Beam Stability R&D for the APS MBA Upgrade

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Libera Workshop 2015

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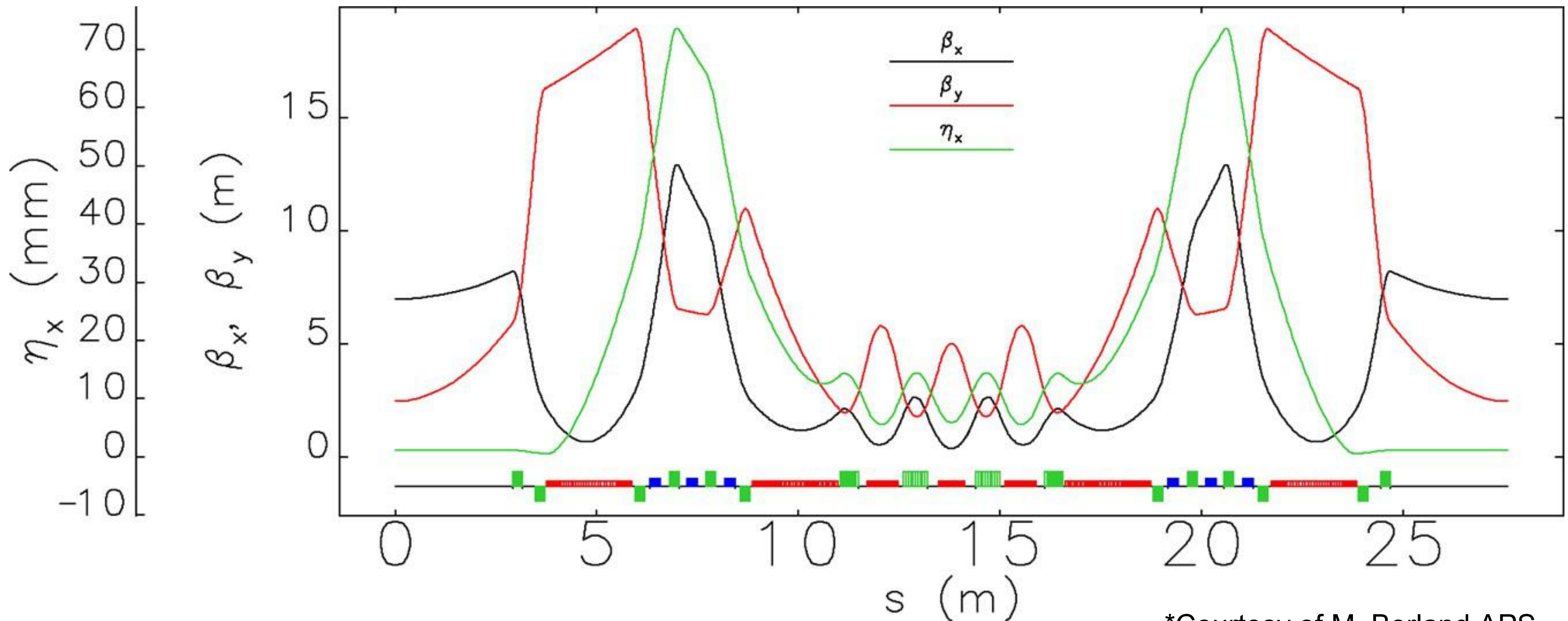
Outline

- MBA Upgrade Lattice Concept
- MBA Diagnostic Systems
- General Diagnostics Requirements
  - Orbit Positioning
  - Stored Beam Stability
  - AC Motion and Long Term Drift Specification
- Integrated Beam Stability R&D
- Mechanical Motion Detection System Development
- X-ray BPM System Development
- Orbit Feedback System Development and Architecture
- Orbit Feedback R&D Topics
  - Libera B+ integration
  - μTCA Feedback Processor Development
- MBA R&D Plan in the APS SR
- Summary

APS Upgrade V6 Magnetic Lattice*



*Courtesy of M. Borland APS

Forty sectors; in each sector:

- Seven dipoles (red)
  - Four with longitudinal gradient
  - Three with transverse gradient
- Sixteen quadrupoles, six sextupoles
- Four fast combined-function eight-pole H/V steering correctors, with skew quad
- Bunch lengthening cavity required to increase lifetime

$$\epsilon_0 \approx \frac{E^2}{N^3_{dipoles}}$$

J. Murphy BNL-42333

MBA Diagnostics Systems

Diagnostic	Quantity/Sector	Total
Arc RF BPMs	12	480
ID RF BPMs (A:P0, B:P0)	2	80
Canted ID RF BPMs (C:P0)	1	10
ID x-ray BPM Electronics, (non-canted)	2	50
ID X-ray BPM Electronics, (canted)	4	40
ID x-ray Intensity Monitor Electronics	2	70
Three Pole Wiggler x-ray BPM Electronics	2	52
Beam Size Monitors	N/A	3
Realtime Orbit Feedback System	N/A	1
Mechanical Motion Systems	1	35
Transverse Multi-bunch Feedback	N/A	1
Current Monitors	N/A	2
Bunch Current Monitor	N/A	1

General Requirements for Orbit Positioning and Stability

- Commissioning -
  - Obtain first turn trajectory (2 mm rms), 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 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

Orbit Stability Requirements

Minimum Expected Beam Size at the IDs

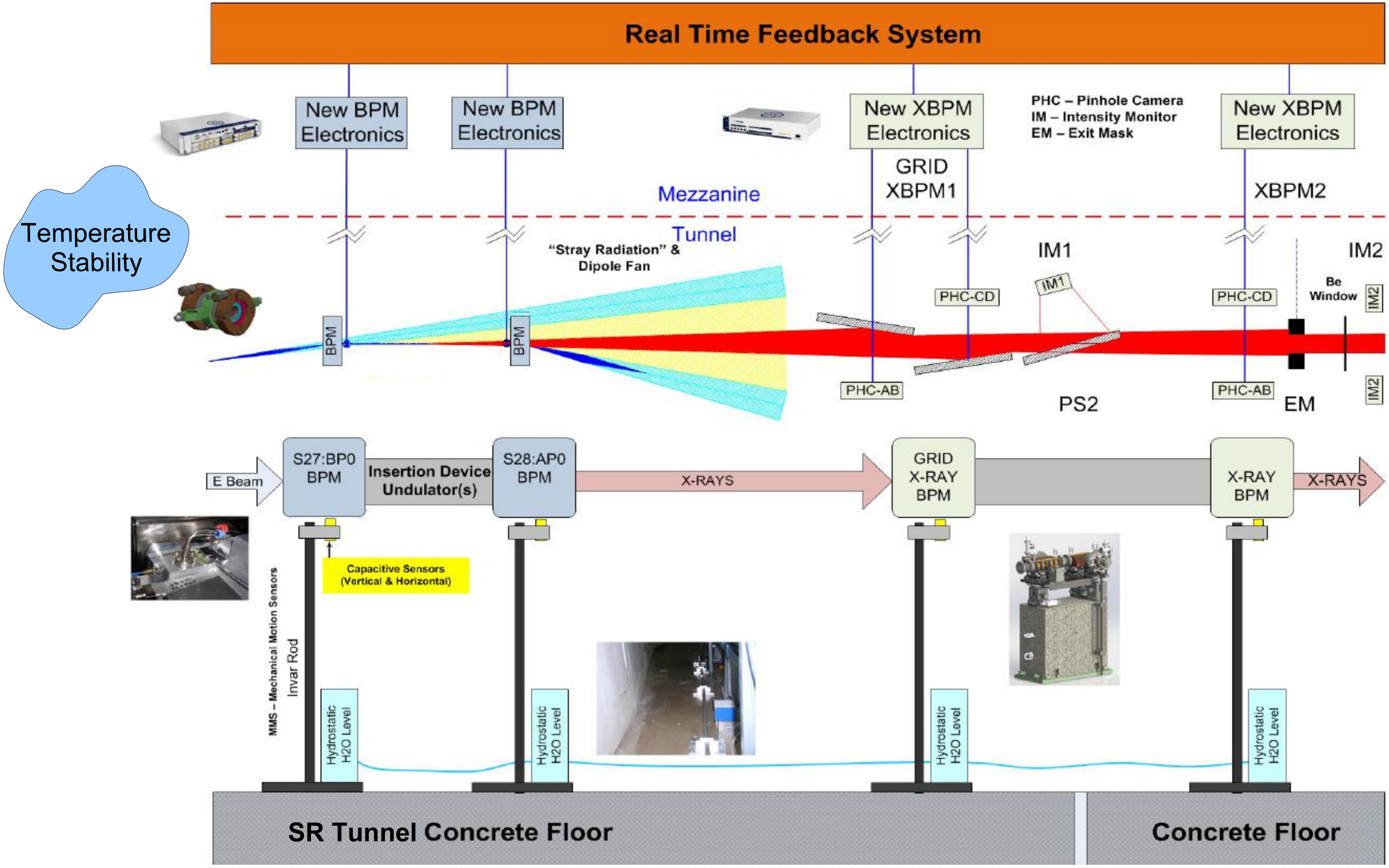
σ_x	$\sigma_{x'}$	σ_y	$\sigma_{y'}$
17 μm	2.6 μrad	4 μm	1.7 μrad

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

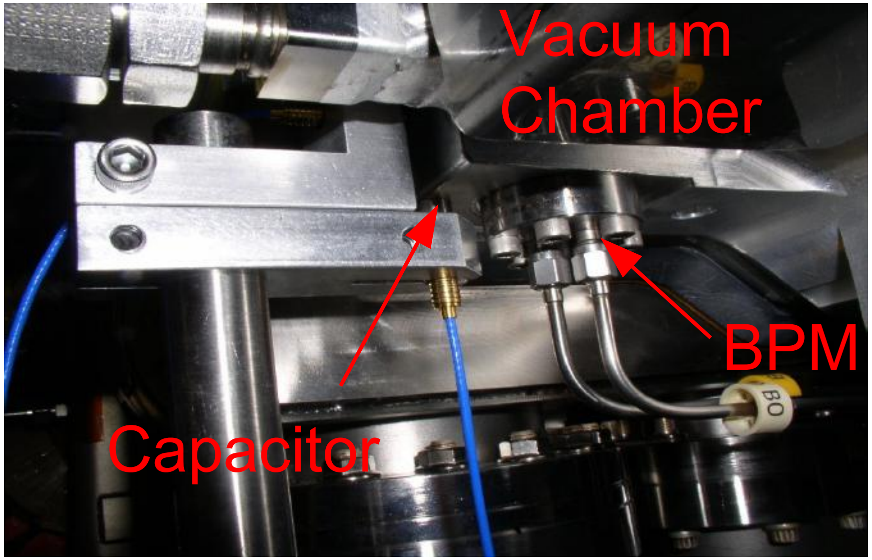
Integrated Beam Stability R&D



- Integrated testing of this hardware in sector 27 is a goal of the R&D plan

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
- Have seen the effect of limit switches for undulator gaps hitting the vacuum chamber with the system (4 μm)!



