DISTRIBUTED FEEDBACK LOOP IMPLEMENTATION IN THE RHIC LOW LEVEL PLATFORM

Freddy Severino, M. Harvey, T. Hayes, G. Narayan, K.S. Smith

Outline

- Brief view of the C-AD Complex
- Review of the RHIC LLRF Upgrade Platform
- Generic Implementation of a Feedback Loop
- RHIC Bunch by Bunch Longitudinal Damper
- Cavity Controller Loops
- Conclusion

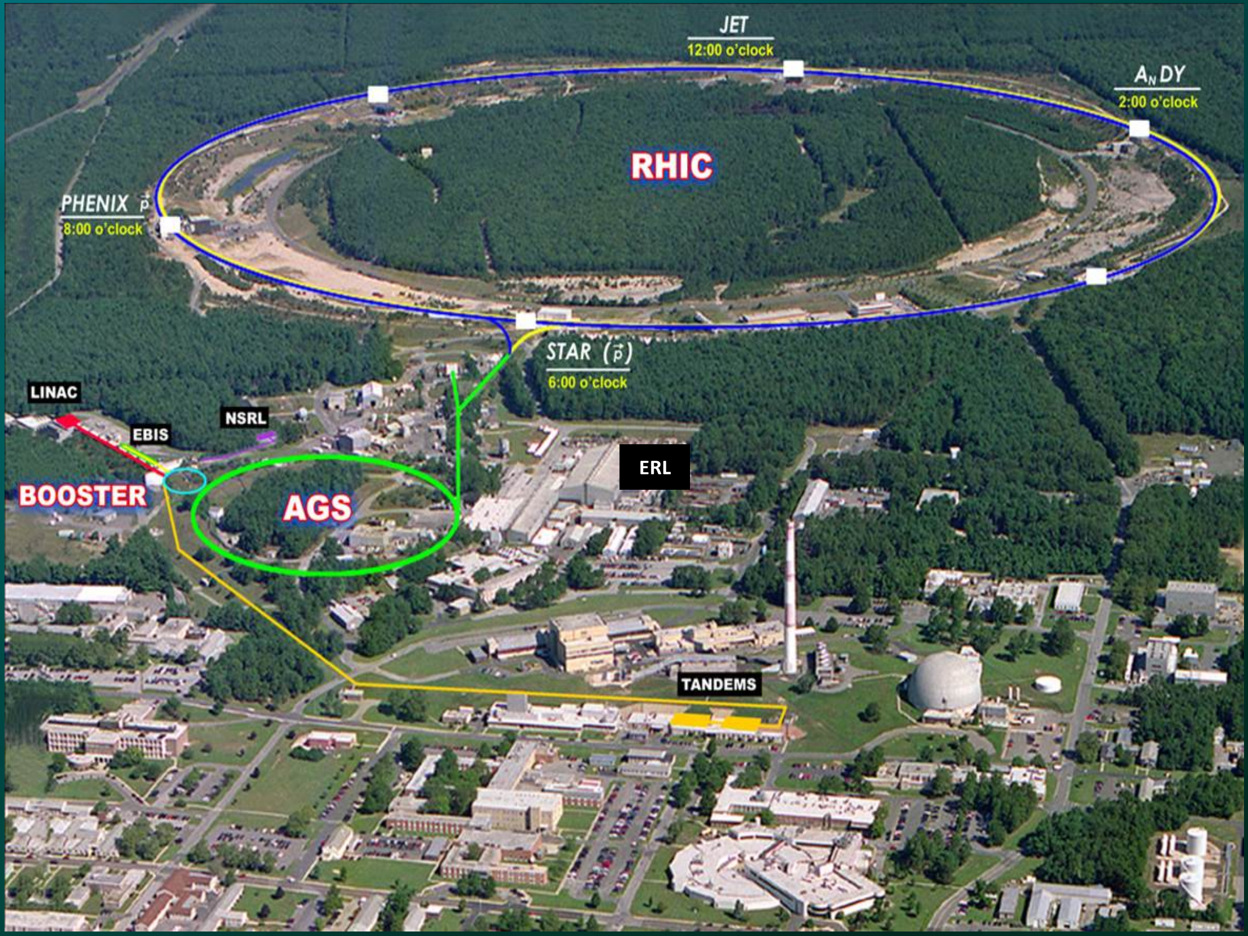
Brief view of the C-AD Complex

RHIC: Relativistic Heavy Ion Collider
- Current RF systems
  - 9 MHz, 28 MHz, 197 MHz
- Future RF systems
  - 56 MHz SRF (Lumi Increase)
  - 4.5 MHz (Low Energy eCooling)

AGS
- Injector for RHIC
- RF systems
  - 600 kHz, 1.2MHz-4.5MHz

Booster
- Injector for AGS
- Accelerator for NSRL facility
- RF systems
  - 400 kHz-4.5MHz

EBIS
- Electron Beam Ion Source
- Ion source for Booster
- RF systems
  - 100.125MHz RFQ, Linac and Bunchers



R&D Energy Recovery Linac
- First application of SRF system at C-AD
- 703 MHz 1MW SRF Photo-Cathode Gun and 5-Cell ERL Cavity

RHIC LLRF Hardware Platform

Platform Chassis showing Carrier, 2 DAC Daughter Boards and 1 ADC Daughter Board

RHIC LLRF Hardware Platform

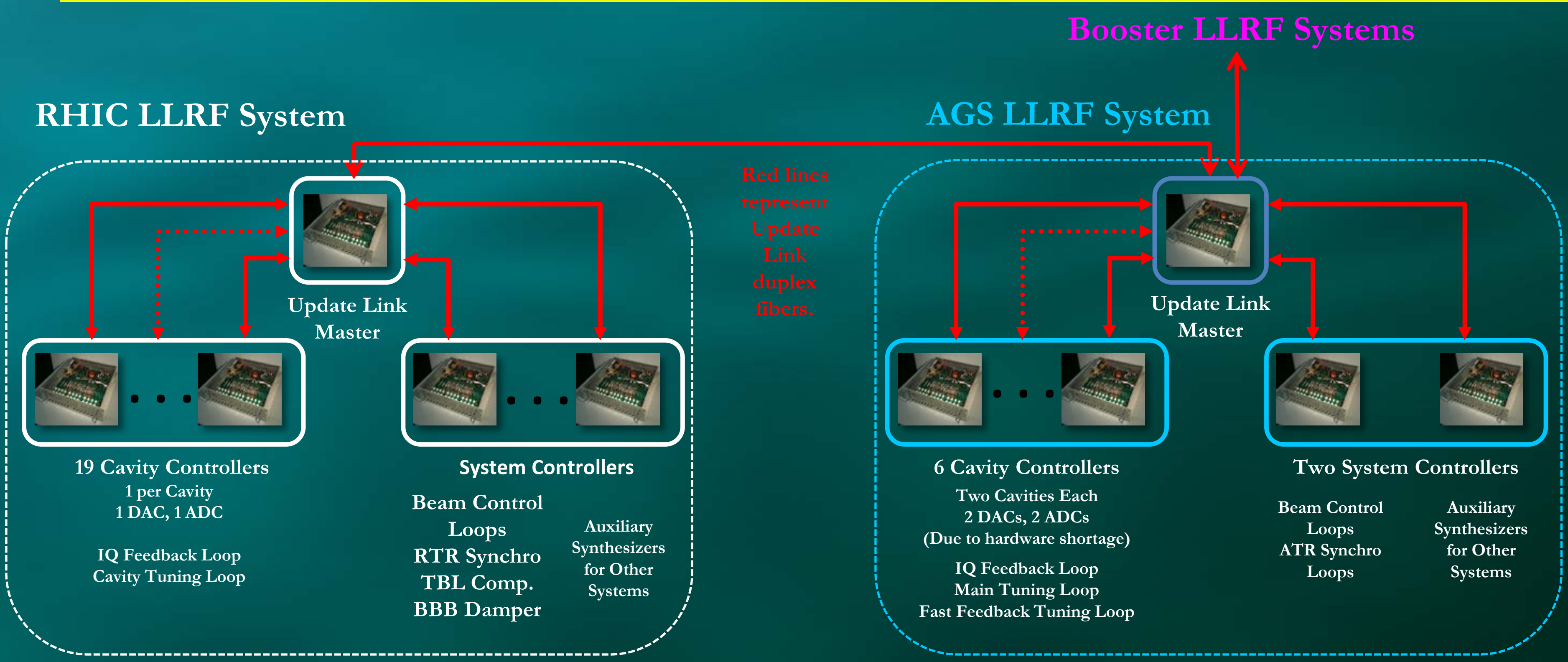
Platform Chassis showing Carrier, 2 DAC Daughter Boards and 1 ADC Daughter Board

RHIC LLRF Hardware Platform

- Hardware and Architecture described in other Workshops, PACs, etc. since 2010.
- Only four major components:
  - Carrier Board
  - 4CH High Speed DAC and ADC Daughter Boards
  - Update Link Master
    - Provides for much of the simplicity and ease of system integration, scaling and synchronization.
- Xilinx Virtex-5 FPGA embedded PowerPC 440 on each Board.
- We designed it to satisfy all the LLRF applications we have across the entire C-AD Complex.
  - Existing: RHIC, AGS, Booster Upgrades
  - Development: EBIS, R&D ERL
  - Unanticipated:
    - Bunch by Bunch Longitudinal and Transverse Damping
    - RHIC Spin Flipper

Platform Chassis showing Carrier, 2 DAC Daughter Boards and 1 ADC Daughter Board

RHIC LLRF Platform Architecture



- Update Link System connects all components.
- Linked to Other Machine via the LLRF Update Link.
- Same hardware, firmware and software.

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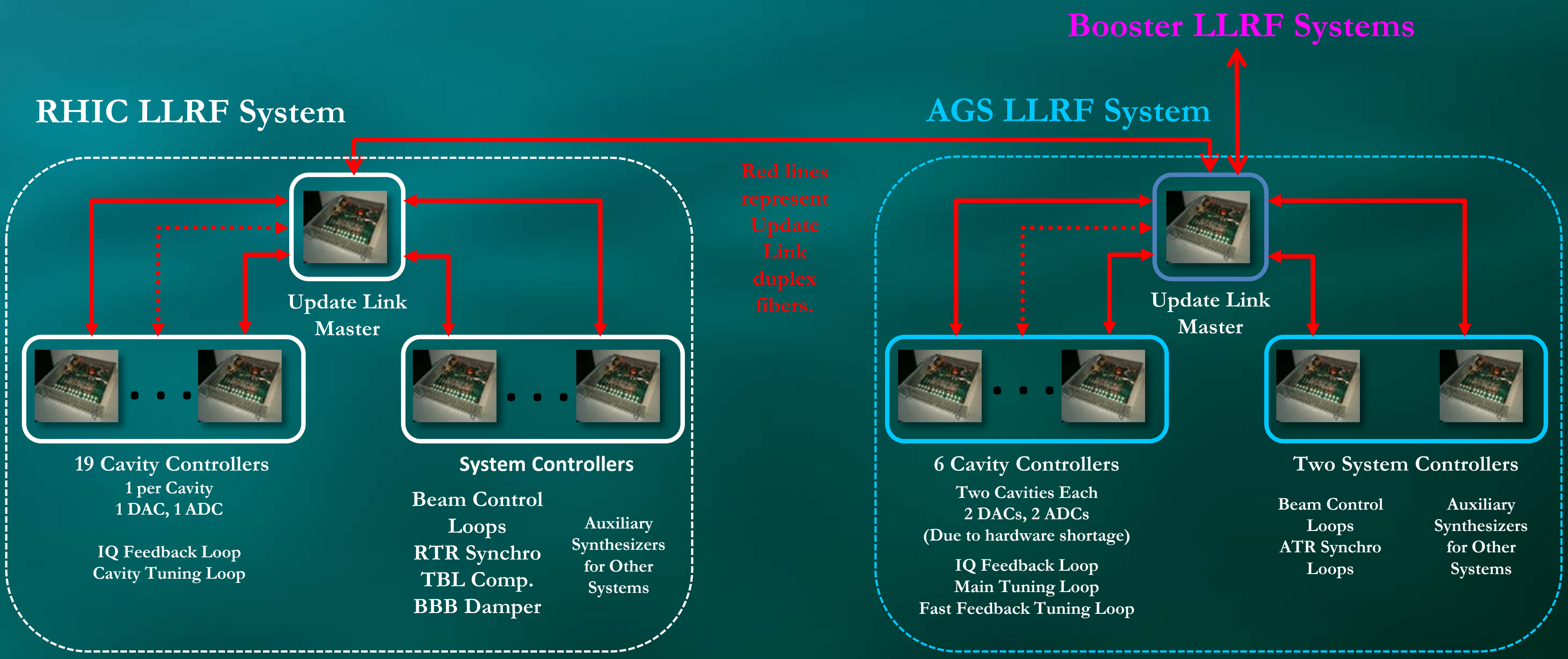

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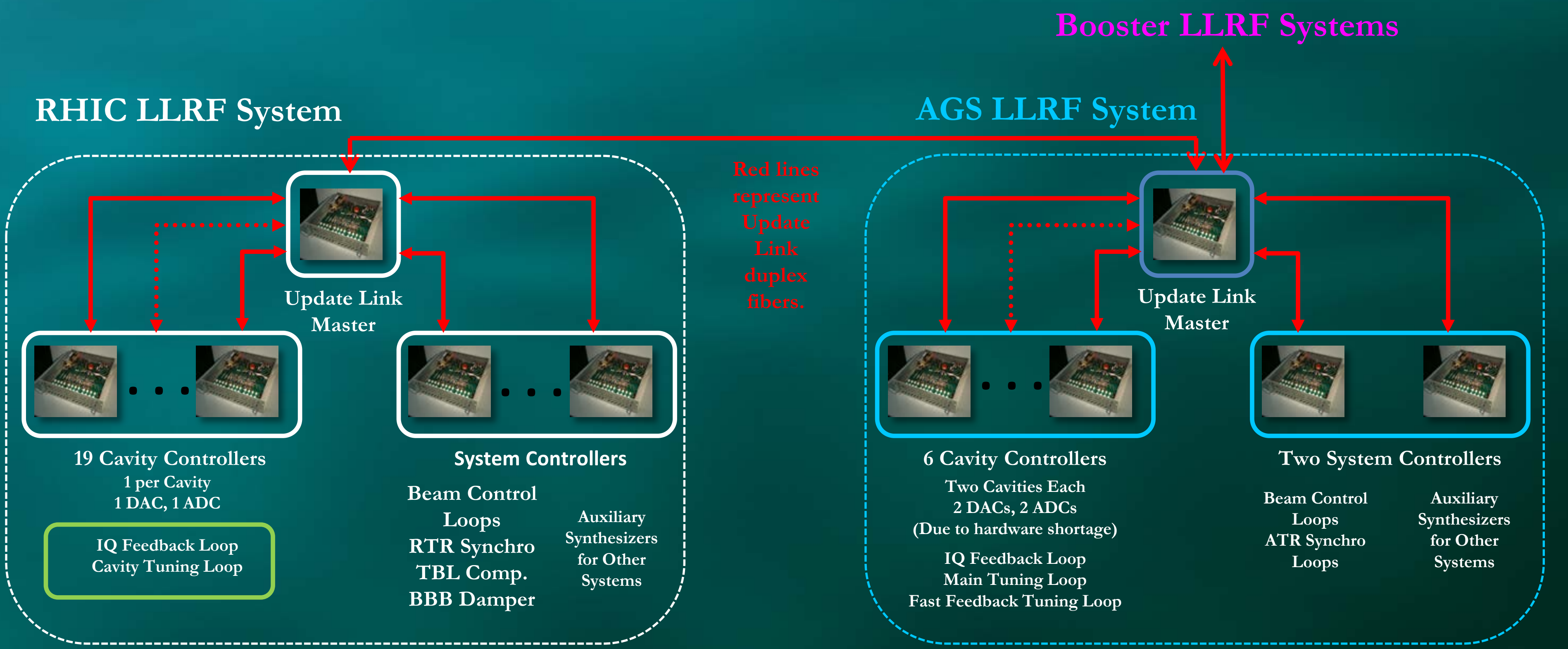

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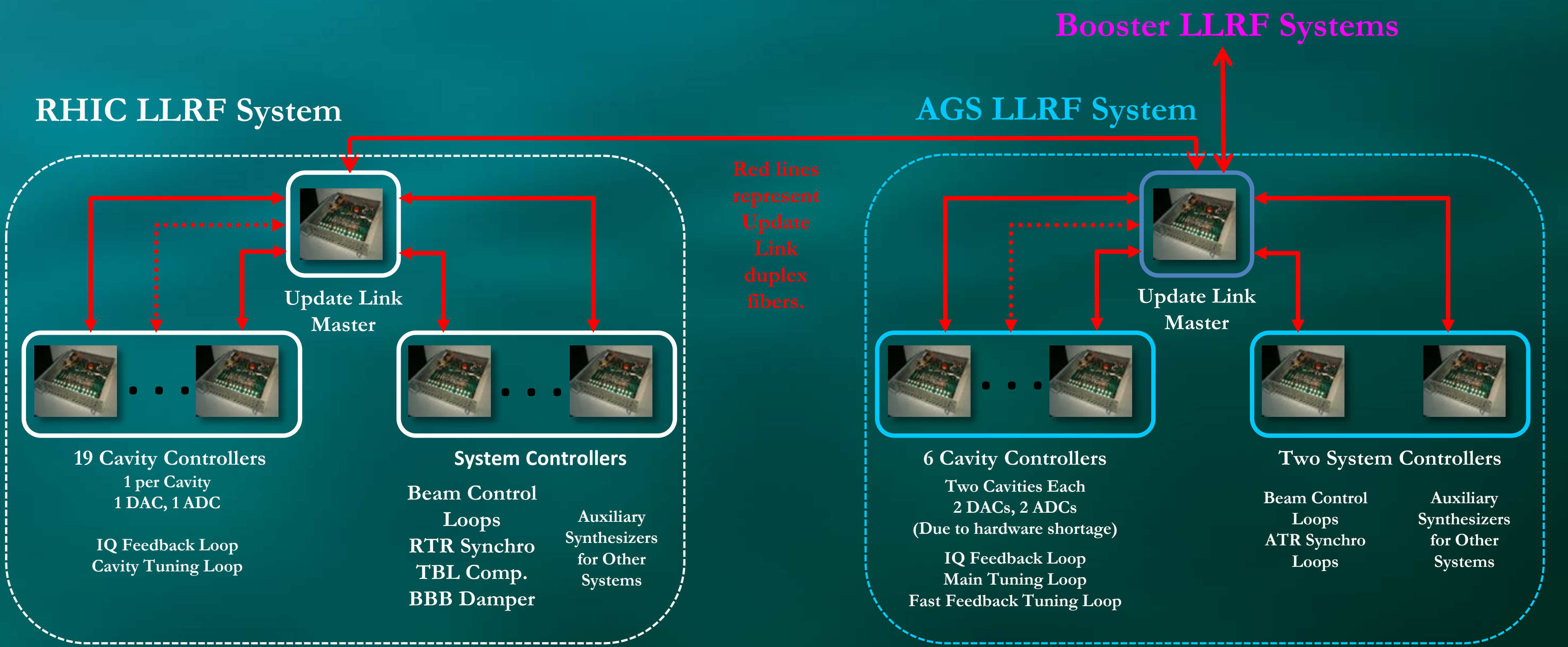

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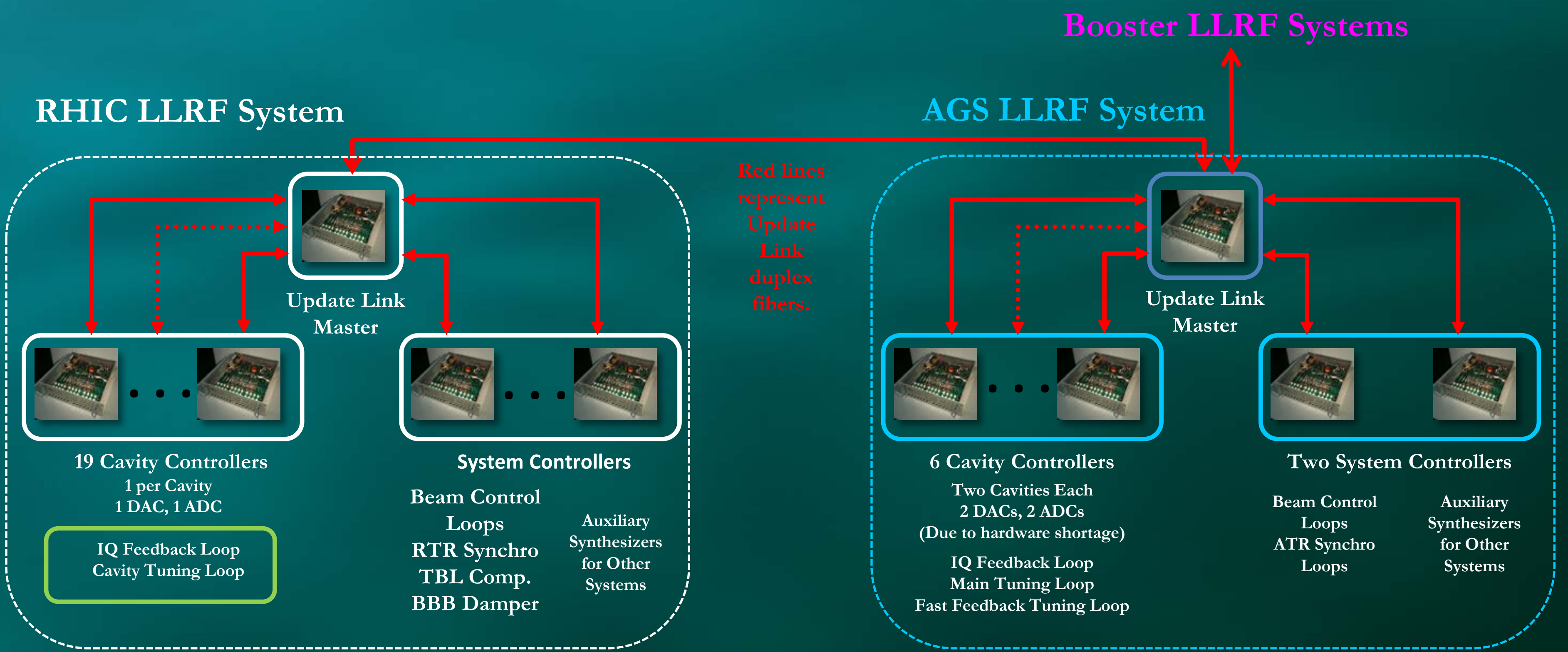

