HiLumi
LARGE HADRON COLLIDER

Research supported by the High Luminosity LHC project

HiLumi LHC:
DA with the field quality specified in the HL-LHC magnets acceptance criteria documents

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Outline

Aim

- New HL-LHC orbit correctors have acceptance criteria on field imperfections:
  - MCBRD: within ± 10 units for a_3/b_3
    within ± 3 units for all other orders
  - MCBXF: within ± 20 units for a_3/b_3
    within ± 5 units for all other orders
- Goal is to probe range with high statistics and investigate impact on DA

Assignment of Field Imperfections

- Magnetic errors have 3 components:
  - **systematic** error ξ_{M}
  - **uncertainty** error ξ_{U} per magnet family
  - **random** error ξ_{R} per magnet

- Total error given by $\xi_{\mathrm{tot}} = \xi_{\mathrm{M}} + \xi_{\mathrm{U}} \frac{\sigma_{1.5}}{1.5} + \xi_{\mathrm{R}} \, \sigma_3$
  - $\sigma_{1.5}$ is a Gaussian random variable capped at 1.5σ sampled once per magnet family
  - σ_3 is a Gaussian random variable capped at 3σ resampled for every magnet

Approach for MCBRD and MCBXF

- Systematic errors are known for specific orders (in existing error tables)
- Uncertainty errors are not assigned
- Random errors are used to probe acceptance criteria:
  - scale up slightly, to have enough statistics for high values
  - equivalent variance of uniform distribution $\sigma_{\text{uniform}} = \frac{\text{interval}}{\sqrt{12}}$
  - ± 5 units $\Rightarrow \xi_R = 2.887$
  - ± 3 units $\Rightarrow \xi_R = 1.732$
- Same value for all multipoles up to 7th order. Orders a_3/b_3 have higher acceptance criteria, however, budget is already taken by systematic error

Setup of Studies

- Very CPU-intensive (2M+ jobs)

  ⇒ submission to BOINC

  Many thanks to the numerous LHC@Home volunteers

- Studies are performed:
  - using HL-LHC v1.4 round collision optics
  - for minimum β^* (15/1000/15/150 cm)
  - without octupoles and with low chromaticity
  - with nominal settings for all other values and errors

Outline

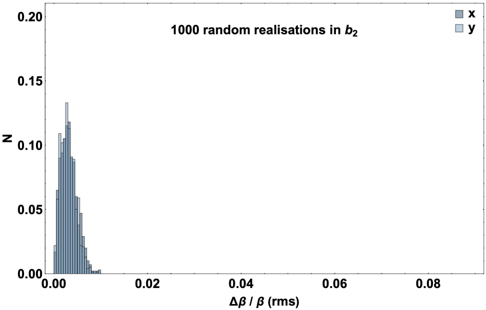
MCBRD New Error Table

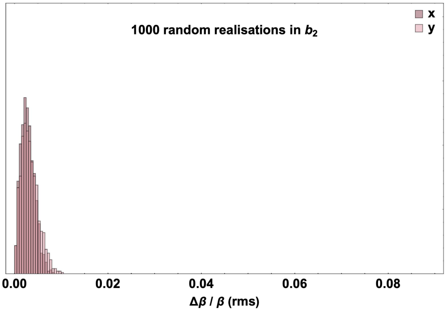
MCBRDH						MCBRDV					
	ξ_M	ξ_R		ξ_M	ξ_R		ξ_M	ξ_R		ξ_M	ξ_R
a_1	0	0	b_1	0	0	a_1	0	0	b_1	0	0
a_2	0	1.732	b_2	0	1.732	a_2	0	1.732	b_2	0	1.732
a_3	0	1.732	b_3	-10	1.732	a_3	10	1.732	b_3	0	1.732
a_4	0	1.732	b_4	0	1.732	a_4	0	1.732	b_4	0	1.732
a_5	0	1.732	b_5	0	1.732	a_5	0	1.732	b_5	0	1.732
a_6	0	1.732	b_6	0	1.732	a_6	0	1.732	b_6	0	1.732
a_7	0	1.732	b_7	0	1.732	a_7	0	1.732	b_7	0	1.732
a_8	0	0	b_8	0	0	a_8	0	0	b_8	0	0
a_9	0	0	b_9	0	0	a_9	0	0	b_9	0	0
a_{10}	0	0	b_{10}	0	0	a_{10}	0	0	b_{10}	0	0
a_{11}	0	0	b_{11}	0	0	a_{11}	0	0	b_{11}	0	0
a_{12}	0	0	b_{12}	0	0	a_{12}	0	0	b_{12}	0	0
a_{13}	0	0	b_{13}	0	0	a_{13}	0	0	b_{13}	0	0
a_{14}	0	0	b_{14}	0	0	a_{14}	0	0	b_{14}	0	0
a_{15}	0	0	b_{15}	0	0	a_{15}	0	0	b_{15}	0	0

