NON-LINEAR COLLIMATION IN LINEAR AND CIRCULAR COLLIDERS

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Abstract

We describe the concept of nonlinear collimation of beam halo in linear and circular colliders. In particular we present the application of such a concept in two different cases: the energy collimation system for CLIC at 3 TeV c.m. energy and a betatron collimation system for LHC at 14 TeV c.m. energy. For each case, the system properties, like chromatic bandwidth, collimator survival and cleaning efficiency, are evaluated and compared with those of the corresponding linear collimation system.

INTRODUCTION

The collimation system of a linear or circular collider must serve multiple purposes and fulfill a number of constraints. In particular, we require that the collimation system should (1) reduce the background in the particle detectors by removing particles at large betatron amplitudes or energy offsets; (2) withstand the impact of a full bunch train in case of machine failure; (3) minimize the activation of accelerator components outside of the dedicated collimation insertions and (4) not produce intolerable wake fields that might compromise beam stability.

The motivation in the case of linear colliders of using such a system is to blow-up the beam size and to reduce the length, taking advantage of the large beam energy spread in comparison with the transverse emittance. In the case of circular colliders the motivation is the reduction of resistive impedance because of the larger aperture of the spoiler. In this situation the transverse emittance is larger than the beam energy spread and there is no need of a large blow-up of the beam sizes.

The basic layout of a nonlinear collimation system is illustrated in Fig. 1. The purpose of the first nonlinear element is to blow up beam sizes and particle amplitudes, so that the collimator jaw can be placed further away from the nominal beam orbit (reducing the wake fields and resistive impedances) and the beam density is decreased (for collimator survival). A second nonlinear element downstream of the spoiler, and at π phase advance from the first nonlinear element, cancels the aberrations induced by the former.

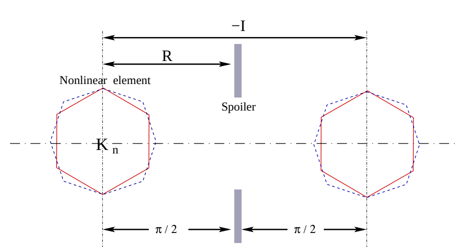

Figure 1: Schematic of a nonlinear collimation system.

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At each nonlinear element a particle suffers deflections $\Delta q'_i = -\partial H_n/\partial q_i$, where H_n is the Hamiltonian of the multipole. As was pointed in [1], higher-order multipoles (decapoles, dodecapoles, etc.) are not useful, because they do not penetrate to the small distances necessary. Skew sextupoles and octupoles could be used.

Different types of nonlinear collimation systems for future linear colliders have been described in the literature [1, 2, 3, 4]:

- For the NLC, in [1] a scheme with skew-sextupole pairs for nonlinear betatron collimation in the vertical plane has been proposed.
- Subsequently, in [2], a halo reduction method with the addition of “tail-folding” octupoles (‘Chebyshev arrangement of octupoles’) in the NLC final focus system has been presented.
- For the TESLA post-linac collimation system a magnetic energy spoiler (MES) has been suggested [3]. An octupole is placed at a high dispersion point between a pair of skew sextupoles (at $\pi/2$ phase advance from the octupole). The skew sextupoles are separated by a optical transfer matrix $-I$. The result is a significant increase in the vertical beam size at a downstream momentum spoiler.

A characteristic feature of all these systems is that they separate between energy and betatron collimation, and typically employ the nonlinear elements only in one or the other half.

A nonlinear collimation system for CLIC with three skew sextupoles was explored in [4]. It contains a single vertical spoiler which collimates in the horizontal and vertical betatron amplitude at both betatron phases as well as in energy. More details of this system can be found in [4].

SYSTEM EQUATIONS FOR SKEW SEXTUPOLE PAIR AND SINGLE SPOILER

In this section we describe a nonlinear energy collimation system using a pair of skew sextupoles and a single spoiler, based on the layout of Fig. 2.

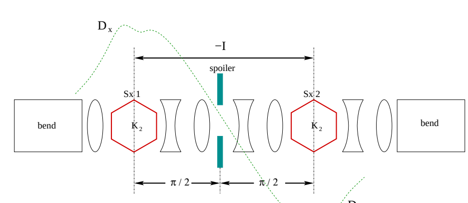

Figure 2: Schematic of a nonlinear collimation system using a pair of skew sextupoles and a single spoiler.

