Beam-Beam DA Simulations

N. Karastathis, Y. Papaphilippou

with many thanks to

R. De Maria, R. Tomas, F. van der Veken

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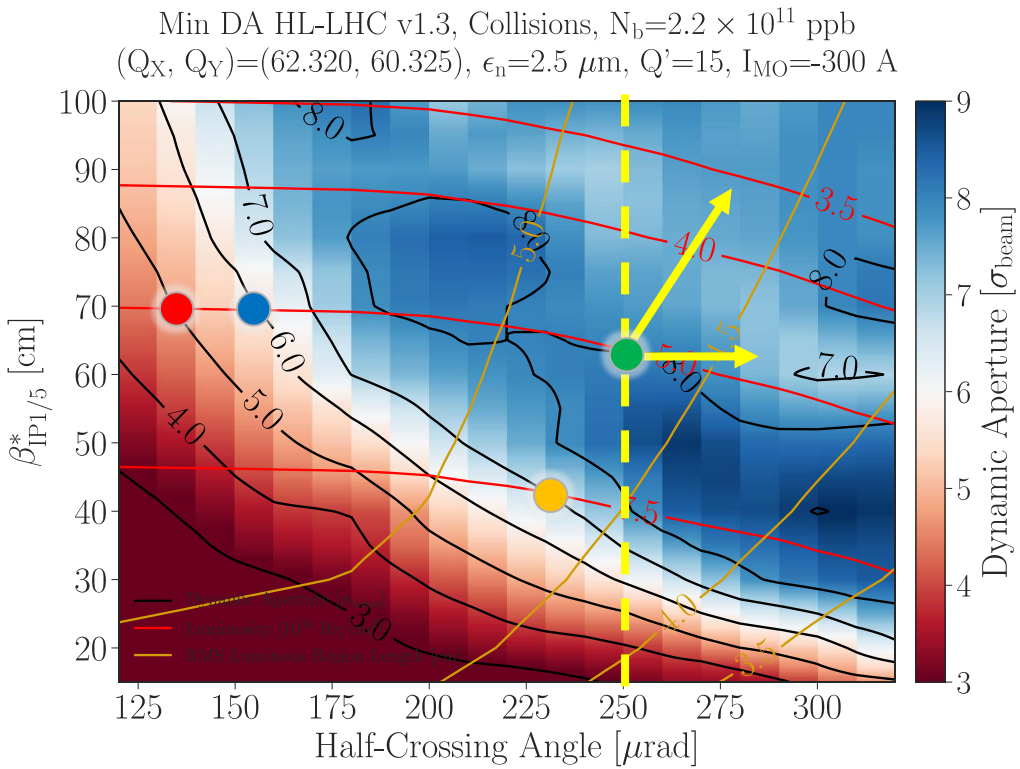
OUTLINE

1. Operation with larger crossing-angle
2. Impact of failing a4/b5 correctors at the end of leveling.
3. Operation below the diagonal.
4. Collapsing the separation bump with CC off.

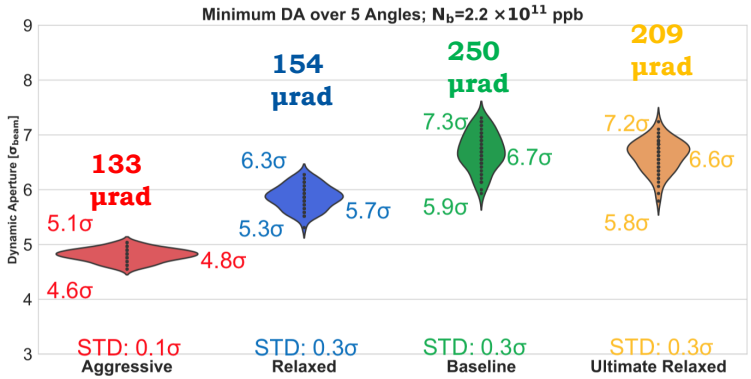
1. Colliding with Larger Crossing Angle

Start of Leveling (CC on)



- Varying the crossing angle around 250 μrad does not have a significant effect on DA (within 1σ, already >7σ)
- Maintaining the $5 \cdot 10^{34}$Hz/cm^2 while increasing the half crossing angle the pileup density increases
  [e.g. (250 μrad, 64 cm) → (300 μrad, 56 cm) ➔ -12% in rms length luminous region]
  (irradiation too!)

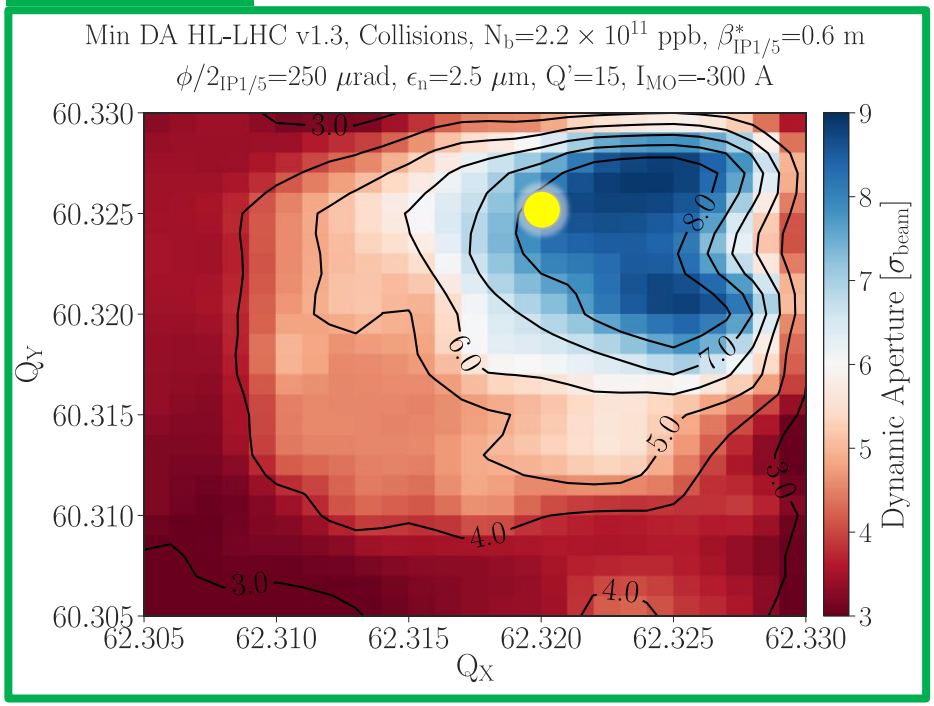
- As a reminder from 7th HL-LHC Collaboration meeting @ Madrid: While the DA is not significantly restricted, the spread of the minimum DA among the 60 seeds is at the level of 0.3 σ, for various half-crossing angle values.



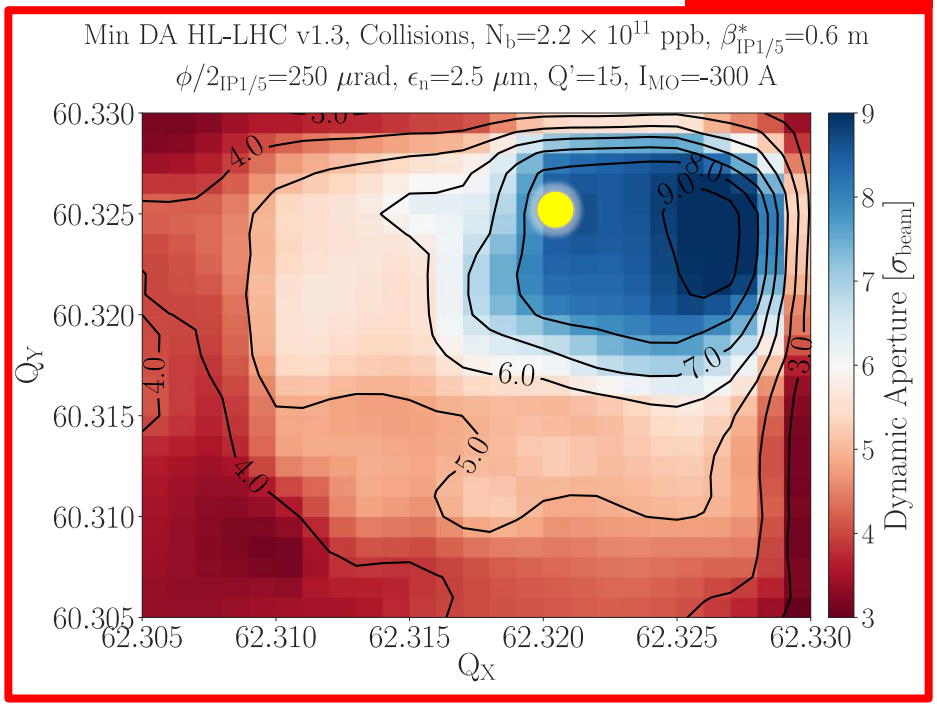
- Spread of 0.3σ, with the exception of the aggressive at ~0.1σ

