Feedback Control of E-Cloud Instabilities

Progress Report

June 2009

LARP Ecloud Contributors

Wolfram Fisher, Riccardo De Maria (BNL)

John Byrd, M.Furman, Stefano De Santis, Jean-Luc Vay, (LBL) Joel Thompson (Cornell)

Gianluigi Arduini, Wolfgang Hofle, Giovanni Rumolo (CERN)

John D. Fox, Mauro Pivi, Claudio Rivetta (SLAC)

Overview and Outline- activities June 2008 through June 2009

Simulation efforts

- Warp
- Head-tail
- Feedback (linear harmonic oscillator) model

SPS Machine measurements June 2008, August 2008, and June 2009

- Tools, techniques to understand time-domain signals

Efforts to compare WARP, Head-Tail and Machine measurements

- sliding window FFT (tune vs. slice vs. time)
- Eigenvalue estimation

Near-term plans

- Lab effort- evaluation of 4 GS/sec. D/A
- Study SPS Measurements from June 2009 - compare with simulations
- Future SPS measurements (driven beam measurements)

Long Range plans, goals

Analysis of Ecloud simulations and Ecloud MD data

Time domain simulations, measurements

Movies are nice, give insight - but quantitatively

- What frequencies are present in the bunch structure?
- How do they evolve over the time sequence?
- Is there useful correlations between parts of the bunch, other bunches?
- How does the filling pattern, energy, machine parameters impact the unstable motion?

Goal - develop normal-mode, other formalisms to extract

- Modes within the bunch (e.g. bandwidth of feedback required)
- growth rates of modes (e.g. gain of feedback channel)
- tune shifts, nonlinear effects (e.g. Stability, robustness of feedback process)

sliding window FFT techniques - check tunes, tune shifts

- within slices
- vs. time

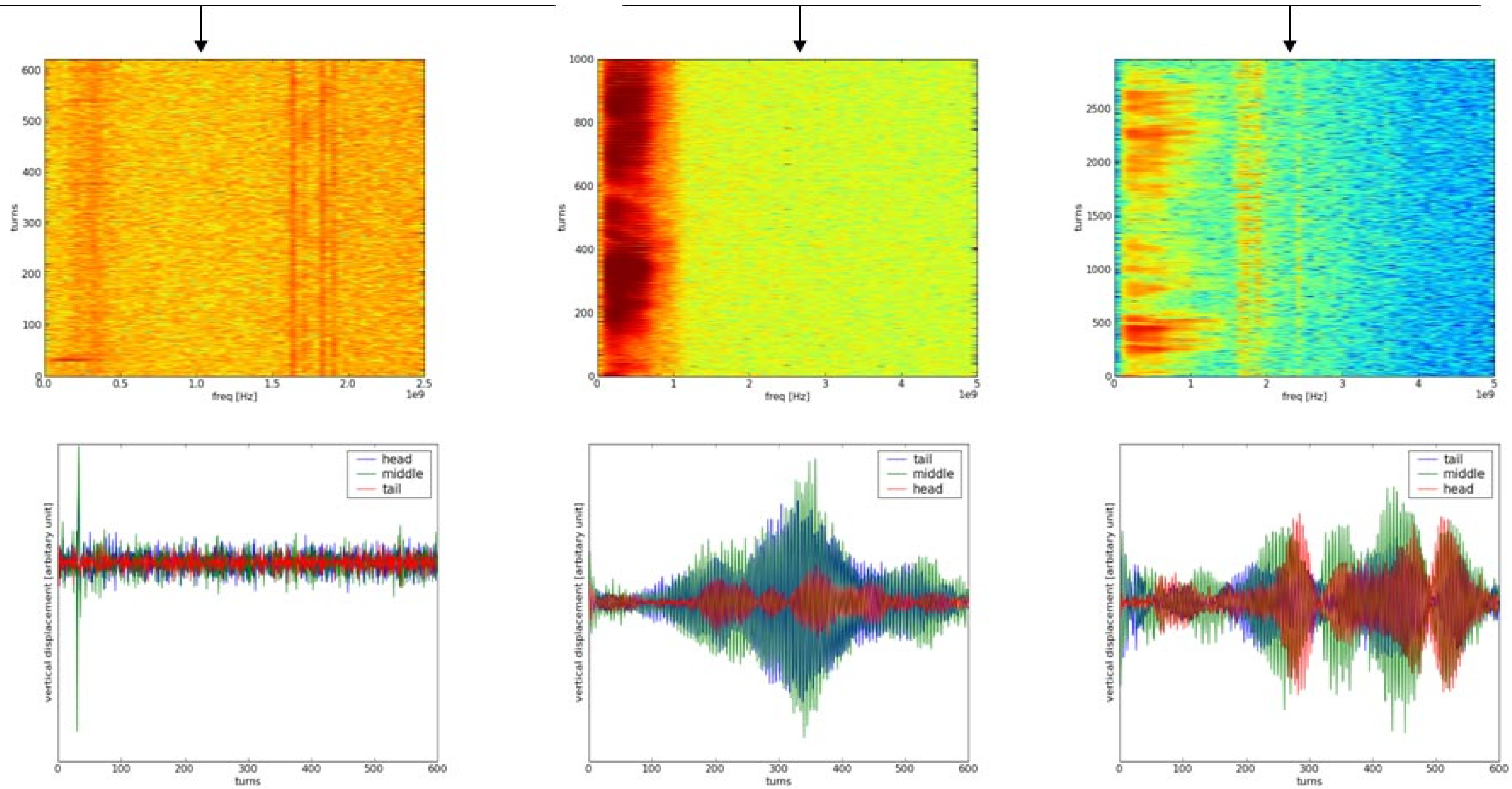
We use existing PEP-II coupled-bunch model, Eigenvalue fitter (not exactly right, but a starting point)

