Noise studies:
On the 50Hz harmonics perturbation

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With important input and help from:

G.Arduini, C.Baccigalupi, M.C.Bastos, A.Beaumont, X.Buffat, J.P.Burnet, M.Buzio, L.R.Carver, R.De Maria, S.Fartoukh, R.T.Garcia, G.Iadarola, T.Levens , E.Metral, O.Michels, D.Nisbet, J.Olexa, M.Solfaroli, H.Thiesen, S.Uznanski, D.Valuch, J.Wenninger.

Thanks to WP2 & WP6

8th HL-LHC Collaboration Meeting, 16th October 2018, CERN

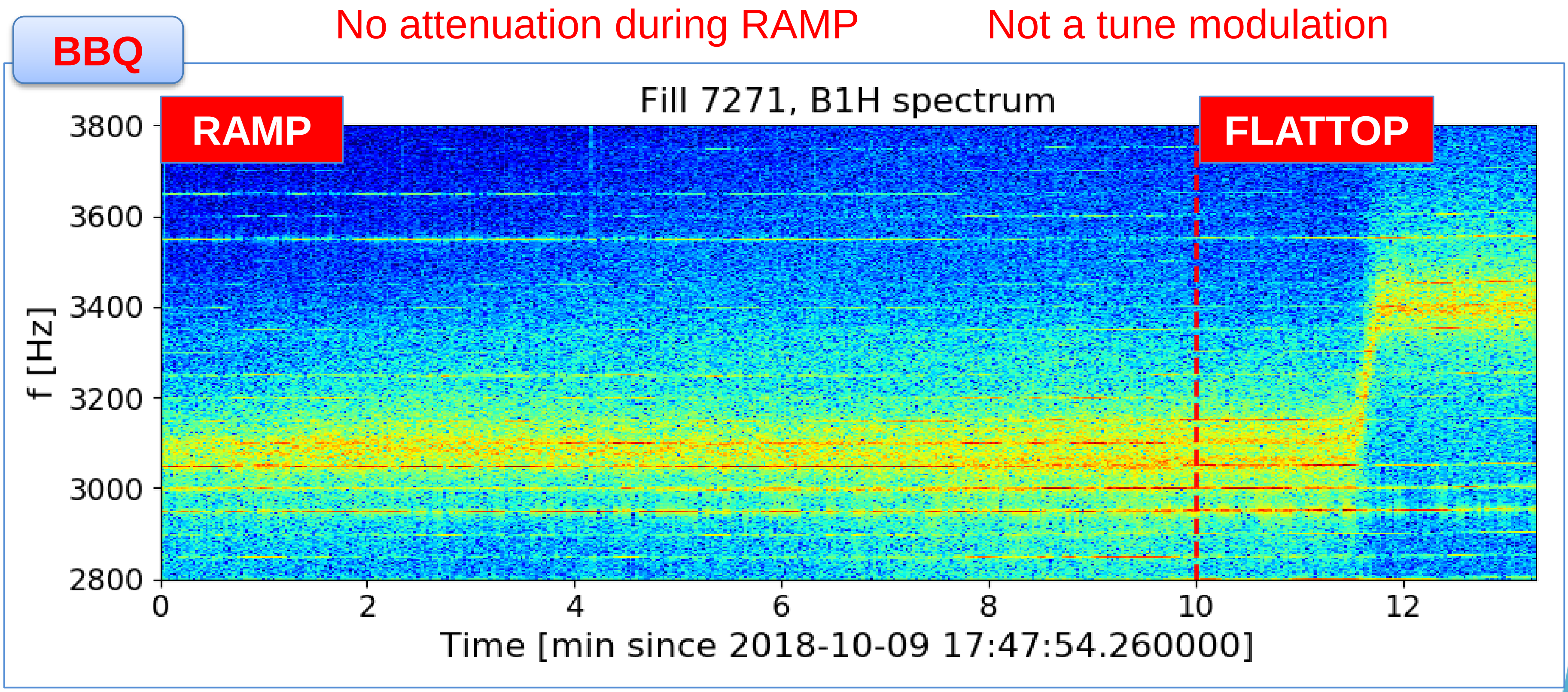
Overview

Motivation: Investigate the **source** of the 50 Hz harmonics and study **possible implications** on LHC & HL-LHC.

- Summary of observations during 2018:
  - Is it an instrumental effect?
  - Possible sources.
  - Tests with active filters of the main bends & correlation with voltage spectrum of sector12.
- Simulations for **LHC**
- Simulations for **HL-LHC**
- Conclusions & next steps

Introduction

- ❑ Harmonics of 50Hz have been observed in the beam spectrum.



Introduction

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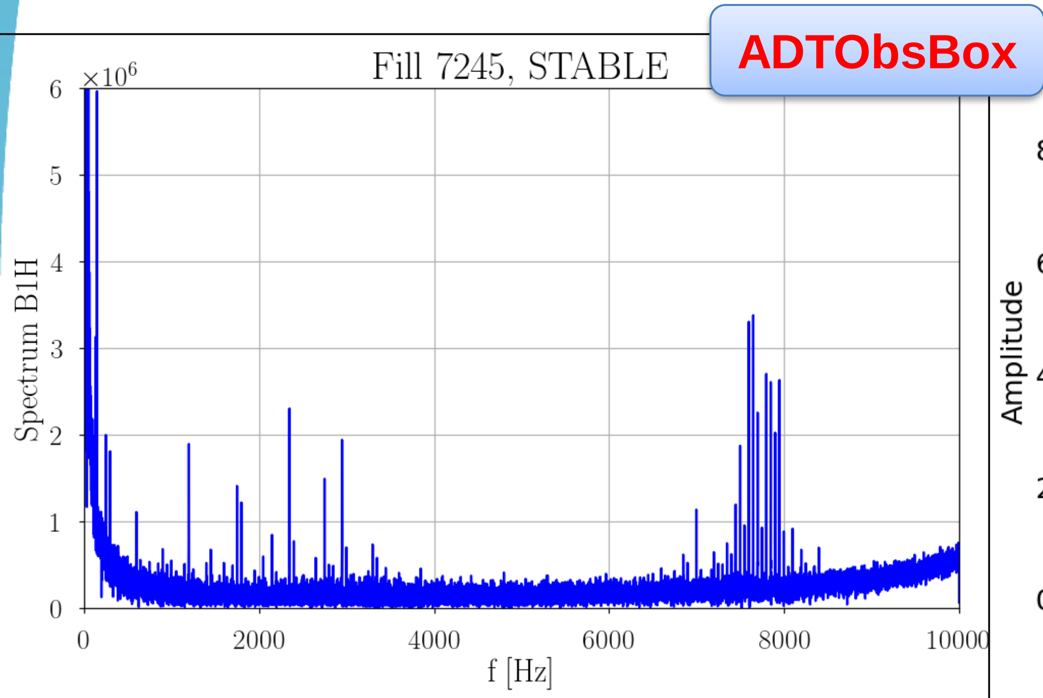

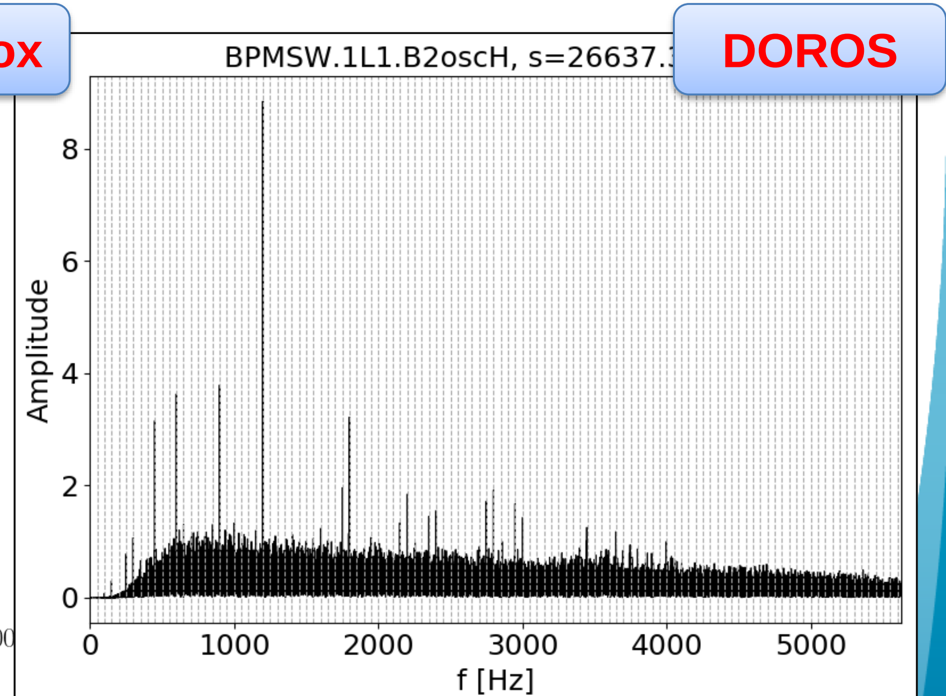

Introduction

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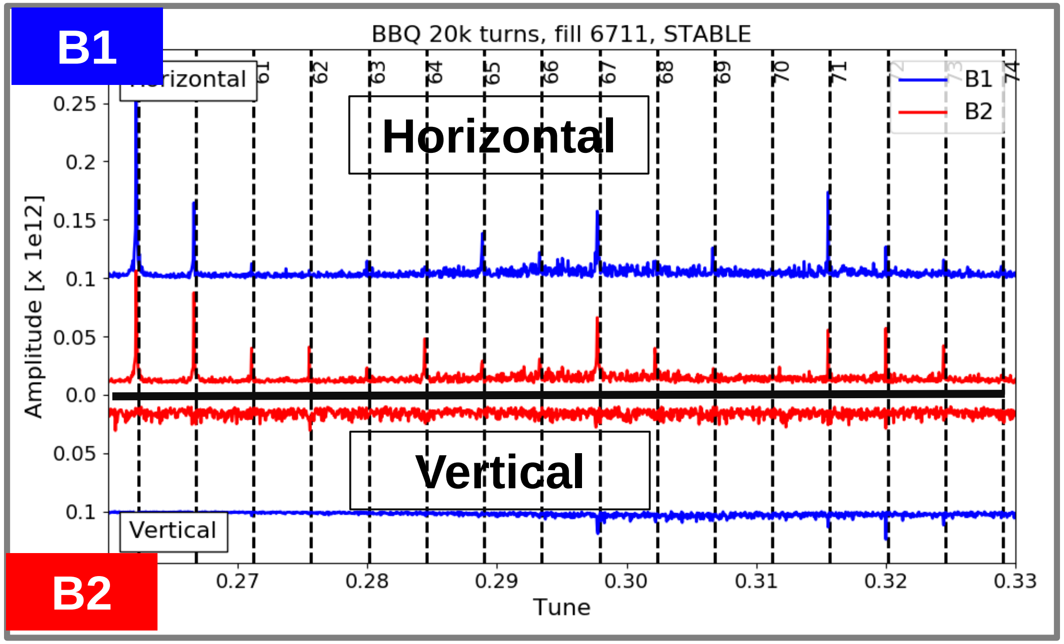
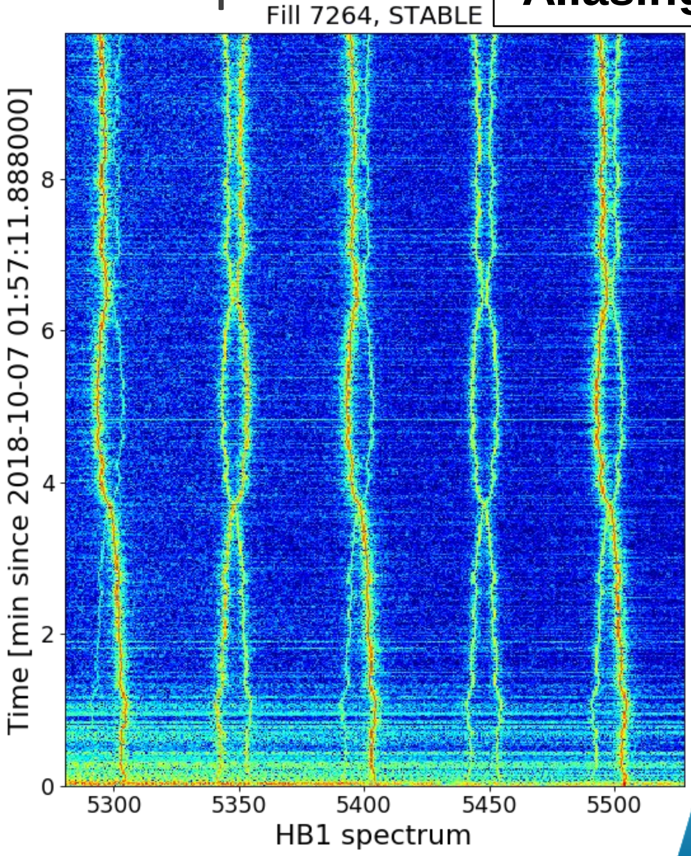
- ❑ Present in several instruments and in all beam modes.
- ❑ Visible in B1 & B2, mainly in the horizontal plane.



