Possibility to suppress the installation of MS in Q10 in IR1 & 5

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INTRODUCTION

- The Baseline HL-LHC lattice foreseen the **installation of 4 additional sextupoles MS in Q10** → 1 additional MS on each side of IP1 & IP5

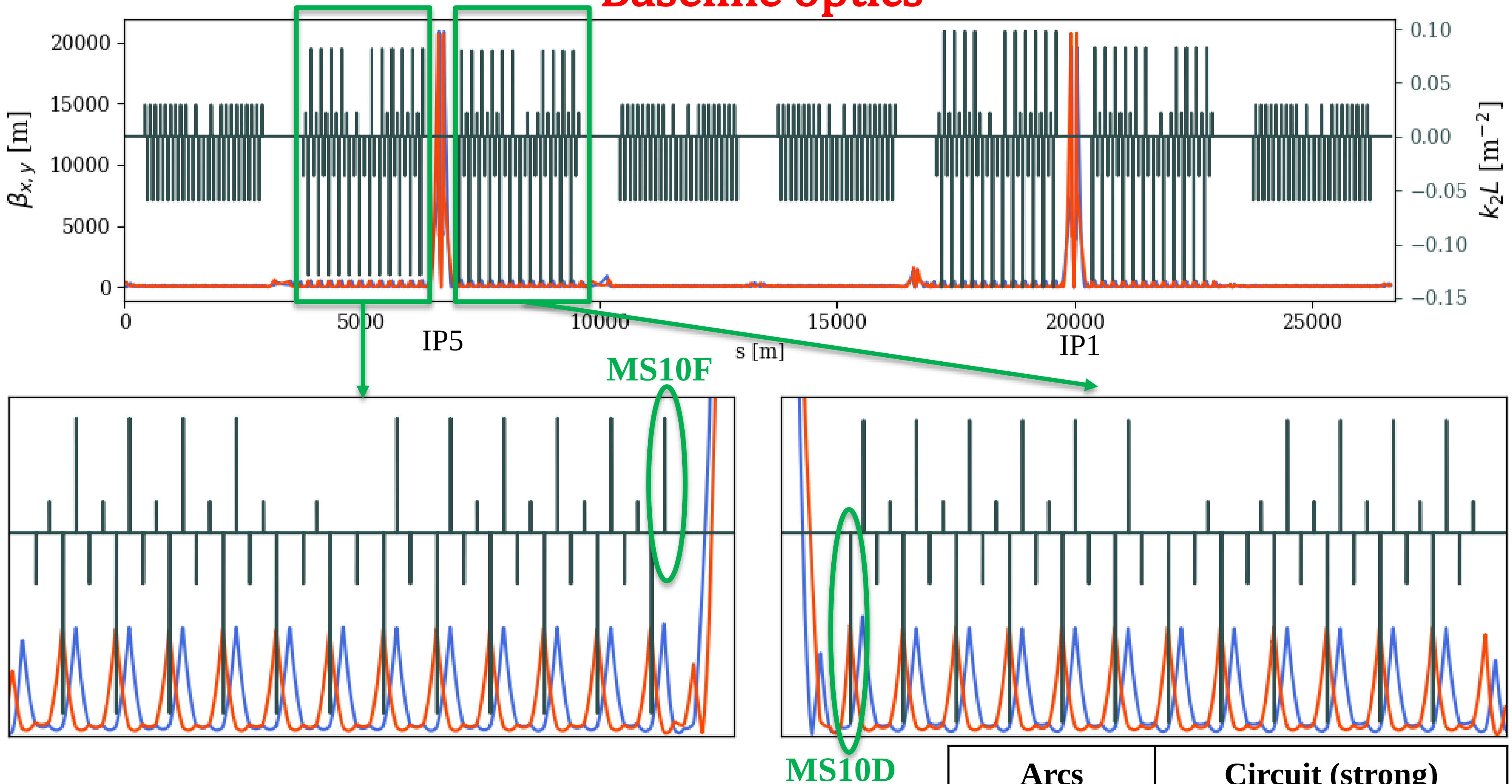
- The additional MS10 allows to **allow to keep the machine DA to a viable level by providing a better compensation of the geometrical aberrations** generated by the MS in the high β regions, adjacent to IR1 and IR5.

- **Alternative sextupole lattices** have been studied and can restore self-compensation of the non-linear resonances to the same level as the Baseline optics but **without MS10**.

The comparison of the different lattices are based on the **round optics at $\beta^*_{x,y}$=15 cm** and using the latest **HLLHCV1.4** optics

INTRODUCTION

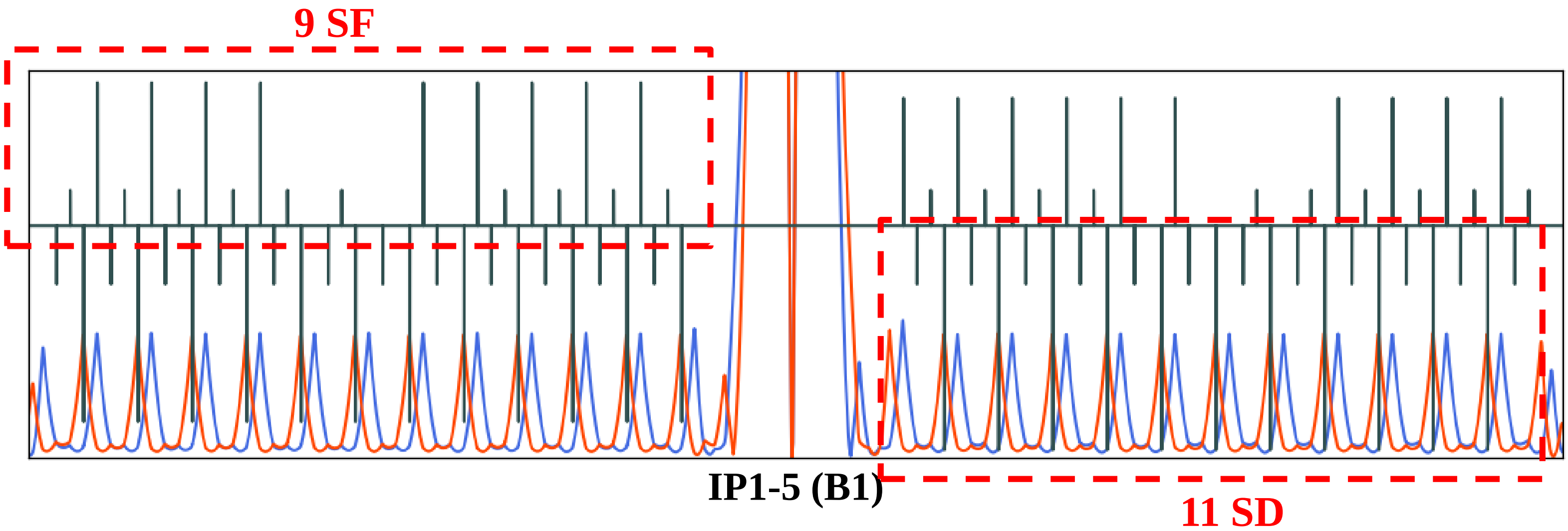
Baseline optics



The additional MS10 in each side of IP1&5 **restore an even number of sextupoles** allowing the cancellation of geometrical aberrations

Arcs	Circuit (strong)
B1: 81, 45	SF1 (**10**), SD2 (**12**)
B2: 81, 45	SF1 (**10**), SD2 (**12**)
B1: 12, 56	SF1 (**10**), SD2 (**12**)
B2: 12, 56	SF1 (**10**), SD2 (**12**)

No MS10 (LHC configuration)

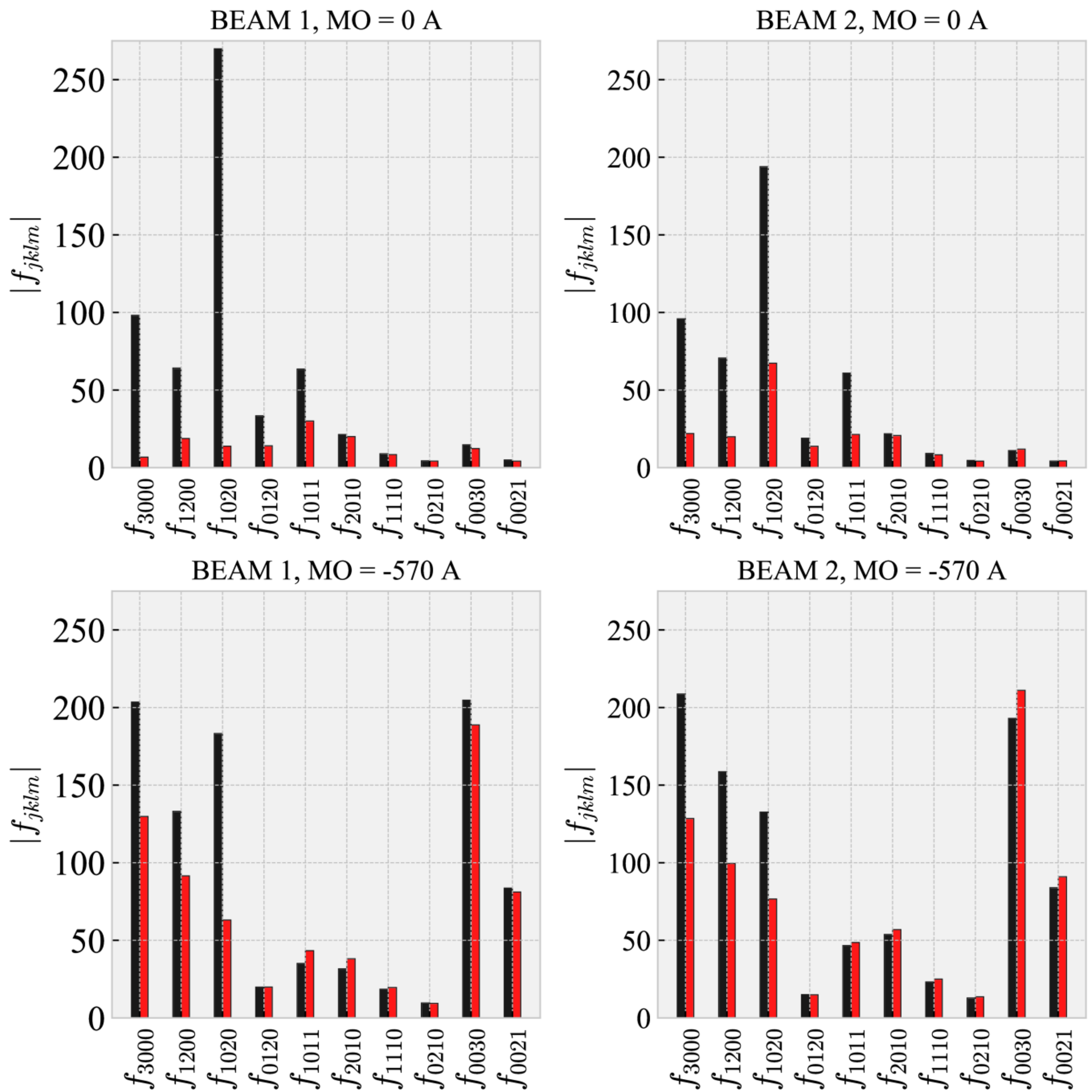


Odd number of sextupoles on each side of IP1&5

Arcs	**Circuit (strong)**
B1: 81, 45	SF1 (**9**), SD2 (**12**)
B2: 81, 45	SF1 (**10**), SD2 (**11**)
B1: 12, 56	SF1 (**10**), SD2 (**11**)
B2: 12, 56	SF1 (**9**), SD2 (**12**)

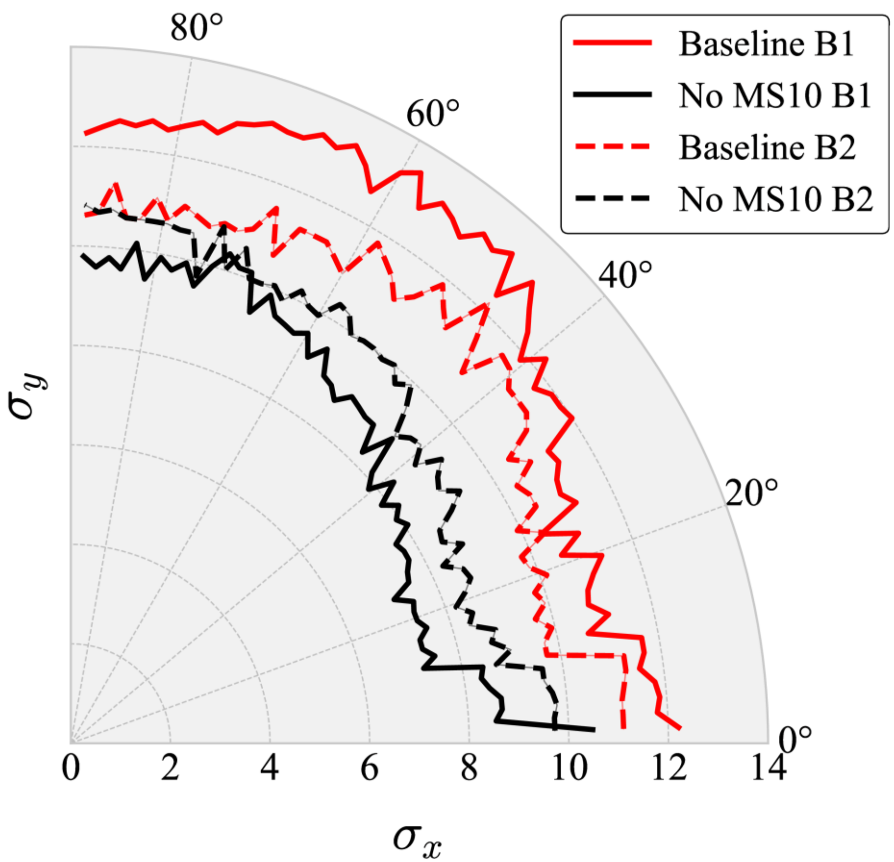
INTRODUCTION

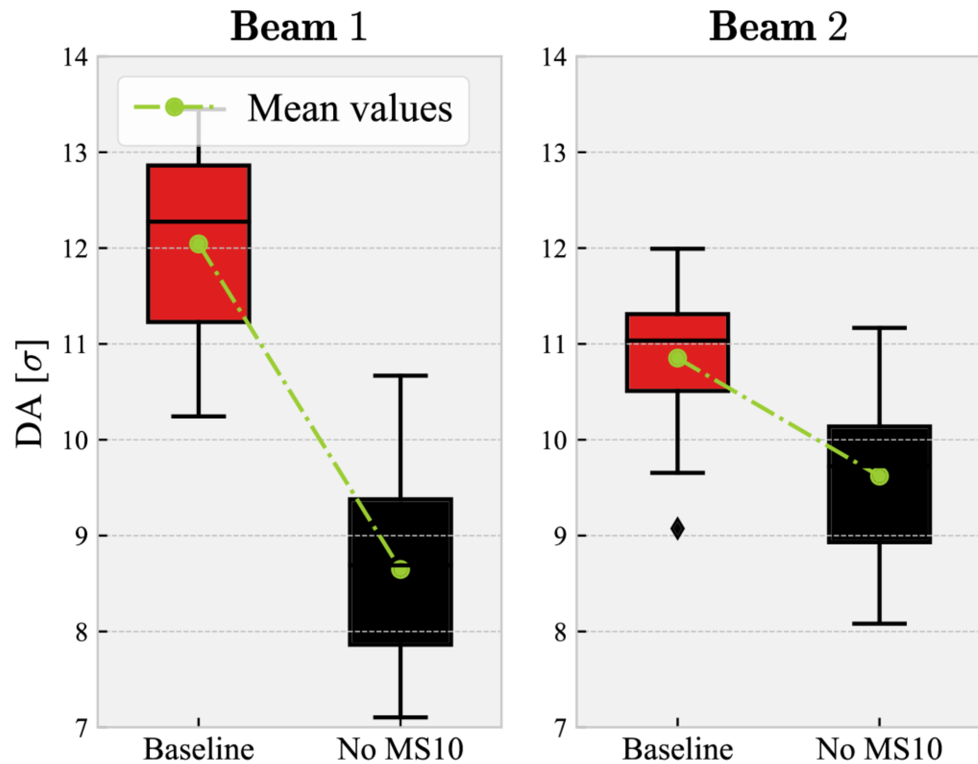
No MS10 vs **Baseline**
Average sextupole RDTs computed at $\beta^*_{x,y}$=15 cm with the crossing scheme and disp. correction



Self-compensation of the geometrical aberrations excited during the ATS can be obtained if the strong sextupole families contain an **even number** of magnets

