Wakefields in the Collimators

A. Latina, on behalf of the CLIC beam dynamics team

- General introduction on the collimation system in the CLIC-BDS
- Wake field kicks from the collimators and model to be used in tracking
- Examples of PLACET tracking along the BDS including the wake fields of flat collimators

  (A. Latina, G. Rumolo, D. Schulte)

Collimation depths for CLIC

- Collimation system has to collimate in the two transverse planes (betatron collimation) and clean in momentum (energy collimation)

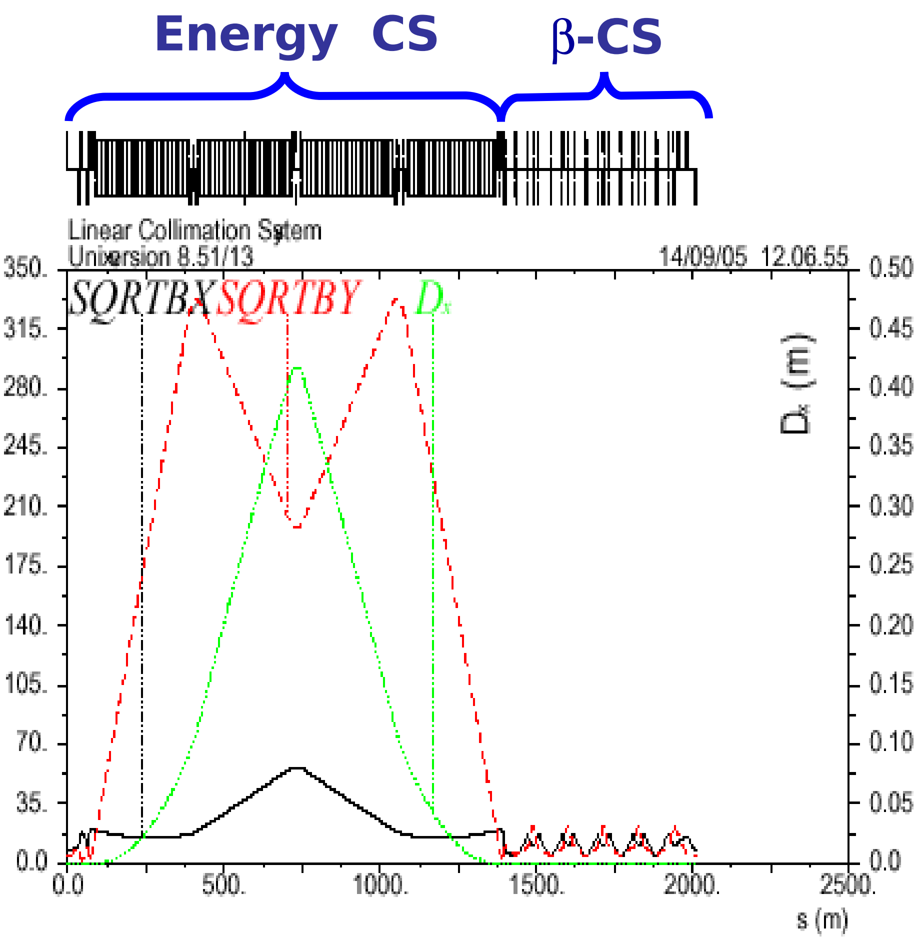
- The collimation depths for betatron collimation determined from the condition that beam particle and SR photons emitted in the final quadrupoles should not hit any magnet apertures on the incoming side of the IP. For CLIC: collimation depths should be less than **14 σ_x** and **83 σ_y**

- The energy collimation depth determined by the failure modes in the linac. For CLIC: protection against misteered or errant beam with energy errors ≥ 1.3%

Overview of the CLIC baseline collimation system (linear)

Collimation parameters

CM energy	**3 TeV**	**500 GeV**
E spoiler gap	± 3.51 mm	± 4.8 mm
β_x spoiler gap	± 80 μm (10 σ_x)	± 300 μm (9 σ_x)
β_y spoiler gap	± 104 μ m (80 σ_y)	± 215 μm (69 σ_y)
Spoiler material	Be (or C)	
Spoiler length	177 mm (0.5 r.l. C)	
Absober material	Ti (Cu coated)	
No. E spoilers	1	
No. of $\beta_{x,\,y}$ spoilers	4	



CLIC Collimation database

s[m]	Name	β_x[m]	β_y[m]	D_x[m]	a_x[mm]	a_y[mm]	Geometry	Material
566.502	ENGYSP	1406.33	70681.9	0.27	3.51	25.4	rect	Be
731.502	ENGYAB	3213.03	39271.5	0.417	5.4	25.4	rect	Ti(Cu coated)
1490.28	YSP1	114.054	483.253	0.	10.	0.102	rect	Be
1506.1	XSP1	270.003	101.347	0.	0.08	10.	rect	Be
1583.3	XAB1	270.102	80.9043	0.	1.	1.	ellip	Ti(Cu coated)
1601.12	YAB1	114.054	483.184	0.	1.	1.	ellip	Ti(Cu coated)
1603.12	YSP2	114.054	483.188	0.	10.	0.102	rect	Be
1618.94	XSP2	270.002	101.361	0.	0.08	10.	rect	Be
1696.14	XAB2	270.105	80.9448	0.	1.	1.	ellip	Ti(Cu coated)
1713.96	YAB2	114.055	483.257	0.	1.	1.	ellip	Ti(Cu coated)
1715.96	YSP3	114.054	483.253	0.	10.	0.102	rect	Be
1731.78	XSP3	270.003	101.347	0.	0.08	10.	rect	Be
1808.98	XAB3	270.102	80.9043	0.	1.	1.	ellip	Ti(Cu coated)
1826.8	YAB3	114.054	483.184	0.	1.	1.	ellip	Ti(Cu coated)
1828.8	YSP4	114.054	483.188	0.	10.	0.102	rect	Be
1844.63	XSP4	270.002	101.361	0.	0.08	10.	rect	Be
1921.83	XAB4	270.105	80.9448	0.	1.	1.	ellip	Ti(Cu coated)
1939.65	YAB4	114.055	483.257	0.	1.	1.	ellip	Ti(Cu coated)

