NON-LINEAR COLLIMATION

On behalf of

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Collimation system functions

- Reduce detector background by removing beam halo
  - Muon suppression near the IP
  - Prevent synchrotron radiation emission in the final quadrupoles
- Ensure collimator survival and machine protection
- No produce intolerable wake fields that might degrade the orbit stability or dilute the beam emittance

The main issues in the design I

- The efficiency in removing the halo
- IR layout and the FFS optics

  collimation requeriments (SR, etc.)
- The mechanical collimator jaws with typical gaps of tens beam σ (~100 μm to ~1 mm)
- Not degrade the luminosity

  (optical aberrations, wakefields)
- Mechanical protection issues

  (beam power densities ~$GWmm^{-2}$)

The main issues in the design II

- Mechanical scrapers:
  - can be damaged by the intense beams at small emittances!
  - induce wakefield kicks which cause emittance dilution !

Posible solution

?

Collimation solutions

- Blow-up beam sizes:
  - Collimators have big gaps and can survive a hit by the beam.
  - Very large β-functions and tight optical tolerances
  - Large system (~km)
  - Non-linear problems !
- Keep β-functions relatively small:
  - Better optical and wakefield performance
  - Looser tolerances
  - Beam could destroy the collimator
    (“consumable collimator”, NLC approach)
  - Shorter and manageable systems

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Non-linear collimation system

State of the art

(N. Merminga et al., SLAC-PUB-5165 Rev. May 1994)

- Two nonlinear elements placed π apart in phase advance with unit magnification

cancels geometric aberrations

- 'Higher-order multipoles (decapoles, dodecapoles, etc.), are not useful because don´t penetrate to the small distances necessary'

Non-linear collimation system

Hamiltonians

- **Skew Sextupoles**:

$$H_s = \frac{K_s}{3!}\left(y^3 - 3\left(x + D\delta\right)^2 y\right)$$

- **Normal Octupoles:**

$$H_o = \frac{K_o}{4!}\left(y^4 + \left(x + D\delta\right)^4 - 6\left(x + D\delta\right)^2 y^2\right)$$

where $\delta \equiv {\Delta p}/{p}$

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Non-linear collimation system

Properties

- Even shorter (I_5 ↓↓ ⇨ l_B ↑↑)
- 1st skew sextupole

  → increase $\sigma_{x,y}$ at spoiler

  → amplifies δ and x_β oscillations

  spoiler at larger amplitude (smaller wake effect)
- $D_x \approx 0$ at spoiler avoids $\Delta E \rightarrow x_\beta$ coupling
- 2nd skew sextupole cancels geometric aberrations
- Single spoiler only (compact, less wakefields)
- 3rd weak sextupole for orthogonal phase
- Comfortable spot size at absorber behind spoiler
- Emittance growth from SR

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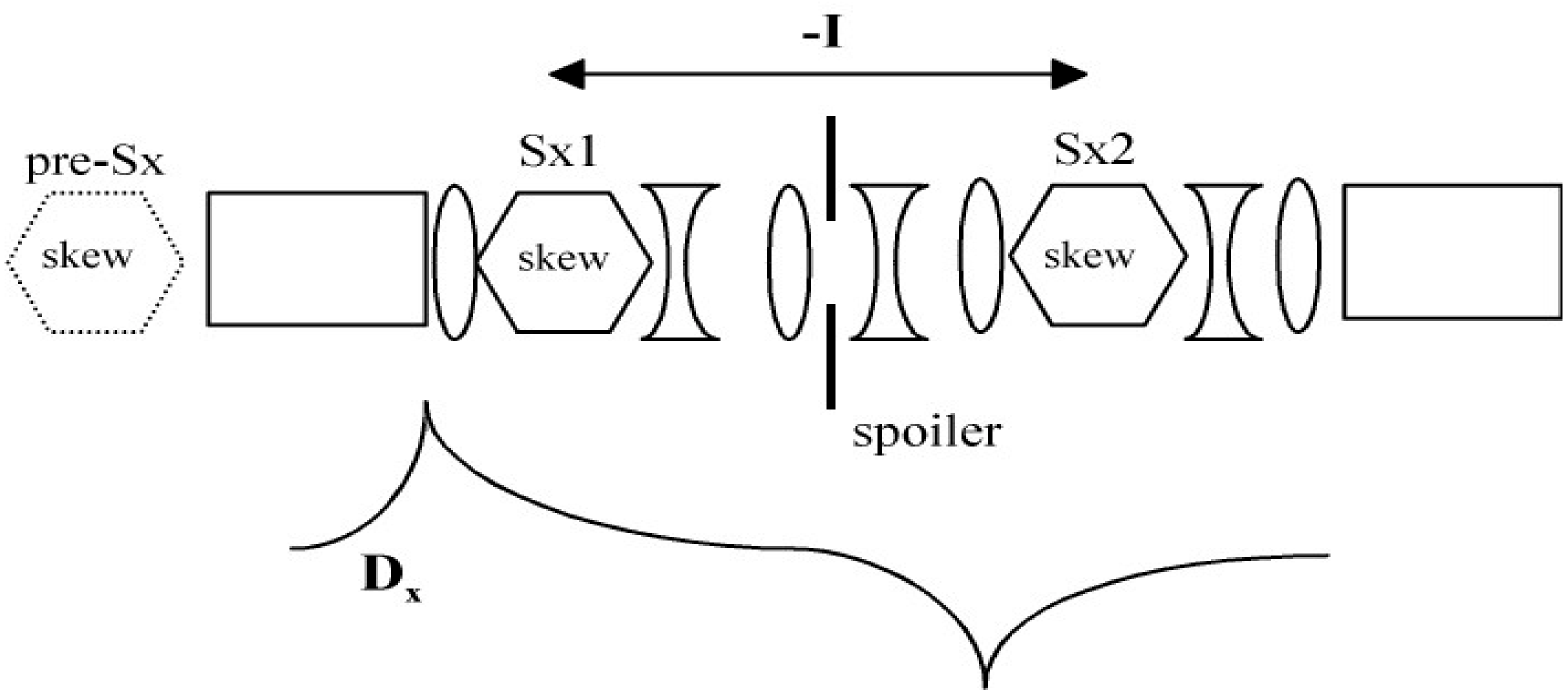
Non-linear collimation system for CLIC