Start of (Nominal) Leveling

CC ON



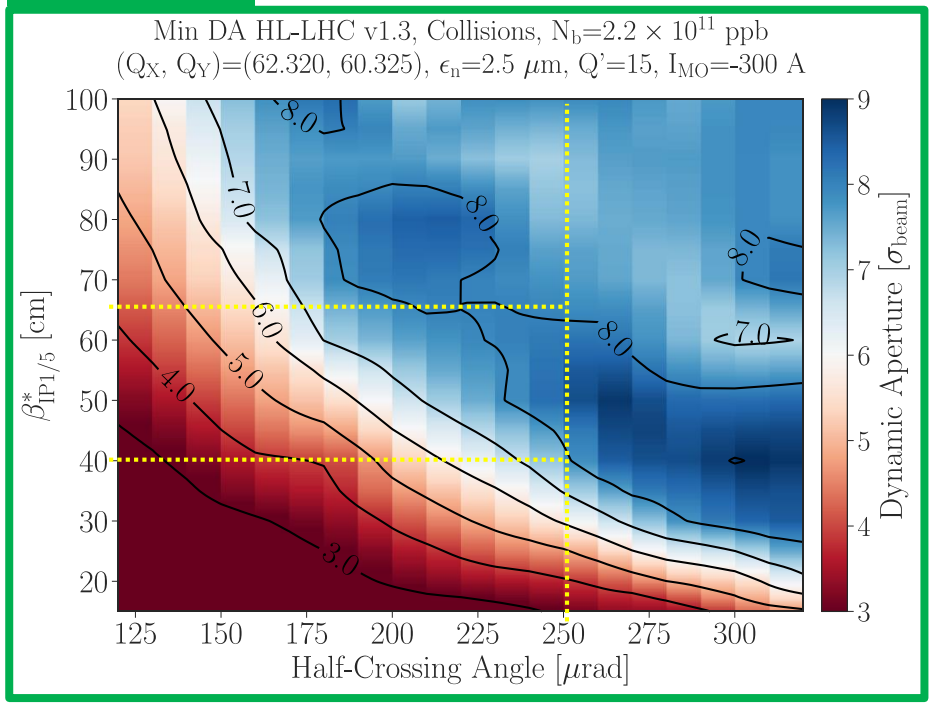
CC OFF



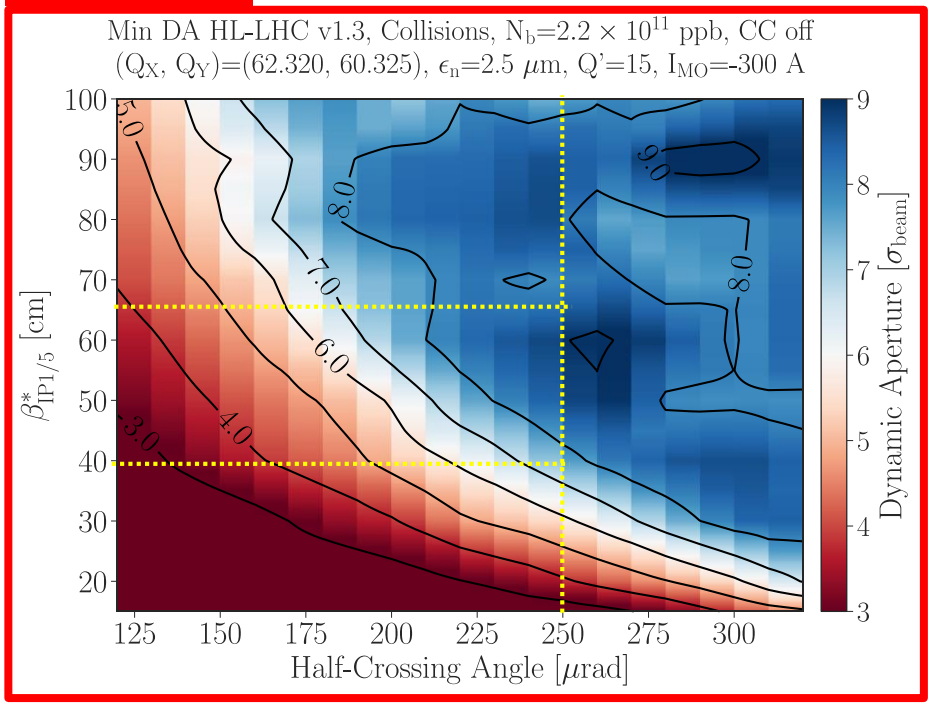
With the CC off, the **available DA area is increased** (especially for DA around 4-5σ), while the **peak DA is not significantly impacted**.

