CLIC Post-linac Collimation Status and Perspectives

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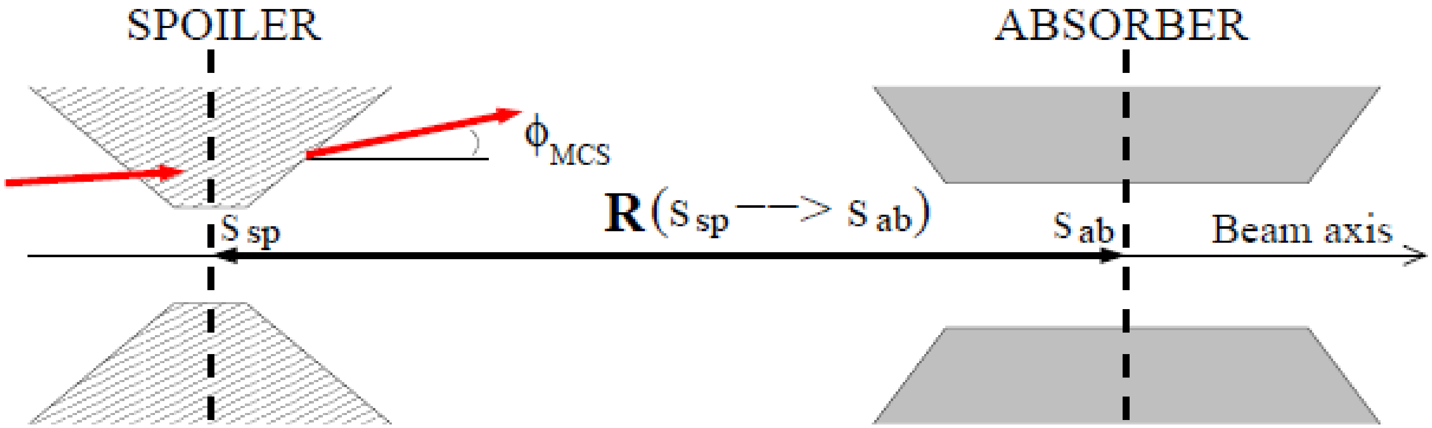
Collimation system

Simple spoiler/absorber scheme

- Thin spoilers (thickness < 1 X_0) scrape the beam halo and, if accidentally struck by the full power beam, will enlarge the spot size via multiple coulomb scattering (MCS).

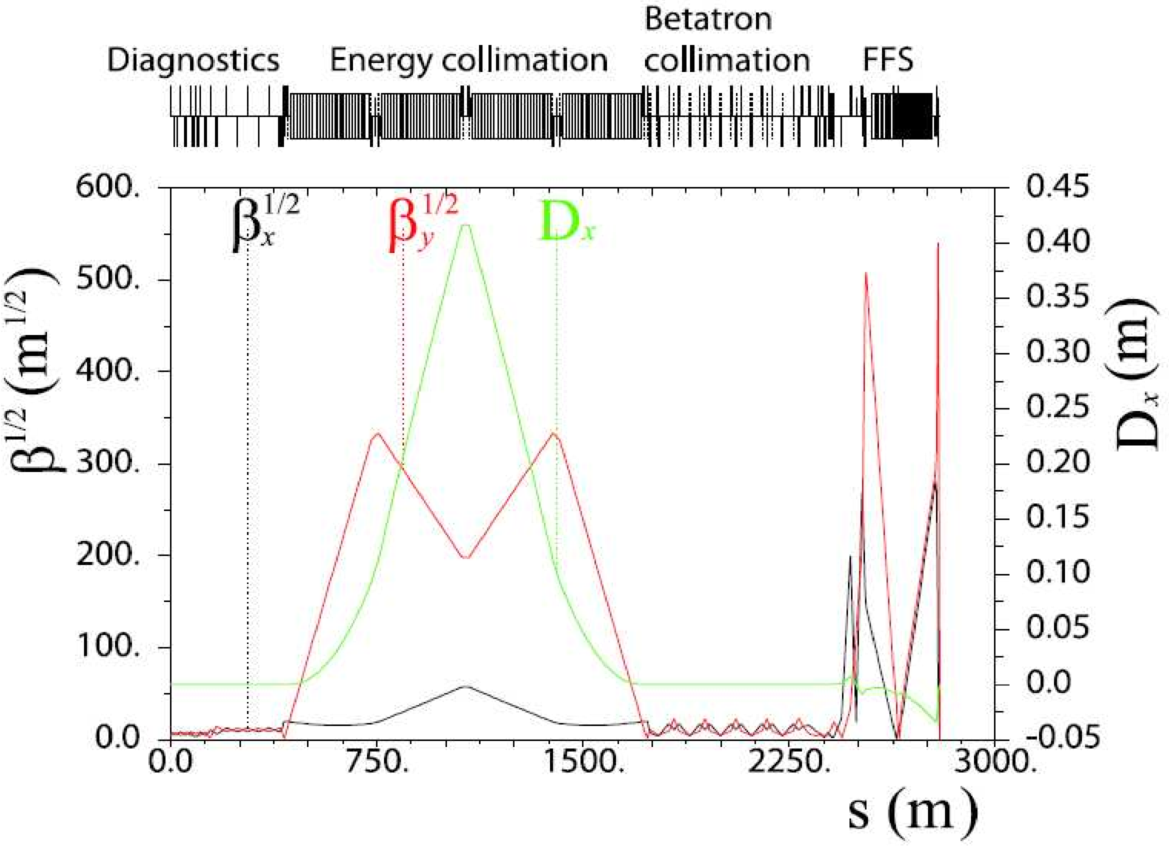
  This increases the beam size at the absorbers and reduces the risk of material damage

- The scattered halo and enlarged beam are then stopped on thick (~ 20 X_0) absorbers



CLIC beam delivery system

Optics layout



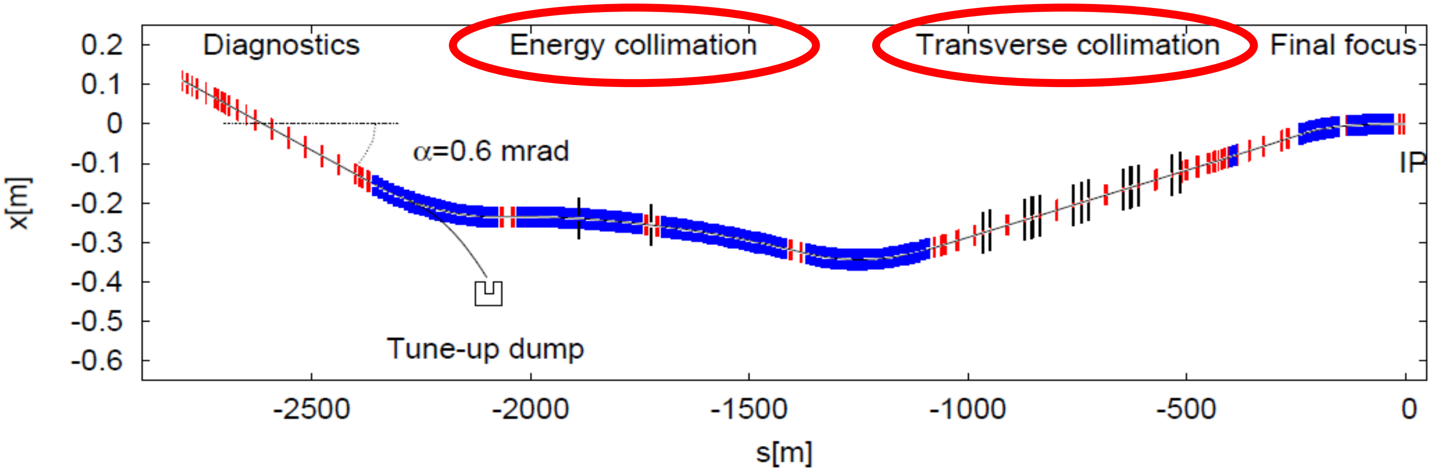
Energy collimation: Protection against miss-steered or errant beams with energy errors **>** 1.3**%**. E-spoiler half-gap: $a_x = D_x\delta = 3.51\text{mm}$

