Feedback Control of E-Cloud Instabilities

CM-12 Progress Report

April 2009

LARP Ecloud Contributors

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Overview and Outline- activities June 2008 through April 2009

Simulation efforts

- Warp
- Head-tail
- Feedback model

SPS Machine measurements June 2008 and August 2008

- a more sophisticated look at August 2008 data

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 August - compare with simulations
- SPS measurements June 2009

5 year Planning for CM-12

Collaboration Progress and Events

MD measurements

Simulation efforts

Lab technology efforts

Biggest impact - tighter multi-lab collaboration on Feedback and Ecloud

- Mini-workshop October 2008 (SLAC)
- LBL meeting (jan 2009)
- SLAC meeting March 2009
- bi-weekly WEBEX meetings

Impact - focus on methods to compare simulations, validate with machine measurements

Can we develop common tool and framework to compare methods?

Common data repository, access to data

Can we validate simulations, for example, with NO ecloud effect?

Jan - April 2009 focus Compare WARP, Head-Tail

Are we studying similar cases? Do they agree?

bunch properties, lattice, Electron density, etc.

post-processor for head-tail

(non-uniform sampling requires upsampling, re-sampling on uniform time coordinates)

sliding window FFT techniques - check tunes, tune shifts

- within slices
- vs. time

structures within bunch -decomposition into spatial harmonics

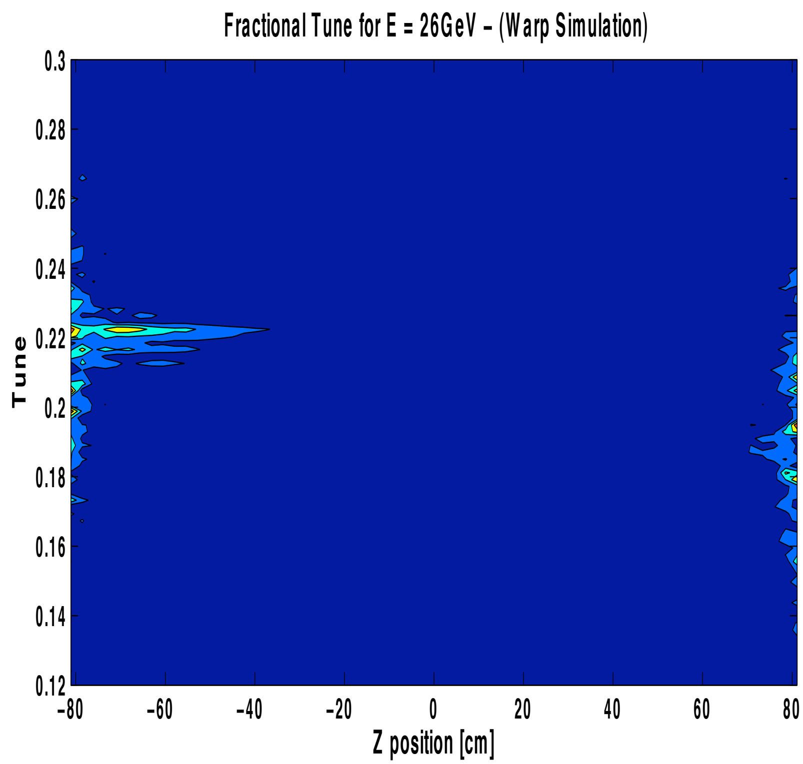
Critical to understand required sampling rate (bandwidth) of within-bunch controller

