CERN

HiLumi LHC
Progress on MCBXF Simulations

F.F. Van der Veken and R. de Maria

Outline

Introduction

- MCBXF have two functions:
  - Create orbit bumps
  - Correct triplet misalignments
- Power setting in optics file is for bumps, triplet correction is set during operation (orbit correction phase)
- Two classes of magnets: A (in the CP) and B (around Q2).
- Two B magnets
- Magnets for horizontal and vertical planes

$\Rightarrow$ 24 magnets in total (IP1 and IP5)

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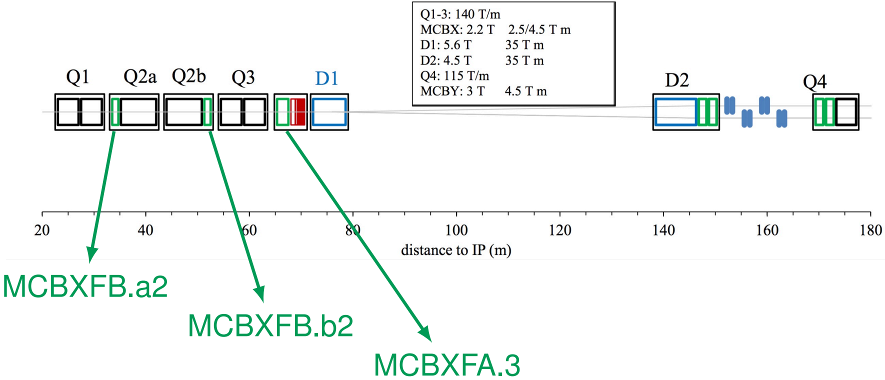

Aim

- Investigate effect of given field qualities on dynamic aperture
- Explore broader:
  - Is there some margin on the field qualities?
  - Can we find the dominant magnet class?
  - Does the result depend on efficient non-linear correction, or is it a robust result?

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Connection Sides

- Connection side of magnet matters!

  $\rightarrow$ if inverted: sign flip for specific orders

- Connections (symbol '=') for the right side of IP:

`IP (=`**B.a2** `Q2a=) (=Q2b` **B.b2**`=) (=Q3a Q3b=) (=`**A.3** `...)`

- Connections for the left side of IP: inverse of above

- Hence magnets that get a sign flip are:

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Absolute vs. Relative Errors

- For most magnets, errors are assigned relative to main field strength
- MCBXF field strength has two components:
  - Deterministic part (for orbit bumps)
  - Variable part (orbit correction)
- Final field strength will be different **per magnet**