Aliasing



Introduction

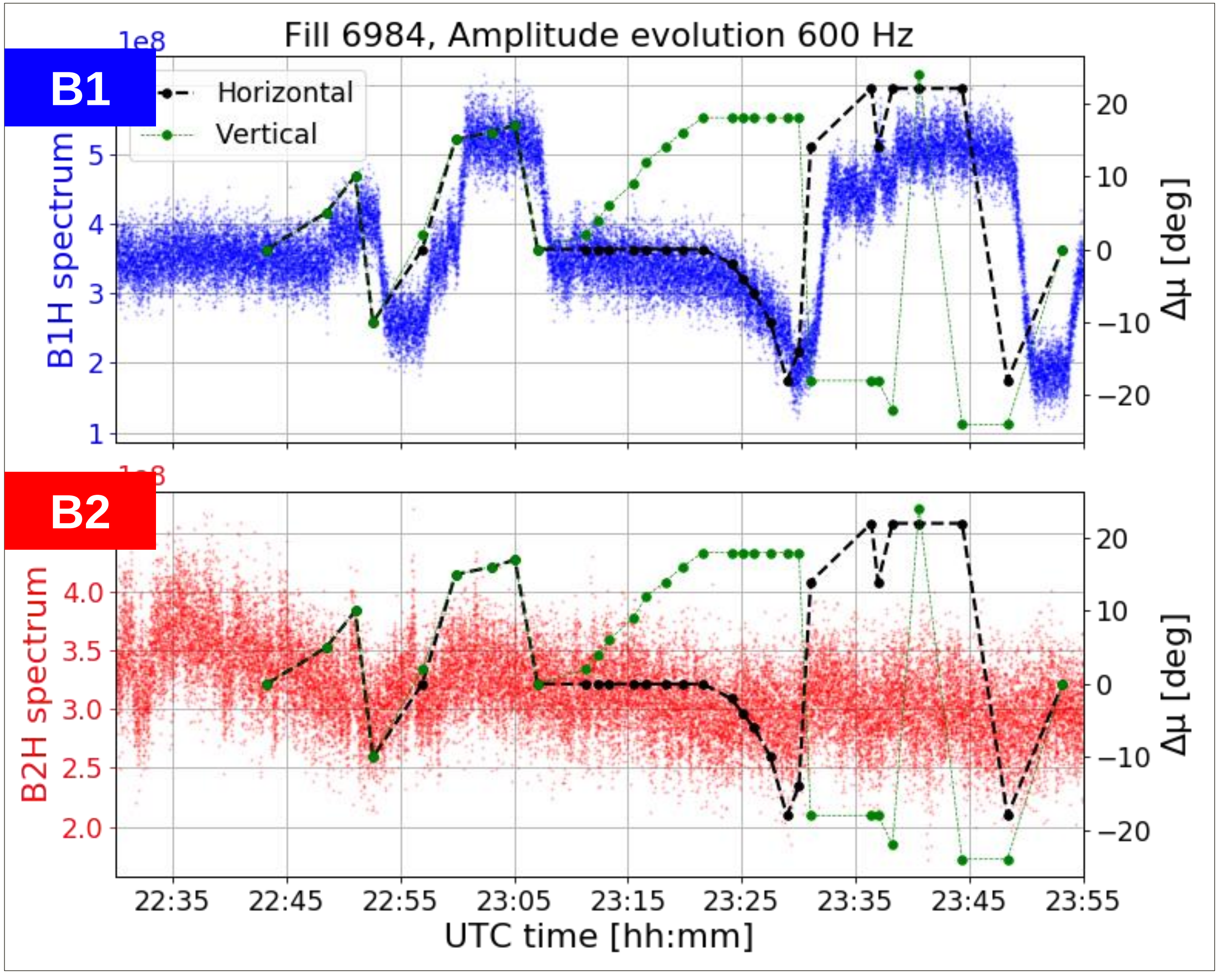
- Harmonics of 50Hz have been observed in the beam spectrum.
- Present in several instruments and in all beam modes.
- Visible in B1 & B2, mainly in the horizontal plane.
- The source of this perturbation is not yet understood.
- According to our observations concerning the source (see next slides), these harmonics may also be present in HL-LHC.
- Learning from the LHC experience, we would like to study possible implications for HL-LHC and define tolerances.

Not instrumental (I)

Phase scan of IP1 & IP5 B1

(MD#3583-Beam-Beam Long Range 2018)

Horizontal



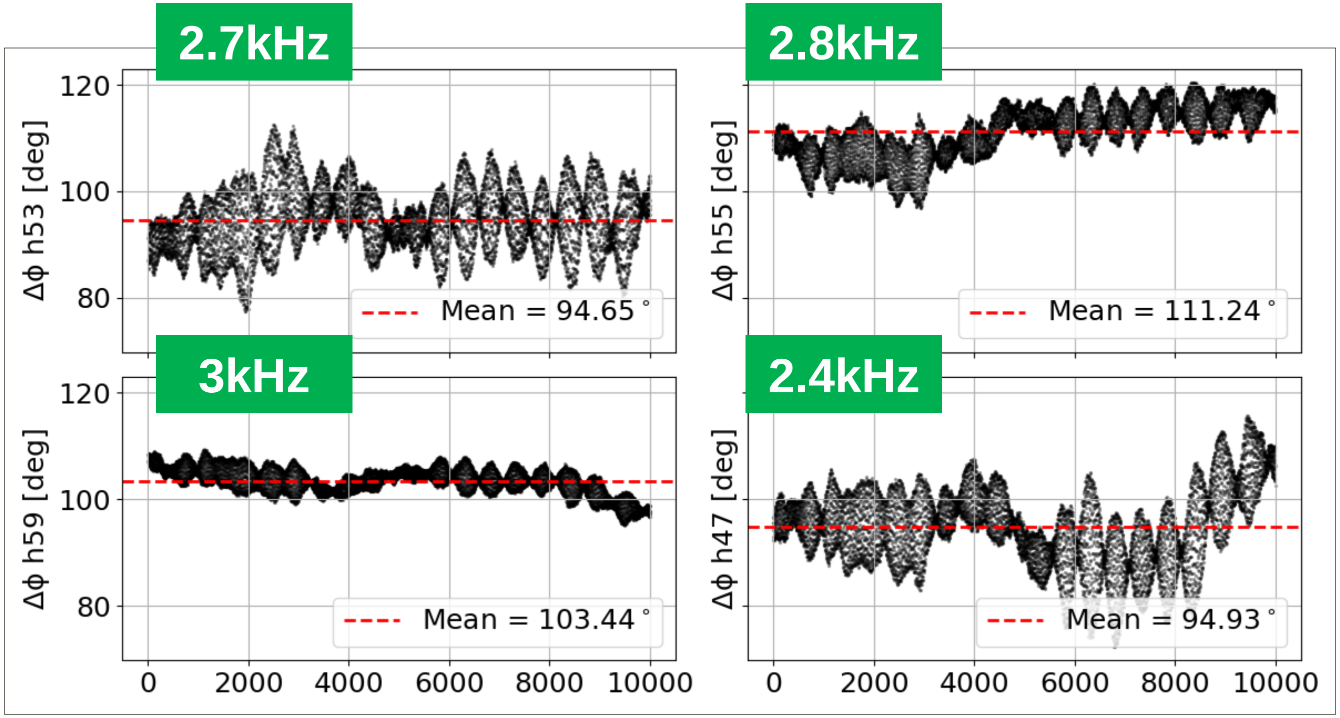
Changing the phase advance between IP1 & IP5 in B1 affects the amplitude evolution of the harmonics in B1.

Not instrumental (II)

Phase advance of 50Hz harmonics

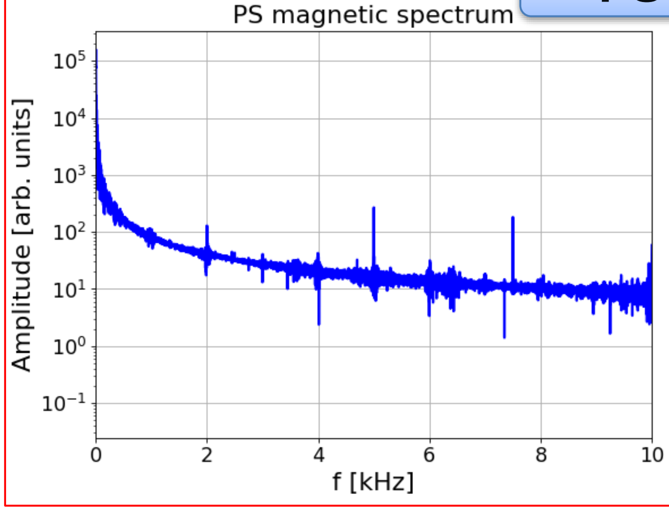
Compatible with the betatronic phase advance