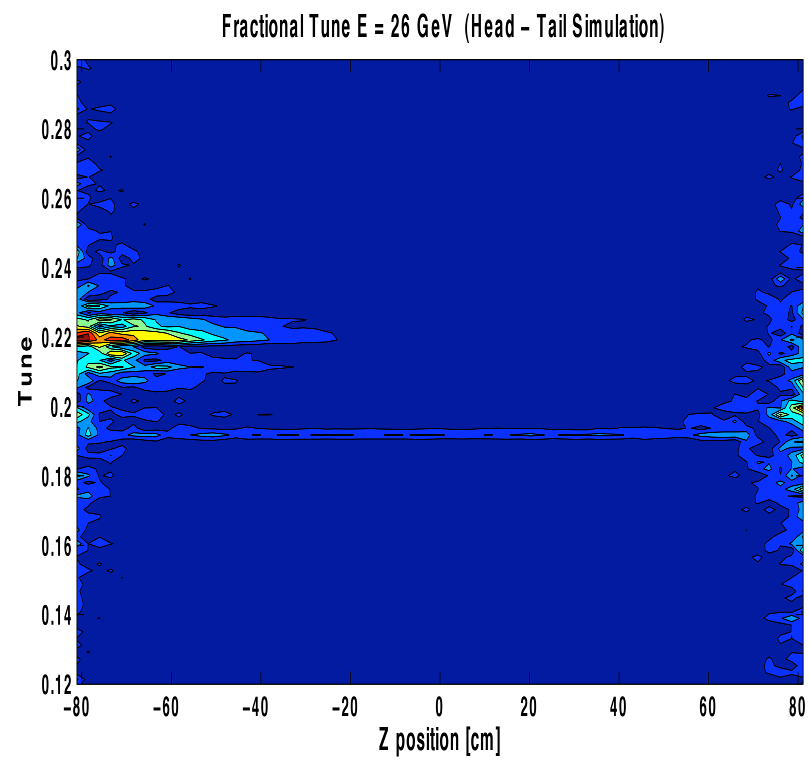
Simulation efforts - Ecloud models

three ongoing directions

- Warp
- Head-tail
- Linear (Feedback evaluation) model

Effort to directly compare WARP and Head-Tail SPS cases for similar initial conditions





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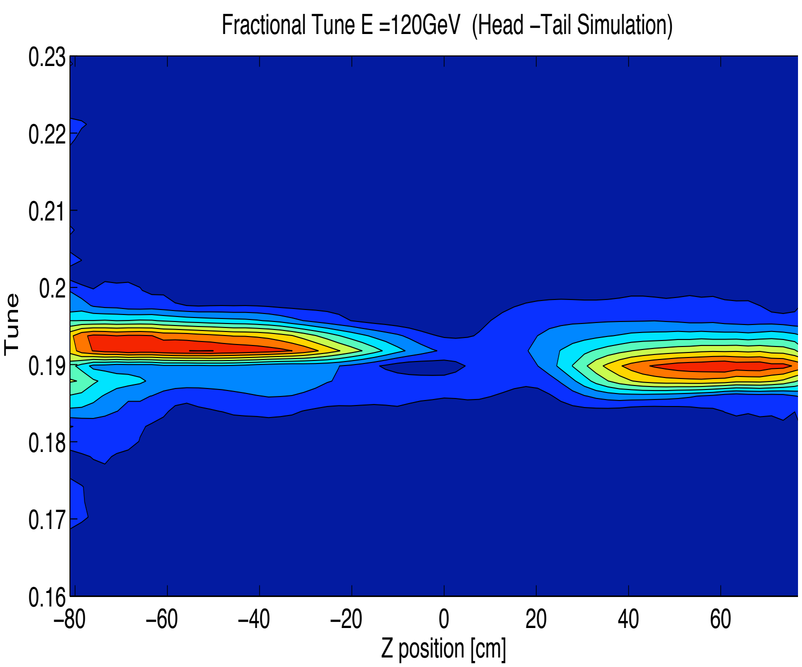
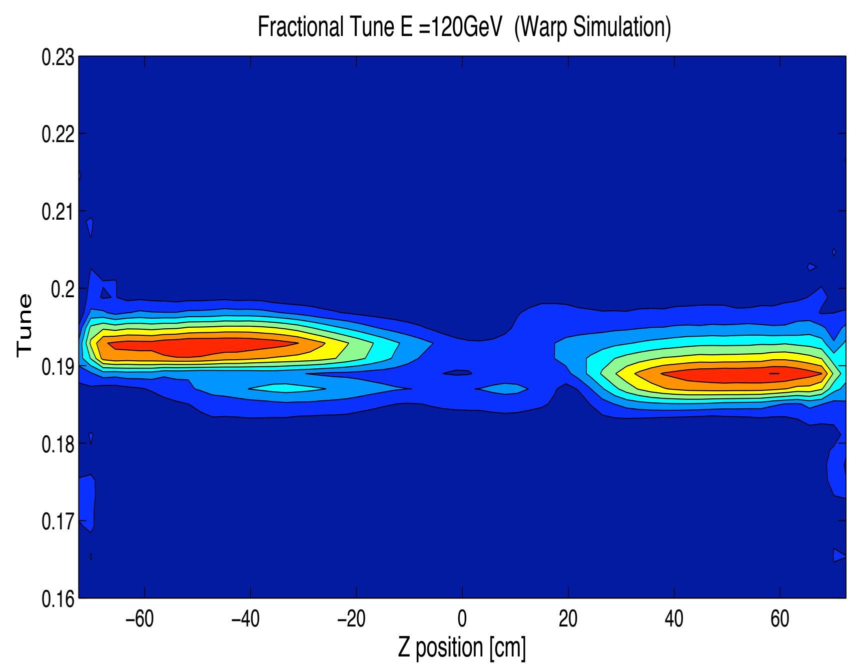




