APS-U Beam Stability Requirements and R&D in Sector 27

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Outline

- Beam Stability R&D Effort at APS
- General Requirements for Beam Positioning and Stability
- APS-U Beam Stability Requirements
- APS-U Beam Stability R&D Scope
- Beam Stability R&D in Sector 27
  - Mechanical Motion Sensing (MMS)
  - GRID XBPM comparison to existing photoemission XBPMs
  - GRID/MMS testing using existing feedback system
- Sector 27 tests of APS-U feedback controller prototype
  - Four bpm, four corrector testing (began testing in ring in February 2016)
  - Integrated testing (coming this fall)
- Summary

APS Beam Stability R&D Effort

- All three APS divisions and FMS
- APS Project Office
- Outside Collaborators (National and International Labs)
- Beam Stability Working Group (G. Srajer chair)
  - Representatives from APS Divisions and Users
  - Discuss improvements to present storage ring beam stability and related items (steering automation, temperature stability etc.)
  - Discuss implications for future MBA upgrade

General Requirements for Orbit Positioning and Stability for the MBA Ring

- Commissioning -
  - Obtain first turn trajectory, close the orbit, store and perform optics correction
- ID steering -
  - Put photon beam on user target within a fraction of the beam size
  - Recover the orbit within a fraction of the beam size at each ID after a shutdown
- Recover the orbit close to the magnetic centers of the multipoles
- Maintain a stable beam trajectory -
  - Long term drift > 100 seconds to 7 days
  - Maintain AC beam motion to a fraction of the beam size
- Ultimately the definitions of beam drift and AC motion “noise” depend on the details of the user experiment...

MBA Orbit Stability Requirements

Minimum Expected Beam Size at the IDs

σ_x	$\sigma_{x'}$	σ_y	$\sigma_{y'}$
17 µm	2.6 µrad	4 µm	1.7 µrad

Beam Stability Goals for the APS Upgrade

Plane	AC rms Motion (0.01-1000 Hz)	AC rms Motion (0.01-1000 Hz)	Long-term Drift (>100 s)	Long-term Drift (>100 s)
Horizontal	1.7 µm rms (>6 µm)	0.26 µrad rms (>1.7 urad)	1 µm rms (~10 µm*)	0.6 µrad rms (~2.8 urad*)
Vertical	0.4 µm rms (>3 µm)	0.17 µrad rms (>0.85 urad)	1 µm rms (~10 µm*)	0.5 µrad rms (~2.8 urad*)

