Simulations for wire BBLR compensation in HL-LHC

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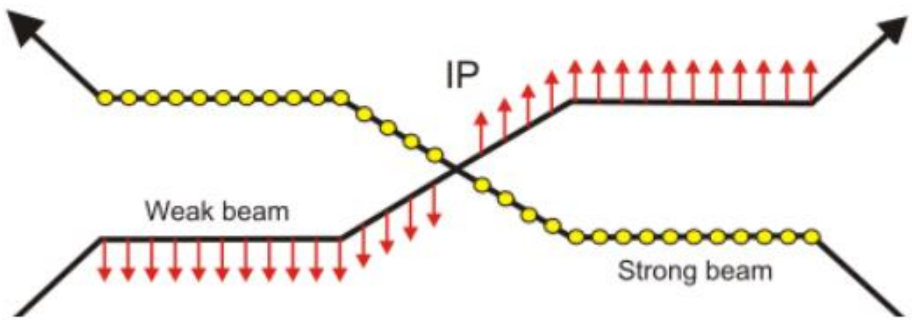
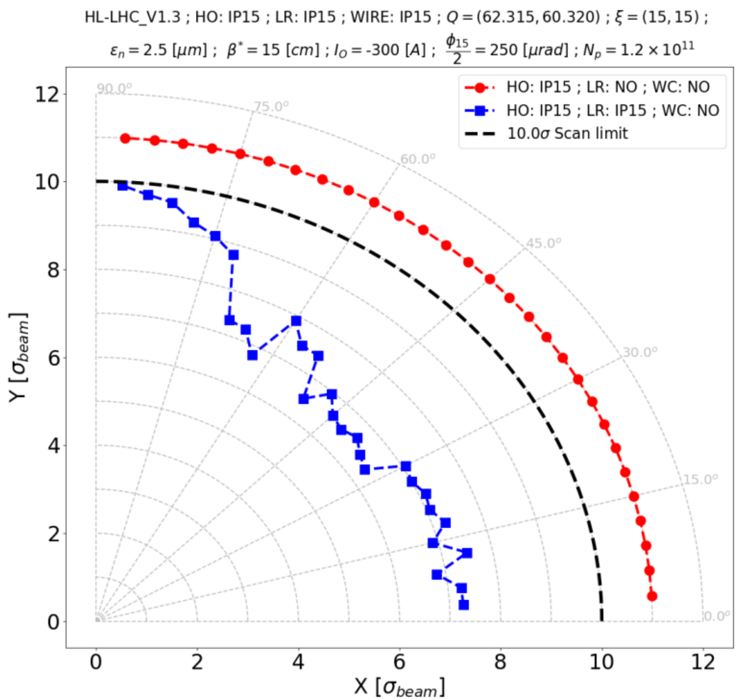
- Quantification and solution of the problem generated from the BBLR interactions.
- BBLR compensation with wire in HL-LHC v1.3.
- Conclusions

Quantification of the BBLR problem





Large DA (lifetime) degradation, at least 3σ, in the present of the beam-beam long range interaction.

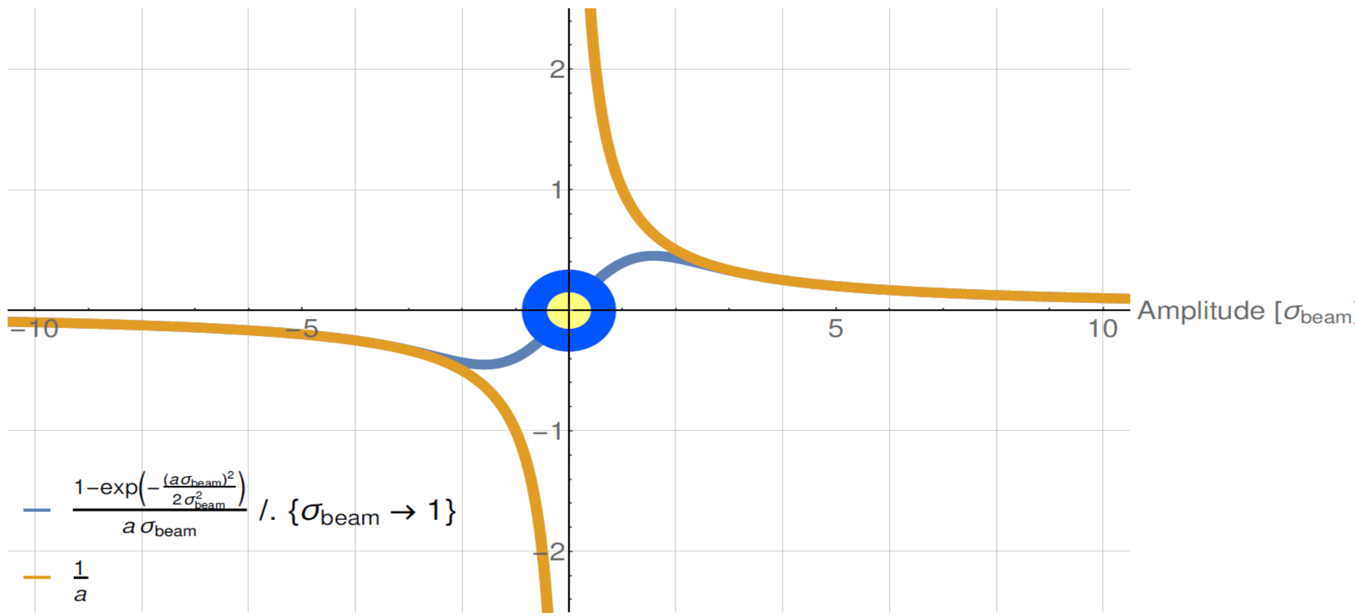
Treatment of the perturbation generated by the BBLR interactions (I)

The integrated electromagnetic field (4D) that is generated by the BBLR encounters (assuming a round beam $\sigma_x=\sigma_y$) is given by:

$$\int_{-\infty}^{\infty} B_\theta \; ds = \frac{N_p \; q \; c \; \mu_0 \; \beta_{st}}{2\pi} \; \frac{1 - Exp\left(-\frac{r^2}{2\sigma^2}\right)}{r}$$

This field is similar to the integrated magnetic filed from an “infinite” current currying wire.

$$\int_{-\infty}^{\infty} B_\theta \; ds = \frac{N_p \; q \; c \; \mu_0}{2\pi} \; \frac{1}{r}$$



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Treatment of the perturbation generated by the BBLR interactions (II)

The wire is calibrated such as to **compensate the non-linear RDT** that are driven by the long-range beam-beam interactions.

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Compensation of the long-range beam-beam interactions as a path towards new configurations for the high luminosity LHC

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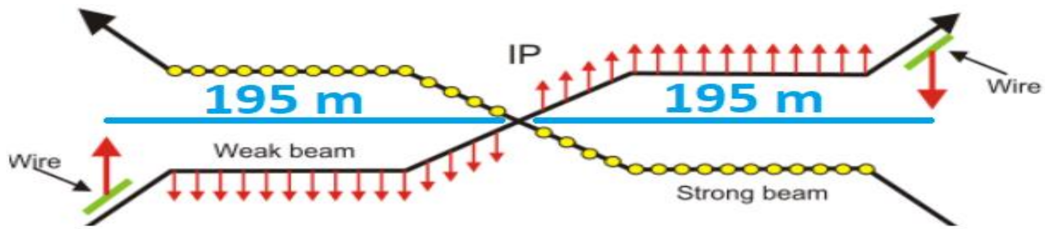
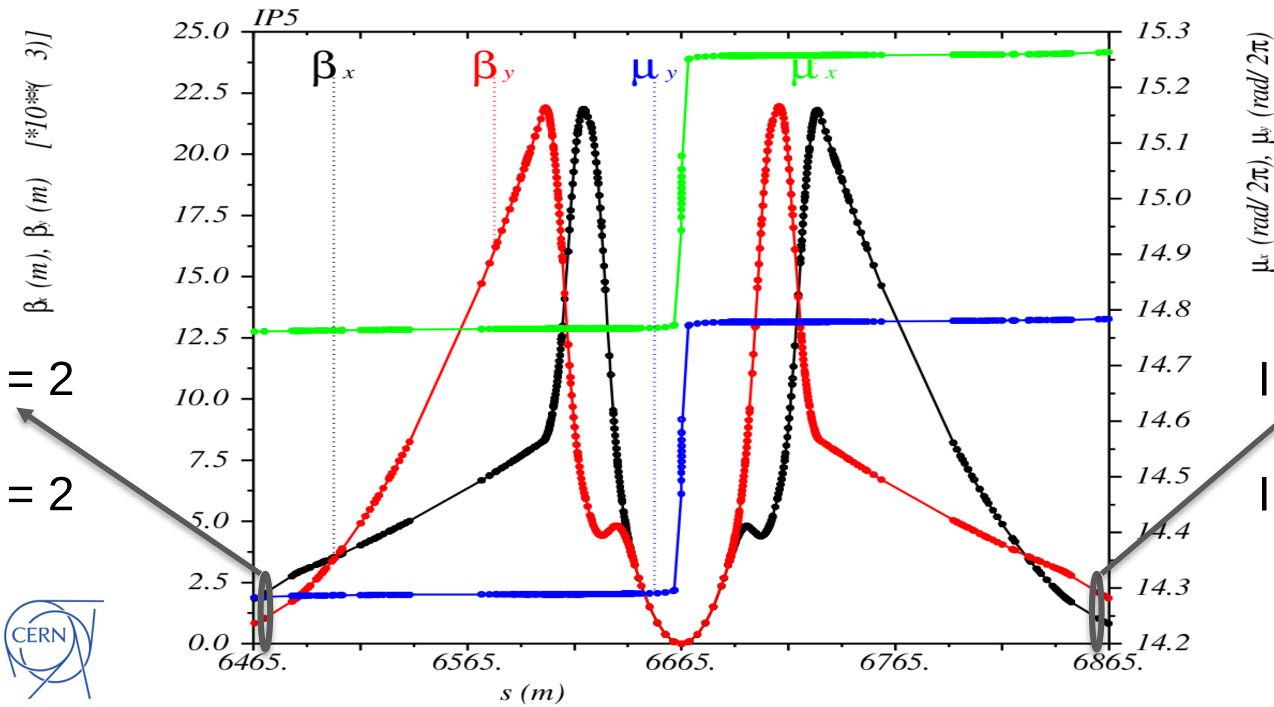




IP5L: βx/βy = 2

IP1L: βx/βy = 2

IP5R: βx/βy=0.5

IP1R: βx/βy=0.5

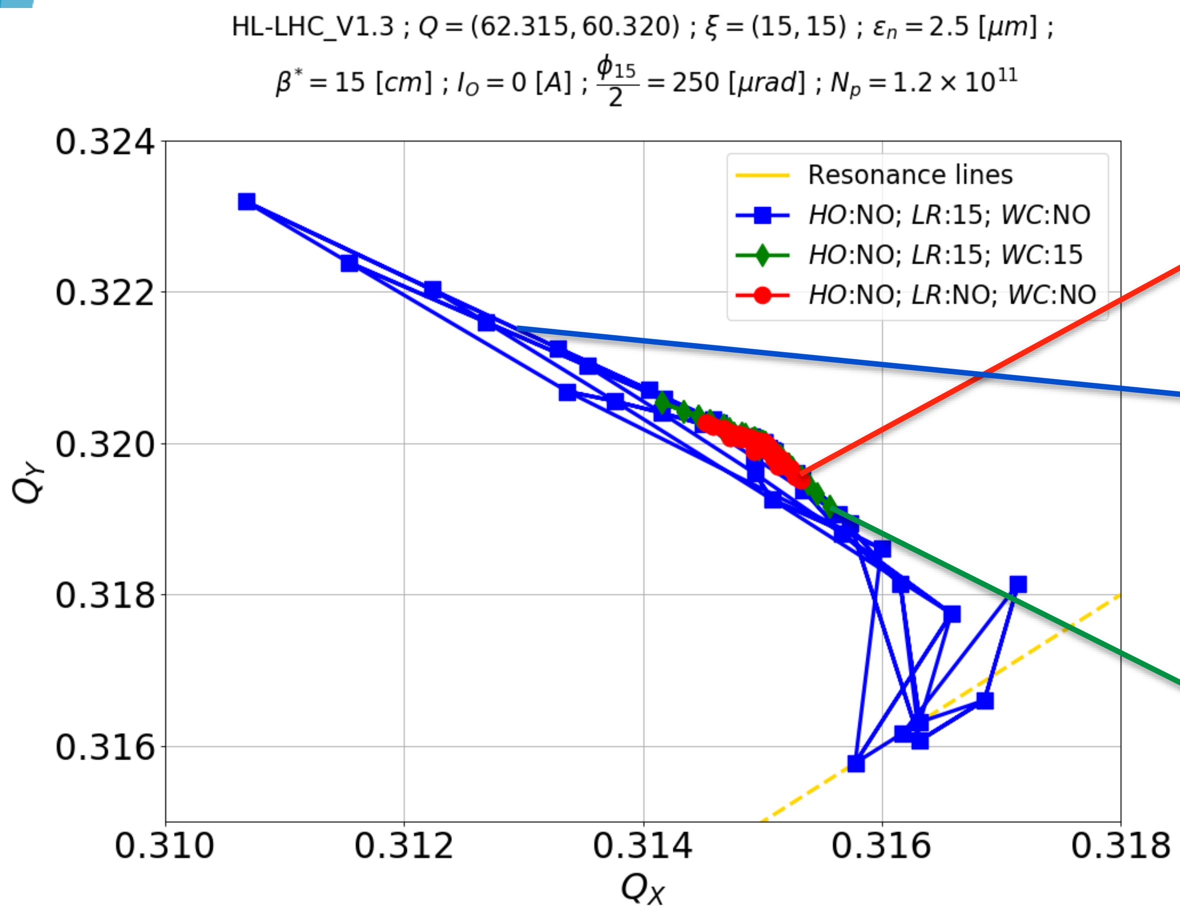
Configuration for the simulated machine

HL-LHC v1.3 configuration table		
Attributes	**Symbol**	**Value [units]**
Energy	E	7000 [GeV]
Bunch population (end of leveling)	N_p	$1.2x10^{11}$ [1]
Normalized emittance	ε_n	2.5 [μm rad]
Horizontal tune	Q_x	62.31 or 62.315 [1]
Vertical tune	Q_y	60.32 [1]
Horizontal chromaticity	ξ_x	15 [1]
Vertical chromaticity	ξ_y	15 [1]
Beta function at IP1 & IP5	β^*	15 [cm]
Half crossing angle at IP1 & IP5	Φ/2	210 – 250 [μrad]
Octupole current	I_o	-300 or 0 [A]
Wires longitudinal position from the IP	S_w	+/- 195 [m]
Number of BBLR kicks per IP per sited	NBBLR	25 [1]
Number of wires per IP per sited	N_w	1 [1]

In order to find the best BBLR compensation for different lattice configurations, a set of DA scans for **different wire current (I_w)** and **wire transvers position (D)** are performed.