Analysis of Ecloud simulations

Time domain simulations

- 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?

Goal - develop normal-mode, other formalisms to extract

- Modes within the bunch
- growth rates of modes
- tune shifts, nonlinear effects

use existing PEP-II coupled-bunch model, Eigenvalue fitter

not exactly right, but a starting point

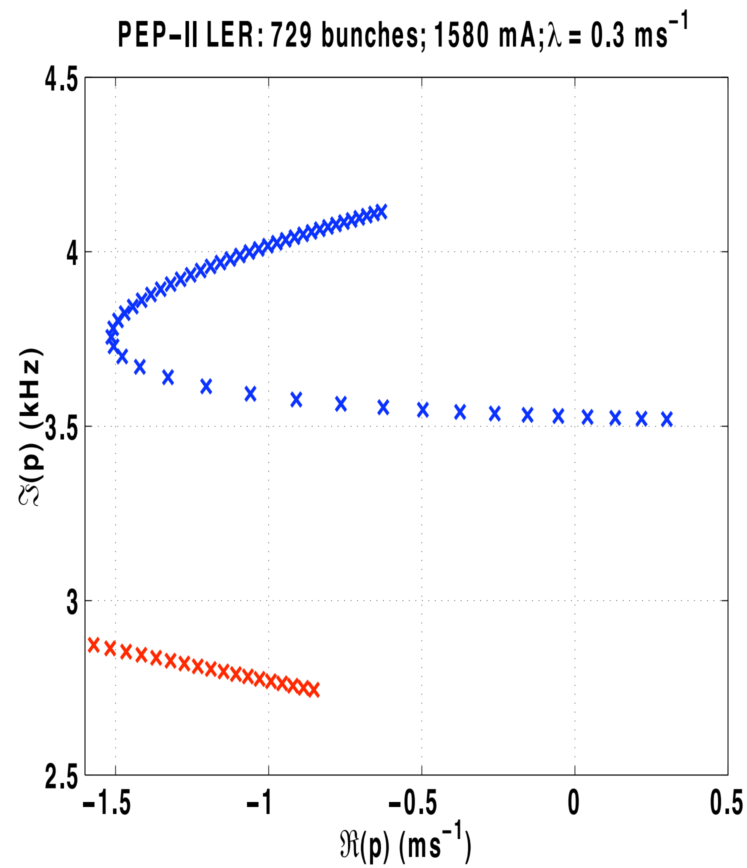
Feedback Design and Estimation

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

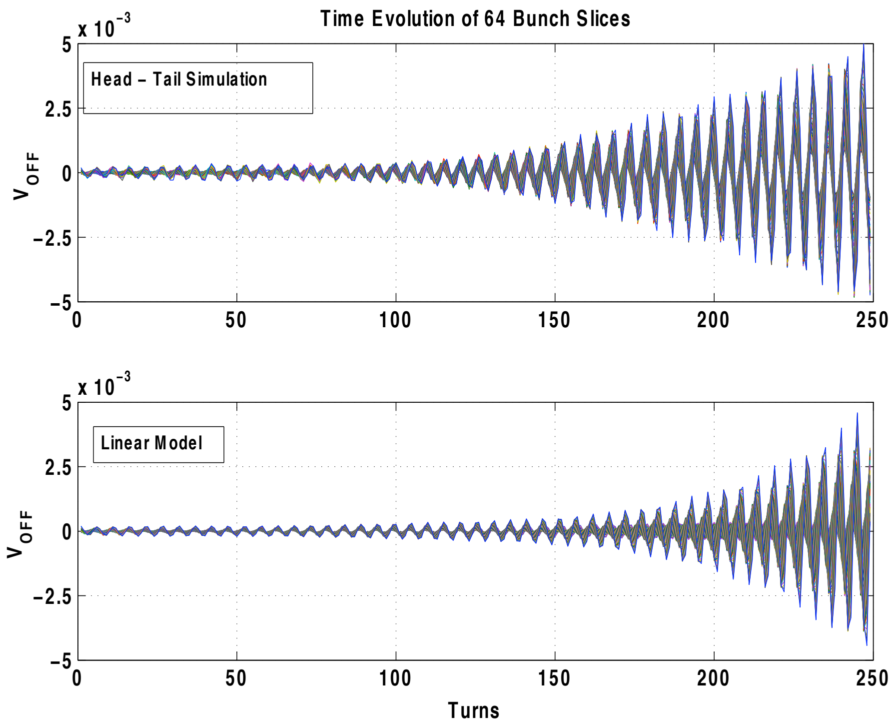
Simulation efforts - Linear Estimation models

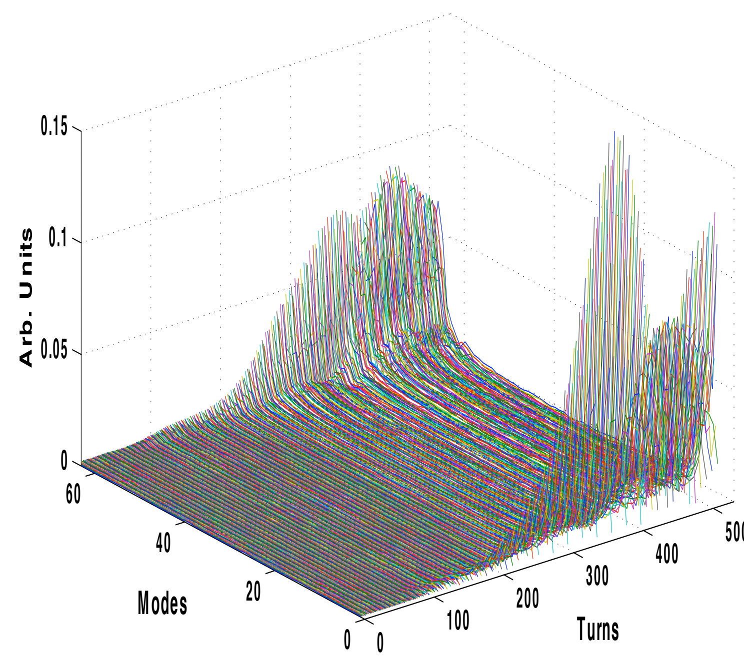
extract information from the numeric simulations to use in a linear analytical (coupled-oscillator) model

Goal - use same technique on SPS data from August 08 and (hopefully) 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