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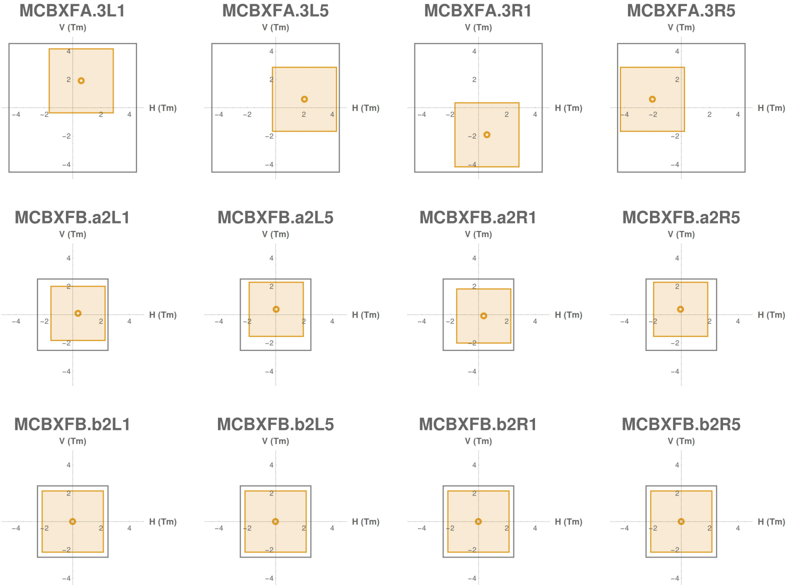
MCBXFA.3L1
V (Tm)
H (Tm)
MCBXFA.3L5
V (Tm)
H (Tm)
MCBXFA.3R1
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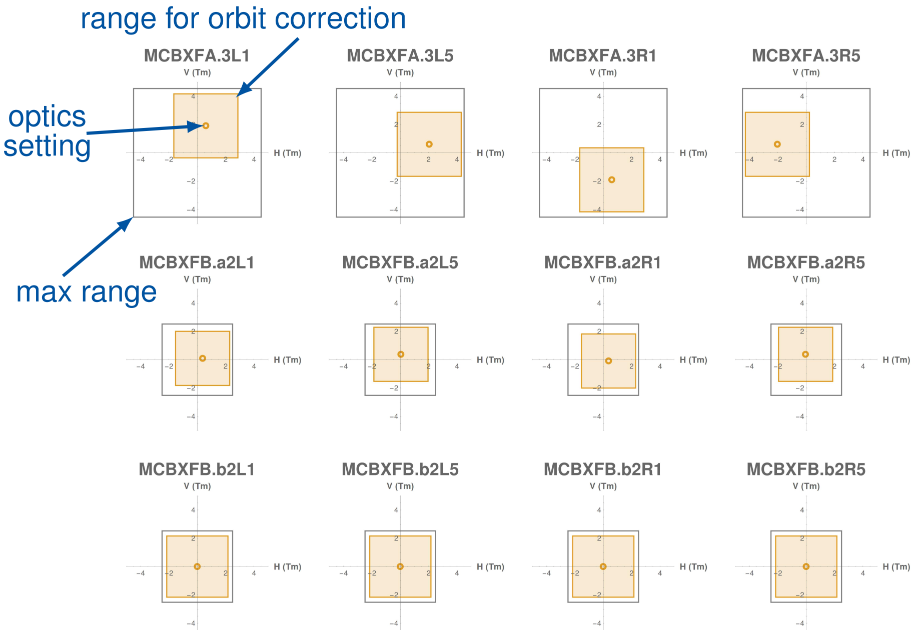

range for orbit correction
optics setting
max range
MCBXFA.3L1
MCBXFA.3L5
MCBXFA.3R1
MCBXFA.3R5
MCBXFB.a2L1
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V (Tm)
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Error Routines for MCBXF

- Absolute errors in MAD: `EFCOMP, dkn:={}, dkns:={};`
- No `radius` nor `order` passed; so include factor $n!\frac{k_L^{\text{ref}}}{|R|^{n-N}}$

- k_L^{ref} is the same maximum strength per class (A or B)
- Is a safe approach, but not necessarily worst-case (there could be internal compensations)

- Individual magnets can have different signs for k_L^{ref}
- AV.1 and AH.5 have fixed sign, so still 2^{20} possibilities!

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- Three possible approaches to handle the sign of the reference fields
  - All reference fields positive
  - Take signs from optics
  - Take signs for A from optics, B Monte Carlo

- As we will see, errors in B magnets don't impact DA much

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Errortable for MCBXF

- Nominal table in slhc/errors2/MCBXFAB_errortable_v1
- Only **systematic** errors, taken from WP3 Meeting #65 (2015-06-02_Progress_on_MCBXFB_Design.pptx, *Jesus Angel Garcia Matos*)
- Reference fields:

$$B_{\mathrm{AH}}^{\mathrm{ref}} = \frac{4.5}{L_{\mathrm{A}}}\ \mathrm{T\ (regular)} \quad B_{\mathrm{BH}}^{\mathrm{ref}} = \frac{2.49}{L_{\mathrm{B}}}\ \mathrm{T\ (regular)}$$

$$B_{\mathrm{AV}}^{\mathrm{ref}} = \frac{4.54}{L_{\mathrm{A}}}\ \mathrm{T\ (skew)} \quad B_{\mathrm{BV}}^{\mathrm{ref}} = \frac{2.52}{L_{\mathrm{B}}}\ \mathrm{T\ (skew)}$$

Errortable for MCBXF

	a_3	a_5	a_7	a_9	a_{11}
MCBXFAV	20.12	-3.04	-3.98	-0.62	0.02
MCBXFBV	-10.33	-3.60	-3.26	-0.58	0.12

	b_3	b_5	b_7	b_9	b_{11}
MCBXFAH	-16.65	-0.35	0.98	0.07	4.30
MCBXFBH	17.37	2.49	0.62	-0.75	3.60

