Wideband Feedback Systems

CM22 Progress and Plans

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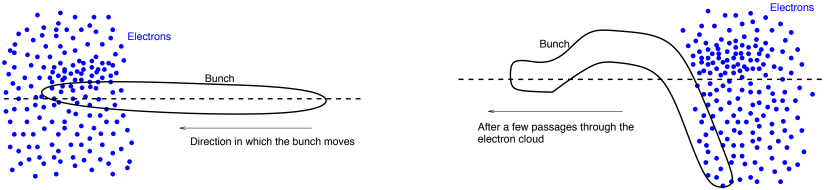
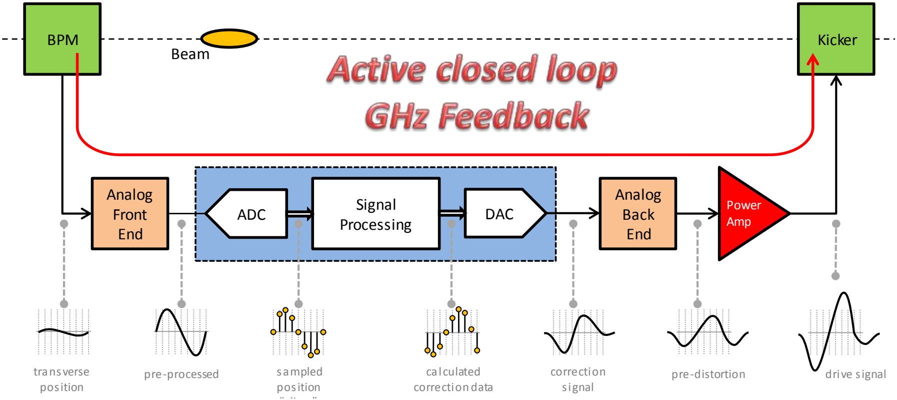
CERN SPS Ecloud/TMCI Instability R&D Effort



- 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

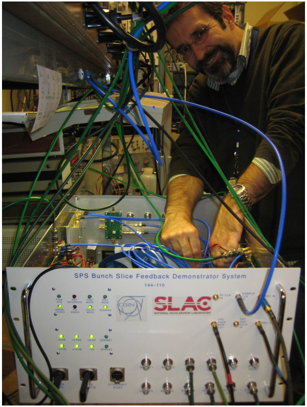


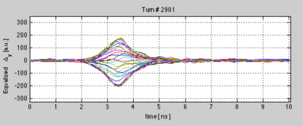
- Control of Non-linear Dynamics
- GHz Bandwidth Digital Signal Processing
- Optimal Control Formalism - allows formal methods to quantify stability and dynamics, margins
- Research Phase uses numerical simulations (HeadTail), Reduced Models, technology development, 1 bunch Demonstrator, SPS Machine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

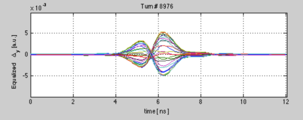
Progress since the 2013 Collaboration Meeting

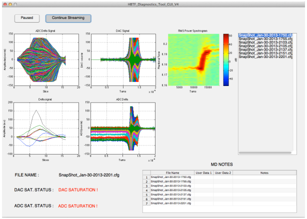
- Demonstrator hardware system
  - Noise Floor improvements
  - Robust timing re-synch
  - Power Amplifier evaluations, specification methods
- Nonlinear simulation codes/feedback model studies
  - Control Methods for Q20 SPS Optics
- Development of MD data analysis methods
  - Validate measurements against models
  - Reduced Model and Control design
- Development of wideband kicker designs
  - Conceptual design report July 2013
  - Mechanical design (Striplines), Fabrication of Stripline prototypes
  - Optimization of Slotline conceptual design for Fab after Stripline
- LARP DOE Project Review - FNAL February 2014
  - Multi-year project proposal with resource plans
  - Proposal to develop full-featured system for post LS2 SPS use
- FY14 priorities - expand Demonstration system for wideband operation, install proto kicker, after LS1 explore controllers and wideband kicker with beam. MD Data Analysis methods, Explore/validate Q20 control methods

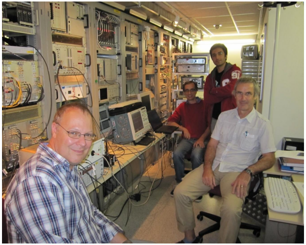
Beam Measurements, Simulation Models, Technology Development, Driven Beams and Demo System



