Emittance growth due to decoherence of external excitations in the LHC and HL-LHC

X. Buffat, S.V. Furuseth, D. Gamba

WP2 meeting – 10.04.2018

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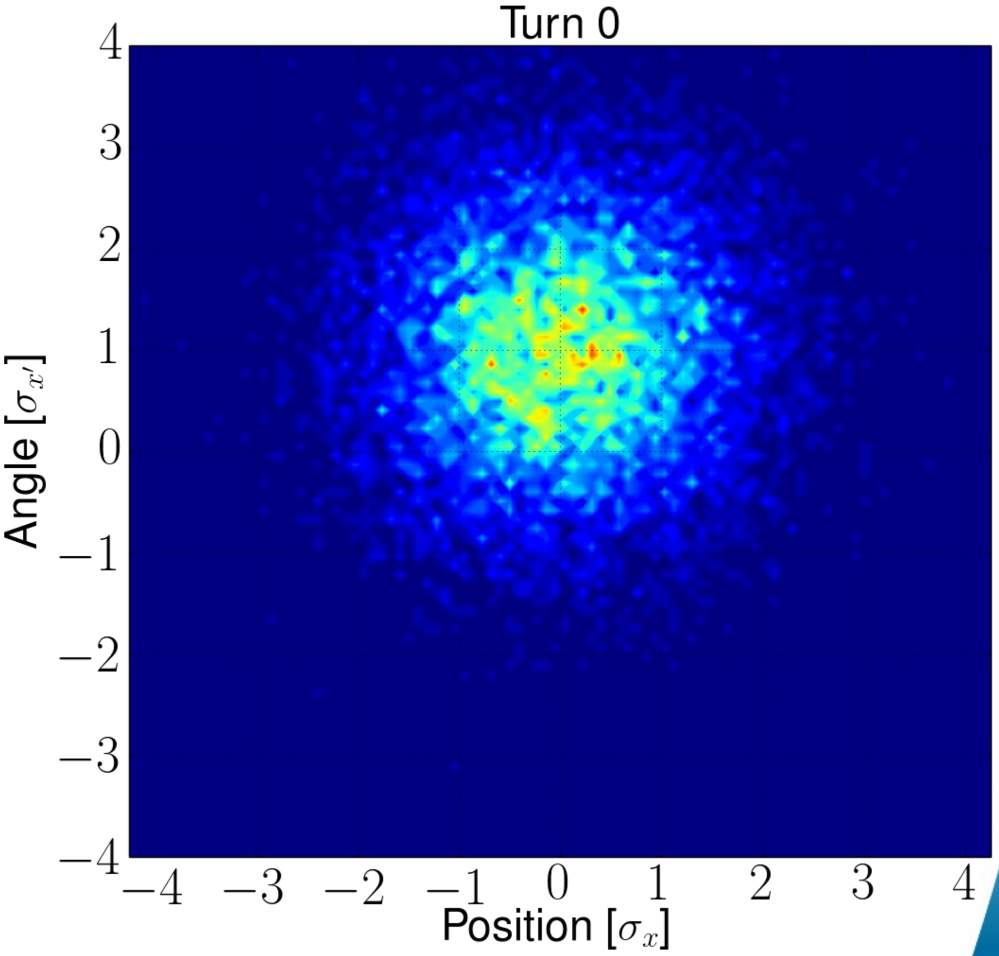
- Decoherence models
- Analysis of external noise sources
  - ADT
  - Field ripple
  - Ground motion
- LHC and HL-LHC
  - Collision
  - Injection

Decoherence model

- The decoherence is the result of damping of a coherent oscillation due the desynchronisation of single particles oscillating with different frequencies
- Requires an excitation at the coherent mode frequency (>kHz)
- The combined effect with resonances (incoherent effects) is neglected



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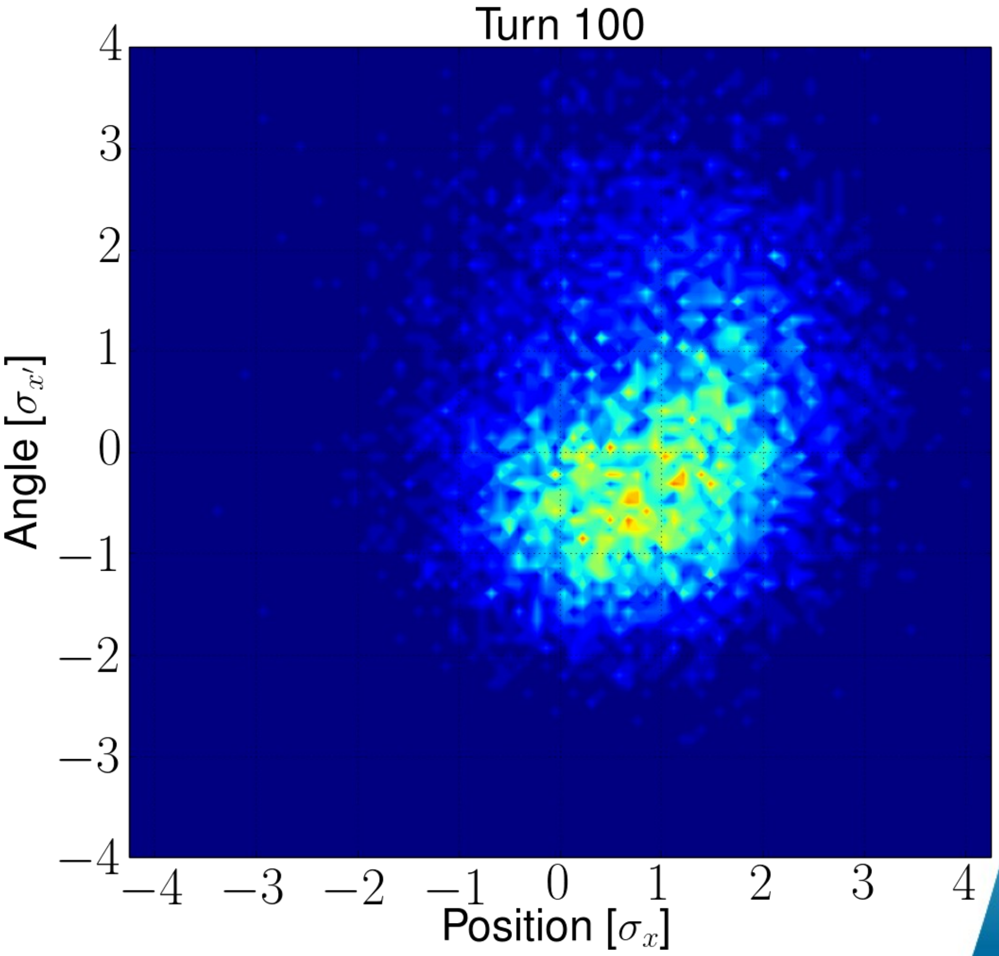

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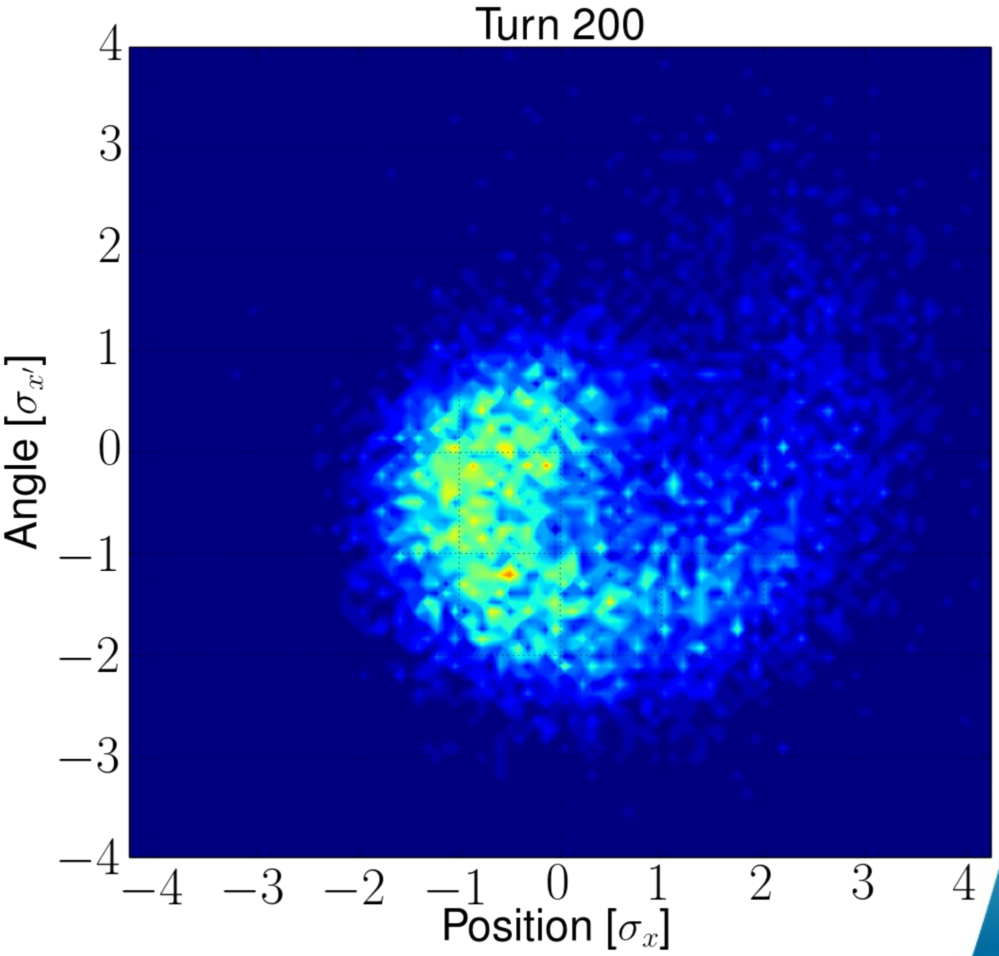