Limits for collimator protection

For spoiler survival in case of full impact by missteered or errant beams:

$$\sigma_{x,\mathrm{sp}}\sigma_{y,\mathrm{sp}} \gtrsim \sigma^2_{r,\min}$$

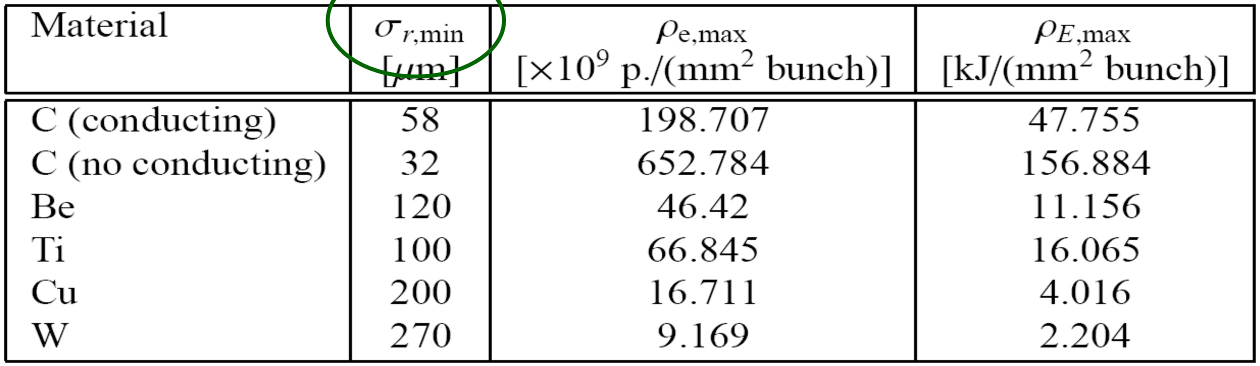
Minimum transverse beam size at the spoiler

$$\rho_{E,\max} = \frac{N_e}{2\pi\sigma^2_{r,\min}} \frac{E_0}{(\mathrm{GeV})} 1.6\times 10^{-10}\,\mathrm{J}$$

$$\rho_E(x,y) \lesssim \rho_{E,\max}$$

Maximum transverse energy

From S. Fartoukh et al., CLIC Note 477



Material	$\sigma_{r,\min}$ [μm]	$\rho_{e,\max}$ [$\times 10^9$ p./(mm^2 bunch)]	$\rho_{E,\max}$ [kJ/(mm^2 bunch)]
C (conducting)	58	198.707	47.755
C (no conducting)	32	652.784	156.884
Be	120	46.42	11.156
Ti	100	66.845	16.065
Cu	200	16.711	4.016
W	270	9.169	2.204

Main contributions to the wake fields in the Beam Delivery System

- Geometric and resistive wall wake fields of the collimators (tapered and flat parts)
- Resistive wall wakes of the beam pipe, especially close to the IP (final quadrupoles)
- Crab cavities LOM‘s and HOM‘s

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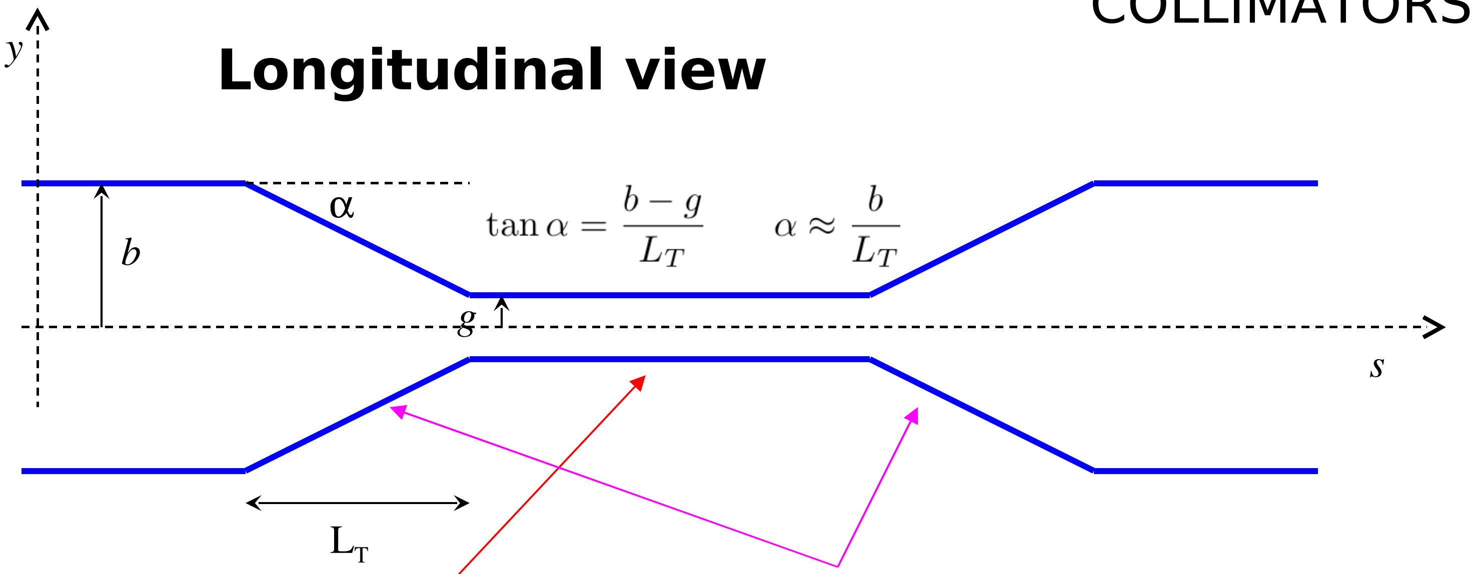
Wake fields can be responsible for severe single- and multi-bunch effects leading to **luminosity loss**