BBLR compensation (I)

Lattice tunes	Io	Half crossing angle	Normalized crossing angle	Luminosity
62.315 ; 60.32	0 [A]	250 [μrad]	10.6	5×10^{34} [$cm^{-2}s^{-1}$]

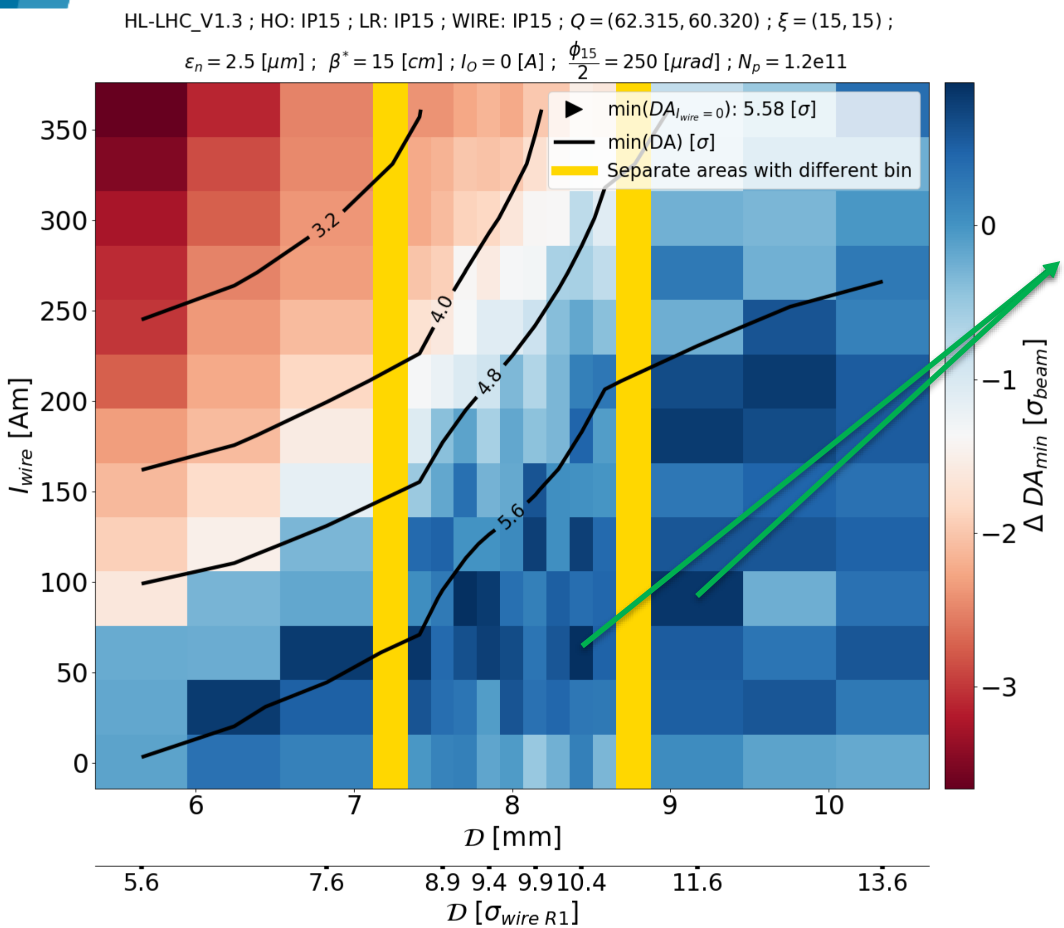


Small tune spread is generated from the lattice sextupoles.

Destructive tune spread (wings formation) is generated from the long range beam beam interactions.

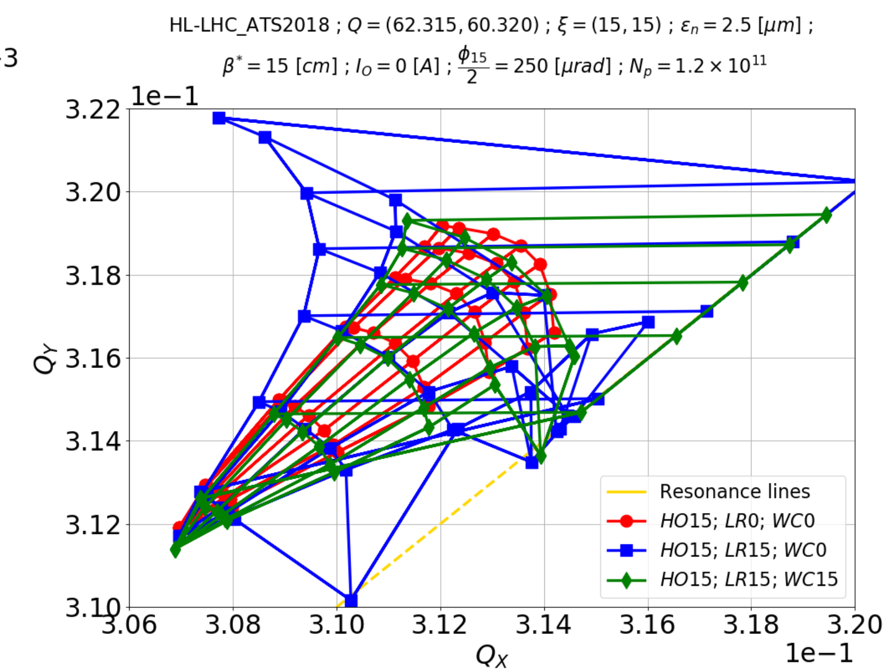
Using the wire the tune spread from the BBLR can be compensated (wings compression).

BBLR compensation (I)



Different wire configurations (Iw & D) guarantee ~**1σ better min DA**.

2 cases with **low wire current** (Iw<130Am) and **large wire transverse distance** (D>10σ) that can guarantee **0.9σ better min DA**.



The good compensation is also visible in the footprint (no wings no twist).

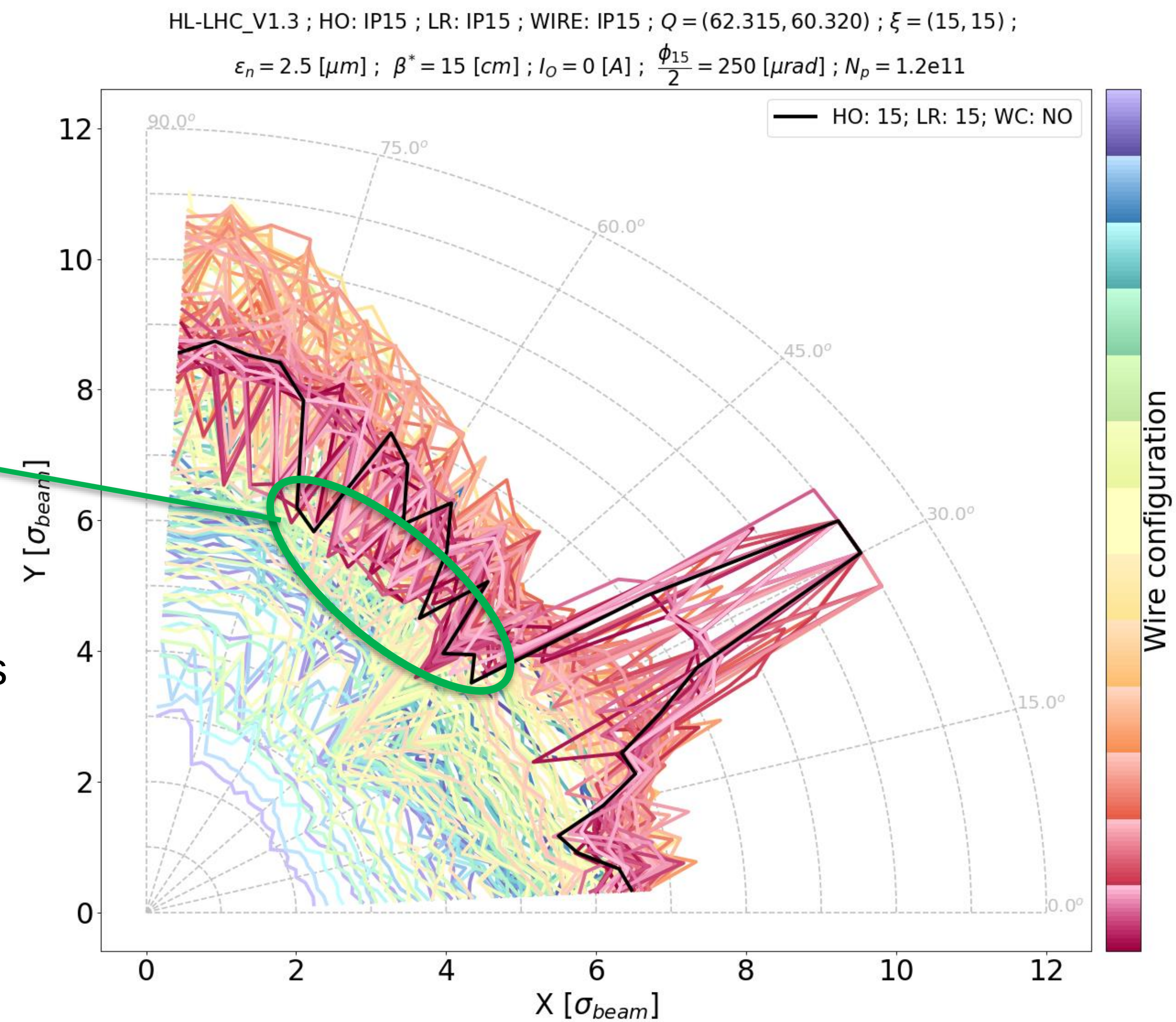
BBLR compensation (I)

A single value that describe the min DA and correspond to a single trajectory in the phase space it is not enough to describe the effect of the wire on the different particles (different phase space trajectories). Thus, a more detailed DA analysis is performed.

The number of the scanned angles is increased to 29.

The area with the worst DAs (effective area) is farther analyzed.

Using a step of 3º , the worst DA without wire (black line) is located between the angles 39º-72º .



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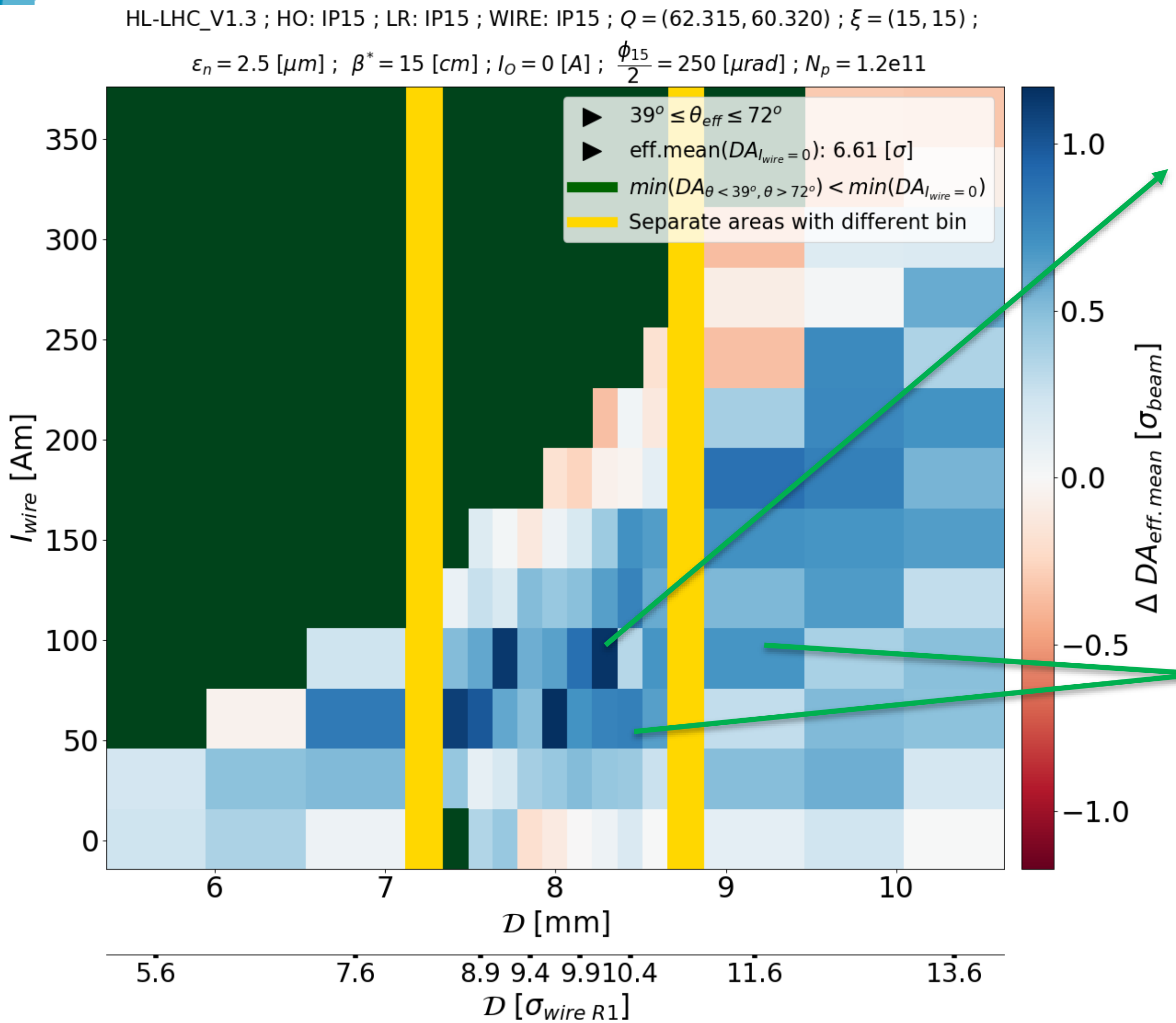
BBLR compensation (I)

Between 39º and 72º where the largest DA degradation occurred there are wire configurations that improve the average DA (effective mean DA) **more than 1σ**.



