm{RF}}}$ RF wave number,

B_n	absolute value of the phasor $\vec{B}_n$,
A_n	absolute value of the phasor $\vec{A}_n$,
ϑ_n	phase of the phasor $\vec{B}_n$;
φ_n	phase of the phasor $\vec{A}_n$.

Strengths of the Multipolar-Kicks Summary Table

TD26_CC: on crest

	Symbol	Input C	Acc Structure	Output C	Units
Quadrupole	S_2	0.002	-	-0.001	GeV/m
Octupole	S_4	-	59.7	-	GeV/m^3

TD26_CCSF: TD26_CC +

- Horizontal dipole kick

	$S_{1,\mathrm{input}}$ [GeV]	$S_{1,\mathrm{output}}$ [GeV]
$\phi = 8°$	$-1.38 \cdot 10^{-5}$	$-4.02 \cdot 10^{-6}$
$\phi = 30°$	$-1.156 \cdot 10^{-5}$	$-3.77 \cdot 10^{-6}$

- Sextupole kick

	$S_{3,\mathrm{input}}$ [GeV/m^2]	$S_{3,\mathrm{output}}$ [GeV/m^2]
$\phi = 8°$	-0.25	0.068
$\phi = 30°$	-0.21	0.059

Comment: we expect TD26_CCSF to perform worse than TD26_CC

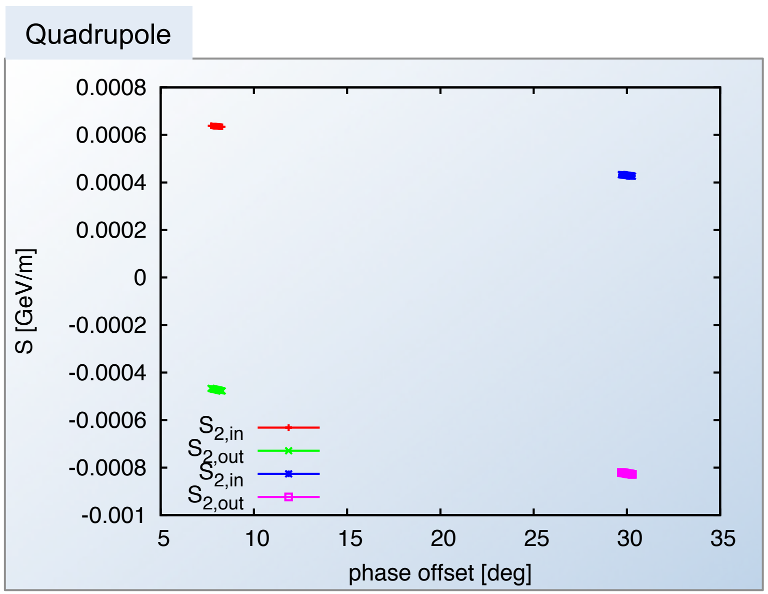
Phase dependence of the strength

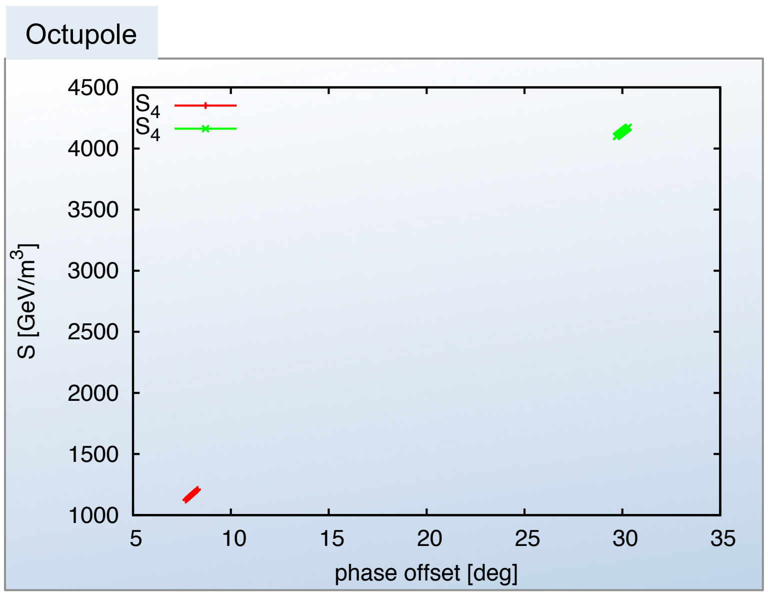
The EM field depends on the phase and so do the transverse kicks.

In the CLIC main linac, the beam is accelerated off-crest, at two phases:

- *8 and 30 degrees.*

The bunch length, 44 microm, accounts for 0.63 degrees phase difference.



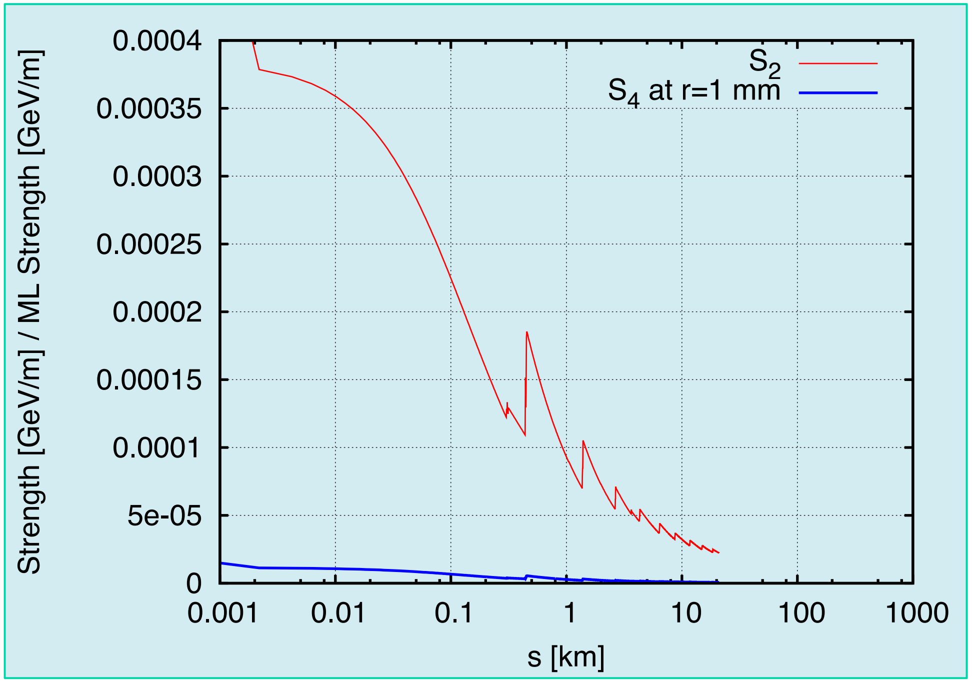


At phi=30 degrees the octupolar component is magnified by a factor ~70 w.r.t. the on-crest particle.

Transverse kick strength in TD26_CC

Compare the integrated strength of the main linac quads vs the couplers' kicks

Couplers strength / Main linac quads strengths

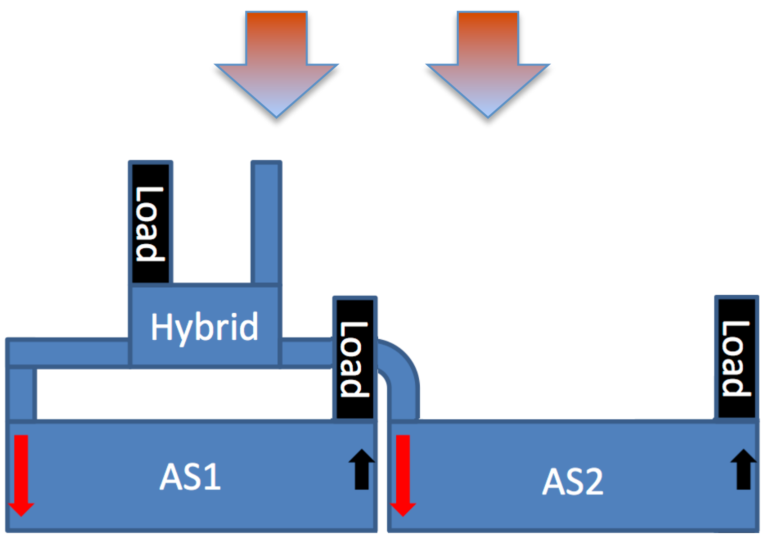


Preliminary conclusion: The coupler kicks are very small.

