CLIC Collimation System Review

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Introduction

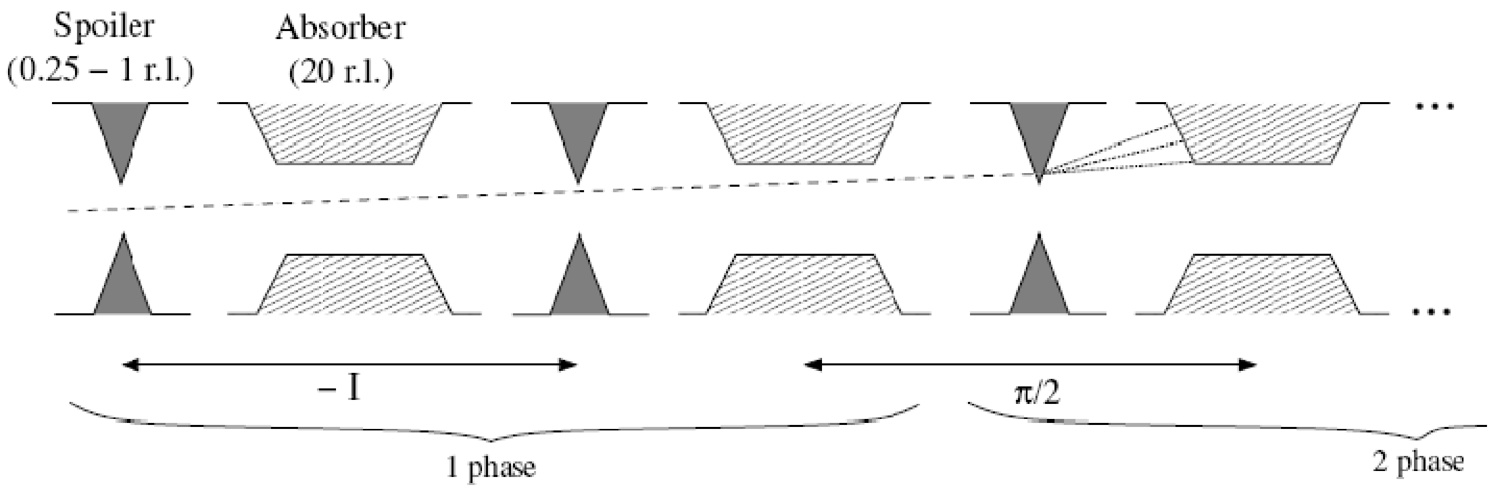
- Since the last CLIC workshop (October 2008) clear progress has been made in the improvement of the CLIC collimation system
  - Study of the collimation efficiency, optimising the collimator apertures
  - Design of spoiler and study of its thermal fracture limit
  - Luminosity loss due to collimator wakefield effects
- Significant progress has also been made in the development of codes for realistic simulations (e.g. BDSIM-PLACET interface), allowing collimation studies simultaneously including wakefield effects and production of secondary particles

Collimation system

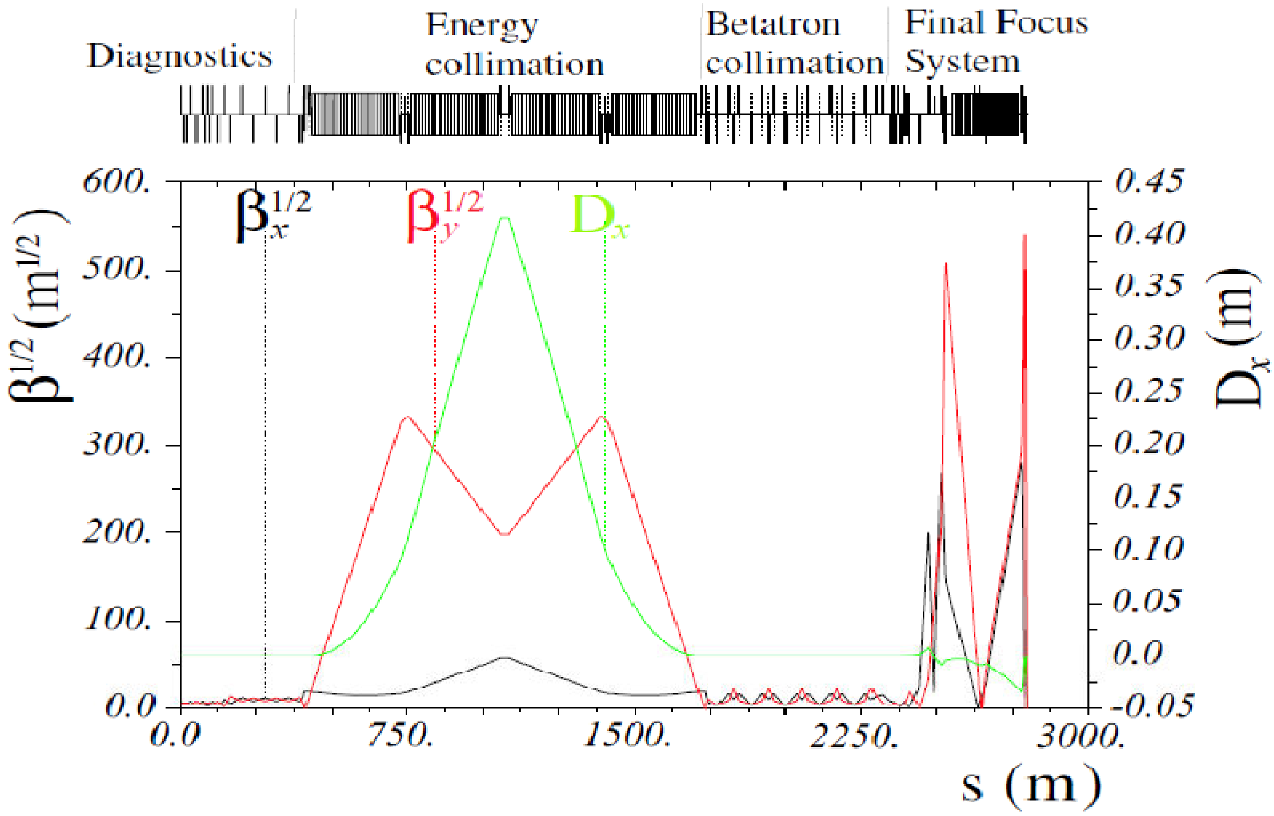
Simple spoiler/absorber scheme

- A conventional postlinac collimation system usually consist of a scheme of spoilers/absorbers

