# Beam Stability R&D at the APS

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**4th Diffraction Limited Storage Ring Workshop**
**ANL/APS**
November 20, 2014

# Outline

- AC Motion and Long Term Drift Specification
- Diagnostics System Overview
- RF BPM Electronics
- GRID/Canted undulator Xray BPM Development
- Mechanical Motion Detection System Development
- Orbit Feedback System Development
- Summary

# AC Motion and Long Term Drift Specification

- Beam stability specification driven by MBA rms beam size[1]
- AC Stability defined as 10% minimum MBA beam size in a given band at ID source points

Minimum expected beam sizes for MBA lattice

| $\sigma_x$ | $\sigma_{x'}$ | $\sigma_y$ | $\sigma_{y'}$ |
|---|---|---|---|
| 17 µm | 2.6 µrad | 4 µm | 1.7 µrad |

Beam Stability Goals for MBA lattice

| | AC rms Motion (0.01-1000 Hz) | AC rms Motion (0.01-1000 Hz) | Long Term Drift (7 Days) | Long Term Drift (7 Days) |
|---|---|---|---|---|
| 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) |

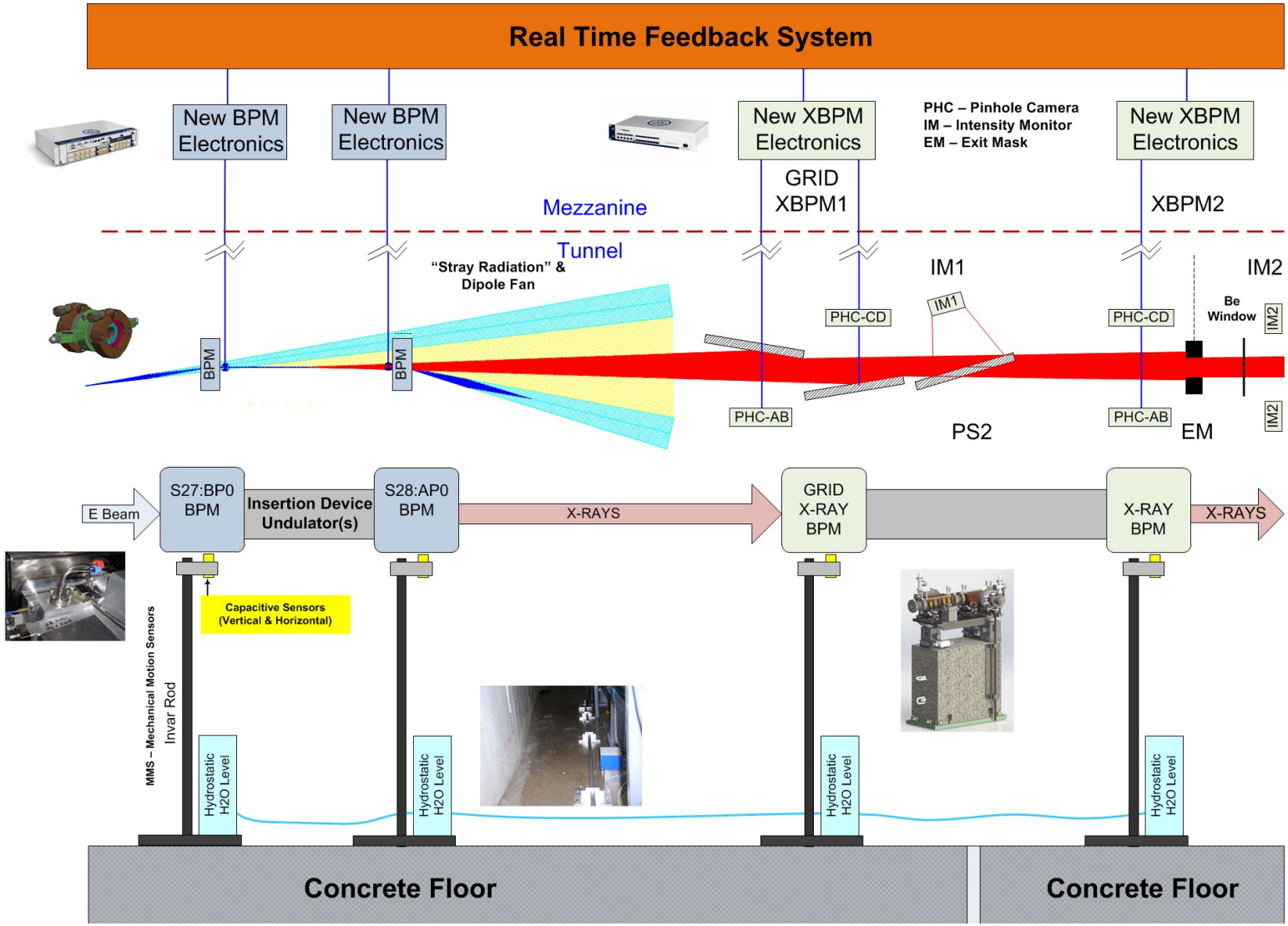
**Present Storage Ring Performance**

[1]APS MBA Accelerator Systems Working Assumptions and Parameter List

# AC Motion and Long Term Drift Specification

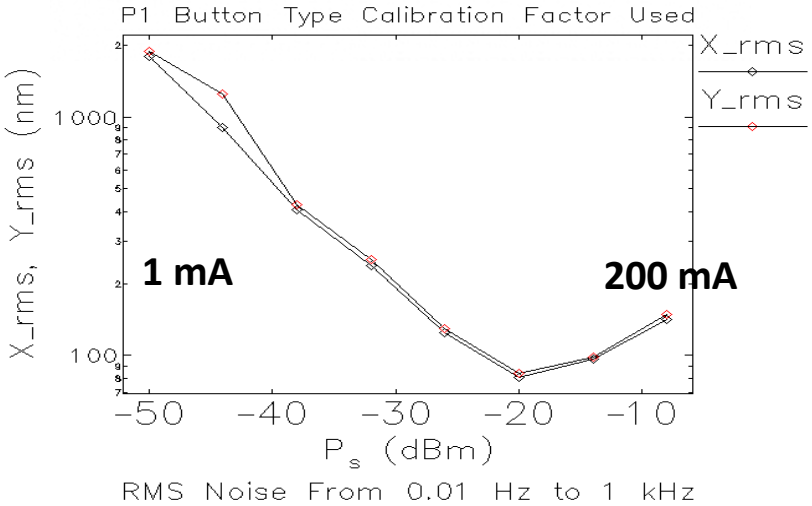
- Beam stability for MBA is challenging (factor 3 – 10 compared to present)
- Replace RF BPM electronics with commercially available (or equivalent)
  - Present Bergoz system at P0, P1 bpms near ID only good at low frequency
  - Present BSP-100 (FPGA) bpms in arc are good for AC but have bunch pattern dependence at DC
- MBA GRID/Canted undulator Xray BPM Development
  - Improve signal/noise over existing photoemission (PE) bpms
  - Reduce systematic gap dependent errors over existing (PE) bpms
- Mechanical motion measurement system development
  - Measure long term drift
  - Inform the mechanical engineering vacuum chamber design for MBA
- Orbit feedback system development
  - Increase closed-loop BW from 100 to 1000 Hz
  - Increase sampling rate from 1.5 to 20 kHz
  - Increase bpm number from 160 to > 600 (rf and Xray bpms)
  - Double fast correctors per sector and *unify slow and fast correctors in a single feedback algorithm*