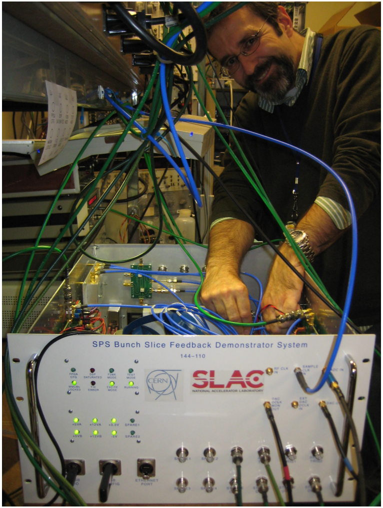


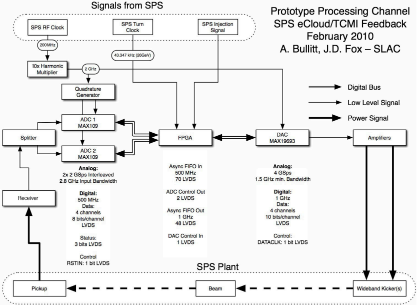






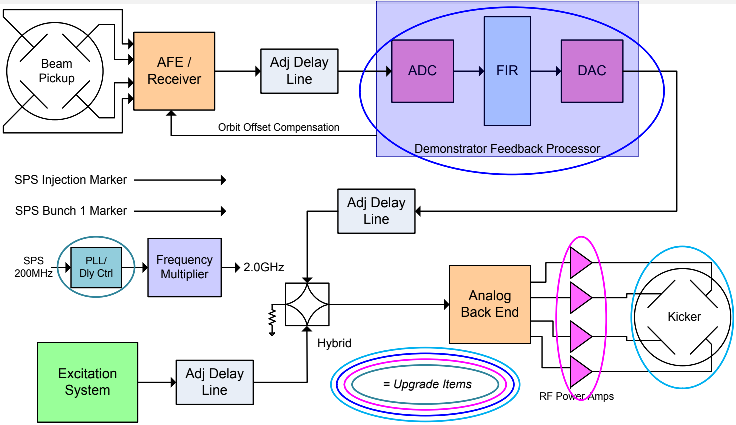
4 GS/s 1 bunch SPS Demonstrator processing system





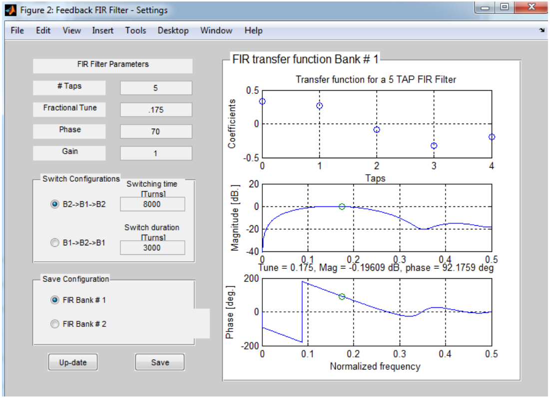
- Proof-of-principle channel for 1 bunch closed loop tests in SPS - commissioned November 2012
- Provides wideband control in SPS after LS1 (installation of wideband kicker)
- Reconfigurable processing - evaluate processing algorithms
- Platform to evaluate control methods and architectures

Upgrades to the SPS Demonstrator

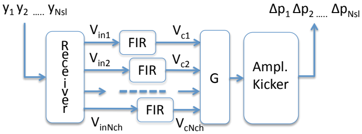


- Fall 2014 - Robust Timing re-synch
- Fall 2014 - New wideband stripline prototypes
- FY14 - Evaluate power amplifier options
- FY14 -FY15 Expand DSP capabilities to multi-bunch, synched excitation

Feedback Filters - Frequency Domain Design



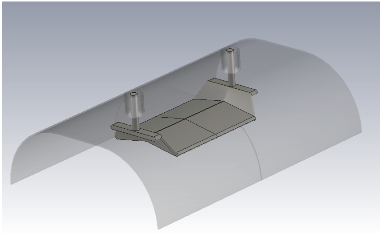
- FIR up to 16 taps
- Designed in Matlab
- Filter phase shift at tune must be adjusted to include overall loop phase shifts and cable delay

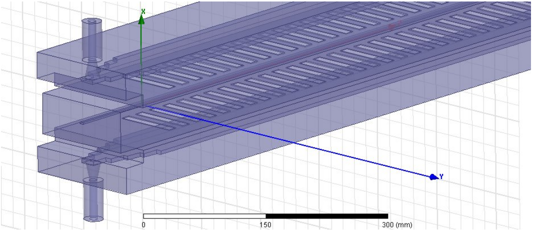


The processing system can be expanded to support more complex off-diagonal (modal) filters, IIR filters, etc as part of the research and technology development

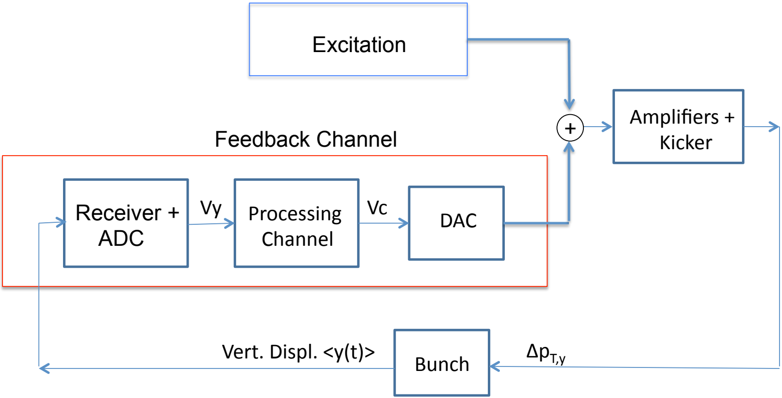
1 GHz wideband kicker development

- CERN, LNF-INFN, LBL and SLAC Collaboration. Design Report SLAC-R-1037
- Evaluate stripline array, overdamped cavity trio and slotline options.
- Reviewed July 2013 at the CERN LIU-SPS Review
- Decision - Stripline prototypes in fab , Slotline prototype in design based on electromagnetic simulations, shunt impedance, overall complexity, number of amplifiers and timing adjustments
- Collaboration: J. Cesaratto (SLAC), S. De Santis (LBL), M. Zobov (INFN-LNF), S. Gallo (INFN-LNF), E. Montesino (CERN), et al