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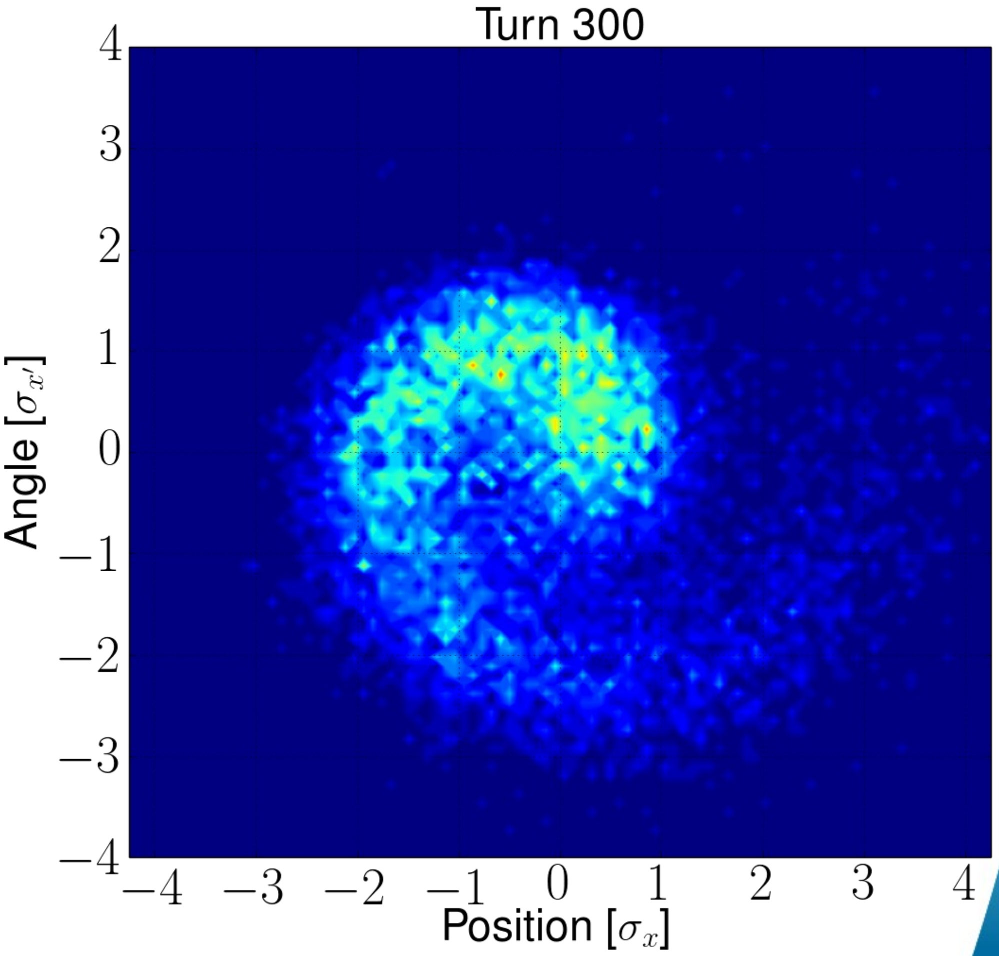

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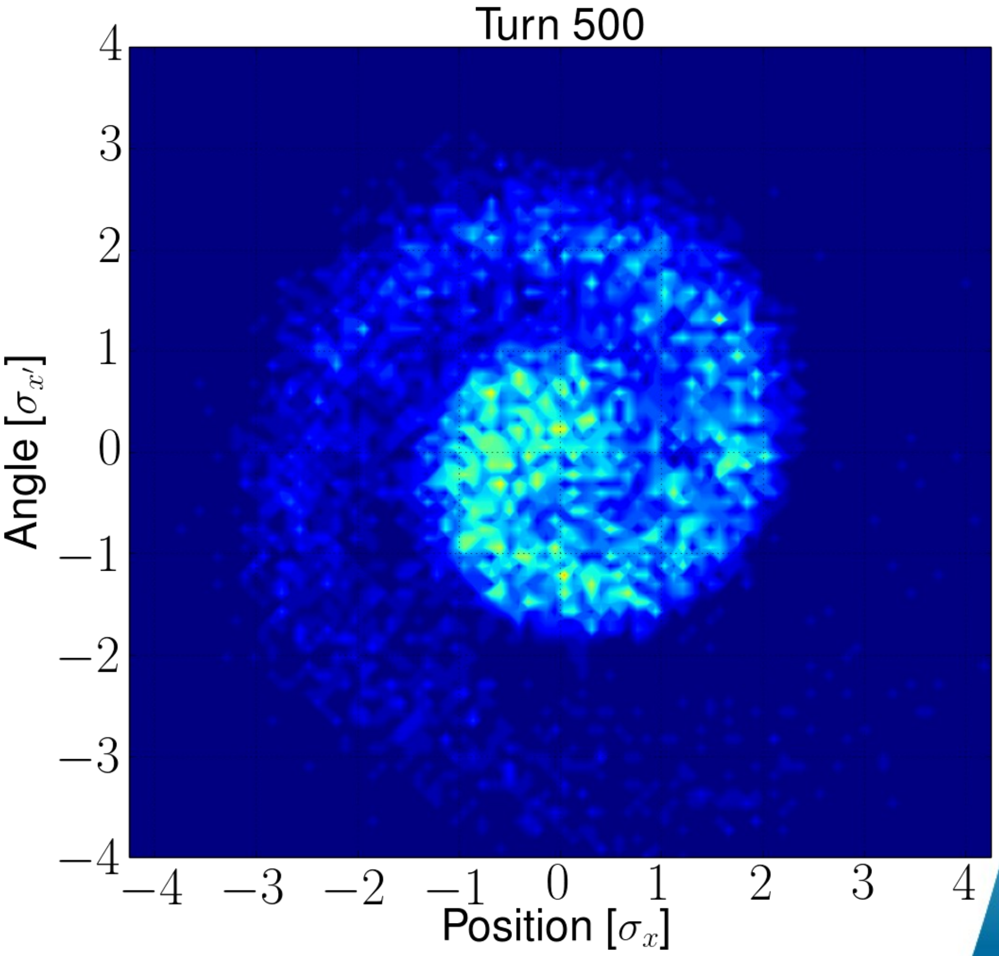

