



Research supported by the High Luminosity LHC project

HiLumi LHC

Update on MCBRD Field Quality

F.F. Van der Veken *in collaboration with M. Giovannozzi and R. de Maria*

Outline

- 1 Introduction
- 2 Beta Beating
- 3 Switching Crossing Planes
- 4 Including Cross-Talk
- 5 Monte Carlo over Signs
- 6 Conclusion

Setup

- In total **420** studies, with on average **600** jobs each
>2.5M jobs \Rightarrow submission to BOINC!



*Many thanks to A. Mereghetti for the new scripts,
and to the numerous LHC@Home volunteers*

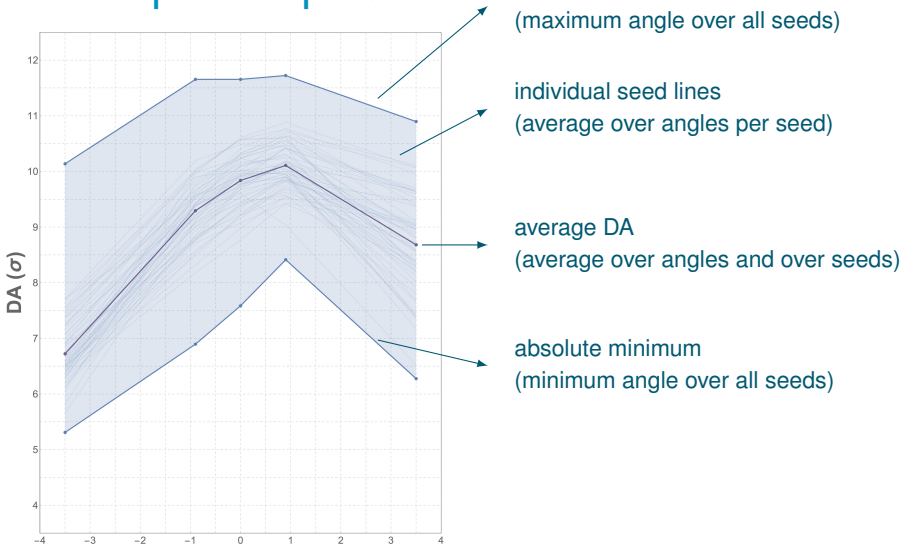
- DA is calculated over 11 angles and 60 seeds
- HLLHC V1.0 optics; to have a well-studied configuration and quick results

$$\beta^* = 0.15/0.15/0.15/0.15\text{m}, Q_x = 62.31, Q_y = 60.32$$

$$\mu_x^{1 \rightarrow 5} = 31.210^\circ, \mu_y^{1 \rightarrow 5} = 30.373^\circ$$

$$d_{\text{sep}}^{1,5} = 2\text{mm}, \theta_c = 250 \text{ mrad}$$

Example DA plot



Introduction

- MCBRD have two functions:
 - Create orbit bumps \Rightarrow setting in optics file
 - Correct orbit distortions \Rightarrow set during operation
- Magnets for horizontal and vertical planes \Rightarrow 8 Magnets
- Power connections:

IP ... {=D2 =MCBRDH MCBRDV=} ...

\Rightarrow MCBRDH.L and MCBRDV.R are inverted

\Rightarrow aperture definitions (iap):

MCBRDH: iap=1 for Beam 1, iap=2 for Beam 2

MCBRDV: iap=2 for Beam 1, iap=1 for Beam 2

Errortable for MCBRD

- Nominal table in [slhc/errors2/MCBRD_errortable_v3](#)
- Only **systematic** errors (with $R_{\text{ref}} = 35\text{mm}$):
 - $b_3 = -10$ (MCBRDH; all other orders zero)
 - $a_3 = +10$ (MCBRDV; all other orders zero)

Taken from 8th Annual HiLumi Meeting

([E. Todesco, et_wp3_hilumi_2018-10-17.pdf](#))