The integrated sextupole strength K_s can be expressed in terms of the sextupole length l_s, the pole-tip field B_T, the magnetic rigidity $(B\rho)$, and sextupole aperture a_s as

$$K_s = \frac{2B_T l_s}{(B\rho)a_s^2} \ . \quad (1)$$

The sextupole at a location with horizontal dispersion $D_{x,\mathrm{sext}}$ deflects a passing particle by

$$\Delta x' = K_s(D_{x,\mathrm{sext}}\delta + x)y \ , \quad (2)$$

$$\Delta y' = -\frac{1}{2}K_s(y^2 - x^2 - D_{x,\mathrm{sext}}^2\delta^2 - 2D_{x,\mathrm{sext}}\delta x) \ , \quad (3)$$

with δ the relative momentum offset.

The position at the downstream spoiler is obtained from

$$x_{\mathrm{sp}} = x_{0,\mathrm{sp}} + R_{12}\Delta x' \ , \quad (4)$$

$$y_{\mathrm{sp}} = y_{0,\mathrm{sp}} + R_{34}\Delta y' \ , \quad (5)$$

where $x_{0,\mathrm{sp}} = x_{\beta,\mathrm{sp}} + D_{x,\mathrm{sp}}\delta$ and $y_{0,\mathrm{sp}} = y_{\beta,\mathrm{sp}}$ are the horizontal and vertical position of the particle at the spoiler without the sextupole, written in terms of the betatronic parts, $x_{\beta,\mathrm{sp}}$ and $y_{\beta,\mathrm{sp}}$, and the horizontal dispersion at the spoiler, $D_{x,\mathrm{sp}}$. R_{12} and R_{34} are the optical transport matrix elements between the skew sextupole and the spoiler.

The transverse root mean squared beam sizes at the spoiler are given by the expressions

$$\sigma_{x,\mathrm{sp}} = \sqrt{\langle x_{\mathrm{sp}}^2\rangle - \langle x_{\mathrm{sp}}\rangle^2} \ , \quad (6)$$

$$\sigma_{y,\mathrm{sp}} = \sqrt{\langle y_{\mathrm{sp}}^2\rangle - \langle y_{\mathrm{sp}}\rangle^2} \ . \quad (7)$$

For spoiler survival, a minimum beam size $\sigma_{r,\mathrm{min}}$ is required so that $\sigma_{y,\mathrm{sp}}\sigma_{x,\mathrm{sp}} \geq \sigma_{r,\mathrm{min}}^2$. This value depends on the spoiler material and determines the minimum value of K_s, R_{12} and R_{34}.

A second skew sextupole downstream of the spoiler with the same strength, with horizontal dispersion $-D_{x,\mathrm{sext}}$ and π phase advance from the first nonlinear element cancels the geometric aberrations and the first order chromatic aberrations induced by the first skew sextupole.

Linear Colliders

For linear colliders we assume that x_β and y_β are small compared with $D_x\delta$ both at the spoiler and at the sextupole. Furthermore the beams are flat $x_\beta >> y_\beta$.

In the approximation the horizontal mean squared position of particles and the average horizontal beam offset at the spoiler is given by

$$\langle x_{\mathrm{sp}}^2\rangle \simeq D_{x,\mathrm{sp}}^2\langle\delta^2\rangle + R_{12}^2K_s^2D_{x,\mathrm{sext}}^2\langle\delta^2\rangle\langle y_{\beta,\mathrm{sext}}^2\rangle \ , \quad (8)$$

$$\langle x_{\mathrm{sp}}\rangle \simeq D_{x,\mathrm{sp}}\langle\delta\rangle \ . \quad (9)$$

In a similar way, the vertical mean squared position and the average vertical offset at the spoiler is

$$\langle y_{\mathrm{sp}}^2\rangle \simeq \frac{1}{4}R_{34}^2K_s^2D_{x,\mathrm{sext}}^4\langle\delta^4\rangle \ , \quad (10)$$

$$\langle y_{\mathrm{sp}}\rangle \simeq \frac{1}{2}R_{34}K_sD_{x,\mathrm{sext}}^2\langle\delta^2\rangle \ . \quad (11)$$