# Diagnostics System Overview (Sector 27 R&D Testing)

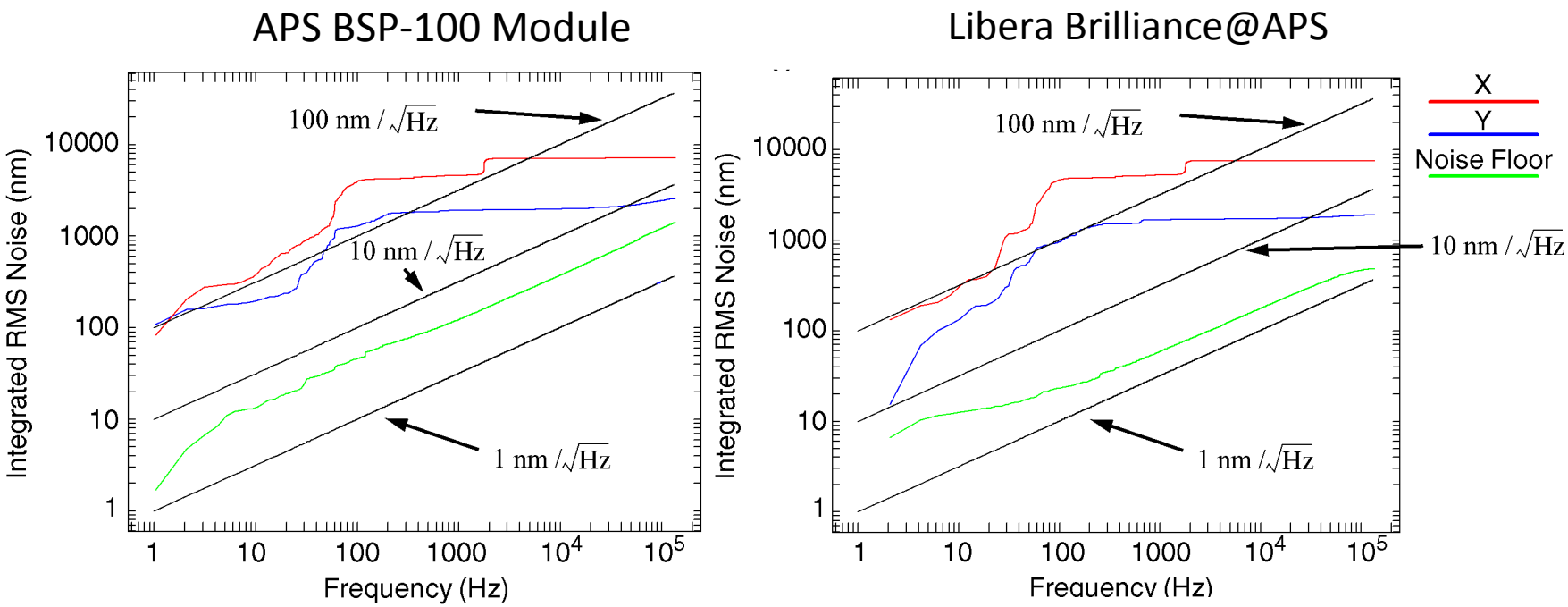


# RF BPM Electronics

- Use commecially available bpm electronics from Instrumentation Technologies
  - Libera Brilliance+: 570 RF bpms
  - Libera Photon: 50 X-ray bpms
- Lab measurements indicate good performance:
  - ~100 nm or less rms noise (0.01-1 kHz)
  - ~100 nm or less long term drift (2.4 days)
- Also investigating NSLS-II solution
- Plan is to use electronics that already exist and we can purchase and/or modify for our MBA upgrade application



# RF BPM Electronics

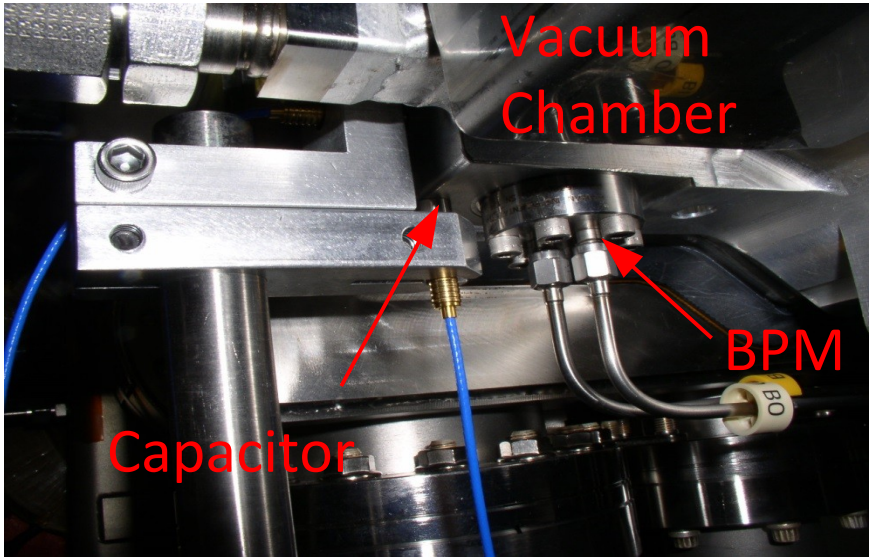


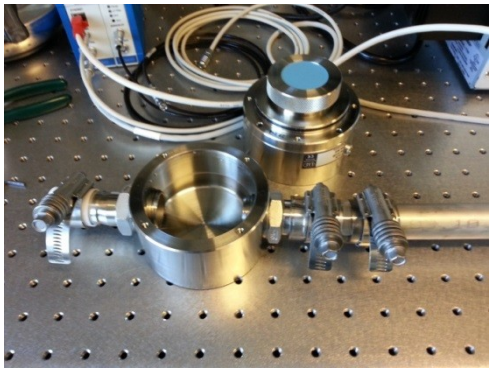

Note: Noise measurement used small-aperture rotated button geometry, with horizontal calibration factor.

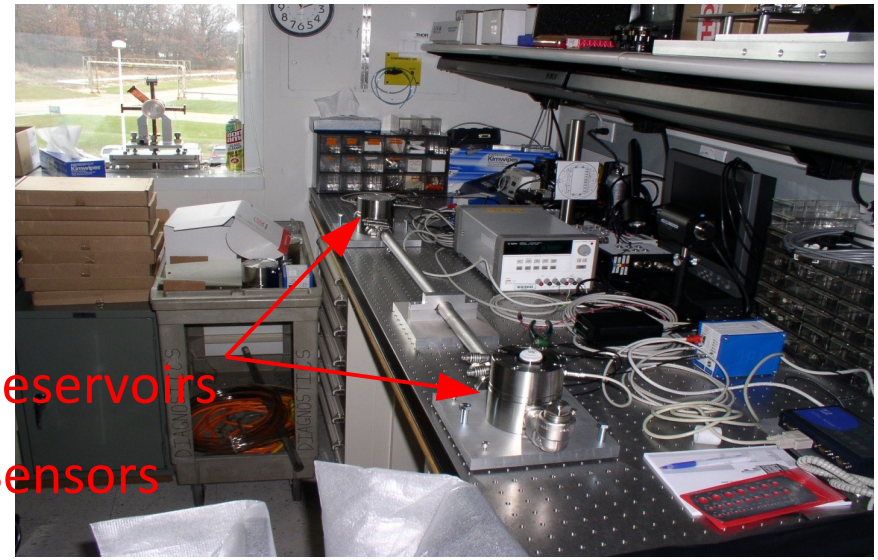
G. Decker, BIW10

# Mechanical Motion Sensing System

- Installed in sector 27 insertion device vacuum chamber
  - Hydrostatic sensor detects relative vertical ground motion
  - Capacitative detectors sense horizontal and vertical vacuum chamber motion (P0 bpms)
- Can detect mechanical motion as small as 20 nm
- Plan to add a similar system to the GRID XBPM in S27