1.2σ better effective mean DA with **low wire current** (Iw<130Am) and **large wire transverse distance** (D>10σ).

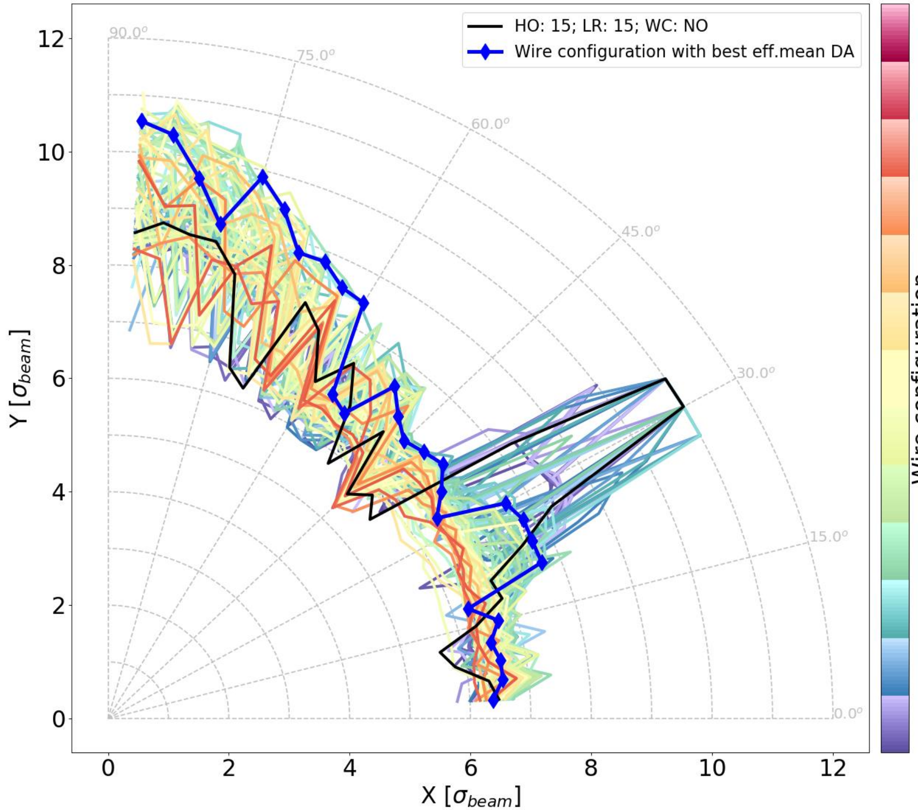
0.8σ better effective mean DA with **low wire current** (Iw<100Am) and **large wire transverse distance** (D>10σ).

BBLR compensation (I)

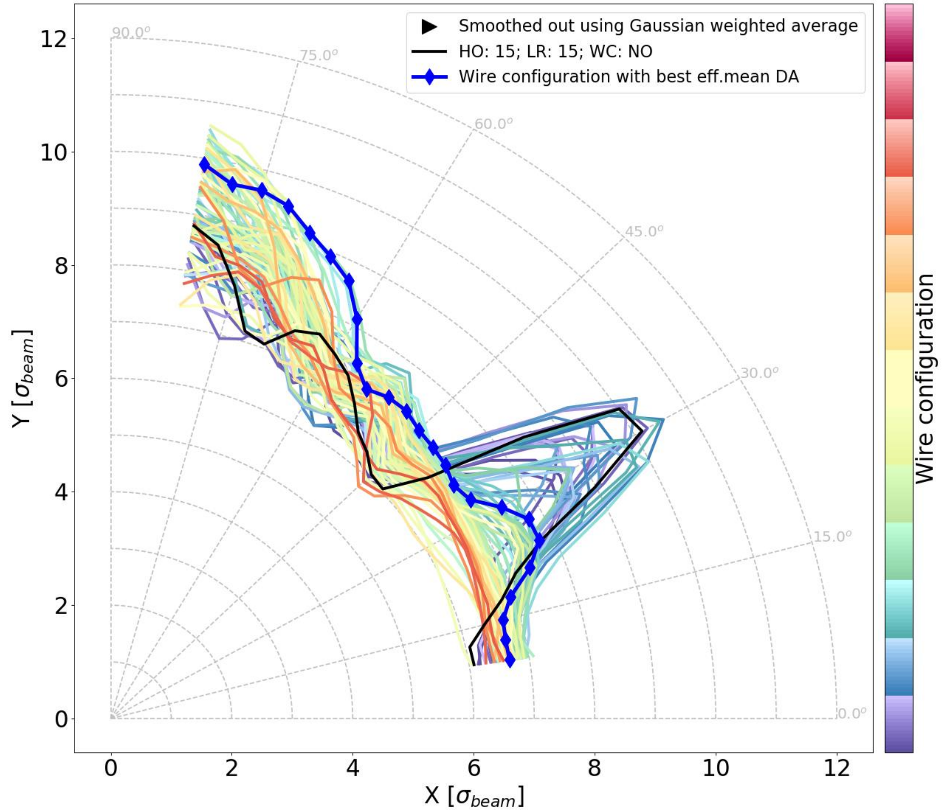
Plotting only the wire configurations with positive effective mean DA it is clear the beneficial effect of the wire (blue curve with rhombus).

A more detailed analysis of the strongest resonances vs angle is needed.

Without smoothing

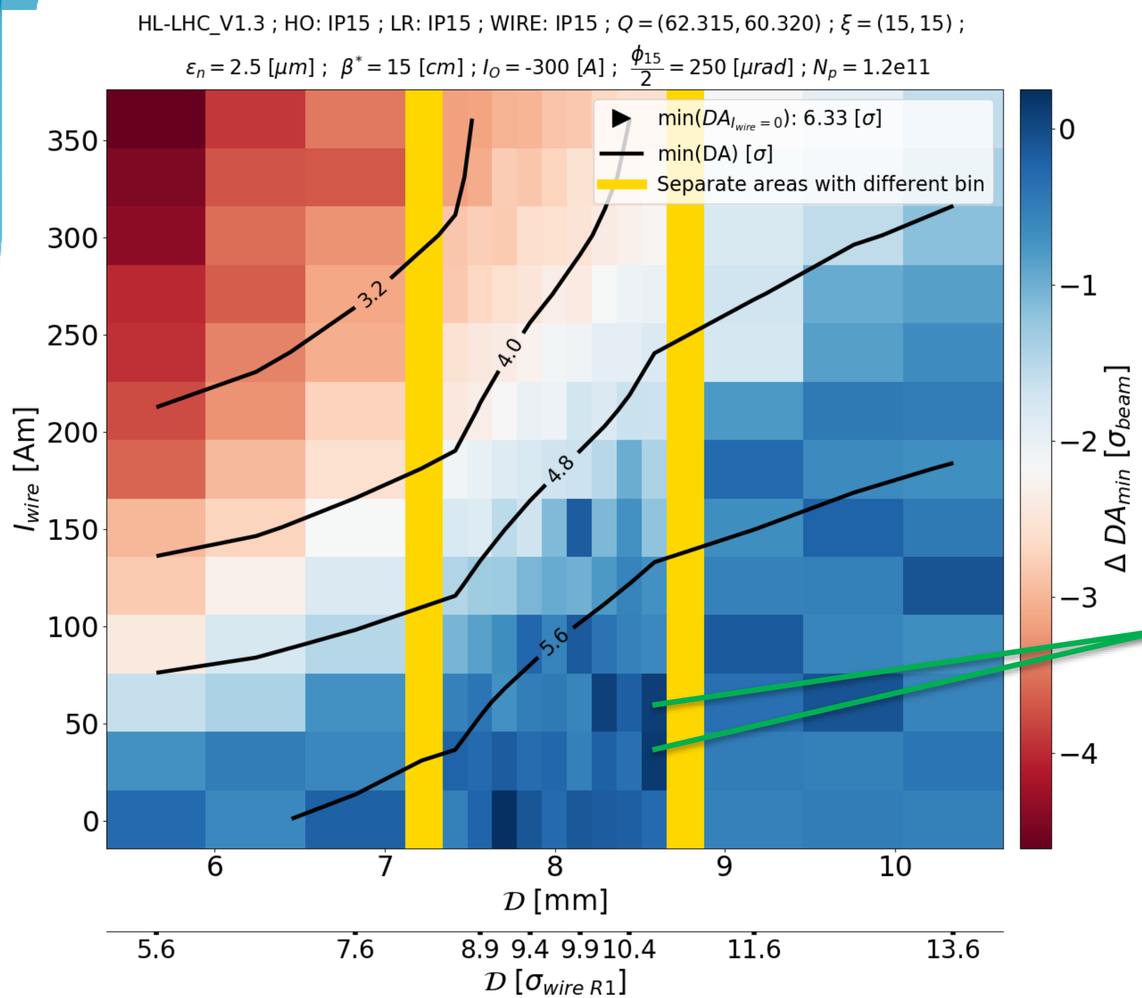


Smoothed using
Gaussian weighted average



BBLR compensation (II)

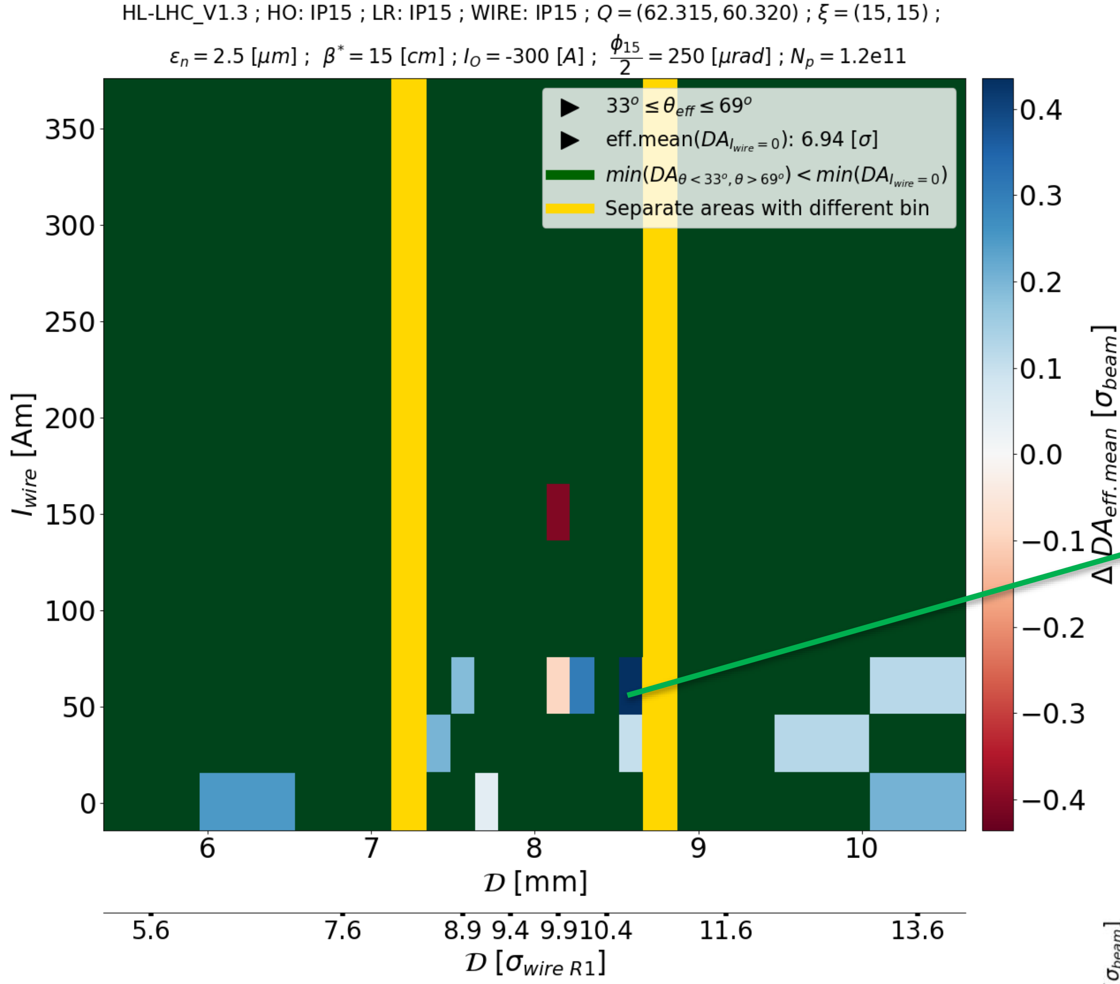
Lattice tunes	Io	Half crossing angle	Normalized crossing angle	Luminosity
62.315 ; 60.32	-300 [A]	250 [μrad]	10.6	5×10^{34} [$cm^{-2}s^{-1}$]



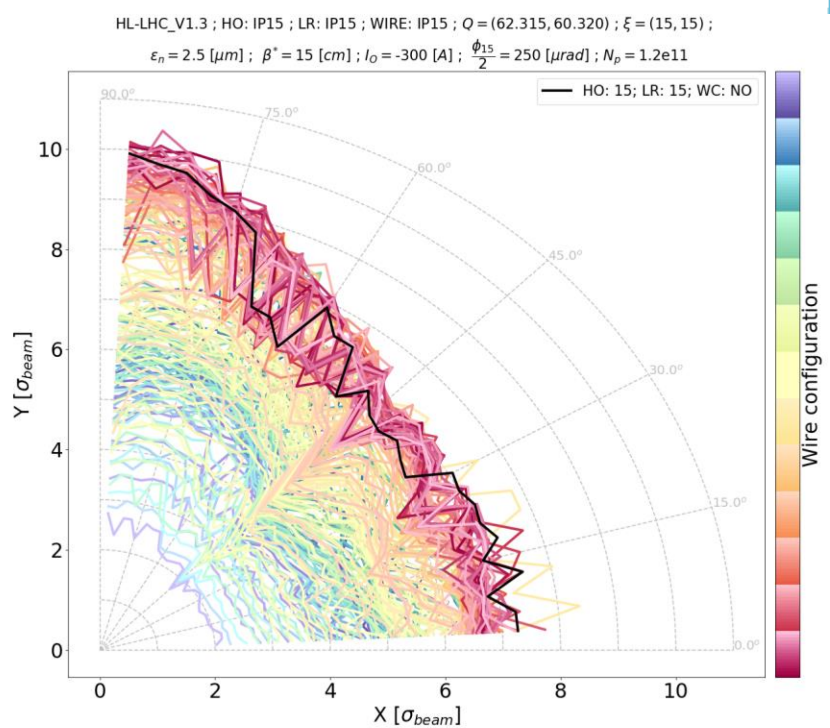
On top of the already improved min DA resulting from the tune optimization, the wire can give some extra DA improvement.

