Impact of the B6 and B10 field imperfections in the triplets at injection for the HL-LHC upgrade.

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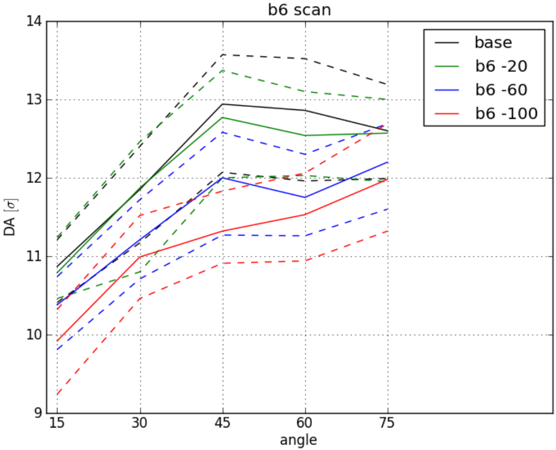
Content and motivation

New triplets for the HL-LHC upgrade may features large B6 and B10 errors at injection due to persistent current generated by the large filament size of the Nb_3Sn cable.

In addition, the injection optics for the HL-LHC may be decreased to 5.5m. Increase the doubling the beta functions in the triplets.

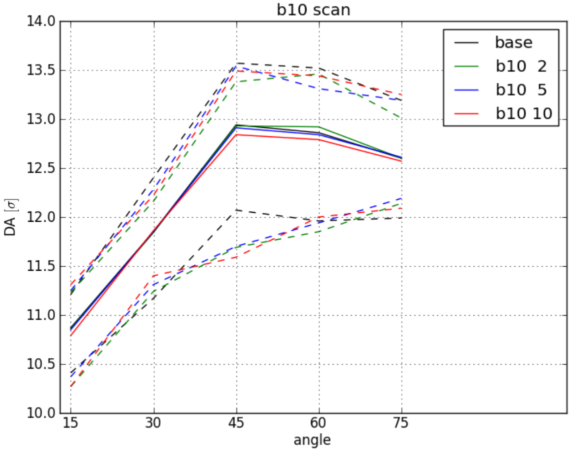
It is therefore useful to investigate the effect on the particle dynamics and whether these imperfections can be easily corrected or not.

DA scan



Scanning systematic b6 (from -20 to -100 units) assuming 20% for the random part.

DA scan



Scanning systematic b10 (from 2 to 10 units) assuming 20% for the random part.

Correction strategy

The triplet error correction follows the strategy envisaged for the LHC [1] with additional corrector magnets for a6, b5, a5.
For each multipole error, some resonance driving terms are cancelled and the rest minimized. For b6 the choice was to cancel (6,0) and (0,6) and minimize (4,2) and (2,4).
The effects of the feed-down is not taken into account.

[1] S. Fartoukh et al. , LHC Project Report 429

Detuning [2]

$$H = H_0 + \Re\left[(b_n + i a_n)\delta(s)\frac{(x+iy)^n}{n}\right]$$

$$\mathcal{H}(J_x, J_y) = < H(x = \sqrt{2J_x\beta_x}\cos(\phi_x), y = \sqrt{2J_y\beta_x}\cos(\phi_y) >_{\phi_x,\phi_y}$$

$$Q_x \simeq \frac{\partial\mathcal{H}}{\partial J_x} \qquad Q_y \simeq \frac{\partial\mathcal{H}}{\partial J_y}$$

$$\Delta Q_x = \frac{1}{4\pi}b_2\beta_x \qquad \Delta Q_y = -\frac{1}{4\pi}b_2\beta_y$$

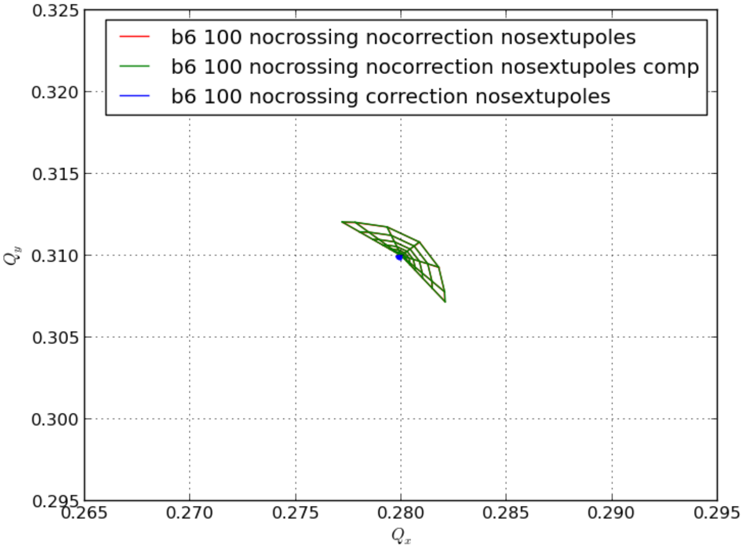
$$\Delta Q_x = \frac{3}{8\pi}b_4\beta_x\left(\beta_x J_x - 2\beta_y J_y\right) \qquad \Delta Q_y = \frac{3}{8\pi}b_4\beta_y\left(-2\beta_x J_x + \beta_y J_y\right)$$

