Simulated Performance of an FIR-Based Feedback System to Control the Electron Cloud Single-Bunch Transverse Instabilities in the CERN SPS

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Outline

- The problem
- Modeling
- Control System
- Future Works
- Conclusions

The Problem

- Transverse instabilities observed in SPS beams due to electron clouds, see presentation by C. Rivetta et al. (SLAC) and J. L. Vay et al. (LBNL)

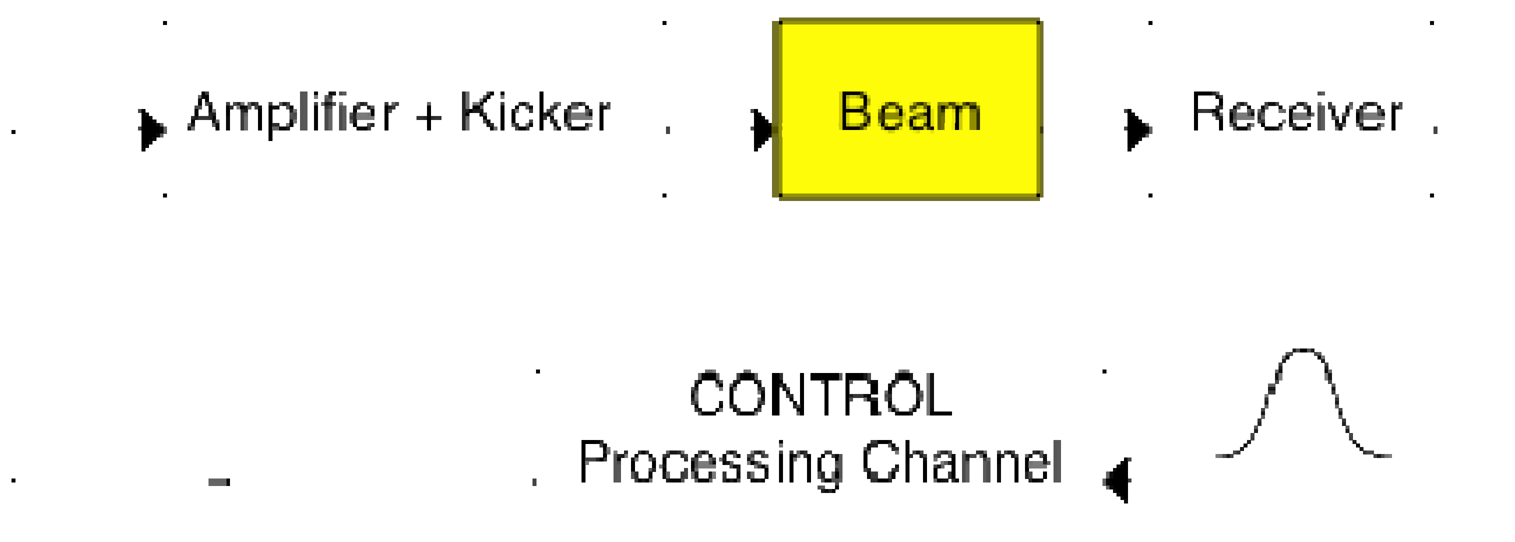
- Interaction between e-cloud and beam leads to large transverse oscillations

- Possible solution: **Feedback System** to control beam transverse motion, (see J.L.Vay et al. Proceedings of IPAC 2010, [1]).

- Use of the Particle-In-Cell framework Warp-Posinst

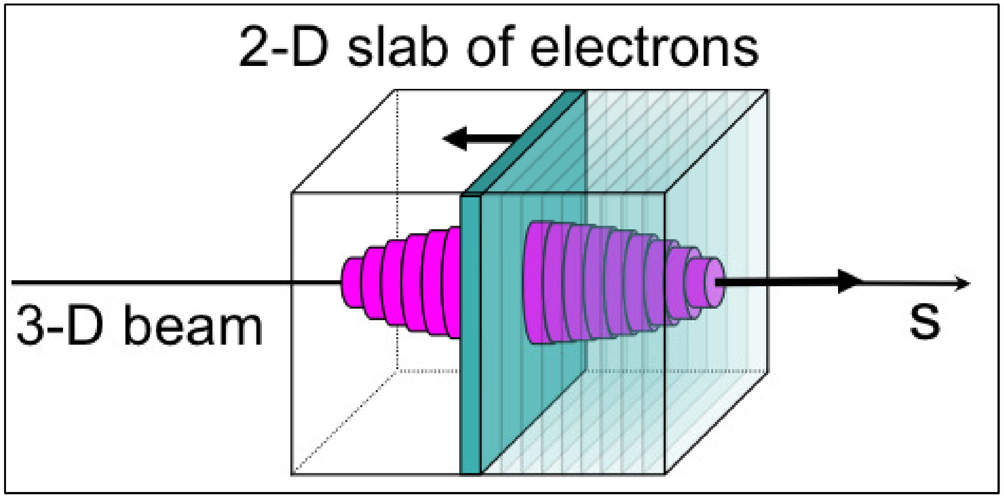
Feedback Model

Scheme of the overall system:



WARP/POSINST framework

- WARP quasistatic model similar to HEADTAIL, QuickPIC. (see presentation by J.L.Vay. et al.)



