HiLumi
LARGE HADRON COLLIDER

Research supported by the High Luminosity LHC project

HiLumi LHC: DA for D2 Specification

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Aim

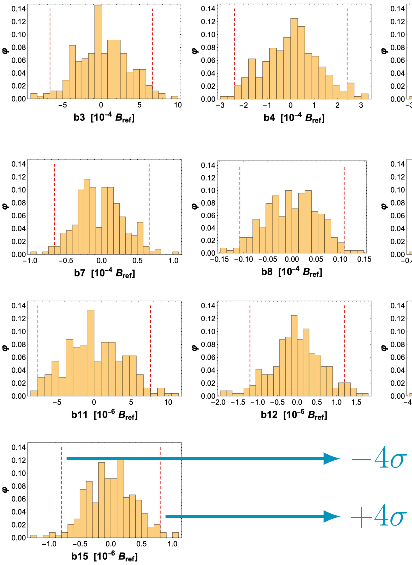
- Effect of D2 errors on DA seemingly under control

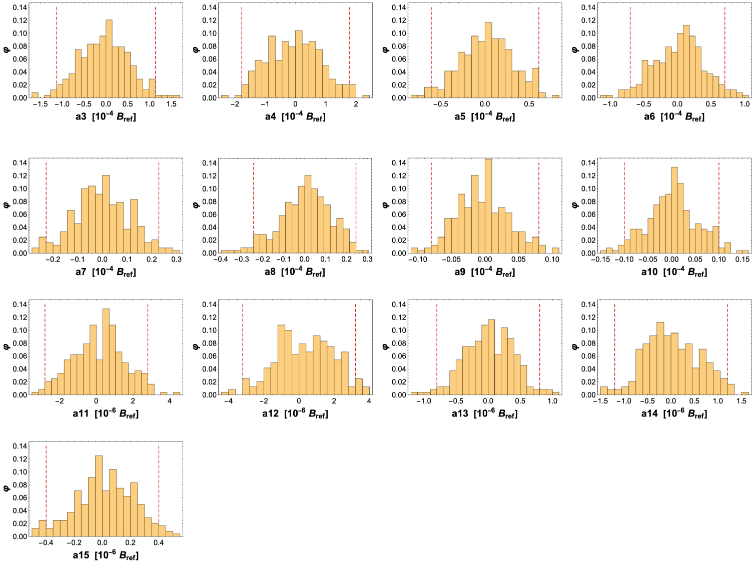
  Need to be sure it isn't due to internal compensations
- Orders b_3 and b_5 might have larger values
- Random errors should be sampled from $[-4\sigma, 4\sigma]$ uniformly

  Existing routines only sample from $[-3\sigma, 3\sigma]$ and Gaussian

Approach

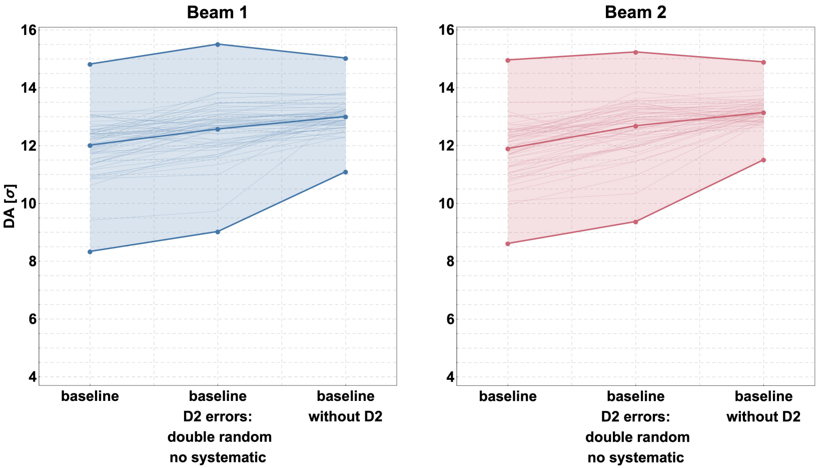
- Magnetic errors have 3 components:
  - **systematic** error ξ_M
  - **uncertainty** error ξ_U per magnet family
  - **random** error ξ_R per magnet
- Total error given by $\xi_\mathsf{tot} = \xi_\mathsf{M} + \xi_\mathsf{U}\,\frac{\sigma_{1.5}}{1.5} + \xi_\mathsf{R}\,\sigma_3$
  - $\sigma_{1.5}$ is 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
- By doubling the value of ξ_R we can make sure to have enough cases at $\pm 4\sigma$


