CERN

DA and Beam-Beam

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We thank Y. Angelis, H. Bartosik, R. De Maria, I. Efthymiopoulos, M. Giovannozzi, G. Iadarola, L. Mether, E. Métral, N. Mounet, Y. Papaphilippou, R. Tomás.

1. Introduction
2. Beam-Beam Studies Results
3. Conclusions

DA as main observable

- HL-LHC performance strongly depends on the **orchestration of several beam and machine parameters during the cycle**.

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DA as main observable

- HL-LHC performance strongly depends on the **orchestration of several beam and machine parameters during the cycle**.
- The Run 3 observations on present e-cloud limitations called for exploring new filling schemes and non baseline HL optics (see R. Tomás' presentation). We will present and discuss the Beam-Beam (BB) implications.
- For the beam-beam and incoherent effects, the selection/validation of the configuration for operation is based on numerical simulation supported by the experience of the past runs: previous studies established a **correlation between beam lifetime from experimental data and DA from simulations** [1].

HL-LHC DA requirements

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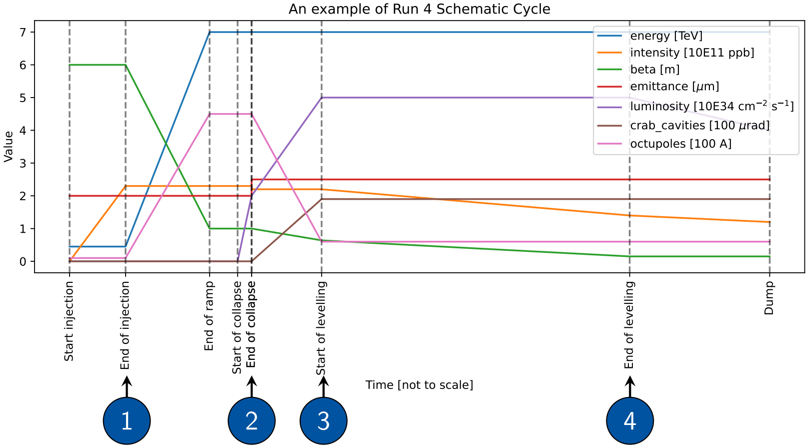
- Working point condition $\mathbf{q_x + 5\ 10^{-3} < q_y}$: no experience operating below the diagonal and tune split of $+5\ 10^{-3}$ to prevent possible instabilities.
- HL-LHC layout V1.5 or V1.6 are assumed (**MS10 included**).

Schematic of the Run 4 Cycle



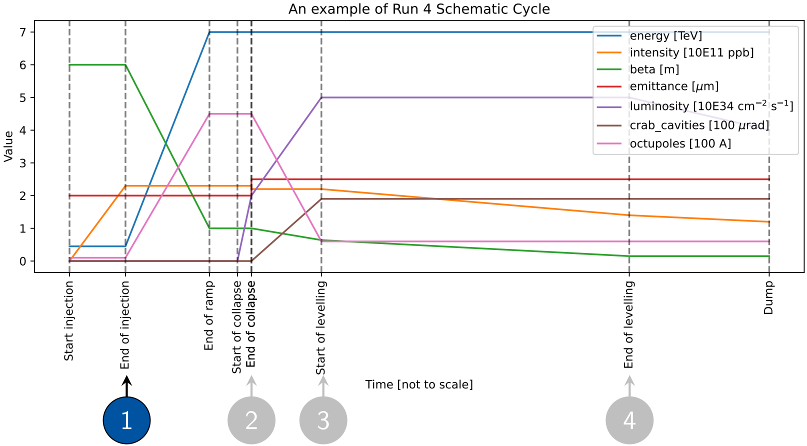
4 special transitions in the cycle (courtesy of R. De Maria).