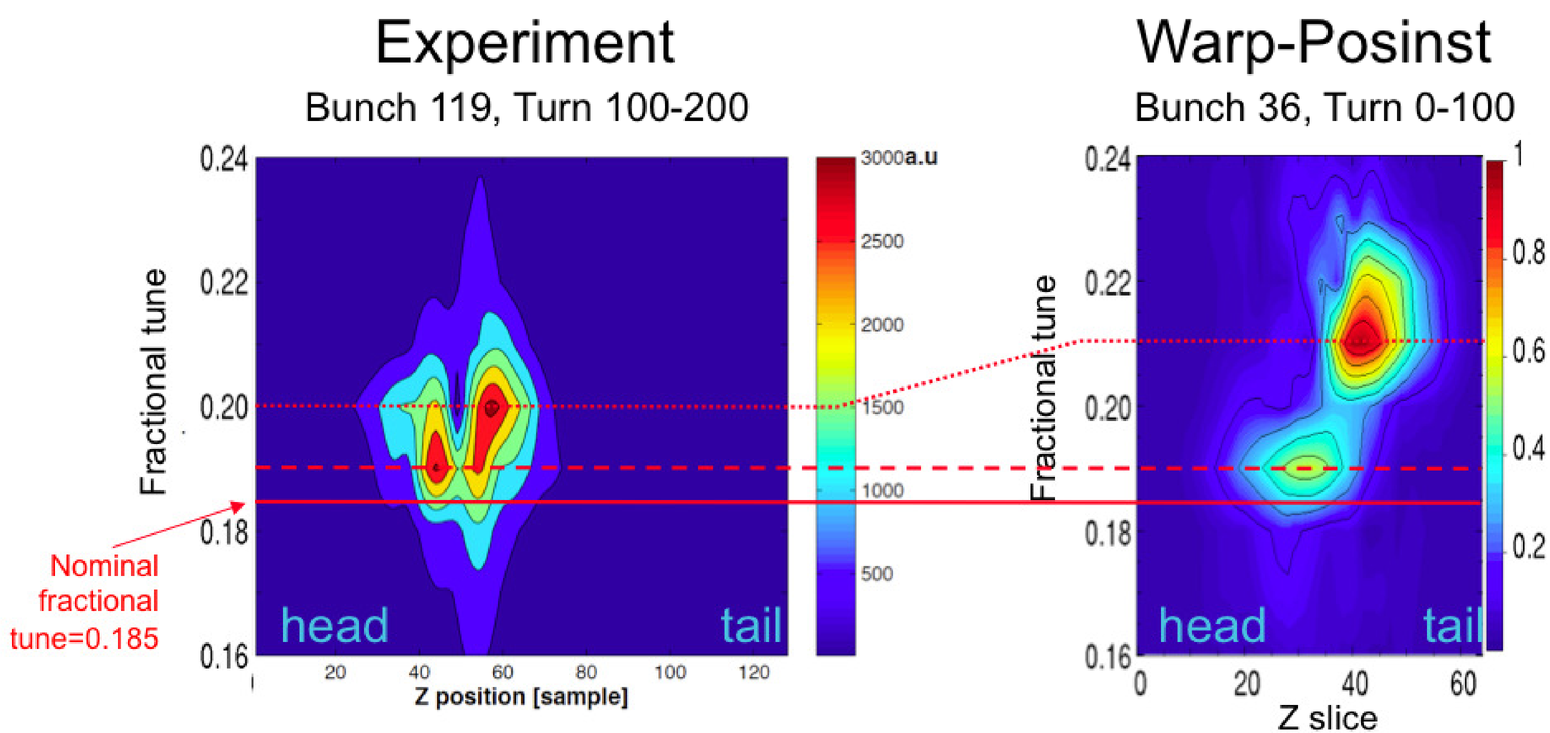
- Option of using POSINST to get secondary emission of electrons; <u>Uniform Ecloud density distribution</u> used in our runs.

Comparison with SPS Data - I

Observation of SPS June 2009 measurements:

- Instabilities within bunches due to Electron Cloud. Head and Tail splitting. (see J. Fox et al. Proceedings of IPAC 2010 [2])

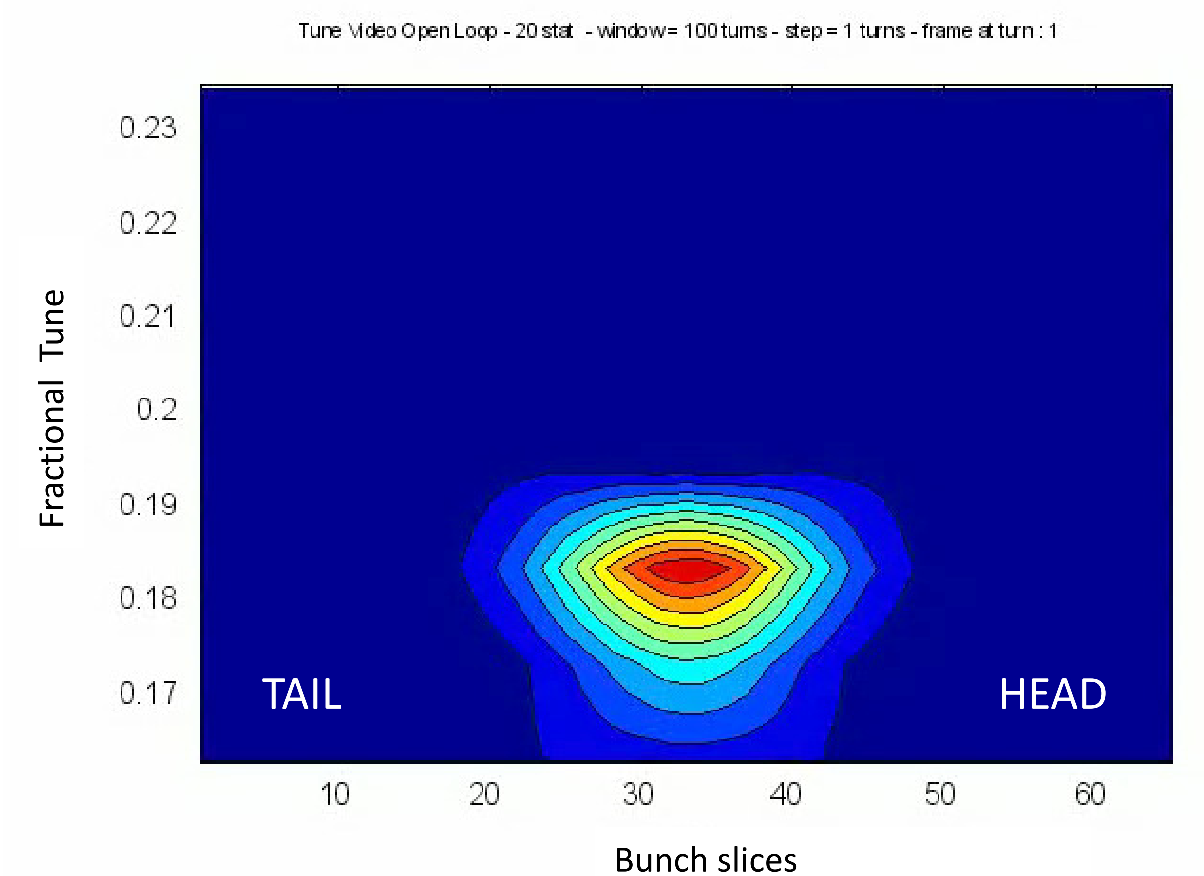
- Frequencies within bunch and estimated bandwidth of instability signal.



