Wideband Feedback Systems

CM24 Progress and Plans

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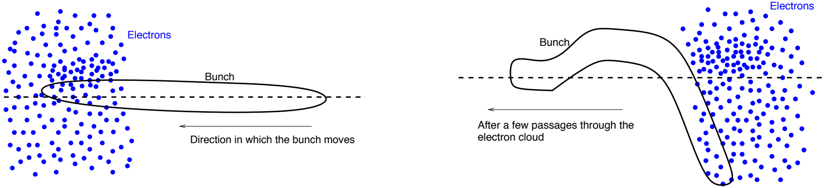
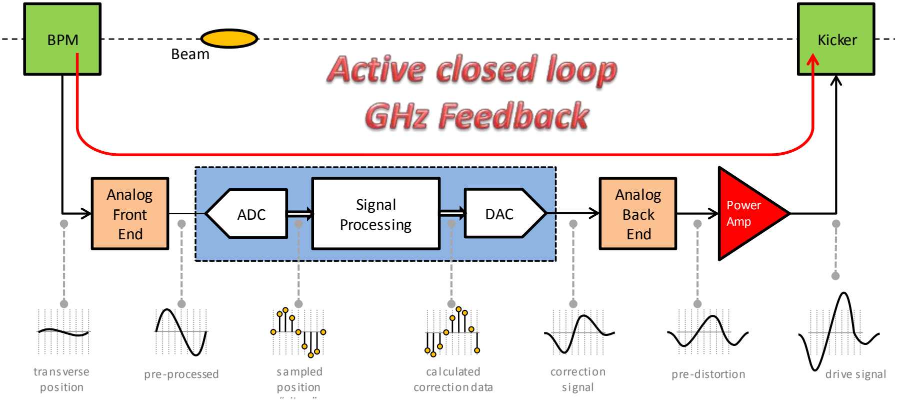
CERN SPS Ecloud/TMCI Instability R&D Effort



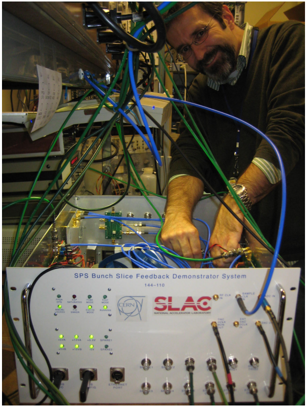
- Ongoing project SLAC/LBL/CERN via US LARP DOE program
- Proton Machines, Electron Cloud driven instability - impacts SPS as high-current LHC injector
  - Photoelectrons from synchrotron radiation - attracted to positive beam
  - Single bunch effect - head-tail (two stream) instability
- TMCI - Instability from degenerate transverse mode coupling - may impact high current SPS role as LHC injector
- Multi-lab effort - SLAC, CERN, LBL, INFN-LNF

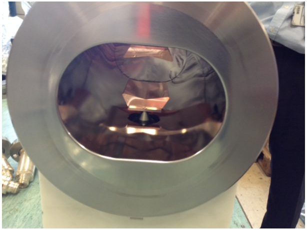
Essential Features

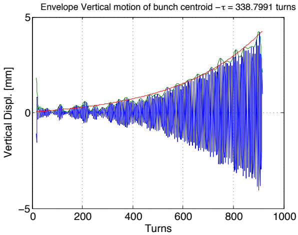


- Control of Non-linear Dynamics (Intra-bunch)
- GHz Bandwidth Digital Signal Processing - 4 GS/s ADC and DAC
- Optimal Control Formalism - allows formal methods to quantify stability and dynamics, margins
- Research Phase uses numerical simulations (HeadTail), Reduced Models, technology development, 1 bunch Demonstrator, SPS Machine Measurements

Beam Measurements, Simulation Models, Technology Development, Wideband Kickers and Demo System







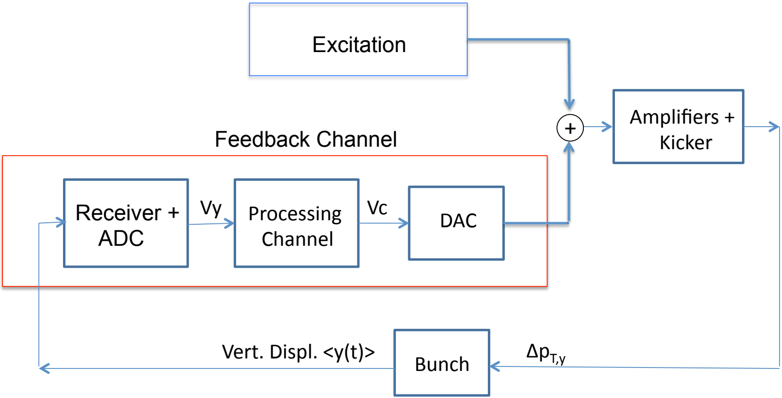
Progress since CM23 KEK November 2014

- WBFS specifications and LIU Design Report
- Demonstrator hardware system (now back to CERN)
  - Noise Floor improvements, Robust timing re-synch
  - Two bunch scrubbing fill controller (5 ns spacing)
  - Power Amplifiers - two 5 - 1000 MHz amplifiers installed and commisioned
- Development of wideband kicker designs
  - Comissioning of Stripline prototype with beam, new amps
  - Optimization of Slotline design for Fab
  - Tunnel infrastructure for new amplifiers, monitoring and control - commissioned
- Intensive MD measurements in December 2014, April 2015
  - Development of special beams for feedback tests
- Simulation codes/feedback model studies, Model-based Control
  - Control Methods for Q20 SPS Optics
  - Development of MD data analysis methods
  - Validate measurements against models
  - Reduced Model and Control design
- FY15 priorities - Expand Demonstration system for multi-bunch operation, commission proto kicker, wideband amplifiers. MD efforts - explore controllers and wideband kicker with beam. MD Data Analysis methods, Explore/validate Q20 control methods

How do you test and quantify Instability Control?

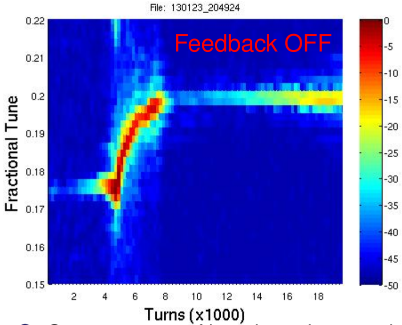
- "Do Feedback on Unstable Beams" - is not the first test!
- The main goal is to use this minimum hardware to quantify the impact of the feedback channel in the beam dynamics
- Validate operation of the system through measurements on single-bunch stable beams, then unstable beams
- We want to validate fundamental behavior of the feedback channel, compare to estimates using the reduced models / macro-particle simulators.
- Excite beam and do closed-loop tests. Measure changes in response due to feedback channel
  - Drive Mode 0, Mode 1, ..., and damp the bunch motion
  - Quantify and study the transients
  - Use switchable FIR coefficients for grow-damp and open-damp transient studies
- To conduct the measurements, Excite and Record via memory of DSP processing with MATLAB offline analysis.
- Technology of 4 GS/S processing and Ghz bandwidth pickups,kickers challenging

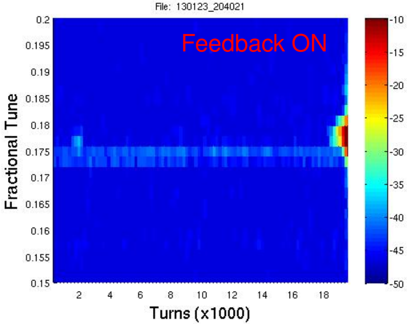
Measuring the dynamic system - open/closed loop