August data equalized and reconstructed by R. De Maria, W. Hofle

Observations of SPS e-cloud instability with exponential pickup

Bunch in the first (stable) batch (June)

Bunch in the last (unstable) batch (June and August)



August data (right) after scrubbing period: data filtered from noise

Observations from June 09 SPS MD Studies

Two batches of 72 bunch trains:

Instability develops after injection of second batch, within 100 turns

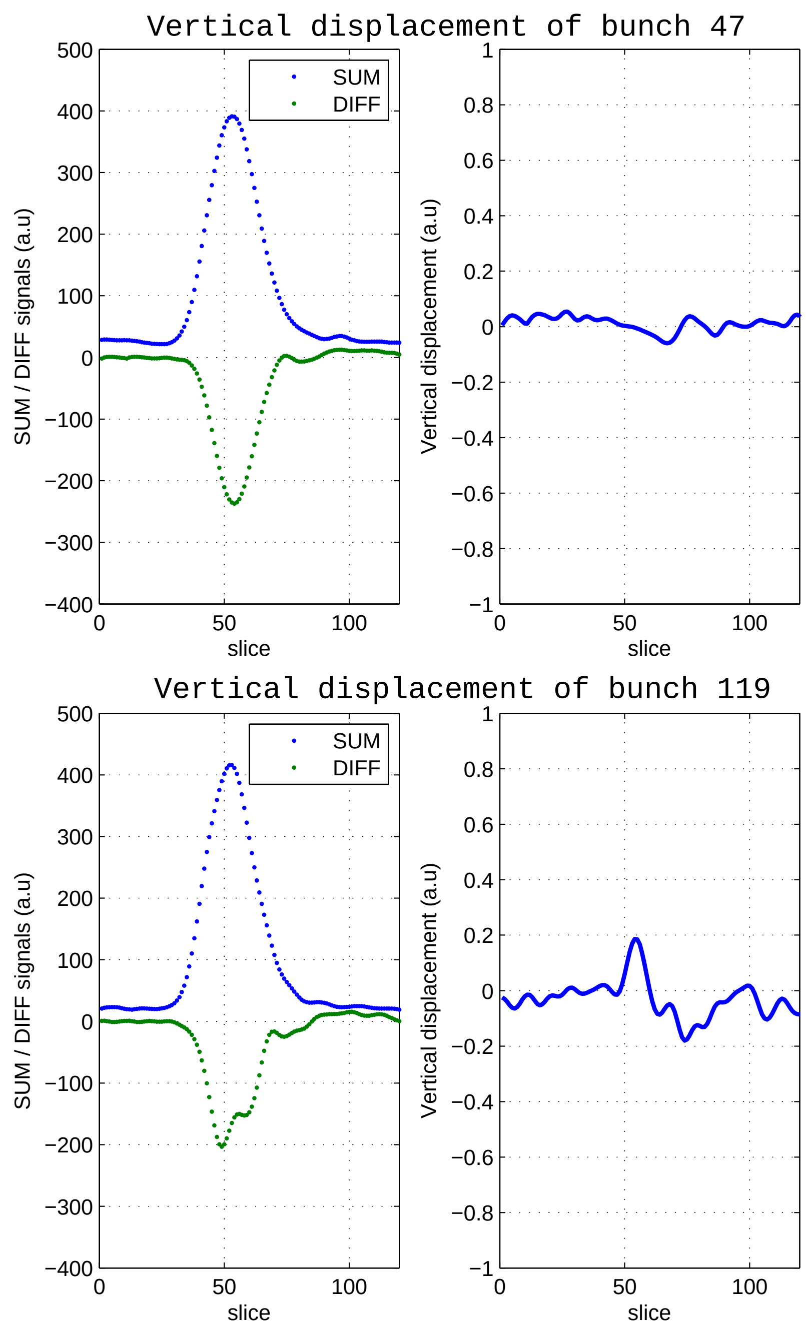
Modes within unstable bunch develop very rapidly at injection- first 100 turns

