Update on the MS10 sextupole lattice study

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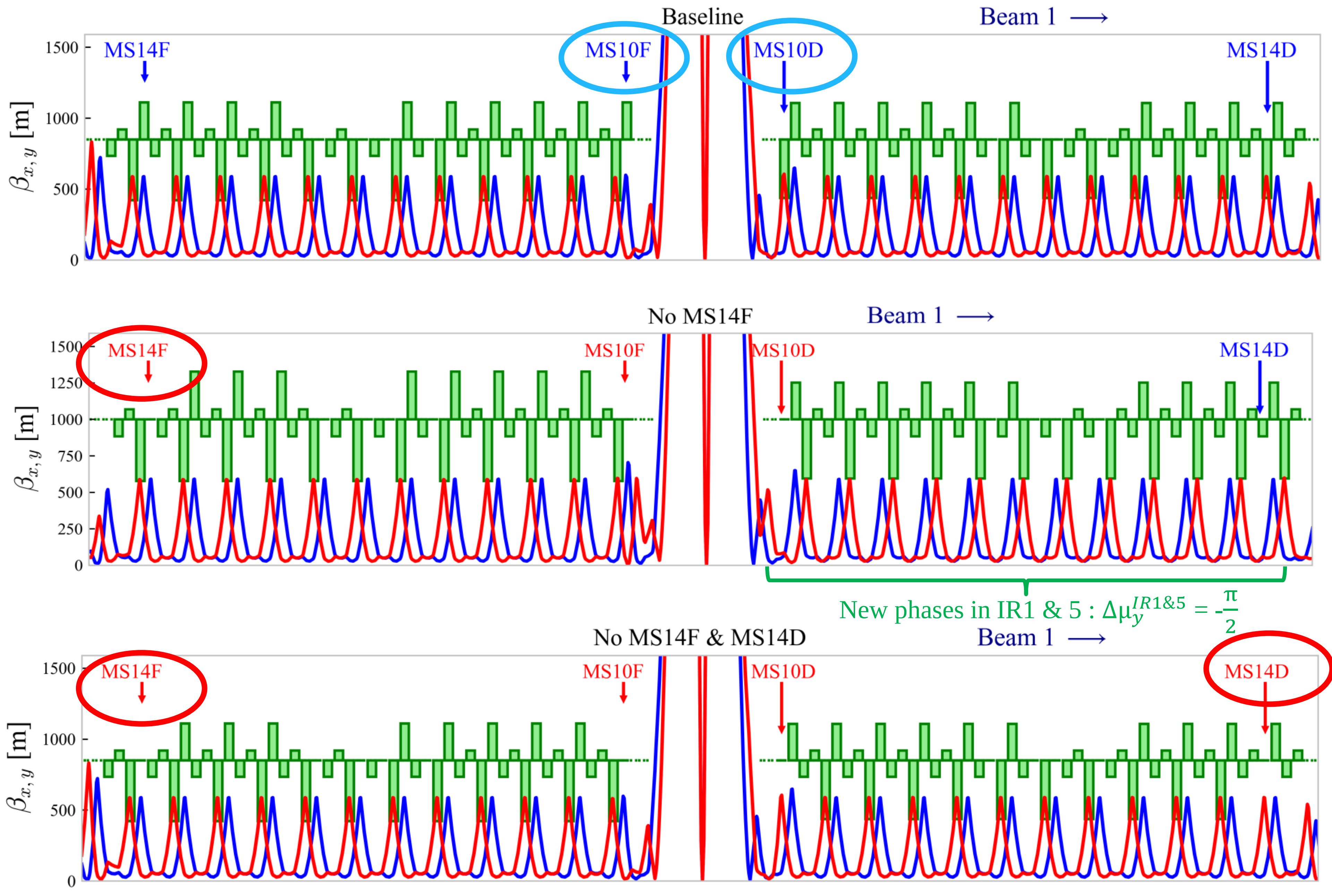
WP2 Meeting 25/02/2020

OUTLINE

- Recall of the 4 sextupole layout options proposed for HL-LHC
- Summary of the main advantages / drawbacks
- DA comparison after phase optimization
- DA comparison including weak-strong beam-beam interactions

Recall of the sextupole layout options



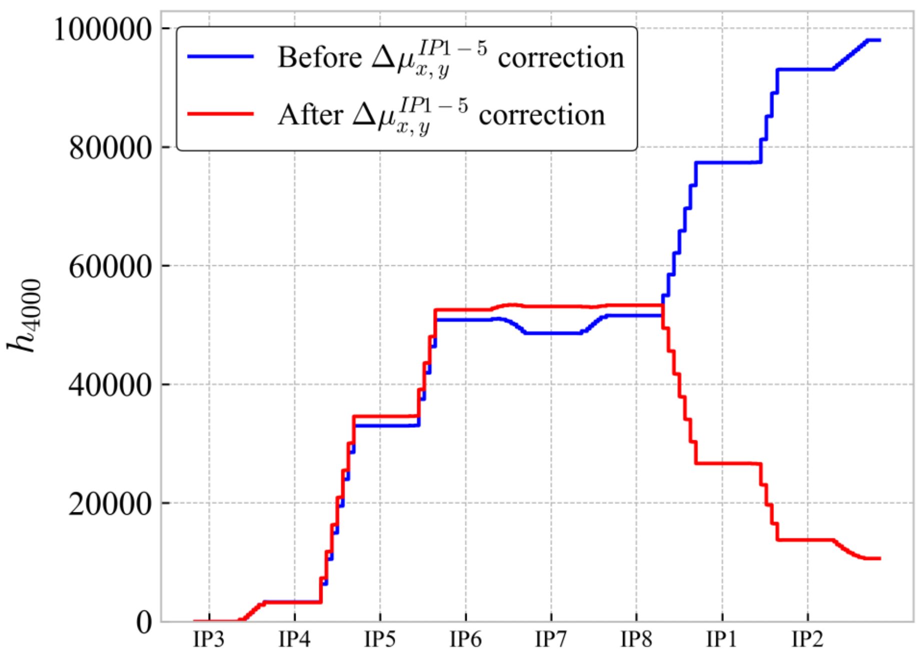
Properties of the proposed alternative options

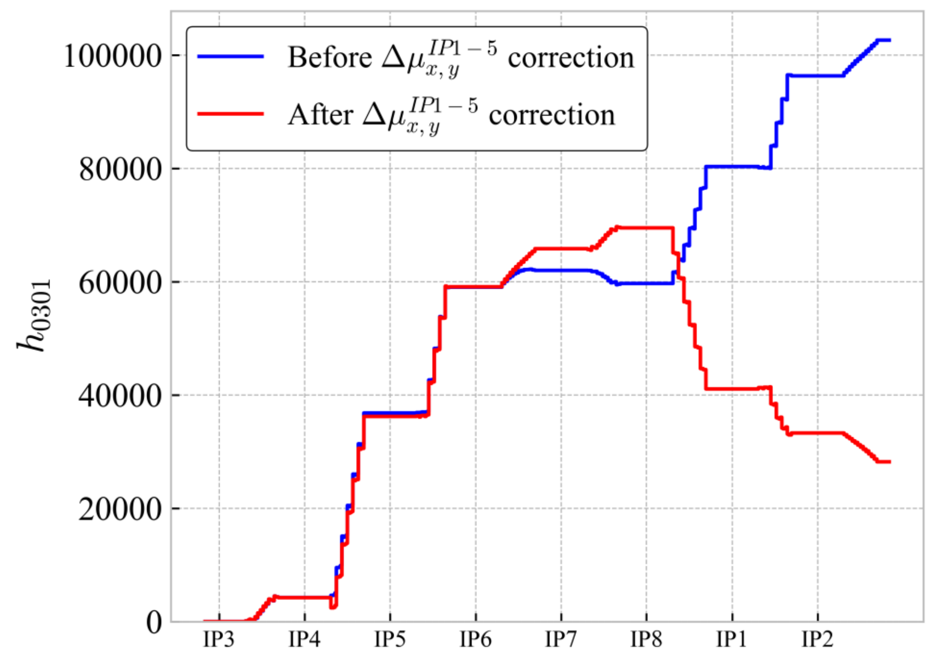
Optics	Pros	Cons
Baseline	• Gain of 20% of sextupole strength • Best DA solution for HL-LHC	• Installation of 4 additional sextupoles (per Beam) • Important hardware modification (time & cost)
No MS10 (LHC-like)	• Same as LHC → No intervention required	• Large geometrical aberrations from the main sextupoles • Important detrimental impact on DA
No MS14F	• No installation required (2 sext. disconnected per Beam) • Better DA solution than LHC configuration	• Important change in optics ($\Delta\mu_y^{IR1\&5} = \frac{-\pi}{2}$) • New squeeze optics
No MS14F & MS14D	• No installation required (4 sext. Disconnected per Beam) • No change in linear optics • Best DA solution without MS10	• +20% sext. Current required • Leakage of vertical chromatic • β-beating, Beam 1 in IR3 ,6 & 7

(see WP2 meeting 158th for more details)