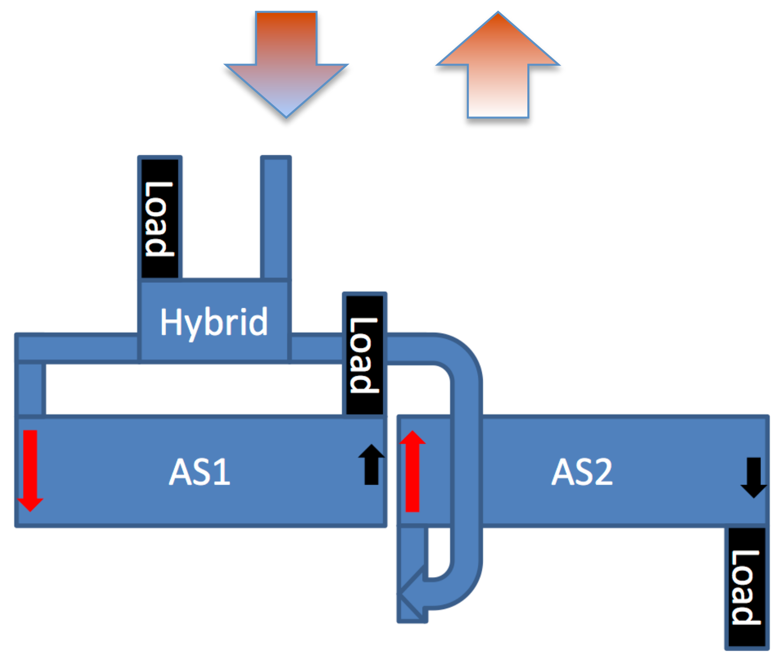
1st order compensation of the dipole kick in TD26_CCSF

To compensate the dipole kick, an alternate pattern has been considered

- Left plot: uncompensated case
- Right plot: 1st order cancellation of the dipole kick



Uncompensated configuration



1st order compensation of the kick: **TD26_CCSF2**

In the following, only the compensated case is considered
(sometimes it's called TD26_CCSF2)

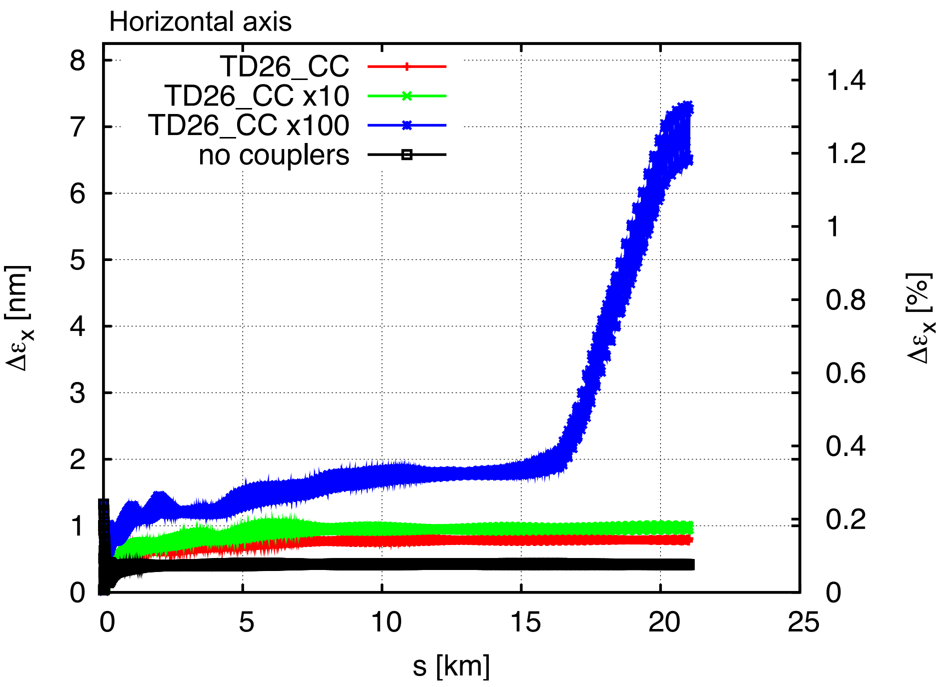
Case studies and simulation results

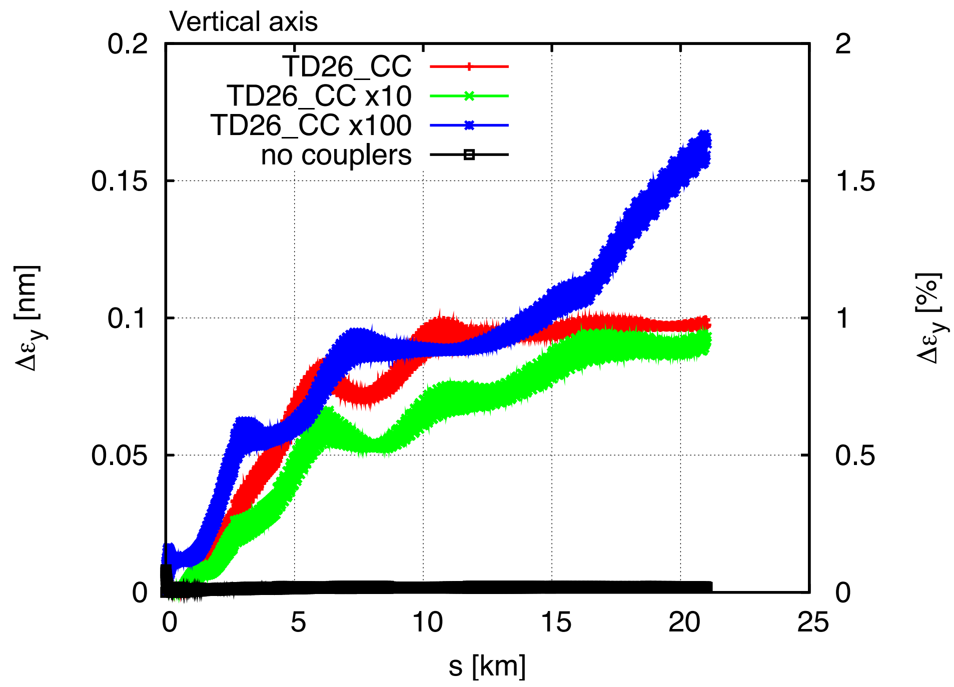
- Impact on a perfect main linac
- Statically misaligned cavities
- Tolerances:
  - Coupler misalignments
  - Cavity RF-gradient
  - Cavity RF-phase
  - Cavity roll
  - Cavity tilt (uncorrected, 1:1 corrected)
  - Cavity tilt bookshelf (uncorrected, 1:1 corrected)

Impact of TD26_CC couplers on a perfect main linac

Emittance growth in a perfect 3 TeV CLIC main linac

- Single-bunch wakefield effects are taken into account



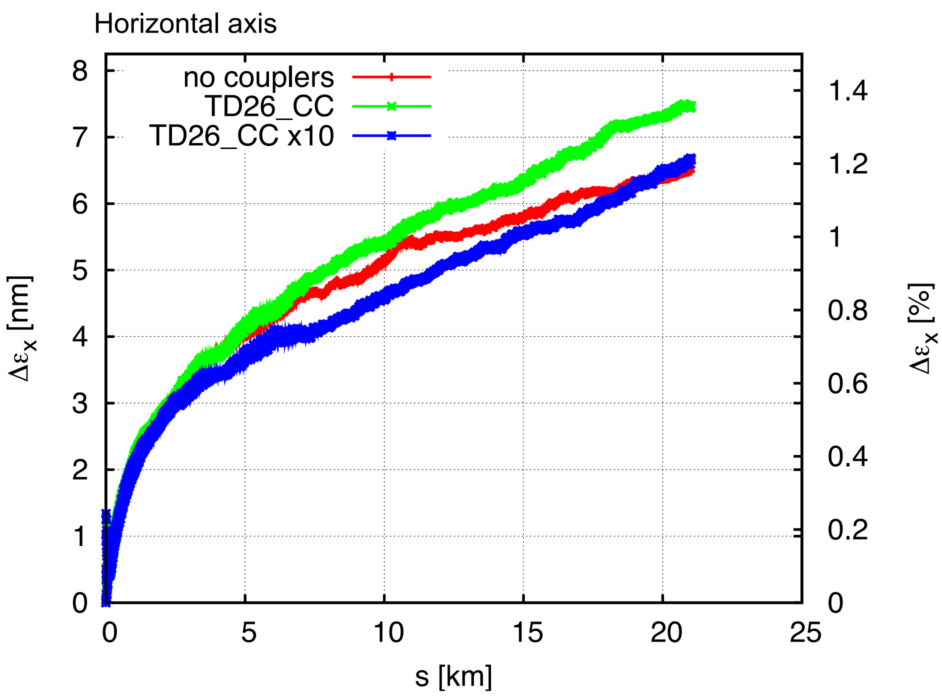


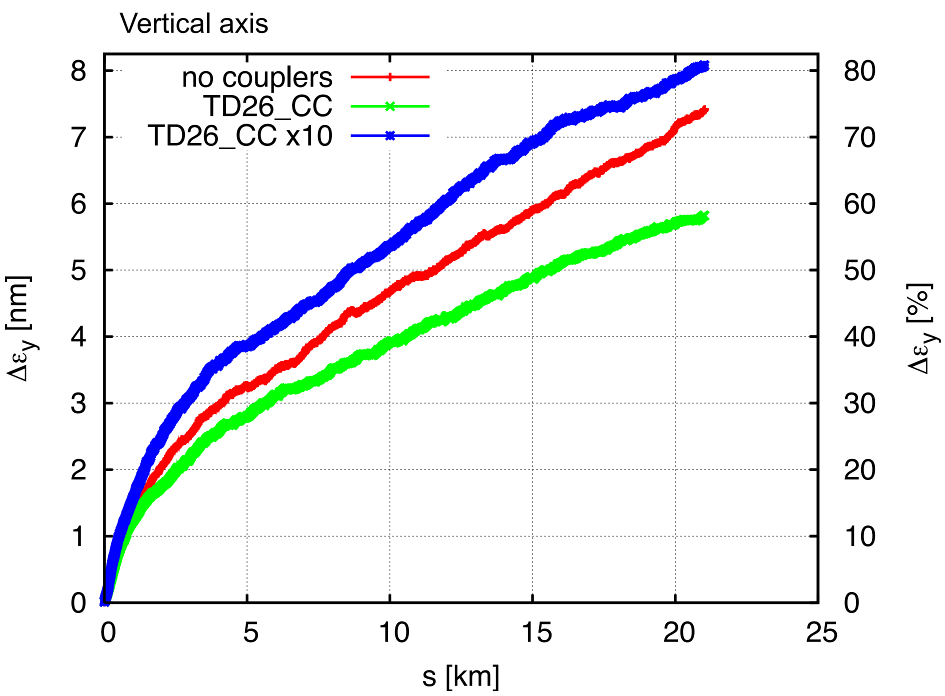
The impact is negligible even if magnified by a factor 100