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

Horizontal BPM Displacement (microns)

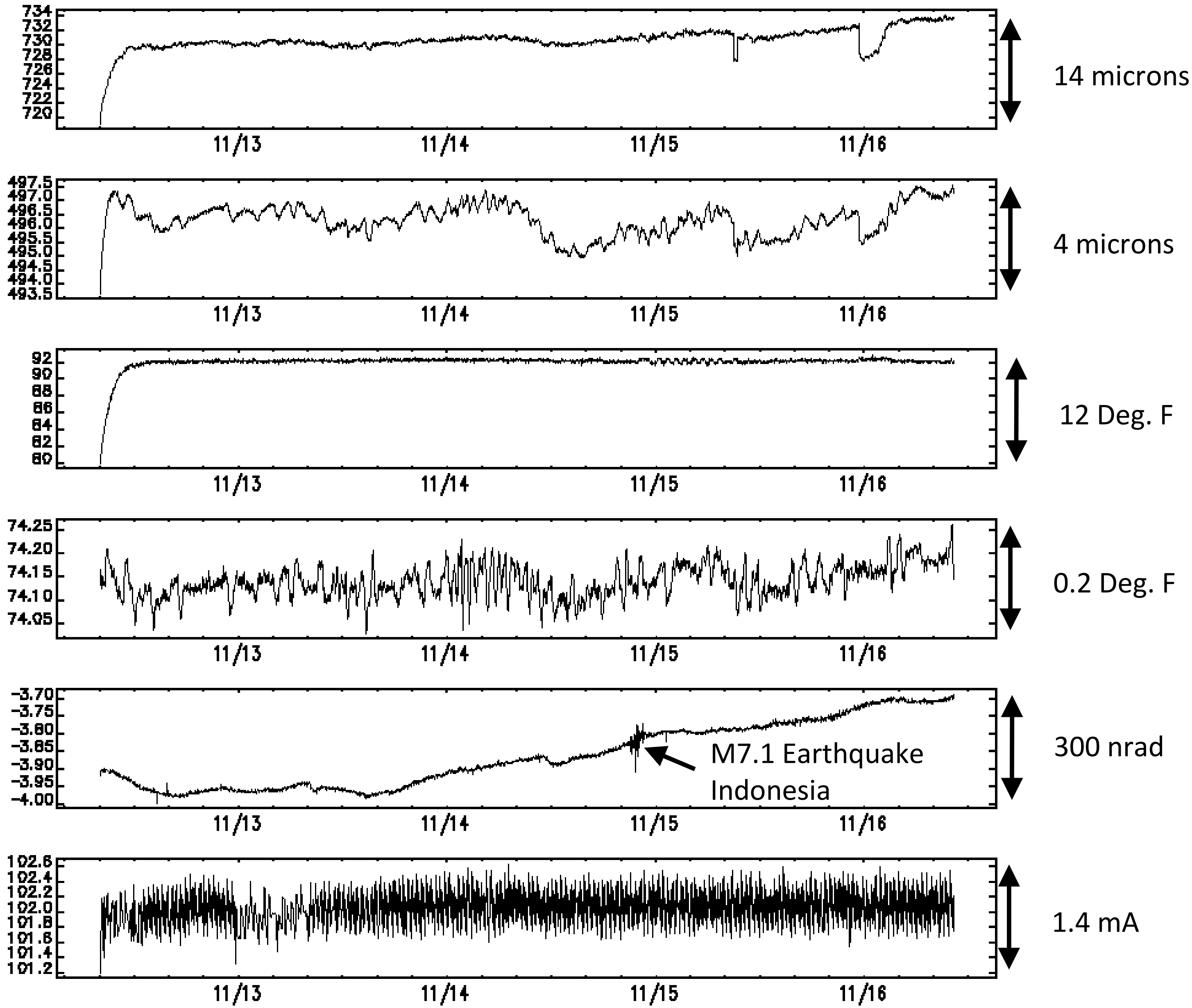
Vertical BPM Displacement (microns)

BPM Chamber Temperature (F)

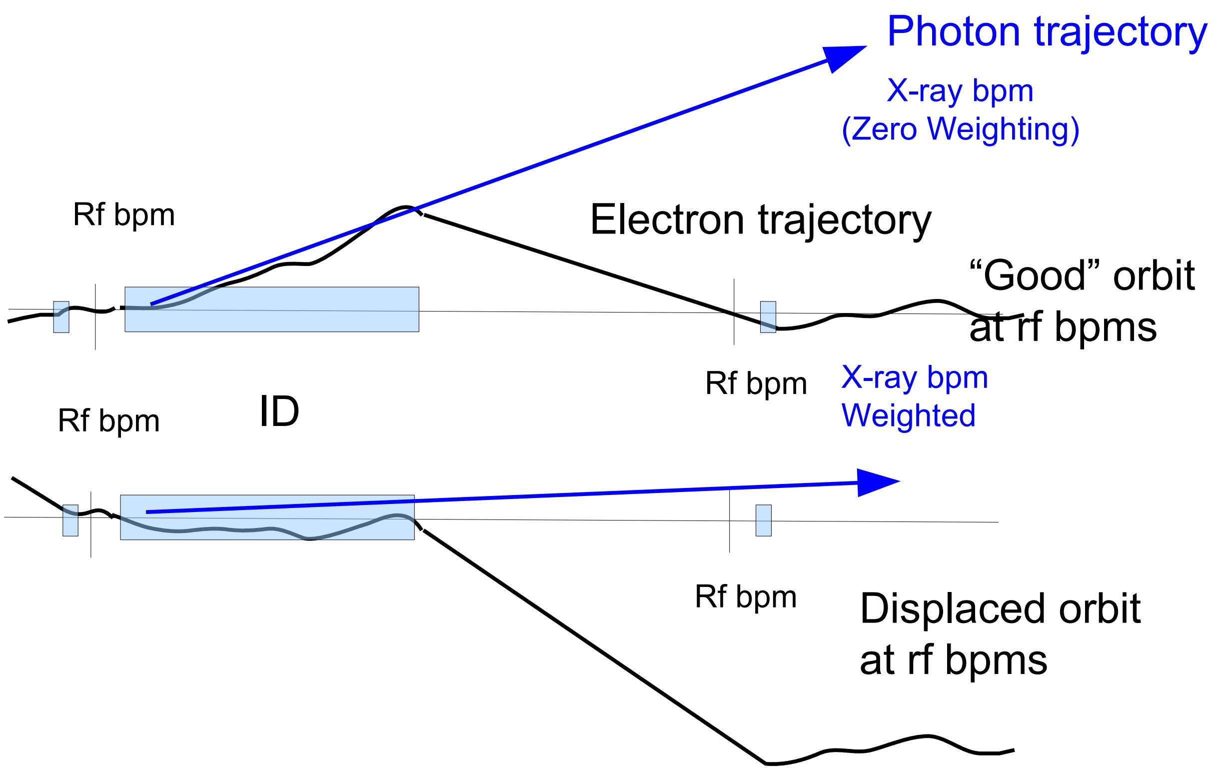
Air Temperature (F)

Floor Tilt (microradians)

Stored Beam Current (mA)

