Feedback Control of E-Cloud Instabilities

CM-13 Progress Report, Ideas for Discussion

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John D. Fox, SLAC

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, Georges Ndabashimiye, Mauro Pivi, Claudio Rivetta (SLAC)

Progress April 2009 - November 2009

Ongoing Simulation efforts (Warp, Head-tail, Feedback model)

SPS Machine measurements June 2009 (and re-visit August 2008)

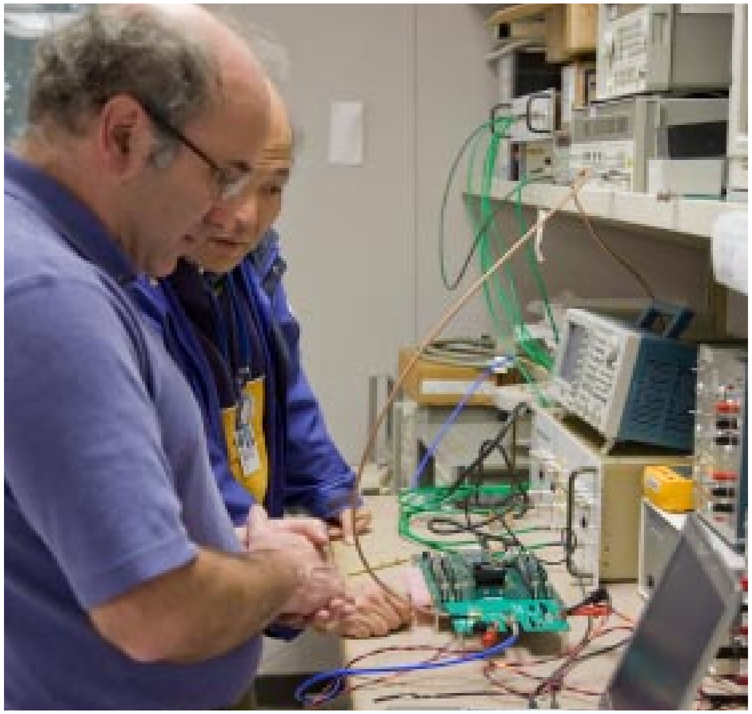
- a more sophisticated look at June 2009 and August 2008 data

Compare WARP, Head-Tail and Machine measurements

- New analysis codes, methods
- Intial results and interesting observations

Ongoing and Near-term plans

- Lab effort- 4 GS/sec. D/A, modulator
- Feedback model, linear beam model, control technique development
- Develop driven beam techniques, hardware and analysis tools
- SPS measurements Spring 2010



Goals - staff profiles, milestones

Progress April 2009 - November 2009

Review of June 2009 SPS MD Beam conditions, machine state

- data recorded, pickup details, data acquisition (bandwidth of bessel filters, etc.)

Goal - develop quantitative analysis methods, normal-mode, other formalisms

- Equalization, suppression of longitudinal motion effects
- 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

- slice FFTs (tune per slice)
- vs. time (modes within a bunch)

RMS techniques - on SUM and Delta (estimation of motion of the beam, time evolution, charge loss)

Analysis of Ecloud simulations and Ecloud MD data

Time domain simulations, measurements

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

Observations

- tune shifts within bunch due to Ecloud, bursting, positions of unstable bunches in trains
- information in SUM signal -
- frequencies within bunch - estimated bandwidth of instability signal, correction signal
- Growth rates of eigenmodes - intial fits and stability observations