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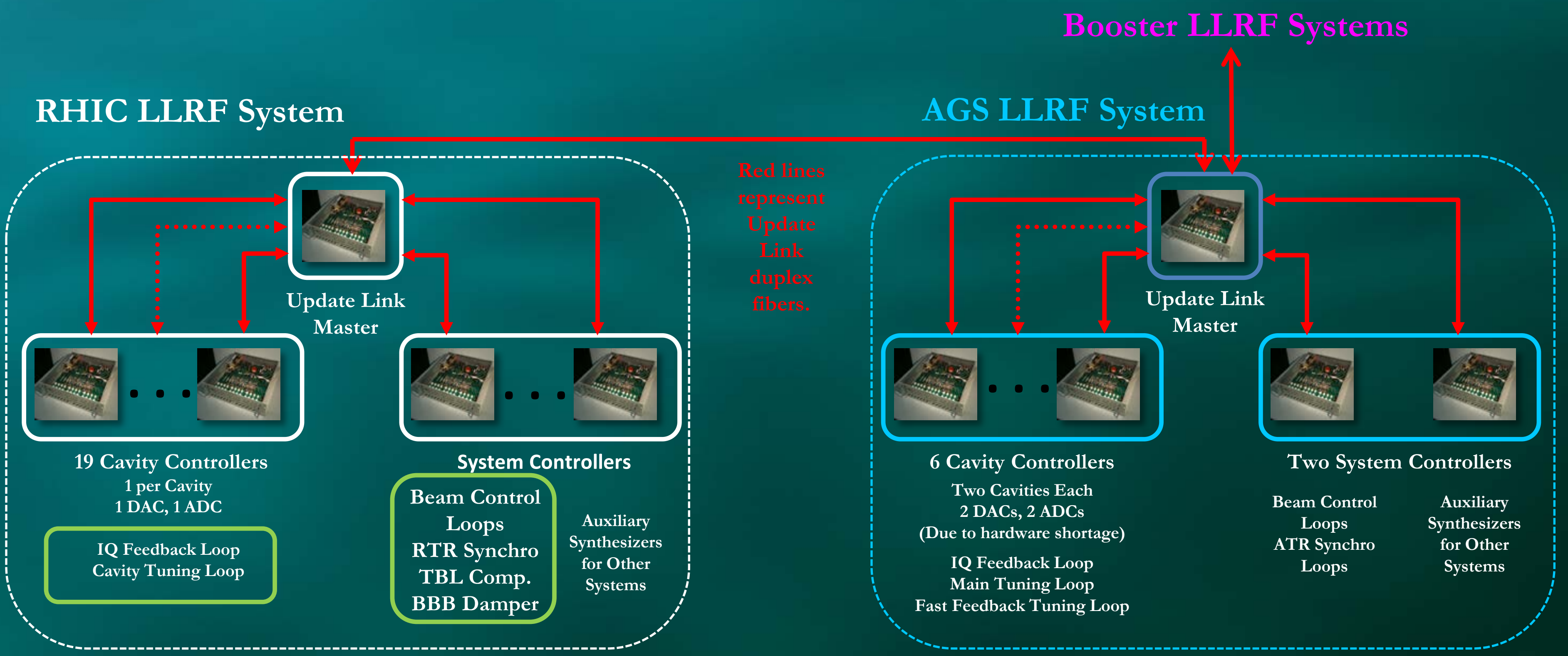

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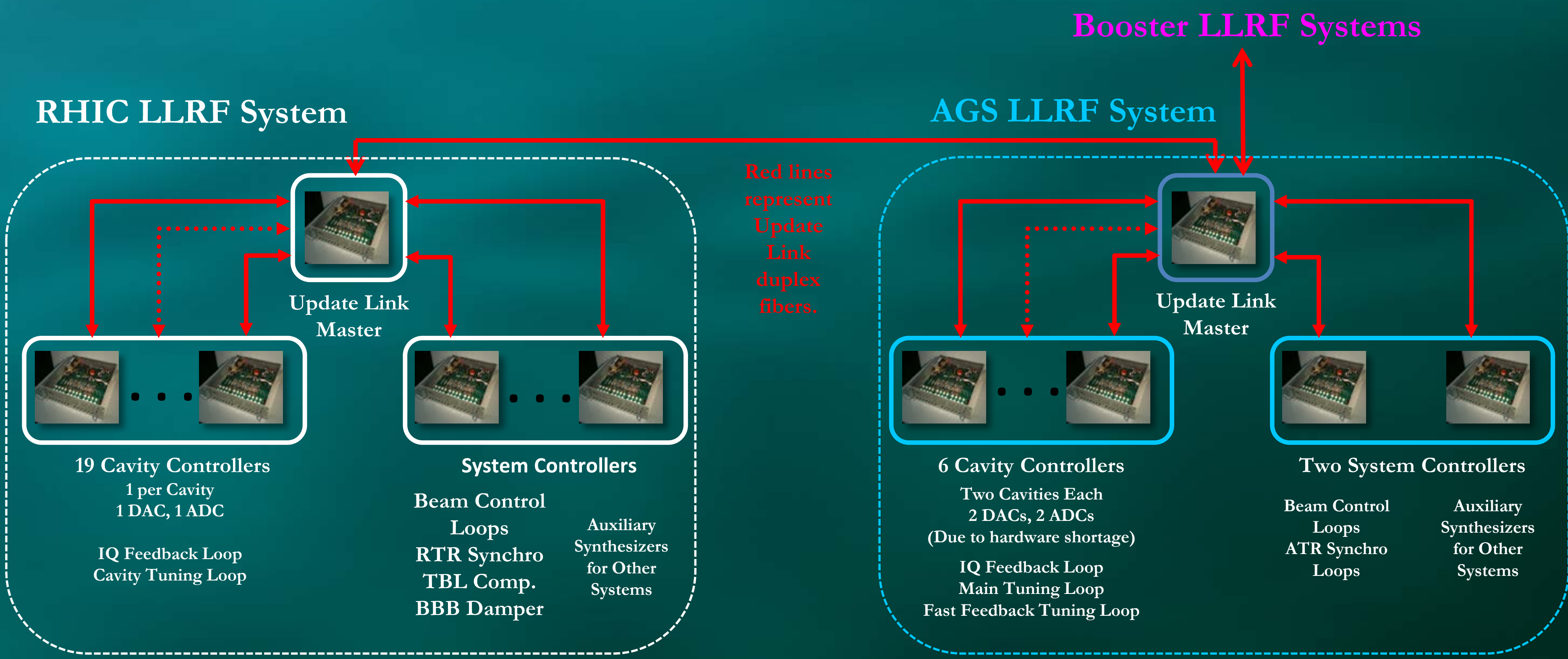

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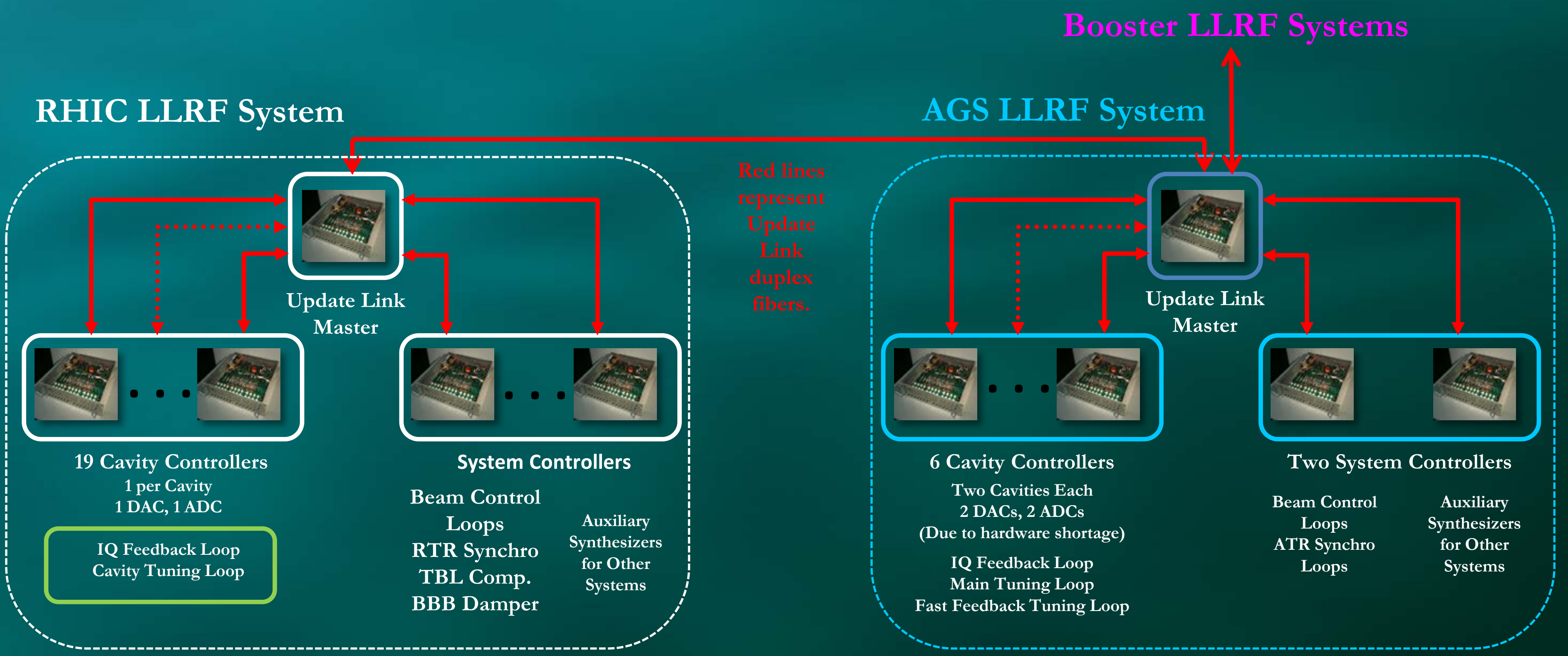

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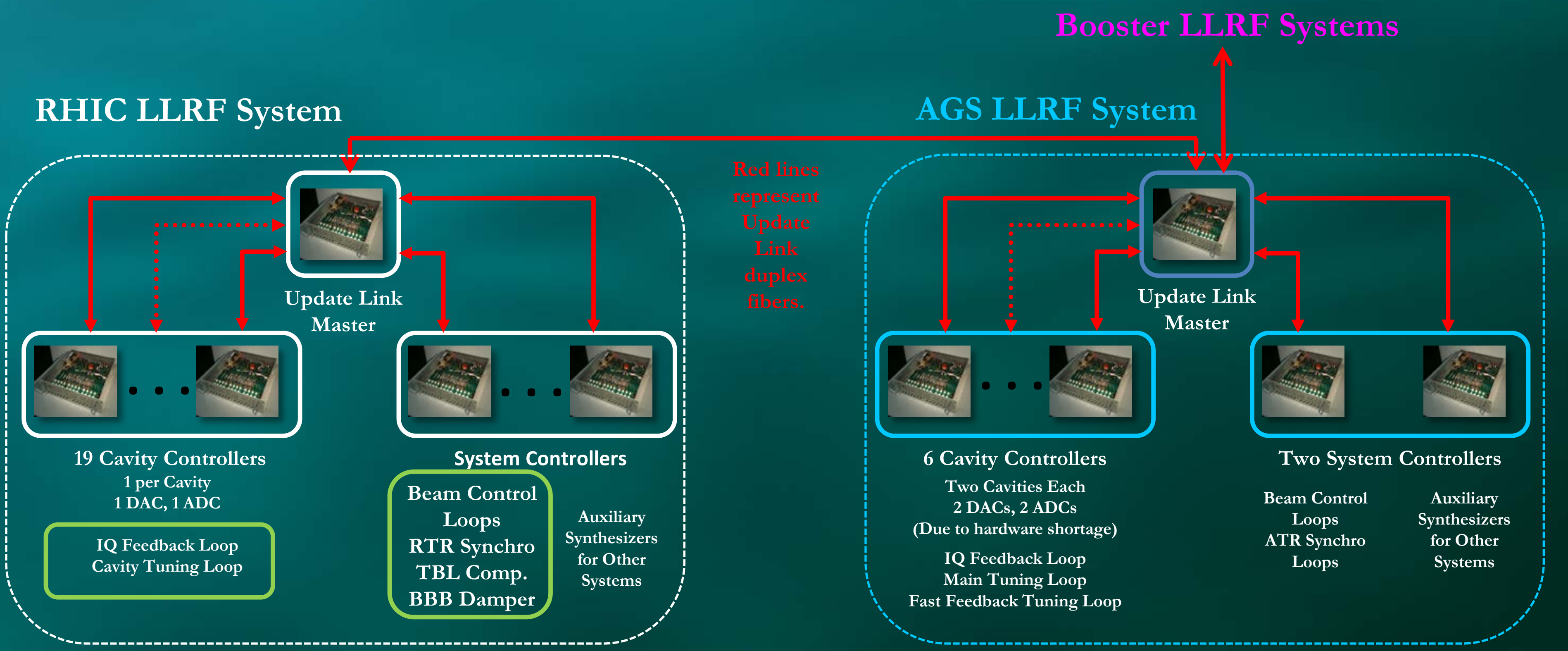

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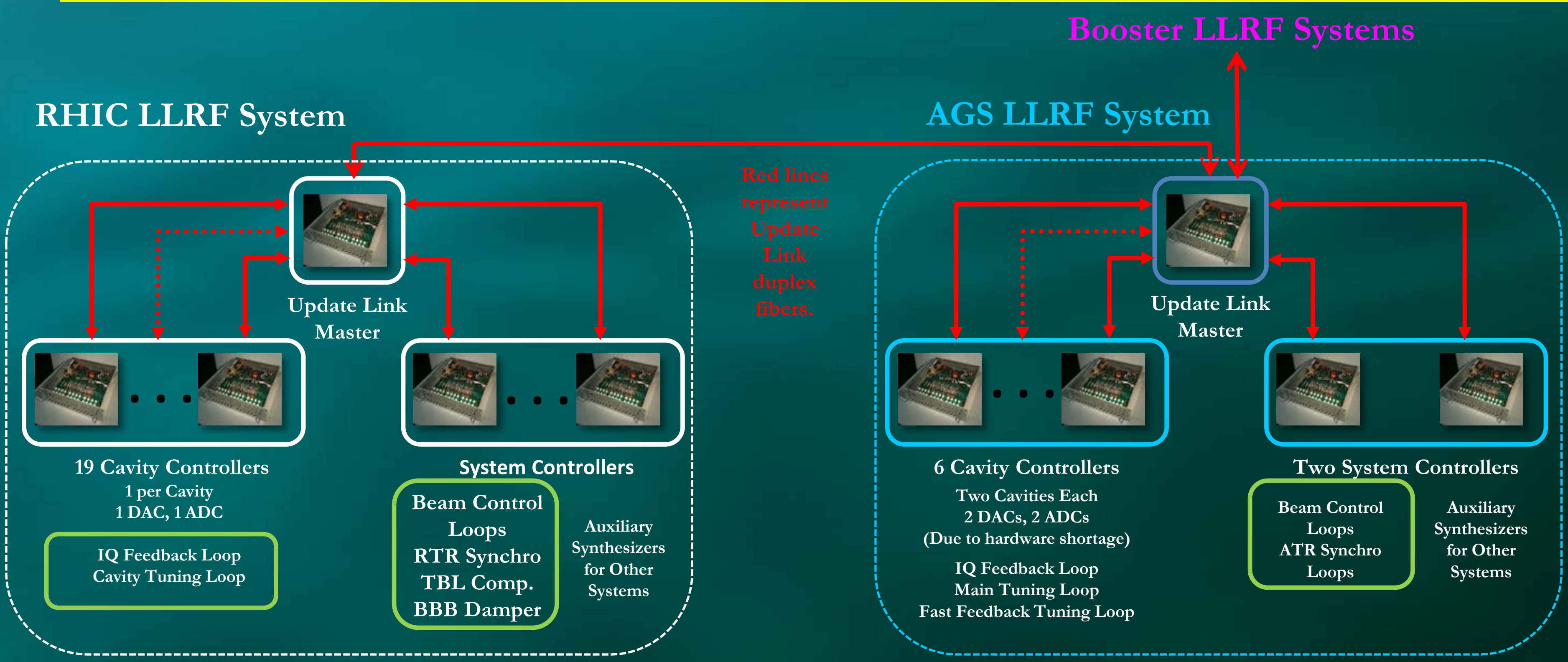

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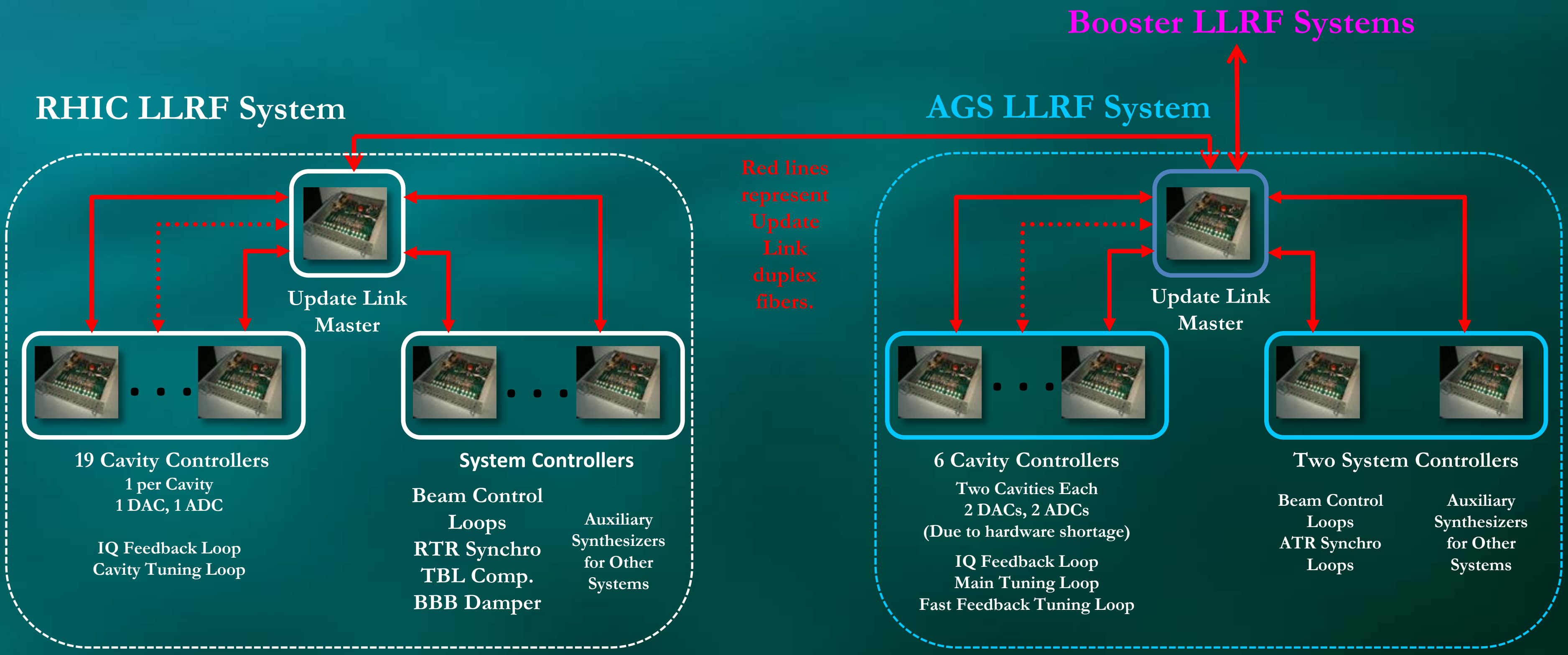

