Table with the expected sources of noise

Characteristics, origin and mitigation measures

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This is a very dense and partial summary of the work of many teams and people

See extensive bibliography at http://noisestudies.web.cern.ch/

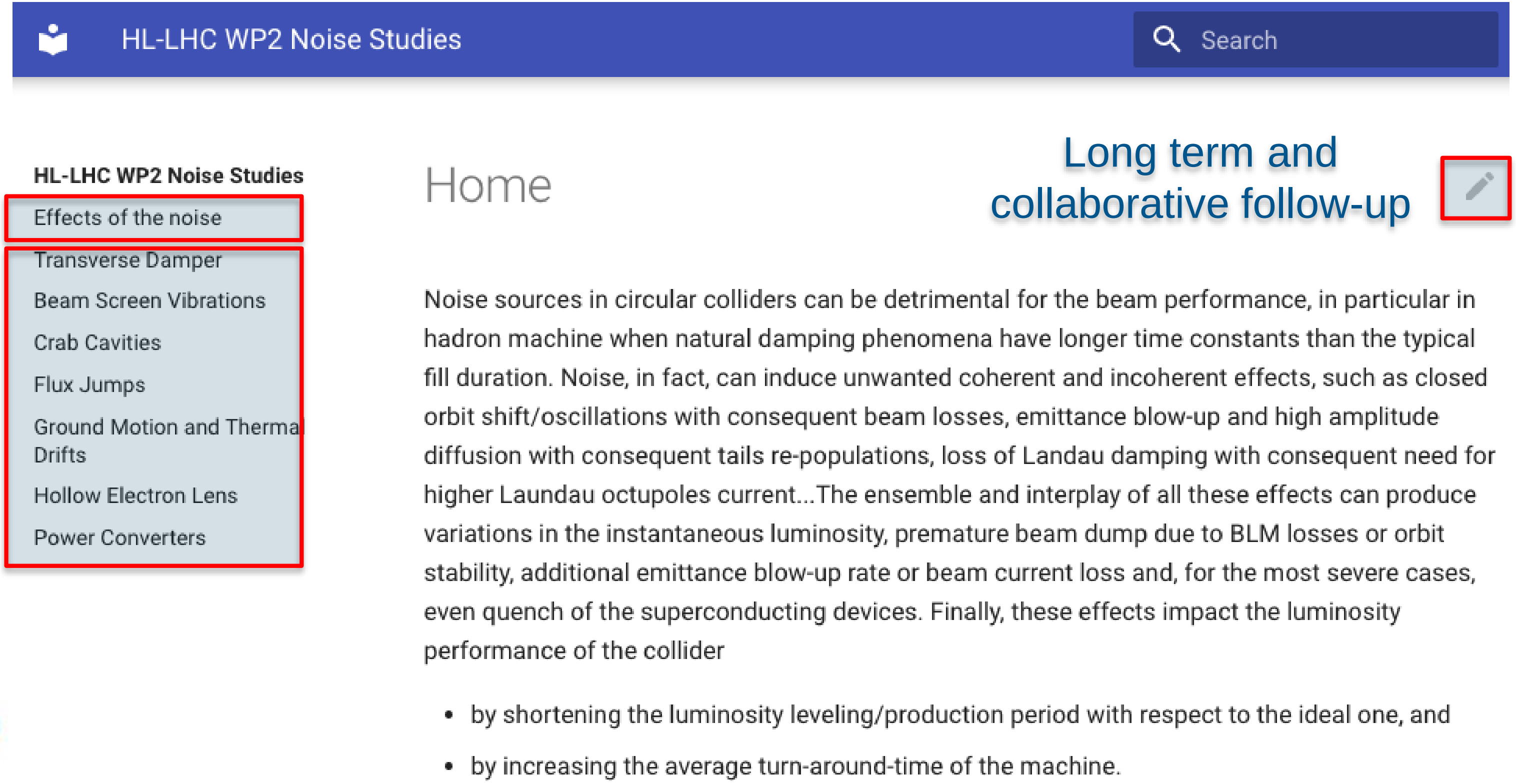
5th May 2020, HL-LHC WP2, https://indico.cern.ch/event/910499/

- We collect at the following site publications and presentations organized per noise source (WP2 action): http://noisestudies.web.cern.ch/