From Eqs. (6), (7), (8), (9), (10) and (11), considering a *Gaussian momentum distribution*:

$$P(\delta) = \frac{1}{\sqrt{2\pi}\sigma_\delta}e^{-1/2\left(\frac{\delta+\delta_0}{\sigma_\delta}\right)^2} \ , \quad (12)$$

with a width σ_δ and with an average momentum offset δ_0, the transverse beam sizes at the spoiler take the form:

$$\sigma_{x,\mathrm{sp}} \simeq \Big(D_{x,\mathrm{sp}}^2\sigma_\delta^2 + R_{12}^2K_s^2 D_{x,\mathrm{sext}}^2(\delta_0^2+\sigma_\delta^2)\beta_{y,\mathrm{sext}}\epsilon_y\Big)^{1/2} \ , \quad (13)$$

$$\sigma_{y,\mathrm{sp}} \simeq \Big(\frac{1}{2}R_{34}^2K_s^2D_{x,\mathrm{sext}}^4(\sigma_\delta^4 + 2\delta_0^2\sigma_\delta^2)\Big)^{1/2} . \quad (14)$$

On the other hand, if we consider the case of a *uniform flat momentum distribution*:

$$P(\delta) = \begin{cases} 0 & \text{for} \quad \delta < -\frac{\delta_{\mathrm{flat}}}{2} + \delta_0 \\ \frac{1}{\delta_{\mathrm{flat}}} & \text{for} \quad -\frac{\delta_{\mathrm{flat}}}{2} + \delta_0 < \delta < \frac{\delta_{\mathrm{flat}}}{2} + \delta_0 \\ 0 & \text{for} \quad \delta > \frac{\delta_{\mathrm{flat}}}{2} + \delta_0 \ , \end{cases} \quad (15)$$

with a full width δ_{flat} and an average momentum offset δ_0, the transverse beam sizes at the spoiler take the form:

$$\sigma_{x,\mathrm{sp}} \simeq \Big(D_{x,\mathrm{sp}}^2\frac{\delta_{\mathrm{flat}}^2}{12} + R_{12}^2K_s^2 D_{x,\mathrm{sext}}^2\big(\frac{\delta_{\mathrm{flat}}^2}{12} + \delta_0^2\big)\beta_{y,\mathrm{sext}}\epsilon_y\Big)^{1/2} \ , \quad (16)$$

$$\sigma_{y,\mathrm{sp}} \simeq \Big(\frac{1}{4}R_{34}^2K_s^2D_{x,\mathrm{sext}}^4 \big(\frac{\delta_{\mathrm{flat}}^4}{180} + \frac{1}{3}\delta_{\mathrm{flat}}^2\delta_0^2\big)\Big)^{1/2} \ . \quad (17)$$

We can perform the energy collimation with a vertical or horizontal spoiler, using either the nonlinear second order vertical dispersion or the linear horizontal dispersion at the location of the spoiler. Alternatively, we can also use a spoiler for both planes with properly chosen horizontal and vertical gap sizes, so that the collimation occurs at the same momentum offset in the two planes.

If we employ a vertical spoiler, the nonlinear terms in the sextupolar deflection also yields a weak collimation for horizontal or vertical betatron amplitudes, at a collimation depth in units of σ_x or σ_y respectively of

$$n_x = \frac{D_{x,\mathrm{sext}}\Delta}{\sqrt{\epsilon_x\beta_{x,\mathrm{sext}}}} \ , \quad (18)$$

$$n_y = \frac{D_{x,\mathrm{sext}}\Delta}{\sqrt{\epsilon_y\beta_{y,\mathrm{sext}}}} \ , \quad (19)$$

where Δ is the energy collimation depth in units of δ. We can solve these equations for the beta functions at the sextupole and match for meaningful values of n_x and n_y. This was the approach chosen in [4], which tended to introduce large chromaticity.

Additionally, we can collimate in the other betatron phase, using the linear optics. Denoting the horizontal and vertical spoiler half gaps by a_x and a_y, respectively, and assuming that the vertical gap is adjusted for collimation at the same offset Δ as the horizontal one, the equivalents to (18) and (19) are (dependent on the plane of linear collimation)

$$n_{x2} = \frac{a_x}{\sqrt{\epsilon_x \beta_{x,\mathrm{sp}}}} \simeq \frac{D_{x,\mathrm{sp}}\Delta}{\sqrt{\epsilon_x \beta_{x,\mathrm{sp}}}} , \quad (20)$$

$$n_{y2} = \frac{a_y}{\sqrt{\epsilon_y \beta_{y,\mathrm{sp}}}} \simeq \frac{1}{2}\frac{R_{34} K_s D_{x,\mathrm{sext}}^2 \Delta^2}{\sqrt{\epsilon_y \beta_{y,\mathrm{sp}}}} , \quad (21)$$

where the subindex (2) refers to the orthogonal betatron phase, considering that the spoiler and the skew sextupole are placed roughly $\pi/2$ out of phase. These equations can be matched for the beta functions at the spoiler.