Observations from June 09 SPS MD Studies

2 72 bunch trains, 1E11 P/bunch, 25 ns separation. Data sampled 10 ps/point

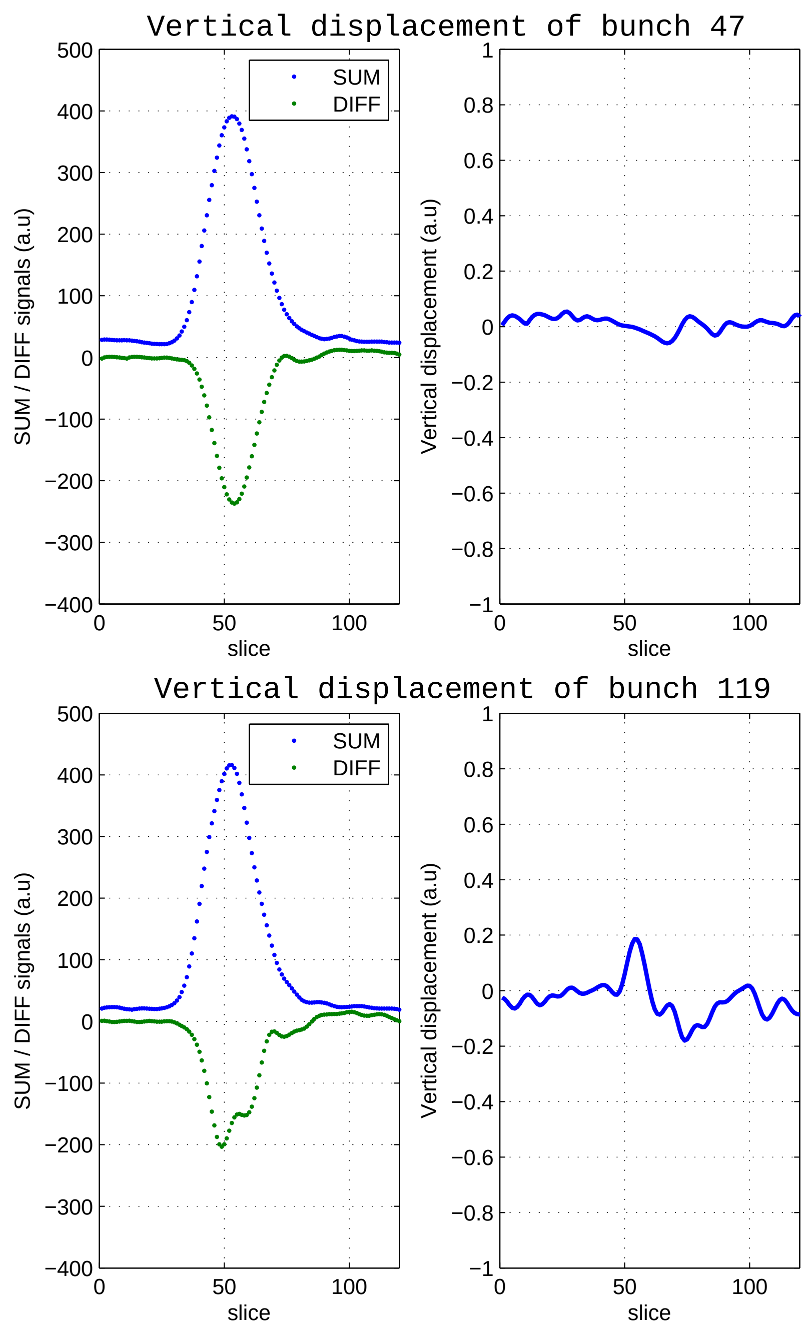
Vertical Instability develops after injection of second batch, within 100 turns. Modes within unstable bunch develop very rapidly at injection- first 100 turns

Time domain figures show bunch charge, and transverse displacement, second figure is vertical displacement after removal of DC transient. Data extracted to show bunch 47 and 119 on turn 80

Stable (bunch 47 and earlier) bunches do not show vertical 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 along bunch axis show (DC structure subtracted):