COLLIMATORS & BEAM

Longitudinal view



$$\tan\alpha = \frac{b-g}{L_T} \qquad \alpha \approx \frac{b}{L_T}$$

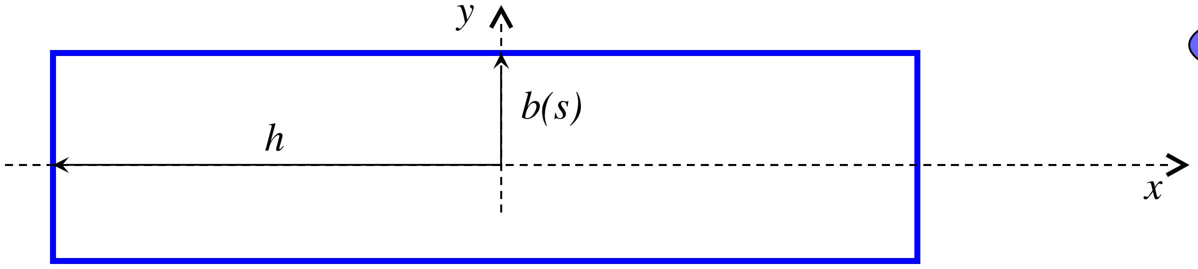
Flat part contribute to:

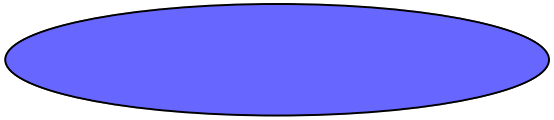
2. Resistive wall wakes

Tapered parts contribute to:

2. Geometric wakes
3. Resistive wall wakes

Cross-sectional view





N part/bunch

σ_z rms-bunch length

γ relativistic factor

In the following a flat geometry will be assumed in the transverse plane: ***b(s)<<h***

Geometric wake

For smooth tapering, the kick is given by *(Stupakov, 1997)*

$$\Delta y' = \frac{N r_e}{\gamma\sqrt{2\pi}\sigma_z}\left[(2\pi h I_2 - 2I_1)\Delta y + 2I_1 y\right]\exp\left(-\frac{z^2}{2\sigma_z^2}\right)$$

$$I_1 = \int_0^{L_T}\left(\frac{b'^2}{b^2}\right)ds \qquad I_2 = \int_0^{L_T}\left(\frac{b'^2}{b^3}\right)ds$$

→ *(x,y,z)* are the coordinates of the particle that feels the wake force

→ *Δy* is the vertical diplacement of the bunch.

$$\boxed{\Delta y' = \frac{N r_e}{\gamma\sqrt{2\pi}\sigma_z}\left[\left(\pi h\frac{(b-g)^2(b+g)}{g^2b^2L_T} - 2\frac{(b-g)^2}{gbL_T}\right)\Delta y + 2\frac{(b-g)^2}{gbL_T}y\right]\exp\left(-\frac{z^2}{2\sigma_z^2}\right)}$$

The old formula was $\Delta y' = \frac{N r_e}{\gamma\sqrt{2\pi}\sigma_z}\frac{(b-g)^2}{gbL_T}\exp\left(-\frac{z^2}{2\sigma_z^2}\right)(0.85\Delta y + 0.43y)$

This formula is only true in the inductive regime, which is defined by *(G. V. Stupakov, 2001):*

$$\alpha \ll \frac{g\sigma_z}{h^2}$$

In diffraction regime $\alpha \gg \frac{g\sigma_z}{h^2}$

$$\Delta y' = \frac{N r_e \sqrt{2}}{\gamma g^2} \exp\left(-\frac{z^2}{2\sigma_z^2}\right)(0.85\Delta y + 0.43 y)$$

whereas in the intermediate regime, the following formula holds:

$$\Delta y' = \frac{2.7 N r_e \sqrt{2\alpha}}{\gamma \sqrt{\sigma_z g^2}} \exp\left(-\frac{z^2}{2\sigma_z^2}\right)(0.85\Delta y + 0.43 y)$$

Purpose of the **Gdfidl** simulations:

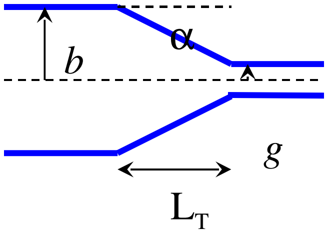
⇒ Check the analytical formulae known from literature (Stupakov) about geometric wake fields

Gdfidl simulations are done by offsetting by $\Delta y=20$ µm a short Gaussian pulse ($\sigma_z=100$ µm) with a 1 pC charge through a taper and calculating the resulting wake potential $w(s)$ (defined as the integrated electromagnetic force felt by a witness unitary charge at a distance s from the source).

