HL-LHC Dynamic Aperture at Injection

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with many thanks to
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Introduction

(**) using 2.5 for margin

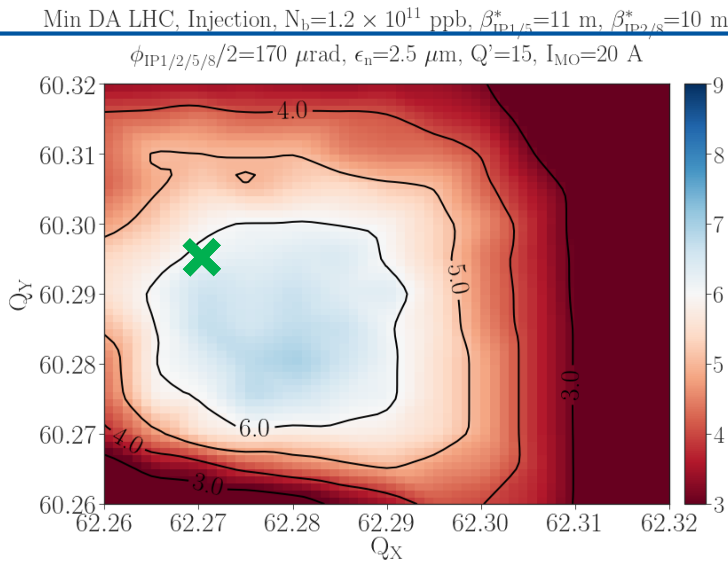
- Motivation:
  Perform a multi-parametric study at the HL-LHC injection plateau to identify the available parameter space.
- To compare with the present situation results for the LHC injection optics used in Run-II and the foreseen settings for Run-III are quickly presented.
- As usual the "full OP configuration" is used for the simulations (i.e. all IPs, worst polarity on the experimental spectrometers etc).
- According to the operational scenario* the beam/machine parameters are:

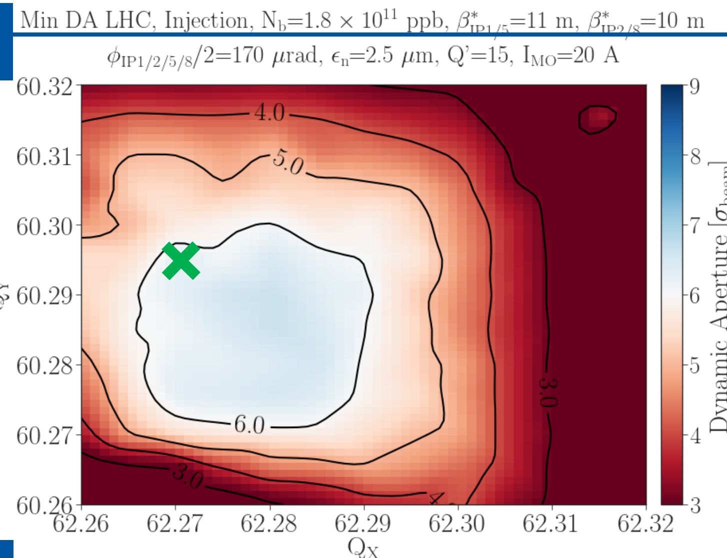
Energy [TeV]	0.45
Bunch Intensity [10^{11} ppb]	2.3
Normalized Emittance [μm]	2.1-2.3 (**)
β* IP1/5 [m]	6
β* IP2/8 [m]	10
Half-Crossing Angle IP1/5 [μrad]	295
Half-Crossing Angle IP1/5 [μrad]	170
Parallel Separation IP1/5 [mm]	2
Parallel Separation IP2/8 [mm]	3.5
Working Point	(62.270, 60.295)
Chromaticity [#]	+20
Octupole Current [A]	-40

* E. Metral et al., "Update of the HL-LHC operational scenarios for proton operation", CERN ACC Notes, CERN-ACC-NOTE-2018-0002, 2018