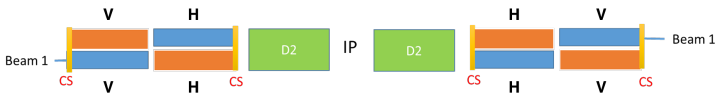
- Reference fields:

$$B_{\text{MCBRDH}}^{\text{ref}} = 5 \text{ Tm}$$

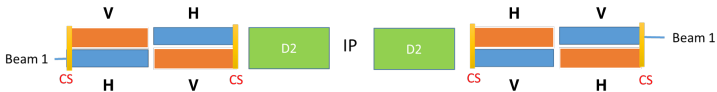
$$B_{\text{MCBRDV}}^{\text{ref}} = 5 \text{ Tm}$$

Different Layouts

v1.0



v1.4



v1.5



Different Layouts

- Beta functions almost unchanged from first MCBRD towards second MCBRD (on one side of IP)
- Effect of two apertures (“cross-talk”) not accounted for in DA simulations
- Hence layout differences are not expected to have any major impact on DA

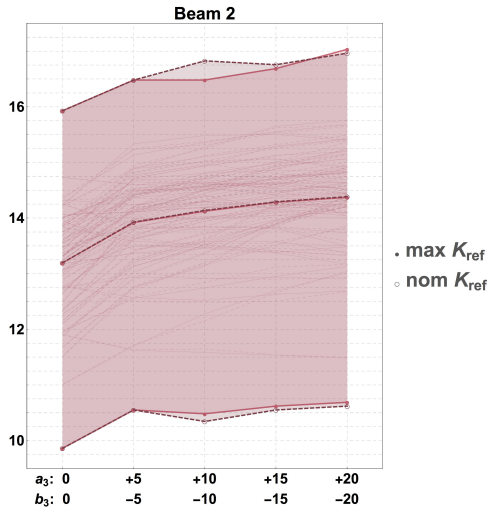
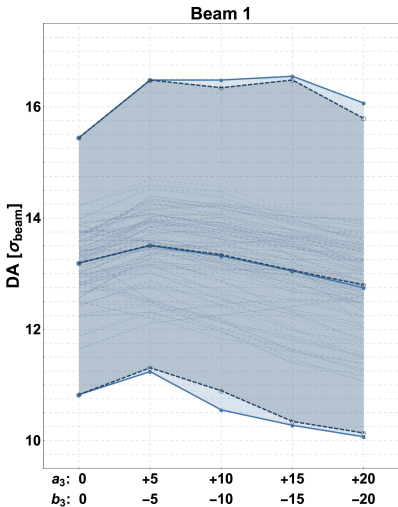
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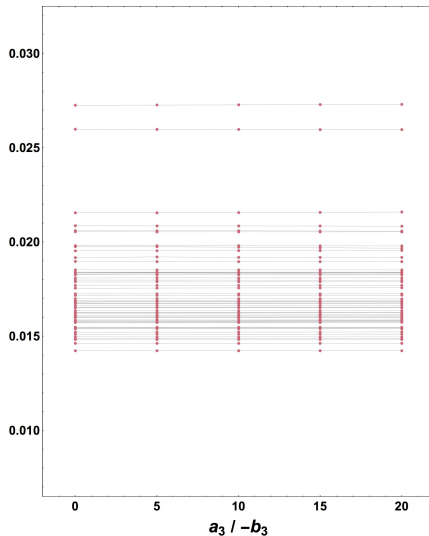
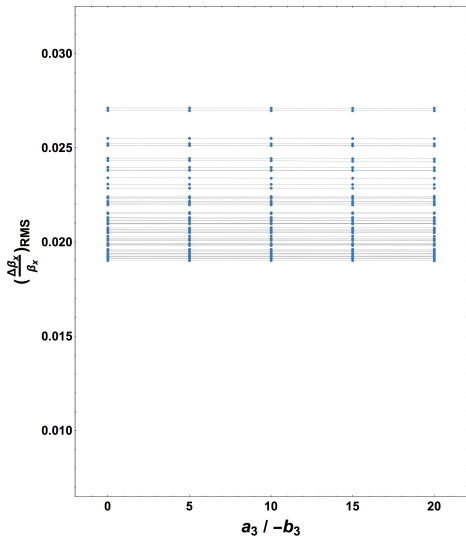
Beta Beating