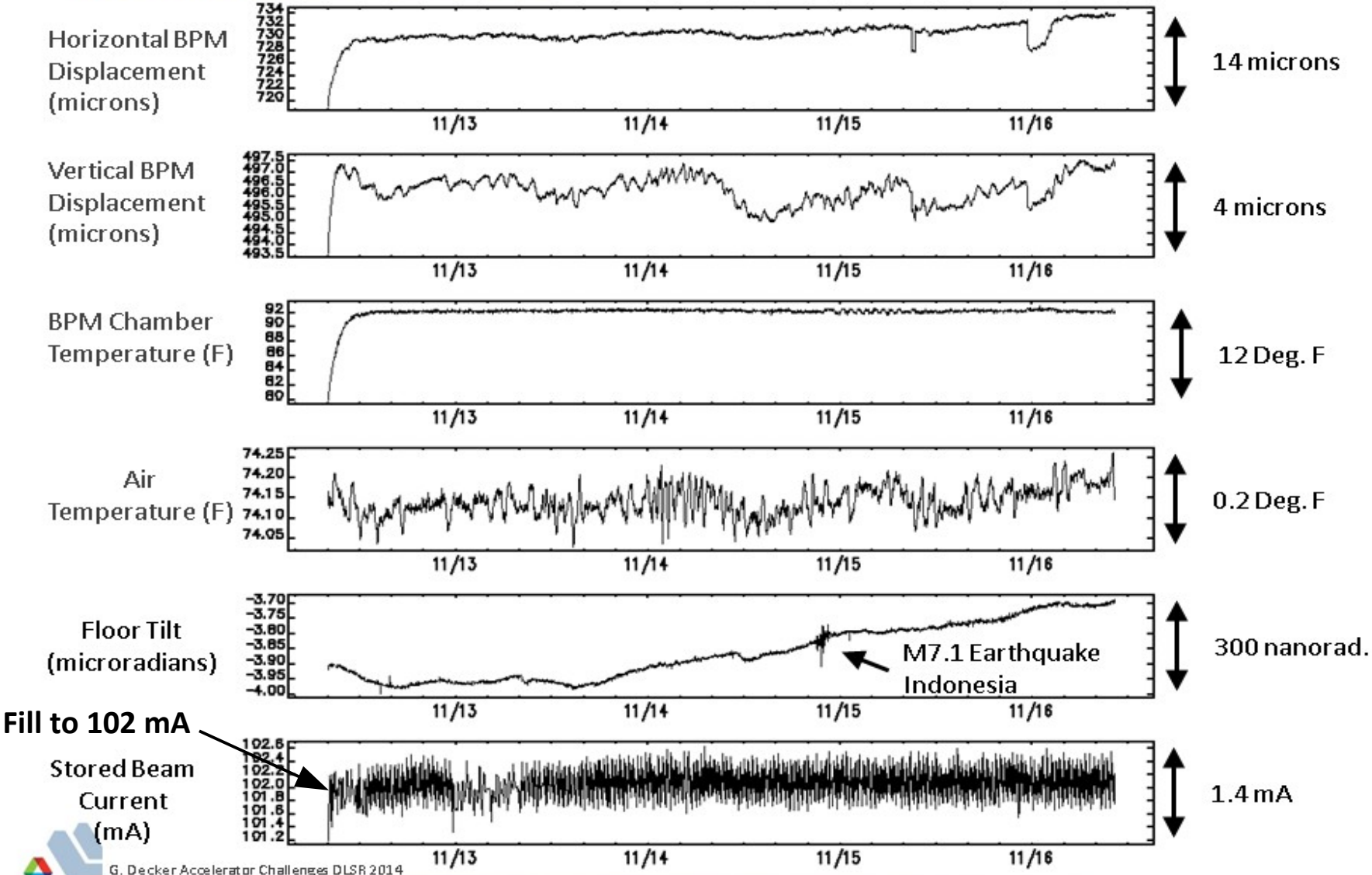




# Mechanical Stability

## 102 mA, 24 Singlets Top-Up

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G. Decker Accelerator Challenges DLSR 2014

# Mechanical Motion Sensing System Data

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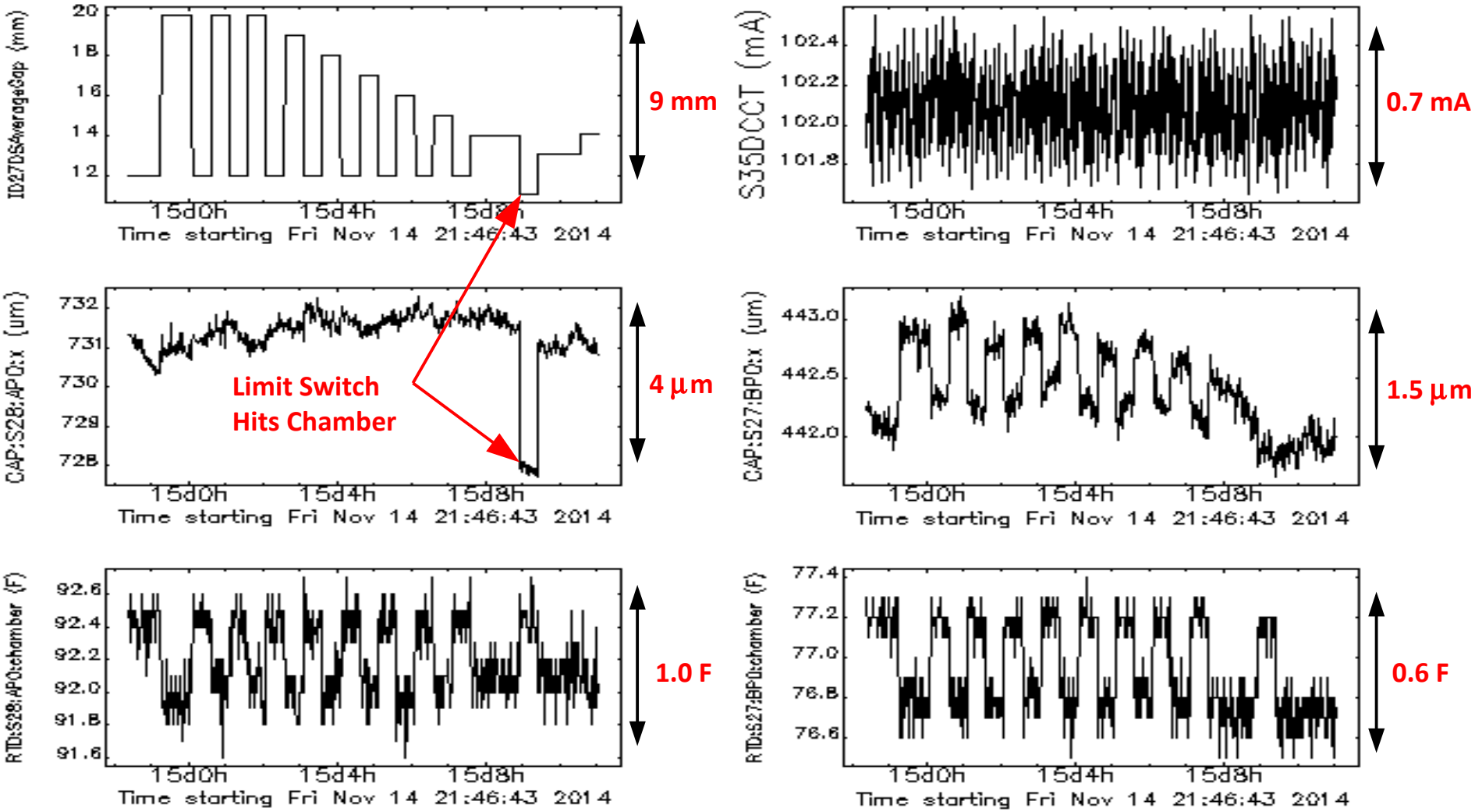

