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Beam-Beam and Noise Studies

S. Kostoglou, G. Sterbini on behalf of WP2 team

Beam-beam Studies

- Injection
- Start of the $\mathcal{L}$-levelling
- End of $\mathcal{L}$-Levelling

Update on Noise Studies

Conclusion

DA as main observable

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

DA as main observable

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

Based on this experience, an operational scenario is characterized as feasible when there are working points that satisfy the following criteria in the simulations:

- A minimum **DA of at least 6 σ**.

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- Working point condition $\mathbf{q}_x + \mathbf{5\ 10^{-3}} < \mathbf{q}_y$: no experience operating below the diagonal and tune split of $+5\ 10^{-3}$ to prevent possible instabilities.

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HL-LHC layout V1.5 assumed

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Injection Main Parameters

Parameters (unit)	HL-LHC (values)
Beam energy (GeV)	450
Bunch population (protons)	**2.3**$\times 10^{11}$
Normalized emittance (μm rad)	**2.3 (standard) / 1.7 (BCMS)**
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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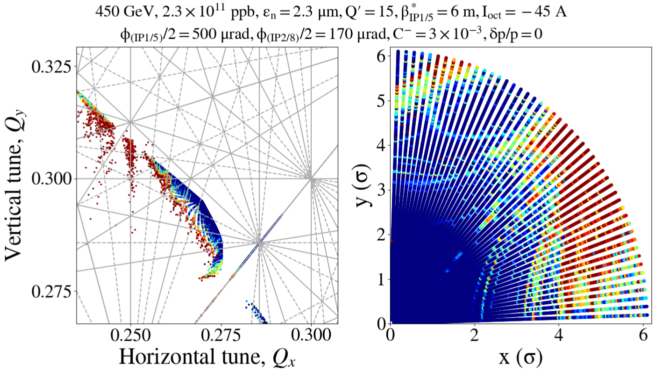
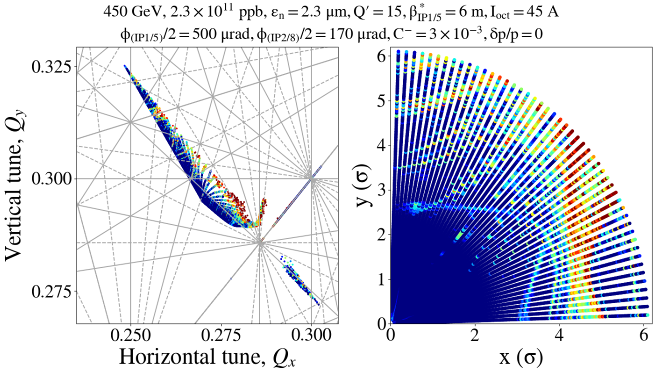
DA dominated by the arc octupoles.