Filling schemes

Depending on the strategy adopted to cure the e-cloud, three different filling schemes are considered:

- **baseline** (**2760** bunches):
  25ns_2760b_2748_2492_2574_288bpi_13inj_800ns_bs200ns
- **hybrid** (**2228** bunches):
  25ns_2228b_2216_1686_2112_hybrid_8b4e_2x56b_25ns_3x48b_12inj
- **8b4e** (**1972** bunches):
  8b4e_1972b_1960_1178_1886_224bpi_12inj_800ns_bs200ns

End of Injection



End of Injection

Parameters (unit)	**HL-LHC (values)**
Beam energy (GeV)	450
Bunch population (protons)	**2.3×10^{11}**
Normalized emittance (μm rad)	**2.3**
Filling scheme	**baseline**
IP1/5 $\beta^*_{x,y}$ (m)	6
IP8/2 $\beta^*_{x,y}$ (m)	10
Nominal working point (Q_x, Q_y)	(62.27, 60.295)
Chromaticity $Q'_{x,y}$	15
IP1/5 half crossing angle (μrad)	500 (H) / 500 (V)
IP2/8 half crossing angle (μrad)	170 (V) / 170 (H)

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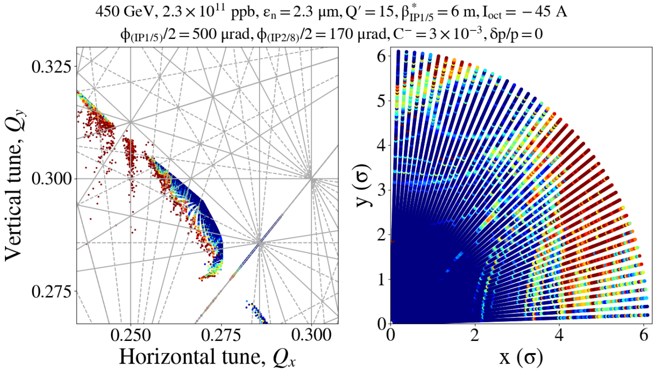
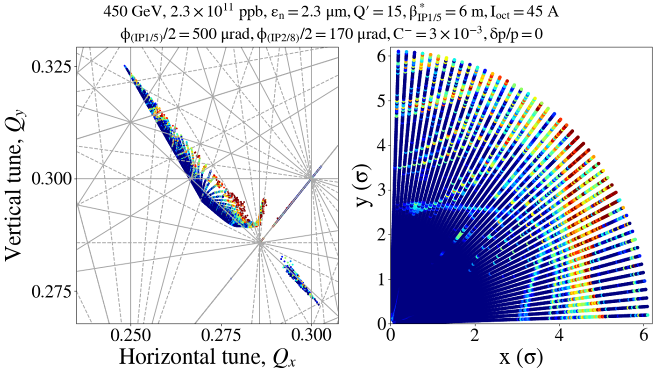
DA dominated by the arc octupoles.

