Status of DA with expected field quality

M. Giovannozzi, T. Pugnat[1], F. Van der Veken[1], CERN, Geneva, Switzerland

[1] Also University of Malta, Msida, Malta

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Outline

- Introduction
- Main results about DA for V1.4
- Summary and outlook

We greatly acknowledge all BOINC volunteers who supported LHC@Home project, giving for free their CPU time and allowing these results to be produced

Introduction

- Dynamic Aperture (DA) is the observable that provides a figure of merit for the nonlinear beam dynamics.
- Its computation involves intense numerical simulations and tools to postprocess the numerical results.
- The target value for its minimum over seeds and angle is 8 σ.
- It is customary to study the impact of the field quality (FQ) of magnet families on DA.
- The first tracking campaign was carried out with V1.0, and we are about to complete the one for V1.4.
- NB: Due to the length of these studies, the version used for these studies usually lags behind the current official optics version.

Introduction

- Several families of magnets have been studied in detail
- The machine configuration is that for nominal collision
- Several aspects have been studied
  - Impact of individual multipoles on DA
  - Impact of individual magnet families on DA
  - Impact of mechanical alignment
- Standard mechanism for error assignment in numerical simulations. However
  - Error routines are for Gaussian-distributed errors, whereas acceptance criteria assume uniform-distributed errors.
  - Gaussian errors are used with $\sigma = \sigma_{uniform} = \frac{Acceptance\ interval}{\sqrt{12}}$

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Main results of FQ studies using V1.0

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Dynamic aperture studies for HL-LHC V1.0

Y. Cai [†], *R. De Maria* [‡], *M. Giovannozzi* [‡], *Y. Nosochkov* [†], *F.F. Van der Veken* [‡,1]
[‡] CERN, CH-1211 Geneva 23, Switzerland
[†] SLAC National Accelerator Laboratory, Menlo Park, CA, USA
[1] Currently, also University of Malta, Msida, Malta

Abstract
Intense efforts have been devoted to the detailed study of the dynamic aperture of the HL-LHC V1.0 optics and layout version, without beam-beam effects, for several configurations, differing by optical properties or properties of the field quality of the new magnets for HL-LHC. In this report, the outcome of these studies is summarised and discussed.

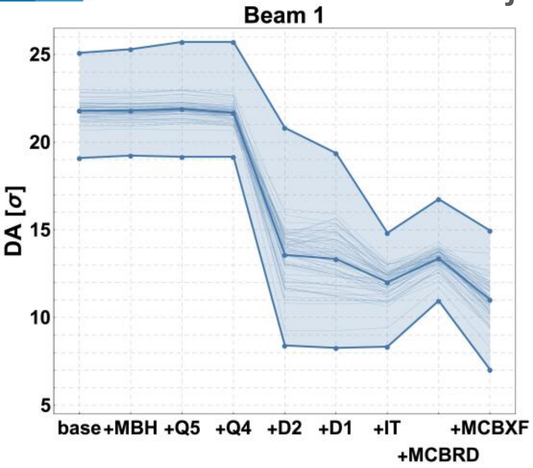
Keywords
HL–LHC, dynamic aperture, field quality

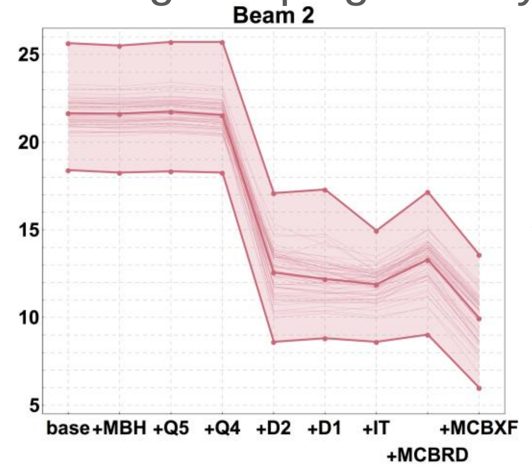
Contents

We are going to summarise the tracking campaign for V1.3 and V1.4 in a similar document

Tracking studies: general case

First results of major tracking campaign for layout V1.4





Collision, round optics
octupoles = 0 A
Q’= 3
Qx = 62.31 Qy = 60.32
xing = 250 μrad