Only systematic errors at expected orders are non-zero

Outline

Strength Assignments

- Can the non-linear correctors in the CP handle the MCBXF errors?
- Variation of strength assignment is linear w.r.t. the error variation
- Correcting all errors, but focus on order with largest errors, i.e. a_3 and b_3

  $\Rightarrow$ (skew) sextupole correctors

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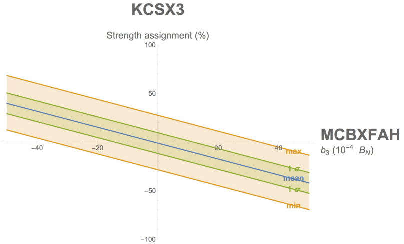
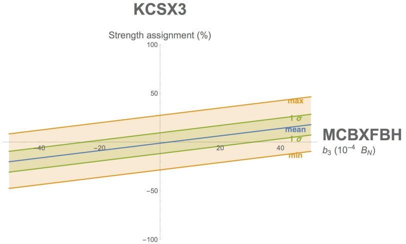
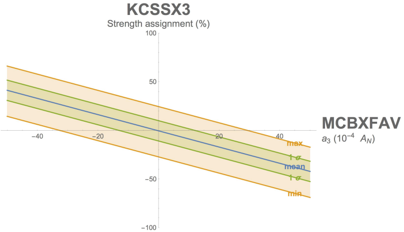
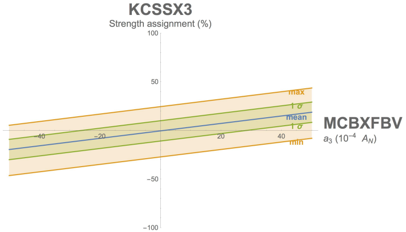
Effect on Sextupole Correctors





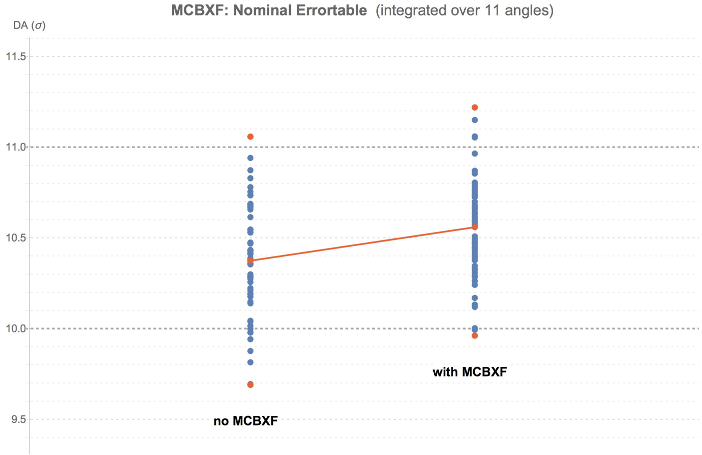




DA for Nominal Errors at all orders

- Compare two studies: baseline (without MCBXF), and baseline with MCBXF (slhc/examples/job_MCBXF.mask)
- Baseline study is HL-LHC V1.0 (slhc/hllhc_sequence.madx) with round collision optics (slhc/opt_round_thin.madx), and with the following errors assigned (all files in slhc/errors2/):
  - Triplet with fringe fields (Efcomp_MQXFbody.madx, Efcomp_MQXFends.madx, ITnc_errortable_v5, ITcs_errortable_v5 and ITbody_errortable_v5)
  - D1 (Efcomp_MBXAB.madx and D1_errortable_v1_spec)
  - D2 (Efcomp_MBRD.madx and D2_errortable_v5_spec)
  - Q4 (Efcomp_MQYY.madx and Q4_errortable_v2_spec)
  - Q5 (Efcomp_MQYL.madx and Q5_errortable_v0_spec)

