4 Ideas for Activities at DAFNE-TF

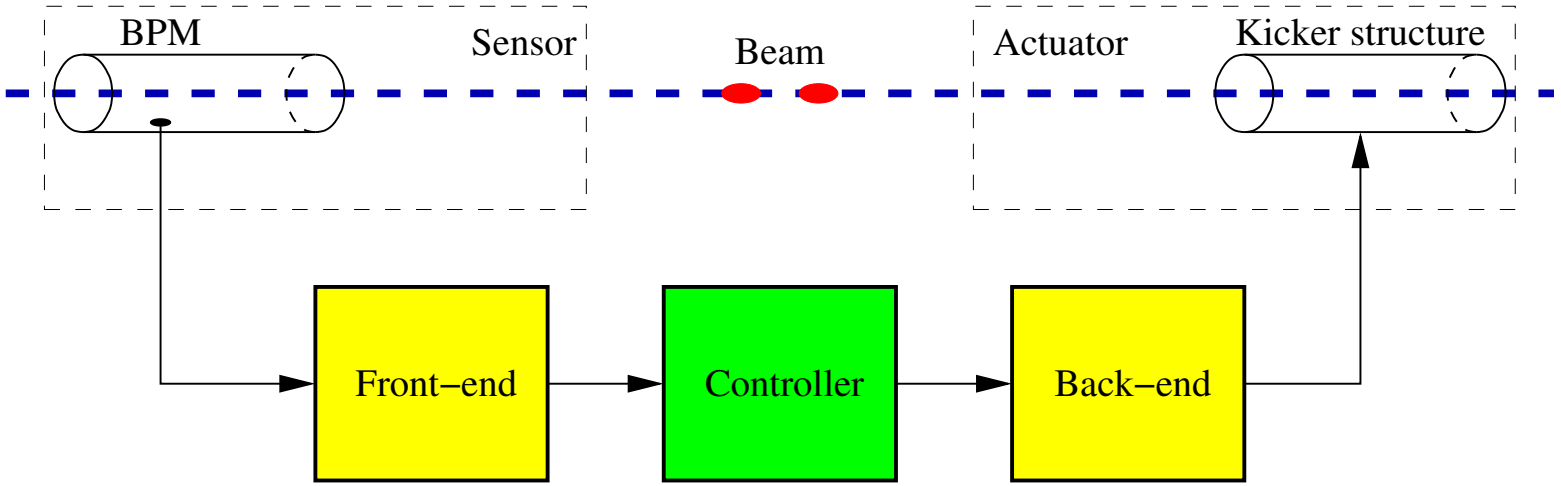
Ideas and Motivations for Discussion

A. Drago, J. Fox, S. Gallo, W. Hofle, D. Teytelman, M. Tobiyama

4 Theme Areas

- High-gain Transverse Instability Feedback Control Methods
  - Motivated by FCC, overcome limits of existing architectures
- Novel Tune and Beam Diagnostics
  - characterize, quantify several methods
  - Passive (closed loop spectra), active (chirps, phase locked excitations)
- Next-generation Wideband Kicker structures
  - Motivated by HL-LHC and FCC
  - expand SPS 1 GHz intra-bunch kicker -> 4+ GHz
  - lab tests and beam evaluations
- hands-on Beam Instrumentation and Feedback School
  - train the next generation of Accelerator Scientists and Engineers
  - In-residence school, expands role of USPAS, CAS, JUAS, AAS, etc.
- Slides are to inspire active discussion and brainstorming
- Utilize the unique aspects of DAFNE and beam availability

High-gain Transverse Instability Feedback Control

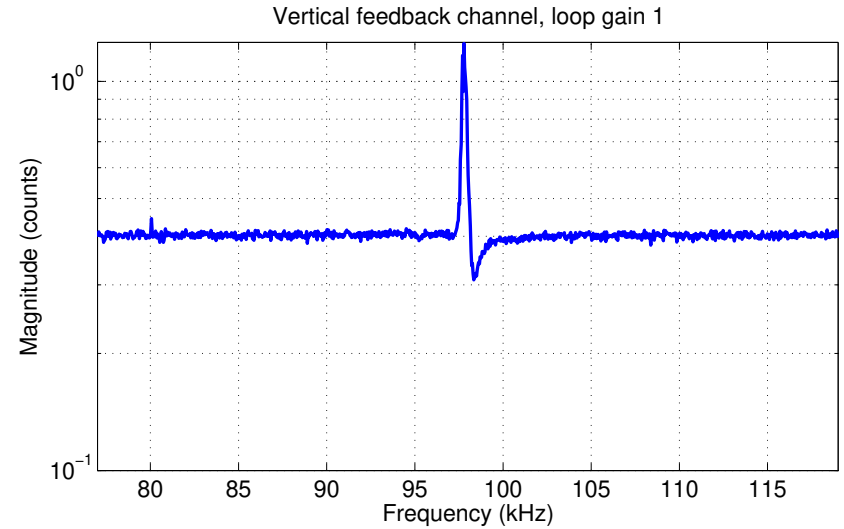


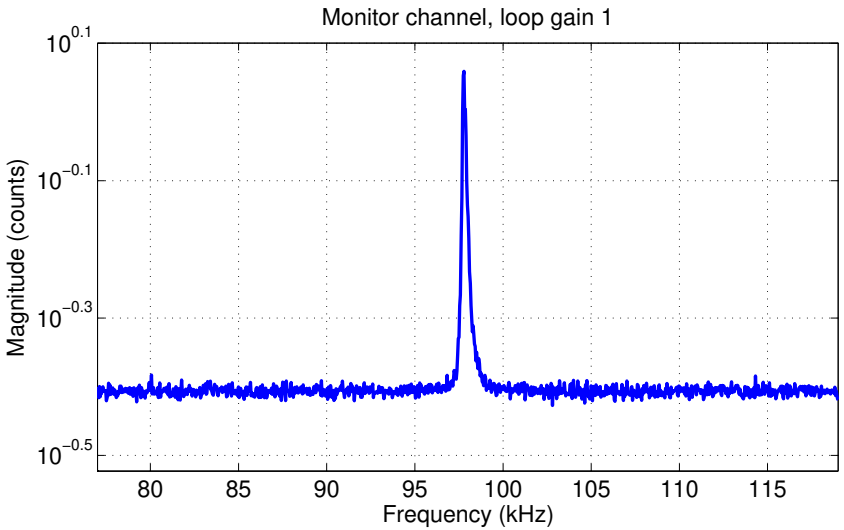
- Explore new techniques required by FCC and high-gain situations
  - Motivated by Noise and Group Delay limitations of of existing schemes
- Develop architectures with multiple pickups
  - reduce noise in channel
  - high gain with single turn of latency
- Can we develop of new processing hardware at DAFNE-TF, for targeted use at FCC, other facilities?

Limitations on feedback gain (achievable damping rates)

- For any causal feedback technique, the system gain and bandwidth are limited
- Gain is partitioned between pickup, receiver, DSP, RF amplifiers and kickers
- for FIR or bandpass filter, 2 gain limit mechanisms
  - Group delay/bandwidth gain limit - phase/gain margins lost as gain is increased, drive instabilities
  - Noise saturation limit - input noise$*$gain saturates kicker
- Impacts of injection transients, driven signals within the system filter bandwidth
- Do we see these limits in operating systems?

Averaged Bunch Spectra vs. Feedback Gain [1]





- Two independent channels monitoring vertical motion, one in the feedback loop, one out of the loop;
- Roughly similar sensitivities, 250 mA in 1000 bunches;
- At low feedback gain a visible residual motion line due to ion excitation;
- Double the feedback gain;
- Again;
- Again;
- Once more;
- A wider bandwidth comparison.

[1] Measurements courtesy of Weixing Cheng of NSLS-II.

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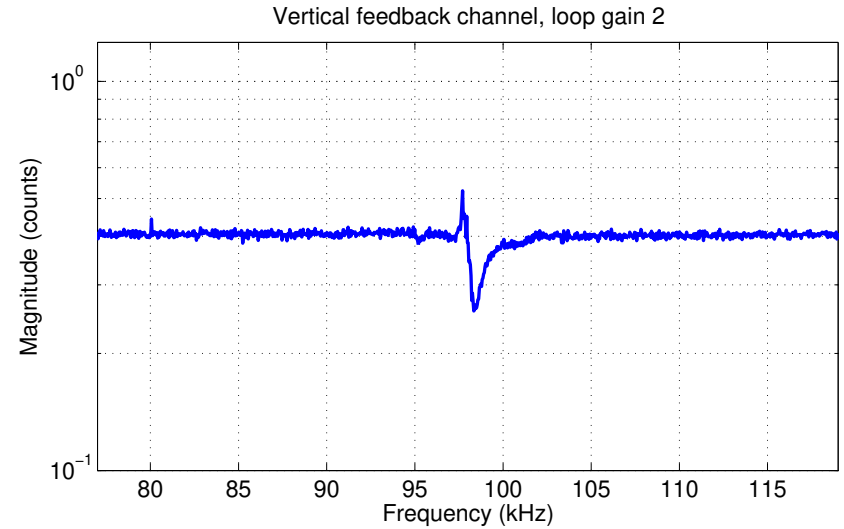