IR magnets are dominating the DA. Strong impact of MCBXF

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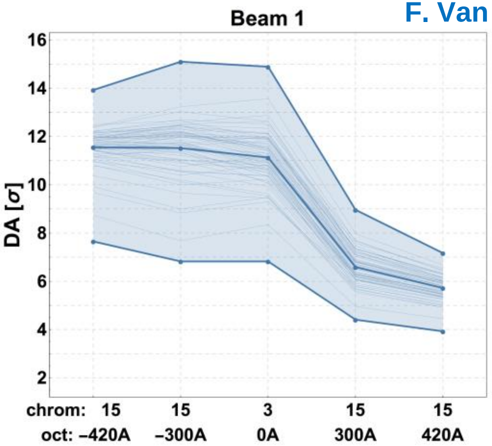

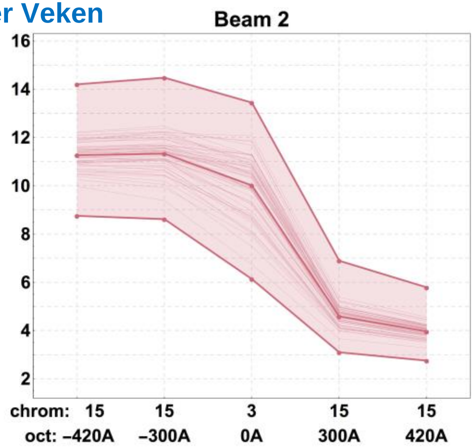

Collision, round optics
Q’= 3 or 15
Qx = 62.31 Qy = 60.32
xing = 250 μrad

Octupoles strongly affect DA

Tracking studies for magnet families

- Intense efforts devoted to the verification of the impact of the field quality on DA (in close collaboration with WP3).
- For the first time, the verification included the impact on beta-beating.
- Magnet families considered
  - MCBXF
  - MCBRD
  - MBRD

Collision V1.4, round optics
octupoles = 0 A
Q'= 3
Qx = 62.31 Qy = 60.32
xing = 250 μrad

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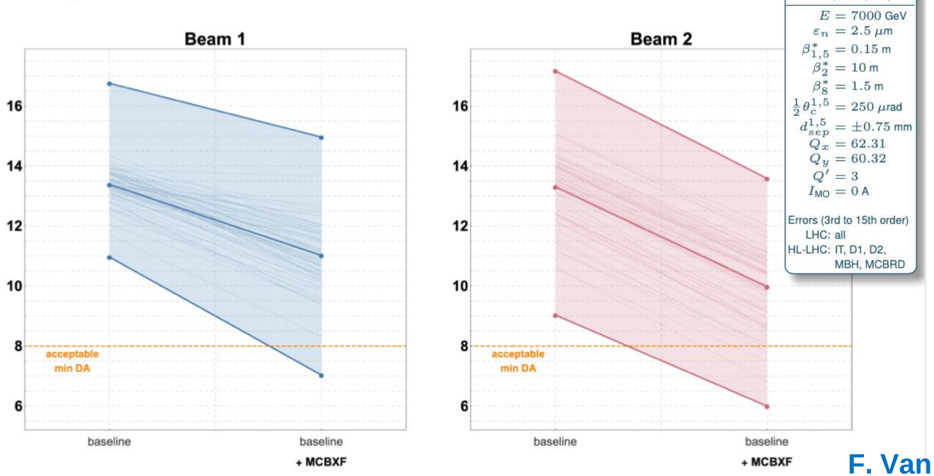
Impact on DA of MCBXF Errors



- Strong impact of MCBXF FQ on DA.
- b3/a3 components of MCBXFA are the culprits.
- The b3 magnet in the CP can correct efficiently the FQ of the MCBXFA.
- Proposal to use the Full Remote Alignment System (FRAS) to cope with the transverse triplet alignment
  - This removes the random component (due to the misalignment) in the strength of the MCBXFs, which reduces the b3/a3 errors.
  - The deterministic component of the FQ of the MCBXF can be corrected using the CP magnets easily.

