03/09/2024

Dynamics aperture study for HL-LHC

End of levelling results with flat optics

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Context

We present the latest DA results for the HL-LHC (run 4, optics v1.6), at the End of Levelling (EoL) phase, for the latest available flat optics:

- opt_flathv_75_180_1500_thin.madx
- opt_flatvh_75_180_1500_thin.madx
- opt_flatvh_75_300_1500_thin.madx

Settings

Constant settings for the DA simulations are:

HL-LHC v1.6

$E = 7\ TeV$

$CC = -190\ \mu rad$

$\Phi/2_{IP_{1,5}} = 250 \mu\text{rad}$

$\Phi/2_{IP_{2,V}} = -170 \mu\text{rad}$

$\Phi/2_{IP_{8,V}} = 170 \mu\text{rad}$

$\sigma_z = 7.61\ cm$

$\varepsilon_n = 2.5\ \mu m$

$C^- = 0.001$

$I_{oct} = 60\,A$

$Q' = 15$ or $Q' = 5$

Polarity $IP_{2,8} = +1/+1$

Settings

Bunch intensity is optimised to be maximal within constraints, i.e.:

$$L_{1,5} \leq 5 \times 10^{34}\ Hz/cm^2 \qquad\qquad PU_{1,5} \leq 160$$

Separation in IP2 is 5σ

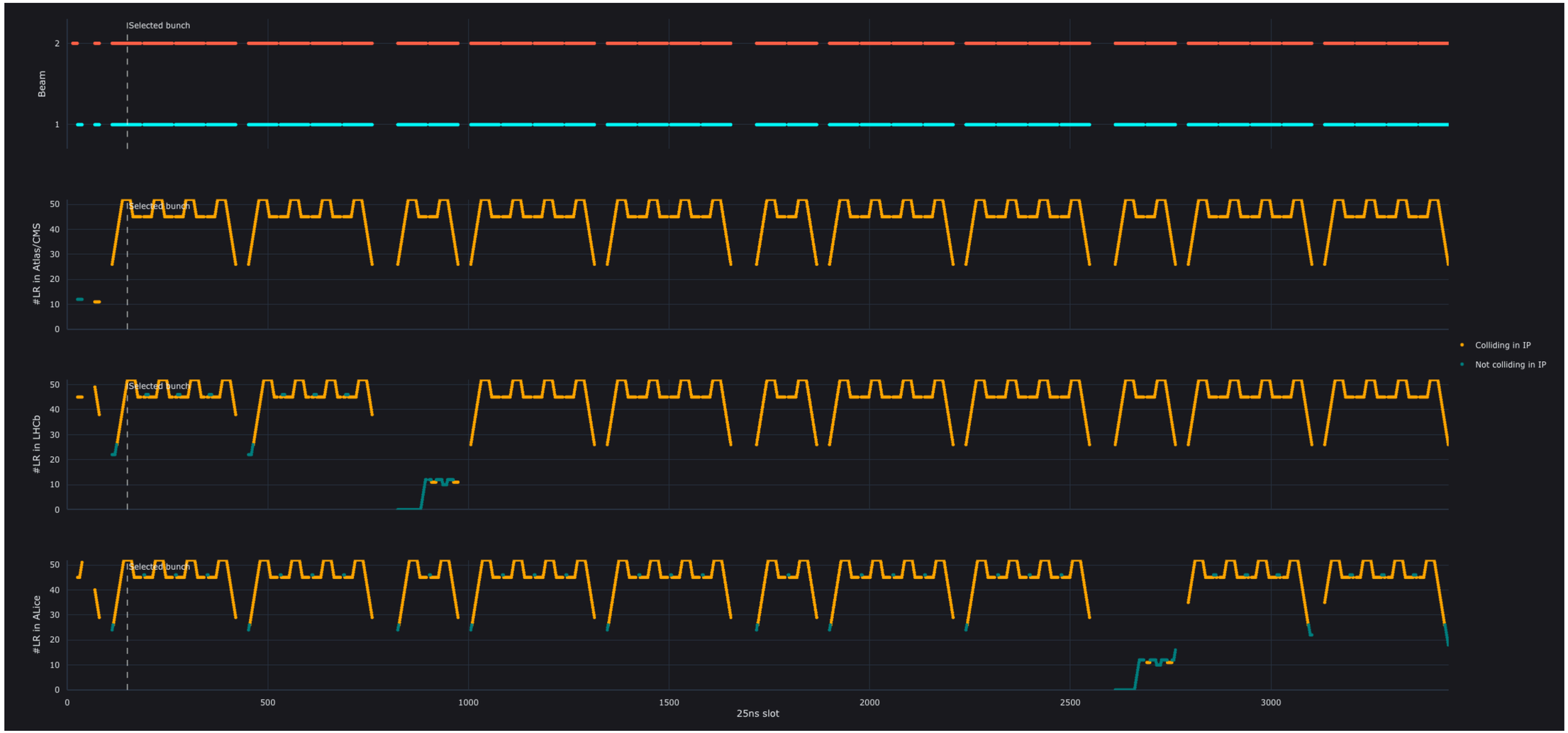
Separation in IP8 is optimised to reach $L_8 = 2 \times 10^{33}\ Hz/cm^2$

As usual, we study the worst bunch in terms of Head-On (HO) + Long-Range (LR) schedule.