About I_{MO} polarity



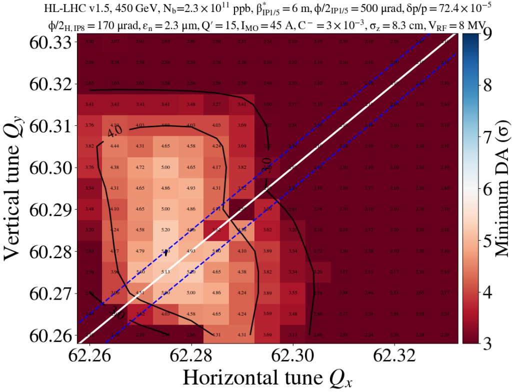
I_{MO} = -45 A

About I_{MO} polarity



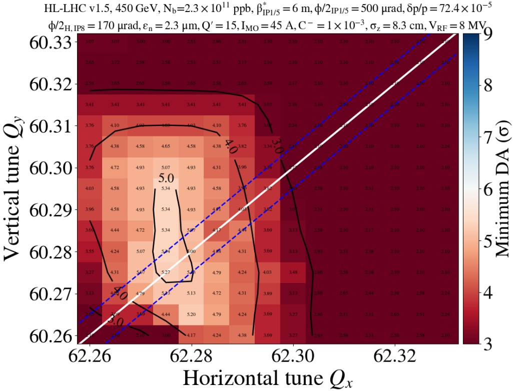
$I_{MO} = +45$ A

Correcting coupling helps



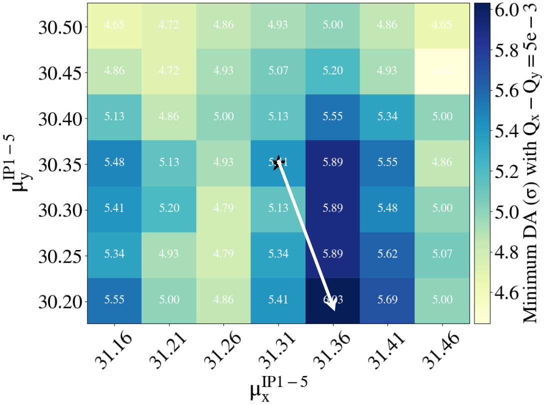
$$I_{MO} = +45\ \text{A},\ \mathbf{C^-} = 3 \times 10^{-3}$$

Correcting coupling helps



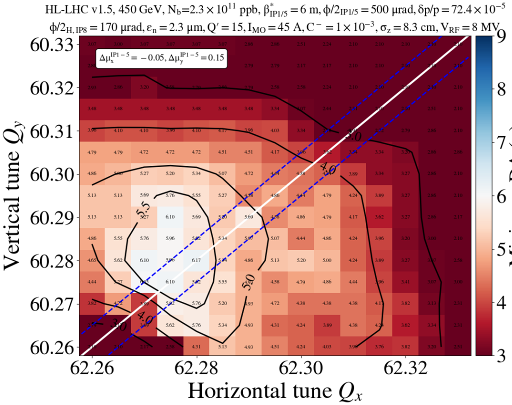
$$I_{MO} = +45\ \text{A},\ \mathbf{C^{-} = 10^{-3}}$$

$\Delta\mu^{IP1\rightarrow IP5}$ optimization



Assuming $I_{MO} = +45$ A, $C^- = 10^{-3}$

$\Delta\mu^{IP1 \to IP5}$ optimization

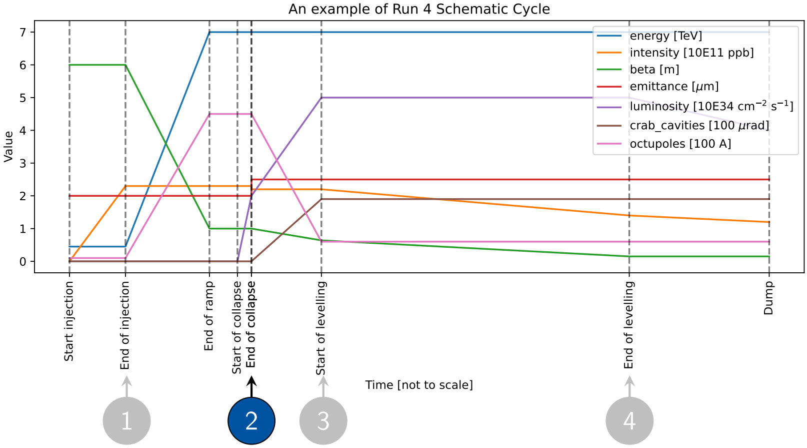


I_{MO} = +45 A, C^- = 10^{-3}, **optimized $\Delta\mu$**

End of Injection Studies Summary

- Incoherent effects at injection dominated by amplitude detuning from octupoles (driven by e-cloud/stability considerations).
- A DA conservative scenario is assumed (I_{MO} =45 A).
- DA target achieved by **positive octupole** current, together with an excellent **coupling control** and **IP1/5 phase optimization**.