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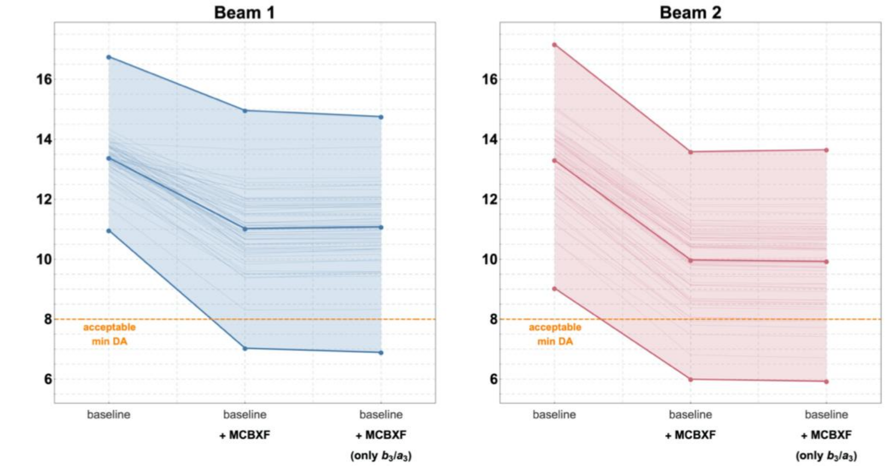
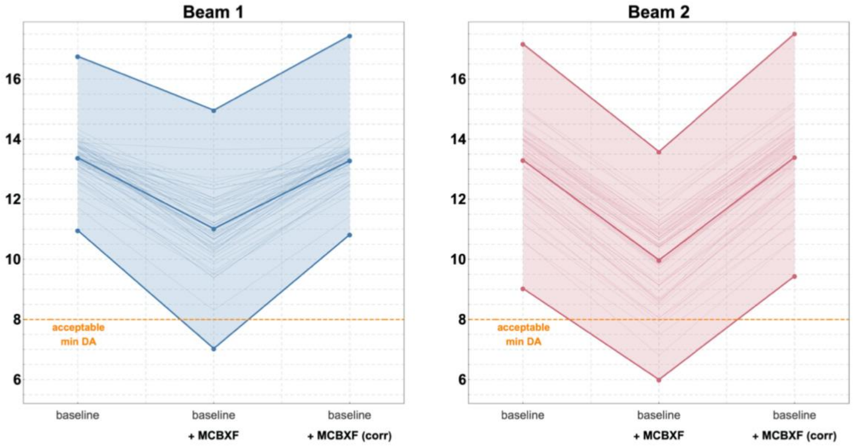
Comparing Multipole Errors



Effectiveness of MCBXF Correction



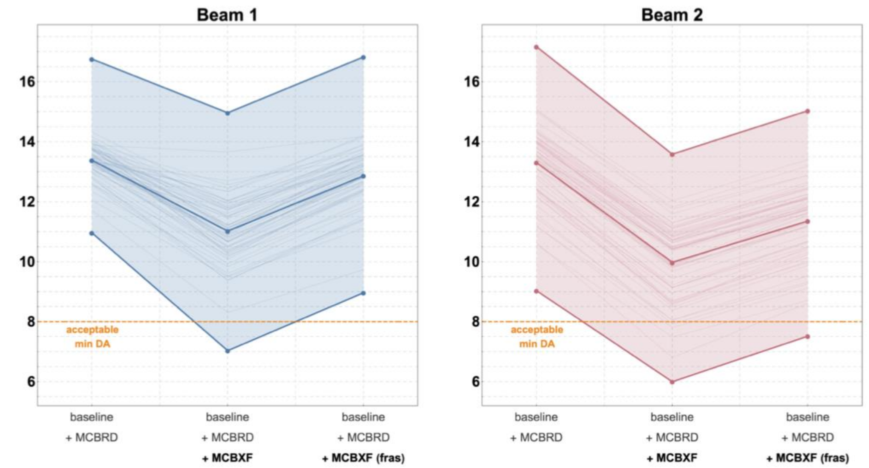
Additional configurations explored for MCBXFs

- The strong impact of b3/a3 on DA is known
- Are increased b5/a5 systematic components also critical for DA?
- b5/a5 systematic varied between -7 and 7 units
- Different strategies for b5/a5 assignment
  - One constant, scan over the other
  - Scan over both (correlated or anticorrelated)
- Concerning b3/a3 two scenarios considered
  - Standard, i.e. without correction
  - With FRAS that reduces the strength of MCBXFs