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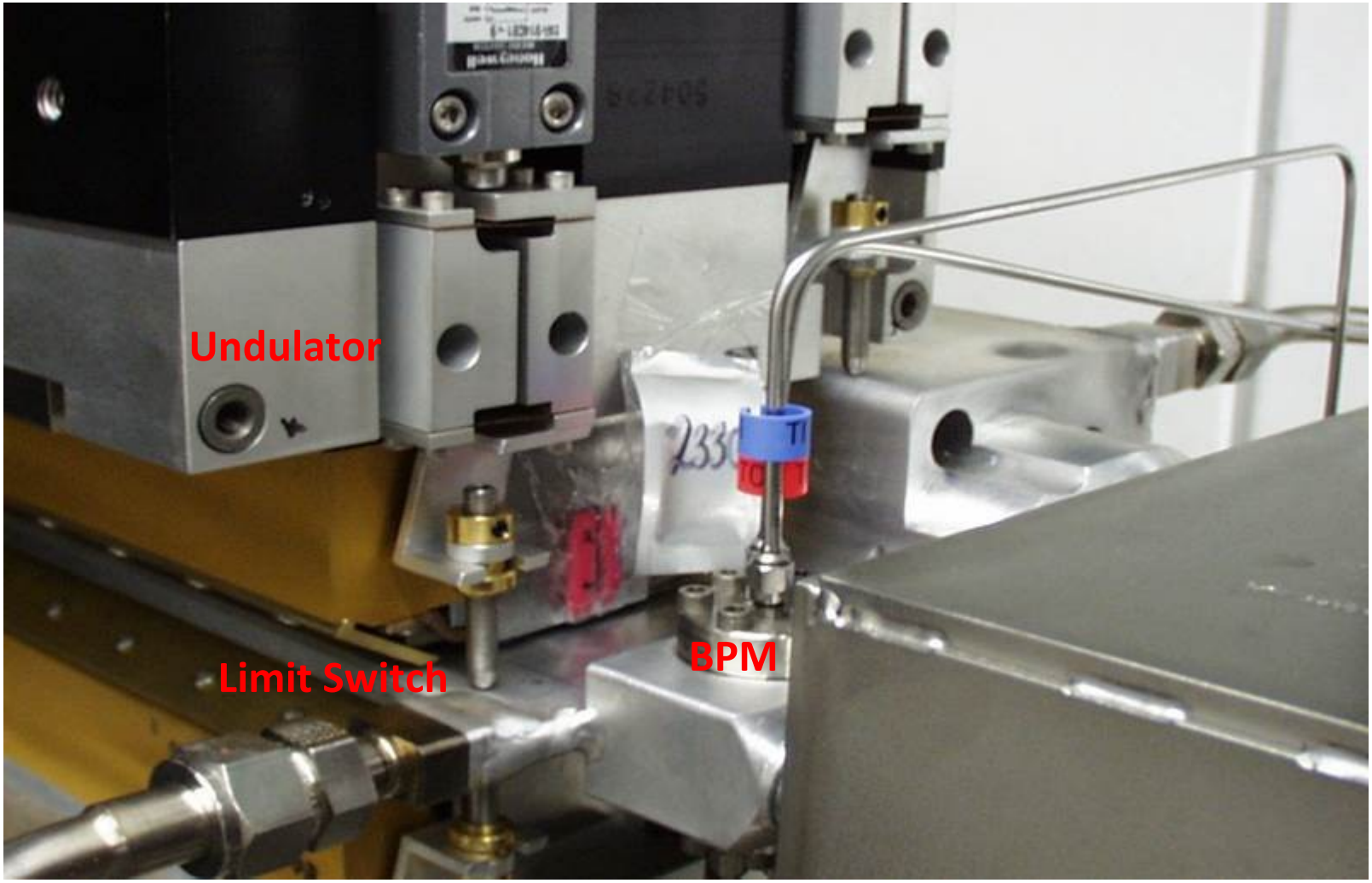
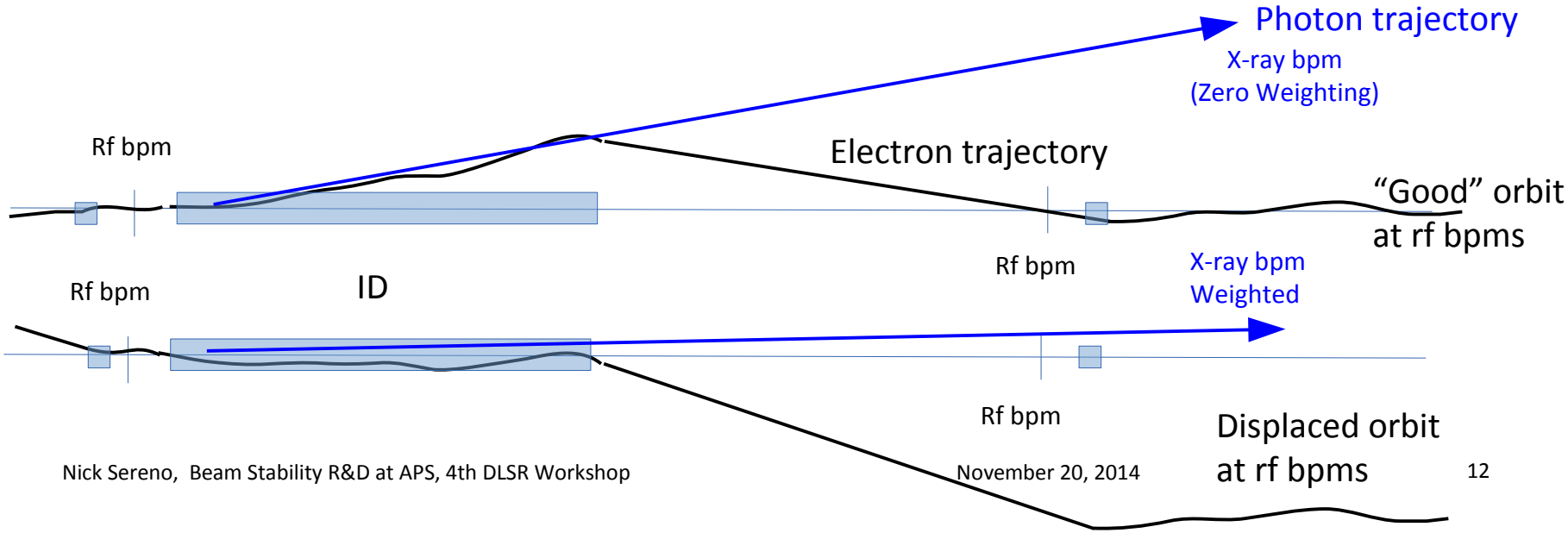


# GRID Xray BPM System

- Installed in sectors 27 and 35 Front Ends
  - Use hard X-ray fluorescence from Cu
  - S/N is ~50 times greater than existing photoemission BPMs
- Gap dependent systematic error reduced by ~>10
- Expect pointing stability to improve by a similar factor