→ The taper geometry is specified in the following:

h scanned from 1mm to 5mm (with step 1mm)

L_T =25mm, b=0.8mm, g=0.1mm



With the parameters used in these simulations it turns out that we are in the so-called „intermediate“ regime -> not very smooth tapering

The condition for smooth tapering is given by:

$$\alpha \ll \frac{g\sigma_z}{h^2}$$

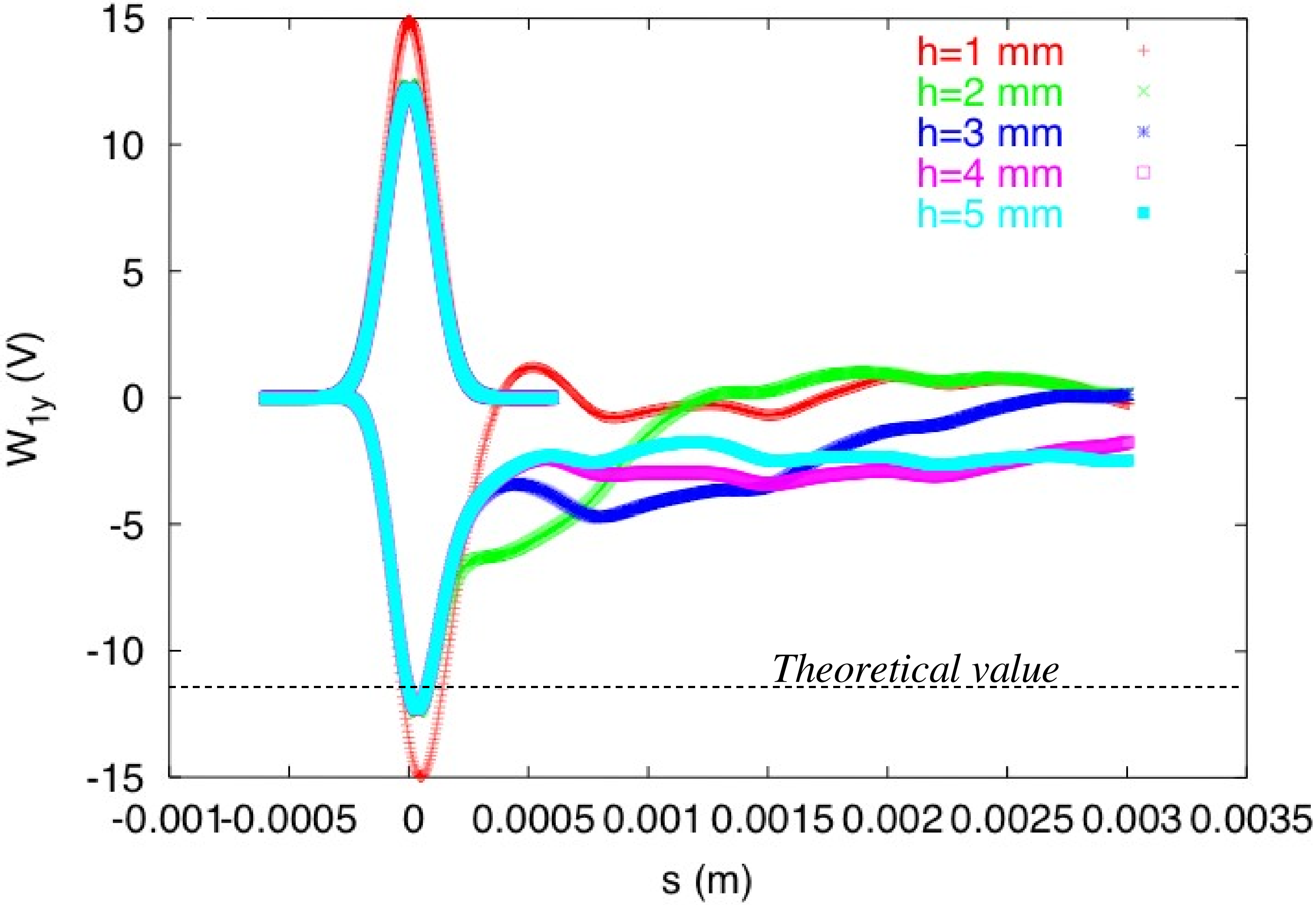
α is the tapering angle

$$\frac{g\sigma_z}{h^2} = 0.08 \cdot \frac{1}{h^2[\mathrm{mm}^2]}$$

$$\alpha = \arctan\left(\frac{b-g}{L_T}\right) = 0.028$$

h should be smaller than 1 mm to meet the condition of inductive regime. Our simulations have been run for h=1 to 5 mm, therefore we will be in intermediate regime.

$$w(s) = \frac{Z_0 c}{4\pi} \frac{2.7\sqrt{2\alpha} N e}{\sqrt{\sigma_z g^3}} \Delta y \exp\left(-\frac{s^2}{2\sigma_z^2}\right) \Longrightarrow w_{max} = \frac{Z_0 c}{4\pi} \frac{2.7\sqrt{2\alpha} N e}{\sqrt{\sigma_z g^3}} \Delta y = 11.5\mathrm{V}$$



Results from W. Bruns‘ Gdfidl simulations.