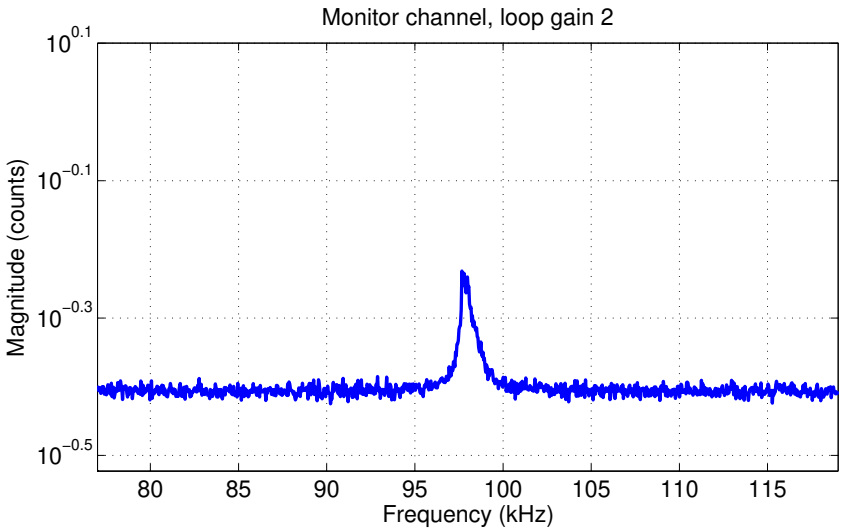

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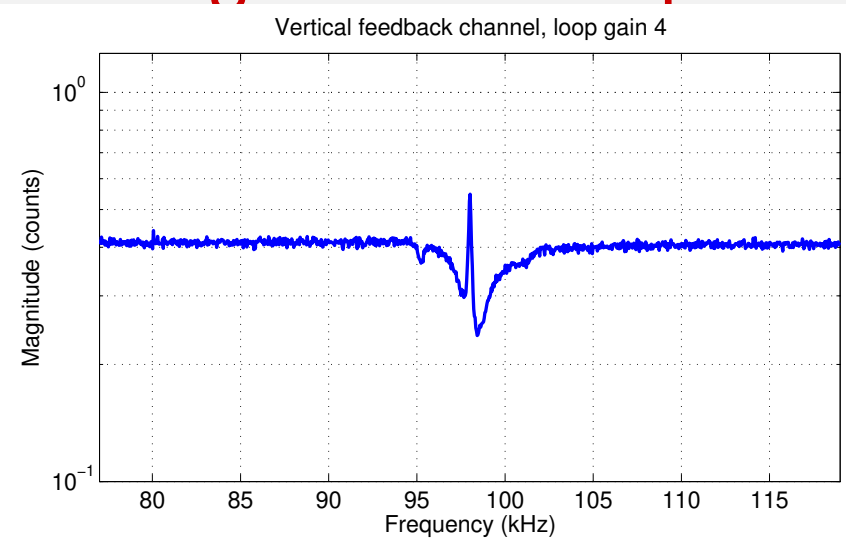

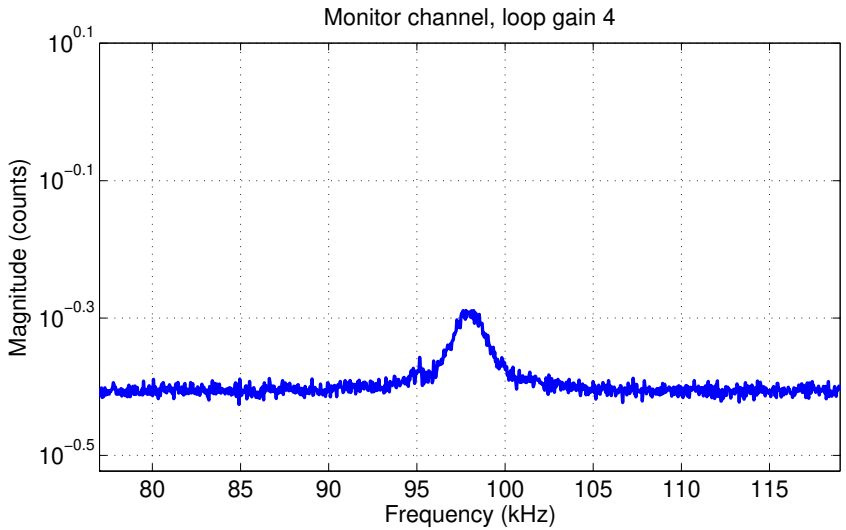

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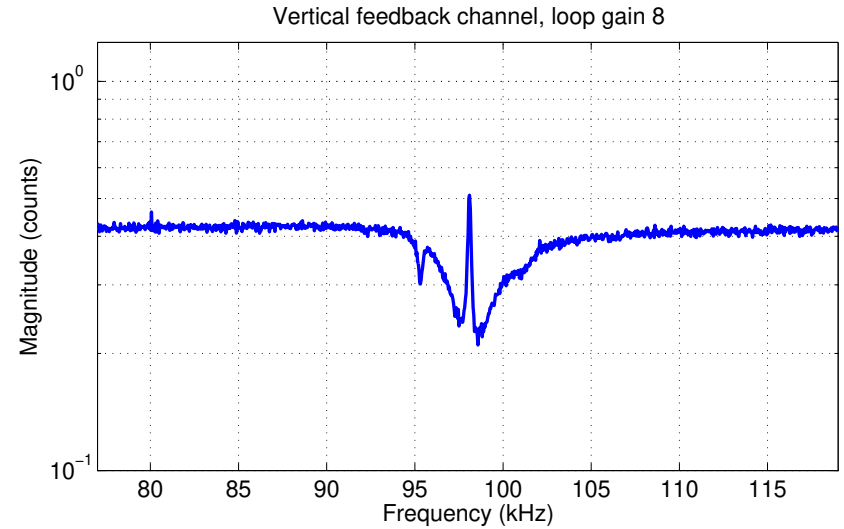

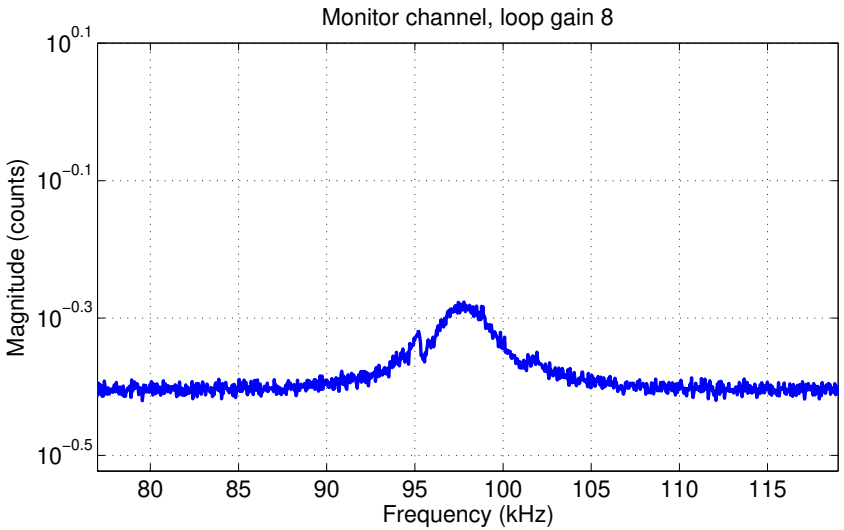

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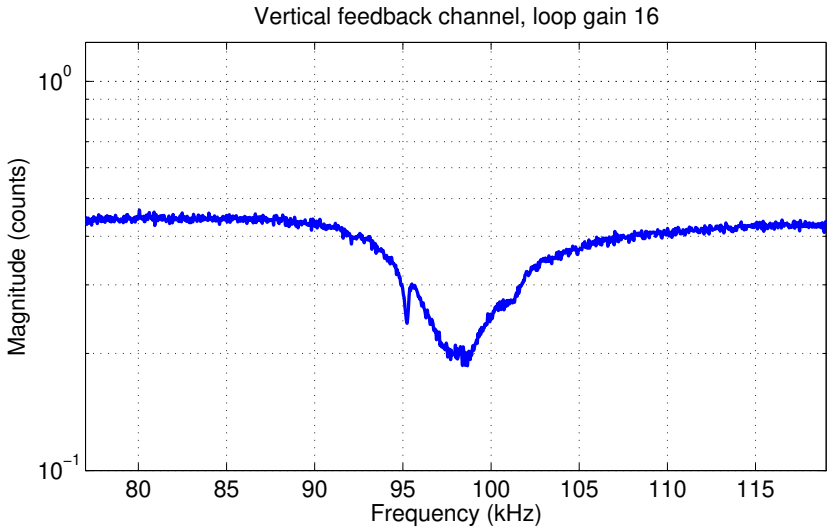

