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Correction Schemes for the Interaction Region

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On behalf of the JAI FCC Team

Thanks to R. Tomas, R. Martin and E. Maclean

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A key to New Physics

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Correction Schemes in the IR

This work contemplates two different studies of errors and correctors schemes within the IR

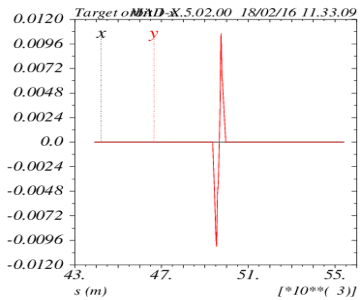
- **First Study:**
  Errors considered: Misalignments in the magnets in the IR
  Motivation: If not compensated for can jeopardize the performance of the machine.
  Study: Consider alignment and field errors in the IR to estimate the tolerance necessary to provide a good correction.

- **Second Study**
  Errors considered: Field errors on the triplet
  Motivation: Low Dynamic aperture observed with inclusion of these errors and crossing angles on.
  Study: Implement non linear correctors into the lattice to minimize the resonance driving terms arising from the non linear errors of the triplet. Dynamic aperture studies are then performed to study the impact of this correction.

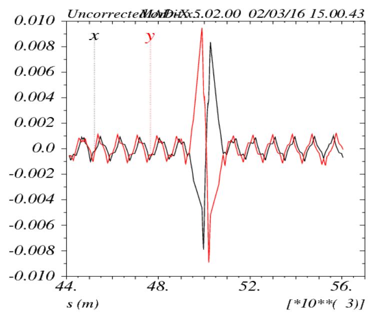
Alignment Errors and linear correctors

- The objective of the correction scheme in the IR is to correct the orbit due to possible misalignments of the quadrupoles in the triplet and the separation dipoles.

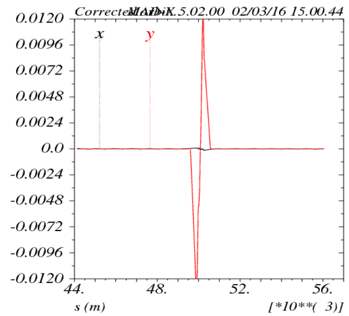
No errors



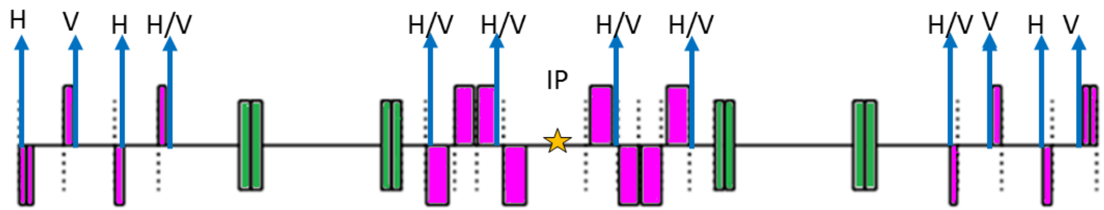
Misalignment errors



Correction



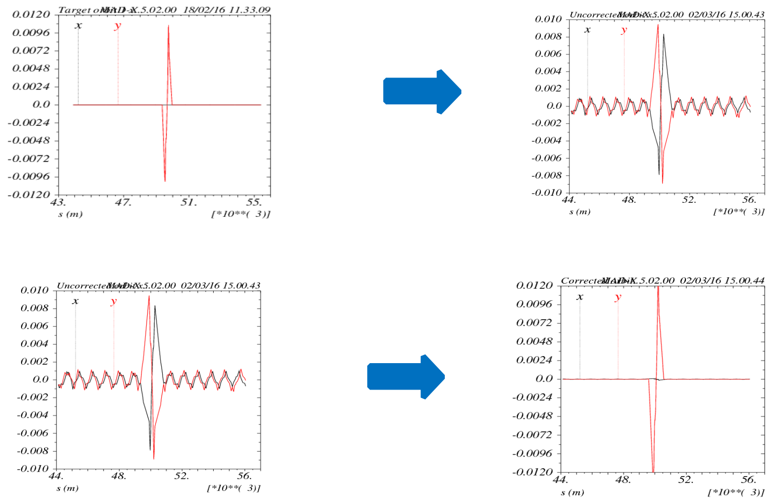
- The corrector scheme in the IR contemplates the following components
  - **Horizontal and vertical correctors** next to the final focus triplet (Q1, Q2, Q3) and the fourth quadrupole (Q4). Also used for crossing angle.
  - **Interleaved horizontal and vertical correctors** next to the quadrupoles in the matching section (Q4th-Q7th quadrupoles, except Q4 consider before) and the dispersion suppressor (8th-13th quadrupole).
  - **Beam Position Monitors** (BPMs) installed along the IR.