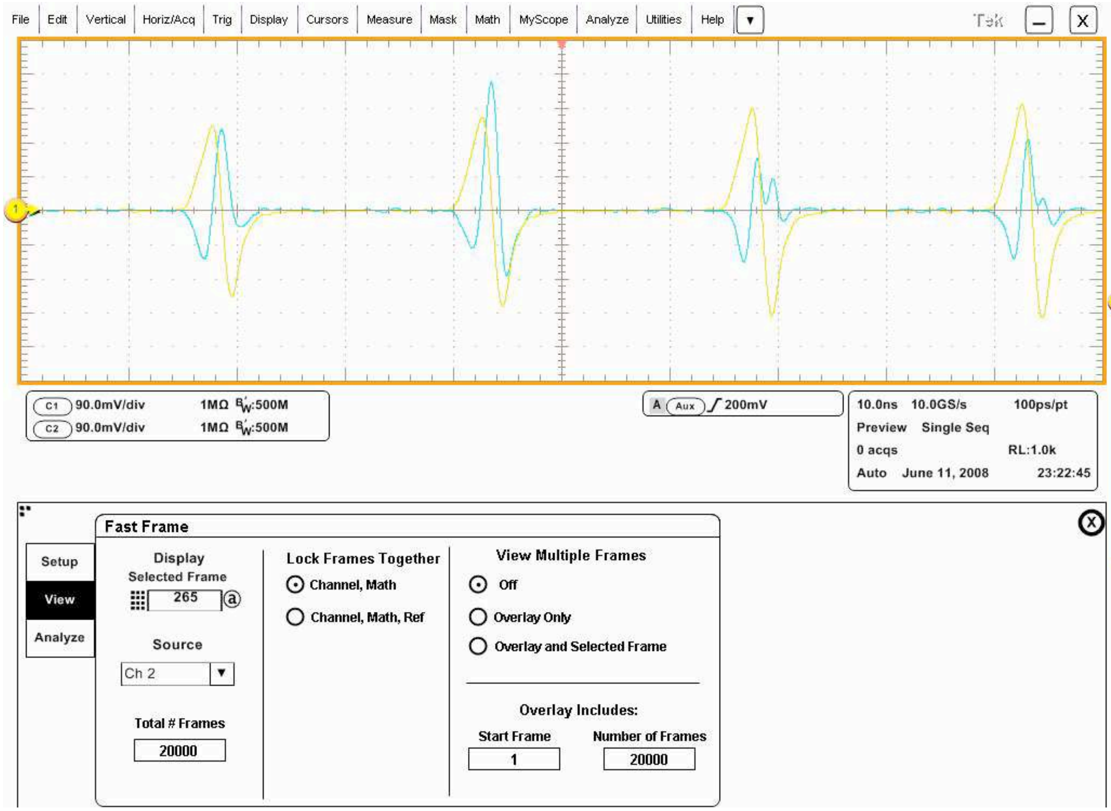


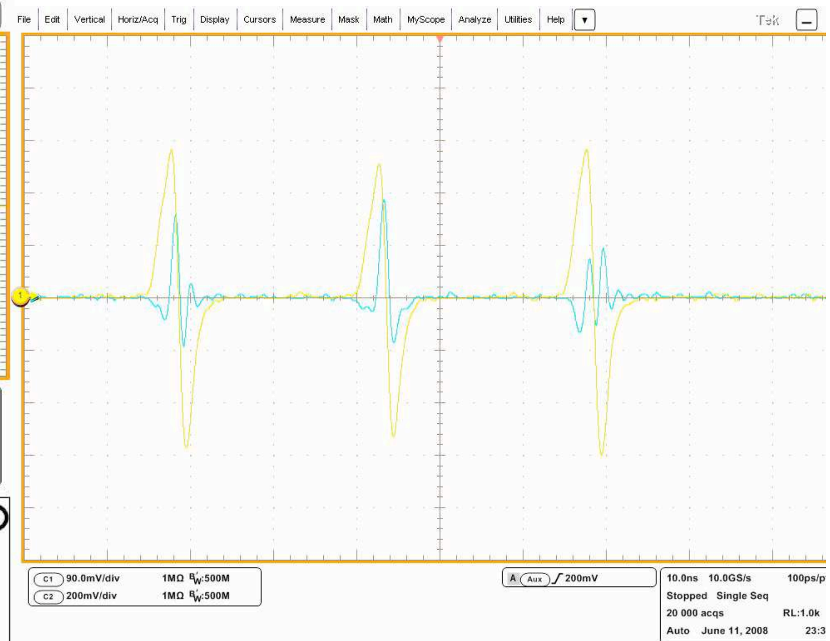
Results from the June 6 MD

W.Hoefle, G. Rumolo, G. Arduini, R. De Maria, J. Byrd et al -

- Dedicated MD in SPS during machine scrubbing
- intensity 1E11 P/bunch, 25 ns separation, 72 bunches/batch, 5 batch injection (4 nominal LHC)
- lowered chromaticity to reduce damping - transverse signal seen after 5th batch injection

Transverse signals from exponential stripline couplers, hybrids (yellow sum, blue vertical)





Results from the August 12 MD

Follow-on from June MD

J. Fox, W. Hoefle, R. De Maria, G. Arduini, G. Rumolo, J. Thompson et al

Tunnel Access to SPS - measure exponential coupler matching, find/fix lousy connections

Move difference hybrids from tunnel to control room, match lengths of long Heliax

