E-Cloud and TMCI Data Studies at CERN SPS

LARP CM-15 November 1-3, 2010

J.D. Fox[1], T. Mastorides[1], C. Rivetta[1], **M. Swiatlowski**[1], O. Turgut[1], M. Furman[2], S. De Santis[2], R. Secondo[2], J. L. Vay[2], G. Arduini[3], W. Hofle[3], G. Rumolo[3], B. Salvant[3]

[1]SLAC, [2]LBL, [3]CERN

November 2, 2010

Outline

SLAC NATIONAL ACCELERATOR LABORATORY

Introduction

Develop Analysis Techniques

- Can we develop a common system to characterize the bunch dynamics interacting with either e-clouds or machine impedances?
  - Capture important characteristics for feedback control design
  - Growth rates of oscillations?
  - Frequency of oscillations?
  - Spread in tunes?

Develop Analysis Techniques

- Can we develop a common system to characterize the bunch dynamics interacting with either e-clouds or machine impedances?
    - Capture important characteristics for feedback control design
    - Growth rates of oscillations?
    - Frequency of oscillations?
    - Spread in tunes?

Develop Analysis Techniques

- Can we develop a common system to characterize the bunch dynamics interacting with either e-clouds or machine impedances?
    - Capture important characteristics for feedback control design
    - Growth rates of oscillations?
    - Frequency of oscillations?
    - Spread in tunes?

What Are They Used For?

- Multiple datasets, instabilities
  - Both TMCI and ECloud conditions
  - Compare different types of instabilities: is one feedback system capable of addressing both?
- Analysis techniques enable comparison of data and multi-particle simulation codes
  - Want to validate codes (WARP, HEADTAIL) using real data from SPS
  - Studies limited by availability of MD days: validated simulation will allow for many more tests
  - Multi-particle simulation codes are a perfect test-bench to understand design models and test identification and analysis tools as well as feedback control design

What Are They Used For?

- Multiple datasets, instabilities
  - Both TMCI and ECloud conditions
  - Compare different types of instabilities: is one feedback system capable of addressing both?
- Analysis techniques enable comparison of data and multi-particle simulation codes
  - Want to validate codes (WARP, HEADTAIL) using real data from SPS
  - Studies limited by availability of MD days: validated simulation will allow for many more tests
  - Multi-particle simulation codes are a perfect test-bench to understand design models and test identification and analysis tools as well as feedback control design

What Are They Used For?

- Multiple datasets, instabilities
    - Both TMCI and ECloud conditions
    - Compare different types of instabilities: is one feedback system capable of addressing both?
- Analysis techniques enable comparison of data and multi-particle simulation codes
    - Want to validate codes (WARP, HEADTAIL) using real data from SPS
    - Studies limited by availability of MD days: validated simulation will allow for many more tests
    - Multi-particle simulation codes are a perfect test-bench to understand design models and test identification and analysis tools as well as feedback control design

What Are They Used For?

- Multiple datasets, instabilities
  - Both TMCI and ECloud conditions
  - Compare different types of instabilities: is one feedback system capable of addressing both?
- Analysis techniques enable comparison of data and multi-particle simulation codes
  - Want to validate codes (WARP, HEADTAIL) using real data from SPS
  - Studies limited by availability of MD days: validated simulation will allow for many more tests
  - Multi-particle simulation codes are a perfect test-bench to understand design models and test identification and analysis tools as well as feedback control design

What Are They Used For?

- Multiple datasets, instabilities
  - Both TMCI and ECloud conditions
  - Compare different types of instabilities: is one feedback system capable of addressing both?
- Analysis techniques enable comparison of data and multi-particle simulation codes
  - Want to validate codes (WARP, HEADTAIL) using real data from SPS
  - Studies limited by availability of MD days: validated simulation will allow for many more tests
  - Multi-particle simulation codes are a perfect test-bench to understand design models and test identification and analysis tools as well as feedback control design

What Are They Used For?

- Multiple datasets, instabilities
  - Both TMCI and ECloud conditions
  - Compare different types of instabilities: is one feedback system capable of addressing both?
- Analysis techniques enable comparison of data and multi-particle simulation codes
  - Want to validate codes (WARP, HEADTAIL) using real data from SPS
  - Studies limited by availability of MD days: validated simulation will allow for many more tests
  - Multi-particle simulation codes are a perfect test-bench to understand design models and test identification and analysis tools as well as feedback control design

What Are They Used For?