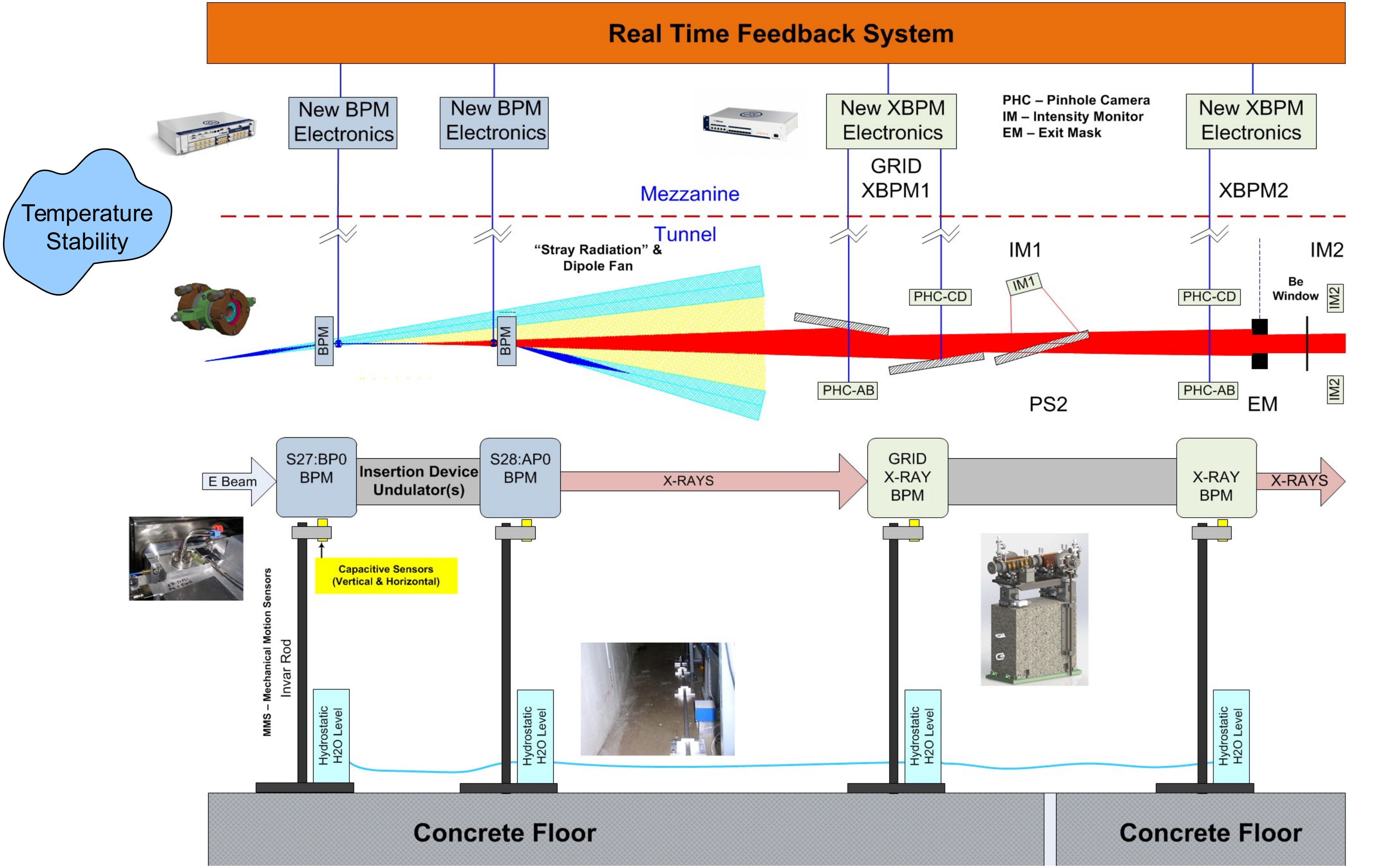
( )Present Storage Ring Performance

* Peak-to-Peak

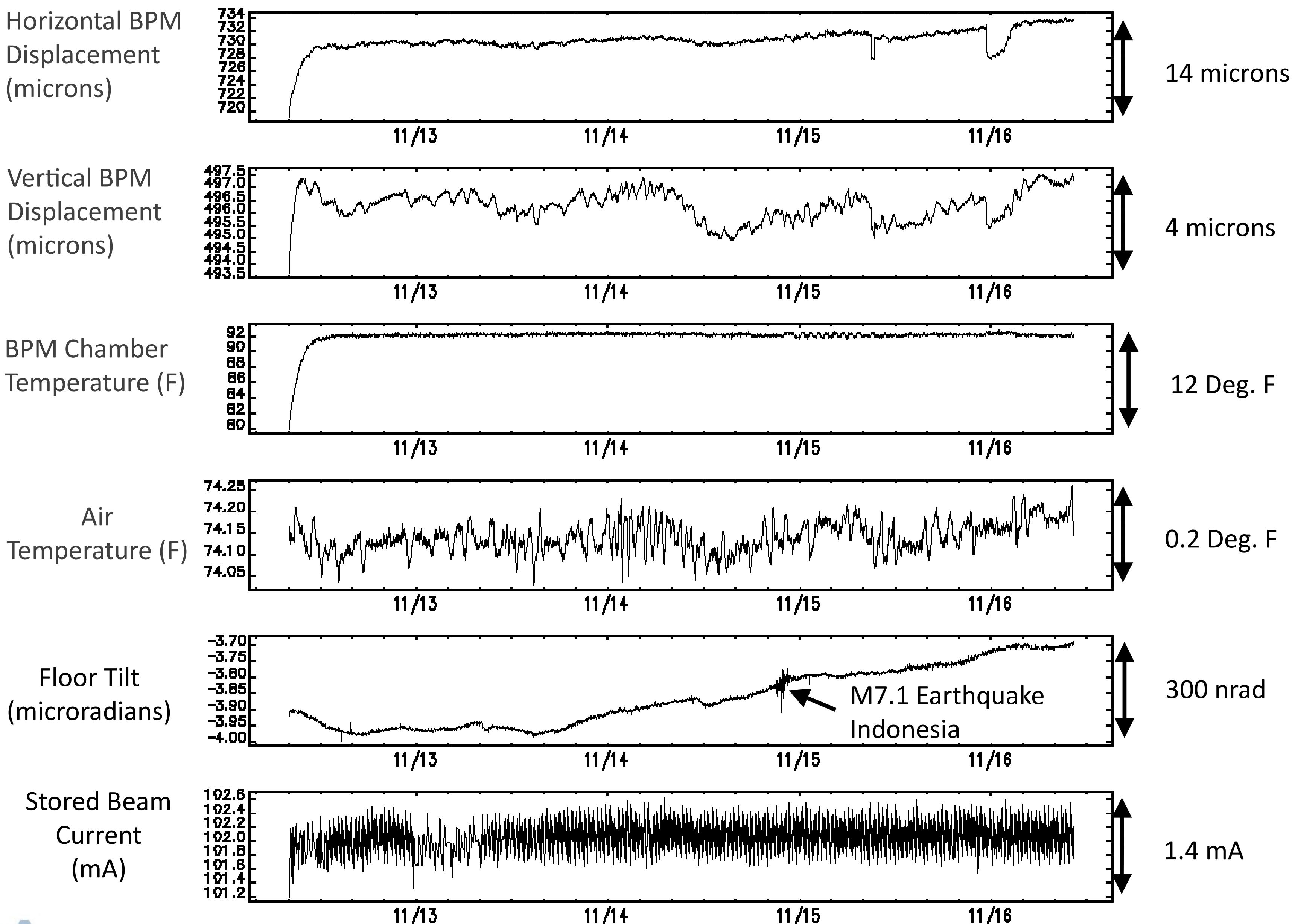
Beam Stability R&D Scope

- Achieving beam stability requirements for APS-U requires integration of many subsystems:
  - Commercial bpm diagnostics (both electron and photon)
  - Fast and slow corrector power supplies
  - Mechanical motion sensing of vacuum chamber motion
  - Main cavity and HHC (bunch lengthening) cavity rf systems, multibunch feedback systems
  - Real-Time Orbit feedback system – updates fast and slow correctors based on beam position information using a “unified” feedback algorithm
  - Good regulation of tunnel air and water temperature systems (Lester’s talk)
  - Comprehensive data acquisition system (DAQ) for diagnostics and all accelerator sub-systems (power supplies, rf, injection, injectors ...)
  - User beamline diagnostic systems
- The integrated system must meet challenging beam stability requirements
- I will discuss sector 27 R&D results and activities

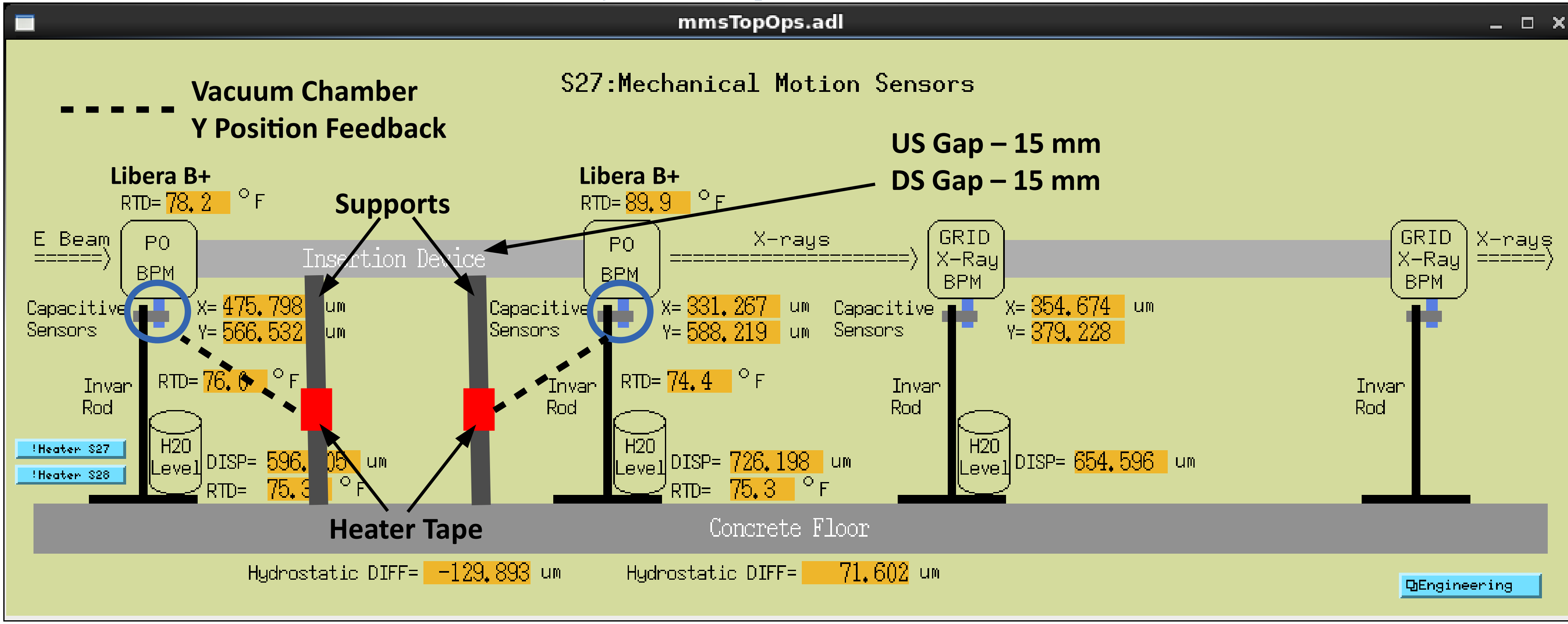
Beam Stability R&D In Sector 27 of the Storage Ring