90-110 degrees between PUs Q7 to Q9

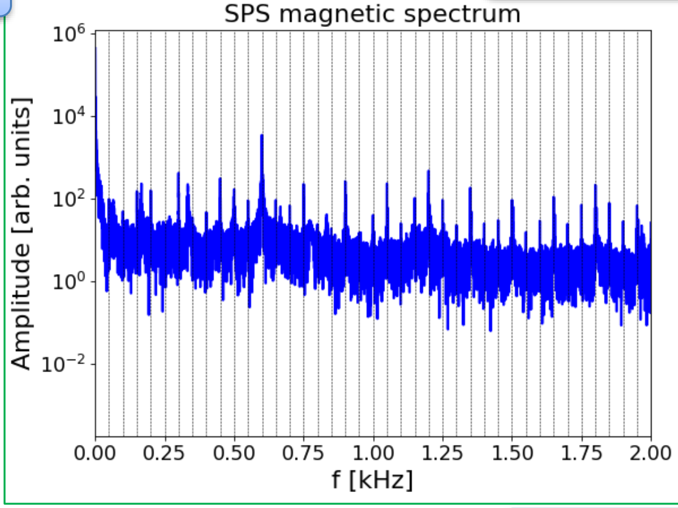


Possible sources

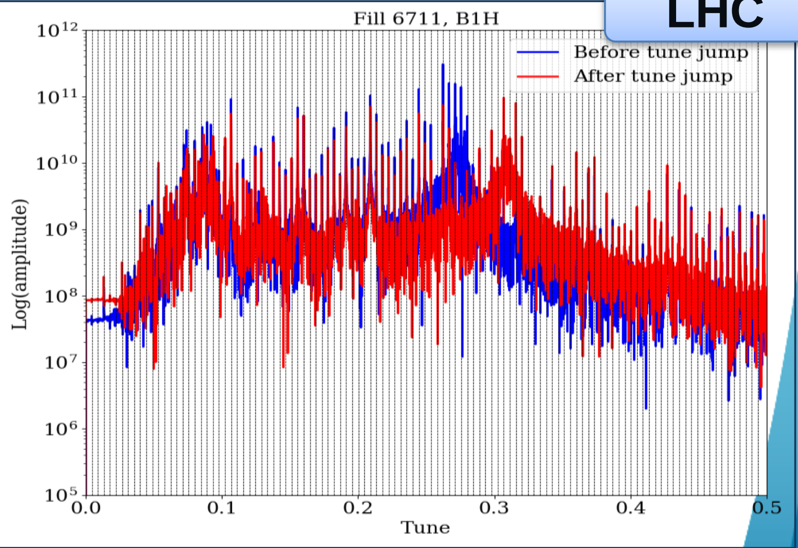
PS



SPS

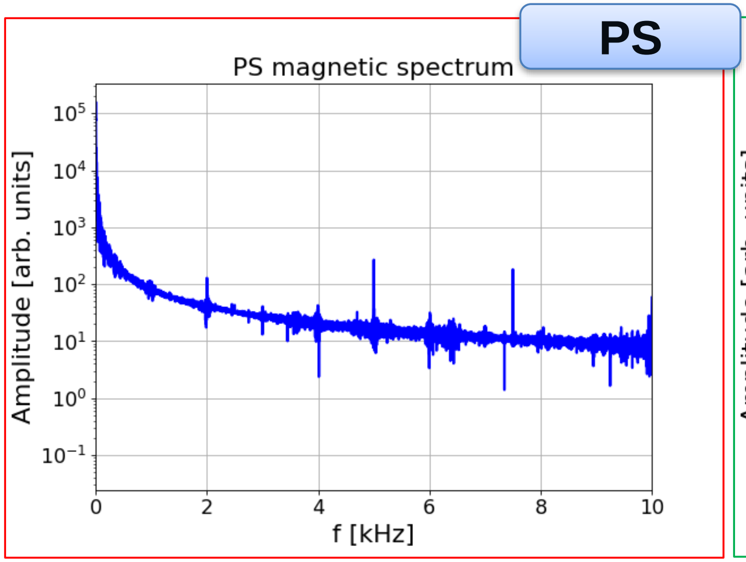


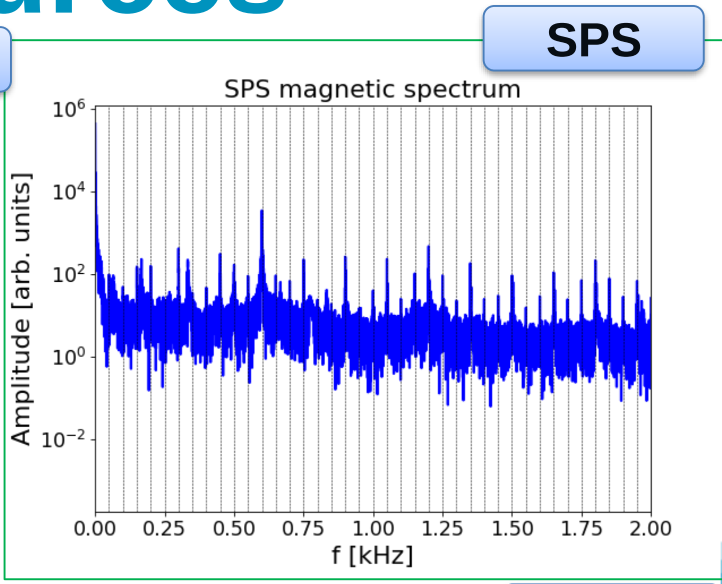
LHC

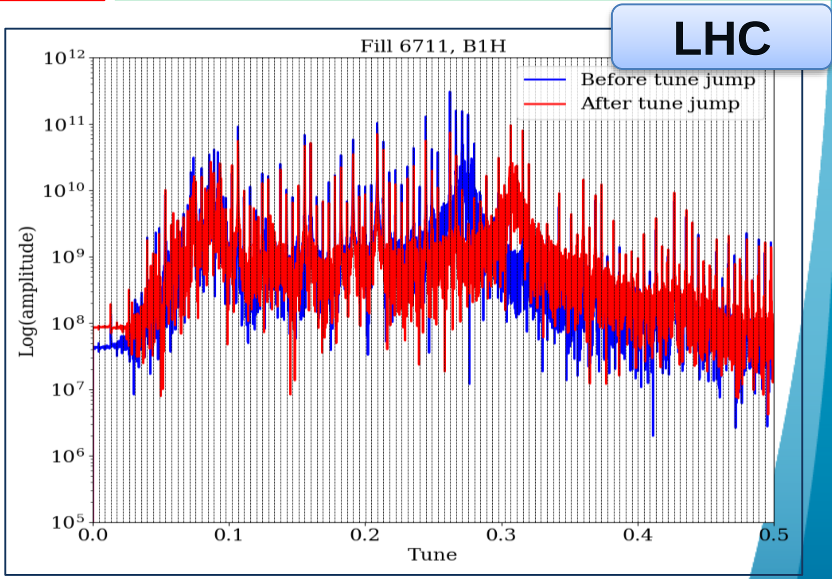


Possible sources

Patterns of Silicon Controlled Rectifier







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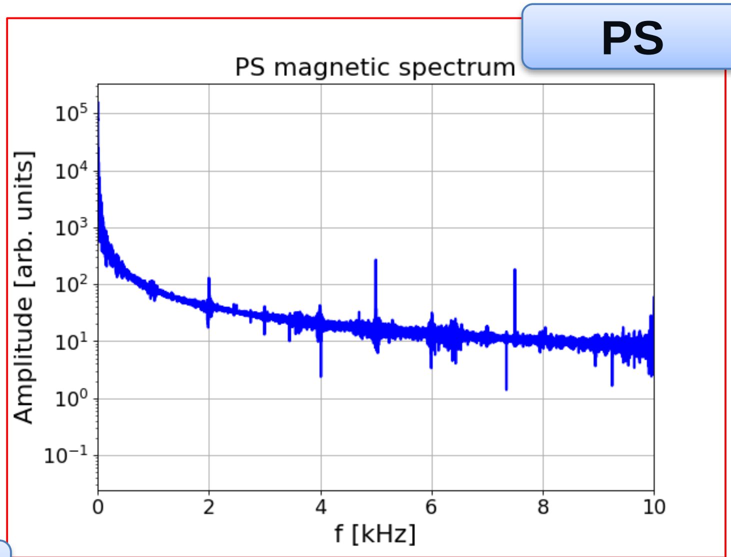
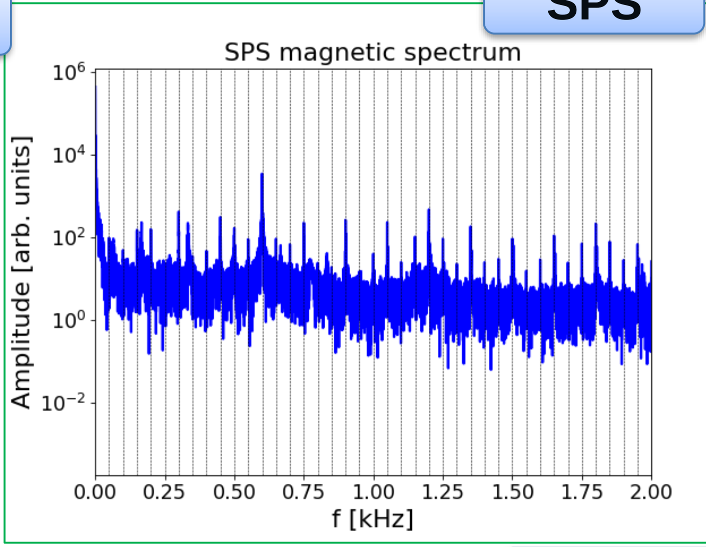
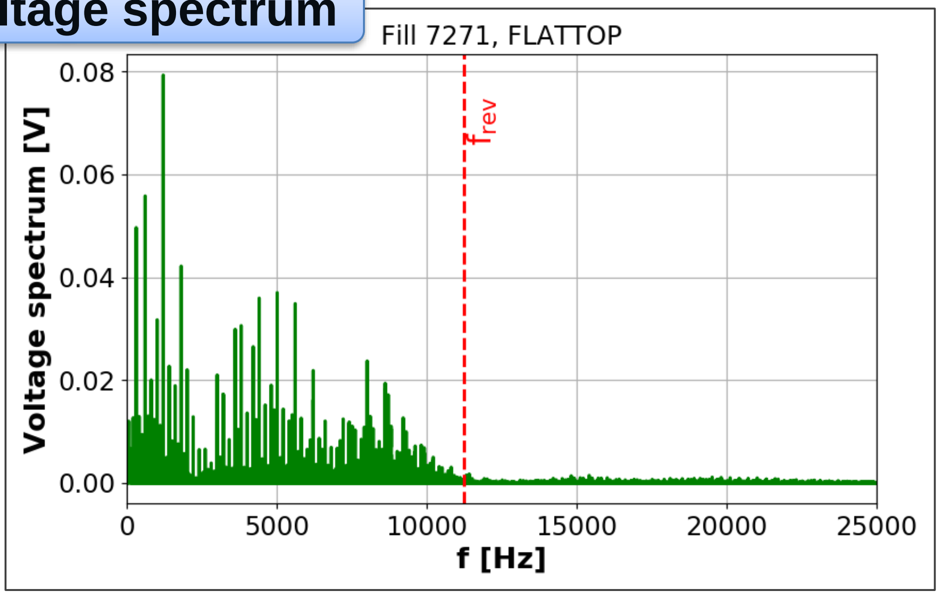


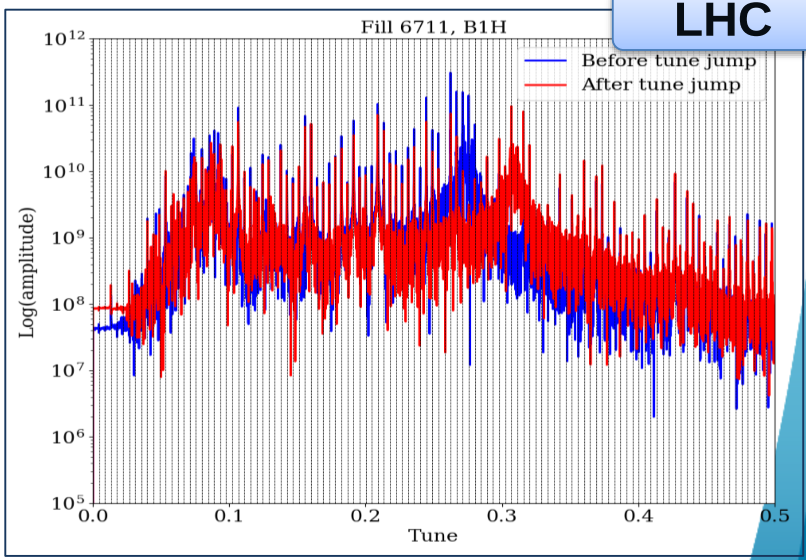
SPS



Voltage spectrum



LHC



Possible sources

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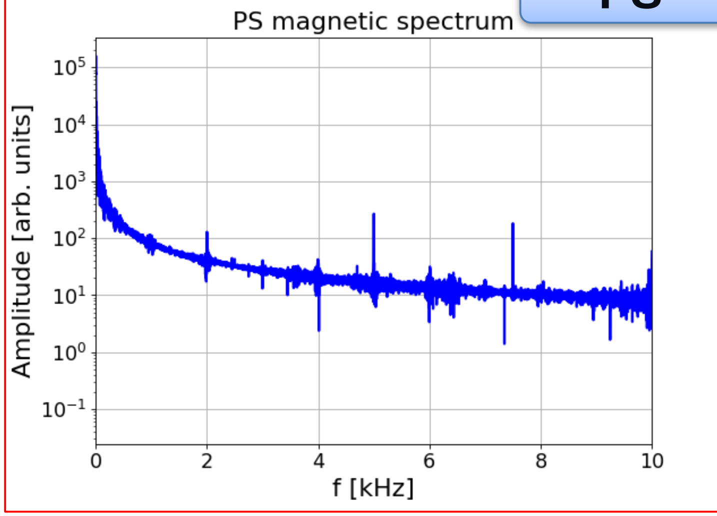
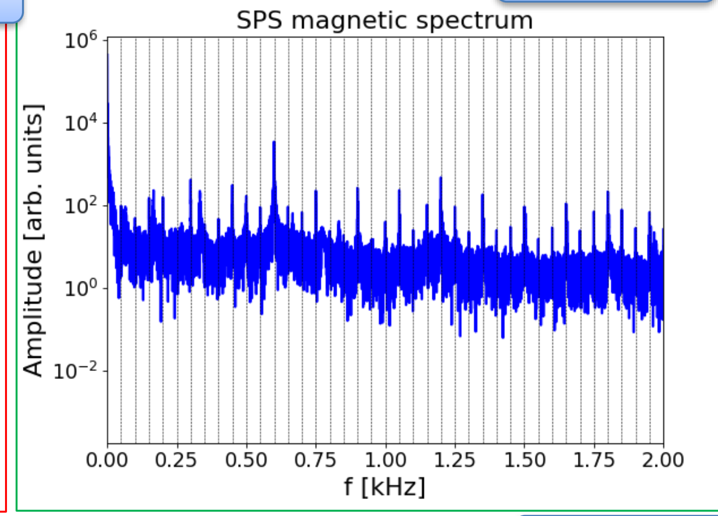
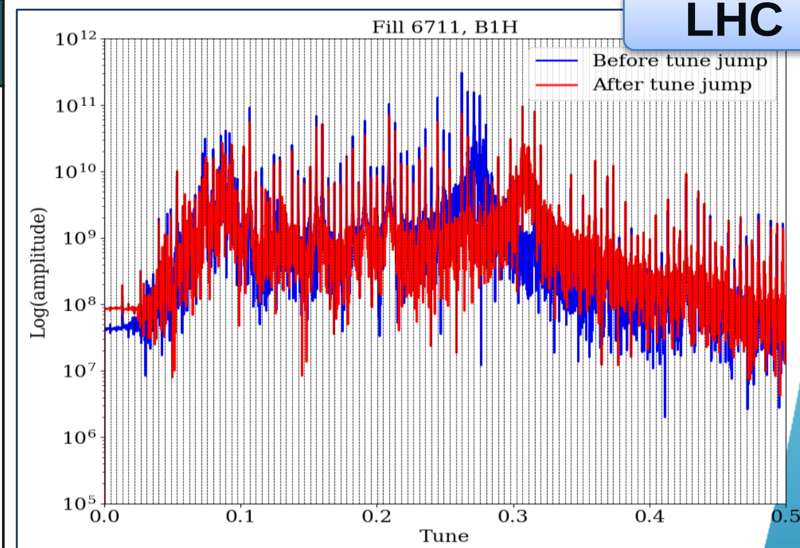