- Multiple datasets, instabilities
  - Both TMCI and ECloud conditions
  - Compare different types of instabilities: is one feedback system capable of addressing both?
- Analysis techniques enable comparison of data and multi-particle simulation codes
  - Want to validate codes (WARP, HEADTAIL) using real data from SPS
  - Studies limited by availability of MD days: validated simulation will allow for many more tests
  - Multi-particle simulation codes are a perfect test-bench to understand design models and test identification and analysis tools as well as feedback control design

Getting to the Data

- Use wide bandwidth beam position monitors (BPM)
  - Run through $\Delta\Sigma$ hybrids to generate sum and difference channels
  - Used TekTronix DPO7000 Oscilloscope, with 40 GSps shared between 4 3GHz bandwidth inputs
- Significant post-processing improves data quality dramatically
  - Pick-up and cable frequency response equalized
  - Synchrotron oscillations removed: fix center of bunch
  - Data separated into different bunches

Getting to the Data

- Use wide bandwidth beam position monitors (BPM)
  - Run through $\Delta\Sigma$ hybrids to generate sum and difference channels
  - Used TekTronix DPO7000 Oscilloscope, with 40 GSps shared between 4 3GHz bandwidth inputs
- Significant post-processing improves data quality dramatically
  - Pick-up and cable frequency response equalized
  - Synchrotron oscillations removed: fix center of bunch
  - Data separated into different bunches

Getting to the Data

- Use wide bandwidth beam position monitors (BPM)
  - Run through $\Delta\Sigma$ hybrids to generate sum and difference channels
  - Used TekTronix DPO7000 Oscilloscope, with 40 GSps shared between 4 3GHz bandwidth inputs
- Significant post-processing improves data quality dramatically
  - Pick-up and cable frequency response equalized
  - Synchrotron oscillations removed: fix center of bunch
  - Data separated into different bunches

Getting to the Data

- Use wide bandwidth beam position monitors (BPM)
  - Run through $\Delta\Sigma$ hybrids to generate sum and difference channels
  - Used TekTronix DPO7000 Oscilloscope, with 40 GSps shared between 4 3GHz bandwidth inputs
- Significant post-processing improves data quality dramatically
  - Pick-up and cable frequency response equalized
  - Synchrotron oscillations removed: fix center of bunch
  - Data separated into different bunches

Getting to the Data

- Use wide bandwidth beam position monitors (BPM)
  - Run through $\Delta\Sigma$ hybrids to generate sum and difference channels
  - Used TekTronix DPO7000 Oscilloscope, with 40 GSps shared between 4 3GHz bandwidth inputs
- Significant post-processing improves data quality dramatically
  - Pick-up and cable frequency response equalized
  - Synchrotron oscillations removed: fix center of bunch
  - Data separated into different bunches

Getting to the Data

- Use wide bandwidth beam position monitors (BPM)
  - Run through $\Delta\Sigma$ hybrids to generate sum and difference channels
  - Used TekTronix DPO7000 Oscilloscope, with 40 GSps shared between 4 3GHz bandwidth inputs
- Significant post-processing improves data quality dramatically
  - Pick-up and cable frequency response equalized
  - Synchrotron oscillations removed: fix center of bunch
  - Data separated into different bunches

Getting to the Data

- Use wide bandwidth beam position monitors (BPM)
  - Run through $\Delta\Sigma$ hybrids to generate sum and difference channels
  - Used TekTronix DPO7000 Oscilloscope, with 40 GSps shared between 4 3GHz bandwidth inputs
- Significant post-processing improves data quality dramatically
  - Pick-up and cable frequency response equalized
  - Synchrotron oscillations removed: fix center of bunch
  - Data separated into different bunches

Goals For Today's Talk

- Show data analysis techniques
- New data from MD's in July, August 2010
- Show first comparisons of ECloud and TMCI data

Goals For Today's Talk

- Show data analysis techniques
- New data from MD's in July, August 2010
- Show first comparisons of ECloud and TMCI data

Goals For Today's Talk

- Show data analysis techniques
- New data from MD's in July, August 2010
- Show first comparisons of ECloud and TMCI data