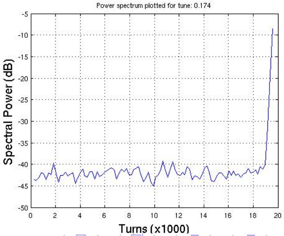
- We want to study stable or unstable beams and understand impact of feedback
- System isn't steady state, tune and dynamics vary
- We can vary the feedback gain vs. time, study variation in beam input, output
- We can drive the beam with an external signal, observe response to our drive
- Excite with chirps that can cross multiple frequencies of interest
- Unstable systems via Grow-Damp methods, but slow modes hard to measure

Feedback control of mode 0

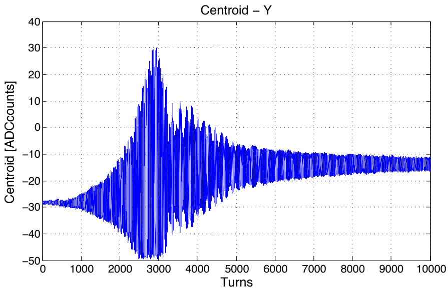


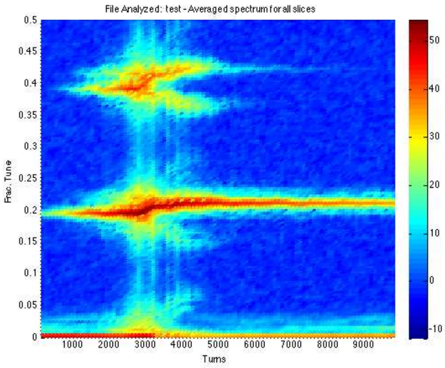


- Spectrograms of bunch motion, nominal tune 0.175
- After chromaticity ramp at turn 4k, bunch begins to lose charge $\rightarrow$ tune shift.
- Feedback OFF -Bunch is unstable in mode zero (barycentric).
- Feedback ON - stability. Feedback is switched off at turn 18K, beam then is unstable



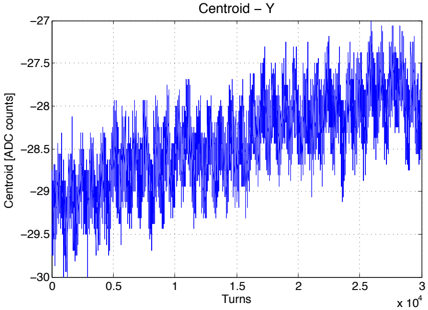
December 2014 "TMCI Unstable" beam - Open Loop

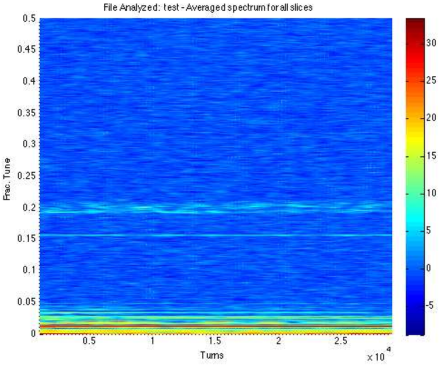




- Open Loop SPS Measurement - Vertical Centroid (left) Spectrogram (right)
- Intensity 2$x10^{11}$ with low chromaticity Q26 lattice (special beam)
- $\nu_y = 0.185$ $\nu_s = 0.006$
- Unstable modes 1 and 2 begin at injection, charge loss starts at turn 2000
- Significant intensity-dependent tune shifts at turn 4500 as charge is lost
- data taken inside the feedback system via snapshot memory

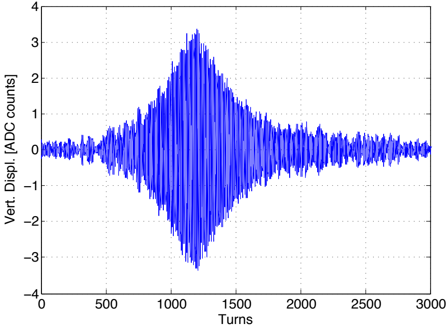
"TMCI Unstable" beam - Stable with feedback control

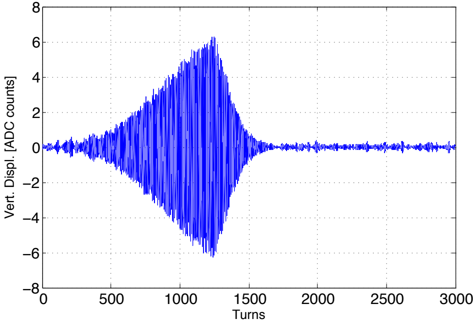




- Closed Loop SPS Measurement - Vertical Centroid (left)l Spectrogram (right)
- Intensity $2x10^{11}$ with low chromaticity Q26 lattice (special beam)
- $\nu_y = 0.185$ $\nu_s = 0.006$
- Unstable Mode 1 and 2 controlled to noise floor (3 μm rms)
- Small residual mode zero driven motion, reduced by the feedback gain.

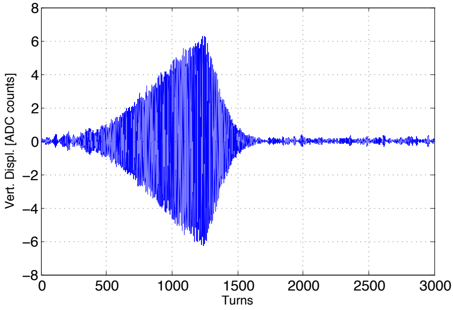
April 2015 SPS MD - Grow/Damp measurements

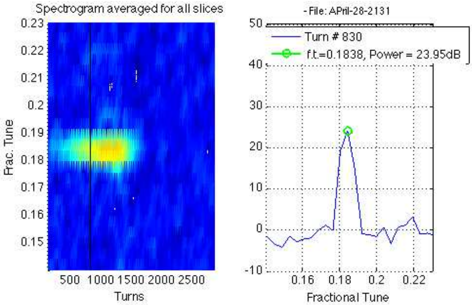




- Grow/damp SPS Measurement - Damping Gain G=4 (left) G=16 (right)
- Intensity $1.1x10^{11}$ with low chromaticity Q26 lattice (special beam)
- $\nu_y = 0.185$ $\nu_s = 0.006$
- Feedback gain is switched to promote instability, then damp it
- Quantifies damping from increased gain of system, compare to models

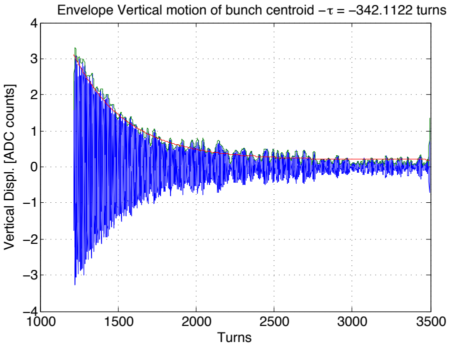
April 2015 SPS MD - Grow/Damp measurements

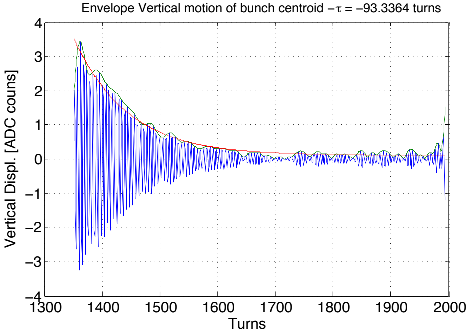




- Grow/damp SPS Measurement - Damping gain G=16 (left) Spectrogram(right)
- Intensity $1.1x10^{11}$ with low chromaticity Q26 lattice (special beam)
- $\nu_y = 0.185$ $\nu_s = 0.006$
- Feedback gain is switched to promote instability, then damp it
- Quantifies damping from increased gain of system, compare to models

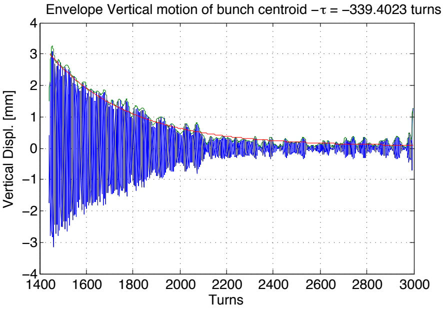
April 2015 SPS MD - Impact of FIR feedback gain