Beta-Beating due to MCBRD

- First investigation is impact of b_2 errors on beta-beating
- Higher orders are not considered as orbit is very small
- High statistics: 1000 seeds

Beta-Beating due to MCBRD





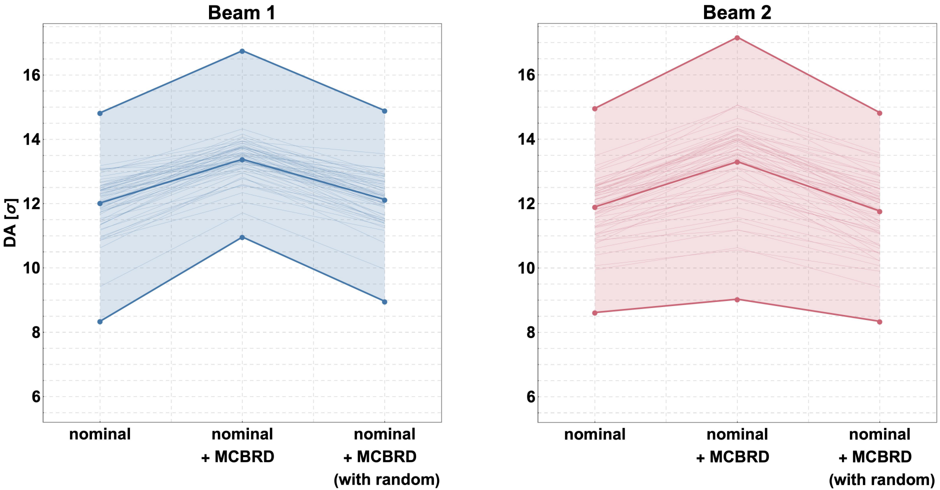
Beta-Beating due to MCBRD

- Beta-beating of around 0.5% $\Rightarrow$ perfectly manageable

DA with Random MCBRD

- To estimate the impact on DA, we compare to nominal baseline
- Also compare impact of systematic vs random
- Errors for all other magnets are assigned (except MCBXF)
- High statistics: 240 seeds

