Status of halo excitation studies at CERN

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Introduction and motivation

- During Run 1, we had LHC beam dumps during squeeze, caused by orbit jumps scraping off beam at collimators
- Such dumps could be mitigated if we could deplete the beam tails – then no beam would be scraped off
- Other enhancements of LHC collimation could also be considered, like the control of impact parameters on the TCP (old papers claimed a beneficial effect on cleaning)
- If tails are depleted, fast crab-cavity failures in HL-LHC pose lower risk to send beam onto sensitive elements

Halo removal

- Goal: Increase diffusion speed of halo while leaving the core unaffected, in order to have a depleted region of (phase space) for particle amplitudes next to collimator cut.
- Possible methods under study:
  - electron lens (studied by G. Stancari et al.)
  - tune modulation
  - ADT narrow-band excitation

Halo removal

- When do we need it in the operational cycle?
  - Most important during the squeeze and collision preparation, before beams are brought into collision (Run 1). Application to stable beams for increased protection during crab cavity failure
- Timeline:
  - Nothing available for 2015 startup as operational tool. Immediate goal is to define what needs to be studied in MDs. Hollow e-lens: not before LS2. What can we do before?

Tune modulation

- Idea: By modulating the tunes at a fixed frequency, resonance sidebands are introduced around the existing resonance lines (Bruning, Willeke PRL 76:3719)

$$lQ_x + mQ_y + n\frac{f_{\mathrm{mod}}}{f_{\mathrm{rev}}} = r, \quad \text{with } l, m, n, r \text{ integers} \tag{1}$$

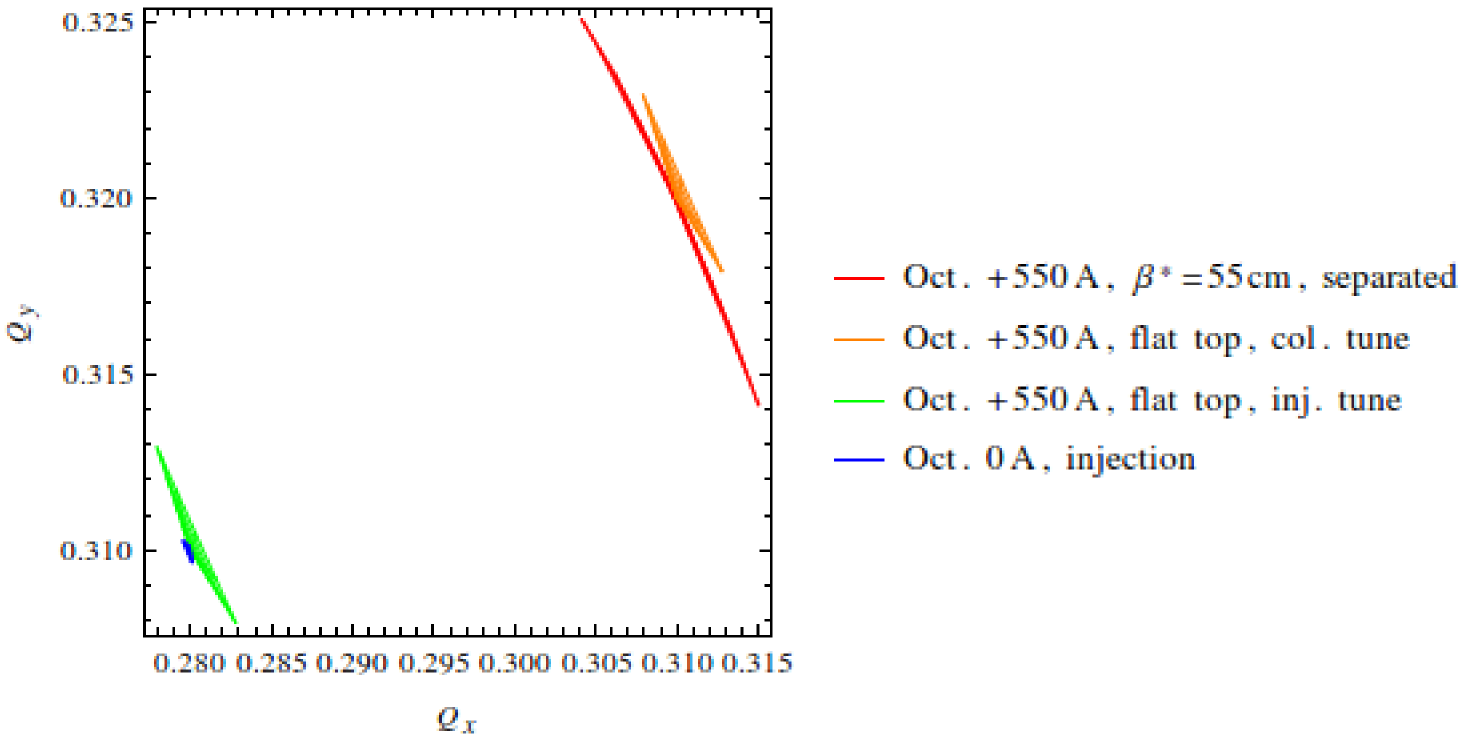
- Use detuning with amplitude of the beam
- By choosing wisely the modulation frequency, we could put a resonance line on the halo, while leaving the beam core unaffected