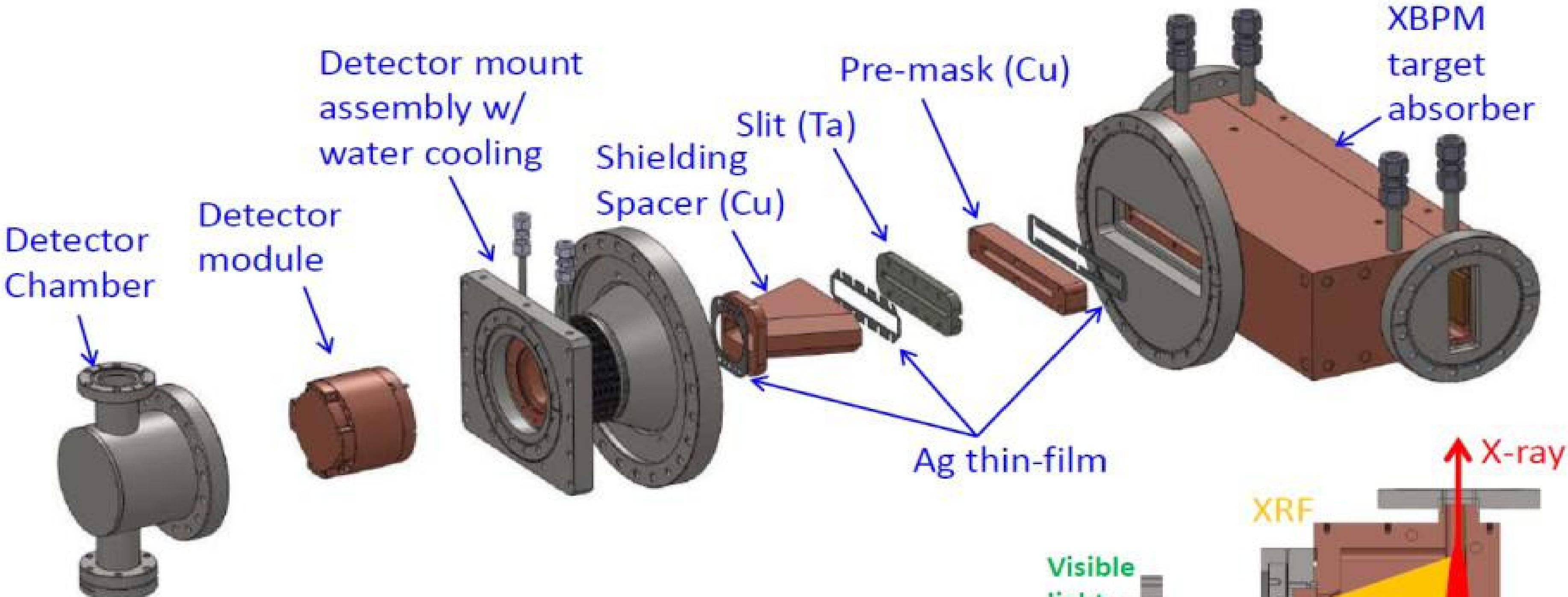


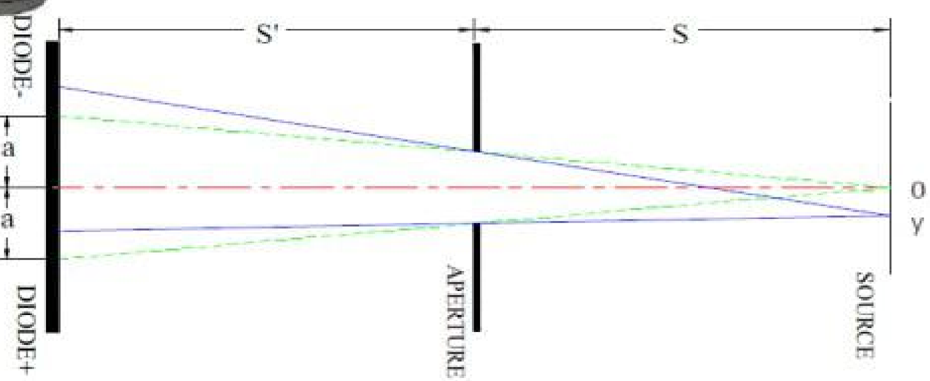
Grid X-ray BPM System



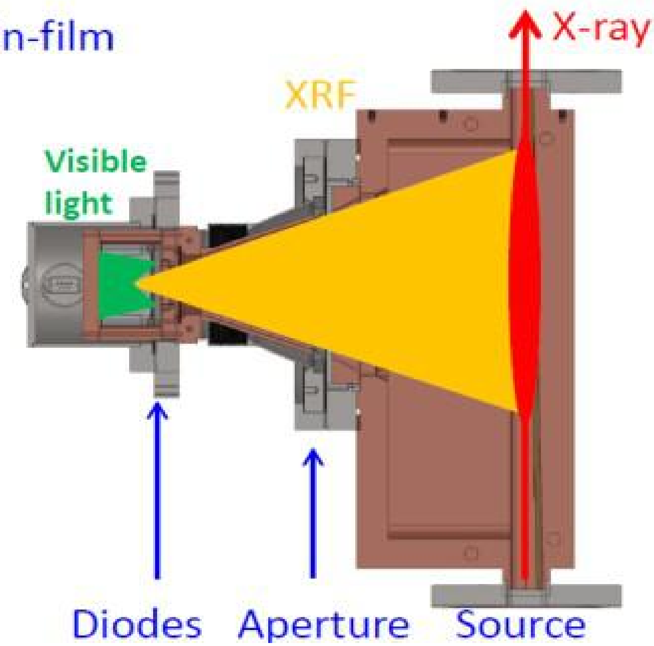
- Based on hard X-ray fluorescense off Cu
- Installed in sectors 27 and 35 front-ends in May 2014
- Signal-to-background ratio is ~50 times better than that for existing photoemission bpms
- Gap dependent systematic effects are reduced by a factor of 10