- The purpose of the spoilers is to increase the angular divergence of an incident beam. This increases the beam size at the absorbers and reduces the risk of material damage



CLIC collimation system



Energy collimation: Protection against mis-steered or errant beams with energy errors **>** 1.3**%**. E-spoiler half-gap: $a_x = D_x\delta = 3.51\text{mm}$

4 pairs of collimators in x,y plane to collimate at IP/FD phases

Collimator apertures (version 2009)

Collimator	β_x [m]	β_y [m]	D_x [m]	a_x [mm]	a_y [mm]	Material
E-SP	1406.33	70681.9	0.27	3.51	~~25.4~~ 8.	Be
E-AB	3213.03	39271.5	0.416	5.41	~~25.4~~ 8.	Ti/Cu
β_y–SP	114.054	483.253	0.	~~10.~~ 8.	0.1	Be
β_y–AB	114.054	483.184	0.	1.	1.	Ti/Cu
β_x–SP	270.003	101.347	0.	0.12	~~10.~~ 8.	Be
β_x–AB	270.102	80.9043	0.	1.	1.	Ti/Cu

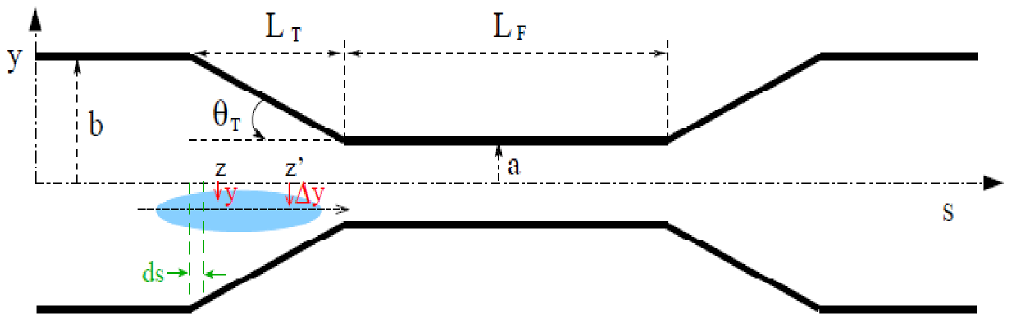
Optimisation of betatronic collimation depths from ray-tracing calculations along FD and IR using the code PLACET: 15 σ_x and 55 σ_y (Barbara Dalena)

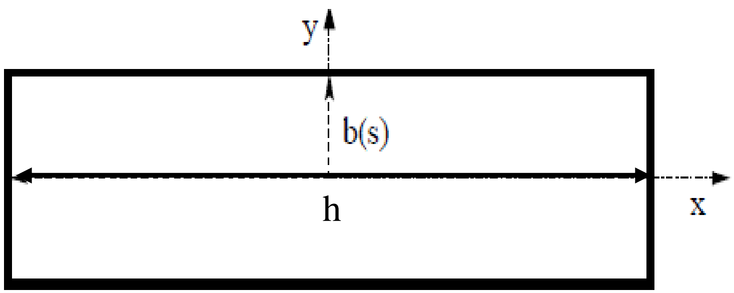
The width of the collimators limited by the beam pipe aperture (8 mm)

Spoiler design and survivability

- CLIC spoiler design criteria:
  - Minimisation of wakefield effects:
    - Geometry with shallow leading and trailing tapers
    - High conductive material to reduce the resistive contribution
  - The spoiler design for energy collimation has to survive the impact of the 312 bunches from the train: high fracture and melting points
  - For betatron collimation consumable spoilers can be used
- Selected materials:
  - Tapers made of Beryllium
  - Flat part made of Beryllium or Titanium alloy (Ti6Al4V)
  - (Be tapers with Ti alloy is the most probable option for the ILC betatron collimation spoiler)

Spoiler geometric parameters





Parameters for Energy spoiler

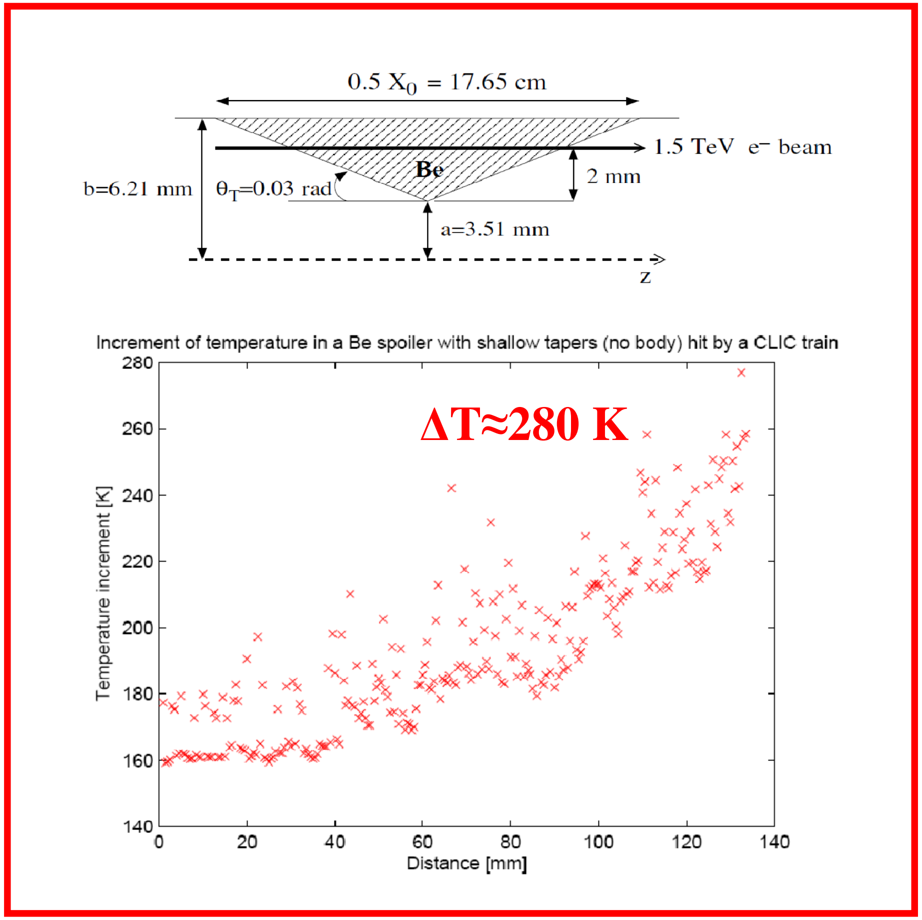
Parameter	**E-sp**	**β_y-sp**	**β_x-sp**
Vertical half gap a_y [mm]	8.0 ($h=2\ a_y$)	0.1	8.0 ($h=2\ a_y$)
Hor. half gap a_x [mm]	3.51	8.0 ($h=2\ a_x$)	0.12
Tapered part radius b [mm]	6.21	2.8	2.78
Tapered part length L_T [mm]	90.0	90.0	90.0
Taper angle θ_T [rad]	0.03	0.03	0.03
Flat part length L_F [X_0]	0.5	0.5	0.5