About I_{MO} polarity



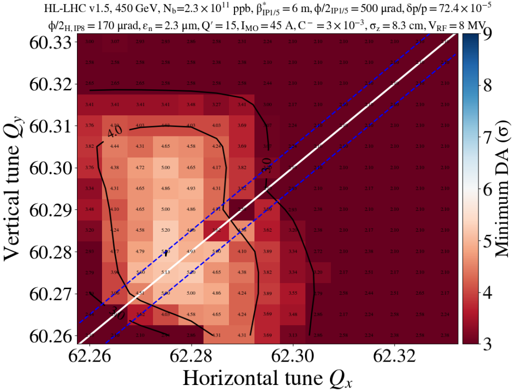
I_{MO} = -45 A

About I_{MO} polarity



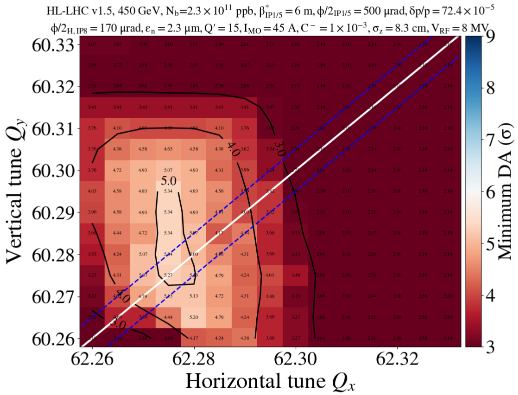
$I_{MO} = +45$ A

Correcting coupling helps



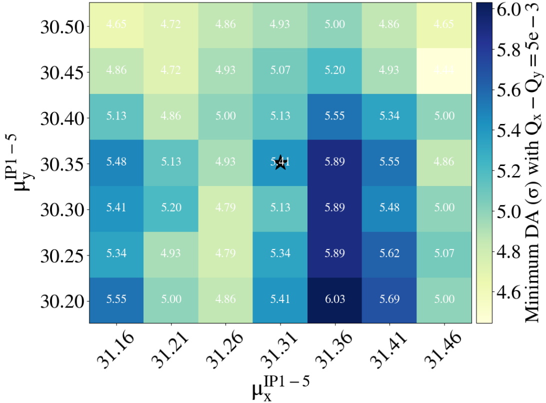
$I_{MO} = +45$ A, $\mathbf{C^-} = 3 \times 10^{-3}$

Correcting coupling helps



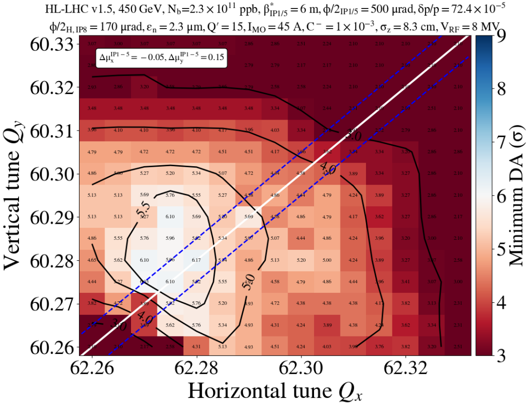
$I_{MO} = +45$ A, $\mathbf{C^{-} = 10^{-3}}$

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



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

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



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

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 a very good **coupling control** and **IP1/5 phase optimization**.

Beam-beam Studies
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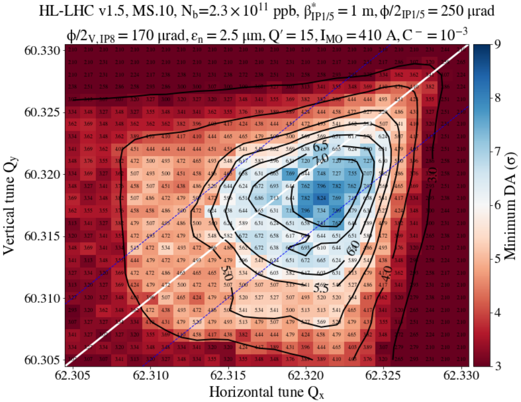
Start of the $\mathcal{L}$-levelling

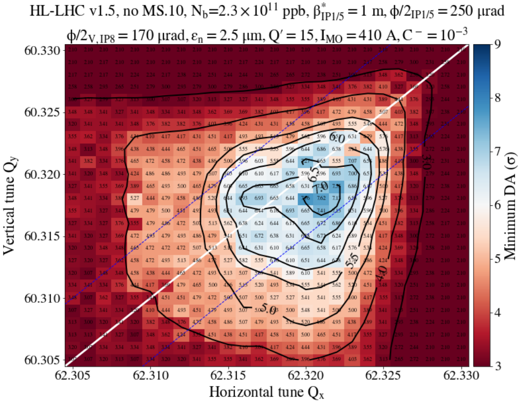
Parameters (unit)	**HL-LHC (values)**
Beam energy (TeV)	7
Luminosity (10^{34} Hz/cm^2)	**2.5**
Bunch population (protons)	2.3×10^{11}
Normalised emittance (μm rad)	2.5 (standard) / 2 (BCMS)
Nominal working point (Q_x, Q_y)	(62.31, 60.32)
Chromaticity $Q'_{x,y}$	15
IP1/5 half crossing angle (μrad)	250(H) / 250(V)
IP2/8 half crossing angle (μrad)	170(V) / 170(V)
IP1/5 $\beta^*_{x,y}$ (m)	**1**
IP8/2 $\beta^*_{x,y}$ (m)	1.5/10
Landau octupoles' current (A)	**410 (standard) / 460 (BCMS)**
Half crab-cavity angle (μrad)	0

