CLIC collimation system review: optics issues and wakefield effects

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Introduction

- Recently the CLIC BDS has been optimised and updated according new beam parameters [R. Tomas]

- 370 m of diagnostics section upstream of the collimation section

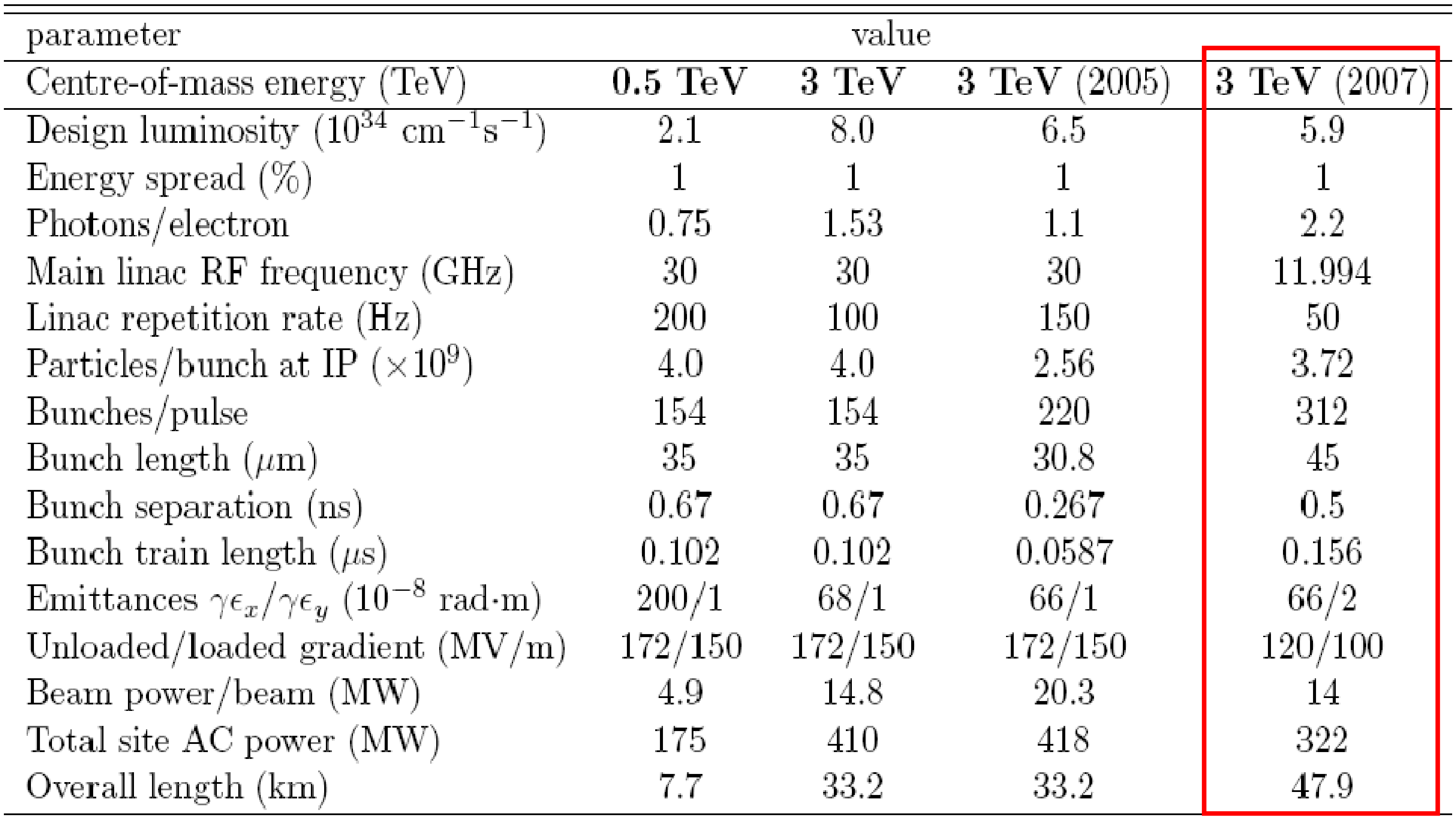
- Shorter FFS

- No significant changes in the collimation system

- New vertical normalised emittance $\gamma\varepsilon_y=20$ rad nm (previous $\gamma\varepsilon_y=10$ rad nm), and new vertical beta functions across the final doublet ✸ new vertical betatron collimator aperture. Necessary to review the collimator wakefield effects and transverse cleaning efficiency

- New beam emittance and bunch intensity. Necessary to review the survivability of the energy spoiler to the impact of an entire bunch train or, at least, to the impact of as many bunches as possible

CLIC parameters



parameter	value			
Centre-of-mass energy (TeV)	**0.5 TeV**	**3 TeV**	**3 TeV** (2005)	**3 TeV** (2007)
Design luminosity (10^{34} cm^{-1}s^{-1})	2.1	8.0	6.5	5.9
Energy spread (%)	1	1	1	1
Photons/electron	0.75	1.53	1.1	2.2
Main linac RF frequency (GHz)	30	30	30	11.994
Linac repetition rate (Hz)	200	100	150	50
Particles/bunch at IP ($\times 10^9$)	4.0	4.0	2.56	3.72
Bunches/pulse	154	154	220	312
Bunch length (μm)	35	35	30.8	45
Bunch separation (ns)	0.67	0.67	0.267	0.5
Bunch train length (μs)	0.102	0.102	0.0587	0.156
Emittances $\gamma\epsilon_x/\gamma\epsilon_y$ (10^{-8} rad·m)	200/1	68/1	66/1	66/2
Unloaded/loaded gradient (MV/m)	172/150	172/150	172/150	120/100
Beam power/beam (MW)	4.9	14.8	20.3	14
Total site AC power (MW)	175	410	418	322
Overall length (km)	7.7	33.2	33.2	47.9

Principle of beam collimation

Main functions

- Reduction of the background in the particle detectors by removing halo (particles at large betatron amplitudes and/or energy offsets)
- Protection of machine components:
  - Minimise the activation and damage of accelerator components outside of the dedicated collimation sections
  - Intercept the beam in case of failure scenarios and abnormal operation (mis-steered or errant beams)