Optics design

[A. Faus-Golfe & F. Zimmermann. CERN-SL-2002-032 (AP)]



First optics solution at 3 TeV

3rd weak skew sextupole

$\Delta\mu=\pi/2$

1st skew sextupole

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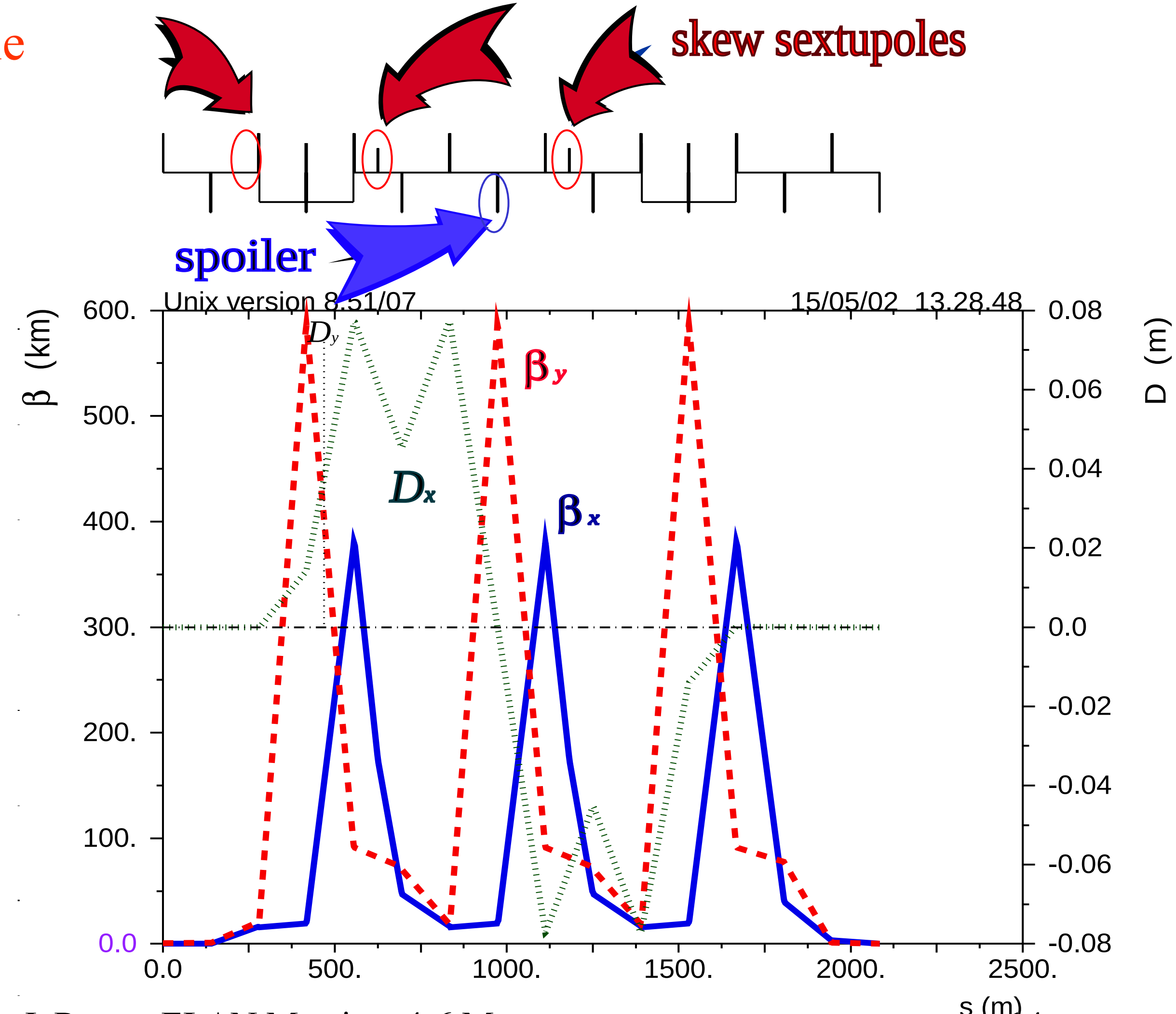
A single spoiler

