# CLIC collimation system review

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# Introduction

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

- No significant changes in the collimation system, ... However:
  - Shorter FFS ✹ the collimator-IP (collimator-FD) phase advance might have been changed. Necessary to review the collimator-IP phase advances for optimum transverse cleaning
  - 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 a 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 ($\mu$m) | 35 | 35 | 30.8 | 45 |
| Bunch separation (ns) | 0.67 | 0.67 | 0.267 | 0.5 |
| Bunch train length ($\mu$s) | 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 and constraints

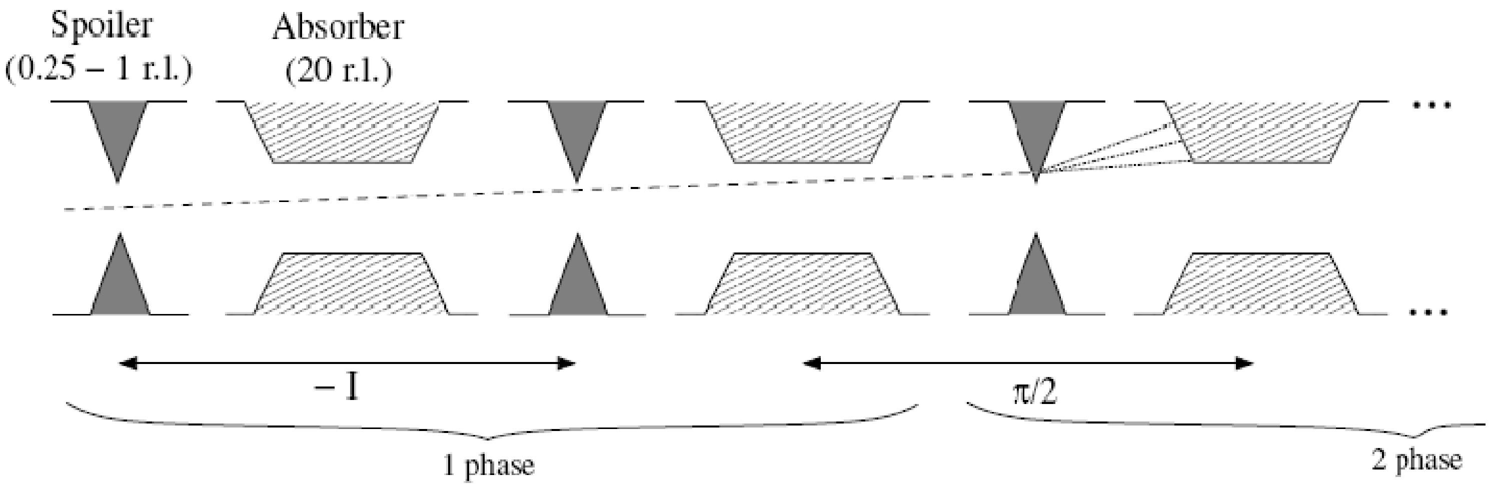
- Reduction of the background in the particle detectors by removing halo (particles at large betatron amplitudes and/or energy offsets)
- Protection of machine components:
    - Minimise the activation and damage of accelerator components outside of the dedicated collimation sections
    - Intercept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



# Collimation depth

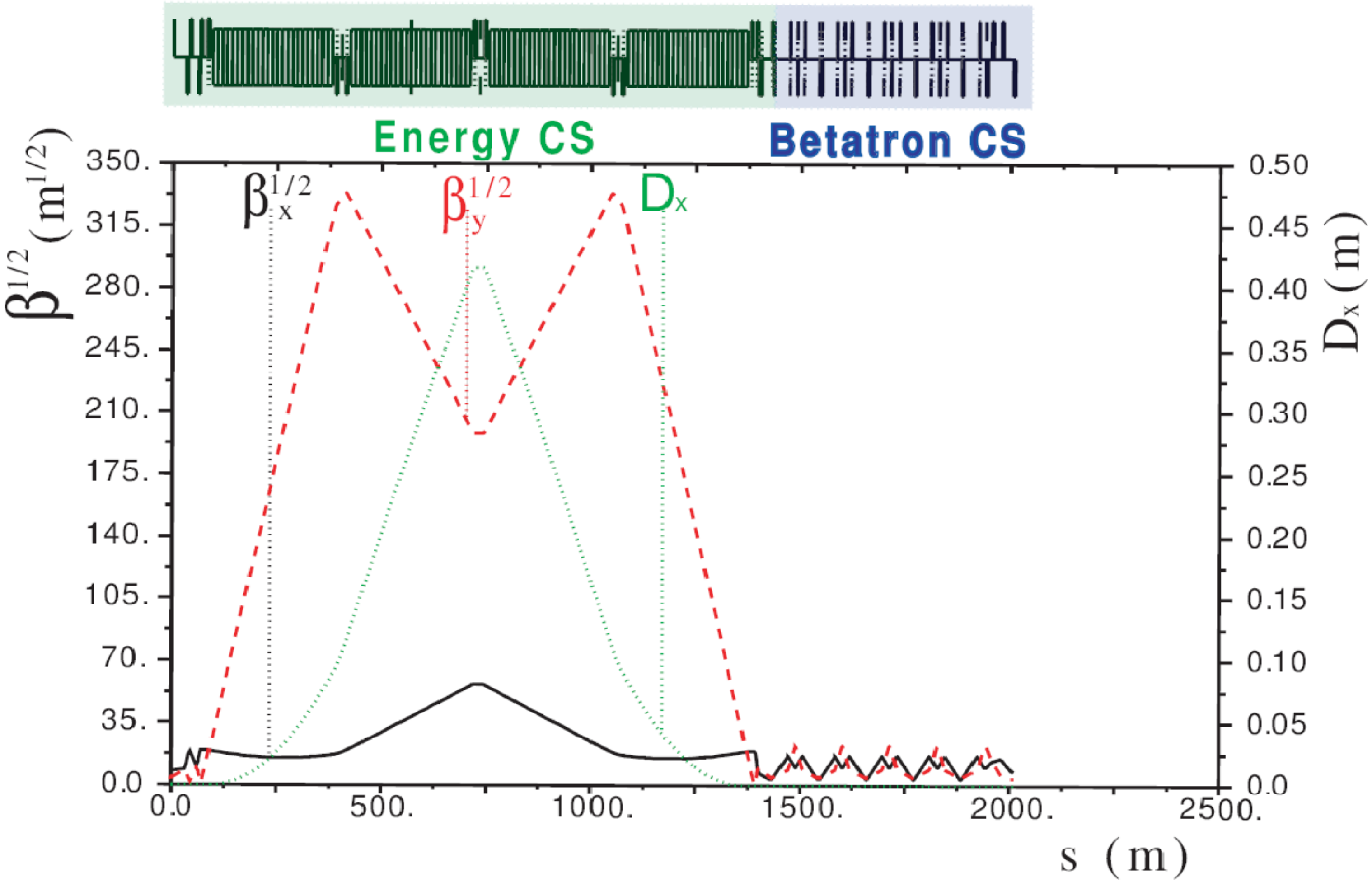
ENERGY COLLIMATION:

- 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 beam with energy errors **> 1.3%**.

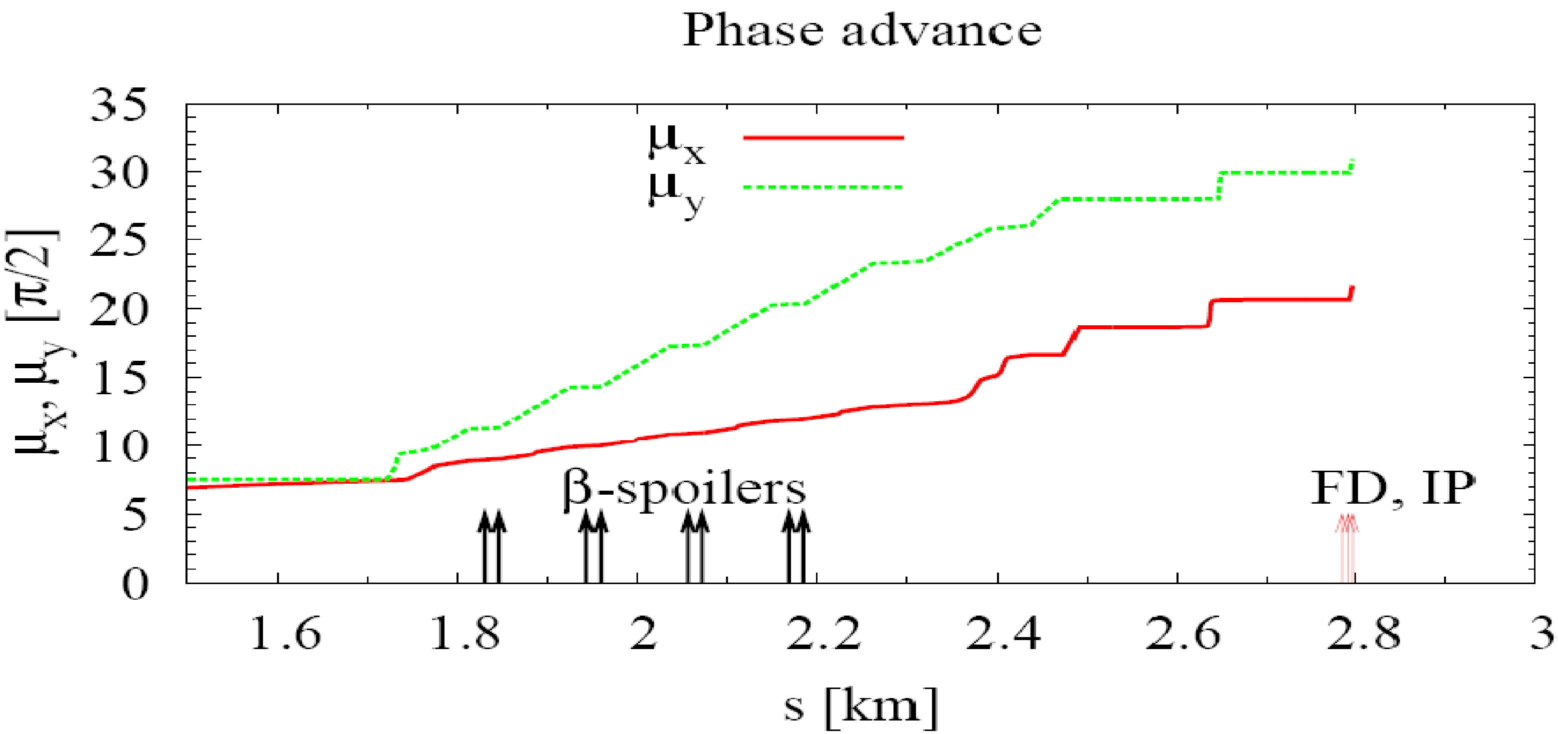
BETATRON COLLIMATION:

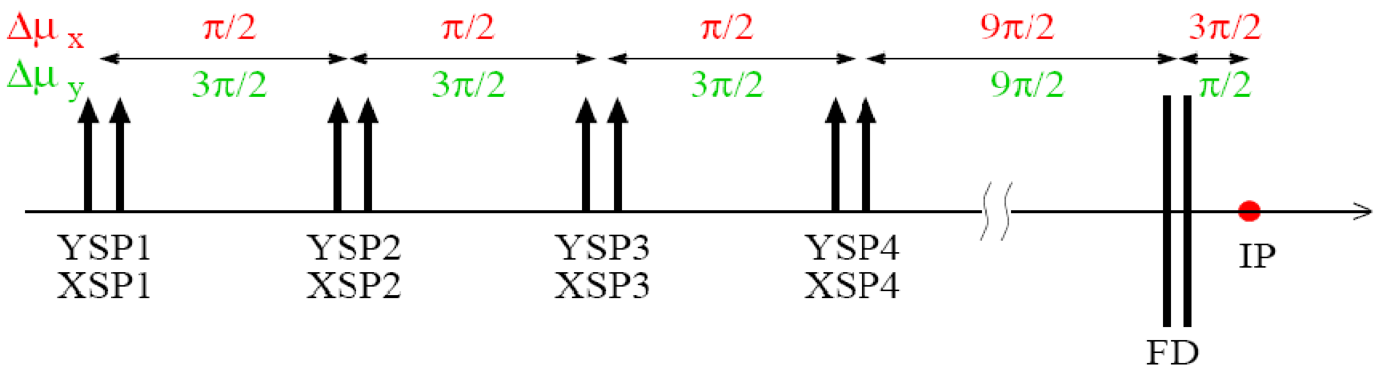
- Betatron collimation depths determined from the condition that beam particles and SR photons emitted in the FD should not hit any magnet apertures on the incoming side of the IP. For CLIC: horizontal collimation depth $\mathbf{10\sigma_x}$; vertical collimation depth $\mathbf{44\sigma_y}$ (version 2008). Previous vertical depth $\mathbf{83\sigma_y}$ (version 2005)

# CLIC collimation section optics



# Collimator position and phase advance review




Javier Resta

# Collimator parameters

| s[m] | Name | $\beta_x$[m] | $\beta_y$[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 $\beta_y$ –spoiler half-gap: $a_y$=0.08 mm (previously $a_y$=0.102 mm)

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

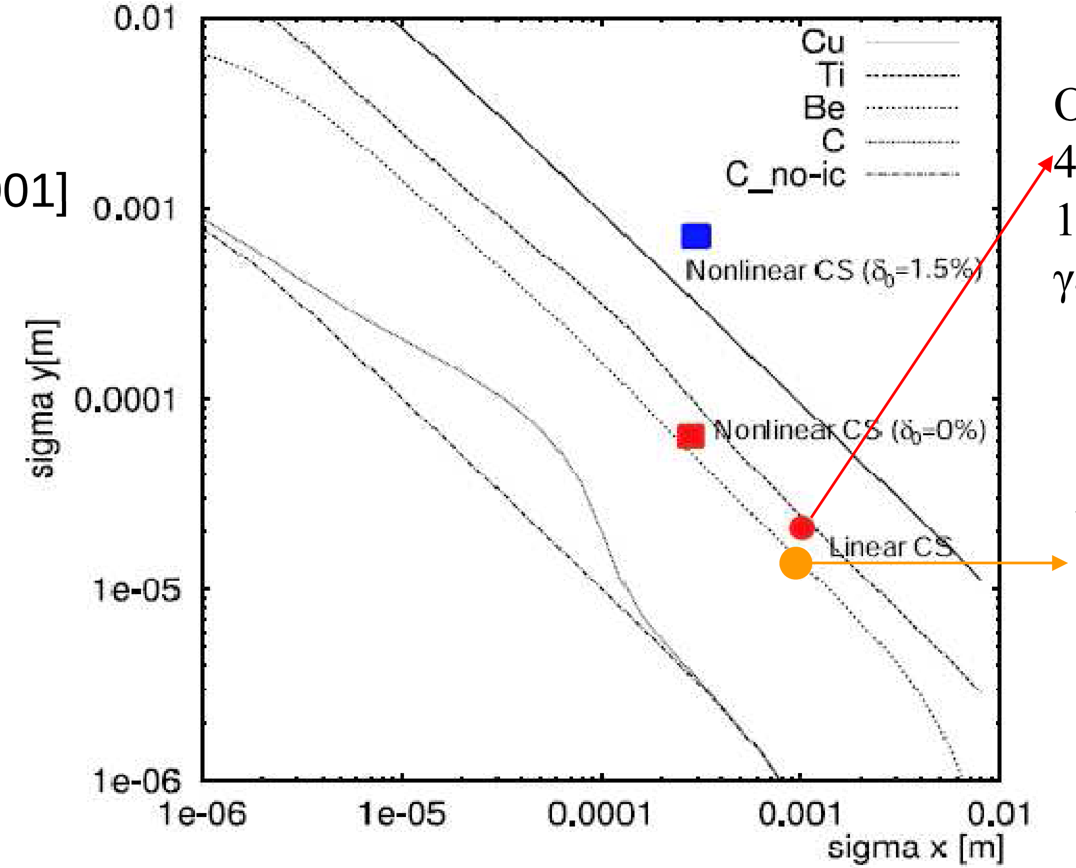
# Spoiler survival

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

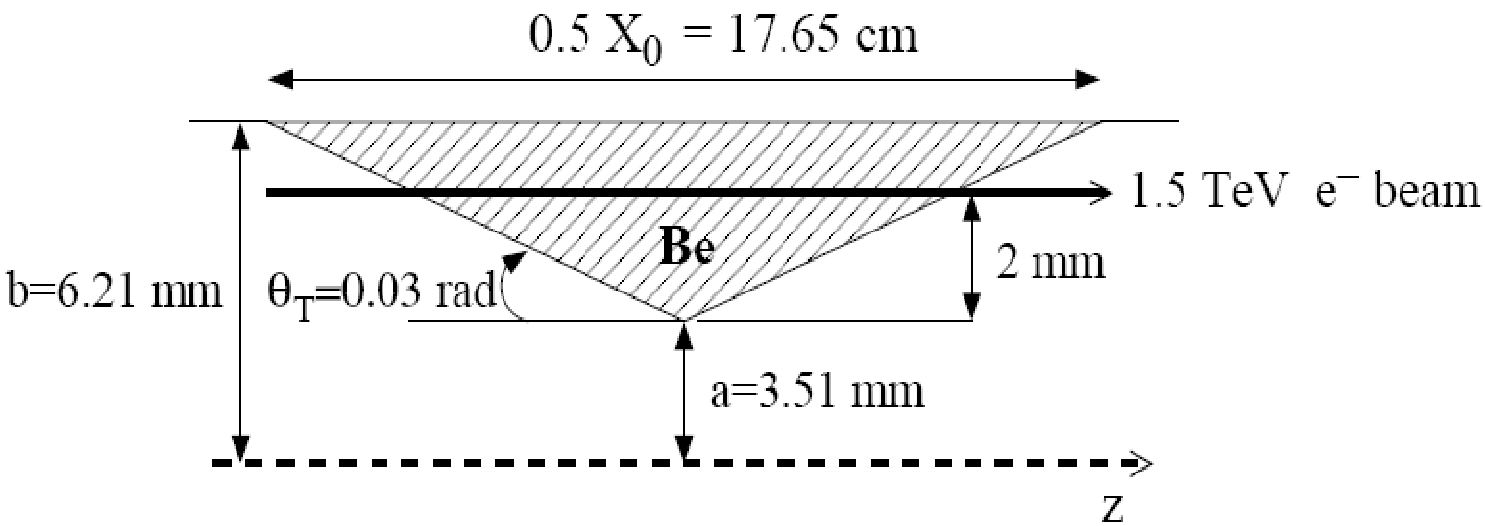
New parameters:
4 x $10^9$ $e^-$
312 bunches/train
$\gamma\varepsilon_y$=20 nm

# Spoiler survival

Recent studies:

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

Energy spoiler design:

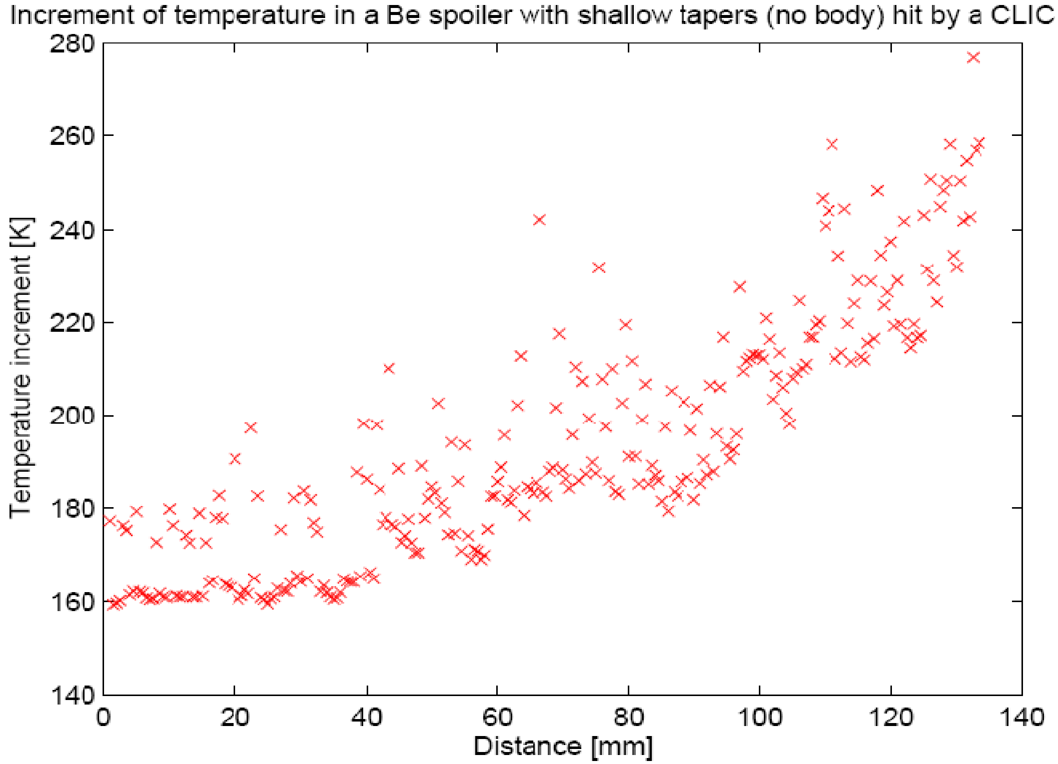


# Spoiler survival

Spoiler heating due to instantaneous energy deposition by direct impact of a bunch train in the Be spoiler

FLUKA simulation

312 bunches
3.72 x $10^9$ particles/bunch
Beam energy 1.5 TeV
(no energy spread)
$\sigma_x/\sigma_y$ = 796 μm / 21.9 μm at spoiler

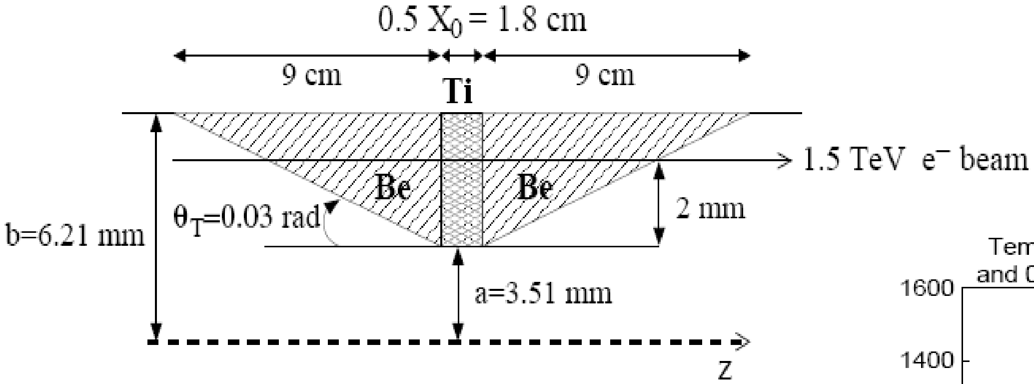



Maximum increment of temperature ≈ 280 K
Below the melting excursion limit 1267 K and the fracture limit 370 K !

# Spoiler survival

## Testing alternative spoiler designs

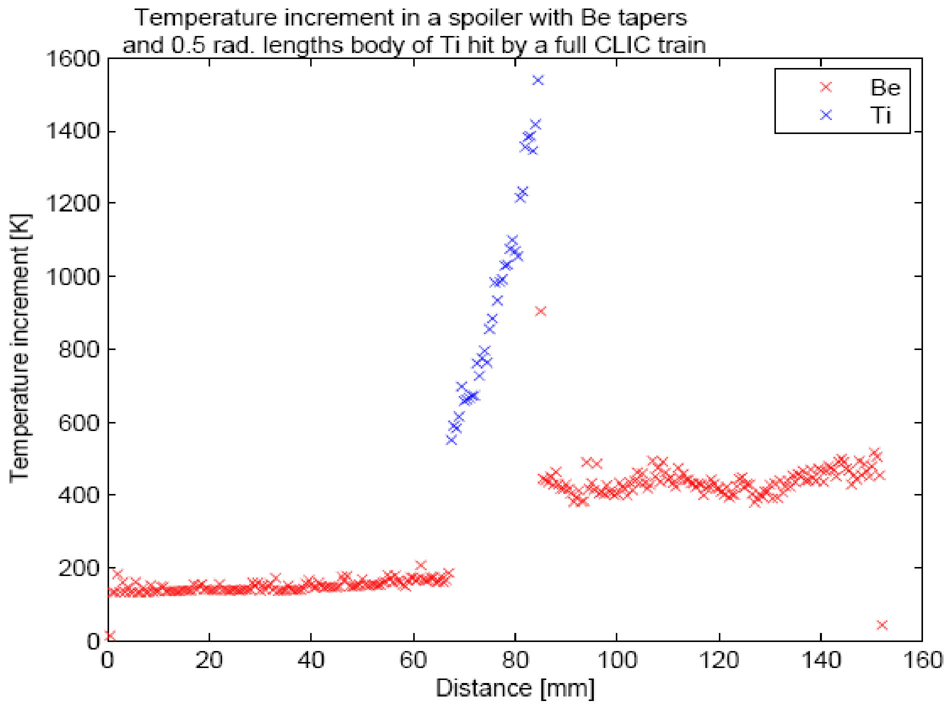
- Spoiler with Be tapers and Ti alloy body:




Maximum increment of temperature ◷ 1600 K

In the worst scenario the spoiler made of Ti alloy + Be might reach the melting limit (1648 K) and the fracture limit (1710 K)

Ti alloy + Be spoiler presents also higher wakefield effects than Be spoiler



# Collimator wakefield effects

## Jitter amplification factors

(A quick analytical estimation)

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

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

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

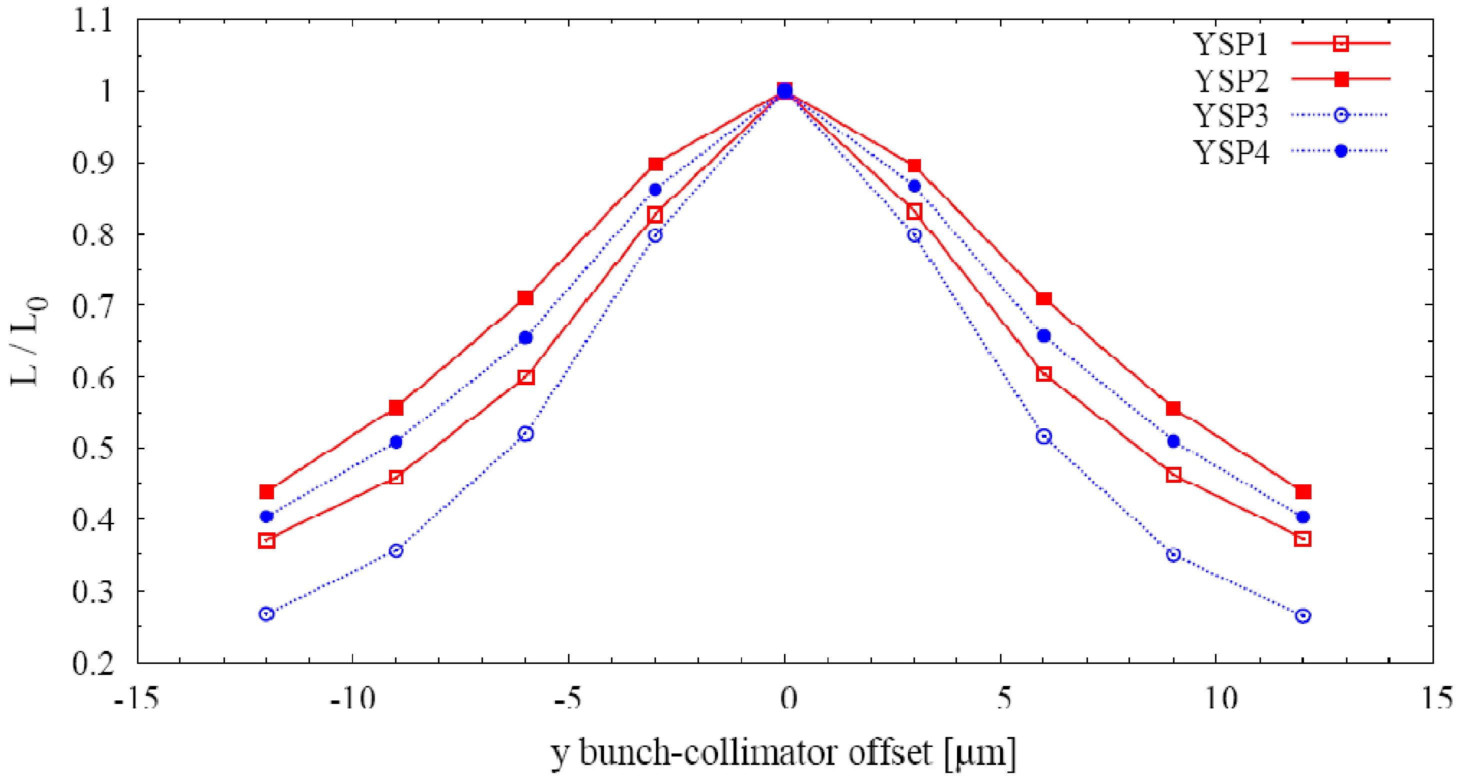
Energy collimators (spoiler and absorber): diffractive regime
$\beta$-spoilers: intermediate regime
$\beta$-absorbers: inductive regime