- Complementary investigation to previous talk: what is the effect of MCBRD on the beta beating?
- The b_3 errors generate a feeddown to b_2 , possibly enhancing beta beating
 - ⇒ does this influence the effect of MCBRD?
 - ⇒ is there a clear correlation between beta beating and DA?

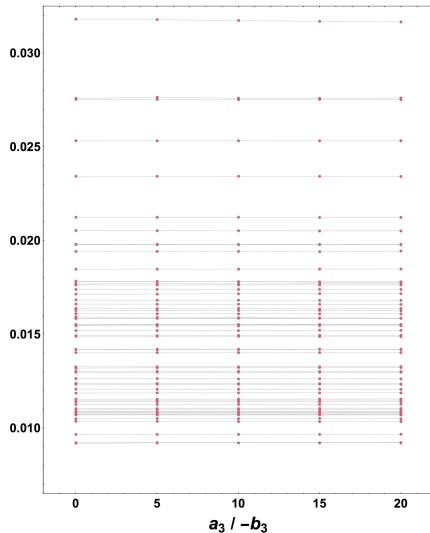
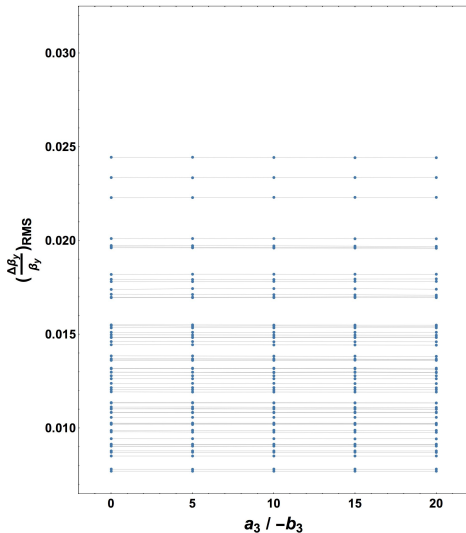
Error investigation of MCBRD (nominal signs), scan over a_3 and b_3