$\Delta\mu=\pi/2$

2nd skew sextupole



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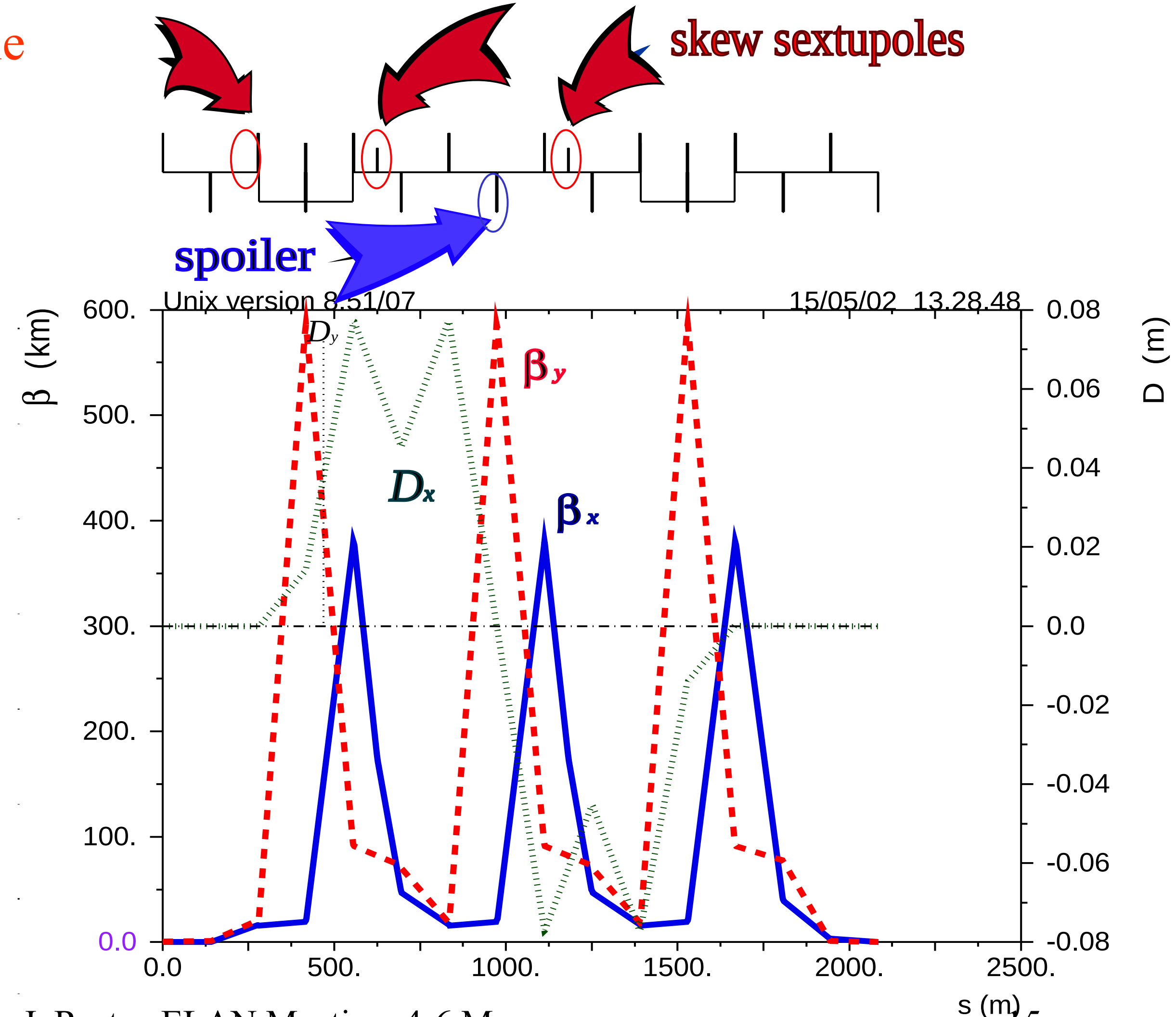
☛Does not include chromatic correction !