In principle, by combining Eqs. (18), (19), (20) and (21), we could collimate in both betatron phases and in energy using a single spoiler. If we opt for nonlinear betatron collimation, the other phase could also be collimated by installing a "pre" skew sextupole with a phase advance of about $\pi/2$ in front of the first skew sextupole, as proposed in [4].

The achievable value of the dispersion $D_{x,\mathrm{sext}}$ is limited by the emittance growth $\Delta(\gamma\epsilon_x)$ due to synchrotron radiation in the dipole magnets. The latter restricts the value

$$\Delta(\gamma\epsilon_x) \approx (4\times 10^{-8}\ \mathrm{m}^2\ \mathrm{GeV}^{-6}) E^6 I_5 < f\epsilon_x \quad (22)$$

to a fraction f of the initial emittance. Here I_5 is the radiation integral [5], $I_5 = \sum_i L_i < \mathcal{H} > /|\rho_i|^3$, where the sum runs over all bending magnets, with bending radius ρ_i, length L_i, and the "curly $\mathcal{H}$" function as defined by Sands [6].

Circular Colliders

For circular colliders $D_x\delta$ smaller than x_β and y_β both at the spoiler and at the sextupole is assumed.

In the approximation the horizontal mean squared position and the average horizontal beam offset at the spoiler is given by

$$\langle x_{\mathrm{sp}}^2\rangle \simeq \langle x_{\beta,\mathrm{sp}}^2\rangle + R_{12}^2 K_s^2 \langle x_{\beta,\mathrm{sext}}^2\rangle\langle y_{\beta,\mathrm{sext}}^2\rangle , \quad (23)$$

$$\langle x_{\mathrm{sp}}\rangle \simeq 0 . \quad (24)$$

In a similar way, the vertical mean squared position and the average vertical offset at the spoiler is

$$\langle y_{\mathrm{sp}}^2\rangle \simeq \langle y_{\beta,\mathrm{sp}}^2\rangle + \frac{1}{4}R_{34}^2 K_s^2 \Big(\langle x_{\beta,\mathrm{sext}}^4\rangle + \langle y_{\beta,\mathrm{sext}}^4\rangle - 2\langle x_{\beta,\mathrm{sext}}^2\rangle\langle y_{\beta,\mathrm{sext}}^2\rangle \Big) , \quad (25)$$

$$\langle y_{\mathrm{sp}}\rangle \simeq -\frac{1}{2}R_{34} K_s \Big(\langle y_{\beta,\mathrm{sext}}^2\rangle - \langle x_{\beta,\mathrm{sext}}^2\rangle \Big) . \quad (26)$$

From Eqs. (6), (7), (23), (24), (25) and (26) the transverse beam sizes at the spoiler take the form:

$$\sigma_{x,\mathrm{sp}} \simeq \Big(K_s^2 R_{12}^2 \beta_{x,\mathrm{sext}}\beta_{y,\mathrm{sext}}\epsilon_x\epsilon_y + \beta_{x,\mathrm{sp}}\epsilon_x \Big)^{1/2} , \quad (27)$$

$$\sigma_{y,\mathrm{sp}} \simeq \Big(\frac{1}{2}K_s^2 R_{34}^2 (\beta_{x,\mathrm{sext}}^2\epsilon_x^2 + \beta_{y,\mathrm{sext}}^2\epsilon_y^2) + \beta_{y,\mathrm{sp}}\epsilon_y \Big)^{1/2} . \quad (28)$$