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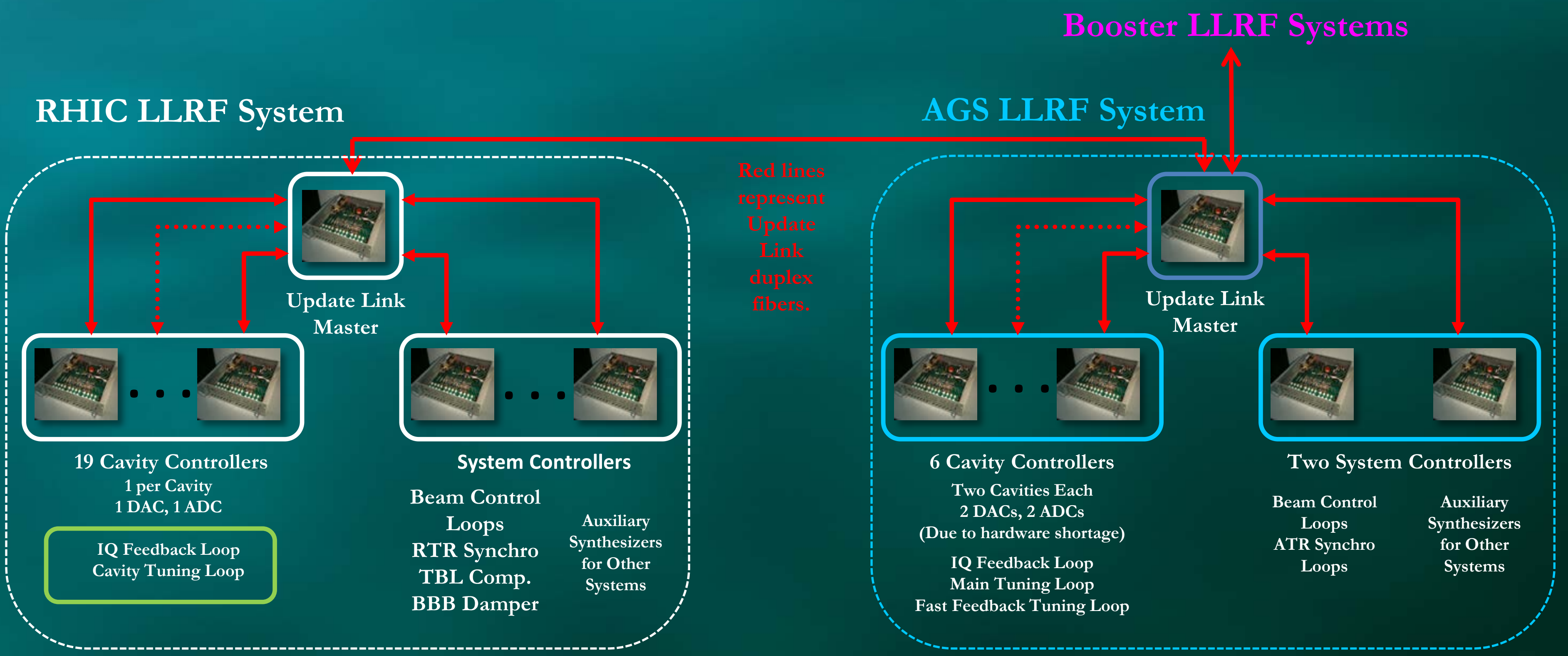

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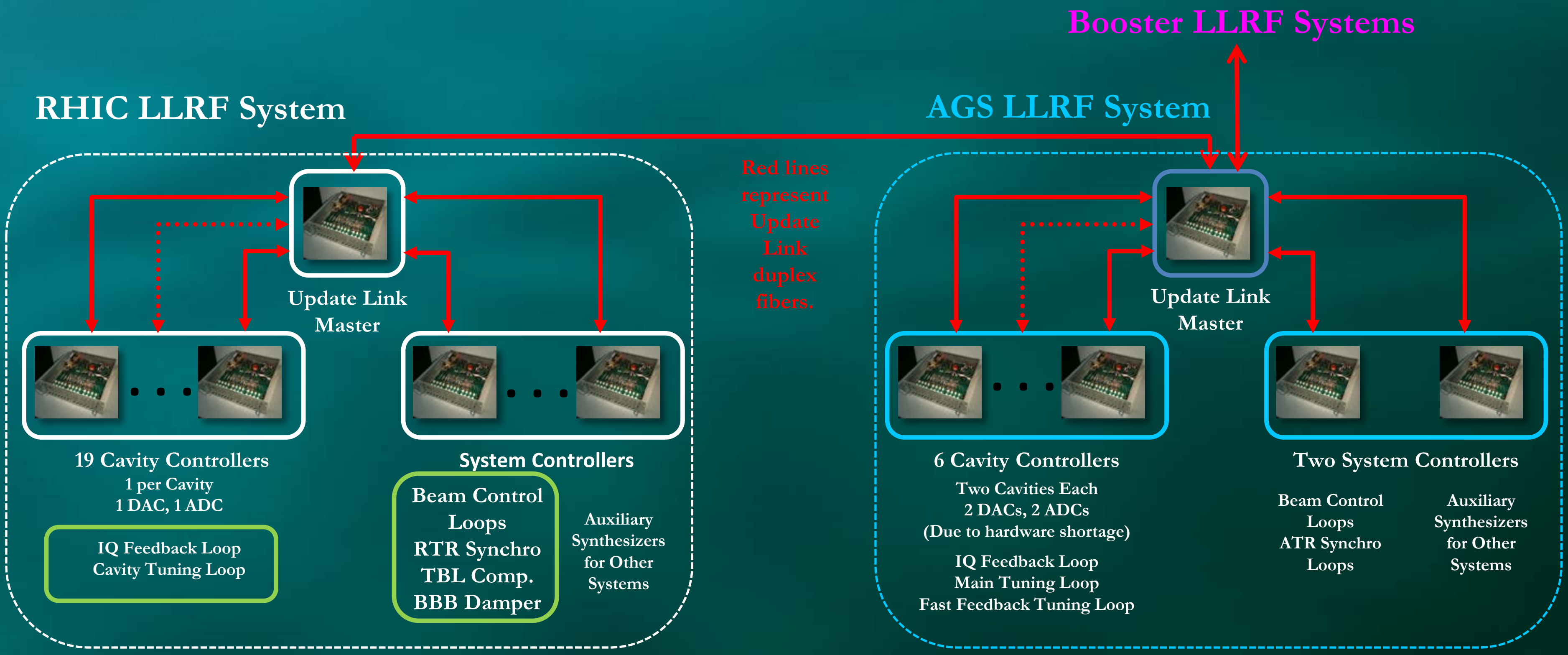

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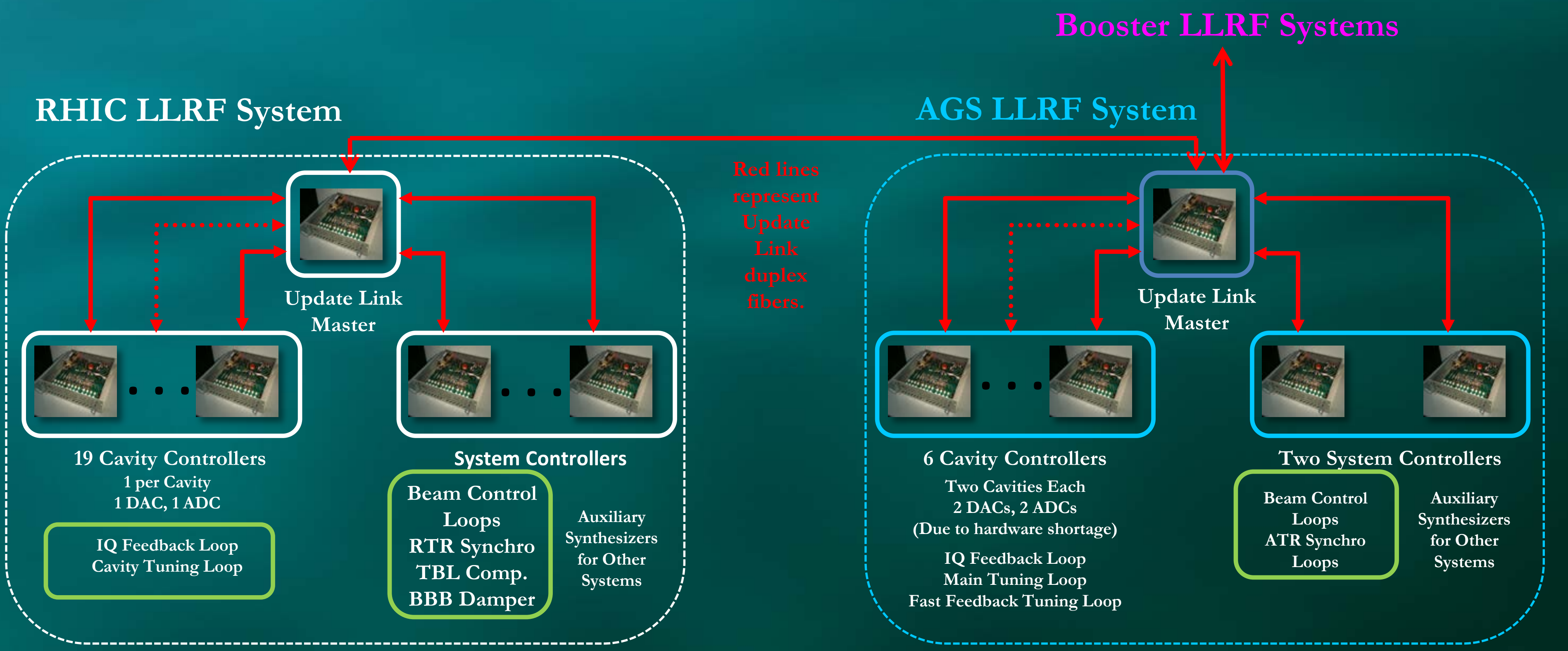

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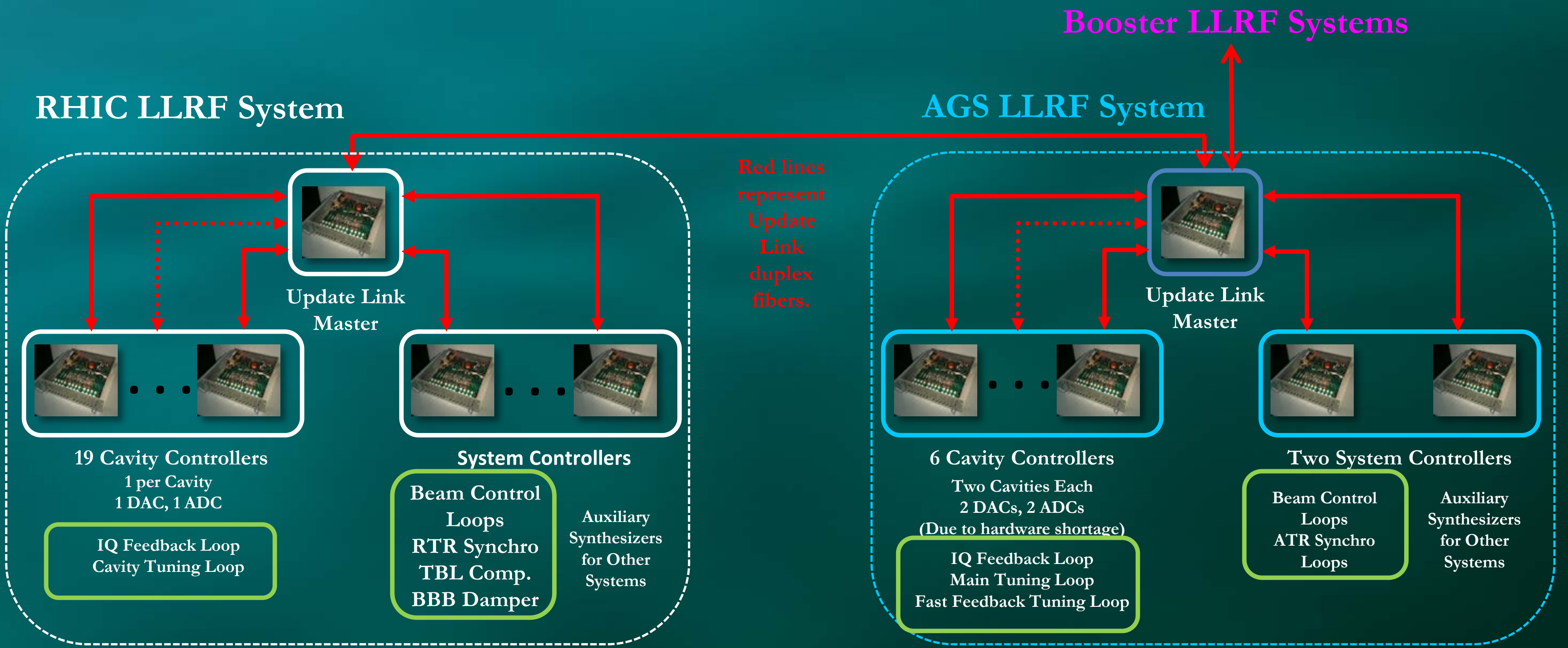

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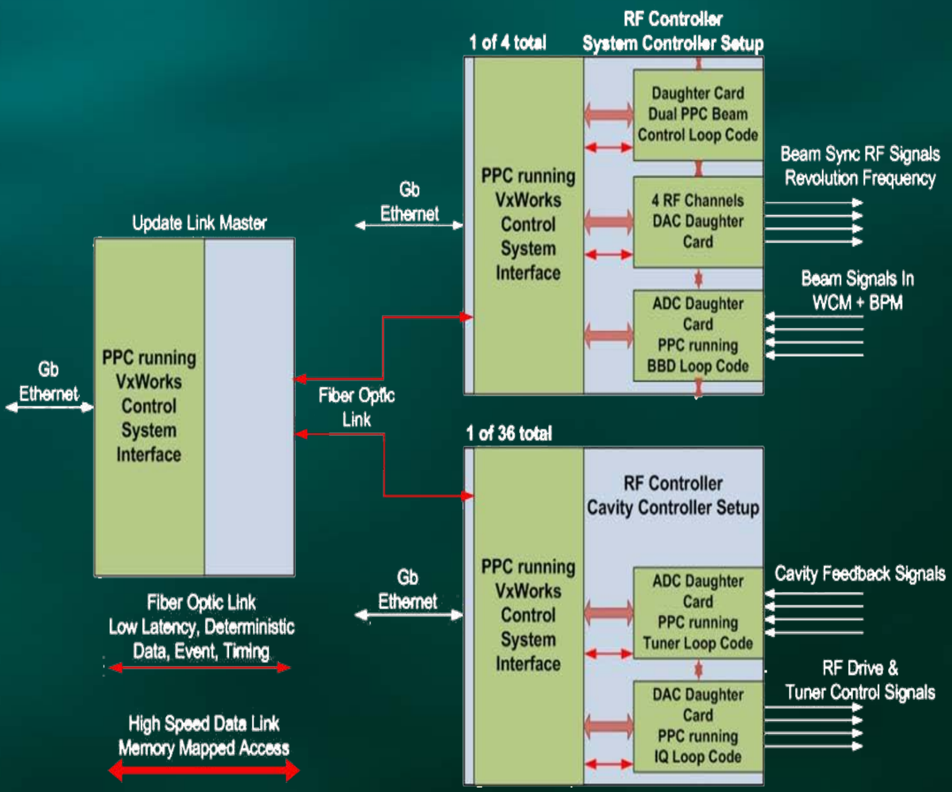
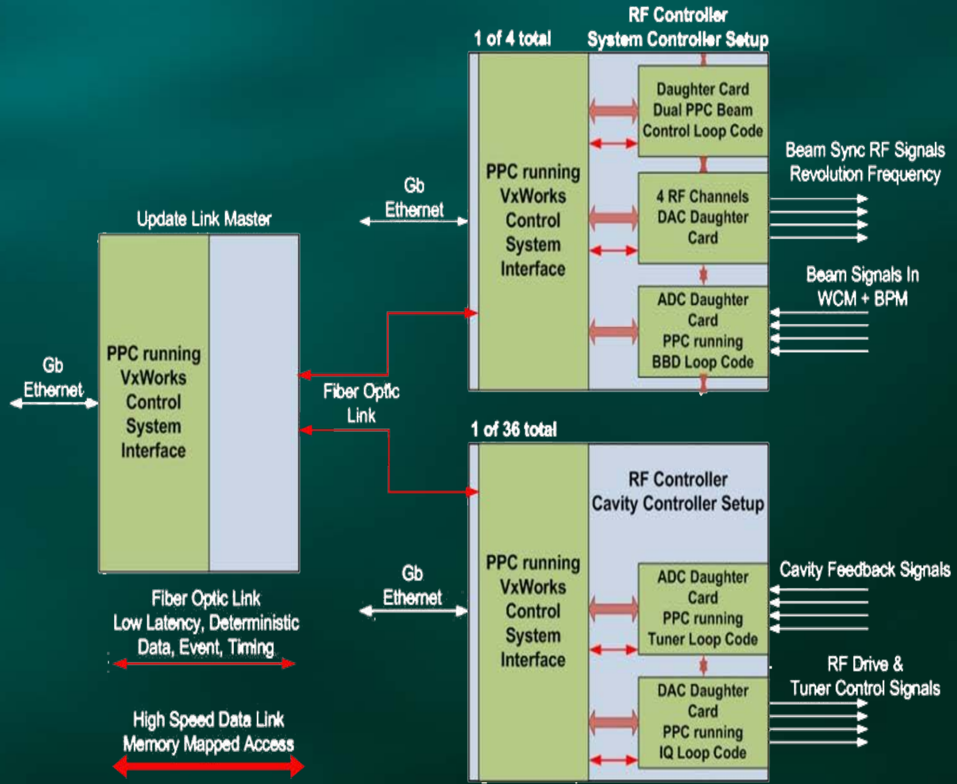


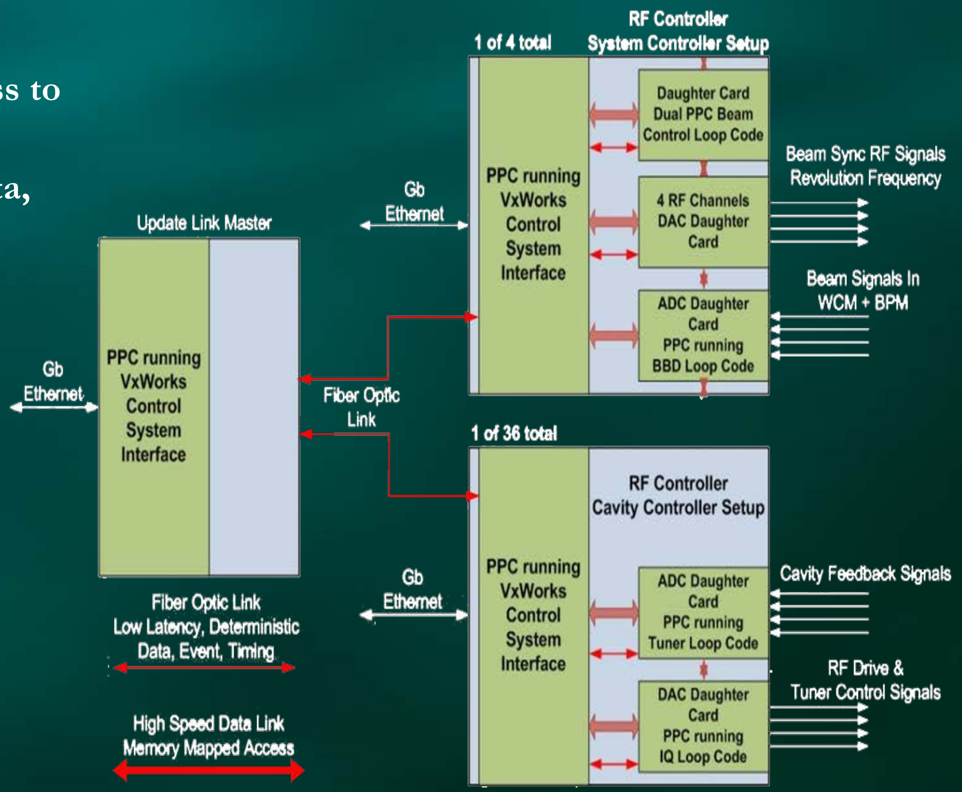
Platform Architecture -continued



Platform Architecture -continued

- RF controller PPC VxWorks, RHIC Control System over Gigabit Ethernet.
- Use daughter card embedded PowerPC for Implementing the Various Loops.
- High Speed Data Link for Memory Mapped Access to VxWorks.
- Deterministic, low latency link for time critical data, events & timing based on Xilinx Gigabit serial transceivers.