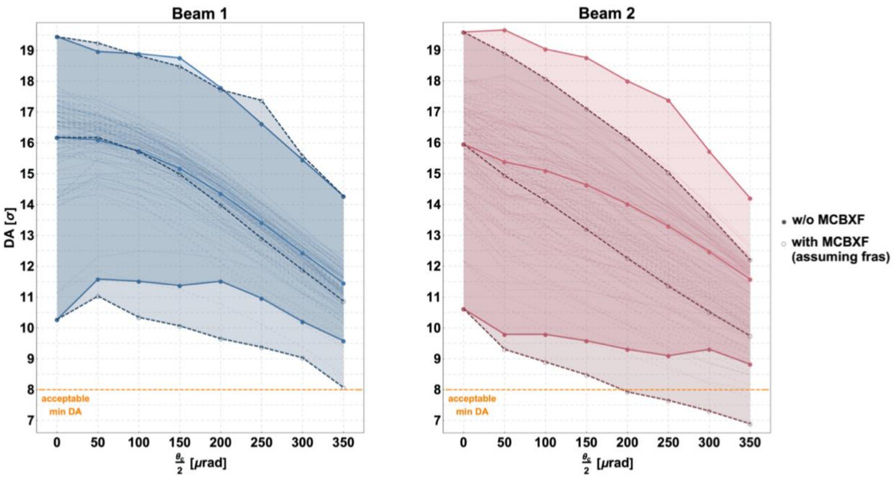
Conclusions

- **No impact observed on DA, no matter how the b5/a5 systematic errors are combined.**
- **The use of FRAS is confirmed to have a positive impact on DA.**

Full Remote Alignment System



Dependence on Crossing Angle



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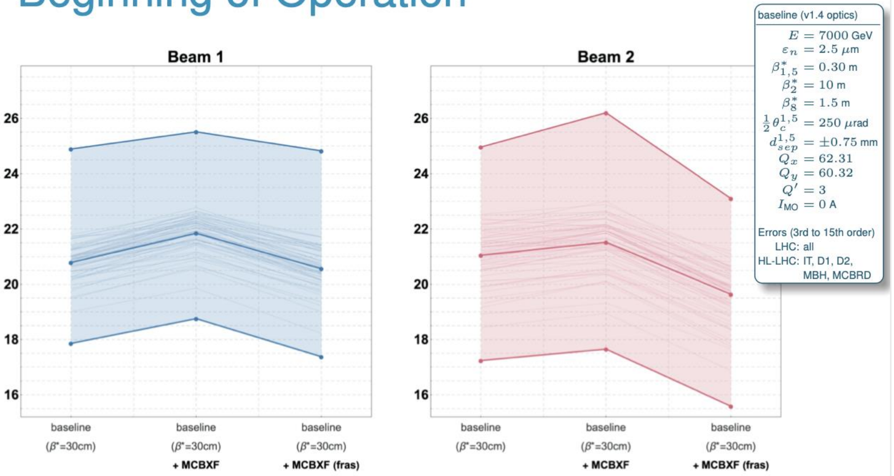
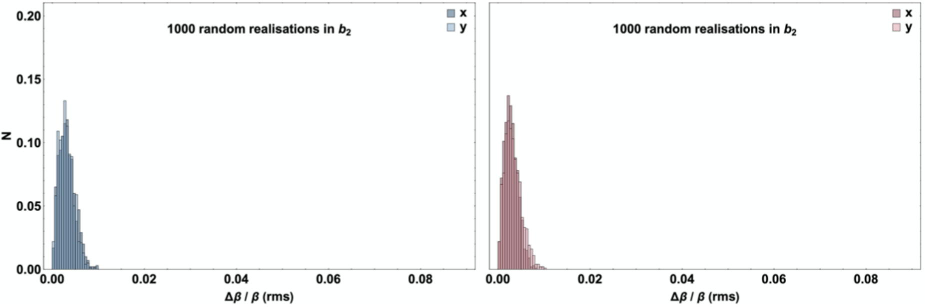
Beginning of Operation