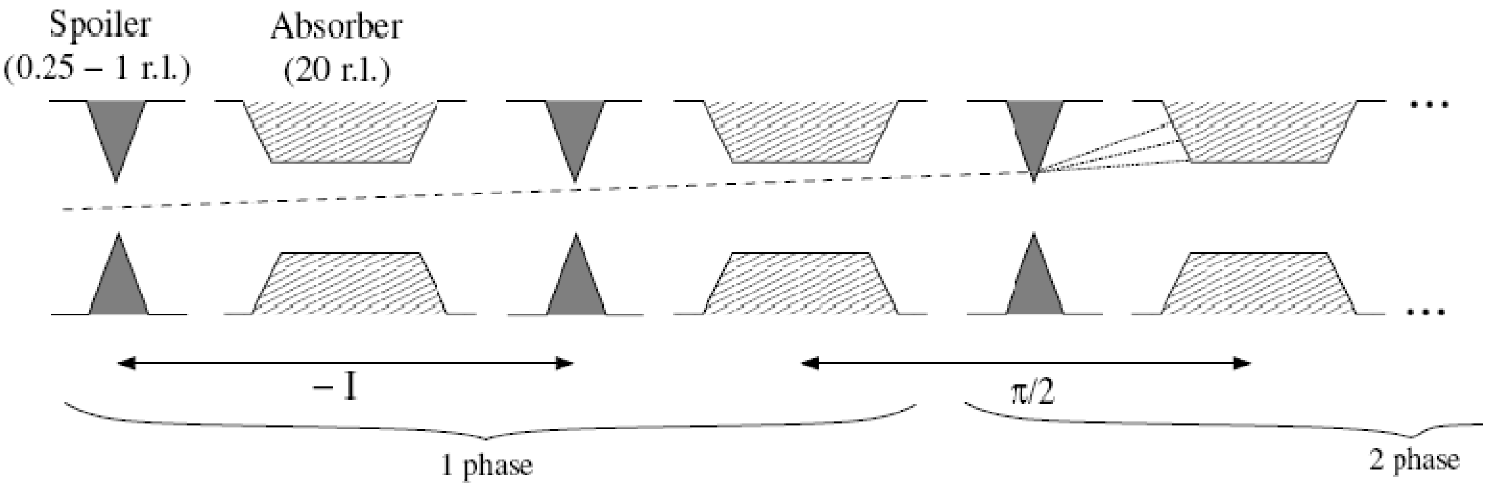
Constraints

- The optics of the system should not adversely affect the beam stability or degrade the nominal luminosity
- The system should not produce intolerable wakefields (impedances) which might compromise beam stability
- Robustness: the system should withstand the direct impact of mis-steered or errant beams

Collimation system

Simple spoiler/absorber scheme

- A conventional postlinac collimation system usually consists 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



Collimation depth

ENERGY COLLIMATION:

- Energy collimation amplitudes determined by the failure modes in the Linac (RF phase jitter, reduced current, …). Errant or mis-steered beams must be intercepted (machine protection). For CLIC: protection against mis-steered or errant beams with energy errors **> 1.3%.**

  E-spoiler half-gap: $a_x = D_x \delta \ (\delta = \pm 1.3\ \%)$

Collimation depth

BETATRON COLLIMATION:

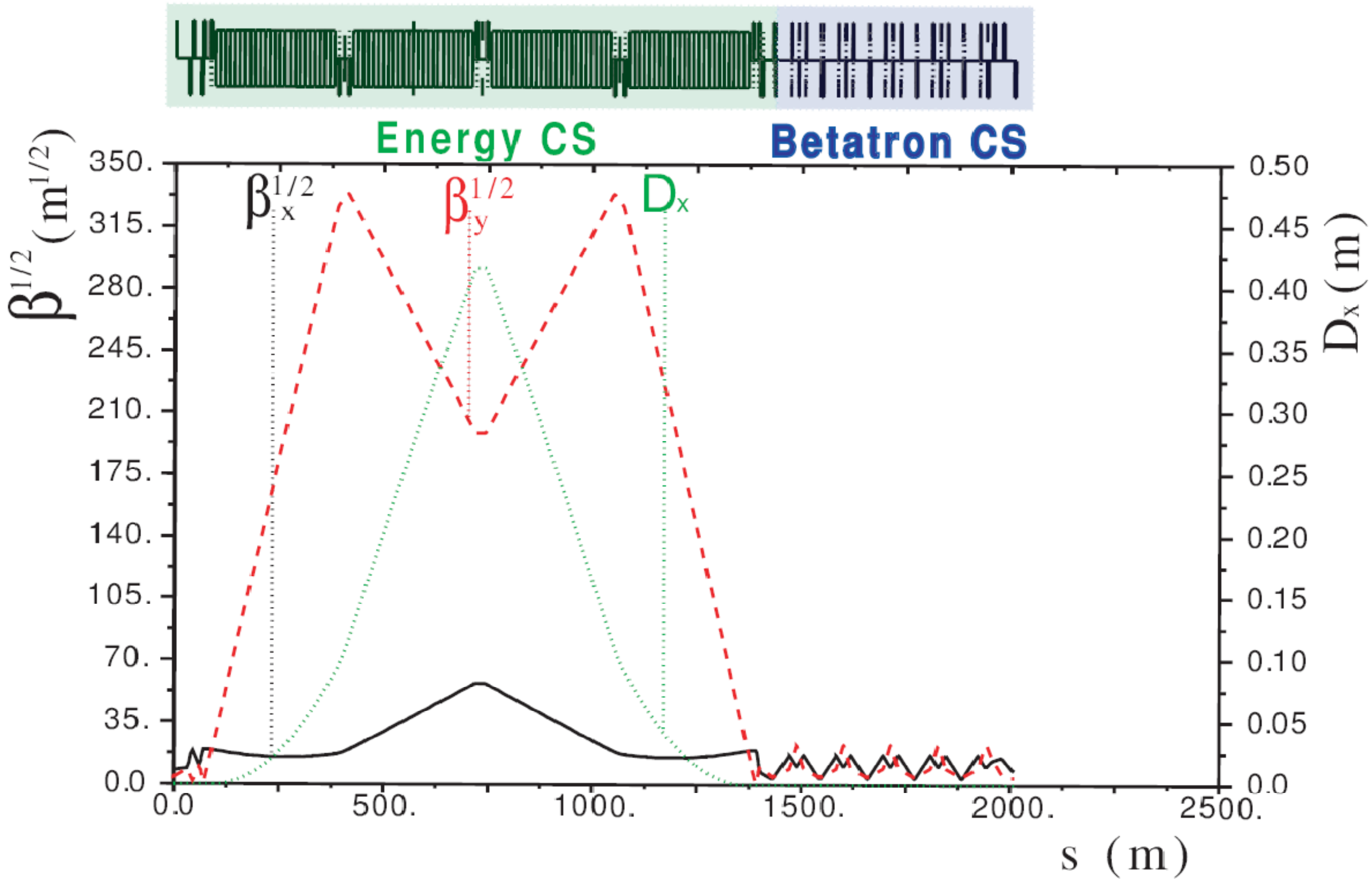
- Conventional criterium:

  Betatron collimation depths determined from the condition that beam particles and SR photons emitted in the FD should not hit any magnet apertures on the incoming side of the IP.