4 pairs of spoilers and absorbers in x,y plane to collimate at IP/FD phases

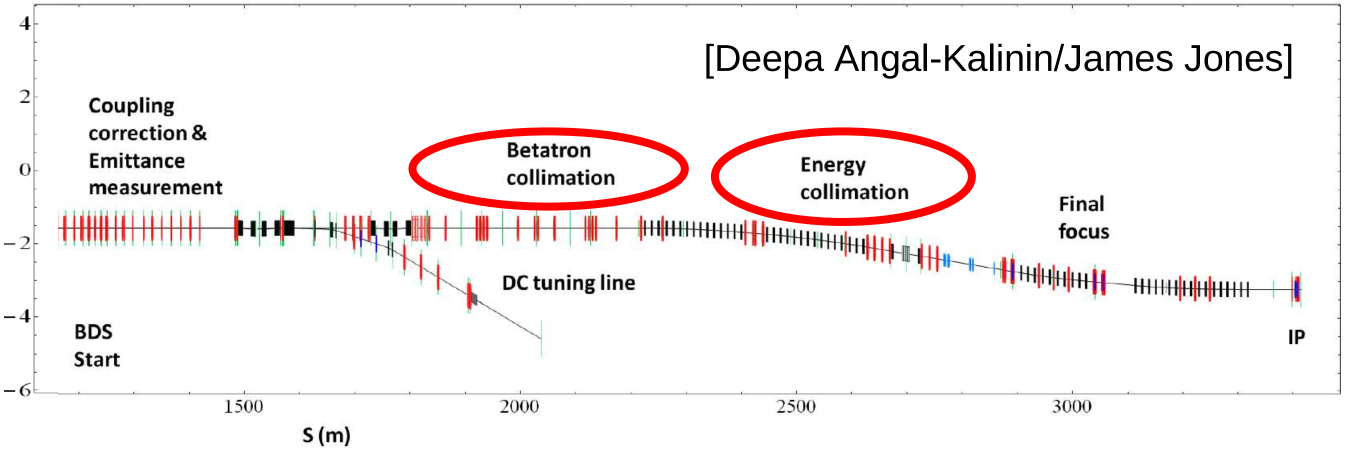
CLIC beam delivery system

CLIC BDS vs ILC BDS

CLIC BDS
3 TeV CM



ILC BDS
0.5 TeV CM



[Deepa Angal-Kalinin/James Jones]

In CLIC BDS the E collimation system is upstream of the betatron one. The main reason of choosing this is because miss-phased or unstable off-energy drive beams are likely failure modes in CLIC, and they are expected to be much more frequent than large betatron oscillations with small emittance beams.

E-collimation system

- Beam power of the CLIC beam in the BDS: $\boldsymbol{P=f_{rep}N_eN_bE\approx 14\ \mathrm{MW}}$**,** which means high damage potential in case of failure !!!

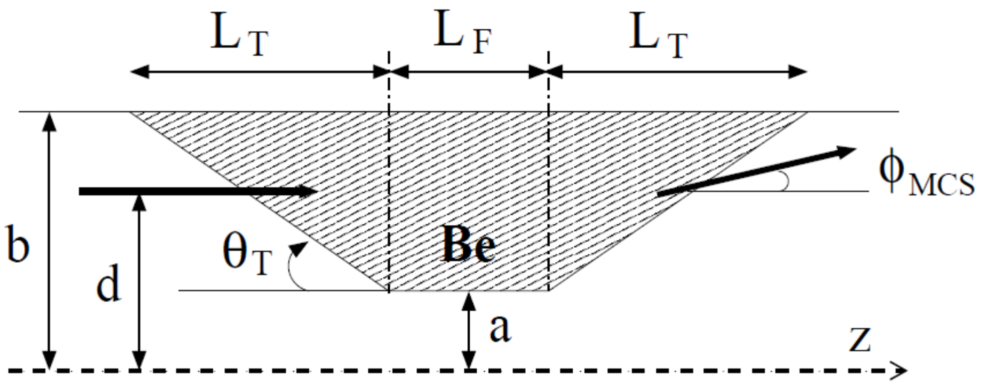
- Passive protection against miss-steered beams due to failure modes in the main linac

- The spoiler/absorber design must be robust enough to provide protection against the impact of an entire pulse

- Beryllium has been considered as a good material candidate for the E-spoiler. Its high electrical and thermal conductivity with a large radiation length compared with other metals makes Be an optimal candidate.

E-collimation system

E spoiler and absorber parameters



Parameter	ENGYSP (spoiler)	ENGYAB (absorber)
Geometry	Rectangular	Rectangular
Hor. half-gap a_x [mm]	3.51	5.41
Vert. half-gap a_y [mm]	8.0	8.0
Tapered part radius b [mm]	8.0	8.0
Tapered part length L_T [mm]	90.0	27.0
Taper angle θ_T [mrad]	50.0	100.0
Flat part length L_F [radiation length]	0.05	18.0
Material	Be	Ti alloy–Cu coating

E-collimation system

Spoiler protection

The instantaneous temperature rise due to beam impact on the spoiler:

$$\Delta T_{inst} = \frac{1}{\rho_{sp} C}\left(\frac{dE}{dz}\right)\rho(x,y) < \Delta T_{fracture}, \Delta T_{melt}$$

For Gaussian beam with horizontal and vertical rms sizes σ_x and σ_y:

$$\Delta \hat{T}_{inst} = \frac{1}{\rho_{sp} C}\left(\frac{dE}{dz}\right)\frac{N_e N_b e}{2\pi\sigma_x\sigma_y} < \Delta T_{fracture}, \Delta T_{melt}$$

For Be spoiler:

ρ_{sp} (material density)=1.84 x 10^6 g/m^3
C (specific heat)=1.825 J/(g K)
$\Delta T_{fracture}$=228 K   (this limit of fracture determined by the so-called ultimate tensile strength of the material. Discrepancies of up to 30% in this parameter can be found between different bibliographic sources)

E-collimation system

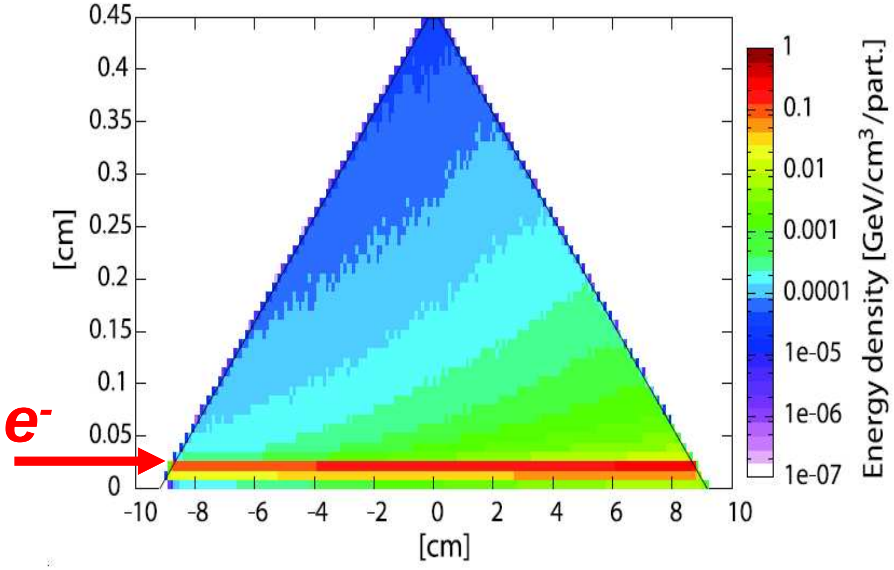
Thermo-mechanical analysis of the spoiler

[L. Fernandez-Hernando]

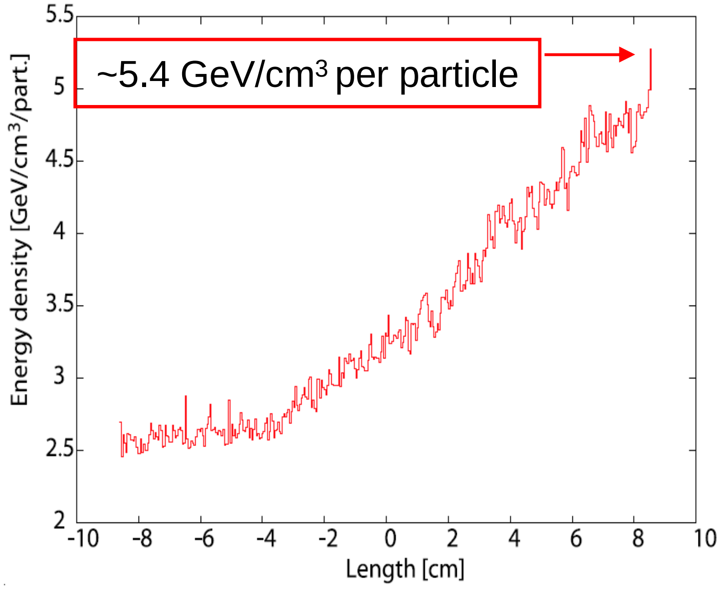
1) Assuming beam deviation of about **$10\sigma_x$** from nominal orbit