DA comparison after phase $\Delta\mu_{x,y}^{IP1\rightarrow5}$ optimization

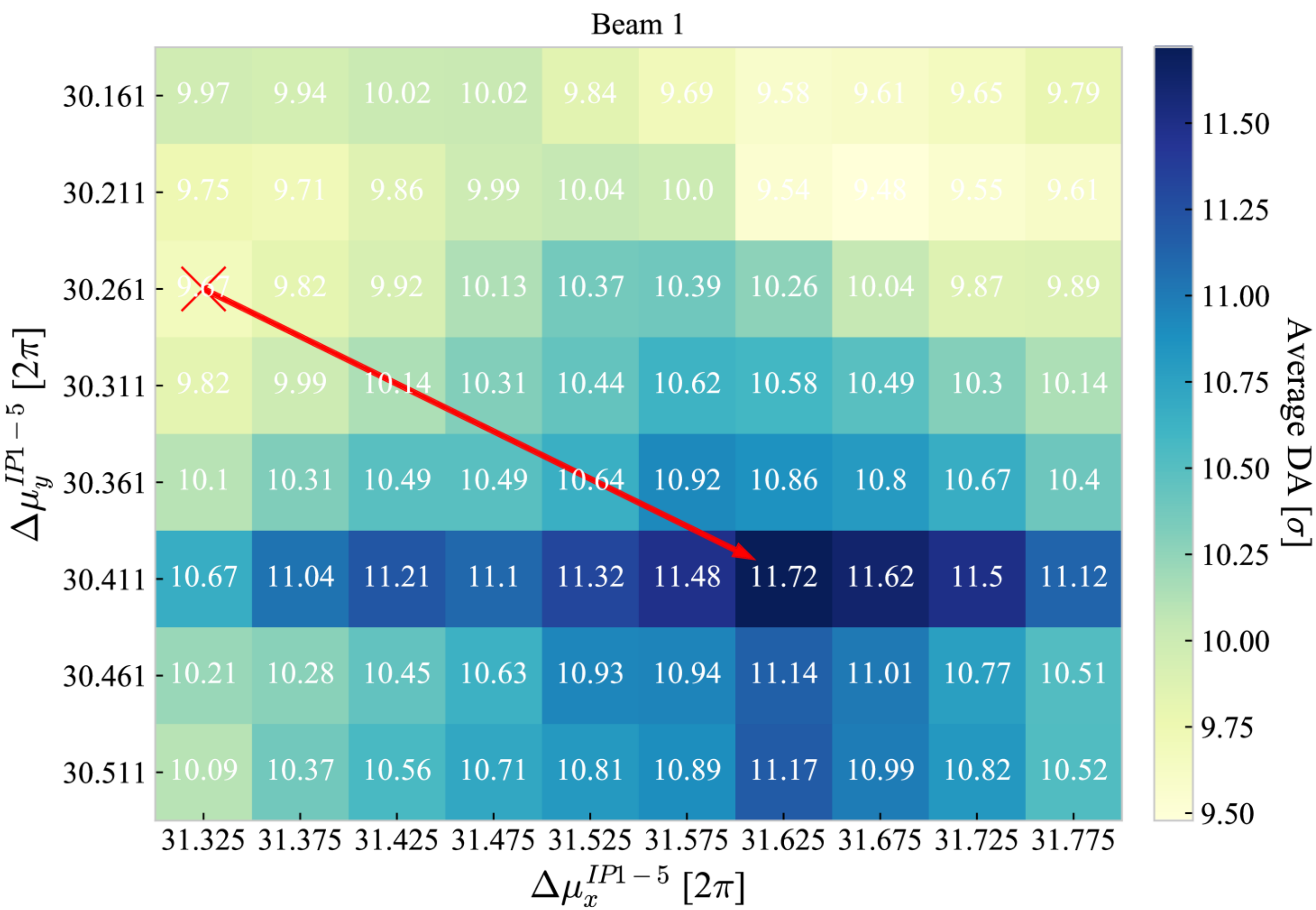
- **Phase optimization between IP1 & IP5** allowing partial compensation of some fourth and higher order resonances in order to improve DA
- While some RDTs are well corrected others increase…
- The mechanism behind the DA reduction is too complex to target some specific resonances for the correction → **optimize the phase directly by observing the DA**





DA comparison after phase $\Delta\mu_{x,y}^{IP1\rightarrow5}$ optimization

- **Phase optimization between IP1 & IP5** allowing partial compensation of some fourth and higher order resonances in order to improve DA
- Phase scan performed without imperfections for each lattice options and both beams
- The optimal phase setup **takes into account the optics constraints** for HL-LHC especially for machine protection



- No field imperfections
- I_{MO} = -570 A
- 10^6 turns
- 60 phase-space angles

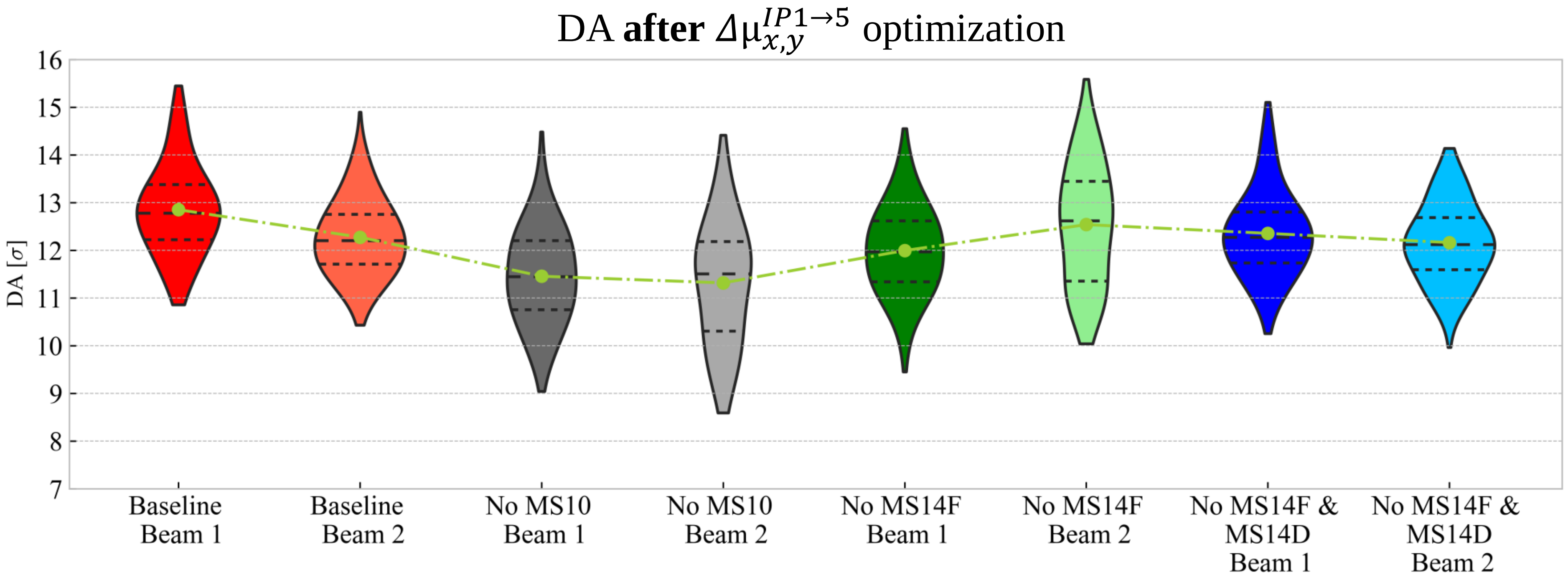
DA comparison after phase $\Delta\mu_{x,y}^{IP1\rightarrow5}$ optimization

- The optimal phase setup **takes into account the optics constraints** for HL-LHC especially for machine protection
- The parameters after phase optimization are within the constraints for IR6 region

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]	≥ 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]	≥145	180.5 / 145.0	145.0 / 176.2	180.5 / 145.0
$\lvert D_{x,\mathrm{TCDQ}}\rvert$ [m]	-	0.6 / 0.4	0.02 / 0.38	0.5 / 0.42
$\mathrm{Gap}_{\mathrm{TCQD,min}}$ [mm]	≥3	4.0 / 3.05	3.3 / 2.99	4.0 /3.05
β_x^{TDE} [km]	≥4	6.37 / 4.92	5.06 / 4.83	6.37 / 4.93
β_y^{TDE} [km]	≥3.2	3.36 / 7.23	8.2 / 6.33	3.36 / 7.72
$(\beta_x\beta_y)_{\mathrm{TDE}}^{\frac{1}{2}}$ [km]	≥4.5	4.62 / 5.98	6.44 / 5.53	4.62 / 6.17
$\lvert\Delta\mu_{x,\mathrm{MKD-TCT,IP1}}\rvert$ [°]	≤20	19.8 / 18.8	9.8 / 18.6	5.0 / 19.6
Q5.L6 [T/m]	160	163 / -164	160 / -162	163 / -165
Q5.R6 [T/m]	160	-159 / 151	-161 / 151	-159 / 152

DA comparison after phase $\Delta\mu_{x,y}^{IP1\to5}$ optimization

- **DA simulated for 10^5** turns over 7 angles including field imperfections (60 seeds) and with I_{MO}=-570 A
- DA is clearly **improved after phase optimization** even when **field errors are included**