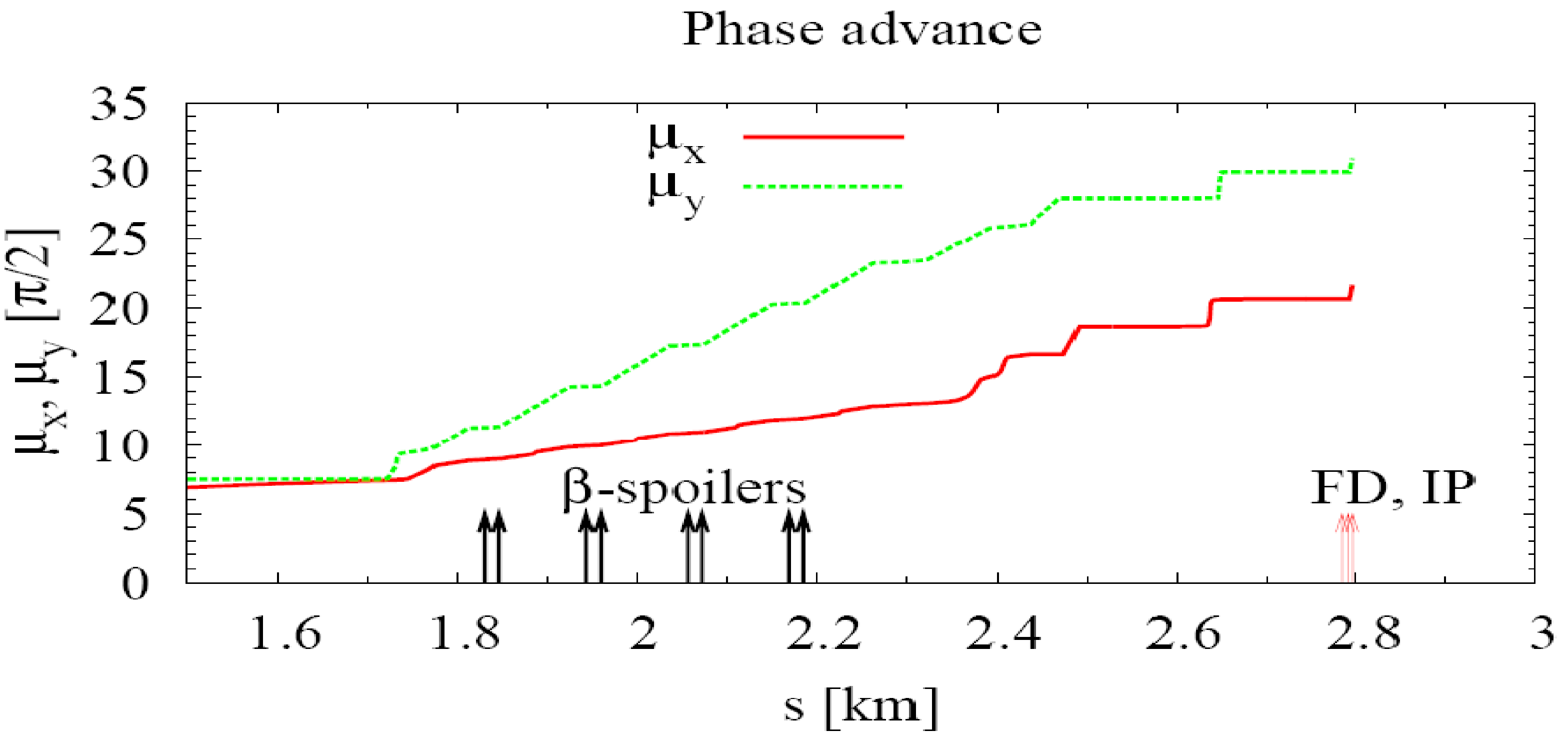
  - CLIC BDS old lattice: horizontal collimation depth $\mathbf{10\sigma_x}$; vertical depth $\mathbf{83\sigma_y}$ (version 2005)
  - CLIC BDS new lattice: horizontal collimation depth $\mathbf{16\sigma_x}$; vertical depth $\mathbf{70\sigma_y}$ (estimate by F. Jackson using SR ray tracing through the interaction region, CLIC Workshop 2008)

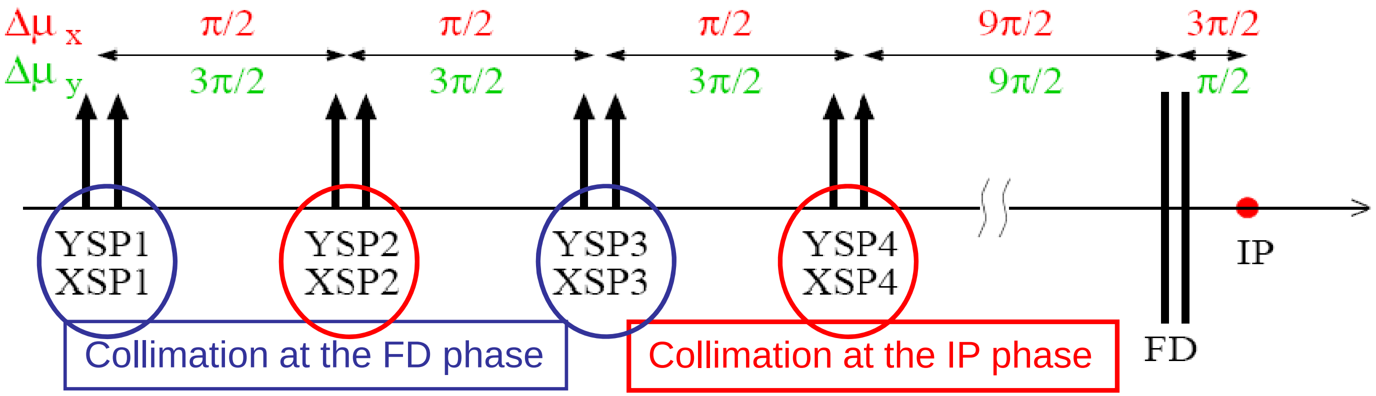
- Safer criterium: protection of the final quadrupole QD0 against particle hitting. The QD0 bore aperture determines the actual collimation depths: horizontal $\mathbf{10\sigma_x}$; vertical $\mathbf{44\sigma_y}$ (CLIC-Note-764) .