GRID Xray BPM System

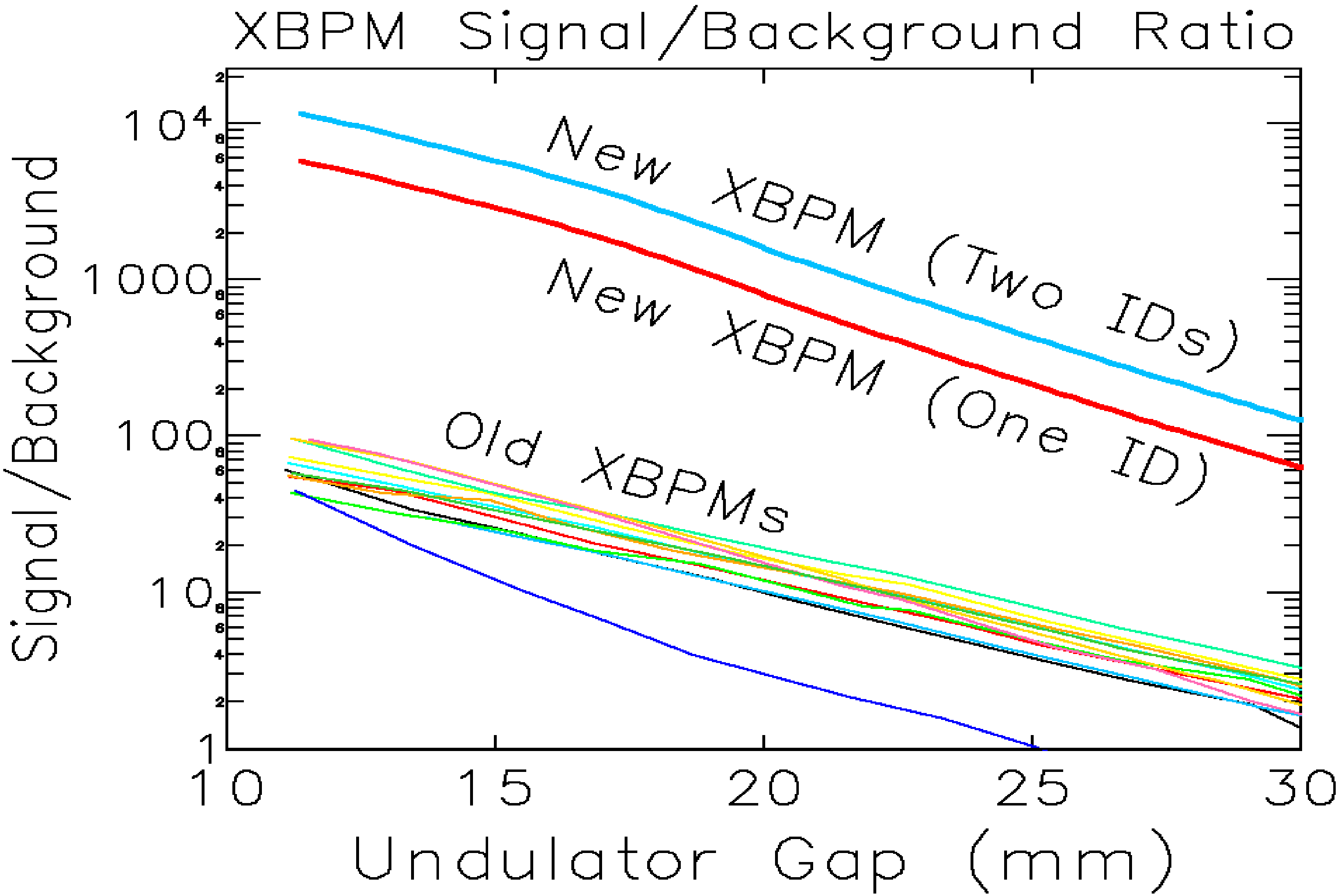




Principle of Pinhole camera

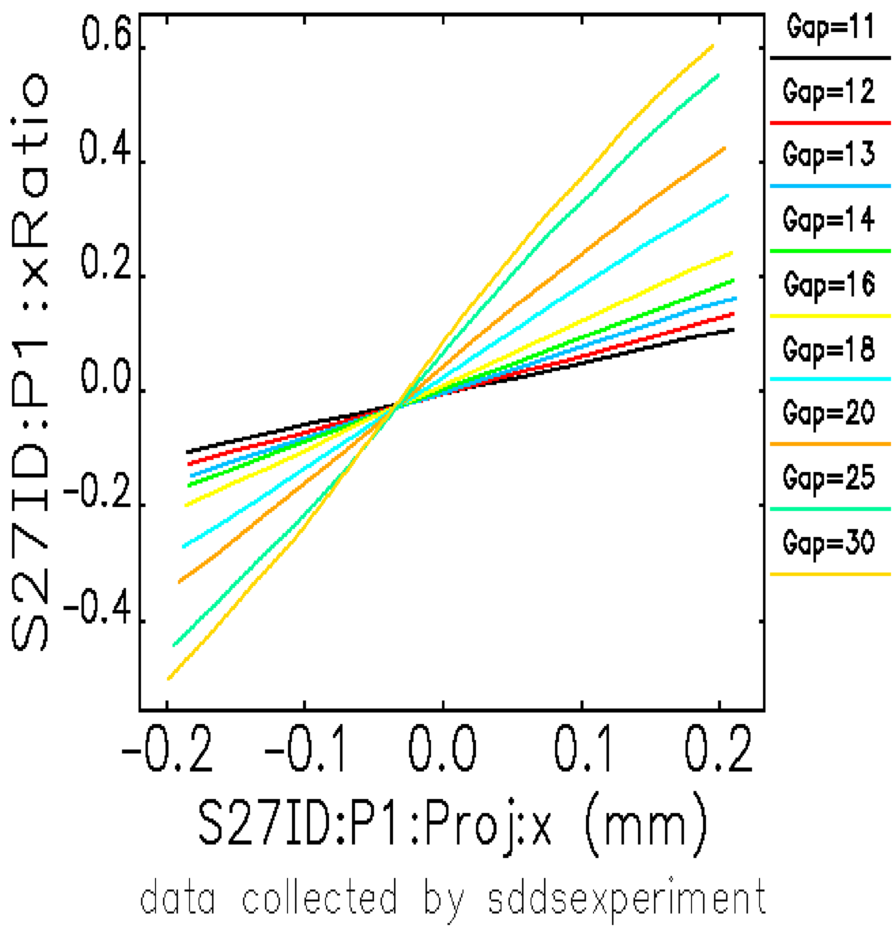


GRID Xray BPM System

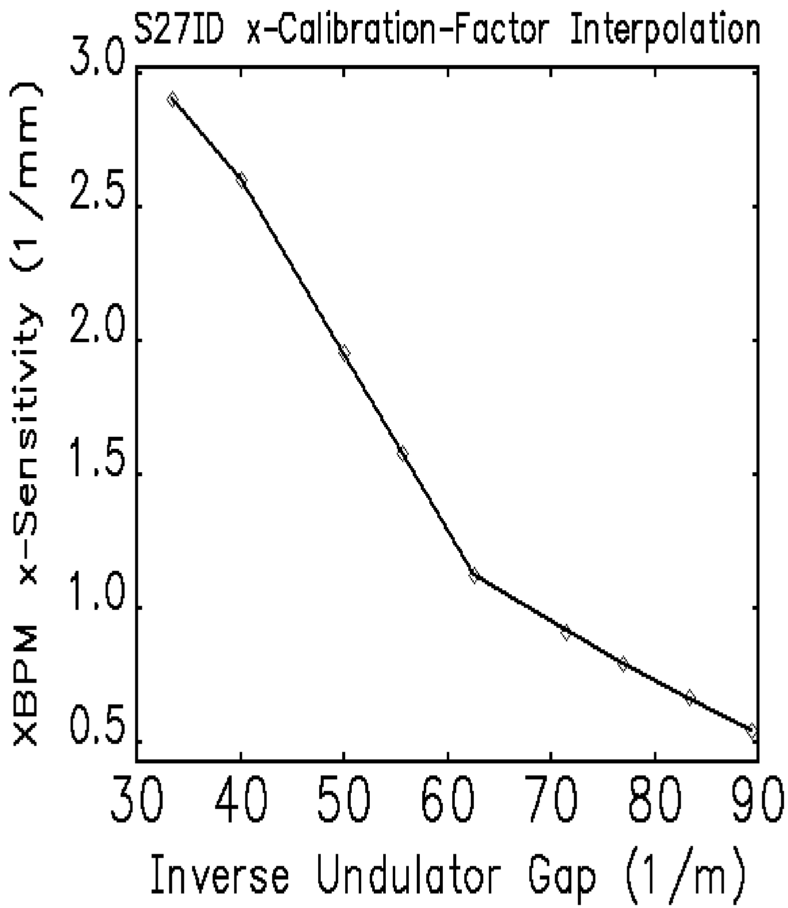


GRID Xray BPM System

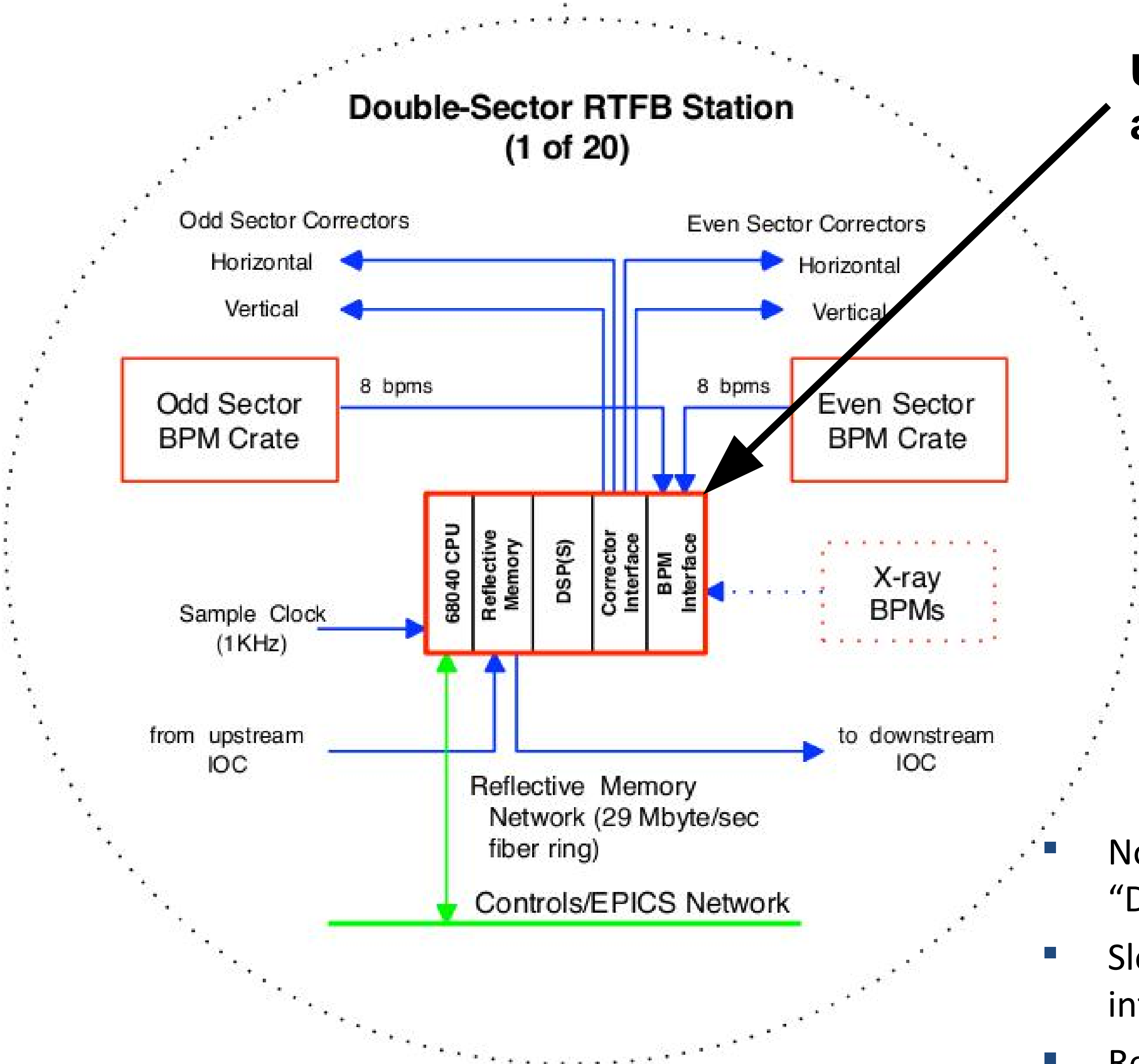
Δ/Σ vs Position from RF BPMs (H Plane)



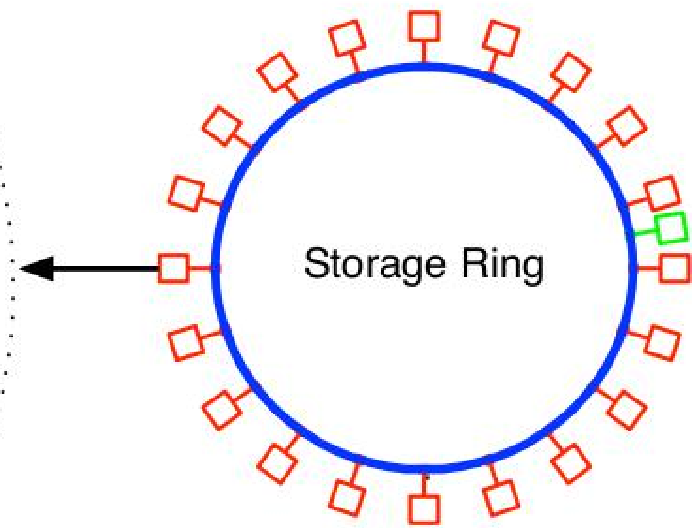
Δ/Σ (H Plane) Slope vs Undulator Gap



Present Orbit Feedback System Architecture



Use the same double sector architecture for MBA



- Not shown is the slow system IOC called “Datapool”
- Slow and Fast system kept from interfering using orbit feedforward
- Relatively poor orbit attenuation in band where the two systems overlap ~1 Hz

Orbit Feedback System Key Parameters Comparison

Parameter	MBA RTFB	Datapool	RTFB
BPM Sample rate	271 kHz (TBT)	10 Hz	1.5 kHz
BPM Orbit Vector transfer rate	271 kHz (TBT)	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

- The present orbit feedback system consists of a slow (Datapool) and fast (RTFB) system[1]
- A main goal for **MBA RTFB** is to **unify** operation of both slow and fast correctors *in a single feedback algorithm*[2]

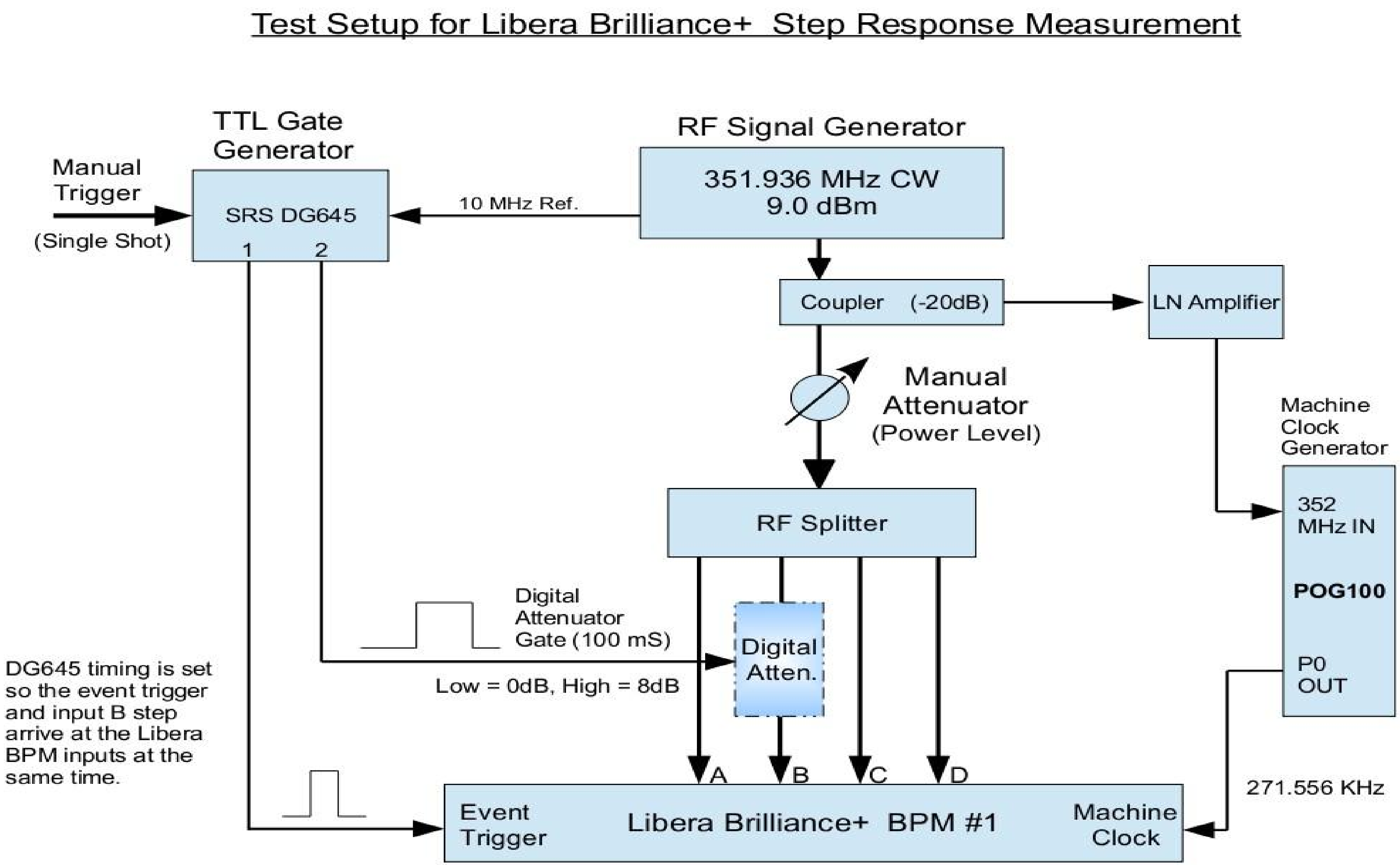
[1] F. Lenkszus, L. Emery, R. Soliday, H. Shang, O. Singh, M. Borland, Proc. Of the 2003 PAC, 2003