End of Collapse



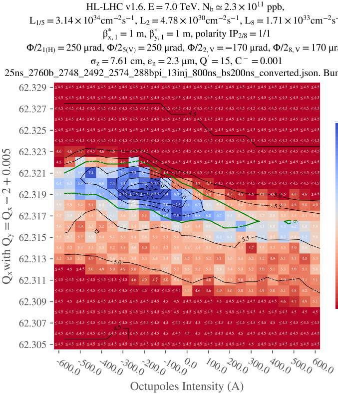
End of Collapse

Parameters (unit)	HL-LHC (values)
Beam energy (TeV)	7
Luminosity (10^{34} Hz/cm^2)	**≈2.5**
Bunch population (protons)	2.3×10^{11}
Filling scheme	**baseline/8b4e**
Normalised emittance (μm rad)	**2** or **2.3**
Nominal working point (Q_x, Q_y)	(62.31, 60.32)
Chromaticity $Q'_{x,y}$	15
IP1/5 half crossing angle (μrad)	250(H) / 250(V)
IP2/8 half crossing angle (μrad)	-170(V) / 170(V)
IP1/5 β^* (m)	**1** (round) or **0.7/2.8** (flat[1])
IP2/8 β^* (m)	10/1.5
Half crab-cavity angle (μrad)	0

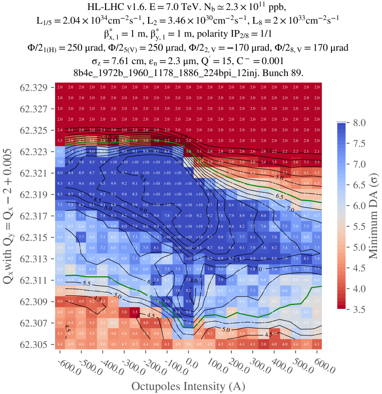
[1] **This is indended to probe an extreme tele-index=4.**

DA vs I_{MO} (round optics)

baseline filling scheme



8b4e filling scheme

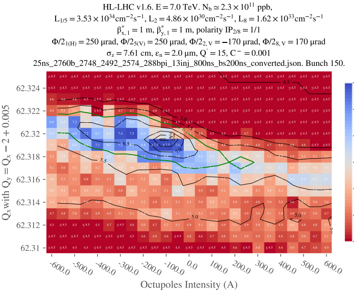


Baseline configuration marginally OK with $I_{OCT} > 0$.

Negative octupoles option interesting to explore.

DA vs I_{MO} (round optics)

baseline filling scheme



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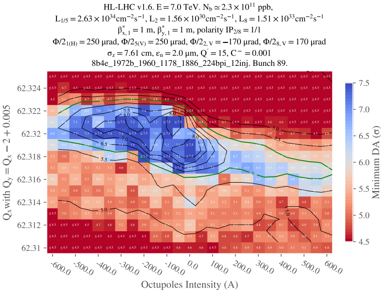
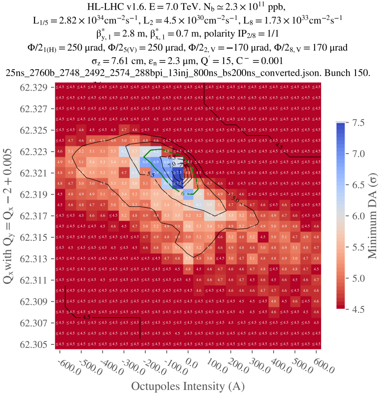


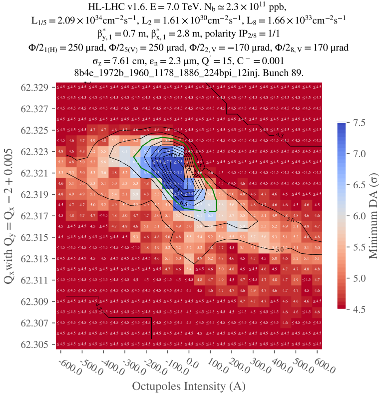
DA gets tighter for smaller emittances ($2.3 \rightarrow 2\ \mu$**rad**).