Overview

7 specific sources of noise

Long term and collaborative follow-up


HL-LHC WP2 Noise Studies

Search

HL-LHC WP2 Noise Studies

- Effects of the noise
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Home

Noise sources in circular colliders can be detrimental for the beam performance, in particular in hadron machine when natural damping phenomena have longer time constants than the typical fill duration. Noise, in fact, can induce unwanted coherent and incoherent effects, such as closed orbit shift/oscillations with consequent beam losses, emittance blow-up and high amplitude diffusion with consequent tails re-populations, loss of Landau damping with consequent need for higher Laundau octupoles current...The ensemble and interplay of all these effects can produce variations in the instantaneous luminosity, premature beam dump due to BLM losses or orbit stability, additional emittance blow-up rate or beam current loss and, for the most severe cases, even quench of the superconducting devices. Finally, these effects impact the luminosity performance of the collider

- by shortening the luminosity leveling/production period with respect to the ideal one, and
- by increasing the average turn-around-time of the machine.

- Noise sources are unwanted **stochastic AND time-dependent** lattice properties affecting, potentially, HL-LHC and LHC performance. The majority of the the studies concentrate on linear effects (**dipolar** and **quadrupolar**).
- The following are **NOT** considered as noise sources
  - static magnetic field quality and/or fringe field,
  - electron cloud,
  - beam-beam effect in nominal and/or PACMAN bunches,
  - emittance blow-up due to luminosity burn-off or intra-beam scattering,
  - injection oscillations,
  - transverse and longitudinal instabilities,
  - long term (> fill duration) reproducibility of the power supplies,
  - high order mode of the RF devices (namely the crab-cavities),
  - aperture restriction due to mis-alignment, mechanical obstructions (ULO) or limited closure of crossing/dispersion/crabbing bumps,
  - contamination of the BS/vacuum chamber (16L2-type),
  - UFO events,
  - quench triggered by spurious EM signals,
  - hardware failure,...

Noise source mechanism

Noise source	Mechanism of beam interaction	Dipolar/quadrupolar
GM: ground motion and thermal effect	**Seismic noise/thermal drift/ancillary mechanical device vibrations** (mechanically coupled with the cold masses/magnets): change of the magnetic center of quadrupole (and higher multipoles).	**Dipolar** effect considered due to quadrupolar feed-down.
BS: beam screen vibrations	Induced by seismic noise and/or by **turbulent He cooling flow**. At high frequency the field follow the BS therefore a vibration is equivalent to dipolar kicks.	**Dipolar** considered (BS offset or BS radius vibration).
ADT: damper	Dominated by the **PU noise** (Lebedev model). The kicker reacts to the noise of the PU and excites the beam.	**Dipolar** (by construction).
PC: power converters	By construction, **harmonics of the commuting frequency** of the semiconductor device perturb the PC output and, after filtering (inductive load, vacuum chamber, beam screen), perturb the magnetic field, hence the beam.	**Dipolar** and **quadrupolar** considered.
CC: crab cavities	Dominated by the **LLRF noise** in terms of amplitude and phase of the RF kick.	**Dipolar** (by construction).
FJ: flux jump	Related to well known physics of the **Nb3Sn technology** (and its mild interplay with the PC). Variation of the field in the magnet.	Much more information on the **dipolar** noise effect. Preliminary consideration on **quadrupolar** effect have been made.
HEL: hollow electron lens	Interaction with the the beam core due to **non-symmetric distribution of the electrons** with respect beam orbit (at the moment no intra-bunch effect is expected/studied). S-shape HEL compensate most of the “edge” effects.	Studies concentrated on **dipolar** kick.