From simulations using the code FLUKA:

Energy density deposition normalised per incident particle



Peaks of energy density deposition



~5.4 GeV/cm^3 per particle

$$\boxed{\Delta \hat{T}_{inst} \approx 570\ \mathrm{K}\ !}$$

This temperature peak is below the melting limit ($\Delta T_{melt} \approx 1267$ K), but above the fracture limit for beryllium

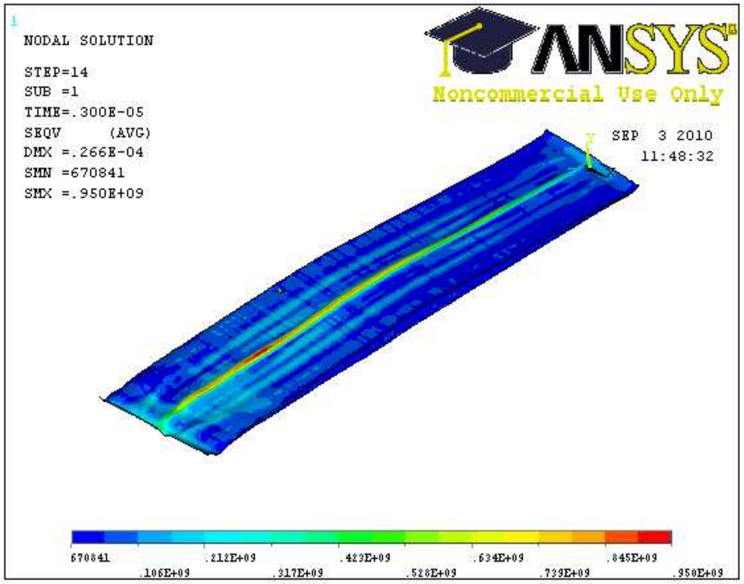
E-collimation system

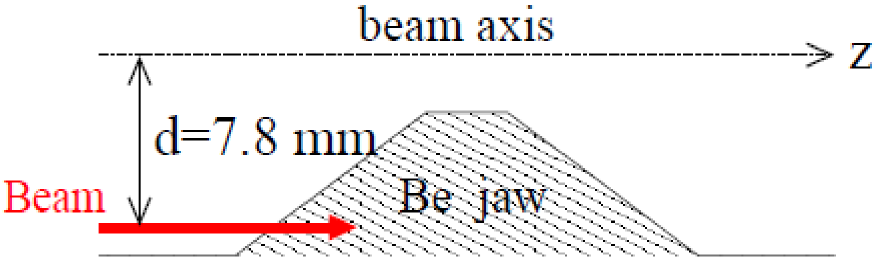
Thermo-mechanical analysis of the spoiler

1) Assuming beam deviation from nominal orbit of **10 σ_x**

Material stress studies using FLUKA + ANSYS:

Stress evolution inside the spoiler up to 4 μs after the bunch train has left.





Stress peak = 950 MPa, tensile strength

>> Ultimate Tensile Strength for Be=370 MPa

Fracture expected !!

[L. Fernandez-Hernando et al., IPAC2011]

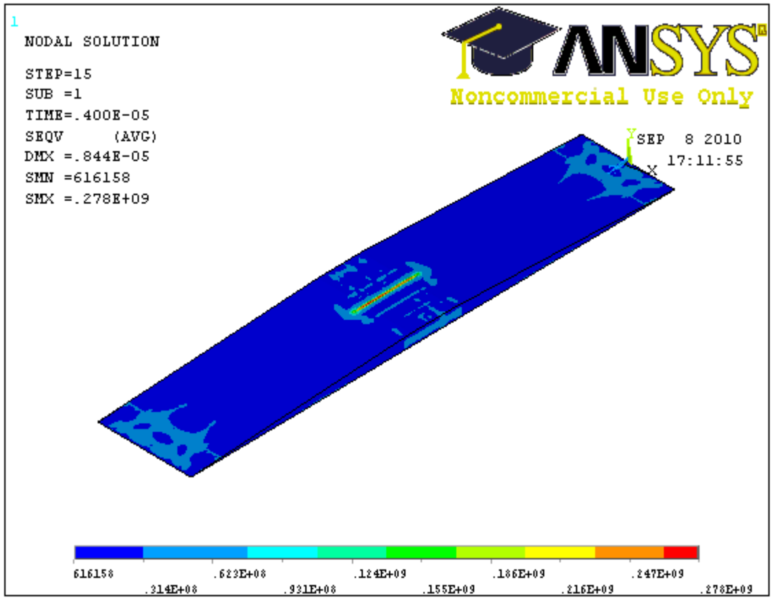
E-collimation system

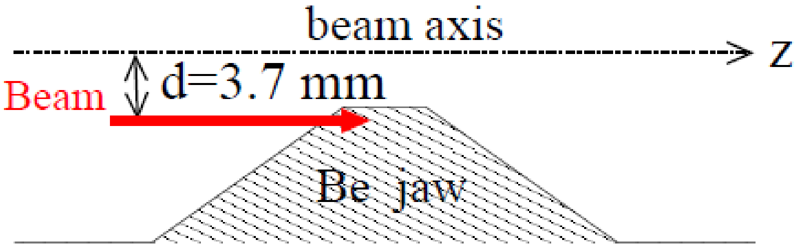
Thermo-mechanical analysis of the spoiler

1) Assuming beam deviation from nominal orbit of **5 σ_x**

Material stress studies using FLUKA + ANSYS:

Stress evolution inside the spoiler up to 4 μs after the bunch train has left.





Stress peak = 340 MPa, compressive strength

< Ultimate Tensile Strength for Be=370 MPa

> Yield Compressive strength for Be=270 MPa

No fracture, but permanent deformation of the jaw surface !!

[L. Fernandez-Hernando et al., IPAC2011]

E-collimation system

Thermo-mechanical analysis of the spoiler

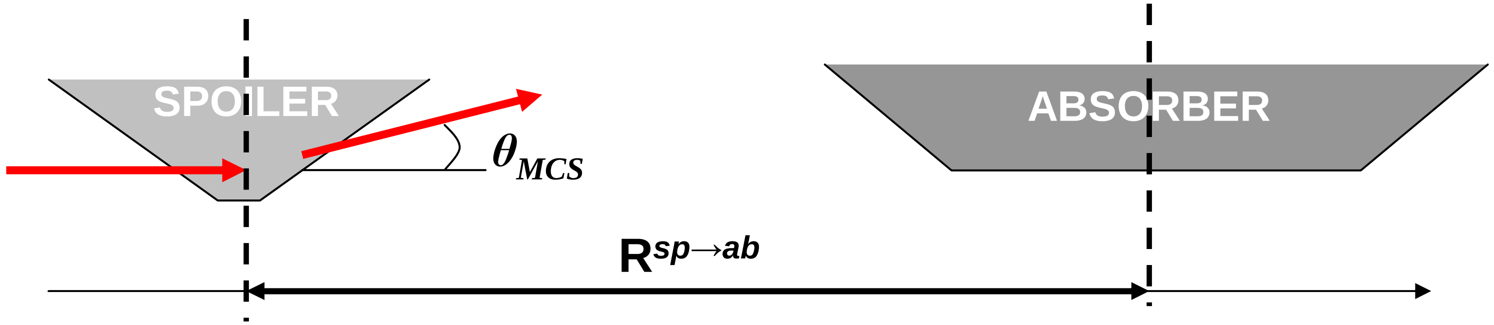
Remarks:

- The previous FLUKA+ ANSYS results correspond to a very pessimistic case:
  - Monochromatic beam (no energy spread) with the nominal energy
  - Assuming nominal emittance at the collimator position
- However, more realistic studies considering 1% energy spread and realistic failure scenarios must be performed
- Miss-steered beams generated at the beginning of the linac would likely filament, thus increasing considerably the emittance when it arrives to the energy spoiler

E-collimation system

Spoiler thickness and absorber protection

- The spoilers must provide enough beam angular divergence by multiple coulomb scattering in order to reduce the damage probability of the downstream absorber and/or another downstream component



For the protection of absorbers made of Ti-Cu coated:

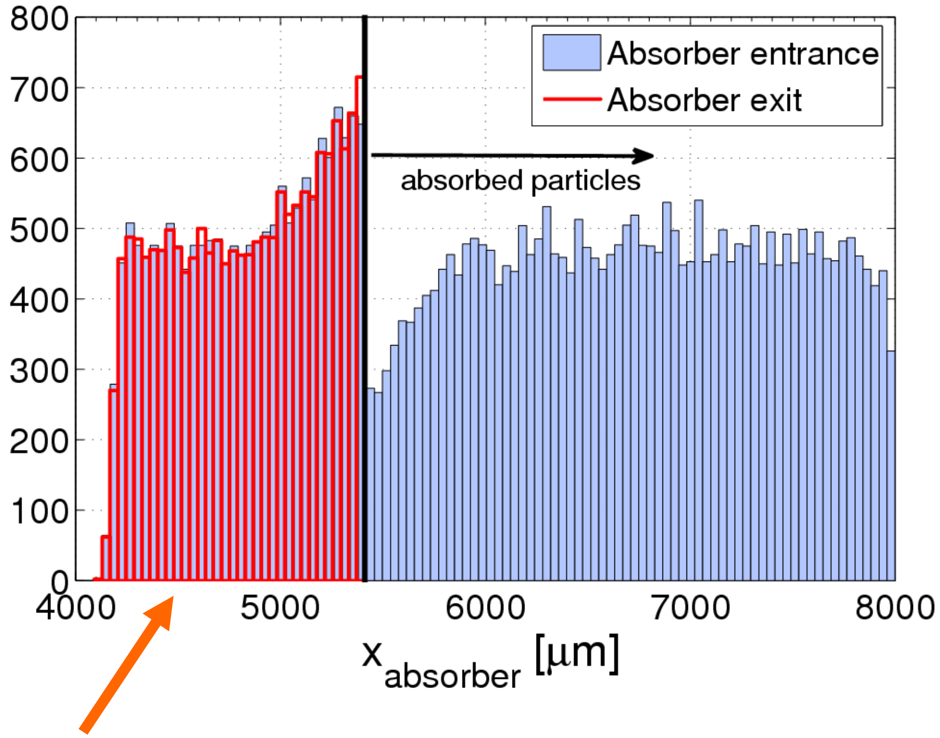
$$\sqrt{\sigma_x \sigma_y} > 600 \ \mu\text{m}$$

Value from studies for the NLC
(see e.g. P. Tenenbaum, Proc. of LINAC 2000, MOA08). Necessary simulations to update this limit.

E-collimation system

Transverse beam distribution at E-absorber

- Considering a beam with 1.5% centroid energy offset and an uniform energy distribution with 1% full width energy spread
- Considering only primary particles
- MCS applied by the E-spoiler

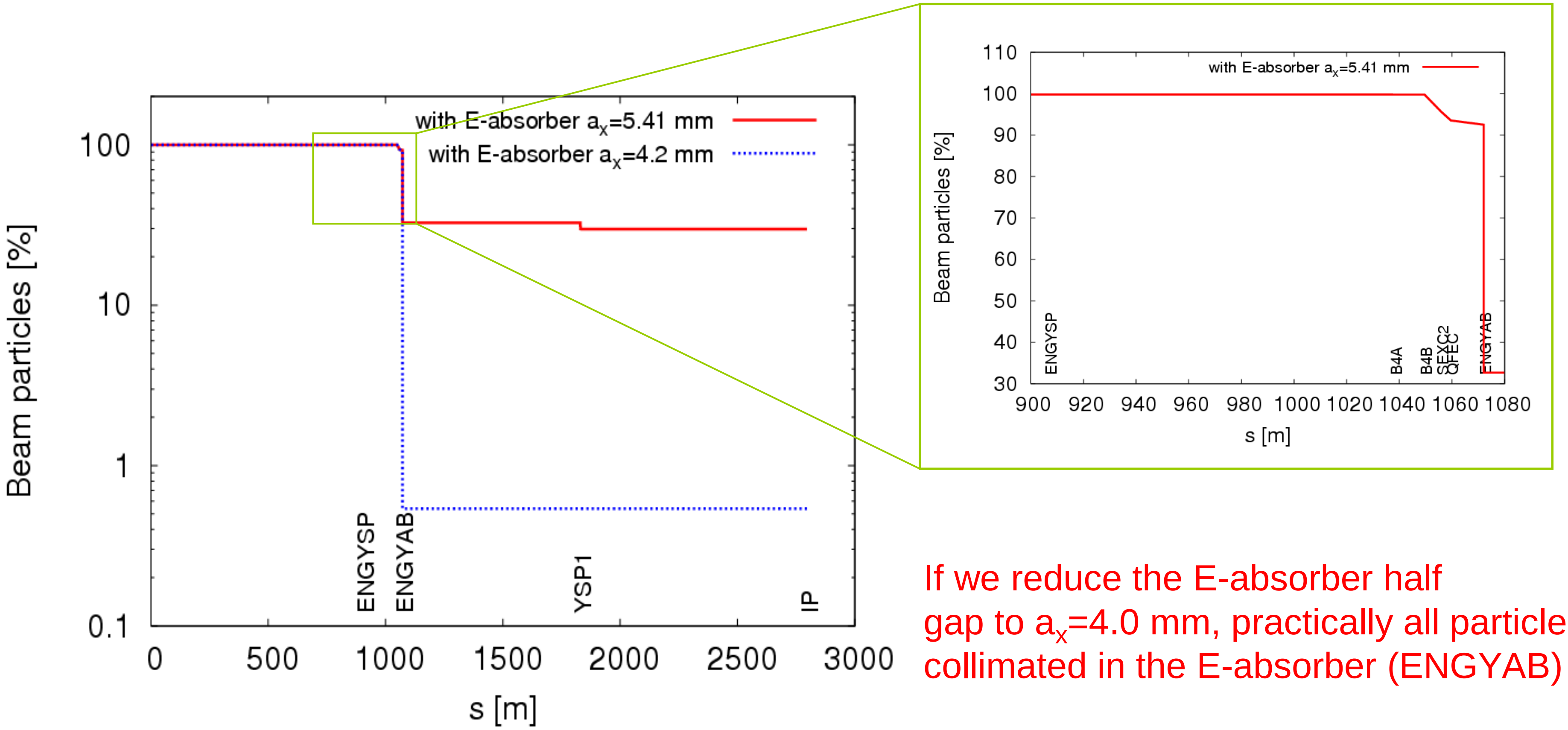


Actually, assuming 1% full energy spread, part of the beam is not hitting the spoiler/absorber

E-collimation system

Collimation of the off-energy scattered beam

Where are the particles deposited of the beam scattered by the E-spoiler?