The upper curve represents the probe bunch (normalized to the highest value of the wake for plotting purposes) and the lower curves are the wakes referring to the labelled cases.

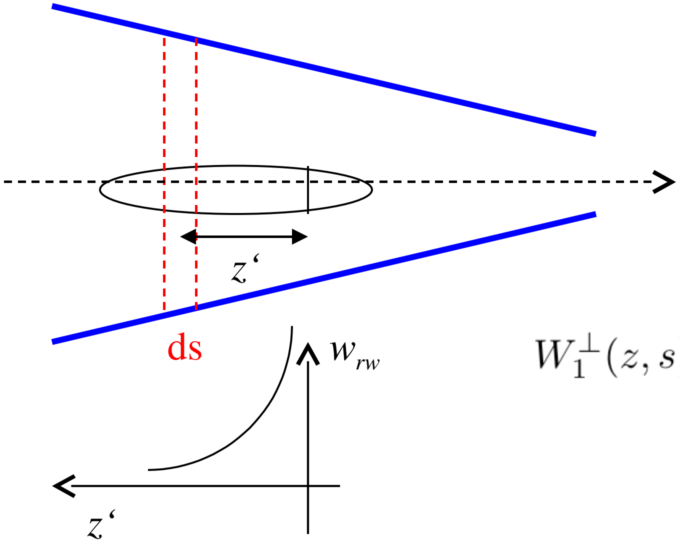
Conclusions that can be drawn from W. Bruns‘ simulations and work yet to be done (..underway)

- As expected, the wake field in the intermediate regime does not depend (strongly) on *h*. The predicted maximum value from the analytical formula matches quite well the results of the Gdfidl simulations.

- From the simulations it appears though that there is a „trailing effect“ at the bunch tail that seems to depend on *h*. For higher values of *h*, the wake does not vanish after the bunch passage, which could matter for multi-bunch effects.

- More simulations are planned to check the analytical formulae in the inductive regime (we are specially interested to cross-check the predicted dependence on *h* of the wake).

Resistive wall wake



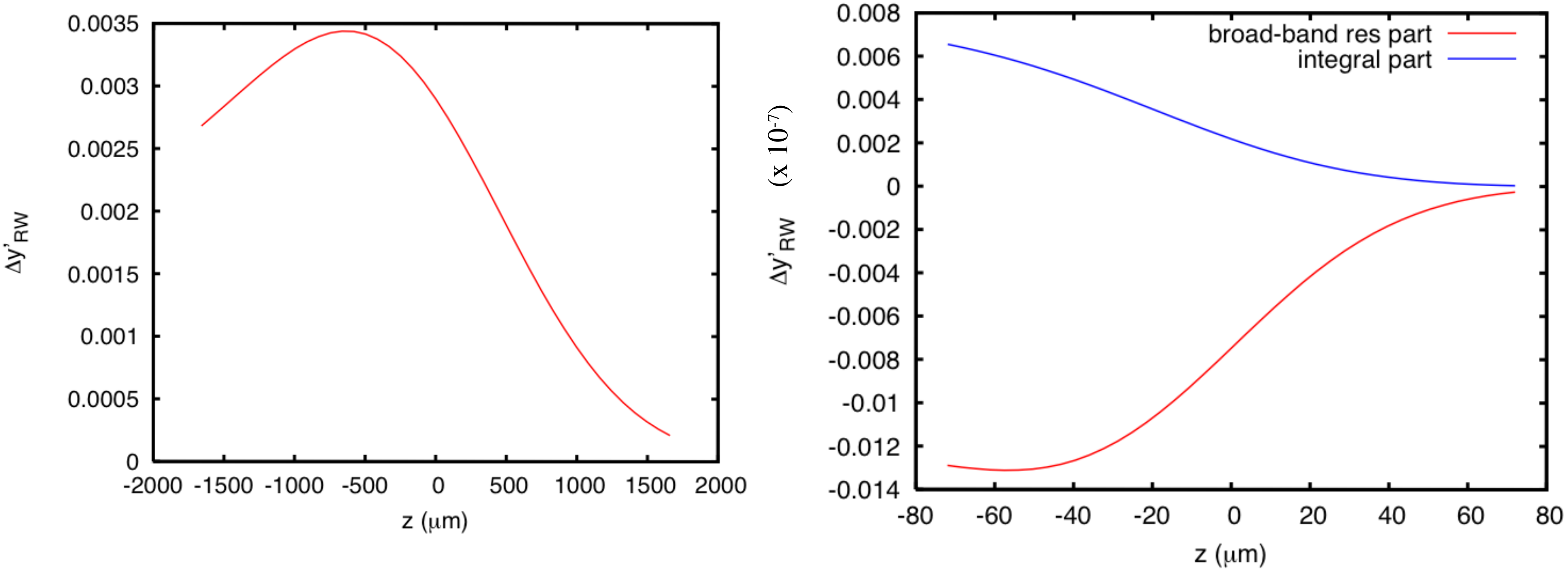
$$W_1^{\perp}(z,s) = \frac{cZ_0}{\pi b^3(s)} \left[\frac{s_0 \exp\left(-\alpha_t \frac{z}{s_0}\right)}{3(\alpha_t^2 + k_t^2)} \left(\alpha_t \cos(k_t \frac{z}{s_0}) + k_t \sin(k_t \frac{z}{s_0}) - \alpha_t \right) - \frac{\sqrt{2}}{\pi} \int_0^z \int_0^\infty \frac{x^2 \exp\left(-x^2 \frac{z'}{s_0}\right) dx}{x^6 + 8} dz' \right]$$

→ In the long-range regime the classical resistive thick-wall formula can be applied.