- RHIC Control System handles:
- Remote configuration, data logging & archiving, monitors system health indicators,…



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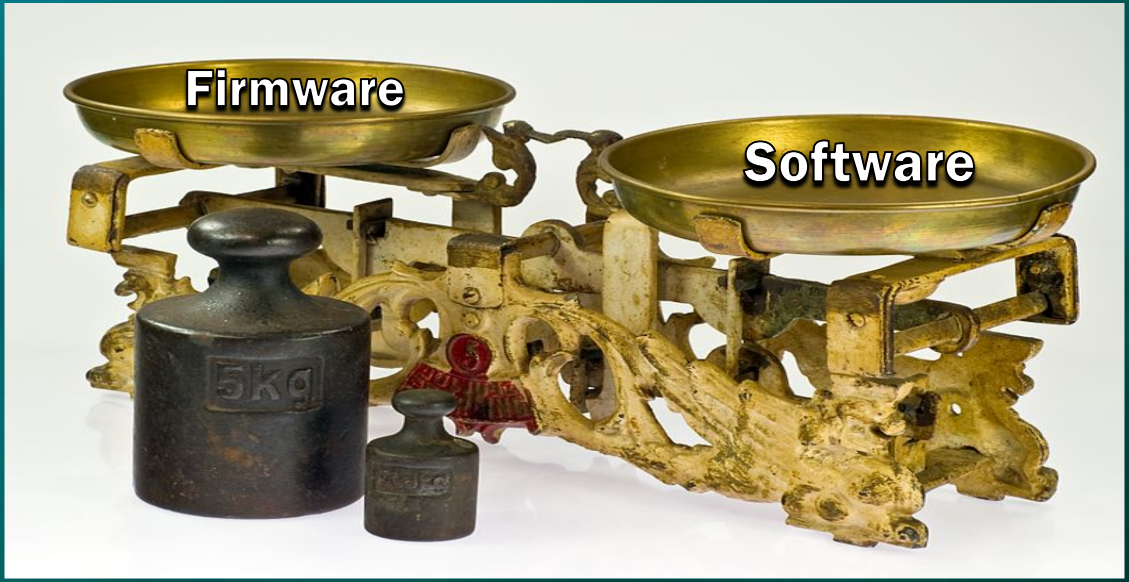

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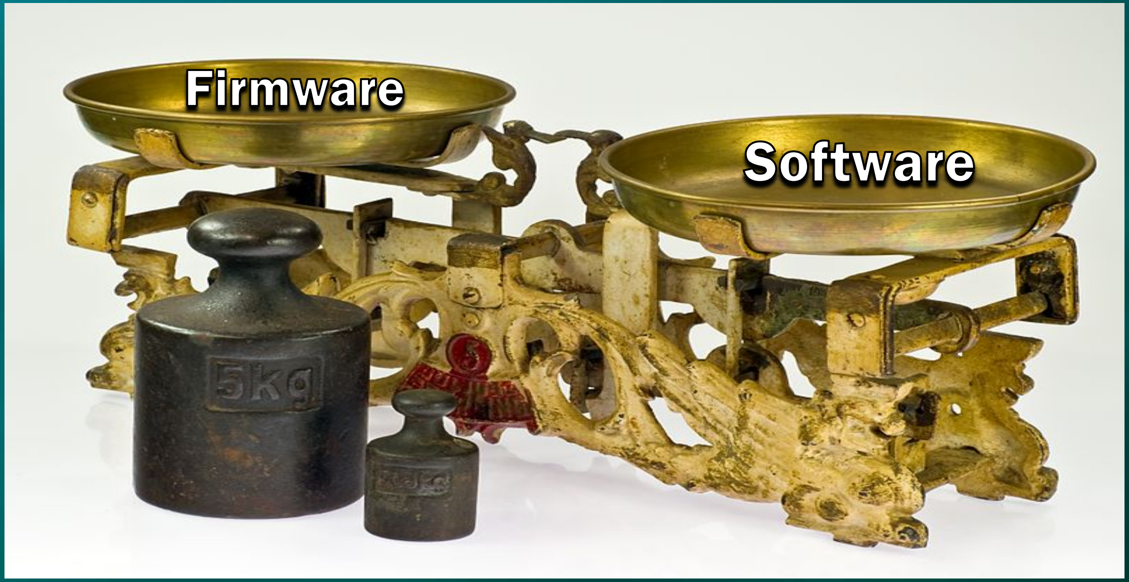

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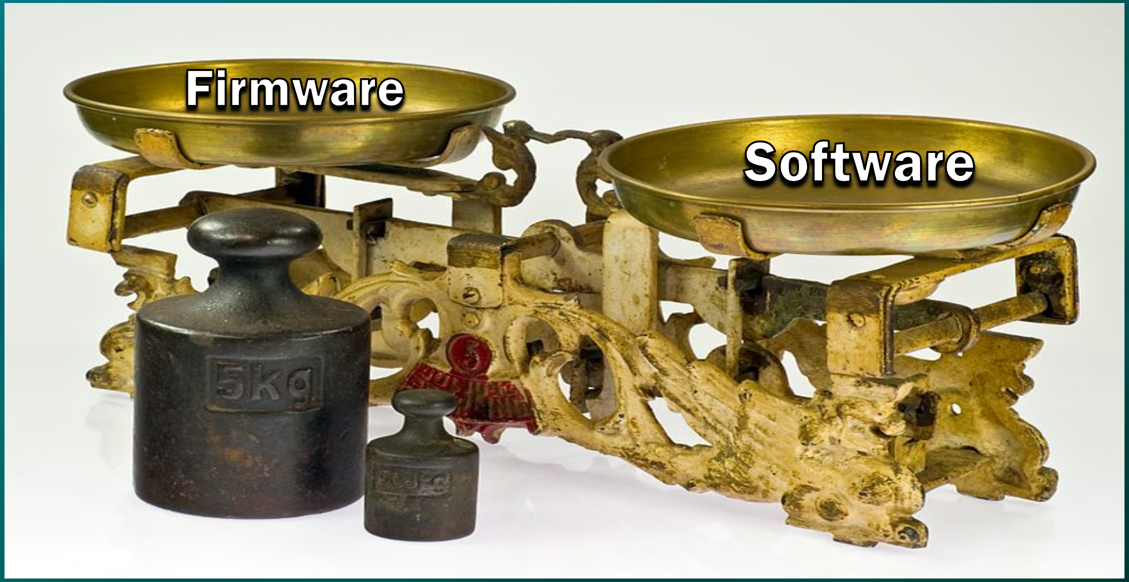
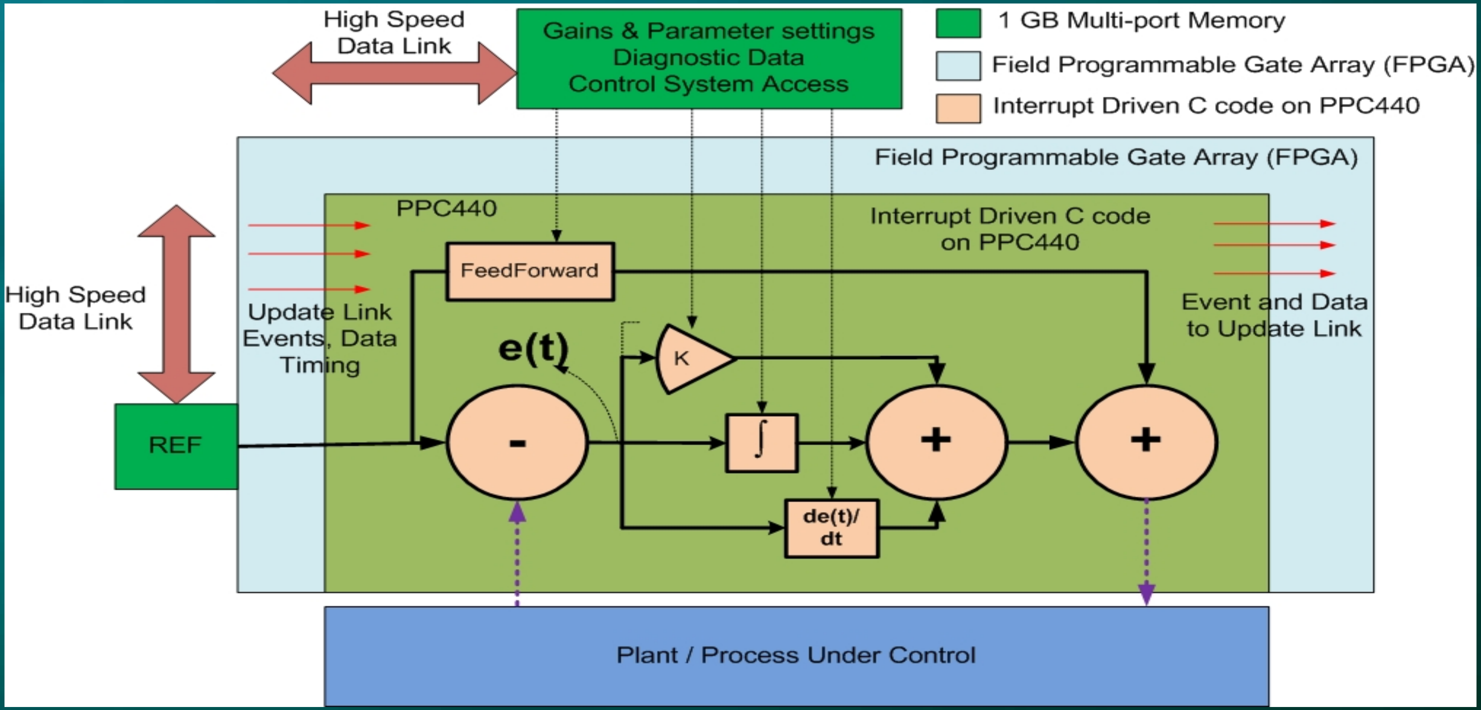


- Combined approach Processor & FPGA fabric.
- FPGA Programmable Logic, gives us power of parallel high speed.
- DDS, fast CIC filters, up to 400 MHz
- CPU based for flexibility, faster & easier development.
- Easy access to FPGA based functions and the control system.

Generic Implementation of a Feedback Loop



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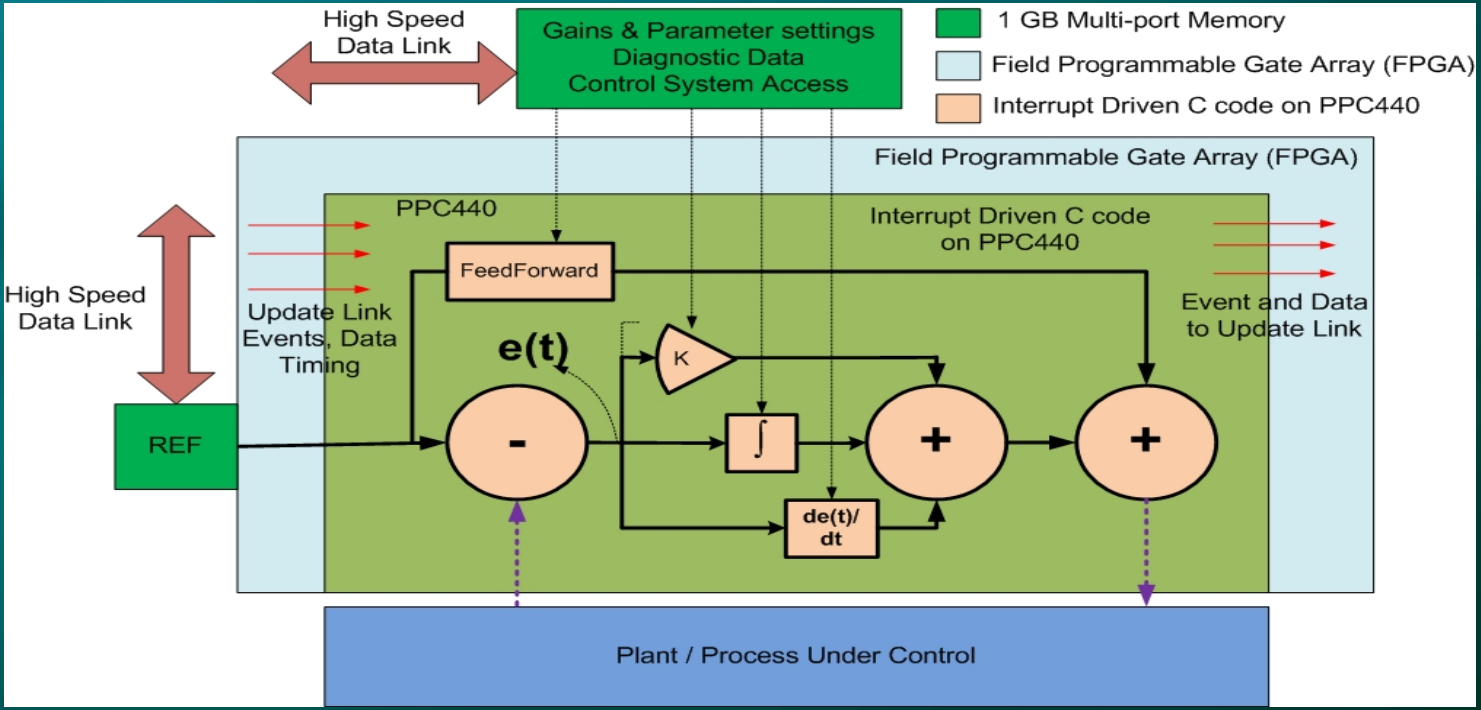

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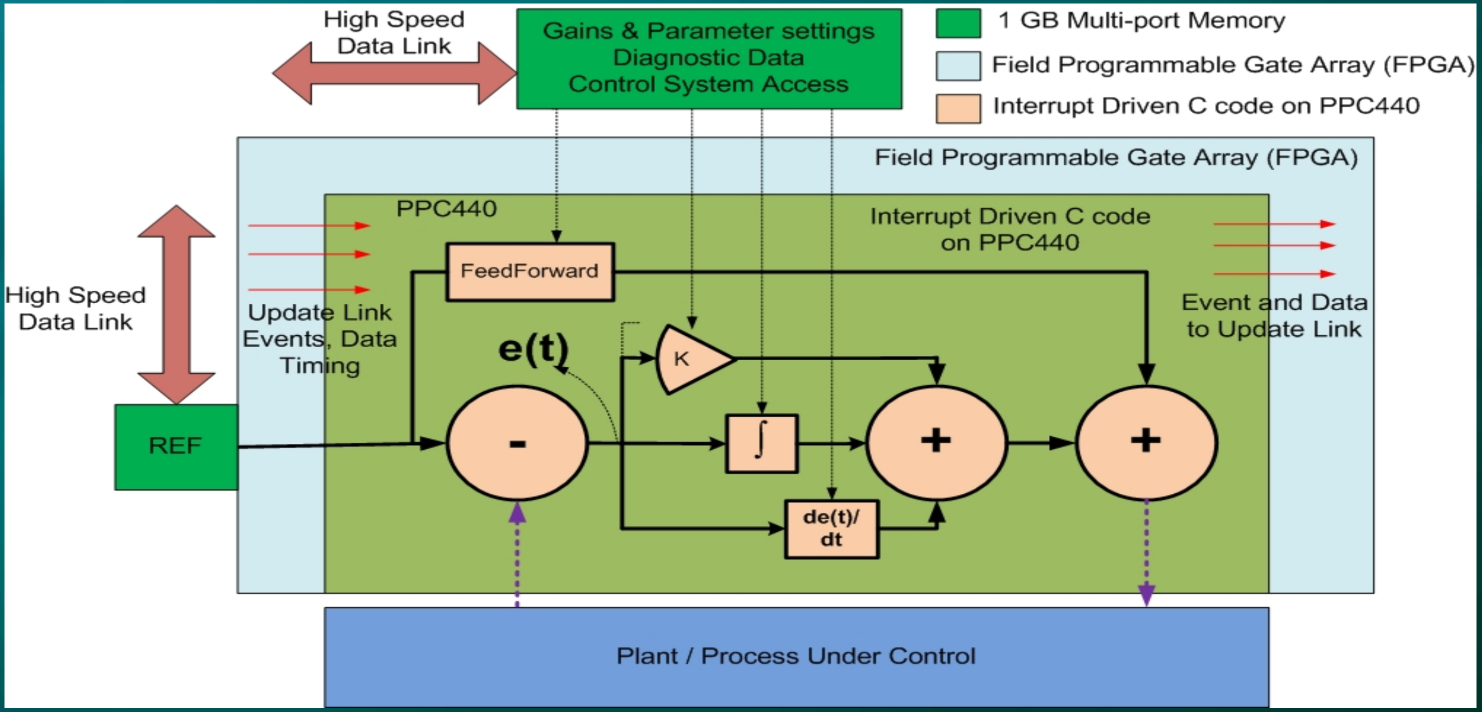
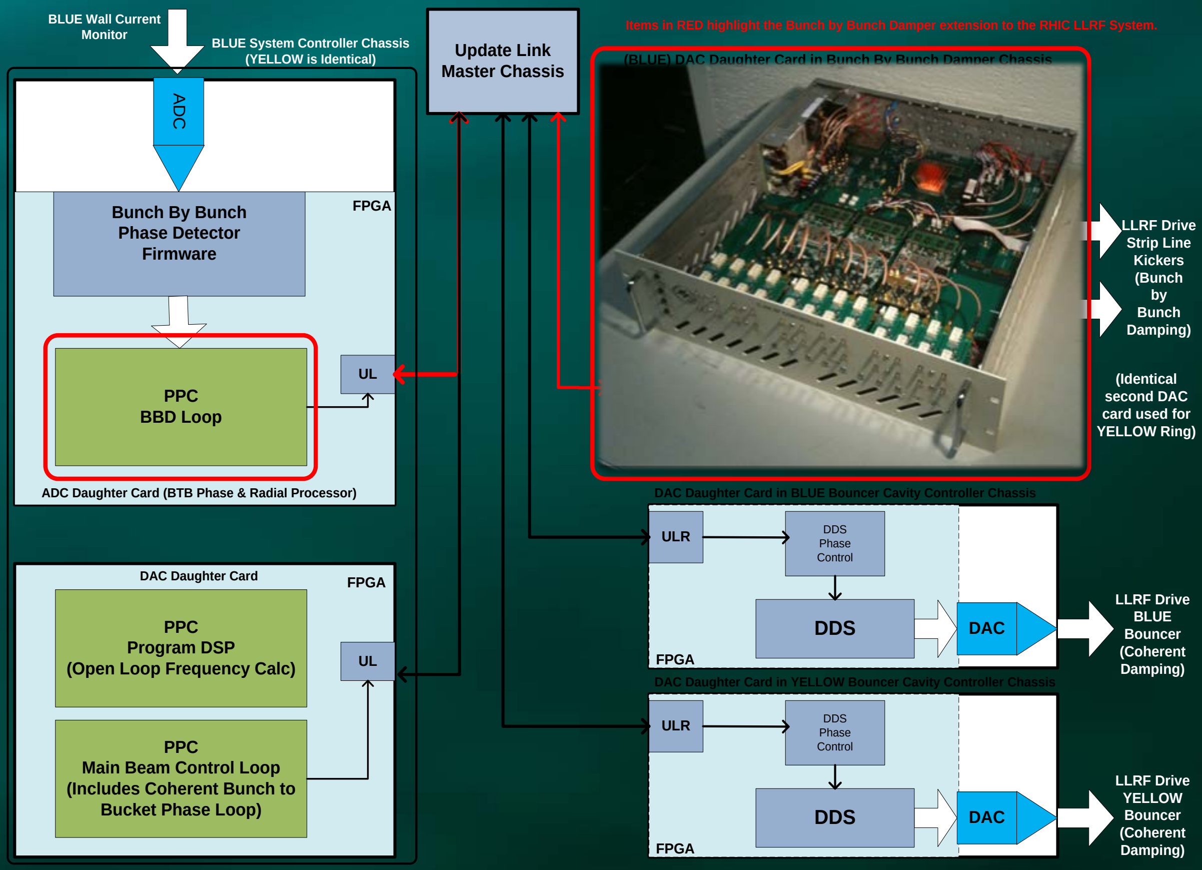


- Loop implemented in a Xilinx Virtex-5 FPGA embedded PowerPC 440.
- Xilinx tools for developing firmware & CPU code.
- In general these loops consist of a PID controller.
- Interrupt driven code written in C.
- Use of Update Link System.

RHIC Bunch by Bunch Longitudinal Damper

RHIC Bunch by Bunch Longitudinal Damper Background

- Polarized Protons are captured and accelerated in a 9MHz RF system common to both rings.
- Above intensities of about 0.5E11/bunch, proton bunches exhibit multiple modes of longitudinal instability.



