Non-linear dynamic β effect

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P.J. Gonçalves, Computation of Linear Optics Distortions due to Head-on Beam-Beam Interactions in Hadron Colliders, CERN-THESIS-2015-404
P.J. Gonçalves, Computation of Optics Distortions due to Beam-Beam Interactions in the FCC-hh, CERN-THESIS-2016-317
P.J. Gonçalves, Observations and measurements of dynamic effects due to beam-beam interactions in the LHC and extrapolation to the FCC-hh, EPFL Master thesis, 2017
L. Medina, et al, CORRECTION OF BETA-BEATING DUE TO BEAM-BEAM FOR THE LHC AND ITS IMPACT ON DYNAMIC APERTURE, IPAC17, Denmark, WEOAB2
R. Tomas, et al., Beam-beam amplitude detuning with forced oscillations, PRAB, publication on going

WP2 meeting – 26.09.2017

Content

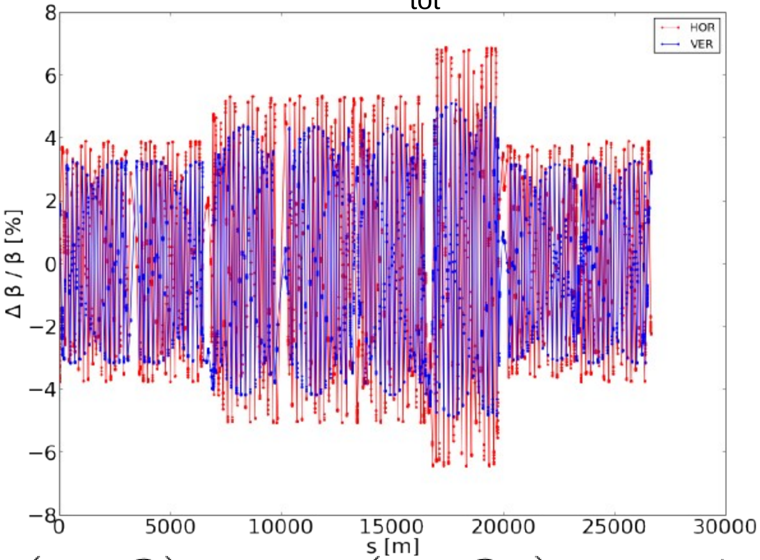
- Linear dynamic β
  - correction
- Non-linear dynamic β
  - The SVD Method
  - Head-on interaction
    - AC dipole measurement
    - Luminosity imbalance
  - Long-range interactions
- Conclusion

Head-on and long-range maximum tune shift

$$cos(2\pi Q) = cos(2\pi Q_0) - 2\pi\xi sin(2\pi Q_0)$$

$$\max\left(\frac{\Delta\beta}{\beta}\right) = \frac{2\pi\xi}{sin(2\pi Q_0)}$$

Head-on and long-range maximum tune shift LHC (ΔQ_{tot} ~ 0.01)



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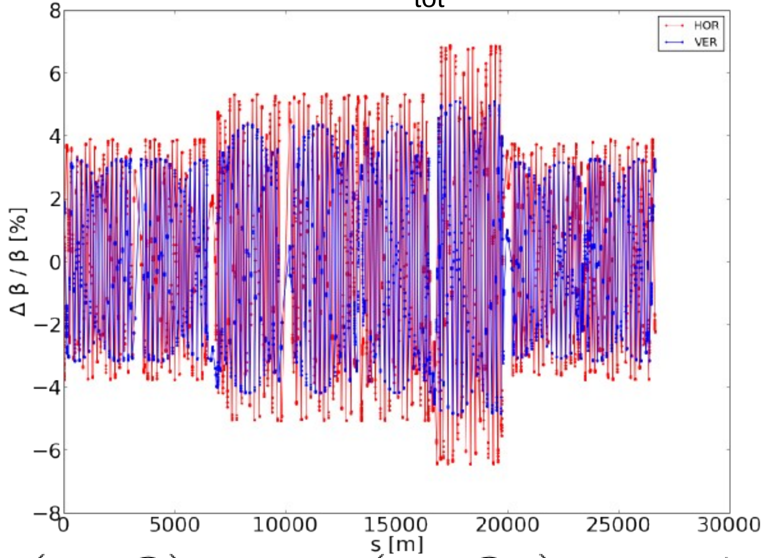
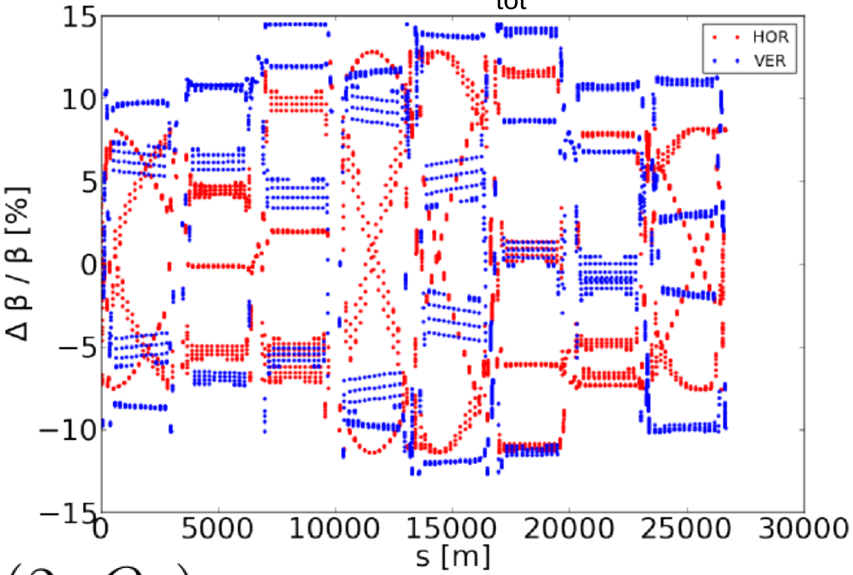


HL-LHC (ΔQ_{tot} ~ 0.02)



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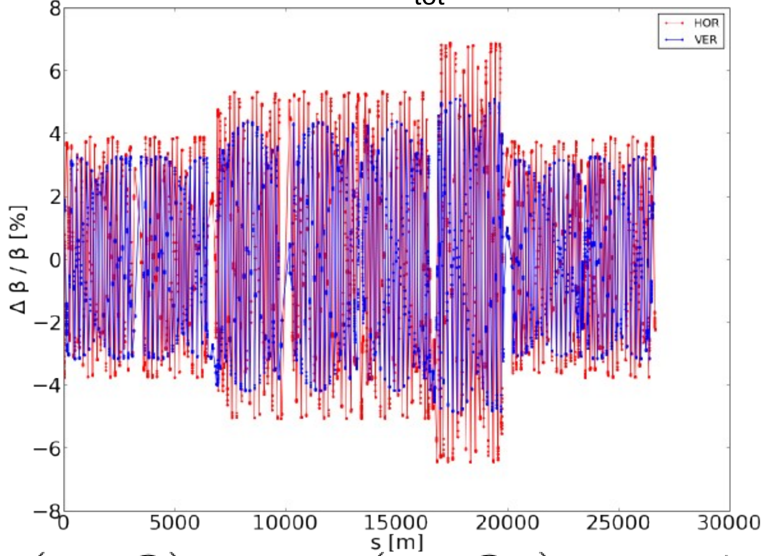

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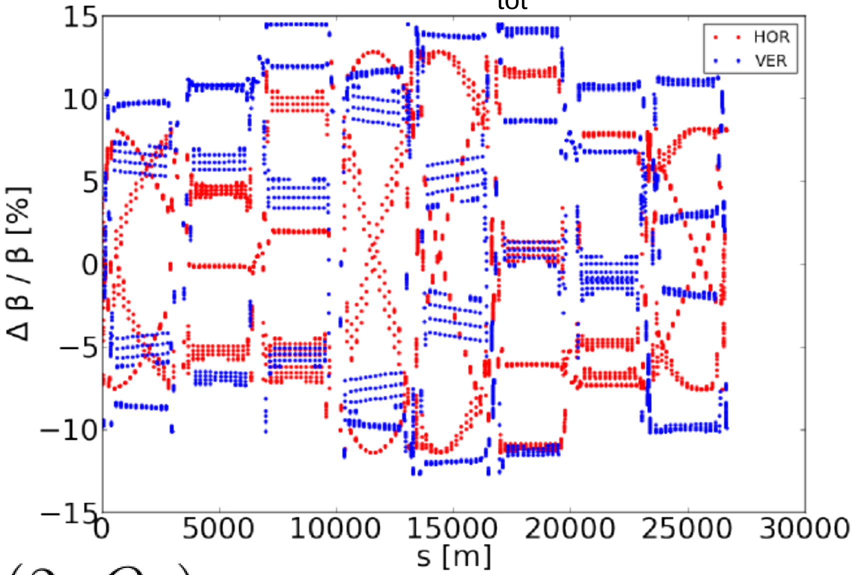

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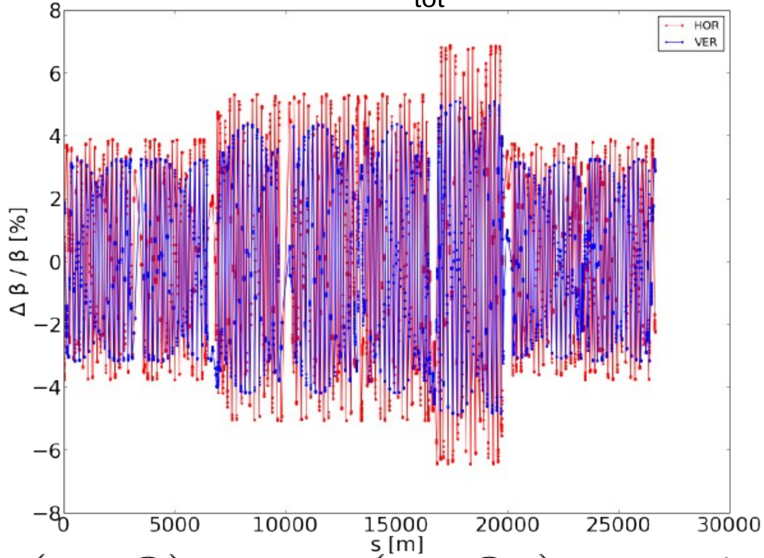

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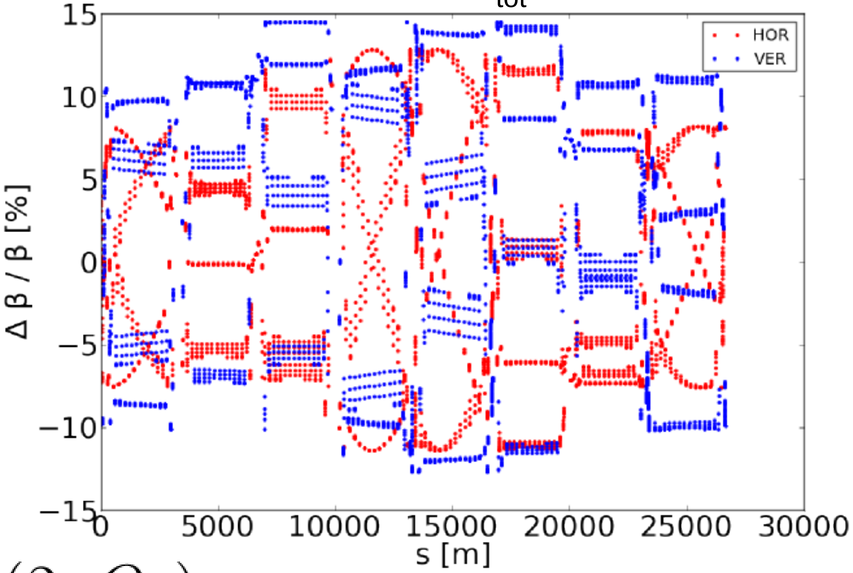

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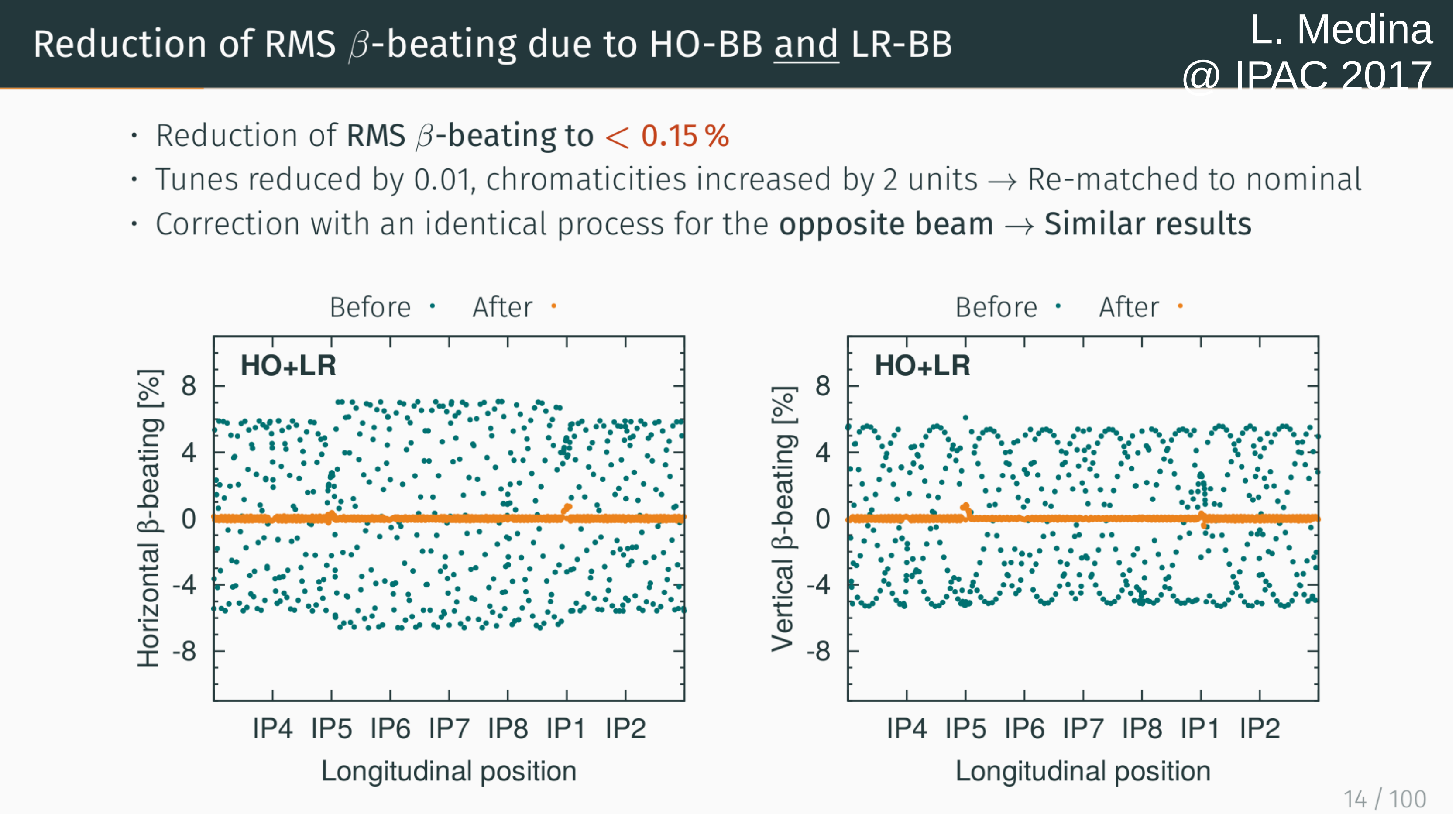
- Can this be corrected ?
- What is the rôle of the non-linearity of the force ?

L. Medina
@ IPAC 2017

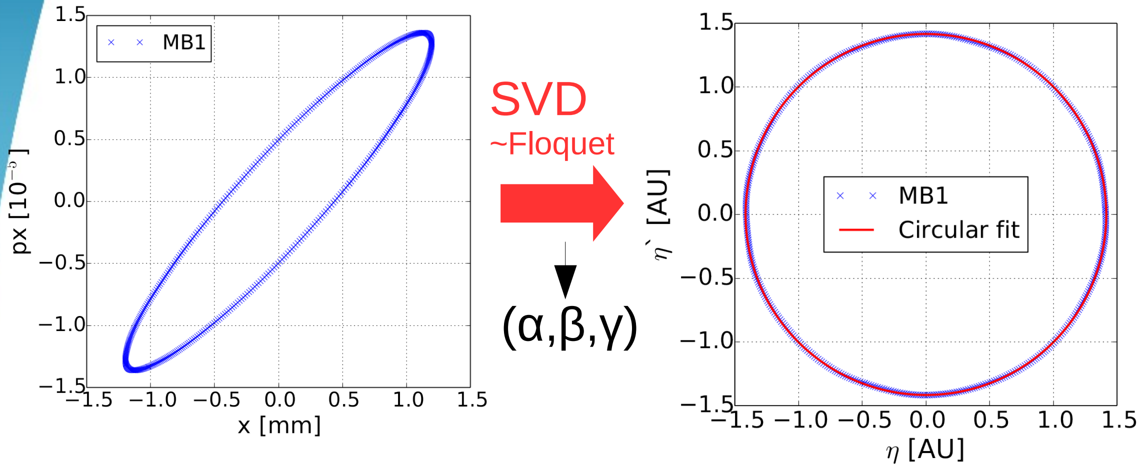


Reduction of RMS β-beating due to HO-BB and LR-BB

- Reduction of **RMS β-beating to** $< 0.15\,\%$
- Tunes reduced by 0.01, chromaticities increased by 2 units → Re-matched to nominal
- Correction with an identical process for the **opposite beam** → **Similar results**

- Successful local correction (LHC) using matching quadrupoles for head-on and common sextupoles for long-range correction
- No significant impact on dynamic aperture

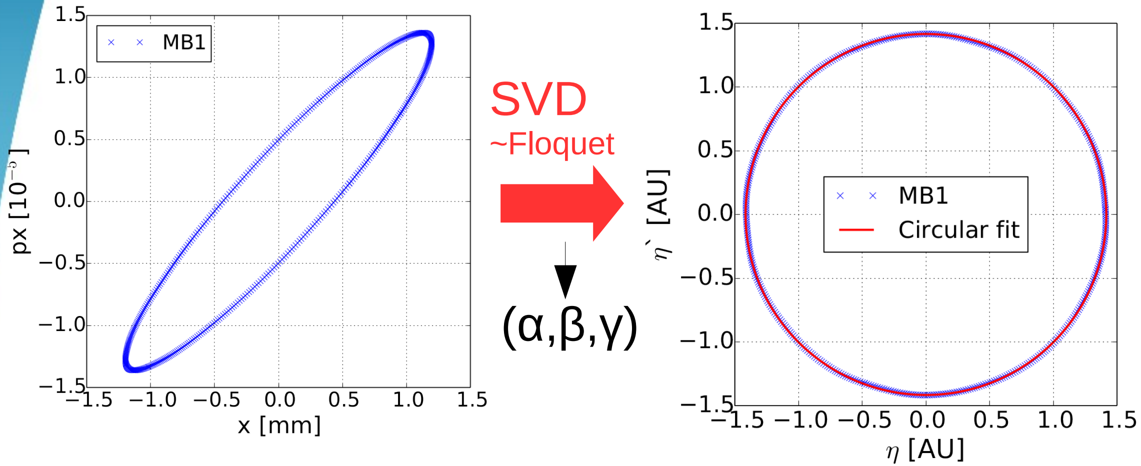
Effective β beating in the presence of non-linearities



SVD
~Floquet

(α,β,γ)

Effective β beating in the presence of non-linearities



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- Painful way of computing the optical functions based on tracking data in the linear regime

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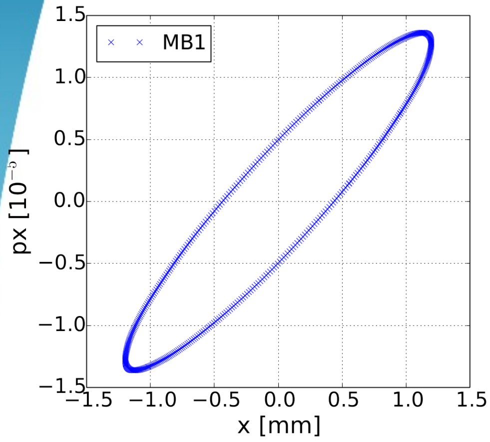
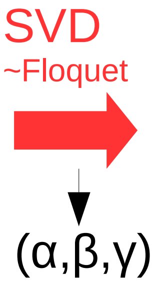
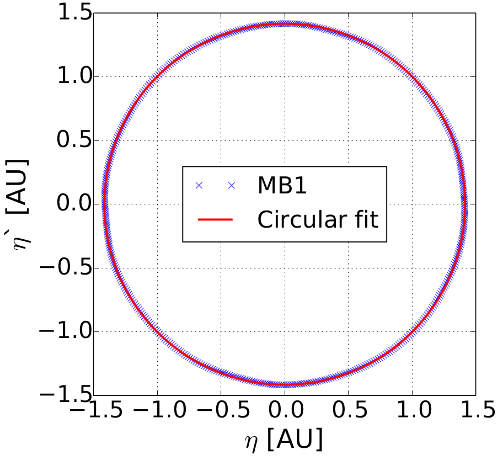
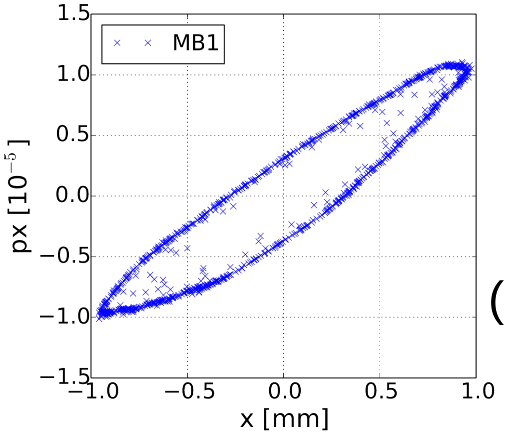


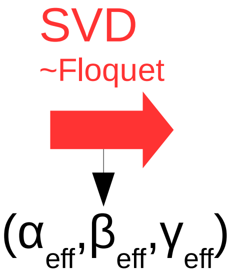


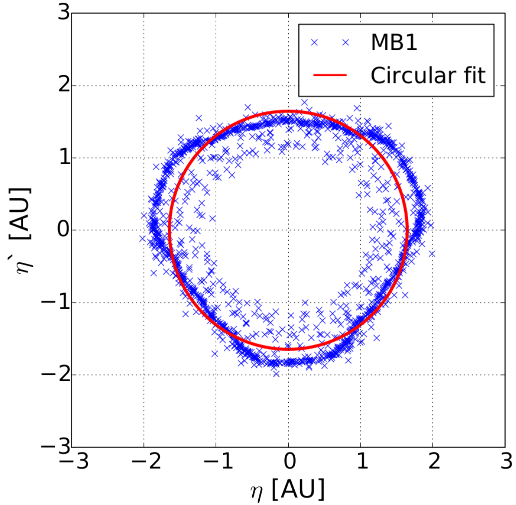


- Painful way of computing the optical functions based on tracking data in the linear regime

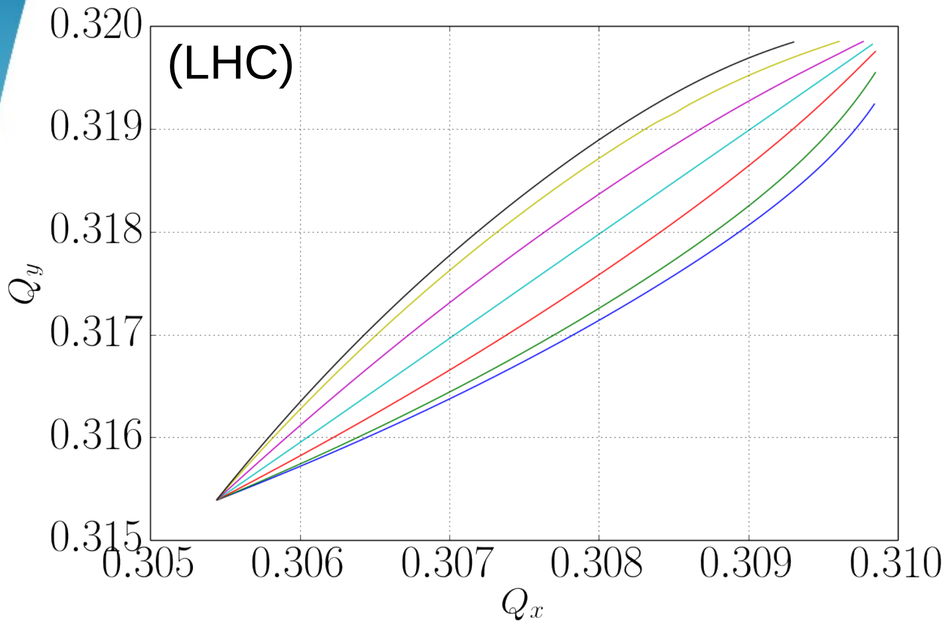
- Can be generalised to arbitrary oscillation amplitude

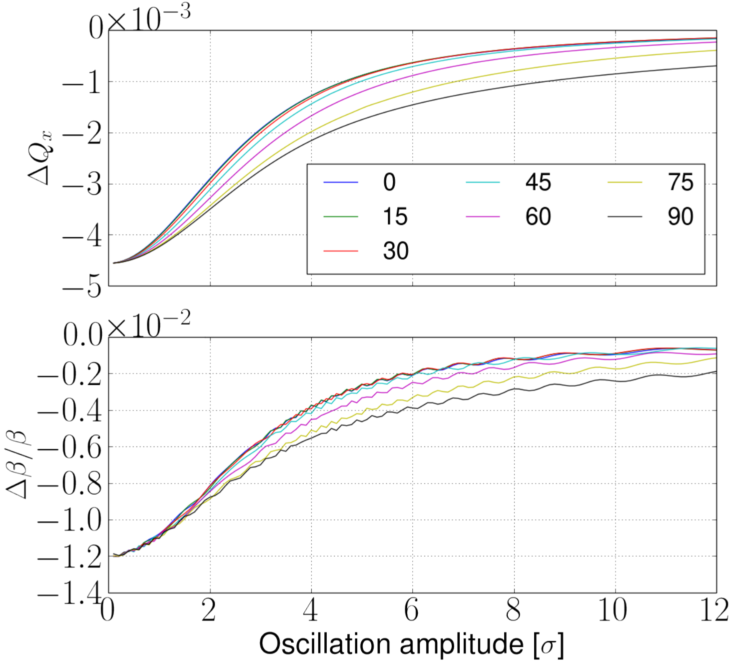






Effect of head-on interactions



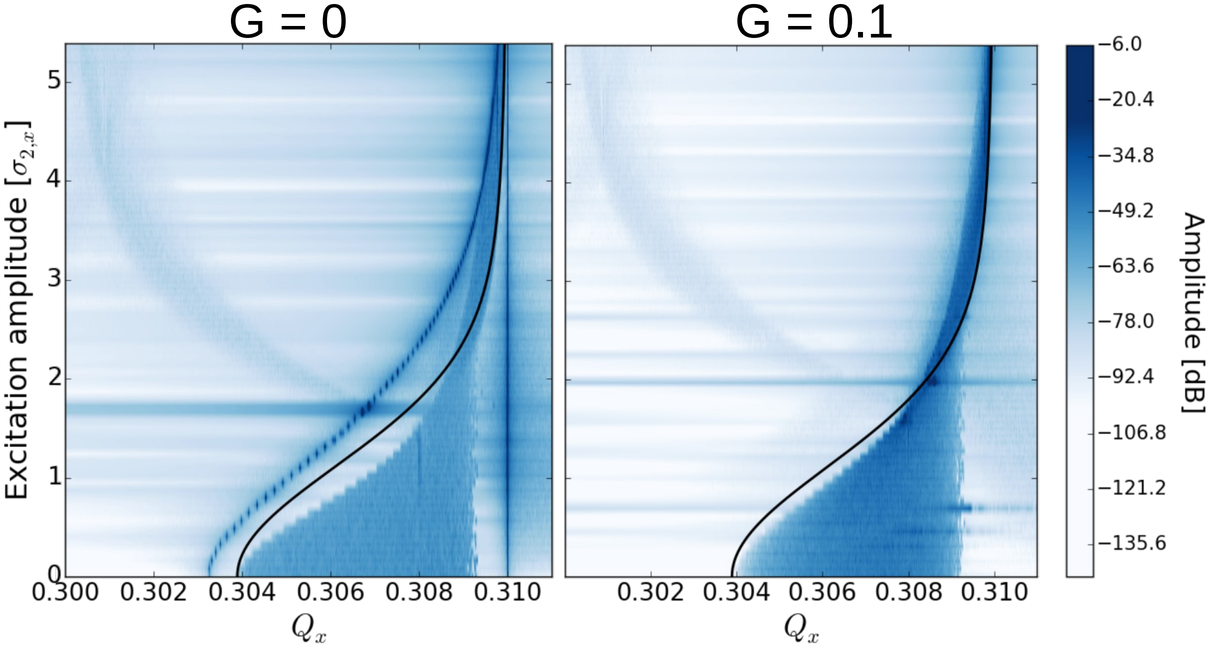


- The effective β beating from one IP follows the proportionality to the beam-beam tune shift (as the equation based on the linear model)

→ Vanishing effect for large oscillation amplitude

→ The correction cannot be optimal for all amplitudes

Simulation of AC dipole measurement



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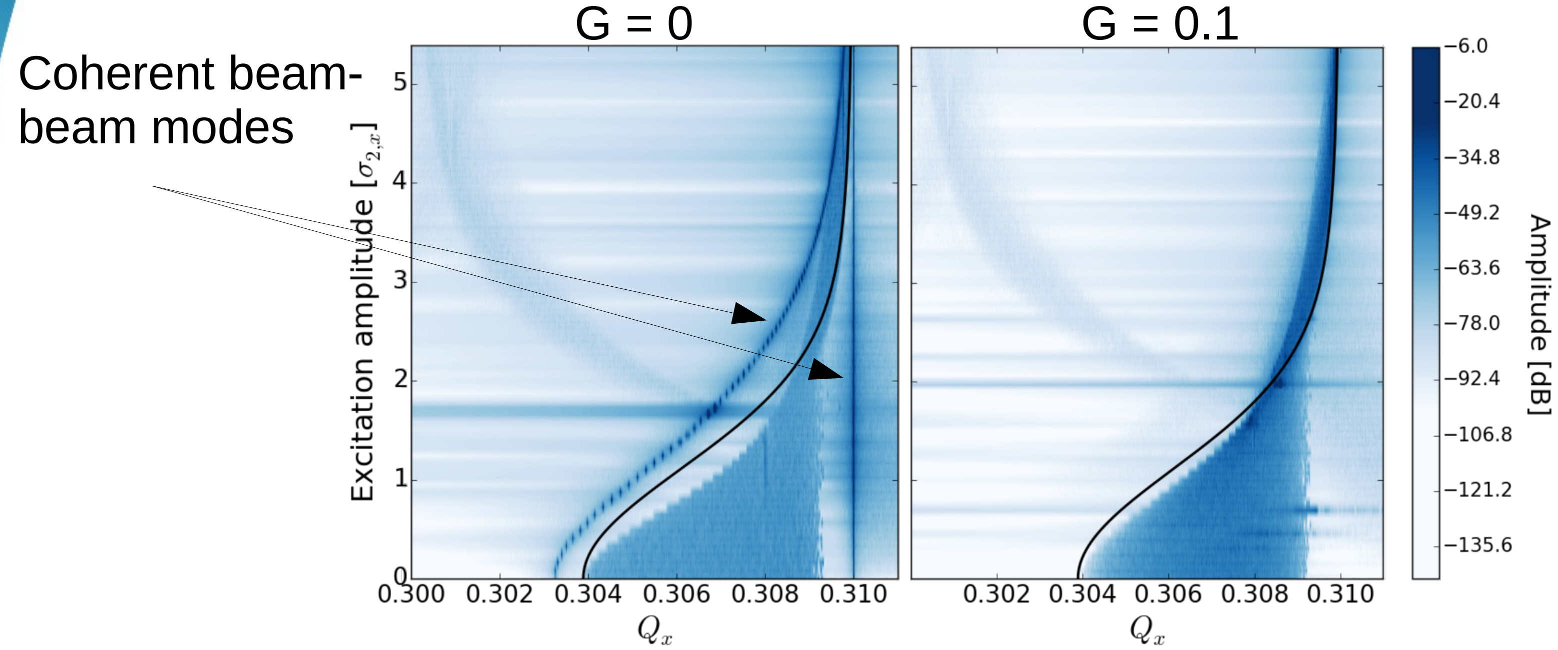
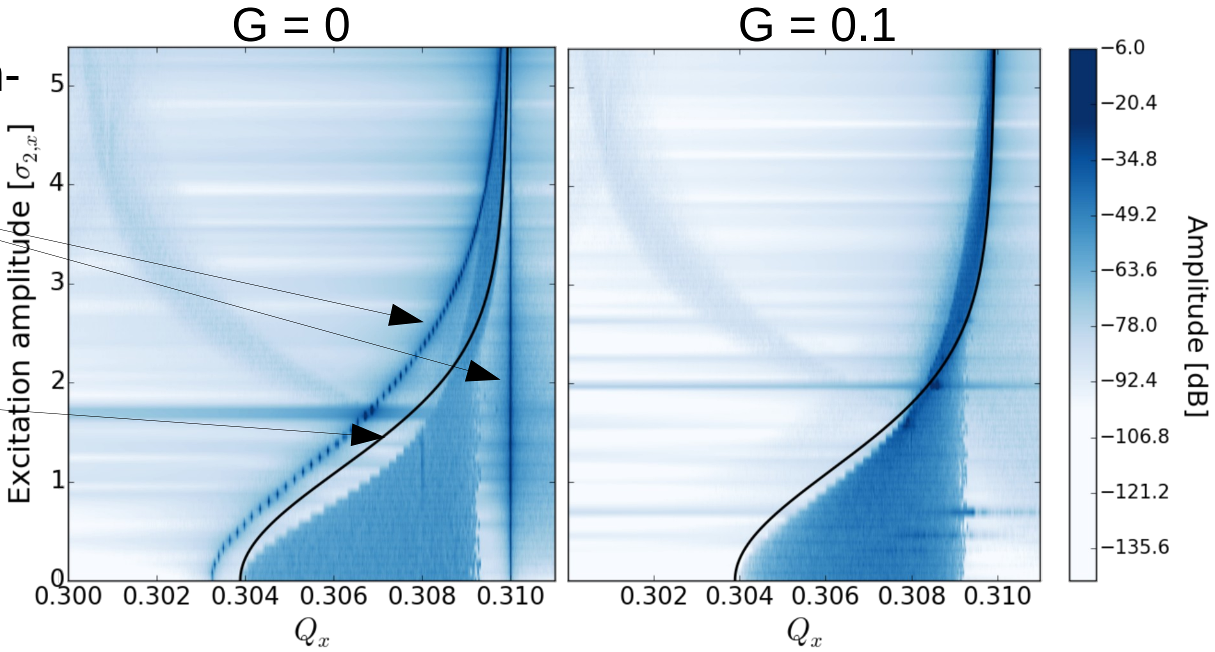


Coherent beam-beam modes

Simulation of AC dipole measurement

Coherent beam-beam modes

Single particle theory (R. Tomas, et al., PRAB, to be published)



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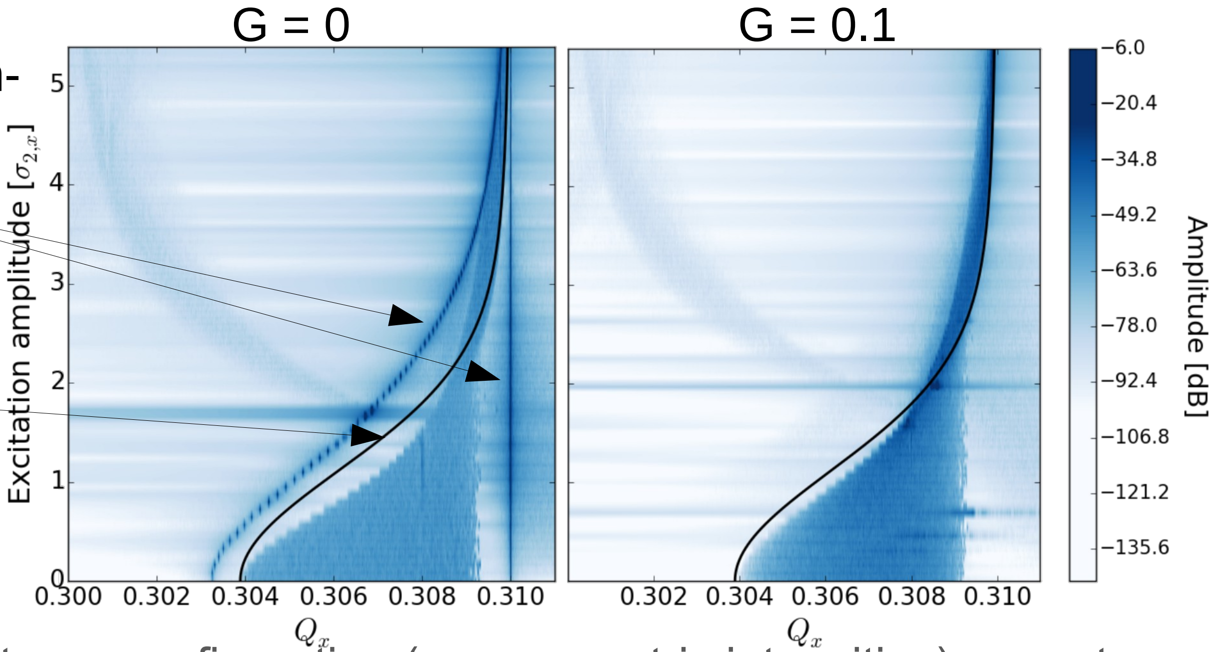


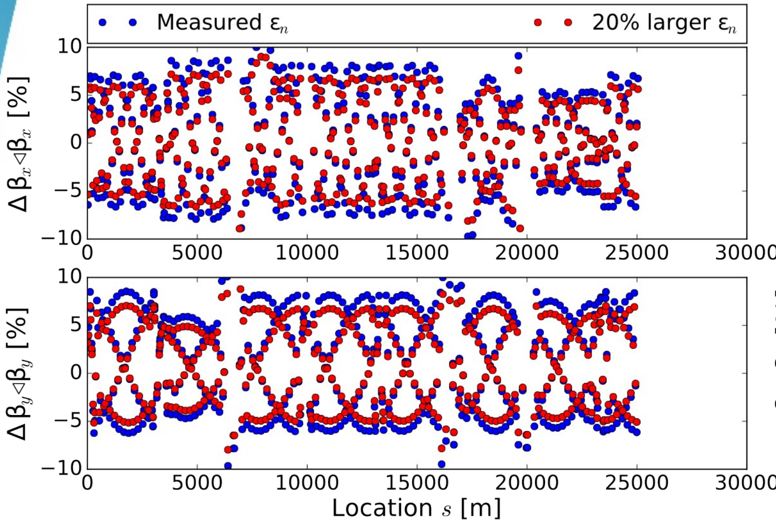
Coherent beam-beam modes

Single particle theory (R. Tomas, et al., PRAB, to be published)

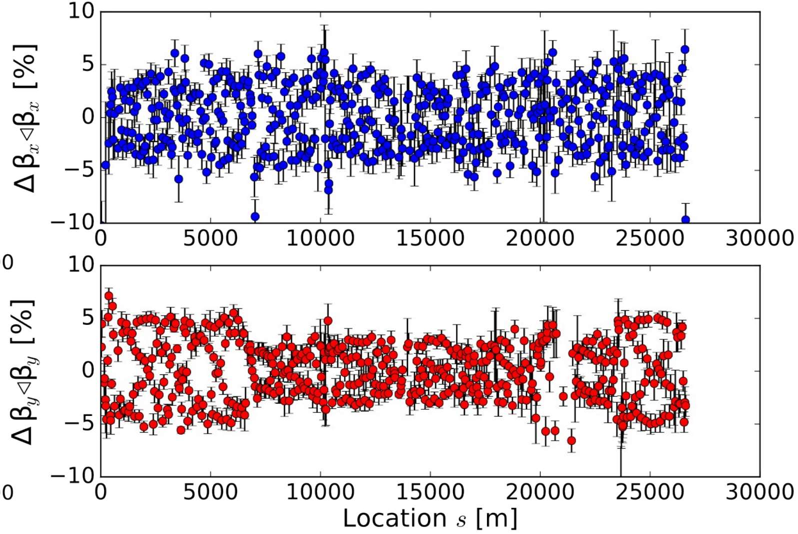
- Either a weak-strong configuration (e.g. asymetric intensities), or a strong ADT gain is needed to perform AC dipole measurements on colliding beams
    - The presence of a large incoherent spread is not compatible with single particle models to compute the β beating from AC dipole measurements
        - only the boundary of low oscillation amplitude particles can be predicted

AC dipole measurement with colliding beams at injection

MAD-X



Measurement



1IP

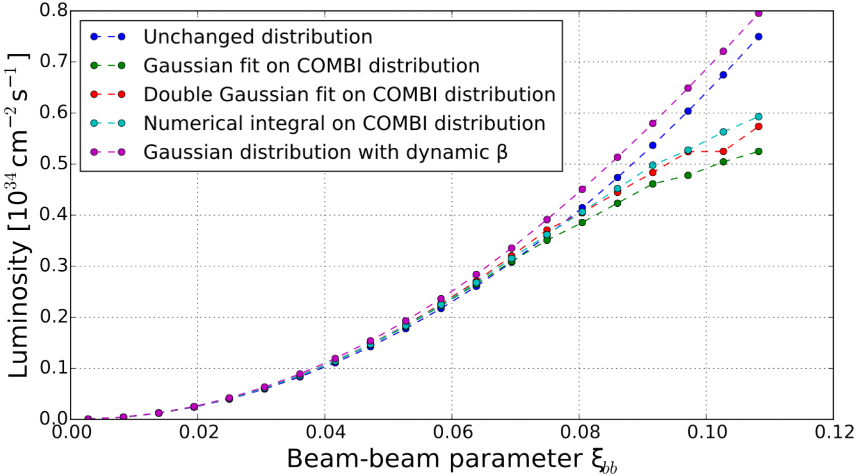
ΔQ~0.013

Q_{AC} = (0.268, 0.278)

A_{AC} = 1.8 σ

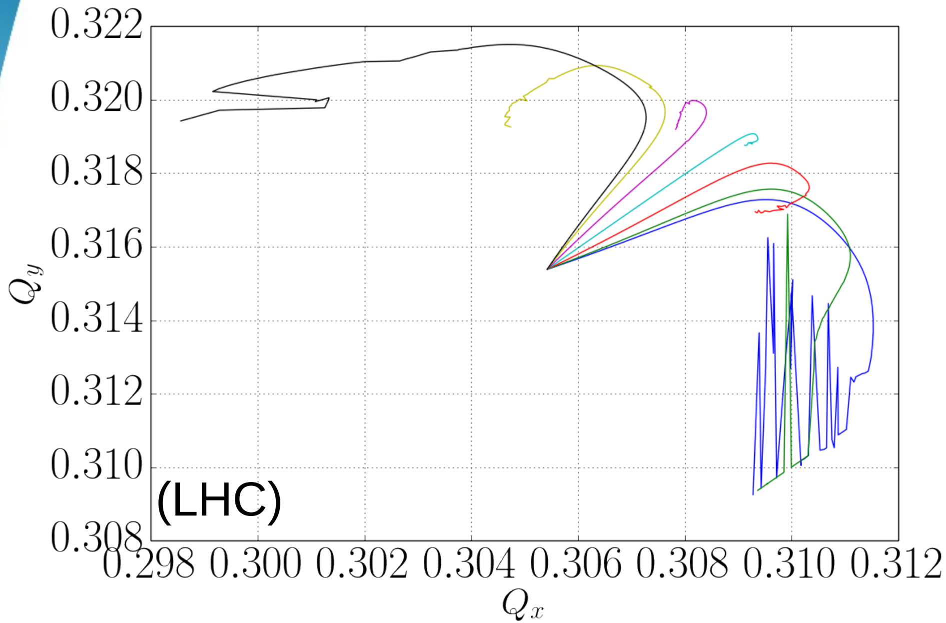
- Experimental data are in qualitative agreement with theory, using empirical algorithm to recover an 'effective' natural tune
  - Important developments are required to take into account the large tune spread (coherent response to the AC-dipole)

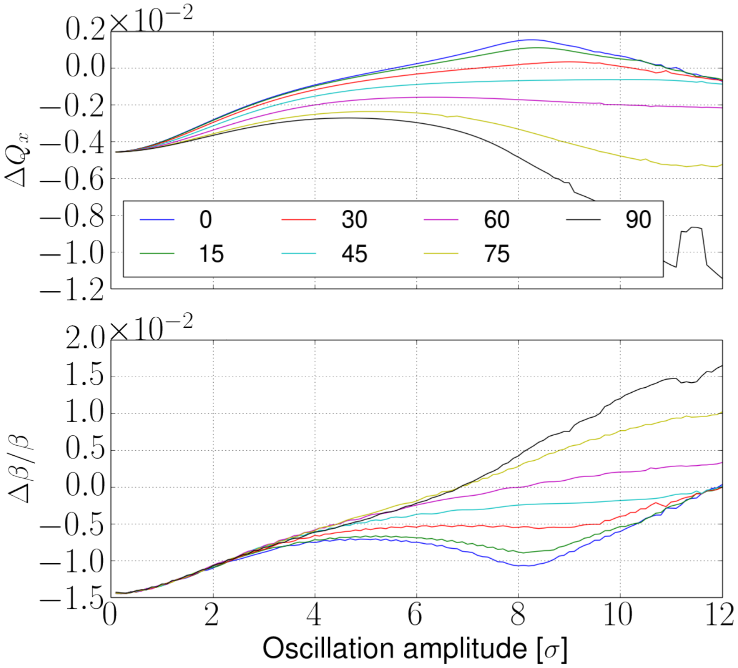
Luminosity imbalance



- The impact of the self-consistent modification of the beam distribution is only relevant at very large beam-beam parameters
- At reasonable beam-beam parameters, the variation of the luminosity is of the order of the dynamic β effect (slightly reduced to due to the strong variation at low amplitude)
  - Since the core is mainly affected, the luminosity imbalance can be corrected with a linear optics correction

Long-range interaction



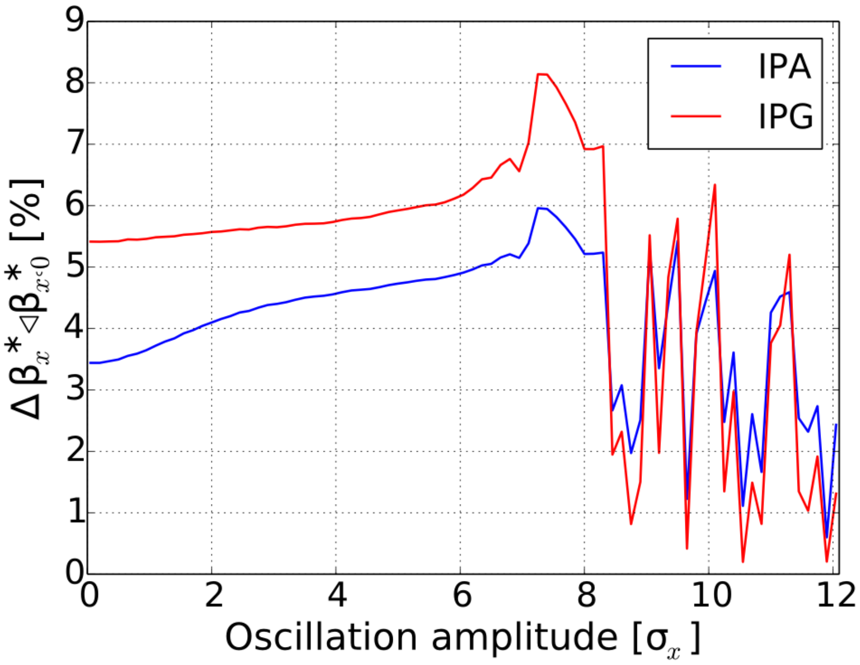


- Long-range interactions are already strong in the LHC
  - No significant detrimental effects were observed on the cleaning inefficiency in collision
- The effective β beating does not follow a linear scaling with the tune shift
  - The tune shift from long-range interactions is passively compensated between the two main IPs → some β beating remains and depends on the phase advance between the IPs

Conclusion

- The distorsion of the linear optics due to beam-beam interactions are strong in the HL-LHC
  - Their correction is possible, however they only apply to particles oscillating with a low amplitude and will result in increased β beating for particles in the tail
- Head-on interactions lead to distorsions of the core of the beam distribution, leading to luminosity imbalance (in the order of a few percents), but the effect on the tail vanishes
  - The effect can be partially mitigated by adjusting phase advance between IPs (and wrt an e-lens)
  - The effect could be mitigated by implementing a local correction or by adjusting the β* to compensate for the imbalance
- AC dipole measurement at injection with large beam-beam tune shift (single bunches) shows qualitative agreement with simulations
  - Theoretical developments are needed to go beyond the single particle approach
- Long-range interactions affect mainly the tails, where the motion aroud the DA can be very non-linear → Need to evaluate the effect in different configurations using the SVD of tracking data
  - First estimations shows a relatively small effect → Robustness to be confirmed in different configurations (round/flat, wires, Hollow e-lens)

Break down of the SVD method



- In some cases, the SVD method breaks down beyond the dynamic aperture as the trajectories become very irregular

BACKUP – Adjustement of the phase advance