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

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

# Collimator wakefield effect on the luminosity

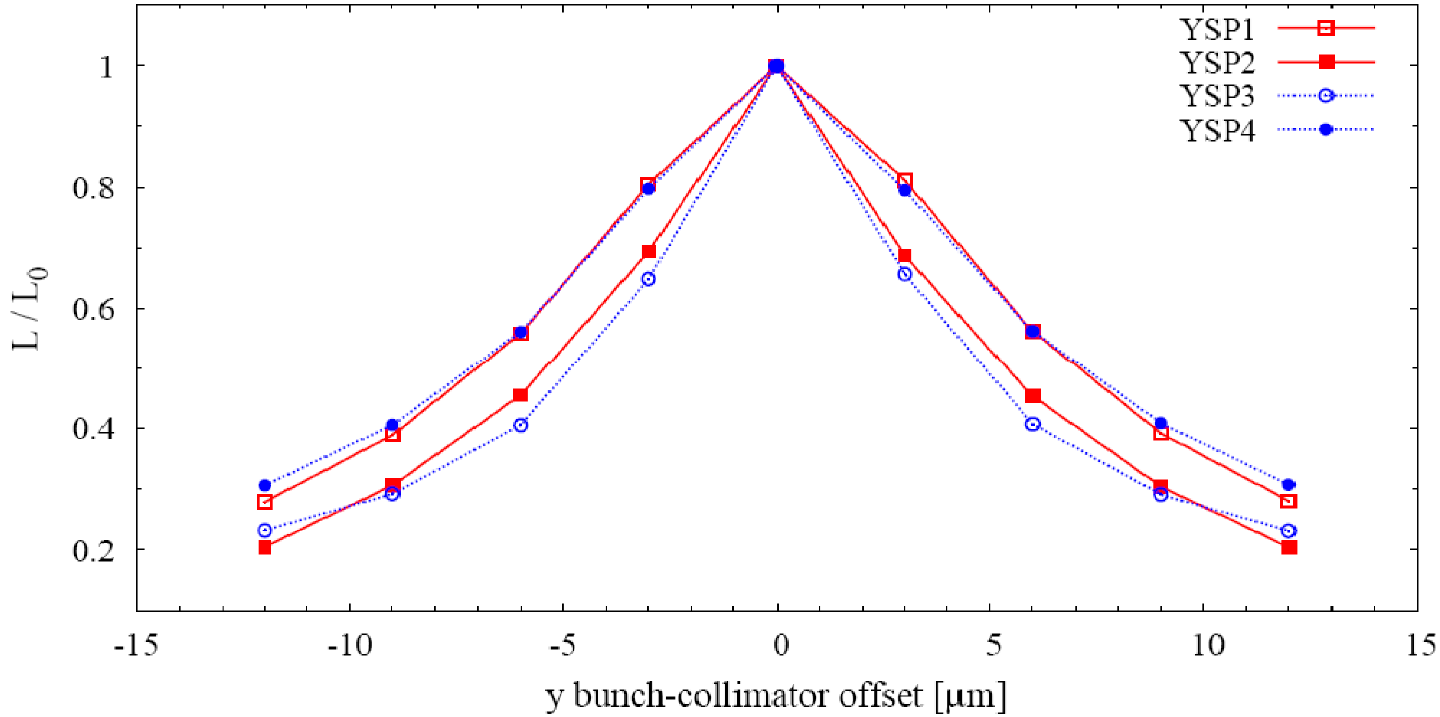
Old lattice & beam parameters 2005:
Vertical spoiler aperture: $a_y$=0.102 mm




YSP3 higher effect!
Tolerance ~ ± 2 μm ⇔ ±1$\sigma_y$

# Collimator wakefield effect on the luminosity

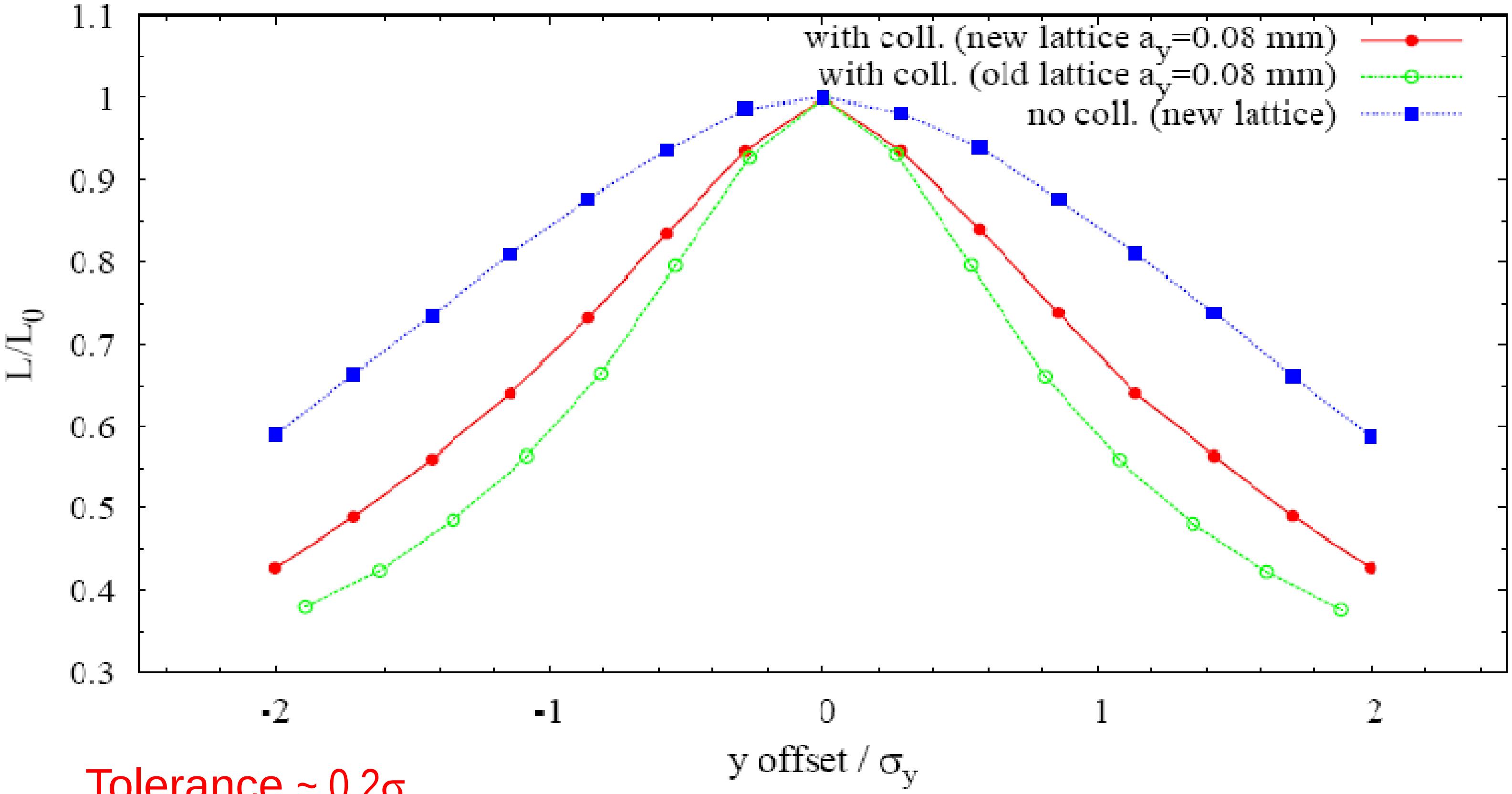
New lattice (with Rogelio's optimisation) & beam parameters 2007:
Vertical spoiler aperture: $a_y$=0.08 mm




Tighter tolerance!
The collimator alignment will be an important and challenging task

# Collimator wakefield effect on the luminosity

Luminosity versus vertical jitter offset at the entrance of the BDS:




Tolerance ~ $0.2\sigma_y$

# Collimation efficiency
## Energy collimation

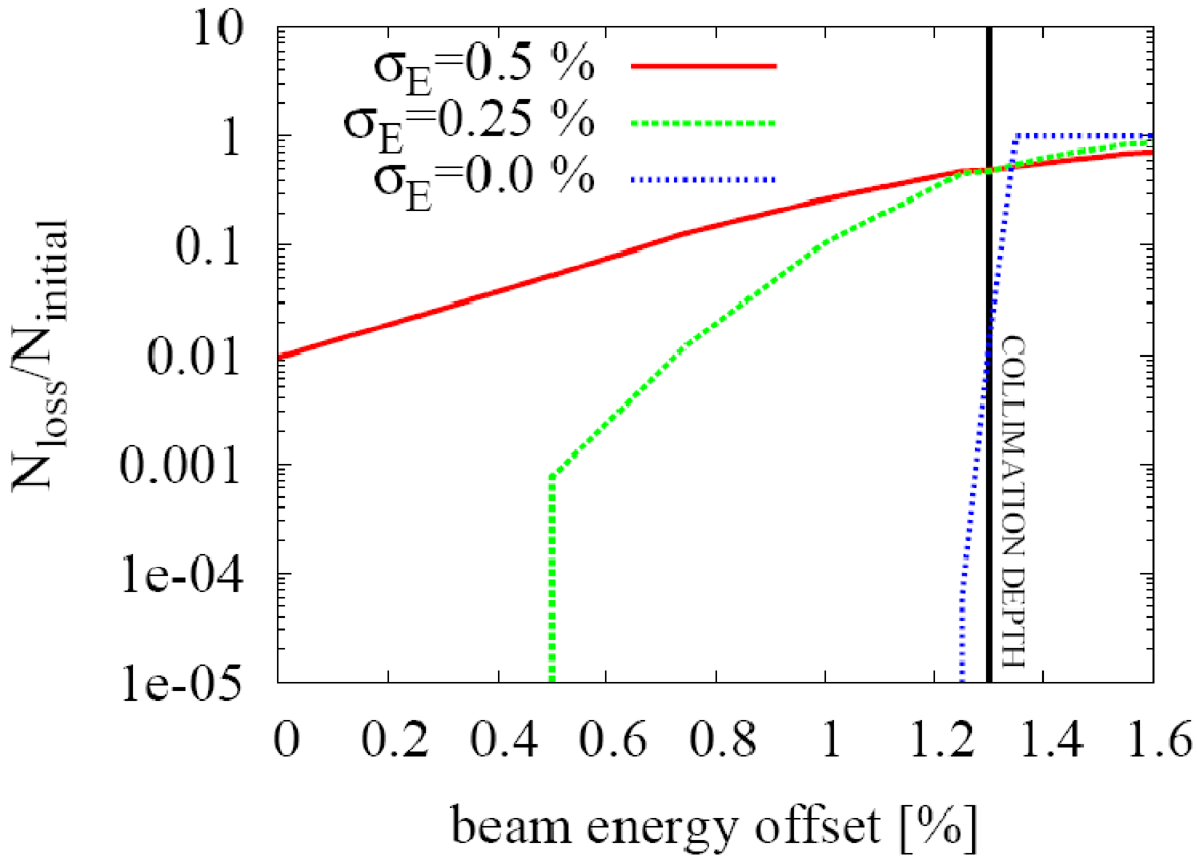
- Goal: spoil mis-steered beams coming from the linac with large momentum error > 1.3 %

- 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 $\sigma_E$



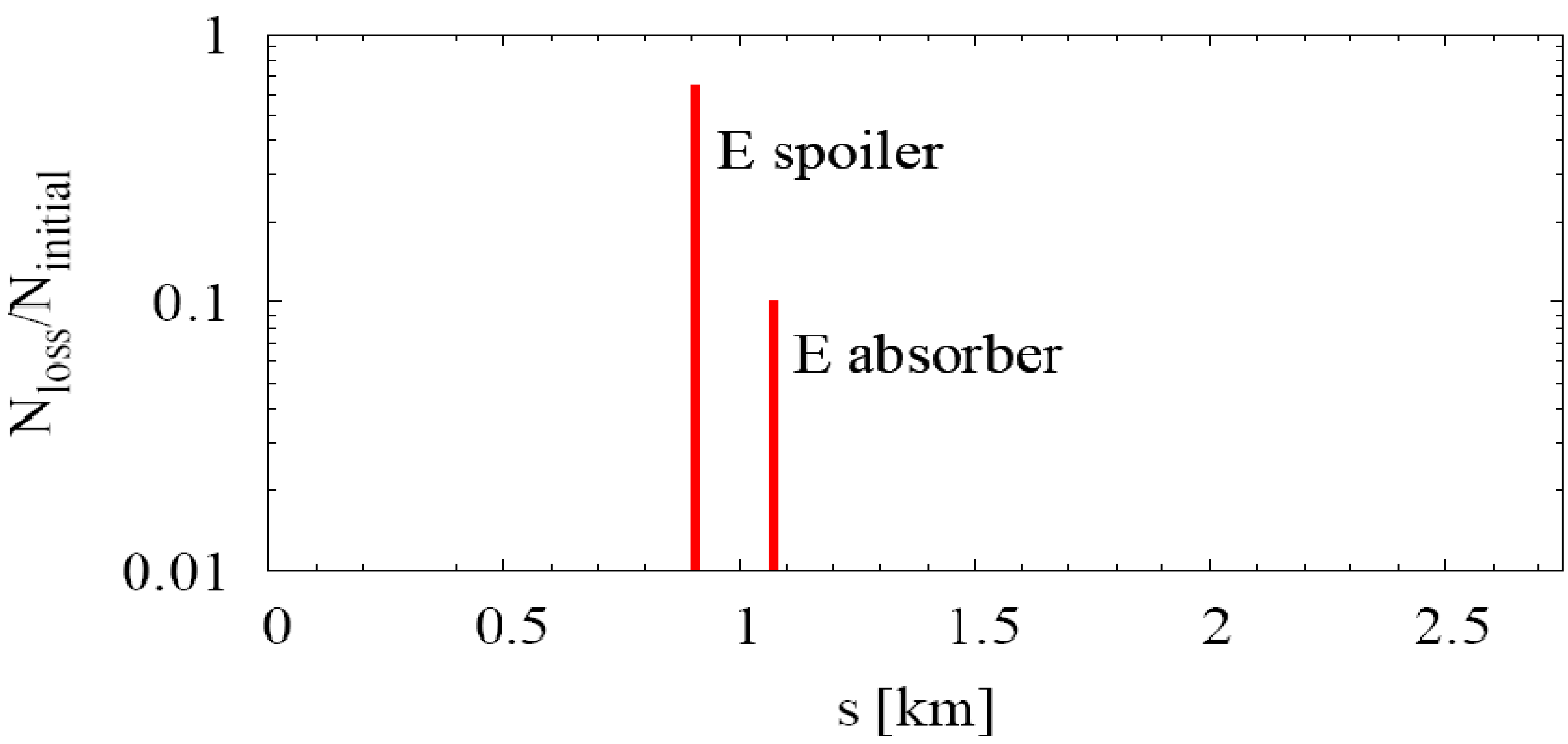

With beam energy off-set 0% and $\sigma_E$=0.5 % ✹ 1 % losses !

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

# Collimation efficiency
## Energy collimation

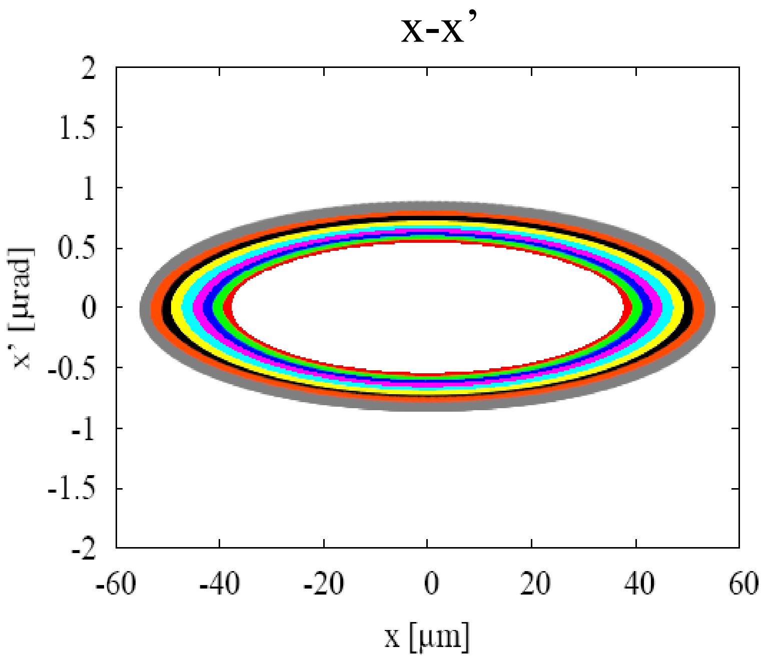
For off-energy beams, losses concentrated at E spoiler and E absorber

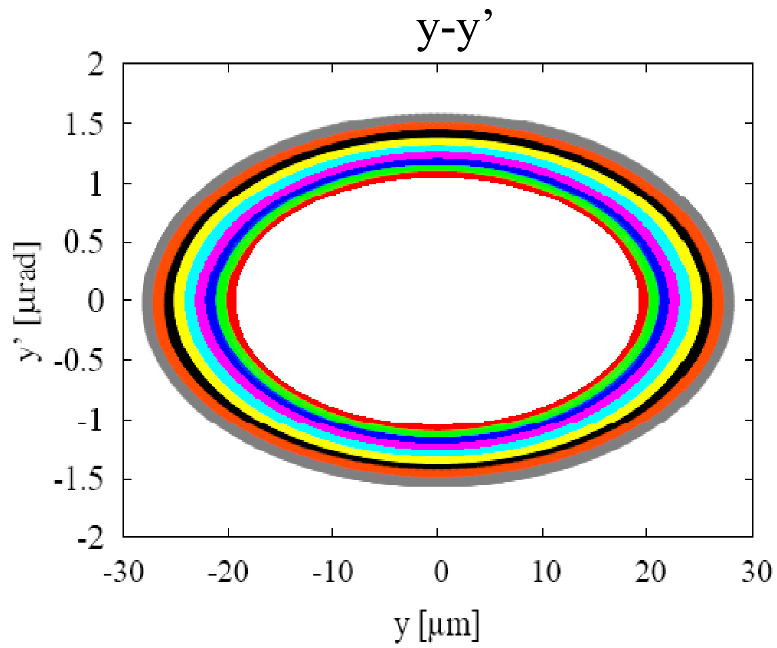
For 1.5 % energy offset and $\sigma_E$=0.5 %