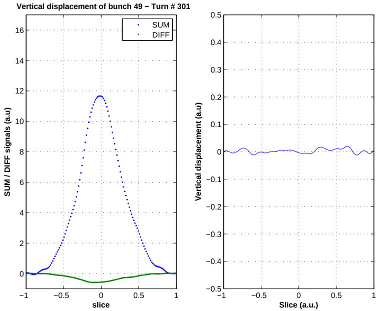
E-Cloud Data

Introduction

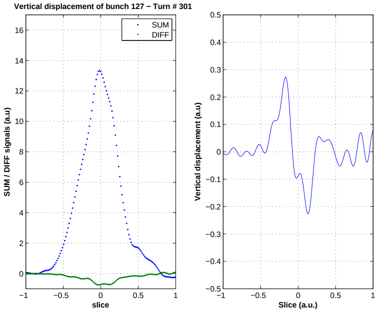
- Inject 4 batches of 72 bunches each
- Here, look at batch 2 and 3 during injection of 3
- Standard synchrotron frequency, 315 Hz

Displacement

- Simplest presentation of data: Δ and Σ channels
- Vertical displacement plot shows $\Delta - \mathrm{mean}(\Delta)$
  - Shows vertical displacements for different section of the bunch: useful for identifying oscillations in head/tail



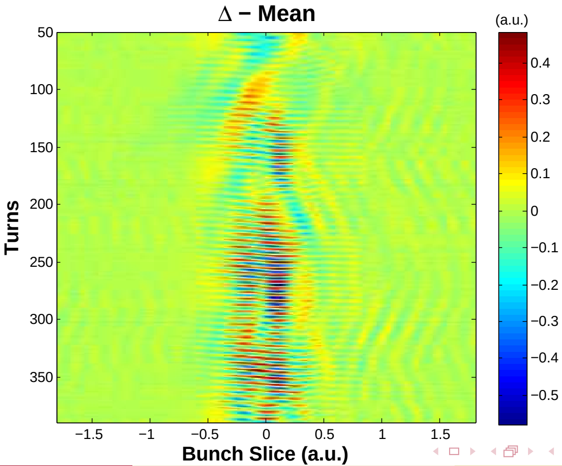
STABLE



UNSTABLE

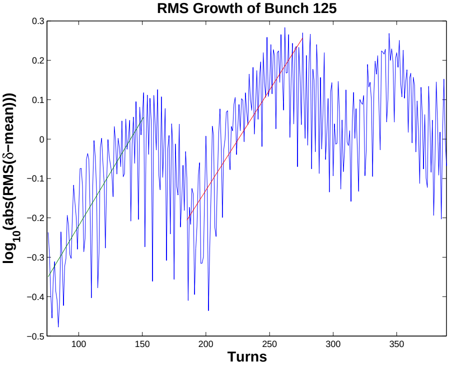
Displacement Over Time

- Vertical axis is turns, z axis is amplitude
- Stable initially, but then large oscillations in tail, turn 125
- Oscillations spread to entire bunch, turn 225



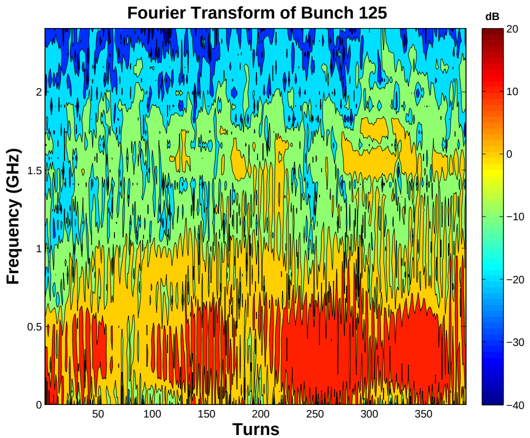
RMS Growth

- Want a metric for energy growth: consider $\left(\sum_i (\Delta - \mathrm{mean}(\Delta))^2\right)^{1/2}$
  - Take RMS of displacement from mean, summed over slices
- Take log plot, fit exponential in linear regions
  - Roughly describes rate of growth of energy in the bunch; is there a different growth rate for individual slices?
  - Note interesting relaxation oscillations