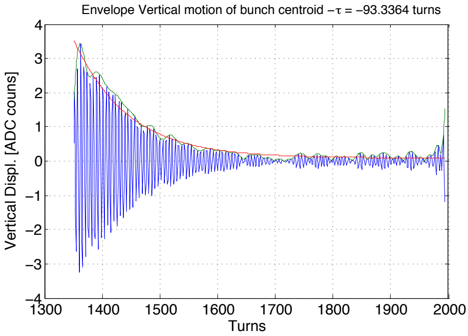




- damping rate SPS Measurement - Damping G=4 (left) G=16(right)
- Intensity 1.1$x10^{11}$ with low chromaticity Q26 lattice (special beam)
- $\nu_y = 0.185$ $\nu_s = 0.006$
- Feedback phase held constant, impact of two gains on achieved dampig
- Quantifies damping from configuration of FIR filter, compare to models
- G=4 $\tau = -342$, G=16$\tau = -93$
- Is this the "best" one can do? what about more sophisticated control methods?

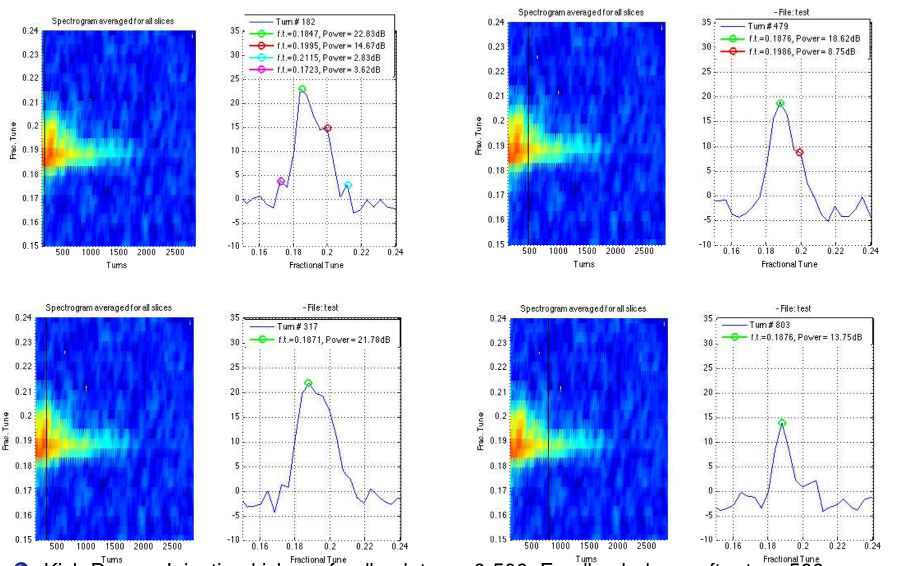
April 2015 SPS MD - Impact of FIR feedback phase





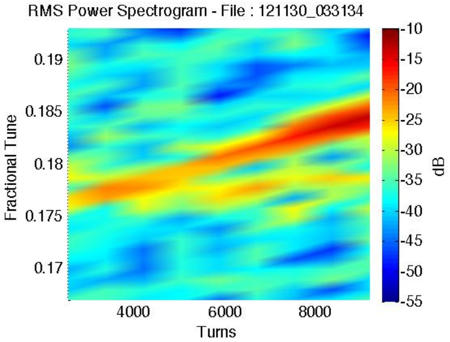
- damping rate SPS Measurement - FIR phase 90 (left) phase 157 (right)
- Intensity $1.1x10^{11}$ with low chromaticity Q26 lattice (special beam)
- $\nu_y = 0.185$ $\nu_s = 0.006$
- Feedback FIR gain held constant, impact of two filter phases on achieved damping
- Quantifies damping from filter phase vs frequency of system, compare to models
- phase= 90 $\tau = -339$, phase= 157 $\tau = -93$
- Is this the "best" one can do? what about more sophisticated control methods?

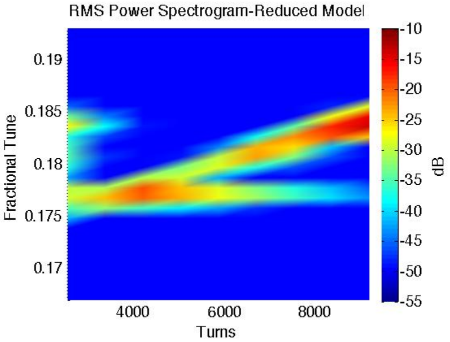
April 2015 SPS MD -Evolution of modes vs. turn



- Kick-Damp - Injection kick, no feedback turns 0-500, Feedback damp after turn 500
- Shows evolution of excited and damped modes

MD vs Model - open loop multiple mode excitations





- Driven chirp- SPS Measurement spectrogram (left) Reduced Model spectrogram (right)
- Chirp tune 0.175 - 0.195 turns 2K - 17K
- 0.177 Barycentric Mode,Tune 0.183 (upper synchrotron sideband)
- Model and measurement agreement suggests dynamics can be closely estimated using fitted model
- Study changes in dynamics with feedback as change in driven response of model

State Space coupled model - fit to measurements

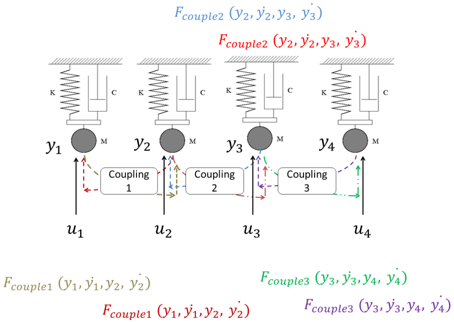


Figure 2 : Reduced model for intra-bunch dynamics.

$$\begin{bmatrix}\dot x_1\\ \dot x_2\\ \ddot x_1\\ \ddot x_2\end{bmatrix} = \begin{bmatrix}0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ k+k_{couple} & -k_{couple} & c+c_{couple} & -c_{couple}\\ -k_{couple} & k+k_{couple} & -c_{couple} & c+c_{couple}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ \dot x_1\\ \dot x_2\end{bmatrix} + \begin{bmatrix}0 & 0\\ 0 & 0\\ 1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}u_1\\ u_2\end{bmatrix}$$

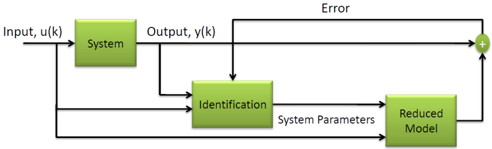
$$\begin{bmatrix}y_1\\ y_2\end{bmatrix} = \begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ \dot x_1\\ \dot x_2\end{bmatrix}$$

$$\dot X = AX + BU$$
$$Y = CX$$

Eig (A) will give us the complex poles of the system, i.e damping and tune

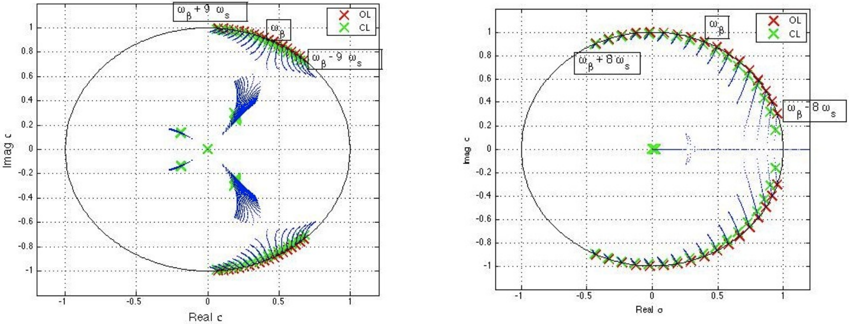
u_1 & u_2 : external excitation
y_1 & y_2 : vertical motion
Coupling parameters : Kcouple and Ccouple