Beta beating (in x) for different values of a_3/b_3 of MCBRD

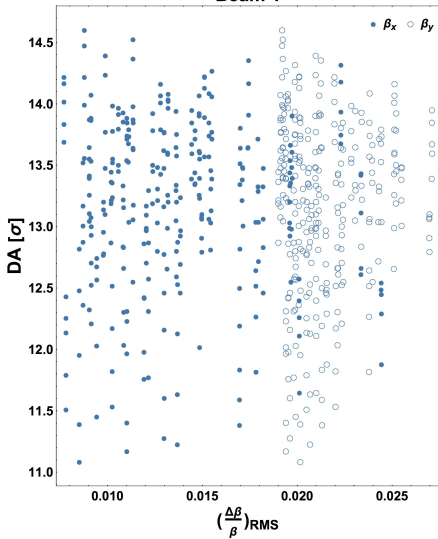


Beta beating (in y) for different values of a_3/b_3 of MCBRD

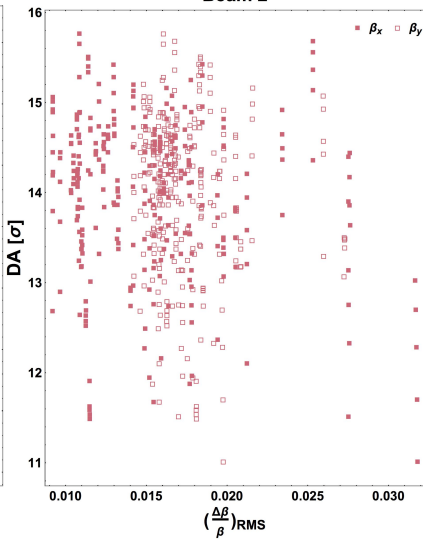


Correlation between beta beating and DA

Beam 1



Beam 2



Outline

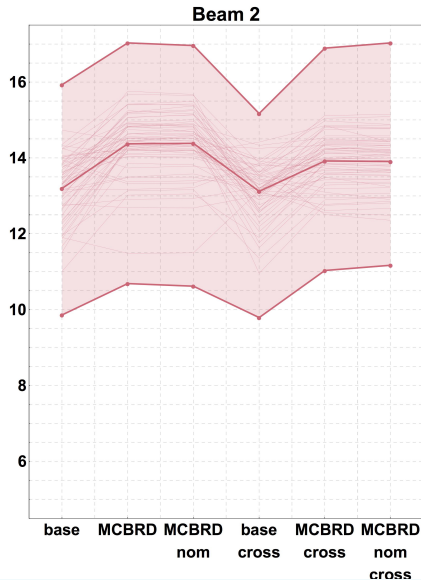
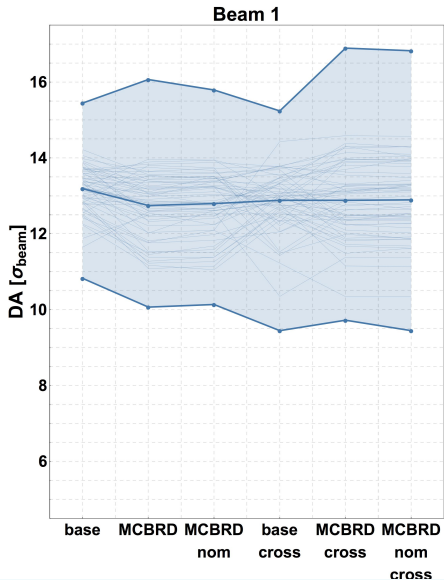
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Switching Crossing Planes

- Typically, the crossing is vertical in IP1 and horizontal in IP5
- Alternative scenario: horizontal in IP1 and vertical in IP5
- To see any effect, errors set at $a_3 = 20$ and $b_3 = -20$

- Tested different cases:
 - **base**: baseline without MCBRD
 - **MCBRD**: baseline with MCBRD
 - **MCBRD nom**: MCBRD, 10% ref strength in separation plane
 - **base cross**: baseline without MCBRD, switched planes
 - **MCBRD cross**: baseline with MCBRD, switched planes
 - **MCBRD nom cross**: with MCBRD, ref strength at 10% in separation plane, switched planes

Effect of changing crossing plane (no octupoles)



Outline

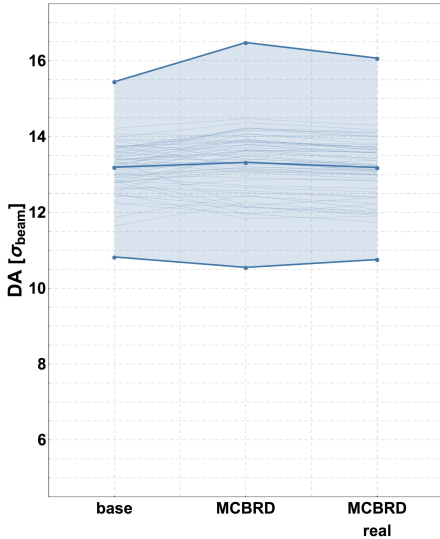
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Including Cross-Talk: Realistic Errortable for MCBRD