Method

1. Assign random errors. Gaussian errors 3σ.

2. Use CORRECT method in MADX.

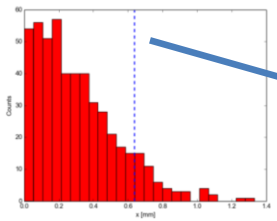


3. Results are analyzed in terms of:
   - **Maximum deviation** with respect to the original orbit (how good is the correction)
   - **Strengths** of the correctors (is the correction achievable)

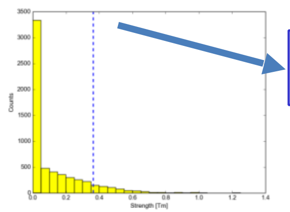
4. Repeat for 100 seeds

5. Calculate value of the maximum orbit deviation and correctors strengths for which 90% of the seeds are included (90-percentile, x_{90})

D. Boutin
Correction arcs



x_{90}

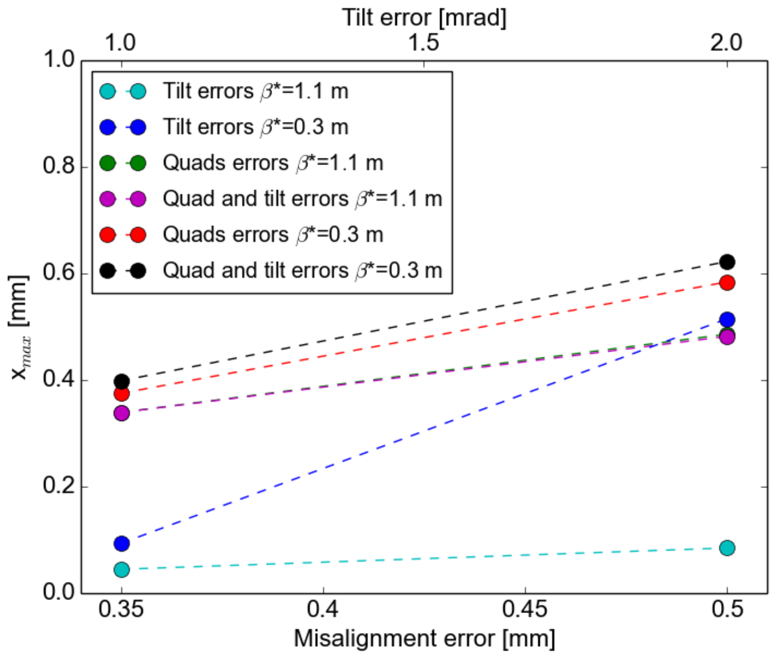


Strength

6. Repeat for different optics (β*=30 cm, 110 cm) and different values for the errors.

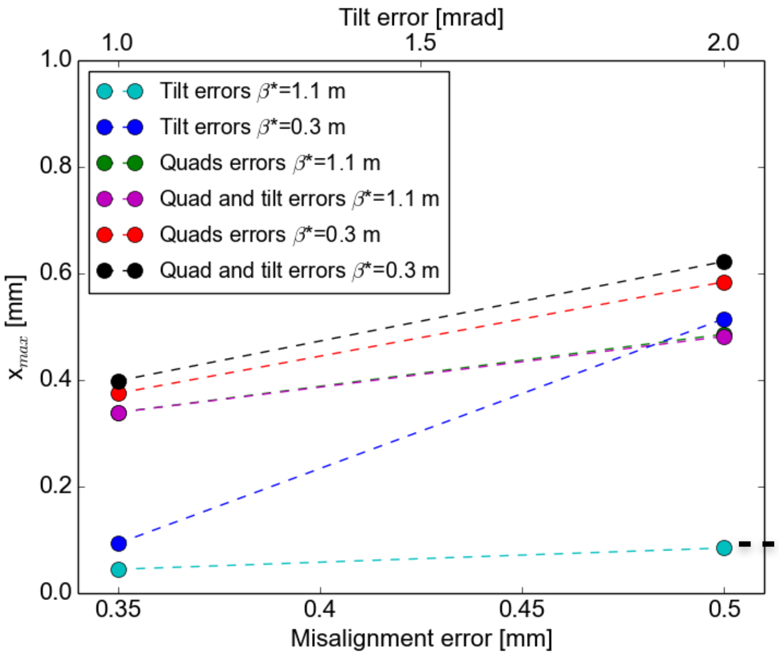
Results - Maximum Deviation