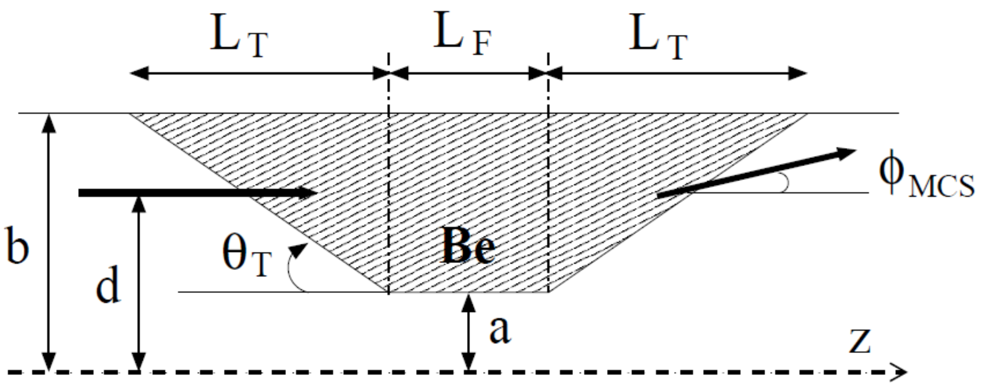


If we reduce the E-absorber half gap to a_x=4.0 mm, practically all particles collimated in the E-absorber (ENGYAB)

Considering perfect collimation by E-absorber and by the limiting apertures downstream of the E-spoiler

E-collimation system

E spoiler and absorber parameters

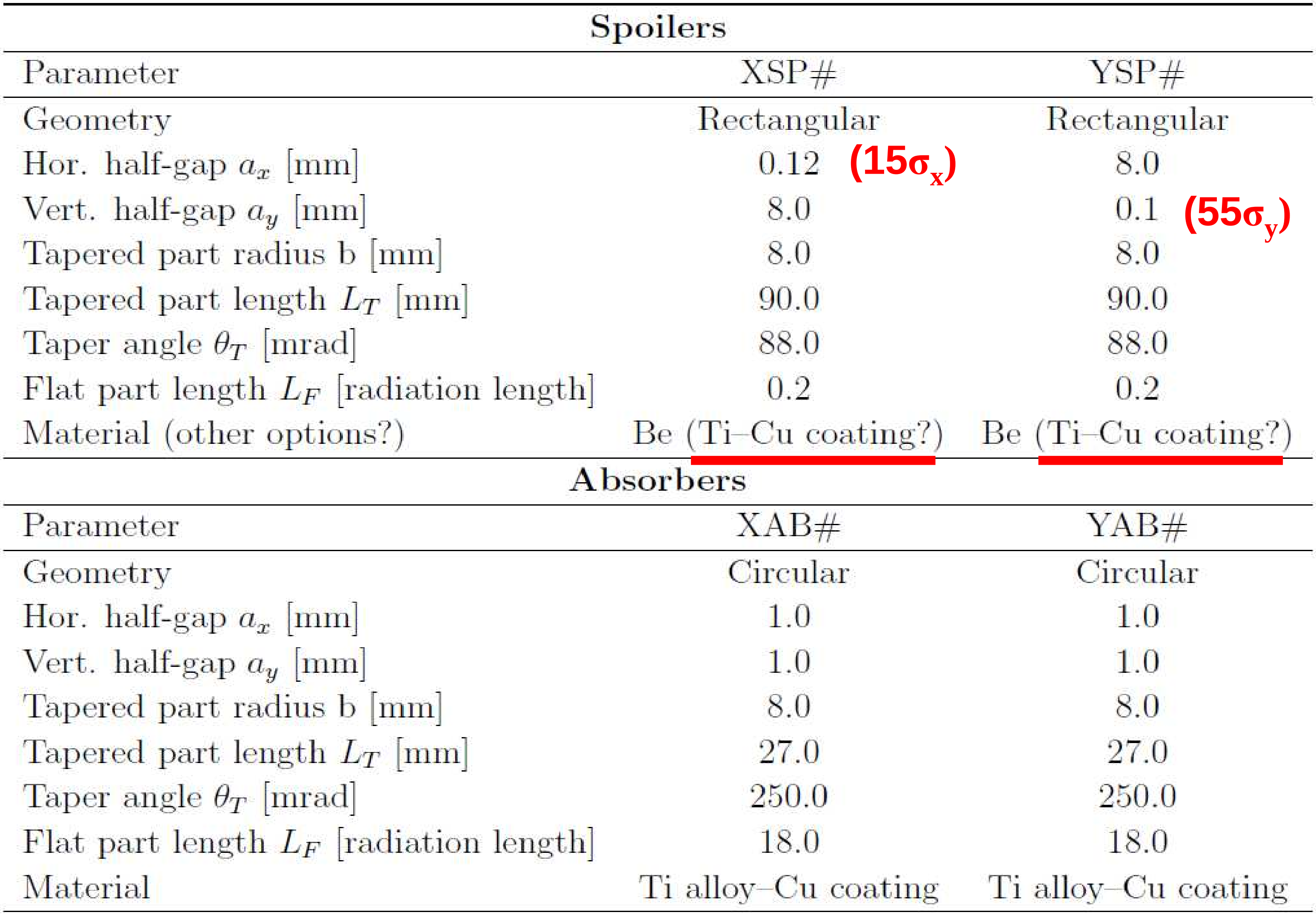


Parameter	ENGYSP (spoiler)	ENGYAB (absorber)
Geometry	Rectangular	Rectangular
Hor. half-gap a_x [mm]	~~3.51~~ 2.5	~~5.41~~ 4.0
Vert. half-gap a_y [mm]	~~8.0~~ 10	~~8.0~~ 10
Tapered part radius b [mm]	~~8.0~~ 10	~~8.0~~ 10
Tapered part length L_T [mm]	90.0	27.0
Taper angle θ_T [mrad]	~~50.0~~ 83	~~100.0~~ 219
Flat part length L_F [radiation length]	0.05	18.0
Material	Be	Ti alloy–Cu coating

For improving the capability of the system to intercept beams with mean energy deviation > 1.3 %

Betatron collimation

Betatron spoiler and absorber parameters



Spoilers

Parameter	XSP#	YSP#
Geometry	Rectangular	Rectangular
Hor. half-gap a_x [mm]	0.12 **(15σ_x)**	8.0
Vert. half-gap a_y [mm]	8.0	0.1 **(55σ_y)**
Tapered part radius b [mm]	8.0	8.0
Tapered part length L_T [mm]	90.0	90.0
Taper angle θ_T [mrad]	88.0	88.0
Flat part length L_F [radiation length]	0.2	0.2
Material (other options?)	Be (Ti–Cu coating?)	Be (Ti–Cu coating?)