DA vs I_{MO} (**flat optics**)

baseline filling scheme



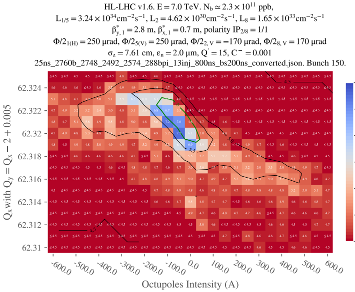
8b4e filling scheme



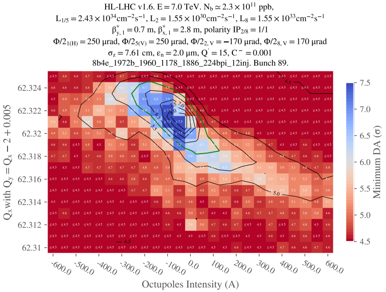
The (**tele-index=4**) flat optics shows a smaller good DA region (but could alleviate the impedance of the CC).

DA vs I_{MO} (**flat optics**)

baseline filling scheme



8b4e filling scheme

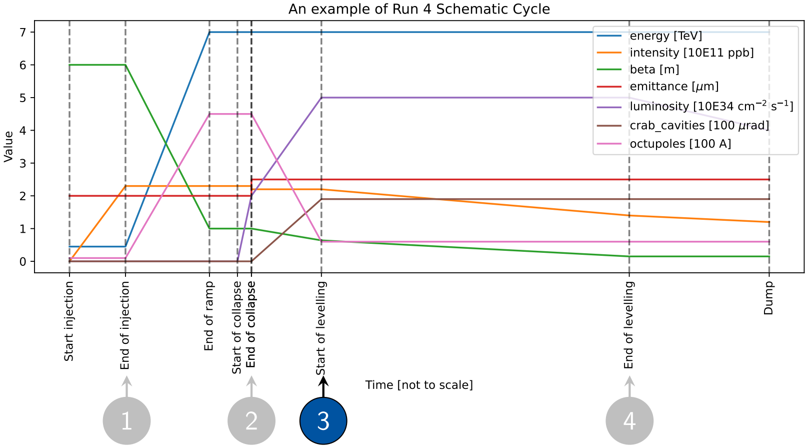


The (**tele-index=4**) flat optics shows a smaller good DA region (but could alleviate the impedance of the CC).

End of Collapse Summary

- Strong effect of the octupoles on DA.
- Baseline optics and filling scheme reaching (marginally) target DA.
- Margin further reduces with lower emittance.
- With 8b4e DA improves (at the clear cost of performance).

Start of $\mathcal{L}$-Levelling



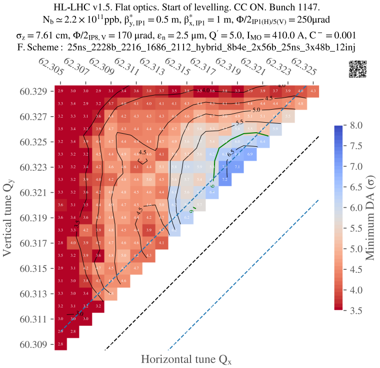
Start of the $\mathcal{L}$-levelling

Parameters (unit)	**HL-LHC (values)**
Beam energy (TeV)	7
Luminosity (10^{34} Hz/cm^2)	**5**
Bunch population (protons)	2.2-2.3$\times 10^{11}$
Filling scheme	**hybrid/8b4e**
Normalized emittance (μm rad)	2.5
Nominal working point (Q_x, Q_y)	(62.31, 60.32)
Chromaticity $Q'_{x,y}$	**5** or **15**
IP1/5 half crossing angle (μrad)	250(H) / 250(V)
IP2/8 half crossing angle (μrad)	-170(V) / 170(V)
IP1/5 β^* (m)	**1/0.5** (flat)
IP2/8 β^* (m)	10/1.5
Landau octupoles' current (A)	**410**[2]
Half crab-cavity angle (μrad)	**190**