Potential effects on the beam

Noise source	Potential effects on the beam	Direct observation in LHC?
GM: ground motion and thermal effect	**Orbit effects** → Instantaneous Luminosity jitter and beam losses at TCP (possible dumps)	**Yes** (during CE work in 2018 or earthquakes). It induced BLM dumps in LHC (10 Hz).
BS: beam screen vibrations	**Orbit effects** → Instantaneous Luminosity jitter and beam losses at TCP (possible dumps) *Higher frequency (>1 kHz) can cause emittance blow-up and halo repopulation.*	**No for f>50 Hz.** Specific test conducted in 2006. New BS will be tested (not in the STRING).
ADT: damper	**Emittance blow-up**, beam lifetime and halo repopulation → Integral luminosity and beam losses, latency in instabilities.	**Yes.** Lower noise PU expected in Run3.
PC: power converters	**Emittance blow-up**, beam lifetime and halo repopulation → Integral luminosity and beam losses, latency in instabilities. *Tune-tracking degraded. Tune-modulation.*	**Yes, dipole noise** (since Run1, extensive observations in 2018). **No, quadrupole noise** (tune modulation).
CC: crab cavities	**Emittance blow-up**, beam lifetime and halo repopulation → Integral luminosity and beam losses, latency in instabilities.	**No.** Extensive MD program in SPS in 2018.