Start of (Nominal) Leveling

CC ON

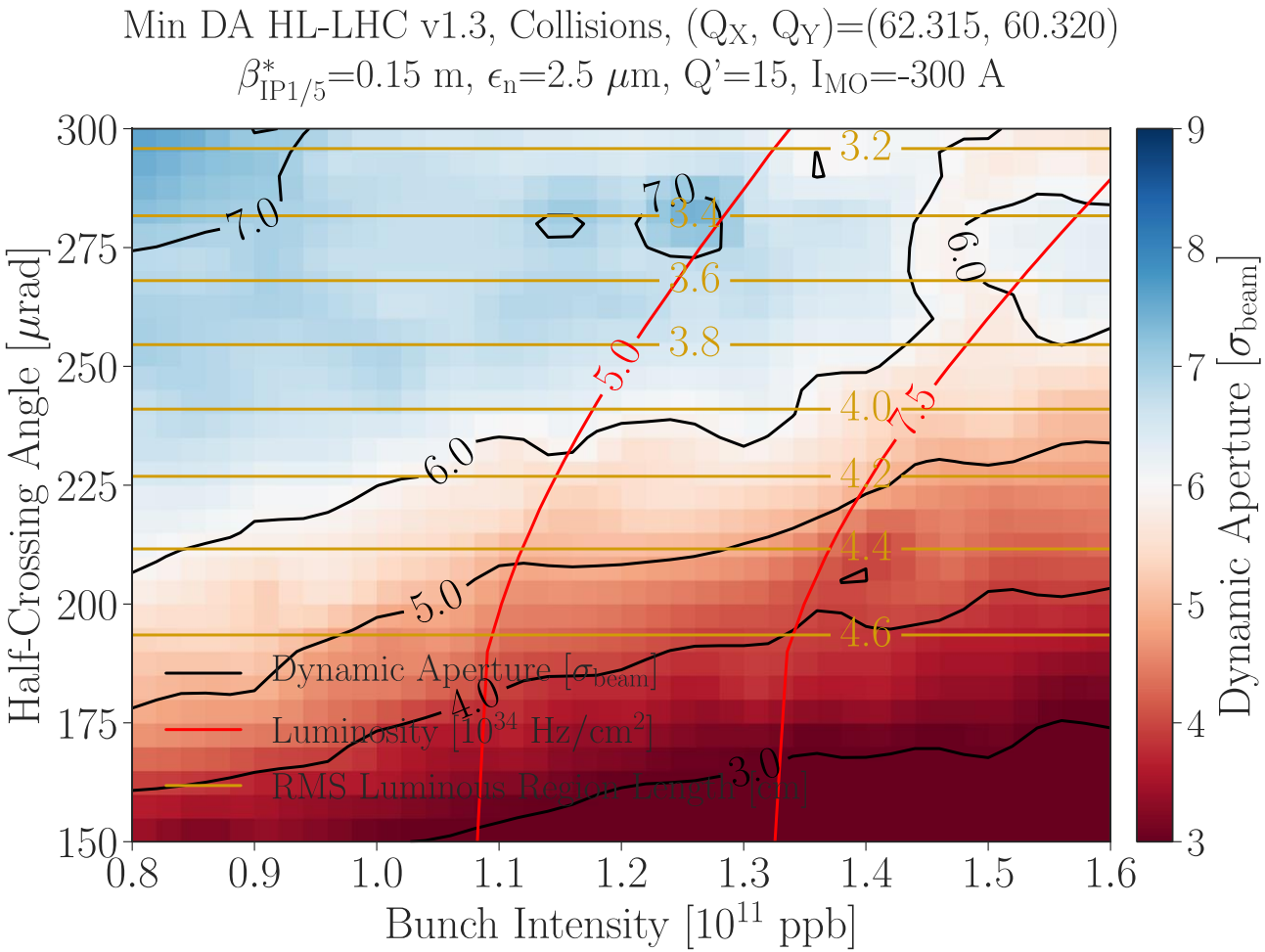


CC OFF



For the given Working Point, **selected to optimize the DA** at the start of leveling, the impact of the CC is not so significant.

End of Leveling

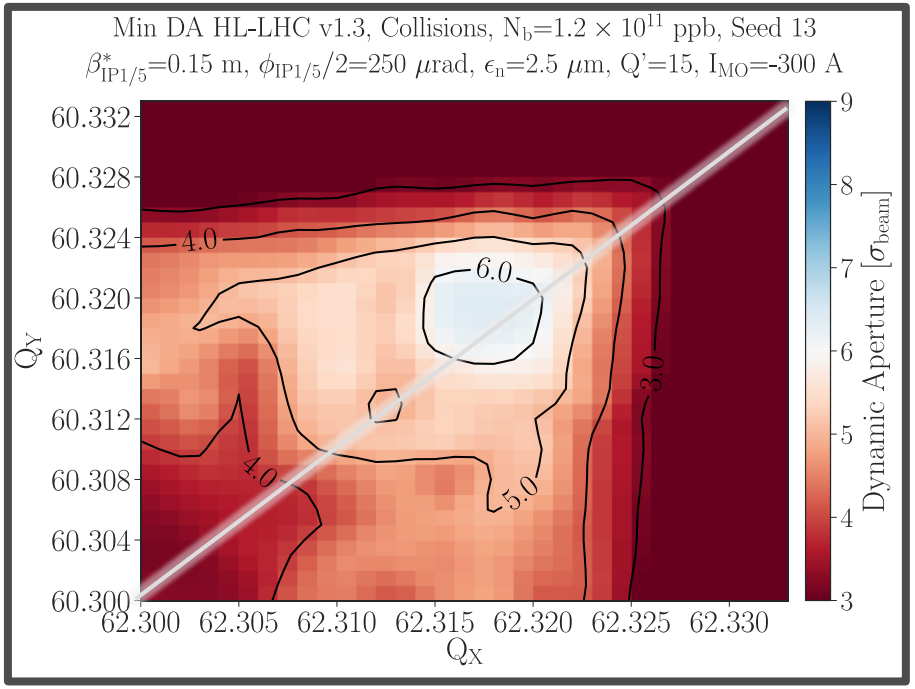


Similar results are found at the end of leveling.

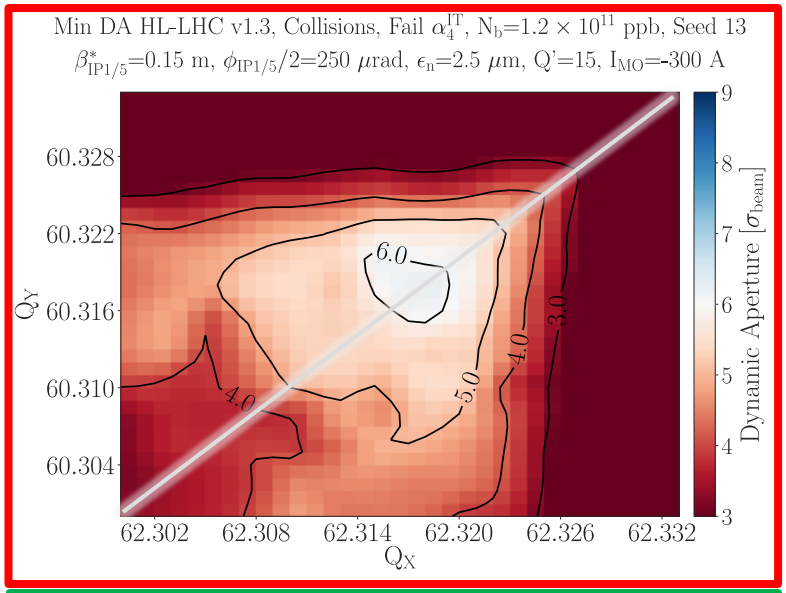
2. Failing IT Correctors a4, b5

IT correctors failure at the end of leveling

For Seed #13

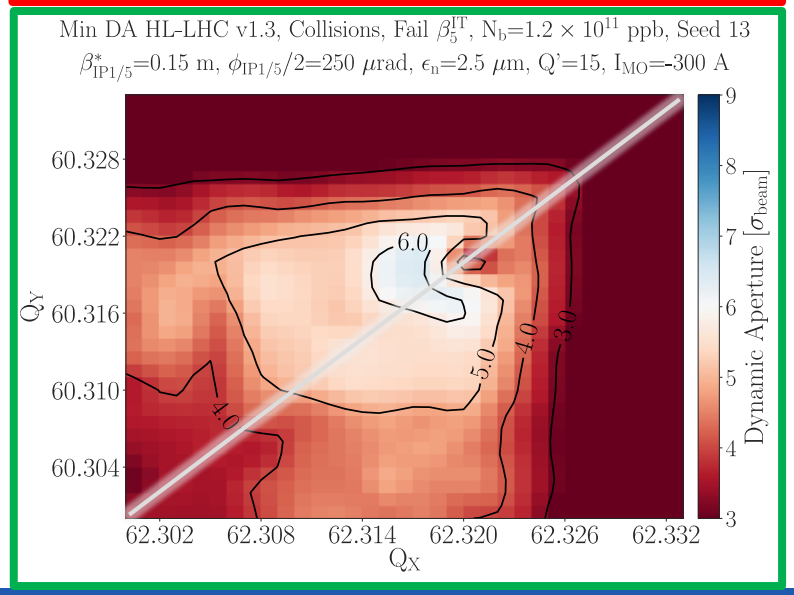


a4



failing a4 (kcsx3)