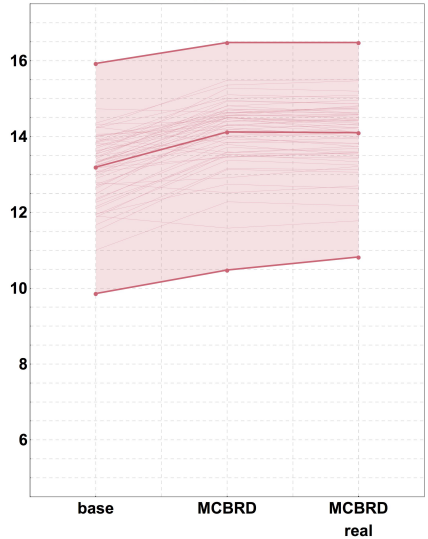
- In a realistic scenario there is cross-talk between the two apertures
- This has been measured in the latest (HV-HV) layout
- Used for simulations in the first (HH-VV) layout
- Expected errors are $a_3 = 15$ and $b_3 = -7$

Realistic errorable for MCBRD

Beam 1



Beam 2



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Sign of MCBRD Reference Field

- sign of reference field is in some cases dominated by deterministic part
- fixed for 8 magnets (crossing plane)
- undefinable for 8 magnets (separation plane)
- scan over undefined signs, in 5 steps
 - ⇒ 625 configurations
 - from these we chose 150 randomly

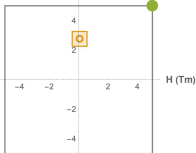
MCBRD.L1.B1

V (Tm)



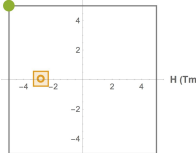
MCBRD.R1.B1

V (Tm)



MCBRD.L5.B1

V (Tm)



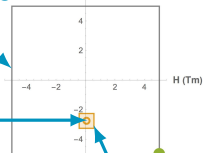
MCBRD.R5.B1

V (Tm)



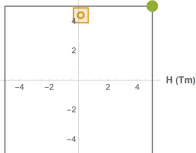
MCBRD.L1.B2

V (Tm)



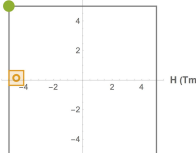
MCBRD.R1.B2

V (Tm)



MCBRD.L5.B2

V (Tm)



MCBRD.R5.B2

V (Tm)

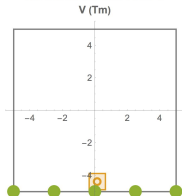
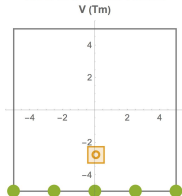
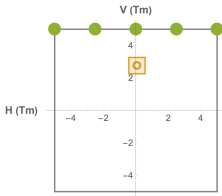
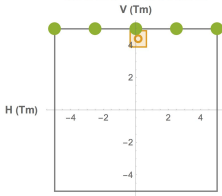
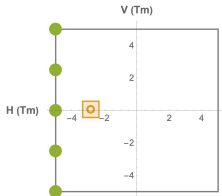
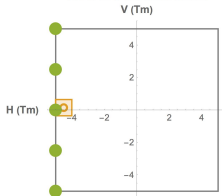
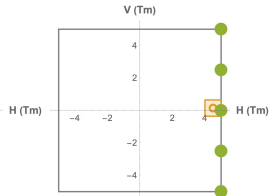
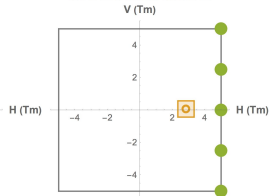