CLIC collimation section optics



Collimator position and phase advance review

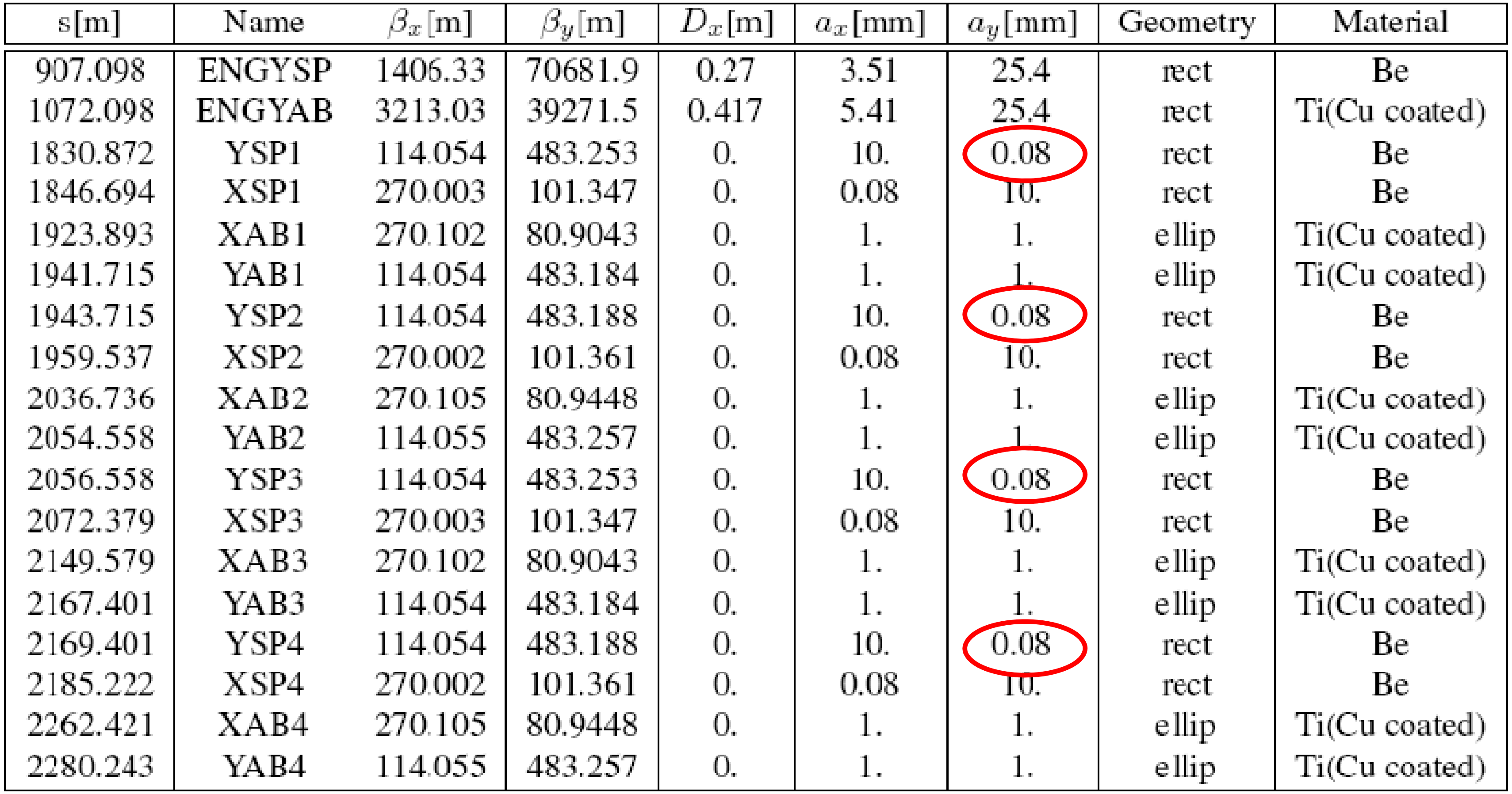




Collimation at the FD phase

Collimation at the IP phase

Collimator parameters



s[m]	Name	β_x[m]	β_y[m]	D_x[m]	a_x[mm]	a_y[mm]	Geometry	Material
907.098	ENGYSP	1406.33	70681.9	0.27	3.51	25.4	rect	Be
1072.098	ENGYAB	3213.03	39271.5	0.417	5.41	25.4	rect	Ti(Cu coated)
1830.872	YSP1	114.054	483.253	0.	10.	0.08	rect	Be
1846.694	XSP1	270.003	101.347	0.	0.08	10.	rect	Be
1923.893	XAB1	270.102	80.9043	0.	1.	1.	ellip	Ti(Cu coated)
1941.715	YAB1	114.054	483.184	0.	1.	1.	ellip	Ti(Cu coated)
1943.715	YSP2	114.054	483.188	0.	10.	0.08	rect	Be
1959.537	XSP2	270.002	101.361	0.	0.08	10.	rect	Be
2036.736	XAB2	270.105	80.9448	0.	1.	1.	ellip	Ti(Cu coated)
2054.558	YAB2	114.055	483.257	0.	1.	1.	ellip	Ti(Cu coated)
2056.558	YSP3	114.054	483.253	0.	10.	0.08	rect	Be
2072.379	XSP3	270.003	101.347	0.	0.08	10.	rect	Be
2149.579	XAB3	270.102	80.9043	0.	1.	1.	ellip	Ti(Cu coated)
2167.401	YAB3	114.054	483.184	0.	1.	1.	ellip	Ti(Cu coated)
2169.401	YSP4	114.054	483.188	0.	10.	0.08	rect	Be
2185.222	XSP4	270.002	101.361	0.	0.08	10.	rect	Be
2262.421	XAB4	270.105	80.9448	0.	1.	1.	ellip	Ti(Cu coated)
2280.243	YAB4	114.055	483.257	0.	1.	1.	ellip	Ti(Cu coated)

New vertical β_y –spoiler half-gap: a_y=0.08 mm (previously a_y=0.102 mm)
E-spoiler half-gap: $a_x=D_x\delta$ ($\delta=\pm1.3$ %)

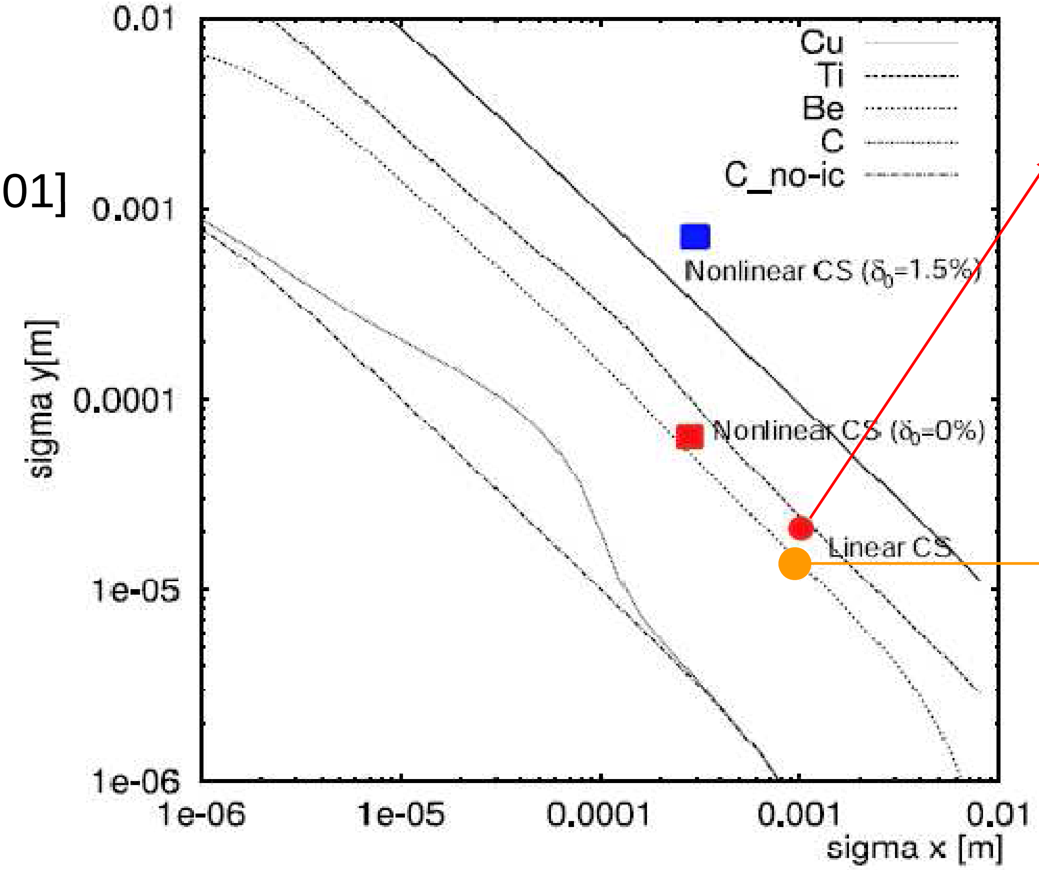
Spoiler survival

The energy spoiler was designed with the condition of surviving in case of a deep impact of the entire bunch train

Earlier studies:

[S. Fartoukh et al.,
CLIC Note 477, 2001]

A spoiler made of Be might be a suitable solution in terms of a high robustness and acceptable wakefields