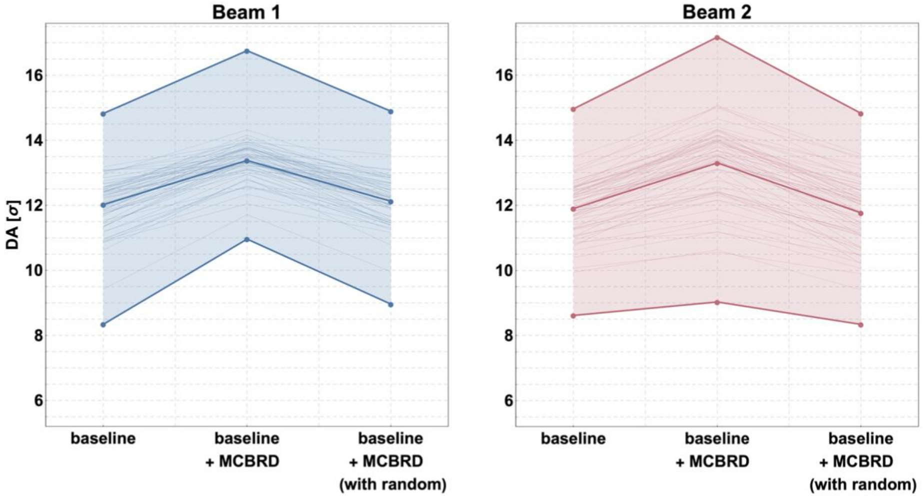


- The use of FRAS is indeed mitigating the impact of the FQ of MCBXF on DA.
- In the initial runs, no need for a correction of the b3/a3 components of MCBXFA using the CP magnets.

Beta-Beating due to MCBRD



DA with Random Error Components of MCBRD



Special runs with 240 seeds: DA_{min} decreases!

DA with Random MCBRD by Order

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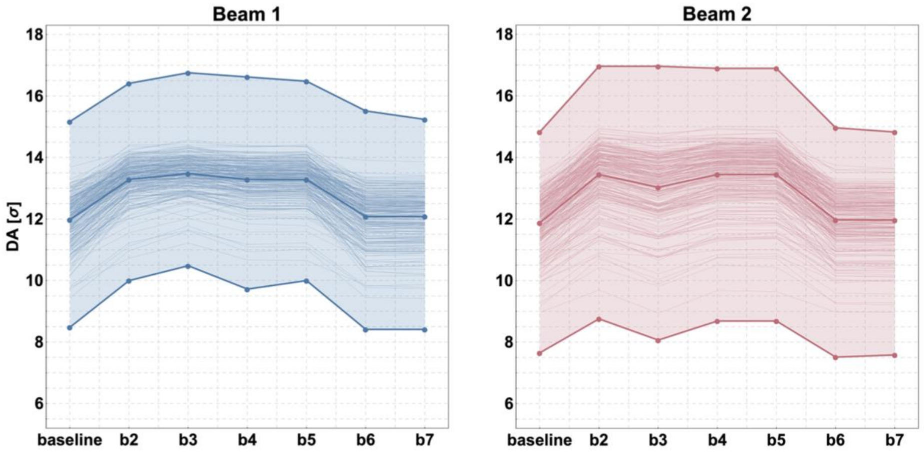
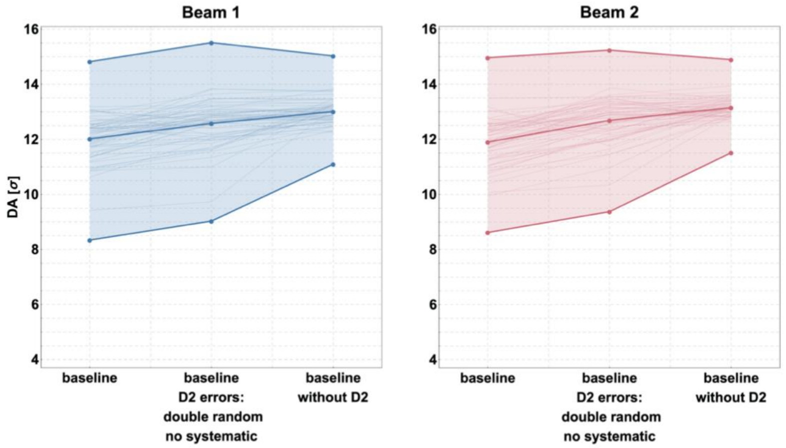
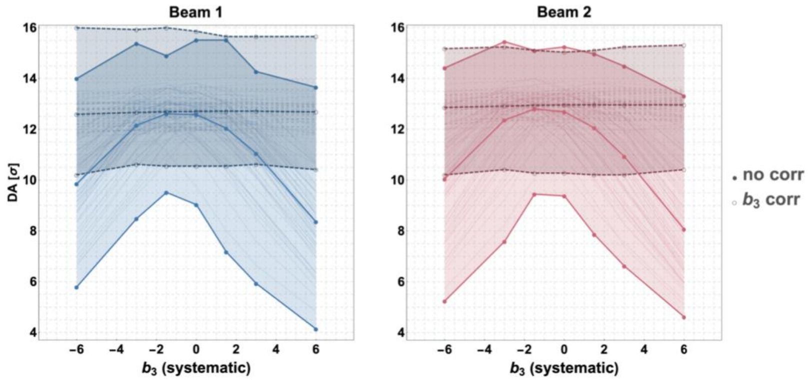