max range

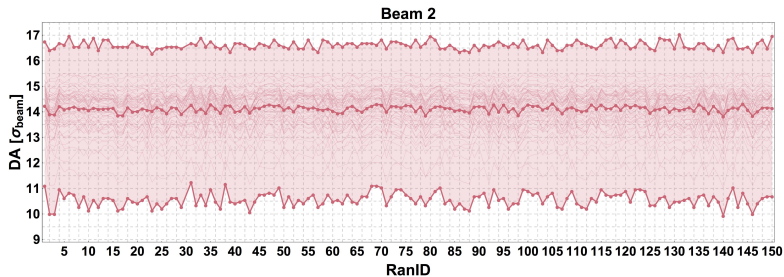
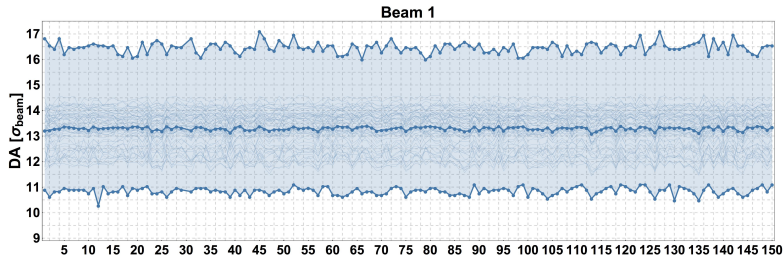
optics setting

range for orbit correction

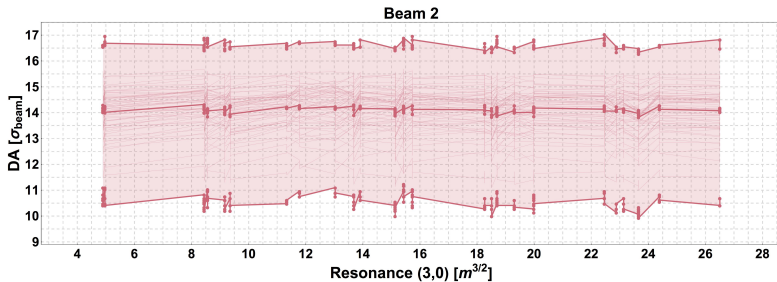
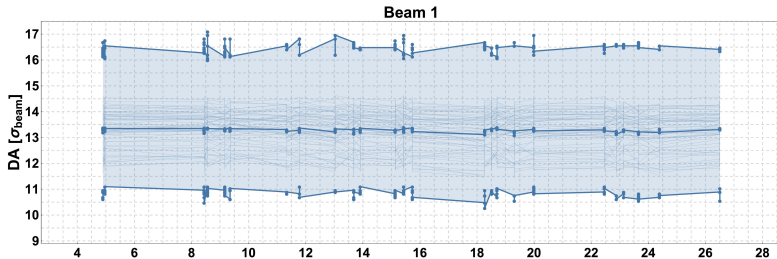
reference field for errors

MCBRD.L1.B1**MCBRD.L1.B2****MCBRD.R1.B1****MCBRD.R1.B2****MCBRD.L5.B1****MCBRD.L5.B2****MCBRD.R5.B1****MCBRD.R5.B2**

Random sign configurations for MCBRD



Random sign configurations for MCBRD



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Conclusions

- Beta beating not influenced by MCBRD: feeddown negligible
- No clear correlation between beta beating and DA
- Switching crossing planes has no effect on DA
- Including cross talk has no effect on DA
- Different random sign configurations have little to no effect:
 - Beam 1: spread on minimum DA is 0.83σ (std 0.15σ)
spread on average DA is 0.31σ (std 0.07σ)
 - Beam 2: spread on minimum DA is 1.3σ (std 0.27σ)
spread on average DA is 0.50σ (std 0.11σ)
 - No clear link with resonance driving terms

Outlook

- Investigate resonance driving terms to clarify difference between Beam 1 and beam 2 (ongoing)
- Test implementation in v1.4 and v1.5, and compare to v1.0
- Implementation of knob to correct beta beating

Thank you for your attention!