Old parameters:
4 x 10^9 e^-
154 bunches/train
$\gamma\varepsilon_y$=10 nm

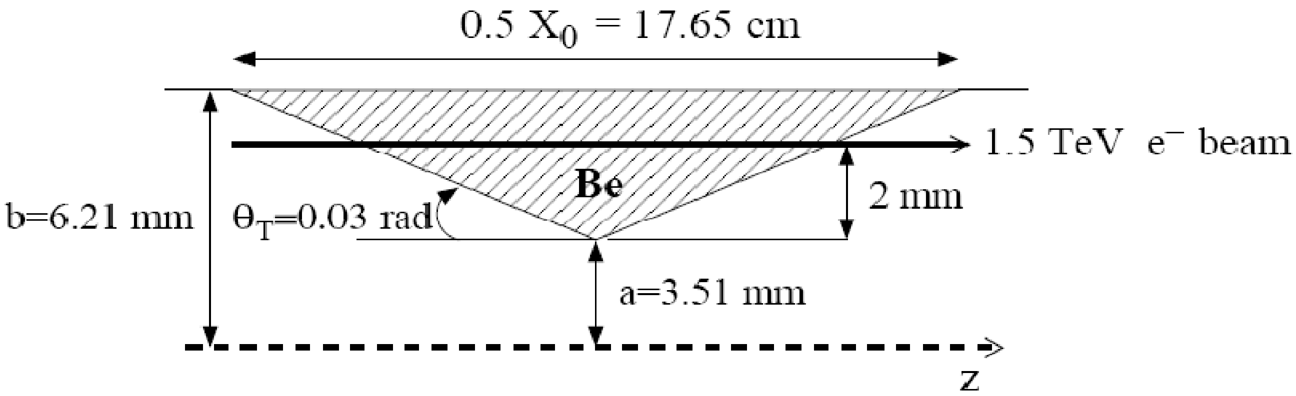
New parameters:
4 x 10^9 e^-
312 bunches/train
$\gamma\varepsilon_y$=20 nm

Spoiler survival

Recent studies:

[J. Resta-Lopez & L. Fernandez-Hernando, EUROTeV-Report-2008-050]

Energy spoiler design:



Testing alternative spoiler designs: see presentation by J. L. Fernandez-Hernando

Collimation efficiency

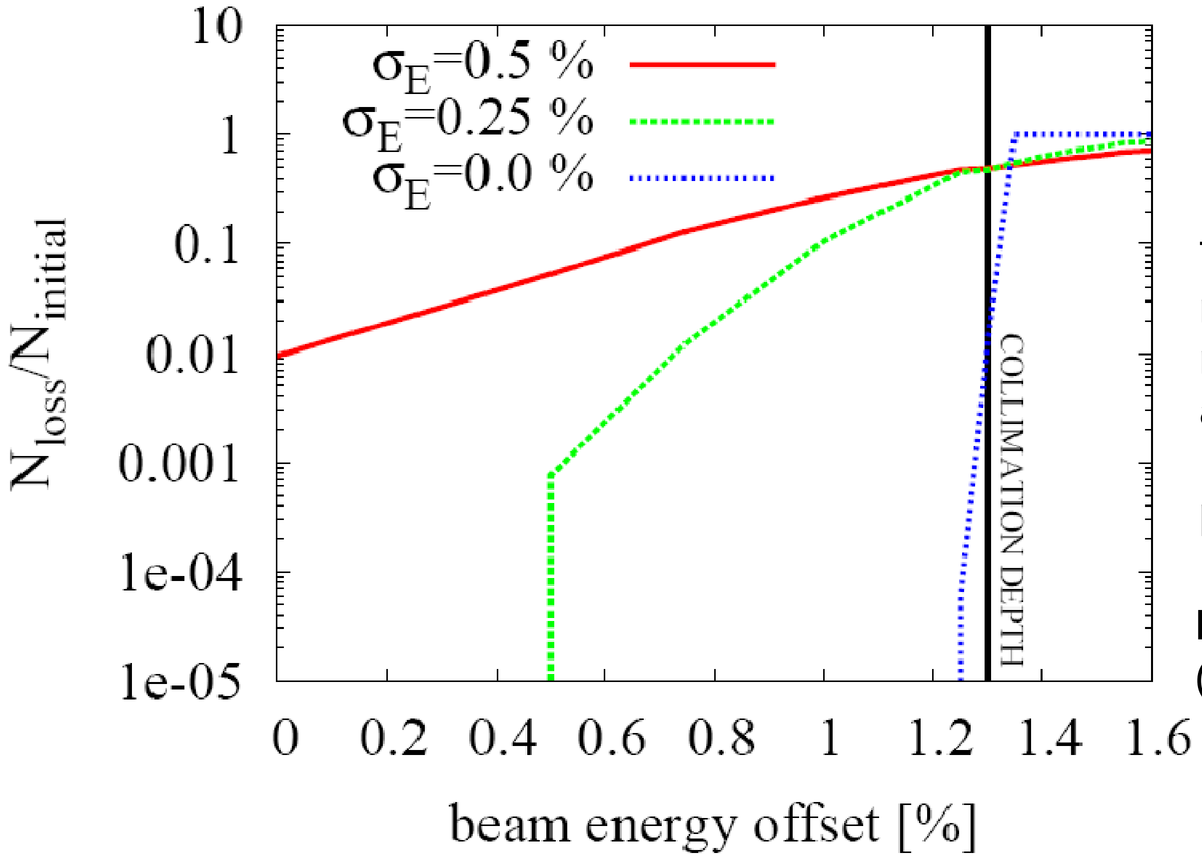
Energy collimation

- Goal: spoil mis-steered beams coming from the linac with large momentum error > 1.3 %
- Simulation conditions:
  - Tracking code PLACET
  - Tracking of initial Gaussian distributions of 10^5 macroparticles off-energy
  - Spoiler treated as perfect ‘hard-edge’. Any macroparticle interacting with the aperture is assumed to be completely absorbed. No secondary particle production

Collimation efficiency

Energy collimation

Relative particle losses versus beam energy offset.
We show the case for three energy distributions with different energy spread width σ_E



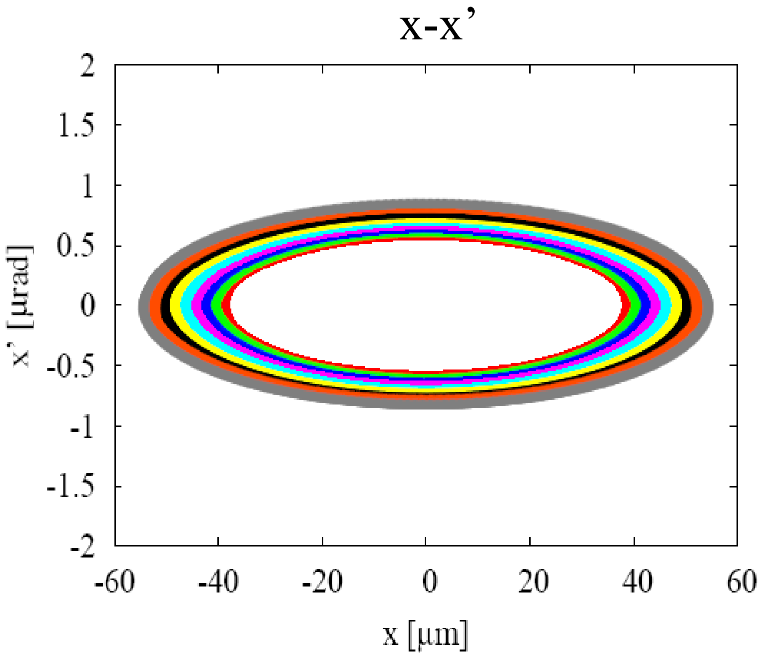
With beam energy off-set 0% and σ_E=0.5 % (energy spread parameters 2005) ✹ 1 % losses !