Tune footprints

- Pre-study of tune footprints and resonance lines can give a first hint on which frequencies could be suitable
  - To know the needed modulation amplitude, we need to know the strength of each resonance in the machine. More advanced simulations needed (frequency map, dynamic aperture)
- Look at tune footprints at
  - injection – for MDs
  - flat top, end of squeeze, collision

Tune footprints with separated beams

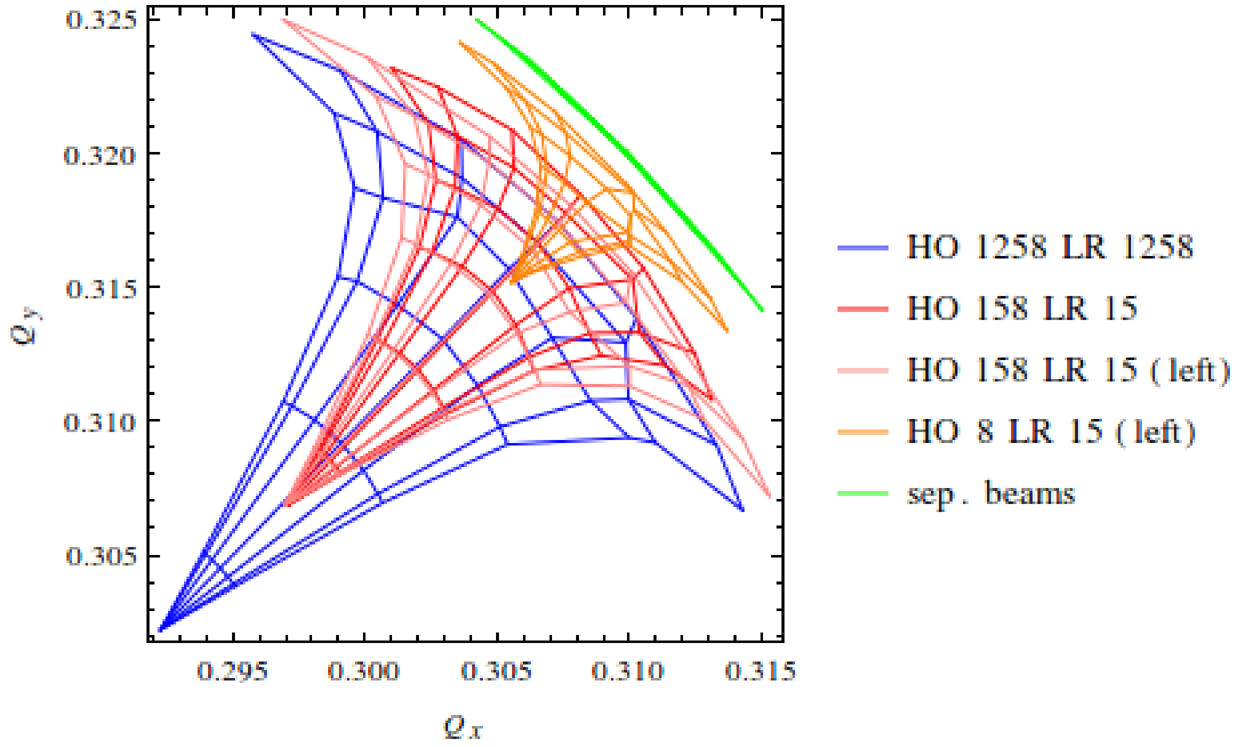
separated beams, 0.45-6.5 TeV, 25 ns, exn=3.75um



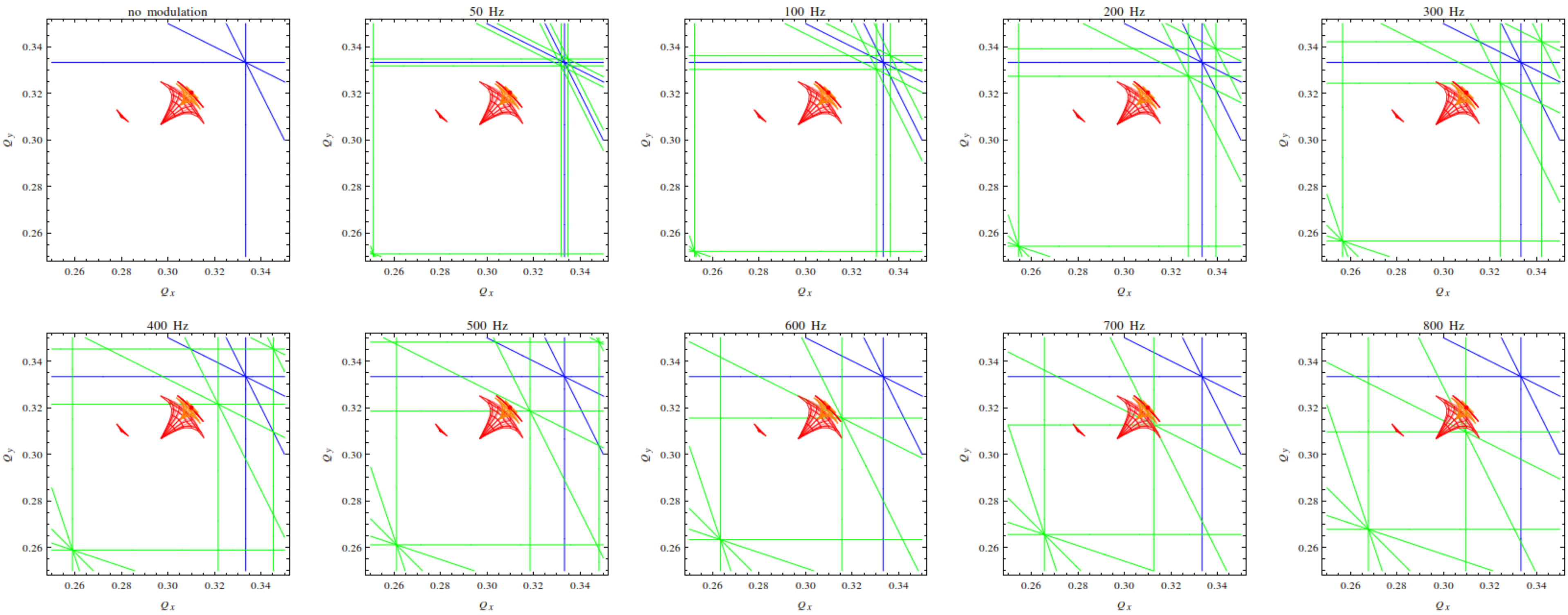
Thanks to X. Buffat and beam-beam team for help and input!

Tune footprints with colliding beams

separated and colliding beams, collision tune, 6.5 TeV, b*=55cm,
142.5 urad, 25 ns, exn=3.75um

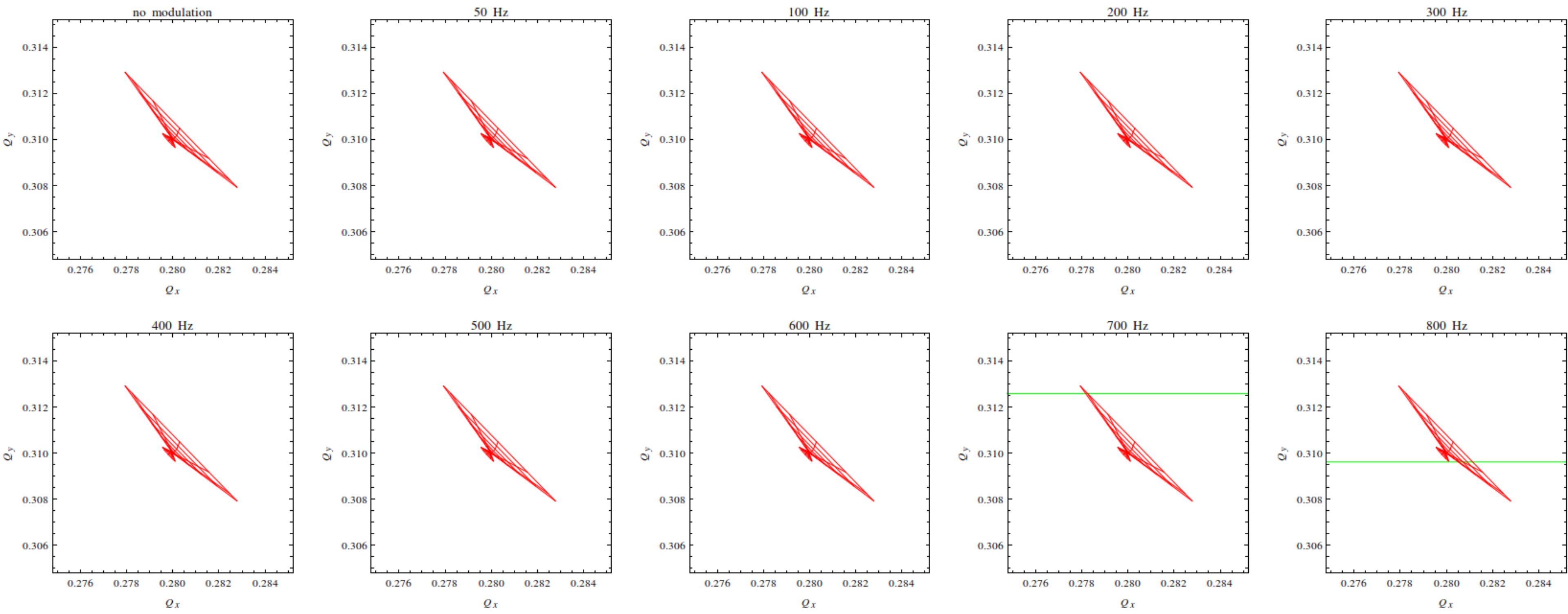


Tune footprints and resonance lines – all footprints, 5th order



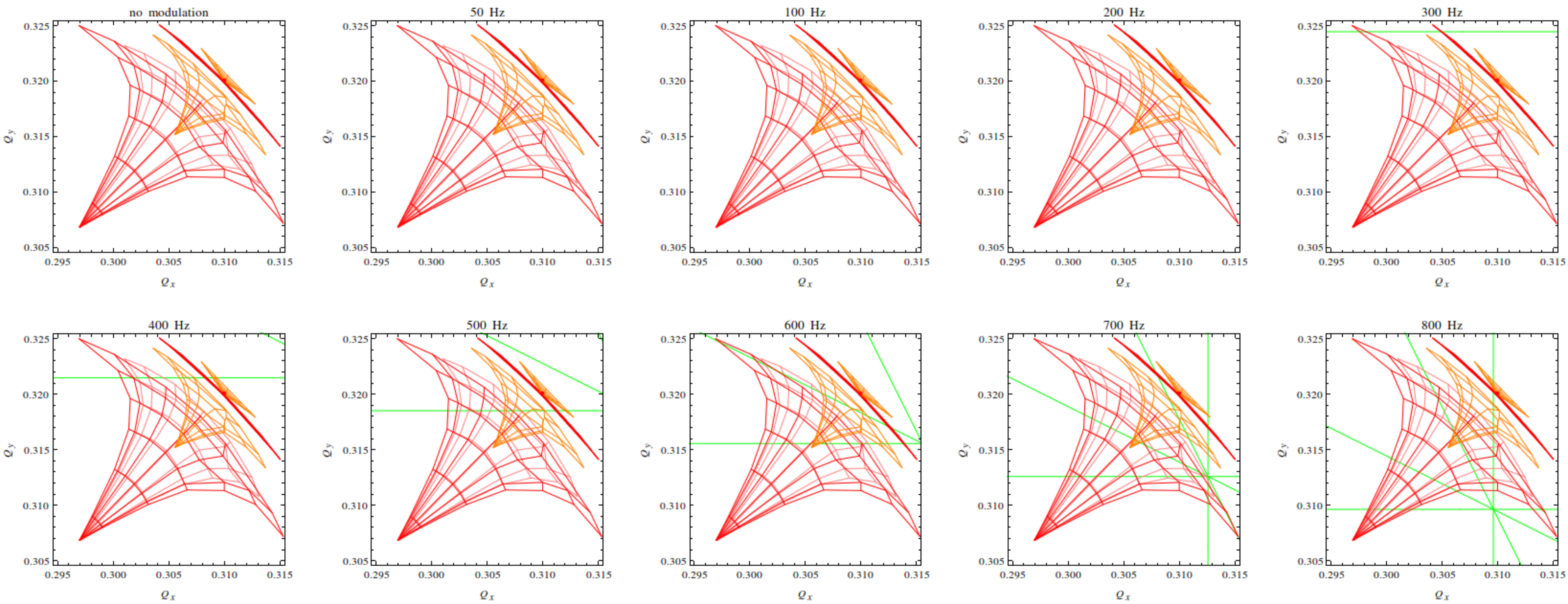
Tune footprints and resonance lines – all footprints, 5th order

Zoom on injection tunes at 450GeV and 6.5 TeV



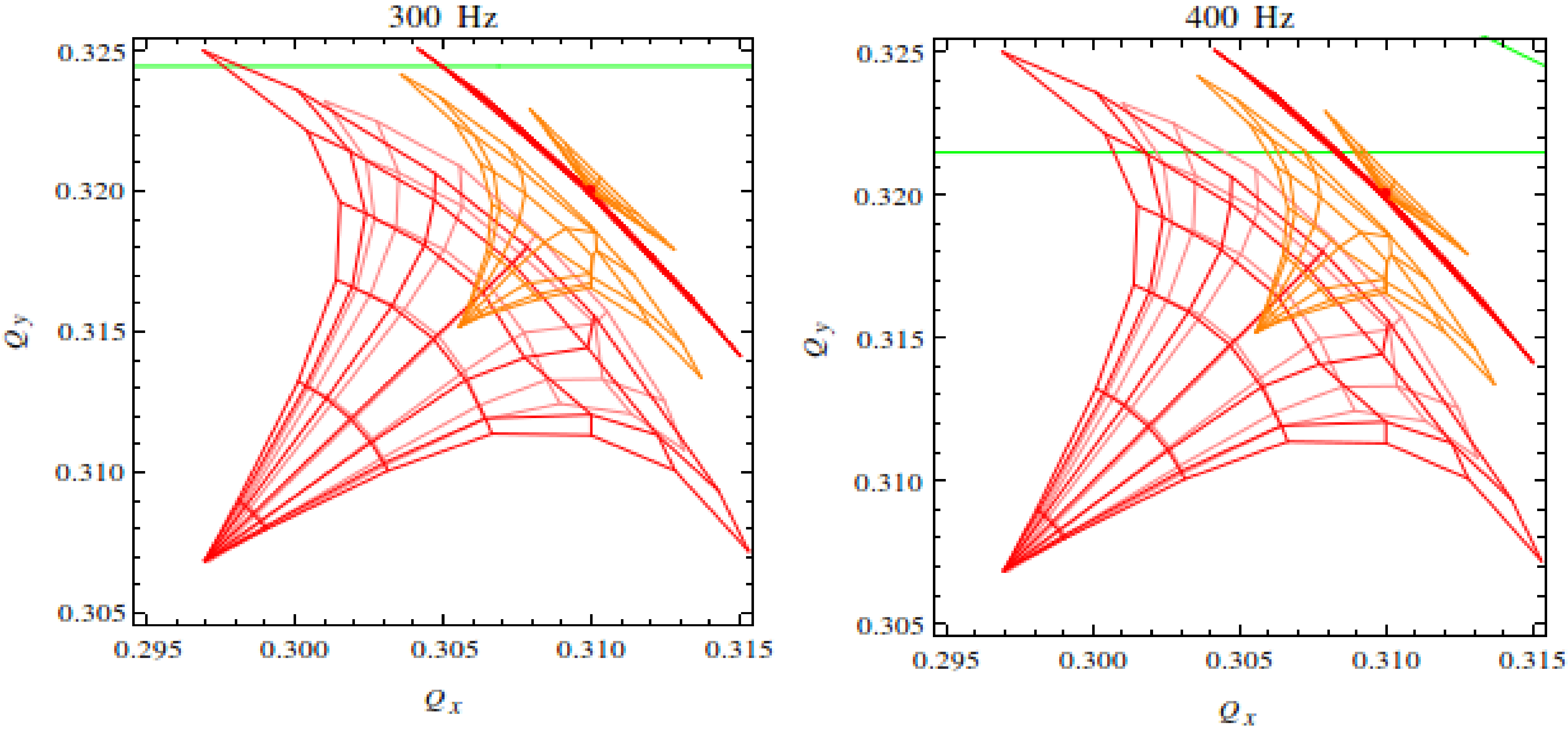
Tune footprints and resonance lines – all footprints, 5th order

Zoom on collision tunes – separated and colliding beams, 6.5 TeV, b*=55cm



Tune footprints and resonance lines – all footprints, 5th order

Zoom on collision tunes – separated and colliding beams, 6.5 TeV, b*=55cm



Preliminary considerations on frequency

- Different frequencies might be needed depending on where in the operational cycle we want to act
- With separated beams
  - Depending on whether we are at injection or collision tune, and which resonance line we want to use: big spread of possible frequencies... 50-800Hz
- In collision
  - At something like 300-400 Hz we start having resonance lines at 7^{th} order touching the halo
  - different bunches have different footprints depending on where they collide. Need to be careful... when hitting the halo in some bunches, we risk to hit the core in others!

Modulation depth

- Previous guess (Oliver, Herman in 2013 collimation review): dQ of 1e-4 needed =>
  - dK of 0.02% when using all IR7 MQW connected in series
  - dK of 3% when using only MQWB.5R7.B1
    - Powered previously at ~20A (to be checked!). We would need about 0.6A
- We should do some more detailed studies with SixTrack to understand what modulation depth is needed (as well as the relative strengths of different resonance lines)
  - Frequency map analysis including realistic magnetic errors
  - Maybe a dynamic aperture study for some selected cases

Power converters

- Discussion with Hugues:
  - using warm IR7 trim quad: can do the modulation on top of existing current without any hardware modifications
  - Max. frequency = 500 Hz (but then not a sin!). Higher frequencies might be possible but requires modifications
  - Inductance of magnet ~ 0.03 H
  - 80V peak-to-peak possible
  - => current variation is U/(2pi f L) = 1 A peak-to-peak at 500 Hz.
  - To verify the power converter capabilities: Measurements planned in week 21

Power converter → B-field

- Might have additional damping due to the magnet and beam screen
- Need to verify what magnetic field we actually have inside the beam screen when the power converter produces modulated current
- Stefano in contact with Marco Buzzio – hoping to do measurements on surface using spare magnet during the year.
- If we don't achieve enough amplitude of the modulation, we could consider using cold magnets (at HERA, a whole arc was used). Compatibility with QPS to be verified
- With all ingredients (hardware capabilities and expected behaviour from theoretical studies) our goal is to plan MDs to be carried out in the LHC in 2015

ADT excitation

- Instead of modulating the tune with a quadrupole, we could use the transverse damper (electrostatic kicker) to make a narrow-band excitation
- Again, rely on detuning with amplitude.
- Simplest approach: Knowing the fractional tune of the halo Qh, apply kick in resonance at frequency frev(n + Qh)
- More advanced ideas: colored noise
- Hardware-wise, no modifications needed
- Should do a theoretical feasibility study with SixTrack
  - Frequency map analysis
  - Possibly dynamic aperture study for some selected case

Pros and cons

- Tune modulation affects both beams simultaneously
- ADT can act not only on a single beam, but also on a single bunch
  - Could imagine having different excitations for different positions in the filling pattern, e.g. hit only bunches with head-on in IR1/5
  - Could allow for "witness bunches" which are not affected. Advantage for early detection of e.g. UFOs
- Both ADT and tune modulation rely on a good knowledge of the tune and detuning with amplitude. Risk to hit the core if parameters are not carefully optimized
  - How well do we know the tune in the squeeze, and how well reproducible is it fill-to-fill? Need convincing validation with beam at the LHC (in particular if these methods are needed continuously in Stable Beams)

Comparing with hollow e-lens

- Hollow e-lens has the advantage of being completely independent on the tune. It selects the particles to kick based only on amplitude
  - Robust against any changes in machine configuration, optics, filling pattern etc
- The e-lens can not resolve single bunches, but with a rise time of 200 ns it can act differently on different trains. Can still allow for witness bunches.
- Tune modulation and ADT rely on existing hardware – no major system changes needed
- Hollow e-lens cannot be available until after LS2
  - If we need halo excitation in the LHC before then, we have to rely on alternative methods

Proposed strategy

- All options should be studied
- Immediate goal: Discuss a consistent parameter set at the CM22 with Fermilab colleagues
  - Coordinate effort and compare results
- Based on theoretical studies and hardware capabilities, we should plan MDs on tune modulation and ADT excitation that can be carried out in 2015
- A collimation fellow or PhD student in ABP expected at next selection will work a fraction of his time on a comparative assessment of all methods
- In parallel, continue work on development of hollow electron lens