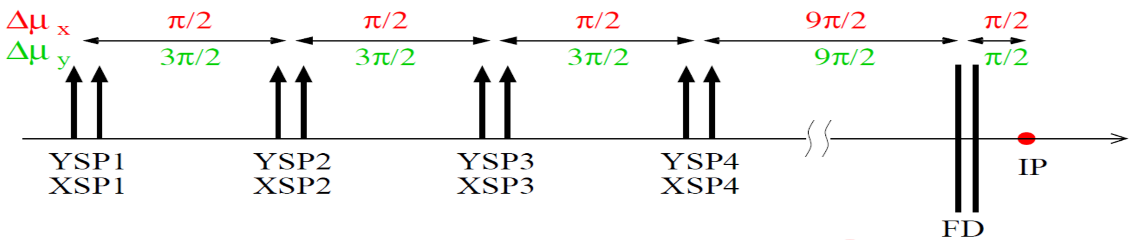
Absorbers

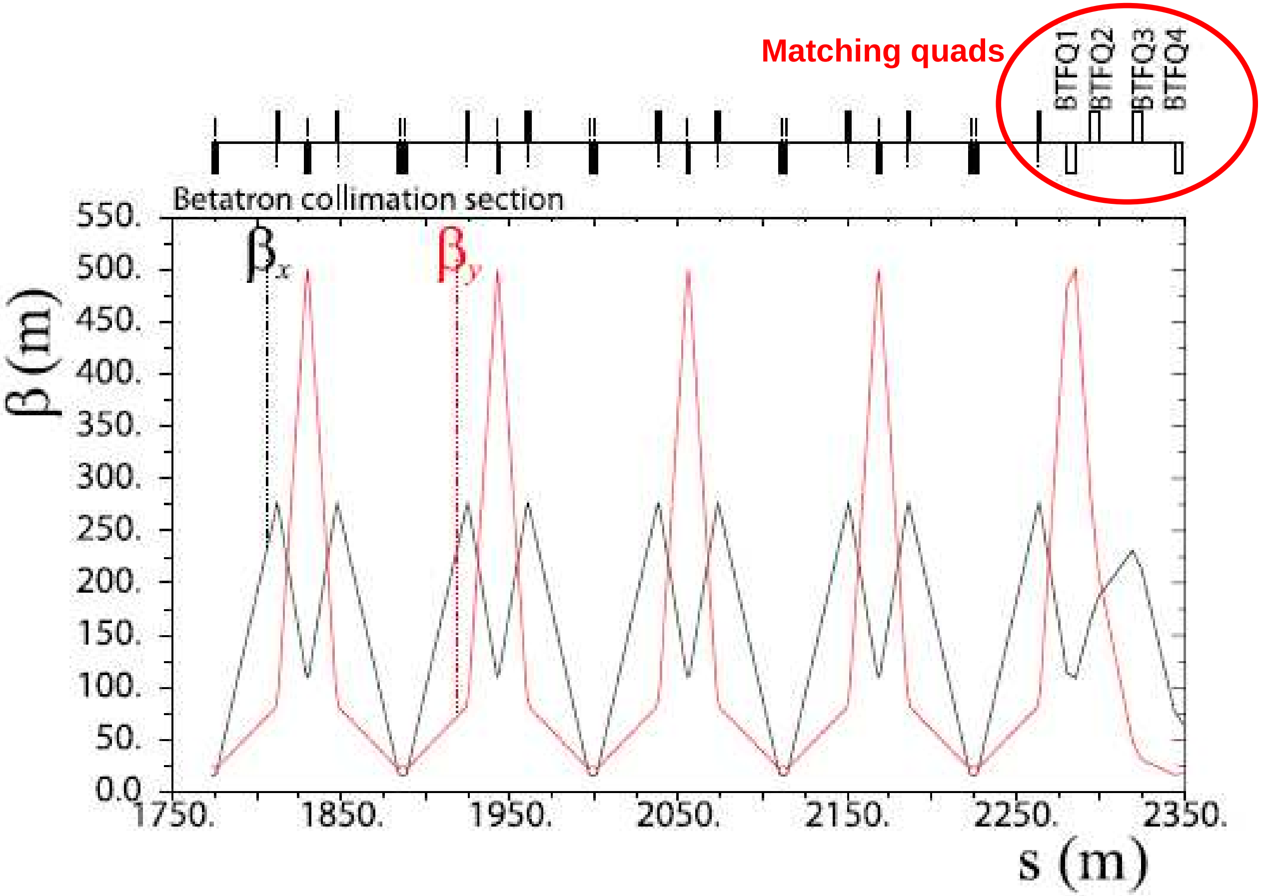
Parameter	XAB#	YAB#
Geometry	Circular	Circular
Hor. half-gap a_x [mm]	1.0	1.0
Vert. half-gap a_y [mm]	1.0	1.0
Tapered part radius b [mm]	8.0	8.0
Tapered part length L_T [mm]	27.0	27.0
Taper angle θ_T [mrad]	250.0	250.0
Flat part length L_F [radiation length]	18.0	18.0
Material	Ti alloy–Cu coating	Ti alloy–Cu coating

Betatron collimation

Optics optimisation

The phase advance of the betatron spoilers respect to the FD and the IP has to be matched for efficient collimation





Betatron collimation

Optics optimisation

[Barbara Dalena, Frank Jackson]

In the lattice version 2008:

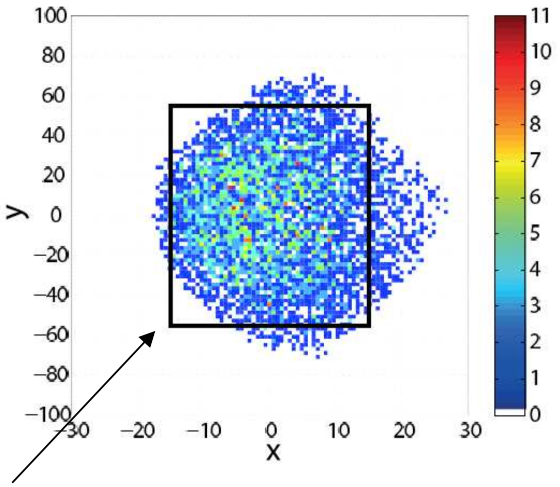
The phase advances between the fourth spoilers (YSP4 and XSP4) and the FD not an exact multiple of $\pi/2$: $\Delta\mu_{x,y}$ (SP4→FD)=9.7 $\pi/2$, 10.6 $\pi/2$

Phase-matched solution:

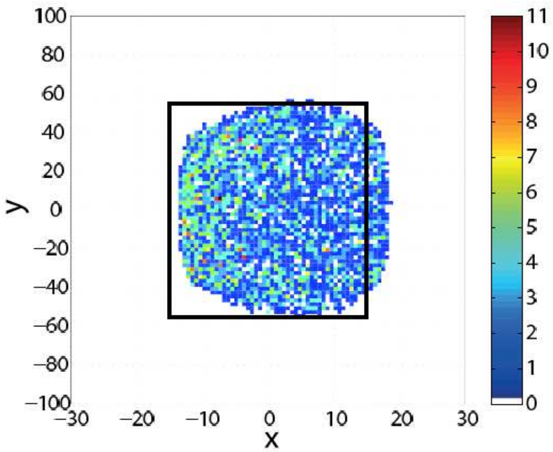
Beam halo x-y profile at the FD entrance:

For $\Delta\mu_{x,y}$ (SP4→FD)=9.7 $\pi/2$, 10.6 $\pi/2$ → For $\Delta\mu_{x,y}$ (SP4→FD)=10 $\pi/2$, 11 $\pi/2$

Optimisation



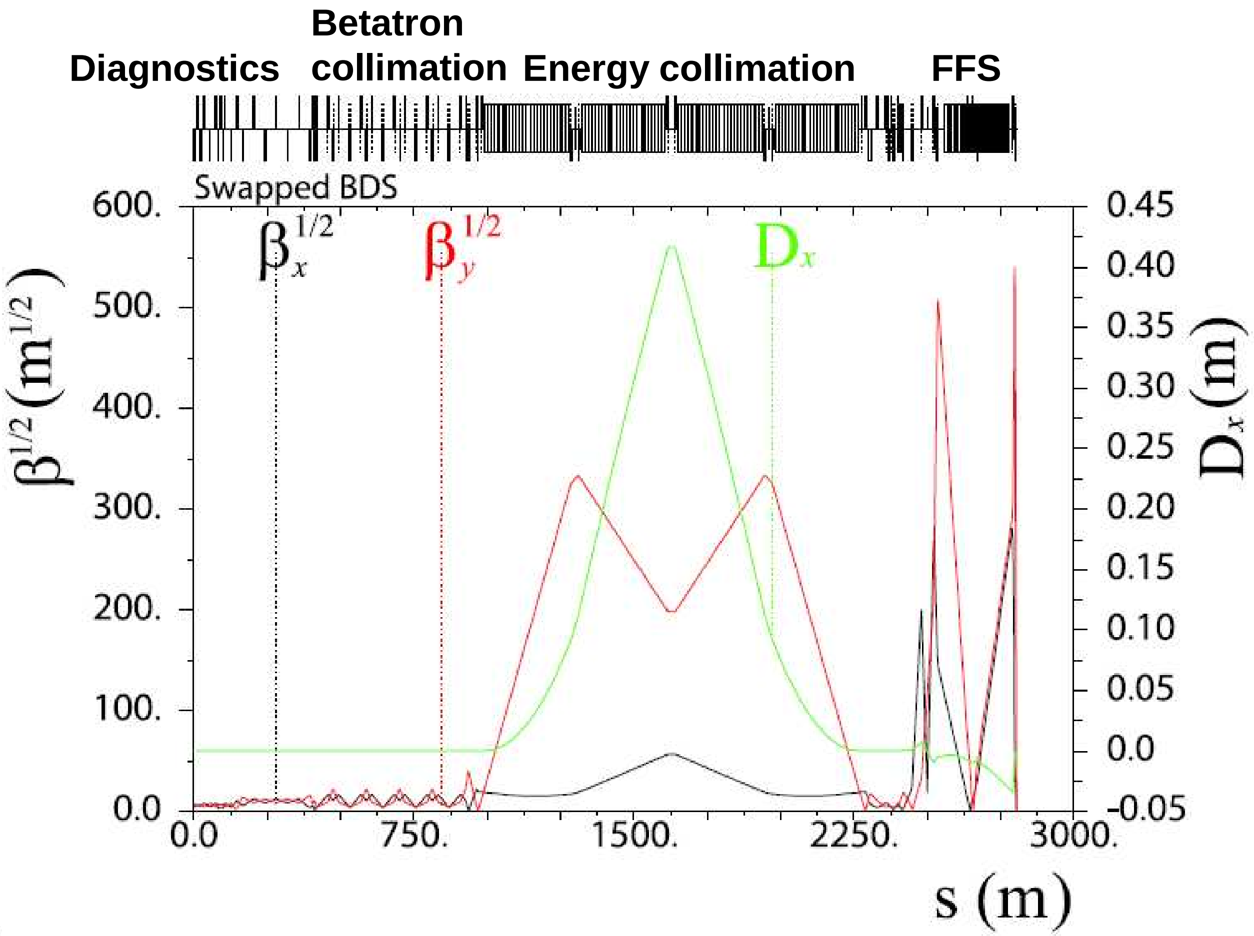
Collimation window



20% collimation efficiency improvement !