Comparison with SPS Data - II

➢ <u>Open Loop simulation shows tuneshift, SPS nominal βy = 0.185</u>

Open Loop simulation, FFT window of the bunch displacement plot for each turn



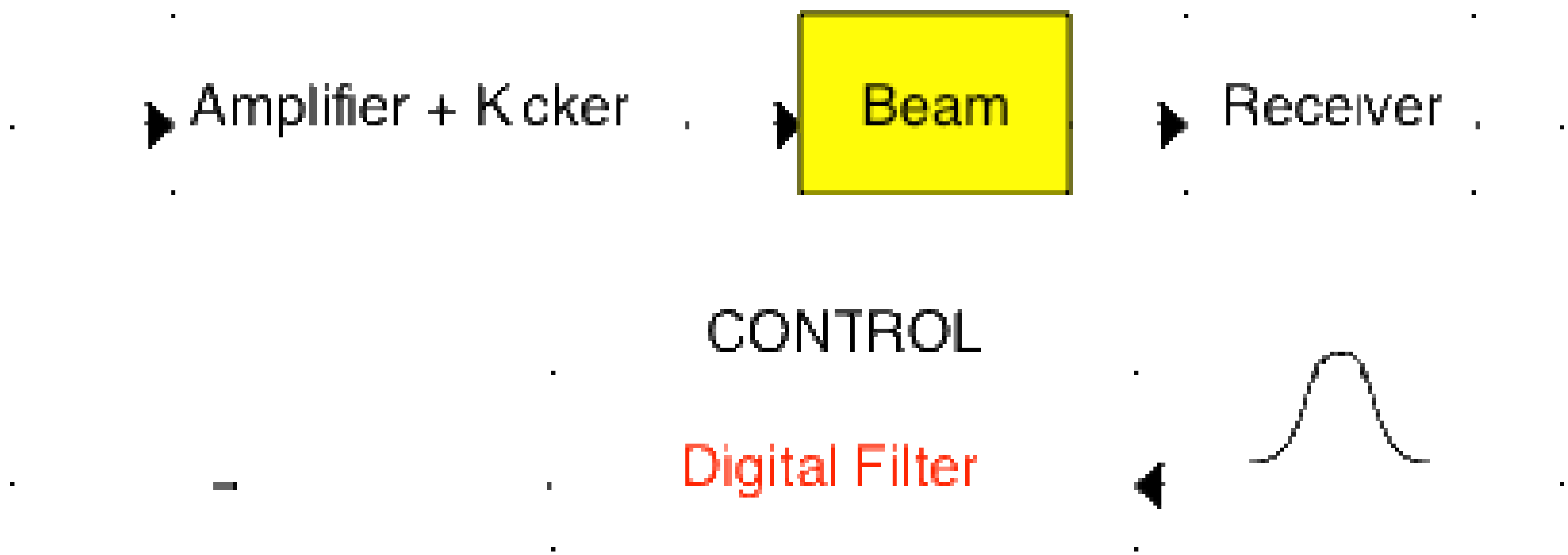
Feedback System – General Considerations

Goal of the Feedback System: stabilize the bunch due to the e-cloud induced instability ideally for all the operation conditions of the machine.