DA for Nominal Errors at all orders

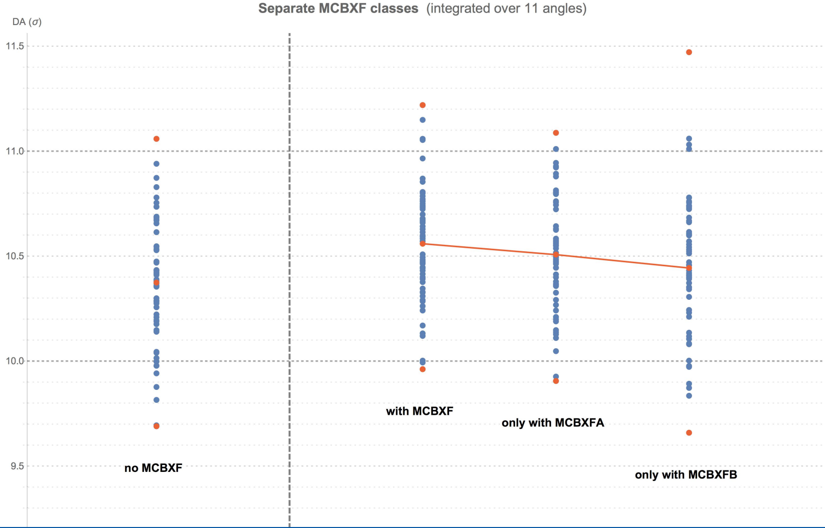


DA for Nominal Errors at all orders

- Internal compensations between the different magnets give positive effect to DA
- We gave all magnets in one class same reference field (and same sign)

  $\rightarrow$ Not necessarily realistic; we should proceed with caution
- Also compensations if we investigate each class separately

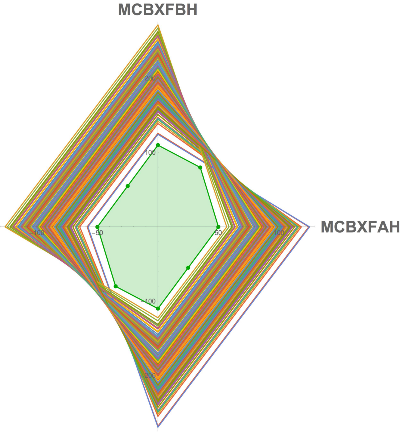
DA for Nominal Errors per Magnet Class

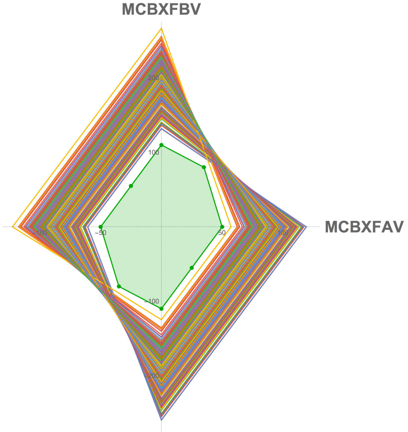


Maximal Correction in the CP

- Use linearity of strength assignments to define a maximal safe region, i.e. the region of errors for which the non-linear correctors are still effective (for all seeds)
- Corrector strength maximises at 100%, take 75% to be safe
- Safe region is defined per error order (a_3 and b_3), i.e. per plane
- Investigate how strongly DA is affected at the boundary of the region

Determination of Safe Region





Determination of Safe Region

- Plotted region per seed and per non-linear corrector; safe region is minimal cross section
- Same for horizontal and vertical planes
- On the plane (MCBXFA, MCBXFB), the border points are:

  (-50, 0), (-25, 55), (0, 110), (35, 80), (50, 0),

  (25, -55), (0, -110), and (-35, -80)

- Investigate DA on one plane at the time; keep other plane and all higher order ($n > 3$) errors at nominal values