Mechanical Stability - 24 bunch, 2-minute Top-up

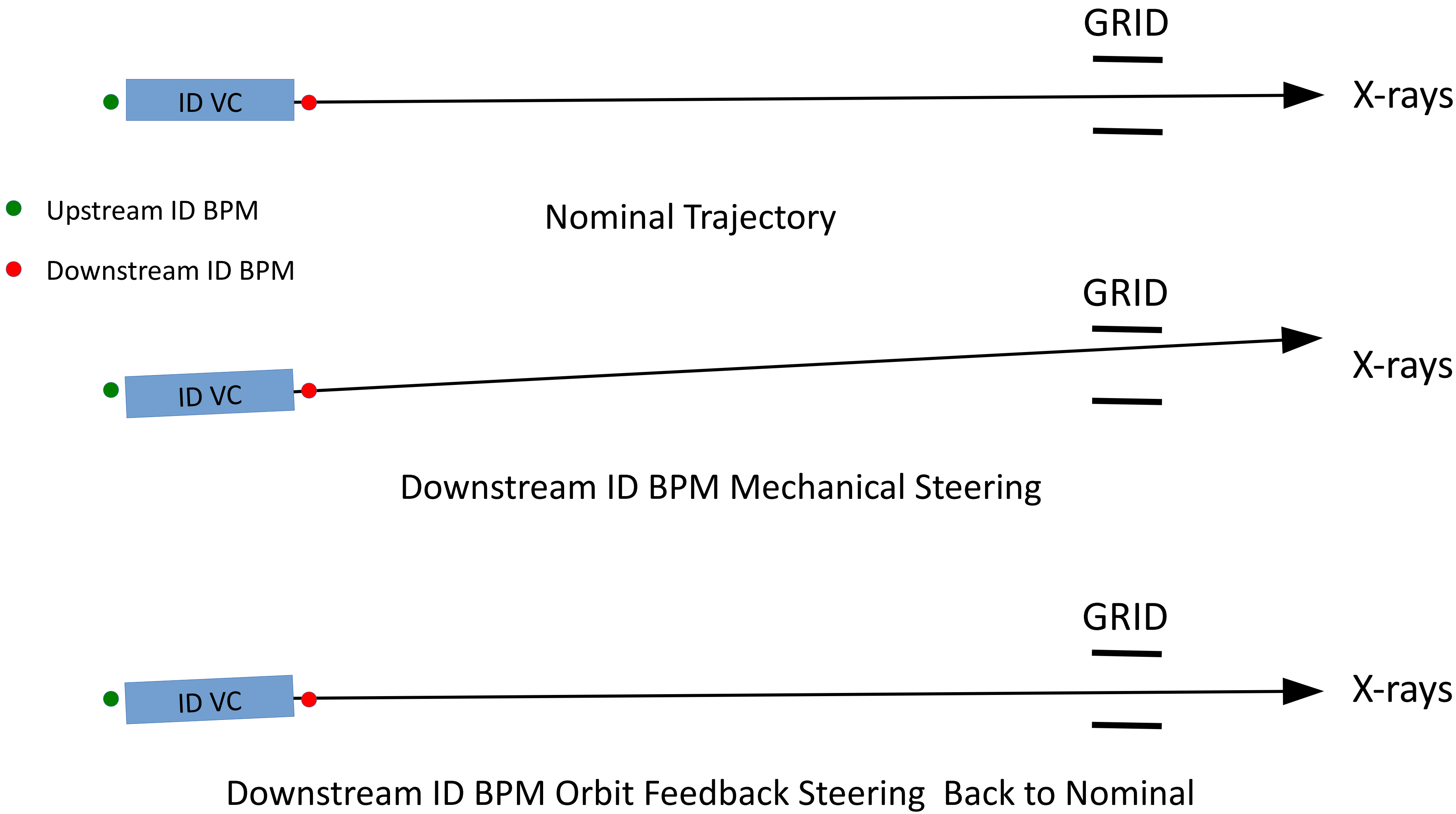


Mechanical Stability - Impact With Orbit Feedback



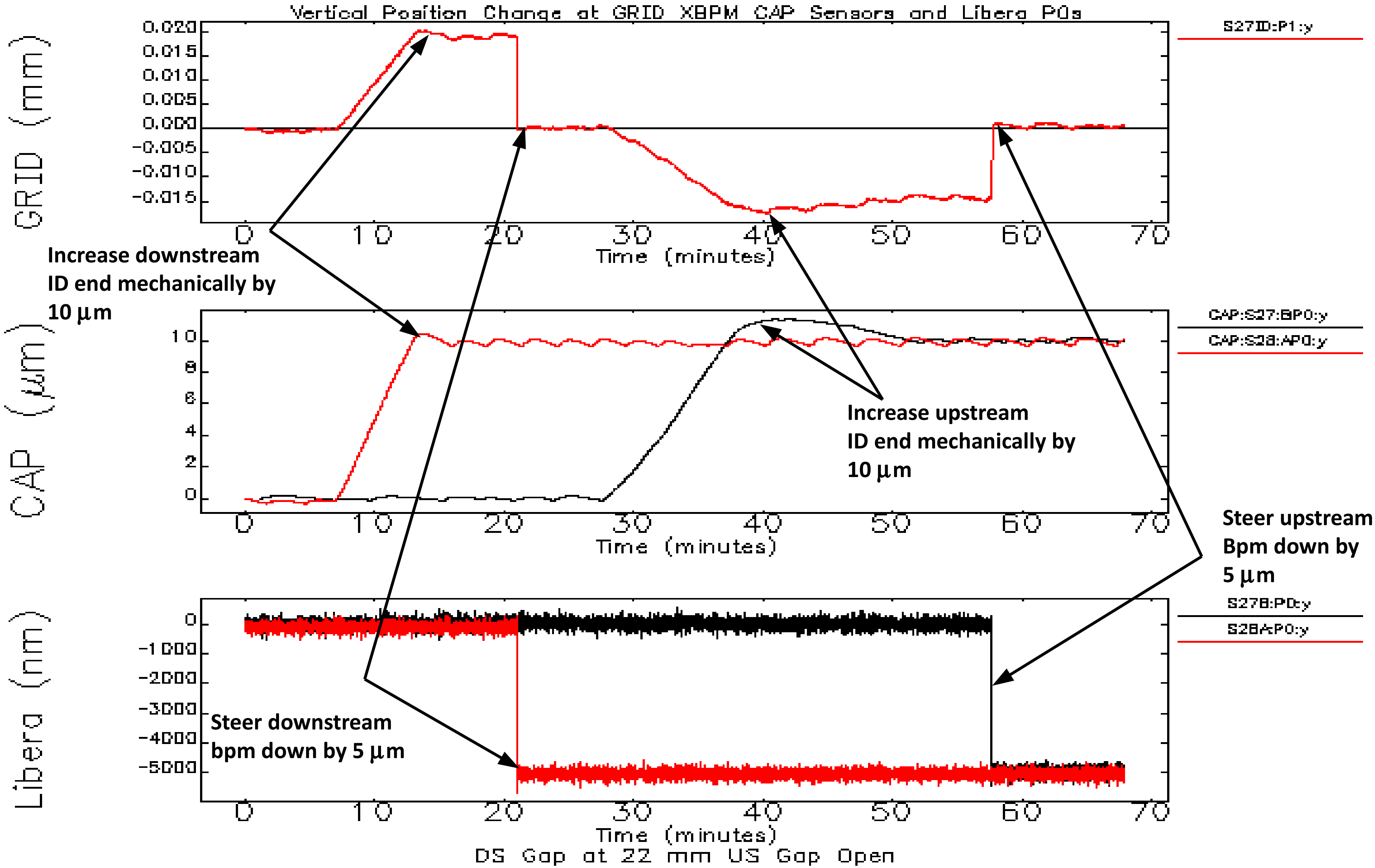
- Performed various experiments using sector 27 diagnostics to quantify how mechanical motion impacts beam motion
- ID vacuum chamber can be moved vertically and held to sub-micron accuracy
- Vacuum chamber vertical position feedback holds vacuum chamber at a user selected mechanical position
  - Uses heater tape to heat or cool (stop heating) supports based on position setpoint
  - Cooling (turning off heater) is relatively slow due to diffusion of heat into the air

Mechanical Stability - Impact With Orbit Feedback cont.

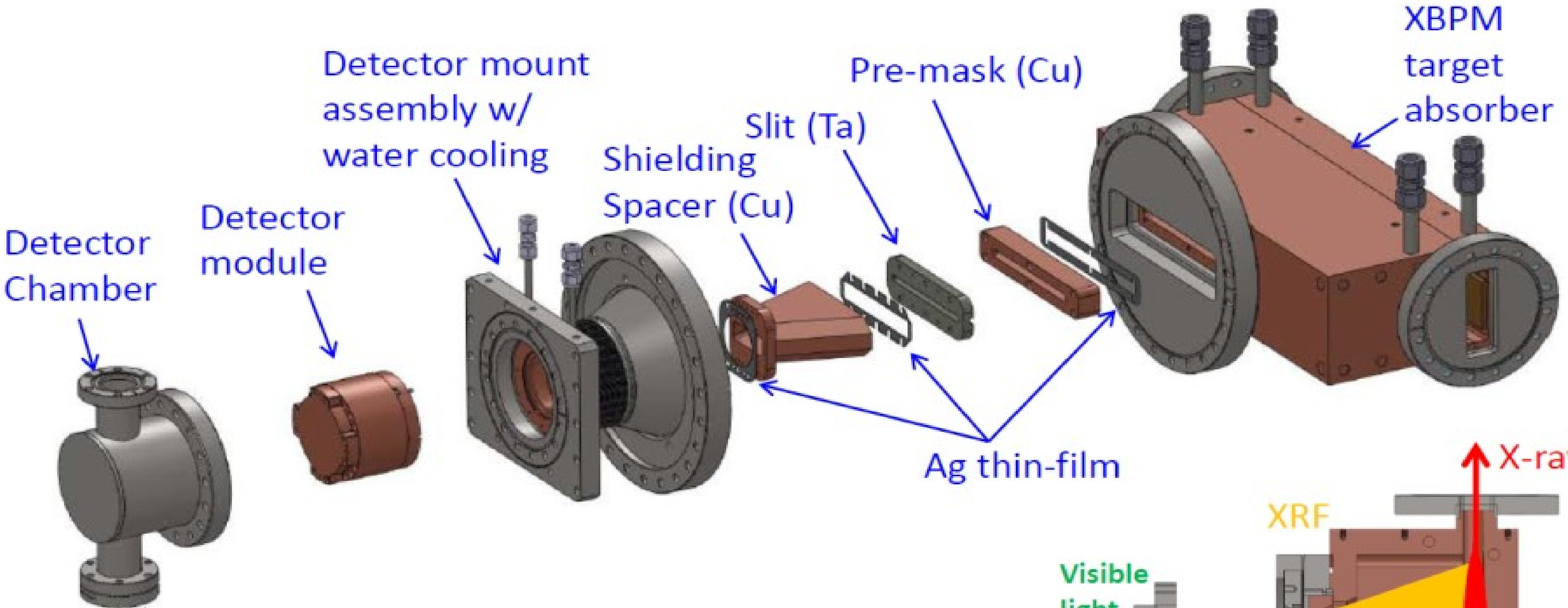


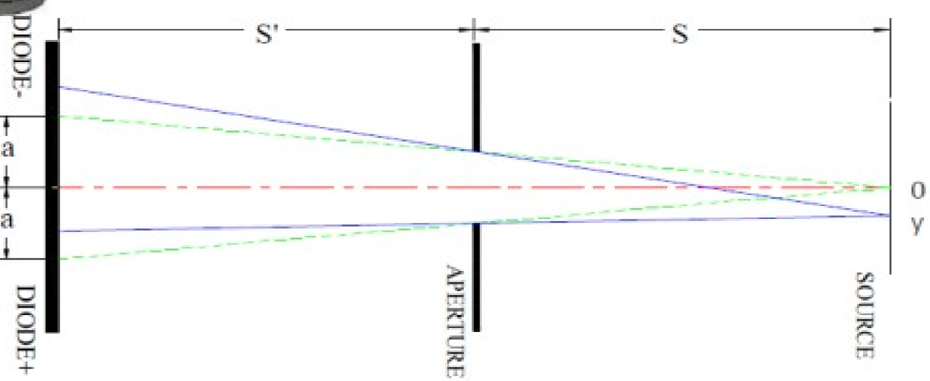
- Note only 1 degree increase in temperature results in 5 μm VC support increase

Mechanical Stability – Impact With Orbit Feedback cont.