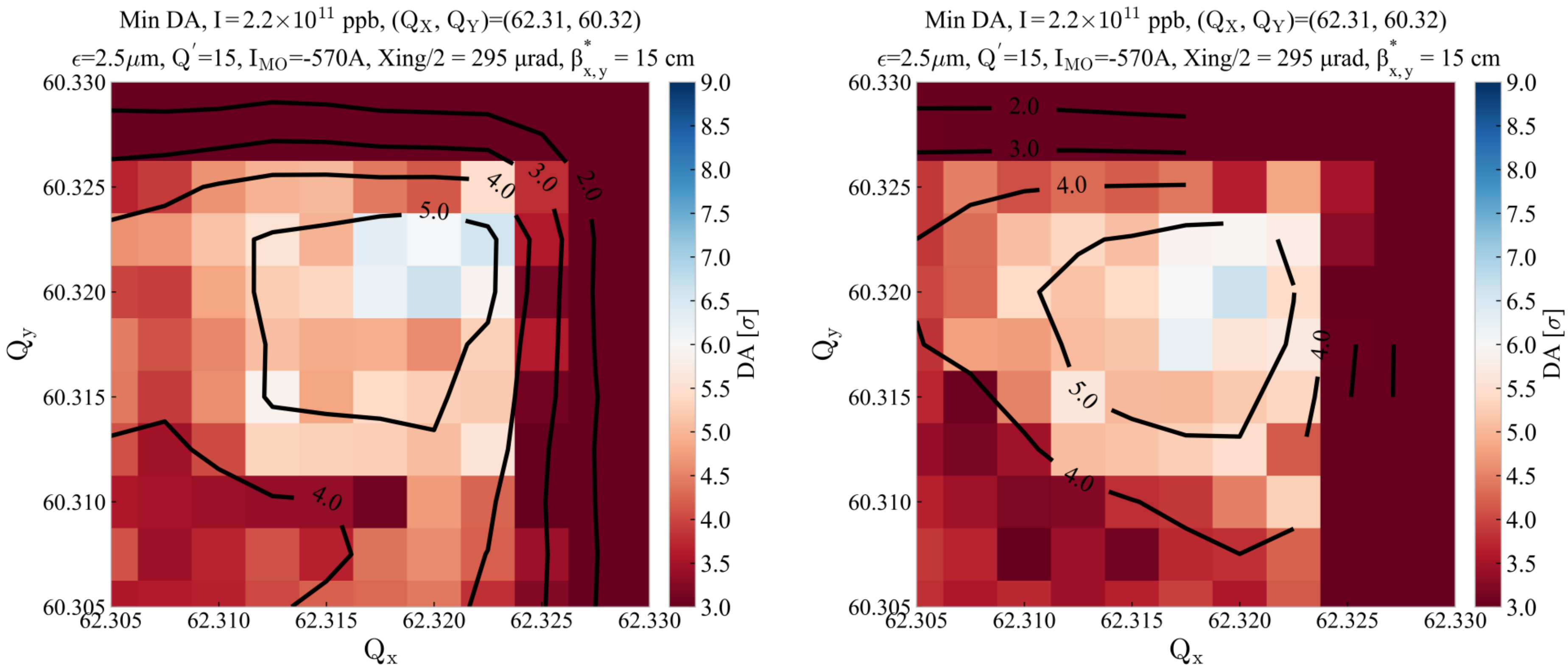
Optics	Average DA (B1/B2) [σ]	Minimum DA (B1/B2) [σ]
Baseline	12.9 / 12.3	10.9 / 10.4
No MS10	11.5 / 11.3	9.0 / 8.6
No MS14F	12.0 / 12.5	9.5 / 10.1
No MS14F & MS14D	12.4 / 12.2	10.3 / 10.0

DA comparison after phase $\Delta\mu_{x,y}^{IP1\rightarrow5}$ optimization including weak-strong beam-beam effects

BASELINE

DA **before** $\Delta\mu_{x,y}^{IP1\rightarrow5}$ optimization

DA **after** $\Delta\mu_{x,y}^{IP1\rightarrow5}$ optimization

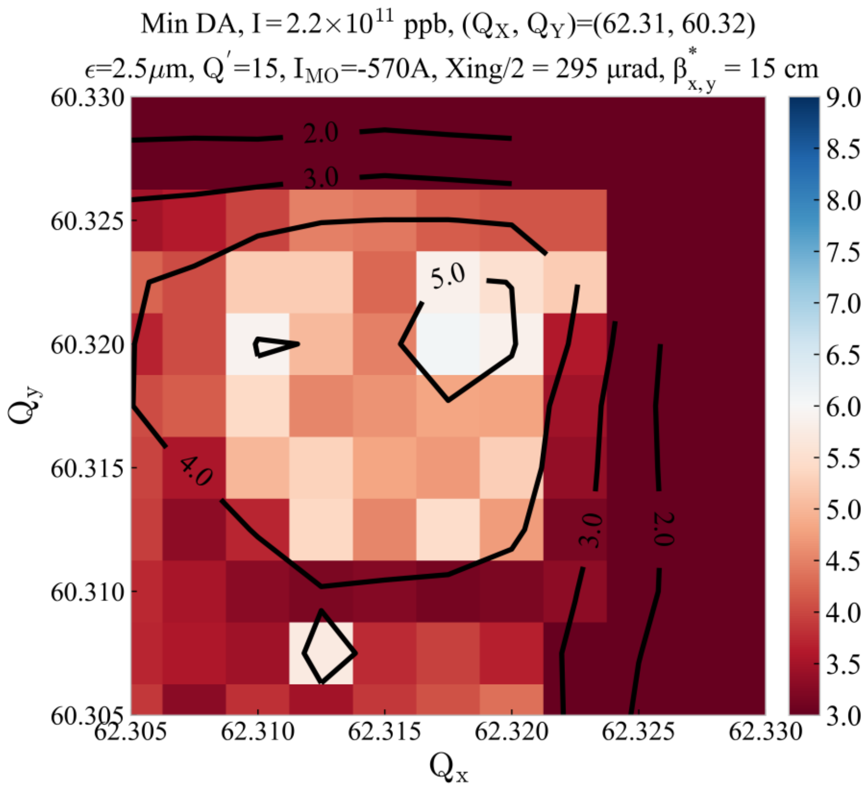


- ❑ **No DA improvement or large degradation after phase optimization** in the case of the **Baseline** when beam-beam is included
- ❑ Both show a **small tune area above the 6σ target** close to the coupling lines

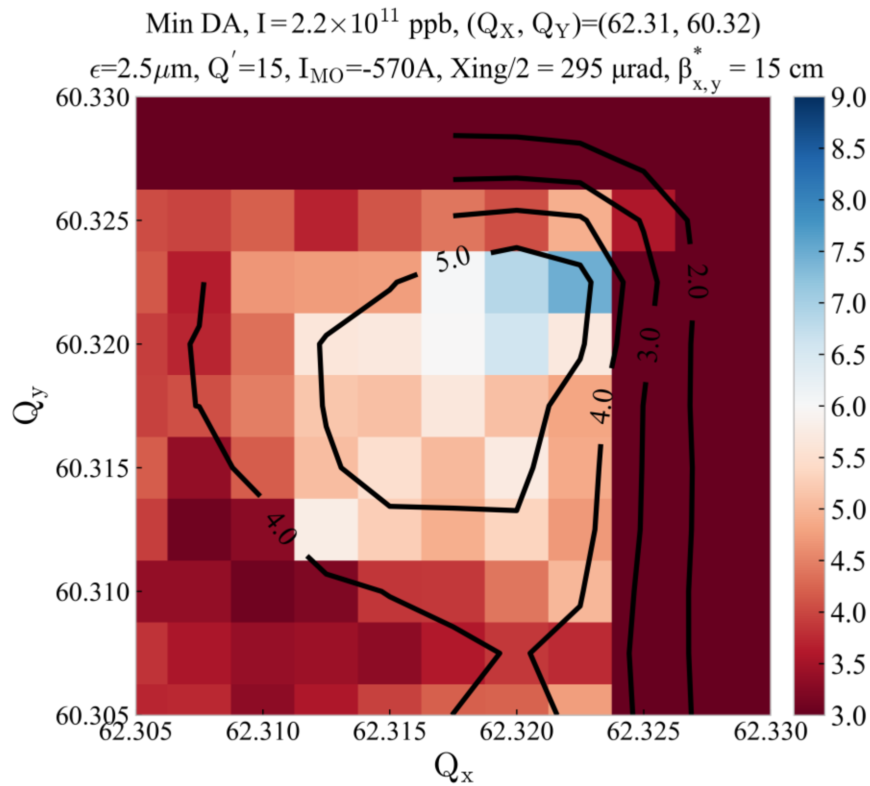
DA comparison after phase $\Delta\mu_{x,y}^{IP1\to5}$ optimization including weak-strong beam-beam effects