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

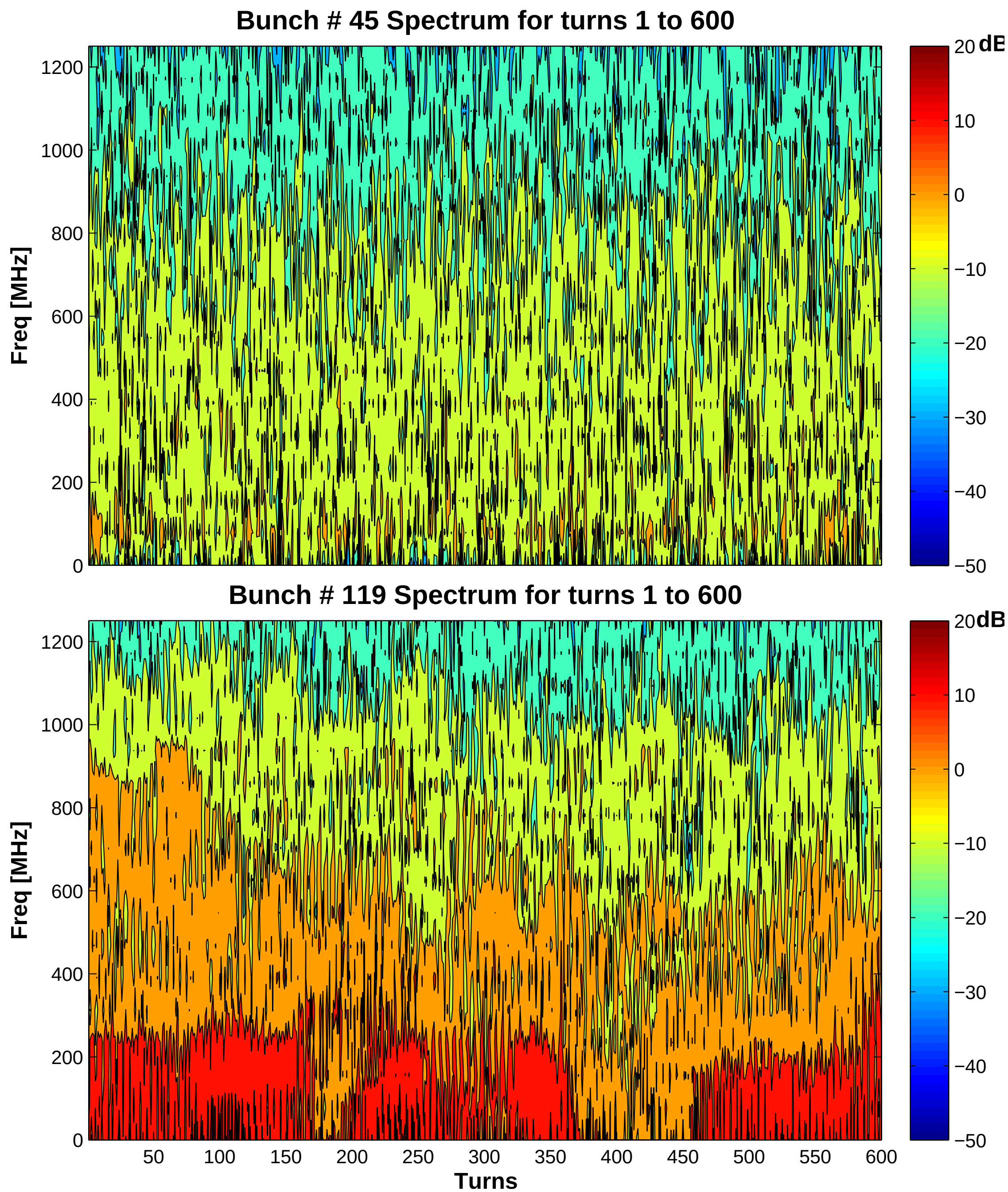
Bunch 119 (unstable) - high frequencies detected

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

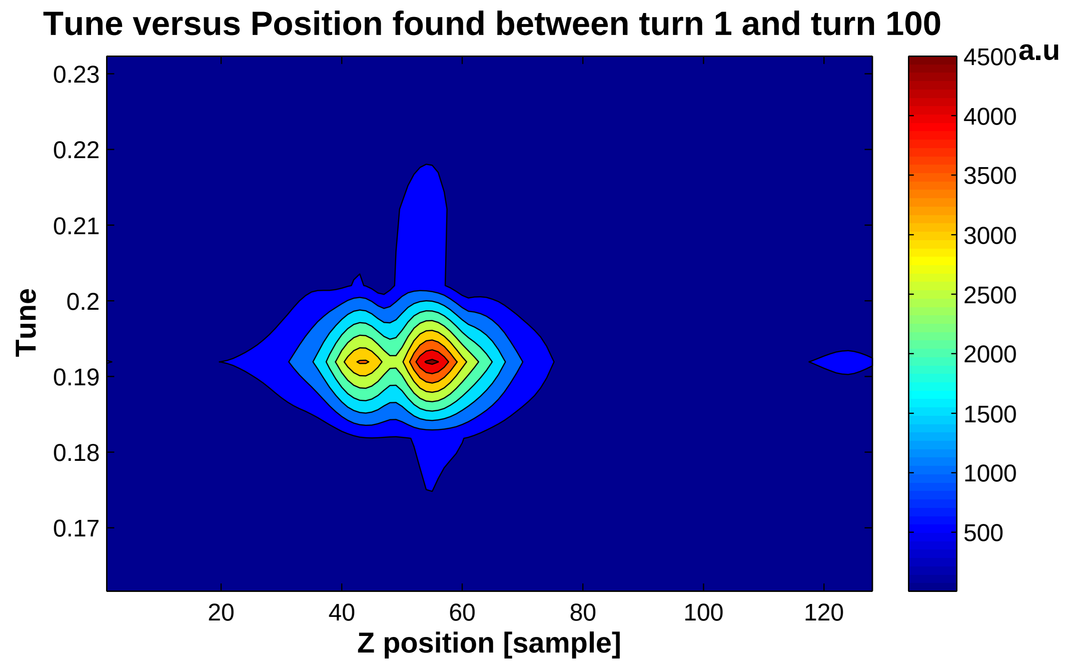
Modes within unstable bunch develop very rapidly at injection- first 100 turns