SPS



RAMPING CONVERTERS	NOT RAMPING CONVERTERS
# ARC Dipoles RPTE.UA23.RB.A12,RPTE.UA27.RB.A23,RPTE.UA43.RB.A34,RPTE.UA47.RB.A45,RPTE.UA63.RB.A56,RPTE.UA67.RB.A67,RPTE.UA83.RB.A78,RPTE.UA87.RB.A81 **# Dog-leg Dipole** (spares of the switching mode converters) RPTG.SR1.RD1.LR1,RPTG.SR3.RD34.LR3,RPTG.SR5.RD1.LR5 **# Septa** RPTM.SR6.RMSD.LR6B1,RPTM.SR6.RMSD.LR6B2 **# Quadrupoles** RPTF.SR3.RQ4.LR3,RPTF.SR3.RQ5.LR3,RPTF.SR7.RQ4.LR7,RPTF.SR7.RQ5.LR7	**# Alice/LHC dipoles** RPTH.SX2.RXSOL.ALICE,RPTI.SR2.RBAWV.R2,RPTI.SR8.RBLWH.R8,RPTJ.USC55.RXSOL.CMS **# ALICE compensator** RPTL.SR2.RBWMDV.L2,RPTL.SR2.RBXWTV.L2,RPTL.SR2.RBXWTV.R2 **# LHCb Compensator** RPTN.SR8.RBXWH.L8,RPTN.SR8.RBXWSH.L8,RPTN.SR8.RBXWSH.R8

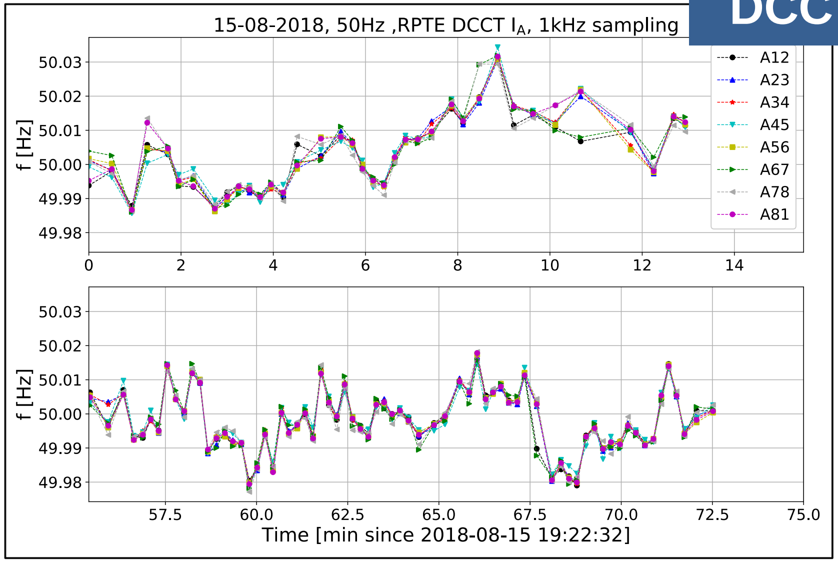
LHC



Jittering of the 50Hz

- These frequencies are not constant in time.
- Similar oscillation observed in all DCCTs, in the beam and in SPS B-Train.

DCCTs



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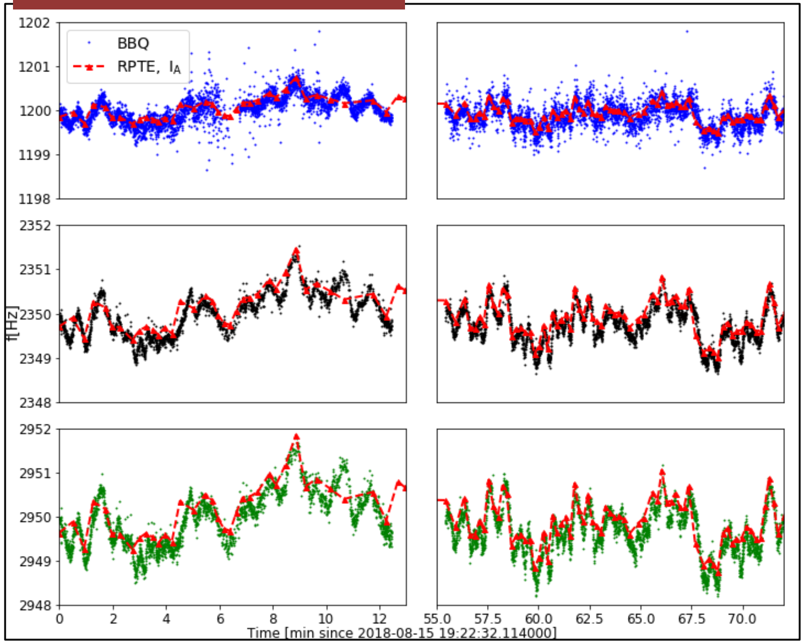
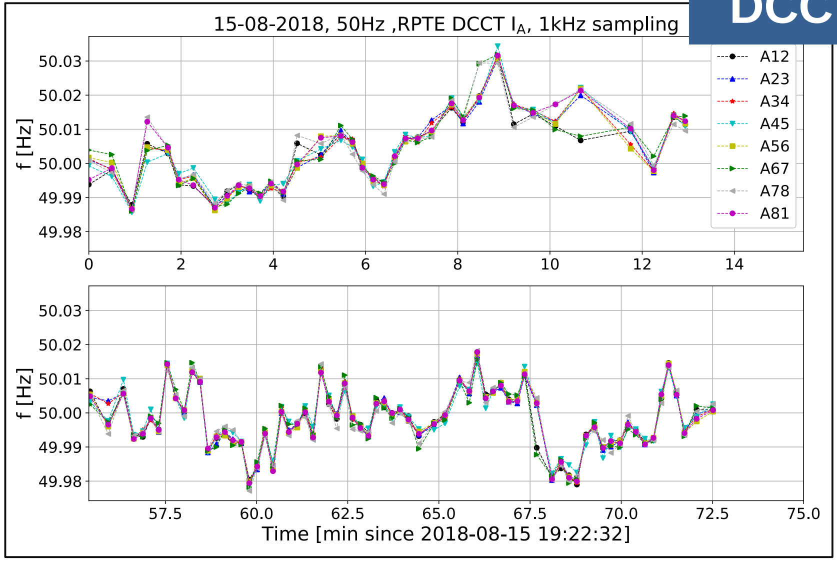
DCCTs & BBQ



DCCTs



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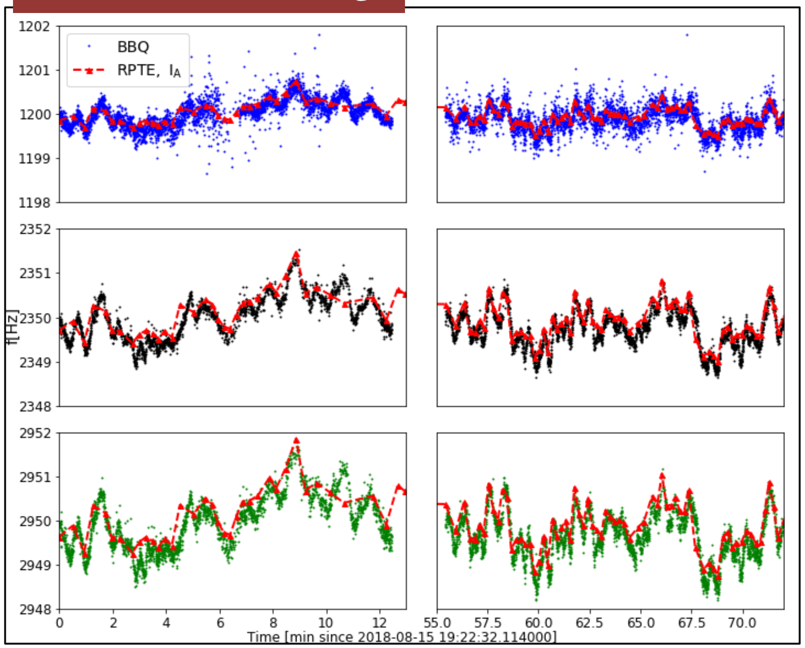
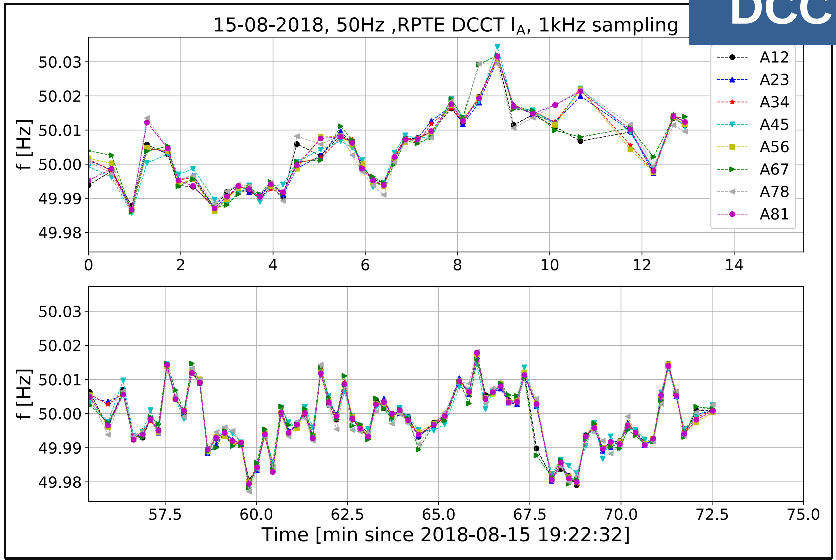
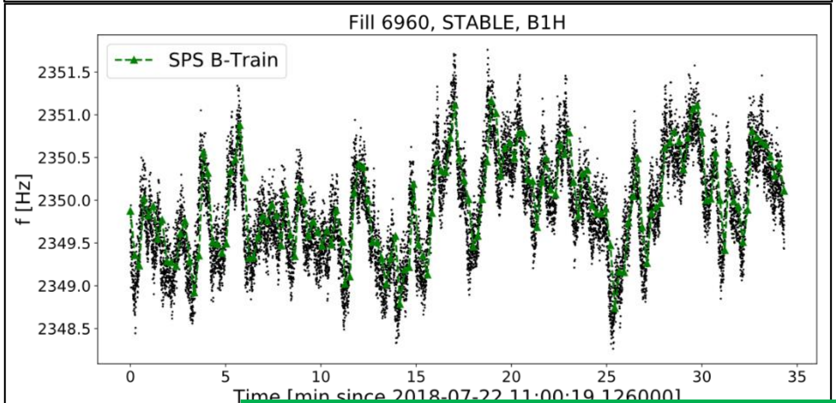