INTRODUCTION





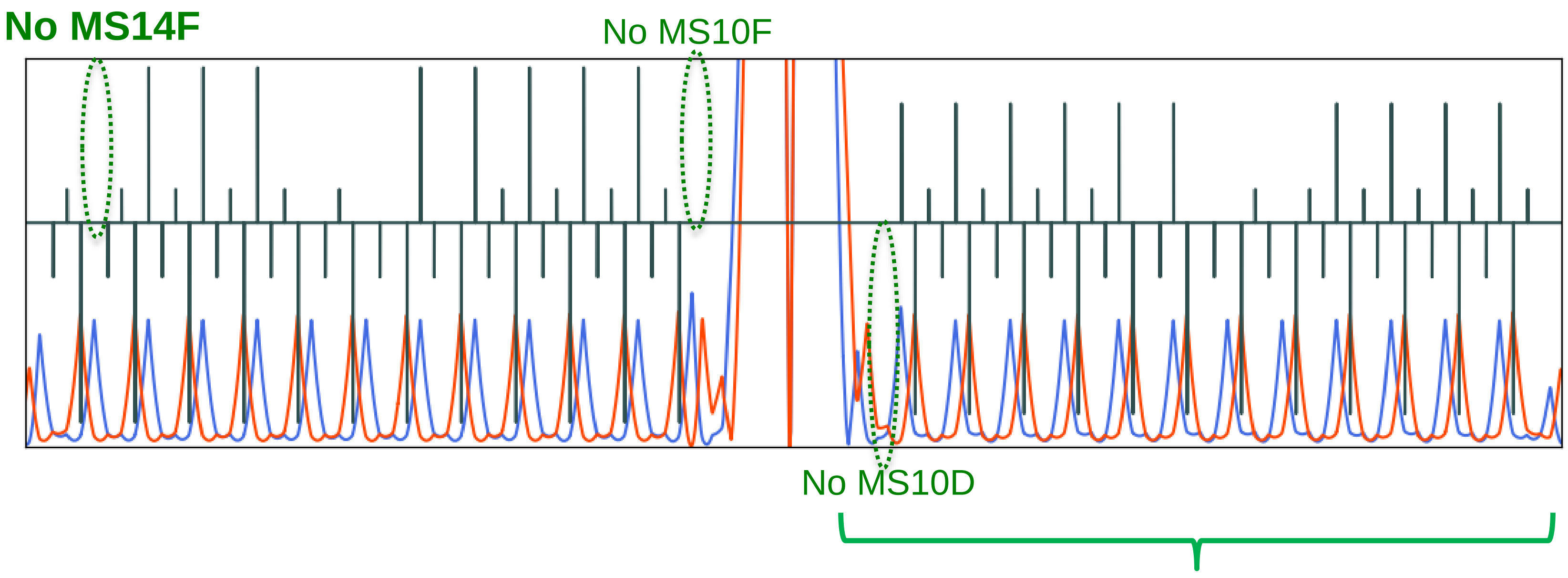
No MS10 vs **Baseline**

DA computation:

xing = **295 μrad**, Q_x= 62.31 / Q_y= 60.32, δ_p= 2.7× 10^{-4}, **without imperfections**, **with dispersion correction**, Q'=**15**, **MO = -570 A**, 10^6 turns, 60 angles

Optics	Avg. DA (B1/B2)	Min. DA (B1/B2)
No MS10	**8.7 / 9.6**	**7.1 / 8.2**
Baseline	**12.0 / 10.9**	**10.5 / 9.6**

Alternative Optics without MS10: No MS14F optics



New phases in IR1 & 5 : $\Delta\mu_y^{IR1\&5} = -\frac{\pi}{2}$

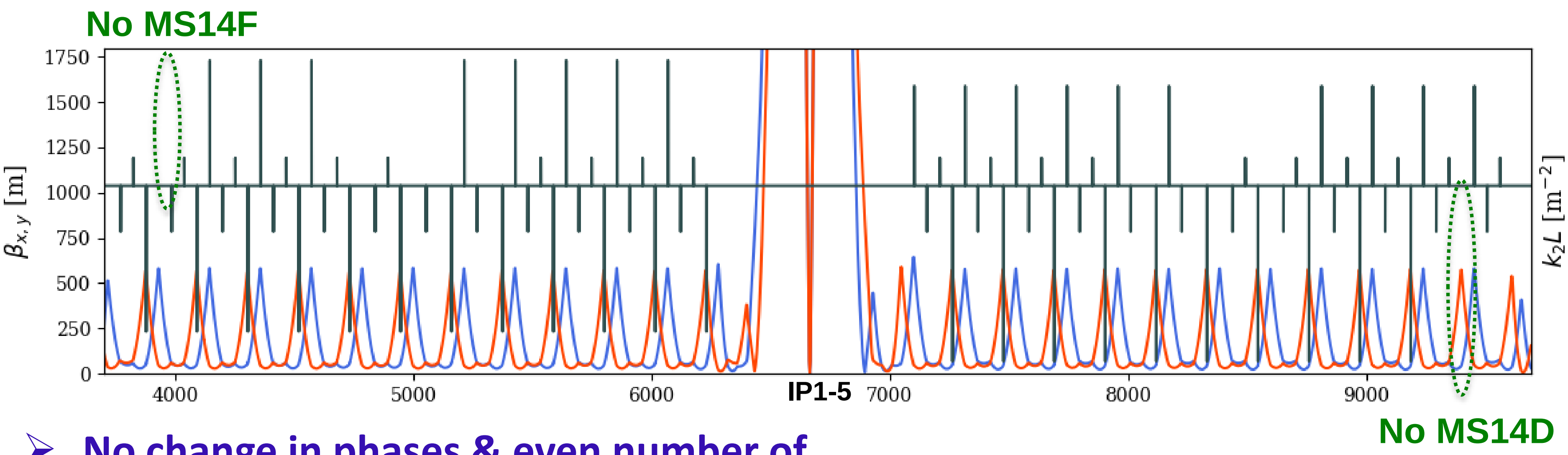
12 strong defocusing & 11 local defocusing sextupoles

- **No additional sextupole and MS14F disconnected (in 81 & 45)**
- **Change of phase and optics rematch (in 12 & 56)**

- Even number of strong sextupoles on each side of IP1&5 → **geom. aberr. Cancellation**
- Orbit and dispersion correction knobs have been modified accordingly

Arcs	Circuit (strong)
B1: 81, 45	SF1 (8), SD2 (12)
B2: 81, 45	SF1 (10), SD2 (12)
B1: 12, 56	SF1 (10), SD2 (12)
B2: 12, 56	SF1 (8), SD2 (12)

Alternative Optics without MS10: No MS14F & MS14D optics



- **No change in phases & even number of sextupoles by disconnecting MS14D**

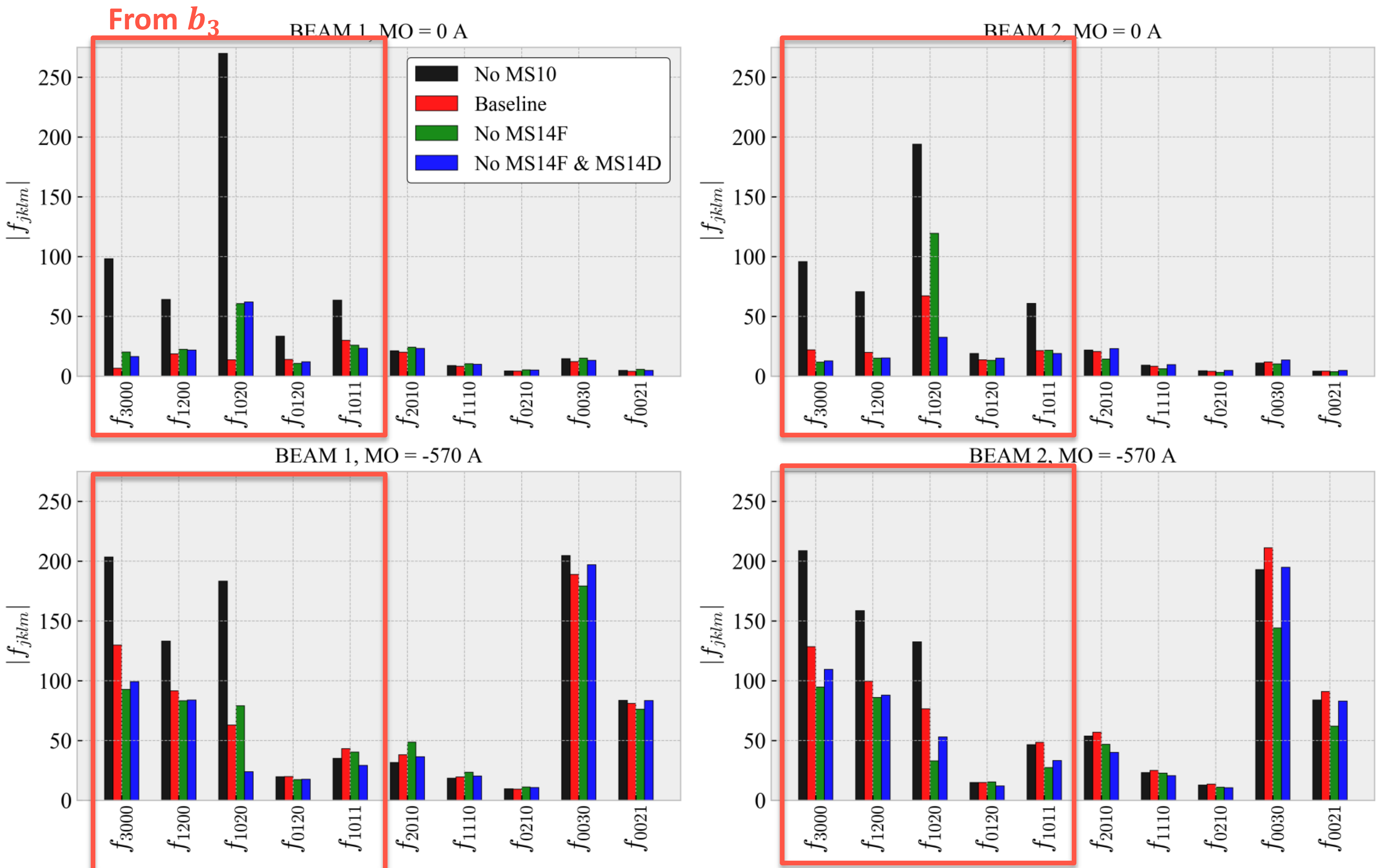
- Requires an **increase of ~20%** of the sextupole strength for chromaticity correction

- **Strong family strength in IR15 kept constant** and weak sextupoles family **strength increased in 23, 34, 67, 78**

Arcs	Circuit (strong)
B1: 81, 45	SF1 (**8**), SD2 (**12**)
B2: 81, 45	SF1 (**10**), SD2 (**12**)
B1: 12, 56	SF1 (**10**), SD2 (**10**)
B2: 12, 56	SF1 (**8**), SD2 (**10**)

- **Worse chromatic correction in the vertical plane:**
  W_y = 220 in IP7 *(W_y = 80 for Baseline)* ; Q''_y = 10983 *(Q''_y = 7630 for Baseline)*

Alternative Optics without MS10: RDT comparison

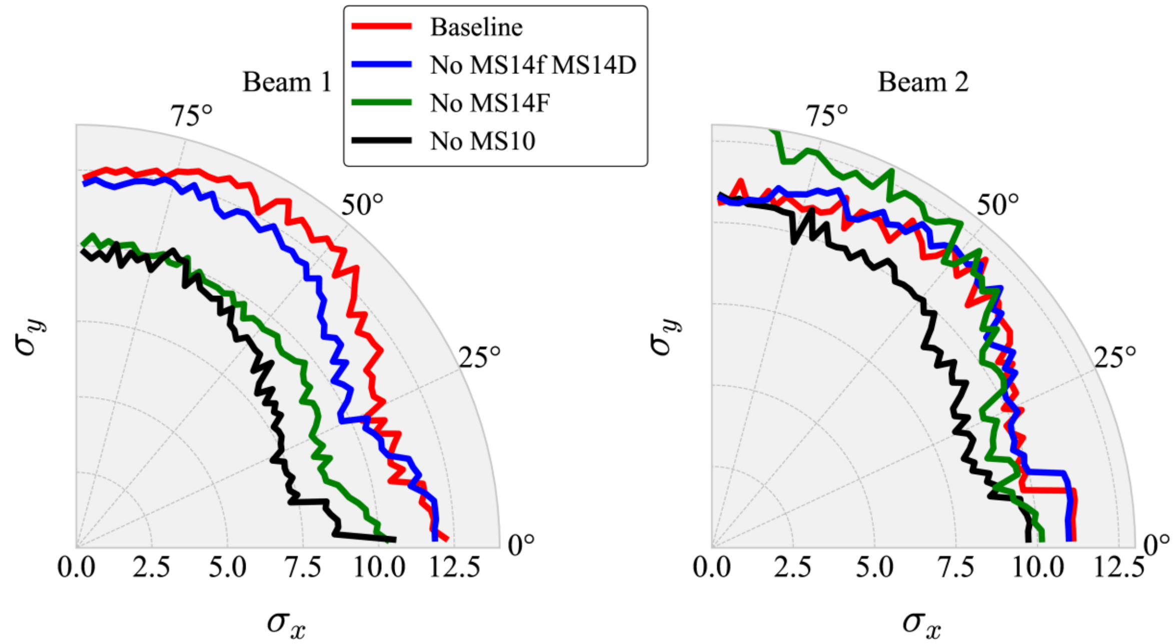


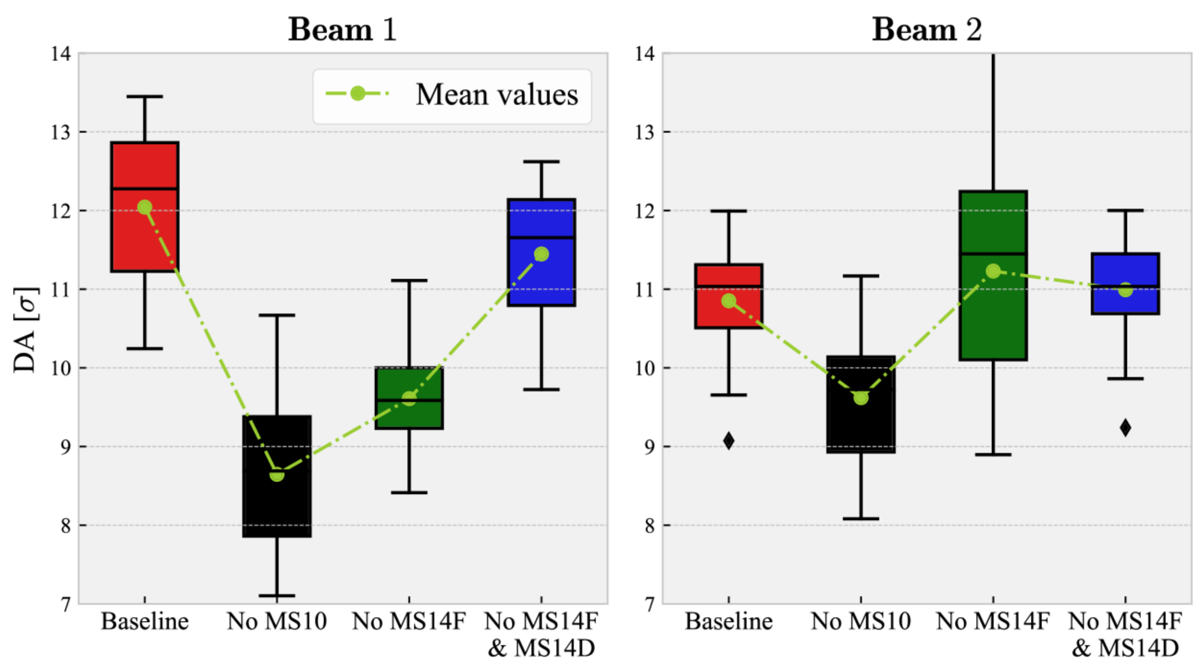
Similar compensation of the geometrical aberrations for the **No MS14F optics** and the **No MS14F & MS14D** optics w.r.t to the **Baseline**

Alternative Optics without MS10: DA comparison

- **Alternative optics shows larger DA than the No MS10** optics for both beams
- Large difference between B1 & B2 for the **No MS14F optics**
- **DA in B2 very similar between Baseline and alternative optics**