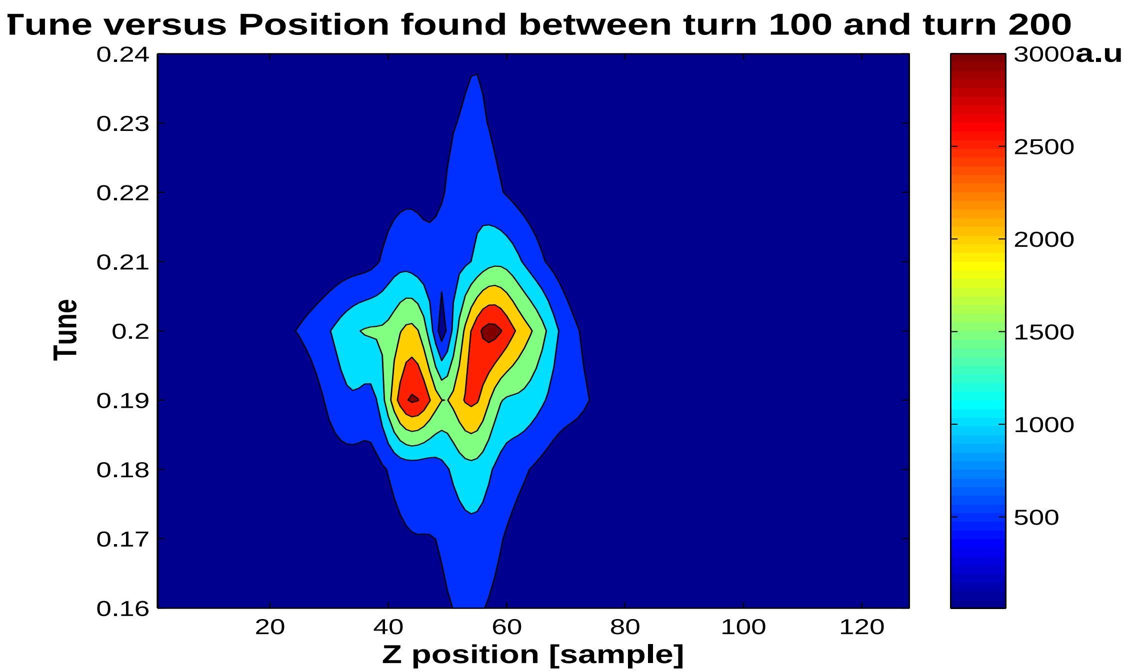
Turns 100 - 200 Motion splits into head and tail, with tune shift between leading and trailing portions of bunch - tail has higher tune. Tune shift shows Ecloud effect