- The beta-beating is perfectly manageable.
- The FQ as from the acceptance tables give a DA within specification (DA_{min} about 8 sigma).

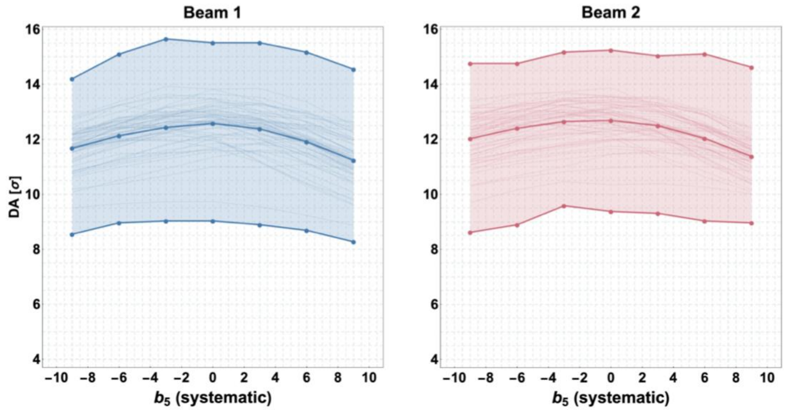
DA



DA from b_3 of D2



DA from b_5 of D2



- The beta-beating is perfectly manageable.
- The FQ as from the acceptance tables give a DA well within specification (DA_{min} about 8 sigma).
- The systematic b3 component has a very strong impact on DA. It can be efficiently corrected by the CP magnet. The corrector strength does not exceed 50% of the budget (including correction of MBXF, MCBXF).
- The systematic b5 component has a very mild impact on the DA.

Correction of D2 field quality with the non-linear correctors

- Intense efforts devoted to the study of correcting the field quality of D2 by using the non-linear correctors:
  - b3: already successfully tested
  - b5: already found problematic. In-depth review **(by J. Dilly):**
    - **Partial compensation between D1 and D2 b5 carefully assessed**
    - **Performance of correction also carefully assessed**

Tracking studies for magnet families

- Magnet families considered
  - Non-linear correctors in the corrector package
- Configurations considered
  - Magnetic errors up to ± 100 units for components from b3/a3 to b7/a7
  - Transfer function error up to $\pm 1\%$
    - Corresponds to ± 100 units for the main component
  - Misalignments up to ± 2 mm and ± 2 mrad

Conclusions

- **No impact on DA** from estimated misalignments, when added individually.
- **No impact on DA** from estimated misalignments when added globally.