Time domain figures show bunch charge, and transverse displacement, second figure is vertical displacement after removal of DC transient. Data extracted to show bunch 119 on turn 80

Stable (bunch 47 and earlier) bunches do not show this motion

Bunch 119 - shows head and tail displacement

Use this technique to compare models, MD data - extract beam dynamics necessary to design feedback. Roughly 25 slices (250 ps) between displacement maxima and minima



Observations from June 09 SPS MD Studies

Sliding spectrograms show:

Bunch 45 (stable) - no high frequency motion in bunch

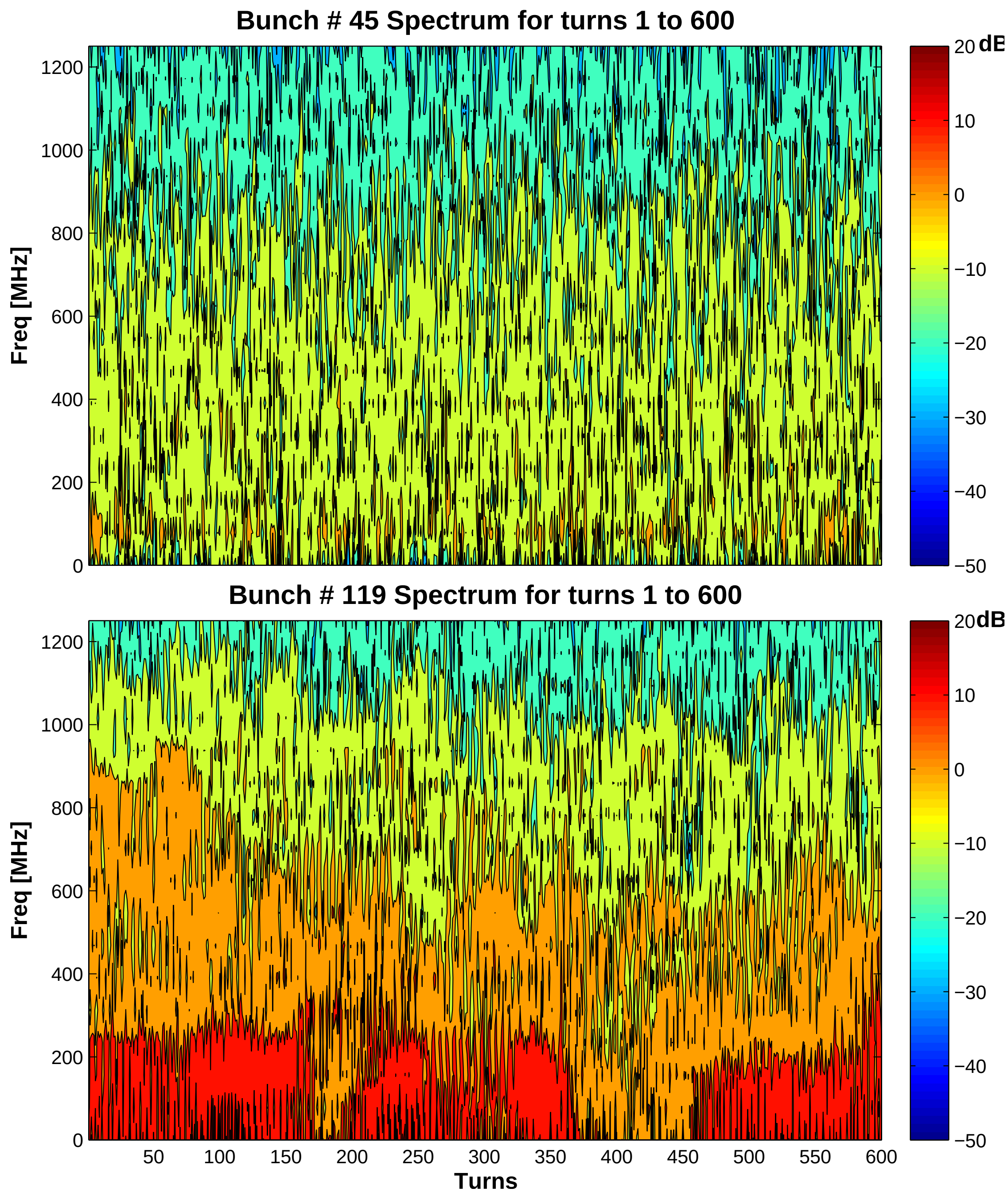
Bunch 119 (unstable) - high frequencies detected