- Fit models to excitation, response data sets from chirps
- Characterize the bunch dynamics - same technique for simulations and SPS measurements
- Critical to evaluate the feedback algorithms



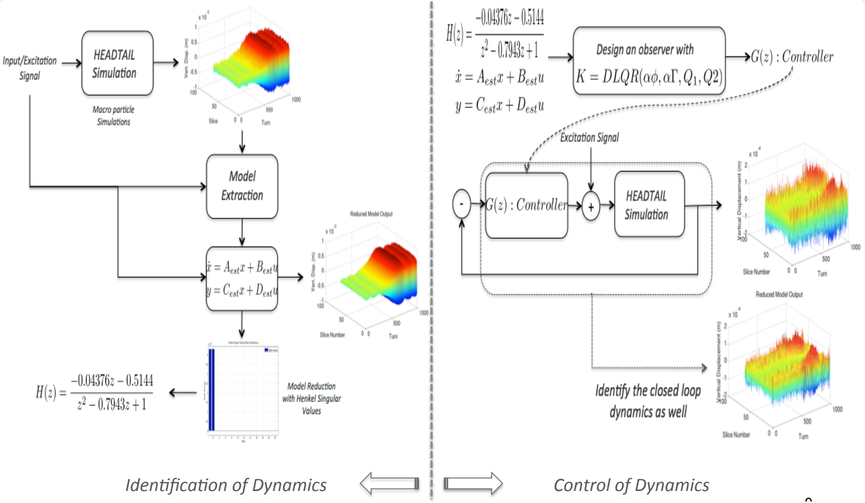
Feedback design - Value of the reduced model

- Controller design requires a linear dynamics model
- The bunch stability is evaluated using root-locus and measurements of the fractional tune.
- Immediate estimates of closed-loop transfer functions, time-domain behavior
- Allows rapid estimation of impact of injected noise and equilibrium state
- Rapid computation, evaluation of ideas
- Q20 IIR controller is very sensitive to high-frequency noise - would higher sampling rate (two pickups) be helpful?



Left: FIR filter controller designed for Q26 at $f_\beta = 0.185$, $f_s = 0.006$
Right: IIR filter controller designed for Q20 at $f_\beta = 0.185$, $f_s = 0.017$

Model based Control

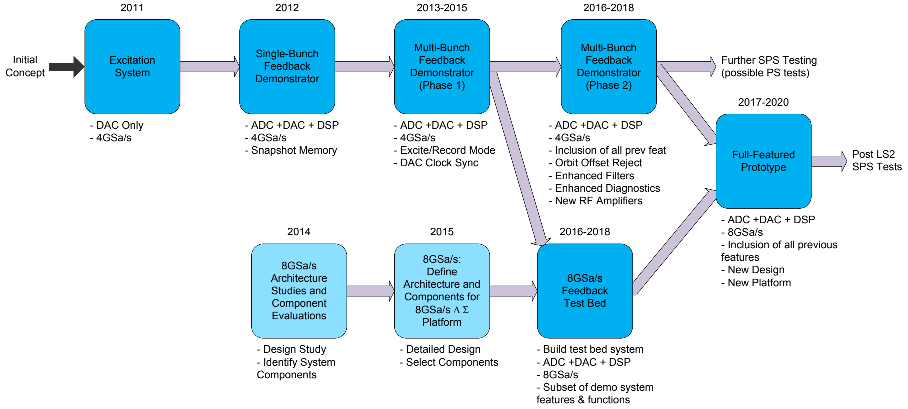


- The dynamics from a head-tail simulation is used to design a controller
- MD data can be used the same way
- model-based controller formal method has better damping for mode 1 than FIR controller

Path Forward

- Wideband Feedback as part of LIU, HL-LHC and US LARP
- MD measurements with wideband DEMO system (SPS beam time and analysis)
  - Single-bunch IIR, scrubbing doublet and FIR multi-bunch control, wideband kicker
  - Diagnostic and beam instrumentation techniques to optimize feedback parameters and understand system effectiveness
  - Continued simulation and modeling effort, compare MD results with simulations, explore new controllers
  - Evaluate new Kickers (Stripline and Slotline) and upgraded tunnel High-Power wideband RF amplifiers for SPS operation
- Technology Development and system estimation for Full-Function system
  - Explore Q20 control methods (New filters? Multiple pickups?) - optimize system performance
  - Low-noise transverse coordinate receivers,orbit offset/dynamic range improvements, pickups
  - Expand Master Oscillator, Timing system for Energy ramp control
- High-speed DSP Platform consistent with 4 -8 GS/sec sampling rates for full SPS implementation
  - Lab evaluation and firmware development
- 2016 CERN Review, Recommendations on Full-Featured System

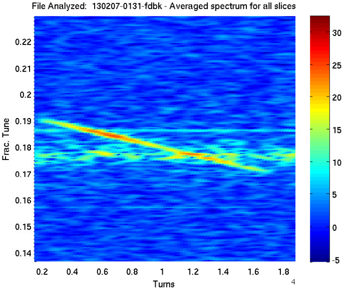
Upgrades to the SPS Demonstrator - Roadmap

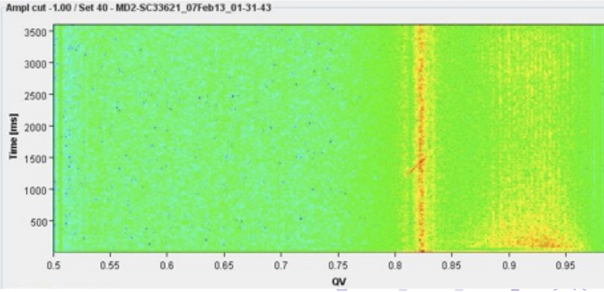


- The Demo system is a platform to evaluate control techniques
- MD experience will guide necessary system specifications and capabilities
- The path towards a full-featured system is flexible, can support multiple pickups and/or multiple kickers
- We will benefit from the combination of Simulation methods, machine measurements, and technology devlopment

Wideband Feedback - Beam Diagnostic Value

- processing system architecture/technology
  - reconfigurable platform, 4 - 8 GS/s data rates
  - snapshot memories, excitation memories
  - applicable to novel time and frequency domain diagnostics
  - Feedback and Beam dynamics sensitive measure of impedance and other dynamic effects
  - Complementary to existing beam diagnostic techniques - use kicker excitation integrated with feedback processing
- Detailed slice by slice information, very complete data with GHz bandwidth over 20,000 turns





Acknowledgements and Thanks

- We especially acknowledge the skillful fabrication, test and installation of the stripline kicker in time for startup this fall (Thanks E. Montesinos and team!)
- We are grateful to the R&K company (Japan) for their rapid prototype amplifier development, and their interest in meeting our unusual time-domain specifications
- We cannot adequately acknowledge the critical help from everyone who made the winter 2012 and 2014, 2015 feedback Demo MDs possible. We are grateful for the collaboration and generous help.
- Thanks to CERN, SLAC, and LARP for support
- We thank our Reviewers from the June 2013 Internal Review, the CERN LIU-SPS July 2013 Review, and the DOE LARP February 2014 Review for their thoughtful comments and ideas

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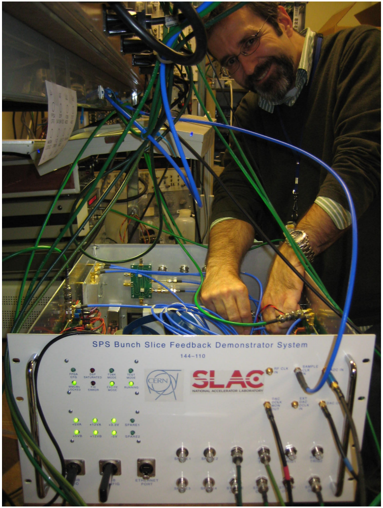
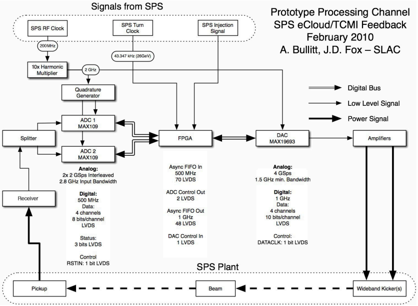
Wideband Intra-Bunch Feedack - Considerations

The Feedback System has to stabilize the bunch due to E-cloud or TMCI, for all operating conditions of the machine.