Betatron collimation

Swapped BDS option

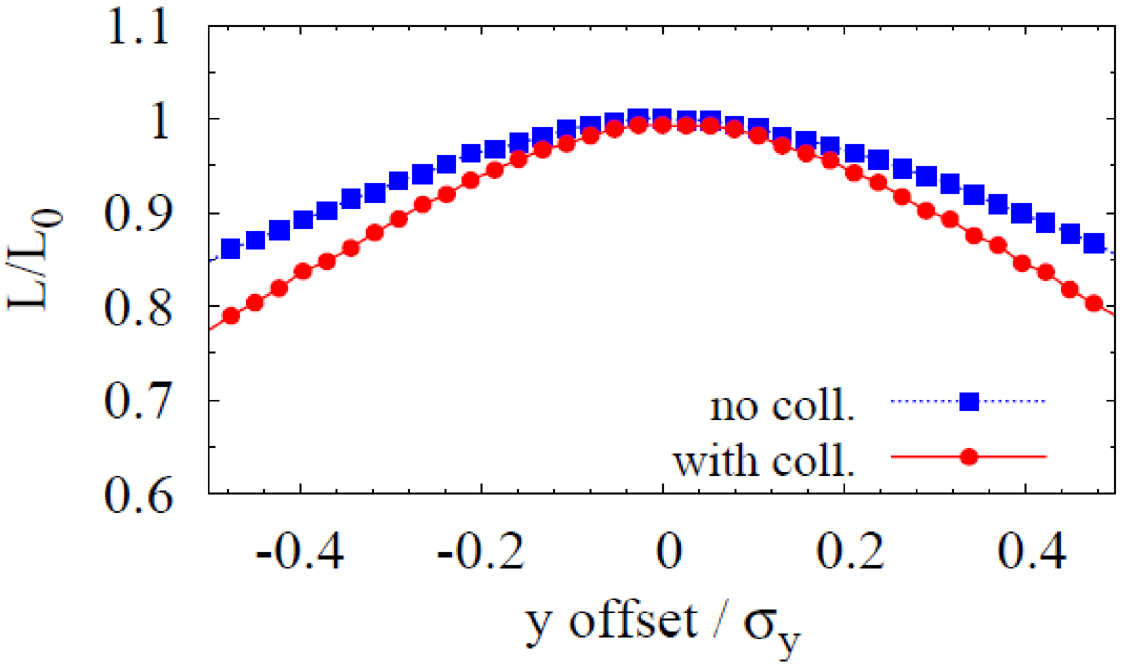


Tracking simulations have shown that swapping the betatron and energy collimation sections results in 40% reduction in muon flux reaching the detector at the IP **[L. Deacon et al., IPAC2010]**

Collimator wakefield effects

Luminosity degradation as a function of vertical beam position offsets

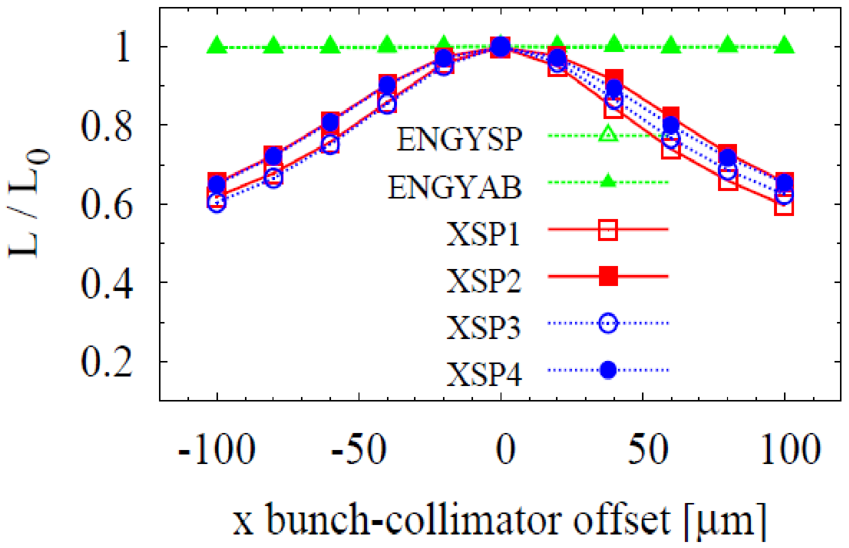
The join effect of all the BDS collimators is considered

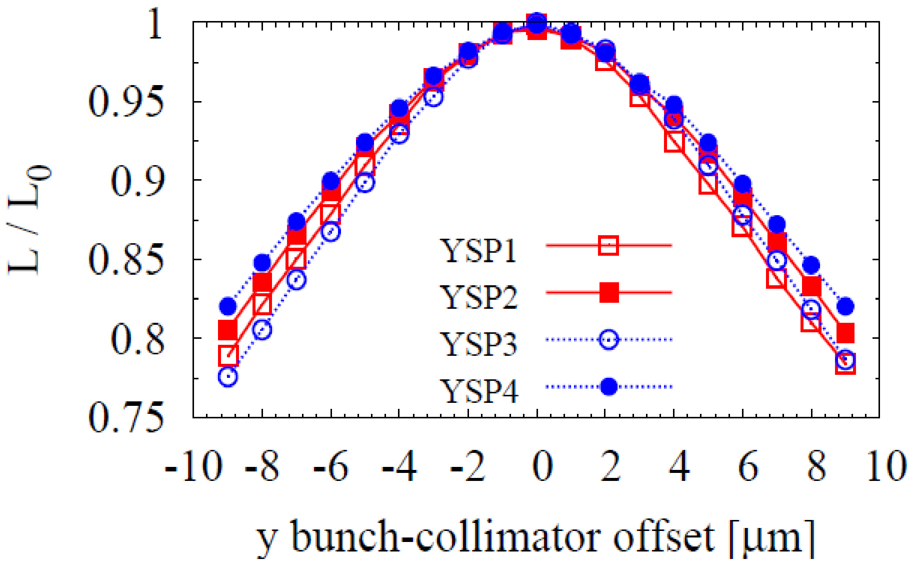


The luminosity loss has been found to amount up to 20% with collimator wakefields, and up to 10% for the case with no wakefield effects for beam offsets of approximately +/-0.4 σ_y

Collimator wakefield effects

Luminosity loss due to horizontal and vertical misalignments (with respect to the on-axis beam) of each spoiler