Key parameters for the Feedback Design:

- Minimum **Gain** required for stability
- Delay in the Control Action
- Achievable **Bandwidth**
- Frequency Response of the Pick-up, Power Amplifier and Kicker
- Minimize noise injected by the feedback to the beam

Use of a Digital Filter



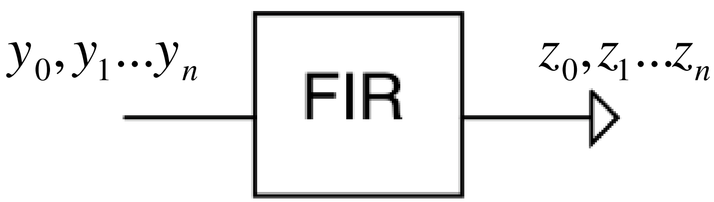
Characteristics of Digital Filters:

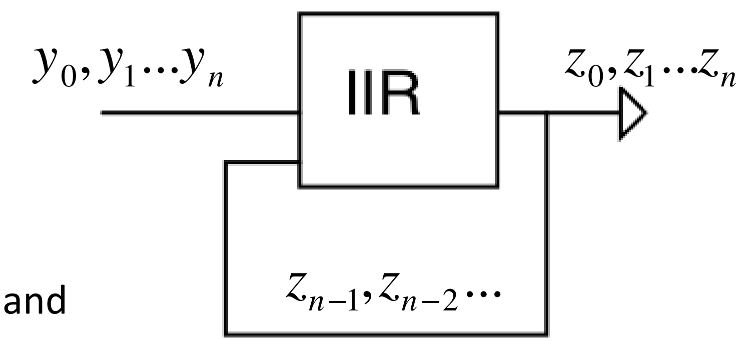
- Programmable, i.e. its operation is determined by a program stored in the processor's memory
- Very much versatile in their ability to adapt to changes in the characteristics of the signal
- Fast DSP processors can handle complex combinations of filters in parallel, making the hardware requirements relatively simple and compact

Filter Choice

- Filter Requirements:
  - Remove static orbit offset
  - Remove out of band signals
  - Phase shift

- A Finite Impulse Response (FIR) filter is non recursive, while an Infinite Impulse Response (IIR) filter is recursive.





Time *t* is equal to *t* = *nh*, where *n* is a positive integer and *h* is the sampling interval

FIR Filter Algorithm

- The FIR Filter has **5 taps** to process bunch slices.

- Each measurement $y_i(k)$ is processed following the algorithm:

$$\boxed{z_i(k) = a_1 y_i(k-1) + a_2 y_i(k-2) + \ldots + a_n y_i(k-N)}$$

Where y = vertical displacement, i = slices, k = turns, N = 5.

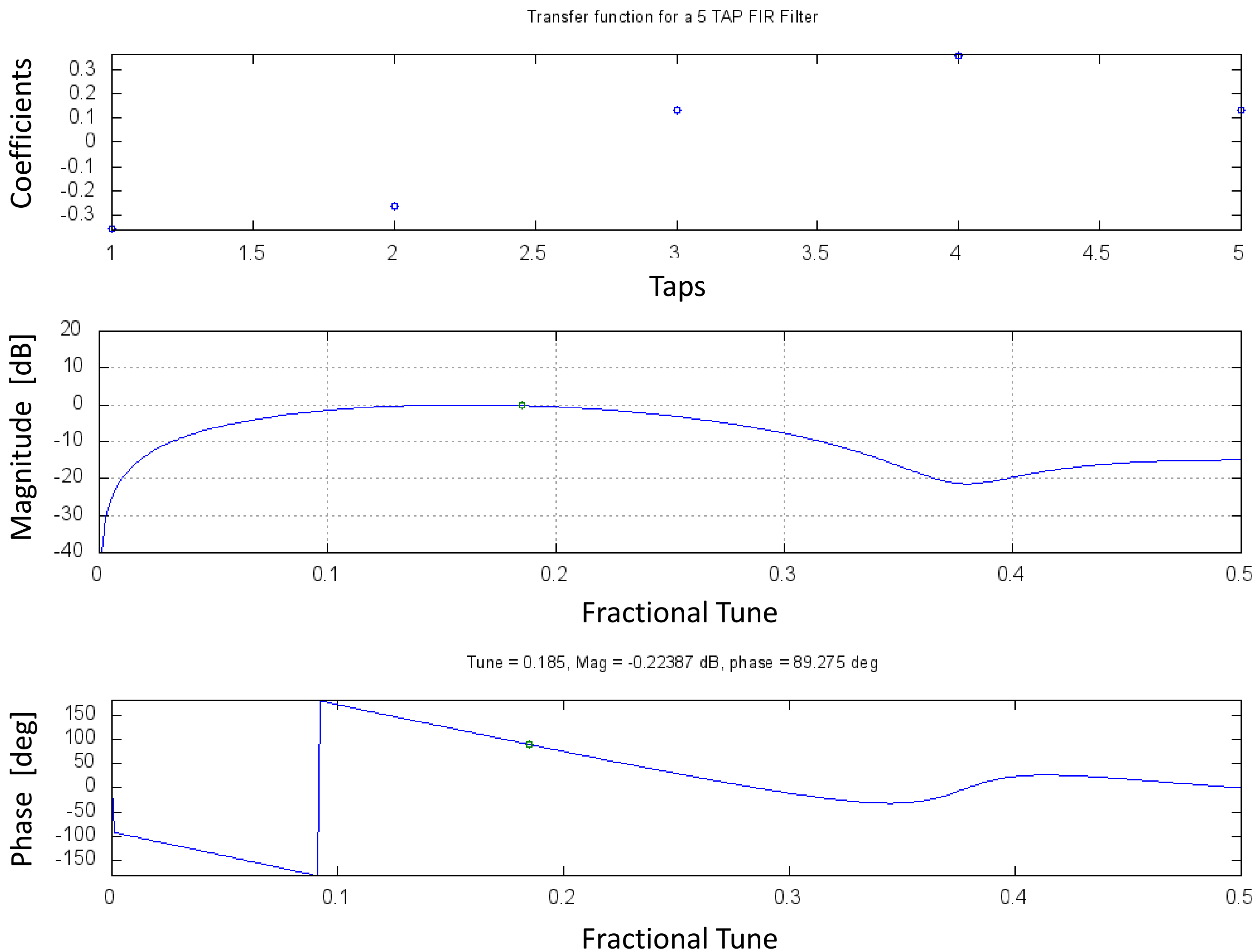
- If the Amplifier/kicker/cable are ideal (no bandwidth limitation), the complete feedback system with gain G can be modeled as:

$$\boxed{C_i(k) = G z_i(k)}$$

Where $C_i(k)$ is the kick signal applied at the i^{th} slice at turn k

- Using <u>**64** slices</u> of the bunch. Applying kick with <u>**1 turn** delay</u>