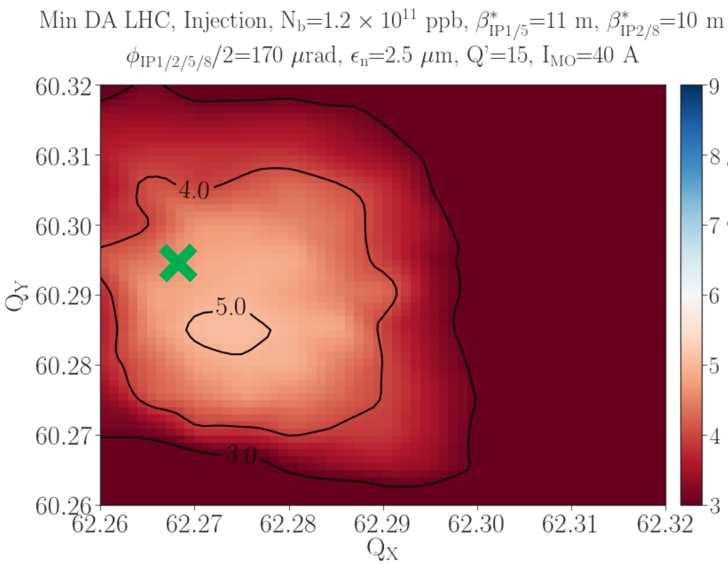
LHC Run-II vs Run-III

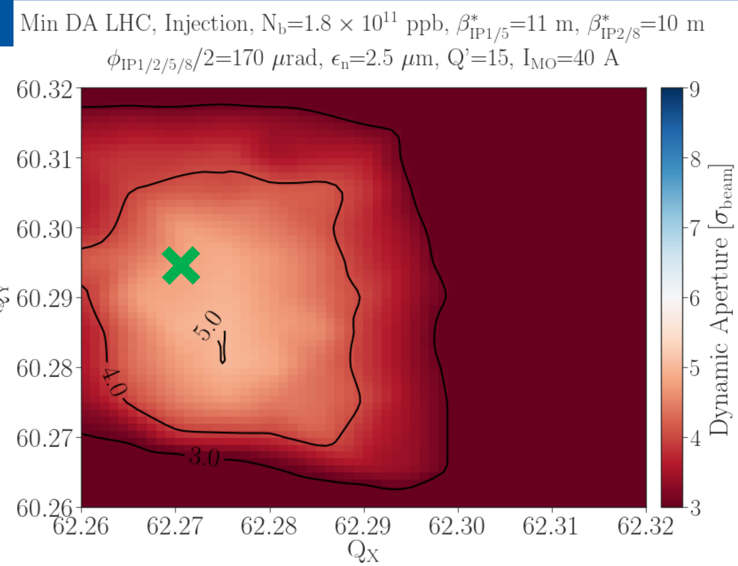
20 A





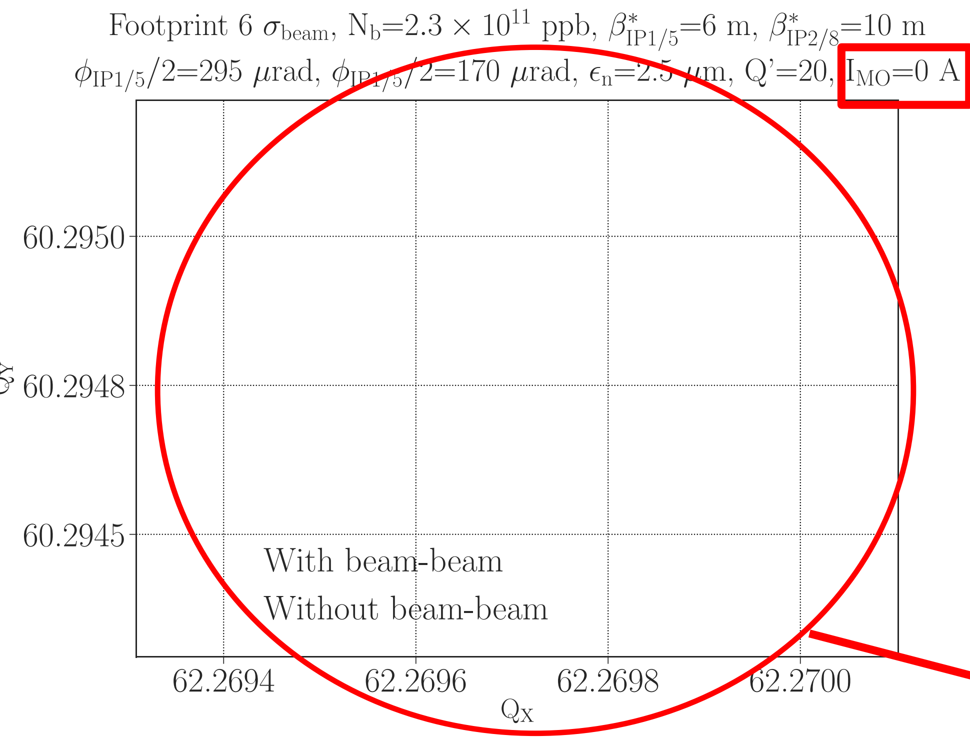
40 A





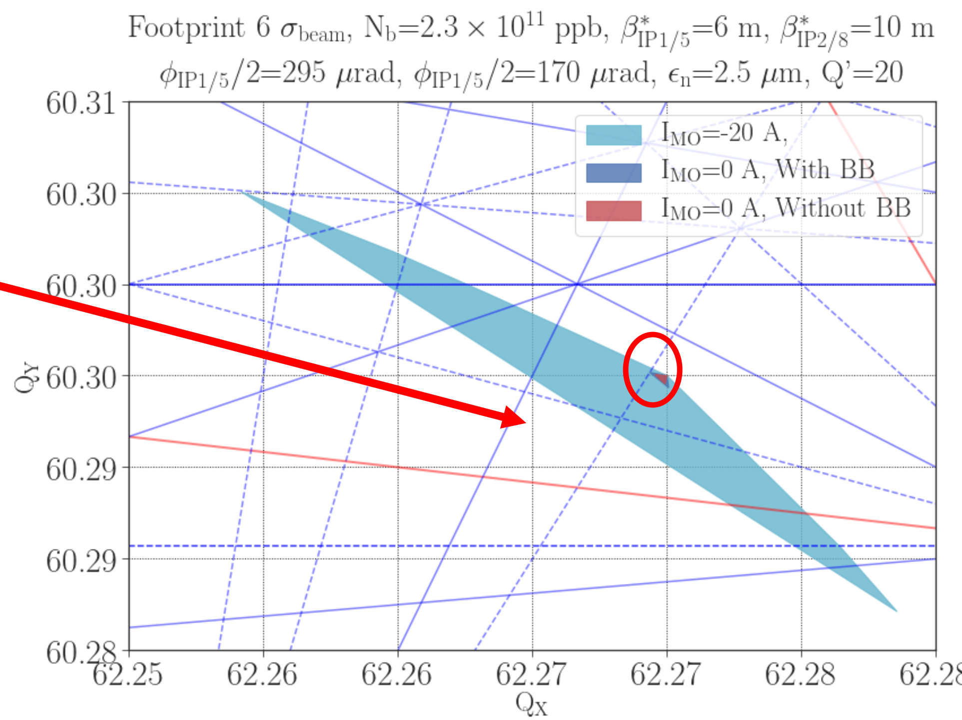
Quick degradation of DA from the increased octupoles, not significant impact of the +50% more intensity.

HL-LHC v1.3

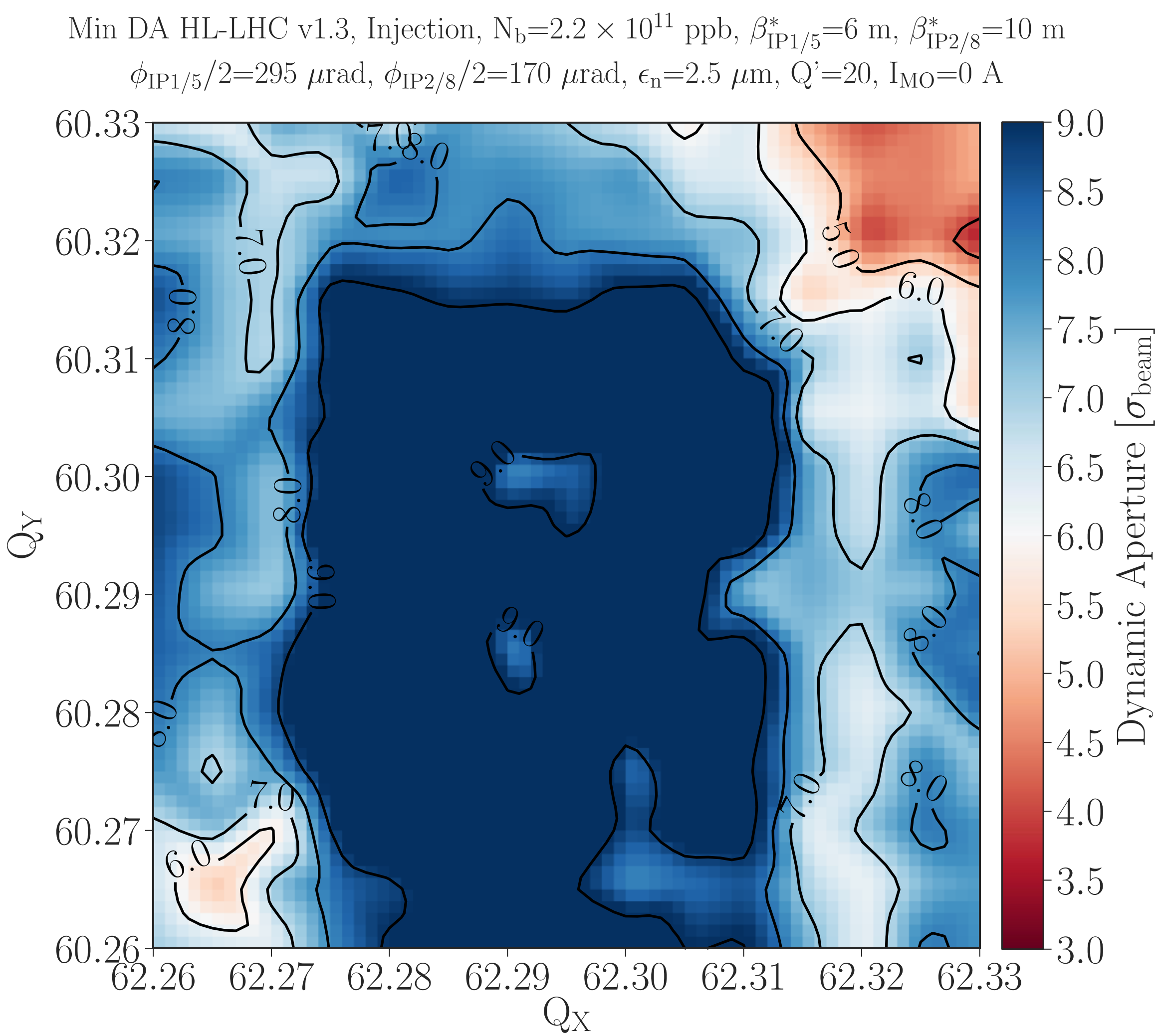


Switching on the BBLR slightly adds to the non-linear detuning coming from the strong sextupoles ➔ $O(10^{-4})$ ➔ The impact of BB is not significant at this plateau.