No MS10

DA **before** $\Delta\mu_{x,y}^{IP1\to5}$ optimization



DA **after** $\Delta\mu_{x,y}^{IP1\to5}$ optimization

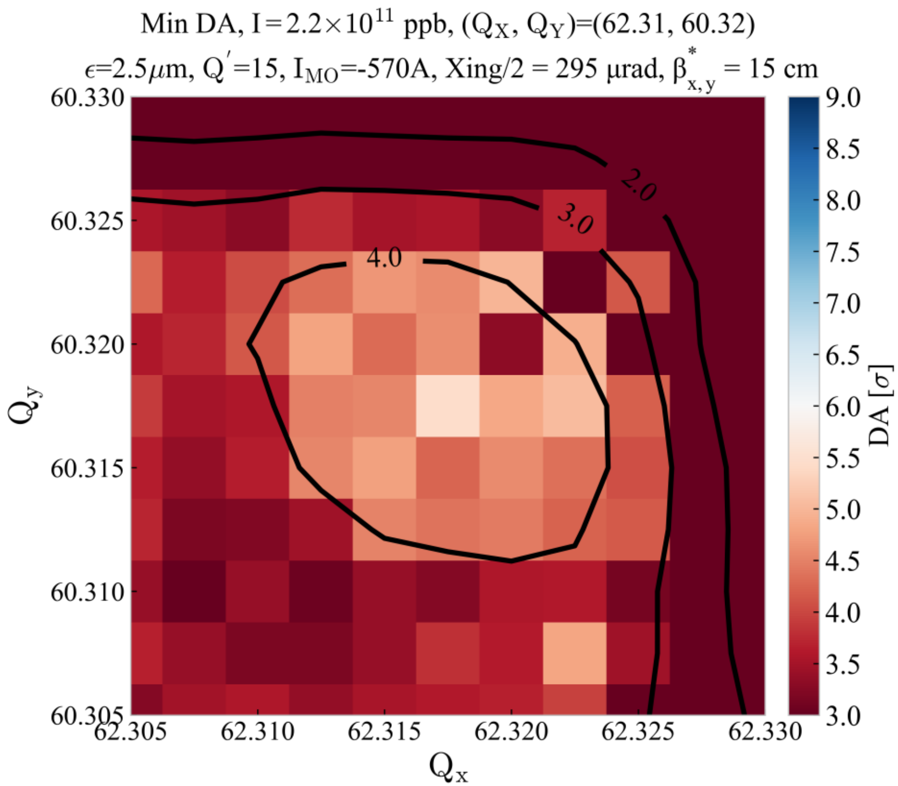


- ❑ **Clear DA improvement after phase optimization** in the case of the **No MS10** when beam-beam is included
- ❑ **Small tune area above the 6σ target** close to the coupling lines after optimization

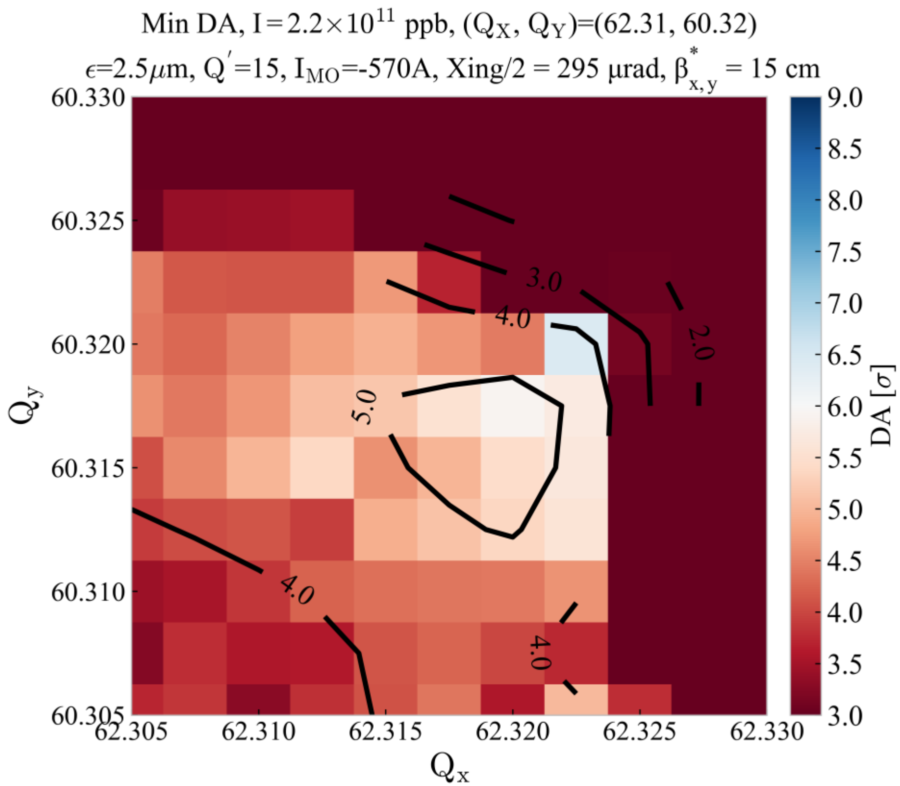
DA comparison after phase $\Delta\mu_{x,y}^{IP1\to5}$ optimization including weak-strong beam-beam effects

No MS14F

DA **before** $\Delta\mu_{x,y}^{IP1\to5}$ optimization



DA **after** $\Delta\mu_{x,y}^{IP1\to5}$ optimization

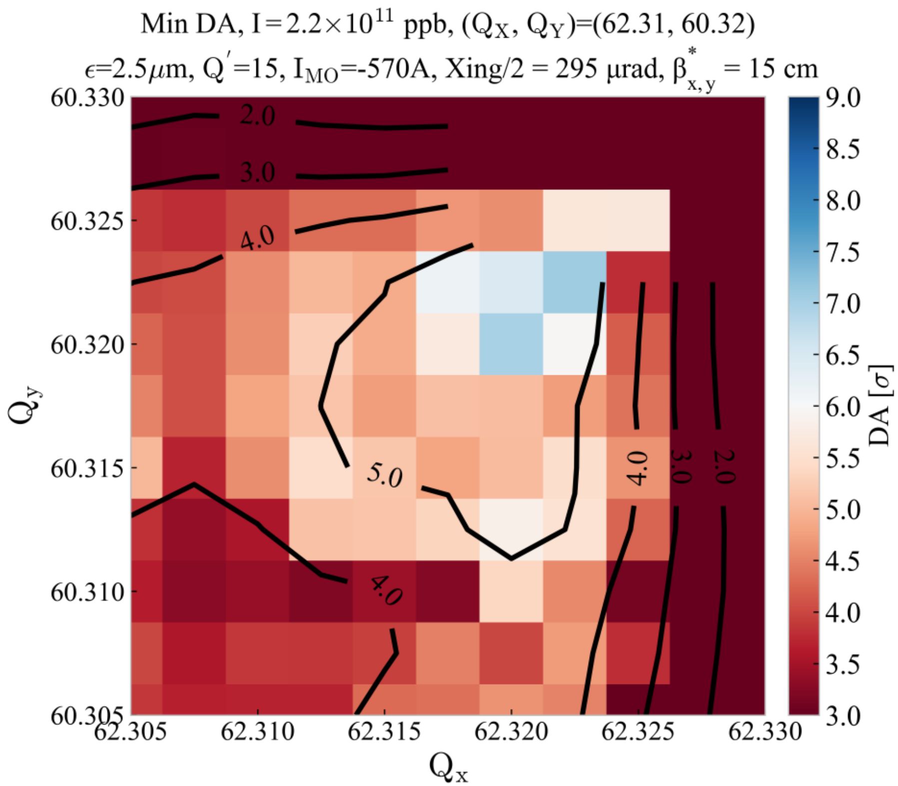


- ❑ **Clear DA improvement after phase optimization** in the case of the **No MS14F** when beam-beam is included
- ❑ **Small tune area above the 6σ target** close to the coupling lines after optimization

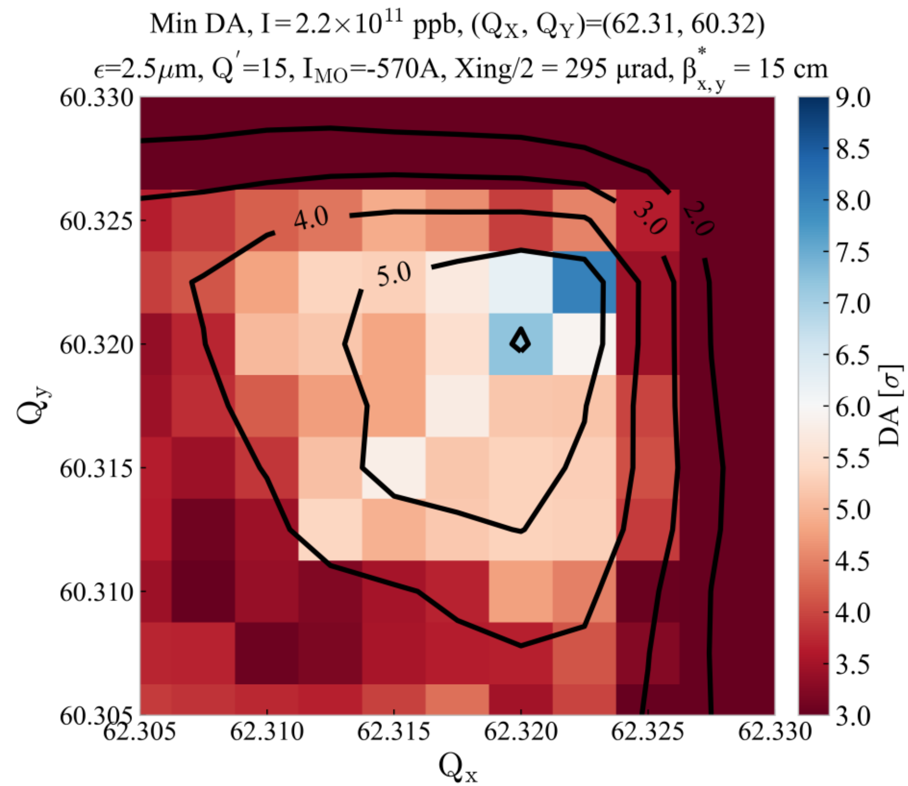
DA comparison after phase $\Delta\mu_{x,y}^{IP1\rightarrow 5}$ optimization including weak-strong beam-beam effects