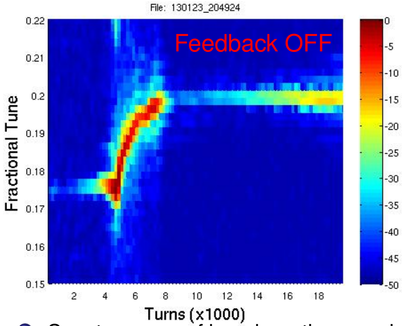


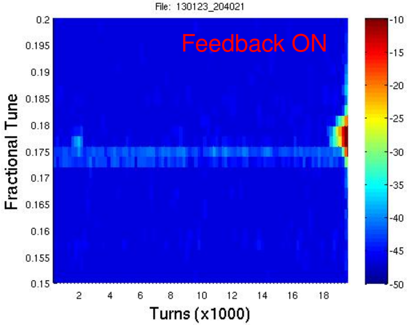
Measuring the dynamic system - open/closed loop



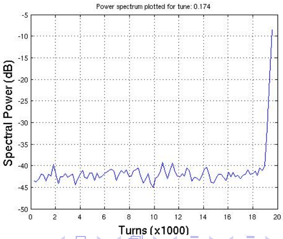
- We want to study stable or unstable beams and understand impact of feedback
- System isn't steady state, tune and dynamics vary
- We can vary the feedback gain vs. time, study variation in beam input, output
- We can drive the beam with an external signal, observe response to our drive
- Excite with 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



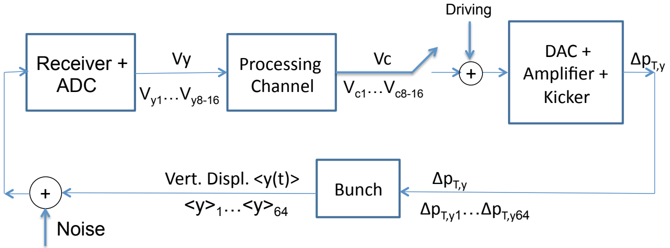


- Spectrograms of bunch motion, nominal tune 0.175
- After chromaticity ramp at turn 4k, bunch begins to lose charge → tune shift.
- Feedback OFF -Bunch is unstable in mode zero (barycentric).
- Feedback ON - stability. Feedback is switched off at turn 18K, beam then is unstable

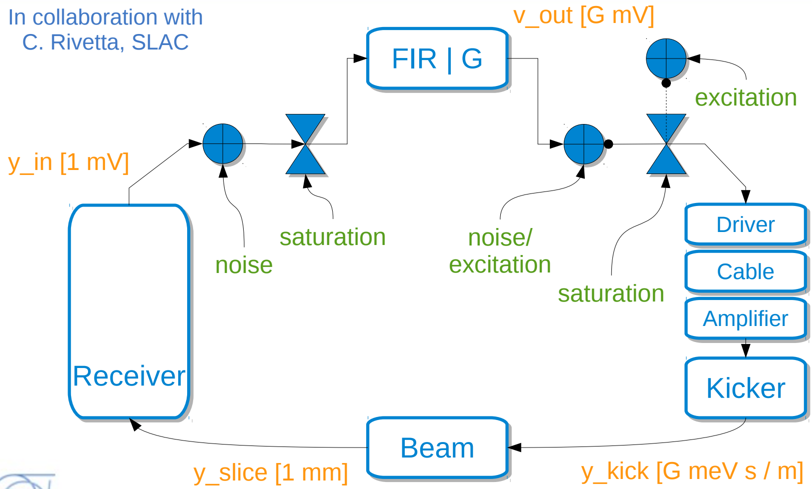


Progress in Simulation Models

- 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



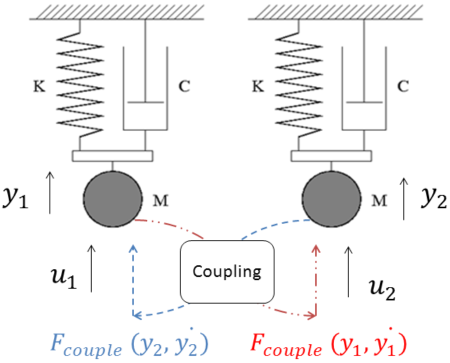
HeadTail Feedback Combined Model



Kevin Li

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

State Space coupled model - fit to measurements



$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ k + k_{couple} & -k_{couple} & c + c_{couple} & -c_{couple} \\ -k_{couple} & k + k_{couple} & -c_{couple} & c + c_{couple} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

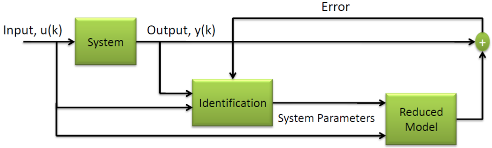
$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \dot{x}_1 \\ \dot{x}_2 \end{bmatrix}$$

$$\begin{aligned} \dot{X} &= AX + BU \\ Y &= CX \end{aligned}$$

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



Comparison of HEADTAIL with Reduced Model

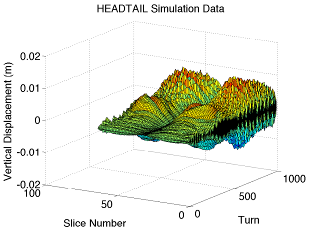


Figure: HeadTail Vert. Motion, Driven by 200 MHz, 0.144 - 0.22 Chirp, 1000 Turns.