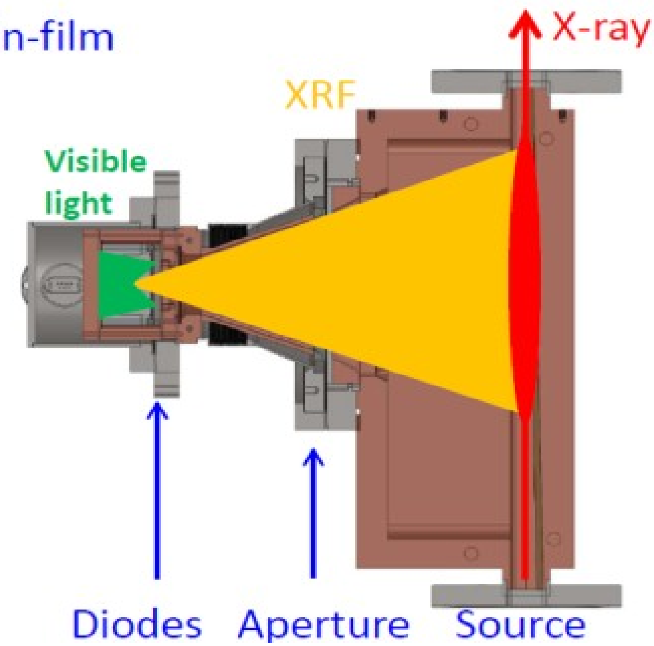


GRID XBPM Commissioning

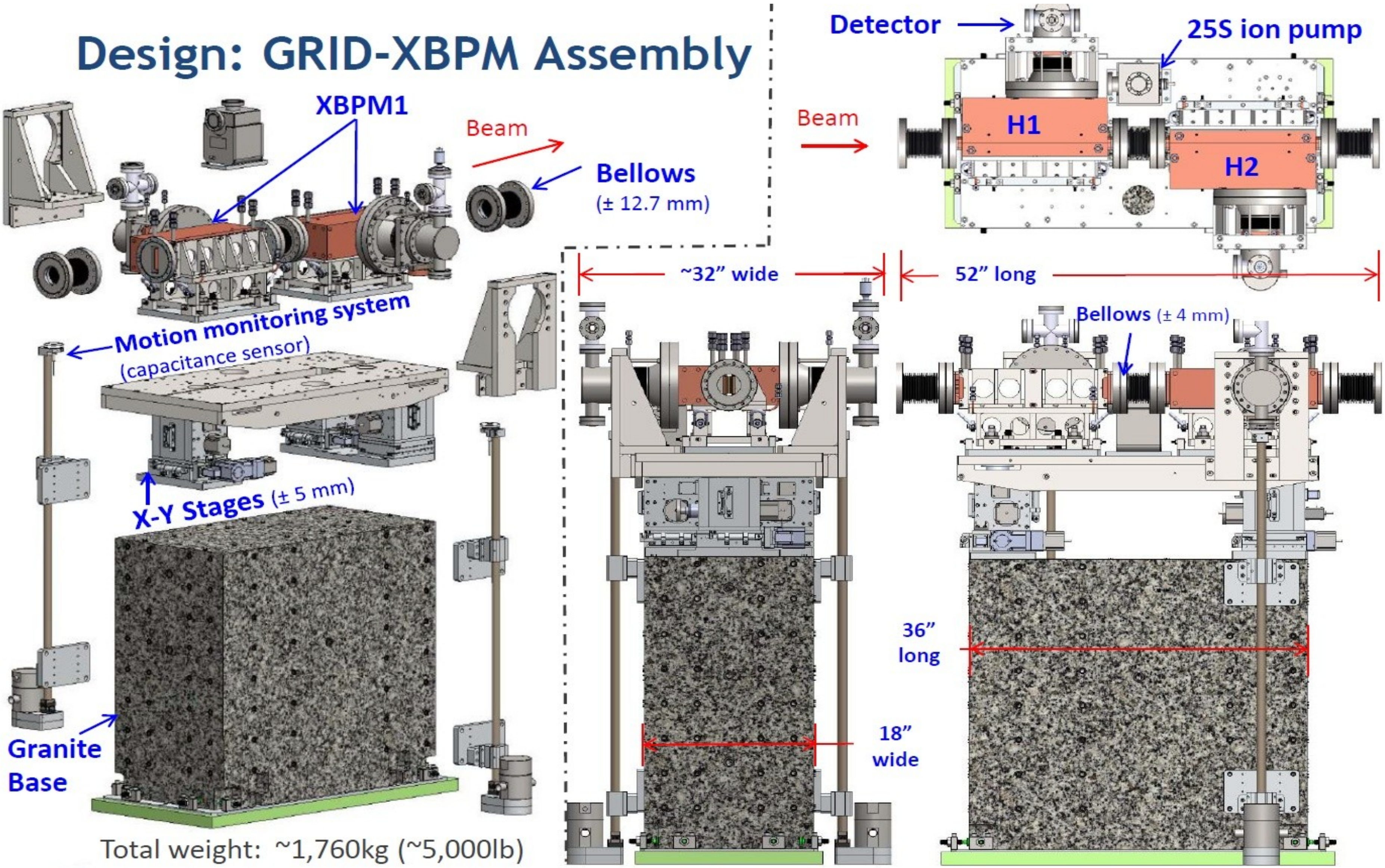




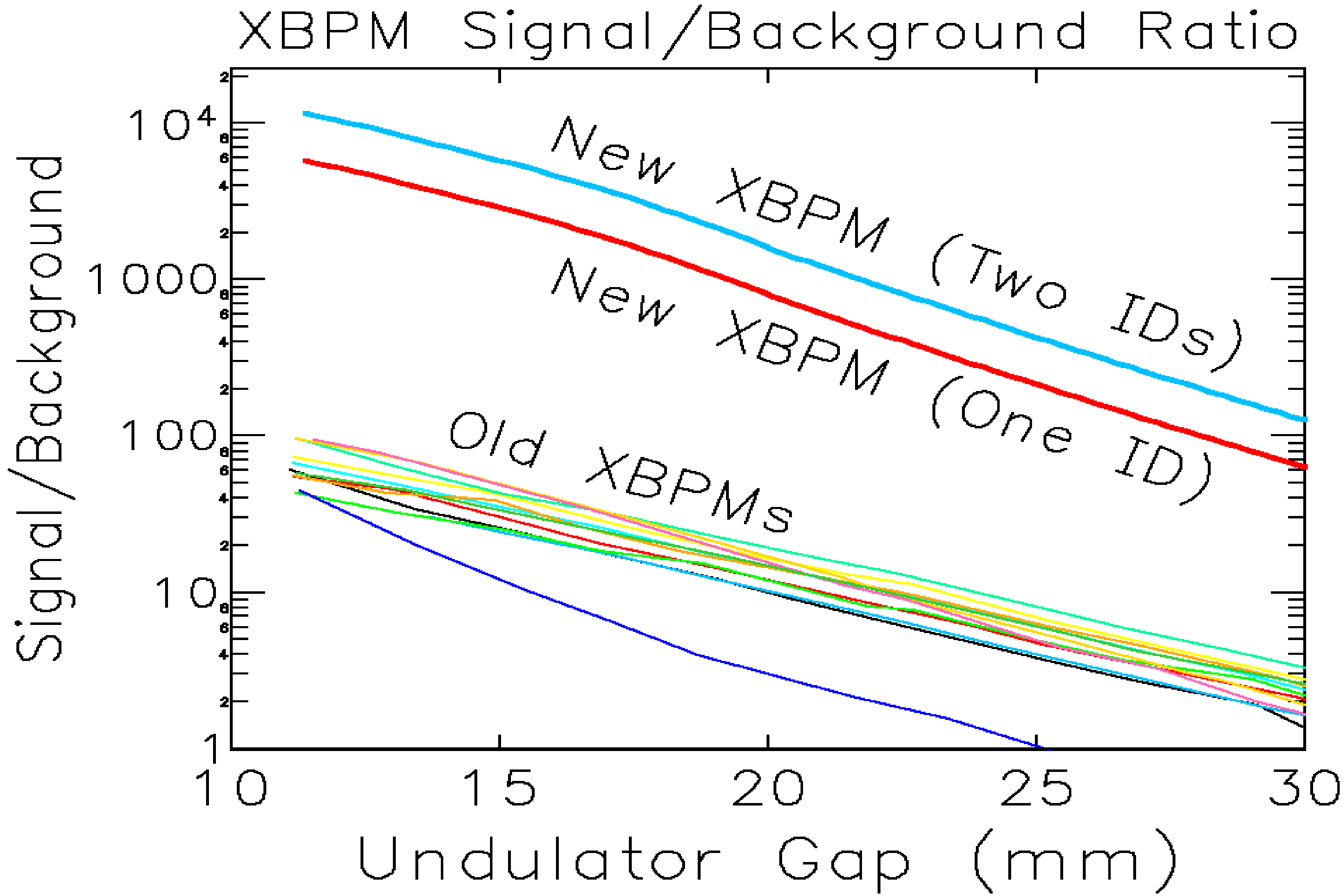
Principle of Pinhole camera