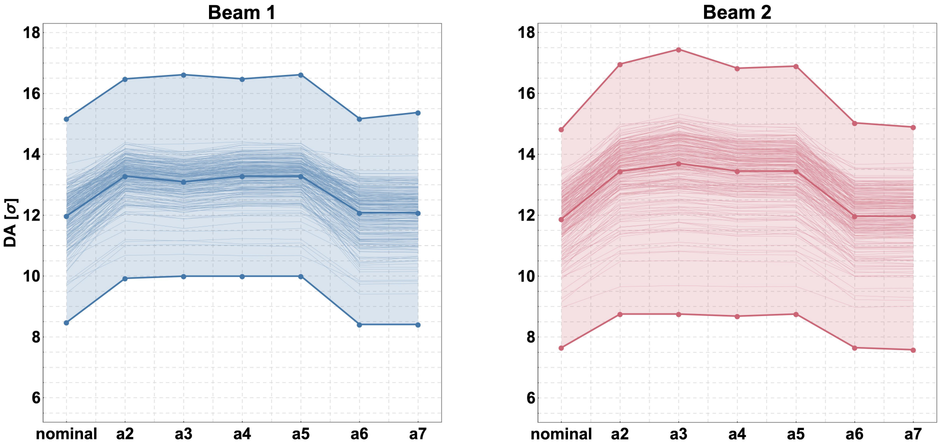
DA with Random MCBRD



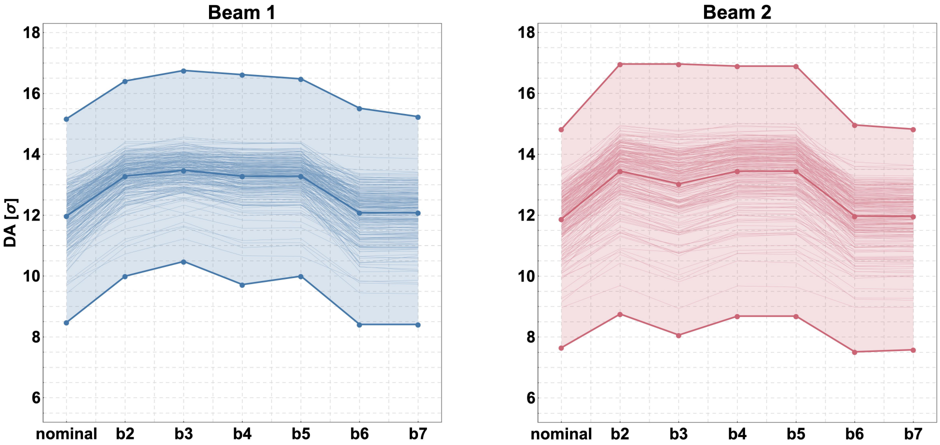
DA with Random MCBRD

- Systematic errors induce internal compensations that enhance DA
- Random errors remove this effect (but don't make it worse either)

DA with Random MCBRD by Order



DA with Random MCBRD by Order



DA with Random MCBRD by Order

- Compensations are created by orders $a_2/b_2 - a_5/b_5$
- Bit peculiar, closer investigation needed
- Overall, MCBRD seems to be acceptable, however, care needs to be taken as behaviour is not completely understood

Outline

MCBXFA New Error Table

	MCBXFAH					MCBXFAV				
	ξ_M	ξ_R		ξ_M	ξ_R		ξ_M	ξ_R		ξ_M	ξ_R
a_1	0	0	b_1	0	0	a_1	0	0	b_1	0	0
a_2	0	2.887	b_2	0	2.887	a_2	0	2.887	b_2	0	2.887
a_3	0	2.887	b_3	-16.65	2.887	a_3	20.12	2.887	b_3	0	2.887
a_4	0	2.887	b_4	0	2.887	a_4	0	2.887	b_4	0	2.887
a_5	0	2.887	b_5	-0.35	2.887	a_5	-3.04	2.887	b_5	0	2.887
a_6	0	2.887	b_6	0	2.887	a_6	0	2.887	b_6	0	2.887
a_7	0	2.887	b_7	0.98	2.887	a_7	-3.98	2.887	b_7	0	2.887
a_8	0	0	b_8	0	0	a_8	0	0	b_8	0	0
a_9	0	0	b_9	0.07	0	a_9	-0.62	0	b_9	0	0
a_{10}	0	0	b_{10}	0	0	a_{10}	0	0	b_{10}	0	0
a_{11}	0	0	b_{11}	4.3	0	a_{11}	0.02	0	b_{11}	0	0
a_{12}	0	0	b_{12}	0	0	a_{12}	0	0	b_{12}	0	0
a_{13}	0	0	b_{13}	0	0	a_{13}	0	0	b_{13}	0	0
a_{14}	0	0	b_{14}	0	0	a_{14}	0	0	b_{14}	0	0
a_{15}	0	0	b_{15}	0	0	a_{15}	0	0	b_{15}	0	0