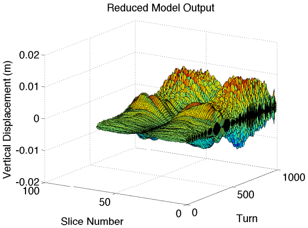


Figure: Vertical Motion of the Reduced Model.

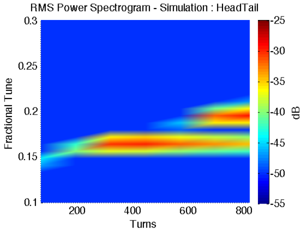


Figure: RMS Spectrogram of HEADTAIL Driven by 200 MHz Chirp Excitation

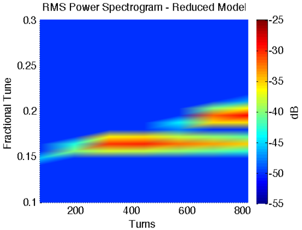
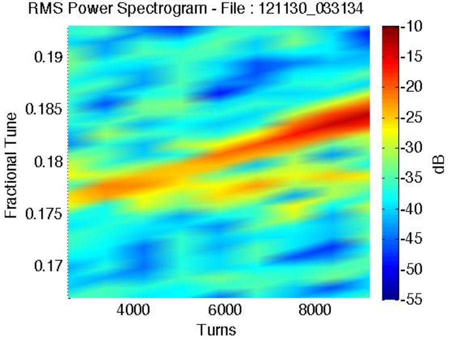
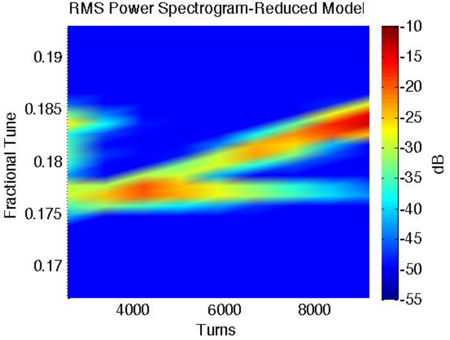


Figure: RMS Spectrogram of Model Driven by 200 MHz Chirp Excitation

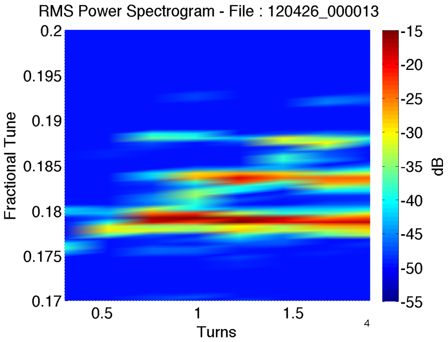
MD vs Model - open loop multiple mode excitations





- 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

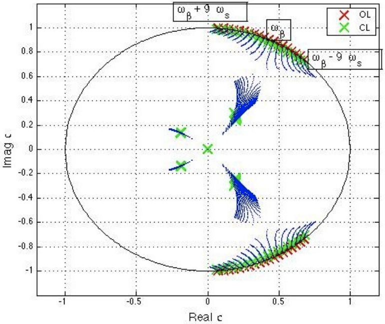
MD vs Model - open loop multiple mode excitations

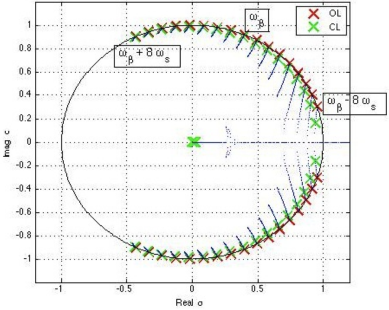


- Driven chirp- SPS Measurement spectrogram (left) Reduced Model spectrogram (right)
- Chirp tune 0.172 - 0.188 turns 2K - 17K
- 0.179 Barycentric Mode,Tune 0.184 (upper synchrotron sideband), 0.189 (2nd sideband)
- Model and measurement agreement suggests dynamics can be closely estimated using fitted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

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 $f_\beta = 0.185$, $f_s = 0.017$

FNAL LARP Internal Review Report June 2013

Wideband feedback systems

The R&D has shown significant progress in the last year, with a successful testing of the single-bunch prototype in the SPS

There is reasonable confidence that an extension of the demonstrated approach will fulfill the requirements of damping high frequency instabilities in the SPS. The general approach can be extended to solving similar problems in the LHC and PS.