GRID XBPM Commissioning cont.

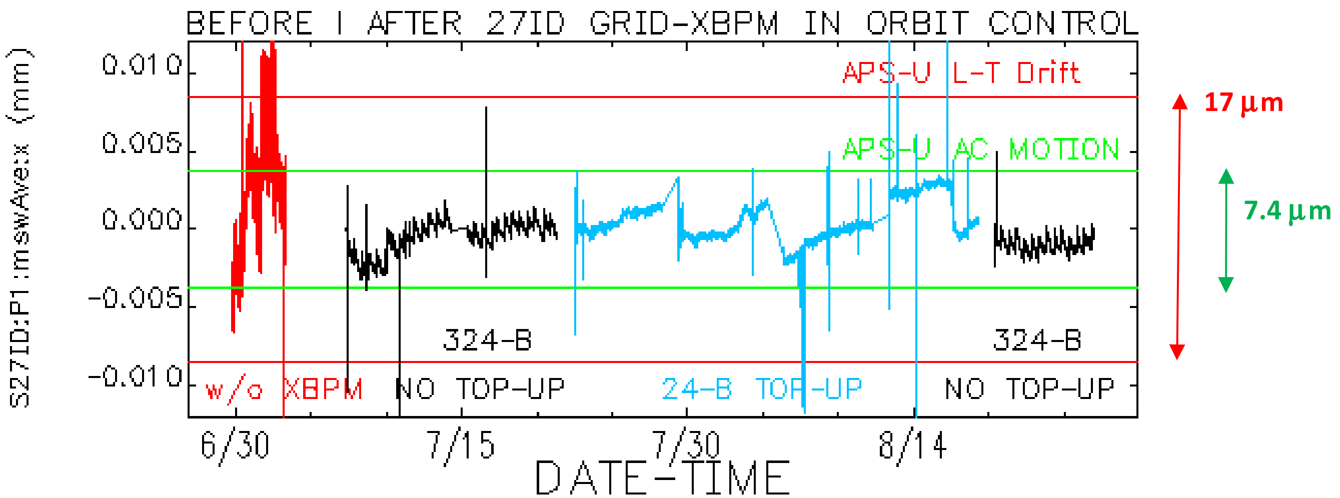


GRID XBPM Commissioning cont.



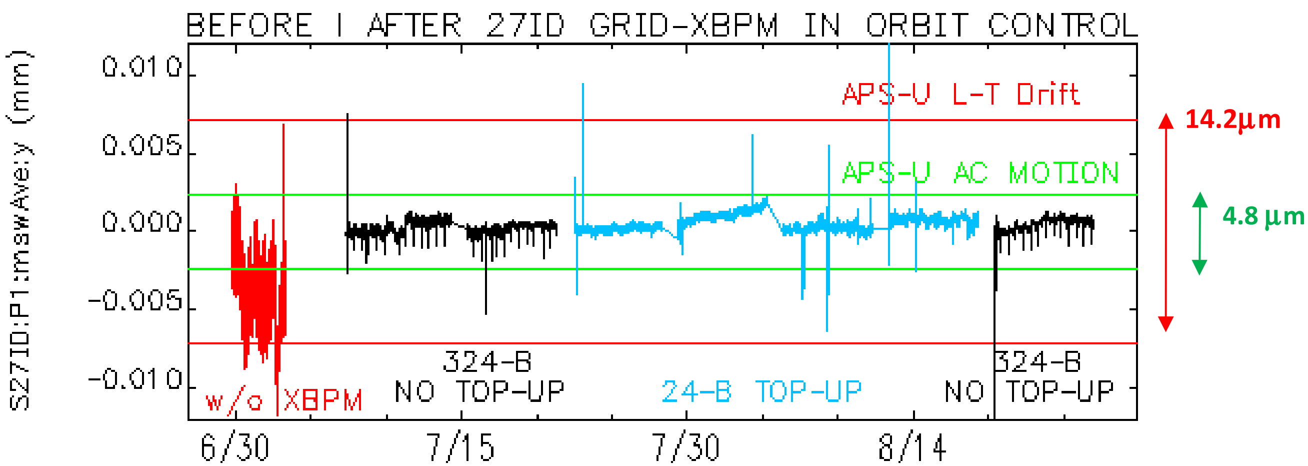
GRID XBPM Commissioning cont.