DCCTs





SPS B-Train & LHC BBQ

Jittering of the 50Hz

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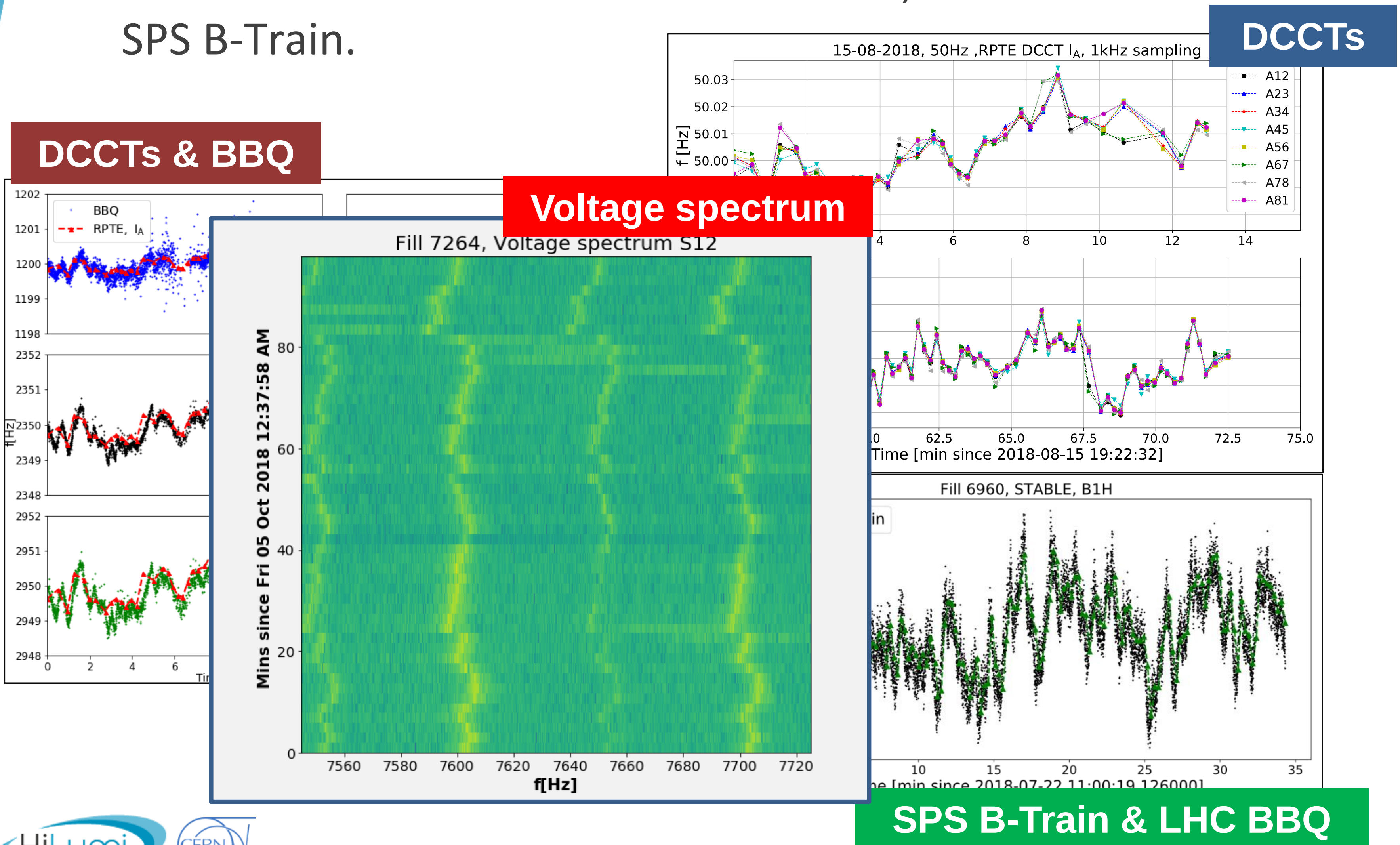
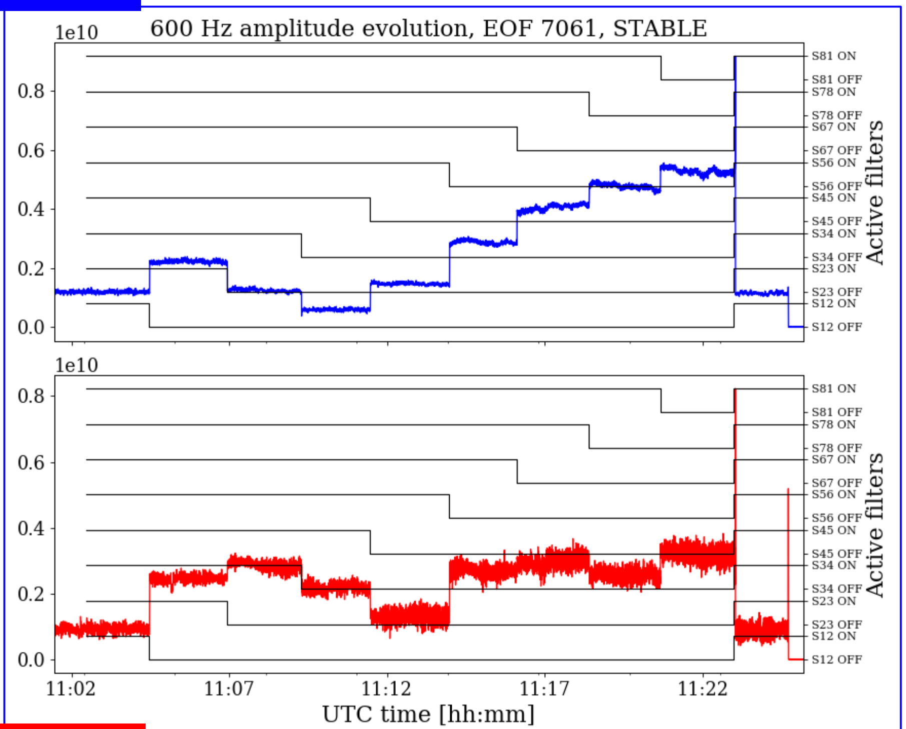
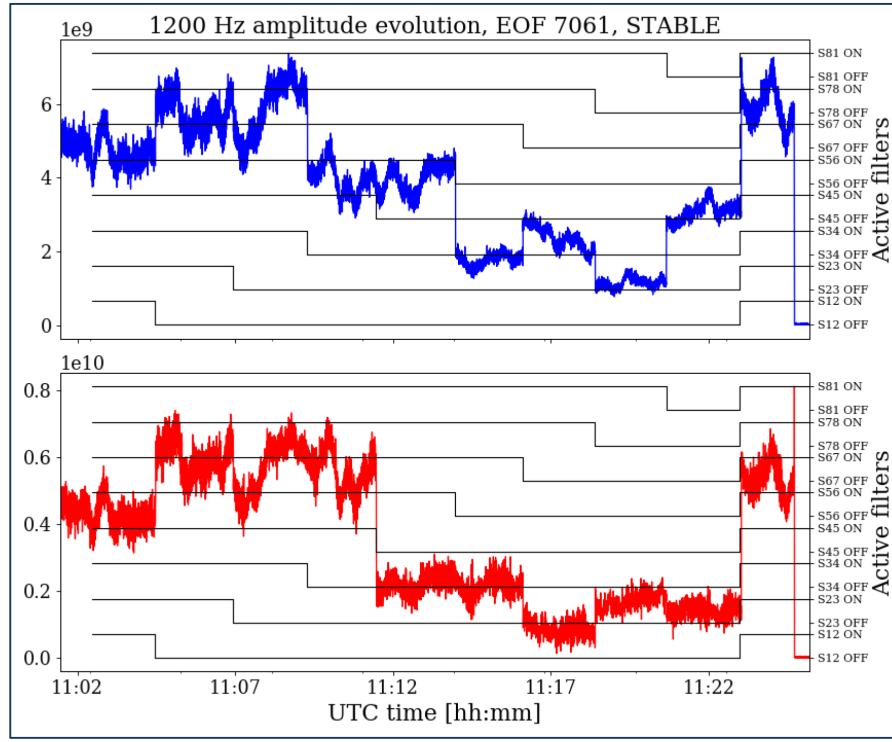


Active filters (I)

- Enabling/disabling the active filters: The status of the active filters of the main bends has an impact on their amplitude evolution.

B1

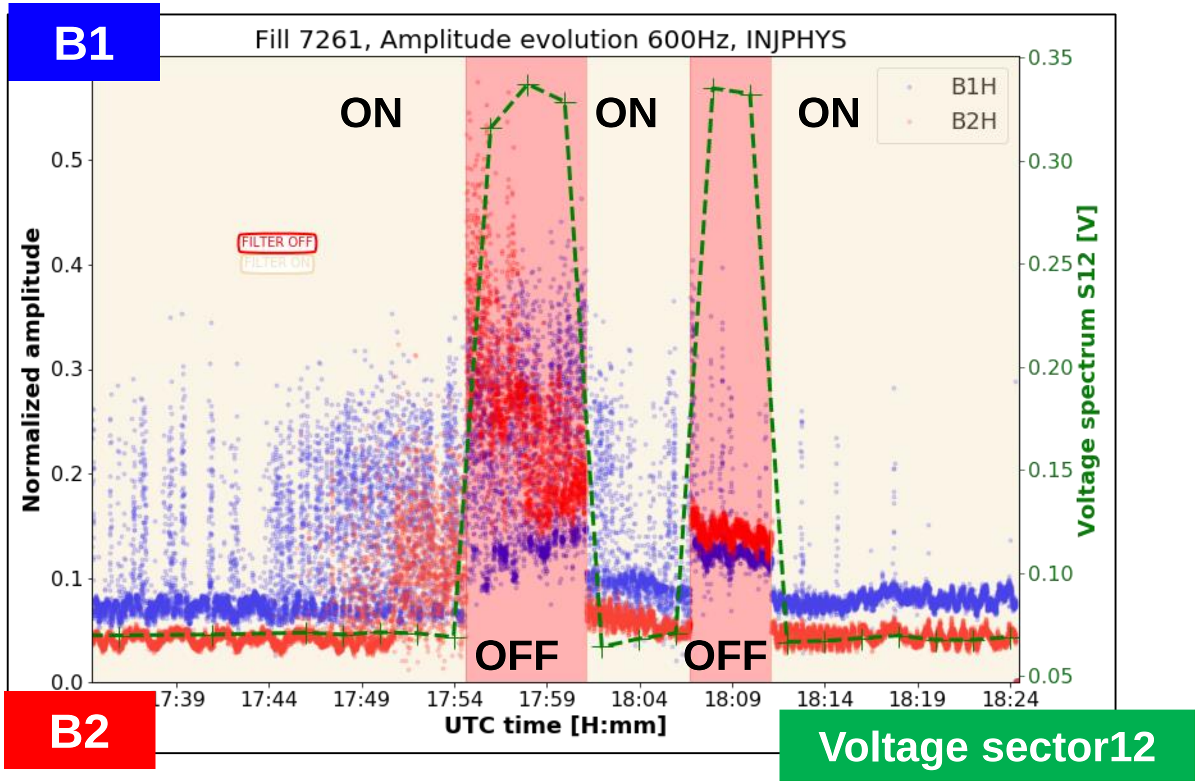




B2

Active filters (II)

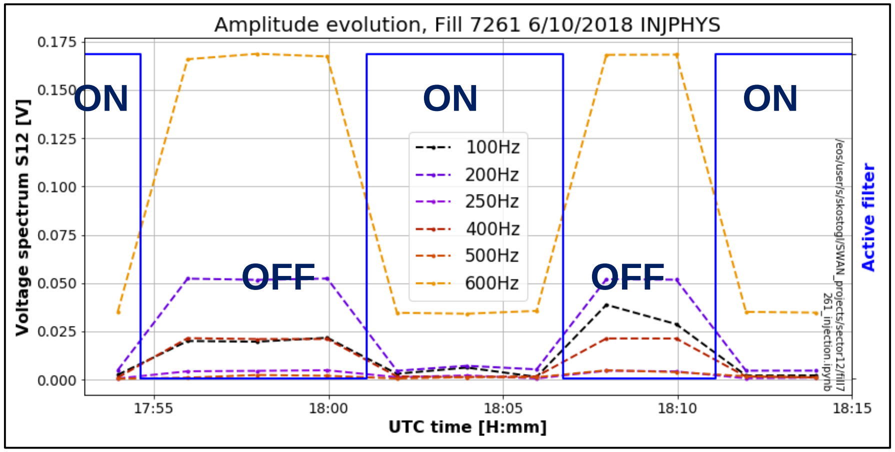
- <u>Enabling/disabling the active filters</u>: Correlation between amplitude evolution of harmonics in the beam and in the voltage spectrum of RPTE.UA23.RB.A12 (instrumentation installed during TS2 from EPC)

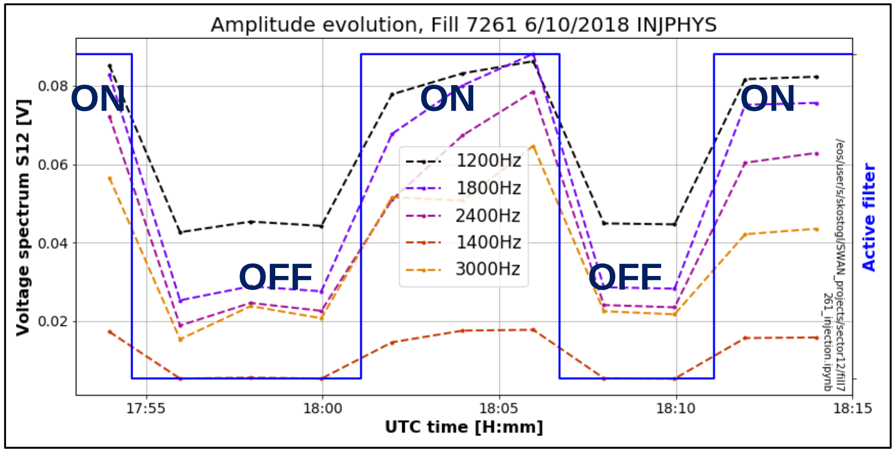


Active filters (III)

- <u>Enabling/disabling the active filters</u>:

  Voltage spectrum sector12:
  - Harmonics up to 1kHz decrease when active filter is enabled.
  - Harmonics beyond 1kHz increase when active filter is enabled.
  - Compatible with the different behaviour observed between 600 & 1.2kHz of the beam.