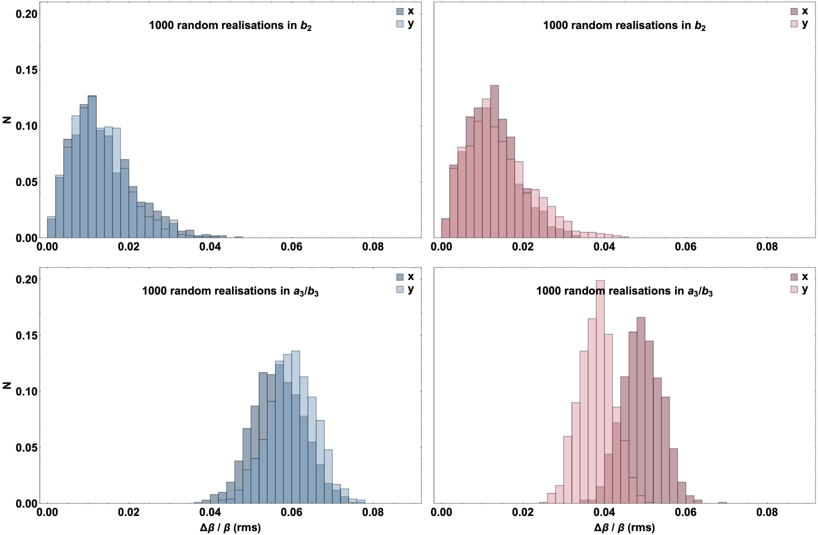
MCBXFB New Error Table

MCBXFBH						MCBXFBV					
	ξ_M	ξ_R		ξ_M	ξ_R		ξ_M	ξ_R		ξ_M	ξ_R
a_1	0	0	b_1	0	0	a_1	0	0	b_1	0	0
a_2	0	2.887	b_2	0	2.887	a_2	0	2.887	b_2	0	2.887
a_3	0	2.887	b_3	17.37	2.887	a_3	−10.33	2.887	b_3	0	2.887
a_4	0	2.887	b_4	0	2.887	a_4	0	2.887	b_4	0	2.887
a_5	0	2.887	b_5	2.49	2.887	a_5	−3.6	2.887	b_5	0	2.887
a_6	0	2.887	b_6	0	2.887	a_6	0	2.887	b_6	0	2.887
a_7	0	2.887	b_7	0.62	2.887	a_7	−3.26	2.887	b_7	0	2.887
a_8	0	0	b_8	0	0	a_8	0	0	b_8	0	0
a_9	0	0	b_9	−0.75	0	a_9	−0.58	0	b_9	0	0
a_{10}	0	0	b_{10}	0	0	a_{10}	0	0	b_{10}	0	0
a_{11}	0	0	b_{11}	3.6	0	a_{11}	0.12	0	b_{11}	0	0
a_{12}	0	0	b_{12}	0	0	a_{12}	0	0	b_{12}	0	0
a_{13}	0	0	b_{13}	0	0	a_{13}	0	0	b_{13}	0	0
a_{14}	0	0	b_{14}	0	0	a_{14}	0	0	b_{14}	0	0
a_{15}	0	0	b_{15}	0	0	a_{15}	0	0	b_{15}	0	0

Beta-Beating due to MCBXF

- Investigation of impact of b_2 errors on beta-beating
- Now feed-down from a_3/b_3 needs to be considered as well
- High statistics: 1000 seeds