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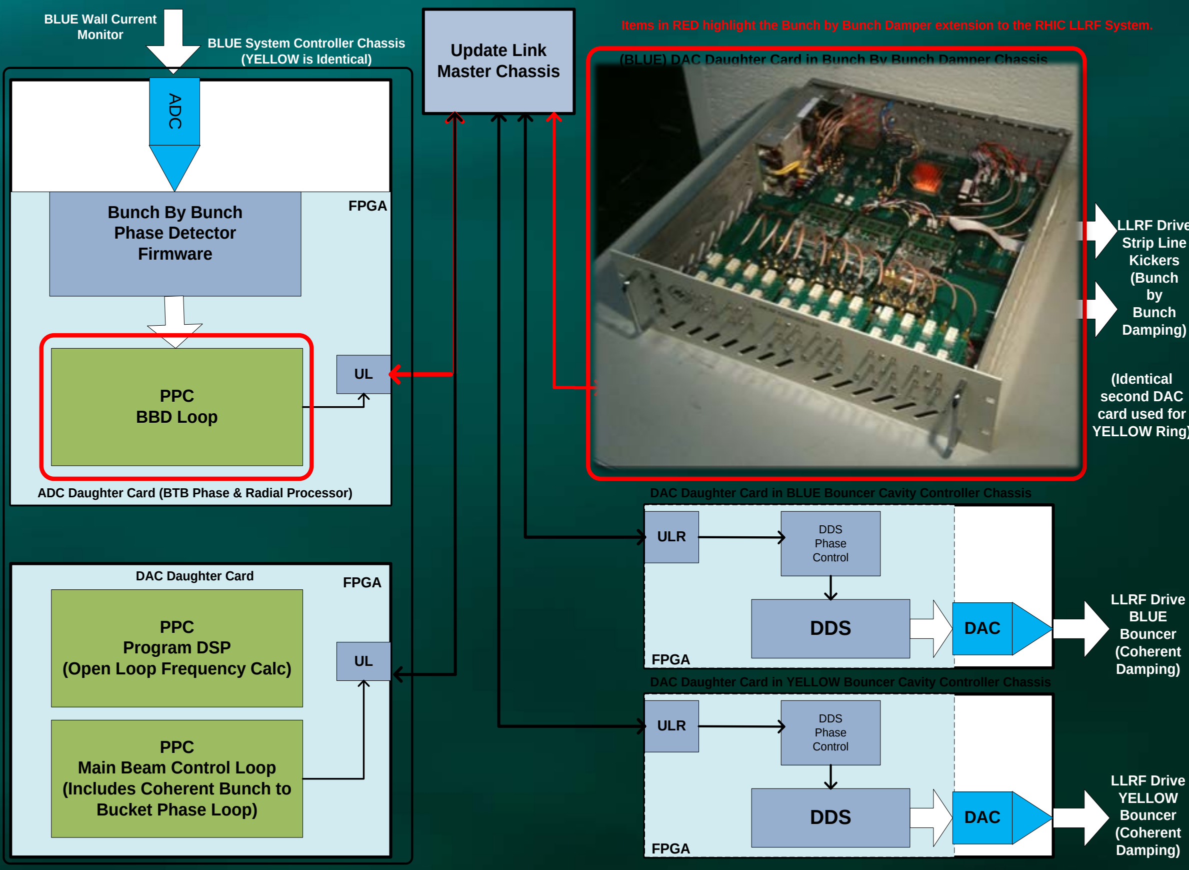

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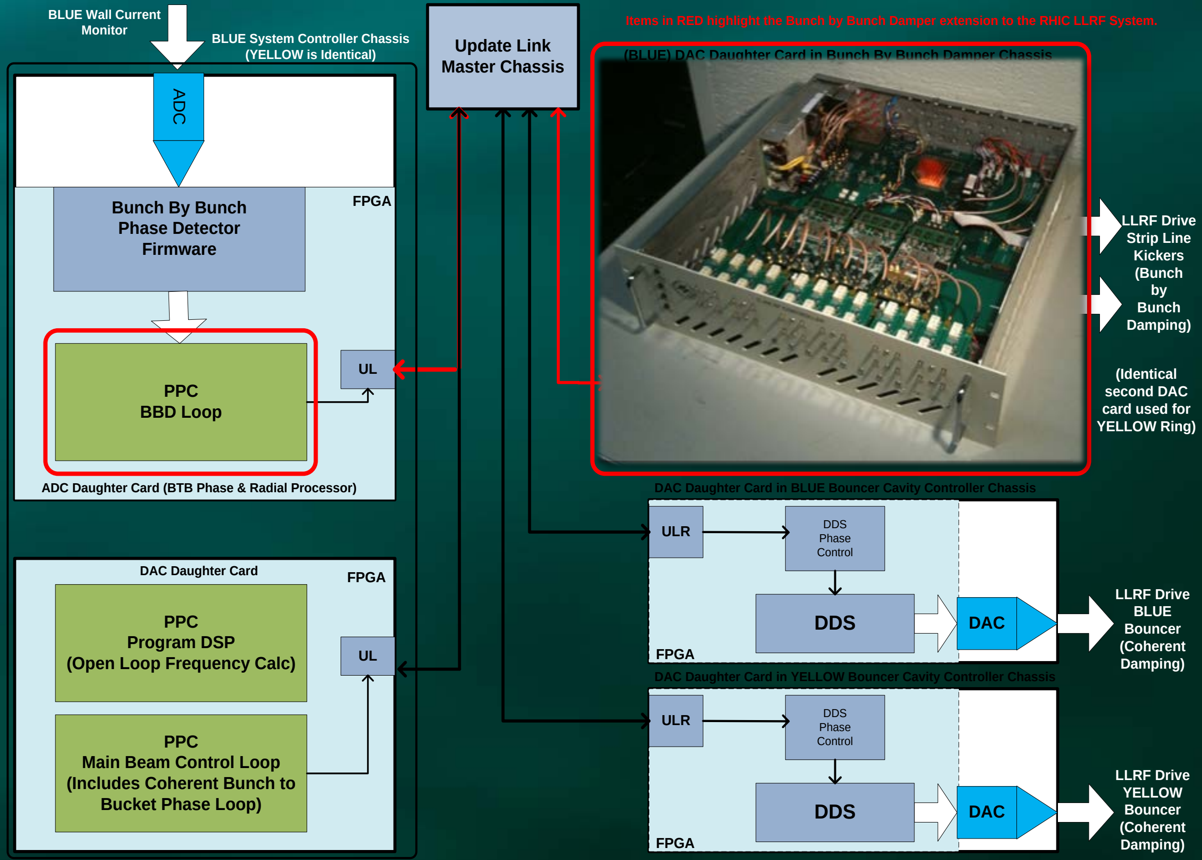
- The existing RHIC LLRF system B2B phase loop damped the coherent dipole oscillations, via 9 MHz "Bouncer" cavities in each ring.
- The RHIC Bunch by Bunch Longitudinal Damper was built to damp the incoherent bunch by bunch dipole oscillations.
- Takes advantage of key platform capabilities allowing for easy integration and system development.
- Commissioned over several four hour machine development periods. Very quickly made operational.



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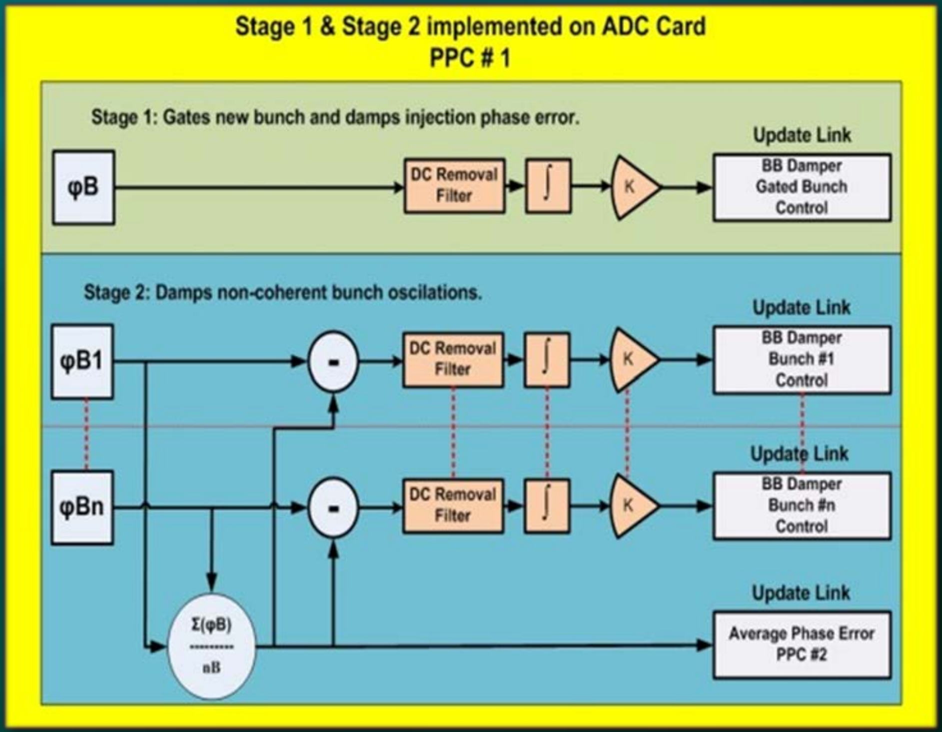

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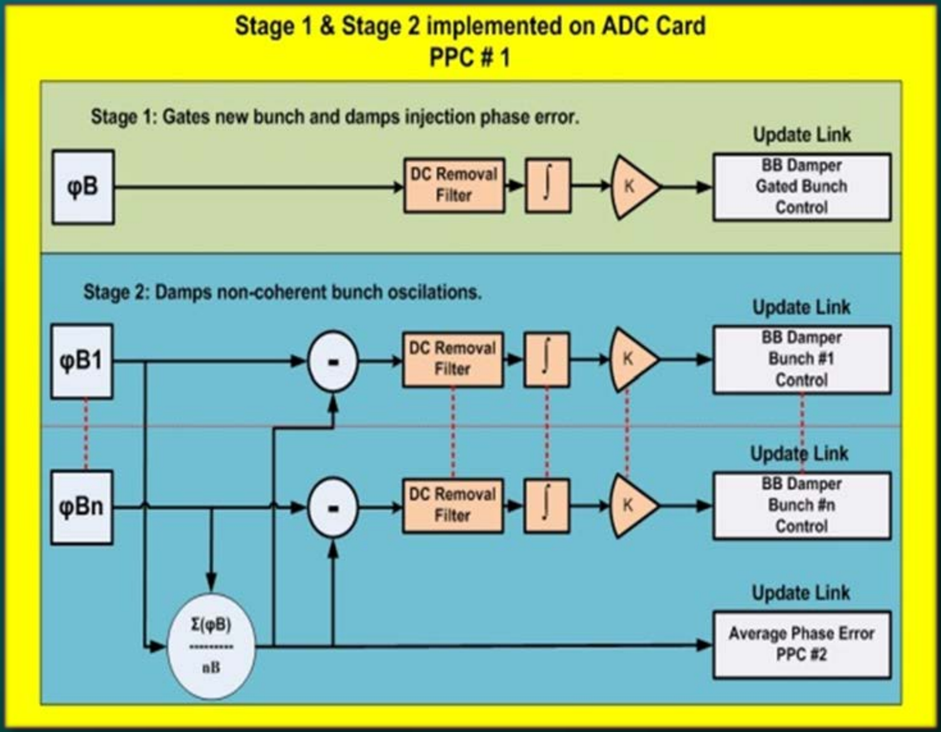
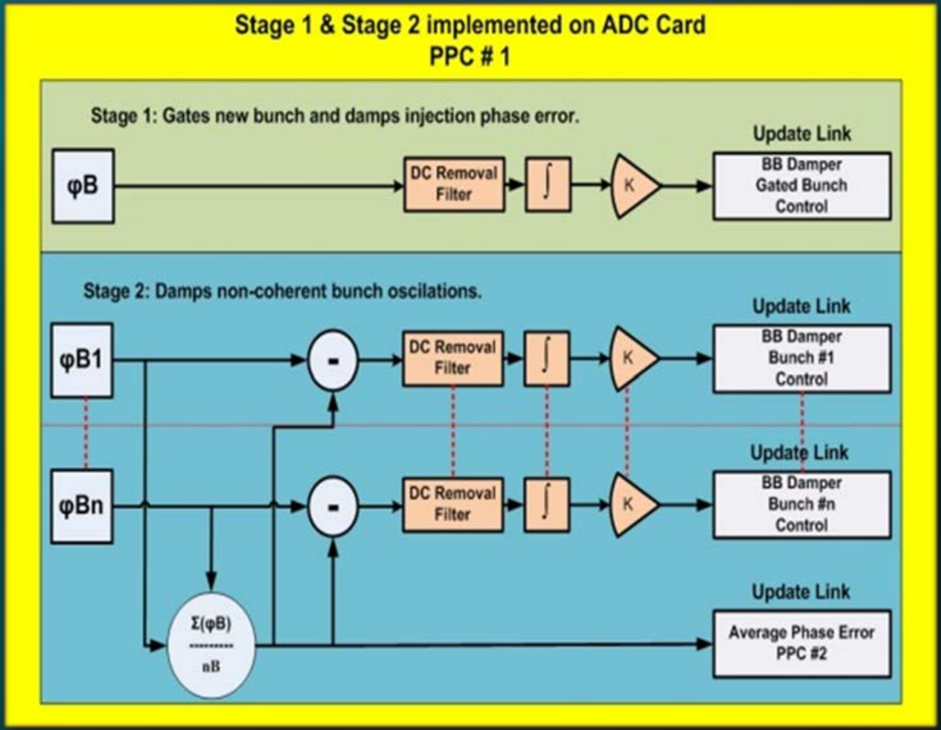


RHIC Bunch by Bunch Longitudinal Damper

RHIC Bunch by Bunch Longitudinal Damper Loop Implementation

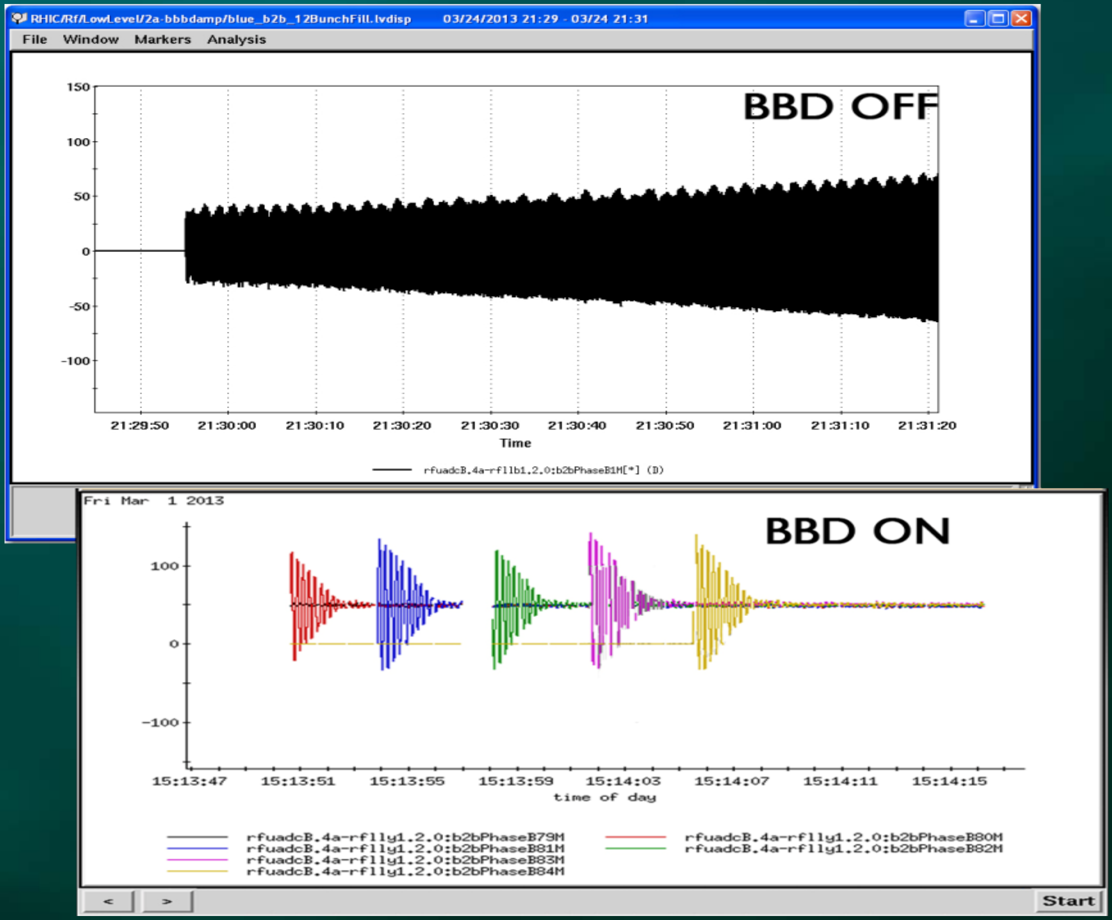


- Stage 1:
- Damps new bunch for 3 Sec with BBLD loop only.
- After injection damped send this bunch info to stage 2.

- Stage2:
- BBLD works on non-coherent bunch oscillations.
- Calculates & sends coherent bunch oscillations to main loop.
- Main loop uses Bouncer cavity to damp coherent/average bunch oscillations.

RHIC Bunch by Bunch Longitudinal Damper

RHIC Bunch by Bunch Longitudinal Damper Loop Damping Injection Oscillations



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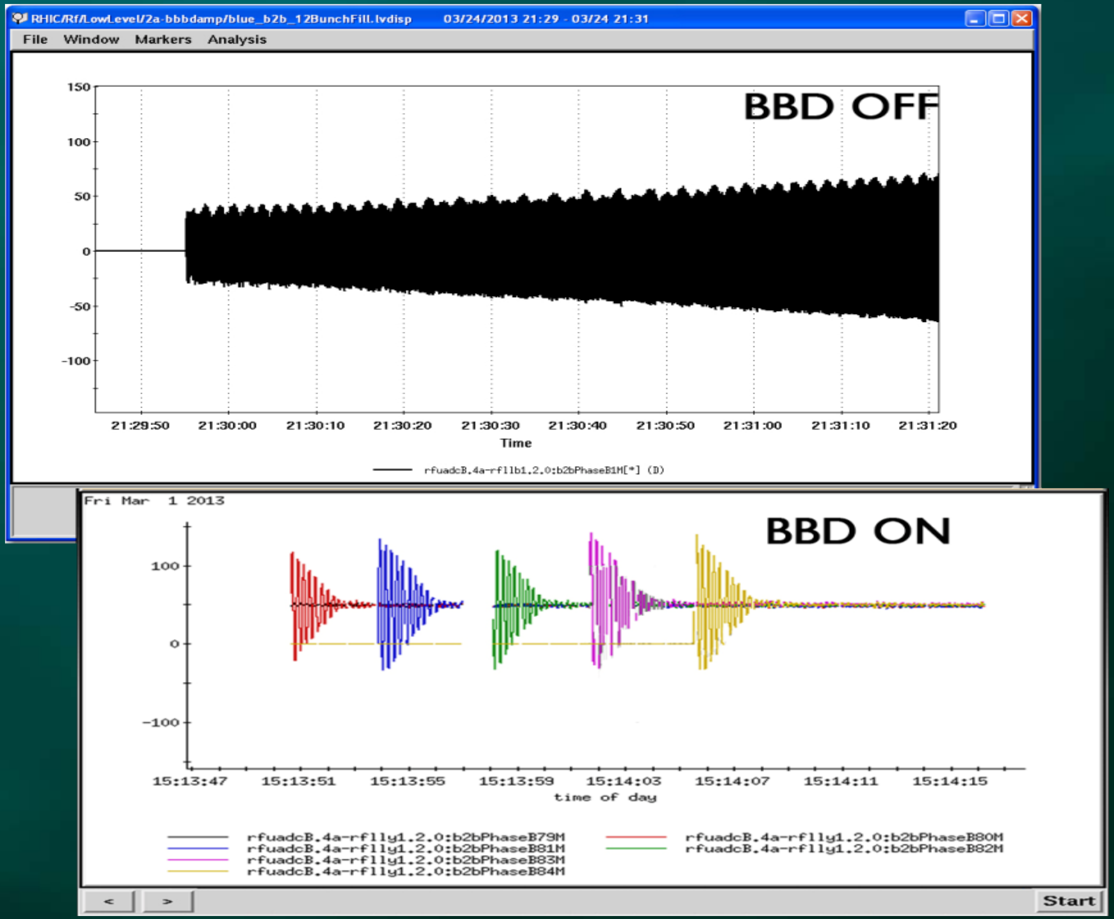
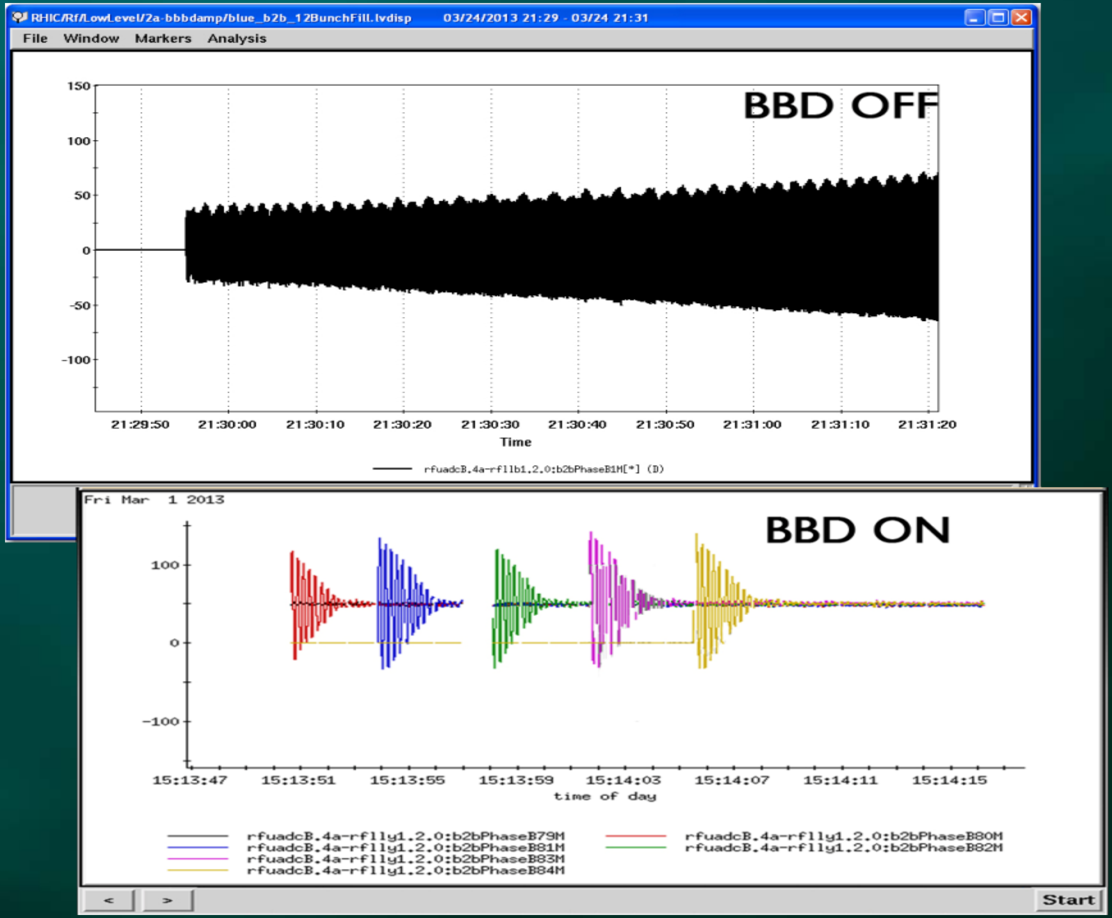


RHIC Bunch by Bunch Longitudinal Damper

RHIC Bunch by Bunch Longitudinal Damper Loop Damping Injection Oscillations

- Single bunch injected with damper OFF.