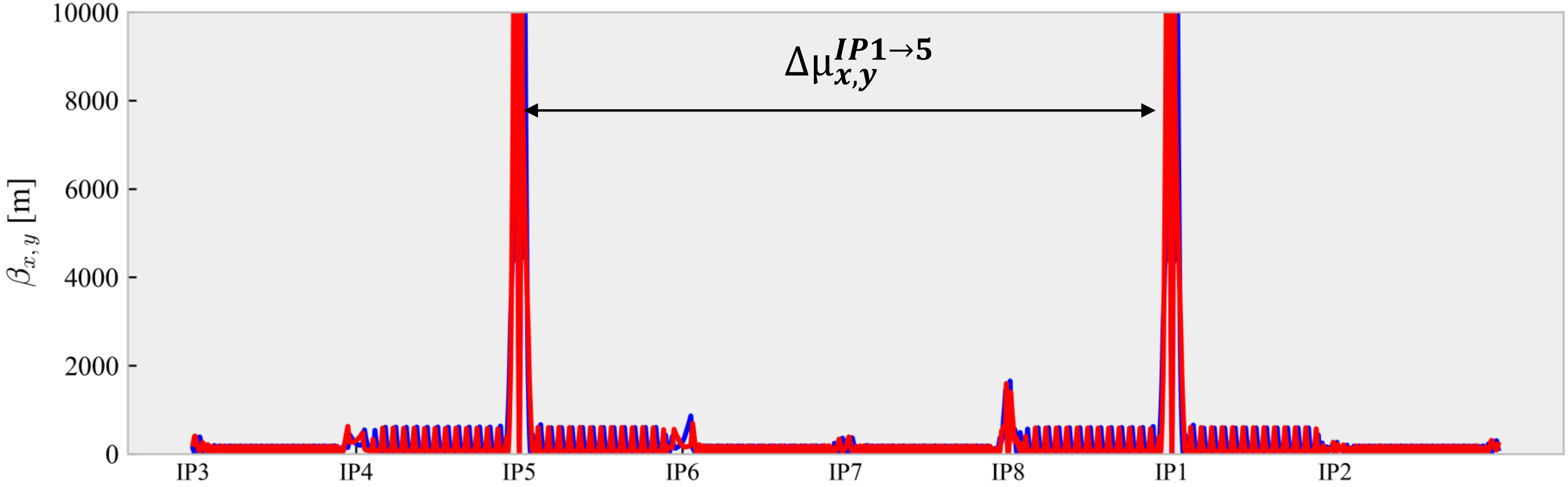
Optics	Avg. DA (B1/B2)	Min. DA (B1/B2)
No MS10	**8.7 / 9.6**	**7.1 / 8.2**
Baseline	**12.0 / 10.9**	**10.2 / 9.1**
No MS14F	**9.5 / 11.2**	**8.3 / 9.0**
No MS14F & MS14D	**11.5 / 11.0**	**9.8 / 9.2**





IP1-5 phase advance optimization

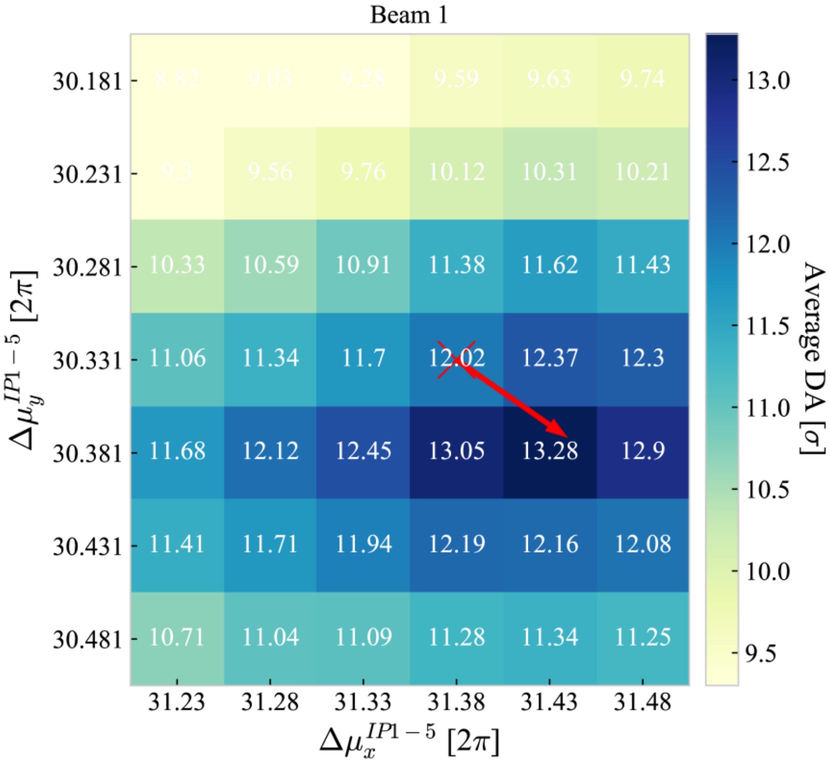
We investigated the possibility to **improve the DA** and **reduce the difference between B1 and B2**, for all optics, by **optimizing** $\Delta\mu_{x,y}^{IP1\rightarrow 5}$

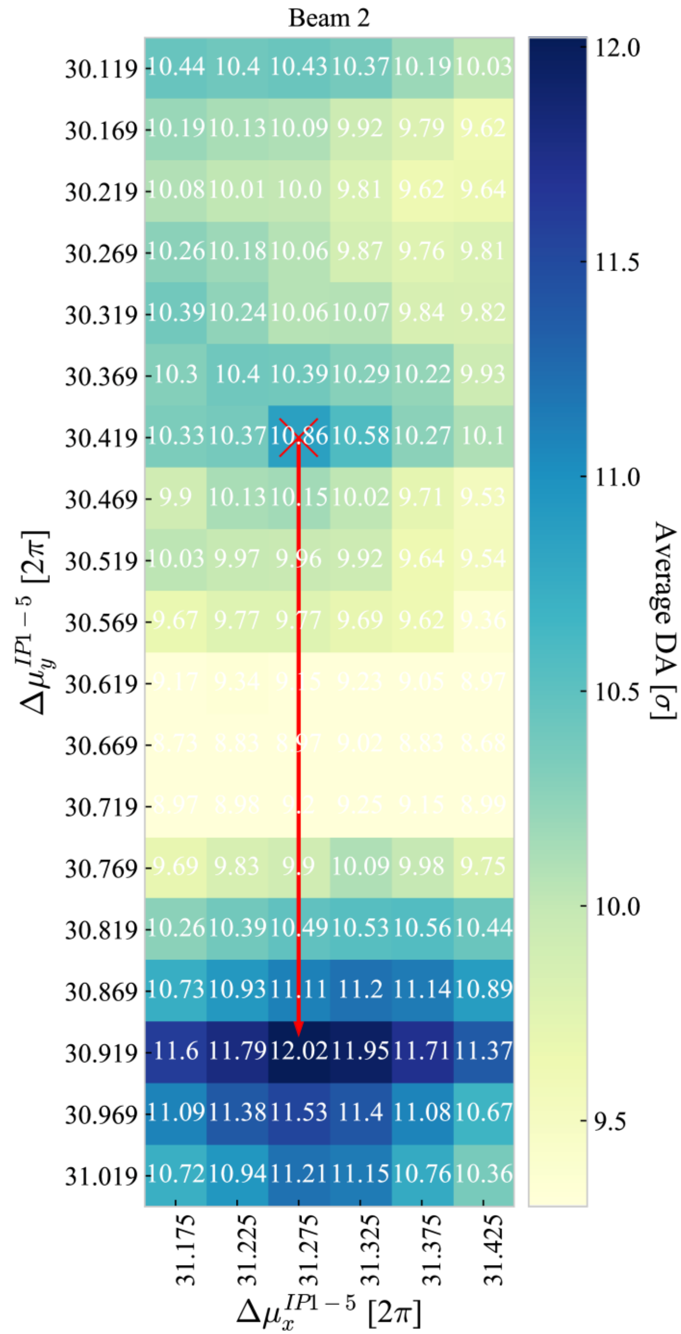


- **important impact on the compensation of some fourth and higher order resonant driving terms and on the tune diagram which can improve DA**
- 2D scan of the x,y phase advance between IP1 & 5 while keeping the overall tune constant
- The new optimized optics **take into account the limitation of the horizontal phase between MKD-TCT in IP1** for machine protection, and all other contraints for the HL-LHC optics

IP1-5 phase advance optimization: Baseline

xing = **295** μrad, Q_x= 62.31 / Q_y= 60.32, δ_p= 2.7× 10^{-4}, **without imperfections,with dispersion correction**, Q'=**15**, **MO = -570 A,** 10^6 turns, 60 angles





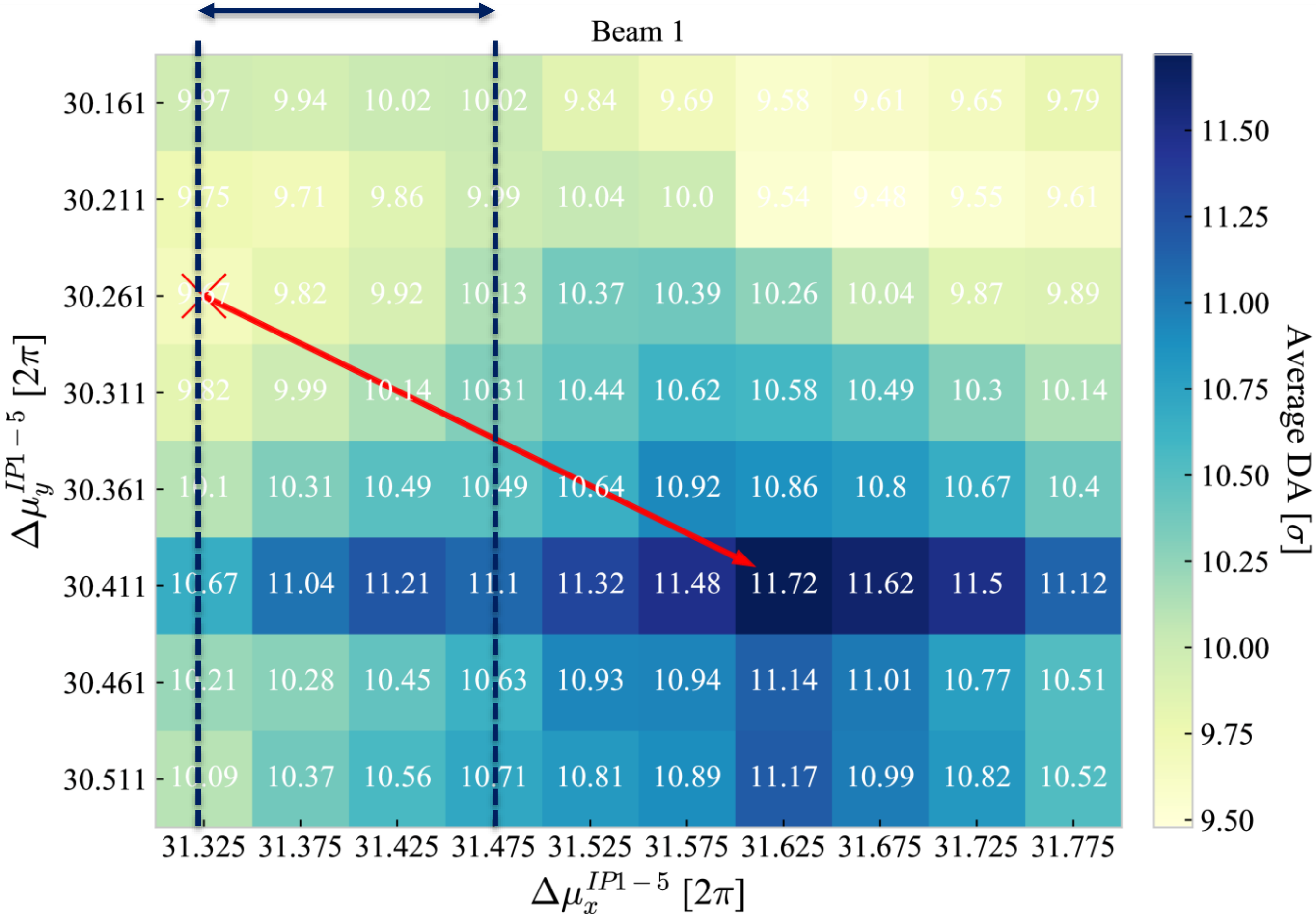
B1: $\Delta\mu_x^{IP1\rightarrow5} = +\frac{\pi}{10}$, $\Delta\mu_y^{IP1\rightarrow5} = +\frac{\pi}{10}$ → **ΔDA = +1.26σ**

B2: $\Delta\mu_x^{IP1\rightarrow5} = +0$, $\Delta\mu_y^{IP1\rightarrow5} = +\pi$ → **ΔDA = +1.16σ**

- Compatible with IR6 constraints (MKD-TCT phase in IP1 below 20°)

IP1-5 phase advance optimization: No MS14F

$\Delta\mu_x^{IP1\to5}$ range where $\Delta\mu_x^{MKD-TCT,IP1} < 20°$



- The $IP^{1\to5}$ phase advance for Beam 1 for No MS14F optics was originally set far from an optimal point for RDTs compensation
- The optimum phase point for DA was found at a $\Delta\mu_x^{IP1\to5}$ not compatible with MKD-TCT phase contraints

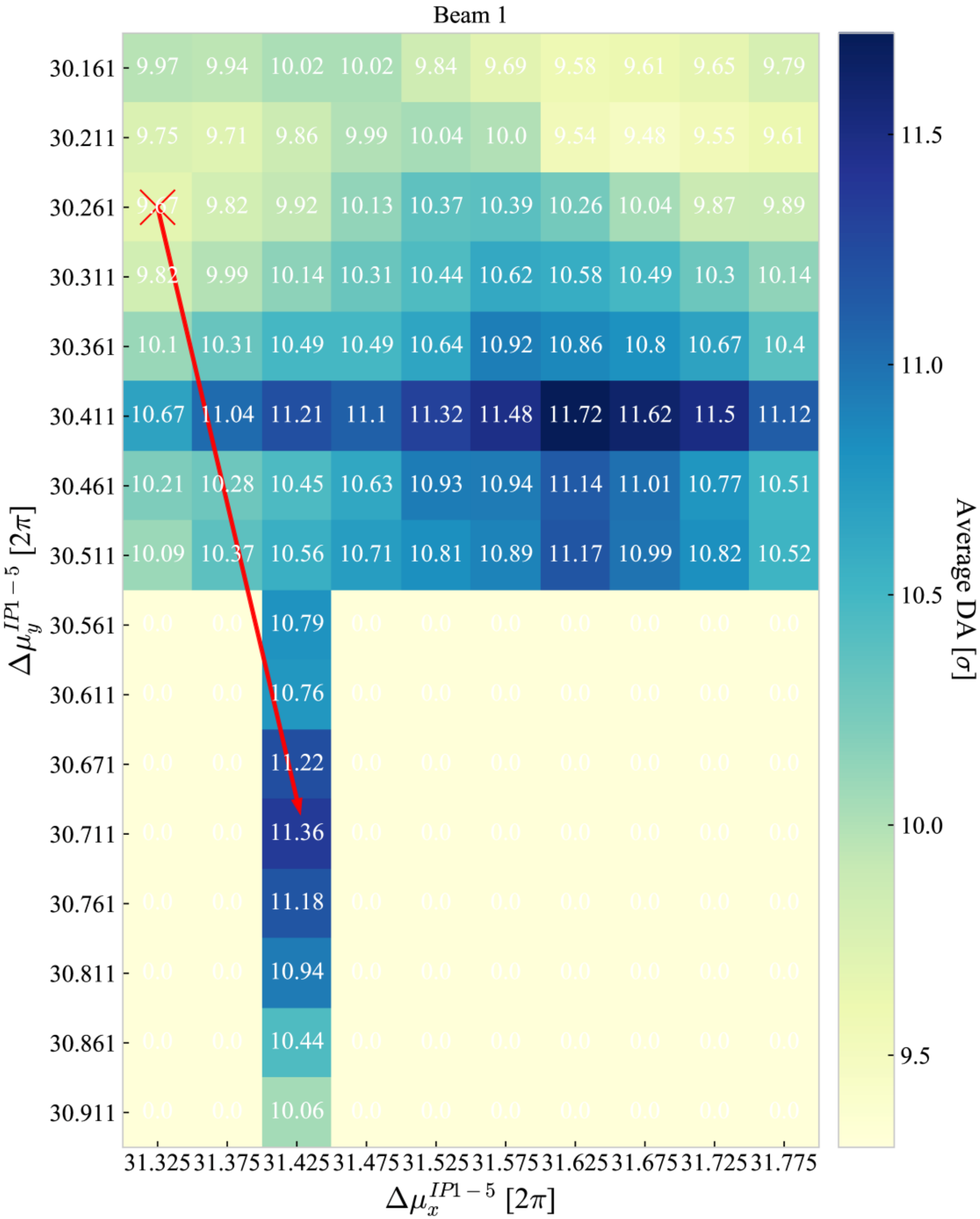
IP1-5 phase advance optimization: No MS14F

- New DA optimum for B1 compatible with IR6 constraints found for larger $\Delta\mu_y^{IP1\rightarrow5}$