Horizontal beam position



Data from User Operations Run 2015-02

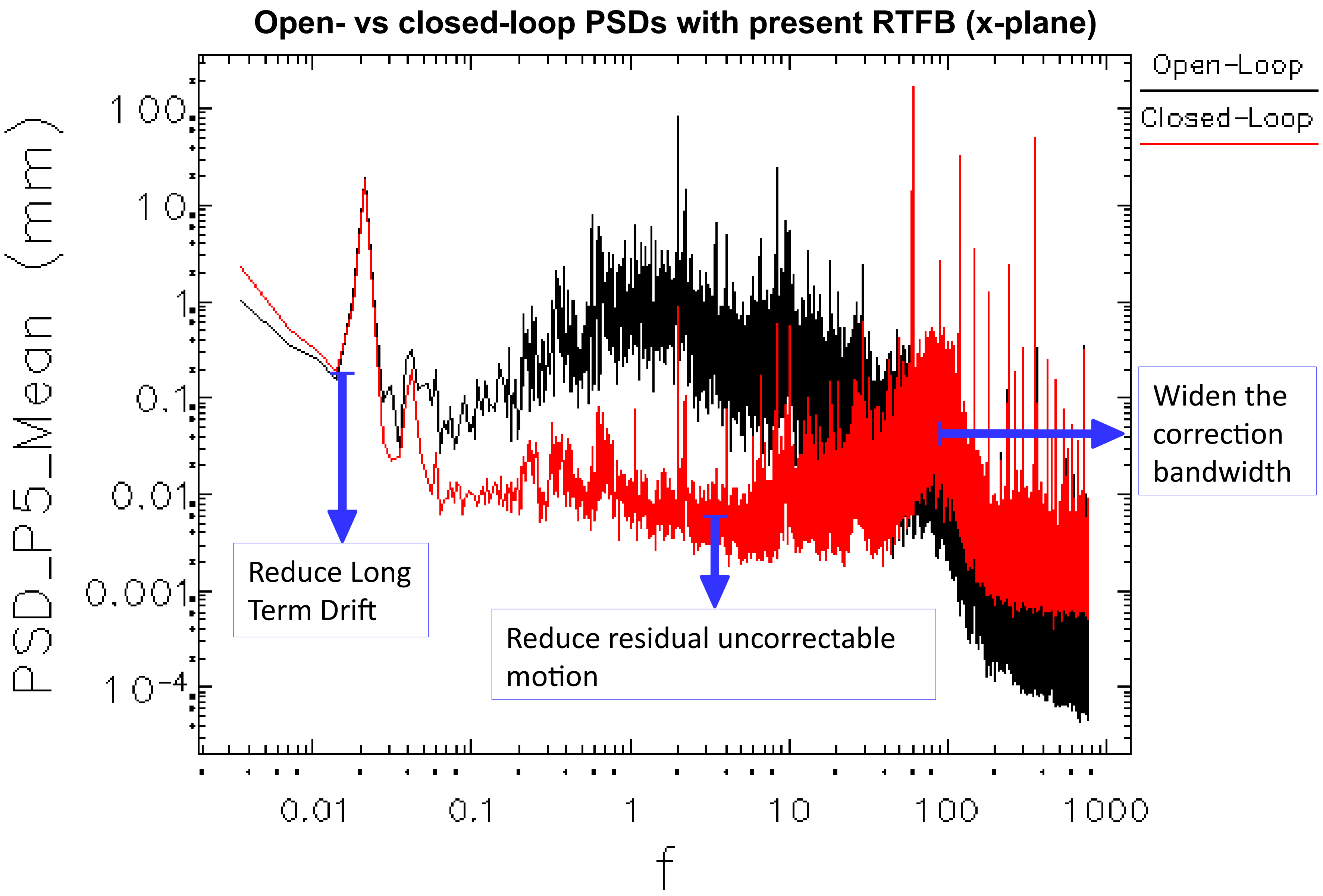
Vertical beam position



Date in Run 2015-2

- Long term performance of the GRID XBPM in sector 27

Targets for Orbit-Feedback Performance Improvements



Orbit Feedback Performance Improvements

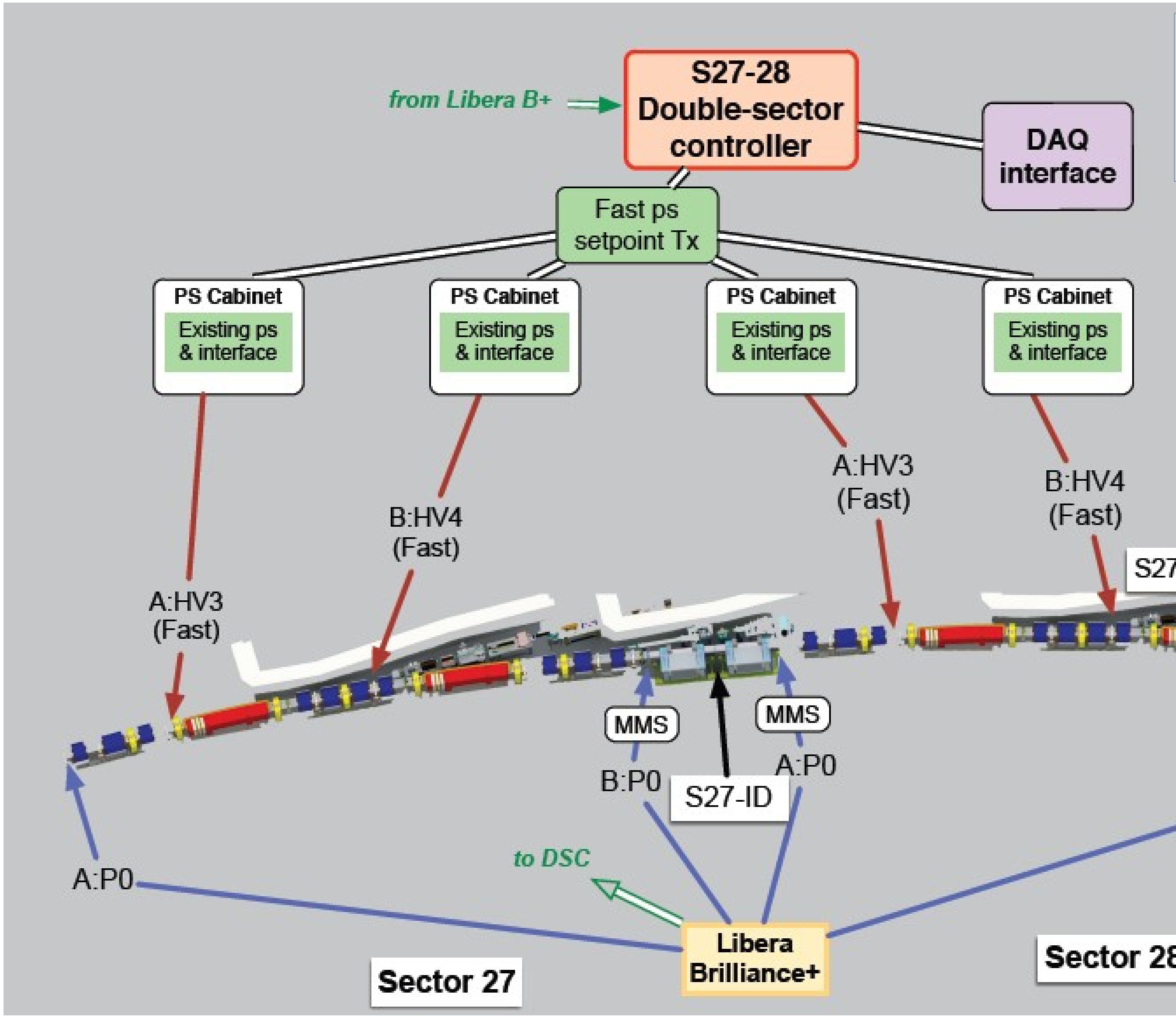
- Reduce long term drift -
  - Measure movement of BPMs using MMS system and correct after ring has "settled"
  - Move ID BPMs off the ID vacuum chamber to their own stable supports
  - Include GRID XBPMs in orbit feedback
  - Good drift performance from BPM electronics (measured in SR ~10 nm over 5 days[1])
- Reduce residual uncorrectable motion
  - Add more fast correctors (2 per sector per plane instead of 1)
  - Improved orbit correction feedback algorithm
- Widen correction bandwidth to 1 kHz (from present ~80 Hz)
  - Fast corrector power supplies small signal bandwidth to 10 kHz
  - Laminated-core 8 pole fast corrector magnet under development at Brookhaven (need DC steering range too)
  - Use thin Inconel chamber to minimize attenuation and time delays for AC field components
  - Minimize latency through the entire system using:
    - Modern data links to feedback controllers (60x faster than present RTFB system)
    - Modern DSPs to process bpm data to corrector setpoints (2000x faster than RTFB)

[1]**A.Brill etal. DIAG-TN-2015-018**

Initial Feedback Controller Testing in S27 (4x4 Test)