Effect of skew sextupole I

Integrated sextupole strength $$K_s = \frac{2 B_T l_s}{(B\rho) a_s^2}$$

Effect of skew sextupole I

Integrated sextupole strength
$$K_s = \frac{2B_T l_s}{(B\rho)a_s^2}$$

deflection:

$$\boxed{\Delta x' = -\frac{\partial H_s}{\partial x} = K_s(x + D_s\delta)y}$$

$$\boxed{\Delta y' = -\frac{\partial H_s}{\partial y} = -\frac{1}{2}K_s\left(y^2 - x^2 - D_s^2\delta^2 - 2D_s\delta x\right)}$$

Effect of skew sextupole II

- Position at downstream spoiler:

$$x_{spoiler} = x_{0,spoiler} + R_{12}\Delta x'$$
$$y_{spoiler} = y_{0,spoiler} + R_{34}\Delta y'$$

- Beam size:

$$\sigma_x \approx \sqrt{\beta_{s,spoiler}\varepsilon_x}$$
$$\sigma_y \approx \sqrt{\frac{9}{5}}\frac{1}{2}\left|R_{34}K_s\right|D_s^2\delta_{rms}^2$$

R_{12} , R_{34} : optical transport matrix elements between the sextupole and the spoiler

Effect of skew sextupole III

- Condition for spoiler survival:

$$\sigma_x \sigma_y \approx \sqrt{\frac{9}{5}} \frac{1}{2} |R_{34} K_s| D_s^2 \delta_{rms}^2 \sqrt{\beta_{x,spoiler} \varepsilon_x} \geq \sigma_{r,\min}^2 \qquad \textbf{(1)}$$

Minimum beam size

- The beta functions:

$$\beta_{x,sext} = \frac{D_s^2 \Delta^2}{\varepsilon_x n_x^2} \qquad \textbf{(2)}$$

Energy collimation depth

$$\beta_{y,spoiler} = \frac{K_s^2 R_{34}^2 D_s^4 \Delta^4}{4 \varepsilon_y n_y^2} \qquad \textbf{(3)}$$

$\pm n_x \sigma_x$

$\pm n_y \sigma_y$

Collimation amplitudes

Effect of skew sextupole IV

- The achievable value of D_s is limited by the emittance growth $\Delta(\gamma\varepsilon_x)$ due to SR in the dipole magnets

$$\Delta(\gamma\varepsilon_x) \approx \left(4\times10^{-8}\, m^2 GeV^{-6}\right) E^6 I_5 < f\varepsilon_x \qquad \textbf{(4)}$$

f: fraction of the initial emittance

I_5: radiation integral

§ PARAMETERS FOR SKEW SEXTUPOLES AND SPOILER

Variable	Value
length	2.07 km
beta functions (x , y) at skew sext.	175, 82 km
dispersion at skew sext.	61 mm
skew sext. pole-tip field, radius, length	1.4 T, 4 mm, 3 m
skew sext. strength K_s	104 m^{-2}
R_{12}, R_{34} from sext to spoiler	110, 307 m
beta functions (x , y) at spoiler	20.5, 586 km
dispersion at spoiler	~0 m
rms spot size (x , y) at spoiler	69, 209 mm
vertical spoiler half gap $a_{y,spoiler}$	16.7 mm

§ PARAMETERS FOR 'PRE' SKEW SEXTUPOLES

$$K_s^{pre} = \frac{2}{\left(n_y^{IP}\right)^2 \beta_y^{pre} \varepsilon_y} \left(\frac{2a_{y,spoiler}}{K_s R_{34}} \right)^{1/2} \frac{1}{R_{34}^{pre}}$$

Variable	Value
hor. beta function at pre skew sext.	5.4 km
vert. beta function at pre skew sext.	19.5 km
pole-tip field, radius, length	23mT, 20 mm, 3 m
strength K_s^{pre}	0.068 m^{-2}
R_{12} from pre-sext. to sext.	290 m
R_{34} from pre-sext. to sext.	113 m

Conclusions

- ✓ Single spoiler for all three degrees of freedom → compact
- ✓ Spoiler at large amplitude → smaller wake effect
- ✓ Comfortable spot size at absorber behind spoiler
- ✓ Emittance growth from SR

On going studies…

Local chromatic correction necessary !

Calculate and minimize residual aberrations !

Comparison with linear system

Efficiency

- Luminosity
- Particle loss
- Bandwidth
- Blow-up emittance (momentun spread, synchrotron radiation)
- … !