#6 Are there additional comments the Committee feels are relevant, regarding either individual tasks or the project as a whole?
We suggest exploring collaboration with RHIC, which has similar instabilities for which it is pursuing feedback damping.

Installation of a prototype wideband kicker in the SPS before the end of LS1 is critical.

Report on the Review of the LIU-SPS High Bandwidth Transverse Damper System

CERN - July 30th 2013

This is the final report of the review committee for the LIU-SPS High Bandwidth Transverse Damper System held at CERN on July 30th, 2013.

Implementing a system capable of combatting electron cloud instabilities could significantly increase the scrubbing efficiency in the SPS. In addition it would ensure that the quality of beams destined for the LHC can be preserved from injection to 450GeV, possibly also allowing the preparation of doublet bunches for scrubbing the LHC. In view of this, the reviewers recommend that the second phase of this project, the construction and test of a multi-bunch high bandwidth transverse damper demonstrator, proceeds as quickly as possible, to allow a final decision on whether or not to build a fully functional system to be taken at the end of 2016.

Question 8: Are there deliverables or studies which need advancing in time, for example before the LARP construction decision?

The short term aim is clearly to get a working multi-bunch high bandwidth demonstrator operational in the SPS, even if this is using a reduced power kicker, a pick-up which is not suitable for the damping of doublet bunches and an electronics which cannot handle a full LHC bunch train. The knowledge gained from this will be invaluable for defining the architecture of the final system.

The two critical parameters which remain to be defined are the kick strength required and the bandwidth of the final system. Simulations and beam studies should therefore be targeted to give this input as soon as possible, as this choice will impact both the kicker type and electronic architecture.

- CERN Review (July 2013) - Impact of new SPS Q20 optics requires new controller design study and stability analysis. Additional work added to original scope of effort

U.S. DEPARTMENT OF ENERGY | Office of Science

2014 Annual Review
of the
LHC Accelerator Research Program

- **The quality and significance of the LARP scientific and technical accomplishments, and the merit, feasibility and impact of its planned development program;**
  - The WBF has made substantial accomplishments with efficiency capitalizing on extant expertise at DOE national laboratories. This work is very much appreciated and encouraged by CERN.
- **What will be the demonstration of these goals? and; The effectiveness and appropriateness of the laboratory interactions to maximize the leveraging of existing infrastructure and expertise available at those laboratories.**
  - This is good example of DOE national lab expertise being used to make substantial contributions on the world stage.
- **The Wide Band Feed Back team has achieved substantial success and has delivered a one bunch feed back system.**
- **Given appropriate funding, they will with high probability deliver the necessary hardware in the appropriate time frame.**
- **Extension to include an LHC WBFS may be natural in the future.**

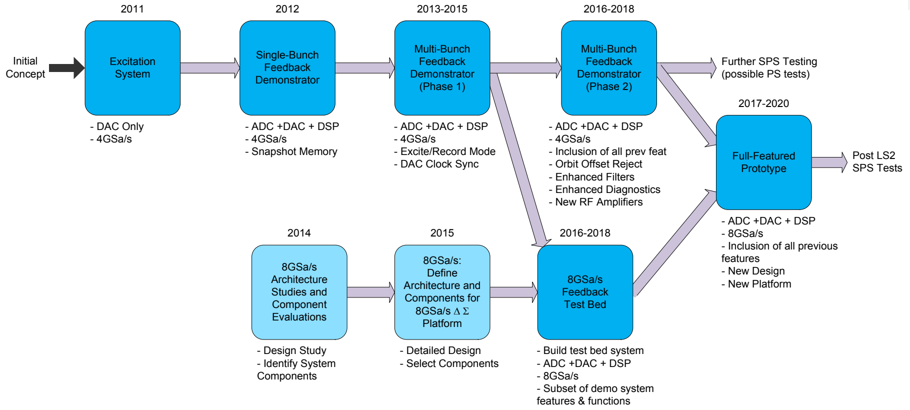
FY2014 Development path - Research Areas

- During LS1 shutdown interval
- Expand Demo system
  - Wideband Kicker Prototype for SPS Installation LS1 (CERN fabrication)
  - Improve Timing synchronization to the SPS RF system,
  - Expand firmware, incorporate tools for analysis
- Evaluate wideband RF Amplifiers, purchase 2 if funded
- 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
- Prepare for SPS re-start and next round of beam studies starting fall 2014

FY2015/2017 Research , Technology path

- MD measurements with wideband DEMO system (SPS beam time and analysis)
  - 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 options for Kickers (wideband? dual band?) and upgrade tunnel High-Power wideband RF amplifiers for SPS operation
- Technology Development and system estimation for Full-function system
  - Wideband 20 - 1000 MHz RF power amplifiers, with acceptable phase response
  - Slotline Kicker protype tests
  - RF amplifier aquisition and support for SPS tests
  - 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
  - estimation of possible bandwidths, technology options for deliverable