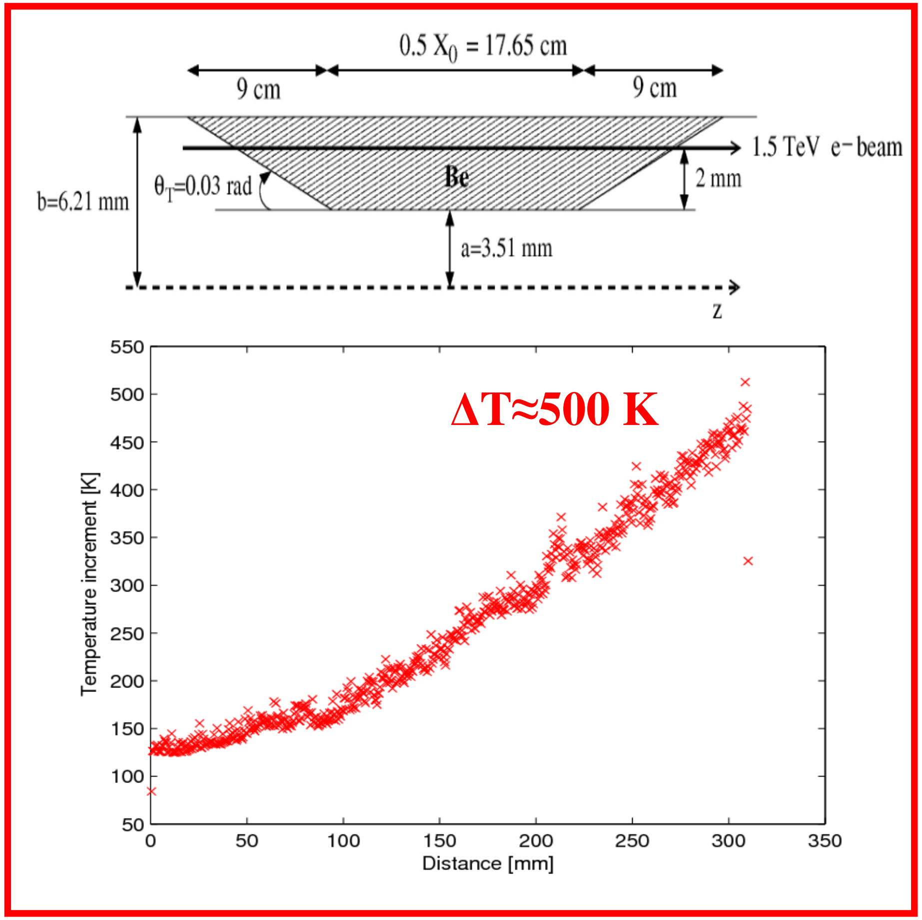
Spoiler design and survivability

Be based spoilers

We have calculated the instantaneous temperature rise in the energy spoiler by the deep impact of a full train (312 CLIC bunches) using the code FLUKA, for options based on Be

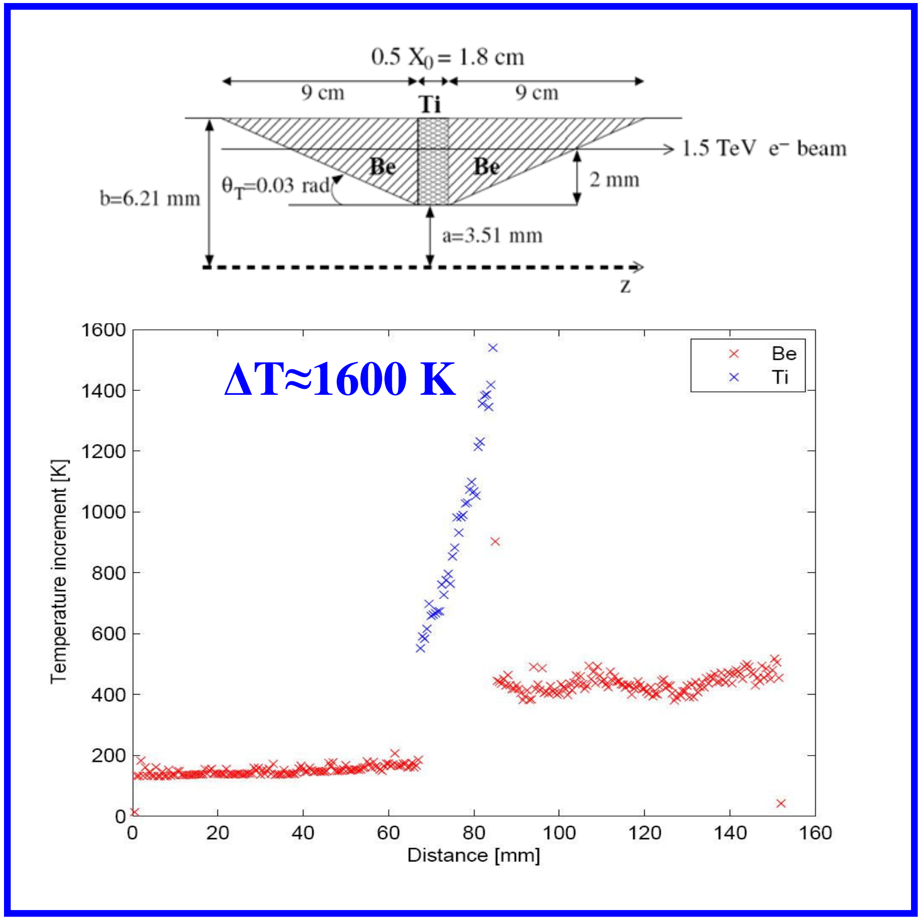
[J. L. Fernandez-Hernando, J. Resta-Lopez, WE6RFP035, PAC09]