Impact of TD26_CC couplers on a main linac with misaligned cavities

Cavity misalignment

- The RMS transverse misalignment of the accelerating cavities is assumed to be ~10 microm





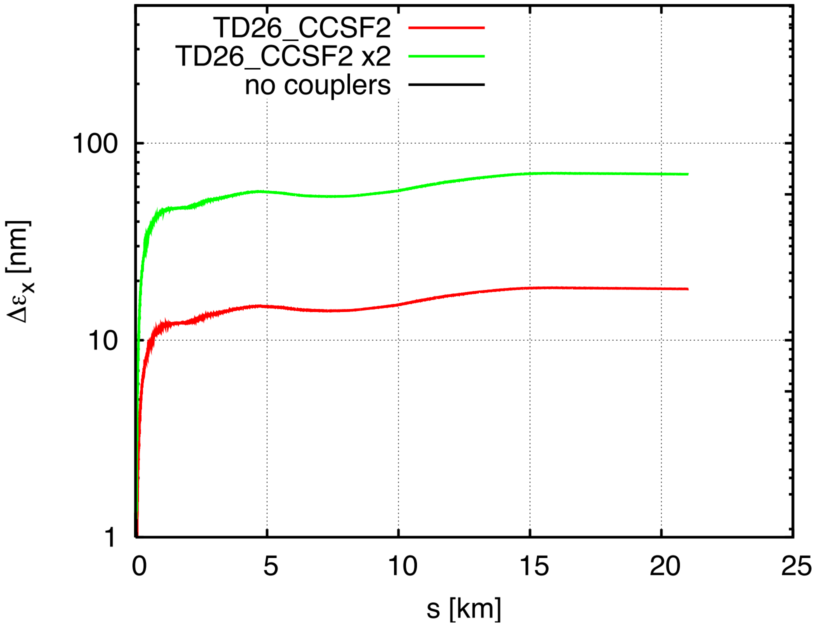
The impact is negligible even if magnified by a factor 10

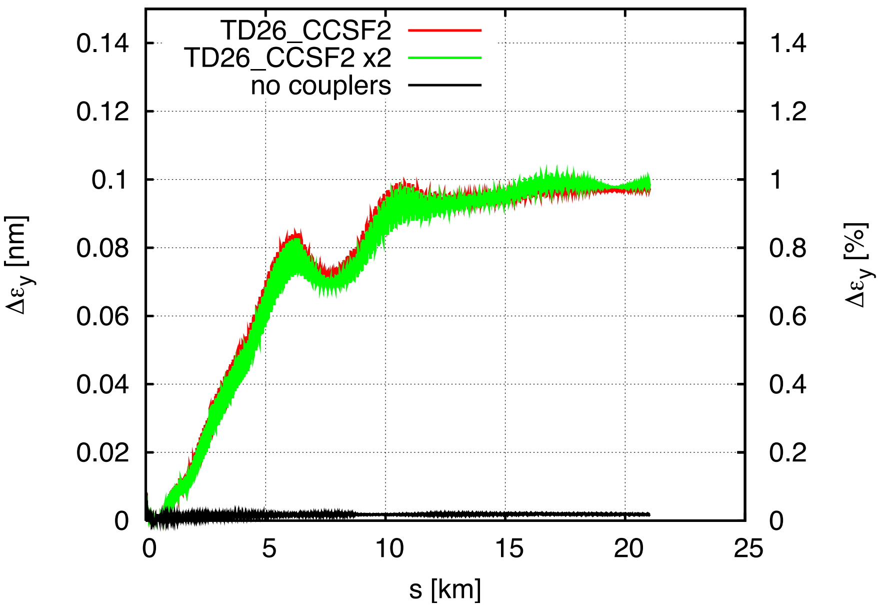
The results are the average of 100 random seeds

Impact of TD26_CCSF couplers on a perfect main linac

Emittance growth in a perfect 3 TeV CLIC main linac

- Single-bunch wakefield effects are taken into account



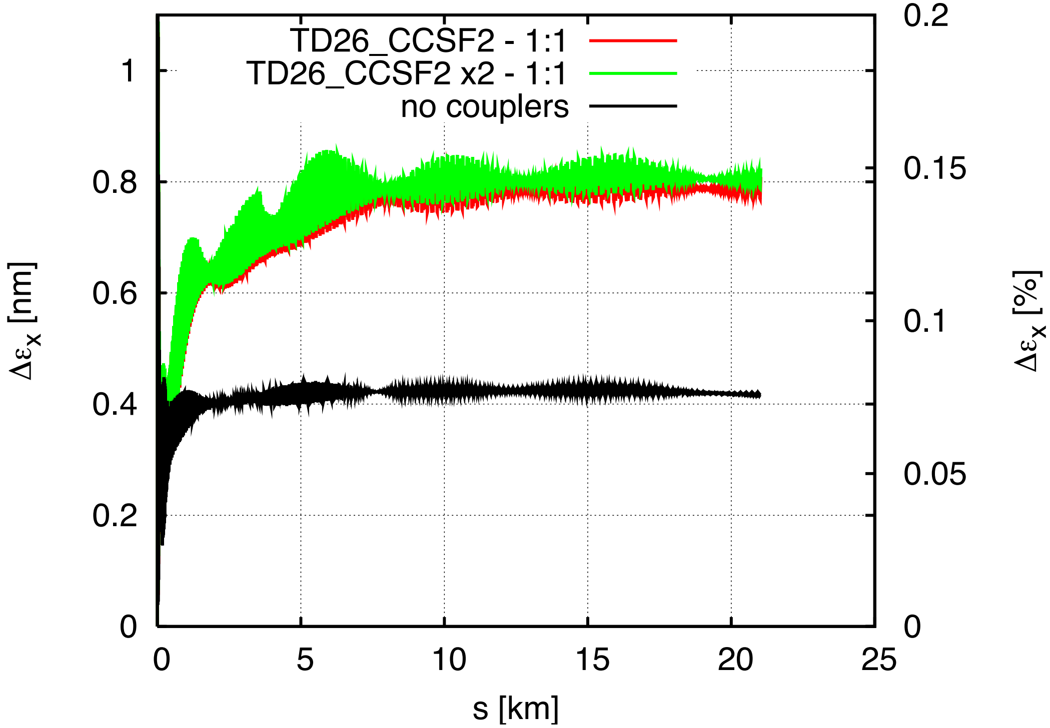


The impact on the horizontal axis is somehow significant
The impact in the vertical axis is negligible even if magnified by a factor 2

Impact of TD26_CCSF couplers on a perfect main linac: 1:1 correction

Emittance growth in a perfect 3 TeV CLIC main linac

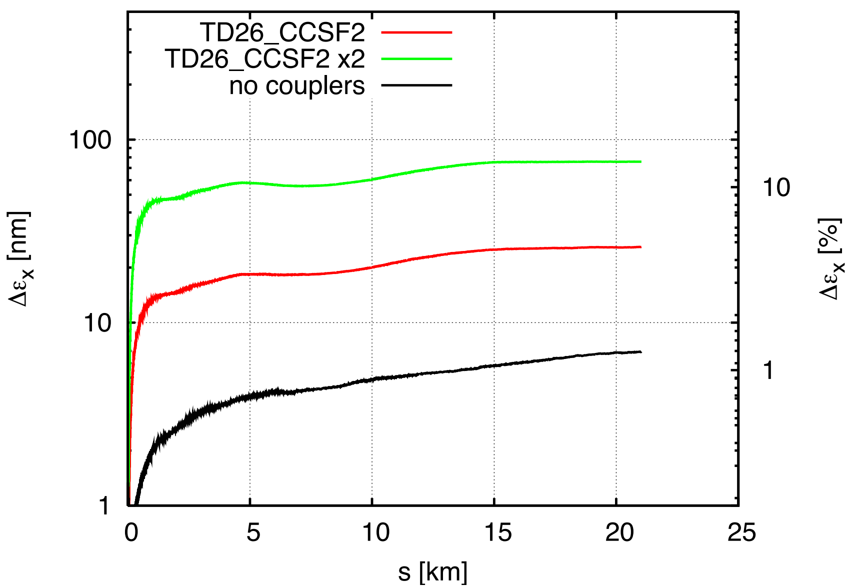
- Single-bunch wakefield effects are taken into account