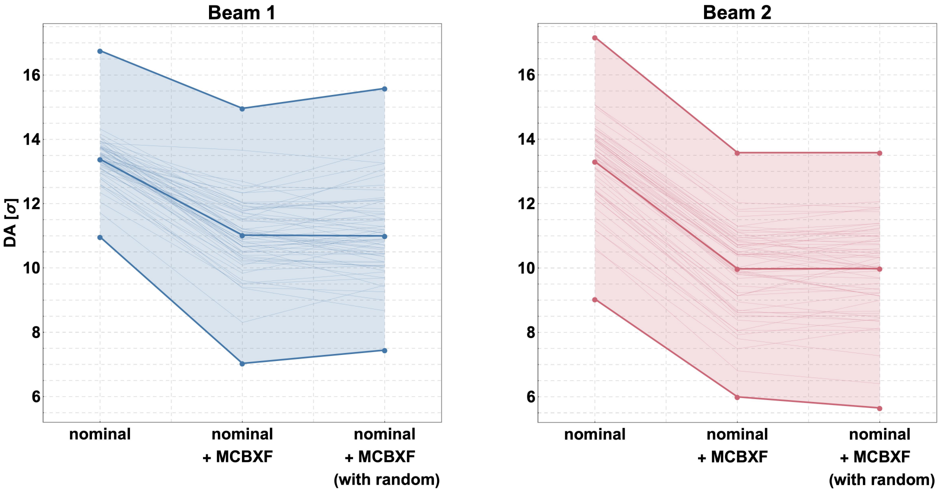
Beta-Beating due to MCBXF



Beta-Beating due to MCBXF

- High beta-beating, especially for feed-down which gives around 6%
- Still manageable
- As shown in previous presentations, feed-down is not responsible for decline in DA

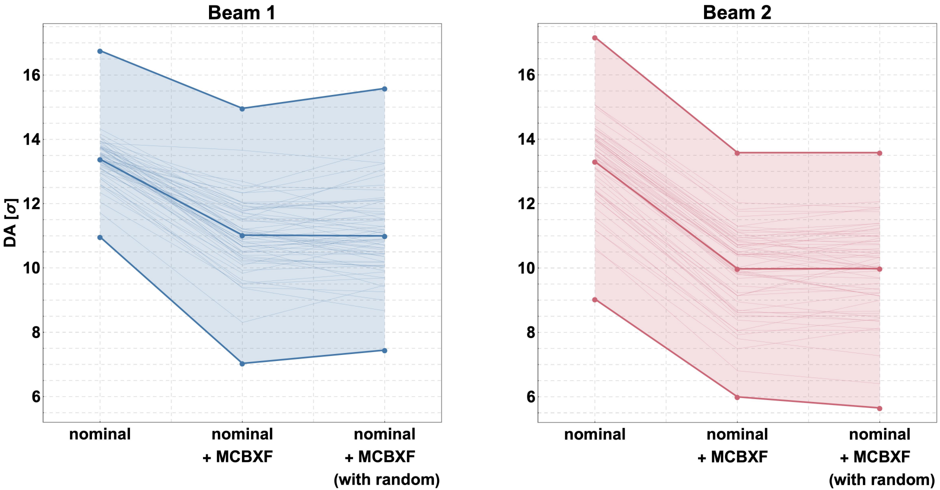
DA with Random MCBXF



DA with Random MCBXF

- To estimate the impact on DA, we compare to nominal baseline
- Also compare impact of systematic vs random
- Errors for all other magnets are assigned (MCBRD: only systematic)
- High statistics: 240 seeds