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

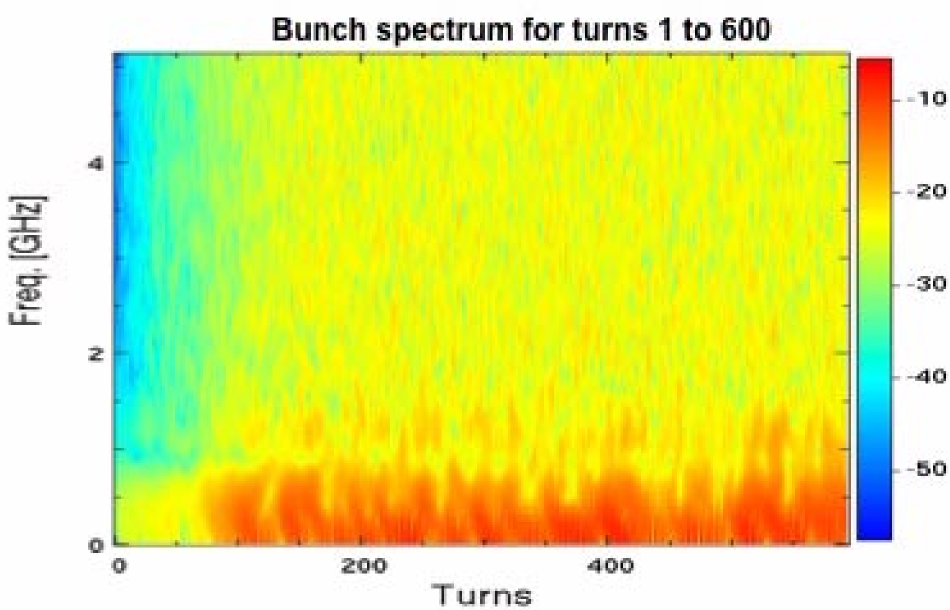




WARP Posinst simulation for SEY 1.3

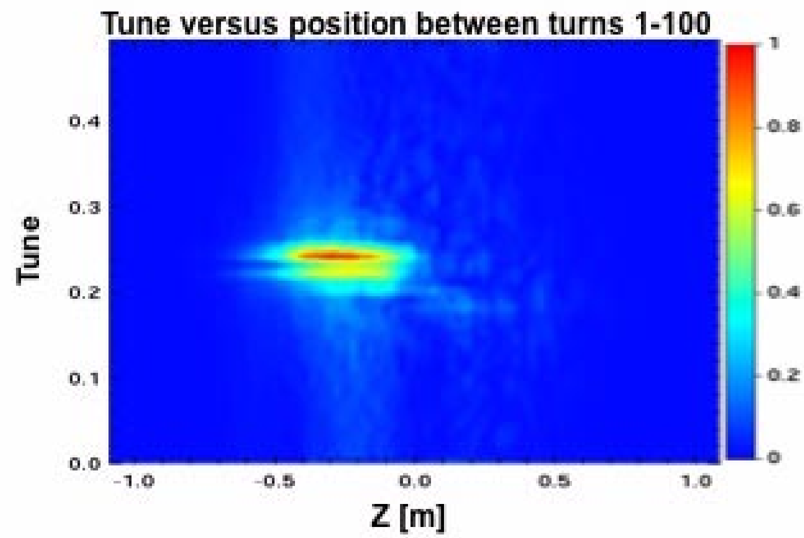
Warp simulation

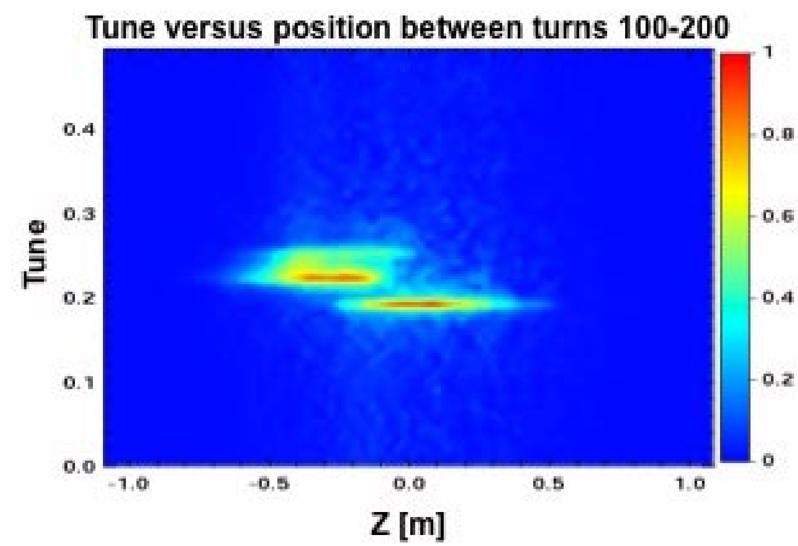
Electron density from Posinst run



Instability grows slowly; affects the tail first

Tune shift larger for tail than for head





Movies of June 16, 2009 SPS MD

MD data at at 1E11 P/bunch, with three chromaticity values (.1, .2 and -.1), 2 RF voltages