Sort out issues with hybrids, measure best 3, build simple receiver

Prepared data recorder, software, use wideband 2 GHz bandwidth, 50 ohm input Z, etc.

MD rescheduled twice from 8/11, finally get 2 AM to 10AM Aug13

Results

4 batches 1E11 P/bunch, 25 ns spacing, 72 bunches batch- better vacuum than June?

lowered chromaticity per June but 4 not 5 batches

NO 700 Mhz Transverse signal at high frequency observed (time or frequency domain)

lots of high-frequency signals > 1700 MHz observed - propagating modes in 10 CM vacuum chamber

added RF voltage modulation to try to excite quadrupole oscillation (increase density)

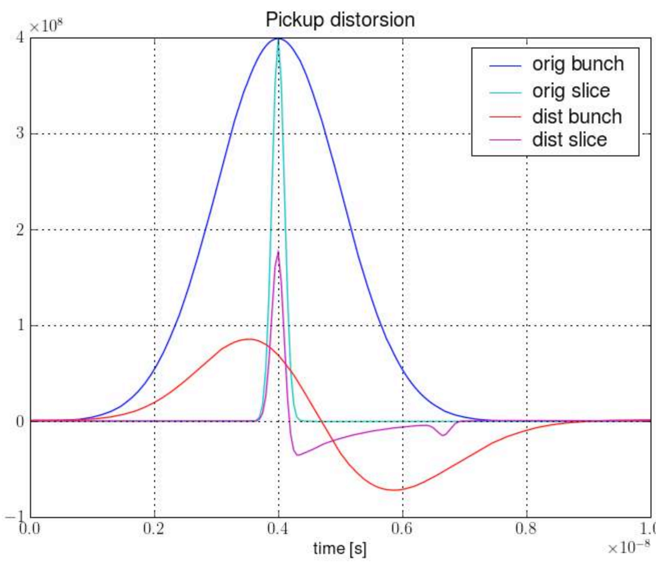
NO Ecloud-like signal observed at the time of the study