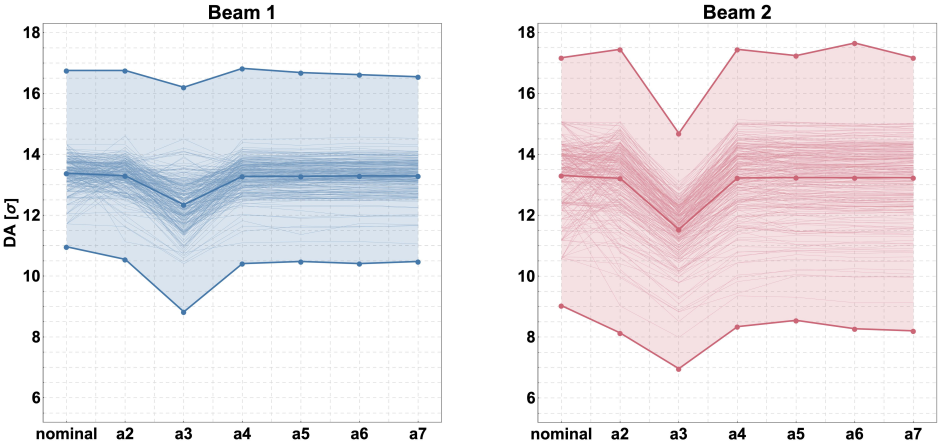
DA with Random MCBXF



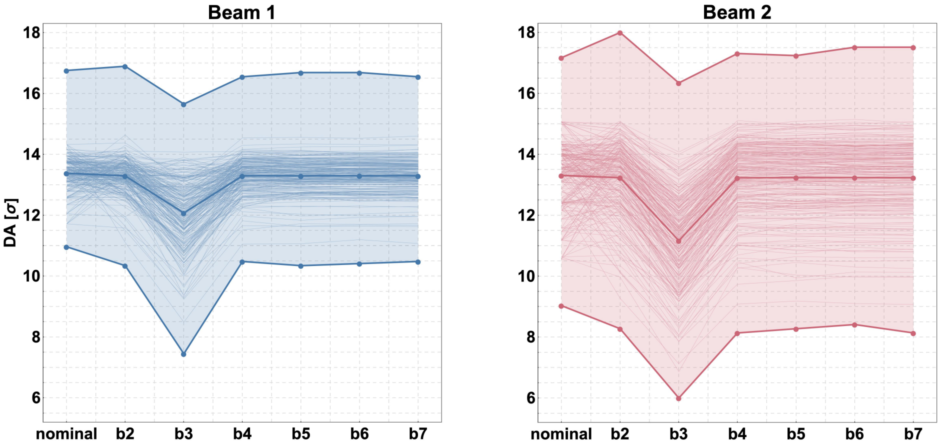
DA with Random MCBXF

- As was already known, DA drops drastically
- Fortunately random errors do not seem to worsen effect

DA with Random MCBXF by Order



DA with Random MCBXF by Order



DA with Random MCBXF by Order

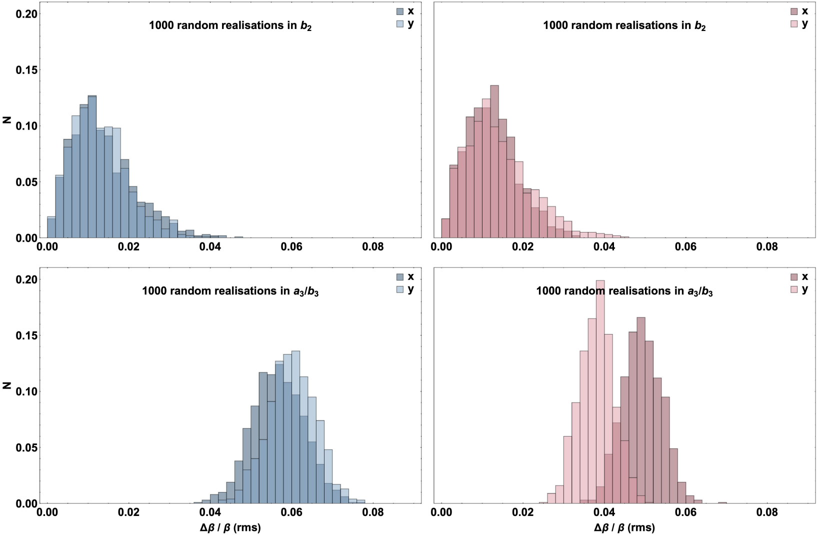
- Strong confirmation that a_3/b_3 is worrisome order
- Other multipole orders are no problem
- Overall, MCBXF is not acceptable, hence solutions have to be found for the third order multipole specifications