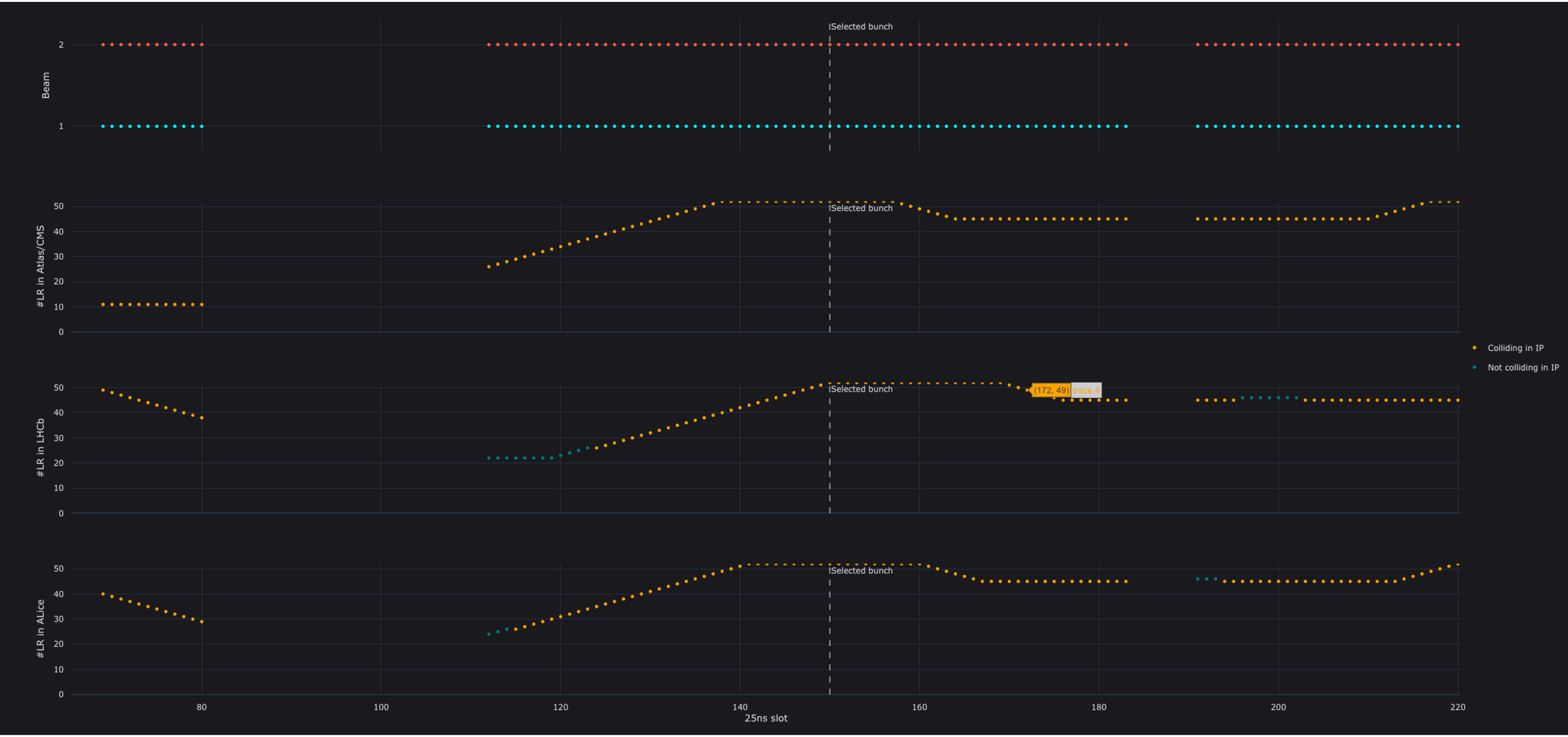
Filling scheme and bunch schedule

We consider the “27 hundreds” filling scheme, a.k.a:

25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns



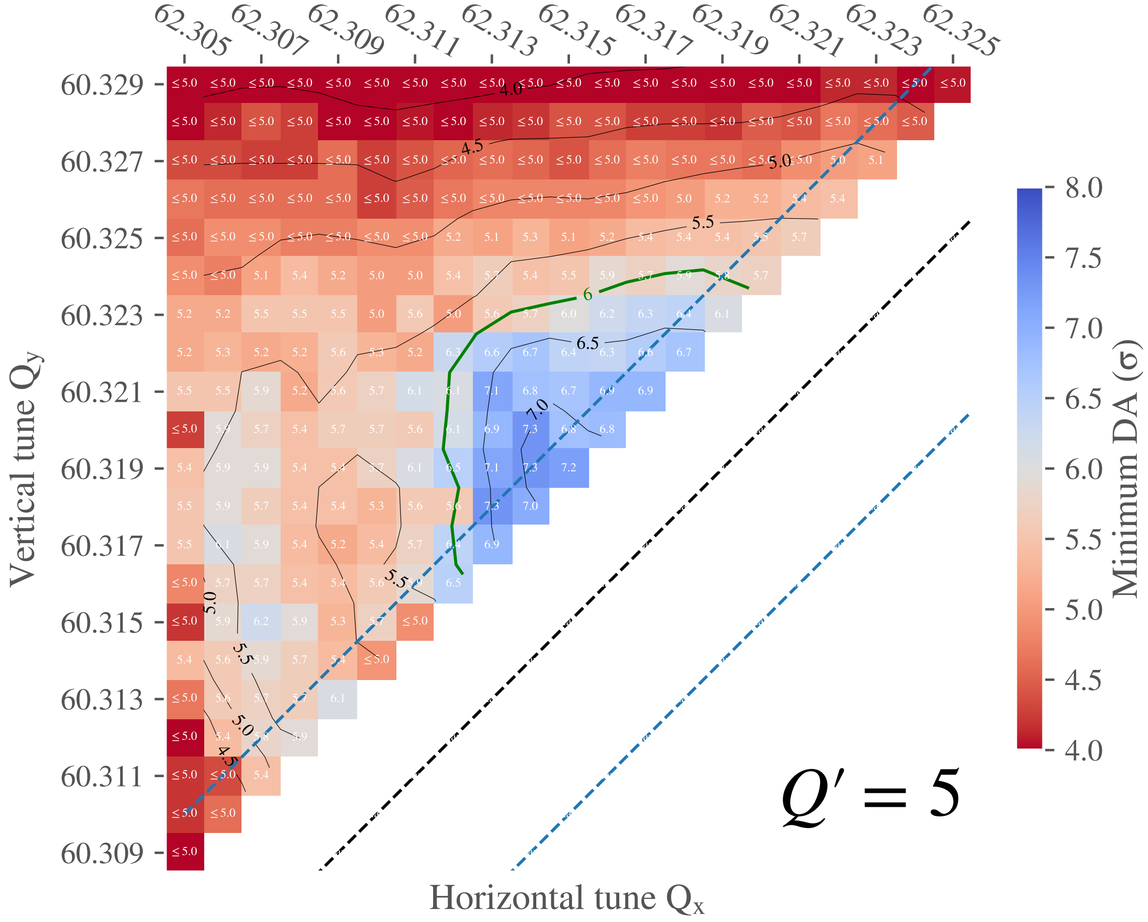
Filling scheme and bunch schedule



Simulations result

opt_flathv_75_180_1500_thin.madx

HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 μrad. $N_b \simeq 1.02 \times 10^{11}$ ppb,
$L_{1/5} = 4.97 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 1.53 \times 10^{30} cm^{-2}s^{-1}$, $L_8 = 1.98 \times 10^{33} cm^{-2}s^{-1}$
$PU_{1/5} = 131$, $\beta^*_{x,1} = 0.18$ m, $\beta^*_{y,1} = 0.075$ m, polarity $IP_{2/8} = 1/1$
$\Phi/2_{1(H)} = 250$ μrad, $\Phi/2_{5(V)} = 250$ μrad, $\Phi/2_{2,V} = -170$ μrad, $\Phi/2_{8,V} = 170$ μrad
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ μm, $Q' = 5.0$, $I_{MO} = 60.0$ A, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns_converted.json. Bunch 149.



HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 μrad. $N_b \simeq 1.02 \times 10^{11}$ ppb,
$L_{1/5} = 4.97 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 1.53 \times 10^{30} cm^{-2}s^{-1}$, $L_8 = 1.98 \times 10^{33} cm^{-2}s^{-1}$
$PU_{1/5} = 131$, $\beta^*_{x,1} = 0.18$ m, $\beta^*_{y,1} = 0.075$ m, polarity $IP_{2/8} = 1/1$
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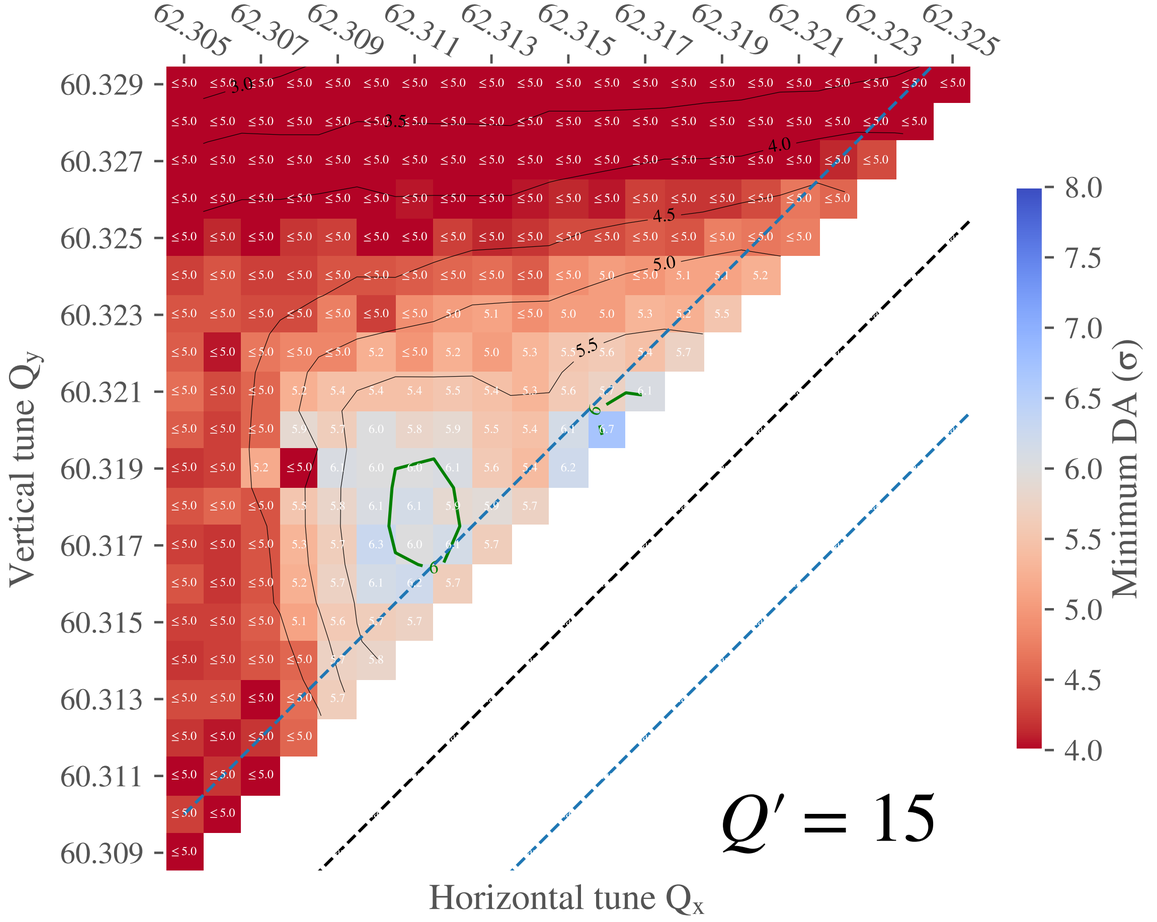
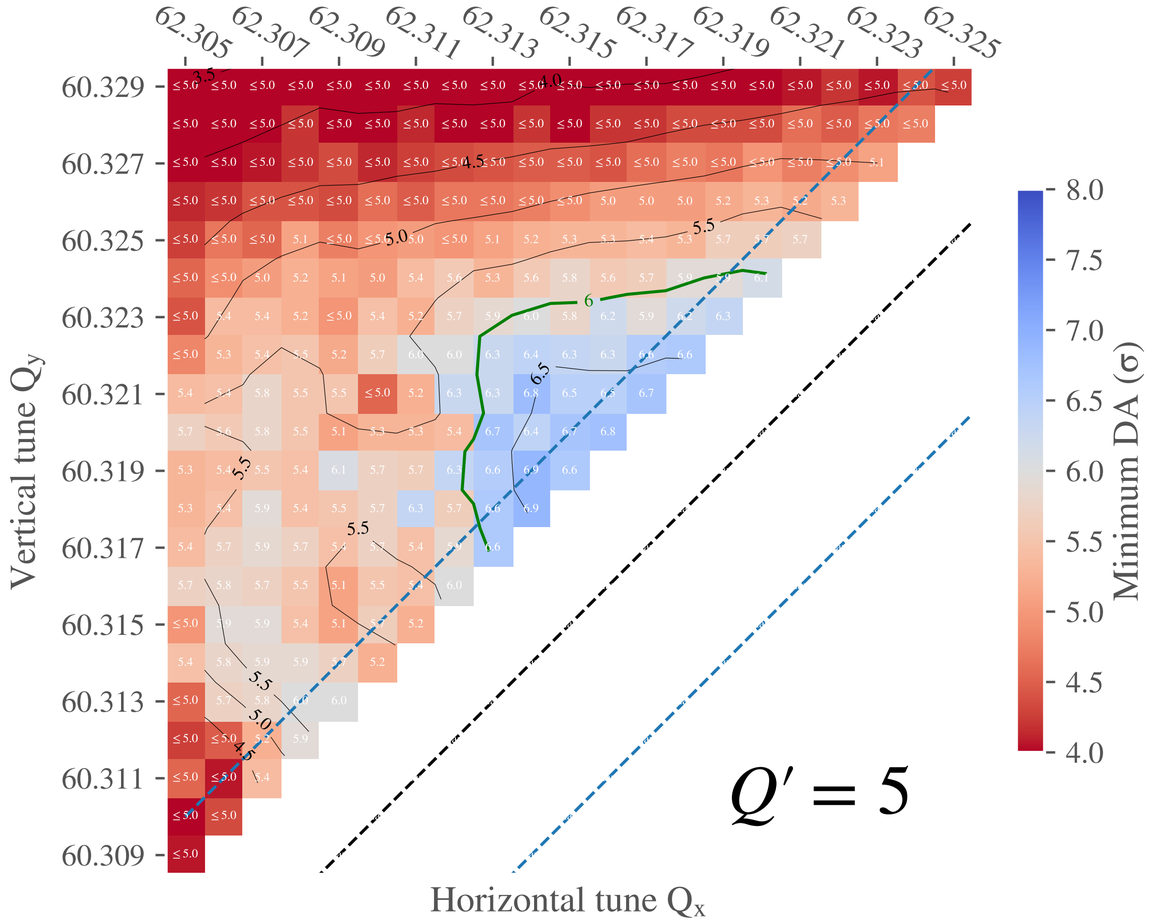
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ μm, $Q' = 15$, $I_{MO} = 60.0$ A, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns_converted.json. Bunch 149.