Spoiler design and survivability

Be & Ti based spoilers



Spoiler design and survivability

Summary of simulated results:

Spoiler	**Max. ΔT[K]**	**Fracture temp. [K]**	**Melting temp. [K]**	**Result**
Full Be (w/o flat part)	~280	370	1267	No fracture
Full Be (with flat part)	~500	370	1267	Fracture
Ti alloy + Be tap.	~500*/1600**	370*/ 1710**	1267*/ 1941**	Fracture

* For the Be.

** For the Ti alloy

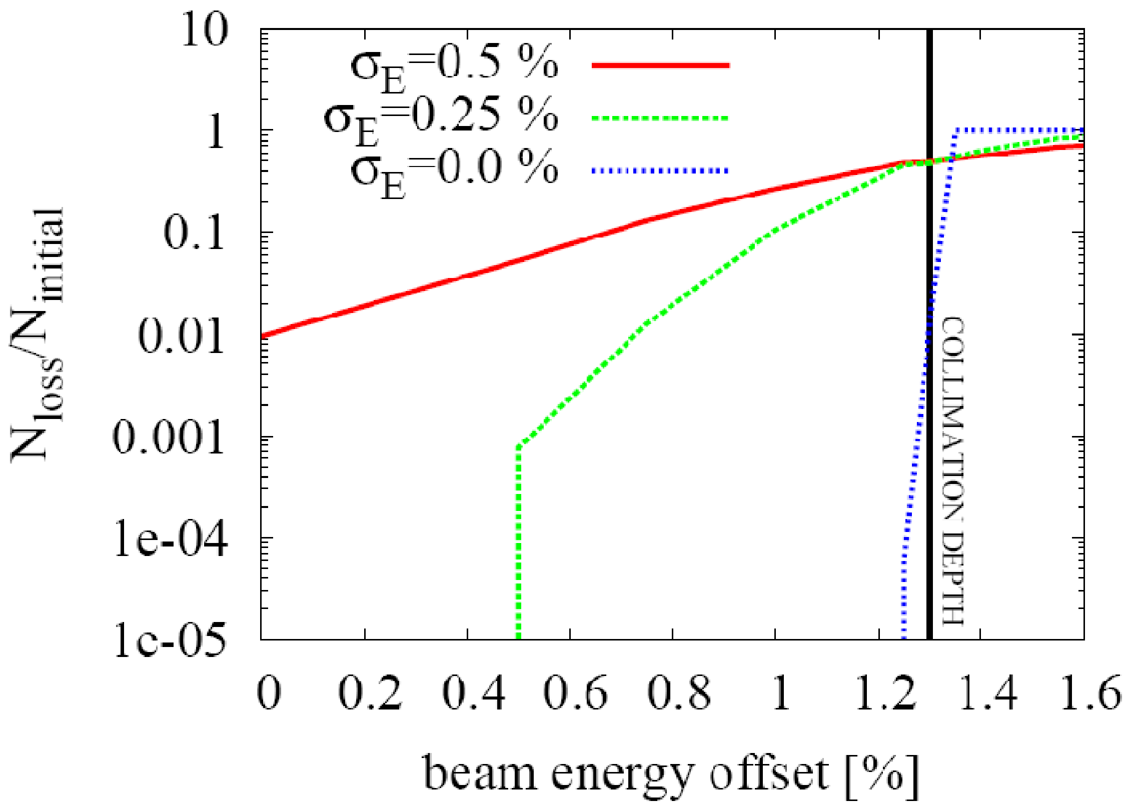
The instantaneous increment of temperature would translate into microfractures

Further studies are needed to understand the effect of these fractures on the spoilers !

Collimation efficiency

Energy collimation

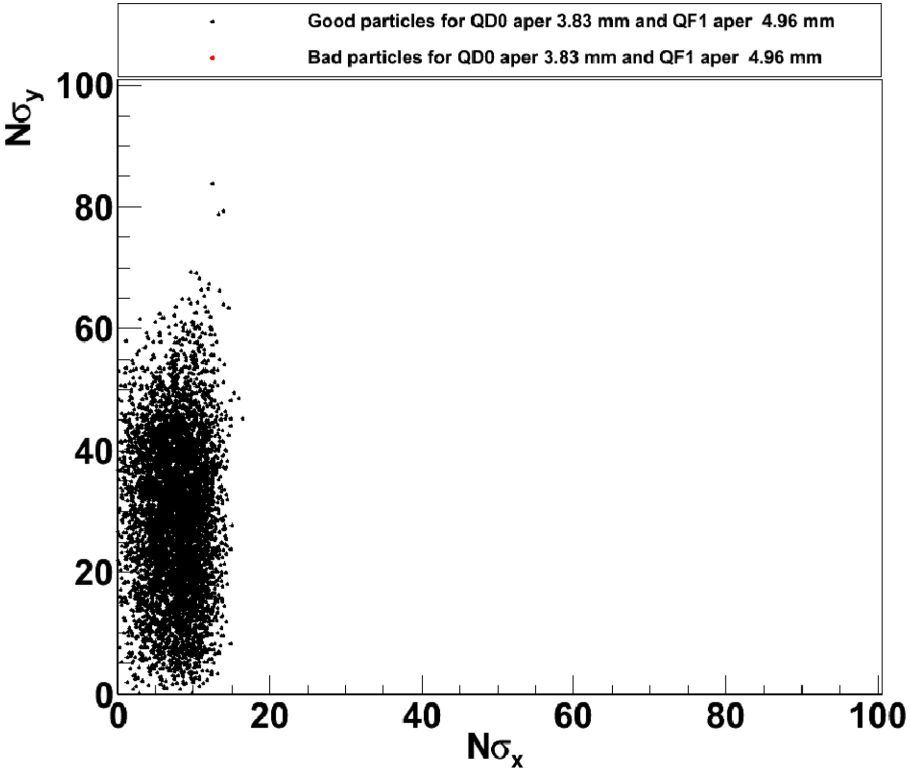
We have studied the efficiency of this system by means of tracking simulations with the code PLACET. Gaussian distributions of 10^5 off-energy macroparticles are tracked through the BDS lattice. The spoiler is treated as a “black” collimator.