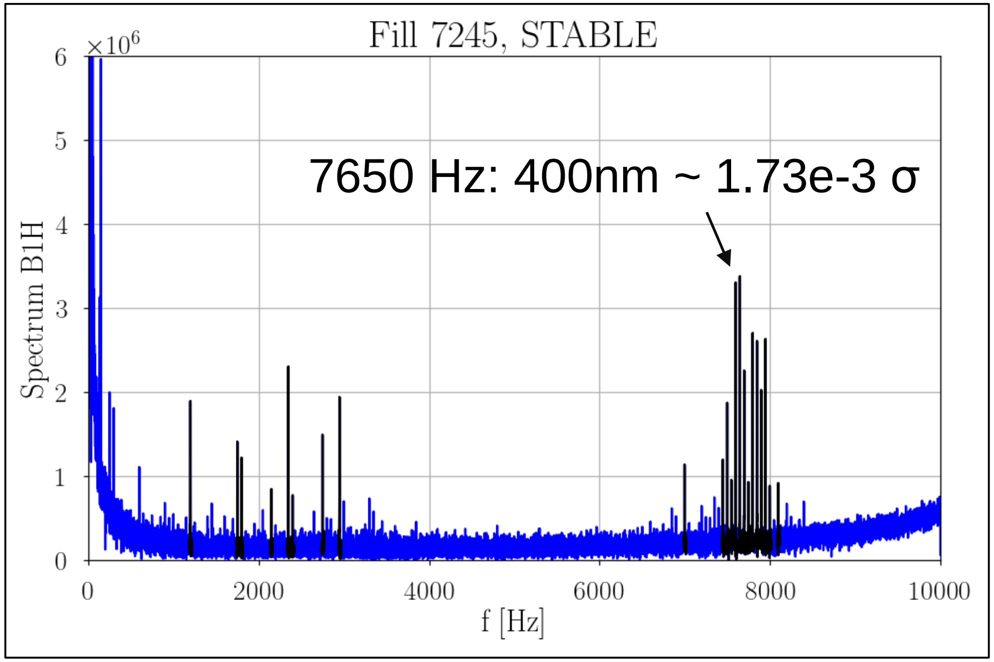
Simulations

LHC simulations

- For a simplified mode, we convert the offset observed in BPMCS.7L4.B1 to an equivalent dipolar kick at the same location.

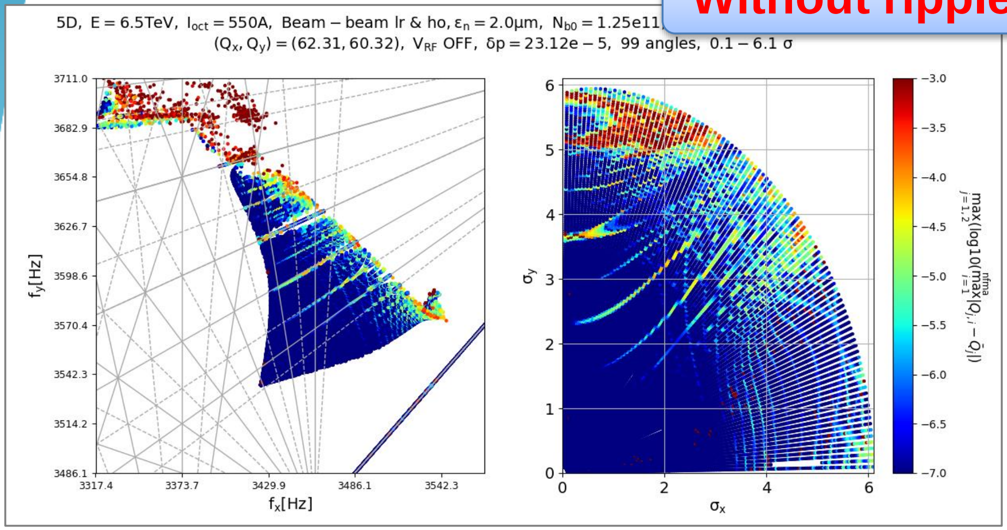
$$|X(s,N)| = \frac{\sqrt{\beta_{\text{Noise}}\beta(s)}\ |A_{\text{Noise}}|}{|1-e^{2i\pi(Q_{\text{Noise}}-Q)}|}$$

- Phase and distribution of the dipolar kicks along the main bends are not taken into account in this simplistic model.