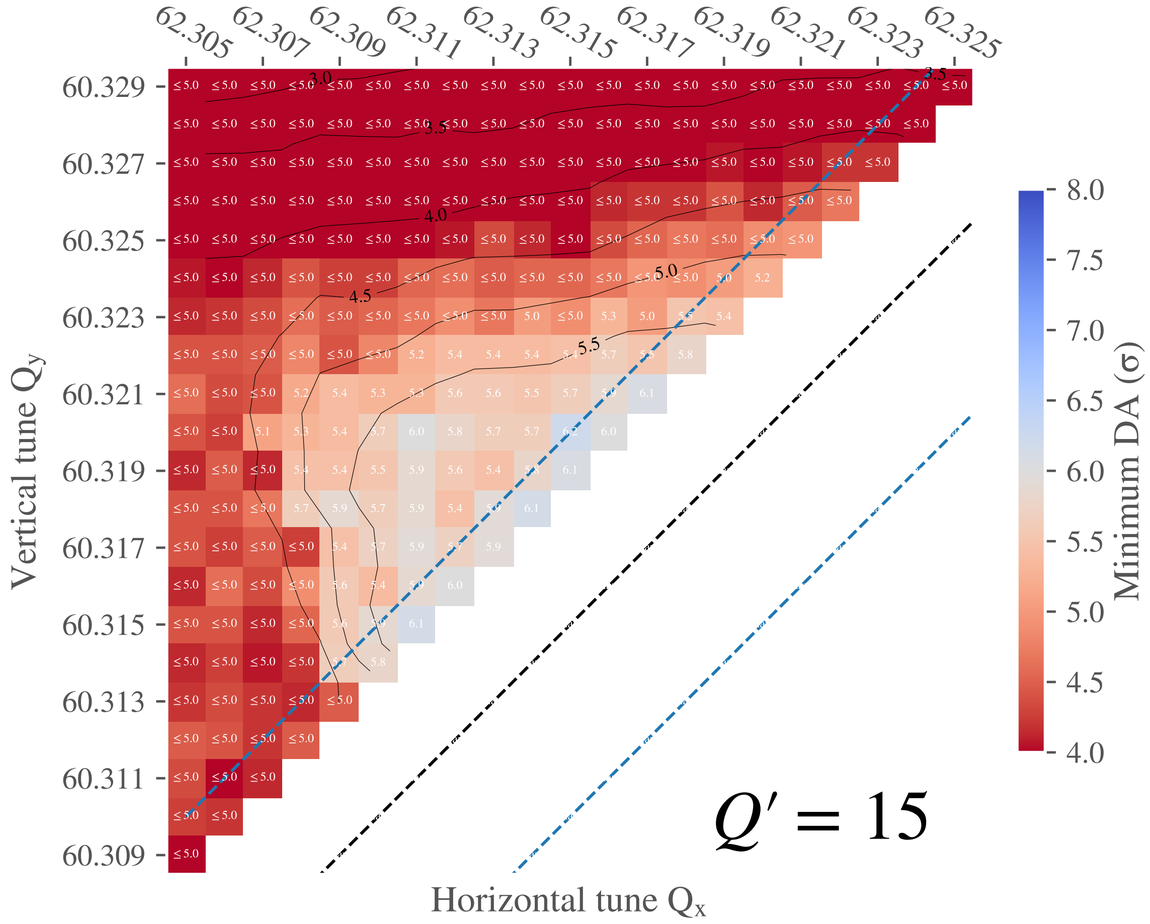
Simulations result

opt_flatvh_75_180_1500_thin.madx

HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 μrad. $N_b \simeq 1.03 \times 10^{11}$ ppb,
$L_{1/5} = 4.99 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 1.12 \times 10^{30} cm^{-2}s^{-1}$, $L_8 = 1.98 \times 10^{33} cm^{-2}s^{-1}$
$PU_{1/5} = 130$, $\beta^*_{x,1} = 0.075$ m, $\beta^*_{y,1} = 0.18$ m, polarity $IP_{2/8} = 1/1$
$\Phi/2_{1(V)} = 250$ μrad, $\Phi/2_{5(H)} = 250$ μrad, $\Phi/2_{2,V} = -170$ μrad, $\Phi/2_{8,V} = 170$ μrad
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ μm, $Q' = 5.0$, $I_{MO} = 60.0$ A, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns_converted.json. Bunch 149.



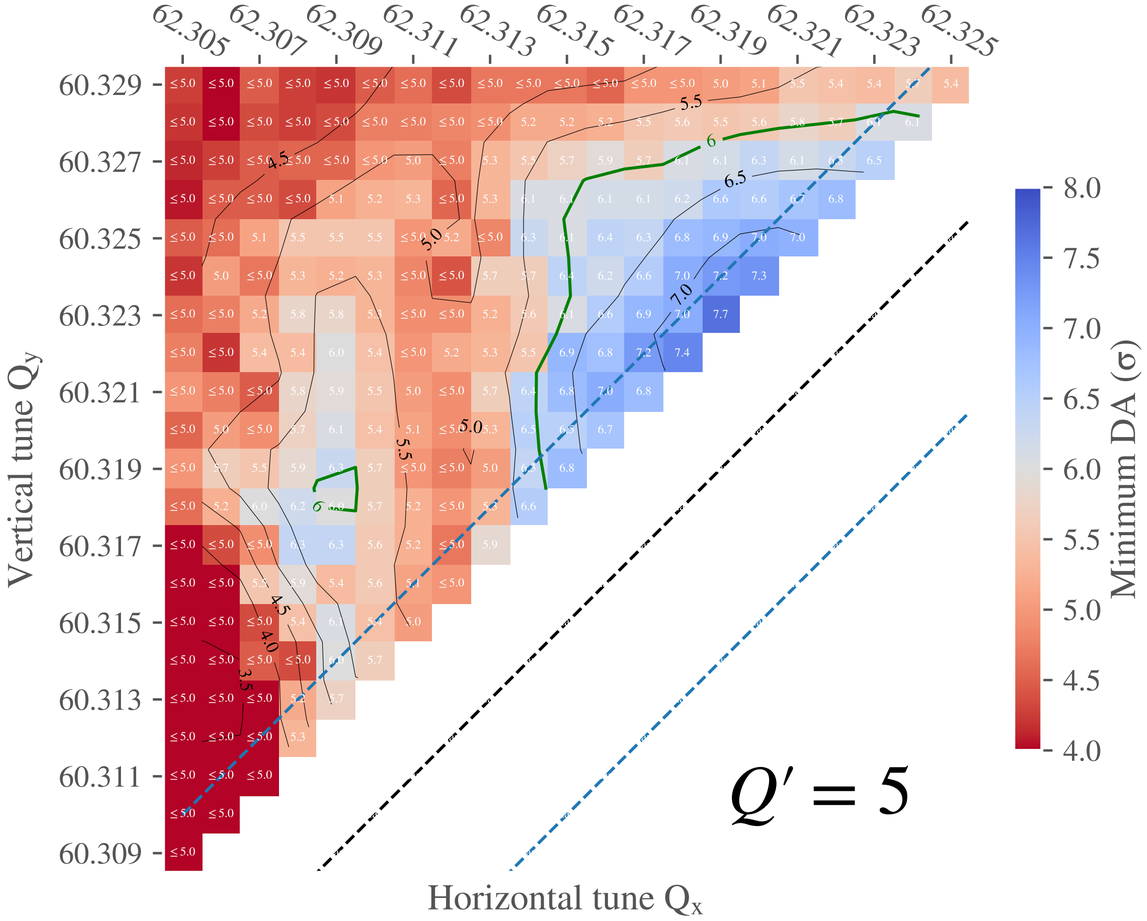
HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 μrad. $N_b \simeq 1.03 \times 10^{11}$ ppb,
$L_{1/5} = 4.99 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 1.12 \times 10^{30} cm^{-2}s^{-1}$, $L_8 = 1.98 \times 10^{33} cm^{-2}s^{-1}$
$PU_{1/5} = 130$, $\beta^*_{x,1} = 0.075$ m, $\beta^*_{y,1} = 0.18$ m, polarity $IP_{2/8} = 1/1$
$\Phi/2_{1(V)} = 250$ μrad, $\Phi/2_{5(H)} = 250$ μrad, $\Phi/2_{2,V} = -170$ μrad, $\Phi/2_{8,V} = 170$ μrad
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ μm, $Q' = 15$, $I_{MO} = 60.0$ A, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns_converted.json. Bunch 149.