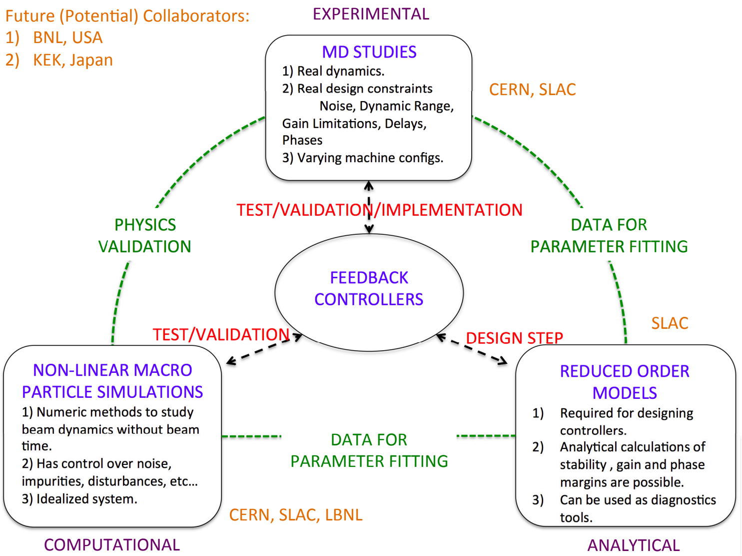
Upgrades to the SPS Demonstrator - Roadmap



- 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

Multi-Lab Collaboration

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



Acknowledgements and Thanks

- We cannot adequately acknowledge the critical help from everyone who made the winter 2012 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

Work supported by DOE contract DE-AC02-76SF00515 and US LARP program

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

Demonstration 1 bunch processor

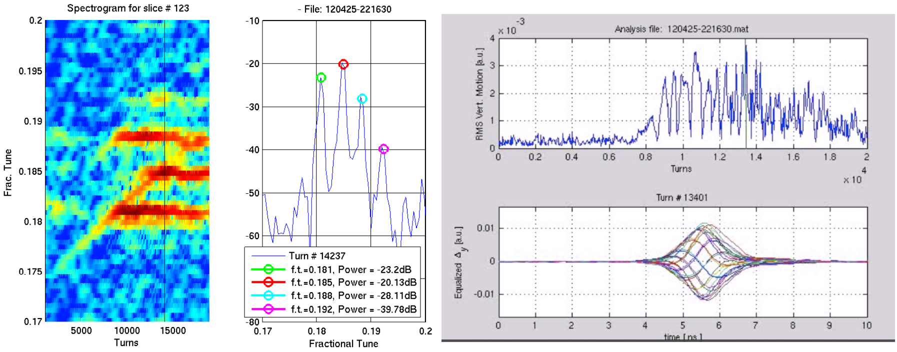
- Synchronized DSP processing system, initial 1 bunch controller
- Implements 16 independent control filters for each of 16 bunch “slices"
- Sampling rate 4 GS/s (3.2 GS/s in SPS tests)
- Each control filter is 16 tap FIR (general purpose)
- A/D and D/A channels
- Two sets of FIR filter coefficients, switchable on the fly
- Control and measurement software to synchronize to injection, manipulate the control filters at selected turns
- Diagnostic memories to study bunch motion, excite beams with arbitrary signals - Key feature for beam diagnostics and analysis
- Reconfigurable FPGA technology, expand the system for control of multiple bunches
- What’s missing? A true wideband kicker. Technology in development. These studies use a 200 MHz stripline pickup as a kicker

MD Results, technology and data analysis

- 2009 - 2012: MD studies of open-loop unstable motion, development of analysis methods, technology development of excitation system and in-tunnel amplifiers, limited bandwidth kicker, driven studies
- 2012 - 2013: MD trials (November, January, February) implement one-bunch feedback control (with 200 MHz bandwidth kicker)
  - 5 and 7 Tap FIR filters, gain variations of 30dB, Φ varied postive/negative
  - Studies of loop stability, maximum and minimum gain
- Driven studies (Chirped excitations)
  - variation in feedback gain, filter parameters
  - multiple studies allow estimation of loop gain vs frequency (look at excitation level of several modes)
  - interesting to look at internal beam modes
- Feedback studies of stable, marginally stable and unstable beams
- Analysis methods to validate feedback performance, validate models

Chirp excitation in represented in frequency and time domain

- same data, two complementary analysis methods
  - Excitation methods (chirps, random, selected modes)
  - mode-specific shaped temporal excitations
  - ability to clearly excite through mode 4



Research and Technology Timeline

2013 - 2014	2015 - 2016	2017 - 2018 - 2019	2020
Demo Prototype Kicker Report/Fab Expand Prototype Beam – Feedback Simulations	Demo Prototype Studies Full-Function Studies/Develop. Beam – Feedback Simulations	Full-Function Wideband Feedback Design-Fabrication Beam – Feedback Simulations	System Tests

2013 - 2014
- Demo Commissioned
- MDs Jan.-Feb. 2013
- Kicker Design, Fabrication and Installation
- Data Analysis, Models and Simulation Tools
- Expand Hardware Capability
- MDs with new Hardware