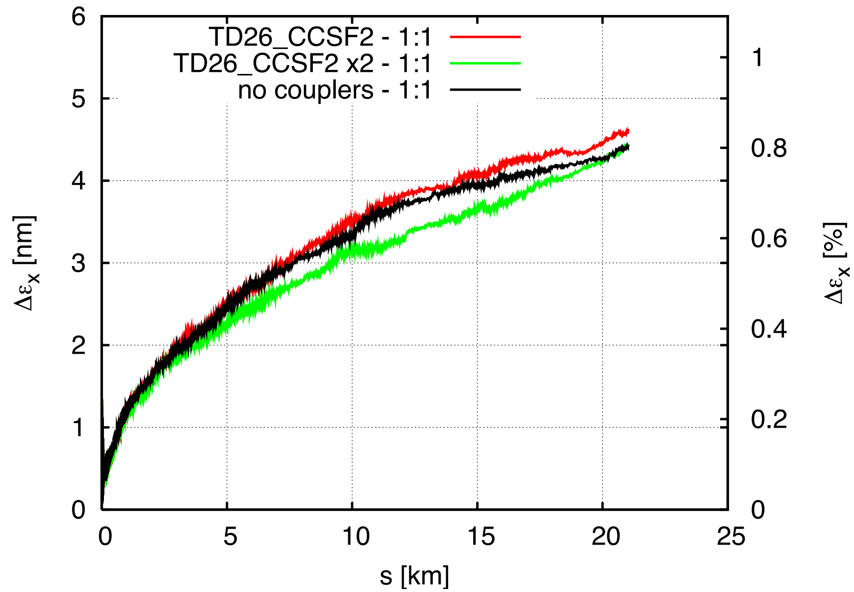


The impact on the horizontal axis is now negligible

Impact of TD26_CCSF couplers on a main linac with misaligned cavities: 1:1 corrected

Impact of 10 um RMS cavity misalignment. Horizontal axis.



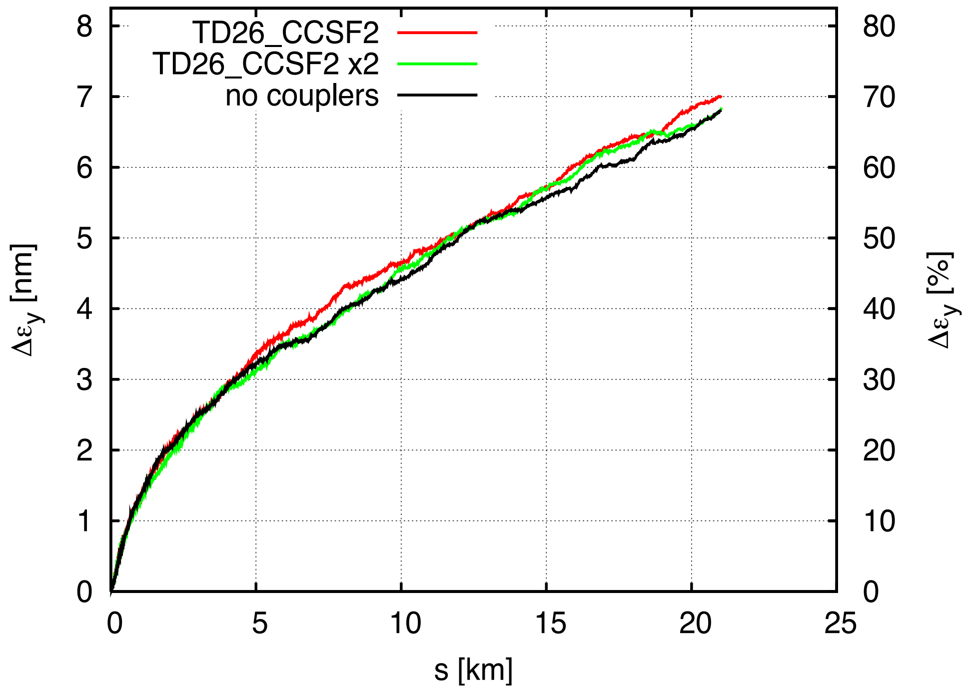


Corrected, the impact is negligible even if magnified by a factor 2

The results are the average of 100 random seeds

Impact of TD26_CCSF couplers on a main linac with misaligned cavities

Impact of 10 um RMS cavity misalignment. Vertical axis.