No MS14F & MS14D

DA **before** $\Delta\mu_{x,y}^{IP1\rightarrow 5}$ optimization



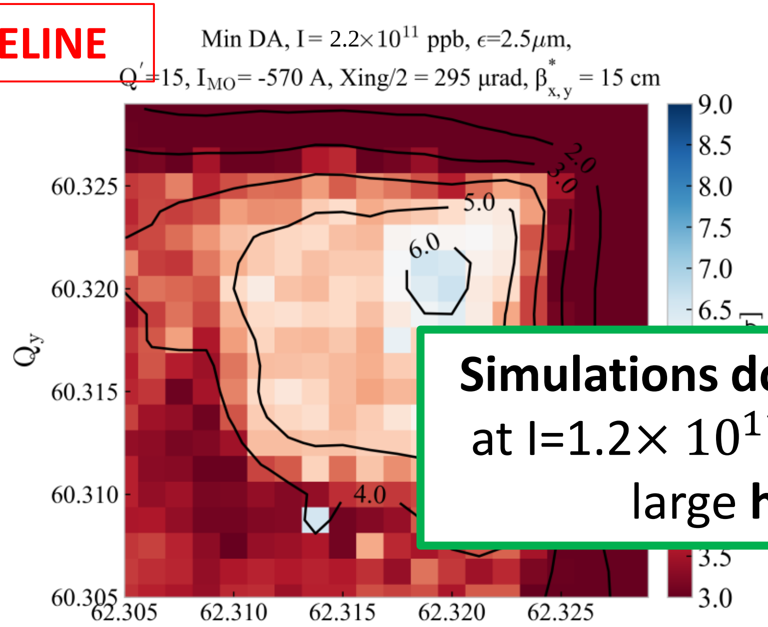
DA **after** $\Delta\mu_{x,y}^{IP1\rightarrow 5}$ optimization



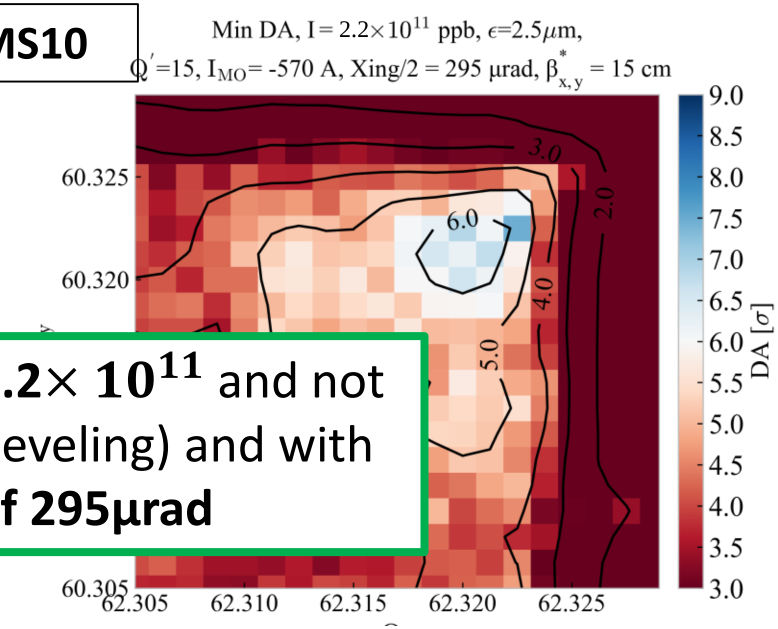
- **Clear DA improvement after phase optimization** in the case of the **No MS14F & MS14D** when beam-beam is included
- **Small tune area above the 6σ target** close to the coupling lines after optimization

DA comparison with beam-beam after optimization

BASELINE

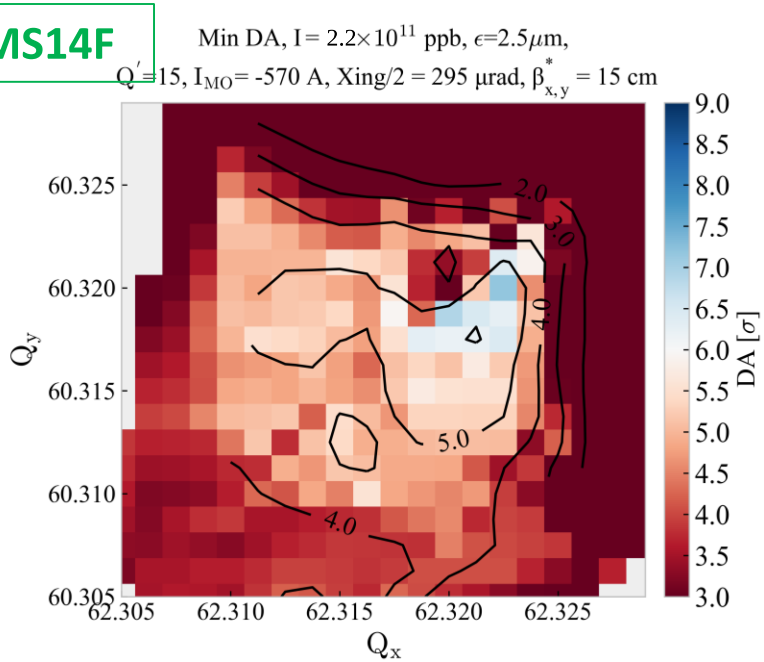


No MS10

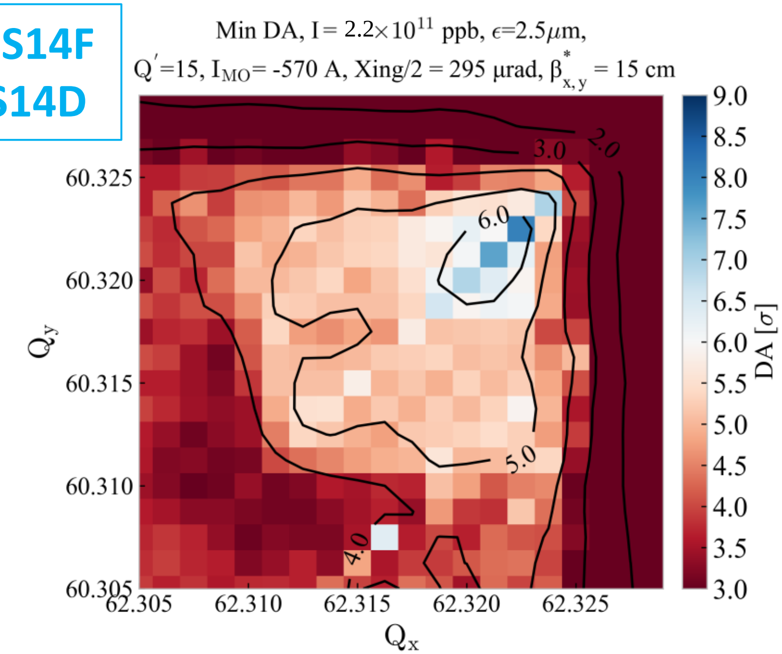


Simulations done at I=2.2× 10^{11} and not at I=1.2× 10^{11} (end of leveling) and with large **half xing of 295µrad**