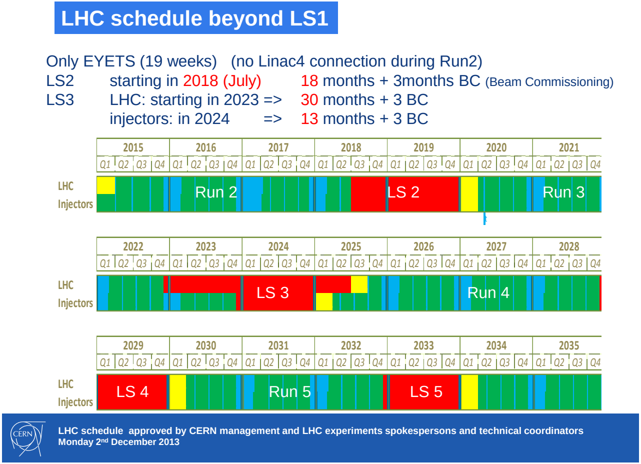
2015 - 2016
- MDs with new hardware
- Multi-bunch operation
- Data analysis, models and simulation tools
- System specifications and capabilities
- Full-function Wideband Feedback Technology Development.

2017 - 2018 - 2019
- Full-Function Wideband Feedback Design-Fabrication
- Continue MD studies
- Validate Energy Ramp
- Analysis, models and simulation tools

2020
- System Integration
- Full interface with CERN Control Room
- Estimation of System Limits and Performance
- LHC? PS? SPS?

- Essential goal - be ready at end of LS2 with full-function system ready to commission
- SPS upgrade after LS2 (new injector, higher currents, new operational modes)
- We must use the demo system, MD time post LS1 to validate control ideas, validate kicker and technical approach. Full Function is only 1 design iteration away from Demo System

CERN HL Plan, Feedback is needed after LS2



- SPS upgrade after LS2 (new injector, higher currents, new operational modes)
- Essential Feedback goal - be ready at end of LS2 with full-function system ready to commission
- Wideband Feedback is different from other LARP projects - it is needed after LS2

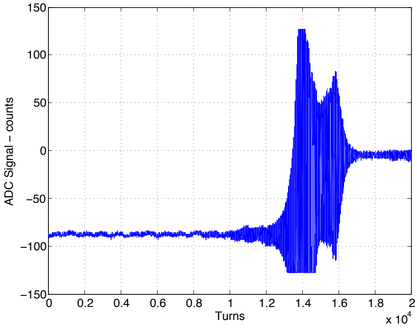
Planning a Realistic Feedback Test MD

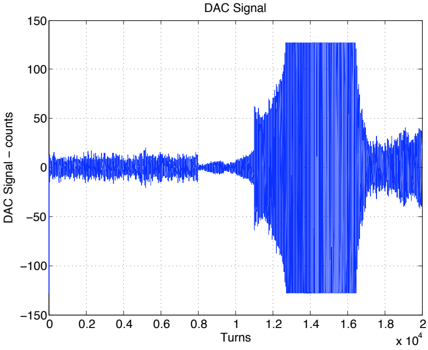
- We are working on MD plans to test this system
- "Do Feedback on Unstable Beams" - is not the first test!
- The main goal is to use this minimum hardware to quantify the impact of the feedback channel in the beam dynamics
- Validate operation of the system through measurements on single-bunch stable beams
- Timing and synchronization
  - As for Excitation, setting up consistent timing of front-end, back-end is critical
  - Use excitation methods to time back-end data stream and beam
  - Working on codes to time front-end data path to beam and define the overall phase of the closed loop system

Planning a Realistic Feedback Test MD, II

- 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, ideally use snapshot memory of ADC data stream, read via PC interface, MATLAB offline analysis.
- To drive the beam, use either the excitation system or the intrinsic capability of the feedback prototype channel.

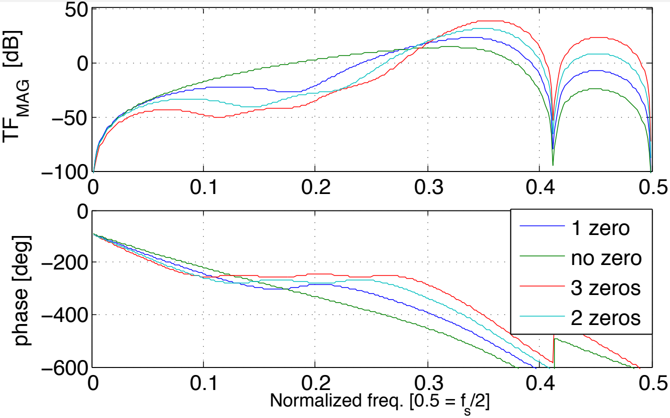
Unstable beam -Input, Output signals via snapshot





- Example of gain reduction during stable control, loss of control after gain restoration 3k turns later. Transient deserves more complete analysis.
- Mode zero unstable beam
- Gain modulated $\times 8$-$\times 2$-$\times 8$ during cycle
- For turns 0-8k, 8k-11k, 11k-end
- Input (left), DSP output (right) Note gain of filter,DC suppression and saturation