Collision V1.4, round optics

octupoles = 0 A
Q'= 3
Qx = 62.31 Qy = 60.32
xing = 250 μrad

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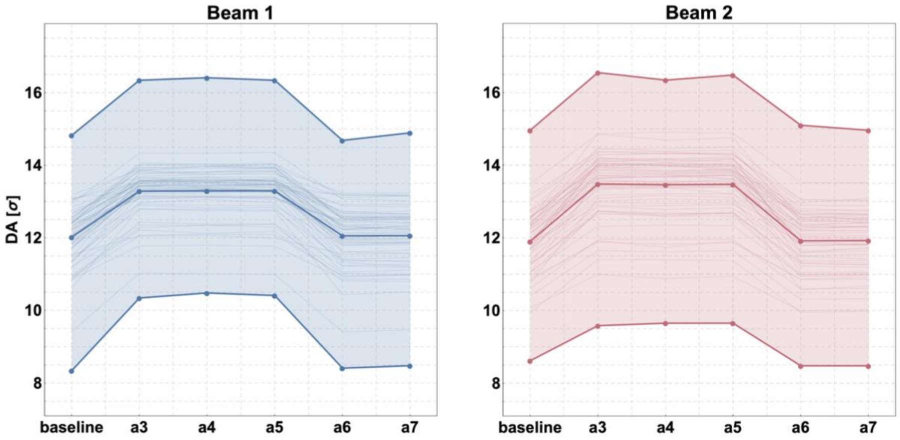
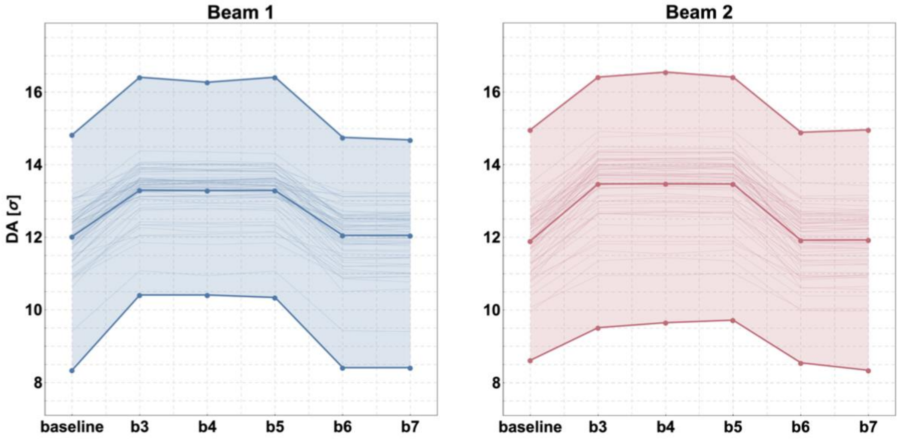
Impact on DA from a_3-a_7



Impact on DA from b_3-b_7



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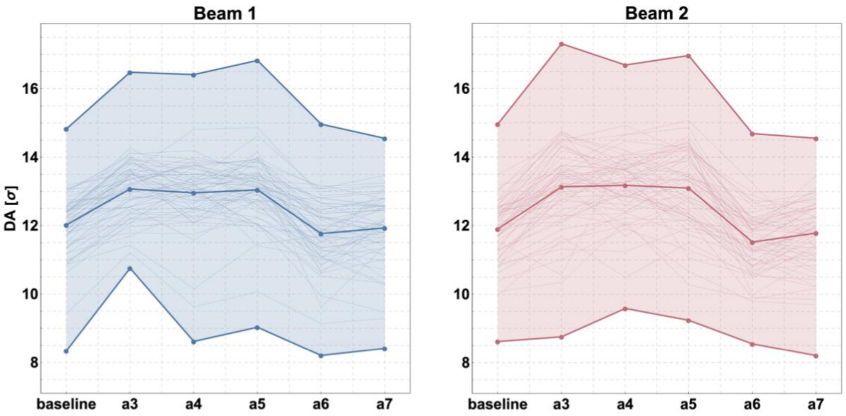
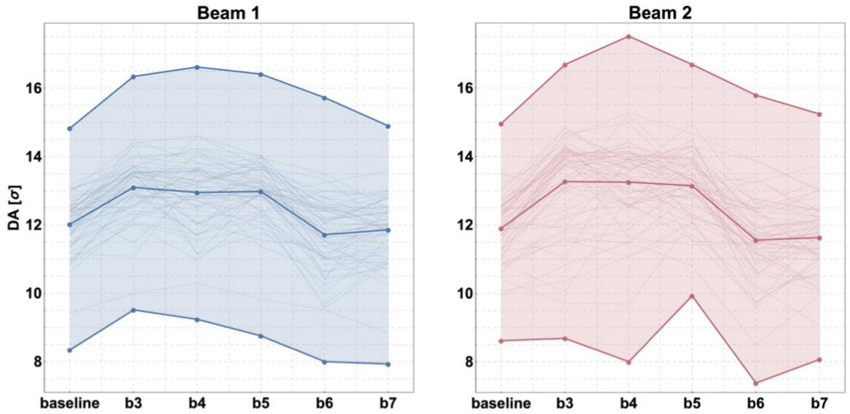
Conclusions