No MS14F

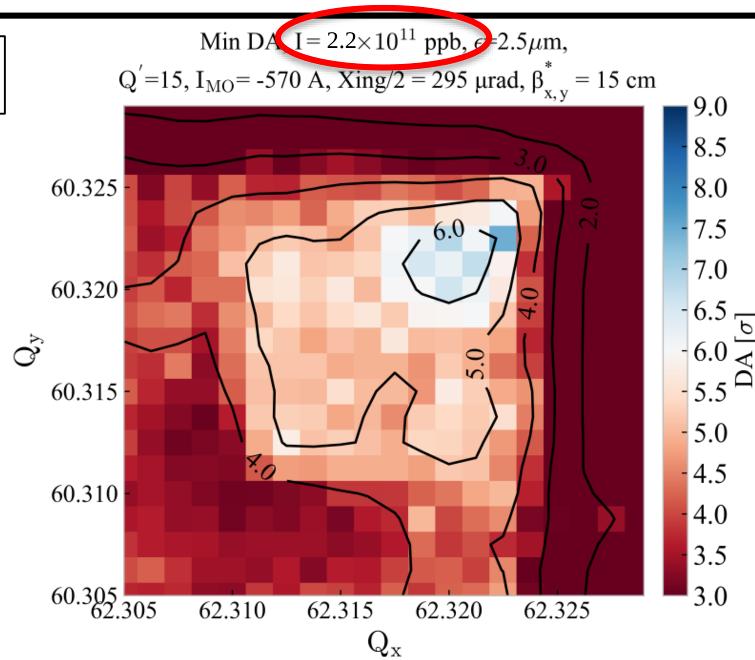


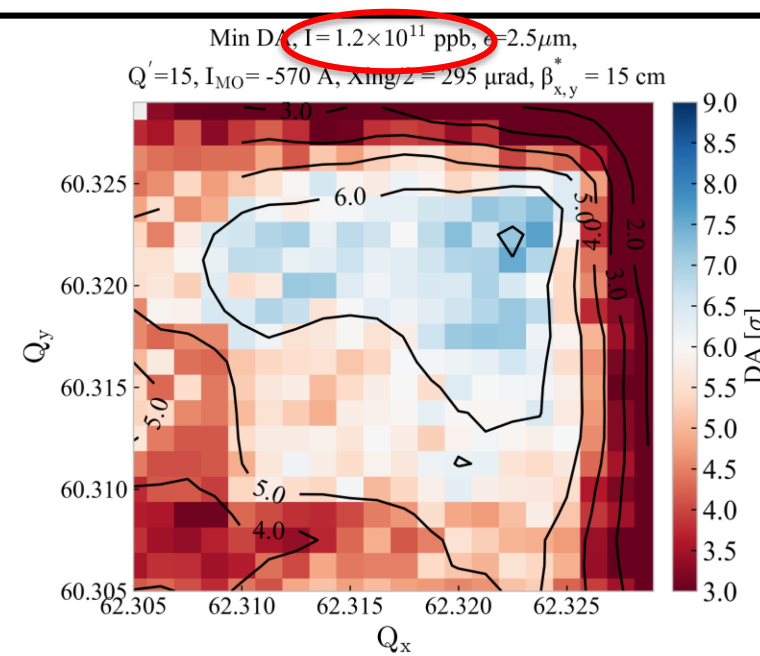
No MS14F & MS14D



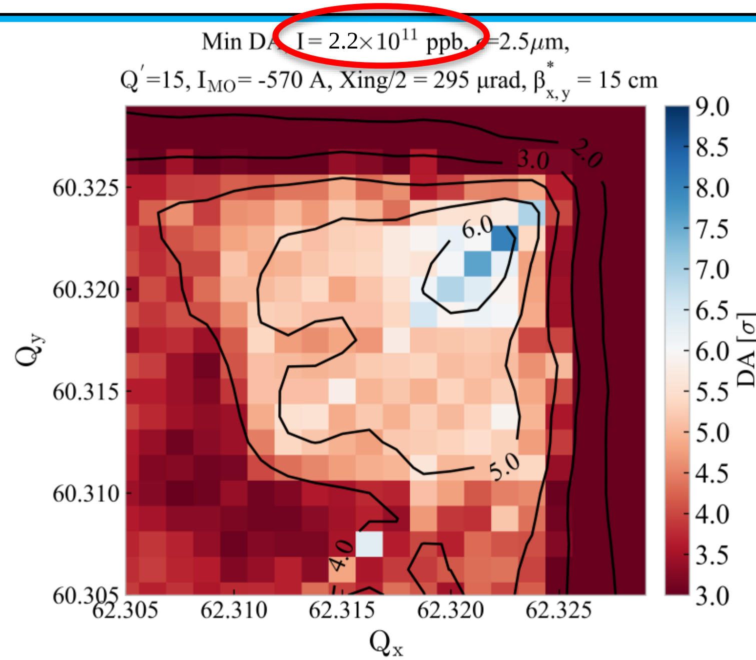
DA comparison with beam-beam after optimization

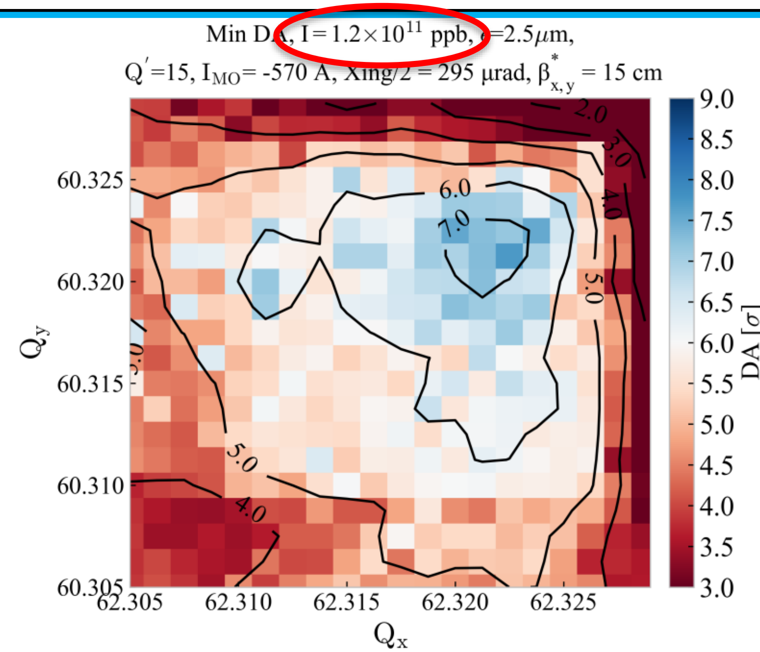
No MS10





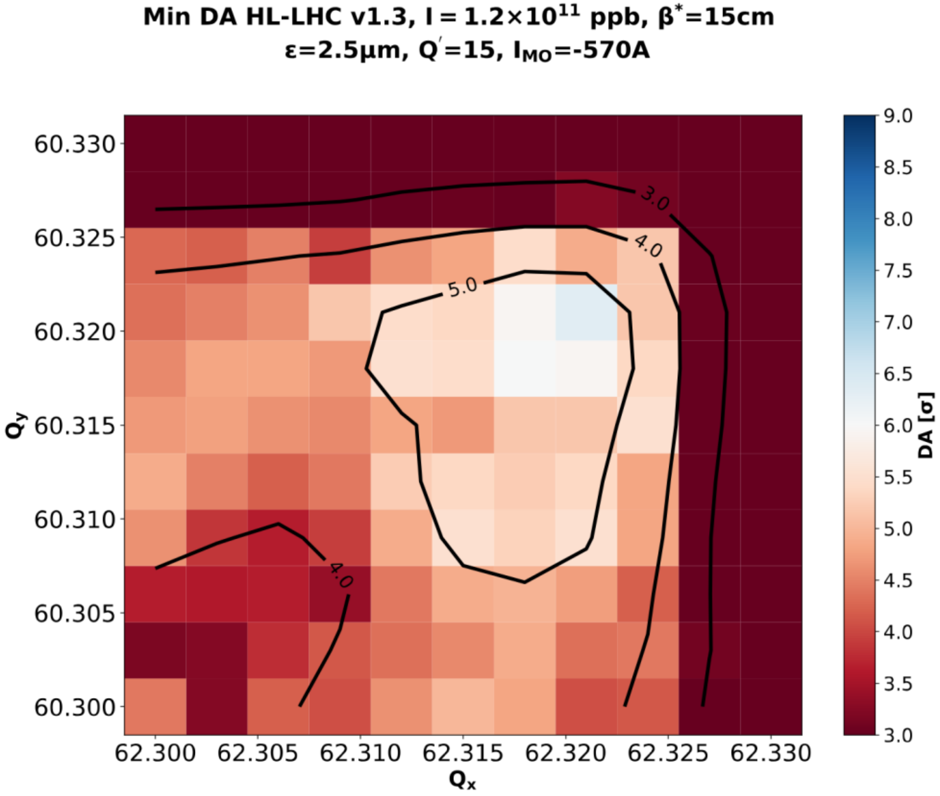
No MS14F & MS14D



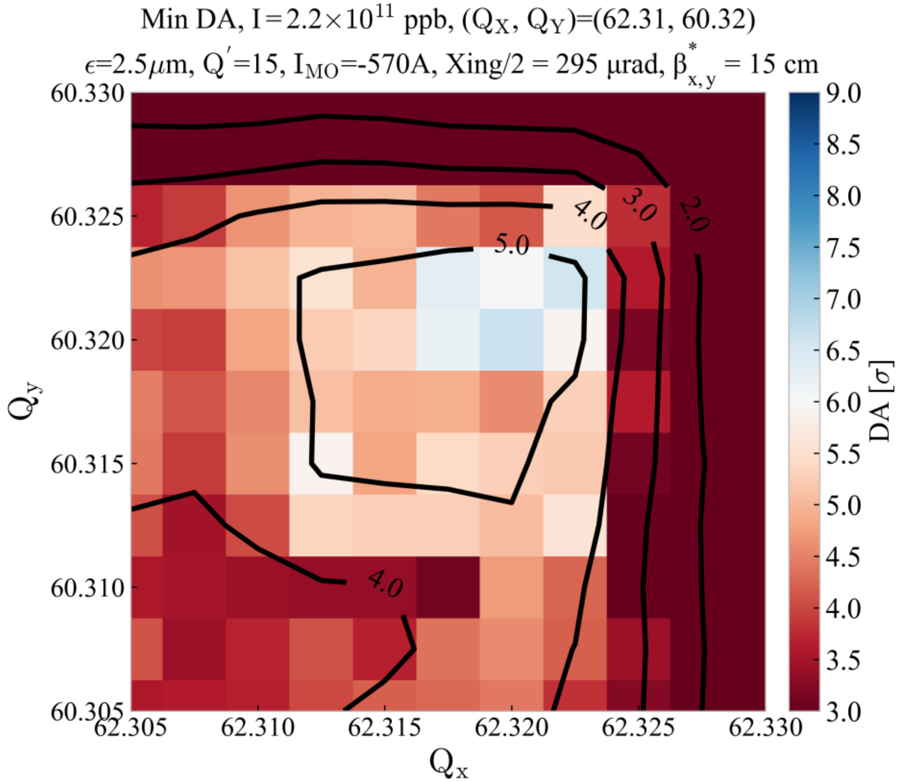


DA comparison for different intensity and crossing angle

HL-LHC v1.3 DA at collision
from
IPAC18 paper MOPMF041
(xing=250μrad & I=1.2× 10^{11})



HL-LHC v1.4 DA at collision
(xing=295μrad & I=2.2× 10^{11})