- Multiple bunches injected with loop ON.



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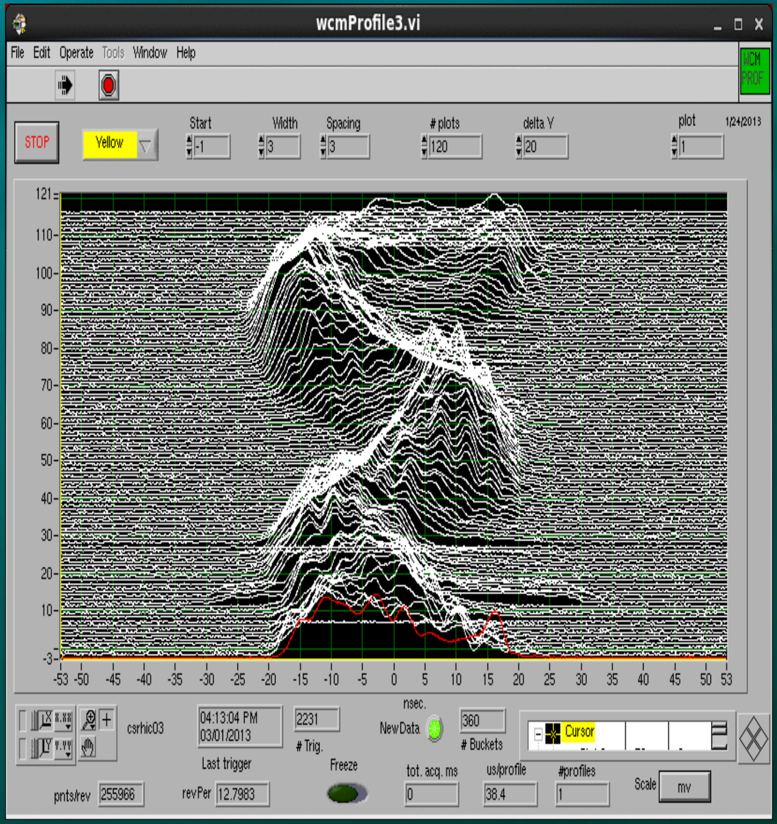
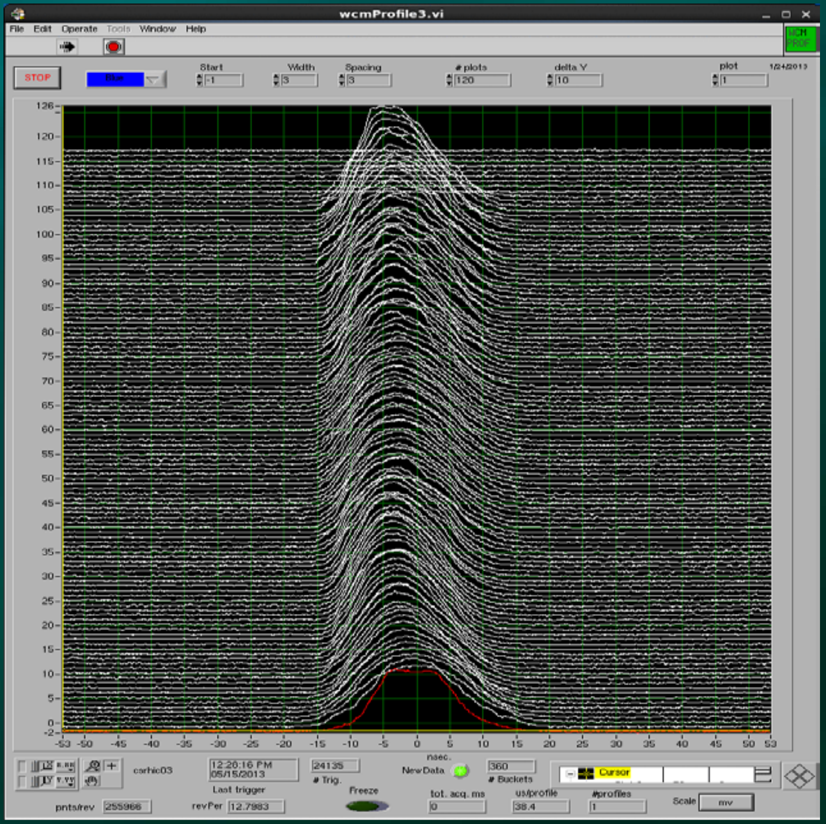
Damper Off

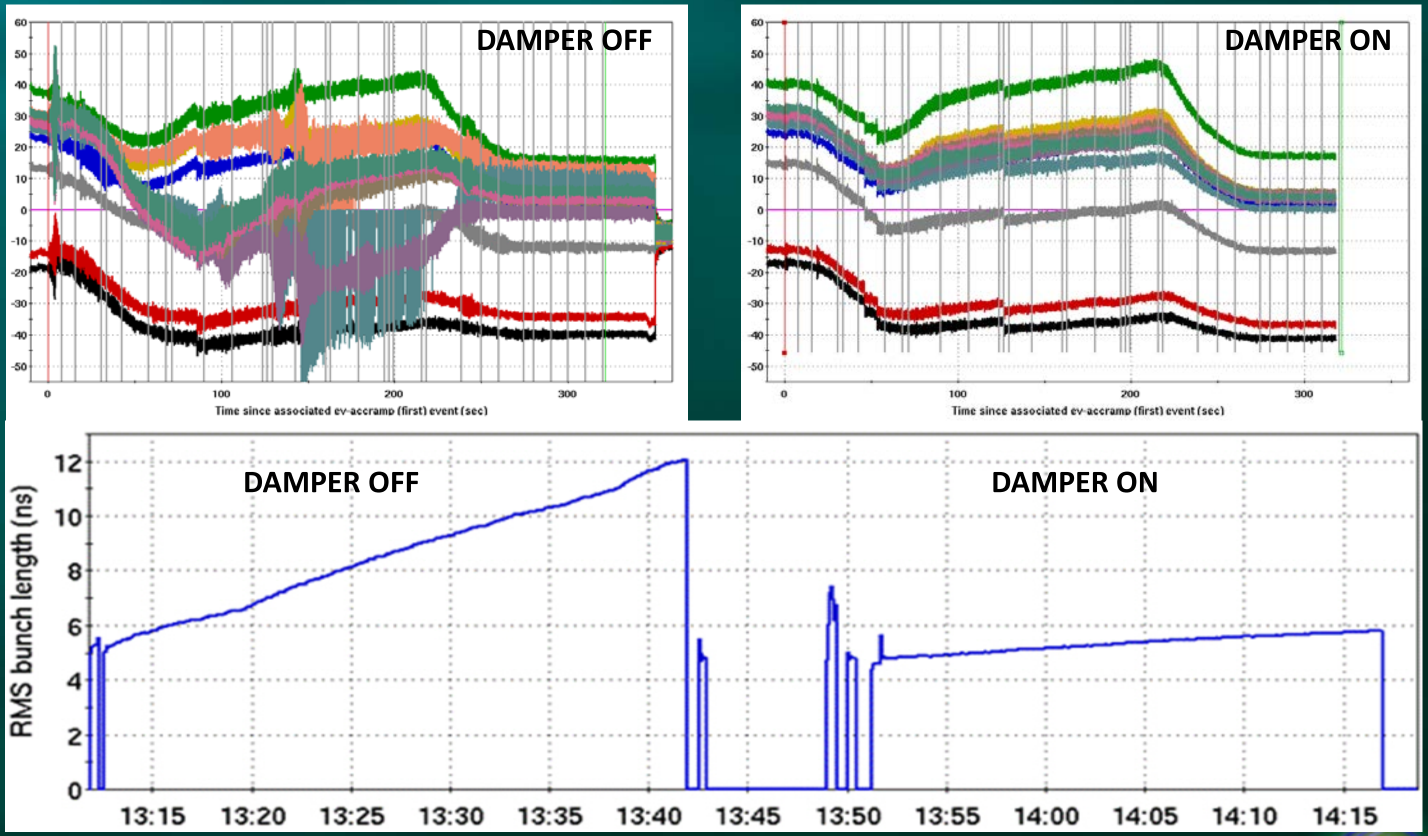


Damper On



One Turn Mountain Range Plots of a 110 bunch RHIC Blue Ring Fill.

RHIC Bunch by Bunch Longitudinal Damper



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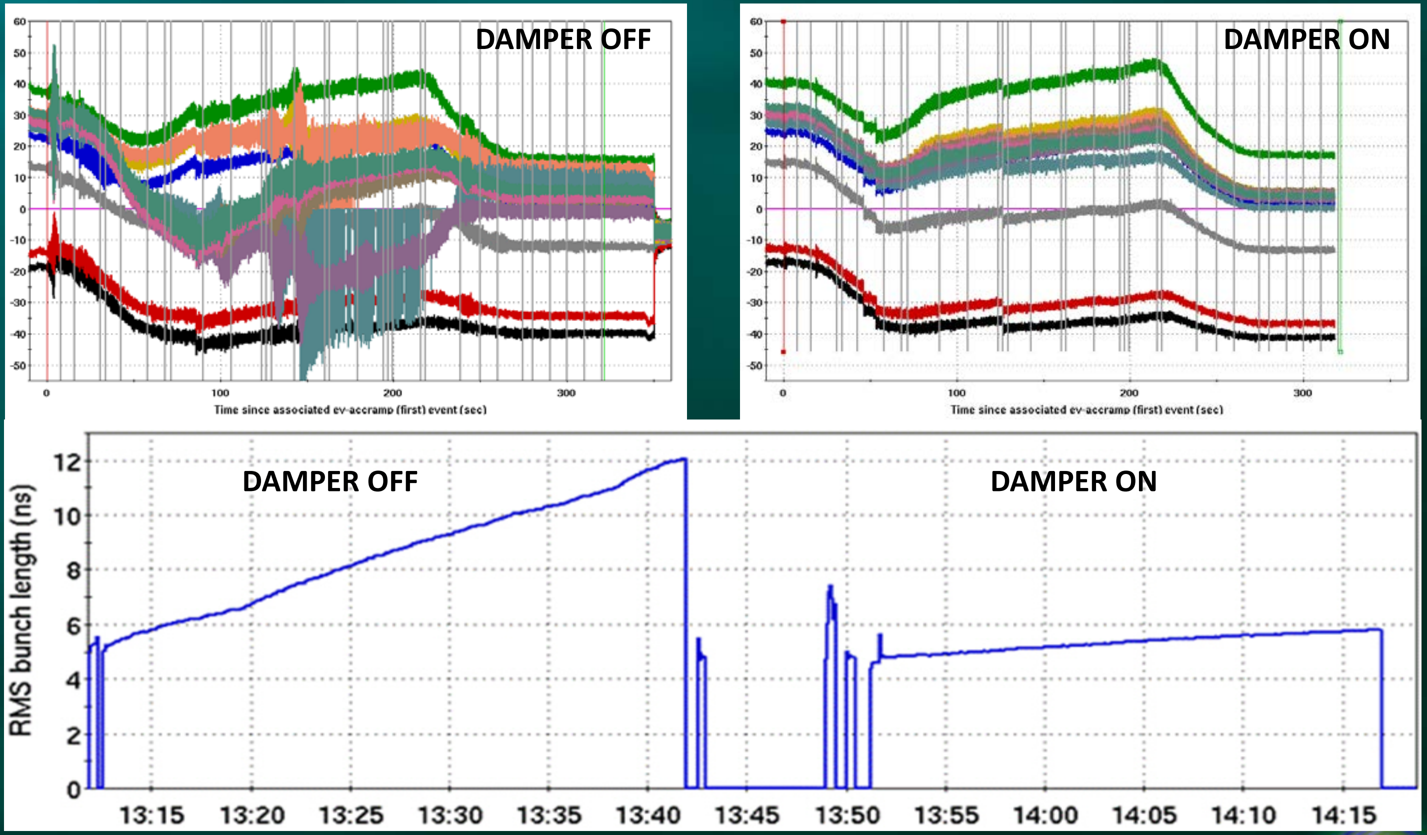
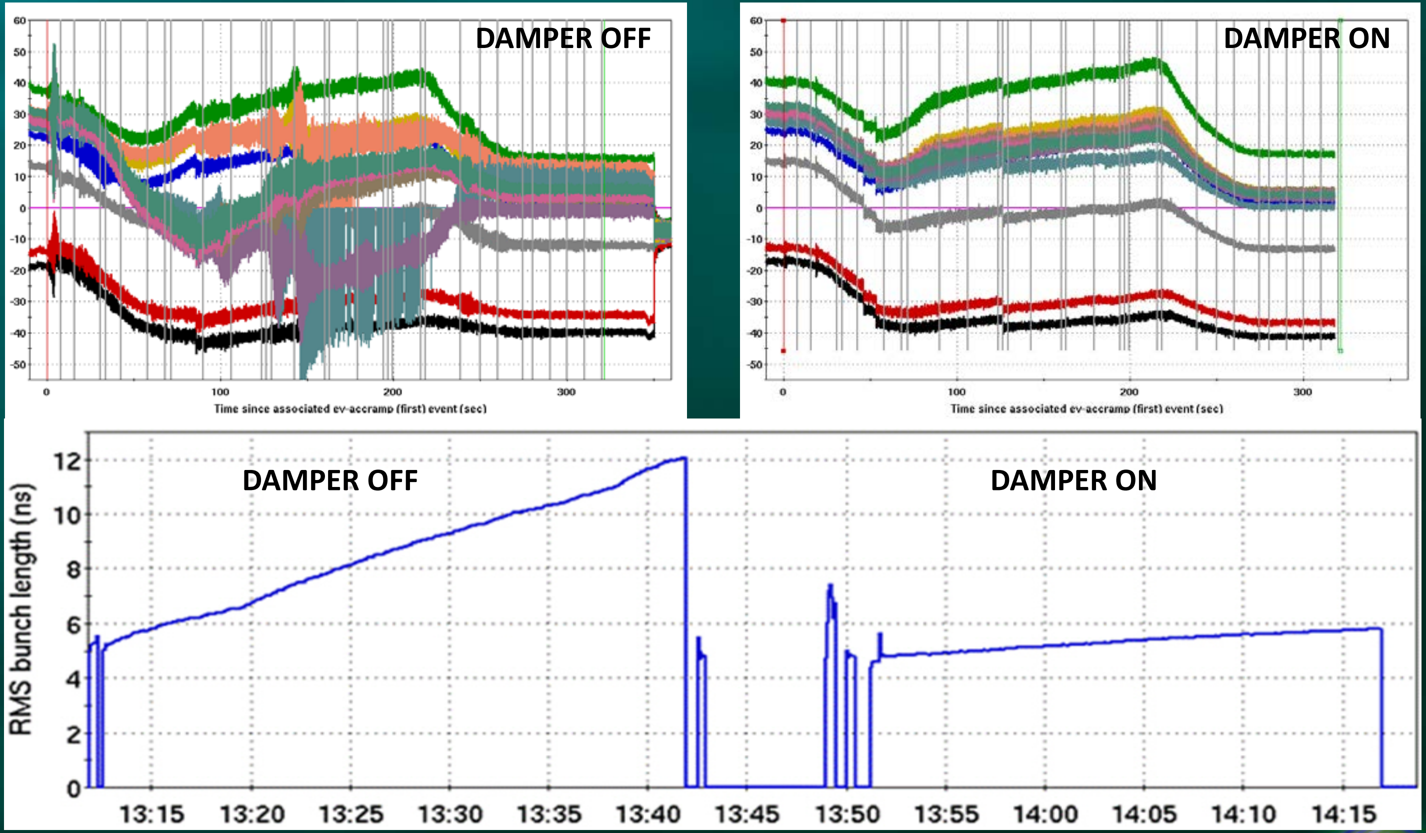


RHIC Bunch by Bunch Longitudinal Damper

RHIC Bunch by Bunch Longitudinal Damper Results

- The damper had a tremendous impact on the longitudinal stability of the beams in RHIC and the resulting longitudinal emittance .
- It allowed for an increase in per bunch intensity of roughly a factor of three compared to using the coherent damper only case (without using 197MHz for Landau damping).
- The operational intensity increased a smaller amount since Landau damping is also used.



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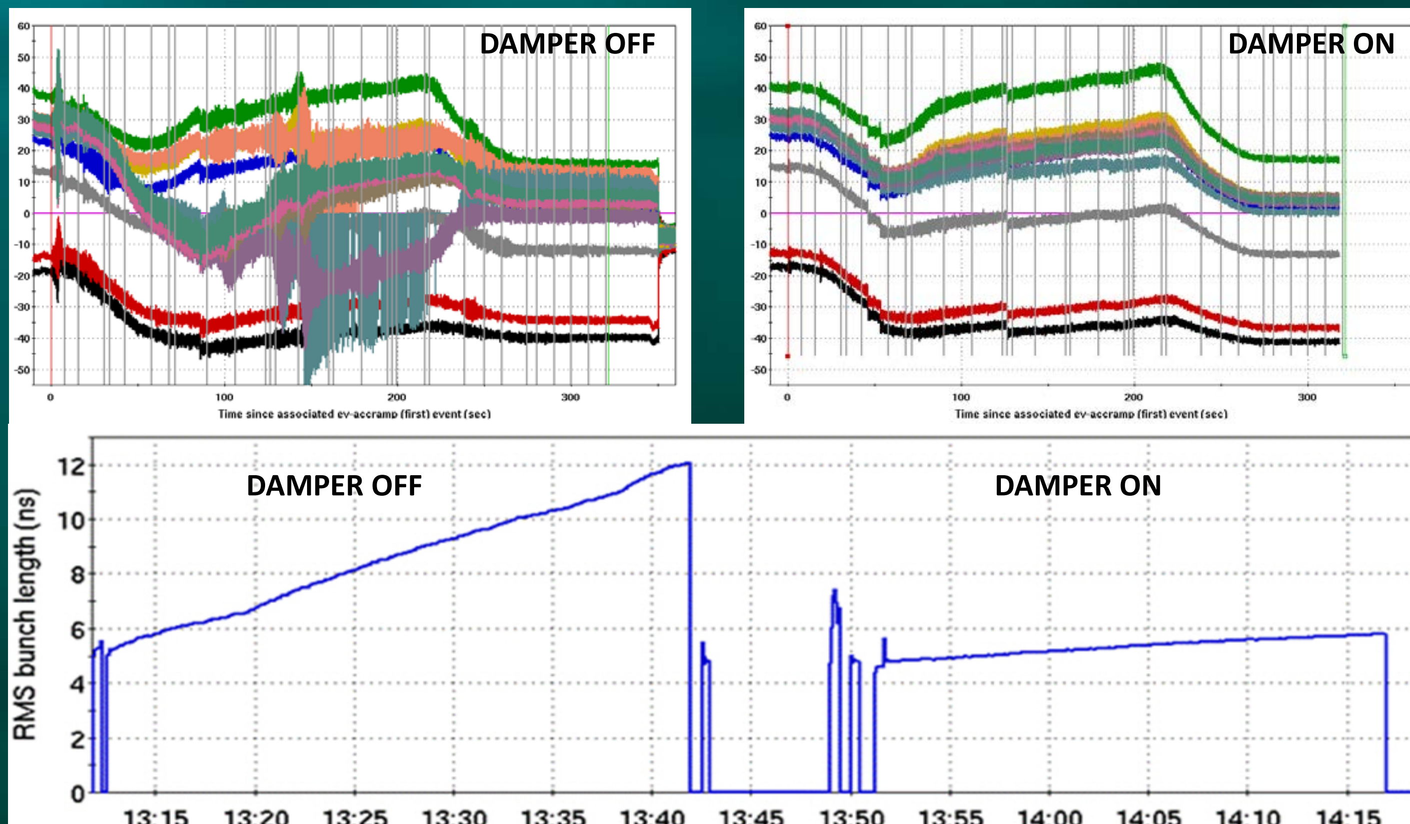

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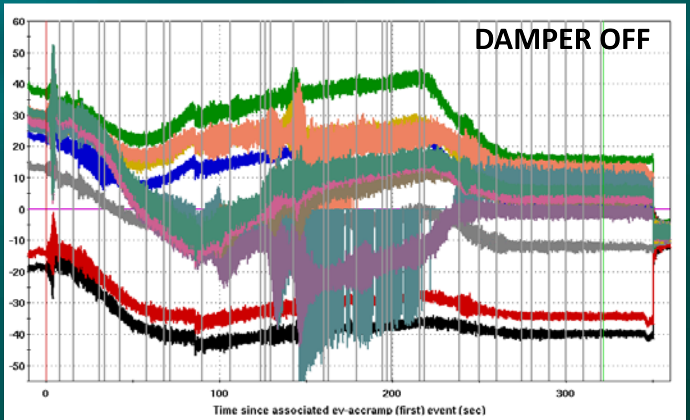