Outline

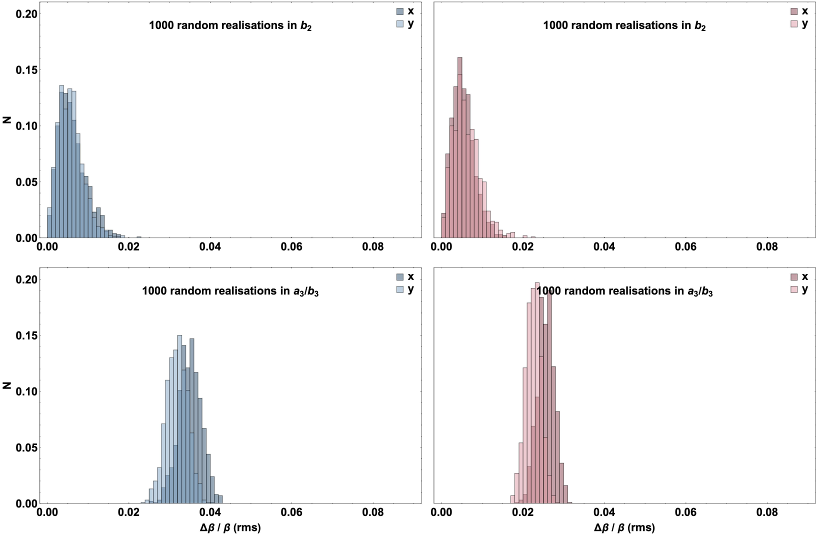
Using FRAS

- If Full Remote Alignment System can be used for IT misalignments:
  - MCBXF becomes deterministic
  - with smaller reference strength
- See Riccardo's talk

Beta-Beating due to MCBXF



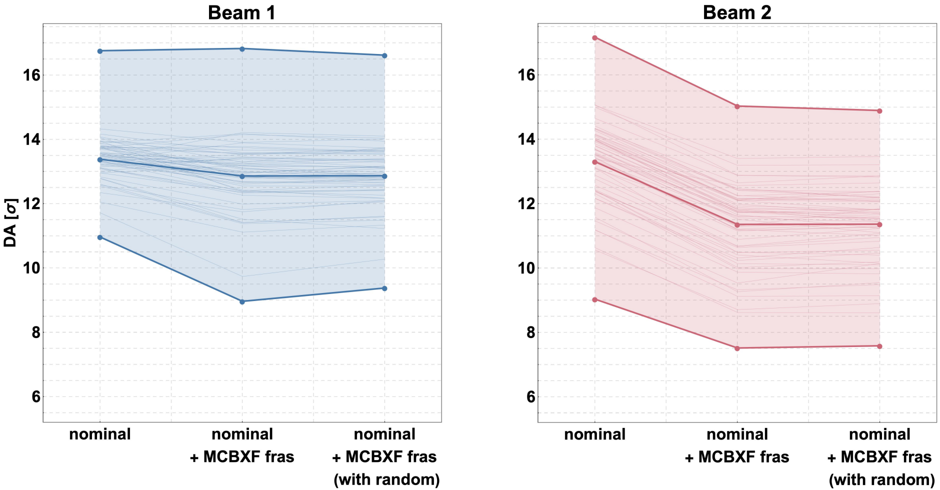
Beta-Beating due to MCBXF (FRAS)



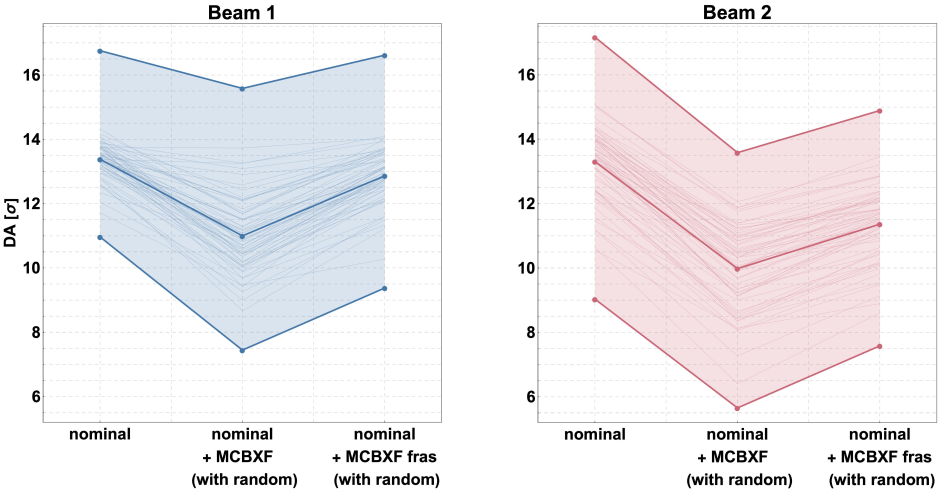
Beta-Beating due to MCBXF (FRAS)