Modes within unstable bunch develop very rapidly at injection

Is the Ecloud signature the low frequency (0 200 MHz) or the band up to 900 MHz?

Intermediate bunches (e.g. bunch 112) show beginnings of instability, similar spectrum of unstable motion)

Use this technique to compare models, MD data - extract beam dynamics necessary to design feedback



Observations from June 09 SPS MD Studies

Sliding tune vs. bunch "slice" show:

Bunch 119 - unstable bunch

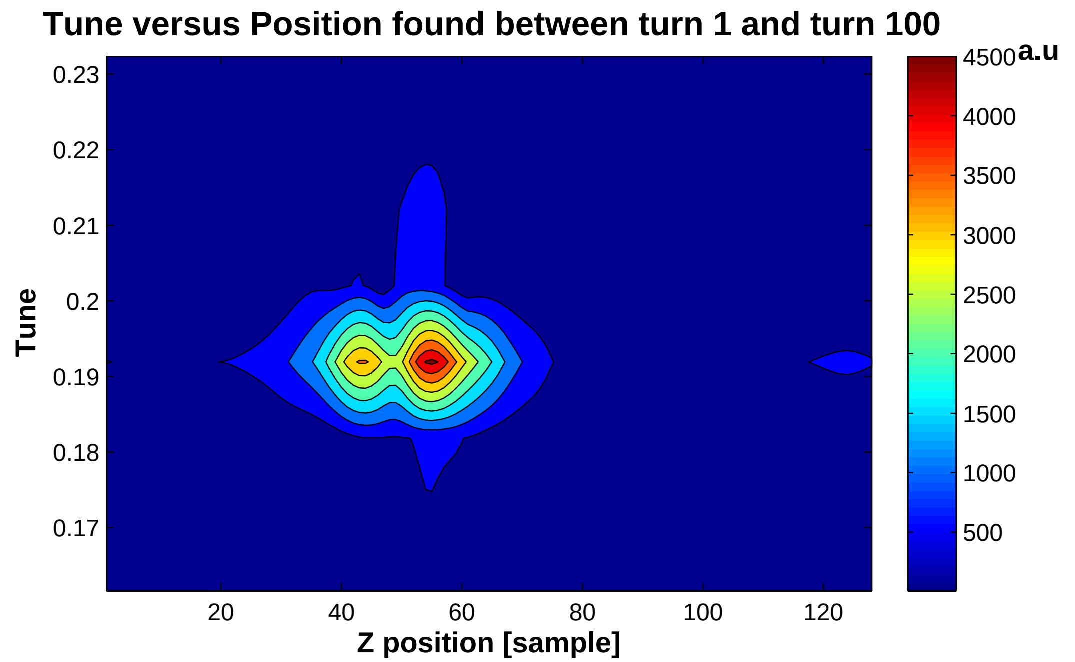
Modes within unstable bunch develop very rapidly at injection- first 100 turns