Effect of the missing MS10



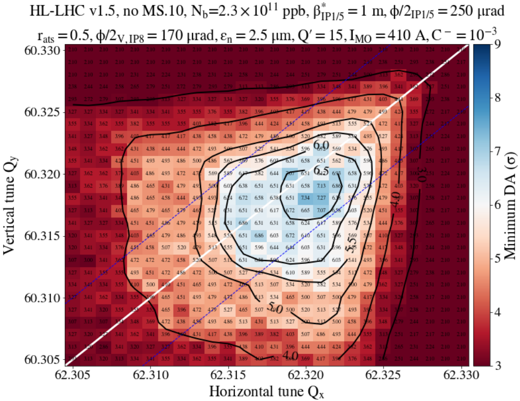
With MS10, tele-index=1

Effect of the missing MS10



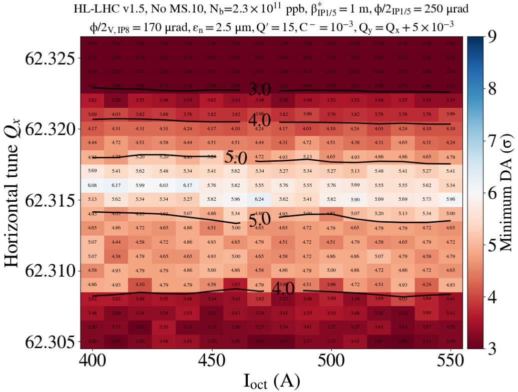
Without MS10, tele-index=1

Effect of the missing MS10



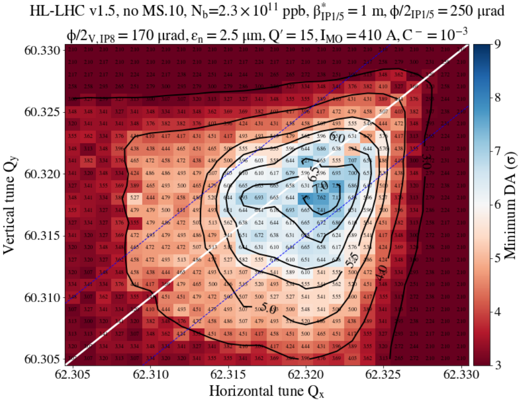
Without MS10, **tele-index=0.5**

DA vs I_{MO}



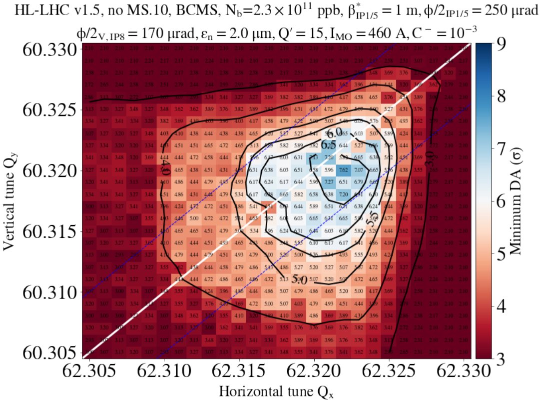
Moderate dependence on I_{MO} in the 400-500 A range (BB dominated).

What about BCMS?



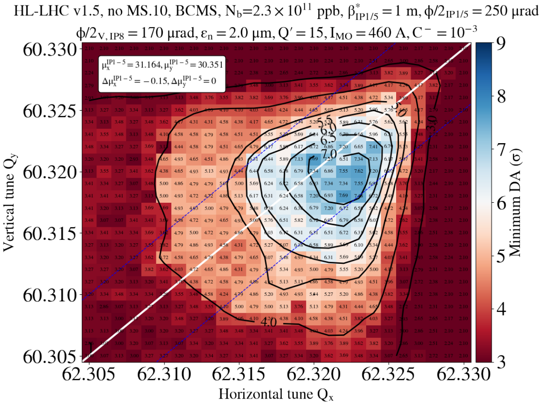
With standard beam ($\epsilon_n = 2.5\ \mu$m).

What about BCMS?



With BCMS beam ($\epsilon_n = 2\ \mu$m).

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



With BCMS beam ($\epsilon_n = 2\ \mu$m)+$\Delta\mu$ opt'ed

Start of $\mathcal{L}$-Levelling Summary

- Layout without **MS10 acceptable** at the clear cost of reduced margins.
- For high brightness beams (2.3 10^{11} ppb and 2 μm), the **DA target marginally met** with phase optimization.