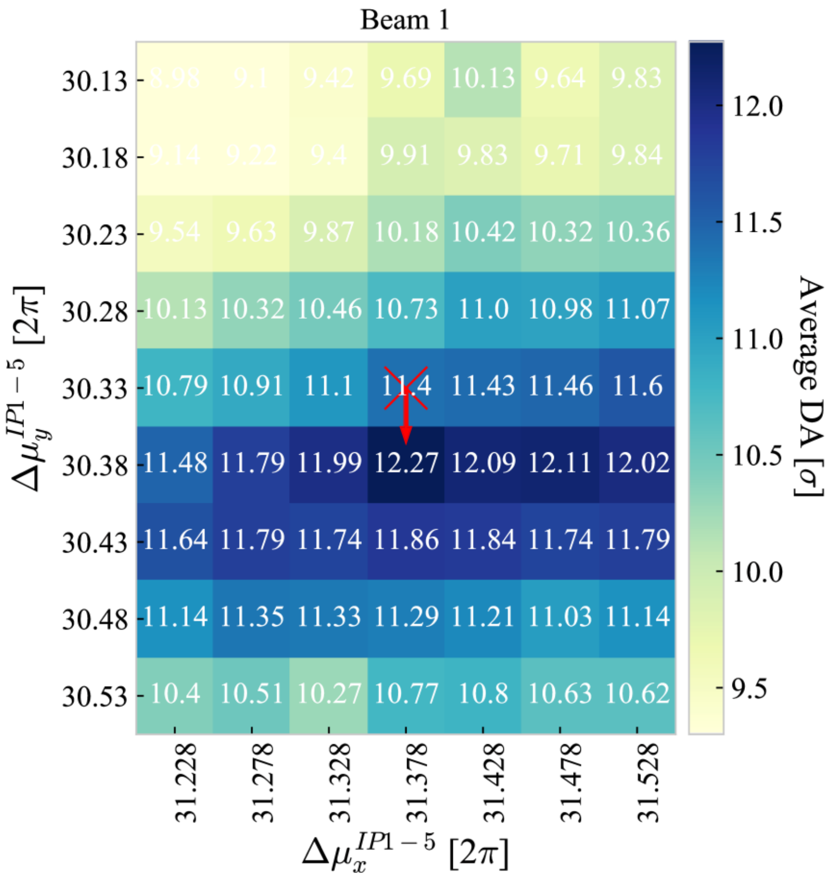
B1: $\Delta\mu_x^{IP1\rightarrow5} = +\frac{\pi}{10}$, $\Delta\mu_y^{IP1\rightarrow5} = +\frac{9\pi}{10}$ → **ΔDA =+1.8σ**

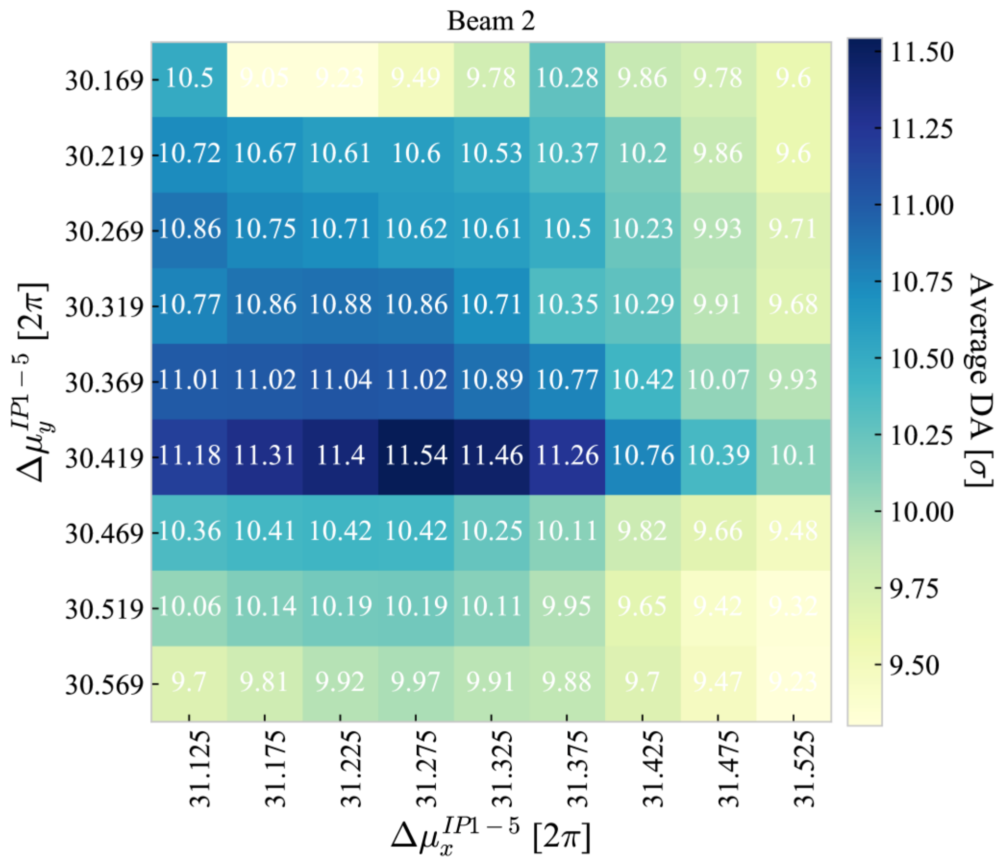
B2: $\Delta\mu_x^{IP1\rightarrow5} = -\frac{\pi}{10}$, $\Delta\mu_y^{IP1\rightarrow5} = +\frac{\pi}{10}$ → **ΔDA =+0.3σ**

- Beam 2 phase was already close to optimum DA point



IP1-5 phase advance optimization: No MS14F & MS14D





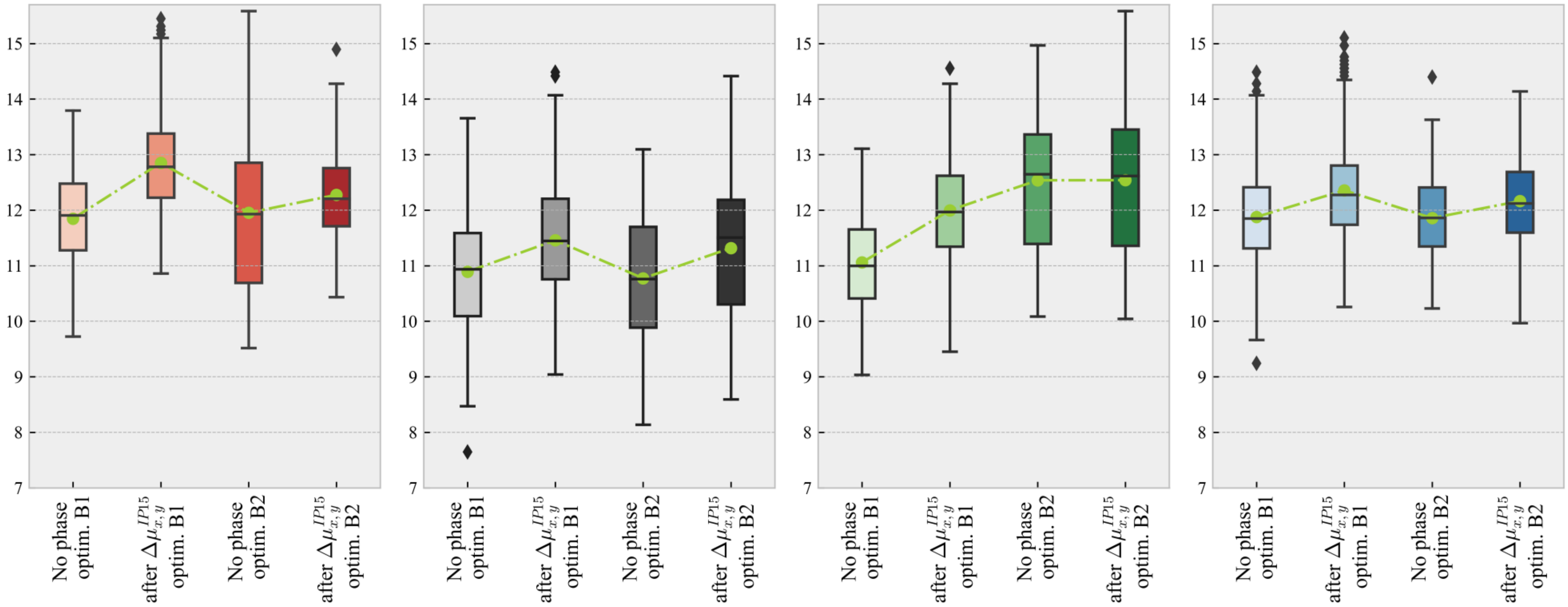
- Optimal phases $\Delta\mu_{x,y}^{IP1\rightarrow5}$ for the No MS14F &MS14D optics are very similar to the ones of the optimized Baseline

B1: $\Delta\mu_x^{IP1\rightarrow5} = 0°$,
$\Delta\mu_y^{IP1\rightarrow5} = +\frac{\pi}{10}$ → **ΔDA = +0.9σ**

B2: $\Delta\mu_x^{IP1\rightarrow5} = 0°$,
$\Delta\mu_y^{IP1\rightarrow5} = +\pi$ → **ΔDA = +0.7σ**

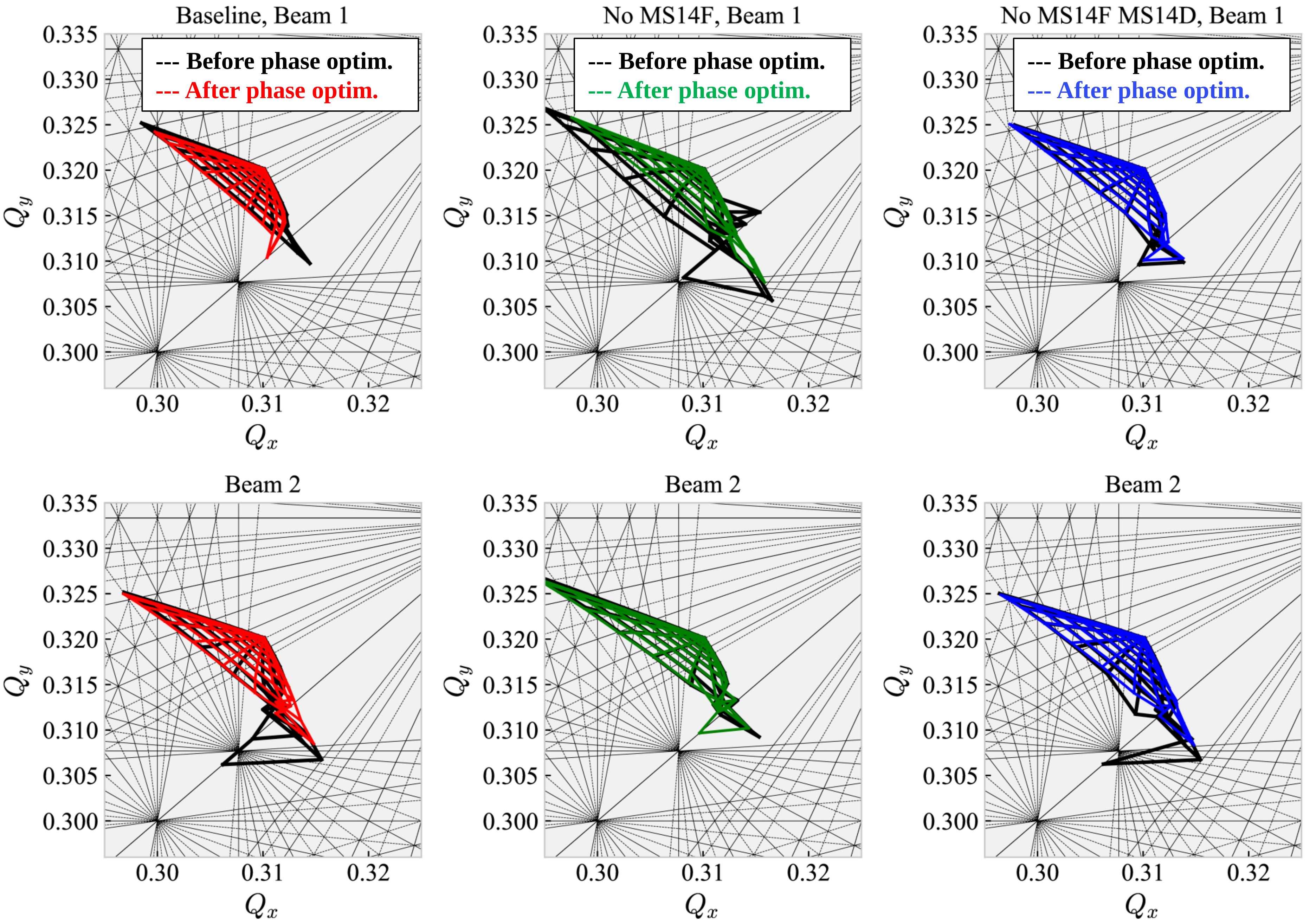
IP1-5 phase advance optimization: DA comparison

xing = **295** μ**rad**, Q_x= 62.31 / Q_y= 60.32, δ_p= 2.7× 10^{-4}, **with imperfections,with dispersion correction**, Q'=**15**, **MO = -570 A,**
10^5 turns, 7 angles

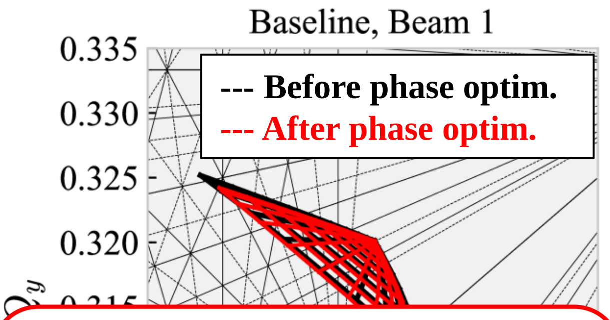


- After optimization of the $IP^{1\rightarrow 5}$ phase advance the **minimum and average DA are improved for all optics and both beams**, taking into account field imperfections *(using the corrected mask from Frederik and without MCBRD and MCBXFA field errors)*

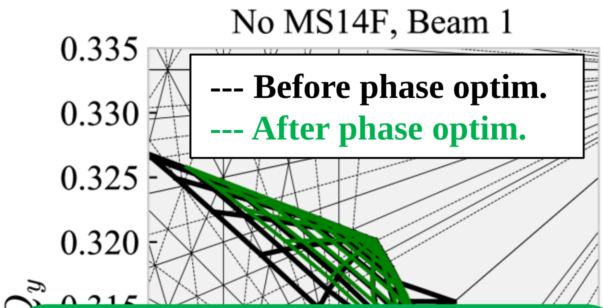
IP1-5 phase advance optimization: Footprint comparison (MO=-570 A)



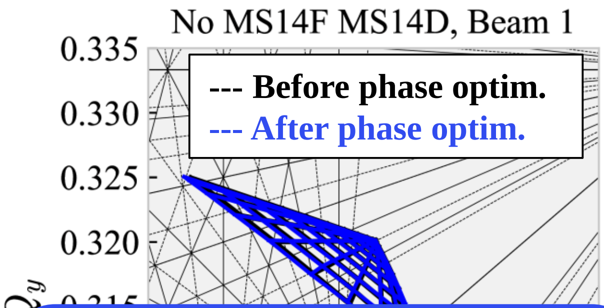
IP1-5 phase advance optimization: Amplitude Detuning (MO=-570 A)



Q_x/ϵ_x	Q_y/ϵ_y	Q_x/ϵ_y
-3.57. 10^5	-3.32. 10^5	1.70. 10^5
-3.69. 10^5	-3.33. 10^5	1.59. 10^5

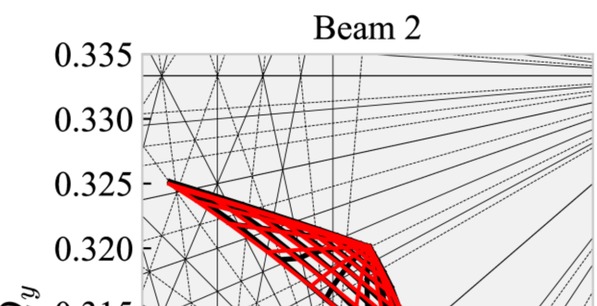


Q_x/ϵ_x	Q_y/ϵ_y	Q_x/ϵ_y
-4.17. 10^5	-3.41. 10^5	1.90. 10^5
-3.95. 10^5	-3.41. 10^5	1.85. 10^5

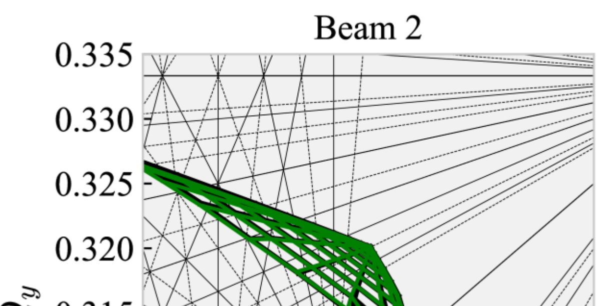


Q_x/ϵ_x	Q_y/ϵ_y	Q_x/ϵ_y
-3.92. 10^5	-3.40. 10^5	1.62. 10^5
-3.91. 10^5	-3.35. 10^5	1.59. 10^5

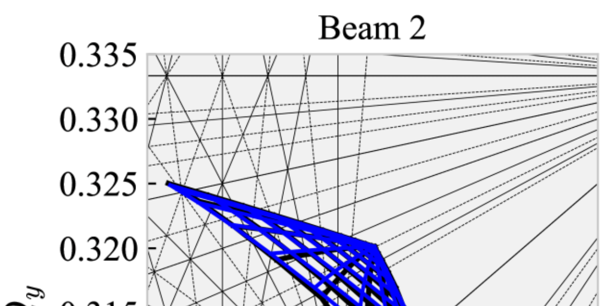
Q_x Q_x Q_x



Q_x/ϵ_x	Q_y/ϵ_y	Q_x/ϵ_y
-4.11. 10^5	-3.16. 10^5	1.70. 10^5
-4.10. 10^5	-3.35. 10^5	1.64. 10^5