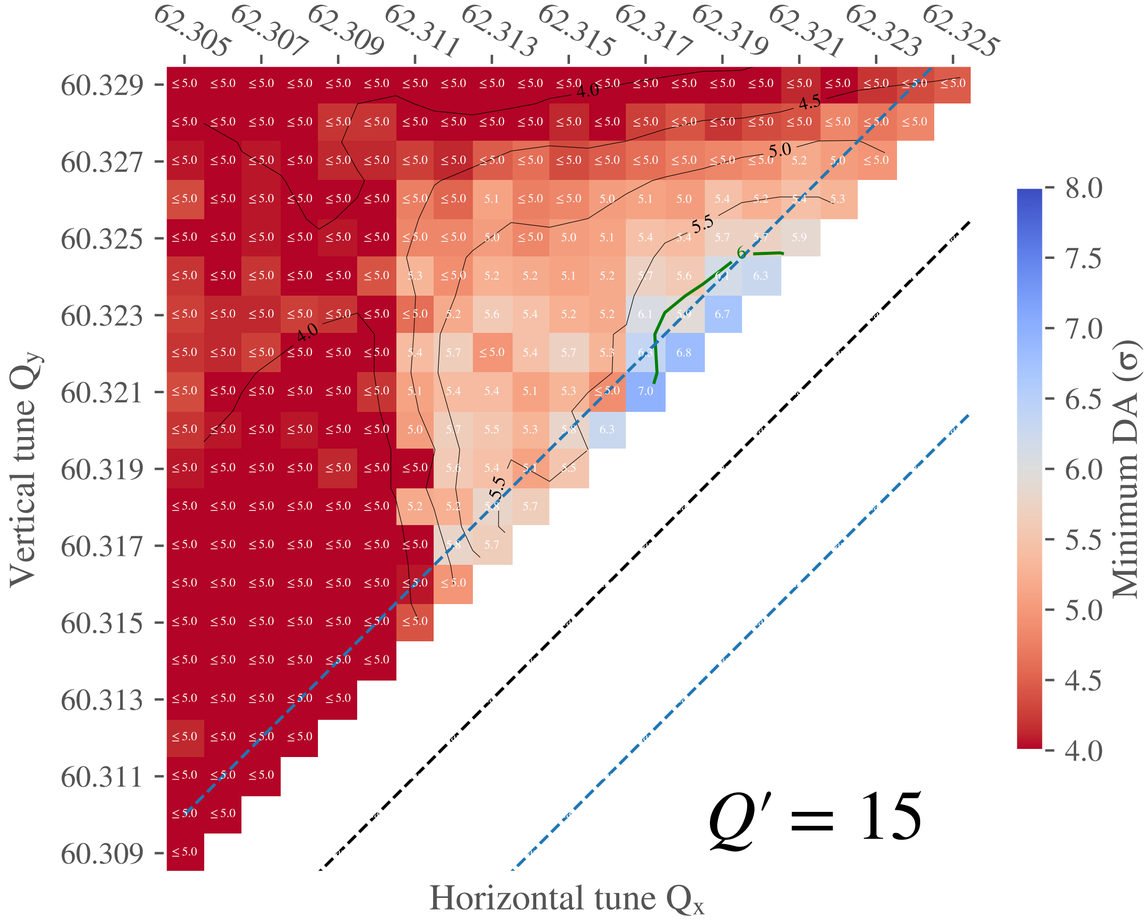
Simulations result

opt_flatvh_75_300_1500_thin.madx

HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 μrad. $N_b \simeq 1.14 \times 10^{11}$ ppb,
$L_{1/5} = 4.98 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 1.43 \times 10^{30} cm^{-2}s^{-1}$, $L_8 = 1.97 \times 10^{33} cm^{-2}s^{-1}$
$PU_{1/5} = 130$, $\beta^*_{x,1} = 0.075$ m, $\beta^*_{y,1} = 0.3$ m, polarity $IP_{2/8} = 1/1$
$\Phi/2_{1(V)} = 250$ μrad, $\Phi/2_{5(H)} = 250$ μrad, $\Phi/2_{2,V} = -170$ μrad, $\Phi/2_{8,V} = 170$ μrad
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ μm, $Q' = 5.0$, $I_{MO} = 60.0$ A, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns_converted.json. Bunch 149.



HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 μrad. $N_b \simeq 1.14 \times 10^{11}$ ppb,
$L_{1/5} = 4.98 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 1.43 \times 10^{30} cm^{-2}s^{-1}$, $L_8 = 1.97 \times 10^{33} cm^{-2}s^{-1}$
$PU_{1/5} = 130$, $\beta^*_{x,1} = 0.075$ m, $\beta^*_{y,1} = 0.3$ m, polarity $IP_{2/8} = 1/1$
$\Phi/2_{1(V)} = 250$ μrad, $\Phi/2_{5(H)} = 250$ μrad, $\Phi/2_{2,V} = -170$ μrad, $\Phi/2_{8,V} = 170$ μrad
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ μm, $Q' = 15$, $I_{MO} = 60.0$ A, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns_converted.json. Bunch 149.