- Studies of the maximum orbital deviation (90-percentile) after the correction in the non-crossing orbit with misalignment errors in the quadrupoles in the triplet and the matching section and tilt errors in the separation dipoles.



Results - Maximum Deviation

- Studies of the maximum orbital deviation (90-percentile) after the correction in the non-crossing orbit with misalignment errors in the quadrupoles in the triplet and the matching section and tilt errors in the separation dipoles.



- Tilt errors are corrected very well. Quad +tilt errors almost the same as quad errors only.

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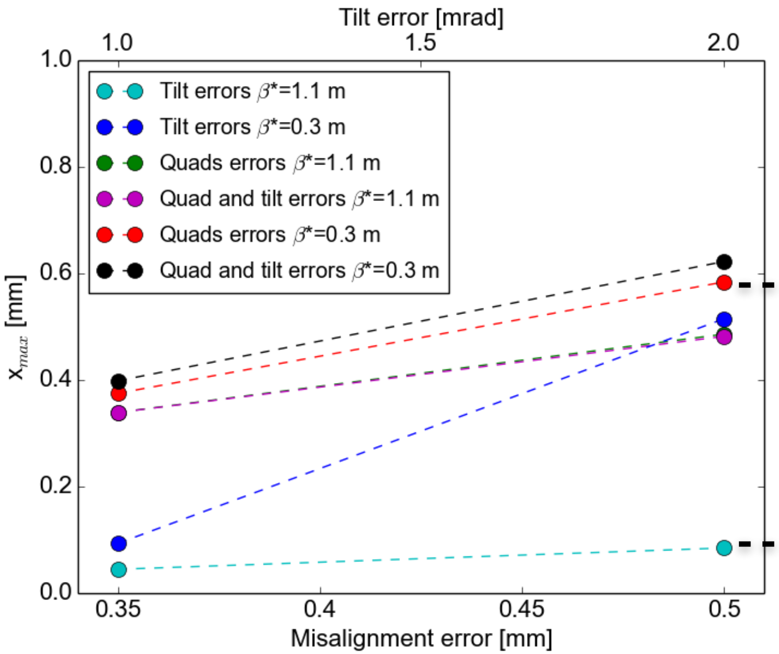

- Most challenging cases with β*=0.3 m and quad errors
- Tilt errors are corrected very well. Quad +tilt errors almost the same as quad errors only.