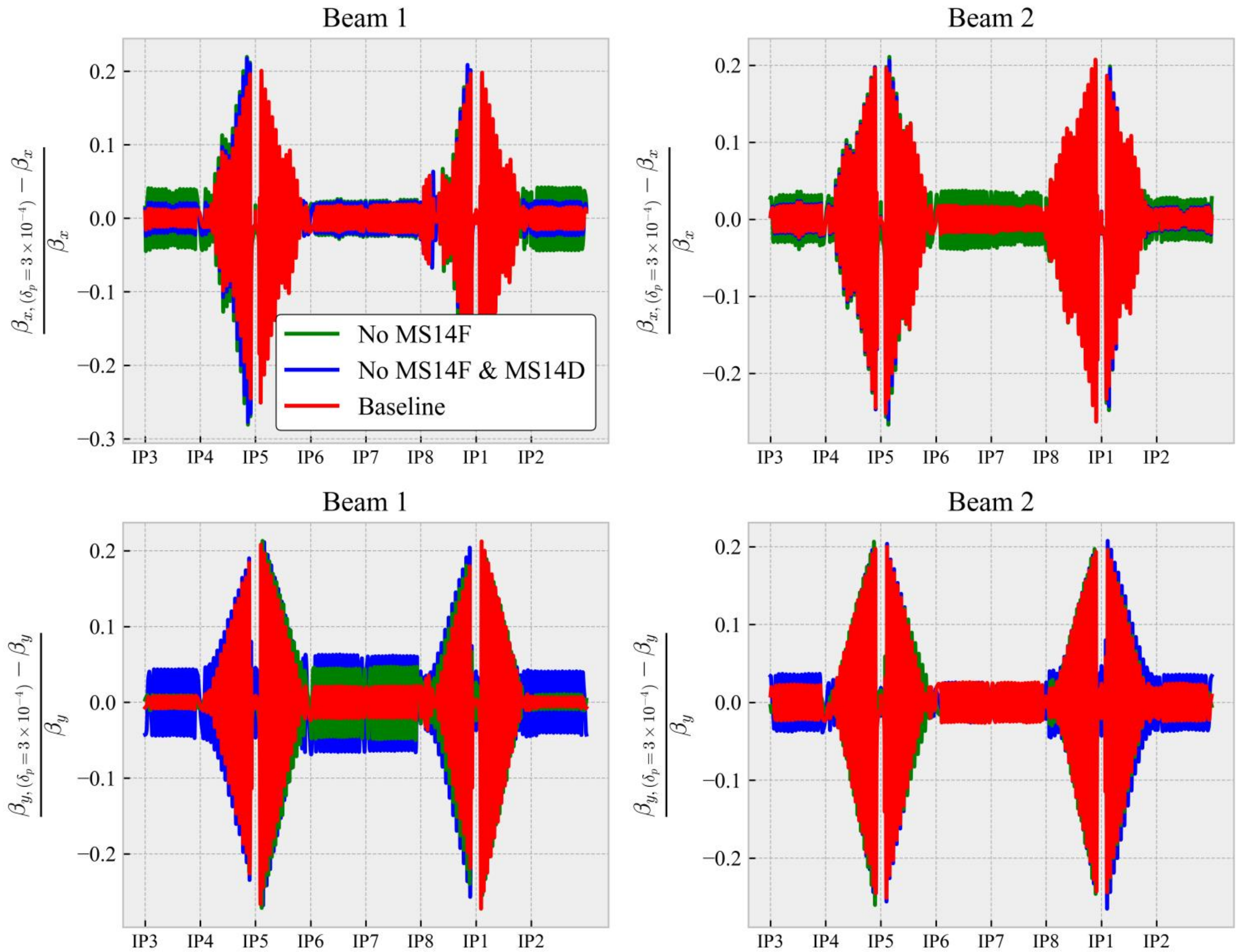
Q_x/ϵ_x	Q_y/ϵ_y	Q_x/ϵ_y
-4.13. 10^5	-3.39. 10^5	1.89. 10^5
-4.21. 10^5	-3.37. 10^5	1.85. 10^5



Q_x/ϵ_x	Q_y/ϵ_y	Q_x/ϵ_y
-4.24. 10^5	-3.18. 10^5	1.63. 10^5
-4.24. 10^5	-3.39. 10^5	1.61. 10^5

Q_x Q_x Q_x

Alternative Optics without MS10: Chromatic Properties

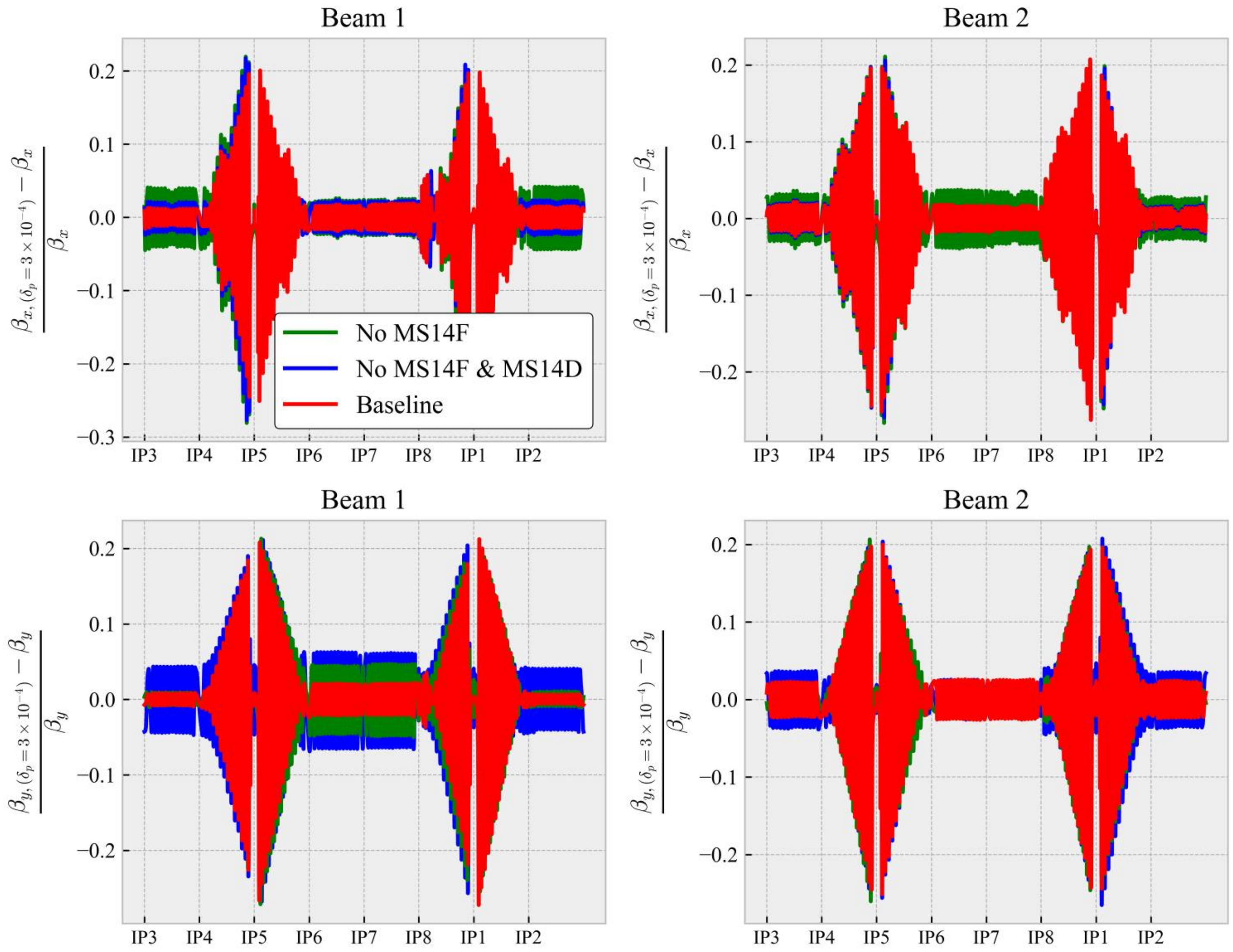


Largest chromatic β-beating in IP7 for Beam 1 in y:

~2% for Baseline , ~4.5% for No MS14F , ~6.4% for No MS14F & MS14D

At $\delta_p = 3\times 10^{-4}$

Alternative Optics without MS10: Chromatic Properties



The residual chromatic β-beating could be further optimized by adjusting the phase advance between MS and the IP1-5

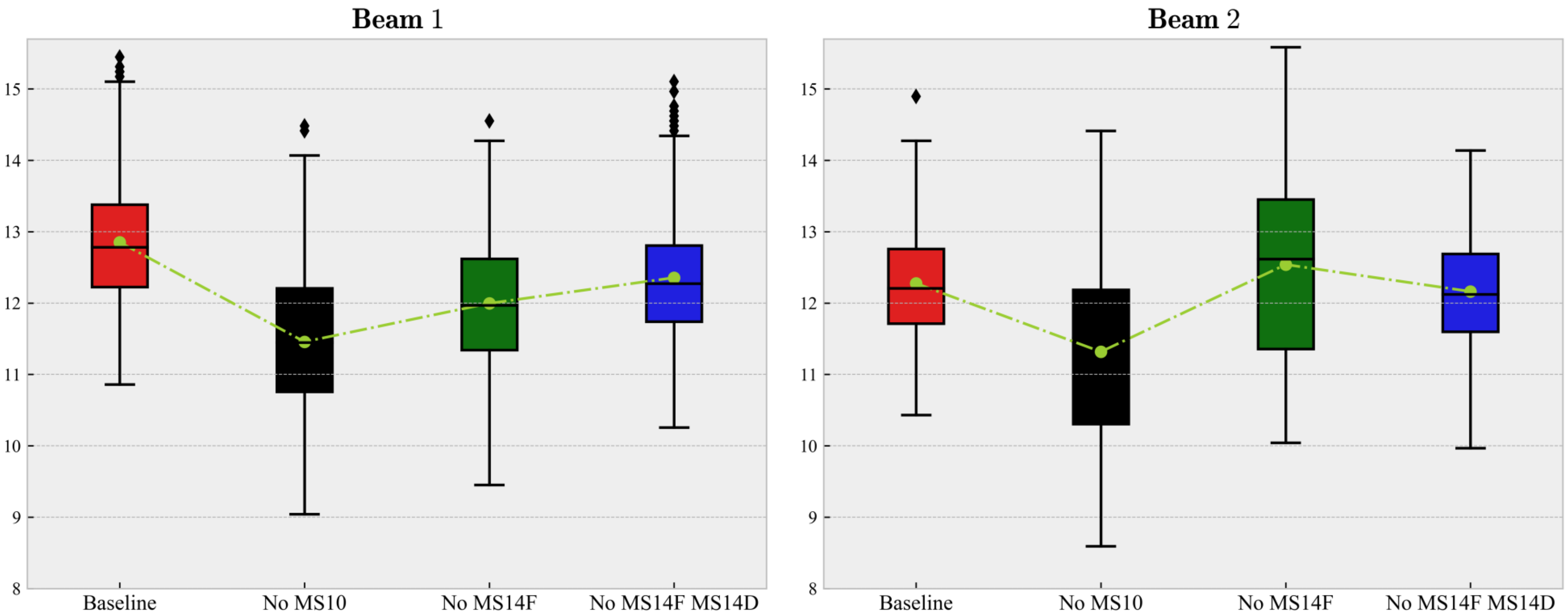
Alternative Optics without MS10: IR6 constraints

- **Optics in IR6 within the constraints after optimization of the $IP^{1\rightarrow 5}$ phase advance**
- Phase advance $\Delta\mu_{x,\mathrm{MKD-TCT,IP1}}$ below 20° to keep the protected aperture at 11.2 σ

Param. B1 / B2	Target values	Baseline	No MS14F	No MS14F&MS14D
$\Delta\mu_{x,\mathrm{MKD-TCDQ}}$ [°]	90°± 4°	86.3 / 93.6	91.5 / 93.6	86.3 / 93.6
β_y^{TCDS} [m]	$\geq$ 200	238.3 / 260.6	283.2 / 200.0	238.3 / 271.0
β_x^{TCDQ} [m]	-	736.4 / 473.3	513.9 / 460.0	736.4 / 474.6
β_y^{TCDQ} [m]	$\geq$145	180.5 / 145.0	145.0 / 176.2	180.5 / 145.0
$\lvert \mathrm{D}_{x,\mathrm{TCDQ}} \rvert$ [m]	-	0.6 / 0.4	0.02 / 0.38	0.5 / 0.42
$\mathrm{Gap}_{\mathrm{TCQD,min}}$ [mm]	$\geq$3	4.0 / 3.05	3.3 / 2.99	4.0 /3.05
β_x^{TDE} [km]	$\geq$4	6.37 / 4.92	5.06 / 4.83	6.37 / 4.93
β_y^{TDE} [km]	$\geq$3.2	3.36 / 7.23	8.2 / 6.33	3.36 / 7.72
$(\beta_x\beta_y)^{\frac{1}{2}}_{\mathrm{TDE}}$ [km]	$\geq$4.5	4.62 / 5.98	6.44 / 5.53	4.62 / 6.17
$\lvert \Delta\mu_{x,\mathrm{MKD-TCT,IP1}} \rvert$ [°]	$\leq$20	19.8 / 18.8	9.8 / 18.6	5.0 / 19.6
$\lvert \Delta\mu_{x,\mathrm{MKD-TCT,IP5}} \rvert$ [°]	$\leq$30	29.5 / 31.4	36 / 30.1	29.5 / 31.9
Q5.L6 [T/m]	160	163 / -164	160 / -162	163 / -165
Q5.R6 [T/m]	160	-159 / 151	-161 / 151	-159 / 152

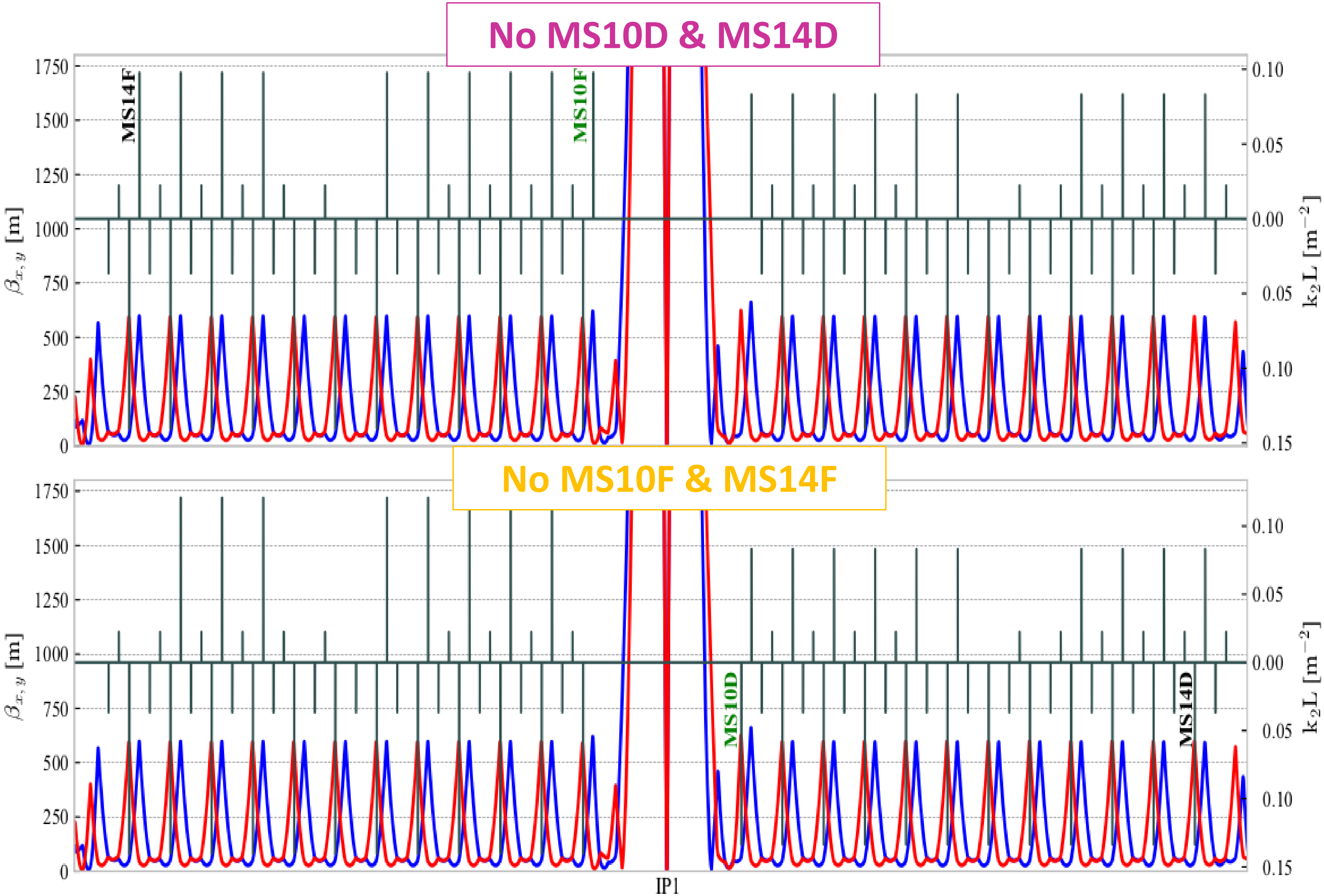
IP1-5 phase advance optimization: DA comparison

xing = **295 μrad**, Q_x= 62.31 / Q_y= 60.32, δ_p= 2.7× 10^{-4}, **with imperfections,with dispersion correction**, Q'=**15**, **MO = -570 A,** 10^5 turns, 7 angles



