# LSWG MD day 2020:
# OMC non-linear optics plans

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*on behalf of*
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# Journal articles from Run2 using nonlinear MD results:

- **Eur. Phys. J. Plus (2020) 135: 77 (2020)**
  Analysis of the non-linear beam dynamics at top energy for the CERN Large Hadron Collider by means of a diffusion model
- **Phys. Rev. Accel. Beams 22, 104003 (2019)**
  Advances on the modeling of the time evolution of dynamic aperture of hadron circular accelerators
- **Phys. Rev. Accel. Beams 22, 061004 (2019)**
  New approach to LHC optics commissioning for the nonlinear era
- **Phys. Rev. Accel. Beams 22, 051001 (2019),**
  Suppression of amplitude dependent closest tune approach and its behaviour under forced oscillations
- **Phys. Rev. Accel. Beams 22, 031002 (2019)**
  First experimental demonstration of forced dynamic aperture measurements with LHC ac dipoles
- **Phys. Rev. Accel. Beams 22, 034002 (2019)**
  Innovative method to measure the extent of the stable phase-space region of proton synchrotrons
- **Phys. Rev. ST Accel. Beams 19, 071003 (2016)**
  Amplitude dependent closest tune approach
- **Phys. Rev. ST Accel. Beams 18, 121002 (2015)**
  First measurement and correction of non-linear errors in the experimental insertions of the Large Hadron Collider

- **4 papers in preparation**
- **15 IPAC papers published on Run2 nonlinear optics MD results**
- **4 external invited seminars on nonlinear optics studies (Fermilab, Saclay, Univ' Goettingen, Univ' Vienna)**
- **Numerous contributions to external workshops & collaborations**

# Split Run3 requests into 3 categories:

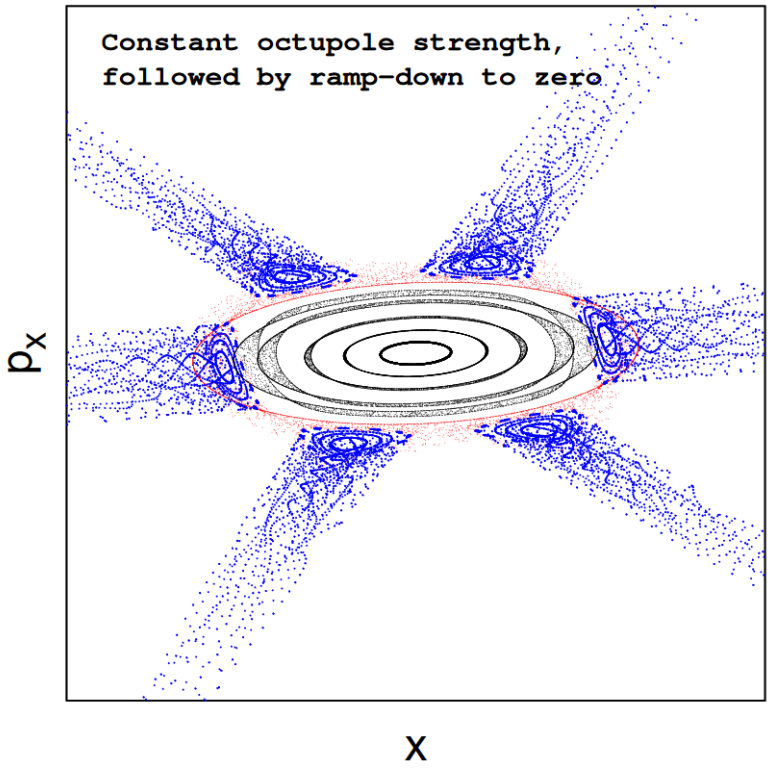
1. **Highest priority MDs.**
   **Relevant to LHC performance or operation**

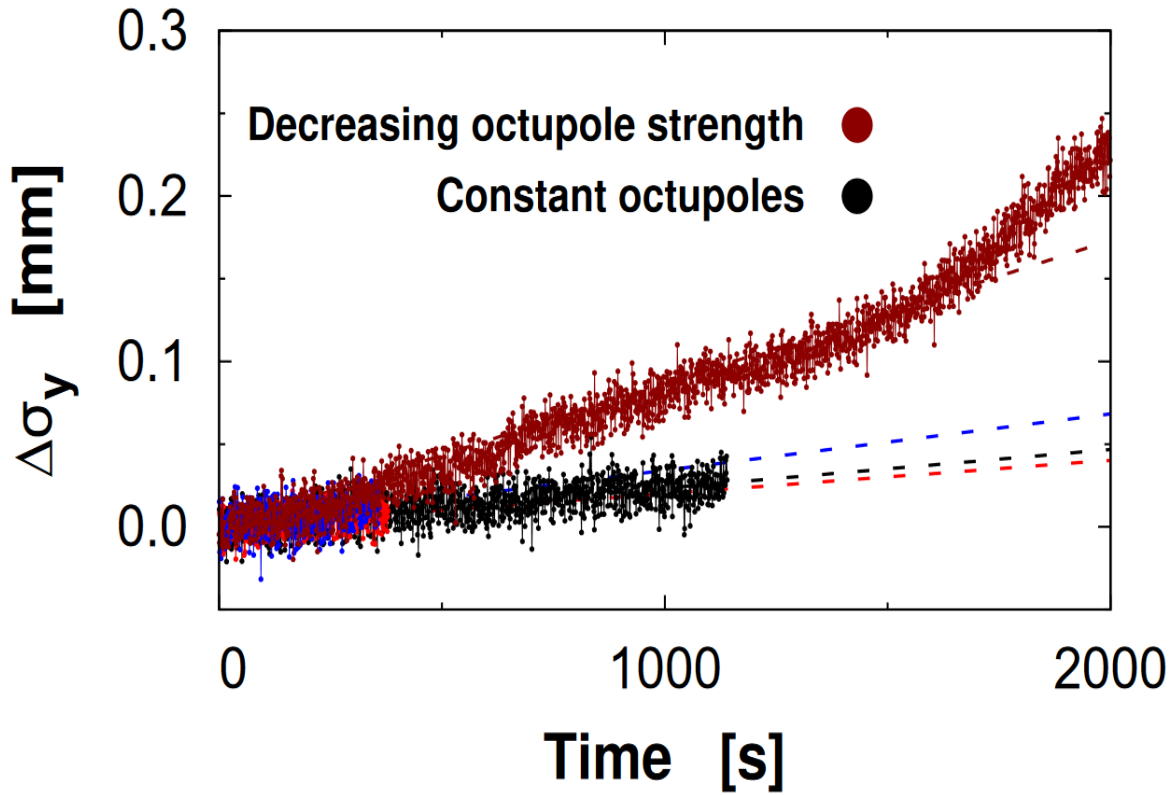
2. **Important questions, but not immediately relevant to operation:** e.g. understanding of previous observations & future collider scenarios

3. **MDs of opportunity.**
   Studies we think are interesting / cool where there isn't an immediate link to LHC or future collider performance

# Understanding / quantifying sources of emittance growth relating to nonlinear optics

- **During Run2 proposed a mechanism for emittance growth in ramp based on particle transport in stable islands**
- **Preliminary studies in MD during 2018 showed some very interesting results**



# Following up on 2018 MD observations is a key priority for Run3

**Initially looking at 2-3 MD requests to study optics-related emittance growth in the Ramp:**
(mix of studies at injection + ramps in various configurations)

- MD to study islands directly
  - > excitation of beam into stable islands with MKA.
  - > study island behaviour vs NL-optics and evolution during Ramp
- MD ramps to test predictions of island-based mechanism
  - > study emittance growth during ramp with various configurations of: working point, Landau octupole polarity, chromaticity
- MD ramps to compare emittance growth of pilot / nominal bunches

Clear synergy between studies of island-based emittance growth and studies of emittance growth more generally

> Should collaborate with other teams studying emittance growth!

# Measurement and correction of third-order resonance driving term at injection

**Very closely connected to possible island-related emittance growth as 3Qy resonance is likely candidate for particle trapping**

**Potential lifetime benefit from better control of RDTs at injection**

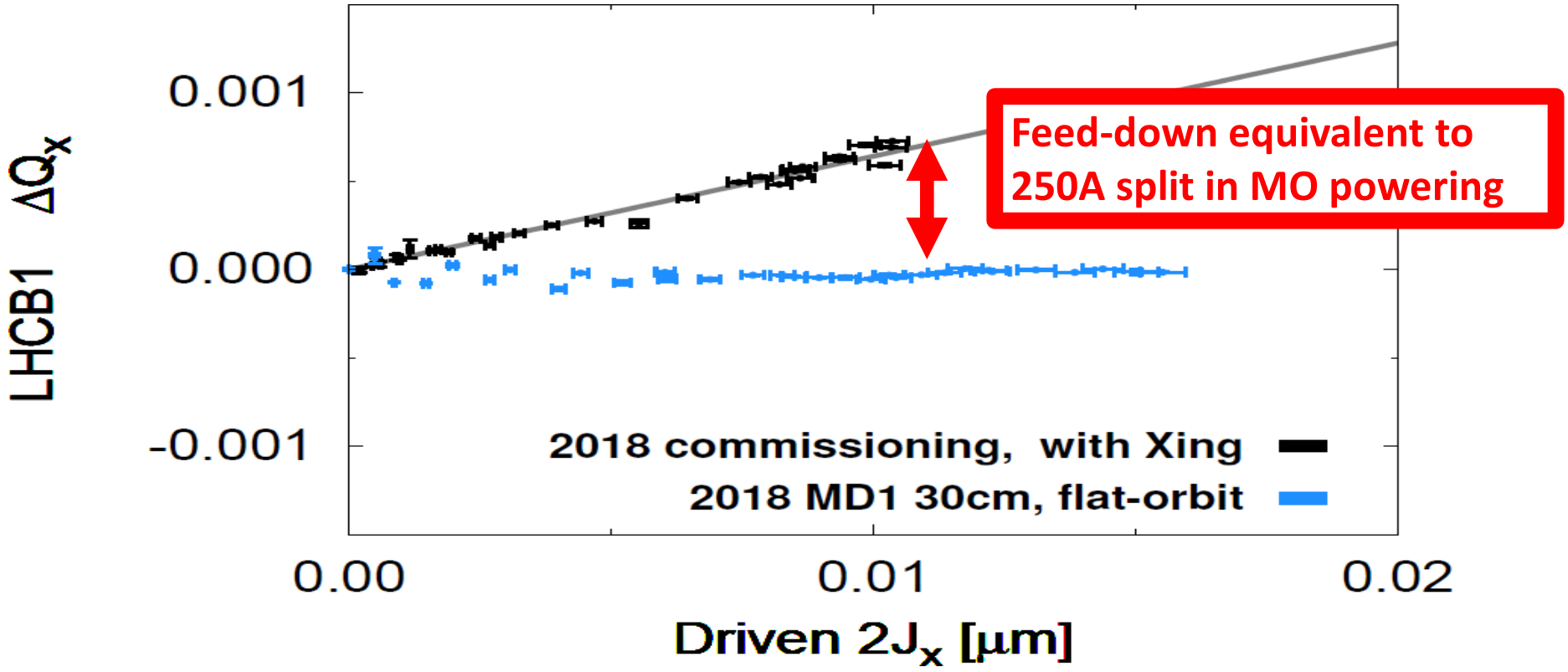
## Initially looking at 1-2 MD request (450 GeV):

- MD to perform RDT measurement at injection, particular focus on applying techniques to distinguish real & BPM nonlinearities
- MD to test RDT correction at injection

# Dodecapole correction at end of squeeze

**HL-LHC commissioning will require high-order nonlinear correction which have not yet been demonstrated with beam**

**Potential benefit to DA and amplitude detuning stability during the squeeze**



## Initially 1-2 MD request (top energy, EOS):

- Expect to begin dodecapole correction in commissioning so exact time will depend on success of nonlinear commissioning
- Understand source of decapole RDTs observed in Run2
- Understand source of large amplitude detuning generated by the crossing-scheme

**VERY KEEN TO USE 0.5um EMITTANCE BEAMS FOR ALL NL-OPTICS STUDIES**

# Refining HL-LHC commissioning strategy

**Previous MDs established that our ability commission the linear optics is deteriorated by strong nonlinearities**

**HL-LHC optics commissioning will be complicated due to interplay between corrections of different multipole orders**

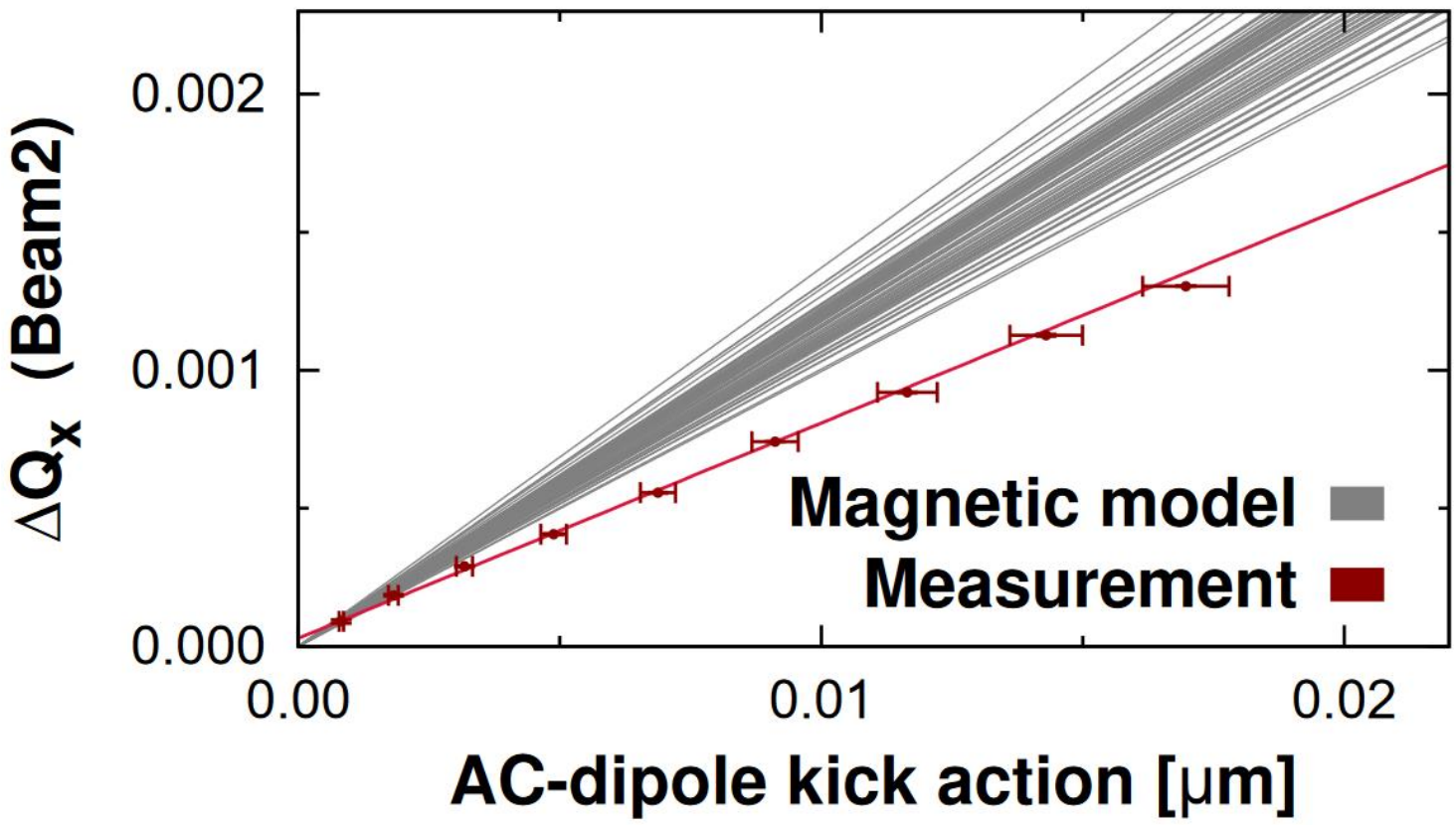
## Initially 1 MD request (top energy, EOS):

- What b6 error can be tolerated for linear optics measurement? (translates to minimum initial β* for initial HL-LHC optics commissioning)
- What is the optimal AC-dipole working point taking into account linear optics measurement quality and nonlinear optimization
- Can we infer IR orbit / corrector offsets online via feed-down in order to feed-forward into HL-LHC optics corrections

# 2

# Possible sources of normal octupole discrepancy with the magnetic model

**Observe discrepancy between required and predicted b4 correction at end-of-squeeze in LHC**




**Want to study potential sources of this discrepancy as they may also be relevant in the HL-LHC**

## Various measurements we wish to perform, but where possible can combine with other MDs:

- Amplitude detuning with CMS solenoid off at EoS
  (dedicated request. Could be performed during commissioning?)
- Amplitude detuning at ballistic and alternative optics
  (combine with linear optics studies)
- Amplitude detuning at EoS with different sextupole configurations
  (could combine with either CMS solenoid detuning study
  or with dodecapole correction MD)


# Amplitude dependent β-beating

**In collaboration with B. Dalena and T. Pugnat (CEA Saclay)**

**Expect a non-negligible amplitude dependent β-beating in HL-LHC generated by triplet nonlinear errors and fringe fields**

**Want to test in LHC whether amplitude dependent β-beat can be measured using existing or new OMC tools**

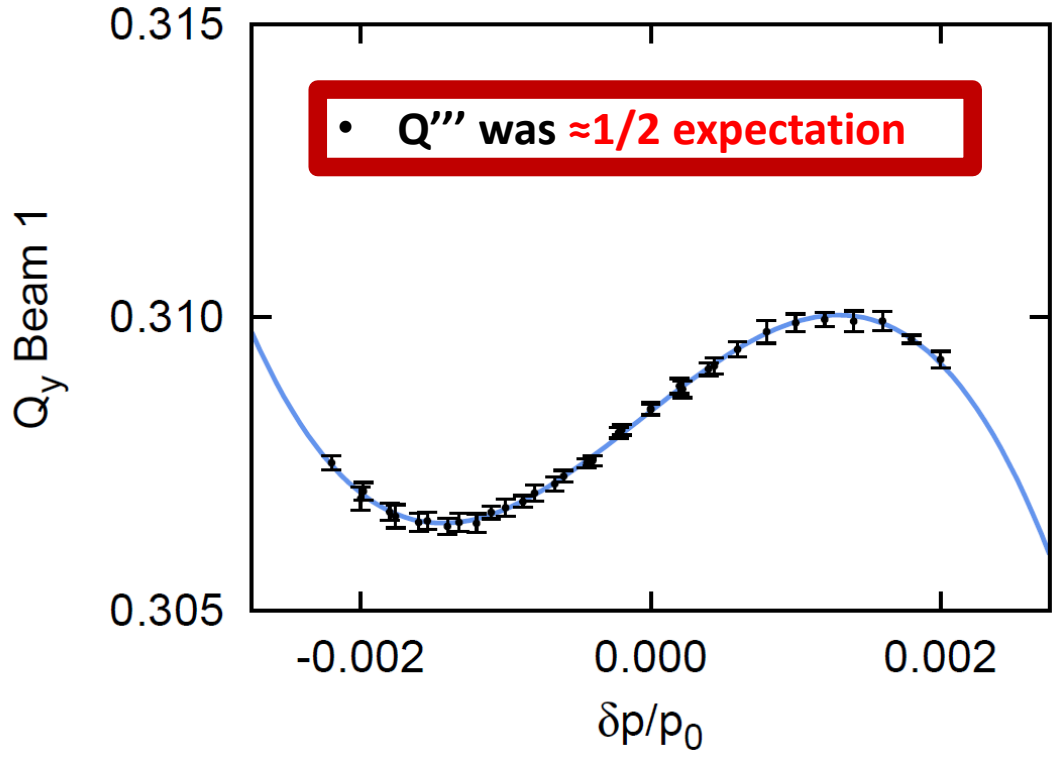
## 1 MD request (could be parallel MD at injection):

- Use MO/MCO to enhance amplitude dependent β-beat to HL-LHC level and see if effect is measurable with AC-dipole
- Test new technique: Amplitude dependent K-modulation
- Test new technique: Amplitude dependent Segment-by-Segment

# Beam and model discrepancies at injection

**Several discrepancies exist between magnetic & beam-based measurement of NL-errors at injection**

- **Discrepancy in required and predicted sextupole strength**
- **Order of magnitude discrepancy in Q”**
- **Factor 2 discrepancy in b5 error inferred from Q”’**




## 1 MD request for various measurements:

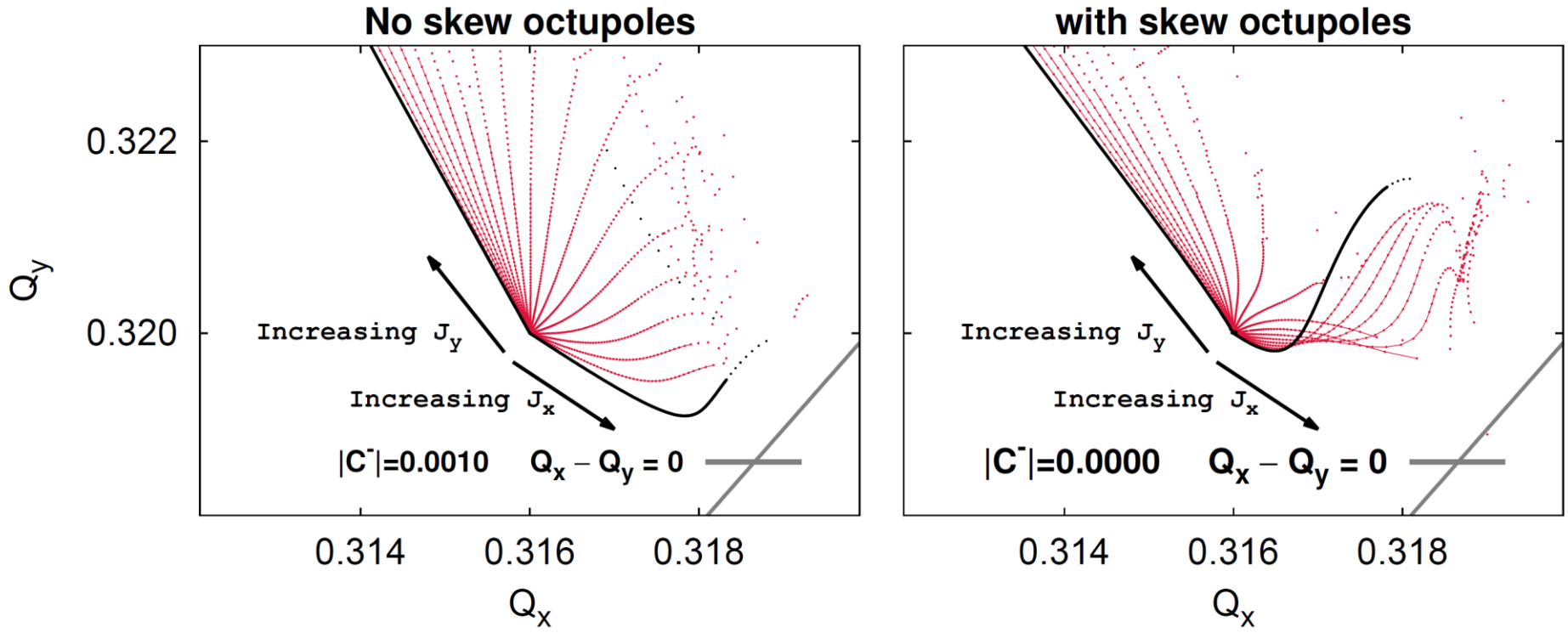
- **Measurement of chromatic amplitude detuning to test b5 model and MCD based correction of Q”’**
- **MCO feed-down, MCDO cross-talk**
- **Natural chromaticty**

# Amplitude dependent closest tune approach (ADECTA) at 6.5TeV

**Large amplitude particles can't approach as close to the Qx-Qy resonance as expected from linear coupling theory**

**" Amplitude dependent closest tune approach "**

**➡ generated by a2+b4 and a4+b4 sources**




**Several MDs in Run1-2 studied ADECTA at injection, but also interested in whether there is any relevance for HL-LHC at 6.5TeV**

# 1-2 MD request (Top energy, EoS):

- 1 MD to measure ADECTA at top energy using single-kicked beams

  > Demonstrated technique at injection in 2018 to measure closest approach of bunch kicked with the MKA. Can we use the MKA at top energy?

  > Alternative method for single-kick excitation proposed with ADT.
  If developed we can apply to study of ADECTA / nonlinear optics at top energy

- 1 MD to study influence of ADECTA from a4 errors on Landau damping
  ( Translates into a tolerance on a4 correction as a function of β* )

  > Would be keen to do joint MD with HSC to study if increasing a4 sources to a level relevant to HL-LHC can cause beams to become unstable?

# 3 Dynamic aperture & RDTs

**Keen to combine with other linear / nonlinear MDs**

- **Comparison of DA with alternative optics**
  - > linear optics MD proposal for half integer
  - > linear optics MD proposal for 60 deg phase advance
- **Effect of b6 correction on dynamic aperture at EoS (can be incorporated into end of dodecapole MD studies)**
- **Effect of 3Qy correction on dynamic aperture at injection (can be incorporated into end of RDT correction MD proposal)**
- **Lots of potential studies which could be performed in parallel at injection** > e.g. effect of NL-chroma on longitudinal profile
- **1 shift request for measurement of RDTs with beam-beam (can combine with beta-beating from beam-beam MD)**

# Summary: how many shifts?

1. 7 dedicated MD shifts requested

2. 2 MD shifts requested
   + additional measurements can be combined with other MDs

3. 5 MD shifts requested
   + lots of potential activities as parallel MD at injection

# Thanks for your attention!

## Lots of interesting plans for Run3!!!