  caveat: only 5 angles $\Rightarrow$ value for baseline shifted

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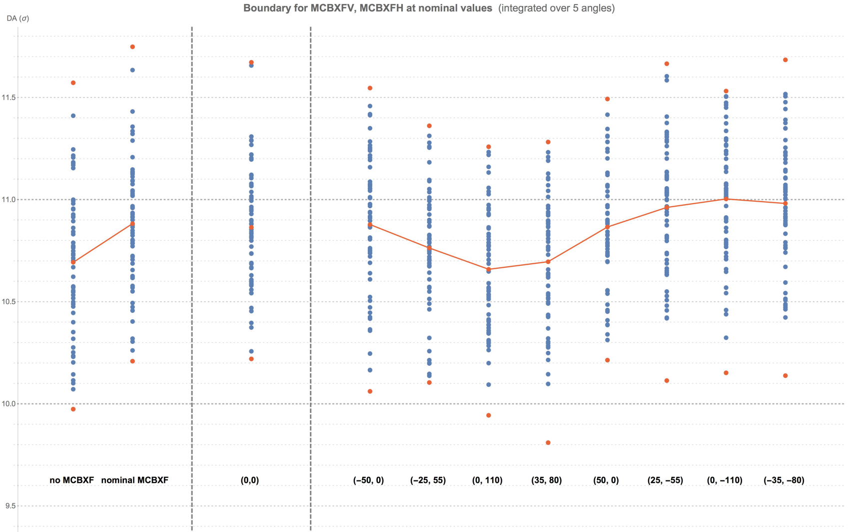
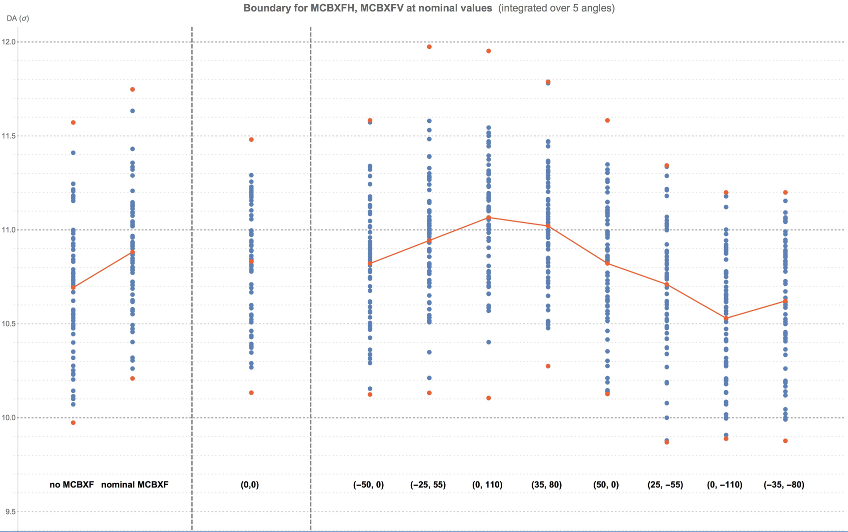
DA for Safe Region Boundary: Vertical



DA for Safe Region Boundary: Horizontal



Usefulness of Non-Linear Correctors

- In the vertical plane the DA drops less than 0.05σ compared to the baseline (without MCBXF magnets), but fluctuates in a range of 0.35σ due to internal compensations
- In the horizontal plane the DA drops a bit more than 0.15σ (and fluctuates in a range of 0.55σ)

- The DA is not impacted much on the safe boundary - the errors are 2.5 resp. 5 times bigger than their nominal values!
- But this setup is too optimistic: the correction algorithm has exact information on the MCBXF field qualities
- Realistic correction will be much more pessimistic