FJ: flux jump	**Orbit effects** (mainly) → Instantaneous Luminosity jitter and beam losses at TCP (possible dumps)	**No.** *More data expected in Run3 (11 T dipoles).*
HEL: hollow electron lens	**Emittance blow-up**, beam lifetime and core diffusion → Instantaneous Luminosity jitter and beam losses at TCP (possible dumps)	**No**. MD studies in LHC during Run2.

Localization of the noise source: s-dependence

Noise source	Single or multiple locations in the lattice?
GM: ground motion and thermal effect	Distributed effect (in principle). In practice **dominated by the triplets** (but exception for the '10 Hz'-event). Depending of the frequency (>3 Hz), *limited spatial correlation is expected*.
BS: beam screen vibrations	In practice **dominated by the triplets**. If induced by the He cooling flow, *no spatial correlation expected.*
ADT: damper	**Localized** at the ADT kickers.
PC: power converters	**Distributed.** *Spatial correlation expected for PCs powering a long string of magnets (difficult to compute above few tens of Hz).*
CC: crab cavities	**Localized** at the CC location.
FJ: flux jump	**Localized** at the Nb3Sn magnets (IR1/5 triplets and 11 T dipoles).
HEL: hollow electron lens	**Localized** at the HEL.

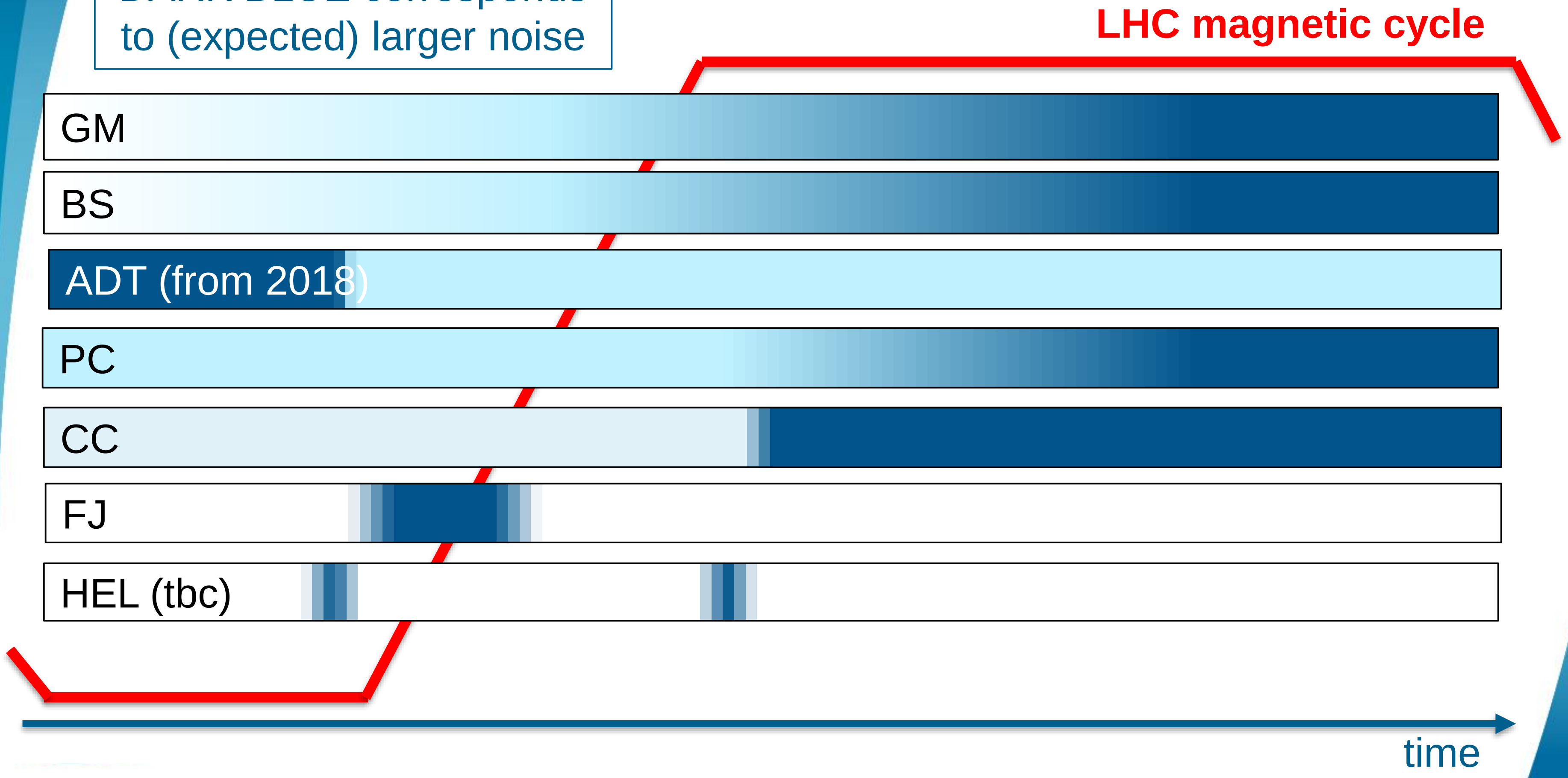
Effects along the beam cycle: t-dependence