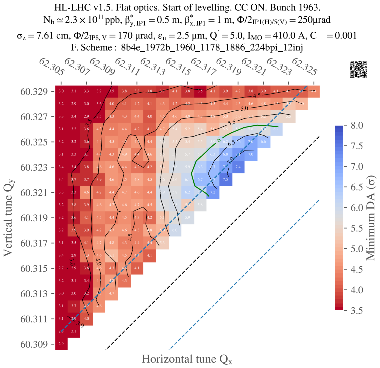
[2]It is expected to be at 60 A $\rightarrow$ **conservative approach**.

Flat optics with Q'=5

hybrid filling scheme



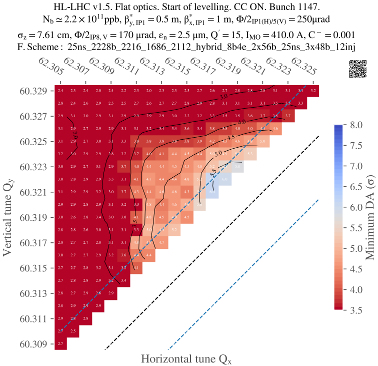
8b4e filling scheme



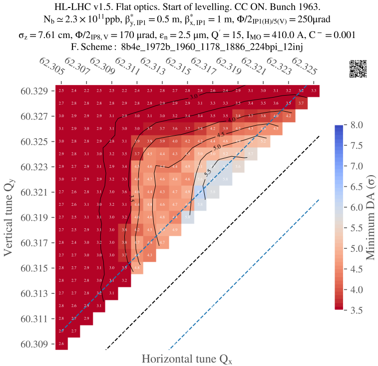
Reasonable DA margin.

Flat optics with Q'=15

hybrid filling scheme

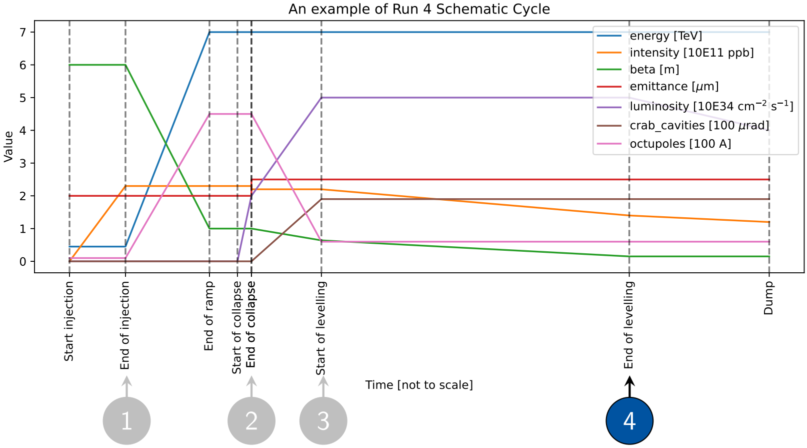


8b4e filling scheme



Detrimental effect on DA by **increasing chromaticity**.