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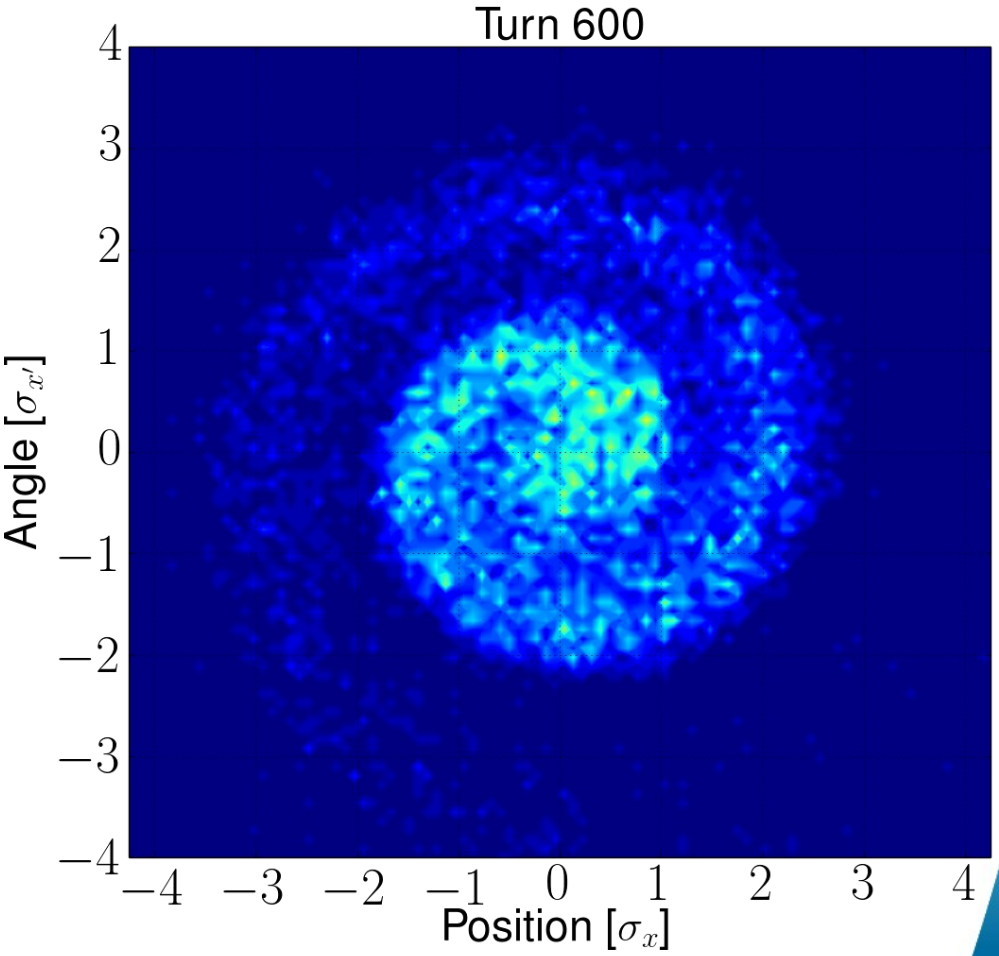

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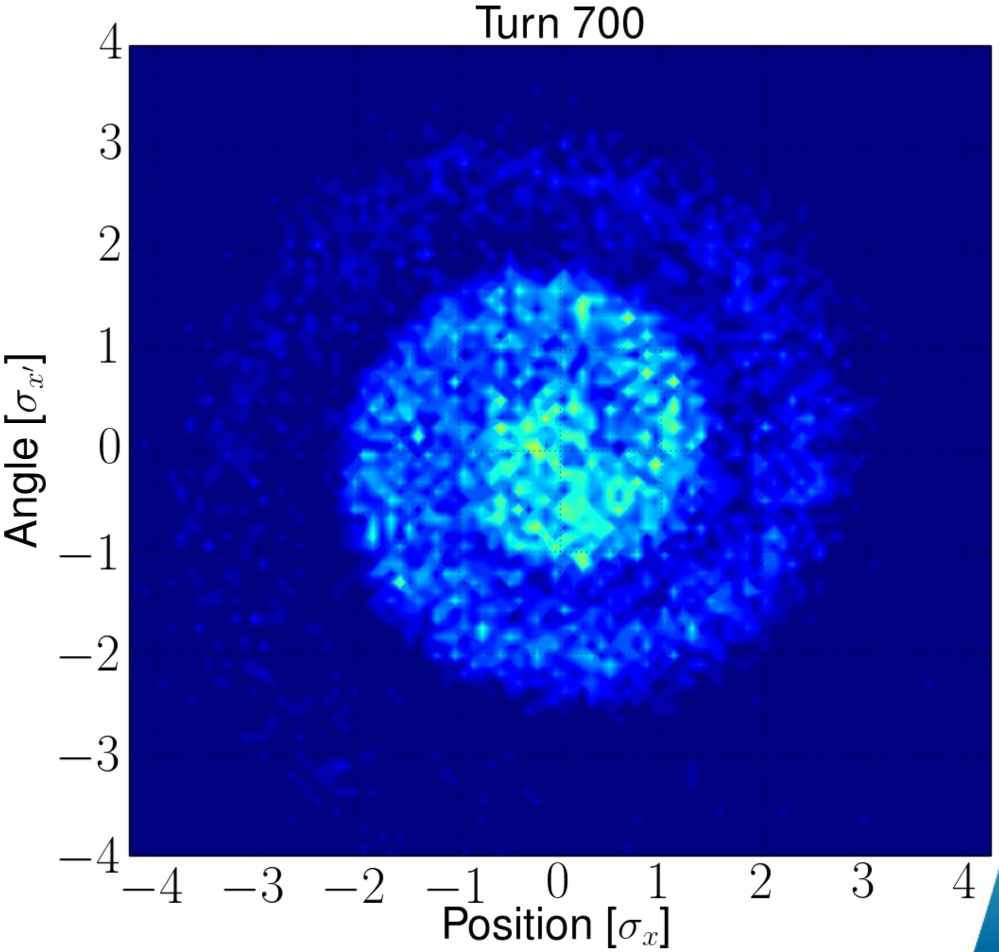

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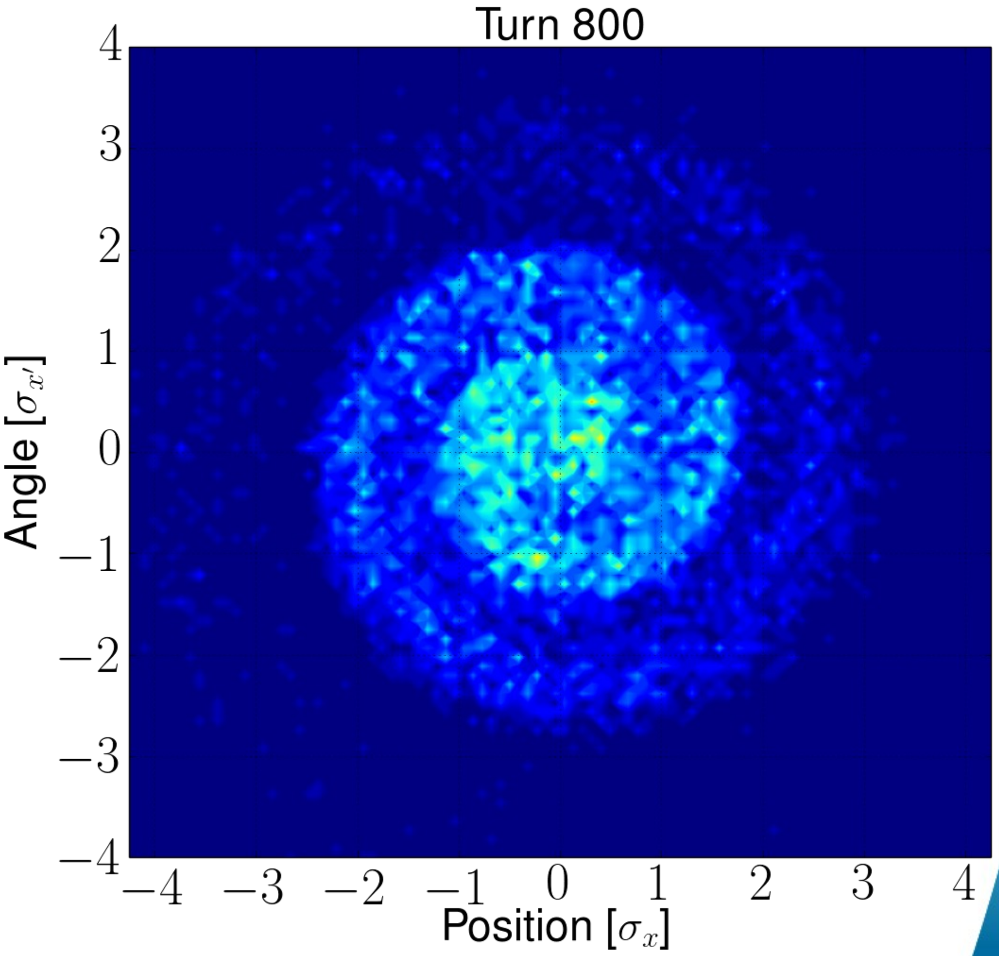