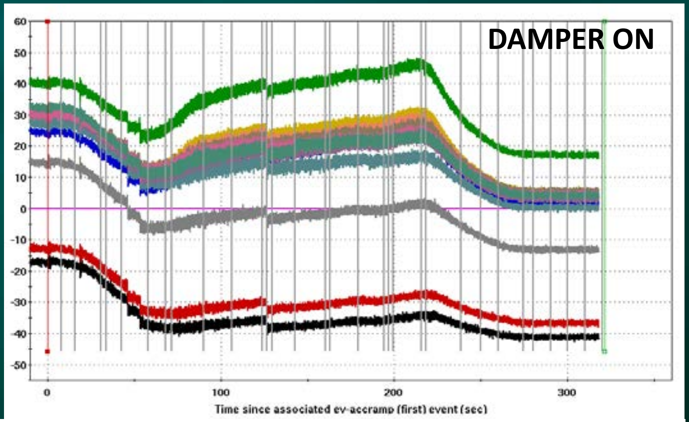

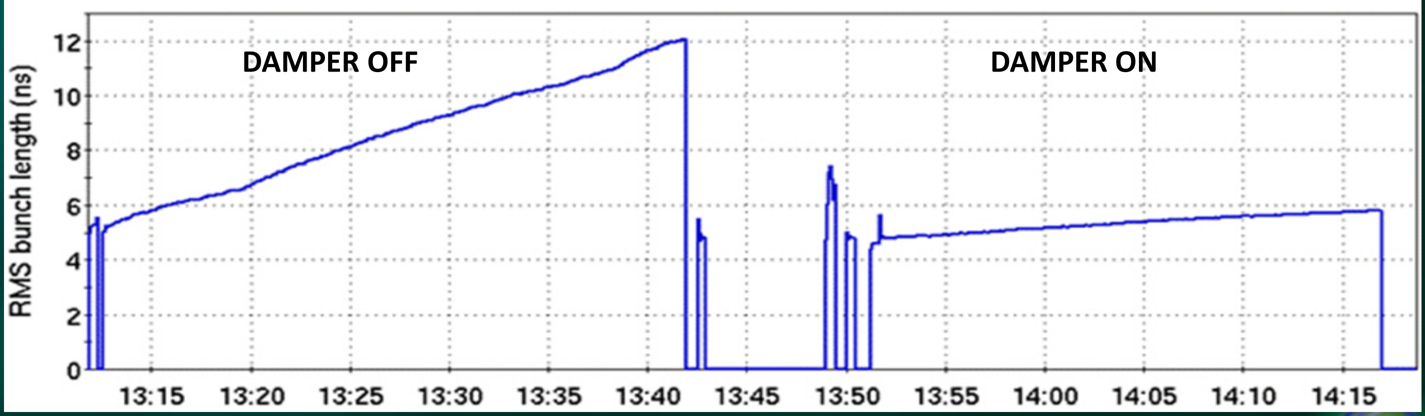

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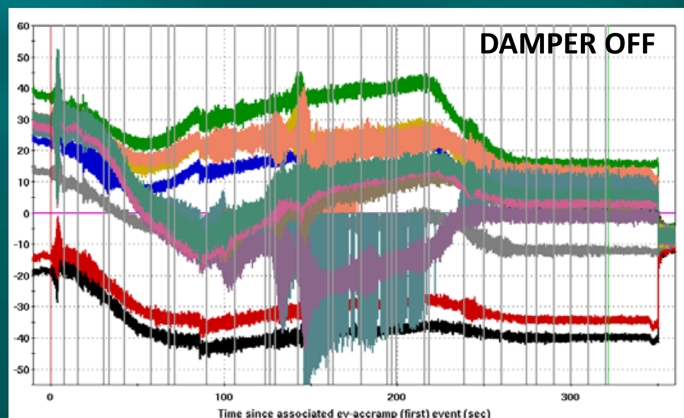
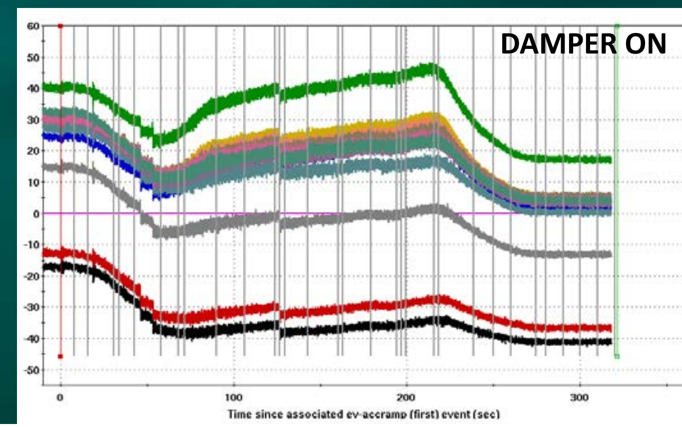
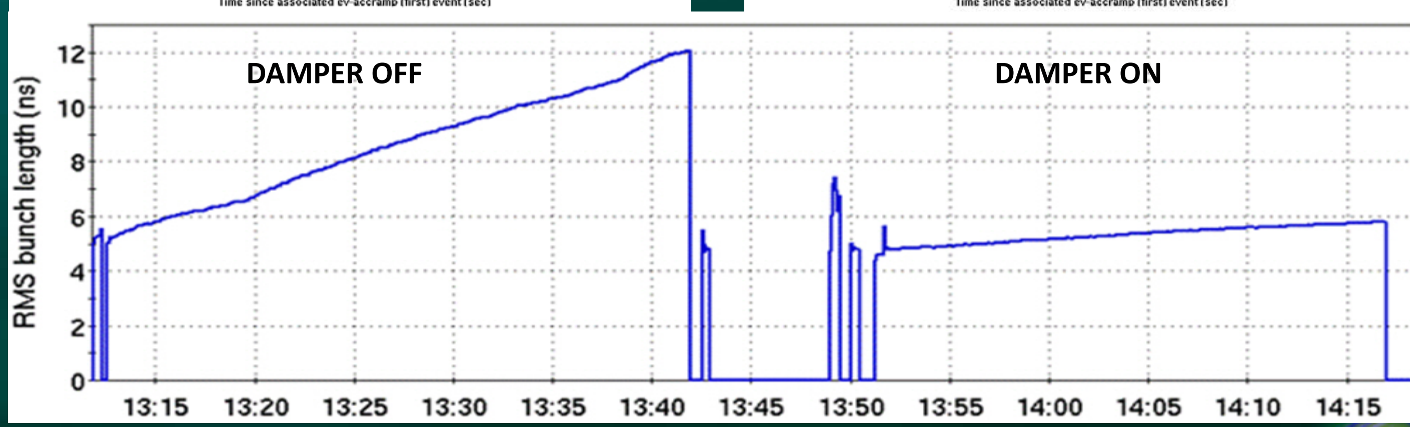
Bunch to Bucket Phase measurement along a RHIC PP energy ramp to 255GeV.

Select measurements for about 10 bunches along the 110 bunch train are shown.







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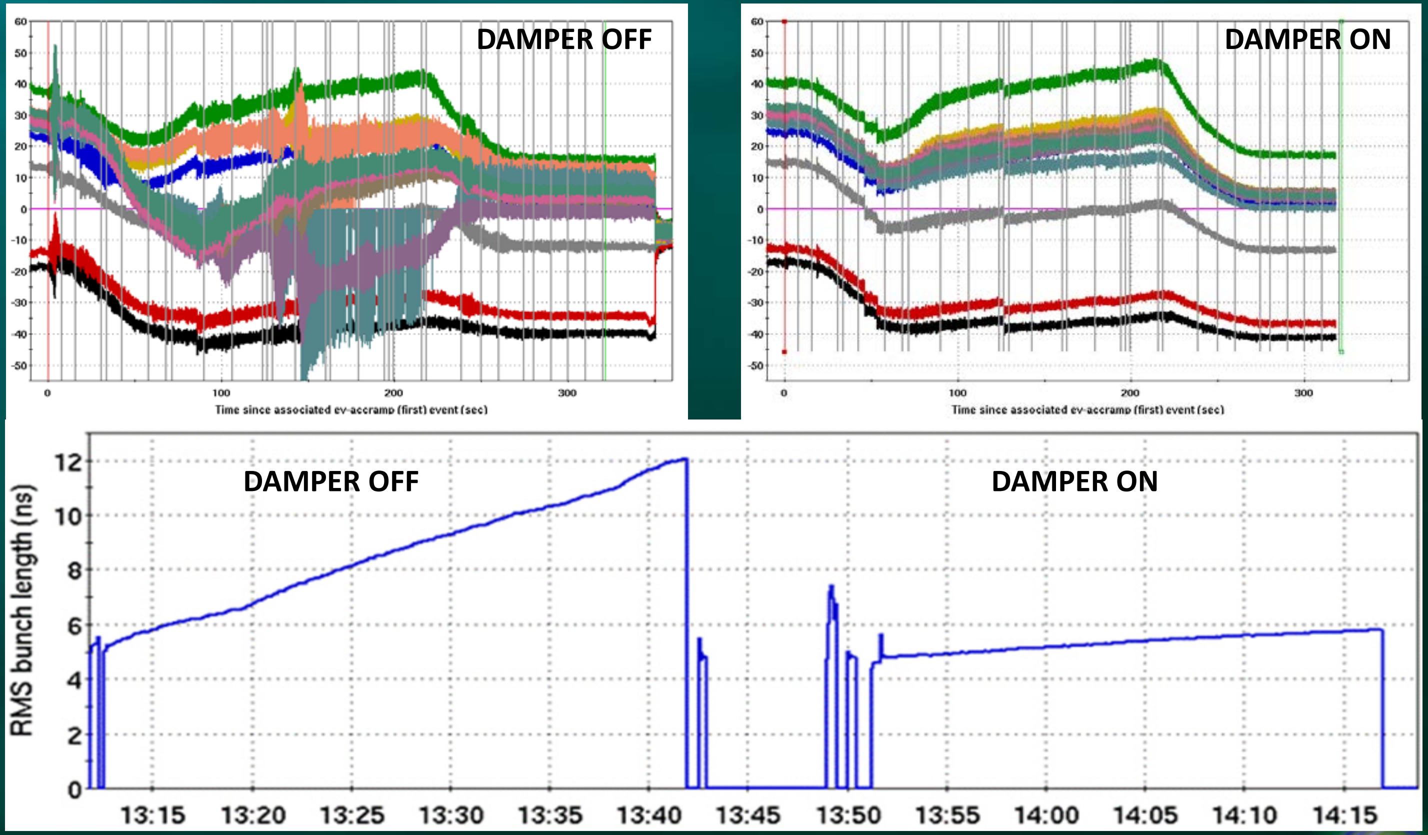

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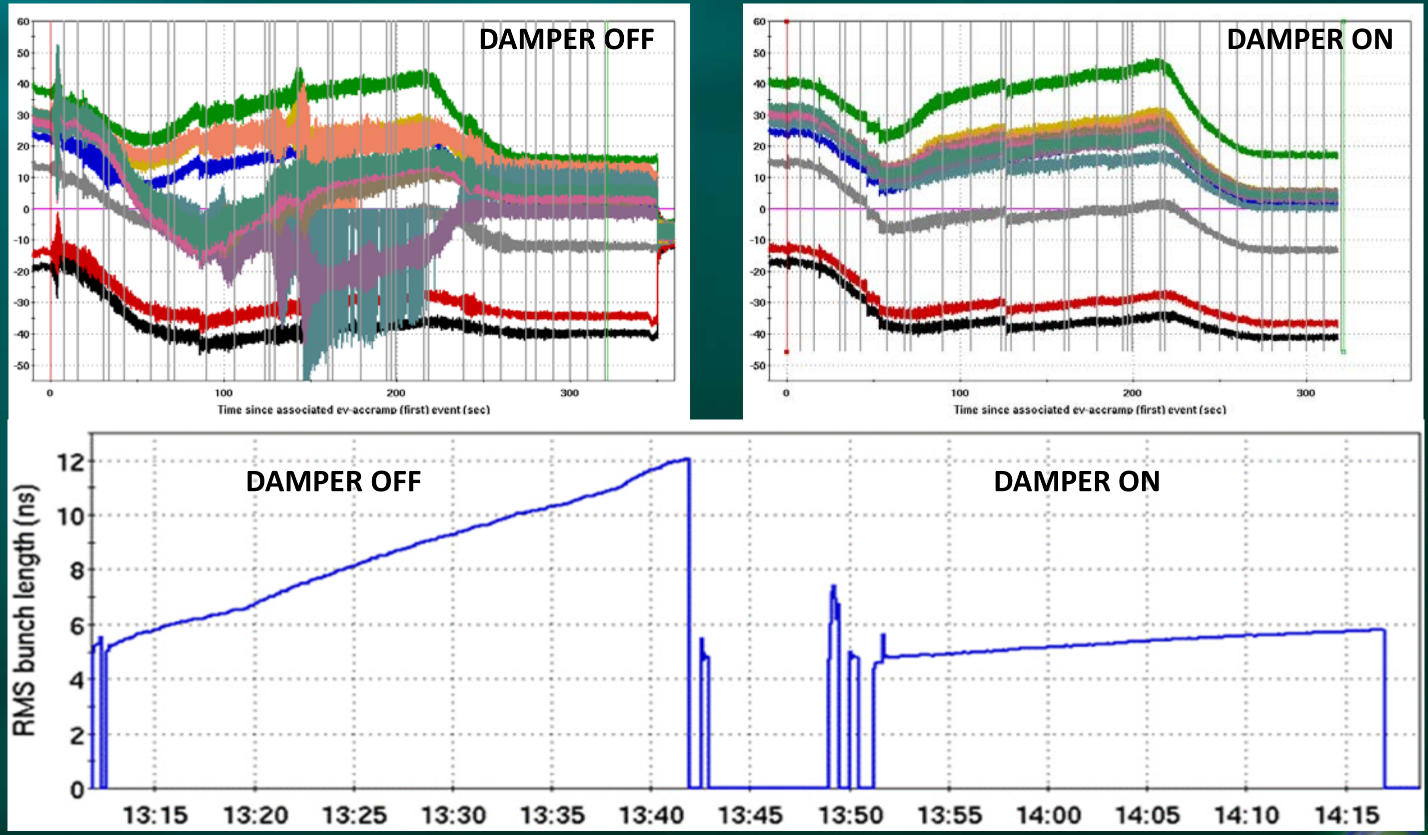

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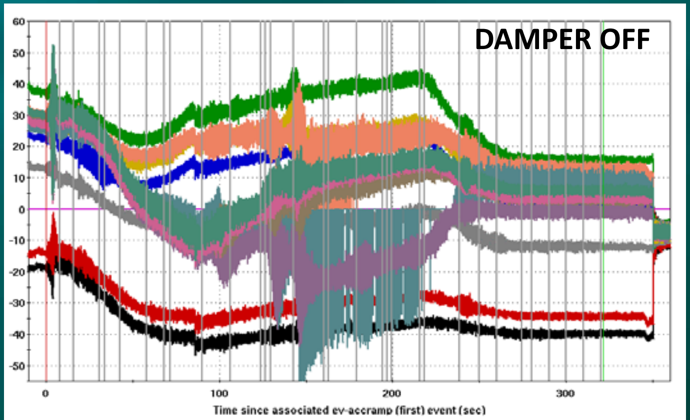
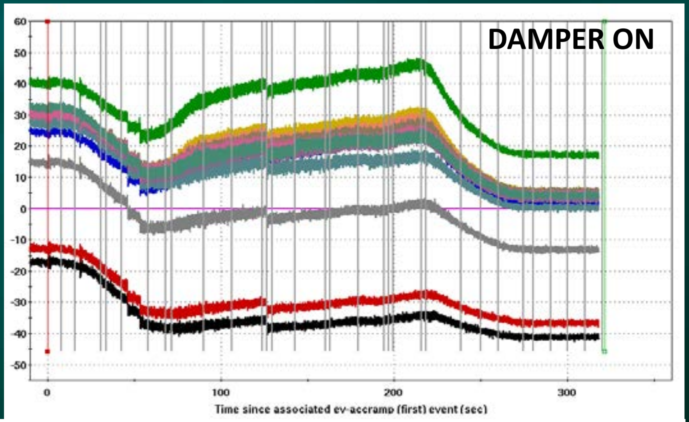
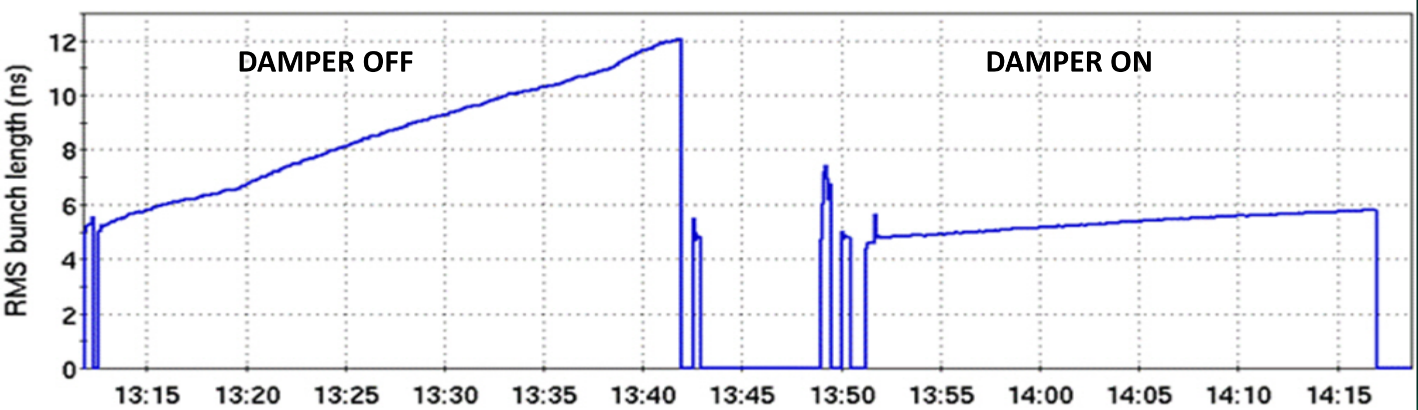






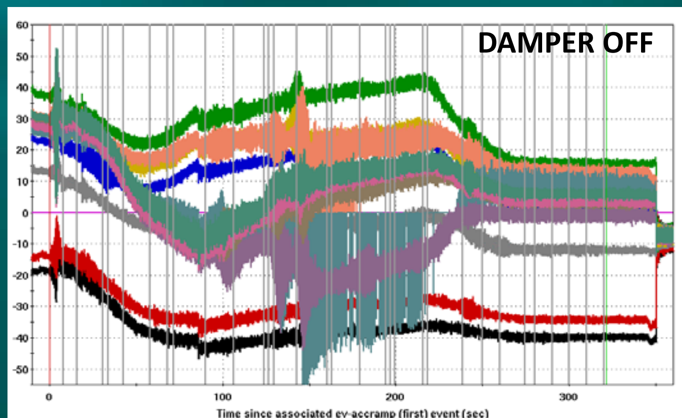
RHIC Bunch by Bunch Longitudinal Damper

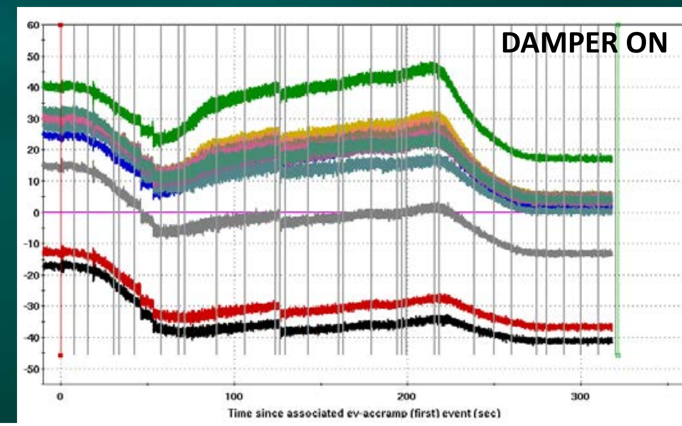
RHIC Bunch by Bunch Longitudinal Damper Results

- The damper had a tremendous impact on the longitudinal stability of the beams in RHIC and the resulting longitudinal emittance .
- It allowed for an increase in per bunch intensity of roughly a factor of three compared to using the coherent damper only case (without using 197MHz for Landau damping).
- The operational intensity increased a smaller amount since Landau damping is also used.

Bunch to Bucket Phase measurement along a RHIC PP energy ramp to 255GeV.

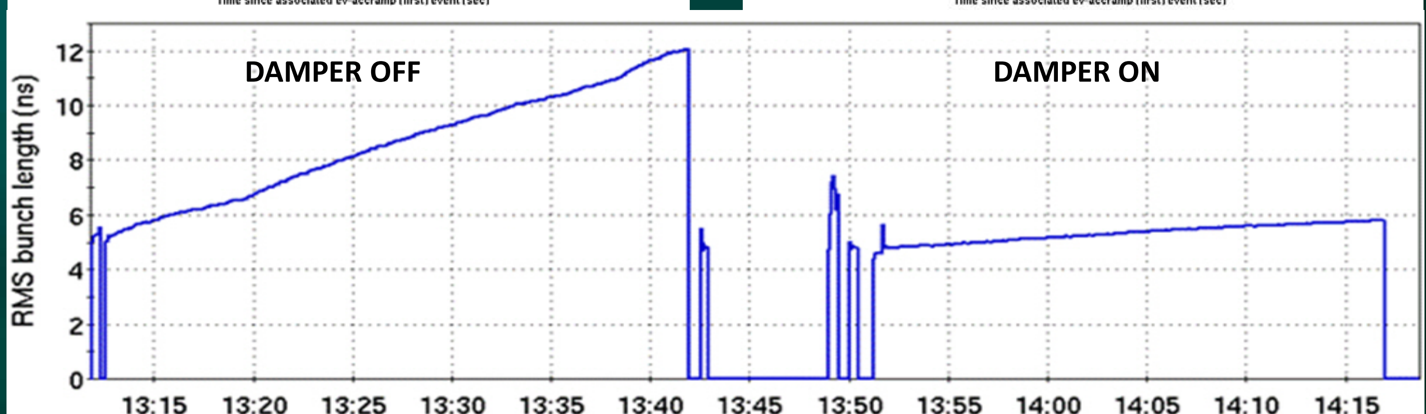
Select measurements for about 10 bunches along the 110 bunch train are shown.