# Collimation efficiency
## Betatron collimation

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



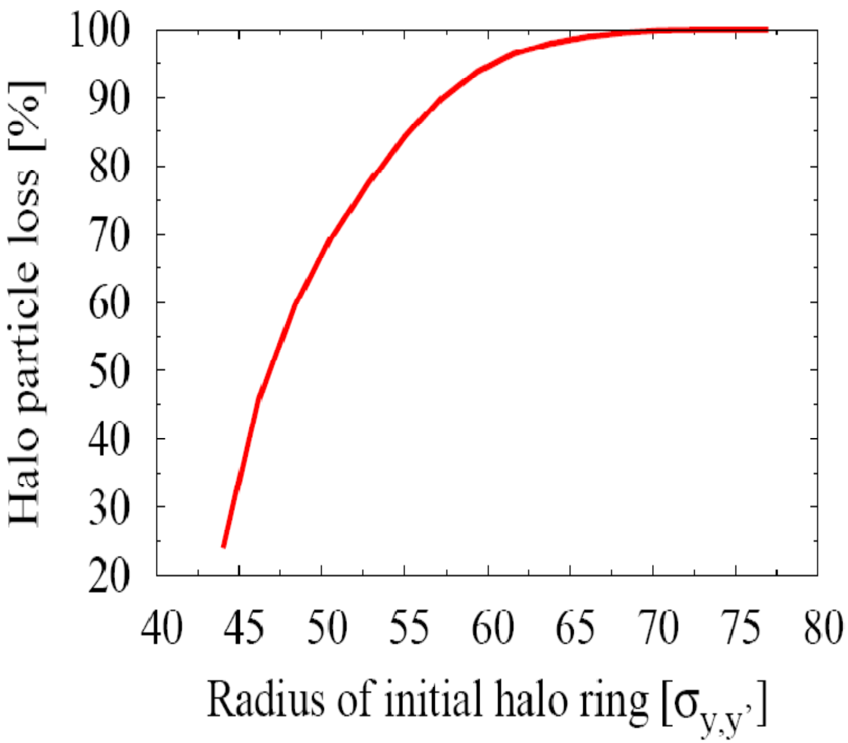



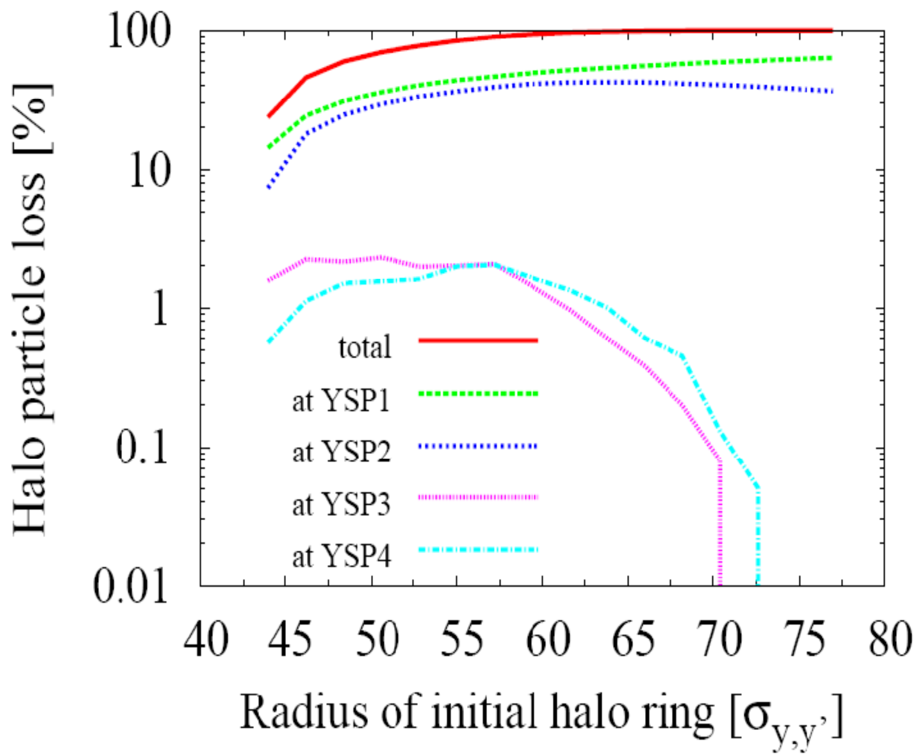
# Collimation efficiency

## Betatron collimation y-y’

Halo particle losses versus the radius of the halo ring:

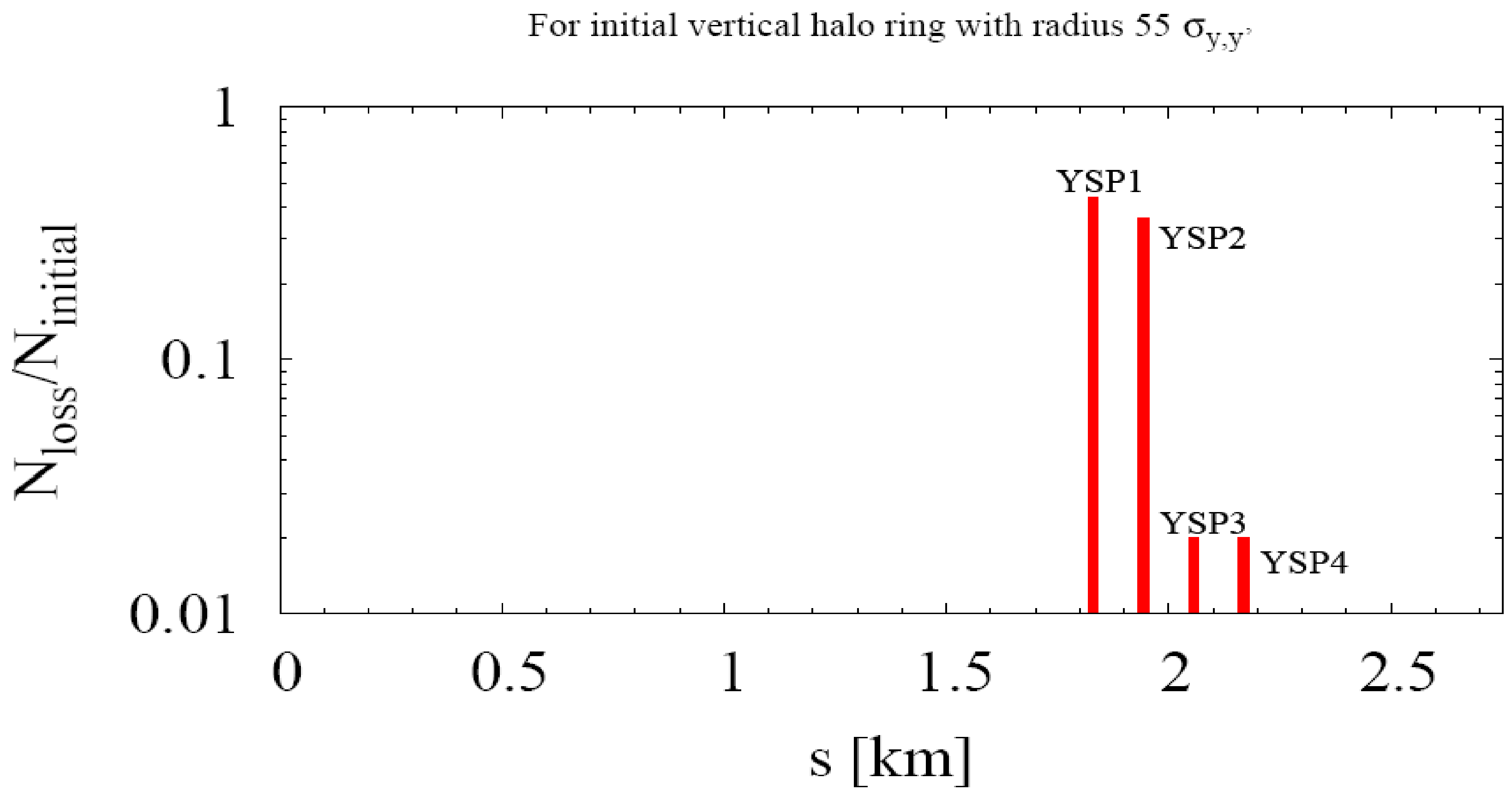
Main losses concentrated in the two first Vertical spoilers YSP1 & YSP2