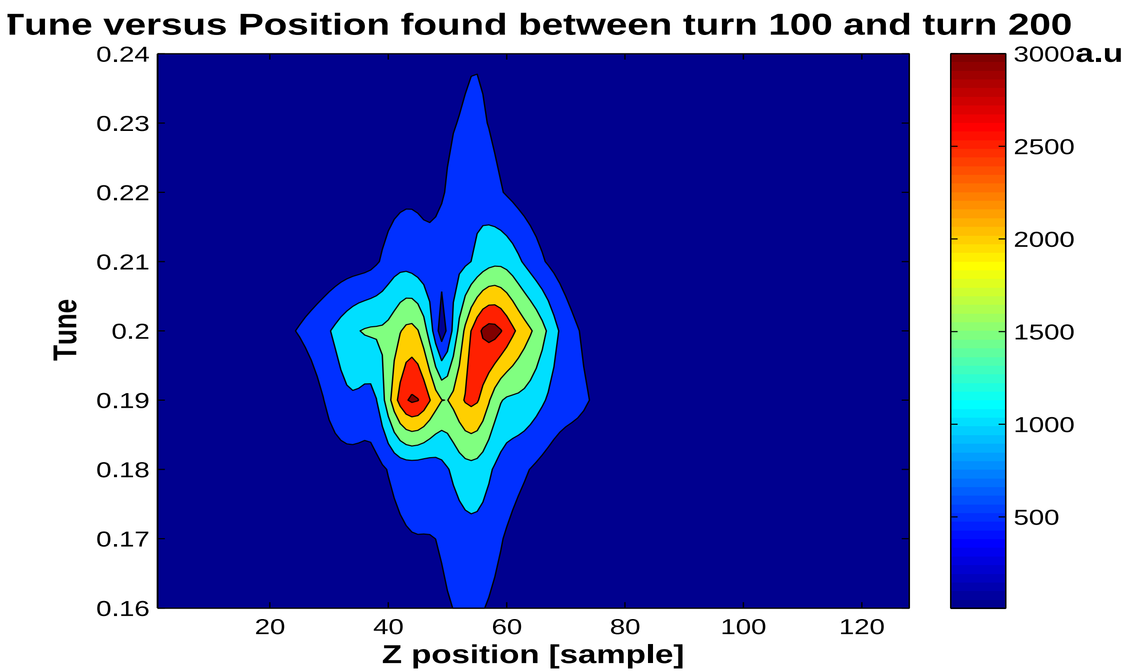
Turns 100 - 200 Motion splits into head and tail, with tune shift between leading and trailing portions of bunch - tail has higher tune. Tune shift shows Ecloud effect

Intermediate bunches (e.g. bunch 112) show beginnings of instability, similar spectrum of unstable motion)

Stable (early) bunches do not show this tune shift or tune vs. position

Use this technique to compare models, MD data - extract beam dynamics necessary to design feedback





Near-term plans

Study SPS Measurements from August 08 and June 09 - compare with simulations

- What conclusions? What modes are seen?
- What energy, current, fill pattern needs study?

Lab effort- evaluation of 4 GS/sec. D/A

- initial measurements show ~250 ps risetime, similar with 1.5 Gs/sec. Triquint D/A used in existing systems
- New Applied Physics Grad student project

Estimation of Feedback Options

- Use linear eigenvalue model, estimate feedback complexity
- Study stability, margins, limits of control

Develop measurement technique - measure driven bunch responses (estimate Ecloud dynamics even for stable system)

- Develop back end and modulator functions

Goals -FY2008/2009 LARP Ecloud effort

understand Ecloud dynamics via simulations and machine measurements

- Participation in E-Cloud studies at the SPS (June, August 2008), additional measurements 2009
- Analysis of SPS and LHC beam dynamics studies, comparisons with Ecloud models
- Adaptation of SLAC's transient analysis codes to Ecloud simulation data structures

Modelling, estimation of E-Cloud effects

- comparisons of Warp and Head-Tail models, results
- comparisons with machine physics data (driven and free motion), validation of models, estimates of dynamics
- extraction of system dynamics, development of reduced (linear) coupled-oscillator model for feedback design estimation
- develop tools to analyze unstable data, quantify and compare system dynamics
- evaluate feasibility of feedforward/feedback techniques to control unstable beam motion, change dynamics. Estimate limits of techniques, applicability to SPS and LHC needs
- Identify critical technology options, evaluate difficulty of technical implementation
- Participation in LHC transverse feedback system commissioning

Summary

Lots of progress on improving collaboration effectiveness from the meetings, web-reports, etc.

- now see initial agreement between Head Tail, WARP
- Similar cases- no Ecloud - tunes agree
- Ecloud effects - for comparable SEY and density, similar tune shifts

Linear Model - first efforts fit well to fastest Eigenfrequencies

- Issue - internal modes, phase relationships
- Work in progress, necessary to develop feedback model, design useful controller

MD programs and data analysis

- impressive effort by W.H. and RDM to post process August 08 data
- Goal - look at June 09 and august 08 data using FFT and Eigenmode tools
- How do they compare? Do they agree with simulation models?