Let $\pm n_x\sqrt{\beta_{x,\mathrm{sext}}\epsilon_x}$ and $\pm n_y\sqrt{\beta_{y,\mathrm{sext}}\epsilon_y}$ be the collimation amplitudes for the horizontal and vertical betatron motion respectively, and $\pm n_{x2}\sqrt{\beta_{x,\mathrm{sp}}\epsilon_x}$ and $\pm n_{y2}\sqrt{\beta_{y,\mathrm{sp}}\epsilon_y}$ the physical transverse apertures of the primary spoiler. Then for the collimation to function in either transverse plane, we must have [7]

$$n_{y2}\sqrt{\beta_{y,\mathrm{sp}}\epsilon_y} = \frac{1}{2}K_s R_{34} n_x^2 \beta_{x,\mathrm{sext}}\epsilon_x , \quad (29)$$

$$n_{y2}\sqrt{\beta_{y,\mathrm{sp}}\epsilon_y} = \frac{1}{2}K_s R_{34} n_y^2 \beta_{y,\mathrm{sext}}\epsilon_y . \quad (30)$$

On the other hand, a horizontal collimator at the same location at the vertical spoiler will intercept particle with simultaneously large amplitudes in both transverse planes. Its half gap aperture of $n_{x2}\sqrt{\beta_{x,\mathrm{sp}}\epsilon_x}$ can be set to,

$$n_{x2}\sqrt{\beta_{x,\mathrm{sp}}\epsilon_x} = K_s R_{12} n_x n_y \sqrt{\beta_{x,\mathrm{sext}}\epsilon_y}\sqrt{\beta_{y,\mathrm{sext}}\epsilon_y} . \quad (31)$$

or to a $\sqrt{2}$ times smaller value depending on the desired collimation border in transverse space. The tightest constraint likely arises from the achievable skew sextupole strength.

NON LINEAR ENERGY COLLIMATION SYSTEM FOR CLIC AT 3 TeV

Optics Design

Various optics designs for nonlinear energy collimation at CLIC were developed and optimized. The main changes with respect to the previous nonlinear collimation optics [4] are: (1) the collimation is performed only in energy. The sole purpose of the first skew sextupole is to the increase vertical spot size at the spoiler. A horizontal spoiler and the linear horizontal optics are used for the energy collimation; (2) we have maximized the overall fraction of the system occupied by bends and decreased the bending angle until the effect of synchrotron radiation became reasonably small. But no bends were installed between the skew sextupoles i.e. R_{16} = 0 (where R_{16} denotes the optical transport matrix between the two skew sextupoles) in order to cancel the geometric and first order chromatic aberrations avoiding any luminosity degradation; (3) we kept the beta functions as regular as possible to avoid the need of a dedicated chromatic correction inside the collimation system.

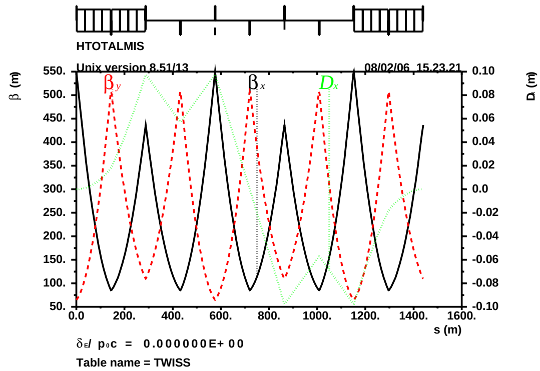

Figure 3: Optics solution proposed for CLIC at 3 TeV with a nonlinear energy collimation system based on two skew sextupoles ans a single spoiler.

One optics showing these features is displayed in Fig.3.

The dispersion at the first main skew sextupole and the skew-sextupole strength are chosen so as to guarantee spoiler survival in case of a full beam impact. The minimum beam size required for spoiler survival is about $\sigma_{r,\min} \approx 120\ \mu$m (allowing for carbon or beryllium as spoiler material) [8]. This value give to us a minimum sextupole strength of $\simeq 20\ \mathrm{m}^{-2}$. In the calculation of the collimation and beam parameters we have considered a *uniform flat momentum distribution*; see Eq.(15). The length of the system was reduced to the minimum value for which emittance growth due to synchrotron radiation does not yet affect the collider performance. The bending angles were adjusted accordingly. A value of $I_5 = 10^{-19}$ m corresponds to $\Delta(\gamma\epsilon_x) \approx 0.046\ \mu$m for CLIC at 3 TeV or to about 7% emittance growth, but chromatic effects may further increase the luminosity degradation due to synchrotron radiation. The value $I_5 = 10^{-19}$ m has been taken as constraint for the dispersion function and dipole angle in the optics design.