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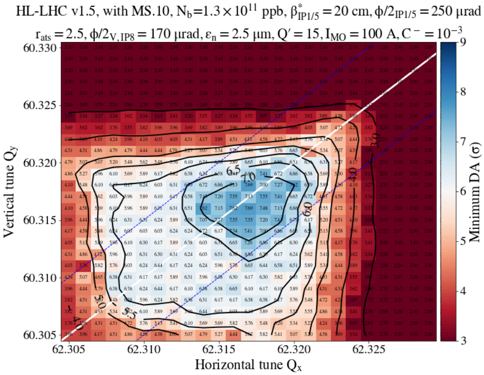
End of the $\mathcal{L}$-levelling

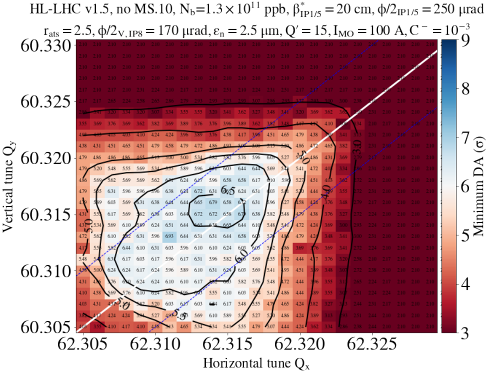
Parameters (unit)	HL-LHC (values)
Beam energy (TeV)	7
Luminosity (10^{34} Hz/cm^2)	**5**
Bunch population (protons)	1.3×10^{11}
Normalized emittance (μm rad)	2.5
Nominal working point (Q_x, Q_y)	(62.31, 60.32)
Chromaticity $Q'_{x,y}$	15
IP1/5 half crossing angle (μrad)	250(H) / 250(V)
IP2/8 half crossing angle (μrad)	170(V) / 170(V)
IP1/5 $\beta^*_{x,y}$ (m)	**0.2**
IP8/2 $\beta^*_{x,y}$ (m)	1.5/10
Landau octupoles' current (A)	**100**
Half crab-cavity angle (μrad)	**190**

Effect of the missing MS10



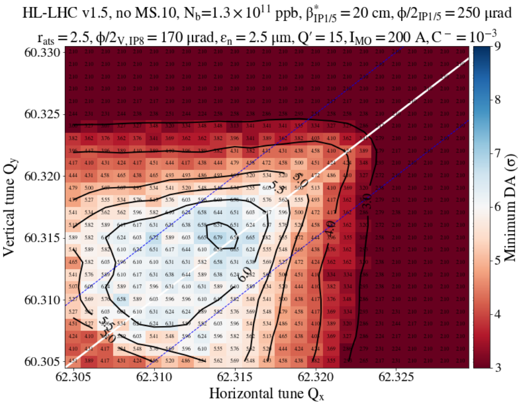
With MS10, I_{MO}=100 A.

Effect of the missing MS10



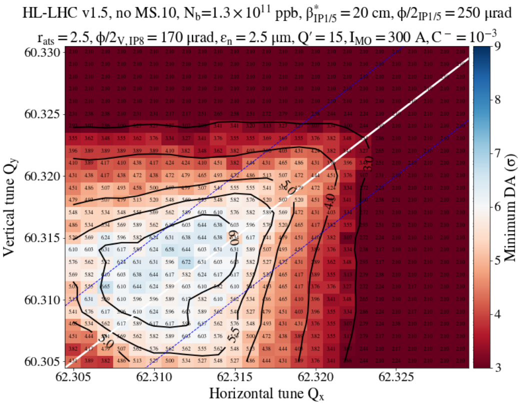
Without MS10, I_{MO}=100 A, good control of the off-momentum coupling is assumed.

Impact of the octupoles



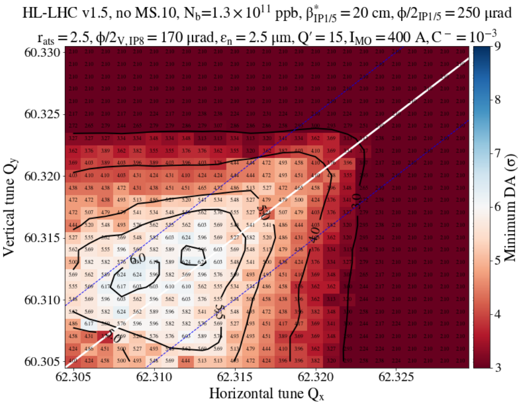
Without MS10, I_{MO}=200 A.