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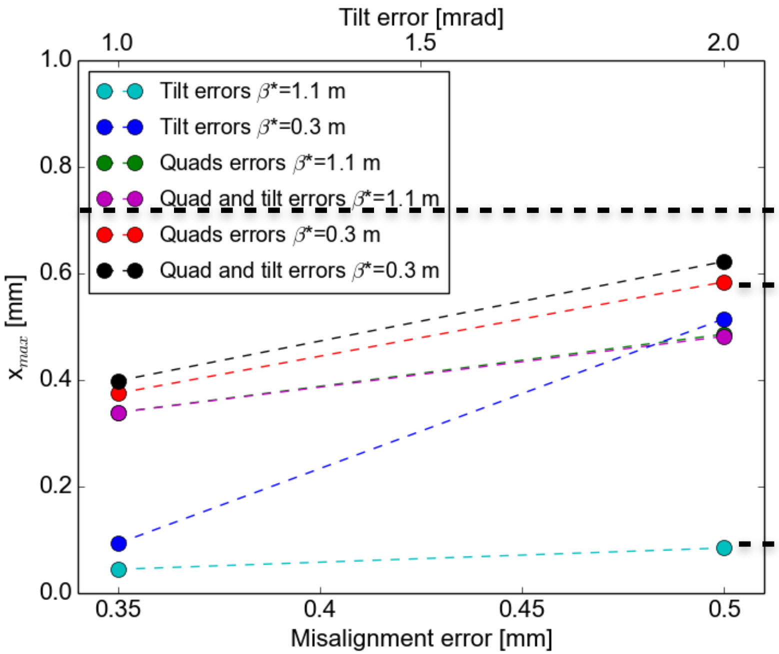

- All cases below 0.7 mm.
- Most challenging cases with β*=0.3 m and quad errors
- Tilt errors are corrected very well. Quad +tilt errors almost the same as quad errors only.

Results - Corrector Strengths

- Studies of the corrector strength (90-percentile) needed for correction with misalignment errors in the quadrupoles in the triplet and the matching section and tilt errors in the separation dipoles.

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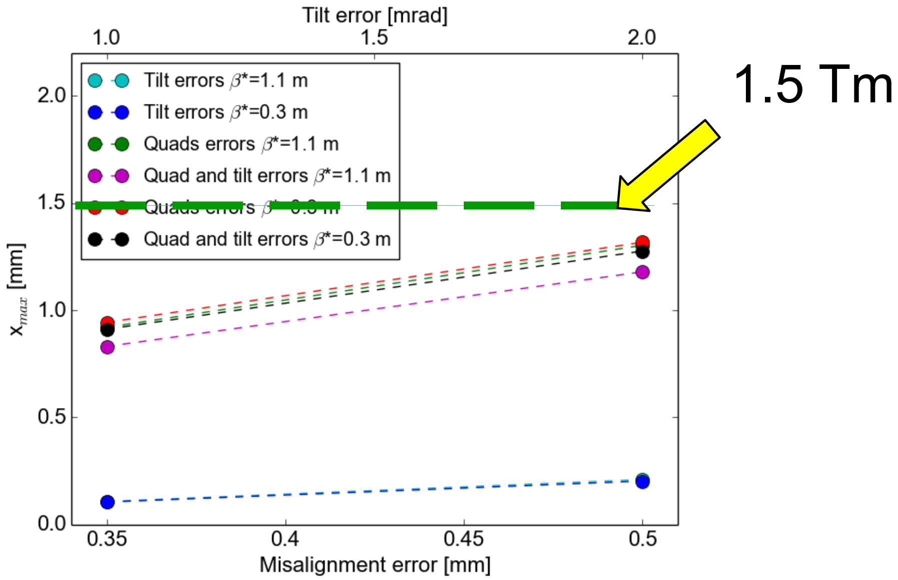
Non-crossing orbit



- The strengths required to correct the non-crossing orbit are all below 1.5 Tm.

- Strength required increases linearly with error and is higher for the optics with β*=30 cm.