~0.2σ better effective mean DA with **low wire current** (Iw<130Am) and **large wire transverse distance** (D>10σ).

BBLR compensation (II)



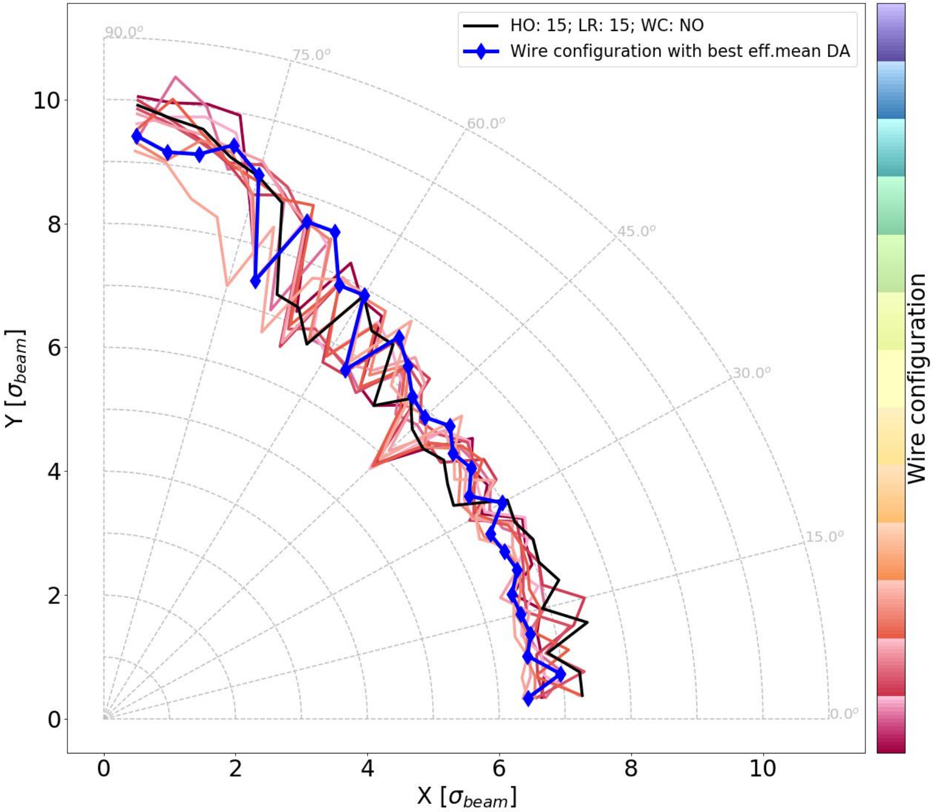
The improvement of the DA is more evident at the areas where the black line (no wire case) has its minimum. The mean DA improved **more than 0.4σ**.



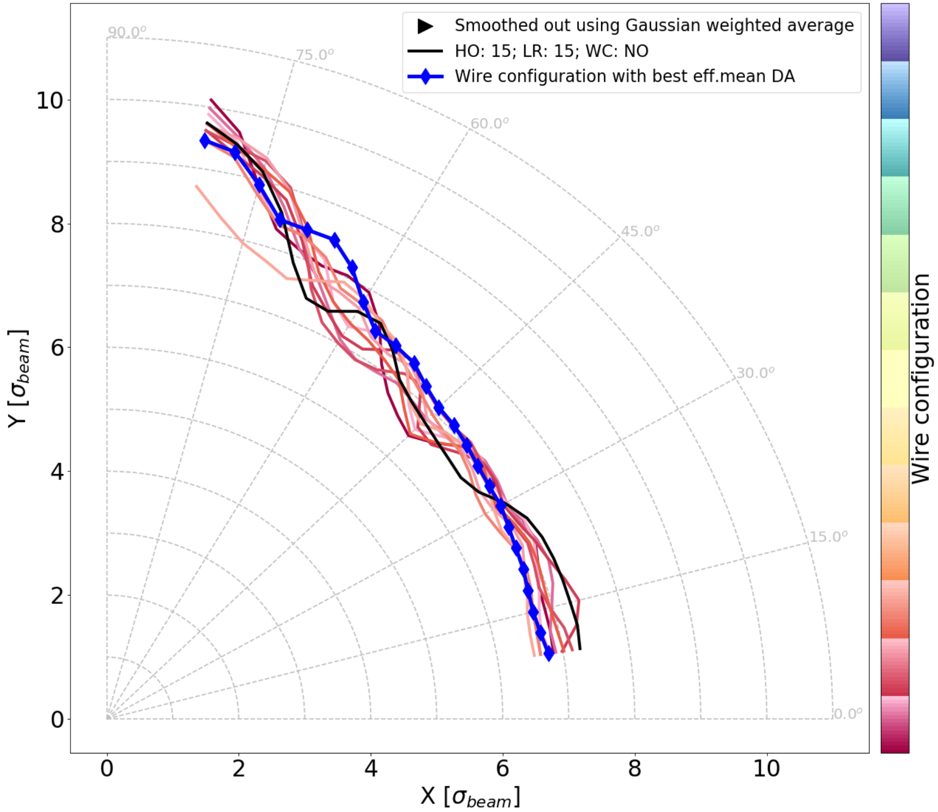
BBLR compensation (II)

Over all the angles the wire configurations with the best positive effective mean DA is slightly better than the case without wire.

Without smoothing

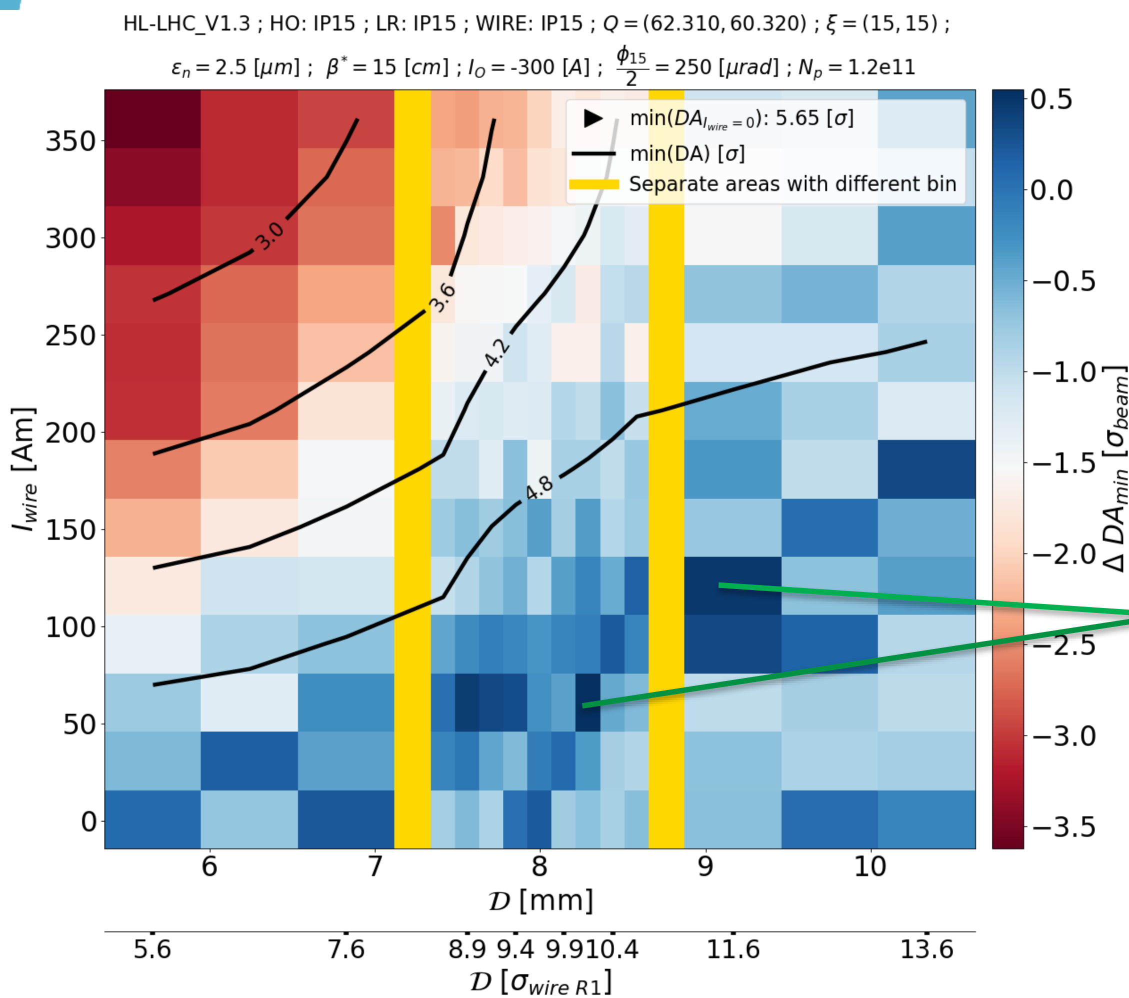


Smoothed using Gaussian weighted average



BBLR compensation (III)

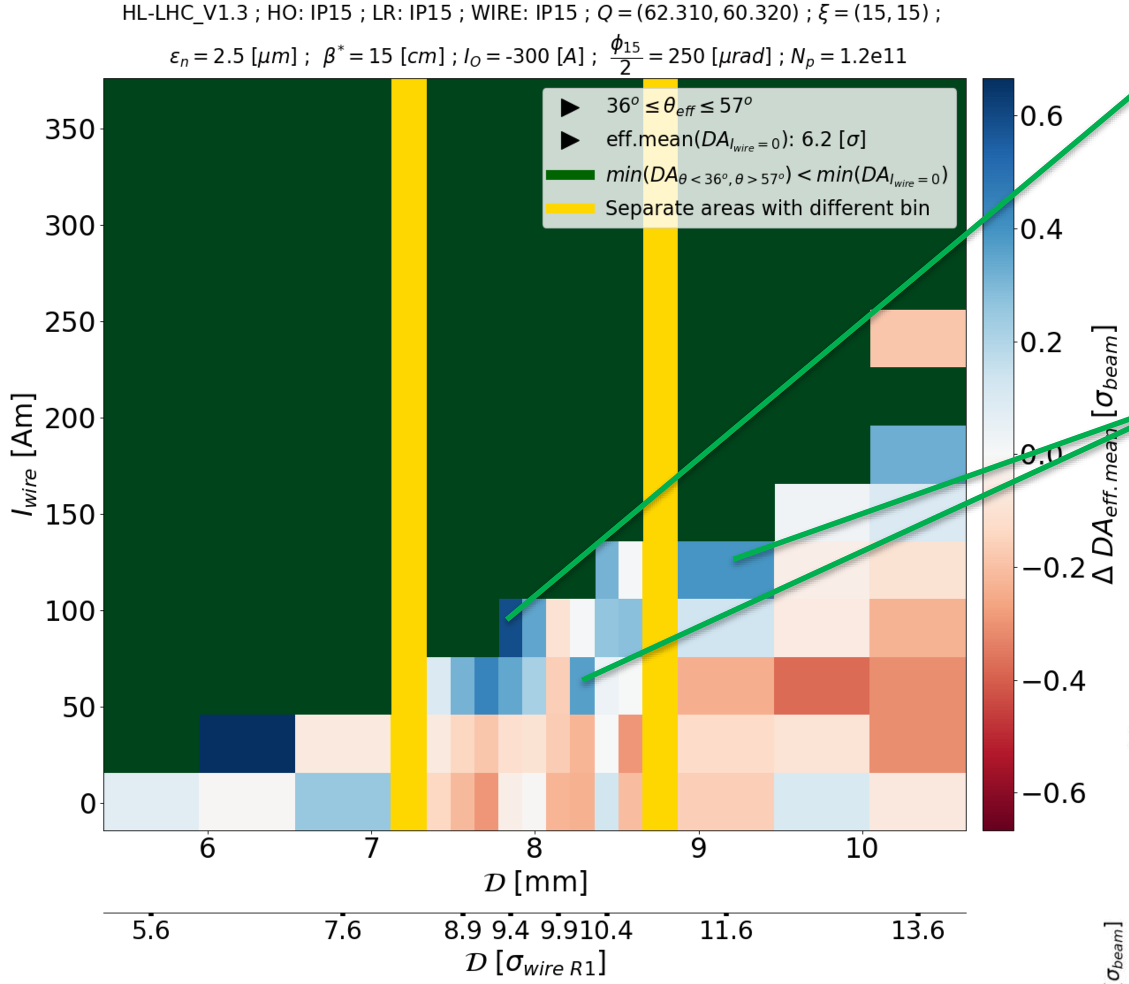
Lattice tunes	Io	Half crossing angle	Normalized crossing angle	Luminosity
62.31 ; 60.32	**-300 [A]**	**250 [μrad]**	**10.6**	**$5x10^{34}$ [$cm^{-2}s^{-1}$]**



Using a non optimized tune, it is possible to adjust the wire properties (I_W & D) so to achieve the same min DA as in the case with the optimized tune.