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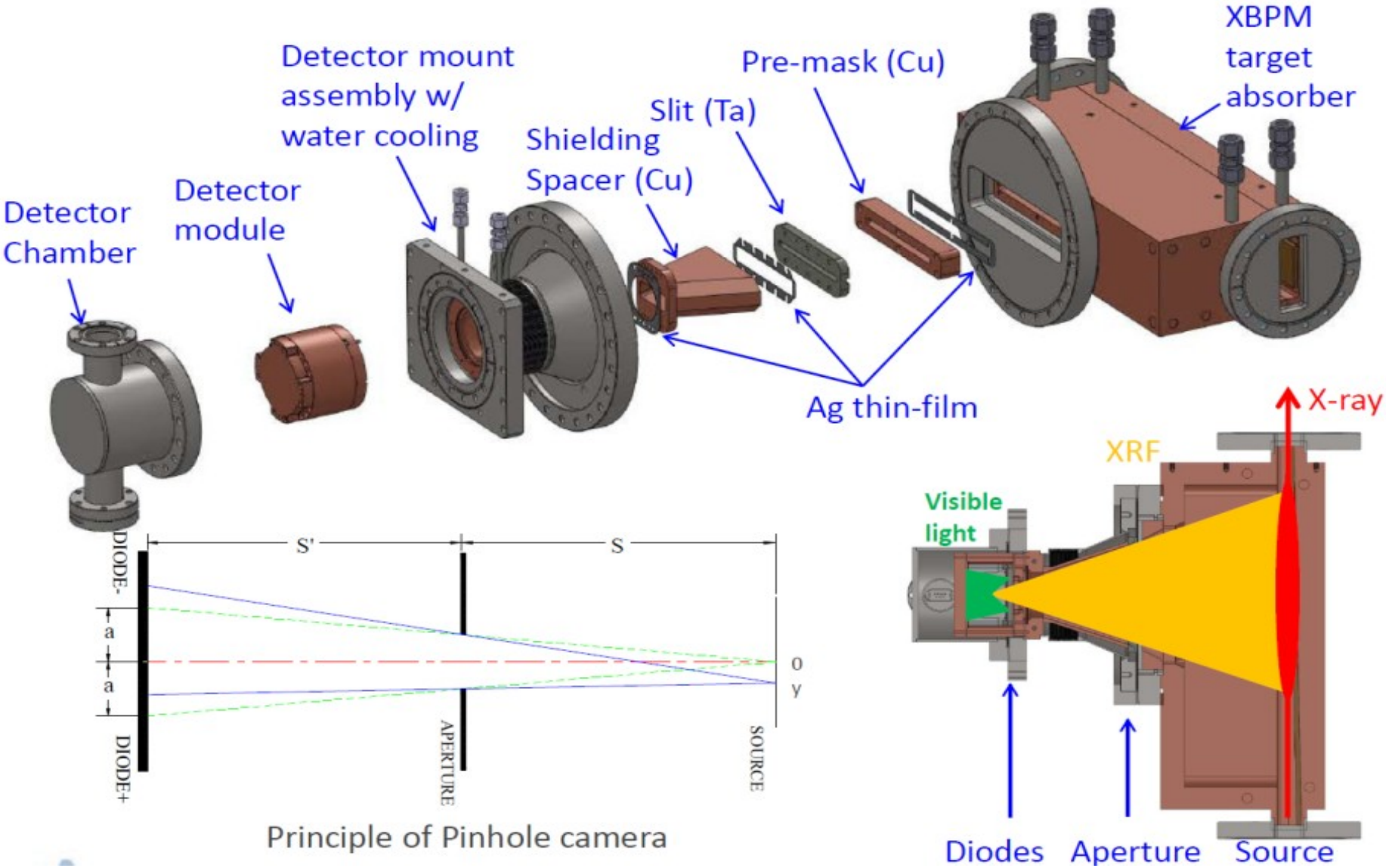

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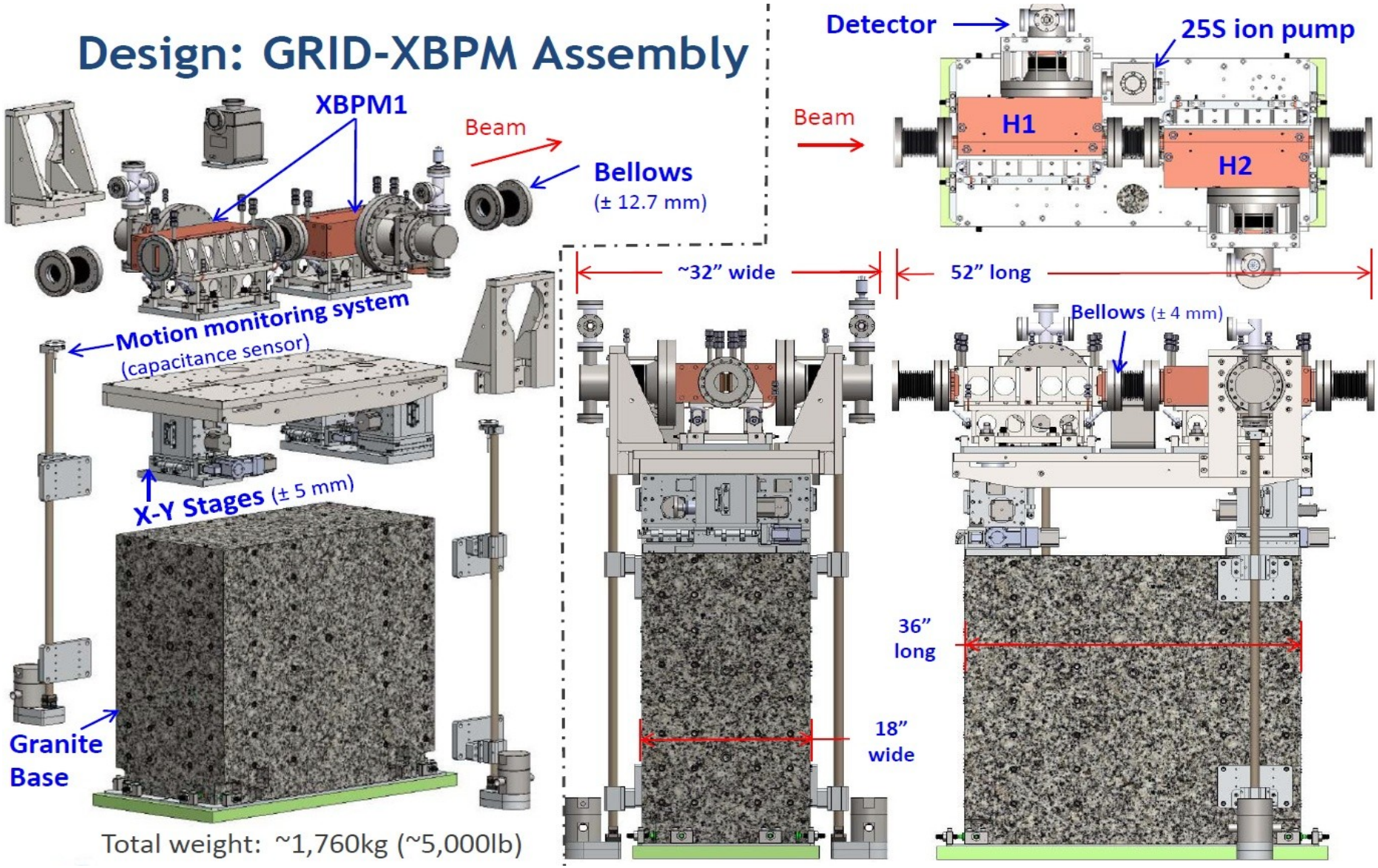
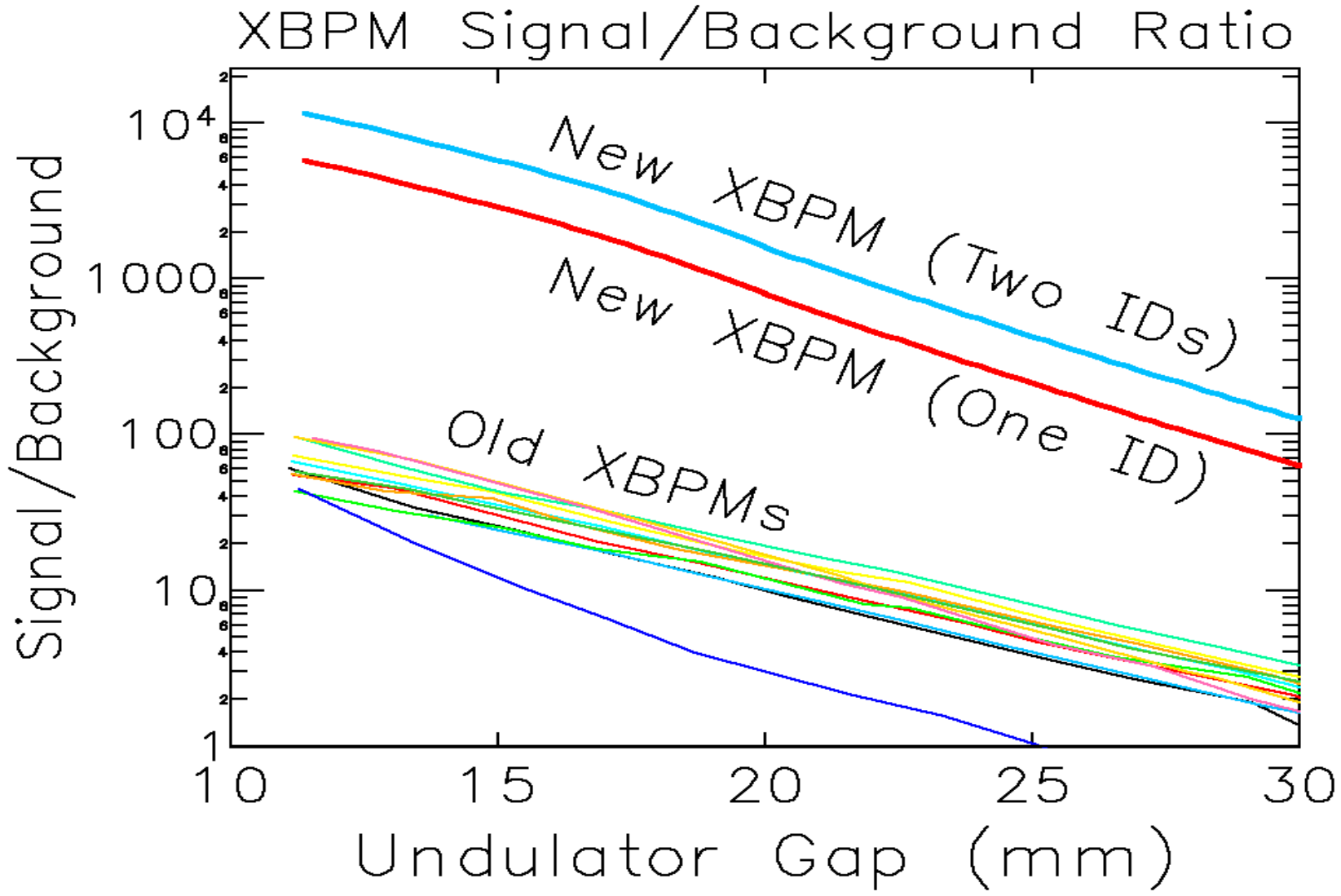