Impact of the octupoles



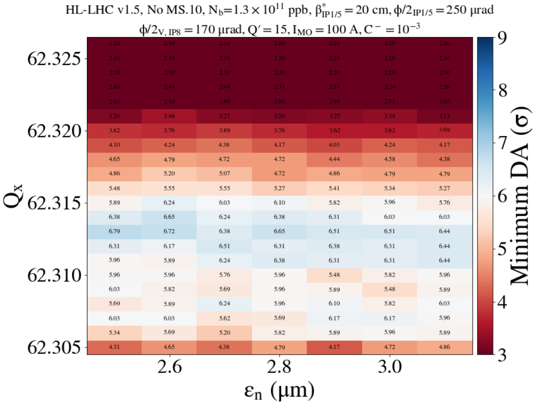
Without MS10, I_{MO}=300 A.

Impact of the octupoles



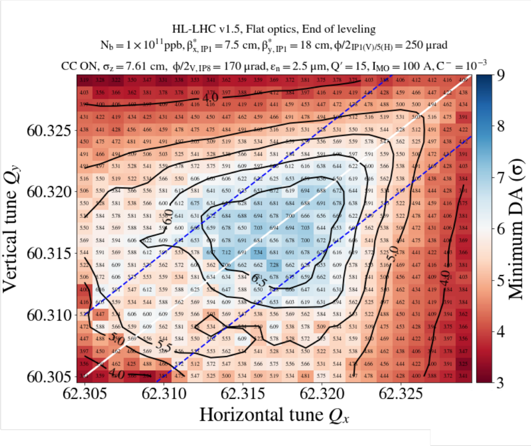
Without MS10, I_{MO}=400 A.

Impact of the emittance growth



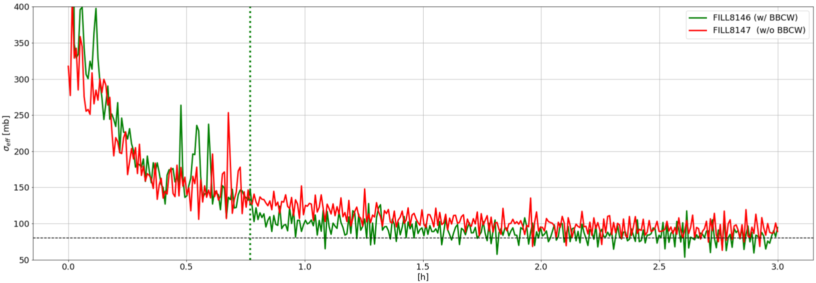
Lowering Q_x can partially recover performance.

Flat optics and BB studies



Flat optics studies and BB are the next important step.

Run3: Wire compensation at the EoL



Beneficial effect of the wire compensation on losses normalized to luminosity (→ WP2/WP13 HL-LHC Satellite Meeting).

End of $\mathcal{L}$-Levelling Summary

- The option without MS10 compatible with the DA targets.
- **Working point to be optimized during the $\mathcal{L}$-levelling**.
- Tight requirements on tune control and off-momentum coupling correction.

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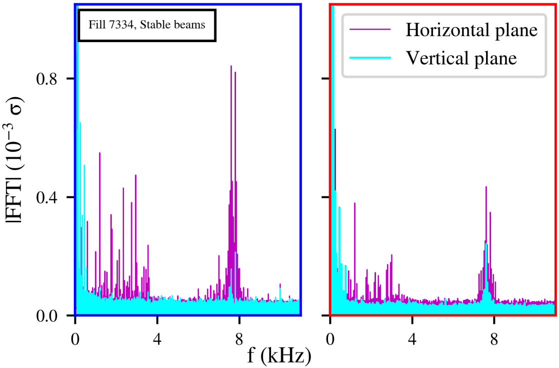
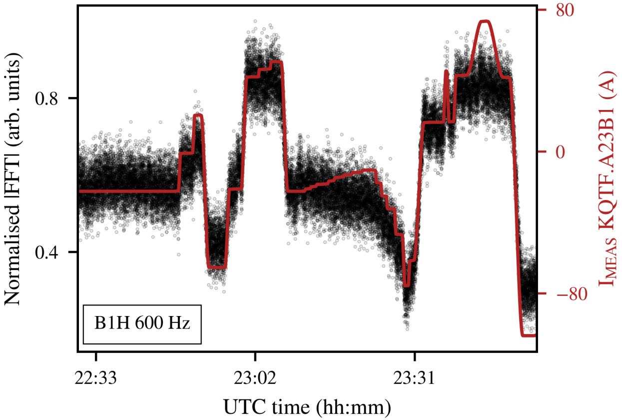
- All previous results consider a machine without noise.
- **Dipolar noise is regularly observed in the beam spectra (Run1/2/3)** [2].
- **There are no evidence of quadrupolar noise (tune modulation)** [3].