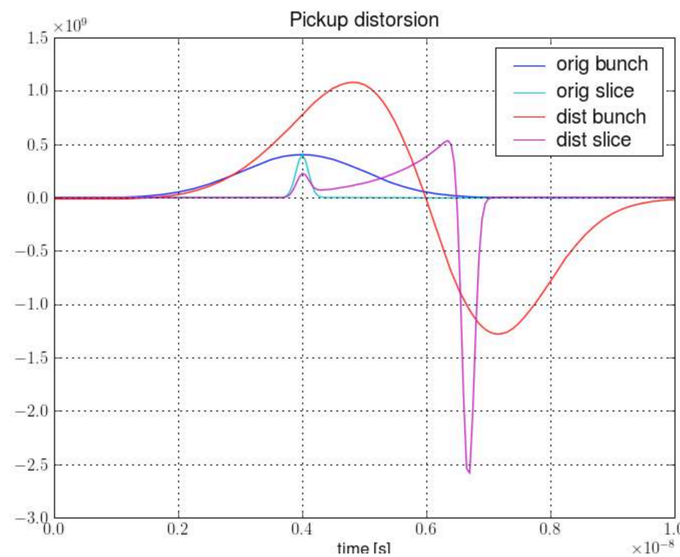
A second look at the Measurements of August 2008

At the August 2009 MD, we observed very complicated high frequency signals on the pickups. During the MD we attributed this to propagating TE modes in the 10cm vacuum chamber (cut off estimated at 1800 MHz). We were not able to see very convincing direct signals in the time or frequency domains that looked like the June 2008 data.

Subsequent to the MD, some investigations revealed:

The exponential stripline couplers in the SPS were placed in two orientations, consistent with their use in the p pbar program. By some luck, we were connected on the “downstream” port of a coupler (it was intended for use with oppositely circulating pbar). This gives a response with nonlinear group delay with frequency, other instrumental effects (below, right). Part of the difficulty in interpreting the August data is from this response, part from propagating modes.