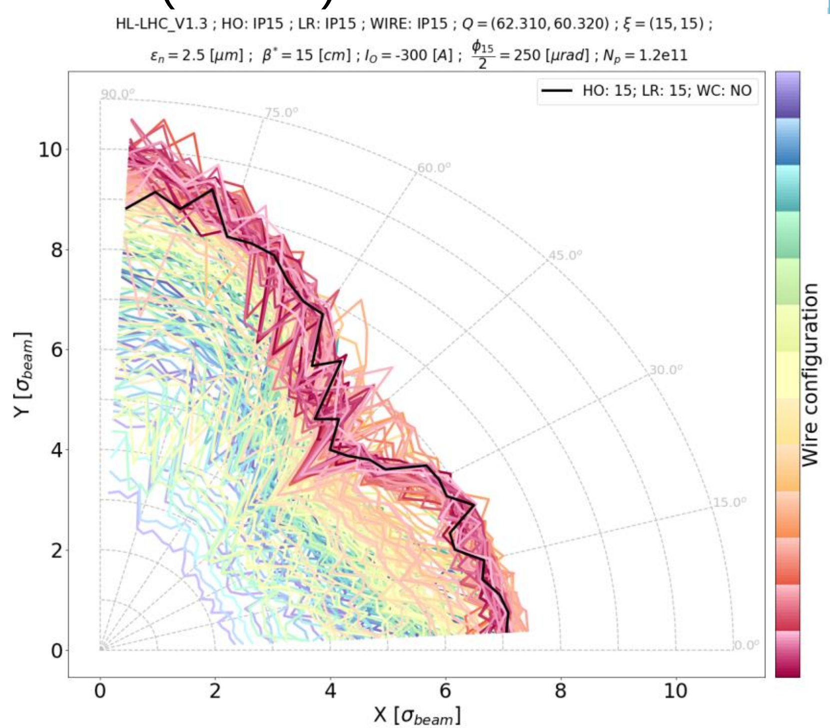
Using a wire with **low current** (I_W<130Am) and **large wire transverse distance** (D>10σ) the **min DA is increased 0.5σ**.

BBLR compensation (III)



The **effective mean DA is increased 0.6σ** at the problematic areas located around the 45º.

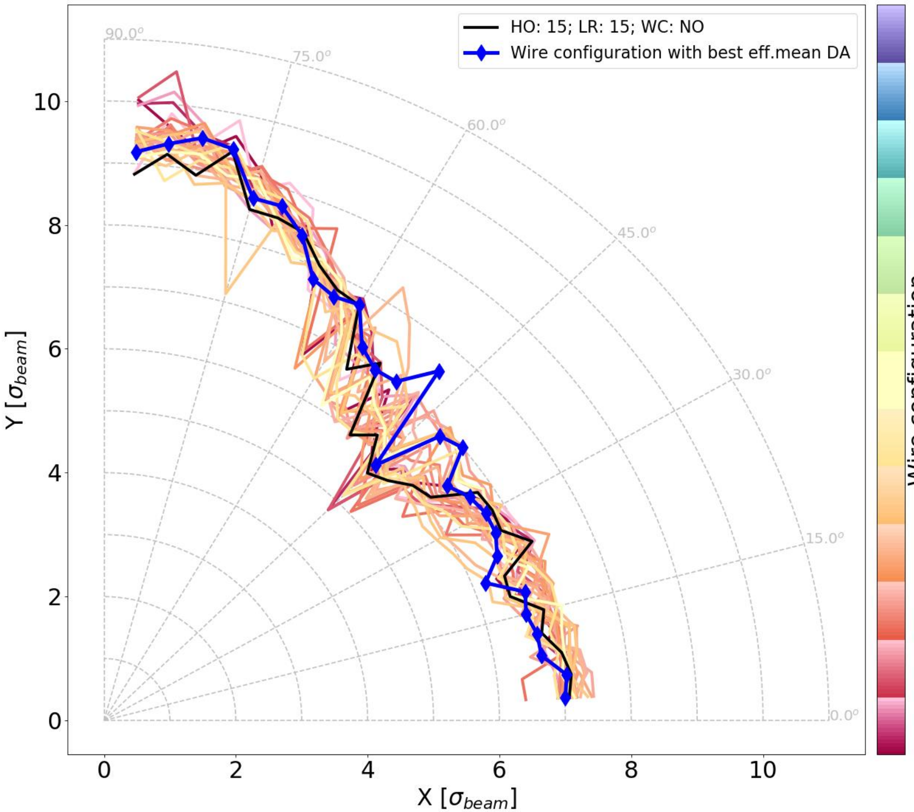
0.4σ better effective mean DA with **low wire current** (Iw<130Am) and **large wire transverse distance** (D>10σ).



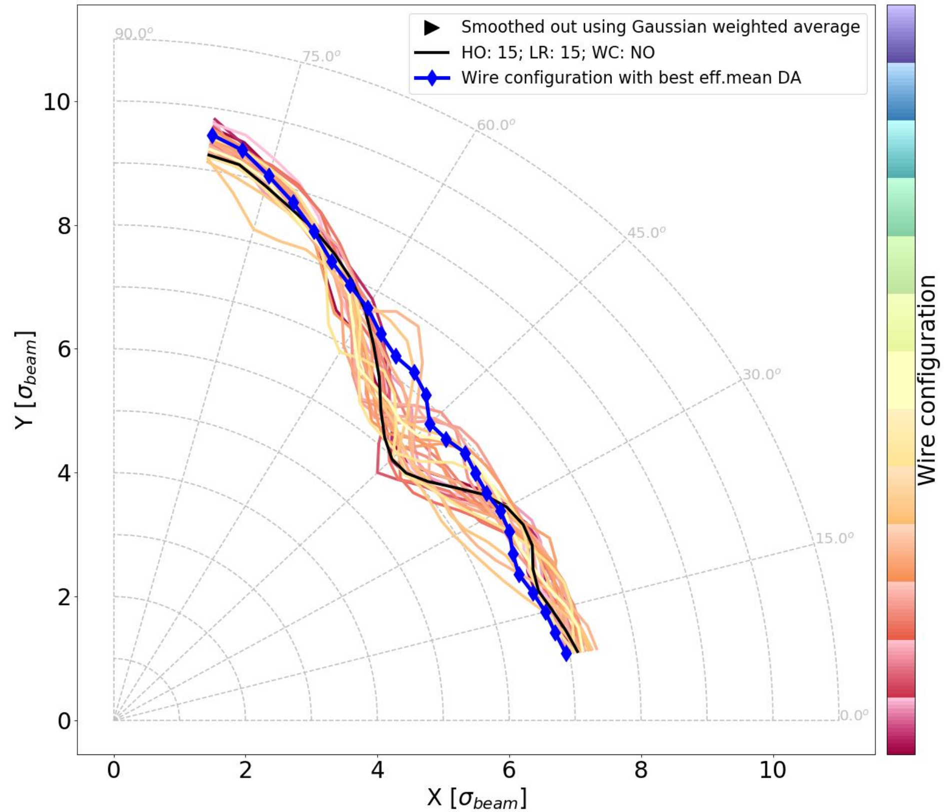
BBLR compensation (III)

The use of the wires not only improve the problem around the 45º but also preserve the very good DA for the rest of the angles.

Without smoothing

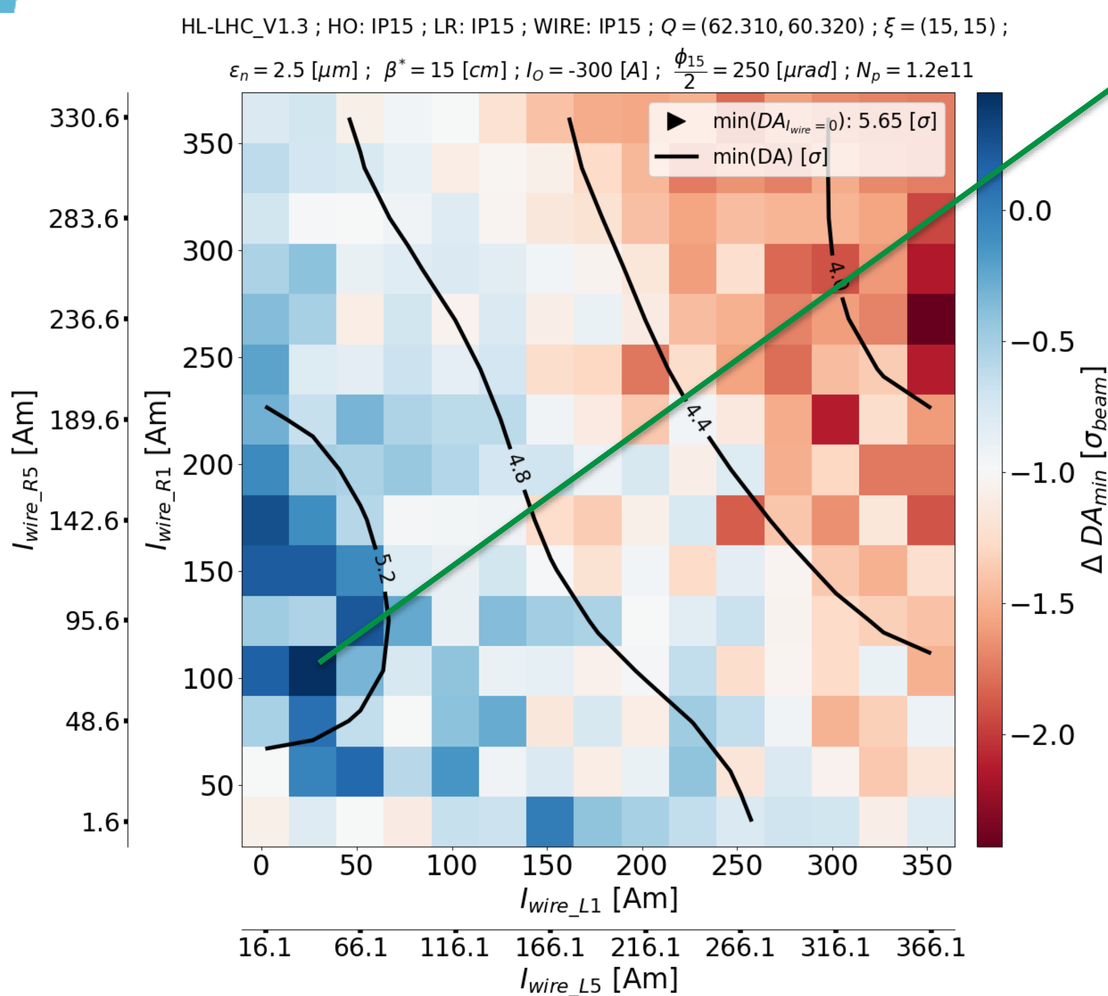


Smoothed using
Gaussian weighted average

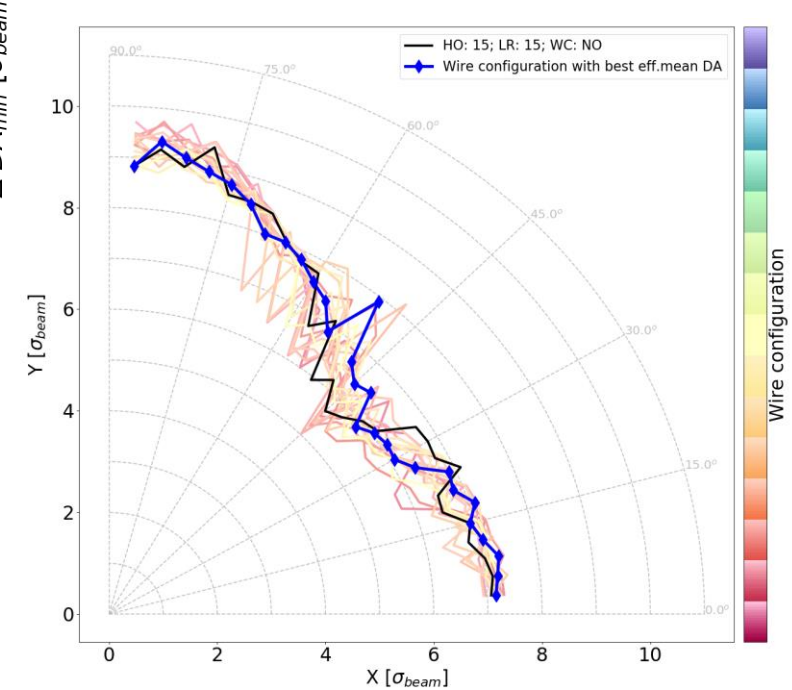


BBLR compensation (III)

By fixing the transvers position of the wires at D~10σ and adjusting the wire current of the left and right wire independently, it is again possible to obtain the same min DA as in the case of the optimized tune.

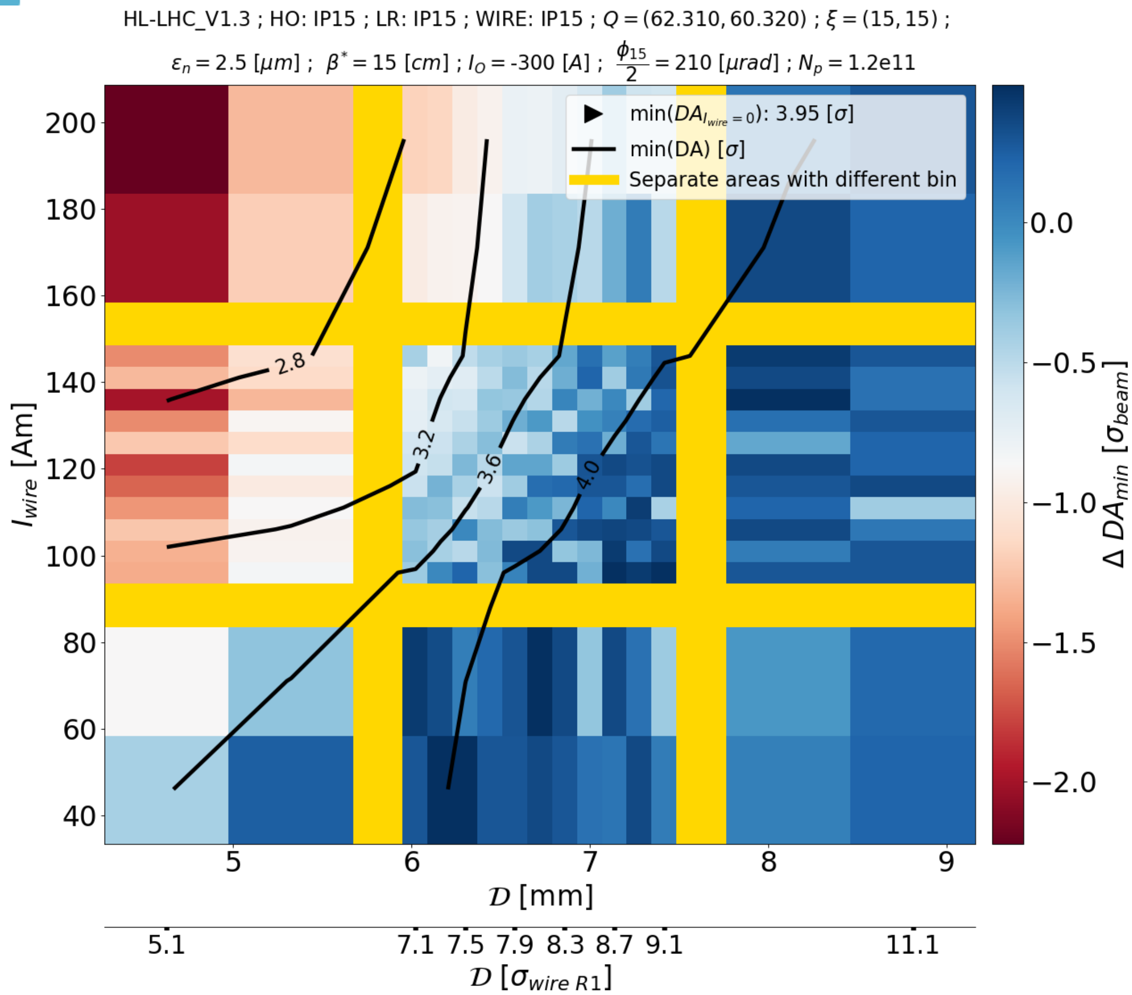


Using a wire with **low current** (Iw<130Am) and **large wire transverse distance** (D~10σ) the **min DA is increased 0.5σ**.