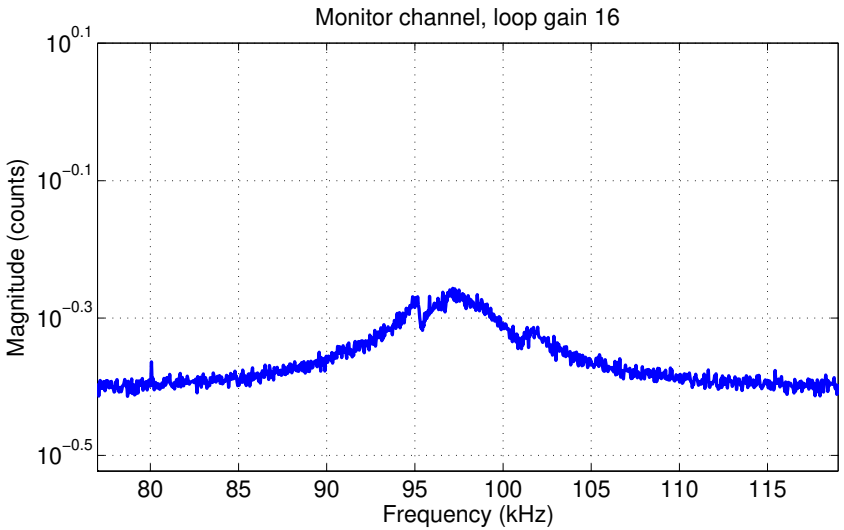

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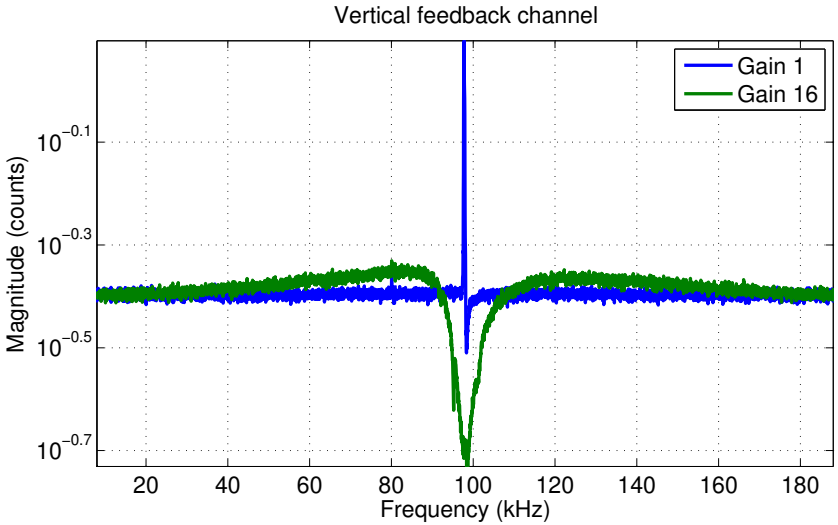

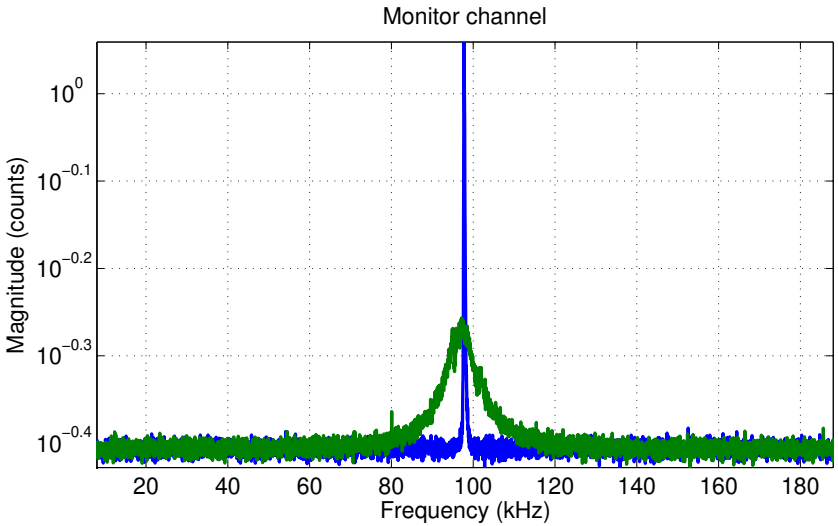

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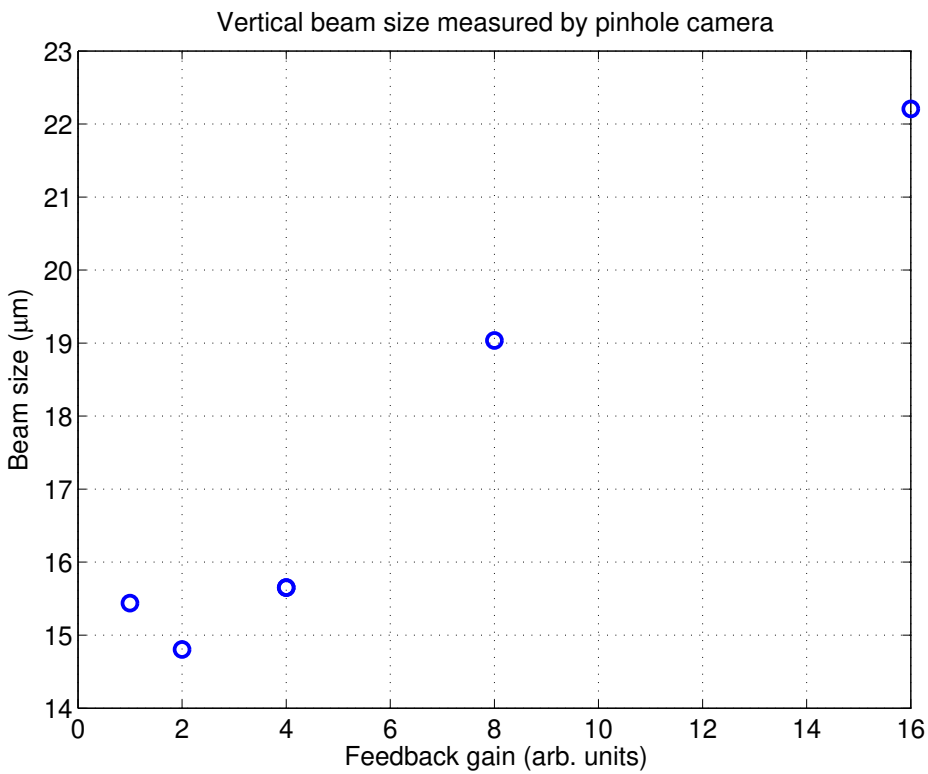
Beam Size vs. Feedback Gain [2]



- Vertical beam size measured by a pinhole camera;
- A superposition of true beam size and residual dipole motion;
- Vertical emittance, calculated from pinhole camera data;
- Beam lifetime is correlated with beam size measurements, suggesting vertical size blow-up;
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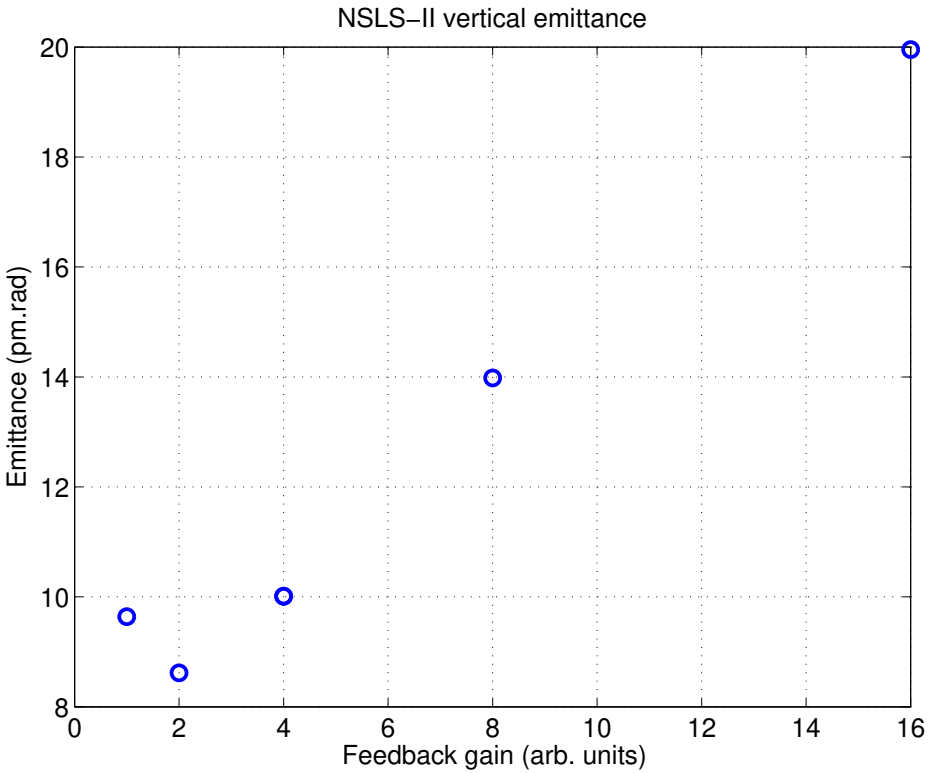