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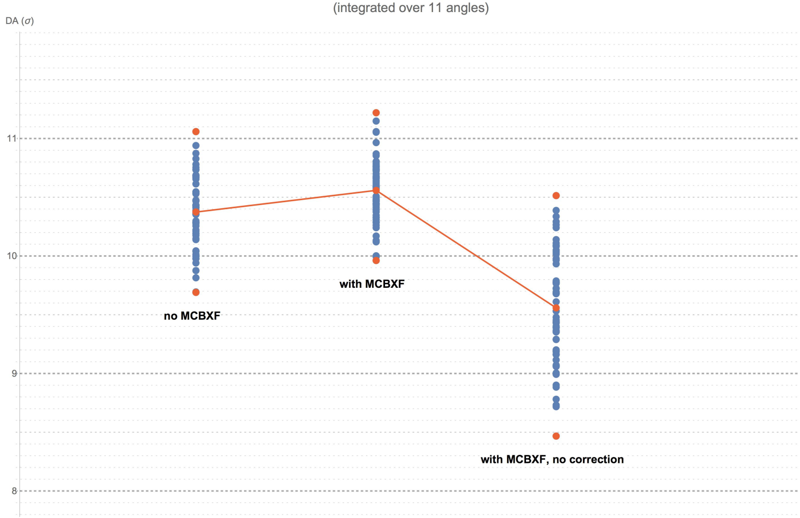
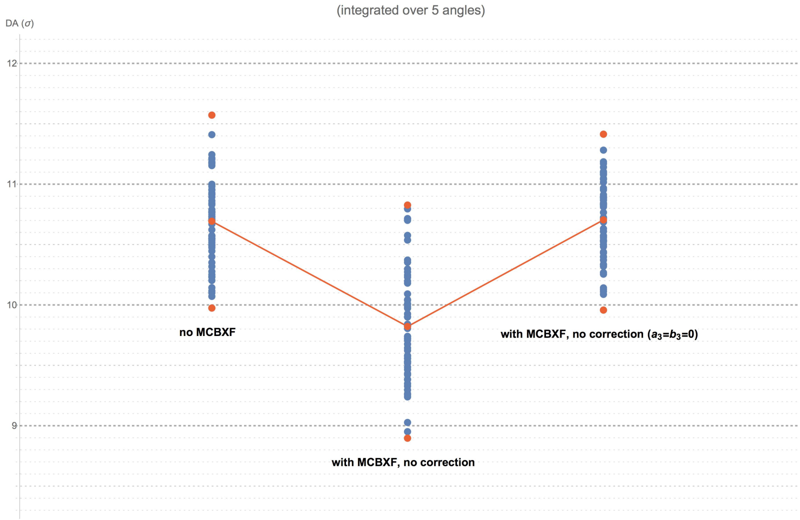


DA for Nominal Errors, no Correction

- DA drops more than 0.8σ!
- Three questions:
  - Is this drop mainly due to a_3 and b_3, or do higher orders contribute (significantly) as well?
  - Can we alleviate the drop by using the correct signs (from the optics) for the reference fields?
  - Is one of the two magnet classes the dominant cause for the drop?

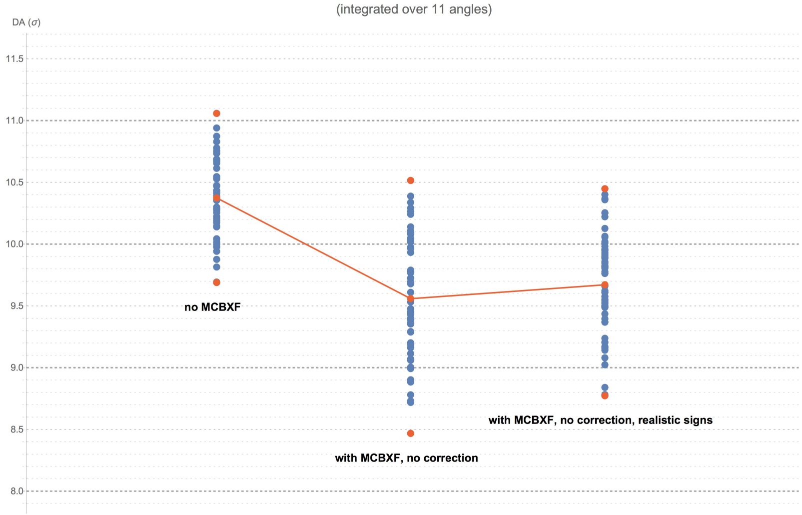
Higher Order Effects



Higher Order Effects

- Higher orders have no visible effect on the DA
- Validates focus on a_3 and b_3