Detuning due to octupoles is the major source of the spread and consequently the key-target for DA optimization.



I_{MO} = 0 A & Q'=20

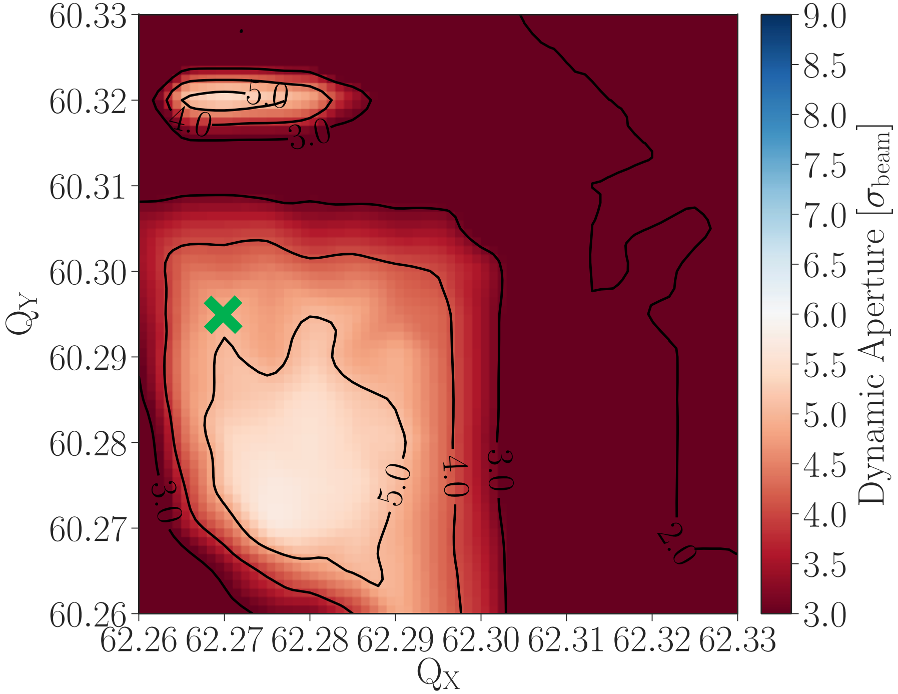


In the case of no octupoles, the available DA space (as expected from the footprints previously) is very large.

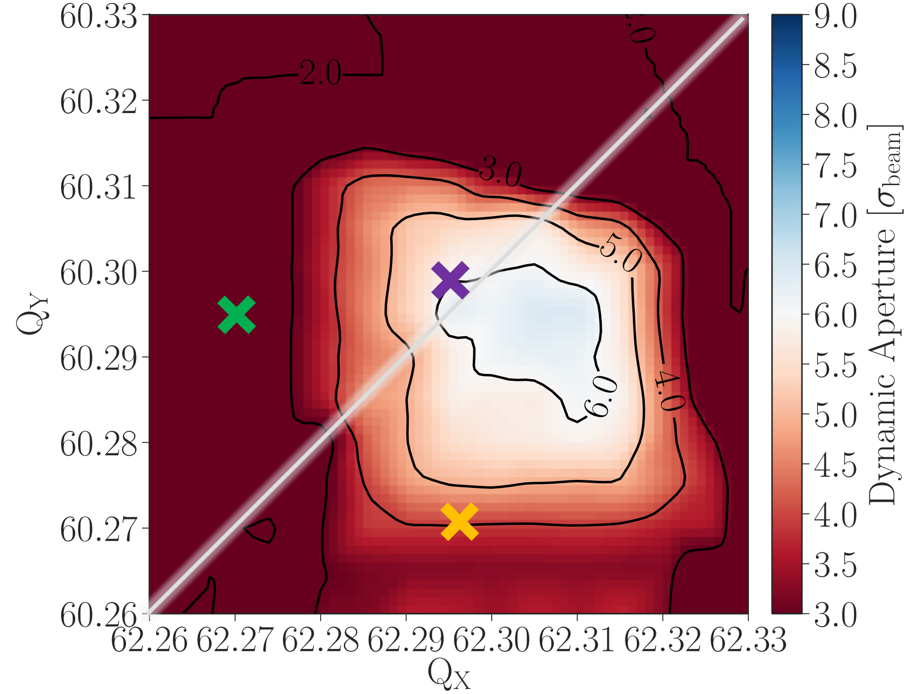
I_{MO} = 20 A & Q'=20

Negative polarity provides slightly better DA → Different resonances?