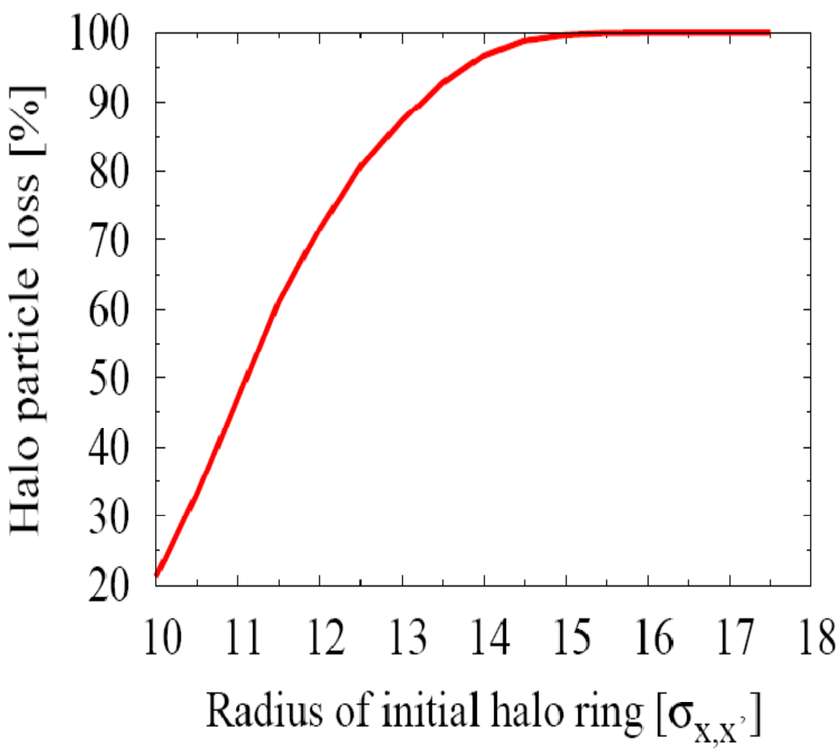
# Collimation efficiency

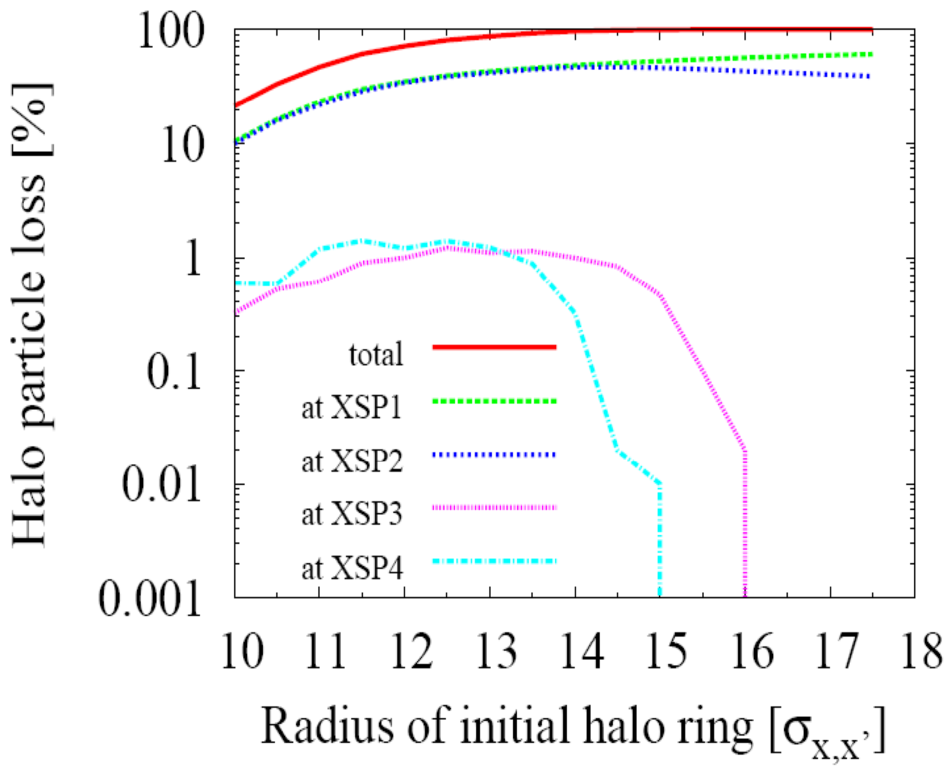
## Betatron collimation y-y’



# Collimation efficiency

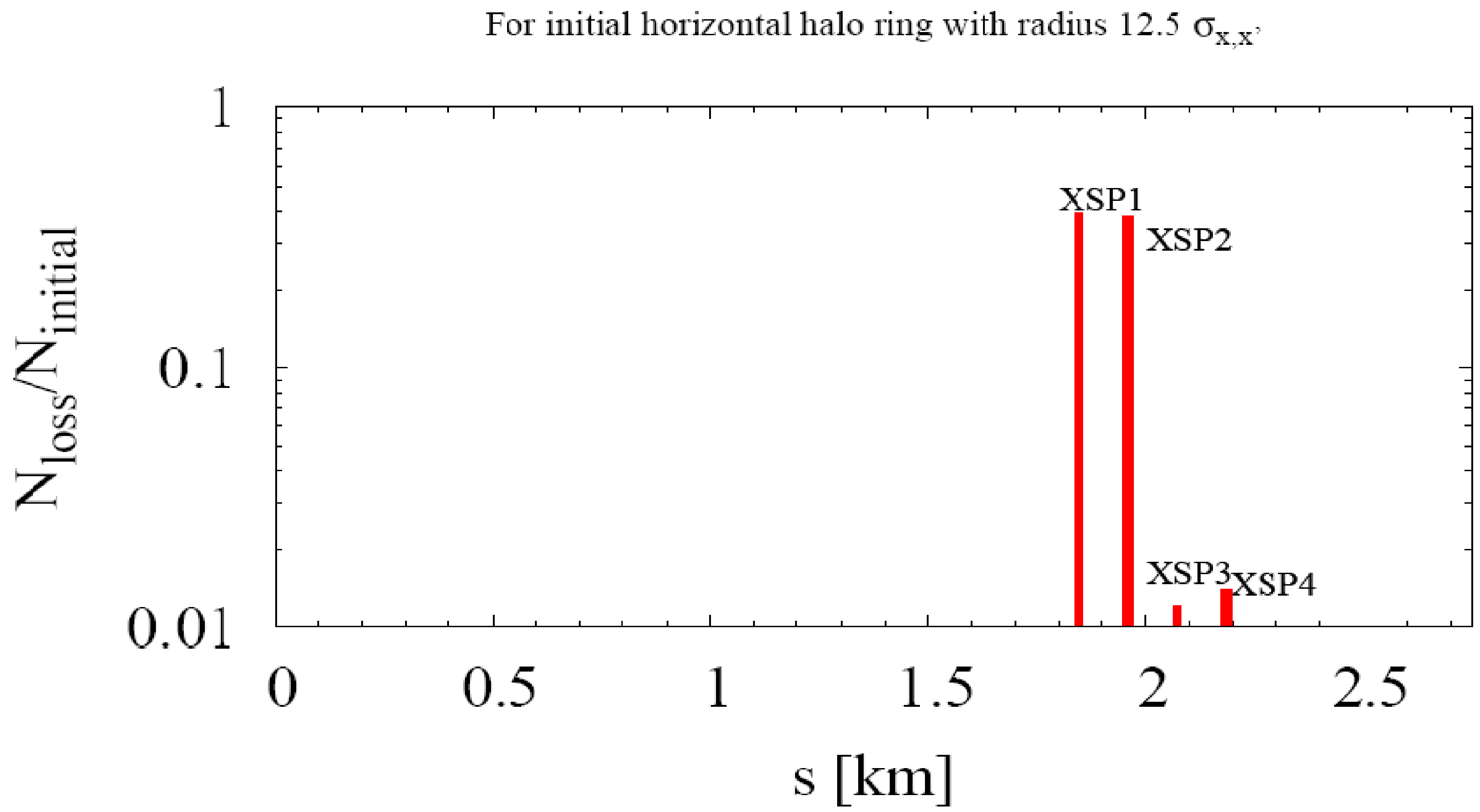
## Betatron collimation x-x'