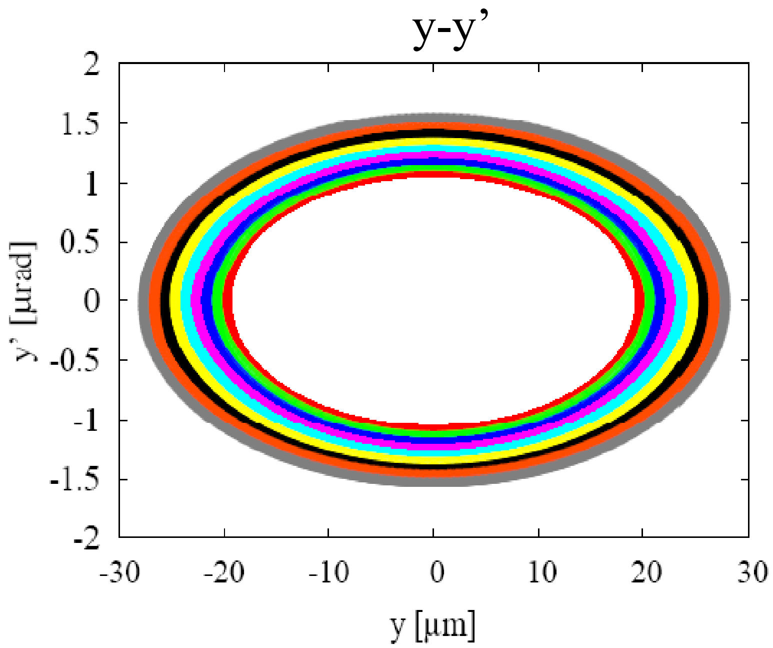
This situation of losses during normal operation has to be minimised to reduce background at the IP. Muons may be generated at a rate of about 10^{-4} per lost electron or positron

Energy spread σ_E=0.29 % (parameters 2008): better scenario

Collimation efficiency
Betatron collimation

- Simulation conditions:
  - Tracking code PLACET
  - Assuming 'black' spoilers
  - Dummy halo model: 10000 macroparticles per ellipse (N/2πr density)



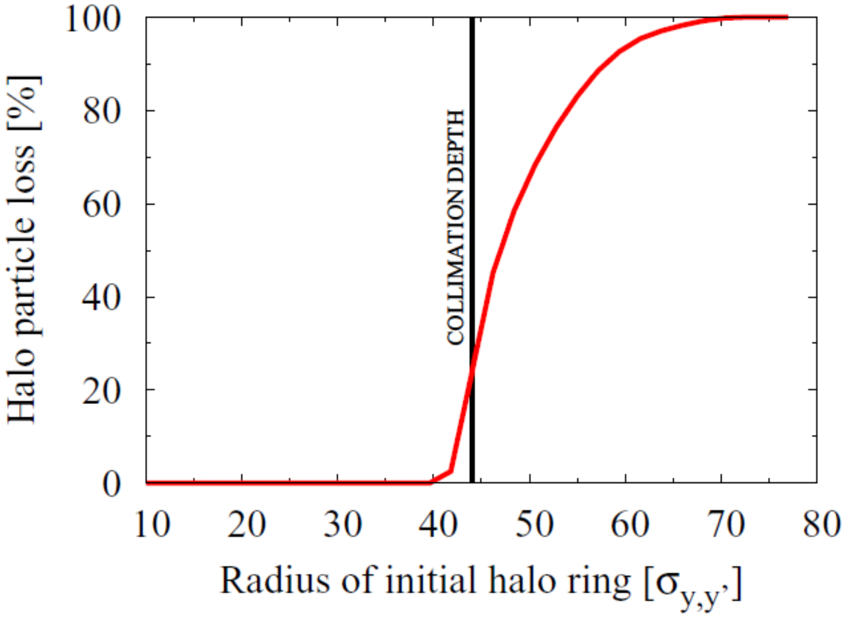


Collimation efficiency

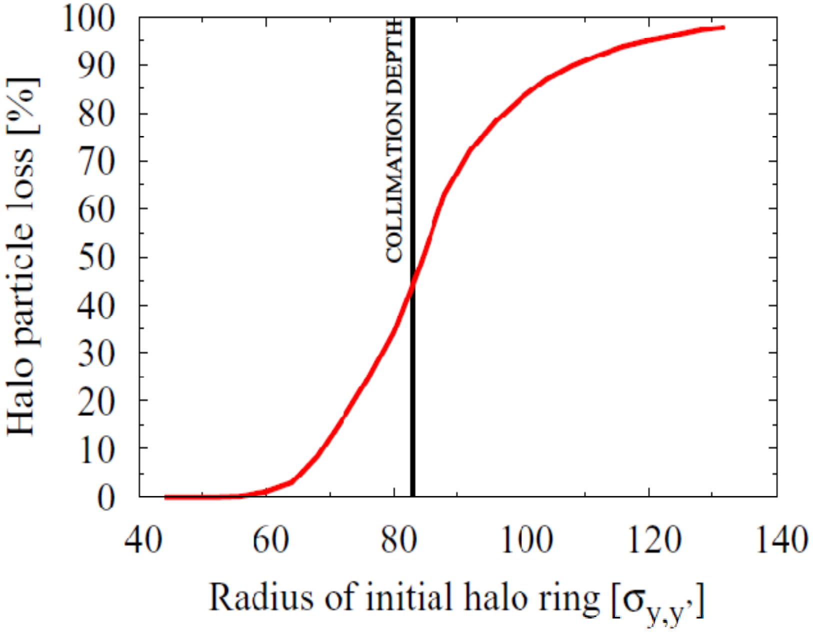
Betatron collimation y-y'

Halo particle losses versus the radius of the halo ring:

New lattice (version 2008)