b3 [10⁻⁴ B_ref]
b4 [10⁻⁴ B_ref]
b5 [10⁻⁴ B_ref]
b6 [10⁻⁴ B_ref]
b7 [10⁻⁴ B_ref]
b8 [10⁻⁴ B_ref]
b9 [10⁻⁴ B_ref]
b10 [10⁻⁴ B_ref]
b11 [10⁻⁶ B_ref]
b12 [10⁻⁶ B_ref]
b13 [10⁻⁶ B_ref]
b14 [10⁻⁶ B_ref]
b15 [10⁻⁶ B_ref]
φ
−4σ
+4σ


φ
a3 [10^-4 B_ref]
a4 [10^-4 B_ref]
a5 [10^-4 B_ref]
a6 [10^-4 B_ref]
a7 [10^-4 B_ref]
a8 [10^-4 B_ref]
a9 [10^-4 B_ref]
a10 [10^-4 B_ref]
a11 [10^-6 B_ref]
a12 [10^-6 B_ref]
a13 [10^-6 B_ref]
a14 [10^-6 B_ref]
a15 [10^-6 B_ref]

- Doubling ξ_{R} indeed gives more representative sampling
- However, in specification: errors are **truncated** at 4σ
  while in this approach seeds beyond 4σ are not discarded
  $\Rightarrow$ actual DA will be slightly higher than reported here

DA


Beam 1
Beam 2
DA [σ]
16
14
12
10
8
6
4
baseline
baseline
D2 errors:
double random
no systematic
baseline
without D2

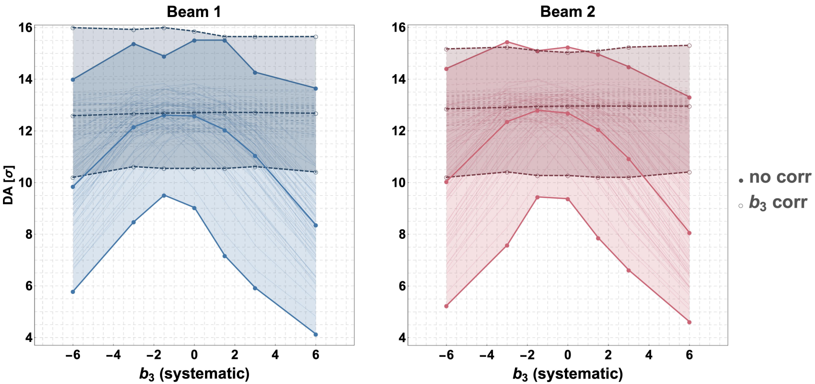
DA

- Baseline: all errors assigned except MCBXF and MCBRD
- Removing systematic D2 errors improves DA for most seeds

$\Rightarrow$ as expected!

hence no compensation effects due to random part

DA from b_3 of D2



DA from b_3 of D2

- D2 with double randoms assigned, only systematic b_3
- Strong impact at high values, more so for positive values
- Best DA achieved at $-3, 0$, or $+3$, depending on seed