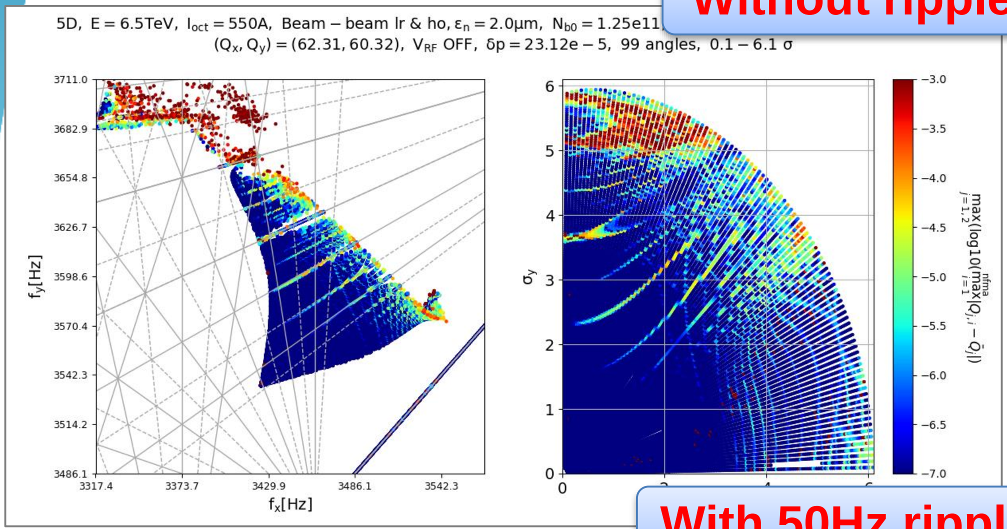
LHC simulations

Without ripple

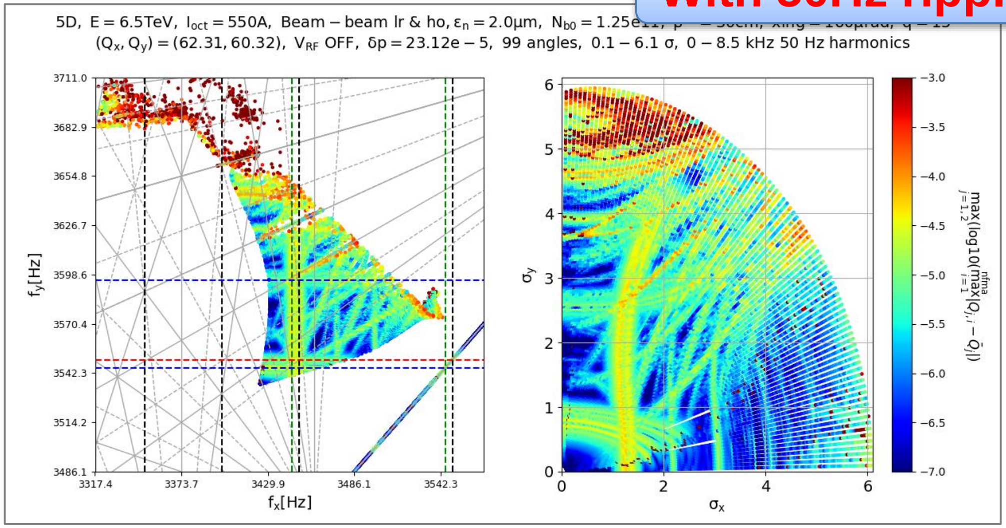


LHC simulations

Without ripple

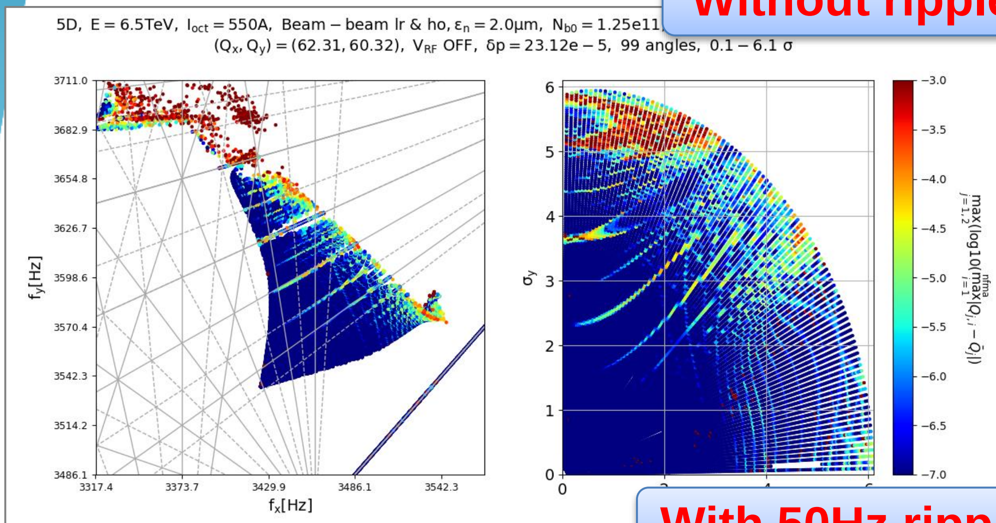


With 50Hz ripples

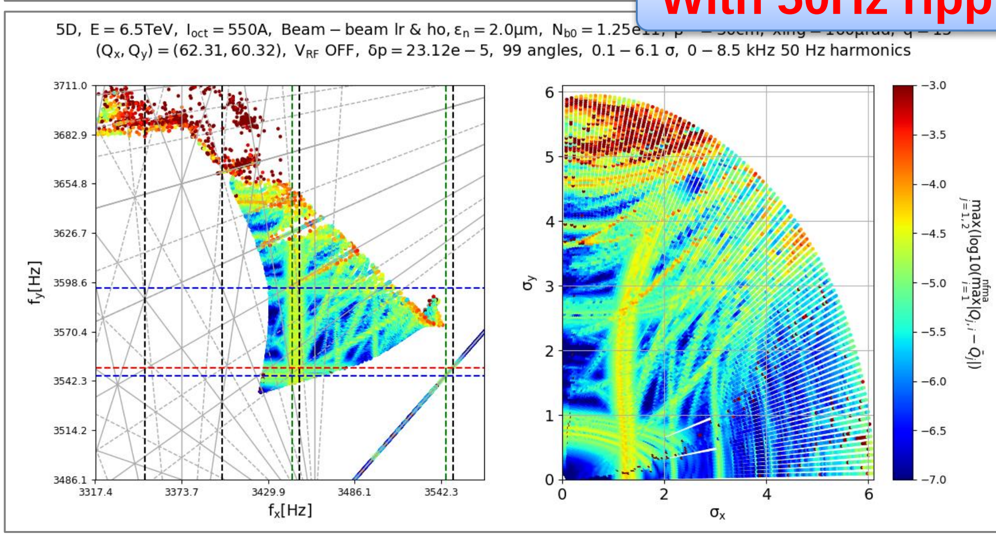


LHC simulations

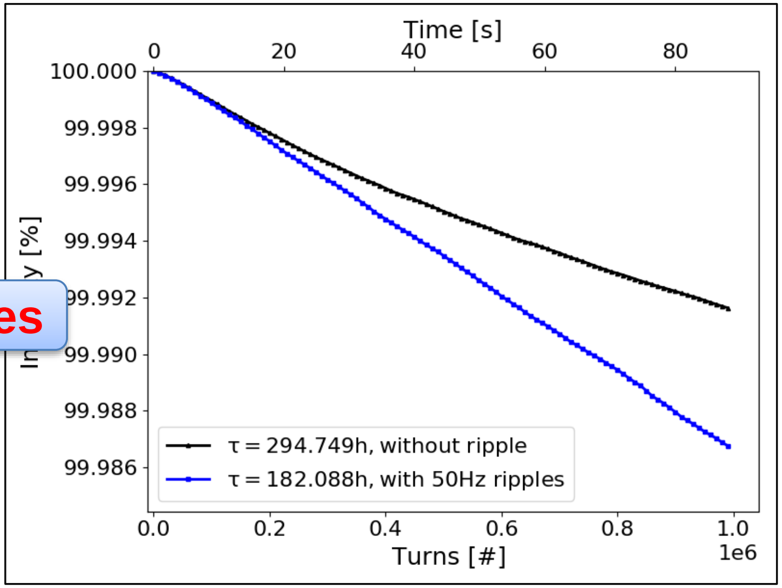
Without ripple



With 50Hz ripples

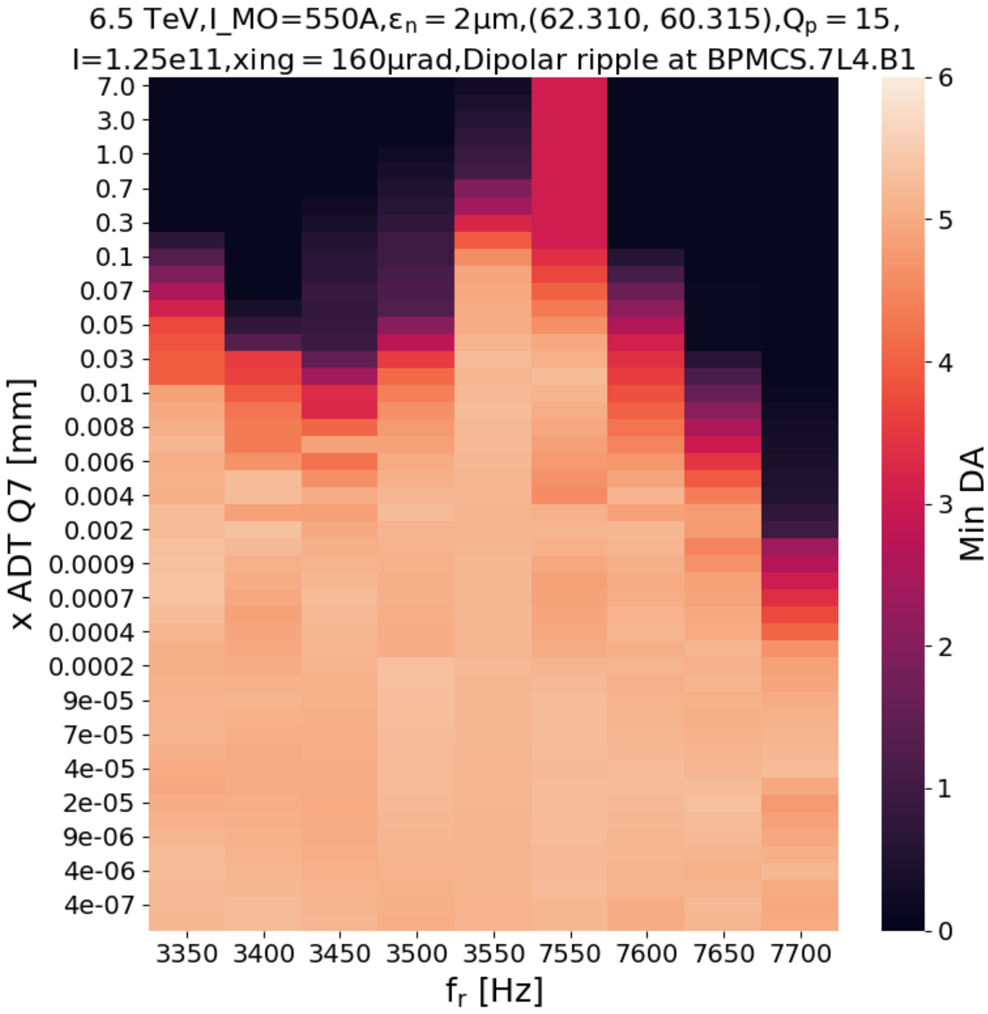


Expected impact on lifetime



Reduction of lifetime from ~295h to ~180h

LHC simulations



Kick in Q7 PU for different frequencies

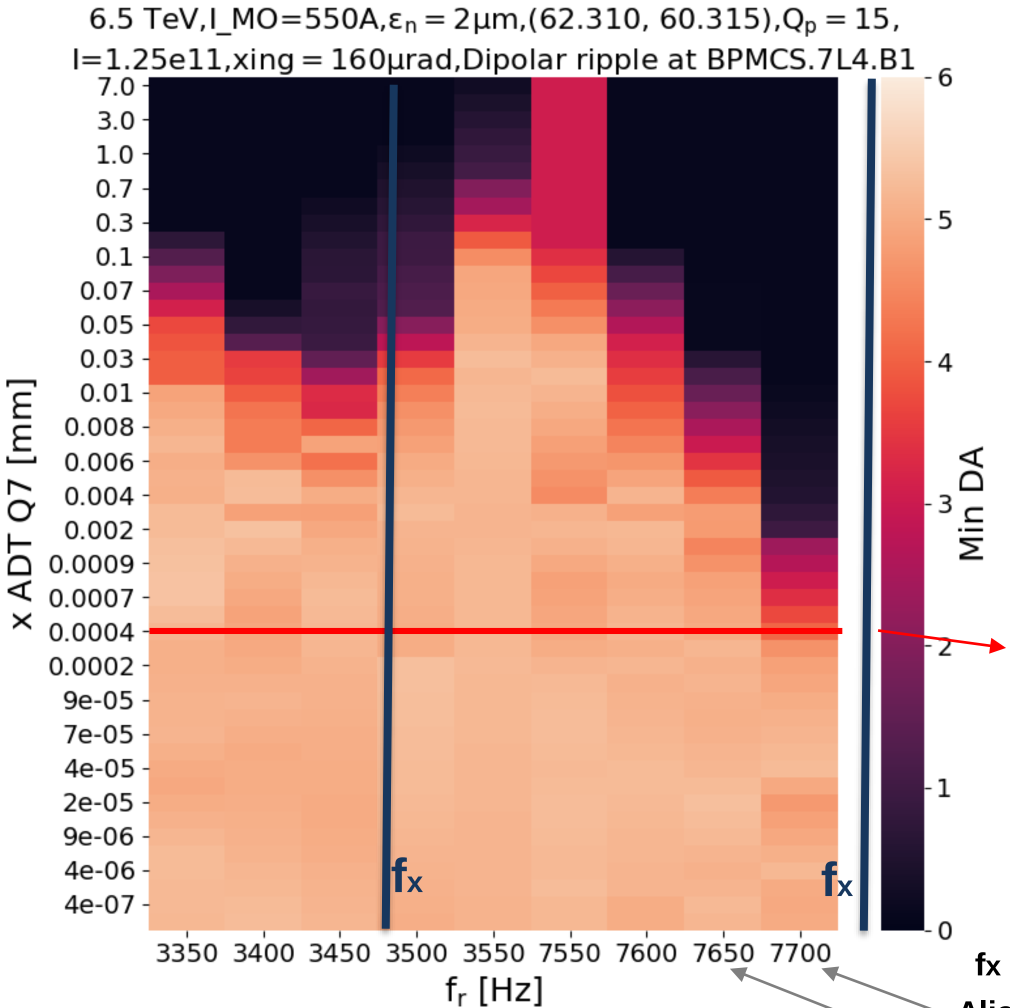
↓

Convert to offset

↓

Compute minimum DA for each scenario

LHC simulations



Kick in Q7 PU for different frequencies

Convert to offset

Compute minimum DA for each scenario

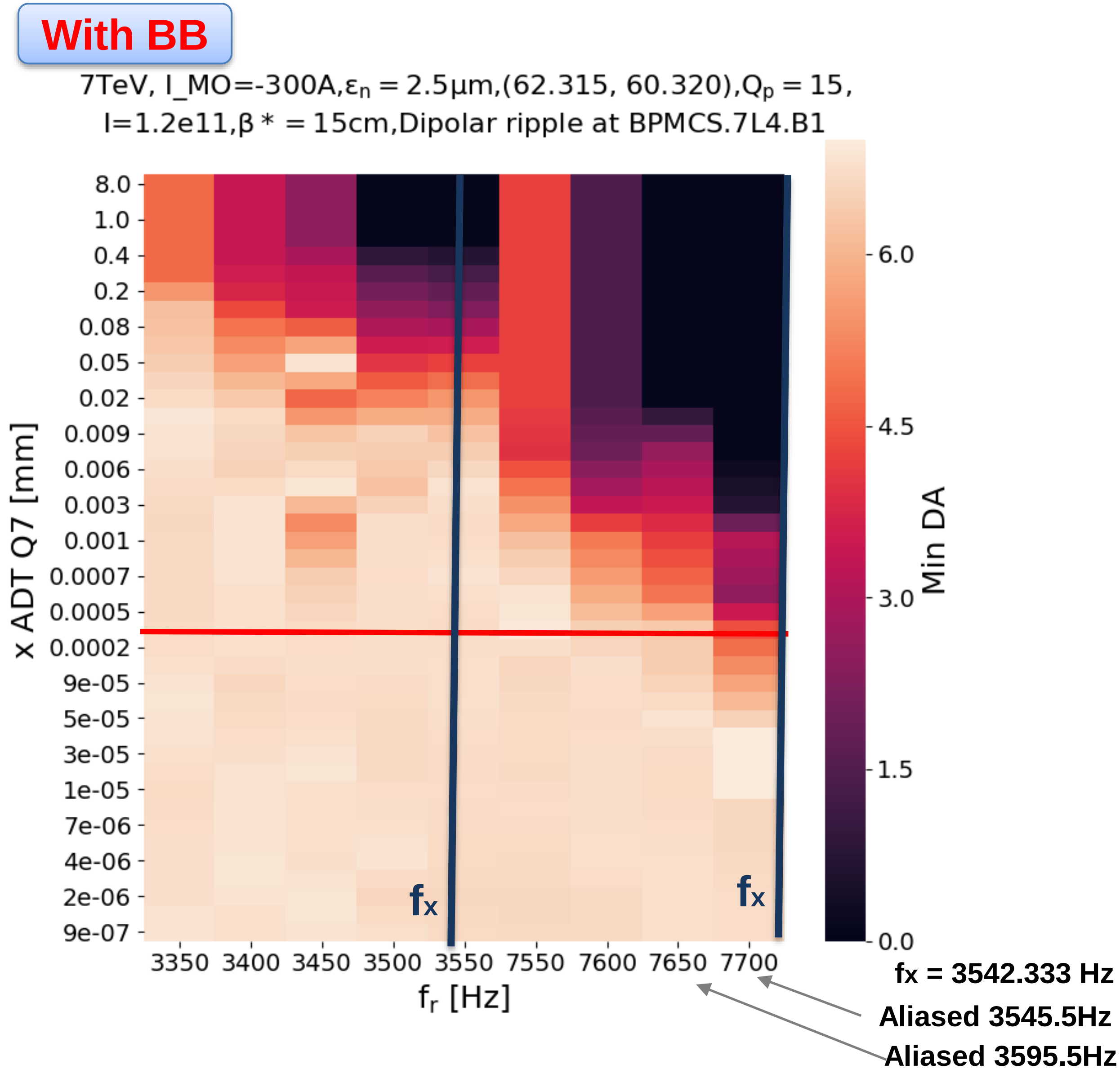
Maximum offset observed

fx = 3486.105 Hz

Aliased 3545.5 Hz

Aliased 3595.5 Hz

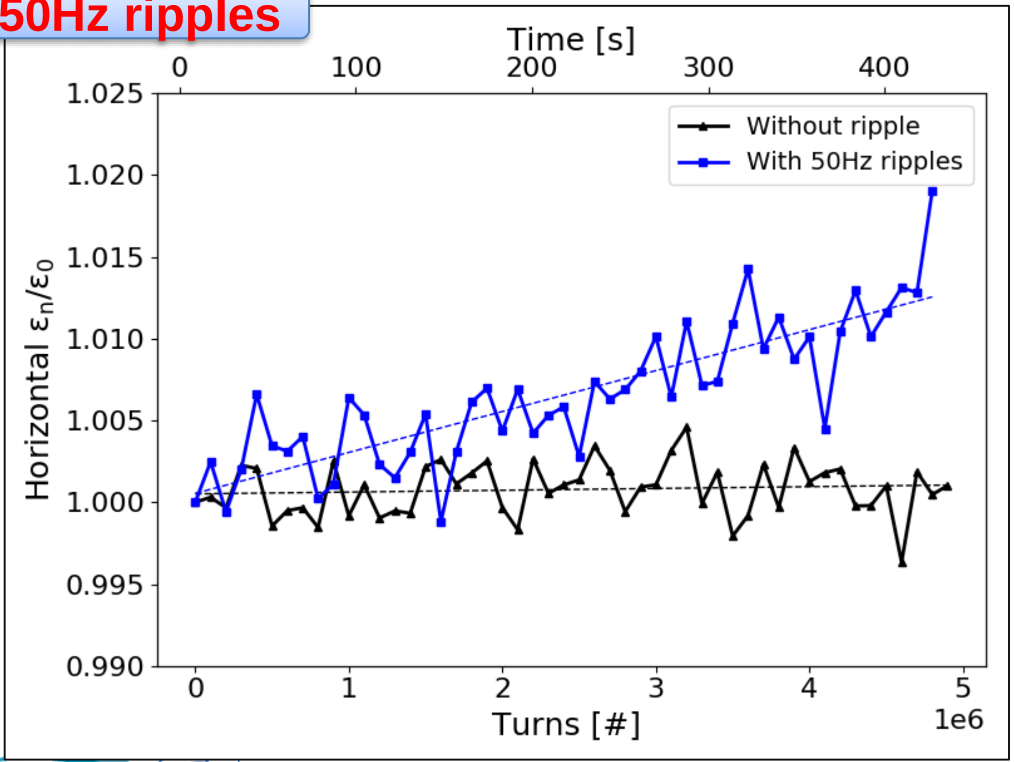
HL-LHC simulations



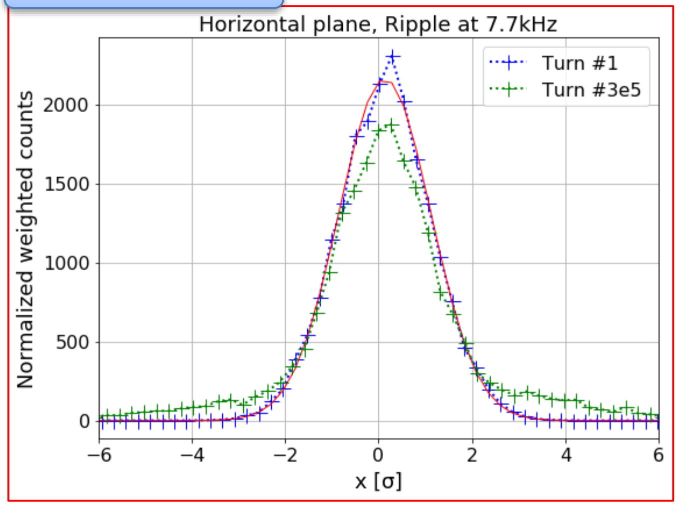
HL-LHC simulations

- By applying an equivalent dipolar kick in the HL-LHC case (without BB at the moment) an emittance growth 0f 0.2μm/h is observed in the horizontal plane.
- However, according to the distribution and phasing of the kicks along the main dipoles, the spectrum can significantly change.

50Hz ripples



At 7.7kHz



Summary

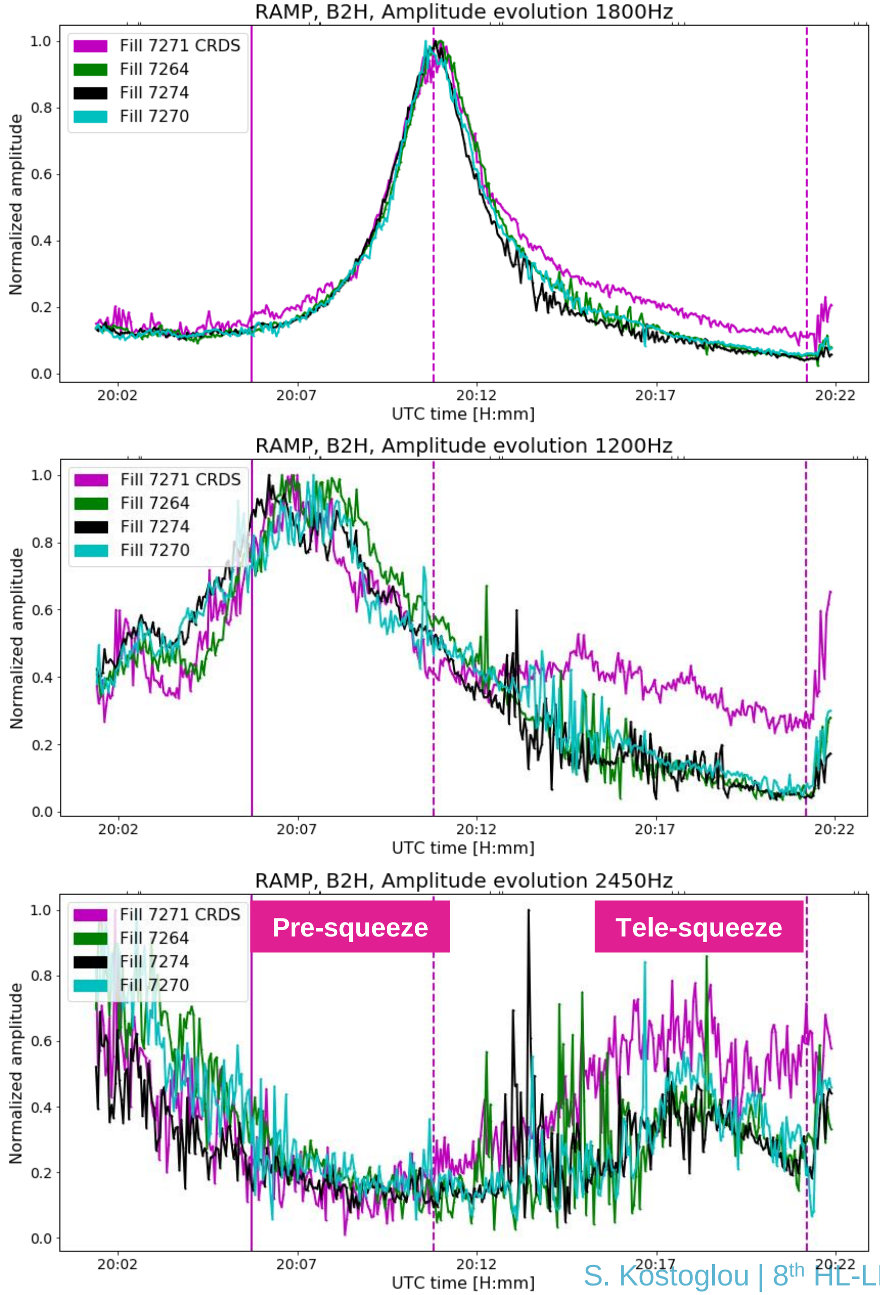
- The 50Hz harmonics are **not an instrumental effect**.
- The spectrum indicates SCR as possible candidates and **a partial correlation between the spectrum of the beam and the spectrum of the power converter of sector12** has been established.
- If the source is indeed the power converters of the main bends (at least for some of the harmonics), 50Hz harmonics **will also be visible in the HL-LHC**.
- Simulations indicate that there is an **impact on the lifetime** of the beam.