For average energy offsets ~> 1.3% practically 100% of the particles of the beam are removed

Collimation efficiency
Betatron collimation

Optimisation of betatron apertures by Barbara Dalena:



"Good particles":
- No emitted photons hitting QD0
- No particles hitting QF1 & QD0

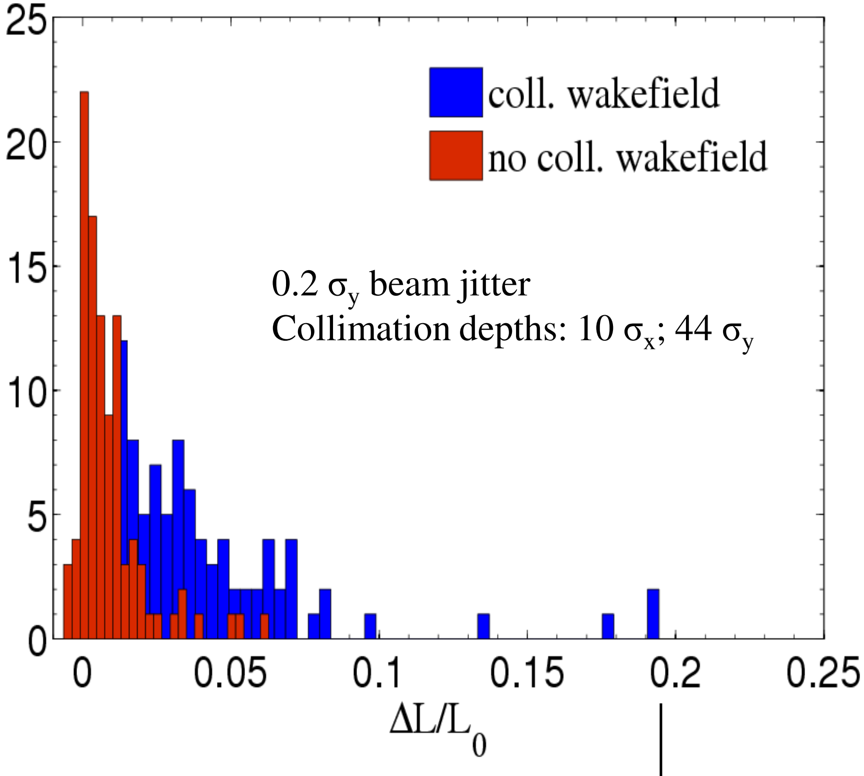
"Bad particles":
- Emitted photons hitting QD0
- Particles hitting QF1 or QD0

Old apertures (10 σ_x & 44 σ_y) clean the dangerous particle efficiently

Larger apertures (15 σ_x & 55 σ_y) give acceptable collimation efficiency, and would help to reduce wakefields

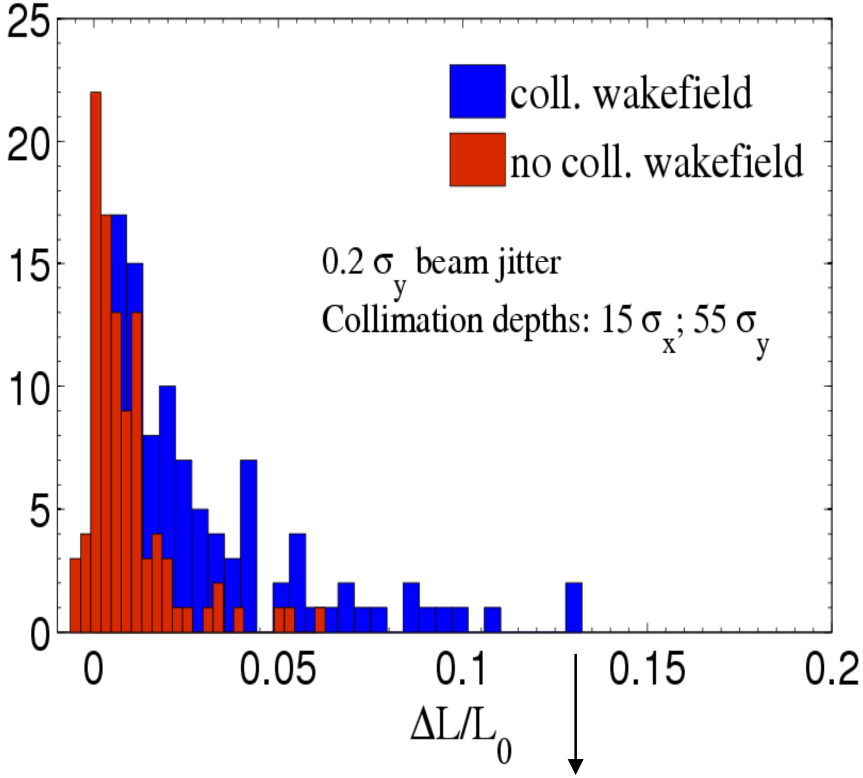
Luminosity loss
Coll. Wakefields + vertical beam position jitter