- unstable system- minimum gain required for stability
- E-cloud - Beam Dynamics changes with operating conditions of the machine, cycle (charge dependent tune shifts) - feedback filter bandwidth required for stability
- Acceleration - Energy Ramp has dynamics changes, synchronization issues (variation in β), injection/extraction transients
- Beam dynamics is nonlinear and time-varying (tunes, resonant frequencies, growth rates, modal patterns change dynamically in operation)
- Beam Signals - vertical information must be separated from longitudinal/horizontal signals, spurious beam signals and propagating modes in vacuum chamber
- Design must minimize noise injected by the feedback channel to the beam
- These questions can only be understood with both MD Studies and Simulation methods
- Receiver sensitivity vs. bandwidth? Horizontal/Vertical isolation?
- What sorts of Pickups and Kickers are appropriate? Scale of required amplifier power?
- Saturation effects? Impact of injection transients?
- Trade-offs in partitioning - overall design must optimize individual functions

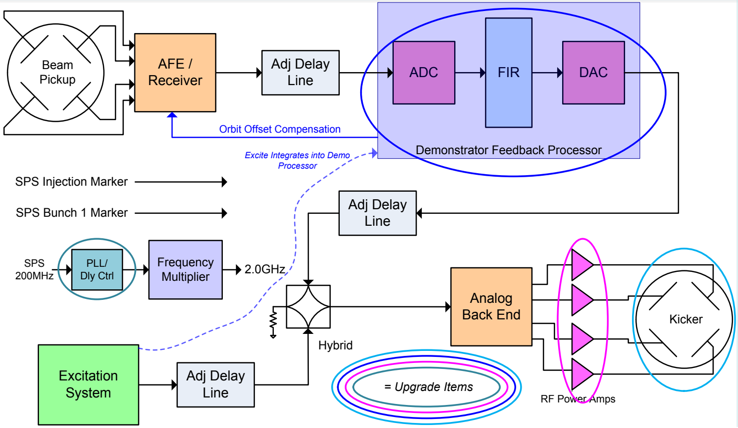
4 GS/s 1 bunch SPS Demonstrator processing system





- Proof-of-principle channel for 1 bunch closed loop tests in SPS - Commissioned November 2012
- Provides wideband control in SPS with installation of wideband kicker and amplifiers
- Reconfigurable processing - Platform to evaluate control methods, algorithms and architectures
- Features upgraded during LS1 - timing/synchronization, noise floor of A/D, scrubbing fill controller.

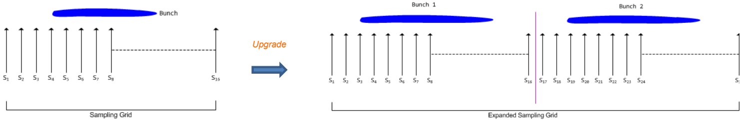
LS1 Upgrades to the SPS Demonstrator System



- Fall 2014 - Robust Timing re-synch, improved digitizer noise floor, integrated excitation
- Summer 2014 - New wideband striplines for beamline
- Summer 2014- Evaluate power amplifier options, Winter 2015 commissioning
- FY14 -FY15 Expand DSP capabilities to Scrubbing fill, synched excitation, multi-bunch

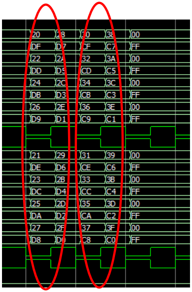
Scrubbing Fill Controller - implemented for December 2014 MD tests

Existing Processing | *New 32-sample Processing*



Processing of Single Scrubbing bunch Doublet

- Enables Demo Unit to process a Single scrubbing pattern doublet (two adjacent bunches) / Feedback, Excitation, FEC, Snap Record
- Idea Proposed by J. Fox
- This will become a special operating mode (scrubbing mode) to the “regular” demo unit operation (single-bunch)
  - Has capability of recording snapshot data (32-sample)
  - Retains Feedback+Excitation Mode as well
  - Mode selection in SW or separate configuration (different FPGA cfg file)
- Status
  - FPGA code complete (for main function, snapshot code expansion in the works)
  - Undergoing simulation verification →
  - Tried test FPGA compile: routed to speed w/o resource issues
  - Will deploy onto HW and test next week
  - Plan is to implement prior to shipping box back to CERN
- What about multi-bunch mode?
  - Not forgotten!
  - Work will start on this as soon as single-bunch scrubbing mode is completed
  - Some of the concepts developed here lend to multibunch mode
  - Completed Winter/Spring 2015



Digital Simulator result – showing two 16-sample bunches being output to DAC

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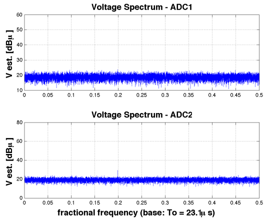
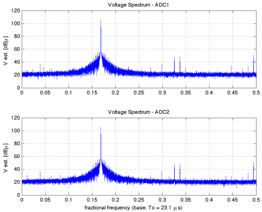
- wideband system allows control with 5 ns bunch spacing

Quantifying Performance of the DEMO A/D System

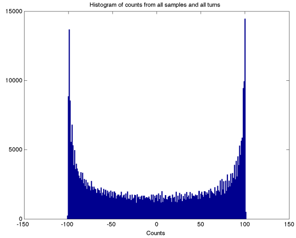
- The dynamic range, linearity and nonlinear behavior of the DEMO system was carefully quantified during LS1- important to estimate impact behavior in beam studies
- Noise pick-up seen in commissioning was addressed with new physical layout of A/D cards, copper ground plate, double-shielded cables
- Full 54dB dynamic range achieved, spurious narrowband interfering signals eliminated
- Performance in the SPS Faraday cage - the next tests



Spectrum of 50 ohm terminated input

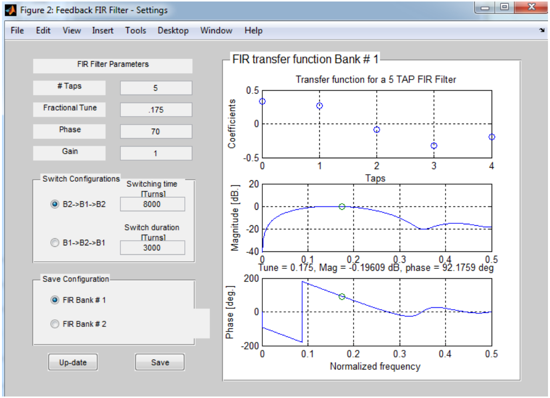


Spectrum of near full scale 200 MHz Input

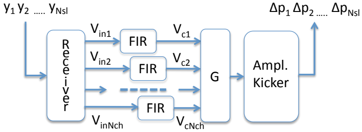


Histogram of near full scale 200 MHz input

Feedback Filters - Frequency Domain Design

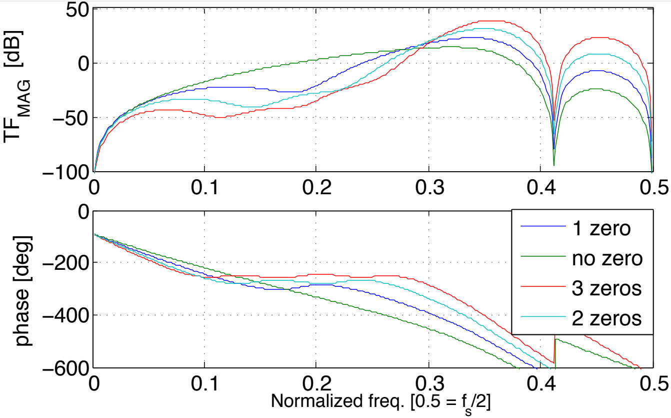


- FIR up to 16 taps
- Designed in Matlab
- Filter phase shift at tune must be adjusted to include overall loop phase shifts and cable delay