I_{MO}>0



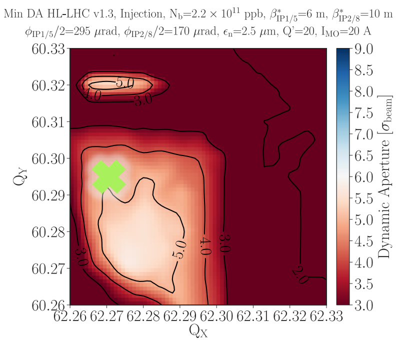
I_{MO}<0



(62.270, 60.295)
(62.295, 60.300)
(62.295, 60.270)

Movement of the optimal WP in the tune space as an effect of the octupoles

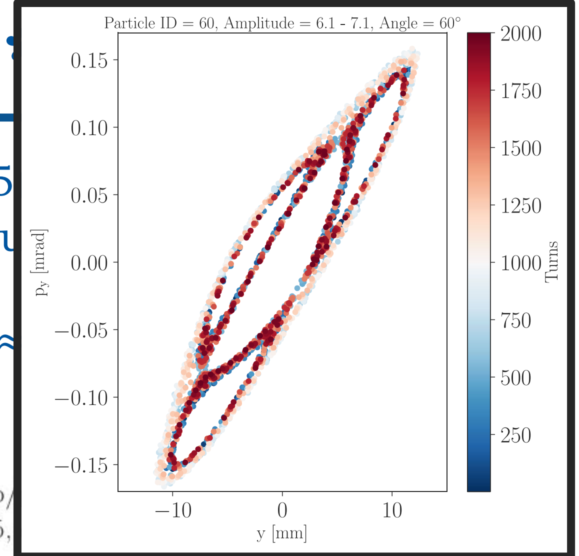
FMA @ I_{MO} = 20 A, Q'=20

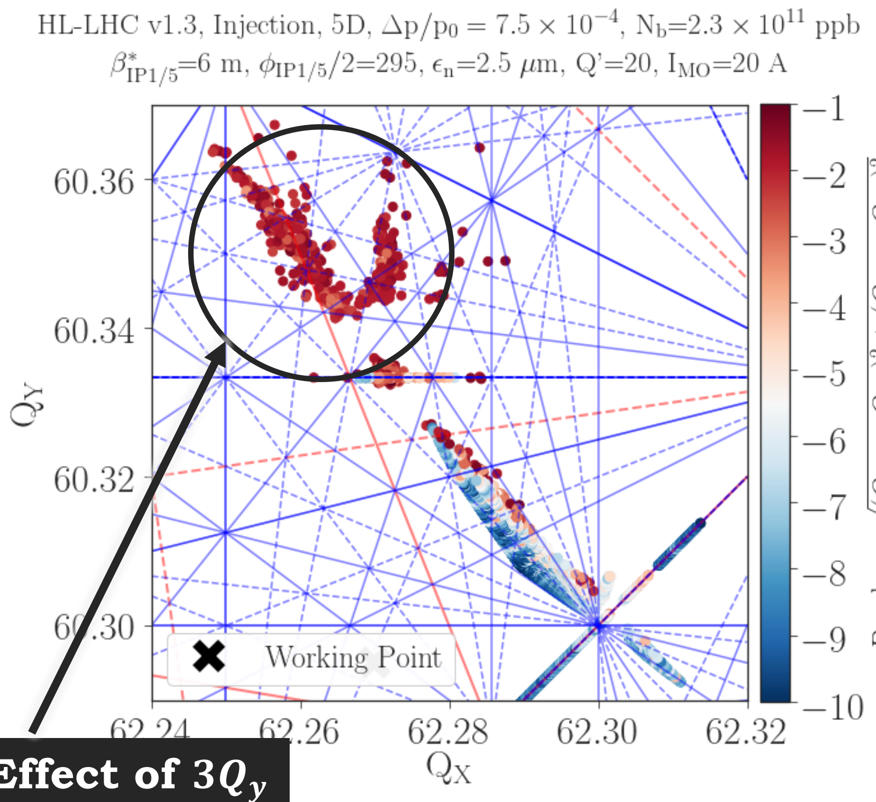


Selecting the WP (Q_x, Q_y)=(62.270, 62.295

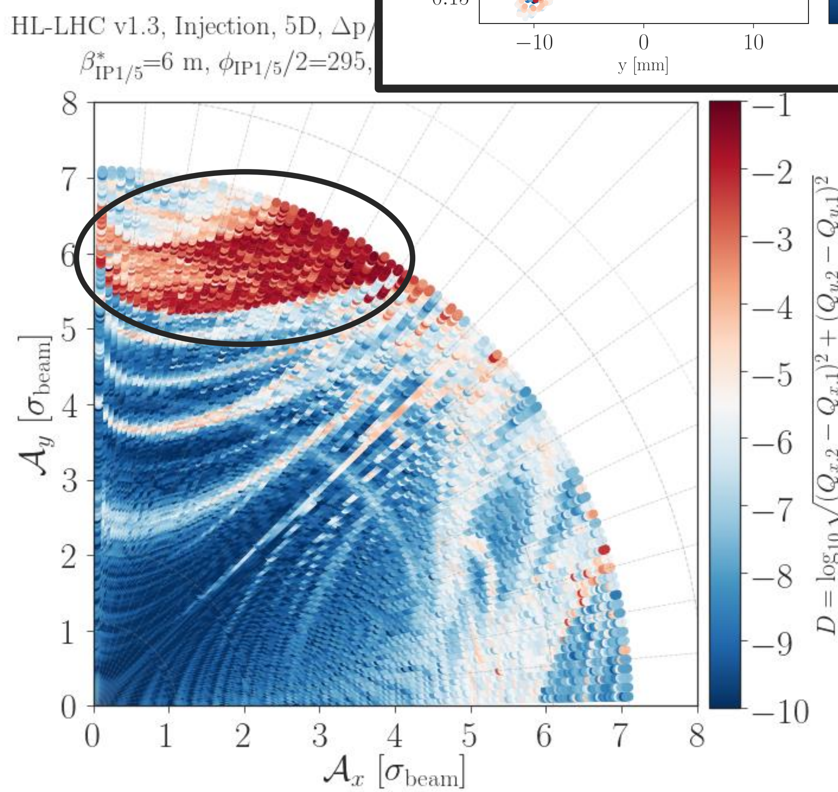
→ Dumping TbT data @ IP3, tune calcu

For $\frac{\Delta p}{p_0} = 7.5 \times 10^{-4}$ and with Q'=20 (→ ΔQ ≈

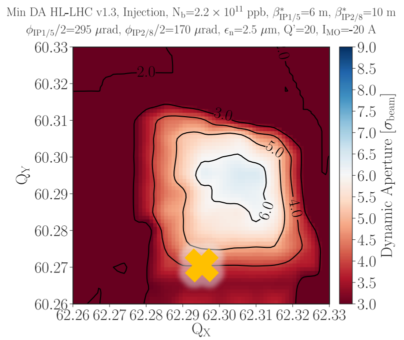




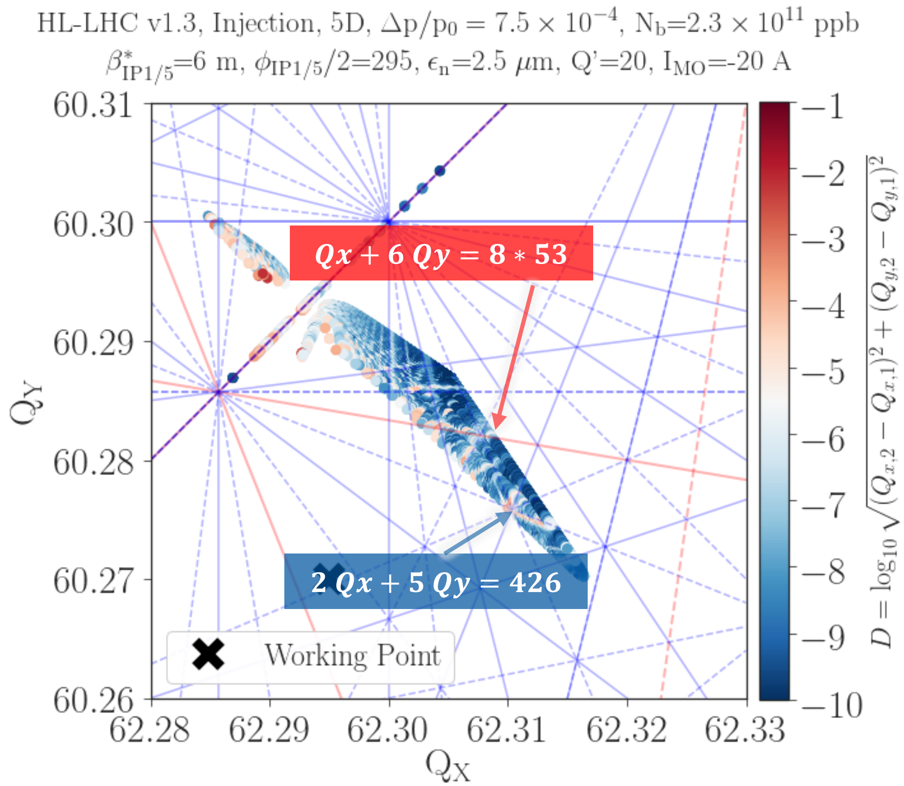
Effect of $3Q_y$

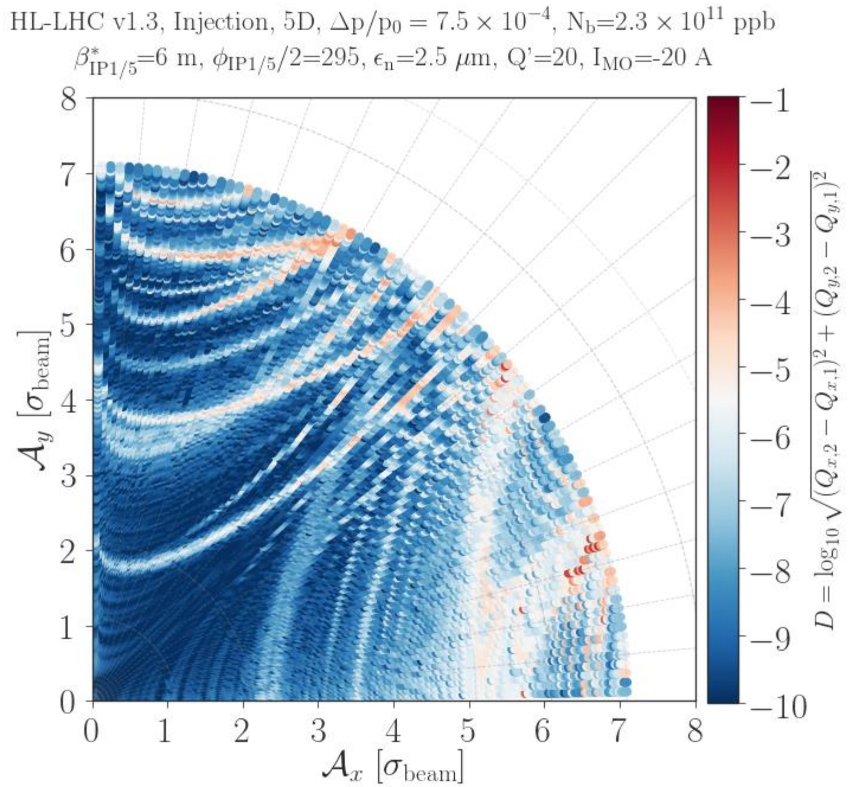


FMA @ I_{MO} = -20 A, Q'=20



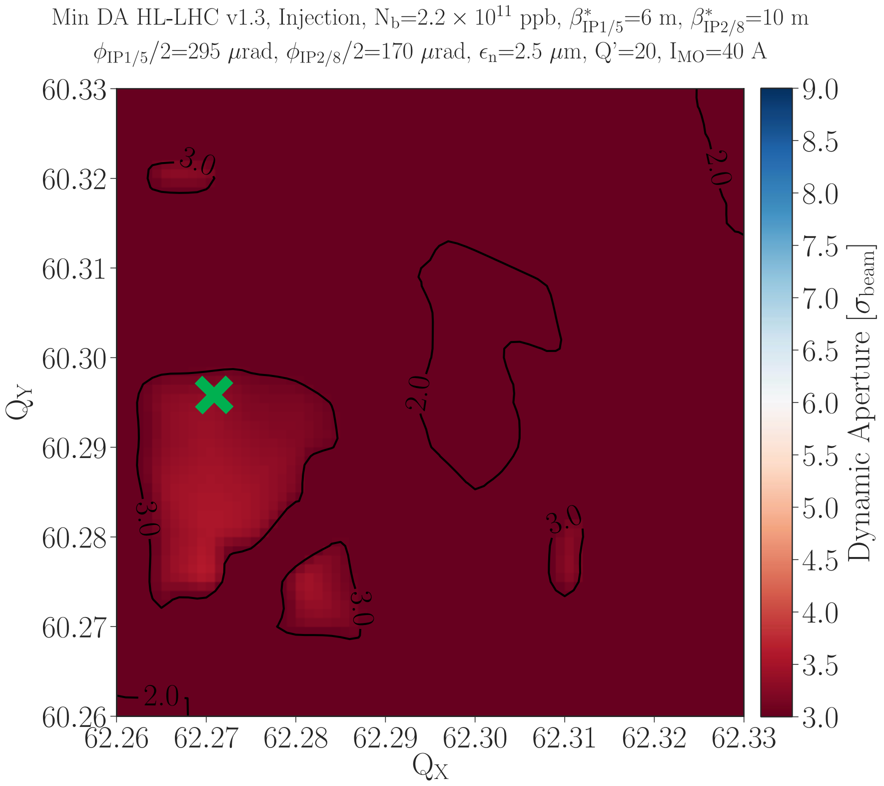
Selecting the symmetric (Qx, Qy)=(62.295, 62.270) for a 5D FMA