End of $\mathcal{L}$-Levelling

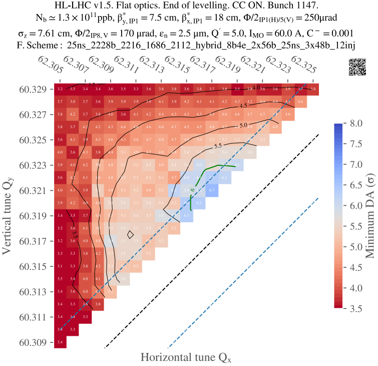


End of the $\mathcal{L}$-levelling

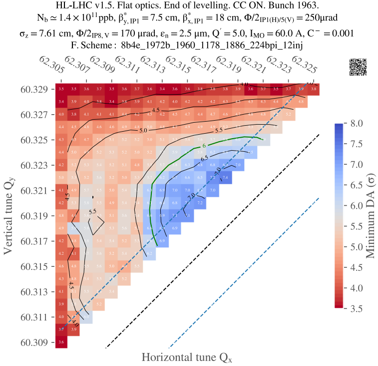
Parameters (unit)	**HL-LHC (values)**
Beam energy (TeV)	7
Luminosity (10^{34} Hz/cm^2)	**5**
Bunch population (protons)	1.3-1.4$\times 10^{11}$
Filling scheme	**hybrid/8b4e**
Normalized emittance (μm rad)	2.5
Nominal working point (Q_x, Q_y)	(62.31, 60.32)
Chromaticity $Q'_{x,y}$	15
IP1/5 half crossing angle (μrad)	250(H) / 250(V)
IP2/8 half crossing angle (μrad)	170(V) / 170(V)
IP1/5 β^* (m)	**7.5/18** (flat)
IP2/8 β^* (m)	10/1.5
Landau octupoles' current (A)	**60** or **100**
Half crab-cavity angle (μrad)	**190**

Flat optics with Q'=5

hybrid filling scheme

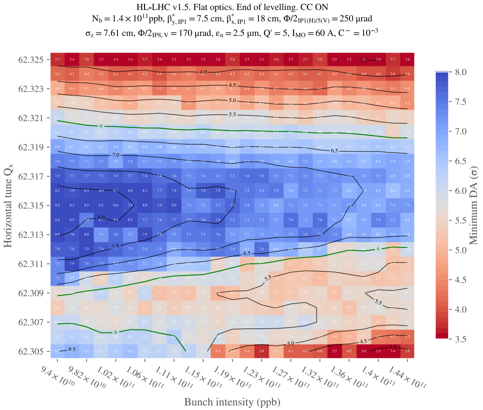


8b4e filling scheme



The DA target is met with Q'=5.

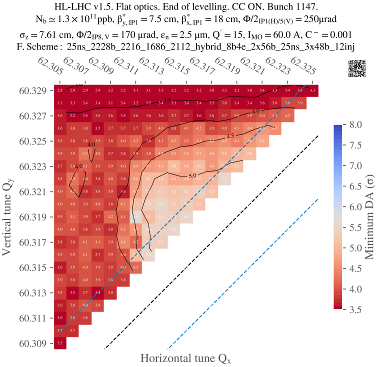
Flat optics with Q'=5



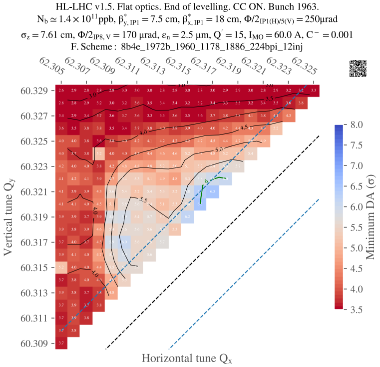
As expected, the DA improves after the end of leveling (plot for 8b4e).