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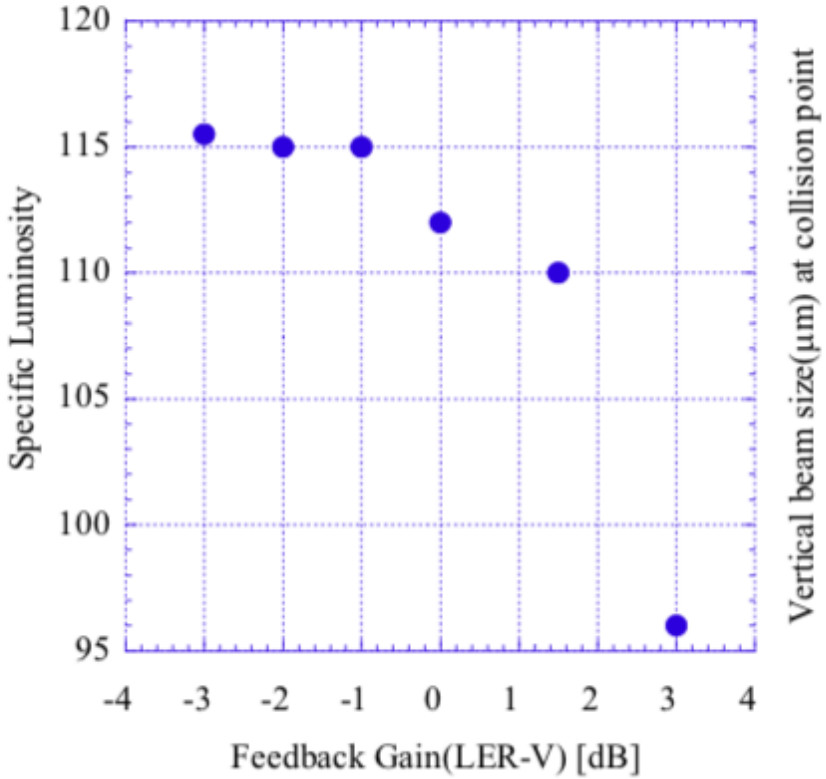
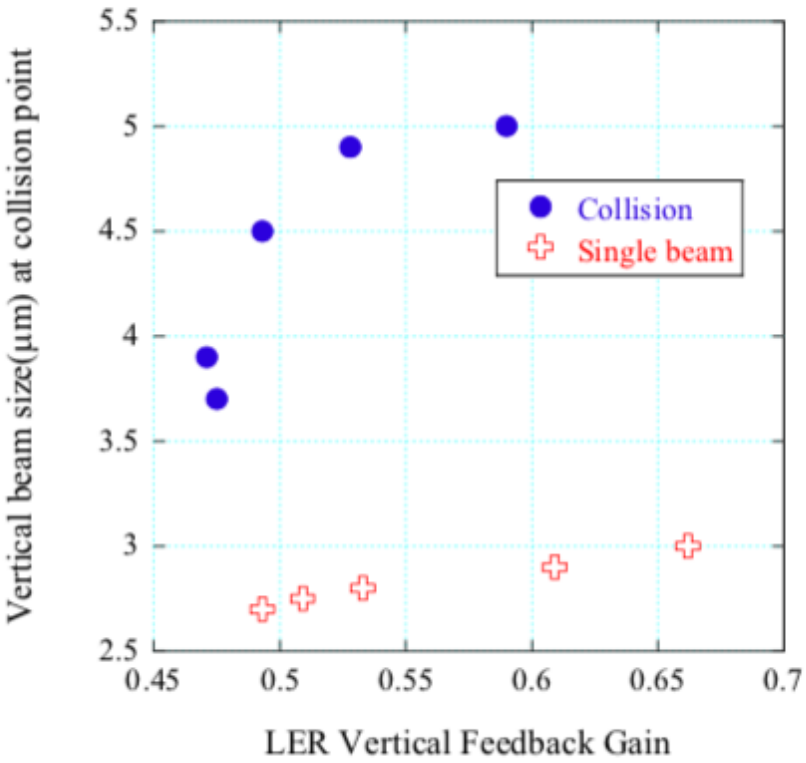
Impacts of feedback noise in beam collision

MOPD73 Proceedings of DIPAC2011, Hamburg, Germany

STUDY OF BEAM SIZE BLOWUP DUE TO TRANSVERSE BUNCH FEEDBACK NOISE ON e^+ e^- COLLIDER*

Makoto Tobiyama# and Kazuhito Ohmi,
KEK Accelerator Laboratory, 1-1 Oho, Tsukuba 305-0801, Japan.





- Discovery of luminosity decrease in KEKB collider, function of vertical feedback gain

KEKB collider Impacts of feedback noise

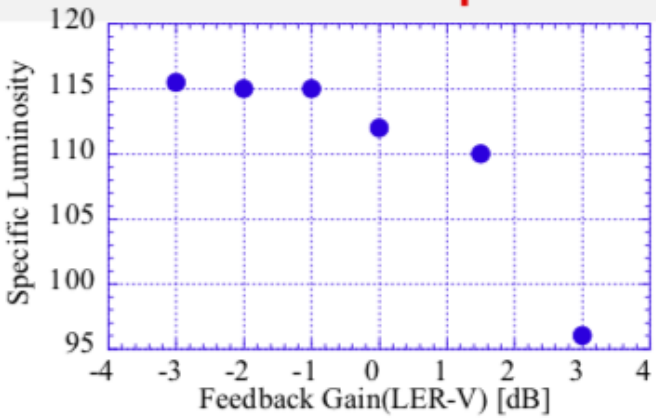


Figure 1: Luminosity reduction with the KEKB-LER vertical feedback gain.

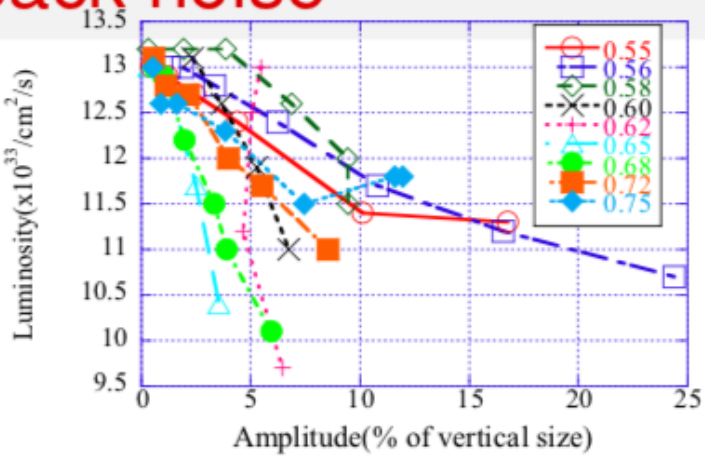
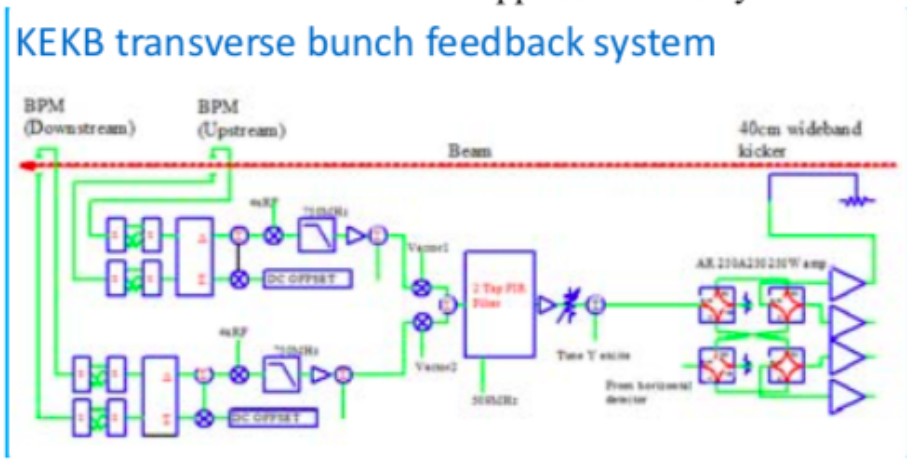


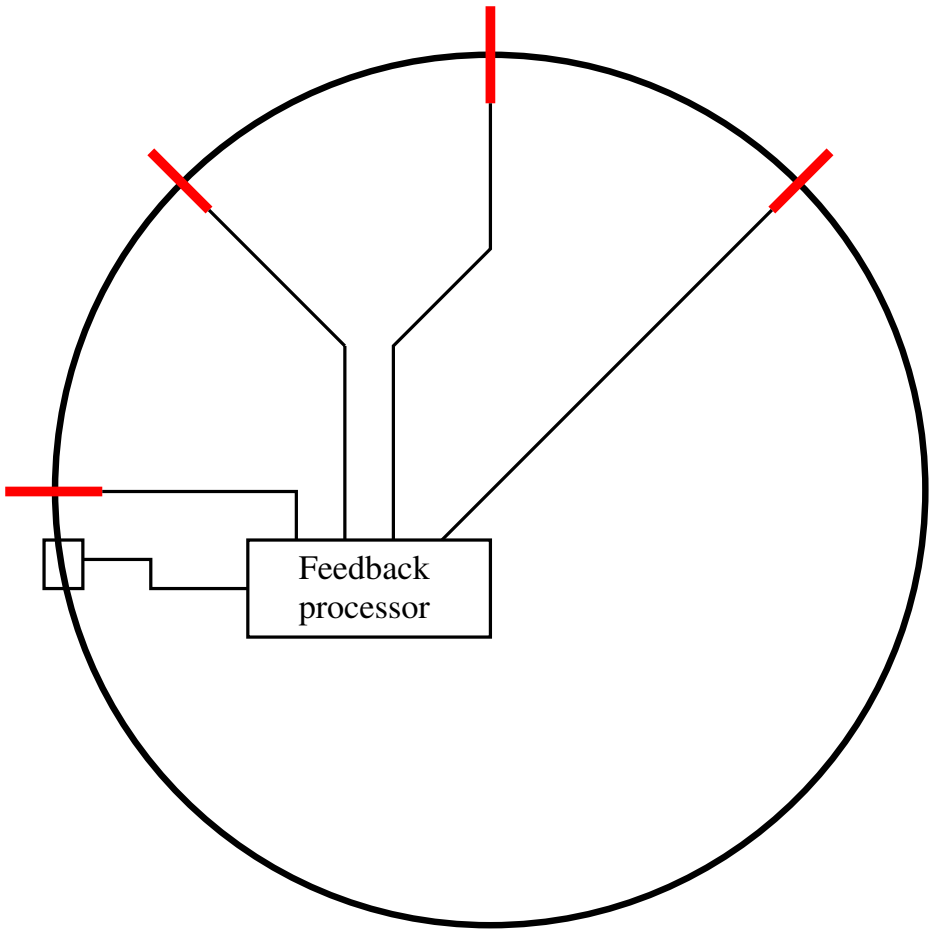
Figure 5: Luminosity degradation due to oscillation applied externally in the feedback system.