BBLR compensation (IV)

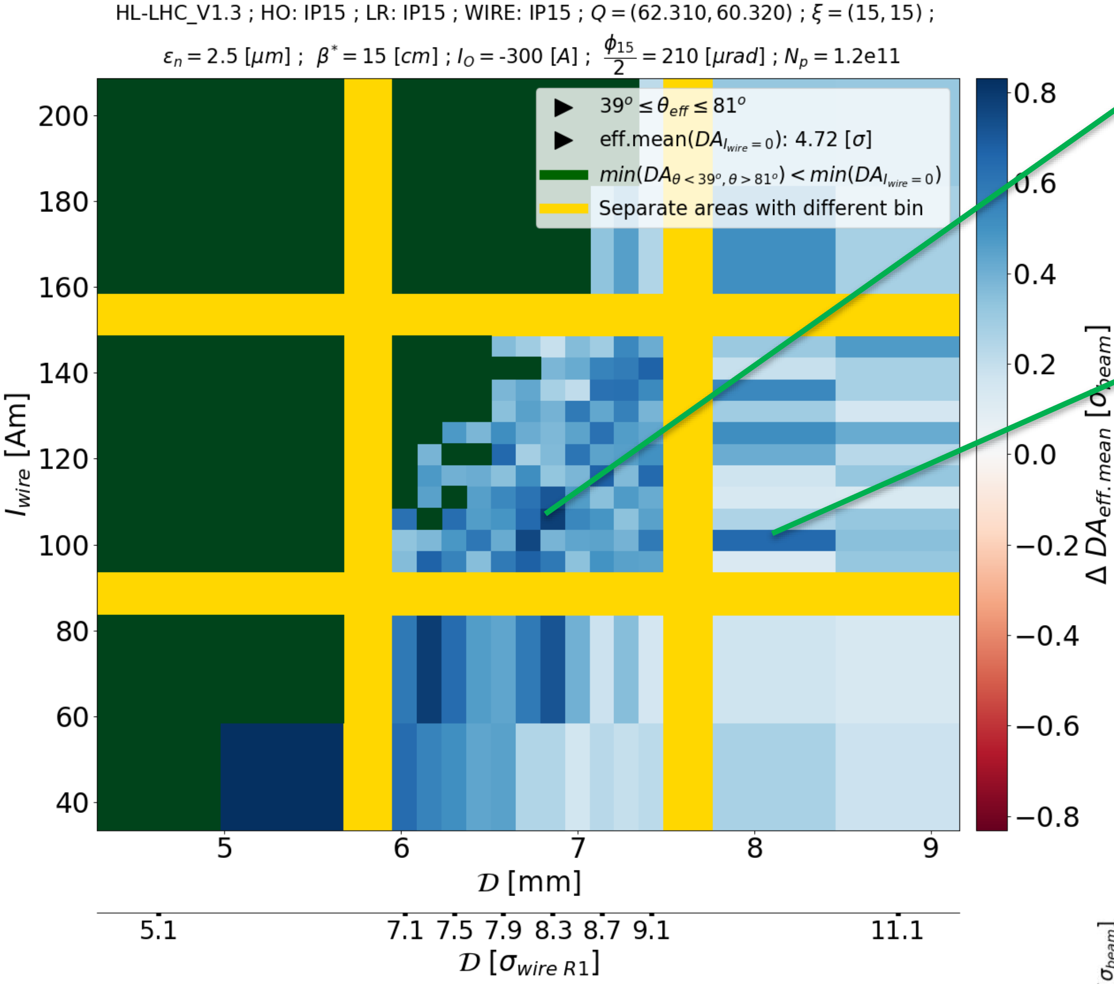
Lattice tunes	Io	Half crossing angle	Normalized crossing angle	Luminosity
62.31 ; 60.32	-300 [A]	210 [μrad]	8.9	5.8x10^{34} [cm^{-2}s^{-1}]



By pushing the crossing angle at 210 μrad and using the old tune, the min DA with the use of the wires is increased up to 0.5σ.

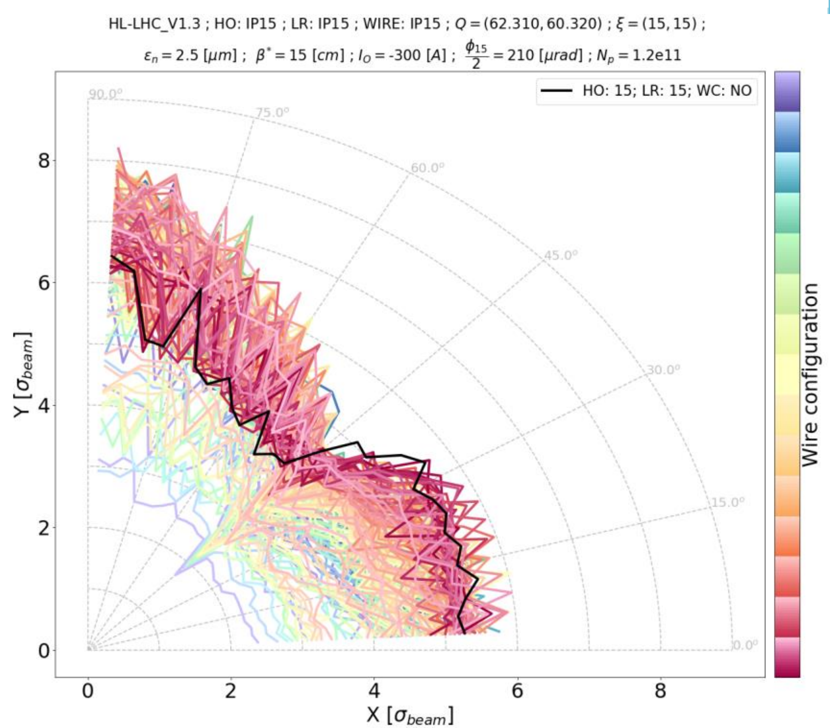
With an extra tune optimization this improvement can be even better.

BBLR compensation (IV)



The effective **mean DA is increased 0.8σ** at the problematic areas.

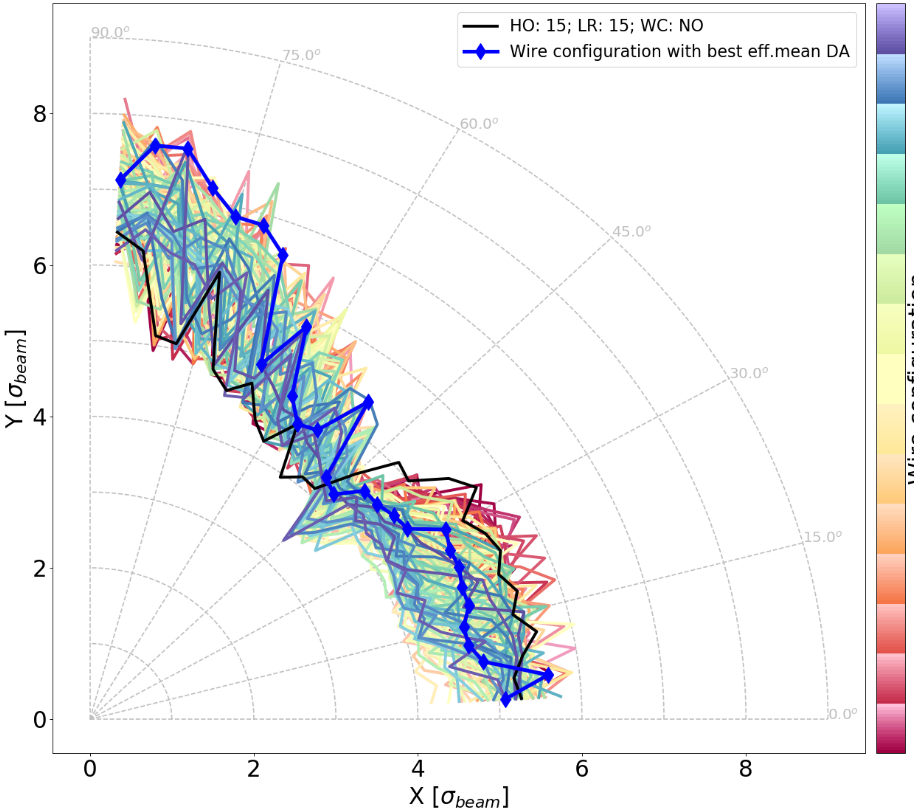
0.65σ better effective mean DA with **low wire current** (Iw<130Am) and **large wire transverse distance** (D>10σ).



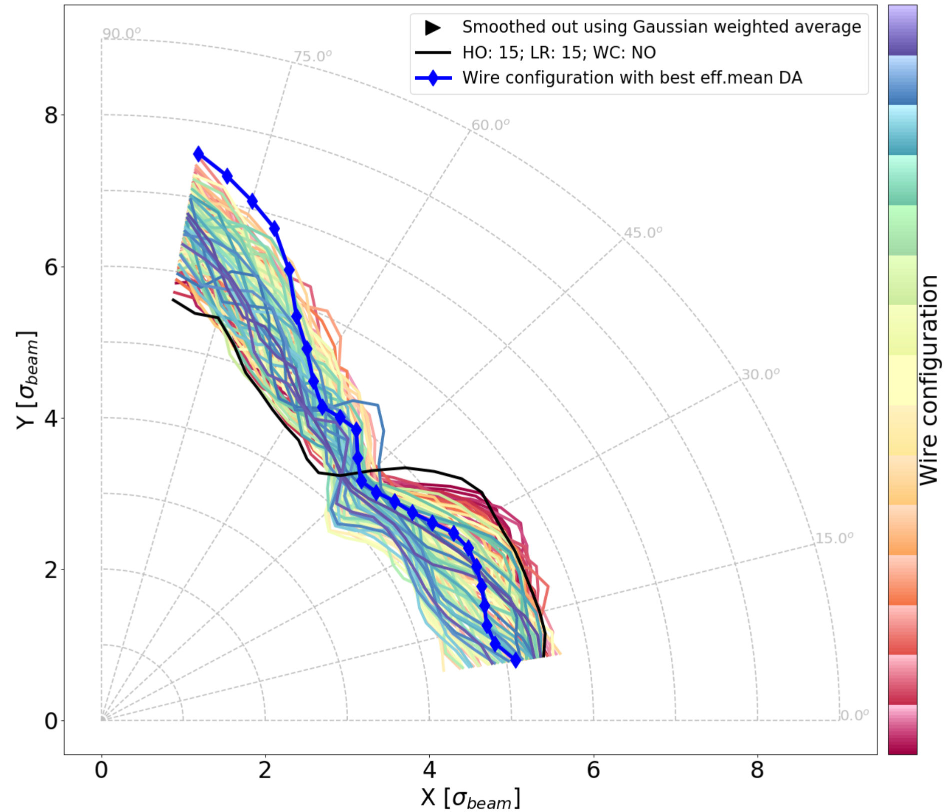
BBLR compensation (IV)

The wire configuration with the best effective mean DA is the one resulting in the preservation of a good DA for the different angles.