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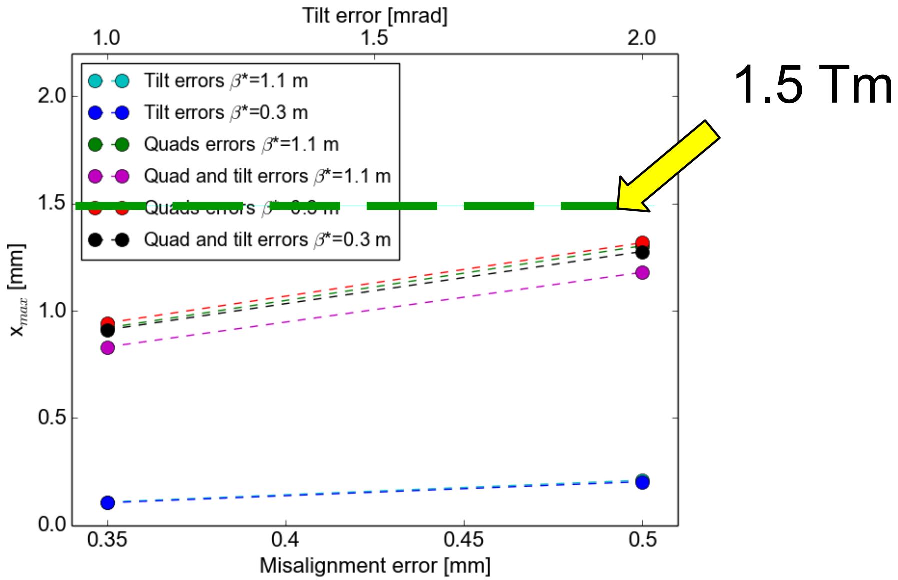
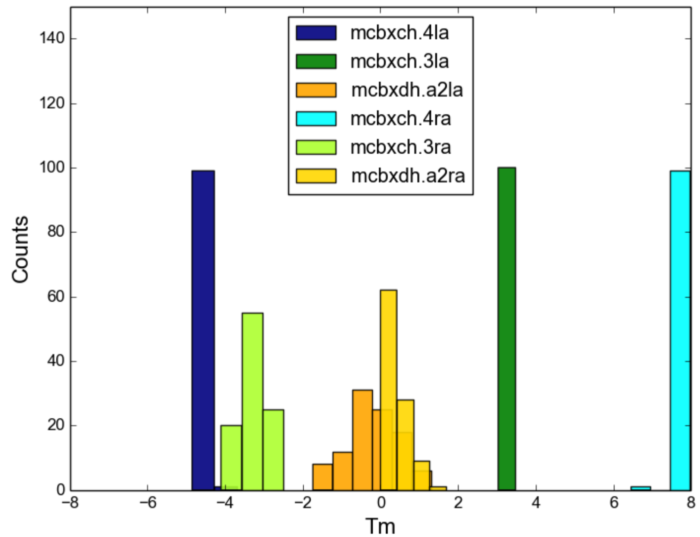


Crossing orbit



- The strengths required to correct the non-crossing orbit are all below 1.5 Tm.
- Strength required increases linearly with error and is higher for the optics with β*=30 cm.
- Higher strength in 4th corrector (MCBXCH.4la and MCBXCH.4ra). This corrector has already a length of 3 m.

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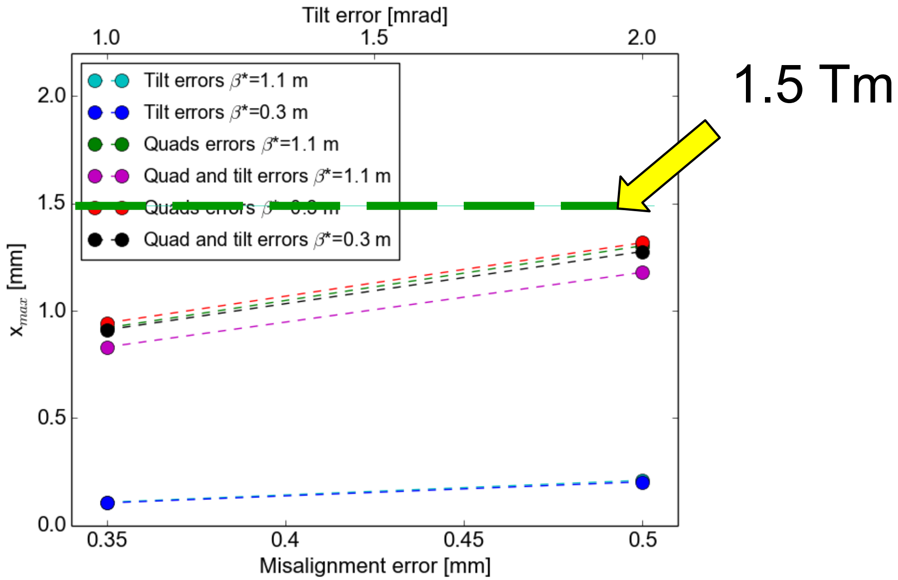
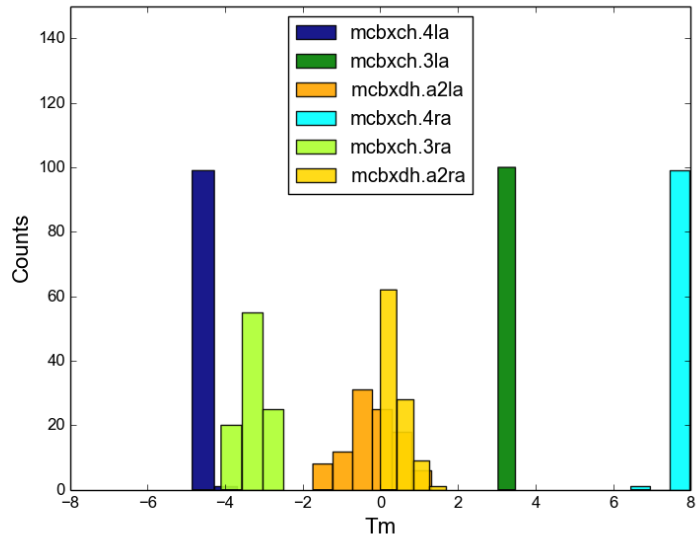
Non-crossing orbit