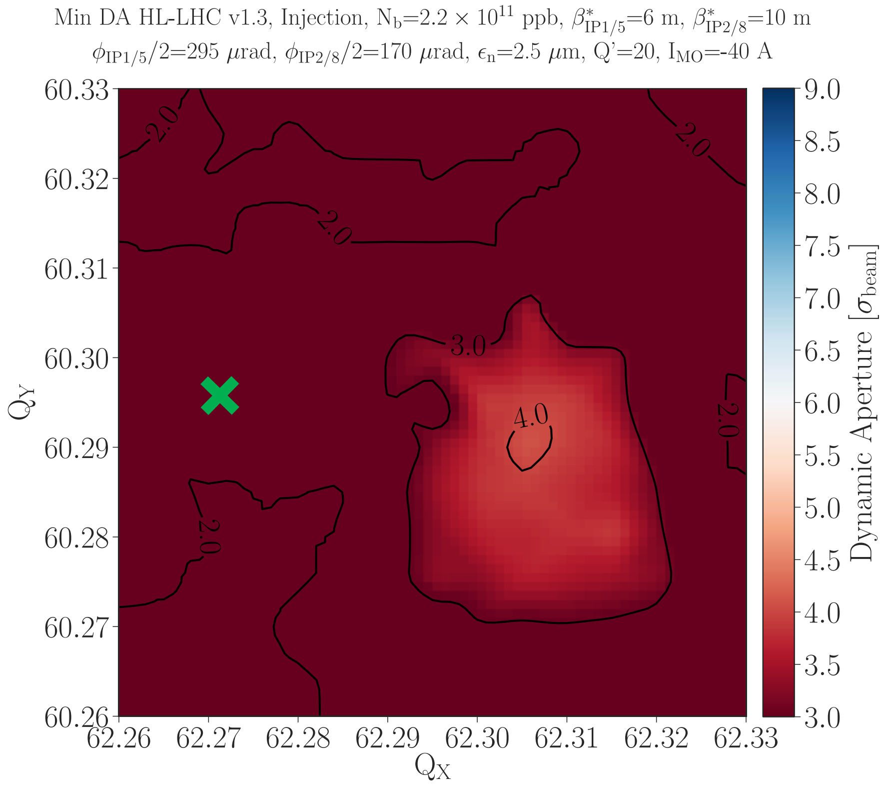


I_{MO} = 40 A & Q'=20

I_{MO}>0

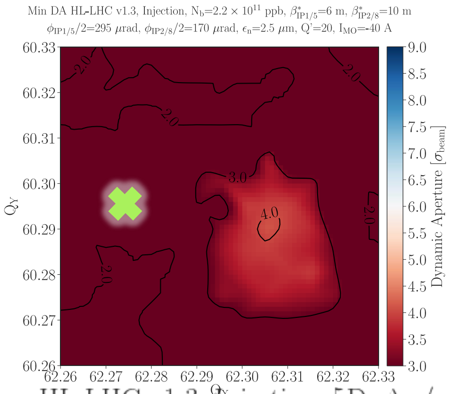


I_{MO}<0



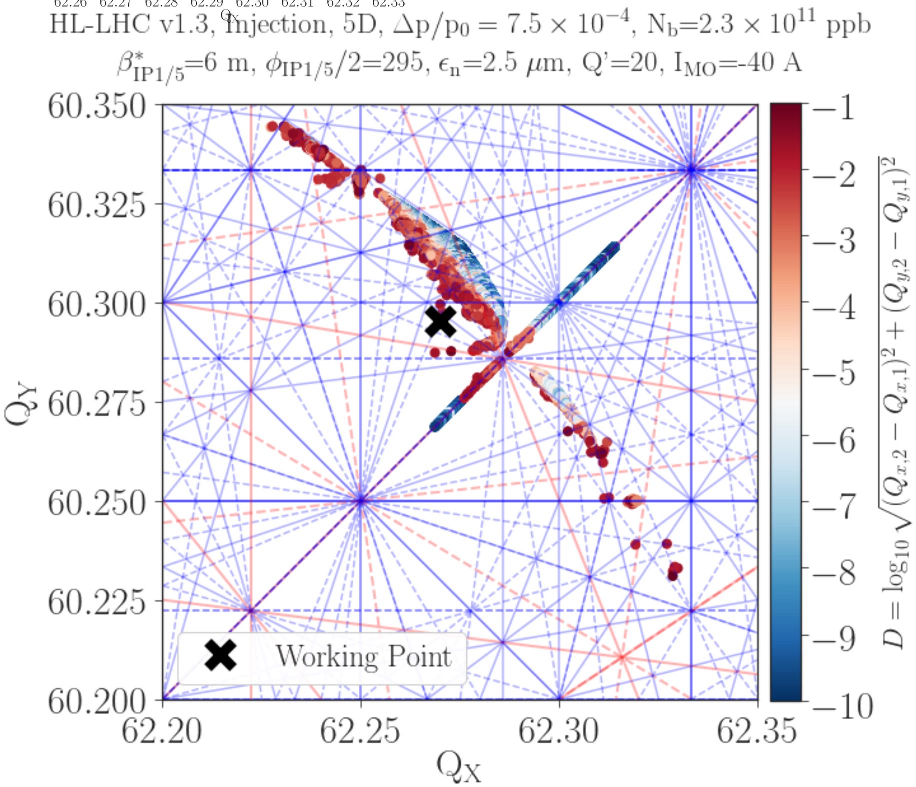
Significantly worse than the LHC case

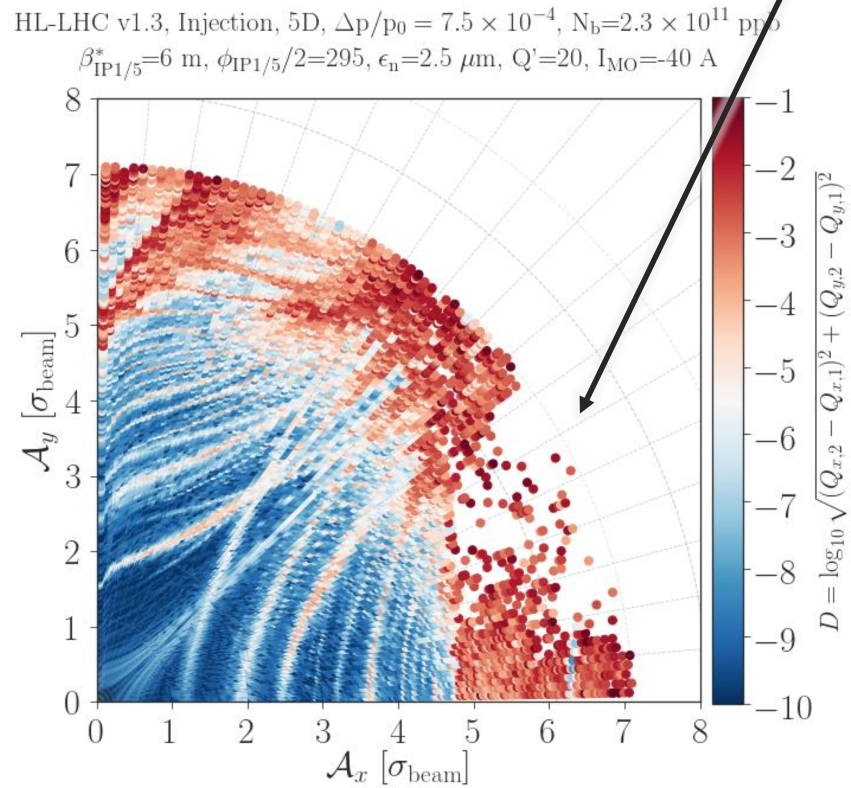
FMA @ I_{MO} = -40 A, Q'=20



Operational scenario WP (62.27, 62.295) for -40A & Q'=20

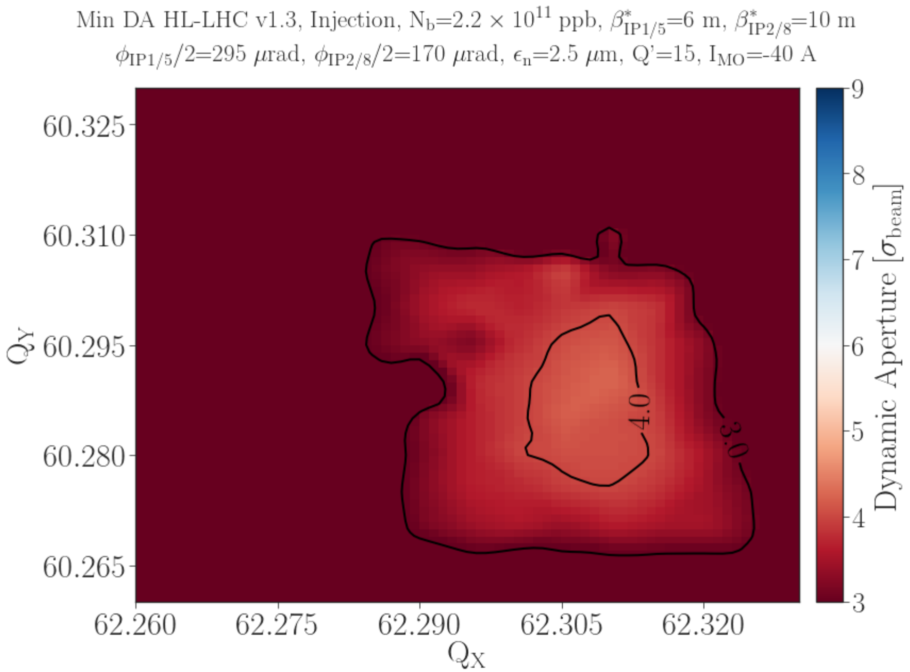
Particle Losses between calculations



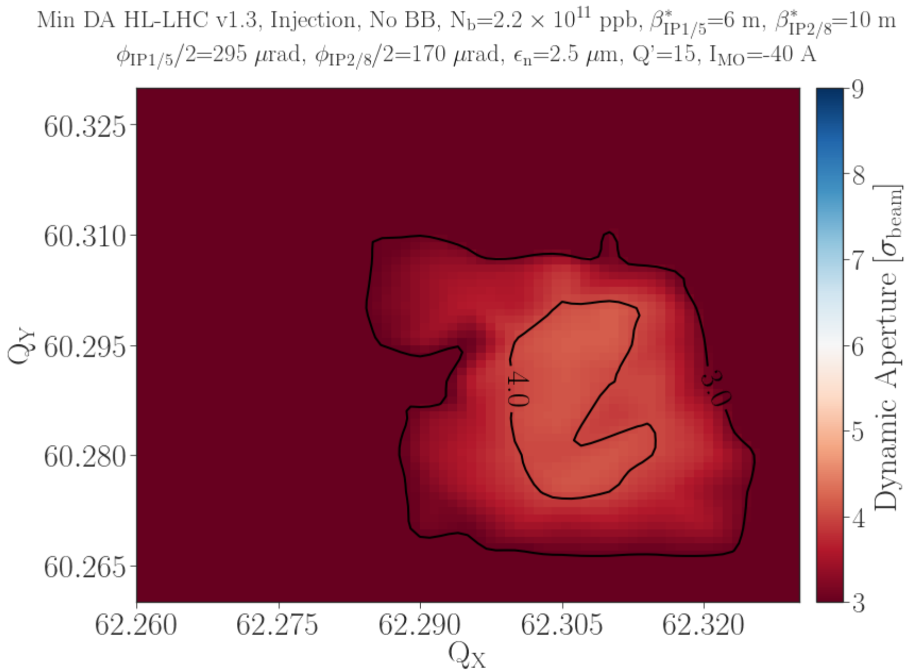


Maybe some BB effect?