Without smoothing



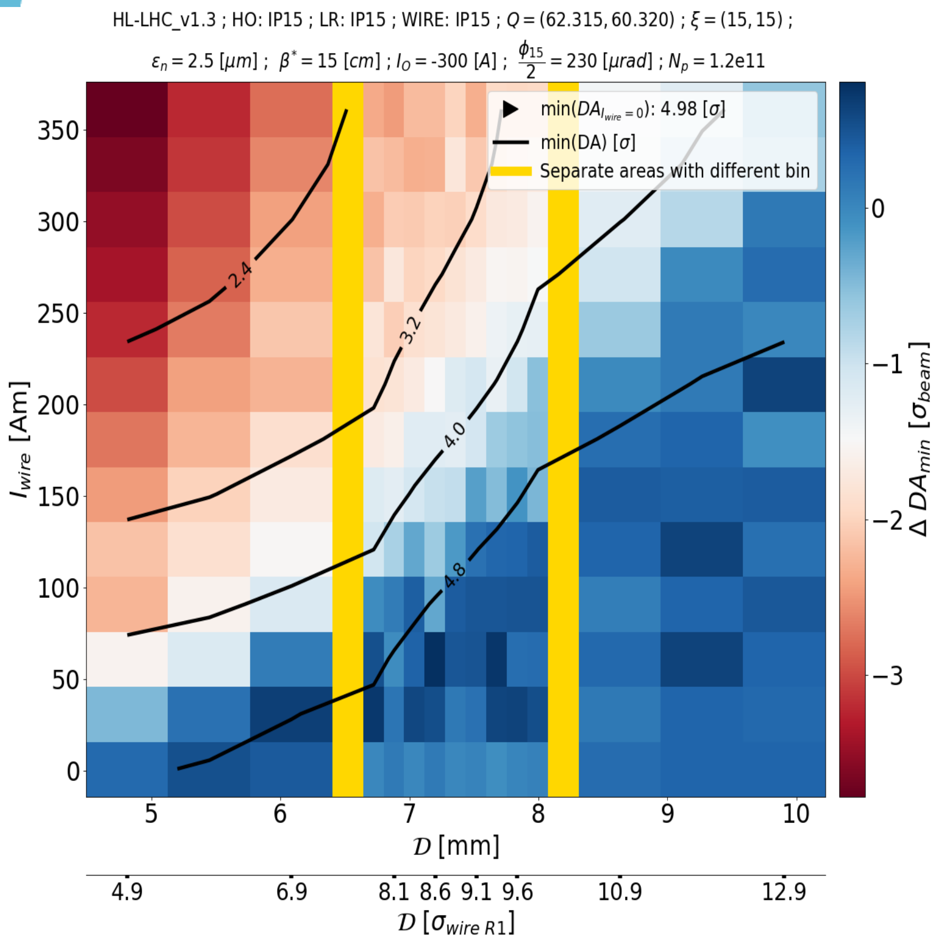
Smoothed using
Gaussian weighted average

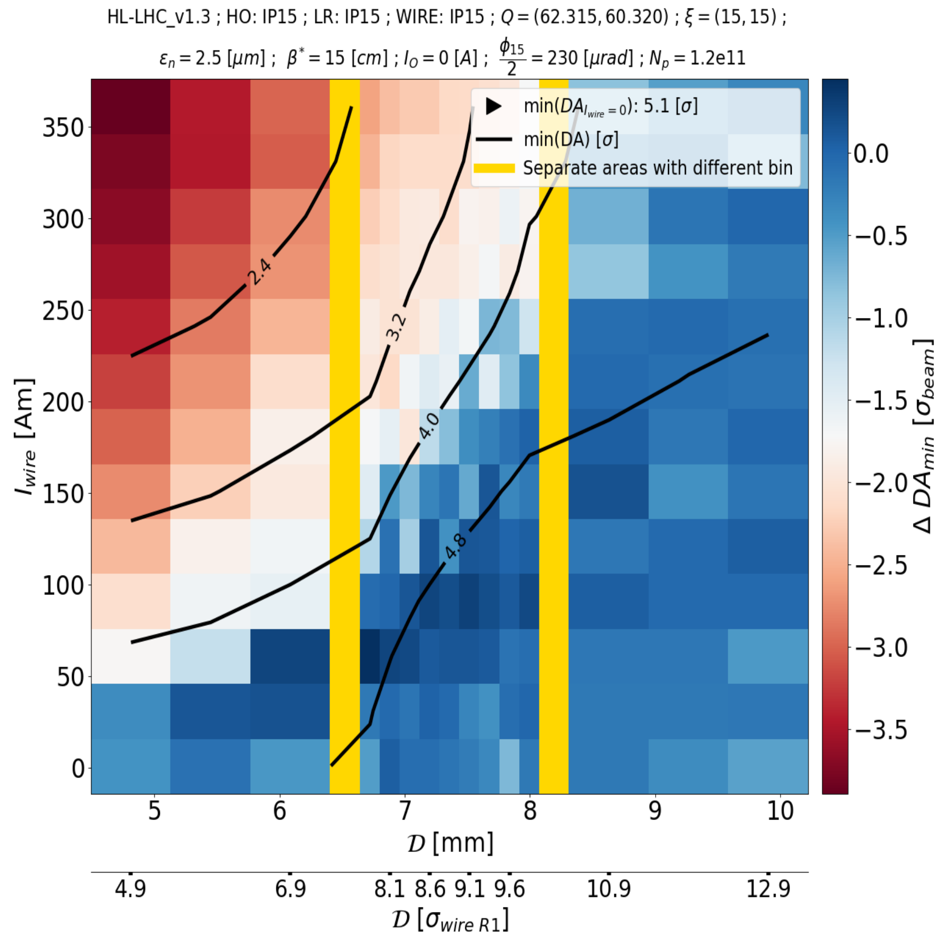


BBLR compensation (V)

Lattice tunes	Io	Half crossing angle	Normalized crossing angle	Luminosity
62.315 ; 60.32	-300 & 0 [A]	230 [μrad]	9.7	5.4×10^{34} [$cm^{-2}s^{-1}$]

Pushing the crossing angle at 230 μrad, the use of the wire guaranty a min DA close to 6σ and a boosted luminosity independent of the octupoles current.

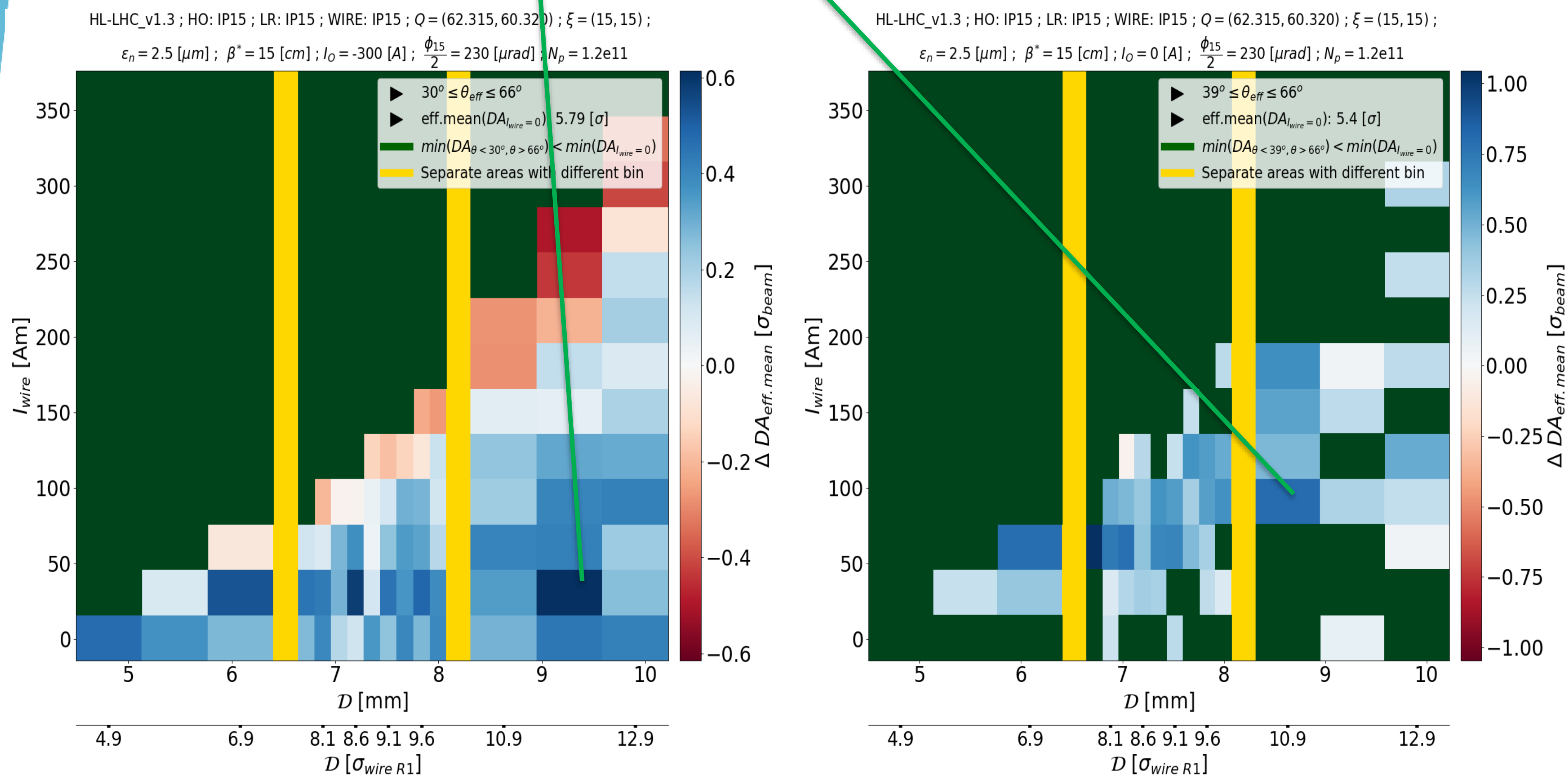




BBLR compensation (V)

The **effective mean DA is increased more than 0.6σ** in the case with negative octupoles and **more than 1σ** without octupoles.

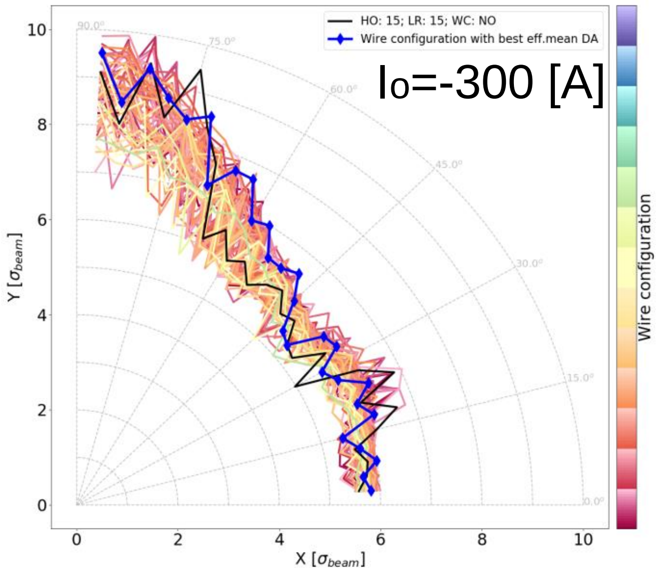
0.6σ and 0.8σ better effective mean DA with **low wire current** (I_w<130Am) and **large wire transverse distance** (D>10σ).

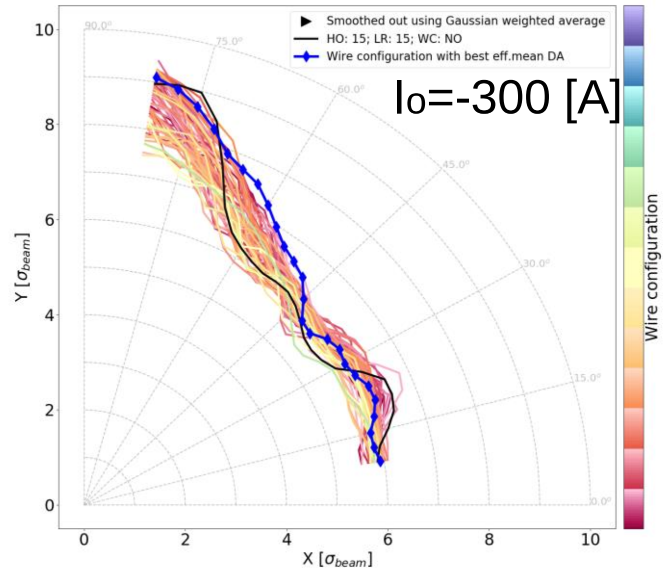


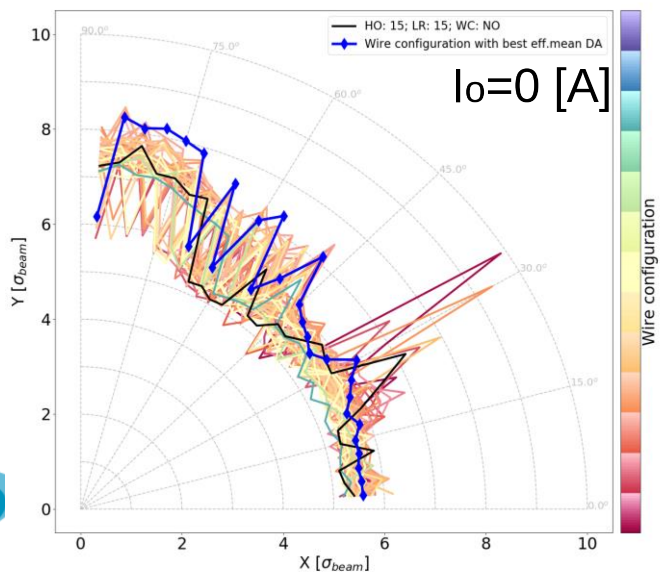
BBLR compensation (V)

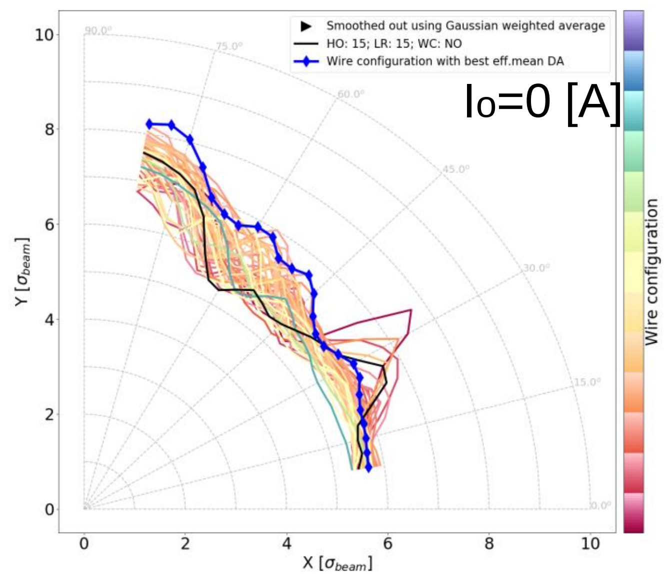
Without smoothing

Smoothed using Gaussian weighted average









Conclusions

- In all the studies a good min or effective mean DA is found at transvers wire distance larger than 10σ and with wire current lower than 130 Am.
- The DA degradation seen when a non optimized tune is used can be overcome if the left and right wire current or the wire current and its transvers position are adjusted appropriately.
- The wire good performances are independent from the octupole current.
- A deeper understanding of the impact of the different resonances is needed through non-linear dynamics analysis (FMAs,…)
- A working point scan for optimized wire currents is on-going.
- The impact of the wire on lifetime will be assessed.