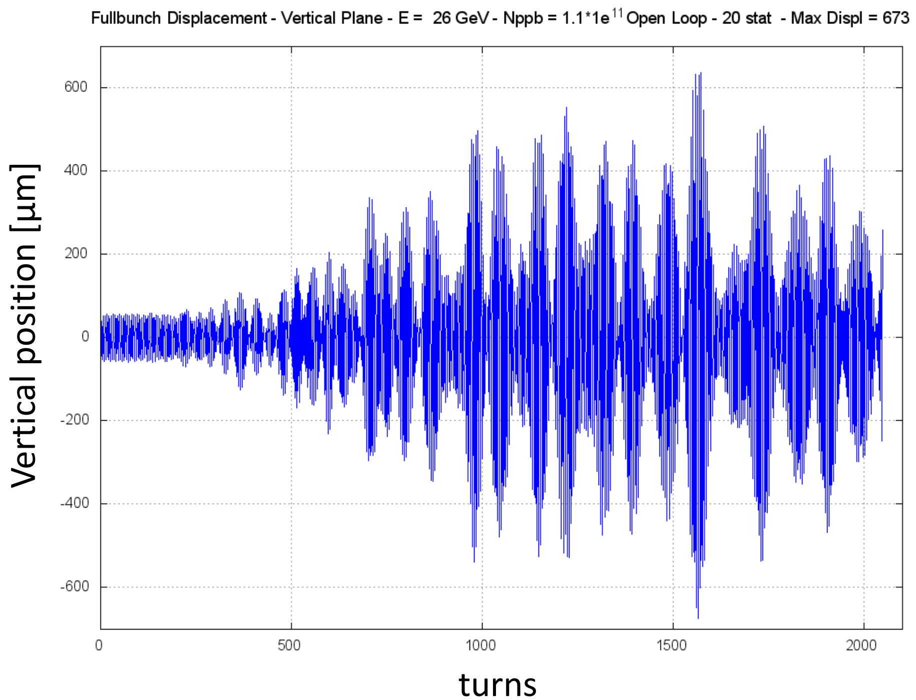
Filter Bode Plot



Feedback System Performance - I

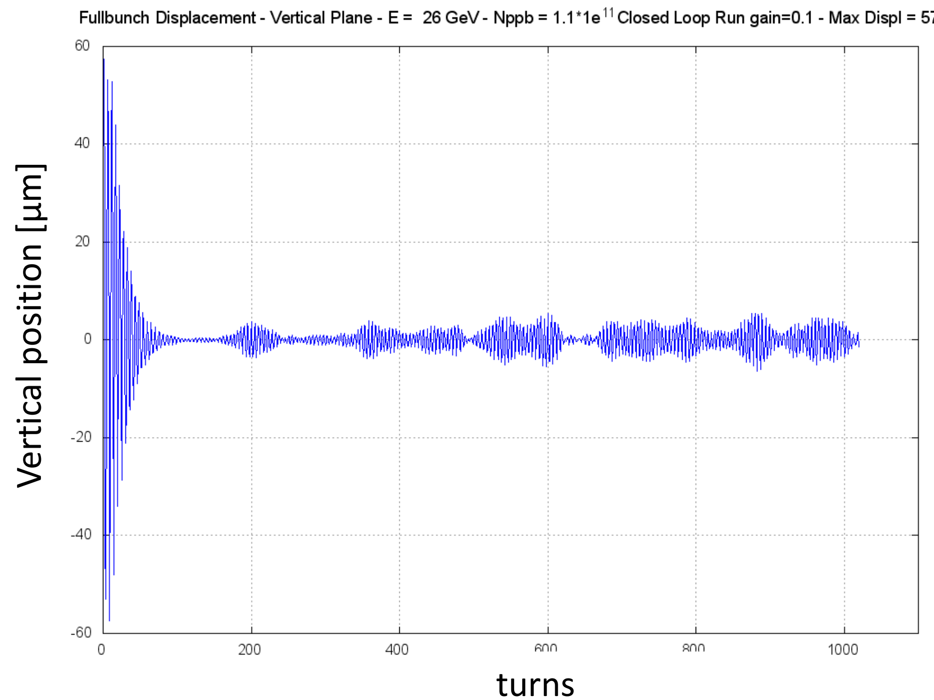
Plot of the Bunch CENTROID over turns in **Open Loop**