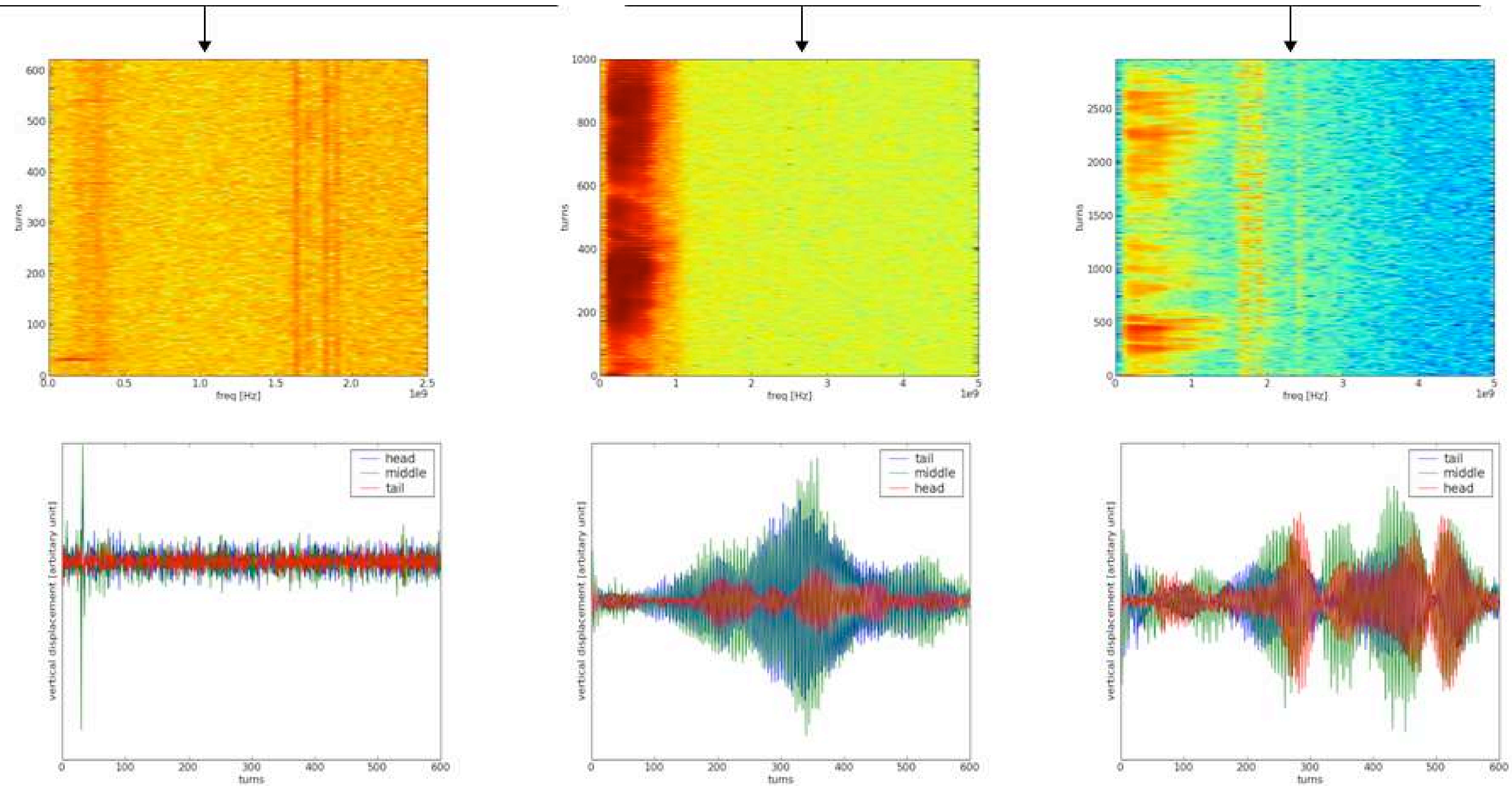


August data equalised and reconstructed by R. De Maria, W. Hofle

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

Near-term plans

Study SPS Measurements from August - compare with simulations

- What conclusions? What modes are seen?
- What improvements do we make for June 2009 MD?

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

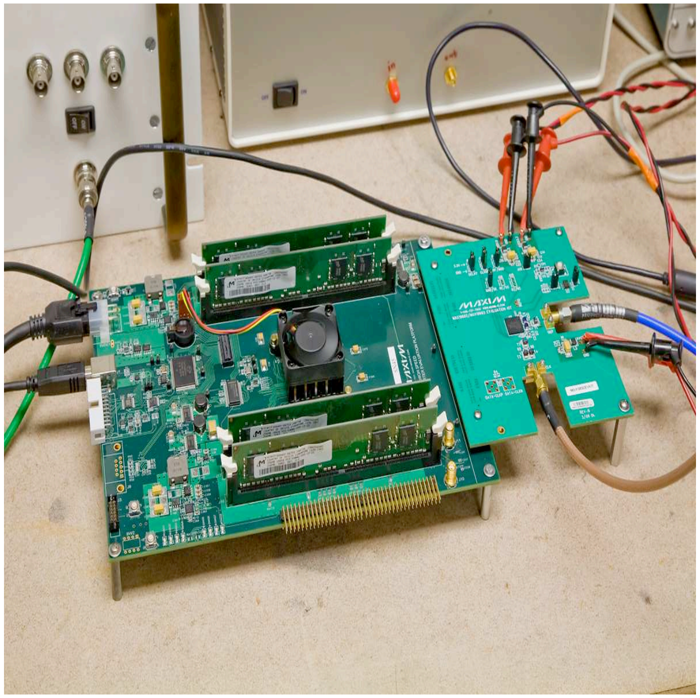
- We have a 4 GS/sec. Maxim D/A running in the lab
- Just starting - initial measurements show ~250 ps risetime, similar with 1.5 Gs/sec. Triquint D/A used in existing systems
- Is this from D/A or support circuitry on evaluation board?
- New Rotation Research assistant (Applied Physics Grad student starts 3/31)
- Project - evaluate frequency response, performance of D/A. Compare with Triquint

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)

LARP SPS and LHC Ecloud 5 year 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

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 analyse 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

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

Summary

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

- now see intial 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

MD analysis

- impressive effort by W.H. and RDM to post process August data
- Goal - look at this data using FFT and Eigenmode tools
- How do they compare?

Plans for June 2009 MD, ongoing anlaysis and simulation efforts