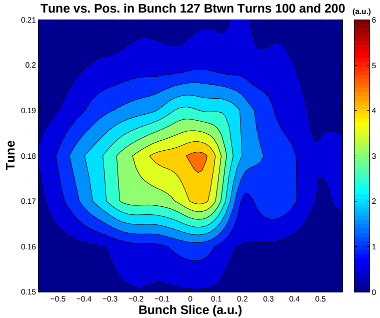
Bandwidth

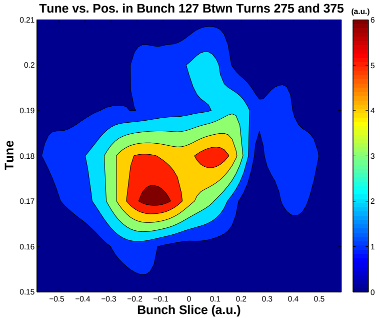
- Need to consider frequency spectrum of signal to be processed by the receiver, amplifiers and kickers
  - Define sampling frequency of ADC/DACs
  - How do the frequencies evolve over time?



Tune Shifts

- Also want to consider tune shifts: how does the E-Cloud affect tune across slices?[1]
- Average across data before E-Cloud instability, and then during/after
  - Tune shifts and amplitude grows, consistent with prior results





[1]Note: different data file from previous plots

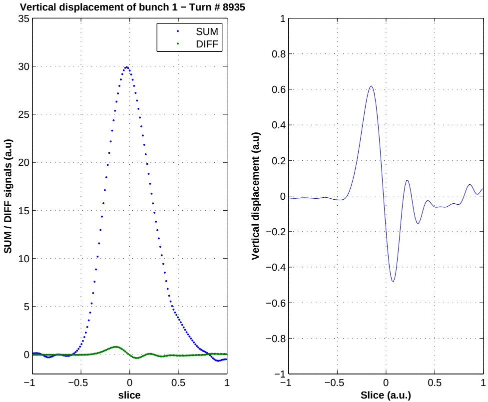
TMCI Data

Introduction

- Single bunch studies for TMCI focus on impedance issues, not E-Cloud
- Variable bunch size: here, 3×10^{11}
- Low longitudinal emittance and voltage $\rightarrow$ low synchrotron frequency (257 Hz)
    - Easier to see generate TMCI instability with low emittance

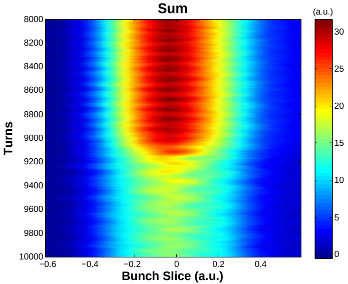
Displacement

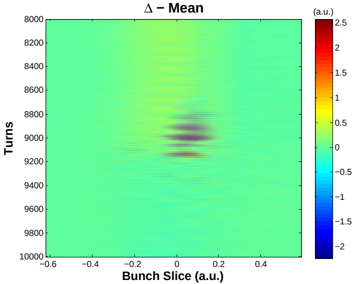
- Only one bunch: can't compare unstable to stable
- Instability is very similar to E-Cloud: head vs. tail oscillations
  - How similar are these oscillations over time, frequency?
  - Can we distinguish TMCI from pure dipole movement?



Displacement Over Time

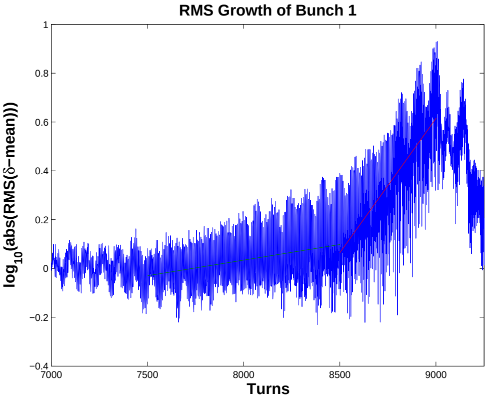
- Over time, similarities and differences with E-Cloud
  - Growth in tail, spreads to head
  - However, massive charge loss (as seen in Σ channel)– don't see this in E-Cloud
  - Makes understanding data after charge loss difficult: too many non-linear effects simultaneously