I_{MO} = -40 A with Beam-Beam

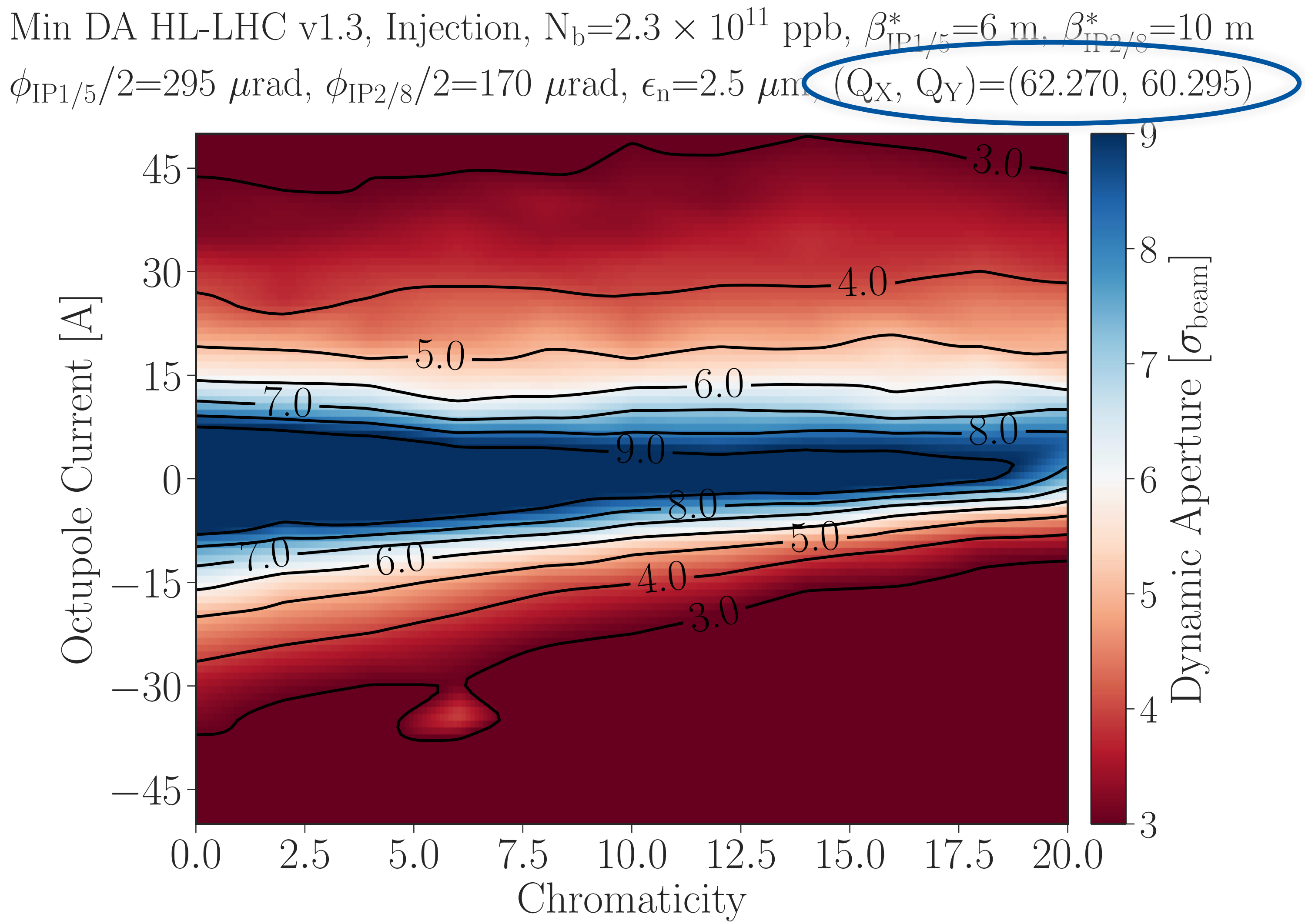


I_{MO}= -40 A without Beam-Beam



As expected from the footprints, the impact on DA is almost negligible.
→ Crossing angle/separation increase is not driven by BB.

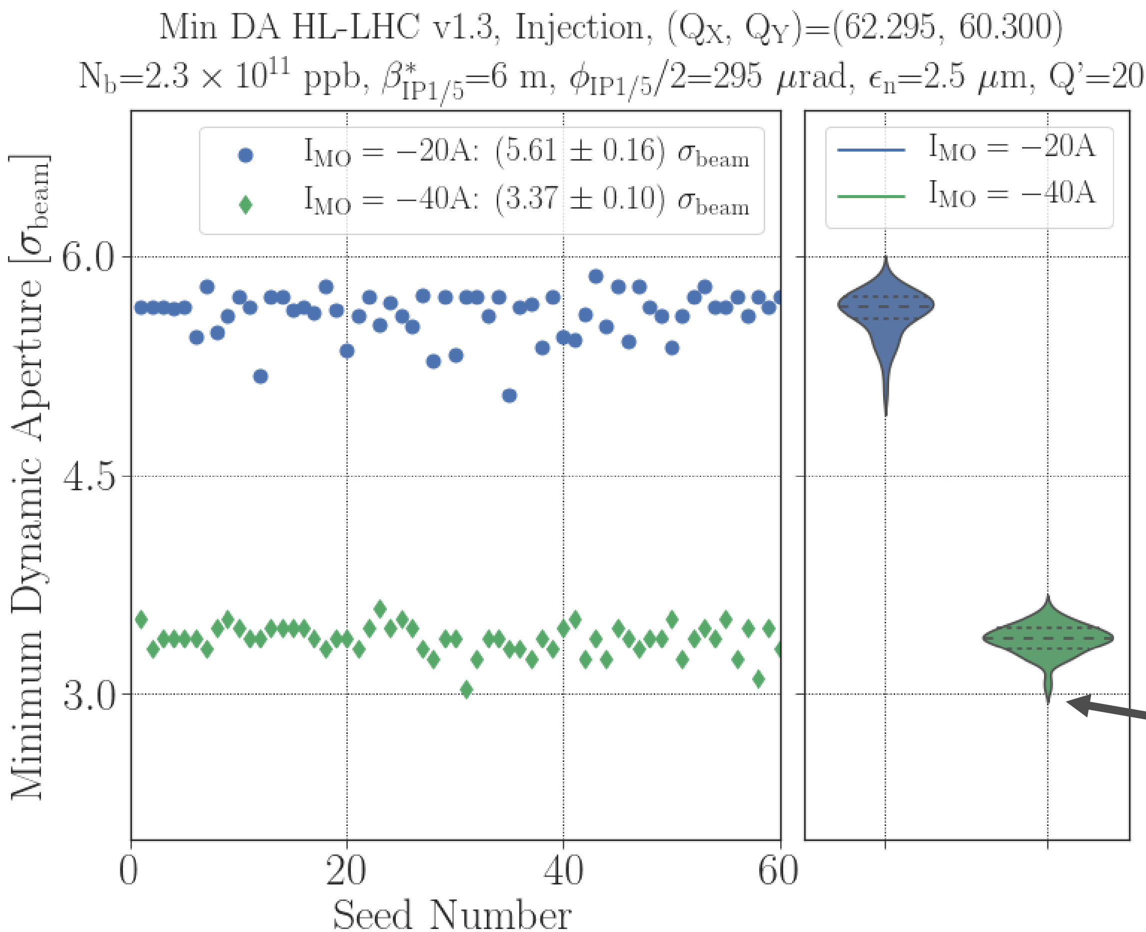
Octupoles vs Chromaticity



Magnetic field errors spread

- Selecting (.295, .300) as WP and calculate for 60 seeds for -20 A and -40 A the minimum DA ➔ Take the mean and RMS of the min DA results.

rms spread of <0.2σ in minimum DA



Drop from mean

0.56 σ

0.34 σ

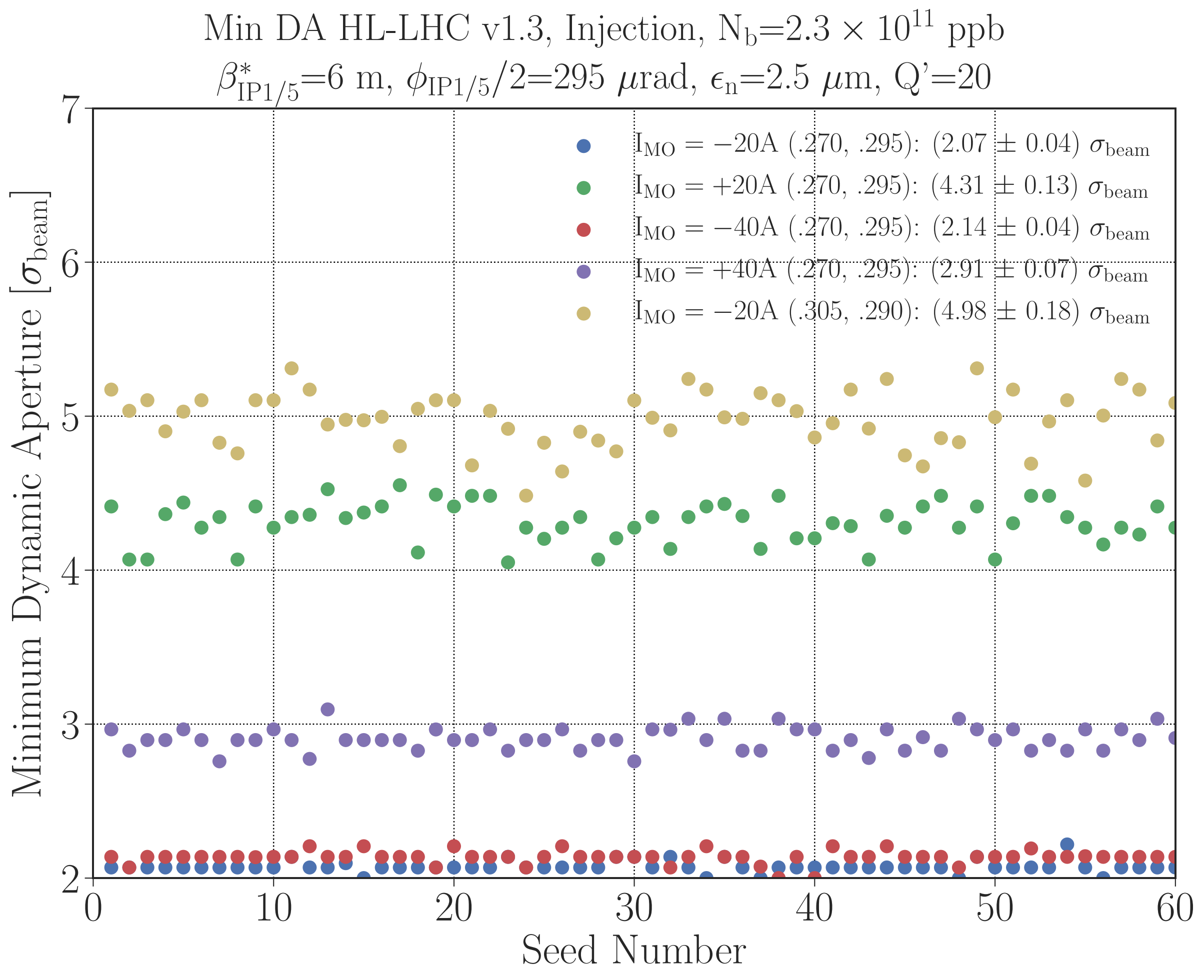
Less spread due to already low DA.