→ In the short-range regime, the resistive wall is broad-band resonator-like impedance, with coefficients α_t, k_t depending whether we are in dc- or ac-conductivity regime (α_t=1 and k_t=1.7 in the dc case)

→ In the intermediate-range regime the more complicated formula above, which reduces to the other two in the limiting cases, has to be used

Intermediate and long range: resistive wall



Geometric part is usually negligible with respect to the resistive wall part

Resistive wall part: the two contributions to the kick coming from the integral and from the broad-band resonator part are shown separately in the intermediate range case

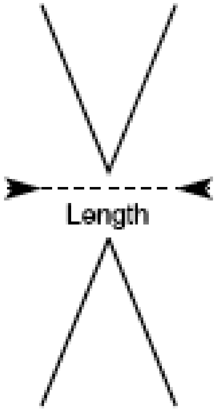
PLACET

Implementation

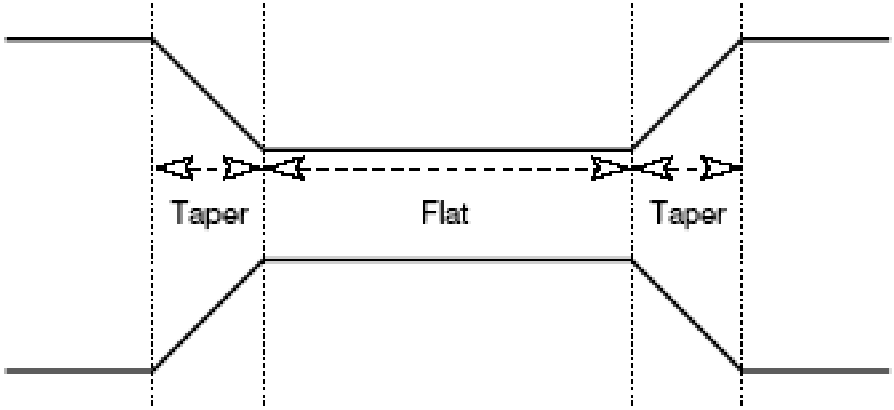
- Created the object **COLLIMATOR** (lattice definition)
  - Input parameters:
    - geometry of the collimator (width, initial and final height, taper length, . . .)
    - properties of the material (conductivity σ, relaxation time τ)
    - type (spoiler/absorber, vertical/horizontal)
  - Output:
    - the KICK in μrad, particle by particle
- Computation:
  - geometric and resistive components are evaluated
  - inductive or diffractive for the geometric wake fields, short- or long-range, intermediate regimes
  - the bunch is subdivided into slices
  - the KICK depends both on the longitudinal and on the transverse coordinates of the particles
  - speed-up using tables of precalculated integrals

Description of the Simulation

- Nominal CLIC bunch through the Main Linac + Beam Delivery System
  - Linear Collimation System in the BDS (lattice by Rogelio Tomás and Javier Resta)
  - jitters in x, x', y, y' ranging in $[-\sigma, \sigma]$ introduced before the BDS
  - Only flat collimators have been considered
- Assumptions
  - tapering angle 30 mrad
  - length of the spoiler 177 mm (corresponding to $\sim 0.5\ \ \lambda_{\mathrm{Be}}$)
  - length of the absorber 712 mm (corresponding to $\sim 20\ \ \lambda_{\mathrm{Cu-Ti}}$)

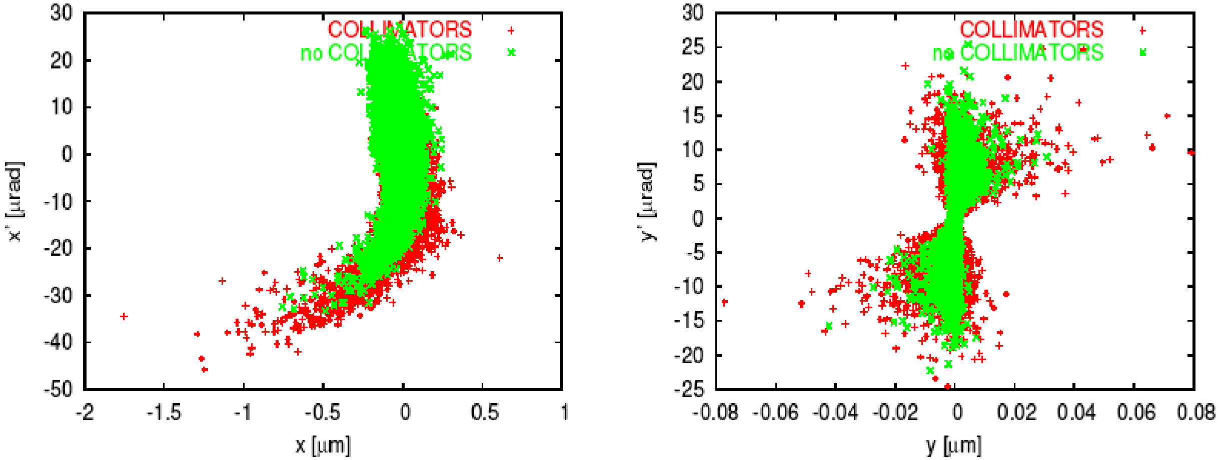


(spoiler)