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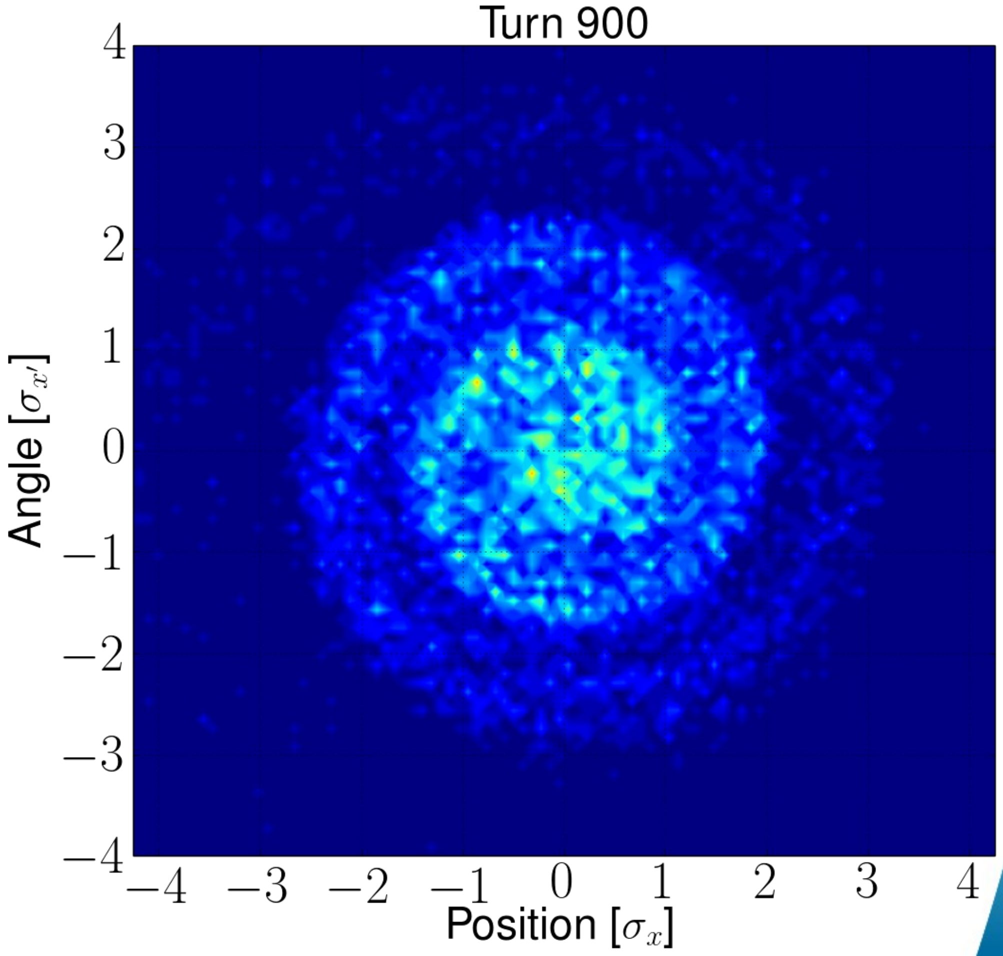

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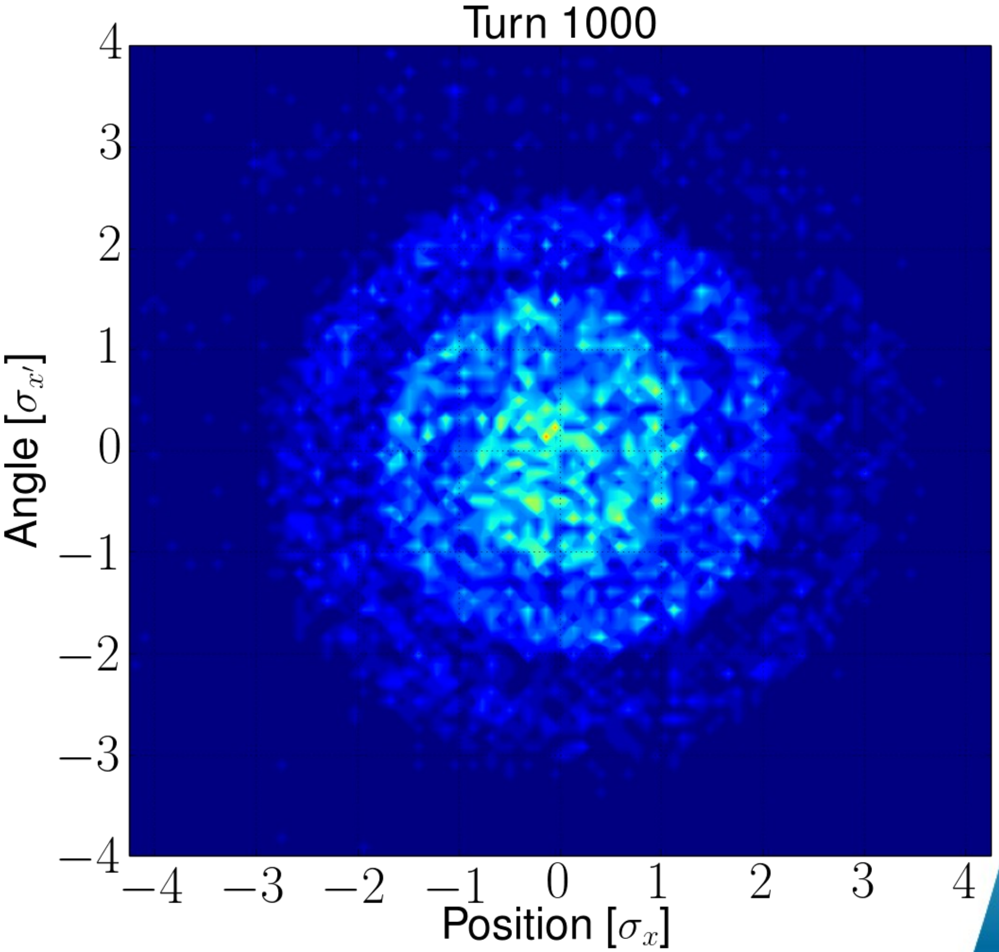
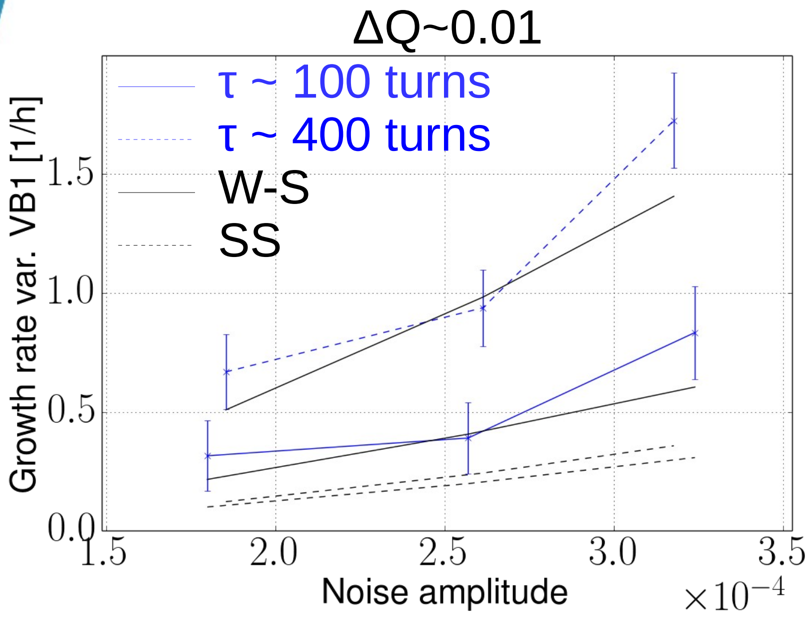
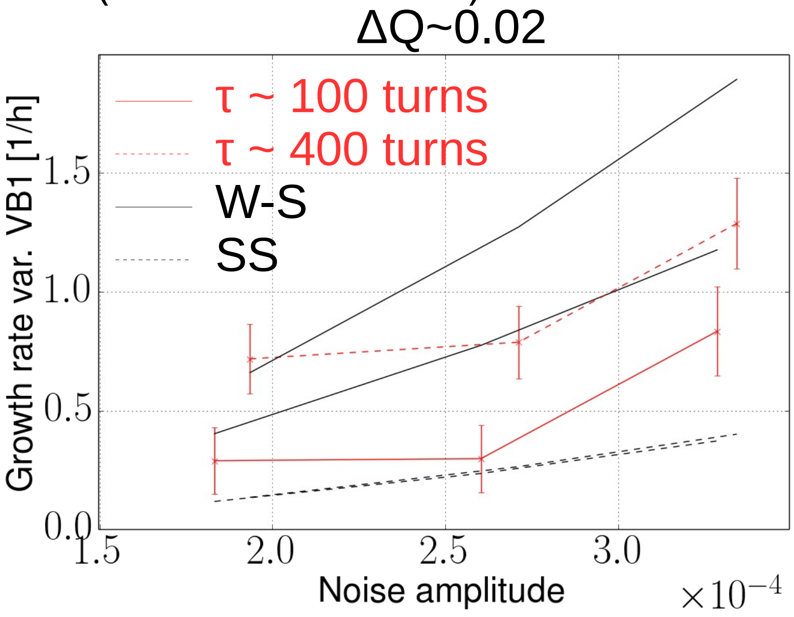


Validity of the models - Experimental results (WP2 13.06.2017)





- The variation of the emittance growth rate due to the head-on beam-beam interactions as a function of the injected noise amplitude follows the W-S model predictions in most cases. In others, the measured variation lies in between the W-S and S-S model, as can be expected depending on phase advance between IPs in the two beams