- Beta-beating is halved
- Logical, as reference strength is also halved

DA with Random MCBXF (FRAS)



DA with Random MCBXF (FRAS)



DA with Random MCBXF (FRAS)

- Indeed, situation is improved
- As before, random errors do not really change the result
- For Beam 4, only half of drop is recovered
- But as now reference strength is deterministic, MCBXF can be potentially corrected

Outline

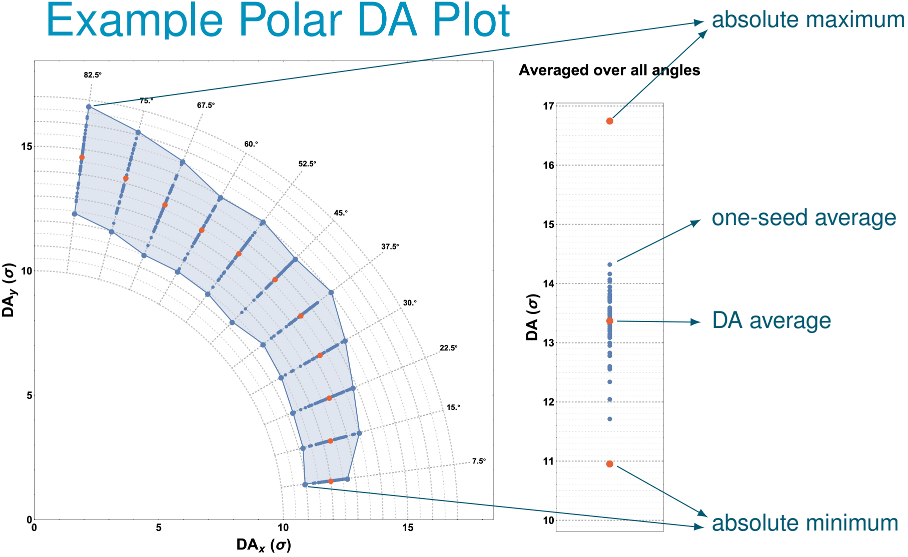
Conclusions and Outlook

- MCBRD is seemingly onder control
- However extra investigation should be done to strengthen this result
- MCBXF is still a problem
- FRAS might offer a partial solution
  (also because then MCBXF might be corrected)
- TODO / In Progress:
  - Understanding compensations by MCBRD
  - Order-by-Order investigation of MCXBF with FRAS
  - MCBXF at high beta* and correction of MCBXF with random errors
  - Acceptance criteria for non-linear corrector package

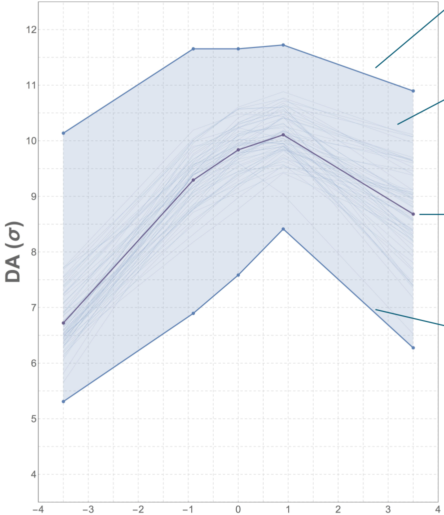
Thank you for your attention!

Backup Slides

Example Polar DA Plot



Example DA Plot



absolute maximum
(maximum angle over all seeds)

individual seed lines
(average over angles per seed)

average DA
(average over angles and over seeds)

absolute minimum
(minimum angle over all seeds)