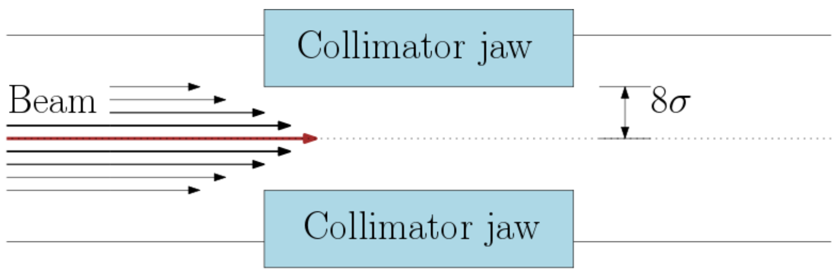
Transverse Beam Dynamics

JUAS 2018 - Exam

1 Exercise: LHC momentum cleaning [3pt]

Particles with large deviations from the nominal momentum impose an important hazard to any accelerator, especially if superconductive. Even the loss of a small fraction of the beam, in a cold region, can induce a magnet quench. In the LHC, in order to intercept losses, movable collimator jaws are installed in the so called "momentum cleaning" section. The collimator jaws are located in a high-dispersion region in order to intercept particles with large energy deviations. Assume that:

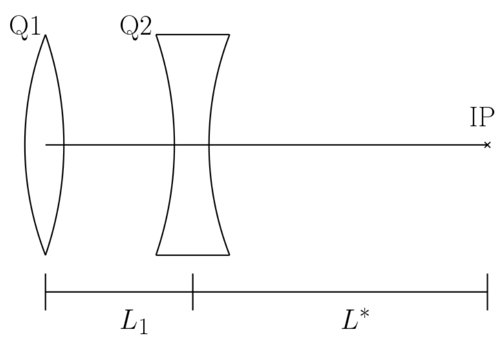
- the collimator's cut is at 8σ (where σ is the half-width beam size for on-momentum particles),
- at the collimator location $\beta_x = 200$ m and $D_x = -2$ m, and
- the beam has a normalised emittance of $\epsilon_{nx} = 3.5\,\mu$m.



1. Compute the maximum momentum deviation allowed by this collimator configuration at injection energy ($E_b = 450\,$GeV). [1.5pt]
2. Perform the same calculation with the beam at collision energy ($E_b = 7\,$TeV). [1pt]
3. In the real machine, do you think the collimator aperture is kept at the same gap at injection and collision energies? Why? [0.5pt]

2 Exercise: CLIC Final Focus System [8pt]

The CLIC Final Focus System focalises 3 TeV electron and positron beams at the interaction point (IP) to produce high-luminosity collisions. This is achieved by means of a quadrupole doublet. The two quadrupoles forming the doublet, Q1 and Q2 and are separated by a distance L_1 and the distance from the second quadrupole to the IP is L^*. The sketch of the electron beam line is,



1. Compute the transfer matrix between the first quadrupole and the IP using the thin lens approximation. [2.5pt]

2. At the IP, which is a dispersion-free point, the β-functions have a minimum, with $\beta_x^* = 7.0$ mm $\beta_y^* = 0.07$ mm. The integrated quadrupole strengths are $(k_1 l)_{\mathrm{Q1}} = 0.14\ \mathrm{m}^{-1}$ and $(k_1 l)_{\mathrm{Q2}} = -0.32\ \mathrm{m}^{-1}$, and the drift lengths are $L_1 = 2.0$ m and $L^* = 6.0$ m. Compute β_x and β_y at the entrance of Q1. [2.5pt]

3. In a linear collider the Final Doublet is the main source of chromaticity. Compute the natural vertical chromaticity ξ_y of the doublet. [2pt]

4. What is the effect of chromaticity at the IP? [1pt]

3 Exercise: FOFO lattice [8pt]

The on-going R&D effort to create accelerators driven by wafefields in plasmas, foresees the use of plasma cells not just to accelerate the beam but also to focus it. In contrast to standard quadrupole magnets, which focus in one direction and defocus in the other, a "plasma quadrupole" focuses simultaneously in both transverse axes, x and y. Imagine, then, to design a FOFO cell using two focusing quadrupoles, each with focal length $f = 50$ cm, and a total cell length of $L = 1$ m (the two quadrupoles are then at distance $L/2$ from each other).

1. Sketch the FOFO cell and draw the beta function. In between two quadrupoles, what functional form does the β-function follow? [1pt]

2. Compute the transfer matrix of the FOFO cell [3pt]

3. Compute: the phase advance, β_{max}, and β_{min} of the FOFO cell [2.5pt]

4. Compute the chromaticity of the FOFO cell [1pt]

5. Would this cell provide a stable lattice? [0.5pt]

4 Exercise: Orbit control [5pt]

Two kickers are located at the two ends of a FODO cell with phase advance 90 degrees and length $L_{\mathrm{cell}} = 1$ m (the two kickers are therefore located at L_{cell} distance from each other). The two kickers have strengths K_1 and K_2 respectively.

1. Write the transfer matrix of the FODO cell [Hint. Write the transfer matrix in Twiss form, in such a way that the initial α parameter is zero.] [1pt]

2. Write the full transfer matrix, inclusive of the two kickers. [Hint. Each kicker acts on the beam as a thin dipole.] [2pt]

3. Compute the strengths of the kickers (in radians), in order to give the beam, initially at (x_i, x_i'), an offset $\left(x_f, x_f'\right) = (50\ \mathrm{cm}, 0)$ at the end of the system. Give the expression of K_1 and K_2 as a function of (x_i, x_i') [2pt]