Comparable tune scan for the HL-LHC for (xing=250μrad & I=1.2× 10^{11})
and for (xing=295μrad & I=2.2× 10^{11}) on the Baseline optics

Conclusions

- **DA comparison between 4 different sextupole lattices proposed for HL-LHC including the impact of field imperfections and weak-strong beam-beam effects**

- The phase advance between IP1 and IP5 has been optimized for each error-free lattice with the goal of maximizing DA

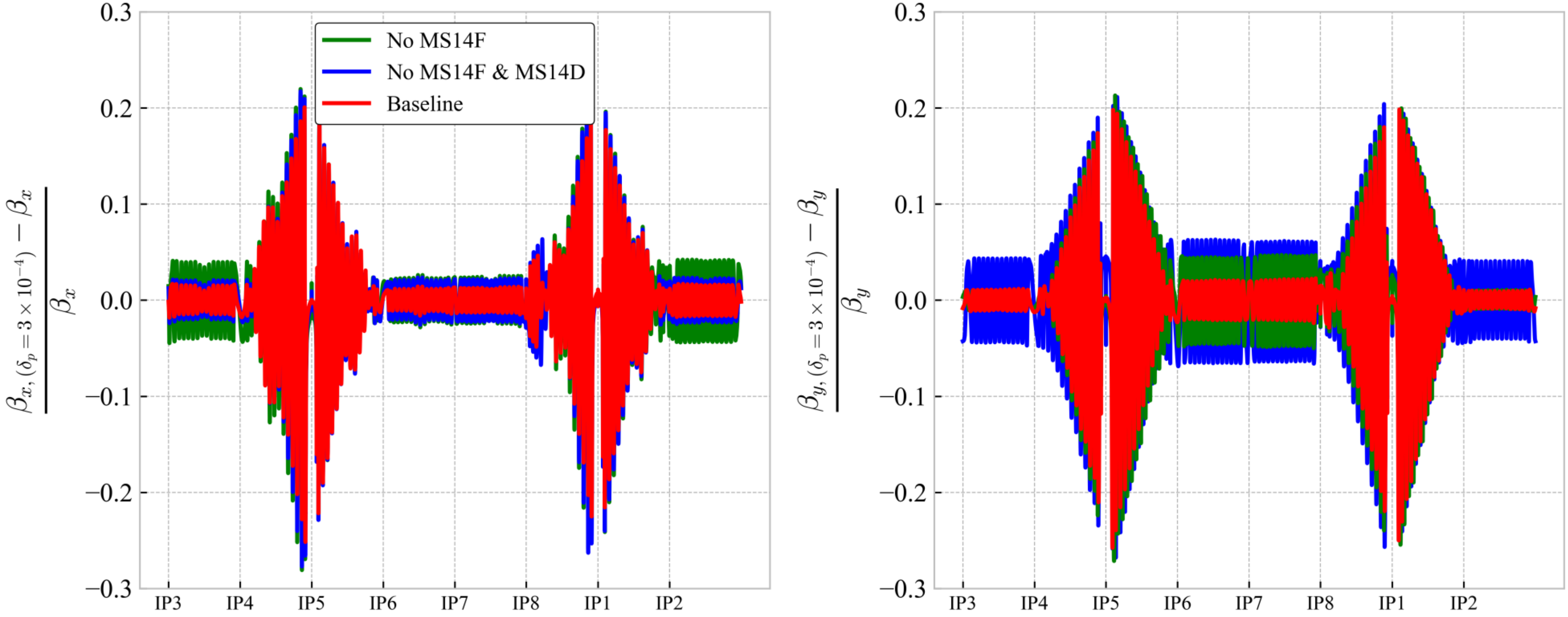
- The **positive impact of the $\Delta\mu_{x,y}^{IP1\to5}$ optimization** on the DA can be important **even when adding field imperfection or by including beam-beam effects**

- After $\Delta\mu_{x,y}^{IP1\to5}$ optimization the **LHC-like sextupole configuration (or No MS10) seems to be a viable option for HL-LHC**

- The No MS14F & MS14D is a robust alternative as the DA is comparable to the Baseline (with MS10) before and after $\Delta\mu_{x,y}^{IP1\to5}$ optimization but requires to push the strength of the strong defocusing sextupole to 95% of their max current to keep chromatic β-beating to the same level

BACKUP

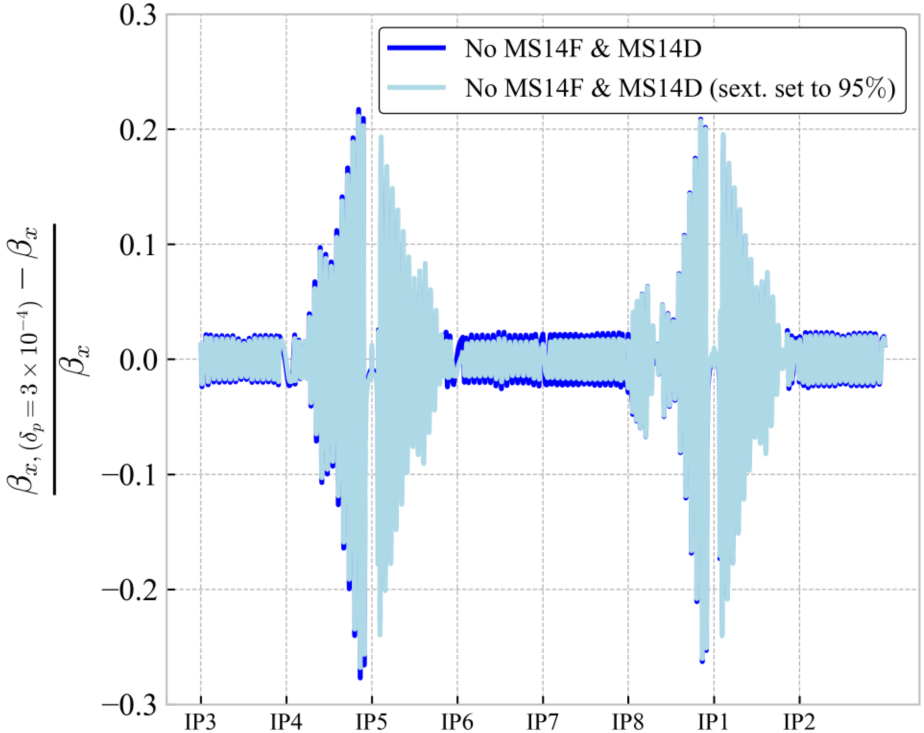
Properties of the proposed alternative options

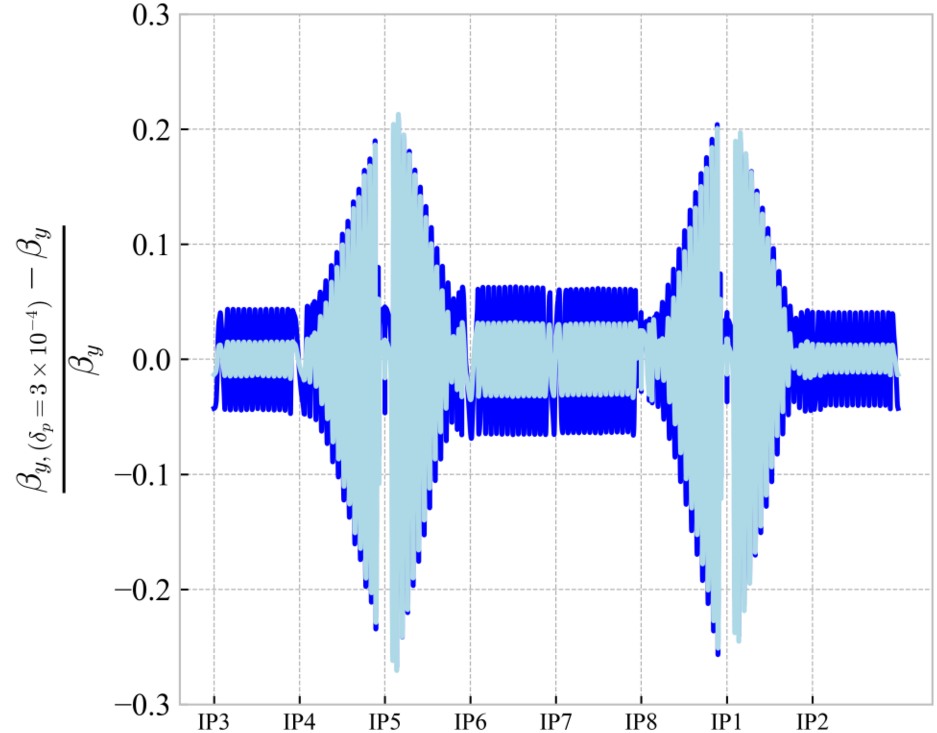


	Baseline	No MS10	No MS14F	No MS14F & MS14D
Horizontal chrom. β-beating (Beam 1) **IP 1/2/5/8** **IP 3/4/6/7**	0.6/ 0.005/ 1.0/ 1.7 0.9/ 0.4/ 1.8/ 1.1	0.8/ 0.003/ 1.3/ 1.7 0.9/ 0.3/ 1.2/ 1.5	0.2/ 0.3/ 1.8/ 0.8 1.5/ 2.0/ 1.8/ 2.4	0.1/ 0.5/ 0.9/ 2.2 1.2/ 1.0/ 0.5/ 2.2
Vertical chrom. β-beating (Beam 1) **IP 1/2/5/8** **IP 3/4/6/7**	0.3/ 0.7/ 0.8/ 1.9 0.7/ 0.5/ 2.4/ 0.2	1.4/ 2.3/ 2.5/ 2.2 2.4/ 1.4/ 3.6/ 3.0	2.3/ 0.08/ 0.5/ 2.7 0.3/ 0.8/ 3.0/ 4.2	3.7/ 4.0/ 4.6/ 2.8 4.2/ 1.0/ 6.4/ 5.8