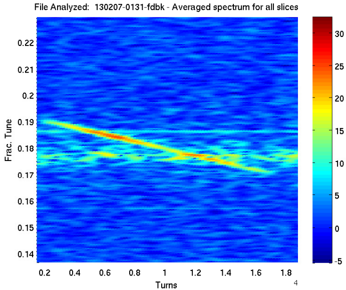
Example Q20 IIR control Filters

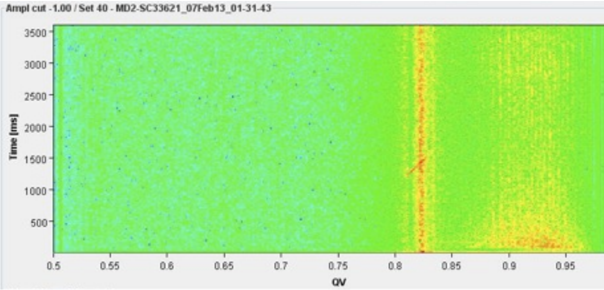


- Q20 optics has much higher synchrotron tune (0.017)
- Impact - much wider control bandwidth
- filters with flat phase response have high gain above the beam motion frequencies - add noise
- Technical direction - Explore multi-pickup sampling (higher effective Nyquist limit, better rejection of noise)

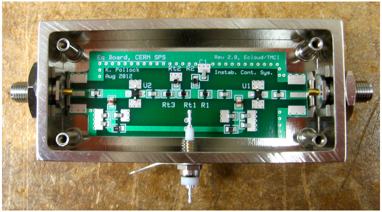
Wideband Feedback - Beam Diagnostic Value

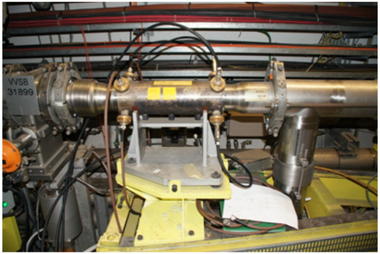
- processing system architecture/technology
  - reconfigurable platform, 4 - 8 GS/s data rates
  - snapshot memories, excitation memories
  - applicable to novel time and frequency domain diagnostics
  - Feedback and Beam dynamics sensitive measure of impedance and other dynamic effects
- Complementary to existing beam diagnostic techniques



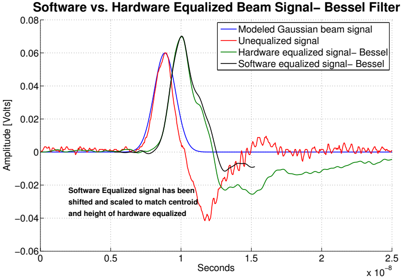


Hardware Equalizer





- Pickup response distorts beam signals
- Long cables also have nonlinear phase response
- Existing software equalizer used in matlab data processing
- we need a real-time (hardware) equalizer for processing channel
- Optimzation technique - can be used for kicker. too



Feedback algorithm complexity and numeric 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.

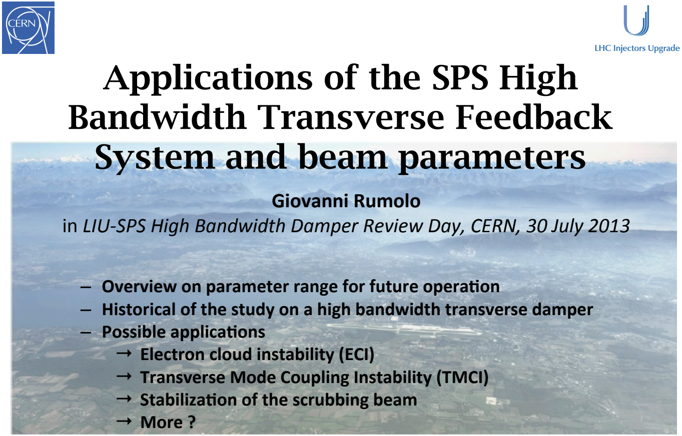
- 1 sample/bunch per turn, 5120 bunches, 16 tap filters, 99 kHz revolution frequency .

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.

Wideband Feedback - Benefits for HL LHC

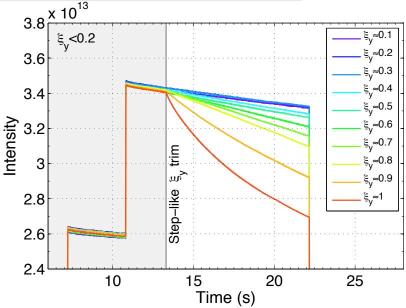
- CERN LIU-SPS High Bandwidth Transverse Damper Review
- Multiple talks, on impacts of Ecloud, TMCI, Q20 vs. Q26 optics, Scrubbing fill, etc.
  - Particular attention to talk from G. Rumolo



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

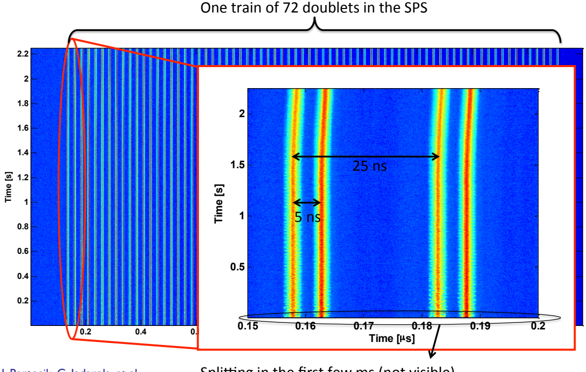
Effect of chromaticity on the lifetime of the 25ns beam in the SPS (2012)



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.