Max displacement **Open Loop**= 600um



Plot of the Bunch CENTROID over turns in **Closed Loop**

Max displacement **Closed Loop** = 60um

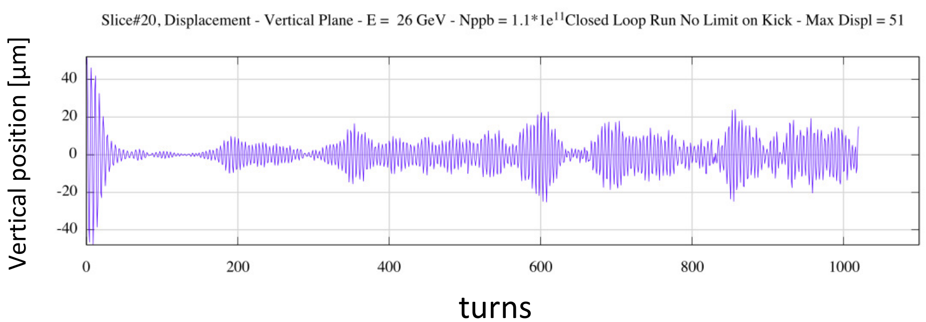


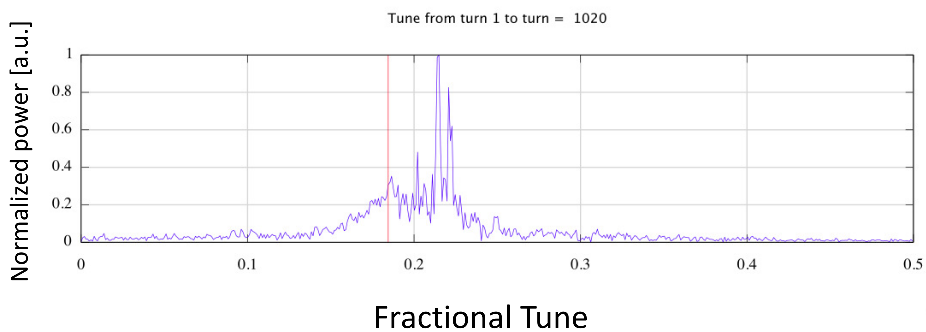
- All simulations were run at Injection Energy E = 26 GeV and with a uniform electron distribution of De = 10^{12} electrons, using a single bunch of $1.1*10^{11}$ protons.

Feedback System Performance - II

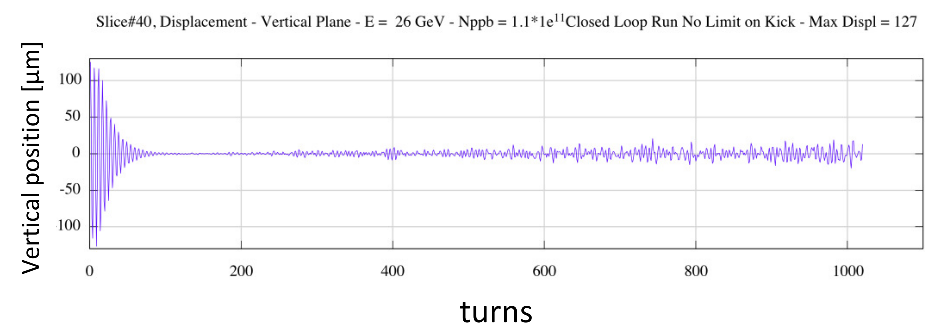
- Closed Loop results with **No Limit** on the Kick applied on the bunch

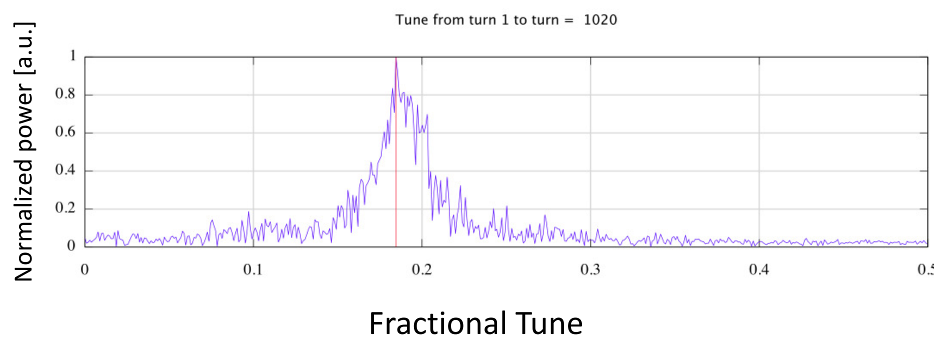
Single Slice vertical displacement in the TAIL





Single Slice vertical displacement in the HEAD



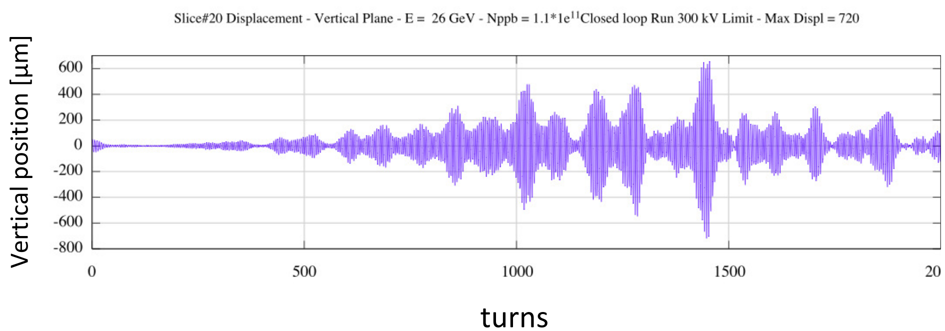


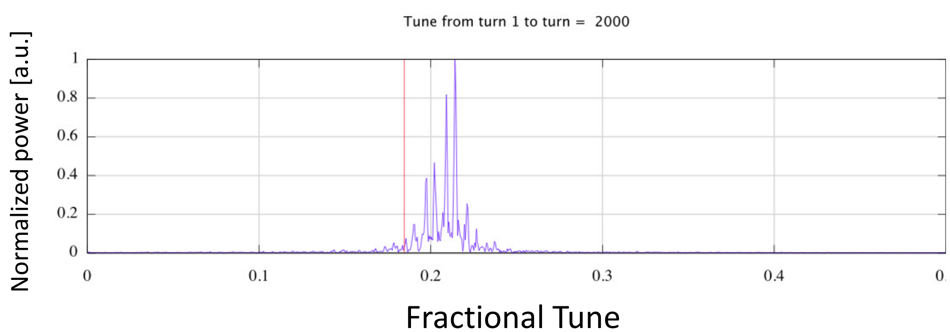
Feedback System Performance - III

➤ Limiting the Electric Field in the Kicker reduces the possibility of stabilizing the bunch via feedback system.