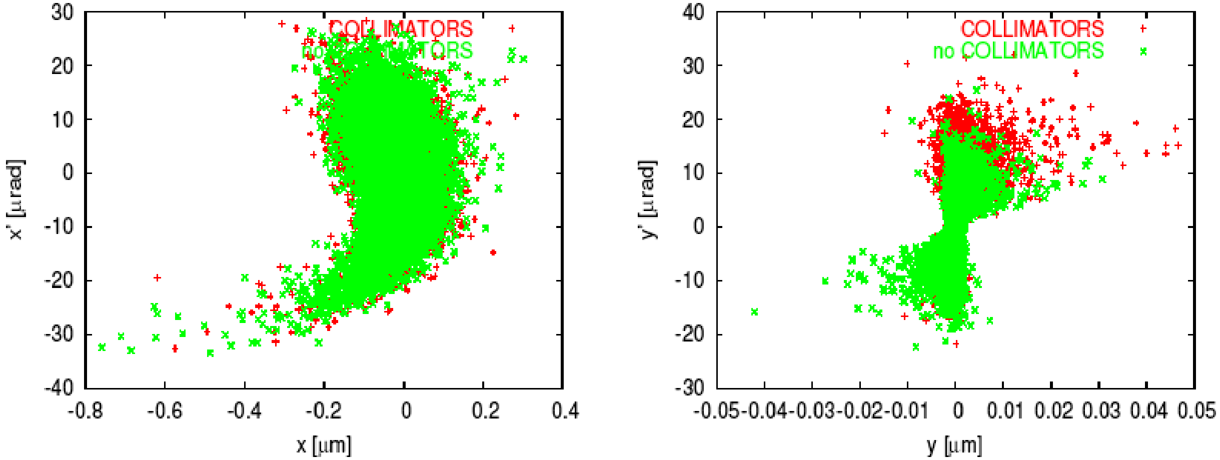
(absorber)

Phase Space Portraits at the end of the BDS w and w/o Collimator Wake Fields with horizontal beam jitter



(jitter = $1\,\sigma_x \sim 4\mu$m)

Phase Space Portraits at the end of the BDS w and w/o Collimator Wake Fields with vertical beam jitter

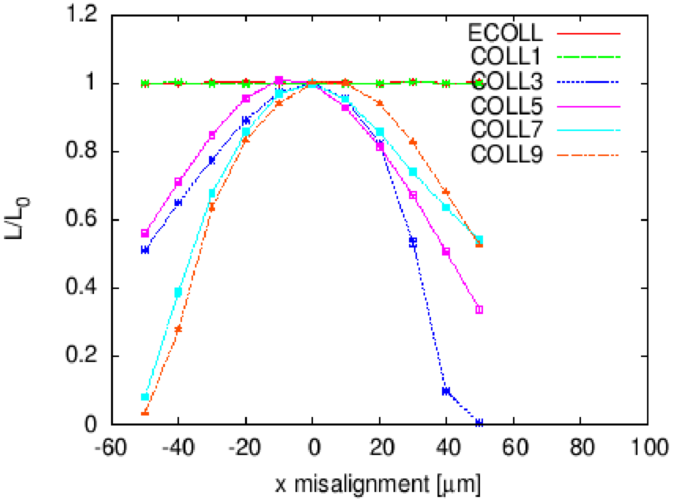


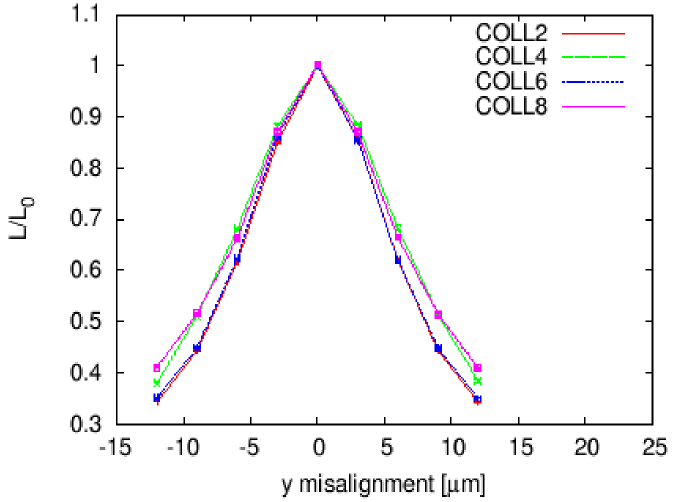
(jitter = $1\,\sigma_y \sim 0.25\mu$m)

Luminosity reduction curves for collimator misalignment:

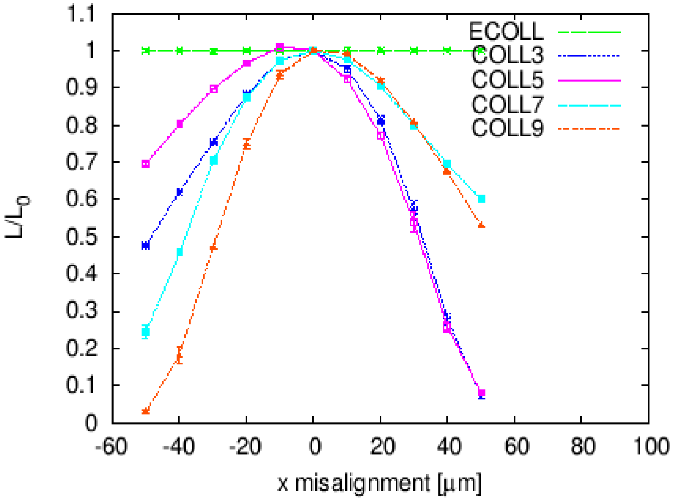
collimators are vertically offset one by one, obviously only the effect of the vertical collimators is visible.