b5

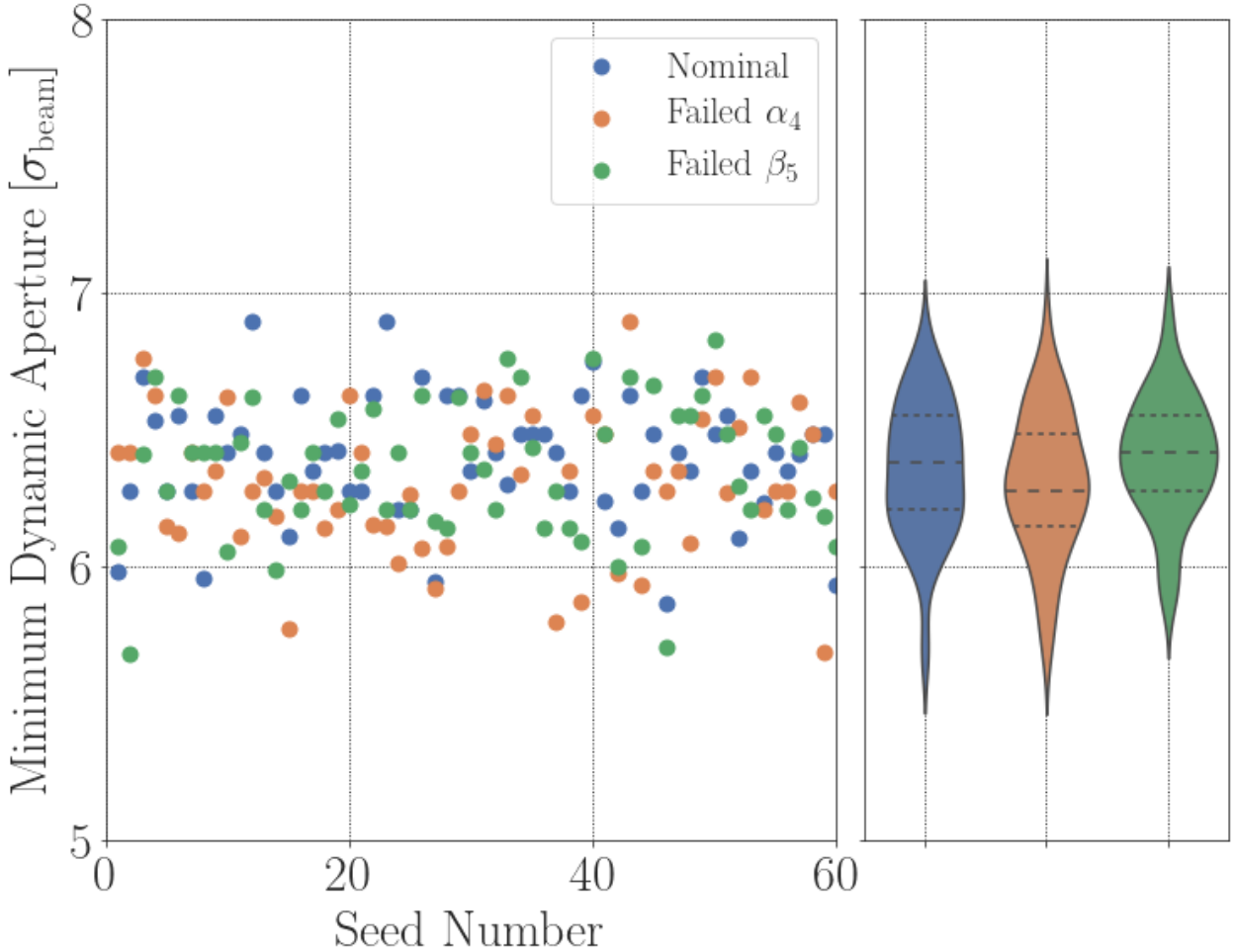


failing b5 (kcdx3)

The impact of the failed correctors is **< 1σ** *(seemingly less significant than b6).*

IT Correctors Failure at β*=15 cm & Nb = 1.2e11 ppb

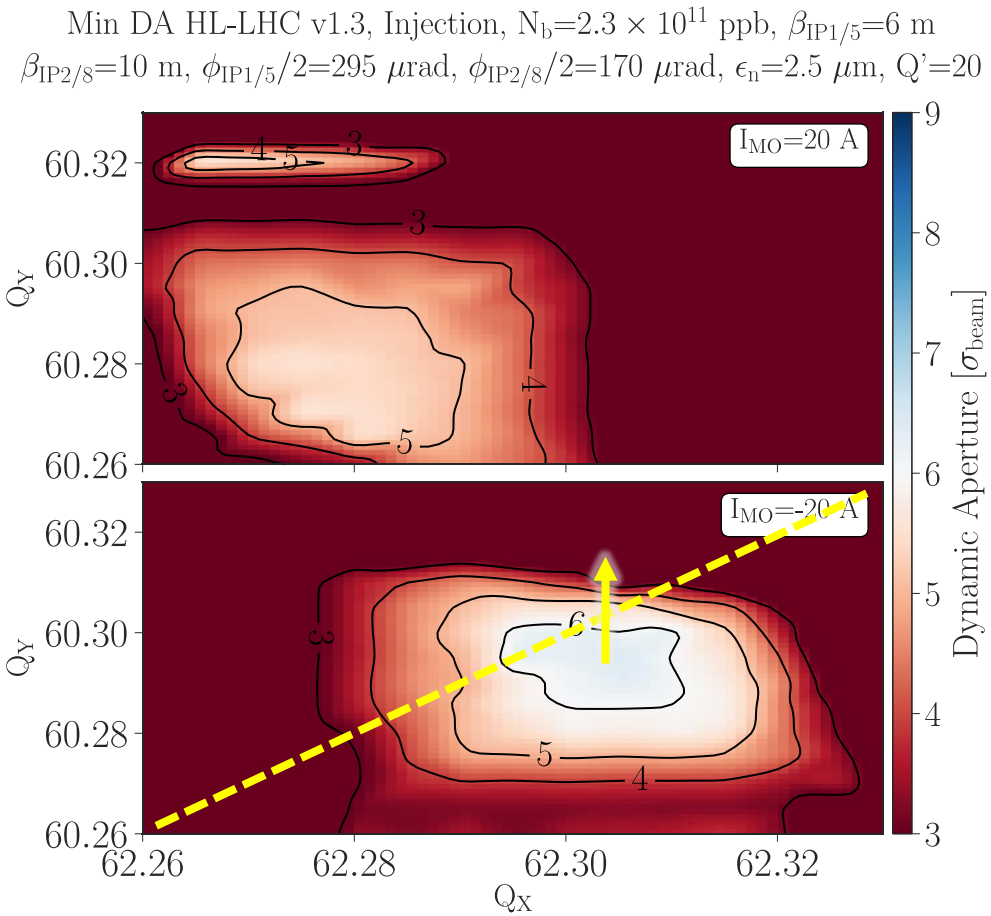
- Choosing $(Q_x, Q_y) = (62.315, 60.320)$ and running for all seeds



3. Operation Below the Diagonal

Injection

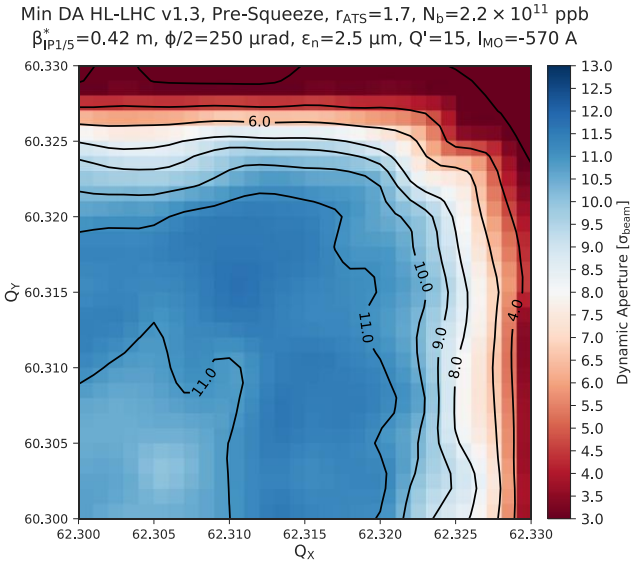
- We have already seen that when the polarity of the octupoles is negative, **if only the incoherent BB part is considered** there is some margin below the diagonal.