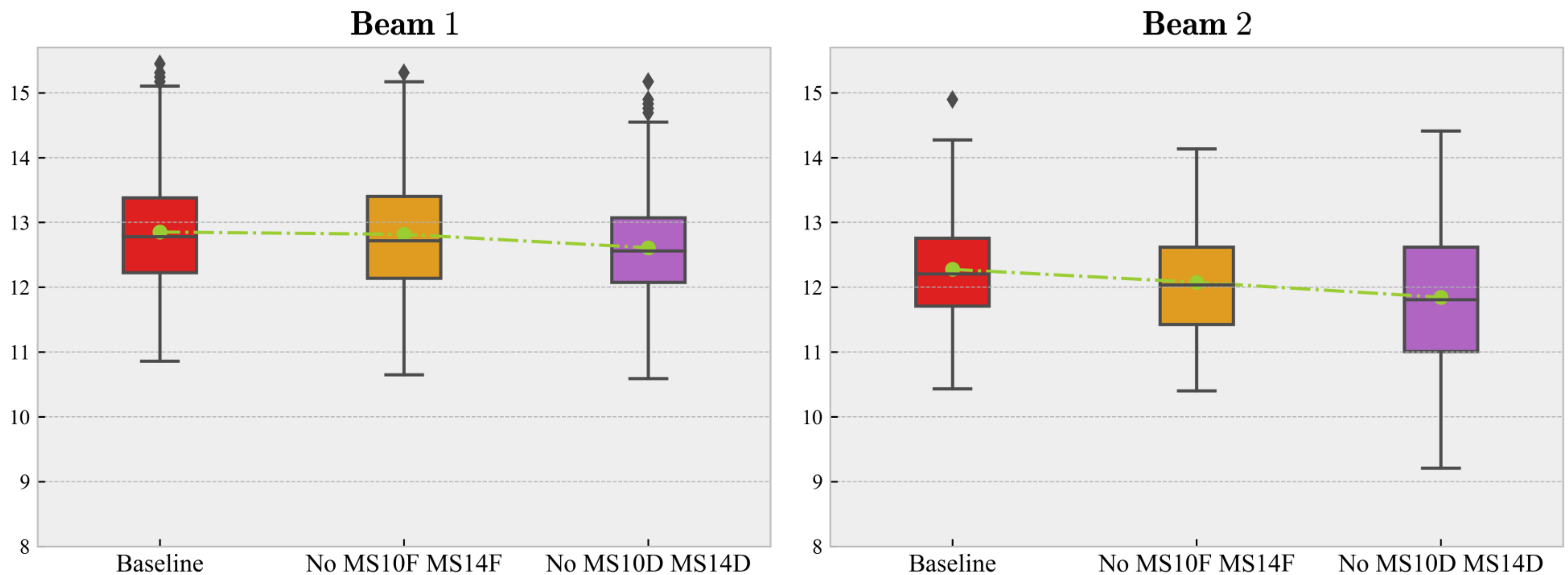
Optics	Avg. DA (B1/B2)	Min. DA (B1/B2)
No MS10	**11.5 / 11.2**	**9.0 / 8.6**
Baseline	**12.9 / 12.2**	**10.9 / 10.4**
No MS14F	**12.0 / 12.5**	**9.5 / 10.0**
No MS14F & MS14D	**12.4 / 12.1**	**10.1 / 10.0**

Alternative optics with only 1 MS10 in IR1&5



Alternative optics with only 1 MS10 in IR1&5

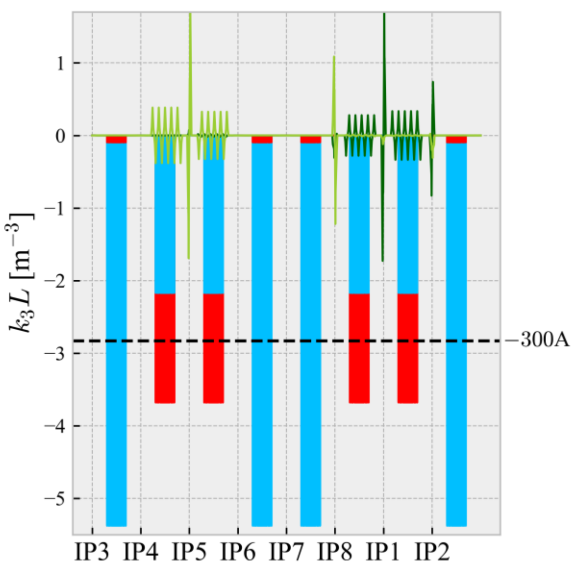
xing = **295** µ**rad**, Q_x= 62.31 / Q_y= 60.32, δ_p= 2.7× 10^{-4}, **with imperfections,with dispersion correction**, Q'=**15**, **MO = -570 A,**
10^5 turns, 7 angles

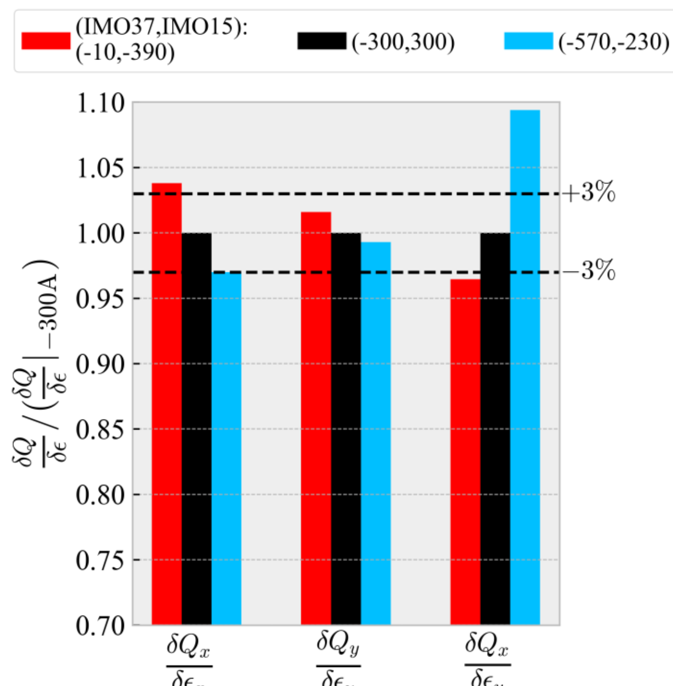


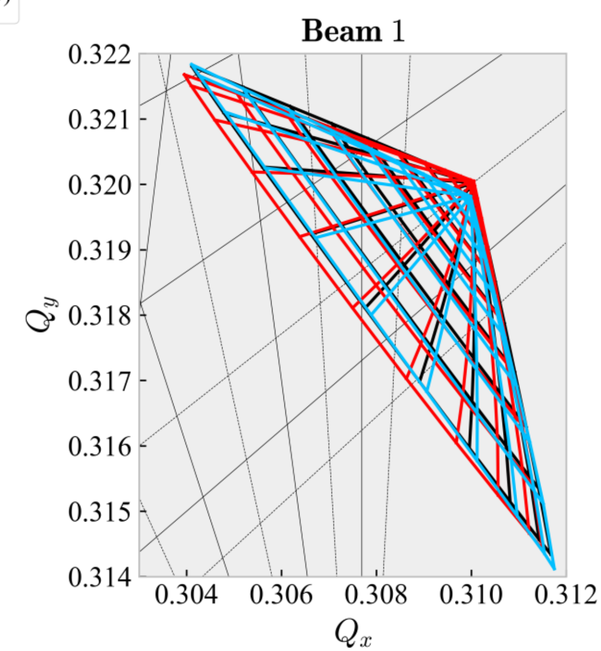
Optics	Avg. DA (B1/B2)	Min. DA (B1/B2)
Baseline	**12.9 / 12.2**	**10.9 / 10.4**
No MS10F & MS14F	**12.9 / 12.0**	**10.7 / 10.3**
No MS10D & MS14D	**12.6 / 11.9**	**10.6 / 9.2**

DA optimization by changing Octupole Powering

- Optimize the Landau Octupole circuit currents to improve DA
- Reducing the RDTs generated at the octupoles by lowering their strength at the orbit bumps for dispersion correction where $\beta_{x,y}$ are larger
- **DA simulations without Beam-Beam included → Octupole power varied for direct detuning terms almost constant**
- Assume amplitude detuning with nominal octupole setting for HL-LHC →**-300 A**
- **IMO37** refers to the octupole currents in sectors 23,34,67,78
- **IMO15** refers to the octupole currents in sectors **81,12,45,56**

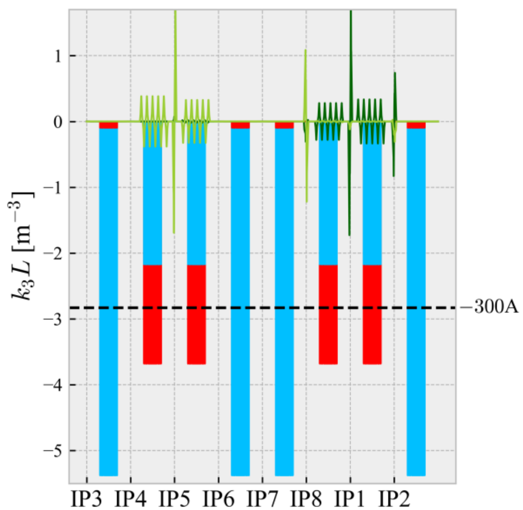


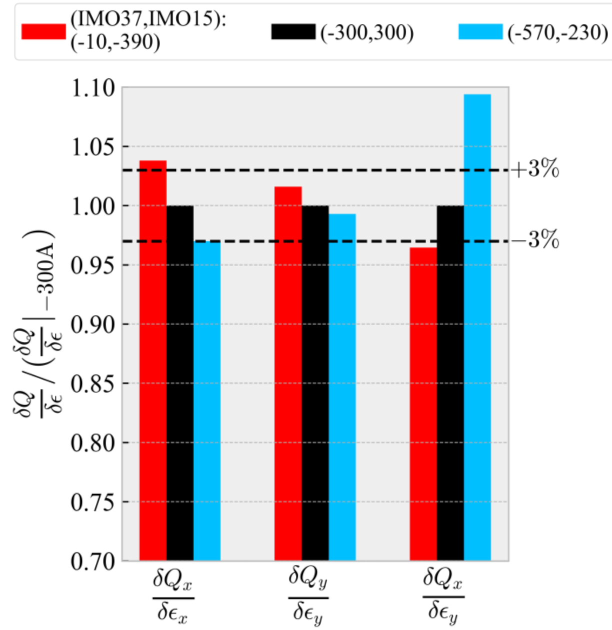


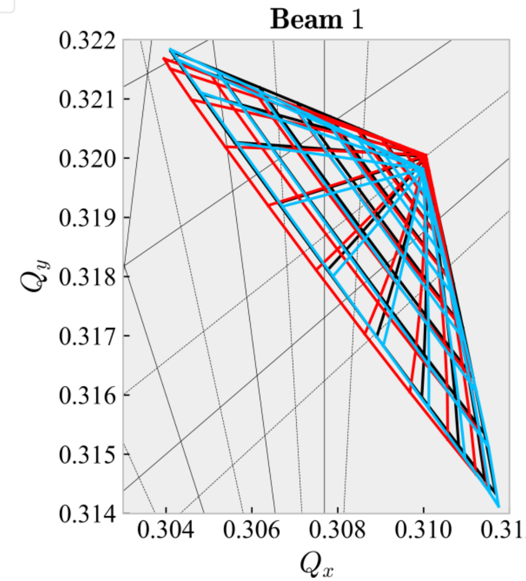


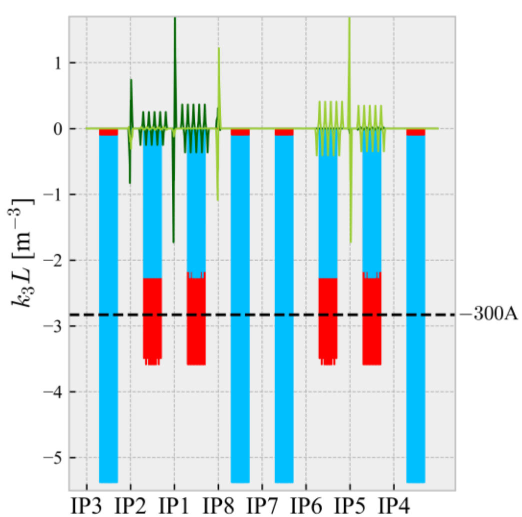
DA optimization by changing Octupole Powering