Pre-processing includes equalization (cable response), suppression of longitudinal motion

(www.slac.stanford.edu/~rivetta/e-clouds/movies_Aug09)

Starring

1E11 P/bunch, 25 ns separation, 72 bunches/batch (June 2009 MD data)

Injection of batch 1 (stable) followed by 2nd batch (which goes unstable)

Movie 1- Vdspl_bunch_47.avi Vdisplacement for bunch 47 1st batch (stable)

Movie 2 - Vdspl_bunch_119.avi Vdisplacement for bunch 47 2nd batch (#119 e-clouds)

Movie 3 - tune_s.avi Sliding Window spectrogram of Bunch 117 vertical signal by slice

Movie 4 - centroid.avi Centroid tune shift along 620 turns

Movie 5 - rms.avi RMS of slice motion with respect to the bunch centroid

More movies in directory, look at Brief description of videos.pdf

Critical data - required sampling rate (bandwidth), growth rates, tune shifts, internal modes

Interesting Issues to sort out

Centroid Motion - consistent with expected performance of transverse damper? (is it on?)

- Horizontal injection transient feedthrough(movie)

Time scale of injection transient vs. Time scale of instability growth

- Injection transient - 50 turns damping
- Instability growth - less than 100 turns

Concern - will injection transients saturate the ecloud feedback?

- Gain partitioning in channel, noise floor in transverse receiver, power levels
- Needs study and straw man design

Tune 0.2 (5 turns/cycle), growth rate 50 turns - 10 cycles

- What gains are required? Stability? group delay limits?

Dynamics change with energy ramp

- bunch length change, synchronous phase change etc. slow compared to instability growth rates
- Analysis supresses longitudinal motion - implications for actual channel

Can we use the simulation codes to help estimate effects?

Feedback Channel - Complexity? Scale?

Frequency spectrograms suggest:

sampling rate of 2 - 4 GS/sec. (Nyquist limited sampling of the most unstable modes)

Scale of the numeric complexity in the DSP processing filter

- measured in Multiply/Accumulate operations (MACs)/sec.

SPS -5 GigaMacs/sec (6*72*16*16*43kHz)

- 16 samples/bunch per turn, 72 bunches/stack, 6 stacks/turn, 43 kHz revolution frequency
- 16 tap filter (each slice)

KEKB (existing iGp system) - 8 GigaMacs/sec.

- 1 sample/bunch per turn, 5120 bunches, 16 tap filters, 99 kHz revolution frequency .

The scale of an FIR based control filter using the single-slice diagonal controller model is not very different than that achieved to date with the coupled-bunch systems.

What is different is the required sampling rate and bandwidths of the pickup, kicker structures, plus the need to have very high instantaneous data rates, though the average data rates may be comparable.

Summary Observations

Next Steps

- Driven bunch experiments
- Plans - what studies should be done during a ramp? What configurations do we want to study?

Dynamics model, feedback model development

- Introducing new student - Alex Bullit (Dynamics and Optimal Control, Stanford Ph.D.)
- Introducing new student - Ozhan Turgut (Instrumentation, Data Analysis, 1st year)

Summary results paper in preparation for PRST (APAC?)

Progress, collaboration effectiveness from the meetings, web-reports, etc.

- now see similarities/agreement between WARP, Head-Tail, MD data - value in simulation
- Similar cases- no Ecloud - tunes agree
- WARP vs. MD - for comparable SEY and density, similar tune shifts, structural patterns

Linear Model - first efforts fit well to fastest Eigenfrequencies

- Issue - internal modes, phase relationships
- Work in progress, required to estimate linear feedback options

Near-term plans

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

- What conclusions? What analysis is useful? Growth rates? Tune shifts?
- What energy, current, fill pattern needs study? what studies should be done during a ramp? What configurations do we want to study?