Magnetic field errors spread (II)

- Calculate for 60 seeds for -20 A and -40 A the minimum DA
  ➔ Take the mean and RMS of the min DA results.

Drop from mean:

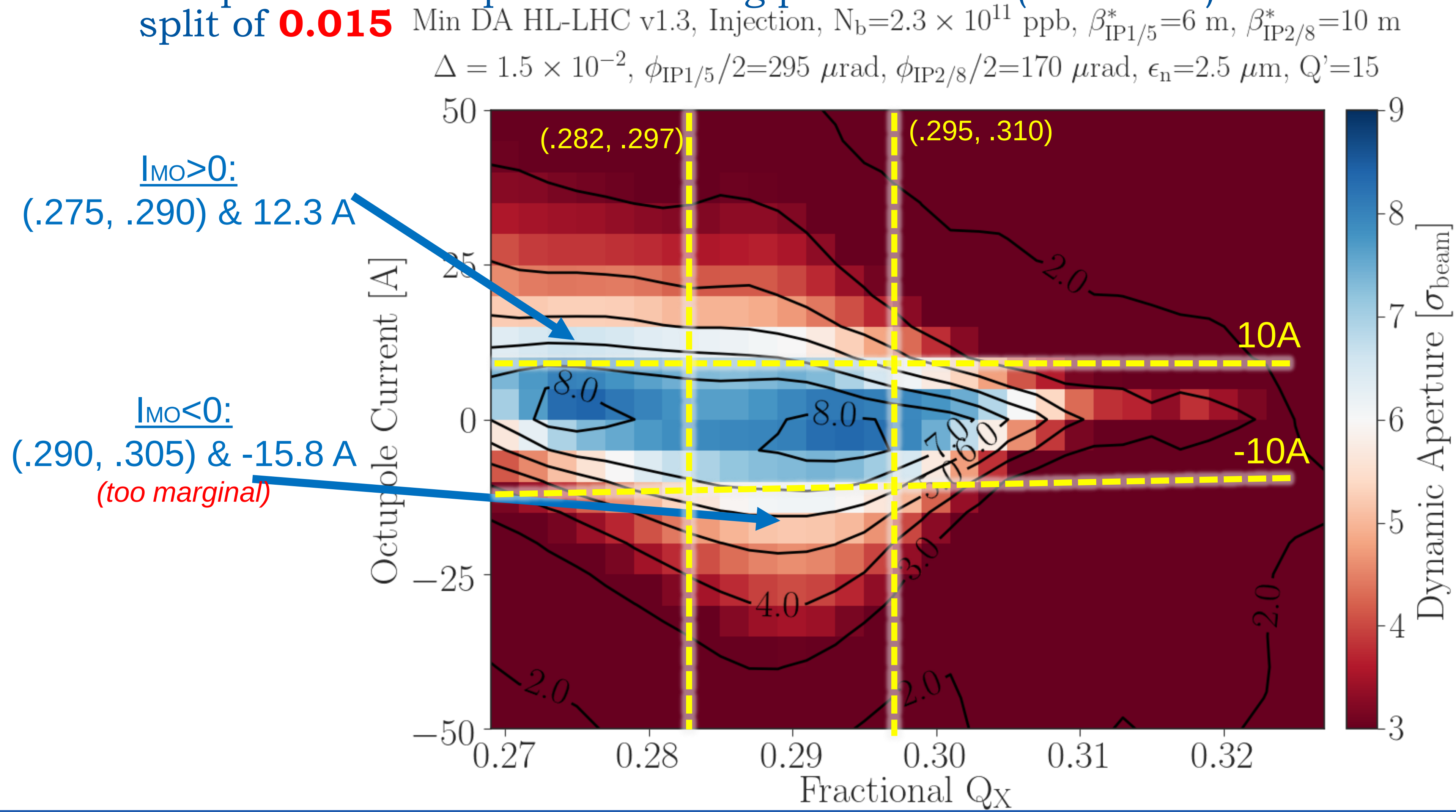
0.07 σ
0.26 σ
0.14 σ
0.15 σ
0.50 σ



The minimum DA can drop by almost 0.5-1σ along the different seeds for various configurations
➔ Some additional margin would help!

Optimal WP vs Octupoles

- Reducing the chroma to **15 units** and evaluating the impact of octupoles on the optimal working point with a (fractional) tune split of **0.015**



Summary

- Comparing with the LHC injection, HL-LHC shows slightly reduced DA at $I_{MO} = |40|$ A
  - The reduced β* at IP1/5 could significantly increase the maximum β and possibly have an impact on DA (??)

- Impact of bunch intensity is relatively small in the LHC result.

- Impact of beam-beam interactions at the nominal crossing/separation values is almost negligible ($\Delta Q \approx 2 \times 10^{-4}$)

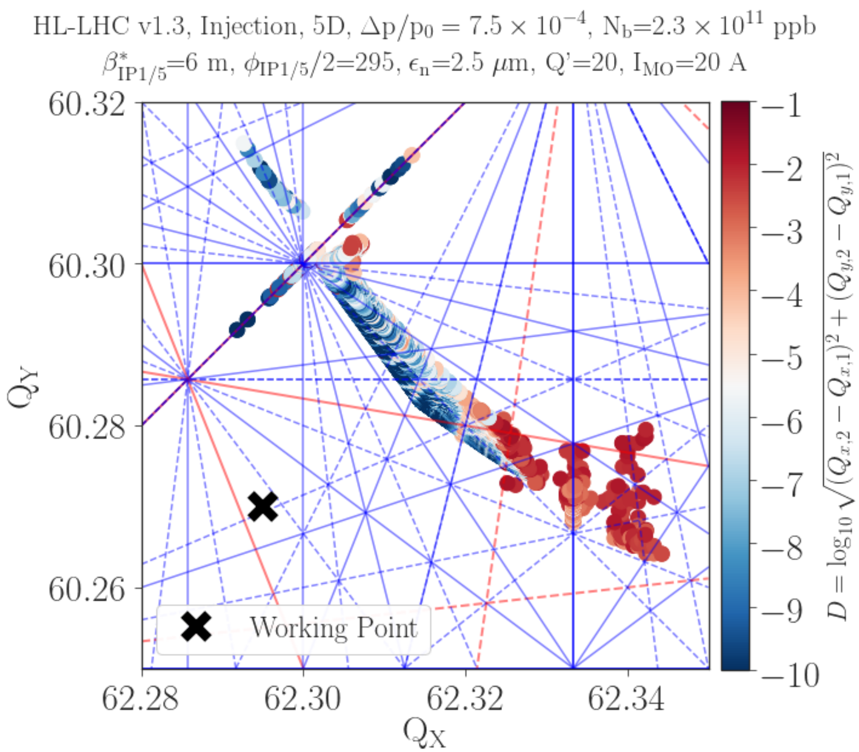
- At injection the transverse detuning from octupoles dominate the final result.
  - Negative octupoles have slightly better DA.
  - The polarity of the octupoles significantly impacts the optimal WP.
  - *What are the lower octupole current limits that we can go in terms of stability?*

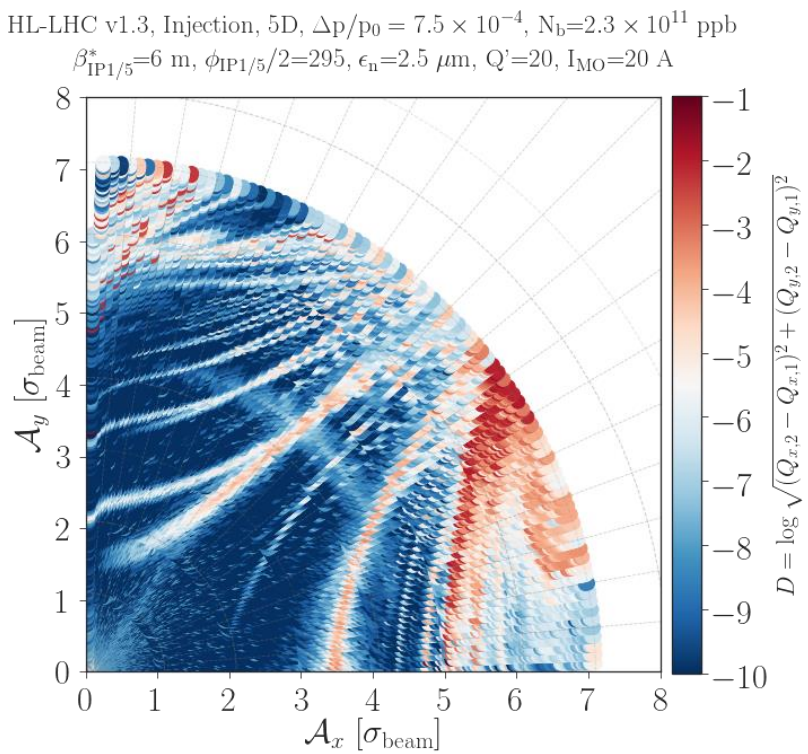
- Chromaticity has a smaller impact compared to octupoles.

- Impact of magnetic field errors at minimum DA is at the level of <0.2σ. Drop from the average of the statistical population around 0.5-1.0σ.