Flat optics with Q'=15

hybrid filling scheme

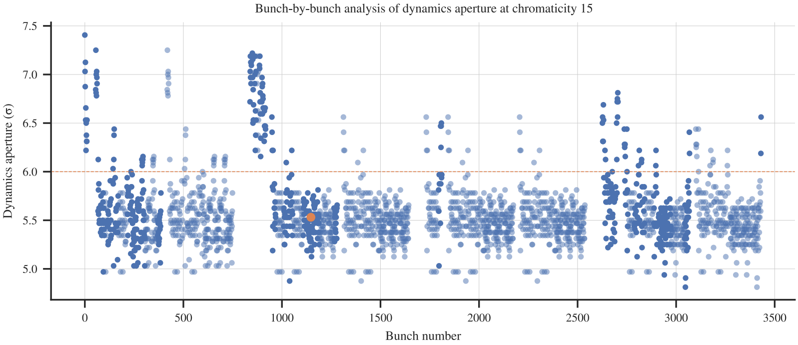


8b4e filling scheme



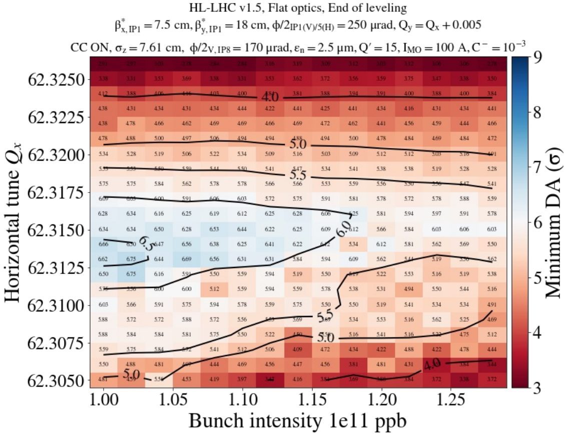
Q'=15 critical for the hybrid filling scheme. Investigations ongoing to improve by IP1/5 phasing optimization and/or negative octupole.

Flat optics with Q'=15



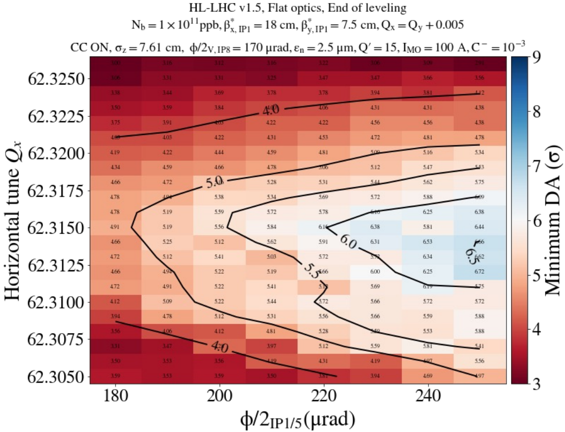
BBB DA: situation can become critical for some bunches.

Flat optics with Q'=15



DA sensitivity vs bunch intensity with (flat optics).

Flat optics with Q'=15



DA sensitivity vs crossing angle (flat optics).

Conclusions

- At 450 GeV, incoherent effects at injection dominated by amplitude detuning from octupoles: DA target achieved with **positive octupole** current, together with a very good **coupling control** and **IP1/5 phase optimization**.
- **DA analysis of flat optics alternative scenarios** is progressing.
- At the end of collapse, **the round optics and baseline filling scheme reaches (marginally) the target DA**. Lower emittances reduce the margins, while negative octupoles improve them. High tele-index flat optics seems only compatible with negative octupoles.
- At the **start of the levelling** the situation, also with flat optics, is more relaxed (in particular with Q' = 5).
- At the **end of the levelling** the situation with **flat, hybrid, Q'=15 and I_{OCT}=60 A** still below target DA. IP1/5 phase scans, negative octupoles (and wire compensation studies) are planned.

Thank you for your attention.

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References (I)

D. Pellegrini, G. Arduini, S. Fartoukh, G. Iadarola, N. Karastathis, Y. Papaphilippou, and G. Sterbini.
Incoherent beam-beam effects and lifetime optimization.
In *Proceedings, 7th Evian Workshop on LHC beam operation: Evian Les Bains, France, December 13-15, 2016*, Geneva, 2017. CERN.