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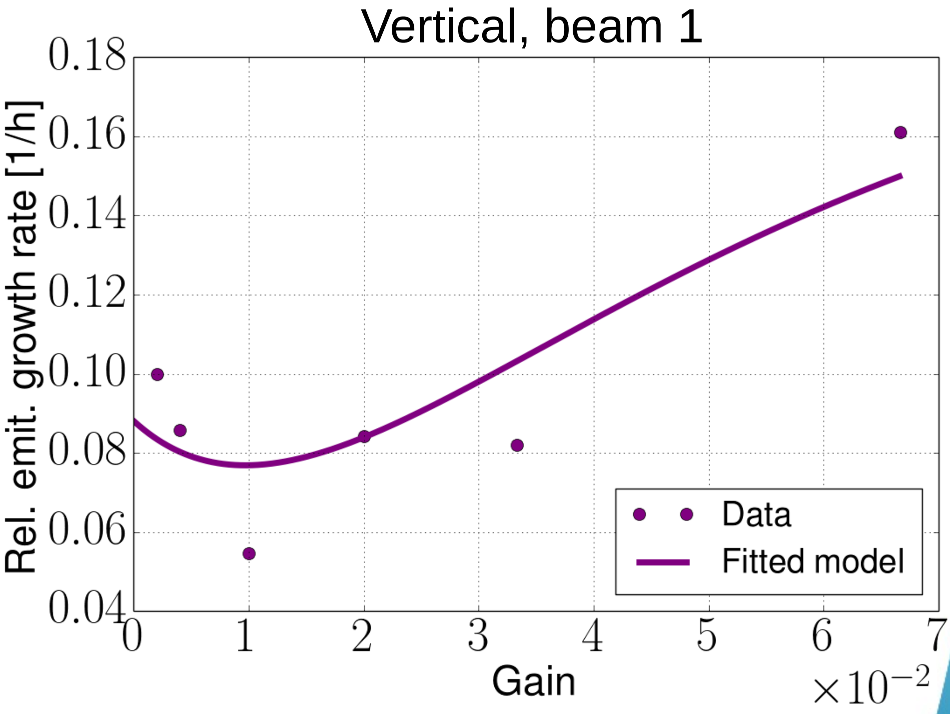
Noise on colliding beams – ADT and lattice noise floor (Madrid 2017)

- We use Lebedev's decoherence model to measure the ADT and lattice noise floor

$$\frac{1}{\epsilon}\frac{d\epsilon}{dt} = \frac{1}{2}\left(\delta_0^2 + G^2\delta_{BPM}^2\right)\left\langle \frac{4\pi^2\left(1-\frac{G}{2}\right)^2\Delta Q^2}{4\pi^2\left(1-\frac{G}{2}\right)\Delta Q^2 + \left(\frac{G}{2}\right)^2} \right\rangle$$



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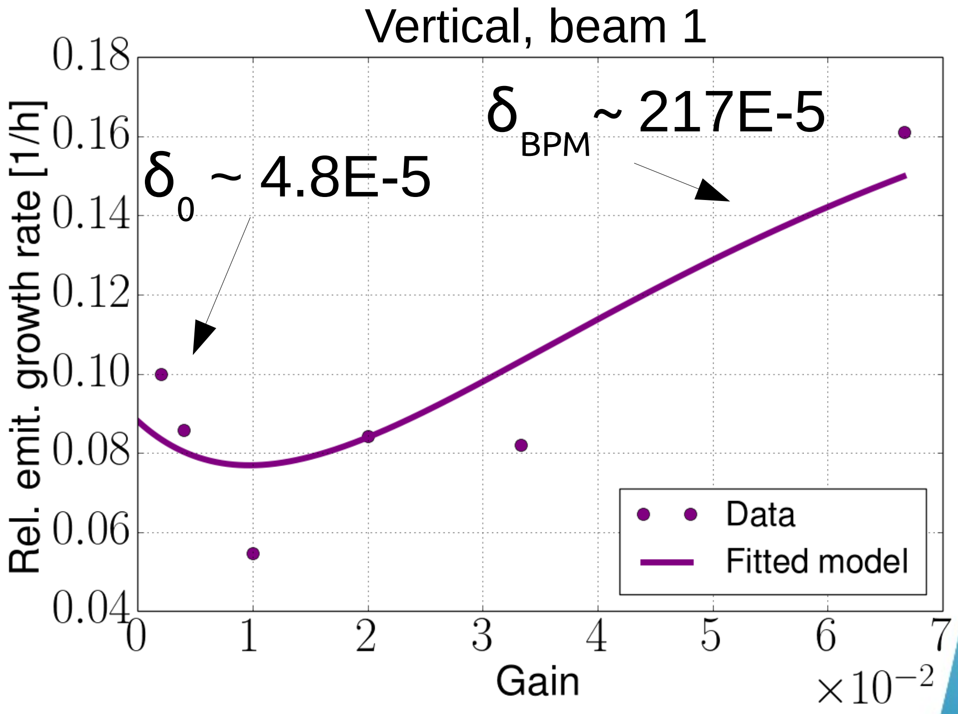

- The pickup noise corresponds to a noise floor of 0.9 μm per pickup (two pickups per beam per plane) compatible with specifications
- Is the natural emittance growth (i.e. without ADT) compatible with other external sources of noise ?

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Dipole and quadrupole field ripple

- The total noise floor is obtained by summing in quadrature the effect of the circuits (independent noise sources) and linearly the effect of the individual magnets, noramlised to the beam divergence :

$$\delta_{tot} = \sqrt{\sum_{i}^{N_{circuit}} \left(\sum_{k}^{N_{magnet}(i)} \frac{\Delta_{i,k}}{\sigma_{x'}} \right)^2}$$

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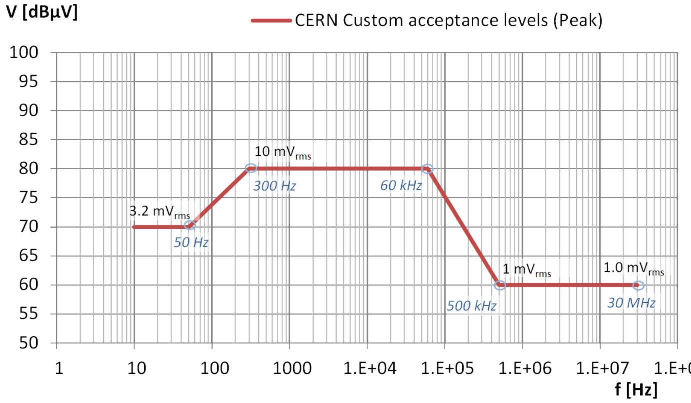

[1] M. Martino, “Modelling of the PC Output to the Magnetic Field,” in HL-MCF Meeting #7, November 2016.
[2] http://te-epc-lpc.web.cern.ch/te-epc-lpc/concepts/converters/emc/emc_emissions.stm

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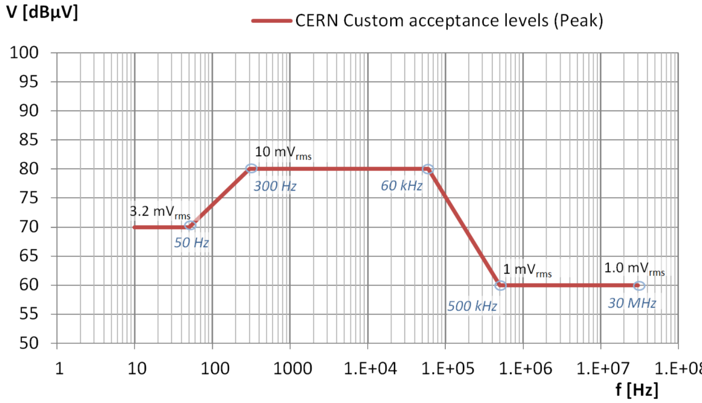