Old coll. apertures



≈ 19% maximum luminosity loss

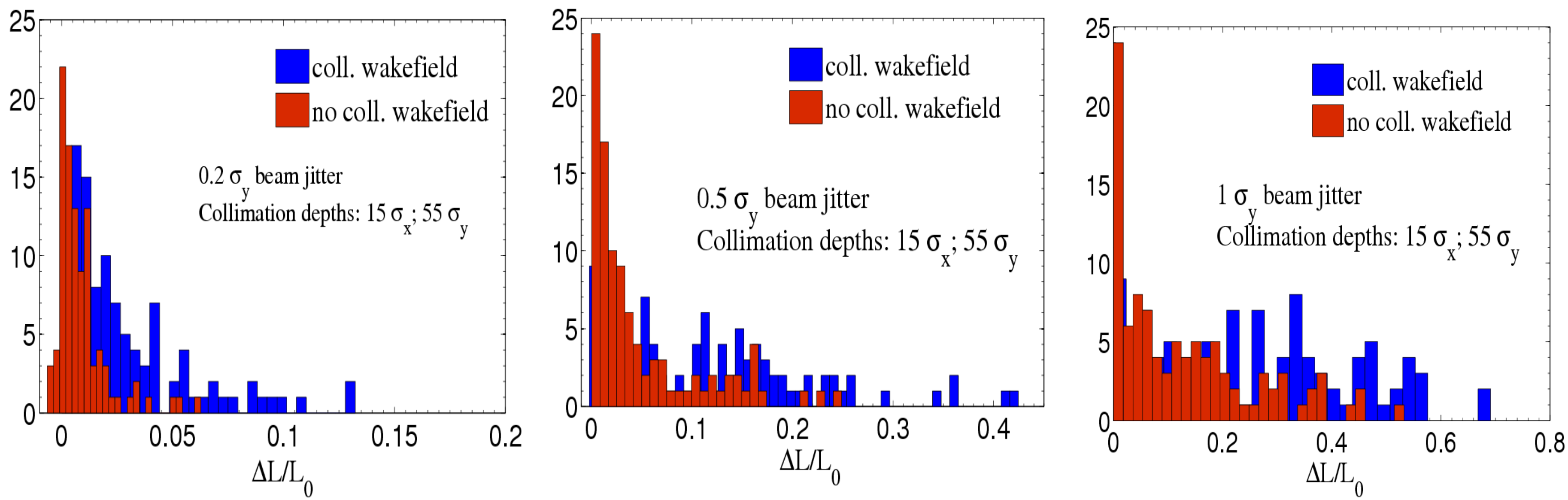
New coll. apertures



≈ 13% maximum luminosity loss

Luminosity loss

Coll. wakefields + vertical beam position jitter



Beam jitter	rms $\Delta L/L_0$ (no coll. wakefields)	rms $\Delta L/L_0$ (with coll. Wakefields)
0.2 σ_y	1.17%	2.85%
0.5 σ_y	5.72%	9.71%
1.0 σ_y	12.91%	17.58%

Collimation system optimisation

- Tapering spoiler angle optimisation:
  - The optimum total length of the tapered spoilers achieved when both geometric and resistive kicks have equal strength

Wakefield kick factors:

Geometric contribution: diffractive regime (from Supakov's criteria): $\kappa_{\perp} = \frac{1}{a^2}$

Resistive contribution from tapered spoiler, w/o flat part: $\kappa_R = \frac{\pi}{8a^2}\Gamma\left(\tfrac{1}{4}\right)\sqrt{\frac{2}{\sigma_z \sigma Z_0}}\frac{1}{\theta_T}$

$$\kappa_{\perp} = \kappa_R \quad \longrightarrow \quad \boxed{\theta_{T,op} = \frac{\pi}{8}\Gamma\left(\tfrac{1}{4}\right)\sqrt{\frac{2}{\sigma_z \sigma Z_0}}}$$

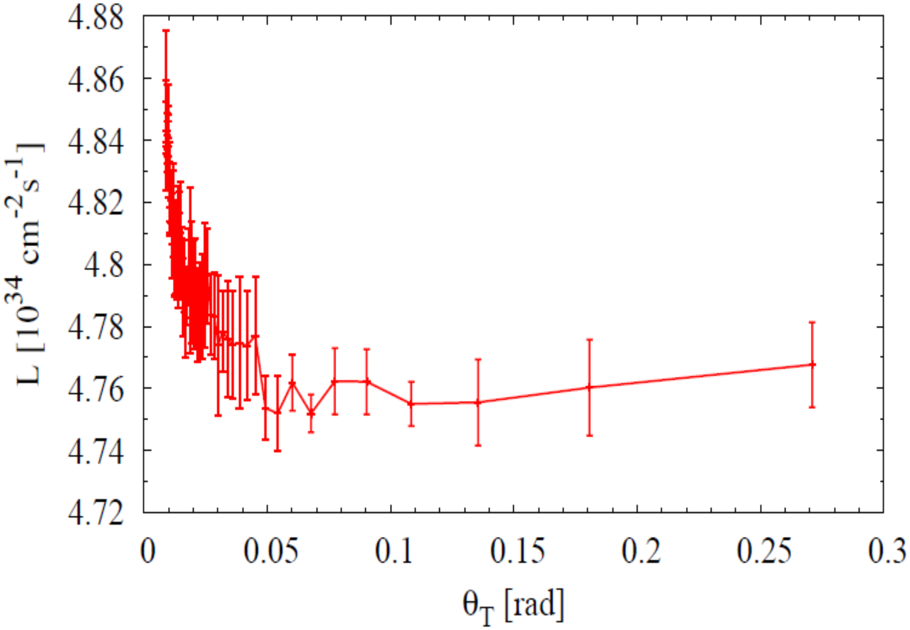
CLIC beam: $\sigma_z = 44\ \mu\text{m}$
Be spoiler: $\sigma = 1.67 \times 10^7\ \Omega^{-1}\ \text{m}^{-1}$
$Z_0 = 376.7\ \Omega$