Tracking and Collimation Efficiency studies

Multiparticle tracking studies were done using an initial *uniform flat momentum distribution* of 10000 particles with 1% full width energy spread, $\delta_{\rm flat}$. Different average energy offsets δ_0 for such a particle distribution were considered. The tracking along the different optical systems considered, from the entrance to the spoiler location, was done using the codes `MAD` [9] and `PLACET` [10]. The simulated horizontal and vertical rms beam sizes at the spoiler were obtained from the tracking result as a function of the skew sextupole strength and δ_0, and compared with the analytical expressions (16) and (17). A good agreement was obtained, more details can be found in [11].

The tracking studies have shown a highly non-gaussian beam profile at the spoiler. In such a case, it is the peak-density of transverse energy which matters for the spoiler survival and not the rms beam size at the spoiler. The maximum acceptable transverse energy density in units of Joule is given by:

$$\rho_{E,\max} \approx \frac{N_{\rm p}}{2\pi\sigma_{r,\min}^2}\frac{E_0}{(\mathrm{GeV})} 1.6\times 10^{-10}\ \mathrm{J}\ , \qquad (32)$$

where $N_{\rm p}$ is the number of particles per bunch and E_0 the nominal beam energy. For the 3-TeV CLIC considered in [8], $N_{\rm p}$ is 4.2×10^9. Further taking $\sigma_{r,\min} \simeq 120\mu$m, we obtain $\rho_{E,\max}$ of 11.156 kJ mm^{-2} per bunch. In Fig. 4 we present the density plots at the spoiler for $K_s = 20.8\ \mathrm{m}^{-2}$ for the different optics solutions. The nonlinear collimation system uses a single vertical spoiler. Unlike the linear collimation system, the beam density is reduced by the nonlinear system as the beam energy offset increases. Both these features help to spoiler survival.

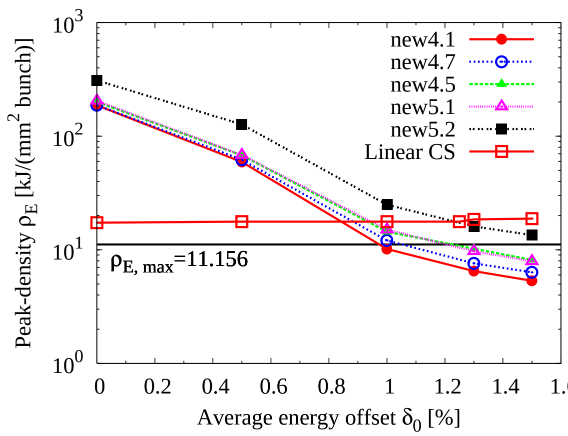

Figure 4: Peak density at the spoiler with an integrated skew sextupole strength of $K_s = 20.8\ \mathrm{m}^{-2}$ for the different optics solutions.

In order to study the luminosity performance of the different optics solutions for nonlinear collimation, we tracked a *uniform flat momentum distribution* of 40000 particles with 1% full width energy spread from the entrance of the collimation system to the interaction point. The synchrotron radiation effect has been considered in these simulations. The luminosity has been computed by the beam-beam interaction code `GUINEA-PIG` [12]. This program performs detailed simulations of the beam-beam interactions at the IP, including the hourglass effect, the pinch effect, beamstrahlung and e^+e^- production. In Fig. 5 we present the simulated luminosity and the peak density at the spoiler as a function of the skew sextupole strength for the optics solution of Fig. 3. For comparison, the luminosity for the linear baseline CLIC collimation system is also included. The luminosity drops with the excitation of the skew sextupoles. High chromatic aberrations of second, third and fourth order are responsible. A local cancellation of higher order aberrations was made using two additional thin multipoles (skew octupole and normal sextupole) using a `Python` based code [13]. The luminosity is improved by more than a factor of two.