- **No impact on DA** from estimated field quality when magnetic errors are included as individual components.
- **Some "lucky" cancellation** effects observed in low-order multipoles.
- The reference field used is the one needed to correct the field quality of the insertion magnets.
- Tests a pessimistic case in which the reference field is the maximum one (to anticipate for future uses of the correctors.

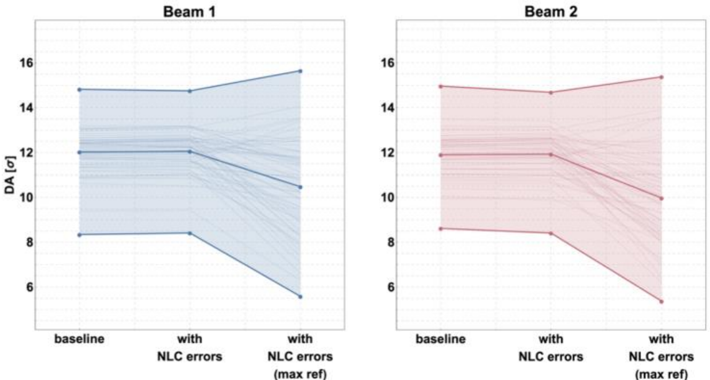
Impact on DA from Magnetic Errors, Maximum Reference



Impact on DA from Magnetic Errors, Maximum Reference



Overview of Impact of Magnetic Errors on DA



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Conclusions

- **No impact on DA** from estimated field quality in terms of a_n.
- **Small impact on DA** from the estimated quality in terms of high-order b_n.
- Including simultaneously all multipole components for all correctors has
  - **No impact on DA** if actual strength is used to normalise the field quality.
  - **Strong impact on DA** if the maximum strength is used to normalise the field quality.

Tracking studies for magnet families

T. Pugnat

- Magnet families considered
  - Skew quadrupole corrector in the corrector package
- Configurations considered
  - Magnetic errors up to ± 100 units for components from b3/a3 to b7/a7
  - Transfer function error up to $\pm 1\%$
    - Corresponds to ± 100 units for the main component
  - a6/b6 systematic between -25 and 0 units
  - a10/b10 systematic between -10 and 0 units

Conclusions

- **Very conservative approach used for assigning the magnetic errors: maximum corrector strength assumed.**
- **No impact of systematic components when added one-by-one and even when added all simultaneously**.

Collision V1.4, round optics

octupoles = 0 A

Q'= 3

Qx = 62.31   Qy = 60.32

xing = 250 μrad

Summary and outlook

- With the current knowledge of the expected FQ, DA seems under control.
- Close collaboration between WP2 and WP3 essential to achieve this goal! For instance:
  - Cross section of D1 and D2 is being reviewed to improve FQ
  - FQ of MCBXF can be controlled by introducing a minor limitation in the magnet strength.
- FRAS is a key mitigation measure for the FQ of the MCBXF, but its use is granted under several conditions.
- Of course, timely follow up of impact on DA of the FQ based on the evolution of the results of magnetic measurements will be a key activity (as usual).

Summary and outlook

- Times are ready to think of magnet sorting! Based on LHC experience, FQ is not the only criterion (aperture and transfer function are other important items) and a hierarchy should be defined between them.
- Tracking activities for V1.4 are being gradually moved to the next optics version.
- To do so
  - **Error routines should be reviewed and adapted (e.g. change of magnets name, orientation, etc.)**
- The intense development of a new tracking code implies the need to develop tools for postprocessing DA data.

Thank you for your attention!