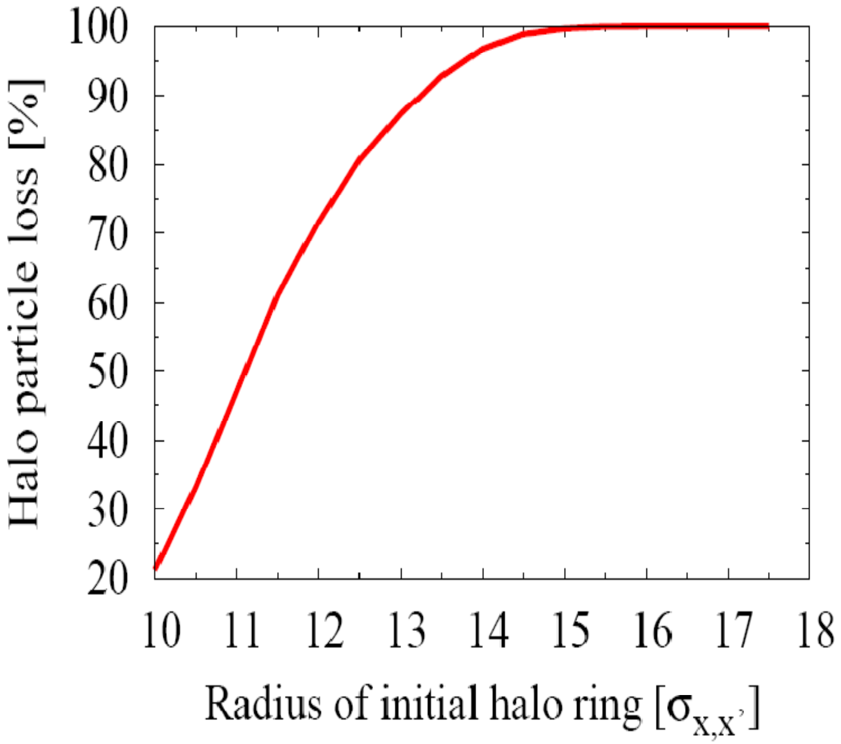


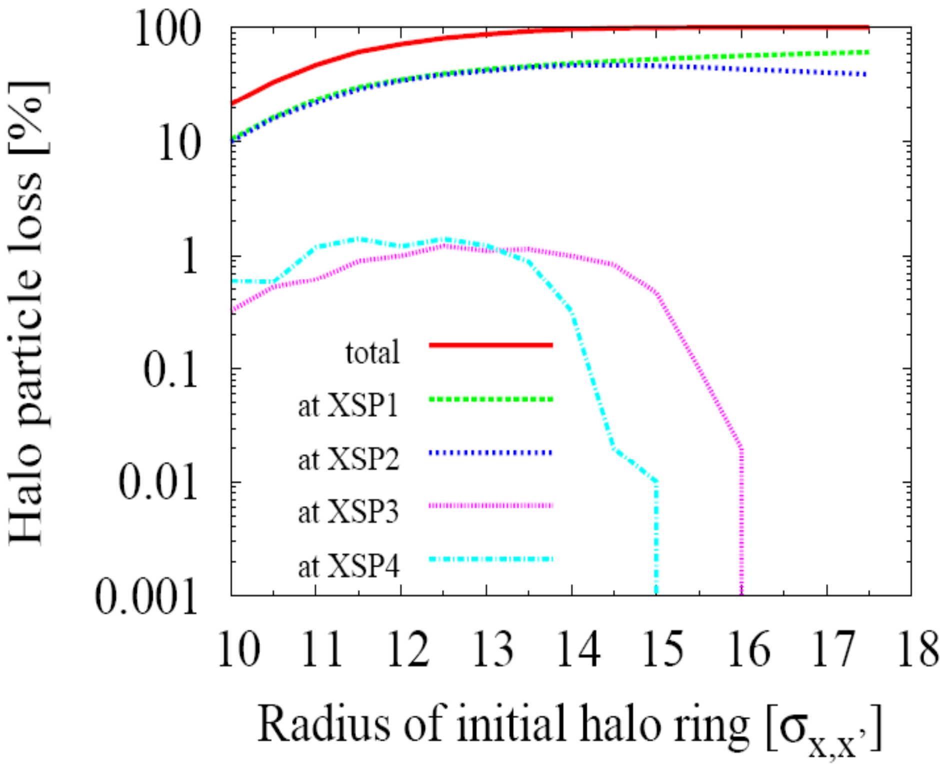
Old lattice (version 2005)



Collimation efficiency

Betatron collimation x-x’





Wakefield discussion

Collimator wakefield effects

Jitter amplification factors

(A quick analytical estimation)

If $D_x \neq 0$ and energy off-set $\delta_0 \neq 0$:

$$\boxed{A_\beta \equiv \frac{\widetilde{n}_{y'}}{\widetilde{n}_y} = \frac{N r_e}{\gamma} \kappa_\perp \beta_y}$$

$$\boxed{A_\delta = A_\beta \frac{D_x \delta_0}{\sqrt{\beta_y \epsilon_y}}}$$

Energy collimators (spoiler and absorber): diffractive regime
β-spoilers: intermediate regime
β-absorbers: inductive regime

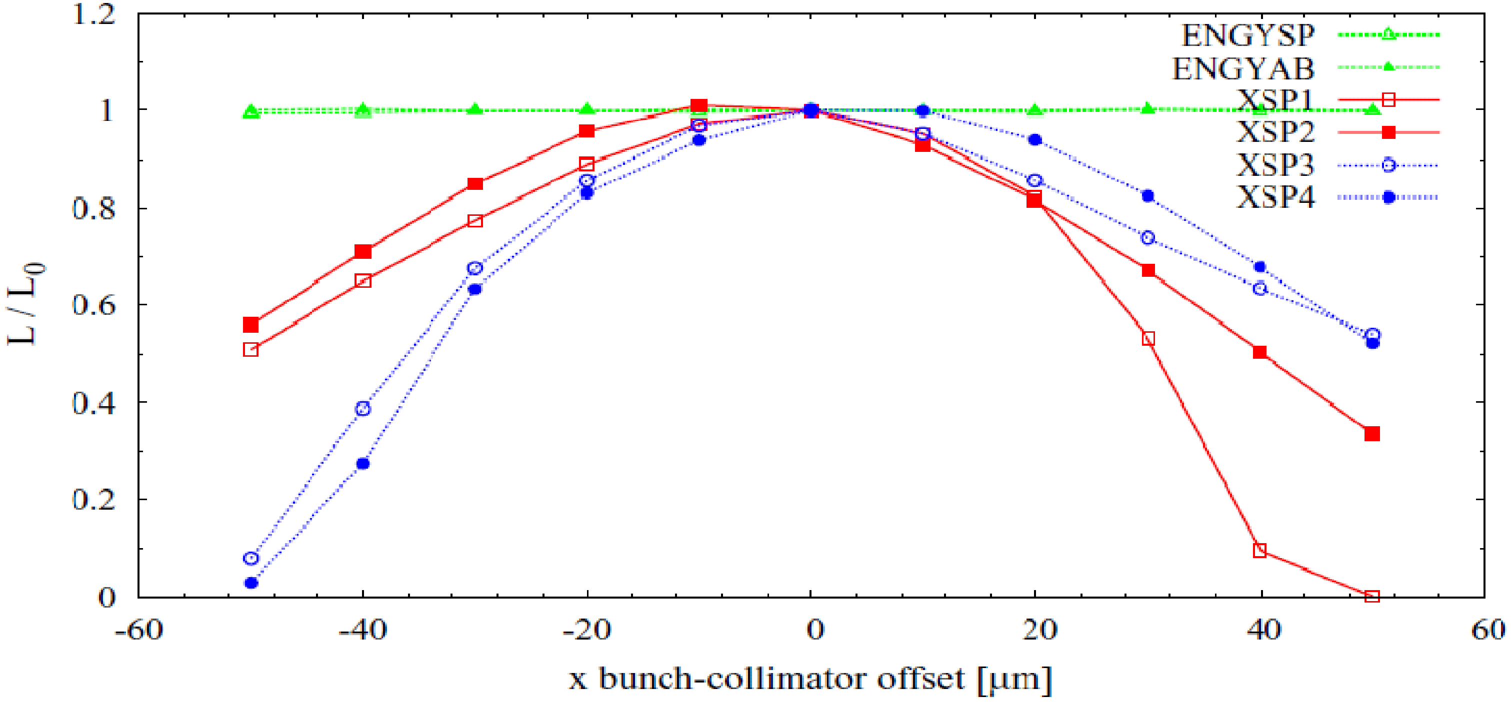
Collimator	Plane	A_β				A_δ
		geometric	Ω taper	Ω flat	Total	$\delta_0 = 1\,\%$
ENGYSP (lineal CS)	X	0.000438	6.68×10^{-5}	0.	0.000505	0.0668
ENGYAB (lineal CS)	X	0.000423	0.000034	0.000122	0.000579	0.0888
* β_y spoilers (a_y=0.08mm)	Y	0.290	0.0438	0.	0.3338	0.
β_x spoilers	X	0.162	0.0247	0.	0.1867	0.
β_y absorbers	Y	0.0169	0.000121	0.00234	0.0194	0.
β_x absorbers	X	0.0169	0.0000676	0.00131	0.0183	0.