Backup Slides

Multipole Expansion

- Errors are expanded in **multipoles**:

$$B_y + iB_x = \sum_{n=0}^{\infty} (B_{n+1} + iA_{n+1}) \frac{(x+iy)^n}{R^n}$$

$$B_y(x, y) \text{ and } B_x(x, y), \text{ but } \frac{\partial B_n}{\partial x} = \frac{\partial B_n}{\partial y} = \frac{\partial A_n}{\partial x} = \frac{\partial A_n}{\partial y} = 0$$

- $B_y = \text{Re} \{B_y + iB_x\}$ $B_x = \text{Im} \{B_y + iB_x\}$
- Expansion is **not** automatically frame invariant!

Multipole Expansion: Signs

- If we interchange $x \rightarrow -x$ (e.g. Beam 4), we have to adapt the multipoles to keep $B_y \rightarrow B_y$:

$$B_y = \sum_{n=0}^{\infty} \left[B_{n+1} \sum_{m \text{ even}} (-)^{\frac{m}{2}} - A_{n+1} \sum_{m \text{ odd}} (-)^{\frac{m-1}{2}} \right] \binom{n}{m} \frac{y^m x^{n-m}}{R^n}$$

- If $x \rightarrow -x$ then

$$\mathbf{A}_{\text{odd}} \rightarrow -\mathbf{A}_{\text{odd}} \quad \text{and} \quad \mathbf{B}_{\text{even}} \rightarrow -\mathbf{B}_{\text{even}}$$

(i.e. skew dipole, regular quadrupole, skew sextupole, ...)

Reference Field

- Reference field is dominant order of magnet
- Errors are several orders of magnitude smaller
- No errors at orders below reference field by definition

$$B_n = 10^{-4} B_N b_n \quad A_n = 10^{-4} B_N a_n$$

$$\text{or } B_n = 10^{-4} A_N b_n \quad A_n = 10^{-4} A_N a_n$$

where $b_{n < N} = 0$

Reference Field: Signs

$$B_y + i B_x = 10^{-4} \frac{B_N}{R^N} \sum_{n=N}^{\infty} (b_{n+1} + i a_{n+1}) \frac{(x + i y)^n}{R^{n-N}}$$

- Main field can be regular (B_N) or skew (A_N)
- Sign of main field changes for B_{even} or A_{odd}
- If x -flip, multipoles have to change sign when

$B_{\text{odd}} a_{\text{odd}}, B_{\text{odd}} b_{\text{even}}, A_{\text{even}} a_{\text{odd}}, A_{\text{even}} b_{\text{even}},$

$B_{\text{even}} a_{\text{even}}, B_{\text{even}} b_{\text{odd}}, A_{\text{odd}} a_{\text{even}}, A_{\text{odd}} b_{\text{odd}}$

Implementation in Error Routines

- **1**: check if x -flip, if yes then **2**: flip correct order

- x -flip in case of:

y -rotation, error convention, and Beam 4

- $y_{\text{fact}} = (-1)^{\text{is_inv} + \text{magnetic_sign} + \text{is_beam4}}$

- Define: $\text{aaa} = y_{\text{fact}}$ $\text{bbb} = 1$

$$\text{aaa} \cdot a_{\text{odd}} \qquad \text{aaa} \cdot b_{\text{even}}$$

$$\text{bbb} \cdot b_{\text{odd}} \qquad \text{bbb} \cdot a_{\text{even}}$$

Implementation in Error Routines

- Instead of changing the sign of the reference field, we change the sign of all multipoles
- Skew magnets are given negative reference radius \Rightarrow `is_skew`
- **But** sign of reference field in case of Beam 4 is already taken into account in optics (due to `bv_aux` flag) or in Beam 4 sequence file
- $y_{\text{factref}} = (-1)^{\text{is_inv} + \text{magnetic_sign}}$
- If $y_{\text{factref}} = -1$: $\text{sign} = (-1)^{\text{is_skew} + \text{order}}$ (order in k^n)
else $\text{sign} = +1$
- `aaa = sign · aaa` `bbb = sign · bbb`

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