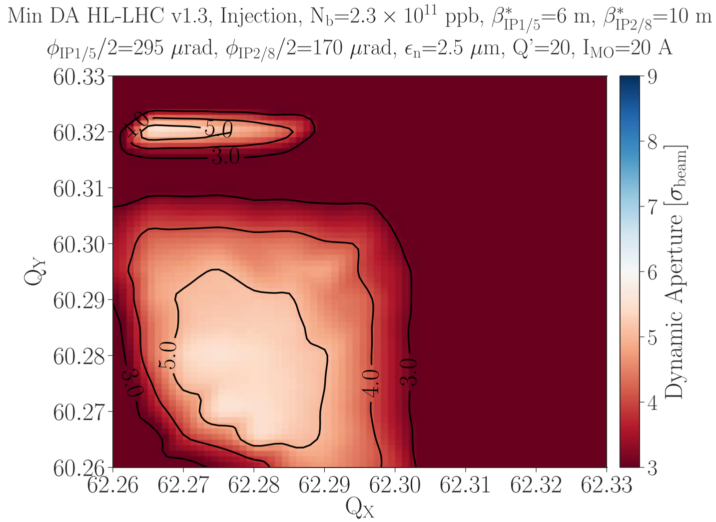
CERN

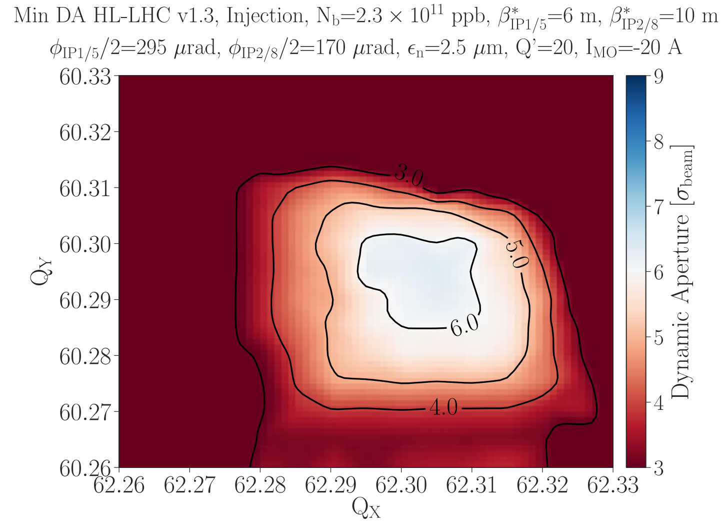
3Qx for symmetric WP @ +20 A?

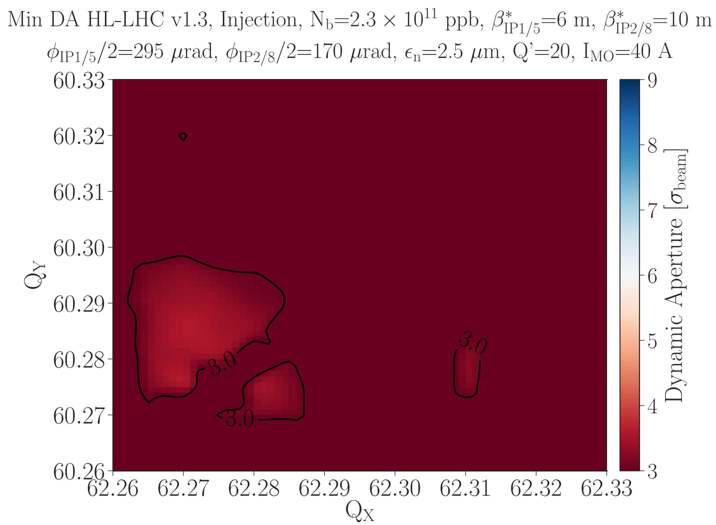


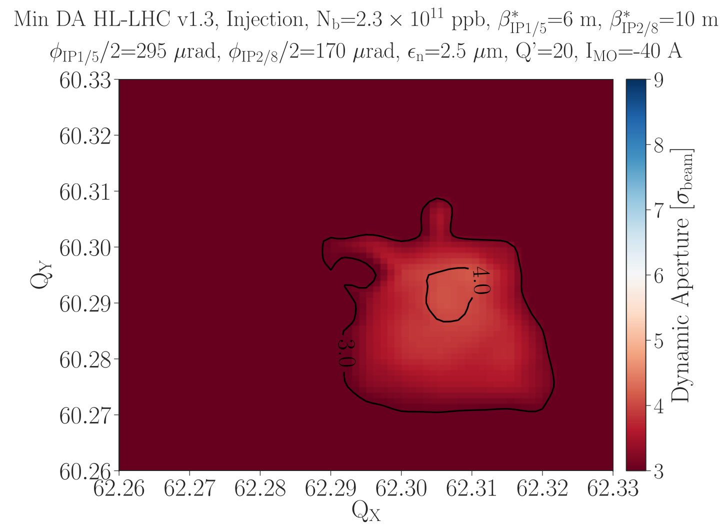


For completeness: Nb=2.3e11 ppb → No impact



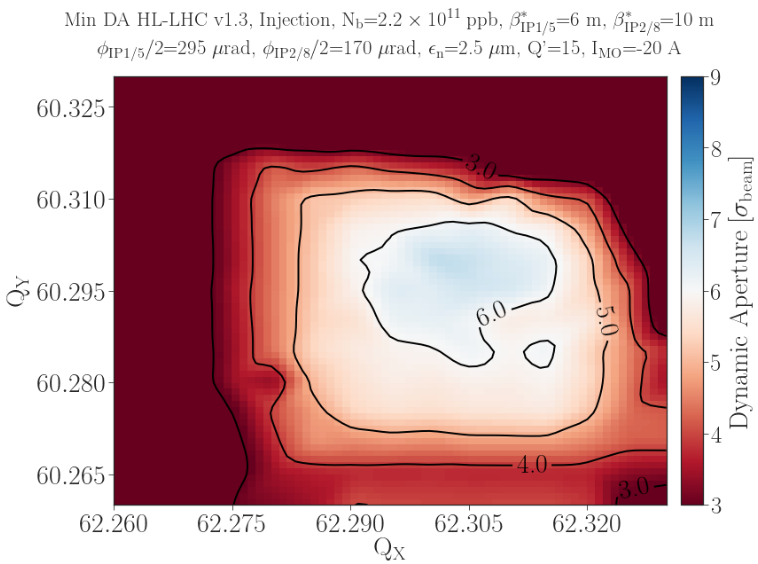




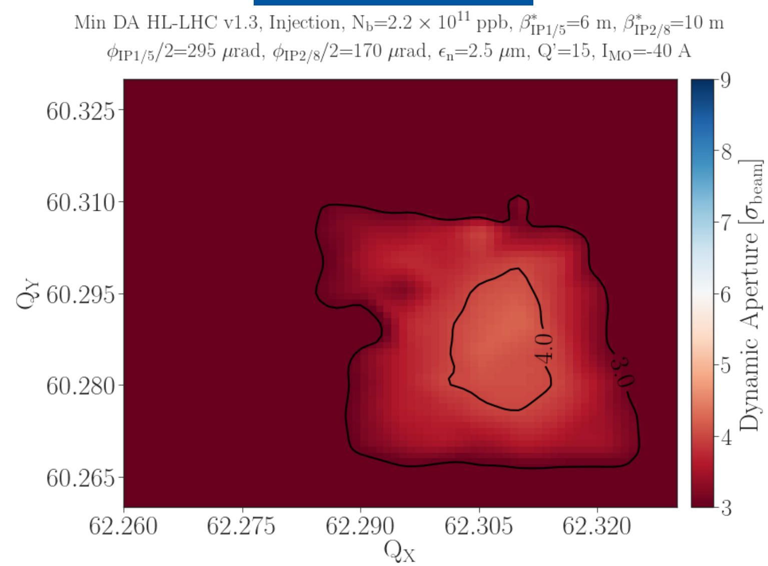


Reducing Chromaticity Q'=15

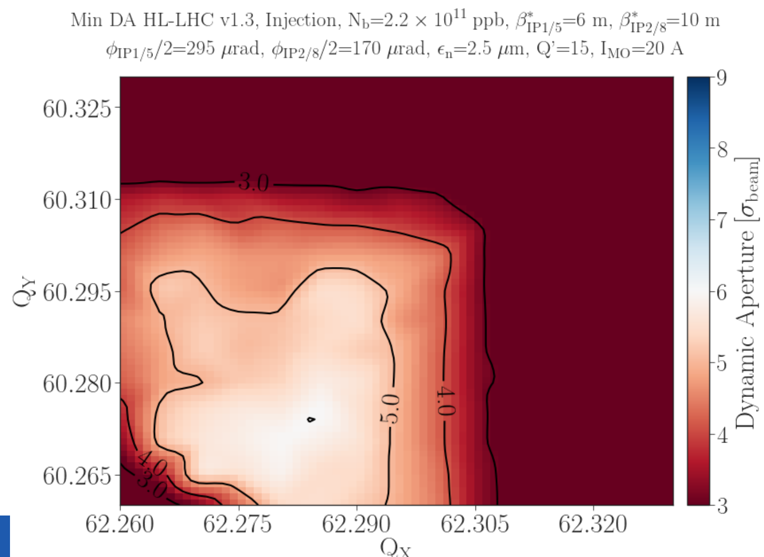
I_{MO} = -20 A



I_{MO}= -40 A



I_{MO}= +20 A



Octupoles vs Chromaticity (I)