# GRID Xray BPM System



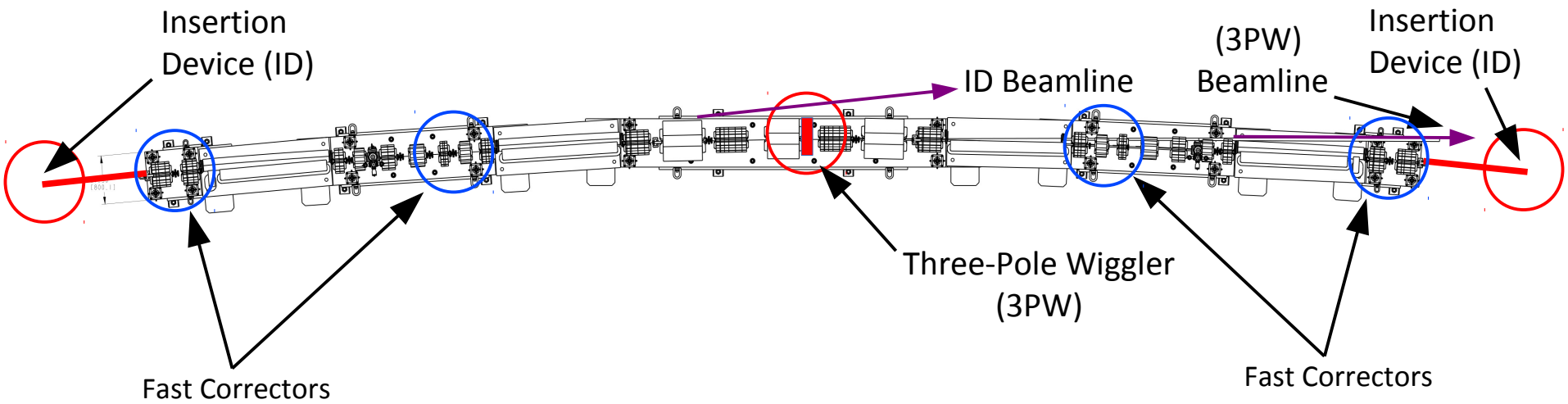
# Orbit Feedback System Development

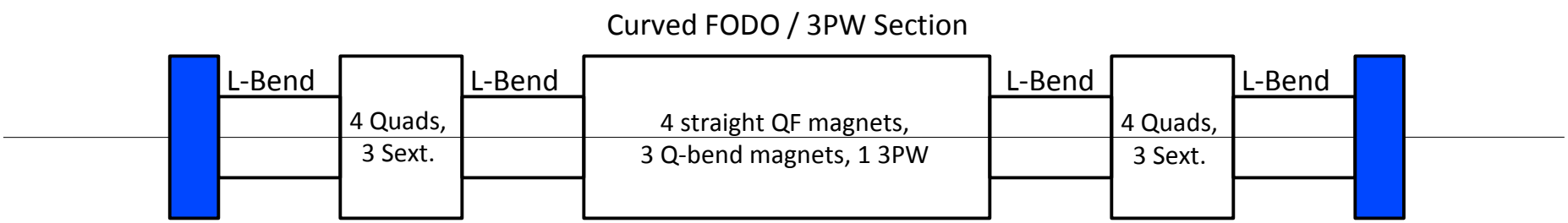
- Motivated by MBA beam stability requirements
- Investigating the possibility to upgrade existing system before MBA
- Developed an MBA R&D plan in sector 27 of the SR:
  - Installed Libera B+ on four ID P0 bpms and testing now with existing feedback system
  - Installed GRID X-BPM and testing it now
  - Installed mechanical motion sensing system in 27 ID vacuum chamber
  - Plan a 4x4 bpm/fast corrector test at higher sampling rate next year
- Developing a FPGA based prototype double sector controller (DSC) processor
- Investigating alternative DSP/FPGA μTCA based DSC processor hardware
- Investigating a way to unify fast and slow correctors in a single feedback algorithm[1]

[1] J. Carwardine, Workshop on Next-generation Fast Orbit Feedback Systems for Storage Rings, May 9, 2013 APS/CNM/EMC Users Meeting