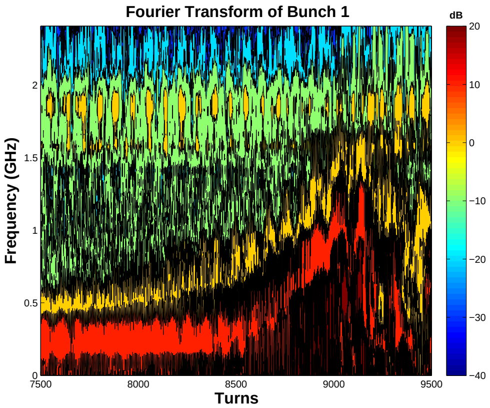
RMS Growth

- Much, much slower growth than in E-Cloud
- Growth rate seems to have two different regions, slow and fast
  - First region is 50x slower growth than E-Cloud



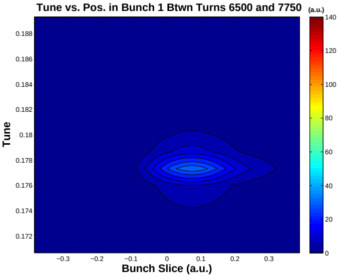
Bandwidth

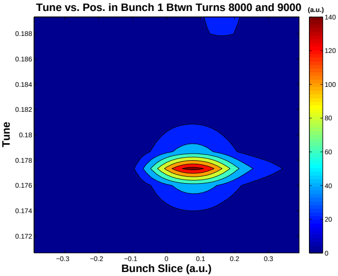
- Very different from E-Cloud situation
  - Instead of bursting, see growth of high-frequency components
  - Black regions have high gradients in amplititude



Tune Shifts

- Difficult to understand: charge loss at peak of instability
- Much finer measurement because of much longer dataset
- No appreciable shift in tune as instability develops, but amplitude does grow





Conclusions

Single Feedback for E-cloud and TMCI?

- E-Cloud and TMCI instabilities exhibit several important differences
  - Tune shift behavior
  - Characteristics of frequency change as instability develops
  - RMS growth rate
- Still, similar enough that single control may be possible
  - Growth rate for E-Cloud is faster than TMCI in this dataset, so E-Cloud system may be able to handle TMCI
    - Difference in synchrotron frequency not enough to explain difference in growth rates
  - Frequency changes are different, but within the same range

Single Feedback for E-cloud and TMCI?

- E-Cloud and TMCI instabilities exhibit several important differences
  - Tune shift behavior
  - Characteristics of frequency change as instability develops
  - RMS growth rate
- Still, similar enough that single control may be possible
  - Growth rate for E-Cloud is faster than TMCI in this dataset, so E-Cloud system may be able to handle TMCI
    - Difference in synchrotron frequency not enough to explain difference in growth rates
  - Frequency changes are different, but within the same range

Single Feedback for E-cloud and TMCI?

- E-Cloud and TMCI instabilities exhibit several important differences
  - Tune shift behavior
  - Characteristics of frequency change as instability develops
  - RMS growth rate
- Still, similar enough that single control may be possible
  - Growth rate for E-Cloud is faster than TMCI in this dataset, so E-Cloud system may be able to handle TMCI
    - Difference in synchrotron frequency not enough to explain difference in growth rates
  - Frequency changes are different, but within the same range

Single Feedback for E-cloud and TMCI?

- E-Cloud and TMCI instabilities exhibit several important differences
  - Tune shift behavior
  - Characteristics of frequency change as instability develops
  - RMS growth rate
- Still, similar enough that single control may be possible
  - Growth rate for E-Cloud is faster than TMCI in this dataset, so E-Cloud system may be able to handle TMCI
    - Difference in synchrotron frequency not enough to explain difference in growth rates
  - Frequency changes are different, but within the same range

Plans For Next MDs and Comparison to Simulation

- Look at additional TMCI data: what is 'real' growth rate?
- What is the growth rate in individual slices?
  - Growth in tail is what we actually want to control
- Now that techniques are developed, look at multi-particle simulations and reduced models
  - Validate simulation: make progress towards specifying feedback system

Plans For Next MDs and Comparison to Simulation

- Look at additional TMCI data: what is 'real' growth rate?
- What is the growth rate in individual slices?
  - Growth in tail is what we actually want to control
- Now that techniques are developed, look at multi-particle simulations and reduced models
  - Validate simulation: make progress towards specifying feedback system

Plans For Next MDs and Comparison to Simulation

- Look at additional TMCI data: what is 'real' growth rate?
- What is the growth rate in individual slices?
  - Growth in tail is what we actually want to control
- Now that techniques are developed, look at multi-particle simulations and reduced models
  - Validate simulation: make progress towards specifying feedback system

Thank you for your attention!