Crossing orbit



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More on Alignments studies: D. Boutin's talk

Dynamic Aperture Studies

Different Dynamic Aperture Studies have been performed for the FCC-hh lattice:

- Studies with errors and correctors in the arcs (B. Dalena)
- At collision energy with no errors, DA= 30-85σ (R. Martin)
- At collision energy with errors on the triplet but crossing angles off, DA=20σ (R. Martin)

- Studies with errors and crossing angles on resulted in a DA of 0σ

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↓

Motivation: Address 0 DA and find methods to increase it

Dynamic Aperture Studies

➢ DA studies were performed in SixTrack :

- Collision energy
- Crossing angles on
- **Field Errors** on the triplet (Model HL-LHC adjusted new aperture)

$$B_y + iB_x = B_{\text{ref}} \sum_{n=1}^{N} (b_n + ia_n) \left(\frac{x + iy}{R_{\text{ref}}} \right)^{(n-1)}$$

$$b_n = b_{nS} + \frac{\xi_U}{1.5} b_{nU} + \xi_R b_{nR},$$

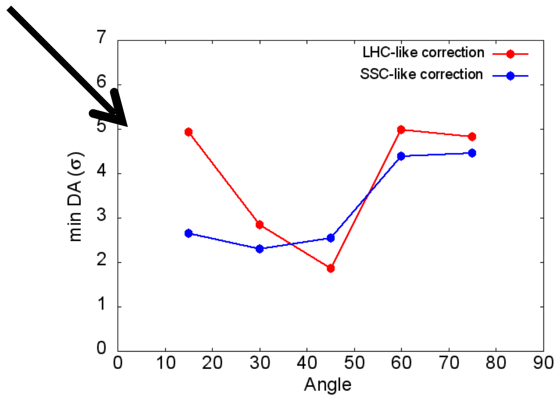
➢ And the following corrections:

- Chromatic and tune correction
- Spurious dispersion correction (LHC like and SSC-like, A. Chance)
- Coupling correction (R. Martin)

➢ Some adjustments in the correction scripts resulted in a **positive DA**

➢ The DA is still low (~**2σ**).

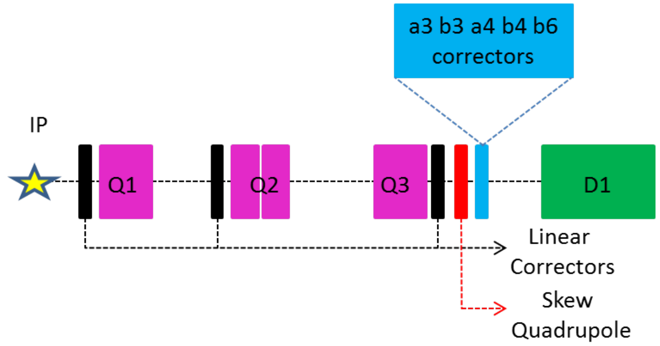
➢ **Motivation:** Find methods to improve the DA



Method

- Add non linear correctors:
  - Normal and skew
  - Left and right of the IR.