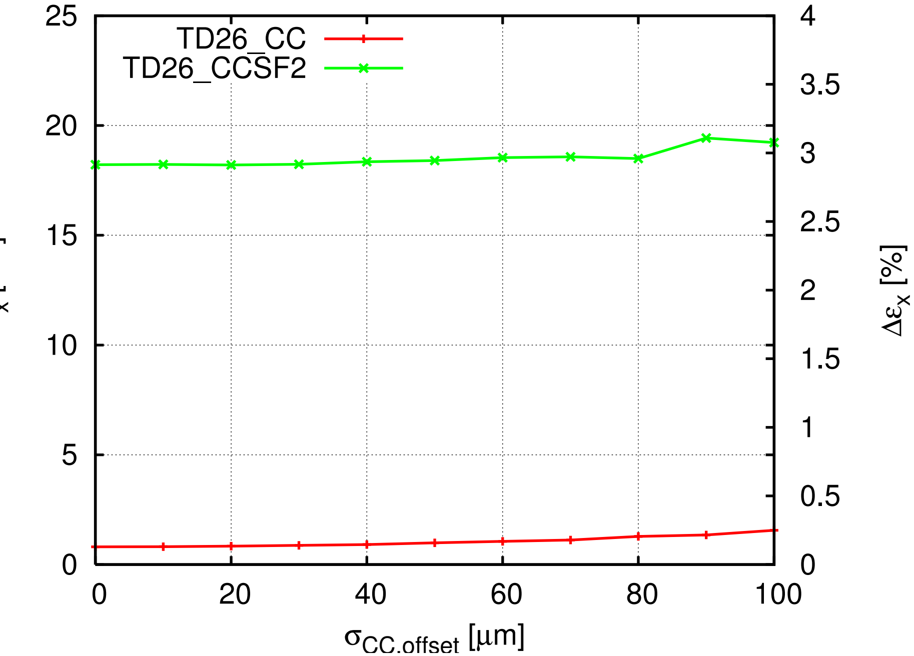


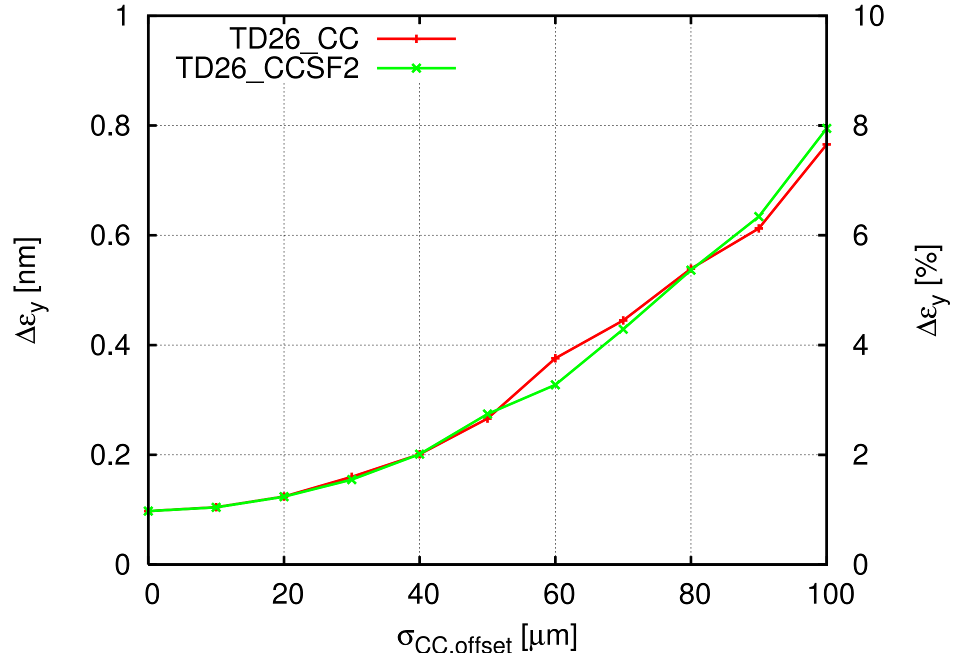
The impact is negligible

The results are the average of 100 random seeds

Tolerances: misalignment

Random offset misalignment of the couplers

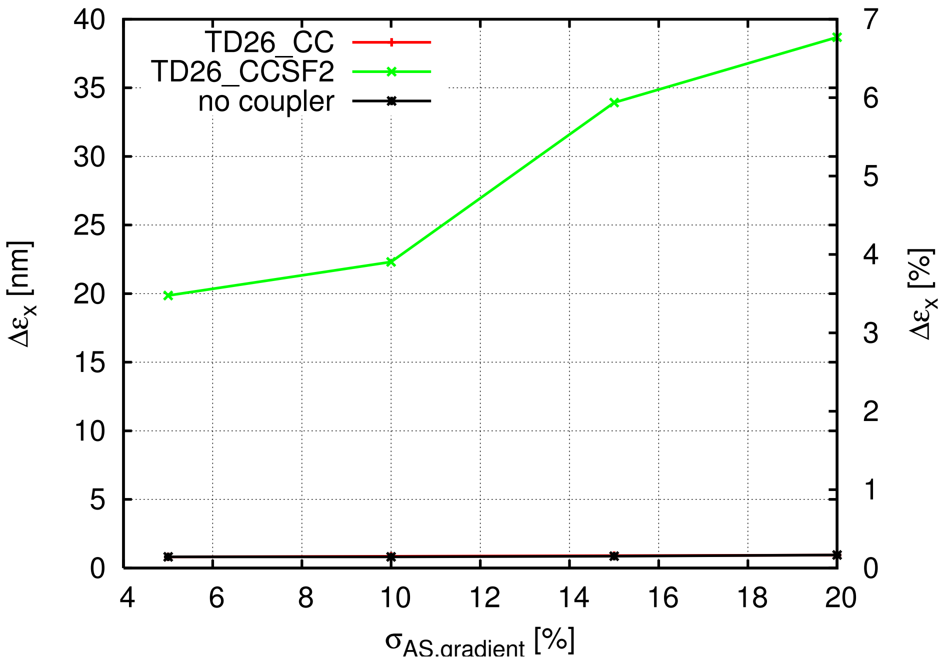


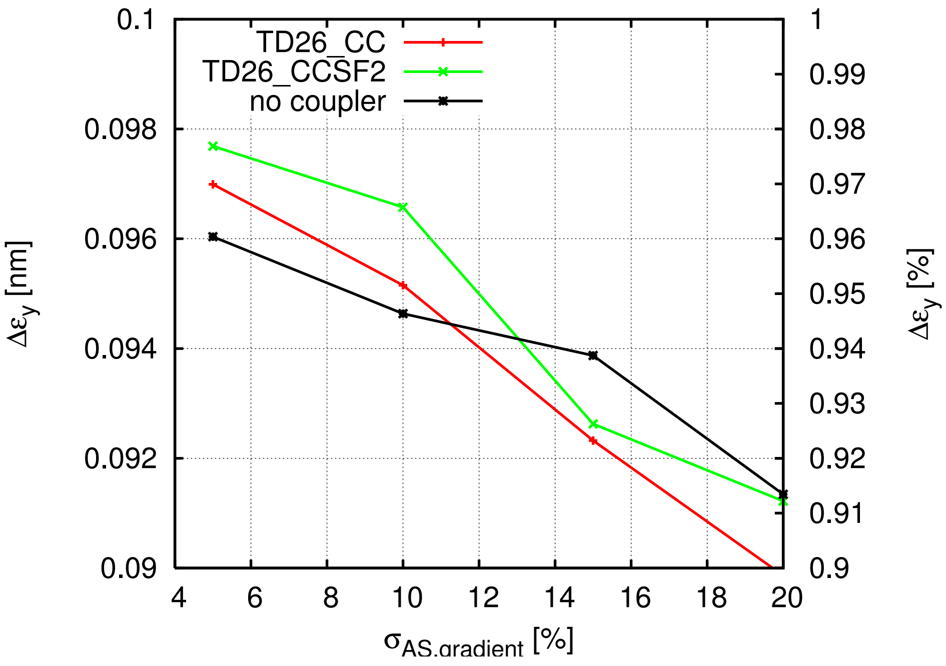


The results are the average of 100 random seeds

Tolerances: cavity gradient

Random gradient changes, the coupler kicks scale with the gradient

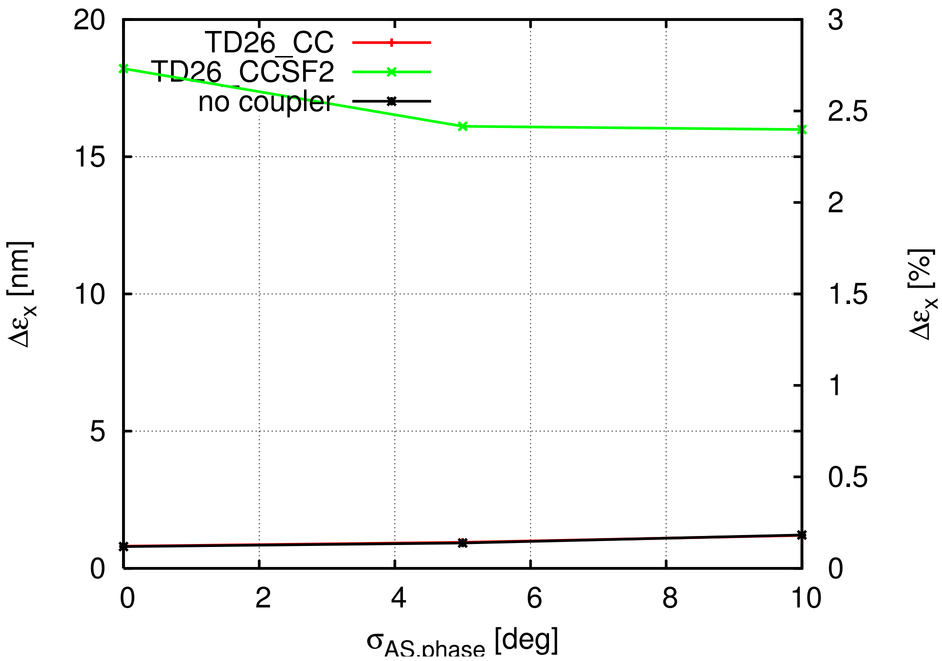


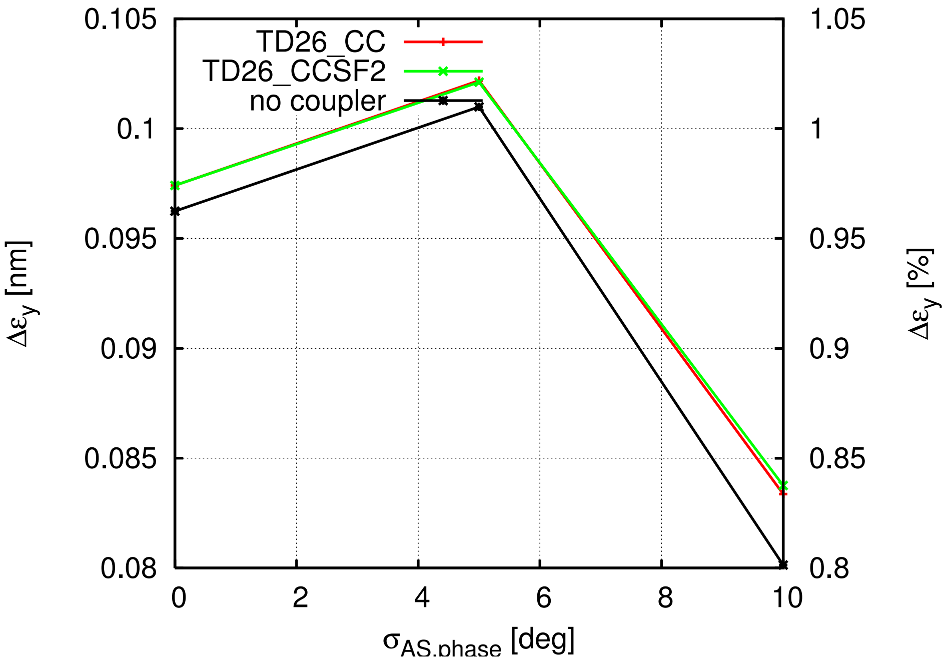


The results are the average of 100 random seeds

Tolerances: cavity phase

Random offsets in the RF-phase, the coupler kicks change accordingly