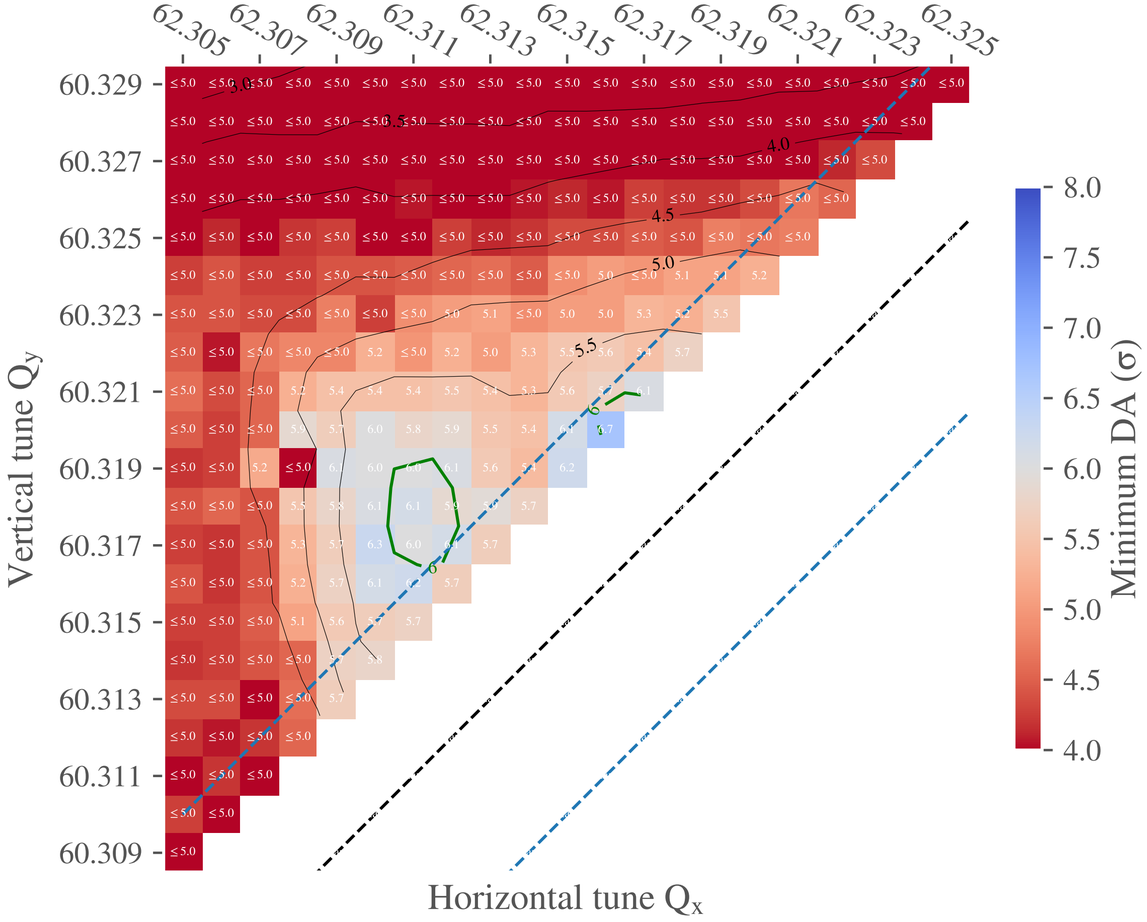


Simulations result

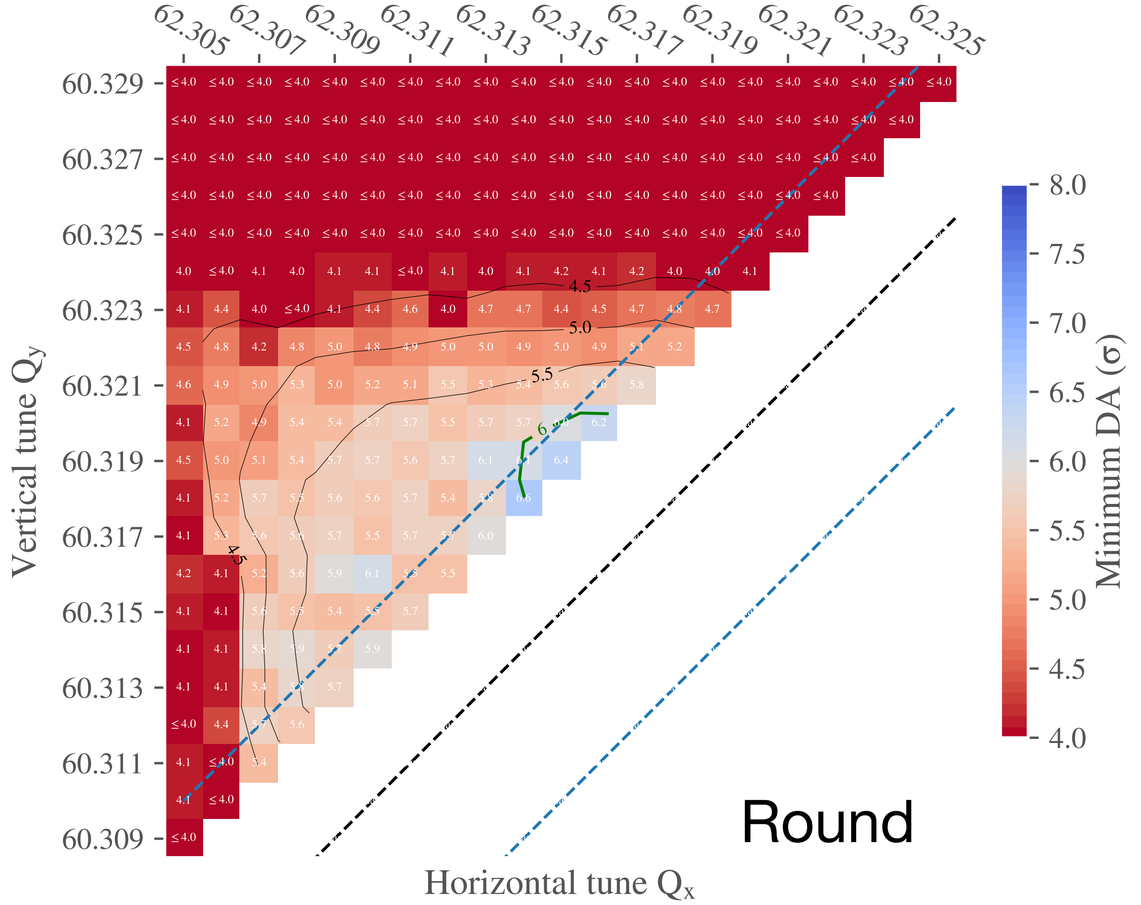
Comparison with round optics (IPAC) $Q' = 15$

opt_flathv_75_180_1500_thin.madx

HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 μrad. $N_b \simeq 1.02 \times 10^{11}$ ppb,
$L_{1/5} = 4.97 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 1.53 \times 10^{30} cm^{-2}s^{-1}$, $L_8 = 1.98 \times 10^{33} cm^{-2}s^{-1}$
$PU_{1/5} = 131$, $\beta^*_{x,1} = 0.18$ m, $\beta^*_{y,1} = 0.075$ m, polarity $IP_{2/8} = 1/1$
$\Phi/2_{1(H)} = 250$ μrad, $\Phi/2_{5(V)} = 250$ μrad, $\Phi/2_{2,V} = -170$ μrad, $\Phi/2_{8,V} = 170$ μrad
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ μm, $Q' = 15$, $I_{MO} = 60.0$ A, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns_converted.json. Bunch 149.



HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 μrad. $N_b \simeq 1.13 \times 10^{11}$ ppb,
$L_{1/5} = 5.06 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 1.96 \times 10^{30} cm^{-2}s^{-1}$, $L_8 = 1.99 \times 10^{33} cm^{-2}s^{-1}$
$PU_{1/5} = 133$, $\beta^*_{x,1} = 0.15$ m, $\beta^*_{y,1} = 0.15$ m, polarity $IP_{2/8} = 1/1$
$\Phi/2_{1(H)} = 250$ μrad, $\Phi/2_{5(V)} = 250$ μrad, $\Phi/2_{2,V} = -170$ μrad, $\Phi/2_{8,V} = 170$ μrad
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ μm, $Q' = 15$, $I_{MO} = -60.0$ A, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns.json. Bunch 150.



Simulations result

Octupoles and Q' scan at optimal tune (.15, .20)

opt_flatvh_75_180_1500_thin.madx

HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 µrad.

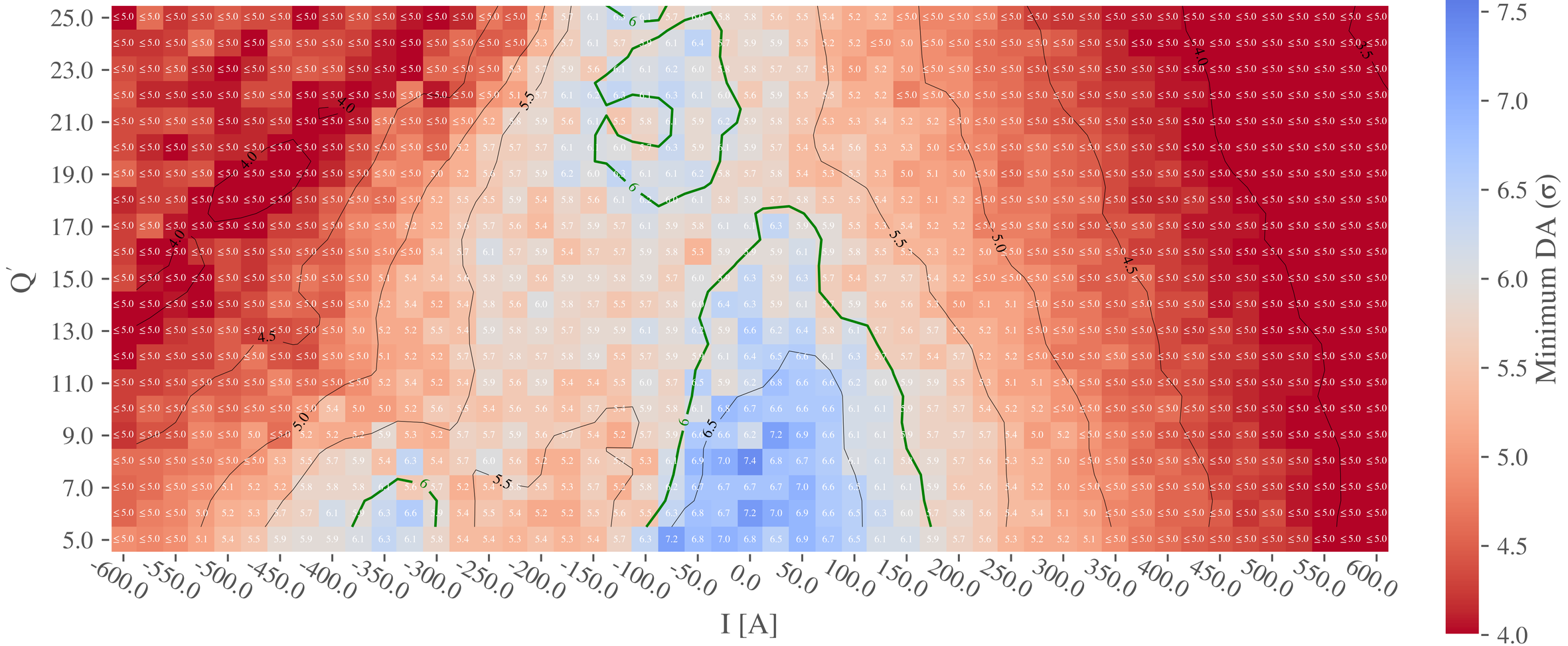
$L_{1/5} = 5.21 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 8.79 \times 10^{29} cm^{-2}s^{-1}$, $L_8 = 1.99 \times 10^{33} cm^{-2}s^{-1}$