- Beam-Beam effect in collision amplifies noise in feedback system
- Understood via simulations and verified with noise injection into system
- Original KEKB vertical system used 2-tap filter, no processing gain. All noise folded into processing channel. SuperKEKB systems expanded with feedback filters

High-gain Transverse Instability Feedback Control

- Explore new techniques to overcome noise and group delay limits
- multiple pickups (unique betatron phases)
  - reduce noise in channel - $\sqrt{N}$
  - high gain with single turn of latency - filter computation in 1 turn

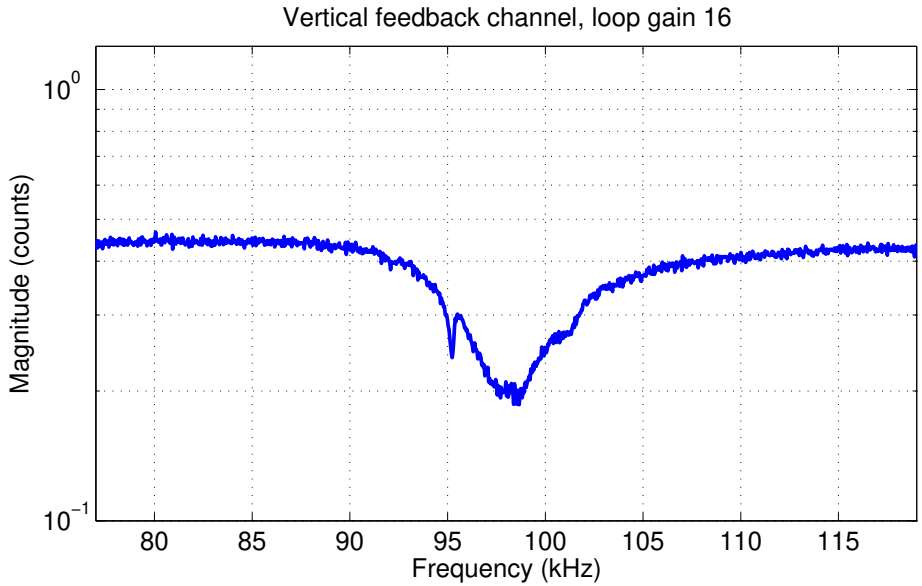


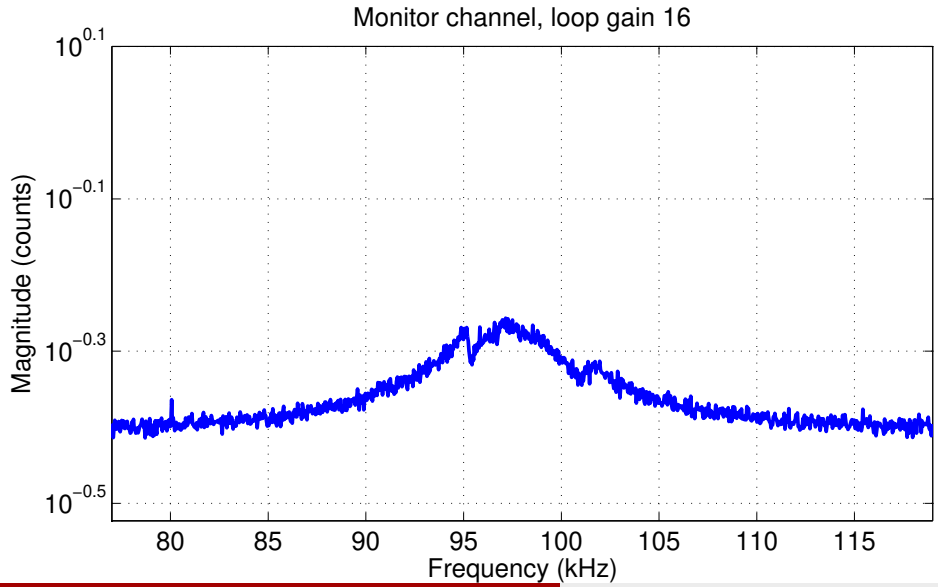
- Scale could be modest, add several new pickups to existing processing, new firmware
- With resources, entirely new processing platform
- Can we demonstrate new processing hardware at DAFNE-TF, for targeted application at FCC, other facilities?
- Multiple Kickers, at unique β possible too

Novel Tune and Beam Diagnostics

- Expand on methods developed to use information within feedback signal processing
- Lots of information on tune, tune modulations, beam-beam tune shifts, nonlinear tune shifts with amplitude, etc.
- Careful expansion of ad-hoc tools, with beam studies and technique refinements
  - closed-loop noise spectra
  - Spectral chirps within feedback channel
  - spectrally-tailored excitations
  - closed loop phase tracking
- Benchmark tools for regions of applicability
- Determine sources of systematic error
- Develop more consistent, accurate beam diagnostic tools
- Potentially new and novel methods
- Report on suite of methods, best applications

Tune measurement via in-loop noise spectra

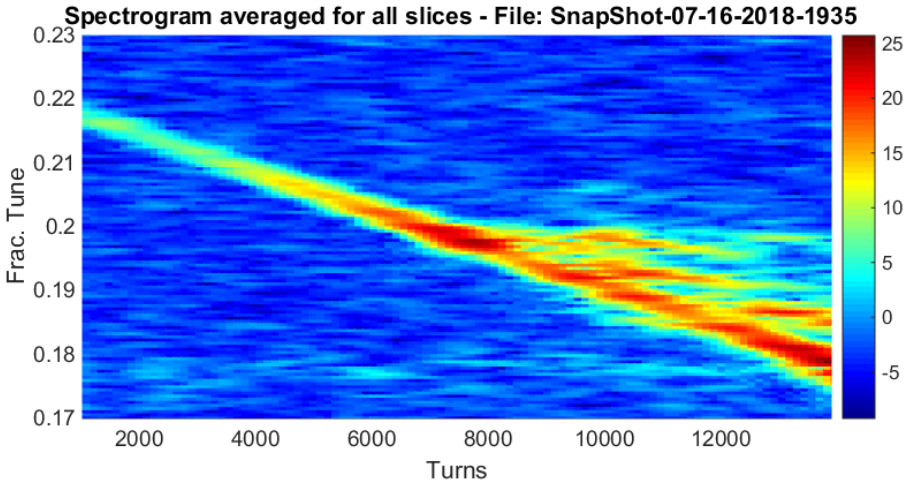


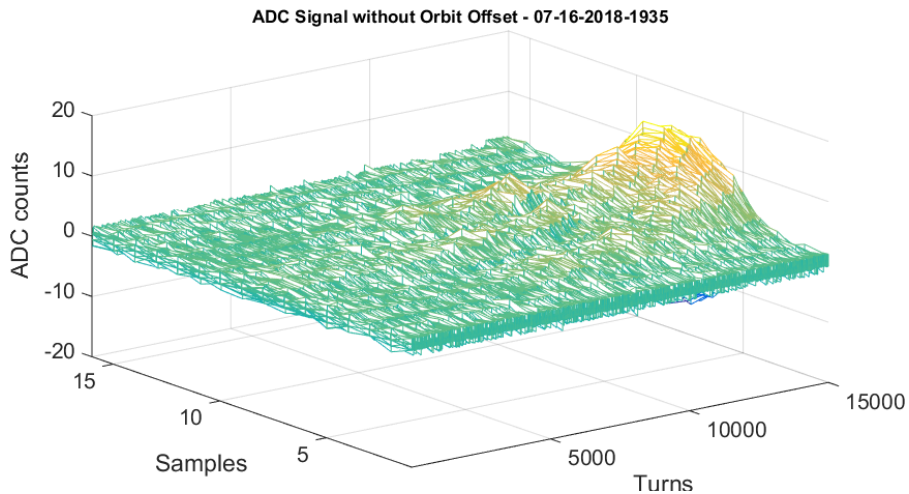


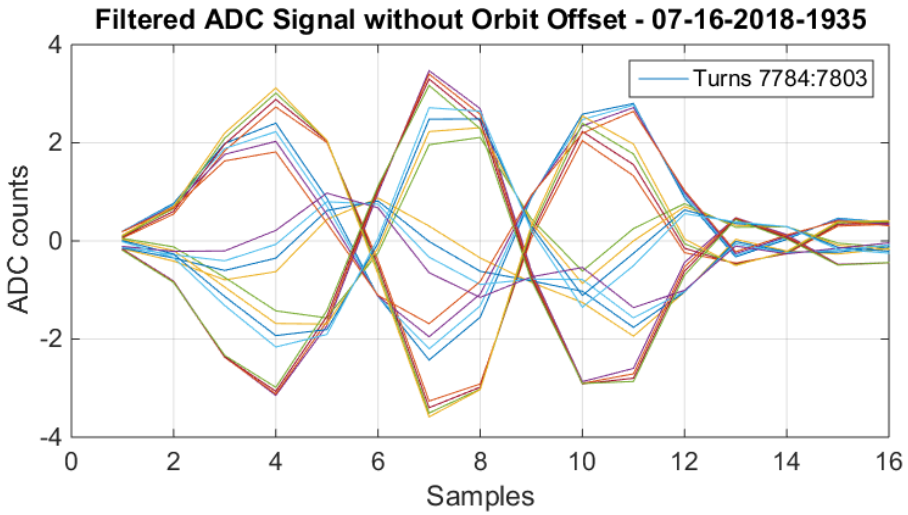
- loop gain is highest at tune resonance, so noise is minimized
- at high gains broad damped structure - what is tune?
- methods to fit response to beam model
- can also measure open-loop noise spectra (helps if reactive feedback)