Plans for future MD studies, ongoing analysis and simulation efforts

- Develop driven beam diagnostics
- evaluate possible feedback architectures, algorithms against linear models

Recent Publications and Talks from the LARP Ecloud Effort

Feedback Techniques and Ecloud Instabilities - Design Estimates. J.D. Fox, T. Mastorides, G. Ndabashimiye, C. Rivetta, D.Van Winkle (SLAC), J. Byrd, J-L Vay (LBL, Berkeley), W. Hofle, G. Rumolo (CERN), R.De Maria (Brookhaven). SLAC-PUB-13634, May 18, 2009. 4pp. Presented at Particle Accelerator Conference (PAC 09), Vancouver, BC, Canada, 4-8 May 2009.

Simulation of a Feedback System for the Attenuation of E-Cloud Driven Instability Jean-Luc Vay, John Byrd, Miguel Furman, Marco Venturini (LBNL, Berkeley, California), John Fox (SLAC, Menlo Park, California) Presented at Particle Accelerator Conference (PAC 09), Vancouver, BC, Canada, 4-8 May 2009

INITIAL RESULTS OF SIMULATION OF A DAMPING SYSTEM FOR ELECTRON CLOUD-DRIVEN INSTABILITIES IN THE CERN SPS J. R. Thompson?, Cornell University, Ithaca, USA, J. M. Byrd, LBNL, Berkeley, USA W. Hofle, G. Rumolo, CERN, Geneva, Switzerland Presented at Particle Accelerator Conference (PAC 09), Vancouver, BC, Canada, 4-8 May 2009.

Performance of Exponential Coupler in the SPS with LHC Type Beam for Transverse Broadband Instability Analysis 1 R. de Maria BNL, Upton, Long Island, New York, J. D. Fox SLAC, Menlo Park, California, W. Hofle, G. Kotzian, G. Rumolo, B. Salvant, U. Wehrle CERN, Geneva Presented at DIPAC 09 May 2009

Feedback control of Ecloud Instabilities, J. Fox et al CERN Electron Cloud Mitigation Workshop 08

E-cloud feedback activities for the SPS and LHC, W. Hofle CERN Electron Cloud Mitigation Workshop 08

Observations of SPS e-cloud instability with exponential pickup, R. De Maria, CERN Electron Cloud Mitigation Workshop 08

Experiments on SPS e-cloud instability Giovanni Rumolo, CERN Electron Cloud Mitigation Workshop 08

Progress on WARP and code benchmarking Marco Venturini, CERN Electron Cloud Mitigation Workshop 08

Ecloud and Feedback - Progress and Ideas, J. Fox Et al LARP CM12 Collaboration meeting Napa CA

Driven Beam Experiments

Develop excitation technique using existing exponential striplines (requires power amps, hybrids, etc.)

Can be frequency domain or time domain study

Idea - use 4 GS/sec DAC hardware to drive noise sequences onto selected bunch(es)

measure excitation, response with two channel fast scope

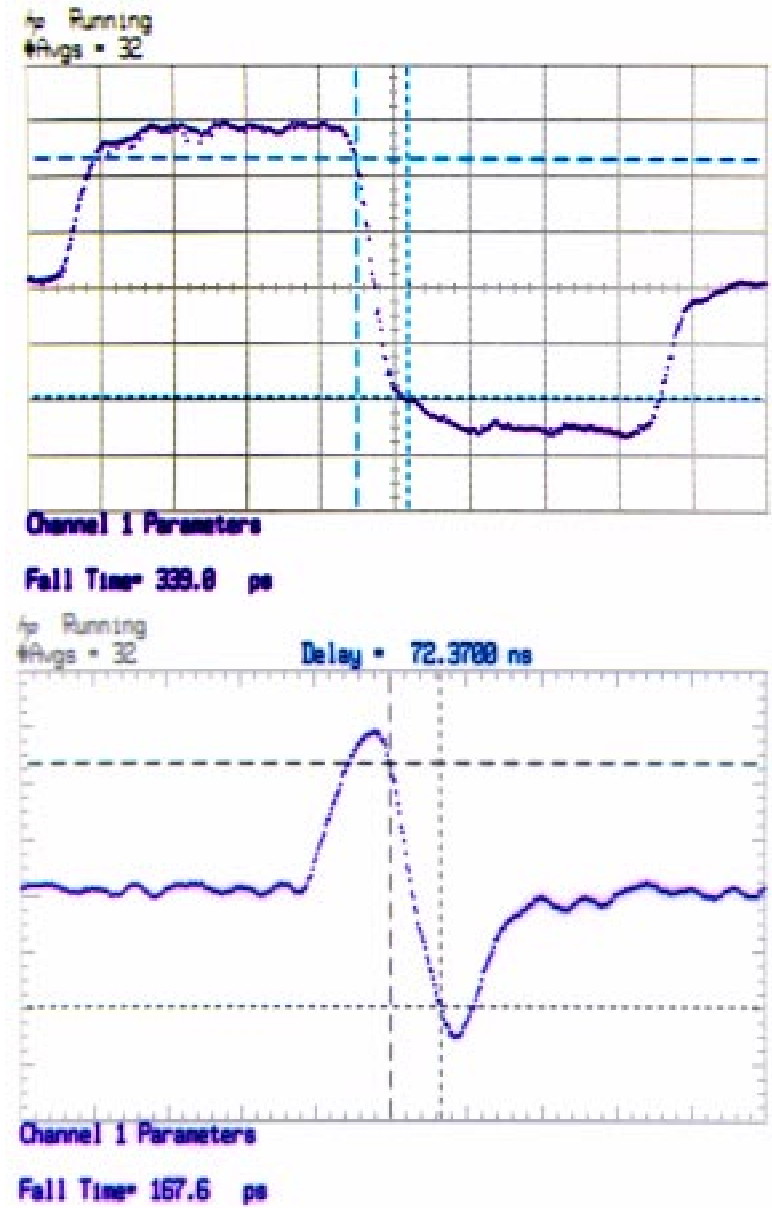
(avoids synchronization complexity)