Noise source	Effects along the beam cycle
GM: ground motion and thermal effect	Despite the GM and thermal effect are always present, effect mainly optics-driven (high value of beta-function in the triplets): **mainly at FLATTOP and for high tele-index.** To consider evolution with Geothermie2020.
BS: beam screen vibrations	See GM. **Mainly at FLATTOP and for high tele-index.**
ADT: damper	**During the full cycle but dependent** on gain of the ADT settings and of the beam tune spread…(Lebedev model).
PC: power converters	**Dipole component: observed during the full cycle.** **Quadrupole component: larger at high tele-index.**
CC: crab cavities	Studies focus when crabbing bump is active (**FLATTOP**).
FJ: flux jump	**Mainly during the first part of the ramp (<3 TeV).**
HEL: hollow electron lens	**Mainly when the HEL is powered in resonant mode** (most likely a cleaning of the tail will be done after the injection and before the squeeze, tbc)

HiLumi HL-LHC PROJECT

Effects along the beam cycle (simplified)

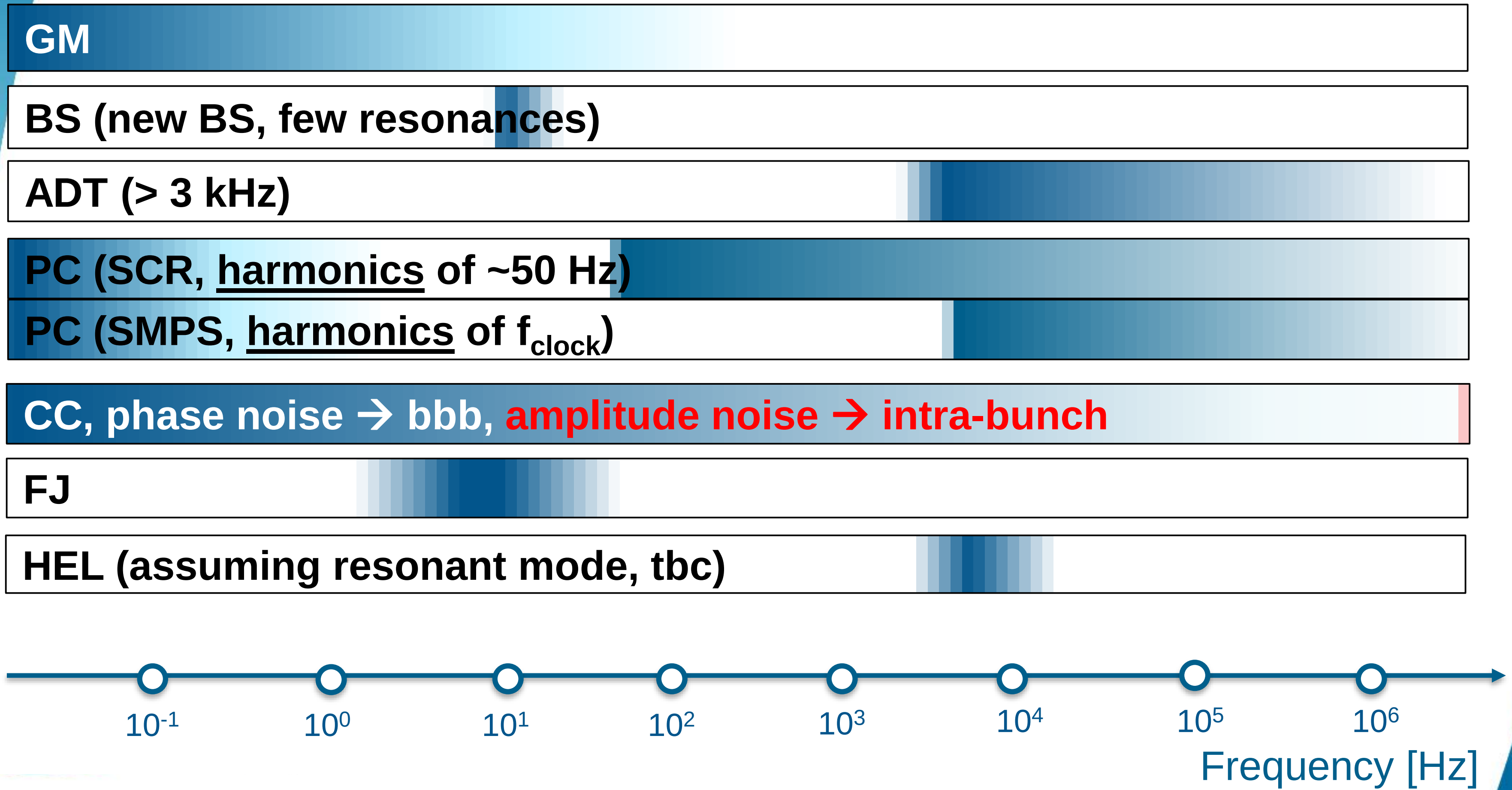
DARK BLUE corresponds to (expected) larger noise



Expected frequency spectrum of the noise

Noise source	Frequency spectrum
GM: ground motion and thermal effect	**From DC to ~100 Hz**, but significant contribution expected at the resonance of the triplets (~21 Hz).
BS: beam screen vibrations	New BS are quite massive due to the tungsten masks (~500 Kg/~10 m). First three modes resonance between **10-20 Hz**. Test of vibration induced by turbulent flow planned but minor effects are expected.
ADT: damper	The noise is in the ATD BW, **3 kHz – 1 MHz** (20 MHz in extended mode).
PC: power converters	**Harmonics of the switching frequency**. Depending on the technology (**SCR**, silicon-controlled rectifier, or **SMPS**, switched-mode power supply), the switching frequency can very different (from ~50 Hz for SCR to up to 200 kHz for the SMPS)
CC: crab cavities	Two very different mechanism: **phase and amplitude noise**. Both originated by the noise of the LLRF loops (from DC to 100 kHz). The first one will appear as a **bbb** kick while the second is equivalent to an **intra-bunch** kick (hence beyond ADT capability)
FJ: flux jump	**Magnetic measurement show effects mainly between 10-100 Hz**
HEL: hollow electron lens	**Spectrum will depend on the powering mode.** Assuming resonant excitation, one should expect noise from the first betatron line (>3 kHz). Intra-bunch kick is not considered.

Expected frequency spectrum (simplified)