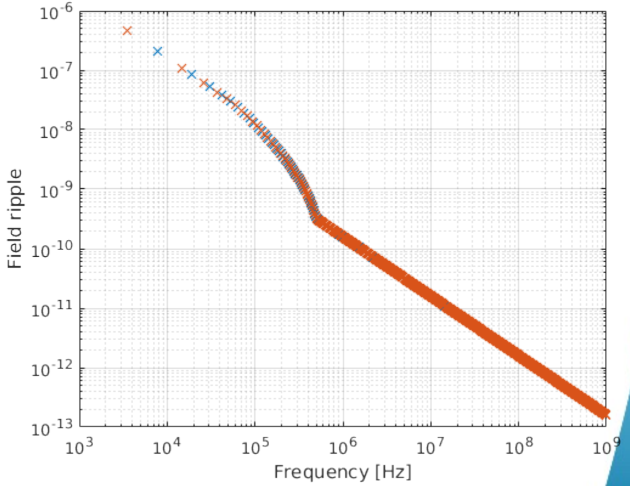

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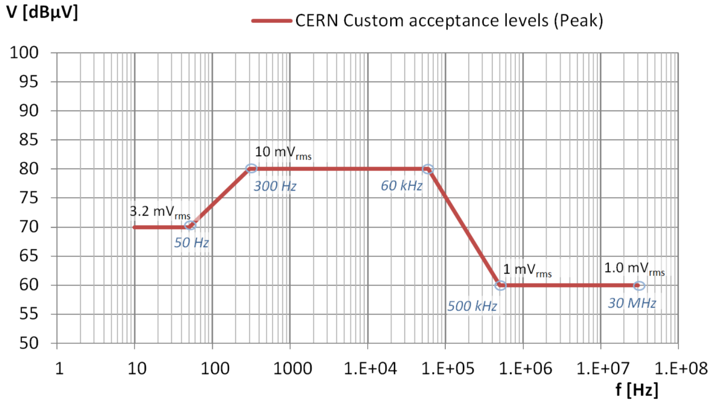
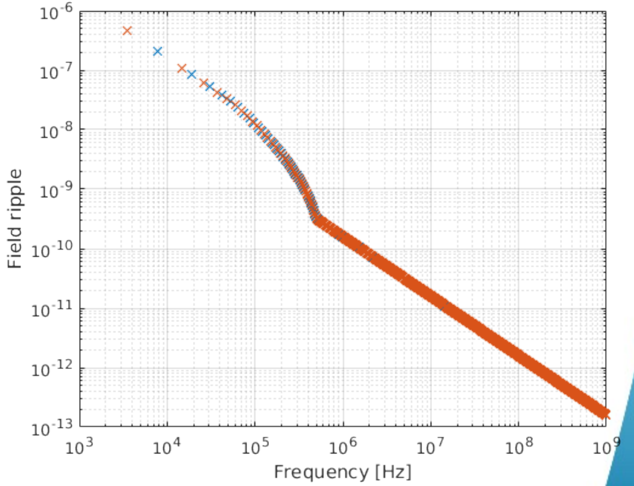
- The quadrupole field ripple have an effect on the noise due to feed-down :

$$k_{0,k}^{nom} \longrightarrow k_{1,k}^{nom}|x_k|$$





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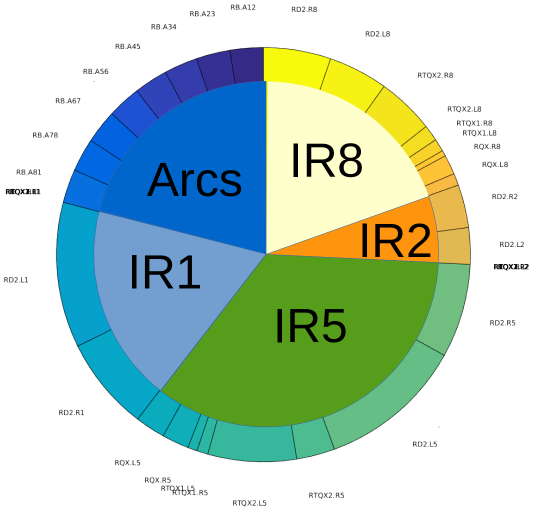
Dipole and quadrupole field ripple

- Preliminary estimations of the different contributions to the lattice noise floor are reasonably close to measurements
- The differences between the planes and beams needs to be further detailed
- Warm dipoles are not included (No info from TE-EPC-MPC)



$\delta_{40cm} = 3.5E\text{-}5$

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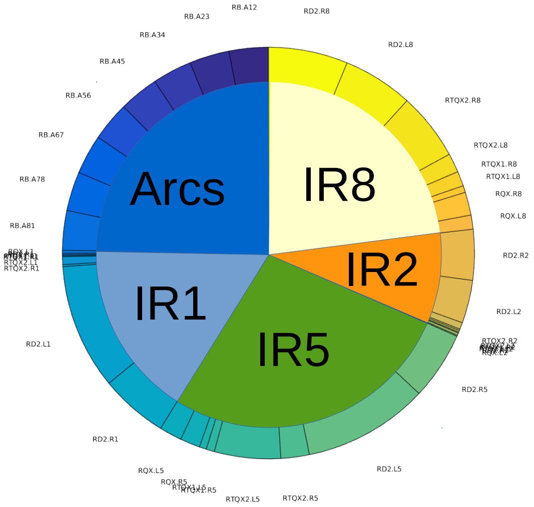
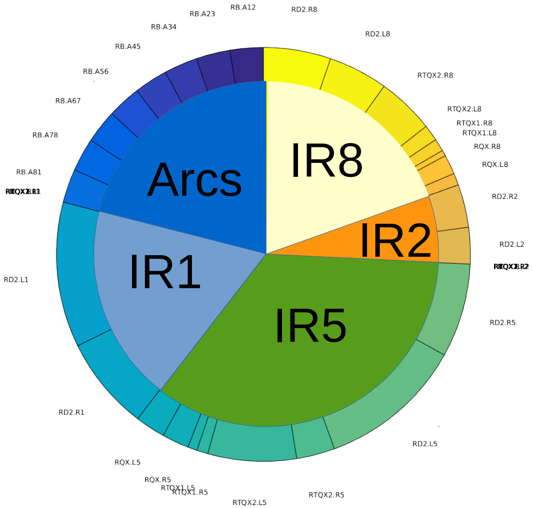


δ_{1m} = 2.6E-5



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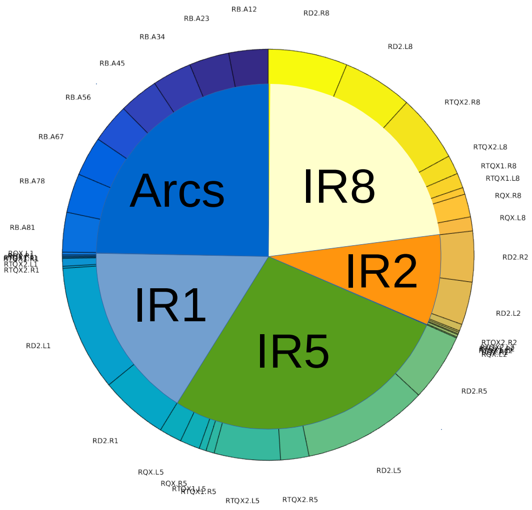

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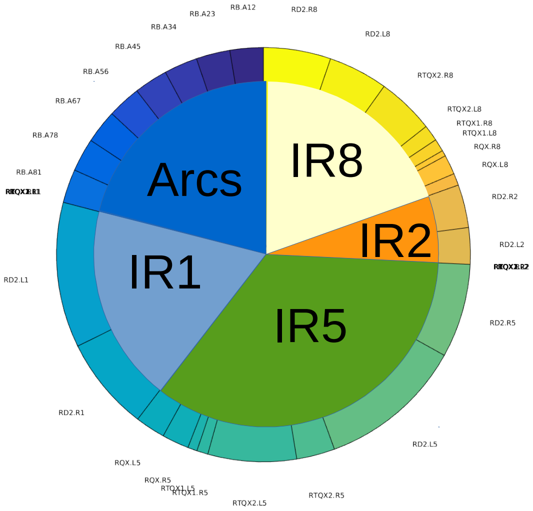

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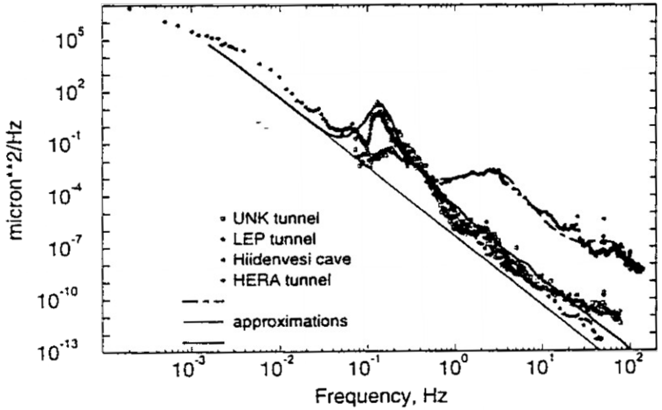
- The fact that the (preliminary) pessimistic model is still below the measurement suggest that it is not complete
  - Other sources of external noise ?
  - Incoherent effects due to the head-on interactions?