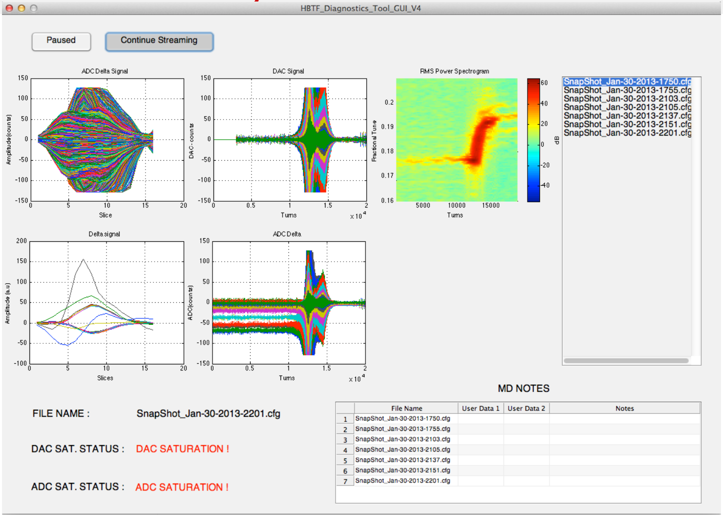
The processing system can be expanded to support more complex off-diagonal (modal) filters, IIR filters, etc as part of the research and technology development

Example Q20 IIR control Filters



- Q20 optics has much higher synchrotron tune (0.017)
- Impact - much wider control bandwidth
- filters with flat phase response have high gain above the beam motion frequencies - add noise
- Technical direction - Explore multi-pickup sampling (higher effective Nyquist limit, better rejection of noise)

Online MD data analysis tool



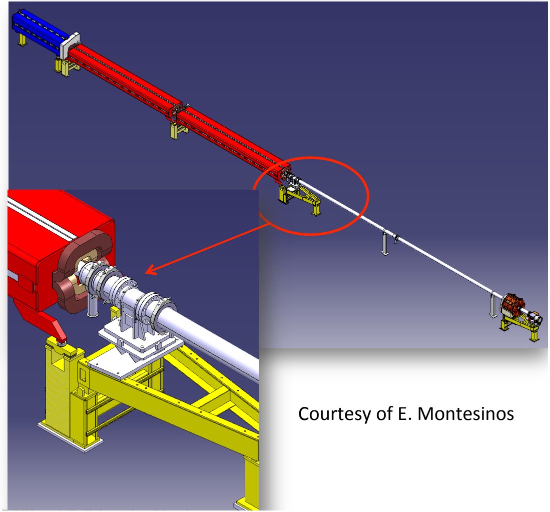
- Intended to run in faraday cage, check as each data set is recorded
- Does quick analysis, shows beam motion, system parameters
- Helps make the MD process more efficient, still have extensive off-line tools and codes

1 GHz wideband Stripline kicker development

- CERN, LNF-INFN, LBL and SLAC Collaboration. Design Report SLAC-R-1037
- Electrical and Mechanical design completed, fabricated by E. Montesinos et al
- Installed with 3 kicker support system fall 2014
- Collaboration: J. Cesaratto (SLAC), S. De Santis (LBL), M. Zobov (INFN-LNF), S. Gallo (INFN-LNF), E. Montesinos (CERN), et al

1 GHz Wideband Stripline Kicker array on beamline

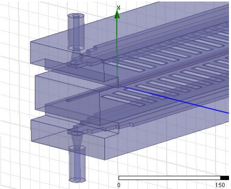
- SPS Sextant 3, LSS3
- Housed in the second half of the 321 period of the SPS.
- Approximately 8 m of usable space following the dipole magnet
- 8 new 7/8" cables pulled to kicker location during LS1
- Power amplifiers still needed
  - Essential for operation of new kickers!
  - Critical items for post LS1 operation



Courtesy of E. Montesinos

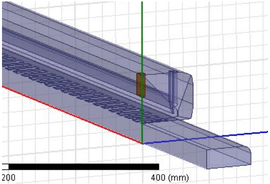
1 GHz Wideband Slotline kicker development

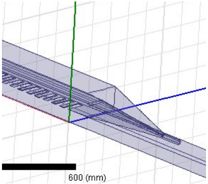
- CERN, LNF-INFN, LBL and SLAC Collaboration. Design Report SLAC-R-1037
- Reviewed July 2013 at the CERN LIU-SPS Review
- Slotline prototype in electrical design and HFSS optimization
- Silvia Verdu to continue effort started by John Cesaratto
- Plan for mechanical design, fabrication by E. Montesino for Fall 2015 SPS installation



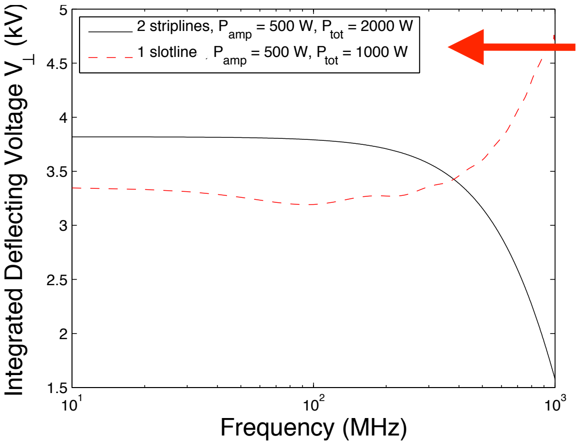
- Down selection needed on port design
  - CERN mechanical engineering department to weigh in on complexity and feasibility
  - 3 port layouts
    - Tapered, lateral provide best matching
  - Currently, waiting for ME resources, following stripline development

- Once choice is made on the port layout, another round of EM optimization needed, then mechanical design can begin.





Complementary Striplines and Slotline



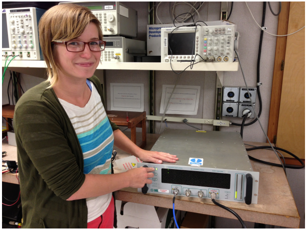
CERN plans to install:

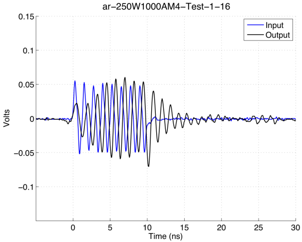
- 2 Striplines
- 1 Slotline

- At low frequencies, the striplines have slightly higher kick strength.
- However, the slotline can effectively cover the bandwidth up to 1 GHz.
- MDs with the new kicker prototypes are ABSOLUTELY ESSENTIAL to validate and confirm the technologies, bandwidth and kick strength needed.