$PU_{1/5} = 135$, $\beta^*_{x,1} = 0.075$ m, $\beta^*_{y,1} = 0.18$ m, polarity $IP_{2/8} = 1/1$

$\Phi/2_{1(V)} = 250$ µrad, $\Phi/2_{5(H)} = 250$ µrad, $\Phi/2_{2,V} = -170$ µrad, $\Phi/2_{8,V} = 170$ µrad

$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ µm, , $C^- = 0.001$

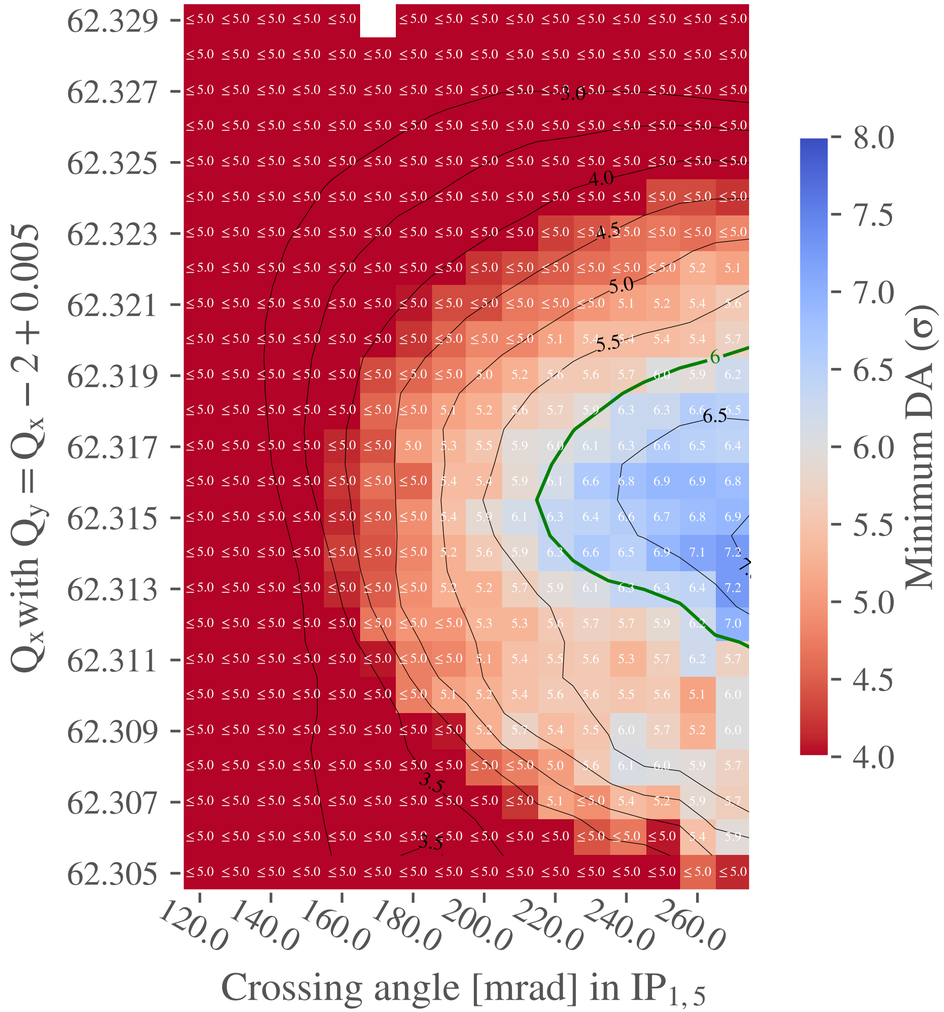
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns_converted.json. Bunch 149.



Simulations result

Xing angle scan along the upper diagonal

HL-LHC v1.6. $E = 7.0$ TeV. $CC = -190.0$ µrad.
$L_{1/5} = 5.22 \times 10^{34} cm^{-2} s^{-1}$, $L_2 = 4.22 \times 10^{29} cm^{-2} s^{-1}$, $L_8 = 2.02 \times 10^{33} cm^{-2} s^{-1}$
$PU_{1/5} = 136$, $\beta^*_{x,1} = 0.075$ m, $\beta^*_{y,1} = 0.18$ m, polarity $IP_{2/8} = 1/1$
$\Phi/2_{2,V} = -170$ µrad, $\Phi/2_{8,V} = 170$ µrad
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ µm, $Q' = 5.0$, $I_{MO} = 60.0$ A, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns_converted.json. Bunch 149.



opt_flatvh_75_180_1500_thin.madx

Conclusion

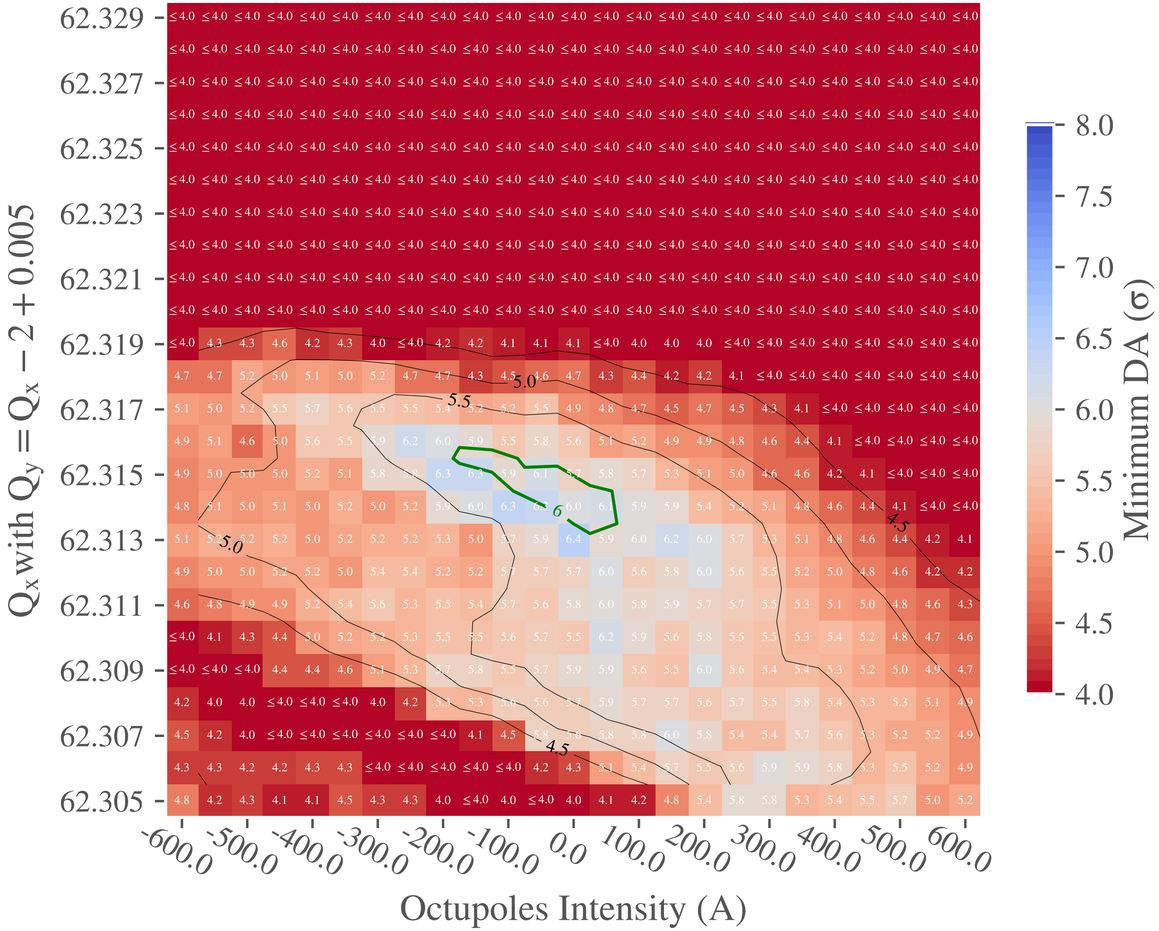
- VH and HV optics yield very similar DA results
- 6σ target can be reached for Q'= 5 and Q' = 15 in the 7.5/30cm case
- 6σ target can be reached for Q'= 5 and very marginally for Q' = 15 in the 7.5/18cm or 18/7.5cm case
- Comparison with round results (15cm) with negative octupoles (-60A) deliver slightly worse results than flat (18/7.5cm) with positive octupoles (60A).
- Octupoles vs Q' scan for 7.5/18cm shows that optimal DA can be reached for various combinations of values. Making a 3D scan (with tune) would probably help understand.
- Crossing angle limit is about 220murad for the 7.5/18cm case with Q'=5