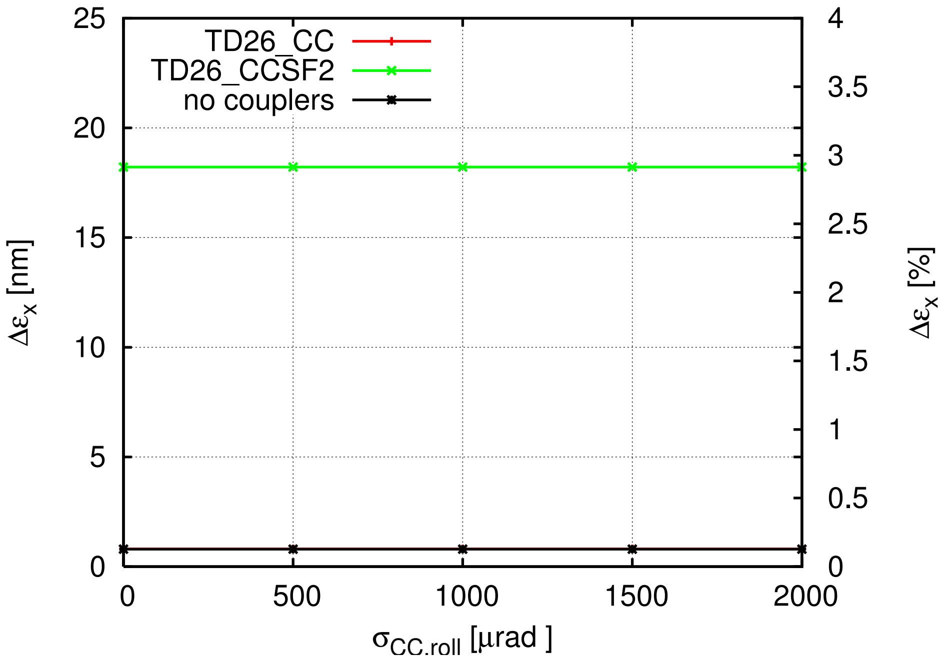


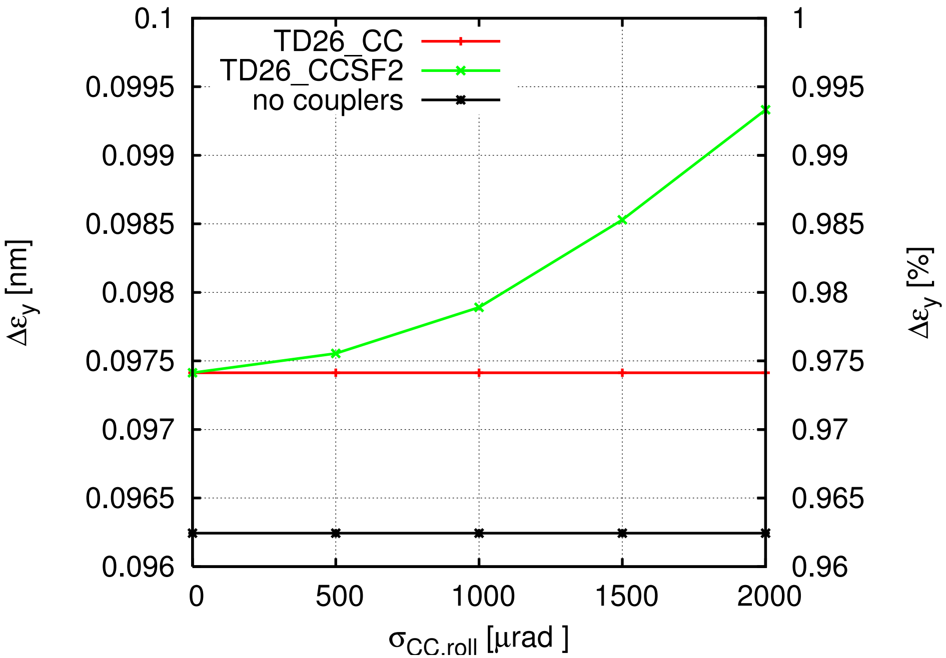


The results are the average of 100 random seeds

Tolerances: cavity roll

Random roll angles of each accelerating structure

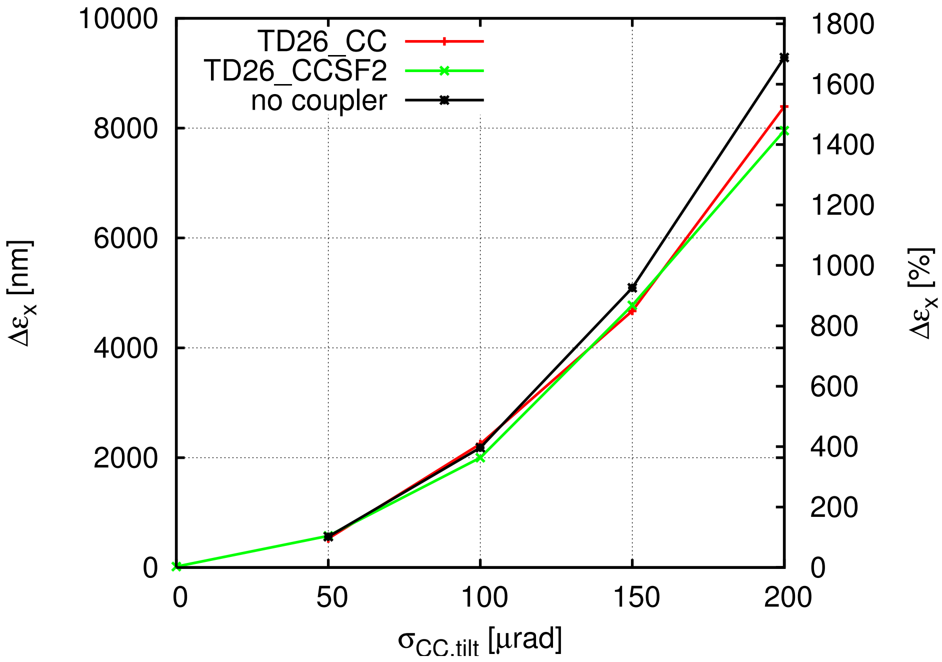


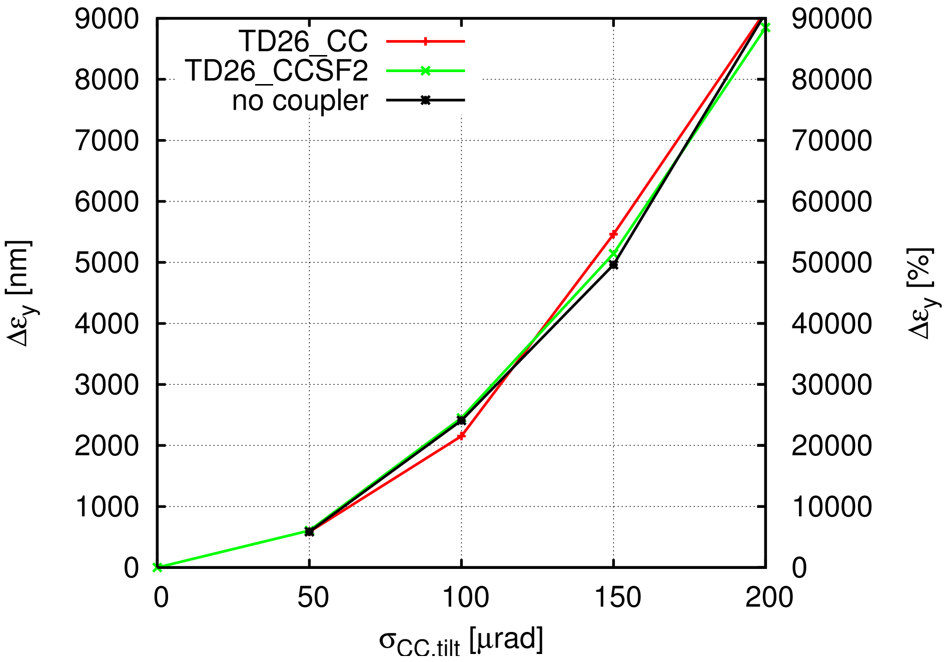


The results are the average of 100 random seeds

Tolerances: cavity tilt

Random offsets in h- and v- angles of the accelerating structures

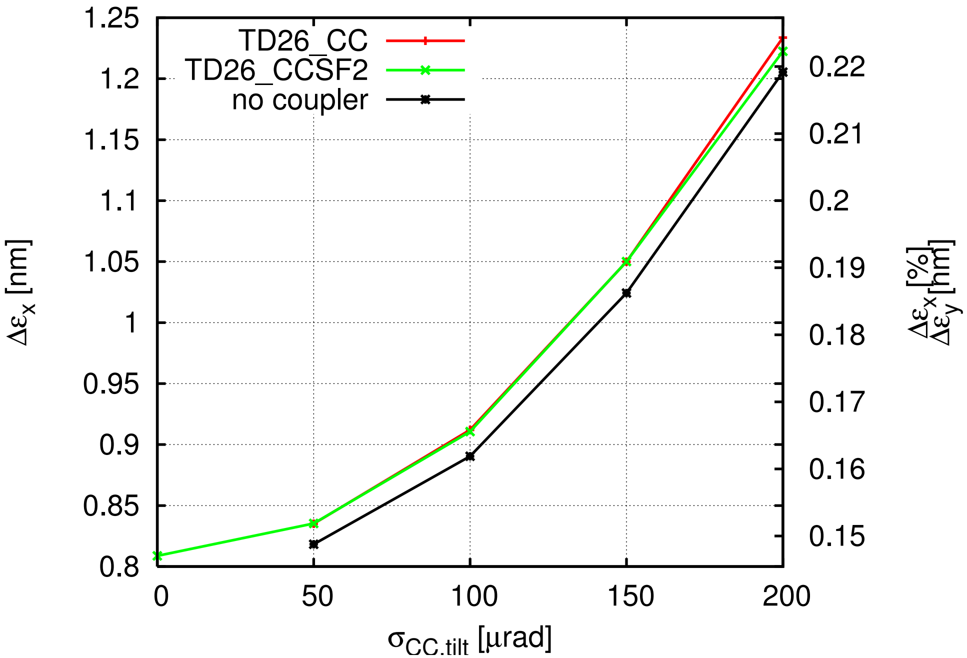


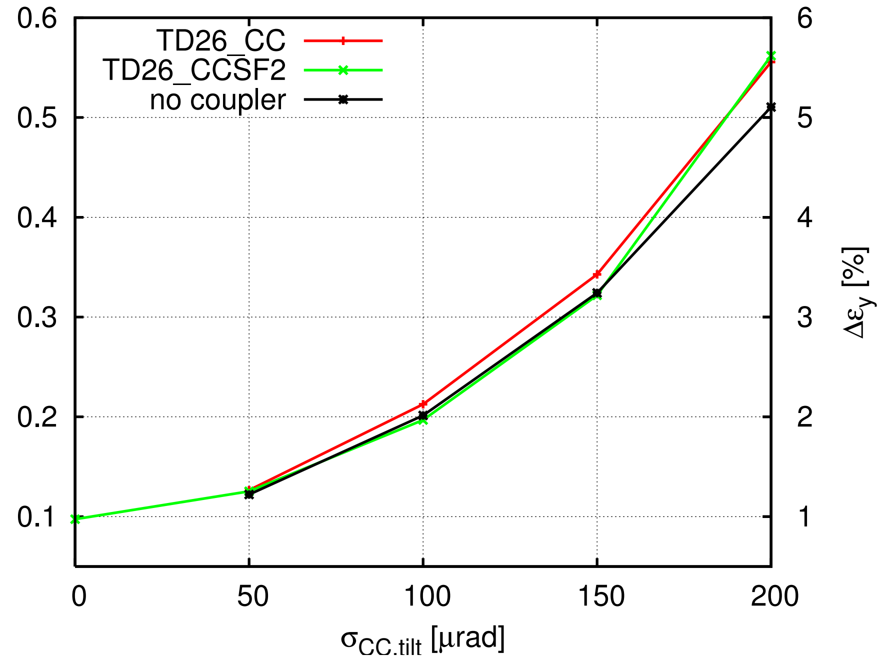


The results are the average of 100 random seeds

Tolerances: cavity tilt, 1:1