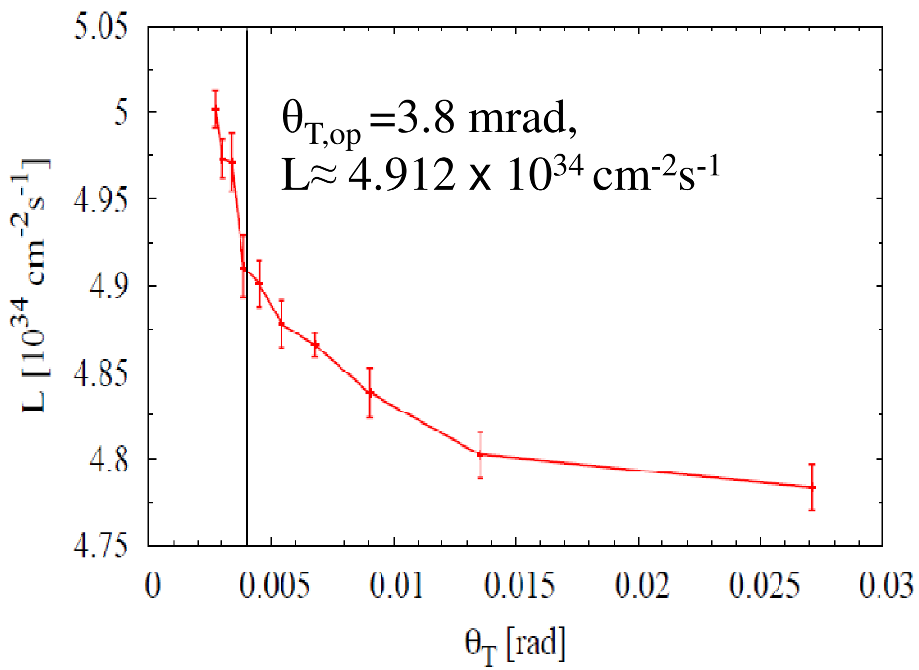
$\theta_{T,op} = 3.8\ mrad$

Collimation system optimisation

- Luminosity versus θ_T of the spoiler YSP1, with an initial vertical beam offset of 5 μm

From Placet tracking through the BDS + Guinea-Pig





Progress in code development for collimation studies

- Significant progress has also been made in the development of codes for realistic simulations (e.g. BDSIM-PLACET interface), allowing collimation studies simultaneously including wakefield effects and production of secondary particles

- Realistic halo generation studies in the Linac and BDS (HTGEN-PLACET interface) (H. Burkhardt et al.)

  [“Tracking studies of the CLIC Collimation System”, I. Agapov et al., PRST-AB 12, 081001 (2009)]

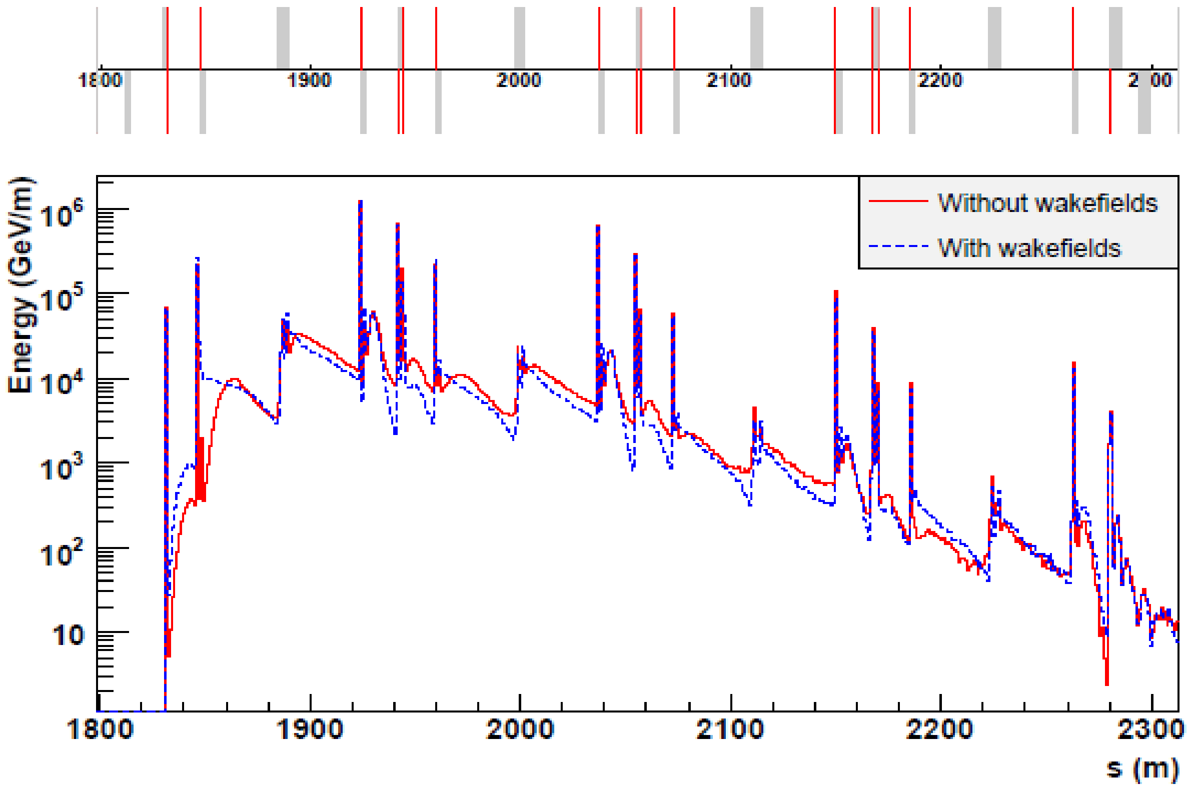
- Algorithm optimisation to speed up the wakefield computation in the tracking code PLACET (A. Toader et al.): interesting for start-to-end tracking simulation studies

Collimator wakefield + Secondary particles

- PLACET-BDSIM interface: simulations including particle tracking, wakefield effects, energy deposition, multiple Coulomb scattering and secondary particle production
- Detailed loss maps in the BDS
- Initial halo distribution for this study:
  - Concentric ellipses in x-x' and y-y', covering the phase space 0-40 $\sigma_{x,x'}$ and 0-190 $\sigma_{y,y'}$
  - Thickness per ellipse: 5 $\sigma_{x,x'}$ and 10 $\sigma_{y,y'}$ respectively
  - 1/r transverse density profile in each phase-space with 1e4 macroparticles per ellipse; 1.52e6 macroparticles total halo population
  - Flat energy distribution of full width 1% about the mean beam energy of 1496 GeV
  - Gaussian longitudinal profile of width 44 μm
  - Hard-edge collimator assumption, and half-gaps: 10 σ_x and 44 σ_y