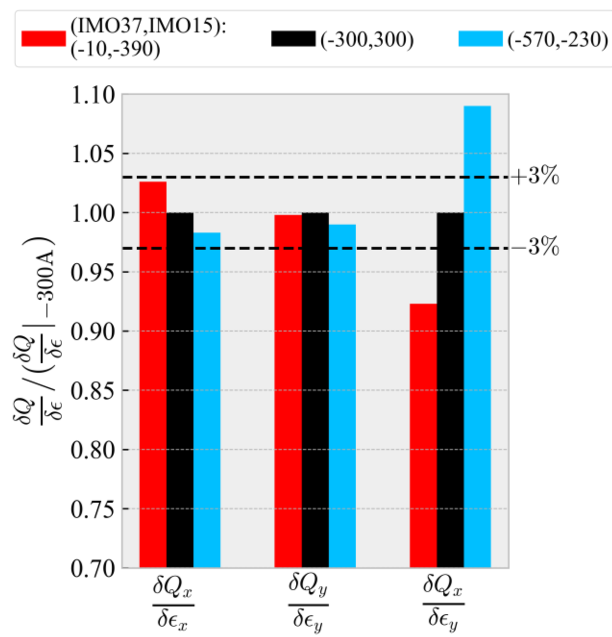
Baseline optics

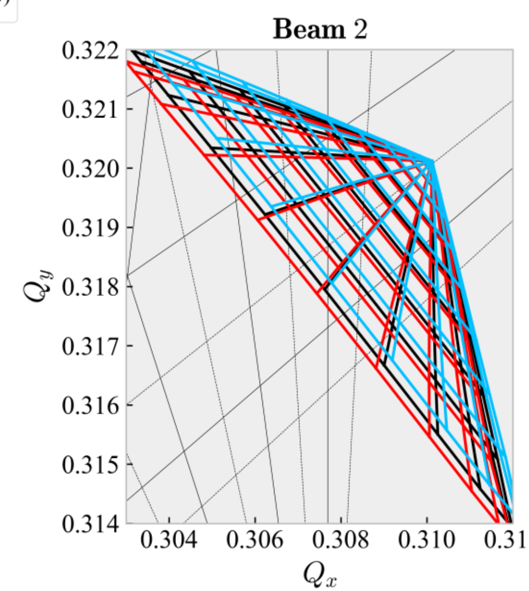






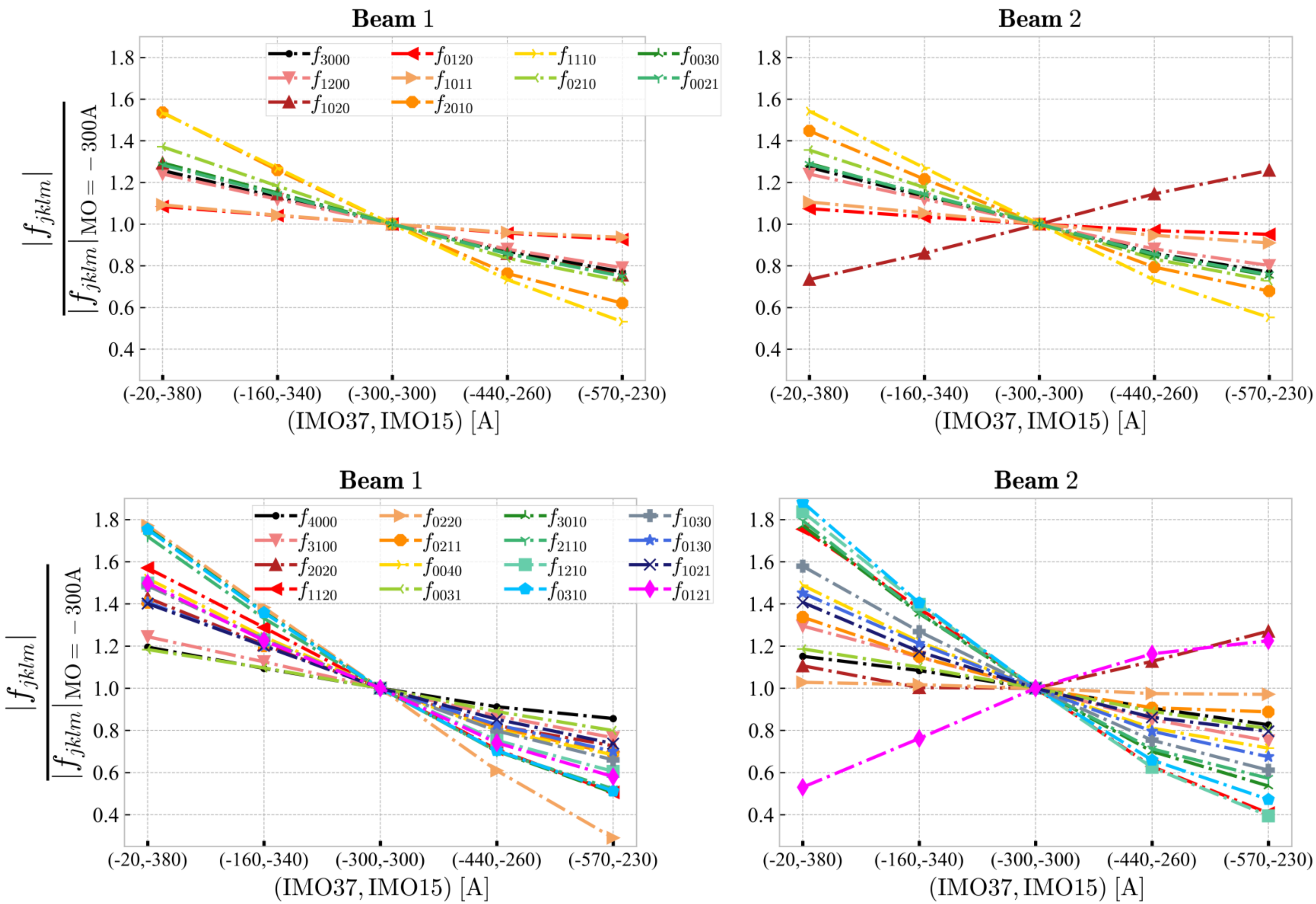




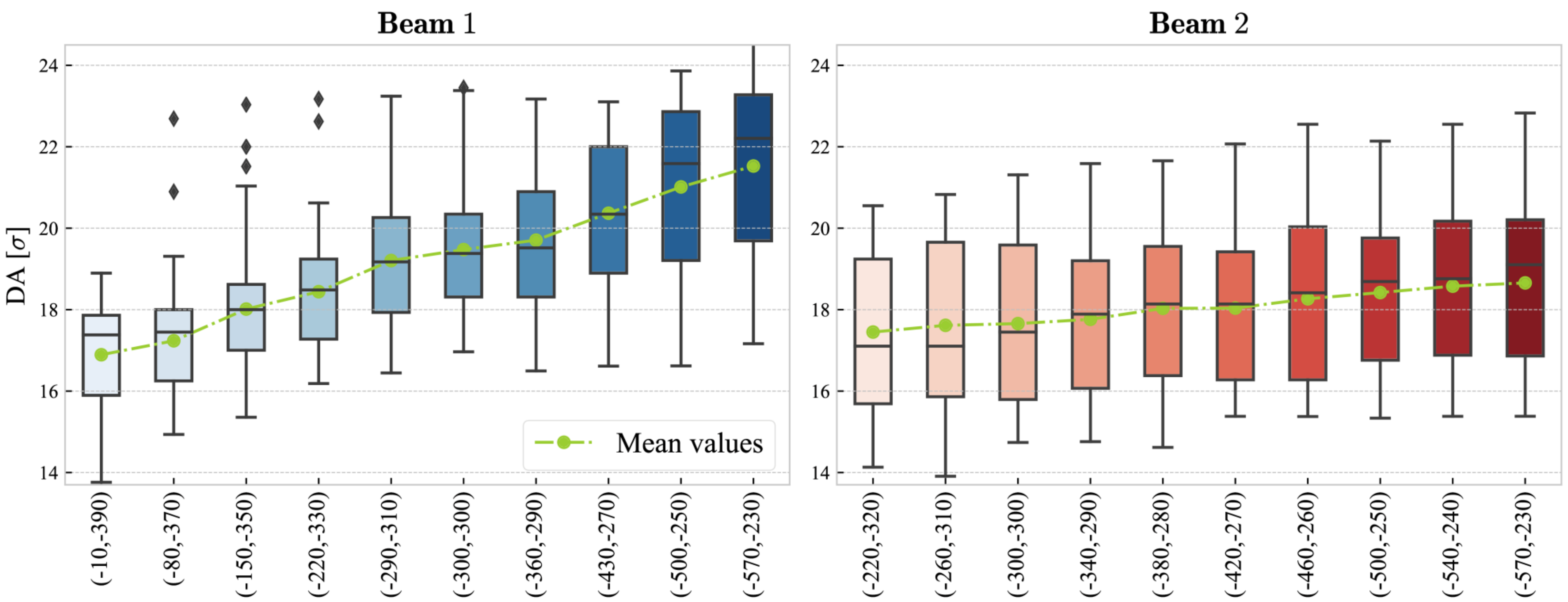


DA optimization by changing Octupole Powering

- RDTs from a_4, b_4 and a_3, b_3 reduce with reduced octupole strength in Sec. 81,12,45 ,56



DA optimization by changing Octupole Powering



- DA increases with reduced octupole strength in Sec. 81,12,45 ,56 thanks to the lower a_4, b_4 and feed-down to sextupole fields a_3, b_3
- For (IMO37,IMO15) = (-570,-230) → **+2σ for B1** ; **+1.3σ for B2 in avg**

CONCLUSIONS

- DA comparison for B1 & B2 on all alternative optics without MS10 at collision with round β^{*}=15 cm using the latest HLLHCV1.4 mask without beam-beam

- The DA has beam improve for all optics by optimizing the phase advance between IP1 and IP5 taking into account optics constraints in IR6

- DA difference w.r.t to **Baseline** optics **with imperfections** (B1 / B2) :

  No MS10 : DA_{avg} = -1.4 / -1.0 σ ; DA_{min} = -1.9 / -1.8 σ

  No MS14F : DA_{avg} = -0.9 / +0.3 σ ; DA_{min} = -1.4 / -0.4 σ

  No MS14F&MS14D : DA_{avg} = -0.5 / -0.1 σ ; DA_{min} = -0.8 / -0.4 σ

- Alternative optics **should be validated with Beam-Beam** included

- Alternative configuration studied with only half additional MS10 w.r.t Baseline:

  No MS10F & MS14F : DA_{avg} = 0.0 / -0.2 σ ; DA_{min} = -0.2 / -0.1 σ

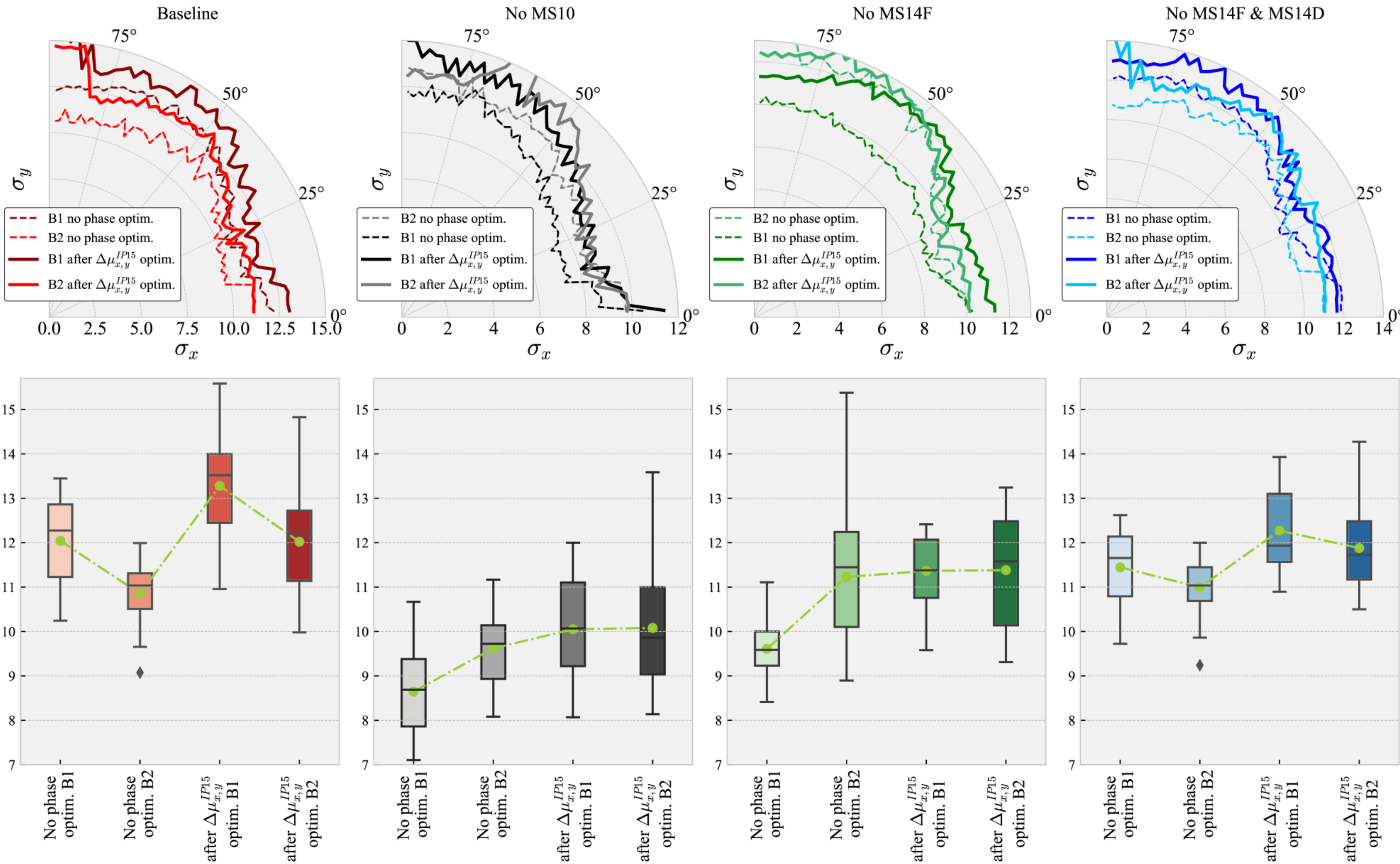
  No MS10D & MS14D : DA_{avg} = -0.3 / -0.3 σ ; DA_{min} = -0.3 / -1.2 σ

- DA can be further improved by reducing the RDTs contribution from octupoles in sector 81,12,45,56 where β^{*} is large and where orbit bumps are used for dispersion correction: **Reduced power in IMO15 while increasing power in IMO37 with constant amplitude detuning → increase of DA**

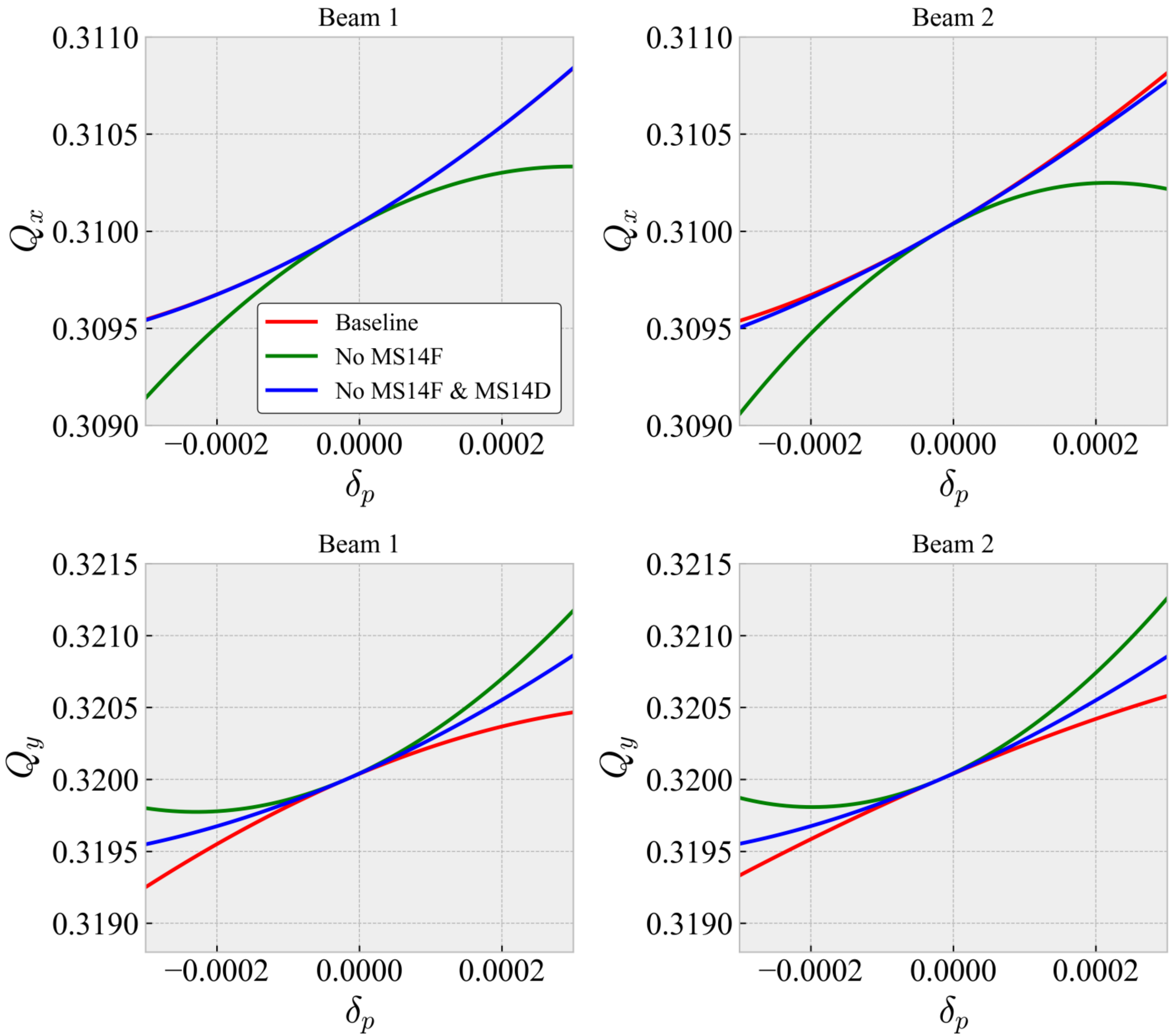
BACKUP SLIDES

IP1-5 phase advance optimization: DA comparison

xing = **295 μrad**, Q_x= 62.31 / Q_y= 60.32, δ_p= 2.7× 10^{-4}, **without imperfections,with dispersion correction**, Q'=**15**, **MO = -570 A,**
10^6 turns, 60 angles



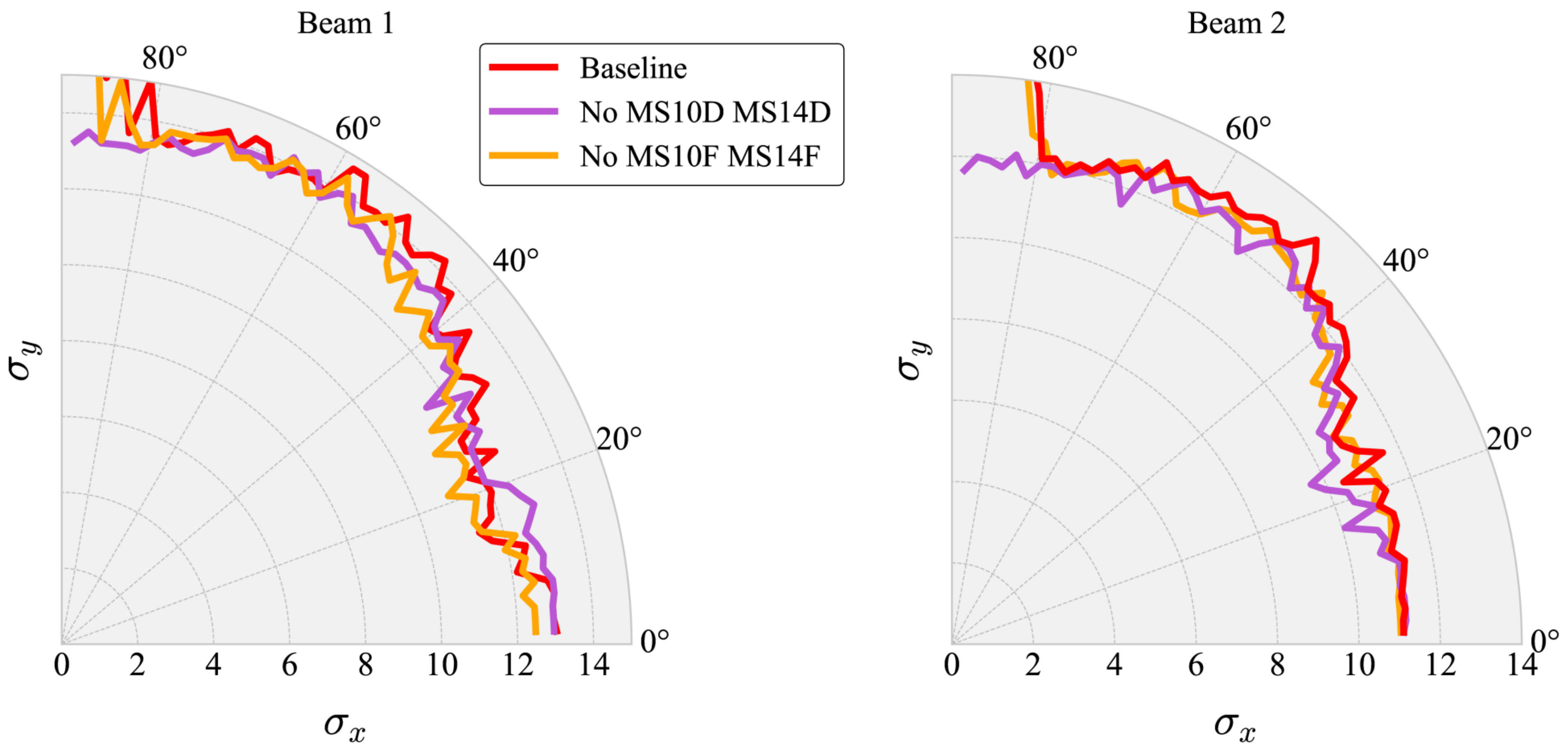
Alternative Optics without MS10: Chromatic Properties