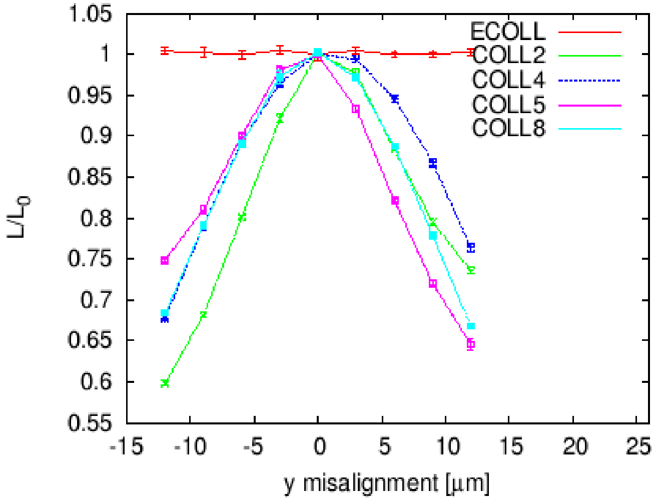
LINEAR BDS:





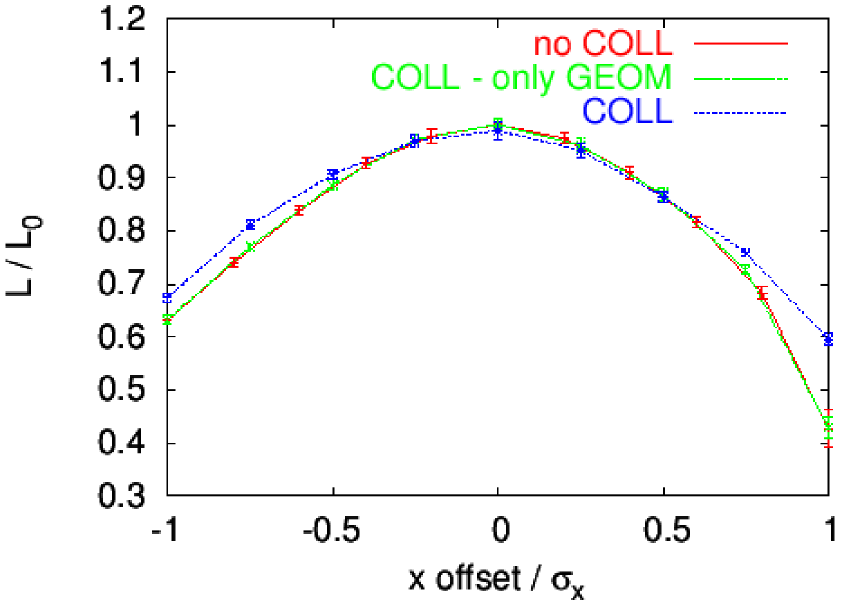
NON-LINEAR BDS:



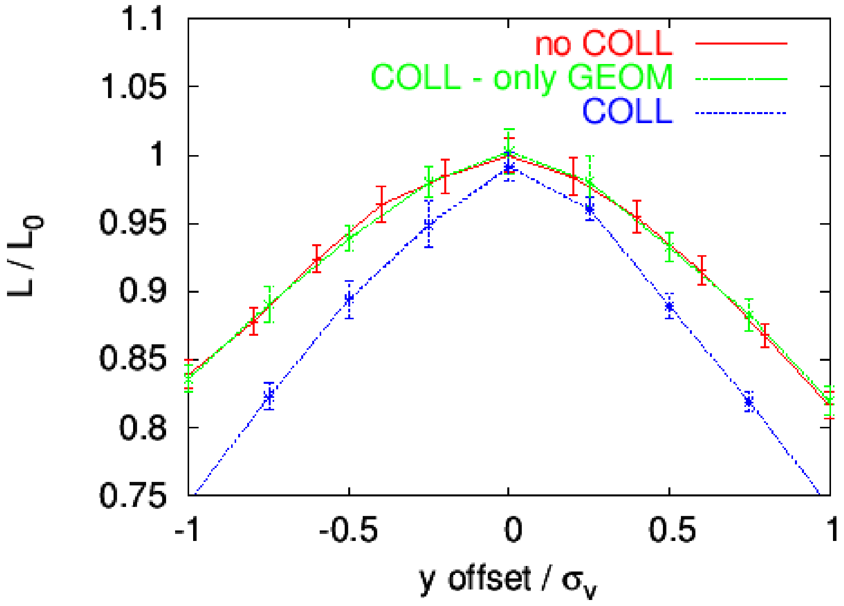


Luminosity reduction curves for collimator misalignment (linear BDS):

Beam Jitter in X and Y



$(\sigma_x \sim 4\mu\text{m})$



$(\sigma_y \sim 0.25\mu\text{m})$

Outlook and conclusions

- Collimator wake fields (both geometric and resistive wall, different regimes) have been implemented in PLACET to allow full tracking
- Luminosity reduction curves due to the wake fields have been obtained for initial jitters and different configurations of collimator misalignments.
- The performances of the nonlinear collimation system including wake fields have to be studied (maybe also the octupole tail folding option?)
- The model for wake fields is planned to be improved (on the short term) to include nonlinear and near-wall effects.