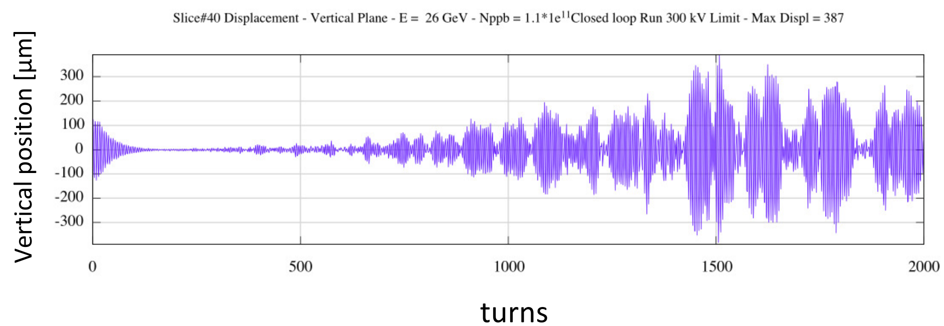
Max Electric Field of the Kicker limited at **300 kV/m**

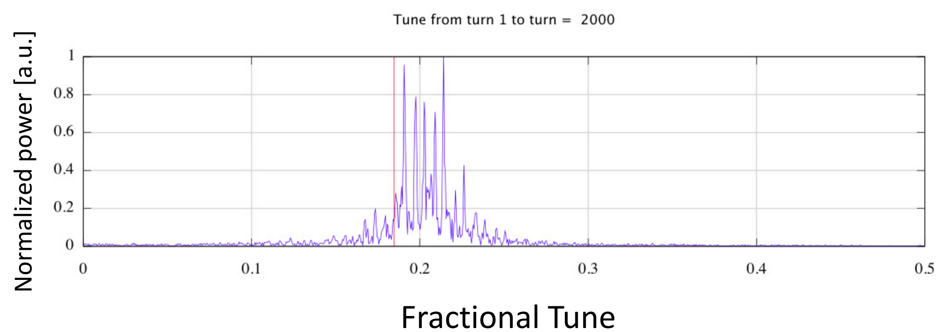
Single Slice vertical displacement in the TAIL





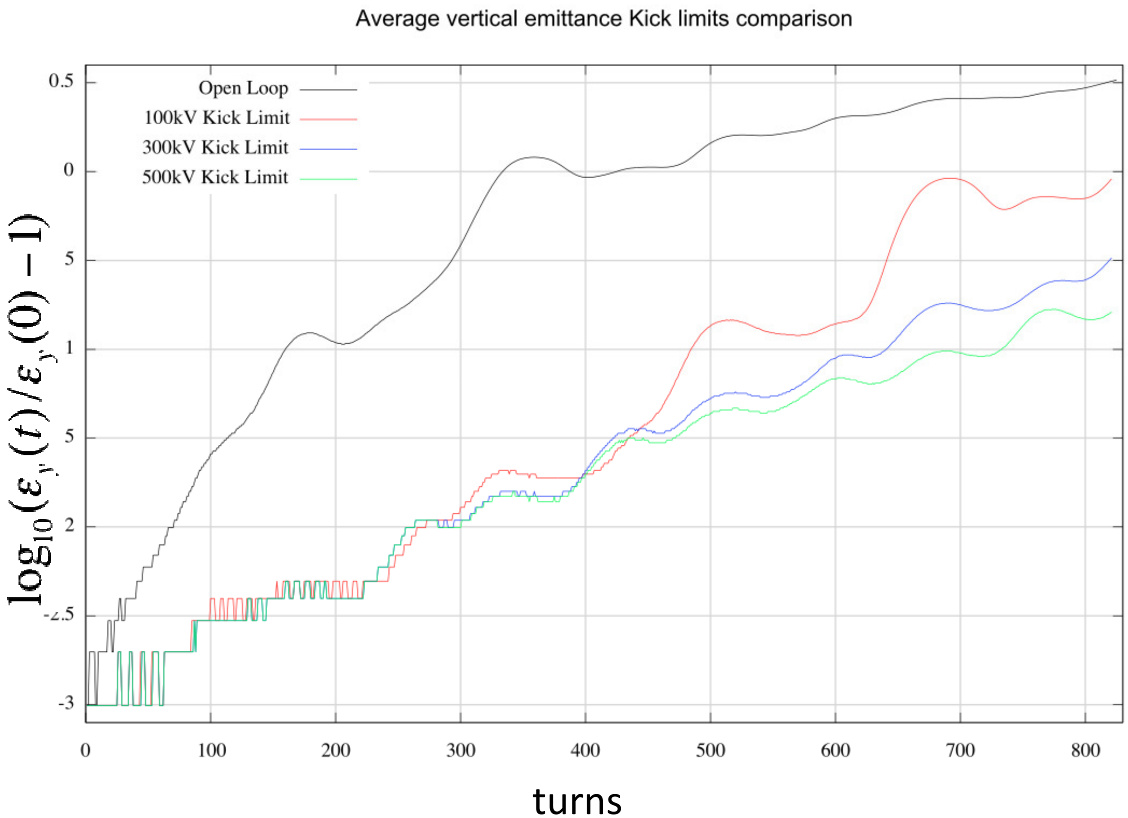
Single Slice vertical displacement in the HEAD