Random offsets in the h- and v- angles of the accelerating structures

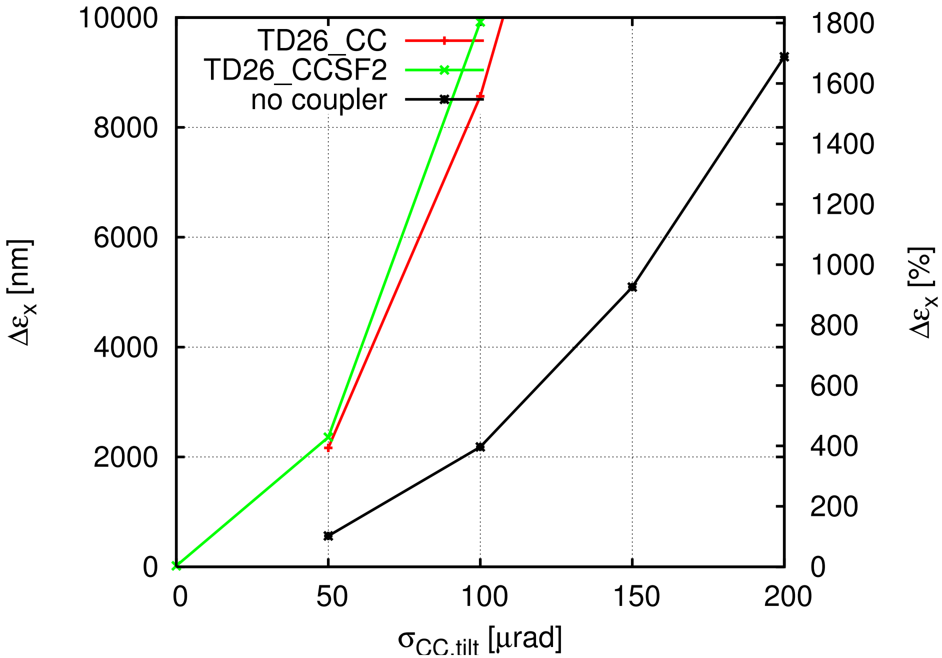


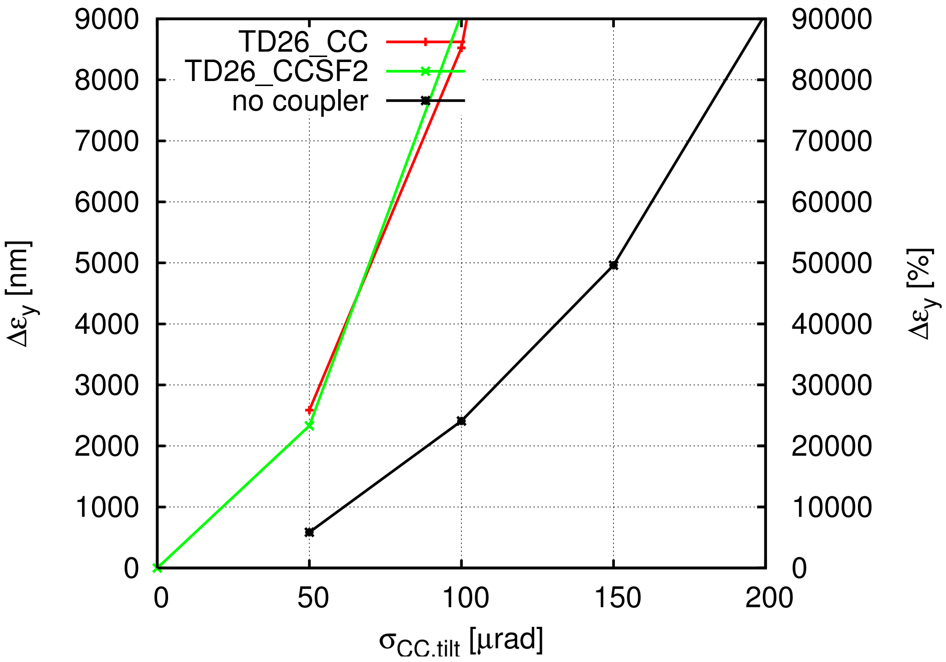


The results are the average of 100 random seeds

Tolerances: cavity tilt, bookshelf

Random offsets in the h- and v- angles of the accelerating structures

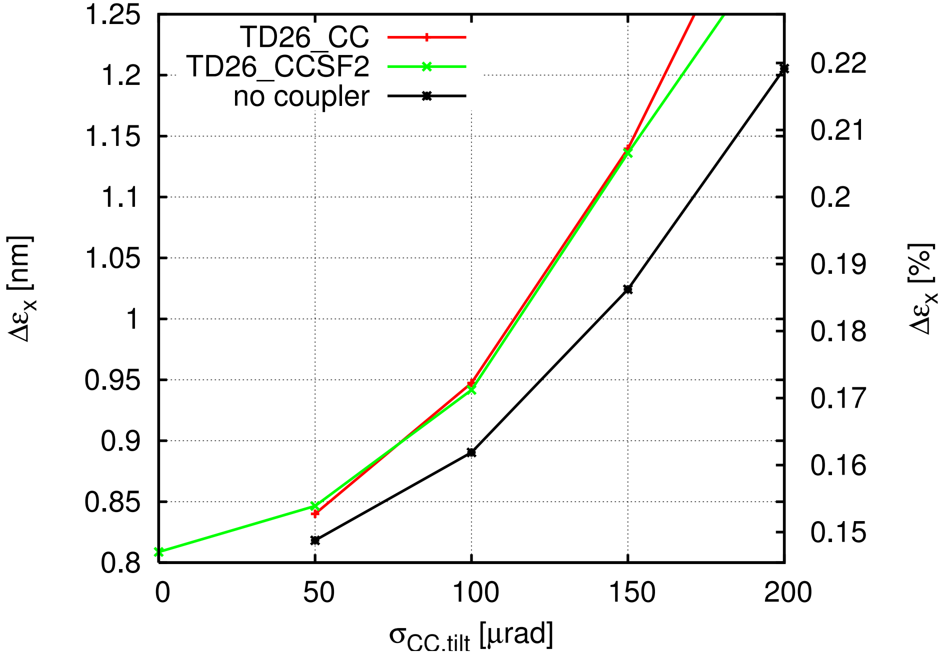


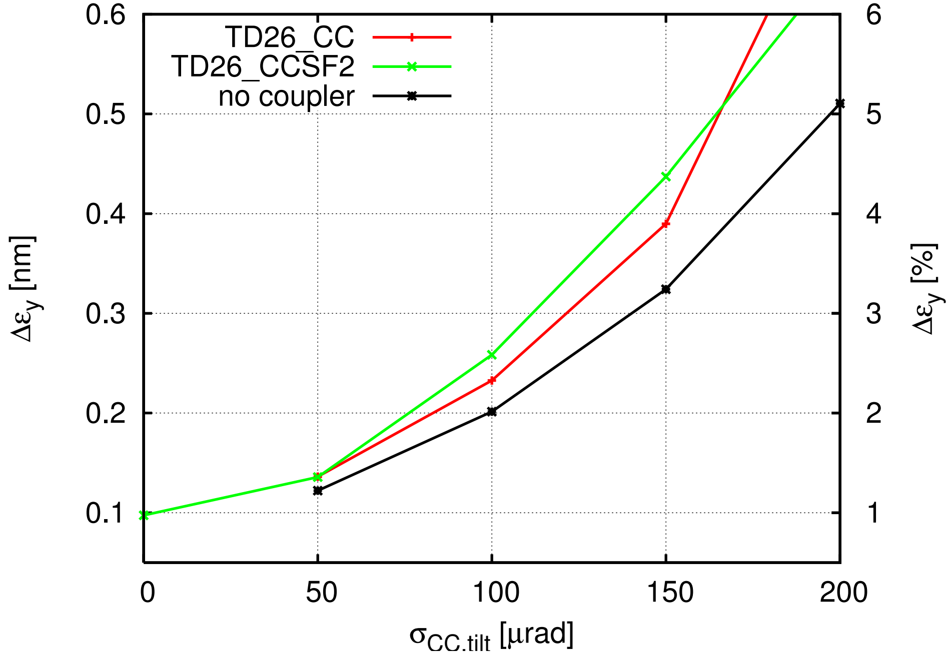


The results are the average of 100 random seeds

Tolerances: cavity tilt, bookshelf, 1:1

Random offsets in h- and v- angles of the accelerating structures

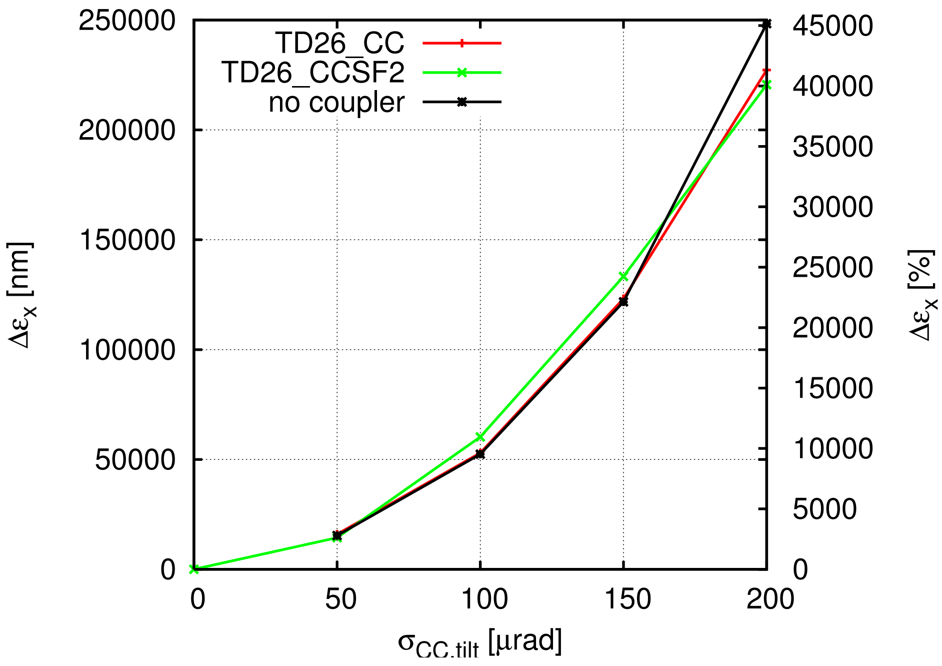


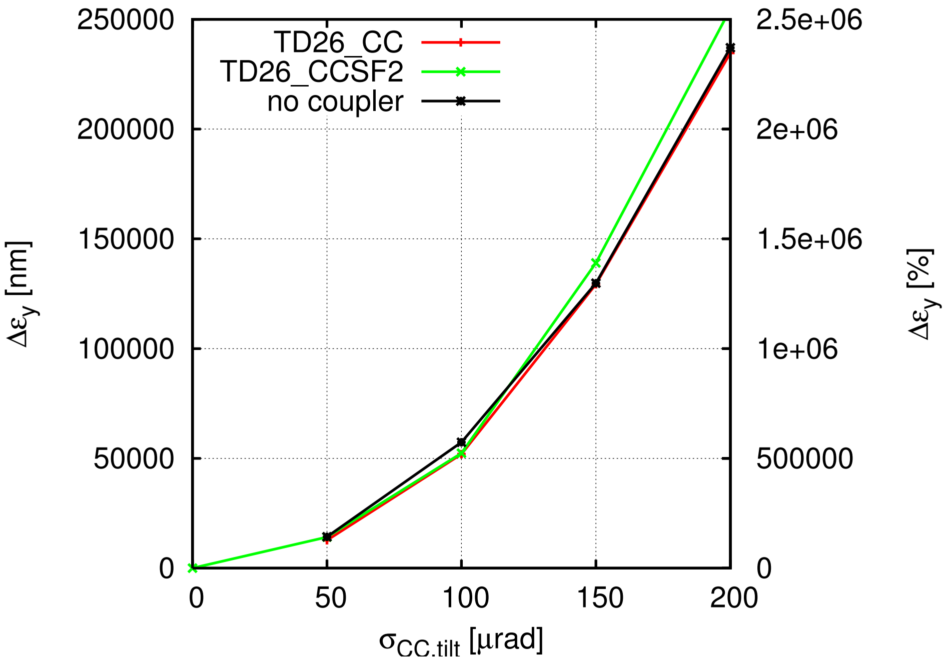


The results are the average of 100 random seeds