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

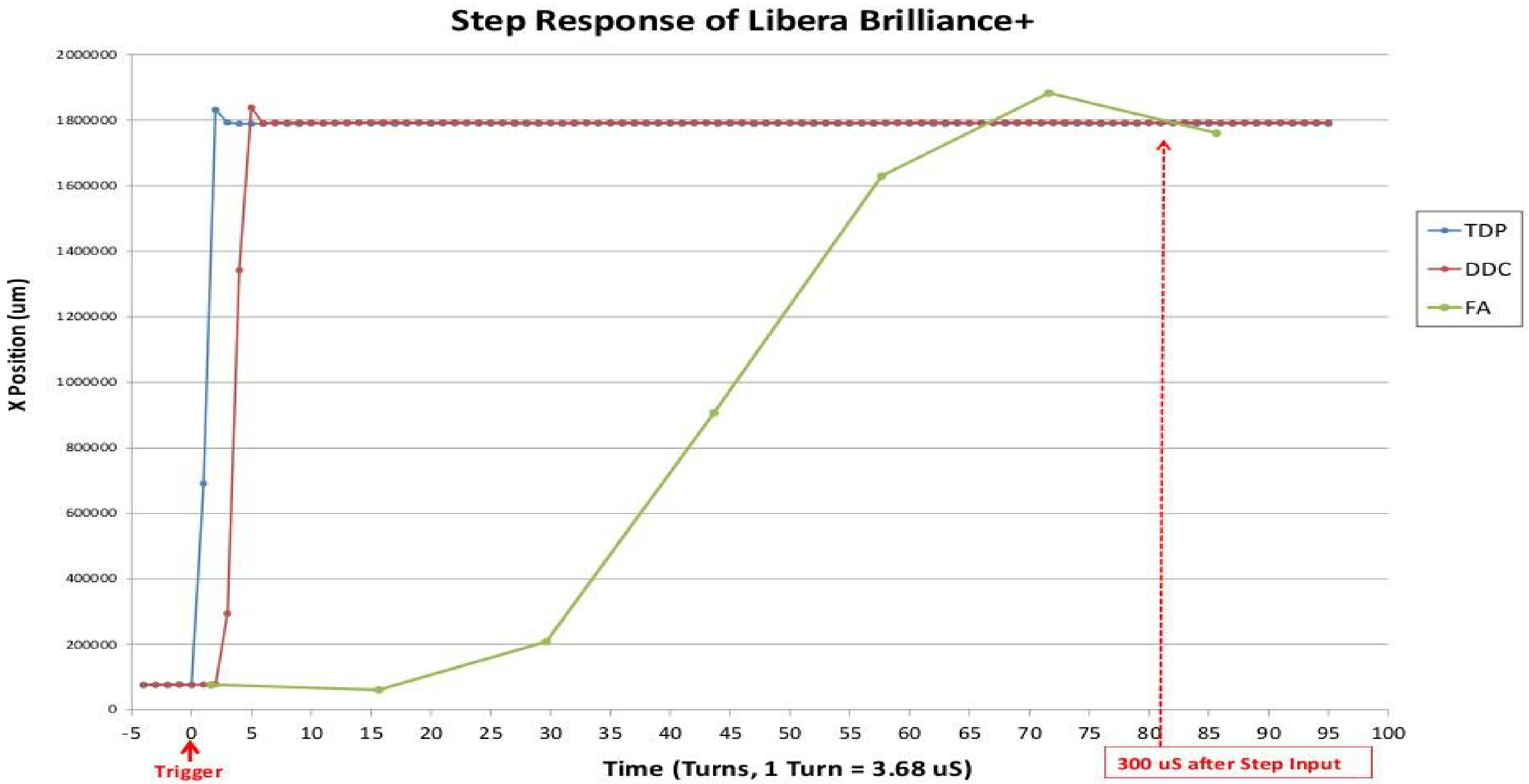
Orbit Feedback R&D Topics

- Orbit feedback system goal is to achieve a 1 kHz closed-loop BW
  - Transferring vector bpm data (latency) around the ring via the fiber network
  - Power supply/magnet/vacuum chamber bandwidth and latency (dominated by the iron core laminated magnet in our case)
  - BPM processor latency and filtering in GDX module
  - DSC latency
  - Orbit feedback system sampling rate
  - First pass phase budget not including fiber network latency, phase delay in the fast power supplies gives 1.5 kHz closed-loop BW for 45 degree phase stability margin
- ID RF bpm mechanical stability
- Synchrotron frequency ~ 200 Hz with large 100 Hz BW due to bunch lengthening cavity
- We are planning two R&D approaches to investigate these topics:
  - Continued orbit feedback simulation development
  - Feedback system R&D plan in sector 27 of the APS SR
- Now focussing our efforts on a uTCA based DSC with fast DSP/FPGA

Libera Brilliance+Step Response Lab Setup

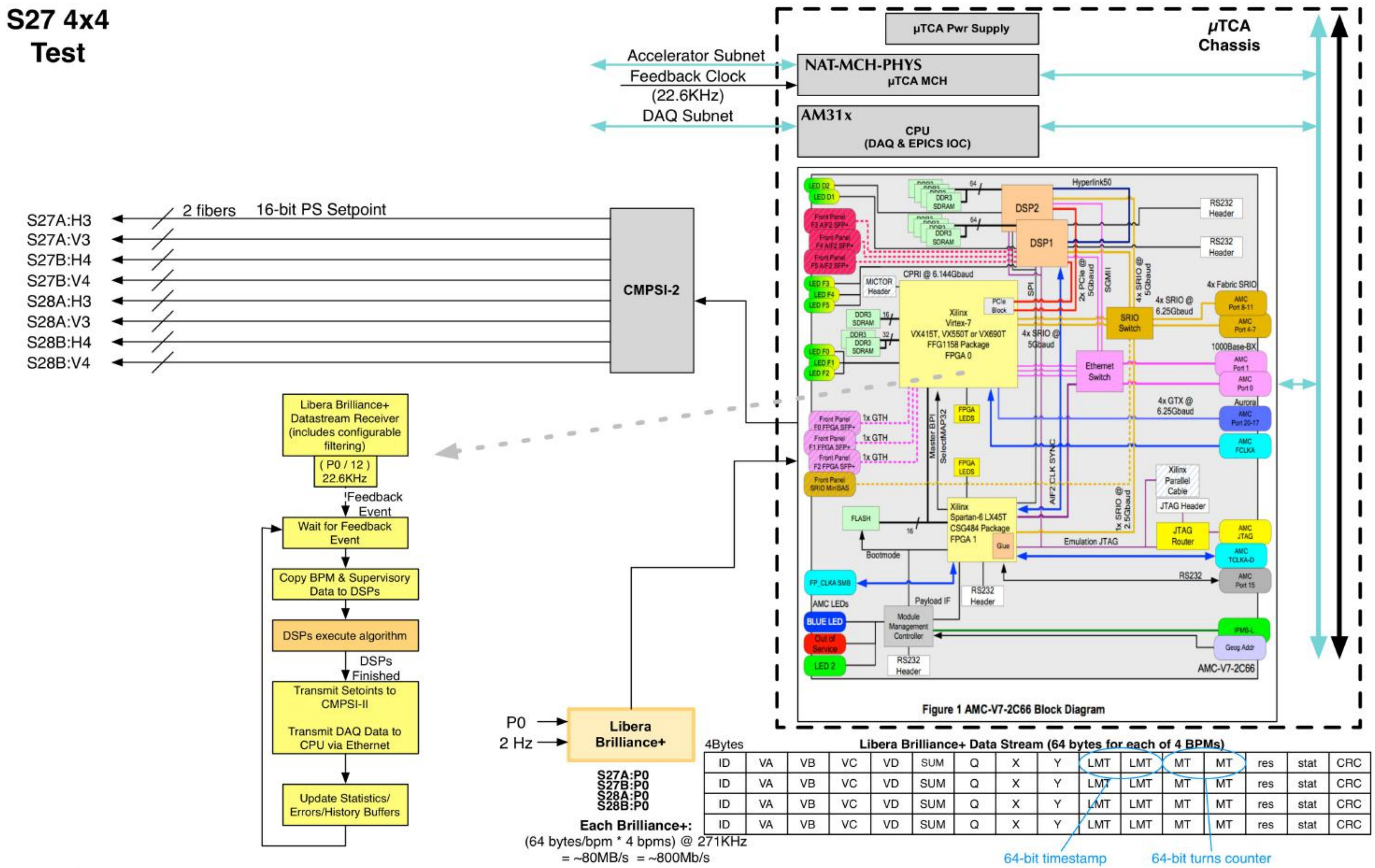


Libera Brilliance+Step Response



- To reduce latency we filter (or turn off filtering) in the GDX at the TBT rate (271 kHz) and send data to the DSC at the full TBT rate (customized for APS)
- All DSCs will have access to the full vector of bpm orbit data no more than 1 turn delayed
- Orbit data is processed in the DSC and setpoints sent to the correctors at a slower rate (ie. 22 kHz)