- By applying a similar perturbation in the HL-LHC case, simulations indicate that **they can cause emittance growth**, with **7.7 kHz** being the most dangerous frequency -for a WP of (62.315, 60.320).

Next steps:

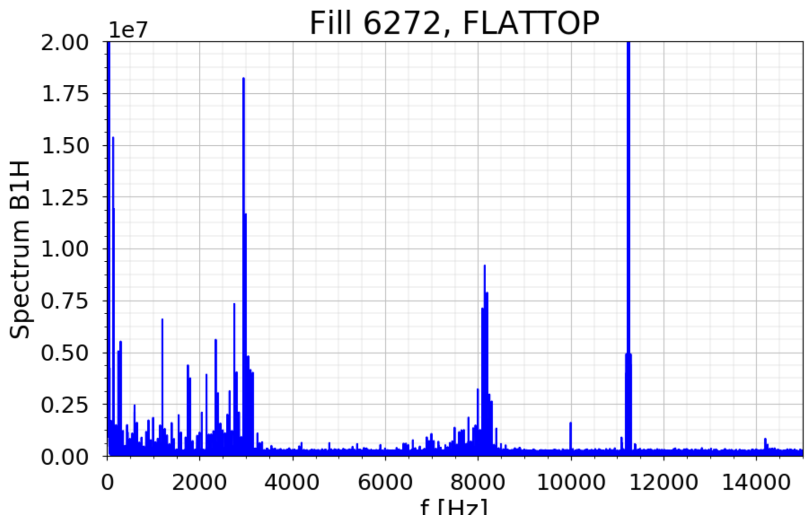
- Analysis of the voltage/current measurements of sector12. Further studies for energy dependence.
- A noise model for the 50Hz from power converters of all sectors, including phase.
- Is there indeed an impact on lifetime?(MD#4)
- Can we inject controlled noise directly on the power converters of the main bends?(MD#4)
- **How can these harmonics attenuate?**

Backup

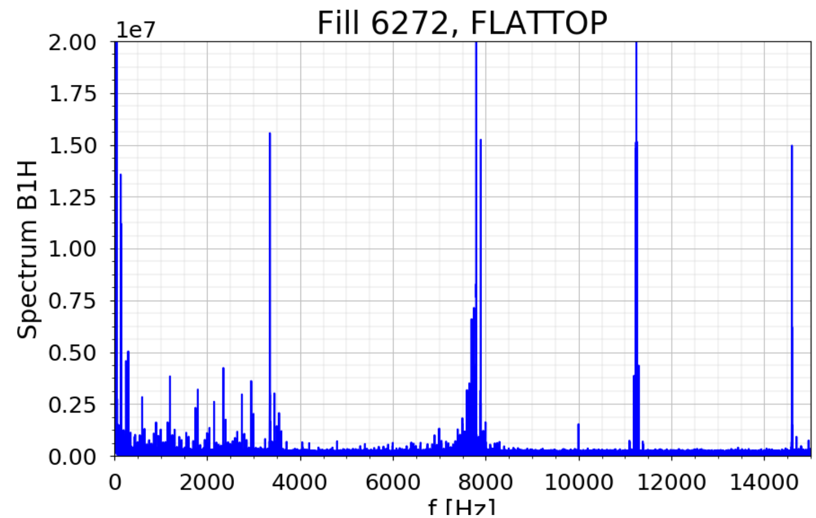
CRDS


RAMP, B2H, Amplitude evolution 1800Hz
Fill 7271 CRDS
Fill 7264
Fill 7274
Fill 7270
Normalized amplitude
UTC time [H:mm]
RAMP, B2H, Amplitude evolution 1200Hz
RAMP, B2H, Amplitude evolution 2450Hz
Pre-squeeze
Tele-squeeze

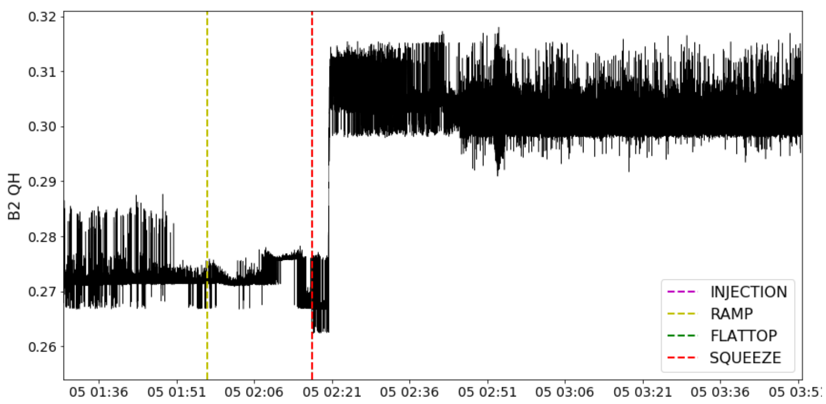
7.5kHz



5/10/2017 02:18 CET, before tune jump



5/10/2017 02:23 CET, after tune jump



LHC simulations

- For a simplified mode, we convert the offset observed in BPMCS.7L4.B1 to an equivalent dipolar kick at the same location.

$$|X(s,N)| = \frac{\sqrt{\beta_{\text{Noise}}\beta(s)}\ |A_{\text{Noise}}|}{|1 - e^{2i\pi(Q_{\text{Noise}}-Q)}|}$$

- Phase and distribution of the dipolar kicks along the main bends are not taken into account in this simplistic model.

Note (I):
The current needed from 1 dipole (eg. MB.A10R3.B1) to observe an offset of 400nm at 7650Hz is:

β=105.98m at Q7 location
β_{noise}=100.84m
Q_{noise} = 7650/11245.5=0.6803->0.3197
Q_x = 0.31
A_{noise} = 2.36e-10rad
θ = 2π/1232~0.005 rad per dipole, I=11kA
I_r = 11[kA]*2.3e-10[rad]/0.005[rad] = 0.519*1e-3A

LHC simulations

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<u>Note (II):</u> There is a change in the spectrum during the tune jump at FLATTOP