Ground motion

- The ATL law [3] predicts a strong reduction of the ground motion amplitude at 'high' frequencies ($1/f^4$)
- The spectrum are usually not measured above 100 to 1000 Hz

→ The effect of ground motion on the emittance through decoherence is expected to be small, TBC



[3]

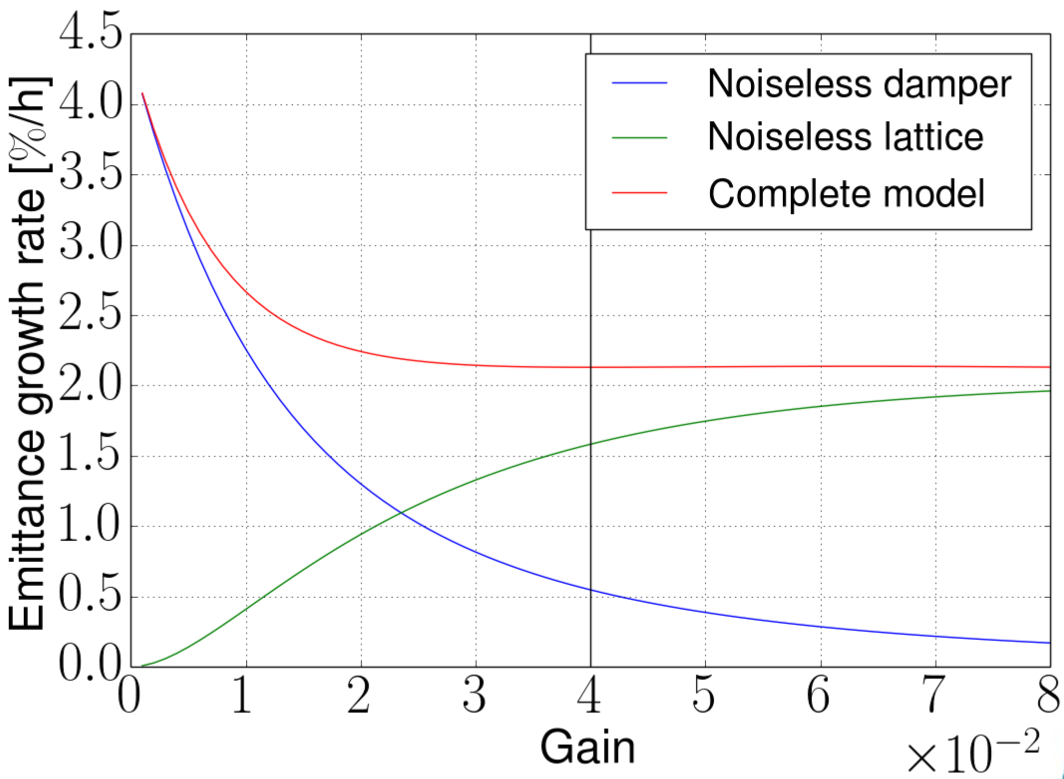
Figure 1: Power spectrum of absolute ground motion. Measured in Protvino (1992), CERN (1993), DESY (1994) and in Finland (1994).

[3] A. Sery and O. Napoly, “Influence of ground motion on the time evolution of beams in linear colliders,” Phys. Rev. E 53, 5323 (1996).

The LHC operational configuration in collision

- The contribution of the ADT is dominant in regular physics fills and most MDs (e.g. ADT MD)
- Overall the effect remains small

  → Experimental studies require special setup (Large beam-beam tune shift, w/o damper)



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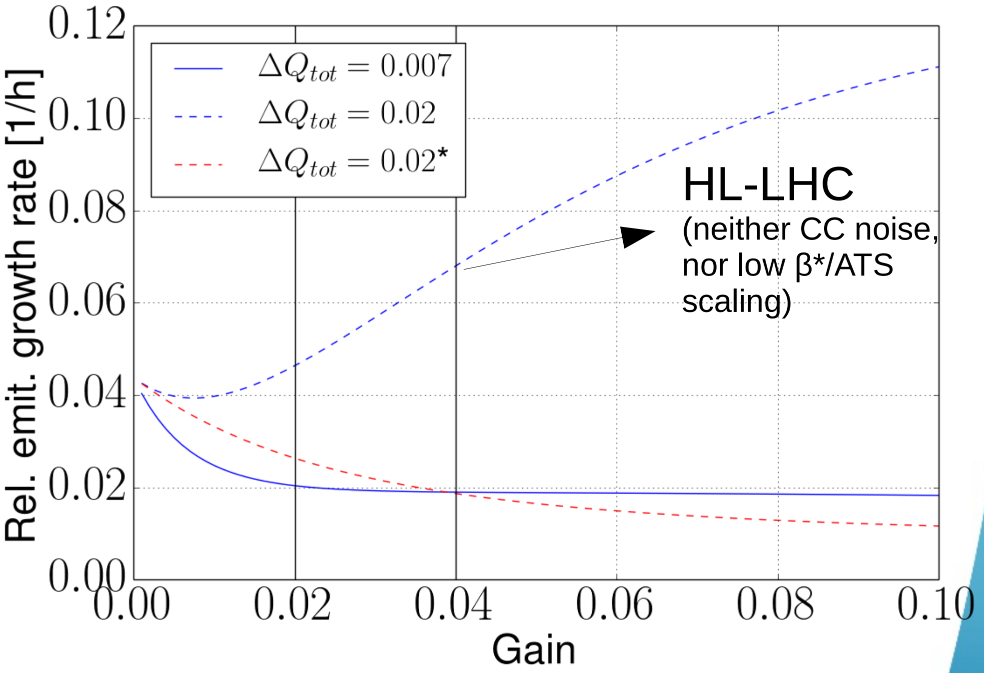
Noise on colliding beams – extrapolation to HL-LHC

- With large tune spread, the ADT becomes less effective against its own noise, leading to a runaway situation with high gains
- A reduction of the noise induced by the ADT is needed to recover a tolerable growth

  → Reduction of the pickup noise floor (See D. Valuch)

  → Reduction of the ADT bandwidth



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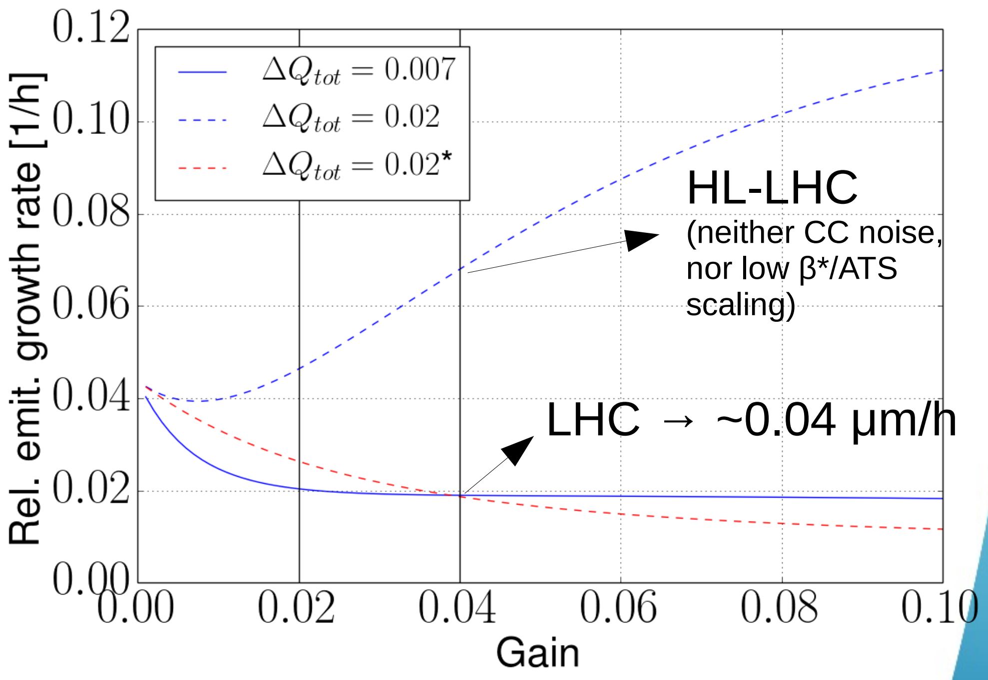

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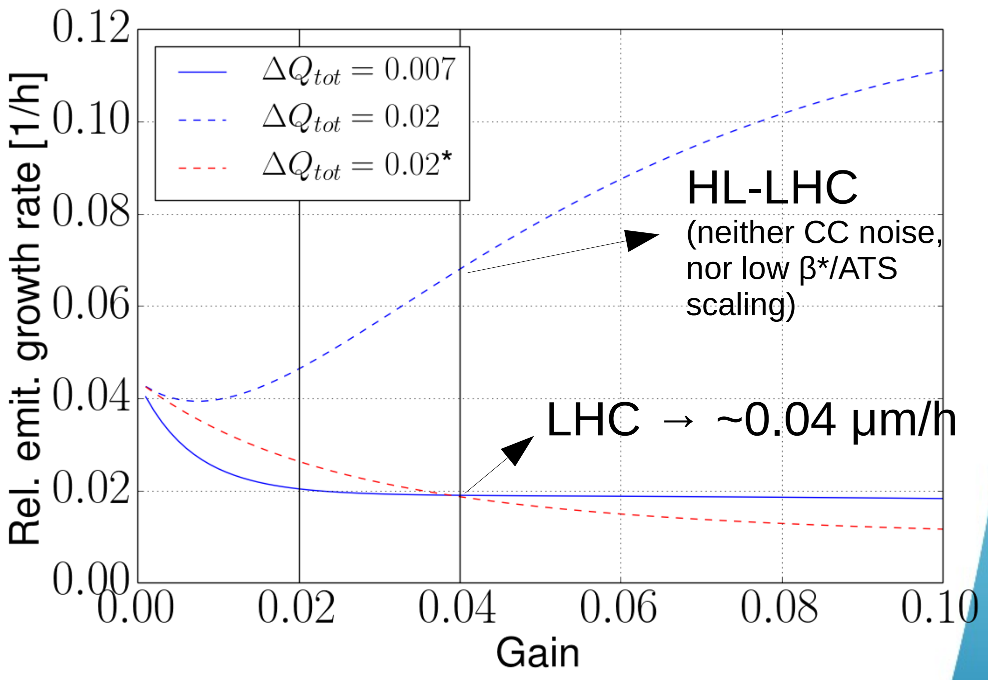
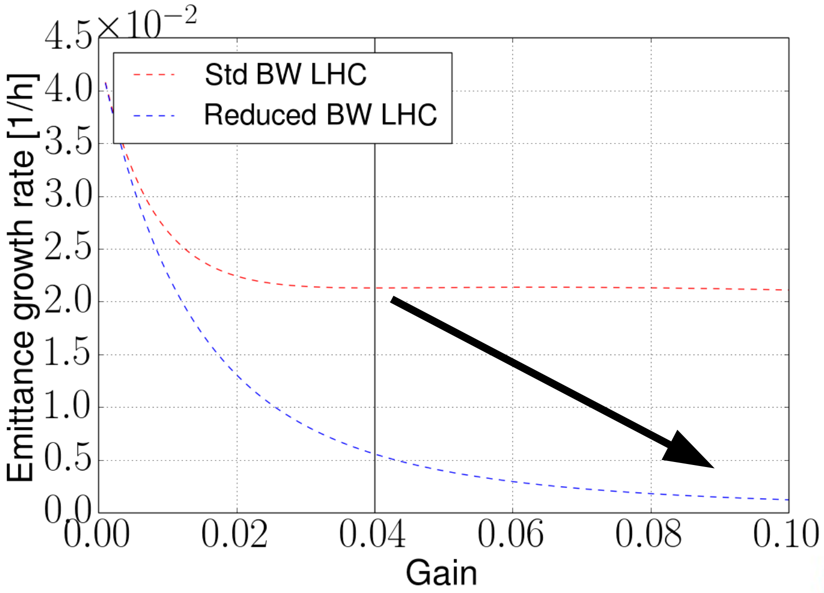


Compromising beam stability and noise induced emittance growth

- The large tune spread due to head-on beam-beam interaction is detrimental for the performance of the ADT, but provides strong Landau damping

  → The need for the ADT for beam stability is reduced

  → Re-optimise the ADT settings in collision to minimise its effect on the beam quality while maintaining the beam stability



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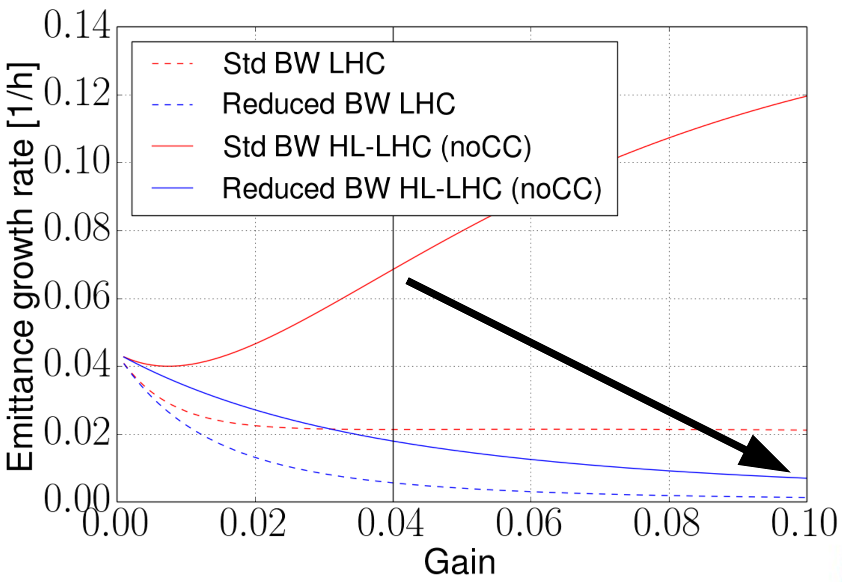
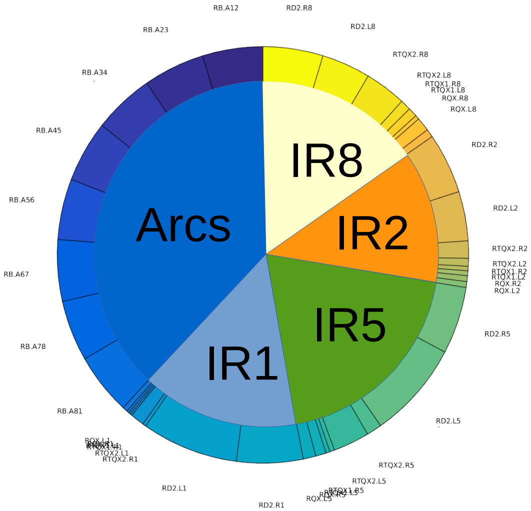


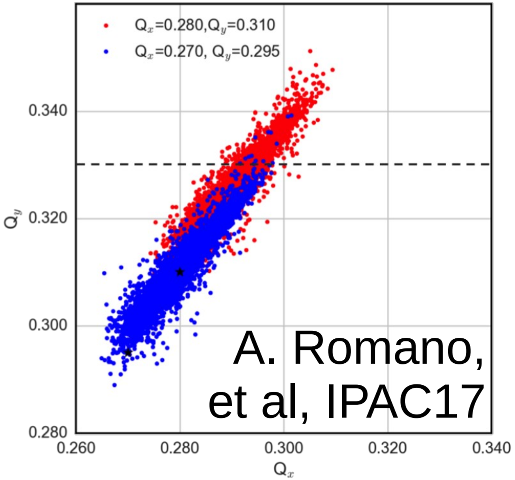
The LHC operational configuration at injection

- Combining the estimations of the field ripple with the estimated tune spread due to chromaticty, octupoles and electron clouds a growth up to 10%/h is expected
  - 20 to 80 %/h are measured

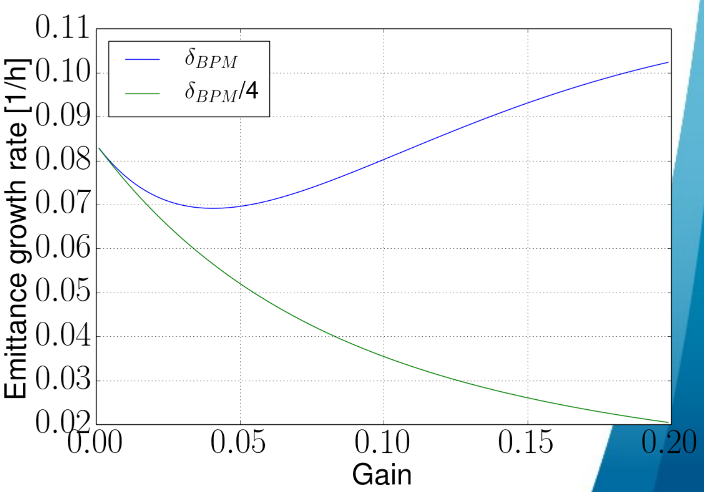
    → Either there are other sources of noise at injection, or the observed growth is not due to decoherence



δ_{inj} = 6.5E-5



- A reduction of the bandwidth cannot be envisaged at injection since the beam stability is already marginal due to electron cloud driven instabilities



Summary

- The emittance growth measured in MDs and during collision in physics fill (IBS subtracted) seem compatible with the decoherence model taking into account the noise due to
  - PC ripple
  - ADT pickup noise
- An incoherent contribution due to the head-on interactions cannot be excluded at this point, since the observations are slightly above the estimated maximum, using a pessimistic noise model
- With large tune spread, the ADT becomes less efficient at suppressing its own noise

  → Needs a mitigation in collision (due to the strong head-on beam-beam interaction) via an improvement of the pickup noise floor or by a reduction of the bandwidth (to be tested and possibly implemented in the LHC)
- The decoherent model do not represent the oberved emittance growth at injection, most likely due to strong incoherent effect of electron clouds