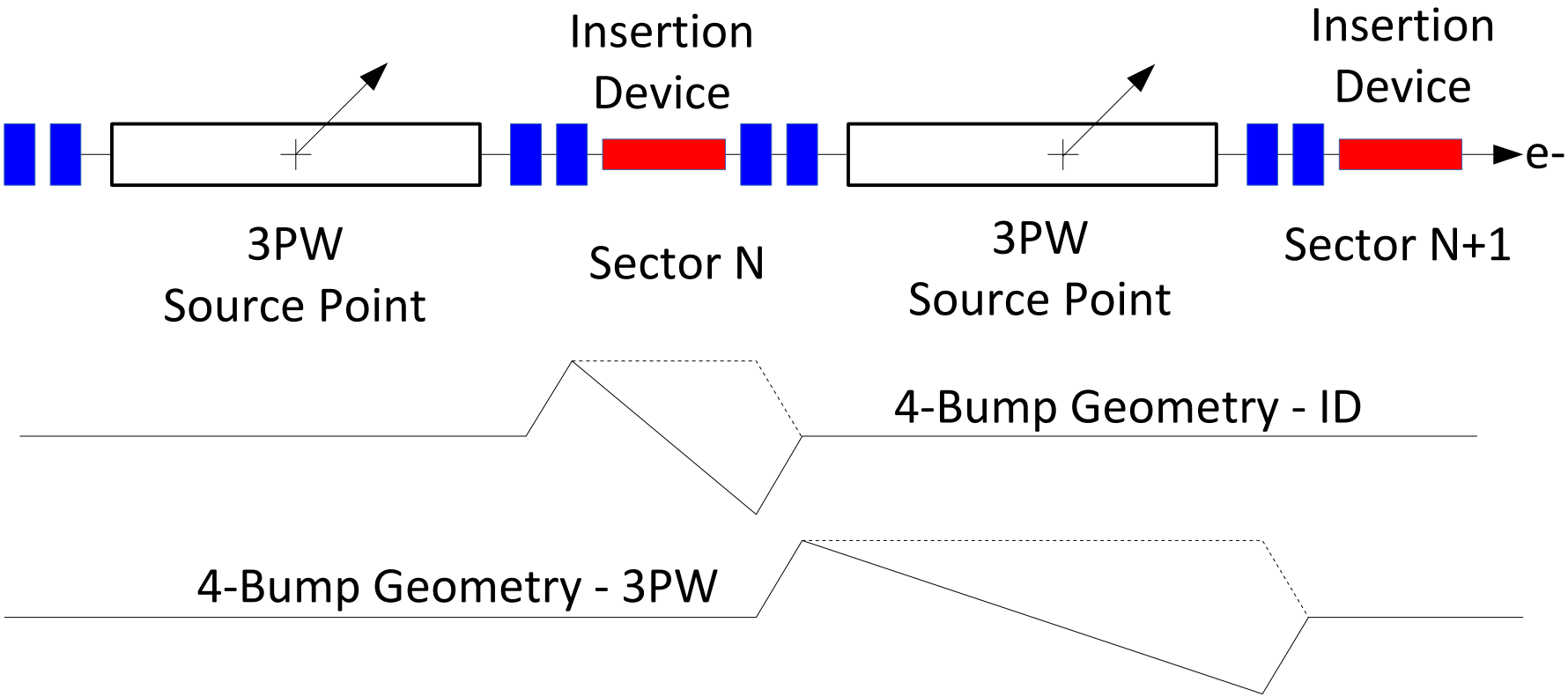
# Source Points and Fast Correctors

- Sector X-ray source points -
- Sector X-Ray beamlines -
- Fast correctors -



# Fast Orbit Feedback Concept




Using two correctors between source points provides each source with the required position and angle degrees of freedom

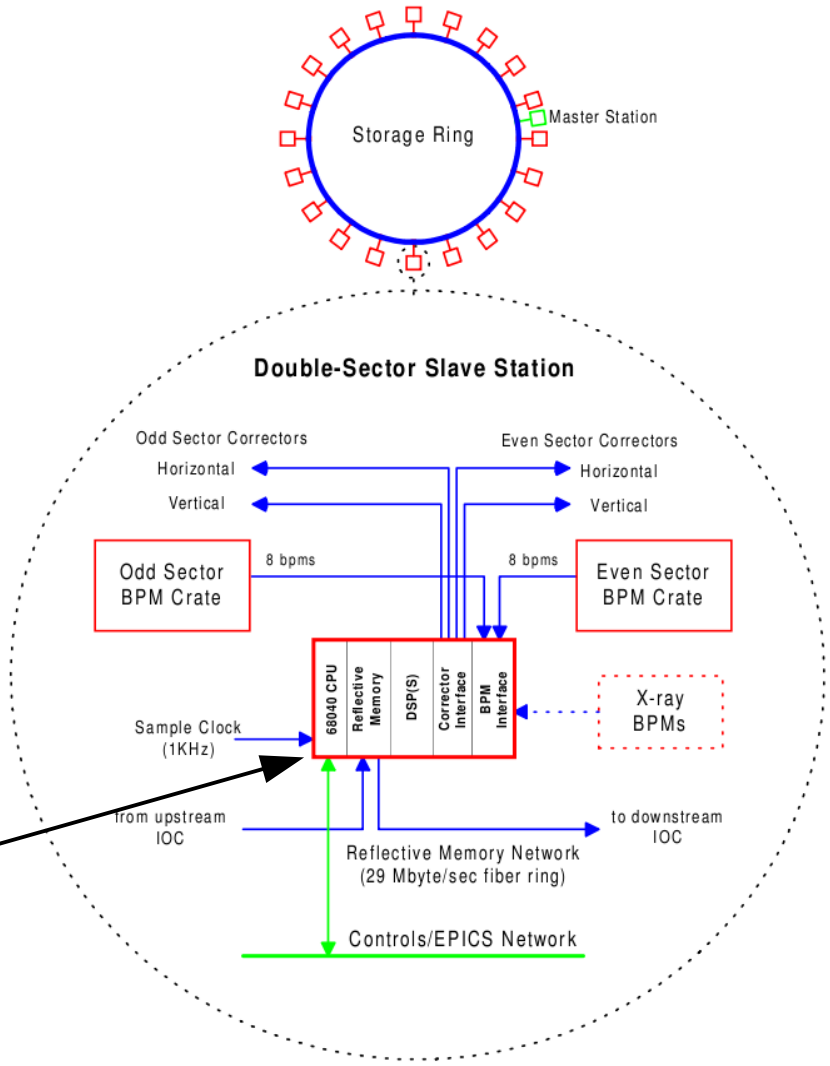
Fast Steering Corrector

Insertion Device

Arc Magnets

# Feedback System Architecture

- Consists of 20 VME crates plus a master crate and reflective memory
- Existing RTFB system DSPs:
  - Read a vector of bpm data during read phase
  - Multiply bpm vector by inverse response matrix
  - Apply PID regulator/filtering and update sector correctors
  - Write bpm data to reflective memory during write phase
- Datapool IOC updates RTFB bpm setpoints for band overlap compensation
- New DSC will "plug" into here
  - New bpm electronics/corrector interface
  - DSC-DSC fast communications network