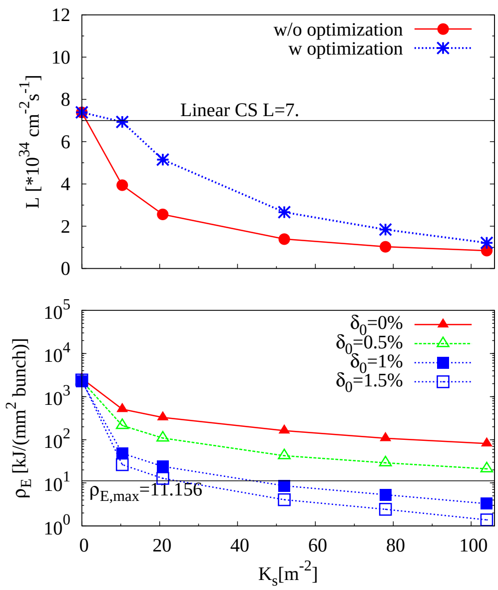

Figure 5: Luminosity and Peak density at the spoiler as function of integrated skew sextupole strength for optics solution of Fig.3.

NON LINEAR BETATRON COLLIMATION SYSTEM FOR LHC AT 14 TeV

Optics Design

For LHC at 14 TeV a minimum beam size $\sigma_{r,\min}$ of about 200 μm is required for spoiler survival in case of beam impact. This condition constrains the minimum values of K_s, R_{12} and R_{34} permitted in Eqs. (29), (30) and (31). Different optics solutions for the betatronic cleaning insertion IR7 of LHC optics version 6.5 have been matched to fulfill the above nonlinear collimation requirements. The matching was done without affecting the optics of the other LHC insertions, and involved only existing quadrupole magnets. To elucidate which of the different optics solutions is best suited for our application, we can choose a number of criteria: (1) minimize the normalized sextupole strength K_s and (2) minimize the nonlinear aberrations introduced by the first skew sextupole, which scale as $\beta_{y,\text{sext}}^{3/2} K_s$ and as $\beta_{y,\text{sext}} \beta_{x,\text{sext}}^{1/2} K_s$.

Fig. 6 shows an optics solution with $\beta_{x,\text{sext}} = \beta_{y,\text{sext}} = 200.0$ m, skew sextupole aperture a_s= 10 mm and skew sextupole strength K_s= 7.0063 m^{-2} for a normalized transverse collimation depth of $n_x = n_y = 6$. Particles at transverse amplitudes $|x| \geq n_x \sigma_x$ and $|y| \geq n_y \sigma_y$ will be caught by a single vertical spoiler of half gap $n_{y2} = 8$, i.e., a physical aperture $2\sigma_y$ higher than that of the primary collimators of the linear collimation system [14]. Assuming $\beta_{x,\text{sext}} = \beta_{y,\text{sext}}$ and $R_{12} \simeq R_{34}$, the horizontal collimator aperture for cleaning in the orthogonal plane is $n_{x2} = 2n_{y2} = 16$.

Tracking and Collimation Efficiency studies

Tracking studies of beam halos with an initial distribution of 5×10^6 macroparticles for 200 turns have been performed by using a modified version of the tracking code `SixTrack` [14]. This tool allows us to calculate the cleaning inefficiency of the collimation system and to save the particles trajectories for an offline analysis of beam losses. The detailed study for the nonlinear collimation system of Fig. 6 in comparison with the linear system is found in [15]. The simulated cleaning efficiency is comparable to that of the linear system [15].

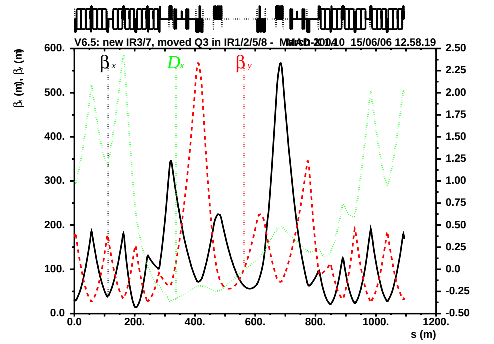

Figure 6: Optics solution proposed for LHC IR7 with a nonlinear collimation section based on two skew sextupoles and a single spoiler.

SUMMARY AND OUTLOOK

A nonlinear collimation system using two skew sextupoles and a single spoiler for the case of linear and circular colliders appears to be competitive with the corresponding linear systems. Compared with the linear system, the transverse energy density is reduced at the spoilers, or primary collimators, thus increasing the probability of spoiler survival in case of miskicked beam impact. For circular colliders the non linear collimation system allows larger aperture for the mechanical jaws, thereby, reducing the collimator impedance.

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