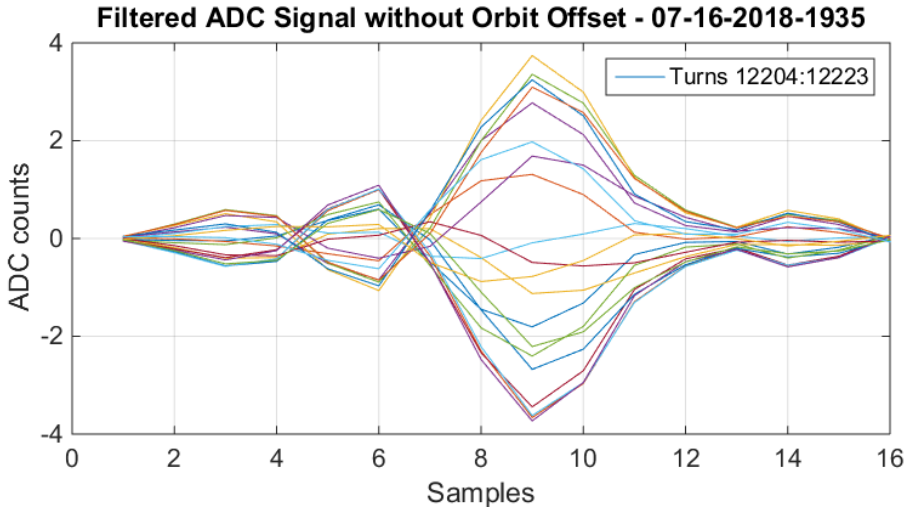
Beam excitations via chirps within feedback channel

- example from SPS shows 4 intra-bunch modes, tunes via spectrograms

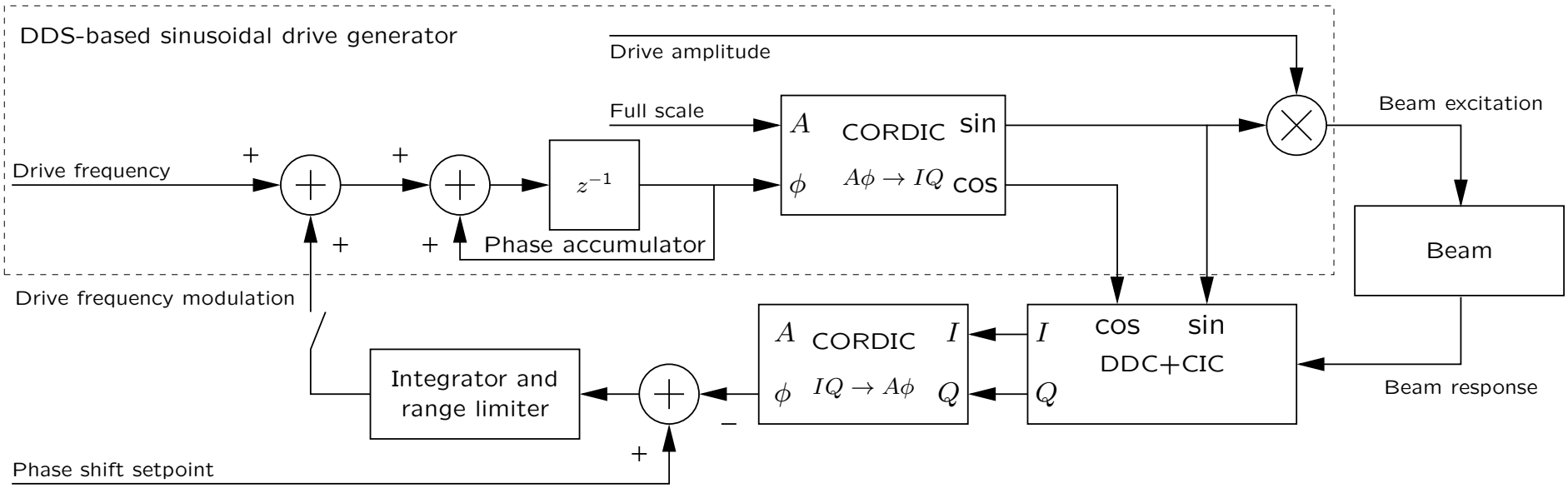






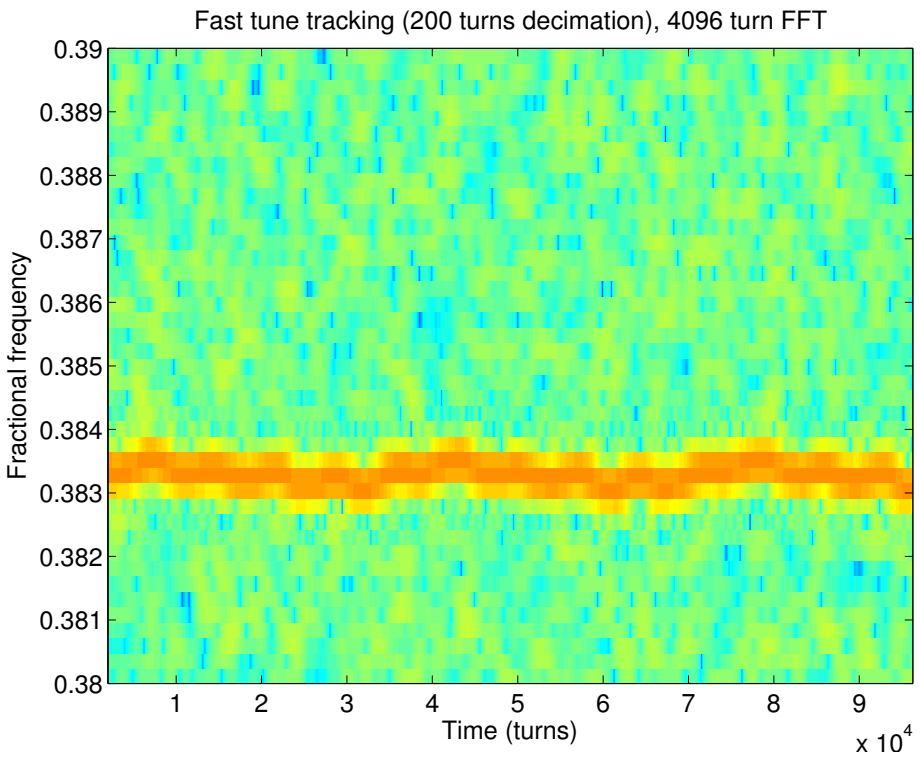


Single Bunch Phase Tracking



- A single bunch is excited with a sinusoidal excitation at low amplitude (20–40 μm);
- Response is detected relative to the excitation to determine the phase shift
- In closed loop, phase tracker adjusts the excitation frequency to maintain the correct phase shift value;
- Adjustable integration time, tracking range, loop gain.

Fast Phase Tracking



- Decimation factor in phase tracker controls tracking bandwidth;
- 200 turns decimaton, 1.77 kHz measurement bandwidth;
- 180 Hz closed loop tracking bandwidth;
- Use time-domain downconversion to better resolve tune modulation;
- Spectrum shows lines at 10 and 50 Hz.

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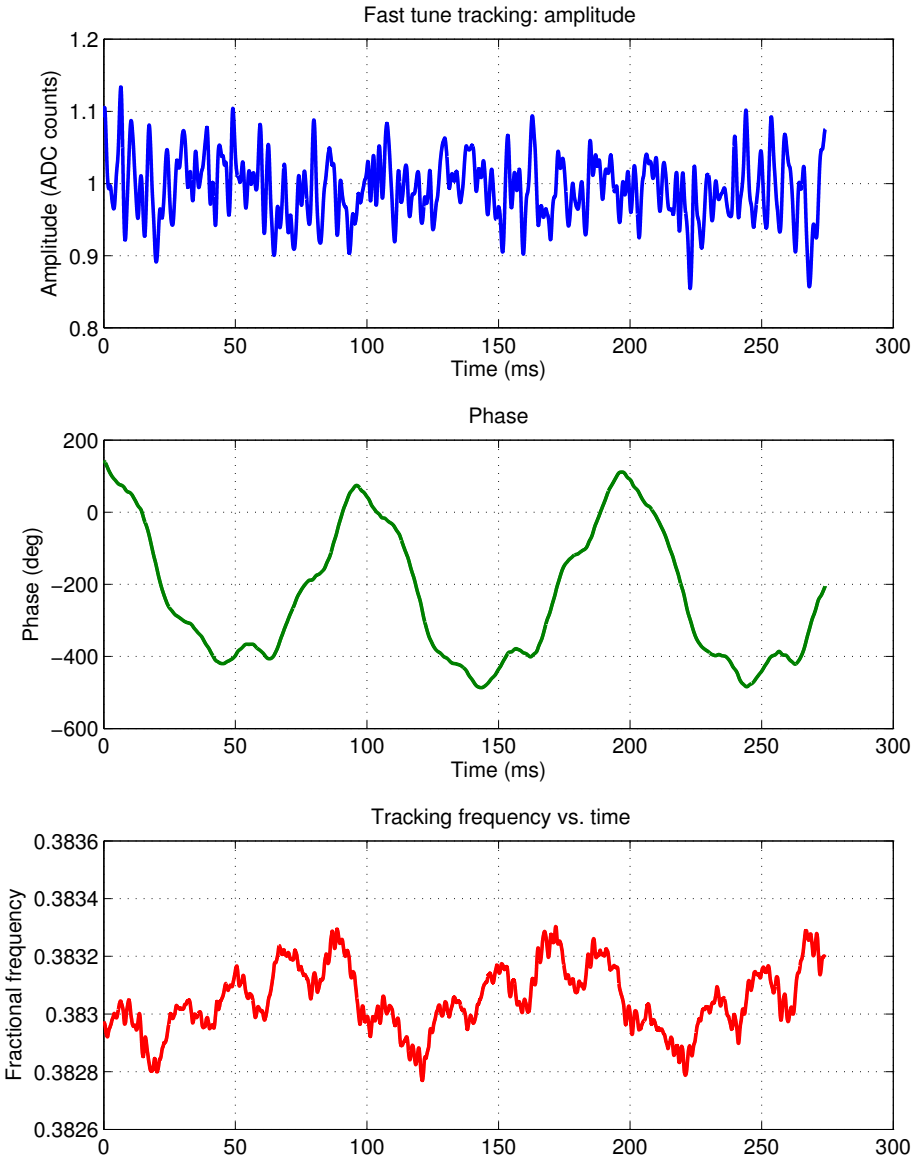