Time domain sequences - transform, average (transfer function estimator)

Frequency response of internal structure and modes

Can be done as excitation in simulation, too.

Valuable step in development of any possible feedback controller (Back End)



Step and Impulse Responses 4 GS/sec D/A

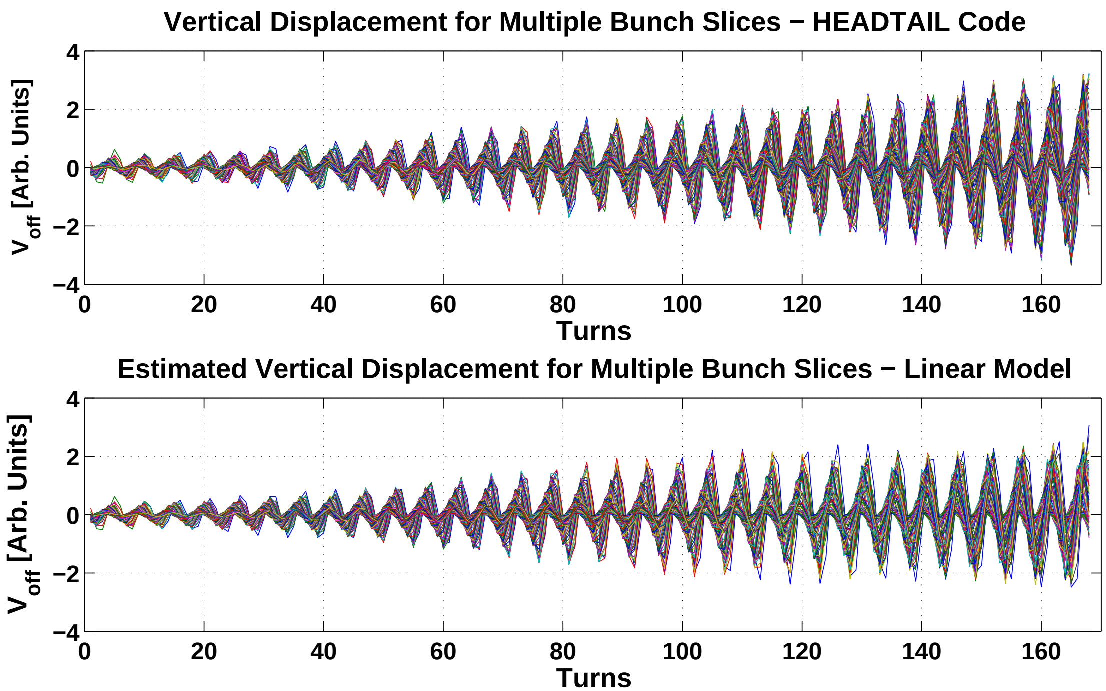
Simulation efforts - Linear Estimation models

We extract information from the numeric simulations to use in a linear analytical (coupled-oscillator) model

Goal - use same technique on SPS data from August 08 and June 09

We can understand dynamics of a linear system, design controllers, estimate limits of control, etc.