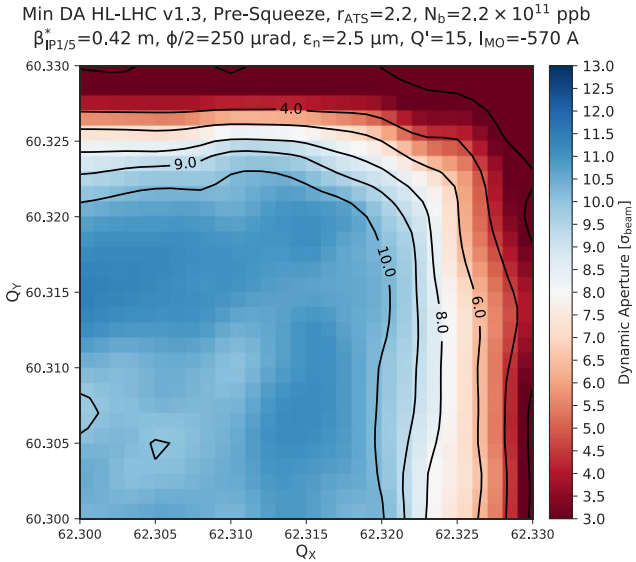
- Our DA simulations **do not include the diffusive effect of e-cloud**.
  - The impact of e-cloud would be to push the vertical tune to larger values, i.e. **approaching the coupling resonance**, if we were operating below the diagonal.
  - We need to include an a **realistic model for the coupling** rather than selecting a tune distance.
  - We need **additional tools** to quantify this in order to even consider it as a viable operational option.

Pre-Squeeze

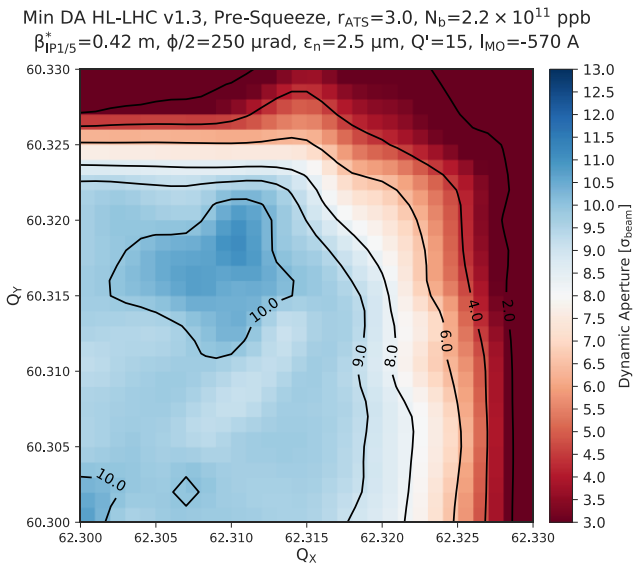
- At Pre-Squeeze the available DA is more than sufficient in any configuration.



r_{ATS} = 1.7



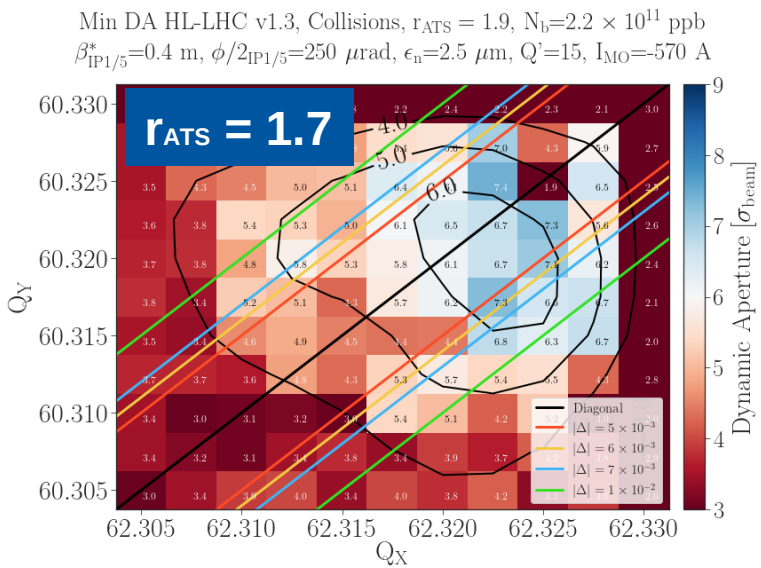
r_{ATS} = 2.2

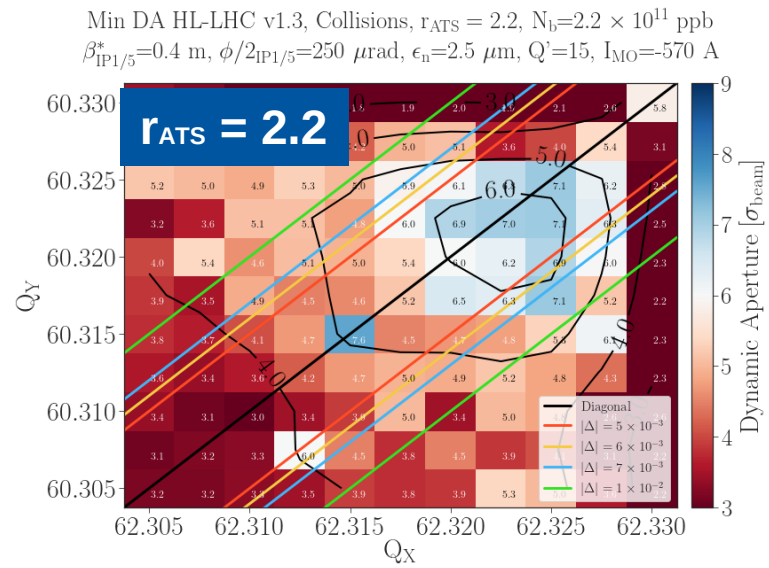


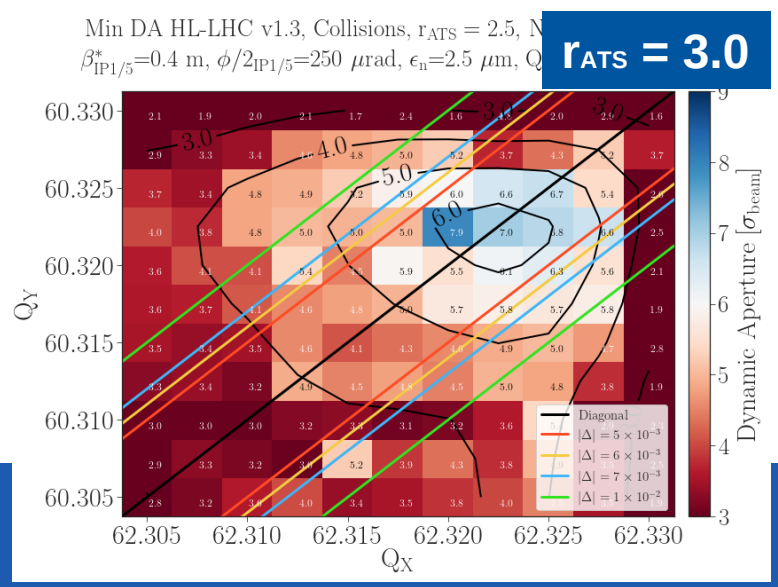
r_{ATS} = 3.0

Start of Collisions (β*=0.4 m)