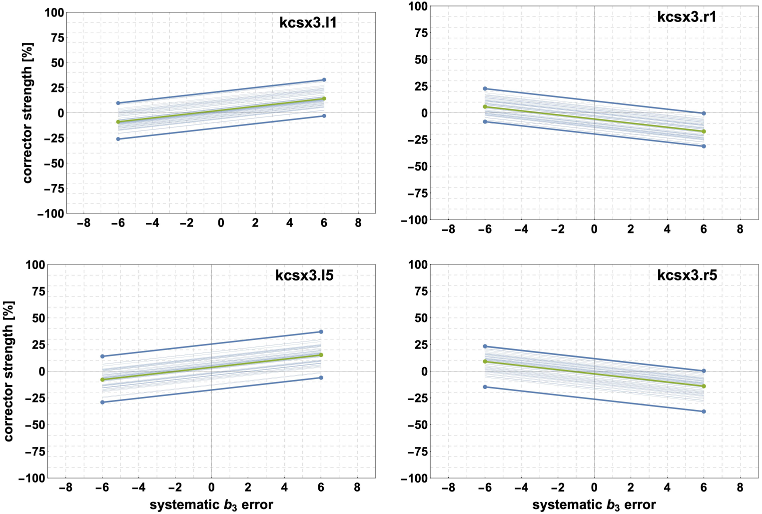
  $\Rightarrow$ seed-dependent compensation from systematic part

- Remember that seeds beyond 4σ are not discarded

  $\Rightarrow$ actual DA will increase

- If we use the non-linear corrector package to correct the b_3 error of the D2 (averaged over both beams), the DA can be fully recovered

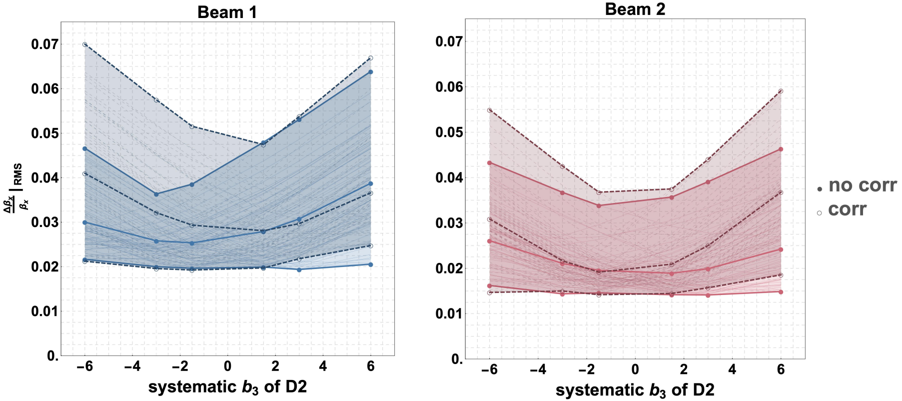
b_3 corrector strengths for D2



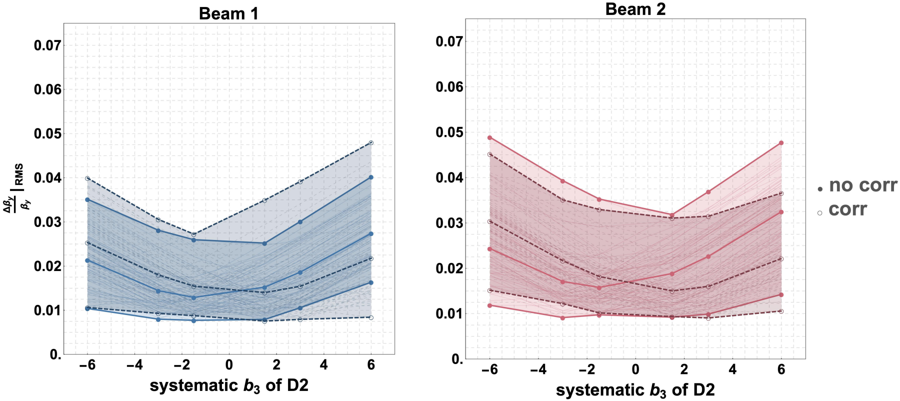
b_3 corrector strengths for D2

- Correcting a systematic $b_3 = \pm 6$ uses $\pm 11.5\%$ of the corrector budget
  - $\Rightarrow$ safe margin, leaving room to correct other magnets
  - $\Rightarrow$ probably even for potentially higher values of b_3
- Do the correctors introduce seizable beta-beating (via feed-down)?