Thank you for your time!

Backup slides

Bassetti-Erskine formulas

- **4D treatment of the beam-beam long range interaction (Bassetti-Erskine)**

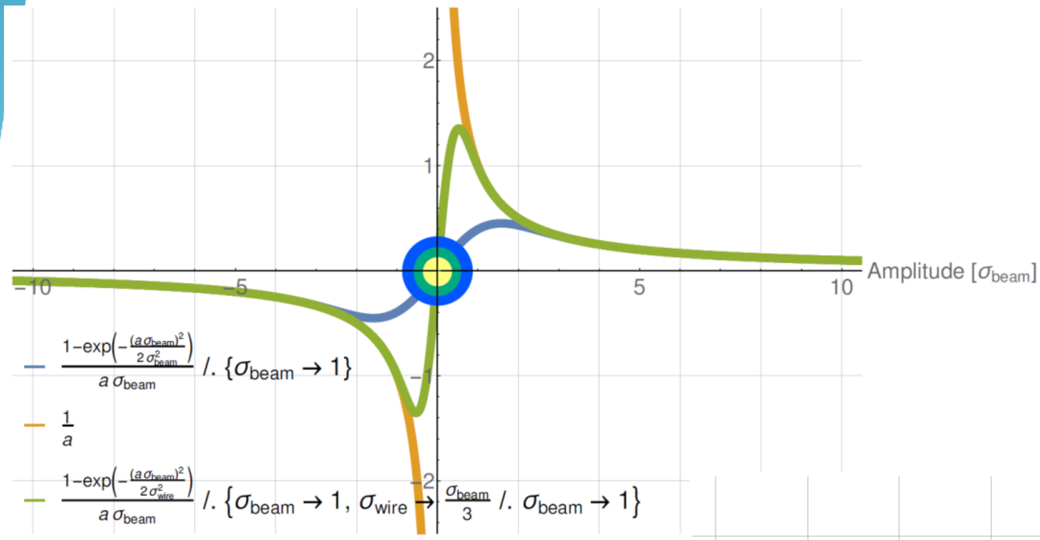
$$B_\theta = -\frac{\beta_{st}}{c} E_r \;\rightarrow\; F_\perp = q\, E_r\, (1 + \beta_{we}\beta_{st}) = q\, E_{reff} \quad \text{and for } \sigma_x > \sigma_y:$$

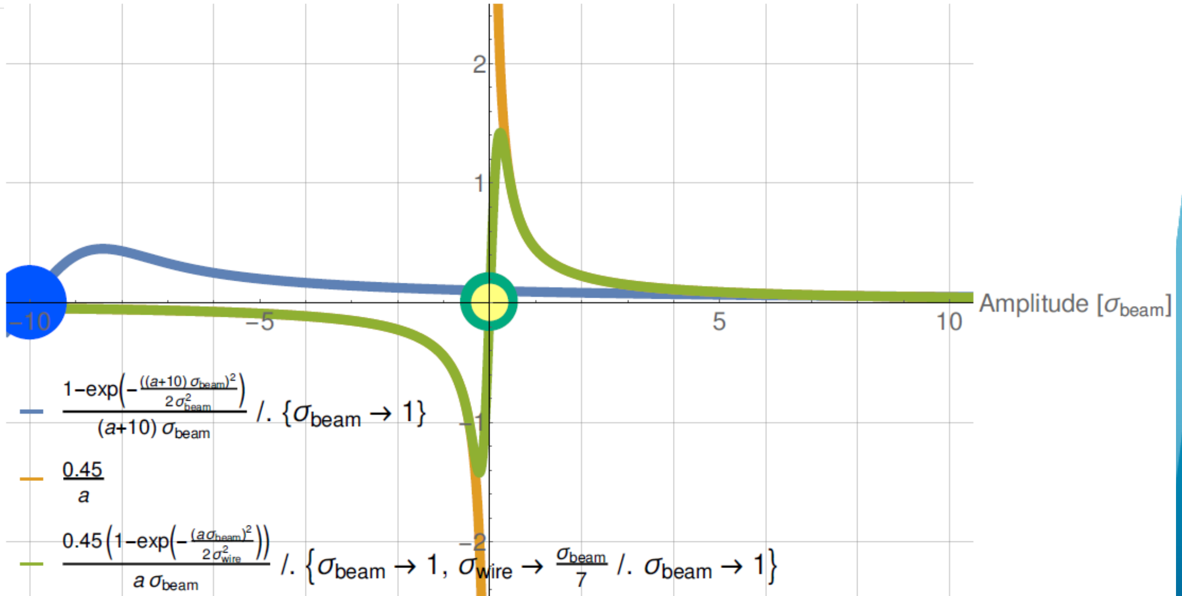
$$\int_{-\infty}^{\infty} E_{xeff}\, ds = \frac{N_p\, q\, (1+\beta_{we}\beta_{st})}{2\epsilon_0 \sqrt{2\pi(\sigma_x^2-\sigma_y^2)}} \Im \left[\mathcal{F}\left(\frac{x+\imath y}{\sqrt{2(\sigma_x^2-\sigma_y^2)}} \right) - Exp\left(-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} \right) \mathcal{F}\left(\frac{x\sigma_y^2 + \imath y \sigma_x^2}{\sigma_x\sigma_y \sqrt{2(\sigma_x^2-\sigma_y^2)}} \right) \right]$$

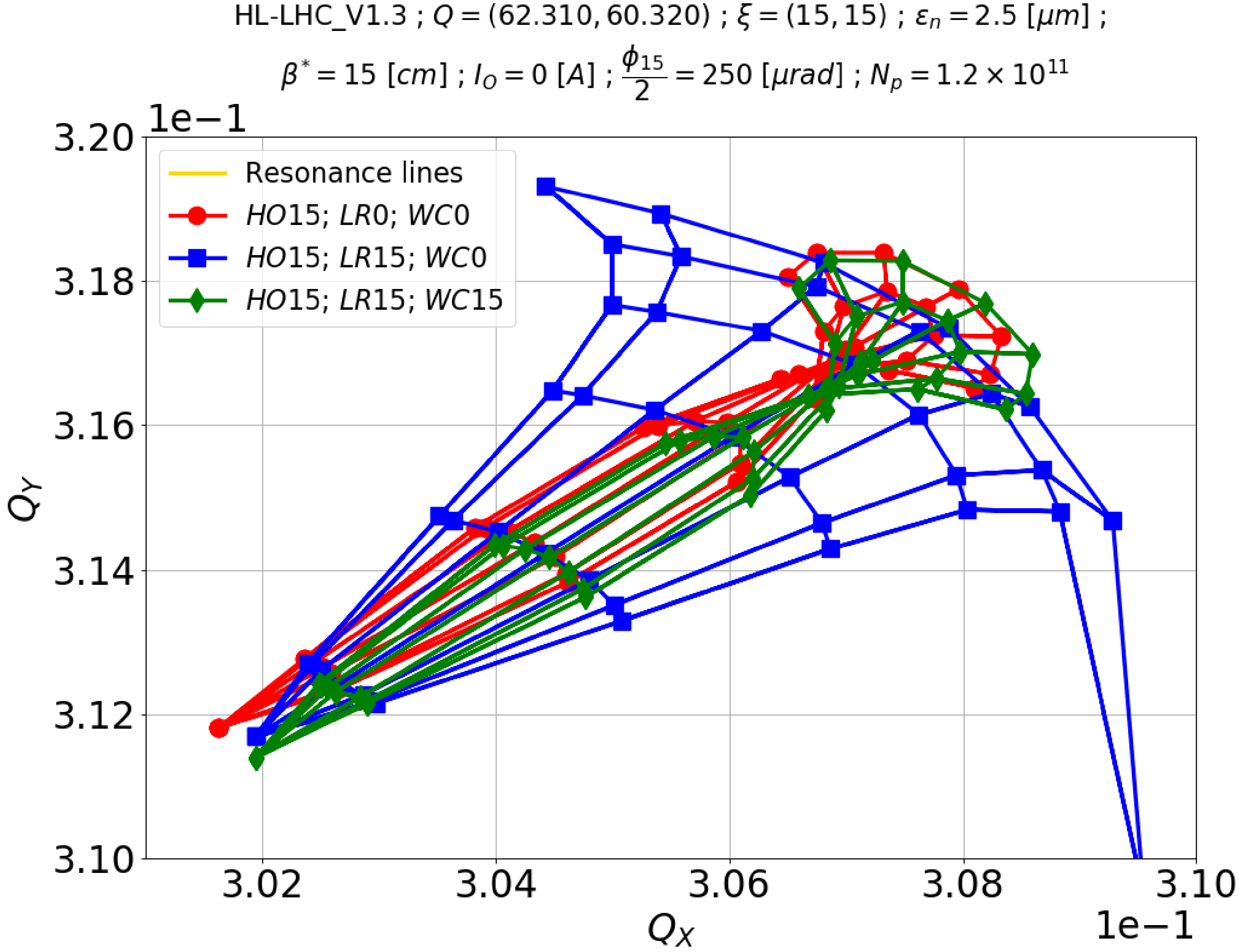
$$\int_{-\infty}^{\infty} E_{yeff}\, ds = \frac{N_p\, q\, (1+\beta_{we}\beta_{st})}{2\epsilon_0 \sqrt{2\pi(\sigma_x^2-\sigma_y^2)}} \Re \left[\mathcal{F}\left(\frac{x+\imath y}{\sqrt{2(\sigma_x^2-\sigma_y^2)}} \right) - Exp\left(-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} \right) \mathcal{F}\left(\frac{x\sigma_y^2 + \imath y \sigma_x^2}{\sigma_x\sigma_y \sqrt{2(\sigma_x^2-\sigma_y^2)}} \right) \right]$$

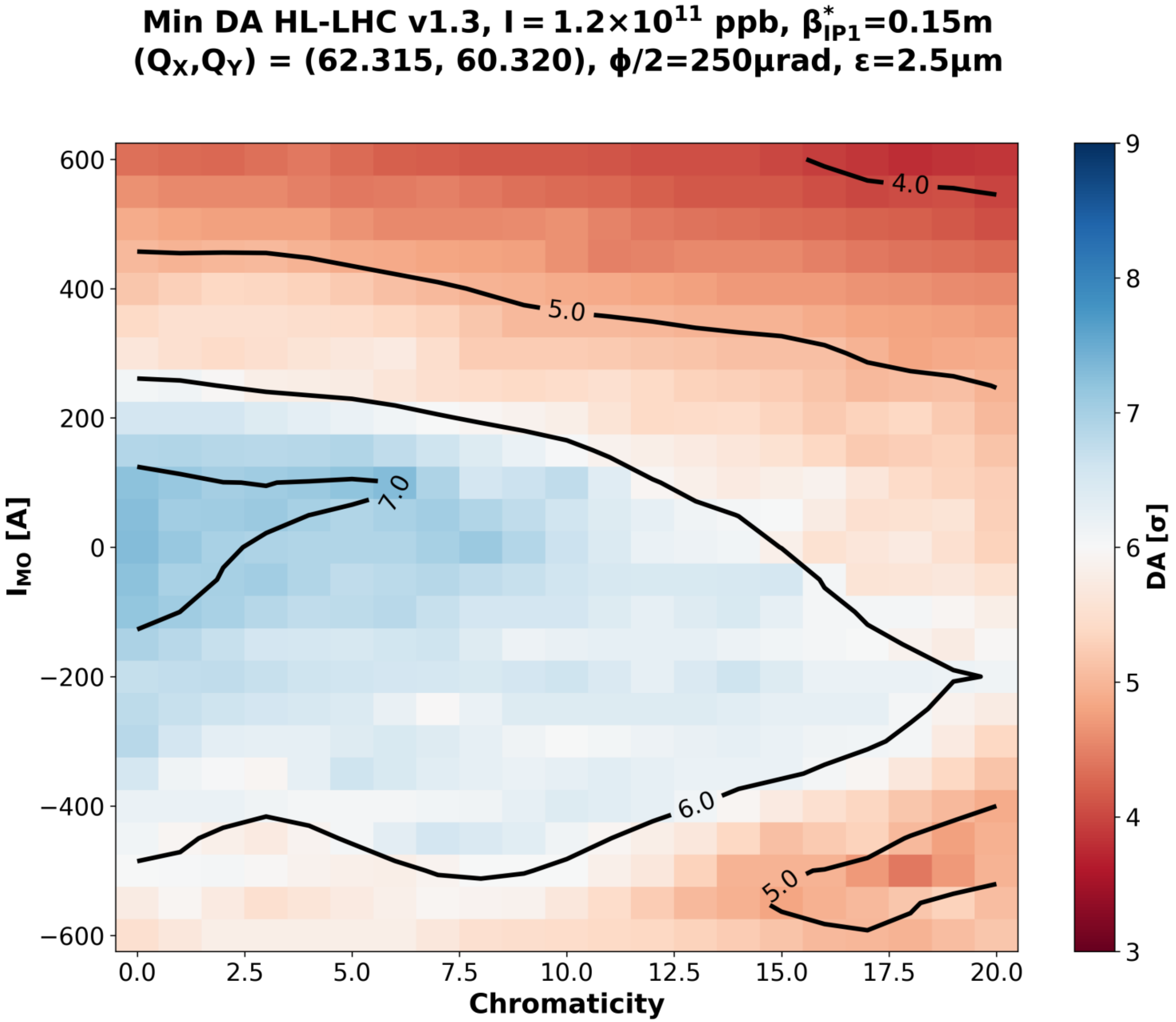
All the quantities are measured from the center of the strong beam in the lab rest frame

Beam-beam field vs wire-like beam-beam field vs wire field






HL-LHC_V1.3 ; $Q = (62.310, 60.320)$; $\xi = (15, 15)$; $\epsilon_n = 2.5$ [μm] ;
$\beta^* = 15$ [cm] ; $I_O = 0$ [A] ; $\frac{\phi_{15}}{2} = 250$ [μrad] ; $N_p = 1.2 \times 10^{11}$
1e−1
3.20
3.18
3.16
3.14
3.12
3.10
Q_Y
Resonance lines
HO15; LR0; WC0
HO15; LR15; WC0
HO15; LR15; WC15
3.02
3.04
3.06
3.08
3.10
Q_X
1e−1



By N. Karastathis