Dipolar noise observed B1/B2



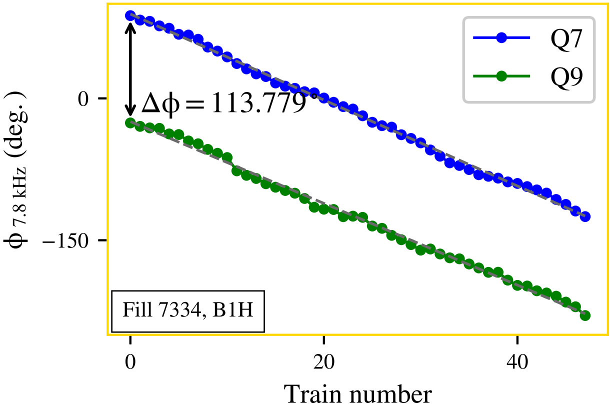
Noise separated in two 50 Hz harmonic clusters.

Dipolar noise observed B1/B2



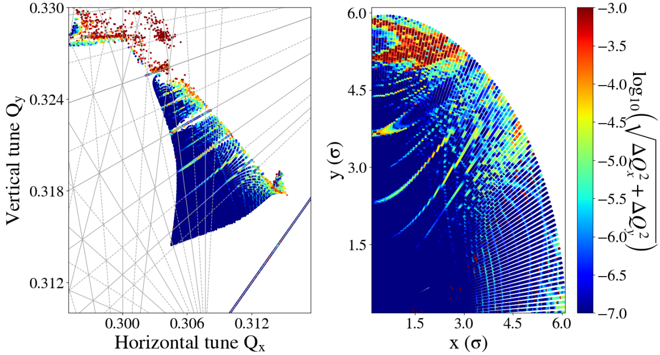
It is not an instrumental effect (e.g. 600 Hz).

Dipolar noise observed B1/B2



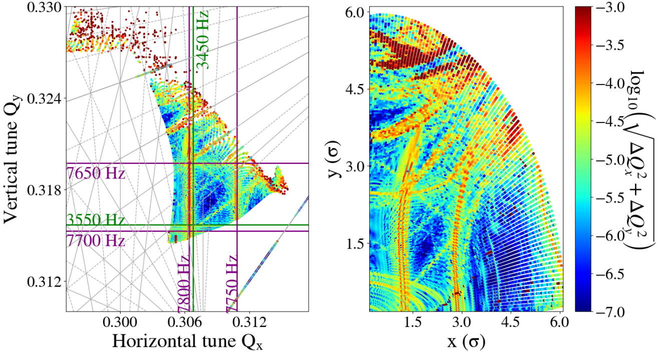
It is not an instrumental effect (e.g. 7800 Hz).

Noise effect on the beam



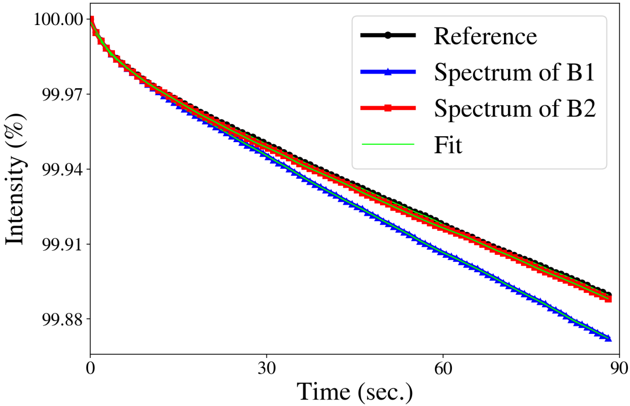
Simulation without noise.

Noise effect on the beam



Adding the observed noise spectra.