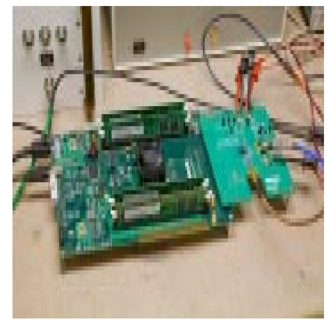
Lab effort- development of 4 GS/sec. D/A

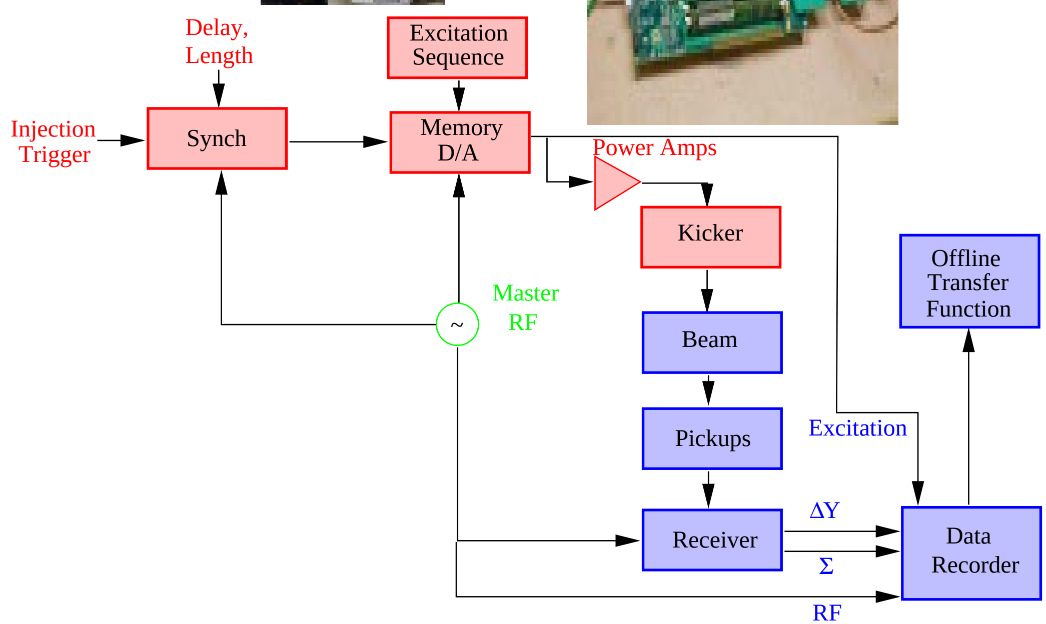
- Develop synchronization, back end and modulator
- New Applied Physics Grad student project

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 systems)





Driven Beam Experiments

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

Can be frequency domain or time domain study

Estimate dynamics below instability threshold(pre-chaotic motion, see tune shifts below threshold)