MicroTCA Based Double Sector Controller R&D Test

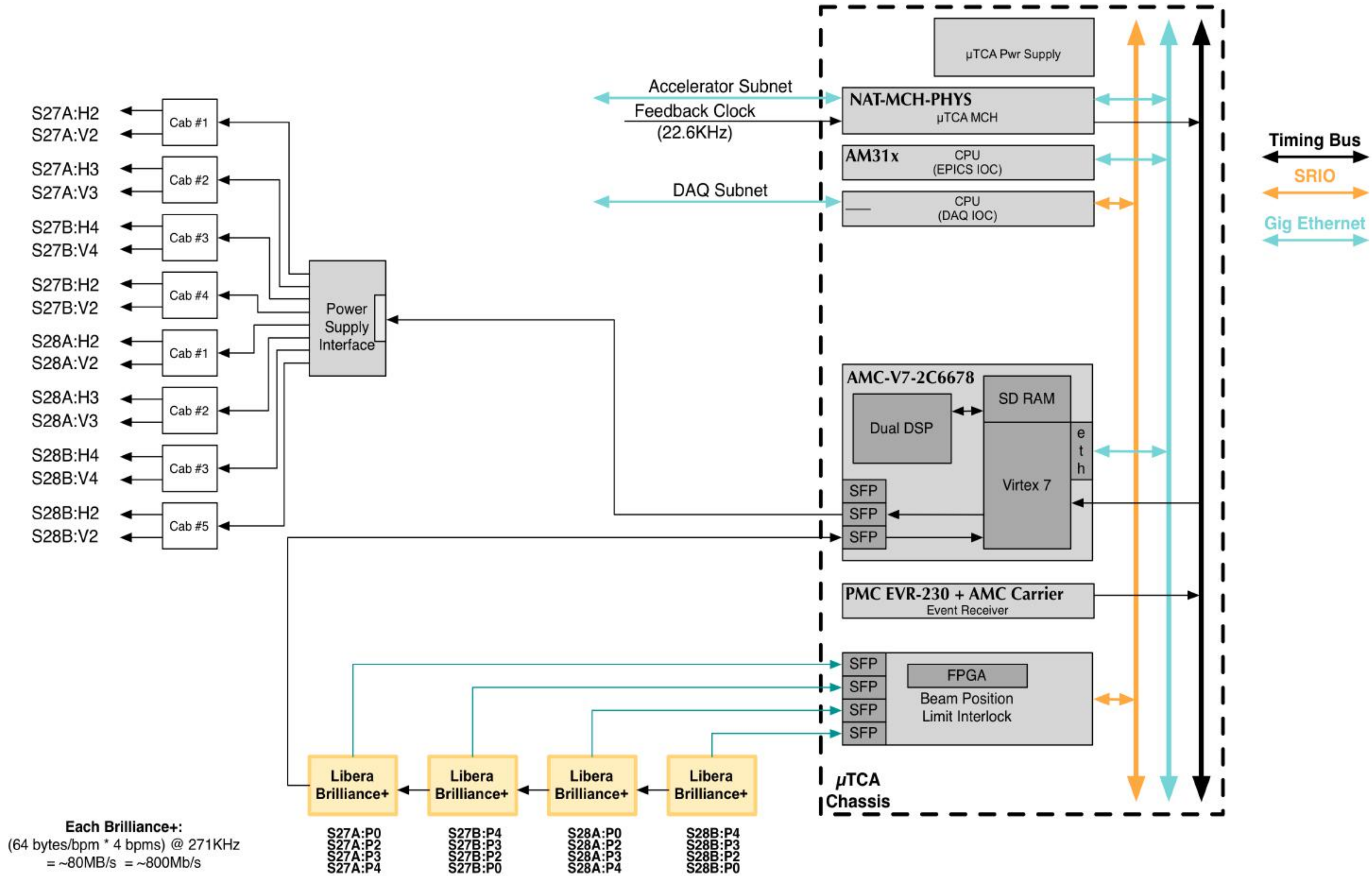


Libera Brilliance+ Data Stream (64 bytes for each of 4 BPMs)

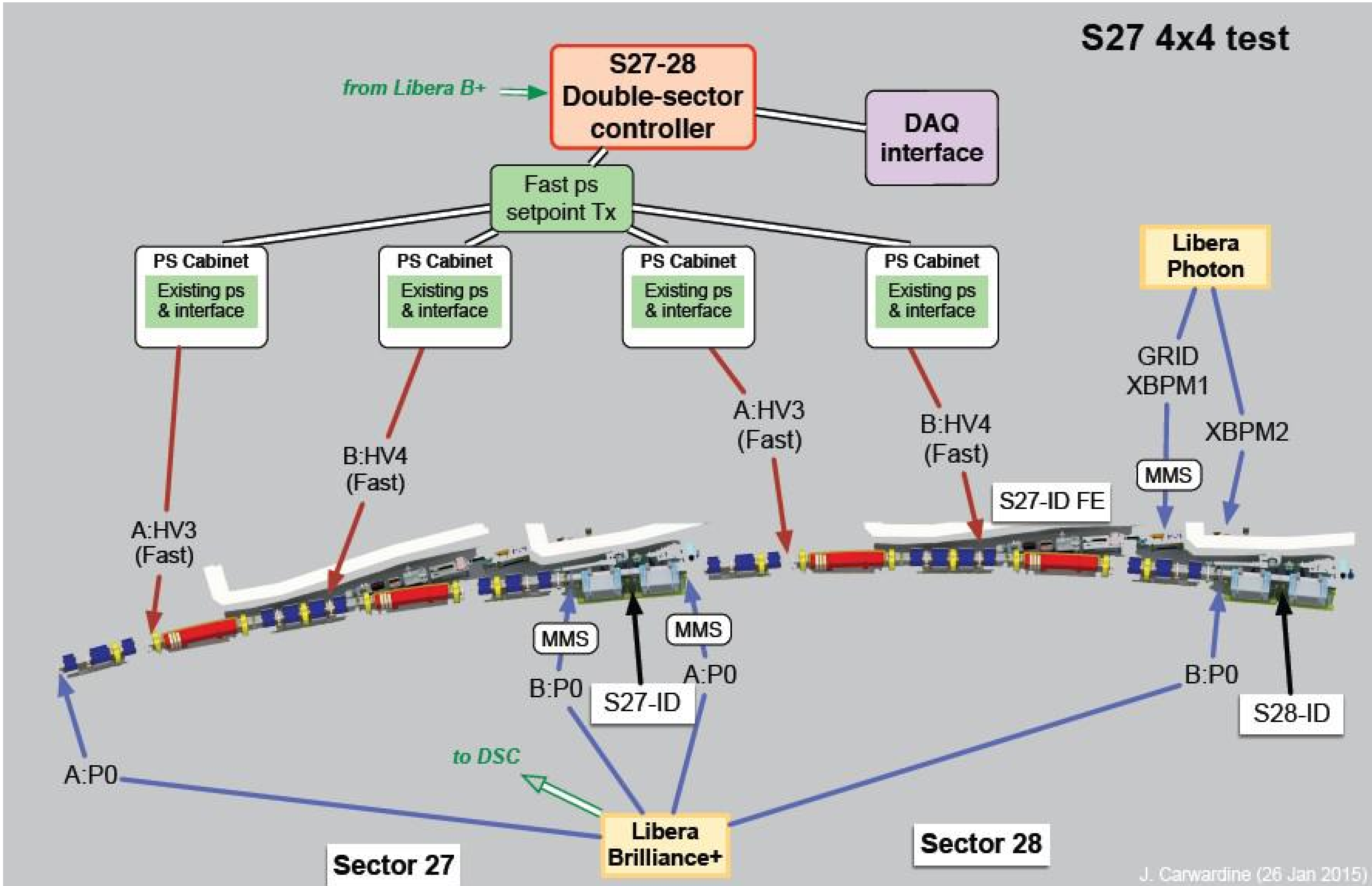
4Bytes

ID	VA	VB	VC	VD	SUM	Q	X	Y	LMT	LMT	MT	MT	res	stat	CRC
ID	VA	VB	VC	VD	SUM	Q	X	Y	LMT	LMT	MT	MT	res	stat	CRC
ID	VA	VB	VC	VD	SUM	Q	X	Y	LMT	LMT	MT	MT	res	stat	CRC
ID	VA	VB	VC	VD	SUM	Q	X	Y	LMT	LMT	MT	MT	res	stat	CRC

MicroTCA Based Double Sector Controller Extended R&D Test

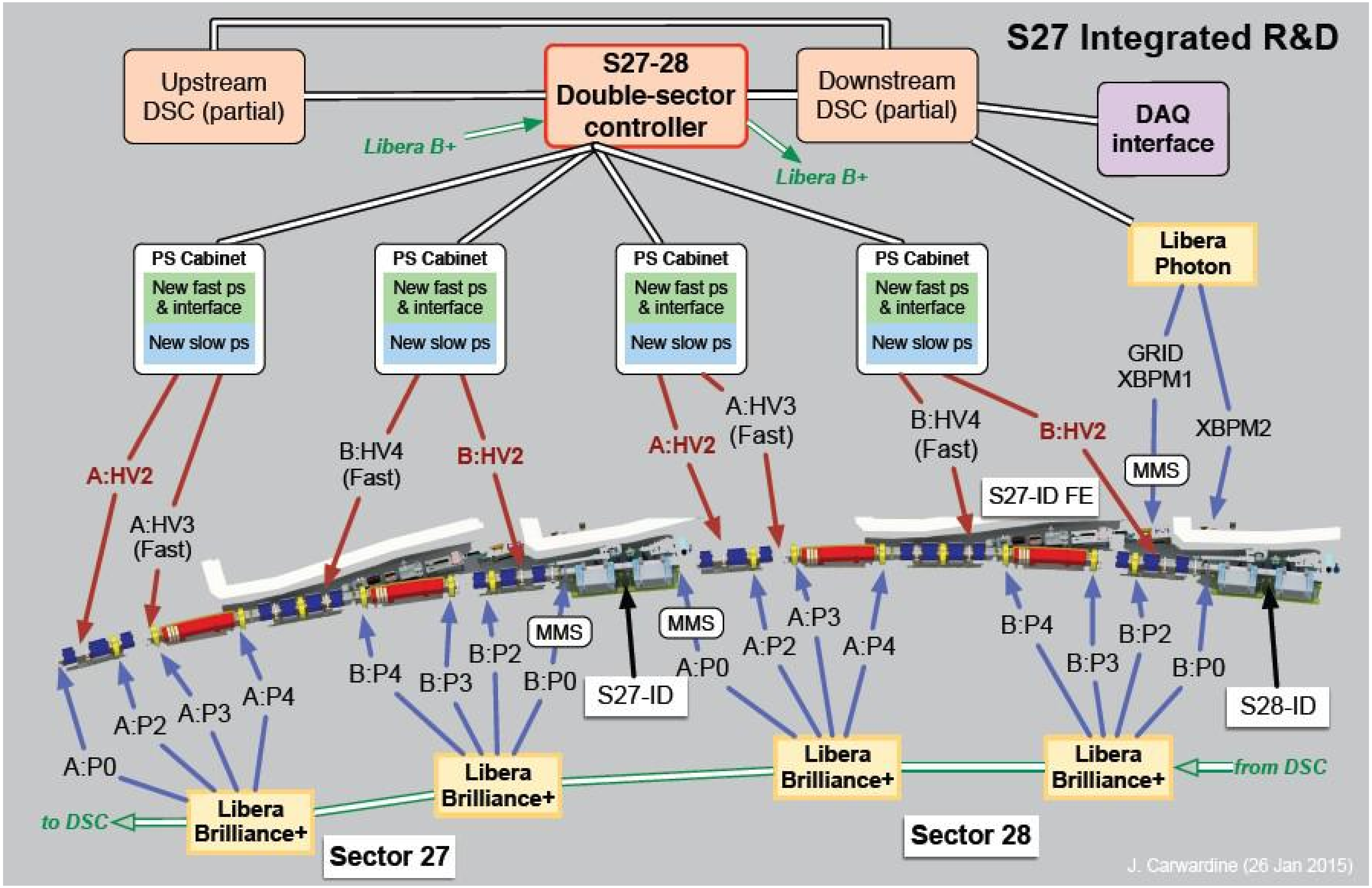


MBA R&D Plan in Sector 27 (First Test)