These models are how we design the feedback controllers, estimate dynamics and limits of control



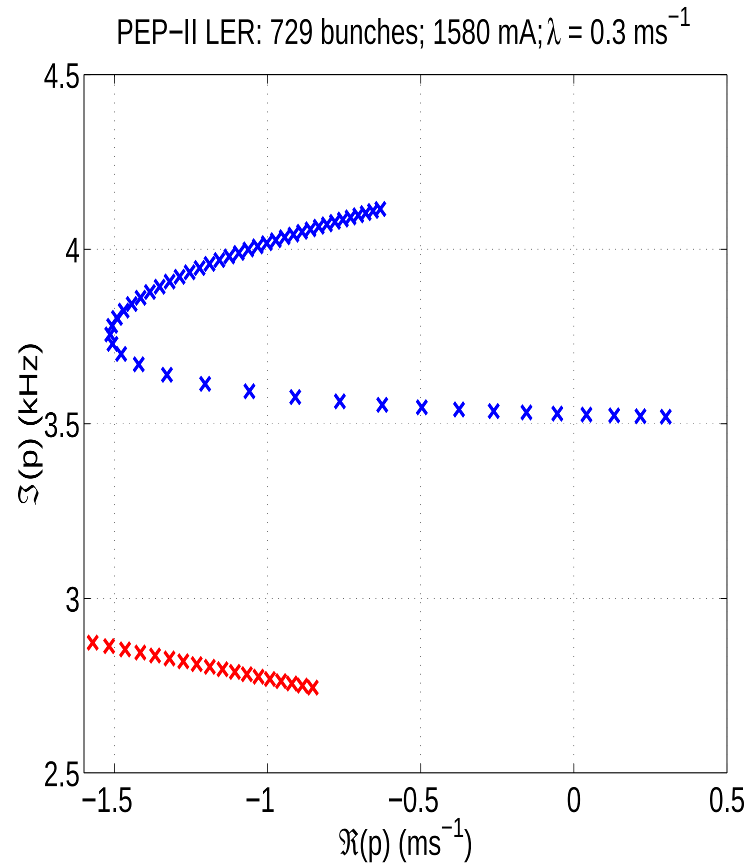
Feedback Design and Estimation

To design feedback, we first need a linear analytical model system

Understand dynamics, design controllers, evaluate stability,robustness

limits of control

- maximum growth rate,
- maximum tune shift,
- maximum excitation with restoration to equilibrium state
- impact of channel noise, offsets on equilibrium state



Only after we have a good controller for a linear system should we try to study this controller on the non-linear time-domain codes

Control theory linear tools (e.g. Root Locus methods)

- linear system - milliseconds of compute time
- WARP code - supercomputer cluster, long runs to simulate a few hundred turns in accelerator

LARP SPS and LHC Ecloud long-range proposal

Overall Goals - R&D effort in 2009 - 2015

- develop beam dynamics/feedback dynamics simulation models
- validate several simulation codes against accelerator measurements
- develop reduced linear dynamics models useful to design/estimate feedback controllers
- develop experimental techniques to estimate Ecloud effects for stable and unstable systems
- evaluate possible control techniques, understand trade-offs between robustness, controllability, and system complexity
- develop the detailed requirements for a new wideband feedback system architecture
- Proof-of-principal technology R&D on GHz bandwidth (e.g. 2 - 4 GS/sec.) processing, backend
- Prototype proof of principle processing channel, implement feedback algorithm, machine studies and comparisons with models.
- Develop diagnostic and operational tools and codes to understand the system performance via accelerator measurements
- Recommend architecture and technology for a general-purpose wideband feedback system useful to control Ecloud-driven instabilties for SPS, LHC and other facilties. Design Report and recommendations

Decision Point - late 2009/2010

Is the Ecloud dynamics feasible for feedback control? What techniques are applicable?

Research Goals - 2010 - 2011

- Modelling of closed-loop system dynamics, estimation of feedback system specifications
- Evaluation of possible control architectures, possible implementations
- SPS Machine Physics studies, development of transient-domain instrumentation

Decision point 2011 - Proof of principle design studies, estimates of performance

Research Goals 2011 - 2015

Technology R&D - Specification of wideband feedback system technical components

Technical analysis of options, specification of control system requirements

- Single bunch control (wideband, within bunch Vertical plane)- Required bandwidth?
- Control alogorithm - complexity? flexibility? Machine diagnostic techniques?
- Fundamental technology R&D in support of requirements - Kickers and pickups?
- wideband RF instrumentation, high-speed digital signal processing

Develop proof of principle processing system, evaluate with machine measurements

System Design Proposal and technical implementation/construction project plan