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

measure excitation, response with two channel fast scope

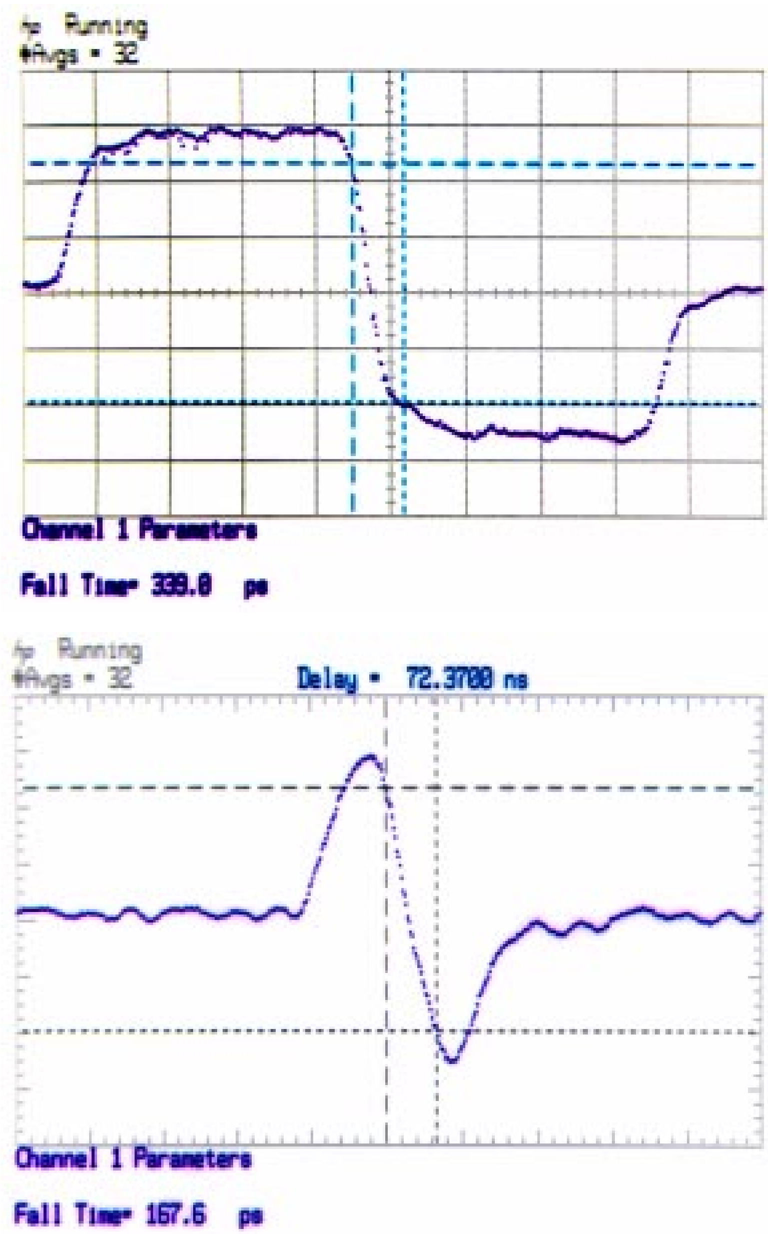
(avoids synchronization complexity)

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

Goals -FY2009/2010 LARP Ecloud effort

understand Ecloud dynamics via simulations and machine measurements

- Participation in E-Cloud studies at the SPS (next opportunity spring 2010)
- 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

- Validation of Warp and Head-Tail models, comparisons to MD results
- comparisons with machine physics data (driven and free motion), validation of models, estimates of dynamics. Crital role of Ecloud simulations in estimating future conditions, dynamics
- extraction of system dynamics, development of reduced (linear) coupled-oscillator model for feedback design estimation
- develop analysis tools , hardware systems to 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 2010

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

Research Goals - 2009 - 2011

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

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

System development Goals 2012 and beyond

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

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

WEBEX Ecloud Feedback mini-workshop August 2009 (joint with SLAC, CERN, BNL, LBL and Cornell)

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

SPS Instrumentation - setup

Pickups - wideband (exponential taper) striplines (T. Linnecar)

(history of directivity, past use in P-Pbar program)

Cable plant from SPS Tunnel to Faraday cage (instrument room)

Hybrid receiver (Anzac H9 Hybrids)

- Cable delays trimmed, matched, hybrids selected for matching
- Issues with 1700 MHz propagating modes - use of 800 MHz (1 GHz etc.) Bessel Filters

Data Acquisition (vertical plane) in Tektronix fast scope (2.5 GHz bandwidth, 10 or 40 PS/sample)

Offline data analysis in Matlab (and Python)

Equalization of stripline signal (thanks WH and RDM), removal of longitudinal motion

RMS techniques (with subtraction of DC transient)

- on SUM and Delta (estimation of motion of the beam, head-tail time evolution, charge loss)

FFT based sliding window techniques

- slice by slice (tune shifts within a bunch)
- within bunch (bandwidth or internal modes)

Information in the SUM signal

SUM signal from hybrid

- shows measure of charge, and a measure of bunch length due to frequency response of pickup/ equaliser
- Integrate each bunch SUM signal - a measure of bunch charge

Several interesting transients (movies)

Examples where the sum signal has a discrete drop correlated with:

- an increasing RMS motion
- tune shift within bunch

Is this charge loss associated with Ecloud motion?

Do all bunches show the same change in SUM?

(compare first, second stack)

We clearly see the bunch length change on injection from PS into SPS bucket