Thank you!

Additional results from previous simulations

Octupoles scan (IPAC, round optics)

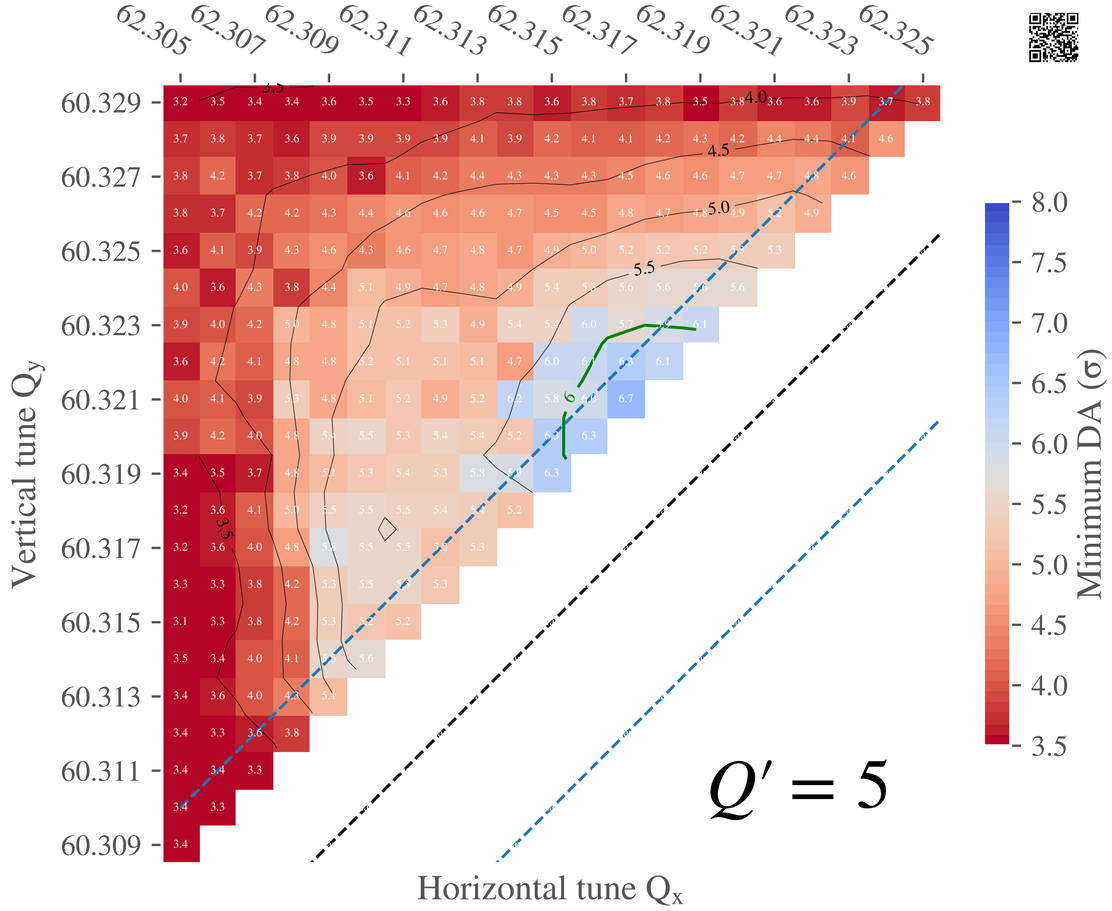
HL-LHC v1.6. E = 7.0 TeV. CC = −190.0 μrad. $N_b \simeq 1.13 \times 10^{11}$ ppb,
$L_{1/5} = 5.27 \times 10^{34} cm^{-2}s^{-1}$, $L_2 = 1.43 \times 10^{30} cm^{-2}s^{-1}$, $L_8 = 1.98 \times 10^{33} cm^{-2}s^{-1}$
$PU_{1/5} = 138$, $\beta^*_{x,1} = 0.15$ m, $\beta^*_{y,1} = 0.15$ m, polarity $IP_{2/8} = 1/1$
$\Phi/2_{1(H)} = 250$ μrad, $\Phi/2_{5(V)} = 250$ μrad, $\Phi/2_{2,V} = -170$ μrad, $\Phi/2_{8,V} = 170$ μrad
$\sigma_z = 7.61$ cm, $\varepsilon_n = 2.5$ μm, $Q' = 15$, $C^- = 0.001$
25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns.json. Bunch 150.



Additional results from previous simulations

Tune scan with hybrid scheme, HL 1.5. No CC.

HL-LHC v1.5. Flat optics. End of levelling. CC ON. Bunch 1147.
$N_b \simeq 1.3 \times 10^{11}$ppb, $\beta^*_{y,\,IP1} = 7.5$ cm, $\beta^*_{x,\,IP1} = 18$ cm, $\Phi/2_{IP1(H)/5(V)} = 250$µrad
$\sigma_z = 7.61$ cm, $\Phi/2_{IP8,\,V} = 170$ µrad, $\varepsilon_n = 2.5$ µm, $Q' = 5.0$, $I_{MO} = 60.0$ A, $C^- = 0.001$
F. Scheme : 25ns_2228b_2216_1686_2112_hybrid_8b4e_2x56b_25ns_3x48b_12inj



HL-LHC v1.5. Flat optics. End of levelling. CC ON. Bunch 1147.
$N_b \simeq 1.3 \times 10^{11}$ppb, $\beta^*_{y,\,IP1} = 7.5$ cm, $\beta^*_{x,\,IP1} = 18$ cm, $\Phi/2_{IP1(H)/5(V)} = 250$µrad
$\sigma_z = 7.61$ cm, $\Phi/2_{IP8,\,V} = 170$ µrad, $\varepsilon_n = 2.5$ µm, $Q' = 15$, $I_{MO} = 60.0$ A, $C^- = 0.001$
F. Scheme : 25ns_2228b_2216_1686_2112_hybrid_8b4e_2x56b_25ns_3x48b_12inj