Collimator wakefield + Secondary particles

Loss map along the BDS



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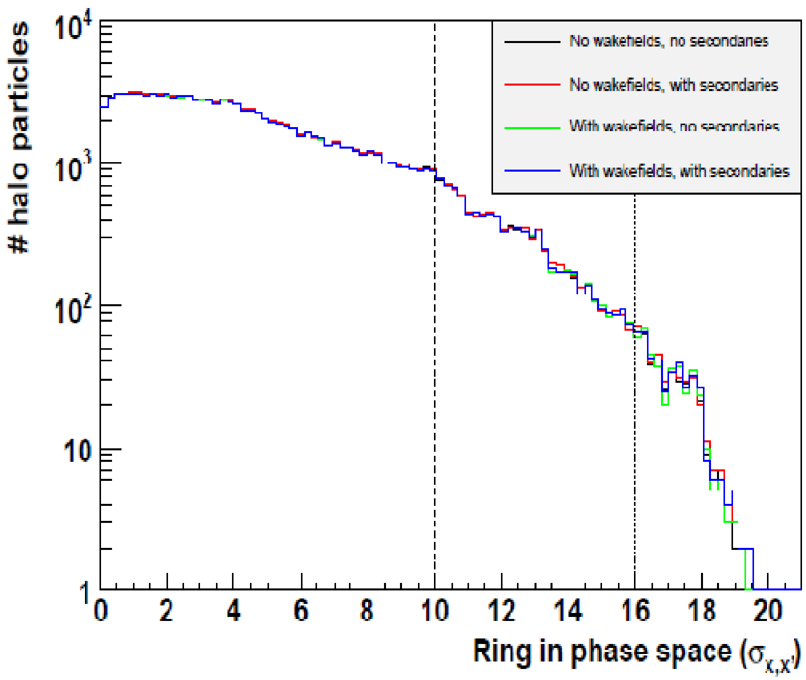
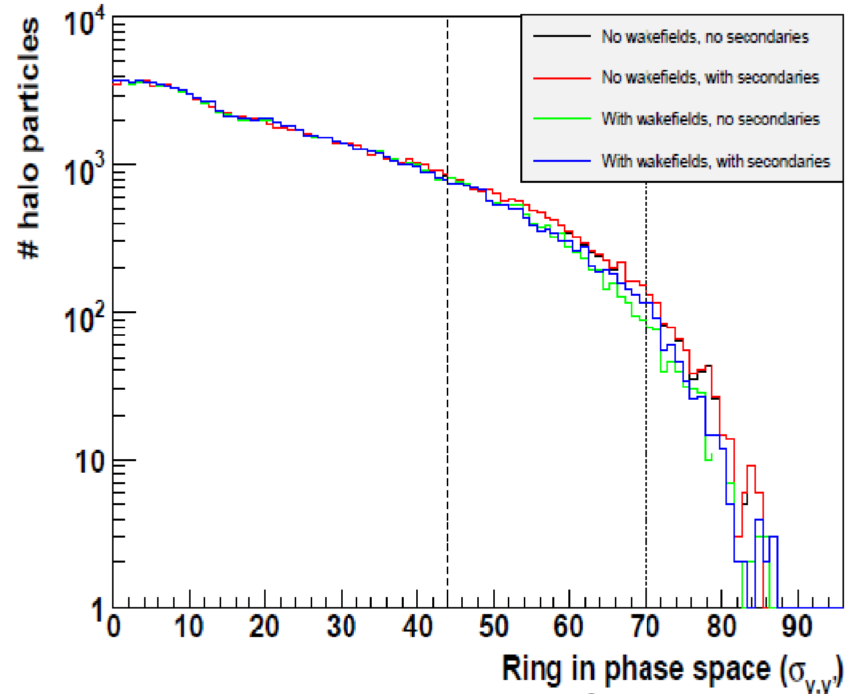
- Considering secondary particle production, losses on the collimators do not differ significantly between the cases with and without wakefields
- Losses closer to the spoiler when wakefields are included

Halo distribution at QD0





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- The distribution in horizontal phase-space does not vary significantly with either wakefield or secondary particle generation

- Vertical distribution is more sensitive:
  - Wakefields decrease the number of particles above the collimation depth
  - Secondary particles increase this number

Collimation alternatives

- First we plan to exploit the “classic” collimation option. However, in parallel it is convenient to explore alternative collimation methods

- For a possible “phase 2” of CLIC collimation:

  - Rotating consumable collimators (experience can be obtained during the LHC phase 2 collimation)

  - Non-linear collimation: preliminary studies have shown a promising performance.

  - Extraction kickers and absorbers in the drive beam section and in the main linac as protection against energy-off beams (R. Assmann & F. Zimmermann, MOPLS09.PDF, EPAC06)

  - More exotic schemes:
    - Materials with special magnetic properties (A. Seryi, J. Stohr et al.)
    - Crystal collimation for lepton beams?

Summary and conclusions

- The CLIC collimation system has recently been reviewed
- Looking for a trade-off between high collimation efficiency and low wakefield effects, recently the collimation depths have been optimised
- We have reviewed the collimator wakefield impact on the luminosity with the new collimator apertures:
  - Vertical position jitter tolerance ~ $0.2\sigma_y \rightarrow \mathrm{rms}\ \Delta L/L_0 \approx 3\%$
- Remarkable progress in the development of software tools for realistic simulations (e.g. PLACET-BDSIM interface), including wakefield effects, energy deposition and secondary particle generation. ACTION: update collimation efficiency studies
- Fruitful efforts (by international collaboration) towards the consolidation of the CLIC collimation system design

Collimator parameters and wakefield regimes

Wakefield regimes for CLIC BDS spoilers:

(From Stupakov's criteria)

- Geometric wakefields:
  - Energy spoiler (E-sp): σ_z=44 μm; $\sigma_z a/h^2$=5.98e-5; θ_T=0.03 rad → $\theta_T >> \sigma_z a/h^2$, not smooth transition: diffractive regime
  - Vertical spoiler (β_y-sp): $\sigma_z a/h^2$=1.1e-5; $\theta_T \approx$0.03 rad → $\theta_T >> \sigma_z a/h^2$, not smooth transition: diffractive regime
  - Horizontal spoiler (β_x-sp): $\sigma_z a/h^2$=1.32e-5; $\theta_T \approx$0.03 rad → $\theta_T >> \sigma_z a/h^2$, not smooth transition: diffractive regime
- Resistive wakefields for CLIC collimators: intermediate (between short- and long-range regimes)