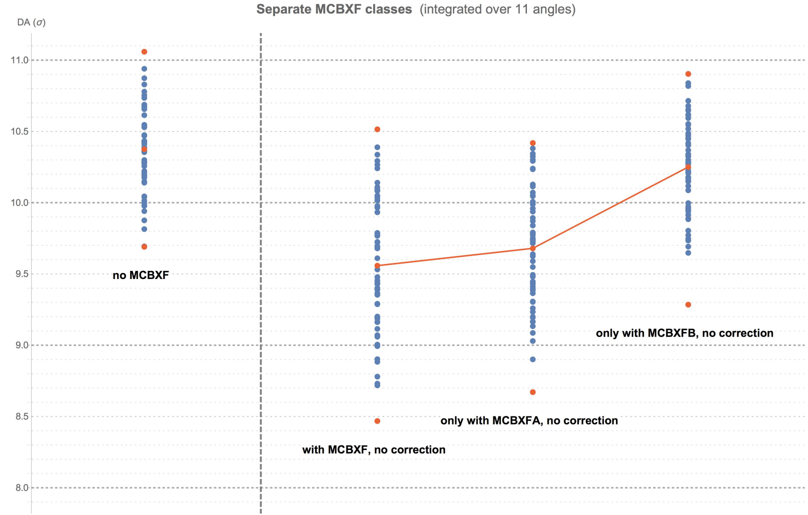
Using Realistic Signs



Using Realistic Signs

- Using the correct signs for the reference fields, as in the optics file, has only a small impact
- Improvement of 0.1σ, still a drop of 0.7σ

DA per Magnet Class, no Correction



DA per Magnet Class, no Correction

- DA drops almost 0.7σ in case of MCBXFA
- DA drops only a bit more than 0.1σ in case of MCBXFB
- Setting fo MCBXFB is already very cautious (because field setting for MCBXFB in optics file is small)

$\Rightarrow$ Effects of MCBXFB can be mainly neglected

$\Rightarrow$ Focus on MCBXFA

- Double check: vary every magnet class and plane separately, keep other $n = 3$ errors at zero and all higher orders at nominal values

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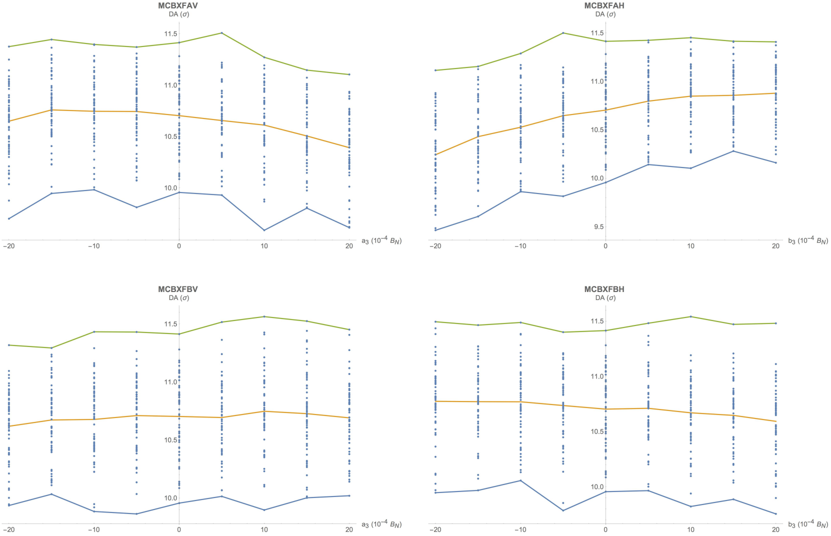
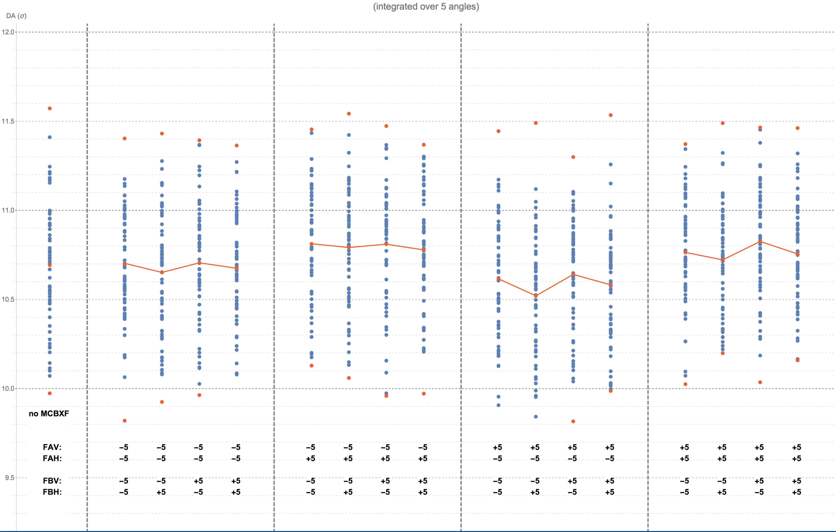
Evolution of DA, no Correction