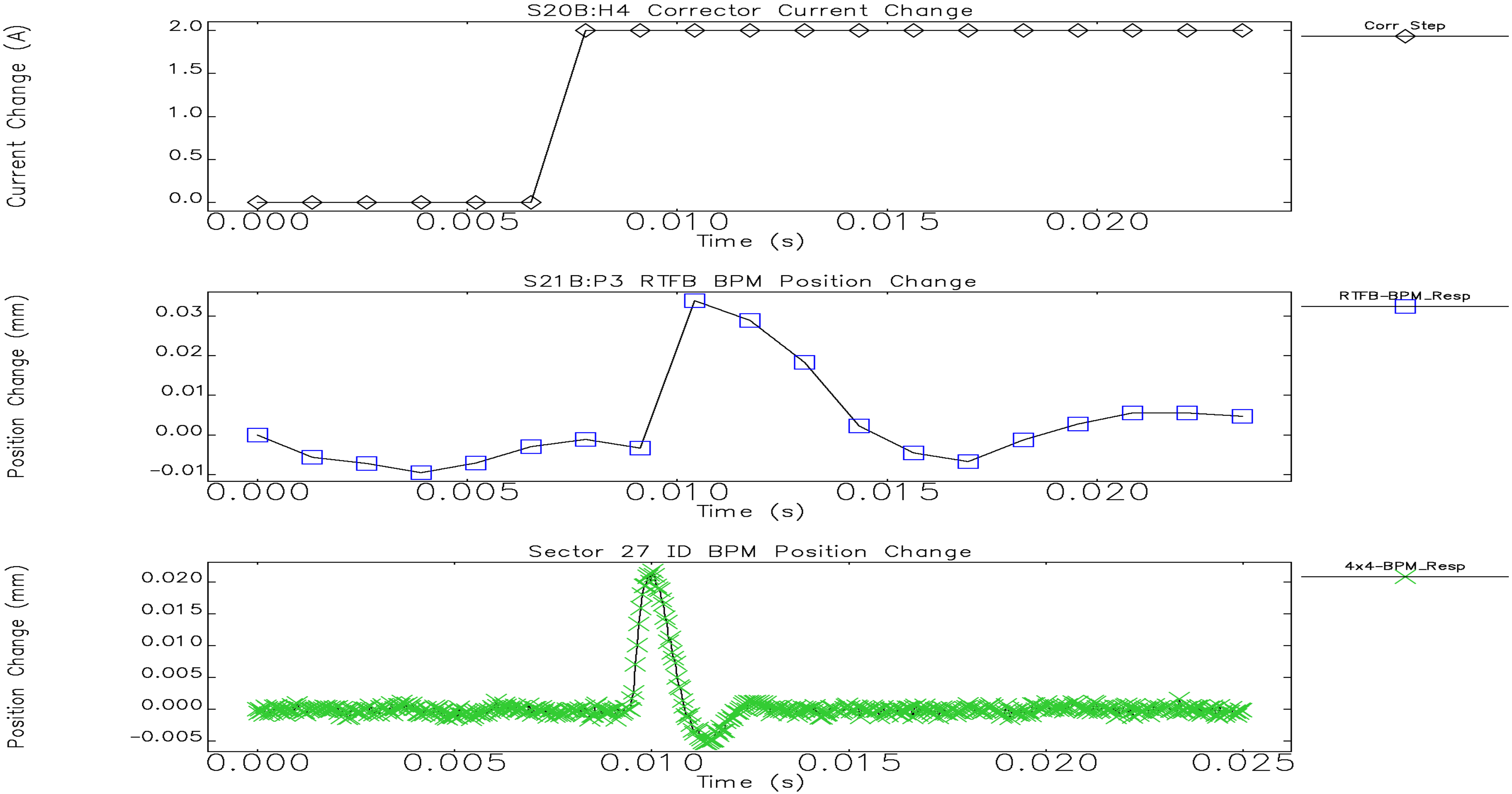
- Configured prototype feedback controller to use:
  - Four commercial bpm electronics (Instrumentation Technologies)
  - Existing fast bpms in sectors 27 and 28
  - Existing DSP code from operations RTFB system
  - Update rate of 22.6 kHz or 15x present RTFB system and closed the loop
  - Performed initial frequency and step response tests

Initial Feedback Controller Testing in S27 (4x4 Test)



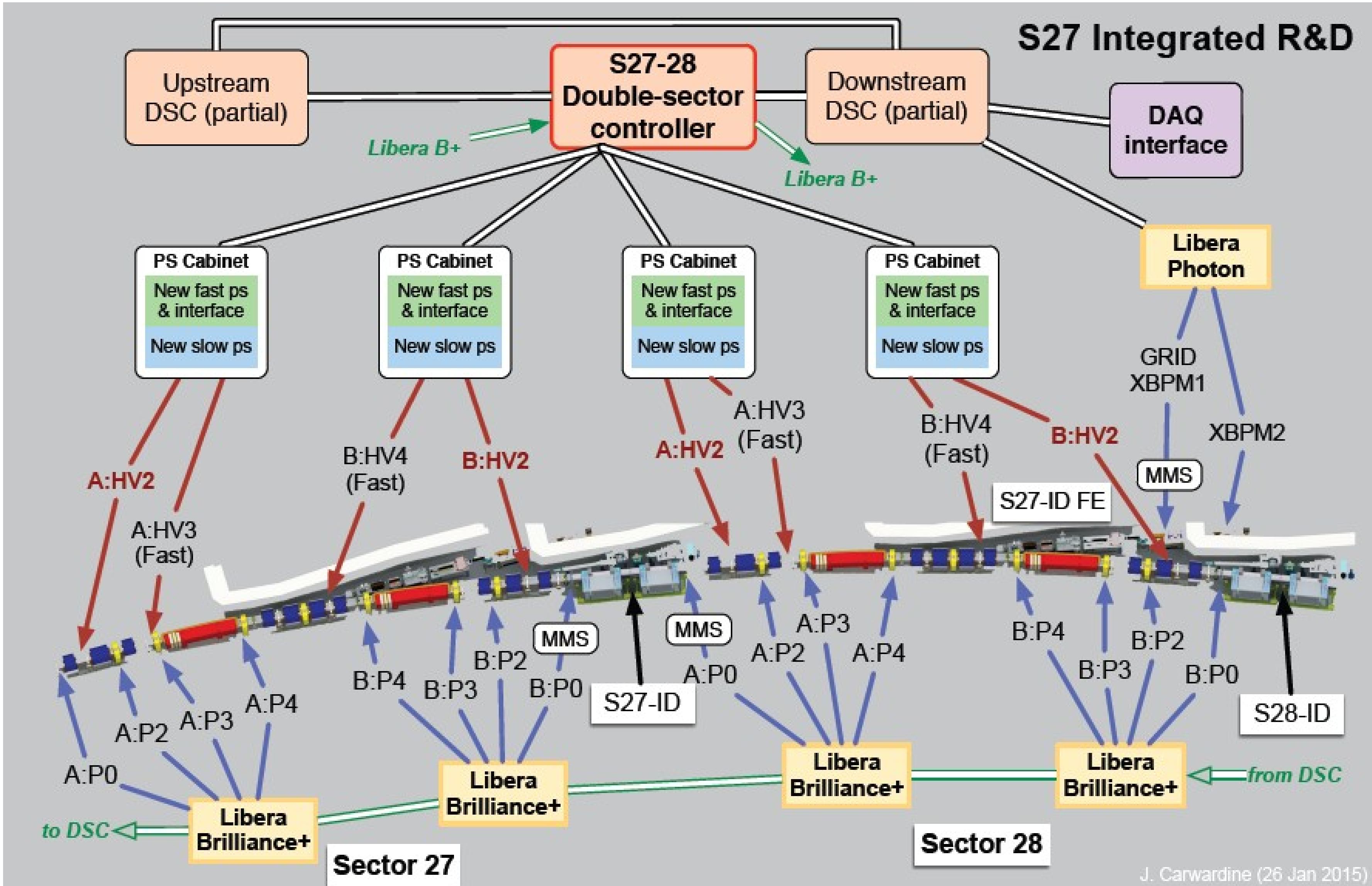
S27 - 4 Corrector
4 BPM Test

Initial Feedback Controller Testing in S27 (4x4 Test)



- Step response comparison between standard RTFB and 4x4 test prototype feedback controller

Integrated Beam Stability R&D Testing in S27 (Fall 2016)