- Four-bpm four-fast-corrector feedback test in sector 27

MBA R&D Plan in Sector 27 (Full System Test)

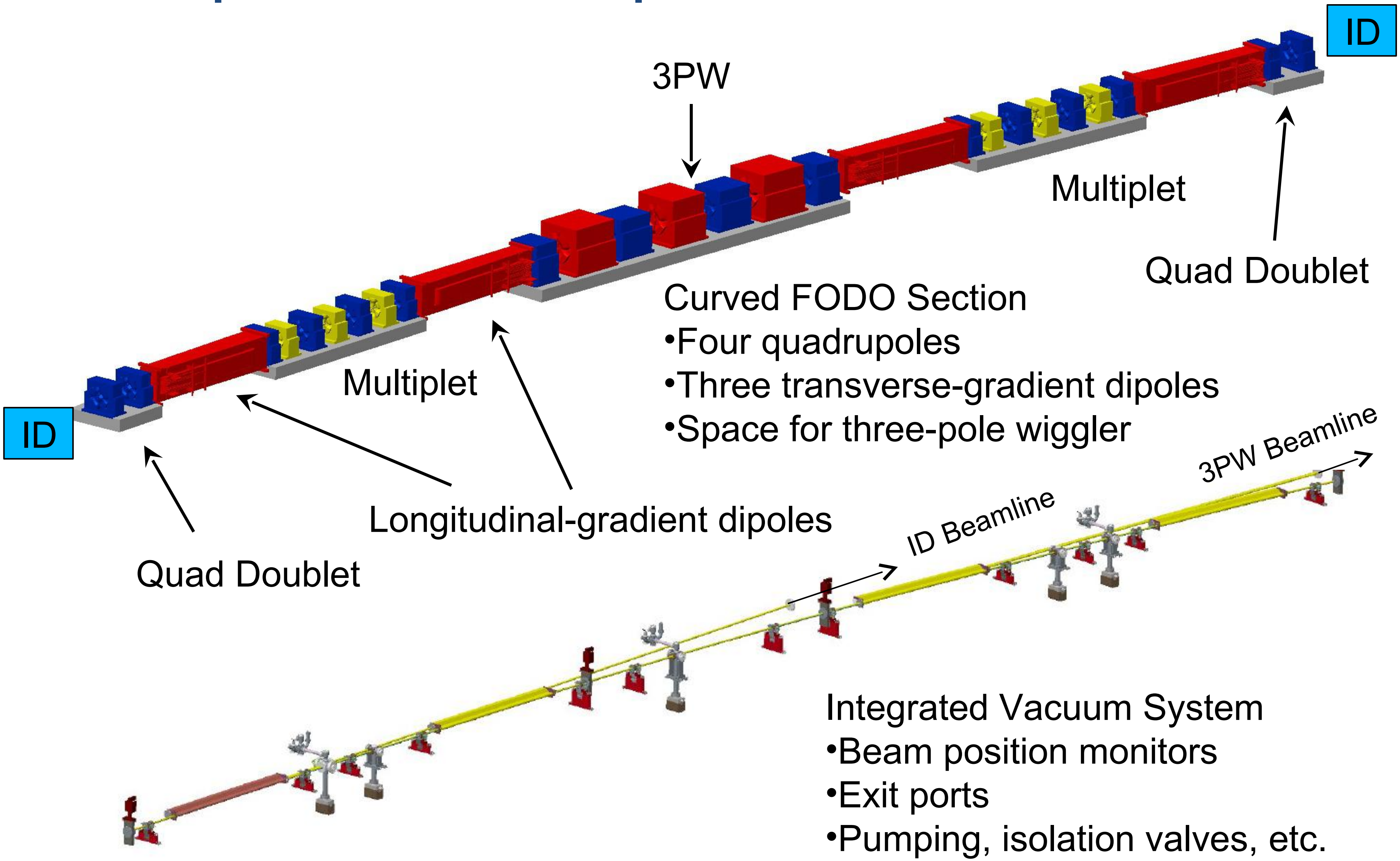


Summary

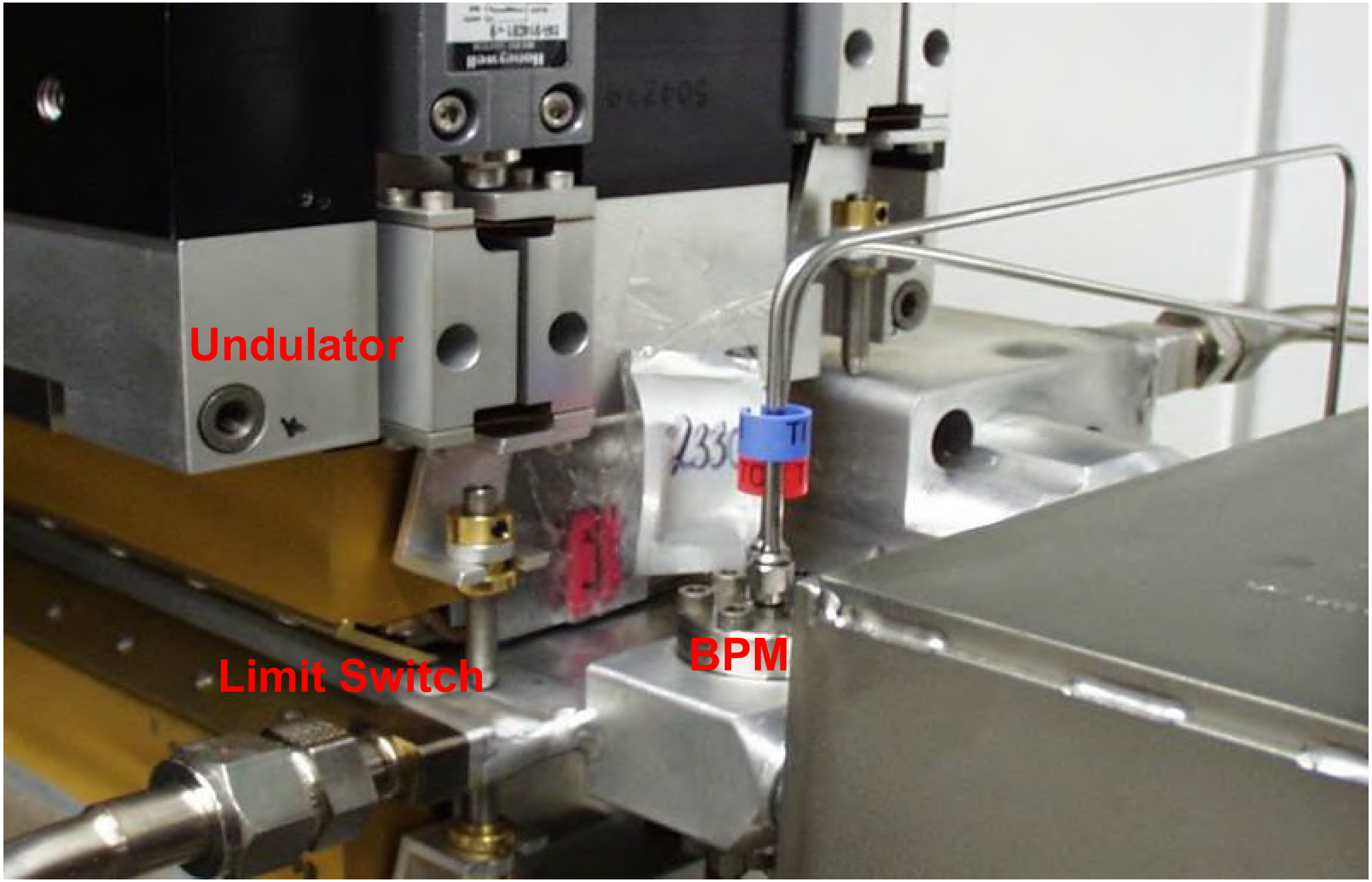
- Beam stability requirements for the MBA Ring are challenging:
  - New beam position monitor systems (rf and X-ray)
  - Adding new mechanical motion sensing system to bpm chambers
  - Pursuing tunnel air and water temperature stability improvements
  - New orbit feedback system hardware and feedback algorithm
- The main R&D goal is integrating the hardware together for testing to retire risk
  - R&D plan in sector 27 aims to test all diagnostic systems with feedback system
  - Investigating many of these systems during machine studies including the unified algorithm
  - Development of a feedback simulation has begun but needs to be extended to the MBA ring
  - We are now investigating a μTCA based solution for the double sector controller