- If we now consider the **start of collisions** with various **tele-indices**

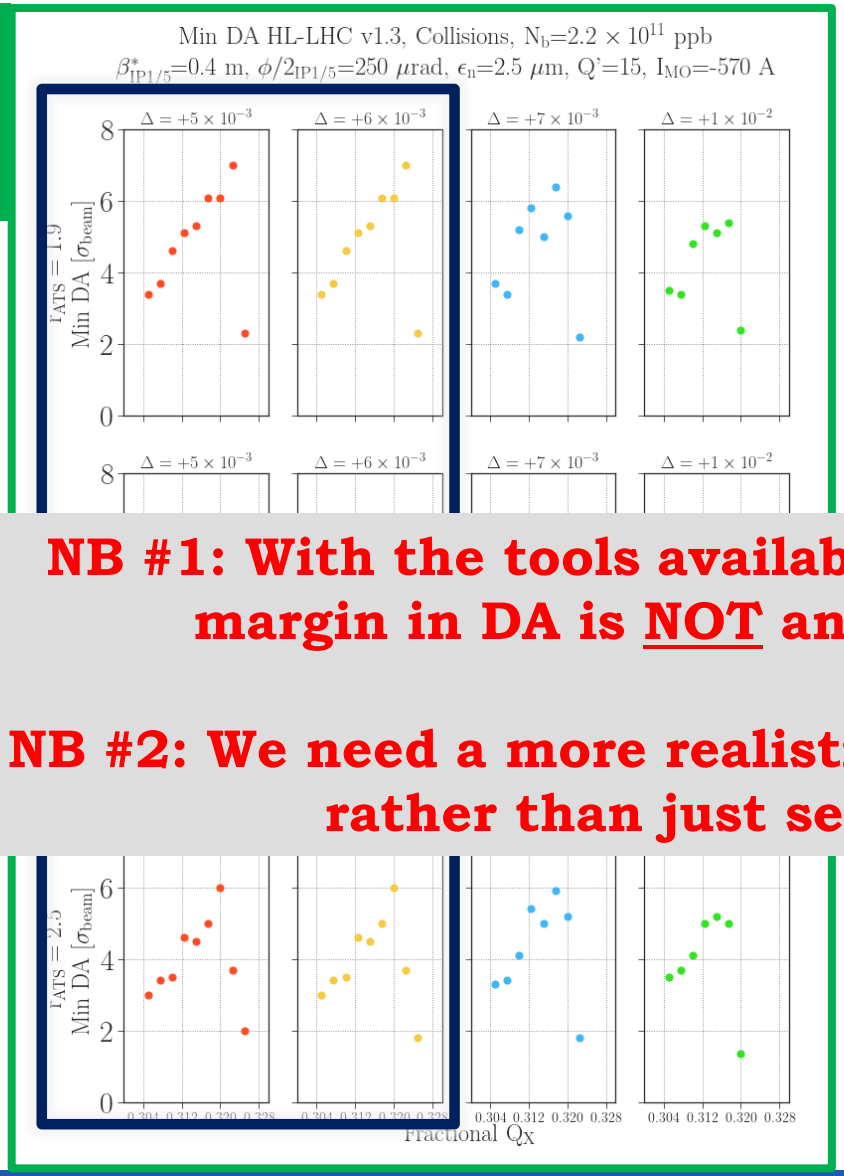


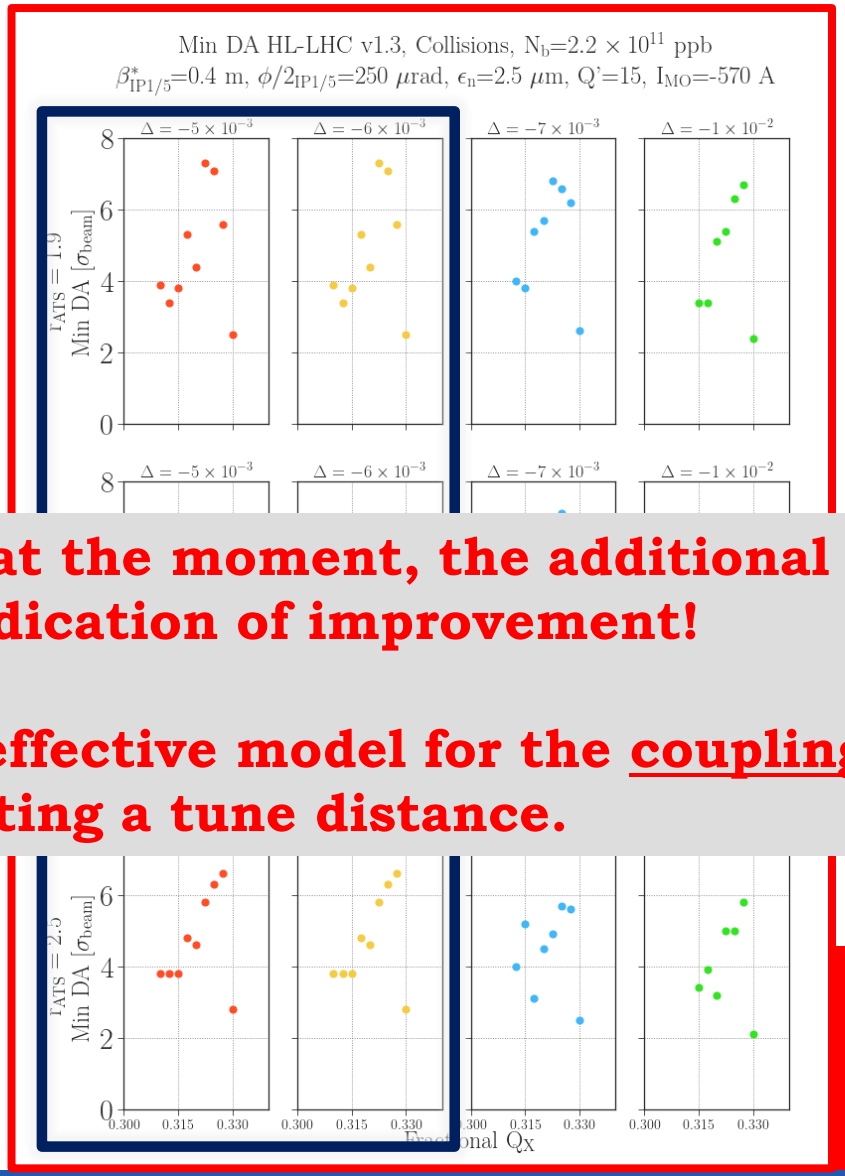




Start of Collisions

ABOVE





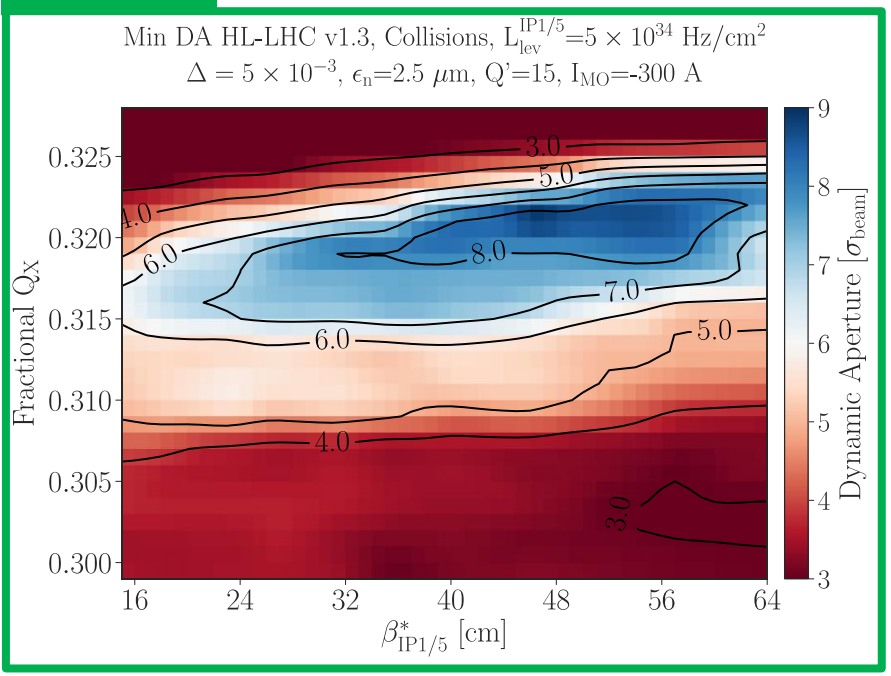
NB #1: With the tools available at the moment, the additional margin in DA is <u>NOT</u> an indication of improvement!

NB #2: We need a more realistic effective model for the <u>coupling</u> rather than just selecting a tune distance.