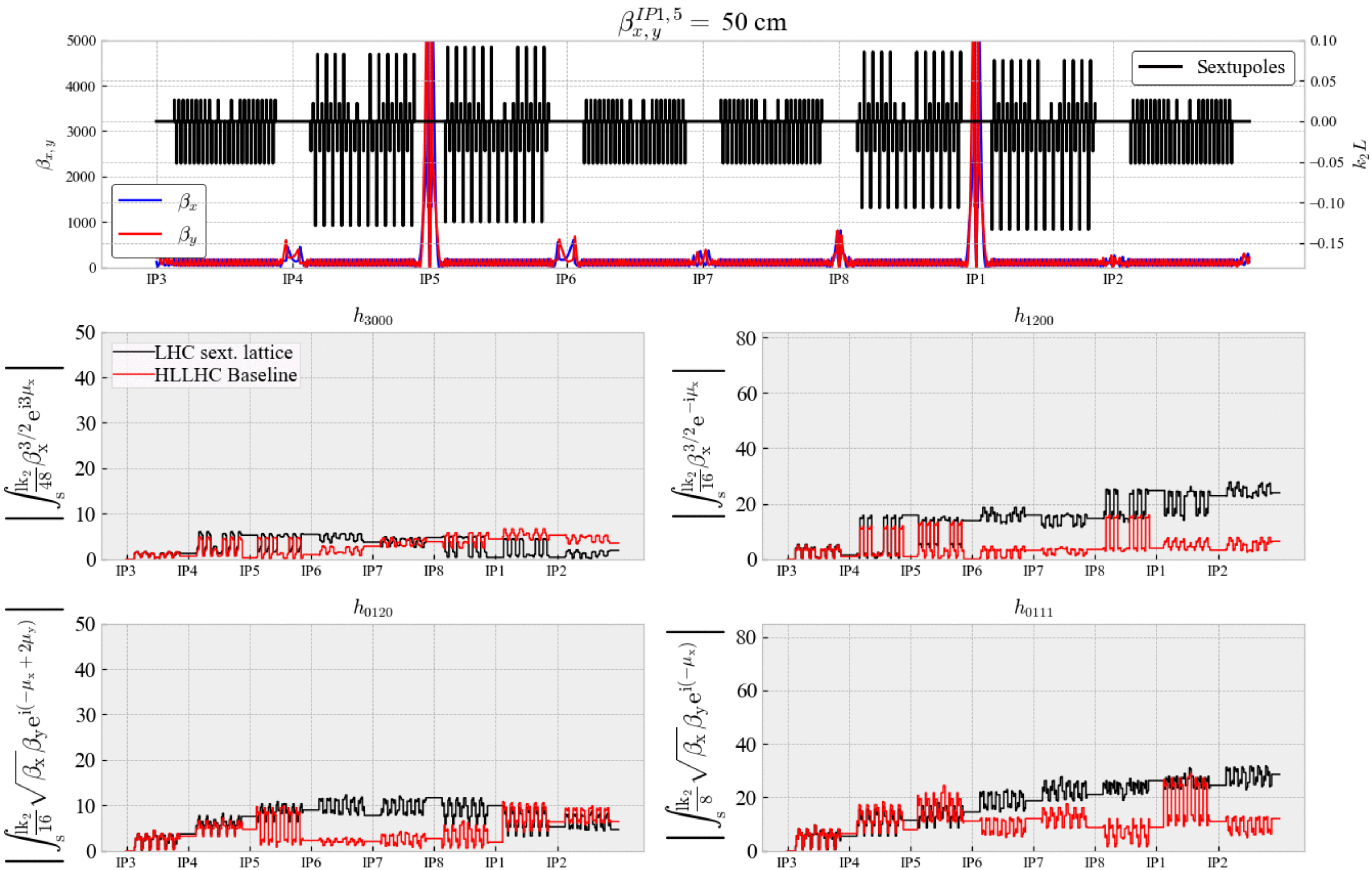
Properties of the proposed alternative options

Increase the current of the defocusing strong sextupole in **R5,L1,R1** to **95% of the maximum strength** (instead of 90%) restore similar chromatic-β beating as Baseline





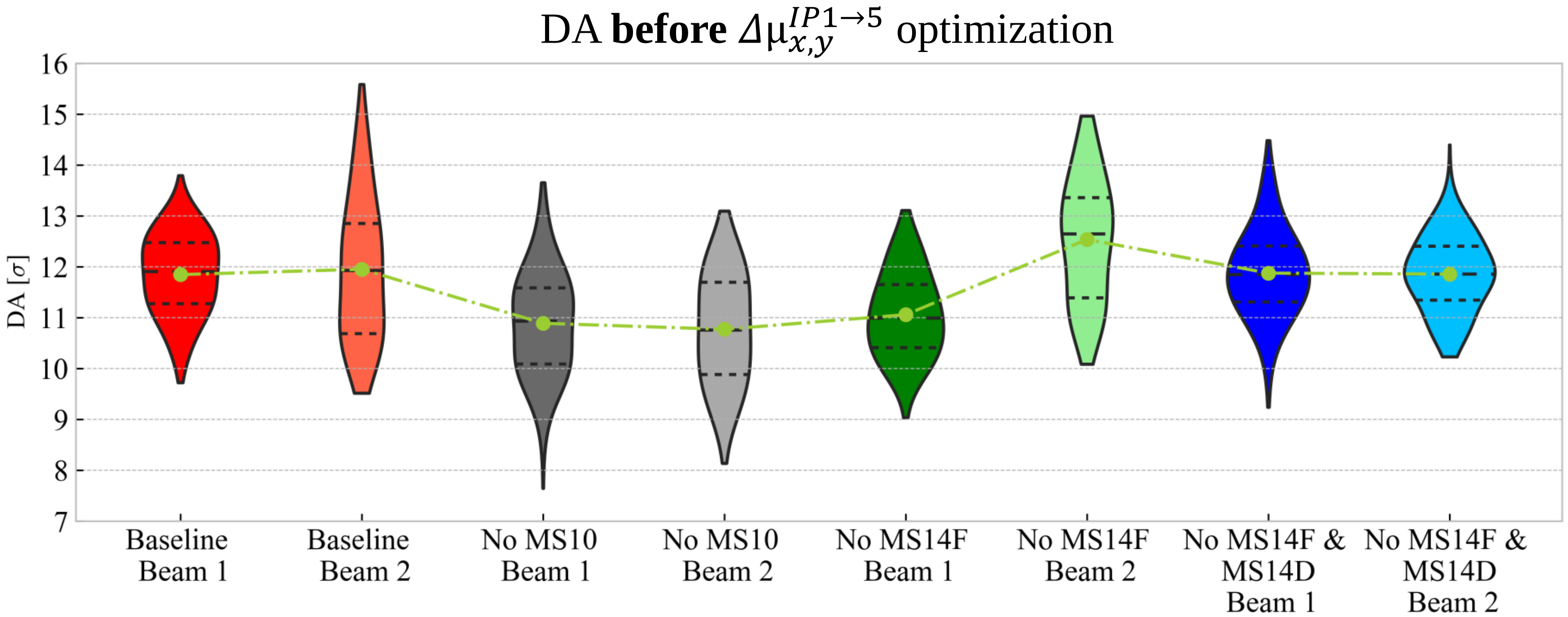
	No MS14F & MS14D	No MS14F & MS14D (k_MS_IR1 ↗ 95%)
Horizontal chrom. β-beating (Beam 1) **IP 1/2/5/8** **IP 3/4/6/7**	0.1/ 0.5/ 0.9/ 2.2 1.2/ 1.0/ 0.5/ 2.2	0.1/ 0.5/ 0.9/ 2.2 1.2/ 1.0/ 0.5/ 2.2
Vertical chrom. β-beating (Beam 1) **IP 1/2/5/8** **IP 3/4/6/7**	3.7/ **4.0**/ **4.6**/ 2.8 **4.2**/ 1.0/ **6.4**/ **5.8**	1.3/ 1.2/ 1.6/ 2.4 1.2/ 0.005/ 3.2/ 3.3



$\beta_{x,y}^{IP1,5} = 50$ cm
Sextupoles
β_x
β_y
$\beta_{x,y}$
k_2L
IP3
IP4
IP5
IP6
IP7
IP8
IP1
IP2
h_{3000}
h_{1200}
h_{0120}
h_{0111}
LHC sext. lattice
HLLHC Baseline

DA comparison before phase $\Delta\mu_{x,y}^{IP1\rightarrow 5}$ optimization

- **DA simulated for 10^5** turns over 7 angles including field imperfections (60 seeds) and with I_{MO}=-570 A



Optics	Average DA (B1/B2) [σ]	Minimum DA (B1/B2) [σ]
Baseline	11.9 / 12.0	9.7 / 9.5
No MS10	10.9 / 10.8	7.6 / 8.1
No MS14F	11.1 / 12.5	9.0 / 10.1
No MS14F & MS14D	11.9 / 11.9	9.3 / 10.2