Joint LARP CM28 /HiLumi Meeting: Toohig Candidacy

Lee Robert Carver

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About Me

- Name: Lee Robert Carver
- Nationality: UK

- Current Position: CERN Fellow Working on **LHC Collective Effects,** focusing on **measurements and tracking simulations**.
- PhD from University of Manchester. ‘Studies on Multi-harmonic Collinear Accelerating Structures for High Gradient Applications’, completed in 2015, focused on **longitudinal dynamics, rf design and impedance simulations**
- BSc from University of Hertfordshire, graduated in 2010.

- For a full list of publications and presentations, please refer to http://cern.ch/lcarver

Overview

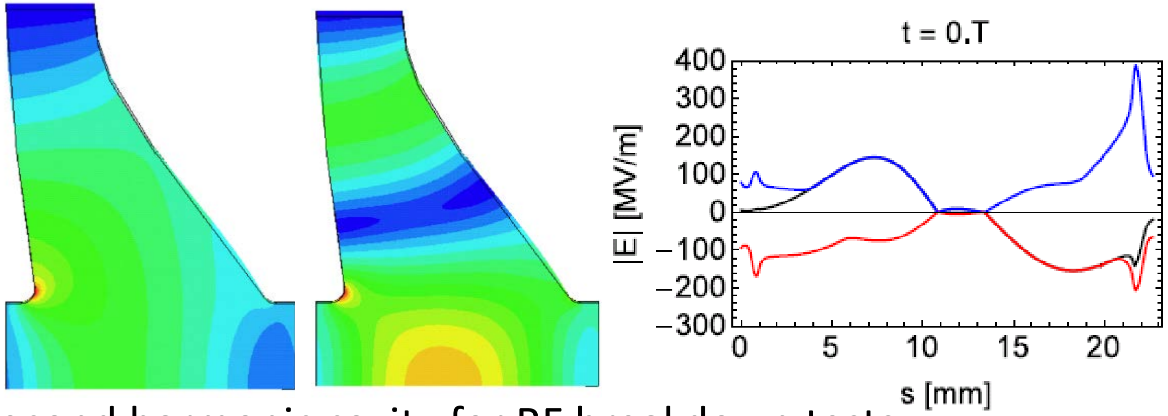
- University of Manchester
  - Multi-harmonic Cavities: RF design and longitudinal dynamics
- CERN
  - Instability Diagnostics
  - Collective Effects in the LHC
  - Effect of Linear Coupling on Transverse Stability
- Research Interests

Multi-Harmonic Accelerating Cavities

- CLIC desires an accelerating gradient of 100MV/m
- Challenging due to issues that include surface heating of cavities and rf breakdown.
- Multi-harmonic cavities can exhibit two useful effects.
  - The temperature rise on the surface of the cavity is **less than for the single mode case for the same accelerating gradient.**
  - Can be used to probe **fundamental characteristics of RF breakdown** using an anode-cathode imbalance on the cavity walls (field away from wall vs field into wall) .
- PhD thesis had large focus on **rf design, impedance and tracking simulations for multi-harmonic cavities.**

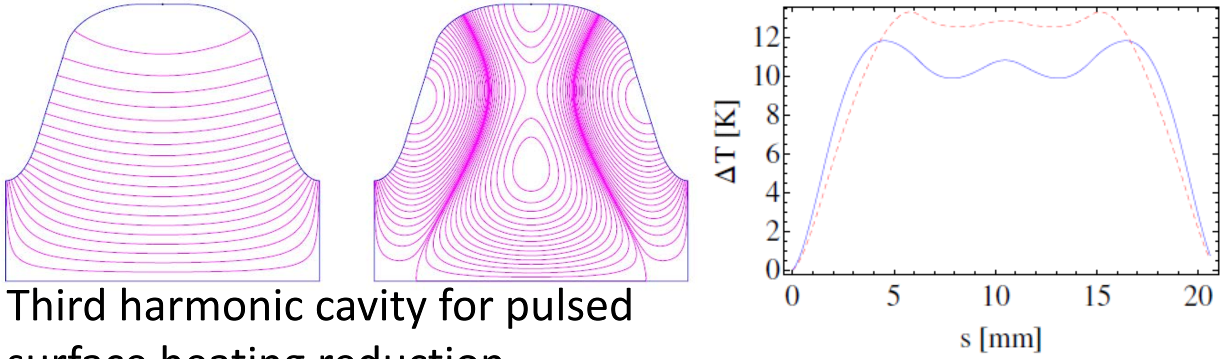
Studies on Multi-Harmonic Collinear Accelerating Structures for High Gradient Applications, L.R. Carver, PhD Thesis, University of Manchester (2015)

3GHz TM_{010} 6GHz TM_{020} Anode, cathode



Second harmonic cavity for RF breakdown tests

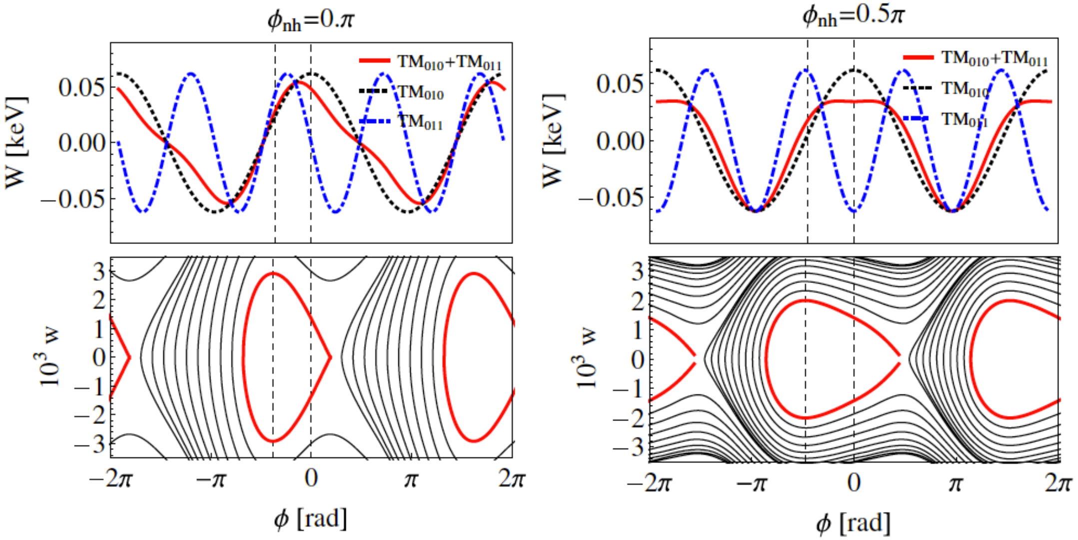
12GHz TM_{010} 36GHz TM_{012} Single, multimode

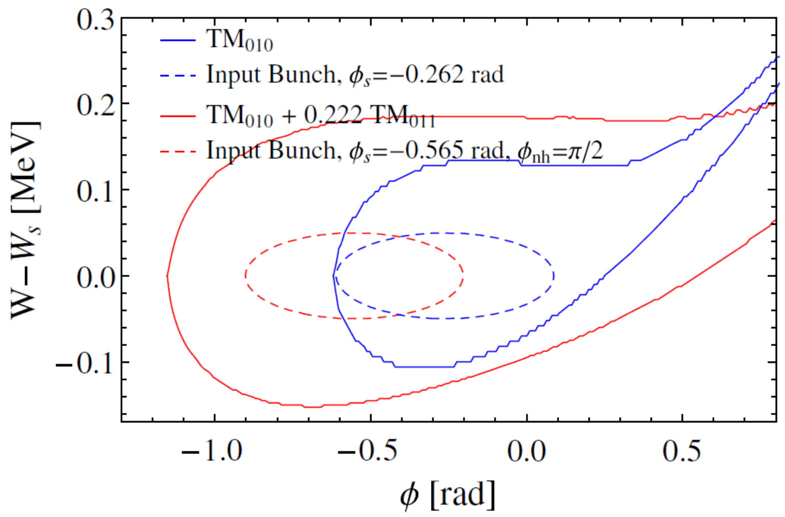


Third harmonic cavity for pulsed surface heating reduction

Longitudinal Stability in Multi-Harmonic Cavities

- Consider a linac comprised of high-gradient multi-harmonic accelerating cavities.
- Can re-derive Hamiltonian for single particle motion in single harmonic linac to include additional mode at harmonic frequency.
- Applied to case where harmonic cavity parameters come from rf design of second harmonic cavity studies.
- Showed that by adjusting phase of harmonic mode, **input acceptance can be increased compared to single mode** (top right)
- Also applied to simplified ESS linac, **input acceptance was again increased** (shown bottom right)





Longitudinal stability in multiharmonic standing wave linacs - L.R. Carver *et al*, Phys. Rev. Accel. Beams 19, 094001 (2016)

Collective Effects in the LHC

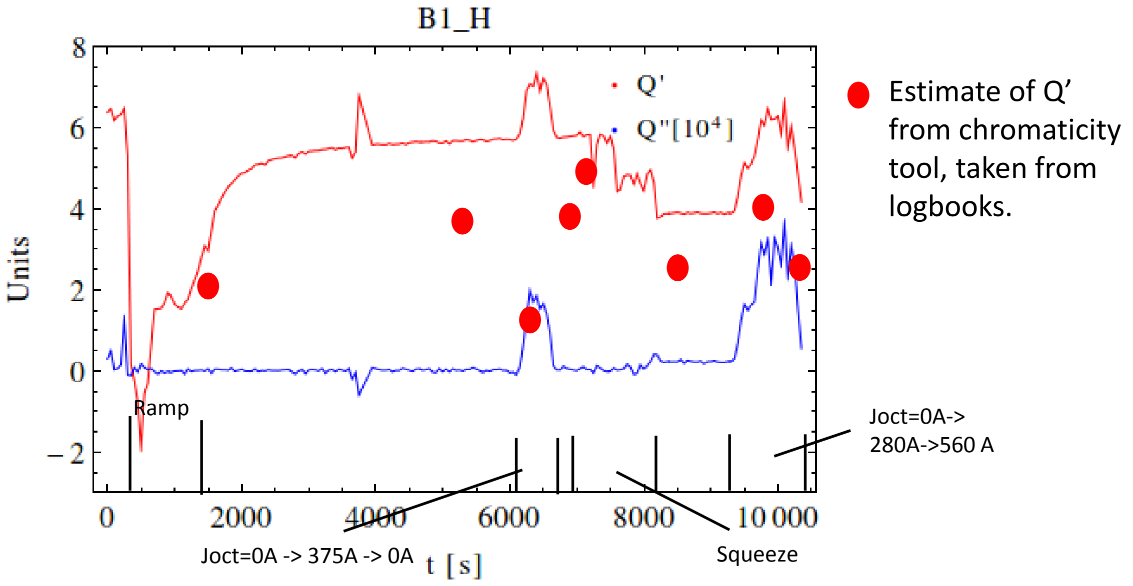
Context

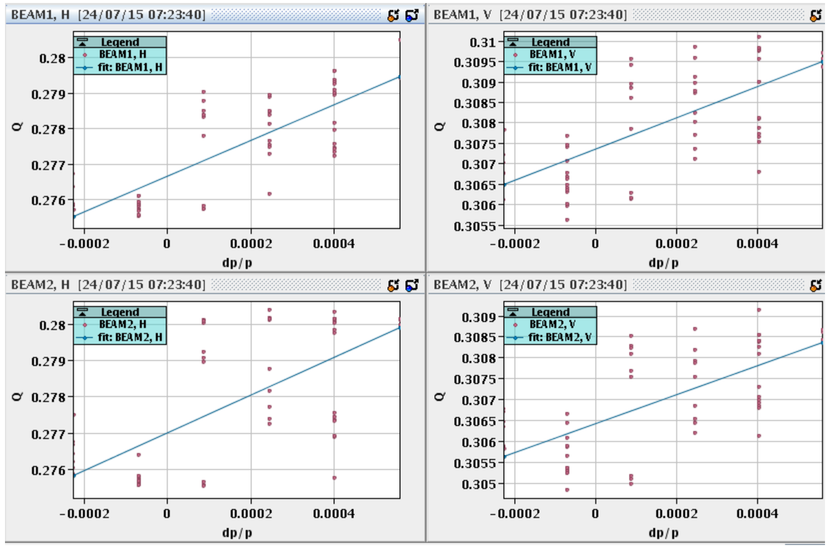
- Joined the instabilities team working on collective effects in the LHC at the **beginning of run II**.
- Early work focused on **improving and testing existing instability diagnostics** (chromaticity measurement, headtail monitor, ADTObsBox).
- Main areas of work during fellowship:
  - Follow LHC operation and work to **solve transverse stability issues** as they arise in the machine.
  - Perform simulations and measurements to **better understand machine observations**.
  - **Plan and carry out measurements** for future running scenarios moving towards HL-LHC.
- Highlights of work include:
  - **Full characterisation** of single bunch instability thresholds at high energy.
  - **Quantifying the effect of electron cloud** at top energy.
  - First test for **potential future stabilising mechanisms** (Q’’).
  - Determination of **linear coupling as a major part of the transverse stability model**.

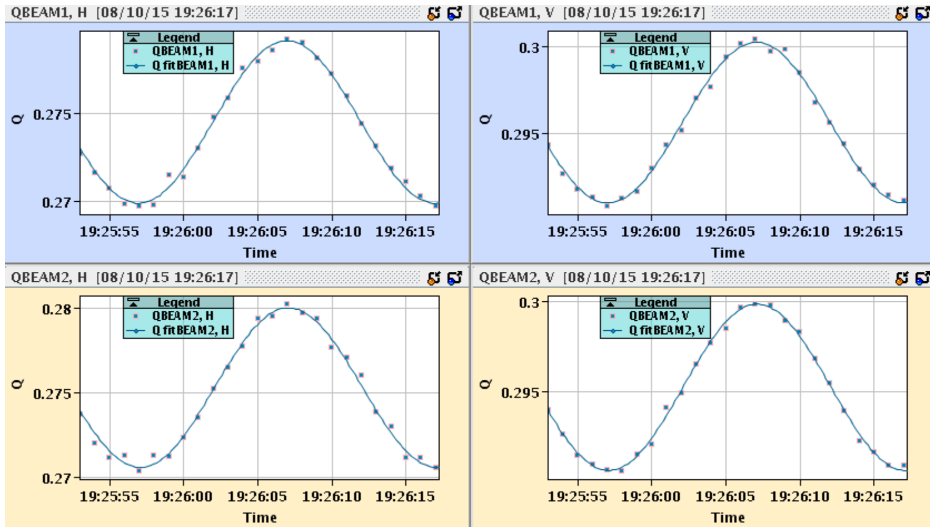
Instability Diagnostics

Chromaticity

- Chromaticity is measured with a slow momentum modulation (period ~20s) and measuring the tune response.
- Previous online tool gave incorrect readings due to phase difference between dp/p and tune signals. Worse for high octupole currents.
- **Reprocessing of dedicated fill highlighted discrepancies, motivated improvements to the tool**.





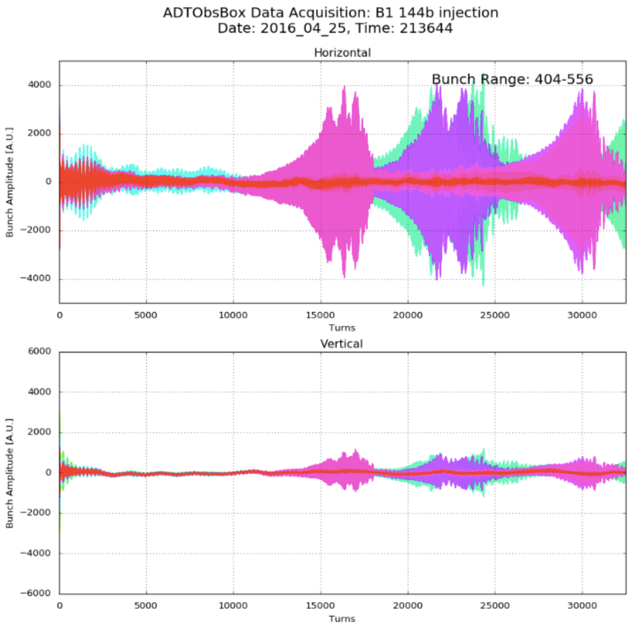


Instability Diagnostics

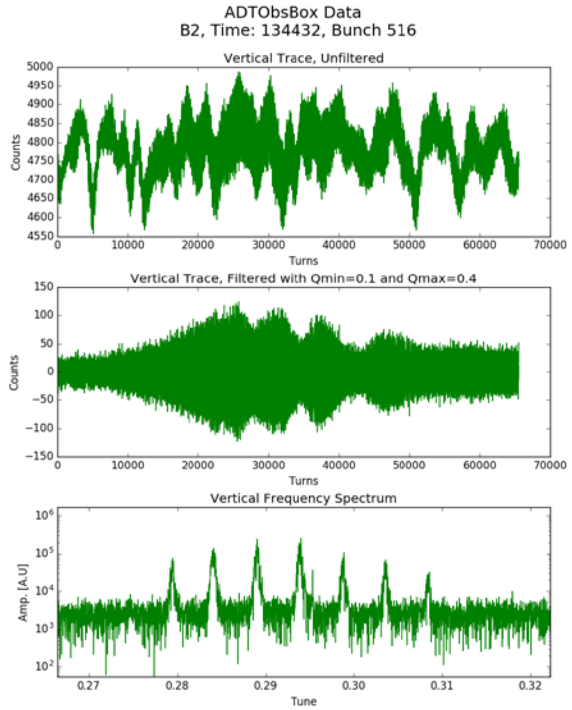
ADTObsBox

- In 2012, instabilities were observed at the end of squeeze that could not be fully explained.
- This motivated the creation of a system that makes available the bunch by bunch turn by turn transverse position data from the Q7 and Q9 pickups of the transverse damper.
- **This system was ready for testing at the end of 2015 and was used heavily in 2016**.
- Developed the scripts to trigger (either manually or linked to a machine process) the buffers to save 32k or 64k turns.
- Incredibly flexible system, invaluable tool for instability detection in all machine phase.
- **Has a wide variety of applications and is now an integral tool for the detection of instabilities**.

IPAC17 Paper in Progress



Bunch by bunch injection oscillations from the 2016 scrubbing run. Acquisition is for unstable injection with 144 bunches.

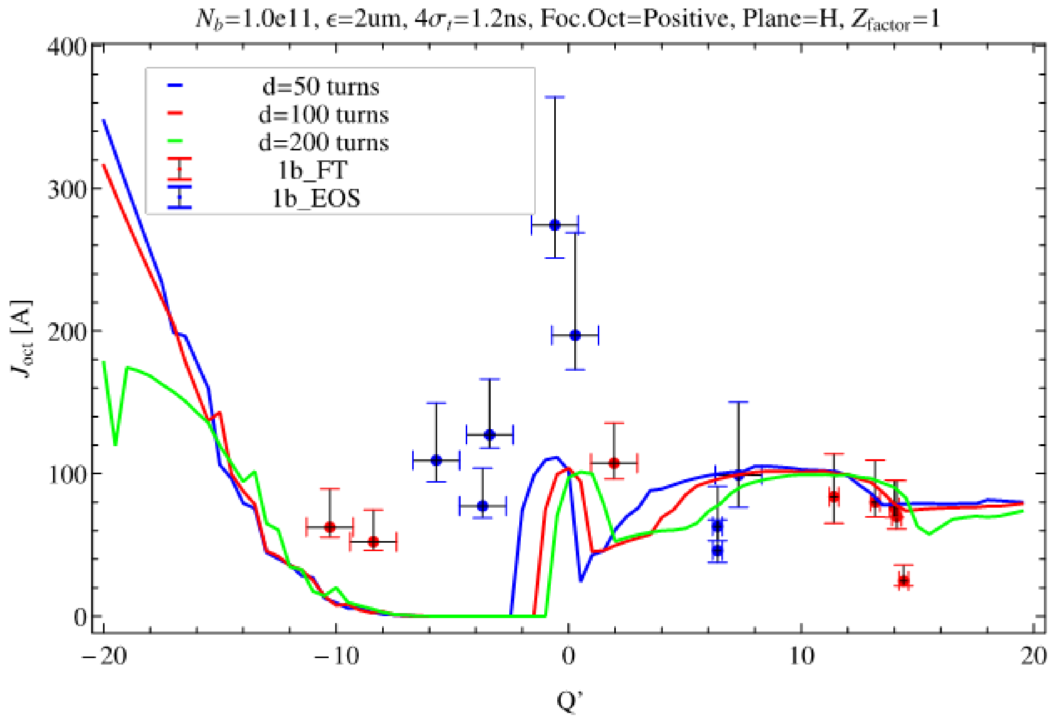


Manually triggered acquisition during stable beams in 2016. A single bunch becoming unstable was captured by the ADTObsBox. Automatic triggers are currently in development.

LHC MD Highlights

Single Bunch Stability Threshold

- Landau octupoles in the LHC provide amplitude detuning. This gives a tune spread which is required to prevent unstable modes from developing.
- Chromaticity changes the way the bunch modes interact with the machine impedance, which can reduce their complex coherent tunes which makes them easier to stabilise against.
- LHC transverse feedback can prevent coupled bunch instabilities by damping dipole motion.
- Campaign of measurements throughout 2015 to **compare single bunch stability thresholds with DELPHI prediction**.
- Results are able to highlight where our prediction is good and where improvements to the model are needed.
- **For operational chromaticities, there is excellent agreement between prediction and model**.



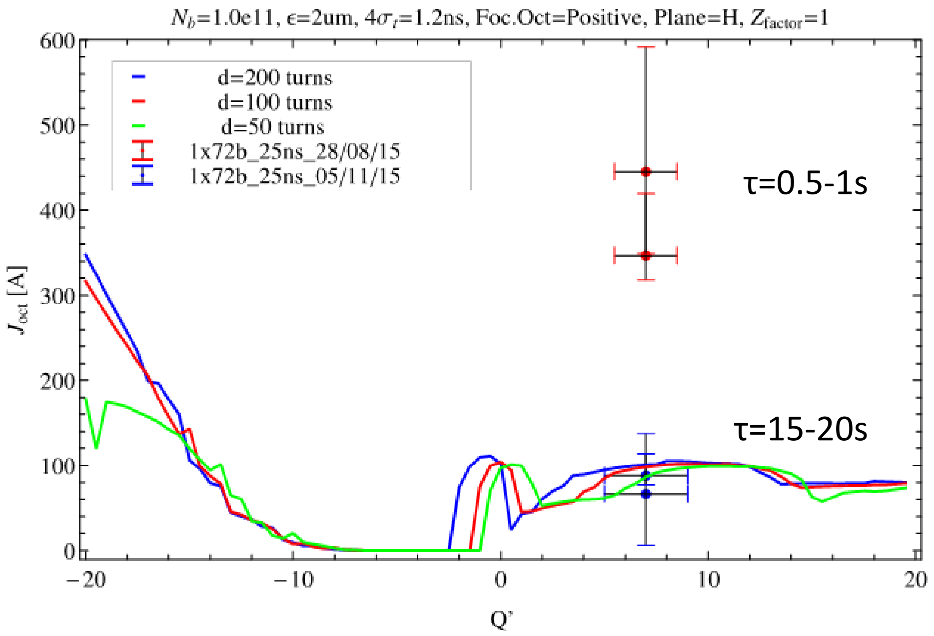
Current Status of Instability Threshold Measurements in the LHC at 6.5TeV, L.R. Carver *et al*, IPAC16, (2016)

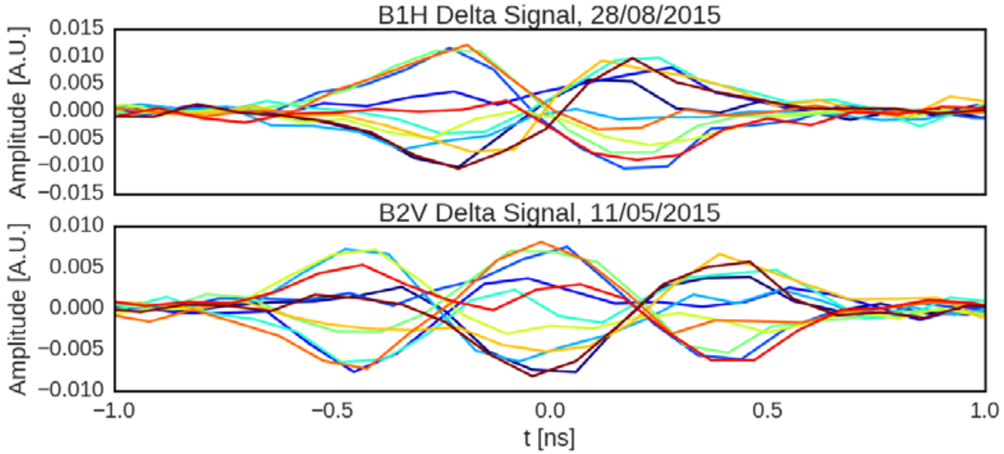
LHC MD Highlights

25ns Trains at Flat Top

- Tested stability threshold at flat top with 72 bunches with 25ns spacing.
- On 28/08/15, an instability with very fast rise time occurred at much higher octupole currents than predicted.
- On 05/11/15, the measurement was repeated and the threshold agreed with single bunch predictions.
- In between two measurements was period of high intensity physics operation which scrubbed machine.
- **Completely different type of instability that was present only at high energy with strong electron cloud.**

MD751: Train Instability Threshold, L.R. Carver *et al*, CERN-ACC-NOTE-2016-004
MD754: Instability Threshold for Train with 25ns Spacing, L.R. Carver *et al*, CERN-ACC-NOTE-2016-0022





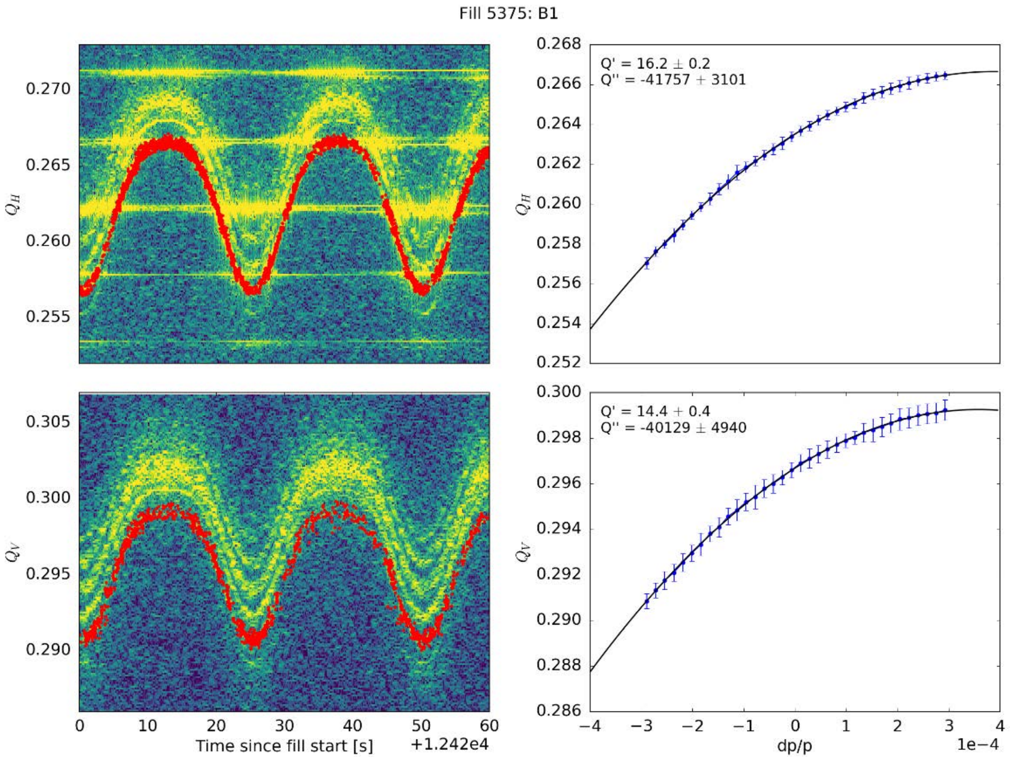
LHC MD Highlights

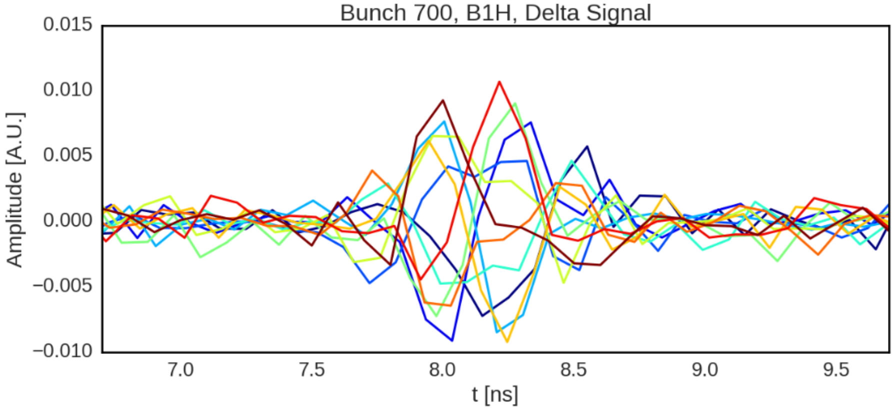
Stabilisation with Q’’

- Second order chromaticity, Q’’, affects the interaction between the bunch modes and the impedance.
- Also (over one synchrotron period) provides transverse detuning based on longitudinal parameters.

$$Q(\delta) = Q_0 + Q'\delta + \frac{Q''}{2}\delta^2 + \cdots$$

- **First test in the LHC showed that we can completely stabilise a single bunch at 6.5TeV using only Q’’.**
- Could be vital for stabilisation in HL-LHC era as it does not depend on transverse emittance (unlike octupoles).



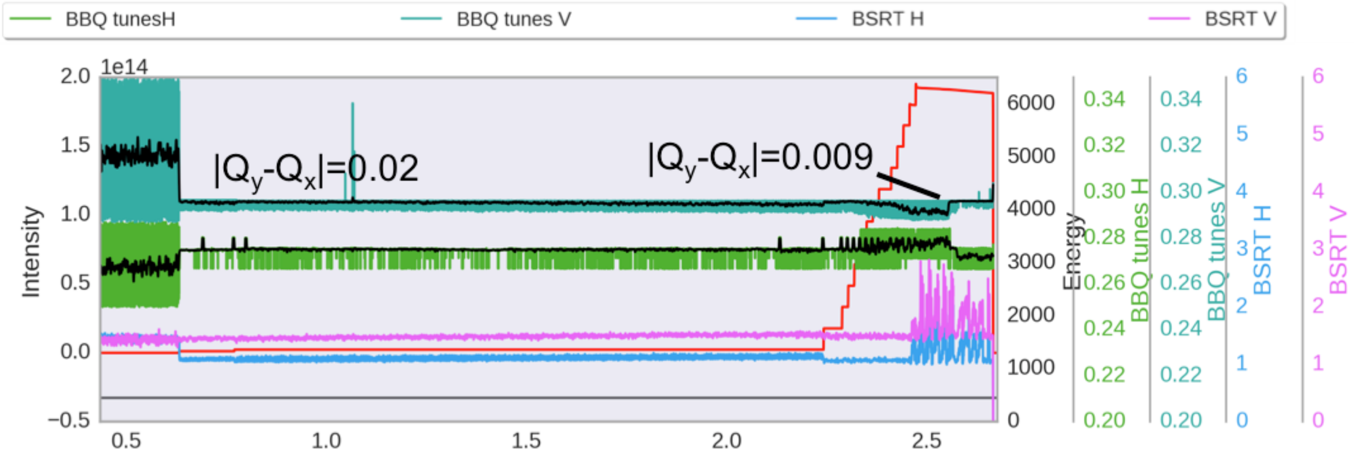


MD1831: Single Bunch Instabilities with Q’’ and non-linear corrections, L.R. Carver *et al*, CERN-ACC-NOTE-2017-0012
IPAC17 Paper in Progress

Linear Coupling

Context

- In run I, there were **many instabilities at the end of the squeeze that were not fully explained**. Instabilities were consistent with single bunch predictions, but much higher octupole currents were needed to stabilise.
- At HERA proton ring, there were observations of transverse instabilities that were believed to be caused by linear coupling.
- In 2015 at injection, **instabilities were observed when horizontal and vertical tunes were moving closer together.**
- Motivated campaign of simulations into effect of linear coupling on transverse stability.



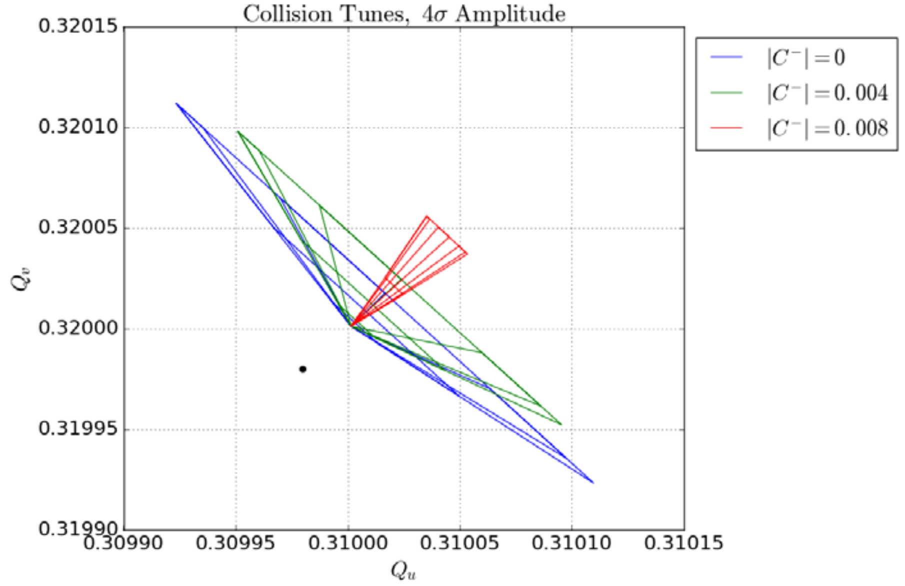
L.R. Carver, 'Instability and beam induced heating in 2015', Proceedings of 6th Evian Workshop, (2015)

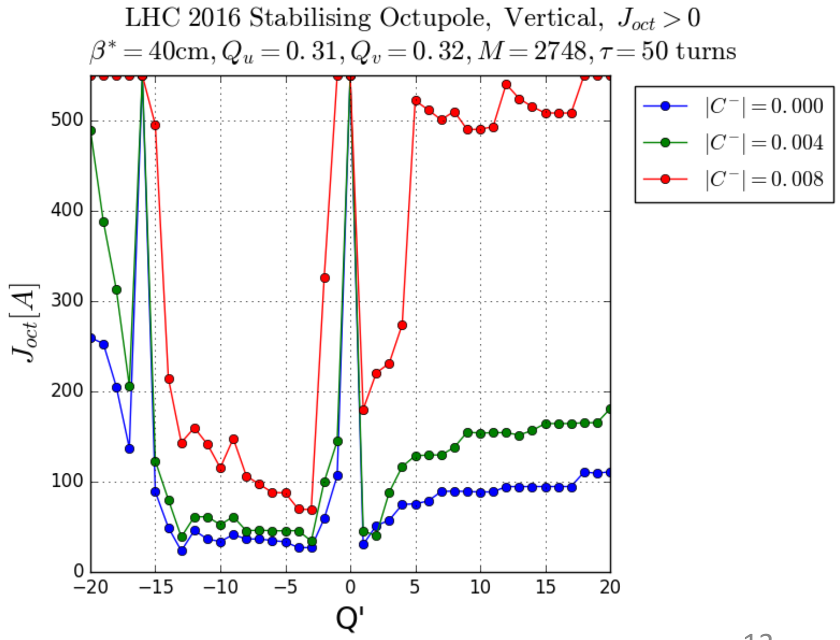
Linear Coupling

Simulations

- Linear coupling can be modelled as a rotation. Reduces effect of normal octupoles and increases effect of skew octupoles.
- Causes shift to detuning coefficients, strongly affects tune spread from Landau Octupoles which can cause a loss of Landau damping.
- MAD-X tracking shows strong impact on tune footprint.
- Time domain simulations and frequency domain computations show that much more octupole current is needed when $|C^-|$ approaches coupled tune separation.
- **Observed instability is consistent with normal uncoupled impedance instabilities, merely a loss of Landau damping.**
- Direct impact on operation, $|C^-|$ must be well corrected after moving to collision tunes (0.31, 0.32) to avoid instabilities.

L.R. Carver, 'The effect of linear coupling on the transverse beam stability in the Large Hadron Collider', Awaiting Submission, (2017)



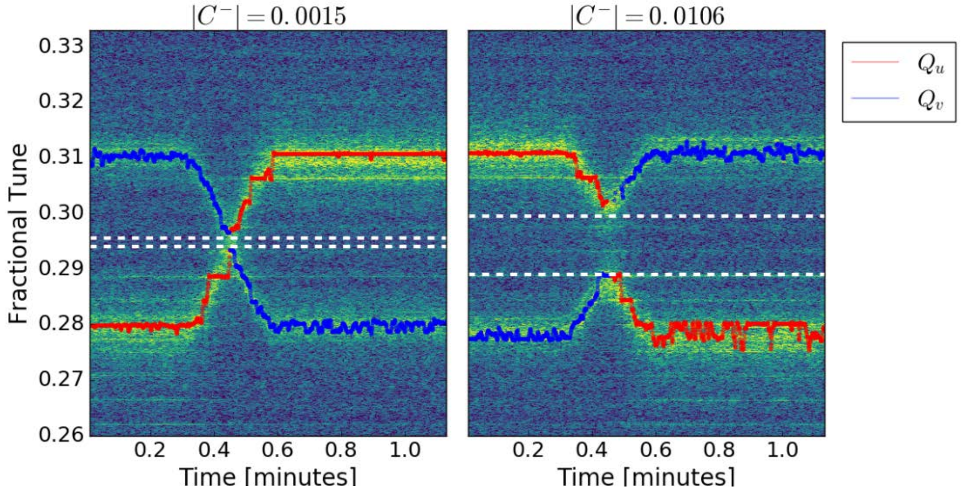


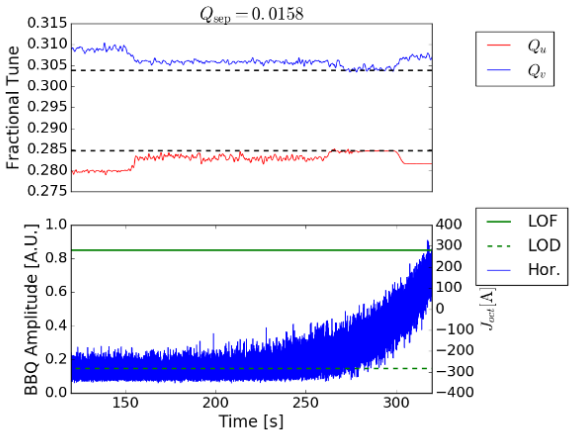
Linear Coupling

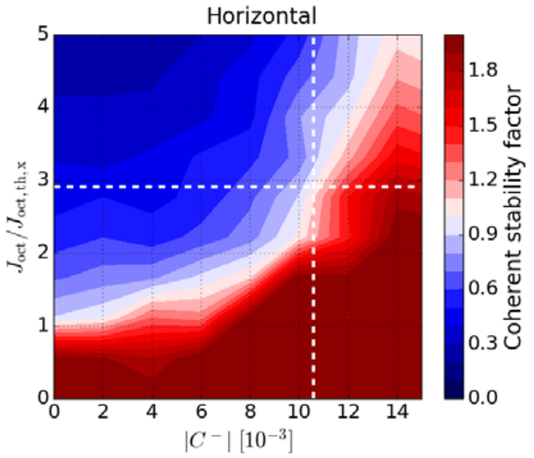
Single Bunch Measurement at Flat Top

- Single bunch measurement at 6.5TeV in the LHC.
- Introduced $|C^{-}|$ and measured with tune crossing.
- With Joct=283A, slowly moved tunes closer together. Observed an instability with Q_{sep}=0.0158
- With measured settings, **factor increase in stability threshold was predicted to be 2.8.**
- Measured increase in stability threshold was **measured as 2.9.**
- Good validation of assumptions and approach. Instability characteristics were again similar to uncoupled instabilities observed in previous measurements.

IPAC17 Paper in Progress.







Research Interests

- HL-LHC promises high beam intensities which will undoubtedly cause unforeseen issues relating to collective effects.
  - Lots of potential areas of study relating to these performance limitations.

- I have knowledge and experience in the area of electron cloud, impedance, transverse collective effects and beam dynamics which could be applicable to a wide variety of the projects within the LARP collaboration.
  - Electron cloud simulations for new prototype magnet.
  - Collective effects simulations for hollow electron lens.
  - Effects of wideband feedback on transverse instabilities.
  - Effect of crab cavity on intra-bunch motion.

- Experience with LHC operation and beam based measurements and techniques
  - Very useful for upcoming SPS tests with wideband feedback and crab cavities.

- Have worked extensively with data from LHC transverse feedback
  - Clear crossover with wideband feedback.

Thanks for listening