Extra Slides

Conceptual Machine Implementation – One Sector

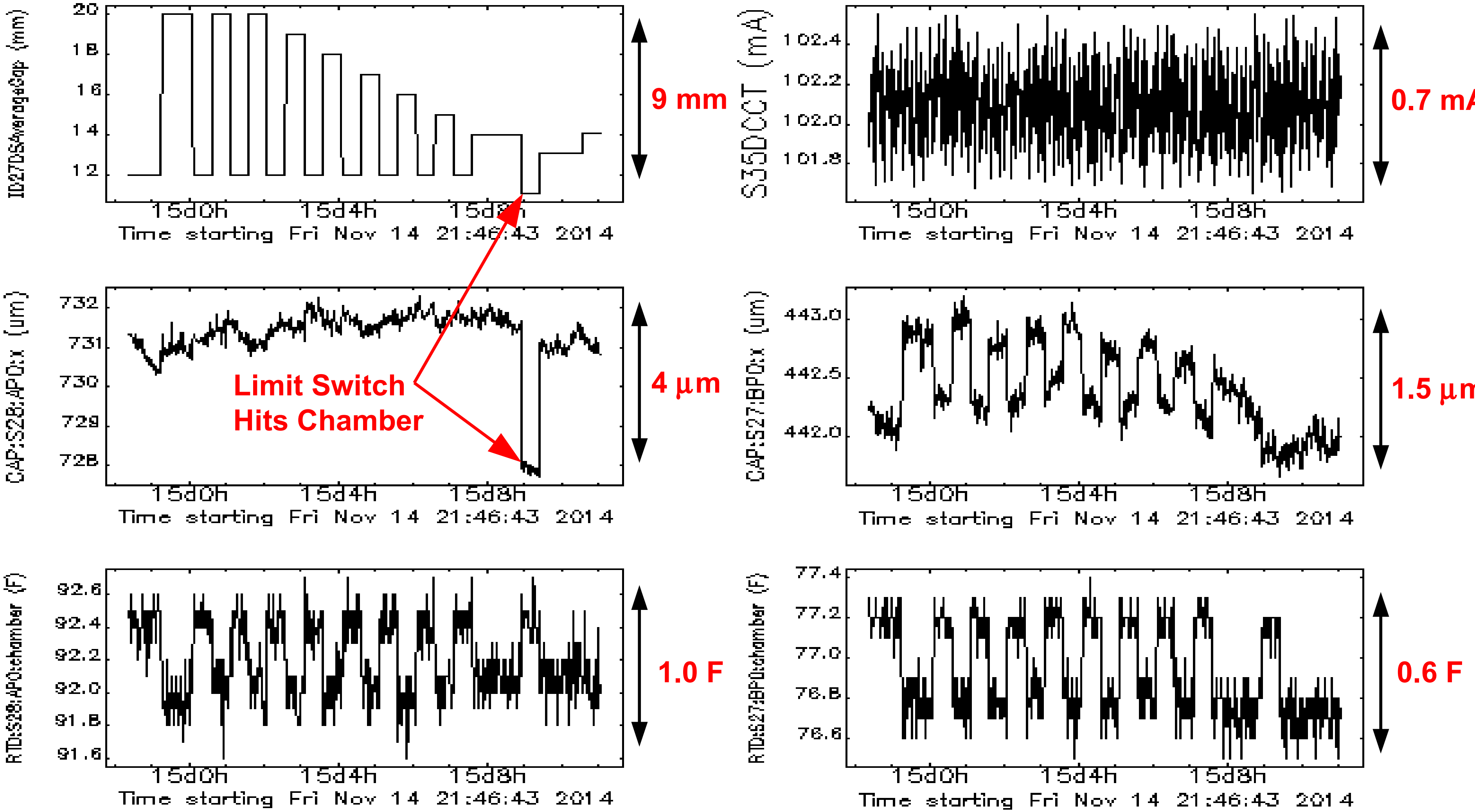


Mechanical Motion Sensing System Data

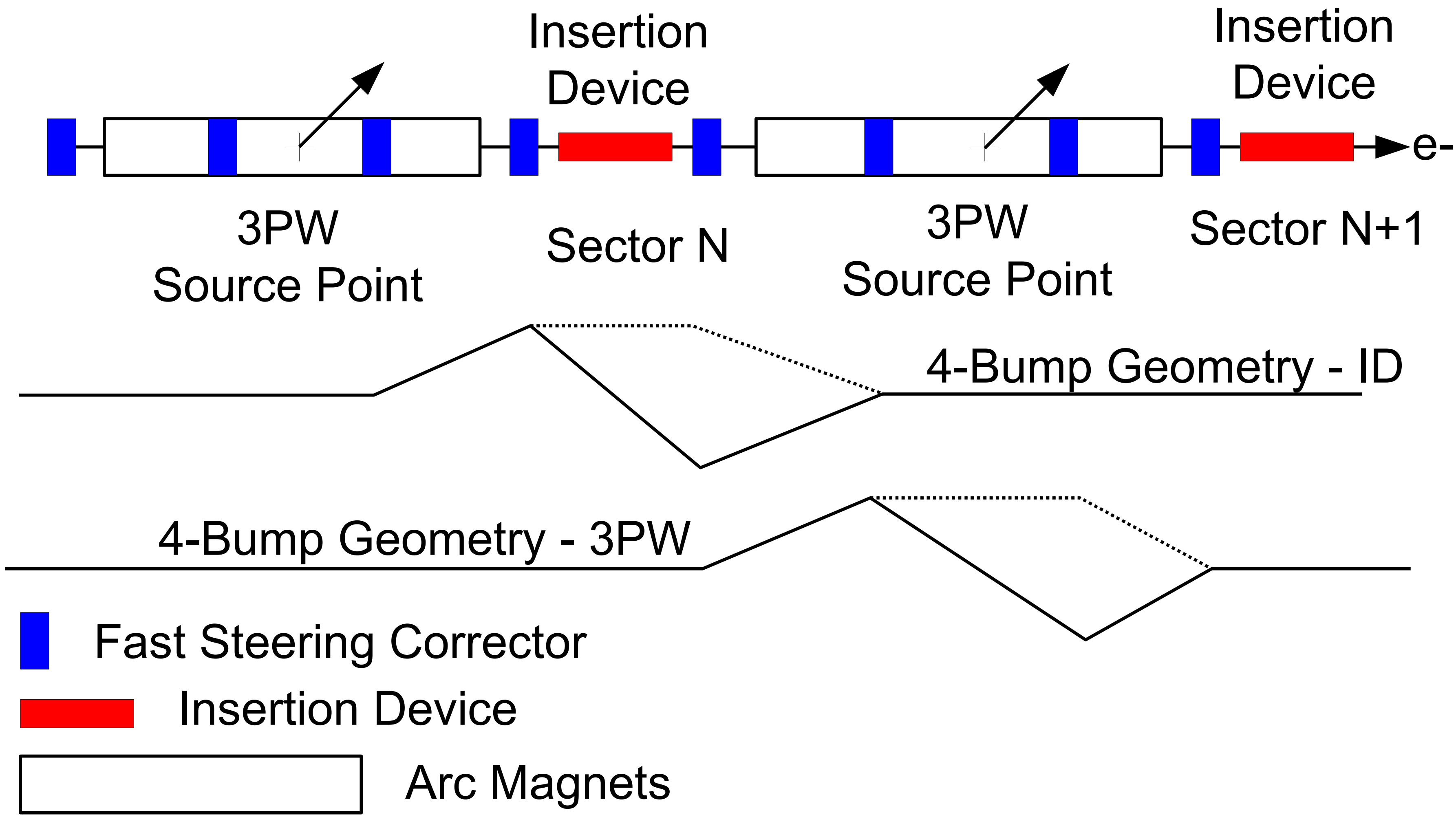


Mechanical Motion Sensing System Data

102 mA, 24 Singlets Top-Up

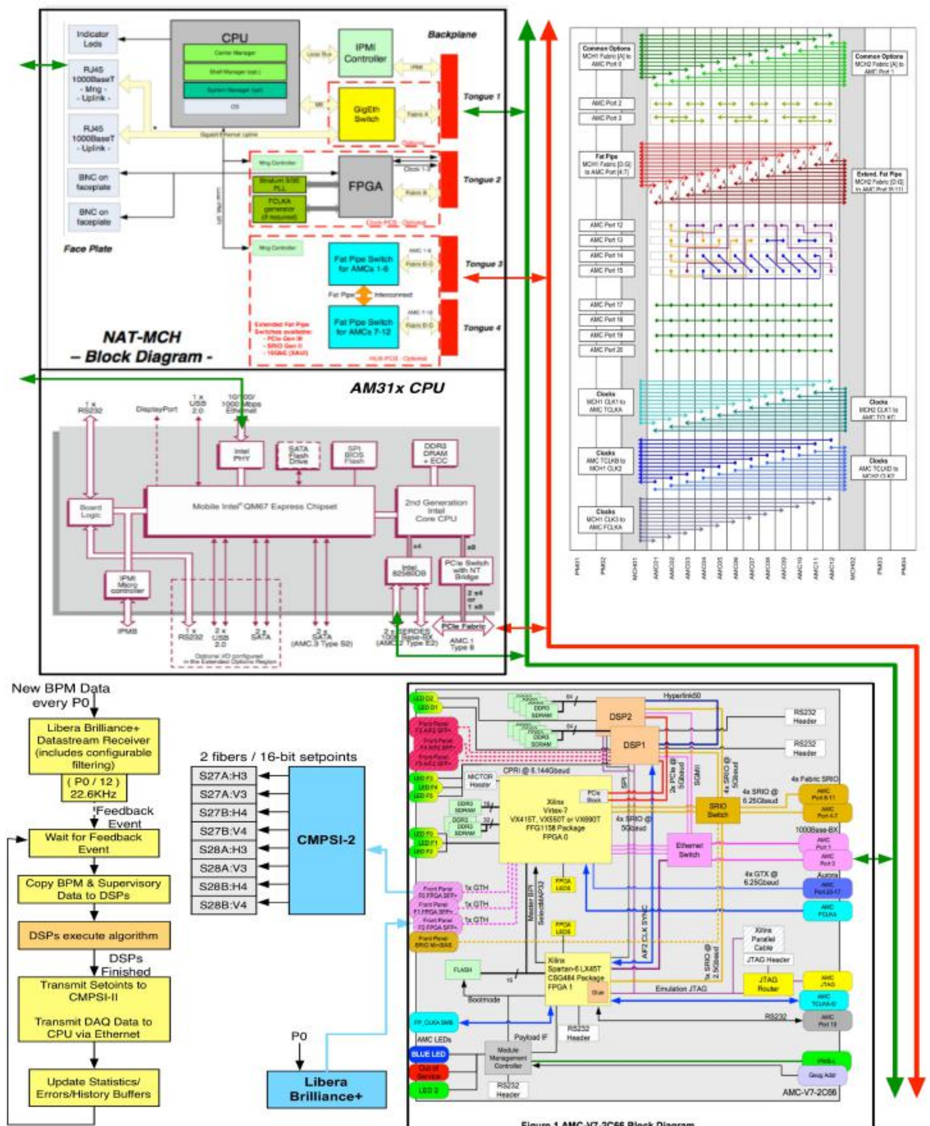


Fast Orbit Feedback Concept for the MBA Ring



- Two fast correctors between each photon source point ensure fast correction of both position and angle at the source

MicroTCA Detailed Block Diagram



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ID	VA	VB	VC	VD	SUM	Q	X	Y	LMT	LMT	MT	MT	res	stat	CRC
ID	VA	VB	VC	VD	SUM	Q	X	Y	LMT	LMT	MT	MT	res	stat	CRC

uTCA_Detailed_Block_Diagram.graffle
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