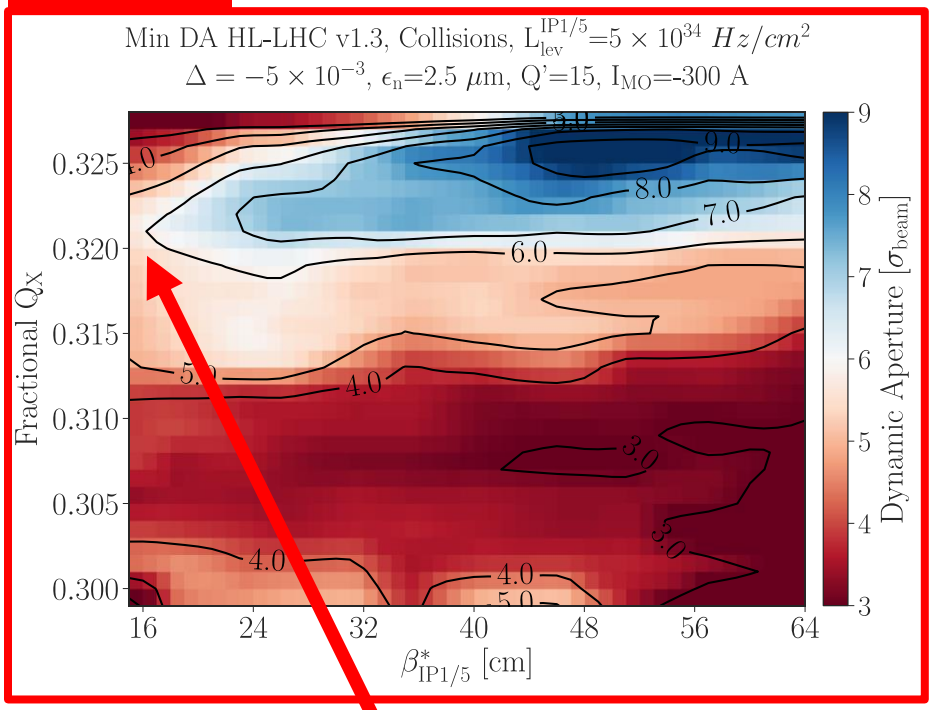
BELOW

During the leveling

ABOVE



BELOW

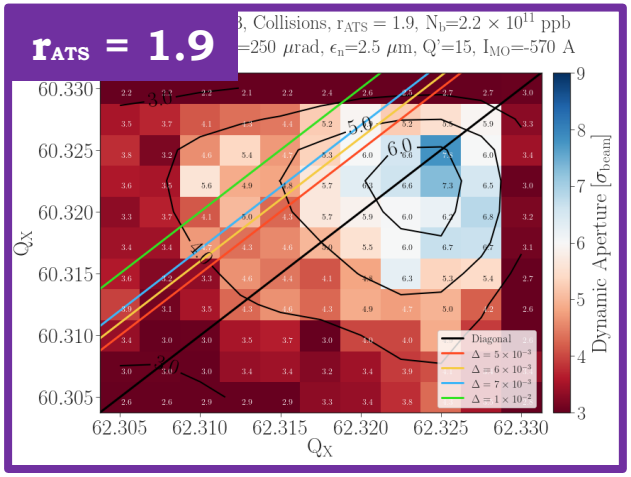


Under this configuration, **reaching 15cm** with DA>6σ **is <u>not</u> possible** when operating below the diagonal (even when no coupling etc) is taken into account!

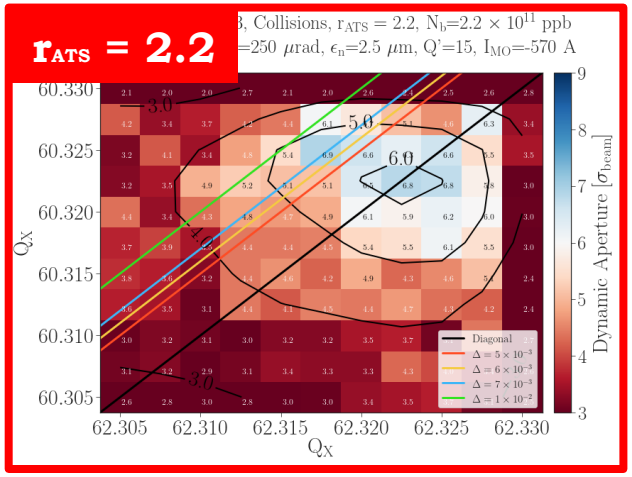
4. Collapsing the separation bump with high tele-index and the CC off

Start of Collisions (β*=0.6 m)

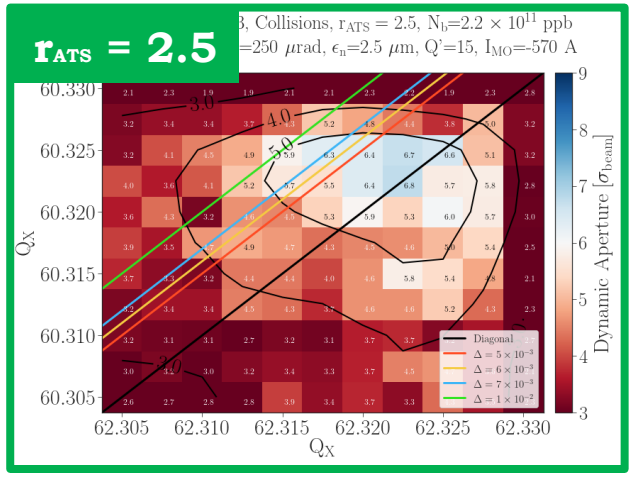
r_{ATS} = 1.9



r_{ATS} = 2.2

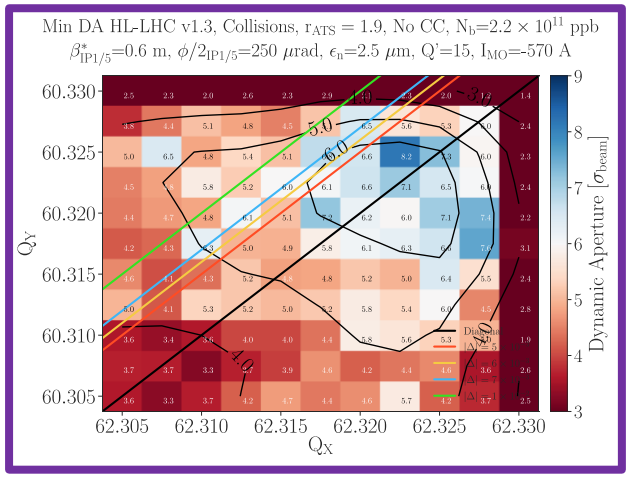


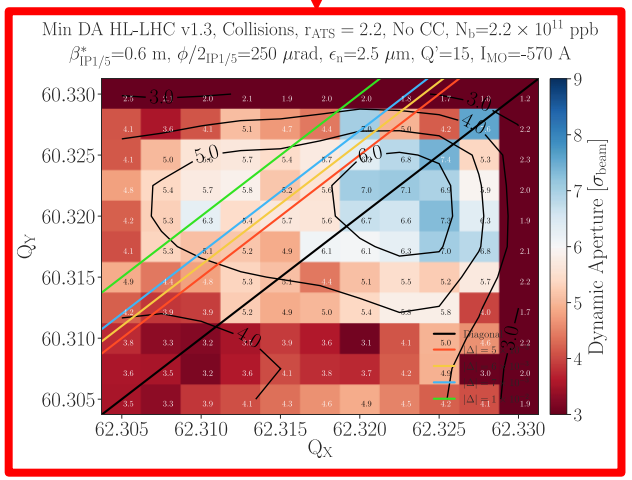
r_{ATS} = 2.5



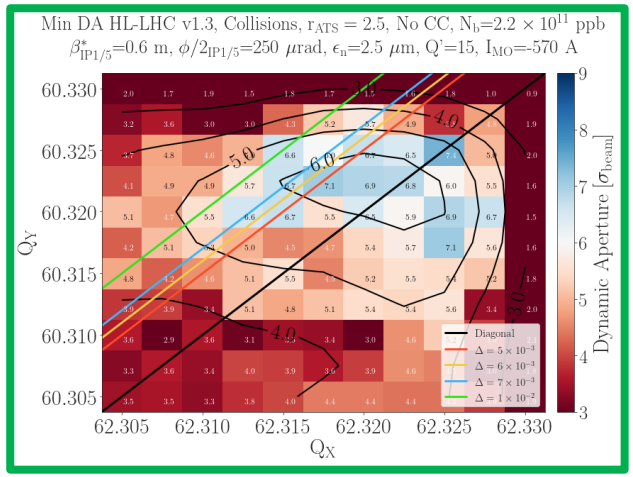
For
$\Delta = 5 \times 10^{-3}$

+10%





+11%



Summary

- **Increasing the half-crossing angle** (above 250 μrad) at the beginning and at the end of the leveling process we **do not gain significantly in terms of DA**.
  - However the **pile-up density** depends on the crossing angle and it **gets worse** with the larger crossing angle.