* Previous value ($a_y = 0.102$ mm): 0.178 0.0272 0.2052

CLIC luminosity simulations

Collimator wakefield effect on the luminosity

- Luminosity loss due to horizontal misalignment of each spoiler:

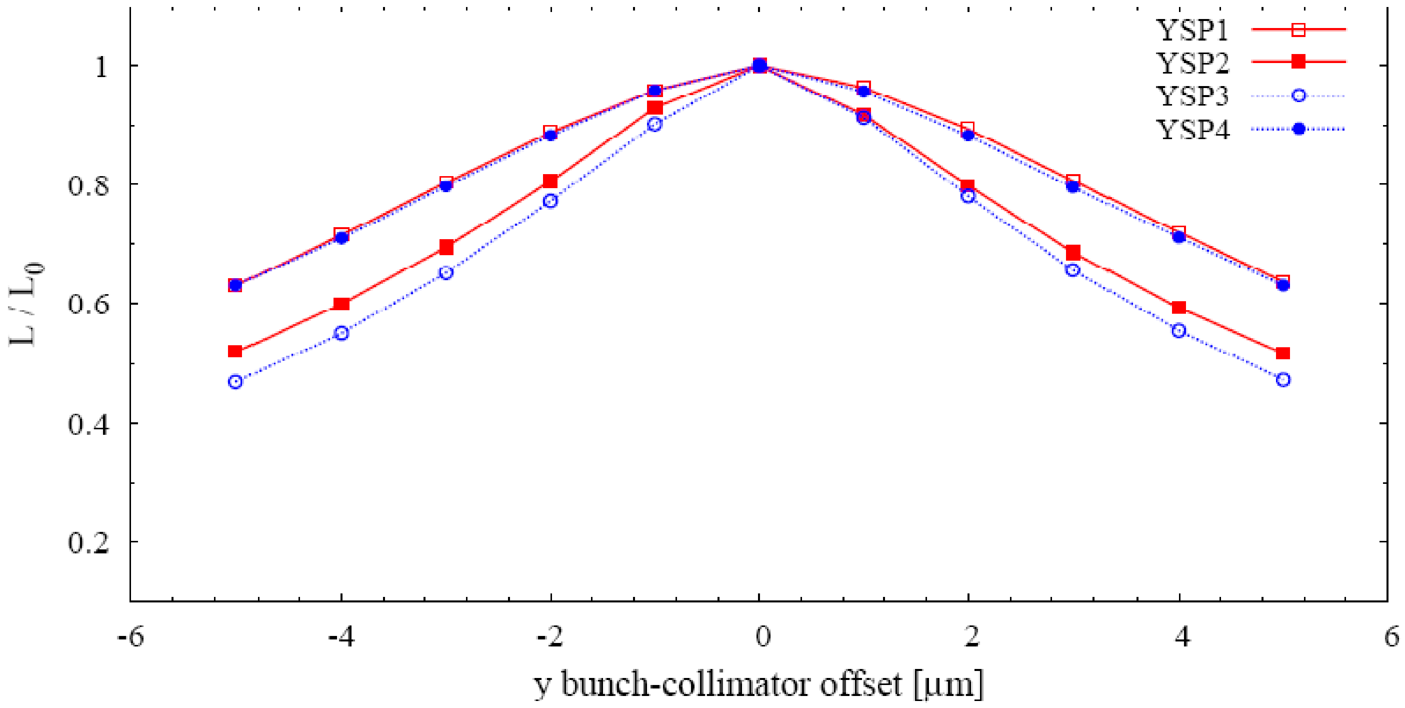


Collimator misalignment tolerance $5/2\ \sigma_x$ 🕓 20 μm (~ 10% luminosity loss), which might be achieved with optical survey alignment techniques

CLIC luminosity simulations

Collimator wakefield effect on the luminosity

- Luminosity loss due to vertical misalignment of each spoiler:

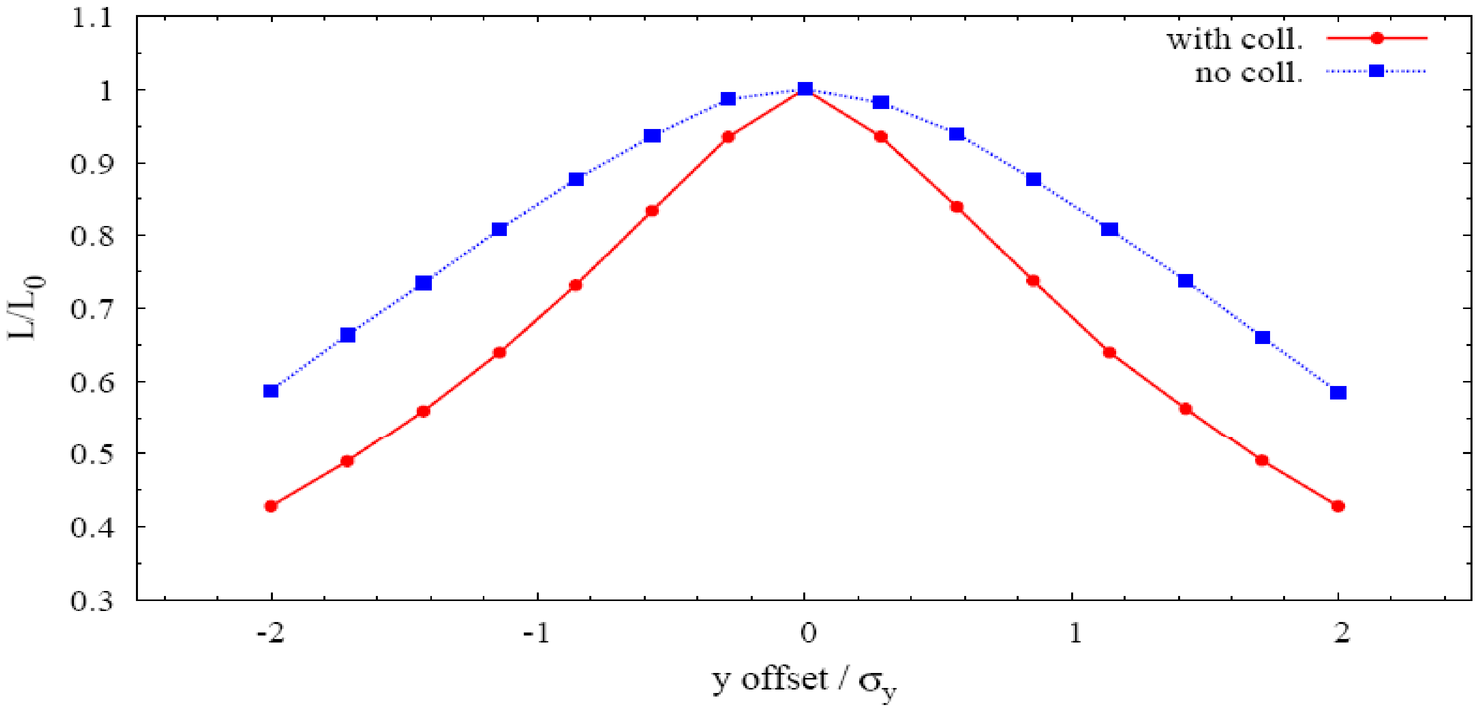


Collimator misalignment tolerance $1/2\ \sigma_y$🕓 $1\ \mu m$ (~ 10% luminosity loss)
(one order of magnitude smaller than ILC tolerance)
Challenging!

CLIC luminosity simulations

Collimator wakefield effect on the luminosity

- Luminosity loss versus initial vertical beam position offset at the entrance of the BDS
- The joint effect of all the BDS collimators is considered



Position jitter tolerance $0.2\,\sigma_y \approx 0.1\ \mu m$ ($\sim 10\%$ luminosity loss)
(Similar to ILC initial jitter tolerance)

Luminosity and emittance distributions

Simulation of 100 machines, assuming $0.5\sigma_y$ jitter at the BDS entrance (using a normal offset distribution)