Expected impact on the beam

Noise	Orbit effect expected	Emittance blow-up
GM	**HL-LHC twice more sensitive than LHC. The 10-Hz noise induced 10 dumps in Run2.** Triplet expected vertical motion (magnetic axis) below 0.04 μm (for f>3 Hz) and a consequent expected luminosity losses <0.1%. Monitor effect of Geothermie2020.	**Negligible**.
BS	**None additional to GM** (rigid motion triplets-BS wrt the CM).	**Negligible**.
ADT	**Negligible.**	**Estimated in LHC (Lebedev model fit, gain of 50 turns) in 2%/h emittance growth in LHC. To maintain a similar level for HL-LHC, ADT PU noise needs be reduced by x4.** Lebedev model implemented in the LHC luminosity model: ~0.12 um/h at injection, ~0.045 um/h in production.
PC	**Negligible.**	DIPOLES: Simulations show **impact on lifetime** (~15% reduction). QUADRUPOLES: **Negligible**.
CC	**Negligible.**	Expected **3.7%/h** (amplitude noise) and **0.94%/h** (phase noise).
FJ	DIPOLE FJ: **below BLM threshold.** QUADRUPOLE FJ: **more critical (induced dumps expected in a non negligible number of beam)** but input needed.	**Negligible**.
HEL	**Negligible.**	MD studies report effects larger than the ones (negligible) expected from simulations. Details depend strongly on the resonance mode selected. The **dipole kick assumed is 15 nrad** (this equivalent to 3e-6 stability of a single main bend).

Possible mitigations*

DIPOLE perturbation

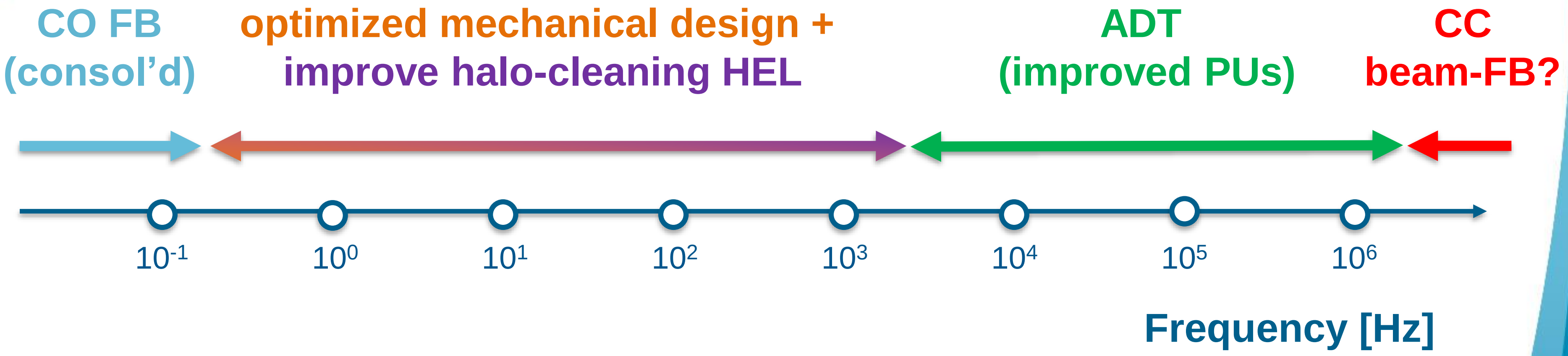
- **ADT** is expected to suppress dipole excitation (**f>3 kHz**, within the limits of the its own noise and of the beam tune spread)
- **CO** feedback will address only slow drift (**f<0.2 Hz**)
- In the region **0.2 Hz<f<3 kHz,** where main triplets/BS/'10Hz' modes lies,
  - optimized **mechanical design** of the new triplets
  - improved cleaning efficiency of halo (**HEL**)
- At the moment, intra-bunch motion (CC amplitude noise and CC RF curvature, **f>40 MHz,** large efforts to reduce LLRF noise) has no safety-net**.** Encouraging simulation results of CC beam-based feedback (but not in the baseline)

QUADRUPOLE perturbation (not critical effect expected)

- **no active way** to address the tune modulation (tune feedback is too low in BW).
- Increase the f_{clock} of the triplets switching-mode PC if possible.

* after having minimized the problem at the source

Possible mitigations* (dipole, simplified)



* after having minimized the problem at the source

Conclusions

For HL-LHC we expect several possible sources of noise. Some of them are present and visible in LHC, others are related to HL specific technology.

They are very diverse with respect to the underlying physics mechanism and cover a wide frequency range (from sub-Hz drift to ~1 GHz intra-bunch kicks). Most of them are dipolar perturbations.

An effort to classify them into common categories has been made trying to find a reasonable balance between synthesis and simplification.

The presented tables should be considered as an entry point for a general overview, useful to bridge the different topics. It should be always backed up by the references and resources collected in http://noisestudies.web.cern.ch/.