$$\Delta Q_x = \frac{5}{8\pi}b_6\beta_x\left(\beta_x^2 J_x^2 - 6\beta_x\beta_y J_x J_y + 3\beta_y^2 J_y^2\right)$$

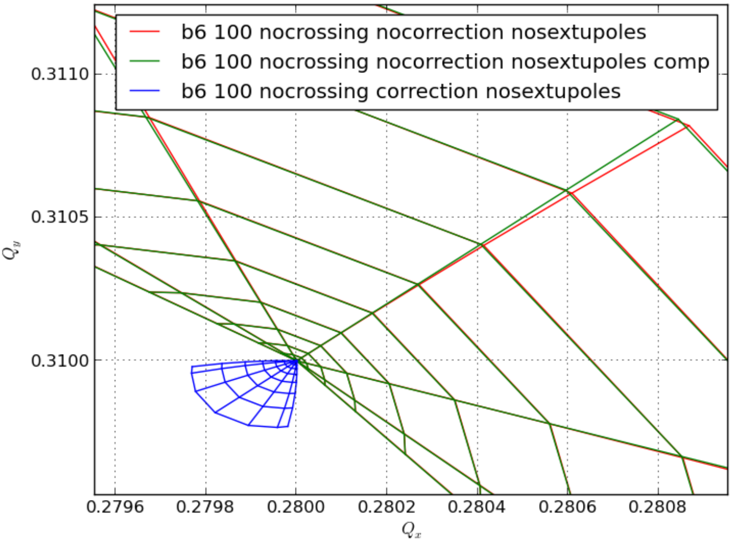
$$\Delta Q_y = -\frac{5}{8\pi}b_6\beta_y\left(3\beta_x^2 J_x^2 - 6\beta_x\beta_y J_x J_y + \beta_y^2 J_y^2\right)$$

[2] $b_{n+1} = \texttt{knl}/n! = \frac{eB_{n+1}}{pR_x^n}$, $a_{n+1} = \texttt{ksnl}/n! = \frac{eA_{n+1}}{pR_x^n}$

Footprint (12σ) without crossing angle



Footprint (12σ) without crossing angle



Feeddown effects

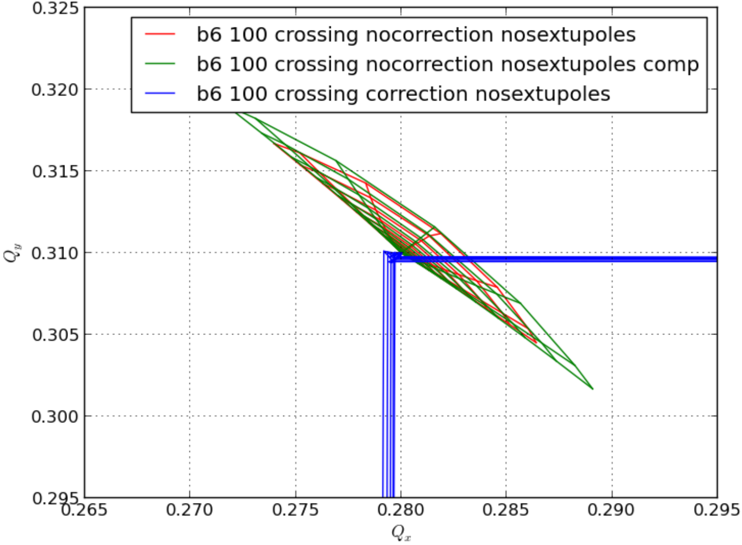
In case of closed orbit in non linear elements, feeddown effects apply:

$$\tilde{b}_n + i\tilde{a}_n = \sum_{k=n}^{N} \binom{k}{n} (b_k + ia_k)(x + iy)^{k-n}$$

In particular:

$$\tilde{b}_4 = b_4 + 15b_6x^2 - 15b_6y^2$$

Footprint (12σ) with crossing angle



Footprint (12σ) with crossing angle