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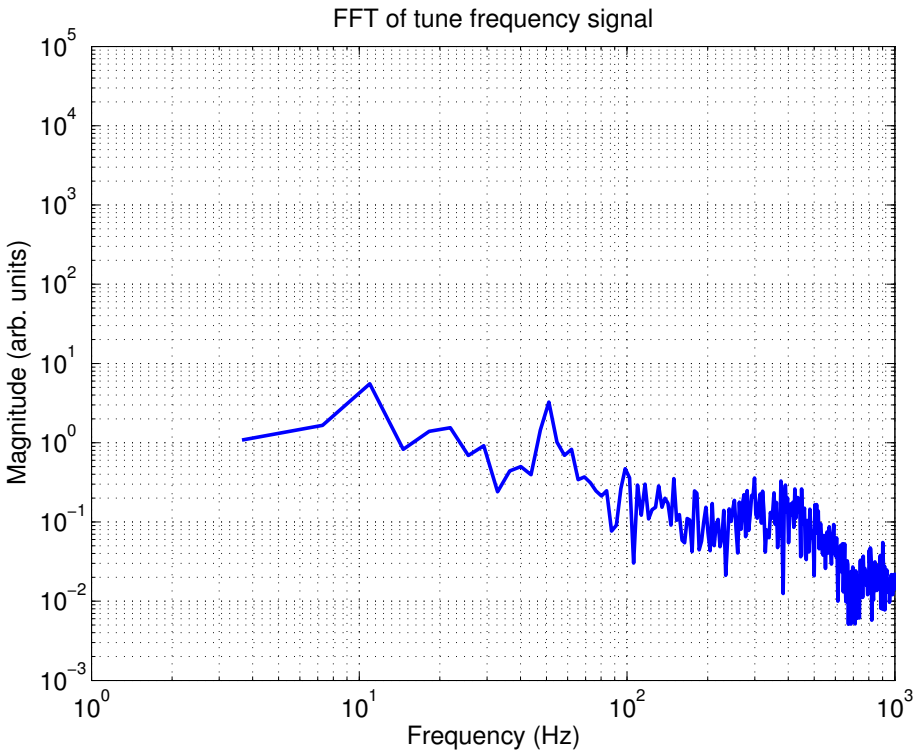

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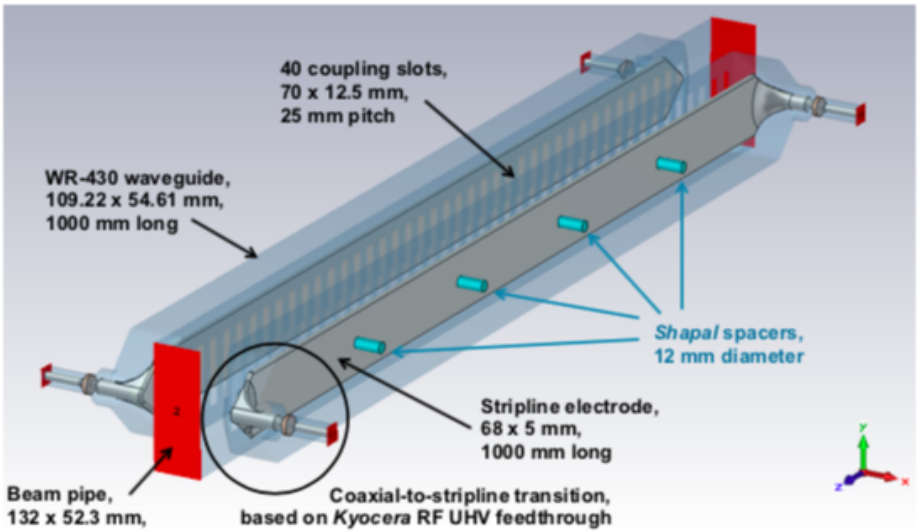
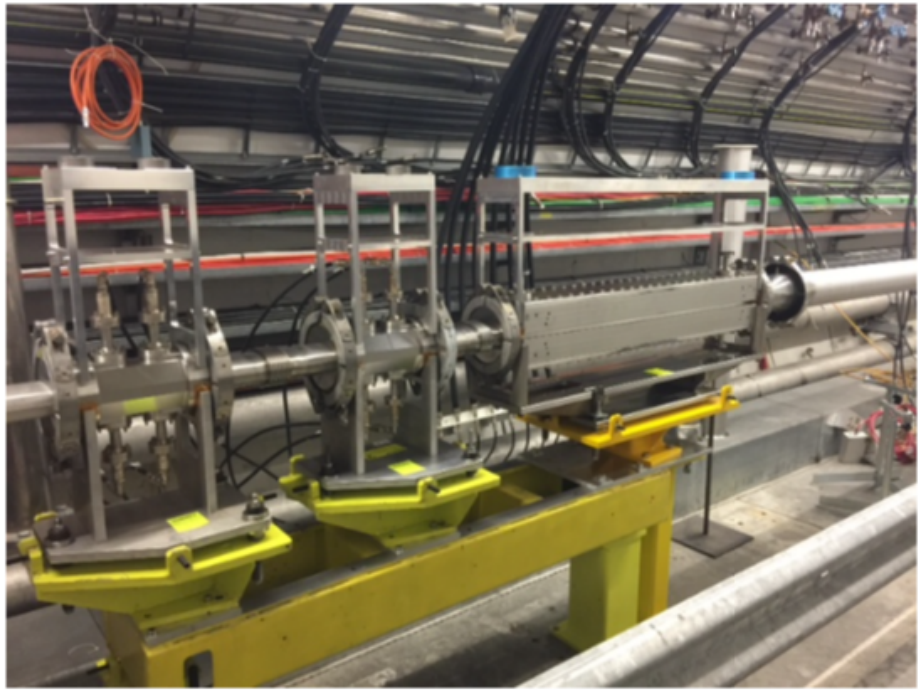
Next-generation Wideband Kicker structures

- 1 GHz Developed for Intra-Bunch feedback demo at SPS

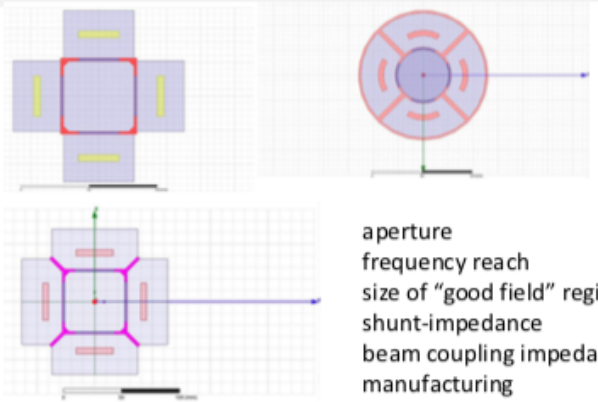




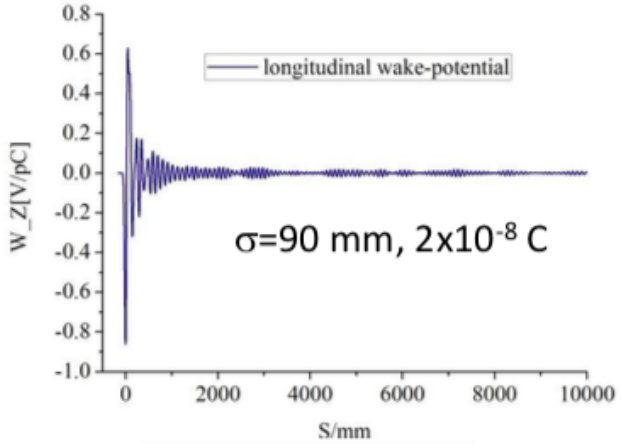
- CERN, LNF-INFN, LBL and SLAC Collaboration. Design Report SLAC-R-1037
- Similar in concept to stochastic cooling pickups, run as kicker
- Advantage - length allows Shunt Impedance AND Bandwidth
- J. Cesaratto, S. Verdu, M.Wendt, D. Aguilera electrical/mechanical design and HFSS optimization, installed Jan 2018, commissioned July 2018)