Evaluating Wideband RF Power Amplifiers

- 11 potential RF amplifiers were evaluated from US, Japanese and European vendors
- Bandwidths of 5 - 1000 MHz (80 - 1000 MHz), with 200 - 250W output power levels
- Use excitation system for wideband time domain excitations
- Study frequency domain and time domain responses. Concerns with phase linearity and time response
- Commercial amplifiers not specified for 100% AM modulation, wideband pulse responses
- Nonlinear effects, thermal tail effects also important



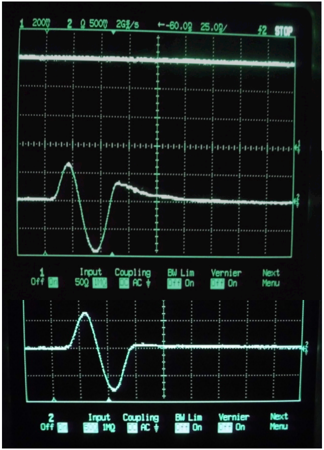


R & K 5 - 1000 MHz amplifier

- R& K Company was interested in developing a new design to meet our wideband requirements
- After initial tests, worked with us to extend low-frequency response, improve transient behavior
- New amplifier design also includes necessary remote control and monitor features for operation in SPS tunnel
- Selection Fall 2014 - purchase of 2 R&K 5 - 1000 MHz 250W amplifiers for December 2014 delivery

Before

After



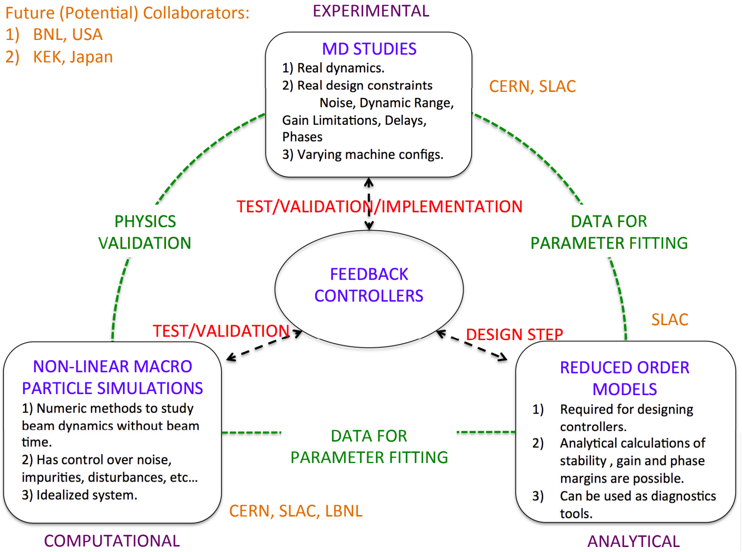
R&K's impulse response measurements

From Demonstration system - to full-featured system

- The Demo system is being used for MD studies, and technology development through the end of 2016
  - Validate multi-bunch control
  - Explore scrubbing fill control
  - Evaluate Q20 control techniques, validate simulation models
  - Explore value of multiple pickups and kickers in system architecture
  - Diagnostic and beam instrumentation techniques to optimize feedback parameters and understand system effectiveness
  - Evaluate Stripline and Slotline wideband kickers and RF Amplifiers with beam
  - Design Report for full-featured system
- Action from LIU Review July 2013
  - End of 2016 - Wideband Feedback System review -Decision to proceed with full-featured system development for SPS installation
- WBFS has been estimated and budgeted within the LARP system for future production decision

Multi-Lab Collaboration

Future (Potential) Collaborators:
1) BNL, USA
2) KEK, Japan



DEMO Upgrade to 8 GS/s system

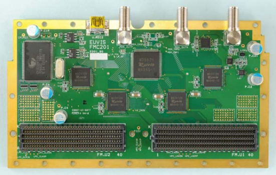
→ The current 4GSa/s architecture allows us to take 16 samples across an SPS bunch

- Increasing the sampling rate to 8GSa/s allows us even greater flexibility:
  - Increased sampling resolution (32 samples across a single bunch / 125ps sample spacing)
  - Increased Flexibility:
    - Single ultra-fast 8GSa/s feedback channel

      -or-
    - Dual 4 GSa/s channels for *two* sets of pickups and kickers
  - Enables delta-sigma/delta-delta/sigma-sigma topologies (modelling studies suggest that these may be necessary for stability control)
  - Enhanced diagnostics

- To accomplish this, we need faster ADCs and DACs and are investigating new components:

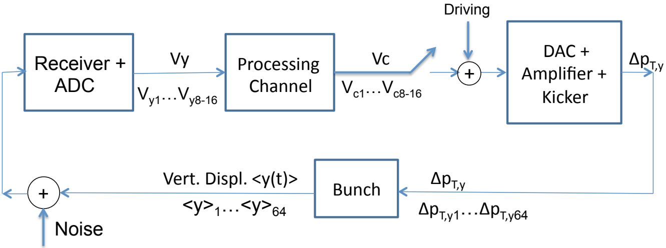
DAC: Have identified a high speed DAC (Euvis, Inc. MD662H DAC device: 8GSa/s, 12-bits) / Have purchased demo board and will begin evaluating



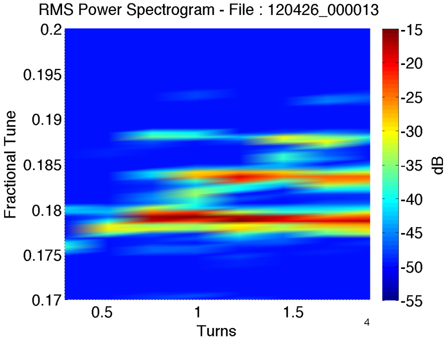
ADC: TI / National Semi has recently released a new 12-bit, 4GSa/s ADC. The AD12J4000 (we can use two in interleaved mode to reach 8GSa/s) / Will purchase a demo board soon and evaluate

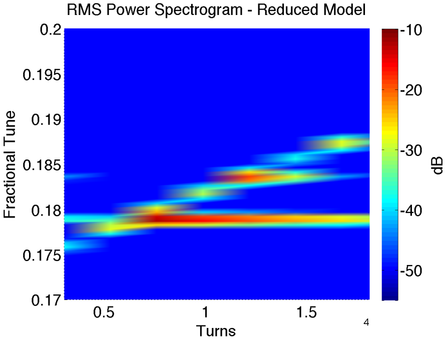
Progress in Simulation Models

- Critical to validate simulations against MD data
- Collaboration and progress from CERN and SLAC, but
  - Need to explore full energy range from injection through extraction
  - Explore impact of Injection transients, interactions with existing transverse damper
  - Still needs realistic channel noise study, sets power amp requirements
  - Still needs more quantitative study of kicker bandwidth requirements
  - Minimal development of control filters, optimal methods using nonlinear simulations
- Continued progress on linear system estimation methods
  - Reduced Models useful for formal control techniques, optimization of control for robustness
  - Model test bed for controller development



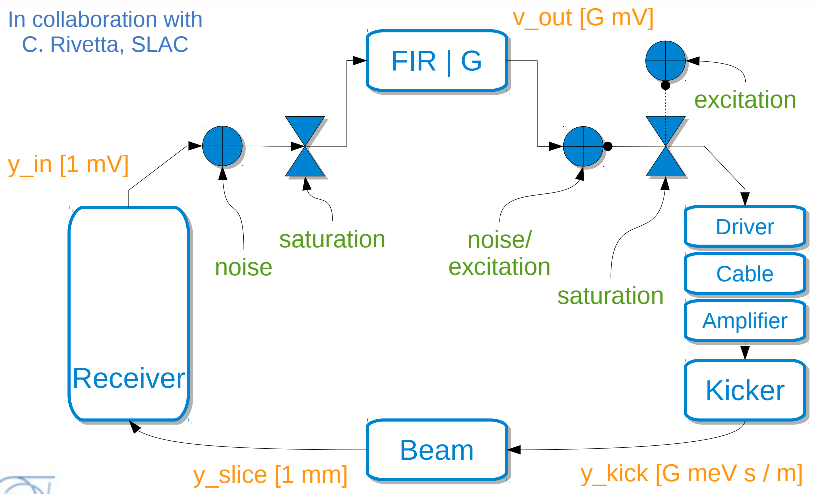
MD vs Model - open loop multiple mode excitations





- Driven chirp- SPS Measurement spectrogram (left) Reduced Model spectrogram (right)
- Chirp tune 0.172 - 0.188 turns 2K - 17K
- 0.179 Barycentric Mode,Tune 0.184 (upper synchrotron sideband), 0.189 (2nd sideband)
- Model and measurement agreement suggests dynamics can be closely estimated using fitted model (4 oscillator model) - but nonlinear effects seen in machine data
- Study changes in dynamics with feedback as change in driven response of model

HeadTail Feedback Combined Model



Kevin Li

- Nonlinear system, enormous parameter space, difficult to quantify margins
- Collaboration K. Li, O. Turgut, C. Rivetta

Comparison of HEADTAIL with Reduced Model

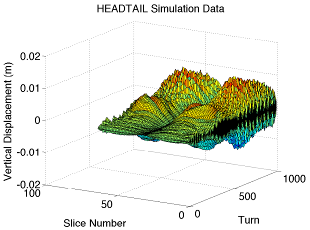


Figure: HeadTail Vert. Motion, Driven by 200 MHz, 0.144 - 0.22 Chirp, 1000 Turns.