Small Region, no Correction



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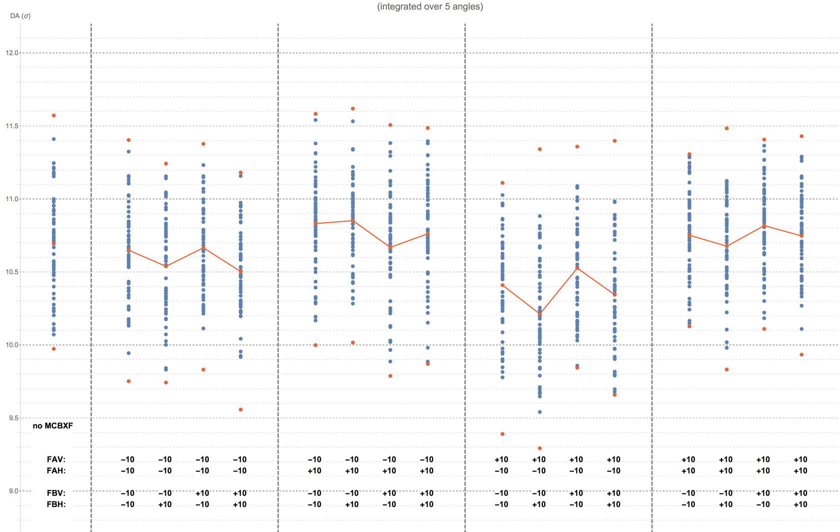


Outlook

Preliminary Conclusions & Outlook

- Non-linear correctors in CP can handle up to 2.5 resp. 5 times the nominal values

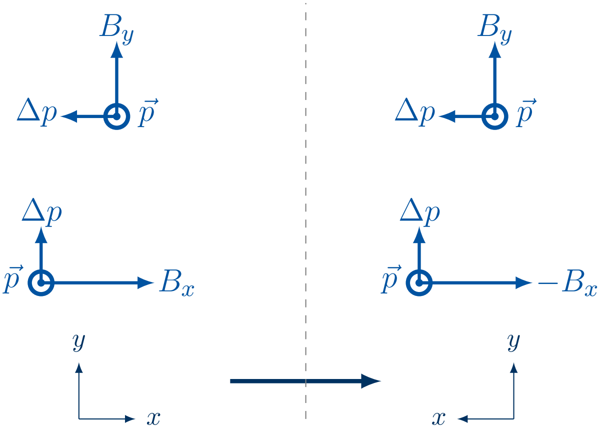
  $\rightarrow$ Different values inside safe region should be investigated
- Without non-linear correction, DA drops more than 0.8σ. However, this is mainly due to the A class magnets.
- Using realistic signs is only a marginal improvement

  $\rightarrow 2^4$ possible sign configurations should be investigated
- Simulations should be expanded over more angles
- Final aim: defining a workable region for MCBXFA

Thank you for your attention!

Backup Slides

Sign of Errors



Multipole Expansion and Main field

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

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

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

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

Error Routines

- Sign of x flips for:

  y-rotation, convention change, and beam 4

- $\mathtt{y}_{\mathtt{fact}} = (-1)^{\mathtt{is\_inv} + \mathtt{magnetic\_sign} + \mathtt{is\_beam4}}$
- Skew magnets (vertical plane) are given negative reference radius $\Rightarrow$ `is_skew`
- $\mathtt{sign} = (-1)^{\mathtt{is\_skew} + \mathtt{order}}$ (`order` as in k^n)
- Only if $\mathtt{y}_{\mathtt{fact}} = -1$ (odd number of flips):

  $a_{\text{odd}} = -\mathtt{sign}\, a_{\text{odd}}\,,\ b_{\text{even}} = -\mathtt{sign}\, b_{\text{even}}\,,$

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