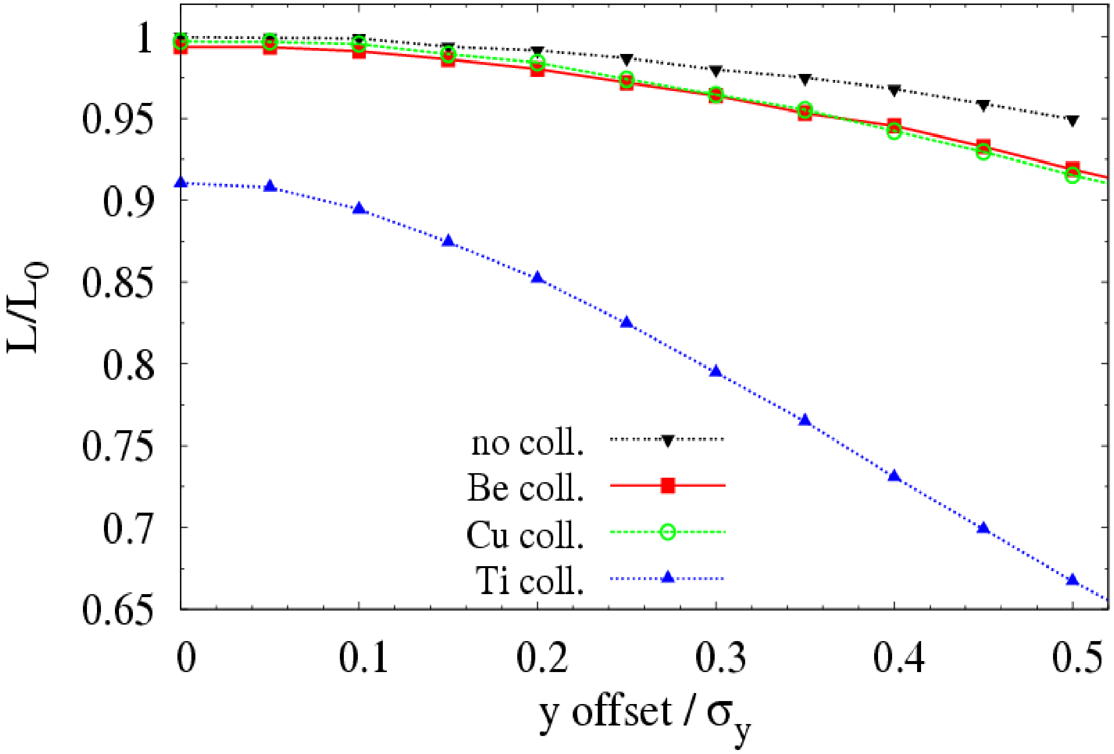


The main contribution to the collimator wakefields arises from the betatron spoilers (apertures ≈ 100 µm)

In comparison with the betatron collimators the energy spoiler (**ENGYSP**) and the energy absorber (**ENGYAB**) practically do not contribute to the luminosity degradation by wakefields

Collimator wakefield effects

Contribution from YSP1 for different materials:



The betatronic spoilers can be sacrificial, so Ti-Cu coating, instead of Be, may be a good solution in terms of wakefield effects

Summary

What has been done so far?

- The design of the CLIC post-linac collimation system have been completed for the CLIC CDR:
  - Parameters and specifications for the spoiler and absorber design
  - Optimisation of the betatron collimation system (optics optimisation, collimator aperture optimisation)
  - Luminosity performance simulations including collimator wakefield effects
  - Preliminary thermo-mechanical analysis of the E-spoiler by means of simulations when a full CLIC bunch train hit it

A complete description is given at:

J. Resta-Lopez, D. Angal-Kalinin, B. Dalena, J. L. Fernandez-Hernando, F. Jackson, D. Schulte, A. Seryi and R. Tomas, "Status Report of the Baseline Collimation System of CLIC," Part I and Part II, arXiv:1104.2426v1 and arXiv:1104.2431v1 [physics.acc-ph], 13-April-2011

What is the next?

- A complete tracking study using a realistic model of the halo and taking into account secondary particle emission + wakefield effects would be convenient.

- More realistic simulations for the thermo-mechanical analysis of the energy collimators must be performed, taking as input recent results of failure mode studies

- To explore other collimation alternatives for a possible CLIC phase II collimation (long term plan), e.g.
  - non-linear collimation ,
  - crystal collimation,
  - other materials with special properties

- Possible experimental program:
  - Measurement of collimator wakefields in the CLIC regime (in available beam test facilities, for example, SLAC End Station B)?
  - Collimator damage studies for different material candidates for the CLIC collimators ?

- We have to think on the concrete engineering design of the collimators and, may be, to built a prototype.

Extra …

E-collimation system

Spoiler thickness and absorber protection

Energy spoiler-absorber:

We have to take into account the dispersive component of the beam size ($D_x\sigma_E$, with D_x the horizontal dispersion and σ_E the rms beam energy spread). In this case, the absorber survival condition can be approximated by

$$\sqrt{\sigma_x\sigma_y} \approx \left(\left|R_{34}^{sp\rightarrow ab}\right| D_x\sigma_E\theta_{MCS}\right)^{1/2} > 600\,\mu\text{m}$$

Considering $R_{34}^{sp\rightarrow ab} = 160\,\text{m}$ and $\sigma_E = 0.5\%$, then

$L_F >\sim 0.02\,\text{X}_0$

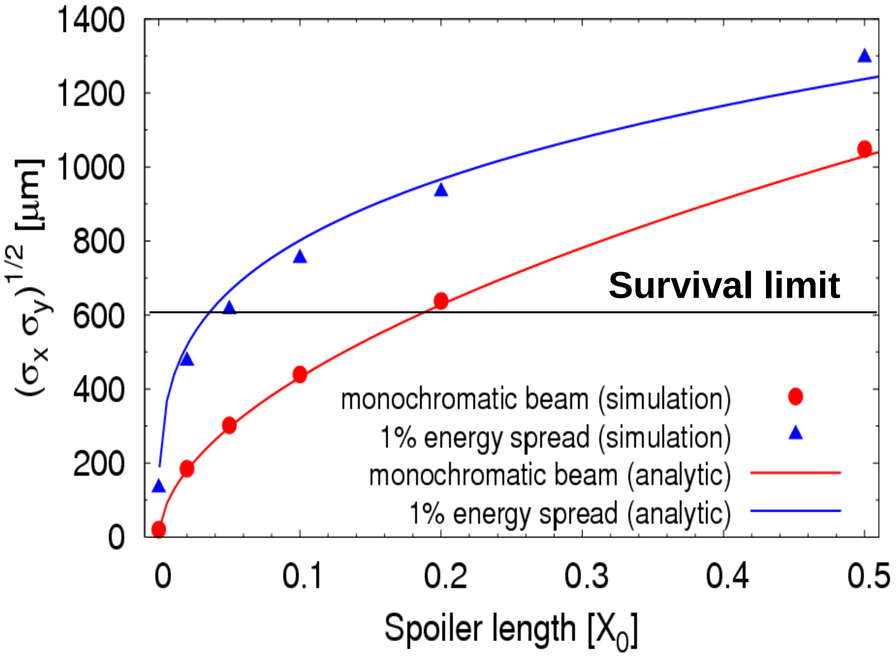
In order to validate these results we have performed montecarlo simulations including MCS at the spoiler position to study the beam density at the downstream absorber for different values of spoiler thickness.

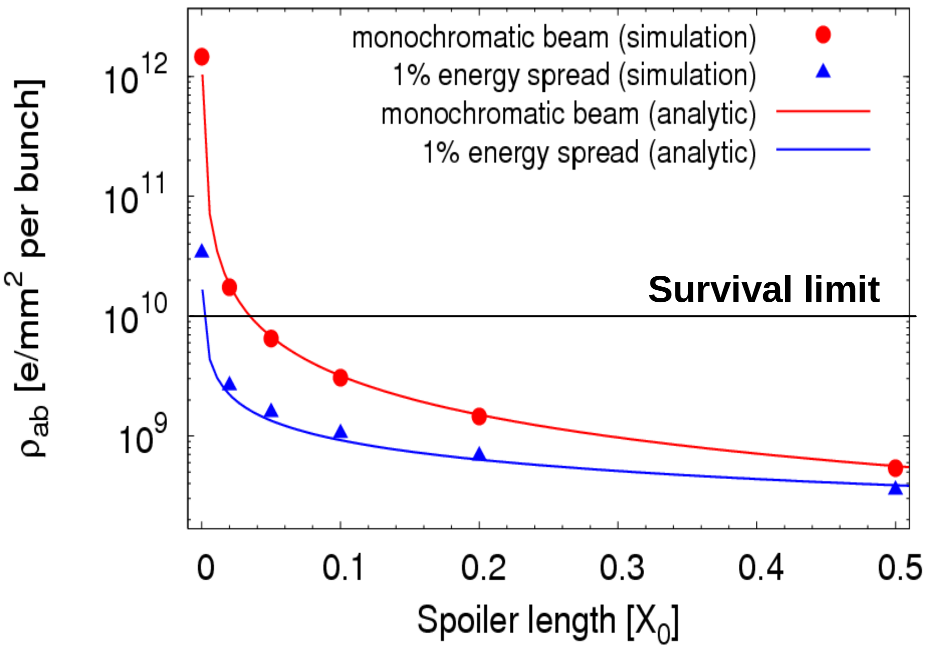
E-collimation system

Transverse beam density at E-absorber

Tracking simulations of 50000 macroparticles, assuming all particles of the beam hit the E-spoiler and full beam transmission through the spoiler, then MCS is applied

$$\hat{\rho}_{ab} = N_e/(2\pi\sigma_x\sigma_y)$$





0.02 X_0 spoiler decreases the transverse beam density at the downstream absorber by almost two orders of magnitude