Tolerances: quadrupole tilt

Random offsets in h- and v- angles of the quadrupoles

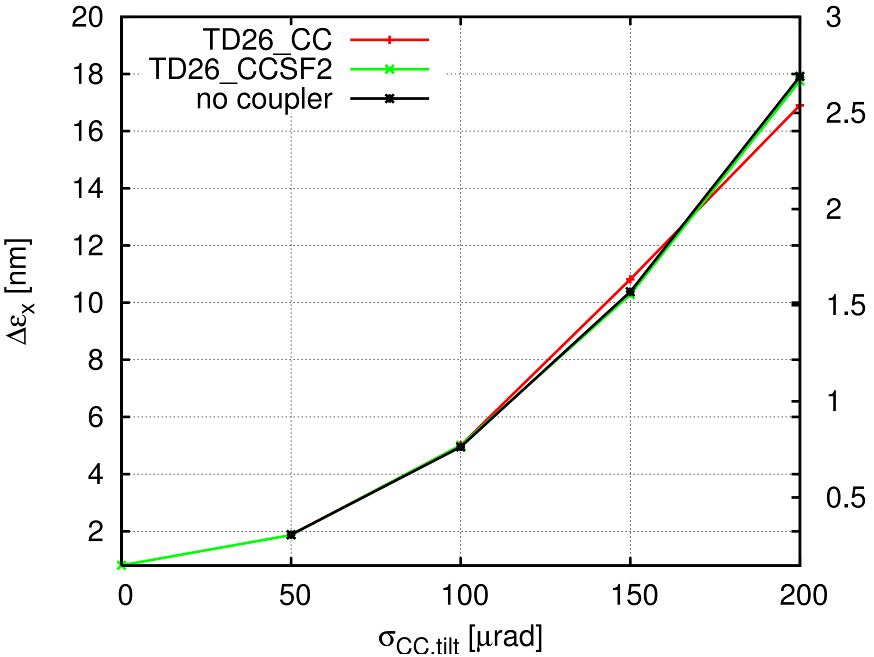


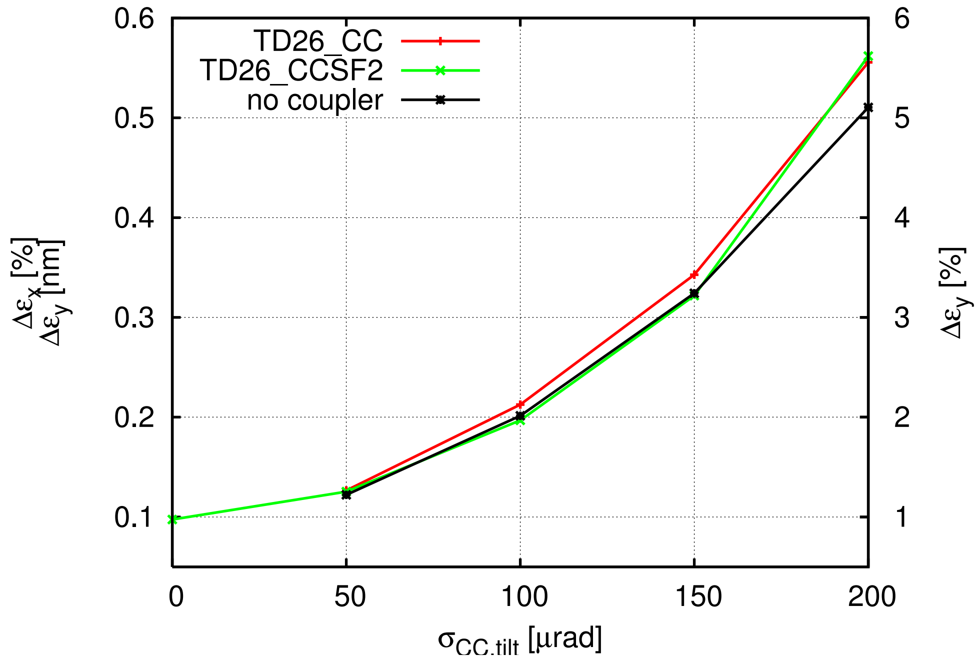


The results are the average of 100 random seeds

Tolerances: quadrupole tilt, 1:1

Random offsets in h- and v- angle of the quadrupoles, 1:1 corrected





The results are the average of 100 random seeds

Conclusions

The impact of the couplers TD26_CC and TD26_CCSF has been studied.

New tools have been created, and PLACET has been modified to implement Rf-Multipoles

The impact of both designs on the beam dynamic seems modest and there seem not to be significant difference between the two designs