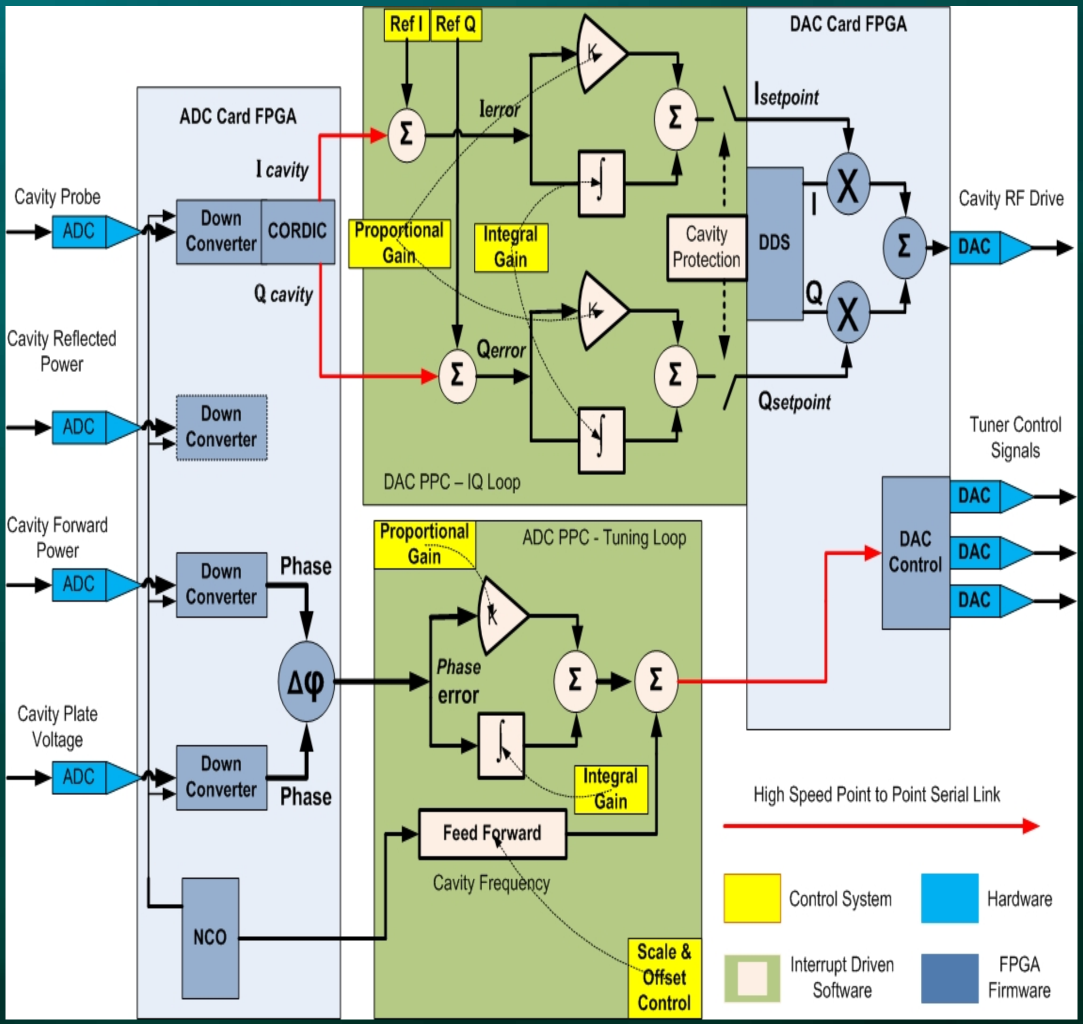


RMS bunch length growth while sitting at injection.

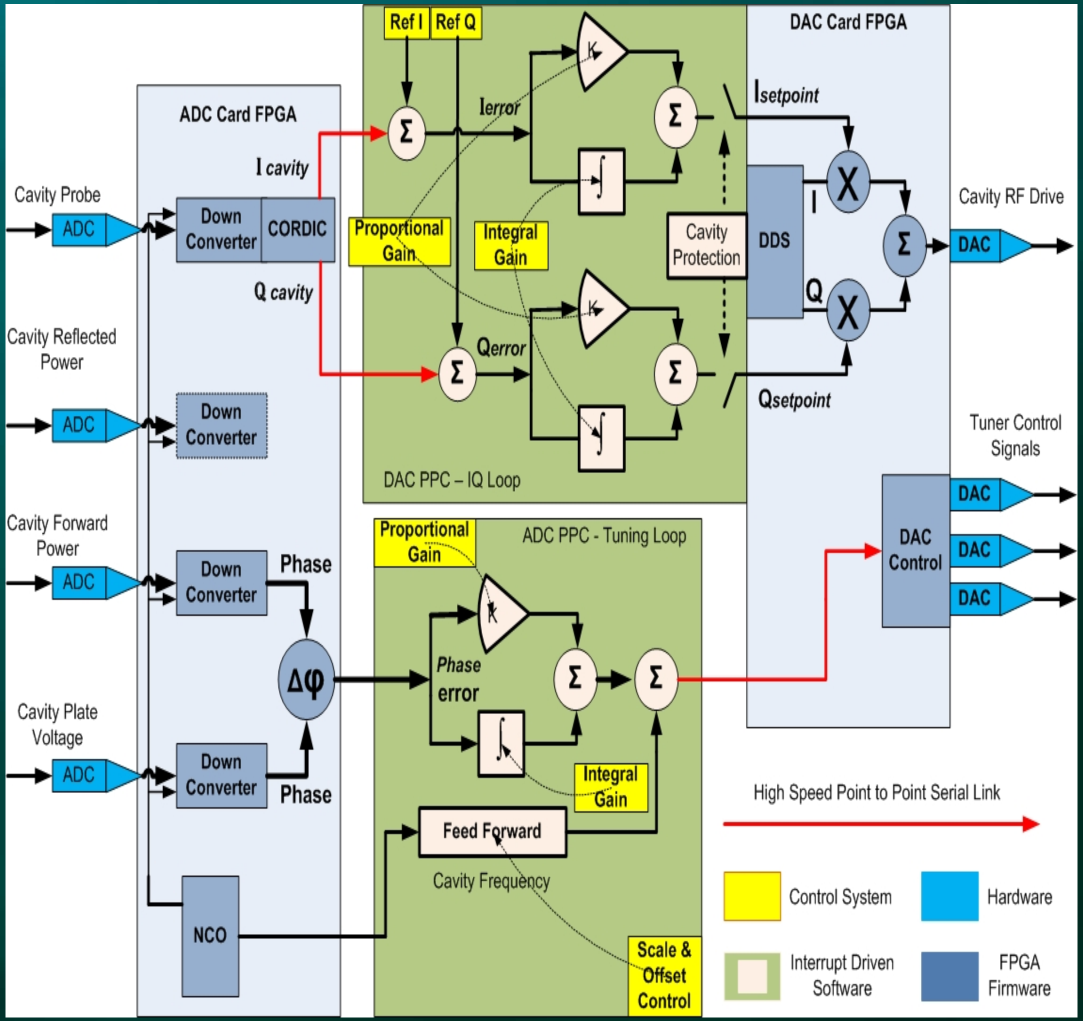
Damper reduces growth from about 140% to 20%. IBS also contributes to growth.



Cavity Controller Loops

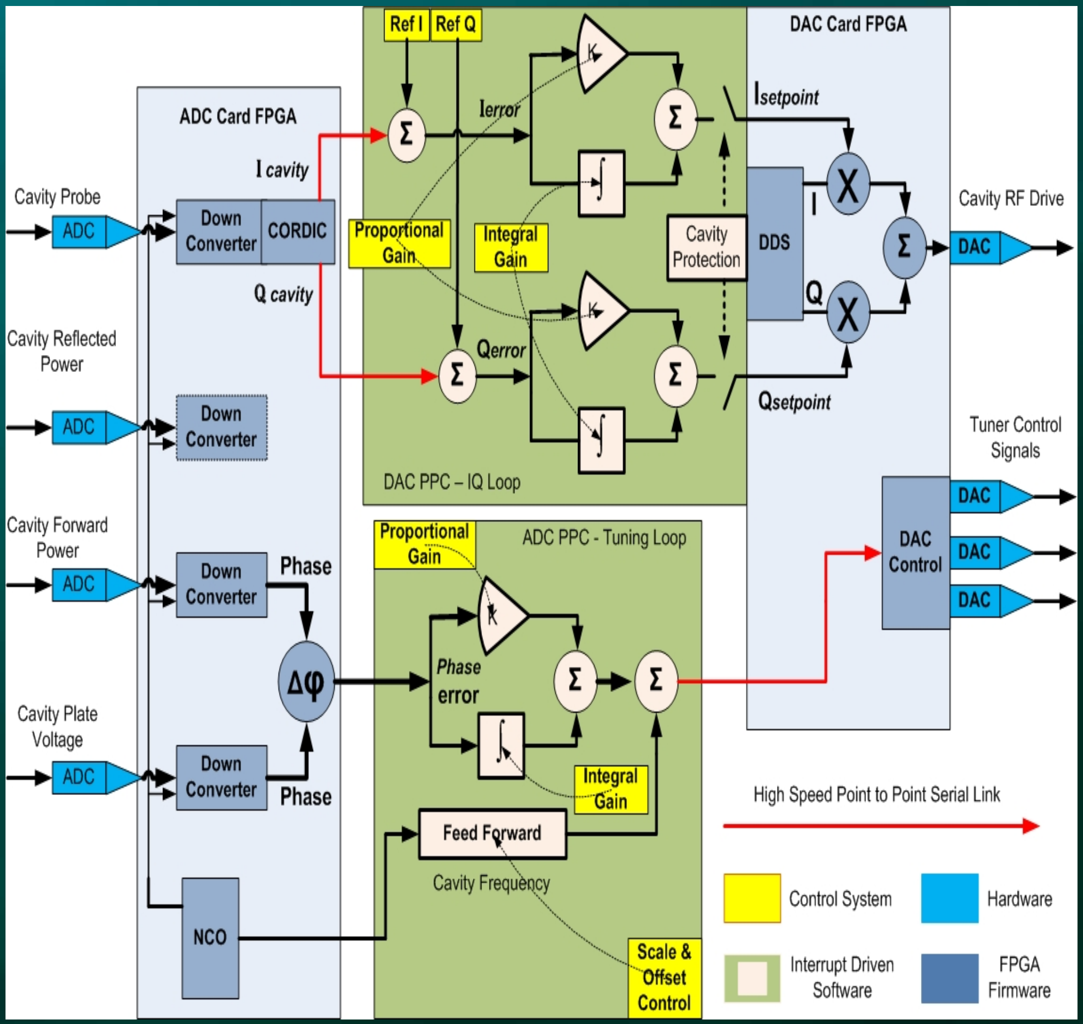


Cavity Controller Loops

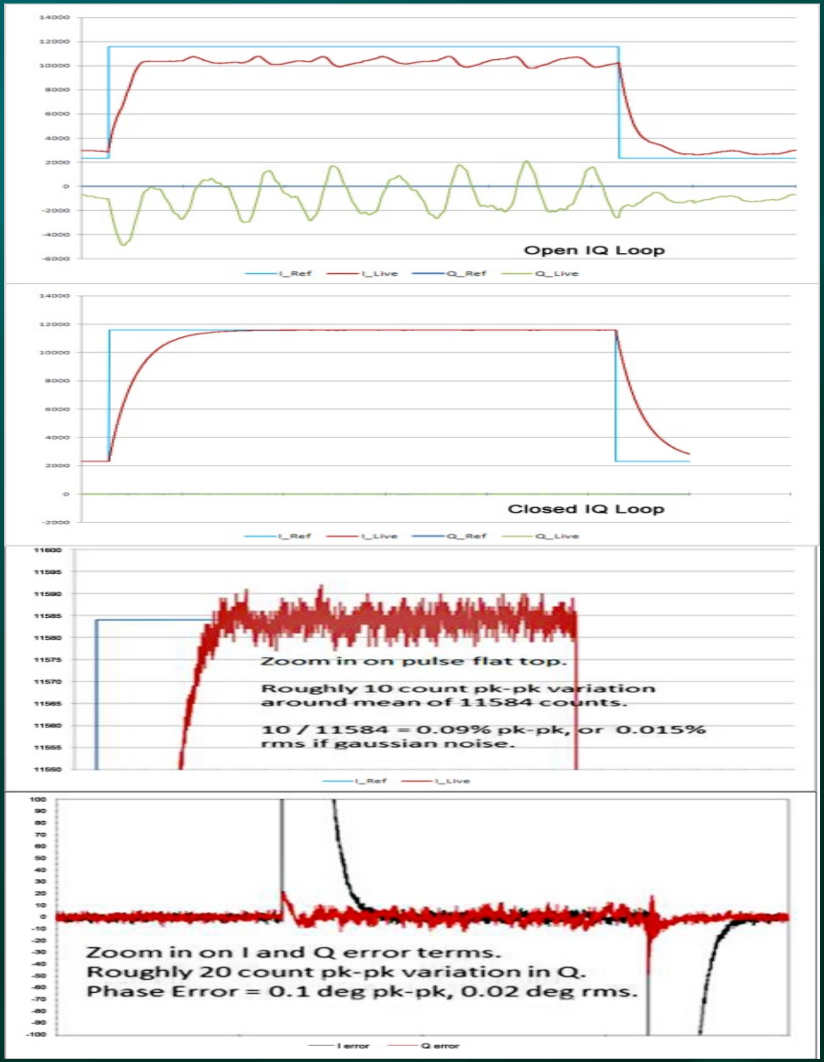


Cavity Controller Loops

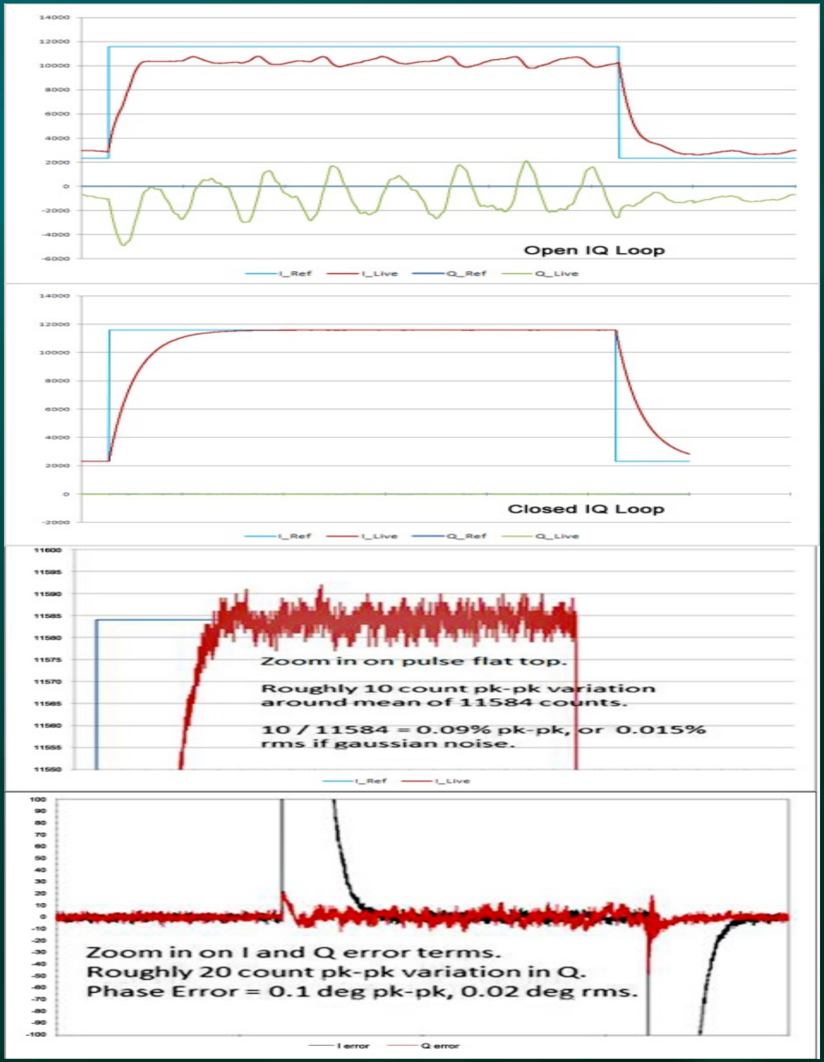
- The cavity controller implements two feedback loops: I-Q feedback for control of cavity field amplitude and phase, and cavity tuning (resonance) control.
- The cavity IQ-Loop resides in the DAC embedded PPC.
- This processor is also responsible for cavity protection which turns OFF the cavity drive based on a variety of possible fault conditions.
- The cavity resonance control loop (tuning loop) is implemented in the ADC embedded PPC.



R&D ERL LLRF Results (5-Cell Cavity)

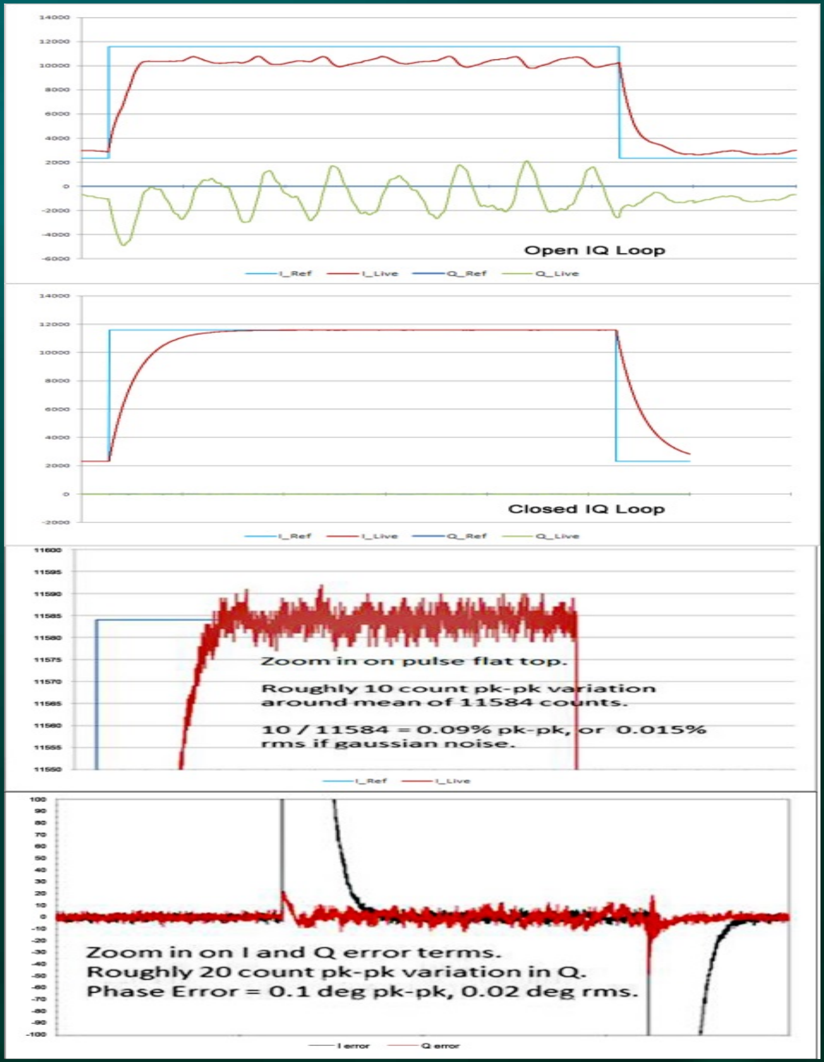


R&D ERL LLRF Results (5-Cell Cavity)



R&D ERL LLRF Results (5-Cell Cavity)

- Results of an IQ-Loop used to control the R&D ERL 703MHz 5-Cell Cavity.
- The open loop response of the cavity has significant error, due to strong microphonic detuning.
- I reference and closed loop response were a pulse gradient is about 4 MV/m.
- The cavity closed loop response follows the reference very closely.
- The closed loop steady state amplitude error is about 0.015% rms, with a phase error of about 0.02 deg rms.



Conclusion

- Various implementations of distributed feedback control loops have been developed using the RHIC LLRF Platform, and deployed throughout the C-AD complex.
- Over the past three years more than forty controllers have been installed into the various machine LLRF systems.
- These controllers, tightly integrated and synchronized via the LLRF Update Link have vastly improved RF system performance, flexibility and reliability.

Thank You !!!

- BNL Mini Oral & Posters:
- MOMIB03
- MOPPC121
- MOPPC075
- MOPPC076
- TUCOCA03
- TUPPC131
- THCOBB03