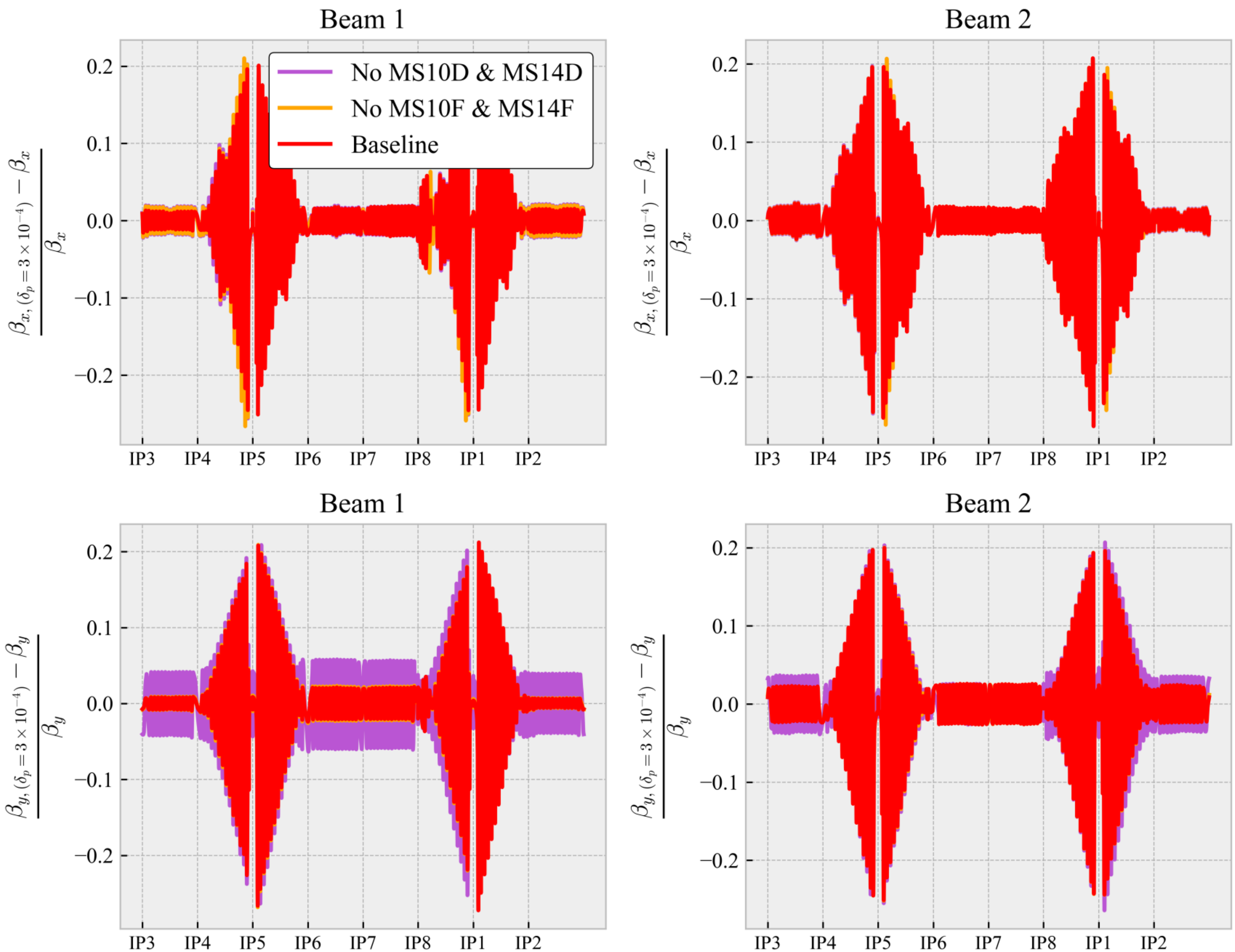
Alternative optics with only 1 MS10 in IR1&5

xing = **295** µrad, Q_x= 62.31 / Q_y= 60.32, δ_p= 2.7×10^{-4}, **without imperfections**,**with dispersion correction**, Q'=**15**, **MO = -570 A,**

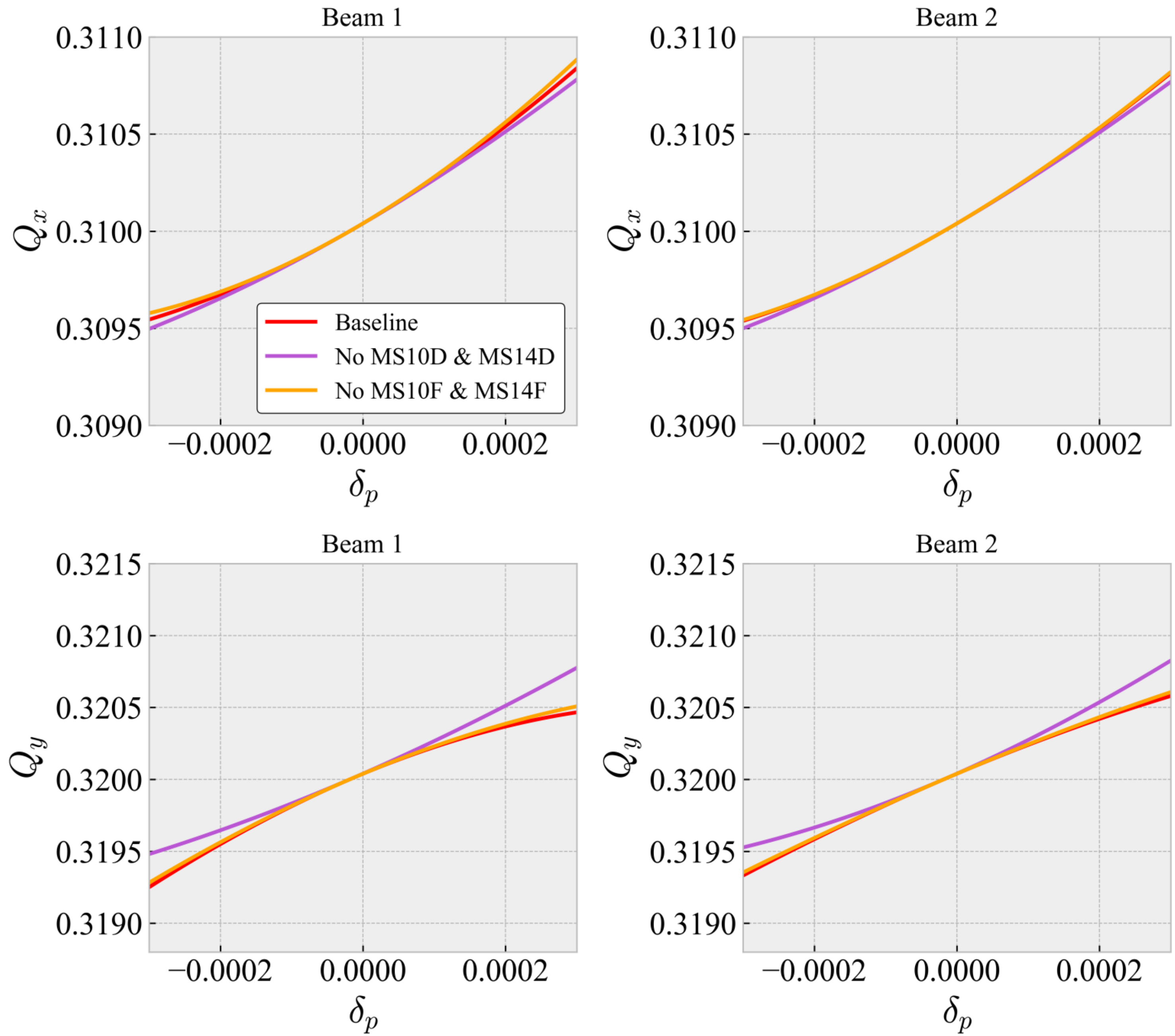
10^6 turns, 60 angles



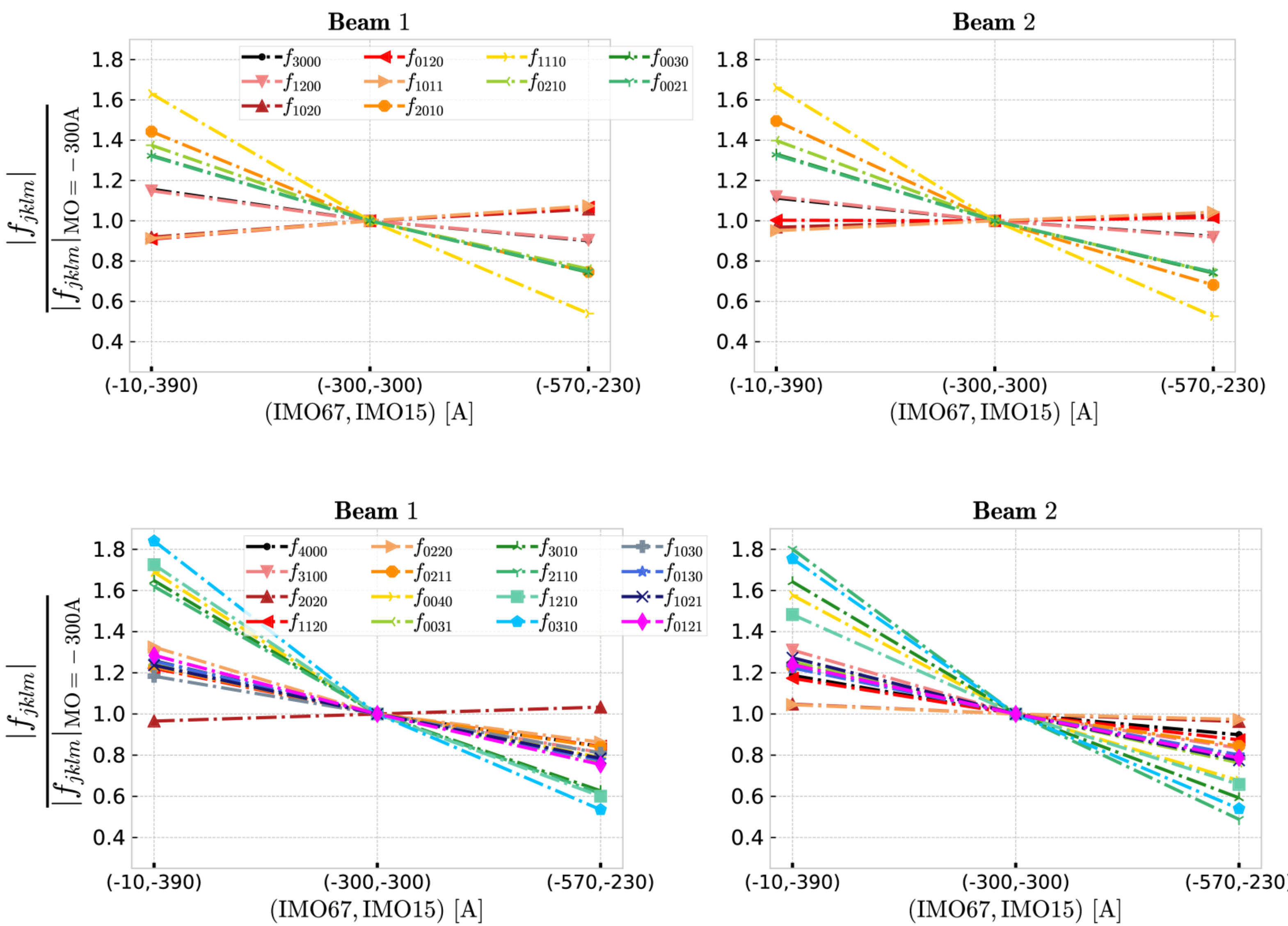
Alternative Optics with only 1 add. MS10: Chromatic Properties



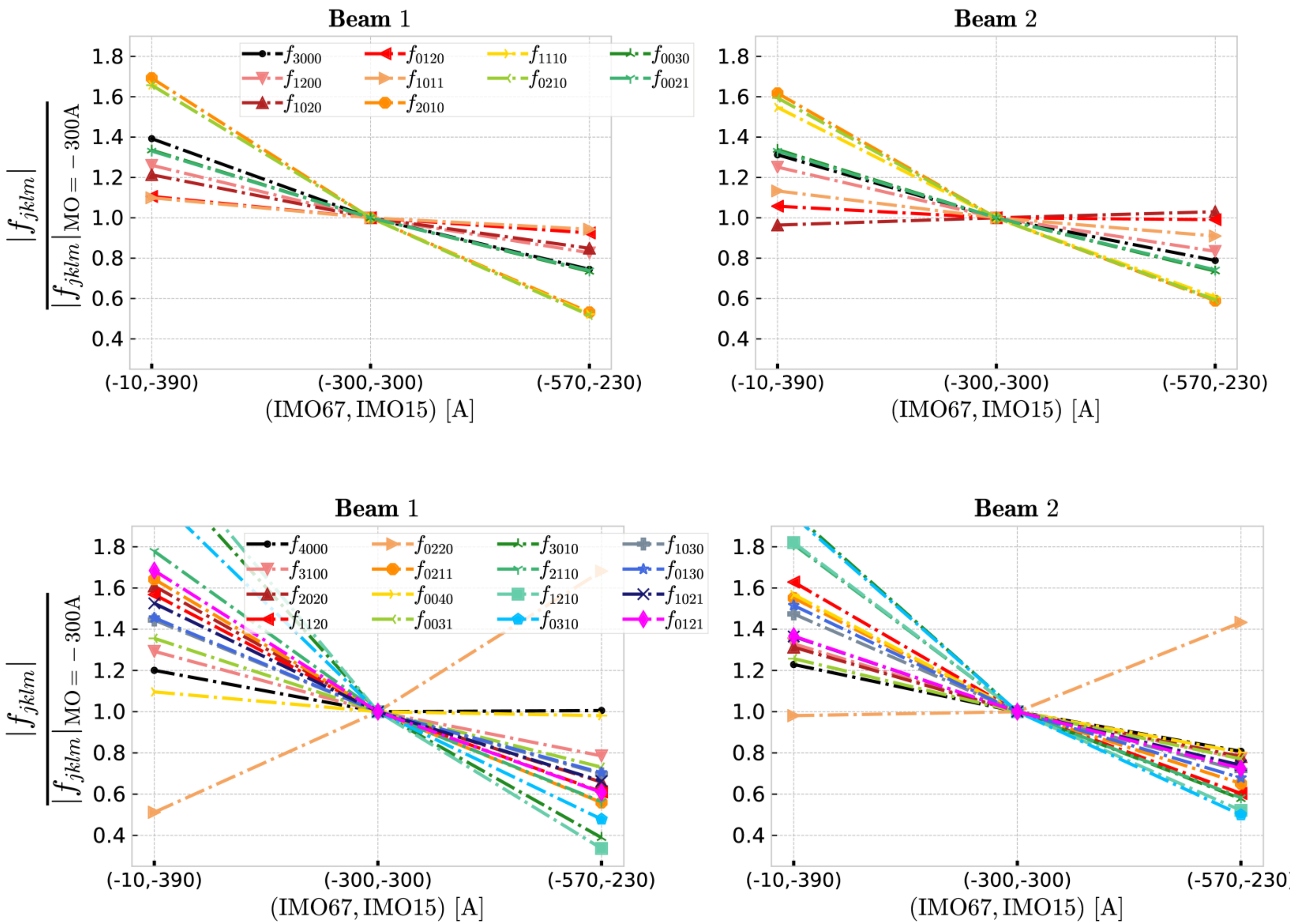
Alternative Optics with only 1 add. MS10: Chromatic Properties



Changing Octupole Powering: Impact on RDTS (No MS14F)



Changing Octupole Powering: Impact on RDTS (No MS14F & MS14D)



Changing Octupole Powering: Impact on RDTS (No MS10)