- Failing the a4 and b5 multipoles (with their nominal values) do not have a strong impact on DA.

- We could think of **operating below the diagonal** (never tried before). However, the estimates we have at the moment are missing the key component of the **e-cloud effect** → The marginally better DA results could easily be washed out by this.
  - **A $\beta^* = 15$ cm is slightly out of reach with $N_b = 1.2 \times 10^{11}$ ppb**
  - We need to **finalize the development of the "incoherent e-cloud" tools** (on-going) in order **to make a quantifiable recommendation**.
  - It could be an interesting point to test during the **Run-III MD period**.

- Collapsing the separation bumps with the **CC switched off**, **improves the available DA** space at the start of collisions.

BACKUP

Operating with Larger Xing

- For a bunched beam with longitudinal density $\rho(z,\sigma_z) = \frac{1}{\sqrt{2\pi}\sigma_z} \cdot e^{-(z/\sqrt{2}\sigma_z)^2}$ **Gaussian**

  luminosity is calculated as $L = \frac{N_{b,1} \cdot N_{b,2} \cdot n_b \cdot f_{\mathrm{rev}}}{4\pi\sqrt{\beta_X^* \cdot \varepsilon_X}\sqrt{\beta_\parallel^* \cdot \varepsilon_\parallel}} \times R_{\mathrm{loss}}$

  where the loss factor $R_{\mathrm{loss}} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} 2 \cdot K \cdot \rho(z-t,\sigma_z) \cdot \rho(z+t,\sigma_z)\, dz\, dt$

  and a kernel:

$$K = \frac{1}{\sqrt{1+(\frac{z}{\beta_X^*})^2}\sqrt{1+(\frac{z}{\beta_\parallel^*})^2}} \times e^{-\left(\frac{d_X\sqrt{\beta_X^*\varepsilon_X}+\phi\cdot z-\frac{\phi_0}{\omega_X V_0(V_X * \cos\omega_X t \sin\omega_X z)}}{2\cdot\sqrt{\beta_X^*\varepsilon_X}\sqrt{1+(\frac{z}{\beta_X^*})^2}}\right)^2} \times e^{-\left(\frac{d_\parallel\sqrt{\beta_\parallel^*\varepsilon_\parallel}+\frac{V_\parallel}{V_0}\cdot\frac{\phi_0}{\omega_\parallel}\sin\omega_\parallel t\cos\omega_\parallel z}{2\cdot\sqrt{\beta_\parallel^*\varepsilon_\parallel}\sqrt{1+(\frac{z}{\beta_\parallel^*})^2}}\right)^2}$$

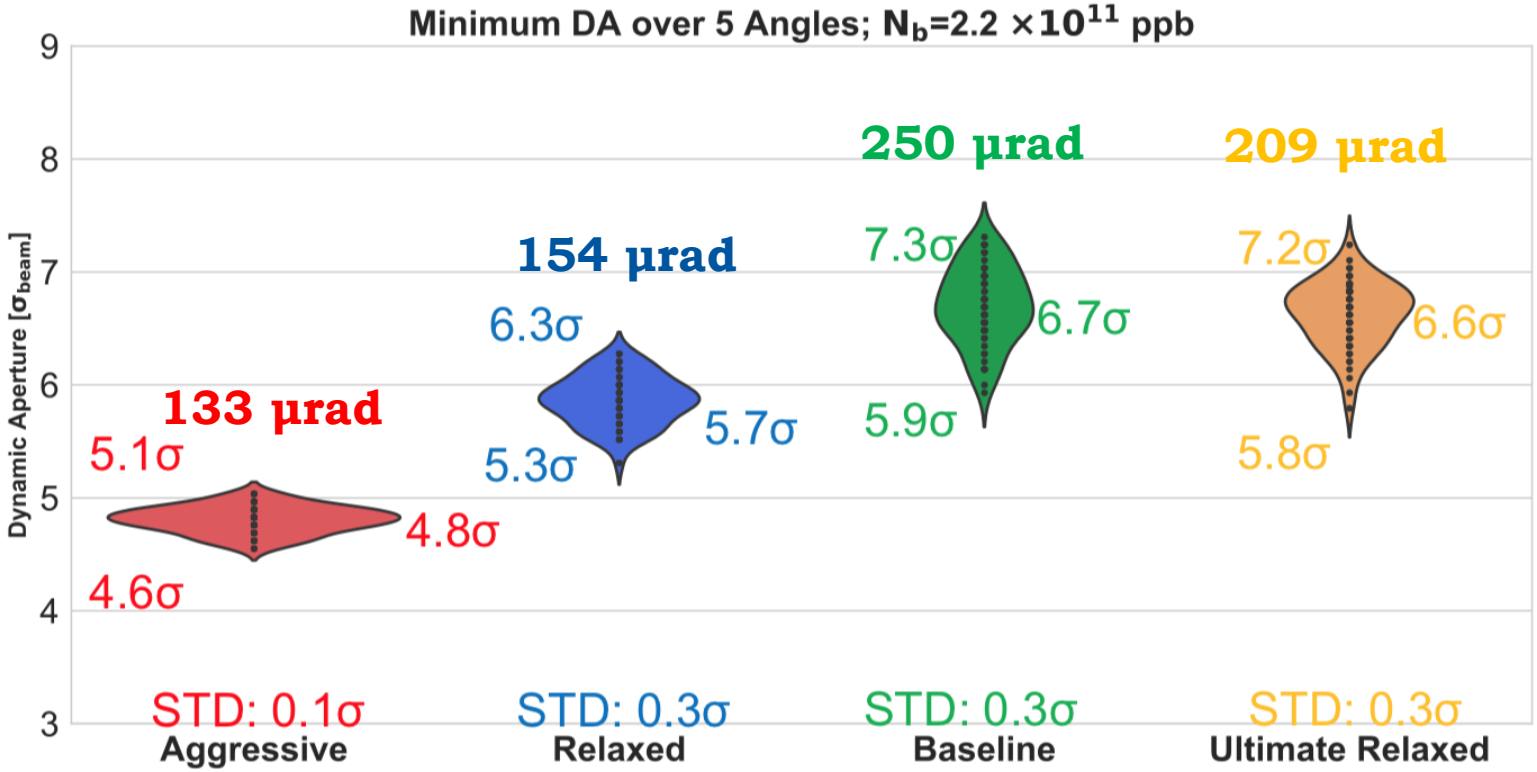
- Therefore the RMS Length of the luminous region is :

$$L_z = \frac{\sqrt{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} 2K\rho(z-t,\sigma_z)\rho(z+t,\sigma_z)\cdot z^2 dz dt}}{R_{\mathrm{loss}}}$$

So in our case depends on β* and φ/2

Errors @ Start of Leveling

7th HL-LHC Collab Meeting



- Spread of 0.3σ, with the exception of the aggressive at ~0.1σ

Extending XB