# Collimation efficiency

## Betatron collimation x-x’

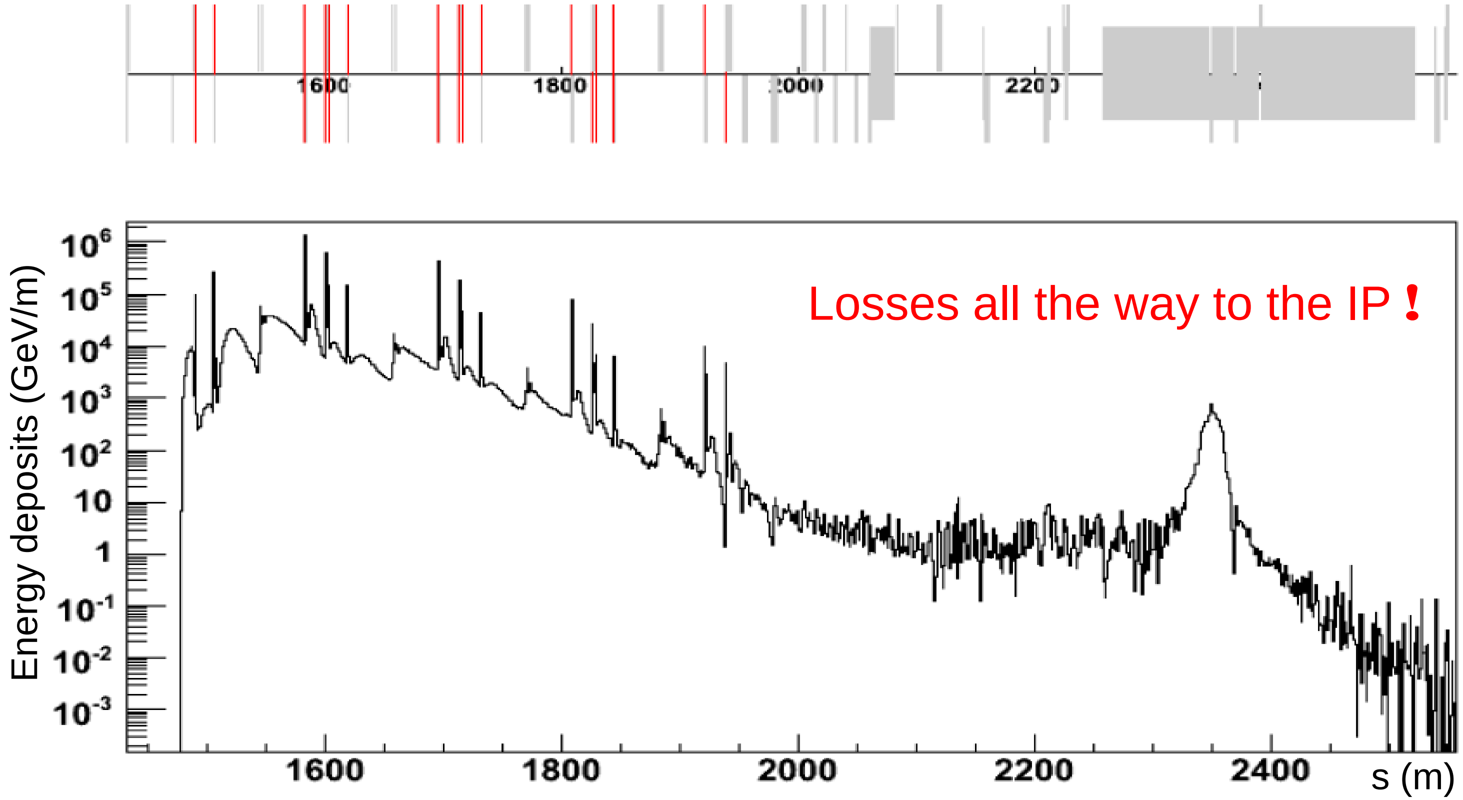


# Collimation efficiency

## Betatron collimation

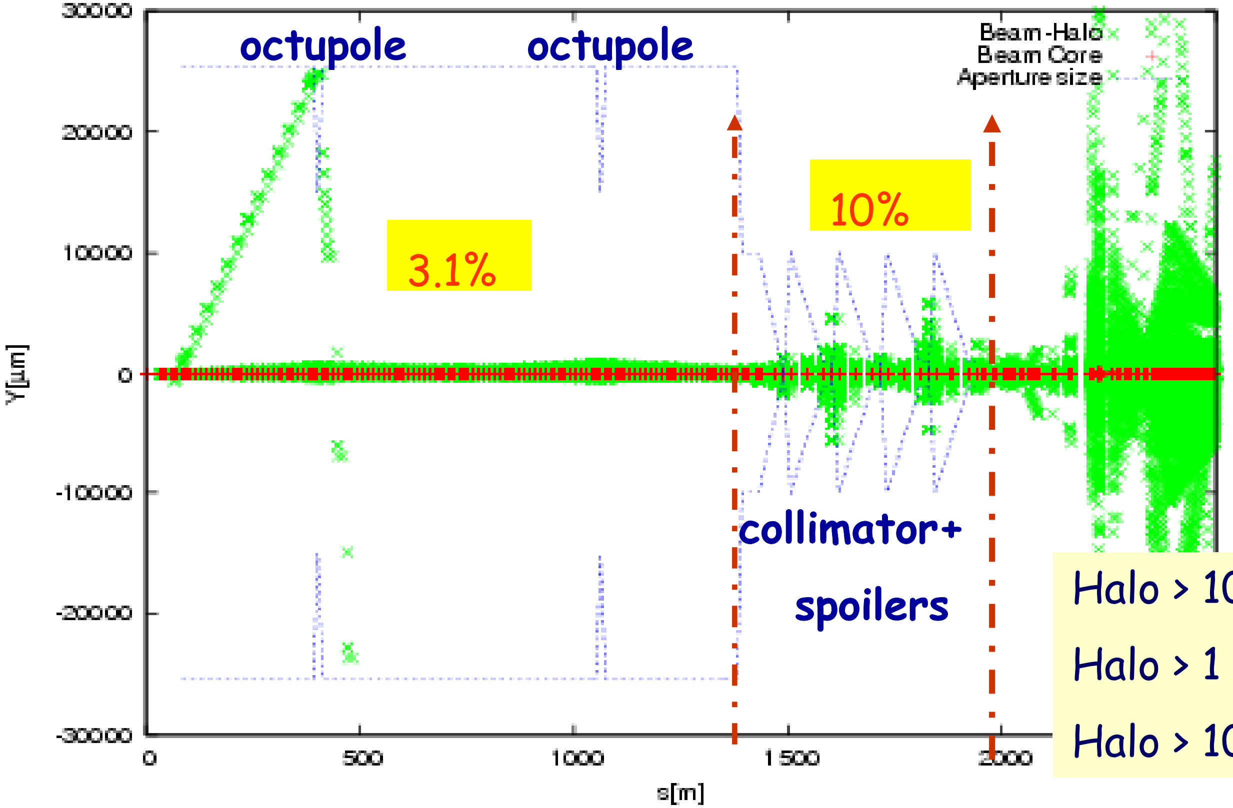
Improving simulations:
Energy deposition with secondary particle production:
Simulations with interface BDSIM-PLACET

[Steve Malton, EUROTeV-Report-2008-001]



# Realistic halo simulations:
## Beam-halo generation studies

[See talk by Ijaz Ahmed]




Halo > 102µm = 30%
Halo > 1 mm = ~ 3%
Halo > 10 mm = ~ 0.5%

# Summary and outlook

- The CLIC collimation system has been revisited with the new CLIC beam parameters (2008): collimator apertures review, collimator wakefields studies, design of the energy spoiler, robustness of the system, collimation efficiency, …
- Passive protection: a beryllium based spoiler might withstand the impact of an entire bunch train
- The alignment precision of the collimators will be crucial to reduce the collimator wakefield effects, although challenging
- We need to understand the halo generation and to use an realistic halo input for the cleaning efficiency studies. Studies have started
- Realistic models combining secondary particle emission, collimator wakefields, more realistic halo models would be very useful for the collimation study performance. Studies have started
- Consolidation of the CLIC collimation system during this workshop?
- After consolidation of the current collimation system, it could be worth to optimise other alternative systems, e.g. nonlinear collimation
- Novel ideas would be warmly welcome!

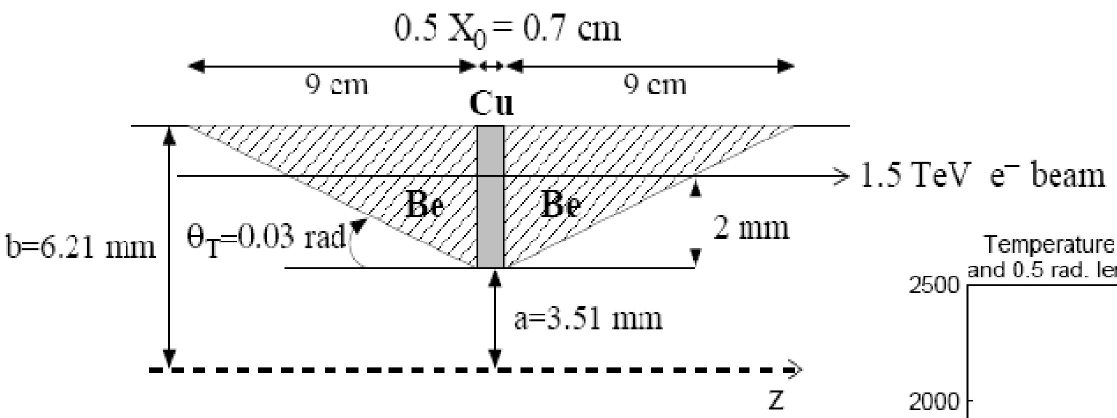
Reservoir

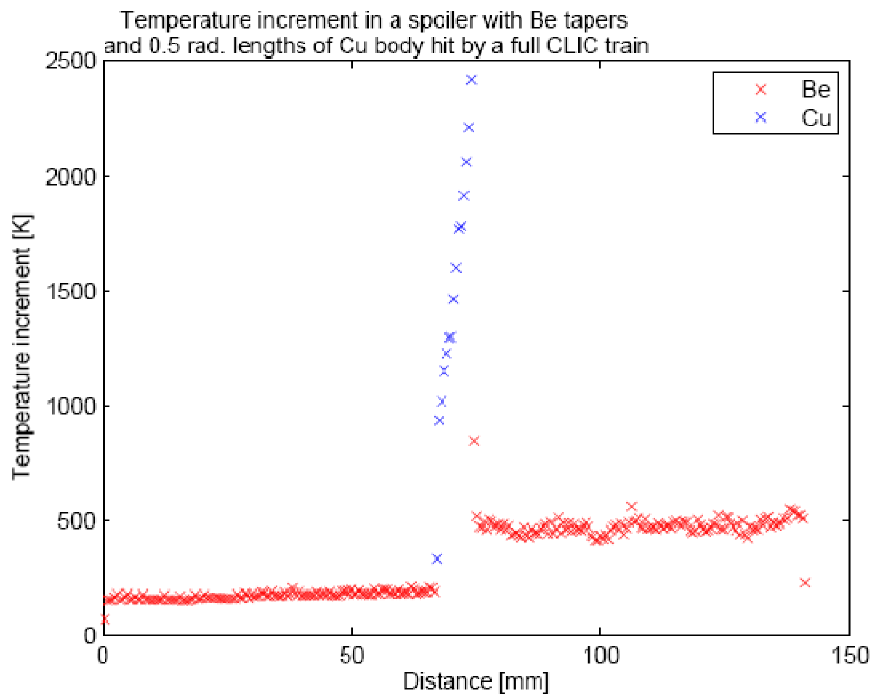
# Energy spoiler/absorber design:
## geometrical parameters

| Parameter | spoiler ENGYSP | absorber ENGYAB |
|---|---|---|
| Vertical half-gap $h$ [mm] | 25.4 | 25.4 |
| Horizontal half-gap $a$ [mm] | 3.51 | 5.4 |
| Tapered part radius $b$ [mm] | 6.21 | 6.21 |
| Tapered part length $L_{\mathrm{T}}$ [mm] | 90.0 | 27 |
| Taper angle $\theta_{\mathrm{T}}$ [rad] | 0.03 | 0.03 |
| Flat part length $L_{\mathrm{F}}$ [mm] | 0.0 | 646 |

# Spoiler survival
## Testing alternative designs:

- Spoiler with Be tapers and Cu body:




Maximum increment of temperature ≈ 2500 K

Clearly superior than both the fracture limit (201K) and the melting limit (1065 K)

Cu + Be spoiler presents lower wakefield effects than Be spoiler

# Spoiler survival

- Instantaneous temperature rise and the cyclic thermal stress calculated using the code FLUKA for the three options of energy spoiler studied

| **Variable** | Be | Ti alloy (0.5 $X_0$ flat part) | Cu (0.5 $X_0$ flat part) |
|---|---|---|---|
| $\Delta\hat{T}_{inst}$ [K] (FLUKA) | 280 | 1600 | 2500 |
| $\sigma_{cyc}$ [MPa] (FLUKA) | 454 | 944 | 2681 |
| $\Delta T_{\mathrm{melt}}$ [K] | 1267 | 1648 | 1065 |
| $\Delta T_{\mathrm{fr}}$ [K] | 370 | 1710 | 201 |

# Collimator wakefield effects

Luminosity versus vertical jitter divergence angle at the entrance of the BDS: