Simulations and measurements of halo excitations at the LHC

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Alternative methods (to electron lenses) for halo removal

Towards the HL-LHC

- The collimation performance have been demonstrated very good so far.
- Still some dumps due to tail scraping. This can be mitigated having an active control of the beam tails.
- Electron lenses are the main method under consideration.
- Alternative methods under consideration to complement standard operation.

Alternative methods:

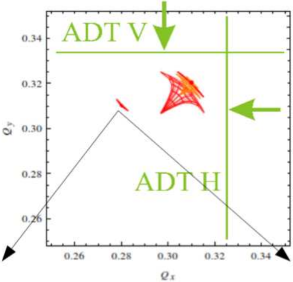
- Narrow-band excitation
- Tune modulation.
- Crab cavity ressonant excitation.
- ,,,

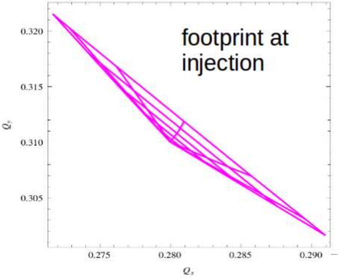
Narrow band excitation

Narrow band excitation

Apply a narrow band excitation using the transverse dumper.

- ADT as the transverse damper.
- Relies on amplitude detuning provided by octupoles.
- Bunch by bunch control.
- No new hardware need to be installed.
- Simplest approach: knowing the fractional tune of the halo, apply an excitation at that frequency.



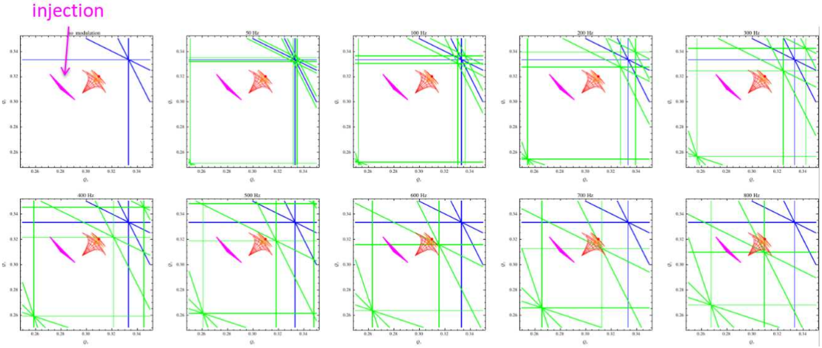


Tune ripple

Principle

A modulation of the quadrupole current induces a tune shift and also the creation of sidebands around the existing resonance lines.

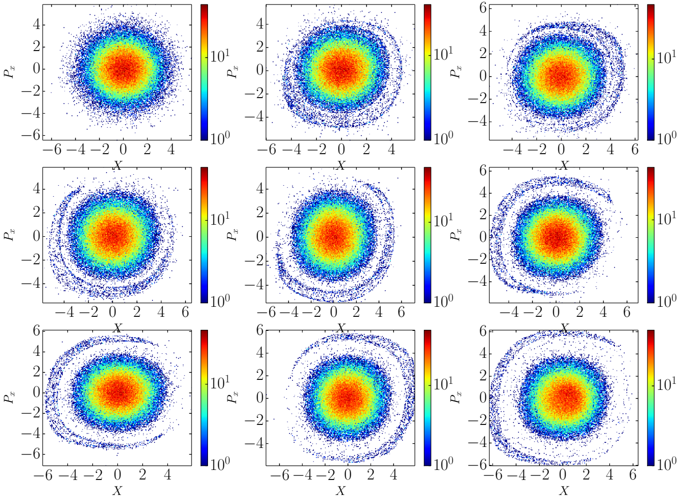
$$lQ_x + mQ_y + n\frac{f_{\text{mod}}}{f_{\text{rev}}} = p \quad l, m, n, p \in \mathbb{Z}$$



Simulations

- To really understand the physics principles we need simulations.
- We created a simple toy model to describe the narrow band excitation with the basic principles .
- One turn map + octupolar terms + dipole kick.
- Next step is to use SixTrack to perform more realistic simulations.
- Narrow band excitation: setting up simulations using dynamic kicks (DYNK) module to modulate ADT kick.
- Need to follow the same procedure for tune ripple simulations.

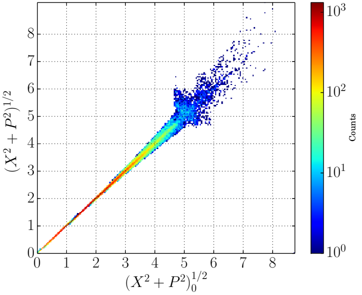
Toy model simulations ($Q_{\mathrm{ADT}} = 0.290 \rightarrow 0.295$)

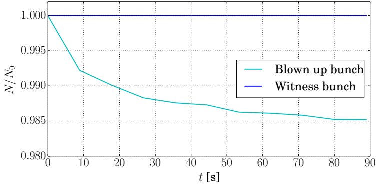


Toy model simulations

Fixed ADT frequency:

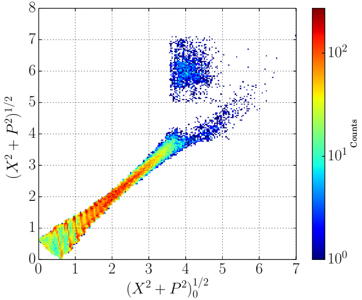
$Q_{\mathrm{ADT}} = 0.295$





Scan ADT frequency:

$Q_{\mathrm{ADT}} = 0.290 \to 0.295$



Interesting results that probably demonstrates the theoretical principle on the paper. But experimental demonstration is required.

Machine Development (MD) sessions

A total of 5 MD sessions have been devoted to Active halo control.

- 4 narrow band excitation.
- 1 tune ripple.

General procedure

Inject one (or more) nominal bunches, blow up to populate tails and perform excitation. Then use available tools (BCT, BLMs, wire scanners, collimator scrapings) to study the evolution of the bunch distribution.

Narrow band excitation

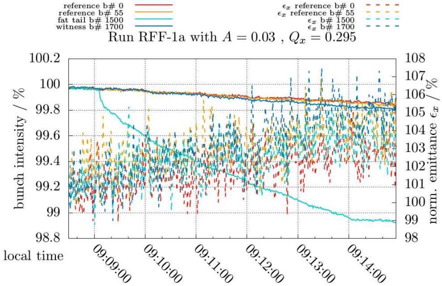
The excitation is applied using the transverse damper (ADT). This has demonstrated to work very well and to be very flexible in such exigent environments.

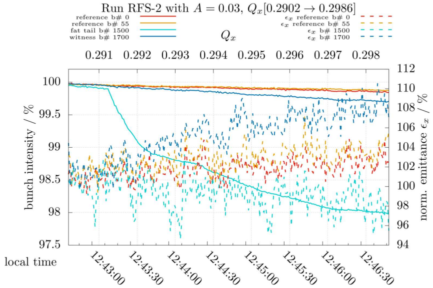
Tune ripple

The modulation is applied in warm quadrupoles in IR3.

Narrow band excitation MDs

- We studied different excitation frequencies, both fixed and sweeps.
- We converged to the study of just two different cases.
  - Fixed frequency: $Q_{\mathrm{ADT}} = 0.295(\sim 5.5\sigma)$
  - Frequency scan: $Q_{\mathrm{ADT}} = 0.2902 \rightarrow 0.2986(\sim 4.5\sigma \rightarrow 6\sigma)$



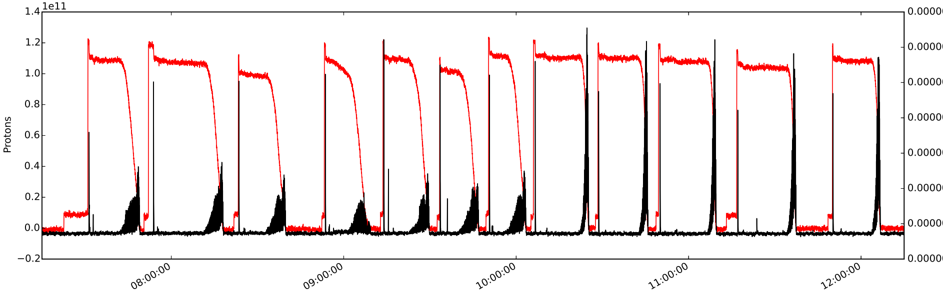


Observations

- Clear intensity decrease in the blown up bunch.
- No intensity decrease in the witness bunch.
- No clear emittance increase in the blown up bunch.
- Good signs but not enough.

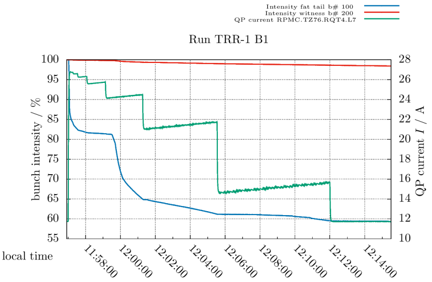
Narrow band excitation last MD

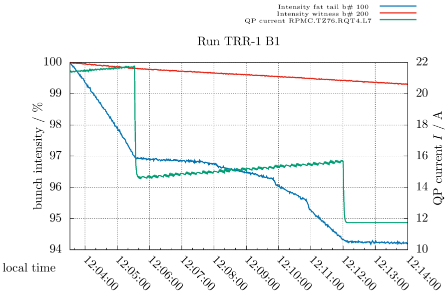
- We studied separately the effect of different excitations in the core and in the tails.



- Detailed data analysis of the collimator scrapings is currently ongoing.

Tune ripple MD





- Ripple in warm quadrupole in IR7.
- Maximum peak-to-peak current: 40 mA
- Maximum frequency: 333 Hz.
- Quadrupole stability problems.

- Quadrupole current jumps. Under investigation.
- We had to activate the tune feedback to control the tune position.
- In stable regions, clear intensity decrease of the blown up bunch.

Conclusions

- 2015/2016 runs have provided a lot of opportunities to test active halo control techniques.
- A total of 5 MDs have been devoted to test narrow band excitation and tune ripple.
- Lots of (relatively complex) data to analyze during EYETS.
- Detailed SixTrack simulations required to understand the basic principles and compare it with MD data.
- Preliminary analysis shows that such techniques might work but still lots of data to analyze.
- Still need to evaluate the performance in multibunch mode.