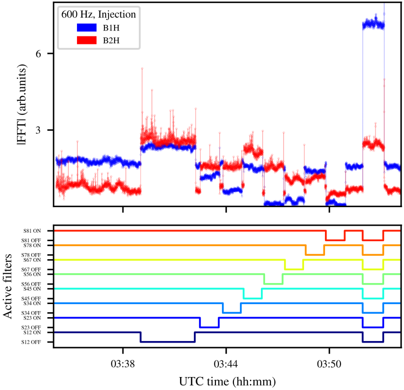
Noise effect on the beam



Effect on the beam lifetime.

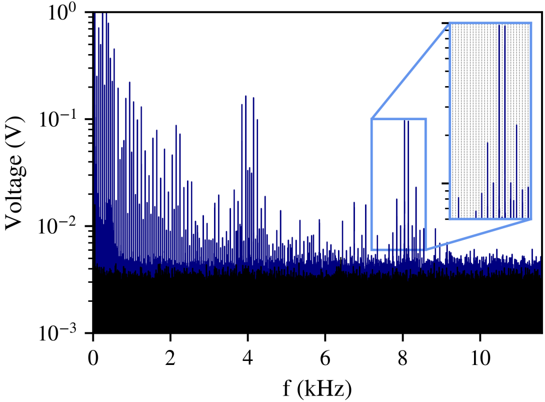
Can we detect the source of noise? Significant effort devoted to answer this question [4].

Contribution from 8 MB circuits



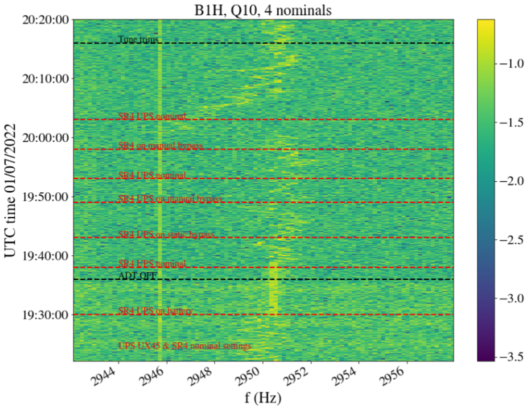
During Run 2, we show a clear effect of the MB circuit on the beam (low-frequency).

Contribution from UPS



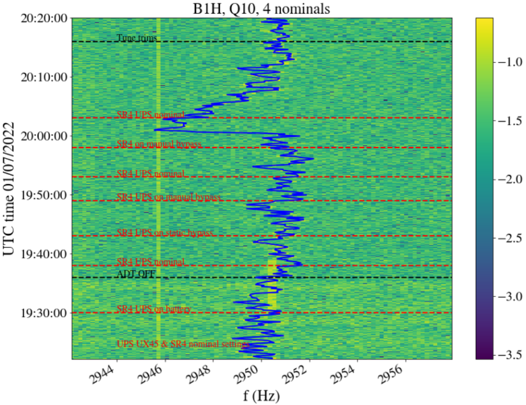
During LS2, the UPS voltage spectra was measured.

Contribution from UPS



This year we observed the UPS effect on B1.

Contribution from UPS



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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**.
- At top energy, layout without MS10 seems acceptable at the cost of reduced margins: e.g. for 2.3 10^{11} ppb and 2 μm, the **DA target marginally met** with phase optimization.
- The **alternative scenarios** are being assessed.
- **Working point to be optimized during the $\mathcal{L}$-levelling**.
- **The source of noise at 8 kHz is still outstanding, an MD proposed to try to address it**.

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.

S. Kostoglou, G. Arduini, Y. Papaphilippou, G. Sterbini, and L. Intelisano.
Impact of the 50 Hz harmonics on the beam evolution of the Large Hadron Collider.
Phys. Rev. Accel. Beams, 24:034002, Mar 2021.

References (II)

S. Kostoglou, H. Bartosik, Y. Papaphilippou, G. Sterbini, and N. Triantafyllou.
Tune modulation effects for colliding beams in the High Luminosity Large Hadron Collider.
Phys. Rev. Accel. Beams, 23:121001, Dec 2020.

S. Kostoglou, G. Arduini, Y. Papaphilippou, G. Sterbini, and L. Intelisano.
Origin of the 50 Hz harmonics in the transverse beam spectrum of the Large Hadron Collider.
Phys. Rev. Accel. Beams, 24:034001, Mar 2021.