- Current location is set next to MQX3



- Make python routine that calculate strengths for each corrector to minimize corresponding RDTs.

$$c(b_n; p, q) = \int_{IR_{\text{left}}} ds K_{n-1}(s) \beta_x^{p/2} \beta_y^{q/2} + (-1)^n \int_{IR_{\text{right}}} dx K_{n-1}(s) \beta_x^{p/2} \beta_y^{q/2},$$

$$c(a_n; p, q) = \int_{IR_{\text{left}}} ds K_{n-1}^s(s) \beta_x^{p/2} \beta_y^{q/2} + (-1)^n \int_{IR_{\text{right}}} dx K_{n-1}^s(s) \beta_x^{p/2} \beta_y^{q/2},$$

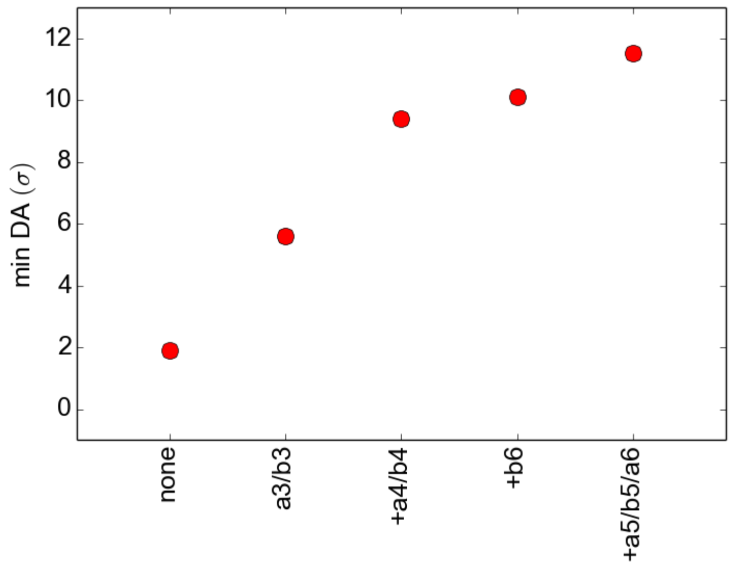
- Include this routine to the tracking mask file calculating the correctors strengths for each of the 60 seeds followed by other corrections (coupling correction, crossing, chrom and tune,…)

- Calculate DA for:
  - On/off momentum studies
  - Different correctors (b3/a3/b4/a4…)
  - Different locations of correctors.

Results

Dynamic Aperture studies were repeated with the implementation of non-linear correctors, giving the results:

- DA=5.6σ with b3 and a3 correctors
- DA=9.4σ with b3, a3, b4 and a4 correctors
- DA=10.1σ with b3, a3, b4, a4 and b6 correctors
- DA=11.7σ with b3, a3, b4, a4, b5, a5, b6, a6 correctors.



All these cases were done with LHC-like spurious dispersion correction. The SSC-like with non-linear correctors is currently under study.

Conclusions

- Correction Schemes have been implemented to compensate for possible errors on the interaction region.

1st Study

- **Alignment errors and linear corrections** gives good results with a maximum deviation of 0.7 mm with respect to the original orbit and correctors strengths below 1.5 Tm for the non-crossing orbit. Crossing orbit requires larger strengths compensated with length.

- Integration with arcs is being followed (D. Boutin)

2nd Study

- Field errors with crossing angles have a big impact on DA. A **positive DA** was obtained without non-linear correctors but is still low (~2σ).

- Encouraging results were obtained by implementing non-linear correctors to minimize resonance driving terms of the non-linear errors on the triplet, **increasing the DA up to 11.7σ.**

- This method relies on knowing the magnetic model of the magnets. Based on the experience on the LHC, magnetic measurements during construction do not always provide a good description of the real machine, and therefore must be complemented by beam-based studies -> Follow LHC studies to study its reliability.

Thanks!