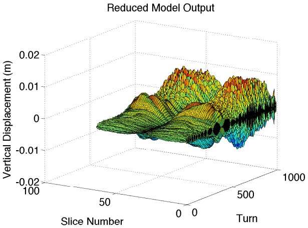


Figure: Vertical Motion of the Reduced Model.

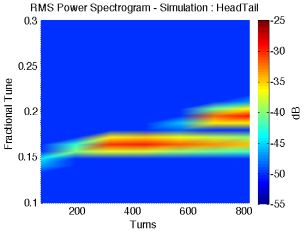


Figure: RMS Spectrogram of HEADTAIL Driven by 200 MHz Chirp Excitation

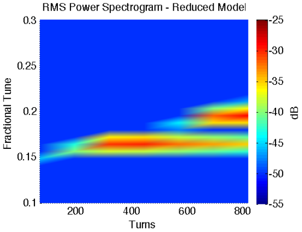
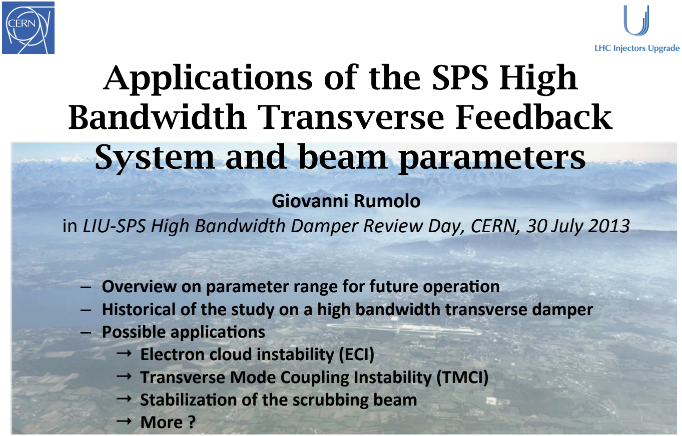


Figure: RMS Spectrogram of Model Driven by 200 MHz Chirp Excitation

Wideband Feedback - Benefits for HL LHC

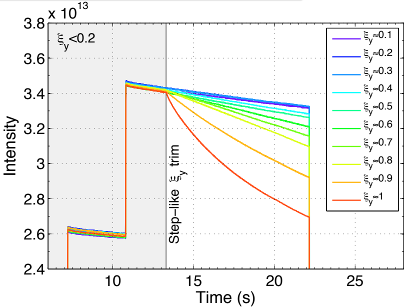
- CERN LIU-SPS High Bandwidth Transverse Damper Review
- Multiple talks, on impacts of Ecloud, TMCI, Q20 vs. Q26 optics, Scrubbing fill, etc.
    - Particular attention to talk from G. Rumolo



SPS wideband Feedback - helps with Ecloud instability control, applicable for possible TMCI

- Feedback is complementary to coatings, grooves, other methods
- Reduces need for chromaticity as cure for instability, low chromaticity beneficial for beam quality
- Provides a measure of flexibility in choice of operating parameters, lattice options
- Emittance growth from any coherent fast motion can be suppressed

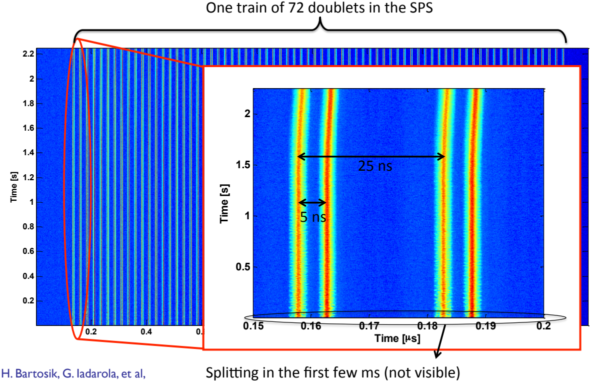
Effect of chromaticity on the lifetime of the 25ns beam in the SPS (2012)



H. Bartosik, G. Iadarola, et al, CERN-ATS-Note-2013-019

SPS wideband Feedback - value for Scrubbing Fill

- Comments from G. Rumolo
- Scrubbing Fill - 5 ns bunch separation
- Exceeds bandwidth of existing transverse damper
- Fill suffers from transverse instabilities and enhanced Ecloud
- Wideband feedback enhances scrubbing, potential use of this fill in LHC



H. Bartosik, G. Iadarola, et al,
Thanks to J. Esteban-Müller et al.

Wideband Feedback - Applications to the PS

- PS might benefit from wideband transverse feedback
- Reconfigurable, programmable architecture can target PS
- Comments from G. Rumolo

  - The **PS** transverse damper (23 MHz at 800 W CW)
    - Has enough bandwidth as to damp the headtail instabilities of the LHC beams at the injection plateau.
    - Has been proved to delay the coupled bunch ECI at 26 GeV/c already in the present functioning mode
    - Cannot damp the instability at transition of the high intensity single LHC-type bunches → larger bandwidth needed as the instability has a spectrum extending to more than 100 MHz.

A. Blas, K. Li, N. Mounet, G. Sterbini, et al.

Wideband Feedback - Applications to the LHC (G. Rumolo)

- Reconfigurable, programmable architecture, technology applicable to LHC
  - **LHC** would benefit of a high bandwidth transverse feedback system in the future to produce 25ns beams with the desired high quality
    - Presently, 25ns beams in the LHC still suffer from detrimental electron cloud effects
      - Instabilities observed at the injection of long trains
      - Emittance blow up along the trains
    - The scrubbing process by only using nominal 25ns beams does not seem to quickly converge to an electron cloud free situation in the LHC
      - The electron cloud still survives in quadrupoles and is at the buildup limit in the dipoles (awakens on the ramp)
      - There seems to be also a fast deconditioning-reconditioning cycle even between fills separated by only few "idle" hours
  - Developing a high bandwidth feedback system in the SPS first ....
    - could allow stabilization of the scrubbing beam in view of its use for the LHC
    - would be an invaluable experience to assess its potential against electron cloud effects and extend its use to LHC, too.

Wideband Feedback - Implementation in LHC

- Architecture being developed is reconfigurable!
- Processing unit implementation in LHC similar to SPS:

	SPS	LHC
RF frequency (MHz)	200	400
f_{rev} (kHz)	43.4	11.1
# bunches/beam	288	2808
# samples/bunch	16	16
# filter taps/sample	16	16
Multi-Accum (GMac/s)	3.2	8

- LHC needs more multiply-accumulation operation resources because of # of bunches, but reduced f_{rev} allows longer computation time (assuming diagonal control).
    - LHC signal processing can be expanded from SPS architecture with more FPGA resources
    - Similar architecture can accommodate needs of both SPS and LHC.
- Still need kicker of appropriate bandwidth with acceptable impedance for LHC. Learn from SPS experience.