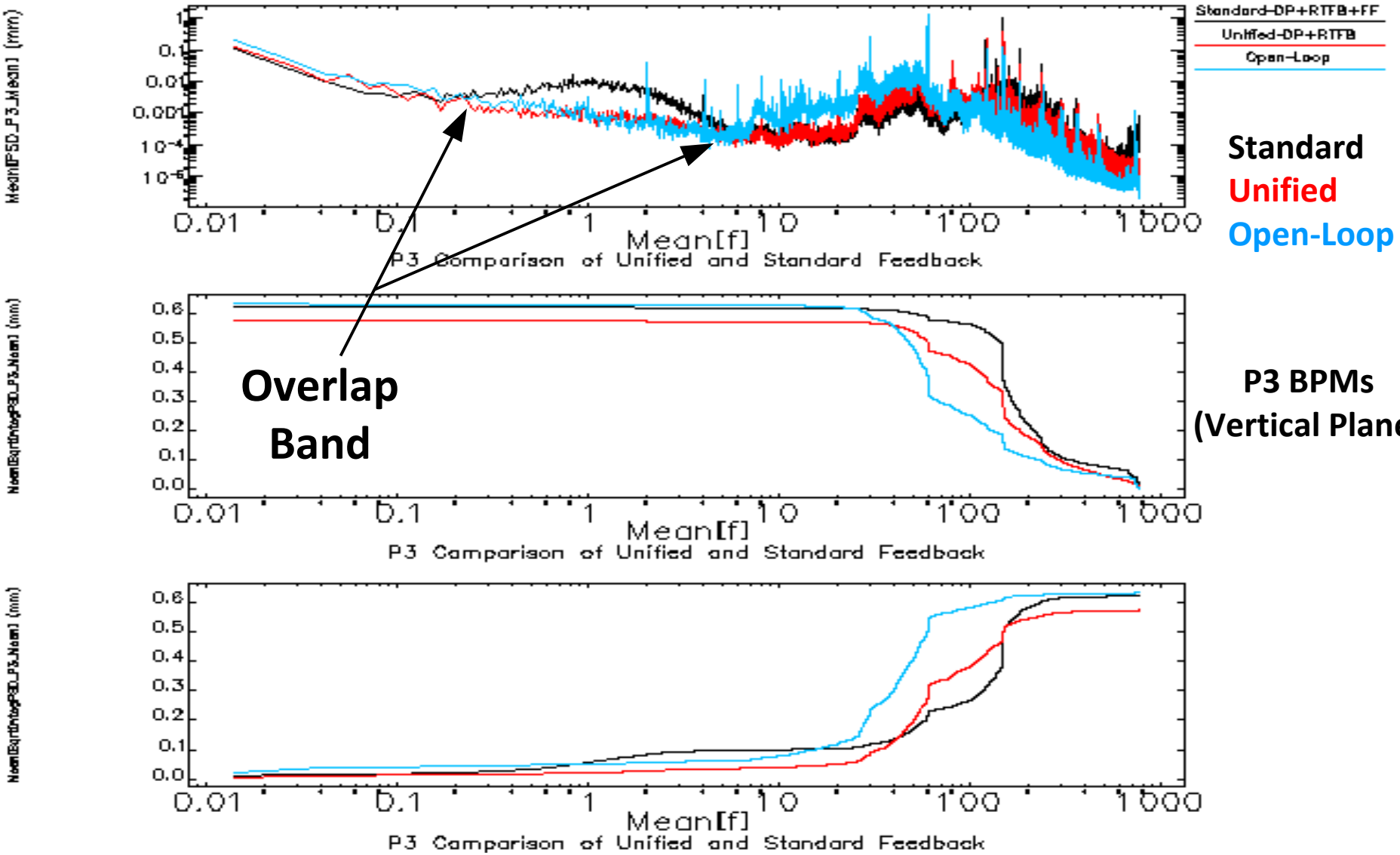



J.A. Carwardine - ICALEPCS '97

# Unified Feedback Machine Studies Results

- Concept is to correct the orbit using both systems configured to correct down to DC
  - RTFB system corrects fewer spatial modes but very fast
  - Datapool corrects many spatial modes slowly
  - How develop the algorithm so the systems work together without fighting in the band where they overlap (~0.2-5 Hz)?
- Took an experimental approach first:
  - Configured RTFB to correct down to DC with its operations set of bpms and correctors
  - Measured the datapool response matrix for datapool correctors and bpms with RTFB running down to DC
- Resulting datapool response matrix is band-diagonal
  - RTFB corrects most of the orbit via local bumps
  - The left over response at bpms within the bumps is what RTFB cannot correct
- Took the inverse datapool response matrix and ran both systems to DC

# Unified Feedback Machine Studies Results

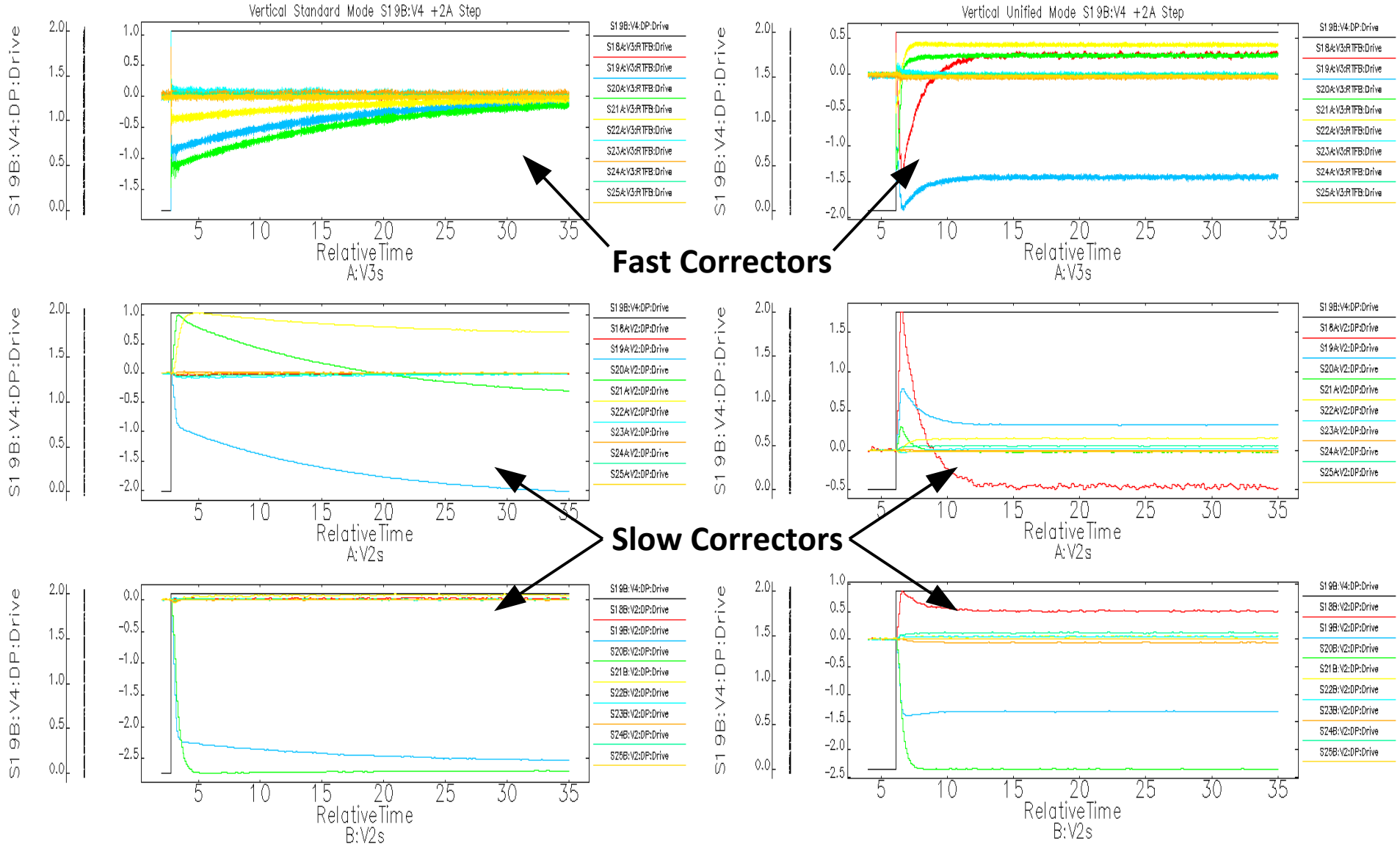



- **Frequency Domain Comparison of Standard and Unified Modes @ P3s**

# Unified Feedback Machine Studies Results

## Standard Feedback

## Unified Feedback




**Vertical plane step response comparison of standard and unified modes**

# Summary

- Beam stability requirements are challenging
- APS has developed a comprehensive beam stability R&D program featuring:
  - New bpm electronics
  - New GRID/Canted undulator X-ray bpms
  - Mechanical motion sensing of vacuum chamber position
  - Tunnel air temperature stabilization
  - Beam size and relative size measurement (coupling feedback)
  - Feedback system hardware and algorithm development
- Unified feedback concept looks interesting and we are pursuing studies (need to restart the simulation effort)
- Sector 27 testing in the next year will help flesh out details