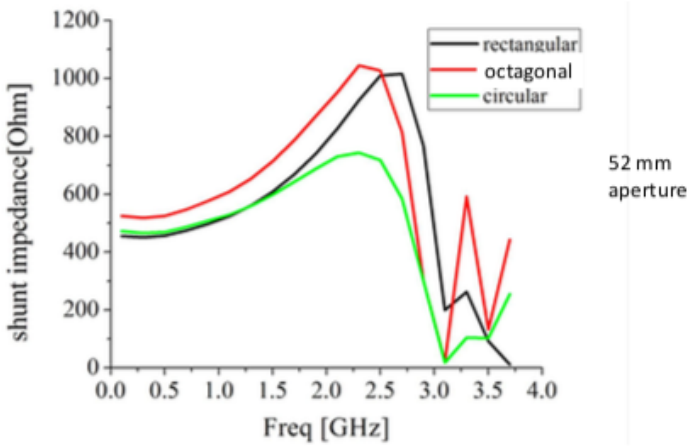
- CERN wants to explore higher frequency 4 GHz structure for HL-LHC and FCC
- Timing of beam tests, CERN LS-2 and LS-3 machine availability
- Could we test such a structure at DAFNE-TA? Can we lengthen the bunch ?
- Obvious open question - is the broadband impedance allowable for DAFNE-TF

Wideband Kicker - initial study for LHC and FCC - broadband Z_l? (G. Zhu)

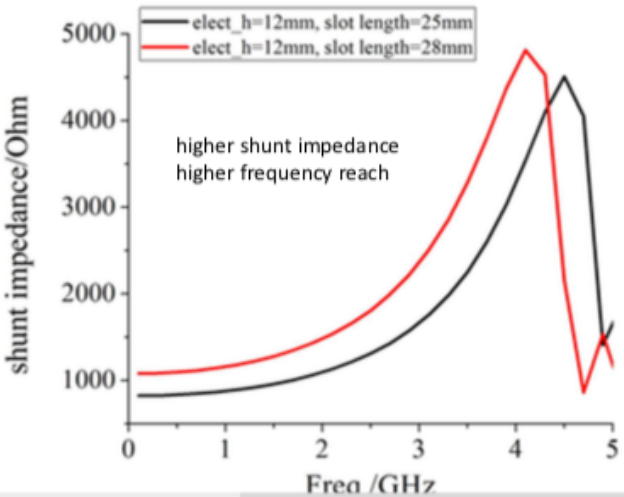


aperture
frequency reach
size of "good field" region
shunt-impedance
beam coupling impedance
manufacturing





52 mm
aperture



Beam Instrumentation and Feedback School

- Excellent existing programs in USPAS, CAS, AAS, JUAS, others
- ECFA Program in development for accelerator physics
- Build ties between accelerator physics and accelerator engineering communities
- Idea - in-residence 4 - 6 week school focused on Beam Instrumentation, Feedback
- Train next generation of scientists and engineers using DAFNE

Recent ECFA Meeting - Accelerator Education

Accelerator Science Education and Schools

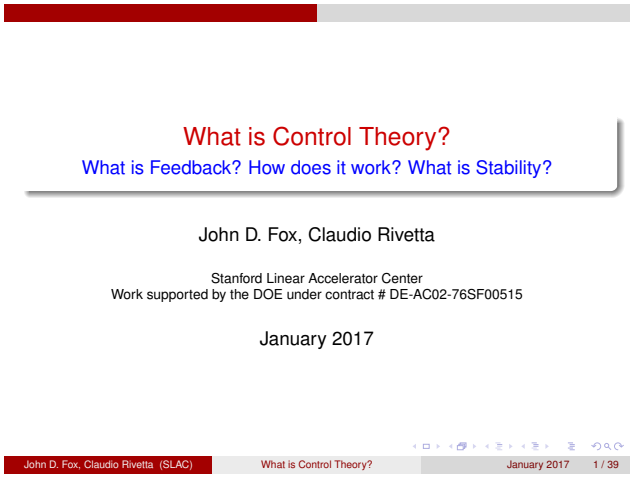
E. Métral (20 min)
(CERN BE/ABP-HSC &
deputy director – and former student – of the JUAS school)

=> On behalf of the team
P. Lebrun and L. Rinolfi (current and previous JUAS directors)
H. Schmickler (current CAS director – deputy director: W. Herr)
P. Burrows (Work Package 2 leader in European project ARIES)
N. Delerue (Task Leader 2.4 in European project ARIES)
Many thanks to G. Arduini and universities' contacts (see Appendix)

- **If Europe wants to prepare well for its future collider projects, education and training in accelerator science are crucial**
- **Are we ready to educate the new generations of accelerator scientists?**

Examples from USPAS

- All had lab and computer exercises- would be better with accelerator lab component
- Control Theory with Applications to Accelerators
- RF Engineering and Signal processing
- Fundamentals of Timing and Synchronization with Applications to Accelerators
- Introduction to Low-Level Radio Frequency Systems, Technology and Applications to Particle Accelerators


What is Control Theory?

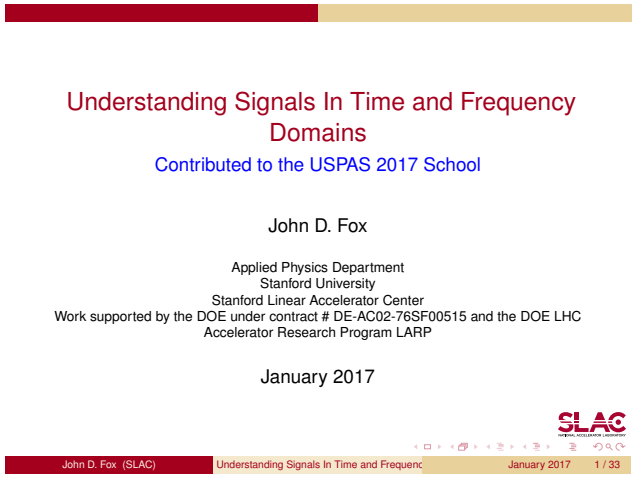
What is Feedback? How does it work? What is Stability?

John D. Fox, Claudio Rivetta

Stanford Linear Accelerator Center
Work supported by the DOE under contract # DE-AC02-76SF00515

January 2017

John D. Fox, Claudio Rivetta (SLAC) What is Control Theory? January 2017 1 / 39


Understanding Signals In Time and Frequency Domains

Contributed to the USPAS 2017 School

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January 2017

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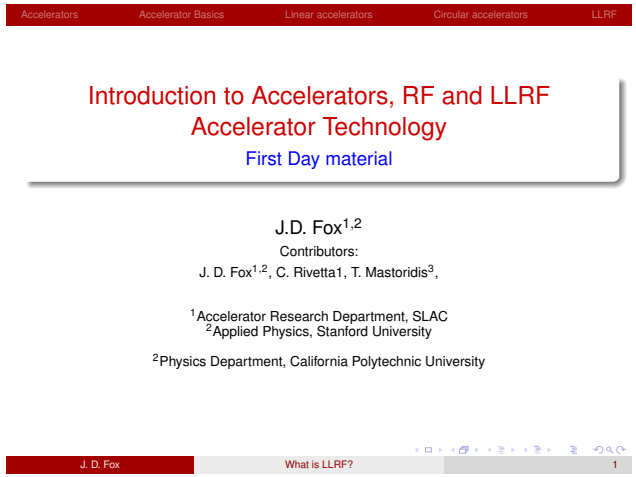
Accelerators Accelerator Basics Linear accelerators Circular accelerators LLRF

Introduction to Accelerators, RF and LLRF Accelerator Technology

First Day material

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J. D. Fox What is LLRF? 1

Beam Instrumentation and Feedback School

- In-residence 4 - 6 week school focused on Beam Instrumentation, Feedback. Sessions 2X a year?
- Train next generation of scientists and engineers using DAFNE
  - Unique opportunity with LNF and DAFNE-TF
  - focus on hands-on exercises with beam
  - Lab exercises with associated hardware development
  - includes accelerator physics concepts, motivate instrumentation
- Beam Instrumentation
  - Synchrotron light diagnostics
  - Bunch length and other diagnostics
  - Position monitors, orbit feedback
  - Tune measurements (X,Y and Longitudinal), lattice characterization
- Feedback and Instability Control
  - Pickups, Kickers
  - Modern Control methods
  - Development of FPGA processing, signal processing coding
  - Beam measurements, Impedances and stability
- 3 - 6 Month Fellowship (Thesis?) possibility (project based)

Open Discussion

- Idea 1 - Novel High Gain Feedback Architectures
  - Advance state-of-the art
  - Motivated by FCC, other machines
- Idea 2 - Novel Tune and Beam Diagnostics
  - Formalize several ad-hoc methods
  - Report on limits, applicability, toolbox
- Idea 3 - develop 4 GHz kickers
  - Builds on LNF, SLAC, CERN skills and report
  - special value - timing relative to LS2 of HL-LHC
  - Is this even feasible from impedance standpoint
- Idea 4 - In-residence Beam Instrumentation and Feedback School
  - Unique facility, hands-on training
  - Synergistic with expanded USPAS, JUAS, workforce development
  - Builds ties between university faculty and expertise, lab experts and technical expertise
  - High impact on future of accelerator science and technology

Thanks to the LNF workshop organizers for travel support to participate in this DAFNE-TF workshop