Beta-Beating from Correctors



Beta-Beating from Correctors



Beta-Beating from Correctors

- For $b_3 = \pm 6$, beta-beating increases slightly ($< 1\%$)

  $\Rightarrow$ under control

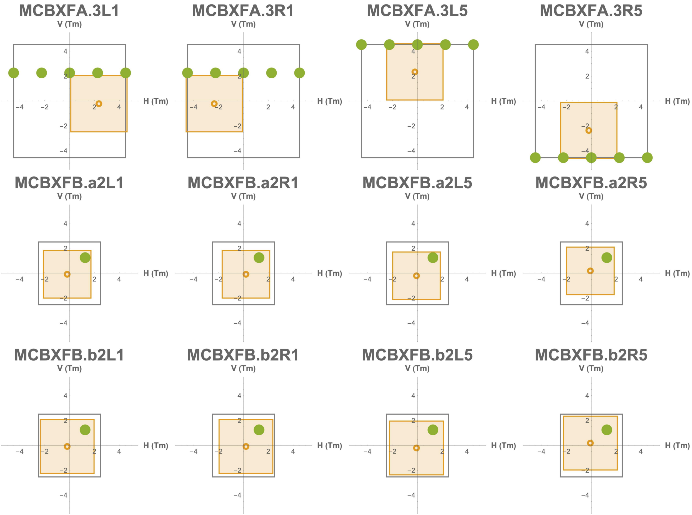
- Is D2 correction compatible with e.g. MCBXF correction?
- Can we estimate (theoretical) budget needed for MCBXF?

  $\Rightarrow$ depends on sign configuration!

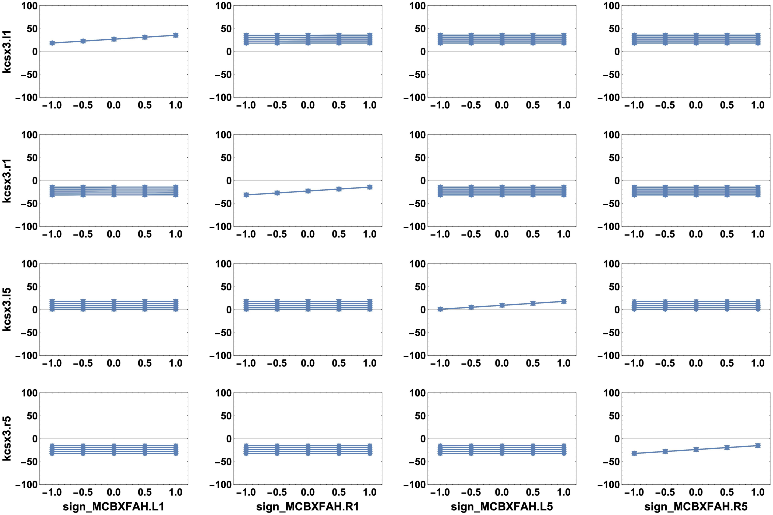
  $\Rightarrow$ test a few (625) configurations, only MCBXFAH, seed 1

  $\Rightarrow$ avoid feasibility discussion . . .