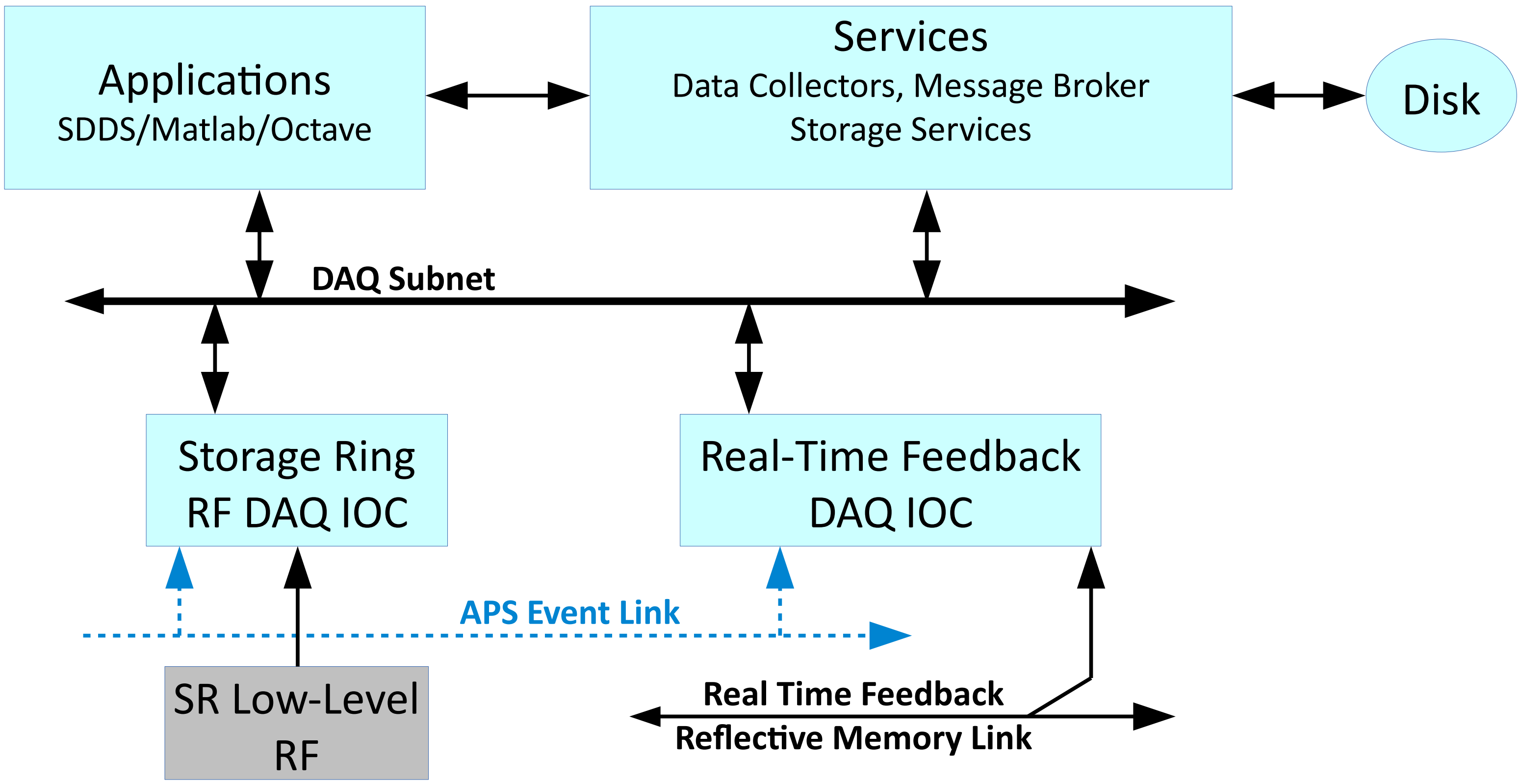
Summary

- Beam stability R&D in sector 27 is well underway to address the challenging requirements for the MBA ring
  - Tested prototype mechanical motion sensing system in sector 27
  - Tested prototype GRID XBPM in sector 27
  - Testing prototype feedback controller now in sector 27, 28 (4x4 test)
  - Integrated testing in sectors 27 and 28 to commence Fall of this year
- Longer term possibilities:
  - Leverage R&D in sectors 27 and 28 and upgrade legacy feedback, bpm, Xbpm systems before upgrade

Beam Stability R&D Team

- AES – Controls:
  - R. Farnsworth, F. Lenkszus, A. Pietryla, S. Shoaf, S. Veseli, S. Xu
- APS Upgrade Project:
  - N. Arnold, J. Carwardine, G. Decker
- ASD – Accelerator Operations and Physics
  - L. Emery, V. Sajaev, H. Shang, A. Xiao
- ASD – Diagnostics:
  - A. Brill, H. Bui, L. Erwin, R. Keane, B. Lill, N. Sereno, B. X. Yang
- ASD – Power Supplies:
  - B. Deriy, T. Fors, J. Wang
- ASD-RF:
  - T. Berenc, H. Ma
- APS Users:
- FMS:
  - M. Kirshenbaum, G. Kailus

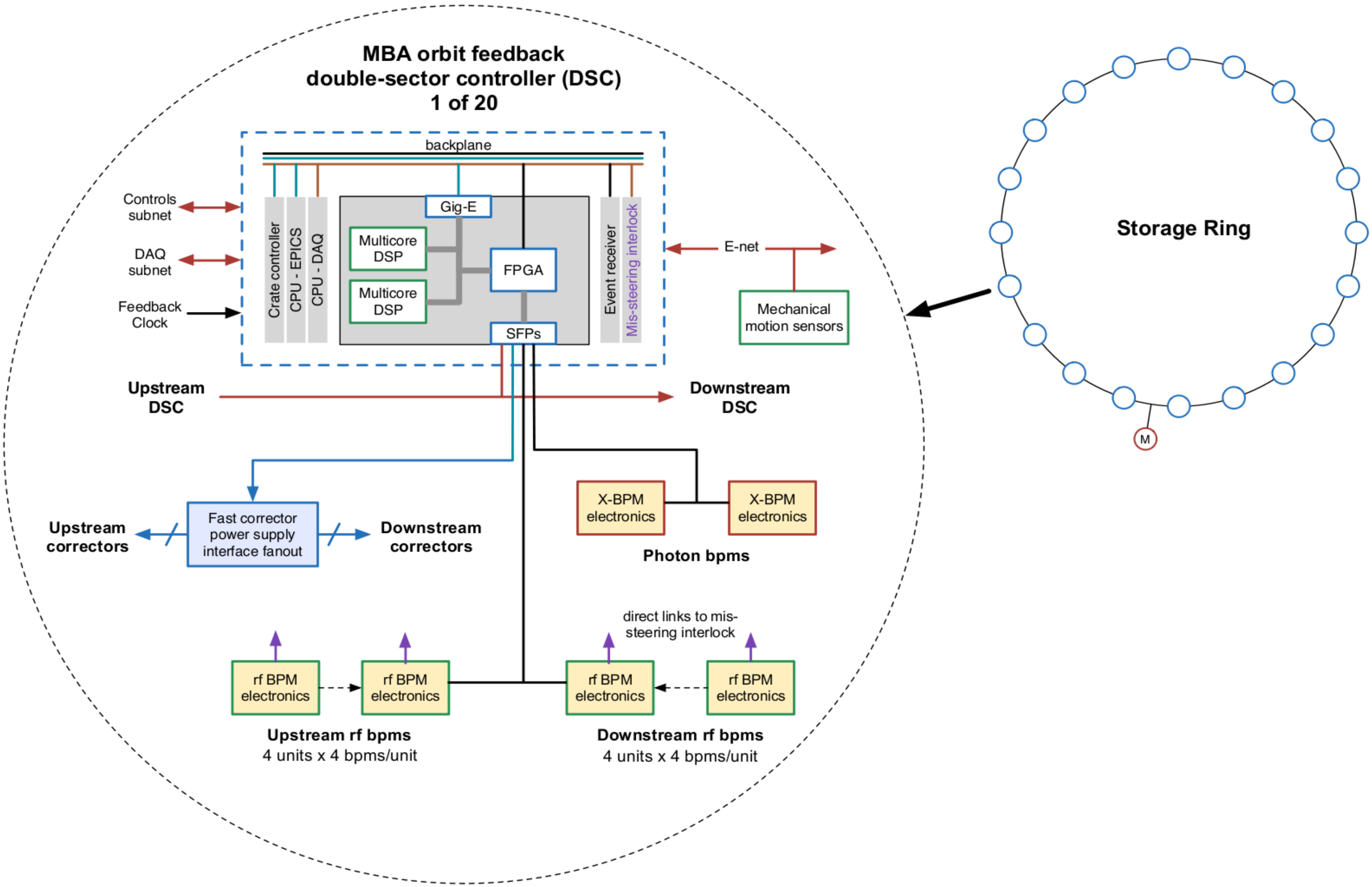
Extra Slide: Data Acquisition System for All Accelerator Subsystems



Block diagram of the prototype DAQ system installed in the APS SR

- Prototype DAQ system can acquire SR LLRF and Reflective Memory data from the existing feedback system at 1.5 kHz
- Future DAQ system acquires timestamped data up to turn-by-turn (271 kHz) rates across all accelerator systems: BPMs, DSC, Power Supplies, RF, Injection ...etc.

Extra Slide: APS - U Feedback Controller Modular Concept



Extra Slide: Feedback System Key Parameters Comparison

Parameter	**MBA RTFB**	Datapool	RTFB
BPM Sample rate	271 kHz (turn-by-turn)	10 Hz	1.5 kHz
BPM Orbit Vector transfer rate	271 kHz (goal)	10 Hz	1.5 kHz
Fast Corrector PS setpoint rate	22 kHz	10 Hz	1.5 kHz
Processing hardware	FPGAs / DSPs	EPICS IOC	DSPs
Rf bpms	570 / plane	360 / plane	160 / plane
ID X-ray bpms	90 / plane	50 / plane	-
Fast correctors	160 / plane	-	38 / plane
Slow correctors	320 / plane	300 / plane	-
Fast corrector bandwidth	10 kHz	-	*700-800 Hz
Slow corrector bandwidth	~1 Hz	~1 Hz	-
Closed-loop bandwidth	DC to 1 kHz	DC - 1 Hz	1 Hz - 80 Hz

* Power supply, magnet and vacuum chamber

- Present system consists of a slow (Datapool) and fast (RTFB) system (standard operations mode)
- A main goal of **MBA RTFB** is to unify slow and fast orbit correction into a single algorithm