Feedback System Performance - IV

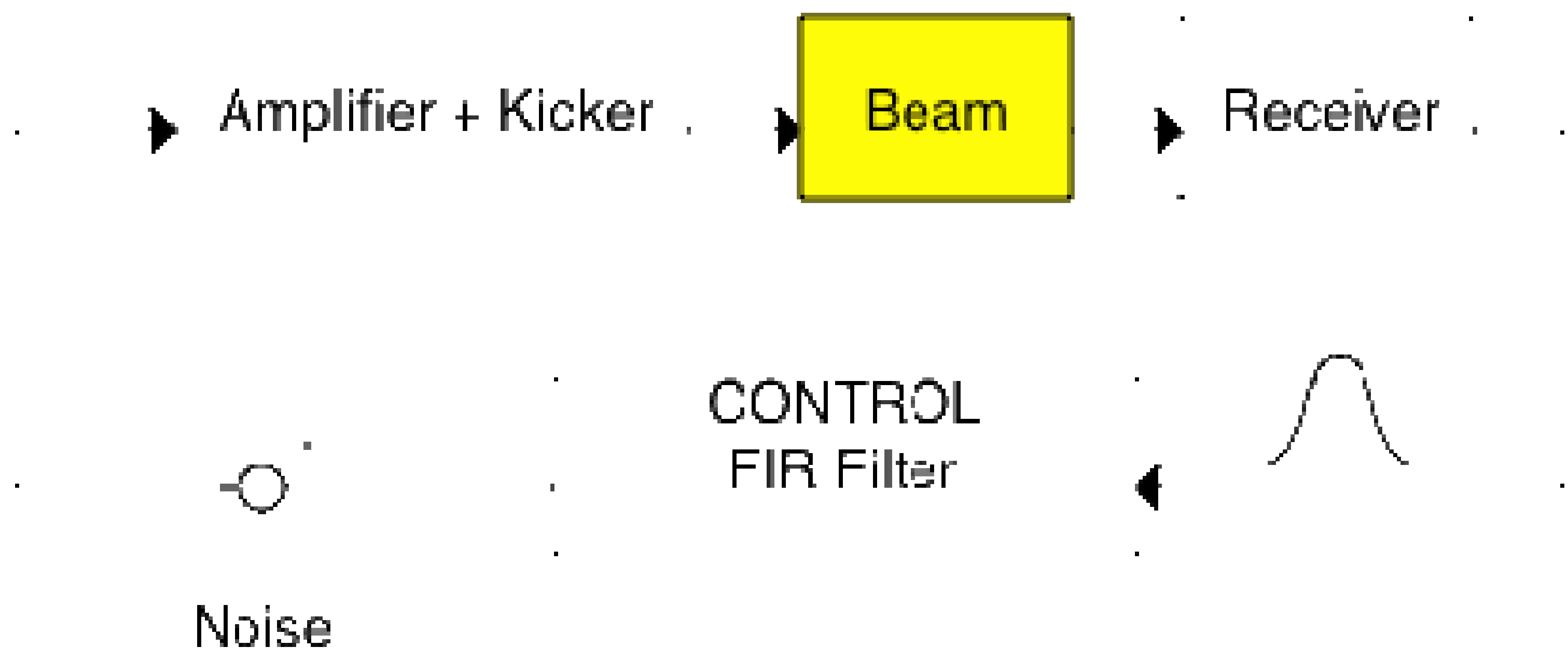
Comparison between Open Loop emittance growth and Closed Loop with Kick Limitation at 100 kV/m and 300 kV/m, 500 kV/m and with No Limitation:



➢ What Limit on the kick can we tolerate to keep controlling bunch instabilities considering higher e-cloud densities?

Improvements to the Feedback Model

- Develop the Feedback System model, making it more realistic:



- Can we still control the single-bunch instability using a reduced number of samples? Pick up sampling rate of 4 Gsamples/sec. Rms Bunch Length: 1 ns.

- Introduce noise in the Feedback chain.

Future Plans

- Improve the Feedback Model, adding all the components that are necessary in order to understand the limits and requirements for the Design of the System

- Apply the model to Multibunch simulations

- Analysis of experimental data took at CERN in 2010 and planning of new MDs

Conclusions

- Transverse single-bunch instabilities observed in the SPS at CERN due to ecloud effect.

- A Feedback Control System is a possible solution

- Use of WARP/POSINST framework to simulate the e-cloud effect in the SPS incorporating it with the model of a Feedback using an FIR filter as a first approach to represent the processing channel

- Future developments will lead to a more realistic system and understanding of limit parameters and requirements of the System

References

- [1] - "Simulation of Electron Cloud driven instability and its attenuation using a feedback system in the CERN SPS". J. L. Vay, J. M. Byrd, M. A. Furman, R. Secondo, M. Venturini, LBNL, USA; J. D. Fox, C. H. Rivetta, SLAC, USA; W. Hofle, CERN, Switzerland. Proceedings of IPAC 2010, Kyoto, Japan.

- [2] – "SPS Ecloud Instabilities - Analysis of machine studies and implications for Ecloud Feedback". John Fox, Themis Mastorides, Georges Ndabashimiye, Claudio Hector Rivetta, Daniel Van Winkle (SLAC, Menlo Park, California), Riccardo de Maria (BNL, Upton, Long Island, New York), Wolfgang Höfle, Giovanni Rumolo (CERN, Geneva), John Byrd, Miguel Furman, Jean-Luc Vay (LBNL, Berkeley, California). Proceedings of IPAC 2010, Kyoto, Japan.