Strengths for MCBXF correction



Strengths for MCBXF correction

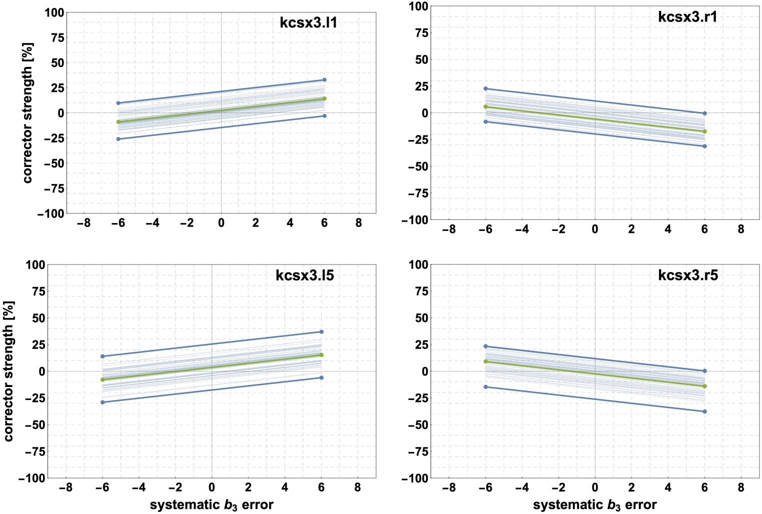


Strengths for MCBXF correction

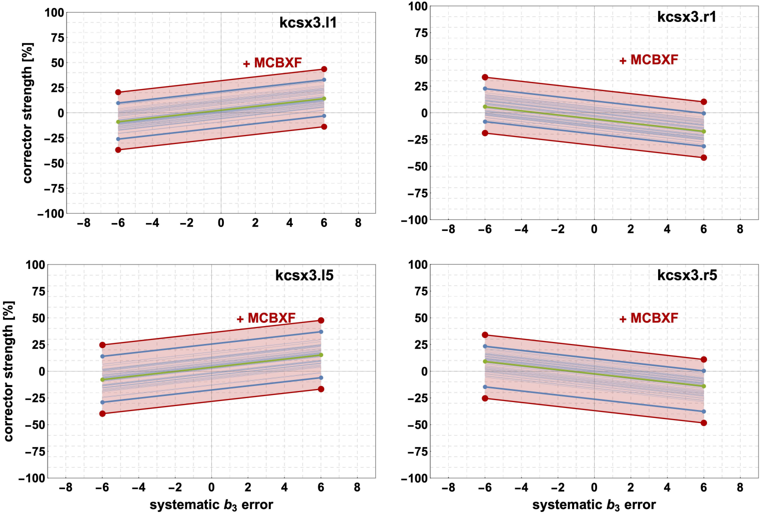
- Correctors are uncorrelated, on each side of each IP
  - $\Rightarrow$ we can safely "ignore" internal compensations...
  - $\Rightarrow$ only sign of MCBXF closest to corrector matters
- Note that this is worst-case, not assuming FRAS...

- Effect of (weak) MCBXFB is $\pm 2.1\%$ of budget
- Effect of MCBXFA is $\pm 8.6\%$ of budget
  - $\Rightarrow$ how does this influence total budget (MCBXF + D2)?

Strengths for MCBXF correction



Strengths for MCBXF correction



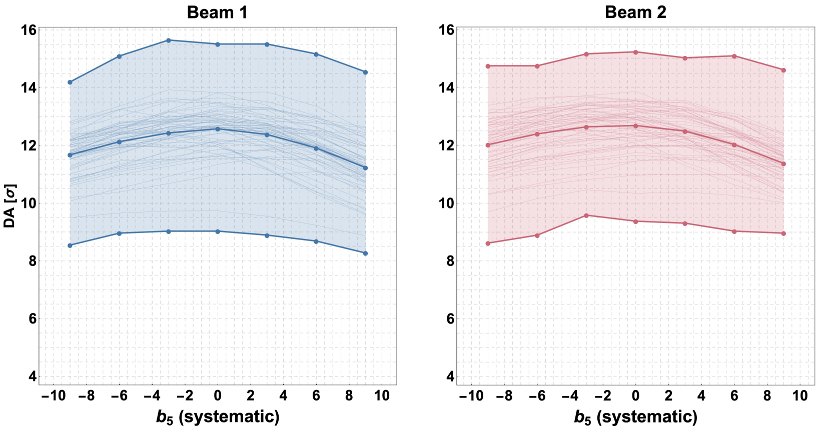
Strengths for MCBXF correction

- Total corrector budget (60 seeds):

$$\text{kcsx3.l1} : [-37\%, 44\%]$$
$$\text{kcsx3.r1} : [-42\%, 33\%]$$
$$\text{kcsx3.l5} : [-40\%, 48\%]$$
$$\text{kcsx3.r5} : [-48\%, 34\%]$$

- Adding D2 to correction algo does not limit other magnets!

DA from b_5 of D2



DA from b_5 of D2

- D2 with double randoms assigned, only systematic b_5
- Very little impact on DA

Conclusion

- Random part does not lead to compensations (most seeds)
- Systematic part clearly leads to compensations
- DA strongly influenced by (large) systematic b_3
- DA not really influenced by systematic b_5

$\Rightarrow$ perfect!

b_3 can be corrected

(while for b_5 no good algorithm exists yet)